# *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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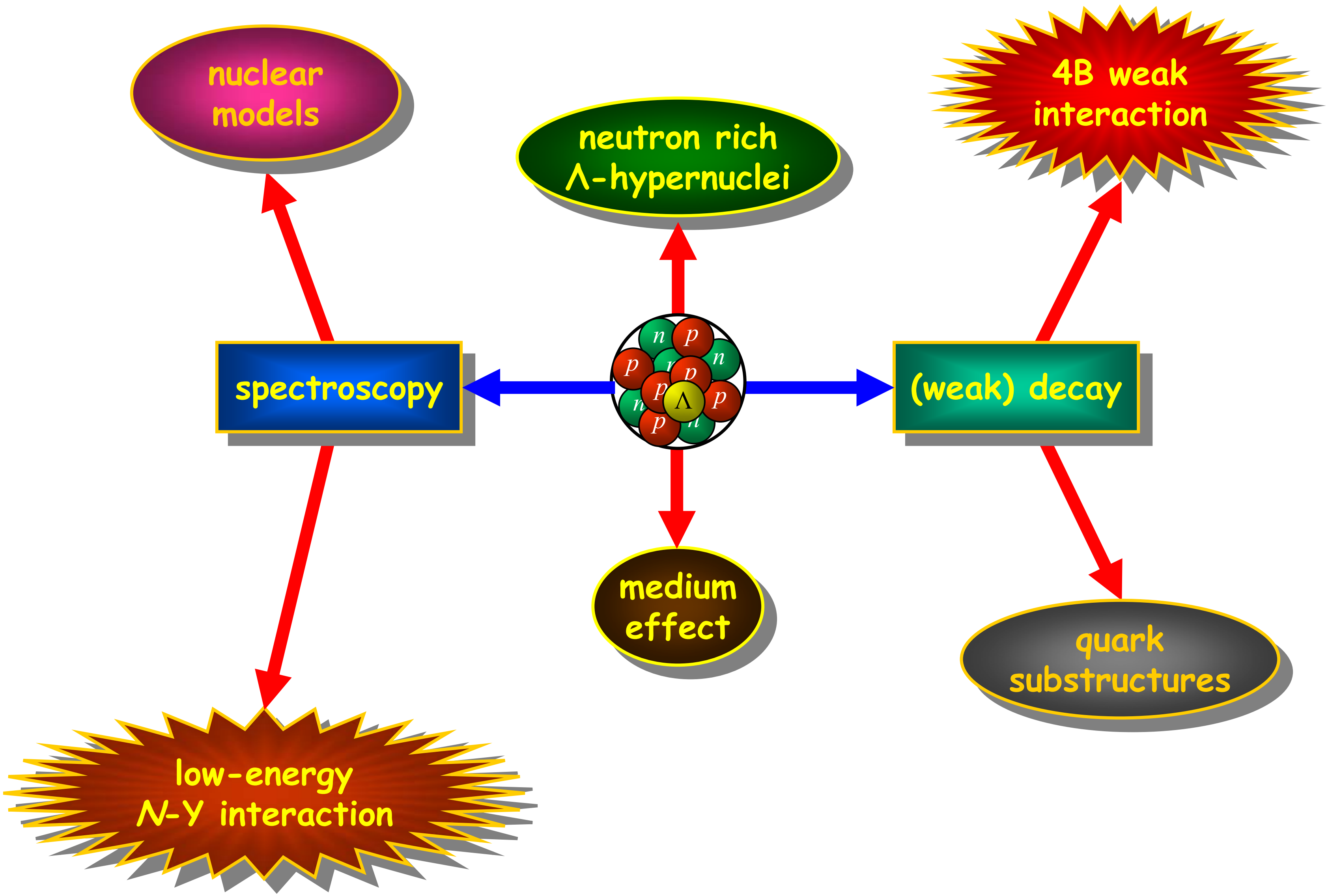
# Outline

