Recent achievements in hypernuclear physics

from the point of view of an experimentalist

EFB 22 The 22nd European Conference on Few-Body Problems in Physics

9-13 September 2013, Kraków, Poland

Alessandro Feliciello

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

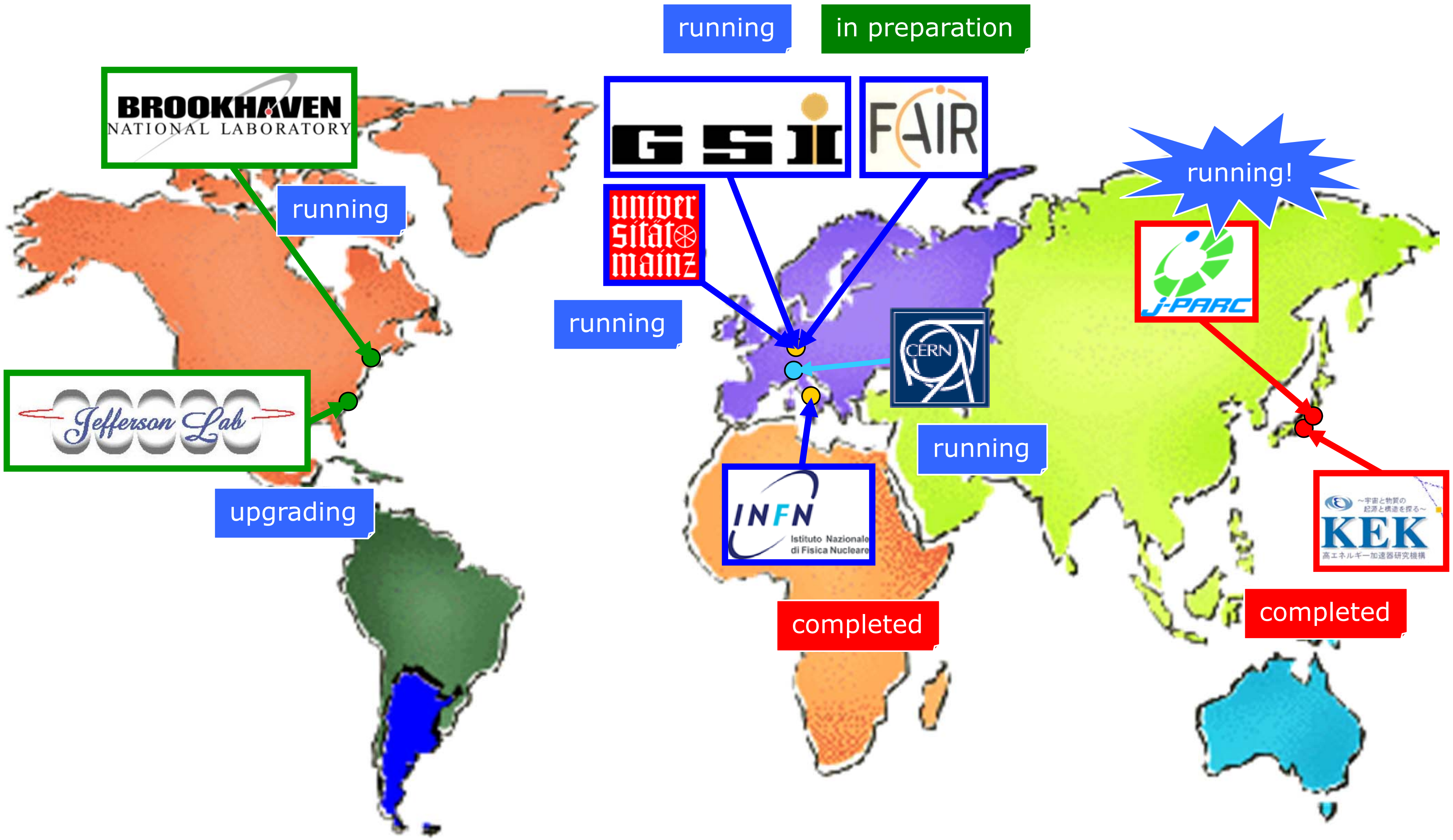
Outline

- The current status of experimental hypernuclear physics

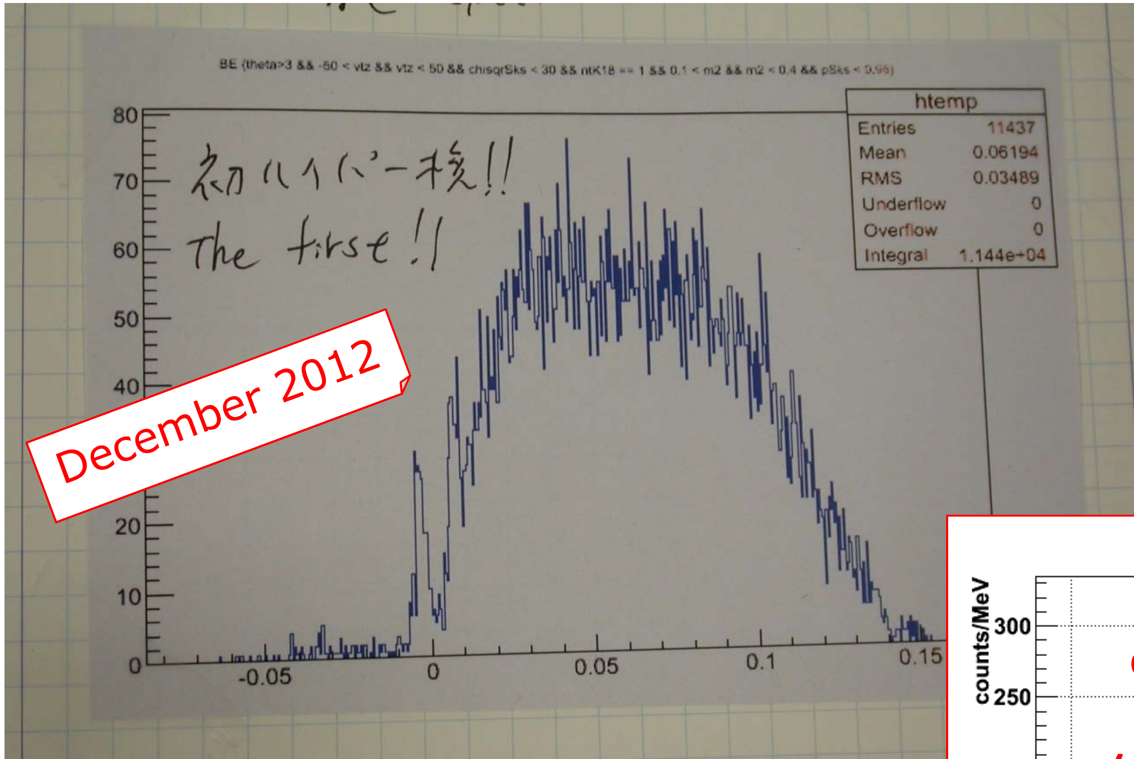
- experimental results:
  - search for neutron-rich hypernuclei
  - antimatter hypernuclei
  - $2\mathcal{N}$ induced hypernucleus weak decay

- A look to the (next) future:
  - waiting for J-PARC

Spring 2013 scenario



First hypernuclei @ J-PARC

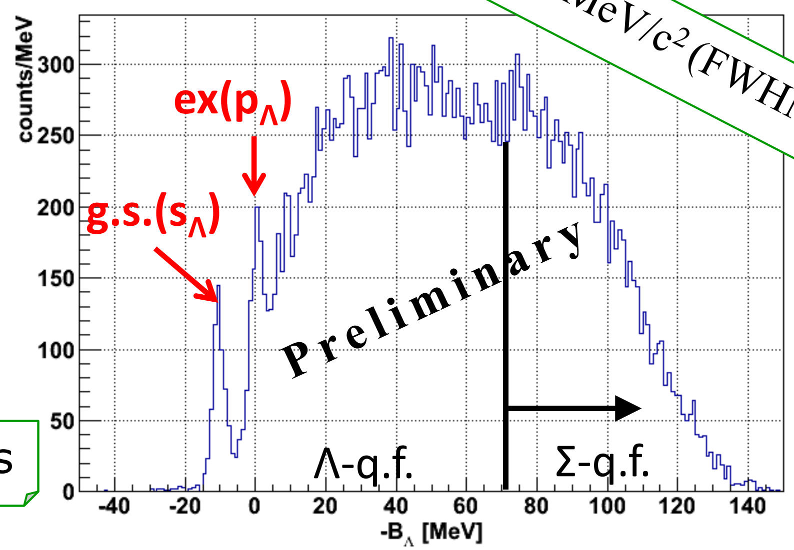


December 2012

$$\pi^+ + {}^{12}C \rightarrow {}^{12}_{\Lambda}C + K^+$$

@ 1.2 GeV/C

ΔB_Λ: 2.8 MeV/c² (FWHM)



