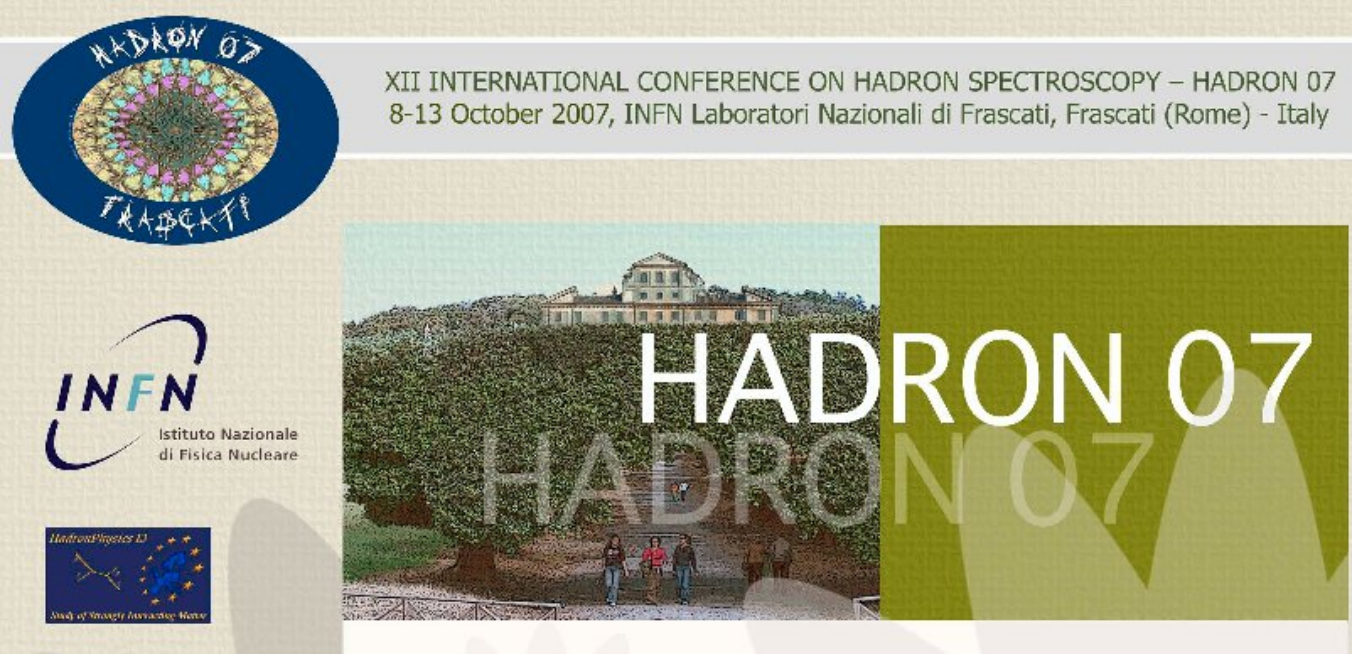


Future prospects on high resolution γ - ray spectroscopy at Frascati

Elena Botta

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

Outline

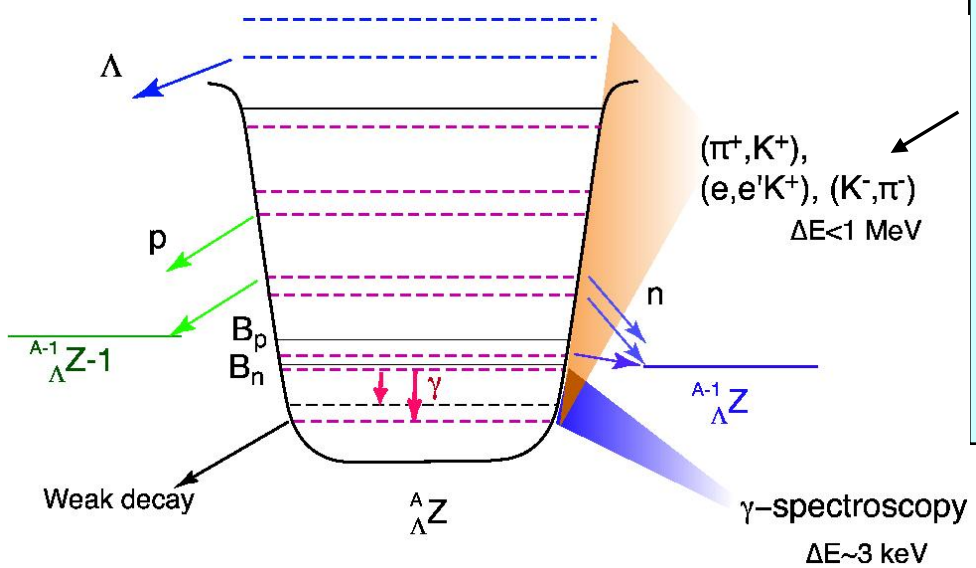
- Discovery potential of the strangeness nuclear physics
  - recent experimental results
  - unexpected effects
- Need of sub-MeV resolution apparatuses
  - γ-ray spectroscopy
- Ideas for FINUDA spectrometer upgrade at DAΦNE/DAΦNE2

Hypernuclear spectroscopy

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

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

$${}^{A}_{\Lambda}Z^* \rightarrow {}^{A}_{\Lambda}Z^{*\prime} + \gamma \quad \text{low lying states}$$



reaction spectroscopy (MM):

- level structure in Λ bound region
- excited states between N and Λ emission threshold
- information on Λ-hyp. structure through M_{hyp}, σ, angular distributions, …

γ-spectroscopy:

- low lying states only
- ultra-high resolution
- spin-dependent ΛN interaction

Highly complementary tools !!