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

# Physics output (S=-1)



# Open questions

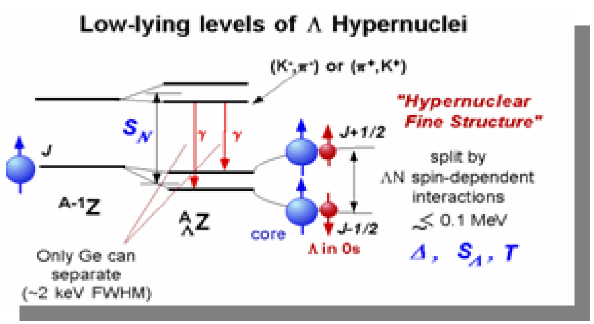
☛ (low-energy) YN interaction

- 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

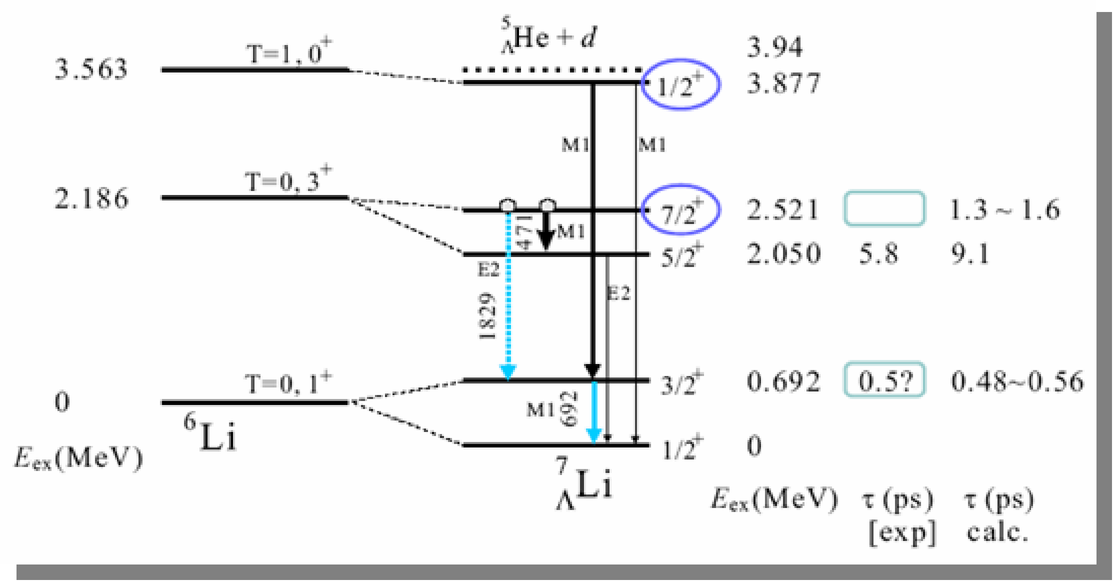
$$V_{\Lambda-N}(r) = V_0(r) + \underbrace{V_\sigma(r)\vec{s}_N\cdot\vec{s}_\Lambda}_{\Delta} + \underbrace{V_\Lambda(r)\vec{l}_{N\Lambda}\cdot\vec{s}_\Lambda}_{S_\Lambda} + \underbrace{V_N(r)\vec{l}_{N\Lambda}\cdot\vec{s}_N}_{S_N} + \underbrace{V_T(r)[3(\vec{\sigma}_N\cdot\vec{r})(\vec{\sigma}_\Lambda\cdot\vec{r}-\vec{\sigma}_N\cdot\vec{\sigma}_\Lambda)]}_{T}$$




Each of the 4 terms (Δ, $S_\Lambda$, $S_N$, 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: $(K^-,\pi^-)\,^7_\Lambda Li$

$\Delta = 0.43$

$S_\Lambda = -0.01$

$S_N = -0.40$

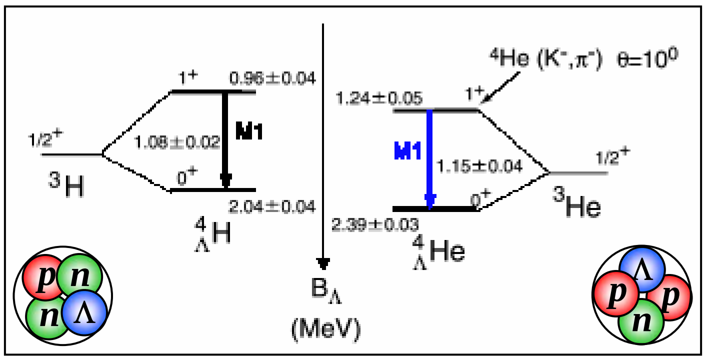
$T = 0.03$

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

# Charge symmetry breaking

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

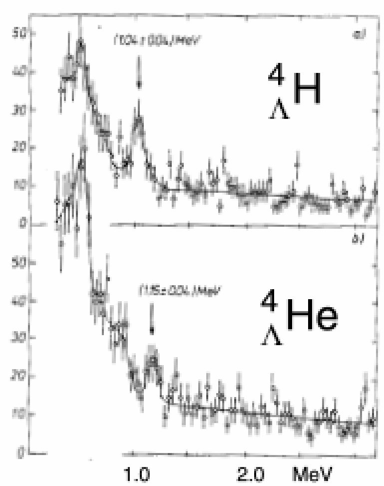
*if the charge symmetry holds exactly*




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

$\Lambda p$ more attractive than $\Lambda n$

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




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

# Open questions

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

- 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 $\Lambda$

# Impurity nuclear physics

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

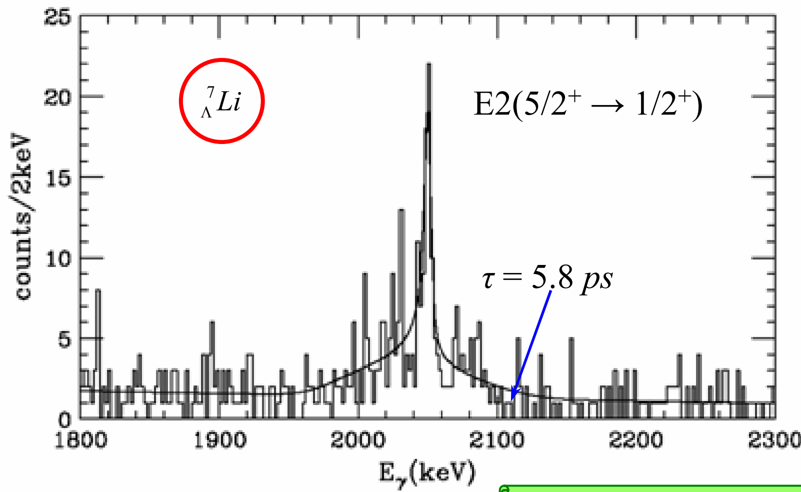
The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure

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

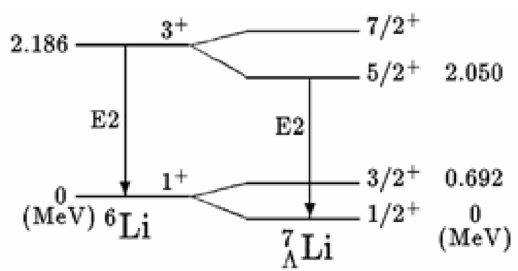
study of hypernucleus level schemes and B(E2) → Doppler-shift attenuation method

# 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) ∝ r⁴ ⇒ shrinkage of ⁶Li core by ~ 20%**

# Open questions

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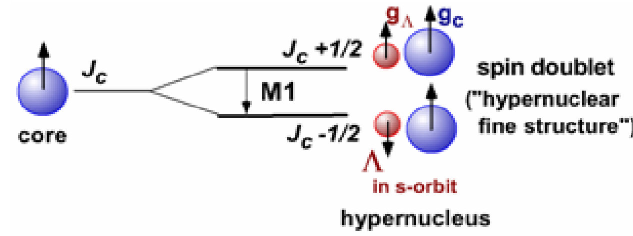
- Impurity nuclear physics
  - measurement of transition probability B(E2)
    - → information on the size and deformation of hypernuclei
    - → measurement of nucleus core shrinking → glue role of Λ
- Properties of hyperons in nuclear matter (medium effect)
  - measurement of transition probability B(M1)
    - → g-factor value for Λ in nuclear matter

# Medium effect

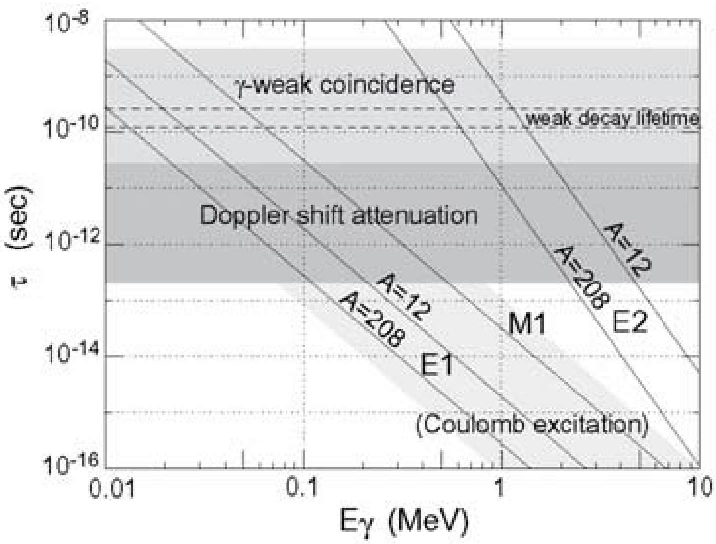
If the mass or the size of a hyperon is modified in a nucleus, its magnetic moment may be changed



