γ-Spectroscopy of ΛΛ-Hypernuclei at P̄ANDA

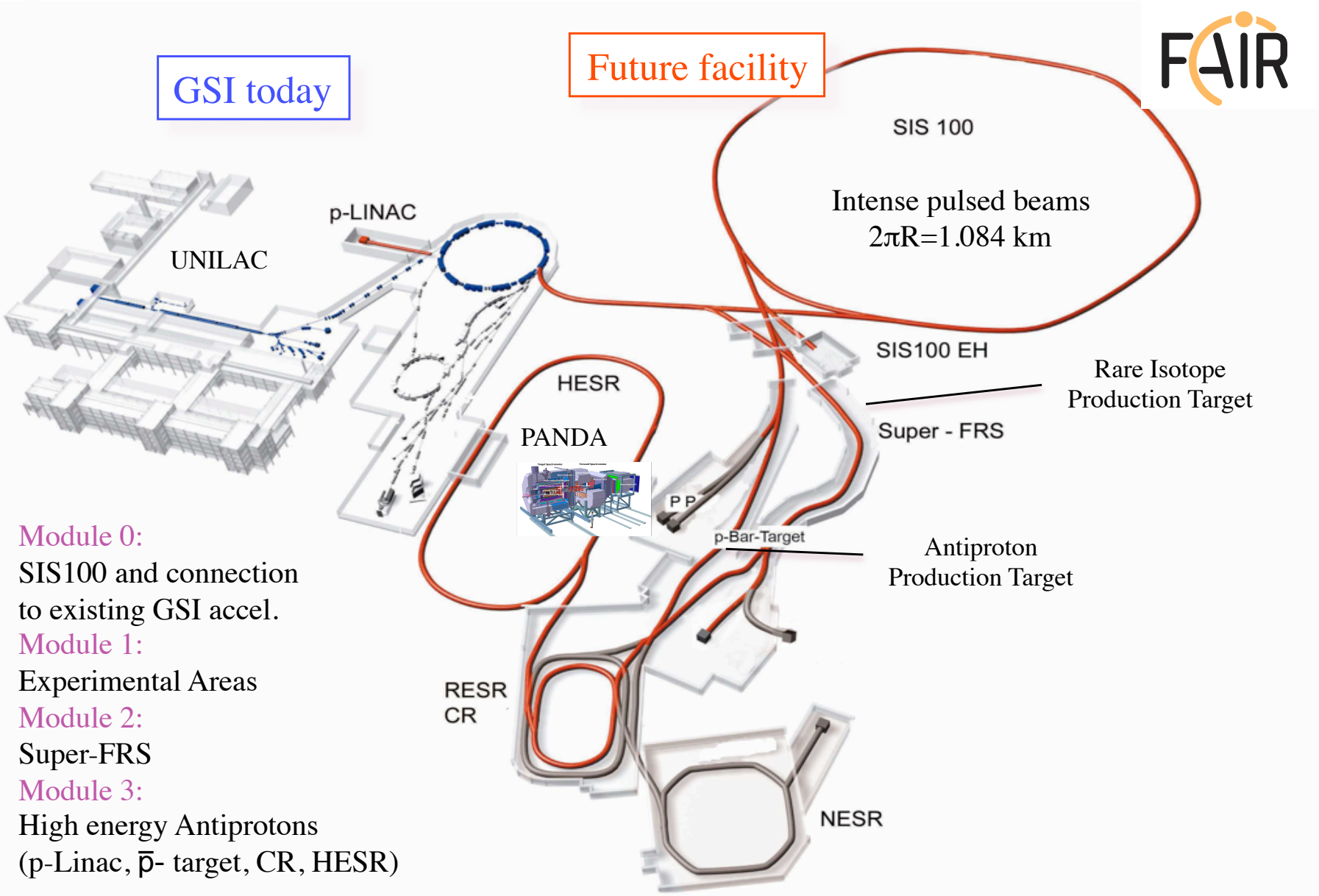
- The PANDA experiment
- Production and Detection of Double Λ hypernuclei
- Double Λ hypernuclei at PANDA
- Technical developments
- Summary

Alicia Sanchez Lorente
on behalf of the PANDA collaboration

FAIRNESS 2012

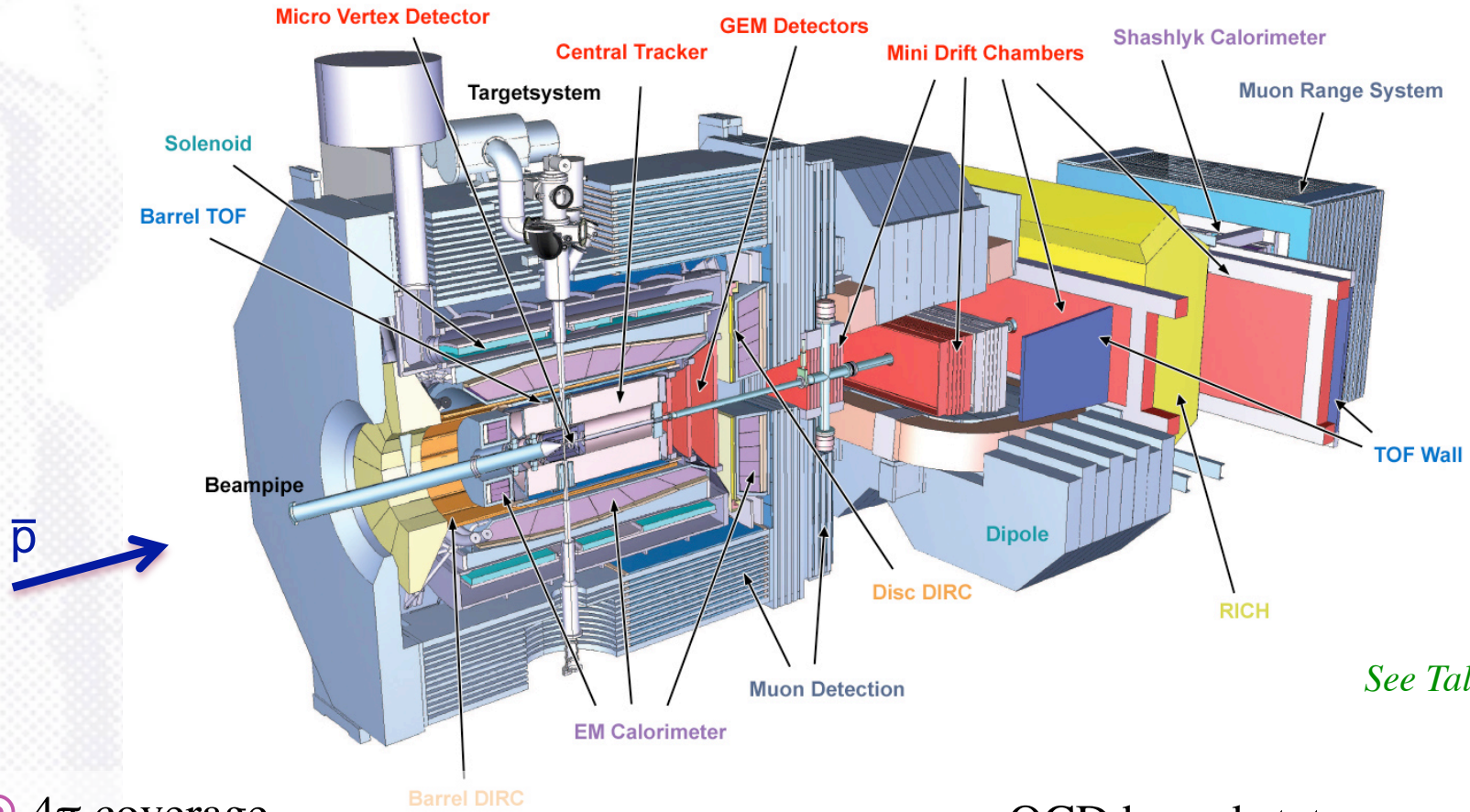
Hersonissos Greece

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, p̄- target, CR, HESR)

The PANDA Spectrometer



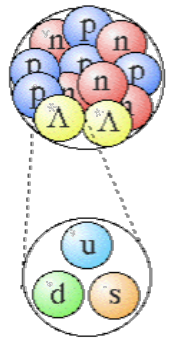
See Talk L. Zotti

- 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

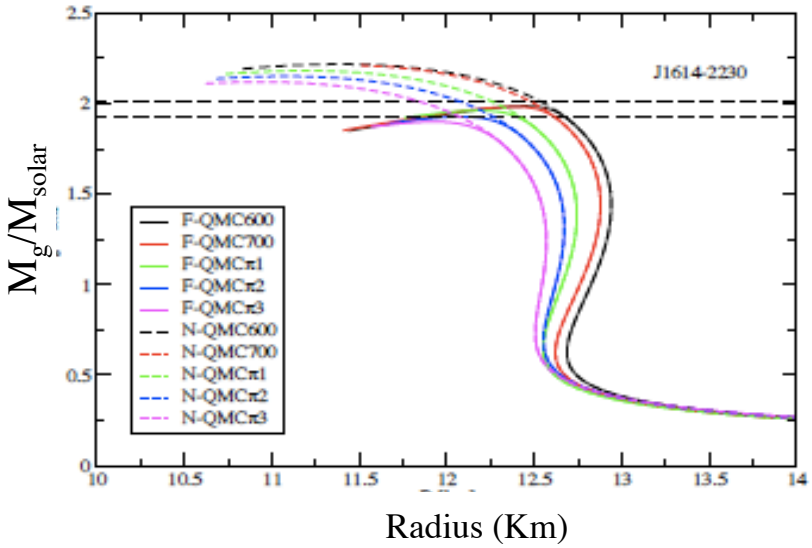


S = -2

- Study of $\Lambda\Lambda$ 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



