Spectroscopy of hypernuclei

Gamma-Ray Spectroscopy in Europe
Present and Future Challenges

ECT*, 8 -12 May, 2006

INFN Istituto Nazionale di Fisica Nucleare

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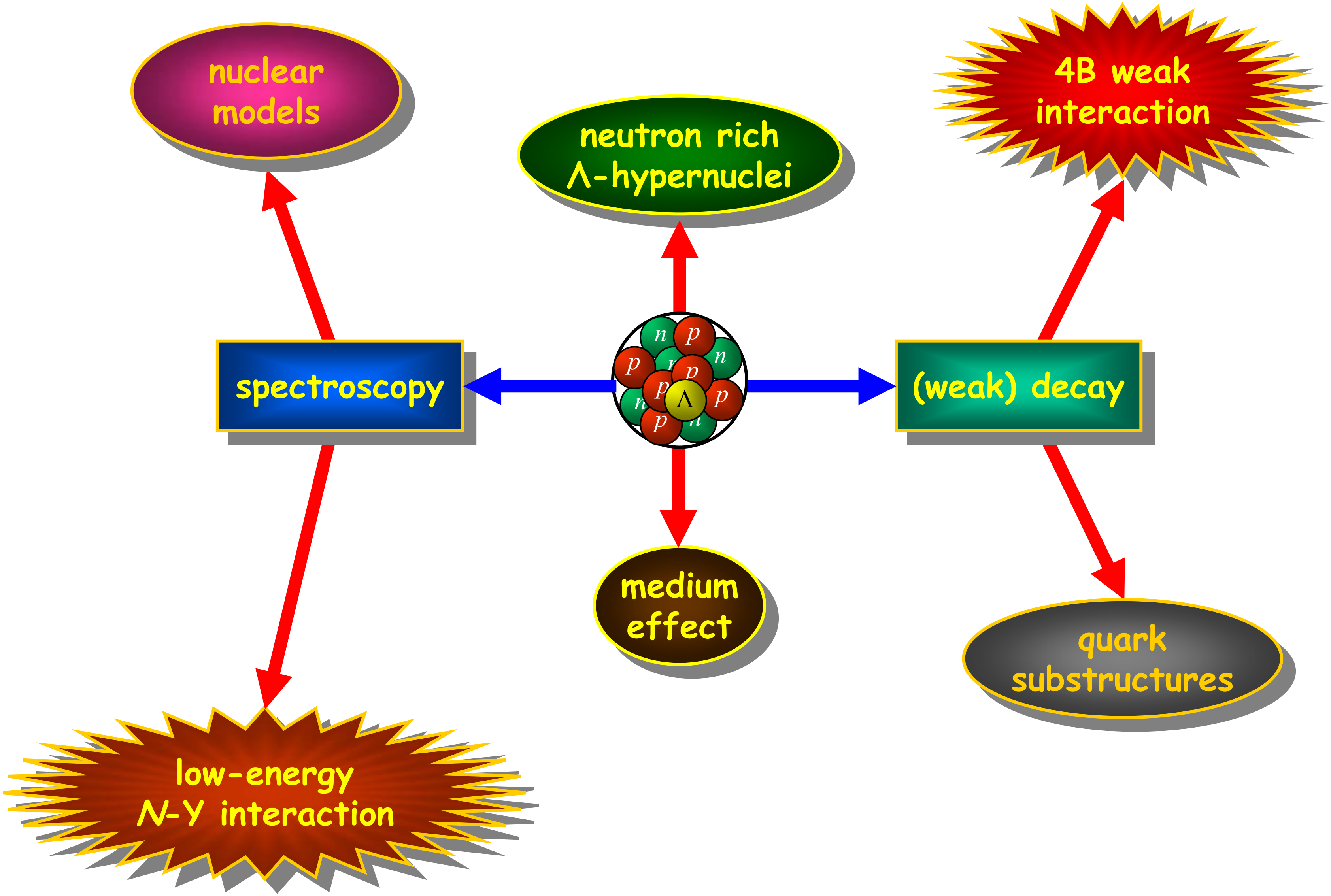
Outline

- Discovery potential of the strangeness nuclear physics
  - recent experimental results
  - unexpected effects
- Need of sub-MeV resolution apparatuses
  - γ-ray spectroscopy
- Proposal for new experiments

Physics output (S=-1)



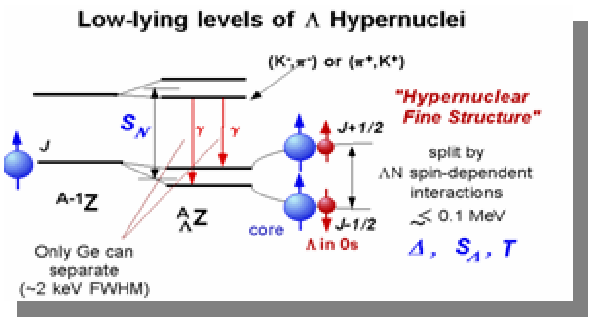
Open questions

- (low-energy) YN interaction
  - detailed knowledge of the hypernuclear fine structure
    - → evaluation of the spin dependent terms of the ΛN interaction
  - measurement of angular distribution of γ-rays
    - → determination of spin and parity of each observed level

Spin-dependent forces

The simple structure of light hypernuclear system can be described in the frame of the shell model

