Hypernuclear Physics at Panda
Experimental Challenges

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with contributions from other PANDA groups

Sept. 2o11

The hypernuclear landscape

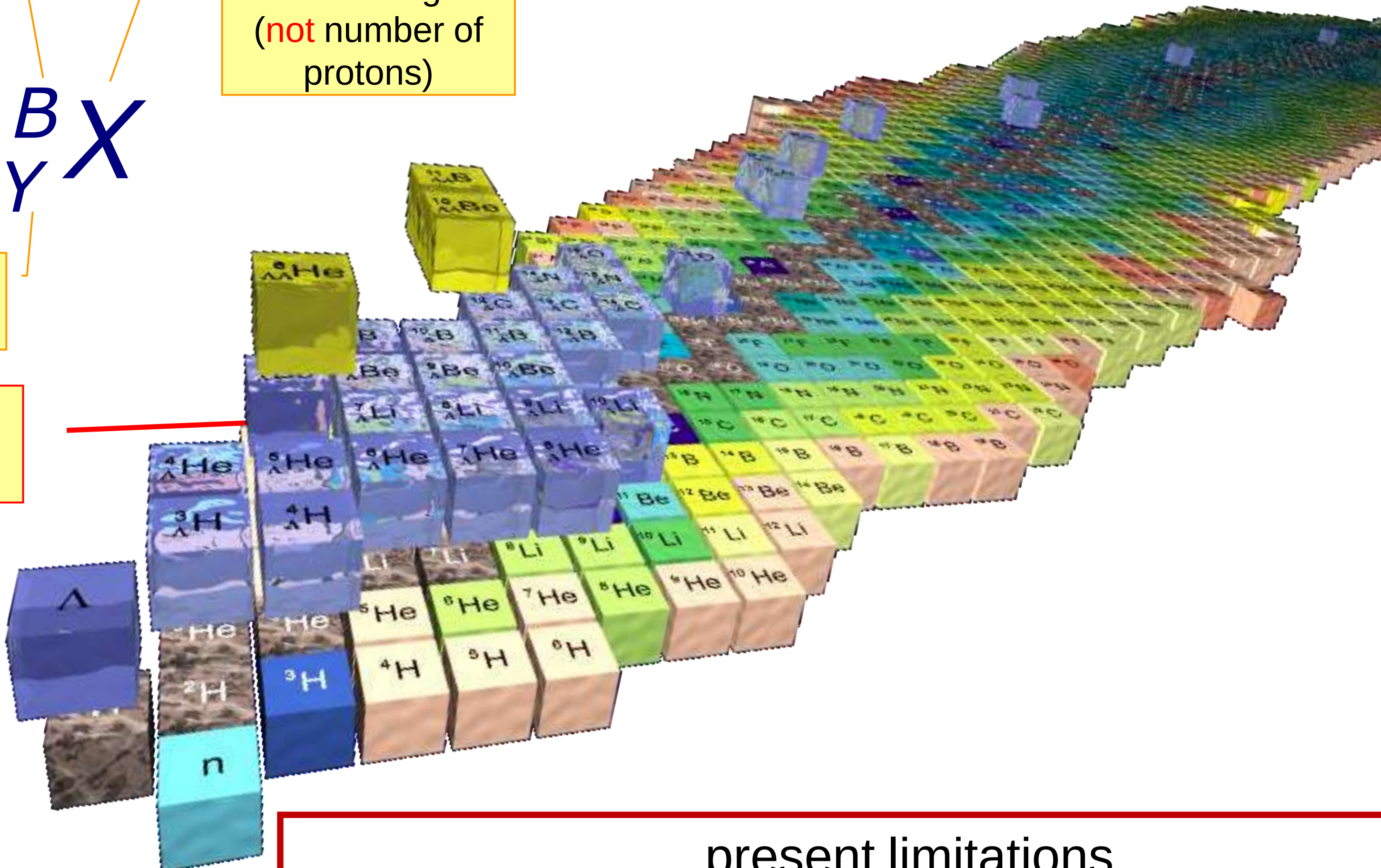
number of baryons $N+Z+Y$

element = total charge (not number of protons)

$^{B}_{Y}X$

number of hyperons Y

Example: $^{7}_{\Lambda}Li$ ($^{6}Li + \Lambda$)



increasing strangeness

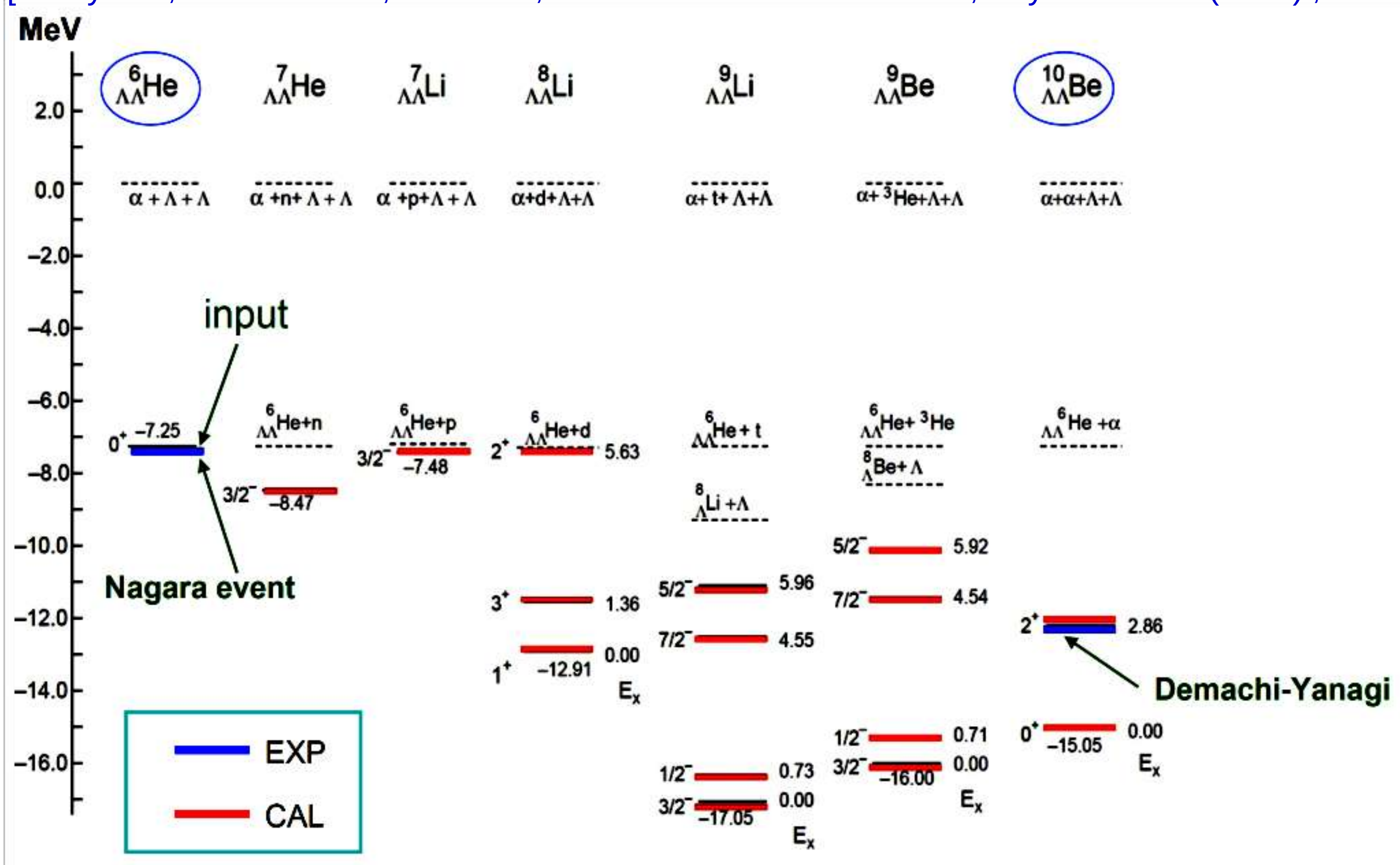
present limitations

– only single Λ-hypernuclei close to valley of stability

– only very few ΛΛ-hypernuclei events

Spectroscopy of ΛΛ-hypernuclei

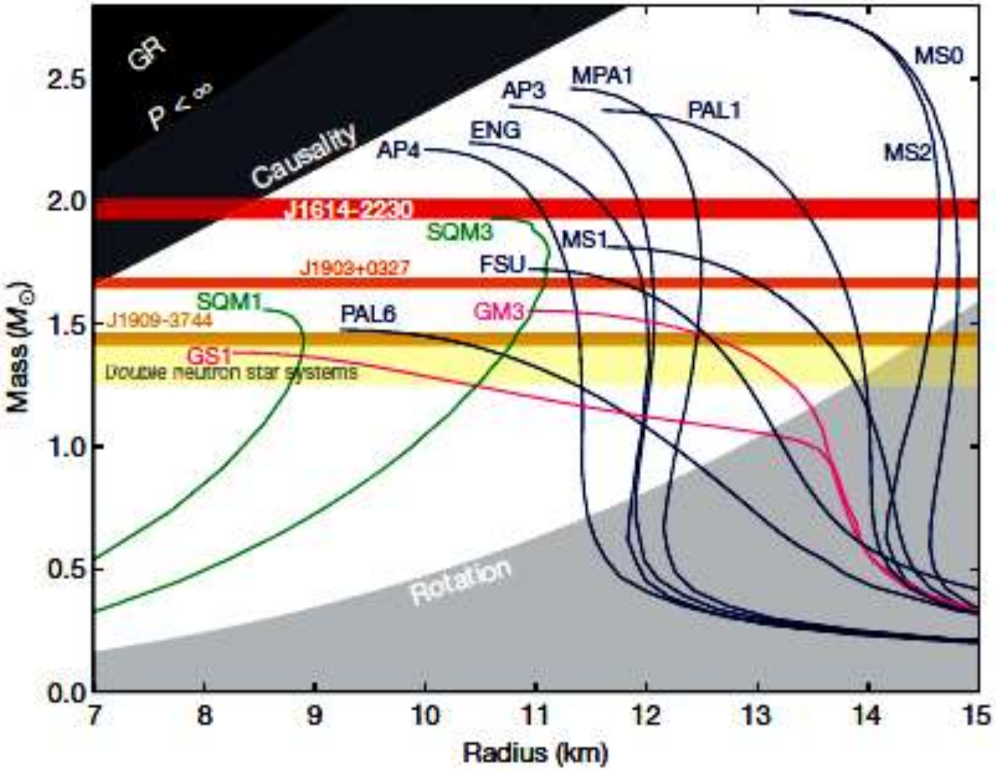
[E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto, Phys. Rev. 66 (2002) , 024007]