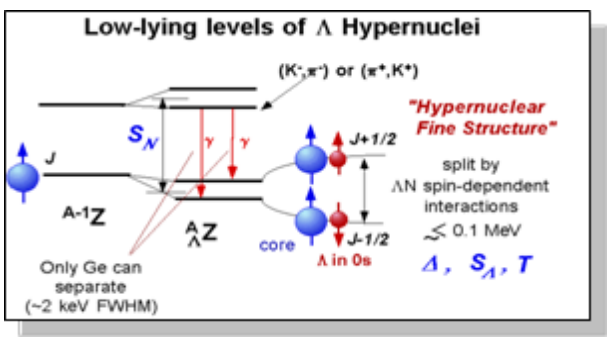
Open questions

- (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

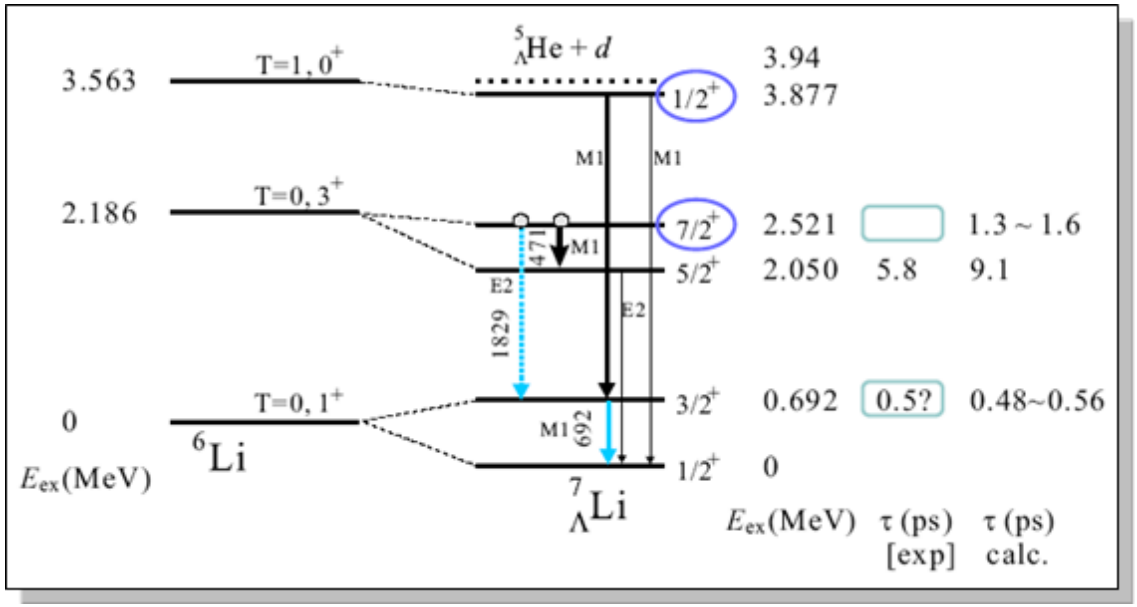
$$V_{\Lambda-N}(r) = \underbrace{V_0(r)}_{} + \overbrace{V_\sigma(r)\vec{s}_N\cdot\vec{s}_\Lambda}^{\Delta} + \overbrace{V_\Lambda(r)\vec{l}_{N\Lambda}\cdot\vec{s}_\Lambda}^{S_\Lambda} + \overbrace{V_N(r)\vec{l}_{N\Lambda}\cdot\vec{s}_N}^{S_N}$$
$$+ \underbrace{V_T(r)[3(\vec{\sigma}_N\cdot\vec{r})(\vec{\sigma}_\Lambda\cdot\vec{r}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



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

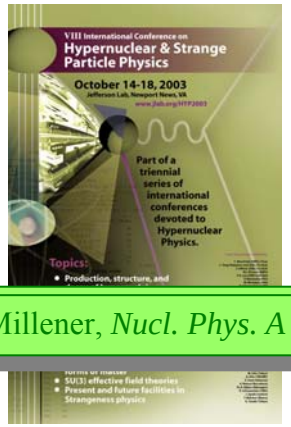
KEK E419: $(\pi^+,K^+)\,^{7}_{\Lambda}Li$

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

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

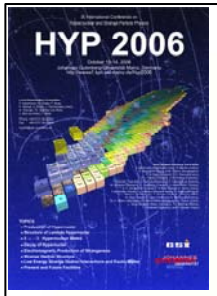
Δ = 0.43 MeV
S_Λ = -0.01 MeV
S_N = -0.40 MeV
T = 0.03 MeV

p-shell hypernuclei

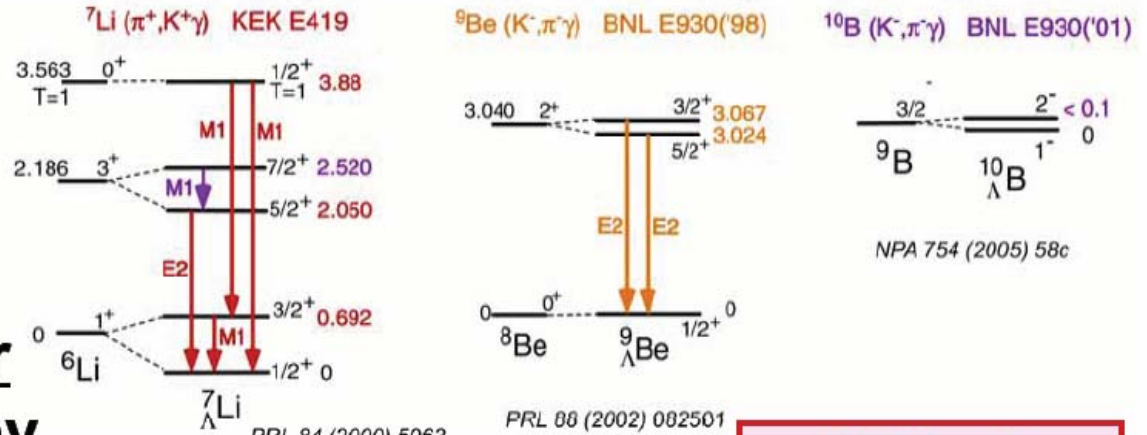


D.J. Millener, *Nucl. Phys. A* 754 (2005) 48c

Where do we stand?



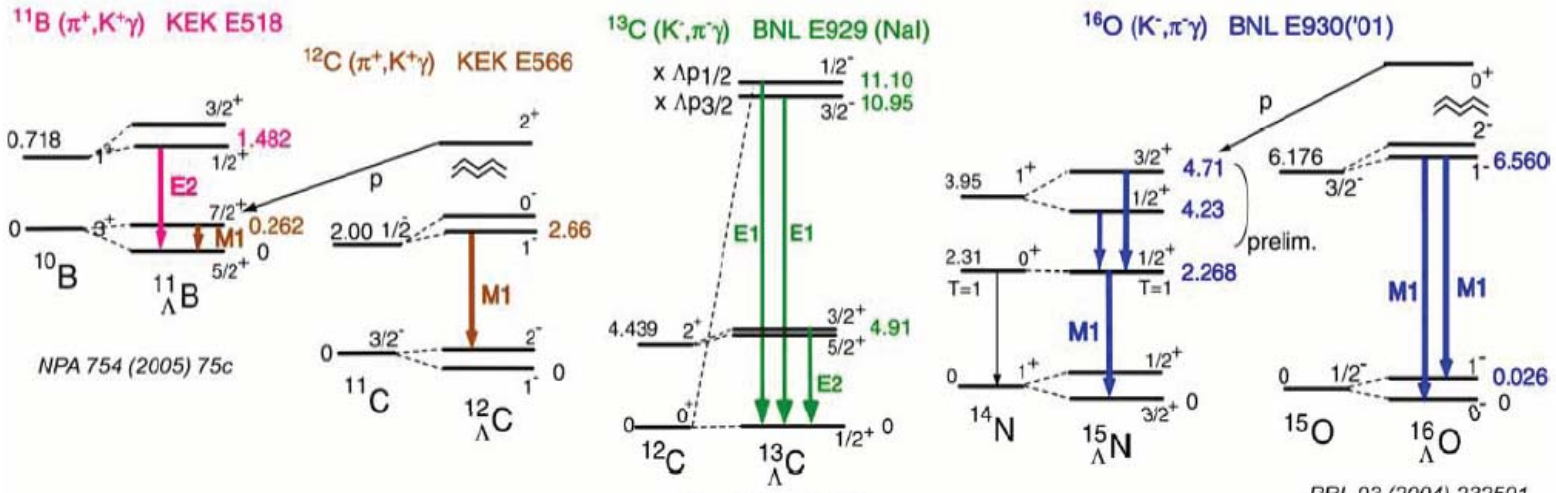
Status of hypernuclear γ spectroscopy



PRL 84 (2000) 5963
PRL 86 (2001) 1982
PLB 579 (2004) 258
PRC 73 (2006) 012501

PRL 88 (2002) 082501
NPA 754 (2005) 58c

=> "Table of Hyper-Isotopes"