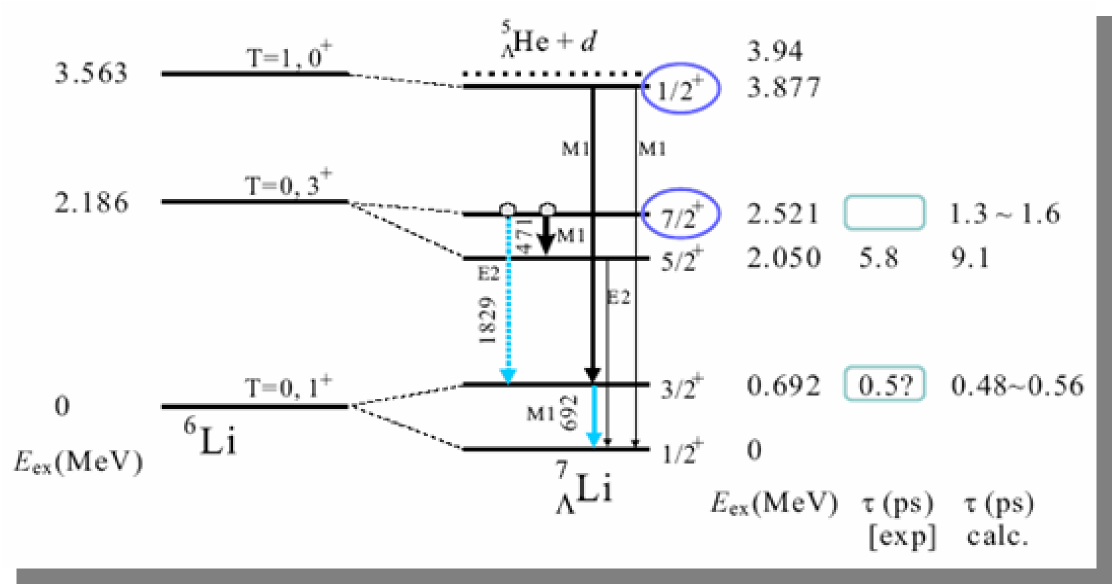
$$V_{\Lambda-N}(r) = \underbrace{V_0(r)}_{} + \overbrace{V_\sigma(r)\vec{s}_N\cdot\vec{s}_\Lambda}^{\Delta} + \overbrace{V_\Lambda(r)\vec{l}_{N\Lambda}\cdot\vec{s}_\Lambda}^{S_\Lambda} + \overbrace{V_N(r)\vec{l}_{N\Lambda}\cdot\vec{s}_N}^{S_N}$$
$$+ \underbrace{V_T(r)[3(\vec{\sigma}_N\cdot\vec{r})(\vec{\sigma}_\Lambda\cdot\vec{r} - \vec{\sigma}_N\cdot\vec{\sigma}_\Lambda)]}_{T}$$



Each of the 4 terms (Δ, S_Λ, S_N, T) correspond to a radial integral that can be phenomelogically determined from the low-lying level structure of *p*-shell hypernuclei

The knowledge of these characteristics of the ΛN interaction allows to improve baryon-baryon interaction description

Where do we stand?



HYPERBALL

KEK E419: $(\pi^+, K^+)\ ^{7}_{\Lambda}Li$

BNL E930: $(K^-, \pi^-)\ ^{7}_{\Lambda}Li$

KEK E509: $(K^-, \pi^-)\ ^{7}_{\Lambda}Li$

$\Delta = 0.43$

$S_\Lambda = -0.01$

$S_N = -0.40$

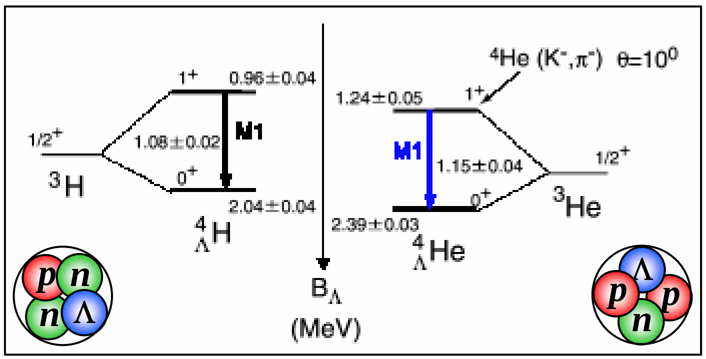
$T = 0.03$

D.J. Millener, *Nucl. Phys. A* 754 (2005) 48c

Charge symmetry breaking

$$\Lambda \begin{cases} I = 0 \\ q = 0 \end{cases} \Longrightarrow \Lambda p = \Lambda n$$

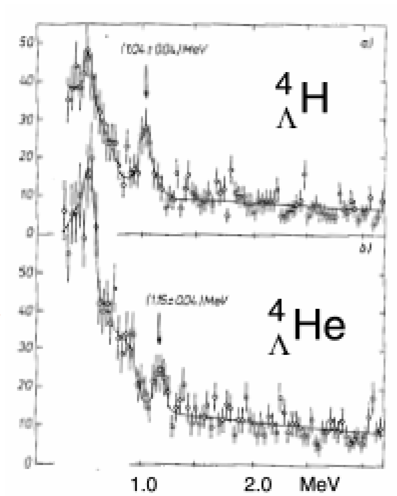
if the charge symmetry holds exactly



$$B_\Lambda({}^4_\Lambda H) \neq B_\Lambda({}^4_\Lambda He)$$

Λp more attractive than Λn

A.R. Bodmer *et al.*, *Phys. Rev.* C 31 (4) (1985) 1400



Possi ons:
- $\Lambda\Sigma^0$ mixing
- $\Lambda N - \Sigma N$ coupling

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- Impurity nuclear physics
  - measurement of transition probability B(E2)
    → information on the size and deformation of hypernuclei
    → measurement of nucleus core shrinking → glue-like role of Λ

Impurity nuclear physics

A hypernucleus can be considered the outcome of a genetic engineering manipulation applied to the nuclear physics domain

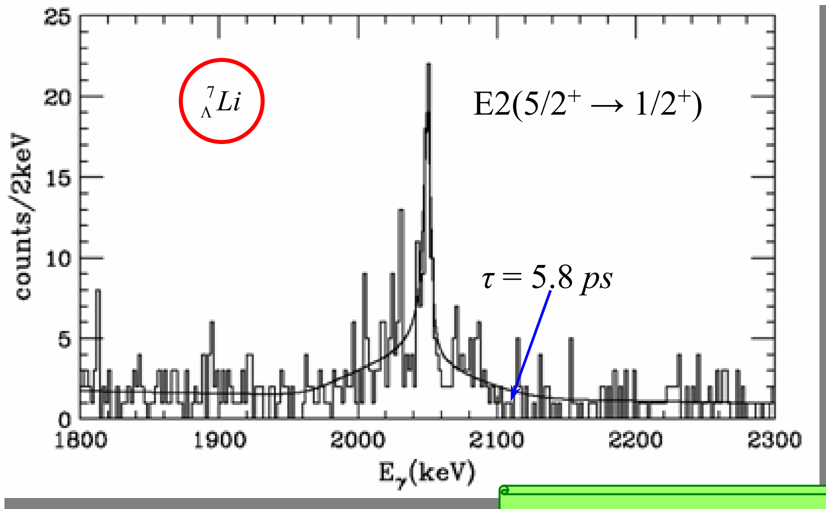
The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure

- changes of the size and of the shape
- changes of the cluster structure
- manifestation of new symmetries
- change of collective motions
- …

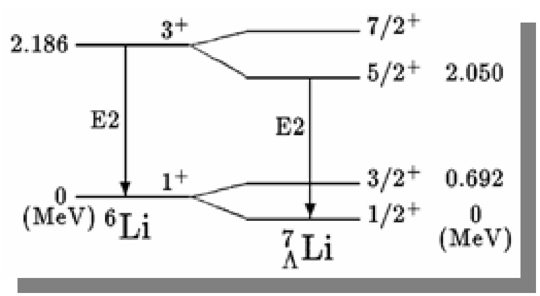
study of hypernucleus level schemes and B(E2) → Doppler-shift attenuation method

The Λ glue-like role

KEK E419



K. Tanida *et al.*, *Phis. Rev. Lett.* 86 (10) (2001) 1982



$$\frac{B(E2;{}^{7}_{\Lambda}Li:5/2^{+}\rightarrow 1/2^{+})}{B(E2;{}^{6}Li:3^{+}\rightarrow 1^{+})}=\frac{3.6\pm 0.5^{+0.5}_{-0.4}\quad e^{2}fm^{4}}{10.9\pm 0.9\quad e^{2}fm^{4}}\approx\frac{1}{3}$$

B(E2) $\propto r^4 \Rightarrow$ shrinkage of ^6Li core by ~ 20%

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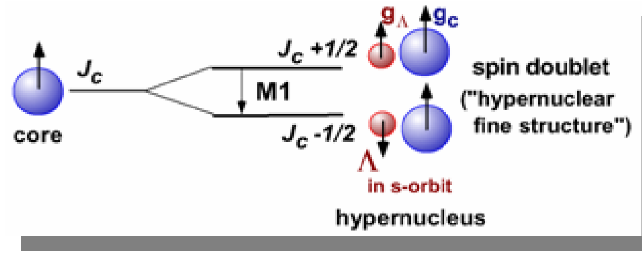
- Properties of hyperons in nuclear matter (medium effect)
  - measurement of transition probability B(M1)
    → g-factor value for Λ in nuclear matter

Medium effect

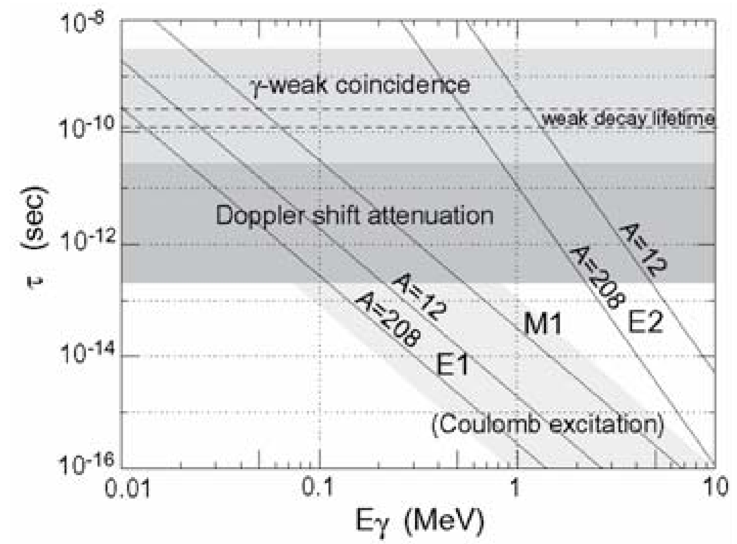
If the mass or the size of a hyperon is modified in a nucleus, its magnetic moment may be changed