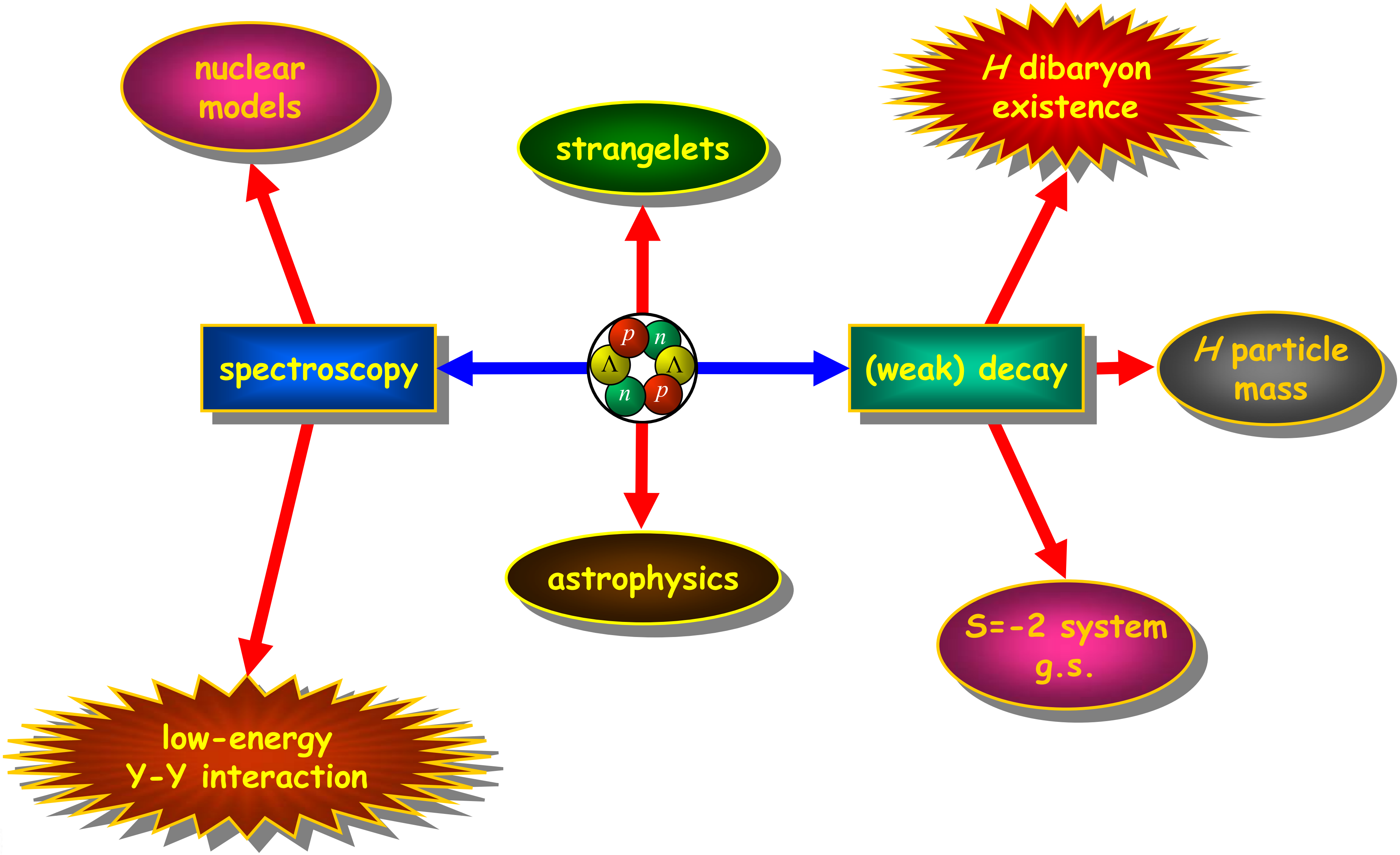

$$B(M1) \propto \left| \left\langle \phi_{lo} \middle| \mu^z \middle| \phi_{up} \right\rangle \right|^2 = \left| \left\langle \phi_{lo} \middle| g_N J_N^z + g_\Lambda J_\Lambda^z \middle| \phi_{up} \right\rangle \right|^2$$
$$\propto ( g_N - g_\Lambda )^2$$

B(M1) can be derived from excited states lifetimes

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



# Physics output (S=-2)

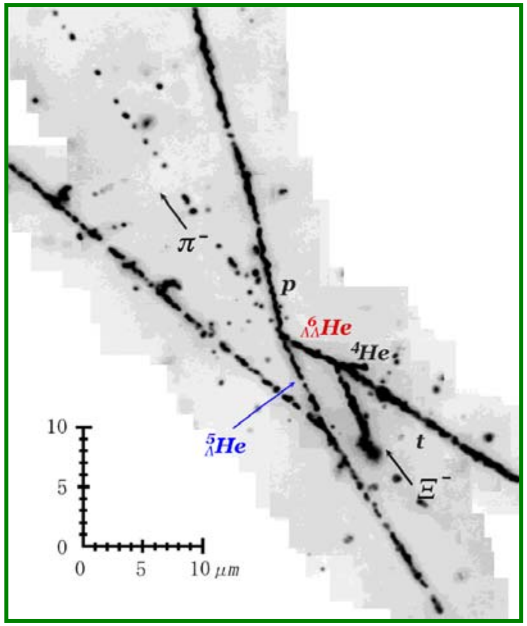


# Observed ΛΛ-hypernuclei

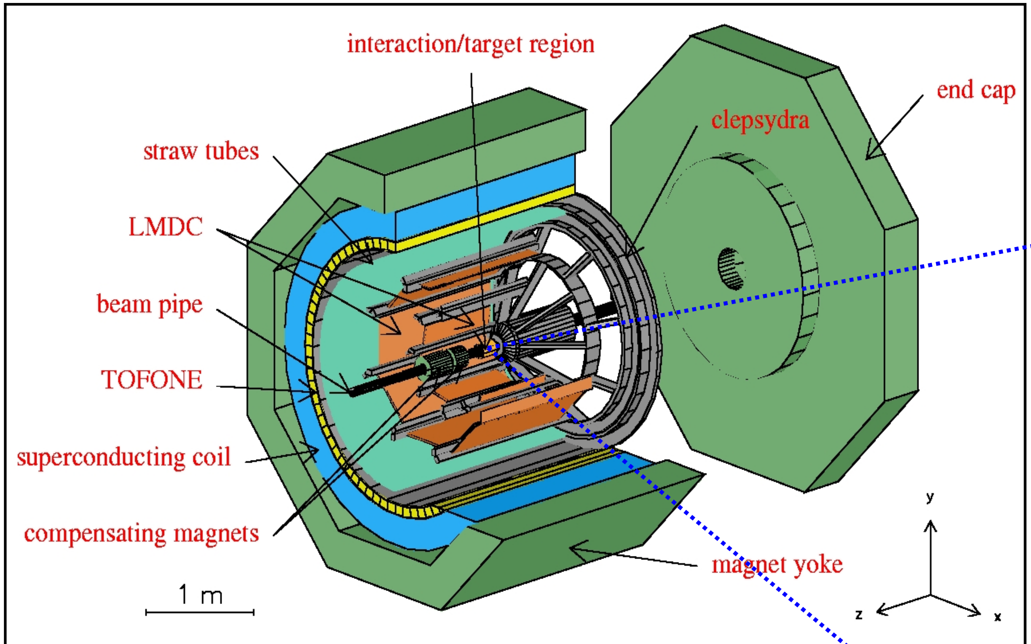
- 1963: Danysz et al. $^{10}_{\Lambda\Lambda}Be$ (emulsion)
- 1966: Prowse $^{6}_{\Lambda\Lambda}He$ (emulsion, Dalitz criticises the interpretation)
- 1991: KEK-E176 $^{13}_{\Lambda\Lambda}B$ (or $^{10}_{\Lambda\Lambda}Be$, emulsion counter hybrid experiment)
- 2001: BNL-E906 $^{4}_{\Lambda\Lambda}H$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

