RIKEN NiSHiNA CENTER
RIKEN Nishina Center for Accelerator-Based Science

International Workshop on Future prospect
on nuclear physics with strangeness
at J-PARC
RIKEN, Tokyo, Japan, May 31 – June 1, 2014

Present situation of $^{6}H_{\Lambda}$, recent advance on non-mesonic hypernuclear decay and future project(s)

Alessandro Feliciello

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

Acknowledgement

A **warm thanks** to the organizers
for the **invitation**

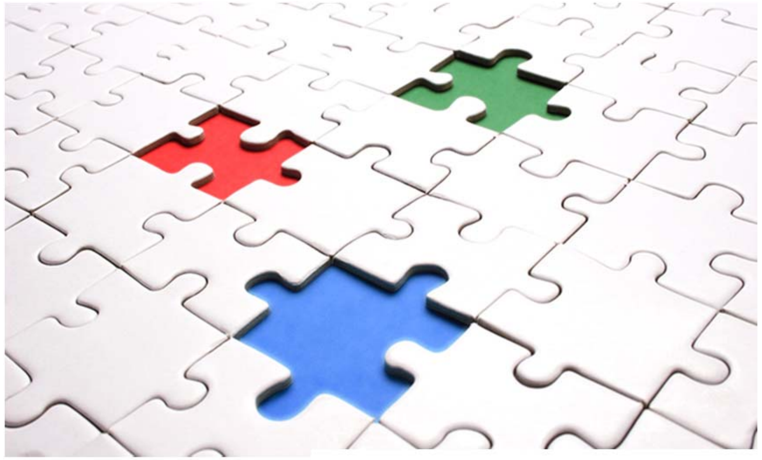
and to

Grant-In-Aid for Scientific Research on Innovative Areas "Nuclear Matter in Neutron Stars Investigated by Experiments and Astronomical Observations"

for the **financial support**

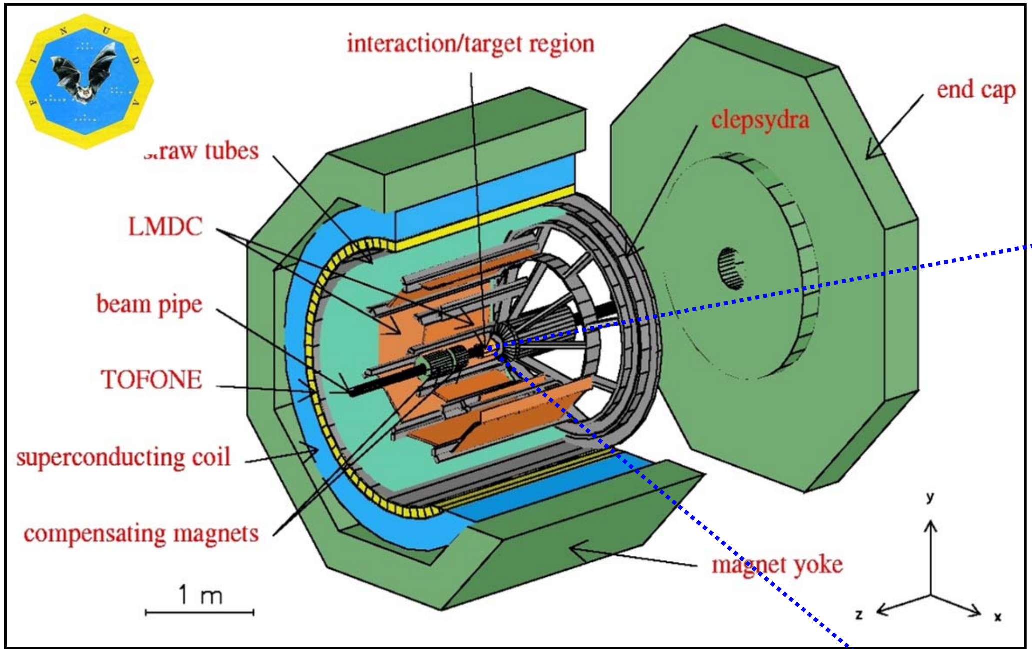
Outline

- recent experimental **results**:
  - FINUDA @ INFN/LNF
  - E10 @ J-PARC



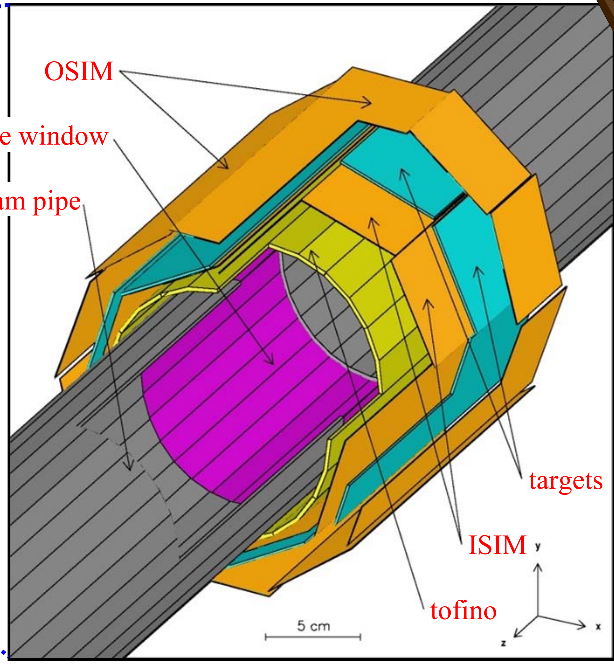
- a look to the (next) **future**:
  - ***J-PARC: what next?***

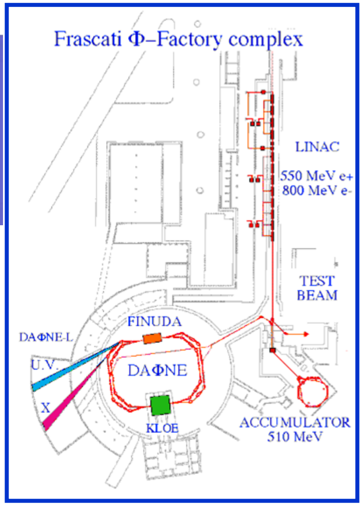
FINUDA @ DAΦNE

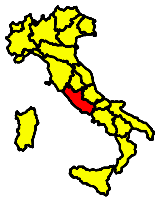


$$e^- + e^+ \rightarrow \phi \rightarrow K^- K^+$$

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







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)

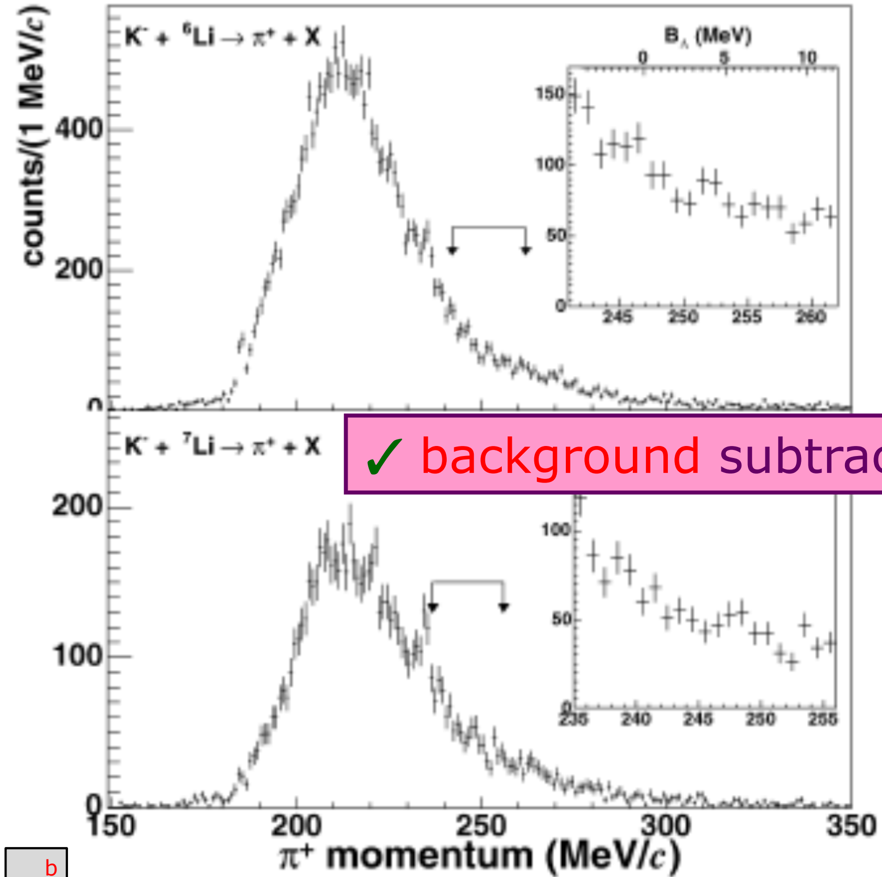
$${}^{A}_{\Lambda}Z \rightarrow \begin{cases} {}^{A}(Z+1) + \pi^- \\ {}^{(A-2)}(Z-1) + p + n \\ {}^{(A-3)}(Z-1) + p + n + n \end{cases}$$

FINUDA key features

- very thin nuclear targets (0.1 ÷ 0.3 g/cm^2)
  - → high resolution spectroscopy
- coincidence measurement with large acceptance
  - → decay mode study ← indirect discovery tool
- event by event K^+ tagging
  - → continuous energy and rate calibration
- irradiation of different targets in the same run
  - → systematic error reduction

The background issue

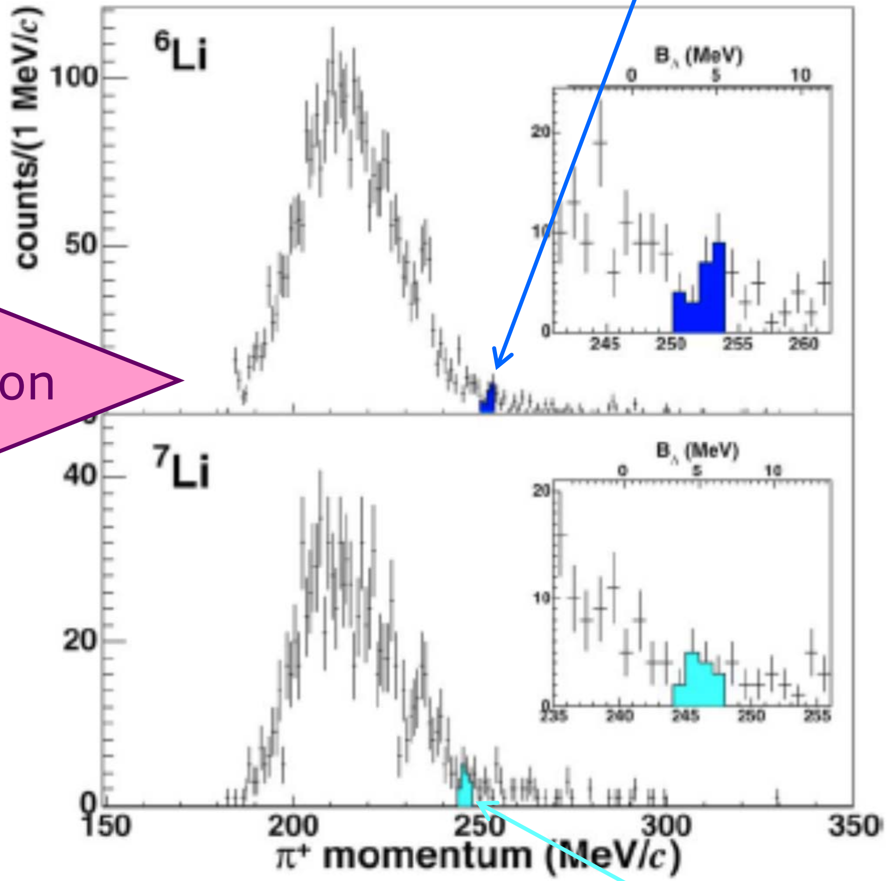
$$K^-_{stop} + {}^AZ \rightarrow {}^A_\Lambda(Z-2) + \pi^+$$



