Hypernuclear Physics at Storage Rings

a non conventional experimental approach

Alessandro Feliciello

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

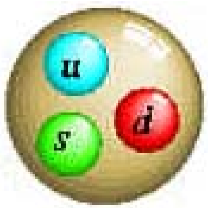
Outline

- Introduction
- Highligths from:
  - COSY-13 @ COSY
  - FINUDA @ DAΦNE
- Looking forward:
  - $\bar{\text{P}}$ANDA @ HESR

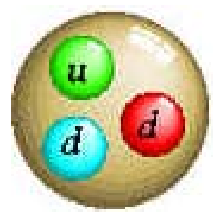
    see next talk by F. Iazzi
  - supernuclear physics @ Super*B*

    see next talk by V. Lucherini

The main actress

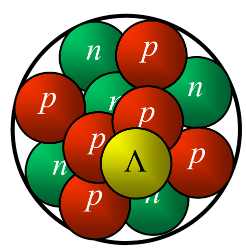


Λ(uds) $I(J^P)$ = 0(½⁺)
mass: 1115.68 MeV
τ: 263.20 ps



n(udd) $I(J^P)$ = ½(½⁺)
mass: 939.57 MeV
τ: 885.70 s

Λ is "just" a fat *n* (+20%)



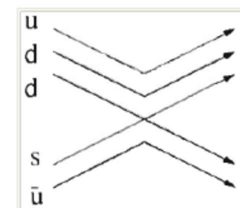
strangeness makes Λ distinguishable

Single Λ-hypernucleus production

A hypernucleus is the outcome of a genetic engineering manipulation applied to the nuclear physics domain

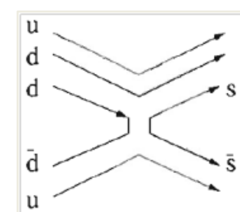
1) strangeness exchange (both in flight and at rest):

$$K^- + {}^AZ \rightarrow {}^A_\Lambda Z + \pi^-$$



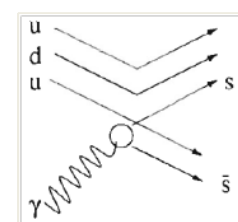
2) associated strangeness production:

$$\pi^+ + {}^AZ \rightarrow {}^A_\Lambda Z + K^+$$

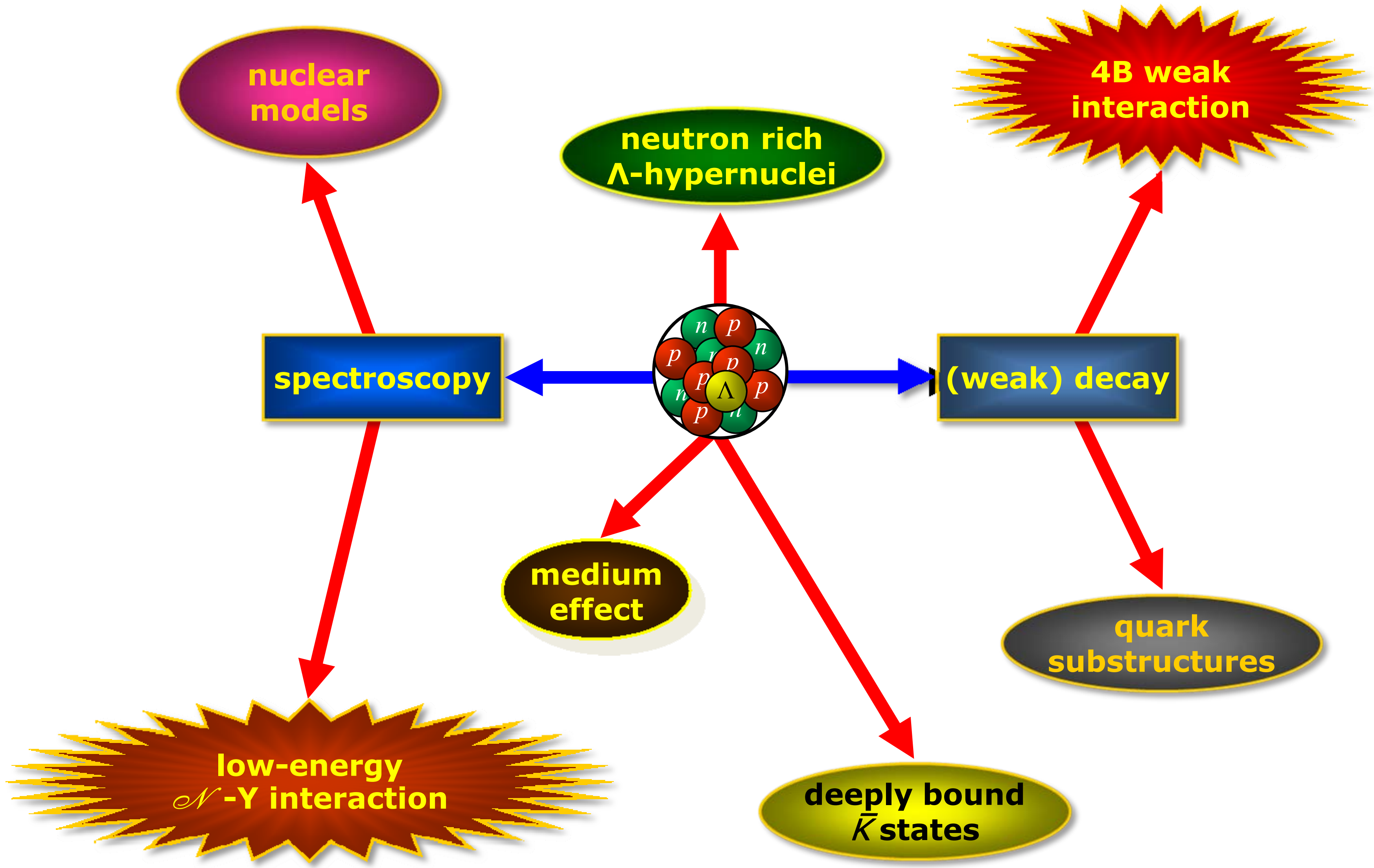


3) "electro-production":

$$e^- + {}^AZ \rightarrow e^{-\prime} + K^+ + {}^A_\Lambda(Z-1)$$



Physics output (S = -1)

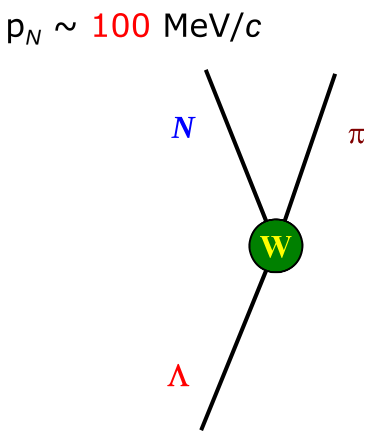


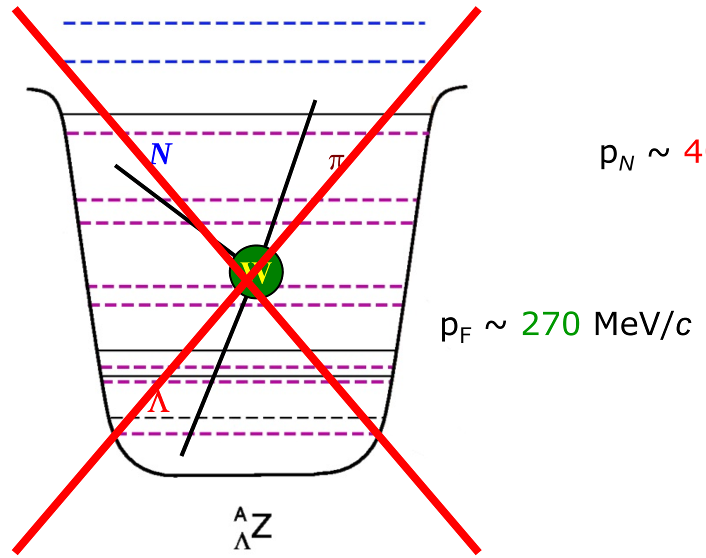
Λ-hypernucleus decay

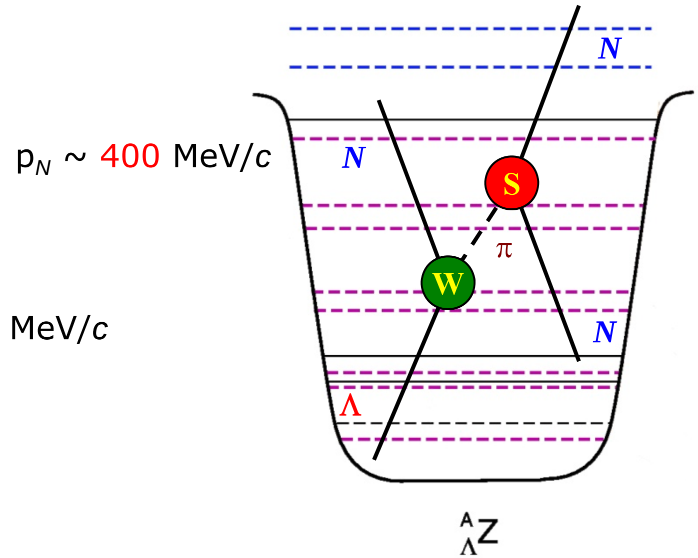
free Λ decay

hypernucleus mesonic decay

hypernucleus non-mesonic decay







$\Lambda \to n + \pi^0 + 41$ MeV (36%)

$\Lambda \to p + \pi^- + 38$ MeV (64%)

$\tau_\Lambda \approx 263$ ps

suspressed by Pauli blocking

$\Lambda + n \to n + n + 176$ MeV

$\Lambda + p \to n + p + 176$ MeV

$\tau_\Lambda \approx$???

ΔI = ½ rule
(not theoretically understood)

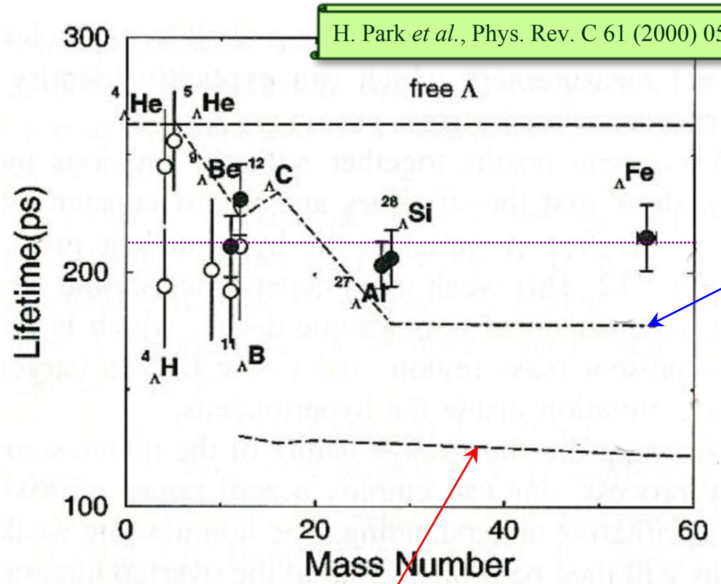
$$\Gamma_T = \Gamma_M + \Gamma_{NM}$$
$$\Gamma_M = \Gamma_{\pi 0} + \Gamma_{\pi -}$$
$$\Gamma_{NM} = \Gamma_n + \Gamma_p + \Gamma_2$$

