Nuclear Physics Institute

public research institution

Academy of Sciences of the Czech Republic

Řež near Prague

BIENNIAL REPORT

2007-2008

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FOREWORD

The Report presents the activities of the Nuclear Physics Institute of the Academy of Sciences of the Czech Republic (NPI) during the years 2007 - 2008. The most important achievements are reported in one- to two-page presentations. The list of publications and the NPI structure are found at the end of the volume.

The start of the year 2007 was an important date for the institute. From this year, the legal status of the NPI, as well as of the other institutes of the Academy of Sciences of the Czech Republic, has changed and the institute has been transformed into the public research institution. This conversion gives to the institute more self-reliance in the utilization of its funds and results of research. Of course, the institute's liability and the requirements on the organization have simultaneously increased. Particularly, the great effort of the Technical and Economic Administration during the transfer process has to be much appreciated.

On the other hand, the course of the research activities has not been much influenced. Activities in the basic nuclear physics go along the main contemporary trends. Many of the studies are done within framework of collaborations with prominent laboratories abroad. The investigation of hot and dense strongly interacting matter is carried out in collaborations STAR (BNL, USA) and HADES (GSI, Germany) whereas the future experiments ALICE (CERN) and CBM (FAIR, Germany) are being prepared. The KATRIN project (FZK, Germany), which aims at determining the mass (or the limit on it) of the elusive neutrino, is in the construction phase. The structure of the exotic nuclei far from the stability line is studied in experiments in laboratories GANIL (France), JINR (Russia), and ISOLDE (CERN). The international collaboration in the field of nuclear astrophysics employs the beams in laboratories abroad (TAMU (USA), LNS (Italy)) as well as at the NPI cyclotron U-120 M. Also the studies in theoretical and mathematical physics keep the high standard.

In the interdisciplinary and oriented research, NPI carries out activities in the thematic fields having its own natural connections and social requirements. By the broadness and quality of the implemented nuclear analytical techniques, NPI is a unique centre even on the international scale. The neutron diffraction and scattering facilities are employed mainly in the material research and offer its capacities within the frame of the FP6 transnational access project. FP6 projects also concern studies of physical processes and data important for the future energy-production technologies carried out mainly at the NPI cyclotron. The investigations in the field of radiation dosimetry, radiation biophysics and related environmental studies possess high interdisciplinary potential. Activities oriented to the research, development and production of radiopharmaceuticals have the strong social requirements. The smooth functioning of the NPI basic facility - cyclotron U-120 M - and development of the related techniques have been of highest importance for many of institute's activities.

The present volume intends to provide information on the fulfillment of the task and mission of the NPI. Certainly, all the results and achievements reported in the following pages have been possible thanks to the considerable effort and dedicated attitude of NPI scientists and all NPI staff.

Jan Dobeš
director

DEPARTMENT OF THEORETICAL PHYSICS

Research activities of the Department of Theoretical Physics (DTP) cover a wide range of topics in

nuclear physics:
- algebraic models for nuclear structure
- electromagnetic and weak meson exchange currents
- production and structure of Λ hypernuclei
- few-nucleon systems both in v/c - expansion approach and covariant framework
- strong interaction effects in π^-, K^-, Σ^- and $\bar{p}$ atoms
- mesonic and nonmesonic decays of light hypernuclei

particle physics:
- effective chiral models for low-energy meson-baryon interaction
- electroproduction of K^+ on protons (isobaric and Regge models)
- processes with high transverse momenta at relativistic energies
- inclusive particle production at high energies
- solutions of Schwinger-Dyson equations in Minkowski space
- macroscopic quantum phases of deconfined QCD matter at finite density
- diquarks and internal baryon structure
- models of the dynamical mass generation
- properties of the Goldstone modes

mathematical physics:
- quantum waveguides and layers: geometrically induced properties
- ideal and leaky quantum wire systems: spectra, scattering, approximations
- magnetic transport: existence and stability of edge-type states
- Zeno and anti-Zeno dynamics of decaying quantum systems
- integrals of motion for spin chain models
- quasi-Hermitean observables in quantum mechanics: spectral properties
- nonlinear supersymmetry and its PT-symmetric representations

These mathematical physics research activities are a part of the center of basic research "Doppler Institute for Mathematical Physics and Applied Mathematics", together with colleagues from Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, and the University of Hradec Králové.

The department regularly organizes:

- the international conferences **Mathematical Results in Quantum Mechanics**,
- the international conferences **Pseudo-Hermitian Hamiltonians in Quantum Physics**,
- the international **Indian-Summer School of Physics**.

Some members of DTP give lectures at Charles University or Czech Technical University in Prague, and supervise both the doctoral and the diploma theses. The department continuously hosts a number of post-doctoral researchers and other medium-term visitors.

Model dependence of the neutrino-deuteron disintegration cross sections at low energies

B. Mosconi[1], P. Ricci[2], E. Truhlík[3], P. Vogel[4]

We have studied model dependence of the reaction rates for the weak breakup of deuterons by low energy neutrinos [1] starting from the cross sections derived from potential models [2] and also from pionless effective field theory [3]. This was done by considering the spread of reaction yields, caused basically by different ways the two-body currents are treated, which provides a measure of the model-dependent uncertainty for the considered reactions of the deuteron disintegration by the solar neutrinos:

$$\nu_x + d \longrightarrow \nu'_x + n + p\,, \tag{1}$$

$$\nu_e + d \longrightarrow e^- + p + p\,. \tag{2}$$

These reactions have recently been intensively studied by the SNO collaboration [4,5] aiming to demonstrate the existence of the neutrino oscillations.

In order to relate the yield of the reactions observed in SNO to the corresponding solar neutrino flux one needs to know the neutrino-deuteron breakup cross sections. These cross sections were carefully evaluated (i) in refs. [2,6,7], where the study was based on the tree currents and the nuclear wave functions generated from realistic nuclear potentials; (ii) in ref. [3] within the framework of the pionless effective field theory, where the cross sections for the reactions (1) and (2)depend on one unknown constant $L_{1,A}$.

To assess the global model dependence of the reaction rates for the breakup processes (1) and (2) we considered [1] the integral yield

$$Y \,=\, \int_0^\infty \Phi_{^8B}(E_\nu)\,\sigma(E_\nu)\,dE_\nu\,, \tag{3}$$

where $\Phi_{^8B}(E_\nu)$ is the normalized spectrum corresponding to the decay of ^8B and the cross section $\sigma(E_\nu)$ is given as

$$\sigma(E_\nu) \,=\, \int_0^{T_l^{max}} \frac{d\sigma}{dT_l}(E_\nu, T_l)\,dT_l\,. \tag{4}$$

Here T_l is the (kinetic) energy of the outgoing (charged) lepton.

The reactions (1) and (2) are triggered by the weak axial current that has one- and two body parts. The main part of the weak axial exchange current contains the model independent ρ-π current and the Δ excitation currents that are model dependent. In our calculations, we adopted the standard π-N-Δ and ρ-N-Δ Lagrangians [8] (model I) and also the gauge symmetric Lagrangians proposed recently [9] (model II). To generate the nuclear wave functions, we used the potentials Nijmegen I (NijmI) and Nijmegen 93 (Nijm93) [10].

We also extracted the low energy constant $L_{1,A}$ from comparison of the cross sections based on the potential models and the EFT form [3]

$$\sigma_{EFT}(E_\nu) \,=\, a(E_\nu) \,+\, L_{1,A}\,b(E_\nu)\,, \tag{5}$$

by averaging (av) or using the least square fit (lsf).

The partial results of our analysis of the reaction rates (3) are presented in Table 1.

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Table 1: *Reaction rates $Y(\times 10^{-42}\mathrm{cm}^2)$ for the weak deuteron breakup by the ^8B neutrinos in the charged (ccd) and neutral current channels (ncd) using the model currents I and II. The yield ratio is $R_i = Y_i(ccd)/Y_i(ncd)$, for i=I, II. In the columns labeled by NijmI and Nijm93, the cross sections are calculated with the wave functions generated from these potentials, the cross sections of the column AV18 are taken from Table I of [6]. The cross sections of the columns labeled by lsf and av are calculated from Eq. (5) with the constant $L_{1,A}$ extracted by the least square fit and by averaging, respectively. In the last column $\Delta S/S$ is the maximum deviation of the quantity corresponding to the given row in per cents.*

		NijmI	lsf	av	Nijm93	lsf	av	AV18	lsf	av	$\Delta S/S$
Y_I	ccd	1.205	1.200	1.193	1.217	1.213	1.205	1.210	1.209	1.207	1.3
Y_I	ncd	0.470	0.468	0.470	0.471	0.469	0.471	0.470	0.470	0.470	0.6
R_I		2.56	2.58	2.54	2.58	2.59	2.56	2.57	2.57	2.57	2.0
Y_{II}	ccd	1.185	1.181	1.173	1.195	1.191	1.183	-	-	-	1.8
Y_{II}	ncd	0.462	0.460	0.462	0.462	0.460	0.462	-	-	-	0.4
R_{II}		2.57	2.57	2.54	2.59	.59	2.56	-	-	-	2.0

In conclusion we note that we have evaluated the spread of the calculated cross sections, and of the corresponding reaction yields, for the electron neutrino from ^{8}B decay induced deuteron breakup reactions. The spread is caused by the different choices of the one-boson-exchange potentials, and in particular, by the ways the Δ excitation currents are treated. Choosing such spread as a measure of the uncertainty we conclude that the neutral current breakup is ~ 2.3 % uncertain, and the charged current one is ~ 3.1 % uncertain. The ratio of the charged to neutral current reaction rates is then ~ 2 % uncertain, using this criterion. These uncertainties are smaller, but basically comparable, to the full effect of the two-body currents. Thus, we have to conclude that the evaluation of the effect of the two-body currents remains to be quite uncertain. We have verified that our conclusions are not changed noticeably when the realistic thresholds and resolution functions of the SNO experiment are used.

This work was supported by the Grant Agency of the Czech Republic (grant No. 202/06/0746).

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Photoproduction of neutral kaons

P. Bydžovský and M. Sotona

The electromagnetic production of strangeness on nucleons provides us with additional information about the structure and interactions of baryons. Besides the information about the reaction mechanism, form factors of hadrons and new "missing" resonances we also need a correct description of the elementary process to study the electroproduction of hypernuclei [1]. Many new good quality experimental data for the K^+ production allow to perform a thorough analysis of the elementary process [2]. The recent data on the photoproduction of neutral kaons off nuclei from Tohoku University [3, 4] is of special importance since it facilitates doing more rigorous tests of elementary amplitudes [5]. We took the active part in the physical analysis and interpretation of the data [3, 4]. We have shown that the cross section for the photoproduction of K^0 on the deuteron is very sensitive to the elementary amplitude [5] and that the data can, therefore, discriminate between the elementary models which otherwise fit the K^+ data equally well.

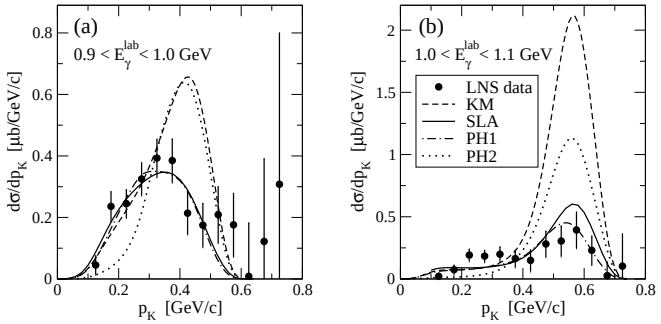

Fig. 1: Inclusive energy-averaged and kaon-angle-integrated momentum spectra for d(γ,K^0)YN' (Y=Λ or Σ). Calculations are performed for the Λp final state (Contributions of the Σ channels are very small in the lower-energy region (a) and at the spectator-kinematics region (the main peak) in (b)). Data are from Ref. [4].

In Figure 1 we show results of calculations with different elementary amplitudes in comparison with the Tohoku data. The Kaon-MAID model (KM) [6] does not describe the data well, especially at the spectator-kinematics region. The Saclay-Lyon model (SLA) [7], fitted to the data in the lower-energy region, gives good results in both energy regions. The phenomenological prescriptions PH1 and PH2 were used to demonstrate a sensitivity of the inclusive spectra to the angular dependence of the elementary cross sections. The angular dependence differs for the discussed models (see Ref. [4] for more details). The analysis shows that the Tohoku data prefer models which give a backward-peaked cross section for the n(γ,K^0)Λ process.

This work was supported by the Grant Agency of the Czech Republic (grants No. 202/05/2142 and 202/08/0984).

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$\bar{K}$-nuclear quasibound states

D. Gazda, J. Mareš and N.V. Shevchenko

We performed the first genuinely three-body $\bar{K}NN - \pi\Sigma N$ coupled-channel Faddeev calculation of the $I = 1/2$, $J^\pi = 0^-$ $\bar{K}NN$ system, finding a deeply bound and broad quasi-bound state, which is a resonance in the $\pi\Sigma N$ channel [1]. The calculations yielded binding energy $B_{K^-pp} \sim 50 - 70$ MeV and width $\Gamma_{K^-pp} \sim 90 - 110$ MeV. It was shown that the explicit inclusion of the second channel is crucial for this system. A complex $\bar{K}N$ potential gives much shallower and narrower three-body quasi-bound state than a full coupled-channel calculation, which has the same range parameter and reproduces the same $\bar{K}N - \pi\Sigma$ observables [2].

We studied in detail the interplay between the underlying dynamical processes and the relevant kinematical conditions which determine the decay widths Γ_{K^-} of deeply bound $\bar{K}$–nuclear states. The widths Γ_{K^-} are mostly determined by phase-space suppression on top of the increase provided by the compressed nuclear density [3]. The results of our comprehensive self-consistent calculations suggest that K^- total decay widths for deeply bound K^- nuclear states ($B_{K^-} > 100$ MeV) are substantial, $\Gamma_{K^-} \sim 50 - 100$ MeV [4], as shown for ^{40}Ca in Fig.1.

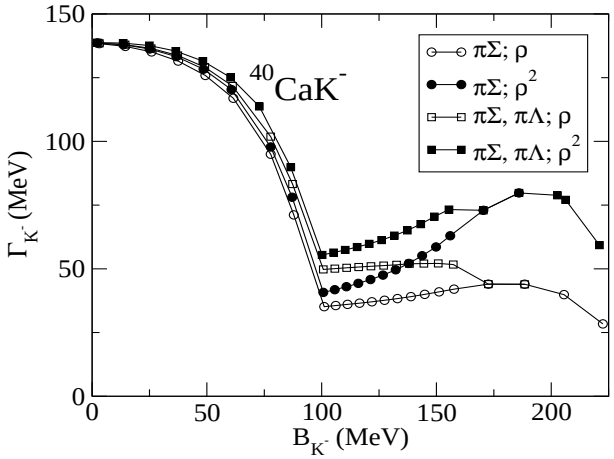

Fig. 1: Widths calculated for the $1s$ K^- quasibound state in ^{40}Ca for absorption through $\bar{K}N \to \pi\Sigma$ with or without $\bar{K}N \to \pi\Lambda$ and with ρ or ρ^2 dependence for $\bar{K}NN \to \Sigma N$ [4].

Multi-$\bar{K}$ nuclear calculations indicate that the separation energy $B_{\bar{K}}$, as well as the associated nuclear and $\bar{K}$-meson densities, saturate with the number of $\bar{K}$ mesons embedded in the nuclear medium. The saturated values of $B_{\bar{K}}$ were found generally to be below 200 MeV, considerably short of the threshold value ≈ 320 MeV needed for the onset of kaon condensation under laboratory conditions. We conclude, that $\bar{K}$ mesons do not provide the physical 'strangeness' degrees of freedom for self-bound strange dense matter [5].

The work was supported by the GA AVCR grant A100480617.

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Dynamical breakdown of Abelian gauge chiral symmetry by strong Yukawa interactions

P. Beneš, T. Brauner, J. Hošek

Generation of masses of elementary particles is one of the major challenges of contemporary high-energy physics. The conventional Higgs mechanism, being a part of the Standard model, provides an operationally well-defined framework. On the other hand, it has its own theoretical drawbacks which lead to the widely shared opinion that it is merely an effective description rather than the ultimate explanation of the origin of masses. Over the years numerous alternatives have been suggested, mostly based on the idea of dynamical breaking of the electroweak symmetry. The simplest of them have already been ruled out by inconsistency with current precision electroweak data, while others will be checked once the Large Hadron Collider at CERN starts operating.

In this contribution we propose a novel mechanism of dynamical electroweak symmetry breaking based on a strong Yukawa interaction of the Standard model fermions with new heavy scalars [1]. Details of calculations can be found in the original paper [2]. The logic is as follows. First, the strong interaction breaks the global chiral symmetry dynamically via quantum loop effects. Subsequently, after the chiral symmetry is gauged, the associated gauge bosons acquire nonzero masses. In order to elucidate the idea in a simple setting, we consider a toy model with just two fermion species and an Abelian chiral symmetry.

Our model is defined by the Lagrangian

$$\mathcal{L} = \bar{\psi}_1 i\not{D}\psi_1 + \bar{\psi}_2 i\not{D}\psi_2 + (D_\mu\phi)^\dagger(D^\mu\phi) - M^2\phi^\dagger\phi - \frac{1}{2}\lambda(\phi^\dagger\phi)^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \\ + y_1(\bar{\psi}_{1L}\psi_{1R}\phi + \bar{\psi}_{1R}\psi_{1L}\phi^\dagger) + y_2(\bar{\psi}_{2R}\psi_{2L}\phi + \bar{\psi}_{2L}\psi_{2R}\phi^\dagger). \quad (1)$$

The Lagrangian possesses a global $\mathrm{U(1)_{V_1}} \times \mathrm{U(1)_{V_2}} \times \mathrm{U(1)_A}$ symmetry. The first two factors correspond to independent conservation of the number of the two fermion flavors. Their axial transformations are coupled by their Yukawa interaction with the scalar ϕ. The axial part of the symmetry is gauged by introducing the covariant derivatives and adding the kinetic term for the Abelian gauge boson A_μ. The two fermions carry opposite axial charges in order to ensure the cancellation of the axial anomaly.

As mentioned above, we first investigate the theory (1) with the gauge interaction switched off. We find symmetry-breaking self-energies of the fermions and the scalar by a non-perturbative self-consistent solution of the Schwinger–Dyson equations [3]. These in general constitute an infinite tower of coupled integral equations for the Green's functions of the theory. In order to make the problem tractable, we truncate them at the level of the propagators, that is, neglect quantum corrections to the interaction vertices. In the fermion sector spontaneous symmetry breaking manifests itself in the chirality-changing scalar self-energies, $\langle\psi_L\bar{\psi}_R\rangle$, denoted as $\Sigma_{1,2}$, which yield nonzero fermion masses upon solving the pole conditions. In the scalar sector, spontaneous symmetry breaking results in the anomalous self-energy $\langle\phi\phi\rangle$. As a consequence, the complex field ϕ cannot describe a charged scalar particle and its antiparticle, but rather two real scalar particles whose mass splitting is proportional to $\langle\phi\phi\rangle$.

The numerical results obtained from the Wick-rotated Schwinger–Dyson equations are displayed in Fig. 1. Nontrivial symmetry-breaking solutions only exist when the Yukawa couplings $y_{1,2}$ are strong enough. In the largest part of the parameter space [regions (I) and (III)] only one of the fermions becomes massive. Close to the "diagonal", $y_1 = y_2$, both fermions acquire dynamically generated masses. In the region (IV) the Euclidean scalar propagator develops a pole and the Schwinger–Dyson equations no longer have a real solution. Within the region (II), but close to the borders with regions (I) and (III), the mass of one of the fermions becomes very small. Our model is therefore capable to explain huge fermion mass ratios, yet with Yukawa

couplings of the same order. For instance, with $y_1 = 77.4$ and $y_2 = 88$, we find $m_1^2/m_2^2 = 10^{-2}$. We consider this feature as one of the main virtues of our approach, the other one being its conceptual simplicity; in contrast to technicolor or similar scenarios, we only need to introduce new heavy scalars in addition to the particles already present in the Standard model. It remains to be seen, of course, whether such a simple framework can reasonably reproduce the pattern of masses of all three known families of the Standard model fermions.

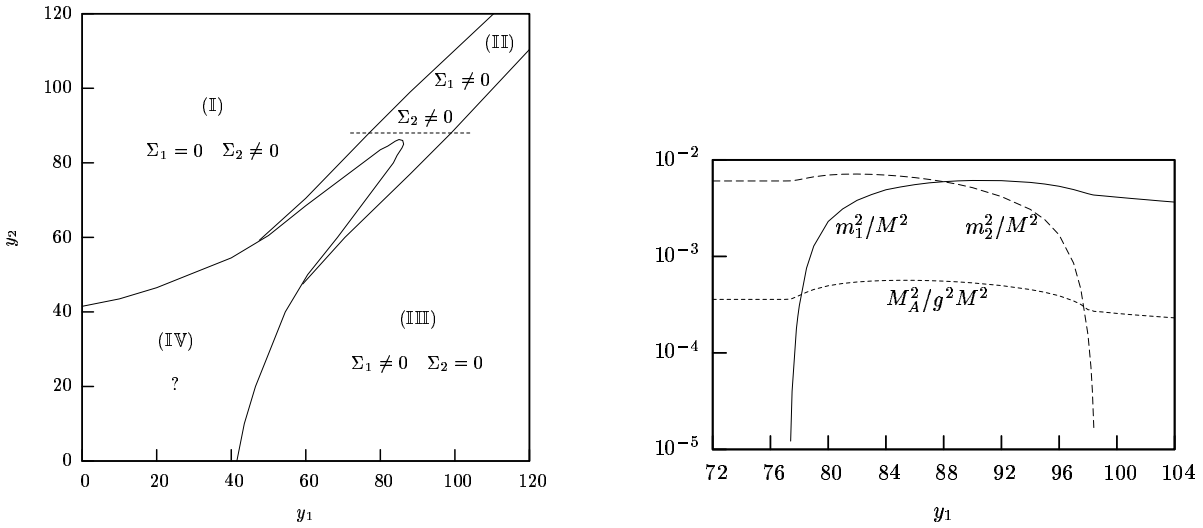

Fig. 1: *Left panel: different types of solutions in the plane of the Yukawa couplings. In the region labelled as* (IV) *the Euclidean scalar propagator has a pole. The dashed line indicates the cross section, along which the fermion and gauge boson masses are evaluated, shown in the right panel of the plot.*

Once the global symmetry is spontaneously broken, we can achieve dynamical generation of the intermediate vector boson mass by gauging it. The necessary condition for nonzero gauge boson mass is a (massless) pole in its polarization tensor [4]. Its residuum then approximates the mass squared of the gauge boson [5]. The massless pole arises from the presence of the Nambu–Goldstone boson of the spontaneously broken global symmetry, which by definition couples to the broken current, hence also to its gauge boson. The value of the coupling may be extracted from the Ward–Takahashi identity for the vertex of the broken current with the fermions and the scalar and their symmetry-breaking propagators [5]. As a result one obtains a sum rule which relates the gauge boson mass to the dynamically generated fermion and scalar masses. This is yet another distinguishing feature of our model.

To conclude, we have presented a novel mechanism of dynamical chiral symmetry breaking, and thus fermion mass generation. Upon gauging the symmetry, this provides a natural candidate to explain spontaneous symmetry breaking in electroweak interactions. The most promising features are the possibility to reproduce vast fermion mass ratios with Yukawa couplings of the same order, and a nontrivial relation between fermion and gauge boson masses.

This work was supported by the Grant Agency of the Czech Republic (grants No. 202/05/H003 and 202/06/0734).

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Location of the nodal set of vibrating membranes

P. Freitas[1], D. Krejčiřík

The simplest mathematical model for a vibrating membrane with fixed edge is the Laplace operator in a planar domain, subject to Dirichlet boundary conditions. The eigenfunctions and eigenvalues of the associated spectral problem are modes and squared frequencies of vibrations, respectively. The zero set of an eigenfunction corresponds to stationary points of the membrane vibrated in a resonant frequency; it is a curve known as the *nodal line*. Depending on the geometry of the membrane, the nodal line forms peculiar shapes, namely various crossing curves or closed loops. It turns out that the shape of the nodal line is directly related to the acoustic properties of the membrane. In particular, it is important to know whether the nodal line of the second eigenfunction can form a closed loop or not.

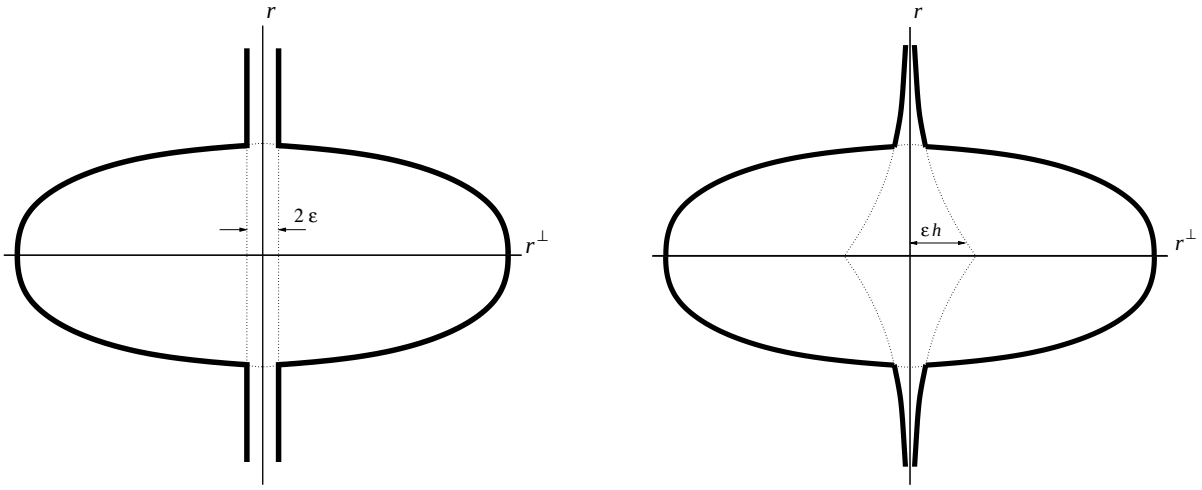

Fig. 1: *Typical unbounded domains for which the nodal line (here coinciding with the axis r) of the second eigenfunction does not touch the boundary.*

In this context, the famous *conjecture* of Payne's [5, (1967)] states that the nodal line of any second eigenfunction of the Dirichlet Laplace operator in any bounded two-dimensional Euclidean domain touches the boundary. So far, it was shown that the conjecture holds for convex domains [4, (1992)] and there exist counterexamples with multiply connected domains [3, (1997)]. Nevertheless, it is still an open question whether the conjecture holds for simply connected domains. Let us also mention that the study of nodal sets of eigenfunctions may be extended in a natural way to higher dimensions, manifolds and unbounded domains with discrete spectra.

In collaboration with Prof. P. Freitas (Lisbon), we contributed to this research field by establishing the following results:

First, in [1, (2007)], we constructed a *counterexample* showing that the restriction to bounded domains is crucial in the conjecture – see Figure 1.

Second, in [2, (2008)], we proved the conjecture for *thin curved tubes* in any dimensions (including *multiply* connected tubes). Actually, it is for the first time when the conjecture was proved for *non-convex* domains without any symmetry conditions. Moreover, we

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located the nodal set near the zeros of solutions of an ordinary differential equations associated in a natural way with the geometry of the tube.

The mathematical handling of the problems itself deserves attention, since it involves a combination of various methods from spectral theory, perturbation theory, partial differential equations and differential geometry in a refined way.

The work was supported by the Czech Academy of Sciences and its Grant Agency within the projects IRP AV0Z10480505 and A100480501, by the project LC06002 of the Ministry of Education, Youth and Sports of the Czech Republic, and by FCT/POCTI/FEDER, Portugal.

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Dynamics of charged fluids and the feasibility of the method of perturbation expansions in the specific dynamical regime of large angular modes

M. Znojil, U. Günther[1]

Classical physics which controls the dynamics of conductive fluids finds numerous applications in non-quantum, large-scale phenomenology. Typically, these applications range from geology (explaining the stability of the magnetic field of the Earth) to astrophysics (where the magnetic fields of stars and galaxies are successfully described via complicated partial differential equations of magnetohydrodynamics).

On this background it proved extremely surprising to reveal that the theoretical description of such fluids appears very closely connected to the mathematics of time-evolution of microscopic, *quantum* systems controlled by so called Pseudo-Hermitian Hamiltonians. These parallels have extensively been reported by the authors from Dresden group during several conferences on Pseudo-Hermitian Hamiltonians organized or co-organized by NPI, during years 2004 - 2007, in Prague, Istanbul and Stellenbosch (cf. papers [1-4]).

A steadily intensifying collaboration between several research centers including NPI in Řež and FZ in Dresden resulted in the discoveries of several new quantum models exhibiting the so called PT-symmetry (cf., e.g., paper [5]). In an opposite direction the transfer of methods of quantum theory (and, in particular, of the well known method of $1/\ell$ expansions as summarized, e.g., in [6]) beyond its natural domain proved successful and productive in 2007 when a particularly interesting magnetohydrodynamics-oriented result has been obtained and published in paper [7]. The essence of the latter methodical proposal is to be briefly outlined in its present brief annotation.

Firstly, let us mention that in the context of (classical) physics our main attention has been paid to the role played by the magnetic fields in the development of the so called dynamo effect. For this purpose we considered the complicated dynamical equations in their comparatively drastic simplification to certain spherically symmetric field configurations under a mean field approximation. The resulting, so called α^2-dynamo model can be then characterized by a coupled pair of *ordinary* differential equations

$$-\partial_r^2\phi(r)+V_u(r)\,\phi(r)-\alpha(r)\,\chi(r)=-\lambda\,\phi(r), \tag{1}$$

$$-\partial_r^2\chi(r)+V_d(r)\,\chi(r)+\partial_r\alpha(r)\partial_r\phi(r)-V_m(r)\,\phi(r)=-\lambda\,\chi(r) \tag{2}$$

where the dynamical flow-induced back-reaction (the so-called $\alpha-$profile $\alpha(r)$) "lives" on interval $r\in(0,R)$ while the kinematical functions $V_u(r)=V_d(r)=V_m(r)/\alpha(r)=\ell(\ell+1)/r^2$ grow quadratically with the angular mode number of the field $\ell=0,1,\ldots$.

Formally, the key challenge lies in the presence of the mixed (Robin) boundary conditions

$$\phi(0)=0,\qquad [\partial_r\phi(r)|_{r=R}+\frac{\ell}{R}\,\phi(R)=0, \tag{3}$$

$$\chi(0)=\chi(R)=0\,. \tag{4}$$

In our proposal we imagined that although the implementation of these (often called "realistic") boundary conditions leads to the serious mathematical difficulties in general, these difficulties decrease with the growth of the integer parameter ℓ, reminding us strongly about the similar quantum-mechanical bound-state eigenvalue problems where the so called $1/\ell$ perturbation expansion methods prove, as a rule, extremely useful and efficient (cf. review [6] for a few very persuasive illustrations).