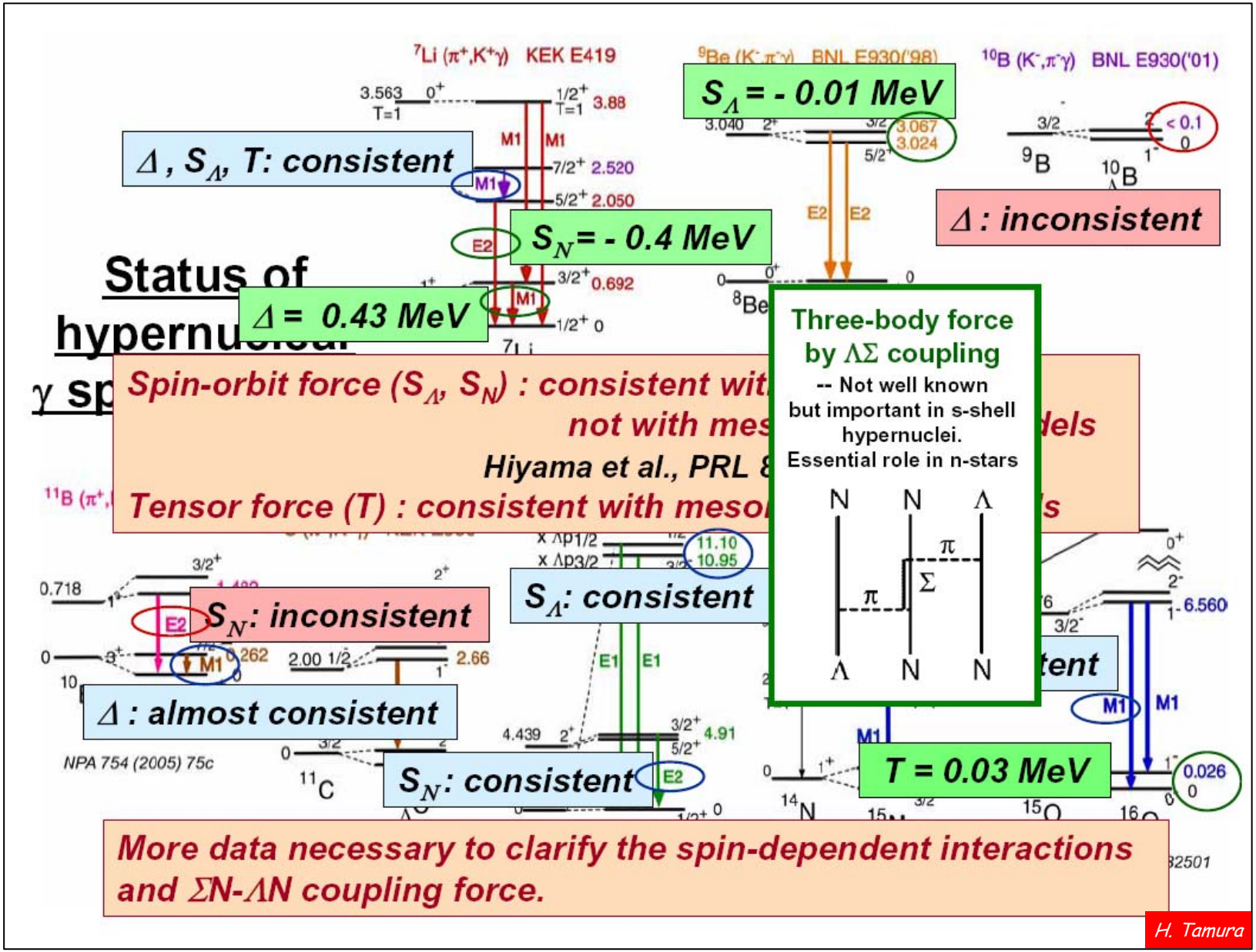
NPA 754 (2005) 75c

PRL 86 (2001) 4255
PRC 65 (2002) 034607

PRL 93 (2004) 232501

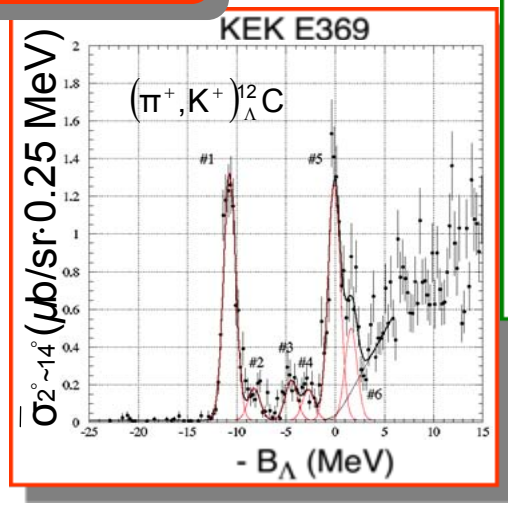
H. Tamura

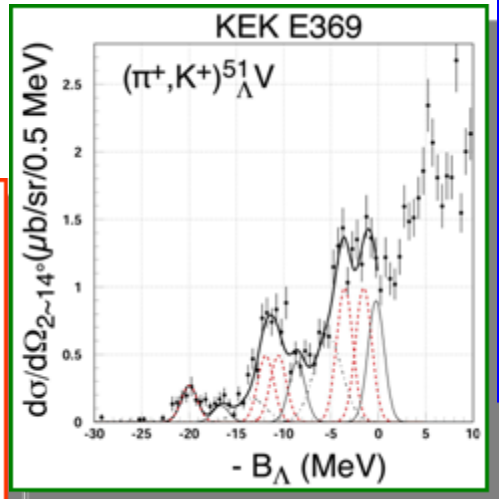
Where do we stand?