dominant in all but the lightest hypernuclei

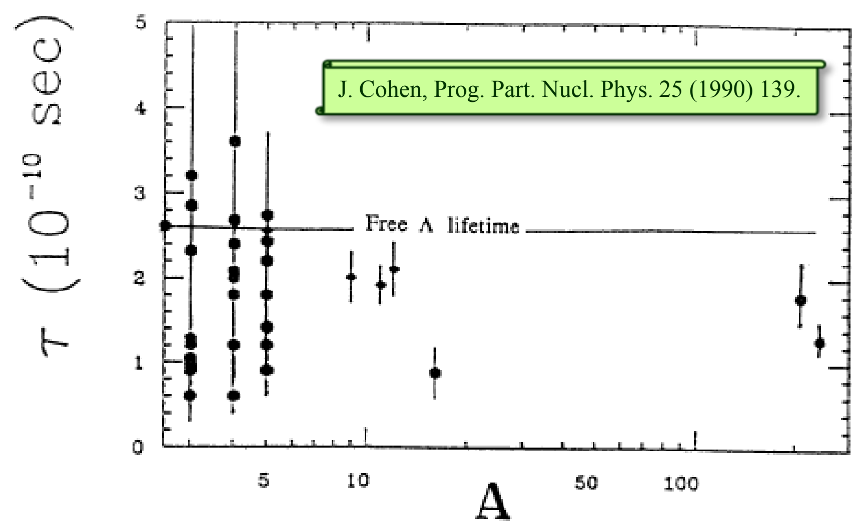
Λ-hypernuclei lifetime

H. Park *et al.*, Phys. Rev. C 61 (2000) 054004.

K. Itonaga *et al.*, Nucl. Phys. A 639 (1998) 329c.

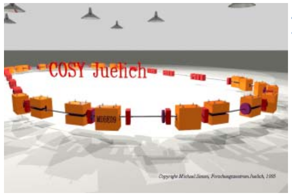


A. Ramos *et al.*, Phys. Rev. C 50 (1994) 2314.



J. Cohen, Prog. Part. Nucl. Phys. 25 (1990) 139.

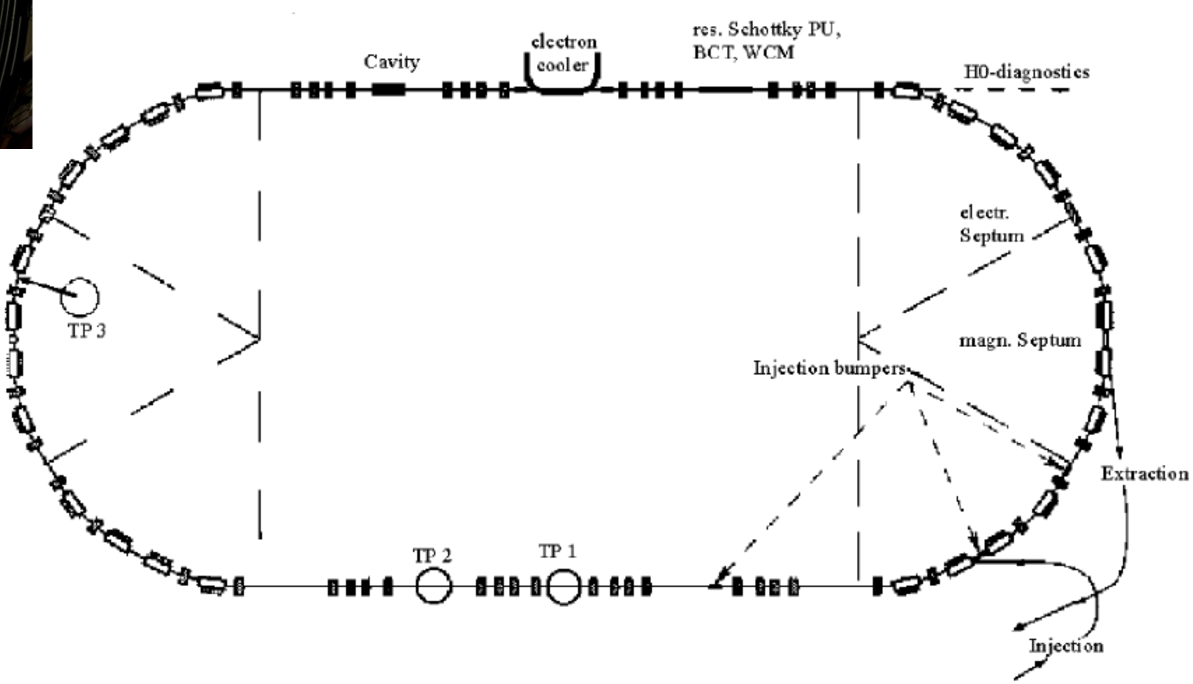
COSY-13 @ COSY



COoler SYnchrotron

- single ring
- 180 m long
- $600 \leq p_p \leq 3700$ MeV/c
- 5×10^{10} *p*

see A. Kasharava talk on Monday

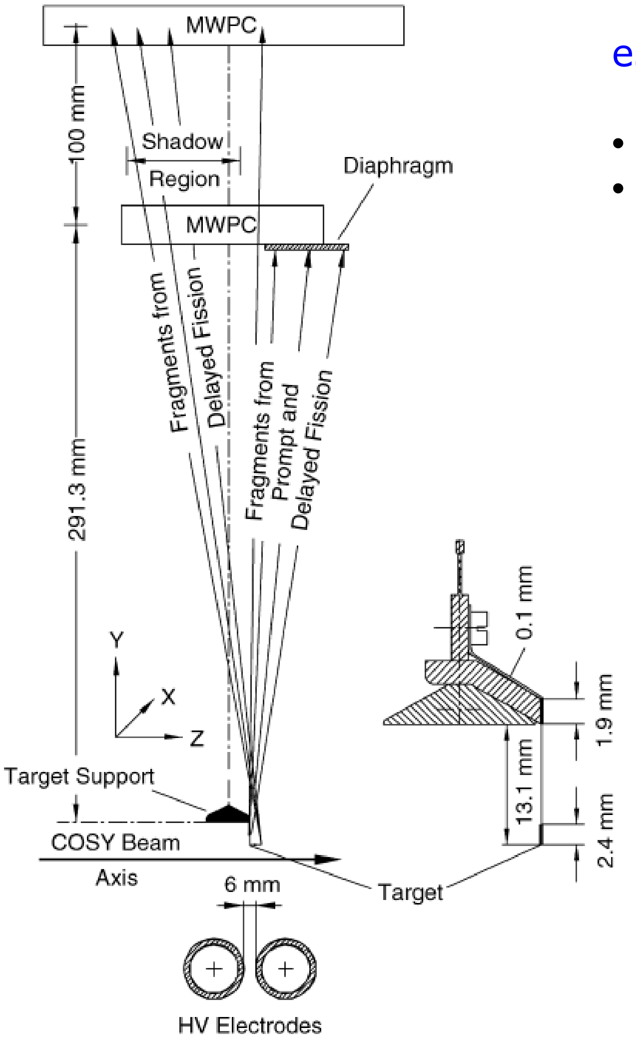


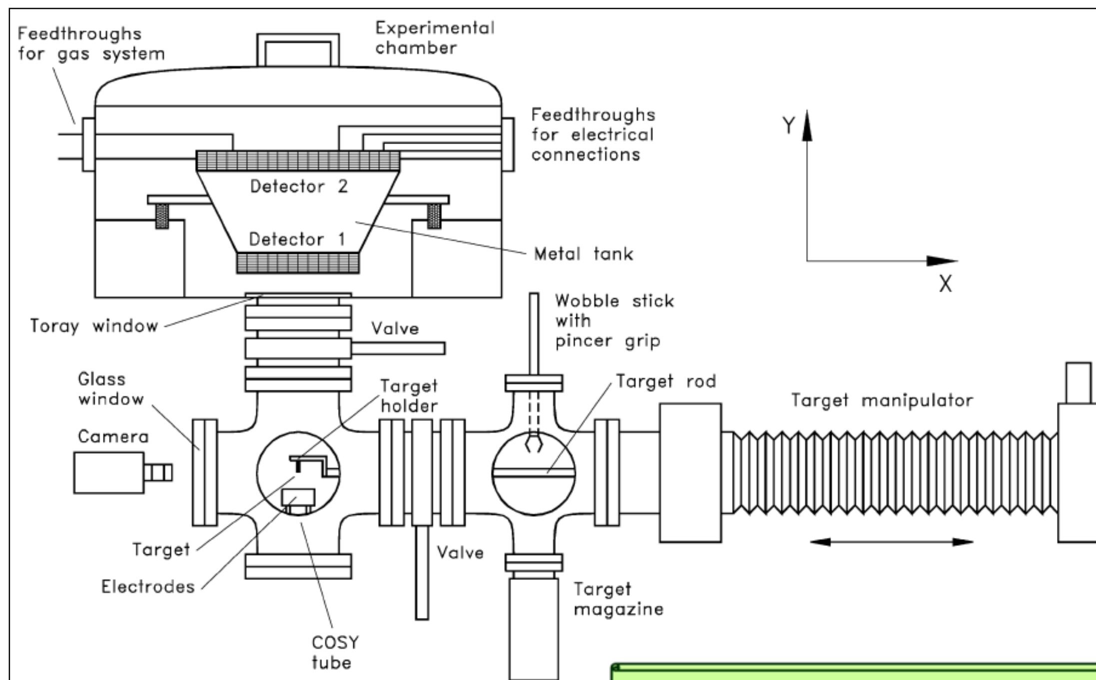
COSY-13 experiment scheme

COSY-13 experiment: heavy-hypernucleus lifetime measurement based on the recoil shadow method

essential requirements for high-precision measurement:

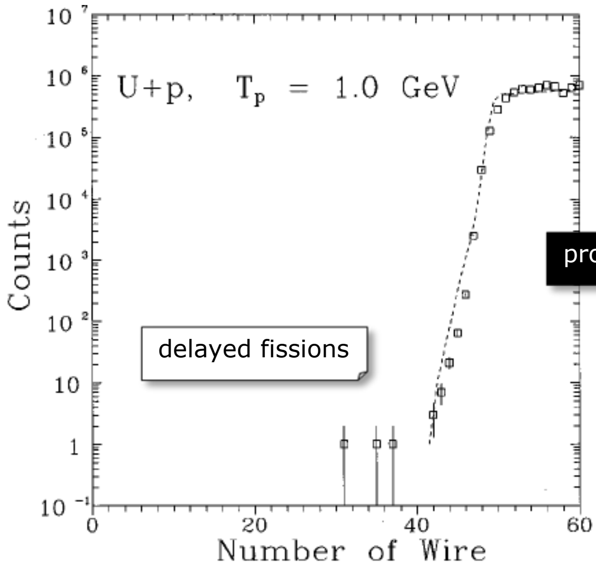
- high-intensity *p* beam (5×10^{10})
- very thin target ($\leq$ 100 μg/cm^2)

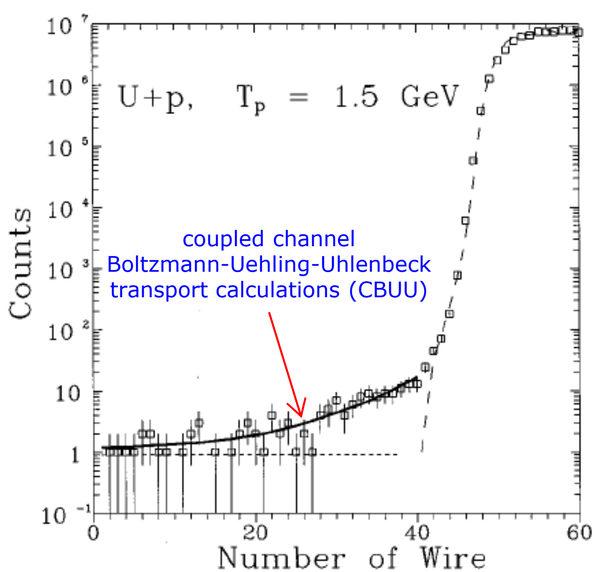




K. Pysz *et al.*, Nucl. Instr. Meth. A 420 (1999) 356.

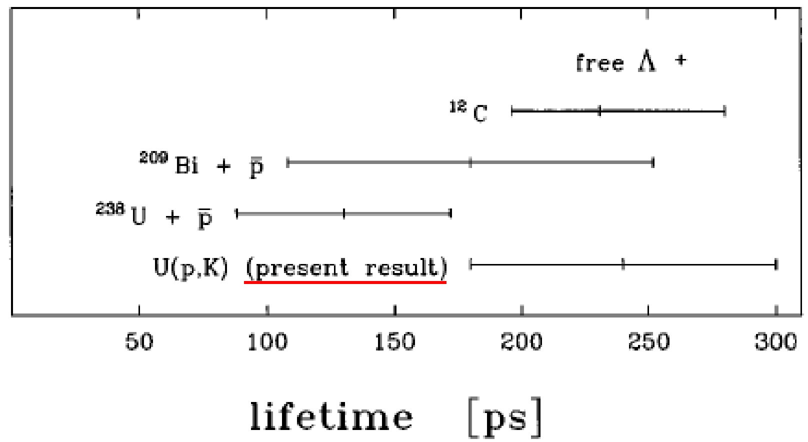
p + U measurement(s)

