Hypernuclear physics studies at the PANDA experiment

- The PANDA experiment
- Production and Detection of Double Λ hypernuclei
- Double Λ hypernuclei at PANDA
- Technical developments
- Summary

Alicia Sanchez Lorente

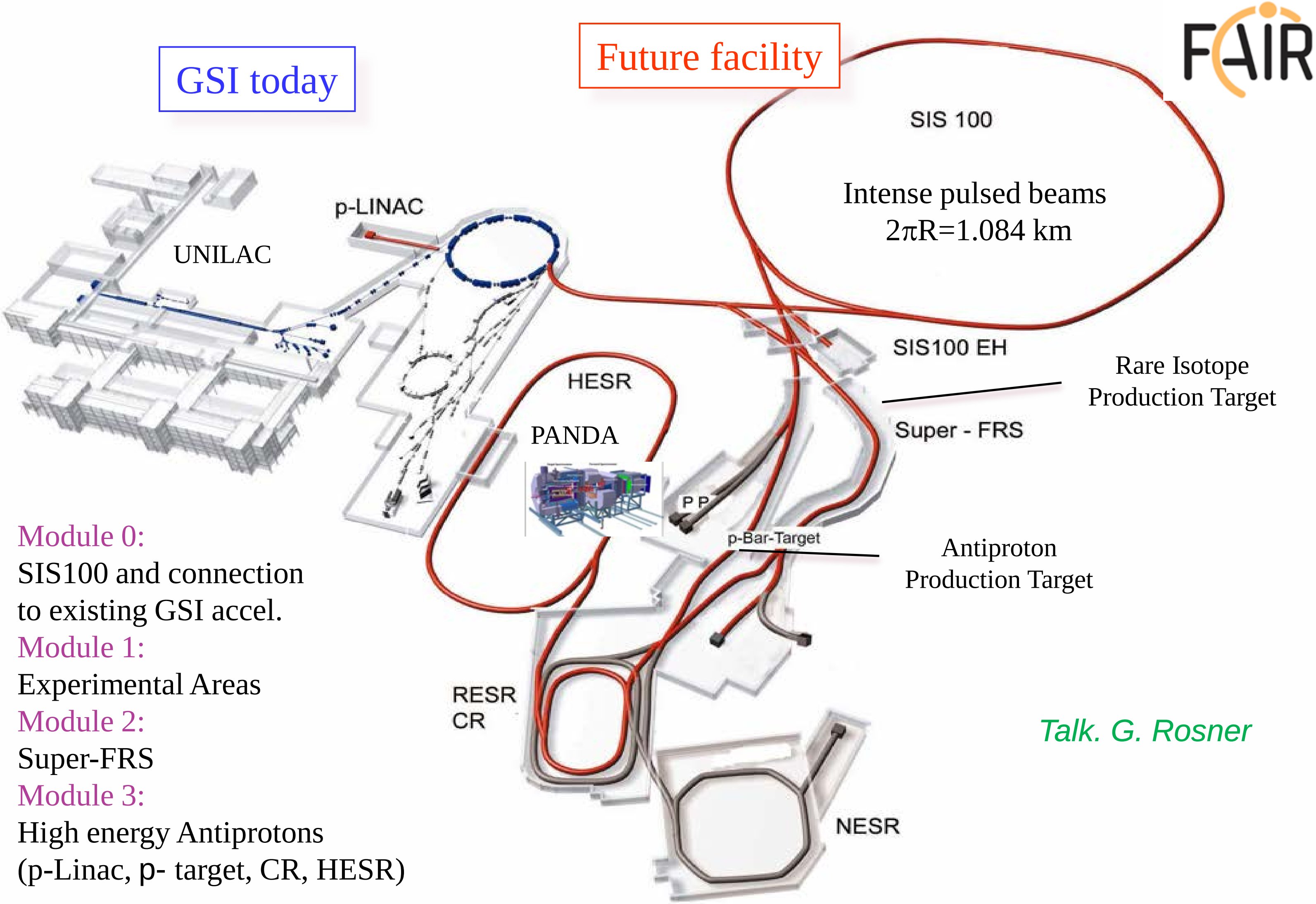
on behalf of the PANDA collaboration

LEAP 2013

10th International conference on

Low Energy Antiproton Physics

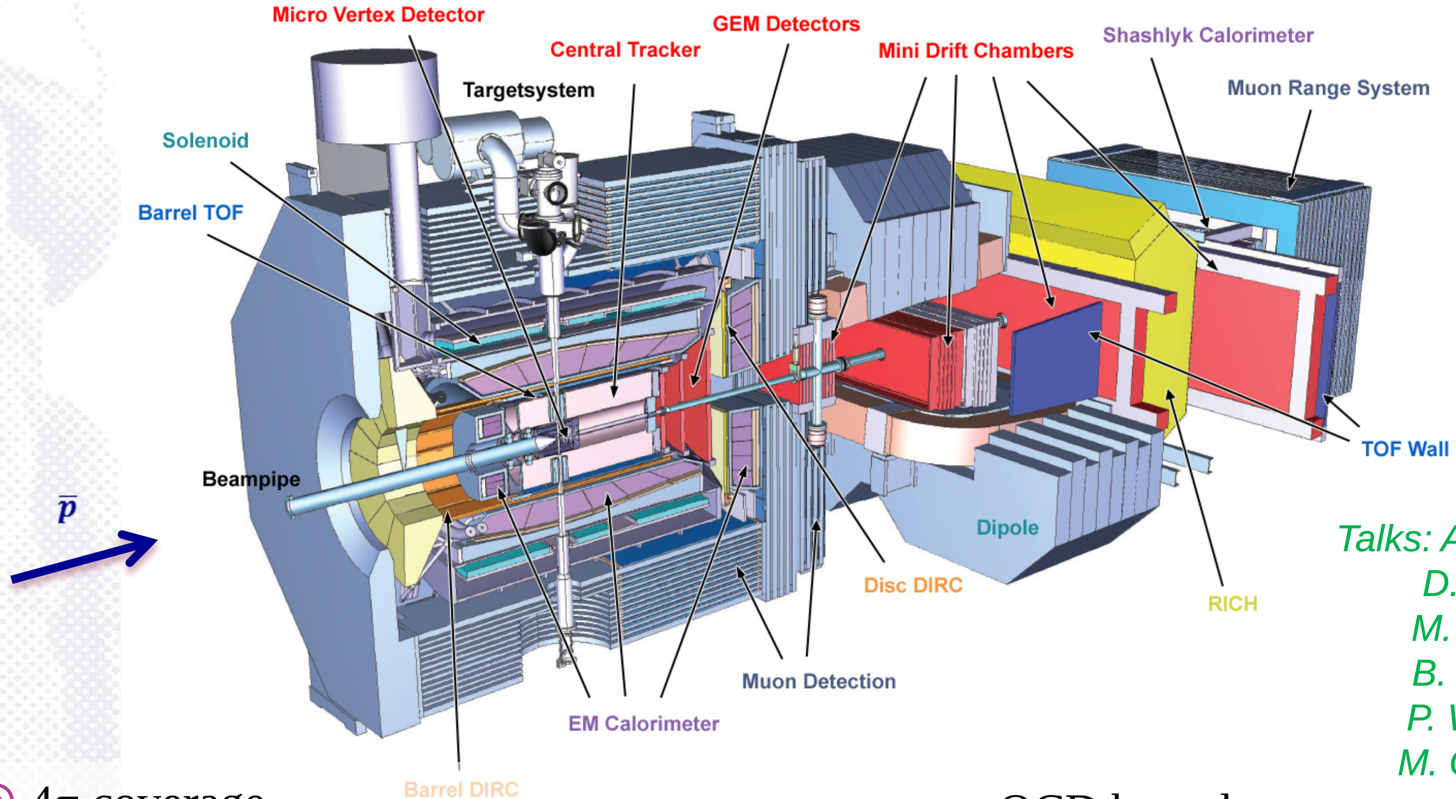
The FAIR facility



Module 0:
SIS100 and connection to existing GSI accel.
Module 1:
Experimental Areas
Module 2:
Super-FRS
Module 3:
High energy Antiprotons
(p-Linac, p- target, CR, HESR)

Talk. G. Rosner

The PANDA Spectrometer



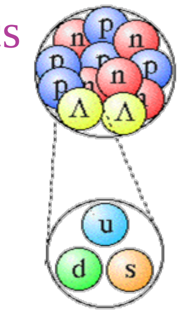
Talks: A. Gillitzer
D. Calvo
M. Maggiora
B. Kopf
P. Wintz
M. C. Mertens

- 4π coverage
- good PID
- high rates and momentum res.
- vertexing for D, Λ and K^0_s
- efficient trigger (no hardware trigger)
- modular design

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

Double Strange Systems as Laboratory

Hypernuclei provide a bridge between nuclear physics and hadron physics

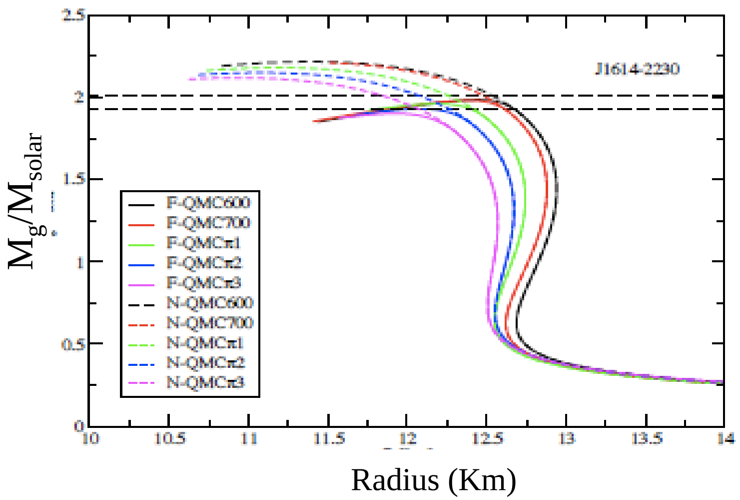


S = -2

- Study of ΛΛ Hypernuclei offers additional information about the Y-Y interaction ($\Delta B_{\Lambda\Lambda} \sim B_{\Lambda\Lambda} - 2\,B_{\Lambda}$)
- relevant for

➢ hyperons in neutron stars :
low masses and small radii
note : Exp. evidences of a 2 $m_{\odot}$ neutron star does not exclude hyperons in the EoS

J.R Stone, P.A.M. Guichon and A.W. Thomas



➢ existence of exotic quarks systems :
H- Particle

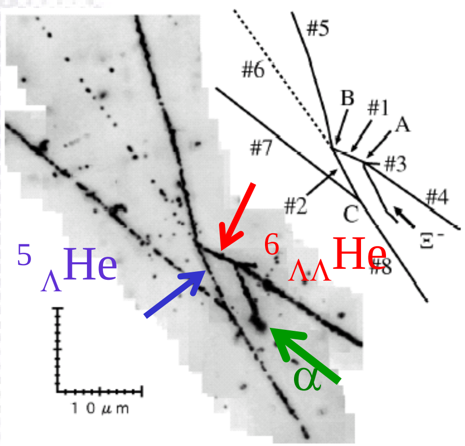
Talk. S. Olsen

The present nuclear chart

Present limitations

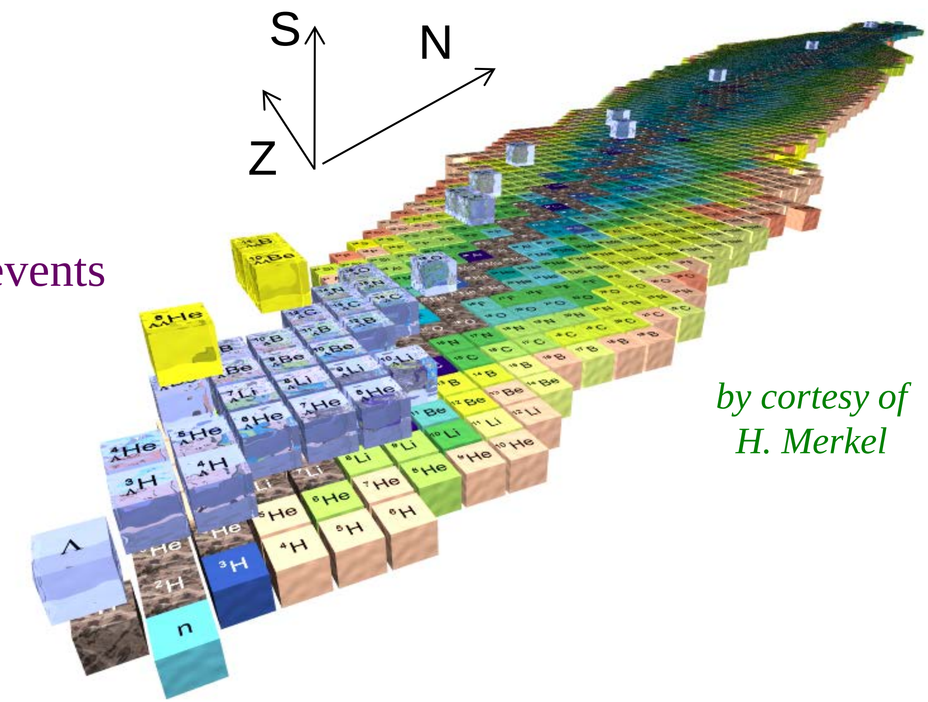
- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events