✓ background subtraction

$$K^-_{stop} + {}^6Li \rightarrow {}^6_\Lambda H + \pi^+$$

${}^6_\Lambda H({}^6Li): u.l. = (2.5 \pm 1.4)\cdot 10^{-5} / K^-_{stop}$ @ 90% $c.l.$



$$K^-_{stop} + {}^7Li \rightarrow {}^7_\Lambda H + \pi^+$$

main background

$K^- + p \rightarrow \Sigma^+ + \pi^-$

$\hookrightarrow n + \pi^+$ $(\sim 130 < p_{\pi^+} < \sim 250$ MeV/c$)$

$K^- + pp \rightarrow \Sigma^+ + n$

$\hookrightarrow n + \pi^+$ $(\sim 100 < p_{\pi^+} < \sim 320$ MeV/c$)$

$\mathscr{L}_{int} \approx 220$ pb^{-1}

M. Agnello *et al.*, *PLB* 640 (2006) 145

The new NRH search strategy

$\mathcal{L}_{int} \approx 1156\ pb^{-1}$ → coincidence measurements

$$K^-_{stop} + {}^6Li \rightarrow {}^6_\Lambda H + \pi^+$$

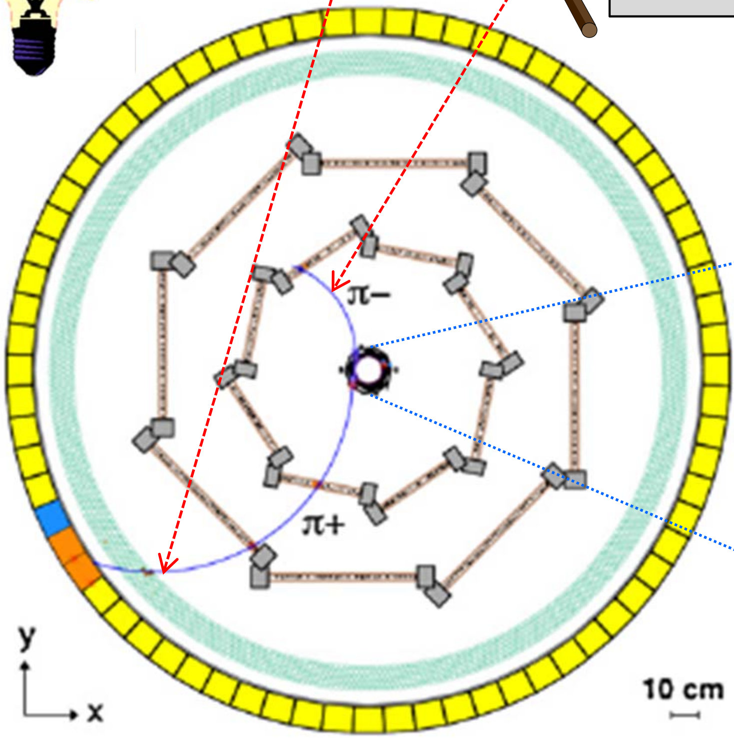
double C-EX
p ~ 252 MeV/c

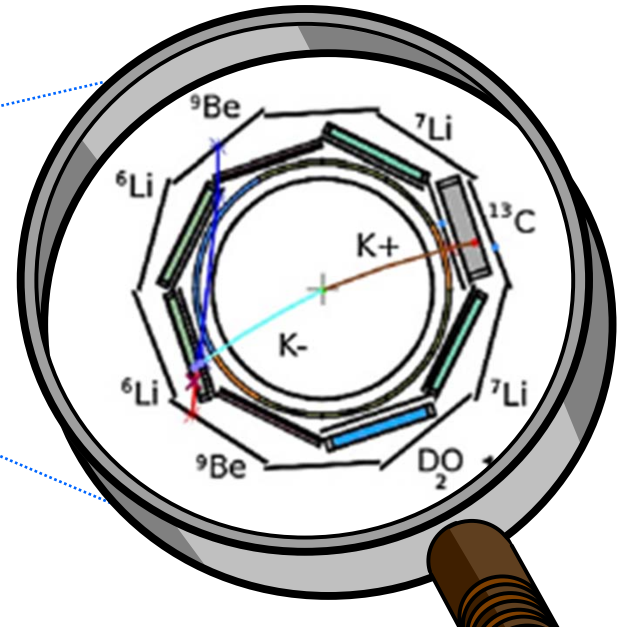
$$^6_\Lambda H \rightarrow {}^6He + \pi^-$$

n.m. decay
p ~ 134 MeV/c

apparatus capabilities:

- selective trigger
  (based on fast scintillator detectors)
- precise K^- vertex identification < 1 mm^3
  (PID + spatial resolution + K^- tagging)
- π, K, p, d, … separation (OSIM & LMDC dE/dx)
- high momentum resolution
  6‰ FWHM π^- @ 270 MeV/c
  6% FWHM π^- @ 110 MeV/c
  (tracker performance + He bag + thin target)





Analysis technique

$$K^-_{stop} + {}^6Li \rightarrow {}^6_\Lambda H + \pi^+$$

$$ {}^6_\Lambda H \rightarrow {}^6He + \pi^-$$

$$(\tau({}^6He) \approx 801 \text{ ms})$$

if ${}^6H_\Lambda$ is a stable system ⇒ 2 independent two-body reactions:

decay at rest

$$M(K^-) + 3M(p) + 3M(n) - B({}^6\mathrm{Li}) = M({}^6_\Lambda\mathrm{H}) + T({}^6_\Lambda\mathrm{H}) + M(\pi^+) + T(\pi^+)$$

$$M({}^6_\Lambda\mathrm{H}) = 2M(p) + 4M(n) - B({}^6\mathrm{He}) + T({}^6\mathrm{He}) + M(\pi^-) + T(\pi^-)$$

atomic mass tables

$$\sqrt{M^2({}^6He) + p^2(\pi^-)} - M({}^6He)$$

$$\sqrt{M^2({}^6_\Lambda H) + p^2(\pi^+)} - M({}^6_\Lambda H)$$

$$M({}^6_\Lambda H) = M({}^5H) + M(\Lambda) - B(\Lambda)$$

$$T(\pi^+) + T(\pi^-) = M(K^-) + M(p) - M(n) - 2M(\pi) - B({}^6\mathrm{Li}) + B({}^6\mathrm{He}) - T({}^6\mathrm{He}) - T({}^6_\Lambda\mathrm{H})$$

$$= 203.0 \pm 1.3 \text{ MeV}$$

$$(203.5 \div 203.3 \text{ MeV with } B_\Lambda = 0 \div 6 \text{ MeV})$$

cut on $T(\pi^+) + T(\pi^-)$: $202 \div 204$ MeV

$^{6}H_{\Lambda}$ production rate

background sources

- accidentals: π^+ (250 ÷ 255 MeV/c) and π^- (130 ÷ 137 MeV/c) 0.27 ± 0.27 ev. BGD2
- $K^-_{stop} + {}^6Li \rightarrow \Sigma^+ + \pi^- + {}^4He + n$ end point ~190 MeV/c
  ↳ $n + \pi^+$ end point ~282 MeV/c 0.16 ± 0.07 ev. BGD1
- $K^-_{stop} + {}^6Li \rightarrow {}^4_{\Lambda}H + n + n + \pi^+$ end point ~252 MeV/c
  ↳ ${}^4He + \pi^-$ $p(\pi^-)$ = 133 MeV/c negligible

production rate

- total background on ^{6}Li: BGD1 + BGD2 = 0.43 ± 0.28 ev.
- Poisson statistics: 3 events DO NOT belong to pure background @ C.L. = 99%

assumption

$$R * BR(\pi^-) = (3 - \mathrm{BGD1} - \mathrm{BGD2}) / [\varepsilon(\pi^-)\varepsilon(\pi^+)(n.\ K^-_{stop}\ \text{on}\ {}^6Li)]$$

$$BR(\pi^-)\,{}^4_{\Lambda}H = 0.49$$

$$R * BR(\pi^-) = (2.9 \pm 2.0)\ 10^{-6} / K^-_{stop}$$

H. Tamura *et al.*, *PRC* 40 (1989) R479

$$R = (5.9 \pm 4.0)\ 10^{-6} / K^-_{stop} \Leftrightarrow (2.5 \pm 0.5^{+0.4}_{-0.1}) \cdot 10^{-5} / K^-_{stop}$$

FINUDA Coll. and A. Gal, *PRL* 108 (2012) 042501

M. Agnello *et al.*, *PLB* 640 (2006) 145

Kinematics and binding energy

T_{tot} (MeV)	p_{π^+} (MeV/c)	p_{π^-} (MeV/c)	$M(^6_\Lambda H)$ prod. (MeV)	$M(^6_\Lambda H)$ decay (MeV)	$M(^6_\Lambda H)$ mean (MeV)	$\Delta M(^6_\Lambda H)$ (MeV)
202.6 ± 1.3	251.3 ± 1.1	135.1 ± 1.2	5802.33 ± 0.96	5801.41 ± 0.84	5801.87 ± 0.96	0.92 ± 1.28
202.7 ± 1.3	250.1 ± 1.1	136.9 ± 1.2	5803.45 ± 0.96	5802.73 ± 0.84	5803.09 ± 0.96	0.72 ± 1.28
202.1 ± 1.3	253.8 ± 1.1	131.2 ± 1.2	5799.97 ± 0.96	5798.66 ± 0.84	5799.32 ± 0.96	1.31 ± 1.28

$$(N+Y)/Z(^6_\Lambda H) = 5 >> N/Z(^8He) = 3$$

formation mass values systematically higher than the ones from decay

(0.98 ± 0.74) MeV

excited states production

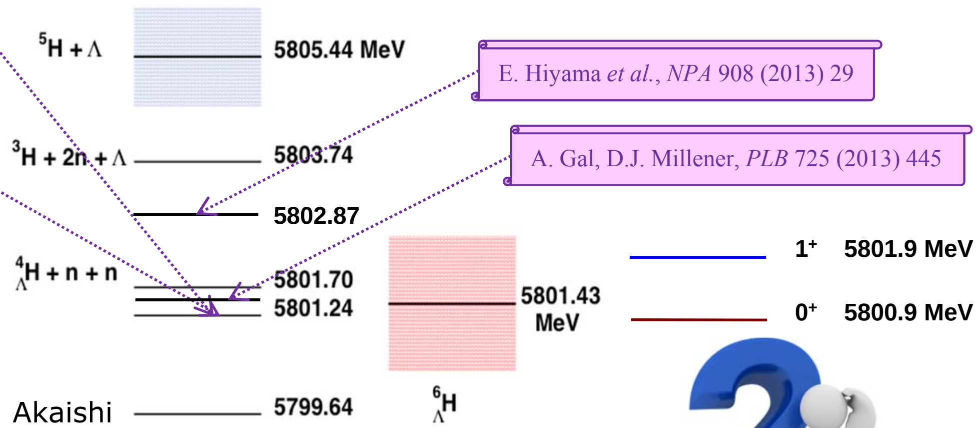
theoretical predictions

- B_Λ = 4.2 MeV — R.H. Dalitz and R. Levi Setti, *NC* 30 (1963) 489
- B_Λ = 4.2 MeV — L. Majling, *NPA* 585 (1995) 211c

B $^4_\Lambda$He 2.39 Λ	$^5_\Lambda$He 3.12 Λ	◇ $^6_\Lambda$He 4.18 n 0.17 xxx	◇ $^7_\Lambda$He 5.23 n 2.92 halo	$^8_\Lambda$He 7.16 n 1.49 xxx	♠ $^9_\Lambda$He (8.5) n 3.9 halo
$^3_\Lambda$H 0.13 Λ	◇ $^4_\Lambda$H 2.04 Λ	^5_nH (3.1) n -1.8 xxx	♠ $^6_\Lambda$H (4.2) 2n -5 xxx	♠ $^7_\Lambda$H (5.2) 3n 0.4 xxx	

nrh prod. rate: ~10^{-2} hyp. prod. rate in (K^-_{stop}, π^-)

$\bar{M}$ = (5801.4 ± 1.1) MeV



E. Hiyama *et al.*, *NPA* 908 (2013) 29

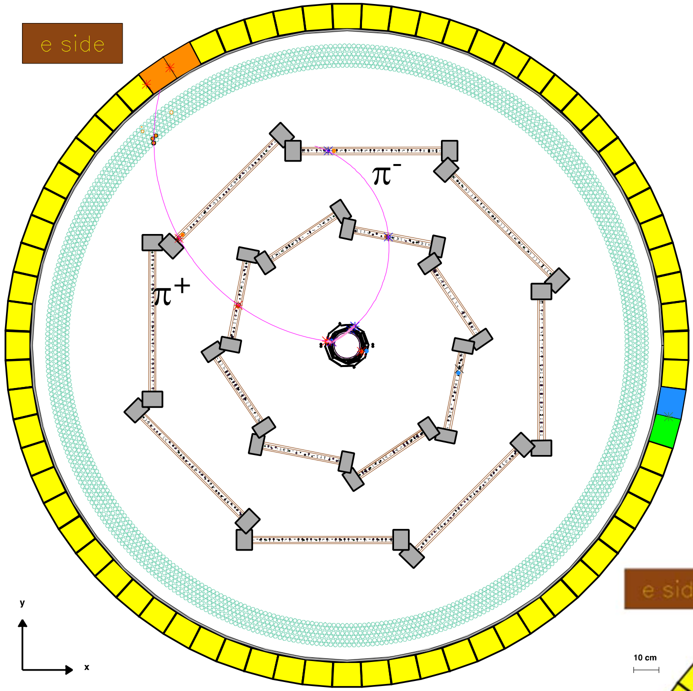
A. Gal, D.J. Millener, *PLB* 725 (2013) 445

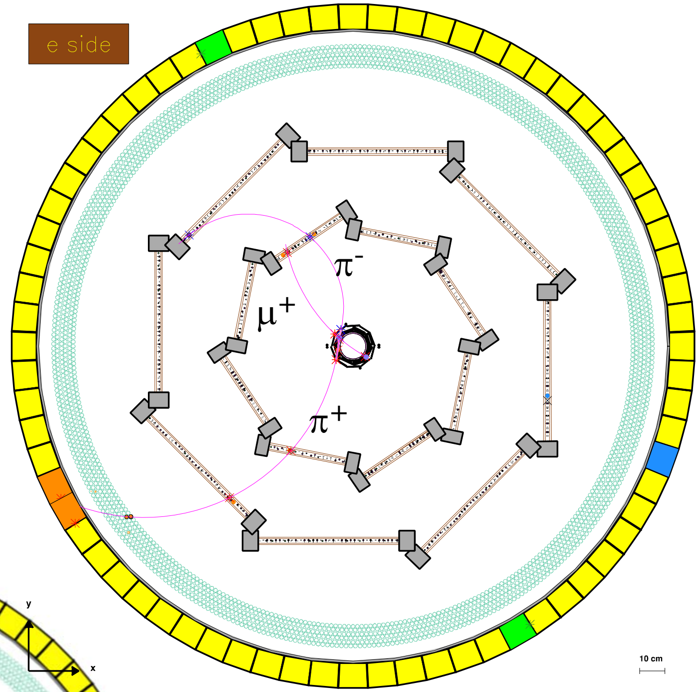
B_Λ = (4.0 ± 1.1) MeV (^{5}H + Λ)