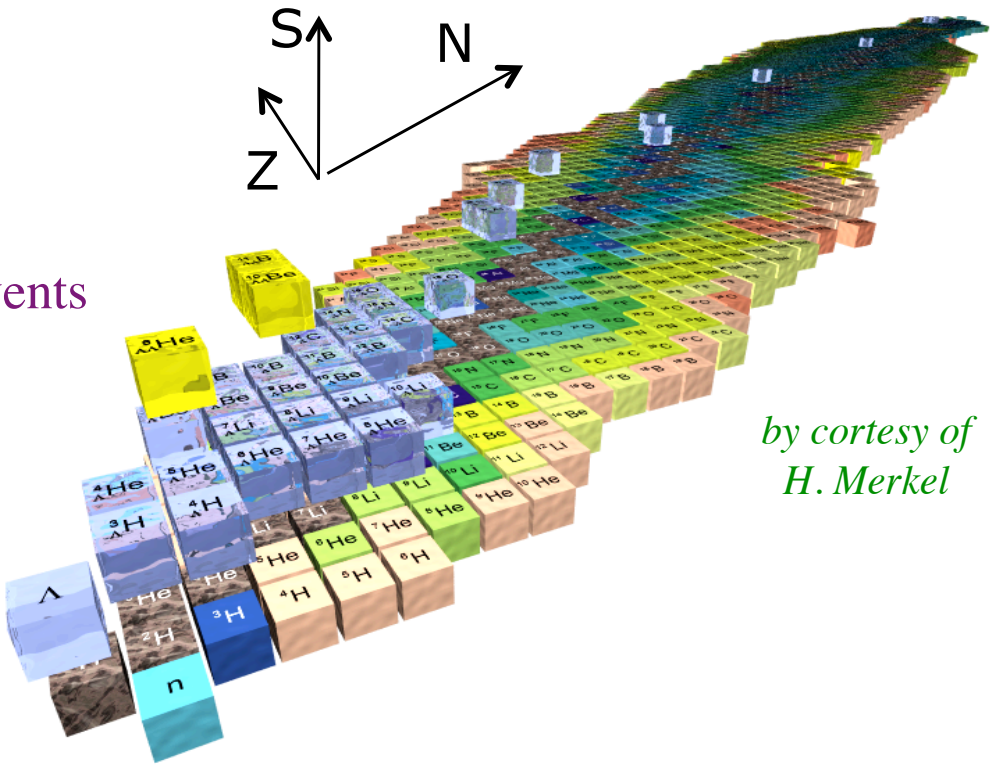
➢ existence of exotic quarks systems :
H- Particle

See Talk S. Banik

The present nuclear chart

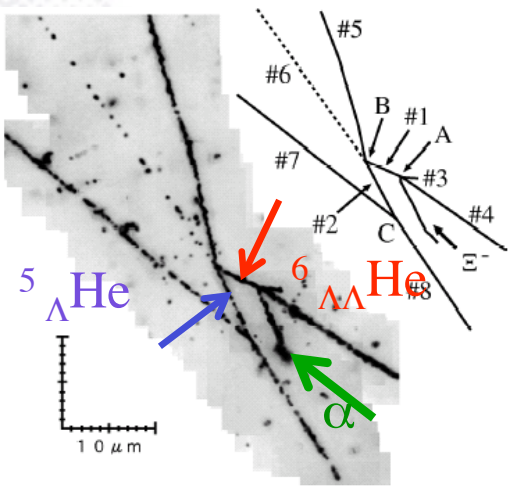
Present limitations

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



by cortesy of H. Merkel

Nagara event



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

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

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

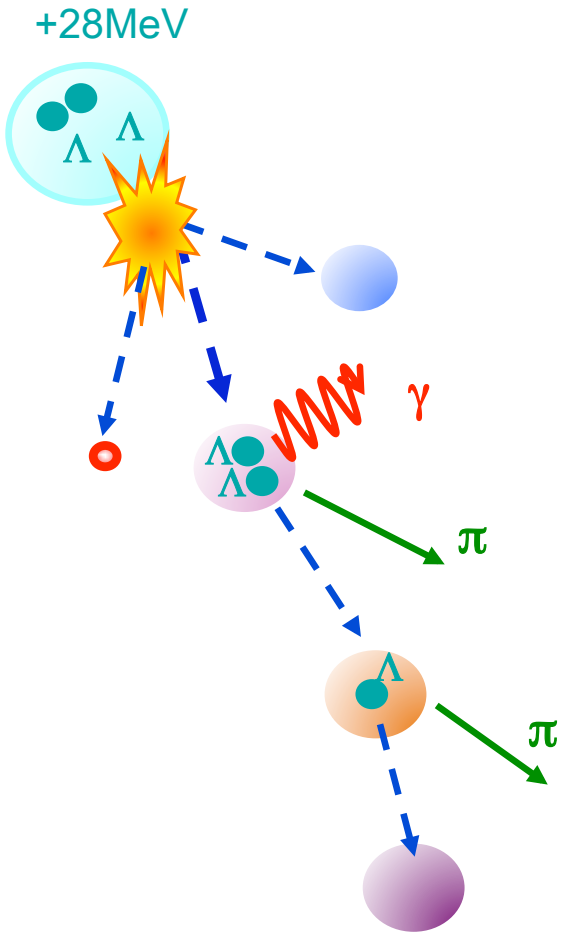
  - Antiprotons
    - in flight : $\bar{p} + p \rightarrow \Xi^- + \bar{\Xi}^+$
      PANDA : level structure, ground state masses

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

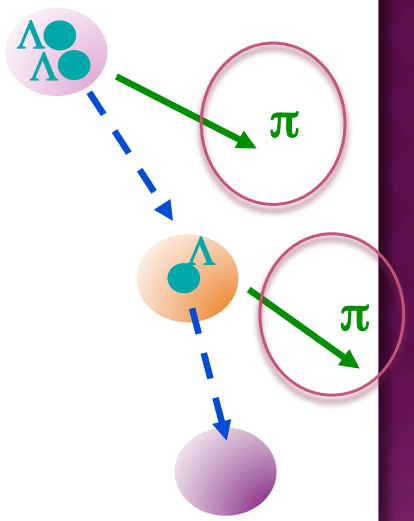


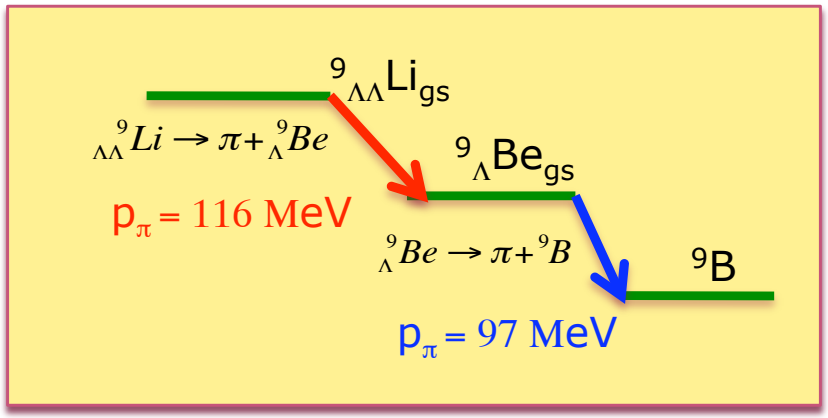
Decay Products of ΛΛ- Hypernuclei

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

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

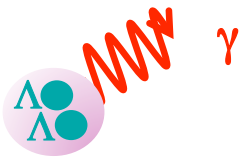
- sequential pionic decay ⇒ BNL-AGS E906 $^{9}Be(K^{-},K^{+})X$
  - two-body decay ⇒ monoenergetic momentum
  - no excited states information
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)
  - experimental resolution limited





Decay Products of ΛΛ- Hypernuclei

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

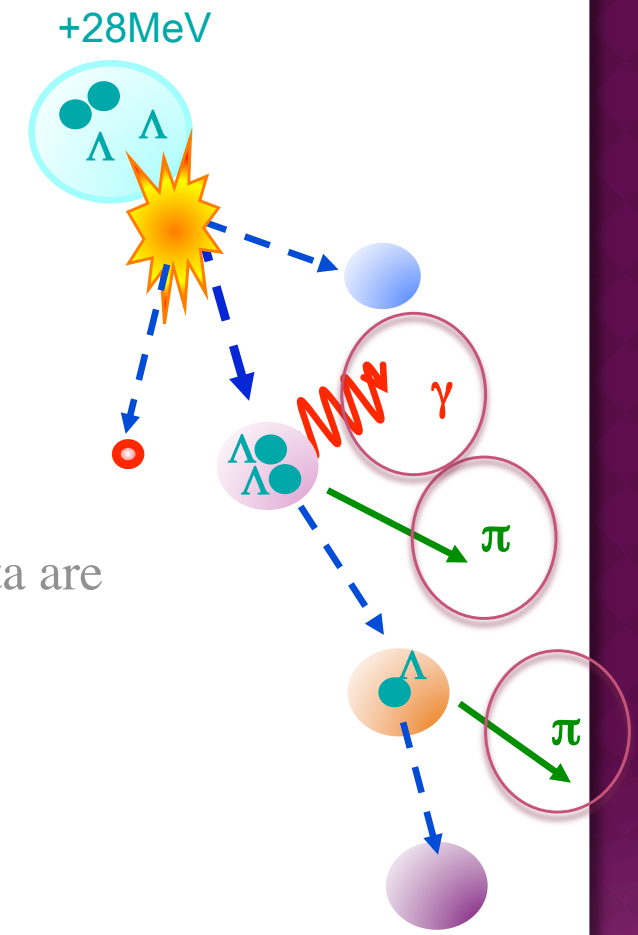


- sequential pionic decay ⇒ BNL-AGS E906 $^{9}Be(K^{-},K^{+})X$
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)
  - experimental resolution limited

- γ- spectroscopy
  - no excited states observed yet, but theoretically predicted

Decay Products of ΛΛ- Hypernuclei

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



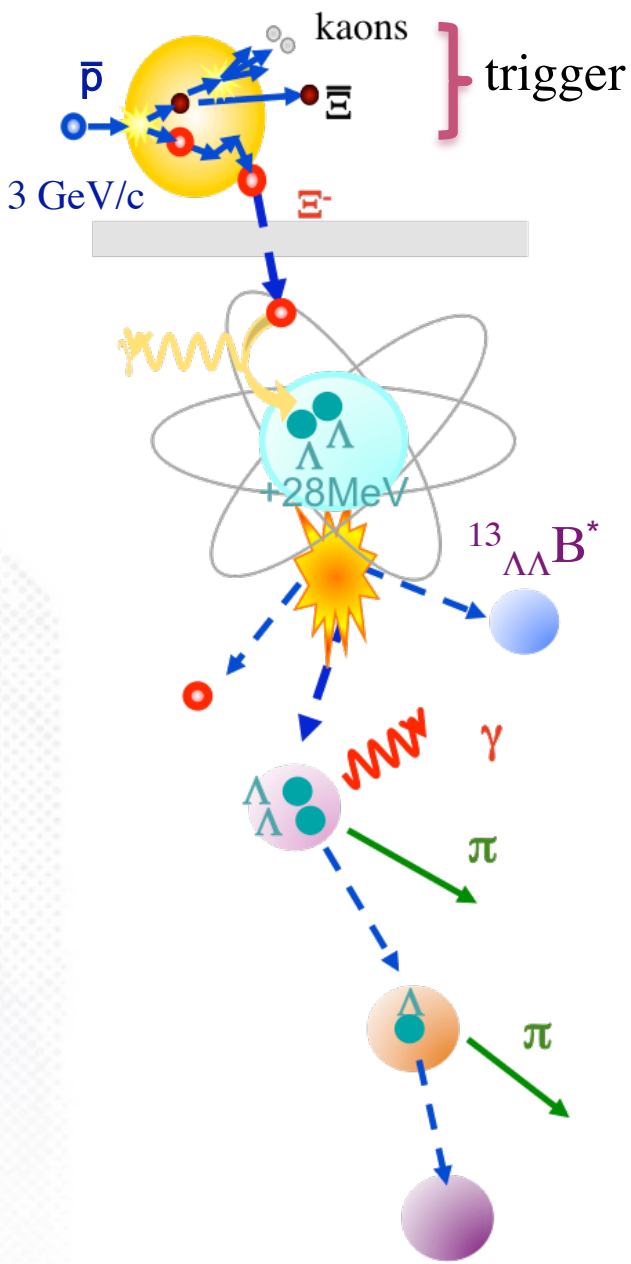
- sequential pionic decay ⇒ PANDA
  - interpretation in most cases not unique because π momenta are similar (70 – 130 MeV/c)

- 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



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

in a primary target

⇒ Slowing down, capture and conversion of Ξ in a secondary active target.