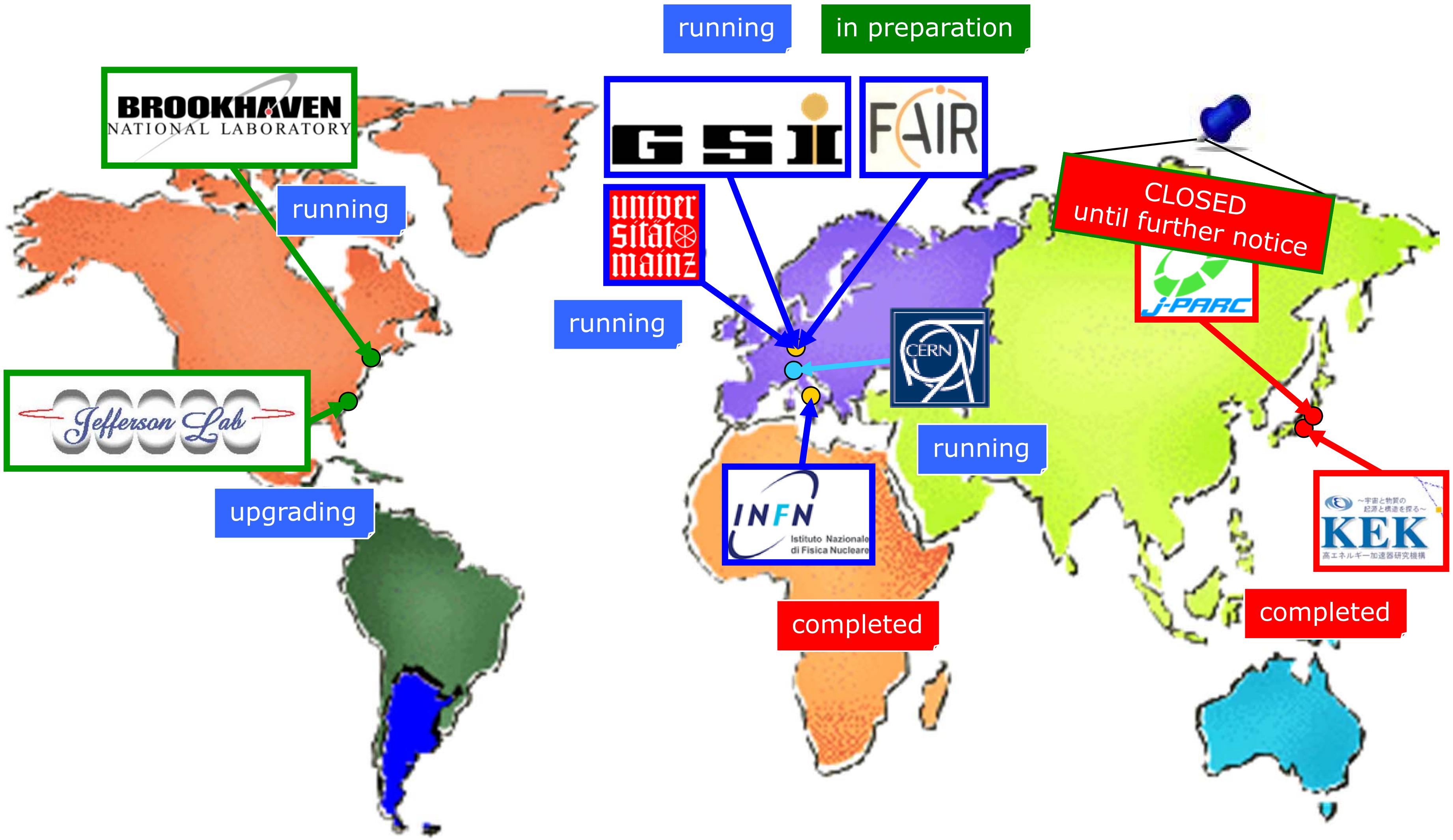
Hadron Hall
K1.8 line

yield (g.s.): ~600 events

See T. Fukuda's talk

H. Sugimura for the E10 Collaboration @ INPC 2013;
@ APPC12.

Fall 2013 scenario



Search for neutron-rich hypernuclei

central issue in hypernuclear physics

See E. Hiyama's talk

See B.F. Gibson's talk

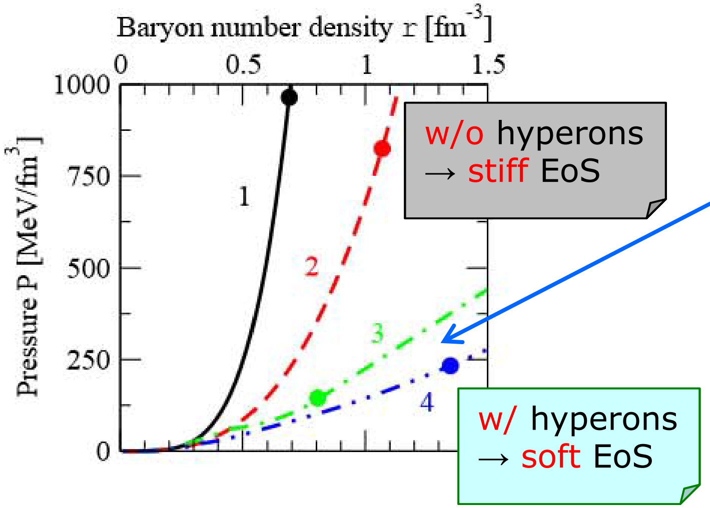
❖ historical paper: R.H. Dalitz and R. Levi Setti, Nuovo Cimento 30 (1963) 489

1. Pauli effect not effective for Λ
2. Λ extra binding energy

⇨ existence of hypernuclei with core nucleus near (or even beyond) the neutron drip line

❖ unique opportunity to study:
- effect of 3-body forces (ΛNN)
- ΛN- ΣN coupling contribution to binding en.
- hyperon behaviour in n-rich environment

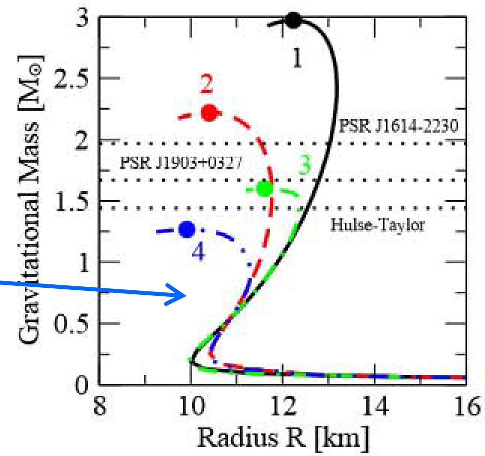
⇩



direct influence on neutron star EoS

prediction of neutron star main parameters

I. Vidaña *et al.*, *EPL* 94 (2011) 11002



The status of the art (as of 2011)

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

- $K^- + p \rightarrow \pi^0 + \Lambda$, $\pi^0 + p \rightarrow \pi^+ + n$: 2-step (S-EX + C-EX)
- $K^- + p \rightarrow \bar{K}^0 + n$, $\bar{K}^0 + p \rightarrow \Lambda + \pi^+$: 2-step (C-EX + S-EX)
- $K^- + p \rightarrow \pi^+ + \Sigma^-$, $\Sigma^- + p \rightarrow \Lambda + n$: 1-step (S-EX)

experimental results

KEK

- ${}^9_\Lambda He({}^9Be) : u.l. = 2.3 \cdot 10^{-4} / K^-_{stop}$
- ${}^{12}_\Lambda Be({}^{12}C) : u.l. = 6.1 \cdot 10^{-5} / K^-_{stop}$
- ${}^{16}_\Lambda C({}^{16}O) : u.l. = 6.2 \cdot 10^{-5} / K^-_{stop}$

K. Kubota *et al.*, *NPA* 602 (1996) 327

INFN-LNF

- ${}^6_\Lambda H({}^6Li) : u.l. = (2.5 \pm 1.4) \cdot 10^{-5} / K^-_{stop}$
- ${}^7_\Lambda H({}^7Li) : u.l. = (4.5 \pm 1.4) \cdot 10^{-5} / K^-_{stop}$
- ${}^{12}_\Lambda Be({}^{12}C) : u.l. = (2.0 \pm 0.4) \cdot 10^{-5} / K^-_{stop}$

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

theoretical predictions

$10^{-6} \div 10^{-7} / K^-_{stop}$

T.Y. Tretyakova *et al.*, *NPA* 691 (2001) 51c

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

- $\pi^- + p \rightarrow \pi^0 + n$, $\pi^0 + p \rightarrow K^+ + \Lambda$: 2-step (C-EX + AP)
- $\pi^- + p \rightarrow K^0 + \Lambda$, $K^0 + p \rightarrow K^+ + n$: 2-step (AP + C-EX)
- $\pi^- + p \rightarrow K^+ + \Sigma^-$, $\Sigma^- + p \rightarrow \Lambda + n$: 1-step (AP)

experimental results

KEK

${}^{10}_\Lambda Li({}^{10}B) : d\sigma / d\Omega = 11.3 \pm 1.9 \;\; nb/sr$

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

theoretical predictions

T.Y. Tretyakova *et al.*, *PAT* 66 (2003) 1681

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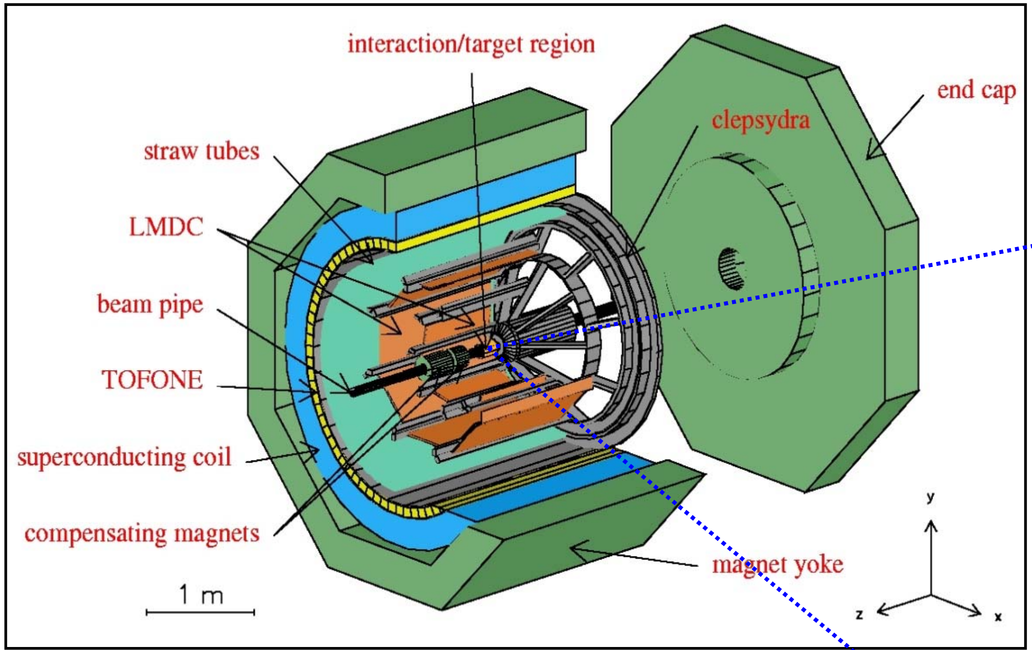
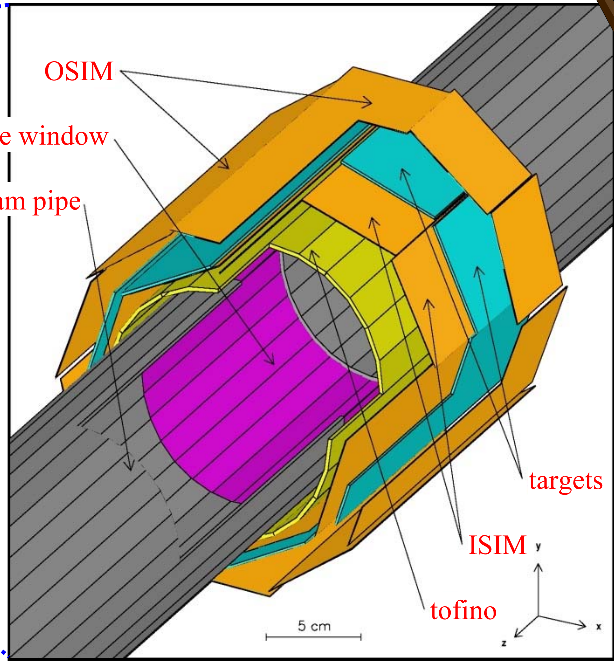
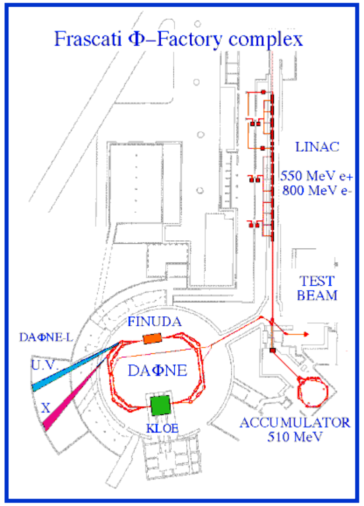
FINUDA @ DAΦNE