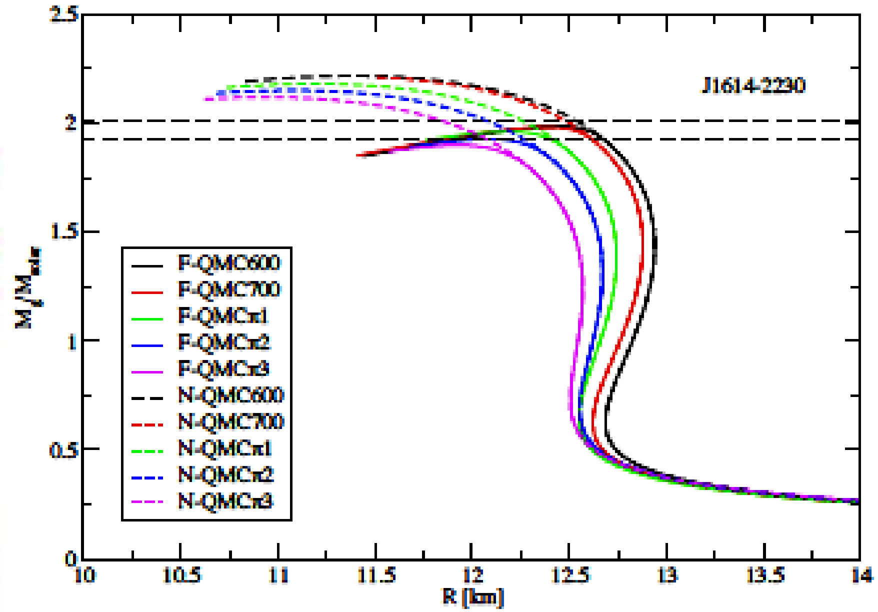


- many excited, particle stable states in double hypernuclei predicted
- level structure reflects levels of core nucleus

Excursion: strangeness in compact stars

YN & *YY* interaction determine equation-of-state (EOS) with strangeness





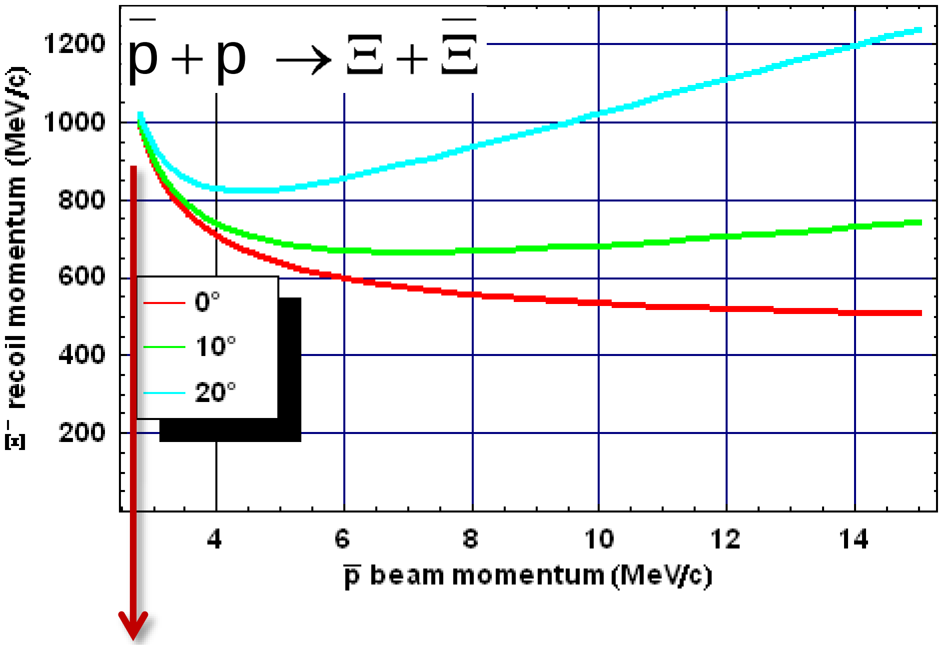
[J.R Stone, P.A.M. Guichon and A.W. Thomas]

We calculate the pulsar mass to be $(1.97 \pm 0.04)M_\odot$, which rules out almost all currently proposed[2–5] hyperon or boson condensate equations of state ($M_\odot$, solar mass).

→ experimental evidences of the 2$M_\odot$ neutron star does not exclude hyperons in the EoS

[P. B. Demorest et al., *A two-solar-mass neutron star measured using Shapiro delay*, Nature 467, (2010) 1081]

Formation of double hypernuclei from Xi particles



1. dE(Ξ^-)/dx → stop + capture
2. hyperatom + atomic decay
3. capture in nucleus ($_{\Xi^-}Z$)
4. conversion: $\Xi^- + p \rightarrow \Lambda\Lambda$
5. hypernuclei ($_{\Lambda\Lambda}Z^*$ or $_{\Lambda}Z^* + _{\Lambda}Z'^*$)

Xi hyperons may produce:

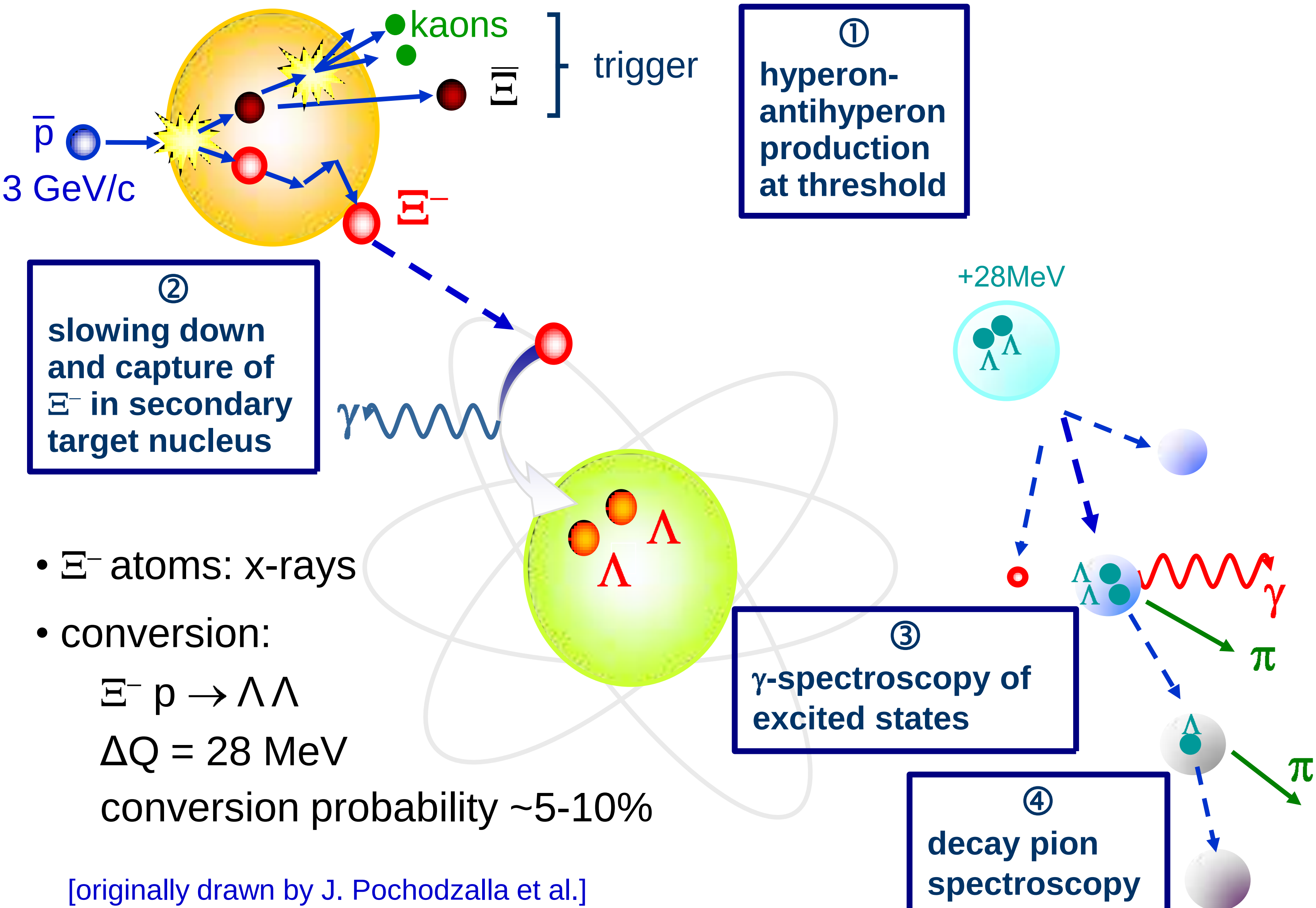
- single hypernuclei: $_{\Lambda}Z$ ($_{\Sigma}Z$)
- twin hypernuclei: $_{\Lambda}Z + _{\Lambda}Z'$
- doubly strange hypernuclei: $_{\Xi^-}Z$
- double hypernuclei: $_{\Lambda\Lambda}Z$
- H particle in a nucleus(?): $\Lambda\Lambda$

strangeness production tagged by anti-hyperon or decay products

→ forward detector
for trigger and particle ID

→ PANDA at FAIR

Production mechanism and detection strategy at PANDA



- Ξ^- atoms: x-rays
- conversion:

  $\Xi^- p \rightarrow \Lambda\Lambda$

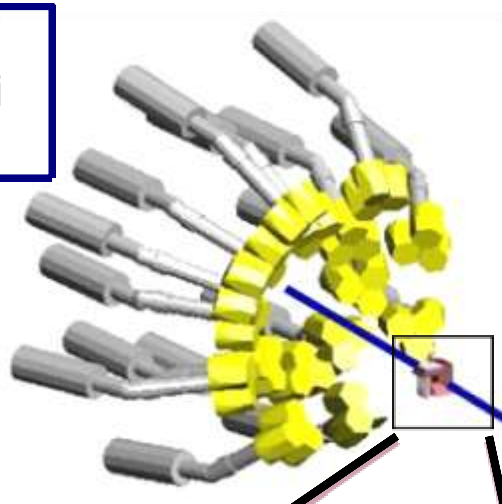
  $\Delta Q = 28$ MeV

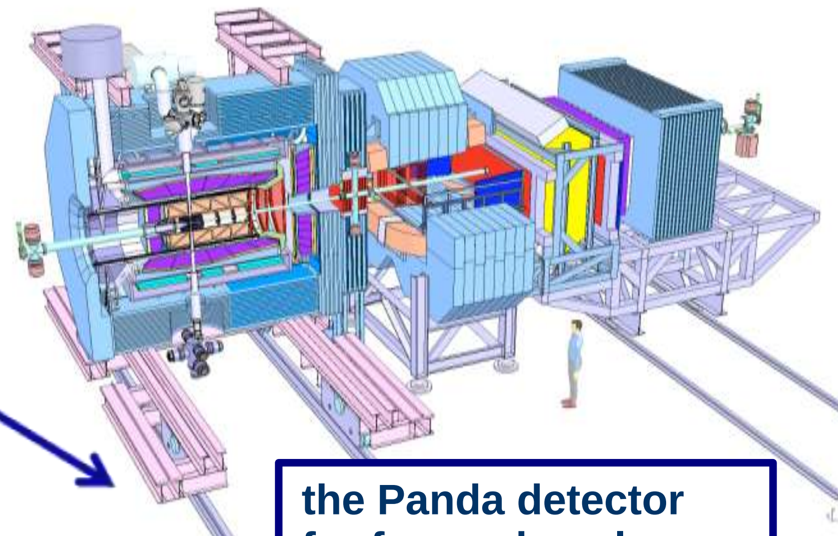
  conversion probability ~5-10%

[originally drawn by J. Pochodzalla et al.]

Instrumentation for hypernuclear physics at PANDA

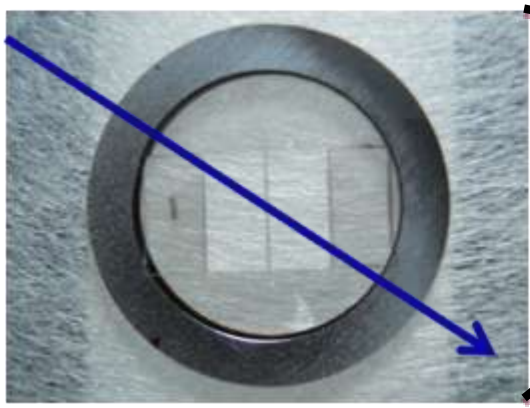
Germanium detector array for hypernuclei spectroscopy

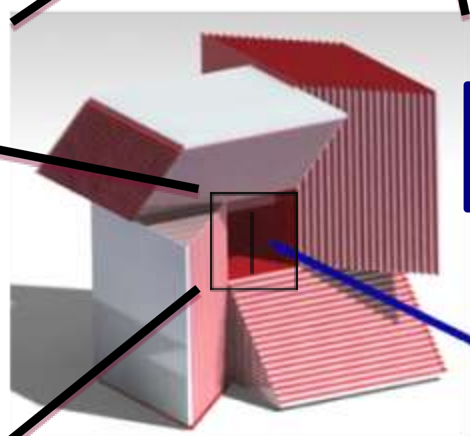




the Panda detector for forward angle particle identification

primary diamond target for Ξ production





secondary target for hypernuclei formation

[Figures from PANDA Meeting 6 Sept. 11]

Open issues being studied by the Panda Hypernuclear Groups

1. design and fabrication of the primary target
2. design and development of the secondary target
3. design and operation of the HPGe γ-array
4. electromechanical cooling of HPGe crystals
5. integration into the PANDA target spectrometer

technical

6. simulation of the expected performance

physics

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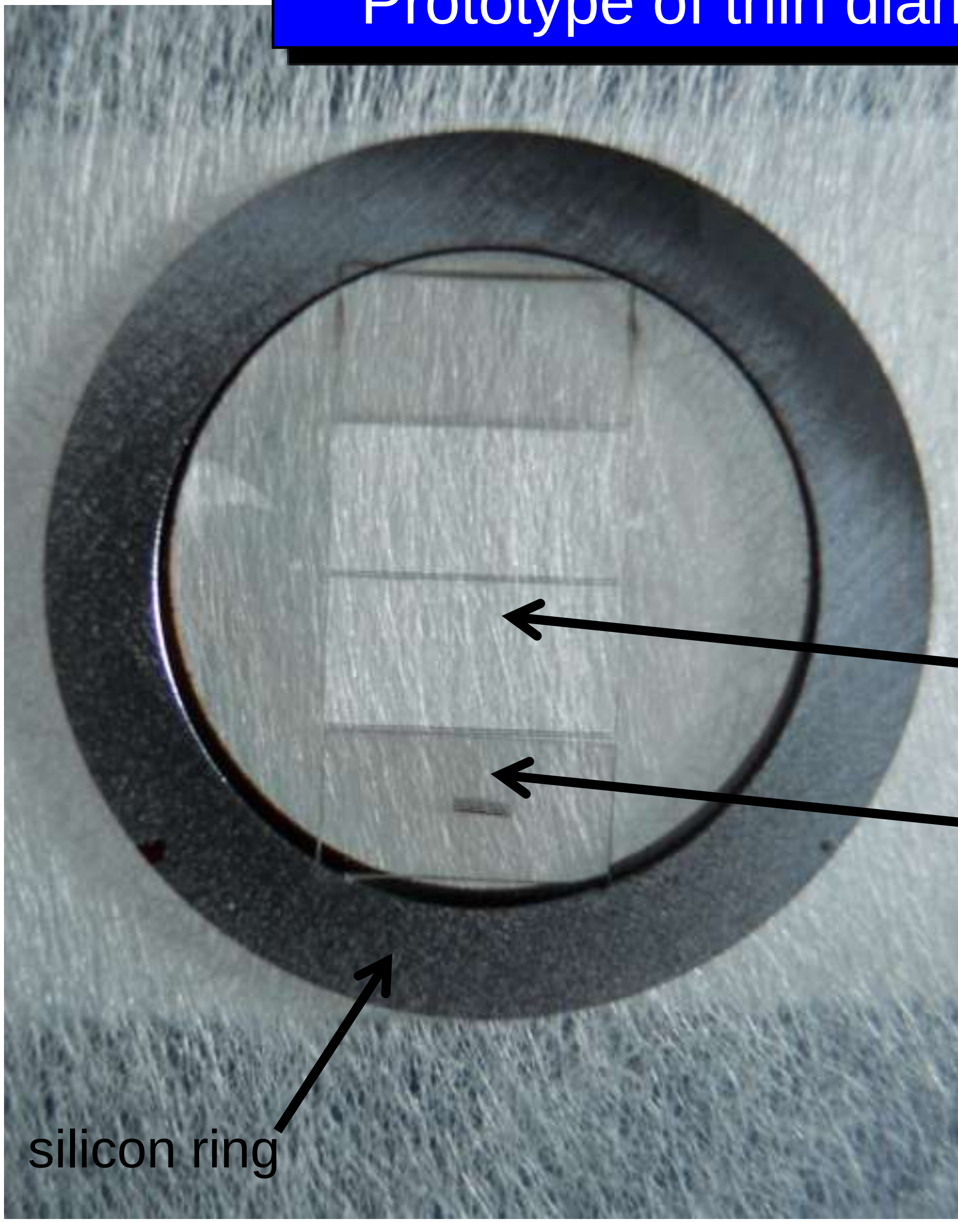
Prototype of thin diamond target



diamond wire

diamond membrane

- silicon ring inner Ø =11 mm
- diamond thickness = 3 μm
- diamond wire width = 99.9 μm