MM spectroscopy

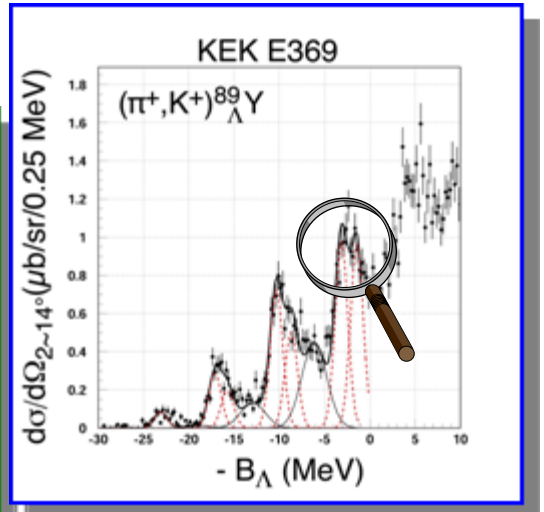
ΔE ~ 1.45 MeV FWHM



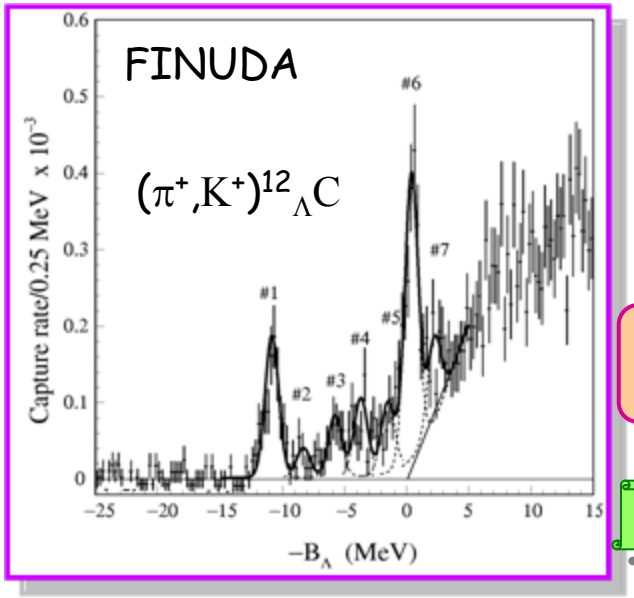


ΔE ~ 1.95 MeV FWHM

T. Nagae, *Nucl. Phys.* A691 (2001) 76



ΔE ~ 1.65 MeV FWHM



ΔE ~ 1.29 MeV FWHM

M. Agnello *et al.*, *Phys. Lett.* B622 (2005) 35

f-orbit splitting into two peaks observed?

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
- 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

Open questions

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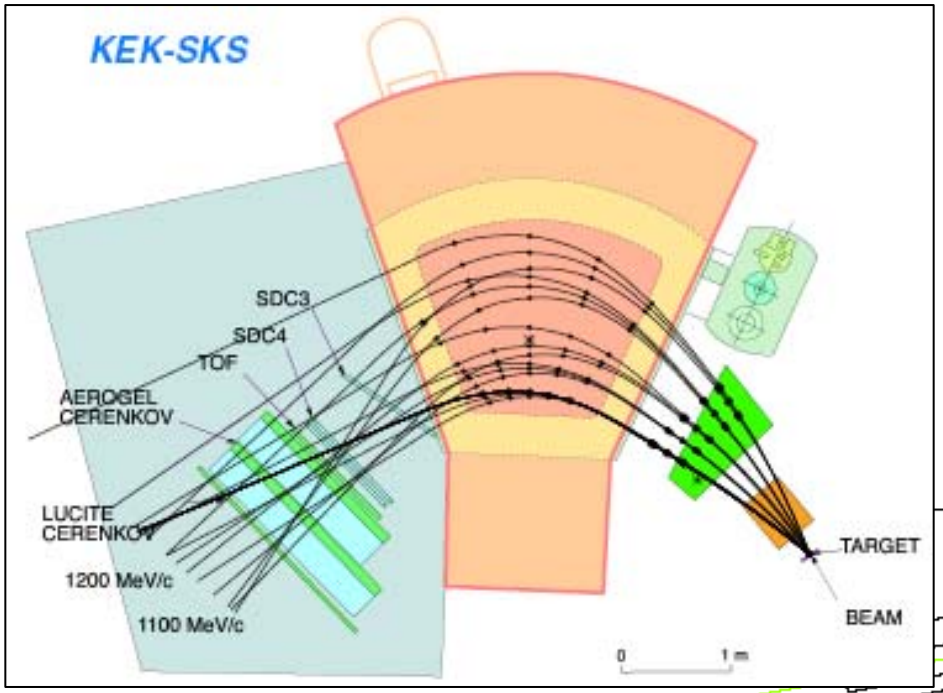
- Impurity nuclear physics
  - measurement of transition probability B(E2)
    → information on the size and deformation of hypernuclei
    → measurement of nucleus core shrinking → glue role of Λ
- Properties of hyperons in nuclear matter (medium effect)
  - measurement of transition probability B(M1)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

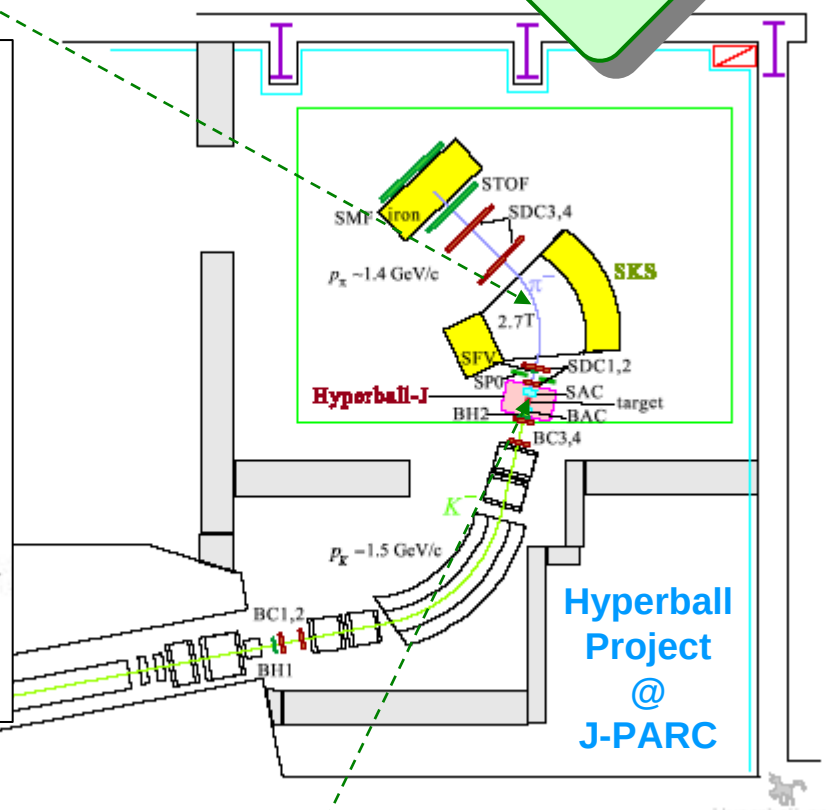
Parallel vs. serial

"Serial" approach: KEK (& AGS)

