FINUDA physics at DAΦNE2

NOVEMBER 28, 29 & 30, 2005

31ST MEETING OF THE

LNF SCIENTIFIC COMMITTEE

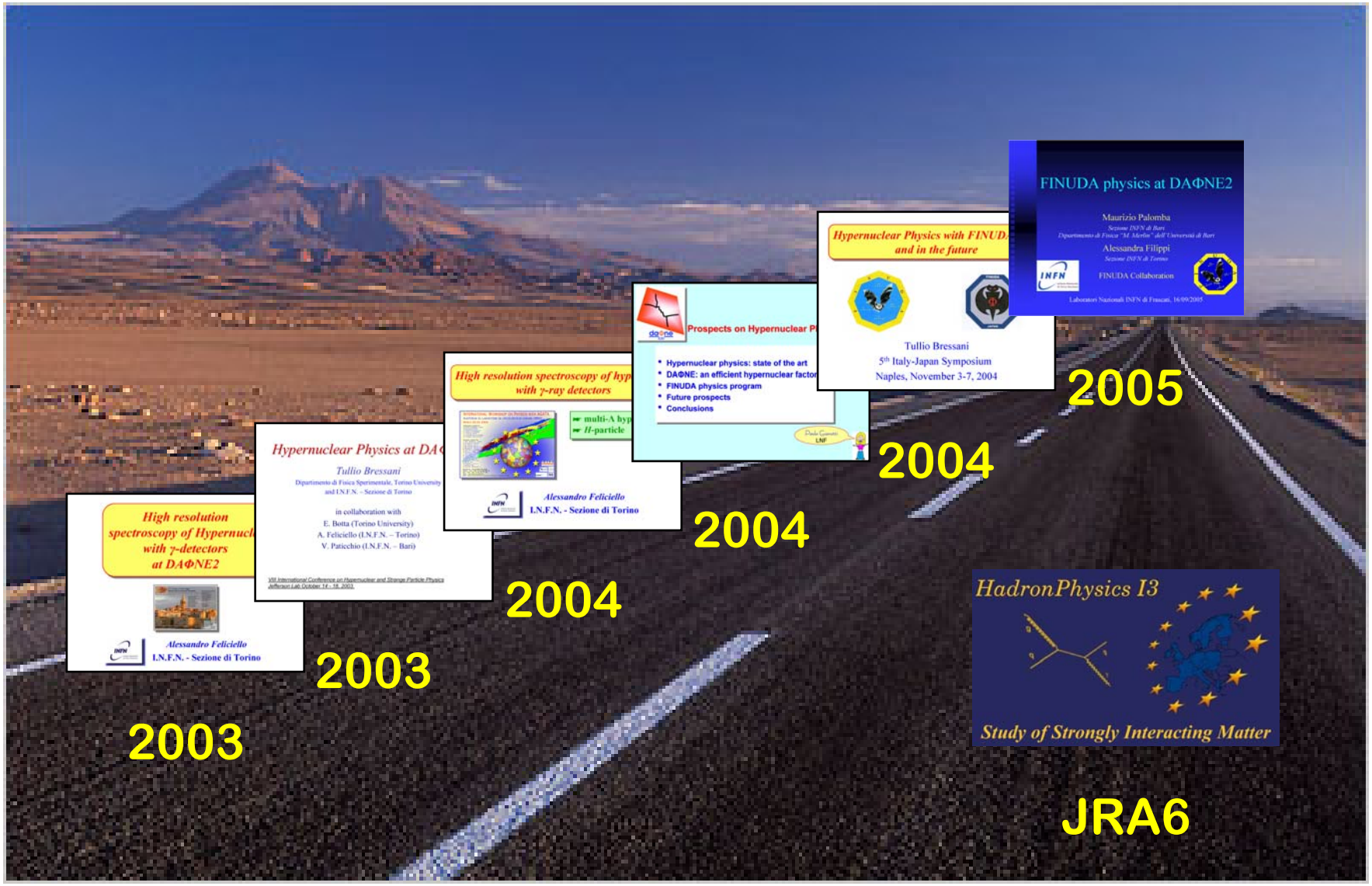
Alessandro Feliciello

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
- Proposal for FINUDA spectrometer upgrade at DAΦNE/DAΦNE2

… not a last minute business!



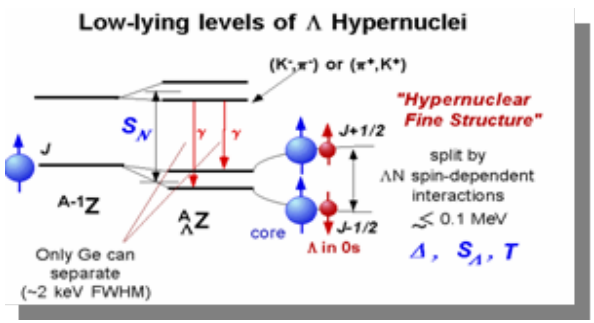
Open questions

- (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 models and to discriminate between the ones based on meson exchange picture and those including quark-gluon degrees of freedom

Where do we stand?

HYPERBALL

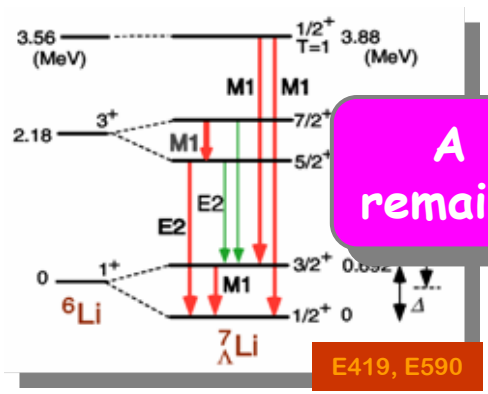
KEK E419: $(\pi^+,K^+)\,^{7}_{\Lambda}Li$

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

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

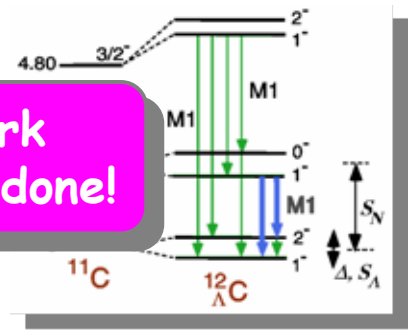
$\Delta = 0.43$
$S_\Lambda = -0.01$
$S_N = -0.40$
$T = 0.03$

