Feasibility studies of double hypernuclei spectroscopy at PANDA

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- General Motivation
- Introduction to Experimental concept
- Detection Strategies
- Background Suppression Methods
- Outlook

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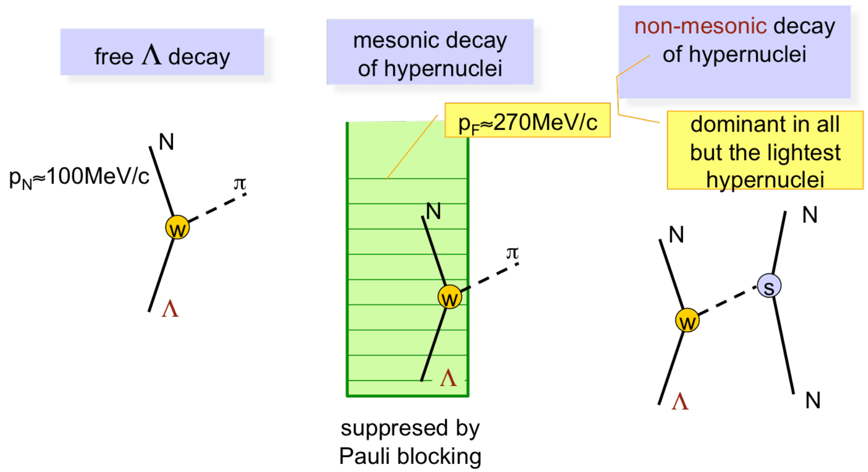
mami MAINZER MIKROTRON

Bundesministerium für Bildung und Forschung

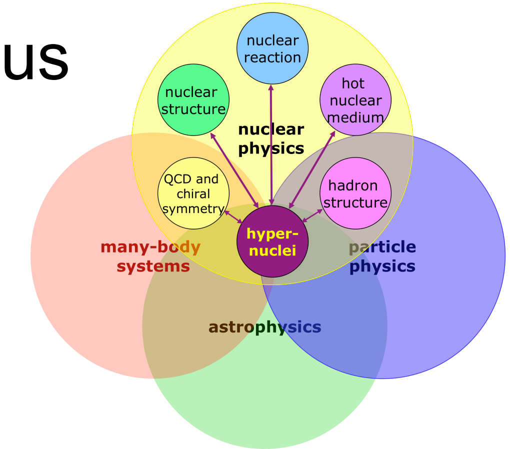
Physics of Hypernuclei

- the (low energy) Y-N interactions
  - the role played by quark degrees of freedom, flavour symmetry and chiral models in nuclear and hypernuclear phenomena
  - the nuclear structure, e.g. the origin of the spin-orbit interaction
  - relevance for dense stellar systems
- Weak decays
  - baryon-baryon weak interactions
  - asymmetries of w.d. and the role of two-meson/σ exchange
  - role of FSI and nuclear structure



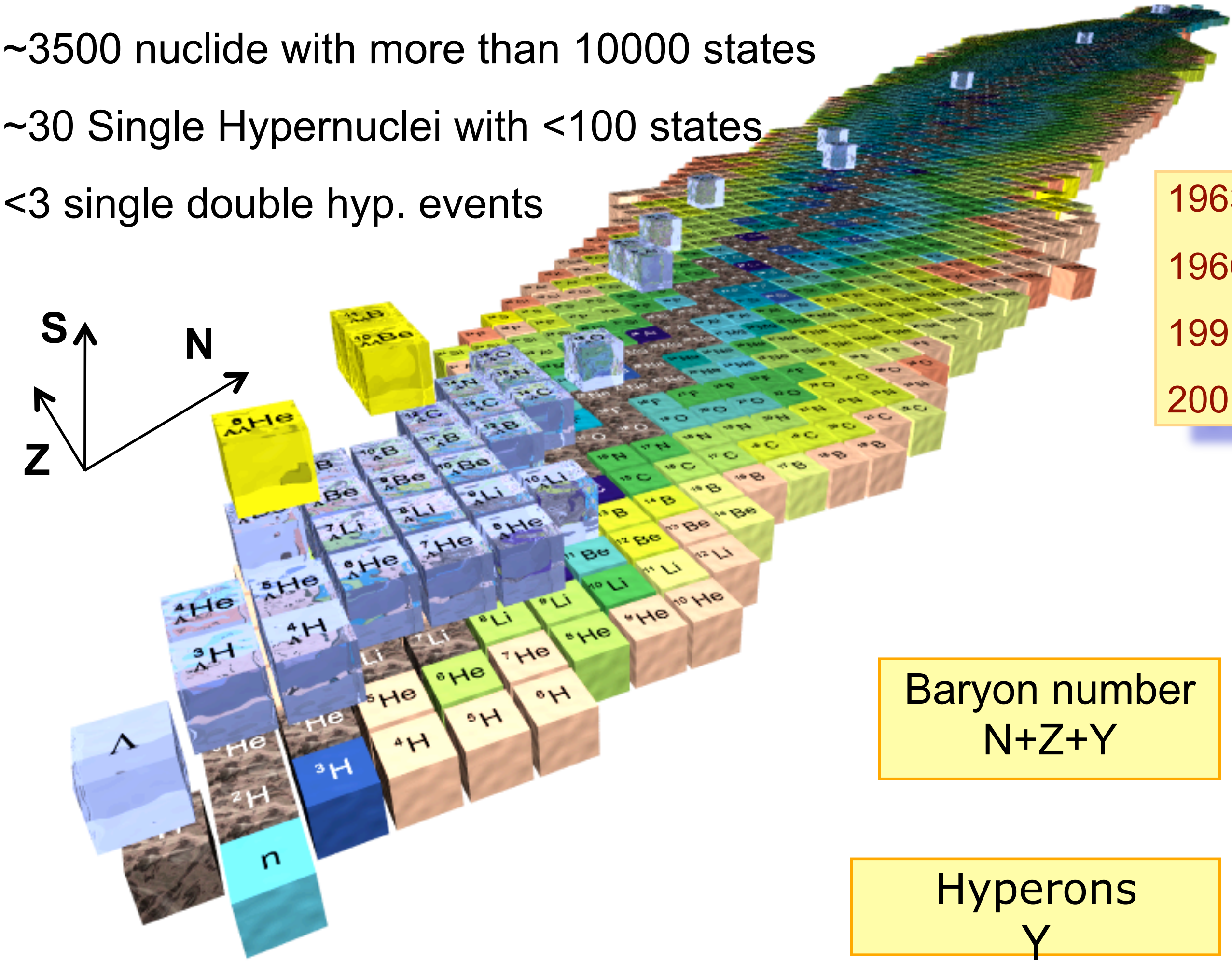
- ΛΛ-hypernuclei
  - Y-Y interaction
  - ΛΛK vertex
- nuclear medium properties of hyperons (Λ, Σ, Ξ) and (anti)meson
- Hypernuclei – a bridge between traditional nuclear physics and hadron physics

Double hypernuclei spectroscopy status



- **Study of Y-Y interaction (ΛΛ Hypernuclei) offers additional information about the B-B interaction**

- ~3500 nuclide with more than 10000 states
- ~30 Single Hypernuclei with <100 states
- <3 single double hyp. events



1963 Danysz event: $^{10}_{\Lambda\Lambda}Be$

1966 Prowse event: $^{6}_{\Lambda\Lambda}He$

1991 Aoki event: $^{13}_{\Lambda\Lambda}B$

2001 Nagara event: $^{6}_{\Lambda\Lambda}He$

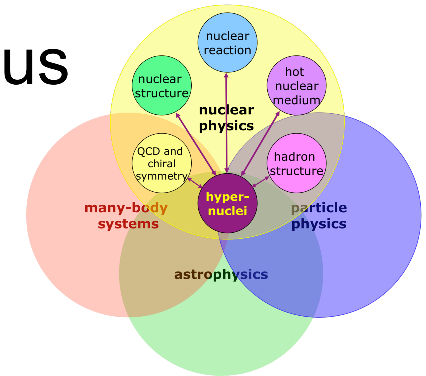
Element = Proton number

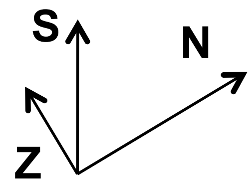
Baryon number N+Z+Y

Hyperons Y

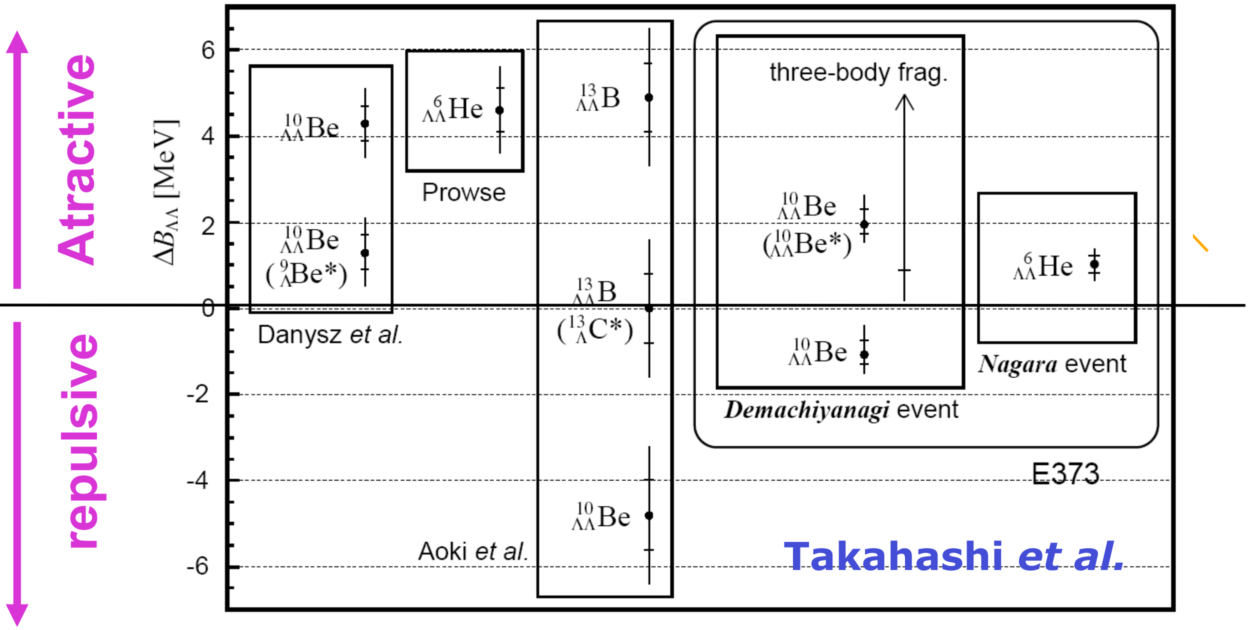
$^{B}_{Y}Z$

Double hypernuclei spectroscopy status

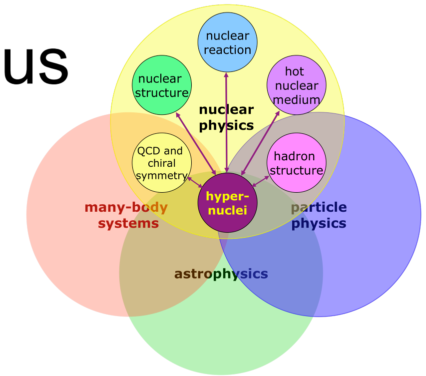


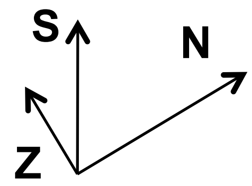


- **Study of Y-Y interaction (ΛΛ Hypernuclei) offers additional information about the B-B interaction**
- **$\Delta B_{\Lambda\Lambda} \sim B_{\Lambda\Lambda} - 2\, B_{\Lambda}$ provides information about Y-Y interaction**
- **Present results on $\Delta B_{\Lambda\Lambda}$ not consistent**
  (Emulsion tech., charged particles, low Statistic, assignment not unique**)**