[Shown by F. Iazzi, PANDA Meeting 6 Sept. 11]

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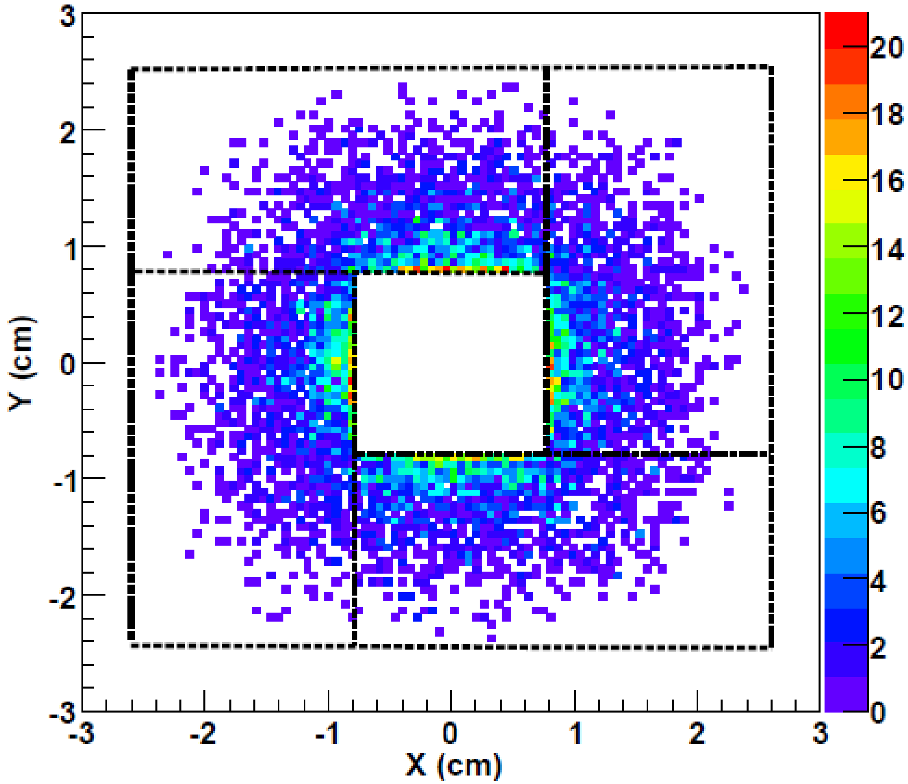
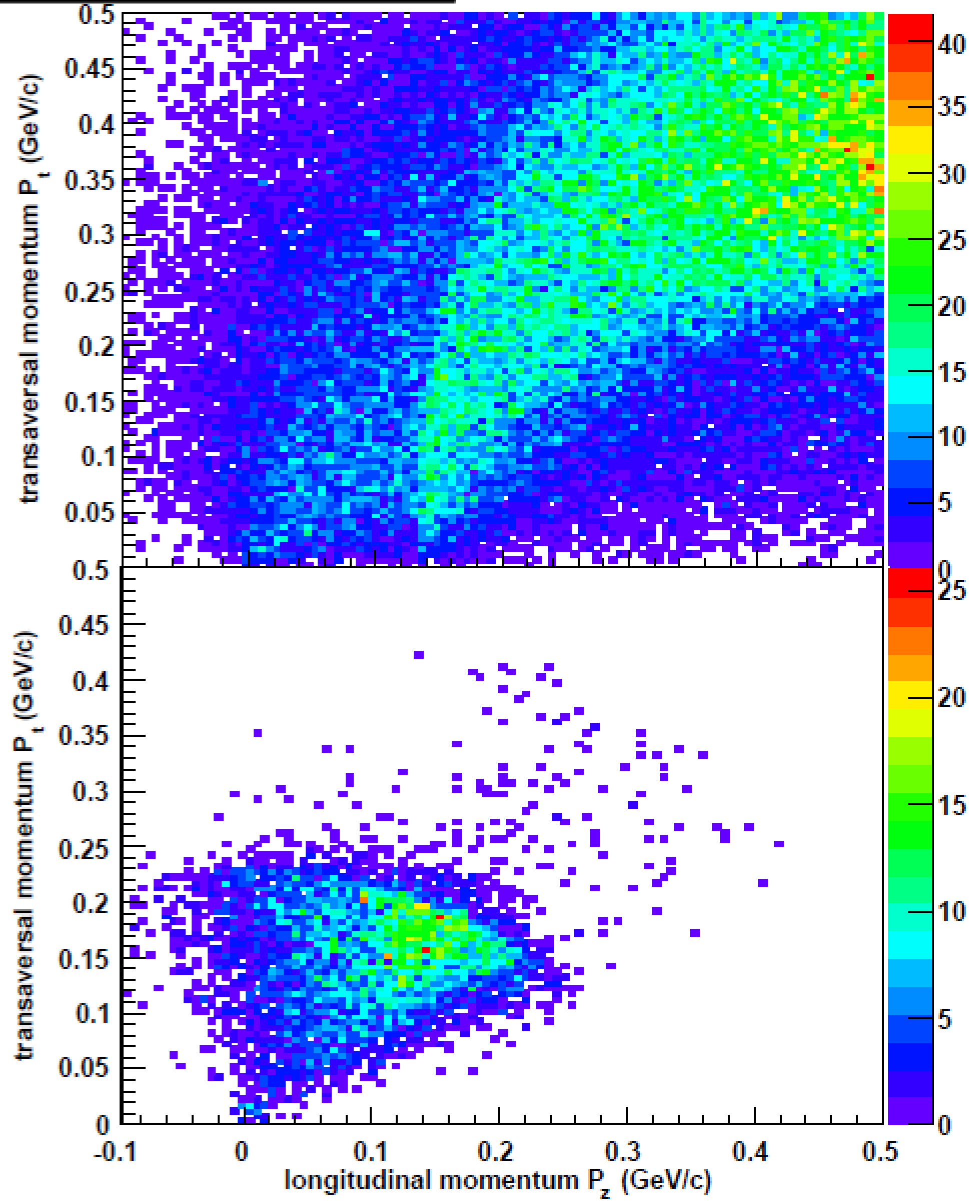
Stopping of the Xi particles

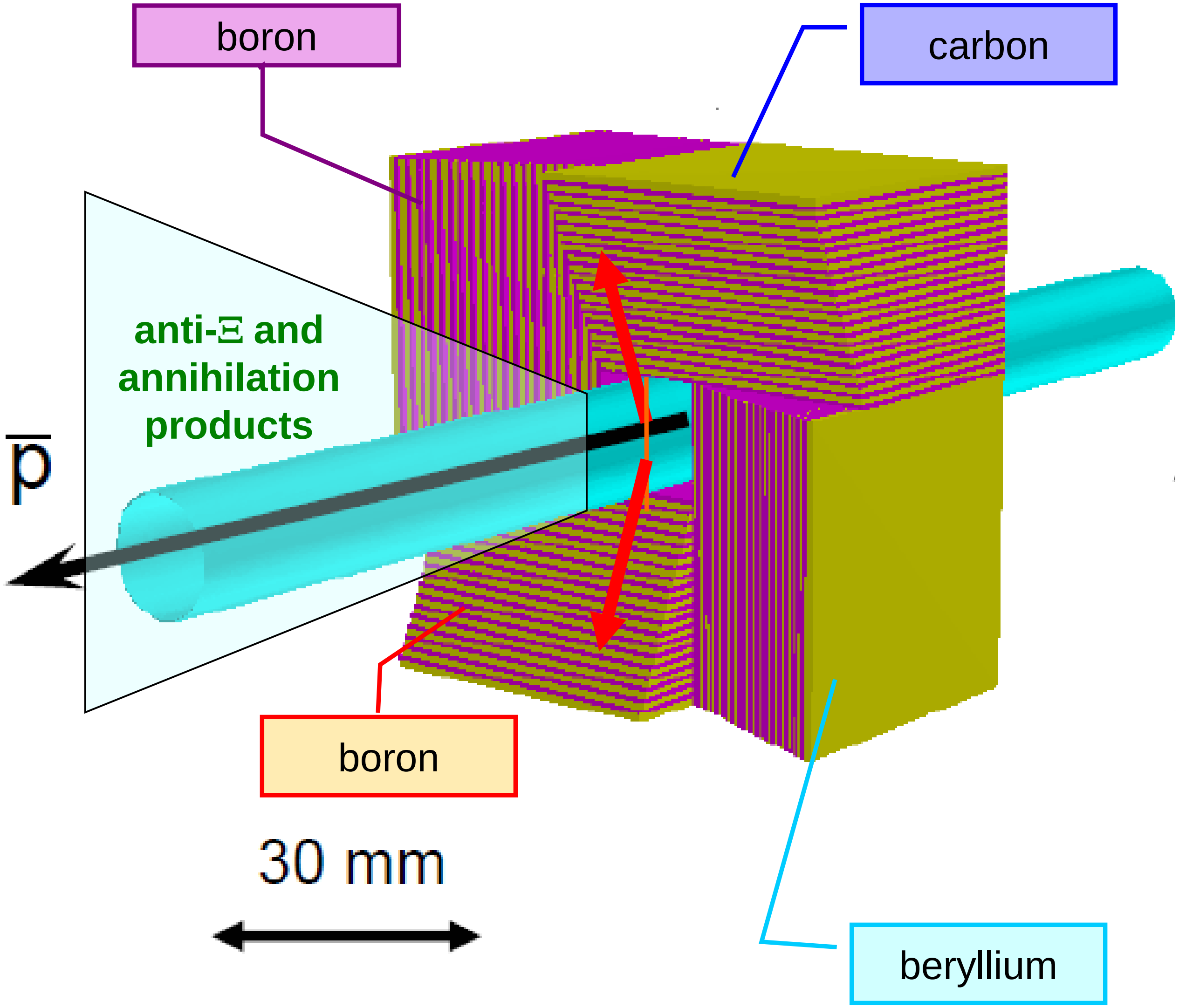




target geometry adjusted to stopping time and lifetime of Ξ-

[PANDA Physics Performance Report, 2009,p.142-3. Simulations by A. Sanchez Lorente]