Our detailed study of the problem revealed its nontriviality resulting from the emergence of several *parallel* mathematical obstructions which disabled us from a direct and quick transfer of

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methods between quantum and classical world. Anyhow, a mathematically consistent path has finally been found towards the use of the inverse mode number ℓ as *the* effective small parameter of the theory of spherically symmetric α^2-dynamos.

A key to our final success has been found in the use of two independent bases *followed* by their coincidence at large ℓ *and further followed* by their rather unusual further split into a pair of two other bases in the "unperturbed" limit. Although such a double trick might look rather subtle, we showed that it makes the transition to the large $\ell \gg 1$ feasible, mainly due to an underlying smearing of boundary conditions. This opened the way towards the universal and more or less routine applicability of our innnovated perturbation formalism of large$-\ell$ expansions

The core of our message is most easily summarized after a full final return to the language of physics. In it one translates our "softening" of the boundary conditions as a two-step removal of the original asymmetry between the (easier) toroidal and (more complicated) poloidal channels. Precisely this asymmetry appears, in our formalism, removable via a fundamental, purely geometric necessary and sufficient supplementary condition. This condition made the method completed and well prepared for its potential phenomenological applications.

This work was mainly supported by the Saxonian Ministry of Science (MZ, grant Nr. 4-7531.50-04-844-06/5) and by the German Research Foundation DFG (UG, grant GE 682/12-3), partially also by GAČR (MZ, grant Nr. 202/07/1307) and by MŠMT ČR (MZ, "Doppler Institute" project Nr. LC06002).

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DEPARTMENT OF NUCLEAR SPECTROSCOPY

Activities carried out at our department are devoted to the latest trends in the experimental nuclear physics and radio-chemically based activation analysis. The collaboration with prominent abroad research institutions plays key role in work of the department. Three groups of the department are since 2007 part of two "Centers of basic research", projects supported by Ministry of Education, Youth and Sports, Czech Republic with the aim to promote the existing and future collaboration among the researchers from participating institutions in order to make the research more effective. The joined teams consists of experienced and talented researchers as well as a strong and active group of young postdocs, PhD and diploma students.

Centre of Experimental Nuclear Astrophysics and Nuclear Physics (CENAP - project LC07050) has broad range of topics related to the Astrophysics exploiting our knowledge in Nuclear Physics studied in collaborating Czech Technical University (Prague), Silesian University (Opava) and our institute. Particularly in our department study of hadron properties inside hot and dense baryonic matter is carried out by Relativistic Heavy Ion Physics Groups, which is member of HADES collaboration at SIS (GSI, Germany) and CBM collaboration at FAIR (GSI, Germany). Members of Electron Spectroscopy Group are participating in the building of KATRIN project (FZ Karlsruhe) with the aim to find out whether the electron neutrino mass is above 0.2 eV or not.

Centre of Physics of Ultra-relativistic Nucleus-nucleus Collisions (project LC07048) is devoted to study of strongly interacting matter and quark-gluon plasma, which is carried out by STAR collaboration at RHIC (BNL, USA) and in future it will be performed within ALICE collaboration at LHC (CERN). These activities are carried out by Czech scientist based in our department and in Czech Technical University (Prague).

In addition to scientific activities carried out in above mention framework, spectroscopy techniques are exploited by Group of Activation Analysis. This group is involved in the development of advanced neutron and photon activation analysis procedures, in both non-destructive and radiochemical modes, and their applications in multidisciplinary research, namely in environmental, biomedical geo- and cosmo-chemical sciences. Particularly it was involved in analysis of sandstones of Angkor temples, Khmer Empire (Cambodia), which were included into the World heritage list in 1992.

Experiments devoted to the measurement of magnetic moments of nuclei exploiting low temperature nuclear orientation are carried out by our colleagues in the frame of broad experimental project probing isospin structure of nuclei at ISOLDE facility (CERN).

Standard spectroscopy techniques based on detection and analysis of gamma spectra emitted by irradiated foils (activation detectors) are exploited by our colleagues involved in detailed studies of neutron production and transport with the aim to verify and improve currently available simulation codes suitable for future design of accelerator driven transmutation systems. Studies are carried out in framework of EFNUDAT project supported by EU as well as of "Energy and Transmutation" collaboration based in JINR Dubna.

All above mentioned activities are carried out at the Department exploiting particularly accumulated experience of our technical staff with various particle and photon detectors as well as exploiting the installed small computer center incorporated into international GRID network.

Several senior researchers of our department read lectures for University students and/or supervise diploma works and doctoral dissertations. And – the last but not the least – they are also involved in outreach activities, particularly writing articles for popular journals and giving lectures to general public about the physics of micro world.

Open charm production in heavy ion collisions at RHIC

J.BIELČÍK, J.KAPITÁN AND M.KRŮS

Suppression of inclusive hadrons with high transverse momentum (p_T) observed in central Au+Au collisions at RHIC is generally interpreted as a consequence of energy loss of fast light partons in nuclear matter. The understanding of energy loss mechanism is an essential part when extracting the information about the properties of nuclear matter created in the collision.

One of the channels used in STAR to measure the open charm production is the measurement of non-photonic electrons (NPE). The NPE are extracted from inclusive electron yield by subtraction of contribution of electrons from gamma conversion and Dalitz decays. They are dominated by electrons from semileptonic decays of charm and bottom.

STAR has previously reported the yields of high-p_T from p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [1]. In central Au+Au collisions the unexpectedly strong suppression was observed, similar to suppression of inclusive hadrons. Recently STAR measured the non-photonic electrons also in Cu+Cu at $\sqrt{s_{NN}}$=200 GeV [2]. The extracted nuclear modification factor of R_{AA}=0.62±0.10(stat.)+0.14−0.16(sys.) for centrality 0-54% is consistent with the suppression of charged pions and the previous measurement of non-photonic electrons in Au+Au collisions.

Additional information about the interaction of heavy quarks with nuclear matter can be inferred from azimuthal correlation between high-p_T (3-6 GeV/c) non-photonic electrons and low-p_T (0.15-0.5 GeV/c) hadrons. The broad modification of the awayside peak in both Cu+Cu and Au+Au central collisions (Fig.1) similar to the di-hadron correlations in Au+Au was observed [3]. This is probably consequence of heavy quarks interaction with the dense nuclear medium.

For the precision study of heavy-flavor quark energy loss and collectivity, direct reconstruction of heavy-flavor hadrons is necessary. The Heavy Flavor Tracker (HFT), a proposed upgrade [4-5] to the STAR experiment, will enable measurement of open charm hadrons by reconstructing their displaced decay vertices. The simulations of HFT detector physics performance showed that it enables to measure D^0 transverse momentum spectra up to 10 GeV/c and D^0 eliptic flow from 0.5 GeV/c up to 5 GeV/c .

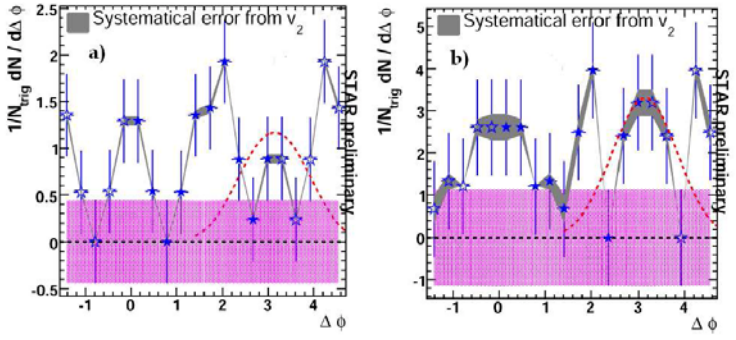

Figure 1. Non-photonic electron-hadron correlations. Panel a) shows correlation in Cu+Cu collisions at 200 GeV, panel b) in Au+Au collisions at 200 GeV after v_2 subtraction ($v_2 = 0.05$). The error bars are statistical and the error band represents ZYAM systematical uncertainty. The dashed curve is the PYTHIA prediction of the away side peak.

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Long-range pseudorapidity correlations in heavy-ion collisions at RHIC

J. Bielčíková for the STAR Collaboration

Heavy-ion collisions at RHIC are a unique environment for investigation of nuclear matter under extreme conditions of high temperature and energy density. One of the notable findings discovered by the STAR experiment in central Au+Au collisions was the observation of an additional long-range pseudo-rapidity ($\Delta\eta$) correlation on the near-side, *the ridge*, which is absent in p+p and d+Au collisions [1].

The ridge studies with charged particles showed that the ridge yield is roughly independent of p_T of the trigger particle (p_T^{trig}) and the p_T spectra of associated particles are similar to the bulk. Recently we have performed detailed measurements of the centrality, system size and collision energy dependences of the ridge for several trigger particle species [2,3]. At a given N_{part} and collision energy the ridge is however independent of the collision system (Fig.1, left). In contrast, the jet-like yield at given $\sqrt{s_{NN}}$ is, within errors, independent of centrality and collision system and is consistent with that measured in d+Au collisions. Both the ridge and jet-like yields are considerably smaller in collisions at $\sqrt{s_{NN}} = 62$ GeV than at $\sqrt{s_{NN}} = 200$ GeV, but the ratio of the two yields remains independent of collision energy. It is also important to investigate particle composition in the ridge which could help to determine the physics origin of the ridge. While the p/π and Λ/K^0_S ratios (Fig. 1 (right)) [3,4] in the jet agree with those measured in p+p, the baryon/meson ratios in the ridge are close to those from the inclusive measurements.

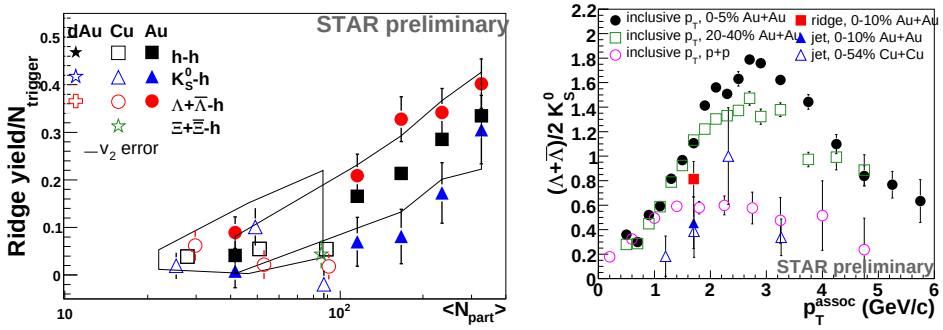

Fig. 1: *(Left) Centrality dependence of ridge yield in d+Au, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The trigger particles were selected with p_T^{trig} =3-6 GeV/c and the associated particles with 1.5 GeV/c $< p_T^{assoc} < p_T^{trig}$. The lines are systematic uncertainties due to the elliptic flow subtraction for unidentified trigger particles. (Right) Λ/K^0_S ratios in jet, ridge and inclusive spectra in p+p, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.*

Further studies at higher-p_T^{trig}, using γ-hadron correlations as well as more differential studies (ridge dependence on the reaction plane, 3-particle $\Delta\eta$ correlations) are being pursued in STAR. Several models are qualitatively able to describe the ridge phenomenon: coupling of induced gluon radiation to longitudinal flow, turbulent color fields, anisotropic plasma, a combination of jet-quenching and strong radial flow, recombination of locally thermal enhanced partons due to partonic energy loss or momentum kick parton acquires while propagating in the medium (for a review see [4]). More quantitative model predictions are required. Ideally, the models should be able to describe simultaneously energy content in the ridge, nuclear modification factors and the interplay of the medium modification of both near and away-side correlation peaks.

Acknowledgments: The work has been supported by the IRP AVOZ10480505, by the grant GACR 202/07/0079 and the grant LC07048 of the MSMT of the Czech Republic.

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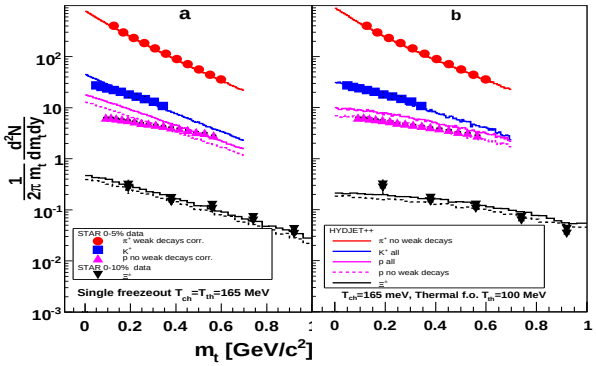
$\pi - \Xi$ correlations: model comparison and $\Xi^*(1530)$ puzzle

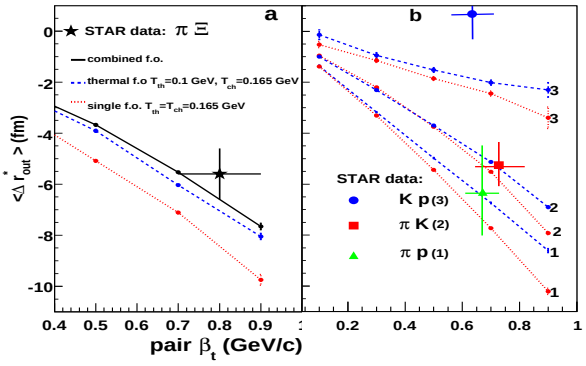
P. Chaloupka, L.V. Malinina[1] and M. Šumbera

Femtoscopic measurements provide important insight into the space-time evolution of the system created in collisions of ultra-relativistic nuclei. The high-statistics data accumulated at RHIC and SPS allow to conclude that space-time structure of the source is strongly affected by collective expansion of the hot and dense matter. Final state interaction between pairs of non-identical particles provides information about the average relative space-time separation between the emission points of two particle species in the pair rest frame [1]. Preliminary results for $\pi^{\pm}\Xi^{\pm}$ system available from STAR Collaboration [2, 3] have revealed that average emission point of the Ξ is positioned more to the outside of the fireball than the average emission point of the pion. This shift may be caused by transverse flow and/or different decoupling time of multi-strange baryons.

To clarify influence of collective flow and resonances on the shift between average freeze-out space time points of Ξ and π we have employed hydrodynamics-parametrized statistical hadronization model HYDJET++ [4]. In [5] we have analyzed particle ratios and m_t-spectra and then the space-time differences of the Ξ and π emission points. We compare different freeze-out scenarios implemented in HYDJET++: *single freeze-out* at $T_{th} = T_{ch}$ and *thermal freeze-out* at $T_{th} < T_{ch}$. In addition to this we introduce into HYDJET++ *combined* scenario when Ξ and $\Xi^*(1530)$ are emitted already at chemical freeze-out while other particles π, K, p are emitted later at the thermal freeze-out.



The m_t-spectra of π^+, K^+, p and $\Xi^{\pm}$ from HYDJET++ within (a) *single freeze-out* scenario and (b) *thermal freeze-out* scenario. STAR experimental data are represented by the solid points, the HYDJET++ calculations by the lines.



The total space-time shift in pair rest frame for (a) $\pi\Xi$ and (b)$\pi p, \pi K, \pi p$ for *combined freeze-out* (solid line), *thermal freeze-out* (dashed line) and *single freeze-out* (dotted line) scenarios compared to STAR data.

Comparison of the m_t-spectra and space-time differences between HYDJET++ and real data was performed. The best agreement with the data was achieved within the *combined* scenario with the following parameters: $T_{ch} = 165$ MeV, $T_{th} = 100$ MeV, $R_{th} = 10$ fm, $\tau_{th} = 8 fm/c$ and $R_{ch} = 9$ fm, $\tau_{ch} = 7$ fm/c. We have also demonstrated that an increase of the relative contribution of Ξ from $\Xi^*(1530)$ decays decreases the $\pi\Xi$ emission asymmetry making an unambiguous interpretation of the results complicated. More precise measurement of Ξ^*/Ξ ratio and $\pi\Xi$ correlation function is thus necessary.

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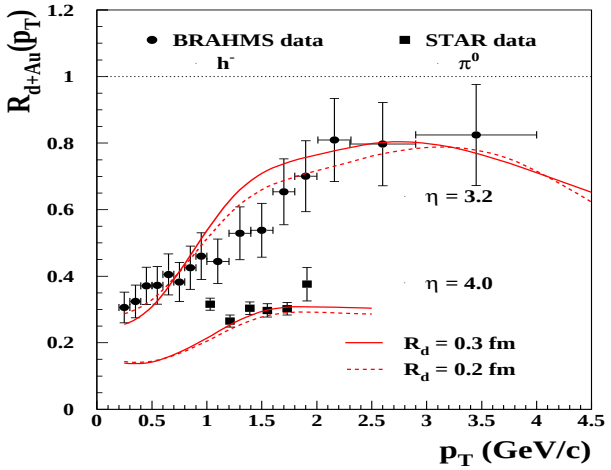
Parton Rescatterings in Large-x Nuclear Suppression at RHIC

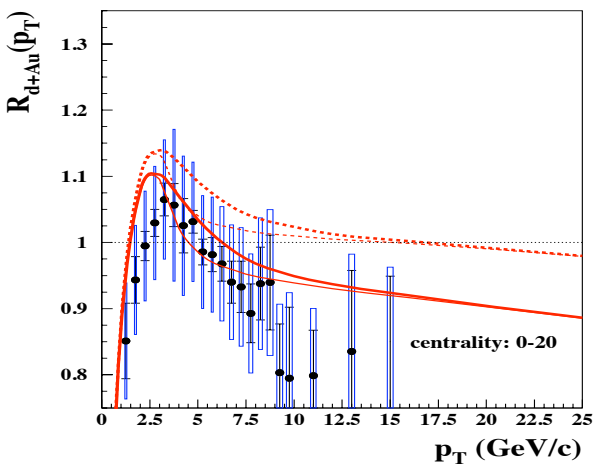
J. Nemchik[1], V. Petráček, M. Šumbera

Spectra of high-p_T hadrons produced in nuclear collisions at large forward rapidities are promising tool to study partonic degrees of freedom in nuclei. Strong nuclear suppression of the spectra observed by the BRAHMS [1] and STAR [2] Collaborations in deuteron-gold collisions at the Relativistic Heavy Ion Collider (RHIC) was a tempting invitation for the parton saturation or the Color Glass Condensate (CGC) motivated phenomenology as its most natural explanation. According to these models the parton coherence phenomena may reveal itself already at RHIC energies showing up first in the wave function of heavy nuclei. Kinematically most favorable region to access the strongest coherence effects is the fragmentation region of the light nucleus 1 colliding with the heavy one 2. At large x_1 (large Feynman x_F at forward rapidities) one can reach the smallest values of the light-front momentum fraction variable $x_2 = x_1 - x_F$ ($2 \times 10^{-4} \leq x_2 \leq 10^{-3}$ in the RHIC kinematic range).

In [3, 4, 5] we have shown that for any large-x reaction considerable nuclear suppression comes from the energy conservation at the level of projectile partons (valence quarks, diquarks and gluons) undergoing multiple rescatterings in nuclear medium. In this model universal and strong nuclear suppression driven by Sudakov factor $S(x_1)$ brings in new scaling: the same nuclear effects at different energies and rapidities corresponding to the same value of x_1. Contrary to CGC models such unified approach allows us to describe the data at forward rapidities (left panel)[3, 4, 5] as well as the physics far outside the region of applicability of coherence phenomena: at RHIC midrapidities for $0.05 < x_2 < 0.1$(right panel) and at lower (SPS, FNAL) energies[4, 6, 7]. It thus seems most likely that the saturation region where the CGC-based models can fully be employed has not been reached yet.



Nuclear modification factor R_{d+Au} for hadrons from $d+Au$ minimum bias collisions at $\sqrt{s_{NN}} =$ 200GeV. Solid and dashed lines are the calculations for different diquark radii.



R_{d+Au} for π^0 from $d+Au$ collisions at $\sqrt{s_{NN}} =$ 200GeV with centrality 0-20%. Solid/dashed lines are the calculations w/o energy conservation restrictions in multiple parton rescatterings. Points are the PHENIX data[8].

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Computing in ALICE and STAR experiments

D. ADAMOVÁ, P. JAKL, M. ZEROLA

The NPI ultrarelativistic heavy ion group participates in two experiments studying strongly interacting matter and the quark–gluon plasma, ALICE at the Large Hadron Collider (LHC) at CERN [1] and STAR at the Relativistic Heavy Ion Collider (RHIC) at BNL [2]. Amount of data to handle by both experiments is enormous. While ALICE after start up of LHC is expected to collect about 4 PB ($4x10^{12}$B) of data per year the STAR experiment is acquiring over 1PB of data per year since 2000.

To manage this huge quantity of data, ALICE has developed a distributed computing infrastructure operated by the Grid middleware AliEn [3] and integrated into the Worldwide LHC Computing Grid (WLCG) [4]. As of today, the project spans over 80 sites representing about 10^4 CPUs and 10 PB of distributed storage. 1-2% of these resources have been delivered by the NPI ALICE group, by means of hardware resources and services provided mainly at the computing center Golias [5] in Prague. The group's responsibility covers local production of simulated data (Monte Carlo simulations of the p+p and Pb+Pb collisions), ~~for~~ control of the end user analysis jobs and maintenance/upgrade of AliEn. During the comprehensive tests of the ALICE computing model and Grid infrastructure in 2007-8, aimed at assessing the physics performance of the detector, the Prague site has contributed by more than 10^5 successfully completed jobs (~ 1,5% of the whole production which represented roughly 330 millions of events). Detailed reports on the NPI ALICE group work for the ALICE Grid project have been presented in [6].

Facing the reality of storage economics, STAR has been engaged in a shift of the analysis model, and now heavily relies on using cheap disks attached to processing nodes. It turns out, that exploiting storage aggregates with enhanced distributed computing capabilities, like dynamic space allocation (lifetime of spaces), file management on shared storages (lifetime of files, pinning file), storage policies or a uniform access to heterogeneous storage solutions, is not an easy task. The NPI contribution in STAR experiment, has thus been targeted on development of a prototype of such a storage aggregation, using low latency data access software suite Xrootd/Scalla. Lately, the work has centered on a fully "gridified" storage solution using the plug-and-play features of Scalla architecture, replacing standard storage access with grid middleware component Storage resource manager [7]. These results are significant also from the viewpoint of grid storage solutions for the LCG.

In order to achieve both fast and coordinated data transfer to collaborative sites as well as to create a distribution of data over multiple sites, efficient data movement is one of the most essential aspects in distributed environment. With such capabilities at hand, truly distributed task scheduling with minimal latencies would be reachable by internationally distributed collaborations seeking for scavenging or maximizing on geographically spread computational resources. But it is often not all clear (a) how to move data when available from multiple sources or (b) how to move data to multiple compute resources to achieve an optimal usage of available resources. Hence another NPI group contribution to STAR has focused on how to resolve the multi-source/multi-site data movement paradigm on the Grid [8]. Using constraint programming, a technique allowing to find solutions in a multi-dimensional space of variables, we have developed a method of creating a model consisting of sites, links and their attributes such as bandwidth for grid network data transfer also considering user tasks as part of the objective function for an optimal solution.

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Dielectron production in A+A and N+N reactions measured with HADES

F. Křížek, A. Kugler, A. Krása, Y. Sobolev, P. Tlustý, V. Wagner
for the HADES [1] collaboration

High Acceptance Di-Electron Spectrometer (HADES) [1] was designed to investigate dielectron emission from heavy ion collisions in the range of kinetic beam energies 1-2 A GeV. Within the rich scientific program of the collaboration, especial attention is devoted (i) to investigation of rare dielectron sources and (ii) to possible modifications of hadron properties inside hot and dense nuclear matter.

In the last two years, HADES measured dielectron production in three systems: d+p at 1.25 A GeV (2007), p+p at 3.5 GeV (2007), and p+Nb at 3.5 GeV (2008). We completed analysis of several previous runs, namely, Ar+KCl at 1.76 A GeV (2005), p+p at 1.25 GeV (2006), and d+p at 1.25 A GeV (2007). Further, HADES collaboration published results of its pioneering runs C+C 1 and 2 A GeV [3,4]. Our group participated also in designing and construction of the Forward Wall detector. The detector was used, e.g., in the d+p run, to pick out the "quasi free" n+p reactions by registering a fast proton spectator from the deuteron projectile.

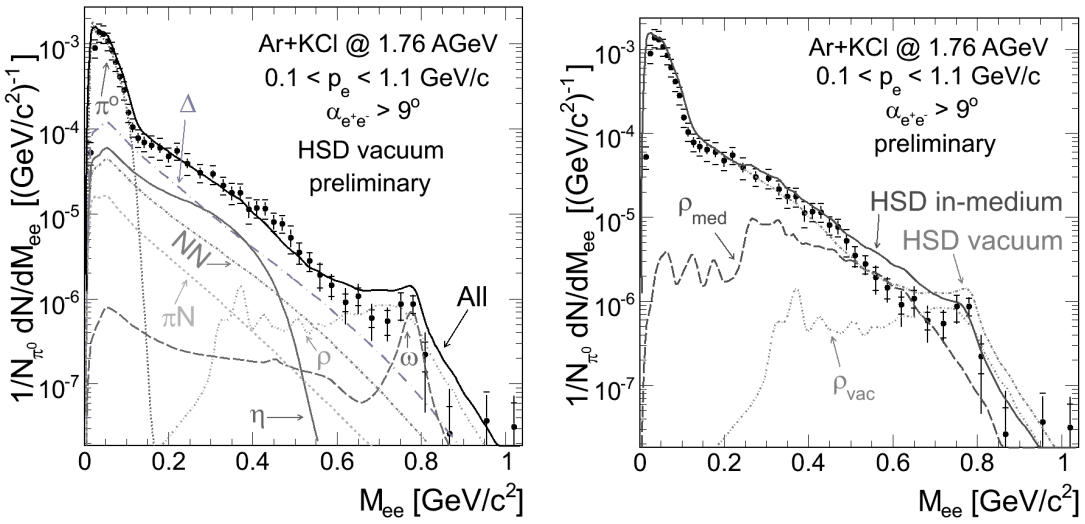

Fig. 1: *Invariant mass distribution of signal e^+e^- pairs from the Ar+KCl run compared with predictions of the HSD transport code [2]. Left: all particles were assumed to have their vacuum properties. Right: ρ^0 and ω changed their width and pole mass based on the surrounding nuclear density. The horizontal error bars of the experimental data points give systematic uncertainty.*

In 2005, the HADES collaboration measured dielectron production in Ar+KCl collisions at a kinetic beam energy of 1.76 A GeV. In Fig 1, we compare an invariant mass spectrum of signal e^+e^- pairs from this run with a dielectron cocktail predicted by the HSD transport code [2]. We may see that HSD provides more or less quantitatively reliable predictions consistent with the measured data. Yet, the code seems to have a problem to describe pair yield in the vector meson mass region. Medium modifications of the vector mesons do not improve the agreement.

A large part of the yield above 0.15 GeV/c^2 can be attributed to short-lived sources which emerge in the early stage of collision, e.g., electromagnetic decays of baryonic resonances (like $\Delta \rightarrow Ne^+e^-$ decay), bremsstrahlung processes, or $\rho^0 \rightarrow e^+e^-$ decay. Up to now, only very little information is known about them. Nevertheless, the dielectron data provided by HADES

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may bring some new insights into this field. By subtracting the contributions of the known late meson decays, like η Dalitz, from the measured dielectron spectrum, we have directly access to the pair yield emitted from the short-lived sources. When we do this procedure for different reaction systems, it is possible to study, how the dielectron yield from the short-lived sources changes with the system size and beam energy.

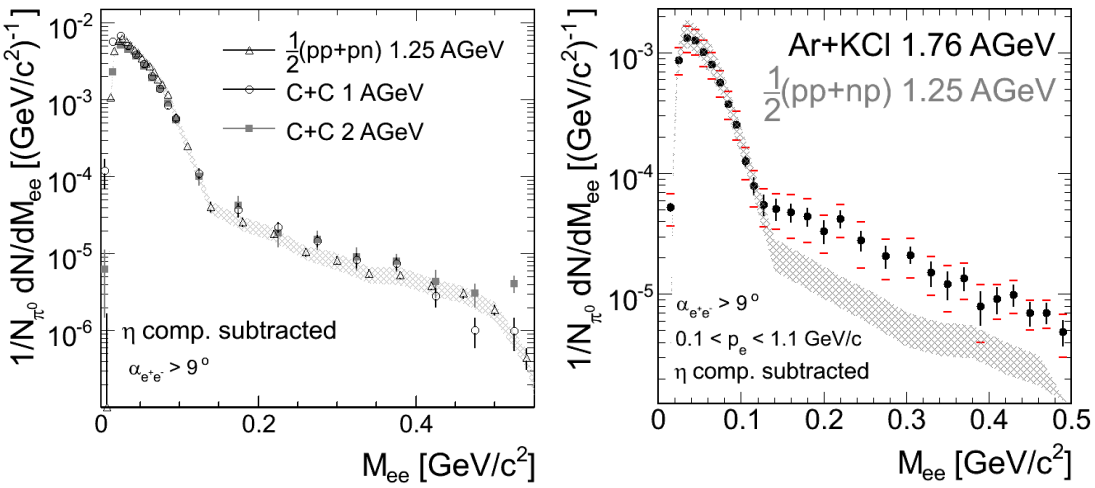

Fig. 2: *Invariant mass distributions of dielectron signal with subtracted $\eta \to \gamma e^+e^-$ contribution. Vertical error bars show statistical errors only. The shaded belt gives systematic uncertainty of (pp+np)/2 spectrum.*

Therefore, HADES examined e^+e^- production in heavy ion collisions and in elementary reactions p+p and quasi-free n+p at 1.25 GeV. In Fig. 2, we contrast dielectron signal from these measurements after the η Dalitz component was subtracted. The π^0 Dalitz component is left in the cocktail to demonstrate that the overall normalization to the total number of neutral pions is under control. In the considered invariant mass range, $0 < M_{ee} < 0.5$ GeV/c^2, contributions from the other long-lived sources, like ω, are negligible. Note, that the dielectron spectra from p+p and p+n were averaged together. The (pp+np)/2 combination gives us an estimate of the dielectron yield which is produced in the first chance collisions.

In the left-hand side panel in Fig. 2, we may see a remarkable agreement between C+C 1 and 2 AGeV data points. This suggests that in the considered mass region, dielectron yield from the short-lived sources scales with the beam energy like π^0 production. Further, we see that the pair mass spectrum from C+C can be well approximated with the elementary (pp+np)/2 cocktail. The shaded band shows systematic uncertainty of the (pp+pn)/2 data points and it gives the reader a measure of our typical systematic errors.

The same kind of comparison can be done also with the reference (pp+pn)/2 cocktail and the Ar+KCl data, see the right-hand side panel in Fig. 2. We see that Ar+KCl points exhibit a strong excess above this cocktail. Let us recall that all spectra are normalized per one neutral pion. Since we know that pion multiplicity scales with the number of participants approximately linearly, the observed enhancement suggests that there is a non linear scaling of the pair yield from the short-lived sources with the number of participants.

This work was supported by the GA AS CR IAA100480803 and MSMT LC 07050.

