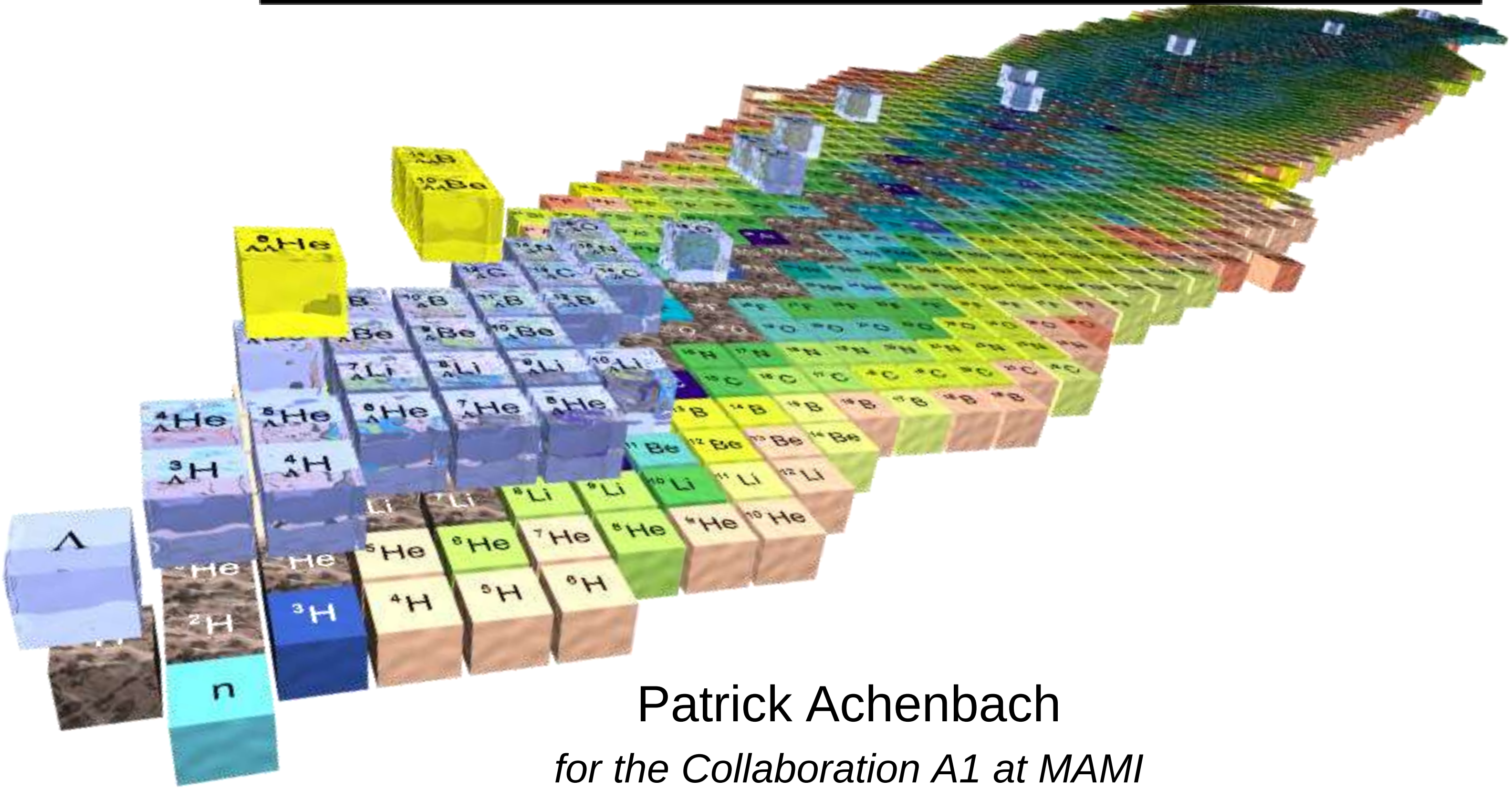
Forming the hypernuclear landscape with MAMI and PANDA



Patrick Achenbach

for the Collaboration A1 at MAMI

and the PANDA group at U Mainz:

P. Achenbach, J. Pochodzalla, A. Sanchez Lorente, et al.

Nov 2oo8

Tour d'horizon

- The hypernuclear landscape
  - – being formed by the international hypernuclear network
- Hypernuclei formation in electroproduction
  - – the KAOS spectrometer at the accelerator MAMI-C
- Hypernuclear physics with anti-protons
  - – the PANDA experiment at FAIR

The hypernuclear landscape

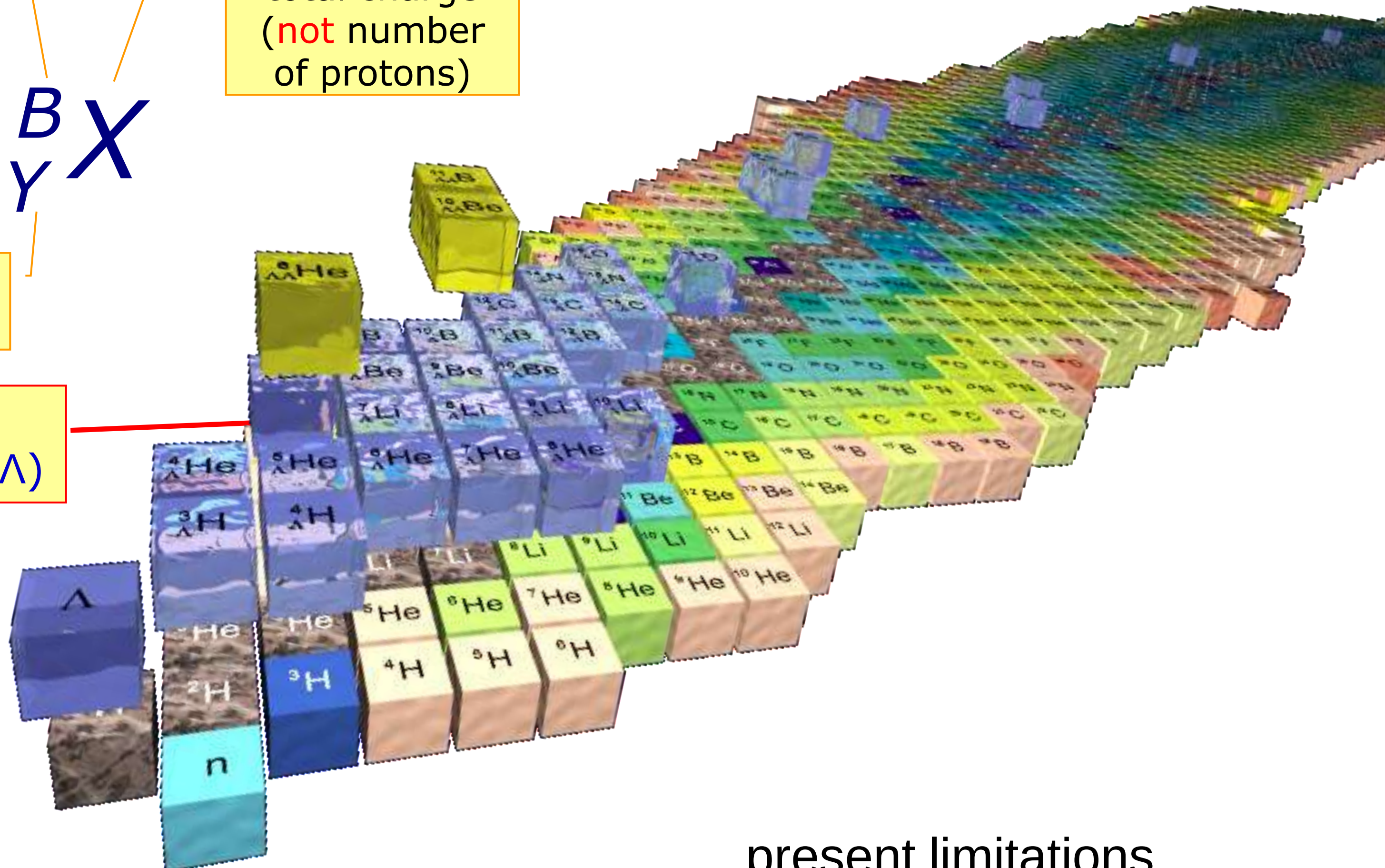
number of baryons $N+Z+Y$

element = total charge (not number of protons)

$^{B}_{Y}X$

number of hyperons Y

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



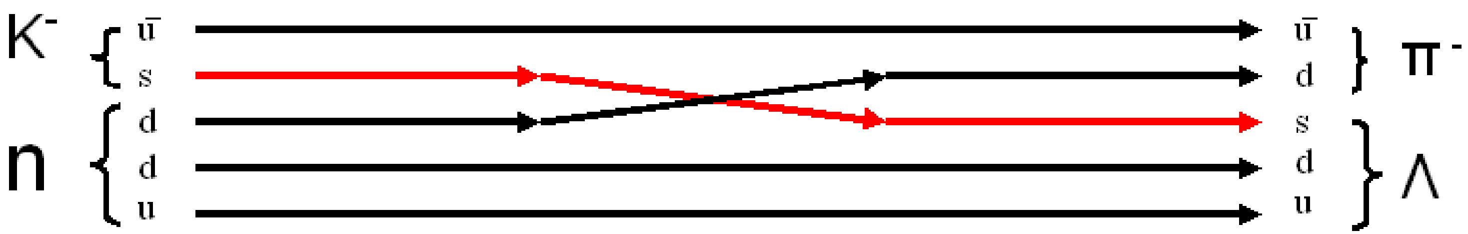
increasing strangeness

present limitations

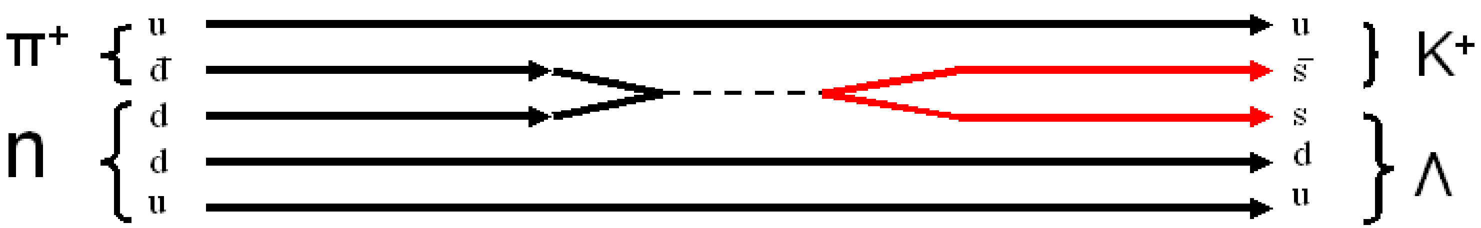
- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events