Nagara event



$^{12}C + \Xi \Rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$

$^{6}_{\Lambda\Lambda}He \Rightarrow {}^{5}_{\Lambda}He + p + \pi$



by cortesy of H. Merkel

$^{B}_{Y}X$

- number of baryons N+Z+Y
- element = total charge (not number of protons)
- (number of) hyperons Y

Production of ΛΛ- Hypernuclei

- coalescence of 2 Λ ⇒ heavy ions : (STAR, CBM, ALICE, HYPHI):
  ground state masses, lifetime

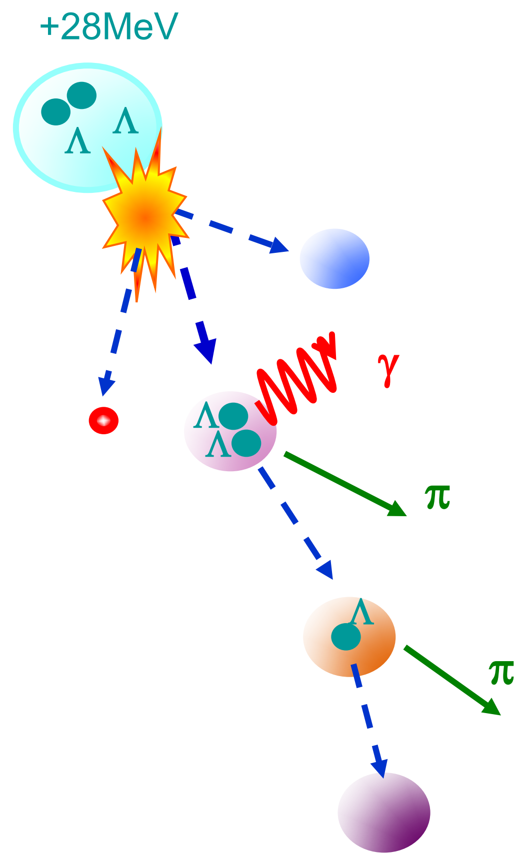
- Ξ^- (uss) conversion in two Λ (uds) : $\Xi^- + p \rightarrow \Lambda + \Lambda + 28\,\mathrm{MeV}$
  ⇒ large sticking probability in the same nuclear fragment
  - $K^- + p \rightarrow \Xi^- + K^+$ (KEK-E373/ E176 , AGS-E906, JPARC):
    lifetime, ground state masses
  - Antiprotons
    - at rest : $\bar{p} + p \rightarrow K^+ + \bar{K}^*$, $\bar{K}^* + p(n) \rightarrow \Xi^- + K_s^0$,
      $\bar{p} + {}^3He \rightarrow K^+ + K_s^0 + \Xi^- + p \rightarrow K^+ + K_s^0 + \Lambda\Lambda$,
      K. Kilian, Proc. 4th LEAR Workshop (1988) 529
      FLAIR : *FLAIR LOI, http://www-linux.gsi.de/~flair Talk: O. Karamyshev.*
    - in flight $\bar{p} + p \rightarrow \Xi^- + \bar{\Xi}^+$ or $\bar{p} + n \rightarrow \Xi^- + \bar{\Xi}^0$
      PANDA : level structure, ground state masses

- two-step process
  ⇒ spectroscopic studies only via the decay products

Decay Products of ΛΛ- Hypernuclei

- nuclear fragments ⇒ emulsion   hadron+nucleus
  - detection of charged products only
    ⇒no neutrons or γ
  - limited to light nuclei

Mass determination $M({}^{A}_{\Lambda\Lambda}Z) = M({}^{A-2}Z) + 2M(\Lambda) - B_{\Lambda\Lambda}$



Decay Products of ΛΛ- Hypernuclei

HELMHOLTZ
GEMEINSCHAFT
Helmholtz-Institut Mainz

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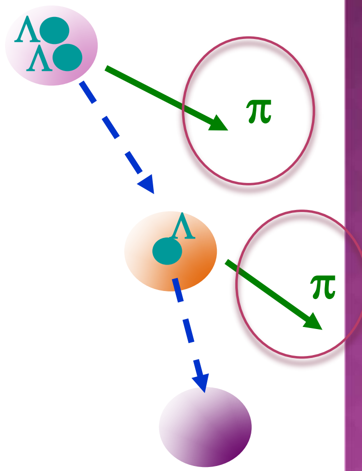
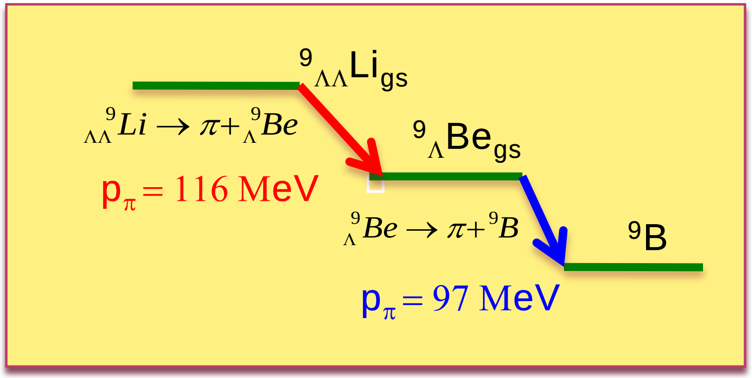
Mass determination $M(^{A}_{\Lambda\Lambda}Z) = M(^{A-2}Z) + 2M(\Lambda) - B_{\Lambda\Lambda}$

- sequential pionic decay ⇒ BNL-AGS E906 $^{9}Be(K^{-},K^{+})X$
  - two-body decay ⇒ monoenergetic momentum
  - no excited states information
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)
  - experimental resolution limited





panda

Decay Products of ΛΛ- Hypernuclei

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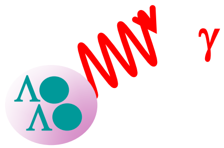
γ



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  - no excited states observed yet, but theoretically predicted

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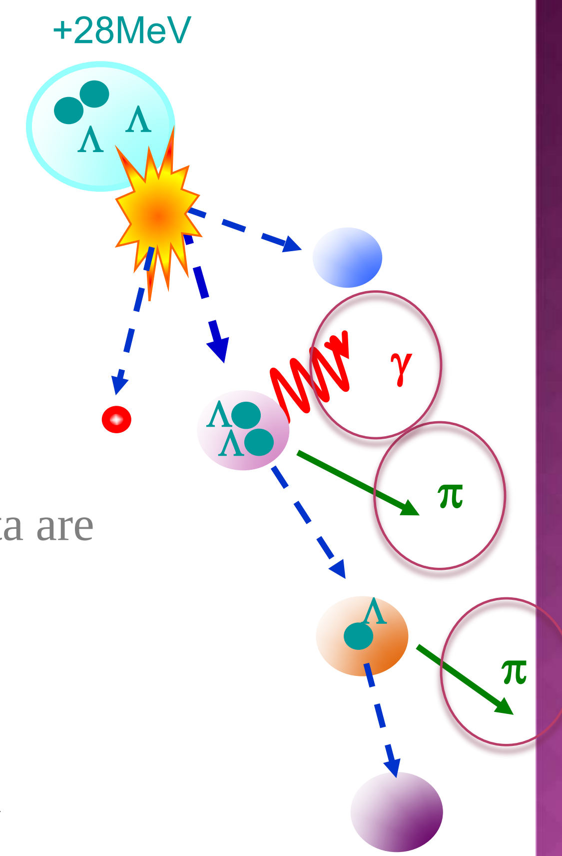
γ



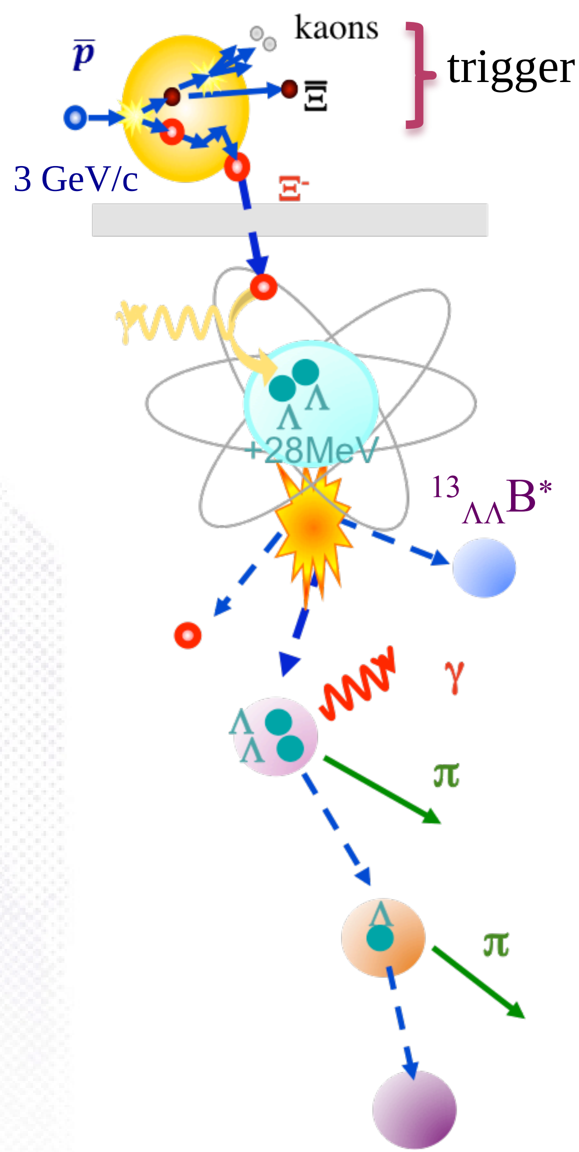
- sequential pionic decay ⇒ PANDA
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)

- γ- spectroscopy ⇒ PANDA $\bar{p}$+A
  - no excited states observed yet, but theoretically predicted

- Different nuclear targets (^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C):

⇒Each target offers a strategy for the unique assignment of observable transitions by comparing the expected yields

ΛΛ- Hypernuclei at Panda



$\bar{p}$ + ^{12}C → Ξ$^-$ + Ξ$^+$ + X

in a primary target

⇒ Slowing down, capture and conversion of Ξ

(Ξ$^-$+ p →Λ+Λ + 28MeV)

in a secondary active target.

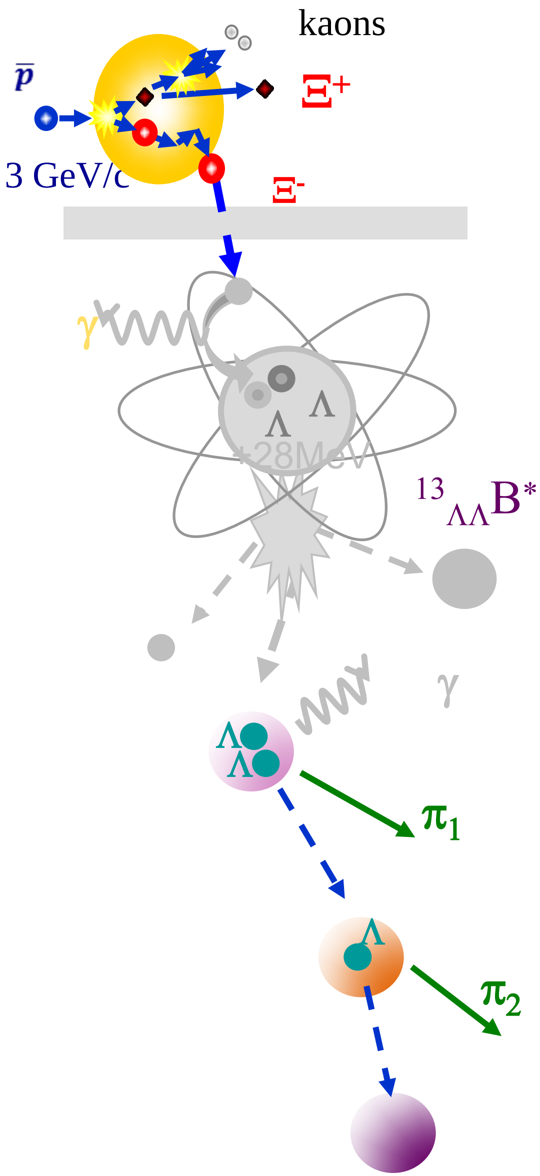
⇒ Statistical decay of slightly excited hypernuclei

