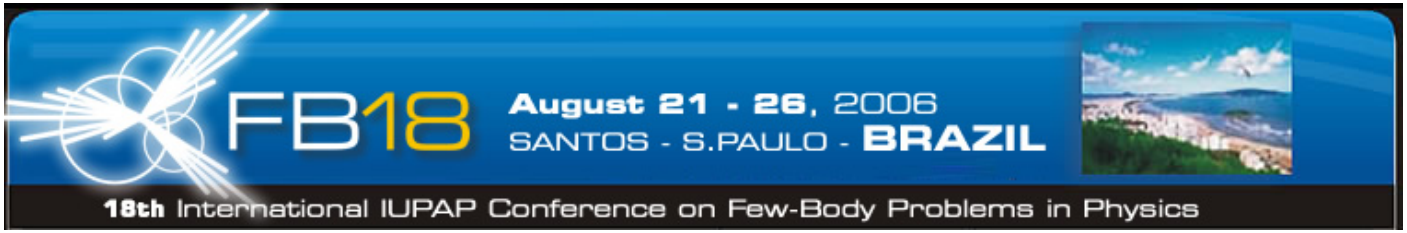
Hypernuclear studies at FAIR with $\bar{P}$ANDA



Alessandro Feliciello

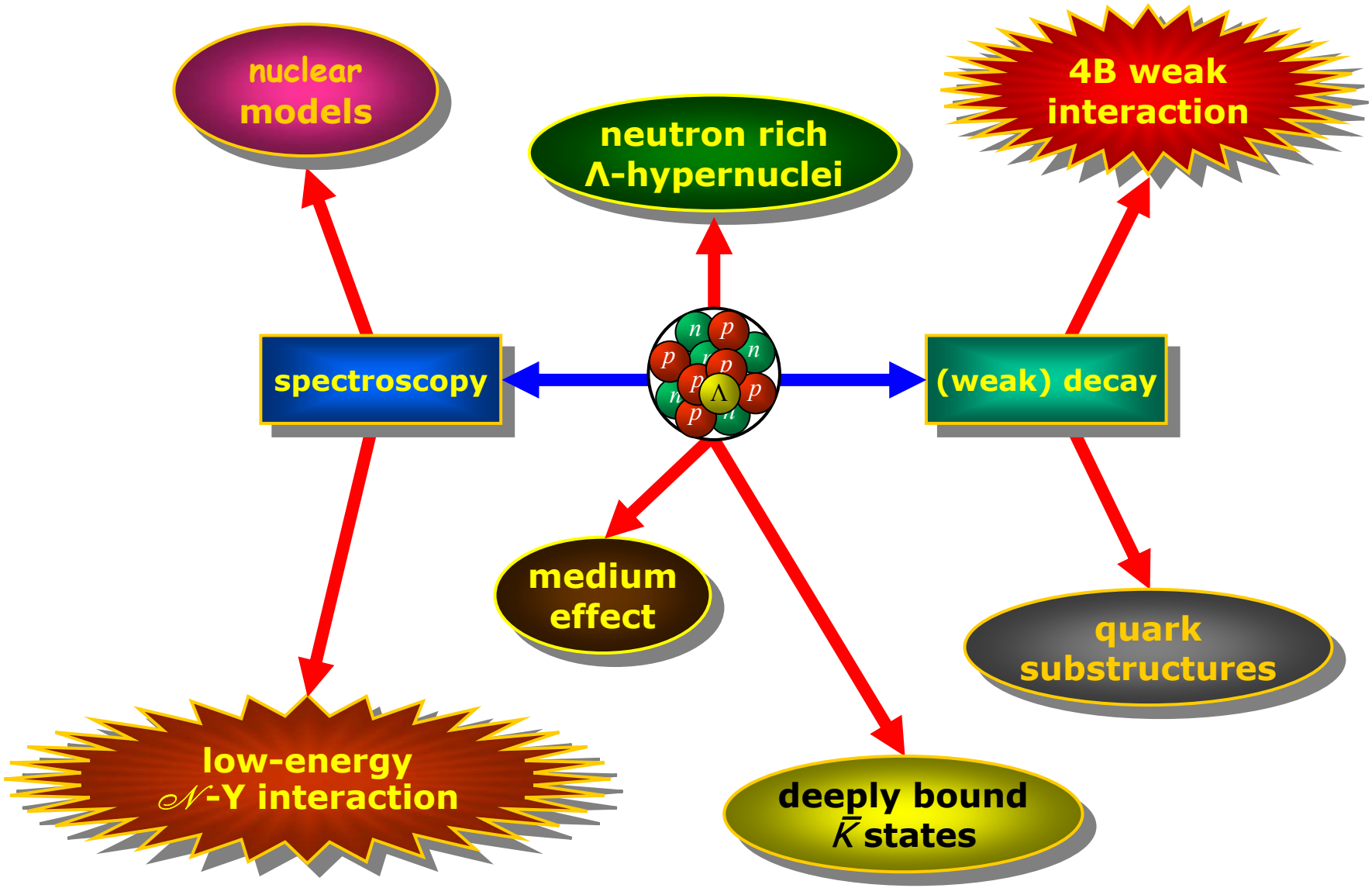
I.N.F.N. - Sezione di Torino

Outline

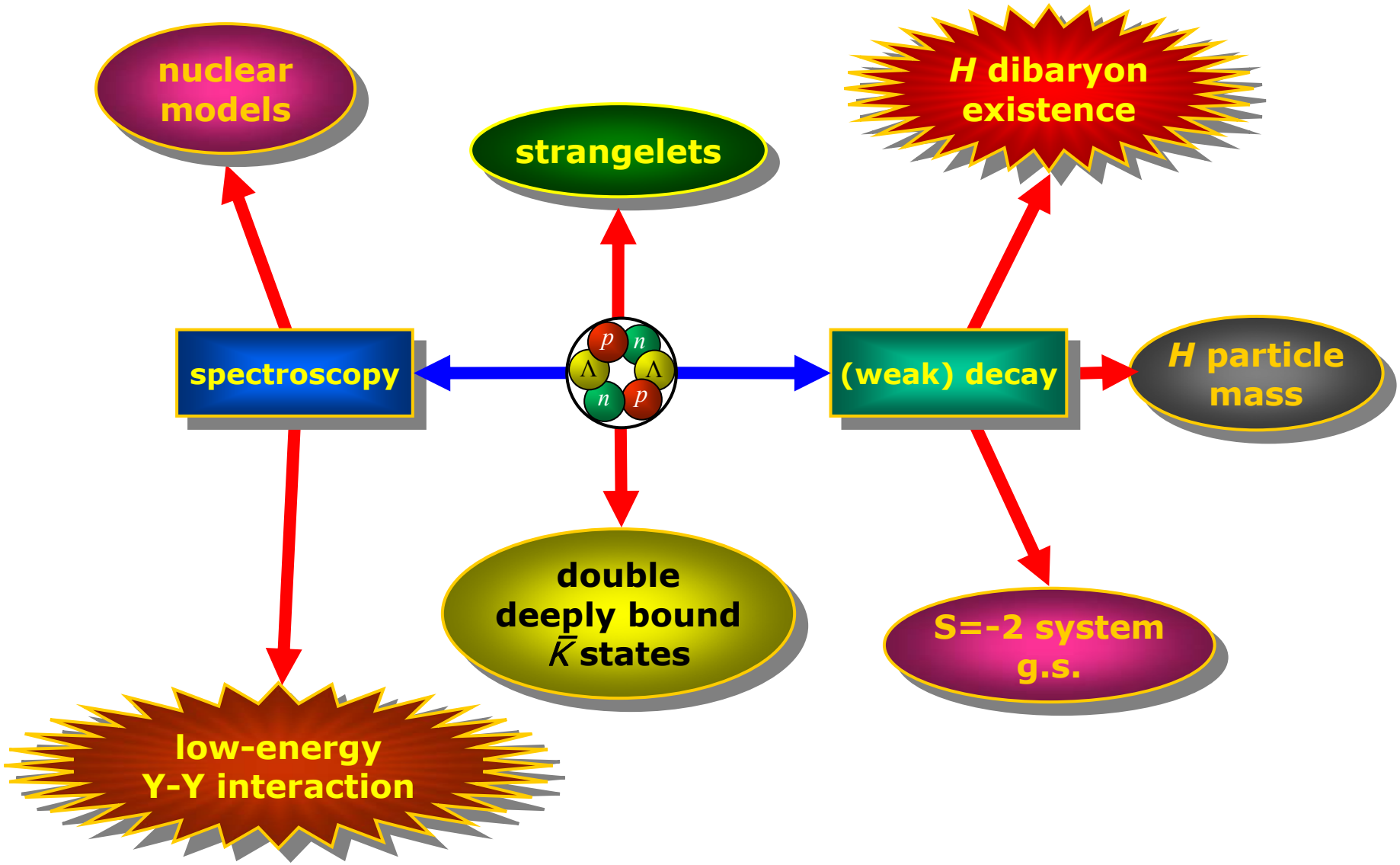
- strangeness nuclear physics:
  - interest
  - discovery potential

