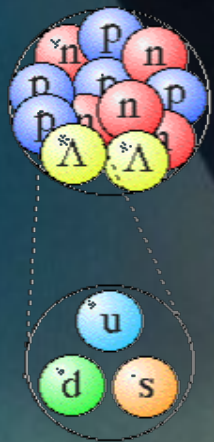
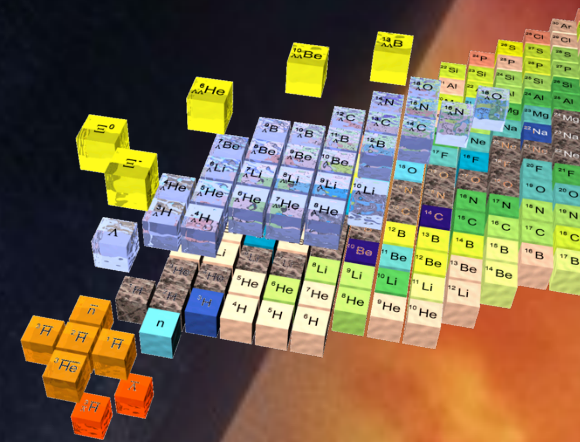
Hypernuclei, the Y-Generation





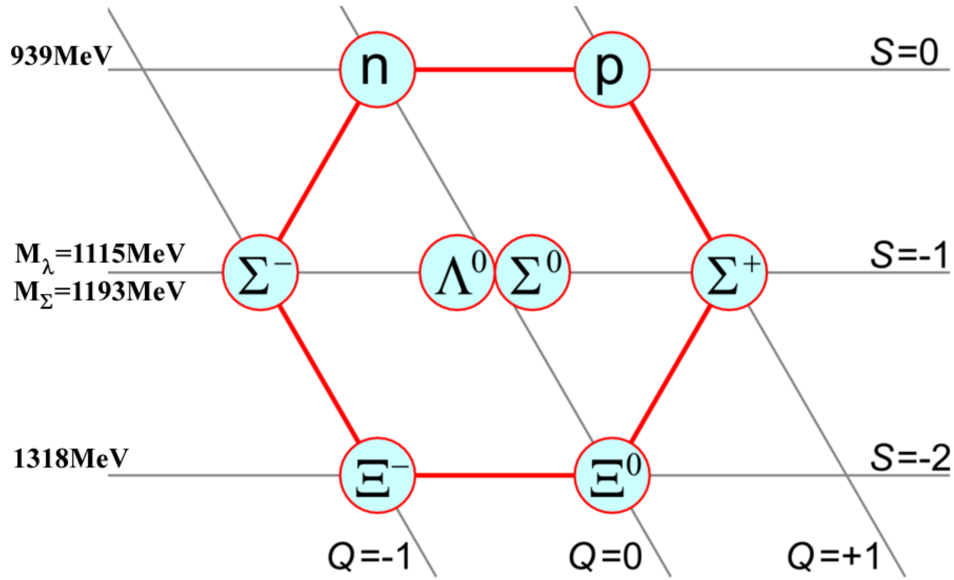
,

Alicia Sanchez Lorente
on behalf of the PANDA Collaboration

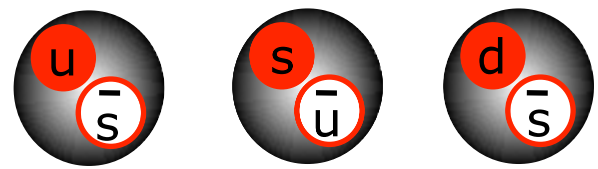
Hadrons Quark-Structure

Matter with Strangeness

Conventional Matter

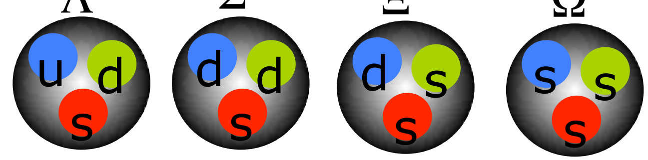


K^+ K^- K^0



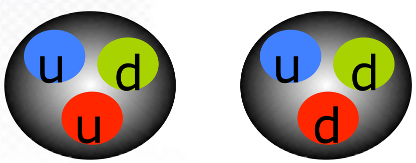
Hyperons and Kaons

Λ^0 Σ^- Ξ^- Ω^-



Nukleons

Proton Neutron



Super Powers of Λ− Hyperons and Kaons

	Λ - Hyperon	K± - Kaon
Mass M:	1115.683 ± 0.006 MeV/c^2	493.677 ± 0.016 MeV/c^2
Lifetime τ:	263 ± 2 ps	12.384 ± 0.024 ns
$ctau$:	7.89 cm	3.713 m
$Charge\ Q$:	0	± 1
Isospin T:	0	$\pm 1/2$
Strangeness S:	-1	± 1
Decay	$\Lambda \rightarrow p + \pi^-$ $63.9 \pm 0.5\%$	$K^+ \rightarrow \mu^+ + \nu_\mu$ $63.43 \pm 0.17\%$
	$n + \pi^0$ $35.8 \pm 0.5\%$	$\pi^+ + \pi^0$ $21.13 \pm 0.14\%$ ...

Strong Interaction preserves strangeness,

- Hyperons decay weakly, relative long lifetime
- Hyperons can be bound to nucleus via Y-N interaction

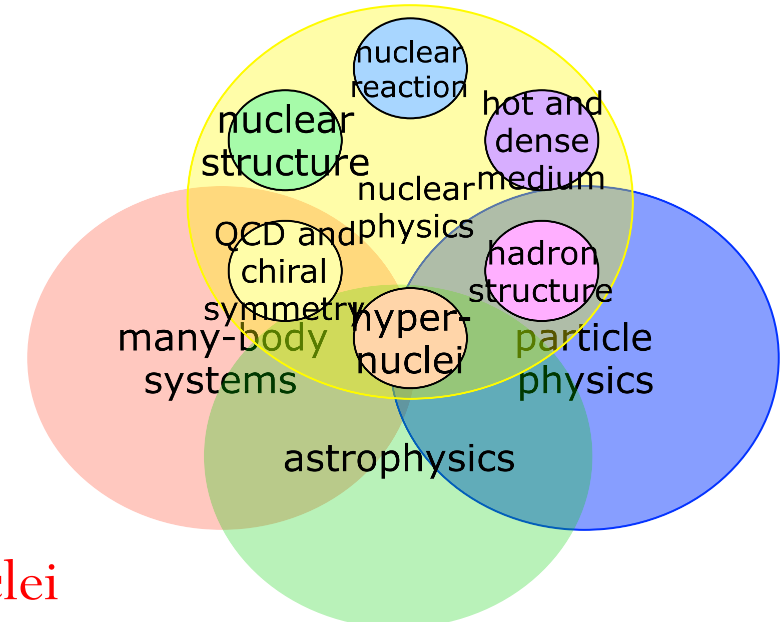
HYPERNUCLEI

Hypernuclei as „Lab-School“ for baryonic Systems

Hypernuclei provide a bridge between nuclear physics and QCD

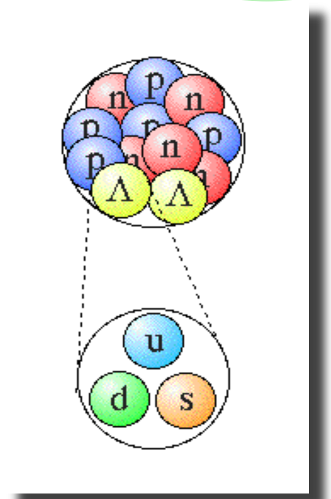
FINUDA
JPARC
KAOS

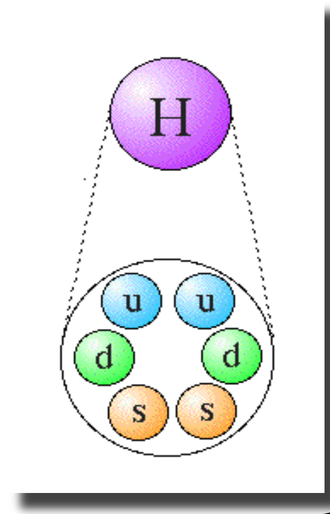
- **S=-1**: Λ-, Σ –hypernuclei
  - Strange baryons in Nucleus
  - Nuclear structure, new Symmetries
  - Hyperon – Nucleon Interaction
  - Weak Decay



FLAIR
PANDA

- **S=-2**: Ξ- Atoms, Ξ-, 2Λ-hypernuclei
  - Nuclear structure
  - Hyperon – Hyperon Interaction, $\Delta B_{\Lambda\Lambda}$
  - H-Dibaryon
  - Weak Decay



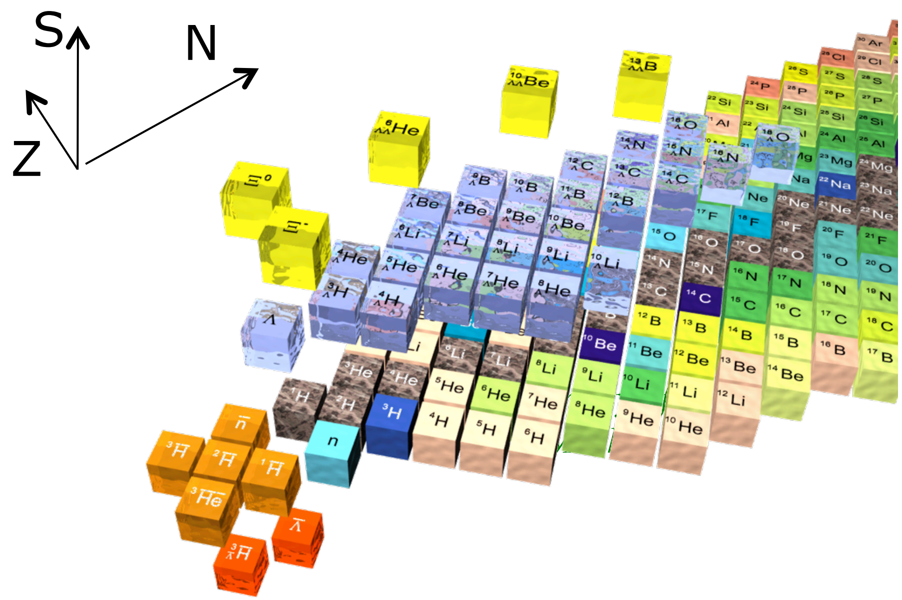


The Present Nuclear Chart

Present limitations

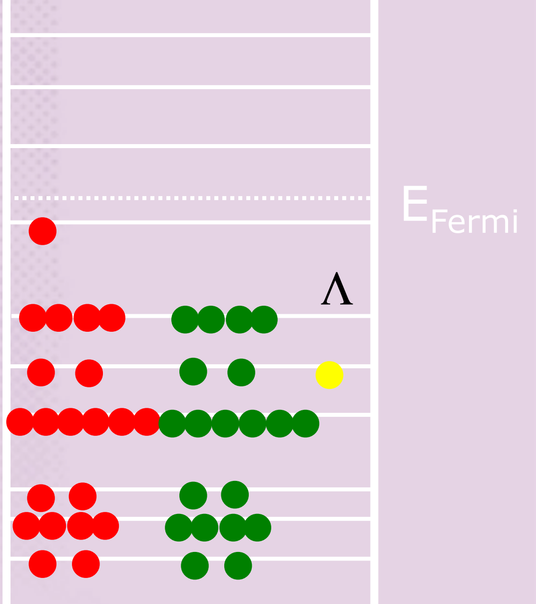
only single Λ-hypernuclei close to valley of stability (~50)

only very few ΛΛ-hypernuclei events



Internal nuclear shell are NOT Pauli-blocked for hyperons

$$\left|{}^{A}_{\Lambda}Z\right\rangle = \left|{}^{A-1}Z \otimes \Lambda\right\rangle$$



number of baryons N+Z+Y

element = total charge (not number of protons)

(number of) hyperons Y

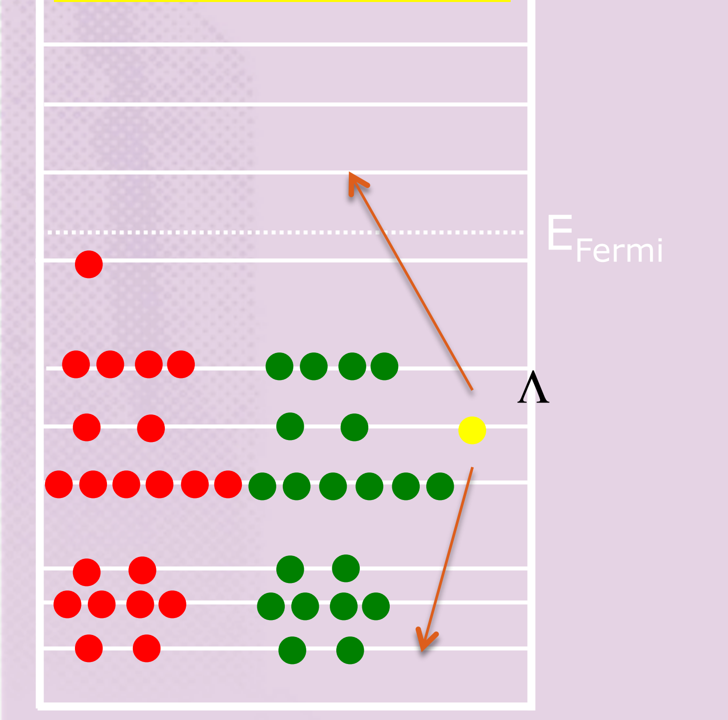
$^{B}_{Y}X$

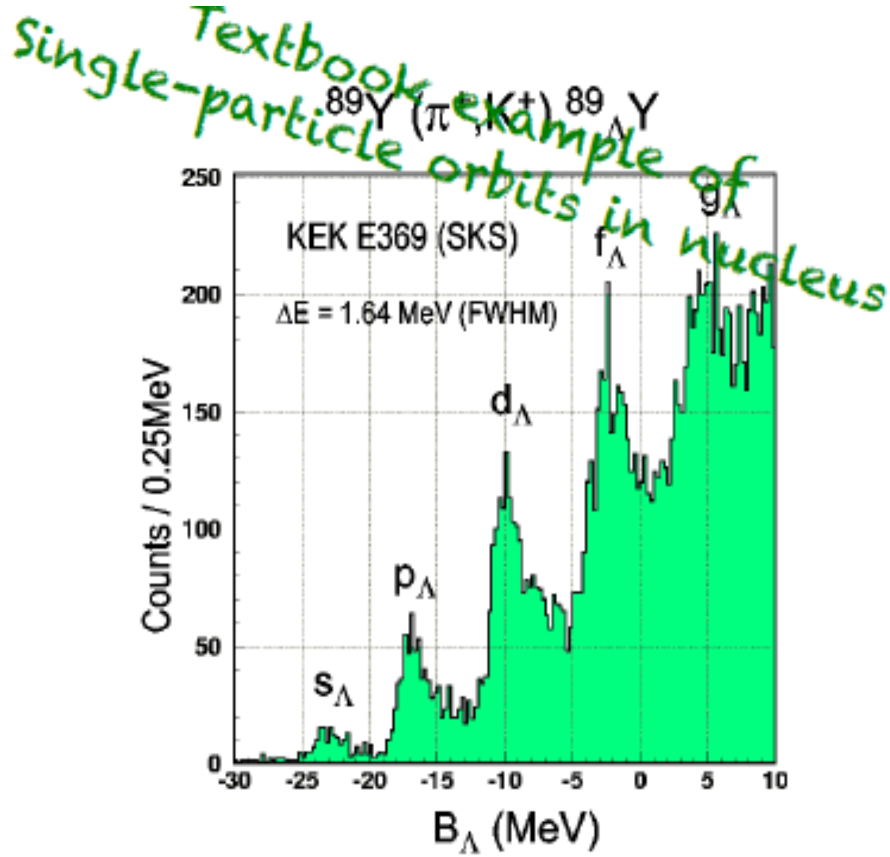
The Present Nuclear Chart

Present limitations

- only single Λ-hypernuclei close to valley of stability (~50)
- only very few ΛΛ-hypernuclei events

$$\left|{}^{A}_{\Lambda}Z\right\rangle = \left|{}^{A-1}Z \otimes \Lambda\right\rangle$$