⇒ Electromagnetic transition to g.s

⇒Sequential mesonic decay

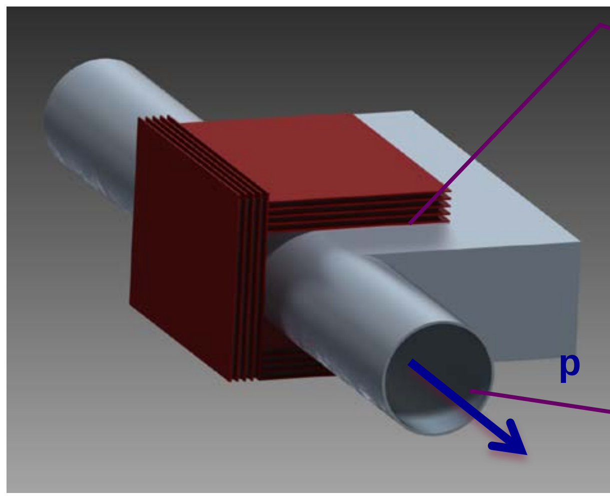
Need of a devoted detector setup

ΛΛ- Hypernuclei at Panda



$$\bar{p} + {}^{12}C \rightarrow \Xi^- + \Xi^+ + X$$

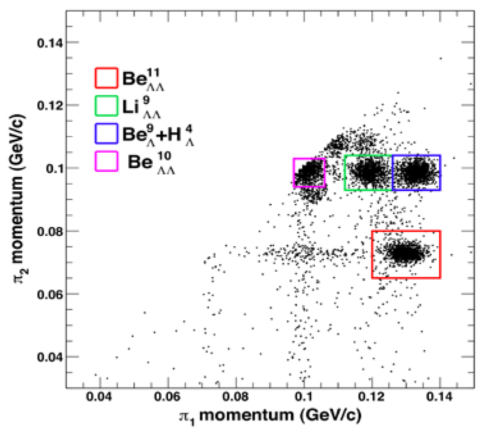
Active secondary target



Secondary target
Si μ–Strip +
Be,B,C absorbers

primary ^{12}C target

Very short life time of Ξ^-: τ = 0.164 ns
⇒ compact structure essential

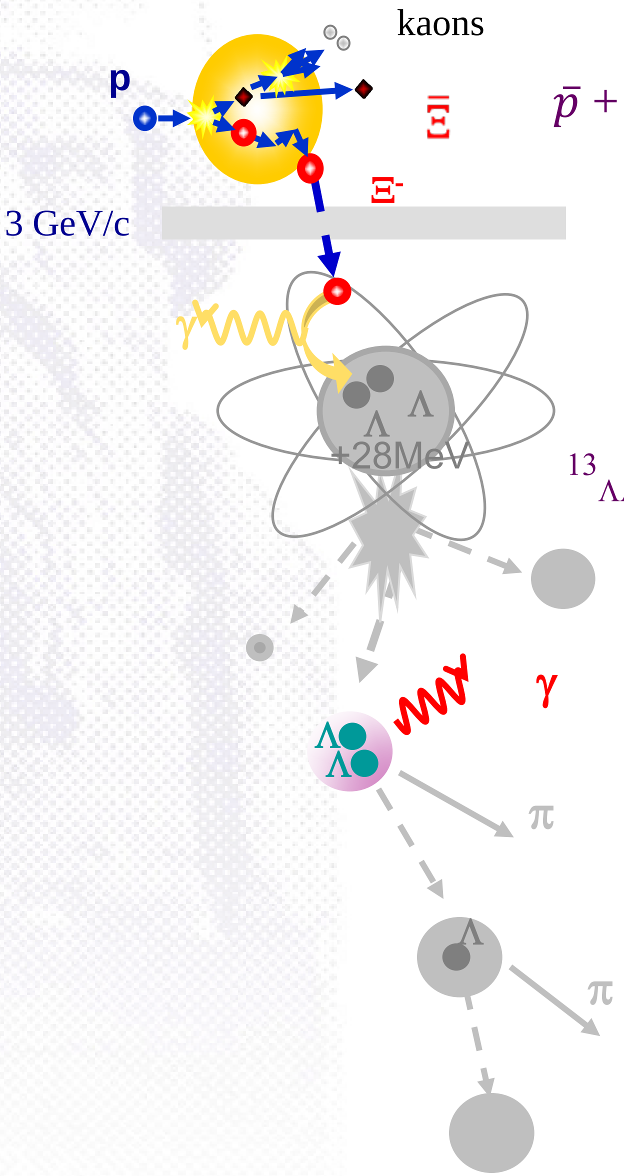


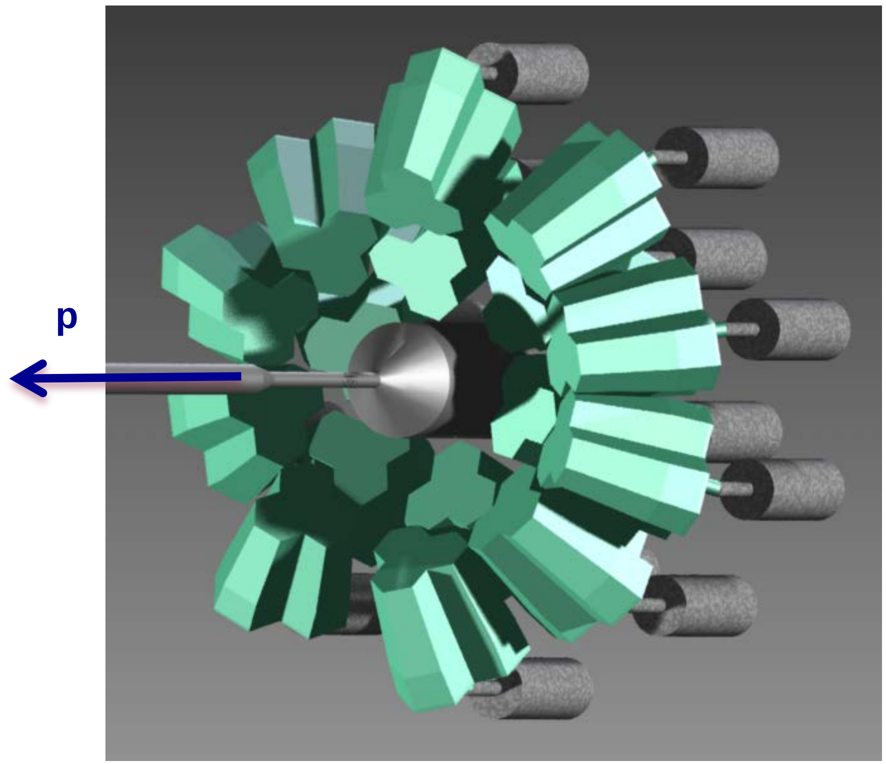
$\pi_1 + \pi_2$ correlation

ΛΛ- Hypernuclei at Panda

$\bar{p} + {}^{12}C \rightarrow \Xi^{-} + \Xi^{+} + X$

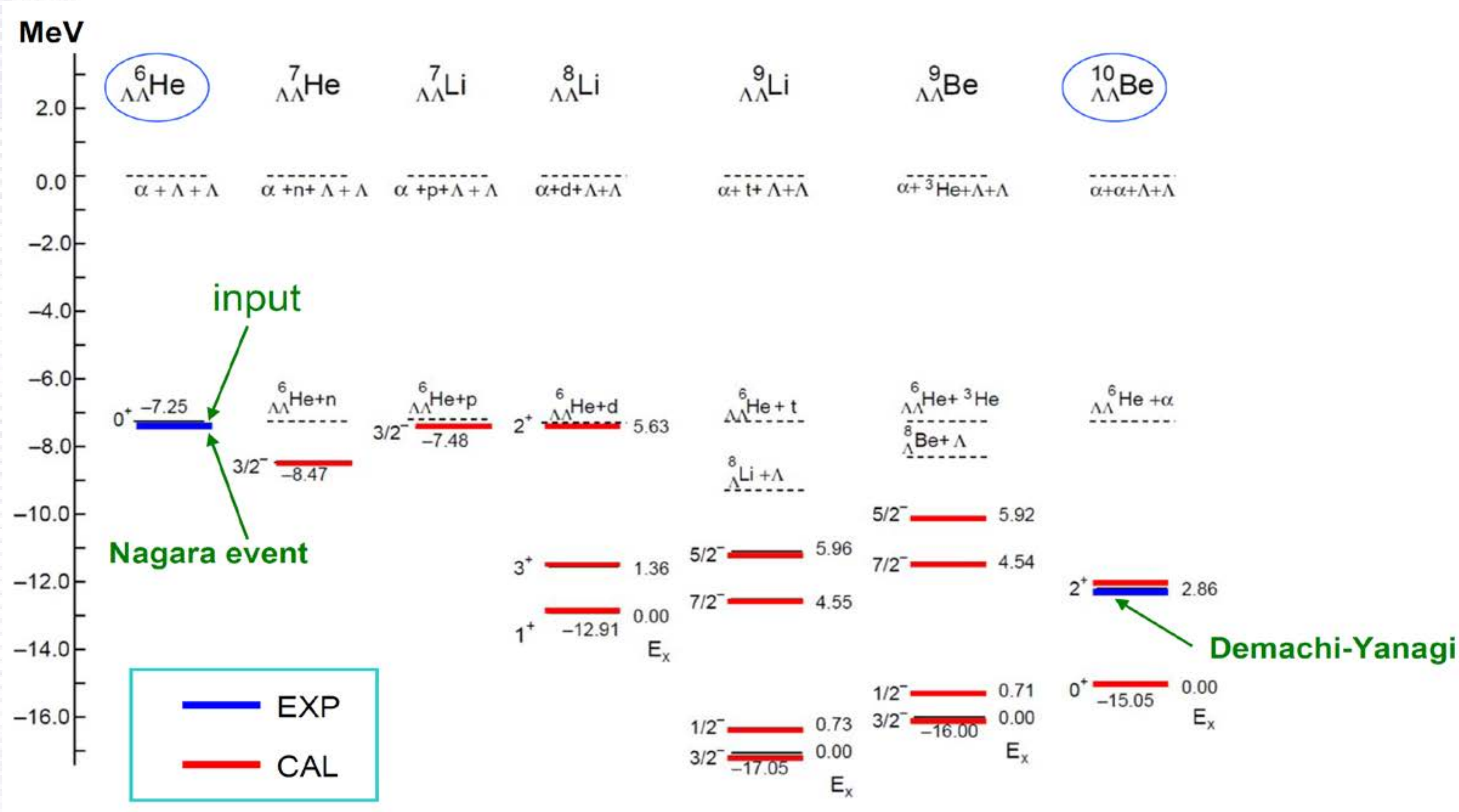
γ- Spectroscopy by using an "existing " array of HPGe





Excited states of ΛΛ- Hypernuclei

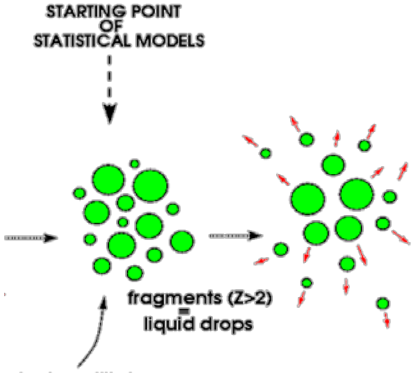
E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto Phys. Rev. 66 (2002) , 024007



- Many excited, individual excited, particle stable states of double hypernuclei have been predicted. *Talk E. Hiyama,,*

Statistical Decay of $^{13}_{\Lambda\Lambda}B^*$

- no excited states observed yet, but theoretically predicted
- What is the chance that individual excited, particle stable states of double hypernuclei are produced ?