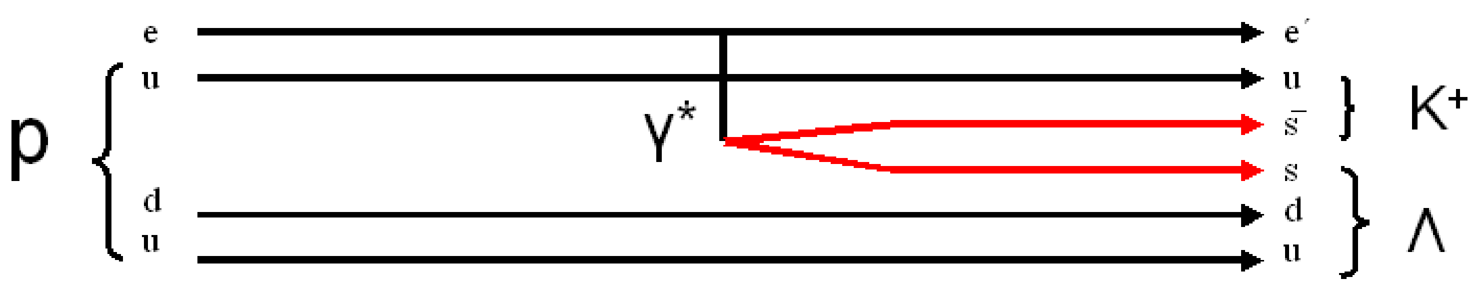
Strangeness reactions

exchange of strangeness

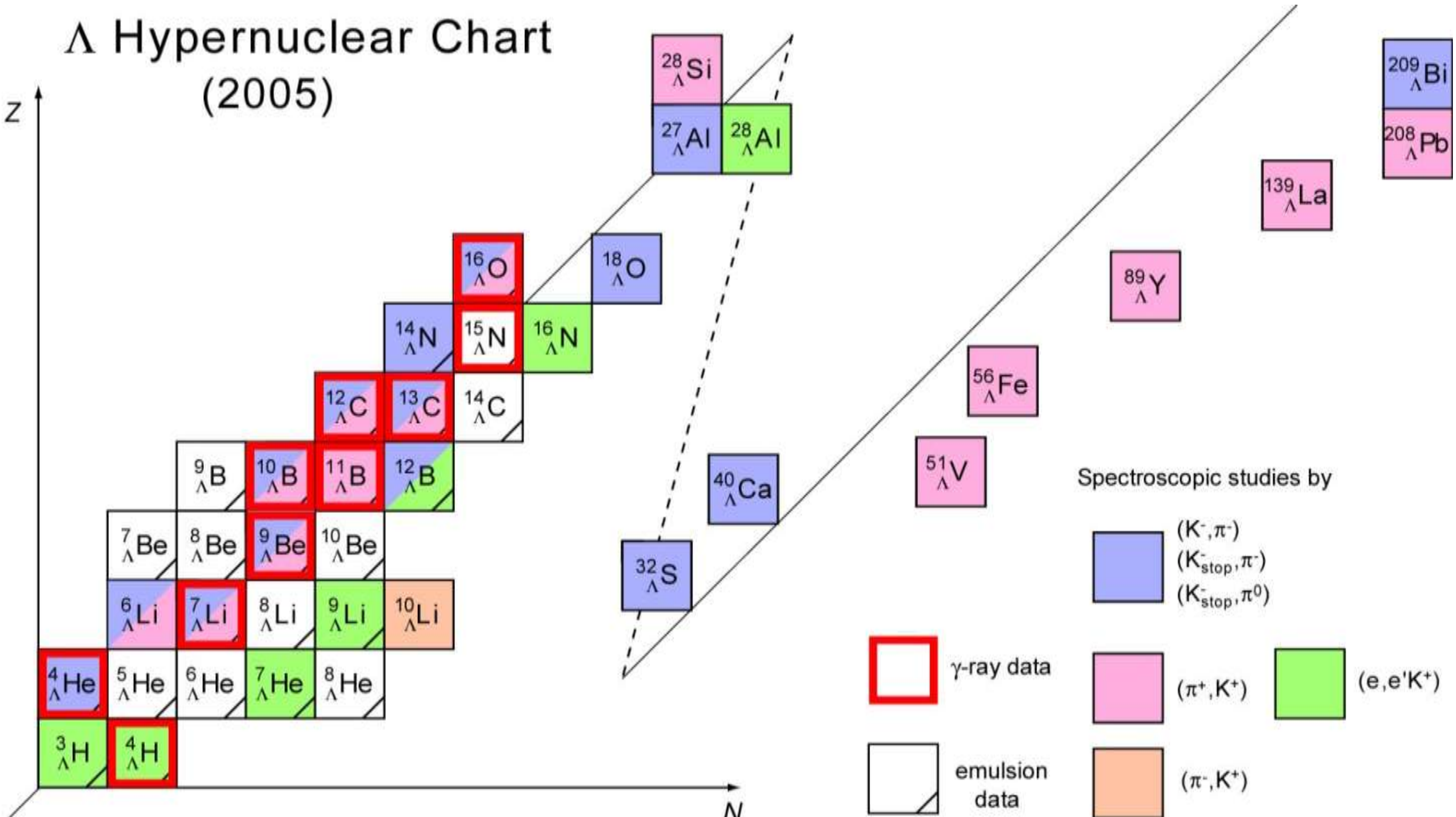


production of open strangeness



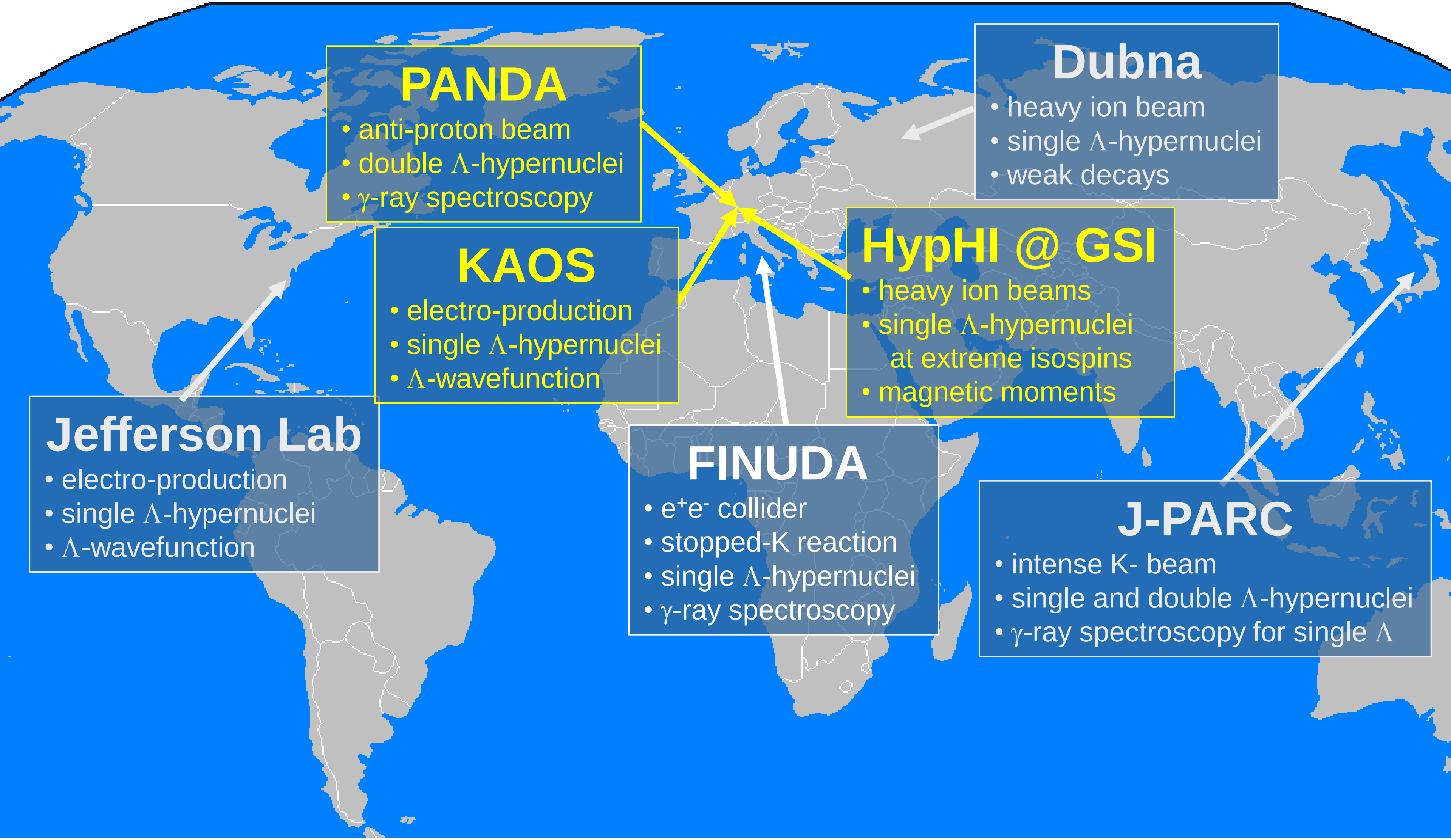


Spectroscopy of single Λ-hypernuclei

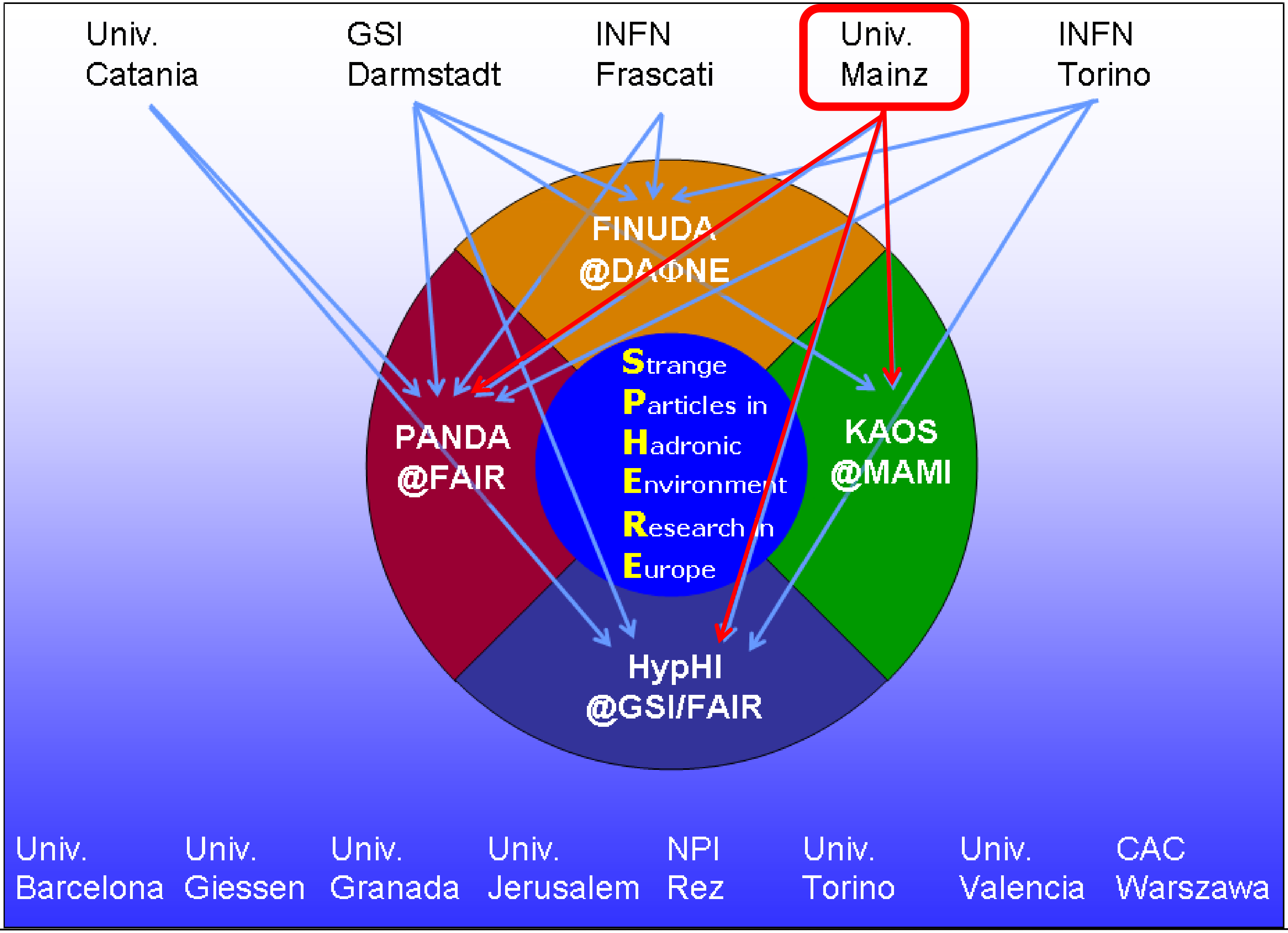


[Updated from: O. Hashimoto and H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564]

International hypernuclear network

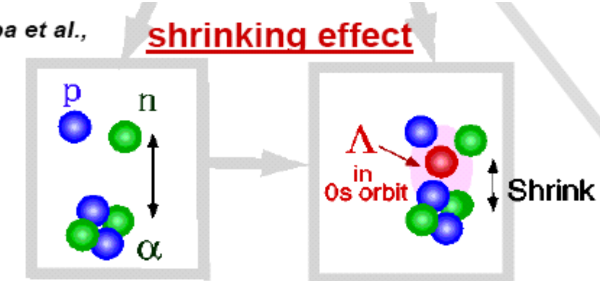


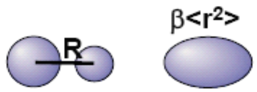
Networking Activity SPHERE (EU FP7 *HadronPhysics2*)



Strangeness impurity effects

Predicted by Motoba et al., Prog.Theor.Phys. 70 (1983) 189.





B(E2) $\propto |\langle f|\, e\, r^2\, Y_2\, |i\rangle|^2$

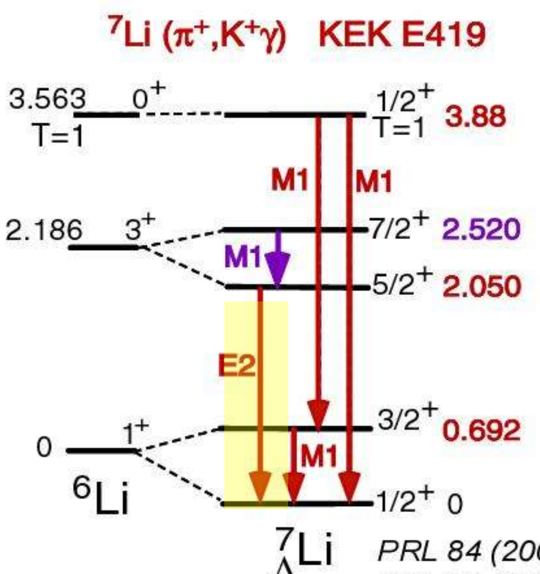
$\propto R^4$ or $(\beta \langle r^2 \rangle)^2$

B(E2) [e^2 fm^4]

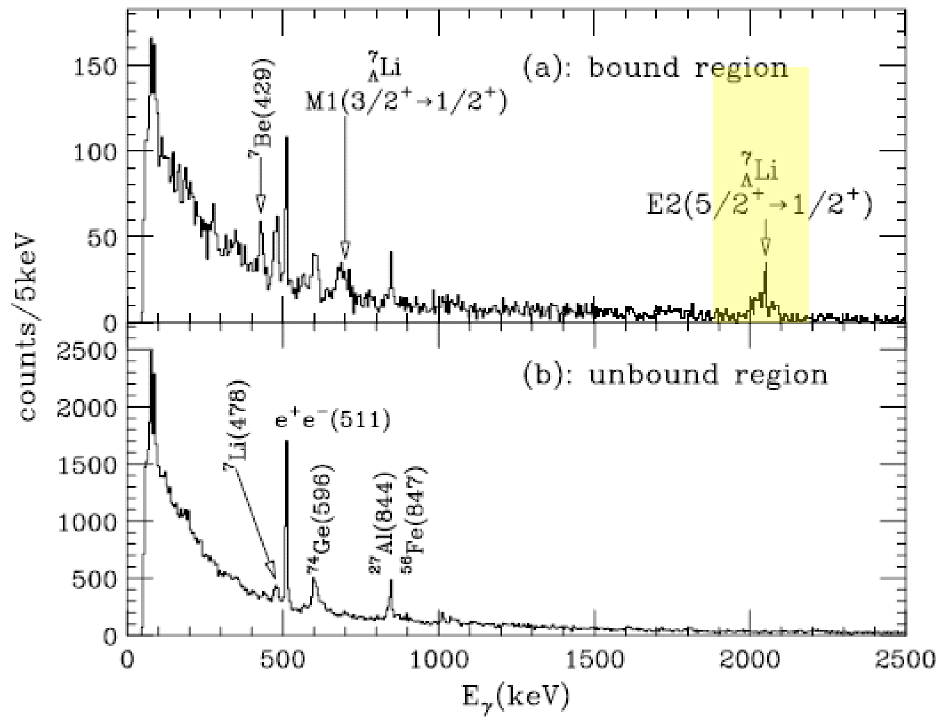
$10.9 \pm 0.9 \longrightarrow 3.6 \pm 0.5 \pm^{0.5}_{0.4}$

$\Rightarrow$ 19±4% shrinkage by Λ

Tanida et al., PRL 86(2001) 1982



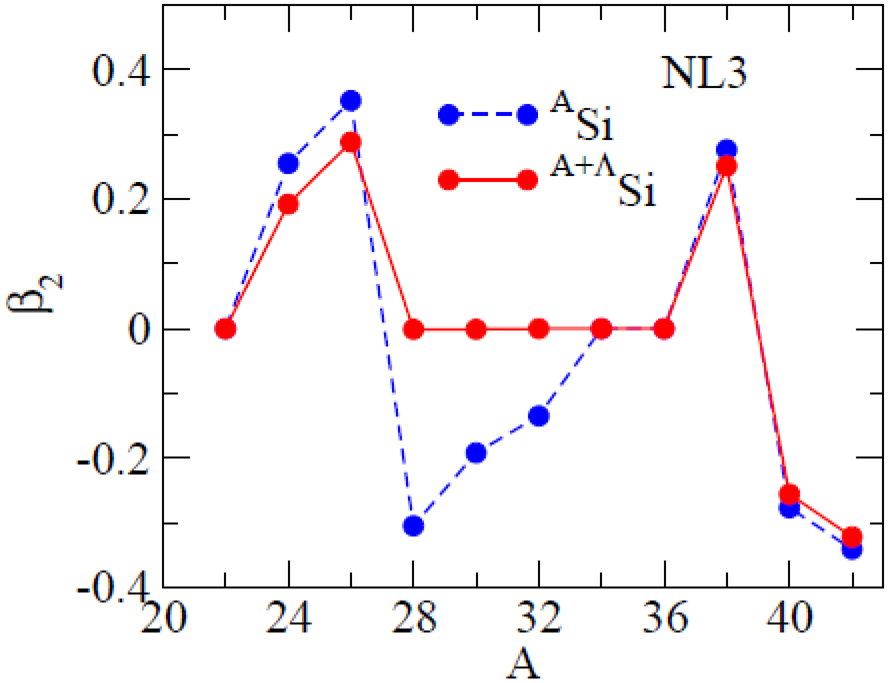
PRL 84 (2000) 59
PRL 86 (2001) 19
PLB 579 (2004) 2
PRC 73 (2006) 01

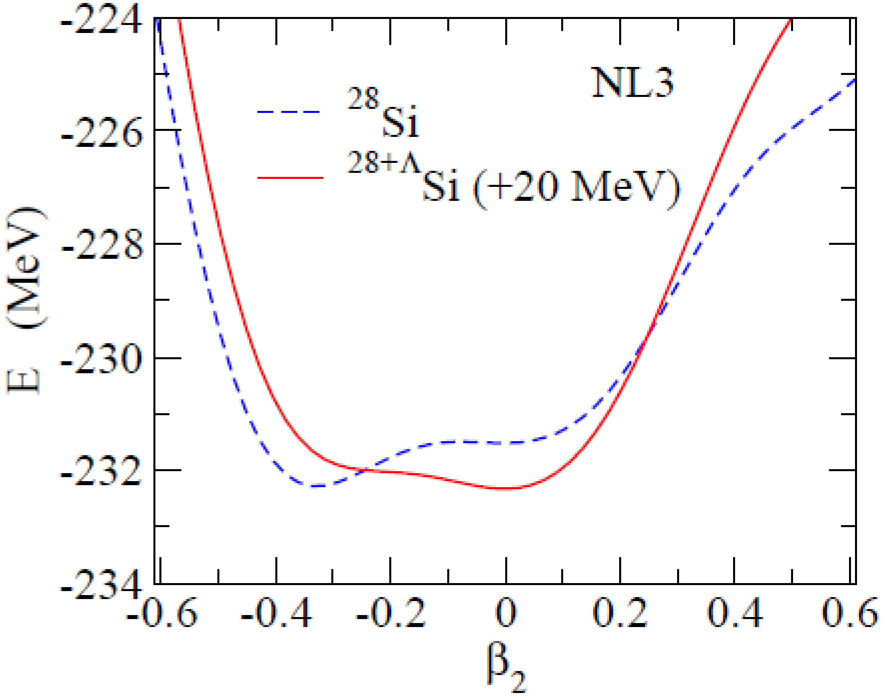


Hypernuclear impurity physics in silicon

$$Q = \sqrt{\frac{16\pi}{5}}\frac{3}{4\pi}(A_c+1)R_0^2\,\beta_2$$

change from oblate to spherical



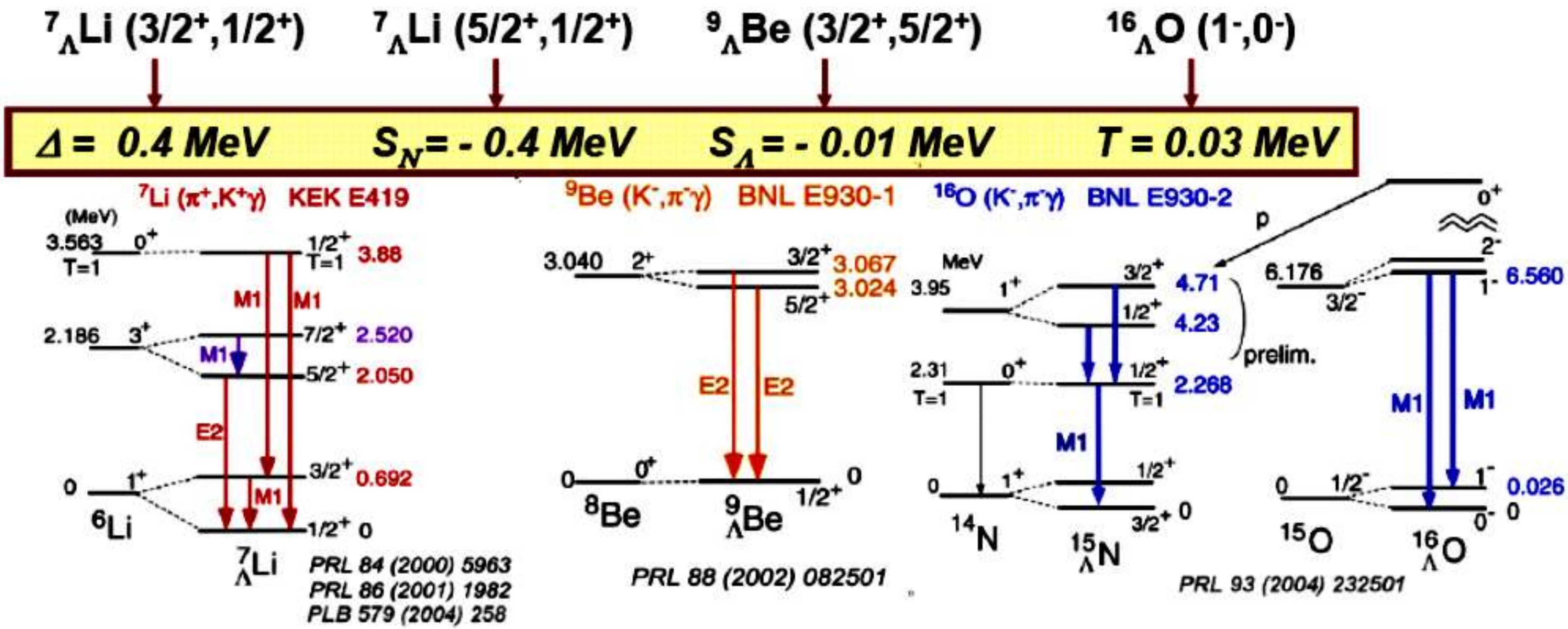


[Myaing Thi Win and K. Hagino: Deformation of hypernuclei, arXiv:0808.3303v1 [nucl-th], 25 Aug 2008]