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

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

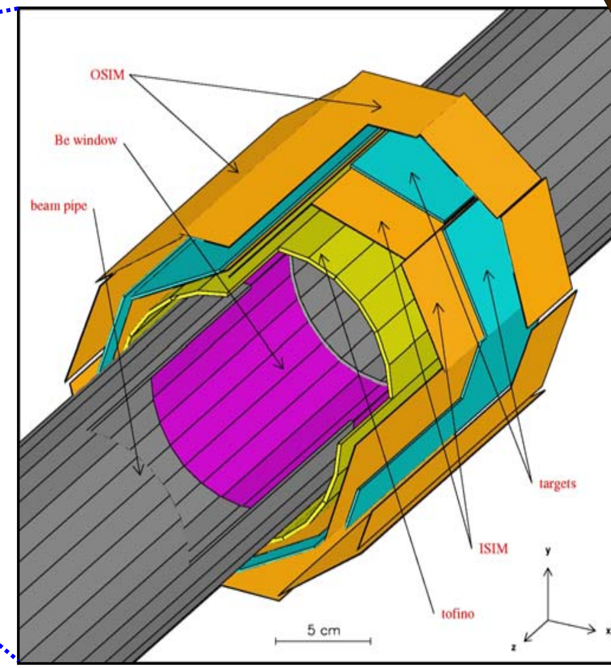


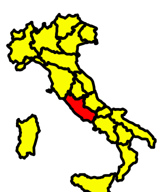
# FINUDA @ DAΦNE

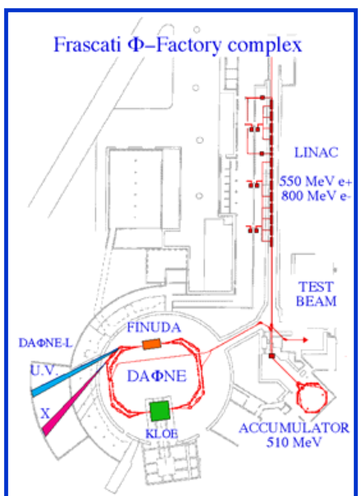



$$e^- + e^+ \to \phi \to K^- K^+$$

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



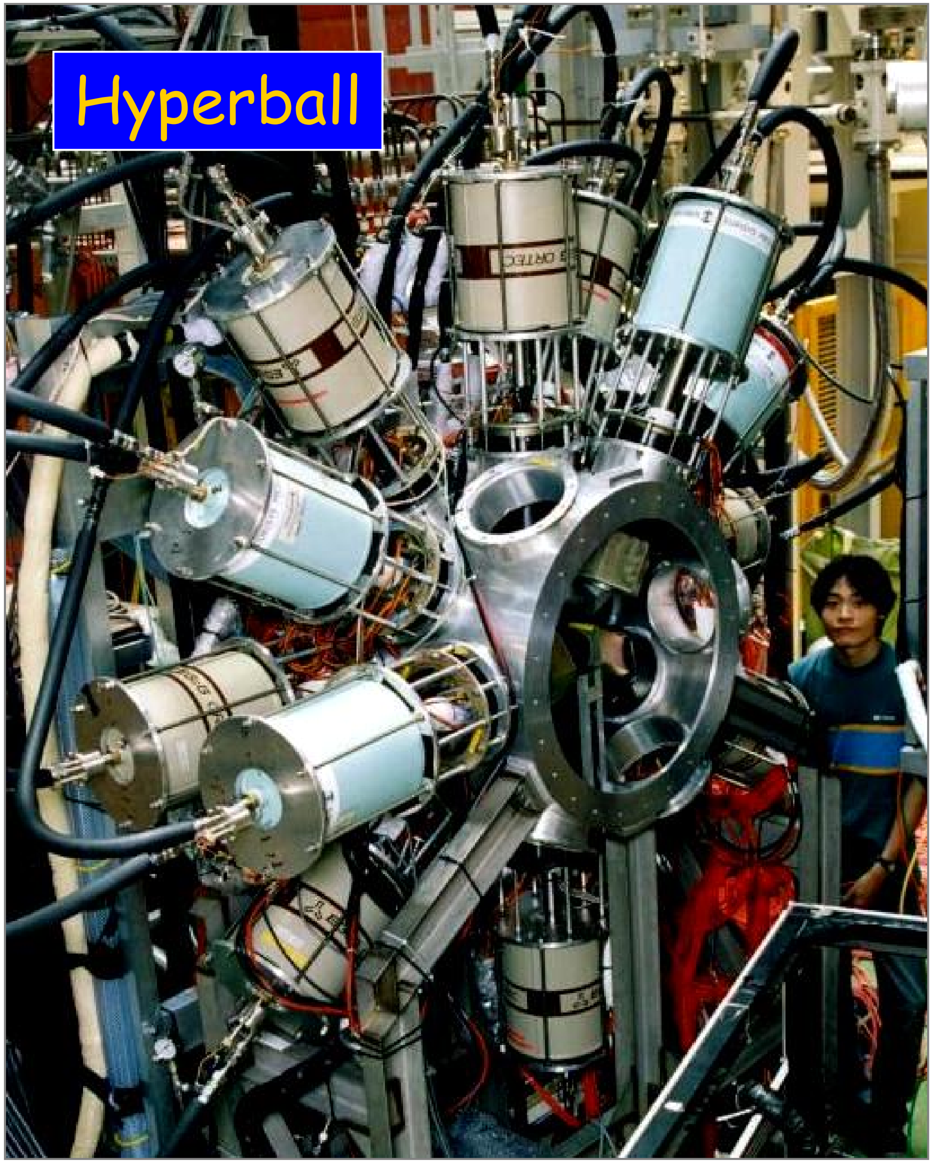