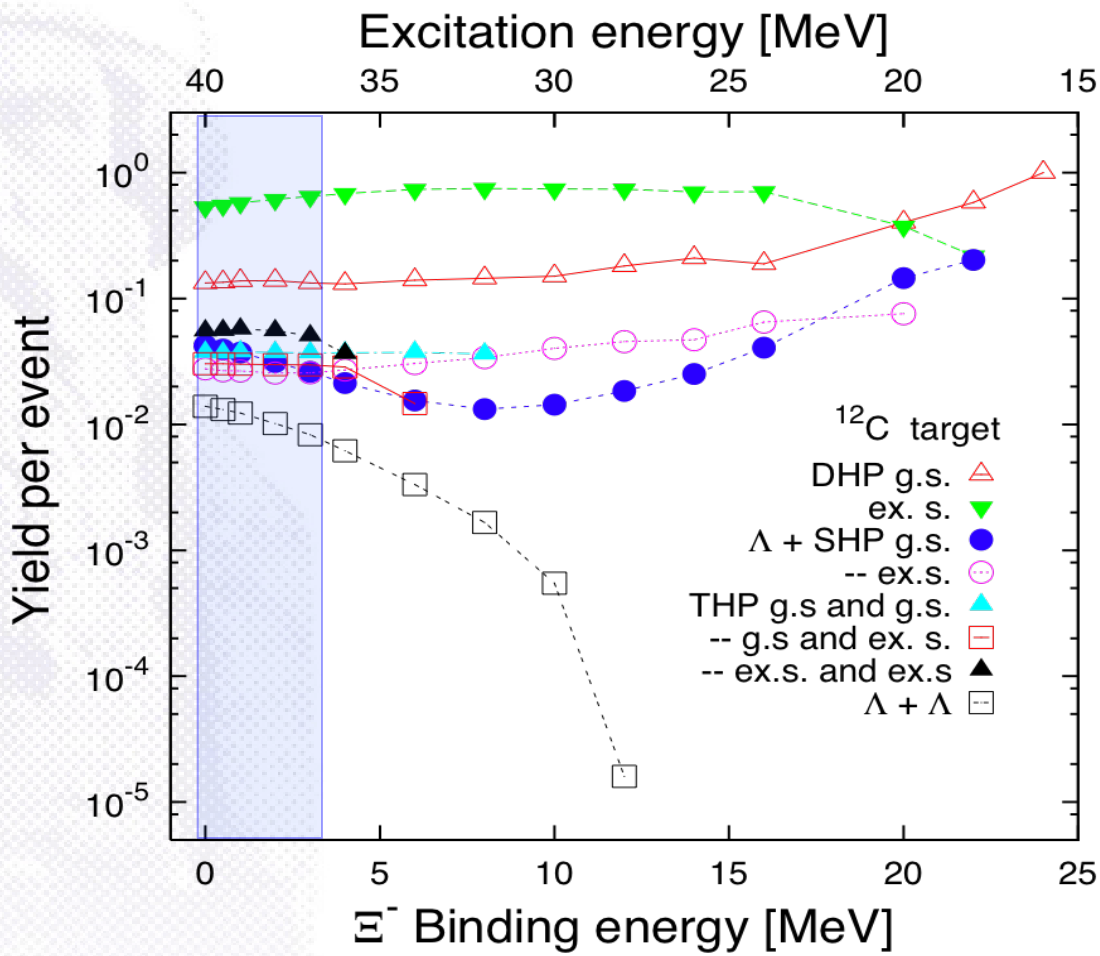
- conversion width $\Xi + p \Rightarrow \Lambda\Lambda$ around Γ=1MeV
- Ξ^- binding energy not precisely known

- Typical ex. energy ~ a few MeV/nucleon
- fragmentation of excited projectile remnants are well understood in that regime
  - De-excitation of light nuclei via Fermi break-up process
  - Conservation of A, Z, H, Energy and momentum

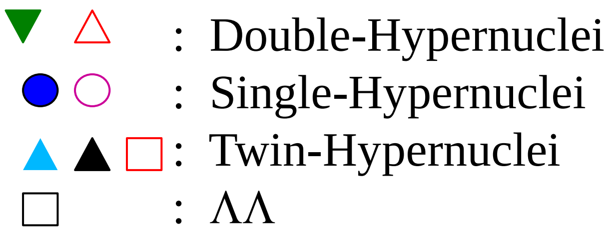
(A. Sanchez Lorente, A. Botvina et J.Pochodzalla, PLB 697 (2011) 222- 228)

Example : $\Xi^- + {}^{12}C \Rightarrow {}^{A+Z+H}_{\Xi}Z \Rightarrow {}^{13}_{\Lambda\Lambda}B^*$

Population of Excited States of $^{13}_{\Lambda\Lambda}B^*$



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

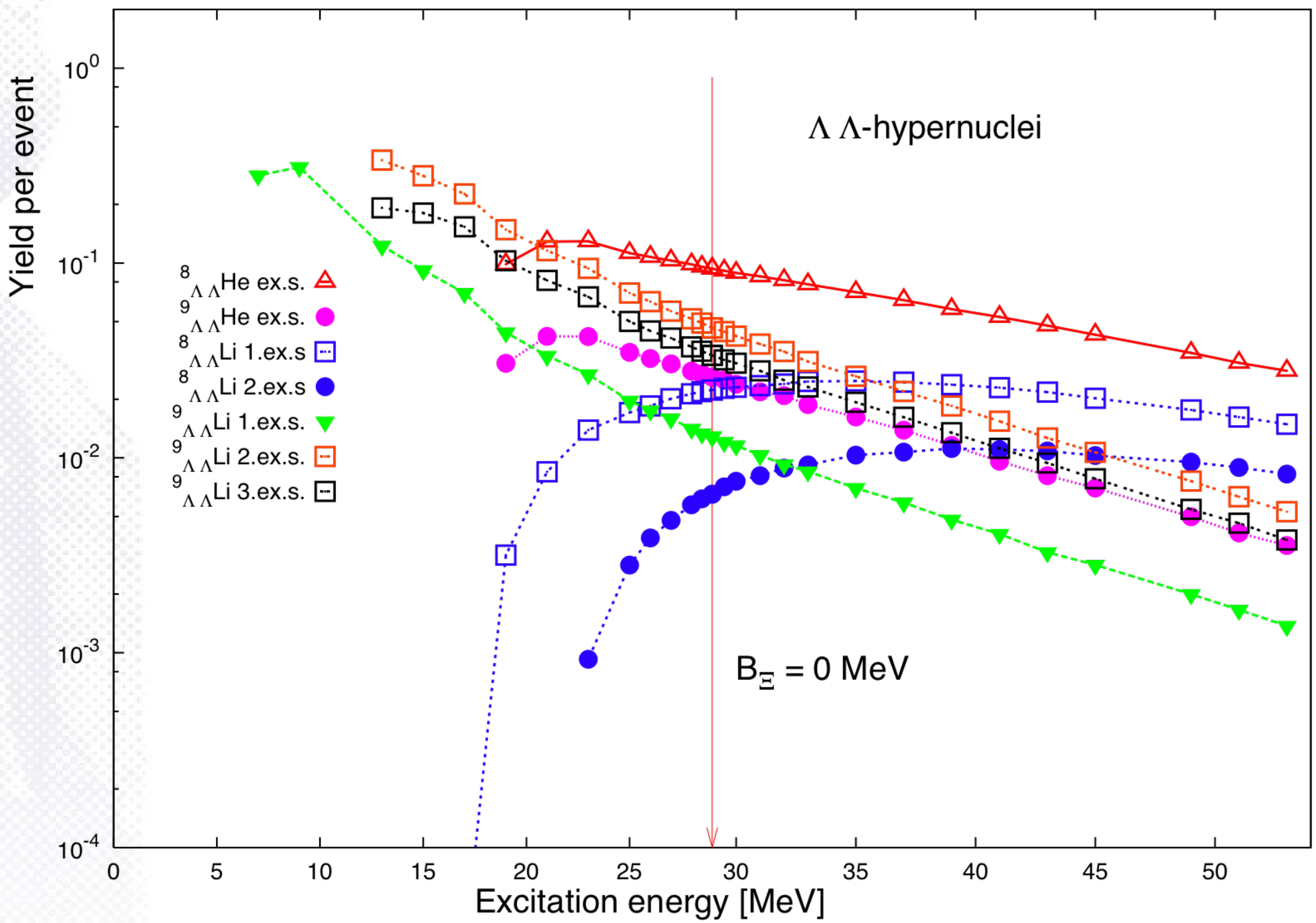


⇒production of excited states of Double Hypernuclei is significant

(A. Sanchez Lorente, A. Botvina et J.Pochodzalla, PLB 697 (2011) 222- 228)

Population of individual excited states

Example: $\Xi^- + {}^9\mathrm{Be} \Rightarrow {}^{10}_{\Lambda\Lambda}\mathrm{Li}^*$ $B_\Xi = 0$ MeV



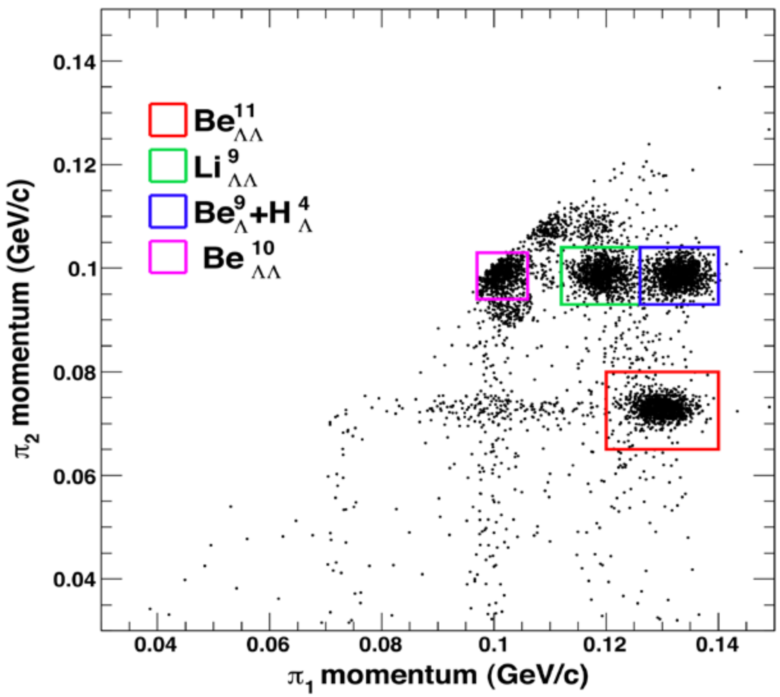
Relevant production of individual excited states

(A. Sanchez Lorente, A. Botvina et J.Pochodzalla, PLB 697 (2011) 222- 228)

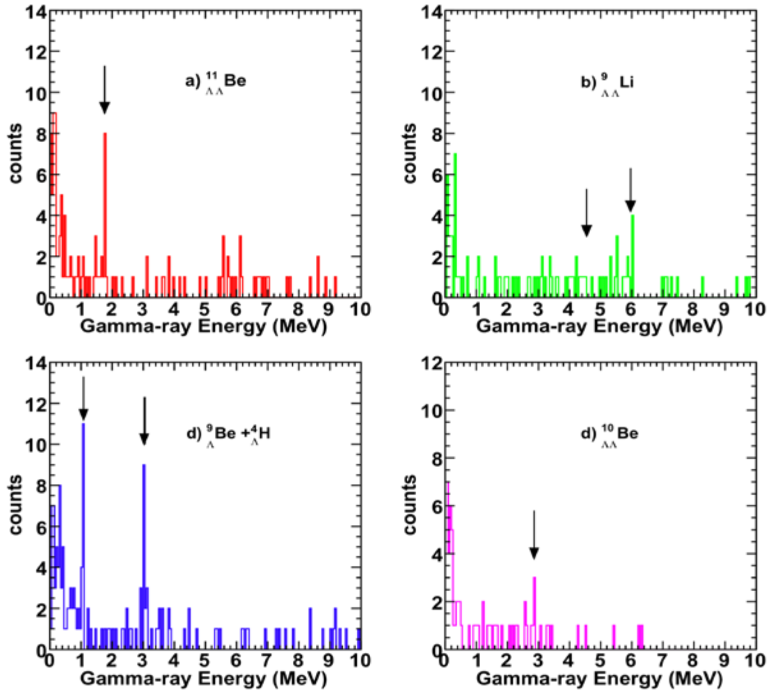
Identification of ΛΛ-Hypernuclei at PANDA

- Mesonic weak decay of the order of 10% of the total width
- Sequential mesonic decay of DHP releasing 2 pions
- 50 % data taking available
- Example: secondary ^{12}C target. Present Statistics runnig period ~ 2 weeks. Prob. Ξ Capture and Conversion ~ 5%. *(arXiv:0903.3905)*

π + π correlation



γ Energy spectra



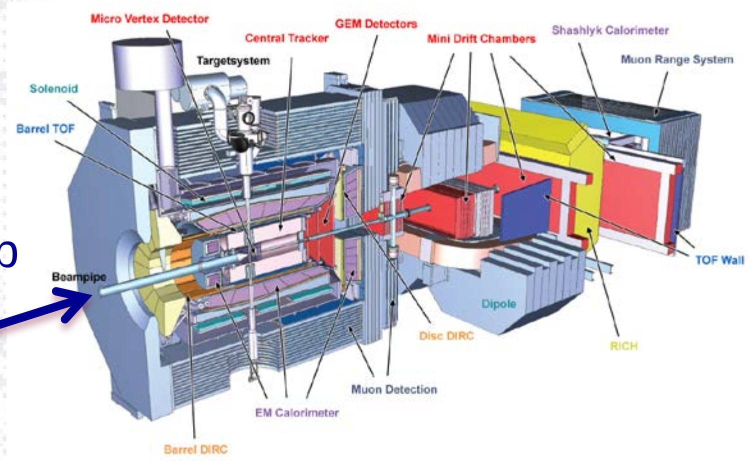
Detector developments

- Integration in the PANDA spectrometer
  - Space limitation
  - High magnetic field
  - Large hadronic background