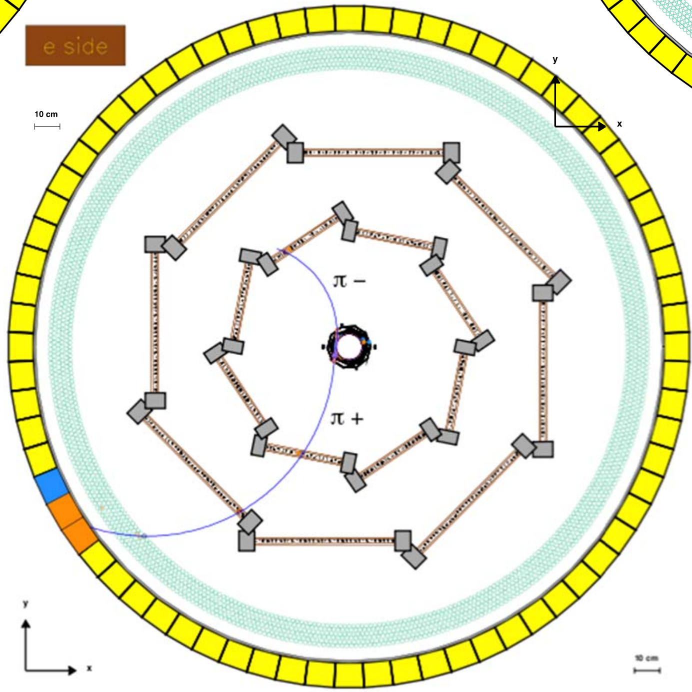
~~B_Λ = 5.8 MeV (^{5}H + Λ)~~
~~ΛNN force ≡ 1.4 MeV~~

FINUDA Coll. and A. Gal, *PRL* 108 (2012) 042501
FINUDA Coll. and A. Gal, *NPA* 881 (2012) 269

Kinematics compatibility: visual scan

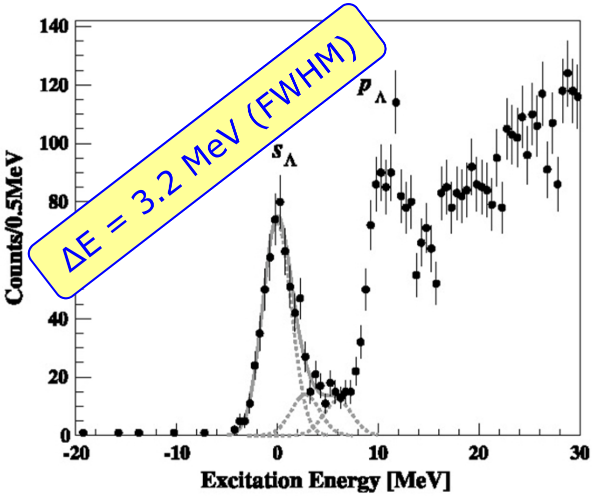






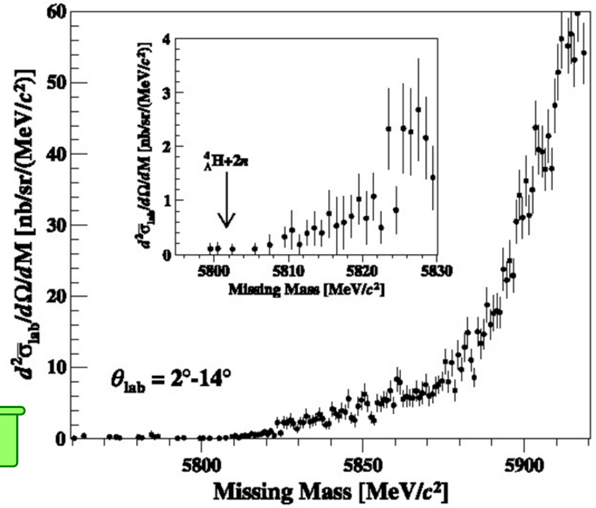
E10: no evidence!?!

J-PARC E10



$$\pi^- + {}^6Li \rightarrow {}^6_\Lambda H + K^+$$

H. Sugimura *et al.*, *PLB* 729 (2014) 39



$$d\sigma / d\Omega \leq 1.2 \ \ nb/sr \ \ (90\% \ \ C.L.)$$

one order of magnitude lower than…

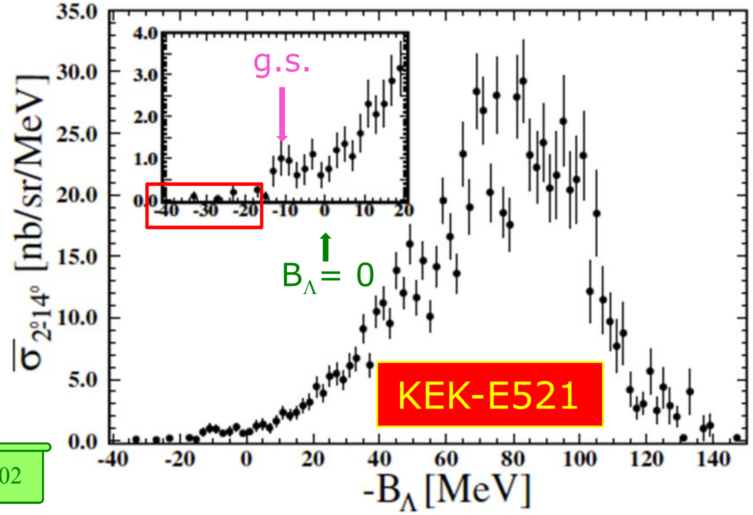
background free reactions

$$\pi^- + {}^{10}B \rightarrow {}^{10}_\Lambda Li + K^+$$

σ_B = 2.5 MeV (FWHM)

$$d\sigma / d\Omega = 11.3 \pm 1.9 \ \ nb/sr$$

P.K. Saha *et al.*, *PRL* 94 (2005) 052502



What next?

Last but not least results from FINUDA:

- first experimental evidence for the heavy hyperhydrogen $^{6}H_{\Lambda}$

- limited number of candidates (3)
- negative results from J-PARC E10
- theoretical predictions not in agreement

Further investigations needed
both experimental and theoretical

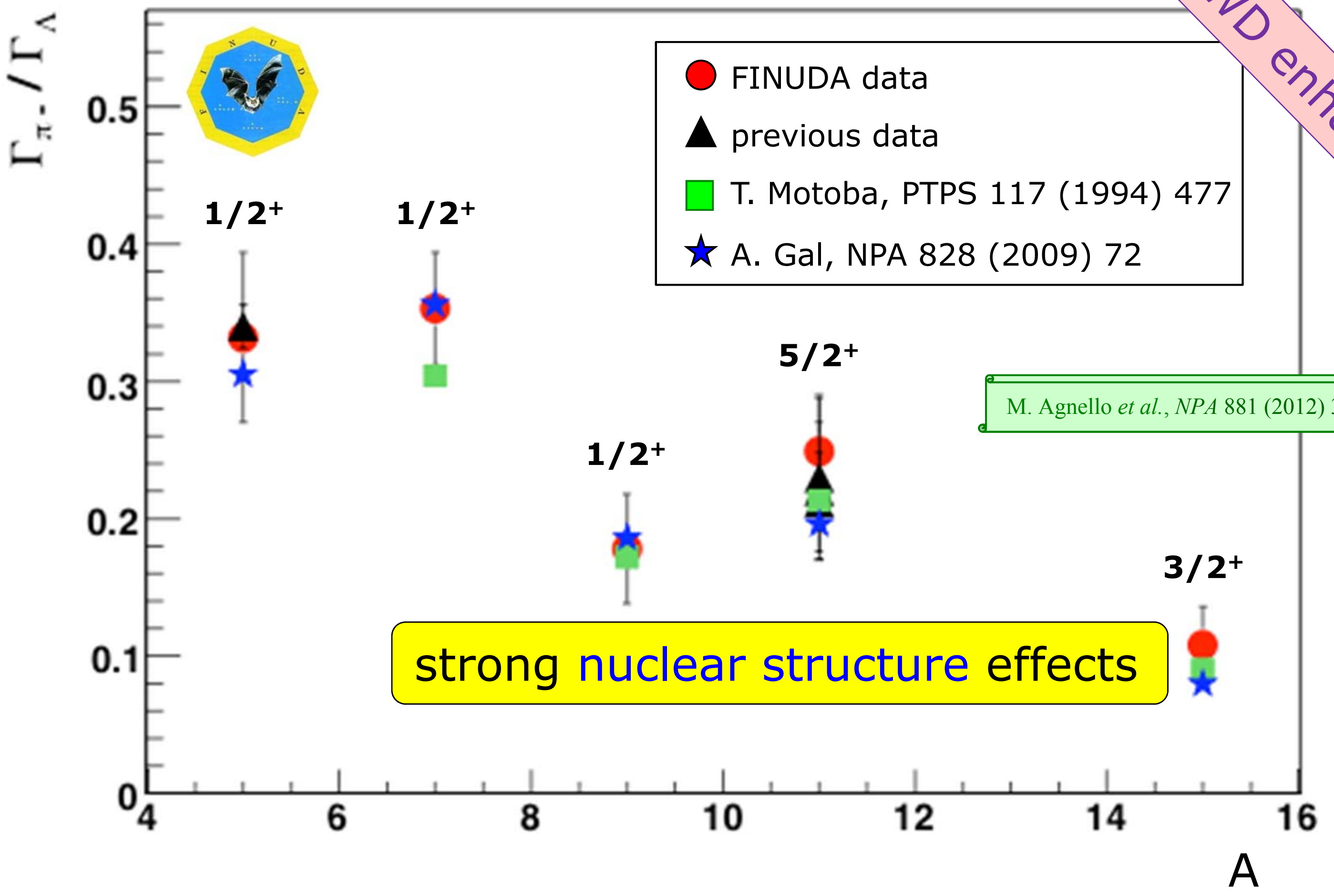
$\Gamma_{\pi^-}/\Gamma_\Lambda$ ratio dependence on A

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

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

fit to measured values for A = 4-12 hypernuclei

π distortion, MWD enhancement proved

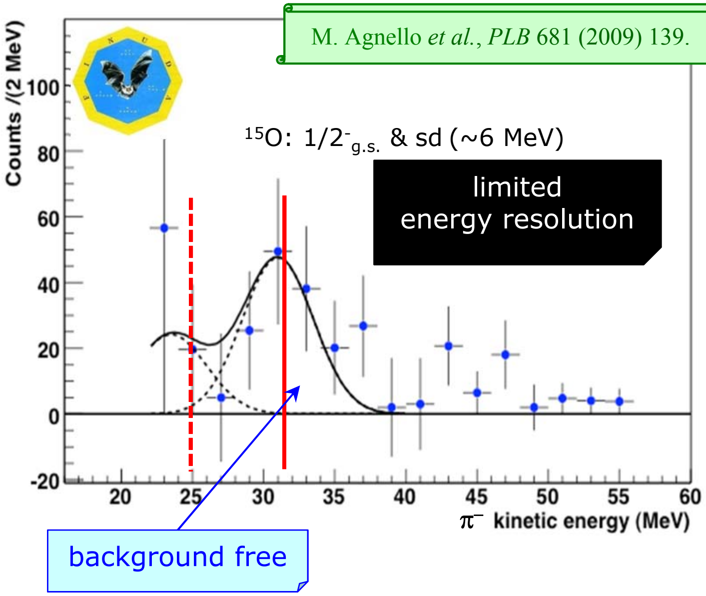


M. Agnello *et al.*, *NPA* 881 (2012) 322.

$^{15}N_{\Lambda}$ J^{π} assignment

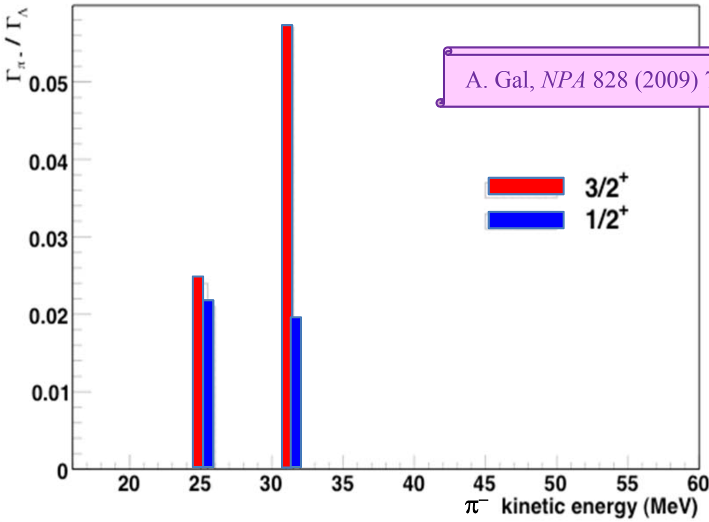
1st experimental determination

M. Agnello *et al.*, *PLB* 681 (2009) 139.

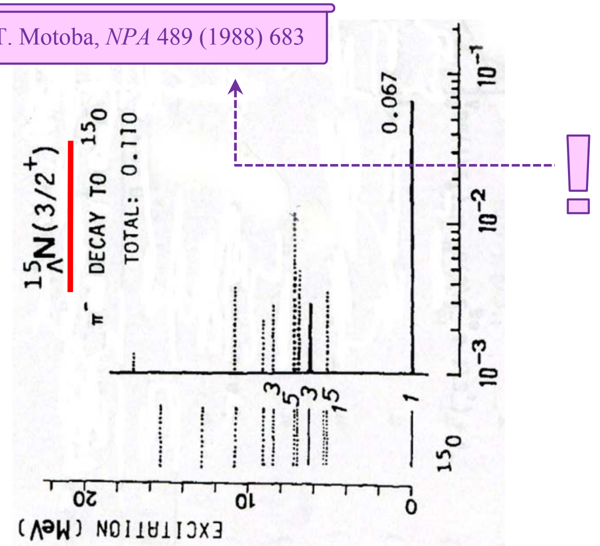


- Clear correspondence with the calculated strength functions:
  - T. Motoba *et al.*, Nucl. Phys. A 489 (1988) 683.
  - A. Gal, Nucl. Phys. A 828 (2009) 72.
- $^{15}N_{\Lambda\ g.s}$ spin not known $J^{\pi}(^{15}N_{\Lambda\ g.s.}) = 3/2^+$
  D.J. Millener, A. Gal, C.B. Dover, Phys. Rev. C 31 (1985) 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)