- the $\bar{P}$ANDA experiment
  - opportunity for hypernuclear physics
  - the apparatus
  - the technological challenges

Physics output (S=-1)



Physics output (S=-2)

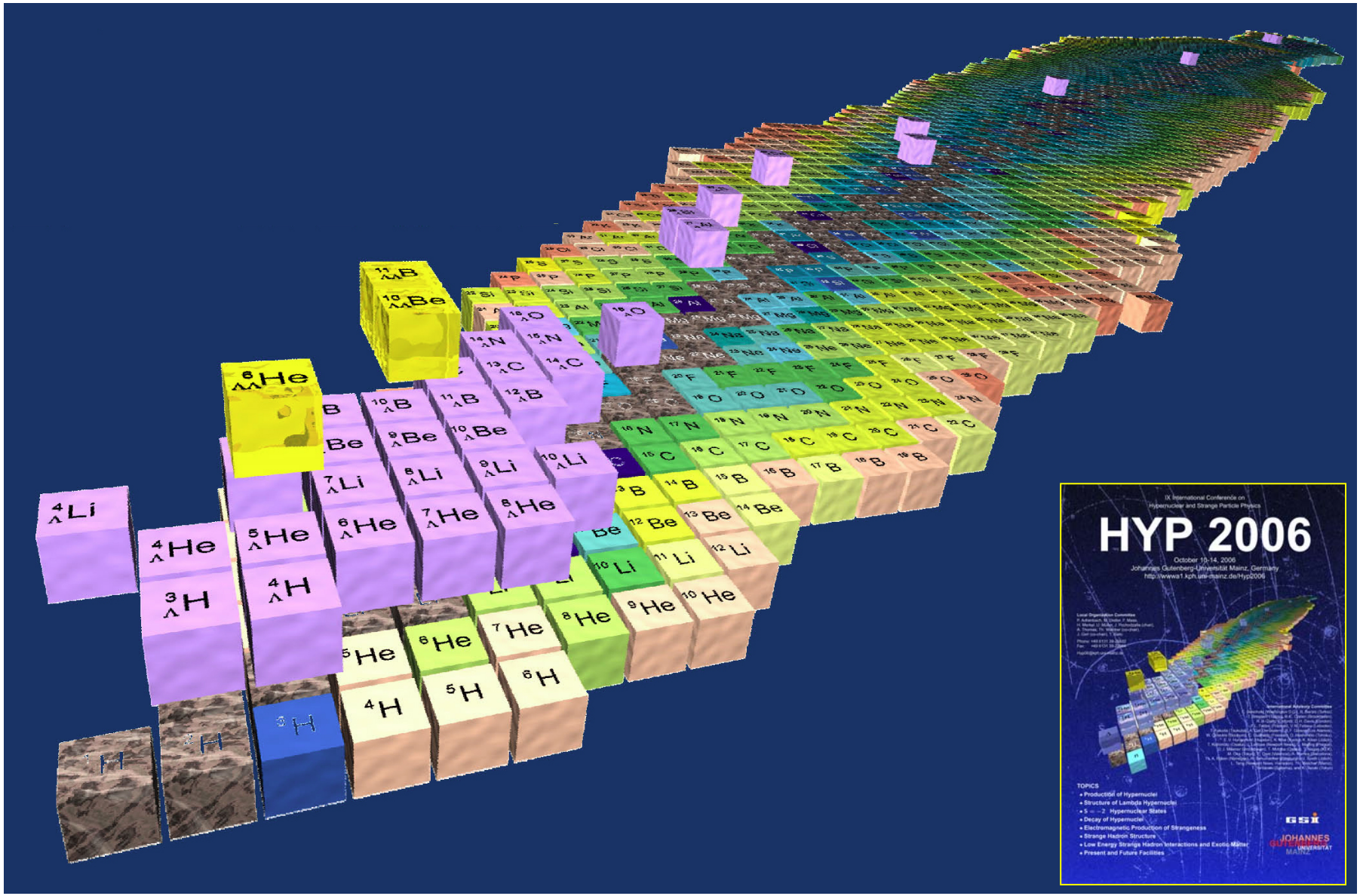


S=-2 systems

S = -2 systems study is not just a simple extension of what has been done for S = -1 system

- new physics items:
  - a detailed and consistent understanding of the quark aspect of the baryon-baryon forces in the SU(3) space will not be possible as long as experimental information on the *YY* channel is not available
  - search for *H* particle
  - existence of S = -2 (deeply) bound $\bar{K}$ states
- experimental challenges:
  - (abundant) production of ΛΛ-hypernuclei is very difficult
  - identification of produced hyperfragments is problematic
  - γ-ray measurement in coincidence

Hypernuclei's chart



The status of the art

single event analysis

reference (year)	hyper nucleus	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]	notes
M. Danysz *et al.*, *Nucl. Phys.* 49 (1963) 121	${}^{10}_{\Lambda\Lambda}Be$	17.7 ± 0.4	4.3 ± 0.4	emulsion exp.; Dalitz' reanalysis
D. Prowse *et al.*, *Phys. Rev. Lett.* 17 (1966) 782	${}^{6}_{\Lambda\Lambda}He$	10.9 ± 0.5	4.6 ± 0.5	emulsion exp.; Dalitz' criticism
S. Aoki *et al.*, *Prog. Theor. Phys.* 85 (1991) 951	${}^{13}_{\Lambda\Lambda}B$	27.6 ± 0.7	4.8 ± 0.7	KEK-E176 emulsion-counter hybrid exp. (*)
S. Aoki *et al.*, *Prog. Theor. Phys.* 85 (1991) 1287	${}^{10}_{\Lambda\Lambda}Be$	8.5 ± 0.7	-4.9 ± 0.7	same event
J.K. Ahn *et al.*, *Phys. Rev. Lett.* 87 (2001) 132504	${}^{4}_{\Lambda\Lambda}H$	---	---	BNL-E906 "mass production"
H. Takahashi *et al.*, *Phys. Rev. Lett.* 87 (2001) 212501	${}^{6}_{\Lambda\Lambda}He$	$7.25 \pm 0.19^{+0.18}_{-0.11}$	$1.01 \pm 0.20^{+0.18}_{-0.11}$	KEK-E373 emulsion-counter hybrid exp.
H. Takahashi *et al.*, *Nucl. Phys.* A 721 (2003) 951c	${}^{10}_{\Lambda\Lambda}Be$	$12.33^{+0.35}_{-0.21}$	---	KEK-E373 emulsion-counter hybrid exp.