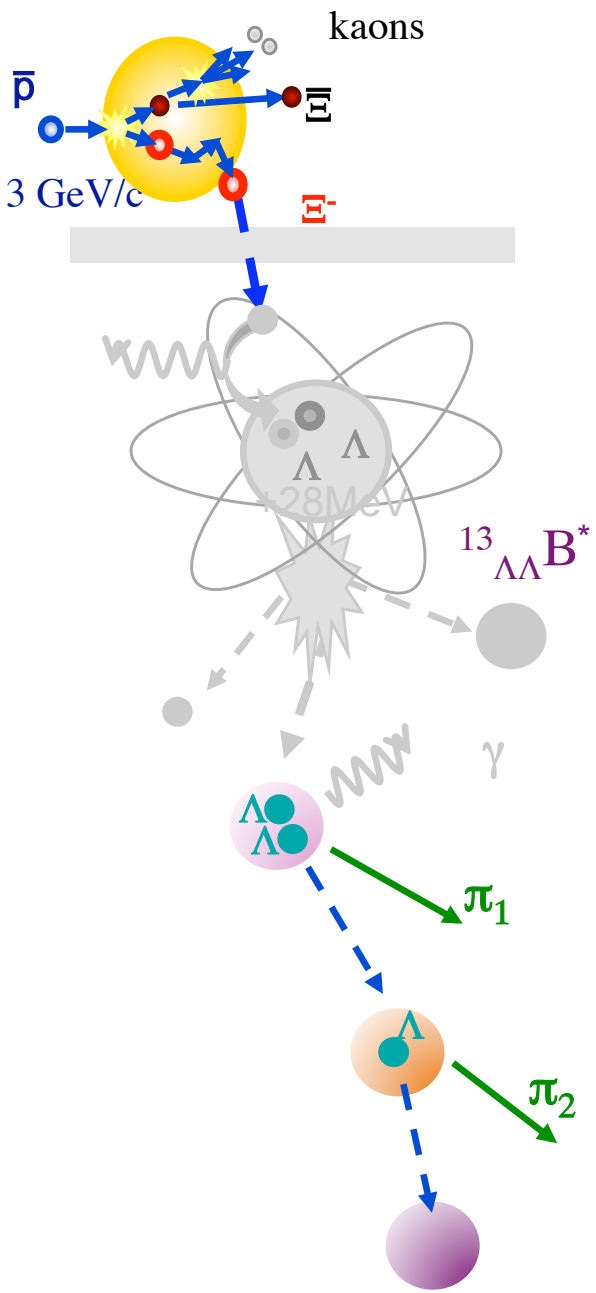
⇒ Statistical decay of slightly excited hypernuclei

