Hypernuclear Physics Studies at the $\overline{\text{P}}$ANDA Experiment at FAIR

- The PANDA experiment at FAIR
- Production and Detection of Double Λ hypernuclei at $\overline{\text{P}}$ANDA
- Hypernuclear Detector Setup
- Outlook and Summary

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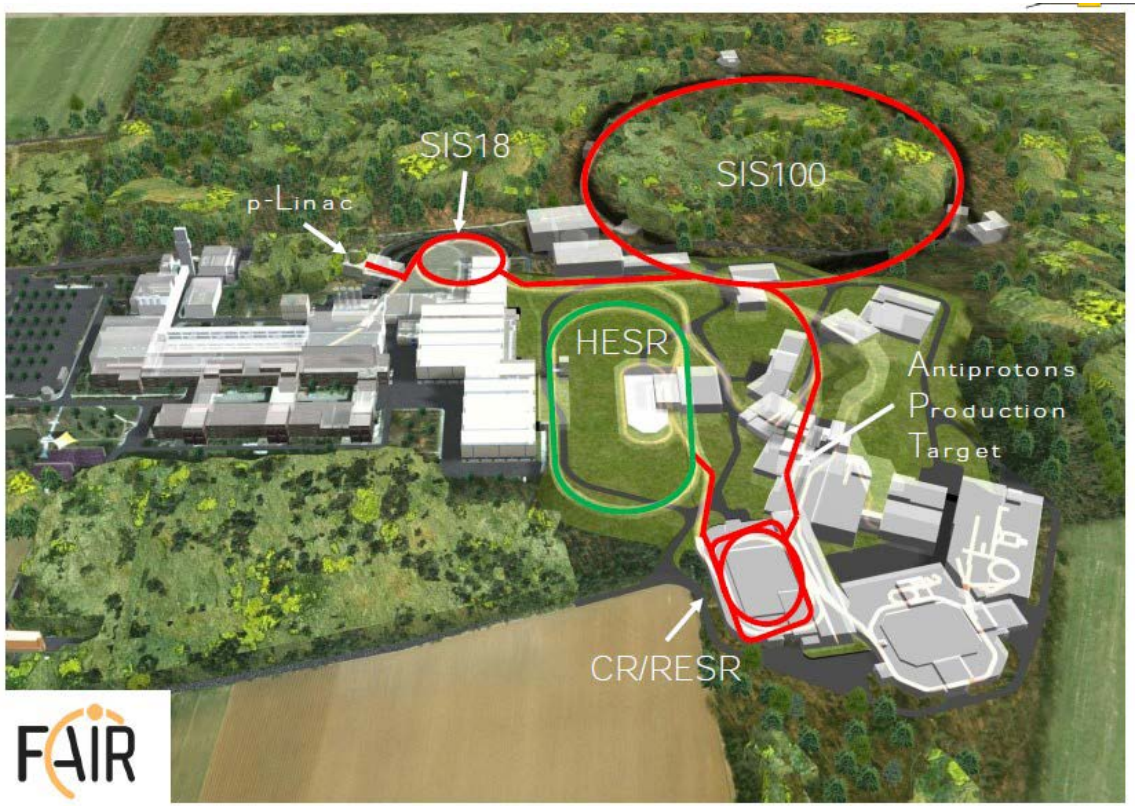
Alicia Sanchez Lorente

on behalf of the $\overline{\text{P}}$ANDA Collaboration

Recent Highlights in Hadron Structure

Orsay, 6. - 7. October 2014

The Fair Facility

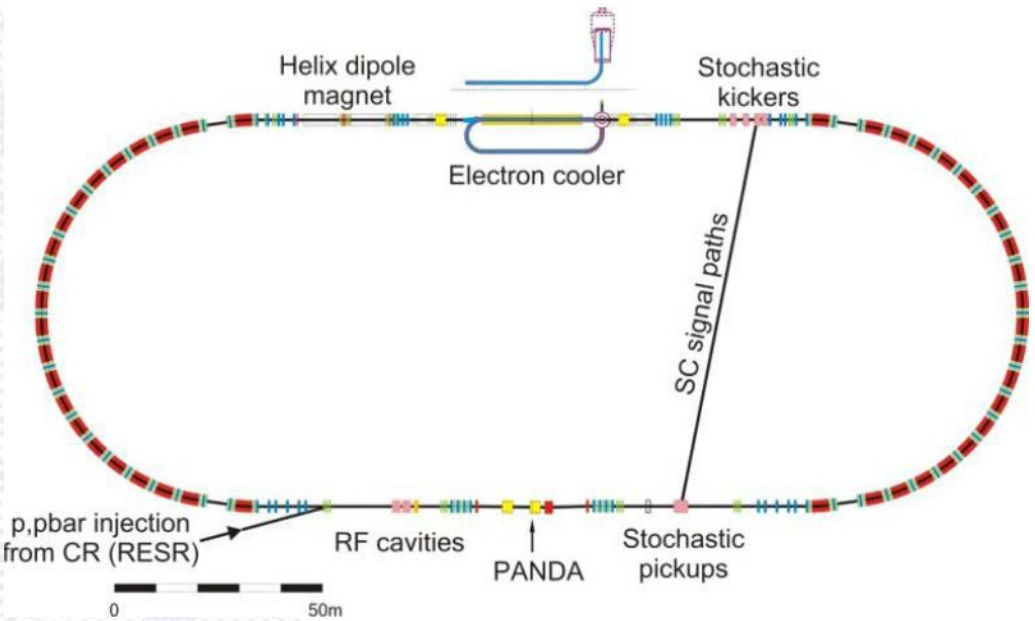


3000 Physicists
50 Countries

Scientific pillars of FAIR:

1. **A**tomic, **P**lasma **P**hysics and **A**pplications – APPA
2. **C**ompressed **B**aryonic **M**atter – CBM
3. **NU**clear **ST**ructure, **A**strophysics and **R**eactors – NUSTAR
4. anti**P**rotons **AN**nihilation at **DA**rmstadt - *PANDA*

HESR : High Energy Storage Ring



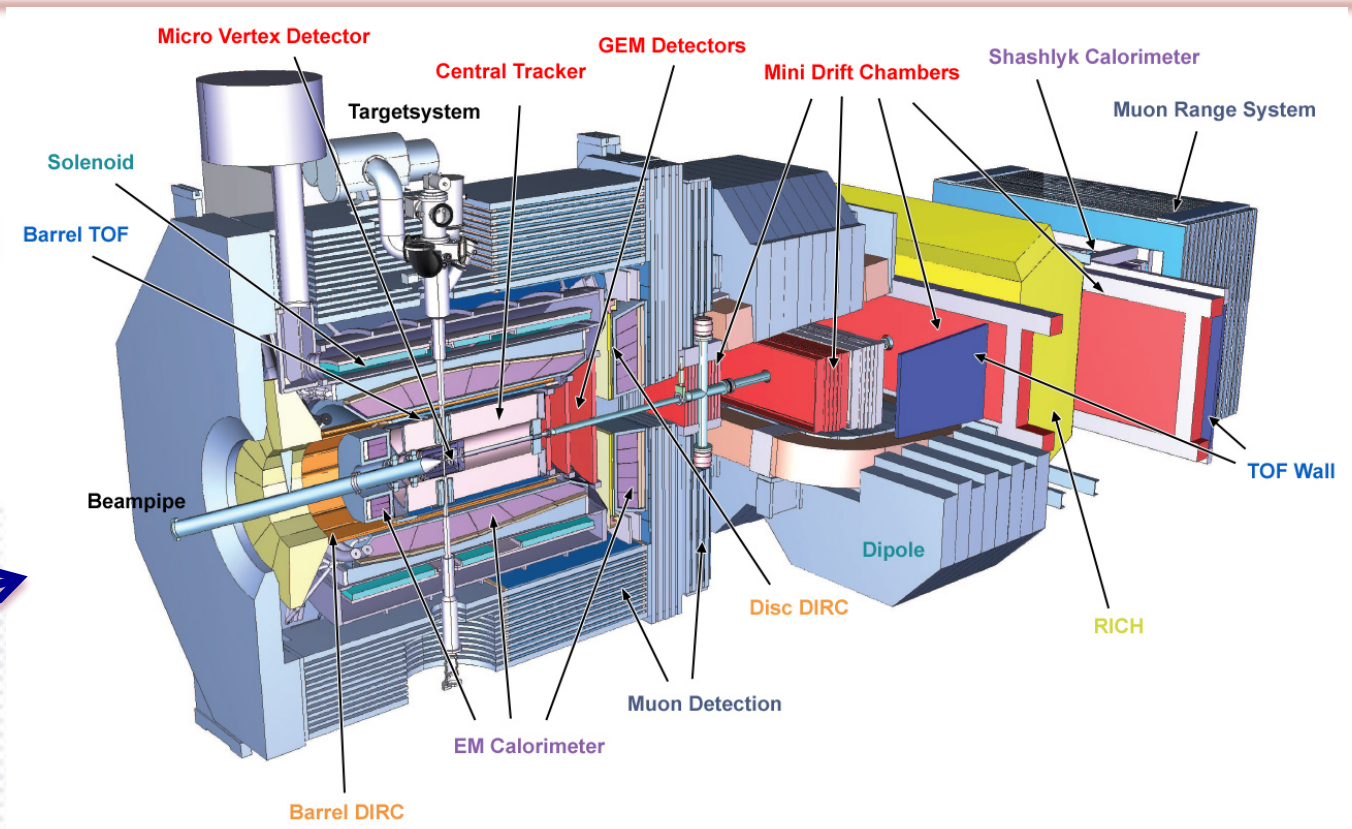
HESR	
575 m	Circumference
1.5 – 15 GeV/c	Momentum
up to 9 GeV/c	Electron Cooling
Full range	Stochastic Cooling

Beam life time >30 min
Thick target: 4 10^{15} cm $^{-2}$

High resolution mode
e- cooling, 1.5≤ p≤ 8.9 GeV/c
10^{10} antiprotons stored
Luminosity up to 2 ·10 ^{31} $cm^{-2}s^{-1}$
$\Delta p/p = 4\ 10^{-5}$

High intensity mode
Stochastic cooling, p≥ 3.8 GeV/c
10^{11} antiprotons stored
Luminosity up to 2 · 10 ^{32} $cm^{-2}s^{-1}$
$\Delta p/p = 2 \square 10^{-5}$

The $\overline{\text{P}}$ANDA Spectrometer



- 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
Electroweak physics
Hypernuclear Physics

Double Strange Systems as Laboratory

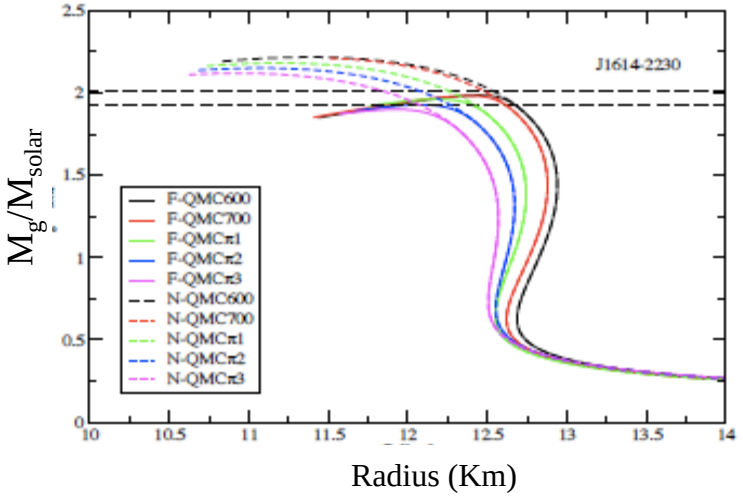
Hypernuclei provide a bridge between nuclear physics and hadron physics

S = -2

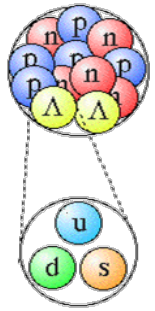
- Study of ΛΛ Hypernuclei offers additional information about the Y-Y interaction ($\Delta B_{\Lambda\Lambda} \sim B_{\Lambda\Lambda} - 2\,B_{\Lambda}$)
- relevant for

➢ 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
D. Lonardoni et al.



