Low-energy kaon/nucleaon nuclei experiments at DAFNE SIDDHARTA and AMADEUS (an update)

Catalina Curceanu, LNF-INFN
(On behalf of SIDDHARTA and AMADEUS)

LEANNIS Kick-off meeting
Prague, 21-23 May 2012

SIDDHARTA

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

- LNF- INFN, Frascati, Italy
- SMI- ÖAW, Vienna, Austria
- IFIN – HH, Bucharest, Romania
- Politecnico, Milano, Italy
- MPE, Garching, Germany
- PNSensors, Munich, Germany
- RIKEN, Japan
- Univ. Tokyo, Japan
- Victoria Univ., Canada

EU Fundings: JRA10 – FP6 - I3HP

Network WP9 – LEANNIS – FP7- HP2: HP3

The scientific aim of SIDDHARTA(-2)

Is an experiment measuring kaonic atoms X-ray transitions -> info about the <u>QCD in non-perturbative regime in the strangeness sector</u>

In particular, it performed precision *measurement of the shift* and *of the width*

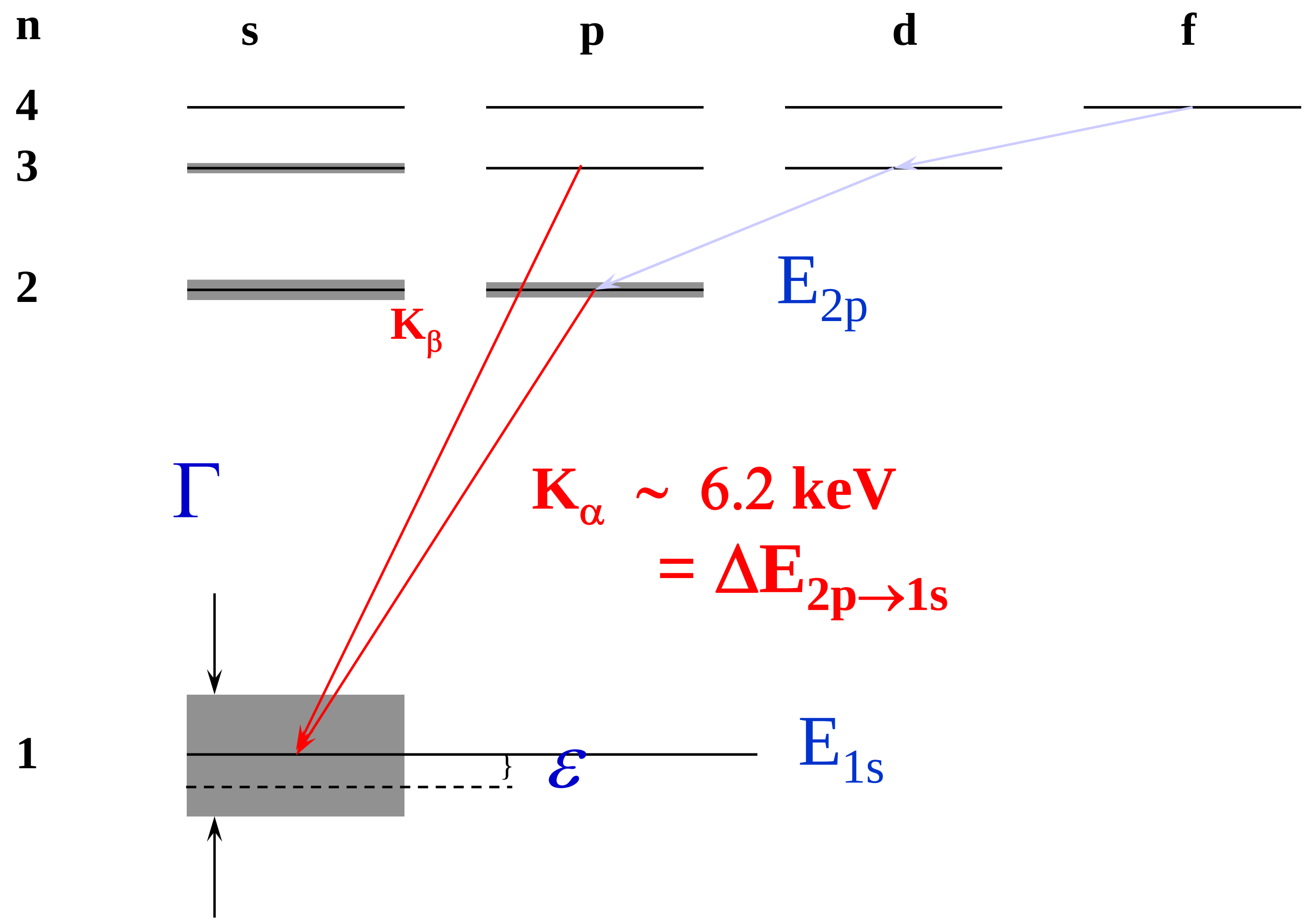
of the 1s level of **kaonic hydrogen** and

the *first esploratory (-> precision measurement in SIDDHARTA-2)* of **kaonic deuterium**

In addition:

Precision measurement of kaonic helium 3 and 4 (2p level)
Other low-Z kaonic atom transitions were measured (kaonic kapton)
Yields measurements (kaonic atoms cascade processes)

Kaonic cascade and the strong interaction



Antikaon-nucleon scattering lengths

Once the shift and width of the 1s level for kaonic hydrogen and deuterium are measured -> scattering lengths

(isospin breaking corrections):

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-p}\ \text{eV fm}^{-1}$$

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-d}\ \text{eV fm}^{-1}$$

one can obtain the isospin dependent antikaon-nucleon scattering lengths

$$a_{K^-p} = (a_0 + a_1)/2$$

$$a_{K^-n} = a_1$$

DAFNE

$e^- e^+$ collider

- **$\Phi \rightarrow K^- K^+$** (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **Less hadronic background due to the beam**