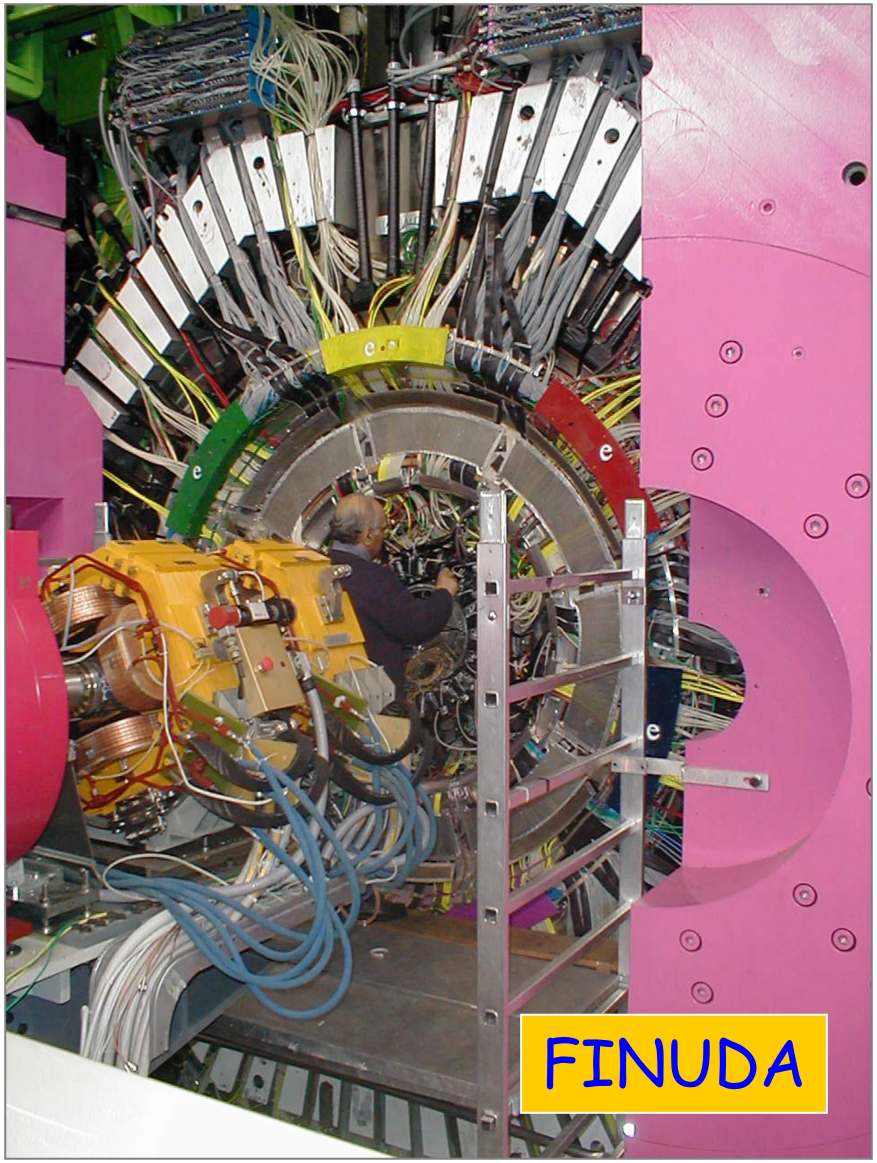



| | |
|---|---|
| energy | 510 MeV |
| luminosity | 5 $10^{32}$ $cm^{-2}$ $s^{-1}$ |
| $\sigma_x$ (rms) | 2.11 mm |
| $\sigma_y$ (rms) | 0.021 mm |
| $\sigma_z$ (rms) | 35 mm |
| bunch length | 30 mm |
| crossing angle | 12.5 mrad |
| frequency (max) | 368.25 MHz |
| bunch/ring | up to 120 |
| part./bunch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