- The primary target
- The Secondary Active target
- The HPGe Array

Dedicated beam pipe / target system

p



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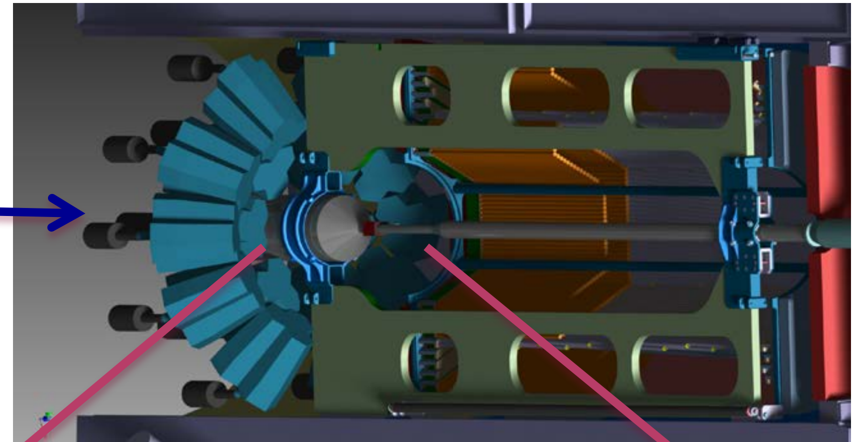
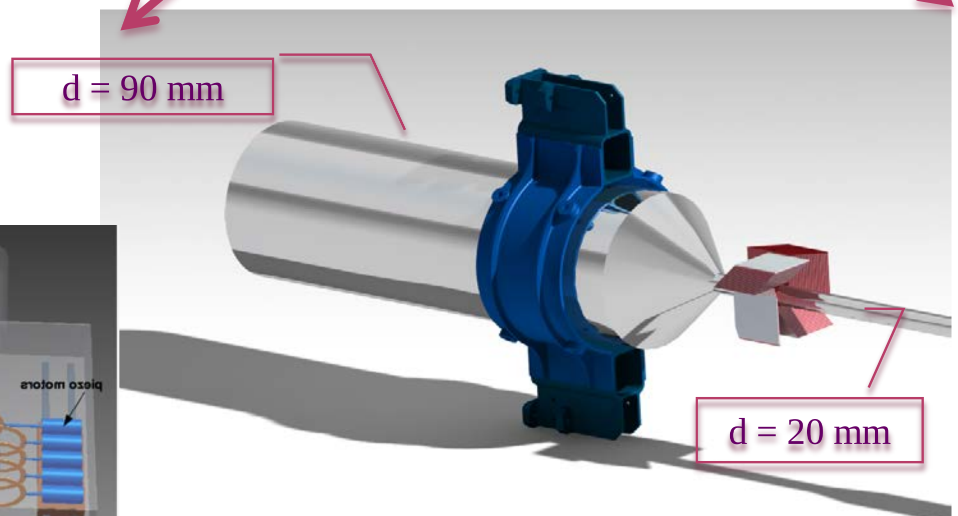
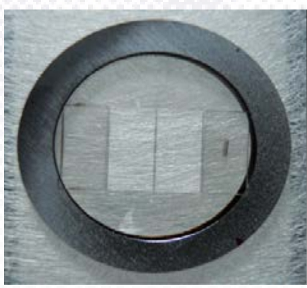
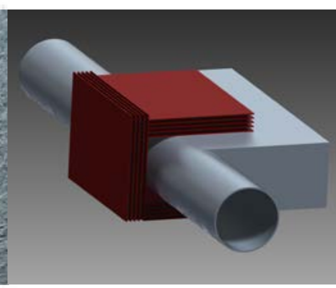


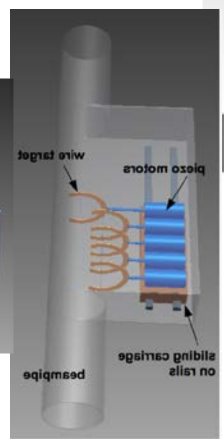


Backward End Cap Calorimeter and MVD will be not used

- Modular structure
- Dedicated beam pipe/target system







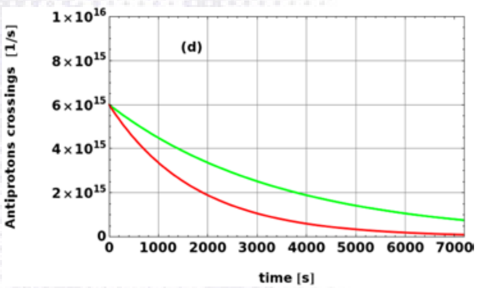
by cortesy of D. Rodriguez, M. Steinen, F. Iazzi and S. Bleser

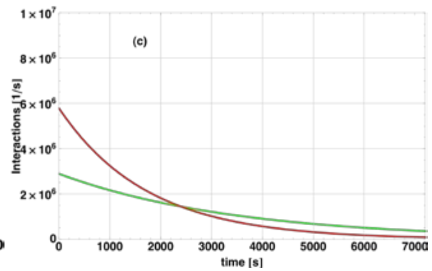
Primary target system

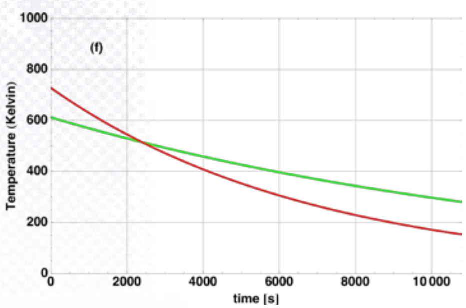
Large Production rate

- Average pbar rate 10^7
- beam losses -> Coulomb scattering
  ->thin target d = few μm

3 X 10^{6} pbar/s -> stable behaviour of luminosity + target stability

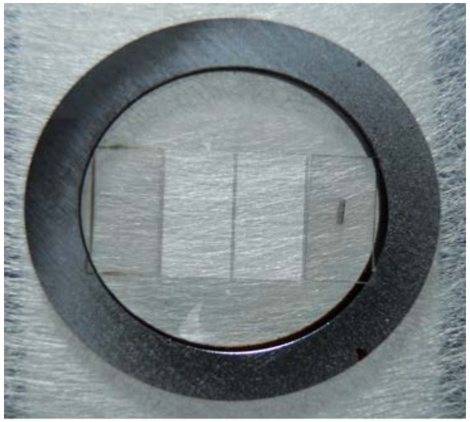




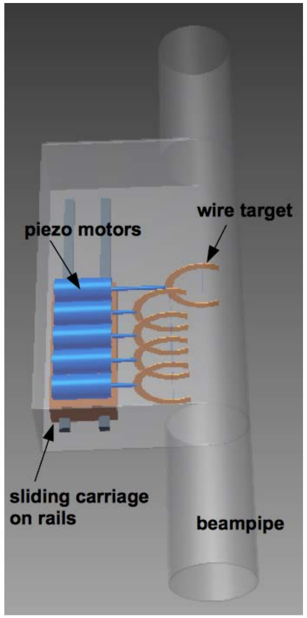


Insertion of the wire target (3 μm)into the beam pipe

- Piezo-motors
- steering of beam and target

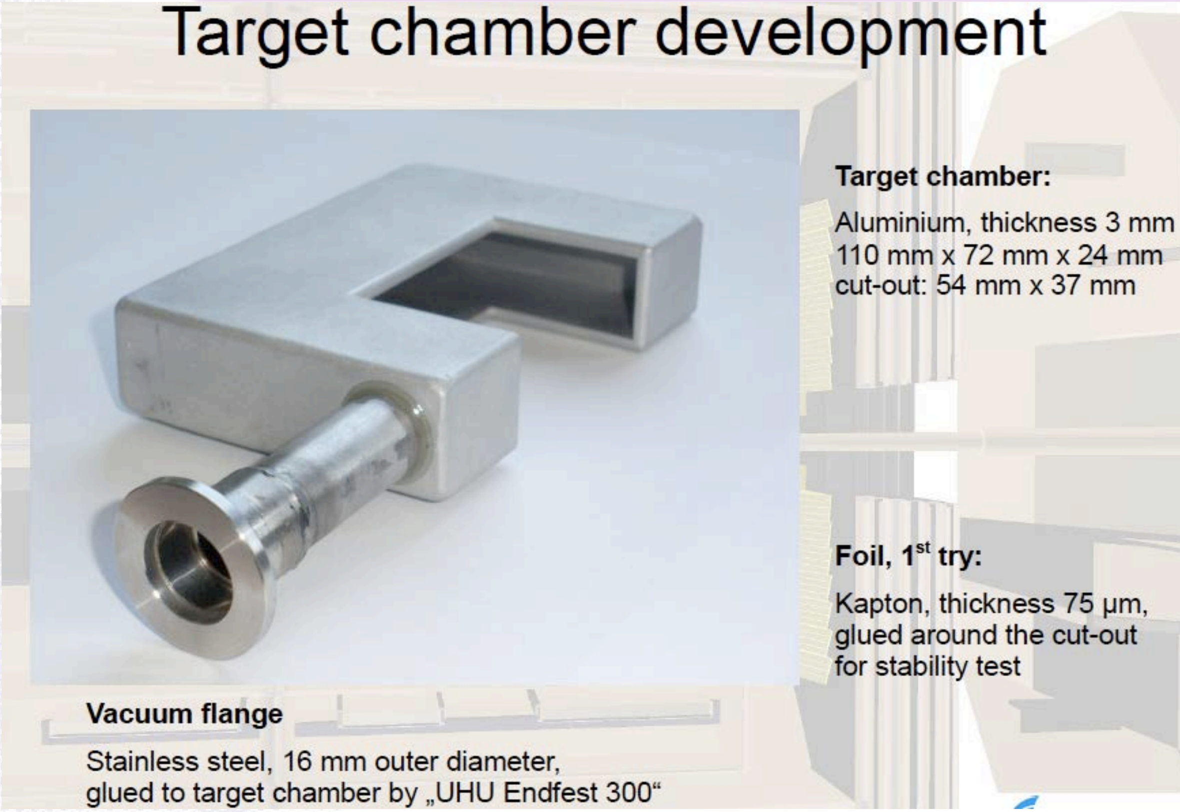


14 mm



by cortesy of F. Iazzi and S. Bleser

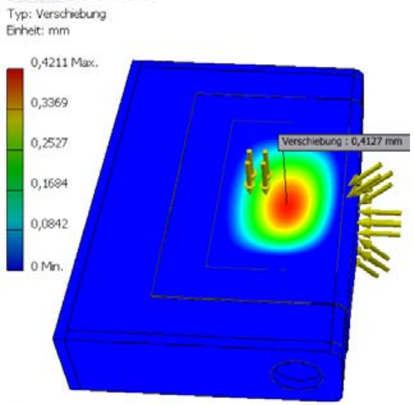
Primary target system



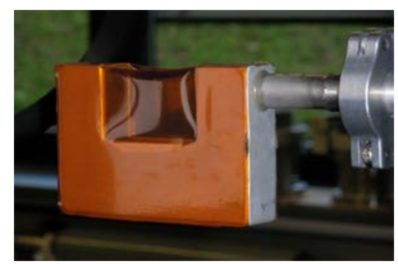
First evacuated target chamber model with a thin wall thickness in the sensor area for less Ξ^- stopping:

75 µm Kapton foil glued on an aluminium frame

→ further stabilization necessary



Finite element analysis
of a 0.5 mm thick titan disk
on an aluminium frame



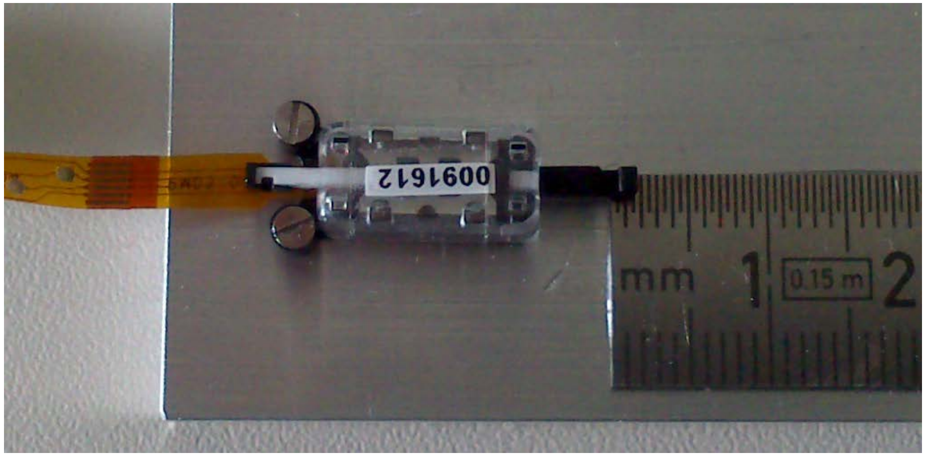
by cortesy
S. Bleser

Primary target system

First piezo motor for tests:

PiezoWave Linear 0.1 N

Manufacturer: PiezoMotor Uppsala AB



<u>Specifications:</u>

Stroke max: 8 mm

Maximum speed: 50 - 100 mm/s

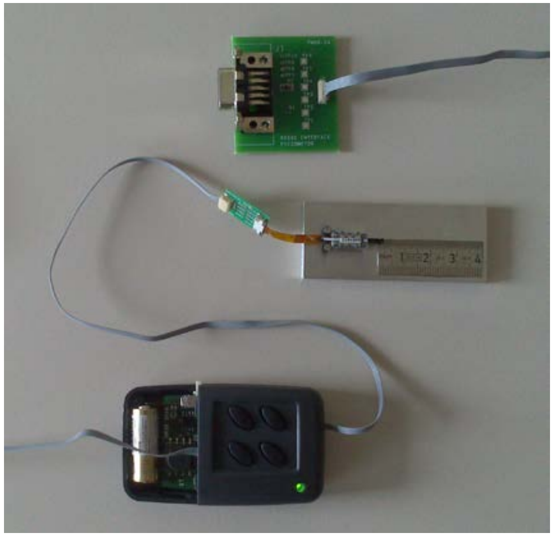
Average step: 0.5 - 1.0 µm

Dynamic force: 0.1 N

Holding force: 0.3 N

Weight: 0.5 g

Size: 14.0 mm x 7.2 mm x 4.4 mm

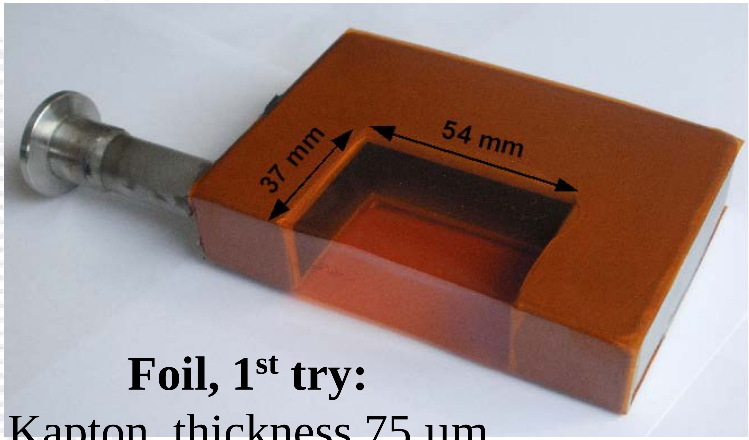


Experimental tests:

The PiezoWave is operated by the Starterkit Demo-Wave-10 and works as expected.