⇒ Electromagnetic transition to g.s

⇒Sequential mesonic decay

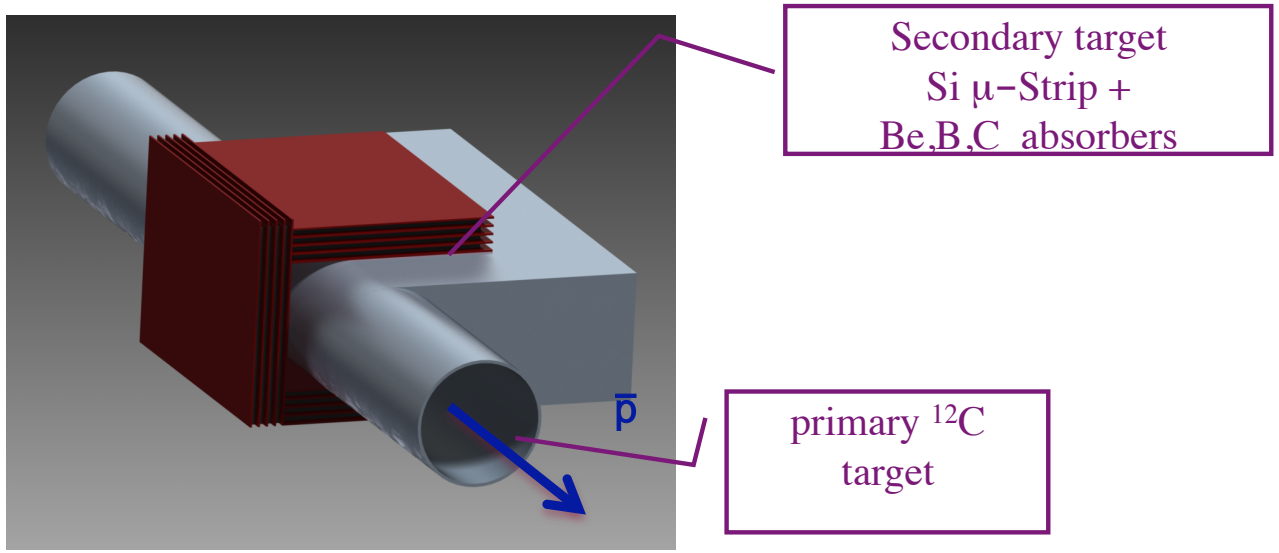
Need of a devoted detector setup

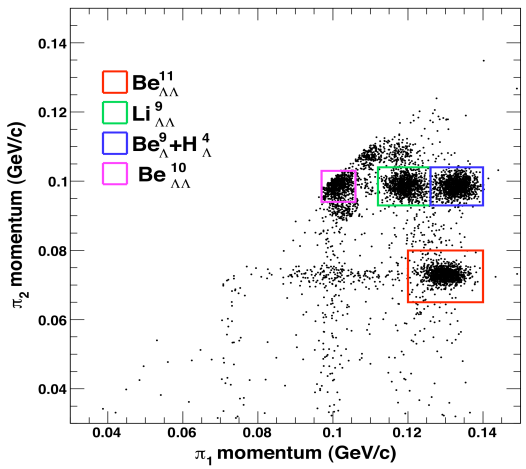
ΛΛ- Hypernuclei at Panda



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

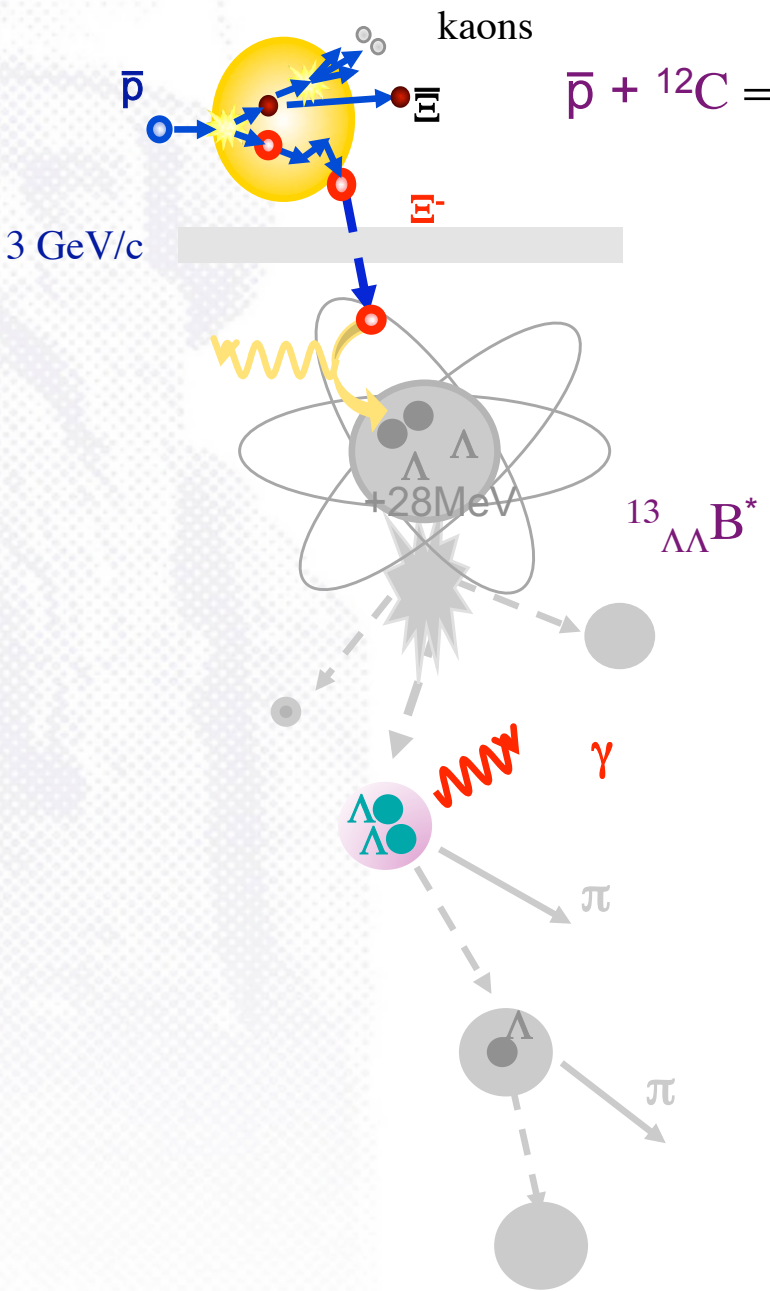
Active secondary target





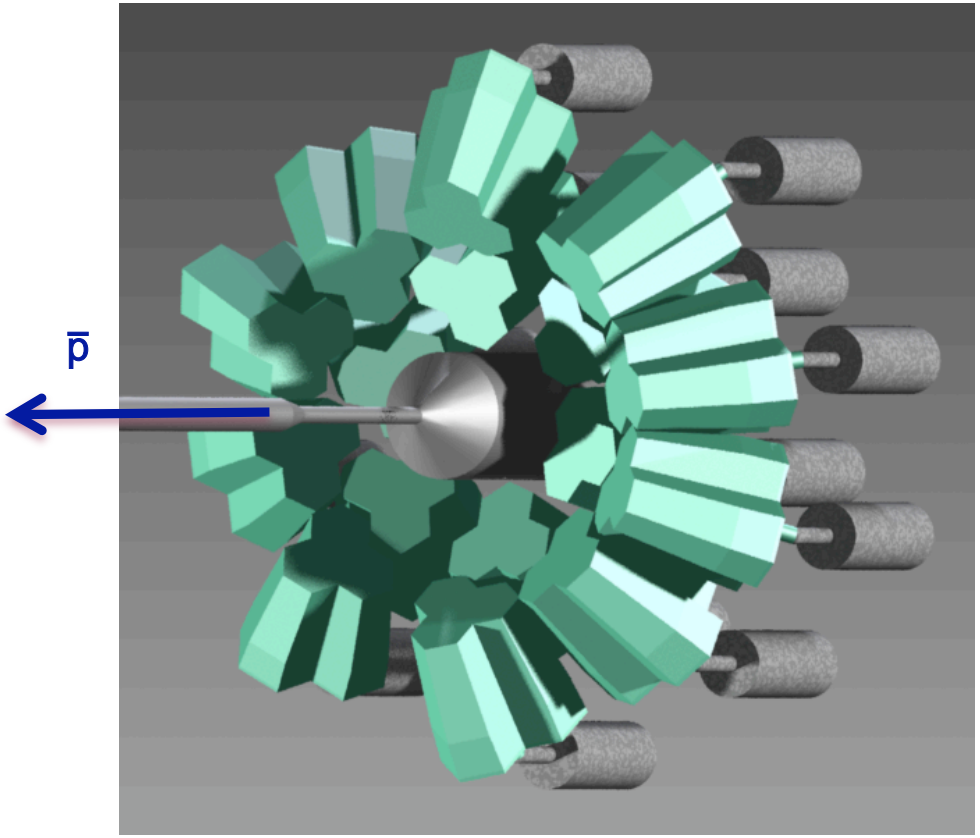
$\pi_1 - \pi_2$ correlation

ΛΛ- Hypernuclei at Panda



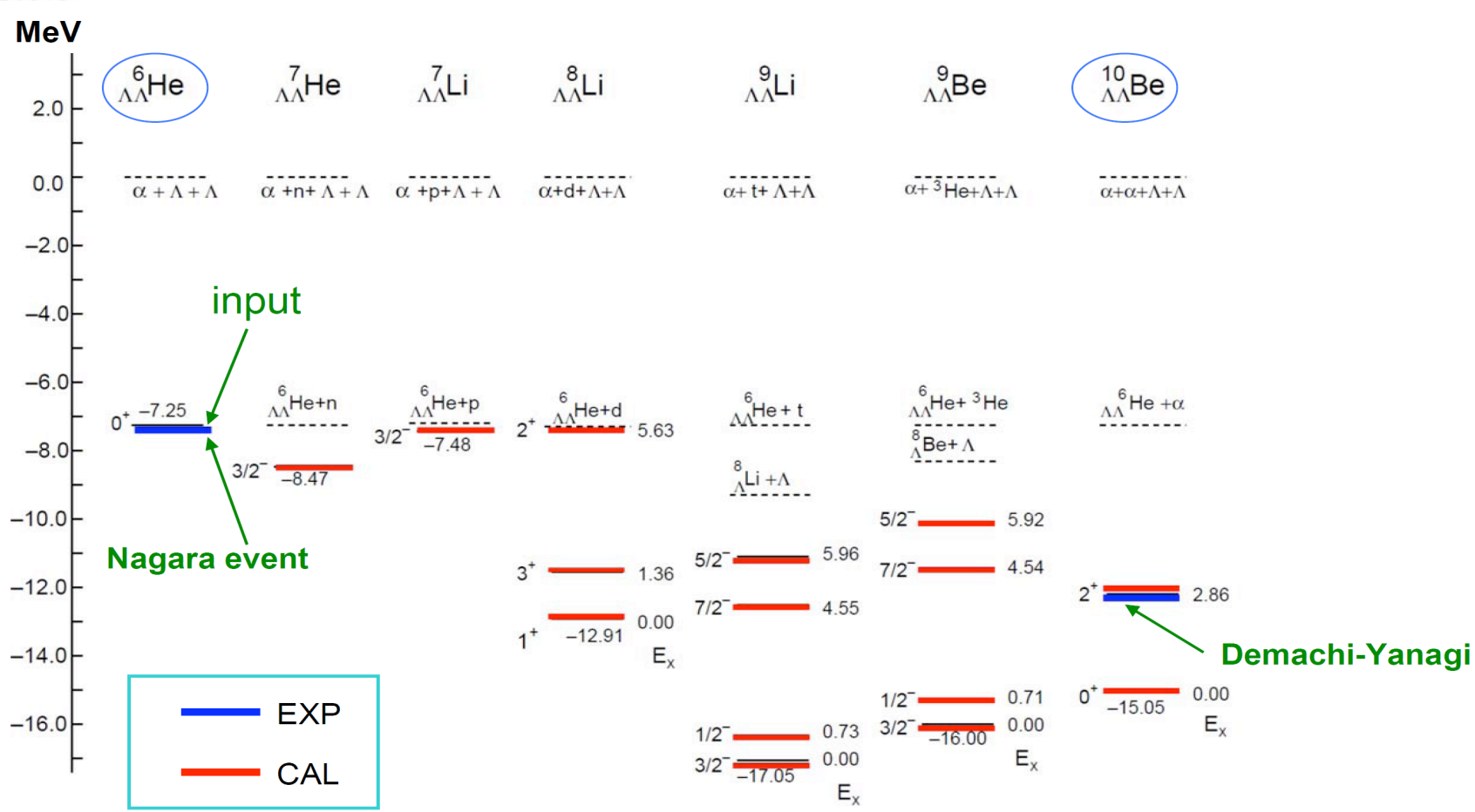
$\bar{p} + {}^{12}C \Rightarrow \Xi^{-} + \bar{\Xi}$

γ- Spectroscopy by using an array of HPGe



Excited states of ΛΛ- Hypernuclei

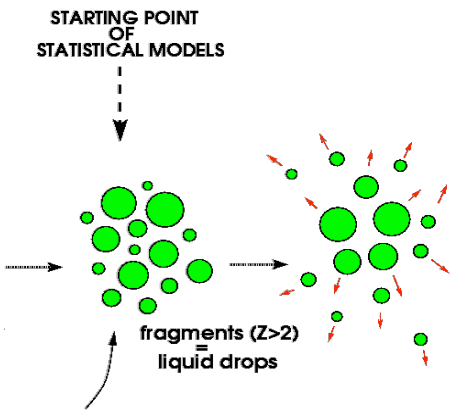
E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto Phys. Rev. 66 (2002) , 024007



- Many excited, individual excited, particle stable states of double hypernuclei have been predicted

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 ?



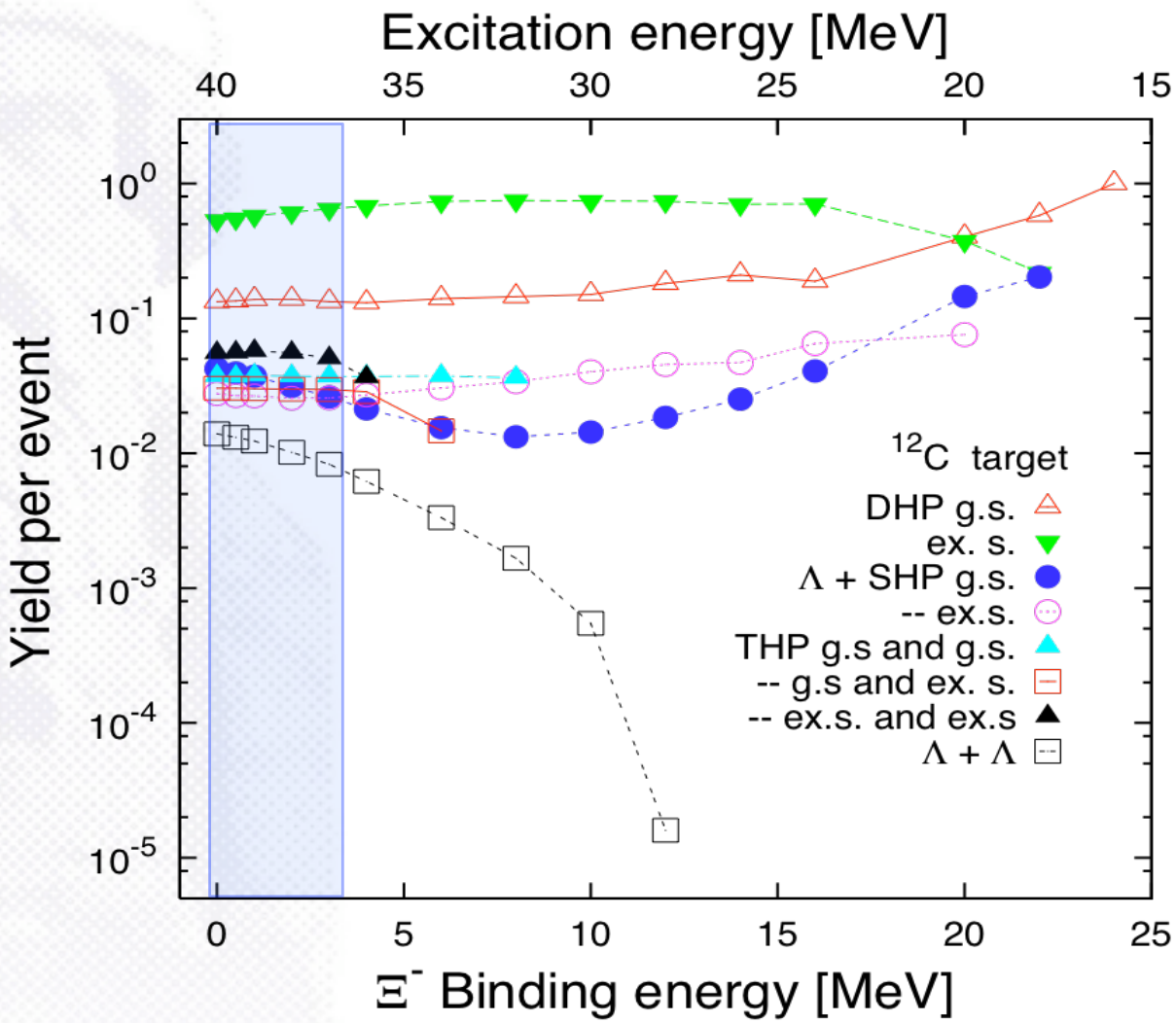
- conversion width $\Xi + p \Rightarrow \Lambda\Lambda$ around Γ=1MeV
- Ξ^- binding energy not precisely known