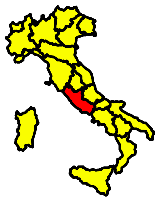
$$e^- + e^+ \rightarrow \phi \rightarrow K^- K^+$$

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





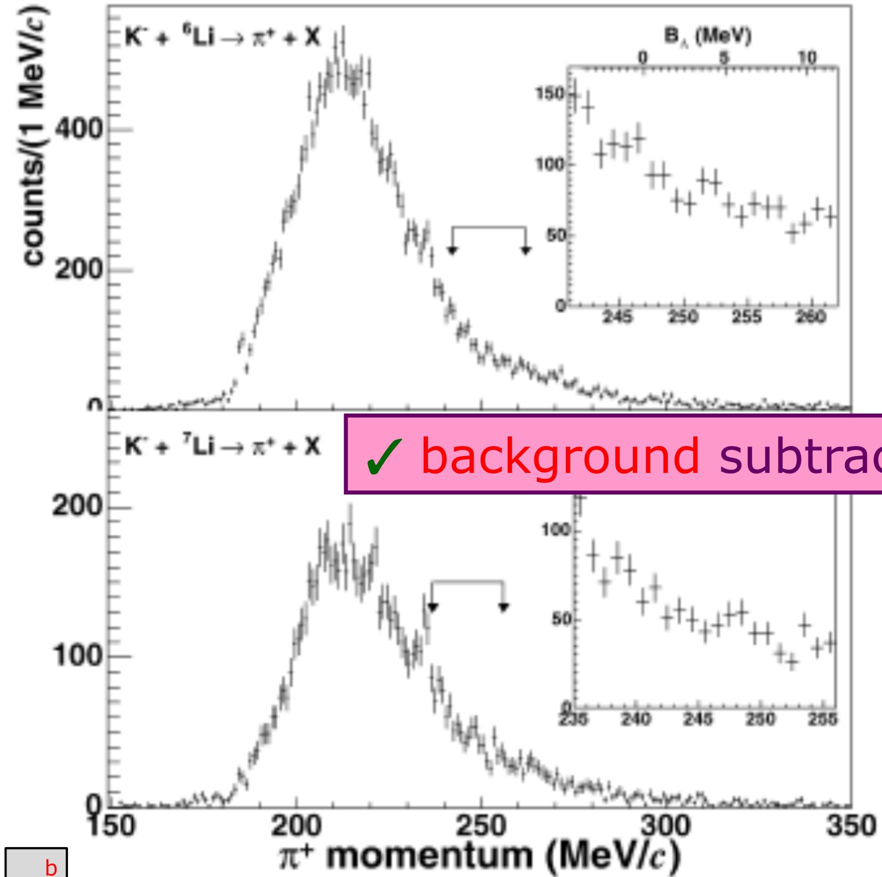
energy	510 MeV
luminosity	5 10^{32} cm^{-2} s^{-1}
σ_x (rms)	2.11 mm
σ_y (rms)	0.021 mm
σ_z (rms)	35 mm
bunch length	30 mm
crossing angle	12.5 mrad
frequency (max)	368.25 MHz
bunch/ring	up to 120
part./bunch	8.9 10^{10}
current/ring	5.2 A (max)



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

The background issue

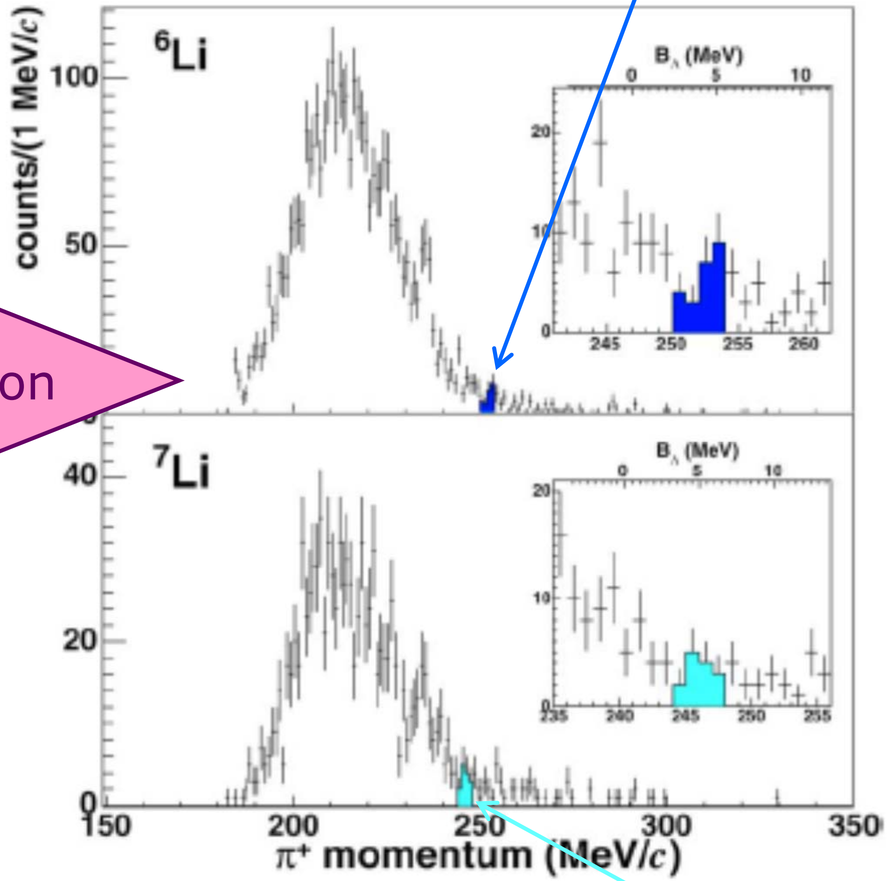
$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}(Z-2) + \pi^+$$



✓ background subtraction

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

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



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

main background

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

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

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

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

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

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

The new NRH search strategy

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

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

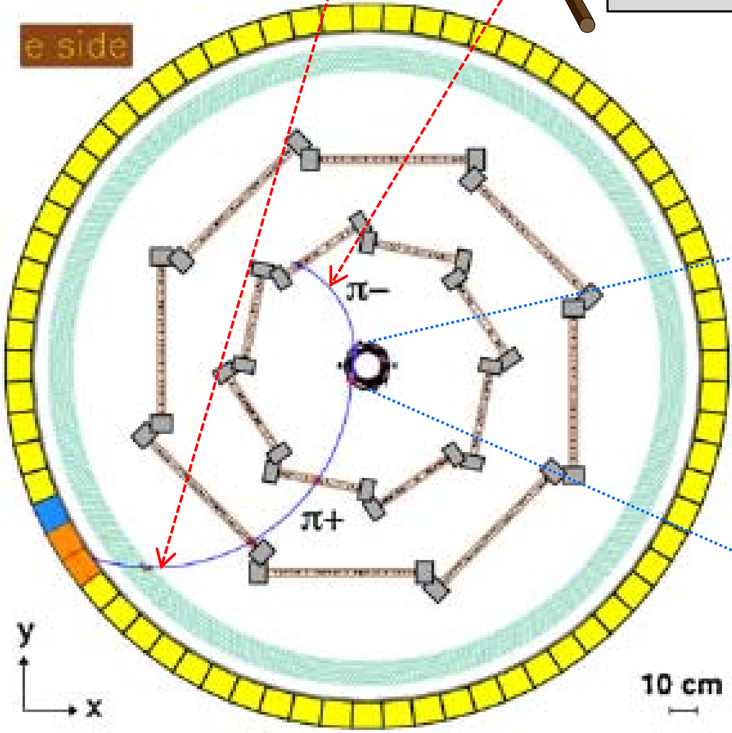
double C-EX
p ~ 252 MeV/c

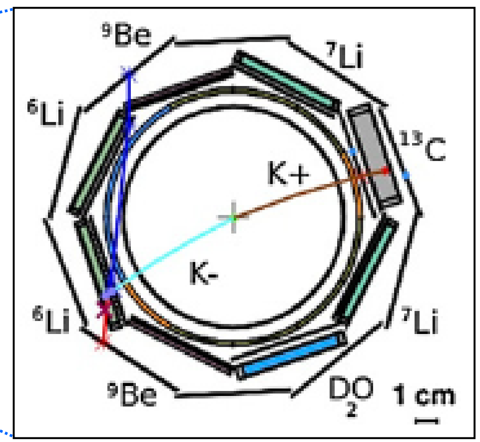
$$^6_\Lambda H \rightarrow {}^6He + \pi^-$$

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

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

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

atomic mass tables

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

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

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

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

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

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

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

Data selection

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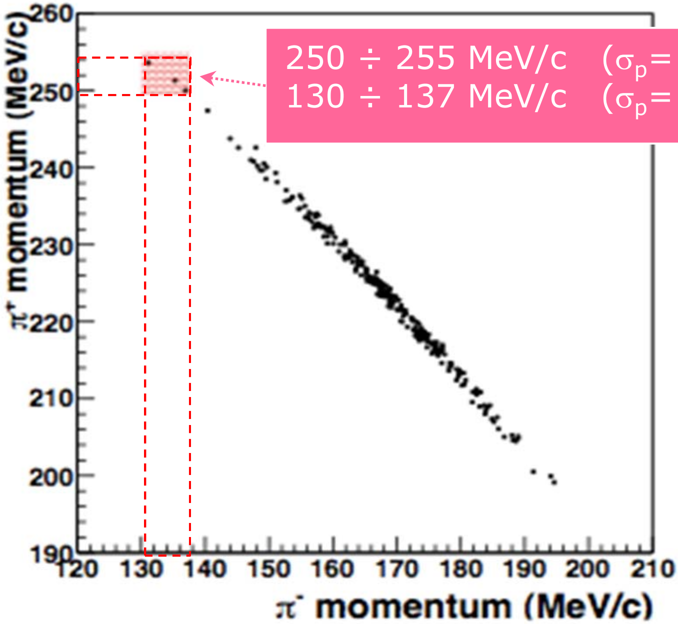
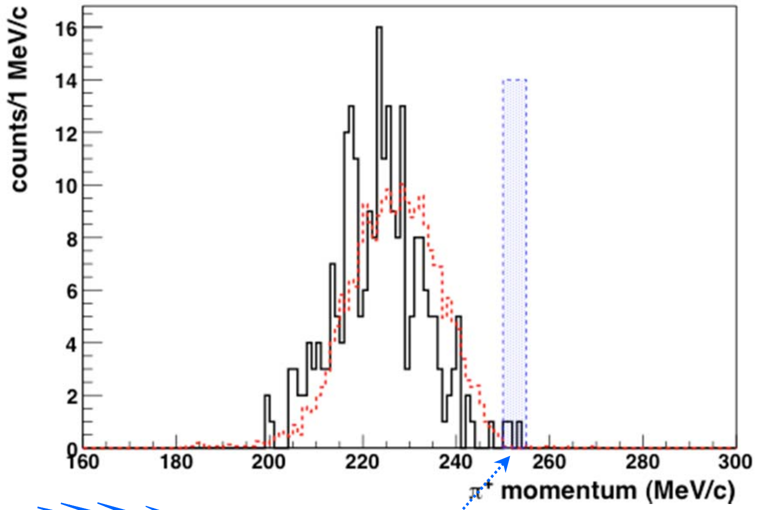
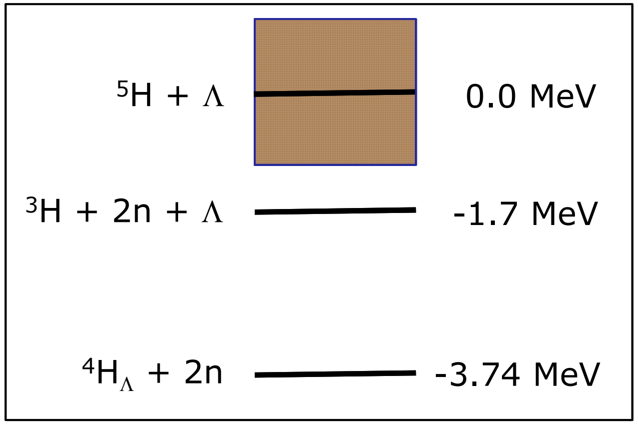