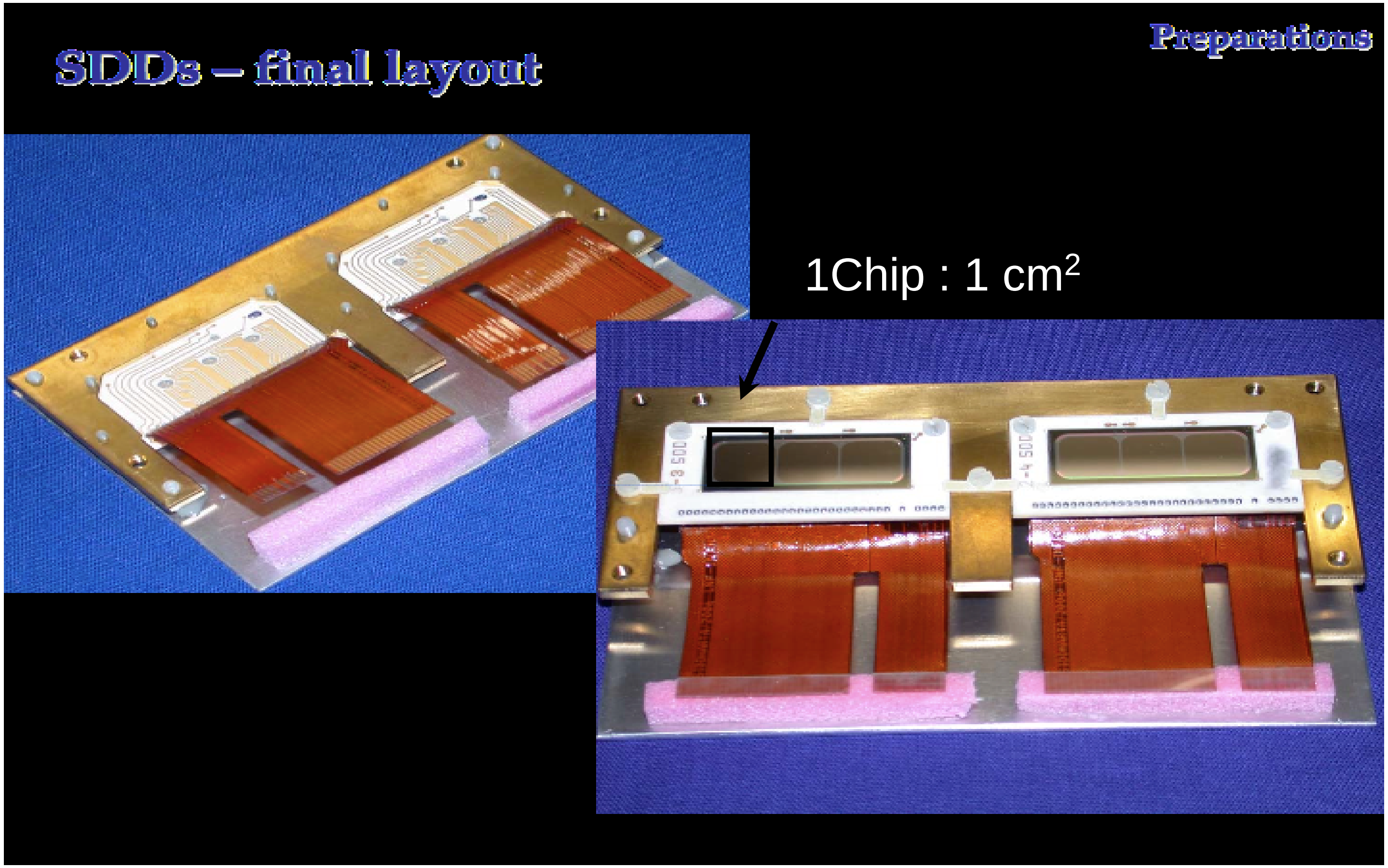
(compare to hadron beam line : e.g. KEK /JPARC)

Suitable for low-energy kaon physics:

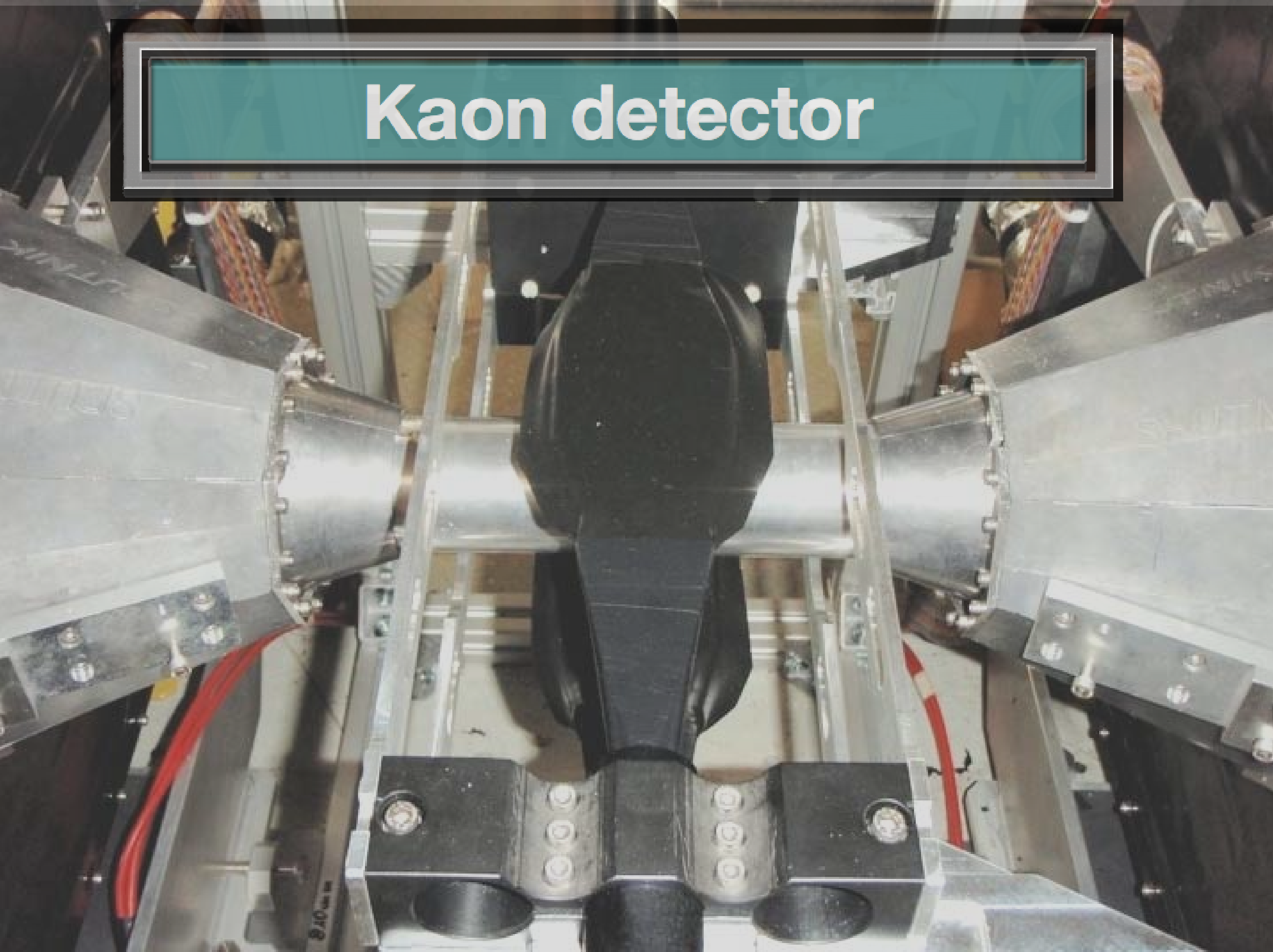
kaonic atoms

Kaon-nucleons/nuclei interaction studies

Silicon Drift Detector - SDD

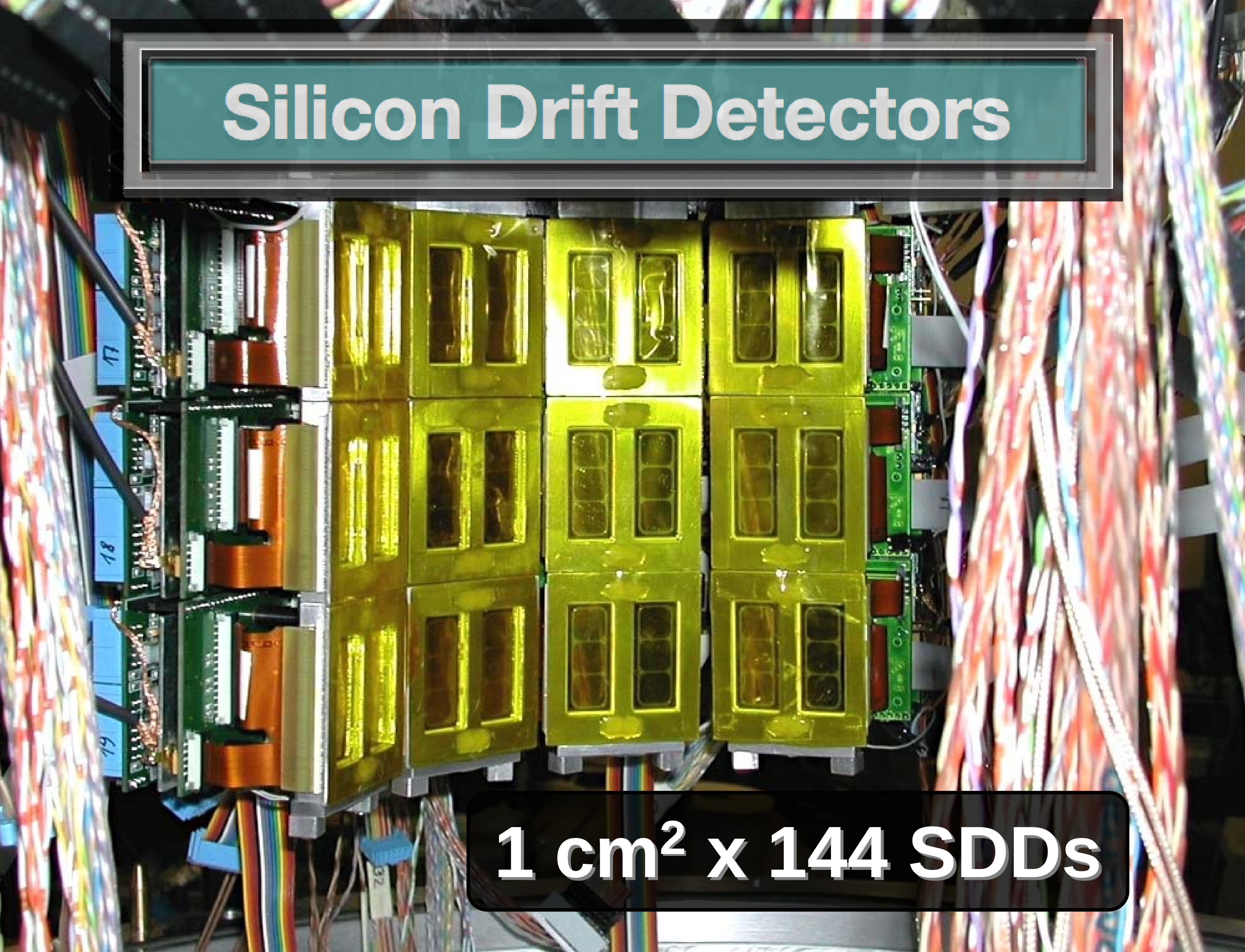


Kaon detector



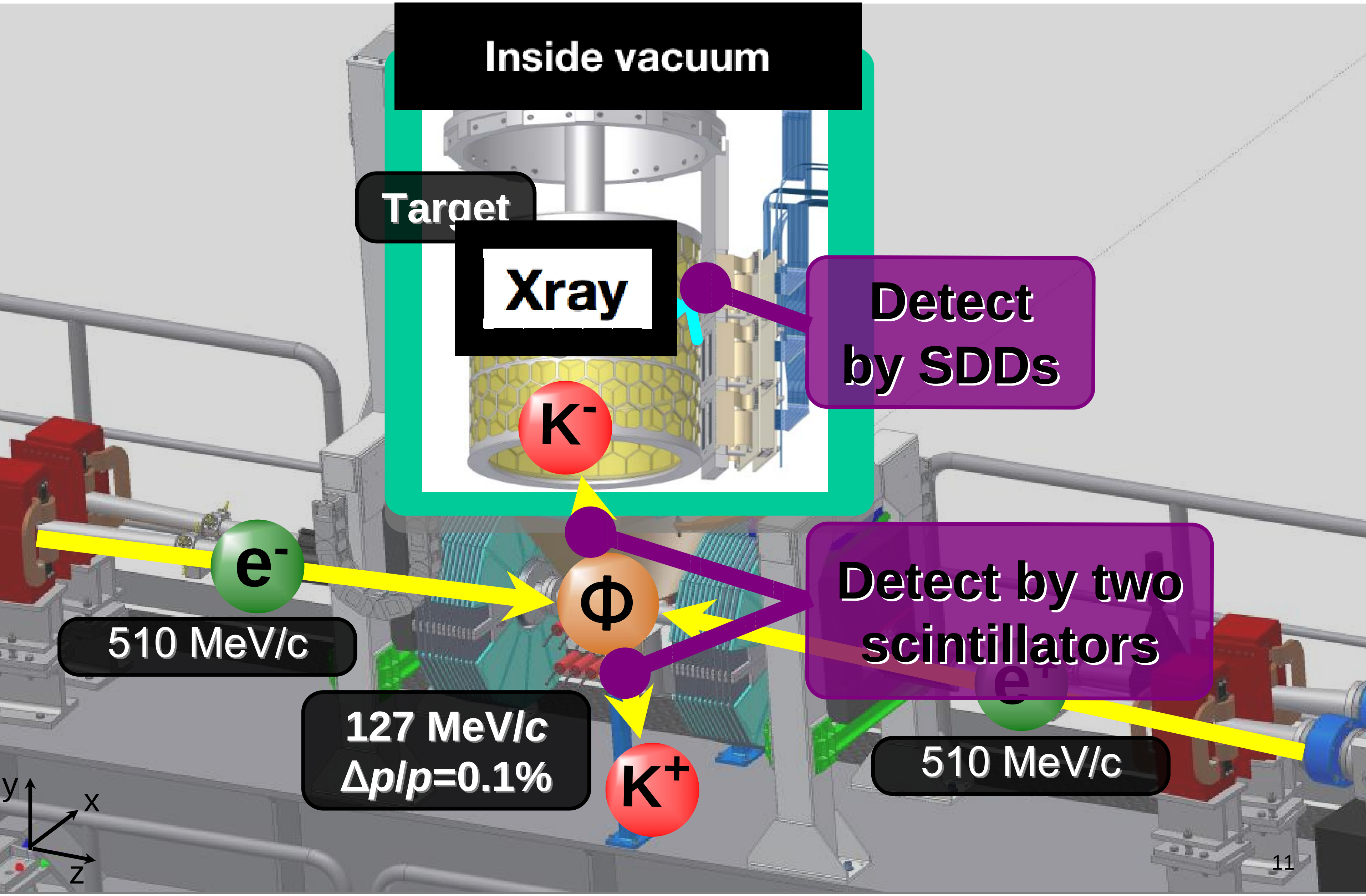
Target cell

Silicon Drift Detectors



1 cm^2 x 144 SDDs

SIDDHARTA overview




SIDDHARTA setup
SDDs & Target
(inside vacuum)
Kaon detector

SIDDHARTA results (2009):

- **Kaonic Hydrogen**: *400pb^{-1}, most precise measurement ever,Phys. Lett. B 704 (2011) 113, Nucl. Phys. A. (2012); Ph D*

- **Kaonic deuterium**: *100 pb^{-1}, as an exploratory first measurement ever, draft of paper in preparation; Ph D*