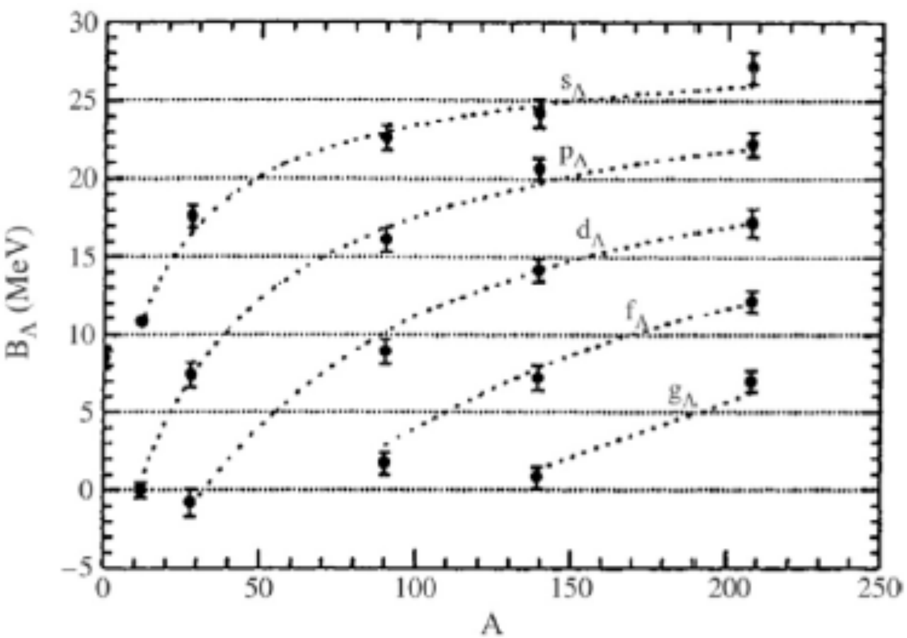




Hotchi et al., PRC 64 (2001) 044302

$$-B_{\Lambda} = M_{HYP} - (M_{Core} + m_{\Lambda})$$

Λ− Nucleon Interaction



Nuclear potential of Λ
V_0^Λ =-30MeV (c.f.U_N =-50MeV)

ΛN force is **attractive** but weaker than NN

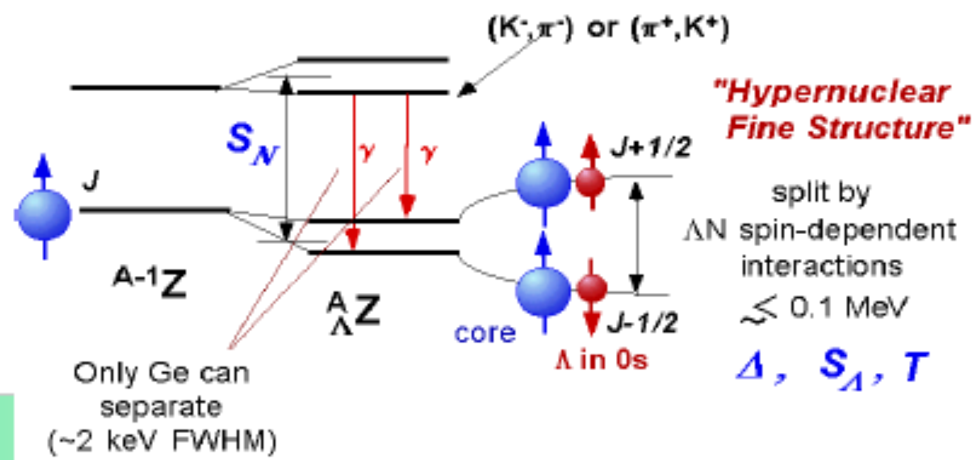
Better resolution is necessary for ΛN spin-dependent forces, ΛN-ΣN force, ..

Woods–Saxon for the Λ hypernuclear potential

$$U_\Lambda = V_0^\Lambda f(r) + V_{LS}^\Lambda \left(\frac{\hbar}{m_\pi c}\right)^2 \frac{1}{r}\frac{\mathrm{d}f(r)}{\mathrm{d}r}\boldsymbol{ls}$$

$$f(r) = [1 + \exp((r - R)/a)]^{-1}.$$

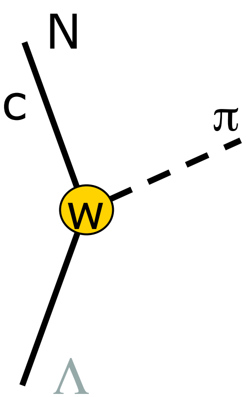
Low-lying levels of Λ Hypernuclei



HYP: What?

Weak decay of hypernuclei

free Λ decay



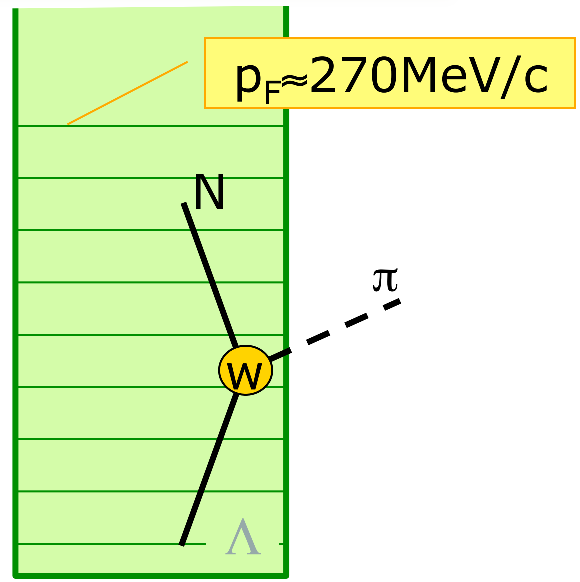
$\Lambda \rightarrow p\pi^- + 38\text{MeV}$ (64%)

$\Lambda \rightarrow n\pi^0 + 41\text{MeV}$ (36%)

$\tau_\Lambda = 263ps$

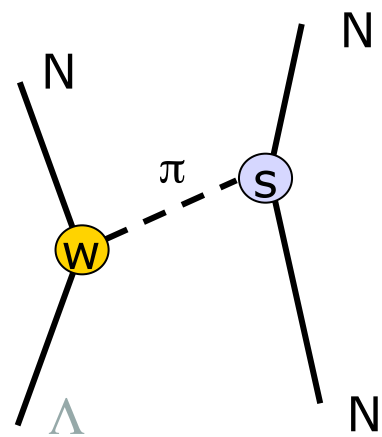
ΔI=1/2 rule

mesonic decay of hypernuclei



suppressed by Pauli blocking

non-mesonic decay of hypernuclei



$\Lambda p \rightarrow np + 176\text{MeV}$

$\Lambda n \rightarrow nn + 176\text{MeV}$

dominant in all but the lightest hypernuclei

▸ q~400 MeV/c ⇒ probes short distances of baryon-baryon weak interaction

How it began

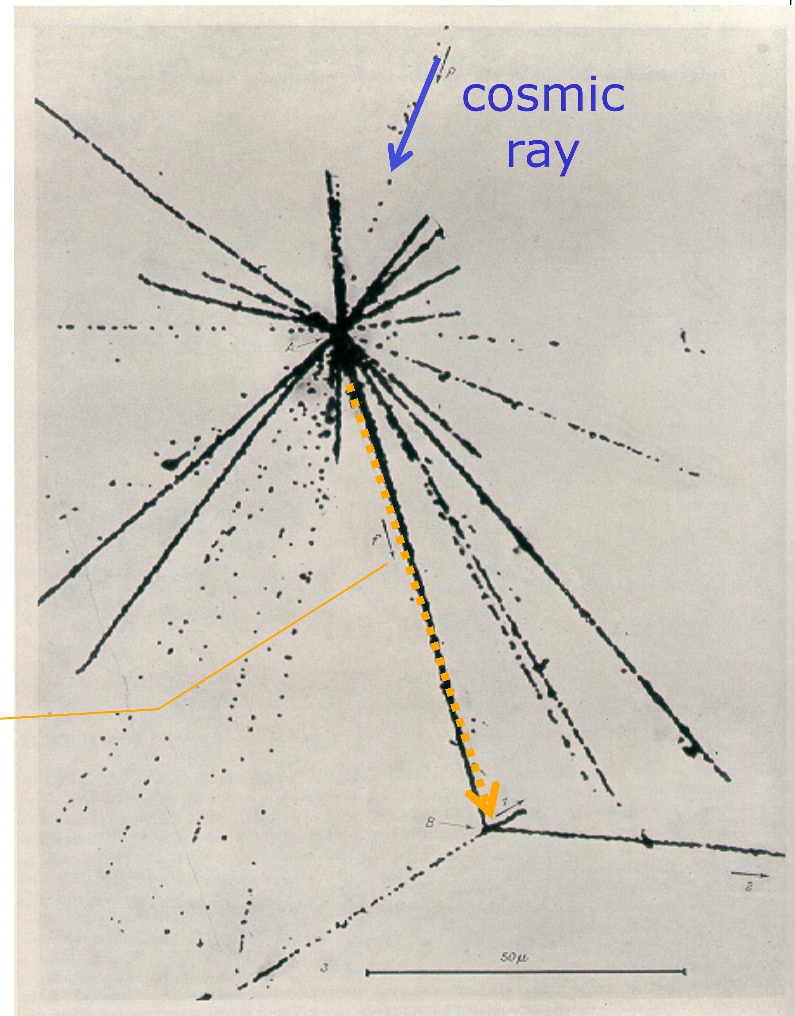
- Marian Danysz, Jerzy Pniewski, et al. Bull. Acad. Pol. Sci. III **1**, 42 (1953)
- Marian Danysz, Jerzy Pniewski, Phil. Mag. **44**, 348 (1953)

- A cosmic ray particle (E≈30 GeV) enters the emulsion from the top
- Interacting with a bromine or silver nucleus the particle creates an upper star.
  - 21 tracks: 9α+ 11H +1 $_{\Lambda}X$
  - Finally, $_{\Lambda}X$ disintegrates initiating the bottom star.
  - second star consists of four tracks:
    - 2 p,d,t or α
    - 1 π, p, d, or t
    - 1 recoil
  - energy release >140MeV

$$t > \frac{s}{c} : \frac{80\mu m}{300000 km/s} \approx 2.6 \cdot 10^{-13} s$$

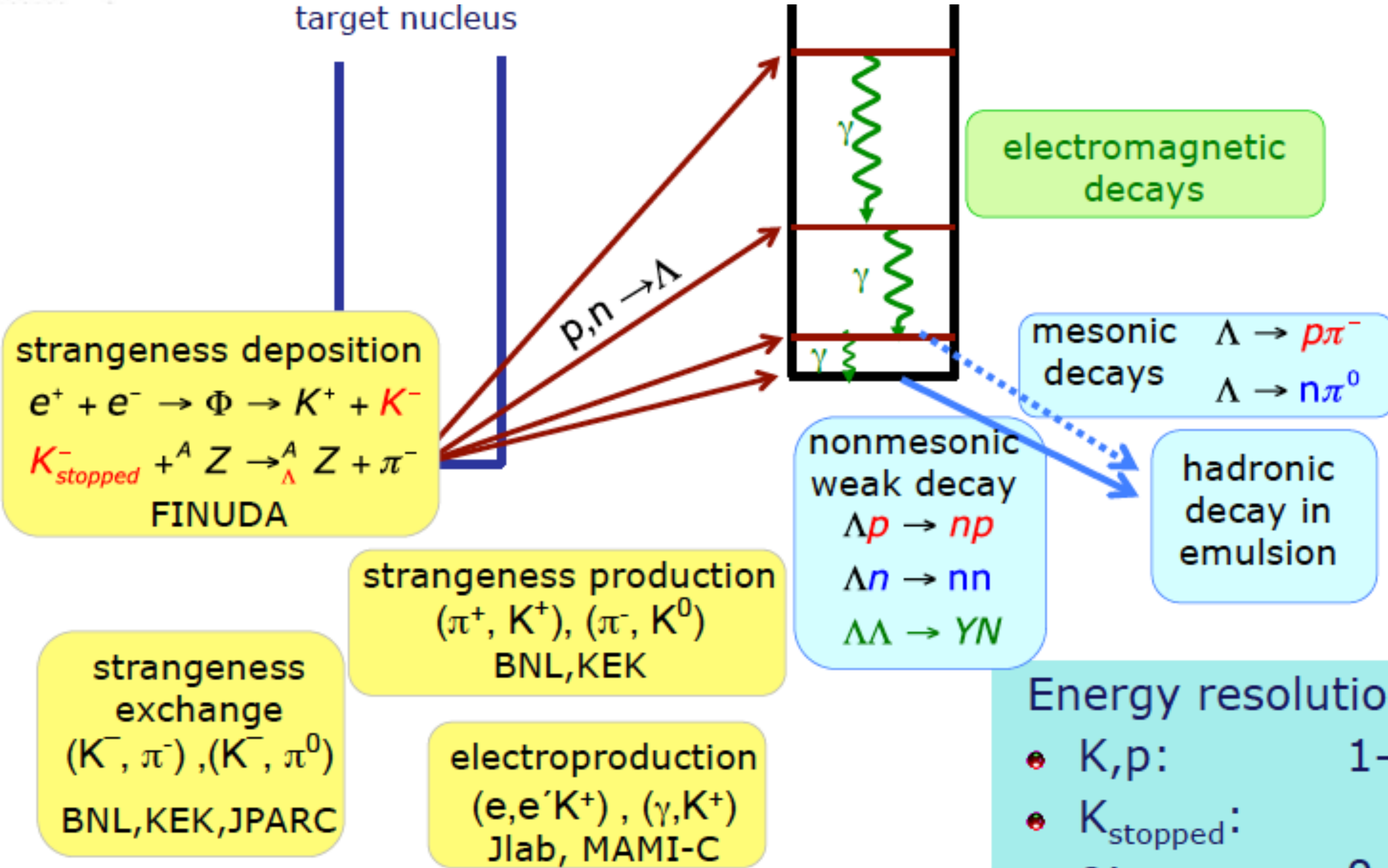
$$\tau(\Lambda) = 2.6 \cdot 10^{-10} s$$