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

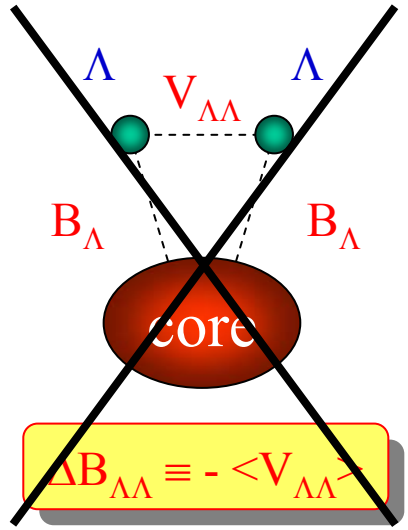
$$\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}({}^{A}_{\Lambda\Lambda}Z) - B_{\Lambda}({}^{A-1}_{\Lambda}Z)$$

(*) see:
C.B. Dover, D.J. Millener, A. Gal and D.H. Davis, *Phys. Rev.* C 44 (1991) 1905

Caveat

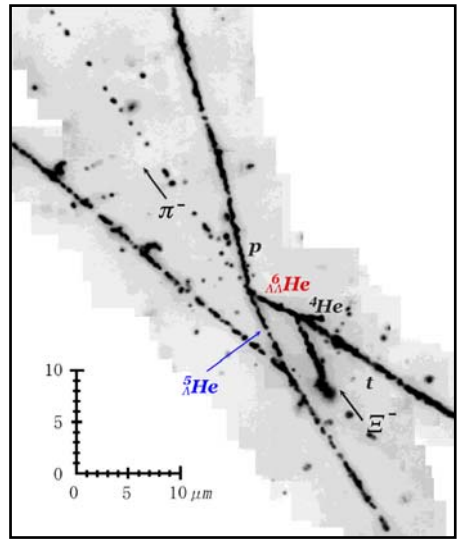
$\Delta B_{\Lambda\Lambda}$ can not be interpret as ΛΛ binding energy because of:

- dynamical change of the core nucleus
- *N*Λ spin-spin interaction for non-zero spin of core
- possible excited states



if ΛΛ- or intermediate Λ-hypernuclei are produced in excited states:

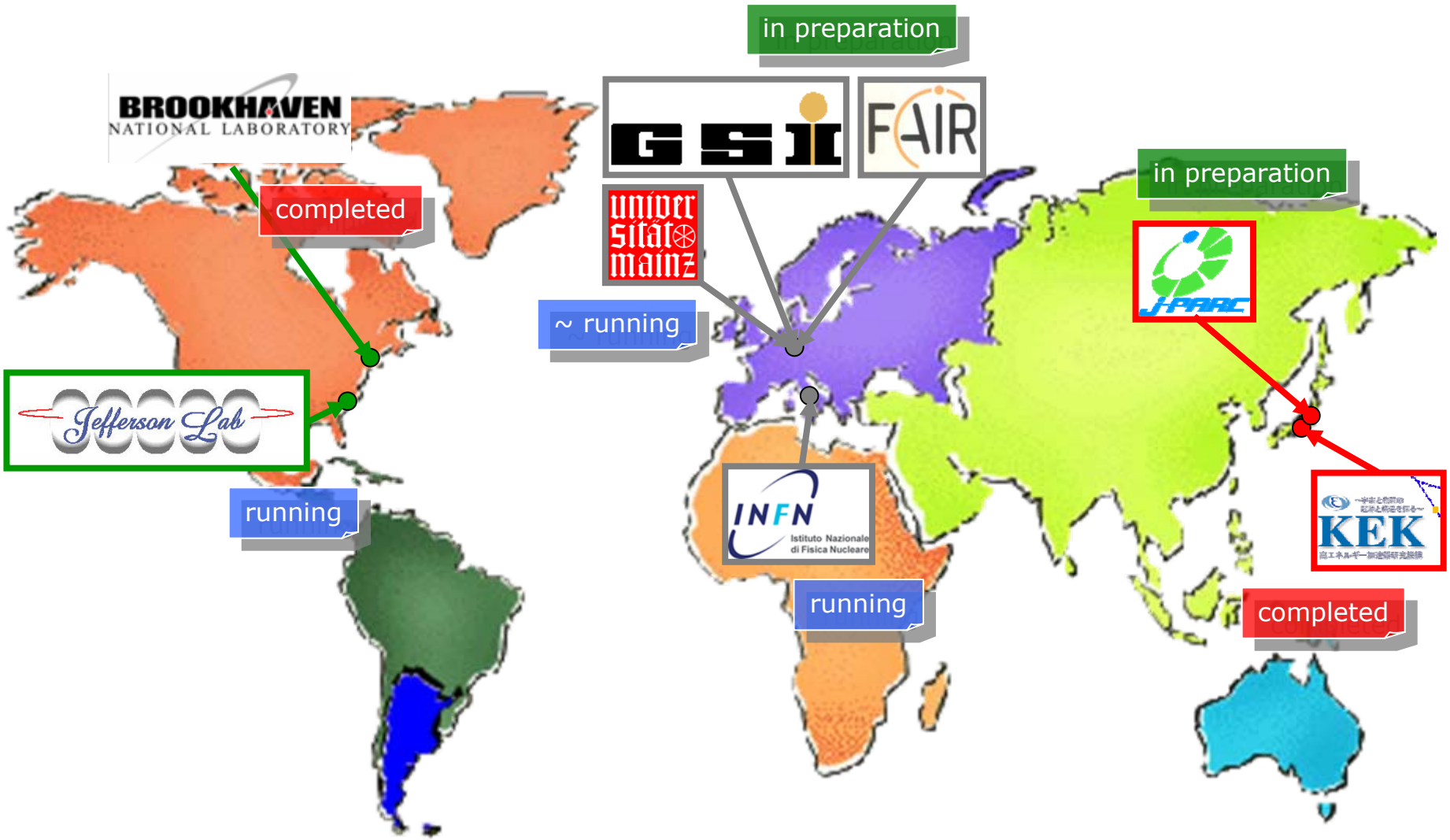
- Q-value is difficult to extract (especially for heavy nuclei)
- nuclear fragments are difficult to identify with usual emulsion technique



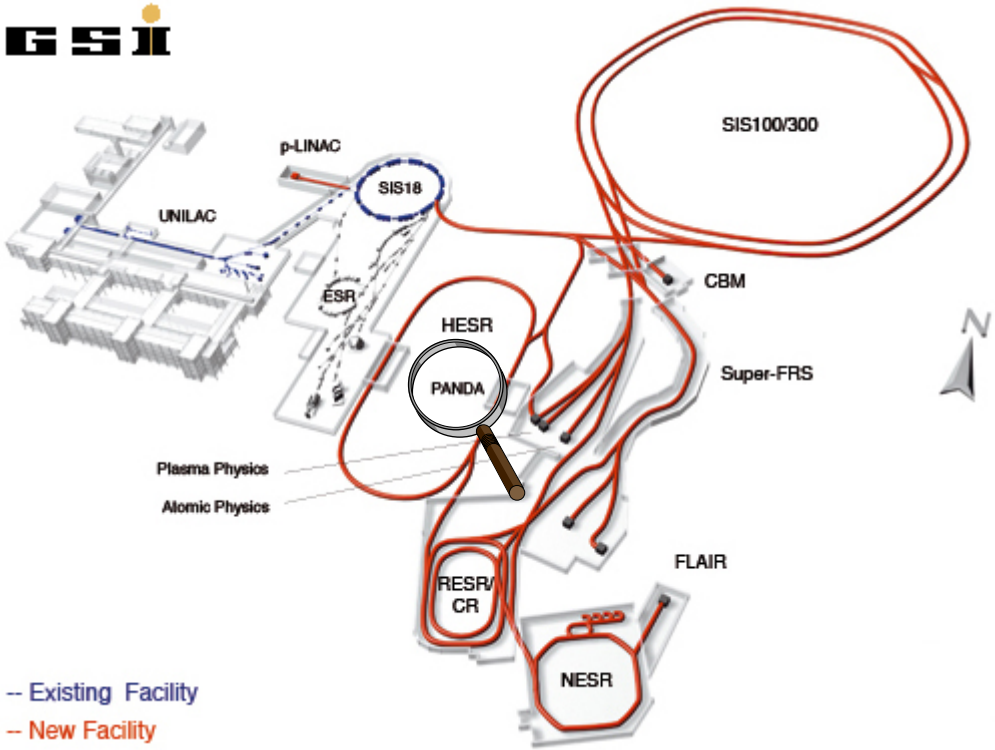
new concept required!