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Charged pion production in C+C and Ar+KCl collisions measured with the HADES spectrometer

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for the HADES [1] collaboration

The study of particle production in nucleus-nucleus collisions at relativistic energies is essential for understanding the dynamics and the approach of the system towards equilibrium as well as for gaining information about the nuclear equation of state. In case of pions, their phase space distributions and yields are affected by collective effects like thermalization, directed and elliptic flow, as well as by possible modifications of the properties of baryon resonances they stem from, in particular the Δ. The subtle interplay of these phenomena is a challenge to theoretical interpretations, and knowledge of precise experimental data is essential.

We have studied charged pion production in ^{12}C + ^{12}C collisions at incident beam energies of 1A GeV and 2A GeV [1], and ^{40}Ar + ^{nat}KCl at 1.76A GeV [2], using the spectrometer HADES [3] at GSI. We have performed a measurement of the transverse momentum distributions of $\pi^{\pm}$ mesons covering a fairly large rapidity interval, in case of the C+C collision system for the first time. Figure 1 exhibits transverse mass distributions in different intervals of normalized rapidity y_0 and angular distribution of π^- for the reaction ^{40}Ar + ^{nat}KCl at 1.76A GeV.

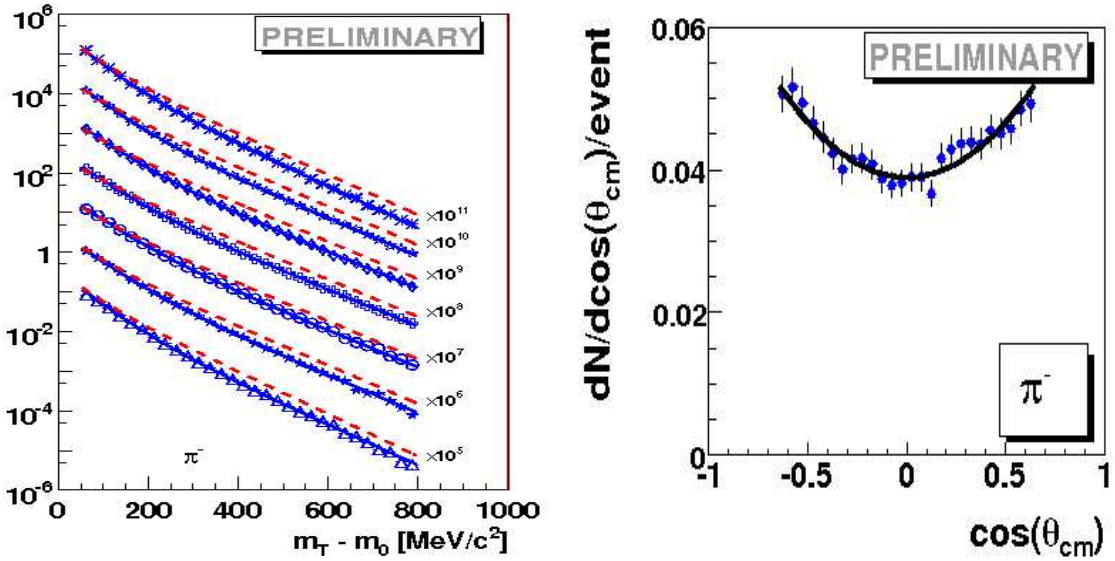

Fig. 1: *Transverse-mass distributions (left) and angular distribution (right) for negatively charged pions.*

The yields, transverse mass and angular distributions were compared with a transport model as well as with existing data from other experiments. A comparison with the results on neutral pions and the UrQMD predictions suggests differences in the reaction dynamics of charged and neutral π mesons, not yet described by transport codes.

This work was supported by the GA AS CR IAA100480803 and MSMT LC 07050.

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Participation in the FAIR project

P. Tlustý, A. Kugler, J. Král [1], A. Krása, F. Křížek, V. Petráček[1], V. Pospíšil[1], and Y. Sobolev, for the CBM and HADES collaborations

The upcoming International Facility for Antiproton and Ion Research FAIR is recently being constructed at GSI Darmstadt. It represents an accelerator complex providing proton, antiproton and heavy-ion beams at energies up to 30 A GeV. The first experiments are expected starting from 2014. Our groups participate in the new CBM experiment [1] designed to study properties of nuclear matter in heavy-ion collisions at beam energies of 20-30 AGeV. The lower energy range from 2-10 AGeV, accessible also with the future accelerator facility, can be covered by an upgrade of the existing HADES di-lepton spectrometer [2].

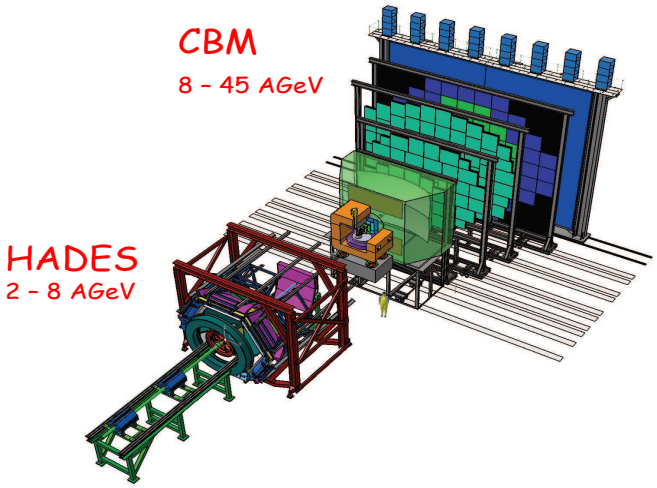

Fig. 1: *Artistic view of the CBM spectrometer (right) along with HADES (left).*

Our involvement in the FAIR project includes the simulations of the measurement with the HADES detector at FAIR energies, activities on the upgrade of the HADES detector for the experiments at FAIR, and participation in developing of the CBM tracking system.

We carried out simulations of dilepton production in heavy-ion collisions at bombarding energies of about 8 AGeV as seen by the HADES detector [3,4]. Results demonstrate that HADES is able to measure dileptons up to this energy. Our participation in the upgrade of the HADES detector for the experiments at FAIR energies includes installation of the Forward Hodoscope for detection of forward emitted spectator fragments, development of the electromagnetic calorimeter for reconstruction of the neutral meson di-photon decay and installation of new fast data acquisition system based on the TRB boards, for details see [5].

In the development of the CBM detector we use our experience with the designing and operating the silicon tracker system in the experiment ALICE. Our activity concentrates on the power supply modules for silicon tracking system STS as well as on the readout electronics of the MAPS modules of the STS detector.

This work was supported by the GA AS CR IAA100480803, and MSMT LC 07050 and LA316.

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A ^{83}Rb/^{83m}Kr source of conversion electrons with their energy stability at the level of ppm

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The mono-energetic conversion electrons from the decay of ^{83m}Kr represent a unique tool for the energy calibration, energy scale monitoring and systematic studies of the tritium beta spectrum measurement in the neutrino mass experiment KATRIN [1]. The long-term monitoring of the high retarding potential of 18.6 kV at a level of about ±60 mV (±3 ppm) in 2 months is necessary. The conversion electrons of the 9.4 and 32.2 keV transitions of the isomeric state of ^{83m}Kr proved to be useful for the calibration and systematic studies in previous tritium neutrino experiments. Particularly, the energy of K conversion electrons of the 32 keV transition is 17824.3(5) eV which is rather close to the tritium endpoint. The production of ^{83}Rb was carried out at the U-120M cyclotron of NPI in Řež with proton beam via the reaction ^{nat}Kr(p,xn)^{83}Rb using a water cooled krypton gas target [2]. The ^{83}Rb/^{83m}Kr sources of conversion electrons were prepared by means of vacuum evaporation. A 50 μm thick aluminium foil or carbon (0.2 mm foil or 1 mm thick disk of highly oriented pyrolytic graphite (HOPG)) served as a ^{83}Rb source backing. During the period 2006-2008, 6 irradiations with krypton gas targets were performed at NPI. From the activity produced, 29 solid ^{83}Rb/^{83m}Kr sources were prepared by vacuum evaporation and measured at gamma and electron spectrometers. The sources were studied in two electron spectrometers, one at NPI Řež (ESA12 differential spectrometer, energy range of 0–20 keV with moderate resolution $\Delta E/E = 0.011$ in the basic measurement mode and resolution ΔE of 1 and 3 eV for energies 2 and 7 keV,respectively in the retardation mode with reduced luminosity) and the second one at Mainz University (integral spectrometer, energy resolution $E/\Delta E = 10000 \div 20000$ for the K-32 electrons, energy range 7-35 keV). Most of the prepared sources were measured in ESA 12 spectrometer, especially the L1 – 9.4 keV conversion line position was accurately determined. The line position was sensitive to the mode of source preparation (chemical procedure and evaporation arrangement) and it was time dependent. The time dependence could be fitted with the straight line with the scatter of individual positions reaching only 60 meV for a period of 3 months or more. The last two vacuum evaporated sources of 5 MBq activities were thoroughly investigated in the Mainz spectrometer. The main attention was paid to the K-32 line position. After installation of the sources into the spectrometer measurements have proceeded for 80 days. After some saturation effect and elimination of some changes in the spectrometer adjustment the drift of K-32 line position was compatible with the stability requirement of ± 60 meV in 2 months.

The experience showed that all future sources must be produced as reproducibly as possible : this concerns not only chemistry,evaporation procedure but even the source activity. Sources with activity of about 10 Mbq and ^{83m}Kr retention of 10–20 % can be used at the monitoring spectrometer for 4–6 months. The further investigation of ^{83}Rb sources will continue including the possibility of ^{83}Rb ions implantation into convenient substrate.

This work was supported by the Grant Agency of the Czech Republic (grants No. 202/06/0002, LA 318 and LC 07050).

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Single-channel spectra evaluation without binning

M. Ryšavý, J. Kašpar

Single-channel measurements are not too frequent today. However, in some experiments they are unavoidable, e.g. in the neutrino experiment KATRIN [1]. When evaluating spectra measured in this manner, the usual method is to re-sort the results (count numbers) into some more or less suitable energy bins. Then, all the items falling into one bin are assumed to have the same energy so that they may be summed together. Into the resulting set of pairs 'energy–counts' the theoretical spectrum shape is then fitted.

Such an approach, however, suffers from a serious shortcoming. The measurement is usually done in "sweeps", i.e. every meshpoint is passed several times. To ensure identical energy in all passes is impossible in practice. And then we sum the counts which do not correspond to the exactly same energy. This can introduce a systematic error, especially in those parts of spectrum where the slope is high.

We have suggested an alternative method of spectra evaluation. Instead of binning the energies (thus obtaining a spectrum of $\sim 10^1$ to 10^2 items) we keep all the 'energy-counts' pairs and re-arrange them following the increasing energies. Now we may have a spectrum of many times higher number of items but no information was lost (or, at least, smeared) by binning. Such a long spectrum may be then evaluated by the least-squares method (LSQ) as any other one – with the present computing power this does not represent any problem.

Nevertheless, there is one more thing to be kept in mind. The usual LSQ minimizes the Neyman's χ^2_N statistic (see e.g. [2]) which is based on the assumption that the measured count rates follow the normal distribution. For higher number of counts in spectrum, this is a good approximation. However, for small number of counts, the Poisson distribution must be applied. Then χ^2_N must be replaced by an appropriate Poisson-like equivalent. There are two possibilities, χ^2_{BC} [2] and χ^2_P [3] – both of them have a structure similar to that of χ^2_N, i.e. sum of some combinations of experimental and theoretical values.

To demonstrate the method we used simulated energy spectra very close to really measured ones. The energy values were taken from a real experiment (L_1–conversion electron line of the 9.4 keV transition in ^{83}Kr). Three different types of spectra were simulated – Gaussian line, Shirley-type [4] line, and Gaussian doublet, all of them having numbers of counts close to those measured. Then all of them were evaluated using both the usual (binning) and new (no-binning) methods. The parameters obtained by the new method were in better agreement with those used to create the spectra. (This was true no matter whether utilizing χ^2_{BC} or χ^2_P.) In more detail, the method as well as the mentioned results are described in [5].

We would like to note that the method is applicable not only to energy spectra. It can be used in any case when we have measured a set of pairs of quantities $\{x_i, y_i\}$ connected by a known function $y = f(x; \vec{a})$ and we need to determine the unknown parameters $\vec{a}$.

This work was supported by the Grant Agency of the Czech Republic (contract No. 02/06/0002) and by the Ministry of Education, Youth and Sports of the Czech Republic (contracts Nos. LA 318 and LC 07050).

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Tests of the Standard Model in beta-decay at ISOLDE

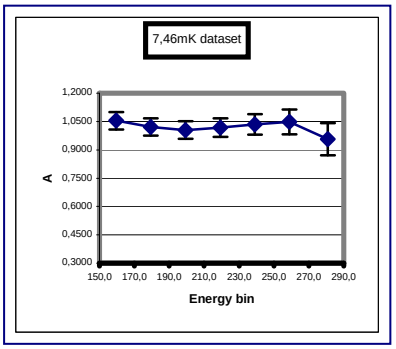
D. ZÁKOUCKÝ for NICOLE, WITCH and ISOLDE collaborations

The Standard Model of Electroweak Interactions is based on a basic assumption about the "V–A" character of the interaction. However, experimental limits for admixtures of scalar and/or tensor interactions are still as high as ~8%.We are currently running experimental projects at ISOLDE,CERN searching for such non-Standard interactions using measurements of specific low energy β-decays .

Study of the correlation between the spin of β-decaying nucleus and momentum of emitted β-particle is a powerful tool to search for new time reversal invariant scalar and tensor components in the weak interaction. Precision measurement of the β-asymmetry parameter in nuclear β-decay is done by the measurement of the angular distribution of β-particles emitted by the oriented sample with the Low Temperature Nuclear Orientation (LTNO) method. We currently run two complementary experimental projects with slightly different technique but very different systematic errors.

First technique uses online LTNO facility NICOLE at ISOLDE,CERN where nuclei are implanted, cooled, oriented and their decay studied. Here the nuclei are oriented due to the strong hyperfine field created in the Fe matrix where the nuclei are implanted – but external magnetic field (~0.1T) orienting the ferromagnetic matrix is quite weak and doesn't significantly influence the emitted low-energy β-particles. Main factor influencing the final error bars comes from the determination of a fraction of nuclei feeling correct orienting hyperfine field. First experiments were already done yielding results A=-0.990(14) with A_{SM}=-1 for the asymmetry parameter of ^{114}In (submitted to Phys.Rev.C) and still preliminary value A=0.427(6) for the decay of ^{67}Cu (A_{SM}=0.447).

Second technique is the Brute-Force LTNO (BF-LTNO) where nuclei are oriented directly by the strong external magnetic field (no hyperfine interaction needed). Here the problem with the fraction of oriented nuclei disappears but the strong magnetic field (~15T) drastically distorts the angular distribution of the low-energy β-particles. For these experiments we constructed a new BF-LTNO set-up equipped with a 17T magnet [1]. Analysis of the first experiment - decay of ^{60}Co (analogous to the famous parity violation discovery experiment of C.S.Wu) - was already finished yielding the value of asymmetry parameter A=1.013(18) with A_{SM}=1 and paper is ready to be published in Phys.Rev.C. Results are illustrated in Figure where the extracted asymmetry parameter A is plotted for electron energy bins (endpoint 318keV) at 7.4mK oriented sample temperature.



Another correlation in β-decay sensitive to the new physics outside of Standard Model is a β-ν correlation. Due to difficulty to detect neutrinos this can be replaced by the study of recoil nuclei. For this purpose a new online facility WITCH has been built at ISOLDE,CERN. This world unique combination of 2 Penning traps and retardation spectrometer allows us to trap radioactive ions produced by ISOLDE separator, cool them, let them decay and probe the energy spectrum od recoiling nuclei by the retardation spectrometer. By precise measurement of the shape of recoil spectrum (specific for different decay modes - scalar, vector) we can determine admixture of (forbidden) scalar component in the dominant vector mode. Facility was constructed and commissioned and first „proof-of-principle" experiment was performed measuring the recoil spectrum of ^{124}In [2], physics run with isotope ^{35}Ar is planned in 2009.

Summarising, we have now 3 different projects looking for exotic types of weak interactions and we operate 3 different experimental setups with different experimental techniques (subject to different types of possible systematic errors). All setups are operational and proof-of principle experiments were already performed, current results are competitive to best world average of comparable experimental data. We are taking new data in order to get well bellow the existing experimental limits on the admixtures of Standard Model forbidden components of weak interactions.

This work was supported by the Grants of the Ministry of Education of the Czech Republic 1P04LA211 and LA08015.

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Instrumental neutron activation analysis of sandstones from the Angkor monuments

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Khmer temples in Angkor, Cambodia, included into the World heritage list in 1992, were built during the golden age of the Khmer Emprire (9^{th} to 13^{th} century). Apart from laterite and bricks, sandstone was the major construction material used in the building of the Angkor monuments. Until now, very little information is available about the sandstone origin and elemental composition. The exact location of quarries from where the sandstone was taken has been unknown until very recently. Exact knowledge of the elemental composition of sandstone, including its petrological characterization and provenance would help in better understanding of construction methods of Angkor monuments and the presently observable stone deterioration processes. The aim of this study was to examine the possibility that a particular elemental and/or mineral composition of the building material is characteristic for a particular architectural style/building period in the history of constructing Angkor monuments.

Sandstone was sampled from building blocks of 19 Angkor temples built in 8 architectural styles/building periods. The cores of up to 7 cm long were extracted with a diamond core drill bit of a diameter of 12 mm. In preliminary experiments, we have found that the elemental composition of samples taken at various distances from the surface of the sandstone blocks differed due to the influence of weathering and/or degradation processes. Therefore, we have selected only the innermost part of the cores (core sections 4 to 5 cm distant from the surface layer) for comparative elemental study. The core sections selected for analysis weighing ~ 2 g were first crushed, then ground and homogenized in an agate ball mill. Test portions (100-200 mg) of fine powder with grain size below 200 mesh were used for analysis. Instrumental neutron activation analysis (INAA) using both short- and long- time irradiations (1 minute and 2 hours, respectively) were performed in the LVR-15 experimental reactor in Řež. The neutron fluence rate was $5 \cdot 10^{13}$ cm^{-2} s^{-1}. Gamma-ray spectra of the induced radionuclides were measured with HPGe coaxial or planar detectors that were coupled to a computer controlled gamma-ray spectrometer Canberra Genie 2000. Various decay and counting times were employed to determine as many elements as possible with a low degree of uncertainty. Details of the experimental procedures have already been given elsewhere [1,2].

For quality control purposes, reference materials of USGS AGV-1 (Andesite), NIST SRM-2704 (Buffalo River Sediment) and NIST SRM-1633b (Coal Fly Ash) were analyzed with each batch of 20 to 25 sandstone samples. The results agreed with the certified and/or information values within the uncertainty margins whenever available, thus confirming the accuracy of our results. Each sandstone sample was analyzed from duplicate test portions. Homogeneity of the test portions was occasionally checked by analyzing three or four replicates. The results showed that the test portions were sufficiently homogeneous for the purpose of this study.

In every sample, we determined the contents of 35 major, minor and trace elements, namely, Na, Mg, Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Zn, Rb, Sr, Zr, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Zb, Lu, Hf, Ta, Th and U. The average values obtained for all 35 elements were scrutinized with cluster analysis using Euclidean distance and average linkage to find out whether the sandstone elemental composition correlates with particular construction period/architectural style of individual temples. Results of cluster analysis showed that there was one distinctly separate cluster corresponding to the sandstone of the Banteay Srei temple, which was built from red quartzose arenite. The other clusters of the averaged elemental composition of the remaining temples constructed from the greay to yellowish quartzo-feldspathic sandstones (arenites) coincided only partly with particular construction periods. We always observed a similar pattern, no matter whether we examined major components, selected minor and trace elements predominantly occurring in various minerals of the sandstones or only the sandstone mineral composition. The two possible reasons for no straightforward correlation found between the chemical/mineralogical composition of the sandstone blocks and any particular construction period of the temples sampled are as follows: (1) the inherent inhomogeneity of sandstone resulting from

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processes of its formation; (2) sandstone building blocks were taken from several sites (quarries) during the construction of a particular temple structure or its part. The latter explanation is a novel one and would alter some of the present presumptions about how the Angkor monuments were built. Its plausibility can only be tested from analysis results of sandstone material taken from ancient quarries, some of them being discovered only very recently. We have succeeded in finding of some of them (hidden in the tropical forest about 60 km from the Angkor site) during our last expedition to Cambodia in 2008. Thus, we still need to complete analyses of the samples collected in the above quarries to be able to conclude about the origin of sandstone used for the construction of the Angkor temples and the relationship of the elemental composition of the sandstone blocks and architectural style/construction period of the Angkor monuments.

Fig. 1. Angkor Wat temple

Fig. 2. Banteay Srei temple

Fig. 3. Ta Prohm temple

Fig. 4. Ancient quarry

This work was supported by projects RP 17/2006, AV0Z 10480505 and MSM 2672244501 of the Czech Republic. The authors would also like to thank to the Apsara Authority, Cambodia and EFEO, France for co-operation.

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Analysis of moldavites and other impact glasses by activation analysis and ion beam techniques

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Impact glasses are formed by the impact of large meteorites on Earth by melting of rock materials at the impact site. Tektites are impact glasses produced from the uppermost surface layers and ejected to the strewn fields distant from the impact crater up to thousands of kilometers. The best known and characterized tektites are moldavites associated with the about 14.5 million years old Ries crater in Bavaria, Germany. Most moldavites have been found in two large substrewn fields in Southern Bohemia and Southern Moravia, the finds from the other two substrewn fields Austria and Lusatia, Germany are quite rare. Recently, a new quite productive moldavite locality has been discovered in the Cheb Basin, Western Bohemia. The world largest tektite strewnfield is the about 800 thousand years old Australasian strewnfield. It includes most of Southeast Asia and stretches southeast across the ocean to cover also a large part of Australia. A parent crater for the Australasian tektites has not been found so far.

The study of tektites and other impact glasses at the Nuclear Physics Institute ASCR (NPI) has been aimed at geochemical characterization of a large collection of moldavites (tektites from the Central European tektite strewn field), irghizites (tektite-like impact glasses from the Zhamanshin crater in Kazakhstan), and several samples of Australasian tektites and Libyan Desert Glass [1-3]. The characterization has been based on determination of about fifty elements using various modes of instrumental neutron and photon activation analyses (INAA and IPAA). Activation analysis techniques have been supplemented by ion beam techniques (PIGE, PIXE, RBS); namely PIGE is unique for lithium and fluorine determination [2]. Recently, also prompt gamma activation analysis (PGAA) has been applied to boron determination [3].

Detailed comparison of the Cheb Basin moldavites with moldavites from other sub-strewnfields in both major and trace element composition has shown that the Cheb Basin is a separate substrewn field. The geochemical data, interpreted with respect to the source materials and processes leading to formation of moldavites, have shown that three groups of Cheb Basin moldavites exist. Significant positive correlations between K, Ca, Mg, and Mn found in the Cheb Basin moldavites and the enrichment in these elements observed generally in all moldavites, as well as other facts, e.g., high K/Na and K/Rb ratios and the reduced conditions during formation of moldavites, suggested a new theory of moldavite formation and their source materials. It concerns a possible contribution of the ash produced by burning of vegetation and soil organic matter present at the pre-impact area as a part of the moldavite source materials [1]. This new theory has been supported by chemical similarity between lechatelierites (silica inclusions in moldavites) and phytoliths (biogenic opals).

A geochemical study of irghizites have confirmed their generally accepted division into two primary groups (acidic, silica-rich, and basic, silica-poor), and suggested their further classification. High contents of Cr, Co, and Ni in the acidic irghizites including the spherules from their surface point to contamination with the extraterrestrial matter, which is supported also by the presence of the cosmogenic radionuclide ^{26}Al. Two intermediate groups of irghizites have been distinguished – a subgroup of the acidic samples less contaminated with the impactor matter, and a subgroup of the basic samples showing mixing of the source materials for both primary groups. The acidic irghizites and the spherules originated from the quartz sand/clay loess surface layers at the early stages of the impact, the basic ones from the deeper crystalline bedrock of prevailing andesite character at the following stages before the final explosion of the impactor. Both subgroups must have originated in between (from both time and space standpoint) the primary groups. Based on the contents of the elements indicative of extraterrestrial matter (Mn, Fe, Cr, Co, and Ni) and their ratios, a chondrite meteorite has been suggested as the impactor and the maximum extratraterrestrial fraction in the acidic irghizites estimated at more than ten percent [3].

The study of moldavites and other tektites and impact glasses at NPI will continue as a part of the grant project “Origin of moldavites - complex geochemical study” (GA205/09/0991) supported by the Czech Science Foundation in the next three years.

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Cross-section Measurements of (n,xn) Threshold Reactions

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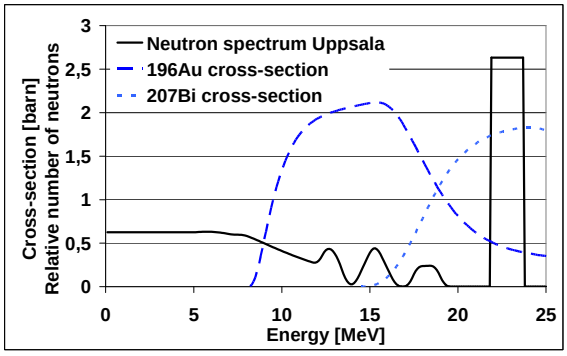
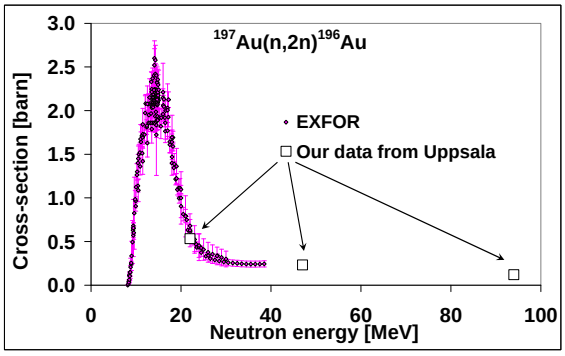
We use activation detectors to determine neutron field during our experiments with the "Energy plus Transmutation" set-up [1]. This assembly consisting of the lead target and natural uranium blanket is irradiated by relativistic protons and deuterons. Obtained data are important part of benchmark tests of codes simulating Accelerator Driven Systems. Unfortunately almost no experimental cross-section data for most of observed threshold (n,xn), (n,p), and (n,α) reactions in Au, Al, Bi, In, and Ta foils are available for higher neutron energies (E > 20 MeV). Therefore, we decided to perform cross-section measurements to fill up these gaps.

For these cross-section measurements by the means of activation analysis, we used high energy neutron source with well known quasi-monoenergetic spectrum available in Europe. In the frame of the EFNUDAT FP6 project [2], we carried out measurements at The Svedberg Laboratory (TSL) in Uppsala. In this laboratory quasi-monoenergetic 11 – 175 MeV neutron source based on the ^{7}Li(p,n)^{7}Be reaction is available [3]. The neutron flux density can be up to $5 \cdot 10^{5}$ cm^{-2}s^{-1}. Second neutron source that we used is at our cyclotron in Řež. This quasi-monoenergetic source has the energy range 10 – 37 MeV due to lower primary proton beam energies [4]. The neutron flux density can be in this case 10^{8} cm^{-2}s^{-1}.

We irradiated Au, Al, Bi, In, I and Ta samples, i.e. same materials as in Energy plus Transmutation experiments. In some irradiations we also tried to measure the cross-sections of threshold reactions on Zn, Ni, Cu and Fe. Samples were irradiated by neutrons obtained with proton beam energies 25, 50 and 100 MeV (Uppsala) and with proton beam energies 20, 25, 32.5 and 37 MeV (Řež). Typical irradiation time was eight hours. Amount of radioactive isotopes produced by different reactions was determined by the means of gamma spectrometry. In the ideal case, the threshold energy of observed reaction lied at the beginning of the neutron peak. Unfortunately, the production of radionuclides by the continuum background neutrons was not negligible for most of isotopes (left figure). This was solved by subtraction of the background contribution, which was determined by folding of the neutron source continuum spectrum and cross-sections for lower energy neutrons from EXFOR or obtained using TALYS code [5]. Our results for well known cross-sections agree with other experimental data from EXFOR (see example on right figure).





This work was supported by EFNUDAT FP6 – 036434 project.

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DEPARTMENT OF NUCLEAR REACTIONS

Basic research

Nuclear astrophysics

Astrophysical activities of the Nuclear Reactions department are concentrated mainly on two types of reactions relevant in stellar environment – particle capture reactions and direct particle transfer processes. The radiation proton capture reactions (^{3}He,d) were studied on the beam of cyclotron U-120M in Nuclear Physics Institute ASCR, p.r.i. at Řež and interpreted in frame of Asymptotic Normalization Coefficients Method. The particle transfer reactions were investigated using the Trojan-Horse Method developed in LNS Catania. These experiments were realized partly in our institute and partly in cooperating laboratories. During the last two years we finished interpretation of capture reaction ^{15}N(p,γ)^{16}O which is an important for stellar CNO processes. Results were published in prestige journals and conferences. We also started research program of investigation connected with the charge symmetry in capture proton and neutron reactions. The differential cross sections of the neutron and proton radiation capture were measured using (d,p) and (^{3}He,d) reactions on ^{14}N and ^{14}C targets. The similar experiments were carried out in Texas A&M University. Particle transfer was investigated using Trojan-Horse model both on our cyclotron and in laboratory of LNS, Catania. For example, (p,α) reactions were studied on ^{11}B and ^{18}O in the inverse kinematics. Analyses of results are under way.

All the experiments were realized under a joint project NSF(USA)-MŠMT(CR) ME 902 in collaboration NPI Řež, Texas A&M University, LNS Catania, Atomki Debrecen and University of Sao Paulo.

Exotic nuclei

The evolution of nuclear structure far from the valley of stability is one of the current topics of nuclear physics. The modifications of the classical magic numbers caused by sudden onset of deformation or other effects can have also astrophysical consequences for s-process. Waiting points of the s-process can be affected due to the shell structure changes and the new data in the models can better account for the observed isotope abundances.

Our recent experimental efforts in mass measurements and in-beam spectroscopy has led to identifying a case of breaking magicity for the shell N=28 in ^{42}Si. Very neutron rich isotopes of nitrogen and carbon were studied by means of gamma spectroscopy and weakening of USD interaction was found when approaching the limits of stability. Mirror properties of p-n tensor force were also experimentally studied for the very neutron-deficient nucleus ^{36}Ca.

The experiments were realized in collaboration Ganil-Řež-Orsay-Bucharest in French laboratory GANIL.

Applied research

Further development and upgrade of the European Fusion File (EFF) and the European Activation File (EAF), their processing and benchmarking are standing issues performed in support of design and licensing activities in the ITER-project and the IFMIF design activities.

The IFMIF (International Fusion Material Irradiation Facility, based on future high-power linear accelerator, is projected to produce an intense neutron flux for qualifying the radiation properties of the materials for fusion power reactors (ITER in the first stage). An assessment of the activation caused by the beam losses in the accelerating components and by the full current in the beam dump during the IFMIF prototype accelerator testing period is one of tasks solved using both the proton and deuteron beams of the NPI cyclotron.