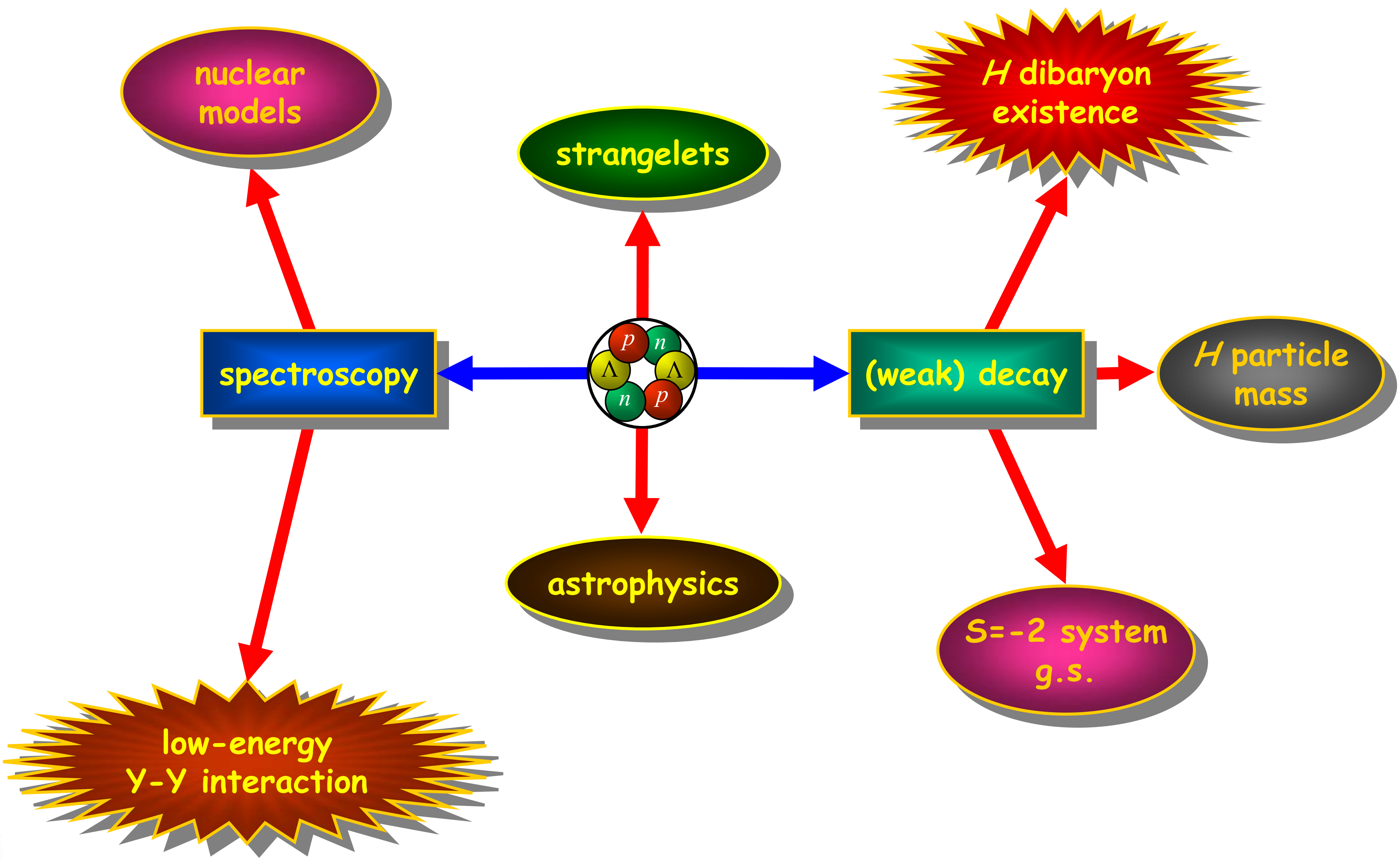
$$B(M1) \propto \left|\left\langle \phi_{lo} \middle| \mu^z \middle| \phi_{up} \right\rangle\right|^2 = \left|\left\langle \phi_{lo} \middle| g_N J_N^z + g_\Lambda J_\Lambda^z \middle| \phi_{up} \right\rangle\right|^2$$
$$\propto (g_N - g_\Lambda)^2$$

B(M1) can be derived from excited states lifetimes

- Doppler-shift attenuation method
- γ-weak coincidence method



Physics output (S=-2)

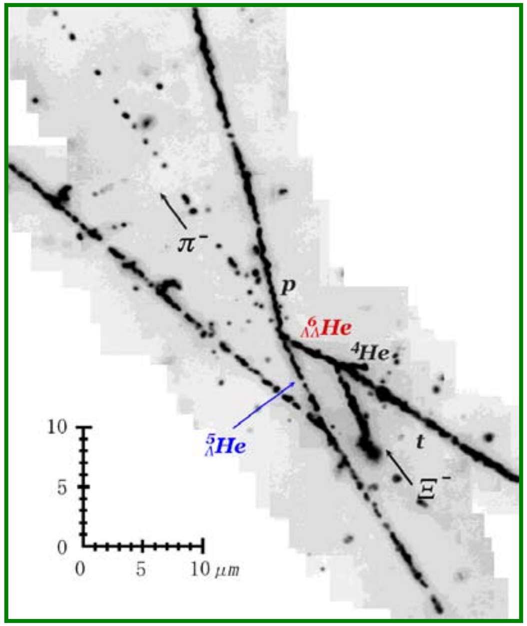


Observed ΛΛ-hypernuclei

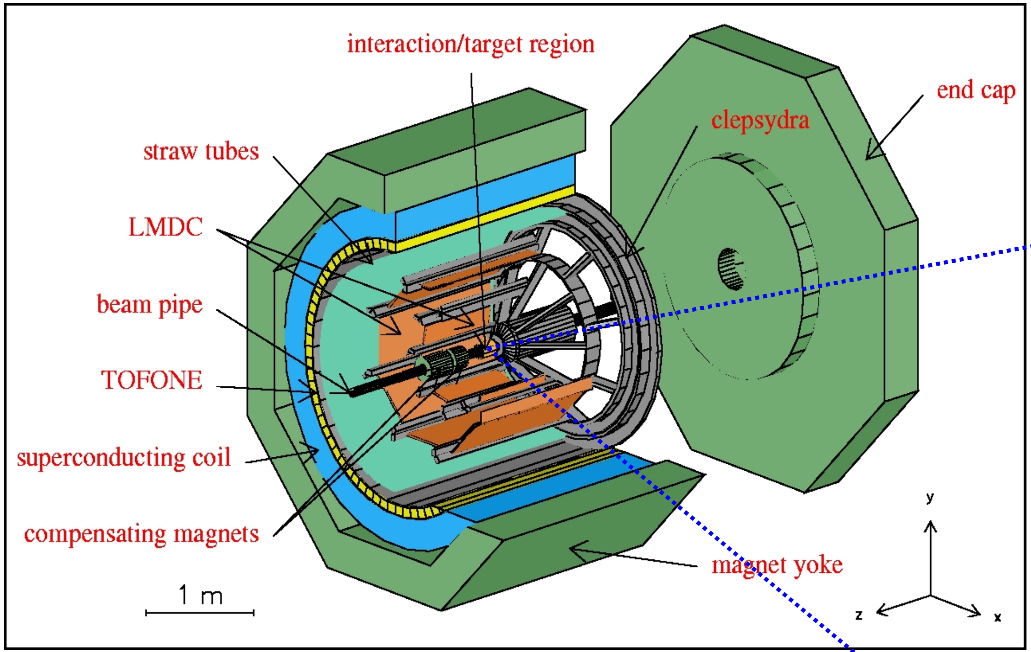
- 1963: Danysz et al. $^{10}_{\Lambda\Lambda}Be$ (emulsion)
- 1966: Prowse $^{6}_{\Lambda\Lambda}He$ (emulsion, Dalitz criticises the interpretation)
- 1991: KEK-E176 $^{13}_{\Lambda\Lambda}B$ (or $^{10}_{\Lambda\Lambda}Be$, emulsion counter hybrid experiment)
- 2001: BNL-E906 $^{4}_{\Lambda\Lambda}H$
- 2001: KEK-E373 $^{6}_{\Lambda\Lambda}He$
- 2001: KEK-E373 $^{10}_{\Lambda\Lambda}Be$

