First determination of the one-proton induced NMWD width for p-shell Λ-hypernuclei

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on behalf of the FINUDA Collaboration

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Summary

✓ Previous FINUDA results:

Γ_{2N} from proton spectra (PLB 685 (2010) 247)

Γ_{2N} from n&p coincidences (PLB 701 (2011) 556)

✓ Revisited analysis

✓ Γ_p for p-shell Λ-hypernuclei

NMWD data: Indian Summer school 2010

References	Exp.	Measurement
Szymanski PRC 43 (1991) 849	BNL AGS, LESB I (K^-,π^-) 800 MeV/c	p spectrum, Γ_p, Γ_n, Γ_{nm} , Γ_n/Γ_p for ${}^5{}_\Lambda$He, Γ_{nm} , Γ_n/Γ_p for ${}^{12}{}_\Lambda$C
Noumi PRC 52 (1995) 2936	KEK PS E160 (π^+, K^+) 1.05 GeV/c	p spectrum for ${}^{12}{}_\Lambda$C, Γ_p/Γ_Λ, $\Gamma_{nm}/\Gamma_\Lambda$, Γ_n/Γ_p for ${}^{11}{}_\Lambda$B and ${}^{12}{}_\Lambda$C
Hashimoto PLR 88 (2002) 045203	KEK PS E307 (π^+, K^+) 1.05 GeV/c	p spectrum and Γ_n/Γ_p for ${}^{12}{}_\Lambda$C and ${}^{28}{}_\Lambda$Si (theory)
H.J.Kim PRC 68 (2003) 065201	KEK PS E369 (π^+, K^+) 1.05 GeV/c	n spectrum for ${}^{12}{}_\Lambda$C and ${}^{89}{}_\Lambda$Y and Γ_n/Γ_p for ${}^{12}{}_\Lambda$C (theory)
Okada PLB 597 (2004) 249	KEK PS E462-E508 (π^+, K^+) 1.05 GeV/c	p, n spectra and Γ_n/Γ_p for ${}^5{}_\Lambda$He and ${}^{12}{}_\Lambda$C (exp)
Sato PRC 71 (2005) 025203	KEK PS SKS E307 (π^+, K^+) 1.05 GeV/c	p spectrum and $\Gamma_{nm}/\Gamma_\Lambda$ for ${}^{11}{}_\Lambda$B, ${}^{12}{}_\Lambda$C, ${}^{27}{}_\Lambda$Al, ${}^{28}{}_\Lambda$Si, ${}_\Lambda$Fe (theory)
Kang PRL 96 (2006) 062301	KEK PS E462 (π^+, K^+) 1.05 GeV/c	p & n spectra, Γ_n/Γ_p for ${}^5{}_\Lambda$He
M.J.Kim PLB 641 (2006) 28	KEK PS E508 (π^+, K^+) 1.05 GeV/c	p & n spectra, Γ_n/Γ_p for ${}^{12}{}_\Lambda$C
Bhang EPJ A33 (2007) 259	KEK PS E462-E508 (π^+, K^+) 1.05 GeV/c	re-analysis of p & n spectra for ${}^5{}_\Lambda$He and ${}^{12}{}_\Lambda$C, Γ_n/Γ_p for ${}^{12}{}_\Lambda$C
Parker PRC 76 (2007) 035501	BNL AGS, LESB II (K^-,π^-) 750 MeV/c	Γ_n, Γ_p, Γ_n/Γ_p for ${}^4{}_\Lambda$He
Agnello NPA 804 (2008) 151	LNF (K^-_{stop}, π^-)	p spectrum for ${}^5{}_\Lambda$He, ${}^7{}_\Lambda$Li and ${}^{12}{}_\Lambda$C
M.Kim PRL 103 (2009) 182502	KEK PS E508	re-analysis of p & n spectra, Γ_n, Γ_p, Γ_{2N} for ${}^{12}{}_\Lambda$C
Agnello PLB 685 (2010) 247	LNF (K^-_{stop}, π^-)	p spectrum for ${}^5{}_\Lambda$He, ${}^7{}_\Lambda$Li, ${}^9{}_\Lambda$Be, ${}^{11}{}_\Lambda$B ${}^{12}{}_\Lambda$C, ${}^{13}{}_\Lambda$C, ${}^{15}{}_\Lambda$N and ${}^{16}{}_\Lambda$O

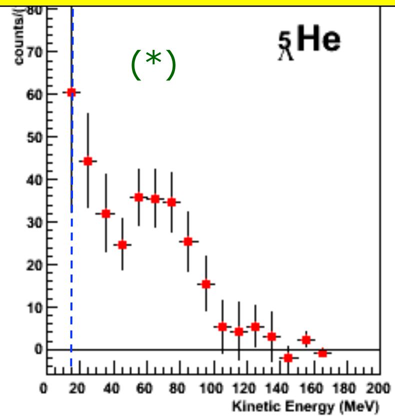
NMWD data: SPHERE meeting 2014

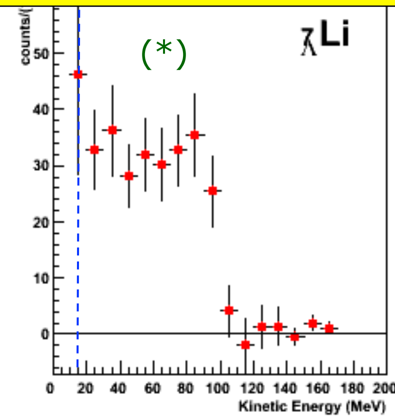
References	Exp.	Analysis
Agnello PLB 685 (2010) 247	LNF (K^-_{stop}, π^-)	Γ_{2N}/Γ_p from (π, p) coincidences for $^5_\Lambda He$, $^7_\Lambda Li$, $^9_\Lambda Be$, $^{11}_\Lambda B$, $^{12}_\Lambda C$, $^{13}_\Lambda C$, $^{15}_\Lambda N$, $^{16}_\Lambda O$
Agnello PLB 701 (2011) 556	LNF (K^-_{stop}, π^-)	Γ_{2N}/Γ_p from (π, p, n) coincidences for $^5_\Lambda He$, $^7_\Lambda Li$, $^9_\Lambda Be$, $^{11}_\Lambda B$, $^{12}_\Lambda C$, $^{13}_\Lambda C$, $^{15}_\Lambda N$, $^{16}_\Lambda O$
Agnello NPA 881 (2012) 322	LNF (K^-_{stop}, π^-)	2N-NMWD evidence (π, p, n, n)
Bufalino NPA 914 (2013) 160	LNF (K^-_{stop}, π^-)	p spectra revision
Agnello sub. to PLB July 2014	LNF (K^-_{stop}, π^-)	Γ_{2N} revisited analysis Γ_p/Γ_Λ for $^5_\Lambda He$, $^7_\Lambda Li$, $^9_\Lambda Be$, $^{11}_\Lambda B$, $^{12}_\Lambda C$, $^{13}_\Lambda C$, $^{15}_\Lambda N$, $^{16}_\Lambda O$
K. Itonaga, T. Motoba, *Progr. Theor. Phys. Suppl.* 185 (2010) 252		theoretical calculations on MWD and NMWD of p-shell Λ-hypernuclei
H. Bhang *et al.*, *JKPS* 59 (2011) 1461	KEK (π^+, K^+)	final KEK results on $^{12}_\Lambda C$ WD widths

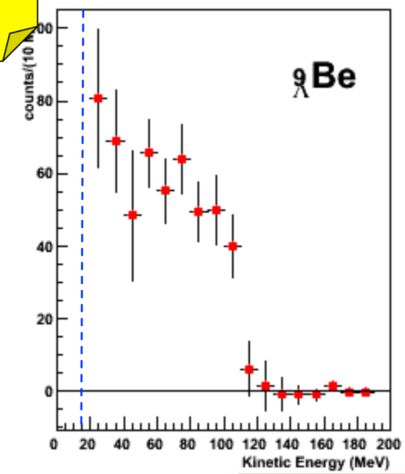
NMWD p inclusive spectra

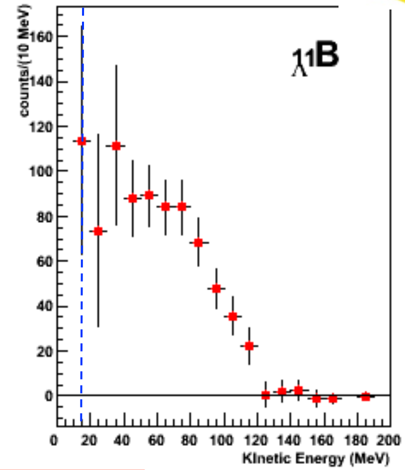
(π^-, p) coincidence
(K^-_{stop} (np)→Σ^- p; Σ^-→n π^-) background subtracted and acceptance corrected

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



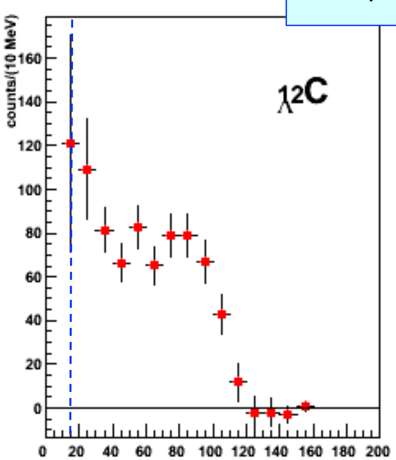


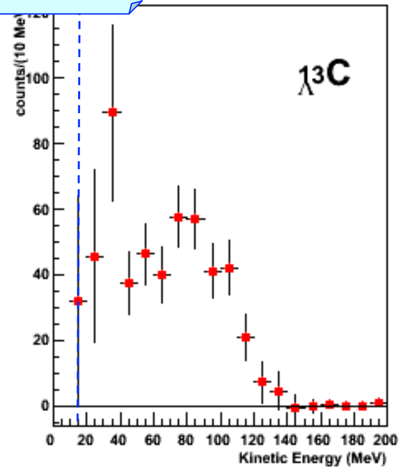


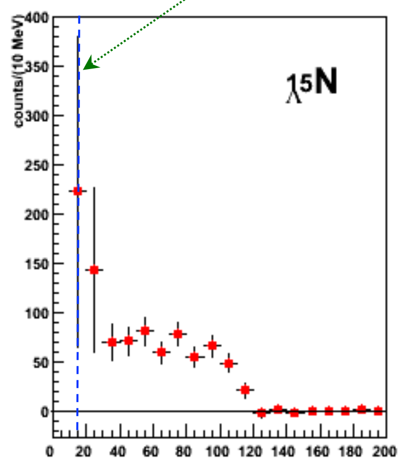


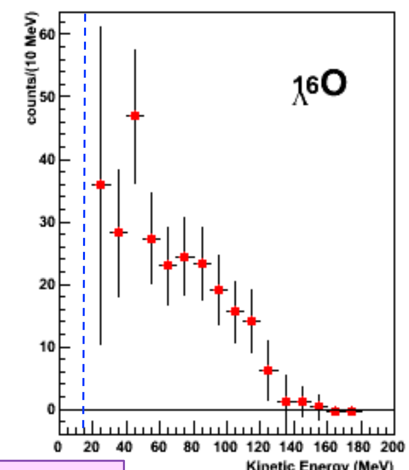
1N , 2N , FSI!!!