The secondary target design



four separated sections:

– 20 layers of double sided silicon strip detectors (thickness 300 µm) in each block

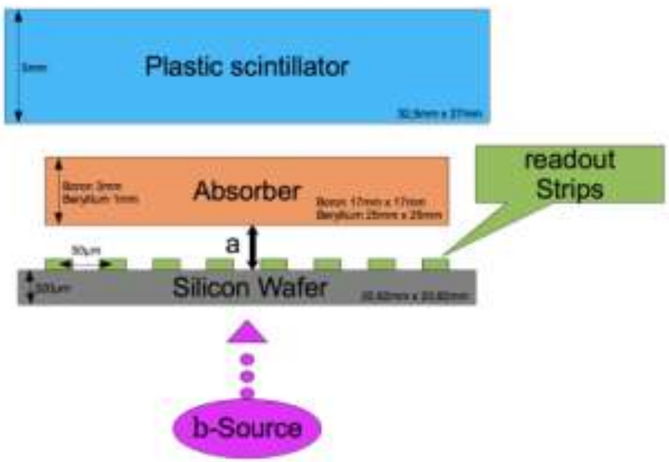
– 20 layers of absorbers (thickness 1 mm) different for each block (Be, B and C)

[PANDA Physics Performance Report, 2009, p. 21]

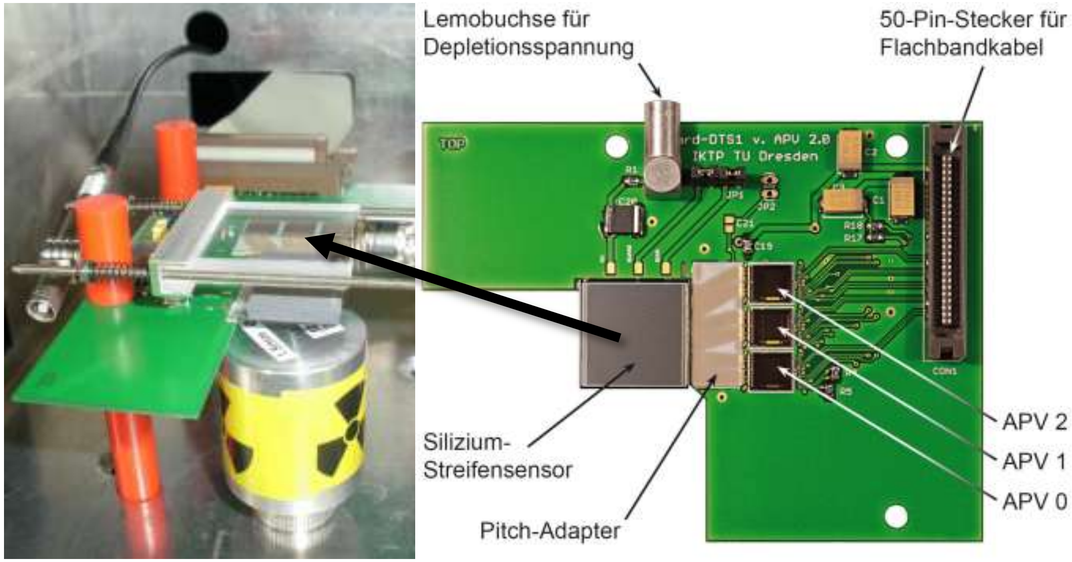
Prototype developments for the secondary target

- compact structure of detector and absorber:

  performance of silicon strip detector in direct contact with absorbers



[S. Bleser, Diploma thesis, U Mainz, Shown at PANDA Meeting 6 Sept. 11]

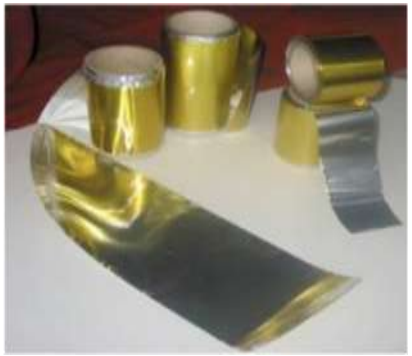


- frontend electronics:

  minimization of mass on detecting volume:

  ultra-thin Al-Polyimide readout cables

  [J.M. Heuser et al., HadronPhysics2/JRA-ULISI]



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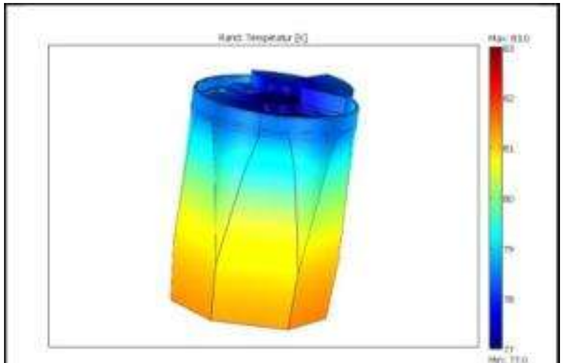
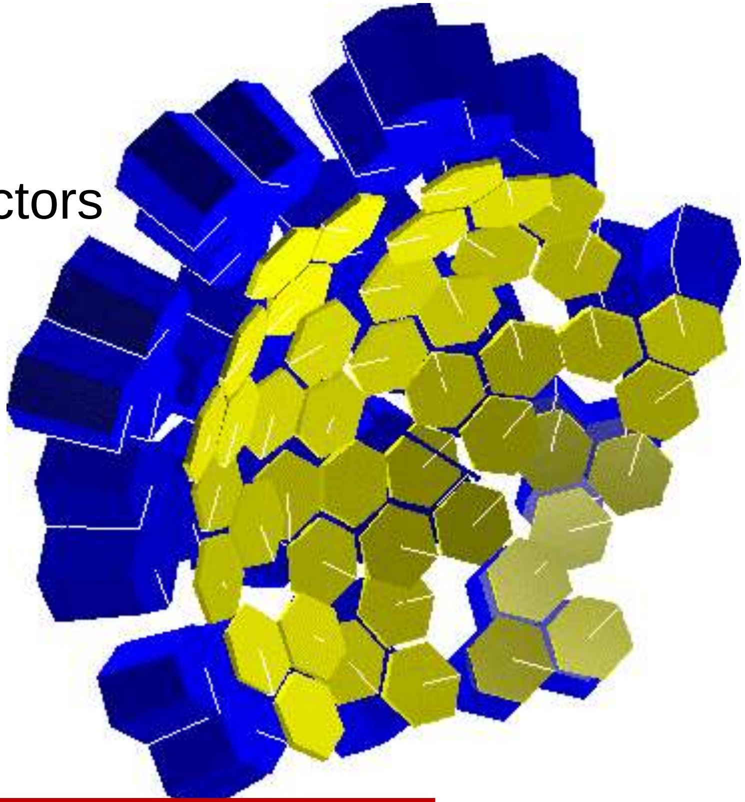
Towards a prototype of HPGe Cluster Array

- simulation of different crystal multiplicities
- operation of double and triple cluster detectors



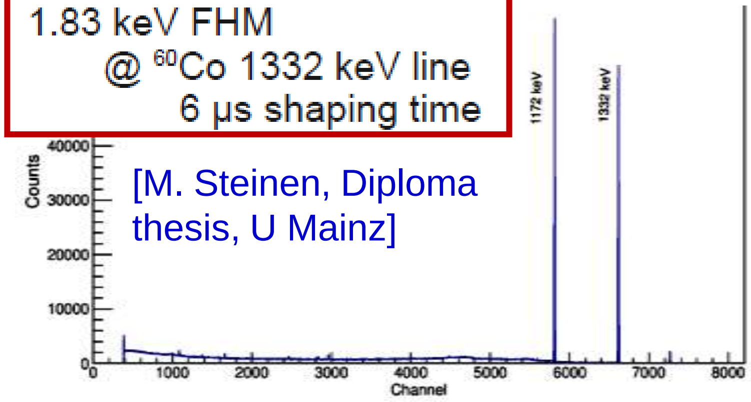
Surface temperature distribution of a single Ge-detector: the heat losses are 2.5 W for an aluminum capsule surface emissivity of 0.14.



- high rate environment:
  radiation damages & pile-up effects
- magnetic field environment:
  loss of resolution

[A. Sanchez Lorente et al., NIM A 573 (2007) 410.]