Within continuing participation on the validation of nuclear data for IFMIF, experiments for the determination of Au cross-sections up to 35 MeV in a quasi-monoenergetic neutron spectrum at the NPI Cyclotron-based Fast Neutron Facility were carried out.

Shell Closures far from the Stability Line

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Collaboration GANIL-Orsay-Dubna-Rez-Bucharest

The evolution of nuclear structure far from the valley of stability is one of the current topics of nuclear physics. New phenomena as nuclear halo or nuclear skin were observed in last two decades, so called Island of Inversion was observed, where the classical magic number N=20 is not anymore valid and region of deformation appears in place where spherical nuclei were expected. The experimental and theoretical efforts have lead to identification of importance of tensor interaction between p-n spin-orbit partners, N-N interactions were and are constantly improved, new calculation methods as MCSM have appeared.

Only recently the new neutron-rich region of magical nuclei at N=28 has started to be experimentally more and more accessible. The magic number N=28 has spin-orbit origin and thus the possible similarity to the case N=20 was a subject to a debate. We have measured masses of very-neutron rich nuclei near the N=20 and 28 shell closures [1] by SPEG spectrometer and TOF method in GANIL. Seven masses were determined for the fist time and 36 masses were significantly improved. The evolution of odd-even staggering (OES) was studied, OES are often taken as an indicator of the strength of pairing correlations. While most theories predict an increase in neutron pairing correlations with increasing N/Z, our results do not indicate an increase of the OES. Changes in the shell structure were observed around N=28 for the P and S isotopes, but not for Si isotopes. The interpretation may be twofold - either the N=28 shell closure is persistent for Z=14 or a very sudden onset of a deformation at ^{42}Si is present.

The questions that have arisen from the previous experiment [1] and indications of sphericity that were presented in [2] have been responded by another our experiment [3], where the energies of excited states of very neutron rich ^{42}Si and ^{41,43}P were measured by SPEG spectrometer and Chateau de Cristal BaF_2 array in GANIL. A low lying gamma transition belonging to Z=14, N=28 nucleus ^{42}Si was identified as a transition from 2_1^+. The low energy of 2^+ 770 keV provides evidence of disappearance of the Z=14 and N=28 spherical shell closures. The new calculations indicate that ^{42}Si is well described as a well-deformed oblate rotor.

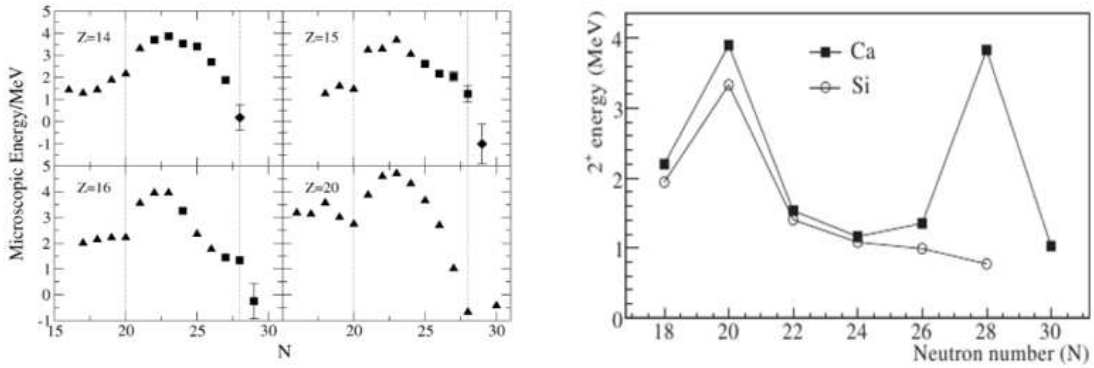

Fig. 1: *Left panel: Mass measurements [1] - the microscopic correction as a function of neutron number. The vertical lines indicate the position of N=20 and 28. Diamonds and squares represent new and improved values. Right panel: Energies of the 2^+ states measured in the Ca and Si isotopes. Present result [3] for ^{40,42}Si brings an evidence for the collapse of the N=28 shell closure at Z=14.*

The structure of $^{19-22}$N nuclei [4] and $^{17-20}$C nuclei [5] was investigated within the collaboration GANIL-Orsay-Dubna-Rez-Bucharest.

Level schemes were constructed for neutron-rich nitrogen nuclei and the experimental results are compared to shell model calculations. The strength of the N=14 and Z=8 (sub)shell closures was discussed. A discrepancy between the calculated and measured energies of the excited states was observed using WBT interaction, which suggest that USD part of the WBT interaction is about 12% stronger then required. and the weakening of the shell model interaction WBT was discussed.

The systematics of 2+ states in C isotopes was extended for the first time to A=20, showing that N=14 subshell closure disappears. Reduced neutron-neutron effective interaction was used (reduced about factor 2 in comparison to the previous reduction for N isotopes) to find agreement between experimental results and shell-model calculations. The study shows a strong analogy with earlier findings at N=28, revealing that a generic mechanism acts to destroy the major shell closures and in this light the $^{78}Ni_{50}$ isotope could turn out to be not doubly magic. For heavier nuclei, the stronger SO force acting on large l values keeps the magicity (^{132}Sn, ^{208}Pb).

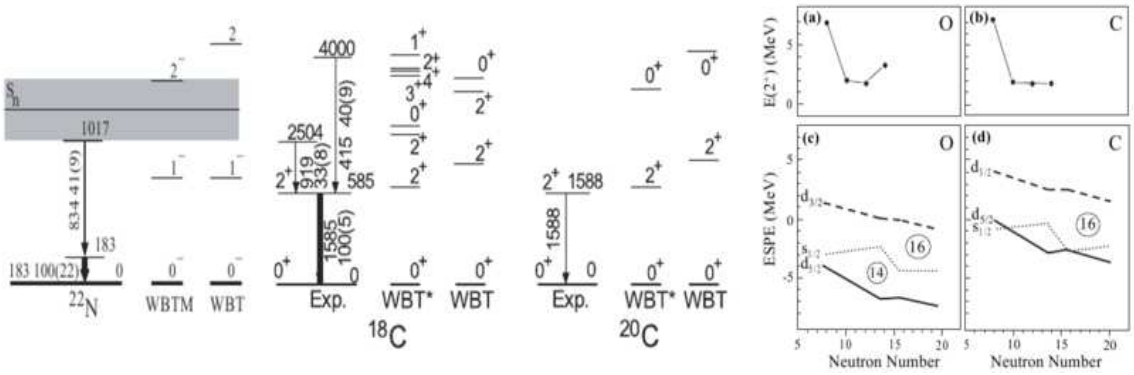

Fig. 2: *Experimentally observed excited levels of selected C and N isotopes and a comparison to WTB and modified WTB interaction. Rightmost panel: evolution of the 2_1^+ energies and effective single-particle energies (ESPE) as a function of the neutron number calculated using the USD effective interaction. Subshell N=14 disappears for C isotopes.*

We have also performed an experiment [6,7] to study the excited states in neutron deficient Ca isotopes. The excited state of ^{36}Ca was searched for to obtain a spin dependence of he N-N interaction near the proton drip line from a comparison with its stable mirror nucleus ^{36}S. The p-n tensor interaction should enlarge the gaps between $d_{3/2}$ $s_{1/2}$ and between $d_{5/2}$ $s_{1/2}$ levels. These shifts lead to high energies of the 2_1^+ state which reflects a spherical rigidity comparable to the double magic ^{40}Ca. Two step fragmentation technique was used and the gamma rays were measured by Chateau de Cristal BaF2 array and SPEG spectrometer in GANIL. The E(2^+) = 3036(11) keV energy in was found in ^{36}Ca, which is 266 keV lower than that of mirror nucleus. This is, besides ^{14}C-^{14}O one of the largest mirror energy difference observed so far for a 2_1^+ state.

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Indirect study of the ^{6}Li(d,α)α reaction as benchmark for testing pole-invariance in quasi-free reactions

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The application of the Quasi-Free (QF) break up mechanisms in the past was mostly connected to an extensive study of nuclear structure [1,2]. Basically, these mechanisms are direct processes in which the interaction between an impinging nucleus and the target can cause the break-up of the target or, that is the same, of the projectile. In particular, the so-called QF are processes having three particles in the exit channel one of which can be thought as "spectator". In the last years, the Trojan-Horse Method (THM) provides an useful application of such QF mechanisms to astrophysically relevant reactions, whose direct study is often hindered by the ultra-low values of their cross sections due to the Coulomb barrier penetration[3,4,5,6]. To overcome such problem, the THM was successfully applied to study the astrophysically relevant ^{6}Li(d,α)α reaction by means of QF reaction ^{6}Li(^{3}He,αα)p. In this case, ^{3}He is TH-nucleus sketched as an d+p cluster configuration. In such conditions the proton will be the spectator while the deuteron will be the participant to the two-body ^{6}Li(d,α)α reaction.

The ^{6}Li(^{3}He,αα)p experiment was performed at the Nuclear Physics Institute ASCR, p.r.i. at Řež on 17.5 MeV ^{3}He beam of cyclotron U-120M. An isotopically enriched lithium floride target ^{6}LiF of about 280 microgram/cm^{2} was used. Two α-particles in the output channel were registered in the coincidence regime. The detection set up consisted of four 50×10 mm^{2} Position Sensitive silicon Detectors (PSD). Two different 450 mm^{2} 25 micron thick Amtec silicon ΔE detectors were placed in front of two different PSDs to allow standard ΔE-E selection of the reaction products. The displacement of detectors inside the scattering chamber was chosen in order to cover as much as possible the kinematical region where a strong contribution of the QF mechanism is expected, i.e. to cover the angular region corresponding to low momentum values of the third particle, the undetected proton. The signals of each detector were processed by standard electronic system that allowed the on-line monitoring and data storage for the off-line analysis. After the angular and energy calibration of the involved detectors, the first step of a typical "TH-analysis" is to discriminate the channel of the three-body reaction of interest from the ones induced by the interaction of ^{3}He on LiF. Under the hypothesis that the third undetected particle had mass number 1, all the variables of interest were further calculated. By means of the energy conservation law, the Q-value spectrum for the selected events was also reconstructed and reported in Fig.1. The presence of a well separated peak around 16.9 MeV must be compared with the theoretical Q-value of 16.87 MeV for the ^{6}Li(^{3}He,αα)p reaction. The agreement is a signature of our good calibration and a precise selection of the three-body channel. Also the scatter plot between the detected α-particles, i.e. the so called kinematical locus on Fig.2 is in agreement with our simulations. The three-body cross section, in QF mechanism approach, can be factorized as [1,2] where KF is a kinematical factor, $\Phi(p_p)$ correspond to the Fourier transform of the radial wave function for p-d inter

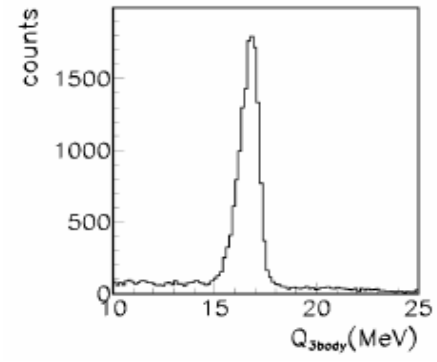

Fig. 1

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cluster motion inside ^{3}He, described usually in terms of Hänkel, Eckart or Hulthén wave function and $(d\sigma/d\Omega)^{N}$ is related to the two-body ^{6}Li+d cross section of interest that may be obtained by inversion of this equation.

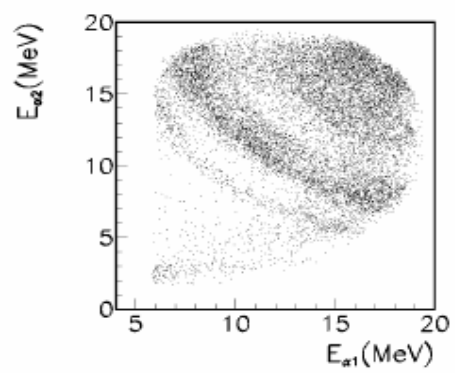

Fig. 2

The QF mechanism is connected with the behavior of the undetected proton in the exit channel. In the QF hypothesis, the proton should maintain in the exit channel the same impulse distribution for the d-p relative motion inside ^{3}He it had before interaction with the ^{6}Li. We expect that, in our case, the extracted experimental momentum distribution should reproduce the theoretical one.

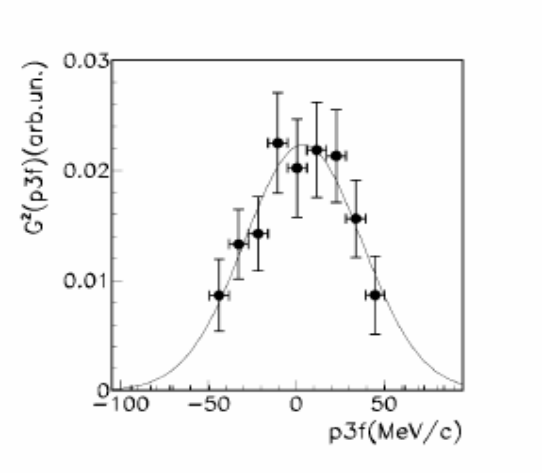

Fig. 3

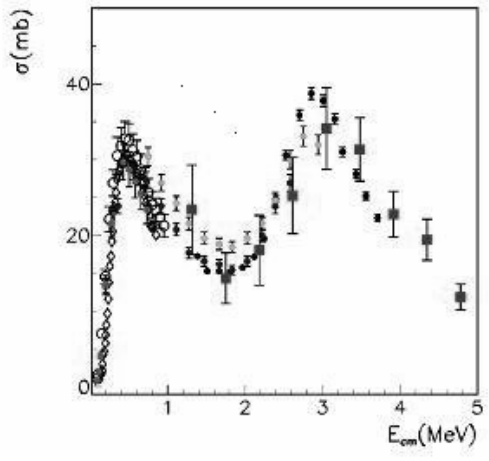

Fig. 4

The experimental result is shown in Fig.3. The good agreement between experimental data and the theoretical Eckart function represents the experimental evidence that the proton acted as a "spectator" during the break-up occurred in the ^{6}Li(^{3}He,αα)p reaction. After selection of the QF mechanism and after some calculations, it was possible to extract the cross section of the two-body interaction ^{6}Li(d,α)^{4}He. The comparison with the direct measurements is presented in Fig.4 as a preliminary result. The black squares are THM data with their experimental errors. Other points refer to the available direct data. The agreement and, in particular, the presence of the resonance at about 3 MeV are an important experimental confirmation of the so-called pole-invariance for QF reactions. Further study is still in progress.

This work was supported by NPI ASCR research plan AV0Z10480505, project NSF and MŠMT ME902 and by research center LC 07050.

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Activation of the IFMIF Prototype Accelerator and Beam Dump by Deuterons and Protons

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The objective of the present work was an assessment of the activation caused by the beam losses in the accelerating components and by the full current in the beam dump during the IFMIF prototype accelerator testing period.

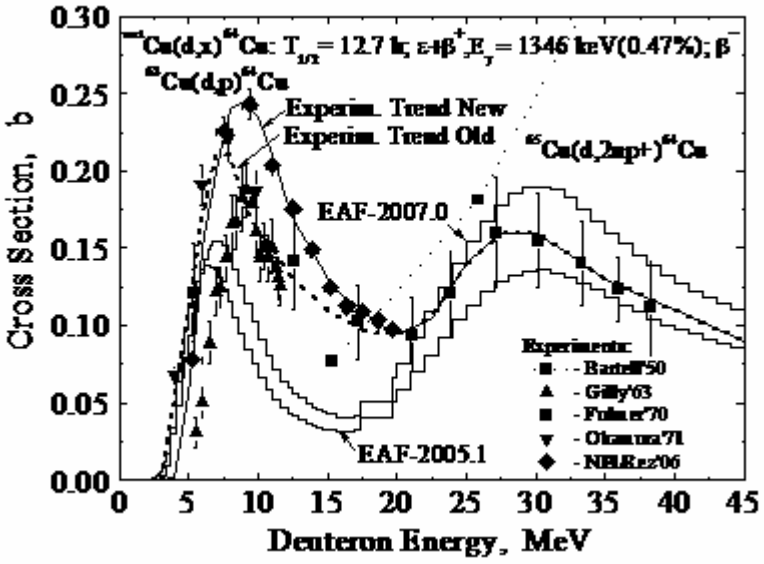

Fig. 1. ^{64}Cu production cross sections in d + ^{nat}Cu reaction

The activation analysis was performed by the European Activation System EASY-2007 recently upgraded to include charge particle induced reactions. To rely on these calculations it is necessary to find the dominant nuclear reactions and check their cross-sections. For instance, the assessment of radioactive inventories produced by deuterons with energy up to 40 MeV in copper (the main structural element of RFQ accelerator) have shown that the ^{nat}Cu(d,x)^{62,65}Zn and ^{nat}Cu(d,x)^{62,64}Cu reactions produce dominant unstable residual nuclei which decay with emission of high energy γ-rays and contribute most to the radiation dose.

Fig. 1 shows available cross-sections data including results of present experiment. The disagreement between the EAF-2007 and measured data is evident. The use of differential cross-sections adjusted to experimental ones (indicated as "experimental trend" in Fig. 1) will perfectly reproduce the cumulative ^{64}Cu yield.

It was concluded that the EAF-2007 library, although reasonably well reproducing the energy dependence of the relevant charged particle cross-sections still needs updating to improve the quantitative agreement with the measurements. In the present calculation EAF-2007 cross-sections (without adjustment to the experimental data) were used, meaning that the uncertainty of the IFMIF prototype accelerator activation analysis caused by nuclear data could be several dozen percent [1].

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This work was supported by EFDA (European Fusion Development Agreement). Authors are indebted to the staff of the NPI cyclotron for faithful operation of the accelerator.

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Activation Cross-section Measurements of Au-197(n,4n)Au-194 Reaction using Quasi-monoenergetic Neutrons below 36 MeV

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The neutron cross-section data of reactions at incident energies E_n > 20 MeV are needed to improve the accuracy of neutronic calculations incorporated with various fission and fusion technologies like Fluoride-Molten-Salt-Reactor systems, IFMIF (International Fusion Material Irradiation Facility) and for the tests of nuclear reaction models as well.

In the framework of continuing the experimental tests of neutron activation cross-section data the activation of ^{197}Au isotope was investigated using fast quasi-monoenergetic neutrons from the NPI cyclotron-based neutron source. Sample foils were irradiated by neutrons with quasi-monoenergetic spectrum peaked at 17.9, 18.9, 21.9, 23.9, 27.1, 29.3, 32.6 and 35.4 MeV. In this report, we presented the results of the (n,4n) reaction. The energy threshold of this reaction is 23.22 MeV.

The target station of quasi-monoenergetic neutron source based on ^{7}Li(p,n) reaction was presented in previous work [1]. It consists of thin (2 mm) Li foil and the carbon stopper. After sample irradiation the induced gamma activities were measured at various cooling times by the gamma spectrometry method using HPGe detectors.

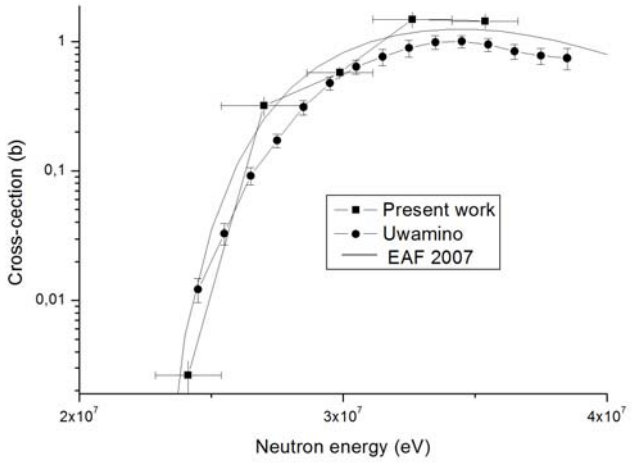

Fig.1. Au-197(n,4n) Au-194 reaction cross-sections

The neutron flux and spectra at sample positions were determined using double-differential cross-section data of the source reaction ^{7}Li(p,n) measured by Uwamino et al.[3].

In the analysis of data, the contribution of lower energy part of the neutron spectra (below quasi-monoenergetic peak) to the measured reaction rates was subtracted using step by step method: the convolution of neutron spectra and measured cross-section is used for the calculation of higher-energy cross-section.

The results are shown in the Fig. 1. Previous Uwamino data [4] and data from database EAF [5] are shown as well. Our results agree with EAF data, but disagree in some cases with those of Uwamino. The further analysis including the contribution of experimental error to the final accuracy of resulting recommended set of cross-section data is in progress.

This work was supported by EFDA (European Fusion Development Agreement). Authors are indebted to technical staff for faithful operation of both the accelerator and neutron target station.

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DEPARTMENT OF NEUTRON PHYSICS

The activity of the Neutron Physics Department in the last two years has been focusing basically in two directions:
- *Fundamental and Applied Research with Thermal Neutrons at the Reactor LWR-15*
- *Nuclear Analytical Methods with Charged Particles at the Van de Graaff Accelerator and Tandetron 4130* .

The neutron research has been carried out at five horizontal beam channels of the reactor LWR-15 which are hired at the Nuclear Research Institute, plc. The experiments were opened and free for external users. Neutron Physics Laboratory has successfully participated in the *Transnational Access to Large Facilities* programme in the frame of FP6 NMI3 project where we have offered for European neutron community 5 experimental facilities for: Neutron strain scanning, Small-angle neutron scattering, Neutron depth profiling, Neutron activation analysis and Radiative thermal neutron capture. In the last two years, much effort of the Neutron diffraction group has been focused on the construction of the medium-resolution powder diffractometer which has been introduced into full operation in 2008. The measured resolution and luminosity parameters of the diffractometer confirmed the expected values received from Monte Carlo simulations. At the end of 2008, effort of the Neutron diffraction group has been focused on the upgrade of the high-resolution double-crystal SANS facility MAUD (formerly DN-2). The upgrade concerned the monochromator unit, the shielding and installation of the new collimator with a saphire filter. The facility should be re-commisioned in September 2009.

Two electrostatic accelerators, old Van de Graaff and new Tandetron 4130 MC have been operated and used for modification and characterization of micro- a nano structured materials. Installation of new analytical devices in the Tandetron laboratory has been progressing. The RBS-channeling device for analyses of crystalline materials and ERDA-TOF device for depth profiling of light elements were put into routine operation. Ion microprobe, unique in Czech Republic, was installed and is being tested. The Tandetron based device for high energy ion implantation has been in routine use. The laboratory is engaged in several research activities mostly conducted in close collaboration with other research institutes and universities in Czech Republic and abroad. Analytical and implantation service for external users is also given.

The research activities of the Neutron Physics Department were supported by several projects financed by the Grant Agency of the Czech Republic, the Grant Agency of AS CR and by IAEA Vienna. The most important project is Research Center LC06041 "*Preparation, modification and characterization of materials by energetic radiation*" (2006-2010) financed by the Czech Ministry of Education. Within the existing collaborations, many complementary experiments have also been carried out abroad.

The most attention has been paid to the following research programmes:

Small-angle neutron scattering (SANS): Investigations of large-scale structures by SANS technique have been aimed at investigation of superalloys (cooperation with TU Braunschweig and TU Košice) and at characterization of nanostructures prepared from two-phase alloys (cooperation with TU Braunschweig). Further, a test measurements were carried out on new high-temperature alloys based on on Co-Re (cooperation with TU Braunschweig and TU Munich). In the field of superalloys, SANS investigation of gamma-

prime precipitate morphology evolution in creep-exposed single-crystal Ni-base superalloy CMSX-4 and microstructural study of a Ni-Fe-based superalloy DT-706 by in-situ SANS brought information on high-temperature characteristics of the given alloys. An interesting feature in SANS data led to a detailed - both theoretical and experimental - verification of SANS contrast dependence on difference in thermal expansions of phases in two-phase alloys.

Neutron diffraction studies of internal stresses in materials: The nondestructive neutron diffraction method of determination of internal stresses has been employed to solve many challenging problems in material sciences and technical applications, namely medical and engineering. In the field of the basic material research, we focused on investigation of deformation and fatigue mechanisms in steels and transformation mechanism in TRIP (TRansformation Induced Plasticity) steels. Our application activities were connected mainly with optimization of welding technologies, development of new kind of stone-processing tools with active NiTi inserts and development of a new generation of the functionally graded ceramic hip prosthesis.

Bragg diffraction optics: Experimental investigations in this field have been concentrated on experimental studies of the dispersive monochromators providing high and ultra-high angular and/or energy resolution. We have done several several tests of ultra-high resolution dispersive monochromators based on multiple reflections excited in elastically deformed perfect crystals. High-resolution monochromatic neutron beams have also opened new possibilities of application for an alternative radiography technique, for the so called phase contrast radiography. World wide collaborations in application of Bragg diffraction optics for neutron scattering instrumentation have been developed within two CRP-IAEA Projects. Namely, it was participation at the development of minifocusing small-angle neutron scattering device designed by Hokkaido University and construction of horizontally and vertically focusing monochromator for KAERI Daejeon and HMI Berlin improving the figure of merit of stress diffractometers by a factor of 10. Further, Monte Carlo simulations of properties of several designed instruments, which are equipped with focusing elements have been done for ILL Grenoble, FRM II in Munich, HMI Berlin, NESCA South Africa and CIAE Beijing.

Radiative thermal neutron capture: The two facilities exploiting reaction (n,γ) was built behind the mirror neutron guide. The two-HPGe-detector γγ -coincidence facility can be used for nuclear spectroscopy as well as for investigation of photon strength functions by means of the two-step cascade technique. Within the framework of Boron Neutron Capture Therapy (BNCT) the for Prompt Gamma Ray Analysis (PGRA) was developed in our department. The facility installed at the LVR-15 reactor is optimized for liquid biological samples. However, trace concentration of isotopes with the high thermal neutron cross section can be promptly and non-destructively determined in a liquid or powder target.

Thermal neutron depth profiling (TNDP): TNDP technique is an isotopic specific, non-destructive nuclear analytical method used for measurement of concentration profiles of technological important light elements (He, Li, B, N, Cl, S, etc.) in the near-surface region of solids. The technique exploits the existence of prompt exoergic non-resonant nuclear reactions of light isotopes with low energy ($< 10^{-2}$ eV) neutrons. The TNDP device in NPI AS CR, v.v.i. Řež (based on a two vacuum chamber spectrometer, see **Fig. 1,** utilizing a multidimensional data acquisition technique) is mostly used for the depth profiling of Li and B in different materials and has become an important investigative tool in materials science and technology. It has been routinely used to determine the elemental profiles in

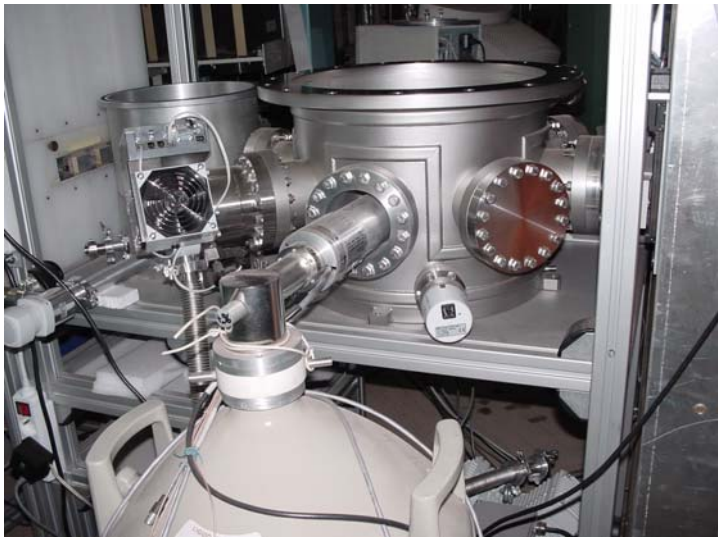

Fig. 1. The NDP spectrometer consisting of two UHV chambers.

various solids, e.g., in ISOL (Ion Separation On-Line) target materials (for a direct study of diffusion coefficients), non-linear optical materials (e.g., $LiNbO_3$), polymers modified by ion and/or chemical doping (prospective for microelectronics and transplantational medicine), and other materials, such as composites synthesized from carbon, nitrogen and boron. The research has been conducted in close collaboration with Czech and foreign research institutes (e.g., CERN Geneva and Institute Laue-Langevin Grenoble). Long-term experience has shown that TNDP is an effective analytical technique (complementary to Rutherford Backscattering), which possesses several unique characteristics, such as nondestructiveness (the samples can be measured repeatedly leaving only trace amounts of residual radioactivity) and isotopic sensitiveness (concentrations of isotopes of a few ppm can be determined, and profiling to depths of a few tens of micrometers can be obtained, with a depth resolution to a few nanometers).

Nuclear analytical methods with charged particles: The research activities of the group has mainly been concentrated on preparation, modification and characterization of polymer-metal composites (collaboration with Institute of Chemical Technology-Prague, the University of J.E Purkyně-Ústí nad Labem and Kazan Physical-Technical Institute-Russia), chalkogenide glasses (University of Pardubice), optical coatings (Institute of Physics AS), B-C-N-Si based hard coatings (University of West Bohemia), bioactive materials (Institute of Physiology AS CR), diamond-like and siloxan based coatings (Masaryk University, TU Brno), magnetic properties of GAN (Faculty of Electrical Engineering, Czech Technical University), properties of laser produced plasma (Institute of Physics AS CR), surface properties of Ti alloys (Faculty of Mechanical Engineering-Czech Technical University). Other activities include the study of diffusion of water solutions in minerals (Nuclear Research Institute), development of ion beam based analytical techniques (collaboration with FZR Rossendorf-Germany) and testing of position sensitive detectors (Institute of Technical and Experimental Physics- Czech Technical University).

Two-step γ cascades following thermal neutron capture in ^{95}Mo

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Recently, a very strong enhancement of the radiative transition rate at low γ-ray energies was reported for γ cascades depopulating levels in $^{93-98}$Mo and ^{56,57}Fe isotopes with initial excitations of 5-8 MeV [1-3]. This enhancement, in original papers called *a softpole mode*, was deduced from detailed analysis of the γ-ray spectra following (^{3}He,^{3}He γ) and (^{3}He,α γ) reactions [1,2]. Additional support for this feature was found for ^{57}Fe in two-step γ cascades (TSC) data from the thermal neutron capture. Due to the extremely intense primary transition the TSC spectra in ^{57}Fe are contaminated by soft bremsstrahlung [4]. This bremsstrahlung may imitate the effect of enhancement of soft primary transitions. It also should be noted that the analysis method of the reactions induced by ^{3}He has a number of assumptions. Therefore possible existence of this low-energy enhanced mode is still questionable and challenging.