Double hypernuclei spectroscopy status





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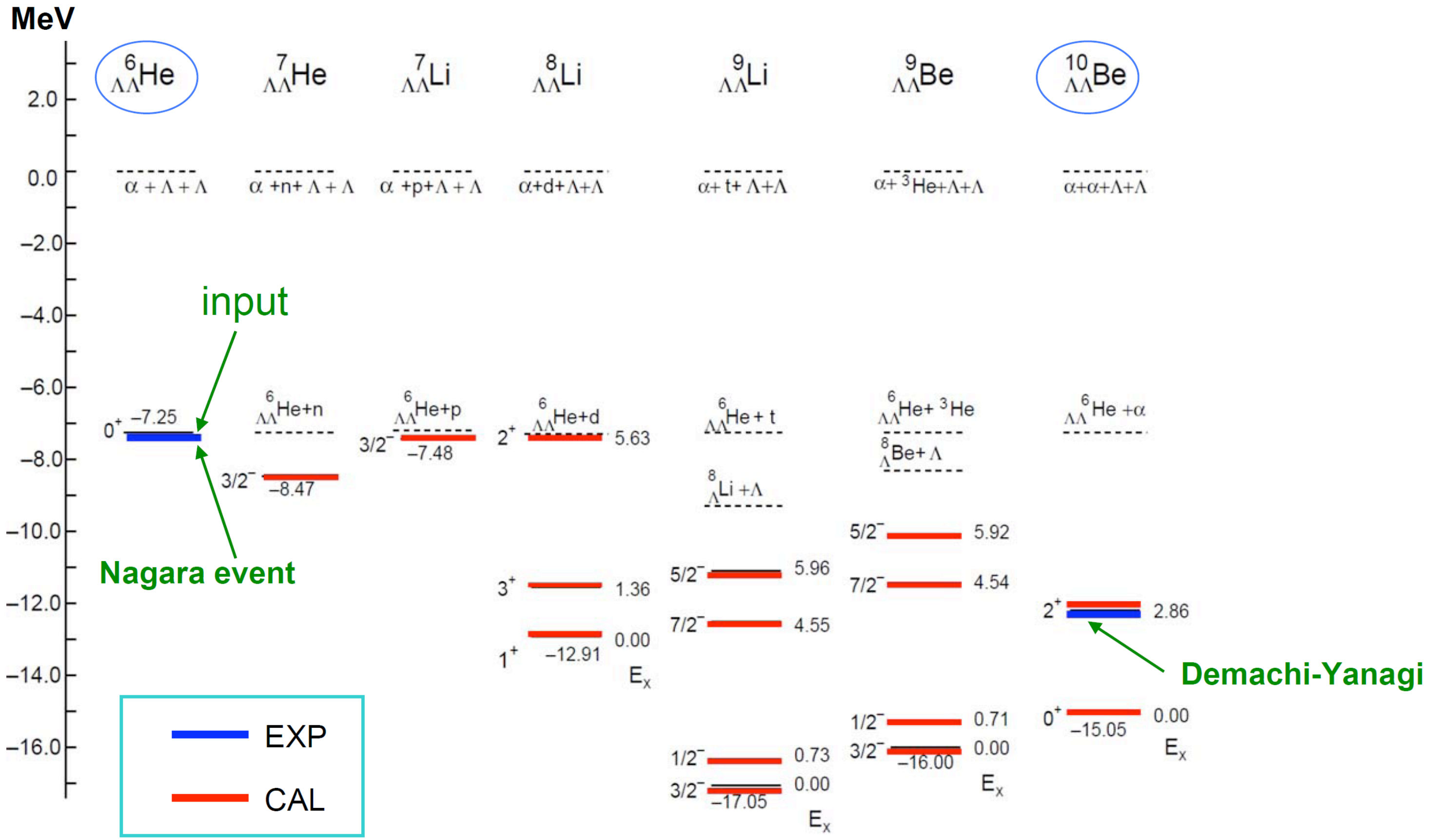
- **Additional information via Gamma Spectroscopy of possible excited states**

- **Need to Investigate :**

  1. Do Excited states of these system exist ?
  Up to now, only theoretical cal. (*Hiyama et al*)
  1. What is the probability to create them ?
  2. Is it possible to develop a strategy to uniquely identify and assign them to γ – transitions?

Spectroscopy of ΛΛ-hypernuclei

E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto
Phys. Rev. 66 (2002) , 024007

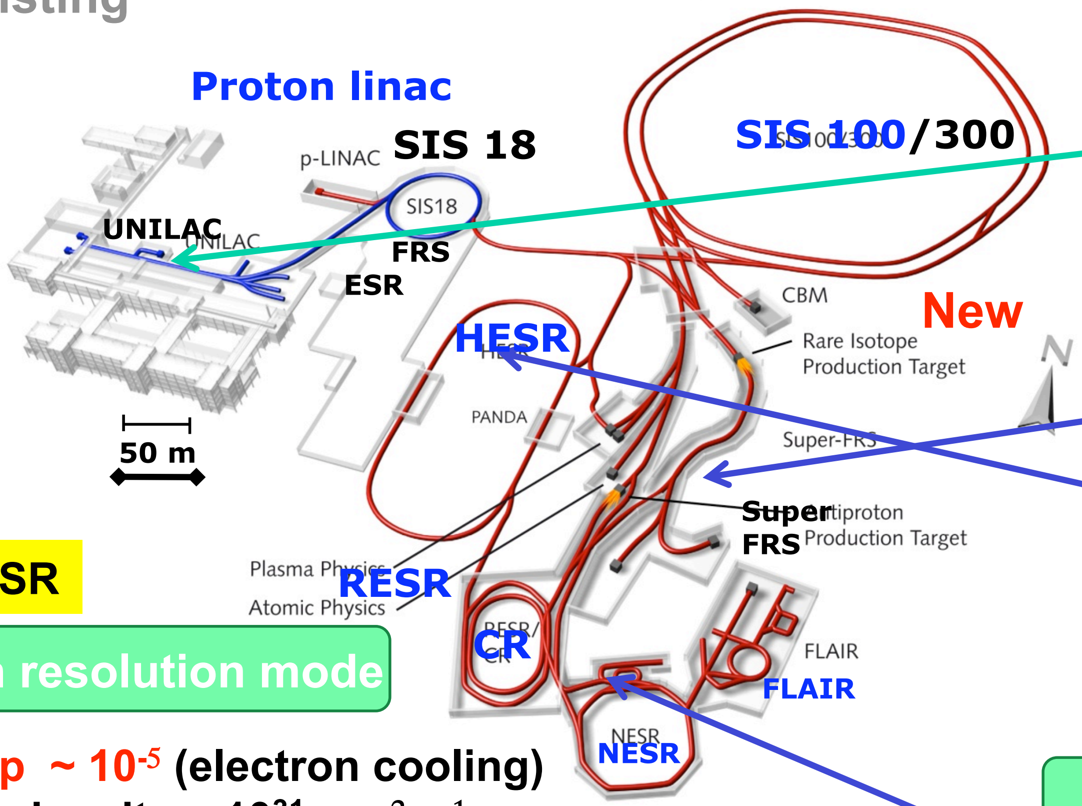


- many excited, particle stable states in double hypernuclei predicted
- level structure reflects levels of core nucleus
- high statistics is needed, about 2 or 3 order of magnitude larger

Facility for Antiproton and Ion Research

FAIR

Existing



Primary Beams

- $2(4)\times10^{13}$/s 30 GeV protons

Secondary Beams

Antiproton production target

- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

10^{11} stored and cooled

0.8 - 14.5 GeV antiprotons

HESR

High resolution mode

$\delta p/p \sim 10^{-5}$ (electron cooling)

- Luminosity = 10^{31} cm^{-2} s^{-1}

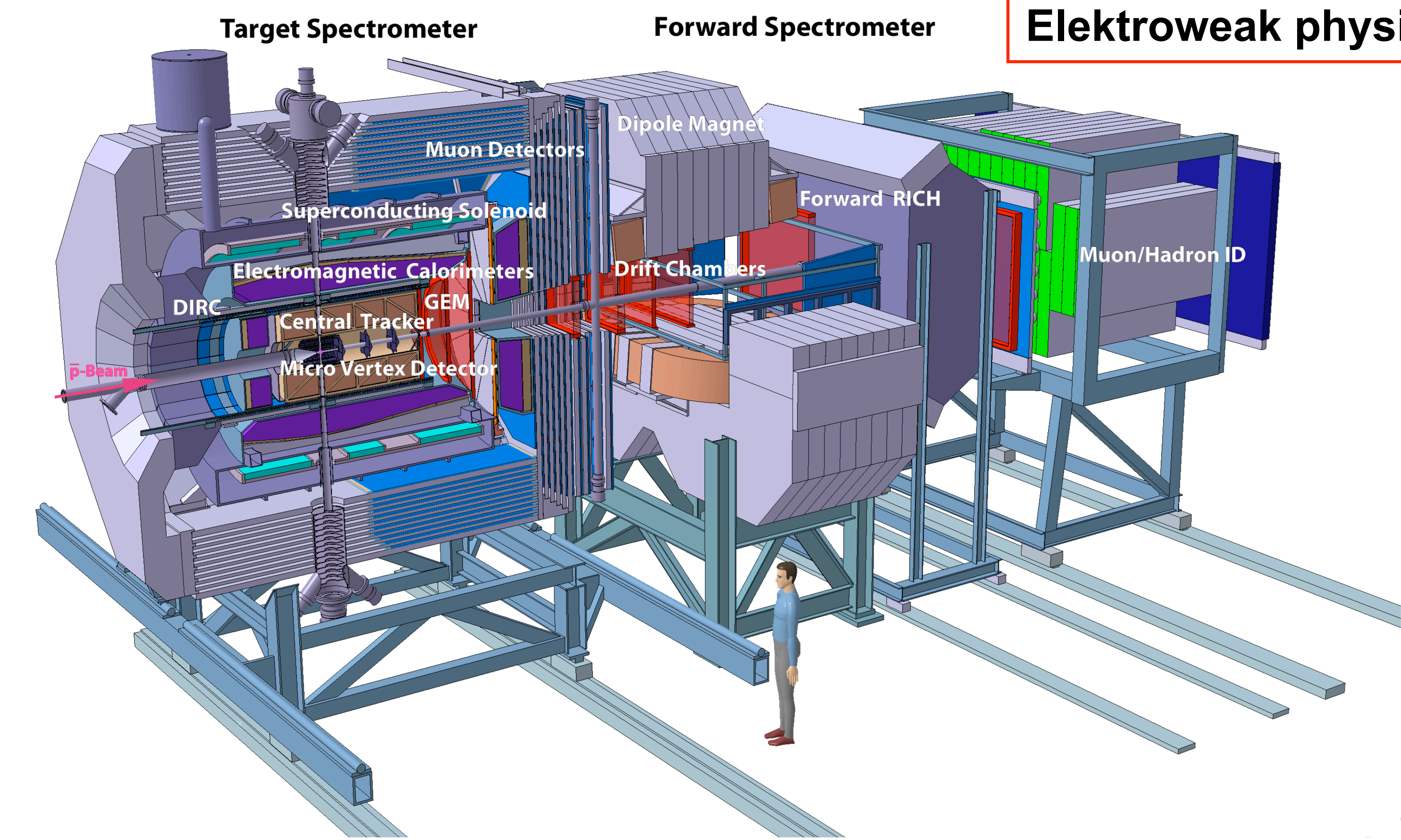
High luminosity mode

- Luminosity = 2×10^{32} cm^{-2} s^{-1}
- $\delta p/p \sim 10^{-4}$ (stochastic cooling)

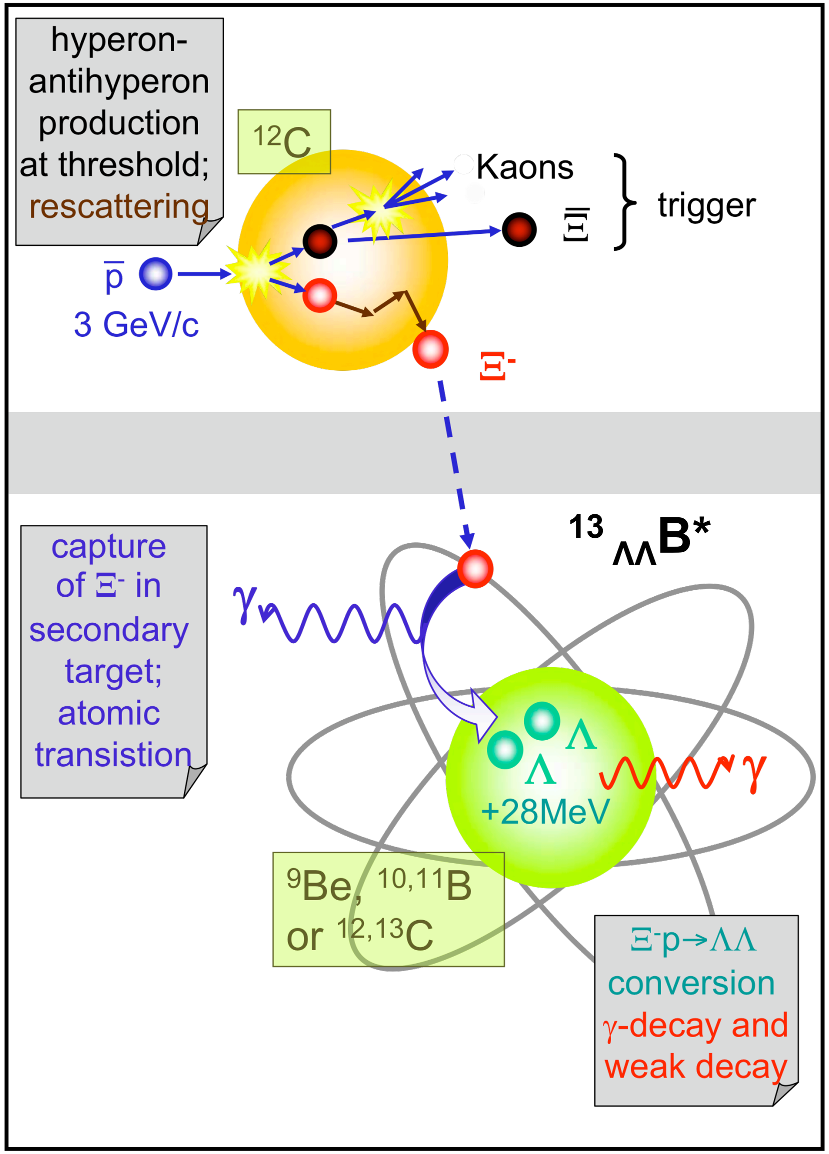
The PANDA Detector

- 4π acceptance
- high resolution for tracking, pid, calorimetry
- high rate capability
- versatile redout and event selection

QCD bound states
Non-perturb. QCD
Hadrons in nuc. matter
Hypernuclear Physics
Electro. Processes
Elektroweak physics

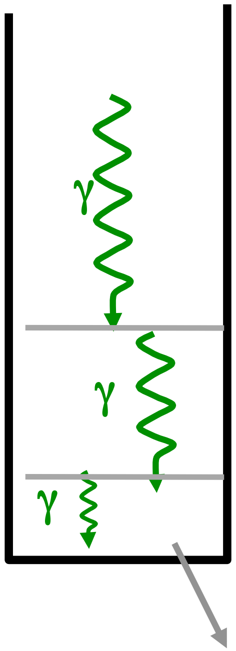


Gamma Spectroscopy of double hypernuclei at PANDA



- $\bar{p}$ +Nucleus->Ξ^- +Ξ^+ at 3GeV/c
  Other Exp. E906 AGS-BNL, JPARC
  (K^- + p -> K^+ + Ξ^-)
- Cross section 2µb
- Luminosity 10^{32} cm^{-2}/s to
  7.10^5 Ξ^- +Ξ^+ hour
- Ξ^- p -> ΛΛ + 28 MeV
- energy release may give rise to the emission of excited hyperfragments ($^{13}{}_{\Lambda\Lambda}B^*$)
- Two-step production mechanism requires a
  1. devoted setup
  2. spectroscopy: decay products