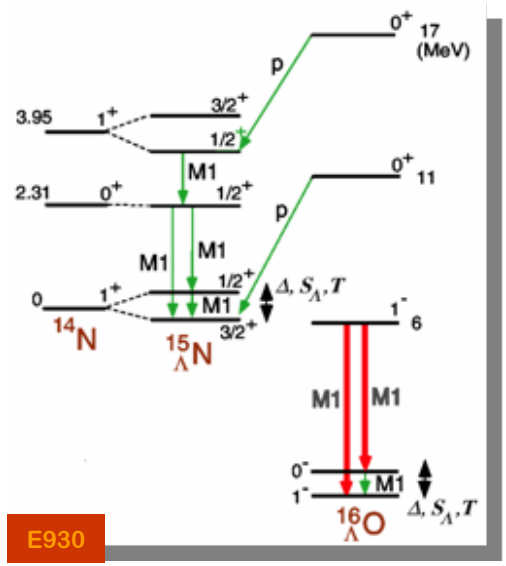
D.J. Millener, *Nucl. Phys. A* 754 (2005) 48c



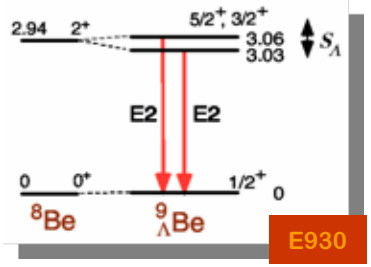
E419, E590

A lot of work remains to be done!





E930

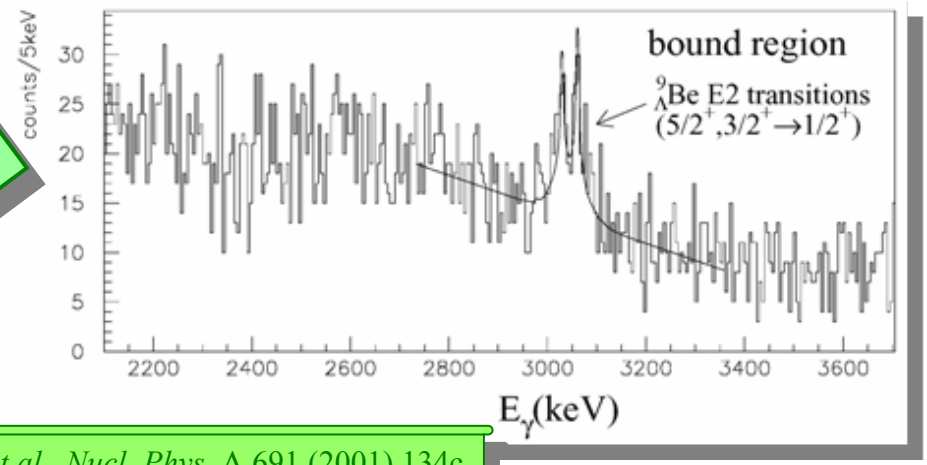


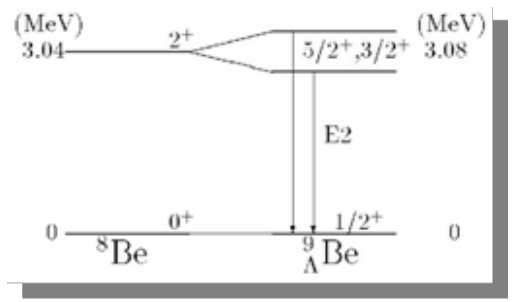
E930

Already observed (E419,E930 ,E509) | To be observed (Target of E930) | Will hopefully be observed

Which model description?

BNL E930





H. Akikawa *et al.*, *Nucl. Phys.* A 691 (2001) 134c

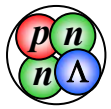
	experiment	OME	QM
$^{9}_{\Lambda}Be(5/2^+ \rightarrow 3/2^+)$	31 ± 2 keV	80 - 200 keV	35 - 40 keV
$^{13}_{\Lambda}C(3/2^- \rightarrow 1/2^-)$	152 ± 36 keV	390 - 960 keV	150 - 200 keV

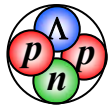
BUT
quark based models have yet to provide
an extensive and satisfactory description of YN interaction

Charge symmetry breaking

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

if the charge symmetry holds exactly

${}^{4}_{\Lambda}H$ 

${}^{4}_{\Lambda}He$ 

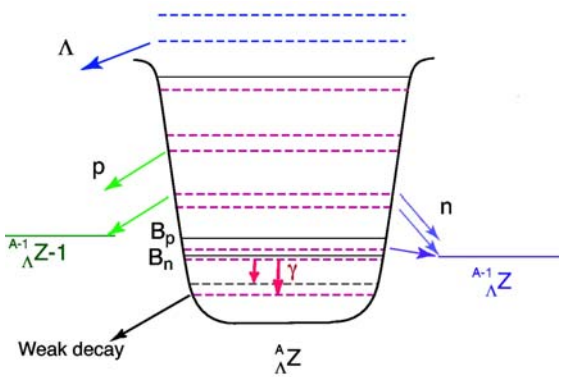
$B_\Lambda({}^{4}_{\Lambda}H) \neq B_\Lambda({}^{4}_{\Lambda}He)$

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

Λp more attractive than Λn

Possible explanations:
- $\Lambda\Sigma^0$ mixing
- ΛN - ΣN coupling

Odd-state interaction



even-states ΛN (*s*-wave)
odd-states ΛN (*p*-wave)
} interactions

$$\frac{s\text{-wave}}{p\text{-wave}} = ?$$

- ND model: attractive odd-state force
- NSC97 model: repulsive odd-state force

in contrast with data on $^{13}_{\Lambda}C$!

odd-states are usually particle unbound for light (A < 50) hypernuclei
→ best candidate hypernuclei $^{89}_{\Lambda}Y$ and $^{208}_{\Lambda}Pb$

D.J. Millener, *Nucl. Phys.* A 691 (2001) 93c

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

Impurity nuclear physics

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

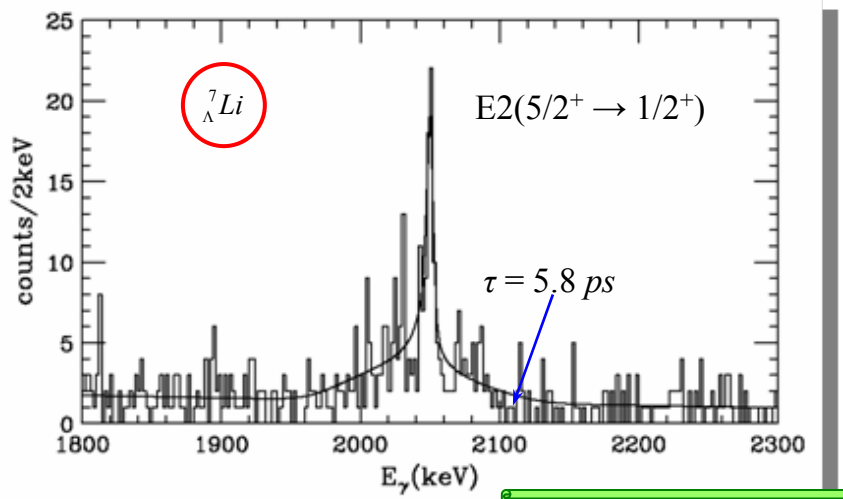
The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure

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

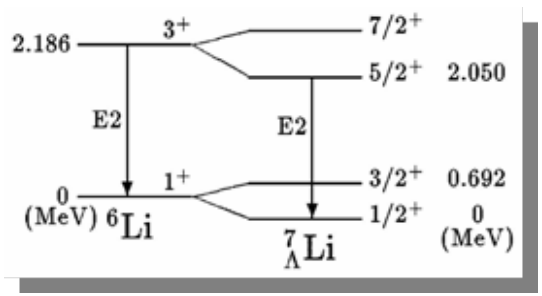
study of hypernucleus level schemes and B(E2) → Doppler-shift attenuation method

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 ^{6}Li core by ~ 20%

Open questions

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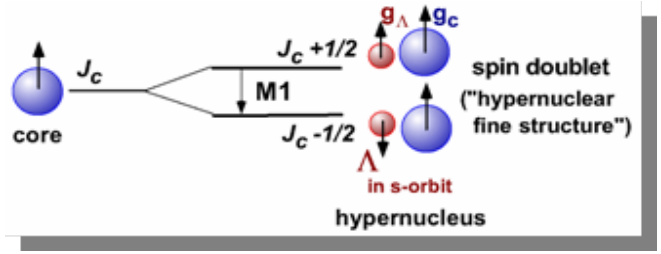
- Impurity nuclear physics
  - measurement of transition probability B(E2)
    → information on the size and deformation of hypernuclei
    → measurement of nucleus core shrinking → glue role of Λ
- Properties of hyperons in nuclear matter (medium effect)
  - measurement of transition probability B(M1)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

Medium effect

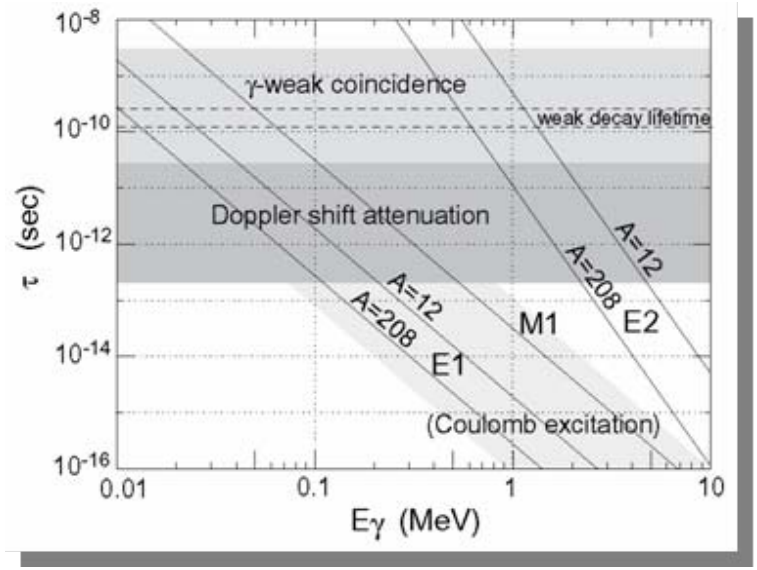
If the mass or the size of a hyperon is modified in a nucleus, its magnetic moment may be changed



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

B(M1) can be derived from excited states lifetimes

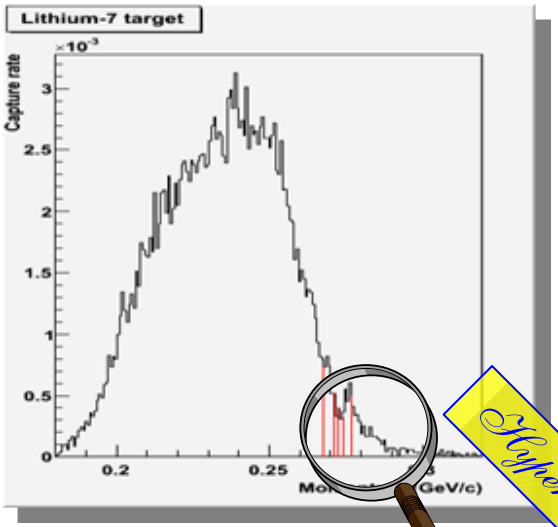
- Doppler-shift attenuation method
- γ-weak coincidence method