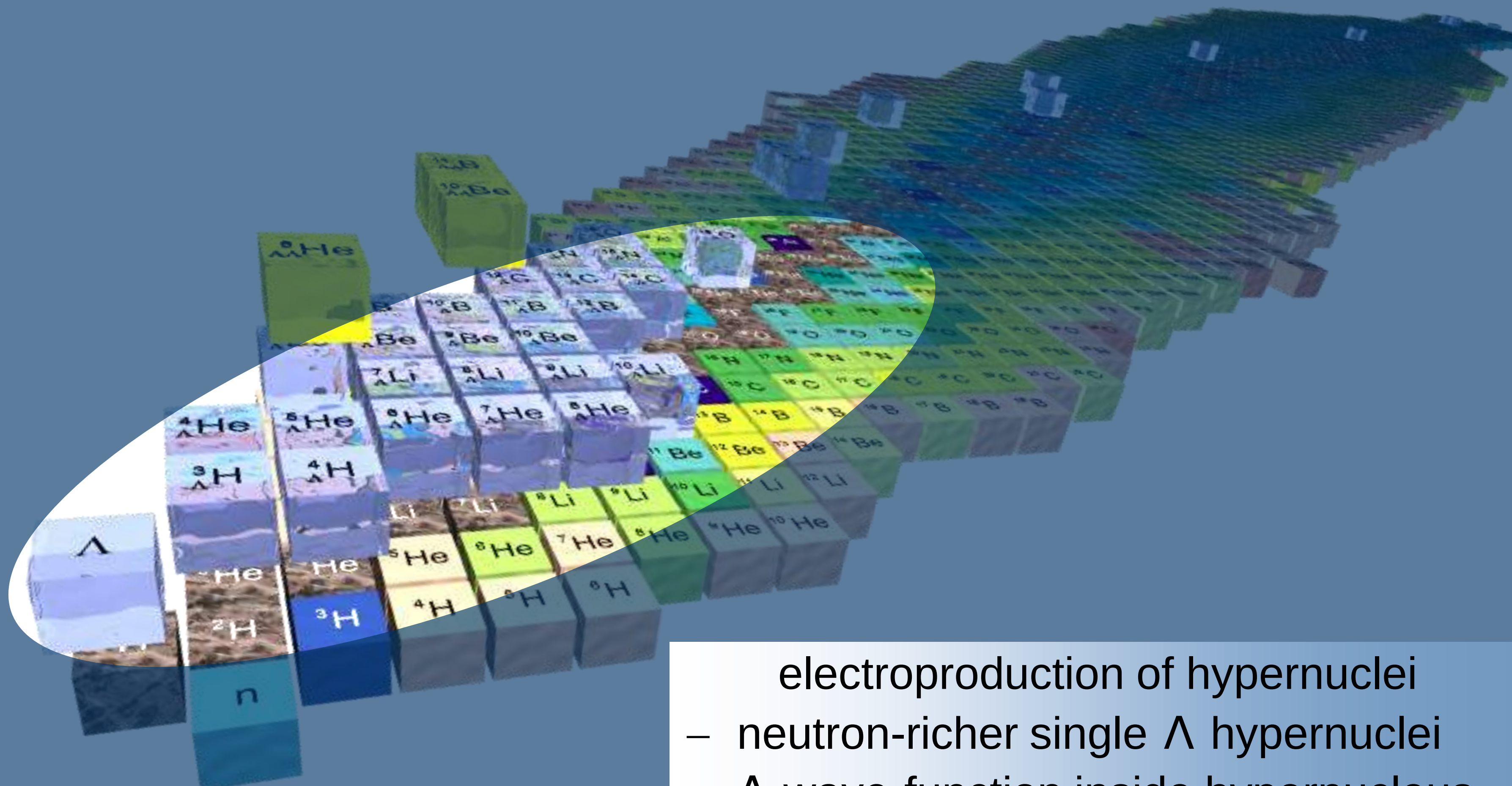
Observed γ-transitions in single Λ-hypernuclei

many excited, particle stable states in single hypernuclei observed
γ-spectroscopy of these states is used to study effective ΛN potential

$$V_{\Lambda N}^{eff} = V_0 + \Delta(\vec{s}_\Lambda \cdot \vec{s}_N) + S_N(\vec{l}_{\Lambda N} \cdot \vec{s}_N) + S_\Lambda(\vec{l}_{\Lambda N} \cdot \vec{s}_\Lambda) + T(s_{12})$$



Strangeness electroproduction

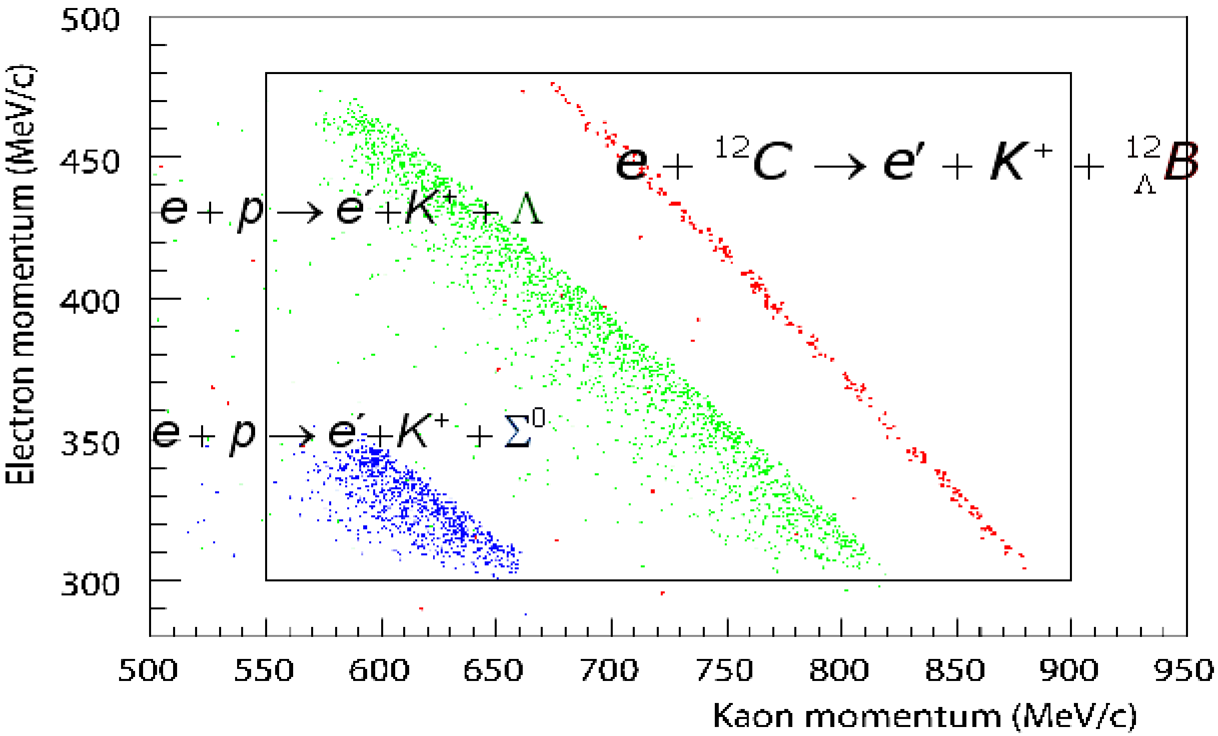


electroproduction of hypernuclei

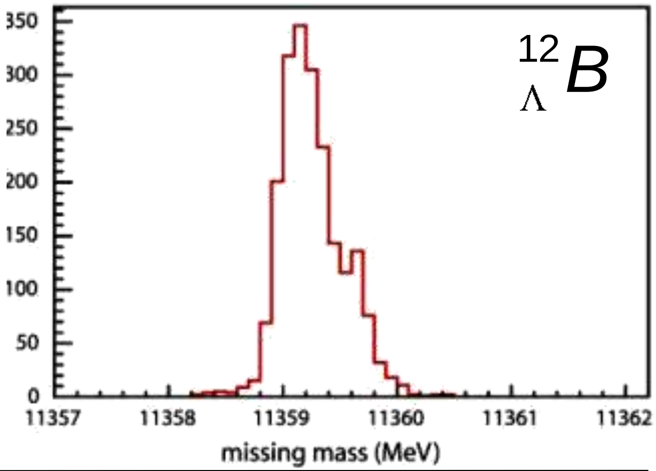
- neutron-richer single Λ hypernuclei
- Λ wave-function inside hypernucleus
- large momentum transfer components

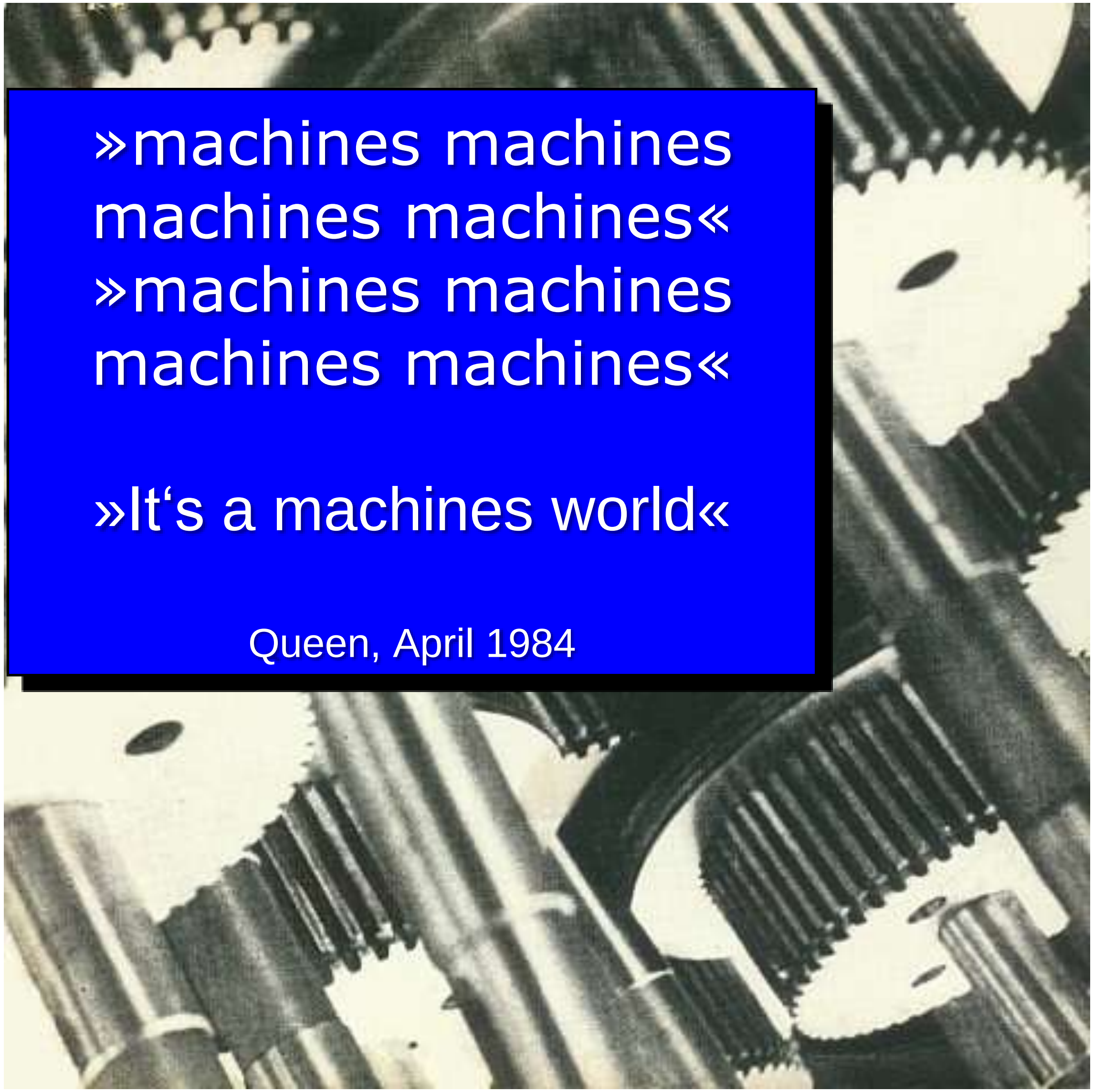
Challenges and prospects

special features of electro-production at MAMI-C (and JeffersonLab)
- better resolution compared to (π^+,K^+) or (K^-, π^-)
- access to new isotopes of hypernuclei (converting p into Λ)
- measurements at different kaon angles map out different parts of the Λ momentum distribution
- unique with KAOS: double spectroscopy in a single spectrometer

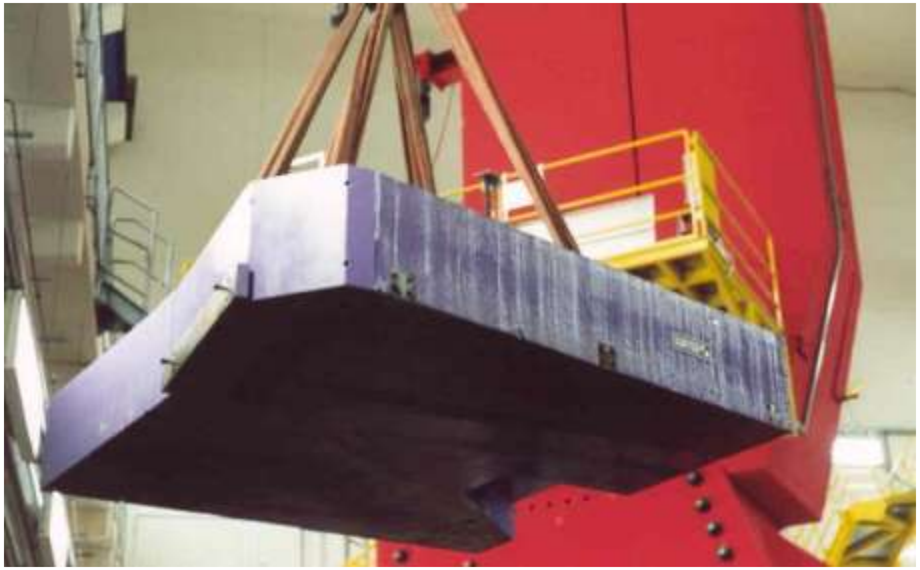


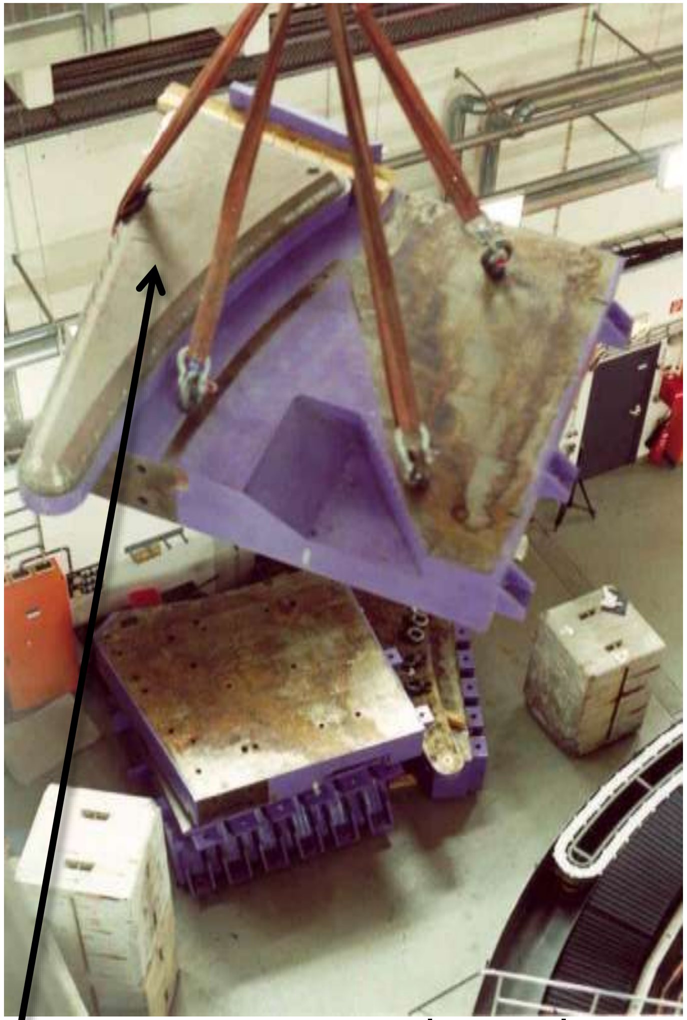
expected mass resolution:
σ_m= 275 keV




»machines machines
machines machines«
»machines machines
machines machines«
»It's a machines world«
Queen, April 1984