How to identify ΛΛ - Hypernuclei



electromagnetic Decay

Non mesonic decay

$\Lambda p \rightarrow pn$

$\Lambda n \rightarrow nn$

$\Lambda\Lambda \rightarrow Yn$

Mesonic decay

$\Lambda \rightarrow p\pi^-$

$\Lambda \rightarrow n\pi^0$

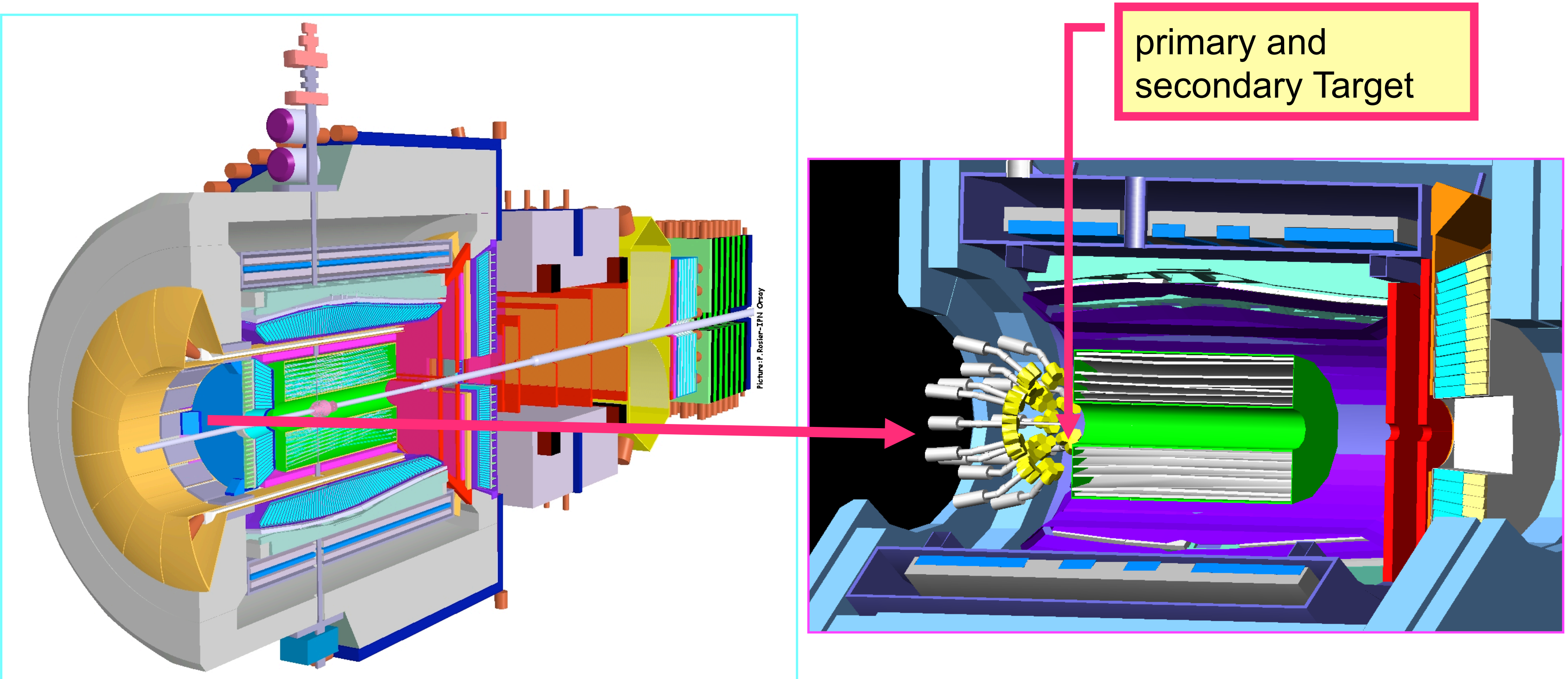
+ fragments

- Spectroscopy studies cannot be based on two body reactions
- detection of charged decay products, only limited to light nuclei
- unique assignment of gamma transitions
- sequential mesonic weak decay
- Up to now no excited states have been observed
- But theoretically have been predicted

Integration in the PANDA Detektor

- $\theta_{lab} < 45°$, Ξ^{+}, K trigger (PANDA)
- $\theta_{lab} = 45°\text{-}90°$,
  1. Primary target : $\bar{p} + {}^{12}C \rightarrow \Xi + \Xi^{-}$,
  2. Secondary target, Ξ^{-} Capture , Hyp. Production
- $\theta_{lab} > 90°$, γ - detection at backward

Neutrons Background (16000 n s^{-1} per Crystal)



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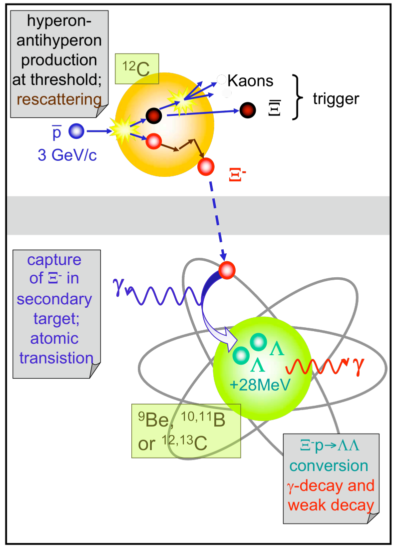

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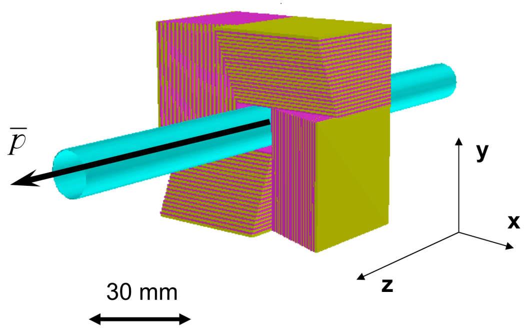
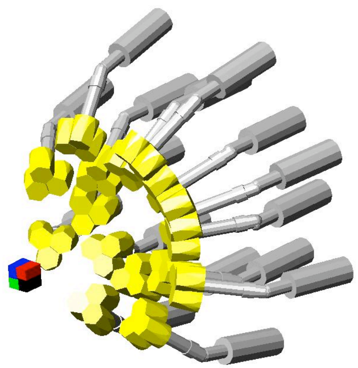
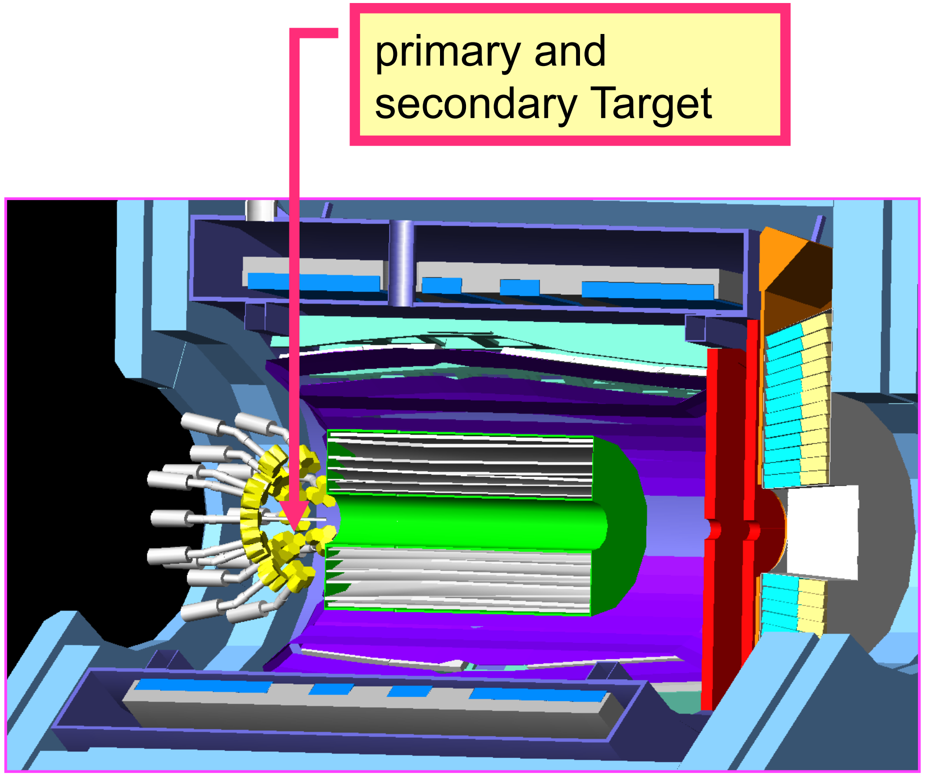


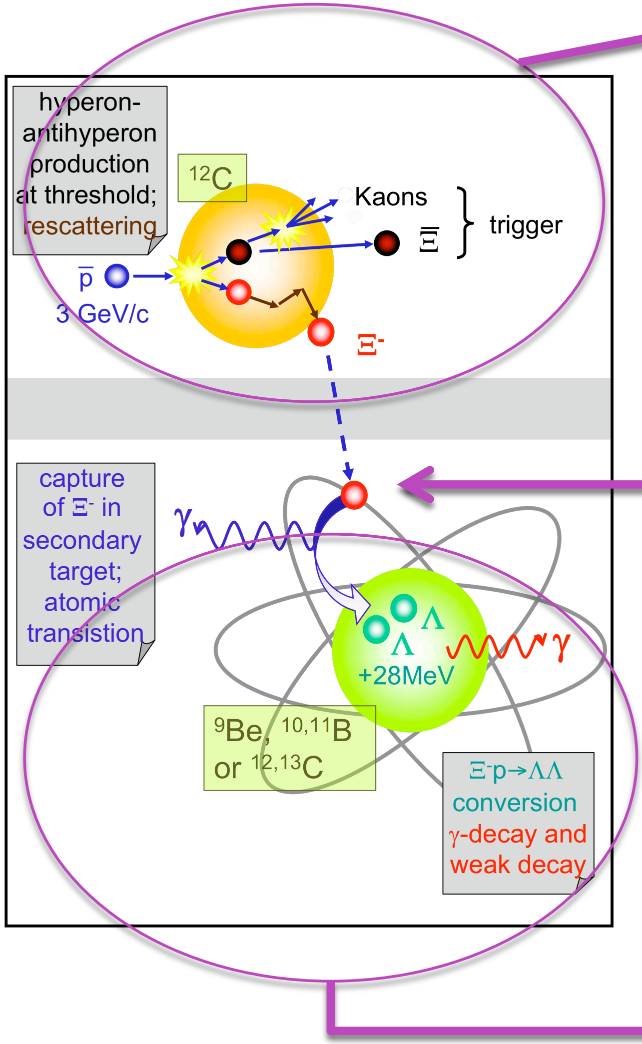




Feasibility studies by means of a Monte Carlo simulation

- Double hypernuclei production mechanism
- Identification strategy
- Background suppression

MC Simulation of multi--step mechanism: Production



- $\bar{p} + ^{12}C \rightarrow \Xi + \Xi^-$,
  - Intra. Nucl. Cascade (*F. Ferro et al*)
  - URQMD extension (*A. Galoyan*)
  - Choice of primary target
- Ξ^- Capture in a ^{12}C:
  - Stopping Ξ – vertexes in absorber

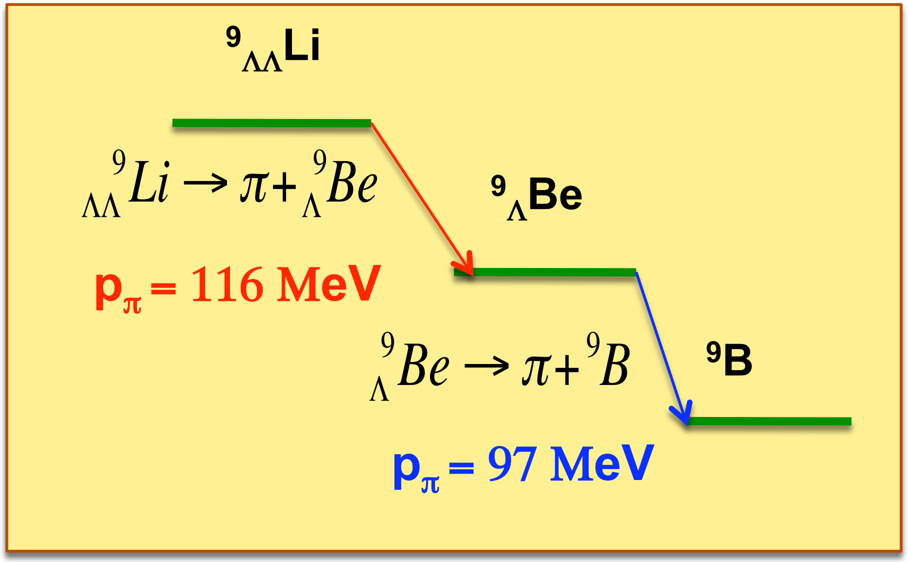
- Hyp. Production: Population of particle stable excited states within a Statistical Decay Model
- Input: Ξ binding energy 4 MeV
- Gamma-spectroscopy in coincidence with the detection of the weak (mesonic) decay products.

Detection strategy: Signal

- Use different light nuclear targets, (^{9}Be, ^{10}B, ^{11}B, ^{12}C and ^{13}C) to study the population of individual excited states.