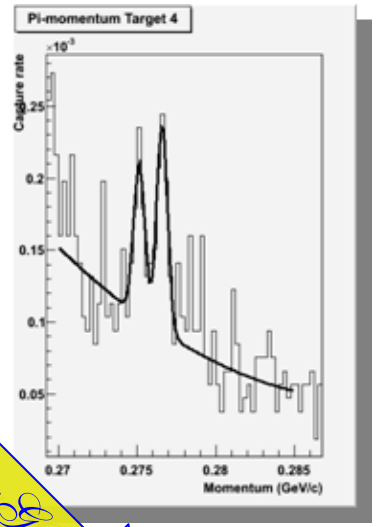


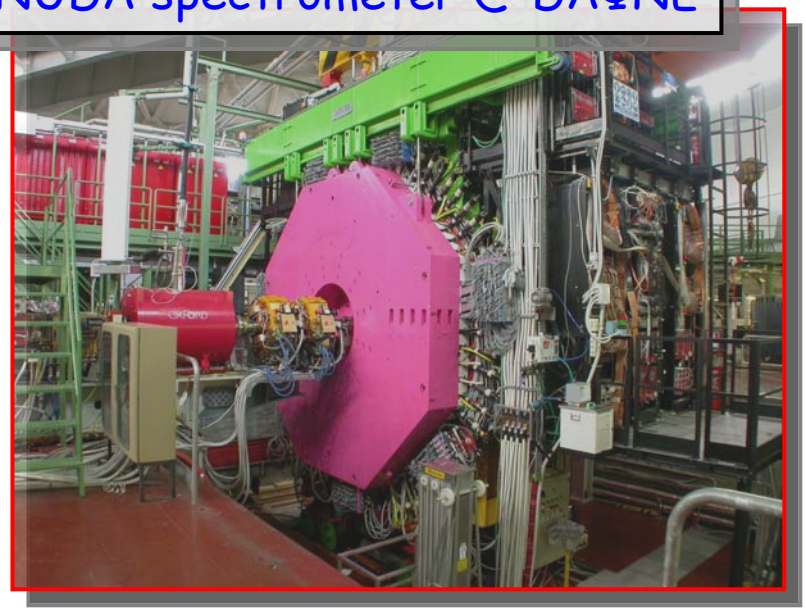
One step beyond

$^{7}Li(K^{-}_{stop},\pi^{-})\ ^{7}_{\Lambda}Li$

The FINUDA spectrometer @ DAΦNE



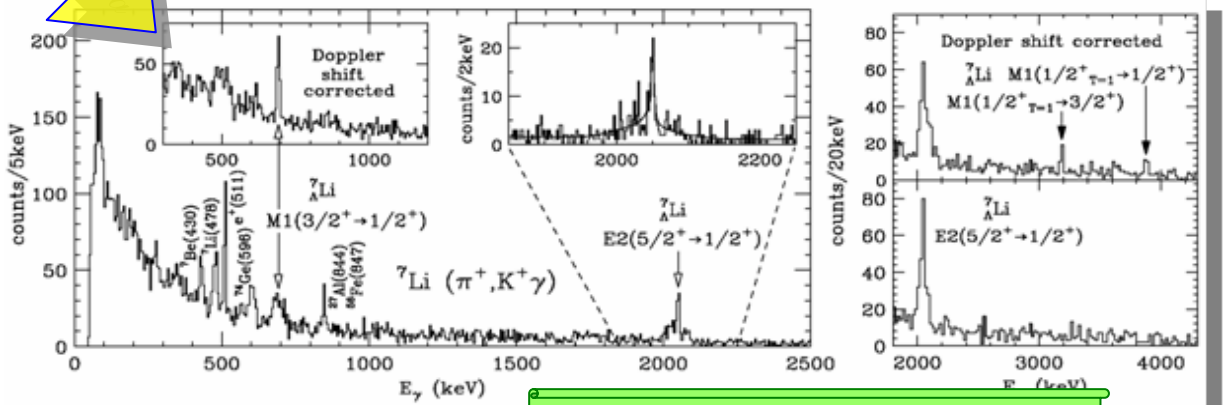




Hyper-Gamma

ΔE ~ 1.9 MeV FWHM

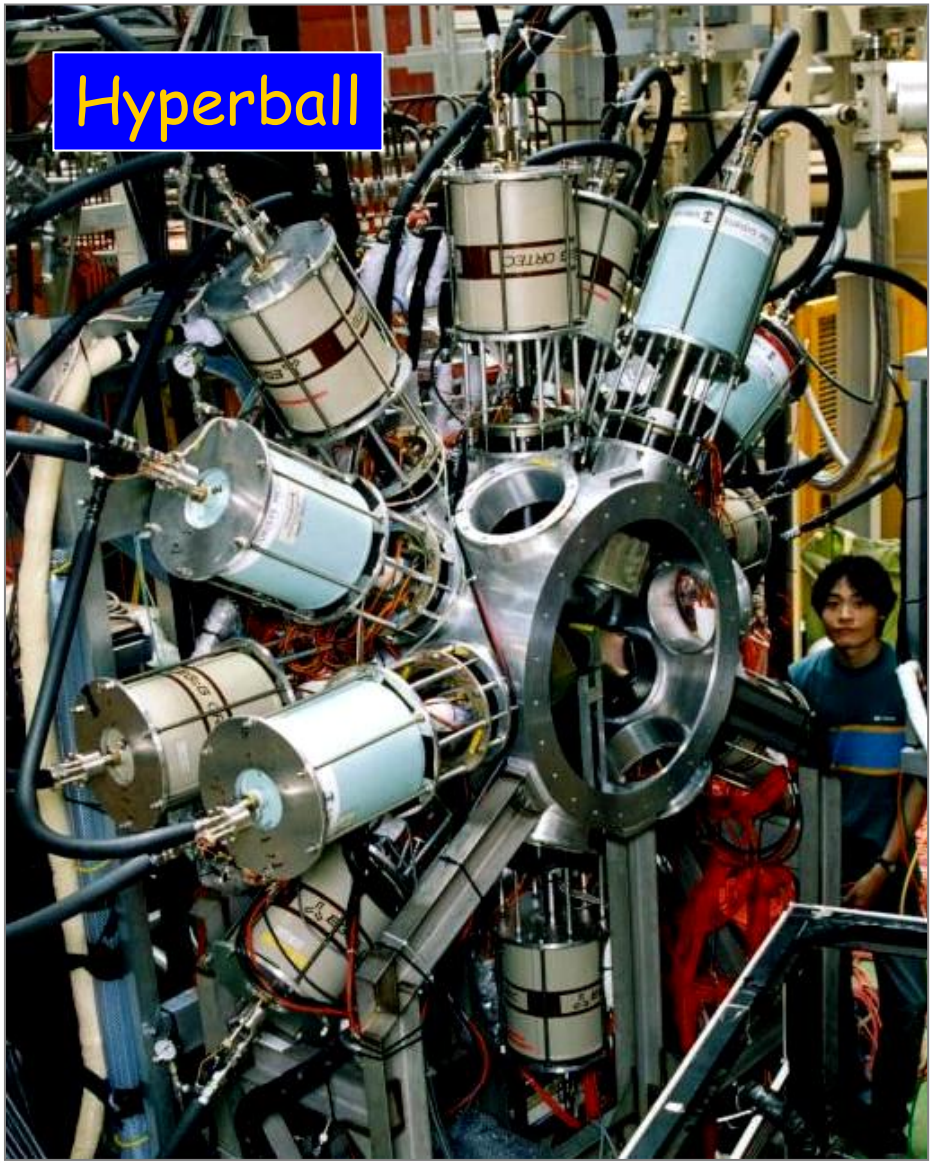
KEK E419



ΔE ~ 2 keV FWHM

H. Tamura, *Nucl, Phis.* A 691 (2001) 86c

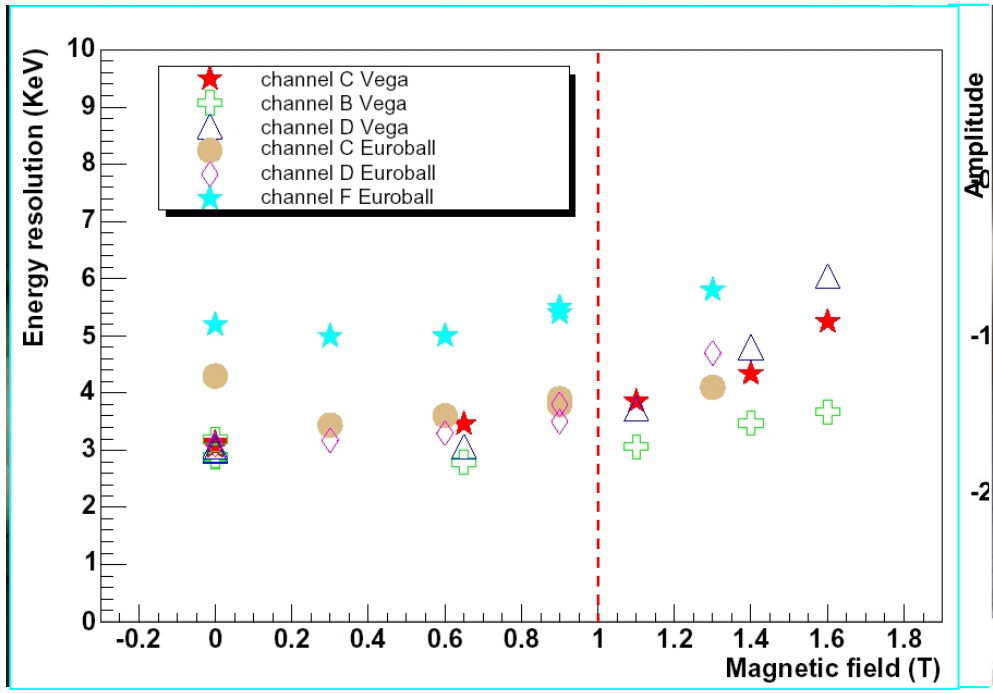
Is the integration possible?