15 MeV threshold!









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

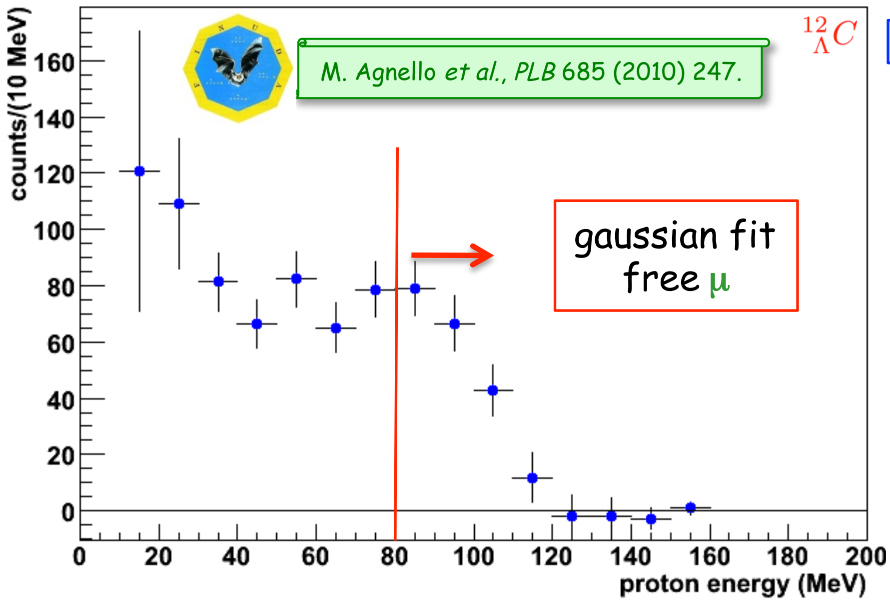
common features:

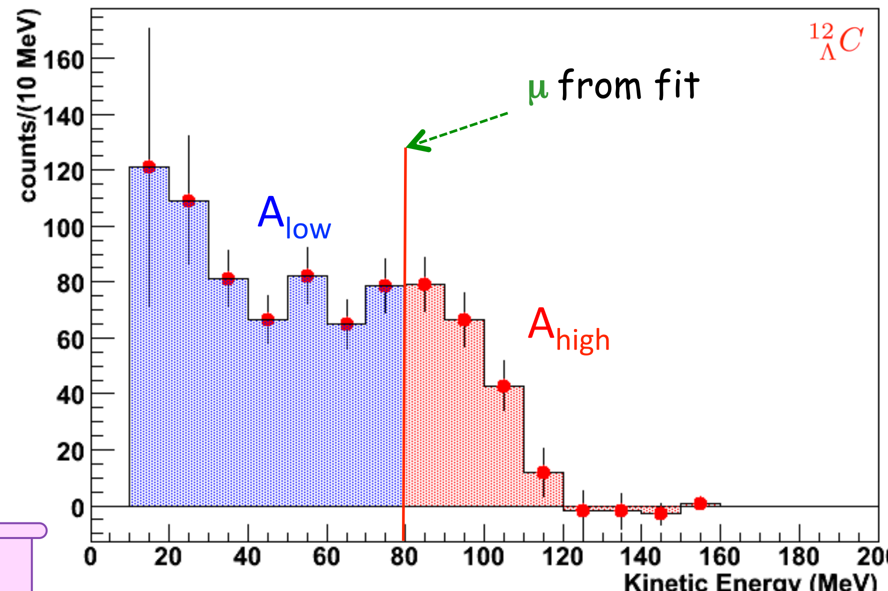
- low energy rise
- structure at ~80 MeV

Γ_{2N} and FSI determination

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

assumption → $\Gamma_{2N}/\Gamma_{NMWD}$, 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.

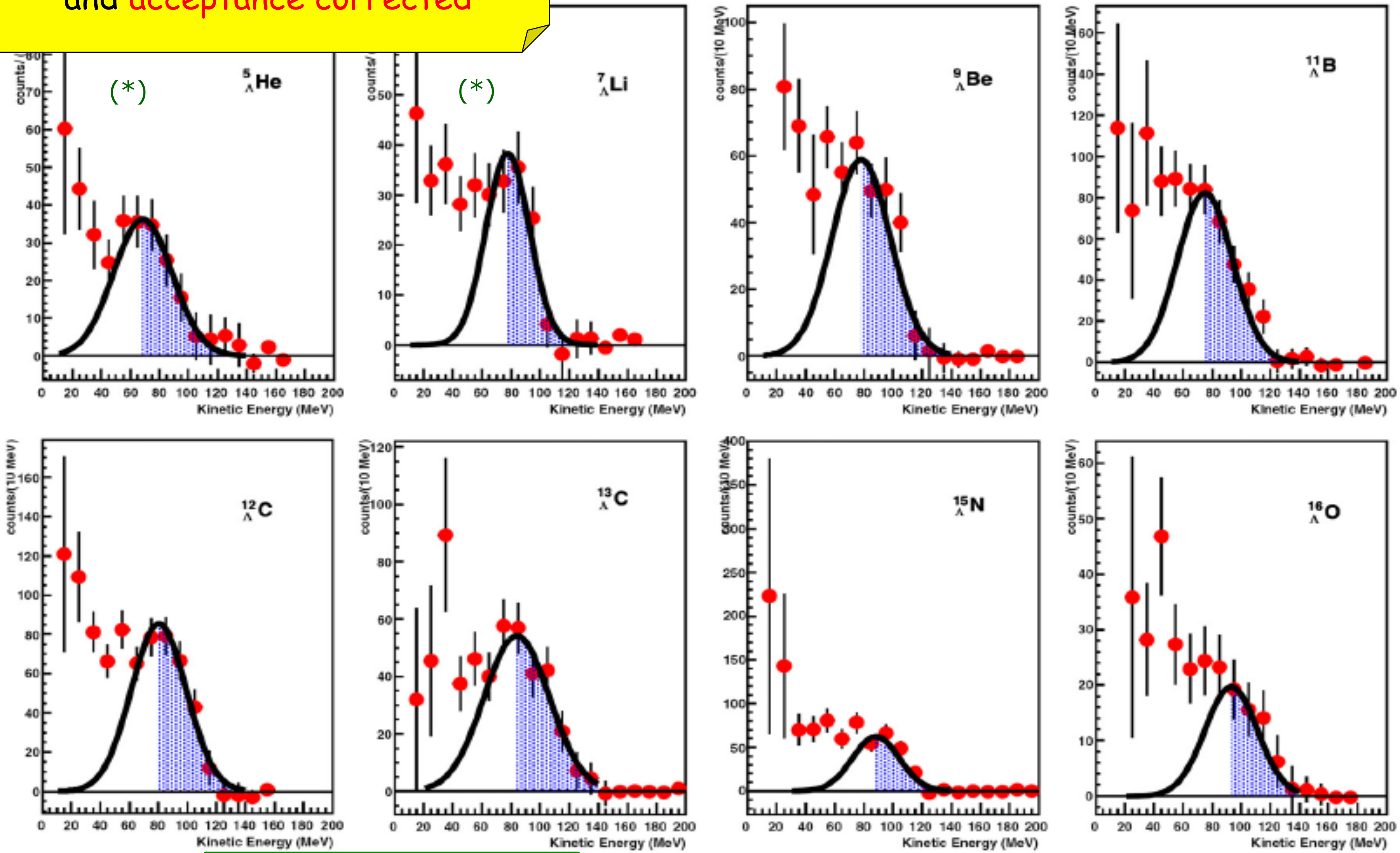
assumption →

- A_{low}: 1N , 2N , FSI
- A_{high}: 1N , FSI; 2N (T_p > 70 MeV) ~5% Γ_{2N}

FSI and 2N induced non-mesonic decay

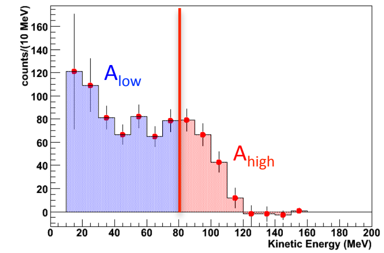
(π^-, p) coincidence
p spectra background subtracted
and acceptance corrected

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



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

Γ_{2N} and FSI 1st determination (π^-, p)