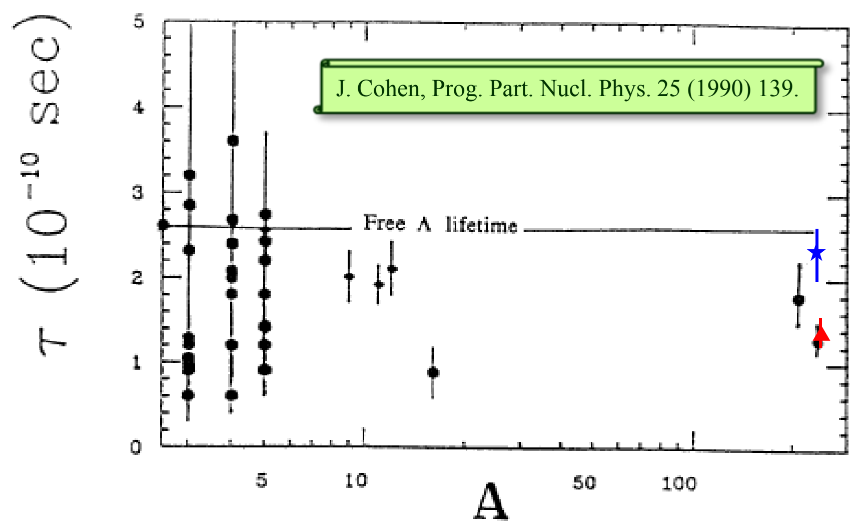




H. Ohm *et al.*, Phys. Rev. C 55 (1997) 3062.

τ_Λ = 240 ± 60 ps = 0.91 $\tau_{\Lambda free}$

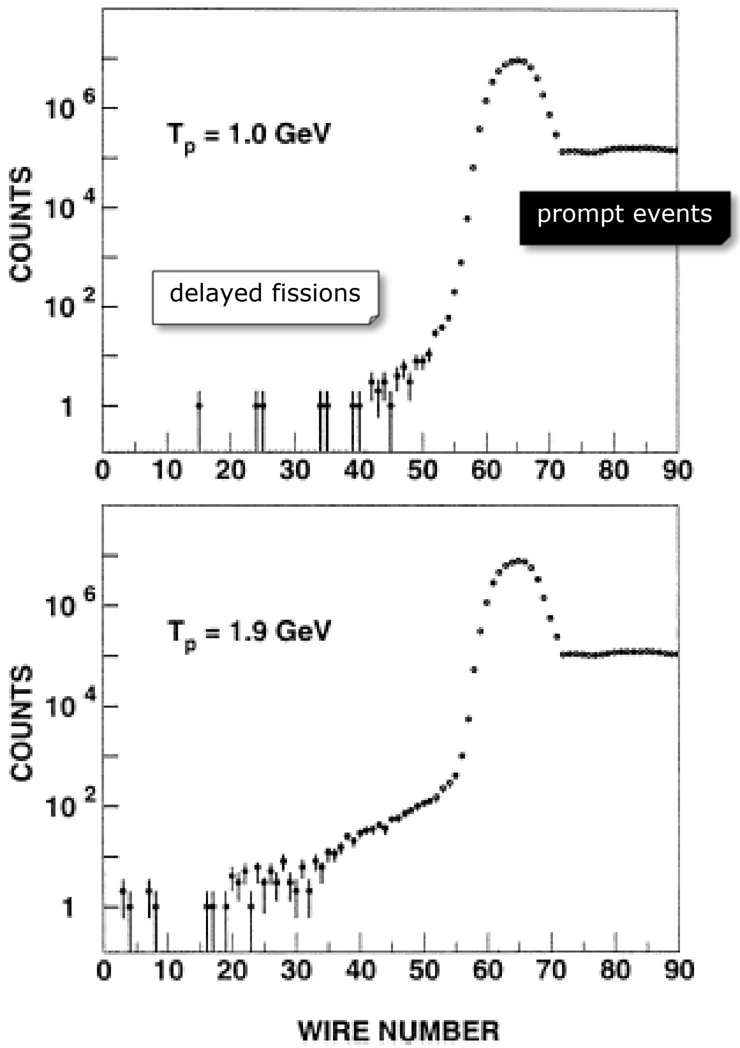


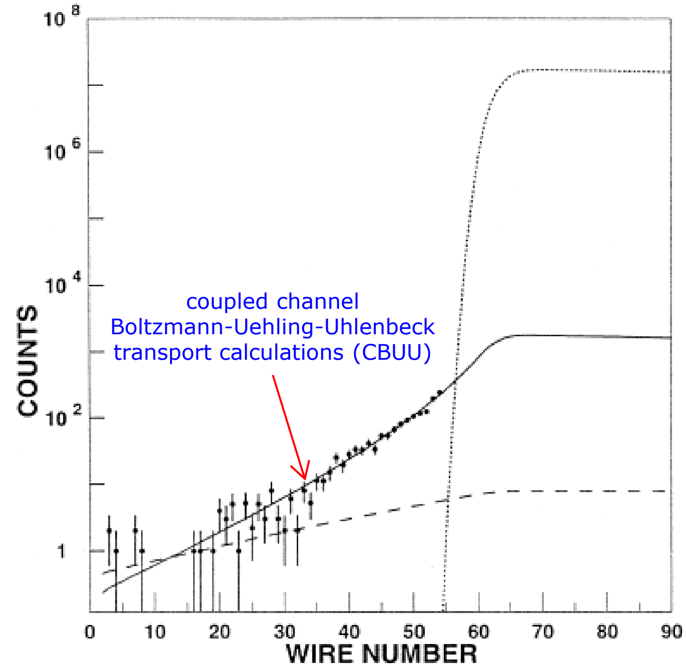


τ_Λ = 138 ± 18 ps = 0.52 $\tau_{\Lambda free}$

P. Kulessa *et al.*, Acta Phys. Pol. B 33 (2002) 603.

p + Bi measurement

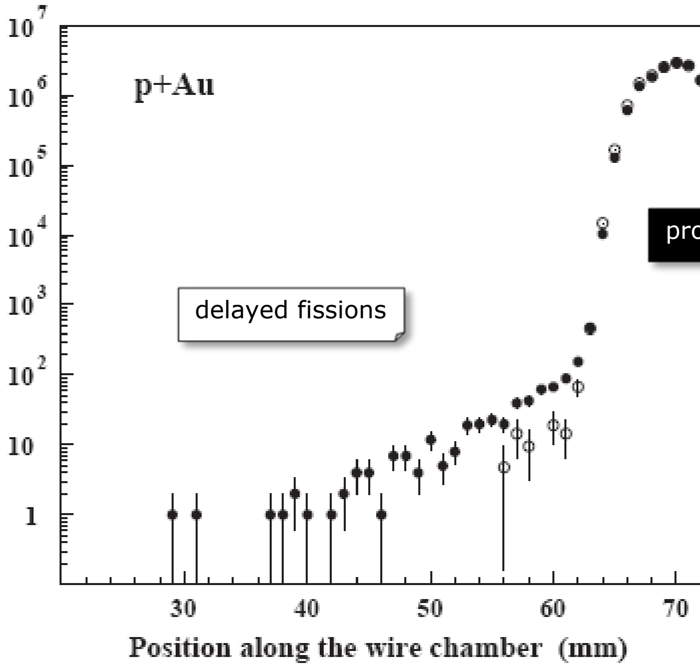


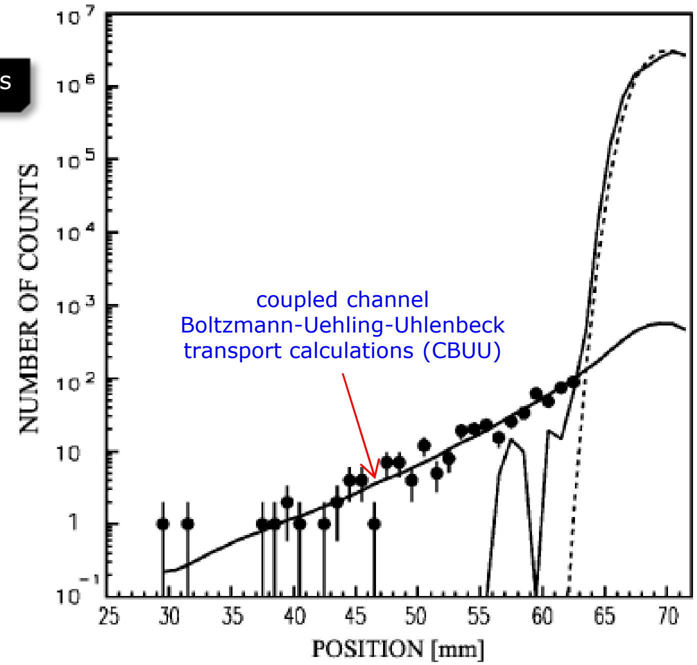


$\tau_\Lambda = 161 \pm 7_{stat} \pm 14_{syst}$ ps $= 0.61\ \tau_{\Lambda free}$

P. Kulessa *et al.*, Phys. Let. B 427 (1998) 403.

p + Au measurement

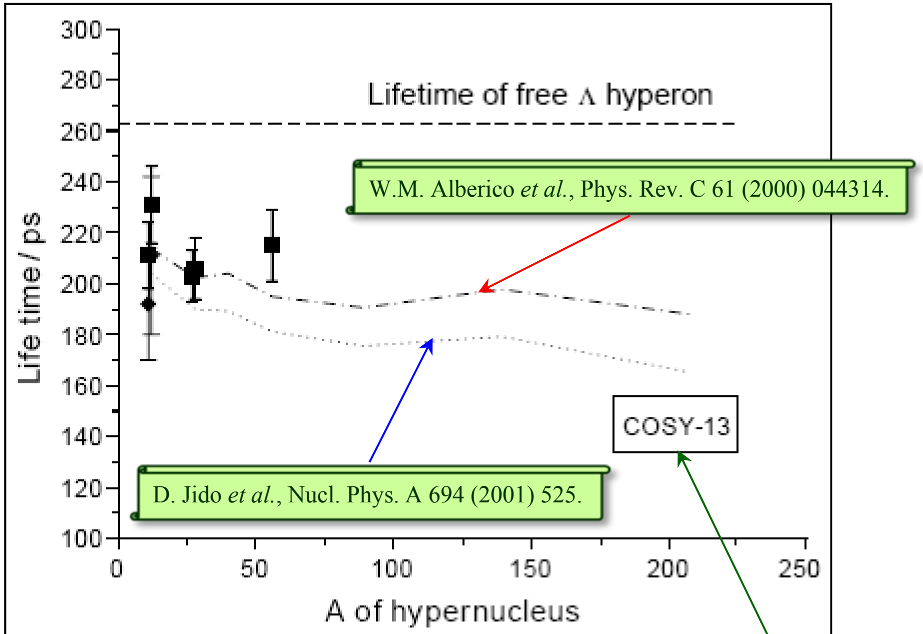




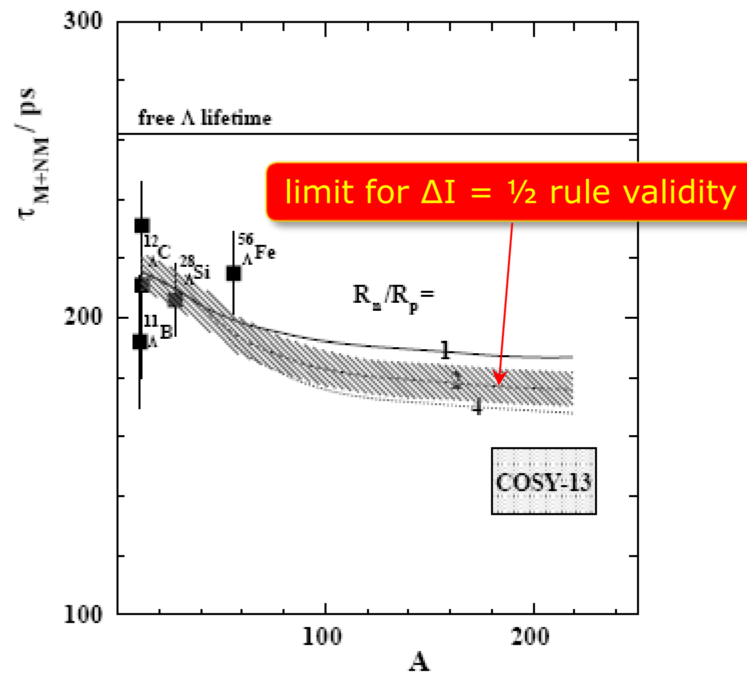
$\tau_\Lambda = 130 \pm 13_{stat} \pm 15_{syst}$ ps $= 0.49\ \tau_{\Lambda free}$

B. Kamys *et al.*, Eur. Phys. J. A 11 (2001) 1.

Hypernucleus τ and ΔI = ½ rule



$$\frac{R_n}{R_p} \approx 2\left(\frac{\Gamma_n}{\Gamma_p}\right) + 1$$



W. Cassing *et al.*, Eur. Phys. J. A 16 (2003) 549.

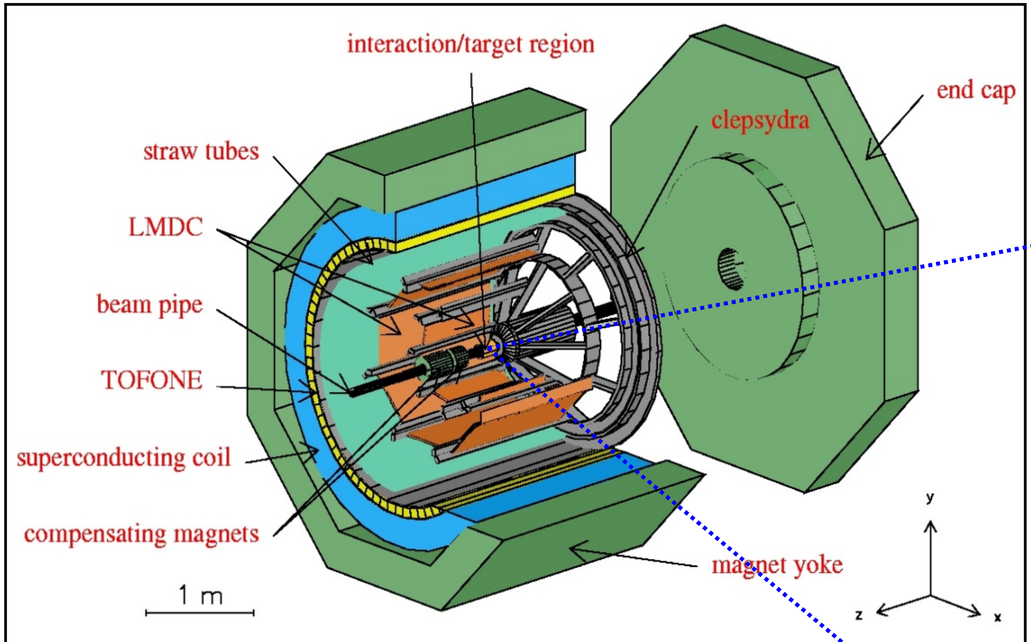
τ_Λ = 145 ± 11 ps

A = 180 - 225

indication for a
strong violation of the ΔI = ½ rule

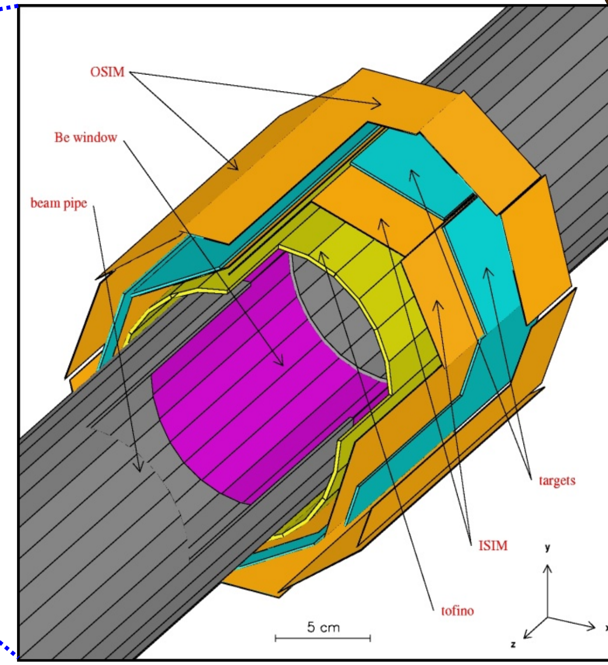
C.L. = 98%

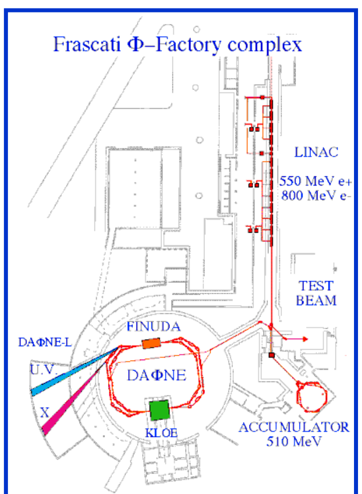
FINUDA @ DAΦNE



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

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





energy	510 MeV
luminosity	$5\ 10^{32}$ cm^{-2} s^{-1}
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)

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

The FINUDA key features

- very thin nuclear targets ($0.1 \div 0.3$ g/cm^2)

  → high resolution spectroscopy

- coincidence measurement with large acceptance

  → decay mode study

- irradiation of different targets in the same run

  → systematic error reduction

The FINUDA physics program

- high-resolution **spectroscopy** of Λ-hypernuclei
- Λ-hypernucleus **decay** — see next talk by S. Bufalino
- neutron-rich Λ-hypernuclei — see next talk by E. Botta
- (deeply) bound kaon-nucleon states — see A. Filippi talk on Tuesday
- ...