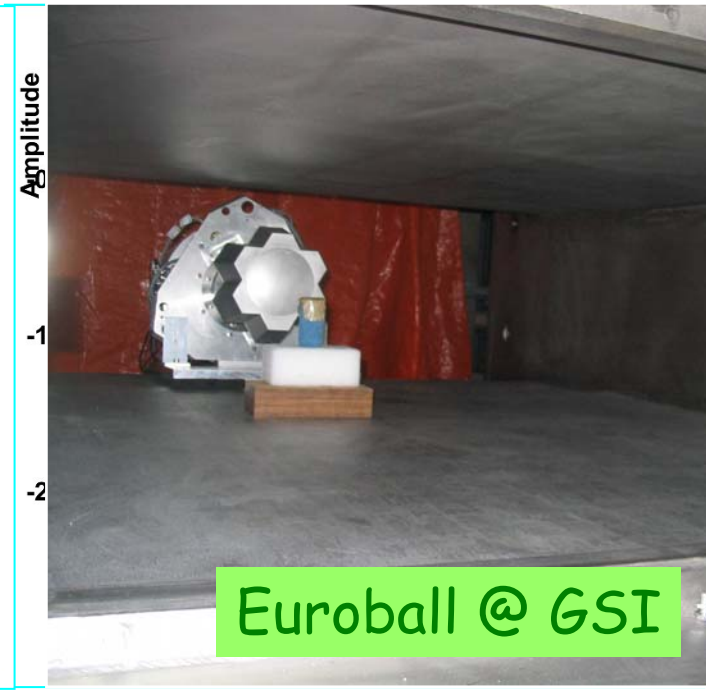


Experimental challenges

JRA6

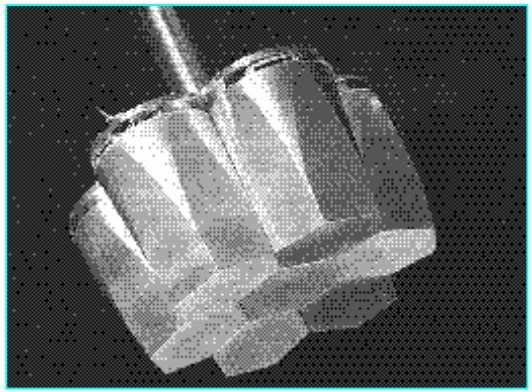
- Do HPGe crystals work in (strong) magnetic field?