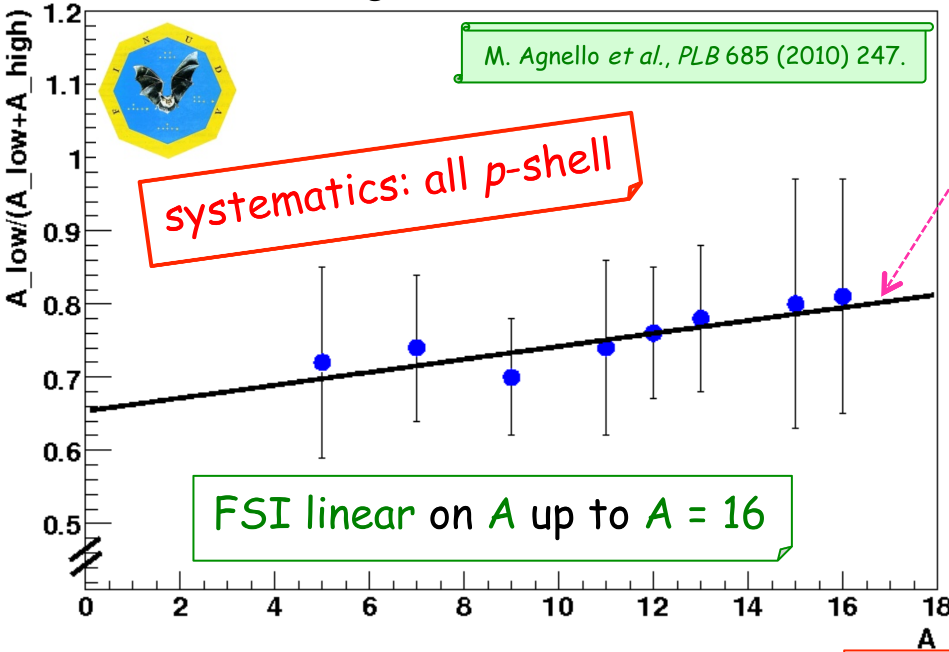


E. Bauer and G. Garbarino, *NPA 828* (2009) 29.

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

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

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



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

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

- 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 $^{12}C_\Lambda$

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

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

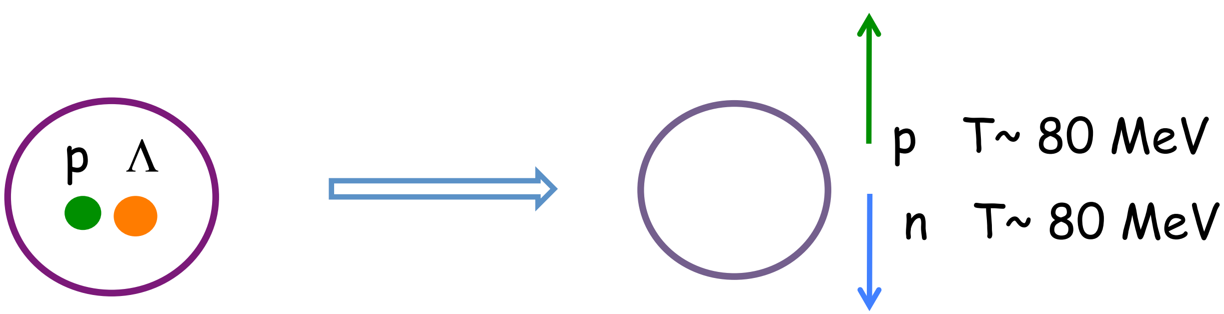
Γ_{2N} improved determination (π^-, p, n)

- it is not possible to disentangle 1N, 2N and FSI contributions on an event basis

- enrich the 2N contribution by rejecting 1N-like events, FSI from A=(5 ± 16)

- 1N NMWD: $\Lambda N \rightarrow NN$: ~2-body reaction, daughter nucleus ~ spectator → $\Lambda p \rightarrow np$: (n, p) b.t.b angular correlation, T(p)+T(n)~160 MeV (+ nuclear medium effects) if no FSI

KEK PS E462 ${}^{5}_{\Lambda}$He: B.H. Kang et al., PRL 96 (2006) 062301
KEK PS E508 ${}^{12}_{\Lambda}$C: M.J. Kim et al., PLB 641 (2006) 28, M. Kim et al., PRL 103 (2009) 182502



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

Γ_{2N} improved determination (π^-, p, n)

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

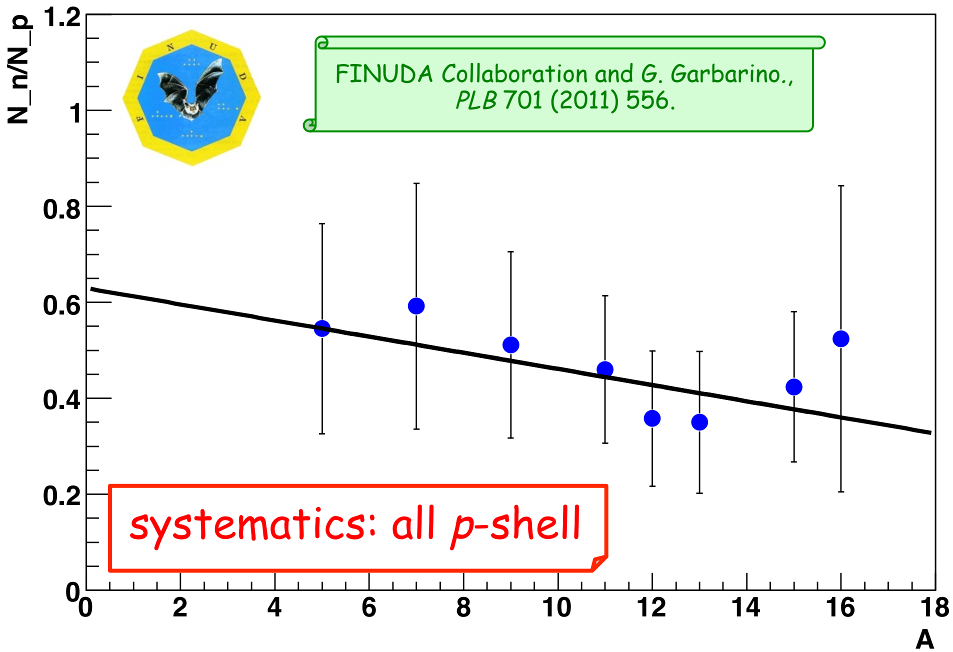
$$R(A) = \boxed{a} + bA = \boxed{\frac{\Gamma_2}{0.5 \cdot \Gamma_p}} + bA$$

assumption

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

Γ_2/Γ_p independent on A

$$\frac{\Gamma_2}{\Gamma_p} = 0.39 \pm 0.16_{stat}\ {}^{+0.04_{sys}}_{-0.03_{sys}}$$



$$\frac{\Gamma_2}{\Gamma_{NM}} = \frac{\Gamma_2/\Gamma_p}{\Gamma_n/\Gamma_p + 1 + \Gamma_2/\Gamma_p} = 0.21 \pm 0.07_{stat}\ {}^{+0.03_{sys}}_{-0.02_{sys}}$$

- M. Kim *et al.*, *PRL* 103 (2009) 182502: 0.29 ± 0.13 $^{12}C_{\Lambda}$.
- M. Agnello et al., *PLB* 685 (2010) 247: 0.24 ± 0.10.

- 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]		$0.21 \pm 0.07_{\text{stat}}\ {}^{+0.03\,\text{sys}}_{-0.02\,\text{sys}}$	$A = 5$–16, np spectra

consistent within large errors

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

"smoking gun" evidence missing!

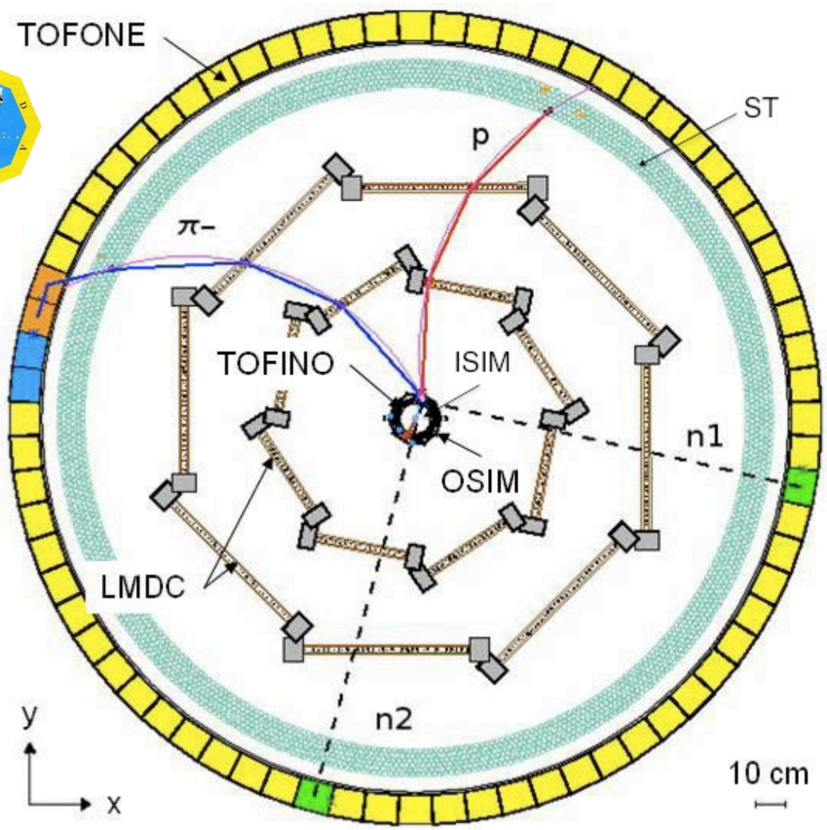
- experimental hardness: 3 nucleons emitted from Λ-hypernucleus g.s.
  4-fold coincidence measurement (π^-, *p*, *n*, *n*)

2N induced decay exp. evidence

Triple coincidence (n+n+p) events @ FINUDA

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

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



$p_{\pi-}$	=	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

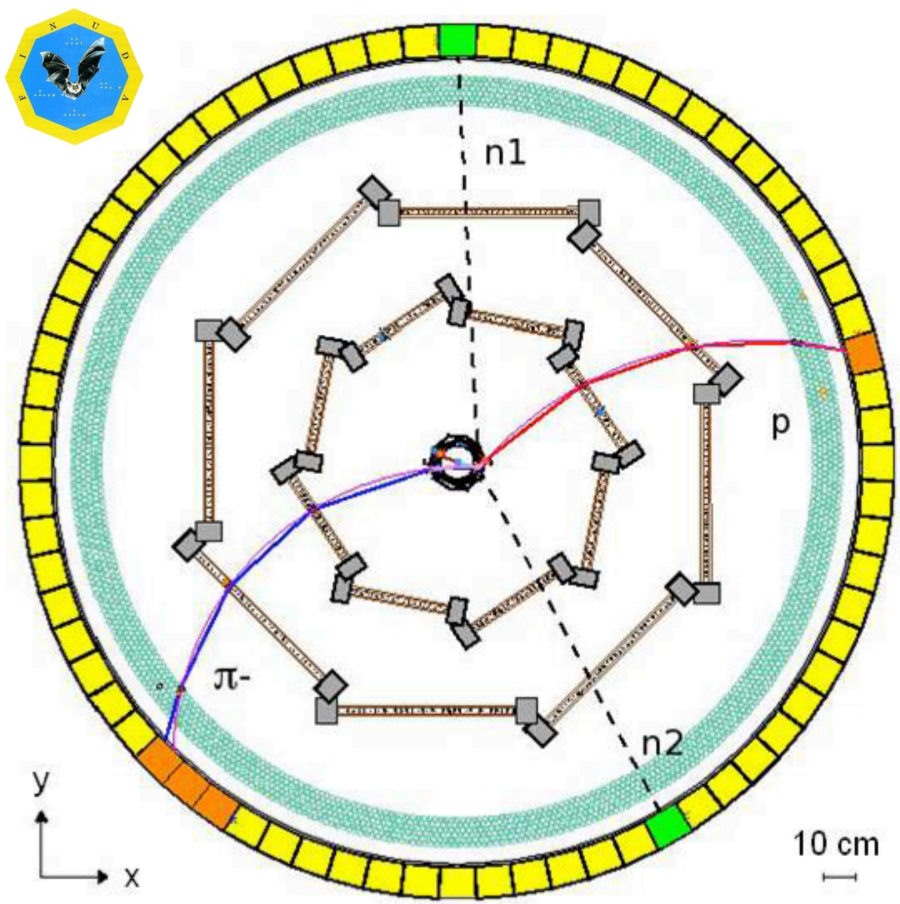
${}^{7}_{\Lambda}\mathrm{Li}$	MM (MeV/c^2)
${}^{4}\mathrm{He}$	3727.4
${}^{3}\mathrm{He}+n$	3748.0
${}^{3}\mathrm{H}+p$	3747.2