Transport of KAOS to Mainz in June 2003

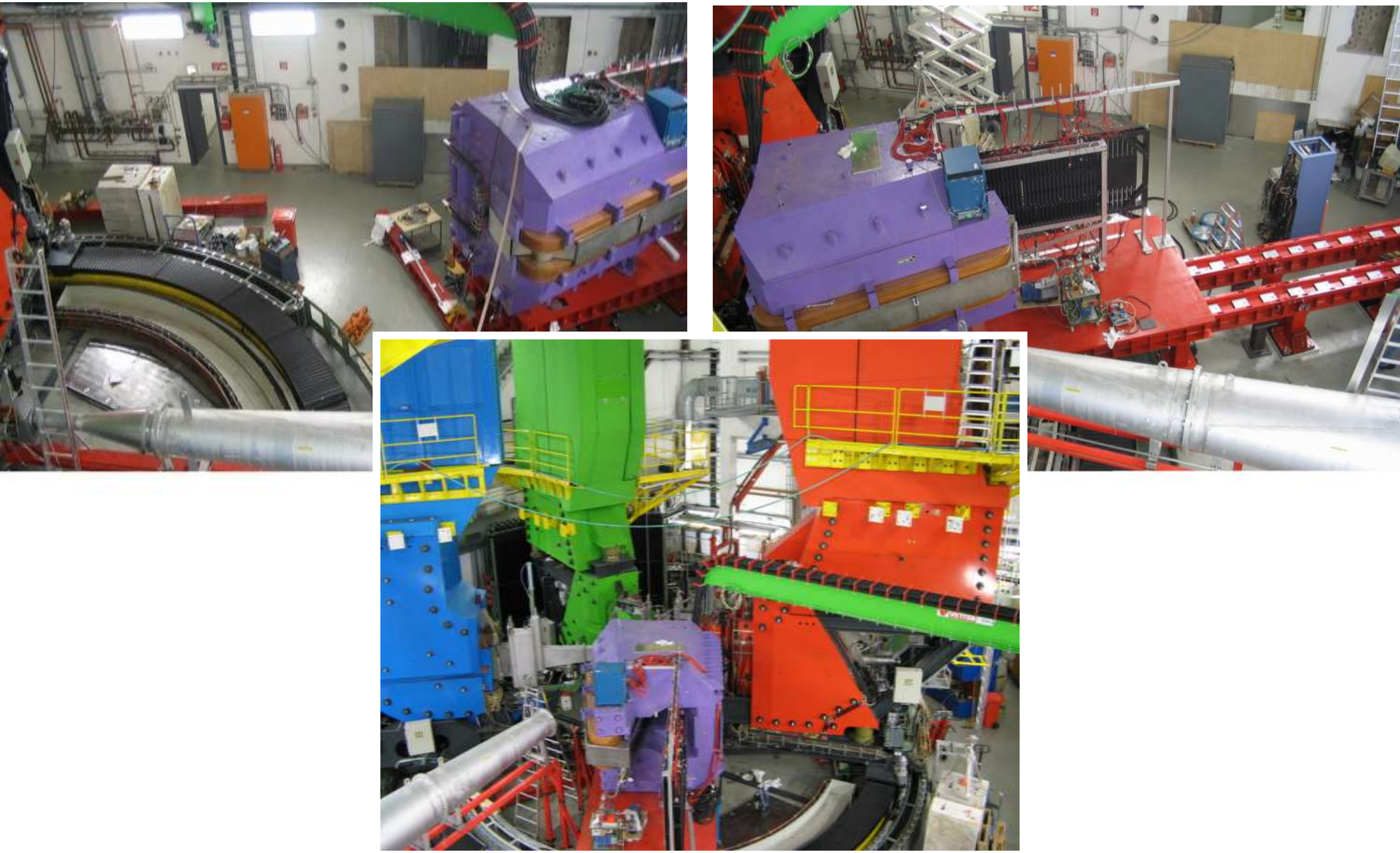




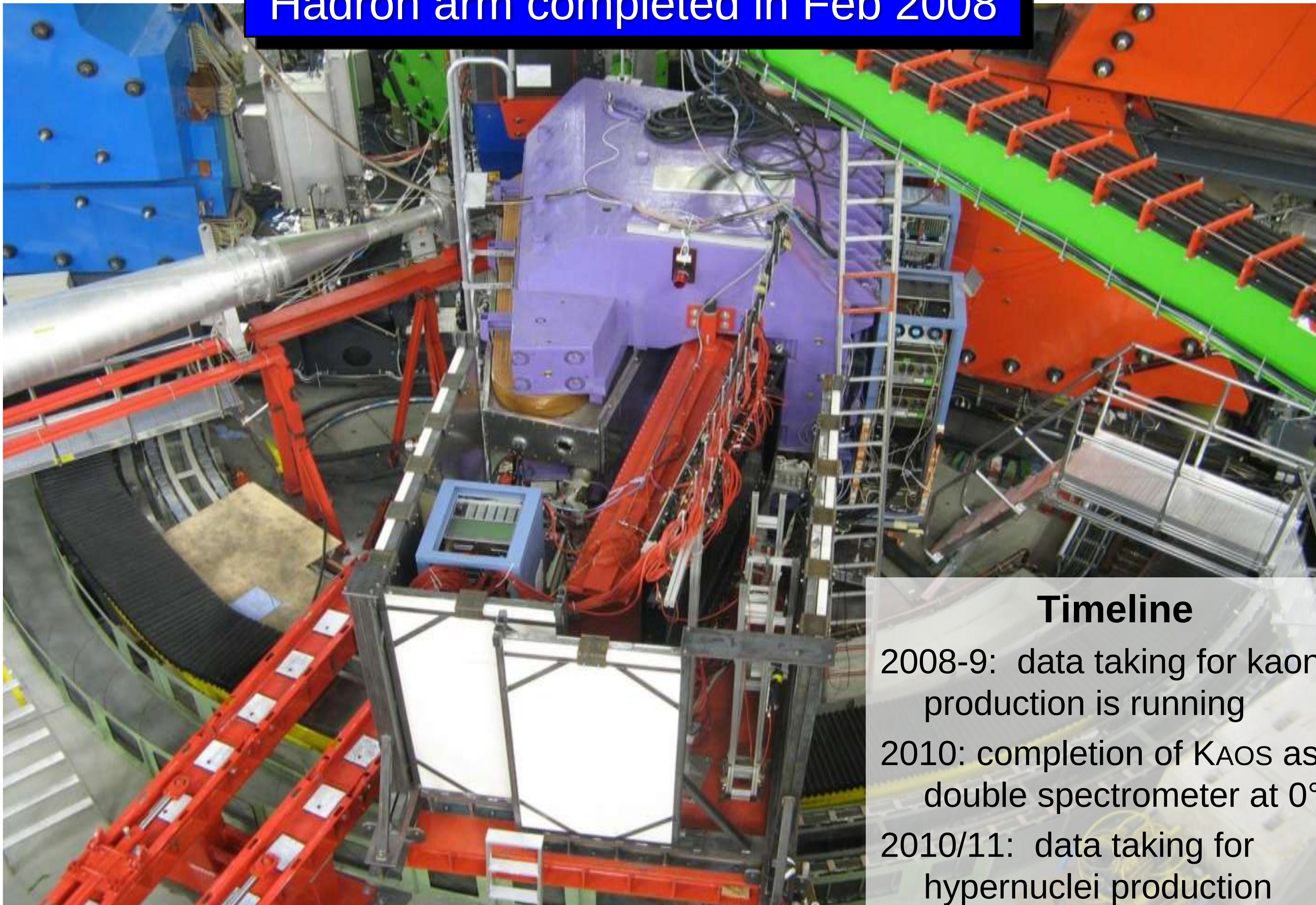
compact, open yoke and
extended pole face

⇒ use as double spectrometer

KAOS installation in 2007



Hadron arm completed in Feb 2008



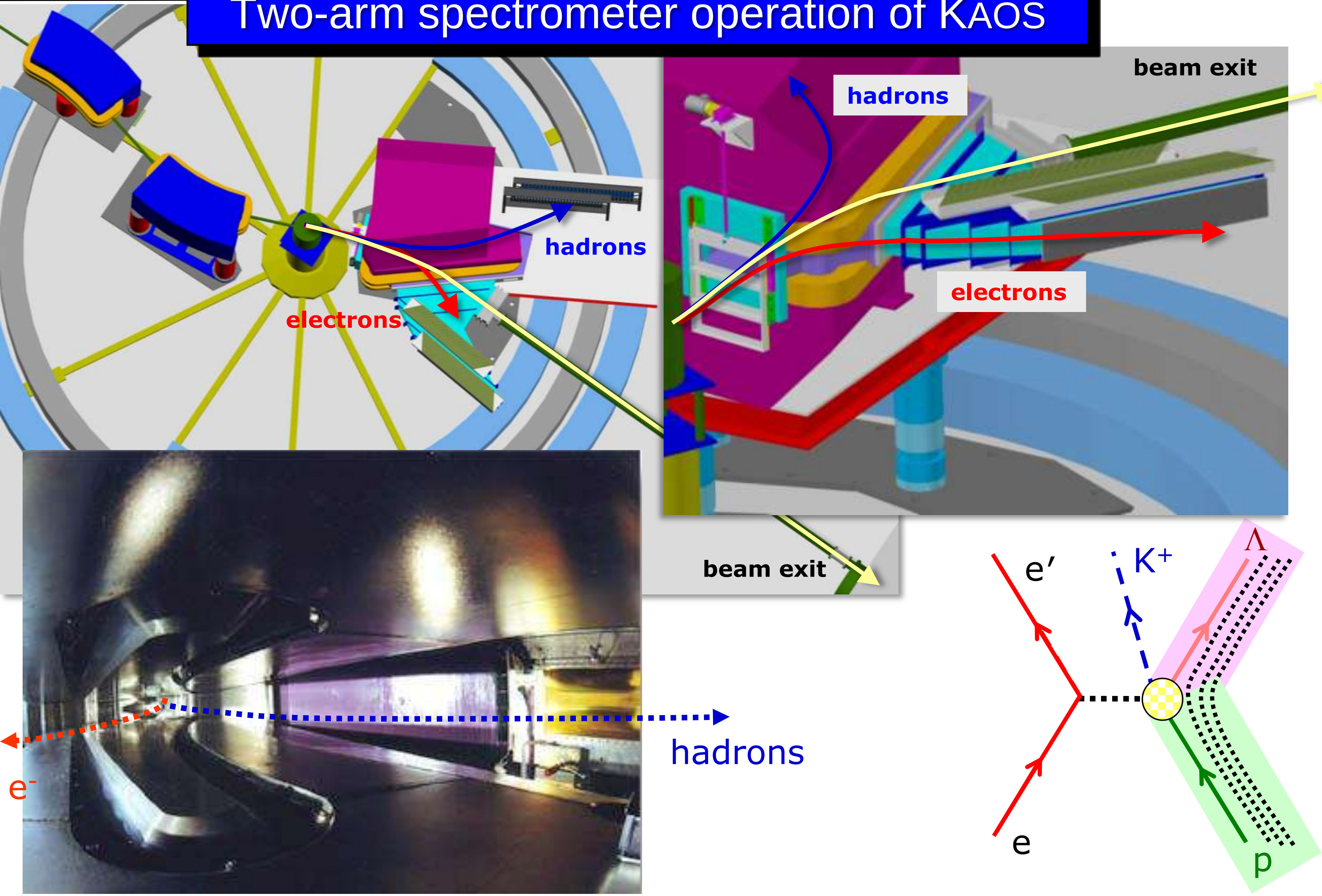
Timeline

2008-9: data taking for kaon production is running

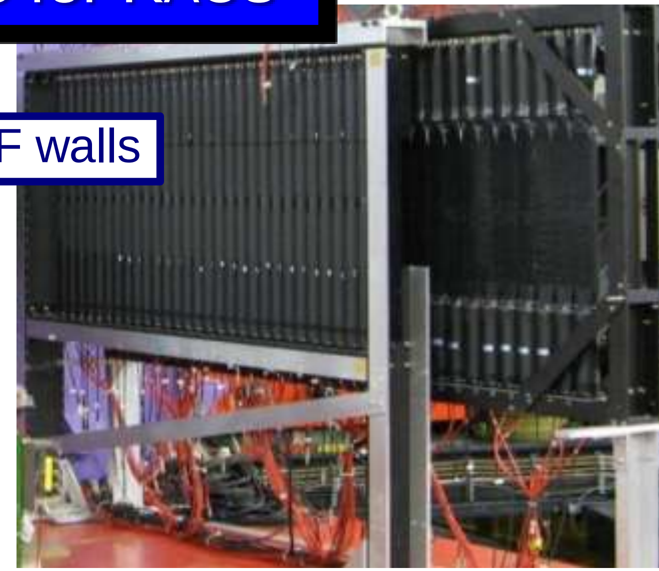
2010: completion of KAOS as double spectrometer at 0°

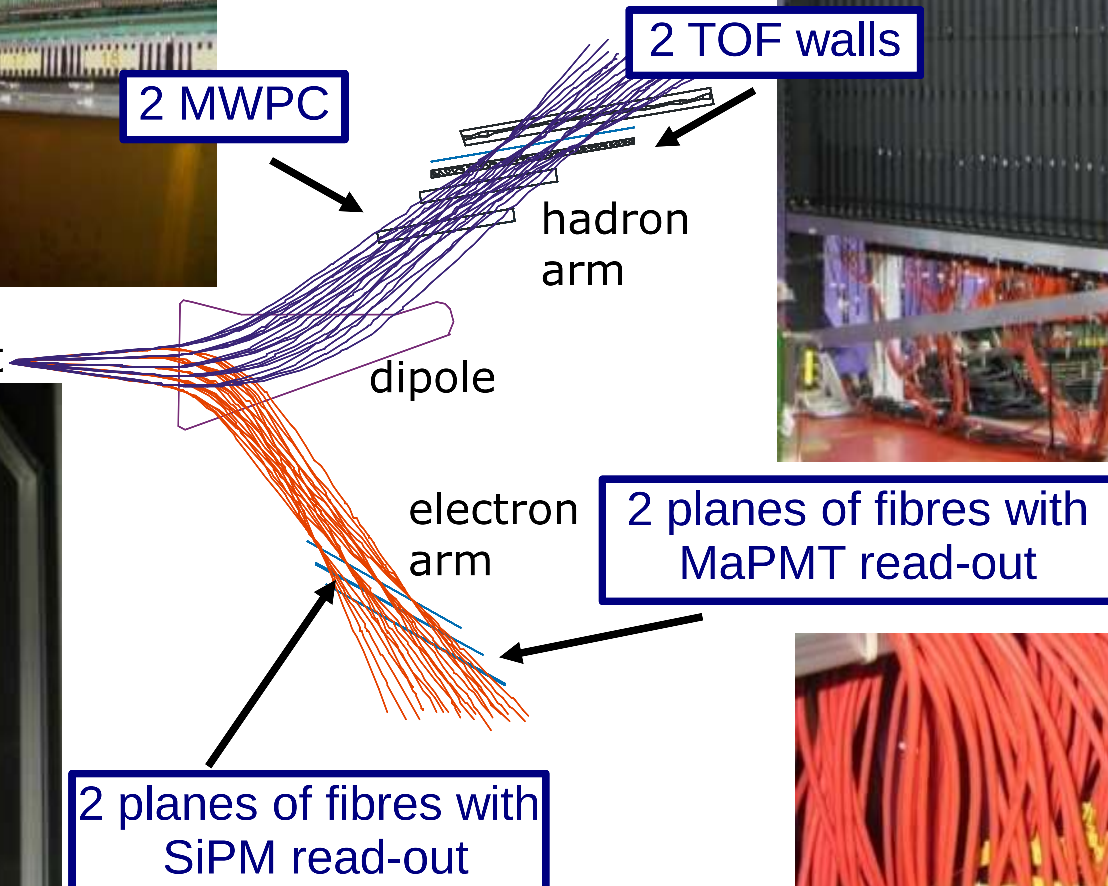
2010/11: data taking for hypernuclei production