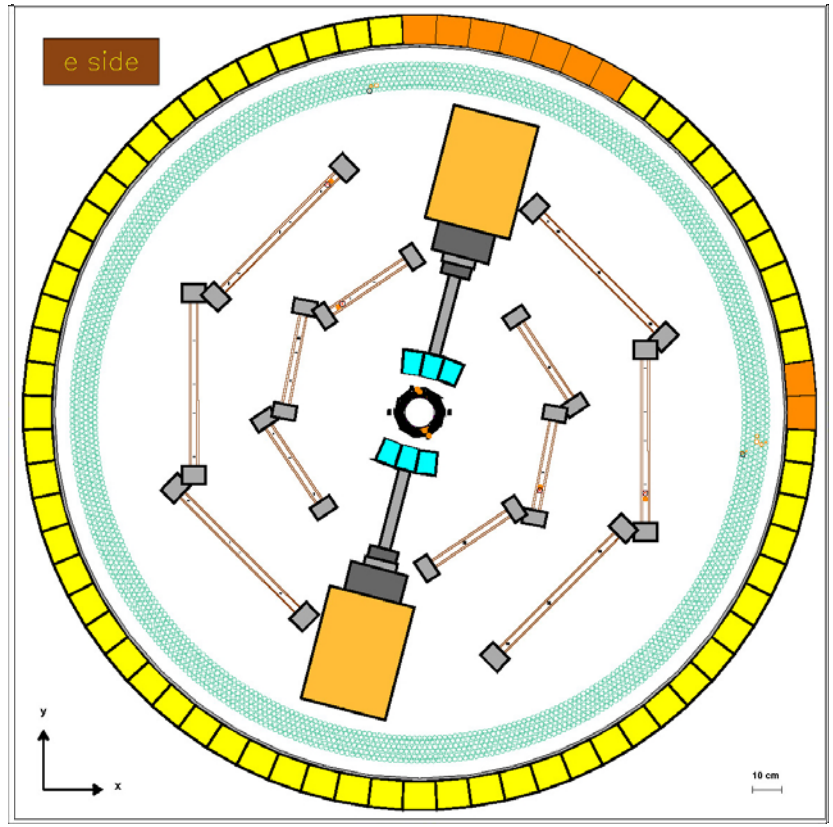


FINUDA2-1

The EUROBALL cluster

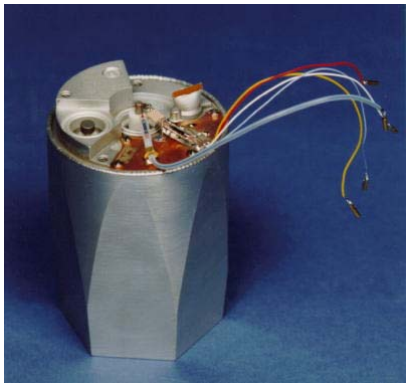


The FINUDA spectrometer



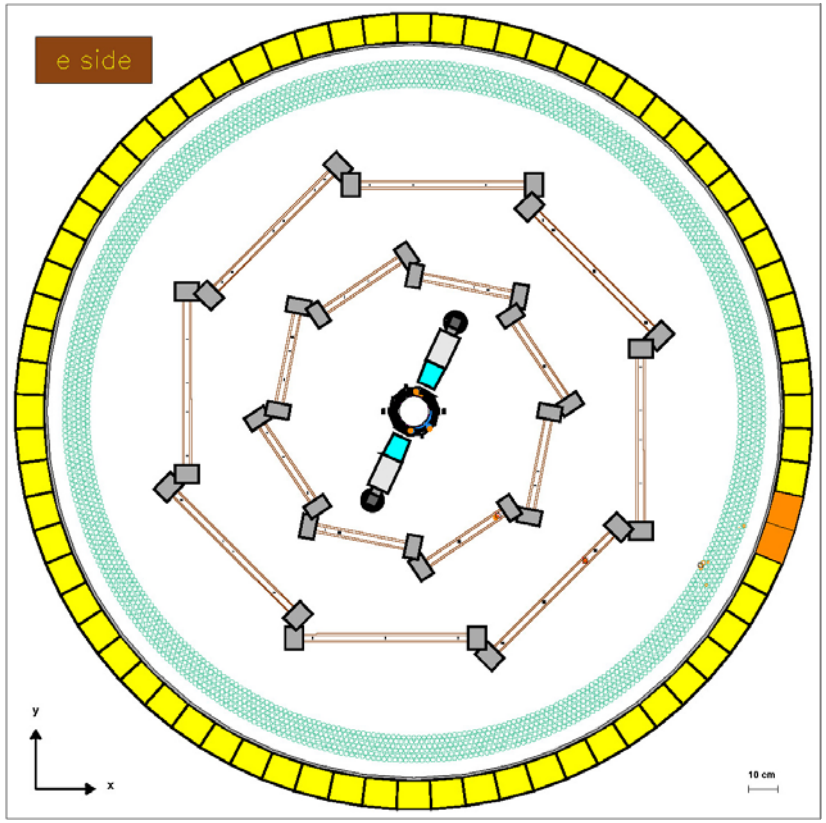
Geometrical acceptance reduced to 72%

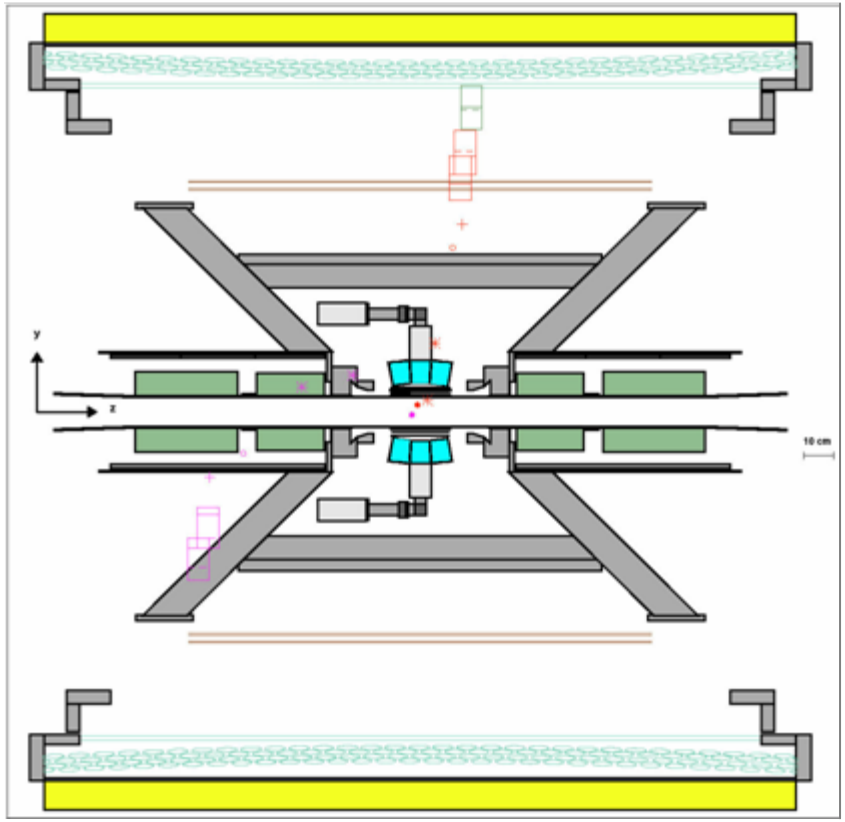
FINUDA2-2



X – COOLER II, AMETEC, ORTEC

Geometrical acceptance reduced to 82%





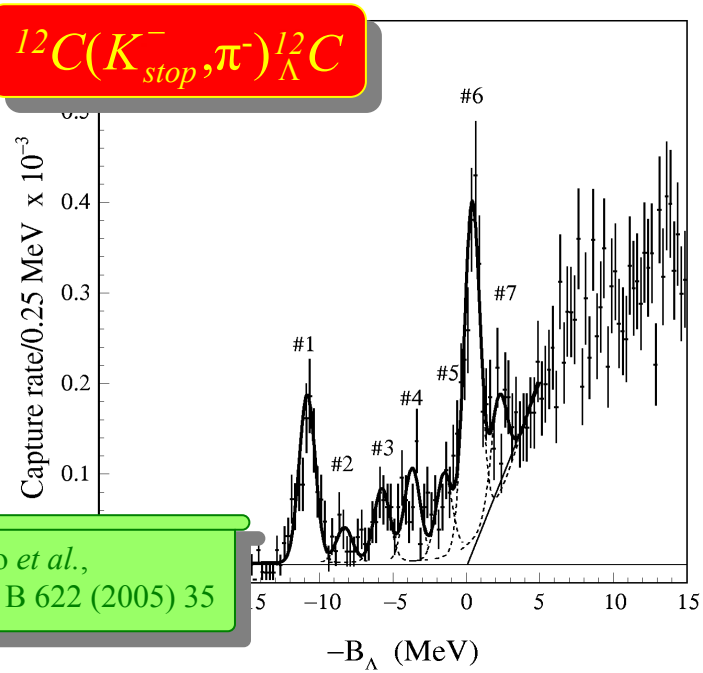
Spectroscopy of light hypernuclei

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

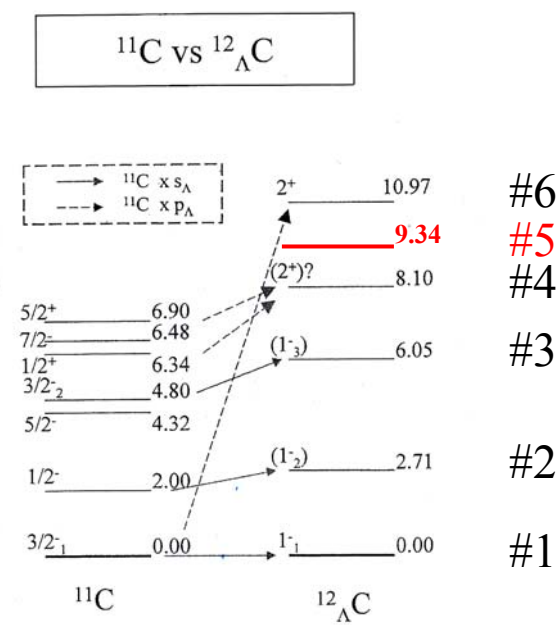
survey of hypernuclei with A < 30:

$${}^{7}_{\Lambda}Li,\ {}^{9}_{\Lambda}Be,\ {}^{10}_{\Lambda}B,\ {}^{11}_{\Lambda}B,\ {}^{12}_{\Lambda}C,\ {}^{13}_{\Lambda}C,\ {}^{23}_{\Lambda}Na,\ {}^{27}_{\Lambda}Al,\ {}^{28}_{\Lambda}Si$$

$${}^{12}C(K^-_{stop},\pi^-){}^{12}_{\Lambda}C$$

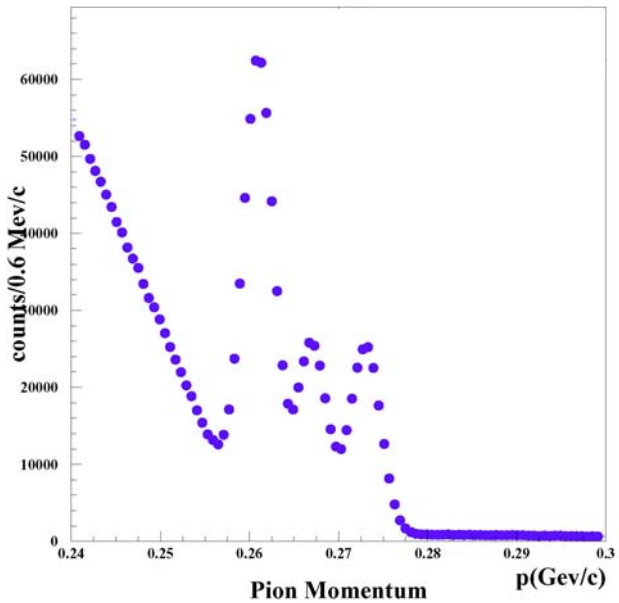


M. Agnello *et al.*, *Phys. Lett.* B 622 (2005) 35

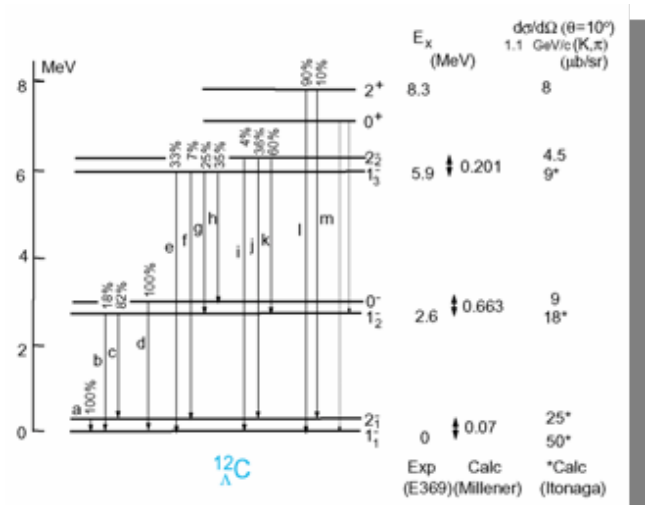


Expected rates

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



8 targets



Expected Yield (5 days)

single				γγ coincidnece with a		γγ coincidnece with c		γγ coincidnece with d	
a	112000	h	1700	c	1900	a	1900	h	55
b	2600	i	64	f	50	g	39		
c	12000	j	580	g	150	k	50		
d	7500	k	1400	j	94				
e	1100	l	2000	k	170				
f	240	m	230	m	31				
g	1300								

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

~ 1500 γ transitions

J-PARC MC data

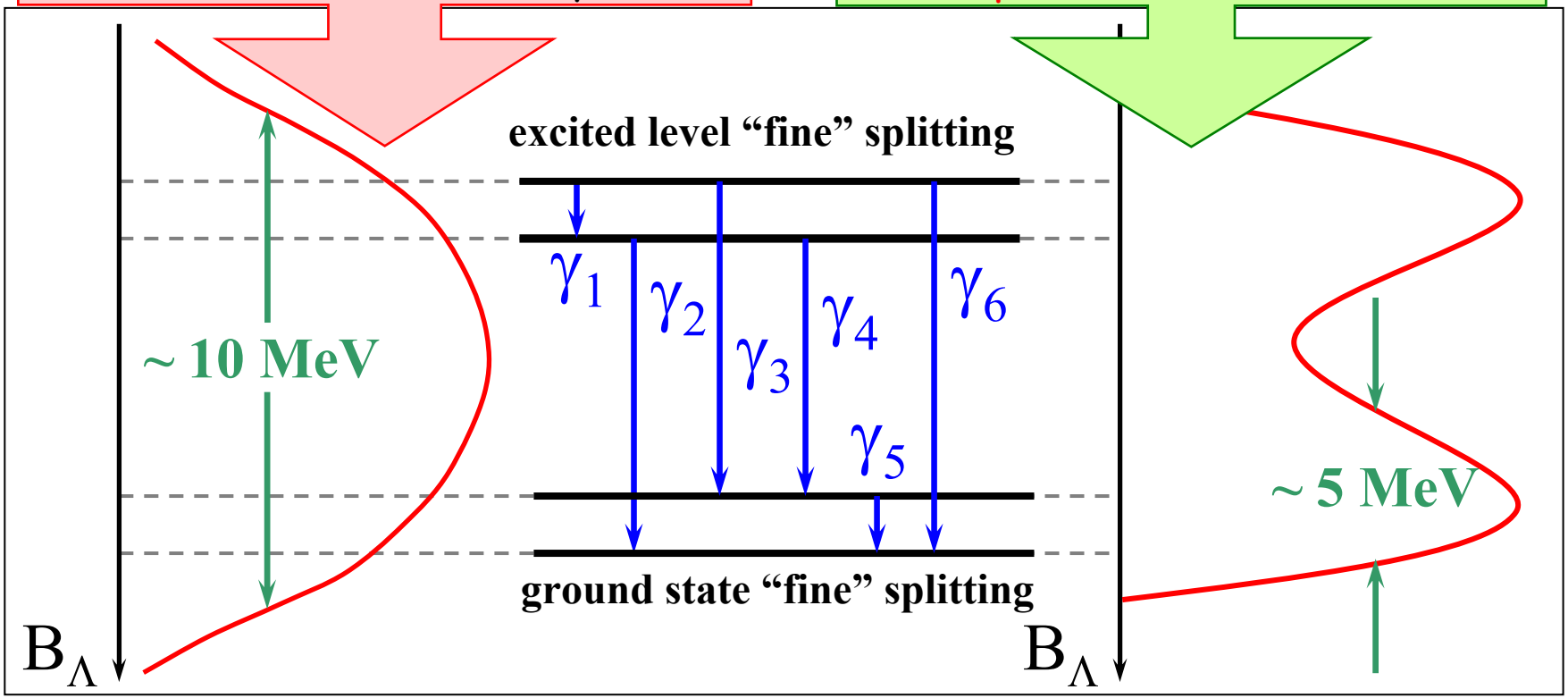
Quality vs. quantity

KEK, JPARC

high energy K^- beam
→ K^- stopping efficiency 10÷20%
→ massive targets
→ $\gamma\gamma$ coincidence mandatory