one-arm spectrometer → small acceptance

- ΔE ~ 4 MeV (FWHM)
- ΔΩ ~ 110 msr





Since 1998
12 GeV KEK PS k6 line
BNL AGS D6 line

HPGe array → large acceptance

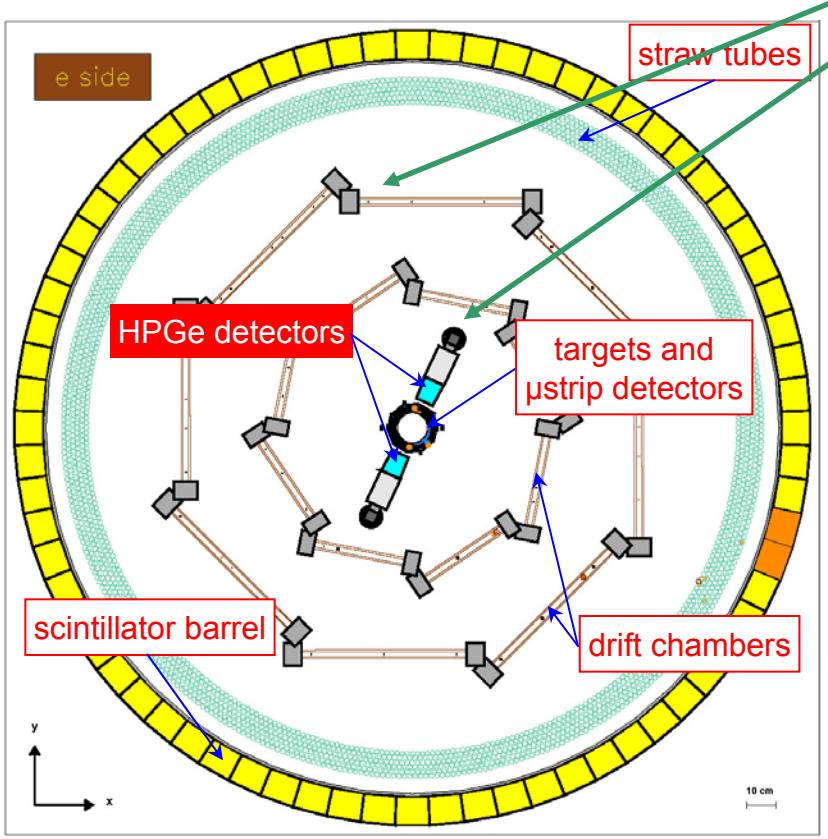
- ΔE ~ 1 ÷ 2 keV (FWHM)
- ε ~ 7% (@ 1 MeV)

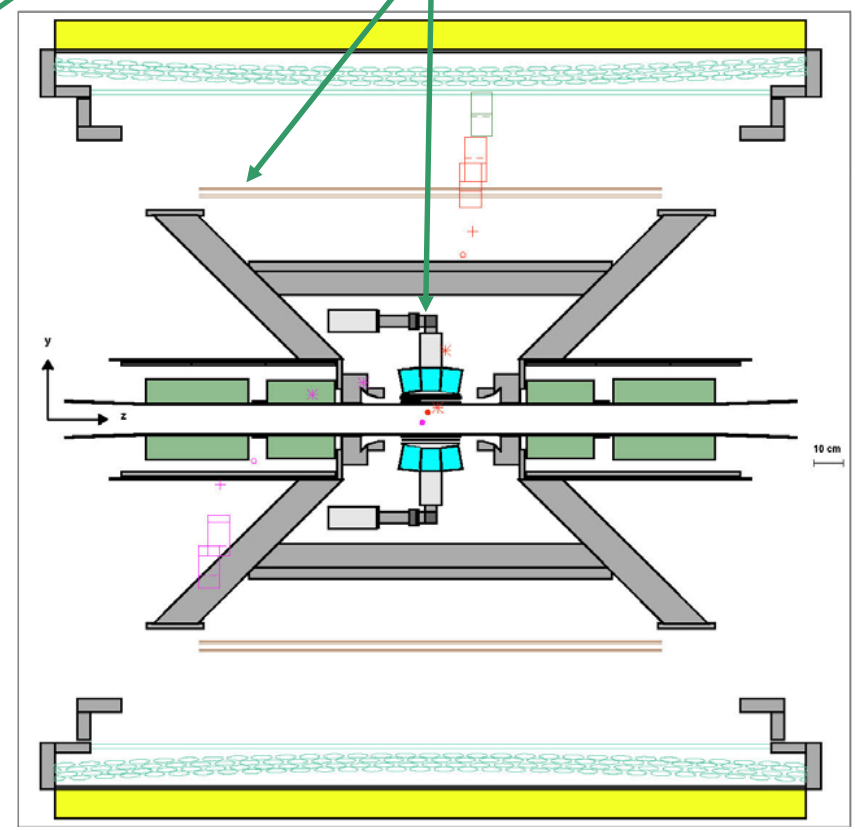
Parallel vs. serial

- non-focusing spectrometer → large acceptance
- thin targets & high transparency → high energy resolution
- coincidence measurement with large acceptance → decay mode study