thanks to the conveners
for the excellent organization of the session

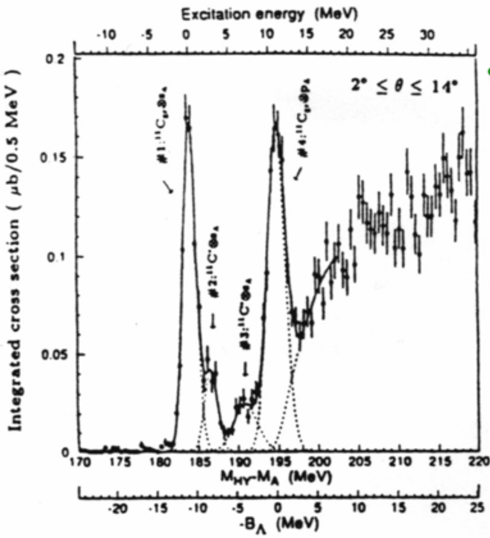
The crucial benchmark: resolution

1996

2005

2008

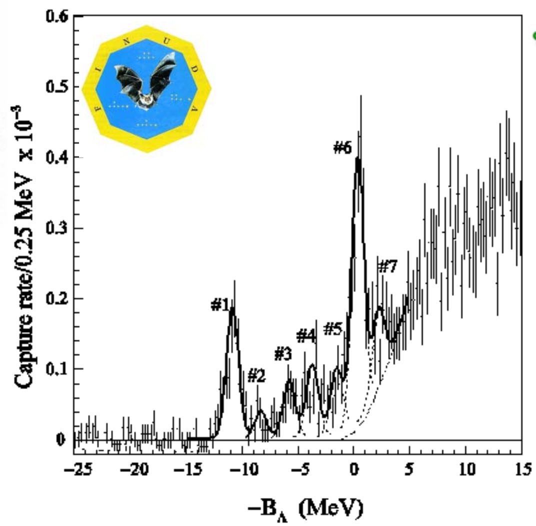
t



T. Hasegawa *et al.*, Phys. Rev. C 53 (1996) 1210

ΔE ~ 1.9 MeV FWHM

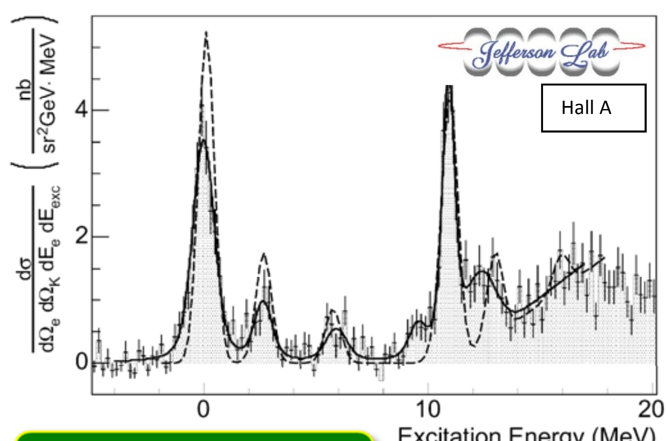
$^{12}C(\pi^+,K^+)^{12}_{\Lambda}C$



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

ΔE ~ 1.3 MeV FWHM

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

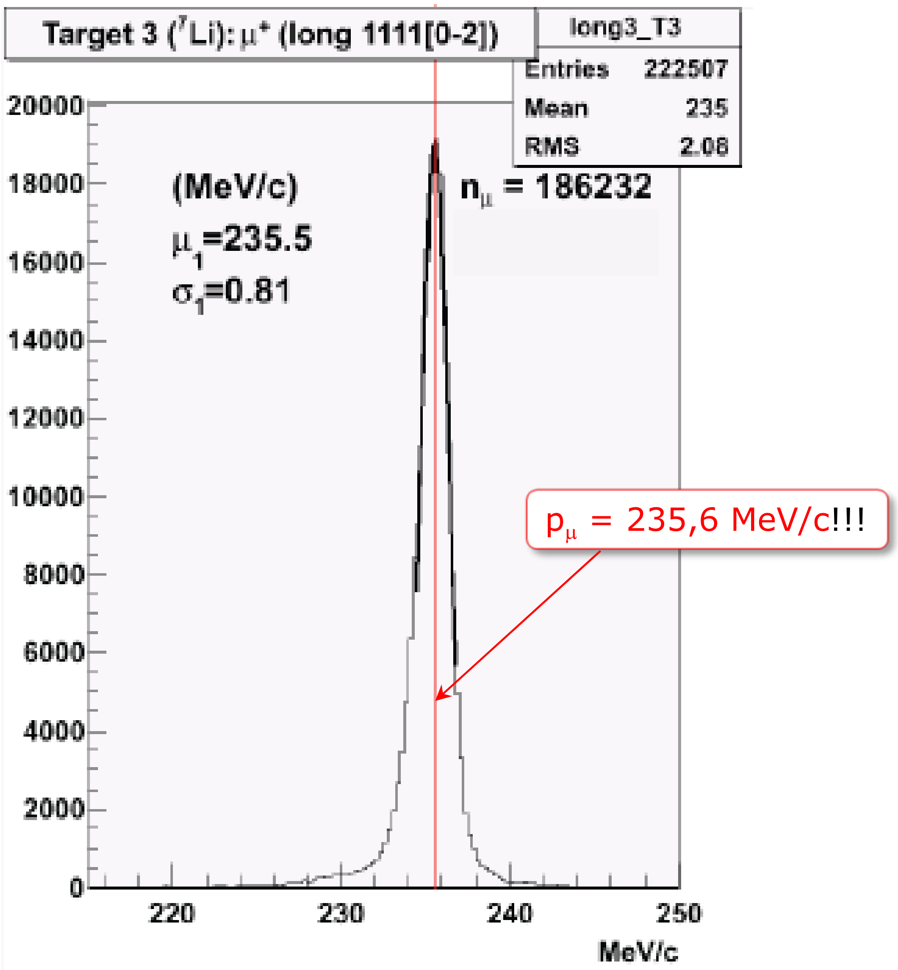


G.M. Urciuoli *et al.*, Nucl. Phys. A 805 (2008) 170

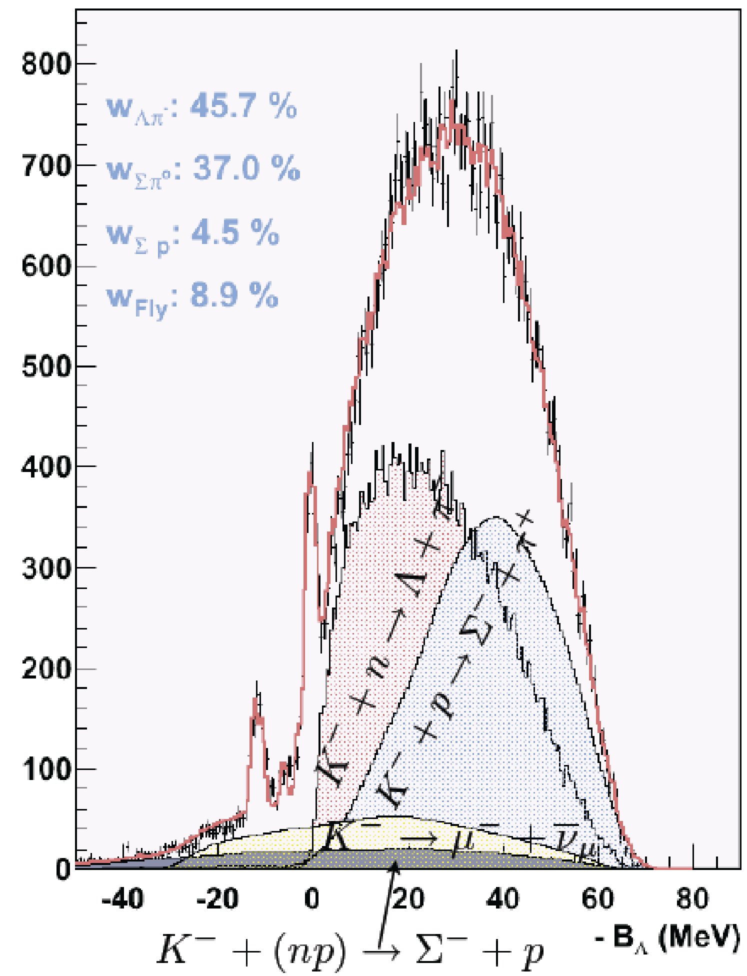
ΔE ~ 0.67 MeV FWHM

$^{12}C(e,e',K^+)^{12}_{\Lambda}B$

Energy calibration and background

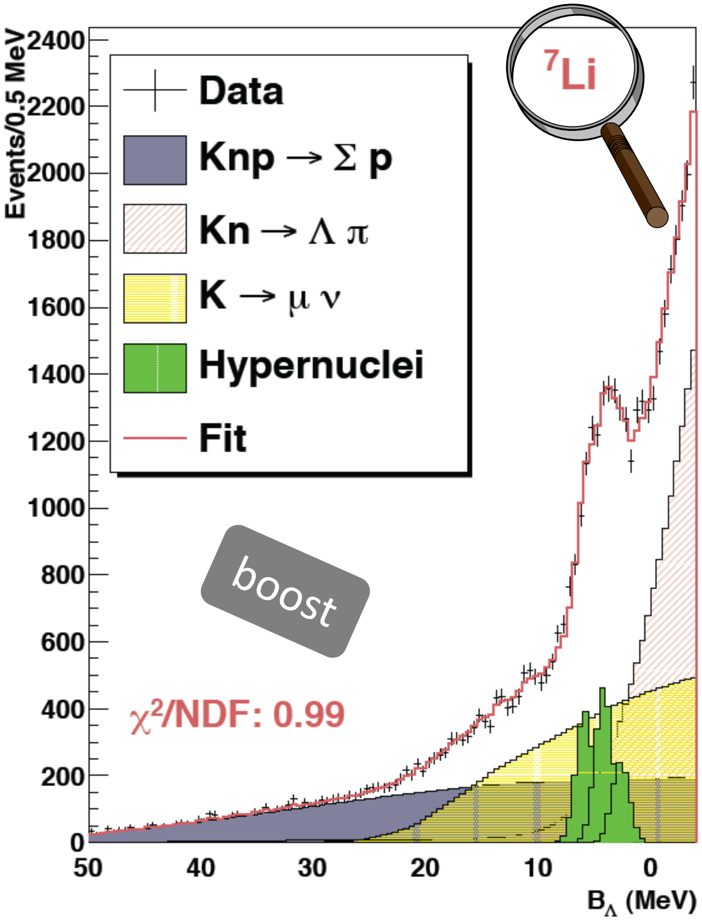


$$K^{+} \rightarrow \mu^{+} + \nu_{\mu}$$



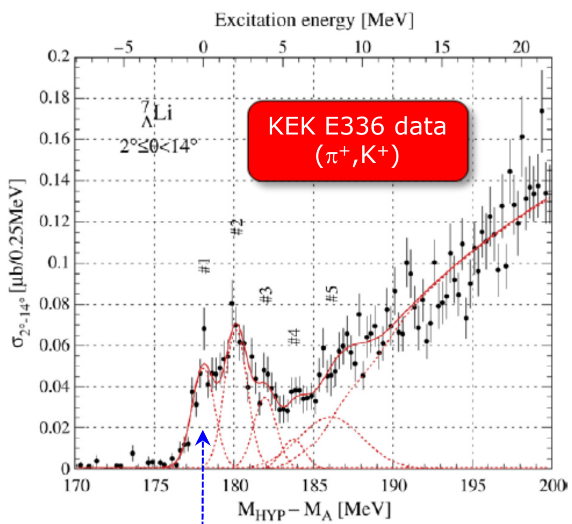
A. Feliciello / STORI '11, Frascati (RM), Italy, October, 9-14, 2011.

FINUDA results on ^{7}Li target



M. Agnello *et al.*, Phys. Lett. B 698 (2011) 219.

^{7}Li	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	5.8 ± 0.4	–	$0.37 \pm 0.04 \pm 0.05$
2	4.1 ± 0.4	1.7	$0.46 \pm 0.05 \pm 0.06$
3	2.6 ± 0.4	3.2	$0.21 \pm 0.03 \pm 0.03$
			$1.04 \pm 0.12 \pm 0.14$

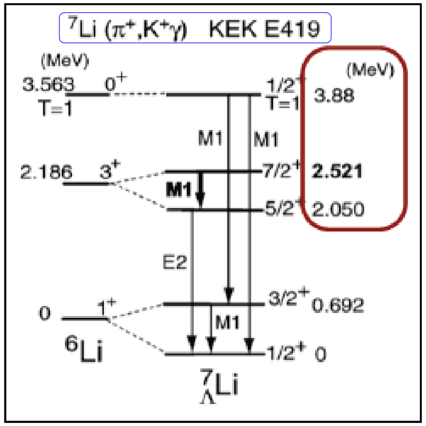


B_Λ = -5.22 ± 0.08 MeV

O. Hashimoto, H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564.

B_Λ = -5.58 ± 0.03 MeV

M. Juric *et al.*, Nucl. Phys. B 52 (1973) 1.



Hyperball

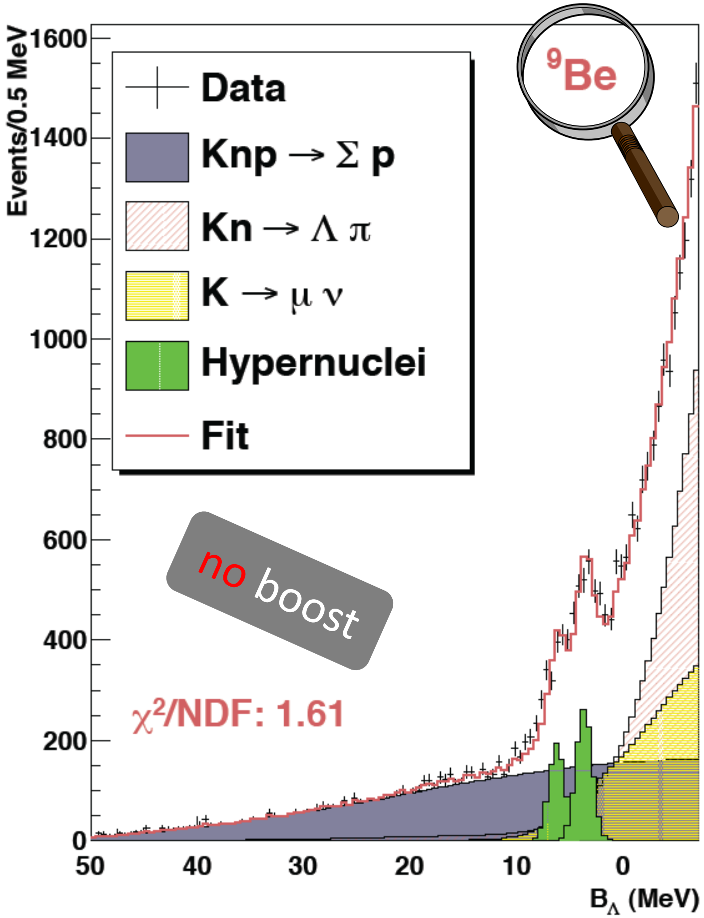
H. Tamura *et al.*, Nucl. Phys. A 754 (2005) 58c.

1st measurement of formation probability

spin-flip amplitude ≈ 0 →

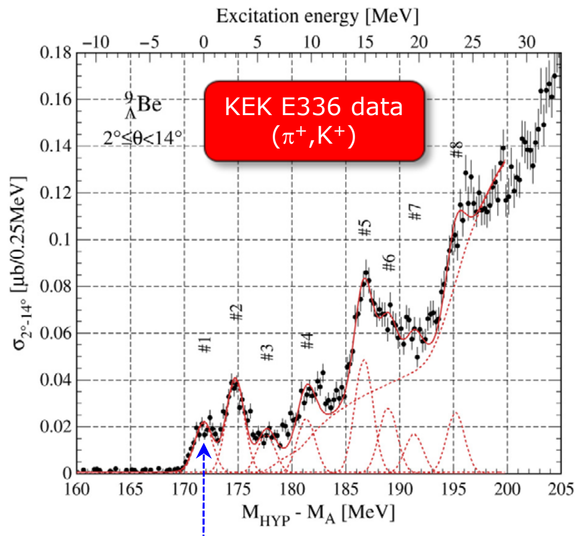
❶ ≡ 1/2+
❷ ≡ 5/2+
❸ ≡ T=1, 1/2+

FINUDA results on ^{9}Be target



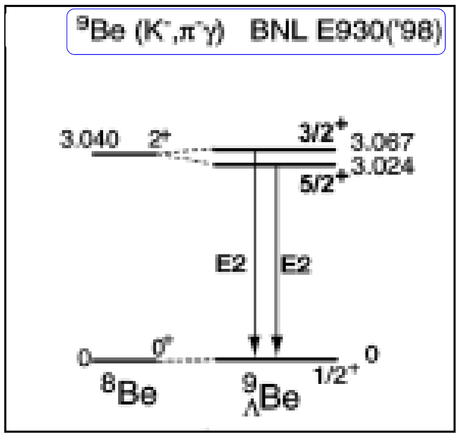
M. Agnello *et al.*, Phys. Lett. B 698 (2011) 219

^{9}Be	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	6.2 ± 0.4	–	$0.16 \pm 0.02 \pm 0.02$
2	3.7 ± 0.4	2.5	$0.21 \pm 0.02 \pm 0.03$
			$0.37 \pm 0.04 \pm 0.05$



B_Λ = -5.99 ± 0.07 MeV

O. Hashimoto, H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564.



Hyperball

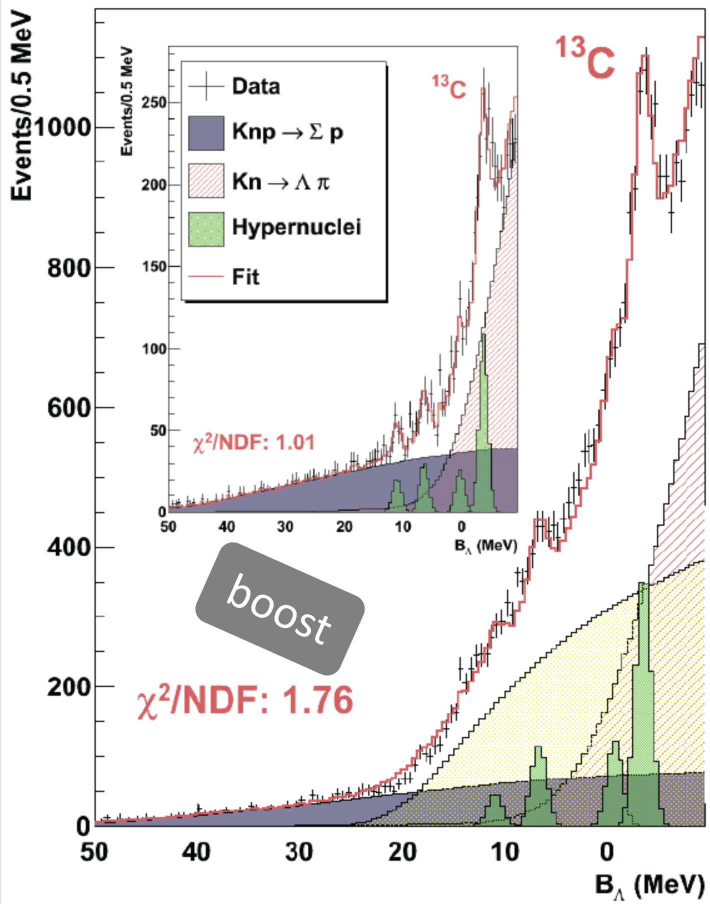
H. Tamura *et al.*, Nucl. Phys. A 754 (2005) 58c..

1st measurement of formation probability

B_Λ = -6.71 ± 0.04 MeV

M. Juric *et al.*, Nucl. Phys. B 52 (1973) 1.

FINUDA results on ^{13}C target

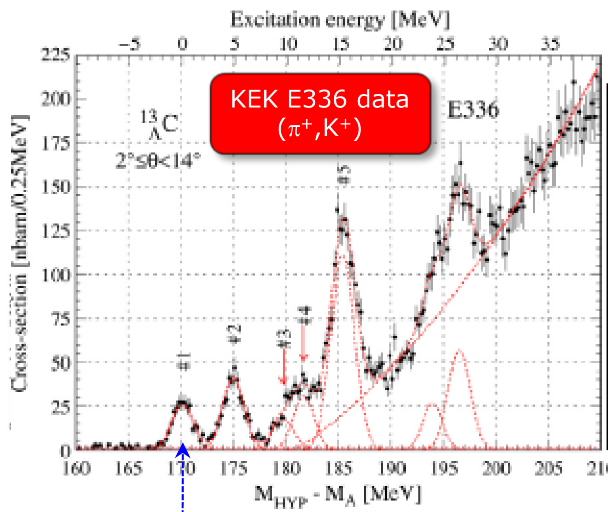


M. Agnello *et al.*, Phys. Lett. B 698 (2011) 219.

^{13}C	$B_Λ$ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	11.0 ± 0.4	–	$0.10 \pm 0.02 \pm 0.01$
2	6.4 ± 0.4	4.6	$0.19 \pm 0.02 \pm 0.03$
3	0.3 ± 0.4	10.7	$0.16 \pm 0.02 \pm 0.02$
4	-3.7 ± 0.4	14.7	$0.47 \pm 0.04 \pm 0.07$ $^{12}C + Λ$

0.45 ± 0.08 ± 0.09

first 3 states only



$B_Λ$ = -11.38 ± 0.05 MeV

O. Hashimoto, H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564.

$^{13}_Λ$C **hypernucleus studied with the ^{13}C($K^-,\pi^-\gamma$) reaction**

ceeded in measuring γ rays from the 1/2⁻ and 3/2⁻ states, which have predominantly a [^{12}C$_{g.s.}$(0⁺)⊗$p_Λ$] configuration, to the GS in $^{13}_Λ$C by using NaI detectors. The splitting was found to be ΔE(1/2⁻−3/2⁻) = +152±54(stat) ±36(syst) keV which was almost 20–30 times smaller than that of single particle states in nuclei around this mass region. The excitation energies of the 1/2⁻ and 3/2⁻ states were obtained as 10.982±0.031(stat)±0.056(syst) and 10.830±0.031(stat)±0.056(syst) MeV, respectively. The $j_Λ = \ell_Λ - 1/2[(p_{1/2})_Λ]$ state appeared higher in energy, as in normal nuclei, which is consistent with theoretical predictions. We also observed γ rays from the 3/2⁺ state to the GS in $^{13}_Λ$C and the excitation energy of the state was obtained as 4.880±0.010(stat)±0.017(syst) MeV.