$\Rightarrow$ typical for weak decay



- many associated particles in primary reaction

Λ− Hypernuclei Production



Energy resolution

- K,p: 1-2 MeV
- $K_{stopped}$: 1 MeV
- e: 0.5 MeV
- γ-transitions: 5 keV

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MAMI MAINZER MIKROTRON

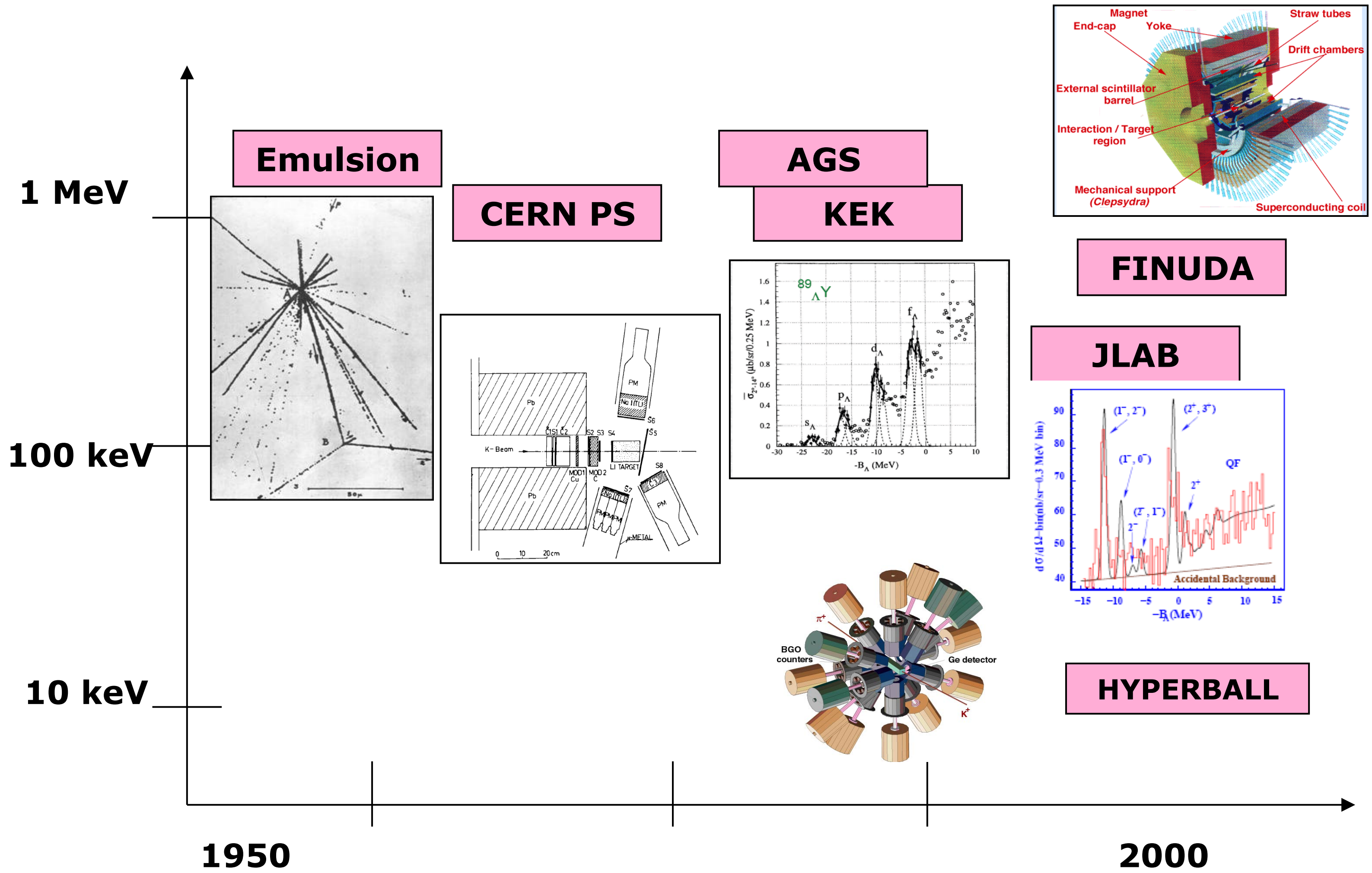
HELMHOLTZ GEMEINSCHAFT

Helmholtz-Institut Mainz

panda

Detection and Identification of Lambda Hypernuclei

Technical Advances



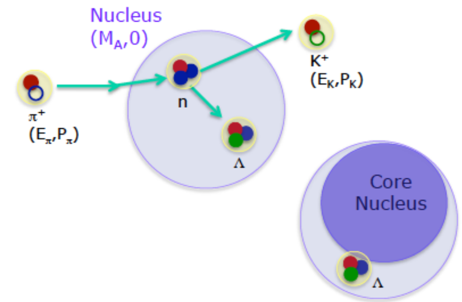
Nuclear Emulsion

- Cecil Frank Powell (1903-1969)
  - Nobel Prize in Physics 1950
  - 1. Speaker of 1. course at Varenna 1953
- Multiple layers of emulsion were historically the first means of visualizing charged particle tracks
  - very high positional precision
  - ionisation density (dE/dx)
  - range
  - 3-dimensional view of the interaction
- An emulsion is made, as for photographic film, of a silver salt, (AgBr), embedded in gelatine and spread thinly on a substrate.
  - grain size 0.2-0.5mm
  - during developement excited grains are reduced to elemental silver
- Data acquisition by automated means (e.g. by scanning the film with a CCD camera) has been found possible in some circumstances.

Tracking and Pattern Recog.

Extracting the inner Energy Level Structure

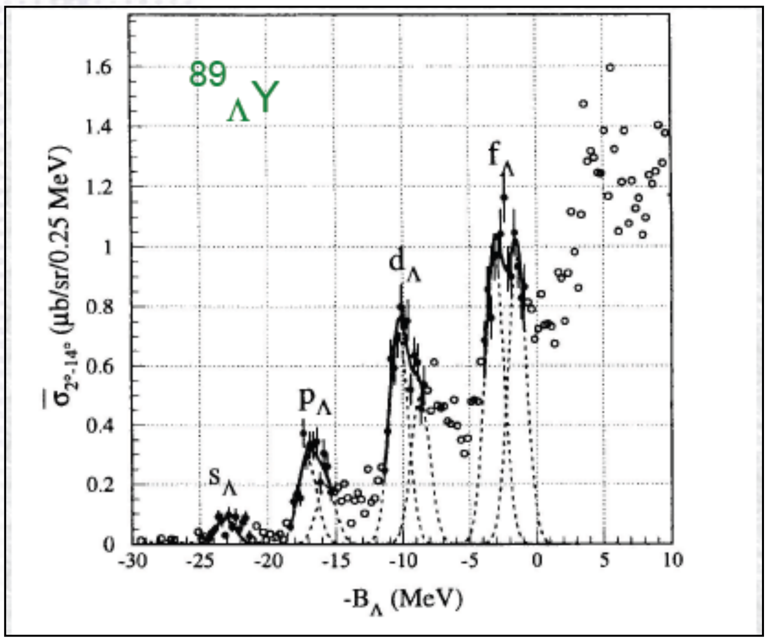
- Reaction Spectroscopy ; Initial and Final products, two-body kinematics,Missing Mass
- Decay Spectroscopy ; decay Products, γ-Spectroscopy

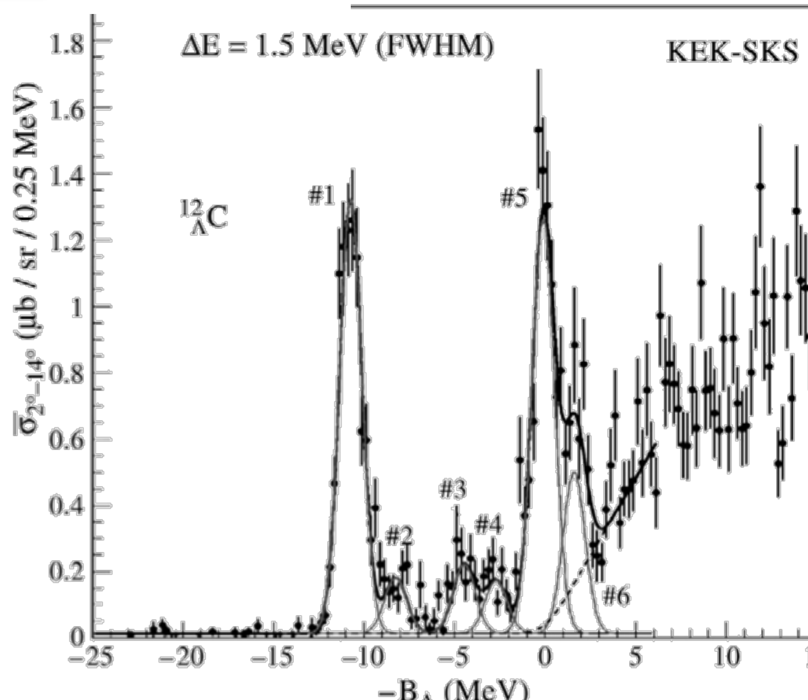


(π^-, K^+)

$$M_{HYP} = \sqrt{(E_\pi + M_A - E_K)^2 - (p_\pi - p_K)^2}$$

$$-B_\Lambda = M_{HYP} - (M_{Core} + m_\Lambda)$$





ΛΛ Hypernuclei at PANDA

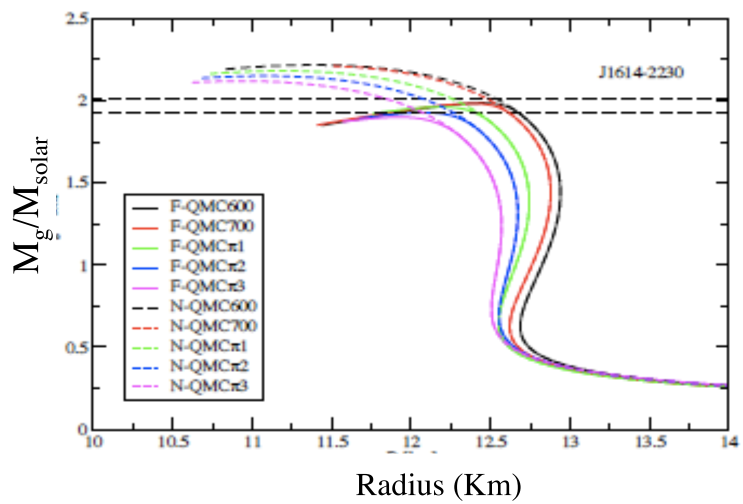
Double Strange Systems as Laboratory

Hypernuclei provide a bridge between nuclear physics and hadron physics

S = -2

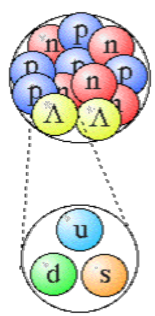
- Study of ΛΛ Hypernuclei offers additional information about the Y-Y interaction ($\Delta B_{\Lambda\Lambda} \sim B_{\Lambda\Lambda} - 2\,B_{\Lambda}$)
- relevant for

➢ 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

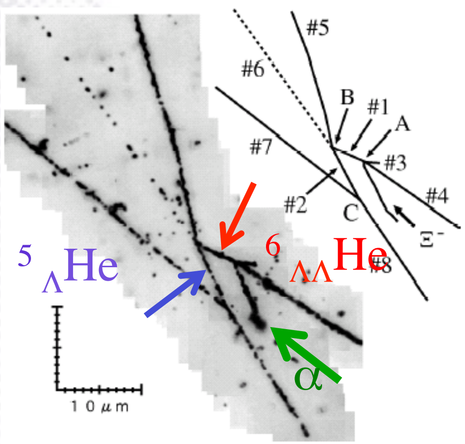


The Present Nuclear Chart

Present limitations

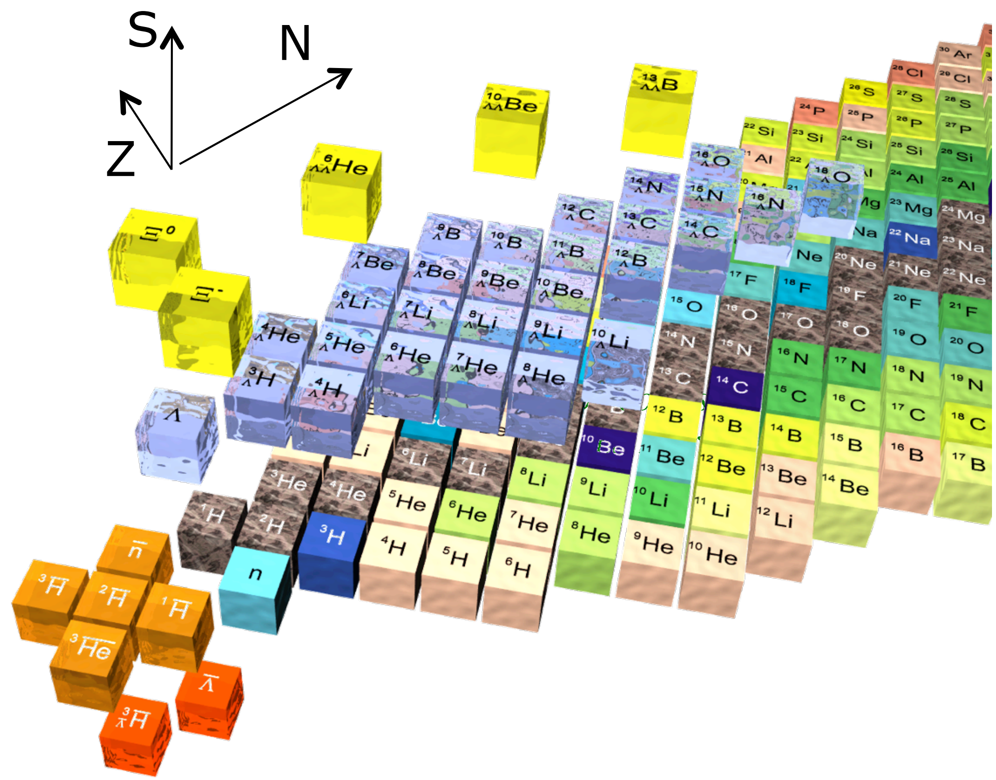
- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events