➢ existence of exotic quarks systems :
H- Particle in nuclei



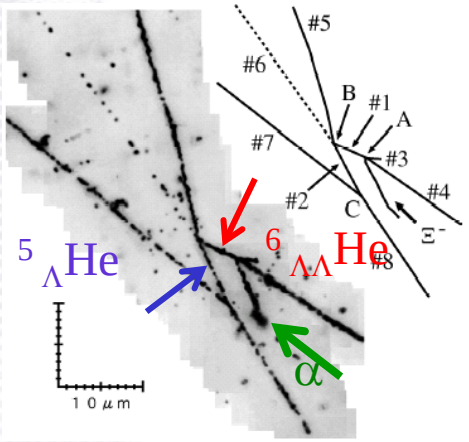
The Present Nuclear Chart

Present limitations

only single Λ-hypernuclei close to valley of stability

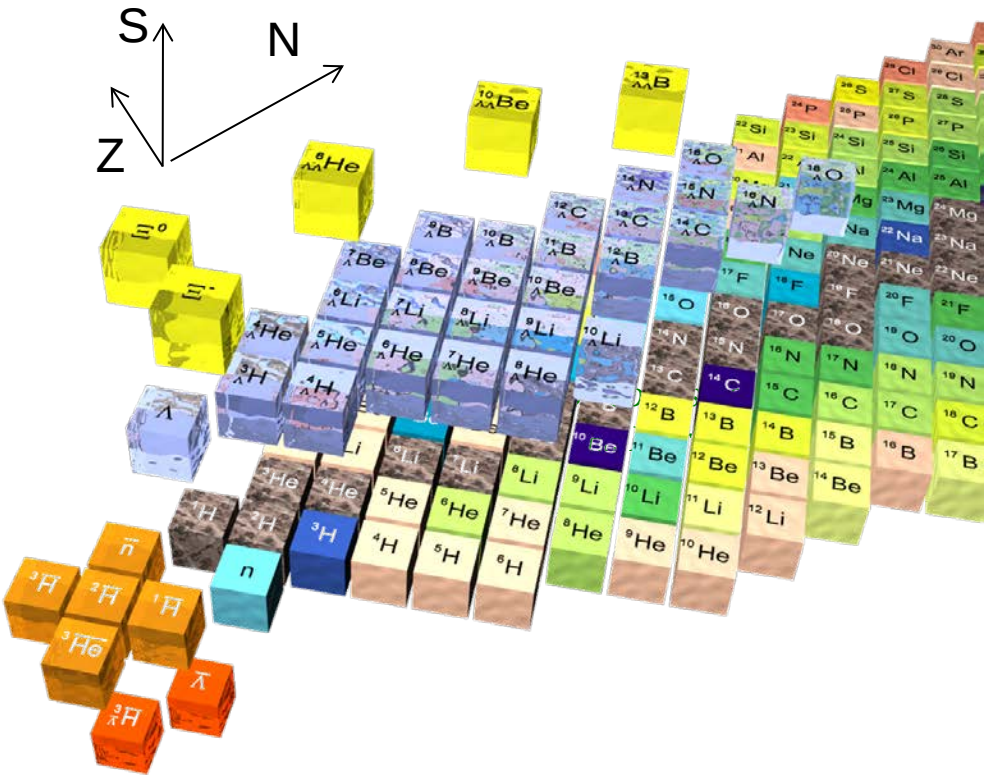
only very few ΛΛ-hypernuclei events

Nagara event



^{12}C + Ξ => $^{6}_{\Lambda\Lambda}$He + ^{4}He + t

$^{6}_{\Lambda\Lambda}$He => $^{5}_{\Lambda}$He + p + π



number of baryons N+Z+Y

element = total charge (not number of protons)

$^{B}_{Y}X$

(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) : $\Xi^- + p \rightarrow \Lambda + \Lambda$, Q= 28MeV
  ⇒ large sticking probability in the same nuclear fragment

  - $K^- + p \rightarrow \Xi^- + K^+$ (KEK-E373/ E176 , AGS-E906, JPARC): lifetime, ground state masses

  - Antiprotons
    - in flight $\bar{p} + p \rightarrow \Xi^- + \Xi^+$
      $\bar{P}$ANDA : level structure (ground state masses)

- two-step process

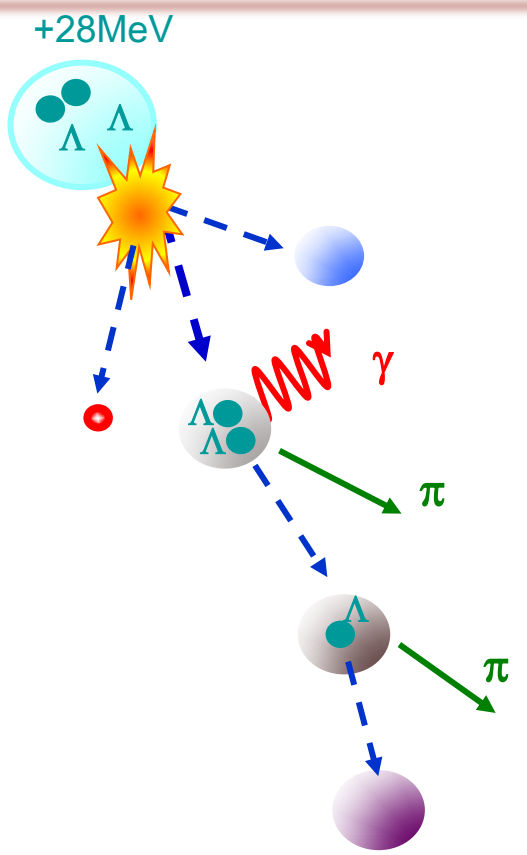
Decay Products of ΛΛ- Hypernuclei

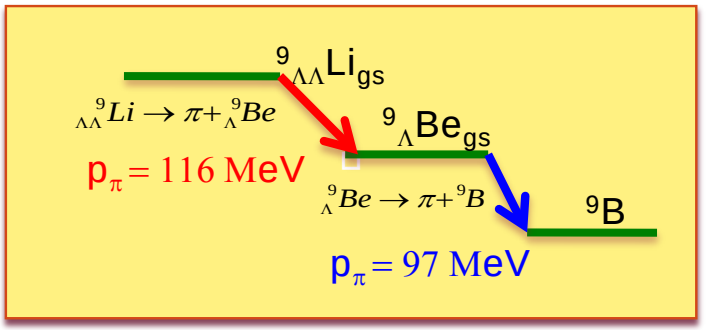
HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Mainz

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

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

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



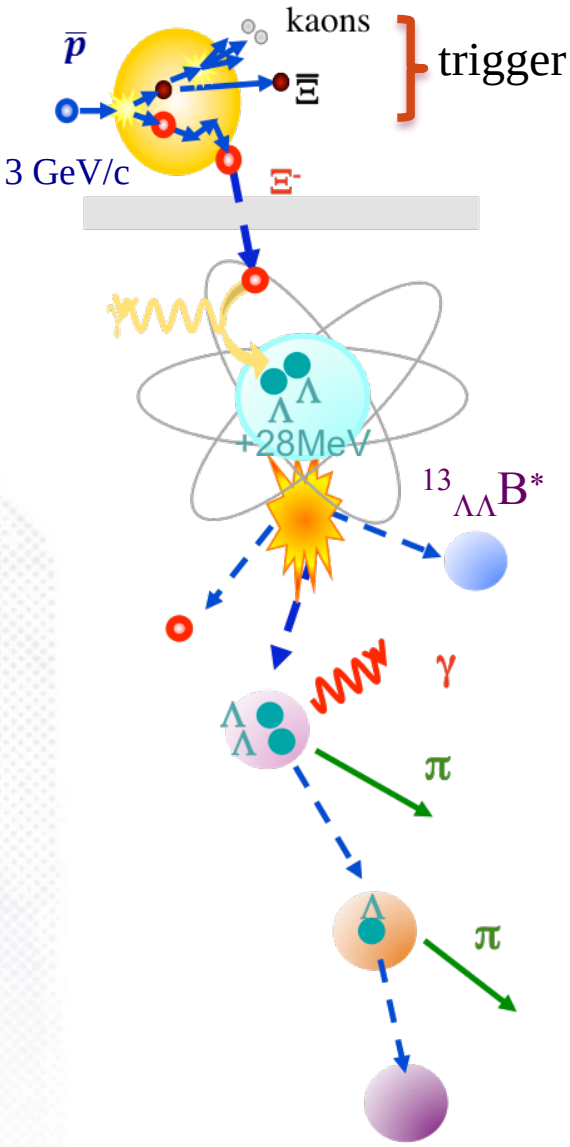


- Different nuclear targets (^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C)

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

panda

ΛΛ- Hypernuclei at PANDA



3 GeV/c $\bar{p} + {}^{12}C \rightarrow \Xi^- + \Xi^+ + X$

in a primary target

⇒ Slowing down, capture and conversion of Ξ

($\Xi^- + p \rightarrow \Lambda + \Lambda + 28MeV$)

in a secondary active target.