To investigated this effect we performed the TSC experiment with ^{95}Mo target. The high neutron binding energy of this isotope, B_n = 9.154 MeV, reduce the role of residual Porter-Thomas fluctuations in the analysis of TSC data. The compressed pellet of natural molybdenum powder with weight of 6 g was irradiated by thermal neutron beam at the 15MW light-water reactor at Řež [5]. Thanks to the relatively high abundance of ^{95}Mo and its large thermal-neutron cross section the contribution of the other Mo isotopes was extremely small and so negligible. The γγ-coincidences were accumulated by two HPGe detectors for approximately 300 hours and processed off-line by means of sum-coincidence technique [6].

Owing to lack of traditional compton background the experimental TSC spectra can be easily compared with theoretical predictions. In this way various models of photon strength functions, which describe probability of γ radiation transitions with given multipolarity and energy, can be tested. Firstly, we tested original formula for the softpole mode with unknown multipolarity proposed in Ref. [2],

$$f^{(pole)}(E_\gamma) = \frac{A}{3(\pi\hbar c)^2} E_\gamma^{-b}, \qquad (1)$$

where the free parameters A and b was fitted by the authors *A= 0.47 mb/MeV* and *b = 2.7*. With respect to unknown multipolarity of this mode we calculate TSC spectra for two alternative assignments, E1 and M1. Note that this softpole was combined with traditional models for E1, M1 and E2 strength functions, the model of Kadmenskij, Markushev and Furman (KMF) [7], the spin-flip (SF) model [8] and the giant quadrupole (GQR) resonance model [8], respectively. The comparison of experimental values of the integrated TSC intensities with calculated values is given in Fig. 1. It can be seen from this comparison that calculated values employing the soft pole mode are in sharp disagreement with our experimental data. The original formula (1) is based on the experimental data from ^{3}He-induced reactions. However, these data are available only for $E_\gamma > 1$ *MeV*. Therefore we replaced the original formula (1) by superposition of two low-lying Lorentzian resonances, *a restricted pole (RP)*. Even this replacement does not removed sharp disagreement with our TSC data. On the other hand, we obtained almost perfect agreement using conventional PSFs, see Fig.2.

Concluding, our TSC data are in contradiction with experimental data from ^{3}He-induced reactions. To clear up this contradiction further investigation of this effect will be needed.

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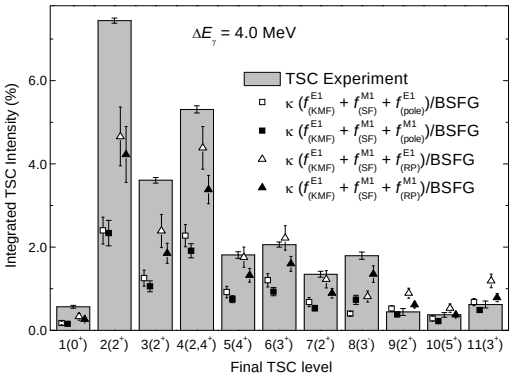

Fig. 1 Comparison of experimental values of the integrated TSC intensities with calculated ones. Squares denote for *the softpole mode (pole)* and triangles for *the restricted pole (RP)*. KMF, SF and BSFG denote Kadmenskij-Markushev-Furman model of E1 strength function, Spin-Flip model of M1 strength function, Back-Shifted Fermi-Gas model of level density, respectively.

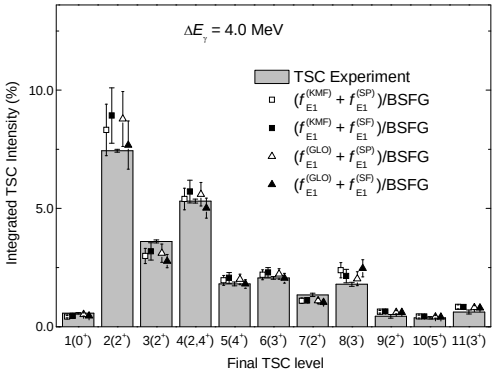

Fig. 2 Comparison of experimental data with theoretical prediction *without* assumption of low energy enhancement. Note that the semi-empirical model GLO proposed in Ref. [9], spin-flip (SF) and single-particle (SP) model were used for E1 and M1 strength functions, respectively. See Fig. 1 for meaning of the other abbreviations.

This work was supported by the Grants Nos. 1PL04LA211 and MSM-002-1620859 of the Ministry of Education, Youth, and Sports of +the Czech Republic, by Institute Research Plan No. AVOZ10480505 of the Academy of Sciences of the Czech Republic.

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Diffusion of Boron in CaF_2

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The on-line isotope separation techniques (ISOL) of short-living radioactive atoms require the fast release of the nuclear reaction products from the GeV proton-irradiated targets. As a first step in the complex transport chain, the fast diffusion of radioactive isotopes (RI) towards the target surface is of considerable importance. Therefore, reliable data about the diffusion of the elements of interest are crucial for the optimization of the ISOL experiments [1,2].

In this study [3], fluoride CaF_2 was examined as a possible ISOL target material for the production of beams of radioactive B. Though RI of B have important applications, currently no RI beam of B exist. It is because of the strong bonds the elemental B has with elements used in the ion source units. This obstacle might be overcome if fluorides and the chemical vapor technique are utilized: at elevated temperatures F can be released in a sufficient amount and, in the presence of B, volatile BF_x molecules can be formed. The required vapor pressure of F can be achieved by heating of BF_x, which could, at the same time, serve as ISOL spallation targets for the production of RI of B.

Diffusion of B in CaF_2 was inspected for the 390 keV ^{10}B ions implanted into CaF_2 to a fluence of 10^{16} cm^{-2}. The samples were gradually annealed from 200 – 700ºC for 4 – 100 hrs. The depth profiles of B on as-implanted and annealed samples were obtained using neutron depth profiling technique.

In Fig. 1, depth profiles of B in CaF_2 (before and after annealing) are shown. The B distribution in the as-implanted sample has a Gaussian-like form which remains unchanged up to 400ºC. Annealing at higher temperatures leads to a non-Fickian diffusion of B from the site of implantation to the CaF_2 surface. The process is triggered around 500ºC, and by 700ºC all B atoms are transferred to the sample subsurface zone (< 0.5 μm). The fraction of the transferred atoms is an increasing function of the annealing time and temperature. Depth distributions at 600ºC point out a 'cascade' diffusion nature, which is perhaps due to the radiation induced defects formed in CaF_2 during the ^{10}B implantation. The defects (due to electronic and nuclear energy transfer) might work as trap-and-release centers for the diffusing atoms, and cause the diffusion favoring only direction towards the surface (this assumption, however, needs to be confirmed).

In conclusion, we have investigated the diffusion behavior of B implanted into CaF_2 in a broad range of annealing temperatures and times. Dramatic one-direction diffusion of B to the sample surface was observed > 500ºC, which might be caused by defects induced by the initial ^{10}B implantation. The experimental data show that CaF_2 could serve as a promising ISOL target for production of the RI beam of B.

The work was supported by Ministry of Trade and Industry of CR under the project No. 1H-PK2/05.

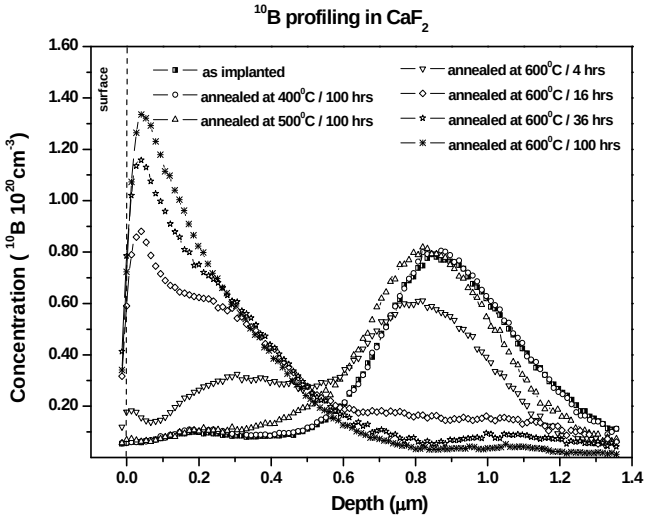

Fig. 1. Depth distributions of the B atoms in CaF_2 before and after thermal annealing.

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Study of protective coatings prepared in rf organosilicon discharges

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The organo-silicon and silicon oxide films are used as anti-scratch coating of plastics, barrier films for food packaging, corrosion protective layers or low-k dielectrics. Thin protective coatings with different structure ranging from organo-silicon plasma polymers to SiO_2-like films were deposited in r.f. capacitively coupled discharges (13.56 MHz) from a mixture of hexamethy1disiloxane (HMDSO) and oxygen onto Si and glass substrates. The film thickness and composition were determined by means of RBS and ERDA nuclear analytical methods using protons and He ions from VdG and Tandetron accelerators at Nuclear Physics Institute. The complexity of samples, comprising hydrogen, carbon, nitrogen and silicon, needs multiple measurements under different experimental arrangements. Typically 5-7 measurements were necessary for the film characterization. Complementary information was obtained from FTIR spectra and mechanical properties of the films were determined by standard techniques [1].

The organic-inorganic crossover of the film character was observed as a function of the HMDSO concentration (5-17%), gas pressure and d.c. self bias. When annealed, the films changed their composition, structure and mechanical properties. Desorption of water, methane and CO or CO_2 from the SiO_2 -like films is observed by RBS and ERDA methods. The hardness of the Si_2-like film, containing 5% carbon and 25% hydrogen, increased with increasing annealing temperature from 5.9 (as deposited) to 11.3 GPa (annealing at 500 ^{0}C). Simultaneously, its fracture toughness was significantly improved. These effects are explained by dehydration and cross-linking of the film. The mechanical properties of highly cross-linked plasma polymer coating were better than those of SiO_2-like coating containing OH related impurities and the former can be used as a protective coating with the hardness above 9.6 GPa up to the temperature of 400 ^{0}C. It was also shown that a hard, cross-linked $SiO_xC_yH_z$ polymer films can be used as a protective coating for polycarbonate. The film hardness and elasticity modulus were 10 GPa and 75 GPa, respectively. Other films deposited from HMDSO/CH_4 and HMDSO/CH_4/H_2 mixtures exhibit attractive properties of DLC films with the partial elimination of some of their drawbacks. The film hardness and elastic modulus were above 22 GPa and 120 GPa, respectively.

The work was performed in collaboration with Masaryk University- Brno and supported by the Grant Agency of the Czech Republic under the project No. 202/07/1669).

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Characterisation of Ni^+ implanted PEEK, PET and PI

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Ion implantation is an efficient method of polymer surface property modification. High-fluence implantation, a unique method of introducing metal species into dielectrics above their solubility limits, provides a useful way of creating metal nanoparticles in polymers. The samples of polyimide (PI), polyetheretherketone (PEEK) and polyethyleneterephthalate (PET) in the form of foils 40, 25 and 50 μm thick, respectively, were implanted with 40 keV Ni^+ ions at fluences ranging from 1.0 x 10^{16} to 1.5 x 10^{17} cm^{-2}. The implantation was performed through the ion beam accelerator ILU-3 at room temperature at the Kazan Physical-Technical Institute. The depth profiles of the implanted Ni atoms and hydrogen were determined from the RBS and ERDA spectra registered simultaneously. An Omicron Nanotechnology ESCAProbeP spectrometer was used to measure the X-ray photoelectron spectra (XPS) (AlKα 1486.7 eV). The UV–vis measurement in a 150–800 nm wavelength band was performed using a Perkin–Elmer device. The polymer surface modification was also studied by measuring the electrical sheet resistance (Rs). The typical depth profiles of the implanted Ni atoms in PET, as determined using the RBS spectra, are shown in Fig. 1 (left). The profiles calculated with the SRIM 2003 code for the pristine polymer are provided for comparison, from which it is clear that the measured depth profiles differ significantly from those simulated. At higher fluences, the shape of the profile changes dramatically with the concentration maximum shifted towards the sample surface. The structural changes during ion irradiation can be better described with the help of the TRIDYN software [1], where the dynamic changes in thickness and composition are taken into account. See the right-hand side of Fig. 1. The UV–vis absorption, as a function of the ion fluence, followed a similar trend like the hydrogen depletion followed by ERDA, for details see [2]. While in the PET, the UV–vis absorption is gradually growing, like in the case of the hydrogen depletion, in the cases of the PEEK and PI, the saturation in the UV–vis absorption and hydrogen depletion was observed at a fluence of 0.75 x 10^{17} cm^{-2}. As expected, the Ni signal from the implanted polymer surface in XPS spectra became stronger as the ion fluence increased. The Ni^0/Ni^{o+} ratio is an increasing function of ion fluence. The electric resistance is a rapidly decreasing function of the ion fluence. In polymers, ion irradiation creates compact carbonaceous clusters, which may be responsible for enhanced electrical conductivity, for a narrower optical band gap and for the higher optical absorbance of the irradiated material. It has also been reported that the mean size of the cluster is higher for polymers with more complex monomeric units, which may be the cause of the different behavior observed in the PI and PET, the former having a more complex monomeric unit.

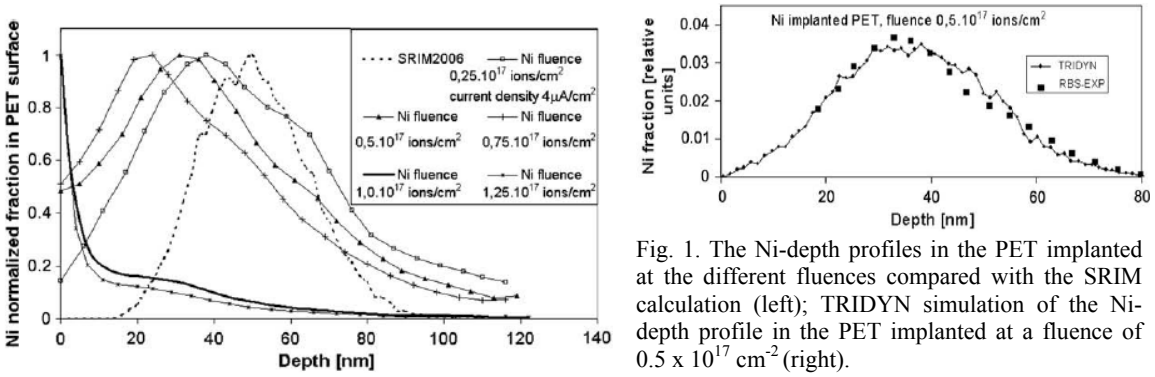

Fig. 1. The Ni-depth profiles in the PET implanted at the different fluences compared with the SRIM calculation (left); TRIDYN simulation of the Ni-depth profile in the PET implanted at a fluence of 0.5 x 10^{17} cm^{-2} (right).

The research has been supported by the Ministry of Education,Youth and Sports of the CR under Research Programme LC06041 and by the GAAS CR under projects KJB 100480601.

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Modification of poly(ether ether ketone) by ion irradiation

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Poly (ether ether ketone) (PEEK, ($C_{19}H_{12}O_3)_n$) is a semi-crystalline polymer with high glass transition (143 ^{0}C) and a high melting (343 ^{0}C) temperatures. The aromatic rings in the PEEK backbone are responsible for its strength, heat and radiation resistance. The ketone side group increases intermolecular spacing, whereas the ether linkage allows flexibility of the main chain. The excellent mechanical stability of PEEK at high temperatures has made it a material of choice in a number of applications in the space, automotive, electrical and chemical industries, among others. In some areas of application, e.g. in nuclear industry or space research, PEEK radiation resistance is of major importance. However, the information on the PEEK resistance to ionizing radiation are scarce and rather qualitative. Very little is known on radiation damages produced by irradiation with energetic ions.

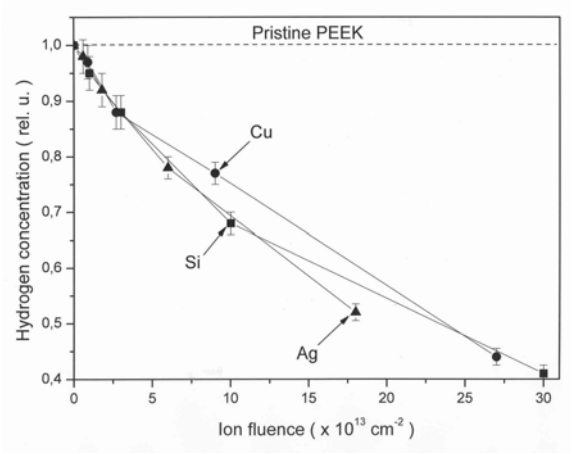

Fig. 1. The dependence of the hydrogen concentration (rel.u.) on the ion fluence for the PEEK irradiated with three ion species. The concentration in pristine PEEK is set equal to 1.

In this work PEEK foils, 0.025 mm thick (ρ=1.3 g.cm^{-3}), supplied by Goodfellow were irradiated with 3.0 MeV Si^{2+} , 3.25MeV Cu^{2+} and 4.8 MeV Ag^{2+} ions to the fluences from 10^{12}-10^{14} cm^{-2} and the effects of irradiation were studied using ERDA, RBS and FTIR methods. The irradiation leads to release of hydrogen from the PEEK surface layer modified by the ion beam. The release is mild for low ion fluences but it becomes more pronounced at the ion fluences above 10^{13} cm^{-2}. At highest ion fluences the hydrogen concentration falls to 20-35 % of its initial value.

The kinetic of the hydrogen release is similar for the three ion species (see Fig.1) and it can be described by a simple formula

$$c(\varphi) = (1 - f) + f \, . \, \exp(-\varphi.\sigma)$$

where $c(\varphi)$ is hydrogen concentration as a function of the ion fluence φ , f is the fraction of H atoms which can be released from the PEEK by ion impact and σ is an effective ion track area (10^{-13} cm^2). The values of adjustable parameters f and σ obtained from non-linear least squares fit of the data from Fig. 1. vary slightly for different ion species ($0.60<f<0.80$, $0.045<\sigma<0.075$).

In contrast to hydrogen no significant oxygen release was observed. FTIR measurement shows deep structural changes of the polymer structure resulting from the ion irradiation.

The work was supported by the Ministry of Education of the Czech republic under the project LC06041 and Academy of Science of the CR under Research program No. KAN400480701.

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Structural phenomena in glassy carbon induced by cobalt ion implantation

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Being one of the promising carbon forms, glassy carbon (GC) conceals great potential owing to a combination of unusual structure and attractive properties. The GC structure is the coexistence of a long-range disorder, with a perfect ordering of six-hold aromatic rings arranged within nanometer-sized graphitic units. The GC reduced density (about 1.5 g/cm^3) suggests a large amount of free volume dissolved in the material, this, as well as gas permeability and high hardness suggest uniform distribution of the free volume as nanopores closed inside the graphitic units. Filling the nanopores with metal would yield a functional nanocomposition attractive for application.

In this study [1] we have applied ion implantation to dope GC by cobalt. The cobalt-carbon nanocomposite is a promising substance for magnetic recording devices. The polished GC plates, with a thickness of 0.5 mm (Tokai Carbon Co.), were implanted by 150 keV Co^+ ions at room temperature in vacuum 10^{-6} Pa using a method of conventional ion implantation. To recognize the catalytic effect of cobalt during carbon structure development under the ion implantation, two different fluences of 1×10^{16} ions/cm^2 (low fluence) and 1×10^{17} ions/cm^2 (high fluence) have been applied. Depth distribution of the implanted cobalt has been analyzed using Rutherford Backscattering Spectroscopy. The carbon structure of the implanted GC samples was evaluated by Raman Spectroscopy (with a 514.5 nm laser wavelength. The surface structure has been analyzed by Atomic Force Microscopy.

It was found that the low- and high-fluence Co^+ ion implantations induce in GC samples rather different structural phenomena. In particular, Raman spectra have revealed the formation of amorphous carbon (a-C) composing 15 % and 5 % of the sp^2 phase after the low- and high-fluence implantations, respectively. The size of the graphitic clusters in the implanted samples was estimated to be 1.1 nm and 2.8 nm, suggesting growth of sp^2 clusters under the long-term implantation. Analysis of the depth profiles argues into the enhanced Co diffusion in a heavily implanted sample. Deconvolution of the a-C Raman peak displays two additional vibration modes (*X* and *Y*, see Fig. 1) arising only in the high-fluence implanted GC together with the general *D* and *G* carbon peaks. The latter reflects the formation of short transpolyacetylene (TRA)-like chains in disordered carbon revealing the first step of the a-C structure ordering. A remarkable correlation of the kinetic effects taken place during the high-fluence implantation confirms the catalytic role of cobalt atoms in the process of carbon structure organization.

The study was supported by Grant Agency of the Czech Republic (grant No. IAA4001701) and Academy of Science of the Czech Republic (grant No. KAN400480701).

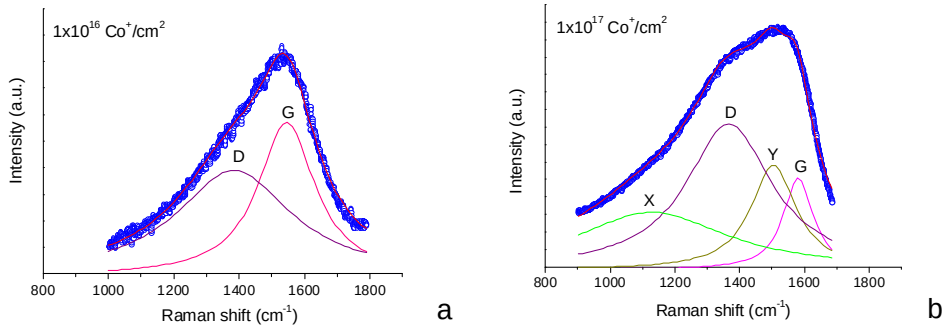

Fig. 1. Lorentz deconvolution of the a-C Raman peak rising in glassy carbon implanted by 150 keV Co^+ ions with fluences of 1×10^{16} ions/cm^2 (a) and 1×10^{17} ions/cm^2 (b).

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Sandwich Type Dispersive Monochromators Based on Cylindrically Bent Perfect Crystals (BPC)

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In many cases, new samples and necessity of measurement of finer effects require a substantial increase of angular and/or energy resolution of conventional diffractometers operating in a conventional performance mode. In such a case, a convenient monochromator plays a key role. Bent perfect crystal (BPC) slabs as neutron monochromators have been already proved as an excellent alternative of conventional mosaic crystals. They provide a way how to increase luminosity and angular/energy resolution of some scattering devices installed usually at steady state sources. An increase of the luminosity is carried out by focusing in real space, while a higher resolution can be achieved by focusing in momentum space and by a rather small effective mosaicity of the BPC elements. Together with construction of new powerful neutron sources, new scattering instruments with improved resolution properties are designed. One of the candidates of monochromators for very high resolution neutron diffractometers and spectrometers appear so called dispersive monochromators based on a dispersive double diffraction process. Recently, it has appeared that the dispersive double diffraction process can be realized by means of a sandwich using two bent perfect crystal slabs of a different cut (see Fig. 1). The choice of the crystal cut provides a freedom in combination of slabs in the sandwich as well as the reflections involved.

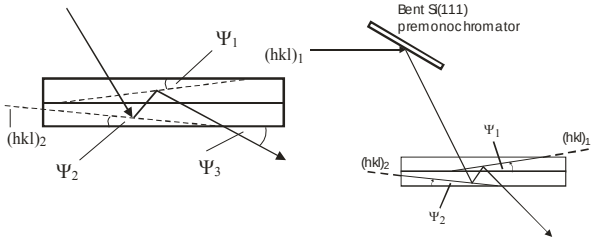

Figure 1: (a) - schematic diagram of a two-step double reflection process realized by two independent slabs put together in the form of a sandwich and (b) - the experimental arrangement used for testing.

Then, the choice of the reflections and the corresponding angles Ψ_1 and Ψ_2 determine the neutron wavelength and the final monochromator take-off angle $2\theta_M = \Psi_3$. In this contribution we present the results of test experiments with such dispersive monochromators. Depending on the cut of slabs one can use many combinations of two reflections realized by the sandwich. For example, the sandwich with the first slab having the main face parallel to the planes (110) and the longest edge parallel to the vector [1-11] and the second slab having the main face parallel the planes (11-1) and the longest edge parallel to the vector [112] provides the following reflection combinations:

Si(220) ($\Psi_{220}=0^o$) + Si(331) ($\Psi_{331}=-22.00^o$) $\quad \theta_{220}=31.39^o \quad \theta_{331}=51.39^o \quad \lambda=0.20$ nm

Si(220) ($\Psi_{220}=0^o$) + Si(33-1) ($\Psi_{33\text{-}1}=-48.53^o$) $\quad \theta_{220}=40.45^o \quad \theta_{331}=88.98^o \quad \lambda=0.25$ nm

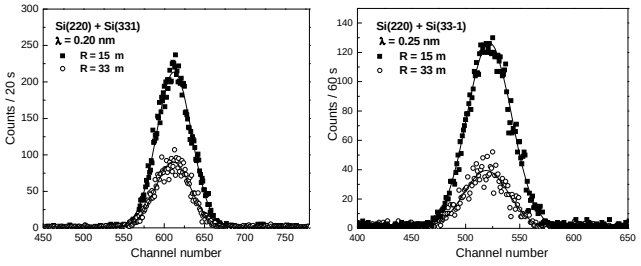

Figure 2: The double reflected beam as seen by 1-d PSD for two different radii of curvature *R* of the sandwiches.

The results of the corresponding measurement are displayed on Fig. 2. It can be seen from Fig. 2 that as expected, the intensity of the double reflected beam strongly depends on the radius of curvature of the sandwich. It should be pointed out that in the case of the Si(220)/Si(33-1) combination, the Bragg angle $\theta_{331}=88.98^o$ (notice back-scattering diffraction geometry) but the take-off angle is only $\Psi_3=97.06^o$. It can be concluded that depending on the bending radius of the sandwich the $\Delta\lambda/\lambda$ resolution and the $\Delta\alpha$ collimation of such dispersive monochromator can be continuously adjusted in the range of $5\text{x}10^{-5}$-$1\text{x}10^{-3}$. In the extremum case, one can work with the back scattering resolution on a conventional instrument with a rather small take-off angle.

This work was supported by the projects MSM2672244501 and AVOZ104805505.

SANS contrast dependence on difference in thermal expansions of phases in two-phase alloys

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In the recent in-situ small-angle neutron scattering (SANS) experiment on Ni-Fe-base superalloy DT706 [1], a rather surprising increase of the measured scattering curve amplitude (without observing any shape change) was detected during cooling at temperatures below 800°C. It is envisaged that an explanation for this observed increase in the SANS intensity could lie in the difference in the thermal expansion coefficients of the matrix and the precipitate. At low temperatures (below 800°C), diffusional processes in Ni-alloys are rather slow and changes in precipitate morphology and composition should be negligible.

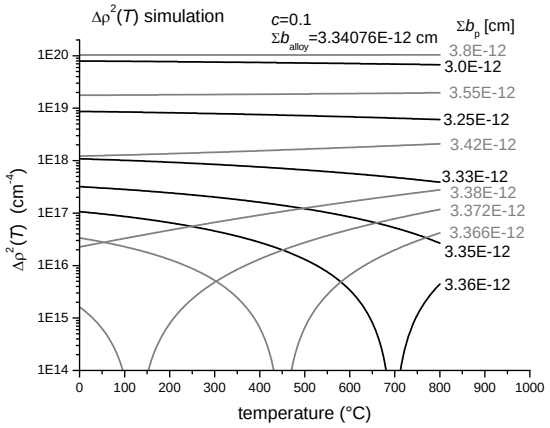

Fig. 1. Simulation of the scattering-length influence on the temperature dependence of the scattering contrast in DT706-like superalloy.

The theoretical expressions describing the dependence of SANS contrast on temperature in the abovementioned region were derived [2]. The theory considers difference in thermal expansion coefficients of the two primary phases in Ni-base superalloys (γ matrix and ordered γ' precipitates). The scattering contrast can be written in the form

$$[\Delta\rho(T)]^2 = \left[\frac{1}{1-c(T)}\left(\frac{[\Sigma b]_p}{a_p^3(T)} - \frac{[\Sigma b]_{alloy}}{v_c(T,c)}\right)\right]^2$$

where $a_p(T)$ is the temperature dependent lattice parameter of the precipitate, $v_c(T,c)$ is average unit cell of the alloy, $c(T)$ is the volume fraction of γ' precipitates and $[\Sigma b_{p,\mathrm{alloy}}]$ is the sum of the scattering lengths of the atoms in the unit cell of the precipitate and average unit cell of the alloy, respectivelly. It was demonstrated, that the difference in thermal expansion of phases is the determining factor for the temperature dependence of the contrast in the case where the sum of scattering lengths in the matrix and in the precipitate are not very different (Fig. 1). The simulations show that the value of scattering contrast is firmly connected with the particular shape of the temperature dependence. This fact can be used for the determination of the scattering contrast without a knowledge of the compositions of the individual phases.

The presented hypothesis on SANS contrast was proven by performing experiment on DT706 [2]. The evolution of lattice parameters of both the matrix and the precipitate phases, necessary for determining the evolution of unit cell volumes with temperature, was obtained from the in-situ wide angle neutron diffraction experiment (FRM-II - SPODI, Stressspec). Then, the theoretical scattering contrast dependence was successfully fitted to the measured SANS integral intensity (Fig. 2). The direct output of this fit is the scattering contrast at RT [$(\Delta\rho_R)^2 = 2.288\times10^{19}$ cm^{-4}] and its temperature dependence.

This work was supported through the EC contract No. RII3-CT-2003-505925 (NMI3).

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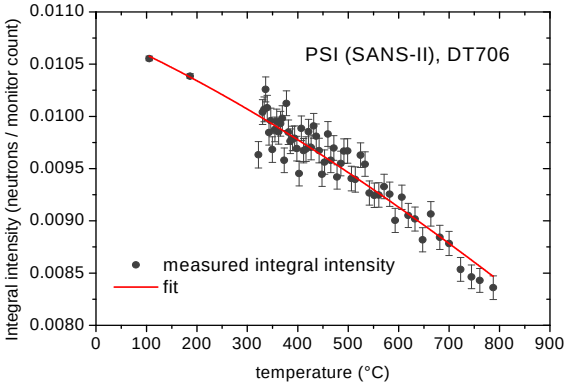

Fig. 2. Partial integral intensity of the SANS measurement in Porod region of DT706 sample together with the fit of the modeled curve.

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Evaluation of Substructure Parameters by Peak Profile Analysis of High-Resolution Neutron Diffraction Spectra

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X-Ray and synchrotron peak profile analysis is well known and efficient tool for characterization of macro- and microstructural parameters in studies of polycrystalline materials. Use of this method is however of great importance in the case of neutron diffraction. Neutron diffraction technique is preferentially used in the case when a deep penetration depth of the radiation probe is necessary. This benefit is used in many *in situ* neutron methods employing various sophisticated sample environments such as deformation testing machines (e.g. [1,2]), furnaces, cryostats and high-pressure cells. Comparing neutrons with X-Ray and synchrotron radiation, as a limiting factor of neutron experiments seems to be usually a lower flux of neutron sources and lower resolution of neutron diffractometers which typically results in longer counting times of neutron diffraction spectra. Characterization of dynamic behavior of the studied system is then more difficult. However, the intensive neutron spallation sources of the new generation and modern efficient powder diffractometers help to overcome this basic problem.