250 ÷ 255 MeV/c (σ_p=1.1 MeV/c)
130 ÷ 137 MeV/c (σ_p=1.2 MeV/c)



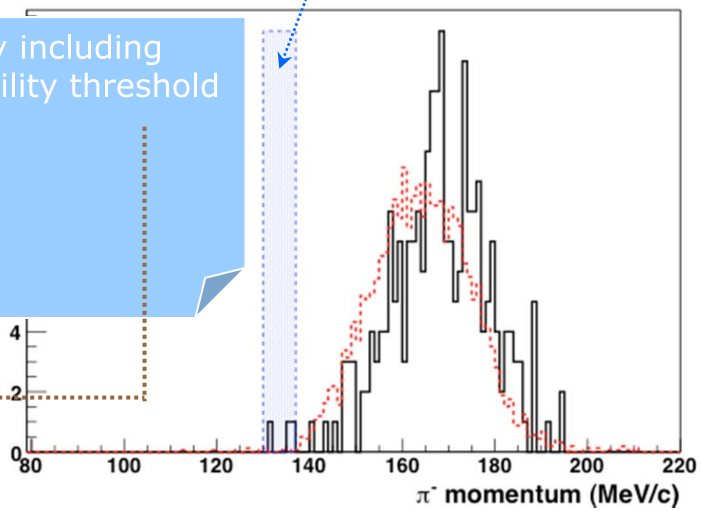
3 candidate events

(out of 27 10^6 stopped K^- events)



selection range fixed by including $^6H_\Lambda$ lowest particle stability threshold
$p_{\pi+}$ = 251.9 MeV/c
$p_{\pi-}$ = 135.6 MeV/c

B_Λ = 1.5 ÷ 6 MeV



Production rate

background sources

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

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

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

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

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

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

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

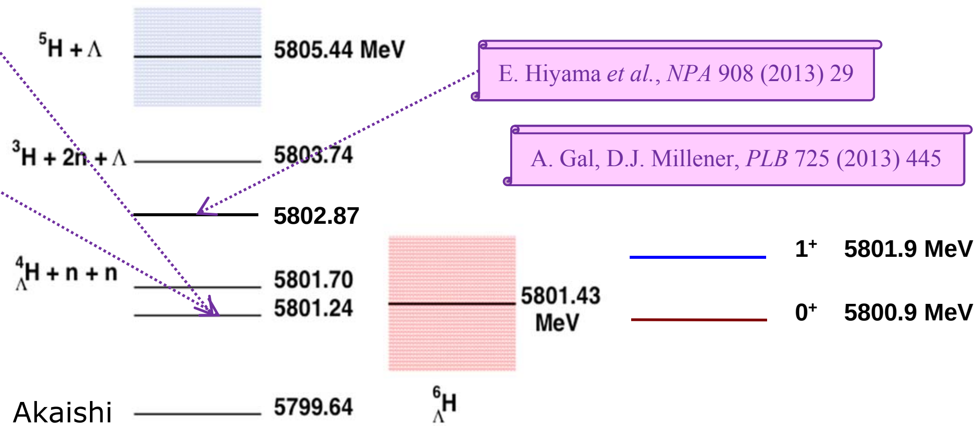
theoretical predictions

- 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 α 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	$^5_\Lambda$H (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

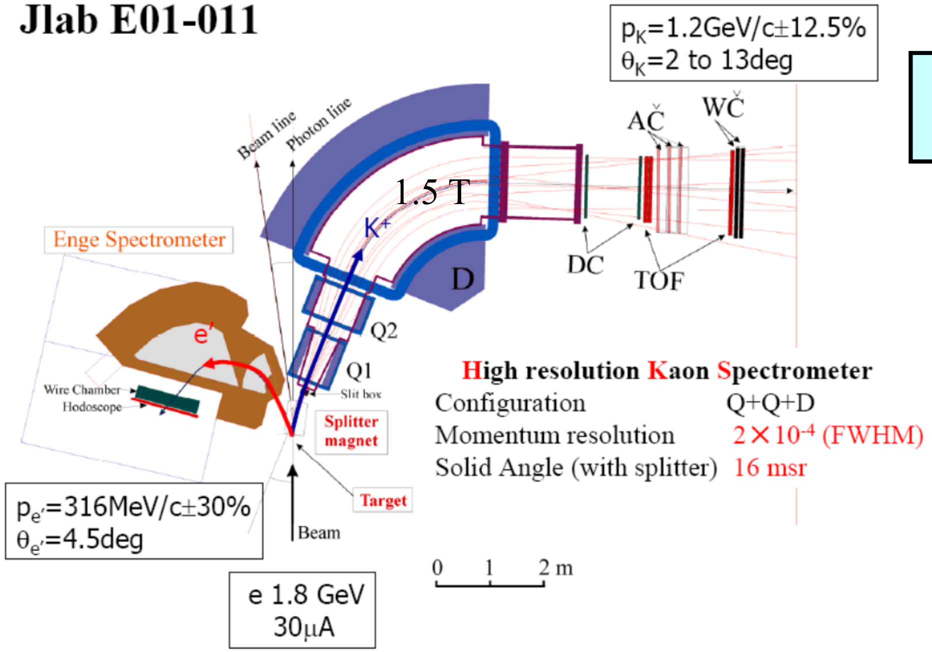
Jefferson Lab

Hall C

$^7He_\Lambda$ observed

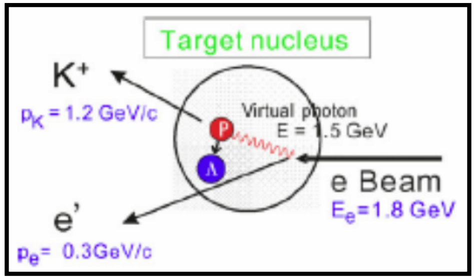
E01–011 HKS

Jlab E01-011

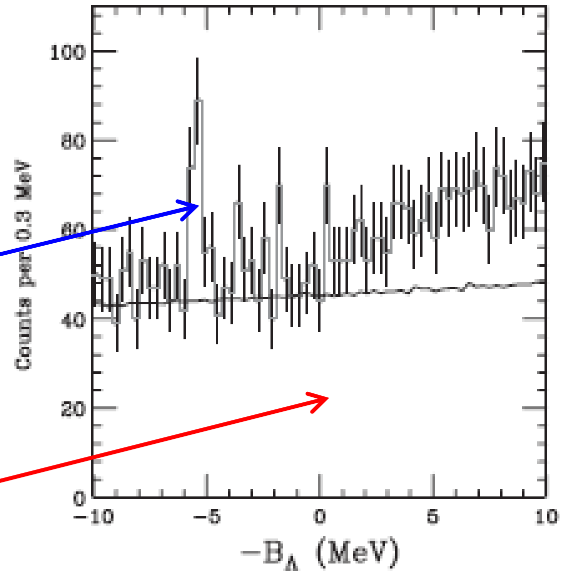


- targets: ~100 mg/cm²

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



$$e^- + {}^7Li \rightarrow e^{-\prime} + K^+ + {}^7_\Lambda He$$



large background
- q.f. hyperons
- accidentals

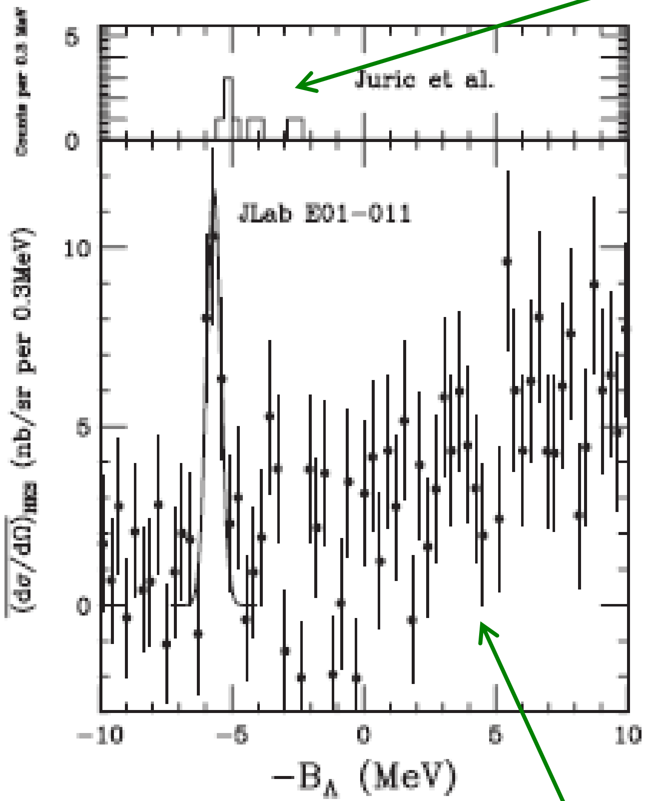
S.N. Nakamura *et al.*, PRL 110 (2013) 012502

Jefferson Lab

A=7, T = 1 triplet

E01–011 HKS

M. Jurić *et al.*, NPB 52 (1973) 1

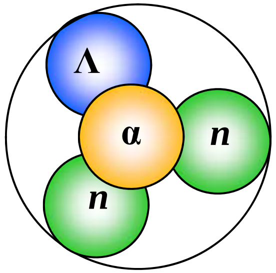


S.N. Nakamura *et al.*, PRL 110 (2013) 012502

$$\left(\frac{d\sigma}{d\Omega}\right) = 26 \pm 5.1 \pm 9.9 \text{ nb/sr}$$

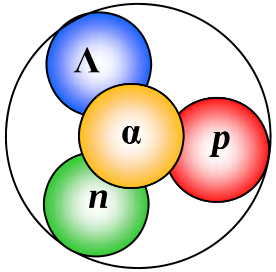
B_Λ [MeV]

$^{7}_{\Lambda}$He



5.68 ± 0.03 ± 0.25

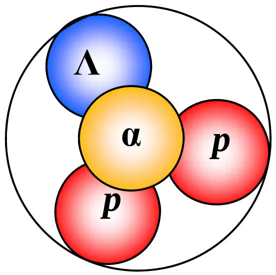
$^{7}_{\Lambda}$Li*



5.26 ± 0.03

M. Jurić *et al.*, NPB 52 (1973) 1

$^{7}_{\Lambda}$Be



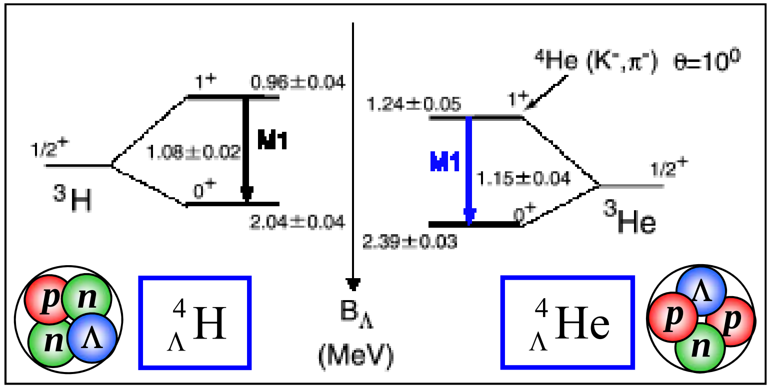
5.16 ± 0.08

M. Jurić *et al.*, NPB 52 (1973) 1
H. Tamura *et al.*, PRL 84 (2000) 5963

Charge symmetry breaking (?)