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

$$\hookrightarrow \; {}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$$

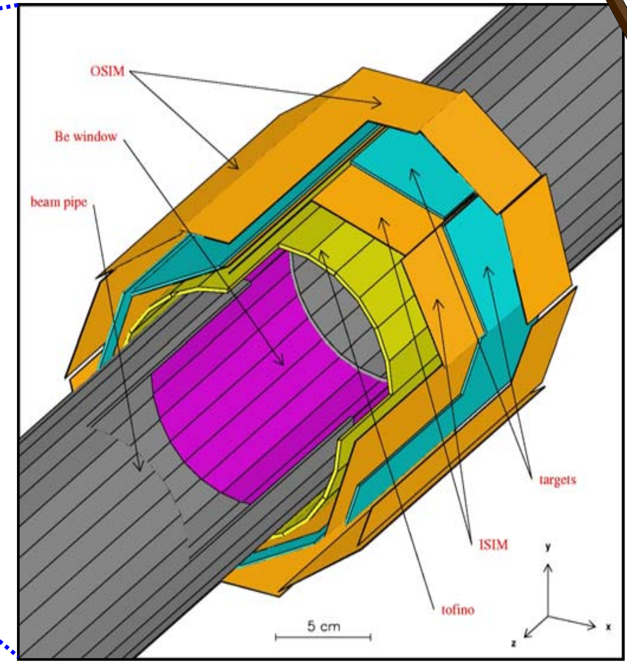


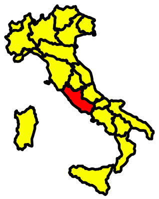
FINUDA @ DAΦNE

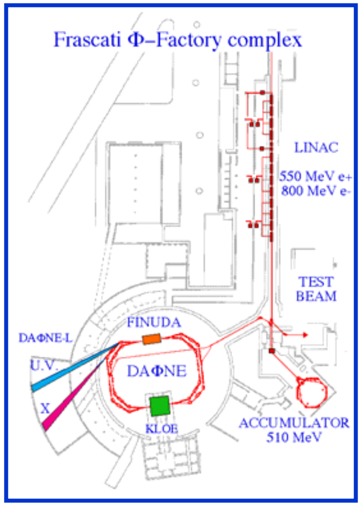


$$e^- + e^+ \rightarrow \phi \rightarrow K^- K^+$$

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



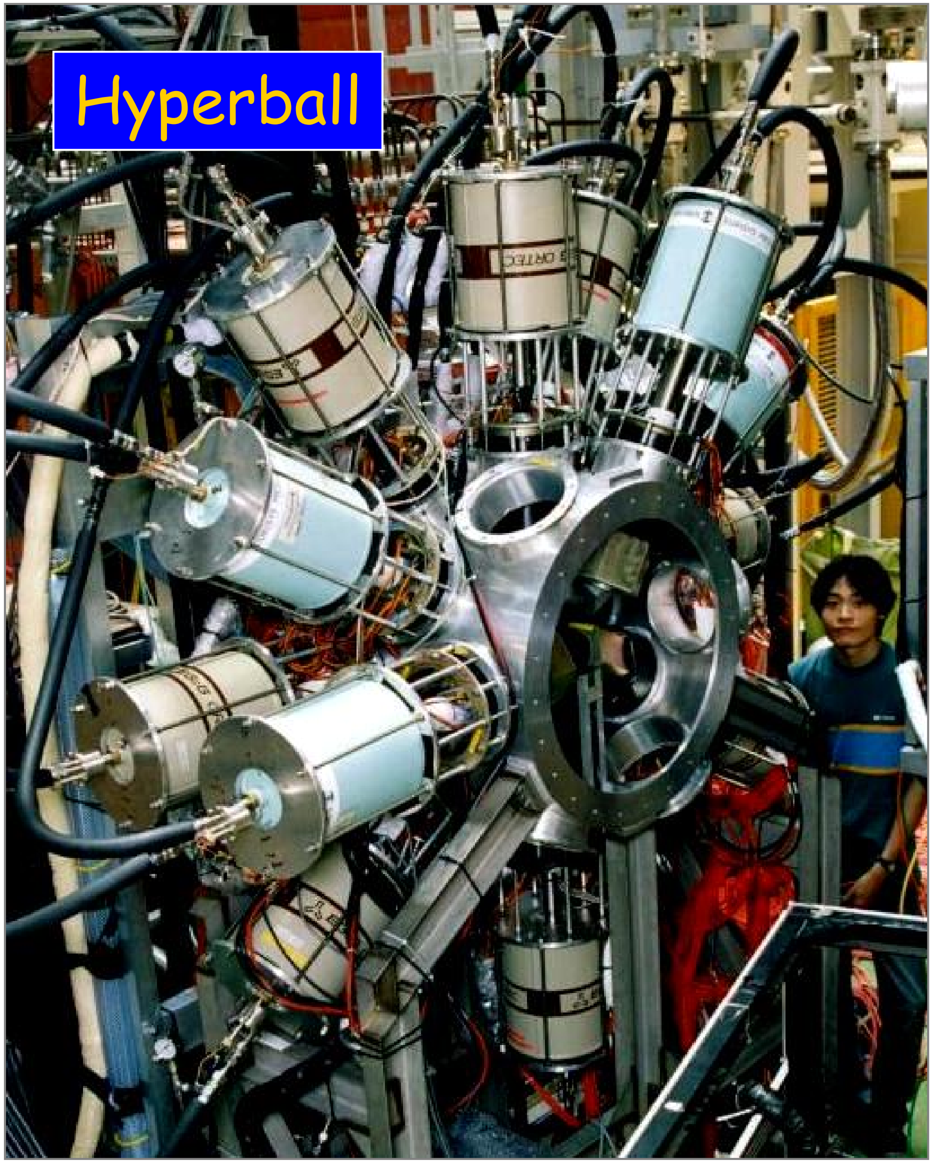


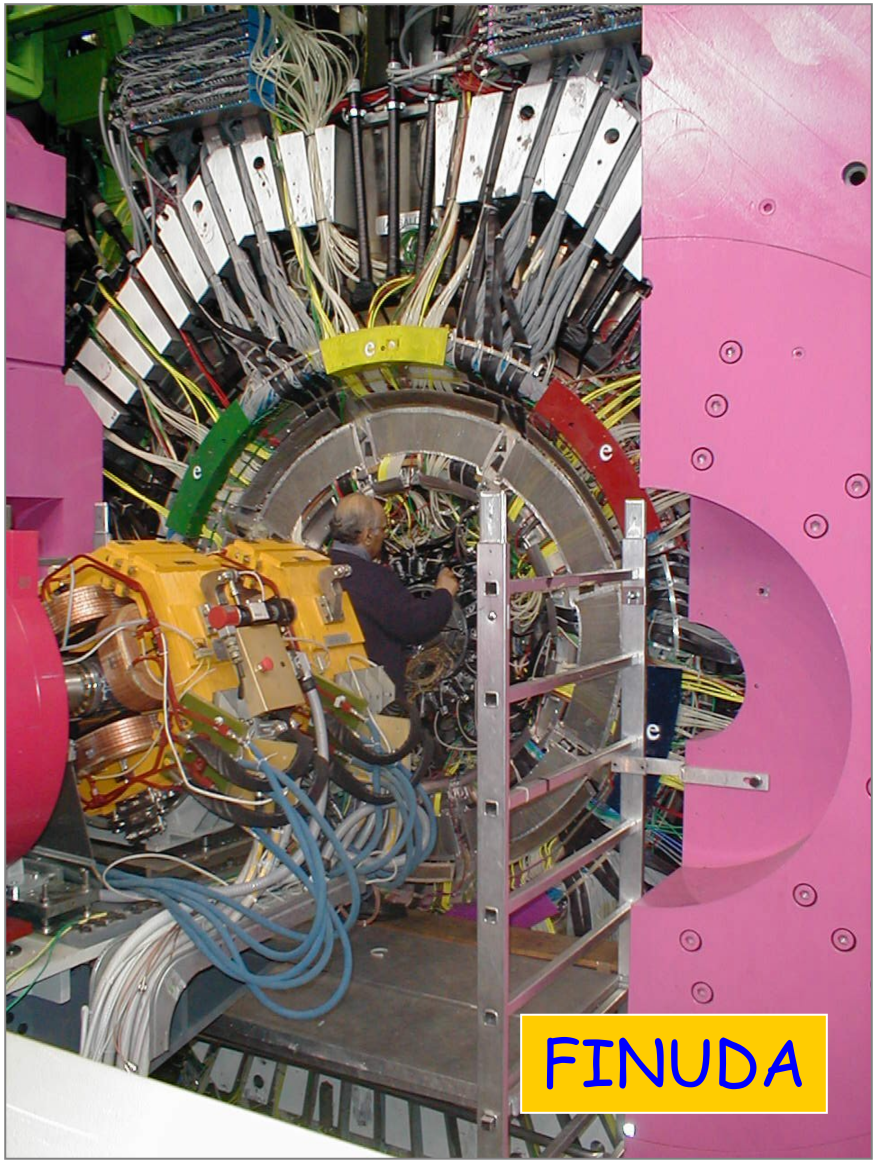


energy	510 MeV
luminosity	5 10^{32} cm^{-2} s^{-1}