⇒ Statistical decay of slightly excited hypernuclei

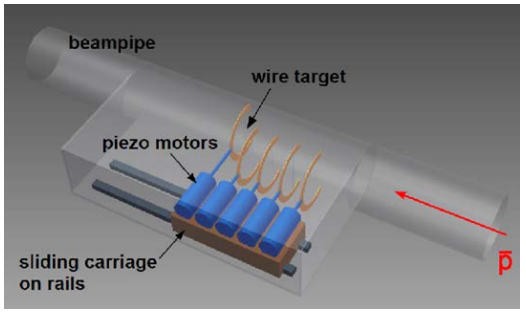
⇒ Electromagnetic transition to g.s

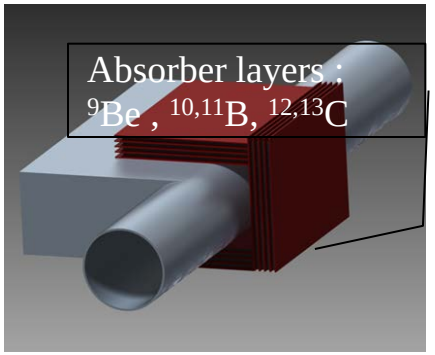
⇒Sequential mesonic decay

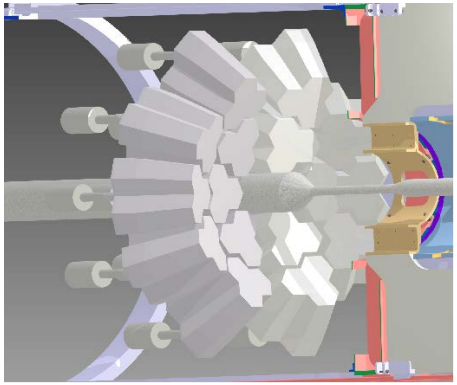
Need of a devoted detector setup

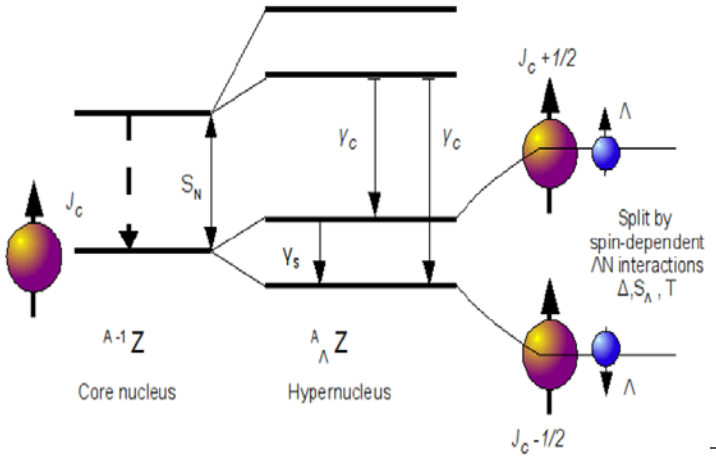
Hypernuclear Detector Setup

- **Integration in the PANDA spectrometer**
  - Space constraints
  - High magnetic field
  - Large hadronic background
- **Physics Performance**
  - **The primary target** :
    production of slow momentum Ξ^-
  - **The Secondary Active target** :
    Stopping of Ξ^- , and detection of
    charged decay products (monoenergetic π^-)
  - **The HPGe Array** : high precision γ detection

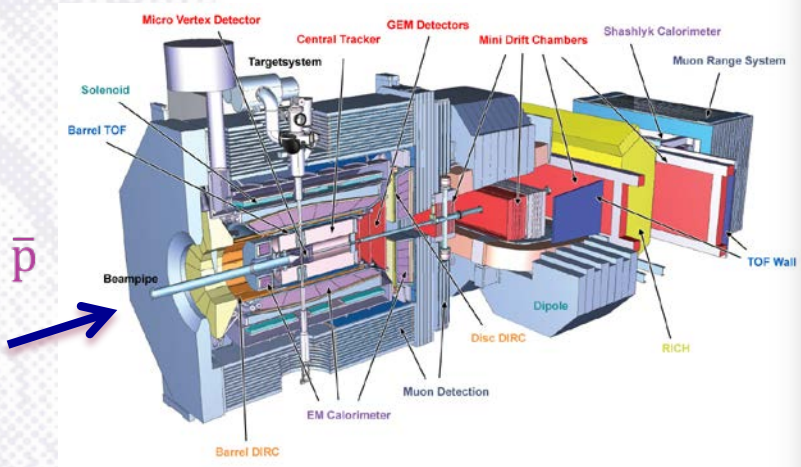


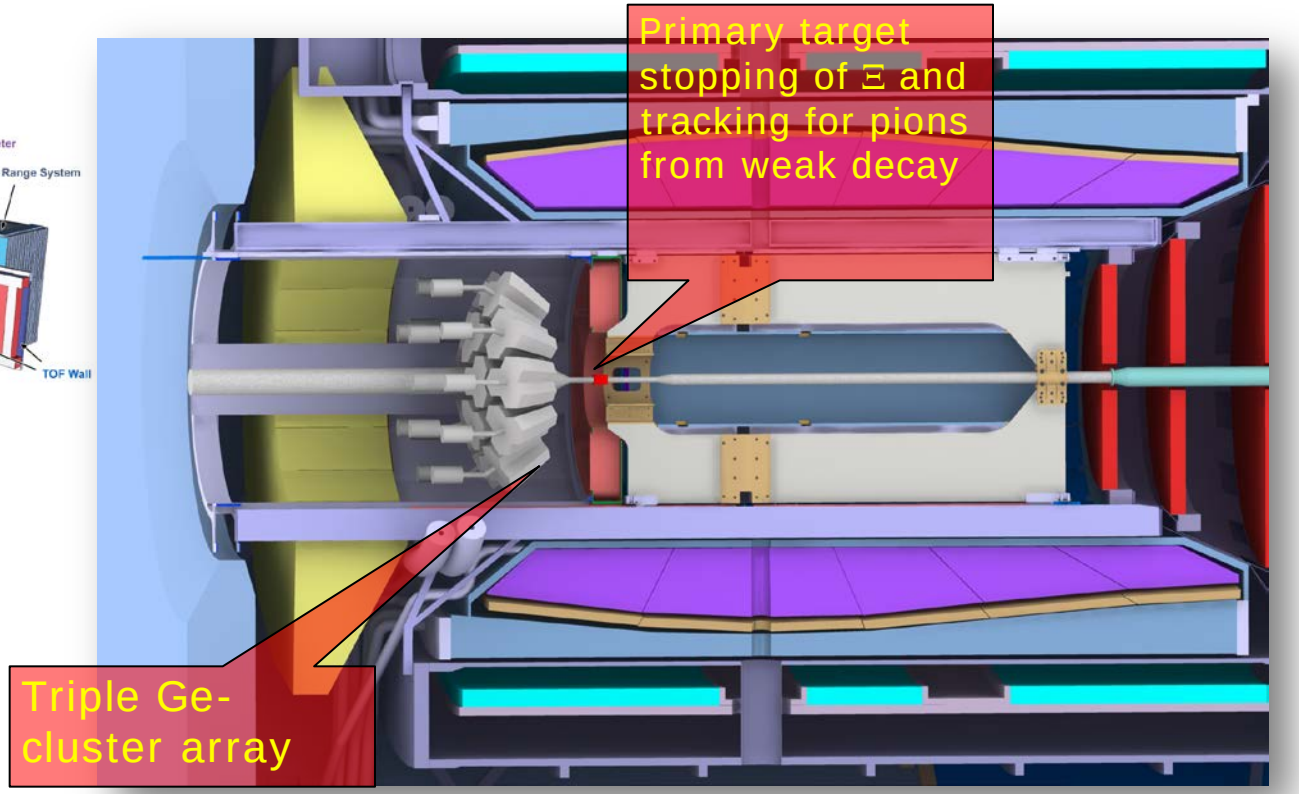






Integration in $\overline{\text{P}}$ANDA





Backward End Cap Calorimeter and MVD will be removed

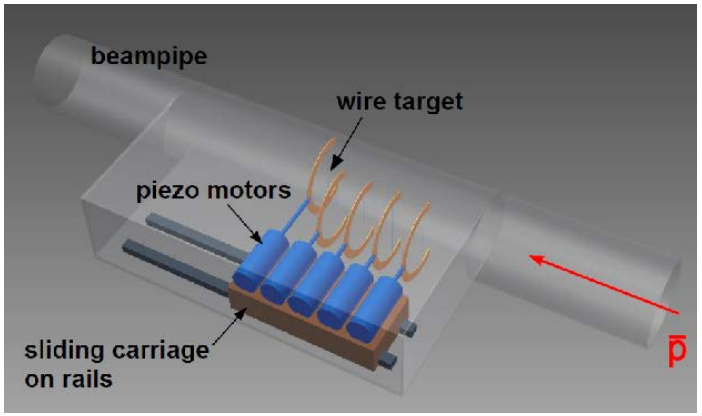
- Modular structure
- Dedicated beam pipe/target system

by cortesy of D. Rodriguez, M. Steinen,

Primary Target System

Task of the primary target:

production of slow Ξ^-



Requirements:

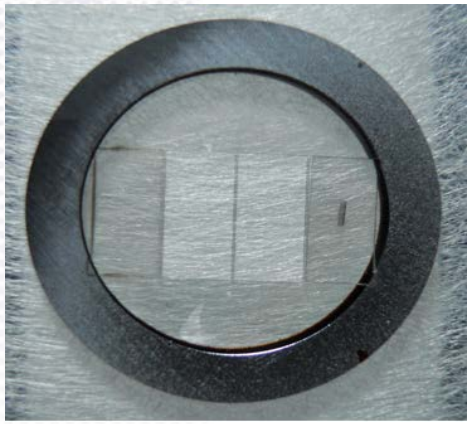
- low hadronic background in backward direction
- constant luminosity of $\bar{p}$-beam

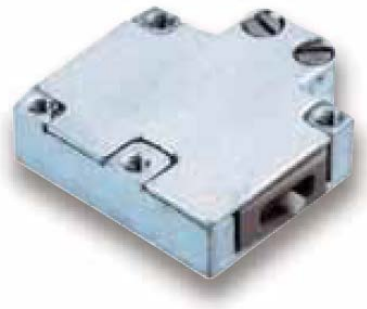
→ beam losses, mainly due to coulomb scattering, must be kept low

→ ^{12}C micro-wire target with thickness 3 µm, width 100 µm

Insertion of the wire target into the beam pipe

- Piezo-motors : easy replacement
- control of the interaction rates by steering beam and target