γ-spectroscopy

Hypernuclei's chart 2



FAIR @ GSI



Primary Beams

- 10^{12}/s; 1.5-2 AGeV; $^{238}U^{28+}$
- Factor 100-1000 over present intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{92+}$ up to 35 AGeV
- up to 90 GeV protons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 AGeV; up to factor 10 000 in intensity over present
- Antiprotons 0 - 30 GeV

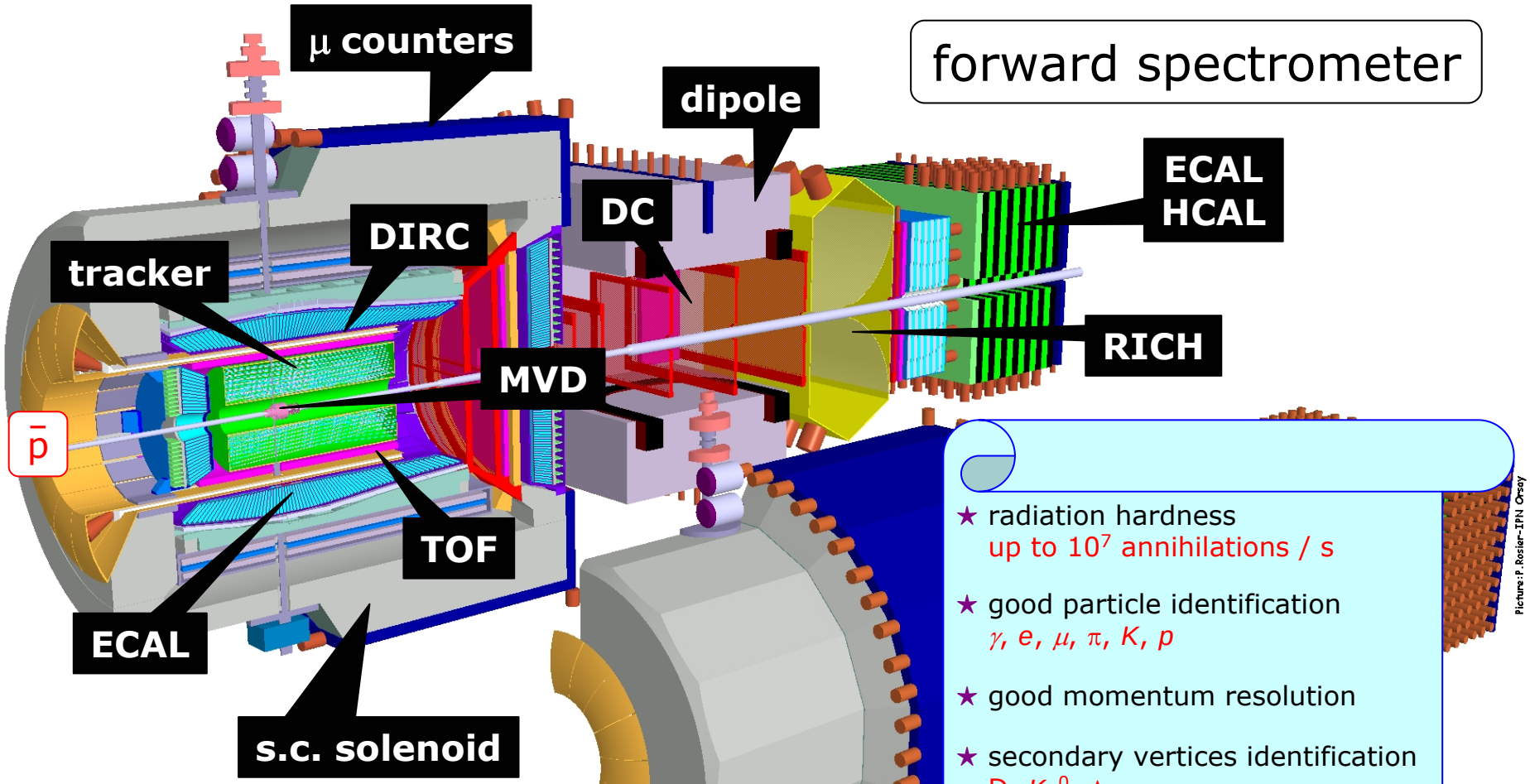
Storage and Cooler Rings

- Radioactive beams
- e^- – A (or Antiproton-A) collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons
- Polarized antiprotons (?)

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets
- Parallel Operation

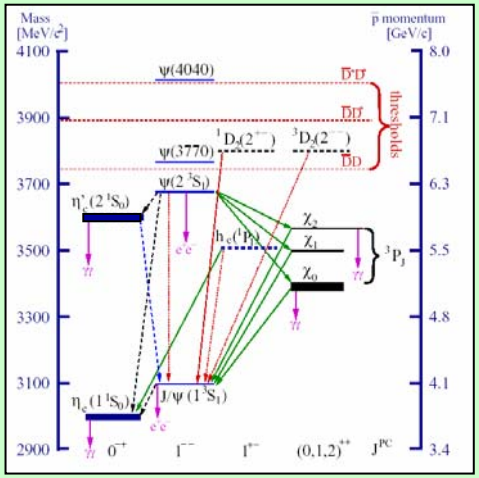
The $\bar{P}$ANDA apparatus



- ★ radiation hardness
  up to 10^7 annihilations / s
- ★ good particle identification
  γ, e, μ, π, K, p
- ★ good momentum resolution
- ★ secondary vertices identification
  D, K_S^0, Λ
- ★ maximum acceptance
  partial wave analysis
- ★ efficient trigger

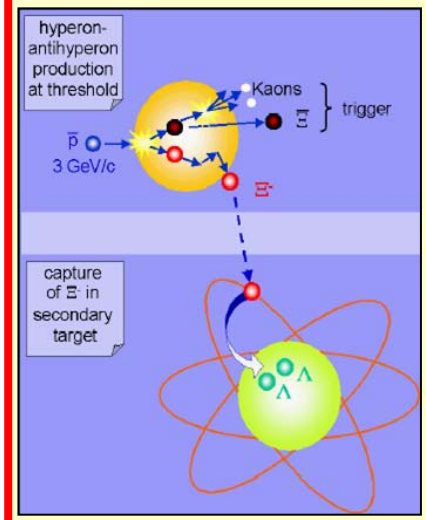
The PANDA physics program

High resolution charmonium spectroscopy



quark confinement

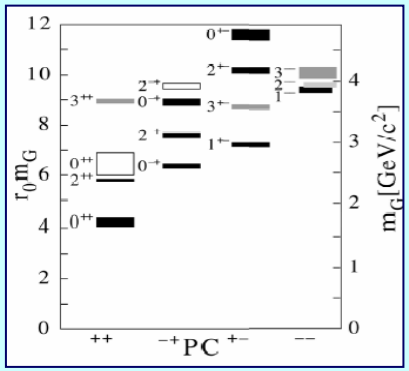
Strangeness nuclear physics



- γ spectroscopy of double Λ ipernuclei

- nuclear structure
- low energy ΛN and ΛΛ interactions

Gluonic excitation

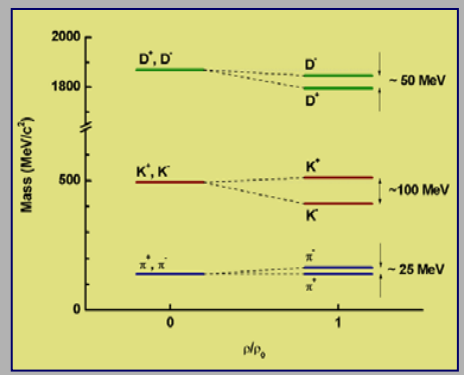


Search for:

- exotics
- hybrids
- glueballs

mass region 3 ÷ 5 GeV/c²

Medium effect



partial restoration of the chiral symmetry?