Nagara event



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

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



$^{B}_{Y}X$

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

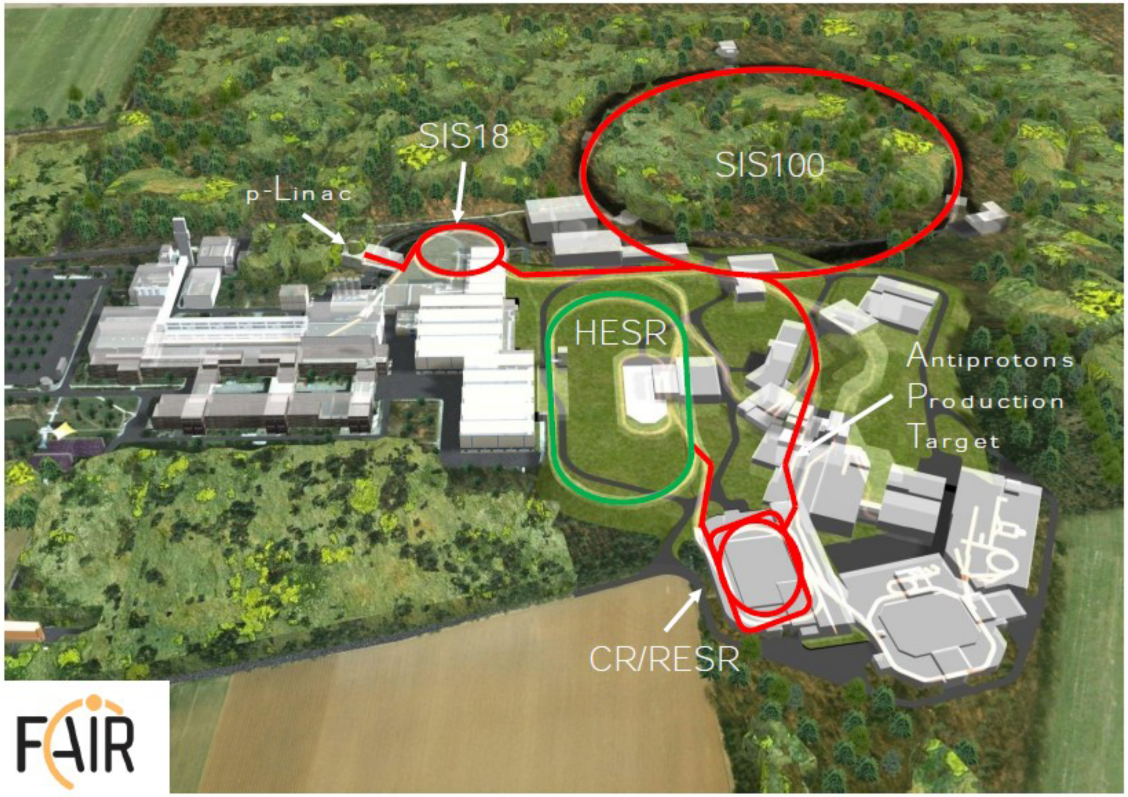
- Ξ^- (uss) conversion in two Λ (uds) : $\Xi^- + p \rightarrow \Lambda + \Lambda$, Q= 28MeV
  ⇒ large sticking probability in the same nuclear fragment

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

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

- two-step process

The Fair Facility

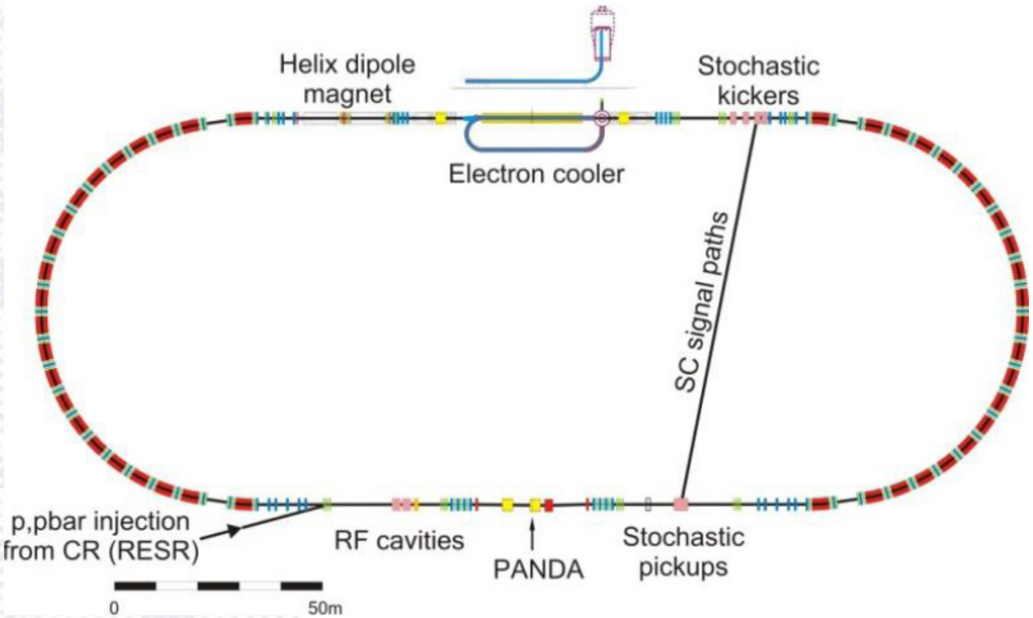


3000 Physicists
50 Countries

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 – NUSTA
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

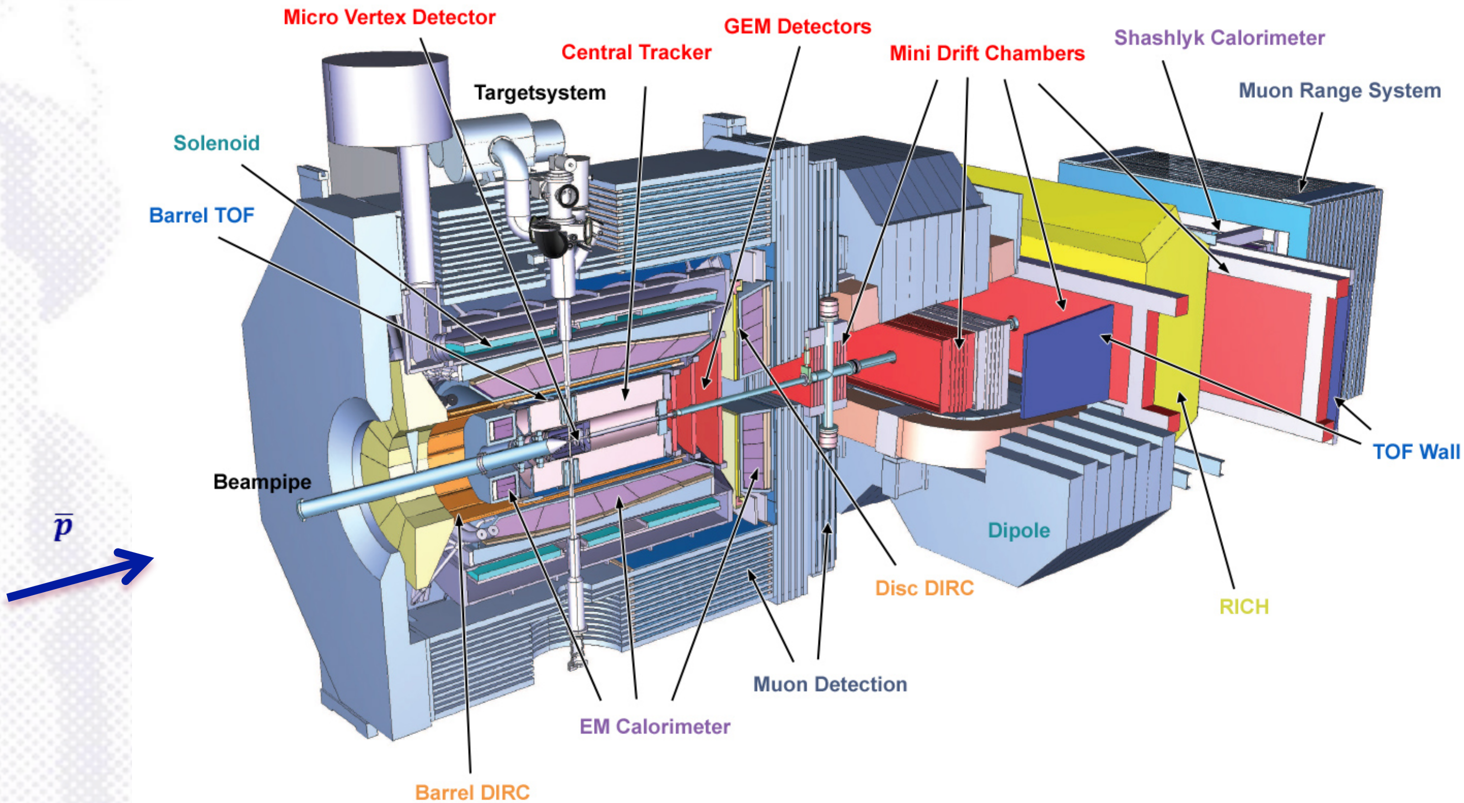
Stochastic cooling, p≥ 3.8 GeV/c

10^{11} antiprotons stored

Luminosity up to 2 · 10 ^{32} cm^{-2}s^{-1}

$\Delta p/p = 2\ 10^{-5}$

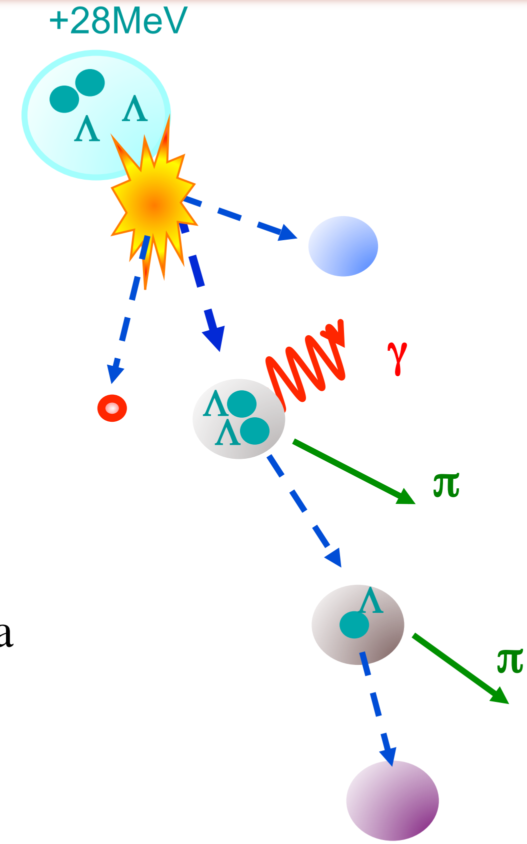
The PANDA Spectrometer



- 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

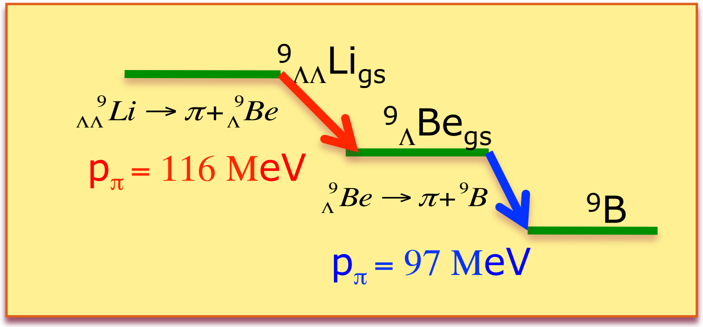
Decay Products of ΛΛ- Hypernuclei



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

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

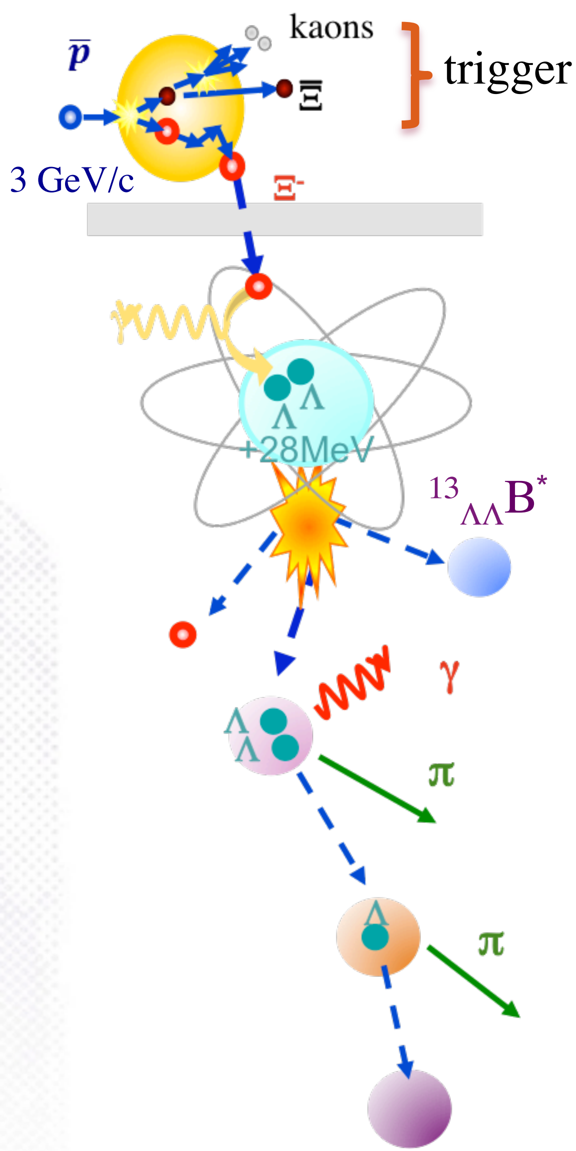
- sequential pionic decay ⇒ BNL-AGS E906 $^{9}Be(K^{-},K^{+})X$
  - two-body decay ⇒ monoenergetic momentum
  - no excited states information
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)
- γ- spectroscopy ⇒ PANDA $\bar{p}$ +A
  - no excited states observed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