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

# Is the integration possible?



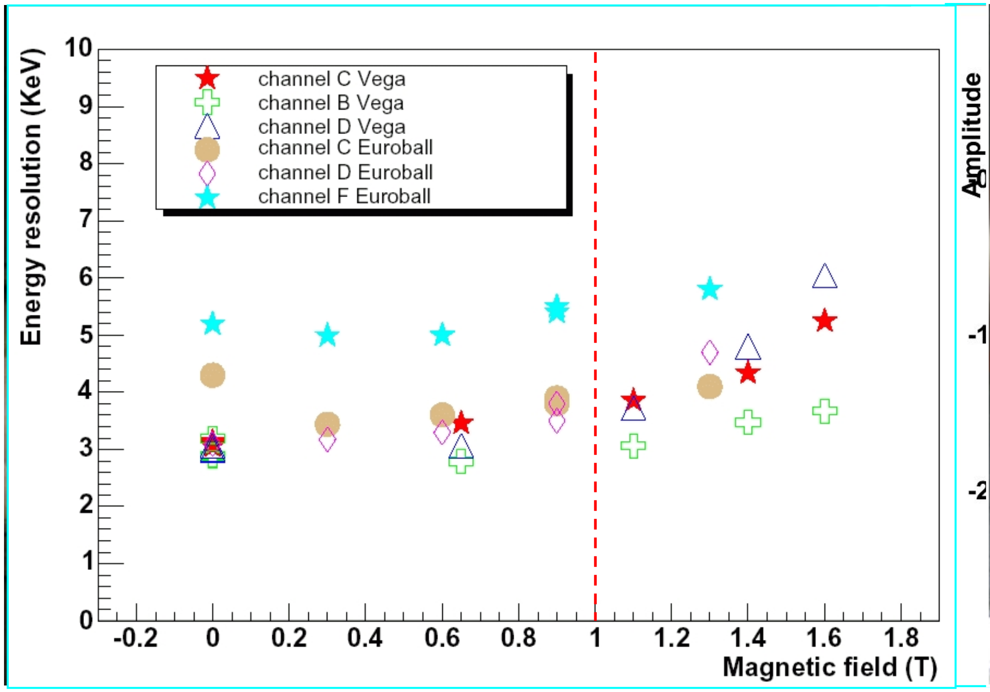



# Experimental challenges

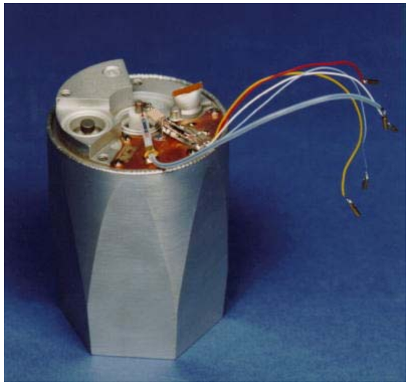
HadronPhysics I3 — Study of Strongly Interacting Matter

JRA6

Do HPGe crystals work in (strong) magnetic field?