- Identification of ΛΛ hypernucleus through sequential weak decay via π^- emission:
    1. in light nuclei the pionic weak decay dominates
    2. the pion kinetic energy is proportional to $\Delta B_{\Lambda\Lambda}$
    3. the pion momentum is monoenergetic
    4. coincidences between two pions help to trace

- Combination of gamma spectroscopy and sequential pionic decay as to identify uniquely double hypernuclei.



- π momentum is monoenergetic: used as fingerprint

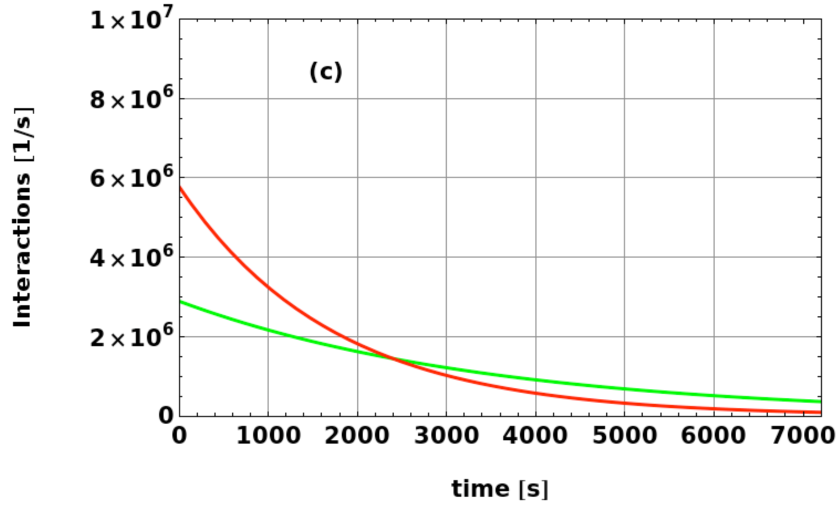
    1. $^{A}_{\Lambda\Lambda}Z \rightarrow \pi_H + ^{A}_{\Lambda}(Z+1)$
    2. $^{A}_{\Lambda}(Z+1) \rightarrow \pi_L + ^{A}(Z+2)$

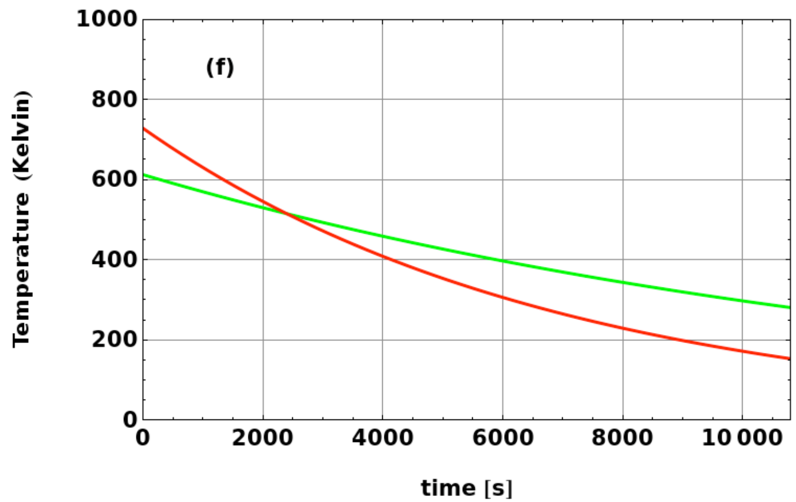
Performance of Target system

- ^{12}C micro ribbons target:
- *n* and X-ray background
- rescattering processes

- thickness 0.02 μm :
- beam fraction 0.005

- Production rate:
- 3 10^6 interactions / s
- Influence of beam loses
- hadronic interactions
- beam lifetime ~3000 s
- acumulation time HESR (~1000s)
- Temperature increment ~500 K
- Diamond 3920 K, graphit 3948 K





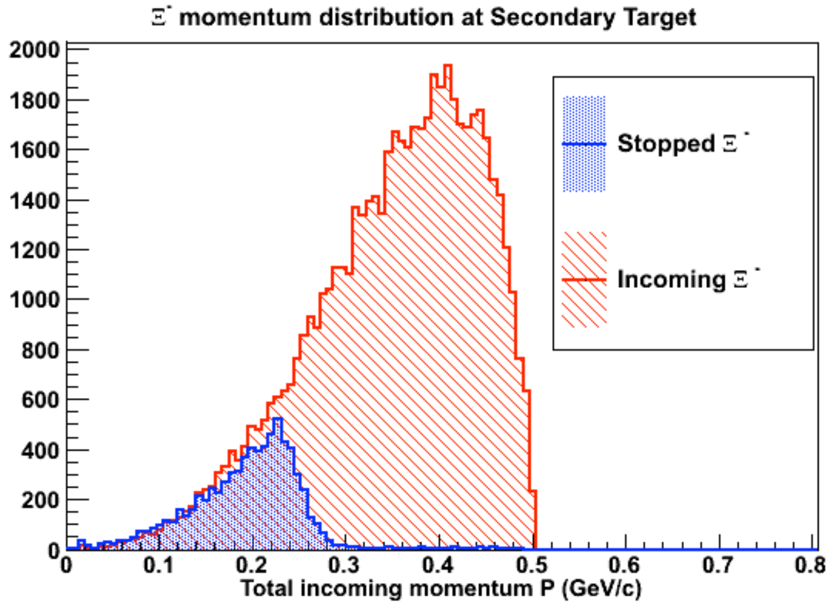
Performance of Target system

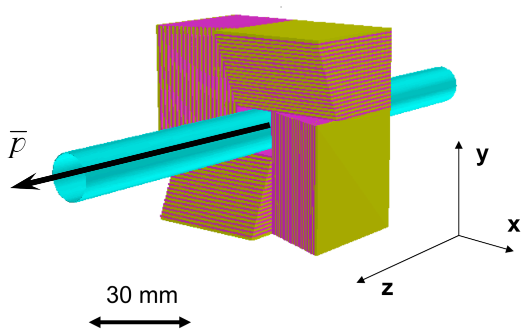
Geometry given by Ξ lifetime:

- Thickness ~30 mm
- Absorber layer ~1 cm
- silicon layer ~300 μm

Deceleration

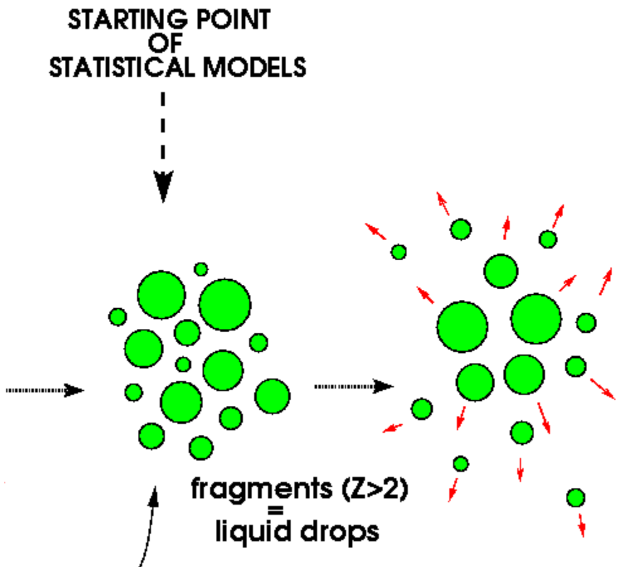
Tracking charged decay products





Population of double hypernuclei states

Statistical model: (*E. Fermi, J.P. Bondorf et al*)



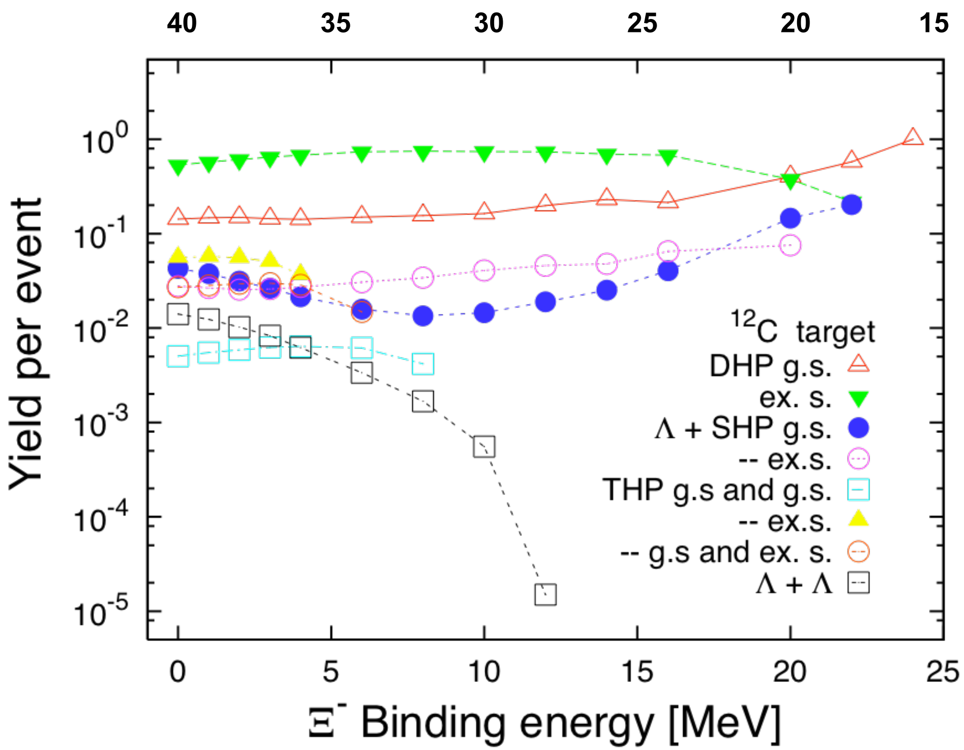
- De-excitation of light nuclei via
  Fermi break-up process
- Conservation of A, Z, H, Energy
  and momentum

Input:

- Light nuclei. p, n, d, t… ^{9}Be, ^{10}B, ^{11}B, ^{12}C,^{13}C and excited states
- existing single hypernuclei masses and excited states
- Theo. And Exp. Double hypernuclei masses(*T. Yamada et al*)
- Theo. Predicted excited states*, (E. Hiyama et al)***.**

Fermi Break up of an excited hypernuclei with double strangeness

$\Xi^- + {}^{12}C \rightarrow {}^{13}_{\Lambda\Lambda}B^*$



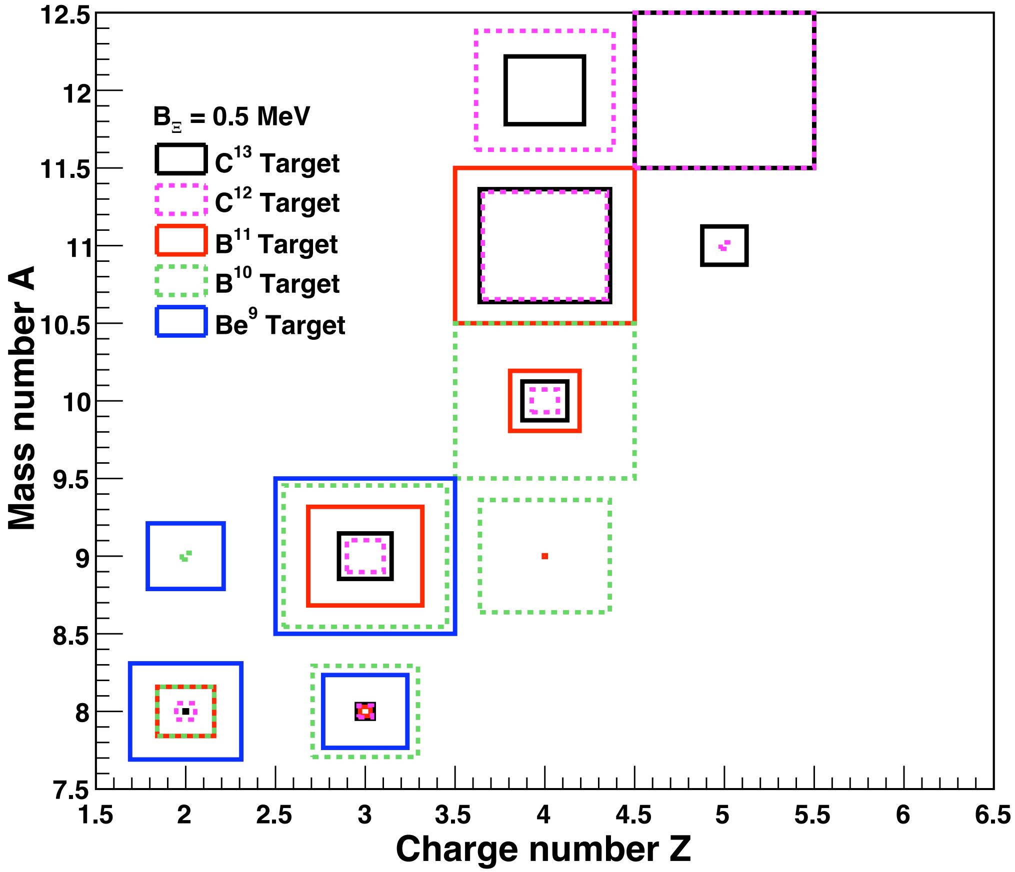
- DHP : double hypernuclei
- SHP : single hypernuclei
- THP : twins hypernuclei

- Maximum energy available 40 MeV
- Ξ^- binding energy not yet known

- Theoretical calculations on Ξ^- nuclear potencial leads to 0.6 – 3.7 MeV (*C.J Batty et al, Aoki et al*)

production of excited states of DHP are significant.