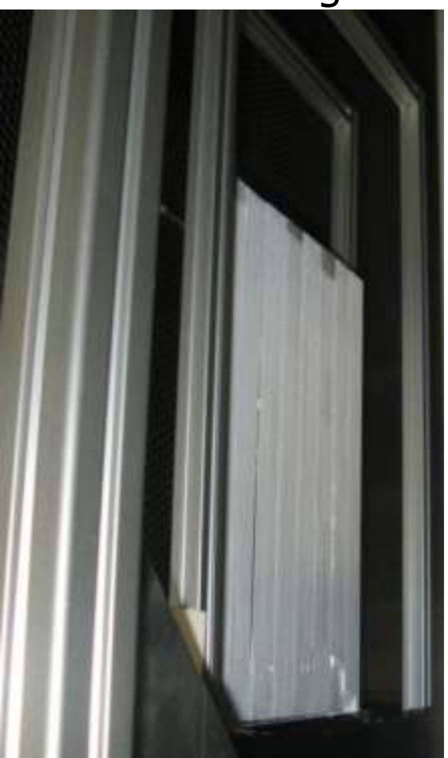
Two-arm spectrometer operation of KAOS

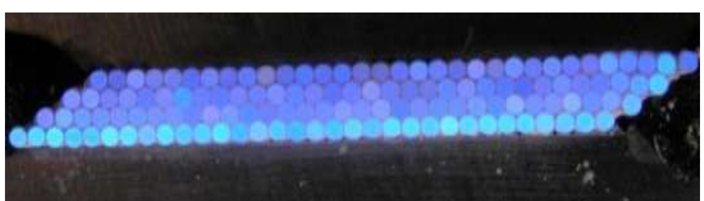


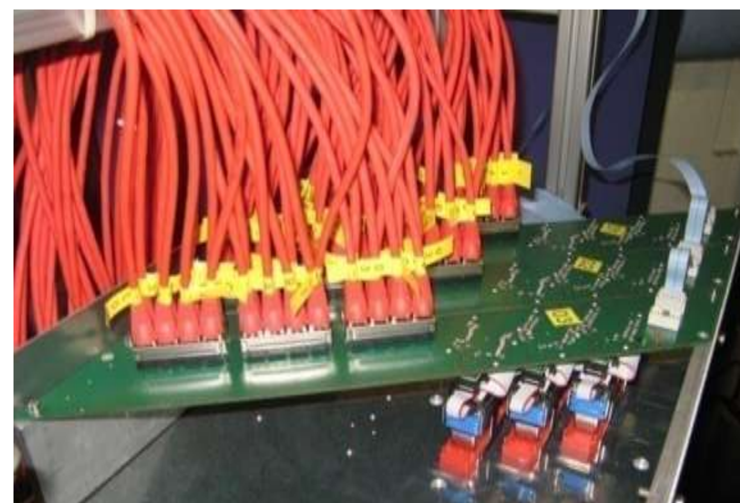
The detector packages for KAOS



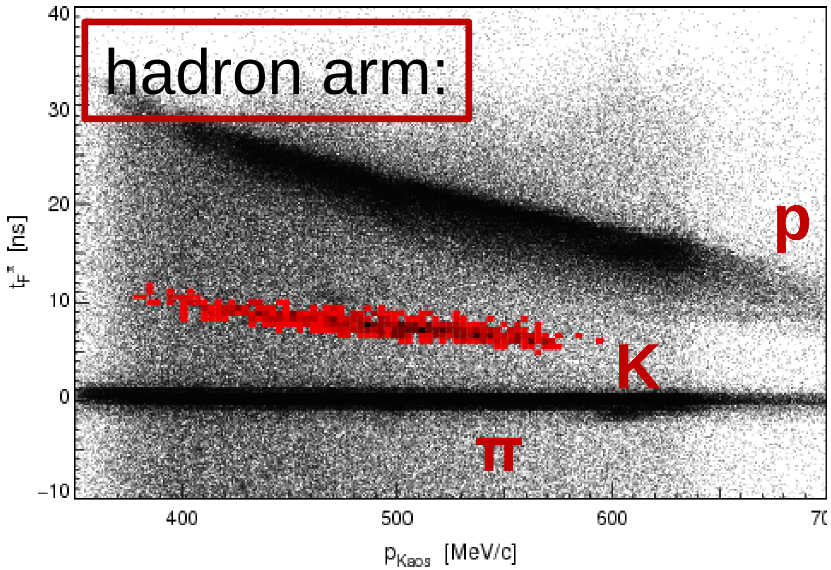


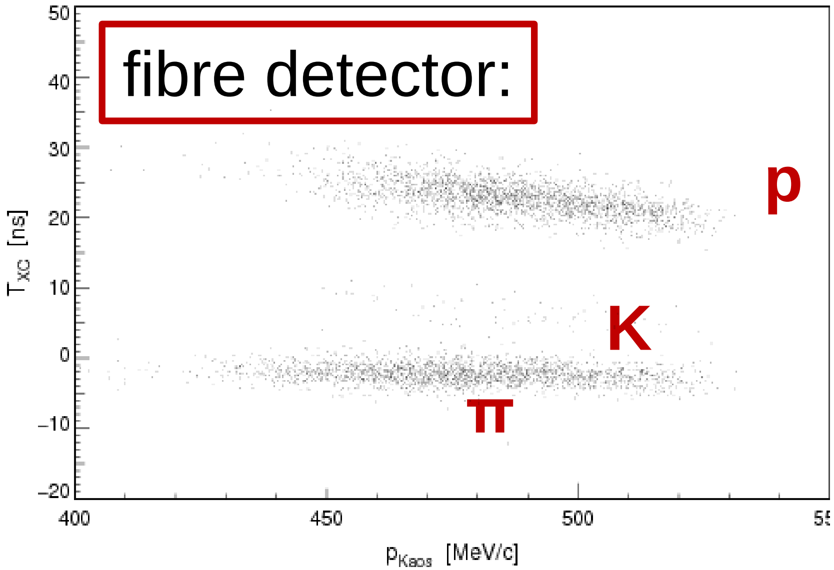




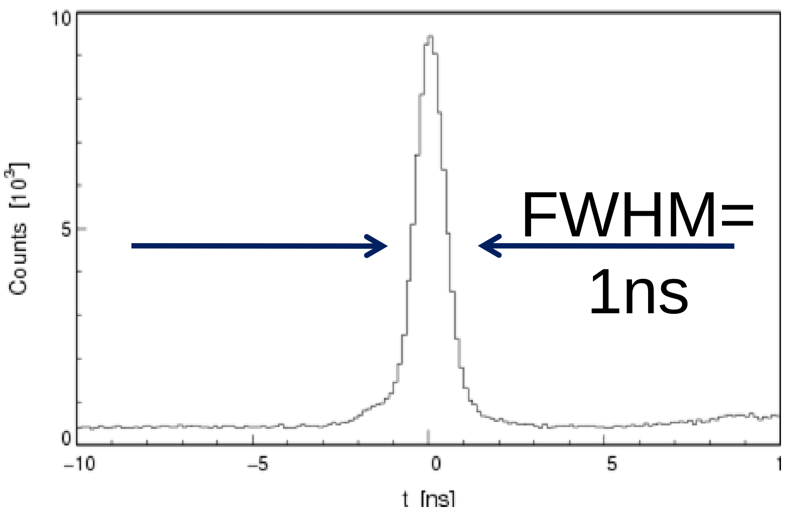


Particle identification by TOF in KAOS

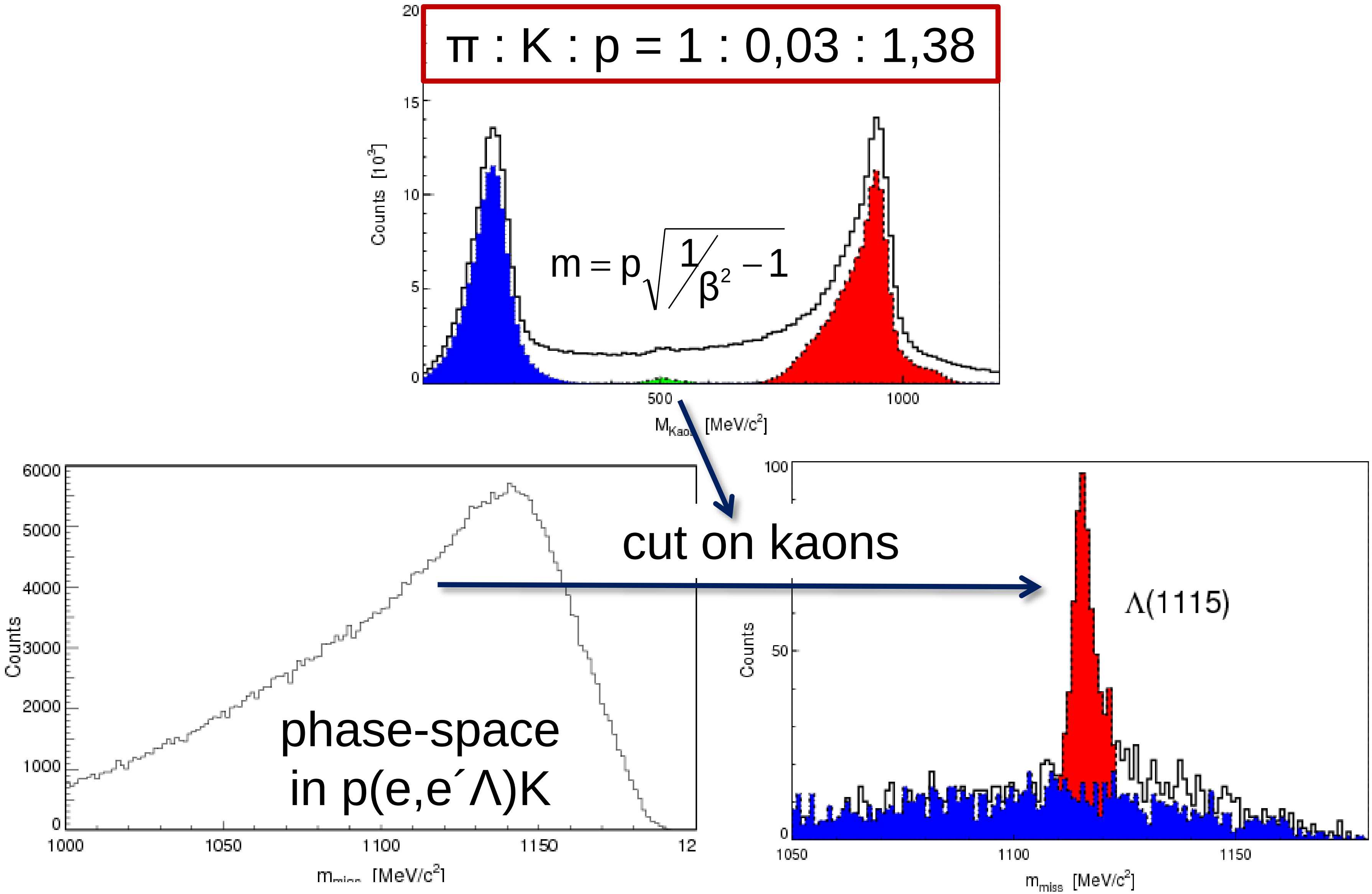




only 288 out of 4608 channels in beam-test!



Missing Mass reconstruction with KAOS

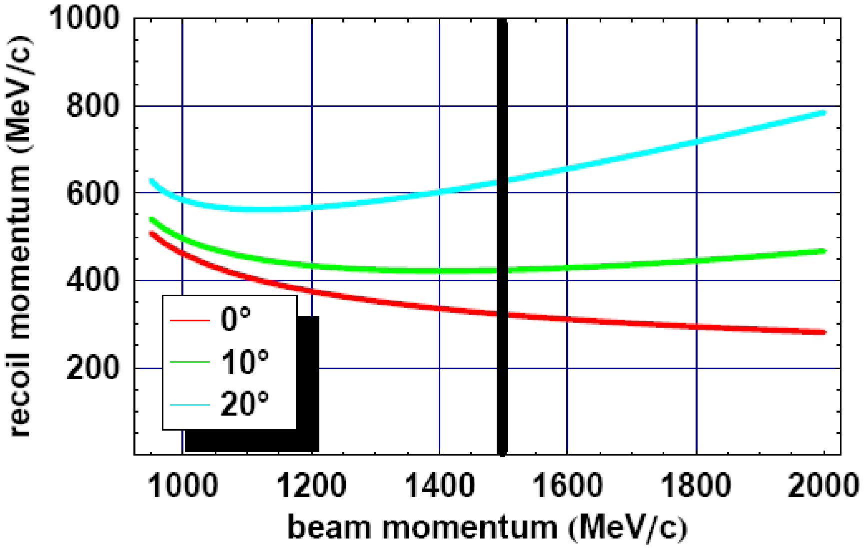


Kinematic differences to meson induced reactions

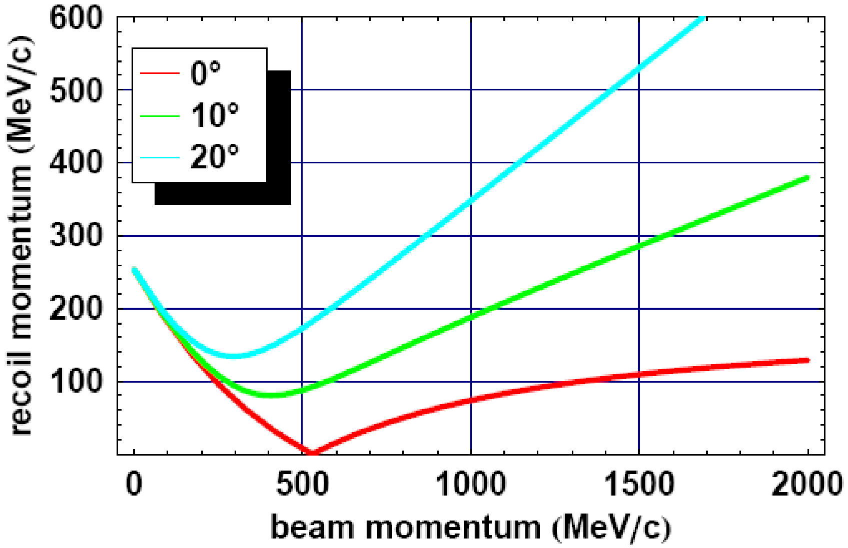
- typical momentum transfers: $\approx 300 - 600$ MeV/c
- minimum momentum transfer for $\theta_K = 0^\circ$
- energy and momentum transfer independent:

$$Q^2 = -q_\mu q^\mu = \omega^2 - \vec{q}^{\,2}$$

- momentum transfer $\longrightarrow 0$ for "magic momentum"
- minimum momentum transfer for $\theta_\pi = 0^\circ$
- momentum distributions cannot be measured



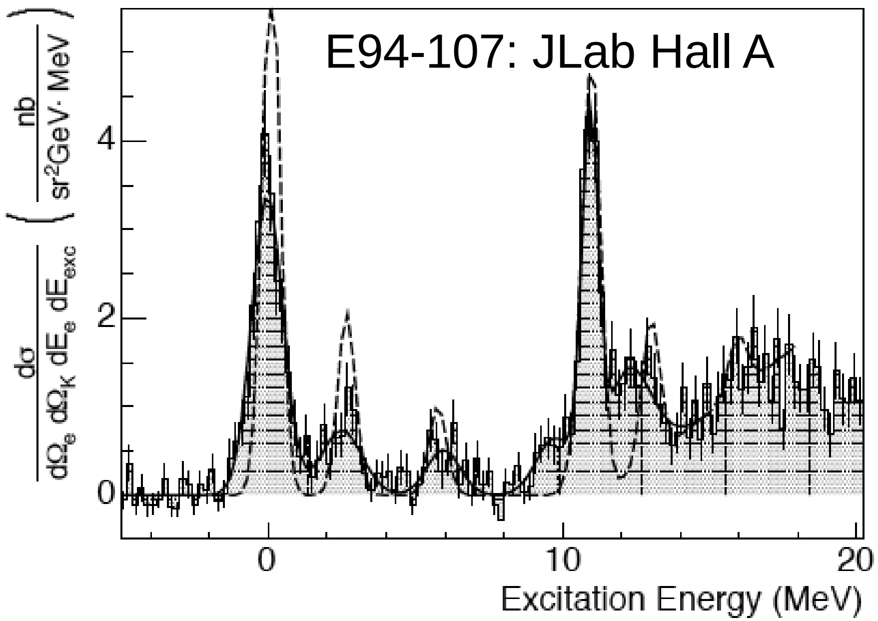
[strangeness electroproduction $(e, e'K^+)$]



[strangeness exchange (K^-, π^-)]

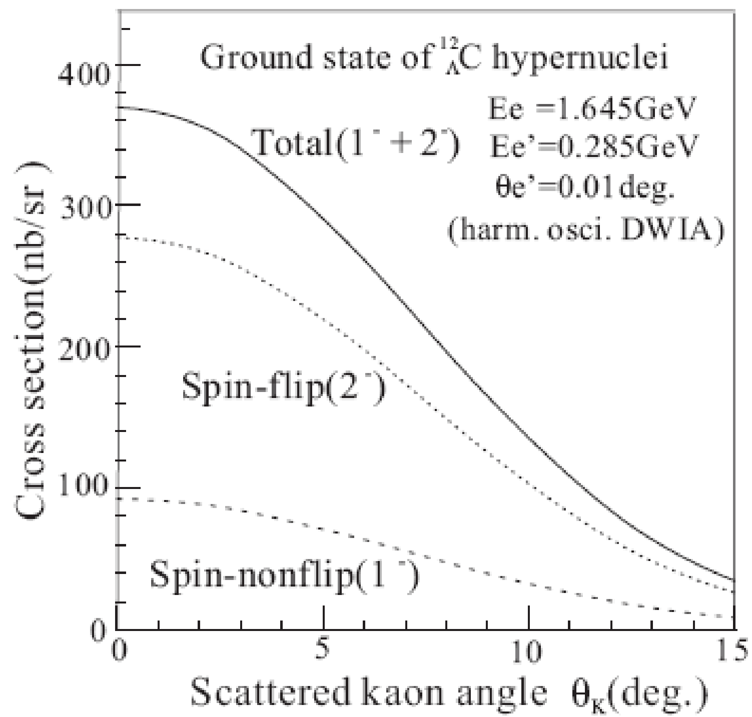
Extracting hypernuclear structure information