The transformed model fitting /TMF/ evaluation procedure [3] based on reciprocal-space modeling and transformed model fitting has been developed especially for treatment of single-line neutron diffraction profiles, exhibiting usually larger statistic errors with respect to X-ray diffraction profiles. The microstructure model created in the reciprocal-space is passing through a set of transformations resulting in the calculated profile corresponding to the experimentally observed diffraction profile. By conventional fitting procedure, the parameters of the microstructural models are refined to receive the best agreement between the calculated and experimental profile. Recently, more sophisticated broadening models based on the Wilkens dislocation model [4] and a log-normal grain size distribution [5] was adopted for the TMF procedure. The new approach in modeling of the broadening effects in real space provides more realistic microstructure parameters [6]. Using the Fourier transformation, this model is transformed to the reciprocal space, smeared by instrumental resolution, and compared with the measured data.

To verify the new dislocation model for TMF procedure, we performed comparative neutron and X-Ray diffraction experiments on the identical set of plain ferritic steel specimens prestrained up to 16% elongation. The microstructure of this steel consists of relatively large grains with the grain size of about 30 μm and the size effect on the profile broadening can be thus neglected.

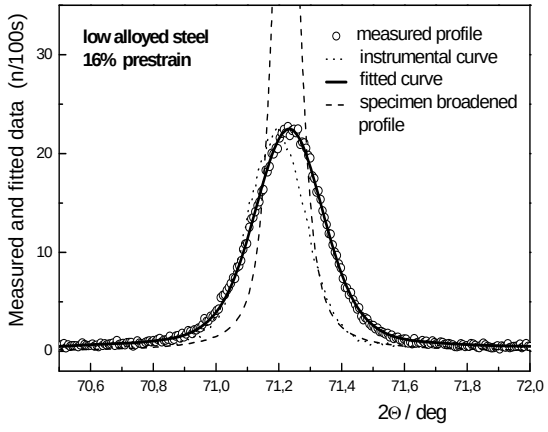

Fig. 1. Example of measured and treated neutron diffraction profile, reflection 110, macroscopic deformation 16%.

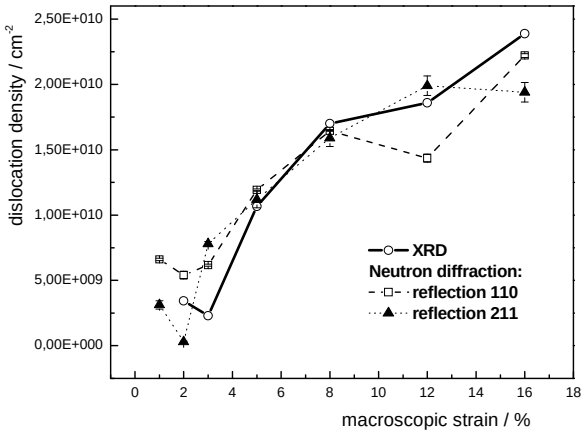

Fig. 2. Dislocation densities as a function of macroscopic strain. Comparison of neutron results (TMF procedure) and X-Ray results (Williamson Hall plot).

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Neutron diffraction profiles were measured at the dedicated stress/strain diffractometer TKSN-400 in NPI Řež. Two reflections 110 and 211 were measured with a relatively high instrumental resolution of $\Delta d/d \sim (2–2.5)\times10^{-3}$. The example of the measured and treated neutron profile is given in Fig. 1. X-Ray diffraction experiment was performed at Charles University in Prague by using the diffractometer Seifert FPM-XRD7 (conventional powder diffraction Bragg-Brentano geometry) and the diffractometer Panalytical X´Pert Pro with automatic divergence slit keeping the irradiated specimen area fixed and the secondary monochromator, both with Cu Kα radiation. In this case, the reflections 110, 200, 211, 220, 310, 222 were measured and analyzed.
The dislocation densities evaluated from individual neutron peaks by the TMF procedure are plotted together with X-ray data in Fig. 2. As it can be seen, a very good agreement was achieved and the new procedure might then be efficiently used in determination of dislocation densities.
The original TMF procedure was designed for treatment of single profiles, however, the proposed dislocation model of peak profile broadening can be easily used in future extension of the program for processing multiple peak spectra. Unlike classical evaluation methods, TMF procedure enables to analyze broadened profiles with arbitrary shape of the instrumental resolution function which offers another excellent prospect for treatment of neutron time-of-flight spectra measured at modern dedicated material powder diffractometers located at neutron spallation sources. These spectra are typically characterized by rather asymmetric or even triangular instrumental resolution profiles.

This work was supported by the Grant Agency of the ASCR (grant No. IAA100480704).

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DEPARTMENT OF RADIATION DOSIMETRY (DRD)

The activities of the DRD in 2007-2008 were connected with both the basic and methodological research in the dosimetry and microdosimetry of ionising radiation, some studies related to the applications of these methods in radiation protection and radiotherapy were also followed.

Long-term studies of anthropogenic influences in the environment have continued. These studies are focused on determination of some radionuclides with semiartificial/artificial origin, particularly ^{14}C. In the last century nuclear weapon tests were important sources of anthropogenic ^{14}C. After the nuclear moratorium on the atmospheric nuclear bomb tests, the ^{14}C concentration in the atmosphere has been decreasing due to an intensive transfer into oceanic and terrestrial carbon sinks. Actual type of the anthropogenic influence on activity of atmospheric $^{14}CO_2$ is characterized by the Suess effect, which can be observed on local, regional, and global scale. This effect which causes a decrease of $^{14}CO_2$ activity as a result of diluting by CO_2 released from fossil fuel combustion was intensely studied. Monitoring of atmospheric $^{14}CO_2$ in several localities, and comparison with results abroad, gives a tool to quantify fossil carbon occurrence from local and regional sources, estimate actual amount of $^{14}CO_2$ in the atmosphere (as a tracer of atmospheric CO_2), and also specify actual ^{14}C activity level more precisely.

The main topic of fundamental research during the mentioned period represented studies of radiation induced damage of bio-molecules. The development of theoretical techniques for predictions of direct and indirect radiation attack to DNA, proteins and their complexes belongs to a long term activity of the department. The yields and composition of DNA damages caused by ionizing radiation within DNA macromolecule depend on radiation type and energy. With increasing LET, DNA lesions are generated closer to each other and the proportion of sites containing isolated damages with respect to clustered damaged sites decreases.

Biological effects of the ionizing radiation depend both on the radiation quantity (absorbed dose) and the radiation quality (space and time distributions on the microscopic level). The radiation quality is the most commonly characterized through the physical quantity linear energy transfer (LET) (ICRU, 1970). LET depends on the type and energy of the particle depositing its energy at a point of interest. Determining of radiation quality needs to measure whole spectra of LET, particularly for complex radiation fields frequently studied in our department, like aircraft and spacecraft board, (mainly International Space Station - ISS), high-energy charged ion therapy beams, and in high-energy particle accelerators environment. To improve the LET spectrometry methodology, studies in heavy high-energy charged particle beams are fruitful. Such studies have to be performed at heavy ion accelerators like HIMAC at NIRS, Chiba, Japan.

Methodical studies concerning the development and use of track etched nuclear track detectors continued as well, mainly their response at nm-scale.

The results of some of these topics are characterised in more detail further.

Applied studies in 2007-2008 have been realised mostly in these directions:

1. New accreditation of the reference standard laboratory was acquired to improve the quality of metrology for all radiotherapy centres in the Czech Republic. More than 45 reference dosimetry systems of Czech radiotherapy centres have been calibrated and/or re-calibrated in air-kerma and/or in absorbed dose in water in the metrology centre of the DRD.
2. Important effort was devoted to the development and application of methods used to estimate environmental radiation, particularly liquid scintillation spectrometry and its use to determine radionuclides like T, ^{14}C, ^{89}Sr, ^{90}Sr, and ^{90}Y. Methods were applied mostly in and around NPP's of the Czech Republic.
3. The DRD has continued to perform individual dosimetry of aircraft crew members of Czech companies, the collective effective doses of aircrew members during 2007 and 2008 years was about close to 4.0 mSv, complex analysis of results obtained since 1998 has been performed and transmitted to the regulatory body of Czech Republic, and presented at international meetings.

Local and regional Suess effect quantification in the Central Europe

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Carbon-14 is a radionuclide with global occurrence and partly natural origin. This radionuclide is a pure beta emitter with the half-life of 5730 years. In the last century nuclear weapon tests were important sources of anthropogenic ^{14}C. Consequently, ^{14}C activity was found about twice larger on the north hemisphere during 1963 and 1964 than activity level given by natural production. After the nuclear moratorium on the atmospheric nuclear bomb tests signed in 1963, the ^{14}C concentration in the atmosphere has been decreasing due to an intensive transfer into oceanic and terrestrial carbon sinks. The most abundant chemical form of atmospheric radiocarbon is $^{14}CO_2$, which represents above 99.9% of ^{14}C atoms. Actual type of the anthropogenic influence on activity atmospheric $^{14}CO_2$ is the Suess effect, which can be observed on local, regional, and global scale. This effect causes a decrease of $^{14}CO_2$ activity as a result of diluting by CO_2 released from fossil fuel combustion. Carbon isotopic mixture in fossil fuels (natural gas, gasoline, oil, coal) does not contain significant amount of ^{14}C.

Suess effect quantification can provide an effective tool to verify the methodologies of CO_2 inventories calculations. To quantify size of regional and local Suess effect, there were utilized the $^{14}CO_2$ activities from several monitoring localities: Prague, Bulovka (bordering part of Prague in the vicinity of a relatively frequented motorway, extended local load from fossil fuel combustion can be expected in this locality); Košetice (this meteorological observatory is located in Czech-Moravian Highland in the area without presence of greater local sources of fossil carbon, the Suess effect can correspond to regional load from fossil fuel combustion only); Dunaföldvár, Hungary (a reference environmental monitoring locality in an agricultural area, prevailing influence can be expected from regional Suess effect); Bratislava, Mlynská dolina, Slovakia (bordering part of Bratislava, where a greater local load can expected) [1-3]. To calculate sum of local and regional Suess effect, reference $^{14}CO_2$ activities from monitoring station Jungfraujoch, Switzerland were utilized (this high mountain station, with influencing negligible from local and minimal from regional fossil carbon sources, is supposed to give the most proper reference data for European localities) [4-8].

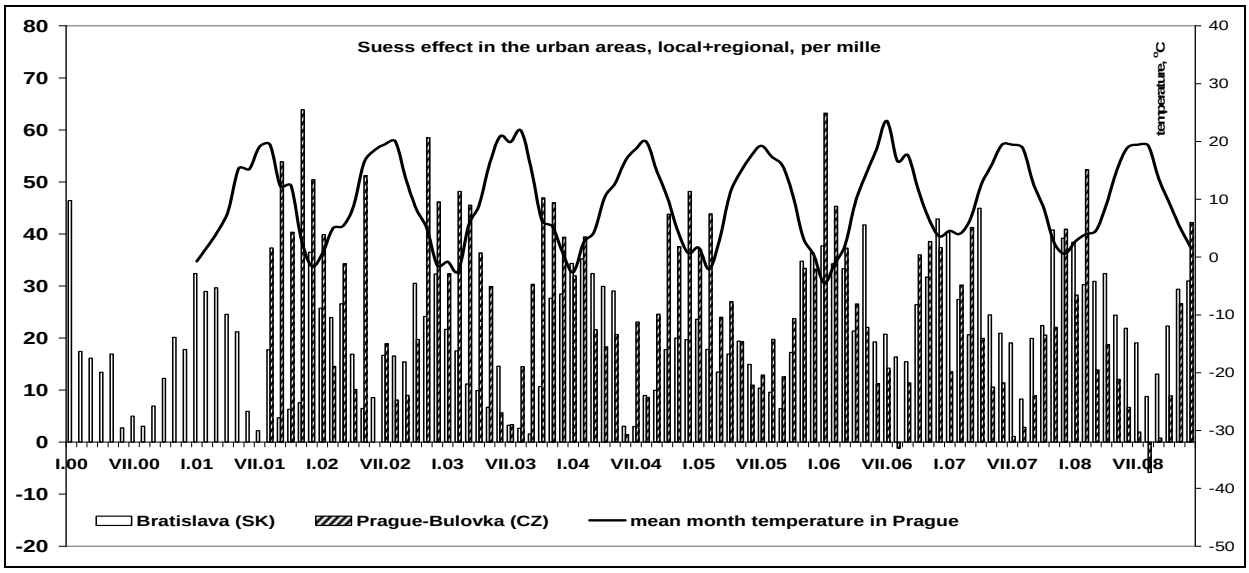

Fig. 1 a, b: Amount of fossil carbon from local/regional sources in carbon isotopic mixture, reported in per mille of atoms. (a) Sum of local and regional Suess effect in urban localities Prague, Bulovka and Bratislava, Mlynska dolina. Influencing by extended local emissions of fossil carbon is amplified by abundant occurrence of atmospheric inversions during cold period of the year. (b) Monitoring localities Košetice and Dunafolfvar with dominant regional Suess effect.

To evaluate sum of local and regional Suess effect, differences from Jungfraujoch monitoring station were calculated according formula, see Fig. 1 a, b:

$$S_{l+r} = \frac{a_{JF} - a_{obs}}{1 + 0.001.a_{JF}} [‰]$$

Where: S_{l+r} is sum of local and regional Suess effect (in per mille of fossil carbon from local and regional sources); a_{JF} is linear fitation of reference ^{14}C activity measured in Jungfraujoch monitoring station; a_{obs} is a value observed in a given monitoring locality [3].
Likewise, local Suess effect for urban areas loaded by extended fossil CO_2 emissions was calculated using analogical formula, see Fig. 2:

$$S_l = \frac{a_{reg} - a_{obs}}{1 + 0.001.a_{JF}} [‰]$$

Where: S_l is local Suess effect, a_{reg} is regional reference activity observed in the close locality where absence of greater local sources of fossil carbon can be supposed. As a partial of S_{l+r}, also local Suess effect is normalized to a_{JF} value.

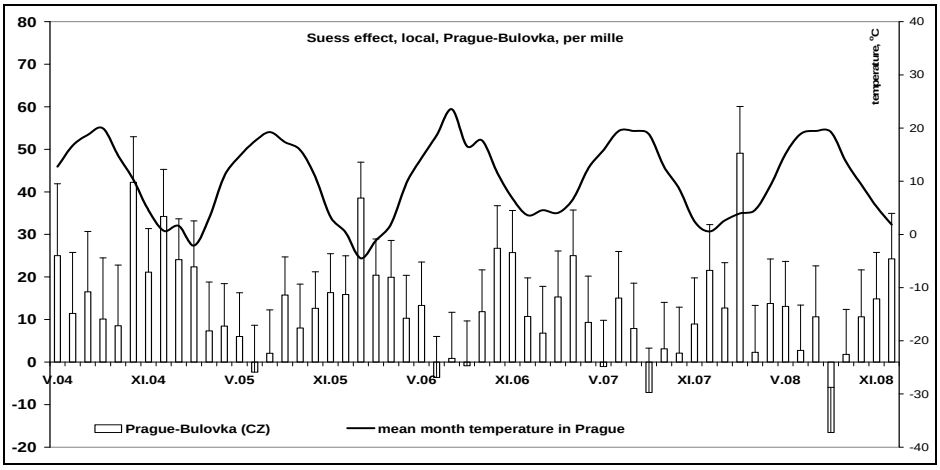

Fig. 2: Amount of fossil carbon from local sources in carbon isotopic mixture, reported in per mille of atoms. Local Suess effect observed in Prague-Bulovka. Calculated utilizing regional reference data from Košetice.

The data from the Hungarian monitoring locality Dunaföldvár and Czech monitoring station Košetice indicate similar grouping and amplitudes, which are typical for regional Suess effect. In the monitoring localities Prague-Bulovka and Bratislava Mlynska dolina, extended Suess effect, with a distinct seasonal behavior, was observed. Nevertheless, during summer period (VI-VIII namely) minimal or even statistically insignificant differences were observed in our monitoring localities in the comparison with reference high mountain monitoring station Jungfraujoch (in the Europe it is supposed to be minimally affected by local and regional fossil fuel combustion).

The work was partly supported by the funding of State Office for Nuclear Safety (SUJ 3/2006).

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Predictions of radiation induced complex DNA damages containing 8-oxoG

M. DAVÍDKOVÁ, V. ŠTĚPÁN

The yields and composition of DNA damages caused by ionizing radiation within DNA macromolecule depend on radiation type and energy. With increasing LET, DNA lesions are generated closer to each other and the proportion of sites containing isolated damages with respect to clustered damaged sites decreases. Complex DNA damages consist of two or more lesions, such as abasic sites, base lesions or single strand breaks occurring within one or two helical turns of the DNA double helix. The clustered DNA damage sites compromise the excision of base lesions and abasic sites. Poor repair efficiency of clustered lesions increases the probability that they will persist through DNA replication, consequently leads to the generation of mutations and thus contributes to deleterious biological effects of ionizing radiation [1]. The most important product of oxidative damage to DNA bases is 8-oxo-7,8-dihydroguanine (8-oxoG). The excision of this damaged base by hOGG1 or Fpg repair protein is retarded if an abasic site or strand break is present on the opposite strand in close proximity [2].

Theoretical calculations were applied to predict yields of simple and complex DNA damages induced by electrons, protons and alpha particles with LET in the range 0.4-160 keV/μm within a 100 base pairs long DNA oligonucleotide [3]. The particular attention has been paid to damages including 8-oxoG, especially those accompanied by a break of the complementary DNA strand.

The molecular structure of two 100 bp long DNA oligonucleotides with different random base sequences was built up and energy minimized using molecular modeling software AMBER 8 [4]. The calculations of DNA damage distributions were performed for 100 keV electrons, 2, 5 and 10 MeV protons and 2, 3, 4, 5 and 10 MeV alpha particles. Track structures of chosen ionizing particles were obtained from simulations performed by the code TRIOL [5]. The spatial coordinates of all energy deposition events of a primary particle and its secondaries together with the type of interaction and the amount of energy deposited were calculated for 100 keV track segments in liquid water. The track segments were randomly placed over the DNA macromolecule and damages caused by direct energy deposition within DNA or indirectly induced by $OH^{\cdot}$ radicals were recorded and analyzed. The chemical reactions within particle tracks were simulated using the model of the radiolysis of liquid water [6] and the $OH^{\cdot}$ radical attack according to model Radack [7]. In the spectrum of damages containing an 8-oxoG, the following damages were included: single 8-oxoG modified base (oMB), combination of an 8-oxoG and a SSB on the complementary strand (oSSB) and the sum of all other complex damages containing 8-oxoG (oOD). The yields are expressed per one successful placement, which is scored, when the random placement of the track segment over the DNA molecule results in at least one DNA damage. For each particle/energy combination, thirty thousand successful placements were considered for 100 track segments. Even for the lowest yields of oSSB, the expected error was less than 5% at 95% confidence level.

The predicted yields of DNA damages are summarized in Fig.1.Left. The yields of all types of complex damages grow with increasing LET. According to Lomax [8], it may be expected that 30-40% of DSB are associated with other lesions for sparsely ionizing radiation and this value should rise to over 90% for densely ionizing radiation. The calculated results show a rise from 43% for 100 keV electrons to 81% for 2 MeV alpha particles. On the other hand, the yields of simple damages decrease with increasing LET. The yields of oMB decrease with LET by about 25% of the yield. For oSSB, which comprises clusters containing 8-oxoG accompanied by a SSB on the complementary DNA strand, the yield non-linearly rises with LET. The yields for oOD are higher and linearly rise from about 0.02 to 0.08. The ratio of oSSB:oMB:oOD is approximately 1:14:6 for 100 keV electrons and 1:5:15 for 2 MeV alpha particles. All types of DNA damages containing 8-oxoG comprise about 8% of the total damage spectrum for all particle/energy combinations. The probability of more than one 8-oxoG in one cluster was always less than 4%.

The distribution of calculated distances between 8-oxoG and SSB on the complementary DNA strand is presented in Fig.1.Right. The shape of the distribution is similar for all charged particles. There are two peaks at relative positions about ± 3 bases from 8-oxoG. This observation reflects the molecular structure of the DNA double helix. The distance of the peak maximum

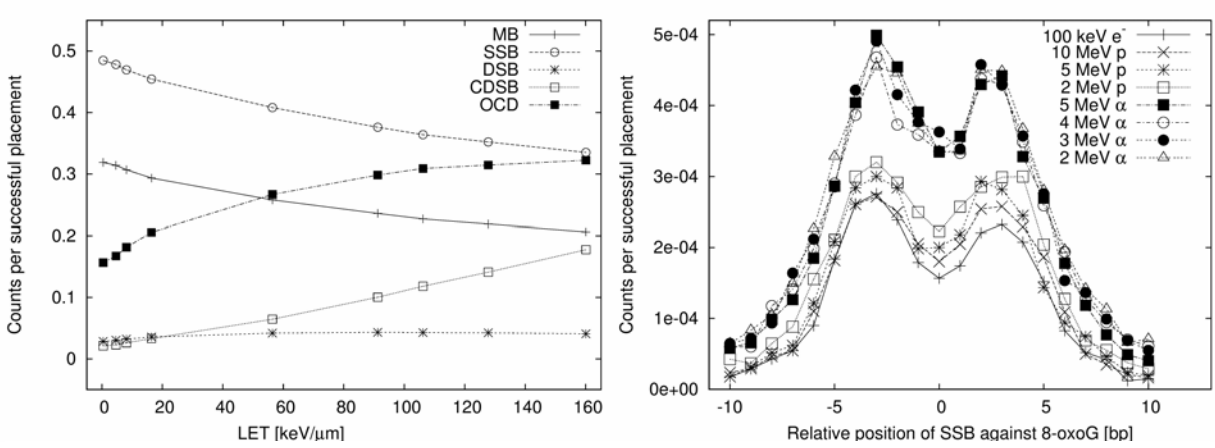

Fig. 1 - Left: The relative yields of simple (MB - modified base, SSB - single strand break) and complex (DSB - double strand break, CDSB - complex double strand break, OCD - other complex damage) DNA damages as a function of LET of incident ionizing radiation. The lines are drawn to guide the eye. Right: The relative yields of single strand breaks induced by charged particles in dependence on localization from 8-oxoG (position 0) on the complementary DNA strand.

corresponds to the lowest distance between the base and the nearest deoxyribose across the minor groove.

The group of Peter O'Neill found the greatest effect of repair inhibition to be for a combination of 8-oxoG with β-δ-SSB for different studied repair proteins [8]. The ability of 8-oxoG excision was reduced especially for complex damages with strand breaks localized ± 1 and ± 3 bases from the damaged base. Combined with our results this suggests that the damages at relative positions ± 3 bases will have an important contribution to unrepaired complex damages of this type.

The calculated yields of complex damage comprising an SSB and 8-oxoG modified base range from $3x10^{-3}$ per successful placement for 100 keV electrons to approximately $6x10^{-3}$ for 2 MeV alpha particles. Even for 2 MeV alpha particles they contribute to the whole spectrum of damages by less than 1%. Nevertheless, due to their incorrect or non-repair, this particular type of damage can have a significant influence on biological consequences of living cell irradiation.

This work was partially supported by the grant n. 202/05/2728 of the GA CR and research project AV0Z10480505. The calculations were performed using computing resources of CESNET Metacentrum computer grid (http://meta.cesnet.cz).

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Measurements and analysis of LET distributions at HIMAC BIO

I. JADRNÍČKOVÁ, F. SPURNÝ, K. BRABCOVÁ, O. PLOC, Z. MRÁZOVÁ

The determination of linear energy transfer (LET) is important for assessing the quality of radiation in mixed radiation fields (for example onboard spacecraft) and also for interpretation of biological effects. In real situation, it is usually necessary to measure LET in the range from about 0.1 to several hundreds of keV/μm (in water); even in high-energy heavier ions fields. The first step of the measurement is proper calibration of used devices in known radiation fields that are as closer as possible to real ones. Further, characteristics of radiation fields under not fully-known conditions can be appreciated.

During experiments, we used four different types of detectors – 2-3 types of thermoluminescent detectors (TLD) (with different dependencies of relative response on LET), 4 types of track etch detectors (TED) (with different sensitivities), MDU–Liulin, and TEPC (type HAWK). All these methods were studied and used in our laboratory for many years[1,2,3]. The calibration was performed during previous years in heavy charged particle beams, mainly at JINR (Dubna, Russia), HIMAC (Chiba, Japan), or at NASA Space Radiation Laboratory (Brookhaven, USA); during 2007–2008 calibration curves were verified and upgraded using HIMAC accelerator in Chiba.

With the exception of TEPC, the used detectors can bring information on LET only for certain region. On the other hand, TEPC can be used, due to its larger dimensions, in irradiation geometry quite different from, for example, typical radiobiological studies. Therefore, it is necessary to combine various methods. The whole shape of LET spectra can be obtained by combining measurements with TED (higher LET region) and MDU–Liulin (lower LET region). To determine total absorbed dose or dose equivalent, TED and TLD (lower-LET region) combine method can be used; this method is now commonly used for space radiation circumstances.

Since year 2008, we have started, within the new joint NPI-NIRS project, measurements at HIMAC-BIO; the main goal of this project is the determination of LET spectra in various conditions (ions from H up to Fe with energy of several hundreds of MeV/n, both MONOenergetic and Spread-Out-Bragg Peak beams) to start to build a database to be used for more profound interpretation of HIMAC-BIO accumulated radiobiological data.

In year 2008, irradiations in two ion beams were performed: C 290 MeV/n and Ne 400 MeV/n, both in configuration MONO. The detectors (passive detectors and Liulin) were placed at various depths along the Bragg curve (after binary filters of various thicknesses). Here, only some results for C 290 MONO are presented.

The Liulin measures the energy deposited in Si; the spectra of energy deposited were transformed to the spectra of LET under the assumption that the particles strike perpendicularly to the sensitive volume of Liulin. On Figure 1, there are shown spectra of LET measured with TED (left) and Liulin (right) for depths up to about 13 cm; the uncertainties are omitted in all figures for better lucidity. Dynamic range of Liulin is to about 21 MeV of deposit energy (it corresponds to about 33 keV/μm in water); above this value all events are stored in the last channel. The LET spectra (measured with TED) for depths around Bragg peak are shown on Figure 2.

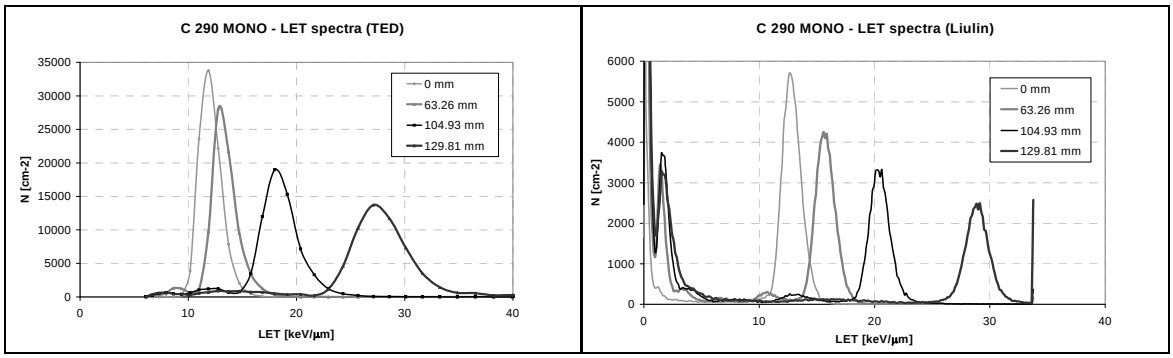

Figure 1. LET spectra in C 290 MeV/n MONO beam measured with track etch detectors (left) and Liulin (right).

Using Liulin data we tried to estimate contribution of particles with LET below 10 keV/μm to the total measured dose. Their contribution ranges from about 2% at the entrance up to about 8% for the depth 129.81 mm.

The absorbed doses (in water) determined with various methods were also compared with the reference one measured using ionization chamber. These depth-dose distributions for C 290 MONO beam are shown on Figure 3; the reference dose at the entrance was 2 mGy. One can see that the results from TLD ($CaSO_4$), TED, and Liulin agree well with the reference ones for the depths up to about 12 cm, then the doses measured with TLD and Liulin are lower than reference doses because of LET limitation of both detectors response in LET. In Bragg peak region, the doses measured with TED are higher than reference ones. One of the possible explanations could be the fact, that TED detectors also register short-range particles (target fragments) with higher-LET; such particles have range only few tens of μm so they can be absorbed in the cover of active detectors.

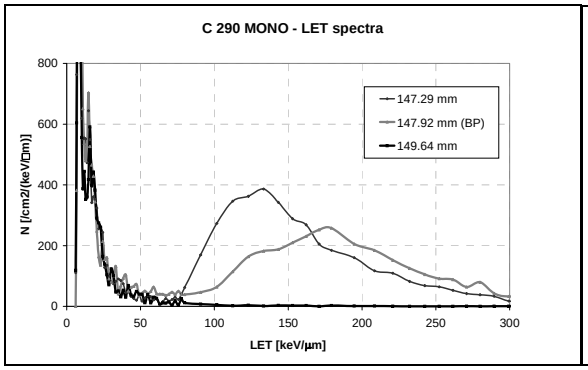

Figure 2. LET spectra in C 290 MeV/n MONO beam for depths around Bragg peak

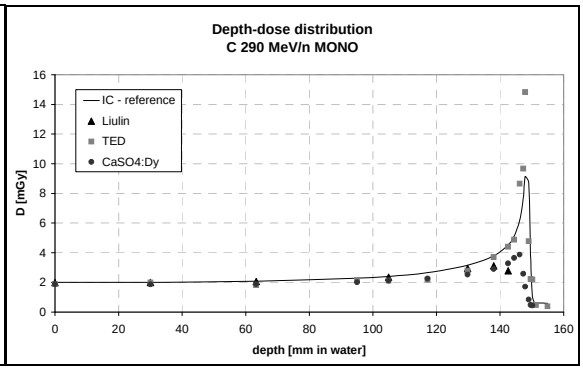

Figure 3. Depth-dose distributions in C 290 MONO beam measured with various method

The results of LET studies at HIMAC-BIO beams proved remarkable consistence of measuring methods chosen to fulfill this complex task. In the future, we plan to use these methods also for further types of ions and energies, both in configuration MONO and also SOBP; the experimental results will be also compared with simulations. The results obtained in this way should largely improve the LET spectrometer methodology.

This work was supported by:

1. COST 724: „Developing of Scientific Basis for Monitoring, Modeling and Predicting Space Weather“. WG2: The radiation environment of the Earth, 2002-2008; 2005-2008 supported by the Czech Ministry of Education (1P05OC032):
2. DOBIES: „Dosimetry for Biological Experiments in Space“, 2004-2008; ESA - ILSRA-2004-248
3. Research Project of the ASCR: AV0Z10480505 “Research in nuclear physics and related topics, including the use of results in other areas.