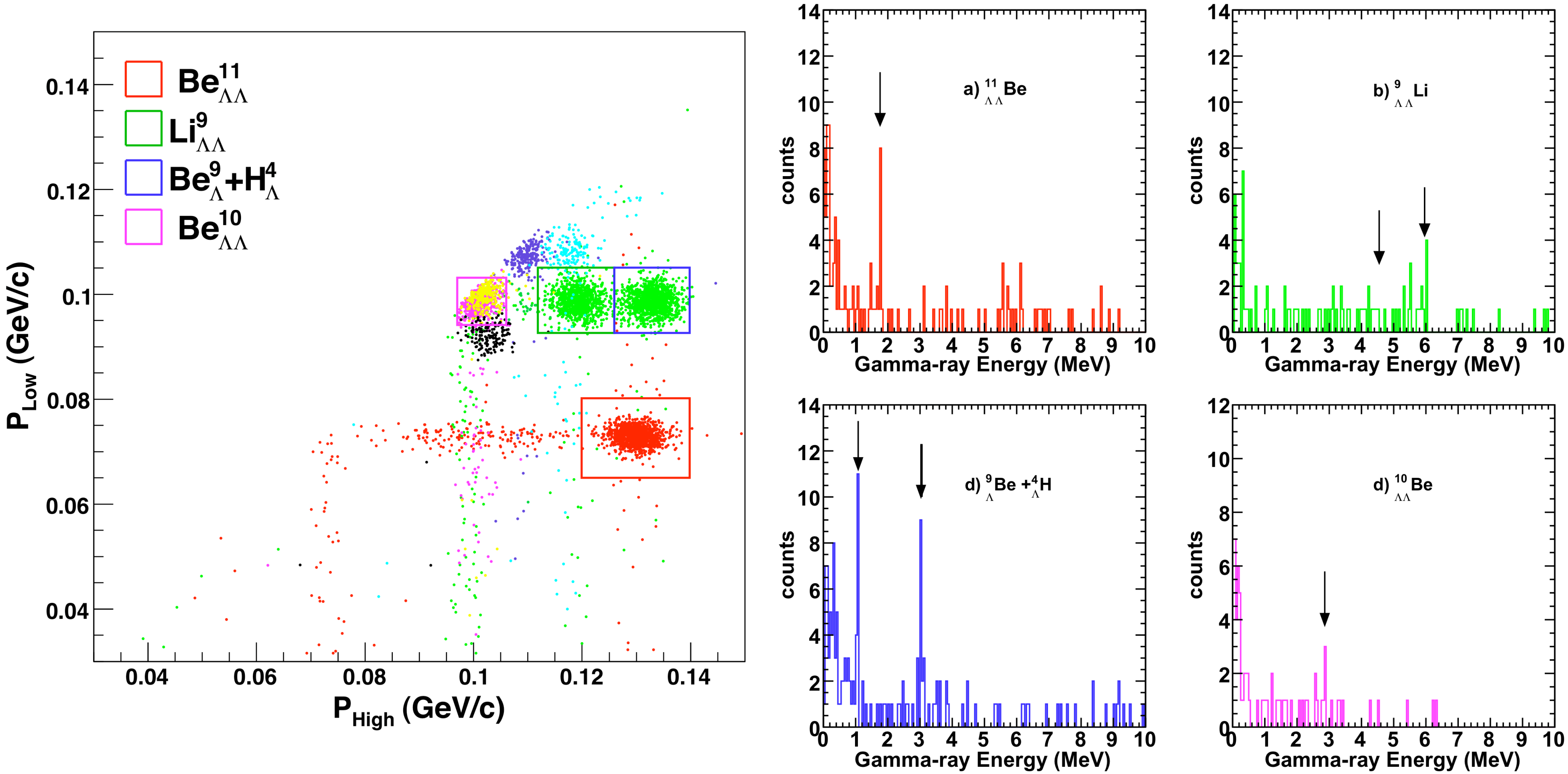
Population of individual excited states with different light nuclear Targets



1. B_Ξ = 0.5 MeV,
2. (0.5—6 MeV) main trend.
3. But, relative population of specific ex. levels may depend on B_Ξ
4. Most probable DHP ^{10}Be, ^{11}Be, ^{9}Li, ^{12}B
5. The production yield is proportional to the squares area
6. Comparison of the expected yields for each target offers a strategy for the unique assigment of observable transitions.

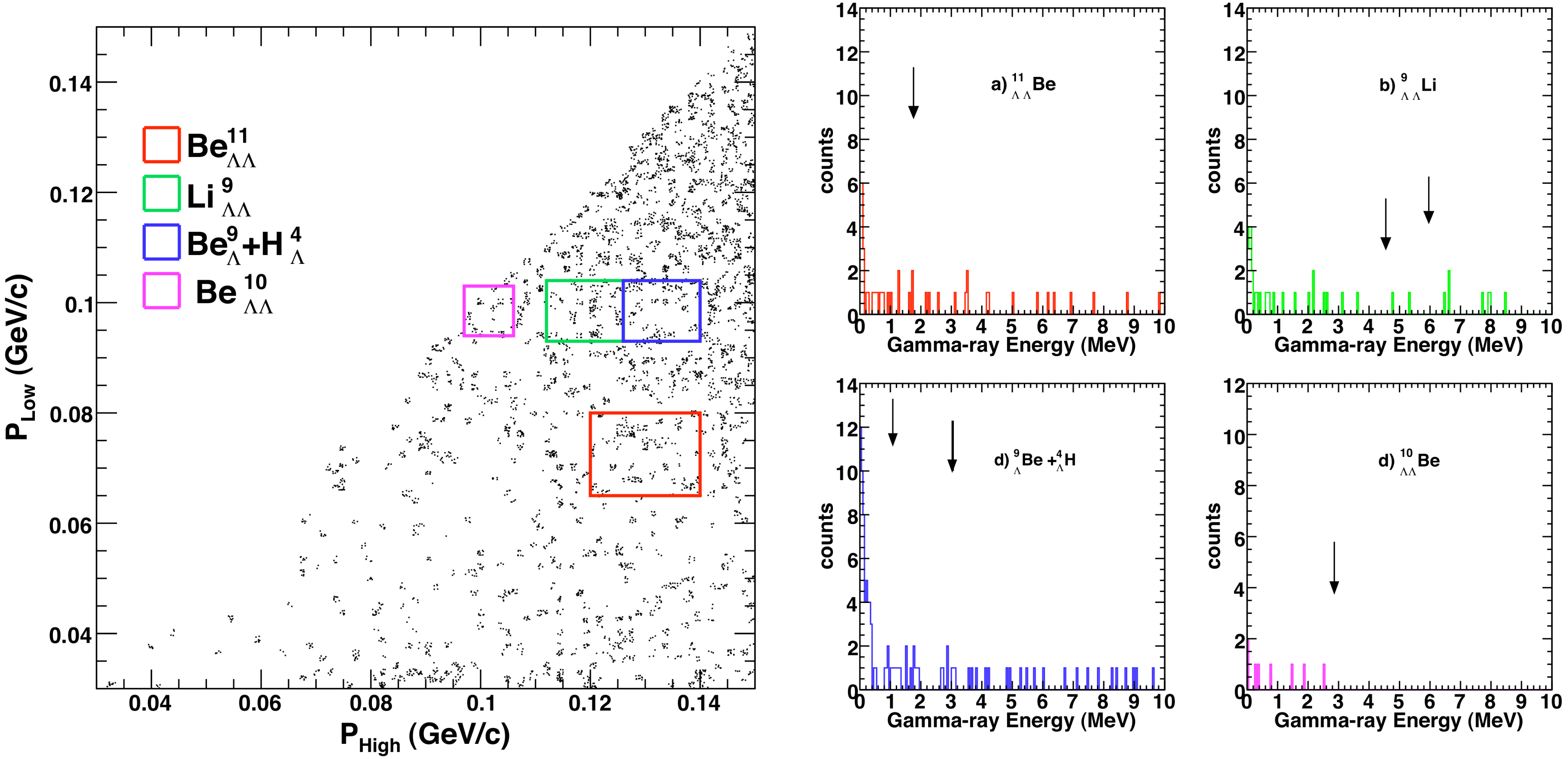
Identification of double hypernuclei: γ + weak decay

1. Mesonic weak decay of the order of 10%
2. Sequential mesonic decay of DHP releasing 2 pions
3. 50 % data taking available
4. Approx. Running time two weeks
5. Detection of NMWD may improve the final rate



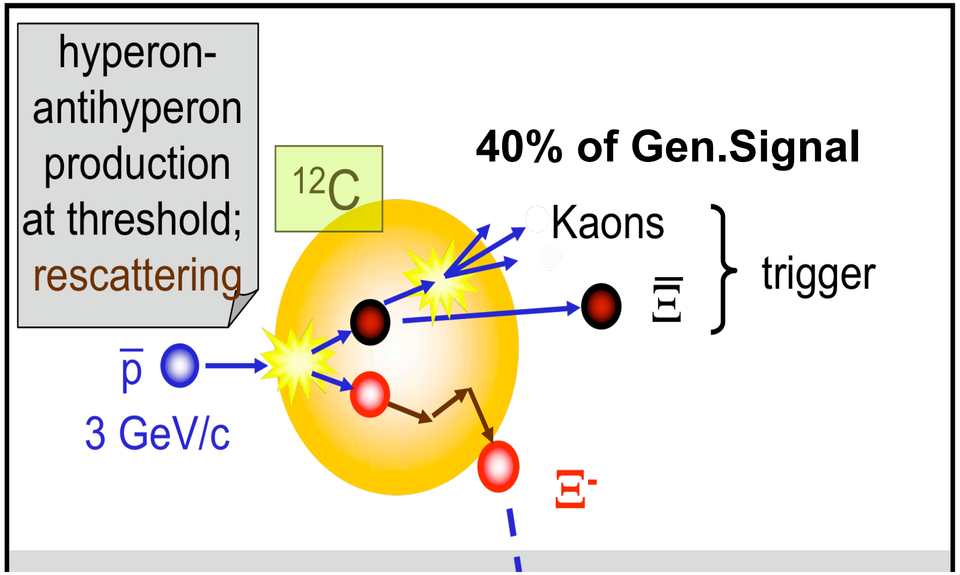
Free Ξ^- + Ξ^+ background contribution

The background of Ξ free decay and Ξ^+ annihilation correlated to the stopped Ξ^-



Relation 3:1 signal to background

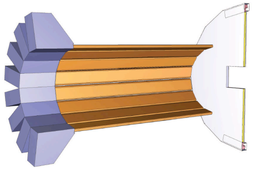
Background Suppression Strategy: Low Momenta Kaon identification



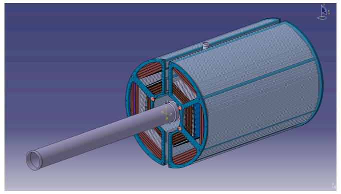
- $\bar{p}$ +Nucleus->Ξ^- +Ξ^+ at 3GeV/c
- Cross section 2μb
- $\bar{p}$ + p , total cross section 50 mb
- Exp.Challenge: $\frac{\sigma(\Xi^-\overline{\Xi}^+)}{\sigma(\bar{p}p)} \approx 4 \cdot 10^{-4}$

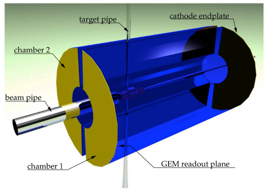
1. Background reactions are a factor 25000 larger than Ξ^- +Ξ^+ prod.
2. Background suppression is mandatory
3. kaon (Ξ^+ annihilation) identification can be used to tag the Ξ^- +Ξ^+ prod.
4. Pion-Pion Correlation technique(sequential pionic decay) and
5. Gamma Spectroscopy .(**arXiv:0903.3905v1 [hep:exp]**)

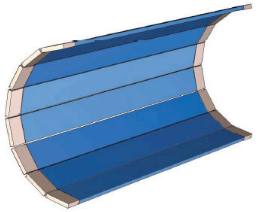
Detection Options:



- DIRC : not for momentum particles below 700 MeV/c
- TPC/STT Use of (dE/dx) for PID
- TPC/STT + TOF detector system :

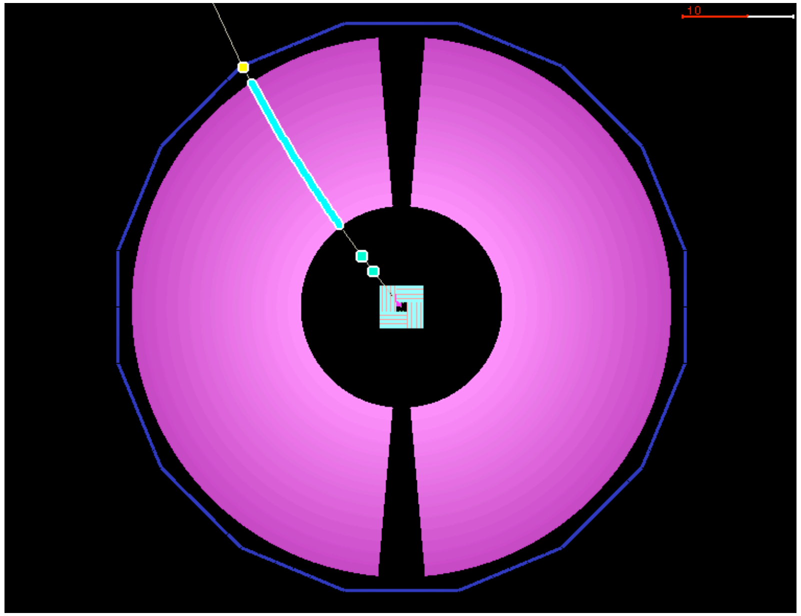


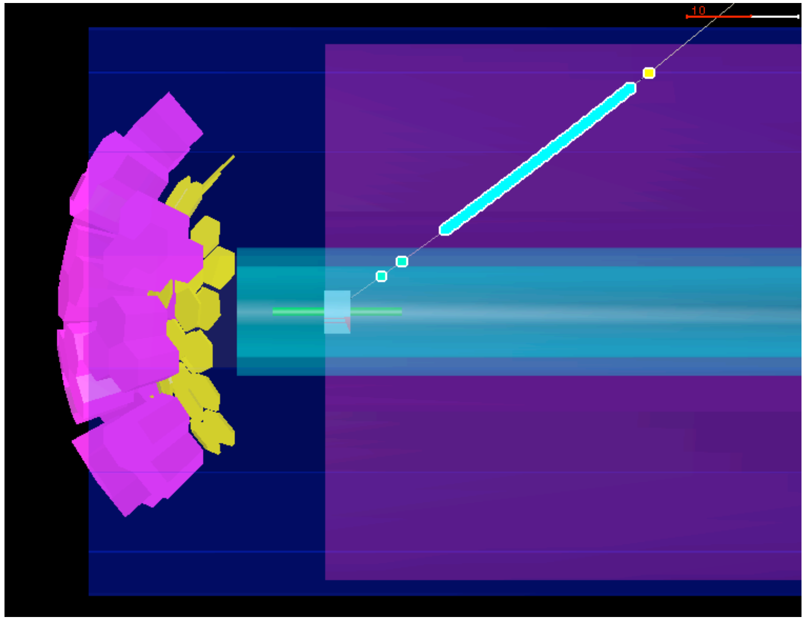




  - Start detector:
    - Scintillator fiber array : 1200 fibers
    - CVD Diamond (*Timing use, E. Bederman et al, Proc. IEEE(2009*)
  - Stop detector : Scint. tof barrel ~16 Slabs ~6 bars or RPC.