- cross sections calculated with harmonic oscillator potential and DWIA
- typical K^+ angular distributions peaked at 0°, falling rapidly:



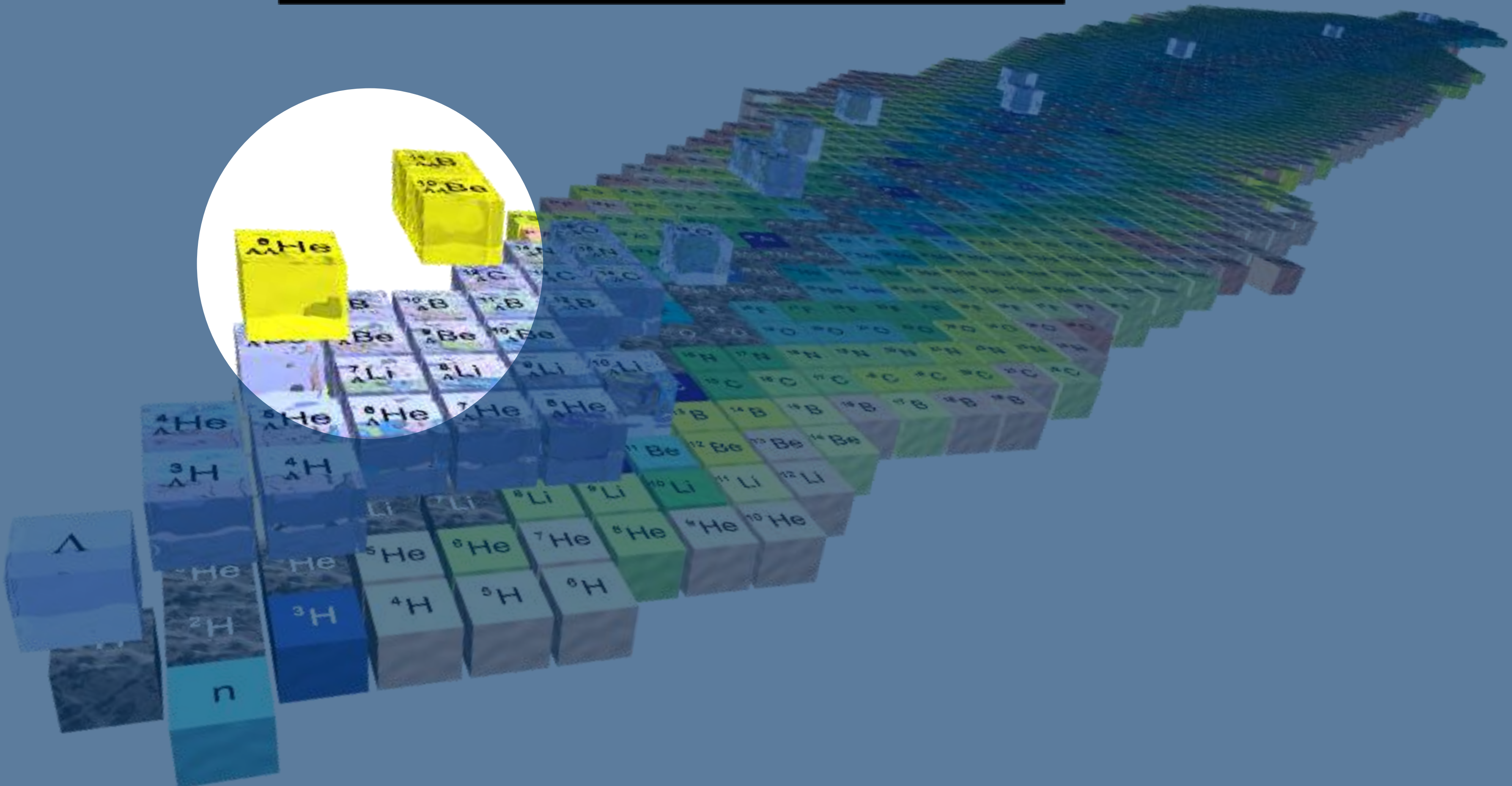
ΔE~650 keV; Core excited states
Theoretical interpretation and publication in progress

[J. Reinhold (FIU), DNP Town Meeting, Dec. 2007]



[M. Sotona and S. Furullani, Prog. Theor. Phys. Suppl. **117**, 151 (1994)]

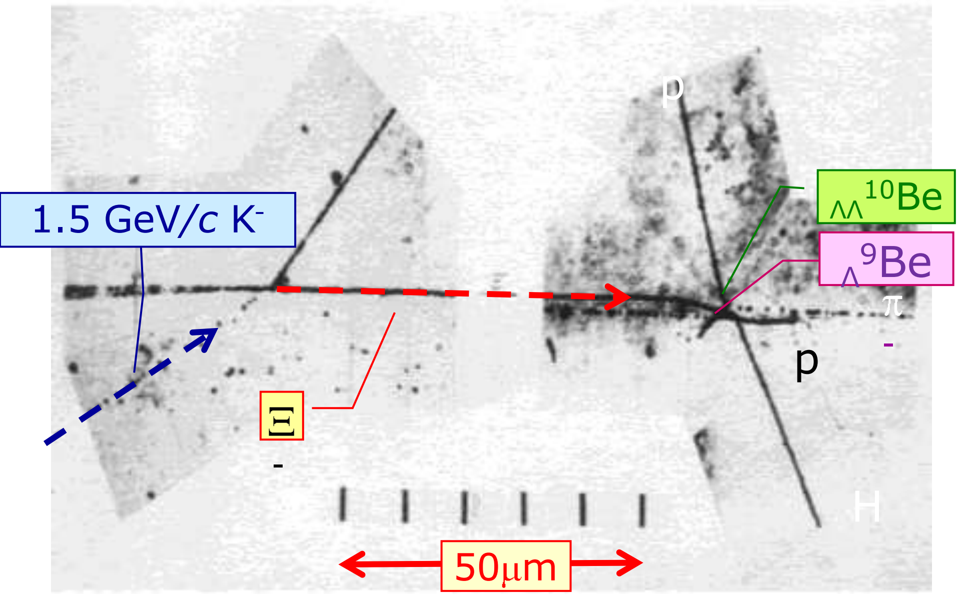
PANDA @ FAIR

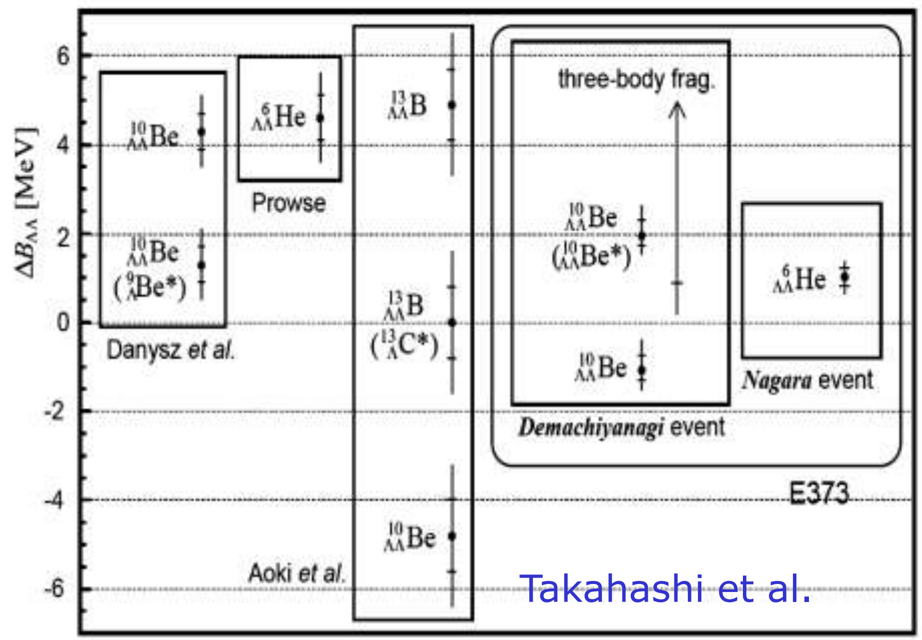


anti-proton beam induced hypernuclei production:

- high resolution γ-spectroscopy of double $\Lambda\Lambda$ hypernuclei
- weak decays

Hyperon-hyperon interaction





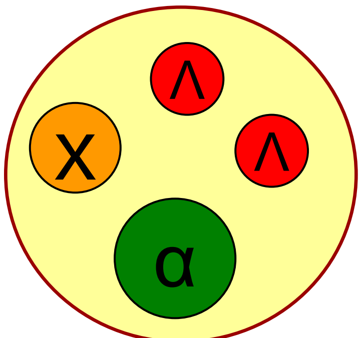
$$B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) \;\;= B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) + B_{\Lambda}({}^{A-1}_{\Lambda}Z)$$

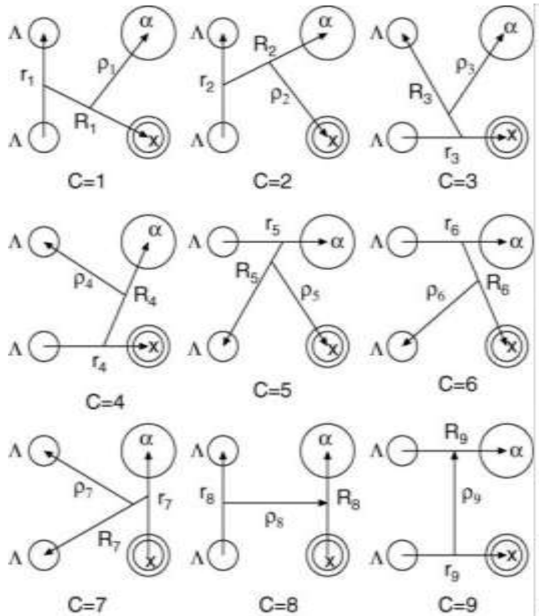
$$\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) - B_{\Lambda}({}^{A-1}_{\Lambda}Z)$$

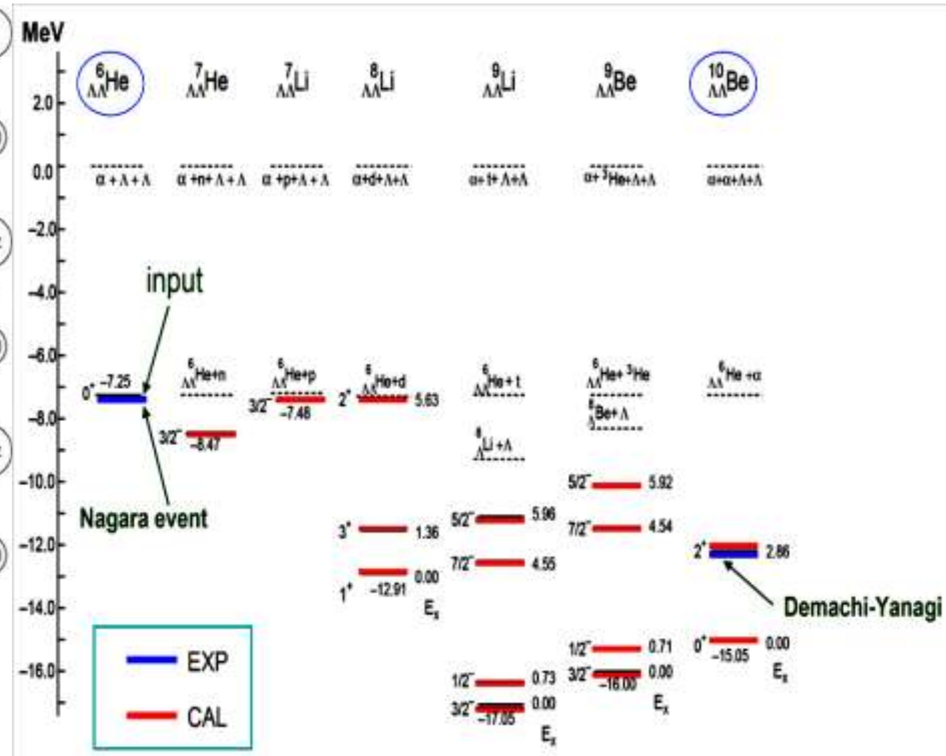
1963: Danysz *et al.* $^{10}{}_{\Lambda\Lambda}$Be
1966: Prowse $^{6}{}_{\Lambda\Lambda}$He
1991: KEK-E176 $^{13}{}_{\Lambda\Lambda}$B
2001: KEK-E373 $^{6}{}_{\Lambda\Lambda}$He
2001: AGS-E906 $^{4}{}_{\Lambda\Lambda}$H ? (~15)

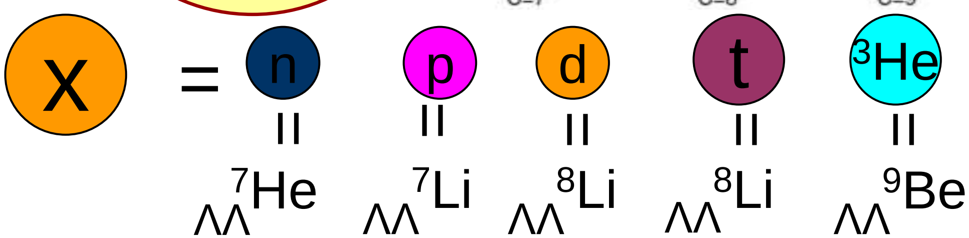
[E. Hiyama, M. Kamimura,T.Motoba, T. Yamada and Y. Yamamoto, Phys. Rev. 66 (2002), 024007]

4-body cluster model for light nuclei:



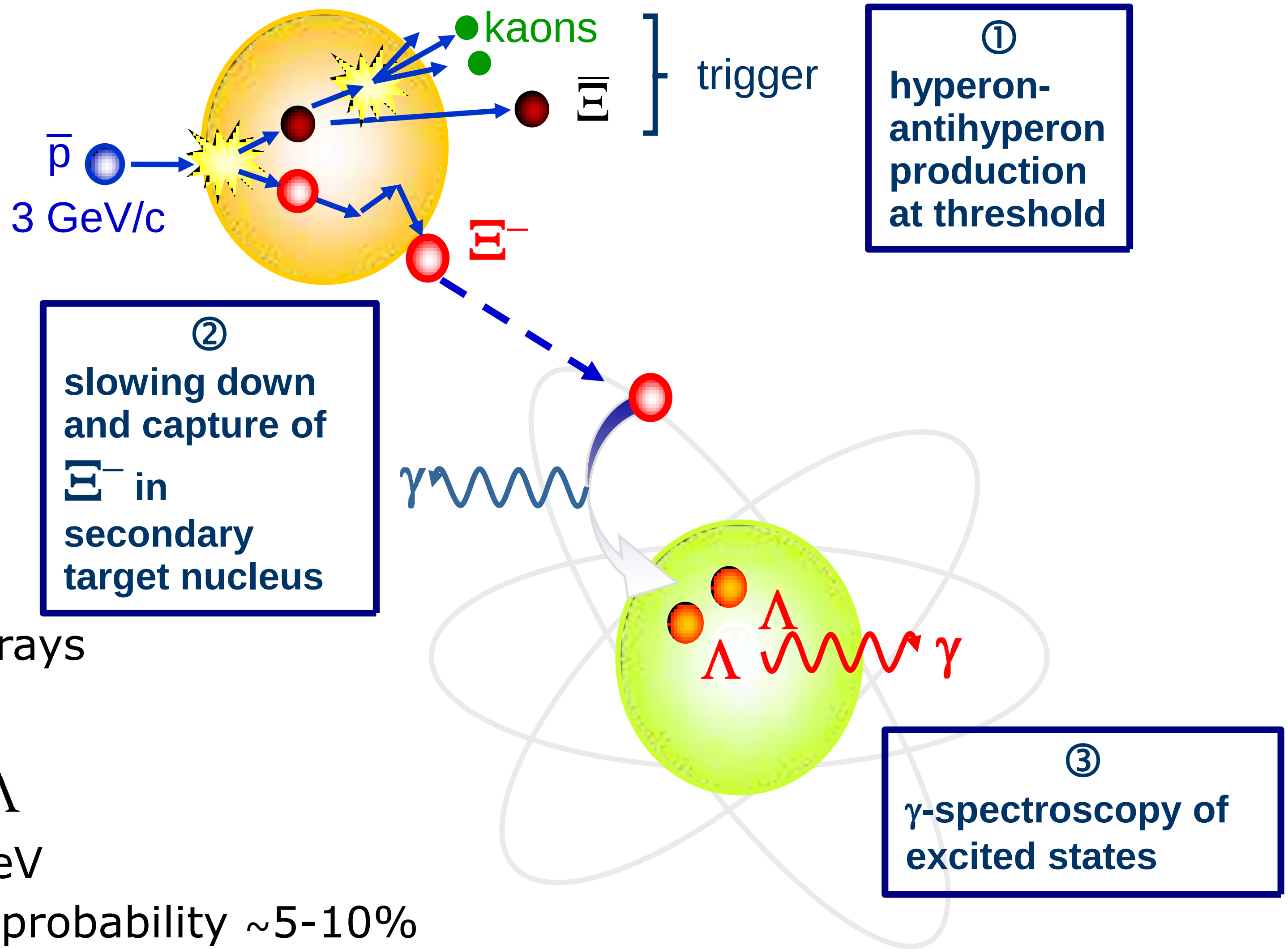






many excited, particle stable states in double hypernuclei predicted
γ-spectroscopy of these states is mandatory to study ΛΛ interaction