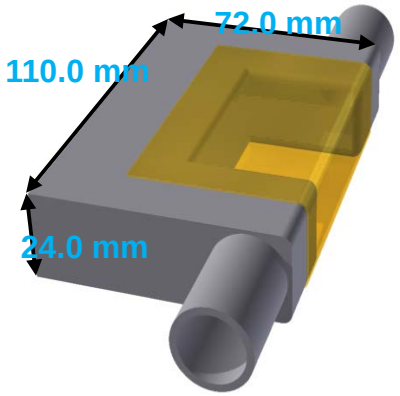




by cortesy of F. Iazzi and S. Bleser

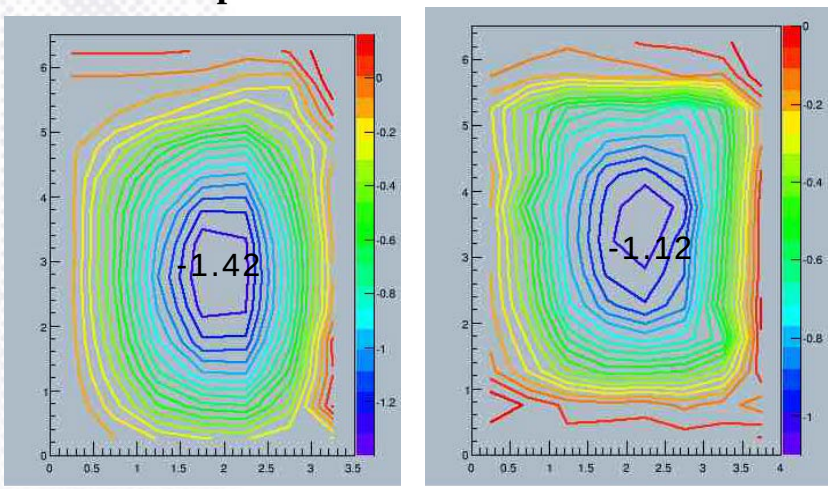
Performance of the target chamber

Performance of the target chamber : with different shapes, materials (brass, Ti, AlMg, Kapton) and thicknesses

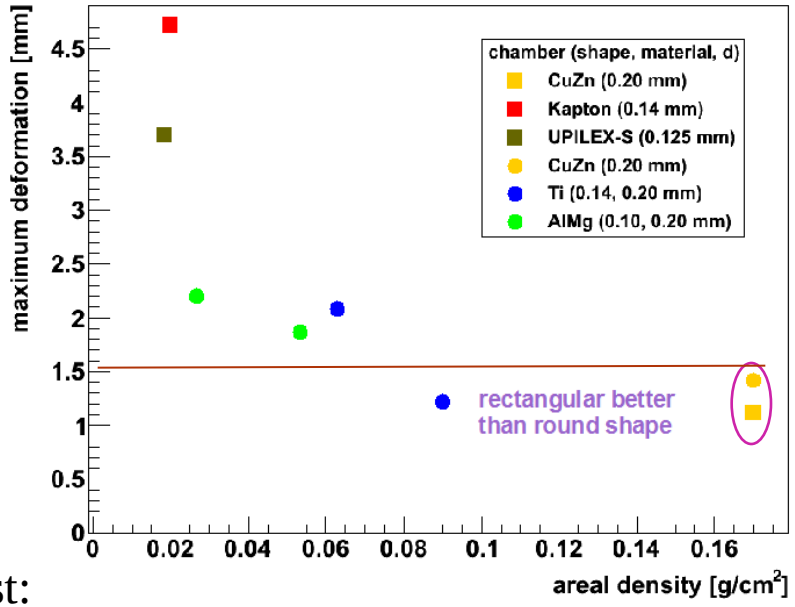


- Mechanical stability (thickness) under vacuum
- Minimum influence of the material budget on the stopping Ξ^- as well as photon absorption

Example : Brass 200 um



by cortesy S. Bleser



Final Test:

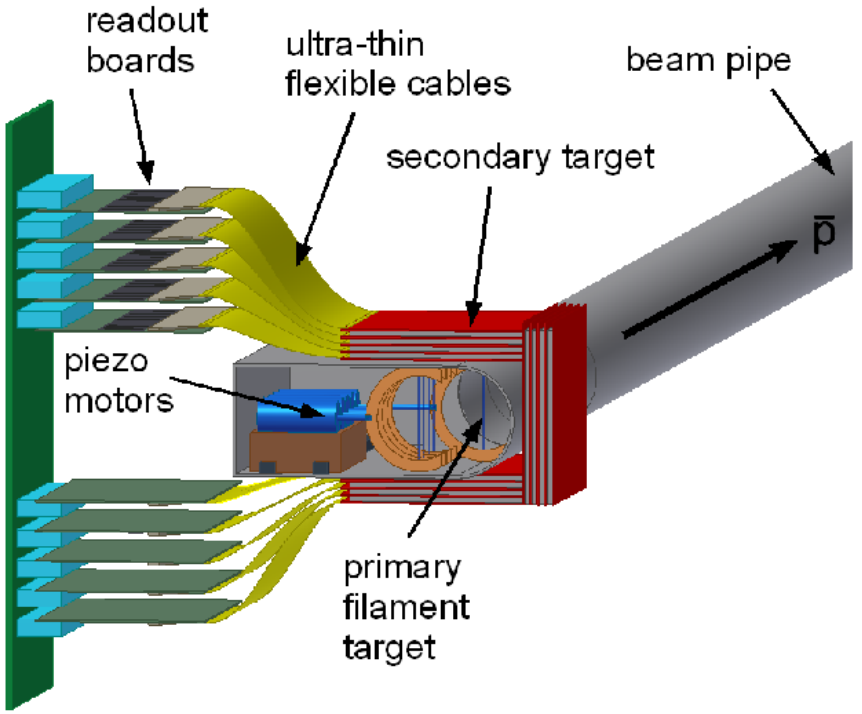
- Titanium 200 µm and AlMg 300 µm on rectang.Frame

Alternative : Boron Carbide Foil and Absorber

Secondary Active Target

Task of the secondary active target:

- Geometry: compact structure determined by the Ξ^- lifetime
- Stopping and absorption of Ξ^-
  Absorber layers : ^{9}Be , $^{10,11}B$, $^{12,13}C$
- Detection of charged decay products by the active volume
  (μ-strips silicon layers)



Requirements:

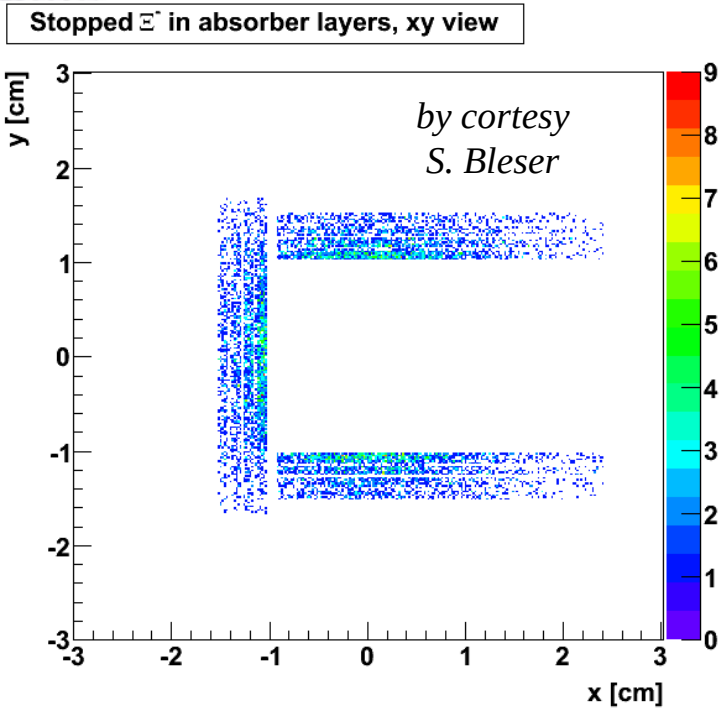
- Feasibility of Silicon Strips Detector in direct contact with absorbers

Ongoing activities :

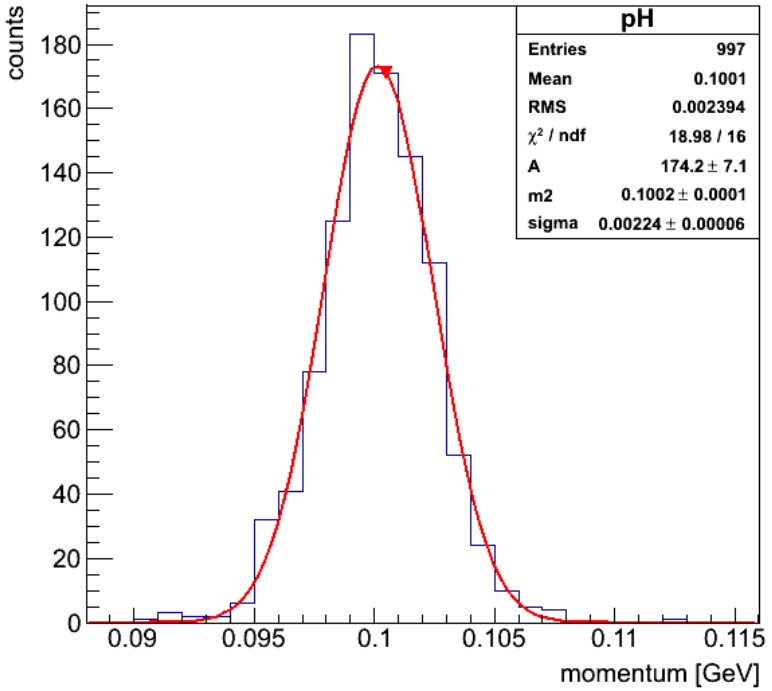
- Minimization of additional material budget on detecting volume:
  - Ultra-thin Al-Polyimide readout cables
  - Effect of the length on the detector analogue signals

Compromise between Tracking and Stopping Power

Momentum distribution of stopped Ξ in the secondary active target



Momentum resolution of 0.1 GeV/c pions



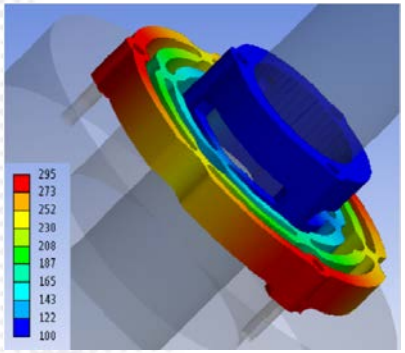
- Only those with a momentum below 500 MeV/c can be stopped in absorber
- Most of the Ξ stop in the first absorbers layers (reducing the material budget)

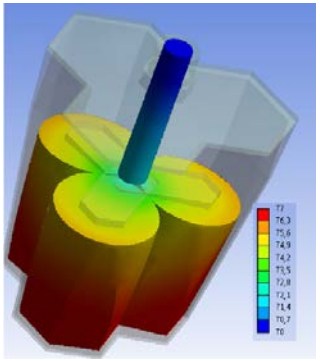
- Δp/p ~ 2.3 % with an improved Tracking Algorithm