- ΔE ~ 1.3 MeV (FWHM)
- $\Delta\Omega$ ~ 2π sr

"Parallel" approach: FINUDA

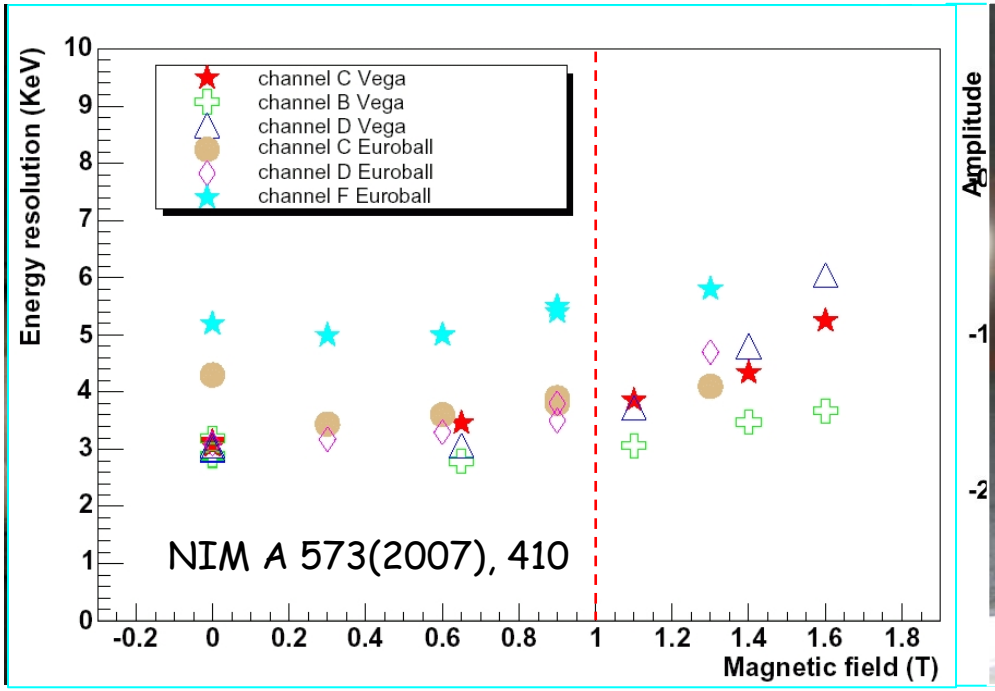


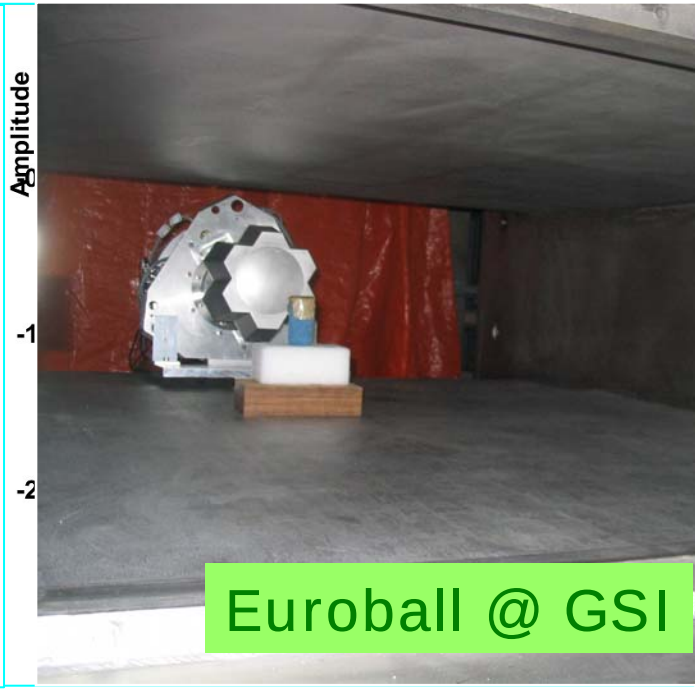


Experimental challenges

JRA6

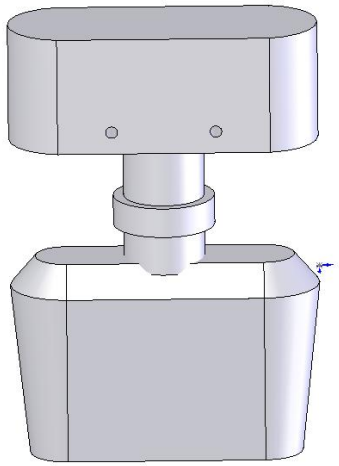
- Do HPGe crystals work in (strong) magnetic field?