Start (SciF or CVD)+TPC + TOF





•Tof barrel (STOP)

Time resolution ~ 80ps

•Scint. fiber ~450 ps

•CVD Diamond Detector (START)

Time resolution ~ 80 ps

•TPC : tracking system

Track Length + P

P/Mass = $\beta * \gamma$

• Geo. Acceptance:

Hyp IP :15°--90°

TS IP : 144° -- 22°

STRATEGY : identification of at least one kaon per event.
(kaon multiplicity trigger)

MC Simulation :

Extended UqmdSmm (A.Galoyan)
Event Generator :

Signal : 200,000 Ξ^- +Ξ^+ events

Background : 100,000 $\bar{p}$ + ^{12}C

Ξ^+ annihilates ~85 %

K+ prod. 40 %

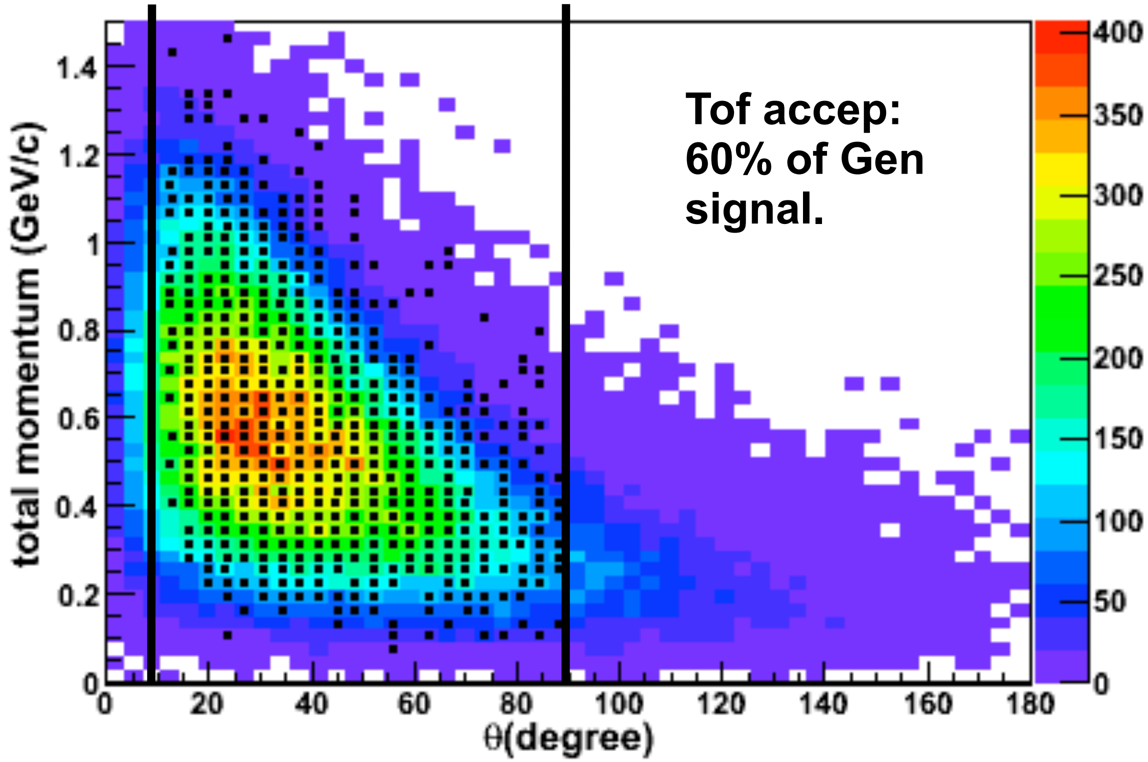
Background : 100,000 $\bar{p}$ +Nucleus

Calculations performed at
B = 1T

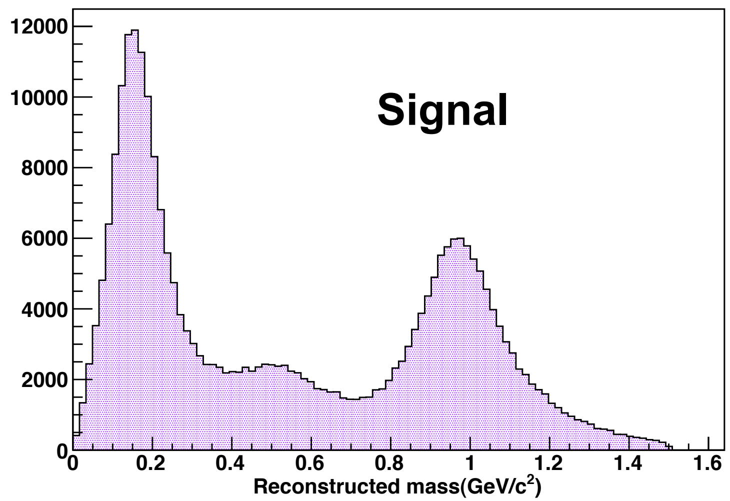
Tracking effciency : 60%

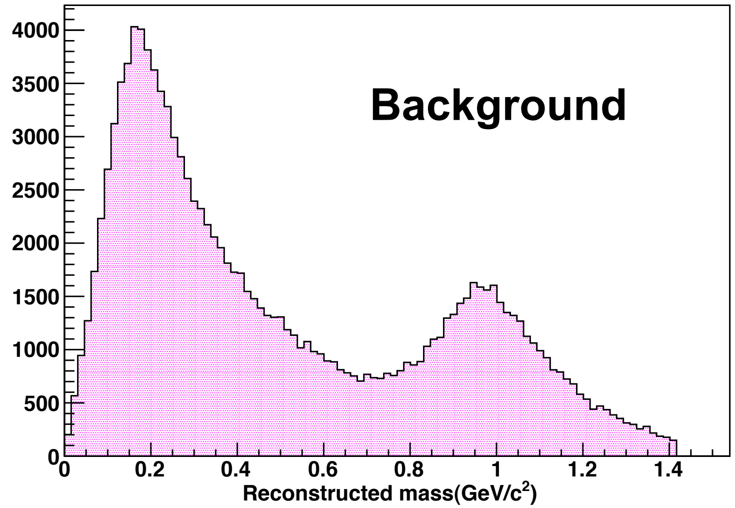
PID efficiency
95 % (80 ps), 50% (450 ps)

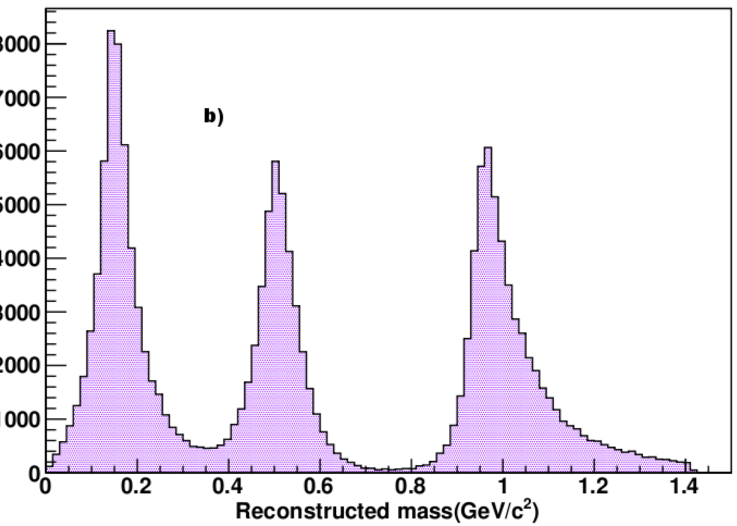
associated positive kaon distribution
at generation vertex

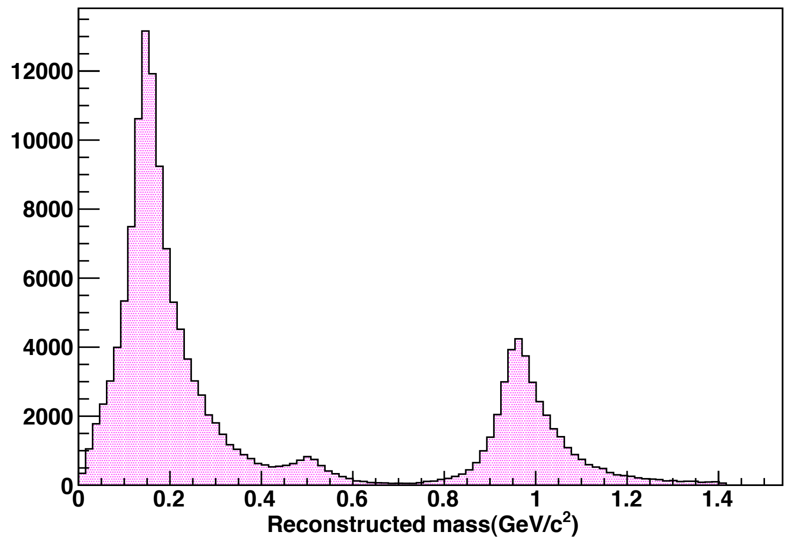


Mass reconstruction spectra









Results

- Applying the kaon trigger,

	Start Det (80 ps)	Start Det (450 ps)
$\Xi^- + \Xi^+$ events	**~30 %**	**~20 %**
$\bar{p}$ + ^{12}C events	**~7.7 %**	**~5.5 %**

A trigger efficiency of ~40% would be desiderable

Other possibility : TOF system + TPC+ DIRC

Rate estimates

$\overline{\text{p}}$ interaction rate	$3 \cdot 10^6 \text{s}^{-1}$
$\overline{\text{p}}$ momentum	$3\,\text{GeV}/c$
internal target	$Z \approx 12$
reactions of interest	$\overline{\text{p}}\text{p} \to \overline{\Xi}^+\Xi^-$
	$\overline{\text{p}}\text{n} \to \overline{\Xi}^+\Xi^0$
cross section ($\overline{\text{p}}N$)	$2\,\mu\text{b}$
rate	$100\,\text{s}^{-1}$
Ξ^- PF	$7.5 \cdot 10^{-2}$
total stopped Ξ^-	648 000 per day
$\Xi^-\text{p} \to \Lambda\Lambda$ conversion probability	5 %
produced $\Lambda\Lambda$ hypernuclei	32 400 per day
probability of individual transition	10 %
target escape probability ($E_\gamma = 1\,\text{MeV}$)	70 %
full energy peak efficiency	2.75 %
trigger efficiency	20–30 %
detected individual transitions	690 per month

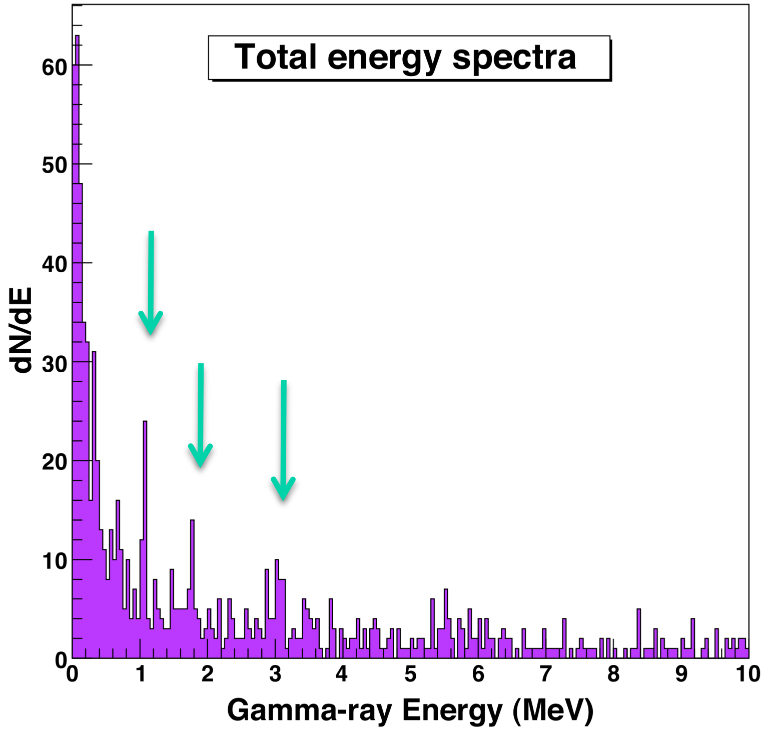
Table 2: Rate considerations for hypernuclear physics with γ-ray spectroscopy. The UrQMD+SMM event generator was used for $\overline{\text{p}}\text{p} \to \overline{\Xi}^+\Xi^-$ generation.