A. Gal, *NPA* 828 (2009) 72.



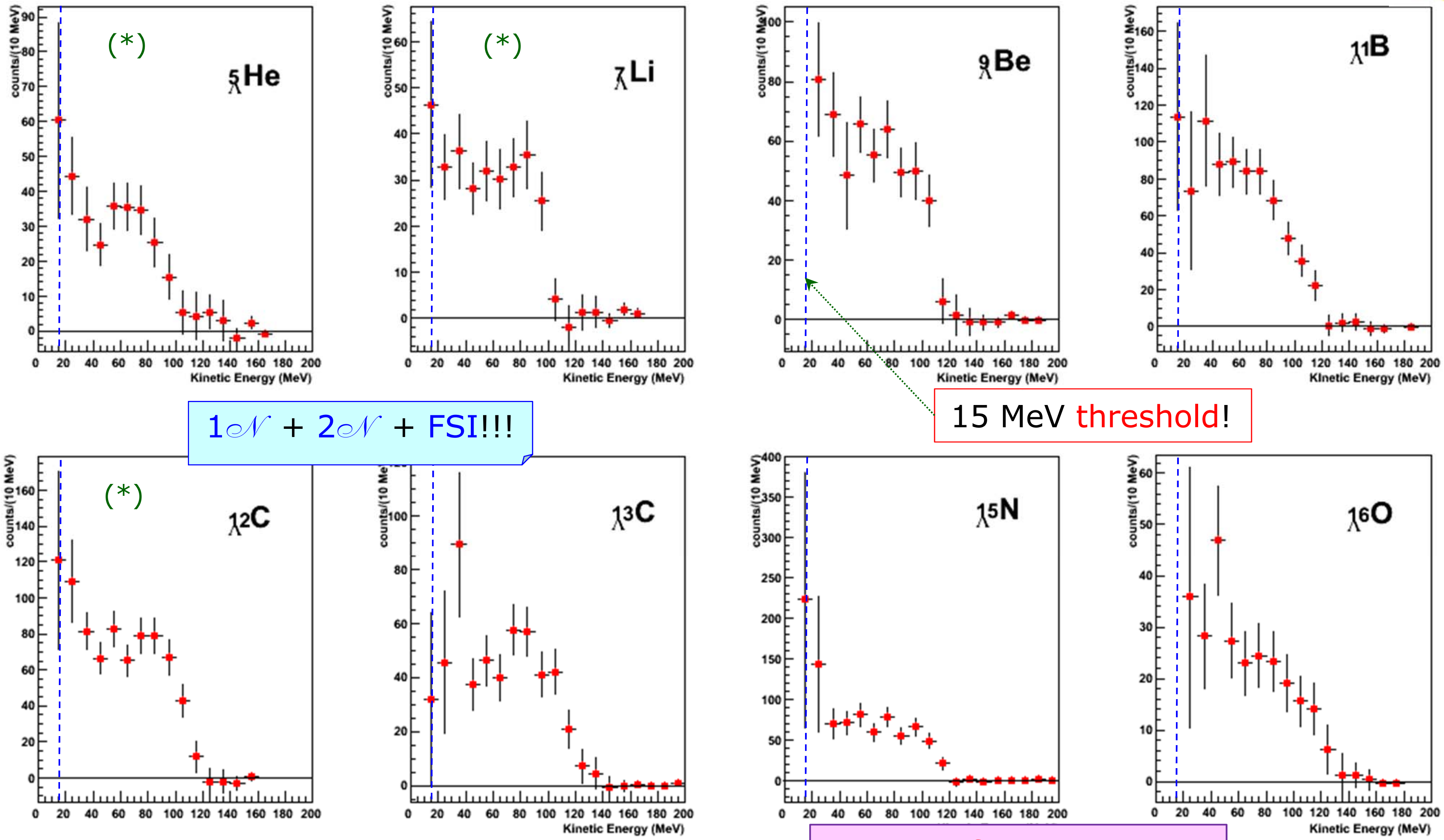
T. Motoba, *NPA* 489 (1988) 683



Anatomy of NMWD p spectra

p spectra $K^{-}(np)$ background subtracted

M. Agnello *et al.*, *PLB* 685 (2010) 247.



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

15 MeV threshold!

(*) M. Agnello *et al.*, *NPA* 804 (2008) 151.

common features:
- low energy rise
- structure at ~80 MeV

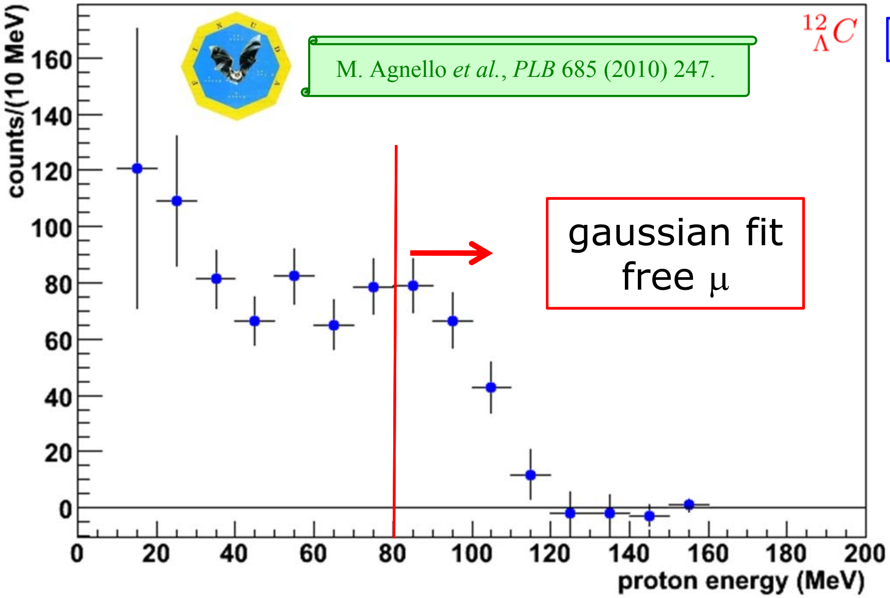
$\Gamma_{2\mathcal{N}}$ and FSI determination

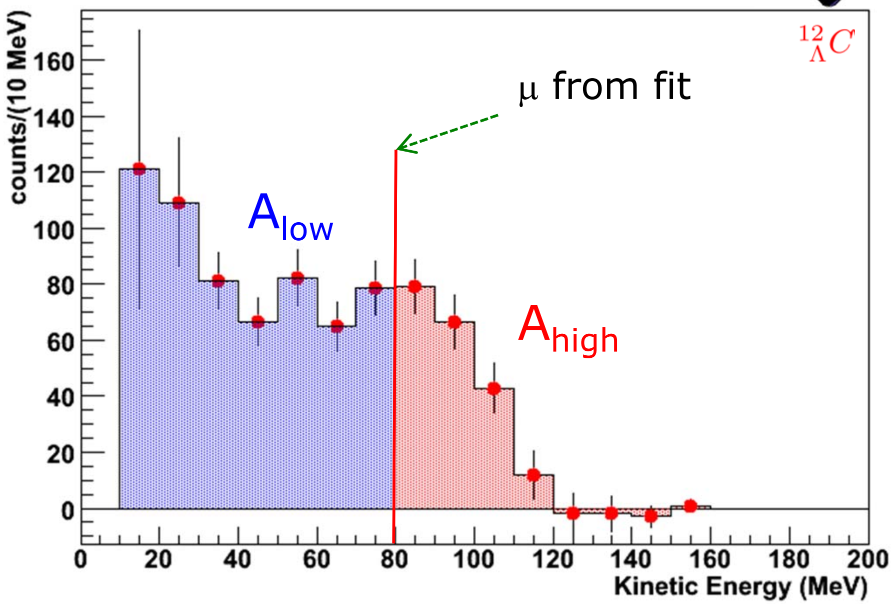
W. Alberico and G. Garbarino, *PR* 369 (2002) 1.

assumption

1) $\Gamma_{2\mathcal{N}}/\Gamma_{NMWD}$
2) Γ_n/Γ_p

independent on A





G. Garbarino, A. Parreño and A. Ramos, *PRL* 91 (2003) 112501.
G. Garbarino, A. Parreño and A. Ramos, *PRC* 69 (2004) 054603.

assumption

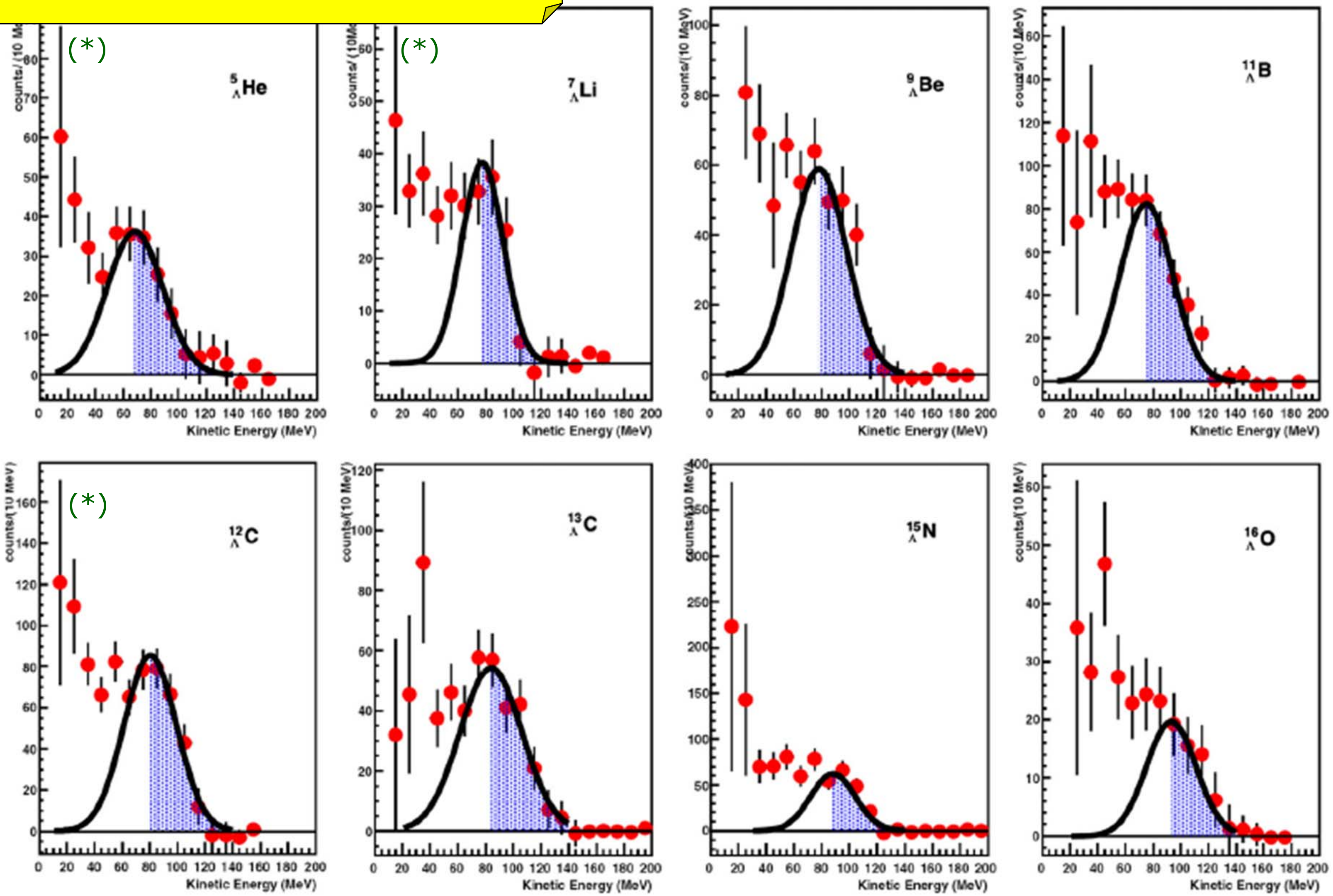
A_{low} ☛ $1\mathcal{N}$ + $2\mathcal{N}$ + FSI

A_{high} ☛ $1\mathcal{N}$ + FSI
$2\mathcal{N}$ (T_p > 70 MeV) ~5% $\Gamma_{2\mathcal{N}}$

FSI and 2N induced non-mesonic decay

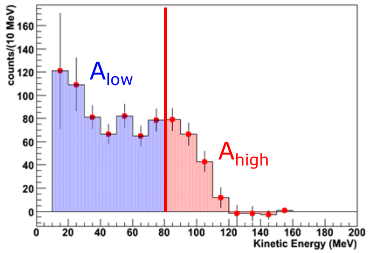
p spectra background subtracted and acceptance corrected

M. Agnello *et al.*, *PLB* 685 (2010) 247.



(*) M. Agnello *et al.*, *NPA* 804 (2008) 151.