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DEPARTMENT OF RADIOPHARMACEUTICALS

The Department was established in 1998 and its task is *research, development and production* of radiopharmaceuticals using the isochronous cyclotron U-120M. In the last decade, radiochemical laboratories have been build and equipped with some 12 hot cells and all the radioanalytical techniques needed for doing the research and development of radioactive substances for medicine. Our production of several radiopharmaceuticals complies with the provisions of *good manufacturing practice.* Let us comment on some more details concerning the three main fields of activity of the Department.

Research of radiopharmaceuticals and, in a broader sense, of radioactive substances for medical purposes, is an important activity of the personnel of the Department. In 2008 we have started to transfer production of radiopharmaceuticals to the recently established company Radiomedic ltd.

PET rafiopharmaceuticals

Development of new fluorinated tracers for imaging cancers with positron emission tomography (PET) including in next step certification of GMP and marketing authorisation are basic tasks in this field. Fluoride 18 is the most suitable radioisotope for PET imaging. The physical half-life allows for high-yield radiosynthesis, transport from the production site (our laboratory) to imaging site and imaging protocols that may span hours, which permits dynamic studies and assessment of potentially fairly slow metabolic processes. R&D was focused on traces for cell proliferation (3´-[^{18}F] fluoro-3´-deoxythymidine, FLT) and study of amino acid transport (O-(2- [^{18}F]fluoroethyl)-L-tyrosine, FET in tumor cells.

Production of yttrium-86 for labeling of prospective biomolecules in PET diagnostics was developed; the fundamental step constituted successful design of the new target system for irradiation of solid preparative on cyclotron U-120M, which was realized in cooperation with the department of accelerators in 2007

Synthesis of the radiopharmaceutical FMISO and FET was finished successfully under the conditions GMP and it is ready for clinical investigation.

Therapeutic β^--emitters

Radionuclide therapy (RNT) employing radiopharmaceuticals labeled with β^- emitting radionuclides is fast emerging as an important part of nuclear medicine. Radionuclide therapy is effectively utilized for bone pain palliation, thus providing significant improvement in quality of life of patients suffering from pain resulting from bone metastasis. R&D of new radiopharmaceuticals for therapy, where the active nuclide is a beta-emitter, is aimed at targeted therapy of tumour diseases and non-invasive treatment of diseases of joints – radiosynovectomy. This was focused on preparation, neutron activation and processing of enriched target for production of Lu-177 chloride precursor were optimized. Precursor will be used within the scope of clinical trial focused on palliative treatment of bone metastasis after labeling with EDTMP. Analytical methods for quality control were designed. Production of precursor is carried out in the laboratories that meet the GMP requirements.

Our effort was aimed also at R&D of pharmaceuticals for treatment of blood generating organs, where the radionuclide must be in a carrier-free form (high purity $^{90}YCl_3$ no-carrier-added) and study new bifunctional polyazaligands, which are used in radioimmunoterapy as new generation of targete supercancerostatics in leukemia therapy and radioimunodiagnosis. A key parameter for these applications is a fast and efficient complexation of a suitable radioisotope (e. g. yttrium 90 and indium 111).

Labelled monoclonal antibodies

We have developed a new labeling strategy for synthetic polymers. It is based on formation of azodye useable for both covalent and chelated binding modalities on the same molecule utilizing L-tyrosine moiety as an anchor for the linker.

At present, dozen of PhD students take part in our research programmes, as well as several diploma students.

Production of short living radiopharmaceuticals is one of the main goals of the Department, since such substances can hardly be imported to our country or cannot be imported at all.

The production of ^{18}F-deoxyglucose (FDG)

It was started in autumn 1999 and FDG is delivered regularly to the PET center Homolka/Prague and to some other hospitals. During the last two years 823 batches of FDG (total activity 30,6 TBq) were produced by our Institute and delivered to five hospitals the Czech Republic and Slovak Republic. In 2008 we have started production of new PET radiopharmaceutical NaF and mostly used for diagnostics of metastasis in bones.

Within the project of IAEA we helped to start the FDG production in the cyclotron Centre in Bratislava, where they started their production on 1.1.2009.

The production of generators ^{81}Rb/^{81m}Kr

has been started in January 2001. The generators are used for lung ventilation studies in many hospitals in our country and in Slovak Republic. The generators are supplied together with the ventilation unit of our construction.

[^{18}F]FMISO - Perspective PET-Compound for Hypoxic Tumours Imaging

J. ZIMOVÁ, J. BAŠTA, L. PROCHÁZKA, M. KROPÁČEK, F. MELICHAR

Fluoromisonidazole (FMISO) has a chemical structure of 1-(2-nitro-1-imidazolyl)-3-fluoro-2-propranol (Fig. 1). It is a derivative of the nitroimidazole group of compounds, which have been investigated as hypoxic cell sensitizers. ^{18}F-FMISO enters cells by passive diffusion, where it is reduced by nitroreductase enzymes and it becomes trapped in cells with reduced tissue oxygen partial pressure and accumulates by binding to intracellular macromolecules.

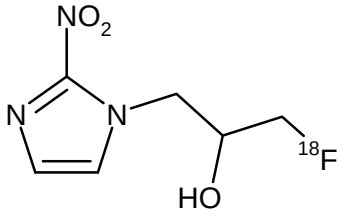

Fig. 1: Structure of [^{18}F]FMISO

Production of [^{18}F]FMISO

[^{18}F]FMISO is synthesized from the commercially available precursor 1-(2V-nitro-1Vimidazolyl)-2-O-tetrahydrofuranyl-3-O-toluenesulfonylpropanediol using nucleophilic substitution of tosyl group of the precursor by carrier-free [^{18}F]fluoride in TRACERLab Mx FDG automat with computer control. After that follows hydrolysis with 1M-HCl at 100 °C and the tetrahydropyranyl group is removed. The reaction mixture is purified with high-performance liquid chromatography (HPLC) on C-18 and alumina columns after it and sterilize by sterilizing filter into sterile vial. This automated synthesis allows the [^{18}F]FMISO with 97 % radiochemical purity and synthesis efficiency 50%. The synthesis time is 35 min. After [^{18}F]FMISO is prepared, quality control includes radiochemical and chemical purity testing before administration.

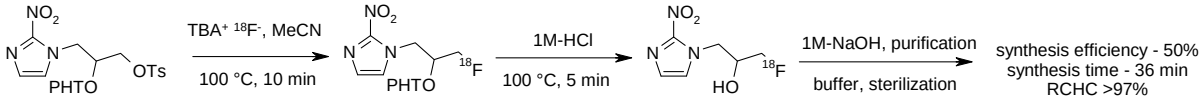

Fig. 2: Production of [^{18}F]FMISO process

Biodistribution of [^{18}F]FMISO

[^{18}F]FMISO is metabolized by the liver and excreted by the kidney and bladder[1]. Biodistribution data in preclinical rat model, measured at two different uptake times (in Fig. 3) have shown that the highest concentration of activity, expressed as a percentage of the injected dose per gram tissue weight (% I.D./gram) was in the urine, with uptake also evident in the bladder. Lower activity was noted in the blood, kidney, spleen, heart, lung, pancreas and brain. Some activity was found in the intestine, liver, and bone muscle. It acknowledge that [^{18}F]FMISO is not entrapped in normal tissue and is excreted in the urine.

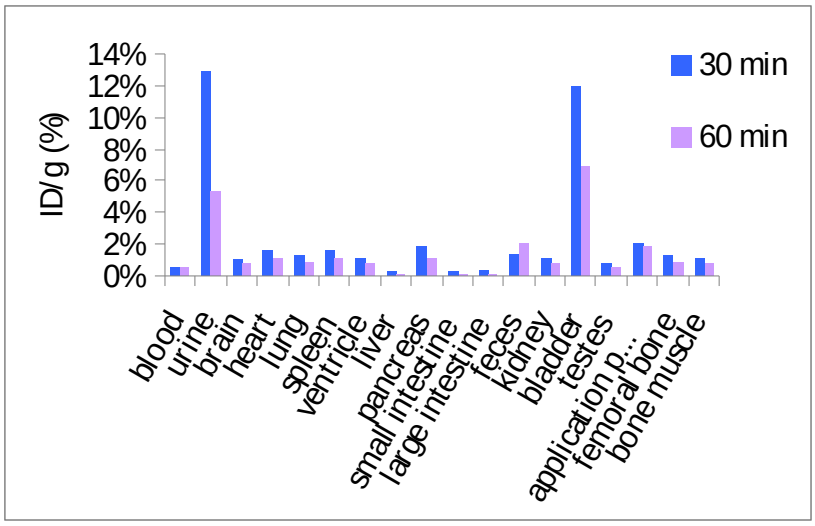

Fig. 3: Biodistribution of [^{18}F]FMISO in preclinical rat model

Preclinical study of [^{18}F]FMISO

The preclinical study of [^{18}F]FMISO was performed in rats with implanted cancerous cells of C6 glioma with the microPET camera. This study was showed that [^{18}F]FMISO is distributed in organism very fast (few tens seconds or minutes) and labels experimental glioma tumours in rats. The accumulation in tumours is not homogenous. It can be identified the hyperactive peripheral tumour part and the hypo functional central tumour part. The active tumour parts accumulate the [^{18}F]FMISO 2 - 10 × faster than normal tissue. These records are corresponding with the literature data[2].

In summary, the [^{18}F]FMISO which is preparing in our laboratory is now ready for the clinical studies and for registration in the State Institute for Drug Control in the Czech Republic[3].

We thank to Laboratory IKEM, Praha 4 - Krč, RNDr. Jan Kovář, CSc., BIONT, a. s., MicroPET Laboratory , Bratislava; MUDr. Svorad Štolc, DrSc., RNDr. Lucia Jakubíková , and ITEST plus, s. r. o., Hradec Králové.
Financial support: the project of MPO 2A-1TP1/055 „Development of PET radiodiagnosic for imaging in oncology and neurology".

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Production of gallium-68 for PET-diagnostics using „ionic“ ^{68}Ge/^{68}Ga radionuclide generator

K. EIGNER HENKE

Gallium-68 is a non-physiologic metallic positron emitter with a half-life of 68 min decaying by 89 % through positron emission (E_{max} = 1.92 MeV), by 11 % through orbital electron capture. The convenient availability from an in-house generator makes it increasingly attractive. It provides an attractive alternative to cyclotron-based positron emitters. The parent ^{68}Ge is produced on accelerator via (p,2n) reaction by irradiating Ga_2O_3 targets. It decays with a half-life of 270.8 d by electron capture. ^{68}Ge is strongly absorbed to different solid supports, such as metal oxides and organic pyrogallol-formaldehyde resins.

In march 2008, commercially available 1,110-MBq device generator based on a TiO_2 phase adsorbing ^{68}Ge(IV) was purchased from Cyclotron Co. Ltd. Nevertheless, this „ionic“ ^{68}Ge/^{68}Ga radionuclide generator is not necessarily optimized for the synthesis of ^{68}Ga-labelled radiopharmaceuticals. An important aspect for wide use of ^{68}Ga in clinical PET is its chemical form and concentration after elution from the generator. The initially generator eluted ^{68}Ga is pre-concentrated and purified using miniaturized column with organic cation-exchanger. The most effective method to eliminate the ^{68}Ge-breakthrough and the generator column material contaminants from the product was developed by Zhernosekov et al. (2007).

In the presented study, much attention was paid to develop and evaluate the analytical methods for quality control of gallium (^{68}Ga) chloride solution for radiolabelling according to the requirements recommended by the European Pharmacopoeia (radionuclidic, radiochemical and chemical purity). The average over-all yield of ^{68}Ga activity obtained after elution and purification was 62,6 ± 4,0 % (n = 46). The radionuclidic purity was estimated by X-ray spectrometry with high resolution. The measurements proved very low level of the only impurity ^{68}Ge. Its content in all tested batches was $< 4{,}0 \cdot 10^{-5}$ % of ^{68}Ga activity. The radionuclidic purity is also much higher than required.

As the determination of all trace impurities incl. estimation of their acceptable concentrations is nearly impossible, a binding efficiency test seems to be much more predicative for declaring the quality than estimating the admissible limits of individual chemical impurities. The standard labeling test (SLT) developed by Eigner Henke et al. (2008) for quality control of no-carrier-added radioyttrium was modified. The ^{68}Ga eluate was evaporated to dry and dissolved in 0.2M HCl. The chelator DOTA (1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetraacetic acid) was dissolved in 0.4M sodium acetate buffer. All labeling reactions were performed at temperatures of 98 °C. The complexation efficiency was recorded by taking aliquots of 2 µL at 20 min. Aluminum-backed silica gel 60 instant thin-layer chromatography (ITLC-SG) was used for analyzing reaction yields. The mixture of water : ethanol : pyridine (4:2:1) as a mobile phase was selected. A pH value of ~2.5 of the reaction mixture was found to be optimum. The labeling yields obtained under optimized conditions were > 95 % by 10^4-fold excess of DOTA to ^{68}Ga.

Such prepared ^{68}Ga is highly suitable for labelling of chelator-conjugated biomolecules, allowing kit production and enabling wide availability.

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New Linker Strategy for Radionuclide Labeling of Synthetic Polymers

J. KUČKA, M. HRUBÝ[1], M. VETRÍK, O. LEBEDA

Radionuclide labeling of bio(macro)molecules and synthetic polymers is important both in research (biodistribution, pharmacokinetics etc.) and in clinical practice (diagnostics, e.g. Octreoscan®, and therapy, e.g. Zevalin®). Since the direct labeling of a molecule of interest is possible only rarely, a suitable linker is usually inevitable. Such a linker should ensure reasonable labeling yields, stability of the labeled molecule under *in vivo* conditions, and should not alter eventual specific binding ability of the biomolecule. Non-specific interactions of the linker in organism should be as low as possible. The linker design depends on the character of radionuclide binding.

We have developed a new labeling strategy for synthetic polymers. It is based on formation of azodye useable for both covalent and chelated binding modalities on the same molecule utilizing L-tyrosine moiety as an anchor for the linker. In the case of synthetic polymers polymerized by radical polymerization, L-tyrosine may be easily introduced by copolymerization of *N*-methacryloyl tyrosinamide [1]. We used the hydrophilic poly[*N*-(2-hydroxypropyl)methacrylamide] and the thermoresponsive poly(*N*-isopropyl acrylamide) as model polymers. Poly[*N*-(2-hydroxypropyl)methacrylamide] is highly hydrophilic biocompatible polymer used for the construction of water soluble drug delivery systems, and poly(*N*-isopropyl acrylamide) is a biocompatible polymer with lower critical solubility temperature, suitable for the construction of thermoresponsive drug delivery systems such as micelles, gels, etc. The commercially available primary aromatic amine derivatives of the selective multivalent cation chelators (DTPA, CHX-A"-DTPA and DOTA, see **Fig 1** for structures of the primary amino precursors) were diazotized and azocopulated with the L-tyrosine containing structures under mild conditions (See **Fig 2** for typical scheme). The resulting azodye is labelable with metal cations by chelation and the phenolic moieties in the azodye structure (as well as unreacted remaining L-tyrosine moieties) are easily radioiodinated. The proposed linker has also an advantage of facile spectrophotometric determination of conjugation yield thanks to the chromophore group in the linker.

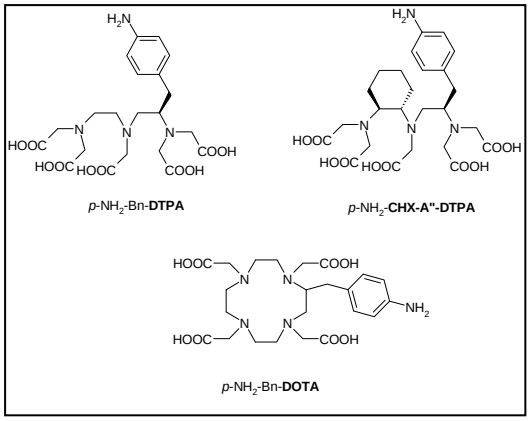

Fig. 1 Primary amino precursors of the chelators

The polymers were successfully conjugated with the chelating agents. The content of labelable moieties (theoretical labeling capacities) was more than sufficient even for therapeutic use of such polymers (see **Table 1**). No significant changes in molecular weight of the polymers were observed during the conjugation reactions (no crosslinking, data not shown). The conjugates were then radiolabeled with both the covalently bound (^{125}I) and chelated (^{111}In) radionuclides in high yield (see **Table 1** for labeling yields) and sufficient *in vitro* stability of the label

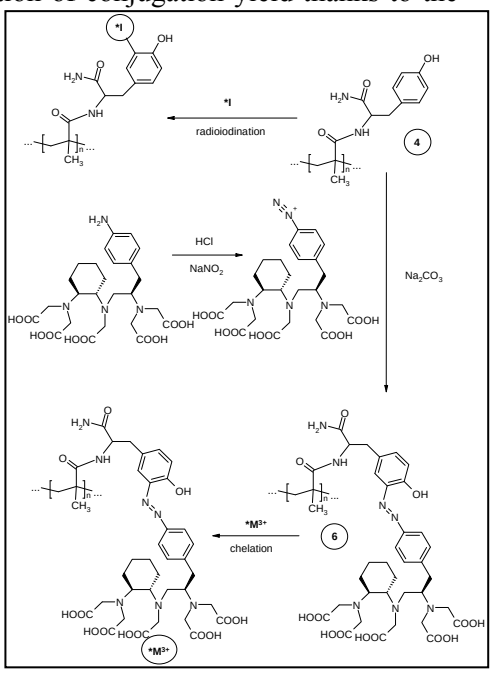

Fig. 2 Introduction of the CHXA``-DTPA chelating groups into the copolymers

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was proven in the environment of competing metal ions.

polymer	main unit	chelating group	group content [μmol/g]	labeling yield ^{125}I	labeling yield ^{111}In	theoretical capacity (^{125}I) [GBq/mg]	theoretical capacity (^{111}In) [GBq/mg]
P 2595	HPMA	CHXA*-DTPA	10.90	94 %	85 %	10.6	18.8
P 2608	HPMA	DOTA	1.49	93 %	83 %	10.6	2.6
P 2611	HPMA	DTPA	6.70	94 %	70 %	10.6	11.5
P 2613	NPAA	CHXA*-DTPA	5.89	95 %	59 %	13.4	10.1
P 2615	NPAA	DOTA	3.09	95 %	62 %	13.4	5.3

Financial support of the Ministry of Education, Youth and Sports of the Czech Republic (grant no. 2B06165 and grant # IM 4635608802) and of the Academy of Sciences of the Czech Republic (grant # KAN 200200651) is gratefully acknowledged.

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DEPARTMENT OF ACCELERATORS

In the years 2007–2008, R&D activities of the Department of Accelerators were connected with the operation and upgrade of the isochronous cyclotron U-120M as well as with the utilization of accelerated ion beams. Several modernization steps of the particular cyclotron subsystems (i.e. vacuum system, RF, control system, extraction deflection system, ion source, beam diagnostics, electric power supply) were completed. As usually, an attention was given to mathematical simulations and calculations of the accelerated beam parameters. The results were used for the design of optimal technical upgrades and also for routine cyclotron operation. New unique target systems were designed, constructed, tested and put into routine operation. They were used for production of "traditional" radionuclides as well as for production of non-conventional radionuclides.

A new agreement between our department and FLNR JINR Dubna, Russia was signed in 2008. The objective of this cooperation is to elaborate a project of production cyclotron with the energy 33MeV of H^- ions.

Electron accelerator – microtron MT 25 – is also operated at our department. It will be shortly introduced in the individual contribution of this report.

Cyclotron upgrade

The main cyclotron upgrade was accomplished on the cyclotron RF system. An old acceleration dee electrode was replaced by the new one. It was designed and constructed with the holes of diameter 20mm. This modification significantly improved vacuum conditions inside the dee in the median plane: Losses of the accelerated H^-, D^- ions on the residual gas decreased, and thus the extracted proton and deuteron beams, especially on the final radii, increased by approx. 30 %. After this reconstruction, complete resonant characteristics of the RF resonator were measured.

In 2008, reconstruction of the old control panel of the cyclotron started. The first part of the old control and indicating elements allocated on the vertical panel of the dimensions $2.5\times6m^2$ were step by step replaced by the new ones. At the same time, related circuits for control and monitoring of the cyclotron parameters were newly designed and installed. Necessary new documentation was also elaborated. The first part of the panel was replaced without interrupting the cyclotron operation. The reconstruction will continue in 2009.

In order to decrease the doses of the cyclotron operation staff, a new shielding box for the PET targets which are highly activated during irradiation was designed and manufactured.

For the development and testing of the new or repaired cyclotron devices and equipments, an universal vacuum stand with independent pumping system was installed.

Mathematical simulation

The database of the previously calculated accelerating regimes of H^- , D^- ions and α particles was calculated and completed analogically also for $^3He^{2+}$ ions. Now, the database covers the whole range of energies of all particles which can be accelerated on the cyclotron and extracted to the beam line system.

Original method for a calculation of the basic accelerated and extracted beam parameter, i.e. emittance, was developed. It enables calculation of horizontal and vertical emittance of the ellipse shape through which pass randomly chosen percentage of the total beam current. Except for the emittance value, the parameters defining ellipse, so-called twiss parameters, are calculated as well. The twiss parameters are required for the standard codes used for the design and calculation of the ion beam line transport systems (e.g. AGILE code developed at CERN). This method is

universal and can be applied for both experimentally measured and mathematically simulated beams.

New radionuclides, target technology

Within the frame of cooperation with ITU Karlsruhe, Germany, radionuclide ^{230}U, one of the promising alpha emitters for application in targeted alpha therapy, was produced. Common project is presented in the individual contribution of this report.

An agreement with the ITU Karlsruhe was extended for the next 3 years. The objective of the further cooperation is to produce ^{230}U via alternative reaction $^{232}Th(p,3n)^{230}U$. Design of a target holder for irradiation of a thick target was completed. It must guarantee effective cooling of ^{232}Th discs in which the power dissipation of the beam will reach hundreds watts. Highly activated target must be automatically ejected into the lead container after irradiation.

An old system for control and operation of liquid targets used mainly for production of ^{18}F for PET scanners was replaced by the new one. Low-pressure valves suffering from a leakage of water and frequent failures were replaced by the new high-pressure and reliable ones. Original filling unit actuated by a stepper motor was replaced by the pneumatically actuated one. For effective cooling of the vacuum and target foils which are thermally stressed by the beam a new He gas cooling system was designed and manufactured. New electronic unit with display and new control software were developed. Reliability of the PET production increased significantly.

Measurement of the activity of the ^{18}F radionuclide after irradiation and its recalculating to EOB (End of Bombardment) is an important parameter. A new system for measurement of activity was developed in cooperation with BQM company. In the defined and constant geometry, the dose rates of enriched water volume with ^{18}F radionuclide are measured by the GM probe. Mutual position of capillar loop and GM probe was optimized, and the system is calibrated for direct calculation of the ^{18}F activity based on the dose rate.

In cooperation with HVM Plasma company, a new gaseous target for production of $^{18}F_2$ gas via reaction $^{20}Ne(d,\alpha)^{18}F$ was developed for the Department of Radiopharmaceuticals. The target holder consists of a beam collimator with a clamping part, two foils (vacuum and target ones) cooled by the He gas and target body which is conical cave of the volume 38 ml. The irradiated gas is a mixture of Ne with 1% of non-active F_2 as a carrier of active ^{18}F. Irradiated gas is transported by the capillary to the chemical box on the distance approx. 40 m. Control panel with high pressure valves resistant against aggressive fluorine is used for manipulation with active and non-active gas and monitoring of parameters during irradiation. All procedures are controlled via electronic control unit and special software developed in our department.

Utilization of the cyclotron U-120M

V. ZACH, J. ŠTURSA

In the period 2007 - 2008 moderate growth in cyclotron operational hours as compared with 2006 was indicated. A small drop of beam time hours for external commercial customers was compensated for the experiments and irradiations dedicated mainly to nuclear astrophysics, production of fast neutrons and production of radionuclides for development of new radiopharmaceuticals.

Cyclotron beam time distribution according to the different means of utilisation is shown in the following Table 1. The diagram of the cyclotron operational hours during the period 2005 - 2008 is in the Figure1.

year:	**2007**	**2008**
Beam to experiments [hours]:		
Astrophysics, nuclear reactions	548	463
Fast neutron generation, ADS, fusion	396	391
^{18}F – FDG production	2059	2204
^{18}F new compounds	39	51
^{18}F gas target	-	25
^{81}Rb /^{81m}Kr generator production	367	420
^{83}Rb production	24	26
^{123}I tests, production	46	34
New radionuclides production (^{124}I, ^{86}Y, ^{73}As, Tc)	68,5	38
Biological samples irradiation	10	3
^{211}At production	2	-
^{230}U production, new target	95,5	-
Beam diagnostics, regime tuning	13	56
Total beam time [hours]	**3 668**	**3 711**

Table 1. Cyclotron beam time statistics.

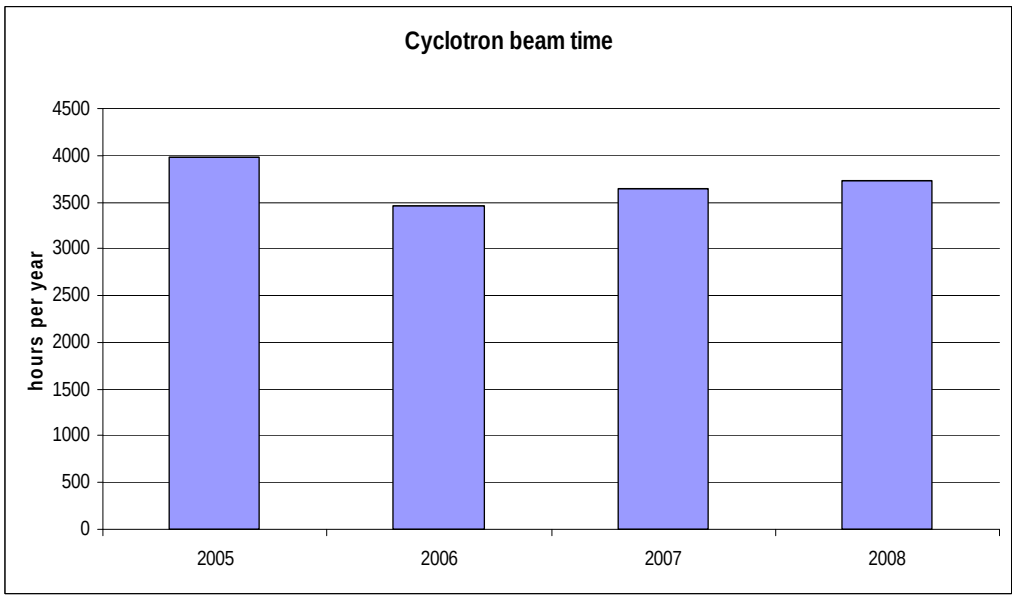

Fig. 1. Cyclotron beam time in the period 2005 – 2008.

Excitation functions for the production of ^{230}U via ^{231}Pa(p,2n) and ^{231}Pa(d,3n) reactions

J. ŠTURSA, O. LEBEDA, A. MORGENSTERN[1], Ch. APOSTOLIDIS[1], R. JIRAN, Z. PULEC, M. ČIHÁK

The uranium isotope ^{230}U (20.8 d) might be an interesting nuclide for alpha immunotherapy. It namely decays to ^{226}Th (30.9 min), a pure alpha emitter. It is parent of a decay chain resulting in quasi-stable ^{210}Pb (22.3 a). All the members of the chain are short-lived alpha emitters (< 40 s). Decay of ^{226}Th to ^{210}Pb is thus accompanied by emission of four alpha particles [1].

The ^{230}U can be directly prepared via the (p,2n) and (d,3n) reactions on ^{231}Pa (32 760 a). This target nuclide is, however, of limited availability (the world stock is ca 100 g), and the excitation functions of both reactions have never been measured. An international collaboration established between the Institute for Transuranium Elements in Karlsruhe (ITU) and the Nuclear Physics Institute (NPI) created a unique opportunity to solve this question.

Cross sections of both reactions were measured using ultra-thin ^{231}Pa targets manufactured by electrodeposition of ^{231}Pa on silver discs, covered by thin aluminium foil, at the ITU. The targets were irradiated on the cyclotron U-120M of the NPI. Proton and deuteron beams were extracted by the stripping from H^- and D^- regimes and delivered to the external target position. Two new types of target holder have been designed and manufactured for this purpose. The first one, with effective cooling system in which cooling water is in contact with the target capsule, was used for irradiation of thick targets, while the second one was exploited in irradiation of thin targets. Many accelerating regimes including parameters of extraction system were calculated and tuned to cover the desirable range of proton and deuteron energies. Beam parameters (energy and intensity) were determined both via beam orbit and integrated beam current measurements, and via parallel monitor reactions on ^{nat}Cu leading to ^{62}Zn, ^{63}Zn and ^{65}Zn using the recommended cross-sections [2] and their activity ratios [3]. The stopping powers of protons and deuterons in the target capsule were calculated with use of a program SRIM 2006 [4]. The activity of ^{230}U and its decay chain members was determined via alpha spectrometry in the ITU.

The measured cross-sections of the both reactions are displayed in Fig. 1 and Fig. 2. The (d,3n) reaction could not be measured in the full range due to the limited deuteron energies available (≤ 20 MeV). However, its maximum and shape are well visible. In general, cross-sections of both reactions are rather low, probably also due to the competing fission. Thick target yield of ^{230}U for a ^{231}Pa target and protons of E_{in} = 25 MeV is ca 0.41 MBq/μAh [5].

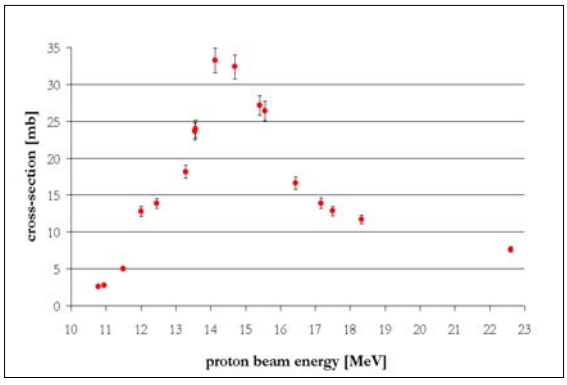

Fig 1. Reaction ^{231} Pa(p,2n)^{230}U.

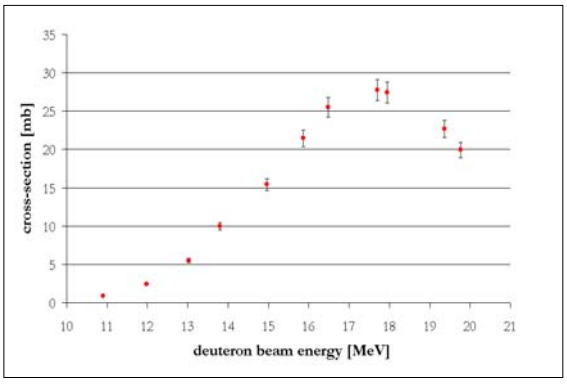

Fig. 2 Reaction ^{231}Pa(d,3n)^{230}U.