1.83 keV FHM
@ ^{60}Co 1332 keV line
6 μs shaping time



[M. Steinen, Diploma thesis, U Mainz]

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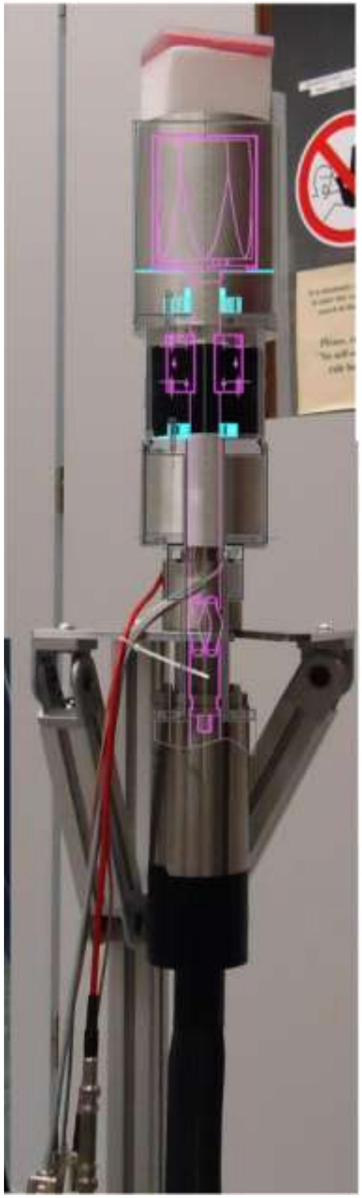
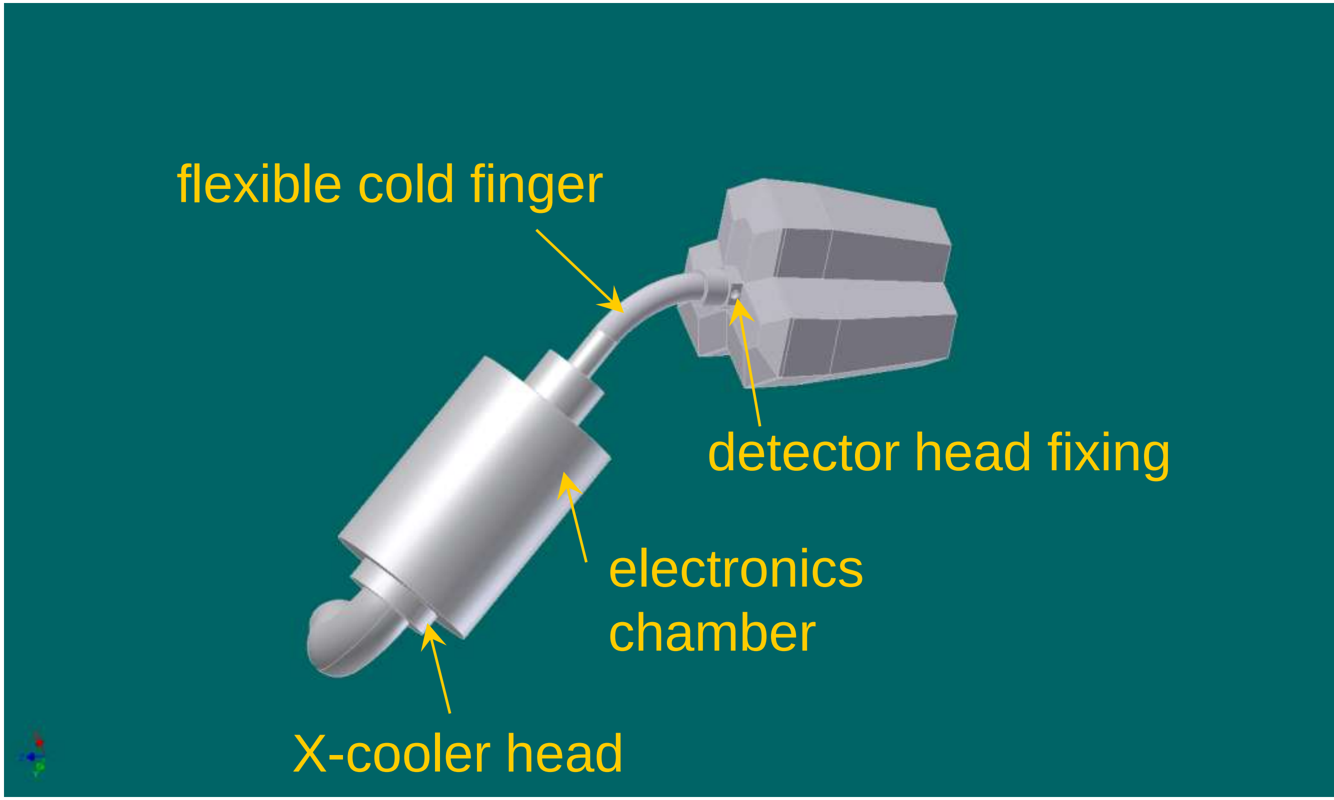


HPGe encapsulated crystal
attached to electromechanical cooler



[M. Steinen, U Mainz, I. Kojouharov, GSI,
Shown at PANDA Meeting 6 Sept. 11]

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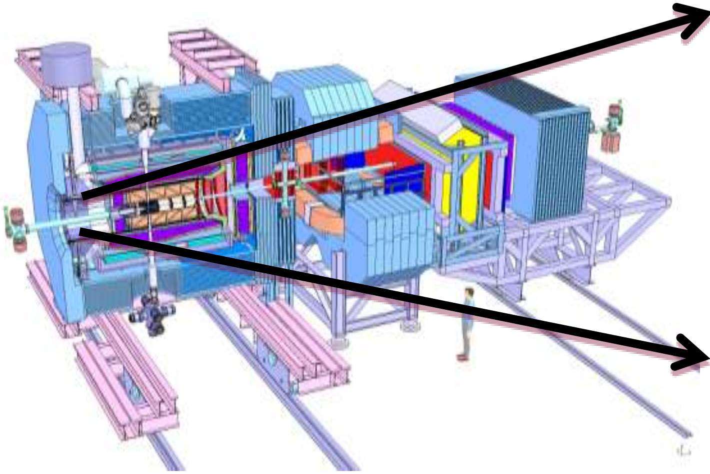
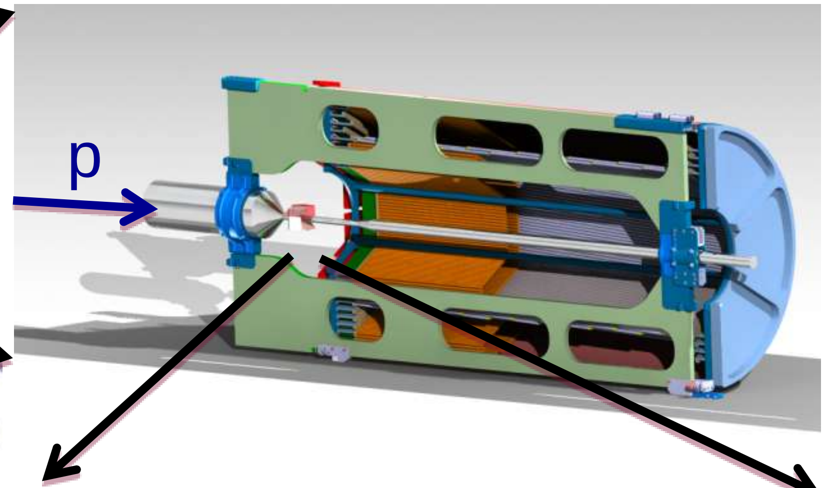
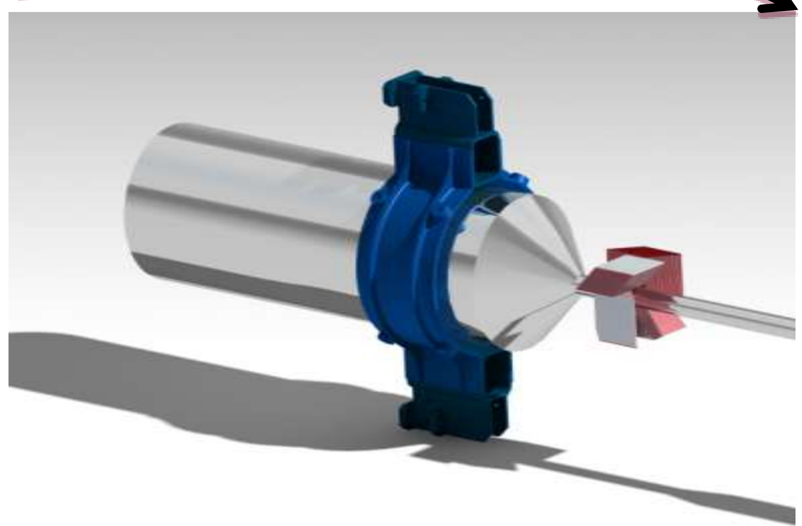
Target integration into the spectrometer