$\Gamma_{2\mathcal{N}}$ and FSI 1st determination

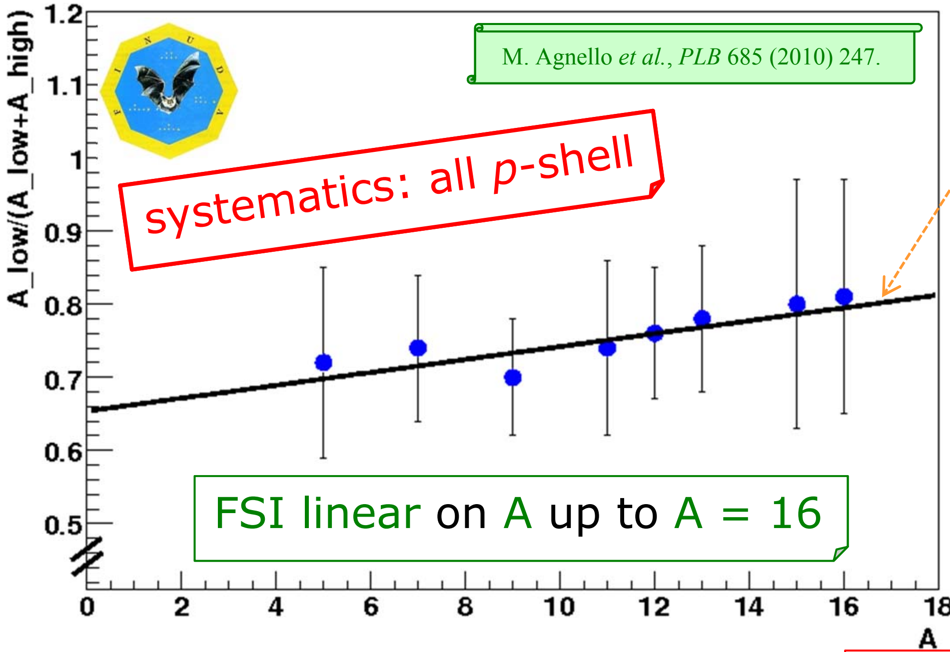


E. Bauer and G. Garbarino, *NPA 828* (2009) 29.

$\Gamma_{np} : \Gamma_{np} : \Gamma_{np} = 0.83 : 0.12 : 0.04$

assumption → $\Gamma_{2\mathcal{N}}/\Gamma_p \sim \Gamma_{np}/\Gamma_p$

$$R = \frac{A_{low}}{A_{low} + A_{high}} = \frac{0.5 \cdot N(\Lambda p \to np) + N(\Lambda np \to nnp) + N_p^{FSI-low}}{N(\Lambda p \to np) + N(\Lambda np \to nnp) + N_p^{FSI-low} + N_p^{FSI-high}}$$



$$R(A) = a + bA = \frac{0.5 + \Gamma_2/\Gamma_p}{1 + \Gamma_2/\Gamma_p} + bA$$

assumption — supported by both experiment and theory

Γ_2/Γ_1 and Γ_n/Γ_p independent on A

$$\frac{\Gamma_2}{\Gamma_p} = 0.43 \pm 0.25$$

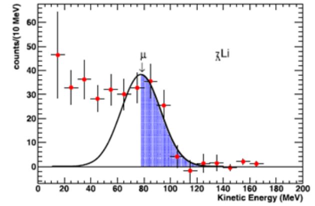
weighted average

$$\frac{\Gamma_2}{\Gamma_{NM}} = \frac{\Gamma_2/\Gamma_p}{\Gamma_n/\Gamma_p + 1 + \Gamma_2/\Gamma_p} = 0.24 \pm 0.10$$

H. Bhang *et al.*, *EPJA 33* (2007) 259.

- E. Bauer and G. Garbarino, *NPA 828* (2009) 29.
- H. Bhang *et al.*, *EPJA 33* (2007) 259: ~0.40 $^{12}C_\Lambda$
- J.D. Parker *et al.*, *PRC* 76 (2007) 035501: ≤ 0.24 $^4He_\Lambda$ (95% c.l.)
- M. Kim *et al.*, *PRL* 103 (2009) 182502: 0.29 ± 0.13 $^{12}C_\Lambda$

$\Gamma_{2\mathscr{N}}$ improved determination



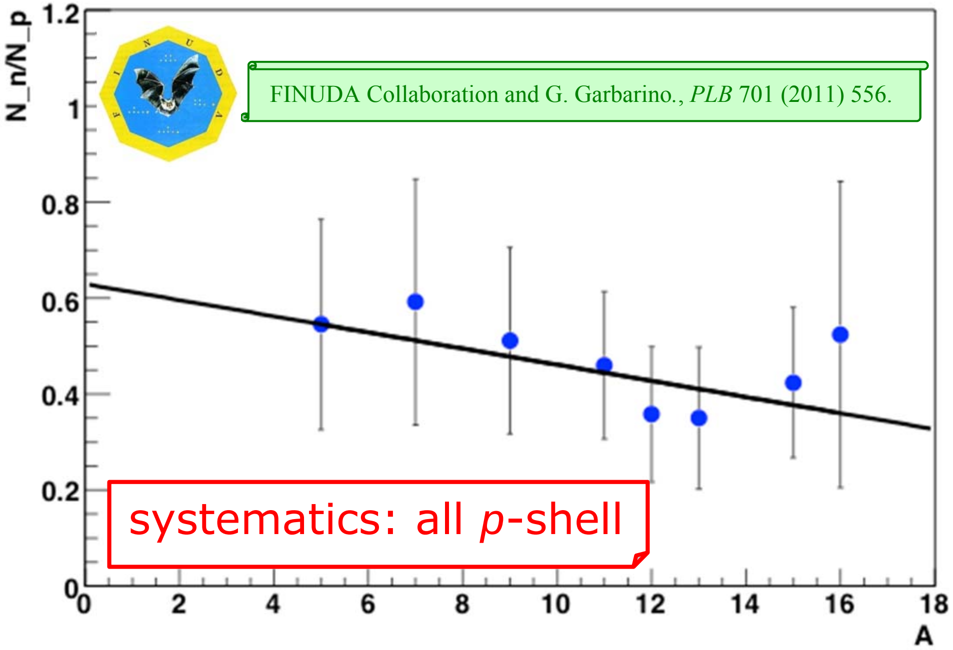
$$R(A)=\frac{N_n(\cos\vartheta\geq-0.8,\;\; E_p<\mu-20\;\;\mathrm{MeV})}{N_p(E_p>\mu\;\; p\;\mathrm{single\;spectra\;fit})}=\frac{N(\Lambda np\rightarrow nnp)+N^{FSI}}{0.5\cdot N(\Lambda p\rightarrow np)+N^{FSI}}$$

$$R(A)=a+bA=\frac{\Gamma_2}{0.5\cdot\Gamma_p}+bA$$

assumption — E. Bauer and G. Garbarino, *PRC 81* (2010) 064315.

Γ_2/Γ_p independent on A

$$\frac{\Gamma_2}{\Gamma_p}=0.39\pm0.16_{\mathrm{stat}}{}^{+0.04_{\mathrm{sys}}}_{-0.03_{\mathrm{sys}}}$$



$$\frac{\Gamma_2}{\Gamma_{NM}}=\frac{\Gamma_2/\Gamma_p}{\Gamma_n/\Gamma_p+1+\Gamma_2/\Gamma_p}=$$

$$=0.21\pm0.07_{\mathrm{stat}}{}^{+0.03_{\mathrm{sys}}}_{-0.02_{\mathrm{sys}}}$$

- M. Kim *et al.*, PRL 103 (2009) 182502: 0.29 ± 0.13 ${}^{12}C_{\Lambda}$.
- FINUDA Collaboration and A. Gal., *PLB* 685 (2010) 182502: 0.24 ± 0.10.

π^-, *p*, *n*, coincidence measurements

- low statistics
- direct measurement
- reduced error

2𝒩 induced weak decay

- relevance first pointed out by: W.M. Alberico *et al.*, *PLB* 256 (1991) 134
- key role in data interpretation ⟹ many theoretical predictions

E. Bauer
G. Garbarino
A. Parreño
A. Ramos

- importance of the effect: ~20-25% of the total NMWD width
- several experimental evidences, but indirect

Ref.	Γ_2/Γ_Λ	Γ_2/Γ_{NM}	Notes
BNL-E788 [47]		$\leqslant 0.24$	${}^4_\Lambda$He, n and p spectra
KEK-E508 [48]	0.27 ± 0.13	0.29 ± 0.13	${}^{12}_\Lambda$C, nn and np spectra
FINUDA [8]		0.24 ± 0.10	$A = 5$–16, p spectra
FINUDA [9]		$0.21 \pm 0.07_{stat} {}^{+0.03\,sys}_{-0.02\,sys}$	$A = 5$–16, np spectra

consistent within large errors

E. Botta, T. Bressani, G. Garbarino, *EPJA* 48 (2012) 21

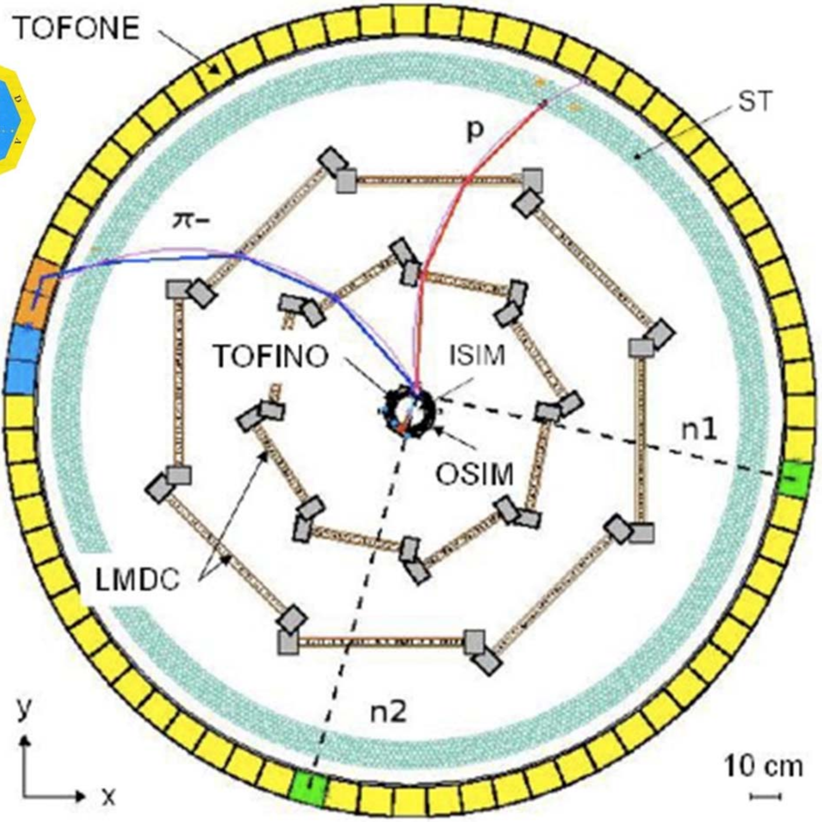
"smoking gun" evidence missing!

- experimental hardness: 3 nucleons emitted from Λ-hypernucleus g.s.
  4-fold coincidence measurement (π^-, p, n, n)

$2\mathscr{N}$ induced decay exp. evidence

triple coincidence: ($n + n + p$) events

exclusive $\Lambda np \rightarrow nnp$ decay event: $^{7}_{\Lambda}Li \rightarrow {}^{4}He + p + n + n$



$p_{\pi-}$ = 276.9 ± 1.2 MeV/c
p_{miss} = 217 ± 44 MeV/c
E_{tot} = 178 ± 23 MeV
MM = 3710 ± 23 MeV/c^2

E(n1) = 110 ± 23 MeV
E(n2) = 16.9 ± 1.7 MeV
E(p) = 51.11 ± 0.85 MeV

ϑ(n1 n2) = 94.8° ± 3.8°
ϑ(n1 p) = 102.2° ± 3.4°
ϑ(n2 p) = 154° ± 19°

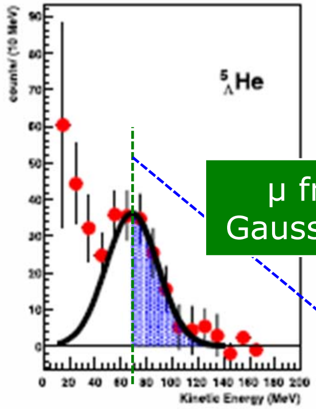
no n-n or p/n scattering

$^{7}_{\Lambda}$Li	MM (MeV/c^2)
^{4}He	3727.4
^{3}He + n	3748.0
^{3}H + p	3747.2

first, direct experimental evidence

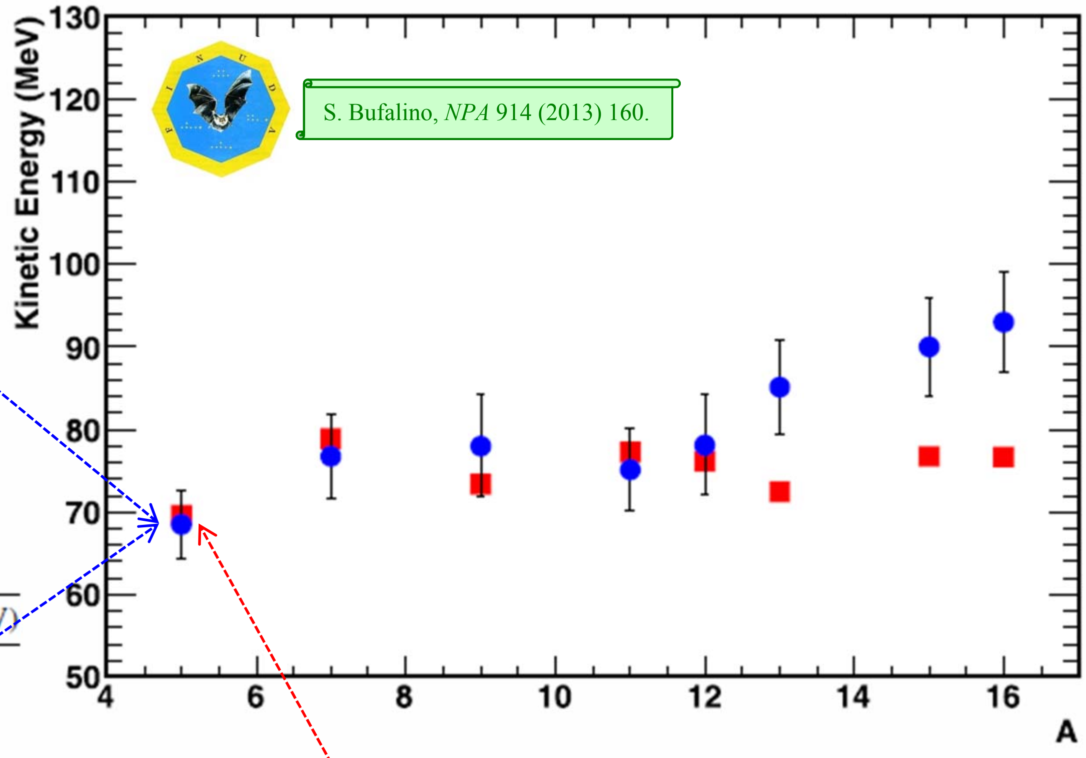
M. Agnello *et al.*, *NPA* 881 (2012) 322

Exclusive NMWD?