σ_x (rms)	2.11 mm
σ_y (rms)	0.021 mm
σ_z (rms)	35 mm
bunch length	30 mm
crossing angle	12.5 mrad
frequency (max)	368.25 MHz
bunch/ring	up to 120
part./bunch	8.9 10^{10}
current/ring	5.2 A (max)

$${}^{A}_{\Lambda}Z \rightarrow \begin{cases} {}^{A}(Z+1) + \pi^- \\ {}^{(A-2)}(Z-1) + p + n \\ {}^{(A-2)}Z + n + n \end{cases}$$

Is the integration possible?

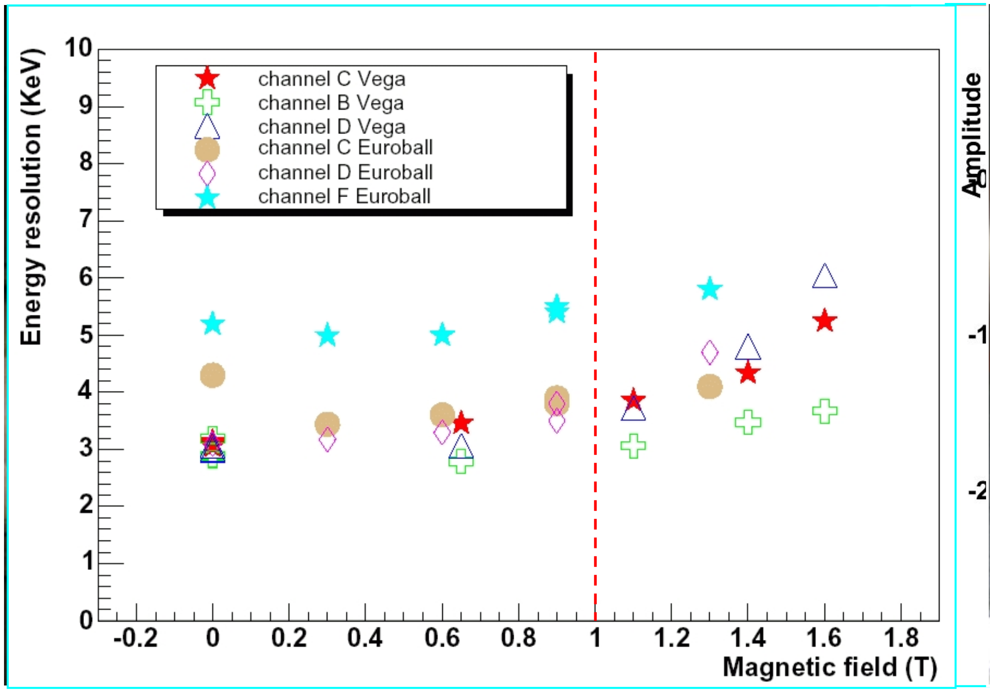




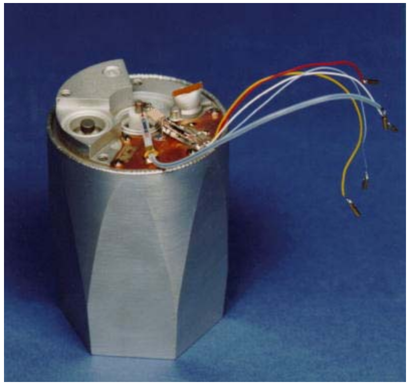
Experimental challenges

JRA6

Do HPGe crystals work in (strong) magnetic field?