- 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 $^{13}_{\Lambda\Lambda}B^*$



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

▼ △ : Double-Hypernuclei

● ○ : Single-Hypernuclei

▲ ▲ □ : Twin-Hypernuclei

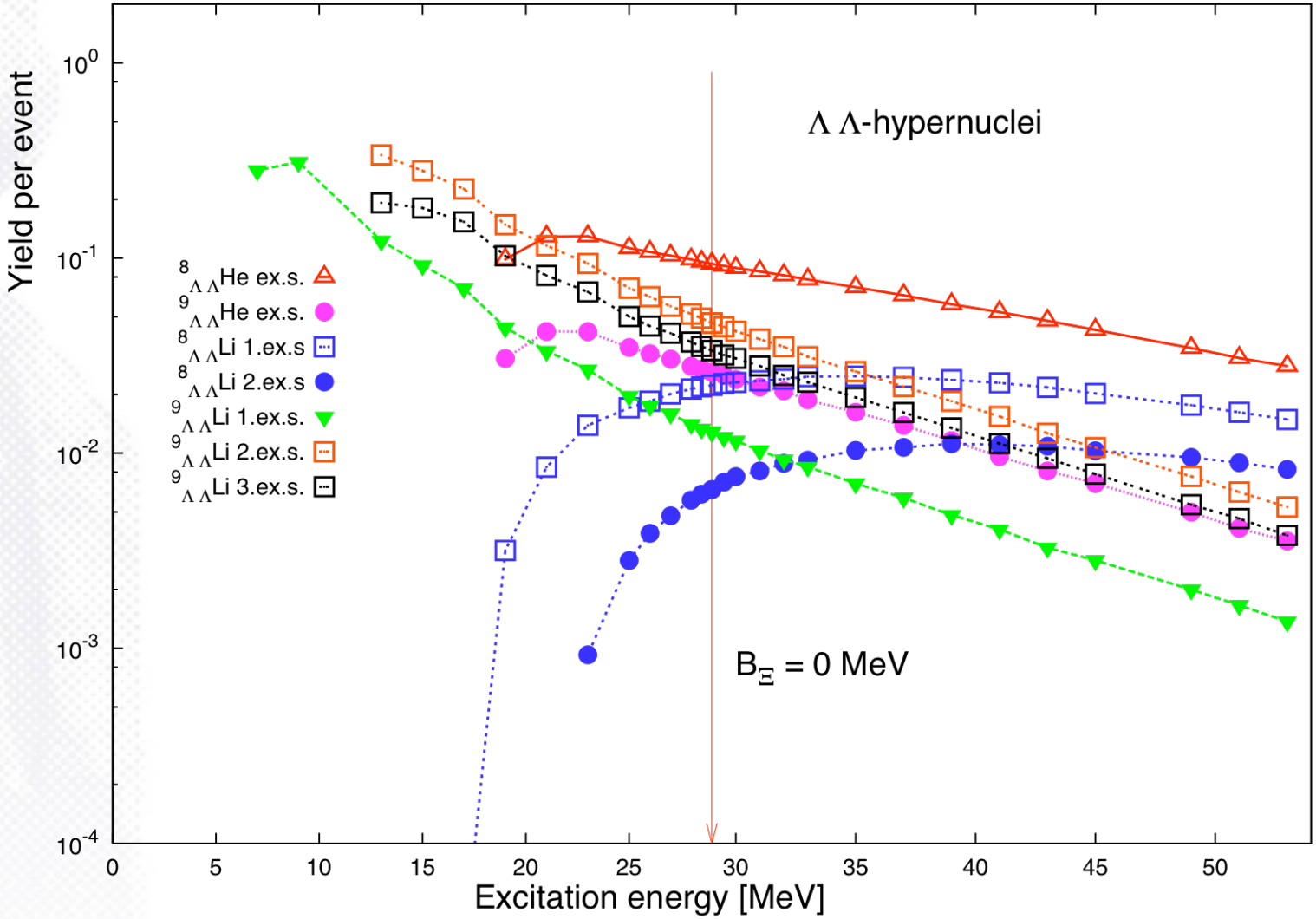
□ : $\Lambda\Lambda$

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



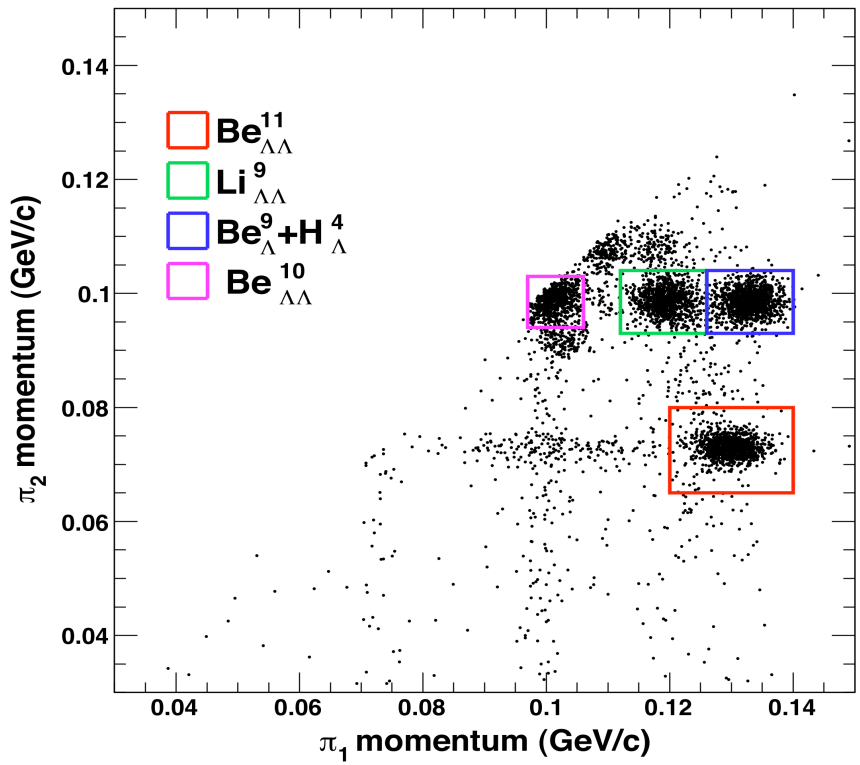
Relevant production of individual excited states

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

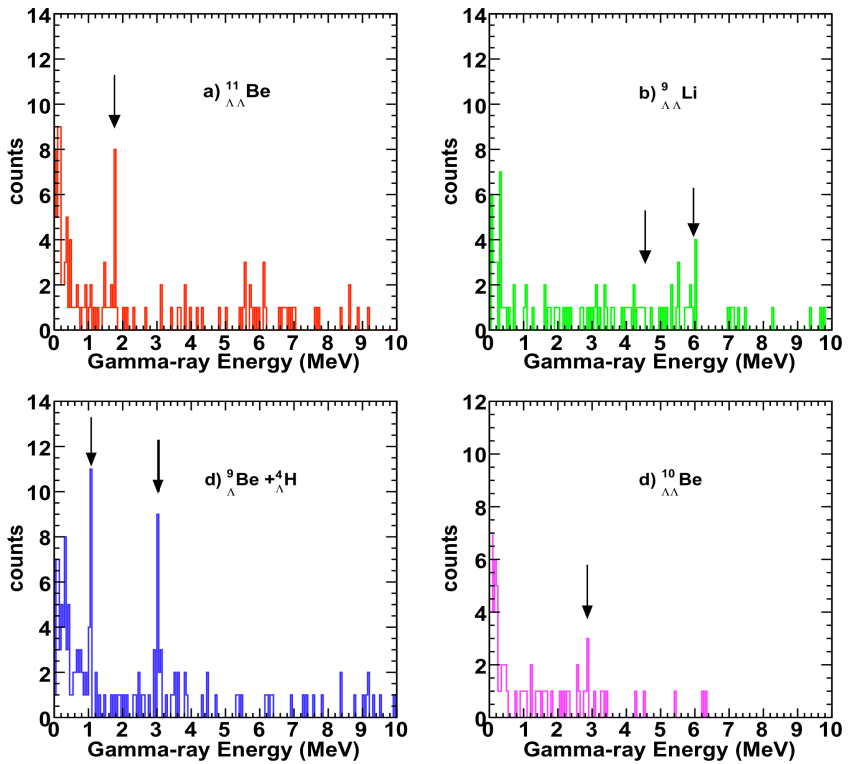
Identification of ΛΛ-Hypernuclei at PANDA