μ from Gaussian fit

theoretical advice urgently needed!

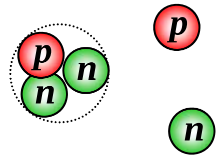


S. Bufalino, *NPA* 914 (2013) 160.

Hypernucleus	μ from fit (MeV)
$^5_\Lambda$He	68.5 ± 4.1
$^7_\Lambda$Li	76.7 ± 5.1
$^9_\Lambda$B	78.2 ± 6.2
$^{11}_\Lambda$B	75.1 ± 5.0
$^{12}_\Lambda$C	78.1 ± 6.1
$^{13}_\Lambda$C	85.1 ± 5.6
$^{15}_\Lambda$N	88.1 ± 6.2
$^{16}_\Lambda$O	93.1 ± 6.2

M. Agnello *et al.*, *PLB* 685 (2010) 247.

simplified hypothesis:

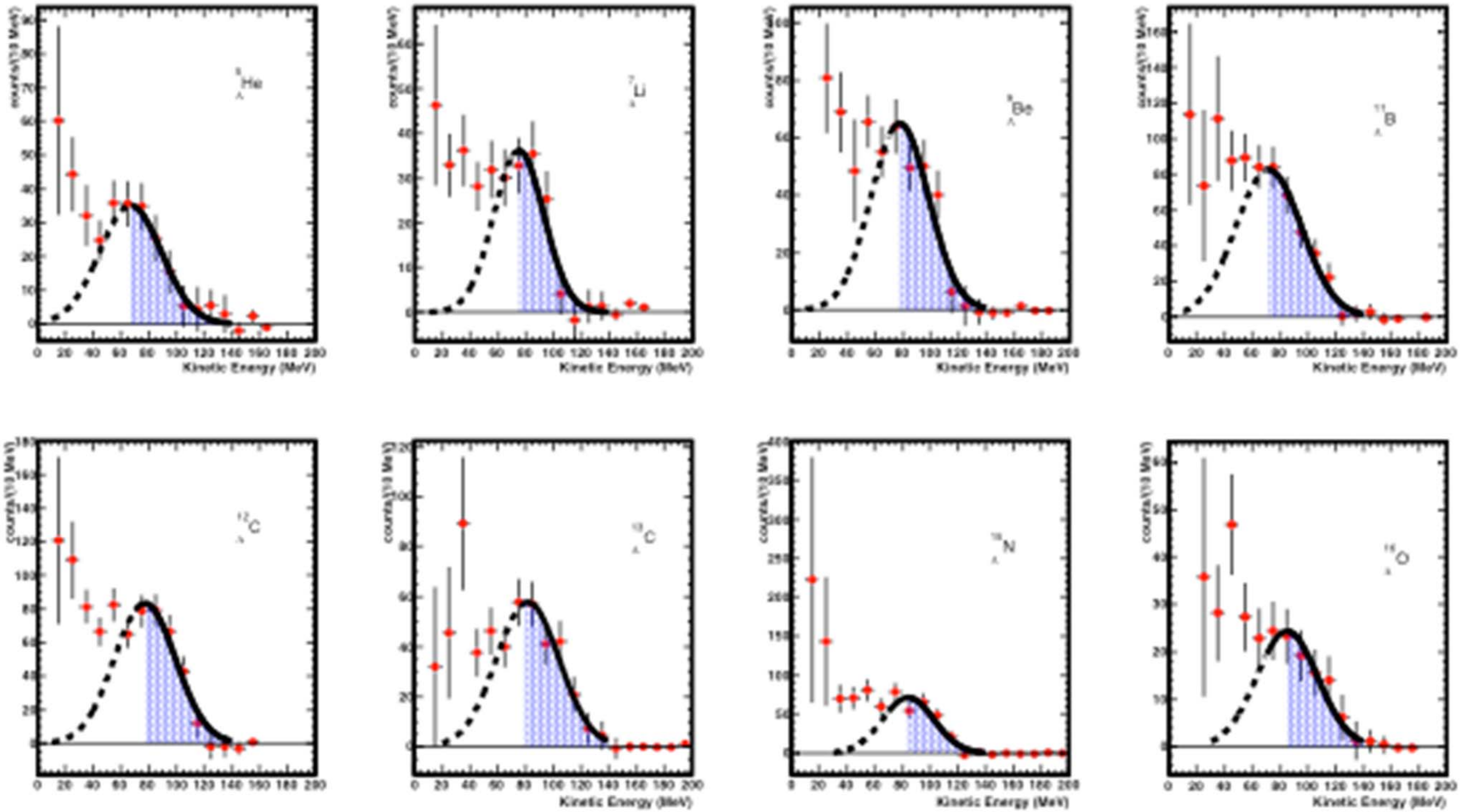


$$^A_\Lambda Z \rightarrow {}^{(A-2)}(Z-1) + p + n$$

Further analysis of the proton spectra

Attempt of improving the fits by lowering the starting points for the fits to 50, 60 and 70 MeV:

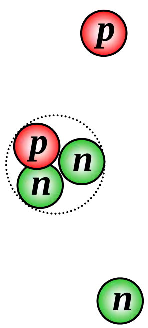
better value of χ^2/n = 1.33 when choosing the start at 70 MeV

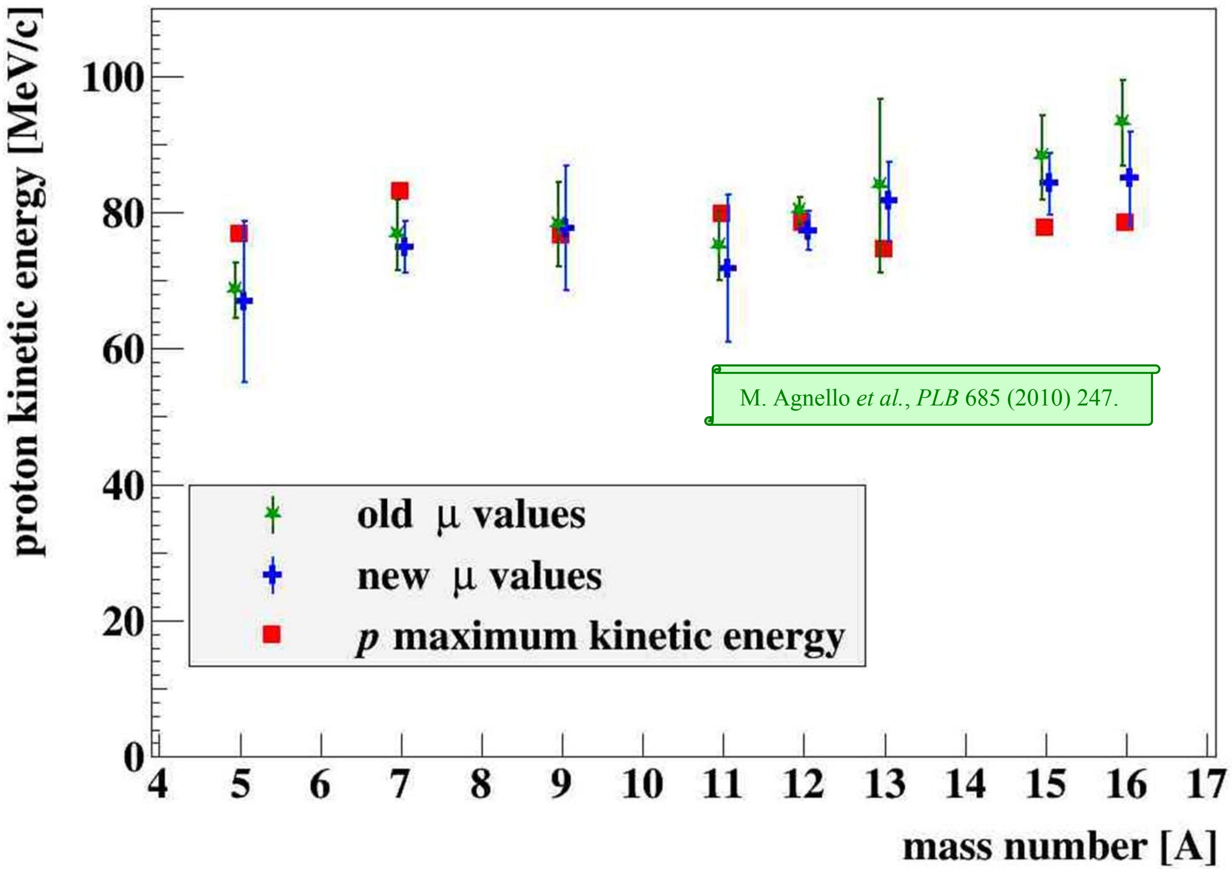


Further analysis of the proton spectra

- fits to Gaussians of experimental proton spectra starting from 80 MeV, with free centers (μ), widths and areas
- disagreement of values of μ from whose expected from exact Q-values (b-to-b kinematics and no-recoil of the residual nucleus) for $^{13}C_\Lambda$ and, especially, $^{15}N_\Lambda$ and $^{16}O_\Lambda$

simplified hypothesis:

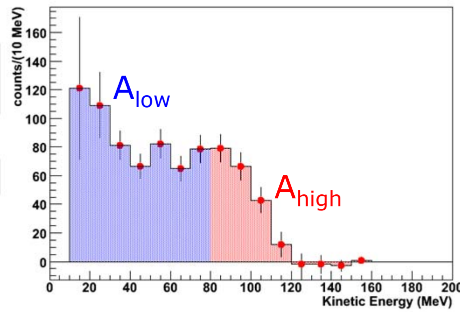




(Slightly) Revised determination of Γ_{2N}

The values of μ were used to divide the full area of the proton spectra into two regions, A_{low} and A_{high}.
It was shown that from the expression:

$$R_1(A) = \frac{A_{low}(A)}{A_{low}(A) + A_{high}(A)}$$



the ratio Γ_{2N}/Γ_p can be obtained
(under the assumption that it is constant in the range A = 5 ÷ 16).
It was found:

$\Gamma_{2N}/\Gamma_p = 0.43 \pm 0.25$ ($\Gamma_{2N}/\Gamma_{NMWD} = 0.21 \pm 0.10$)

With the new values we find:

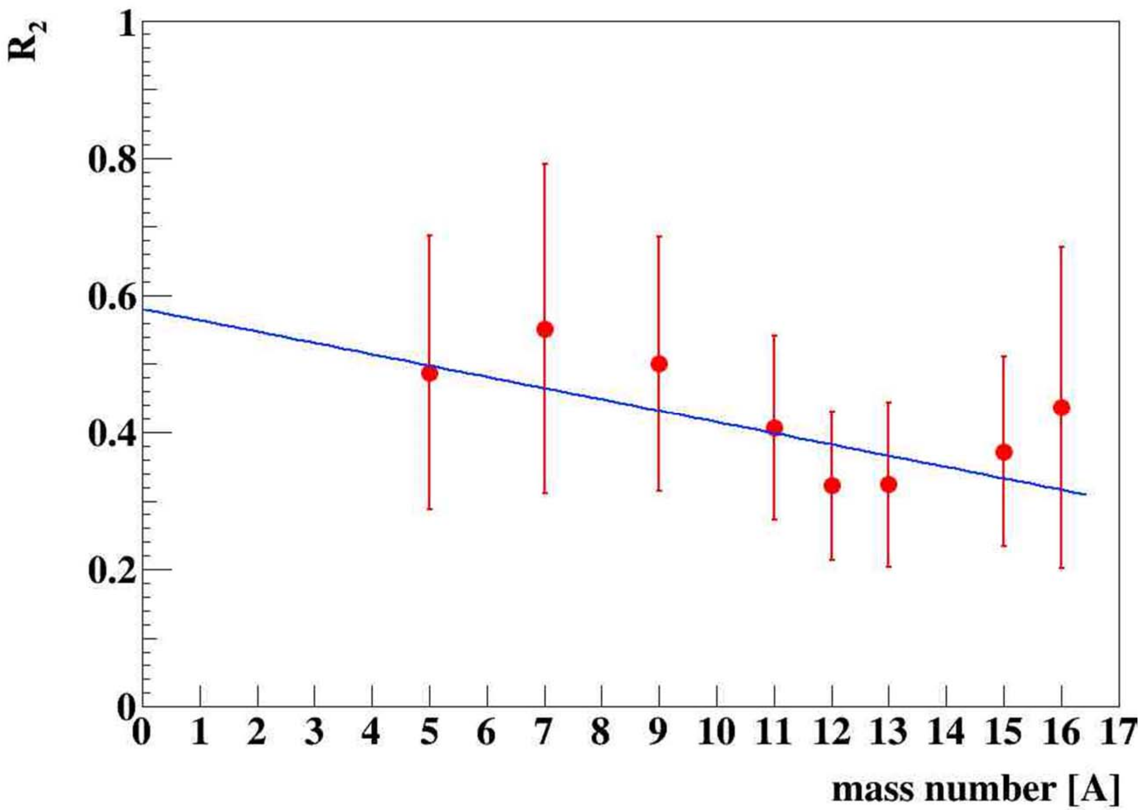
$\Gamma_{2N}/\Gamma_p = 0.50 \pm 0.24$ ($\Gamma_{2N}/\Gamma_{NMWD} = 0.25 \pm 0.12$)

compatible with the previous one, within the errors.