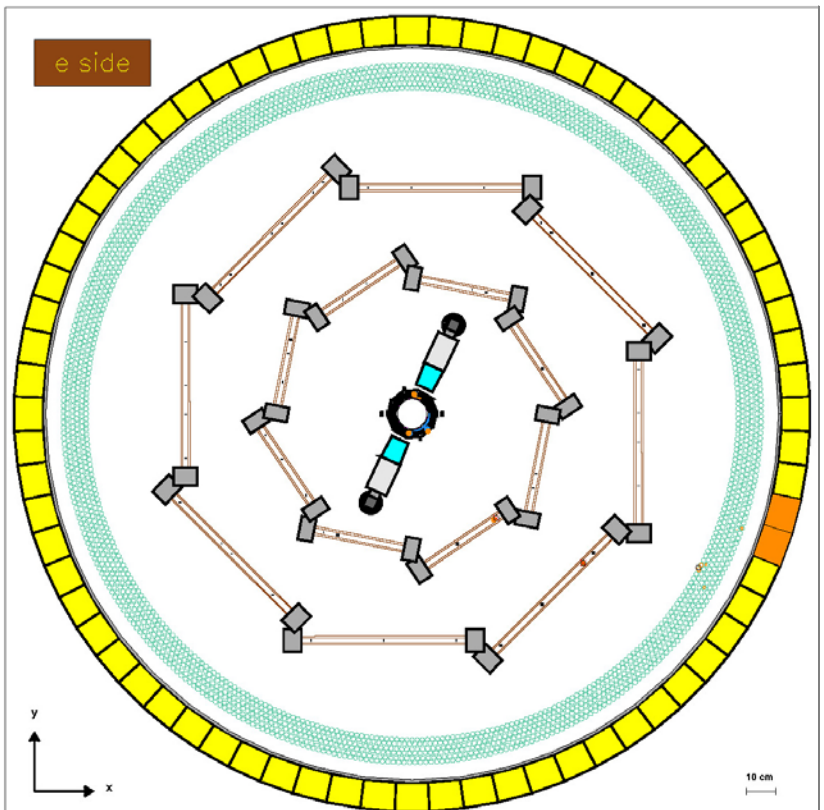


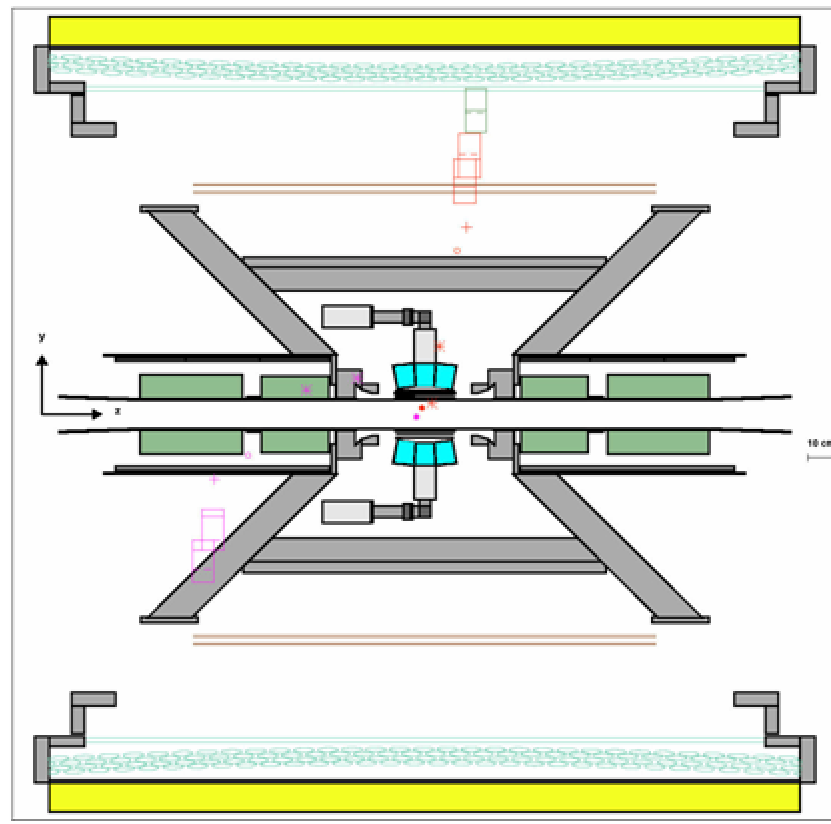
FINUDA2



X – COOLER II, AMETEK, ORTEC

Geometrical acceptance reduced to 82%





Interested community

HadronPhysics I3

Study of Strongly Interacting Matter

JRA6

? → Hyper Gamma

Strategy

Total synergy with the I3HP JRA6 project

- study of HPGe crystal performance in strong magnetic field

Close collaboration with TORTOLISO experiment, approved by INFN CSN 5

- Cagliari-Torino Collaboration
- production of LYSO crystals by an Italian firm

Contacts with INFN Groups, with solid experience on HPGe

- exploitation of previous INFN investment

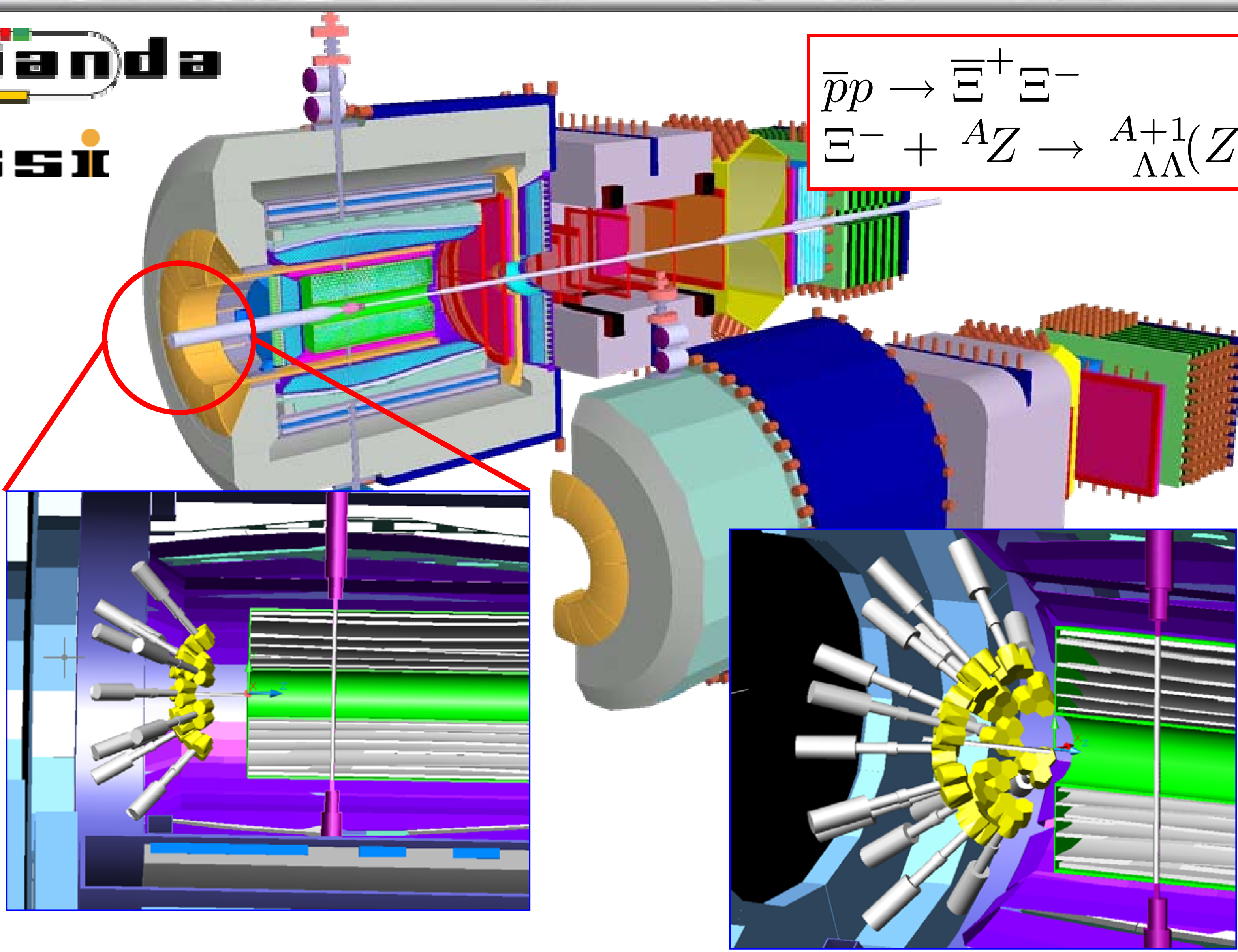
PRIN dedicated to an operative test of final HPGe configuration in magnetic field

- last step before to go

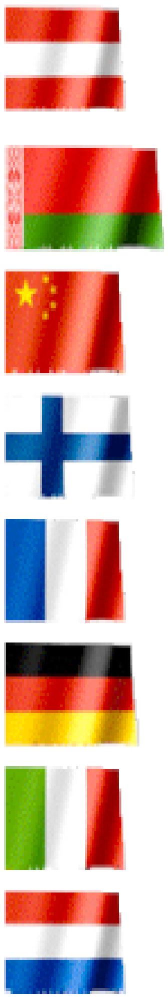
FAIR Facility for Antiproton and Ion Research

$$\bar{p}p \longrightarrow \overline{\Xi}^{+}\,\Xi^{-}$$

$$\Xi^{-} + {}^{A}Z \longrightarrow {}^{A+1}_{\Lambda\Lambda}(Z-1)$$



PANDA Collaboration



Universität Basel, IHEP Beijing, Ruhr-Universität Bochum, Universität Bonn, Università di Brescia + INFN, Università di Catania, University of Silesia, University Cracow, GSI Darmstadt, TU Dresden, JINR Dubna, JINR Dubna, University Edinburgh, Universität Erlangen, Northwestern University, INFN Sezione di Ferrara, Universität Frankfurt, LNF-INFN Frascati, INFN Sezione di Genova, Università