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

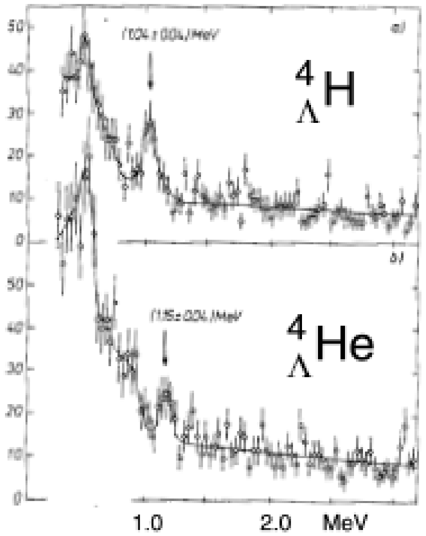
if the charge symmetry holds exactly



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

Λp more attractive than Λn

A.R. Bodmer *et al.*, PRC 31 (4) (1985) 1400



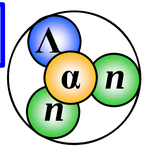
M. Bedjidian *et al.*, PLB 83 (1979) 252

Coulomb effect is small:
- $-\Delta B_\Lambda = 0.050 \pm 0.020$ MeV
- $-\Delta B^*_\Lambda = 0.025 \pm 0.015$ MeV

possible explanations:
- $\Lambda\Sigma^0$ mixing
- $\Lambda N - \Sigma N$ coupling

Charge symmetry breaking (?)

$^{7}_{\Lambda}\mathrm{He}$



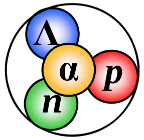
$B_\Lambda(\mathrm{th.}+\mathrm{CSB}) = 5.16$ MeV

$B_\Lambda(\mathrm{th.}) = 5.36$ MeV

$B_\Lambda(^{7}_{\Lambda}\mathrm{He}, 1/2^{+}) = 5.68 \pm 0.03$ MeV

S.N. Nakamura *et al.*, PRL 110 (2013) 012502

$^{7}_{\Lambda}\mathrm{Li}^{*}$



$B_\Lambda(^{7}_{\Lambda}\mathrm{Li}^{*}, 1/2^{+}) = 5.26 \pm 0.03$ MeV

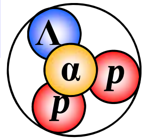
$B_\Lambda(\mathrm{th.}) = 5.28$ MeV

$B_\Lambda(\mathrm{th.}+\mathrm{CSB}) = 5.29$ MeV

E. Hiyama *et al.*, PRC 80 (2009) 054321

M. Jurić *et al.*, NPB 52 (1973) 1

$^{7}_{\Lambda}\mathrm{Be}$



$B_\Lambda(^{7}_{\Lambda}\mathrm{Be}, 1/2^{+}) = 5.16 \pm 0.08$ MeV

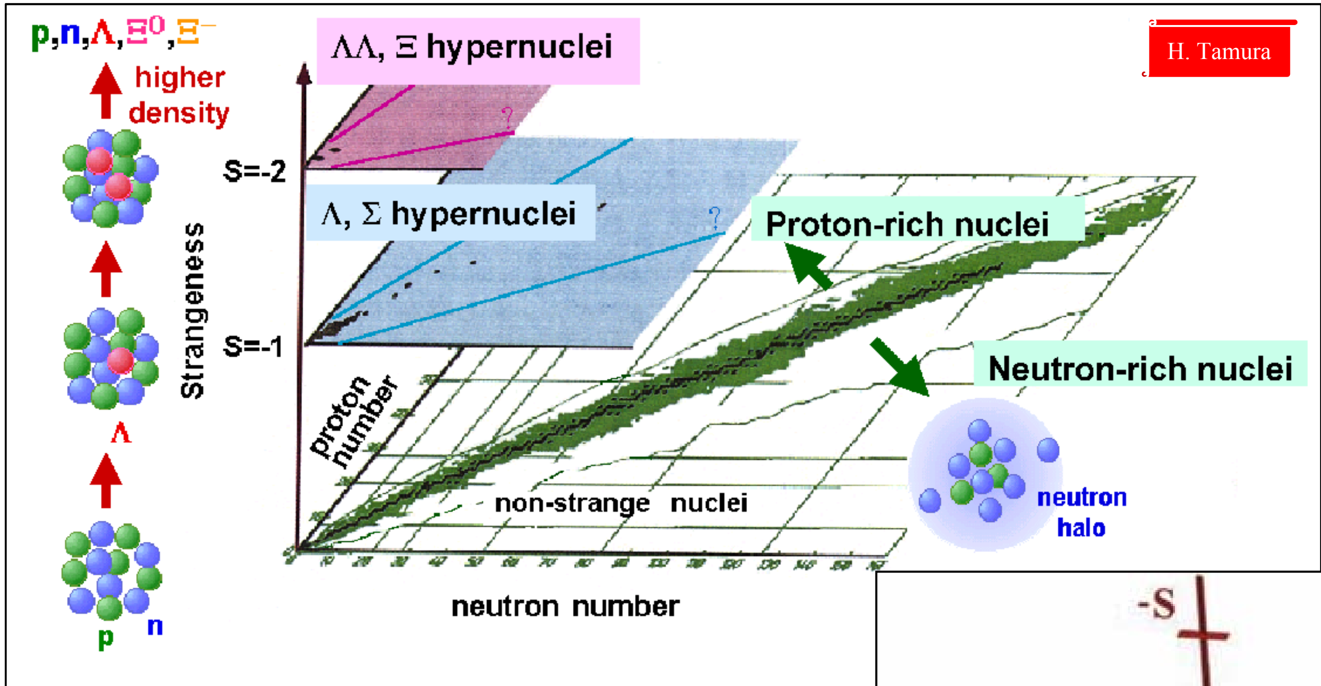
$B_\Lambda(\mathrm{th.}) = 5.21$ MeV

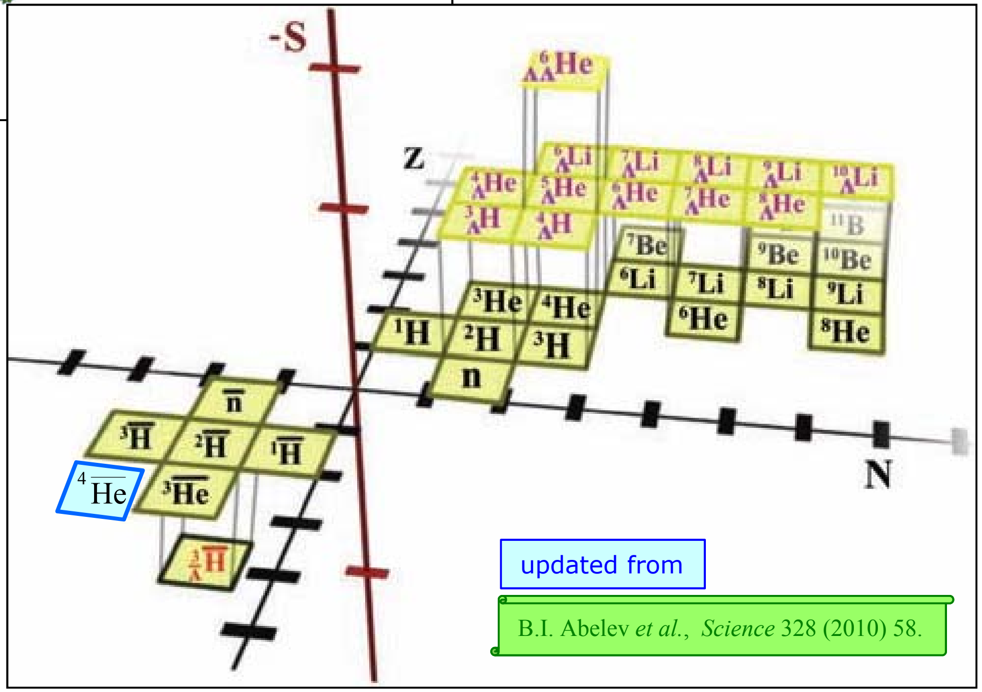
$B_\Lambda(\mathrm{th.}+\mathrm{CSB}) = 5.44$ MeV

exp. (solid red line)
th. (solid blue line)
th. + CSB (dashed blue line)

M. Jurić *et al.*, NPB 52 (1973) 1
H. Tamura *et al.*, PRL 84 (2000) 5963

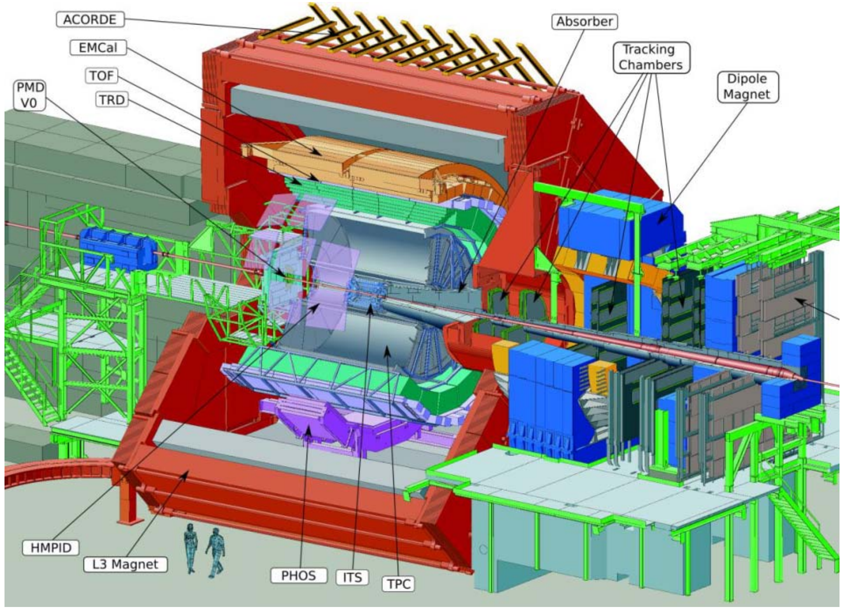
Expanding the horizon…





Hypernuclei in HI collisions

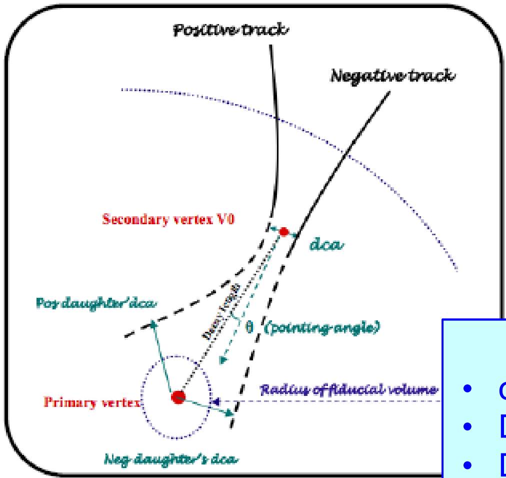
Kraków, Poland, September 9 – 13, 2013
22nd European Conference on Few-Body Problems in Physics
Alessandro Feliciello