(Slightly) Revised determination of Γ_{2N}

Subsequently a more precise determination of Γ_{2N}/Γ_p was obtained, by considering the (n,p) coincidence.
We defined the ratio

$$R_2(A) = \frac{N_{np}[\cos\vartheta(np) \geq -0.8,\ \ E_p \leq (\mu - 20)\ \ \text{MeV}]}{N_p(E_p > \mu\ \ p\ \text{single spectra fit})}$$



(Slightly) Revised determination of Γ_{2N}

and we found:

$$\frac{\Gamma_{2N}}{\Gamma_p} = 0.39 \pm 0.16_{stat}\,{}^{+0.04}_{-0.03}{}_{sys} \qquad \left(\frac{\Gamma_{2N}}{\Gamma_{NMWD}} = 0.21 \pm 0.07_{stat}\,{}^{+0.03}_{-0.02}{}_{sys} \right)$$

With the new μ values, we got:

$$\frac{\Gamma_{2N}}{\Gamma_p} = 0.36 \pm 0.14_{stat}\,{}^{+0.04}_{-0.03}{}_{sys} \qquad \left(\frac{\Gamma_{2N}}{\Gamma_{NMWD}} = 0.20 \pm 0.08_{stat}\,{}^{+0.03}_{-0.02}{}_{sys} \right)$$

fully compatible with the previous one, within the errors.

First determination of Γ_p for 8 Hypernuclei

$$\frac{\Gamma_p}{\Gamma_\Lambda} = \frac{\Gamma_T}{\Gamma_\Lambda}\frac{2(N_p - N_{2N}) + \alpha(N_p - N_{2N})}{N_{Hyp}}$$

where α accounts for FSI $\left(\frac{\alpha}{2+\alpha}\right)$ protons lost

on the basis of Γ's experimental values from FINUDA and KEK
$\Gamma_{2N}/\Gamma_p = 0.36 \pm 0.14$,
$\Gamma_n/\Gamma_p = 0.45 \pm 0.10$ ($^5He_\Lambda$), $\Gamma_n/\Gamma_p = 0.51 \pm 0.15$ ($^{12}C_\Lambda$), we got:

- $\Gamma_p/\Gamma_\Lambda = 0.223 \pm 0.032$ ($^5He_\Lambda$)
- $\Gamma_p/\Gamma_\Lambda = 0.494 \pm 0.060$ ($^{12}C_\Lambda$)

it is then possible to determine

- $\alpha_5(5) = 1.154 \pm 0.263$
- $\alpha_{12}(12) = 2.483 \pm 0.463$

under the hypothesis of a linear scaling with A:

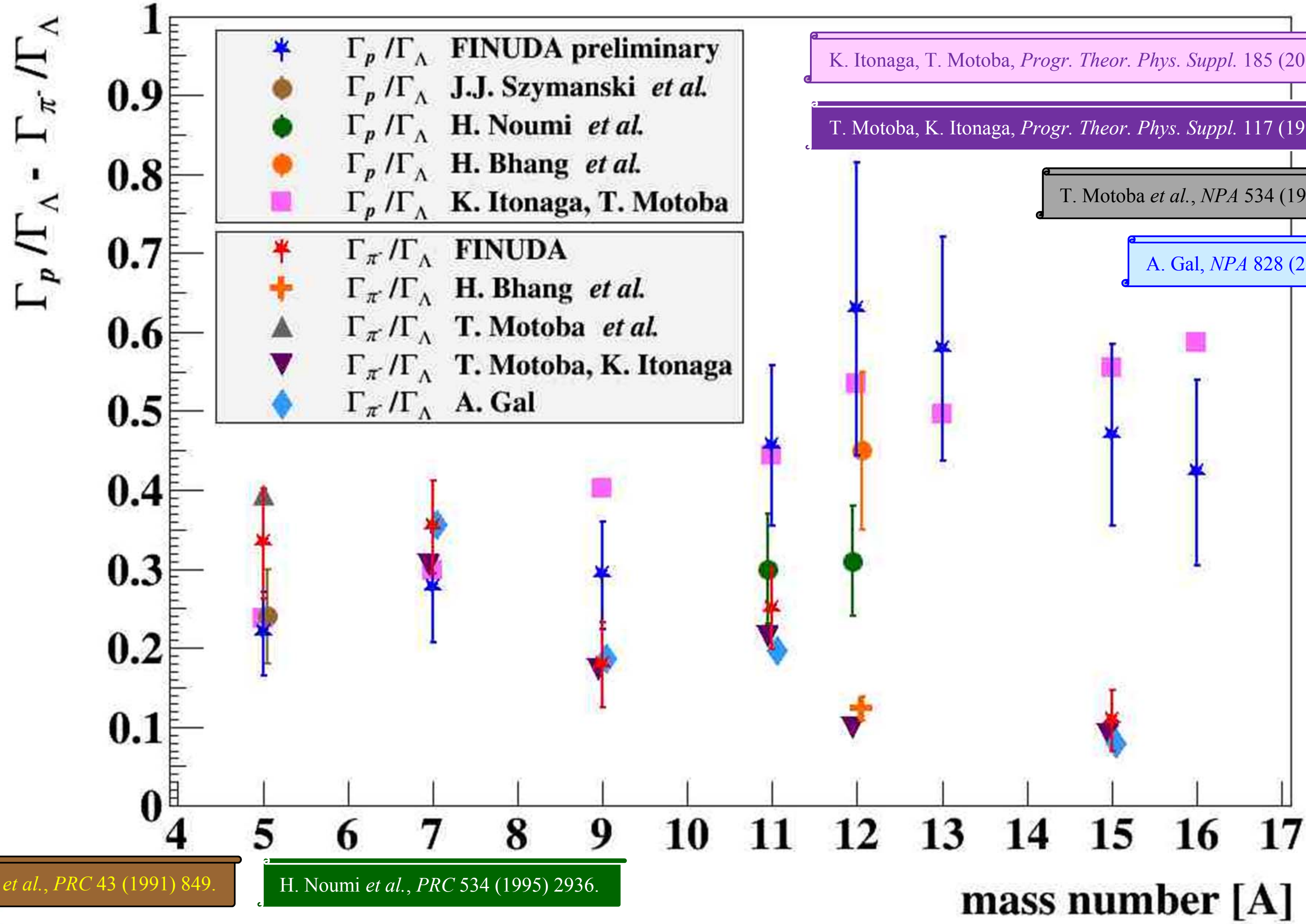
- $\alpha_5(12) = 1.035 \pm 0.193$ $\overline{\alpha_5} = 1.076 \pm 0.156$
- $\alpha_{12}(5) = 2.770 \pm 0.632$ $\overline{\alpha_{12}} = 2.583 \pm 0.373$

general expression:

$\alpha(A) = (0.215 \pm 0.031)A$

preliminary

First determination of Γ_p for 8 Hypernuclei



K. Itonaga, T. Motoba, *Progr. Theor. Phys. Suppl.* 185 (2010) 252.

T. Motoba, K. Itonaga, *Progr. Theor. Phys. Suppl.* 117 (1994) 477.

T. Motoba *et al.*, *NPA* 534 (1991) 597.

A. Gal, *NPA* 828 (2009) 72.

J.J. Szymansky *et al.*, *PRC* 43 (1991) 849.

H. Noumi *et al.*, *PRC* 534 (1995) 2936.

H. Bhang *et al.*, *JKPS* 59 (2011) 1461.

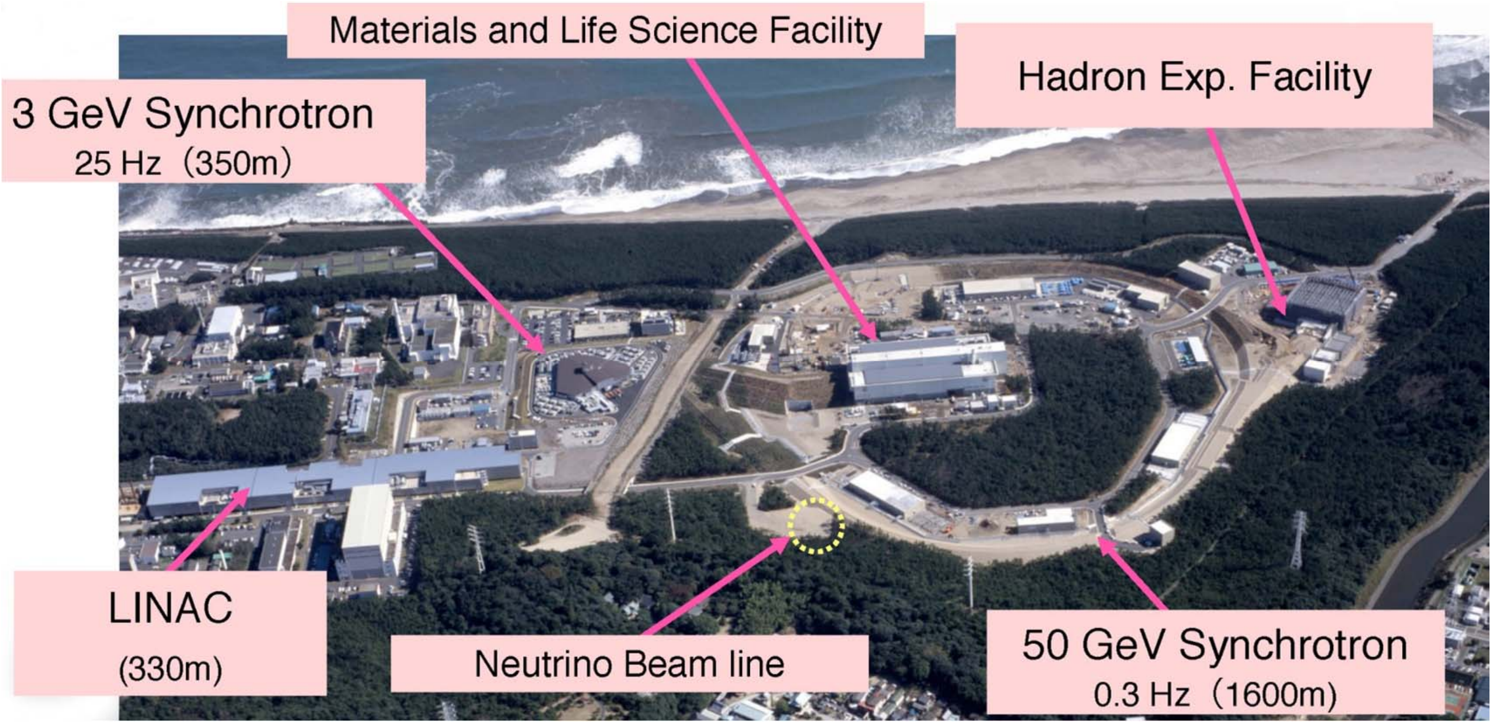
M. Agnello *et al.*, *PLB* 681 (2009) 139.

Future dedicated experiments

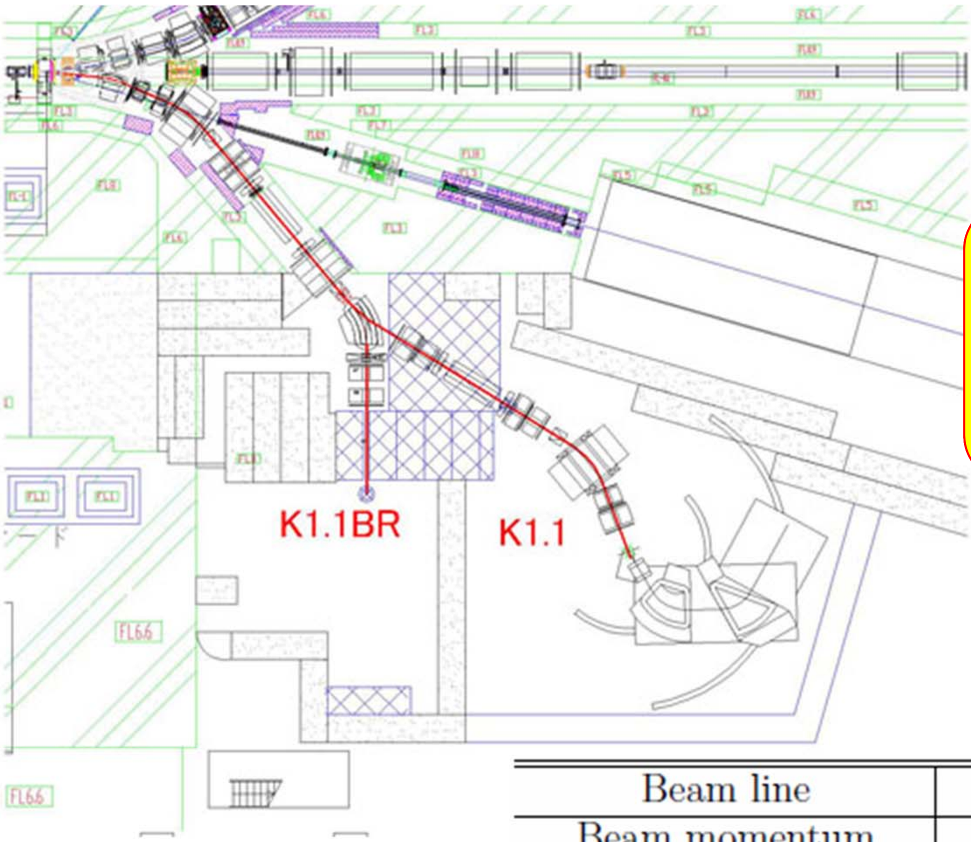
E18 — Coincidence measurement of the weak decay of $^{12}C_{\Lambda}$ and the three-body weak interaction process

E22 — Exclusive study of the $\Lambda\mathcal{N}$ weak interaction in A = 4 Λ-hypernuclei

@ K1.8 beam line



J-PARC K1.1 beam line



one order of magnitude
more efficient data collection
expected
with respect to K1.8 beam line