- **Kaonic helium 4** *– first measurement ever in gaseous target; published in Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264 and Phys. Lett. B 697 (2011); PhD;*

- **Kaonic helium 3** *– 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D,*

- **Ongoing:** *widths and yields of KHe3 and Khe4; kaonic kapton yields; KH yields -> publications*

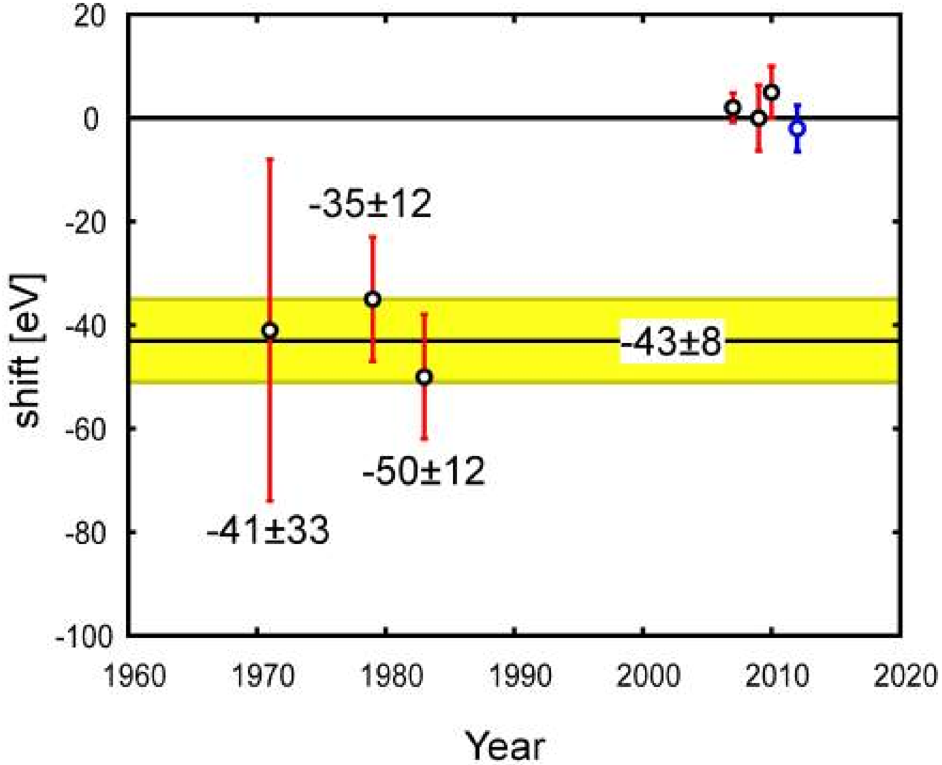
SIDDHARTA – important academy for young researchers

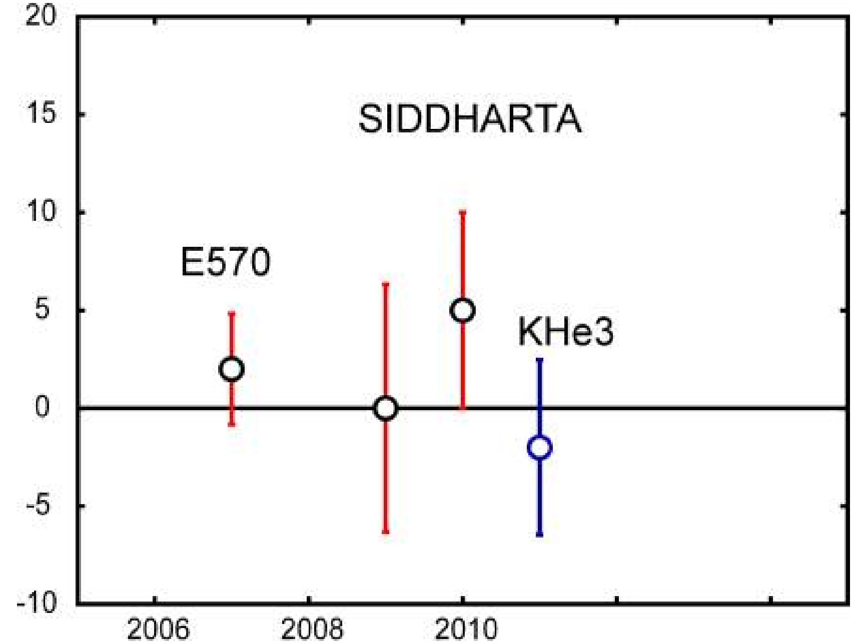
Kaonic Helium 3 and 4

T. Ishiwatari

Comparison of results – with SIDDHARTA the era of precision measurements

	Shift [eV]	Reference
KEK E570	**+2±2±2**	**PLB653(07)387**
SIDDHARTA (He4 with 55Fe)	**+0±6±2**	**PLB681(2009)310**
SIDDHARTA (He4)	**+5±3±4**	**arXiv:1010.4631, PLB697(2011)199**
SIDDHARTA (He3)	**-2±2±4**	





***error bar** $= \pm\sqrt{(stat)^2 + (syst)^2}$

Kaonic Helium results:

- first measurements of KHe3 and in gas He4

- if any shift of 2 p level is present – is small ; same for the width

- undergoing – yields determination -> paper

- KHe3 measurement took 3 days!!! – ***proves how EXCELLENT is SIDDHARTA-like method at DAFNE***

- SIDDHARTA-2 – can do much better: KHe3,4 at eV and try measurement of 1s levels!

Kaonic Hydrogen and deuterium

M. Cargnelli

Kaonic Hydrogen results:

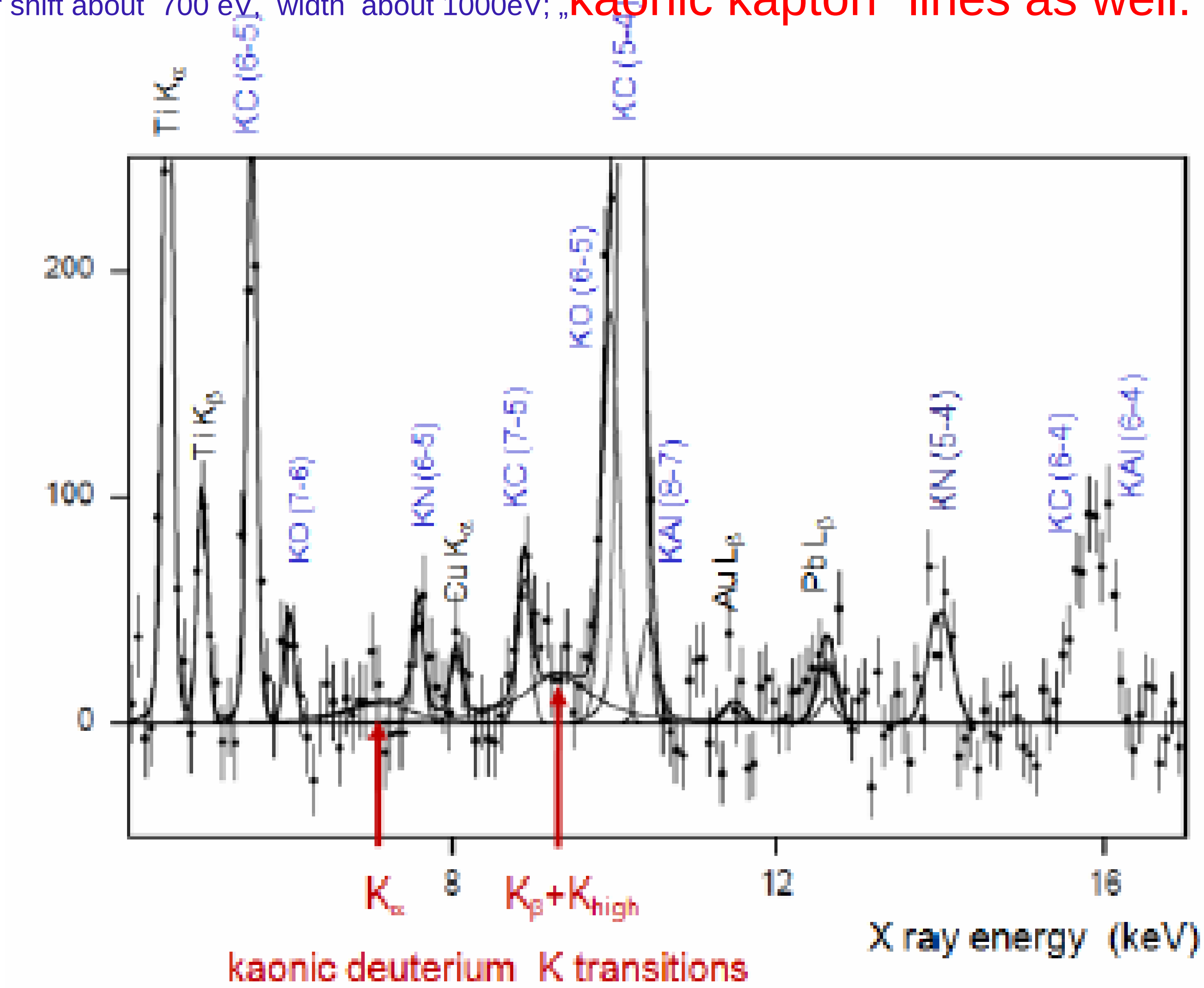
- most reliable and precise measurement ever

Our determination of the shift and width does provide new constraints on theories, having reached a quality which will demand refined calculations of the low-energy $\overline{K}N$ interaction.

- need to go for Kd! -> SIDDHARTA-2

Kaonic deuterium spectrum – exploratory measurement:

fit for shift about 700 eV, width about 1000eV; „kaonic kapton“ lines as well:



crossing angle		
quadratic sum	0.1033	0.1

Efficiency = 0.69 ±0.02(stat) $^{+0.10}_{-0.17}$ (syst only MC) %

$$\frac{N_X^{exp}/R_X^{acc}}{N_{trig}^{exp}/R_{trig}^{acc}} = \frac{N_X^{MC}}{N_{trig}^{MC}} \cdot Y_{abs}$$

Kaonic hydrogen K_α yield

$Y_{K\alpha}$ = 1.29 ±0.08(stat) $^{+0.38}_{-0.15}$ (syst only MC)

Preliminary!

An overlay with recent calculations

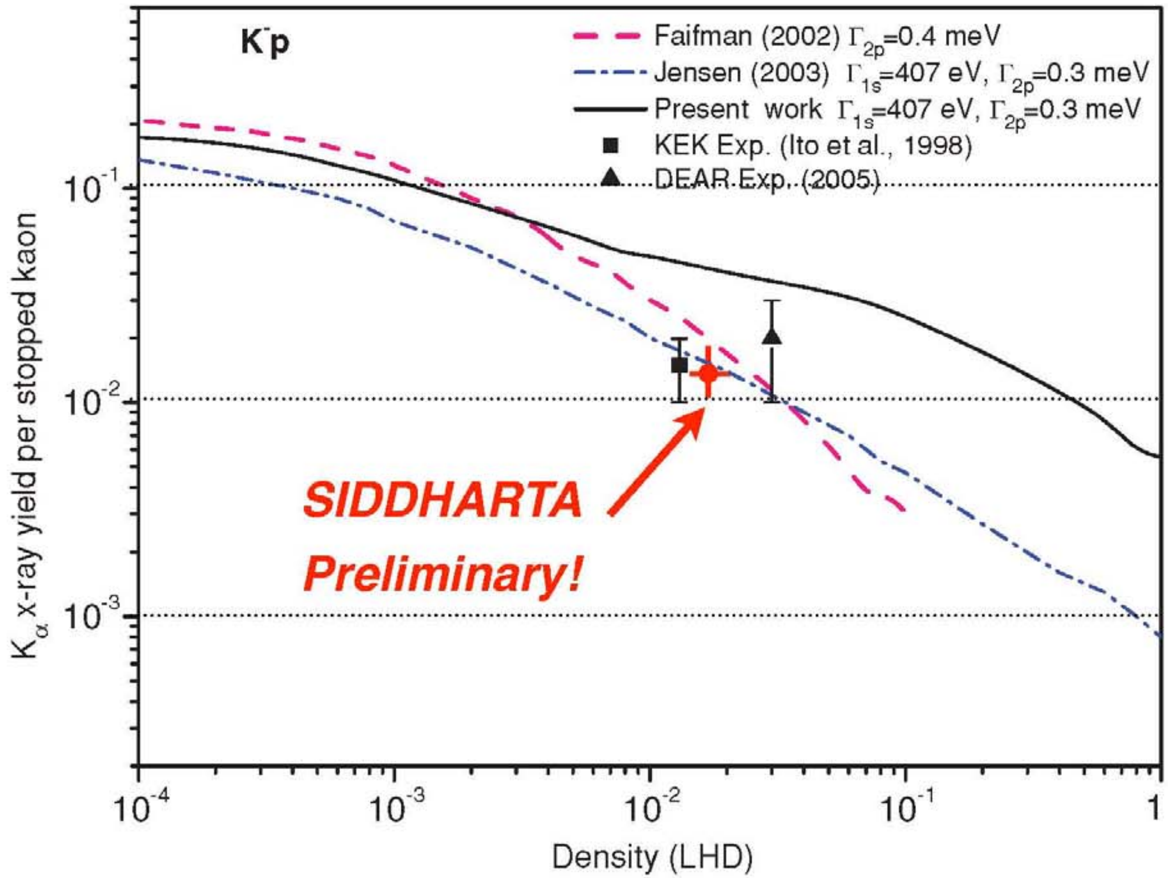


FIG. 5. (Color online) Comparison of the present density dependence of K_α x-ray yield (solid line) with the Faifman [13] (dotted line) and Jensen [14] (dashed-dotted line) works for $K^- p$ atoms. The experimental results from KEK [16] and DEAR [17] have also been shown.

S.Z. Kalantari and M. Raeisi G.
Phys. Rev. C ***81****, 014608 (2010)*

The yield is very sensitive to Γ_{2p}, the hadronic absorption width of 2p state.