$$\mathrm{Pb+Pb} @ \sqrt{S_{NN}} = 2.76\ \mathrm{TeV}$$

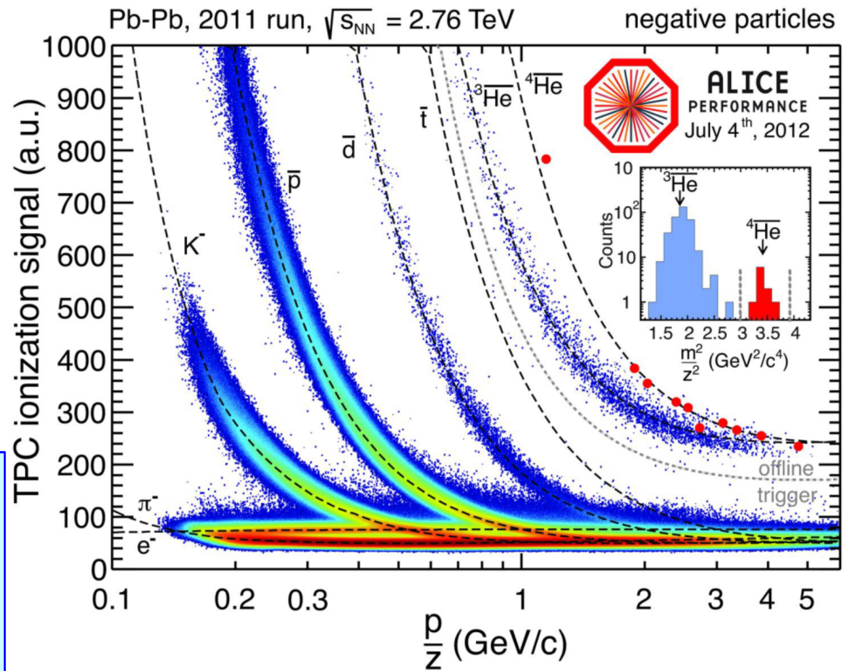
$$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$$

$$^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+}$$



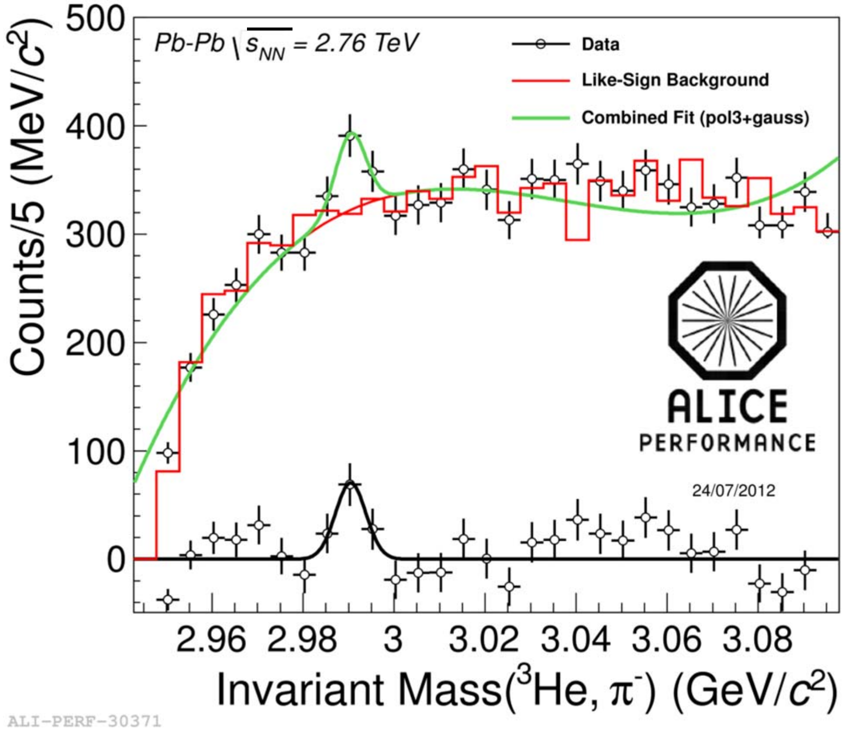
topological cuts

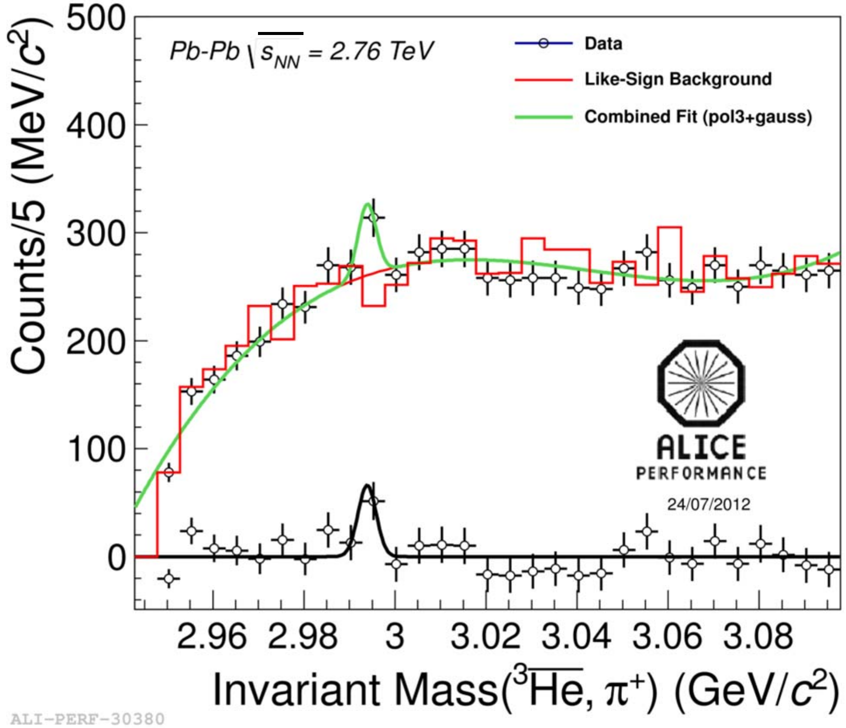
- cos(pointing angle) > 0.9
- DCA π track to PV > 0.4 cm
- DCA between tracks < 0.7 cm
- $p_T(^3\mathrm{He},\pi)$ > 1 GeV/c
- $c\tau$ > 1 cm



R. Lea, *NPA* 914 (2013) 415.

Hypernuclei in HI collisions





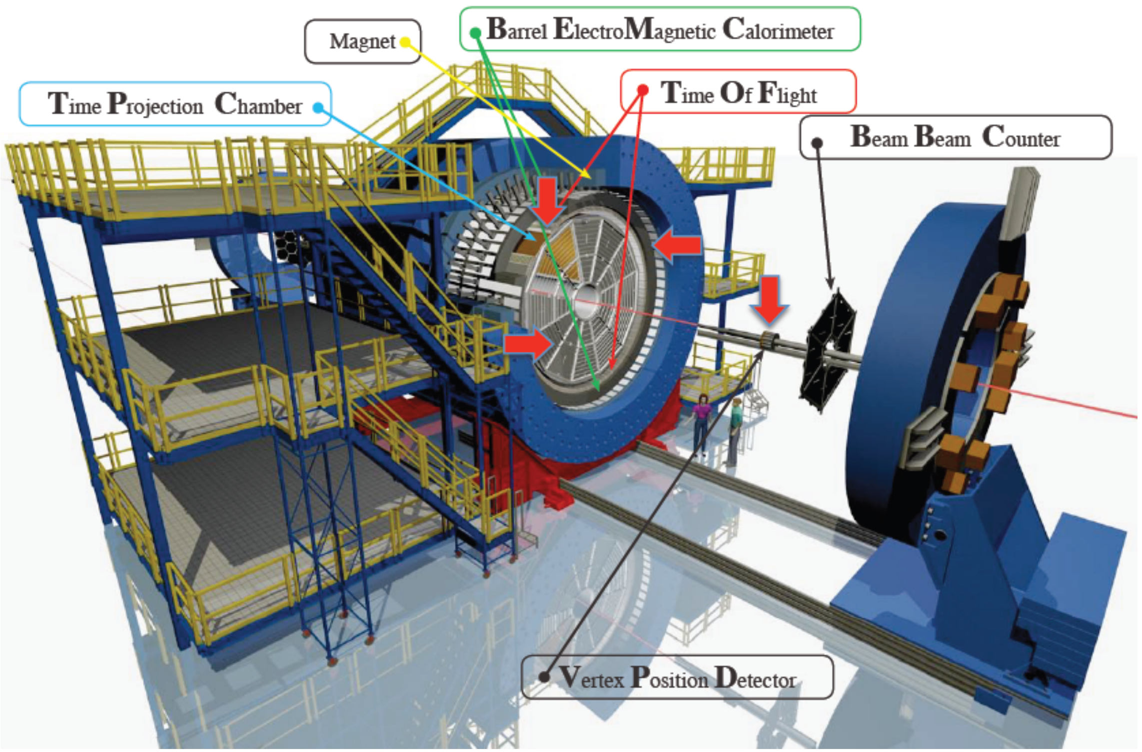
- μ = 2.990 ± 0.001 GeV/c^2
- σ = (3.35 ± 0.70) × 10^{-3} GeV/c^2
- N_{raw} = 119 ± 35
- S/√(S+B) = 4.6

- μ = 2.993 ± 0.001 GeV/c^2
- σ = (2.00 ± 1.20) × 10^{-3} GeV/c^2
- N_{raw} = 77 ± 22
- S/√(S+B) = 3.6