- 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 − ray energy



JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MAINZER MIKROTRON

HELMHOLTZ GEMEINSCHAFT

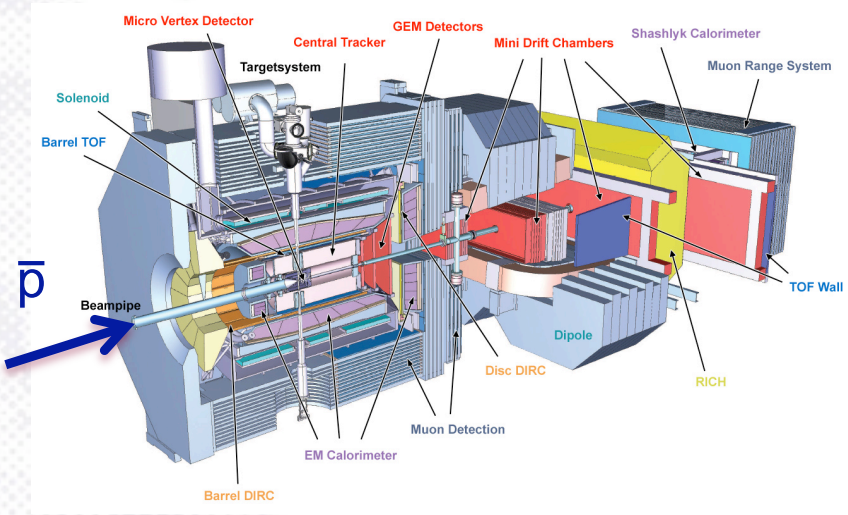
Helmholtz-Institut Mainz

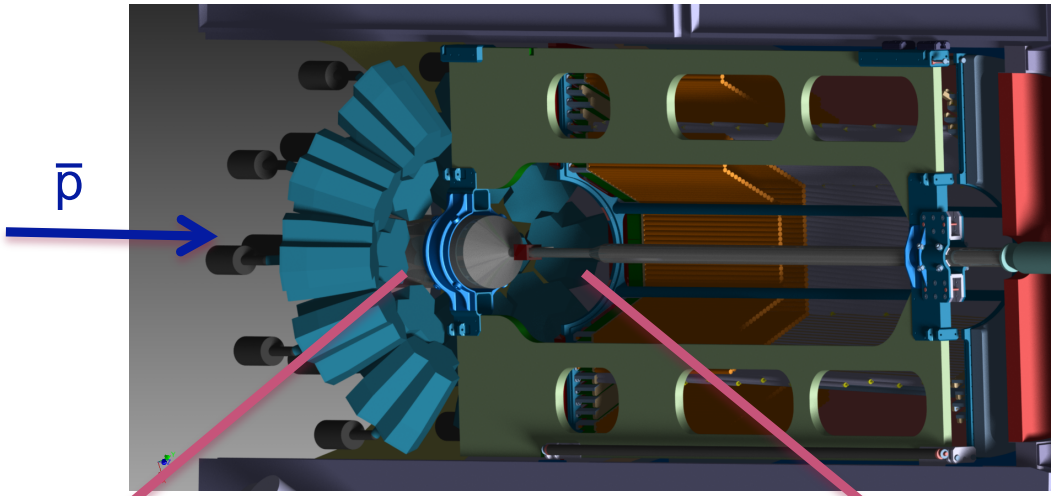
panda

Detector developments

- Integration in the PANDA spectrometer
- The Secondary Active Target
- The HPGe Array

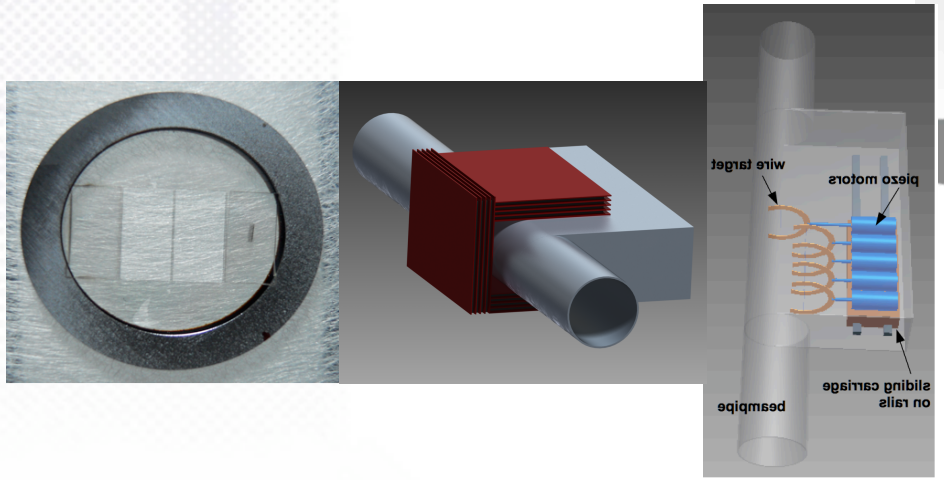
Dedicated beam pipe / target system

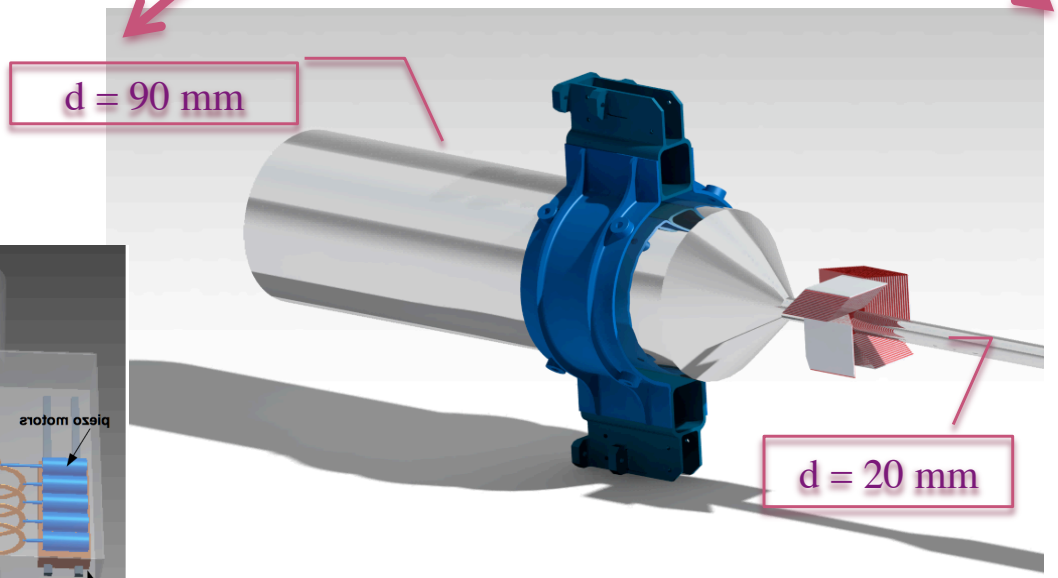




Backward End Cap Calorimeter and MVD will be not used

- Modular structure
- Dedicated beam pipe/target system

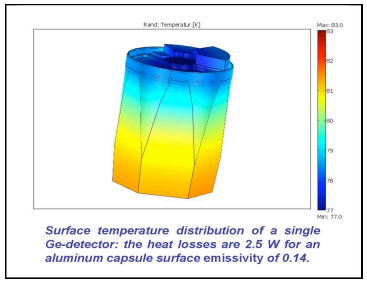


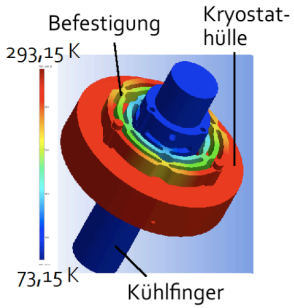


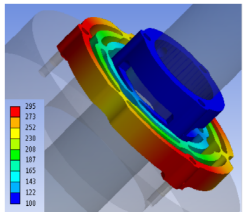
by cortesy of D. Rodriguez, M. Steinen, F. Iazzi and S. Bleser

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

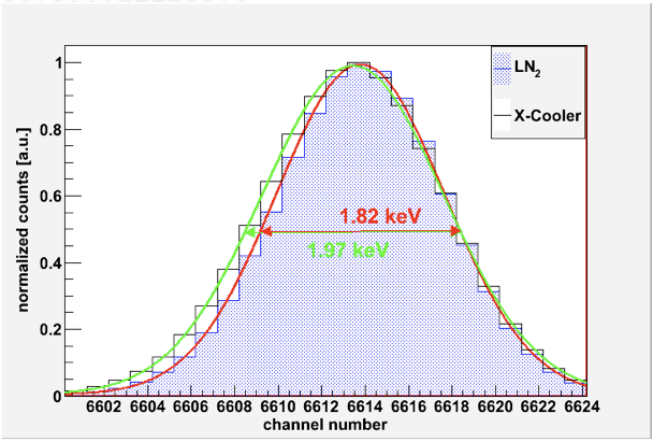
- Ongoing activities: High Rate environment:
  - Radiation Damage studies with a prototype
  - Pile-Up effects
  - Pulse shape analysis

by cortesy of M. Steinen and I. Kojoujarov

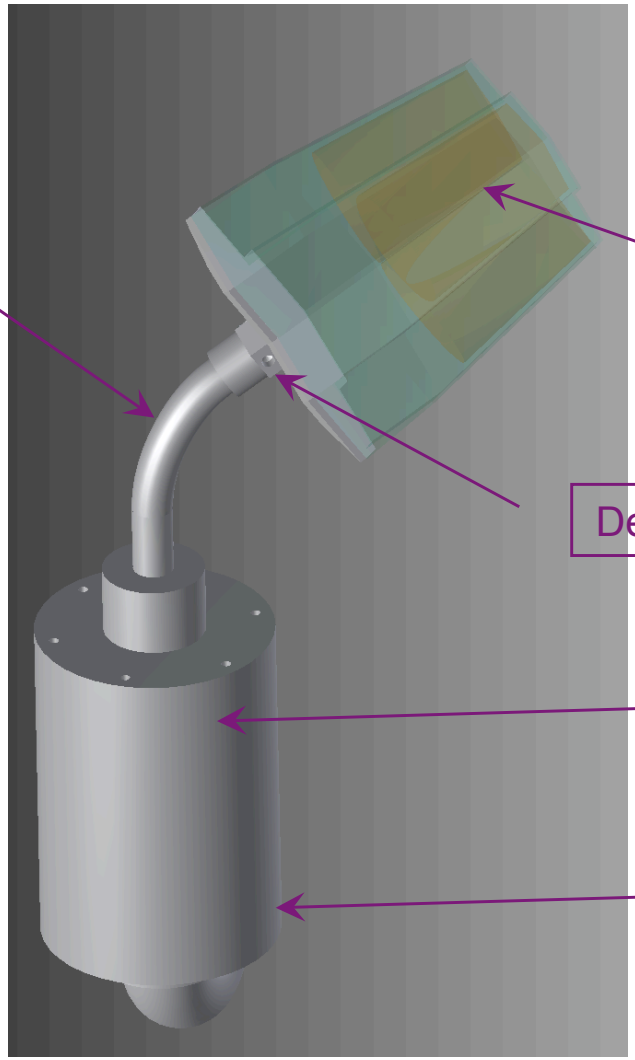
Further considerations concerning the X-Cooler

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

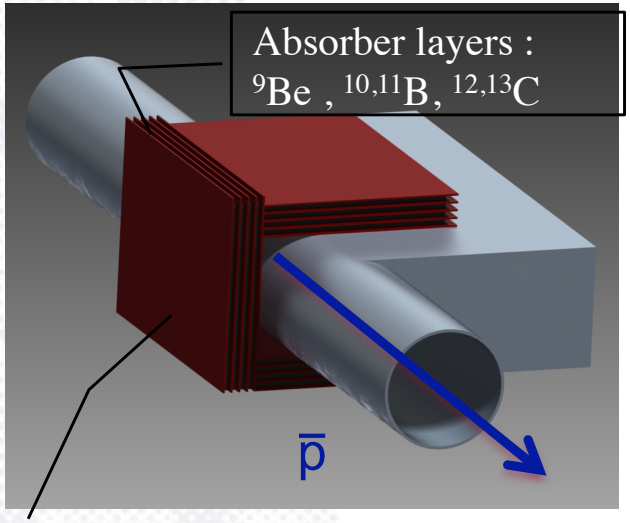
Detector Head fixing.