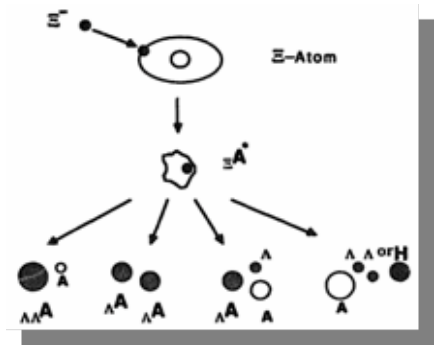
Double strangeness production

Ξ^- atomic capture reaction at rest
is one of the most effective way to look for double Λ-hypernuclei

- compound double Λ state:

$$\Xi^- + {}^{A}Z \rightarrow {}^{(A-1)}(Z-1) \oplus \Lambda \oplus \Lambda$$

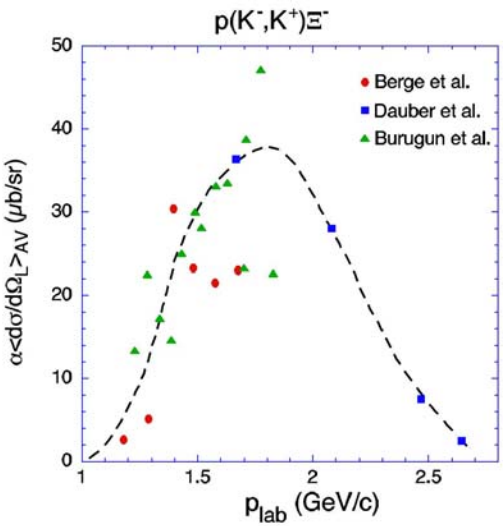
$$\Xi^- + p \rightarrow \Lambda + \Lambda + 28\ \mathrm{MeV}$$



- quasi deuteron model:

$$\Xi^- + {}^{A}Z \rightarrow {}^{A}_{\Lambda\Lambda}(Z-1) + n$$ ← high energy

$$\Xi^- + \text{“d”} \rightarrow \text{“}\Lambda\Lambda\text{”} + n$$ ← high energy



$$K^- + p \rightarrow \Xi^- + K^+$$ q.f.

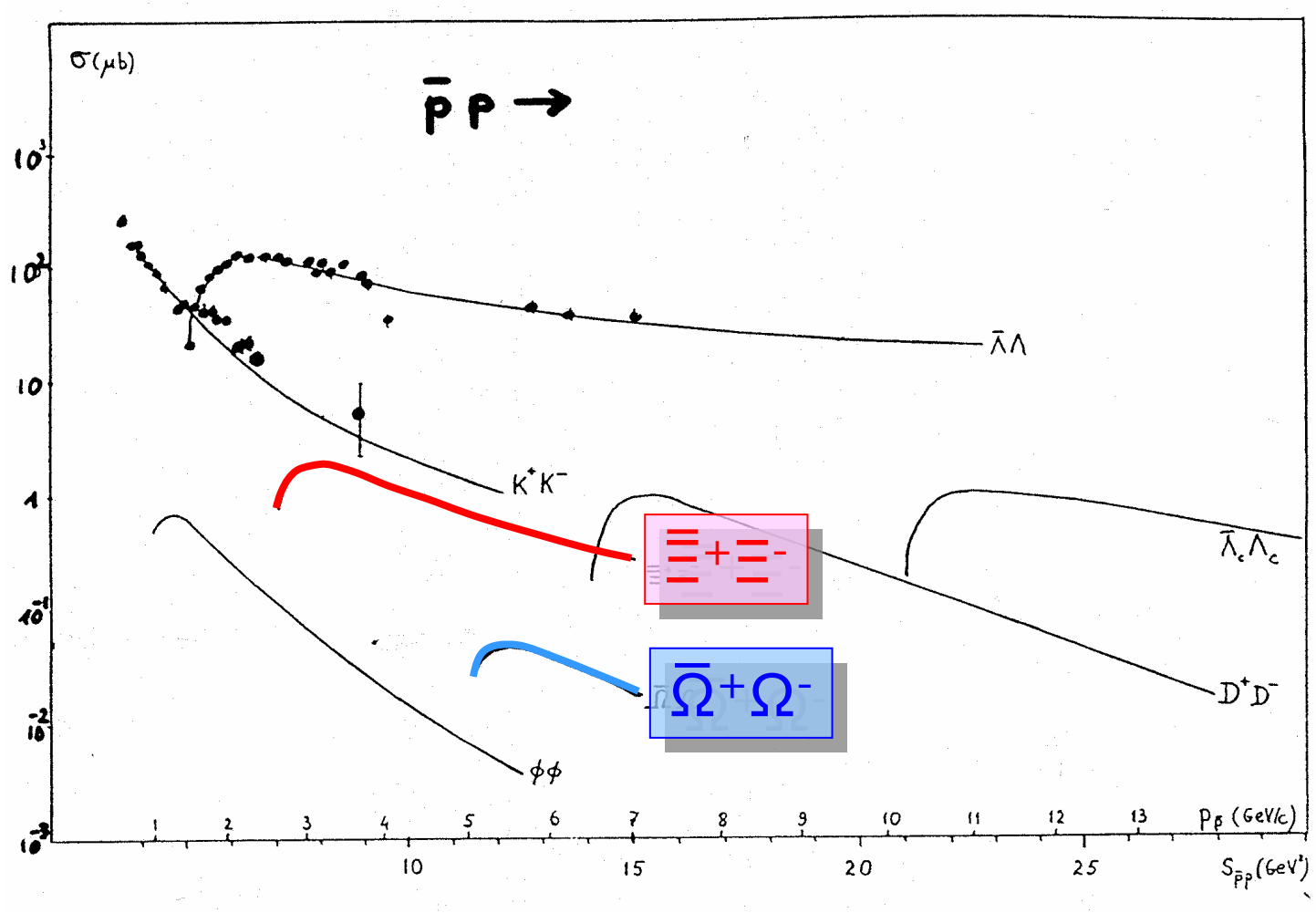
$$K^- + {}^{A}Z \rightarrow {}^{A}_{\Xi}(Z-1) + K^+$$

K^- beams:

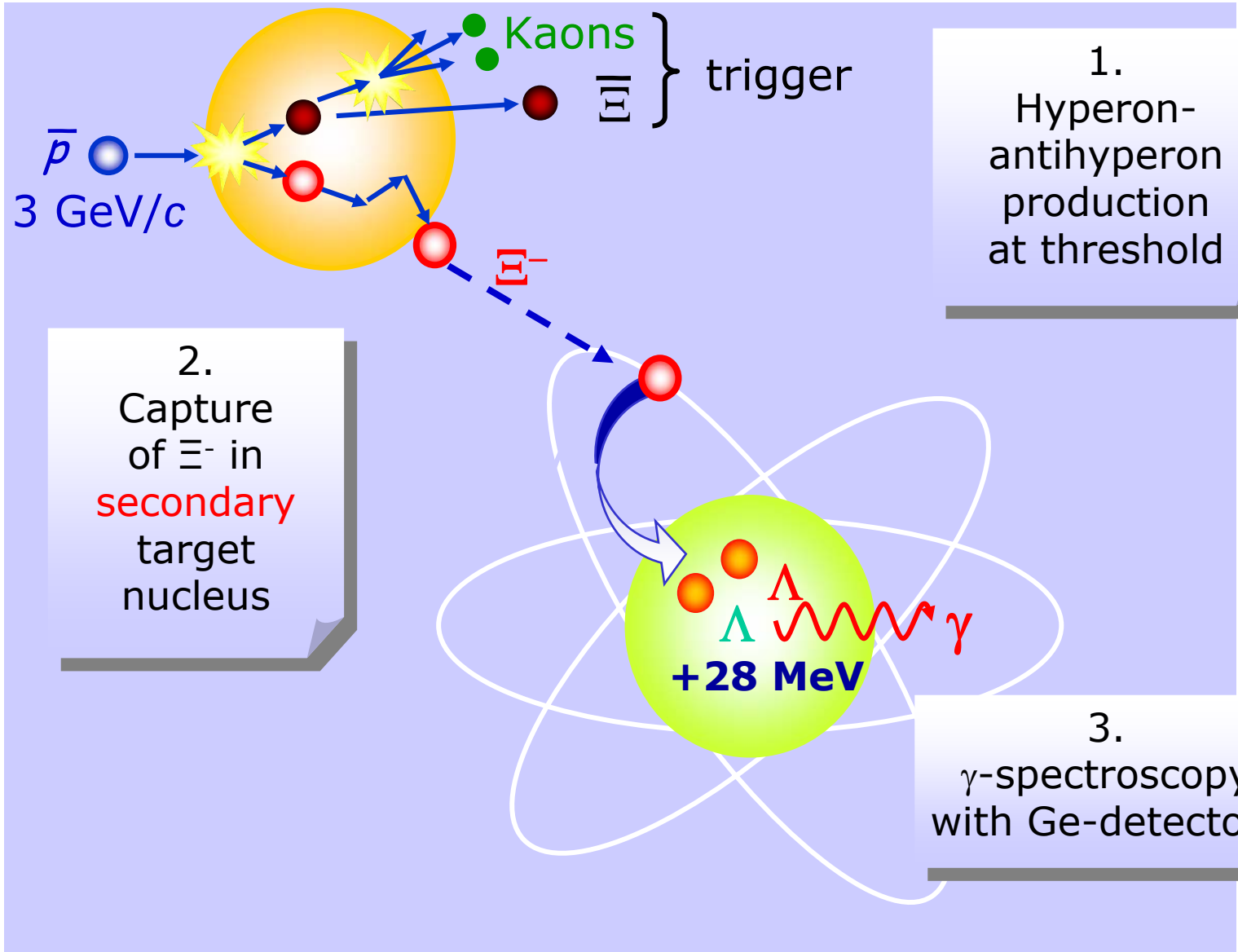
@ BNL 1.88 GeV/c
@ KEK 1.66 GeV/c
@ J-PARC 1.80 GeV/c