BNL AGS-E929

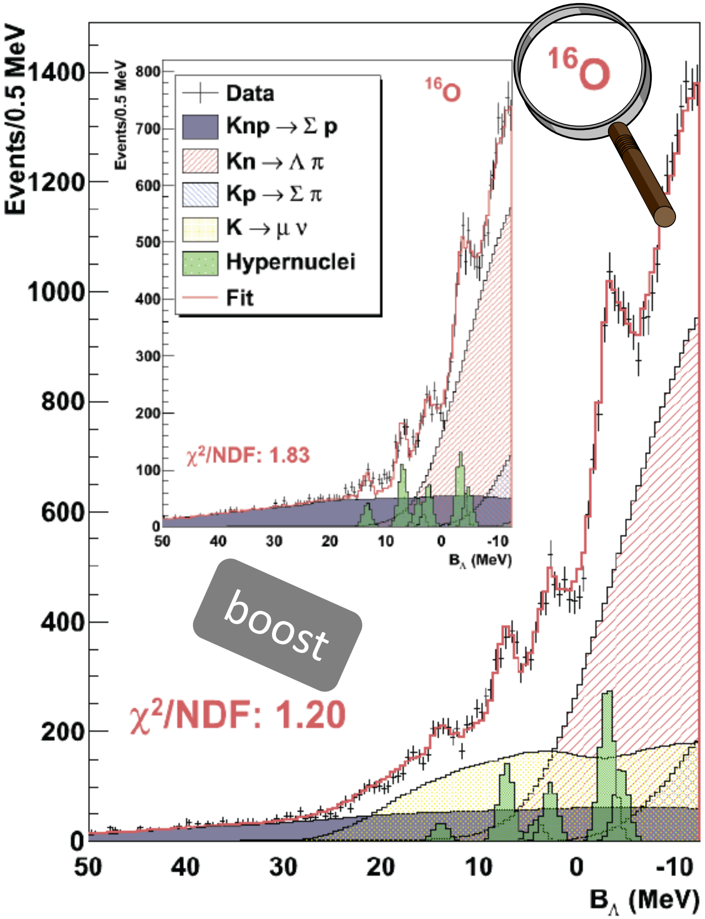
H. Kohri *et al.*, Phys. Rev. C 65 (2002) 034607.

1st measurement of formation probability

$B_Λ$ = -11.71 ± 0.08 MeV

M. Juric *et al.*, Nucl. Phys. B 52 (1973) 1.

FINUDA results on D_2O target

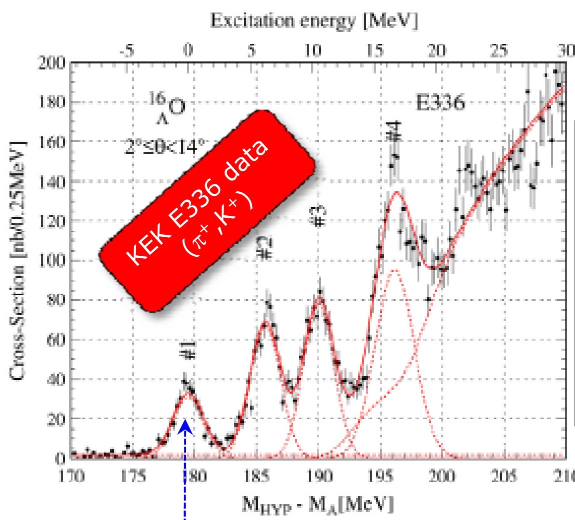


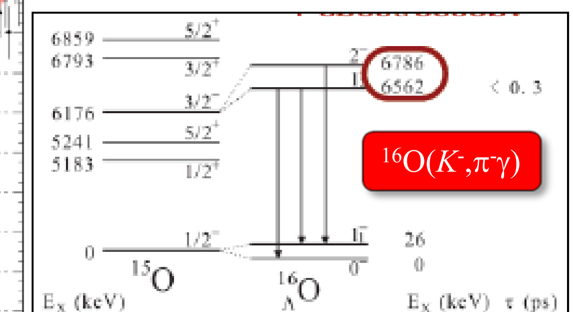
^{16}O	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	13.4 ± 0.4	–	$0.10 \pm 0.02 \pm 0.01$
2	7.1 ± 0.4	6.3	$0.26 \pm 0.04 \pm 0.04$
3	4.3 ± 0.4	9.1	$0.13 \pm 0.03 \pm 0.02$
4	2.4 ± 0.4	11.0	$0.15 \pm 0.03 \pm 0.02$
5	-3.3 ± 0.4	16.7	$0.55 \pm 0.07 \pm 0.08$
6	-4.7 ± 0.4	18.1	$0.28 \pm 0.06 \pm 0.04$

States 1–2: $^{16}_{\Lambda}O$; states 3–6: $^{15}_{\Lambda}N + p$

0.36 ± 0.06 ± 0.05

first 2 states only





Hyperball

M. Ukai *et al.*, Phys. Rev. C 77 (2008) 054315.

B_Λ = -12.42 ± 0.05 MeV

M. Agnello *et al.*, Phys. Lett. B 698 (2011) 219

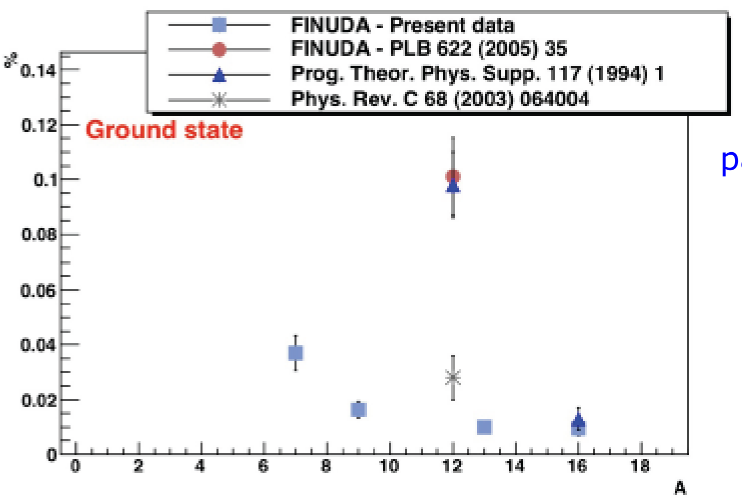
O. Hashimoto, H. Tamura, Prog. Part. Nucl. Phys. 57 (2006) 564.

KEK data (K^-,π^-) — B_Λ = -12.9 ± 0.4 MeV — H. Tamura *et al.*, Prog. Theor. Phys. Suppl. 117 (1994) 1.

Jlab Hall A data (e,e′K^+) — B_Λ = -13.76 ± 0.16 MeV — F. Cusanno *et al.*, Phys. Rev. Lett. 103 (2009) 202501.

Un unsatisfactory summary

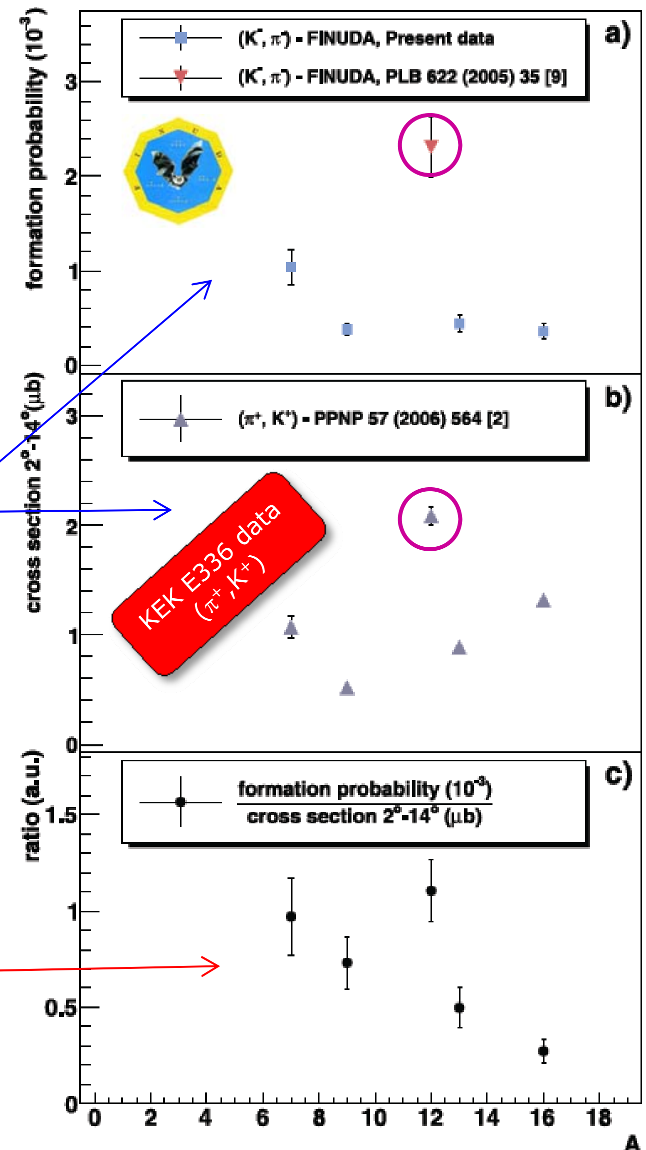
It is difficult to draw
a simple dependence on A
for the formation probability



K_{stop} induced reactions

particle (p) stable levels only

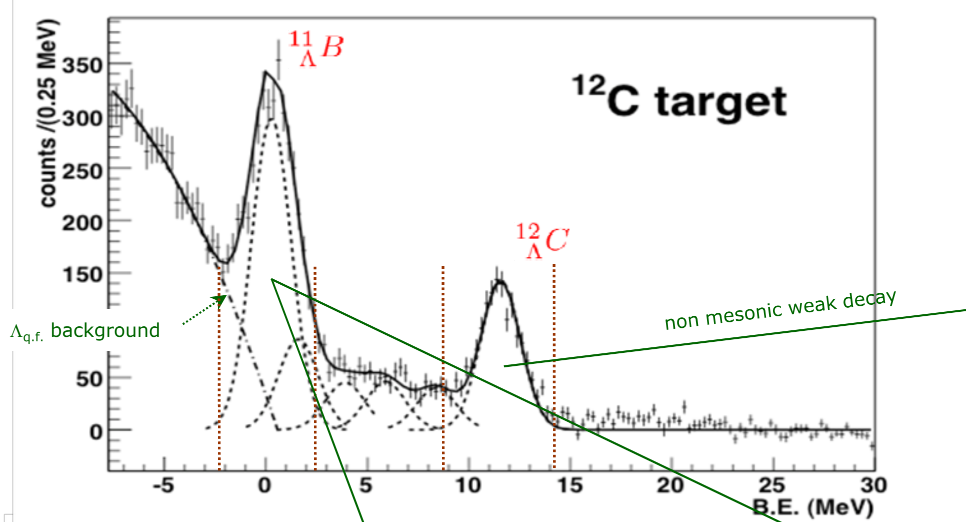
large spread



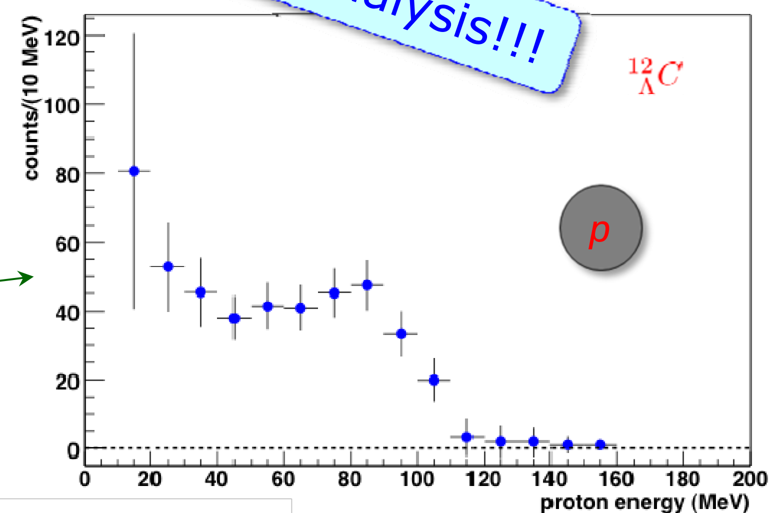
M. Agnello *et al.*, Phys. Lett. B 698 (2011) 219.

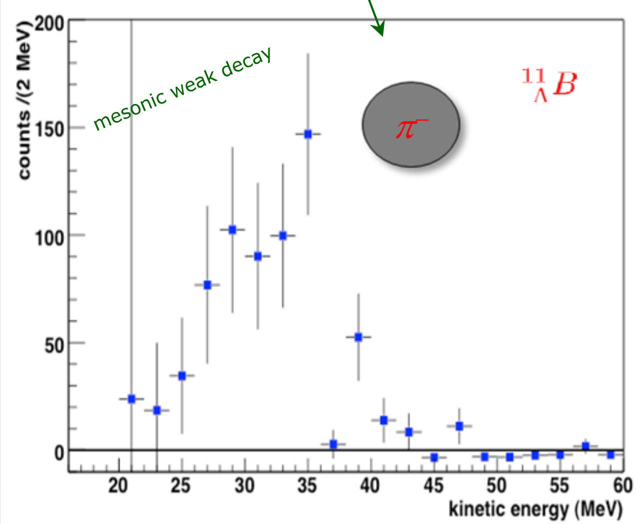
Hypernucleus decay: the FINUDA stategy

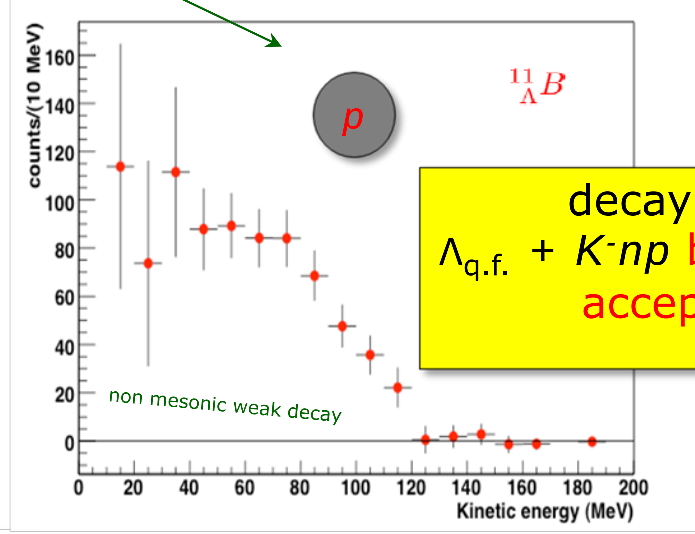
inclusive production π^- spectra
$K^- np$ background subtracted



magnetic analysis!!!