Production mechanism at PANDA



- Ξ^- atoms: x-rays
- conversion:

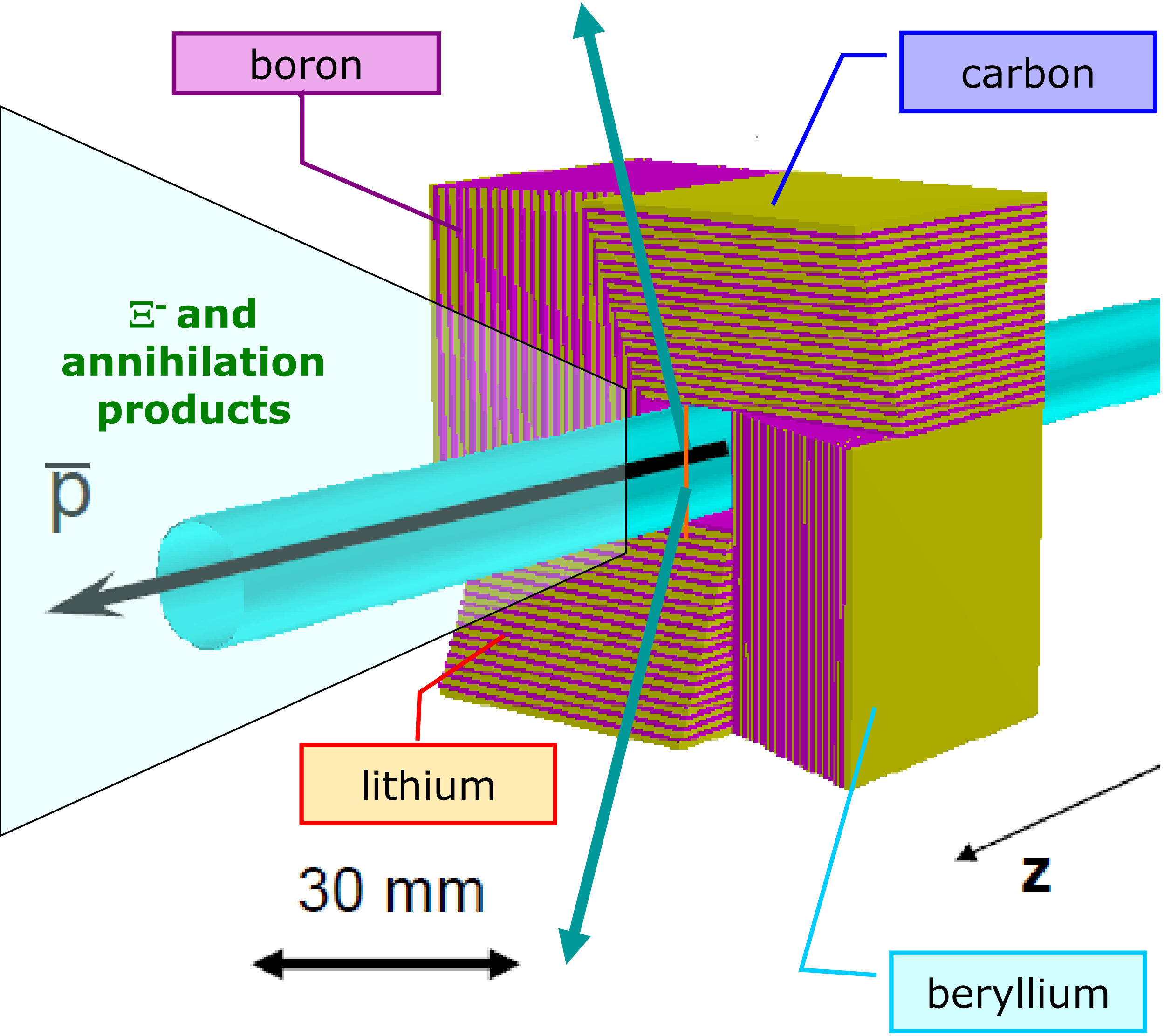
  $\Xi^- \, p \rightarrow \Lambda \, \Lambda$

  $\Delta Q = 28$ MeV

  conversion probability ~5-10%

[Y. Hirate et al., Nucl. Phys. **A639**, 389c (1998),
Y. Hirate et al., Prog. Theor. Phys. **102**, 89 (1999)]

The secondary target design

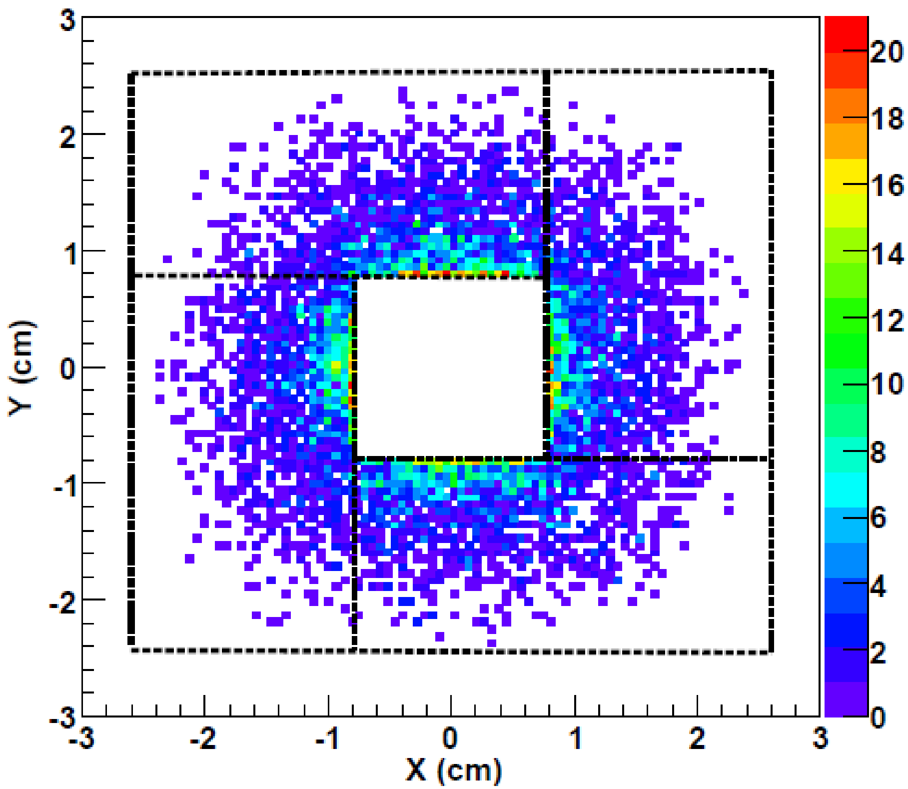


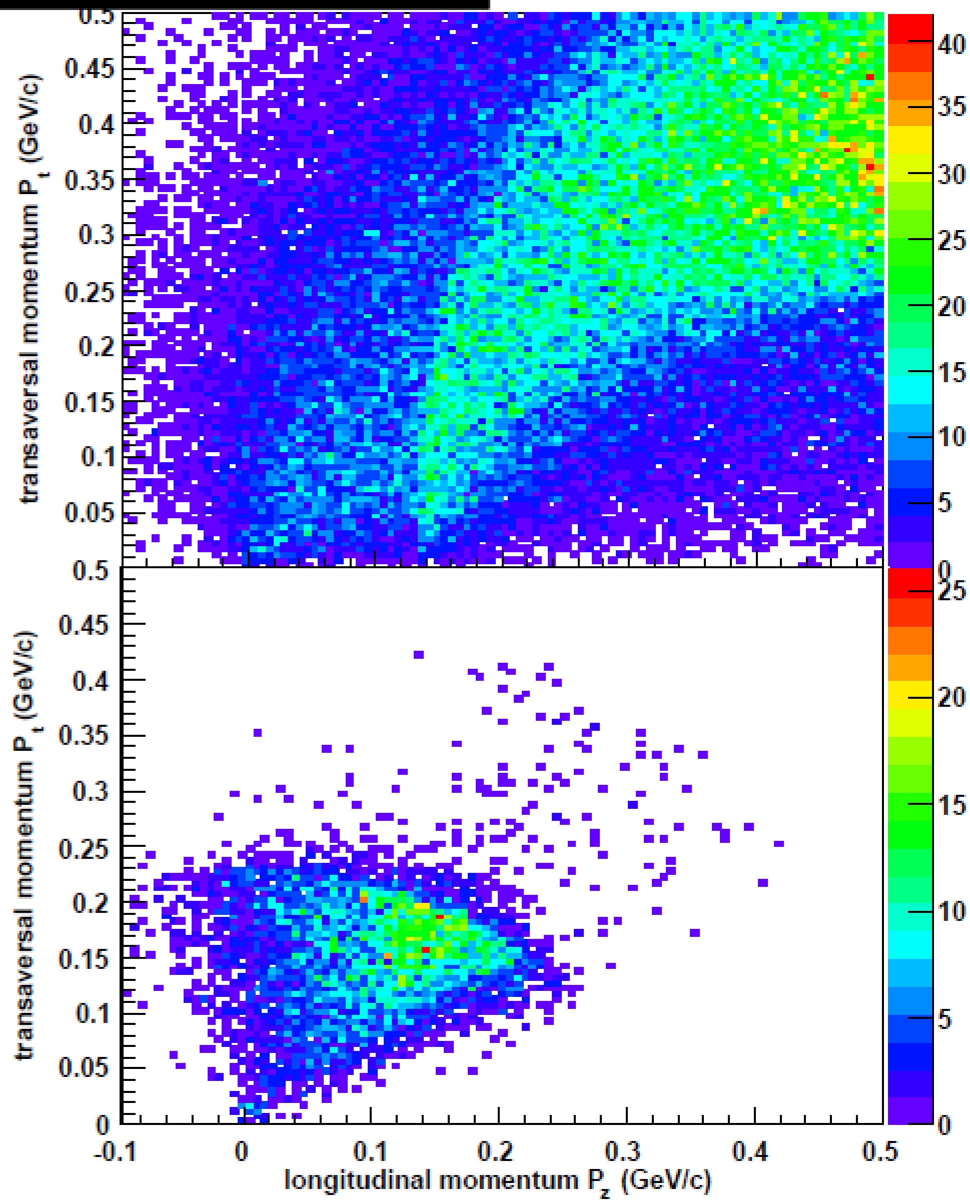
low secondary masses (Li, Be, B, C) in four separated sections:

- identification can rely on existing information on single hypernuclei
- low γ-ray absorption
- no x-ray background

[J. Pochodzalla et al., PANDA Physics Performance Report, to be published 2009.]

Stopping of the Xi-hyperons





[A. Sanchez Lorente, P. Achenbach, J. Pochodzalla, and S. Sánchez Majos: Detector developments for the hypernuclear programme at PANDA, Conference Proceedings of IEEE NSS 2008.]

Gamma spectroscopy

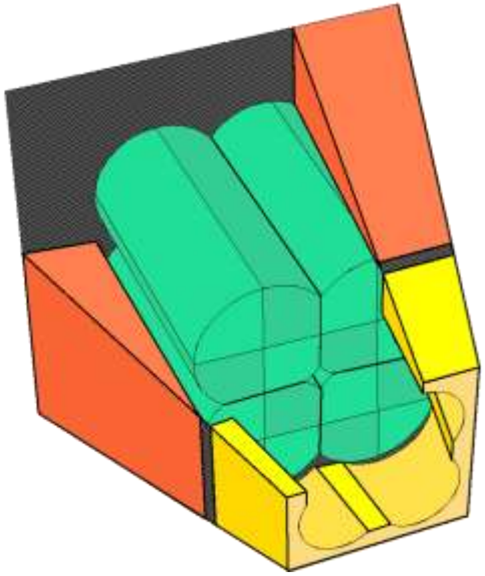
HPGe array based on crystal clover or cluster design with common cooling

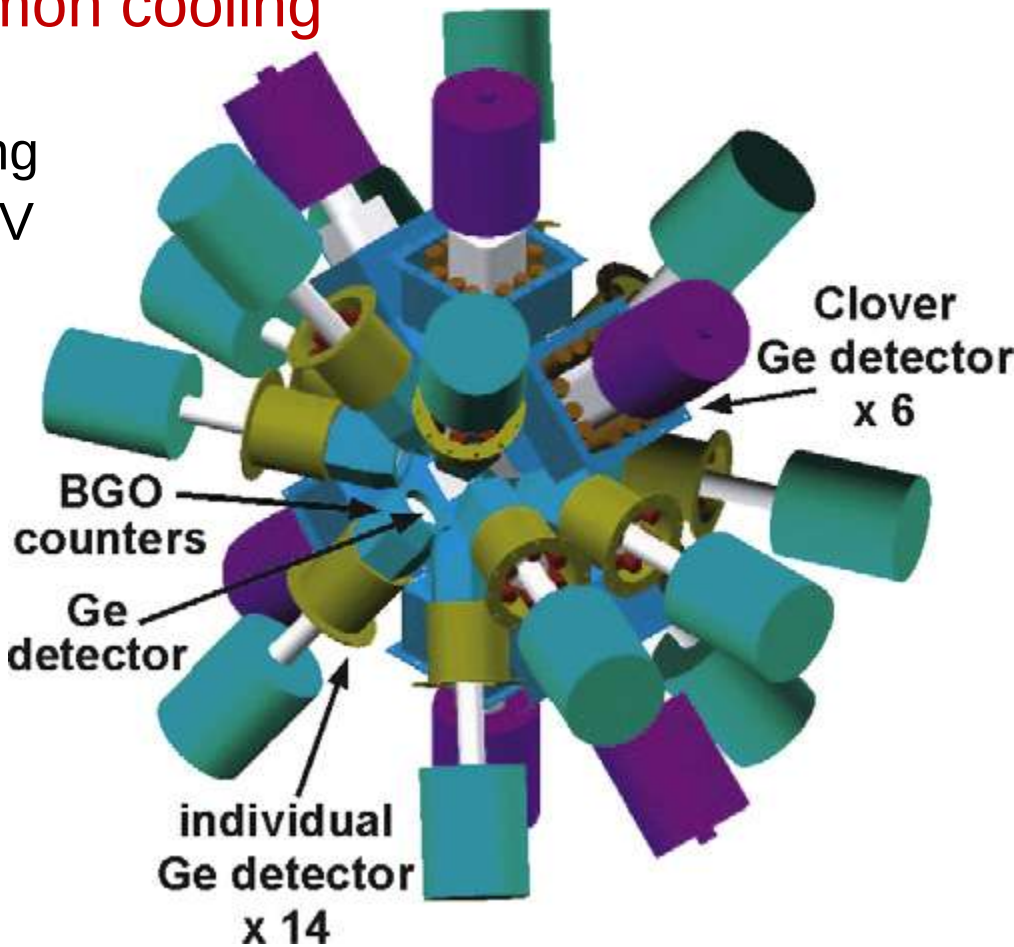
VEGA-type detectors:

segmented Clover: 7 cm ∅, 14 cm long

4 segm. Clover, ε_{ph} = 0.13 @ 1.33 MeV

Energy resolution ~ 0.5 %



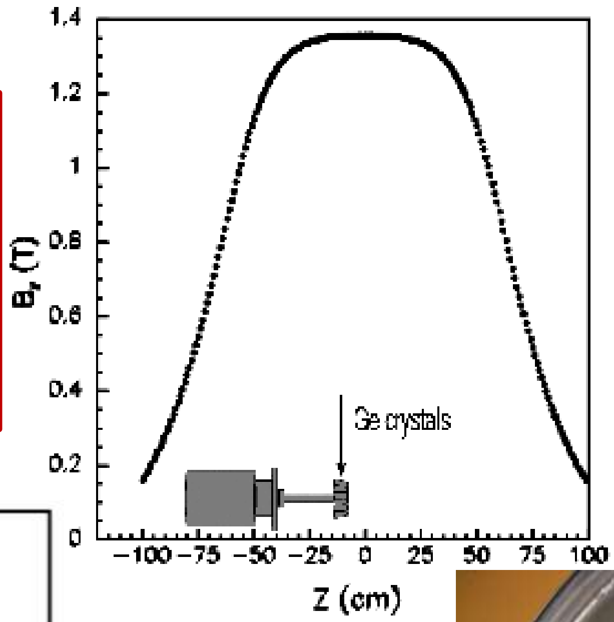


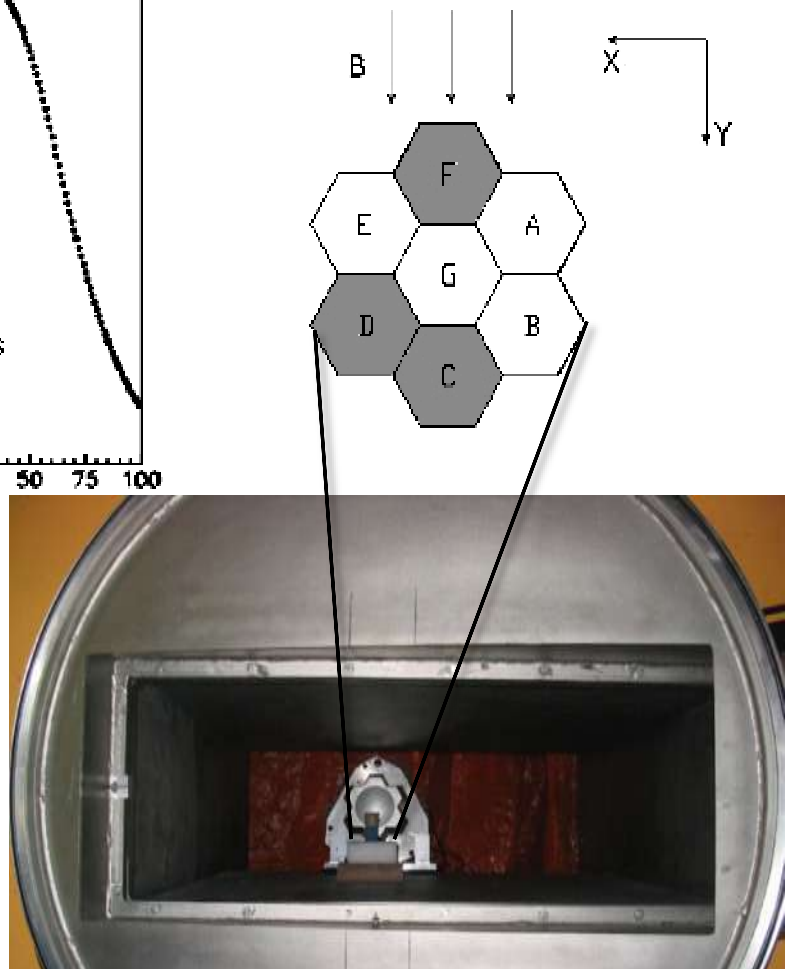
[H. Tamura et al: Gamma-ray spectroscopy of hypernuclei, Nuclear Physics A 804 (2008) 73–83.]