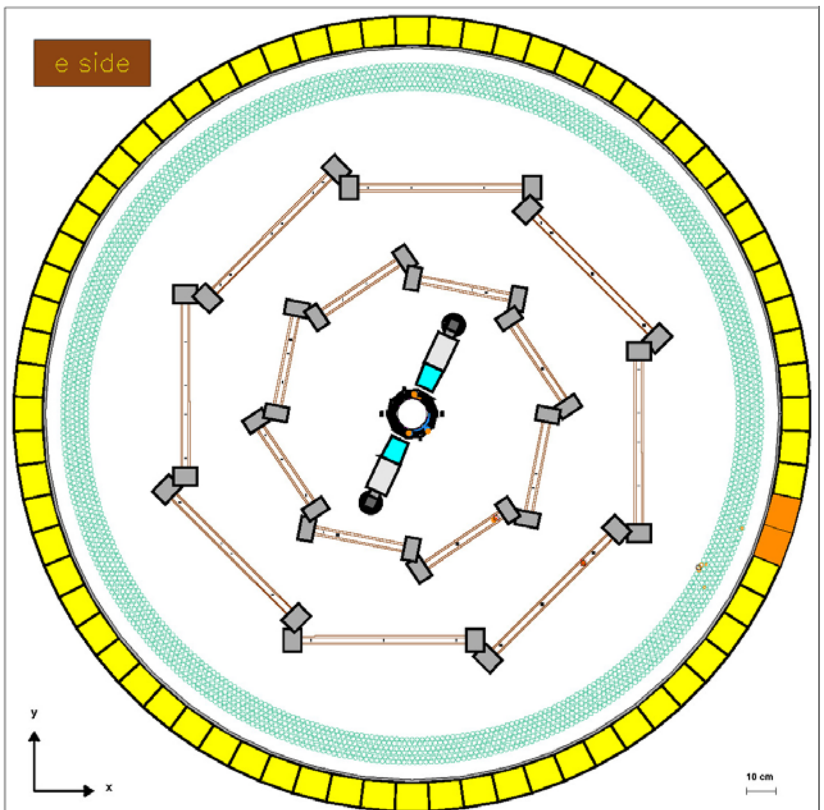


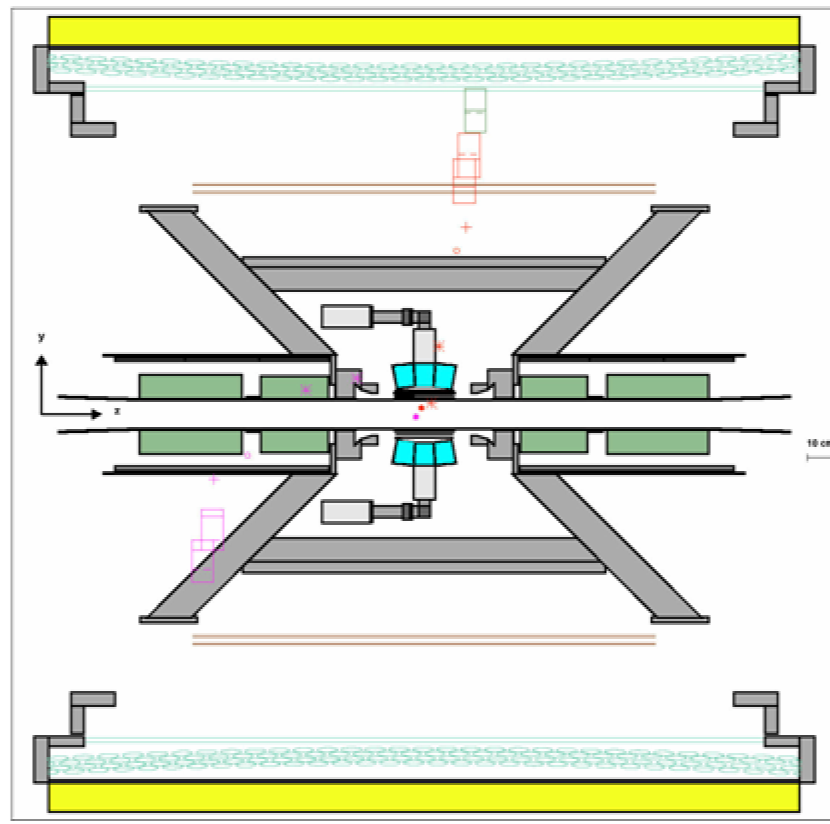

# FINUDA2



**X – COOLER II, AMETEK, ORTEC**


Geometrical acceptance reduced to 82%



# Interested community

FINUDA

HadronPhysics I3

Study of Strongly Interacting Matter

JRA6

INFN Istituto Nazionale di Fisica Nucleare

KEK

RIKEN

INFN Istituto Nazionale di Fisica Nucleare

Politecnico di Torino 1859 – 1906

GSI

Universität Mainz

Shahid Beheshti University Tehran-Iran Founded 1960

Universitet Stockholms

Vetenskap och Konst

Kungl Tekniska Högskolan

Y

? → 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

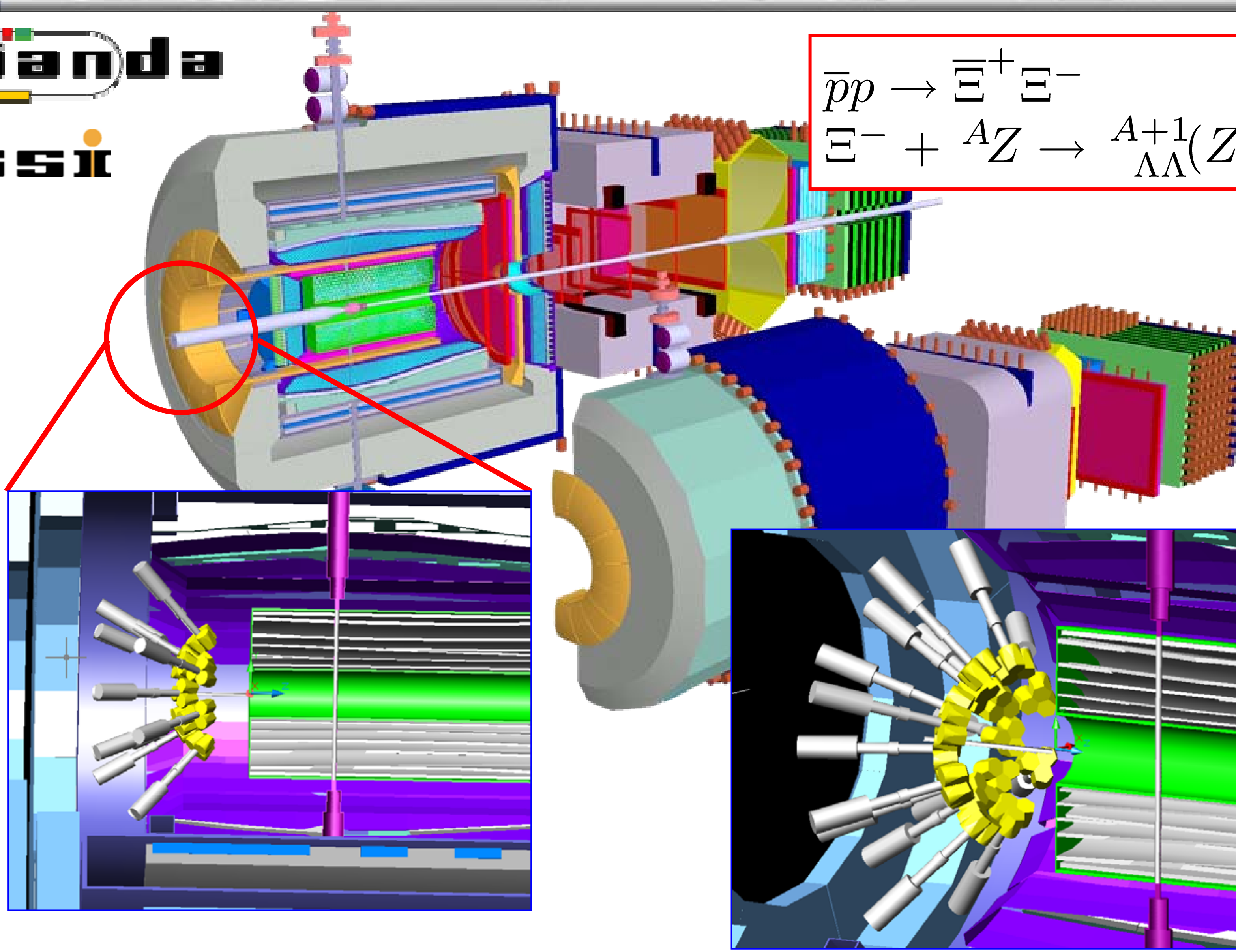
PRIN dedicated to an operative test of final HPGe configuration in magnetic field

- last step before to go

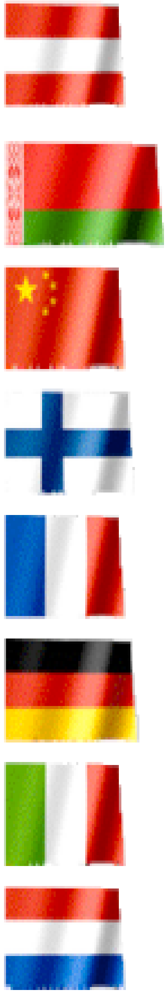
# FAIR Facility for Antiproton and Ion Research

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

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



# 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