The basic idea

$$\Xi^- + p \rightarrow \Lambda + \Lambda + 28\ \mathrm{MeV}$$



ΛΛ-hypernucleus production @ PANDA

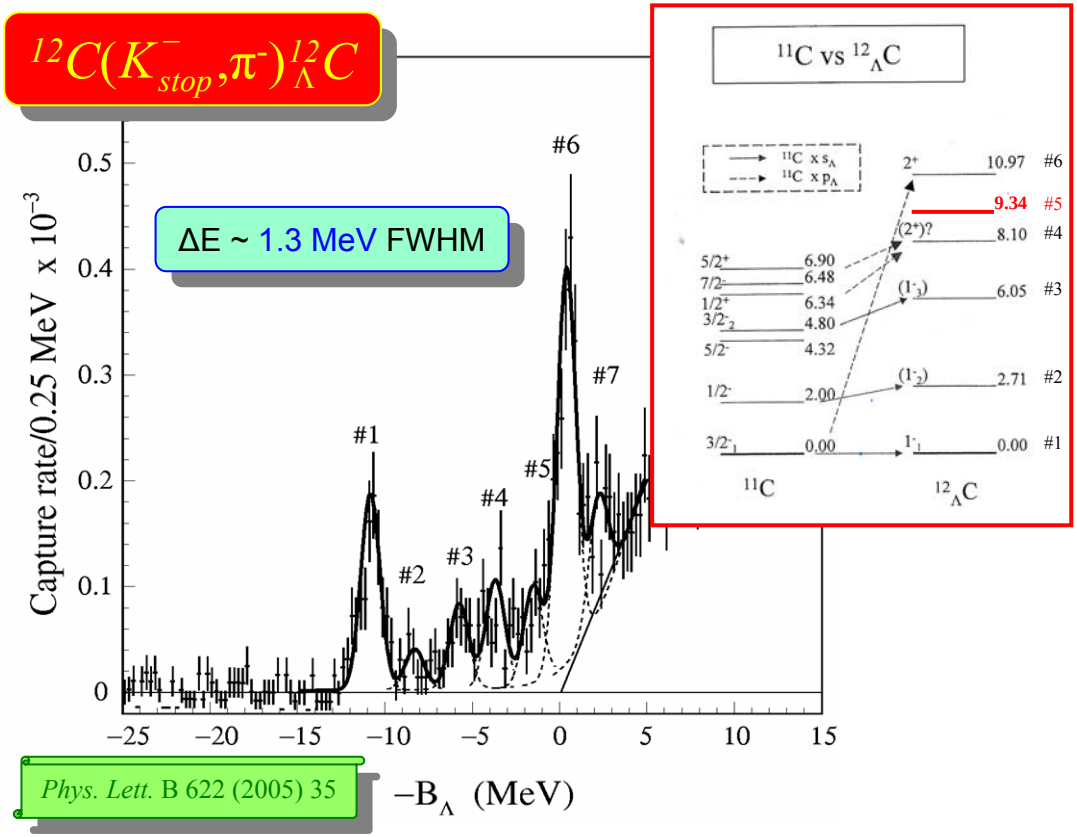


Λ- vs. ΛΛ-hypernucleus identification

@

2 body reaction:

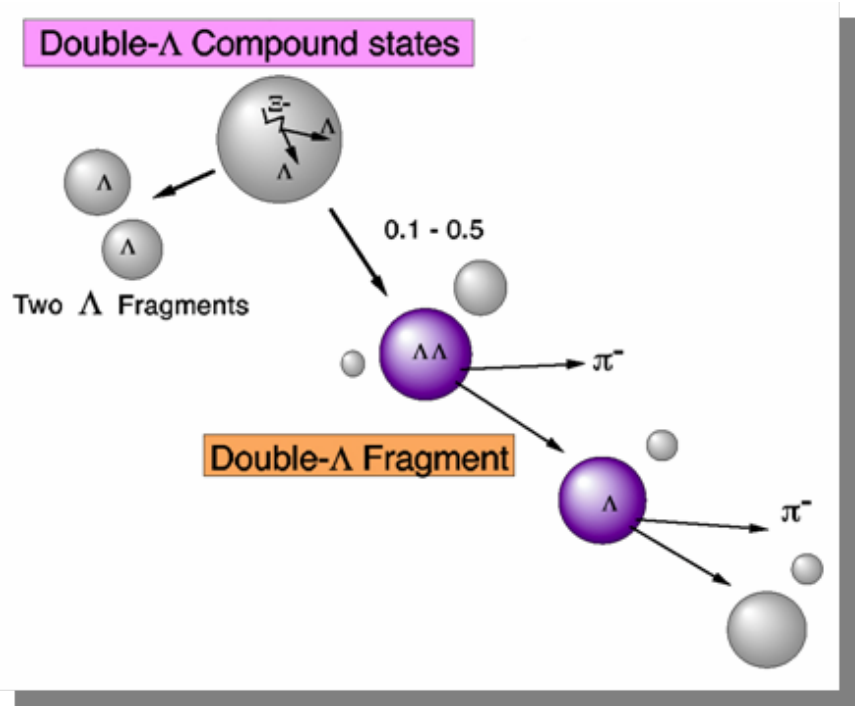
$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$$



2 step process:

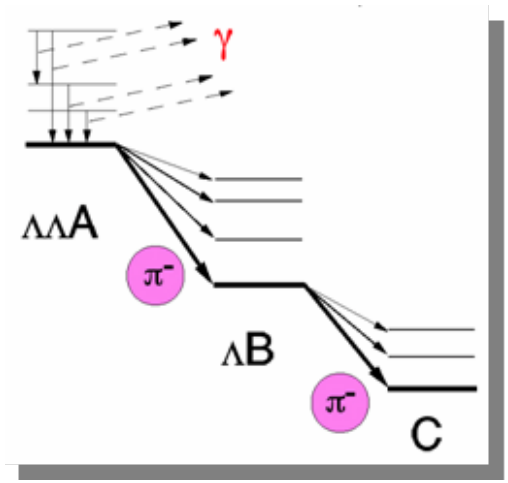
$$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$$
$$\Xi^- + {}^{A}Z \rightarrow {}^{A+1}_{\Lambda\Lambda}(Z-1)$$

How to identify a ΛΛ-hypernucleus



sequential pionic decay

$${}^{A}_{\Lambda\Lambda}Z \rightarrow {}^{A'}_{\Lambda}Z' \rightarrow {}^{A''}_{\Lambda}Z''$$



limited target choice
(at least for the pilot runs)