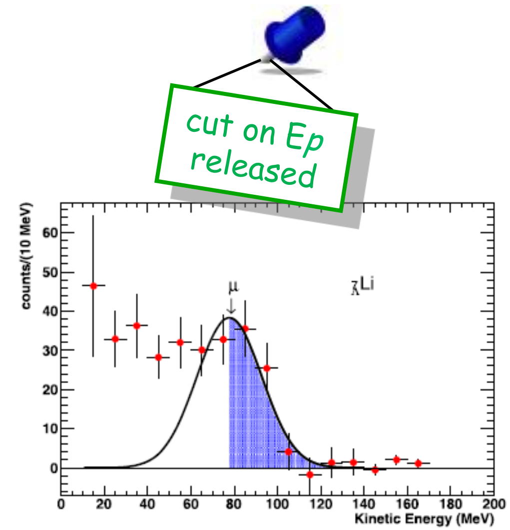
first, direct experimental evidence

2N induced decay exp. evidence

Triple coincidence (n+n+p) events @ FINUDA

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





p_{π^-} = 276.5 ± 1.2 MeV/c
p_{miss} = 447 ± 18 MeV/c
E_{tot} = 147.1 ± 4.2 MeV
MM = 3720.3 ± 4.7 MeV/c^2

E(n1) = 21 ± 2.0 MeV
E(n2) = 35.3 ± 3.6 MeV
E(p) = 90.83 ± 0.50 MeV

ϑ(n1 n2) = 126.5° ± 5.4°
ϑ(n1 p) = 53.5° ± 4.3°
ϑ(n2 p) = 124.6° ± 3.9°

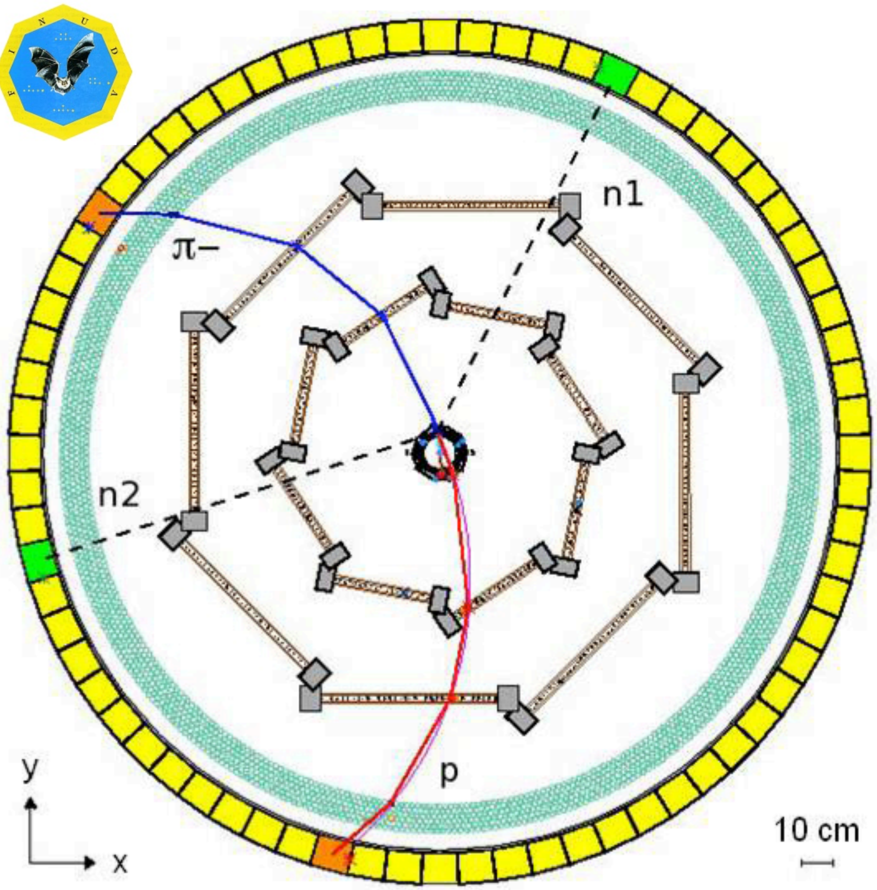
no n-n or p/n scattering

2N induced decay exp. evidence

Triple coincidence (n+n+p) events @ FINUDA

exclusive $\Lambda np \rightarrow nnp$ ${}^{9}_{\Lambda}Be \rightarrow {}^{3}He + {}^{3}H + p + n + n$ decay event

cut on Ep released



p_{π^-} = 286.7 ± 1.2 MeV/c
p_{miss} = 253 ± 18 MeV/c
E_{tot} = 123.5 ± 4.9 MeV
MM = 5617.3 ± 5.0 MeV/c^2

E(n1) = 20.2 ± 2.5 MeV
E(n2) = 31.5 ± 4.2 MeV
E(p) = 71.77 ± 0.80 MeV

ϑ(n1 n2) = 133.6 °± 7.5°
ϑ(n1 p) = 128.5°± 5.5°
ϑ(n2 p) = 95.4°± 3.6°

no n-n or p/n scattering

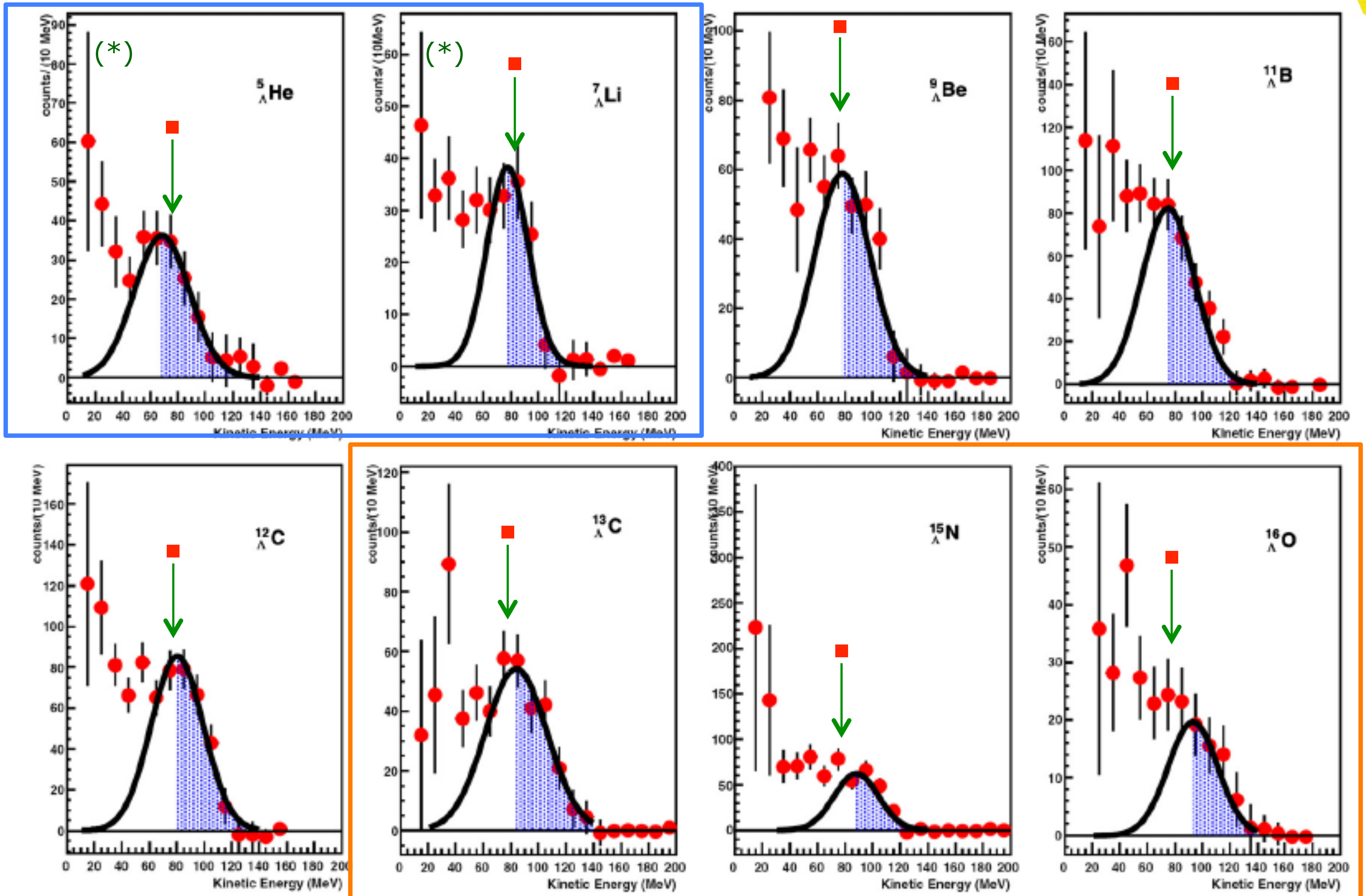
${}^{9}_{\Lambda}Be$	MM (MeV/c^2)
${}^{6}Li$	5601.5
${}^{5}Li + n$	5607.2
${}^{4}He + d$	5603.0
${}^{3}He + {}^{3}H$	5617.3