→ Next step: vacuum integration and performance tests

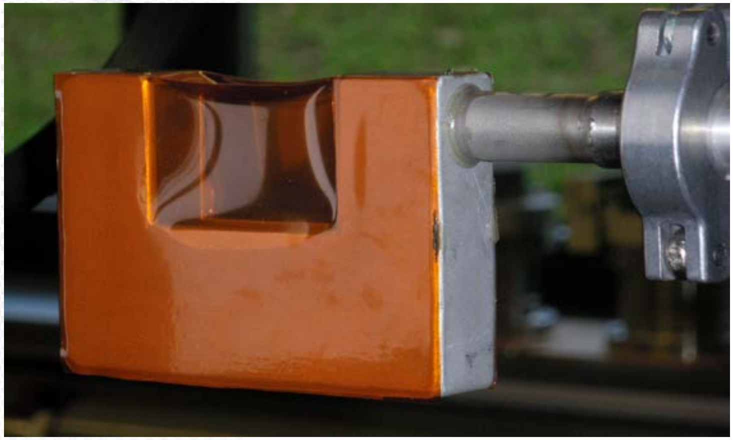
Primary target system



Foil, 1st try:
Kapton, thickness 75 µm

Foil, 2nd try:
Brass,
thickness 200 µm

Stability tests in vacuum:



by cortesy
S. Bleser

- Kapton foil did not tear but is highly bent to the inside (≈ 7 mm per side)
  → not applicable
- Maximum bending of brass foil ≈ 1.3 mm
  → but brass not practical for high vacuum

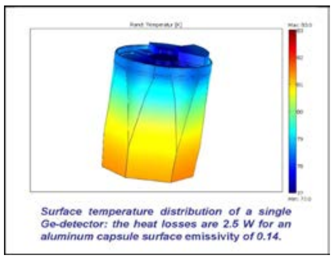
-> further thicknesses and materials for tests (titanium, AlMg, fiber reinforced plastics) and tests of material fatigue

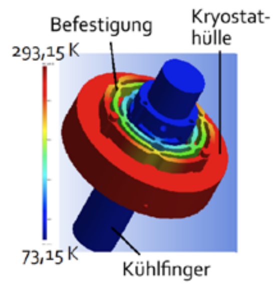
Toward a prototype of HPGe Cluster Array

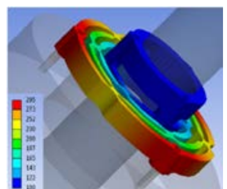
- Limited space :

  Recent activities : X- Cooler system
    - Influence on Ener. Resolution
    - cooling efficiency for a double and triple cluster detector.

HPGe encapsulated crystal attached to the X-Cooler







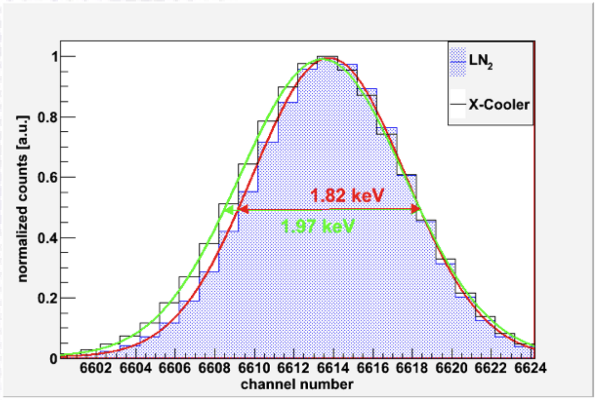
- Ongoing activities: High Rate environment:
  - Radiation Damage studies with a prototype
  - Pile-Up effects
  - Pulse shape analysis

by cortesy of M. Steinen and I. Kojoujarov

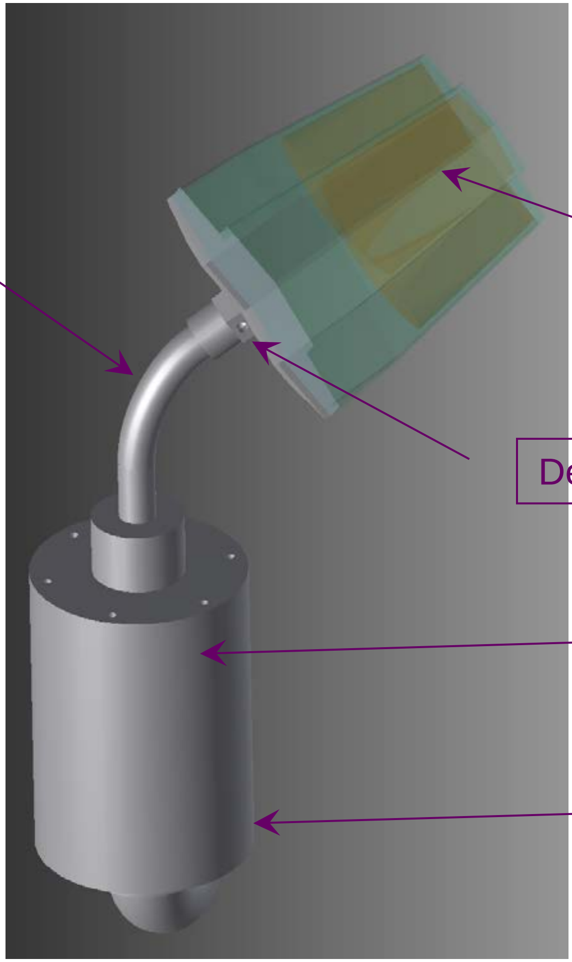
Further considerations concerning the X-Cooler

Flexible cold finger and flexible cold finger tube. Allows full use of the space available for detectors.

Influence of X-Cooler device on the energy resolution



by cortesy of M. Steinen and I. Kojoujarov



Encapsulated HPGe . crystals

Detector Head fixing.

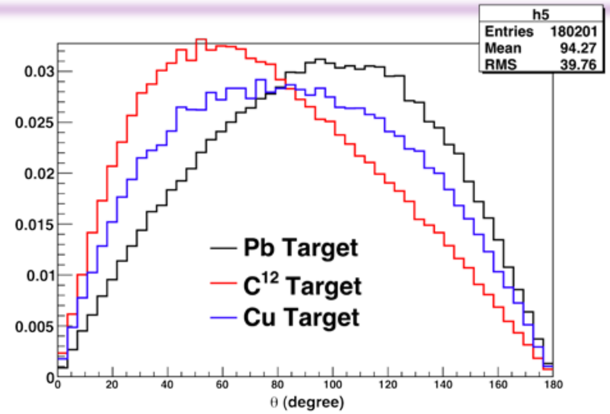
Electronics chamber

X-Cooler Head, partiallly hidden inside the electronics chamber

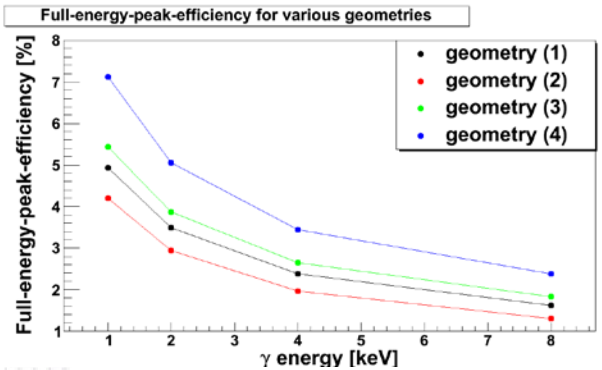
Optimization of the geometrical acceptance

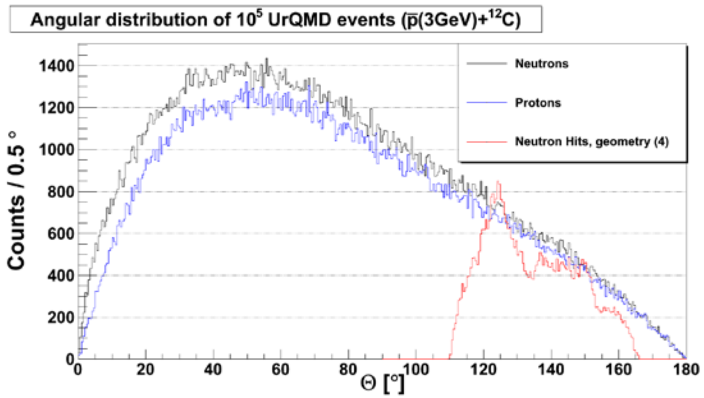
- Effect of hadronic background
  from primary interaction
  at backward angles

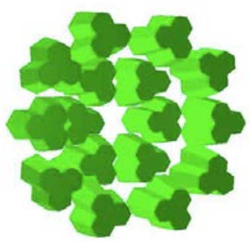
  by cortesy of M. Steinen

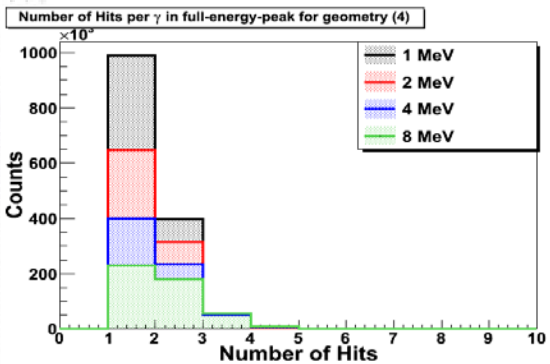


(4





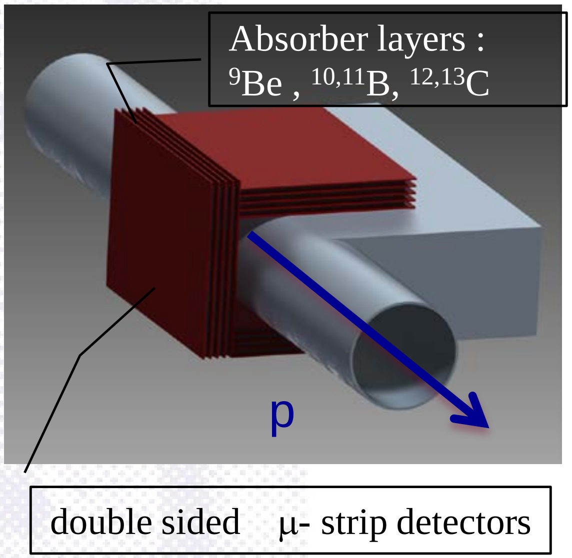


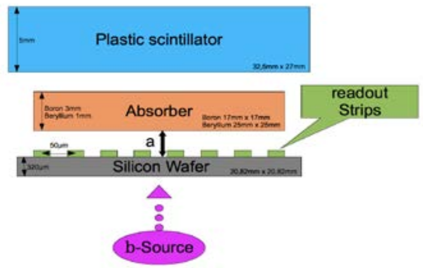


- Exposure of the germanium crystals to the high hadronic environment, mainly thermal neutrons, which is simulated using UrQMD.
  The maximum neutron load per crystal for geometry (4) is 12 kHz. At the expected reaction rate of $2 \cdot 10^6$ Hz this results in $3.4 \cdot 10^9$ n/cm^2 after 100 days of irradiation with a duty cycle of 0.5.