^{6}Li, ^{7}Li, ^{8}Be, ^{9}Be, ^{12}C

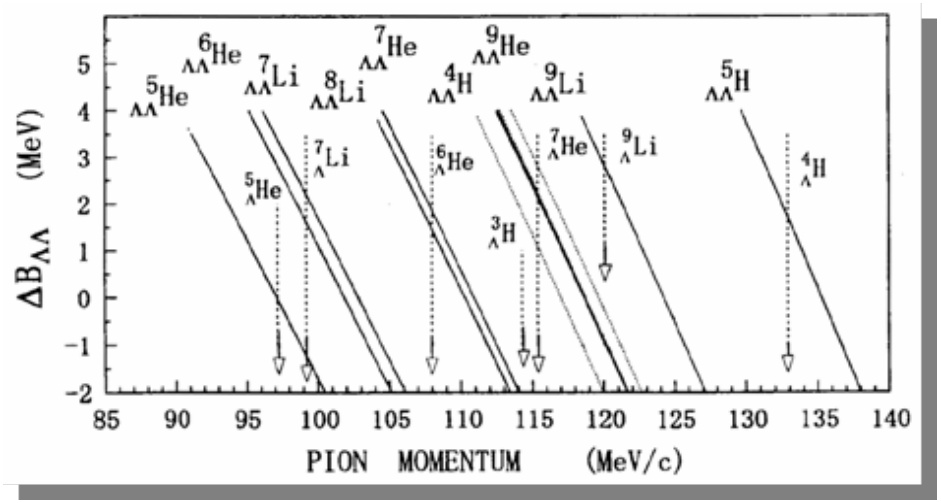
main background

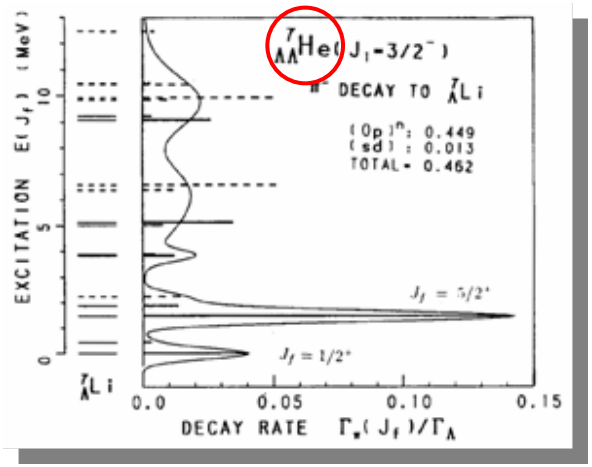
$$\Xi^- \rightarrow \Lambda + \pi^-$$

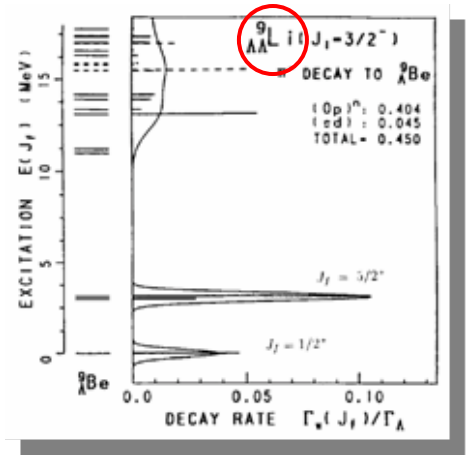
critical!