Dynamics of NMWD: exclusive NMWD?
p spectra A=(5-16)

b-t-b hypothesis

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

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



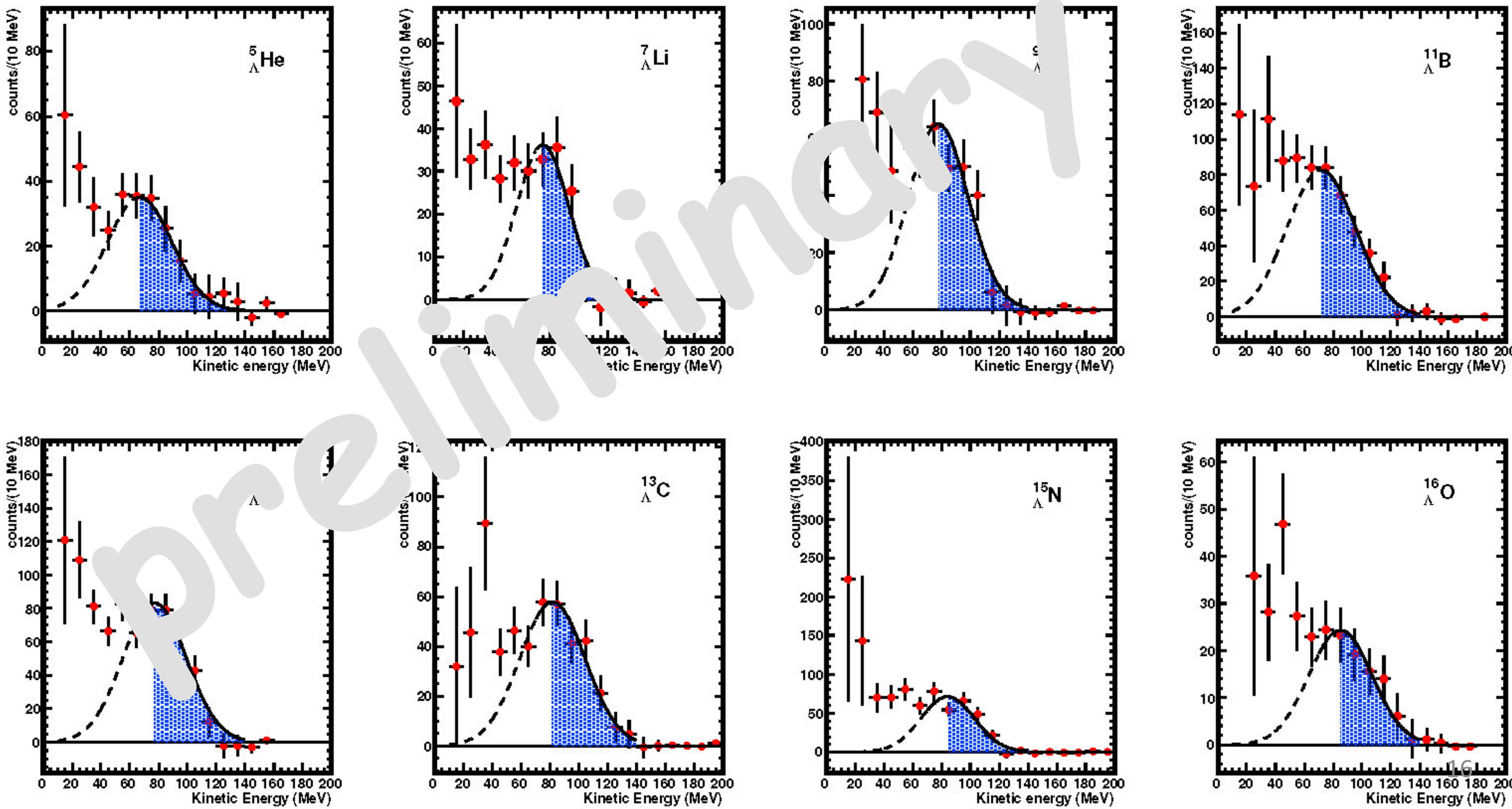
(*) M. Agnello *et al.*, *NPA* 804 (2008) 151.

■ "simple" kinematical calculation: btb kinematics

Revised analysis of the proton spectra

Attempt of improving the fits by shifting down the lower edge for the fits to 50, 60 and 70 MeV:

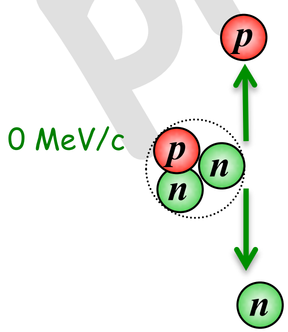
better value of $\chi^2/n = 1.33$ when choosing the starting point at 70 MeV

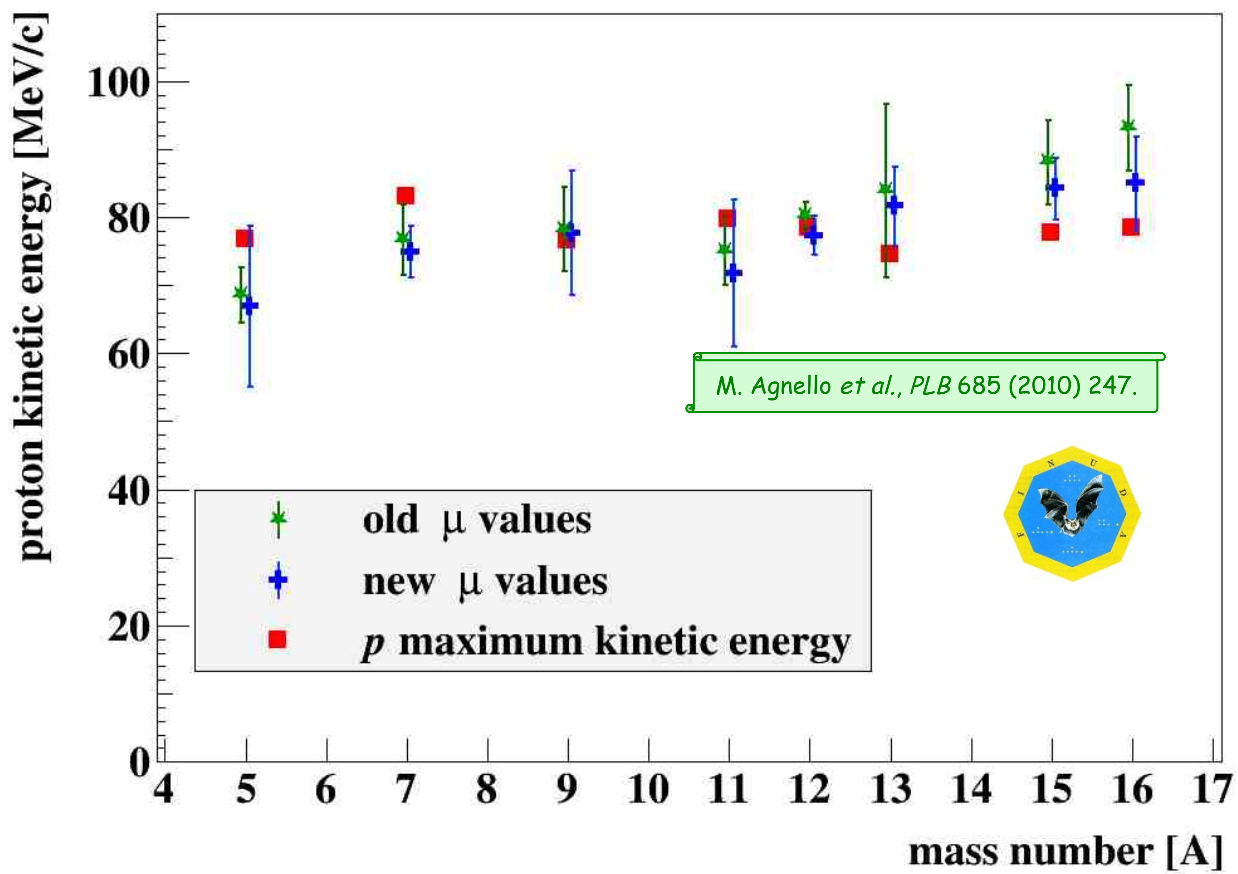


Revised analysis of the proton spectra

- 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 ${}^{16}O_{\Lambda}$

p maximum kinetic energy





Refined determination of $\Gamma_{2N} / \Gamma_{NMWD}$
inclusive proton spectra, (π-, p) coincidence

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

$\Gamma_{2N} / \Gamma_{NMWD}$, Γ_2/Γ_1 and Γ_n/Γ_p *independent on A* in the range *A* = 5 ÷ 16

$\Gamma_{2N}/\Gamma_p = 0.43 \pm 0.25$ ($\Gamma_{2N}/\Gamma_{NMWD} = 0.24 \pm 0.10$)