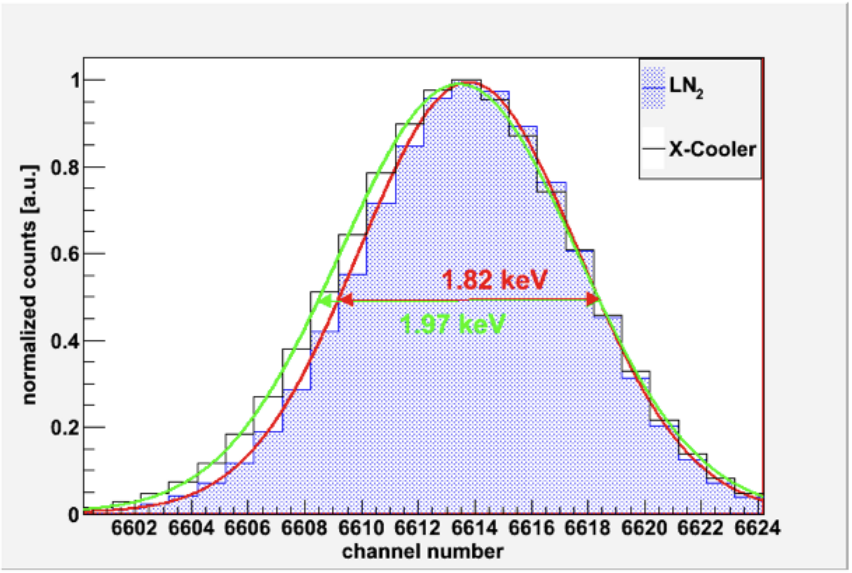
Toward a prototype of HPGe Cluster Array

- Limited space :

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

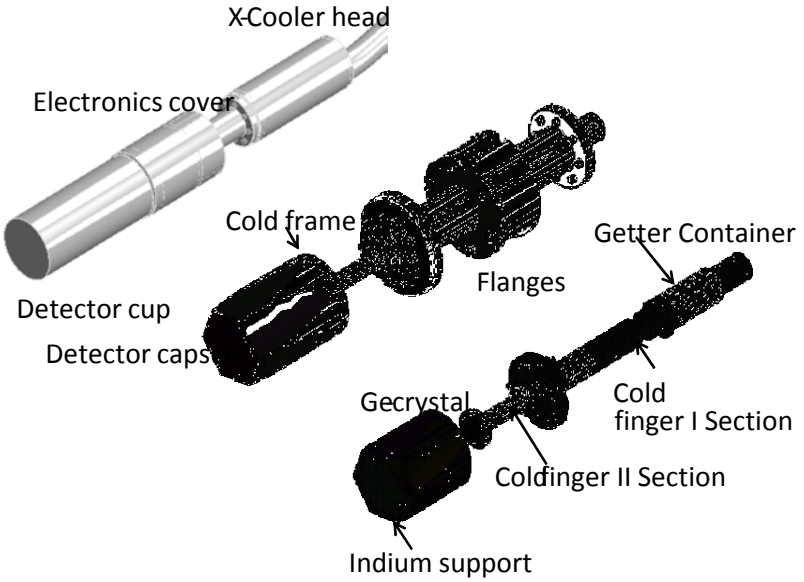






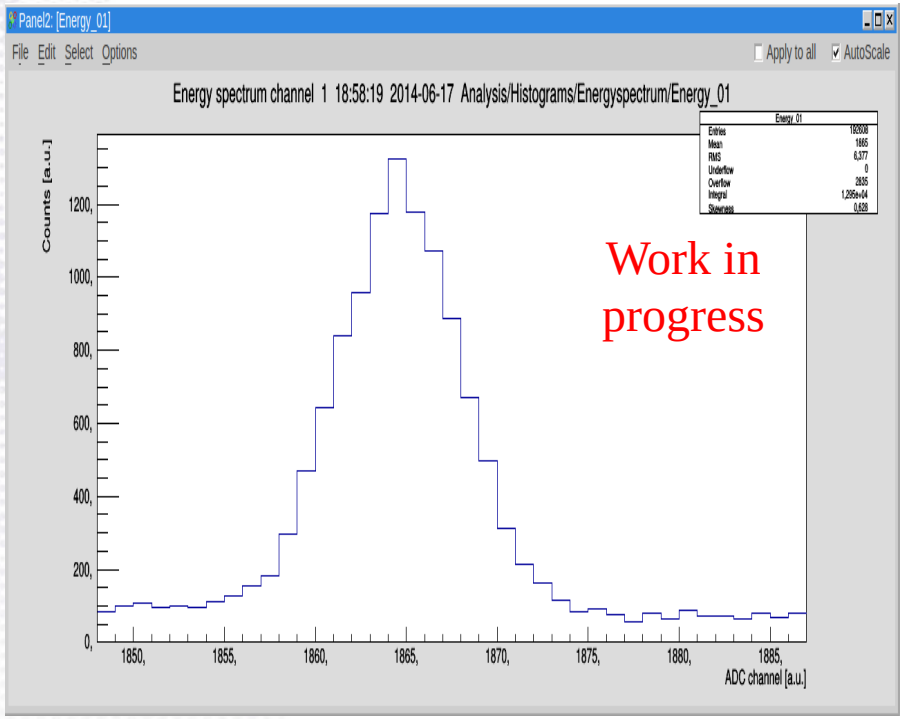
- Ongoing activities: High Rate environment:
  - Radiation Damage studies with a single crystal prototype at COSY
  - Pulse Shape Analysis

by cortesy of M. Steinen and I. Kojoujarov

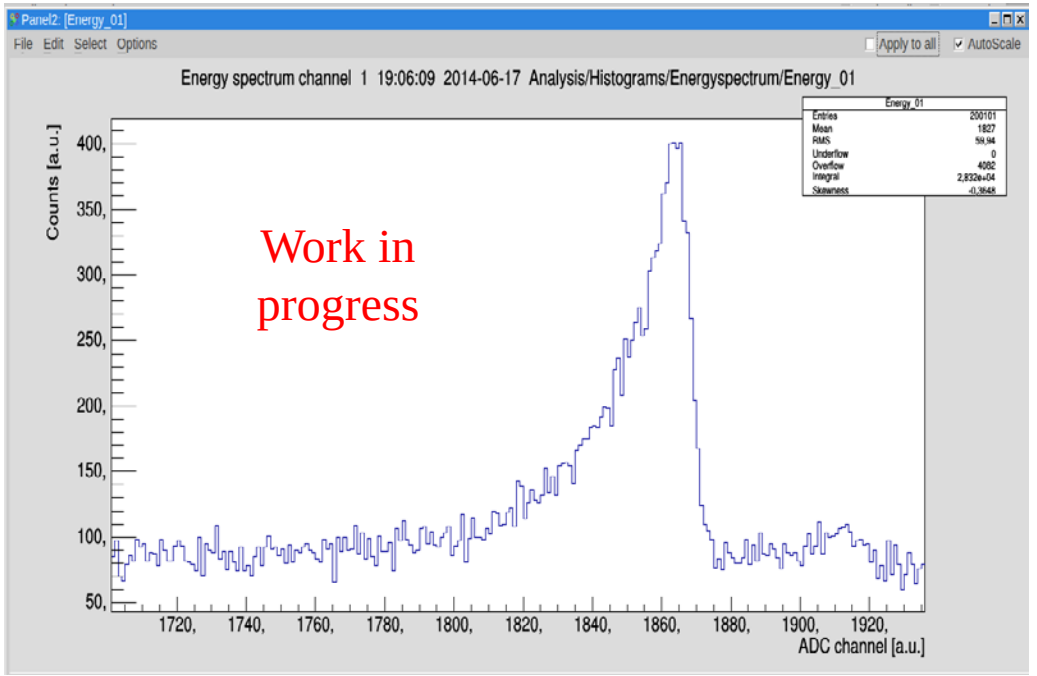


Radiation Damage at COSY

- Expected 3 10^9 n/cm^2 accumulated over 3 months of $\overline{\text{P}}$ANDA conditions
- First Beam Test end of 2013 / June 2014
  - Thick Carbon target in beam (~ 2.78 GeV/c protons) for particle production background
  - ^{60}Co source
- Ongoing Activity : conversion from beam doses to Neutron flux



Before Irradiation

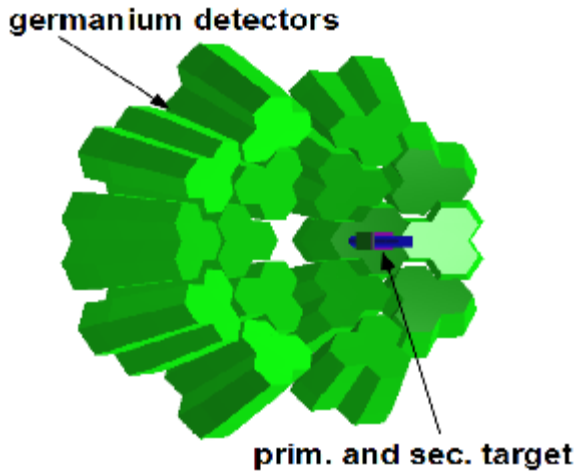


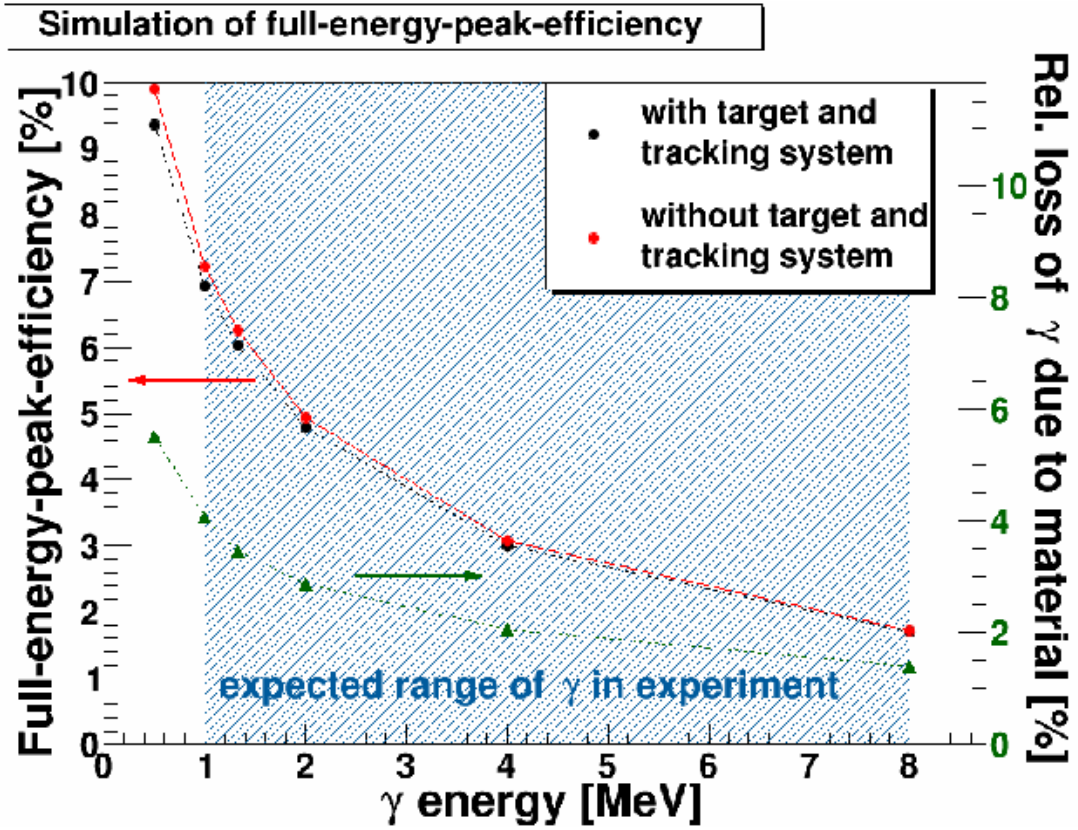
After Irradiation

Optimization of the geometrical acceptance

by cortesy of M. Steinen

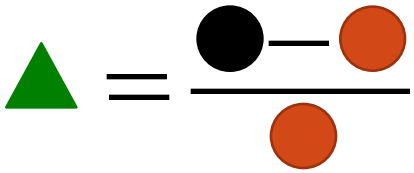
- Effect of hadronic background from primary interaction at backward angles