Electronics chamber

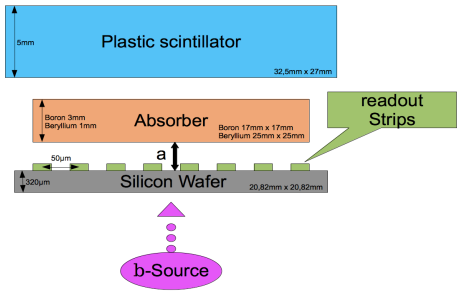
X-Cooler Head, partiallly hidden inside the electronics chamber

The Secondary Active Target

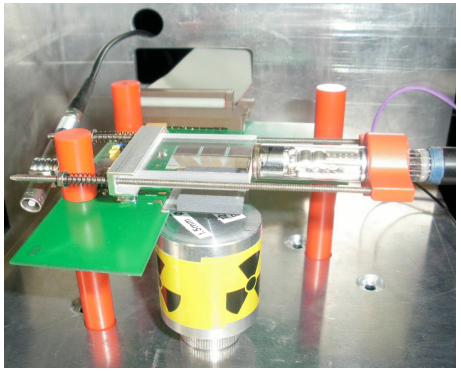
- Compact Structure of detector and absorber:
  - Performance of Silicon Strips Detector in direct contact with absorbers



double sided μ - strip detectors



by cortesy of S. Bleser



- Ongoing projects:

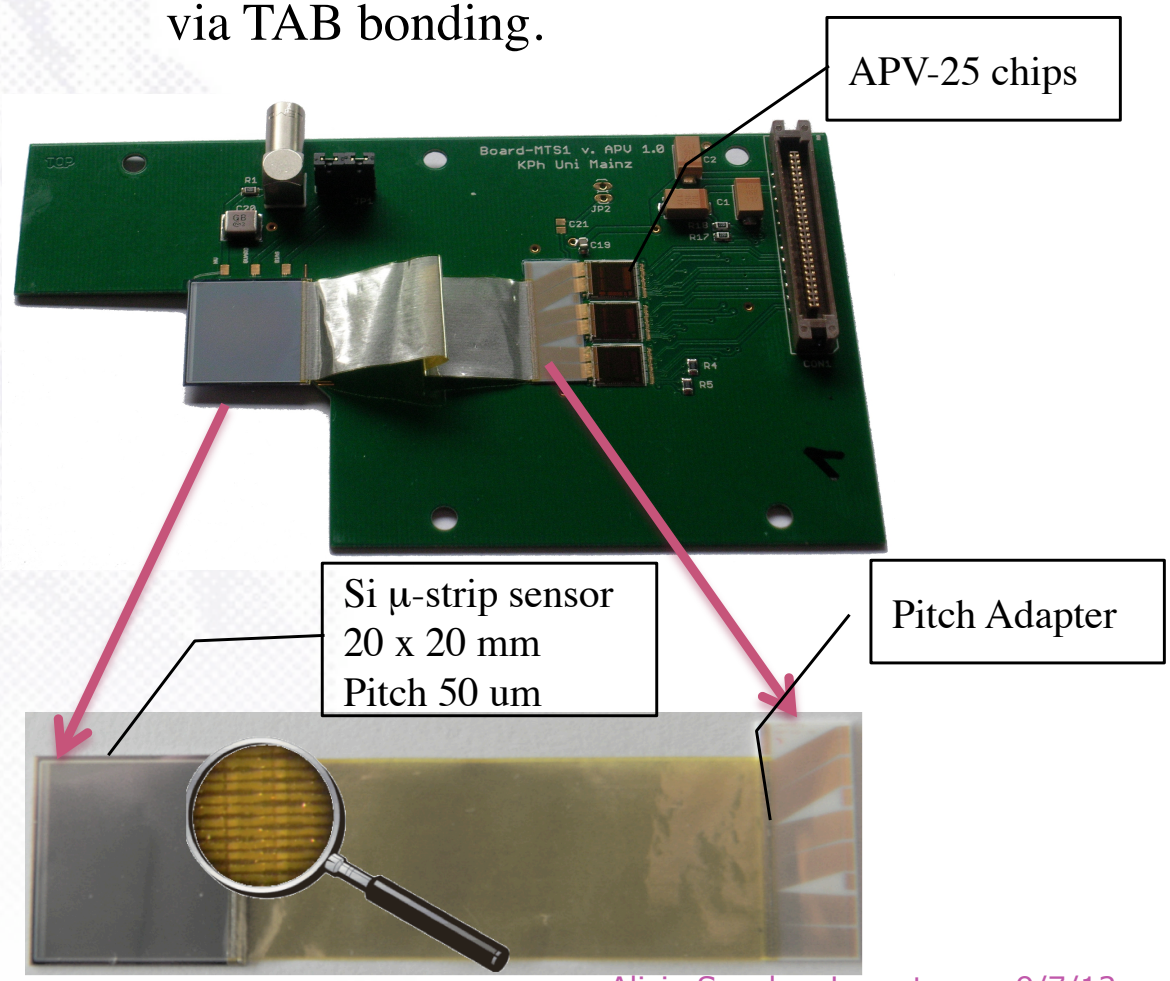
  Space required for frontend electronics:
  - Minimization of additional material budget on detecting volume:
  - Ultra-thin Al-Polyimide readout cables

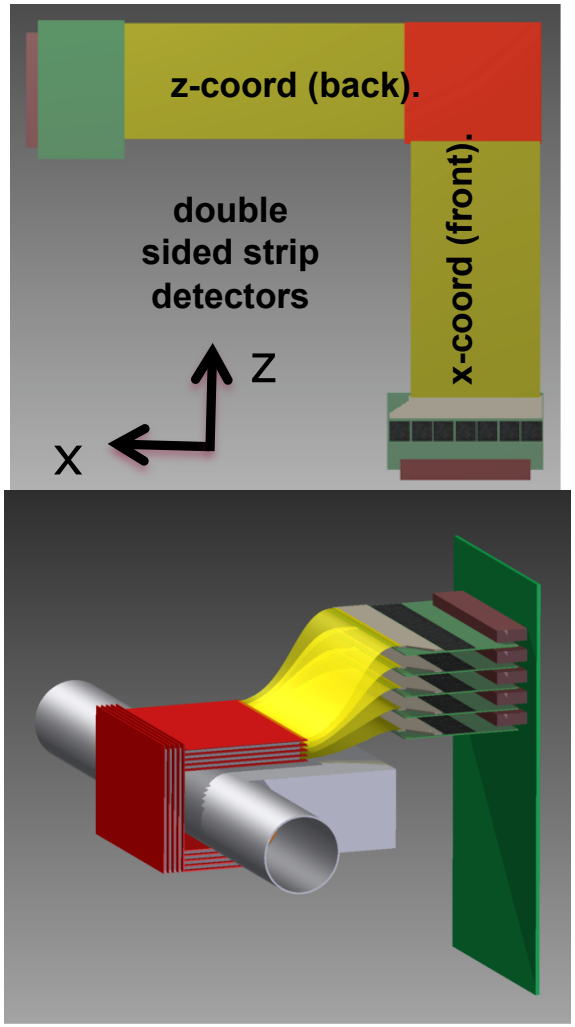
    J.M. Heuser et al. HadronPhysics2/JRA-ULISI

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.





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

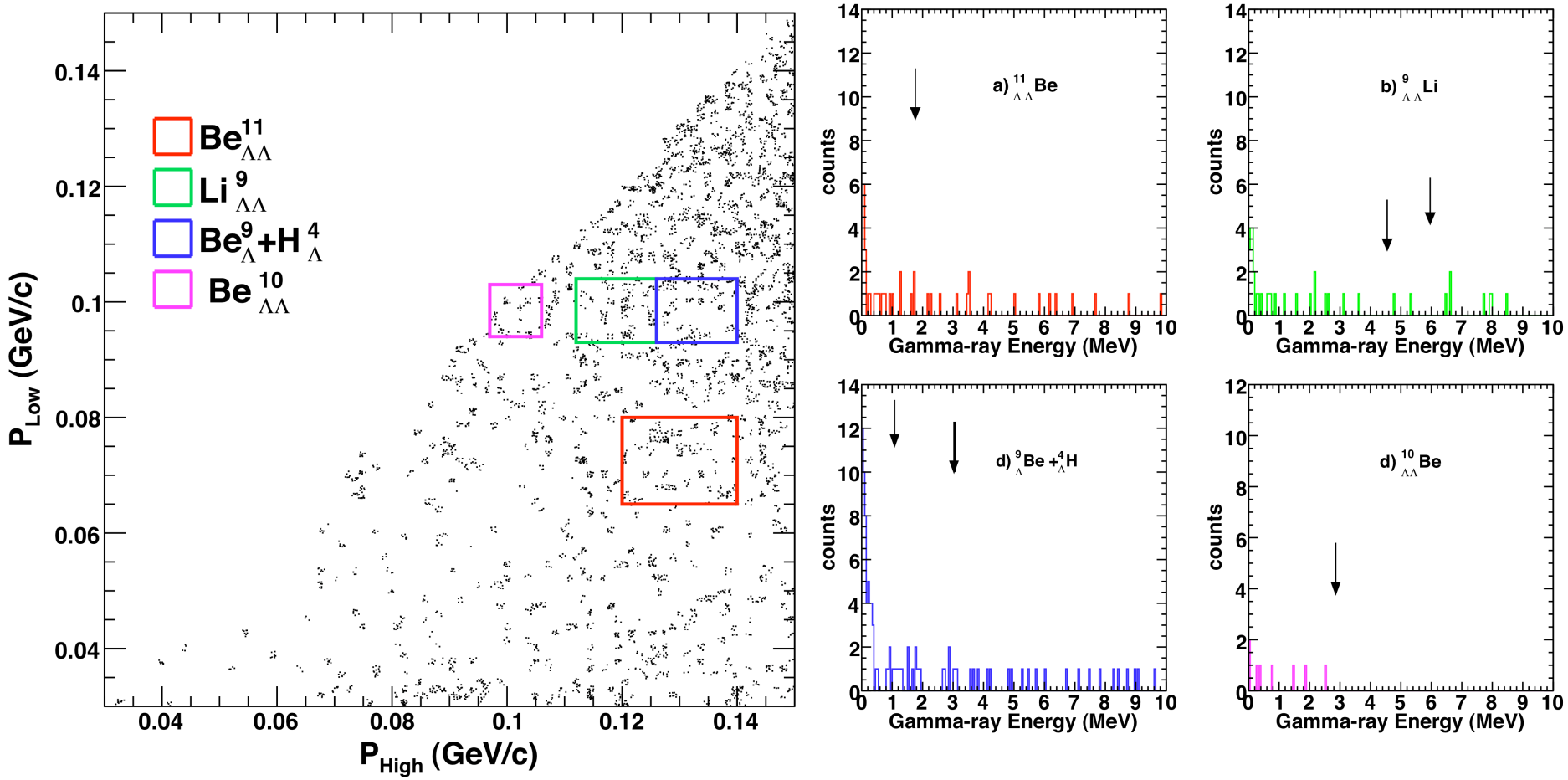
U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