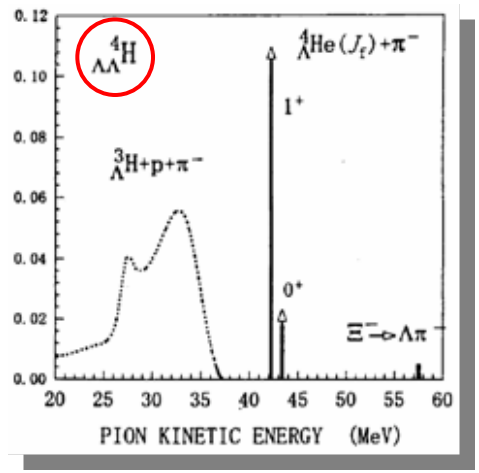
$$\Lambda \rightarrow p + \pi^-$$

Expected π^- momentum spectrum

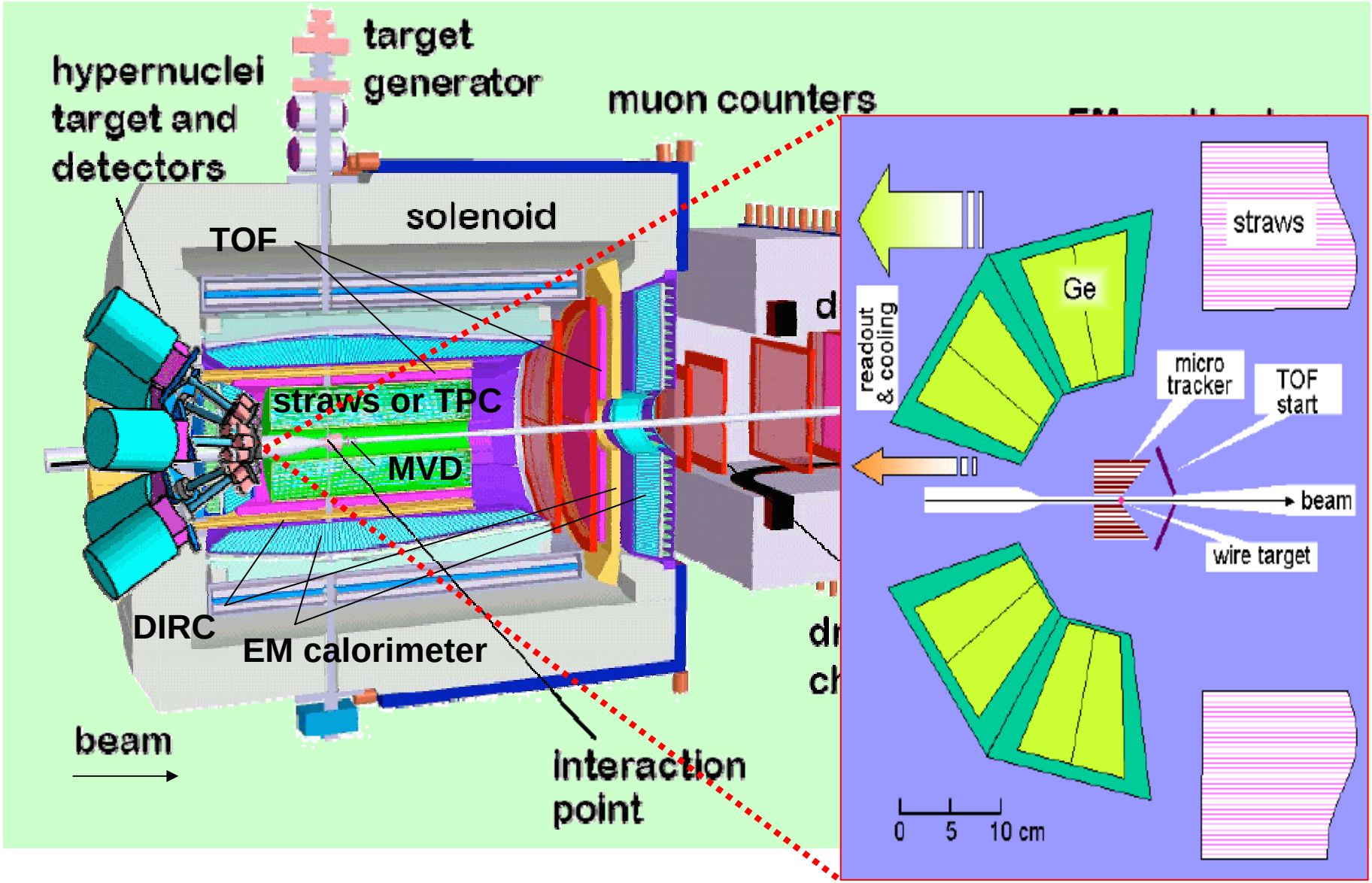








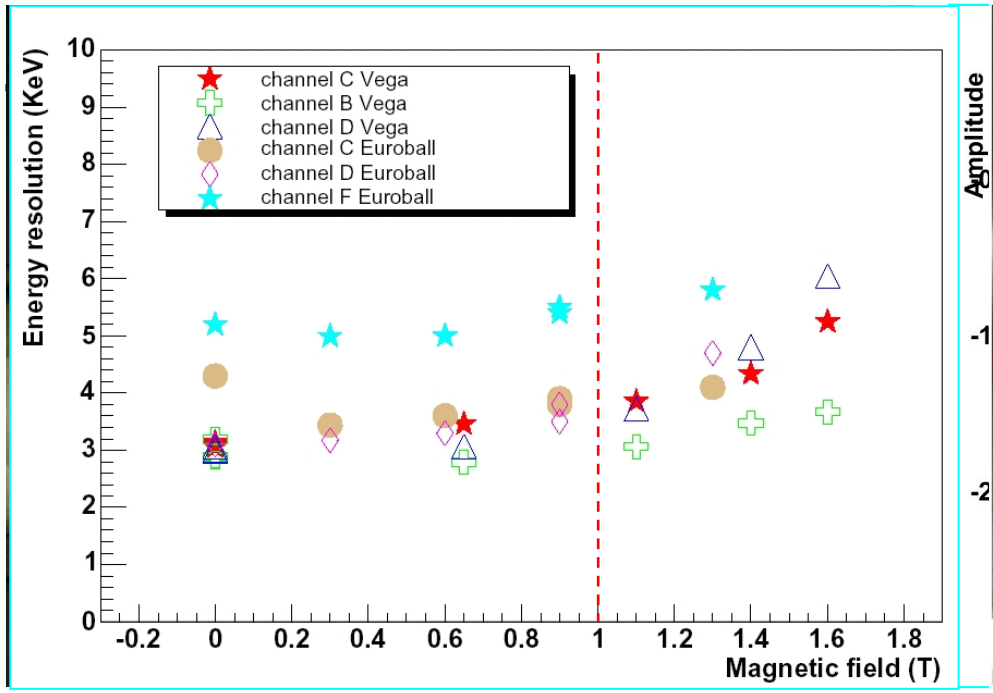
The hyper $\bar{P}$ANDA apparatus



Experimental challenges

JRA6

- Do HPGe crystals work in (strong) magnetic field?

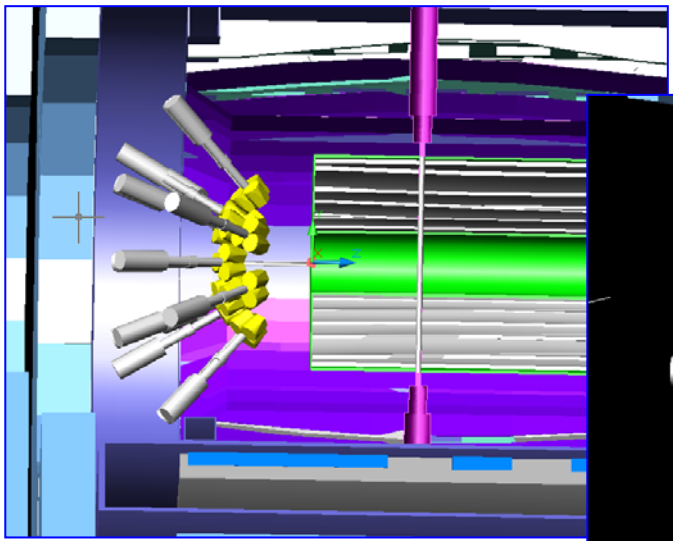


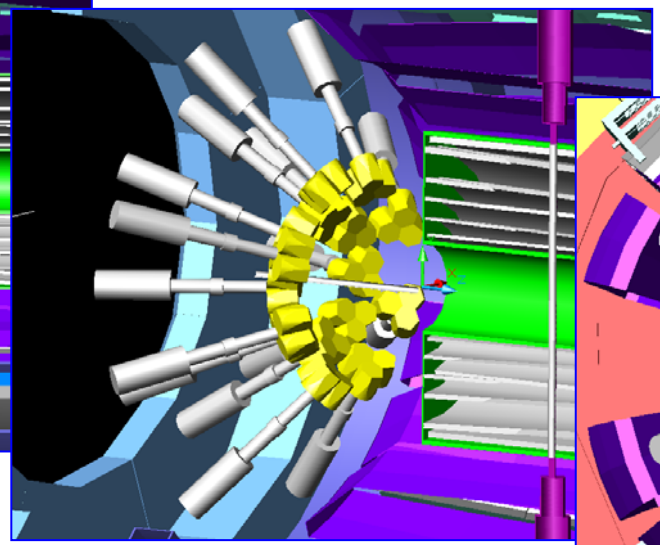
Mechanical interferences

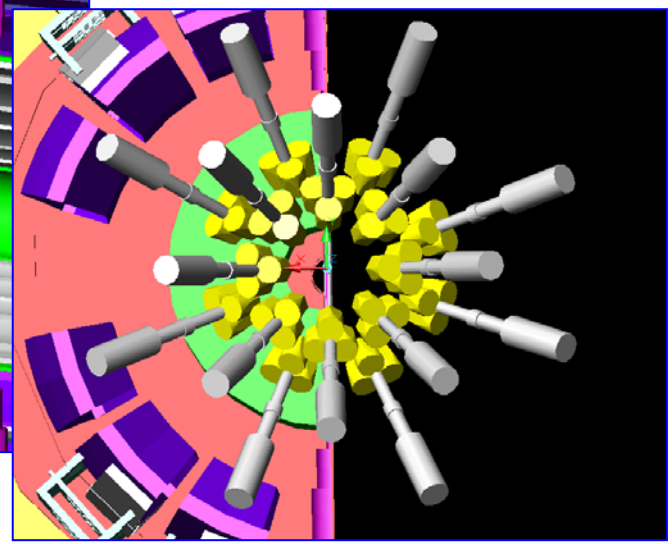
HadronPhysics I3
Study of Strongly Interacting Matter

JRA6

X – COOLER II, AMETEC, ORTEC







Expected rates

$$\sigma_{\bar{p}p}(\Xi\bar{\Xi}) \approx 2 \;\; \mu b \;\; @ \;\; 3 \;\; \mathrm{GeV}/c$$

$$\sigma_{\bar{p}A}(\Xi\bar{\Xi}) = A^{2/3} \cdot \sigma_{\bar{p}p}(\Xi\bar{\Xi})$$

by using, e.g., a ^{12}C wire target:

@ $\mathscr{L} = 10^{32}$ cm^{-2} s^{-1} HESR will produce $\Xi^-\bar{\Xi}^+$ pairs @ ~ 7×10^2 Hz

- joint $\Xi^-\bar{\Xi}^+$ escape probability: 5×10^{-4}
  (trigger on $\bar{\Xi}^+$ + p_{Ξ^-} = 100 – 500 MeV/c)
- $\bar{\Xi}^+$ reconstruction efficiency: ~ 50%
- Ξ^- stopping and capture prob.: ~ 20%

→ ~ 3×10^3 captured Ξ^- /d

- $\Xi^- p \rightarrow \Lambda\Lambda$ conversion probability: 5%

→ ~ 150 ΛΛ-hypernuclei /d

- γ-ray emission/event: 50%
- γ-ray Ge photopeak efficiency: 10%

→ ~ 7 "golden events" /d

- K^+K^+ trigger

→ ~ 700 events /d

Summary

- ✓ The fifty-year-old field of strangeness nuclear physics is still alive and has a great discovery potential
  - 👍 number of (young) experimental physicist involved is increasing
  - 👍 dedicated beams and apparatus
  - 👍 main item in several future physics program at new facilities
  - 👍 significative theoretical effort well tuned on exp. data

- ☛ By exploiting the potentialities of the new HESR machine a large number of ΛΛ-hypernuclei will be produced, allowing a significative step forward in multi-strange systems knowledge

- 🎂 2013 will be the 50th anniversary of ΛΛ-hypernucleus discovery: FAIR could successfully celebrate it with a long series of interesting results

The PANDA Collaboration

~ 350 physicists | 47 institutions | 15 countries

Austria – Belarus – China – Finland – France – Germany – Italy – Poland
Romania – Russia – Spain – Sweden – Switzerland – U.K. – U.S.A.

- AAS Wien
- Minsk U.
- IHEP Beijing U., Lanzhou U.
- Helsinki U.
- IPN Orsay
- Bochum U., Bonn U., Dresden TU, Erlangen U., Frankfurt U., Gießen U., GSI, FZ Jülich, Mainz U., München TU, Münster U., Tübingen U.
- INFN Catania – Ferrara – Genova – LNF – Milano – Pavia - Trieste, Piemonte Orientale U., Torino U. (2), Politecnico di Torino
- Cracow U., Katowice U., SINS Warsaw, Warsaw TU
- IFIN Bucharest
- JINR Dubna, BINP Novosibirsk, IHEP Protvino, PNPI St. Petersburg
- Valencia U.
- KTH Stockholm, Stockholm U., TSL Uppsala, Uppsala U.
- Basel U.
- Edinburgh U., Glasgow U.
- Northwestern U.

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