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

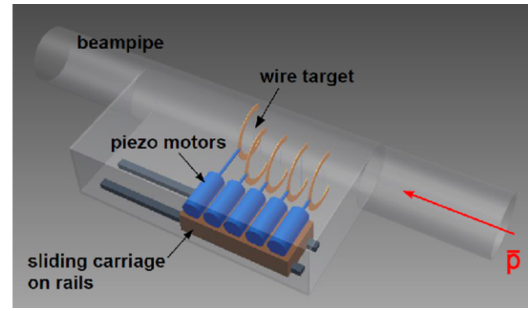
⇒ Electromagnetic transition to g.s

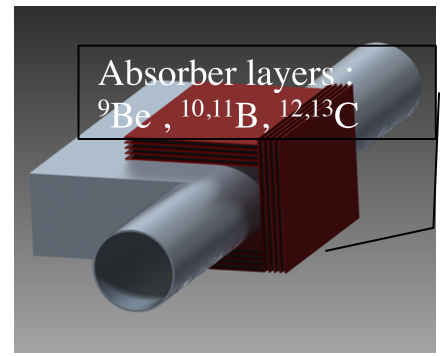
⇒Sequential mesonic decay

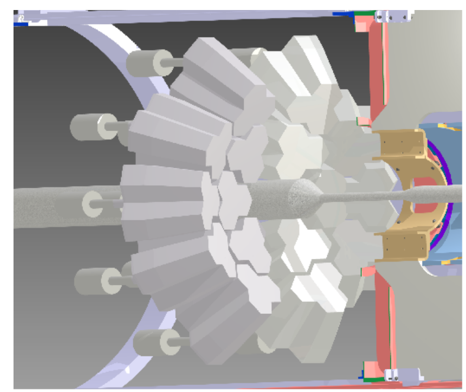
Need of a devoted detector setup

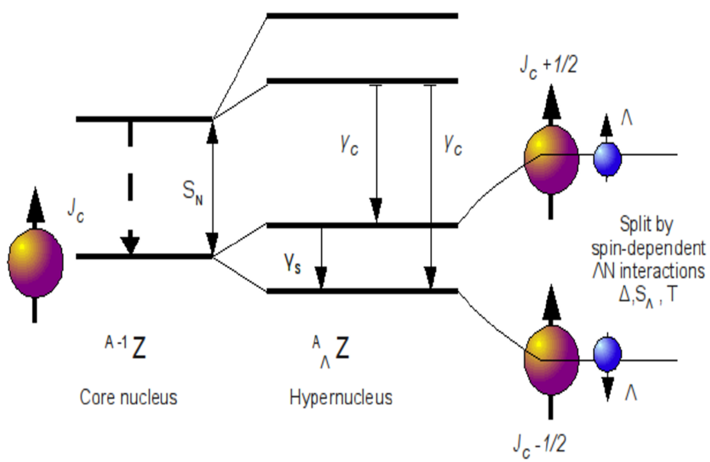
Hypernuclear Detector Setup

- **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



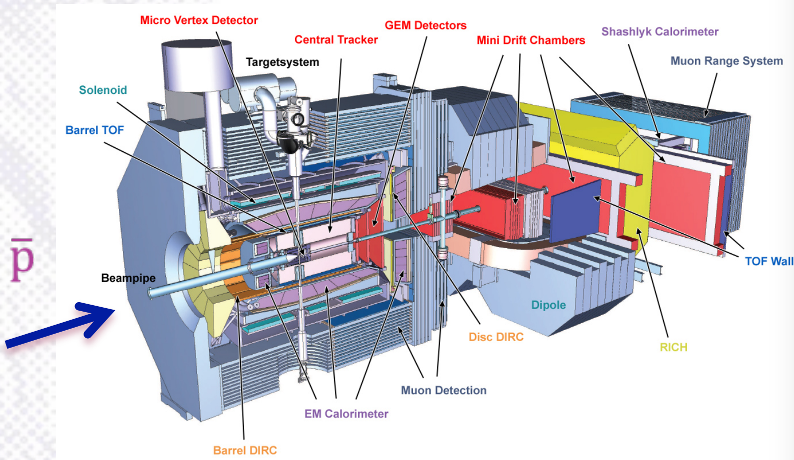


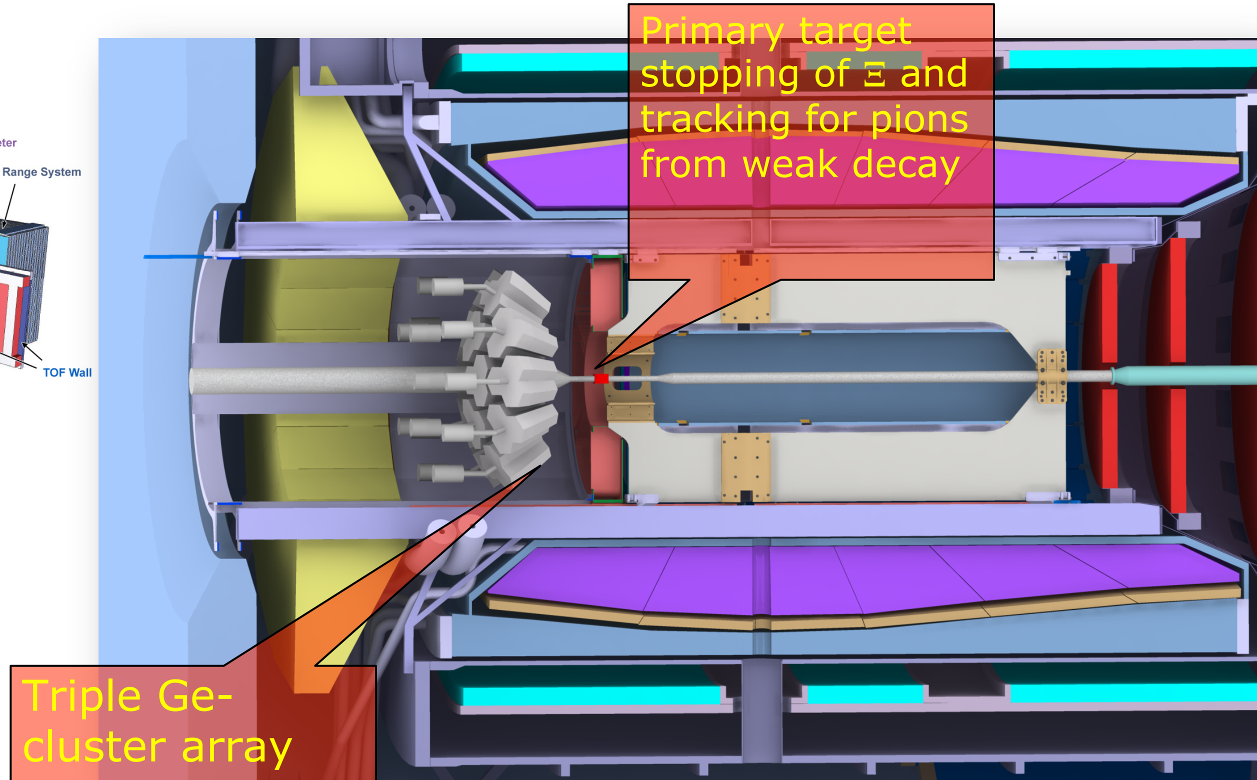




Integration in PANDA

HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Mainz





Backward End Cap Calorimeter and MVD will be removed

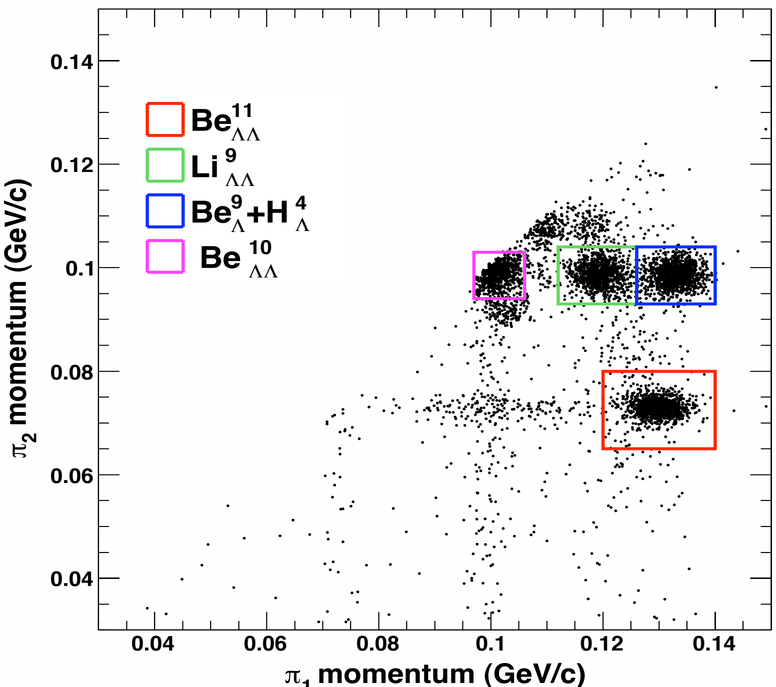
- Modular structure
- Dedicated beam pipe/target system

by cortesy of D. Rodriguez, M. Steinen,

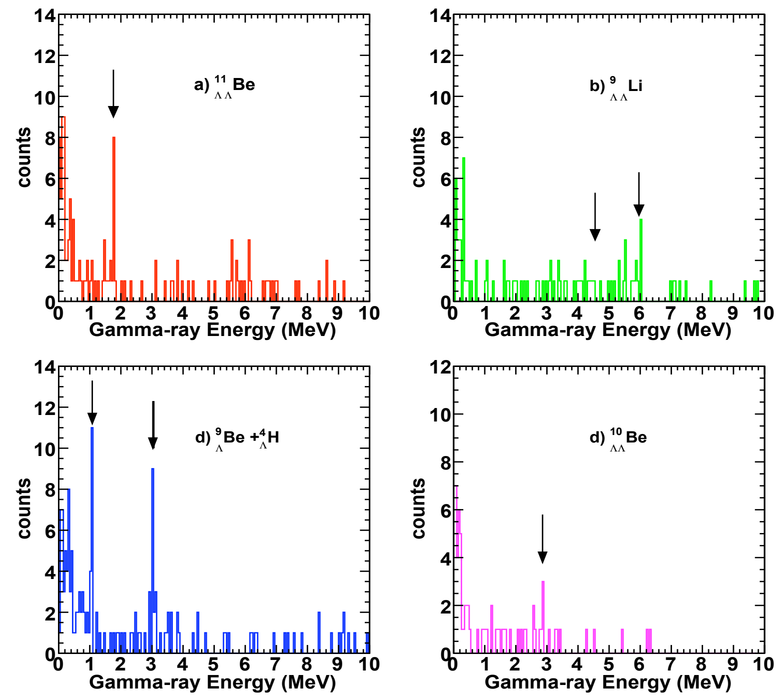
Identification of ΛΛ-Hypernuclei at PANDA

- 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

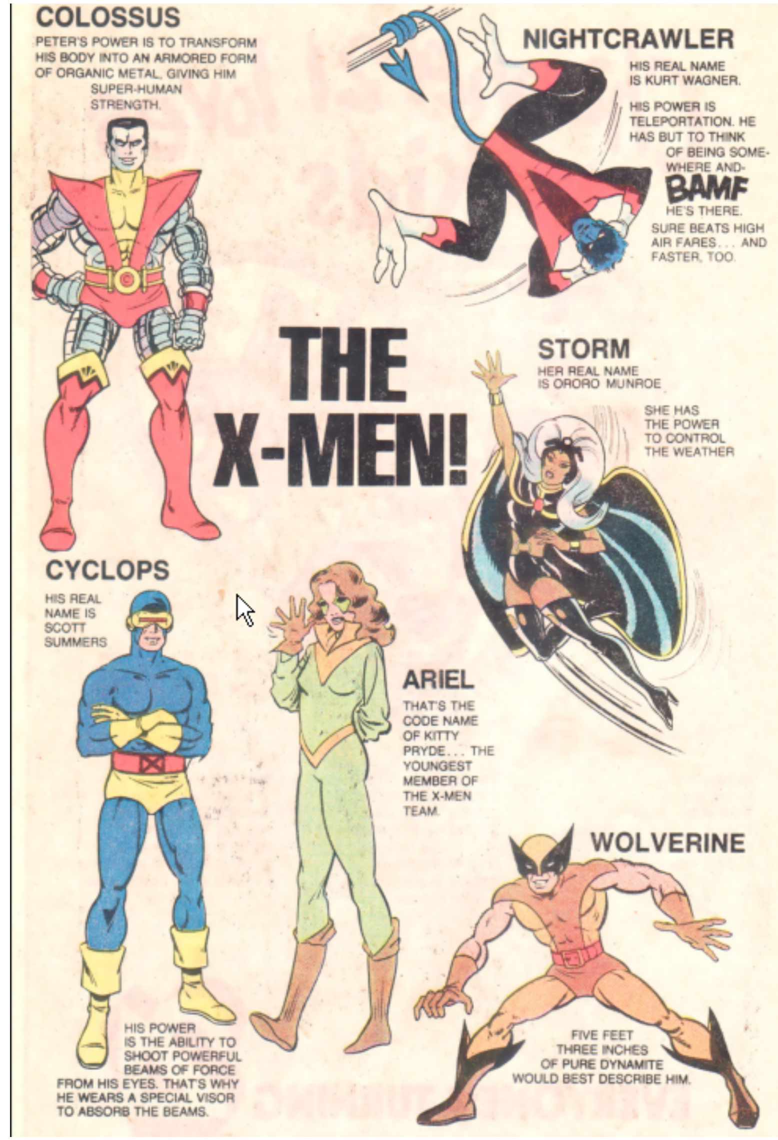


- Hyperons in nuclei help to explore fundamental questions
  - How do nucleons and nuclei form out of quarks?
  - Can nuclear structure be derived (quantitatively) from QCD?
  - Strange Hadrons in Nuclei and the Structure of QCD vacuum?
- Hypernuclei - a bridge between traditional nuclear physics and hadron physics