- Pandaroot framework

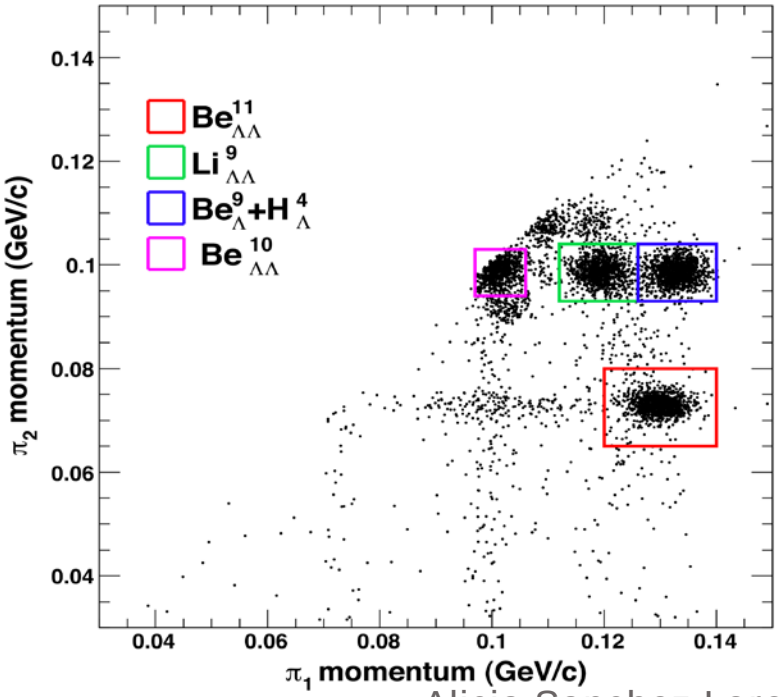
- Relative loss of γ,



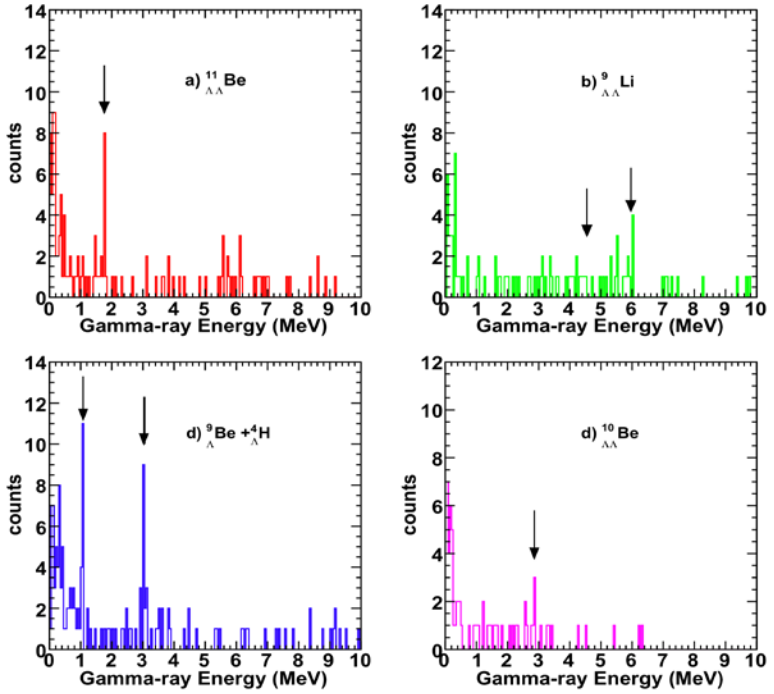
Identification of ΛΛ-Hypernuclei at PANDA

- 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)*

$\pi + \pi$ correlation



γ Energy spectra



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 $\Xi^- + \bar{\Xi}^+$ pairs in nuclei at moderate momenta
- Need for a devoted detector setup inside the PANDA spectrometer.
- Activities toward a hypernuclear detector setup are in progress.

the panda collaboration

More than 400 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
U & INFN Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
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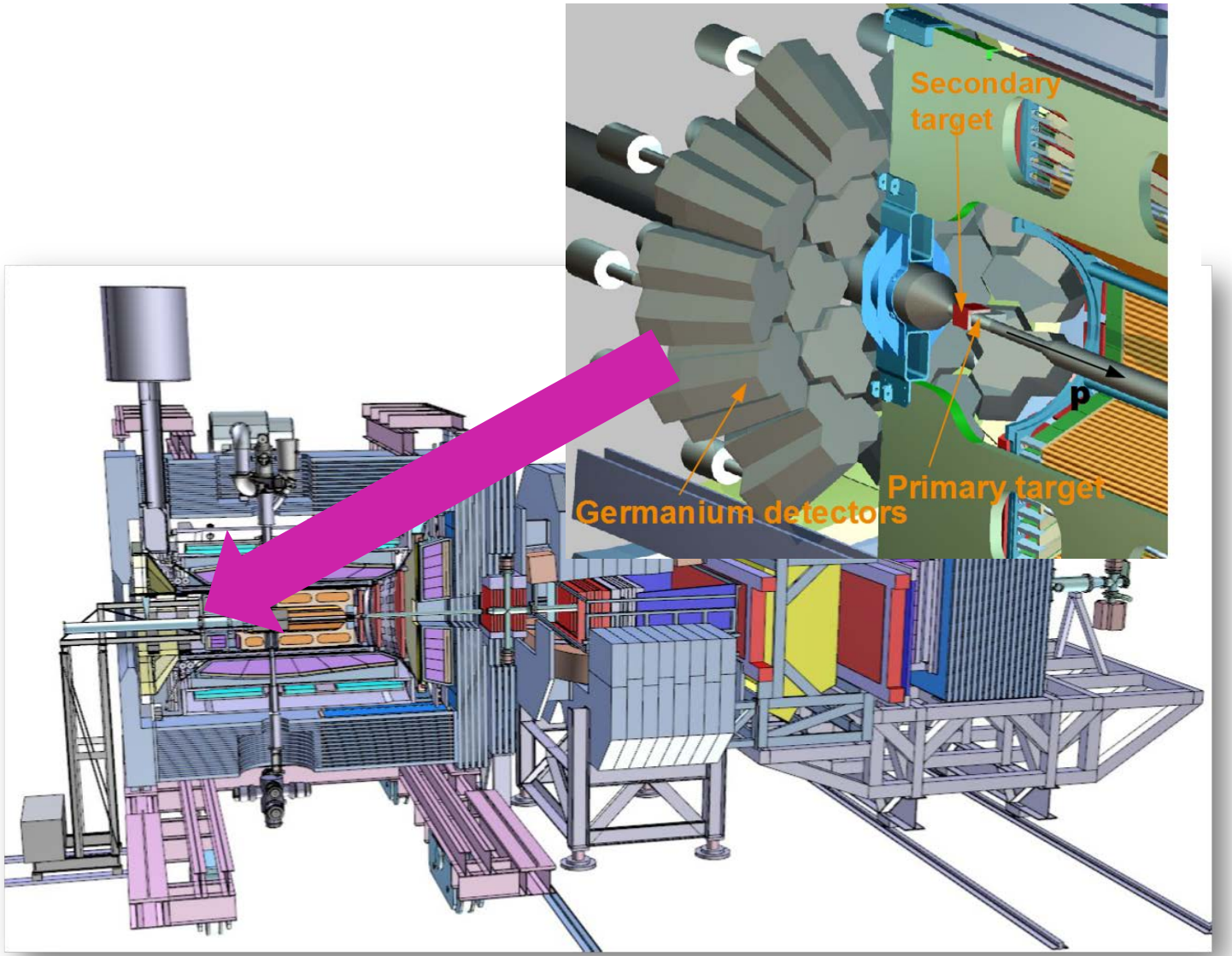
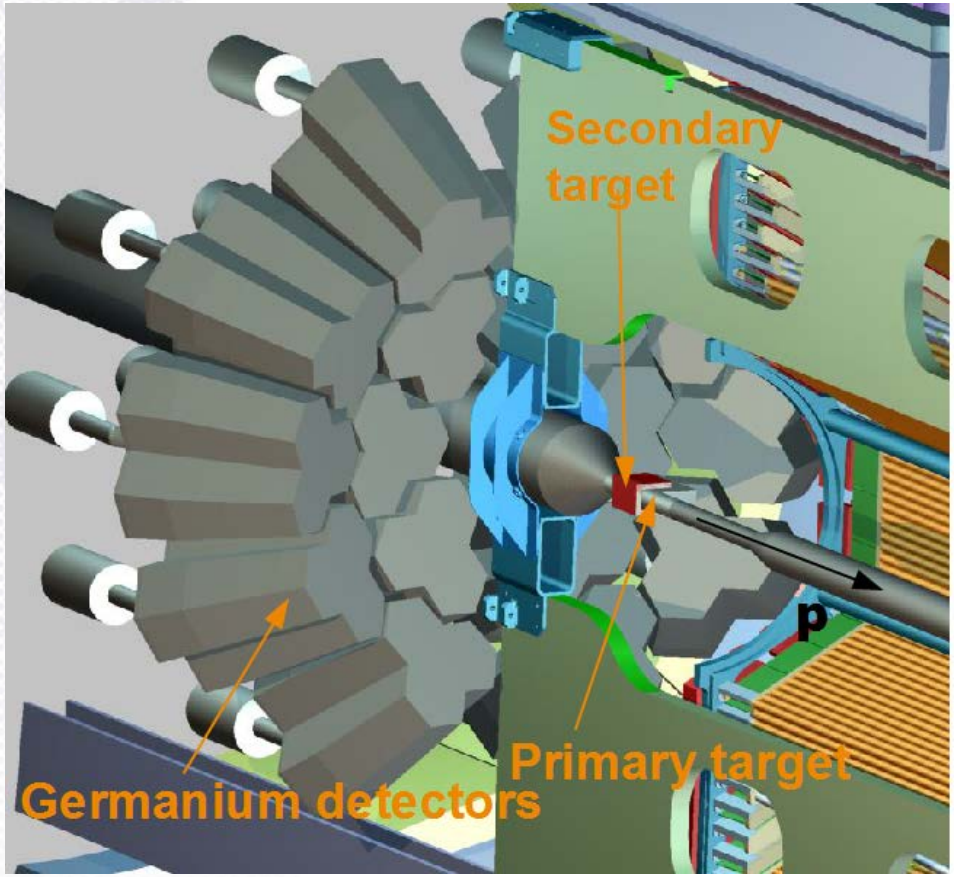
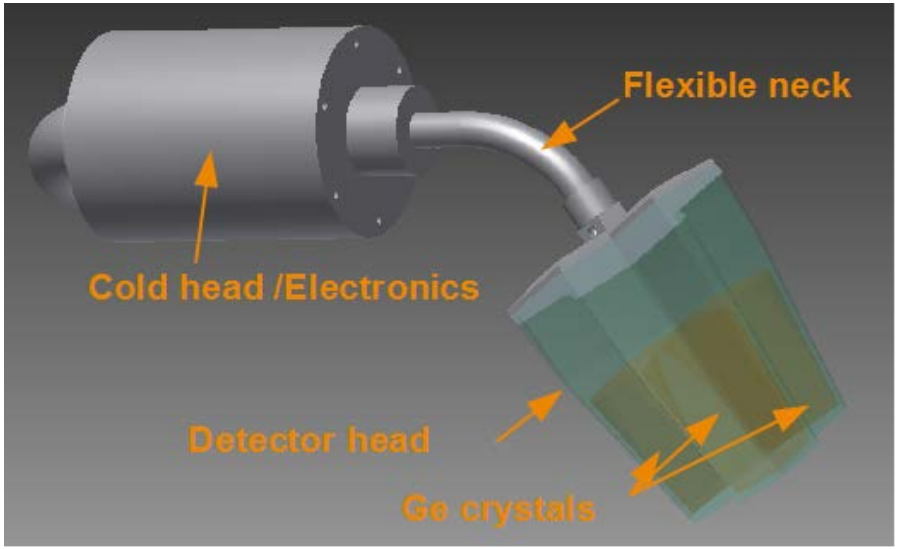
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw


Secondary target
p
Primary target
Germanium detectors

γ- Detection

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

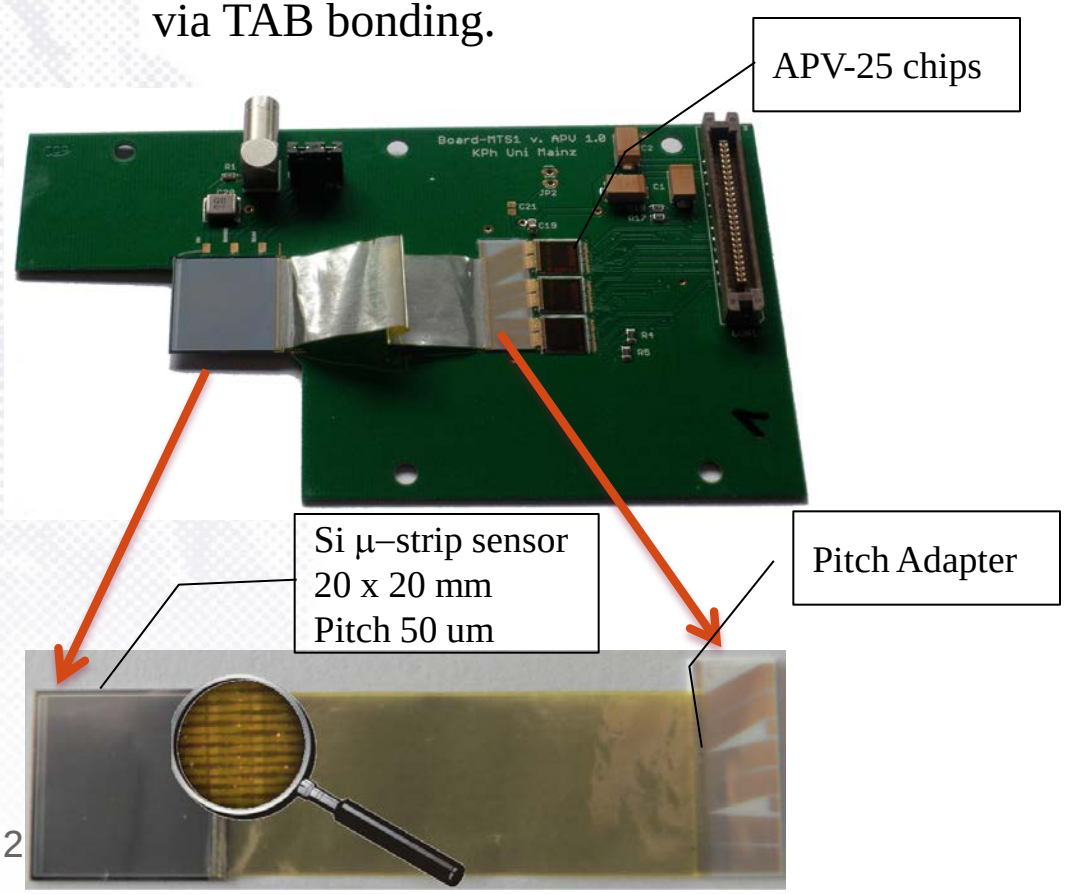


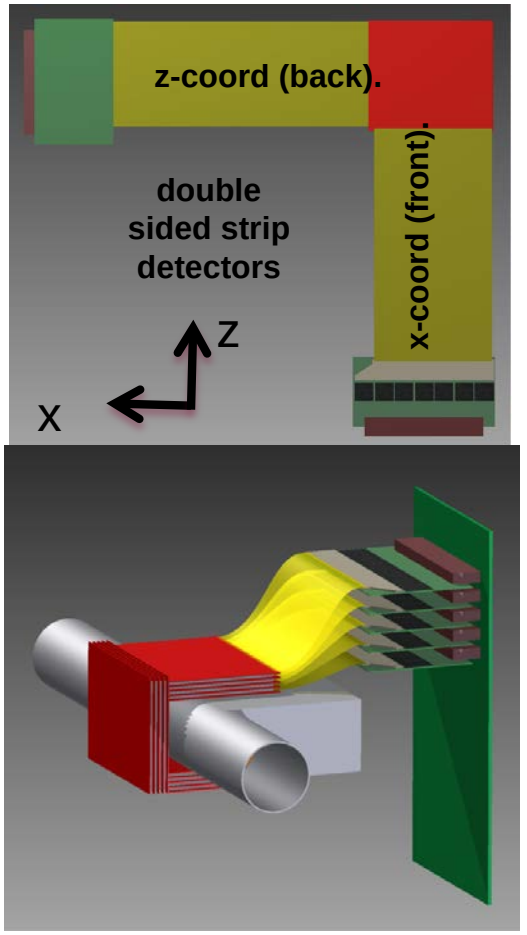


Effect of microcables on detector analog signals

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.



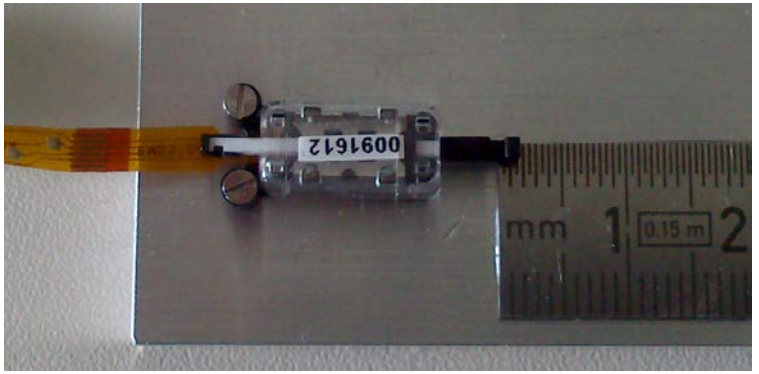


Piezo Motor as steering device

Piezo motor:

PiezoWave Linear 0.1 N

Manufacturer: PiezoMotor Uppsala AB



Size: 14.0 mm x 7.2 mm x 4.4 mm

Specifications:

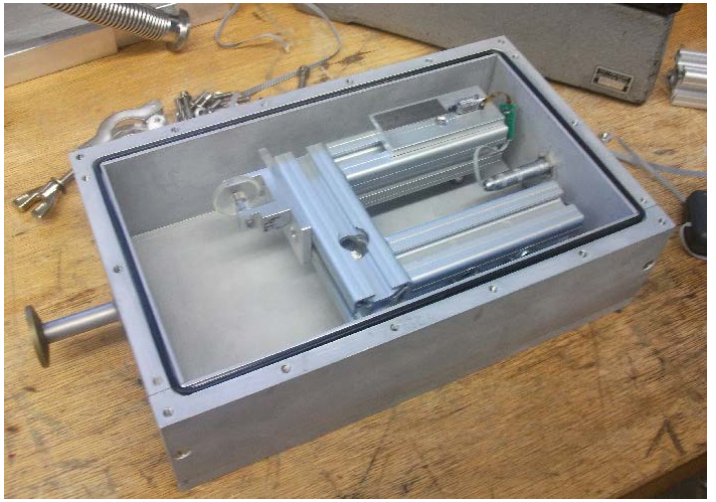
Stroke max: 8 mm

Average step: 0.5 - 1.0 µm → 0.95 µm

Dynamic force: 0.1 N → 0.15 N

Holding force: 0.3 N → 0.88 N

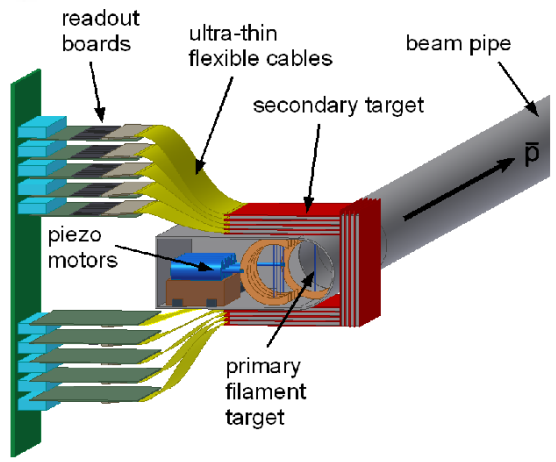
Piezo motor and vacuum chamber with holding frame:

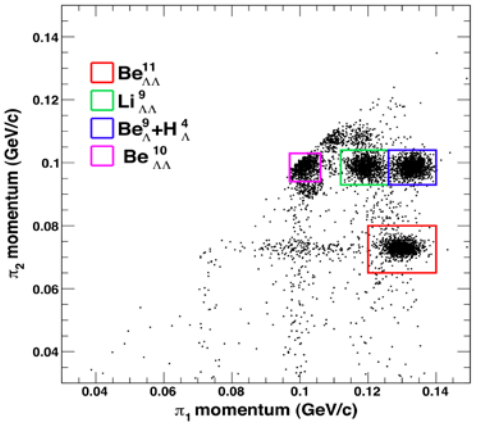


- proper running in vacuum proved for some weeks
- no influence of a magnetic field of 1.3 T

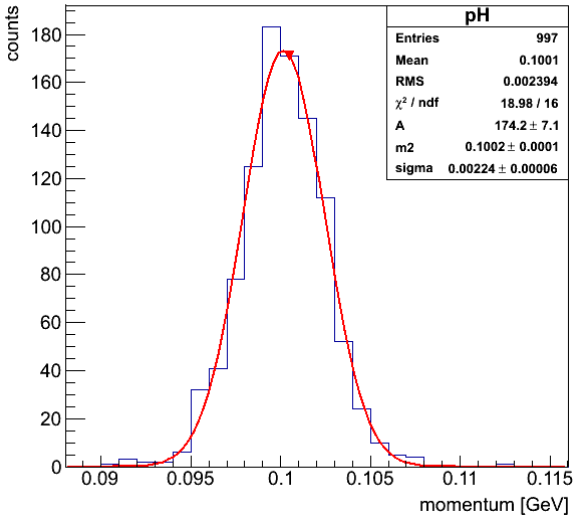
- next:
  Verification of Radiation Hardness : (TRIGGER/ COSY)

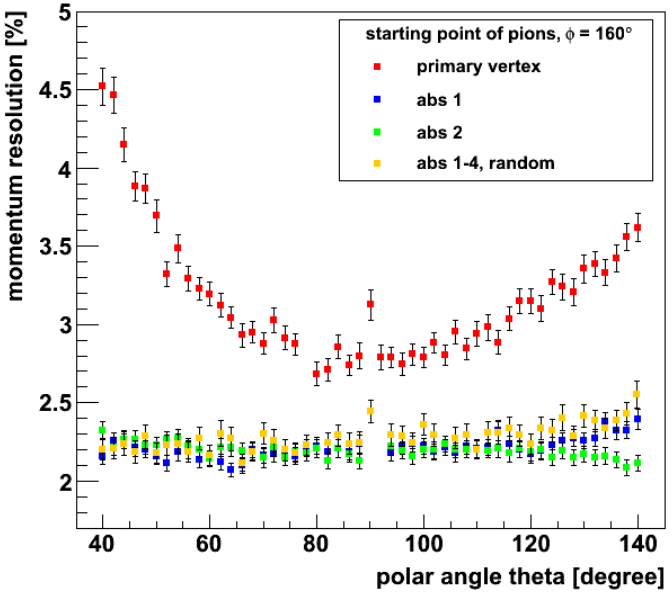
Low momentum pion tracking





Status of 2009
simplifying assump.
P res. 2%





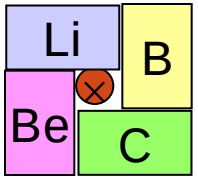
Present results:

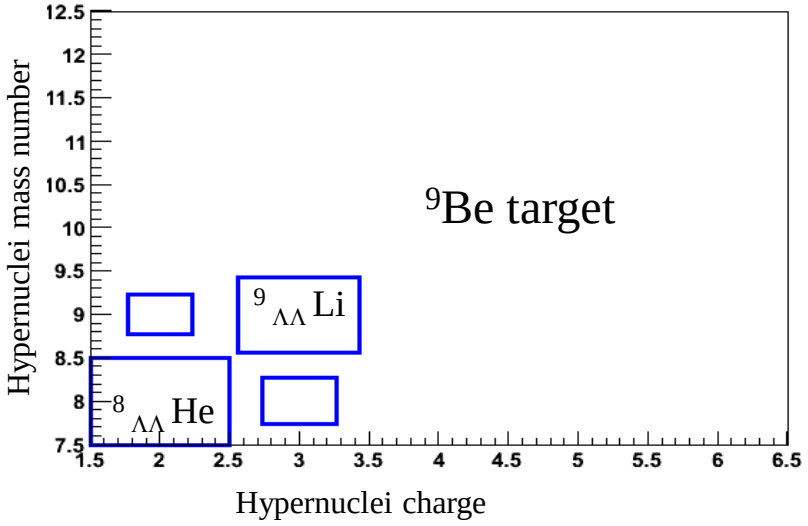
P res ~ 2.3 %
Improved Tracking Alg.

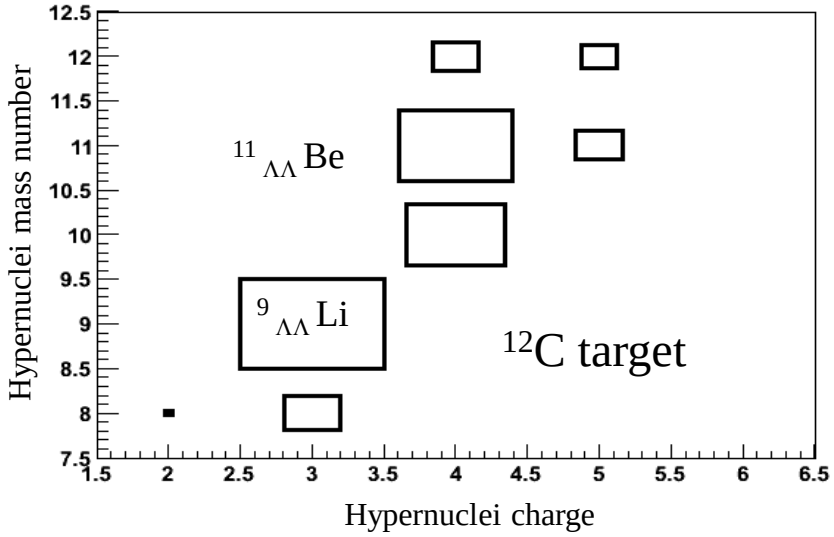
Identification of ΛΛ-Hypernuclei

- 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.



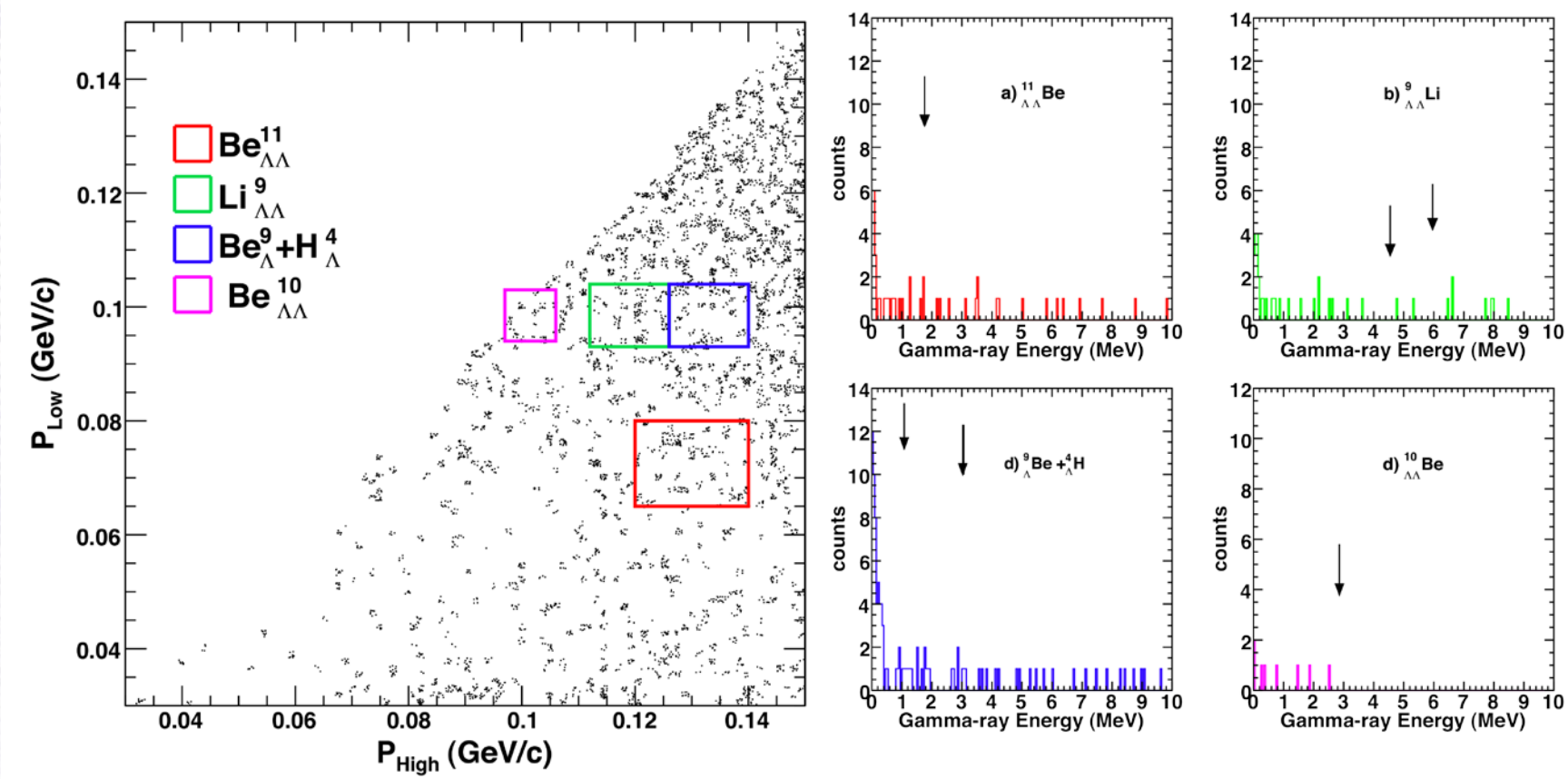




⇒Each target offers a strategy for the unique assignment of observable transitions by comparing the expected yields

Free Ξ⁻+Ξbar background contribution

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



p + ^{12}C background contribution

- More statistic is needed