di Genova, Universität Gießen, University of Glasgow, KVI Groningen, Institute of Physics Helsinki, FZ Jülich - IKP I, FZ Jülich - IKP II, IMP Lanzhou, Universität Mainz, Università di Milano, TU München, Universität Münster, BINP Novosibirsk, IPN Orsay, Università di Pavia, PNPI Gatchina St. Petersburg, IHEP Protvino, Stockholm University , Università di Torino, Università de Piemonte, Università di Trieste + INFN, Universität Tübingen, Uppsala Universitet, TSL Uppsala, Universidad de Valencia, Stefan Meyer Institut für subatomare Physik, Vienna, SINS Warschau

15 countries – 47 institutes – 370 scientists

Strategy

possible Joint Research Project
in the Seventh Framework Programme (FP7)

- further study of HPGe crystal performance with the electromechanical cooling system
- design of a 3-crystal cluster, equipped with new readout electronics

strict collaboration with INFN Groups, with solid experience on HPGe

- exploitation of previous INFN investment

PRIN dedicated to an operative test of chosen HPGe configuration in magnetic field

- last step before to go

Summary

- strangeness nuclear physics still has a great discovery potential

- spectroscopy of hypernuclei offers a couple of interesting opportunity to successfully employ the existing HPGe detectors:
  - FINUDA at DAΦNE (LNF/INFN)
  - PANDA at HESR (FAIR/GSI)

- A. Bracco, F. Camera and S. Lenzi valuable support is warmly acknowledged