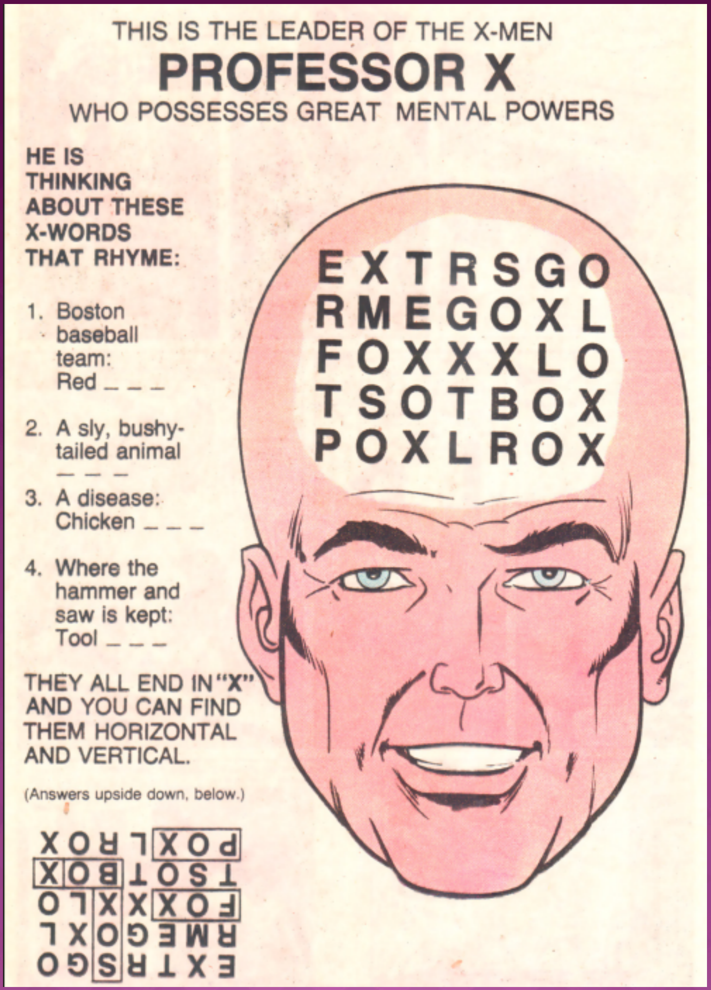
THANK YOU,

for your attention
and
specially to my
super heroes,

Marcell Steinen
Sebastian Bleser
Marta Martinez Rojo



BACKUP SLIDES



BACKUP SLIDES

Primary Target System

Task of the primary target:

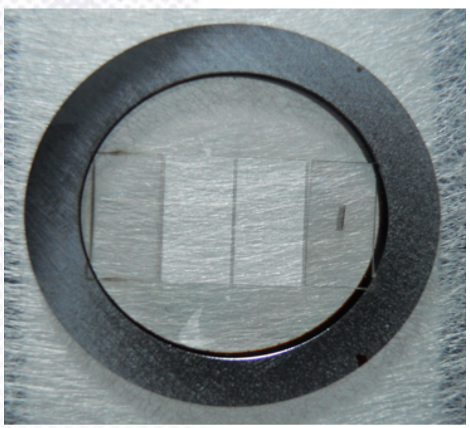
production of slow Ξ^-

Requirements:

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

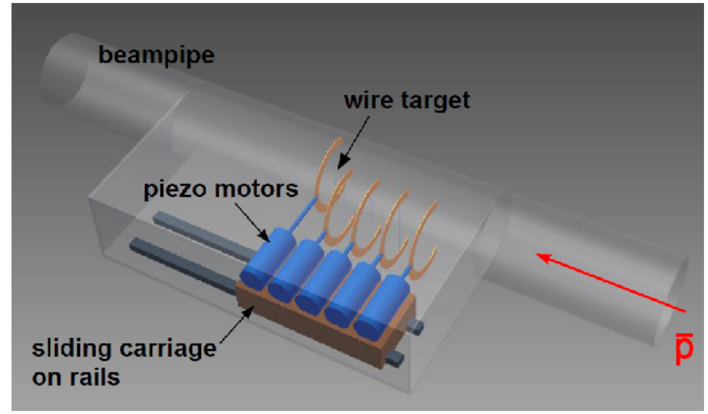
→ beam losses, mainly due to coulomb scattering, must be kept low

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



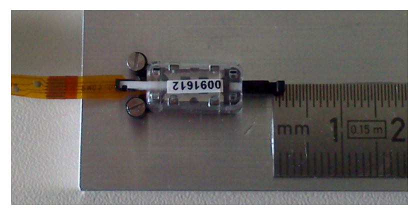
14 mm

by cortesy of F. Iazzi and S. Bleser



Insertion of the wire target into the beam pipe

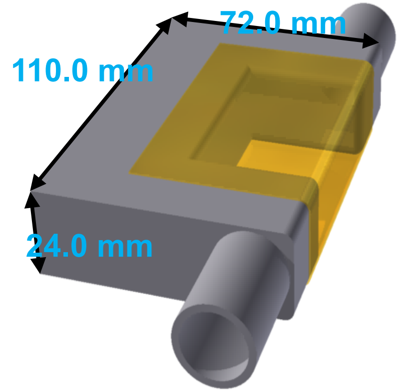
- ➢ Piezo-motors : easy replacement
- ➢ control of the interaction rates by steering beam and target

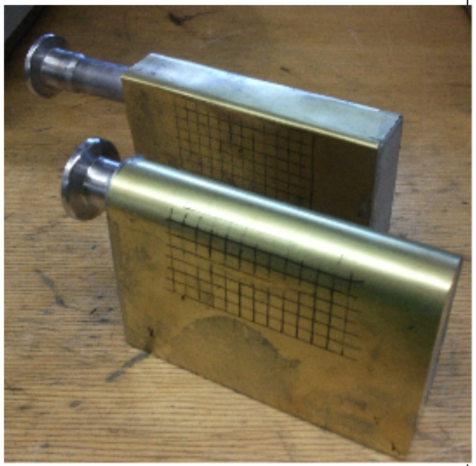


Performance of the target chamber

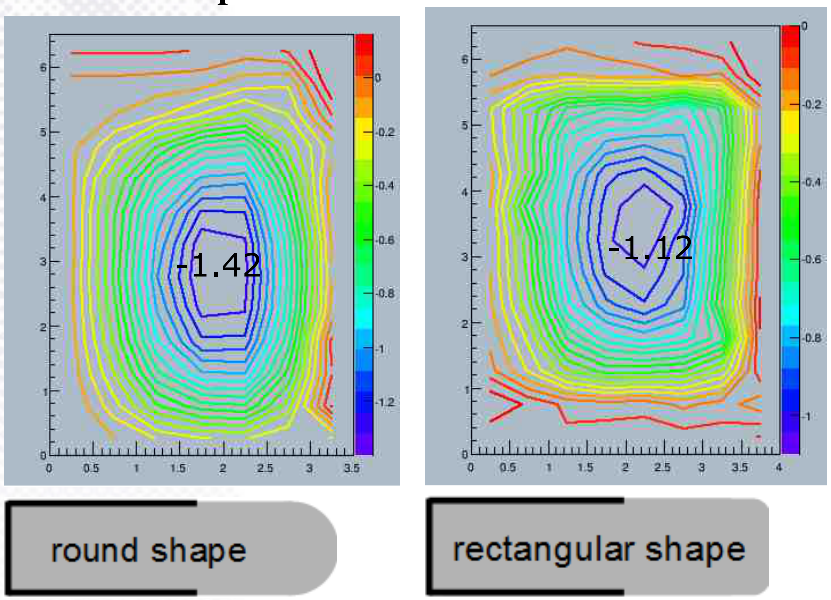
Performance of the target chamber : with different shapes, materials (brass, Ti, AlMg, Kapton) and thicknesses

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

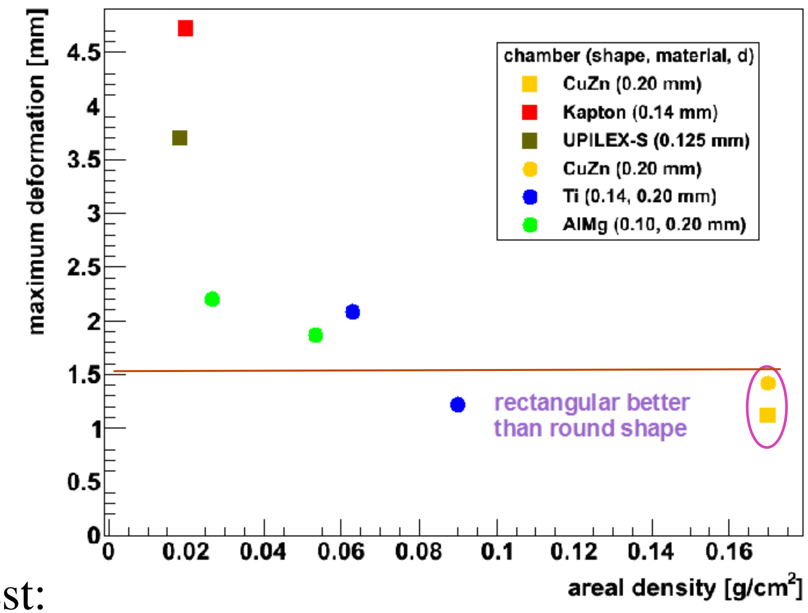




Example : Brass 200 um



by cortesy S. Bleser



Final Test:

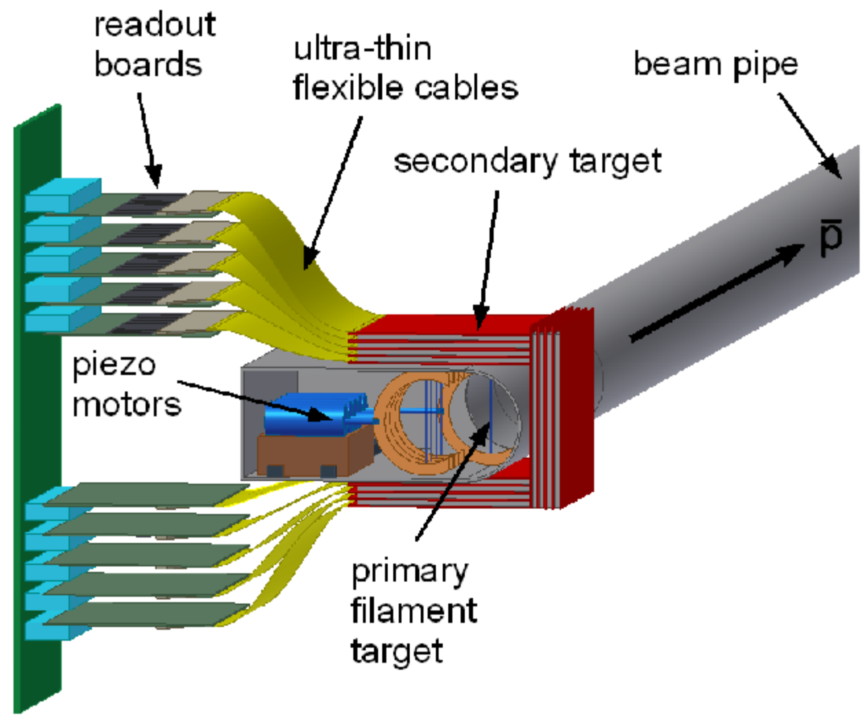
- Titanium 200 µm and AlMg 300 µm on rectang.Frame

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:

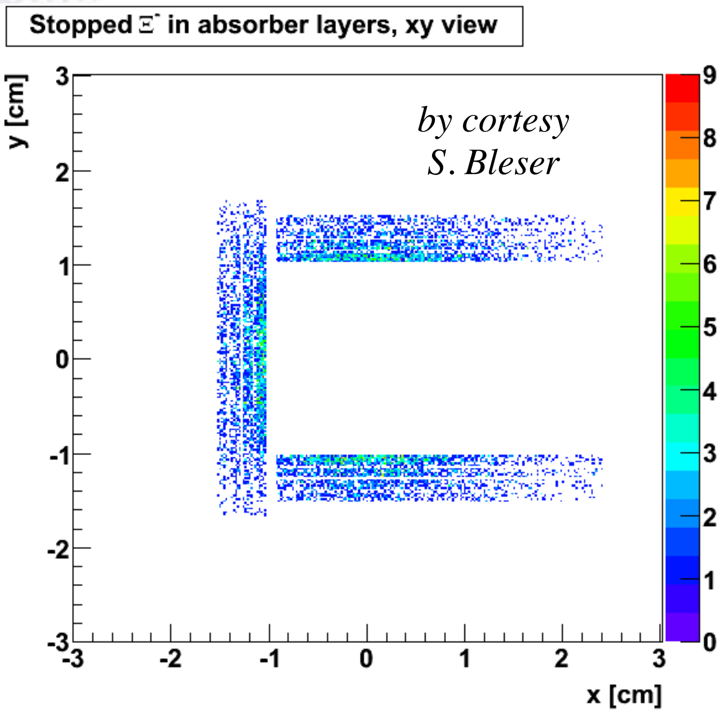
- Feasibility of Silicon Strips Detector in direct contact with absorbers

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

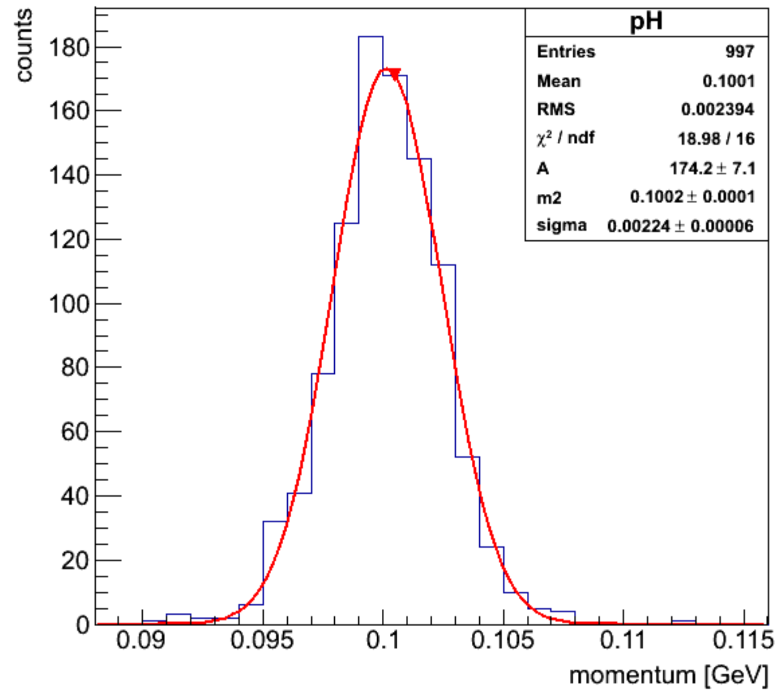
Compromise between Tracking and Stopping Power

Momentum distribution of stopped Ξ
in the secondary active target



- 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)

Momentum resolution of 0.1 GeV/c pions

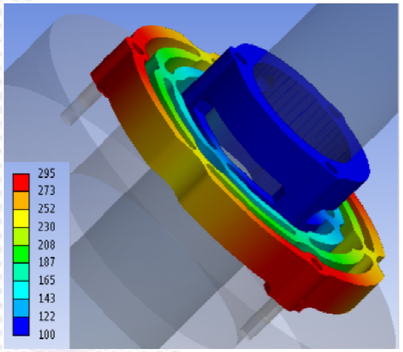


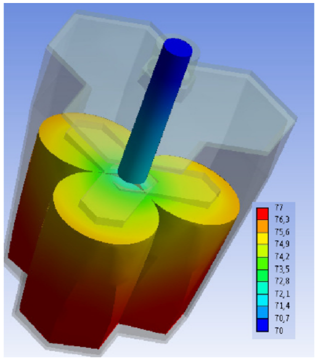
- $\Delta p/p \sim 2.3$ % with an improved Tracking Algorithm