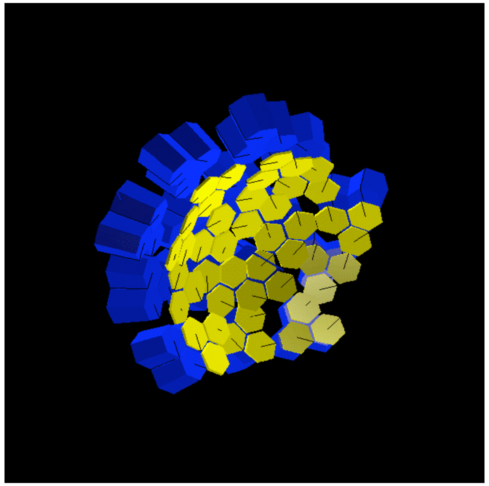
SUMMARY

- Statistical decay model extended to excited hypernuclei
- Production of excited double Lambda hypernuclei is significant
- Production and detection of double hypernuclei at PANDA seems feasible

Identification of double hypernuclei : gamma decay

1. Electromagnetic decay





Energy per bin 50 keV

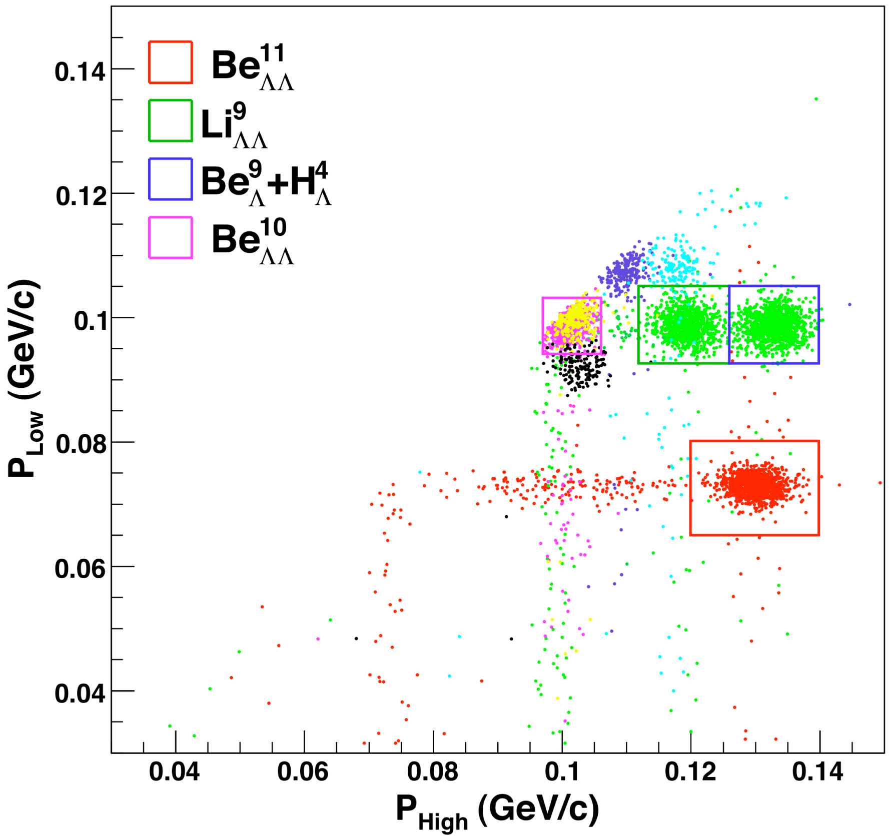
Expected resolution less than 10 keV

Observed 1, 1.68 and 3 MeV γ- transition

For an unique assignment one needs obviously additional experimental information

Identification of double hypernuclei: weak decay

1. Mesonic weak decay of the order of 10%
2. Sequential mesonic decay of DHP releasing 2 pions



- After Stat. dec. 7400 excited Ξ^- SHP
- 14800 charged tracks reconstructed
- 8300 assigned to pions
- Strong correlation of two pion momenta
- Silicon Sensor strip pitch 100µm
- Tracking : Kalman Filter
- Combination between two pions
- Cuts on pion--pion correlation

STRATEGY : identification of at least one kaon per event.
(kaon multiplicity trigger)

Requirements :

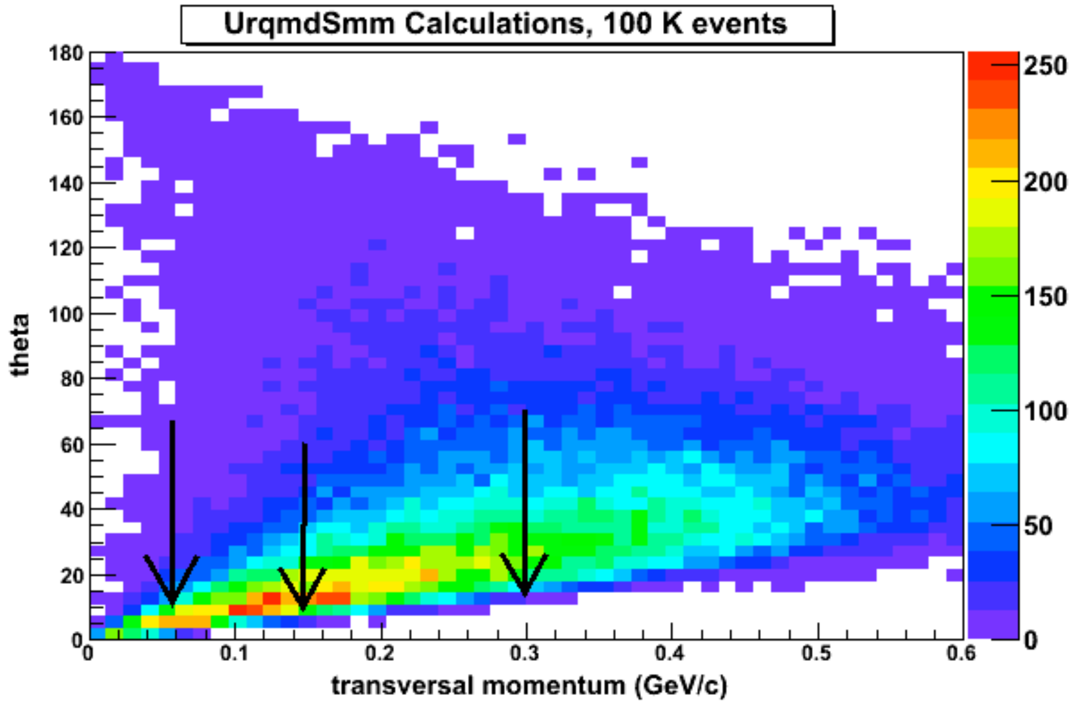
Central Tracker + Tof radius ≈ 0.5 m

P_T = 0.3*Q*B*Radius

B = 2 T, kaon Pt ≈ 0.3 GeV/c

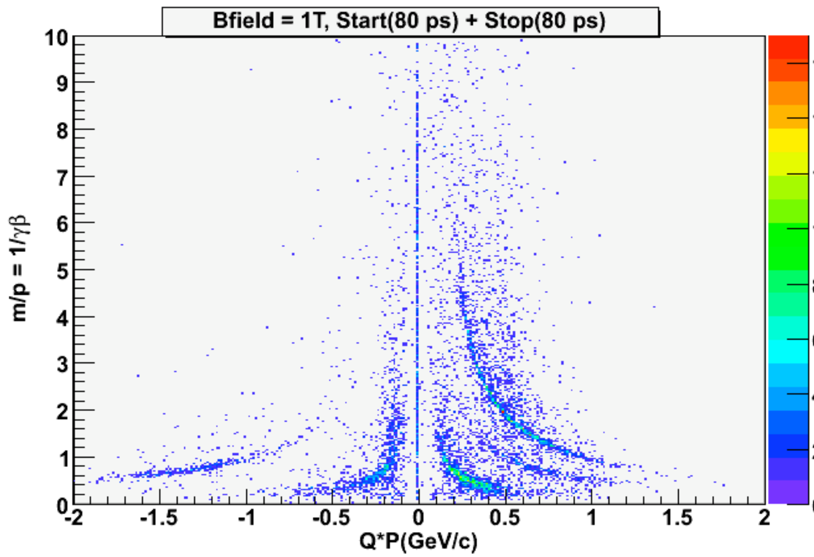
B = 1T, kaon Pt = 0.150 GeV/c
(*FINUDA, ALICE, CDF*)

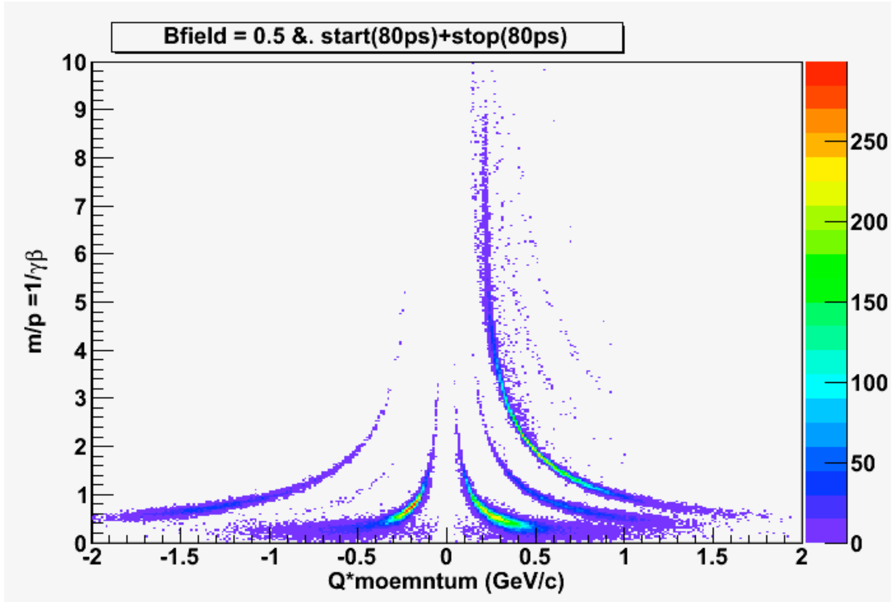
B = 0.5 , kaon Pt = 0.075 GeV/c
(*ALICE*)



associated positive kaon distribution
at generation vertex

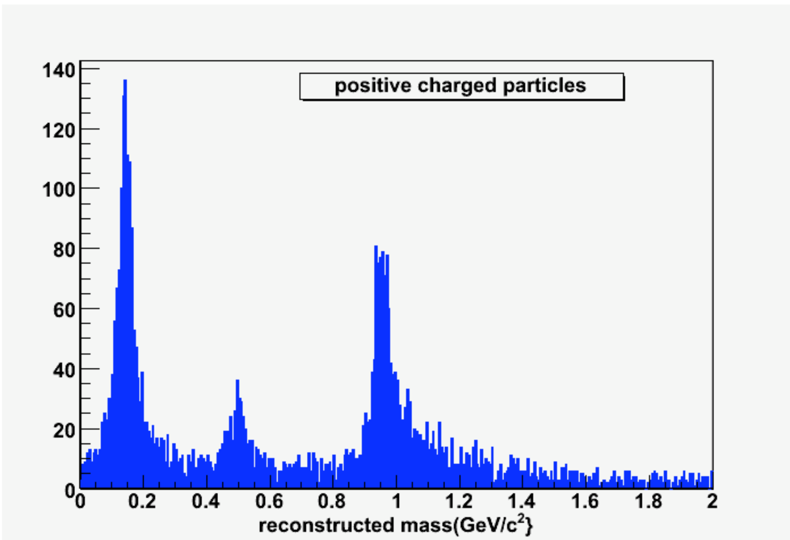
Tof Studies at different magnetic field values