~23 × 10^6 events

R. Lea, *NPA* 914 (2013) 415.

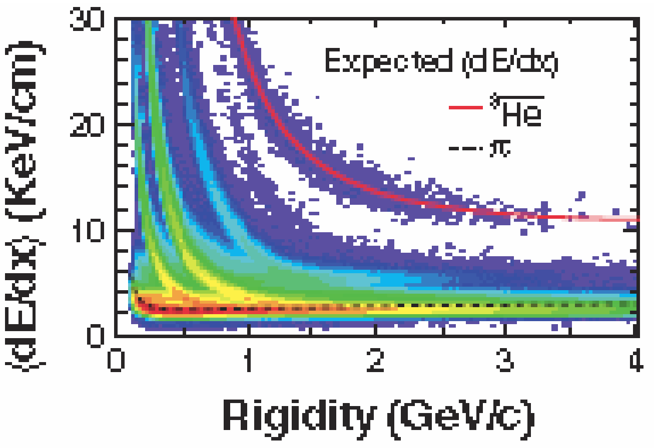
STAR $^{3}\bar{H}_{\bar{\Lambda}}$ signal

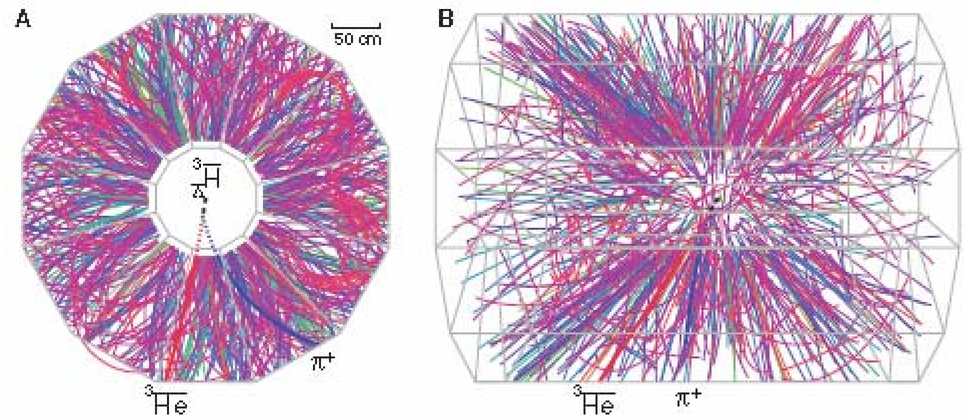


$$Au + Au @ 200\ \mathrm{GeV}$$

$$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$$

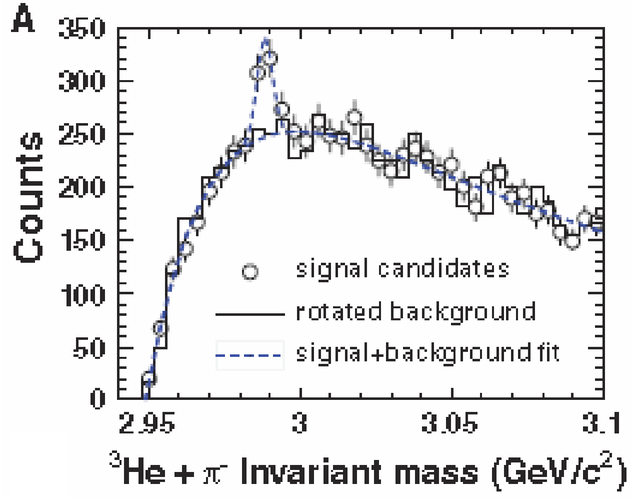
$$^{3}_{\bar{\Lambda}}\bar{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$$



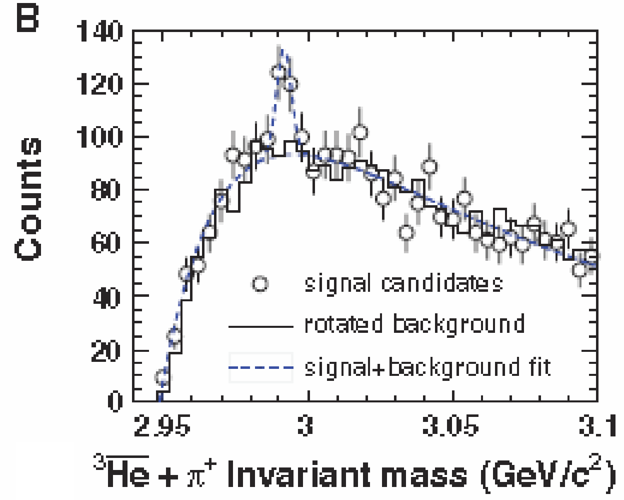


B.I. Abelev *et al.*, *Science* 328 (2010) 58.

Hypernuclei in HI collisions

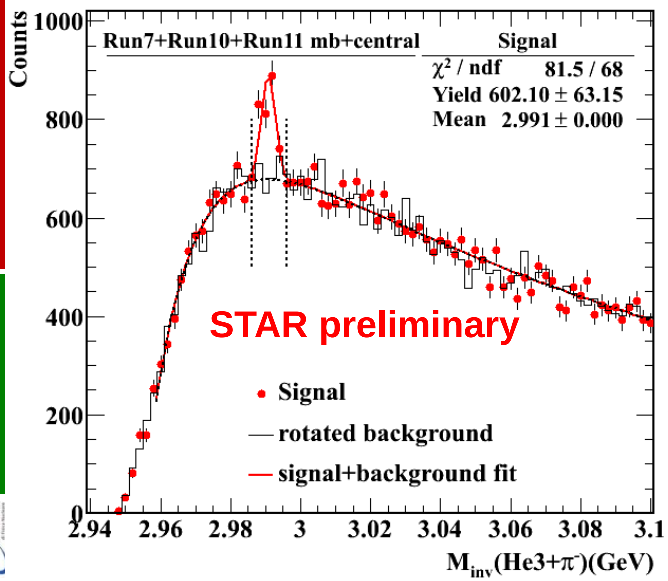


- μ = 2.989 ± 0.001 ± 0.002 GeV/c²
- σ ≡ 0.0025 GeV/c²
- significance = 5.2 σ



- μ = 2.991 ± 0.001 ± 0.002 GeV/c²
- σ ≡ 0.0025 GeV/c²
- significance = 4.1 σ

B.I. Abelev *et al.*, *Science* 328 (2010) 58.



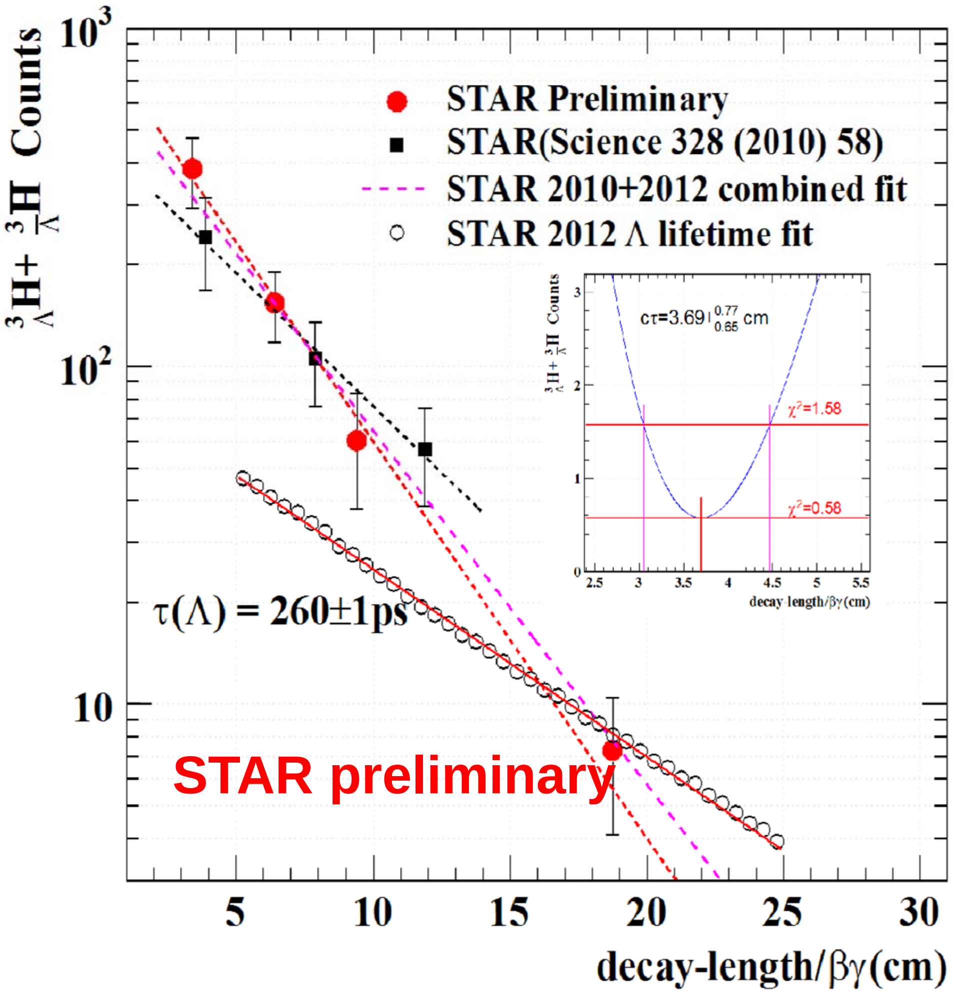
~610 × 10⁶ events

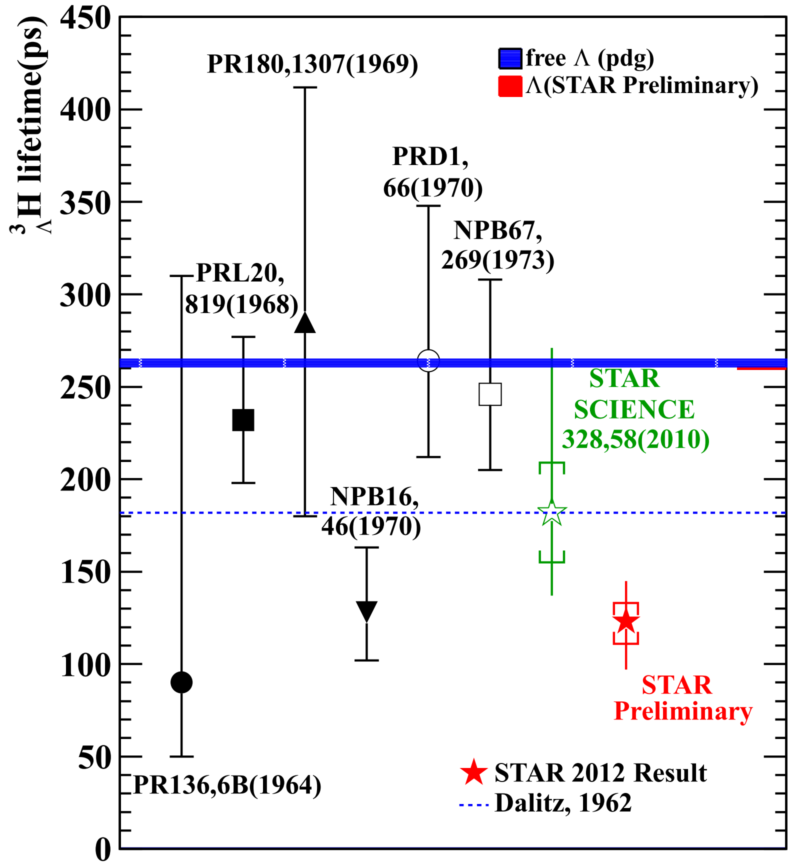
★ Signal observed from the data (bin-by-bin counting [2.986,2.996] GeV): **602±63**, significance: **9.6σ**

★ Background estimation: rotated background

J.H. Chen @ HYP 2012.
Y. Zhu, *NPA* 904-905 (2013) 551c.