An overlay with '90s theoretical calculations

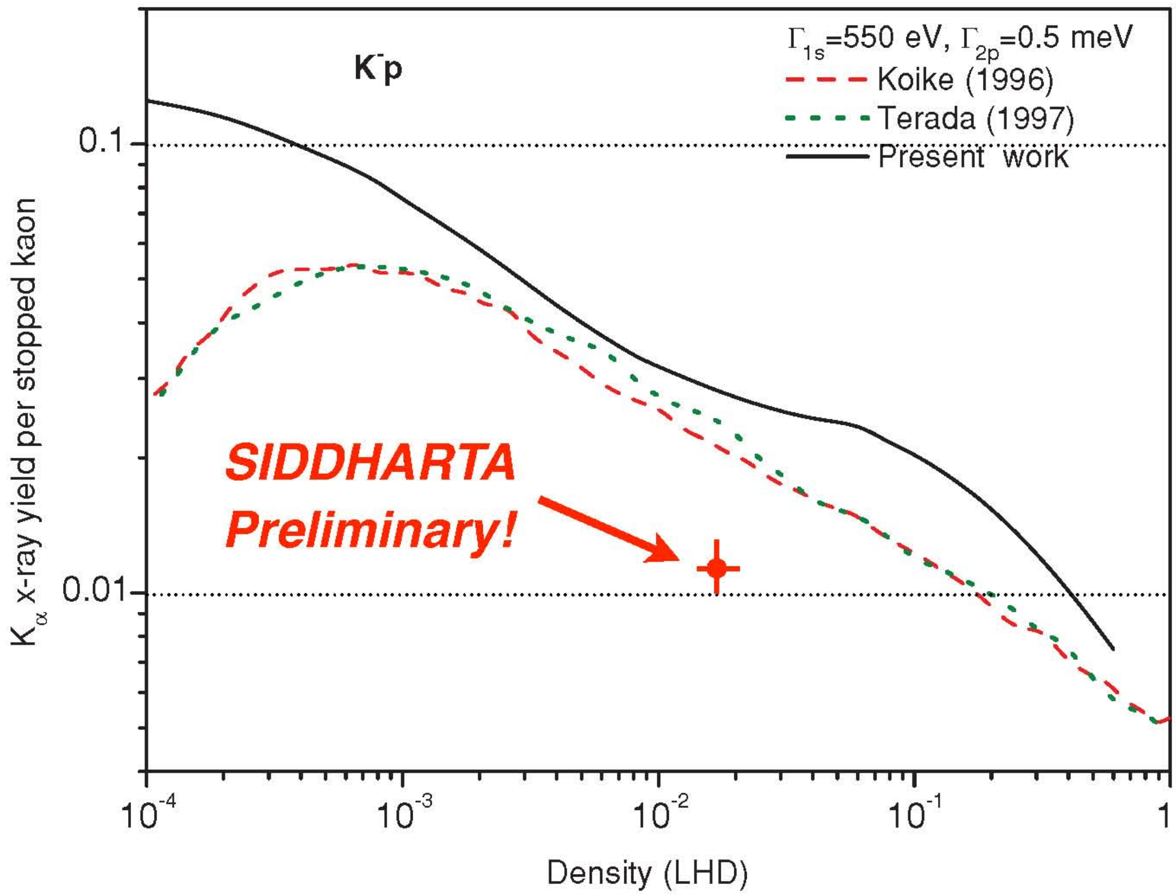


FIG. 2. (Color online) Comparison of the present density dependence of K_α x-ray yield (solid line) with the Koike [5] (dashed line) and Terada [12] (dotted line) works for $K^- p$ atoms.

S.Z. Kalantari and M. Raeisi G.
Phys. Rev. C ***81****, 014608 (2010)*

SIDDHARTA2 strategy – phases

1) Kaonic deuterium measurement - 1st measurement: and R&D for other measurements – J. Zmeskal

2) Kaonic helium transitions to the 1s level – 2nd measurement, R&D

3) Other light kaonic atoms (KO, KC,…)

4) Heavier kaonic atoms measurement (Si, Pb…)

5) Kaon radiative capture – Λ(1405) study

6) Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)

7) Kaon mass precision measurement at the level of <10 keV

Participating Institutions

- Stefan Meyer Institut für subatomare Physik, Vienna, Austria
- Univ. Victoria, Victoria B.C., Canada
- Univ. Zagreb, Croatia
- INFN, Laboratori Nazionali di Frascati, Frascati, Roma, Italy
- INFN Sezione Roma1 and Ist. Superiore di Sanita’, Roma, Italy
- Politecnico Milano and INFN Milano, Milano, Italy
- Univ. Tokyo, Japan
- RIKEN, Japan
- Excellence Cluster, TUM, Munchen, Germany
- IFIN-HH, Bucharest, Romania

To the LNF-INFN Director, Dr. Umberto Dosselli

To the Director of the LNF Accelerator Division, Dr. Pantaleo Raimondi

July 2011

Support letter for the SIDDHARTA-2 scientific case

We are writing this document to express our strong support to the scientific line presently pursued at the DAΦNE Accelerator by the SIDDHARTA-2 Collaboration. DAΦNE represented since its birth a unique facility for the study of the low-energy kaon-nucleon/nuclei interaction, for obtaining key-experimental results promoting the understanding of low-energy QCD in the strangeness sector, not accessible in any other way.

This successful history was pioneered by the DEAR experiment, which performed the measurements of kaonic hydrogen and nitrogen. The DEAR results certainly represented a step forward in understanding low-energy QCD.

This success was then continued by the SIDDHARTA experiment, which combined the excellent kaon beam delivered by DAΦNE with new techniques for precision X-ray measurements, by using a large array of high resolution Silicon Drift Detectors for the first time in triggered mode on an accelerator. The kaonic hydrogen precision measurement performed by SIDDHARTA, together with the kaonic helium 3 and 4 ones, represent the best measurements ever performed in this sector.

This successful history was pioneered by the DEAR experiment, which performed the measurements of kaonic hydrogen and nitrogen. The DEAR results certainly represented a step forward in understanding low-energy QCD.

This success was then continued by the SIDDHARTA experiment, which combined the excellent kaon beam delivered by DAΦNE with new techniques for precision X-ray measurements, by using a large array of high resolution Silicon Drift Detectors for the first time in triggered mode on an accelerator. The kaonic hydrogen precision measurement performed by SIDDHARTA, together with the kaonic helium 3 and 4 ones, represent the best measurements ever performed in this sector.

These results are already actively used by several theory groups working in the field of low-energy QCD. The deduced antikaon-proton scattering length serves as a basic constraint in effective field theories investigating the interplay of spontaneous and explicit chiral symmetry breaking in QCD with strange quarks.

In order to reach a breakthrough in the field and to complete the picture, the kaonic hydrogen result must be complemented with a measurement of kaonic deuterium. This would allow extracting the complete set of isospin-dependent antikaon-nucleon scattering lengths in combination with a proper theoretical treatment of deuteron binding and absorption. Establishing accurate values for both the antikaon-proton and antikaon-neutron scattering lengths is not only providing essential input for chiral SU(3) effective field theory. It is also the prerequisite for explorations of antikaon-nuclear systems that are under very active discussion, from the quest for antikaon-nuclear clusters to the role of strangeness in the core of neutron stars.

We strongly support the proposal put forward by the SIDDHARTA-2 Collaboration, namely the measurement of kaonic deuterium X-ray transitions, as being one of the most important measurements in the strangeness sector of low-energy QCD. There is not any other beam of comparable quality available in a foreseeable future in order to perform this very challenging and important measurement. At the same time, the expertise of the SIDDHARTA-2 Collaboration is well recognized and represents the best guarantee of success.

We plead the LNF Director and INFN management to find a way to assure the realization of this measurement which is expected to bring further worldwide scientific acknowledgement to DAΦNE and INFN.