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
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

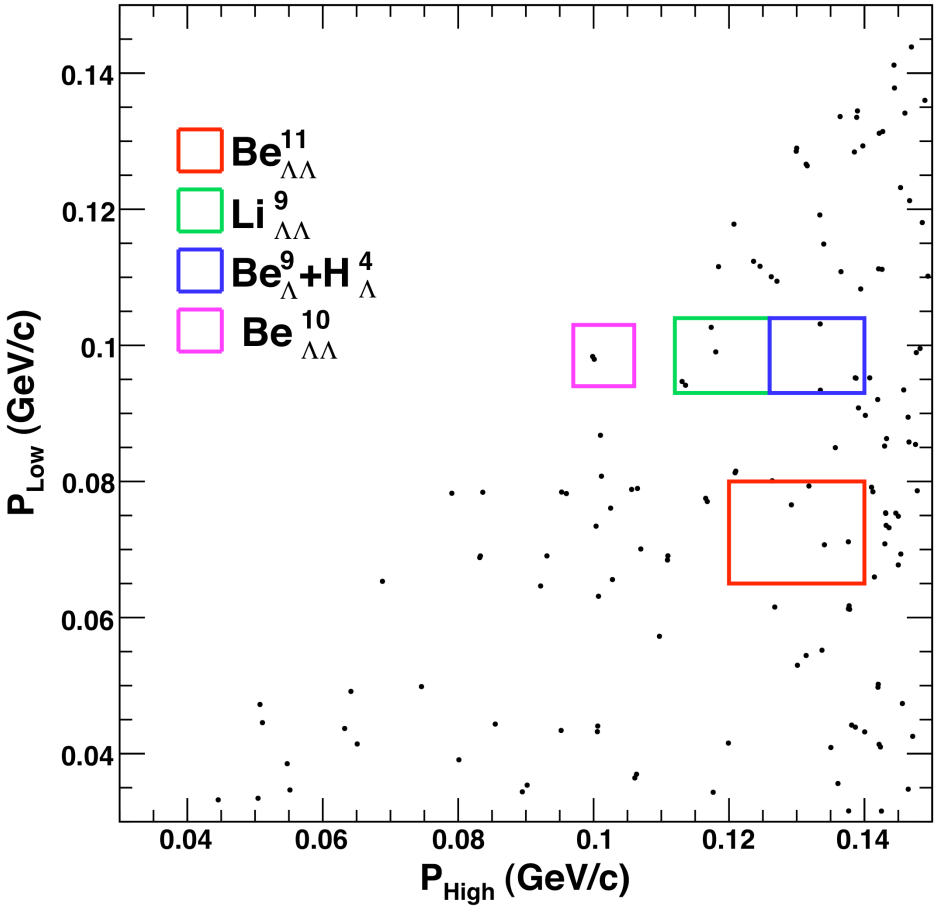
Free $\Xi^- + \bar{\Xi}$ background contribution

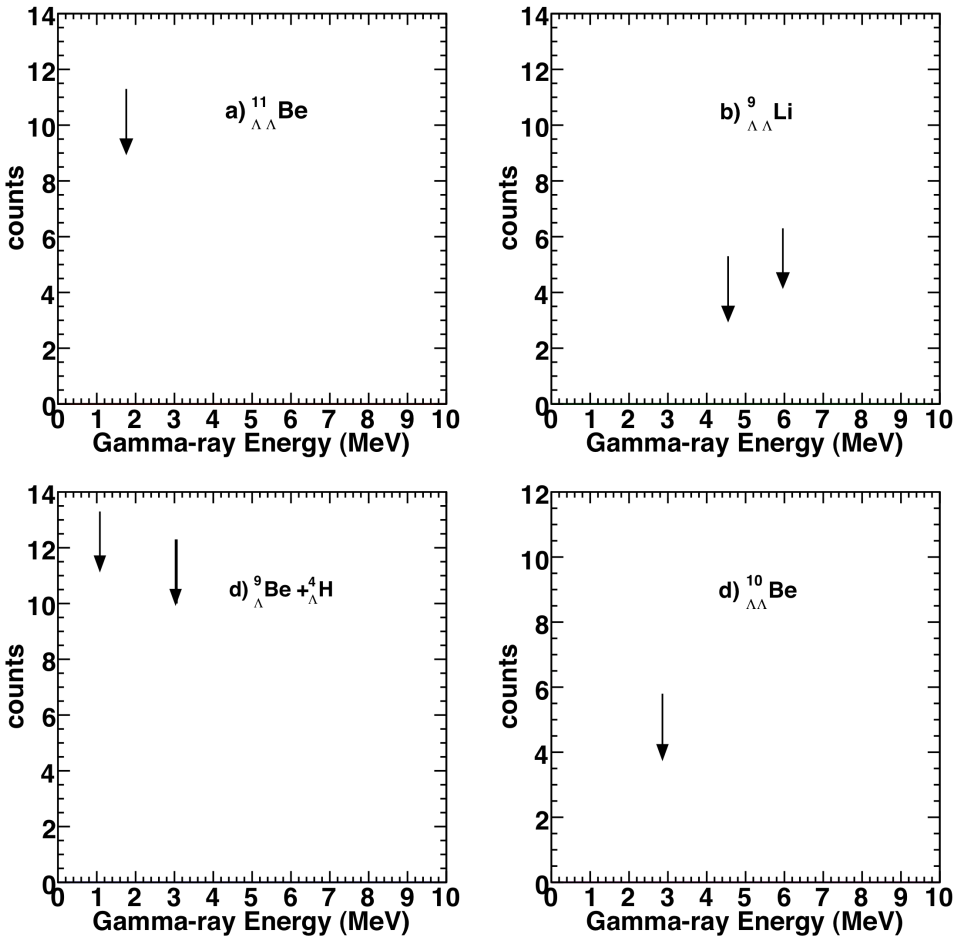
- The background of Ξ free decay and Ξ^+ annihilation



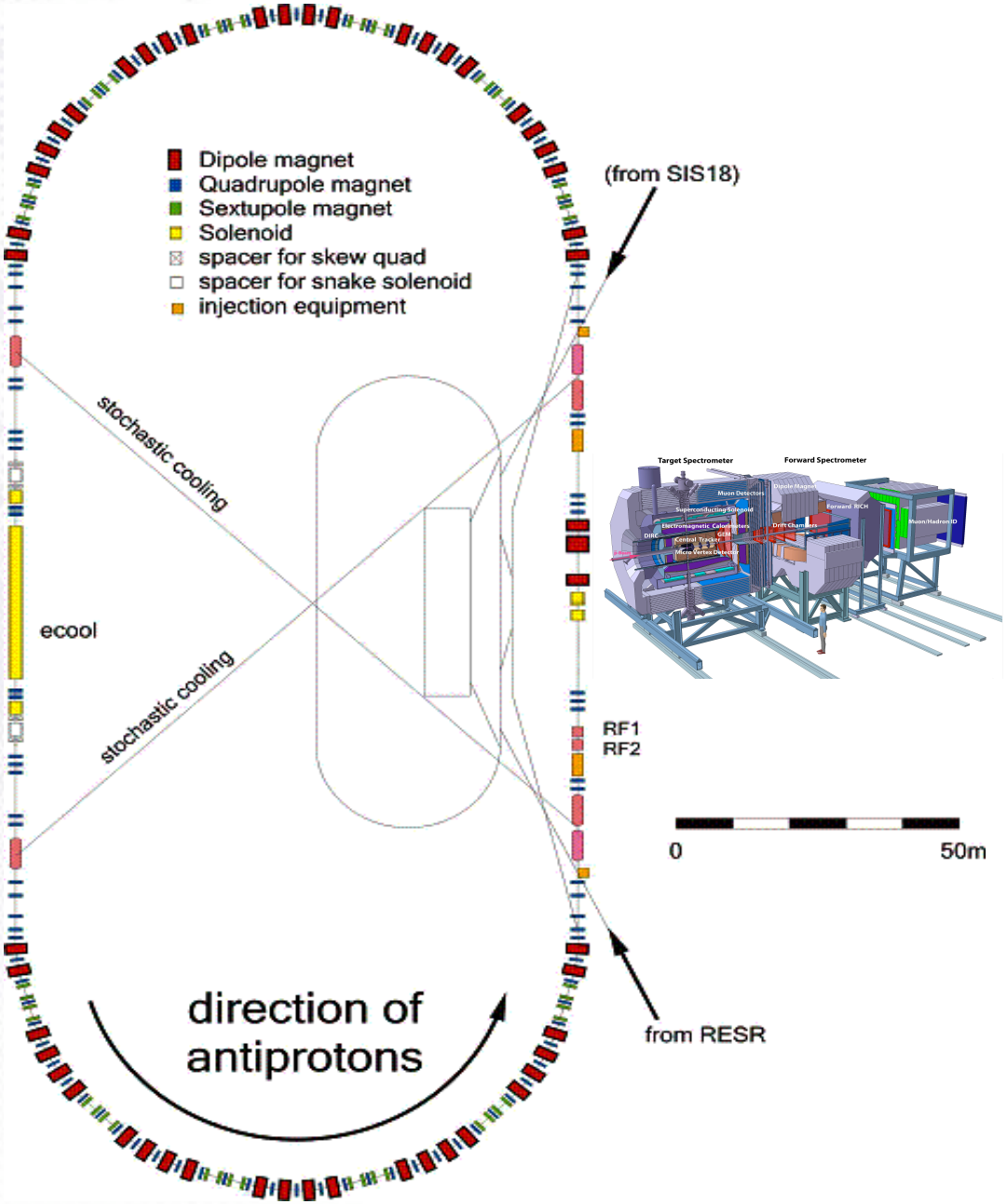
$\bar{p}$ + ^{12}C background contribution

- More statistic is needed





HESR : High Energy Storage Ring



Storage Ring

- p = 1.5 – 15 GeV/c

High intensity mode

- $\mathcal{L} = 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, $\delta p/p = 10^{-4}$
- Electric cooling

High resolution mode

- $\mathcal{L} = 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, $\delta p/p = 10^{-5}$
- Stochastic cooling