Beam line	K1.8	K1.8BR	K1.1
Beam momentum	1.5 GeV/c	1.1 GeV/c	1.1 GeV/c
Beam intensity	0.5×10^6/spill	1.2×10^6/spill	1.0×10^6/spill
$\frac{d\sigma}{d\Omega}({}^7_\Lambda\text{Li}(3/2^+), \theta = 10^0)$	$7.1\mu b/sr$	$17\mu b/sr$	
Relative γ-ray yield	1	5.7	4.8
K/π ratio		< 0.9	~ 3
γ-ray peak broadening	8.2%	6.1%	

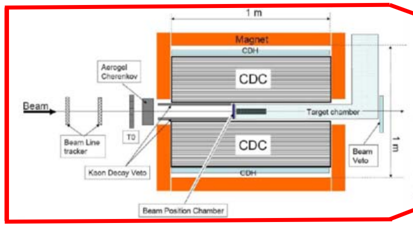
old (2008) conservative (?) perspective

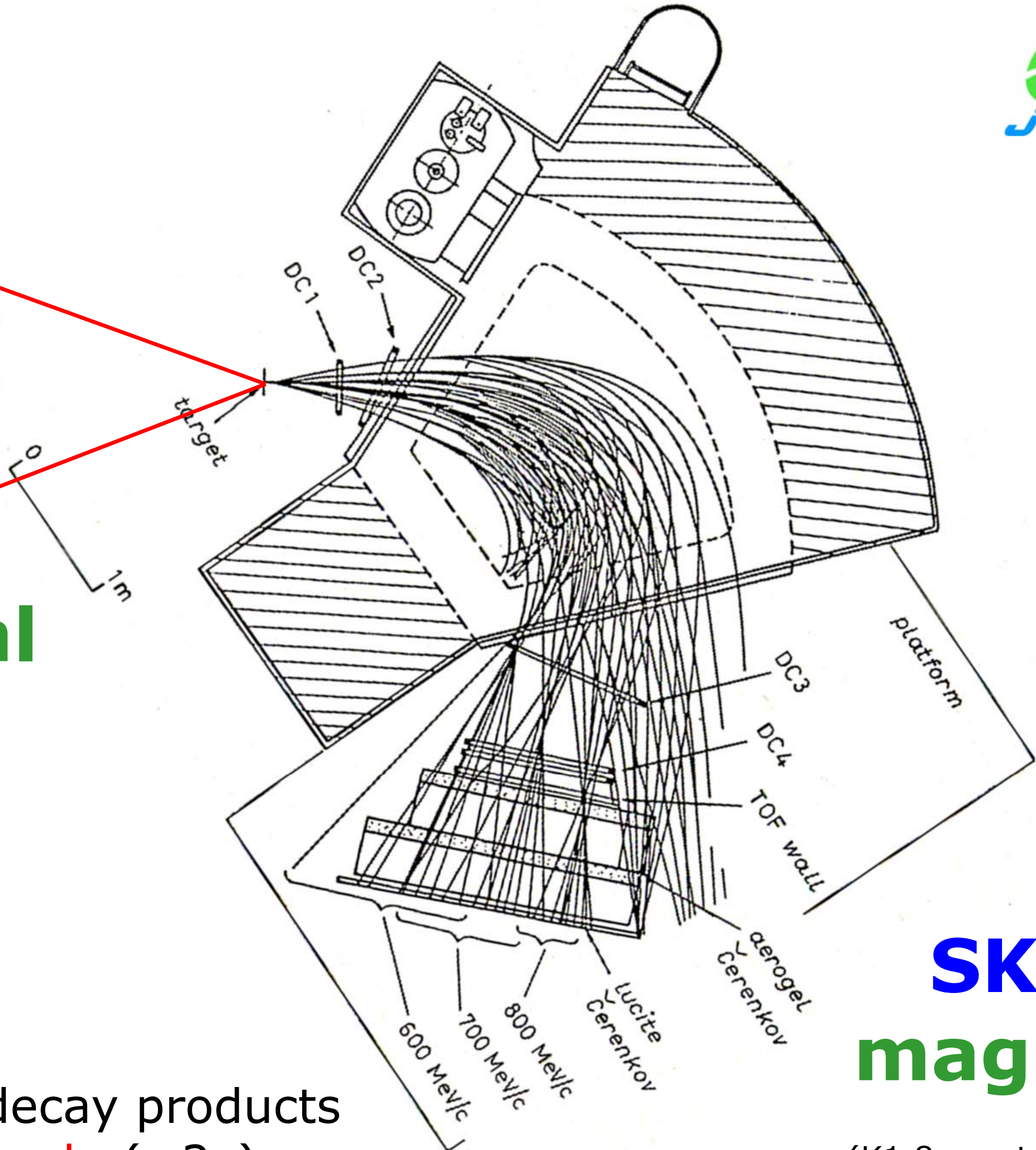
E10 published data: $> 1 \times 10^7\ \pi^+$/spill

H. Sugimura *et al.*, *PLB* 729 (2014) 39.

A possible apparatus concept layout

unavoidably biased
by the FINUDA experience





Cylindrical Detector System

(K1.8BR spectrometer)

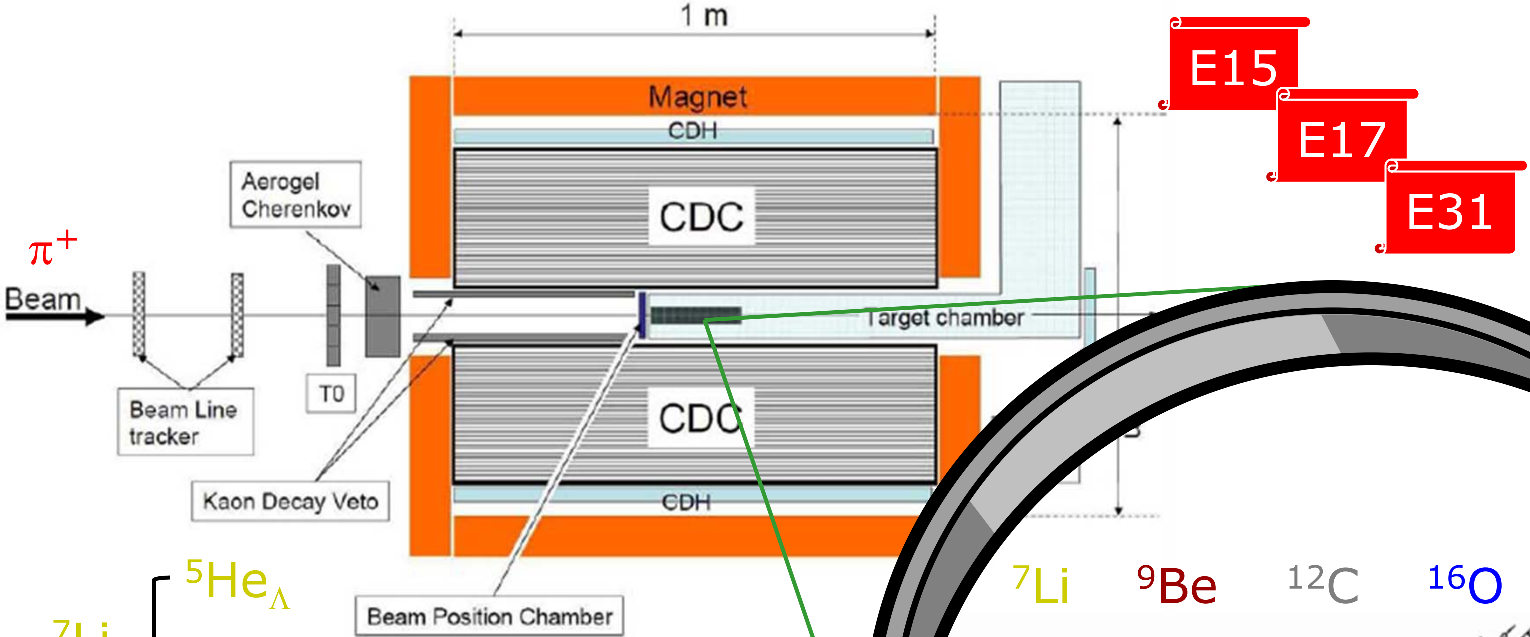
SKS magnet

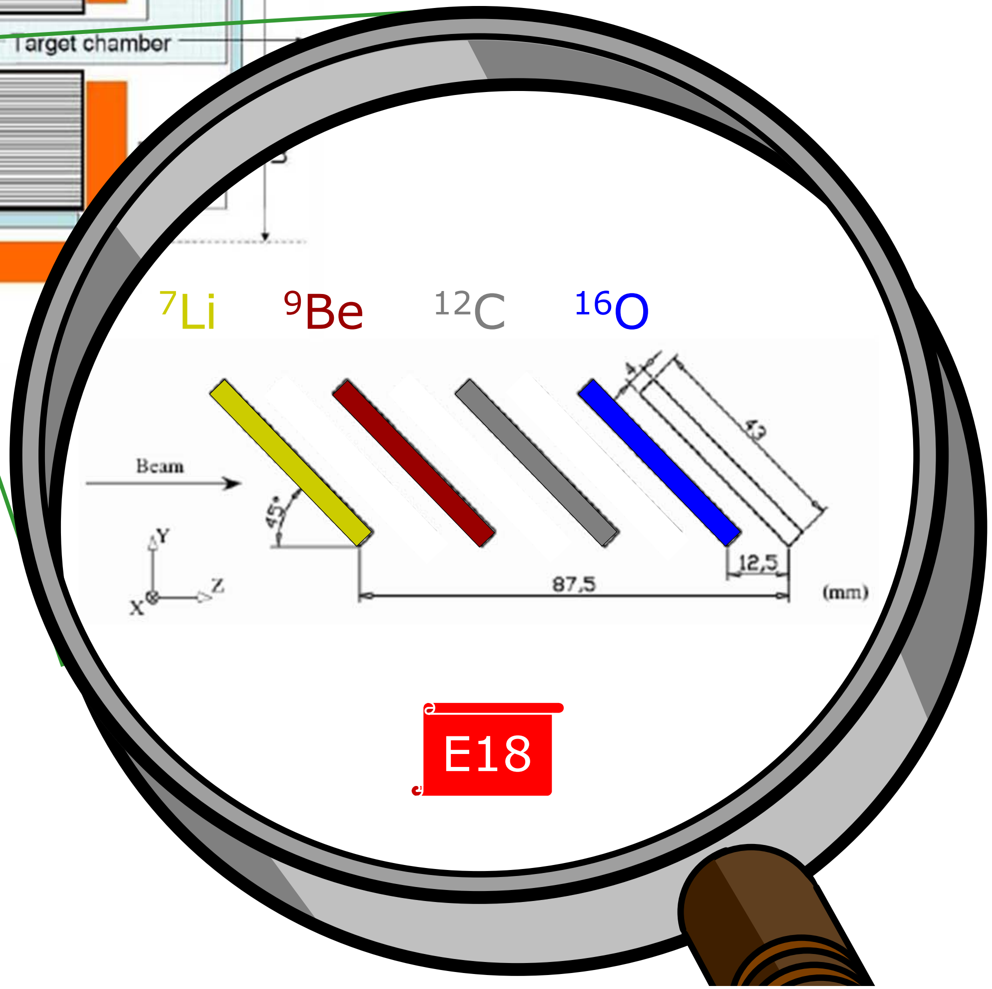
(K1.8 spectrometer)

essential requirements

- magnetic analysis of decay products
- large detection solid angle (~2π)

A possible apparatus concept layout





^{7}Li: ^{5}He$_{\Lambda}$, ^{7}Li$_{\Lambda}$

^{9}Be: ^{9}Be$_{\Lambda}$

^{12}C: ^{11}B$_{\Lambda}$, ^{12}C$_{\Lambda}$

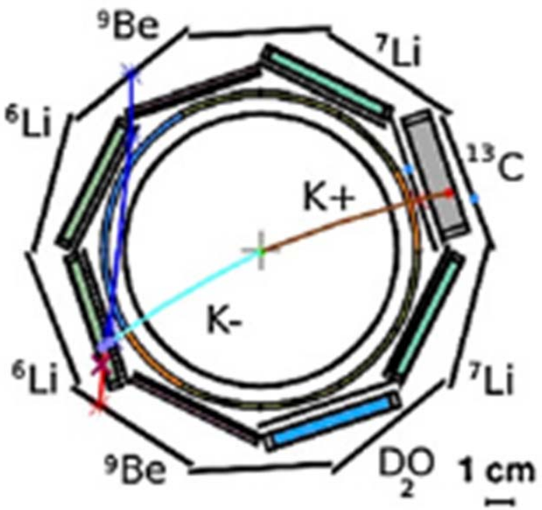
^{16}O: ^{15}N$_{\Lambda}$, ^{16}O$_{\Lambda}$

target thickness:
0.7 gr/cm^2

along the beam:
1.0 gr/cm^2

Detector (minimal) requirements

- threshold for proton detection: ~ 20 – 25 MeV
- energy resolution: ~ 3 MeV (FWHM)
- good YN vertex localization: ~ 1 – 2 mm (FWHM)



- time resolution: < 200 ps (FWHM)

Expected rates (rough estimate)

educated guess → $\sim 10^8\ \pi^+$ / spill

H. Sugimura *et al.*, *PLB* 729 (2014) 39.

$> 1 \times 10^7 \pi^+$/spill

interspill: 3.5 s → $\sim 10^{12}\ \pi^+$ / day

from previous experience → $\sim 10^4\ {}^{12}C_{\Lambda\ g.s.}$ / day

KEK-PS:
E336, E369, E419, E462, E508

$\sim 1\ {}^{12}C_{\Lambda\ g.s.} / 10^8\ \pi^+$

formation ratio on 1 g/cm^2 target

B.R. (0.5), $\Delta\Omega$ (0.5), $\varepsilon_{riv/rec}$ (0.5) → $\sim 10^3\ {}^{12}C_{\Lambda\ g.s.}$ / day

E18 request:
$4 \times 10^{12}\ \pi^+$ on target(s)

beam time request:

10 days

Aknowledgement

A special thanks to:

- Michelangelo Agnello
- Elena Botta
- Tullio Bressani
- Stefania Bufalino