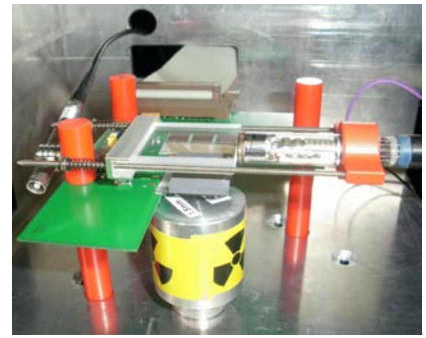
The Secondary Active Target

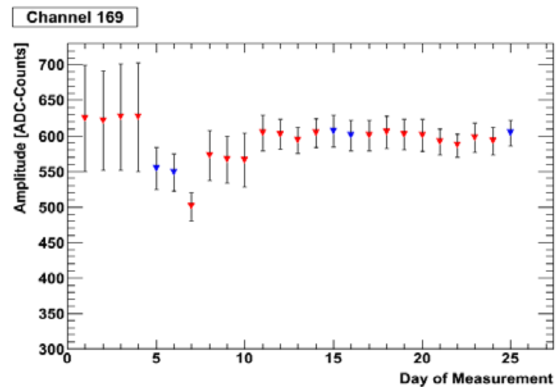
- Compact Structure of detector and absorber:
  - Performance of Silicon Strips Detector in direct contact with absorbers





by cortesy of S. Bleser





- Ongoing projects:

  Space required for frontend electronics:
  - Minimization of additional material budget on detecting volume:
  - Ultra-thin Al-Polyimide readout cables

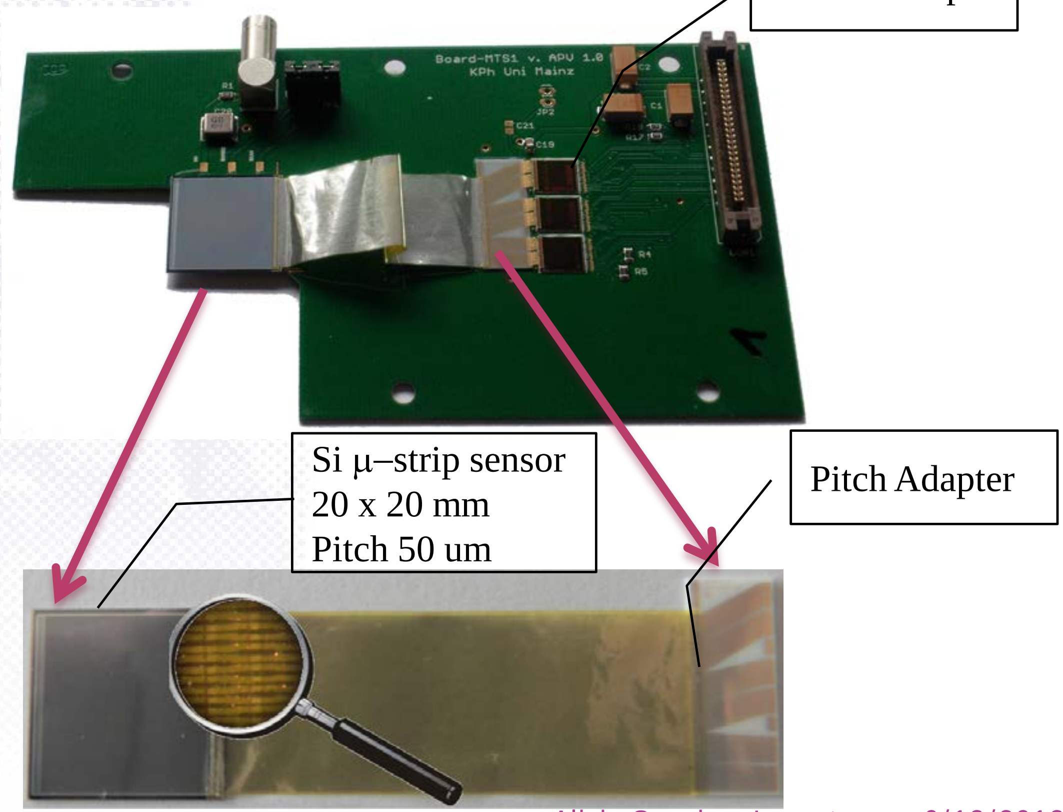
  J.M. Heuser et al. HadronPhysics2/JRA-ULISI

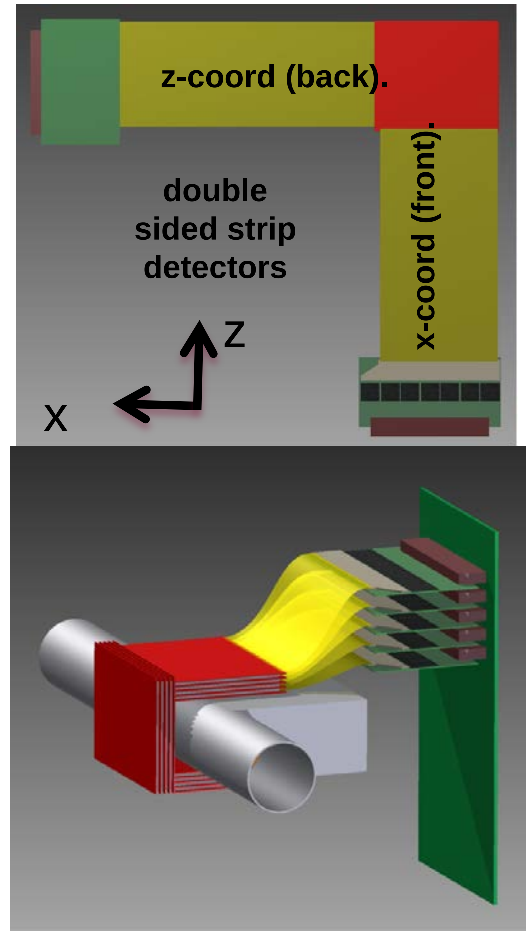
Effect of microcables on detector analog signals

by cortesy of S. Bleser and SERSTII

- Secondary Active Target :
  - Fan out of the readout electronics.
  - Sensors and readout boards connected by Ultra-thin microcables via TAB bonding.

- Readout boards hosting pitch adapter, frontend chips and connector.

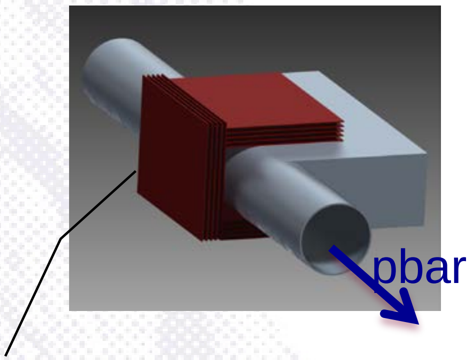




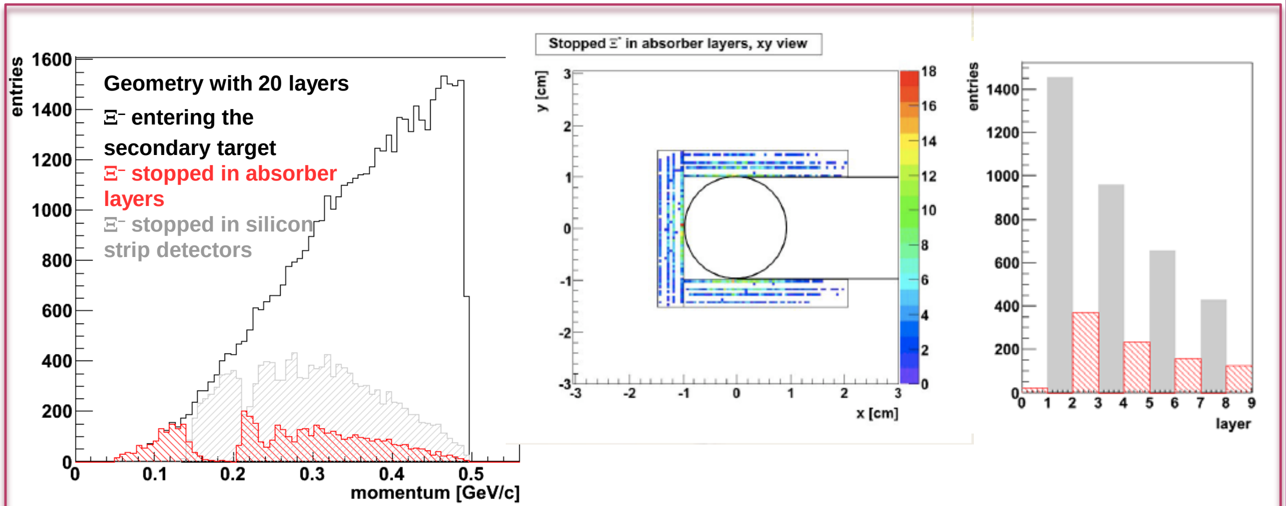
Detector performance

- **Compromise between tracking capabilities and stopping power**:
  - Momentum distribution of stopped Ξ in the secondary active target

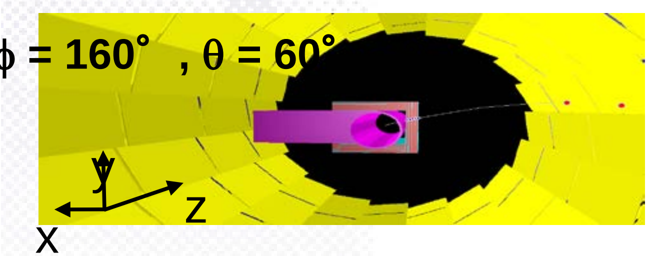
by cortesy S. Bleser

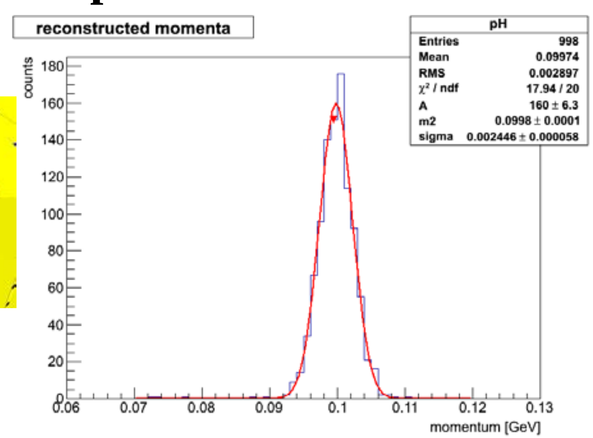


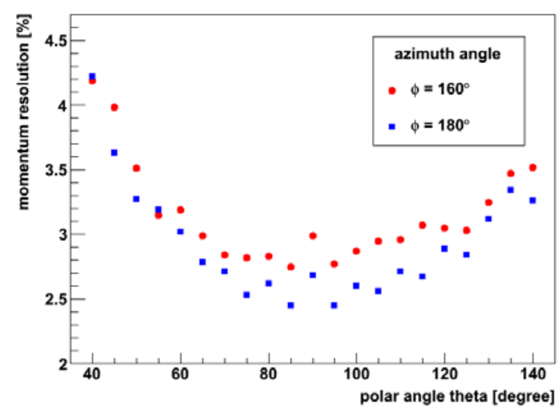
double sided μ- strip detectors



- **Tracking of low momentum pions**





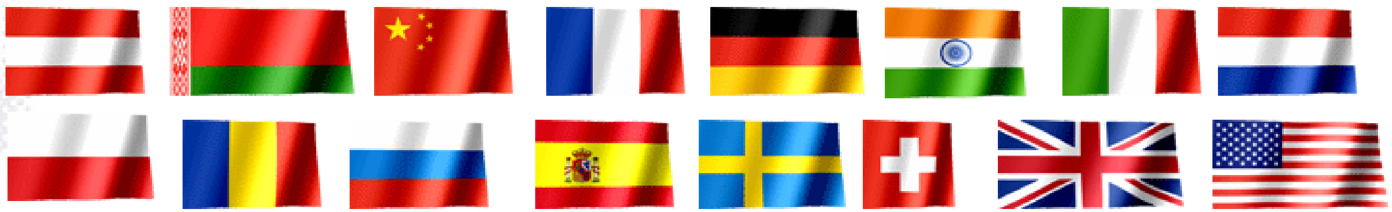


Summary

- Hypersystems provide a link between traditional nuclear physics and hadron physics
- They allow to study basic properties of strongly interacting systems
- Antiproton collisions with nuclei are the ideal tool to produce exclusive cascade-anticascade pairs in nuclei at moderate momenta
- A statistical model predicts a large probability for the population of individual, excited states in double Λ hypernuclei
- Need for a devoted detector setup inside the PANDA spectrometer.
- γ-spectroscopy of these double hypernuclei at PANDA seems therefore feasible