New $^3H_\Lambda$ τ measurement





★ STAR 2012 preliminary result: $\tau = 123 \pm^{26}_{22} \pm 10$ ps

★ STAR 2010 + 2012 combined fit: $\tau = 138 \pm^{23}_{20}$ ps

J.H. Chen @ HYP 2012.
Y. Zhu, *NPA* 904-905 (2013) 551c.

2$\mathscr{N}$ 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]		$0.21 \pm 0.07_{\text{stat}}\,{}^{+0.03}_{-0.02}{}_{\text{sys}}$	$A = 5$–16, np spectra

consistent within large errors

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

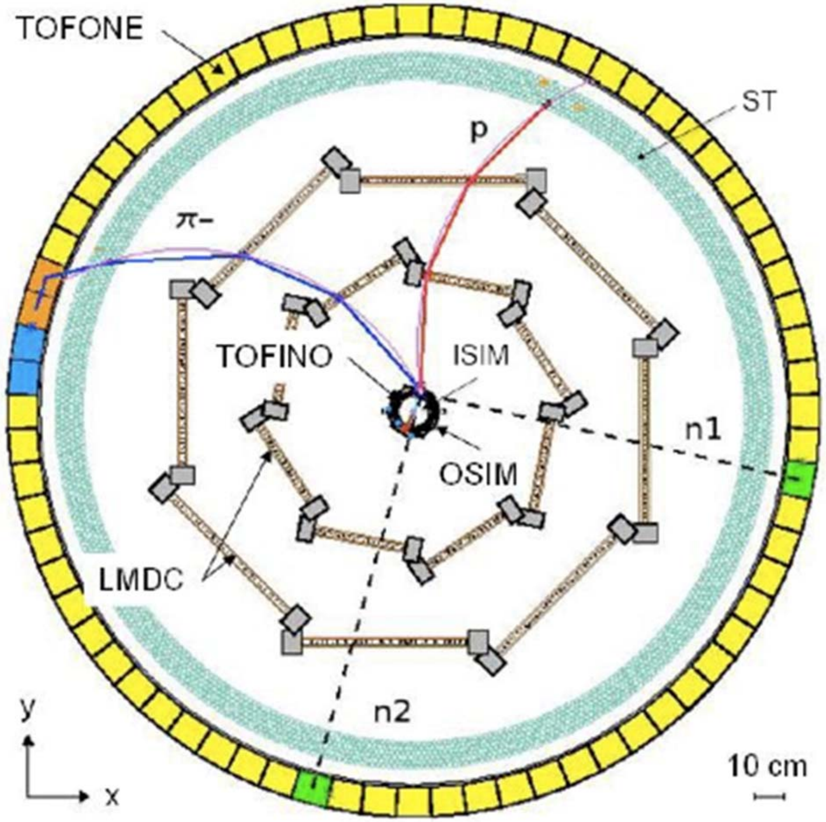
"smoking gun" evidence missing!

- 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

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

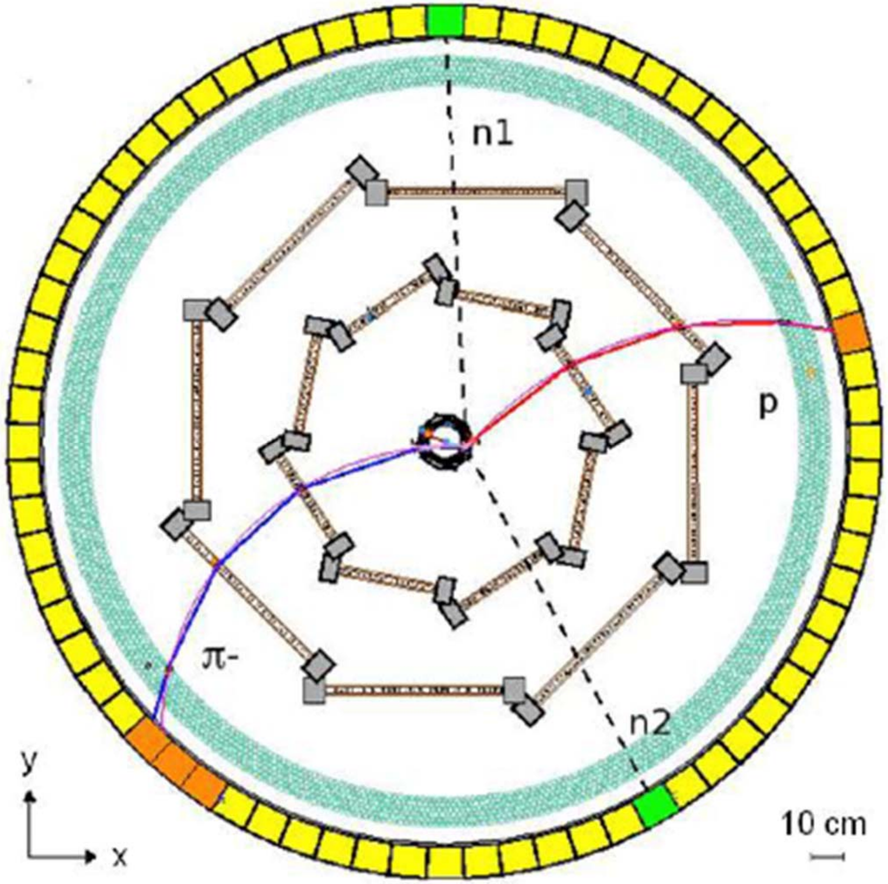
first, direct experimental evidence

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

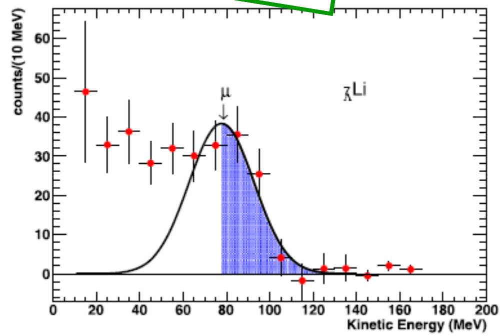
2$\mathcal{N}$ induced decay exp. evidence

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

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



cut on E_p released



$p_{\pi-}$	=	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°

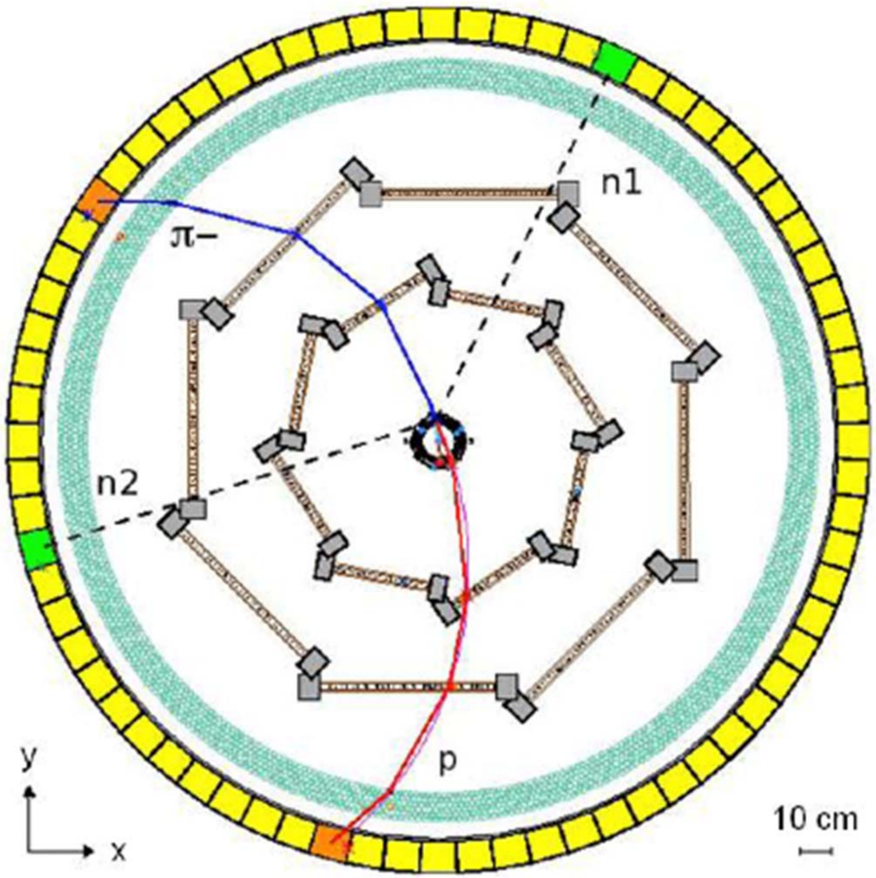
no n-n or p/n scattering

2𝒩 induced decay exp. evidence

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

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

cut on E_p released



$p_{\pi-}$ = 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°

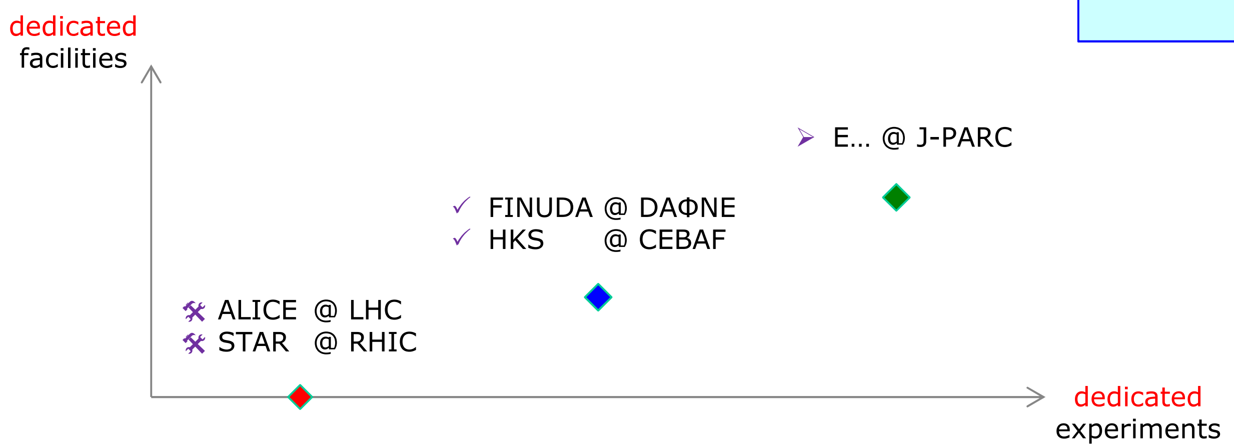
no n-n or p/n scattering

$^{9}_{\Lambda}$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

Summary

a good wealth of interesting and sometime unexpected hypernuclear physics results has been recently produced

no longer running or not dedicated experiments



we are now looking forward for new and exciting world class results @ J-PARC