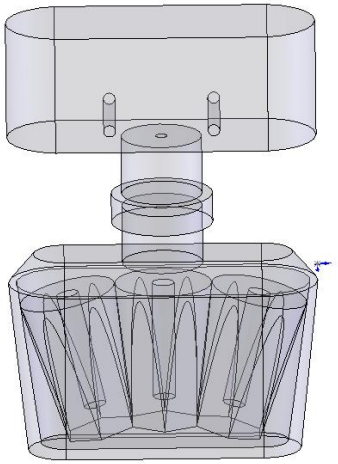




The hyper-triple cluster concept design

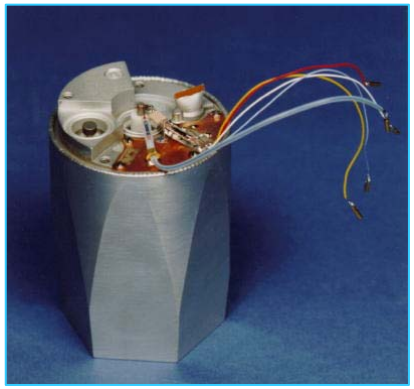
X – COOLER II, AMETEC, ORTEC



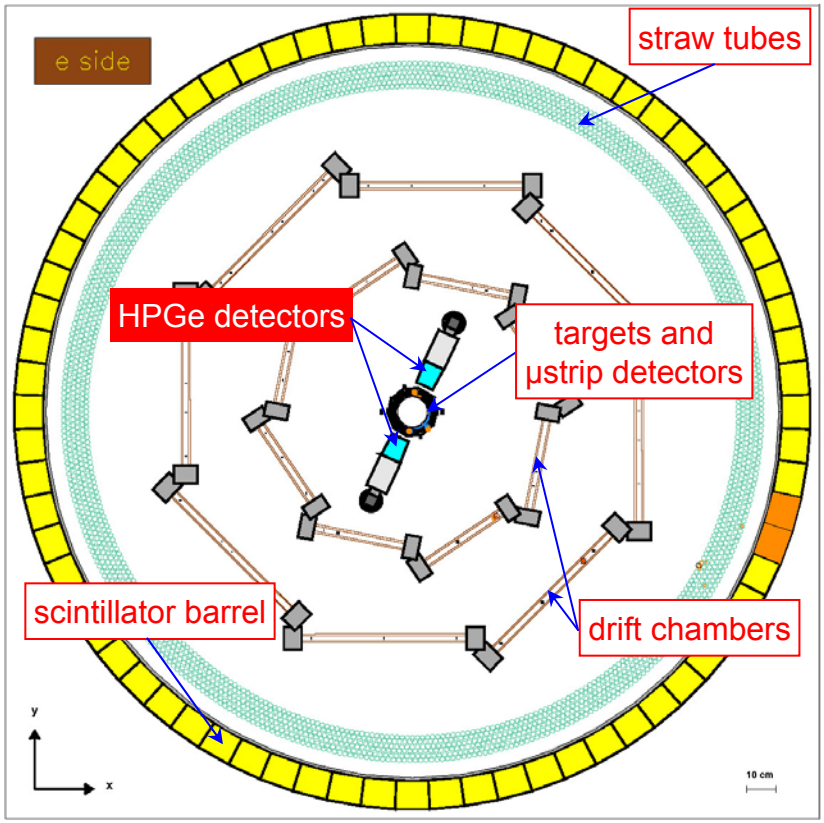


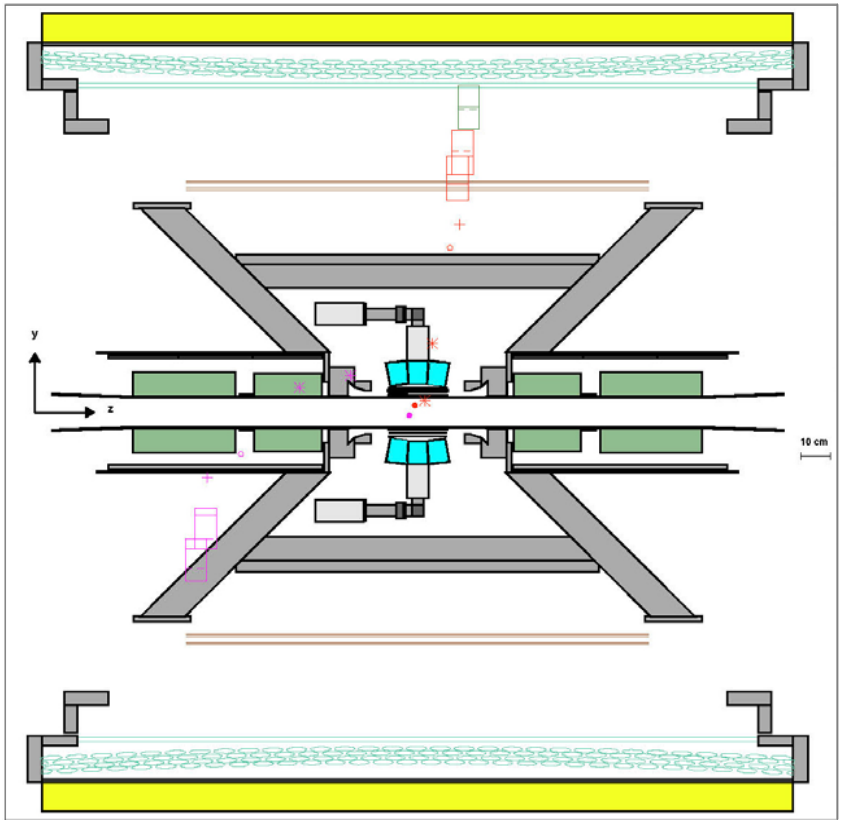
I. Kojouharov, T. Engert

An exacting integration



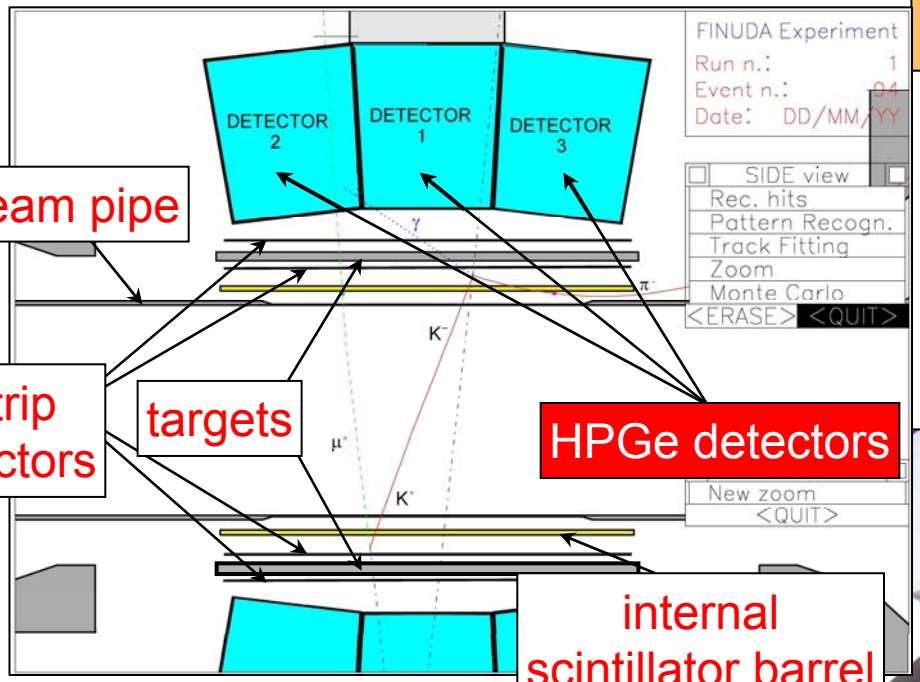
Geometrical acceptance reduced to 82%





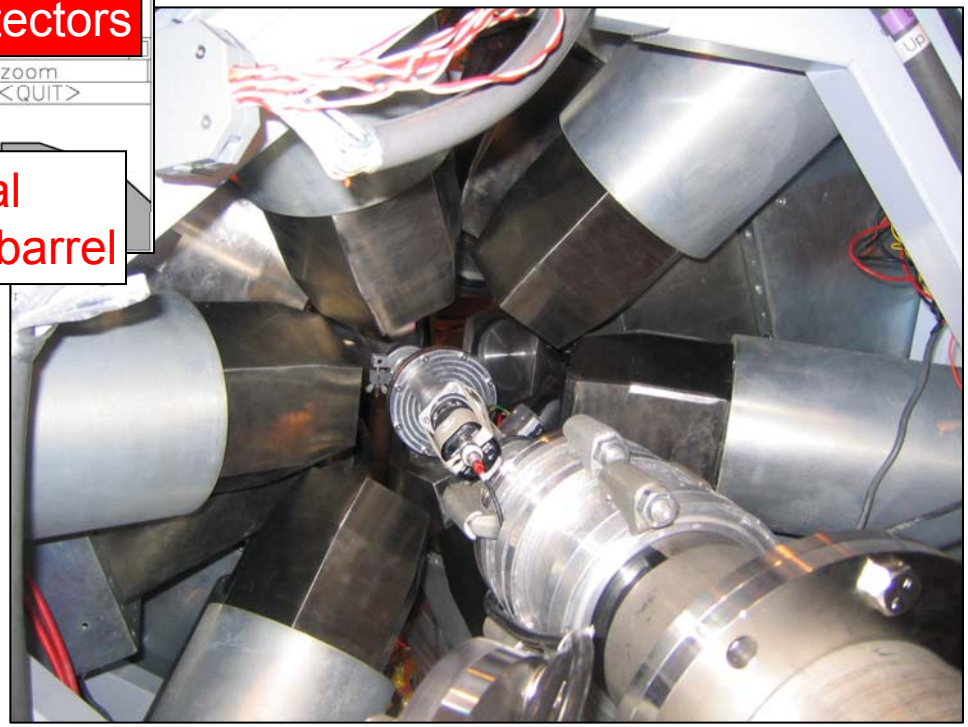
e.m. vs. hadronic machines

two 3 HPGe crystals systems
12% 4π sr



FINUDA2 project @ LNF

Hyperball2 @ Tohoku Cyclotron



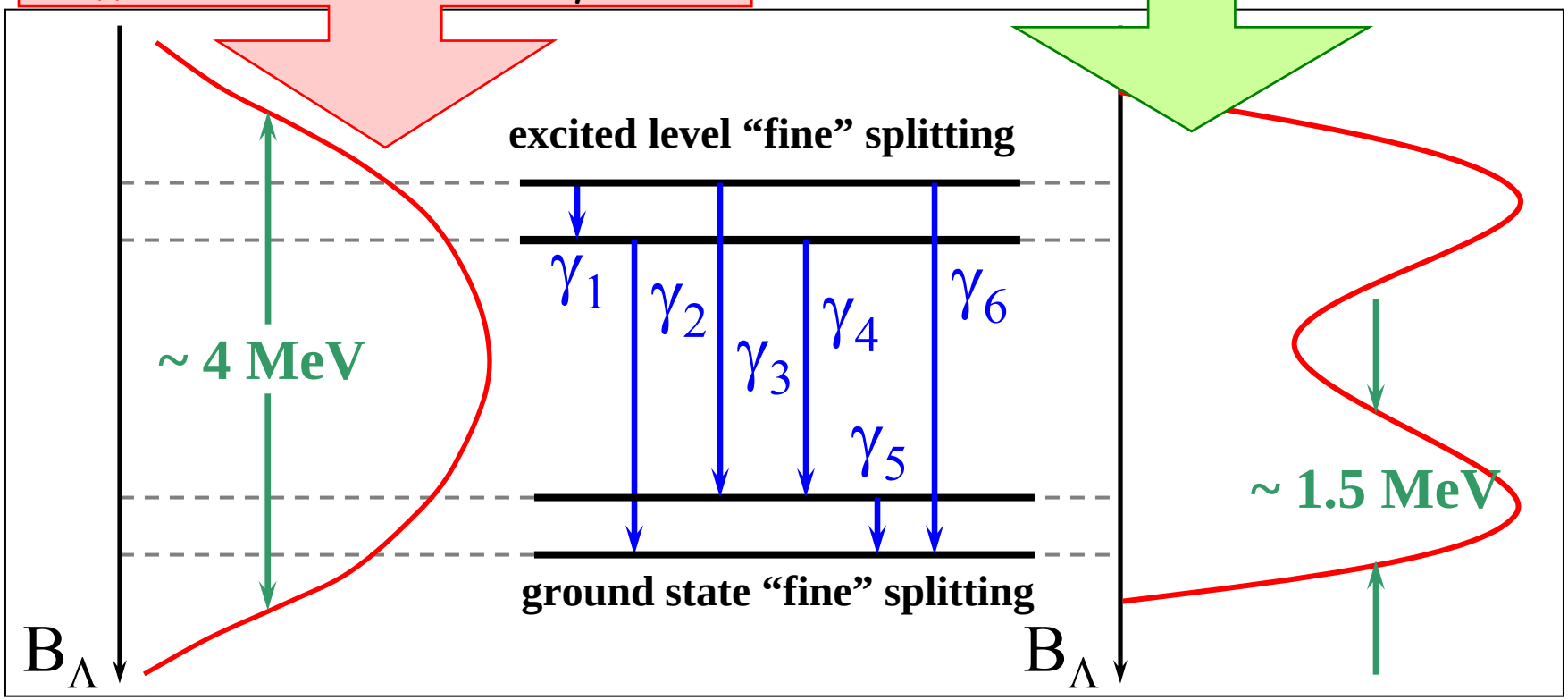
Quality vs. quantity

KEK, JPARC

high energy K^- beam
→ K^- stopping efficiency 10÷20%
→ massive targets (20 g/cm^2)
→ $\gamma\gamma$ coincidence mandatory

DAΦNE (DAΦNE2)