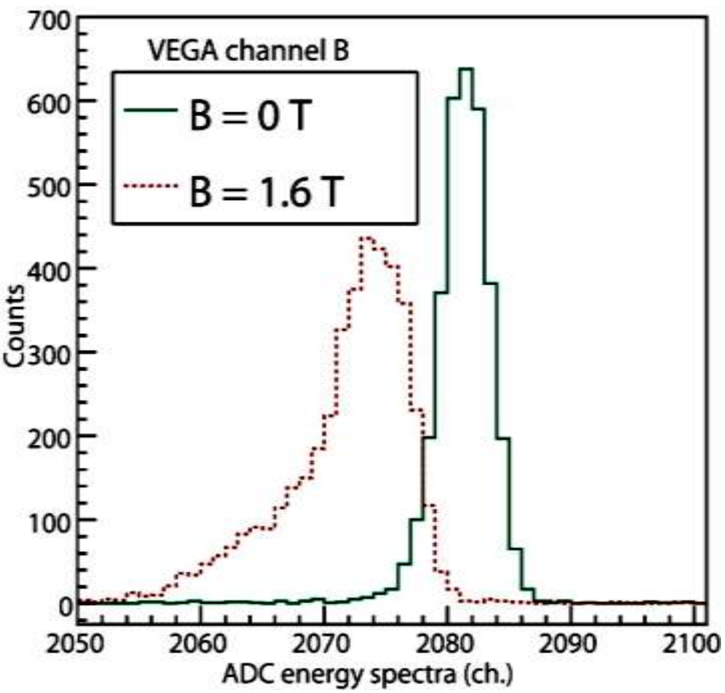
Performance of HPGe detectors in magnetic fields

experimental set-up:

- ALADiN dipole magnet
- Co source of 370 kBq
- VEGA clover and
- Euroball cluster







[A. Sanchez Lorente et al., Performance of HPGe detectors in high magnetic fields, Nucl. Instr. Meth. A 573 (2007) 410.]

Performance of HPGe detectors in a high radiation field

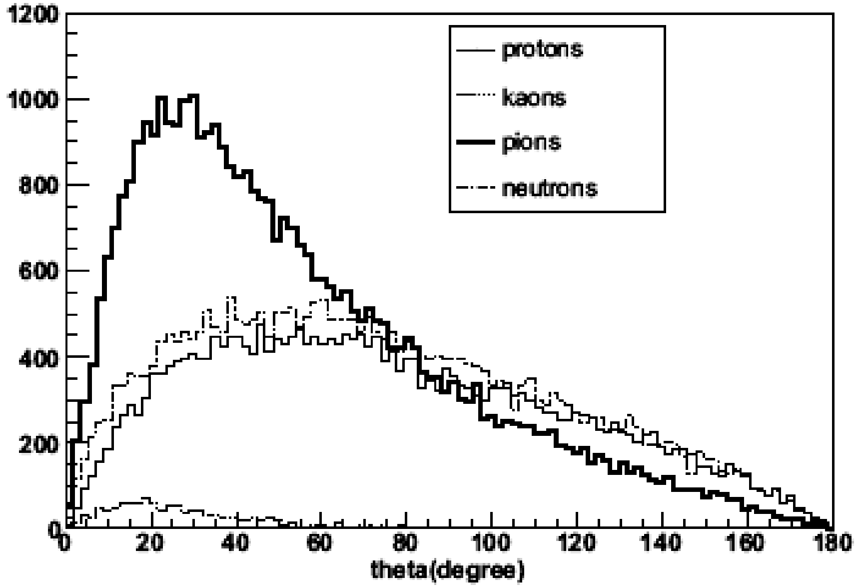


Figure 4.81: Distribution of produced particles from background reactions. The Germanium detectors will be affected mainly by particles emitted at backward axial angle.

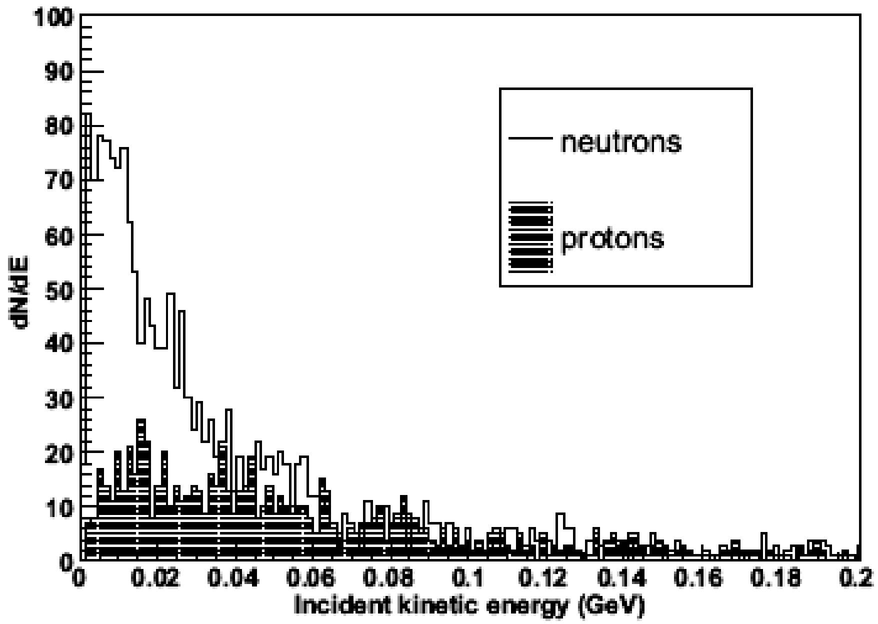


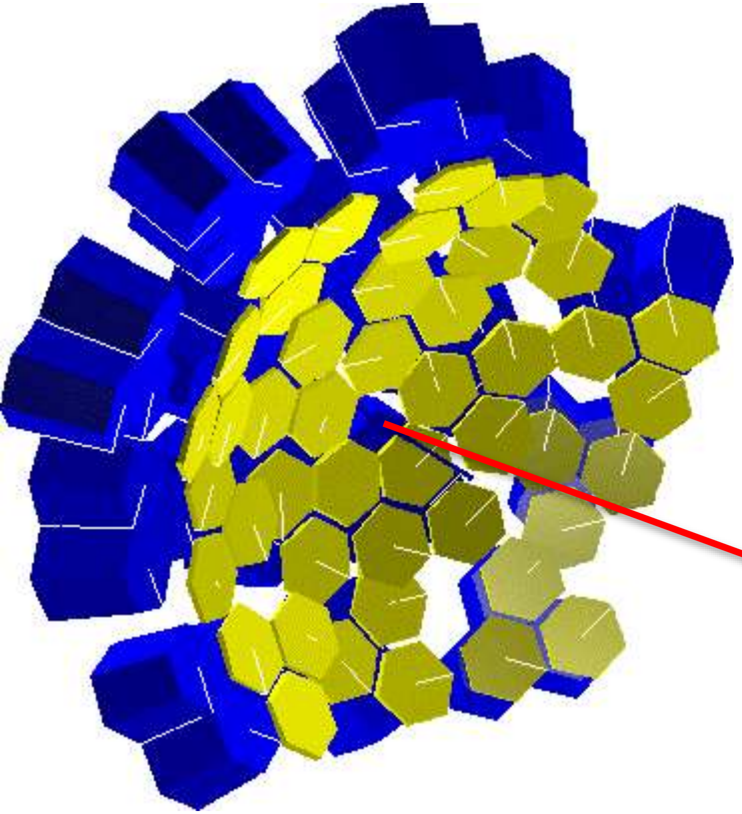
Figure 4.82: Incident kinetic energy of protons and neutrons entering the Germanium detector surface. The main contribution to a possible radiation damage of the detector is provided by neutrons.

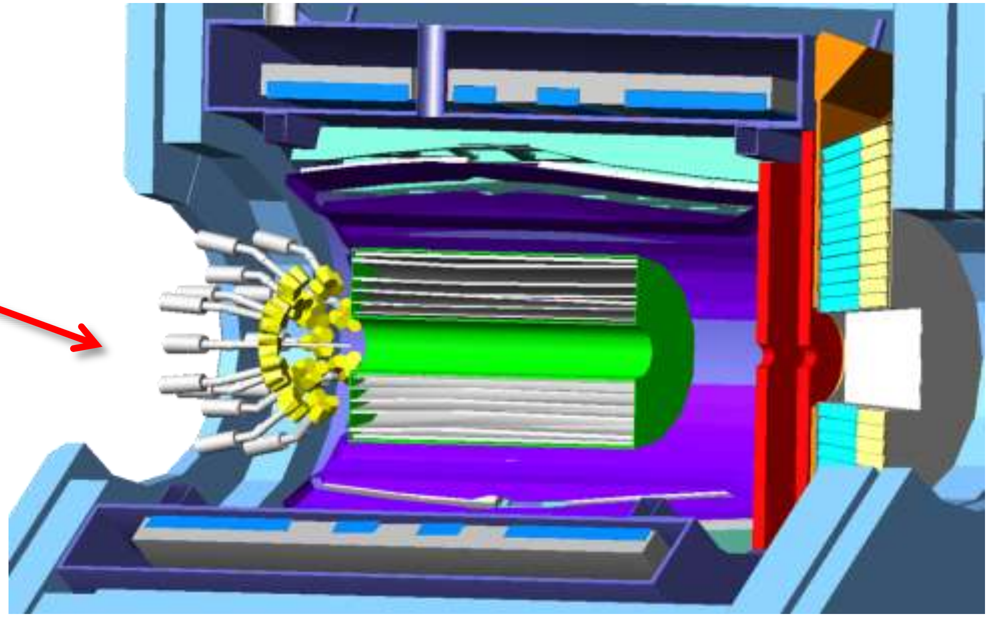
[J. Pochodzalla et al., PANDA Physics Performance Report, to be published 2009. Simulations by A. Sanchez Lorente, U Mainz.]

dynamics of damage formation for a 6 months PANDA beam-time needs to be evaluated

Integration into PANDA spectrometer

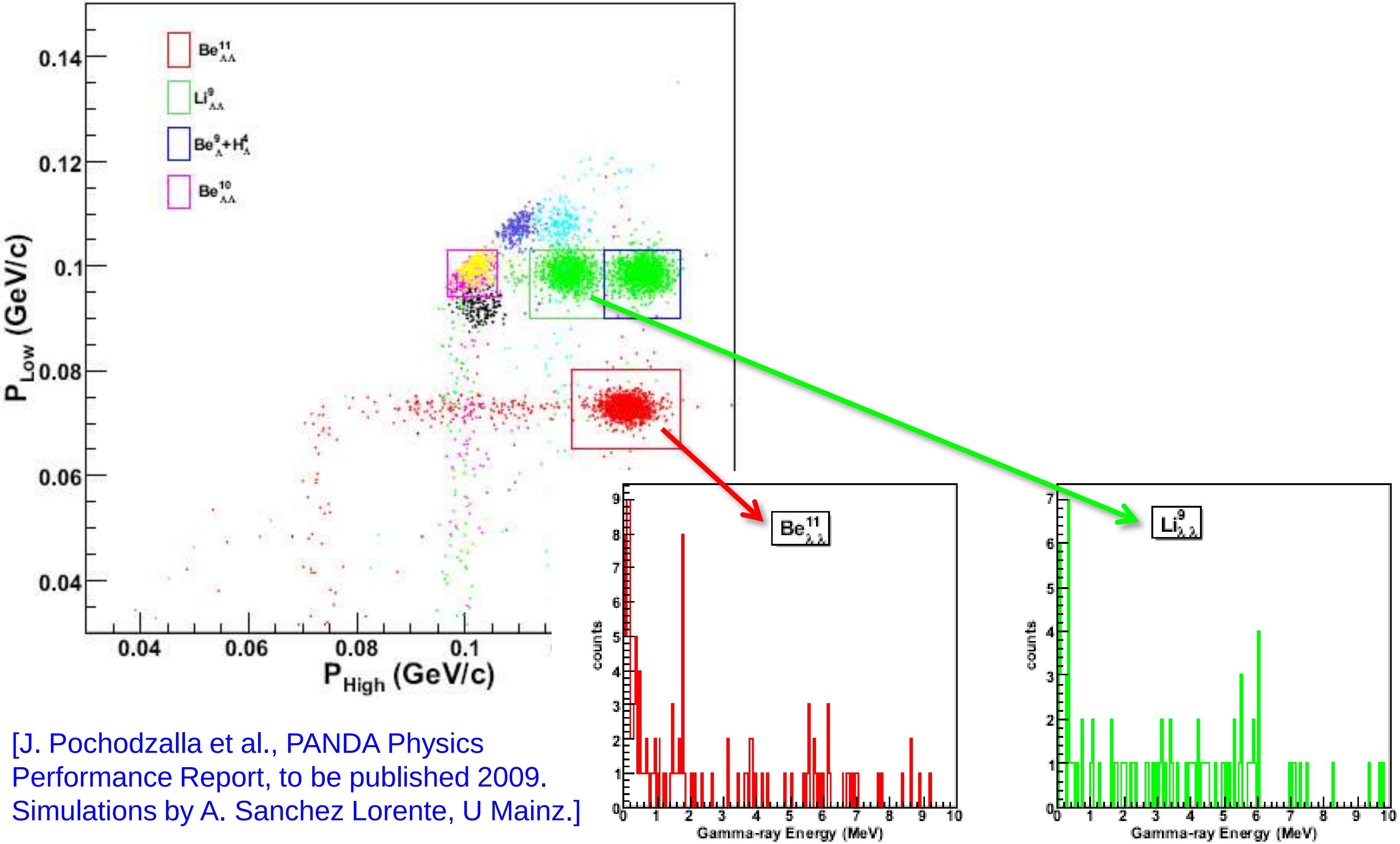
- $\theta_{lab}< 45°$: Ξ-bar, K trigger and PID in PANDA spectrometer
- $\theta_{lab}= 45°\text{-}90°$: Ξ-capture and hypernuclei formation
- $\theta_{lab}>90°$: γ-detection with HPGe at backward angles





[PANDA Technical Progress Report, 2005.]

Decay pion correlation for hypernuclear event selection



[J. Pochodzalla et al., PANDA Physics Performance Report, to be published 2009. Simulations by A. Sanchez Lorente, U Mainz.]

Estimated count rates

"Golden events":

luminosity $2 \cdot 10^{32}$ cm^{-2}s^{-1} and

2 mub $\Xi^+\Xi^-$ cross-section	$\Rightarrow$	700 Hz
momentum range (100-500 MeV/c)		$p_{500} \approx 0.0005$
Ξ^+ reconstruction probability		$p_{REC} \approx 0.5$
stopping and capture probability		$p_{CAP} \approx 0.20$
total captured Ξ^-	$\Rightarrow$	3000 / day
Ξ^- to $\Lambda\Lambda$–nucleus conversion probability		$p_{\Lambda\Lambda} \approx 0.05$
total $\Lambda\Lambda$ hypernucleus production	$\Rightarrow$	4500 / month
gamma emission/event,		$p_{\gamma} \approx 0.5$
γ-ray peak efficiency		$p_{GE} \approx 0.1$

~ 7/day „golden" γ-ray events with Ξ^+ trigger
~ 700/day with *KK* trigger

Conclusion

1) The hypernuclei programme at GSI (HypHI) is embedded in an European framework of laboratories and theory groups in this field

2) Co-operators and collaborators of HypHI are involved in strong hypernuclei programmes at MAMI and PANDA at FAIR

3) Hypernuclear physics helps to explore fundamental questions on nuclear shape and nuclear potentials