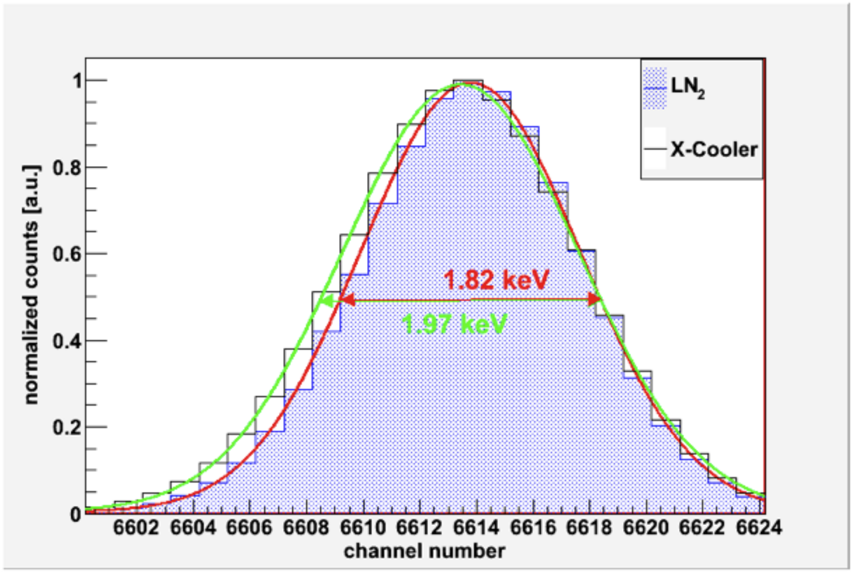
⊙ Limited space :

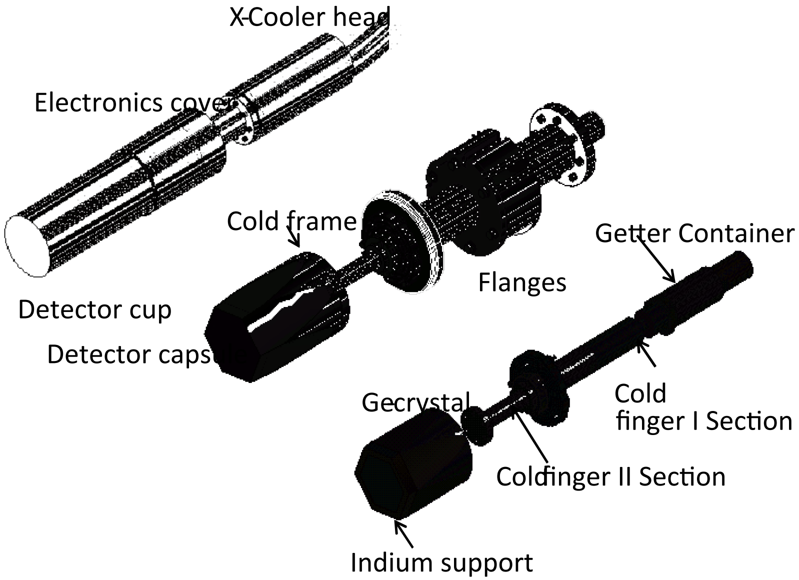
Recent activities : X- Cooler system

- Slight Influence on Ener. Resolution
- cooling efficiency for a triple cluster detector.







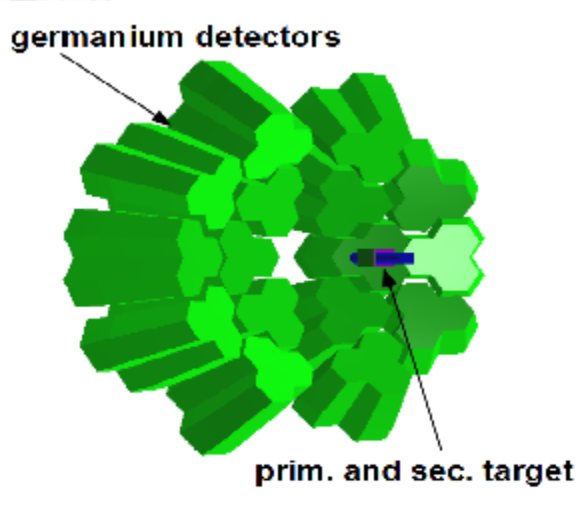


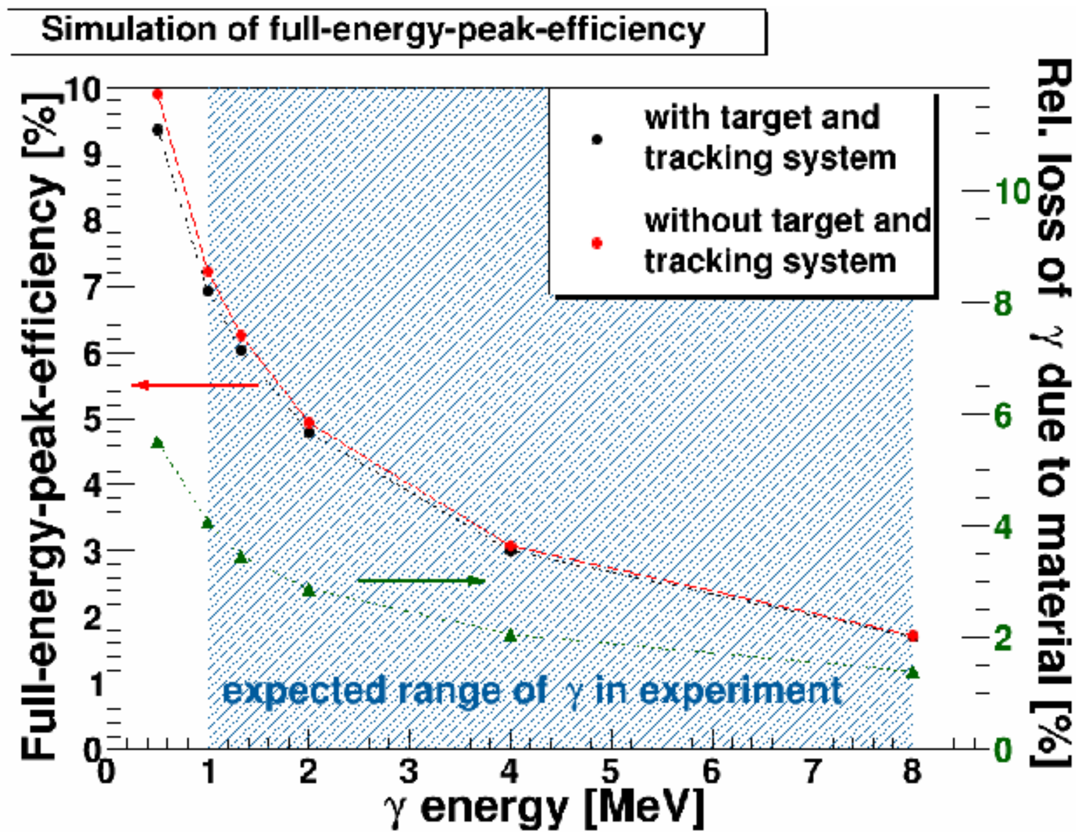
⊙ Ongoing activities: High Rate environment:

- Radiation Damage studies with a single crystal prototype at COSY
- Pulse Shape Analysis

by cortesy of M. Steinen and I. Kojoujarov *by cortesy of M. Steinen*

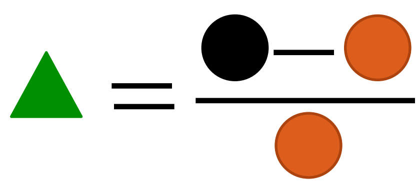
- Effect of hadronic background from primary interaction at backward angles





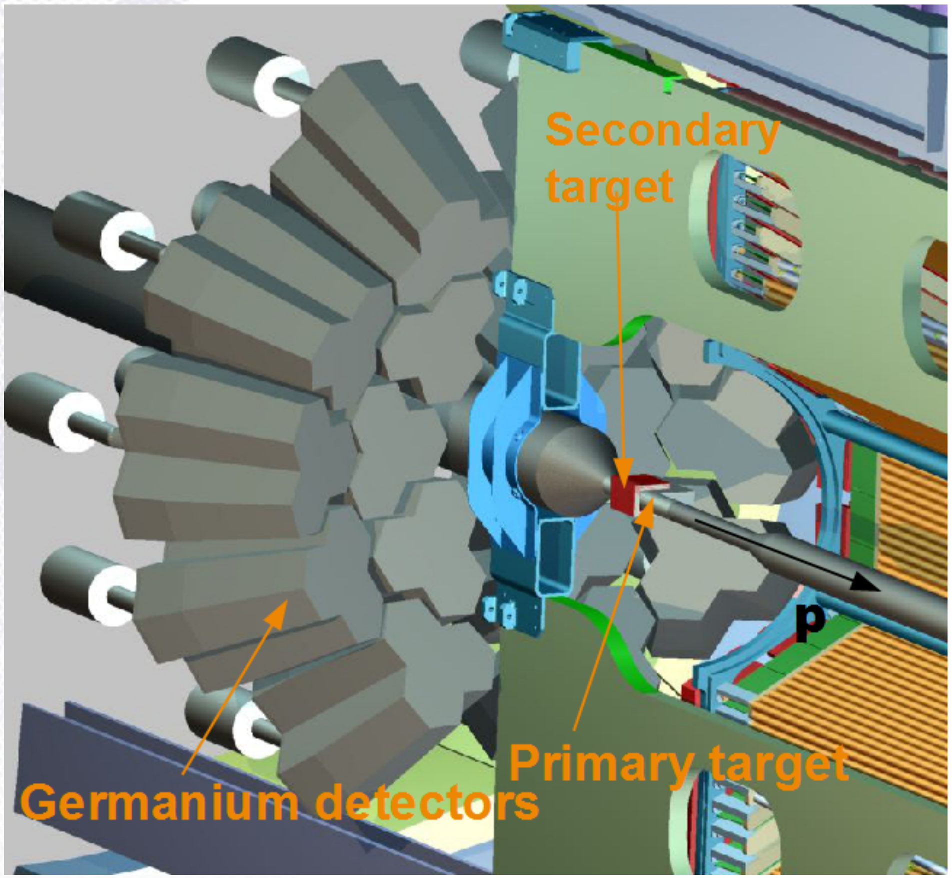
- Pandaroot framework

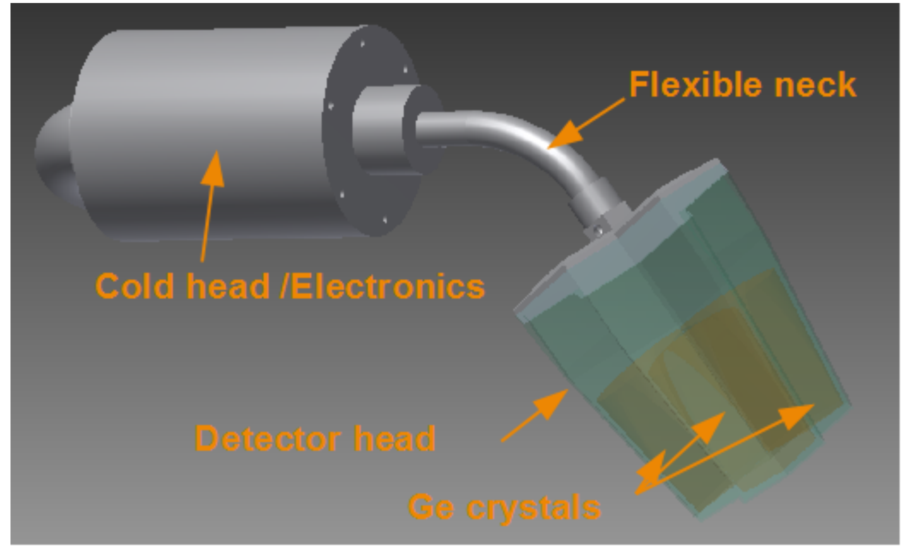
- Relative loss of γ,



γ- Detection

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





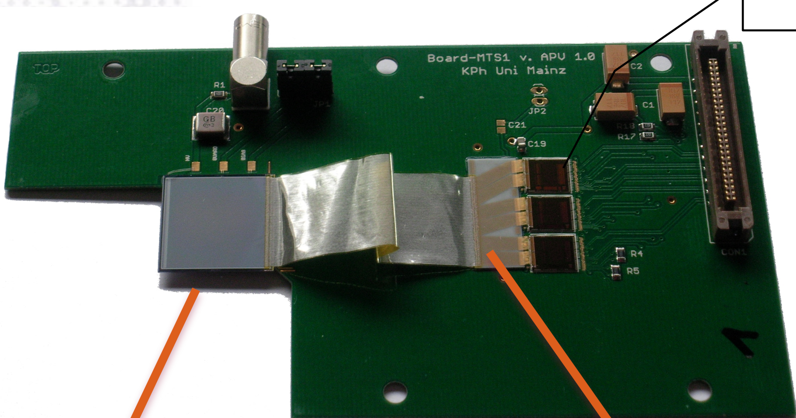
Effect of microcables on detector analog signals

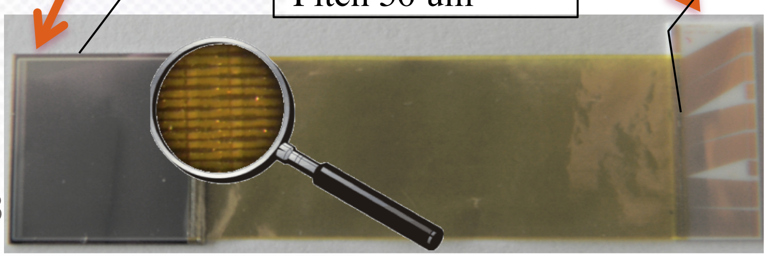
by cortesy of S. Bleser and SERSTII

- 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.