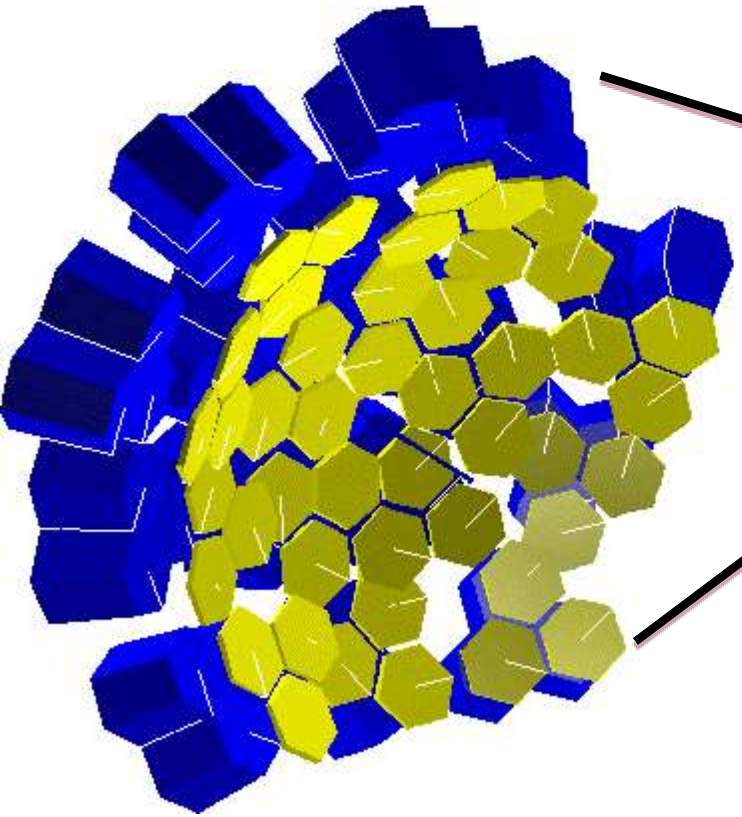


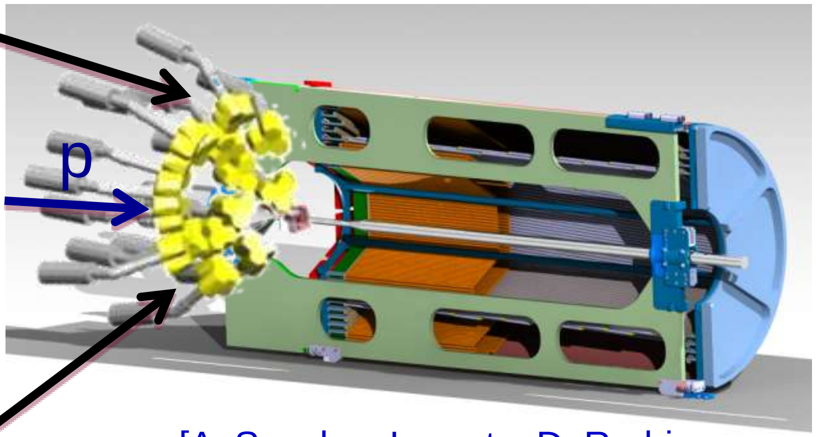


- dedicated beam pipe going from 150 mm to 20 mm diameter
- backward end cap calorimeter and MVD will not be used
- modular structure

[A. Sanchez Lorente, D. Rodriguez, Shown at PANDA Meeting 6 Sept. 11]

HPGe array integration into the spectrometer





[A. Sanchez Lorente, D. Rodriguez, Shown at PANDA Meeting 6 Sept. 11]

[PANDA Technical Progress Report, 2005.]

- $\theta_{lab} < 45°$: Ξ-bar, K trigger and PID in PANDA spectrometer
- $\theta_{lab} = 45°\text{-}90°$: Ξ-capture and hypernuclei formation
- $\theta_{lab} > 90°$: γ-detection with HPGe at backward angles
  integration of electromechanical coolers for HPGe

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Statistical decay model for excited hypernuclei

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

Population of excited, particle-stable states in double hypernuclei?

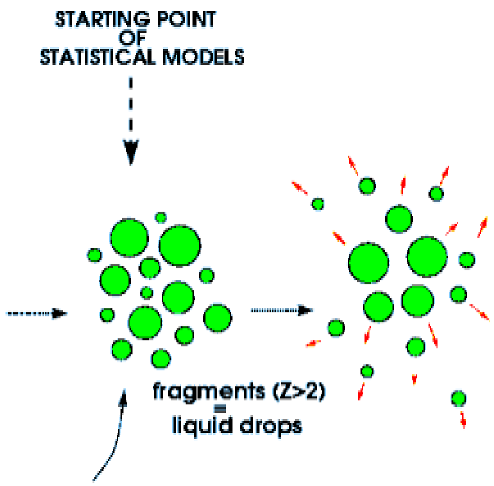
conversion width $\Xi + p \Rightarrow \Lambda\Lambda$ about $\Gamma = 1$MeV

precise Ξ^- binding energy not yet known (0.6 – 4 MeV)

typical excitation energy ~ a few MeV/nucleon

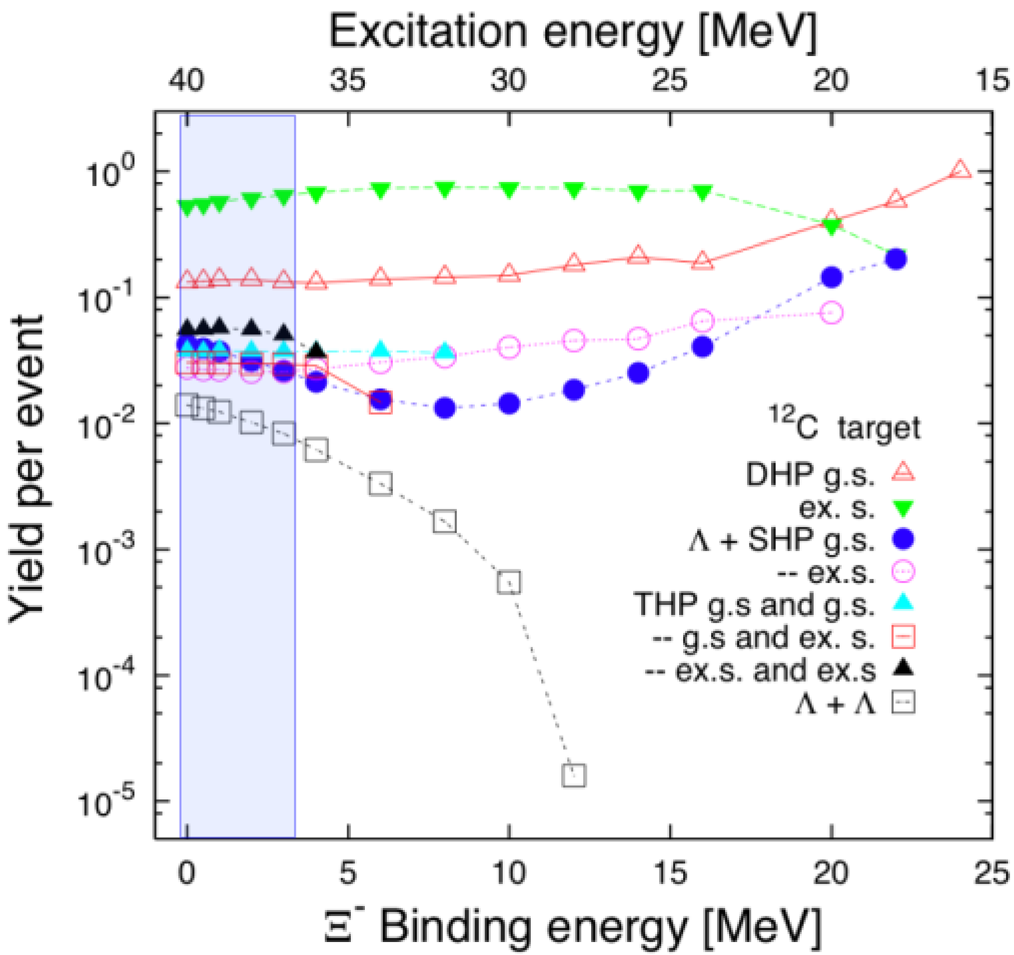
fragmentation of excited projectile remnants
are well understood in that regime