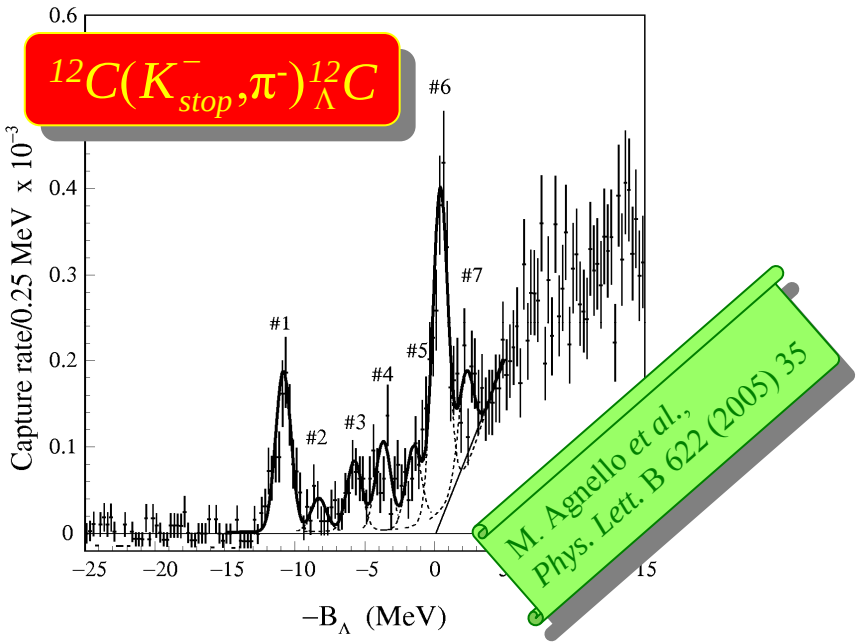
very low energy K^- beam
→ K^- stopping efficiency 90%
→ thin targets (0.2 g/cm^2)
→ independent γ measurement



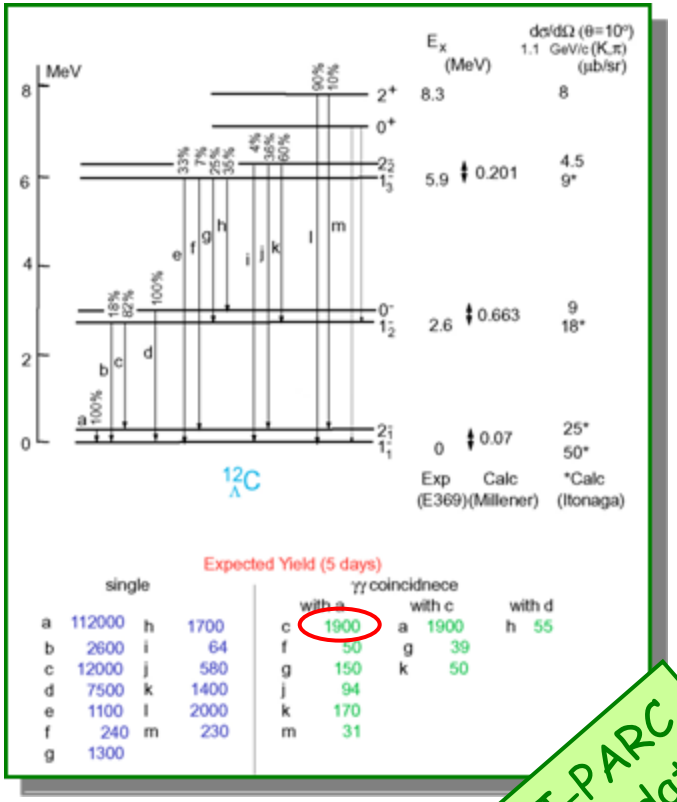
once more the DAΦNE K^- characteristics make our setup competitive

Expected rates

with 500 pb^{-1} FINUDA can observe ~ 2.5 × 10^4 ev from $^{12}_{\Lambda}C$ g.s.



8 targets



J-PARC MC data

- spectrometer acceptance: 82%
- Ge array acceptance: ~ 12%
- ε_{Ge}: ~ 10%

~ 1500 γ transitions

Summary

- strangeness nuclear physics still has a great discovery potential
- explorative run on γ-ray spectroscopy is feasible with:
  - present DAΦNE machine
  - minor investment on FINUDA apparatus
- DAΦNE luminosity upgrade will allow European Groups to carry on a significant γ-ray spectroscopy program