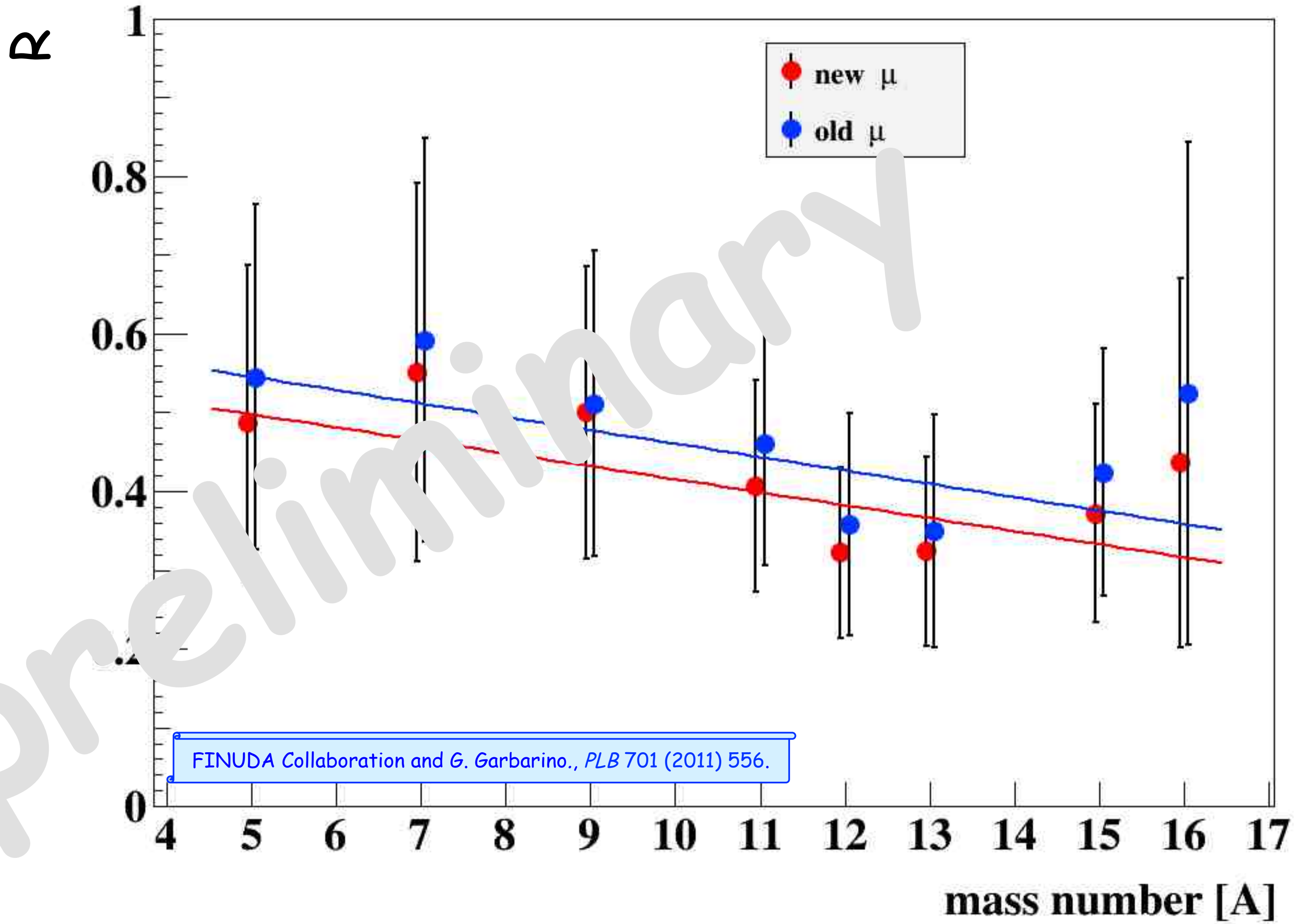
With the new μ values we find:

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

- compatible with the previous one, within the errors.

Refined determination of $\Gamma_{2N}/\Gamma_{NMWD}$ (π-, p, n) coincidence

Following PLB 701 (2011) 556:



Refined determination of $\Gamma_{2N}/\Gamma_{NMWD}$ (π-, p, n) coincidence

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

FINUDA Collaboration and G. Garbarino., *PLB* 701 (2011) 556.

With the new μ values, we got:

$$\frac{\Gamma_{2N}}{\Gamma_p} = 0.36 \pm 0.14_{stat}\,{}^{+0.05_{sys}}_{-0.04_{sys}} \qquad \left(\frac{\Gamma_{2N}}{\Gamma_{NMWD}} = 0.20 \pm 0.08_{stat}\,{}^{+0.04_{sys}}_{-0.03_{sys}}\right)$$

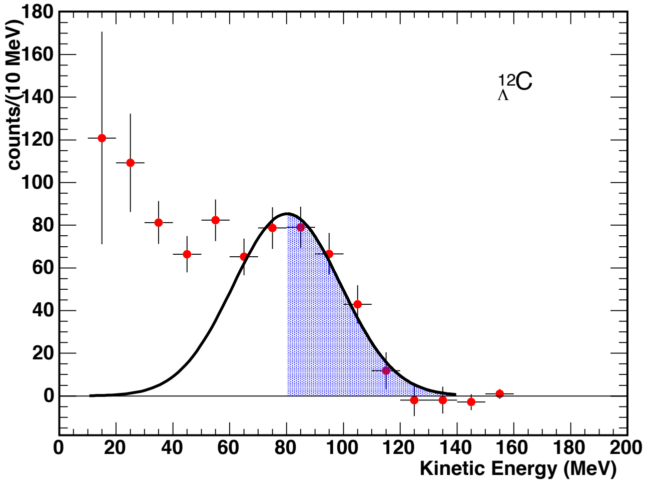
- fully compatible with the previous one, within the errors.

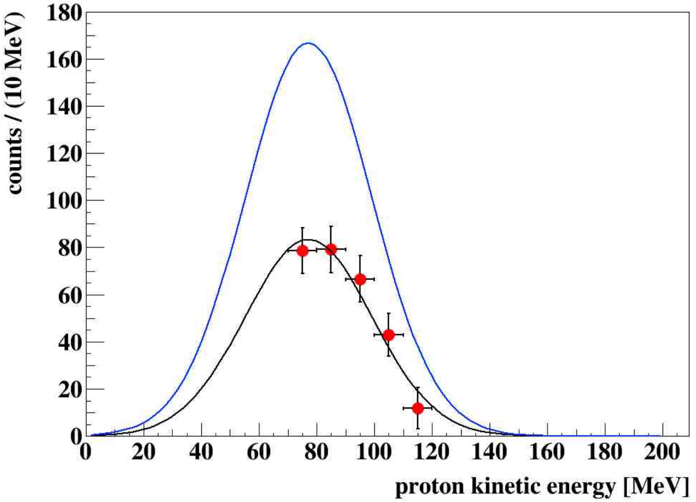
M. Kim *et al.*, *PRL* 103 (2009) 182502: 0.29 ± 0.13.

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

First determination of Γ_p/Γ_Λ for 8 Hypernuclei

Some information can be extracted by the proton spectra, but
how it is possible to extract the "true" number of protons from NMWD?
Spectra are severely distorted by several FSI effects





At least 3 effects: G. Garbarino, A. Parreño and A. Ramos, *PRC* 69 (2004) 054603.

a) number of primary protons from NMWD decreased by FSI
b) in a given region of the spectrum increase due to the FSI not only of higher energy protons, but of neutrons as well
c) quantum mechanical interference effect among p of different sources

In the upper part, Ahigh, of the experimental spectrum b) and c) ~ negligible

How to calculate a) or (a)+b)+c)) without resorting to any INC models, but only from experimental data?

First determination of Γ_p/Γ_Λ for 8 Hypernuclei

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

from exp. spectra (A_{high})

BR(1p NMWD) = Np_{NMWD} /NHyp

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

measured for $^5He_\Lambda$ and $^{12}C_\Lambda$

$$\frac{\Gamma_T}{\Gamma_\Lambda} = \frac{\Gamma_{\pi^-}}{\Gamma_\Lambda} + \frac{\Gamma_{\pi^0}}{\Gamma_\Lambda} + \frac{\Gamma_p}{\Gamma_\Lambda} + \frac{\Gamma_n}{\Gamma_p}\cdot\frac{\Gamma_p}{\Gamma_\Lambda} + \frac{\Gamma_{2N}}{\Gamma_p}\cdot\frac{\Gamma_p}{\Gamma_\Lambda}$$

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:

$\Gamma_p/\Gamma_\Lambda = 0.22 \pm 0.03$ ($^5He_\Lambda$) $\Gamma_p/\Gamma_\Lambda = 0.49 \pm 0.06$ ($^{12}C_\Lambda$)

"true": no FSI

J.J. Szymanski et al., Phys. Rev. C 43 (1991), 849

H. Noumi et al., Phys. Rev. C52 (1995), 2936.

M. Kim et al., Phys. Rev. Lett. 103 (2009), 182502.

H. Bhang et al., Jour. Kor. Phys. Soc. 59 (2011), 1461.

not used

it is then possible to determine

$\alpha_5(5) = 1.15 \pm 0.26$ $\alpha_{12}(12) = 2.48 \pm 0.46$

under the hypothesis of a linear scaling with A

$\alpha_5(12) = 1.04 \pm 0.19$ $\overline{\alpha_5} = 1.08 \pm 0.16$

$\alpha_{12}(5) = 2.77 \pm 0.63$ $\overline{\alpha_{12}} = 2.58 \pm 0.37$

general expression: $\alpha(A) = (0.215 \pm 0.031)\, A$

no INC calculation

preliminary

First determination of Γ_p/Γ_Λ for 8 Hypernuclei

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

$^{5}He_\Lambda$

Γ_T/Γ_Λ = 0.96 ± 0.03 (w.a.)
Γ_n/Γ_p = 0.45 ± 0.11
Γ_{2N}/Γ_p = 0.36 ± 0.14
$\Gamma_{\pi-}/\Gamma_\Lambda$ = 0.34 ± 0.02 (w.a.)
$\Gamma_{\pi0}/\Gamma_\Lambda$ = 0.20 ± 0.01 (w.a.)

$^{12}C_\Lambda$

Γ_T/Γ_Λ = 1.22 ± 0.04 (w.a.)
Γ_n/Γ_p = 0.51 ± 0.13
Γ_{2N}/Γ_p = 0.36 ± 0.14
$\Gamma_{\pi-}/\Gamma_\Lambda$ = 0.12 ± 0.01 (w.a.)
$\Gamma_{\pi0}/\Gamma_\Lambda$ = 0.17 ± 0.01 (w.a.)