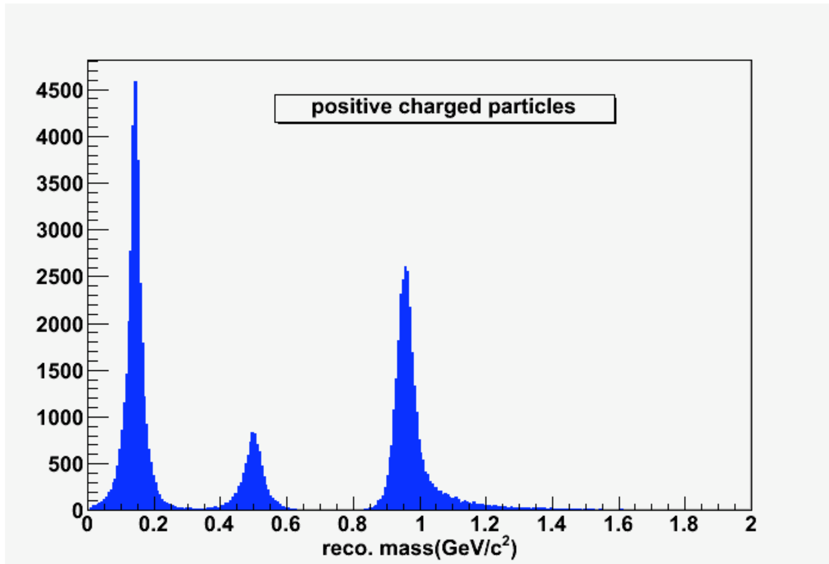




550 reco. kaons

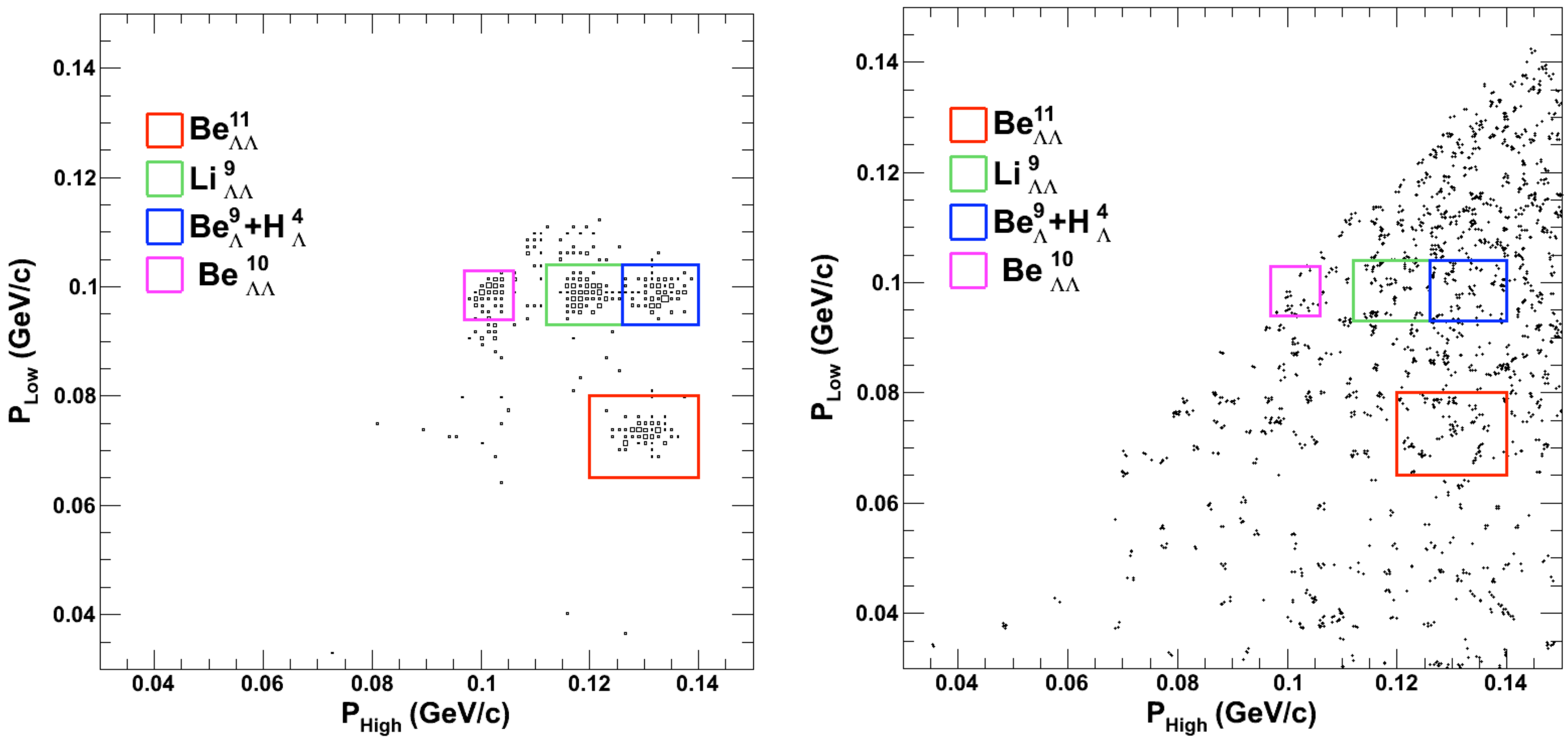
8760 reco. kaons





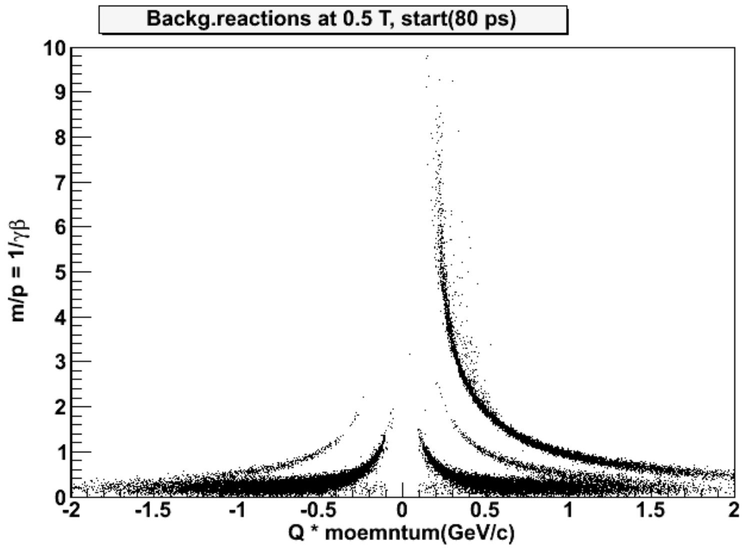
Cut on accepted kaon candidates at B=0.5 T

- Tagging on at least one kaon : 764 absorbed Ξ^- events
- Secondary target: 15000 Ξ^- absorbed
- Event Generator : 200,000 Ξ^- +Ξ^+ events
- S/N = 3:1 gamma energy spectra

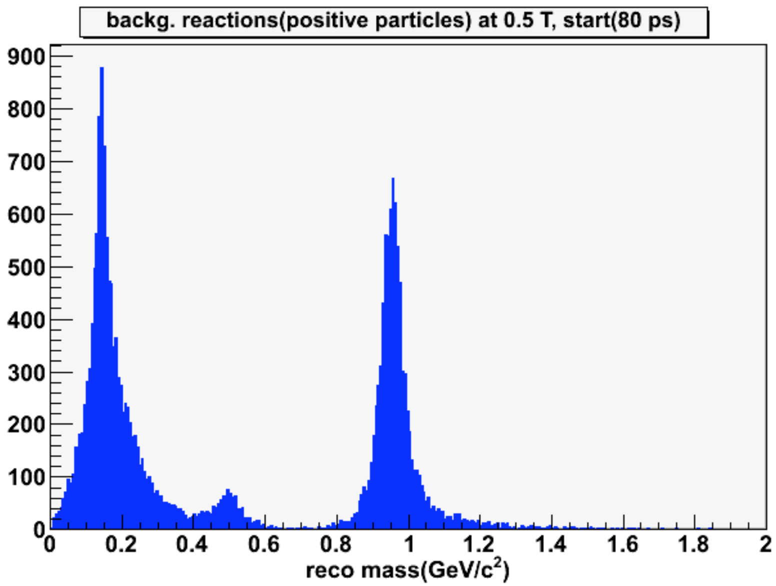


p̄ + Nucleus background contribution

(Urqmd+Smm, A. Galoyan et al)



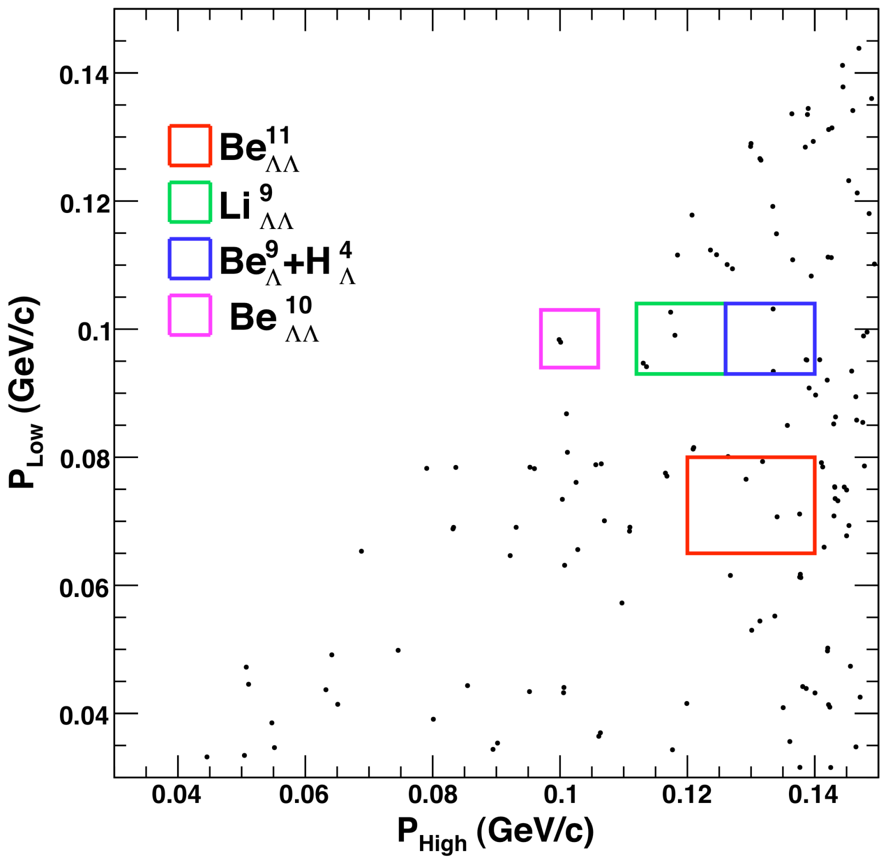
- magnetic field value 0.5T
- start(80 ps)
- 100,000 p̄+Nucleus reactions

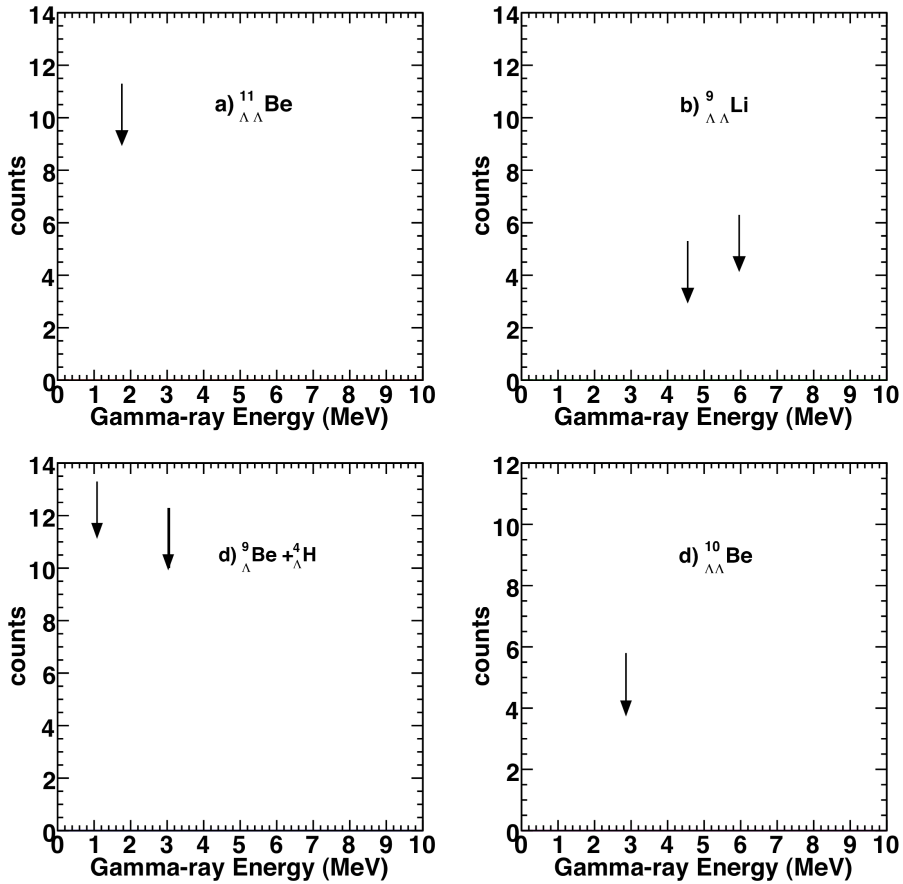


- 3206 rec. kaons
- No signal

$\bar{p}$ + Nucleus background contribution

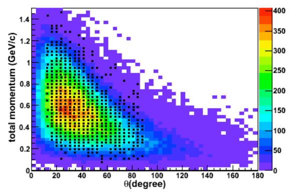
(Urqmd+Smm, A. Galoyan et al)

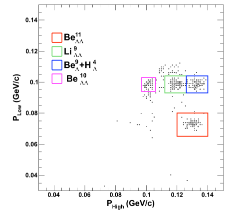


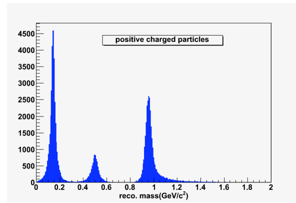


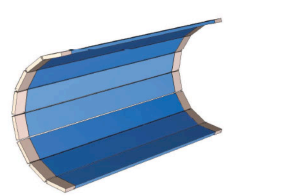
More statistic is needed

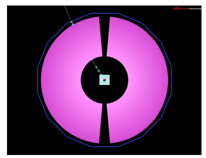
Conclusions:











1. Multiplicity kaon trigger based on TOF helps for background suppresion but statistic regarding p+Nucleus should be improved.

2. Tracking information from Sec. Target has to be used complementary.

3. B = 0.5 T increases the kaon identification acceptance

4. A possible start detector solution: diamond detector with a time resolution of about 90 ps, example. HADES)

5. The use of a TOF barrel detector will help in the identification of Double –Lambda Hypernuclei at PANDA.

Radiation hardness study

- Sim. 2.3 10^4 n+p/s at av. 25 MeV
- Rad. Damage:

  electron irrad. vs (NIEL) of p/n
  had. damage ~64 times stronger
  annealing will not help
  12 days at 5 10^6 collions/s

ADC spectra from SiPMT before and after radiation with 3 10^8 electrons

by S. Sanchez Majos