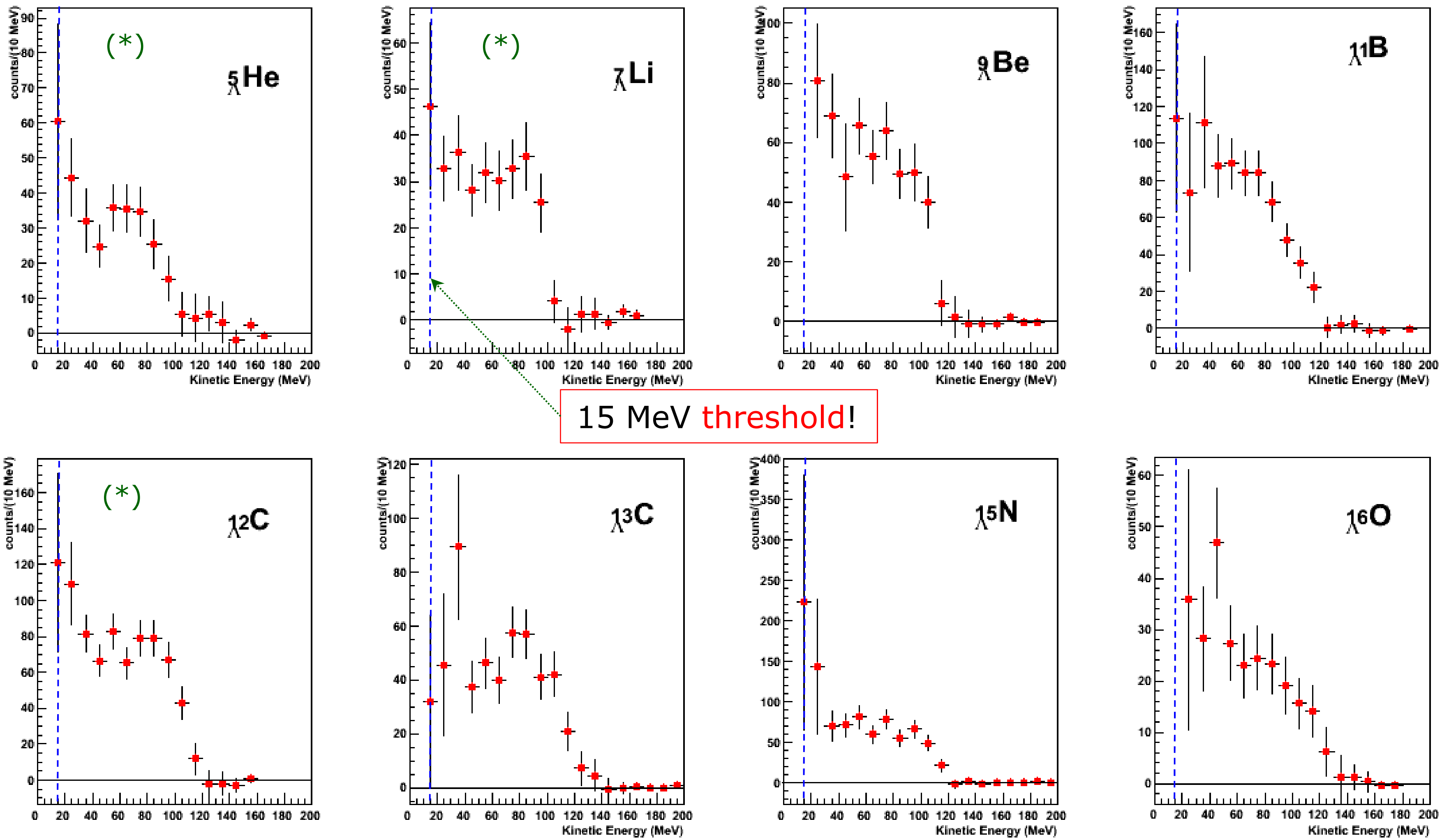
decay π^- and p spectra
$\Lambda_{q.f.}$ + $K^- np$ background subtracted
acceptance corrected

A. Feliciello / STORI '11, Frascati (RM), Italy, October. 9-14, 2011.

Non-mesonic weak decay p spectra

p spectra *K⁻np* background subtracted

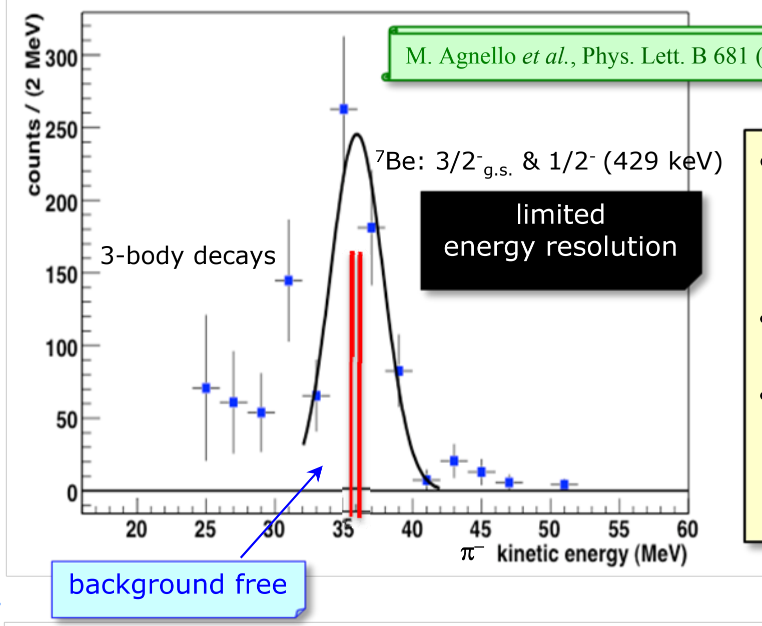
M. Agnello *et al.*, Phys. Lett. B 685 (2010) 247.



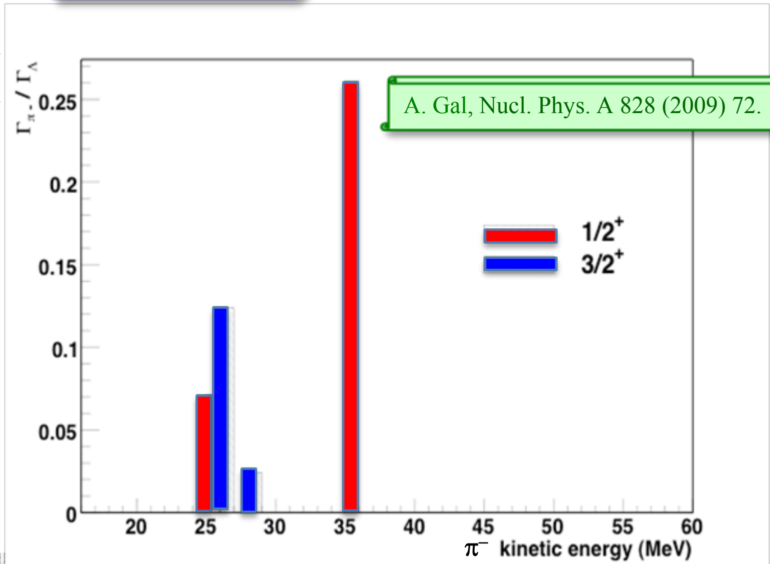
(*) M. Agnello *et al.*, Nucl. Phys. A 804 (2008) 151.

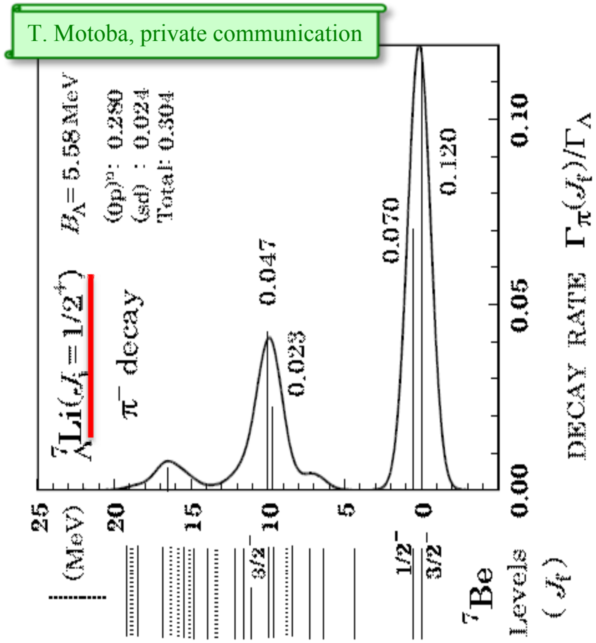
$1\mathcal{N} + 2\mathcal{N}$ + FSI!!!

$^7Li_\Lambda$ J^π assignment



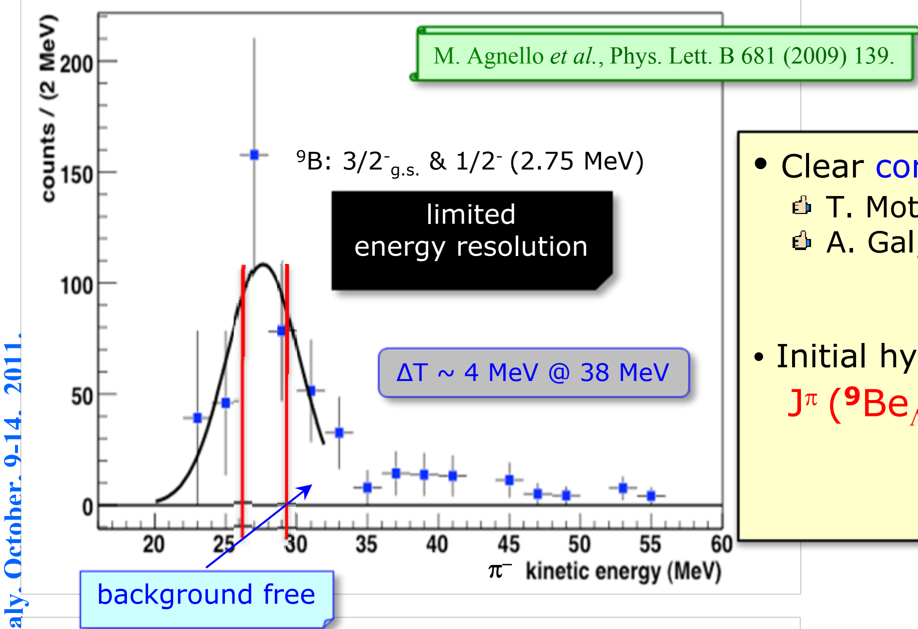
- Clear correspondence with the calculated strenght functions:
  - T. Motoba et al, Progr. Theor. Phys. Suppl. 117 (1994) 477.
  - A. Gal, Nucl. Phys. A 828 (2009) 72.
- Formation of different excited states of the daughter nucleus
- Initial hypernucleus spin
  $J^\pi(^7Li_{\Lambda g.s.}) = 1/2^+$ (J. Sasao, Phys. Lett. B 579 (2004) 258.





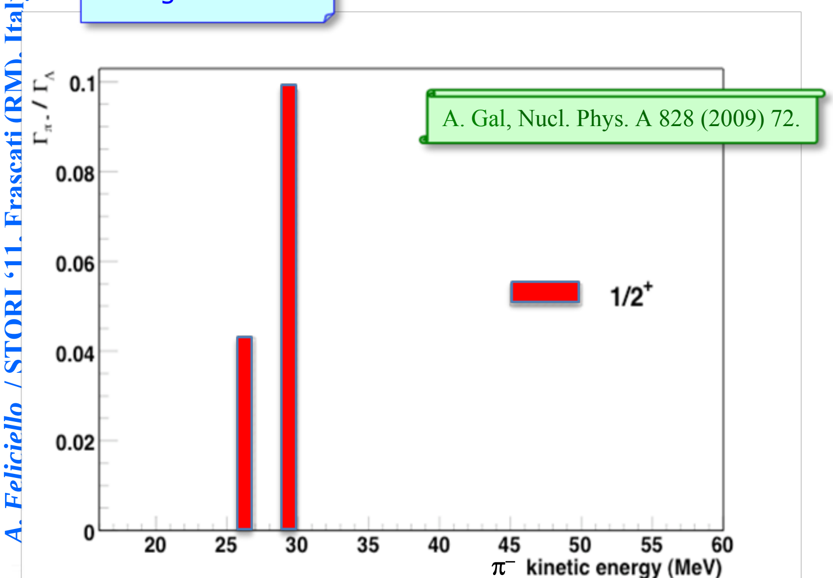
A. Feliciello / STORI '11, Frascati (RM), Italy, October, 9-14, 2011.

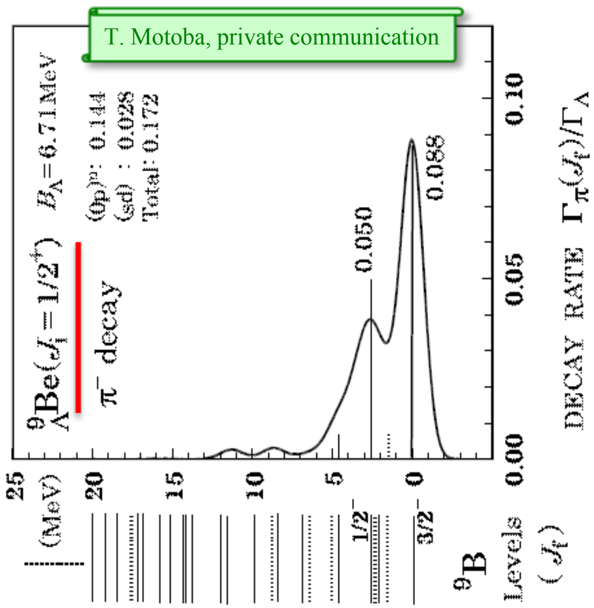
$^{9}Be_{\Lambda}$ J^{π} assignment



- Clear correspondence with the calculated strenght functions:
  - T. Motoba *et al.*, Progr. Theor. Phys. Suppl. 117 (1994) 477.
  - A. Gal, Nucl. Phys. A 828 (2009) 72.

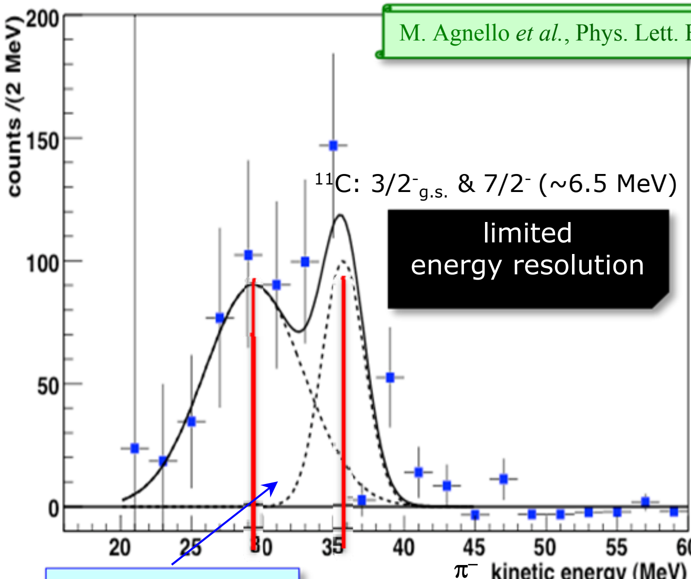
- Initial hypernucleus spin
  J^{π} ($^{9}Be_{\Lambda g.s.}$) = $1/2^{+}$ (O.Hashimoto *et al.*, Nucl. Phys. A 639 (1998) 93c.)