J.J. Szymansky *et al.*, PRC 43 (1991) 849
S. Kameoka *et al.*, NPA 754 (2005) 173c

S. Kameoka *et al.*, NPA 754 (2005) 173c
A. Park *et al.*, PRC 61 (2000) 054004

B.H. Kang *et al.*, PRL 96 (2006) 062301

M. Kim *et al.*, PRL 103 (2009) 182502

FINUDA, this work

J.J. Szymansky *et al.*, PRC 43 (1991) 849
S. Kameoka *et al.*, NPA 754 (2005) 173c
M. Agnello *et al.*, PLB 681 (2009) 139

J.J. Szymansky *et al.*, PRC 43 (1991) 849
H. Noumi *et al.*, PRC 52 (1995) 2936
Y. Sato *et al.*, PRC 71 (2005) 025203
H. Bhang *et al.*, JKPS 59 (2011) 1461

S. Okada *et al.*, NPA 754 (2005) 178c
J.J. Szymansky *et al.*, PRC 43 (1991) 849

S. Okada *et al.*, NPA 754 (2005) 178c
A. Sakaguchi *et al.*, PRC 43 (1991) 73

$\Gamma_p/\Gamma_\Lambda(^{5}He_\Lambda)$ = 0.22 ± 0.03

$\Gamma_p/\Gamma_\Lambda(^{12}C_\Lambda)$ = 0.49 ± 0.06

$\alpha_5(^{5}He_\Lambda)$ = 1.15 ± 0.26
$\alpha_5(^{12}C_\Lambda)$ = 1.04 ± 0.19

$\overline{\alpha_5}$ = 1.08 ± 0.16
$\overline{\alpha_{12}}$ = 2.58 ± 0.37

$\alpha_{12}(^{12}C_\Lambda)$ = 2.48 ± 0.46
$\alpha_{12}(^{5}He_\Lambda)$ = 2.77 ± 0.63

a scaling linearly with A

$\alpha(A)$ = (0.215 ± 0.031) A

no INC calculation

Preliminary

First determination of Γ_p/Γ_Λ for 8 Hypernuclei

	Γ_T/Γ_Λ	α_A	Γ_p/Γ_Λ this work	Γ_p/Γ_Λ previous works	Γ_p/Γ_Λ [26]
$^{5}_{\Lambda}$He	0.962±0.034 [4, 18]	1.08±0.16	0.22±0.05	0.21±0.07 [4]	0.237
$^{7}_{\Lambda}$Li	1.12±0.12	1.51±0.22	0.28±0.07		0.297
$^{9}_{\Lambda}$Be	1.15±0.13	1.94±0.28	0.30±0.07		0.401
$^{11}_{\Lambda}$B	1.28±0.10 [5]	2.37±0.34	0.47±0.11	0.30±0.07 [5]	0.444
$^{12}_{\Lambda}$C	1.242±0.042 [18, 22]	2.58±0.37	0.65±0.19	0.31±0.07 [5] 0.45±0.10 [24]	0.535
$^{13}_{\Lambda}$C	1.21±0.16	2.80±0.40	0.60±0.14		0.495
$^{15}_{\Lambda}$N	1.26±0.18	3.23±0.47	0.49±0.11		0.555
$^{16}_{\Lambda}$O	1.28±0.19	3.44±0.50	0.44±0.12		0.586

S. Kameoka *et al.*, *NPA* 754 (2005) 173c

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

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

A. Park *et al.*, *PRC* 61 (2000) 054004

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

$(0.990\pm0.094) + (0.018\pm0.010) \cdot A$

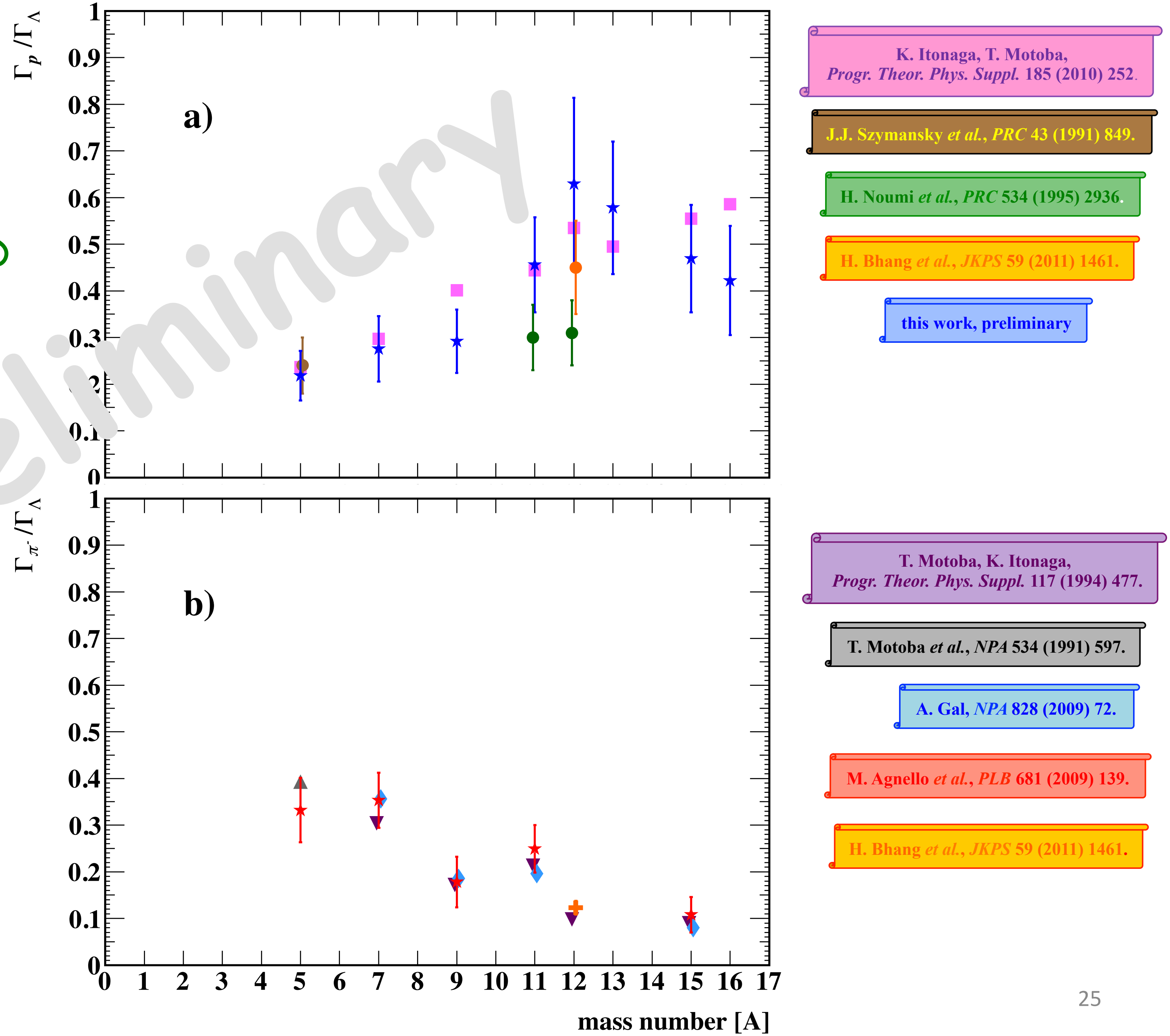
M. Agnello et al., PLB 681 (2009) 139

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

Preliminary: sub. to PLB

1p NMWD

π⁻ MWD



a)
b)
$\Gamma_p / \Gamma_\Lambda$
$\Gamma_{\pi^-} / \Gamma_\Lambda$
mass number [A]
preliminary
K. Itonaga, T. Motoba, *Progr. Theor. Phys. Suppl.* 185 (2010) 252.
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.
this work, preliminary
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.
M. Agnello *et al.*, *PLB* 681 (2009) 139.
H. Bhang *et al.*, *JKPS* 59 (2011) 1461.

Conclusions

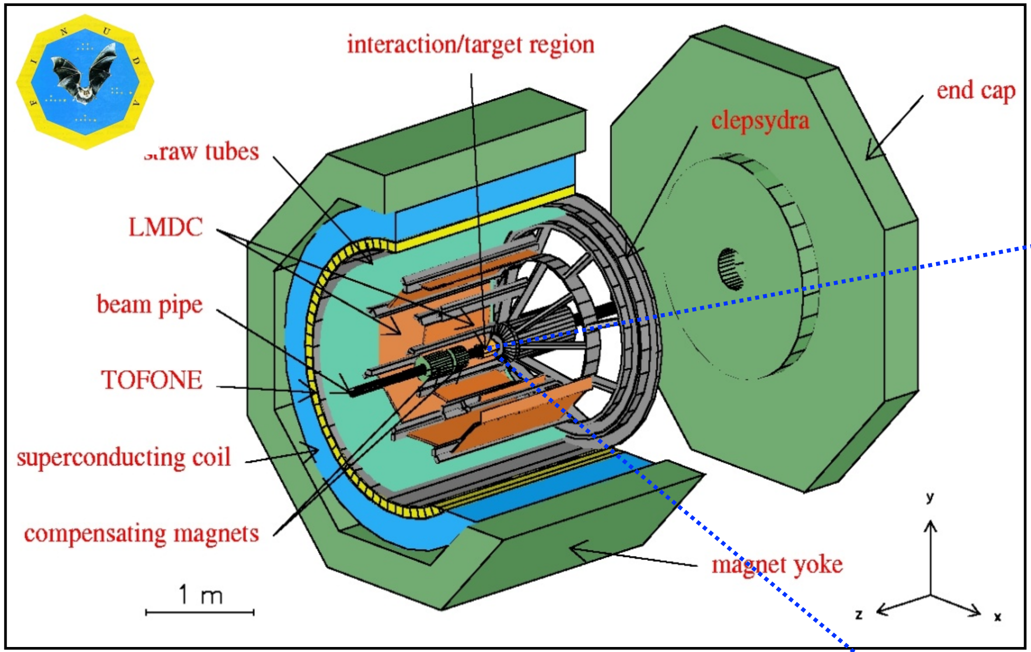
- **First** systematic determination of $\Gamma_p / \Gamma_\Lambda$ for *p*-shell Hypernuclei
- experimental data agree with the latest calculations by Itonaga & Motoba, (even though the errors are quite large…)

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

- First experimental verification of the complementary between MWD and NMWD, at least for charged channels
- J-PARC scientific program restart…

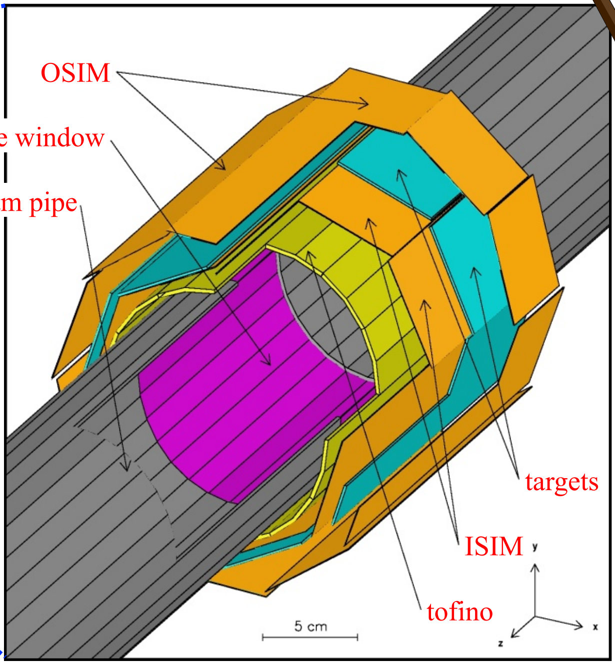
Thank you!