THE PANDA COLLABORATION

More than 400 physicists from 53 institutions in 16 countries



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IHEP Beijing
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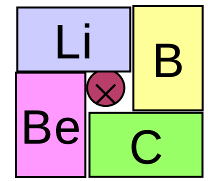
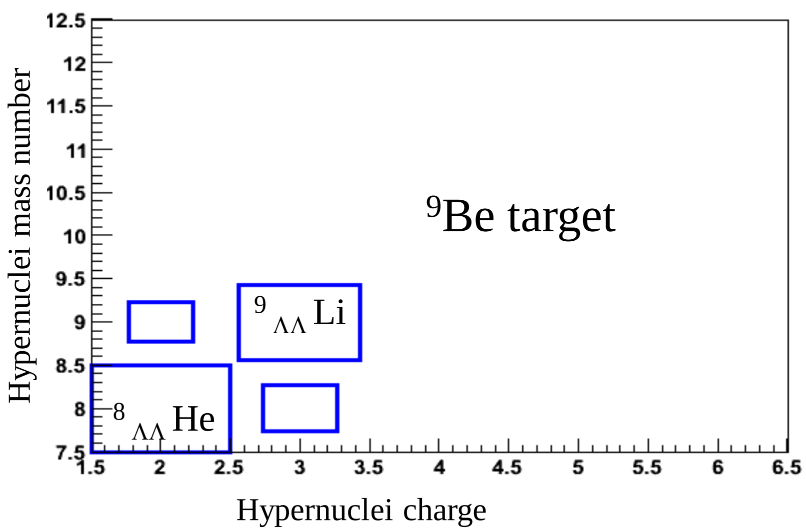
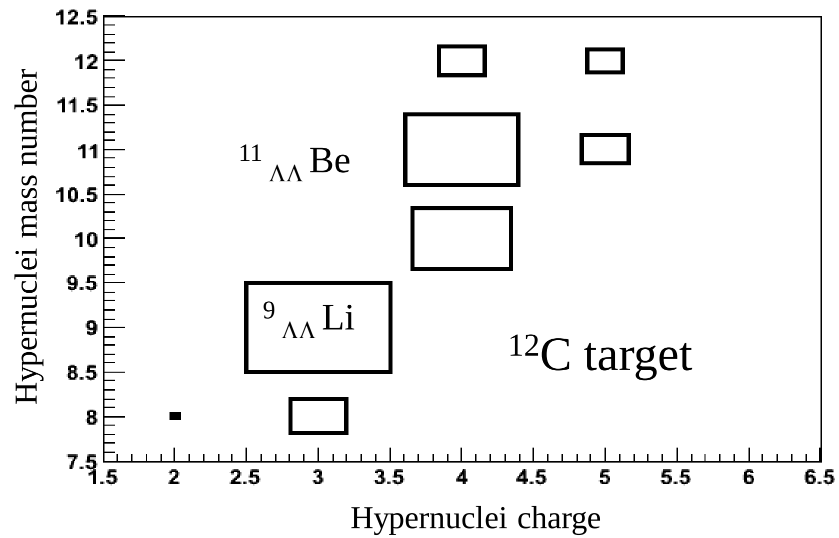
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

Identification of ΛΛ-Hypernuclei

- PANDA will explore several secondary targets: ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C
  - Sum of excited states
  - B_{Ξ} = 0.5 MeV
  - Sequential pionic decay prob. ≈ 0.45 - 0.03A
  - Prod. prob x Pionic Decay prob.



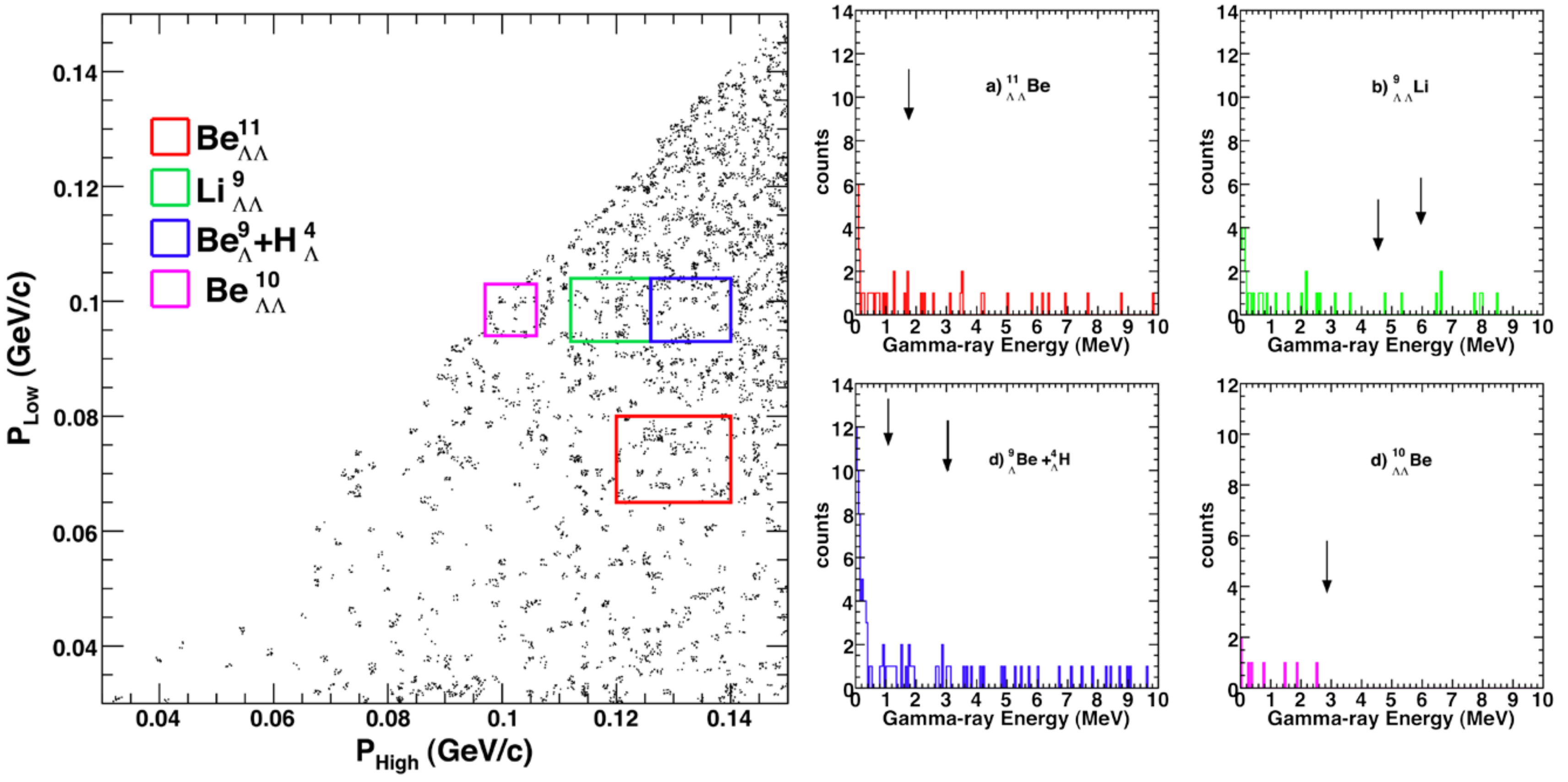




⇒Each target offers a strategy for the unique assignment of observable transitions by comparing the expected yields

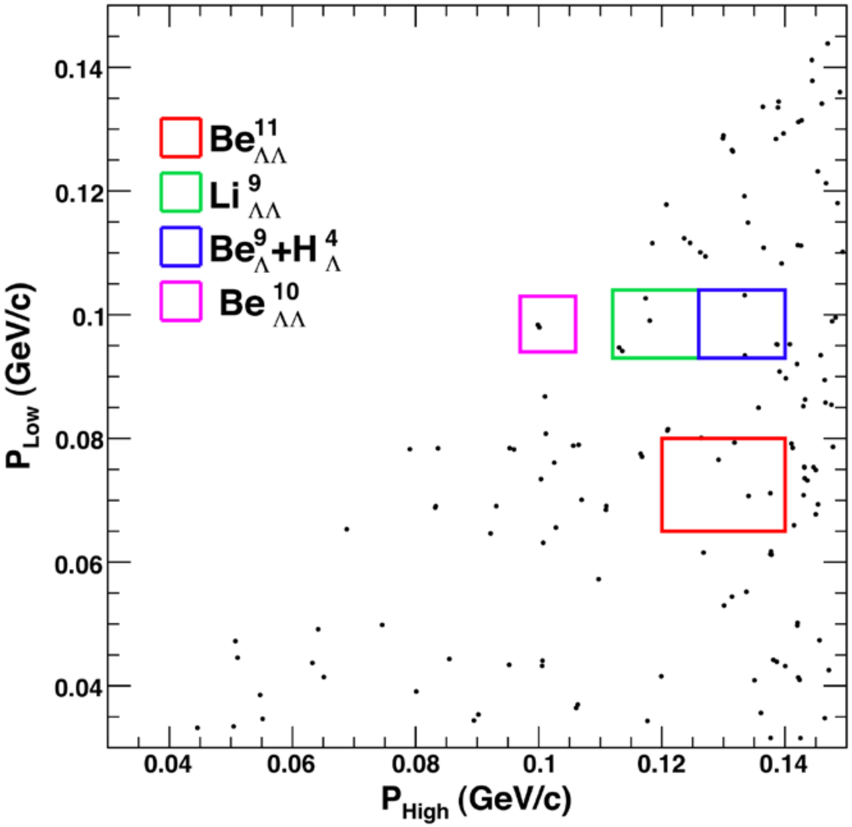
Free Ξ⁻+Ξbar background contribution

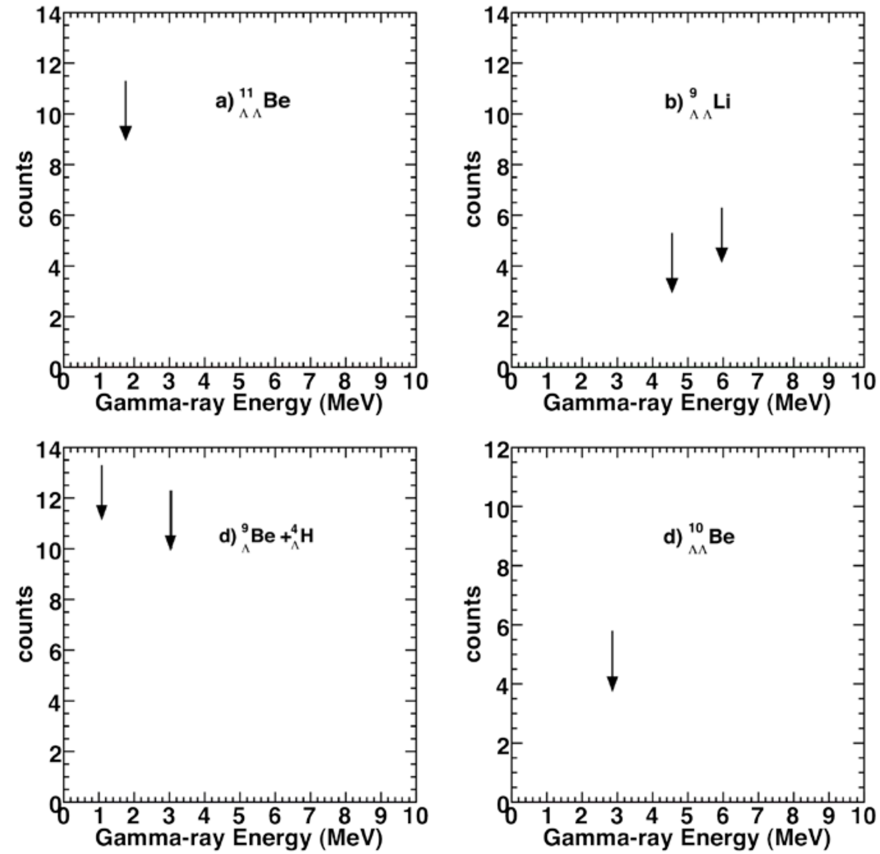
- The background of Ξ free decay and Ξ^+ annihilation



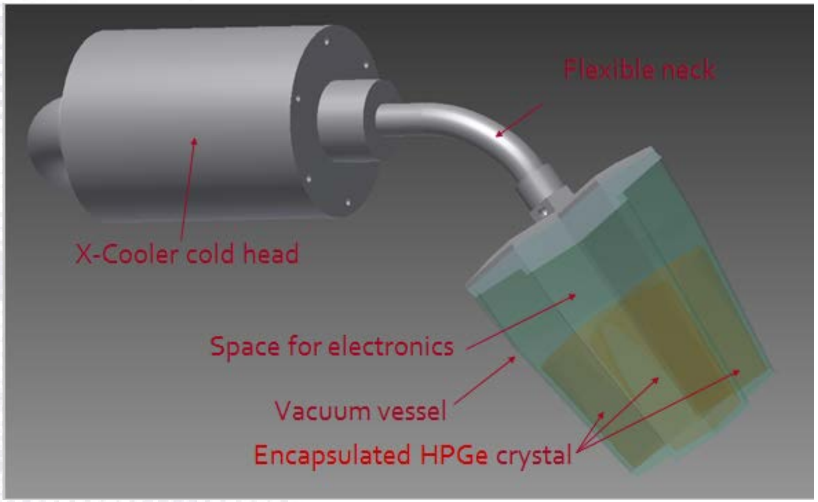
p + ^{12}C background contribution

- More statistic is needed





Further considerations concerning the X-Cooler



X-Cooler Head, partiallly hidden inside the electronics chamber

by cortesy of M. Steinen and I. Kojoujarov

Prototype for a single Euroball Crystal cooled electromechanically