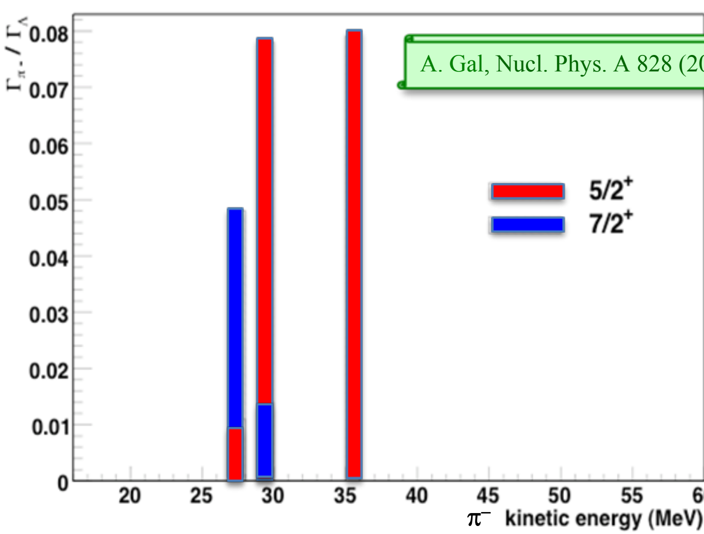
$^{11}B_{\Lambda}$ J^{π} assignment

M. Agnello *et al.*, Phys. Lett. B 681 (2009) 139.

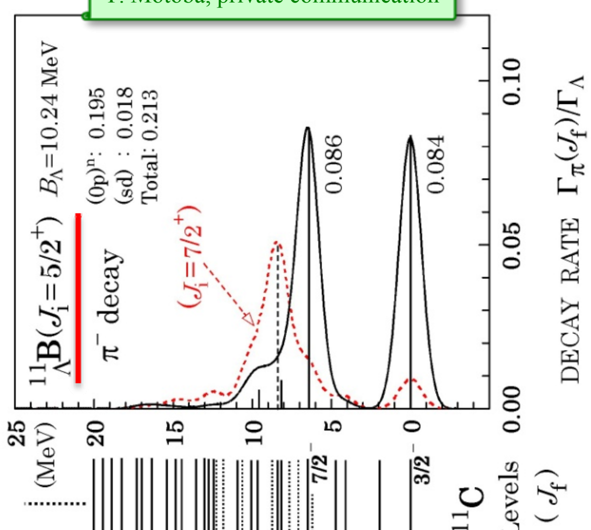


- Clear correspondence with the calculated strenght functions:
  - H. Bandō et al, Pers. Meson Science (1992) p.571
  - A. Gal, Nucl. Phys A 828 (2009) 72.
- Two contributions of the ^{11}C ground state $5/2^-$ and its $7/2^-$ excited state
- Initial hypernucleus spin
  J^{π} ($^{11}B_{\Lambda\ g.s.}$) = $5/2^+$ experimental confirmation by different observable (Y. Sato et al., Phys. Rev. C 71 (2005) 025203)

A. Gal, Nucl. Phys. A 828 (2009) 72.

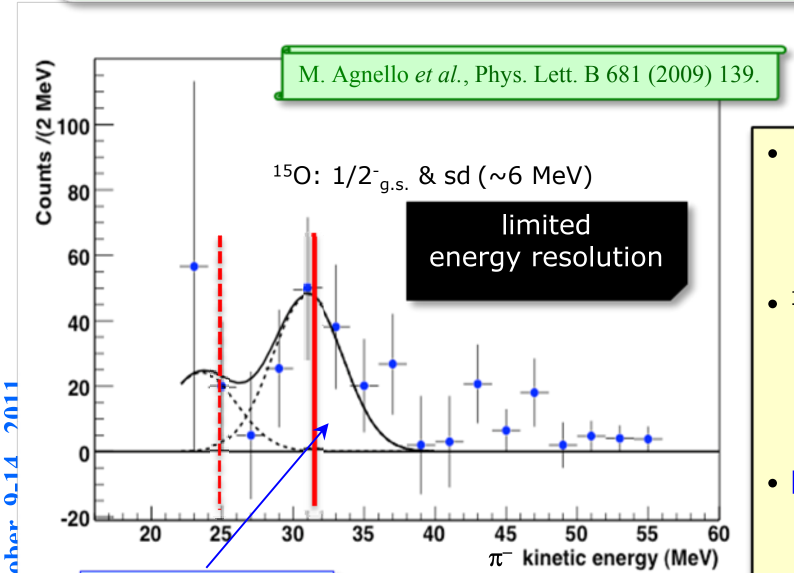


T. Motoba, private communication

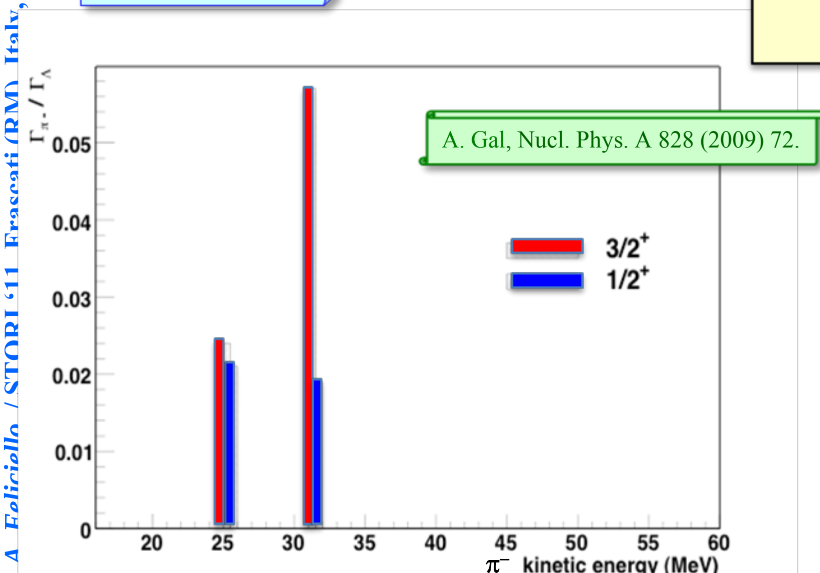


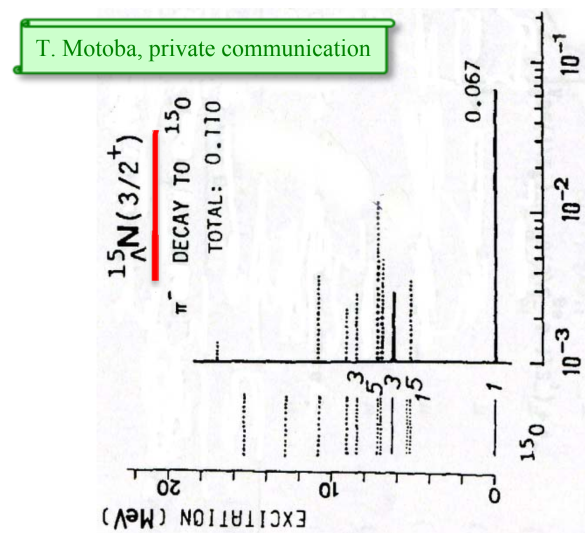
$^{15}N_\Lambda$ J^π assignment

1st experimental determination



- Clear correspondence with the calculated strenght functions:
  - T. Motoba *et al.*, Nucl. Phys. A 489 (1988) 683.
  - A. Gal, Nucl. Phys. A 828 (2009) 72.
- $^{15}N_{\Lambda\ g.s}$ spin not known $J^\pi(^{15}N_{\Lambda\ g.s.}) = 3/2^+$
  D.J. Millener, A. Gal, C.B. Dover, Phys. Rev. C 31 (1985) 499.
  Spin ordering not obtained from γ-rays of $^{16}O_\Lambda$
  M. Ukai *et al.*, Phys. Rev. C 77 (2008) 054315.
- First experimental determination of
  $J^\pi(^{15}N_{\Lambda\ g.s.}) = 3/2^+$ from decay rate value (and spectrum shape)





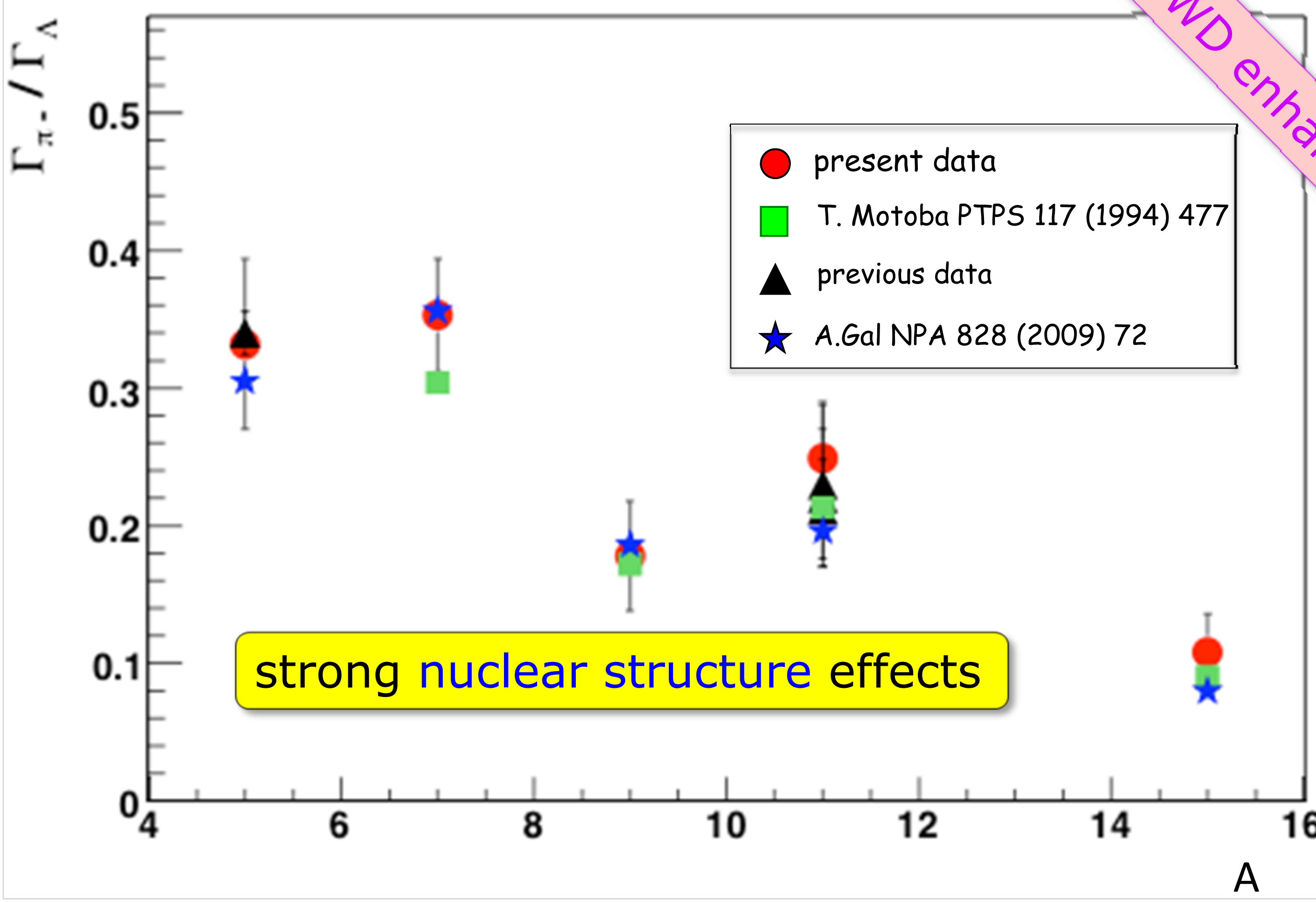
$\Gamma_{\pi^-}/\Gamma_\Lambda$ ratio dependence on A

$\Gamma_{\pi^-}/\Gamma_\Lambda = \Gamma_{tot}/\Gamma_\Lambda \; BR_{\pi^-}$

$\Gamma_{tot}/\Gamma_\Lambda = (0.990 \pm 0.094) + (0.018 \pm 0.010)A$

fit to measured values for A = 4-12 hypernuclei

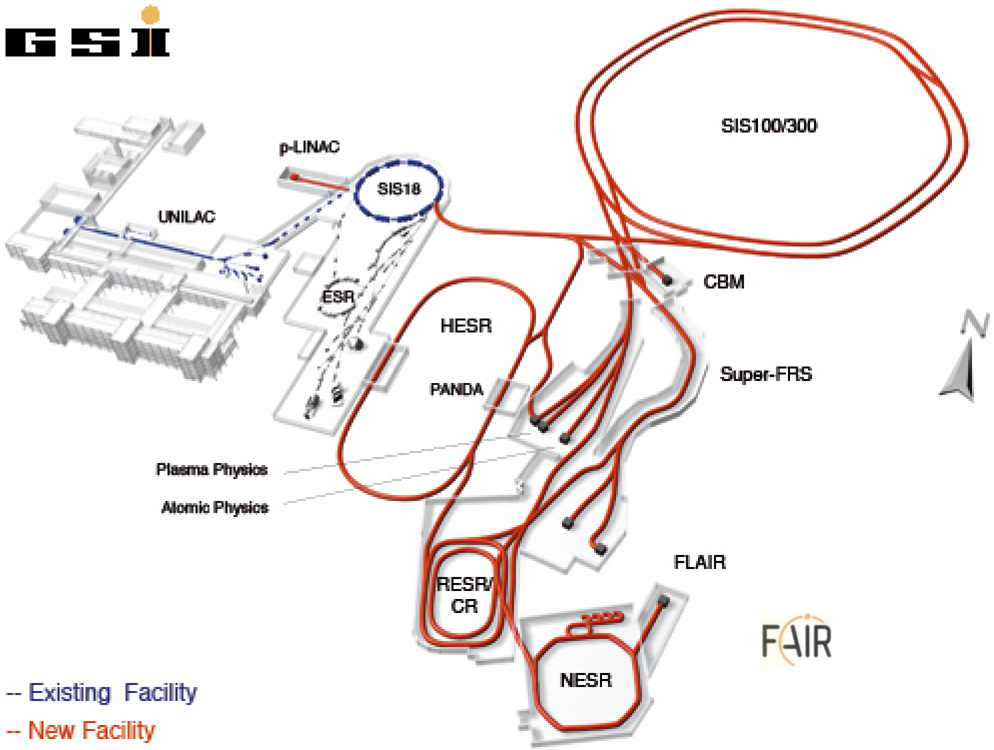
π distortion, MWD enhancement proved



strong nuclear structure effects

FAIR @ GSI

see A. Lehrach talk on Wednesday



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 10000 in intensity over present
- $\bar{p}$ 0 - 30 GeV

Storage and Cooler Rings

- radioactive beams
- e^- – A (or $\bar{p}$-A) collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV $\bar{p}$
- polarized $\bar{p}$ (?)

Technical Key Features

- cooled beams
- rapidly cycling superconducting magnets
- parallel operation

ΛΛ hypernuclei @ $\bar{P}$ANDA

Hadron Spectroscopy

Observables: *masses, widths & quantum numbers J^{PC} of resonances*

Charm Hadrons: *charmonia, D-mesons, charm baryons*

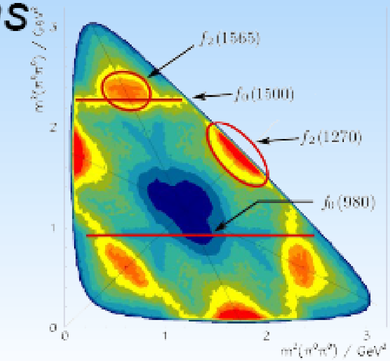
➔ Understand new XYZ states, $D_s(2317)$ and others

Exotic QCD States: *glueballs, hybrids, multi-quarks*

Spectroscopy with Antiprotons:

Production of states of all quantum numbers

Resonance scanning with high resolution



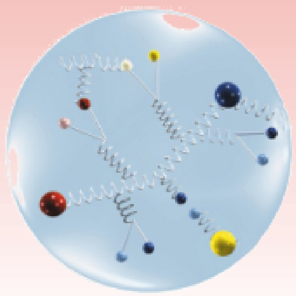
Hadron Structure

Generalized Parton Distributions

➔ Formfactors and structure functions, L_q

Timelike Nucleon Formfactors

Drell-Yan Process

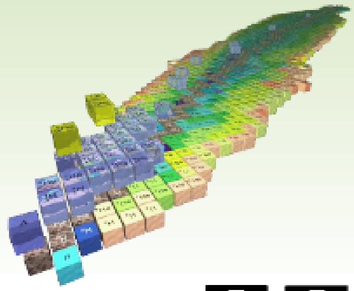


Nuclear Physics

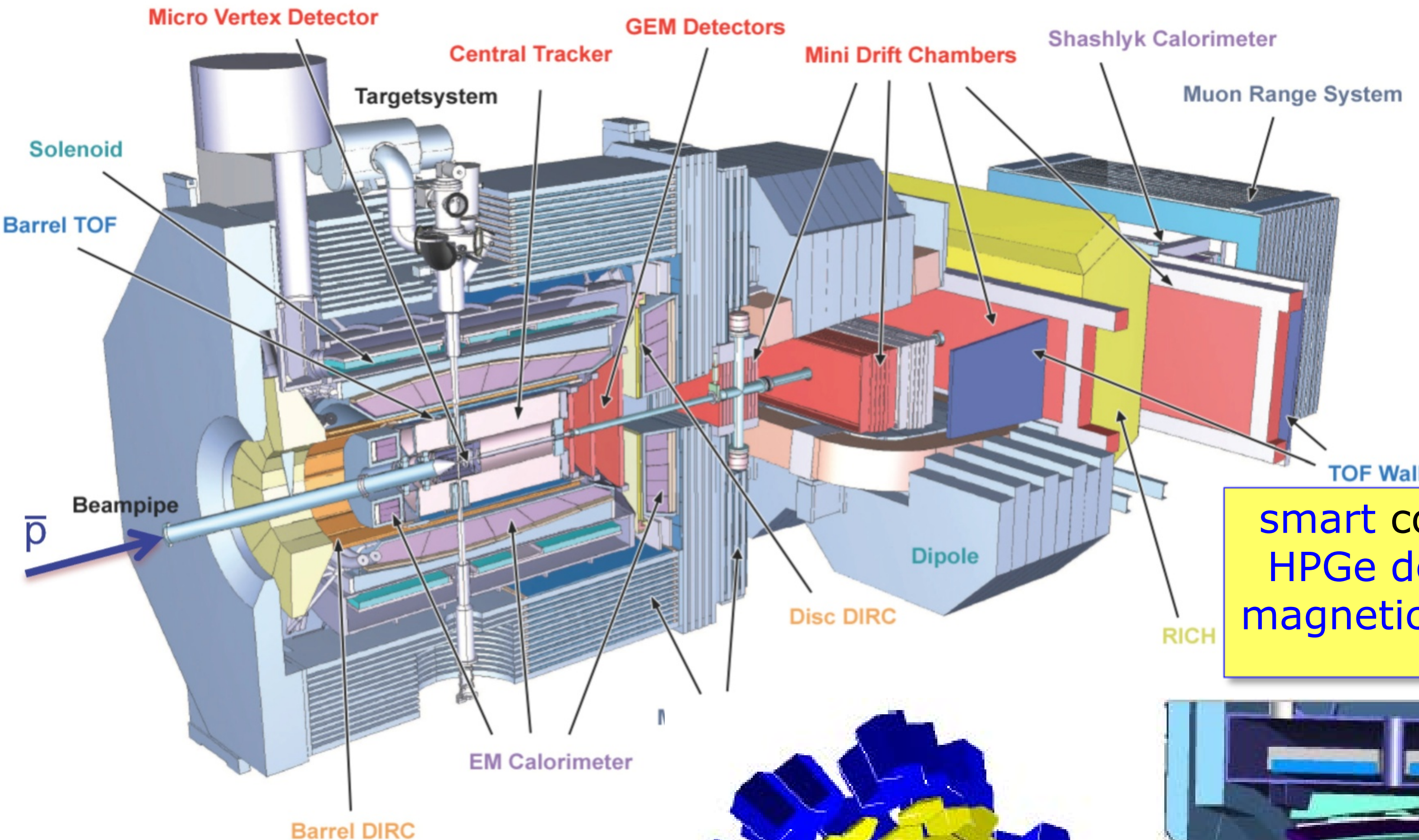
Hypernuclei: Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction

Hadrons in Nuclear Medium

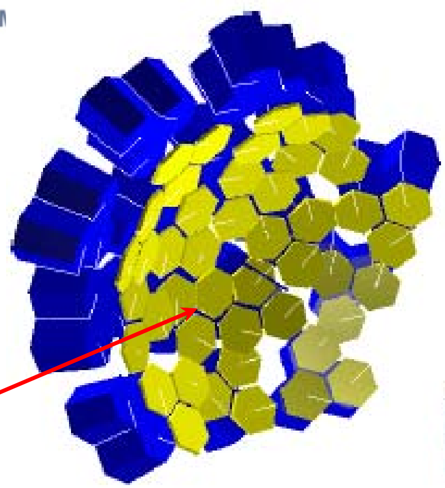


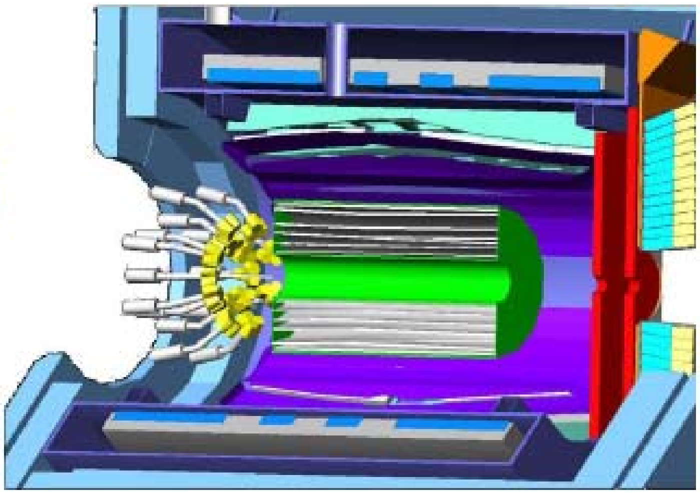
The hyper P̄ANDA spectrometer



smart combination of HPGe detectors and magnetic spectrometer

“trio” cluster HPGe array





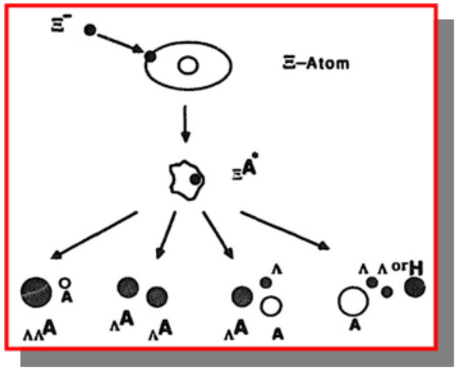
Double strangeness production

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

- compound double Λ state:

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

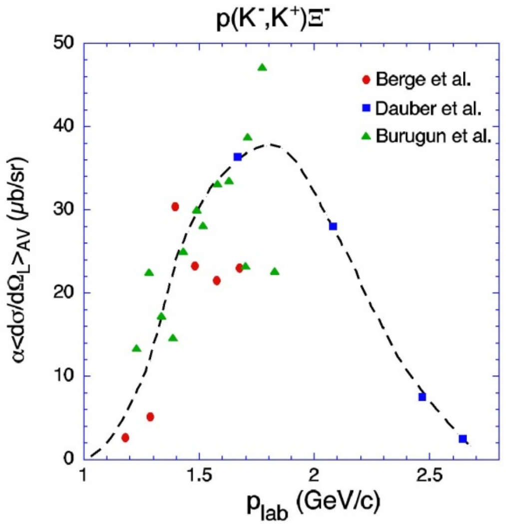
$$\Xi^- + p \rightarrow \Lambda + \Lambda + 28\ \mathrm{MeV}$$



- 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



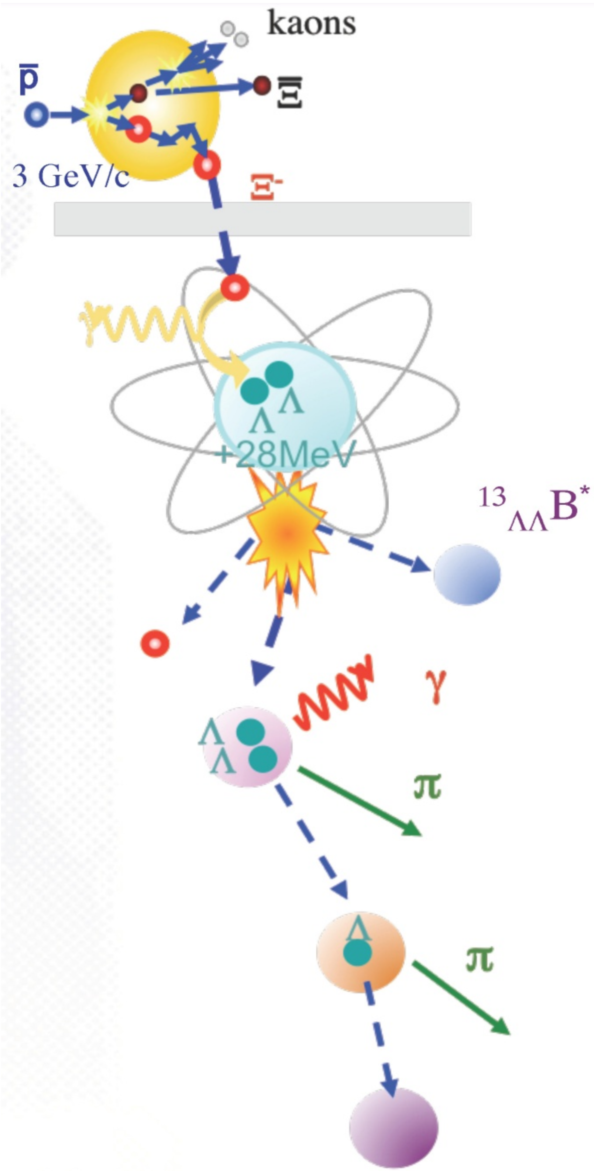
$$K^- + p \rightarrow \Xi^- + K^+$$ q.f.

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

K^- beams:

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

$\Lambda\Lambda$ hypernucleus production and detection @ $\bar{P}$ANDA



$\bar{p} + {}^{12}C \Rightarrow \Xi^- + \bar{\Xi}$ Primary target

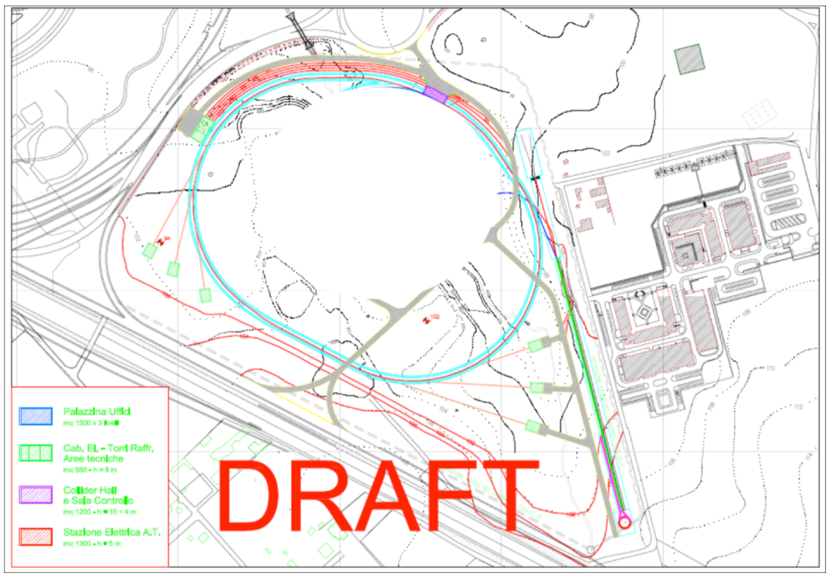
Secondary target

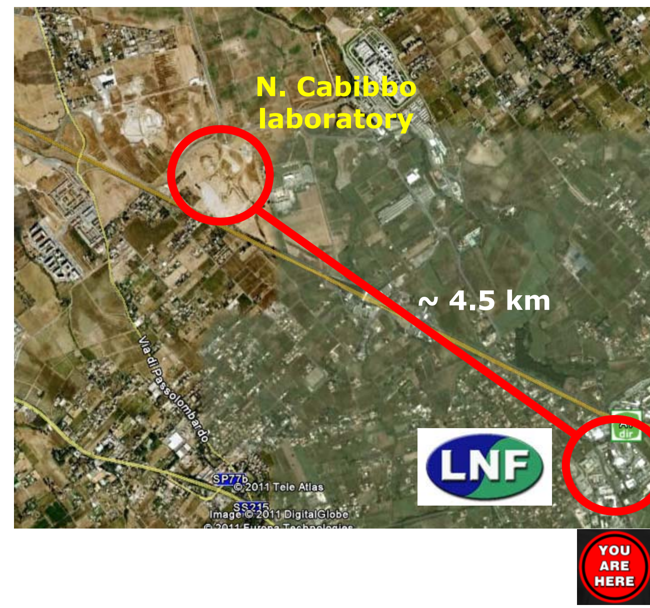
1. Deceleration and capture of Ξ^-
2. $\Xi^- + p \Rightarrow \Lambda\Lambda + 28$ MeV
3. $^{13}_{\Lambda\Lambda}B^* \Rightarrow$ Statistical decay
4. Excited hyperfragments
5. Sequential pionic decay

The SuperB project

see F. Wilson talk on Tuesday

- Super*B* is a flagship INFN project
- It was approved and funded in December 2010 by Italian Education and Research Minister





- Conceptual Design Report: arXiv:0709.0451v2 [hep-ex]
  http://web.infn.it/superb/images/stories/upload_file/superb-cdr.pdf
- Accelerator Progress Report: arXiv:1009.6178v2 [physics.acc-ph]

Event rate rough estimate (I)

$e^- + e^+ \rightarrow \Upsilon(4S)$ σ ≈ 1.1 nb $\mathscr{L} \approx 1 \times 10^{36}$ cm^{-2}s^{-1} ≈ 1.1 kHz

$B^- + B^+$ $76.7\ MeV \lesssim T_{B^\pm} \lesssim 273.7\ MeV$ ≈ 550 Hz

$B^-_{stop} + \mathcal{N}_{bound} \rightarrow \Lambda_b^0 + \pi^{-0}$

$B^-_{stop} + \mathcal{N}_{bound} \rightarrow \Sigma_b^{\pm} + \pi^{-0+}$

$B^-_{stop} + \mathcal{N}_{bound} \rightarrow \Sigma_b^{\pm *} + \pi^{-0+}$

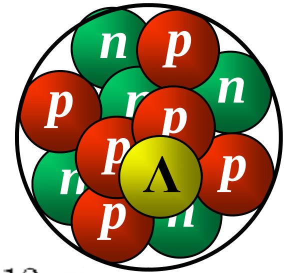
$B^-_{flight} + \mathcal{N}_{bound} \rightarrow \Xi_b^{-0} + K^{+0}$?

~~$B^-_{flight} + \mathcal{N}_{bound} \rightarrow \Omega_b^- + K^+ + K^0$~~

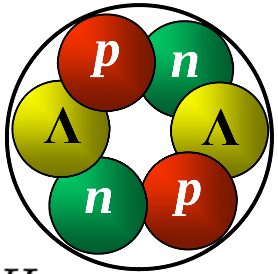
From hyper- to super-nuclear physics

$\Lambda(uds)$

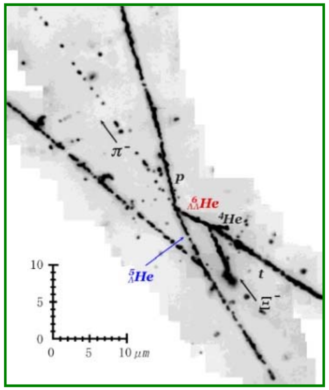
m = 1115.7 MeV
τ = 263.1 ps



$^{12}_{\Lambda}C$



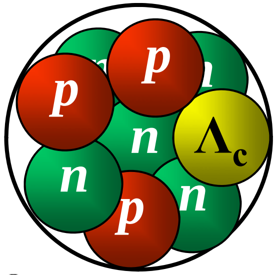
$^{6}_{\Lambda\Lambda}He$



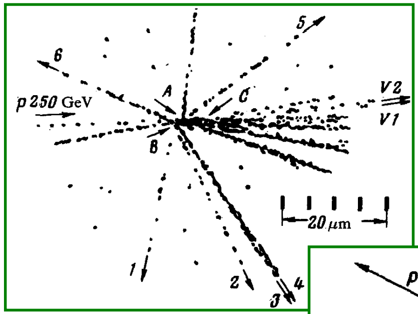
Phys. Rev. Lett. 87 (2001) 212502

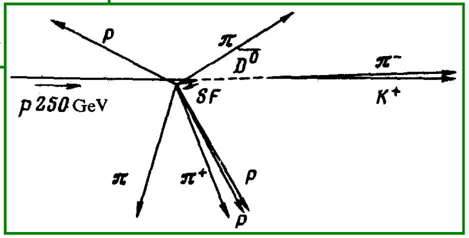
$\Lambda_c^+(udc)$

m = 2286.5 MeV
τ = 200.0 fs



$^{9}_{\Lambda_c}B$



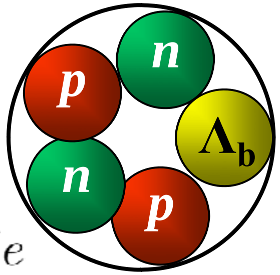


JETP Lett., 33 (1981) 52

$\Lambda_b^0(udb)$

m = 5620.2 MeV
τ = 1391 .0 fs

?



$^{5}_{\Lambda_b}He$

Outlook

storage rings are complementary playgrounds for hypernuclear physics:

COSY-13: - elegant method
- refined technique
- puzzling results

FINUDA: - really complete apparatus
- unique *K* "beams"
- wide spectrum of systematic results

panda - first attempt of "smart" combination of γ and magnetic spectrometer
- promising experiment

Super*B*: - a step forward… towards "terra incognita": from hypernuclear to supernuclear physics