Univ. Prof. Dr. Manfried Faber
Technische Universität Wien, Austria

Prof. Eli Friedman
The Hebrew University of Jerusalem, Israel

Prof. Paolo Gensini
Sezione di Lecce, INFN, Italy

Prof. Dr. Ing. Paul Kienle
Excellence Cluster Universe, Technische Universität München, Germany

Dr. Jiri Mares
Jiri Mares Nuclear Physics Institute Rez/Prague, Czech Republic

Prof. Dr. Ing. Paul Kienle
Excellence Cluster Universe, Technische Universität München, Germany

Dr. Jiri Mares
Jiri Mares Nuclear Physics Institute Rez/Prague, Czech Republic

Prof. Dr. Ulf-G. Meissner
Helmholtz Institut für Strahlen und Kernphysik, Bonn, Germany

PD Dr. Akaki Rusetsky
Helmholtz Institut für Strahlen und Kernphysik, Bonn, Germany

Prof. Ryoichi Seki
California State University, USA

Prof. Dr. Wolfram Weise
Technische Universität München, Germany

Prof. Slawomir Wycech
Soltan Institute for Nuclear Studies, Warsaw, Poland

Prof. Dr. Toshimitsu Yamazaki
The University of Tokyo and RIKEN, Japan

DAΦNE represents (as always did) an (THE) EXCELLENT FACILITY in the sector of low-energy interaction studies of kaons with nuclear matter.

It is actually the IDEAL facility for kaonic atoms studies as SIDDHARTA has demonstrated

SIDDHARTA-2 team is ready to restart the measurements, having a multi-step strategy, strating with the Kaonic deuterium

Conclusion

We are confident that with the planned setup improvements and with an integrated luminosity of about 600 pb-1, SIDDHARTA-2 will be able to perform a first X-ray measurement of the strong interaction parameters - **the energy displacement and the width of the konic deuterium ground state,** which are eagerly awaited by theoreticians.

WE STRONGLY NEED LEANNIS SUPPORT!

Conclusion

The other campaign measurements will be dedicated to:

-kaonic helium measurements to 1s levels

-kaonic oxygen

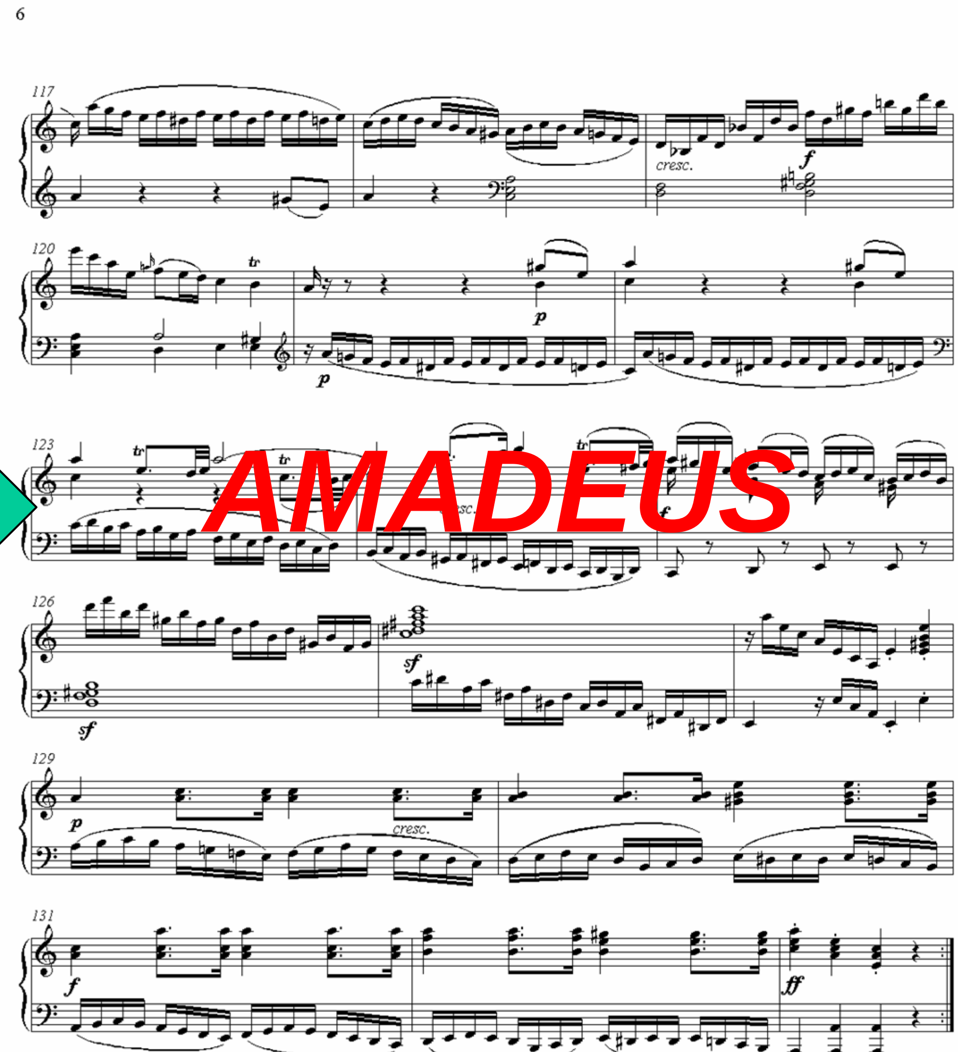
-solid target measurements : Sn, Si, Ca, Ni targets

- MeV measurements for radiative kaon capture in hydrogen (re-measuring kaonic hydrogen as well)

▪ measurements with a setup below the beam pipe could be done in parallel with the others measurements

➢ crystal spectrometer measurements need completely new setup – the strategy is under evaluation.