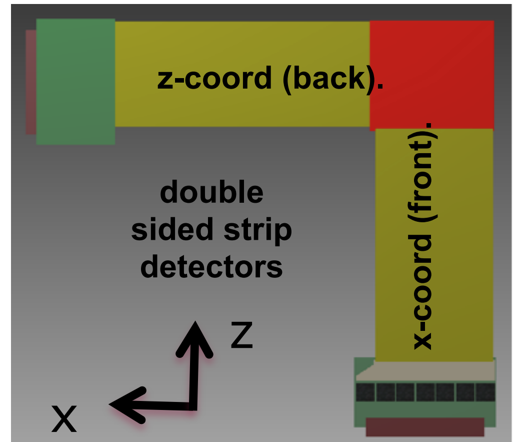
APV-25 chips

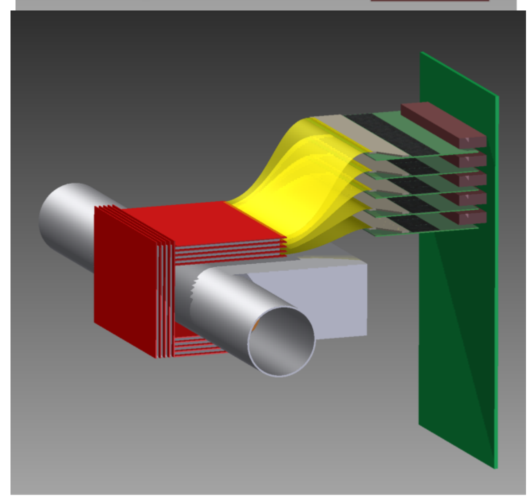




Si µ-strip sensor
20 x 20 mm
Pitch 50 um

Pitch Adapter

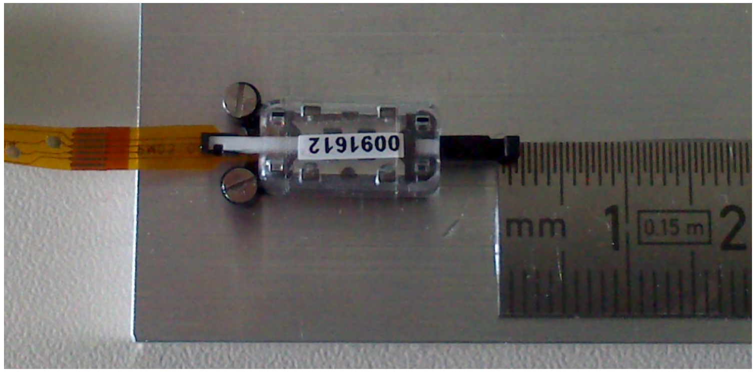




Piezo Motor as steering device

Piezo motor:

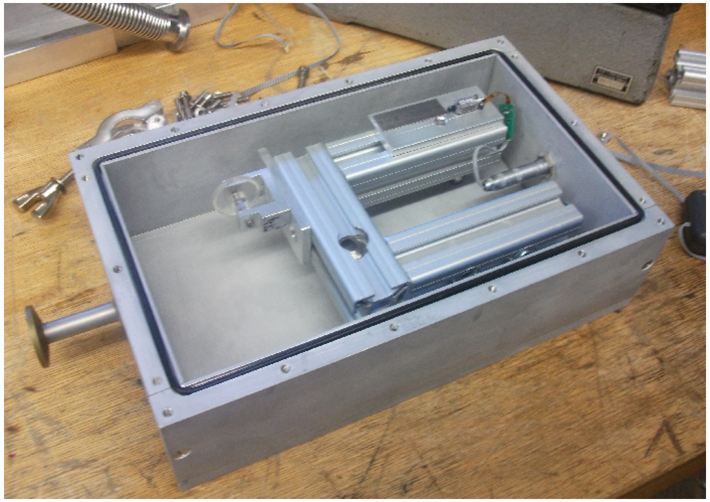
PiezoWave Linear 0.1 N
Manufacturer: PiezoMotor Uppsala AB



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

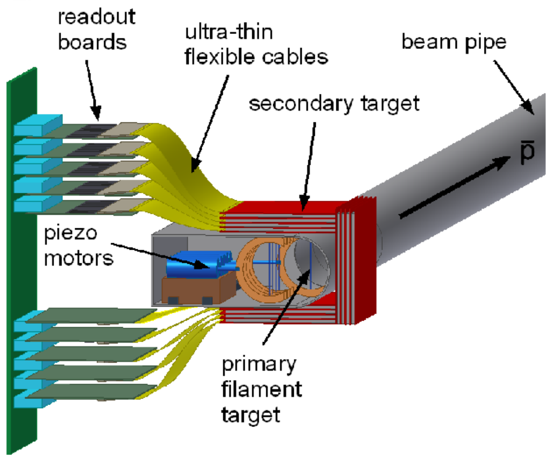
Piezo motor and vacuum chamber with holding frame:

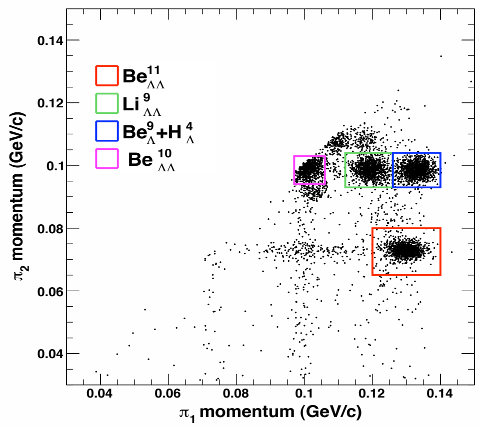


- proper running in vacuum proved for some weeks
- no influence of a magnetic field of 1.3 T

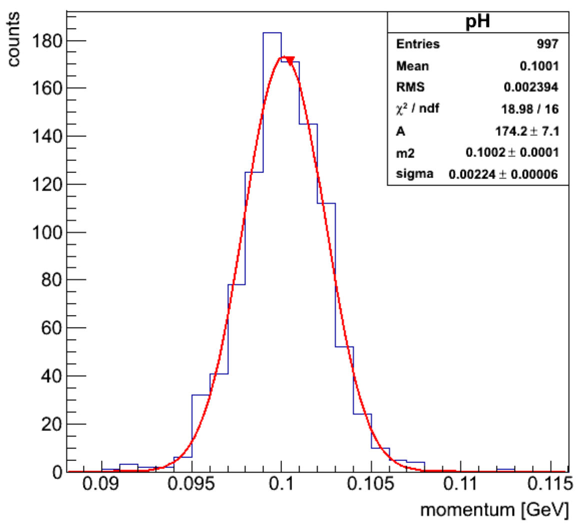
- next:
  Verification of Radiation Hardness : (TRIGGER/ COSY)

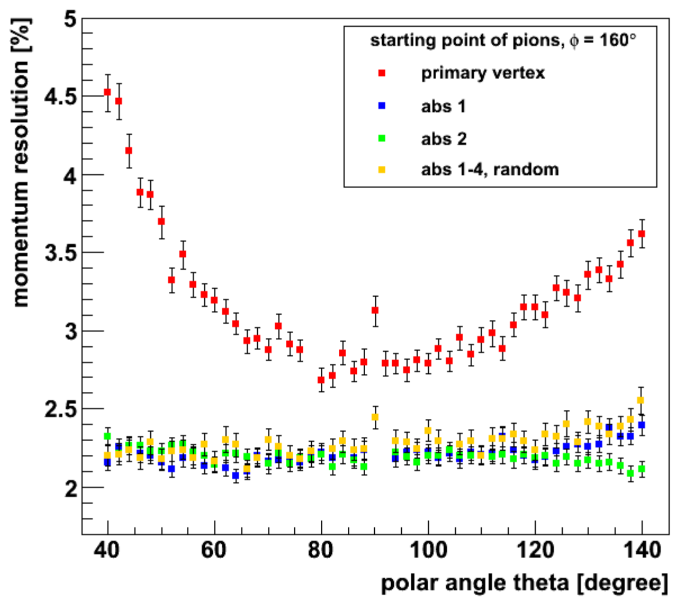
Low momentum pion tracking





Status of 2009
simplifying assump.
P res. 2%



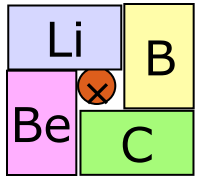


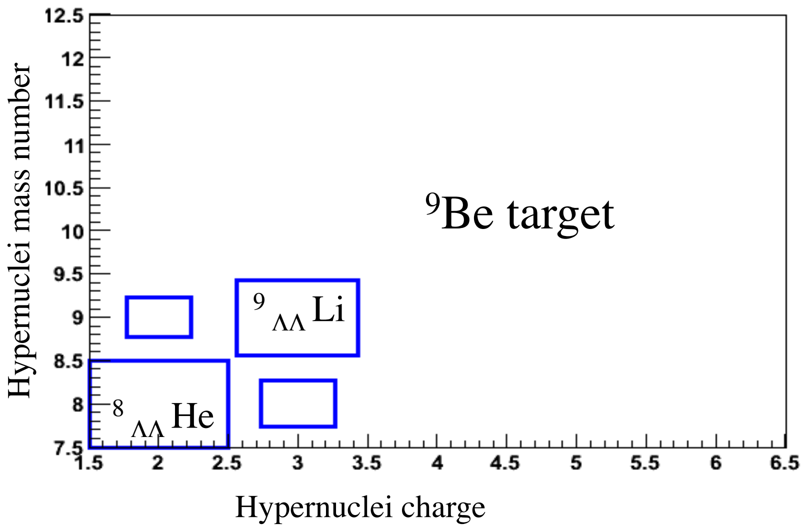
Present results:

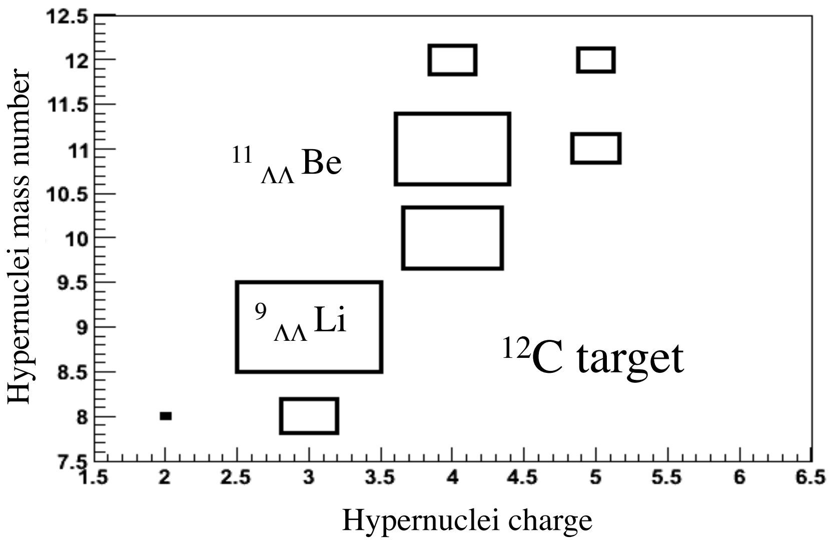
P res ~ 2.3 %
Improved Tracking Alg.

Identification of ΛΛ-Hypernuclei

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



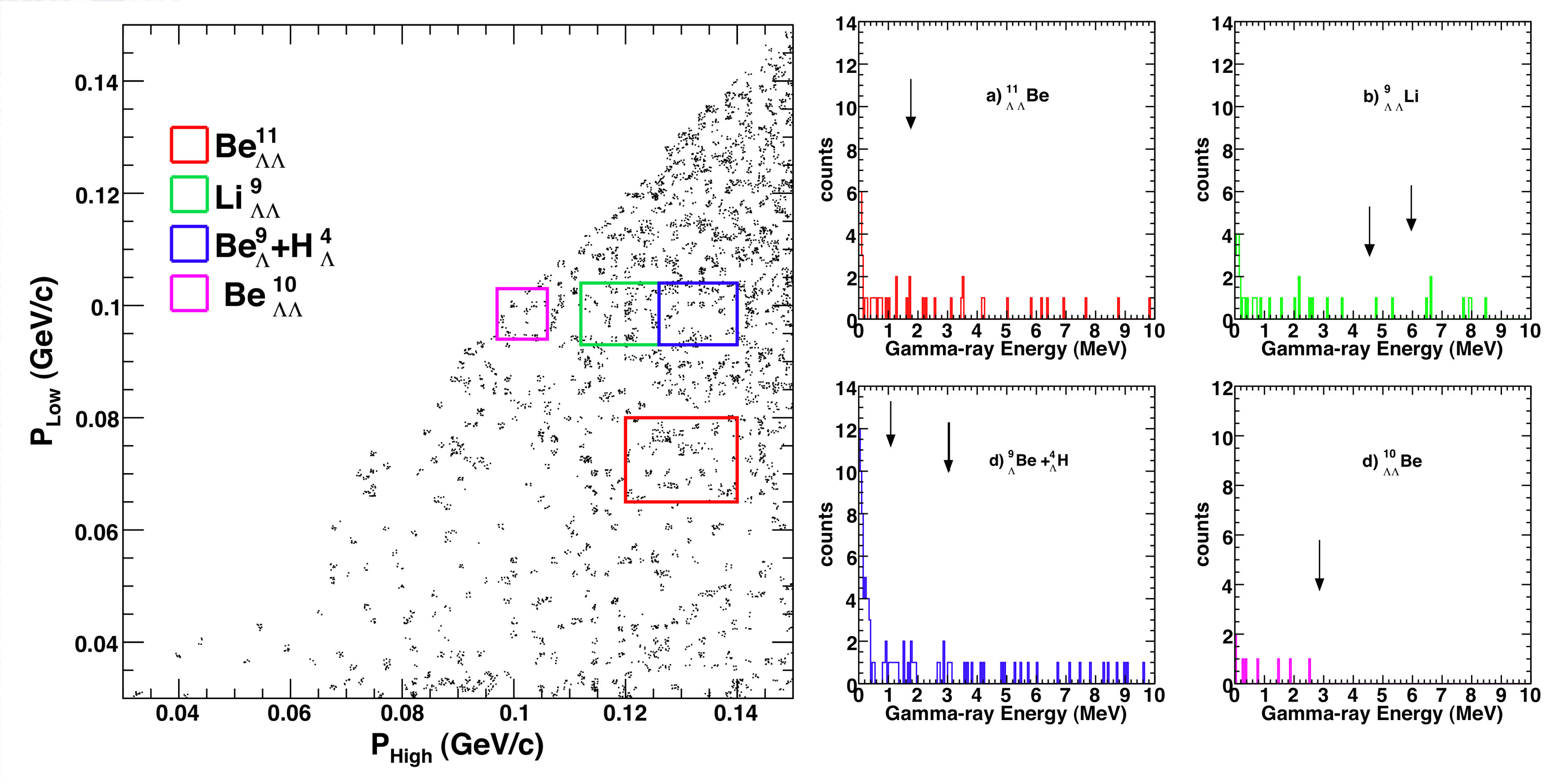




⇒Each target offers a strategy for the unique assignment of observable transitions by comparing the expected yields

Free Ξ⁻+Ξbar background contribution

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



$\bar{p}$ + ^{12}C background contribution

- More statistic is needed