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New distribution system of liquid nitrogen for diffusion pumps

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Very important condition for acceleration of H^-, D^- ions on the cyclotron U-120M is vacuum limit reached in the vacuum chamber because negative ions are lost from acceleration process very easily after collisions with molecules of residual gas. Therefore an extensive vacuum system with pumping speed of several thousands l/s must be installed on the cyclotron. The diffusion pumps are the main units to maintain the operating pressure in the cyclotron vacuum chamber. In order to prevent from penetration of oil vapour from diffusion pumps to the vacuum system, special baffles on the temperature of liquid nitrogen are used. In addition, these baffles are extremely effective pumping units for water vapour which have very high cross section for collisions with accelerated beams and are then undesirable component in residual gas spectrum.

There was built-up new distribution system of liquid nitrogen (LN_2) for baffles of diffusion pumps which superseded an old system based on Dewar vessels (32dm^3).

The new LN distribution system for diffusion pumps consist of two main parts:

1. LN station (storage tank of LN_2).
2. Piping system (vacuum jacket line)

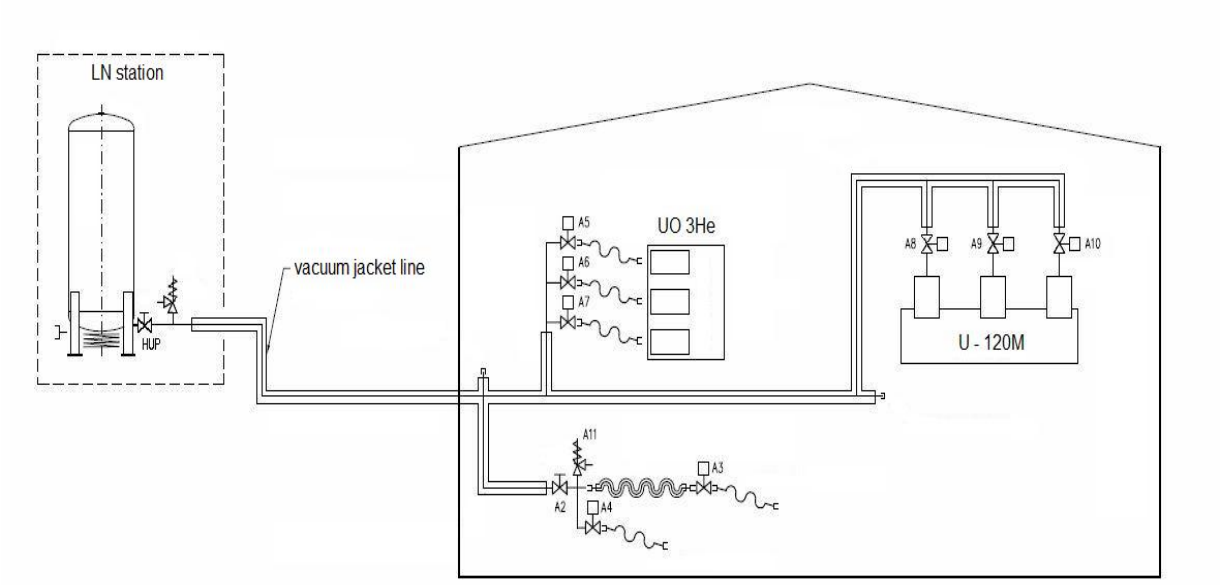

Fig. 1: Scheme of the new distribution LN system.

The storage tank (5 m^3) with required valves is located outside the cyclotron building. The LN_2 is supplied by piping system directly to the baffles of diffusion pumps and to recovery system of ^{3}He (UO3He). The piping is covered by a special vacuum insulation (vacuum jacket line). The main LN_2 supply is divided into three different lines to the diffusion pumps. The flow through each line is regulated by a motor actuated valve. The temperature in the baffle of the each line is measured by special temperature sensors.

There are two main advantages of this new distribution system. First, long term runs mainly for astrophysical experiments need not be interrupted approx. each 8 hours by exchange of Dewar vessels and second, doses of cyclotron operation staff were decreased.

Microtron Laboratory

Laboratory of microtron MT-25 is a detached part of the Department of Accelerators. The laboratory deals mainly with the following three projects.

The first project concerns a further step toward the full automation of the Prague microtron, the high frequency part of which has been modernized on the basis of new magnetron and modulator types. The automatic adjustment of the magnetron frequency to the actual resonant frequency of the resonator is indicated as the critical point of automation of the operation of the microtron. One solution of this problem was theoretically described and solved by Zhilinskiy, Lukanenko and Mirzoyan (Avtomaticheskaya podstroyka chastototy v mikrotrone).

The fundamental component for the automatic frequency regulation of the HF source is a phase comparator for evaluating the phase difference between the transmitted and reflected waves. From several types we propose to employ the 3 dB hybrid interface (phase comparator). The installation of this device was done in close collaboration between the Microwave company and the Microtron laboratory.

The second project deals with the design of the mathematical model and control system of microtron (HF cyclic electron accelerator with Kapitza's resonator). This accelerator type was controlled manually till now. The designed automatic control system should increase the accelerated electrons current value and should improve the beam stability. It is very important to provide the agreement of the power supply HF frequency (magnetron 2.8 GHz) with the resonant frequency of accelerating cavity. These frequency values are time variable due to temperature changes during the microtron operation. The quotient of the electric field inside the accelerating cavity and outside the magnetic field is the next parameter which determines quality of acceleration. Its quantity must be set up very carefully to satisfy accelerating conditions. The mathematical model of microtron was designed for the testing and for the setting up the new accelerator control system. This model includes the description of the base values that influence on its operation. Further values have been set up empirically on the basis of the previous operation experiences. This is one of reasons why the fuzzy controller way has been chosen.

The third project is the study of short-lived products of photonuclear reactions (γ, n), (γ, p), (γ, α) and photoexcitation reactions (γ, γ') induced by bremsstrahlung of MT-25 microtron and their application to instrumental photon activation analysis (IPAA).

Microtron modelling and control

D. CHVÁTIL, P. KRIST, M. VOGNAR, Č. ŠIMÁNĚ

This work deals with the design of the mathematical model and control system of microtron (HF cyclic electron accelerator with Kapitza's resonator). This accelerator type was controlled manually till now. The designed automatic control system should increase the accelerated electrons current value and should improve the beam stability. It is very important to provide the agreement of the power supply HF frequency (magnetron 2,8 GHz) with the resonant frequency of accelerating cavity. These frequency values are time variable due to temperature changes during the microtron operation. The quotient of the electric field inside the accelerating cavity and outside the magnetic field is the next parameter that determines quality of accelerating. Its quantity must be set up very carefully to satisfy accelerating conditions. The mathematical model of microtron was designed for the testing and for the setting up the new accelerator control system. This model includes the description of the base values that influence on its operation. Further values have been set up empirically on the basis of the previous operation experiences. This is one of reasons why the fuzzy controller way has been chosen.

Introduction

In 1944 the Russian physicist Veksler proposed a modification of cyclotron for electrons called microtron. This accelerator has a constant and homogenous magnetic field and a constant accelerating rf voltage. The wave length makes usually about $\lambda = 10$ cm ($f = 2{,}8$ GHz). It is the microwave band that gives its name.

The electrons trajectory in a microtron is a system of circles with the increasing diameter and with one common point placed in accelerating cavity [1].

Frequency stabilization

A stable acceleration process in a microtron is ensured by coincidence of the frequencies of the microwave oscillator (magnetron) and the acceleration cavity (resonator). Theoretical estimates and experiments show that in order to maintain stability of the accelerated electron current with an accuracy of 10 % the relative frequency drift of the oscillator must not exceed ±0.01 % for a loaded-cavity. In the oscillator, however, frequency drifts by several tenths of a percent are commonly observed when the operating mode changes. Moreover, the natural frequency of the accelerating cavity changes due to its heating [2]. This is why a system for automatic frequency control of the accelerating cavity was developed.

Figure 1 shows the block diagram of the automatic frequency control. The basic element is a mismatch sensor with phase detection (3 db hybrid coupler). Zero phase difference in forward and backward wave means the corresponding frequencies.

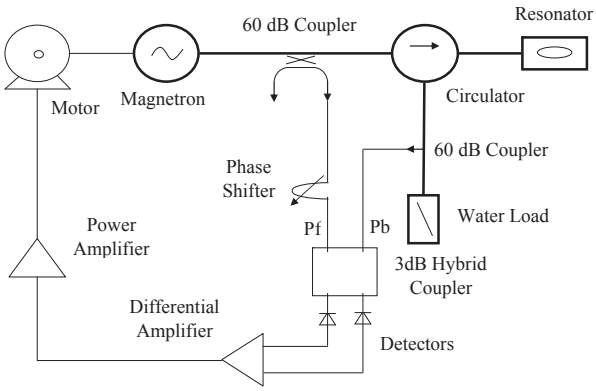

Figure 1. System for the automatic frequency control.

Mathematical model

The four equations of motion describe the motion of the electrons in an alternating electric field of constant frequency and in the constant uniform magnetic field. Outside accelerating cavity is only the constant uniform magnetic field. The motion has a cyclic character. So, the computer calculation must be divided on two parts. The numerical calculation was solved for the following initial conditions:

The electrons left with zero velocity ($v_x = v_y = 0$) the surface of the emitter placed in line with internal surface of the cavity ($y = 0$, $x = x_0$), see Figure 2. The calculation is provided for the definite orbit number. There are maximal 25 orbits in the Prague microtron MT25.

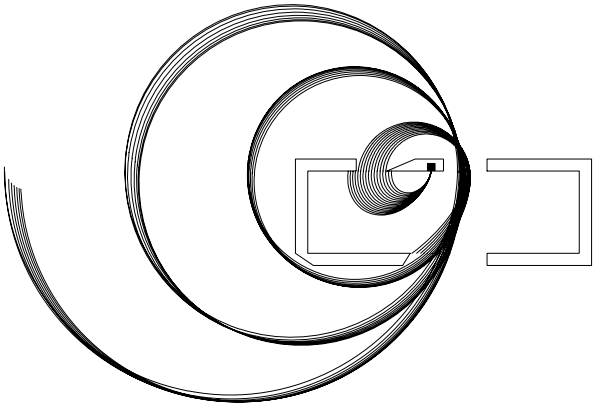

Figure 2. System of the electrons trajectories (3 orbits).

Beam current computation

The initial condition and whether the electron achieves a specified orbit can be found from the general equation of motion. The orbit number together with the magnetic field value determines its energy. Because we need to know the beam current value, we must calculate for a various initial phase value φ_0. The phase width (satisfying the accelerating condition) is a general beam current value indicator. The next parameters determining current are cathode temperature and microwave power. Emission capacity in dependence on temperature was measured in [3]. The quotient of the maximum beam current and the microwave power was measured on the Prague microtron MT25 in several points.

Fuzzy controller

The beam current computation supposes the correct amplitude of the electric field intensity inside accelerating cavity. That must by constant and depends on the outside magnetic field magnitude and the accelerating cavity thickness [3]. This value is crucial for satisfaction of the accelerating condition and it is immeasurable. And so it is well-suited use the fuzzy logic controller.

The fuzzy logic regulator with mathematical model was designed in MatLab Simulink (see Fig. 3).

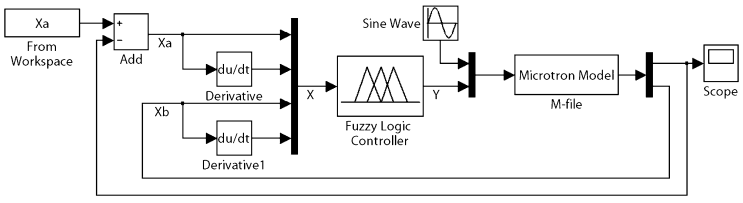

Figure 3. Fuzzy logic controller test circuit.

This work was supported by project DRIBs (Protocol No. 3769-5-07/09).

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1. **Kašpar, J. – Ryšavý, M.**
Optimal distribution of measurement time in single channel measurements.
Řež: NPI ASCR, report TECH-12/2008 (arXiv: 0812.0461).

2. **Kovář, I. - Malušek, A. - Orčíková, H. - Spurný, F.**
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Praha: Oddělení dozimetrie záření ÚJF AV ČR, v.v.i., 2008. 3 p. - (Výzkumná zpráva ODZ ÚJF AV ČR 593/08)

3. **Kovář, I. - Malušek, A. - Orčíková, H. - Spurný, F.**
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4. **Kovář, I. - Malušek, A. - Orčíková, H. - Spurný, F.**
Vyhodnocení úrovně ozáření posádek letadel společnosti Grossmann Jet Service, s.r.o. za rok 2007.
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5. **Kovář, I. - Malušek, A. - Orčíková, H. - Spurný, F.**
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10. **Spurný, F. - Ploc, O.**
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11. **Spurný, F. - Jadrníčková, I. - Brabcová, K.**
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12. **Strunz, P. – Mukherji, D. - Wiedenmann, A. - Prevost, P. - Keiderling, U. – Šaroun, J.**
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14. **Světlík, I. - Janovský, D.**
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15. **Turek, K. - Dajkó, G. - Orčíková, H. - Kovář, I. - Spurný, F.**
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VI. Popular papers, editorials and other articles without original results

1. **Bittner, M. - Juha, L. - Vacík, J.**
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2. **Fring, A. - Jones, H. - Znojil, M.**
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4. **Mach, Rostislav**
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Vesmír 87 (2008), no. 3, 168. ISSN 1214-4029.

5. **Macková, A. - Malinský, P.**
Dvě strany jedné mince -jaderná fyzika pomáhá v lékařství a technologie jaderných zbraní.
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6. **Wagner, V.**
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Svět no. 7 (2008). ISSN 1802-2278.

7. **Wagner, V.**
V laboratořích CERNu začíná největší experiment lidstva.
21. století no. 11 (2008), p. 70-77.

8. **Wagner, V.**
   Velký srážeč hadronů před spuštěním.
   Národní 3: revue pro vědu a umění no. 3 (2008), p. 32-33.
9. **Wagner, V.**
   Jaderné zdroje pro vesmírnou kolonizaci.
   Kozmos 49 (2008), no.1, p. 24-28; no. 2, p. 25-28; no. 3, p. 25-27; no. 4, p. 25-27.
10. **Wagner, V.**
    30 popular contributions in the internet newspaper *Osel*.
    http://www.osel.cz/ (2008, online only).
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VII. Edited volume

1. **Exner, P. (ed.) - Keating, J. P. (ed.) - Kuchment, P. (ed.) - Sunada, T. (ed.) - Teplyaev, A. (ed.)**
   Analysis on Graphs and Applications.
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OTHER ACTIVITIES IN 2007-2008

Conferences and meetings organized or co-organized by NPI

Analytic and Algebraic Methods in Physics, Prague, 20 Febuary 2007, 3 April 2007, 19 June 2007, 21 October 2008

4th International Summer School and Workshop „Nuclear Physics Methods and Accelerators in Biology and Medicine“, Prague, 8-19 July 2007

6th International Workshop on Pseudo Hermitian Hamiltonians in Quantum Physics, London, 16 - 18 July 2007

European School of High Energy Physics, Třešť, 19 August – 1 September 2007

Topical workshop on electronics for particle physics (TWEPP), Prague, 3-7 September 2007

XIXth Indian-Summer School „Few-Body Techniques & EFT“, Řež, 9-7 September 2007 (next August 27-31, 2008)

4th International workshop on Neutron Measurements, Evaluations and Applications, NEMEA-4, Prague, 16-18 October 2007

Workshop on physical, biological and medical aspects of higher – LET radiation energy transfer in the matter, Prague, 25–28 February 2008.

ALICE physics week in Prague, 3-7 March 2008

VIIth Workshop „Quantum Physics with Non-Hermitian Operators”, Benasque (Spain), 29 June - 11 July 2008

XXth Indian Summer School „Hadrons in Nuclear Medium“, Řež 27-31 August 2008

University courses given by NPI staff members

J. Adam: *Quantum Mechanics II*
J. Adam: *Field Theory*
J. Adam, J. Mareš: *Physics of Atomic Nuclei*
P. Bém, A. Kugler, J. Štursa: *Neutron Sources for Accelerator Driven Systems*
J. Bielčík: *Applied Nuclear Physics*
J. Bielčík: *Basic Exercises in Experimental Physics*
J. Bielčík: Physics
J. Bielčík: *Statistical Physics for Nuclear Physicists*
J. Bielčík, J. Bielčíková: *Discussions on the Quark-Gluon Plasma*
J. Bielčíková: *Advanced Exercises in Experimental Nuclear Physics*
J. Bielčíková: *Foundations of Quantum Chromodynamics*
D. Chvátil: *Exercises in Radiation Detection and Dosimetry*
D. Chvátil: *Selected Analytical Methods*
M. Davídková: *Foundations of Clinical Radiobiology*
M. Davídková: *Radiation Protection*
M. Davídková: *Radiobiology*
J. Dobeš: *Theory of the Atomic Nucleus*
P. Exner: *Mathematical Methods of the Quantum Theory*
M. Fikrle: *Basic Principles and Applications of Roentgen Fluorescent Analysis*
V. Hnatowicz: *Nuclear Analytical Methods*
J. Kučera: *Instrumental Radioanalytical Methods and Their Applications for Environment Monitoring*
J. Kučera: *Neutron Activation Analysis of Biological Materials and Environmental Samples*
V. Kushpil: *Inteligent Systems in the High-Energy Physics*
O. Lebeda: *Radionuclids Preparation*

A. Macková: *Computer Methods in Science and Technology*
A. Macková: *Experimental Analytical Methods in the Physics of Materials*
A. Macková: *Introduction to the Measurement Theory*
A. Macková: *Physics*
A. Macková: *Physics Teaching*
A. Macková: *Physics IV – Atomic and Nuclear Physics*
F. Melichar: *Foundations of Nuclear Medicine - Radiopharmaceuticals*
J. Mizera: *Radionuclids Applications I, II*
J. Novotný: *Numerical Computation in Quantum Mechanics I, II*
J. Novotný: *Quantum Mechnics II – Exercises*
Z. Řanda: *Radioanalytical Methods in Geology*
F. Spurný: *Energy Transfer in an Environment, Foundations of Microdosimetry*
F. Spurný: *Integral Methods of Ionizing Radiation Dosimetry*
F. Spurný: *Microdosimetry*
F. Spurný: *Neutron Dosimetry*
J. Šaroun, J. Vacík: *Experimental Nuclear Physics*
J. Vacík, J. Šaroun: *Neutron physics*
V. Wagner: *Foundations of Nuclear Physics*
V. Wagner: *Foundations of Nuclear Spectroscopy*

Seminars presented in other institutions

T. Brauner

Goldstone bosons in presence of charge density
22.2.2007, Norwegian University of Science and Technology, Trondheim

Spontaneous symmetry breaking and the Goldstone theorem
23.2.2007, Norwegian University of Science and Technology, Trondheim

Relativistic BCS-BEC crossover and collective excitations
23.4.2008, Institute for Theoretical Physics, Frankfurt University

Thermodynamics of the O(N) model in the 1/N expansion
16.10.2008, Institute for Theoretical Physics, Frankfurt University

A. Cieplý

Chiral approach to low energy anti-K N interactions
15.10.2008, IHEP Beijing

M. Davídková, F. Spurný

Radiation damage to biomolecules, results of theoretical and experimental studies
August 2007, NIRS, Chiba, Japan

J. Dittrich

On an infinite chain of dynamical equations
2.10.2008, BLTP JINR, Dubna

P. Exner

Unusual ways to decay
20.2.2007, Weierstrass Institut Berlin

Geometrically induced spectral properties of quantum layers
21.2.2007, Weierstrass Institut Berlin

New insights into unstable system dynamics
3.5.2007, University College London.

Classical and quantum isoperimetric problems solved using inequalities for means of Chords
6.2.2008, Humboldt Universität Berlin

Quantum graphs modelling networks
14.5.2008, Universite de Monastir, Tunisia.

Quantum graphs and squeezing of Dirichlet networks
24.6.2008, Universität Mainz

Quantum graphs and their vertex couplings
25.9.2008, Kochi University of Technology.

Approximations of quantum graphs by shrinking networks
1.10.2008, Gakushuin University, Tokyo

Shrinking networks approximations of quantum graphs vertices
7.10.2008, Okayama University

Shrinking limit of tube networks and coupling in vertices of quantum graphs
8.10.2008, Kanazawa University

J. Hošek

O původu hmotnosti
11.1.2007, Charles University, Faculty of Mathematics and Physics, Prague

Dynamical mass generation
27.3.2007, INFM Frascati

I. Jadrníčková

Spectrometry of linear energy transfer and its use in radiotherapy and radiation protection in high-energy particle fields
12.-13.2.2007, LRB JINR, Dubna

Spectrometry of linear energy transfer and its use in radiotherapy and radiation protection in high-energy particle fields
8.8.2007, NIRS, Chiba, Japan

Dosimetry and *LET spectrometry in C 290 MeV/n and Ne 400 MeV/n ion beams at HIMAC by different thermoluminescent detectors, track detectors and Liulin*
19.11.2008, LRB JINR, Dubna

I. Jadrníčková, F. Spurný

Spatial distribution of absorbed dose onboard of International Space Station
19.11.2008, LRB JINR, Dubna

D. Krejčiřík

Quantum traveller on manifolds
12.3.2007, Centro de Matemática e Aplicações, Universidade Nova de Lisboa, Caparica, Portugal

Non-Hermitian operators in quantum theory and PT-symmetry
26.3.07, Grupo de Física Matemática da Universidade de Lisboa

Nodal set of the Laplacian
25.4.2007, Department of Mathematics, Royal Institute of Technology, MESTO

Hardy inequalities in twisted waveguides
29.11.2007, IMDEA Mathematics Foundation, Universidad Autonoma de Madrid

The Brownian motion in twisted waveguides
8.1.2008, Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Prague

Opérateurs non auto-adjoints en mécanique quantique et la PT-symétrie
7.5.2008, Centre de Physique Théorique CNRS, Marseille

Kvantový cestovatel na varietách
27.5.2008, Department of Theoretical Physics, Comenius University, Bratislava

Spectral geometry of the Laplacian
8.7.2008, Dipartimento di Matematica „F. Casorati", Universita di Pavia.

V. Lavrentiev

From MICRO to NANO: selective topics of ion beam application
25.1.2007, Leibniz-Institute für Oberflächenmodifizierung e.v., Leipzig

L. Majling

Neutron-rich hypernuclei are coming: What they tell us?
October 07, Skobeltsin Institute of Nuclear Physics, Moscow State University

P. Mikula

Neutron scattering activities at the reactor LVR-15 in Řež
11.2.2008, IAEA Centrum, Vienna.

Neutron scattering structure studies of materials loaded by high neutron fluence
18.2.2008, IAEA Centrum, Vienna.

Bragg diffraction optics for high and ultrahigh resolution diffractometry and spectrometry
9.8.2008, KURRI Kumatori, Japan

Dispersive monochromators based on multiple reflections excited bent perfect crystals for high resolution diffractometry and spectrometry
22.8.2008, Hokkaido University, Sapporo, Japan.

F. Spurný

Exposure of aircraft and spacecraft crew - selected problems
12.-13.2.2007, LRB JINR, Dubna

Nuclear Physics Institute of the Czech Academy of Sciences - General survey; Activities and results in space- and aircraft crew dosimetry; Related international collaborations.
7.8.2007 NIRS, Chiba, Japan

Exposure of aircraft crew and passengers to cosmic radiation: General overview, results of measurements, individual dosimetry in Czech Republic
18.3.2008, Czech Technical University, Institute of Technical and Experimental Physics, Prague

P. Strunz

Characterization of Core-Shell Nanoparticles by Small Angle Neutron Scattering
4.12.2007, Charles University, Faculty of Mathematics and Physics, Prague

Small angle neutron scattering
28.11.2008, Charles University, Faculty of Mathematics and Physics, Prague

I. Světlík

Holocenní sedimenty řeky Moravy (Strážnické Pomoraví) klíč k rekonstrukci přírodních a antropogenních vlivů na chování říčního systému
2.4.2007, Charles University, Faculty of Science, Prague

Radiouhlíkové datování vzorků - princip, postupy, kalibrace, možnosti, záměry
12.2.2008, ASCR, Prague

Radiouhlíkové datování vzorků dřev povodňových sedimentů
28.11.2008, Masaryk University, Faculty of Science, Brno

J. Šaroun

Ray-trancing simulations of neutron scattering instruments by ResTrax
13.08.2008, South African Nuclear Energy Corporation

Neutronové difrakční experimenty v ÚJF Řež
19.11.2008, Charles University, Faculty of Mathematics and Physics, Prague

K. Turek

Electrochemical etching of track detectors and some applications (Elektrochemiczne trawienie sladowych detektorow i niektóre ich zastosowania)
9.11.2007, IFJ, Krakow

J. Vacík

Nuclear Methods for Chemical Analysis with Ion and Neutron Beams in NPI ASCR Rez
2.12.2008, University of Pune, Pune

Diffusion of Boron in ISOL Targets
5.12.2008, University of Pune, Pune

Nanotechnology of Transition Metal - Fullerene Composites
11.12.2008, Inter University Accelerator Centre, New Delhi

M. Znojil

Quantum Theory of Catastrophes
14.3.2007, Dept. of Physics, Stellenbosch University

Modelling instabilities in quasi-Hermitian Quantum Mechanics
15.5.2007, Dept. of Physics, Comenius University, Bratislava

Can we get observable, real spectra from non-Hermitian Hamiltonians?
30.5.2007, Dept. of Physics, The University of the Balears Islands, Palma de Mallorca

Models with a nontrivial metric in quantum mechanics
13.11.2007, Centre for Mathematical Science, School of Engineering and Mathematical Sciences, City University, London

Which operator generates time evolution in Quantum Mechanics?
3.4.2008, University of Valladolid

The review of the merits of the apparently non-Hermitian representations of observables in the so called Pseudohermitian Quantum Mechanics
16.6.2008, Zhejiang University, Hangzhou

Available menu of Hilbert spaces offering the consistent picture of bound states and their modifications needed for the parallel description of scattering
17.6.2008, Zhejiang University, Hangzhou

Which operator generates the covariant version of the time evolution of a system in modern Quantum Mechanics?
20.6.2008, Zhejiang University, Hangzhou

Cryptohermitian operators of observables in Quantum Mechanics
11.8.2008, Eastern Mediterranean University, Phys. Dep., Gazimagusa

Ten years of PT-symmetric Hamiltonians in Quantum Physics
29.10.2008, Universidad de Santiago de Chile, Phys. Dep.

Scattering Theory using non-Hermitian Hamiltonians
7.11.2008, Pontificia Universidad Catolica de Chile, Math. Dep.

Three-Hilbert-space formulation of Quantum Mechanics
24.11.2008, National Institute of Theoretical Physics in Stellenbosch

Seminars in NPI given by external speakers

Y. E. Penionzhkevich (JINR Dubna), 14.2.2007
Study of the interaction of loosely bound ^{6}He and ^{6}Li radioactive ion beams with different targets

M. Ebihara (Tokyo Metropolitan Univ.), 27.3.2007
The solar system of the elements: How well do we know them after all?

J. Kubieniec (Czech Technical University, FNSPE), 5. 4. 2007
On the representations of Lorentz group

K. Bugaiev (Bogolyubov Institute for Theoretical Physics, Kiev), 17.4.2007
Exact Analytical Solution of the Hills and Dales Model and the Problem of Surface Entropy

P. Geltenbort (ILL Grenoble), 26.4.2007
Ultra-Cold Neutrons and Searches for an Electric Dipole Moment

J. Revai (KFKI Budapest) , 31.5.2007
On extracting hadron-nucleus interaction from hadronic atam level shifts

G. Brauer (FZR Rossendorf), 15.6.2007
Slow positron implantation spectroscopy - a tool to characterize vacancy-type damage in solids

S. Tanimura (Graduate School of Informatics, Kyoto University, Japan), 28.6.2007
A new formulation of the uncertainty relation and its implication for the double-slit experiment

M. Jílek (Czech Technical University, FNSPE), 19.9.2007
Straight quantum waveguide with Robin boundary conditions

R. Roychoudhury (Indian Statistical Institute, Kolkata), 1.10.2007
A few remarks on pseudo-Hermitian Hamiltonians

E.-M. Graefe (University of Kaiserslautern), 18.10.2007
The spectrum of an open two-mode Bose-Hubbard system

J. Vrbik (Brock University, Canada), 11.12.2007
Monte Carlo computations of ground-state-energy derivatives

H. Garcilazo (University of Mexico City), 19.12.2007
Few-body physics with quark model based potentials

C. Wilkin (University College London), 31.1.2008
The production of KK-bar pairs in proton-proton and proton-deuteron collisions

J. Kubieniec (Czech Technical University, FNSPE), 20.3.2008
A method for calculating the spectrum of the Casimir operator of the group SO(1,2) in the supplementary series of unitary representations of the group SO(1,3)

V.N. Bhoraskar (University of Pune, India), 26.3.2007
Swift Heavy Ion-Induced Damages in Silicon and Applications

C. Spitaleri (INFN - LNS Catania), 31.3.2008
Recent results of Trojan Horse application in nuclear astrophysics

L'. Balková (Czech Technical University, FNSPE), 28.4.2008
Discrete Schrodinger operators with aperiodic potentials

S. Rauch-Wojciechowski (Linkoeping University), 12.5.2008
Schroedinger, Newton, KdV and Harry Dym equations

S. Hledík (Silesian University, Opava), 22.5.2008
Test particles motion in the vicinity of black holes and space-time visualisation using embedding diagrams

Angela Mestre (DI & KM FJFI), 22.5.2008
The combinatorics of n-point functions via Hopf algebra in quantum field theory

D. Fink (Helmholtz-Zentrum Berlin für Materialien und Energie Berlin), 3.6.2008
On the way to autonomous electroactive bio-sensing devices

D. Mukherji (TU Braunschweig), 10.6.2008
Nano-structures from simple metallic alloys

B. Cuadros-Melgar (Universidad de Santiago de Chile), 12.6.2008
Brane World Cosmology

Š. Gmuca (Institute of Physics SAS, Bratislava), 27.6.2008
Relativistic mean field approach to asymmetric nuclear matter

Š. Gmuca (Institute of Physics SAS, Bratislava), 27.6.2008
Relativistic mean field model: Fock term

P. Navrátil (Lawrence Livemore NL), 21.7.2008
Ab initio many-body calculations of nucleon-nucleus scattering

O. Post (TU Berlin), 18. 9. 2008
Approximation of delta and delta'-interactions by Laplaceans on manifolds

D. Hook (Imperial College, London), 2.10.2008
Isospectral Hamiltonians

P. Freitas (University of Lisbon), 6.11.2008
Will it burst? or Everything you don't want to know about brain aneurysms

G.G. Gulbekyan (FLNR JINR, Dubna), 11.12.2008
FLNR heavy ion cyclotrons for scientific program

B.N. Gikal (FLNR JINR, Dubna), 11.12.2008
FLNR heavy ion cyclotrons for applied research and industrial technology

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Department of Radiation Dosimetry

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