Antikaonic Matter At DAΦNE: an Experiment Unraveling Spectroscopy

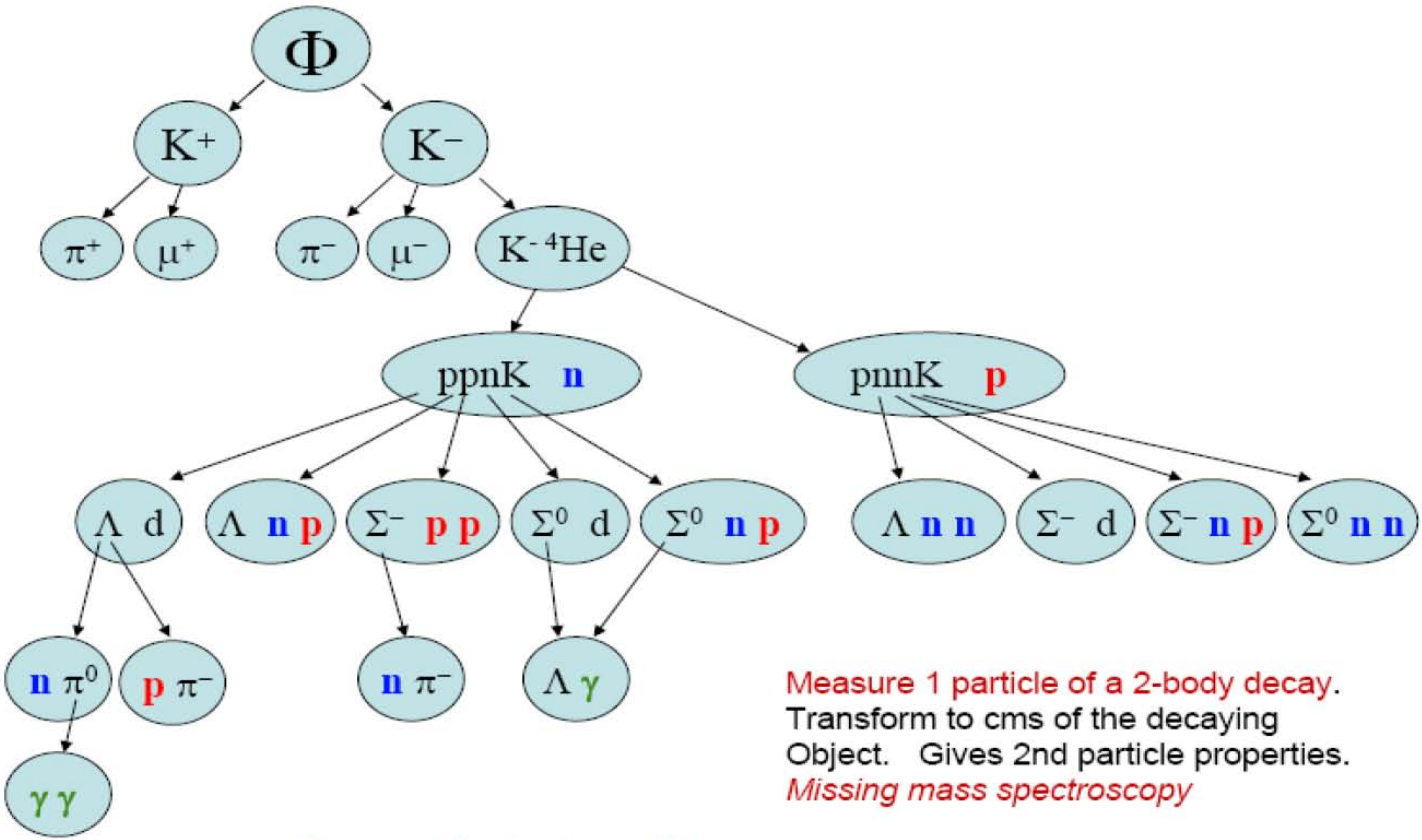


Experimental programme AMADEUS (1)

- study of the (most) fundamental antikaon deeply bound nuclear systems, the **kaonic dibaryon states: ppK$^-$ and (pnK$^-$)** produced in a ^{3}He gas target, in formation and decay processes

- as next step, the **kaonic 3-baryon states: ppnK$^-$ and pnnK$^-$** produced in a ^{4}He gas target, in formation and decay processes

Reactions channels (simplified)



Measure 1 particle of a 2-body decay. Transform to cms of the decaying Object. Gives 2nd particle properties. *Missing mass spectroscopy*

Measure all outgoing particles to obtain the total cms energy = *invariant mass of the object*

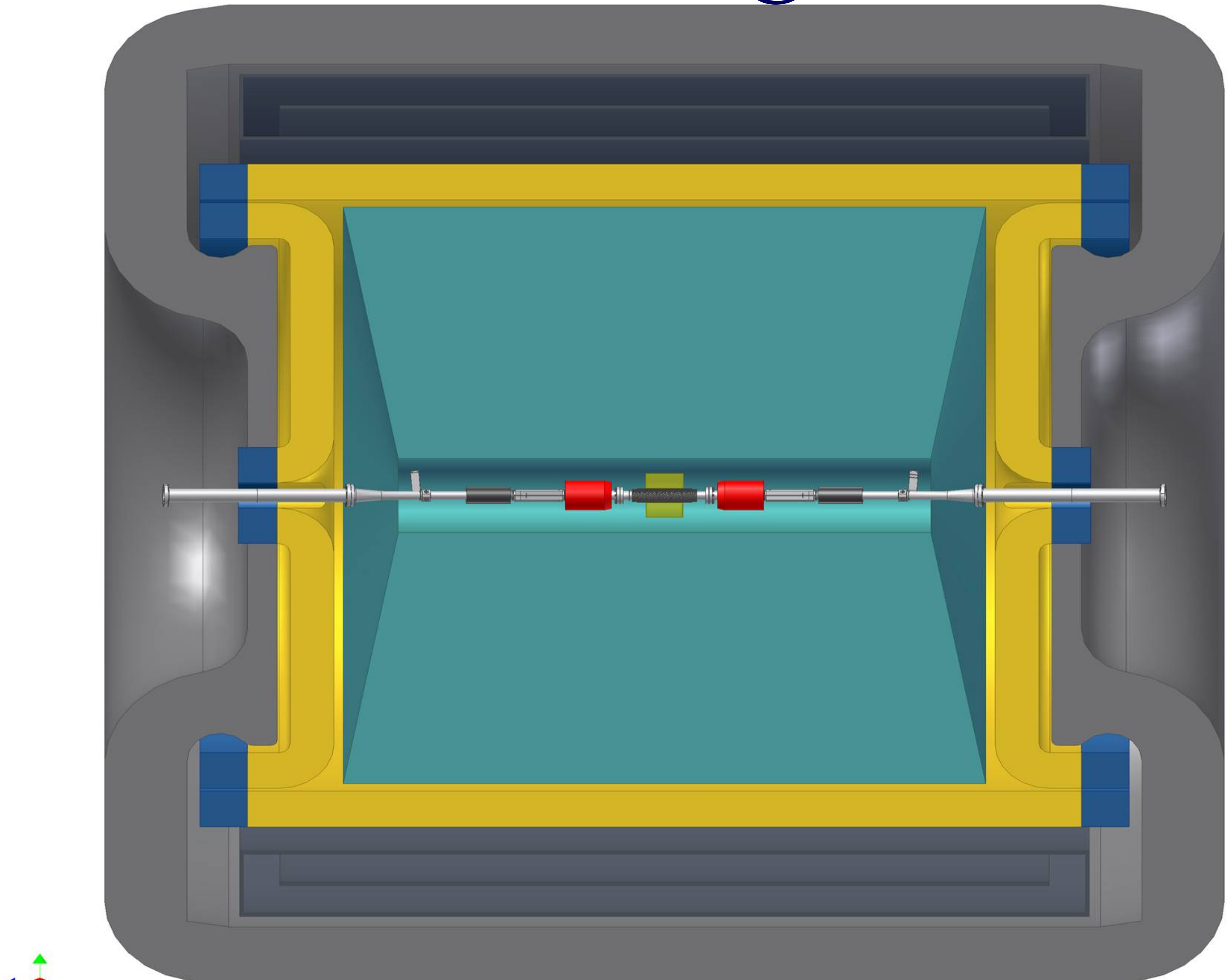
Experimental programme AMADEUS phase-1 (2)

- Low-energy charged kaon cross sections on Hydrogen, Deuterium, Helium(3 and 4), for K- momentum lower than 100 MeV/c (missing today);

Excellent feasibility test –
Oton Vazquez Doce
Kristian Piscicchia
(KLOE data)

- Resonance states as the elusive-in-nature but so important $\Lambda(1405)$ or the $\Sigma(1385)$ could be better understood with high statistics; their behaviour in the nuclear medium can be studied too.

AMADEUS @ KLOE



DAFNE represents a unique opportunity to study in a complete way the kaon-nucleon/nuclei physics at low energy