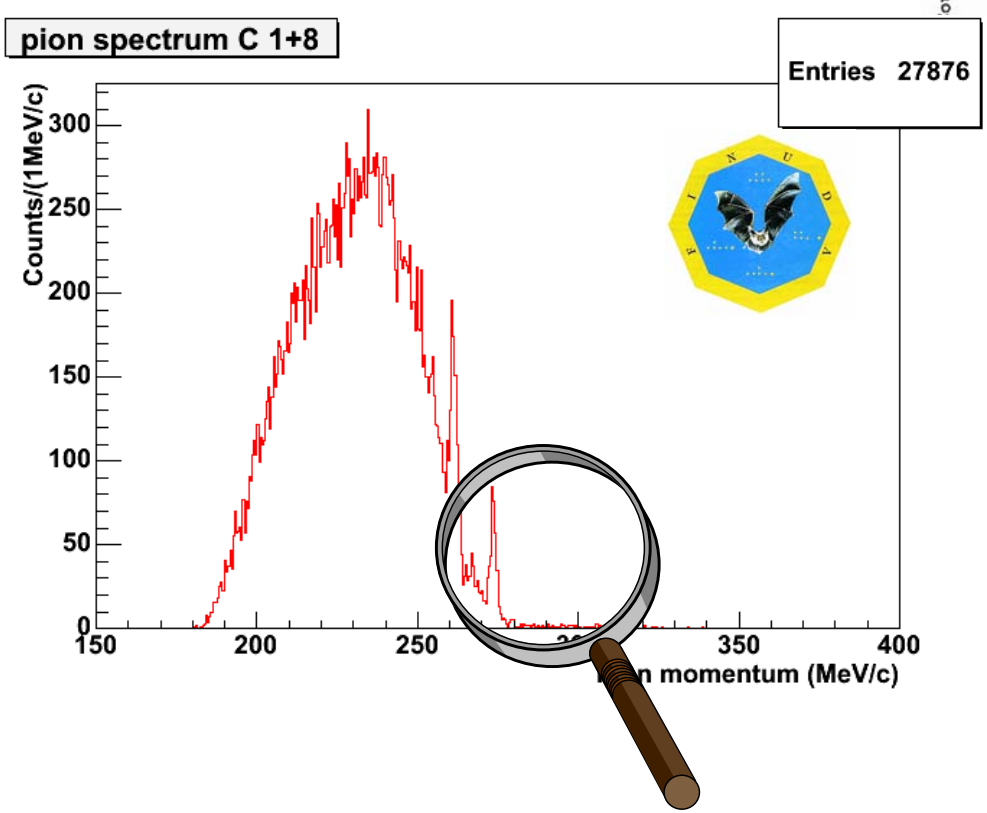
DAΦNE

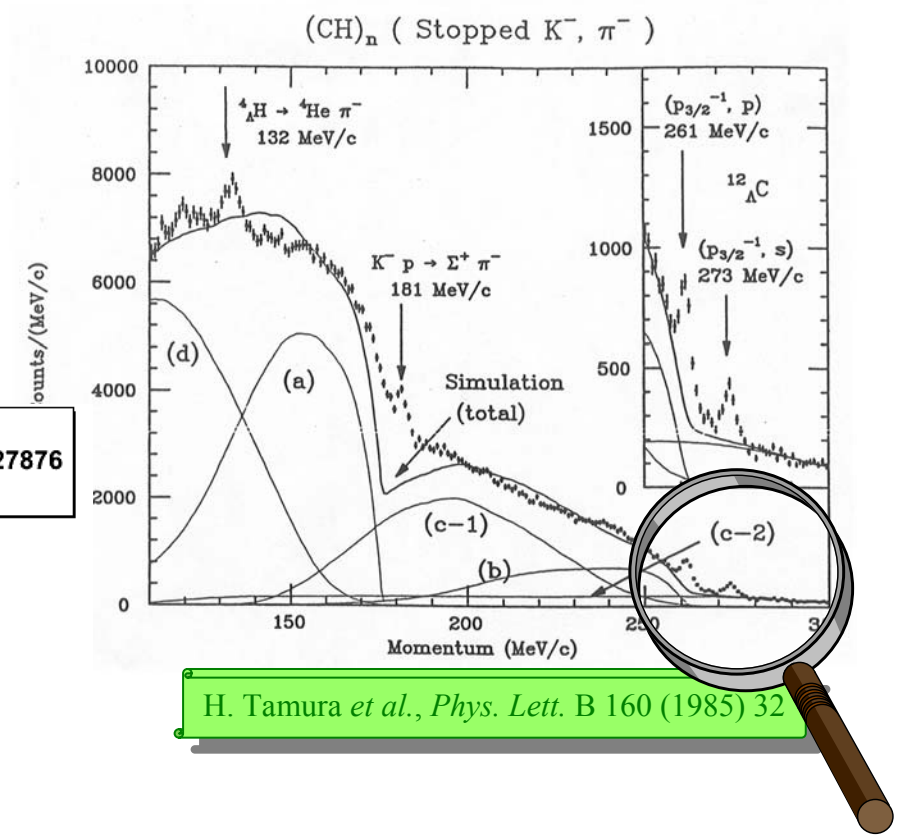
very low energy K^- beam
→ K^- stopping efficiency 90%
→ thin targets
→ independent γ measurement



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

Quality vs. quantity





H. Tamura *et al.*, *Phys. Lett.* B 160 (1985) 32

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 V

- 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

Interested community

HadronPhysics I3

Study of Strongly Interacting Matter

JRA6

INFN Istituto Nazionale di Fisica Nucleare

INFN Istituto Nazionale di Fisica Nucleare

KEK

RIKEN

Politecnico di Torino

GSI

universität mainz

Shahid Beheshti University Tehran-Iran Founded 1960

Stockholms Universitet

Kungl Tekniska Högskolan

Hyper Gamma

Costs

- 12 + 3 HPGe detectors — 450 k€
- 4 + 1 electric cooling systems — 50 k€
- front-end electronics — 50 k€
- DAQ system upgrade — 50 k€

Time schedule

- 2006: Letter of Intent
- 2008: completion of FINUDA physics program
- 2009: FINUDA upgrade
- 2010: pilot run at DAΦNE1 (500 pb^{-1})

- 201X: DAΦNE upgrade
- 201X: 1st data taking period (1 fb^{-1})
- 201X: 2nd data taking period (1 fb^{-1})

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 to our community to maintain a main role in the field
  - the FINUDA upgrade could represent the opportunity to install a liquid ^{4}He target for studying *K* deeply bound states