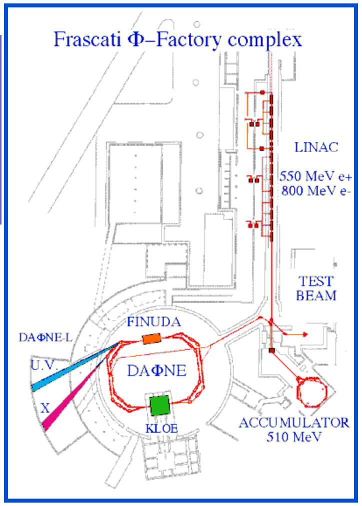
FINUDA in a nutshell



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

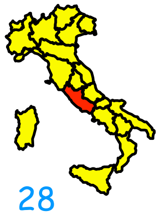
$$K^-_{stop} + {}^AZ \rightarrow {}^A_\Lambda Z + \pi^-$$





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 measurements with large acceptance (2π sr)

  → decay mode study

* event by event K^+ tagging

  → continuous energy and rate calibration

* irradiation of different targets in the same run

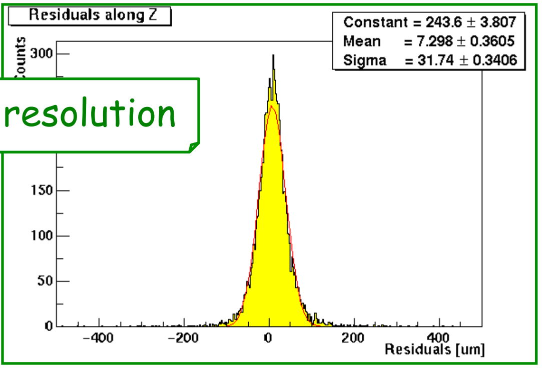
  → systematic error reduction

  systematics on *A*

FINUDA sub-detectors performances

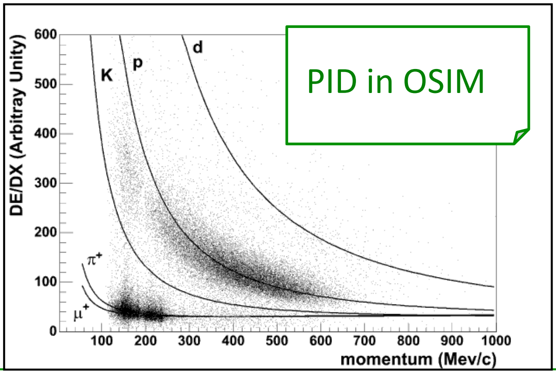
- **s.c. solenoid**: B = 1.0 T; field homogeneity within 2%
- **interaction/target region**: K^+/K^- identification, hypernucleus production and detection

ISIM/OSIM: σ_z = 30 μm; ΔE = 20% FWHM
TOF_{in}: $\sigma_t \approx$ 300 ps



- **tracking devices**: measurement of trajectories and momenta of charged particles (Δp/p 3.5‰)

LMDC: σ(ρ, φ) = 150 μm; $\sigma_z \leq$ 1% wire length
STB: σ(ρ, φ) = 150 μm; σ_z 500 μm

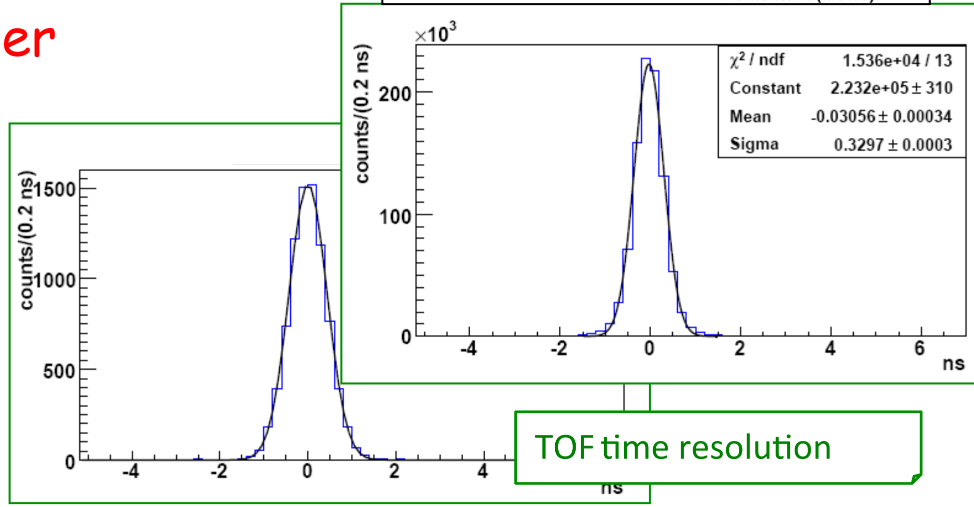


- **external scintillator barrel**: trigger and neutron detection

TOF_{out}: $\sigma_t \leq$ 500 ps FWHM
efficiency ≥ 10%; ΔE = 8 MeV

- **He chamber**: minimization of particle multiple scattering

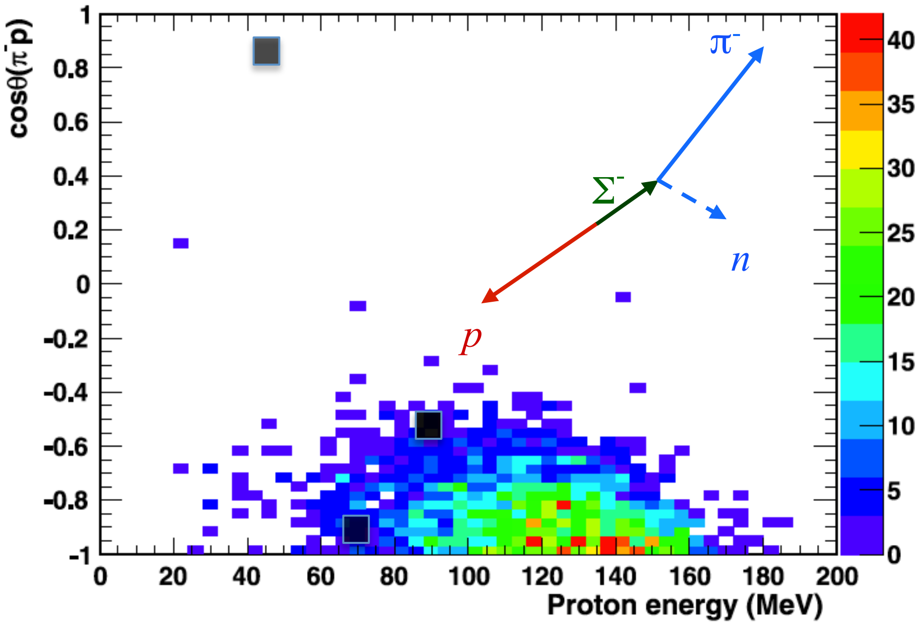
Δp/p: He atmosphere = 3.5‰
air = 2%

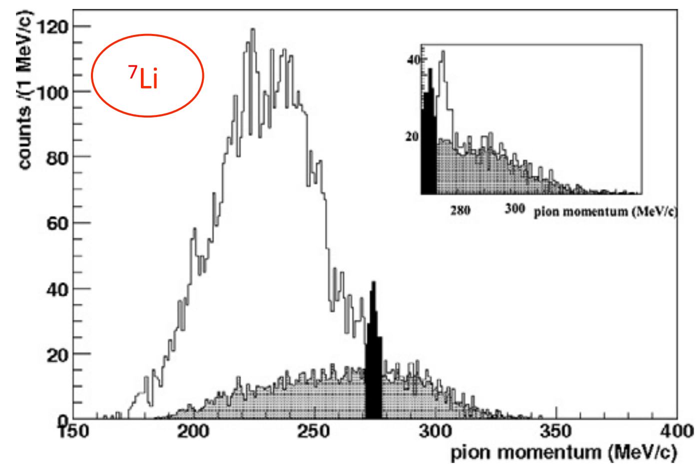


Background evaluation

$$K^- + (np) \rightarrow \Sigma^- + p$$

$$\Sigma^- \rightarrow \pi^- + n$$





Target	$\vartheta(\pi^- p)$	E_p (MeV)
^{7}Li	33.4 ° ± 3.7°	51.11 ± 0.85
^{7}Li	121.7 ° ± 3.2°	90.83 ± 0.50
^{9}Be	159.3 ° ± 5.9°	71.77 ± 0.80

- significant back-to-back correlation → this feature rules out completely the first event on ^{7}Li
- the correlation between cos$\vartheta(\pi^- p)$ and E_p was studied for the simulated background: major contribution from this source when π and p are emitted nearly back-to-back and $E_p \geq 100$ MeV
- evaluation of the number of simulated events surviving to a 3σ cut on cos$\vartheta(\pi^- p)$ and E_p on ^{7}Li and ^{9}Be: ~10^{-3} events were found for both targets

the 2 $\Lambda np \rightarrow nnp$ real events DO NOT belong to background to a confidence level ≥ 99%.

preliminary

Q/2 ↓

	ρ (MeV)	μ_0 (MeV)	μ_1 (MeV)	σ (MeV)
${}^{5}_{\Lambda}$He	76.65	68.5±4.1	66.9±11.8	22.3±9.9
${}^{7}_{\Lambda}$Li	82.99	76.7±5.2	74.9±3.8	18.0±2.1
${}^{9}_{\Lambda}$Be	76.48	78.2±6.2	77.7±9.1	20.8±10.8
${}^{11}_{\Lambda}$B	79.72	75.1±5.0	71.7±10.8	23.8±5.5
${}^{12}_{\Lambda}$C	78.36	80.2±2.1	77.3±2.9	22.0±2.1
${}^{13}_{\Lambda}$C	74.44	83.9±12.8	81.6±5.8	22.6±3.5
${}^{15}_{\Lambda}$N	77.55	88.1±6.2	84.2±4.5	18.6±2.8
${}^{16}_{\Lambda}$O	78.25	93.1±6.2	85.0±6.8	21.9±3.5