de-excitation of light nuclei via Fermi break-up process



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

Population of excited double hypernuclear states



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

▼ △ : double hypernuclei

● ○ : single hypernuclei

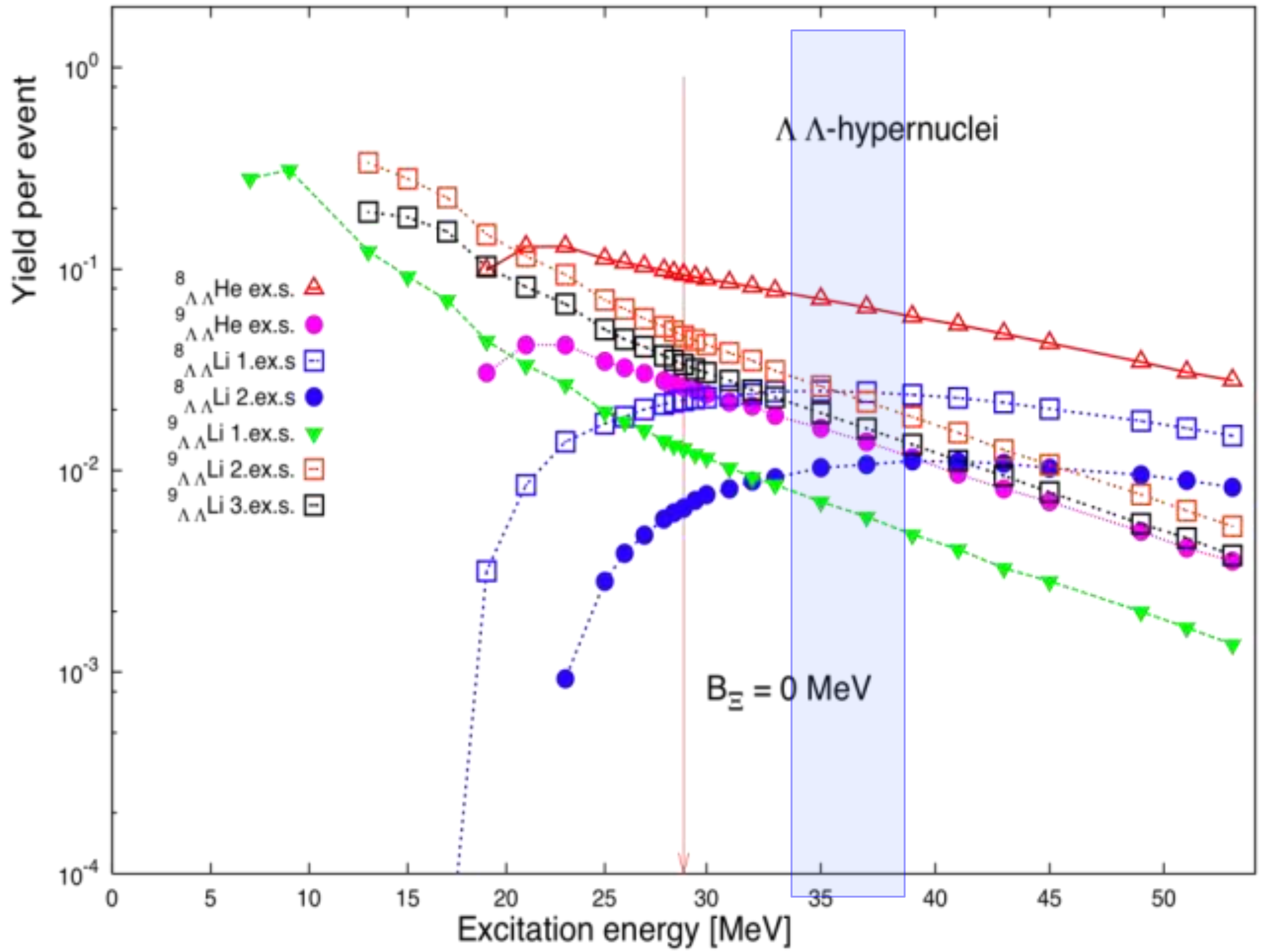
▲ ▲ □ : twin hypernuclei

□ : ΛΛ

$\Rightarrow$ production of excited states of double hypernuclei is significant

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

Population of excited double hypernuclear states

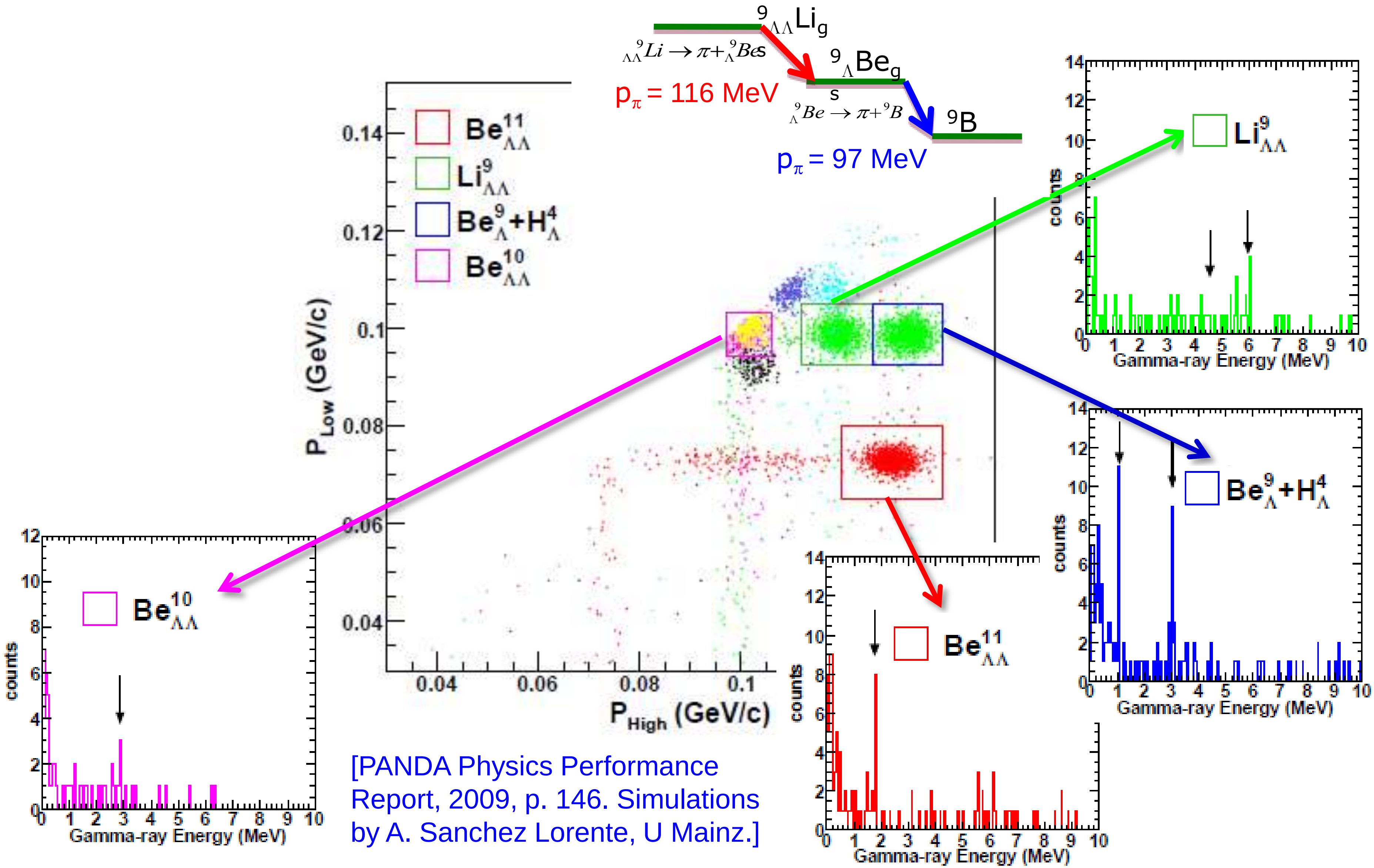


$\Xi^- + {}^{9}\mathrm{Be} \Rightarrow {}^{10}_{\Lambda\Lambda}\mathrm{Li}^*$

⇒ production of excited states of double hypernuclei is significant

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

Background suppression by decay pion correlation

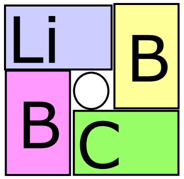


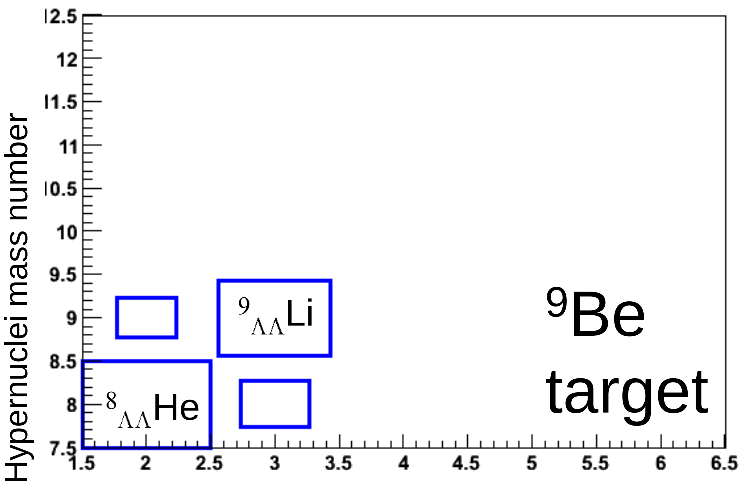
[PANDA Physics Performance Report, 2009, p. 146. Simulations by A. Sanchez Lorente, U Mainz.]

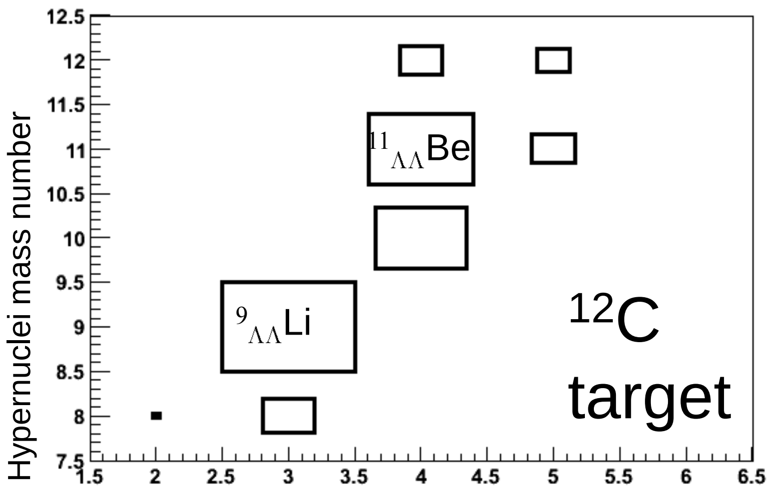
Identification of individual isotopes

PANDA will explore several 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
- production probability · pionic decay probability







⇒ each target allows for the unique assignment of observable transitions by comparing the expected yields

[Simulations by A. Sanchez Lorente, U Mainz.]

Summary

- Hypersystems provide a link between nuclear physics and QCD to study basic properties of strongly interacting systems
- antiproton collisions with nuclei are the ideal tool to produce exclusive Xi-antiXi pairs in nuclei at moderate momenta
- many experimental challenges have to be overcome to realize such measurements
- A statistical model predicts a large probability for the population of individual, excited states in double Λ hypernuclei
- γ-spectroscopy of these double hypernuclei at PANDA is feasible