UNIVERSITÀ DEGLI STUDI DI TORINO
ALMA UNIVERSITAS TAURINENSIS

INFN Istituto Nazionale di Fisica Nucleare

Neutron-rich Hypernuclei: observation of $^{6}_{\Lambda}H$ and search for $^{9}_{\Lambda}He$

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for the FINUDA Collaboration

MESON 2012

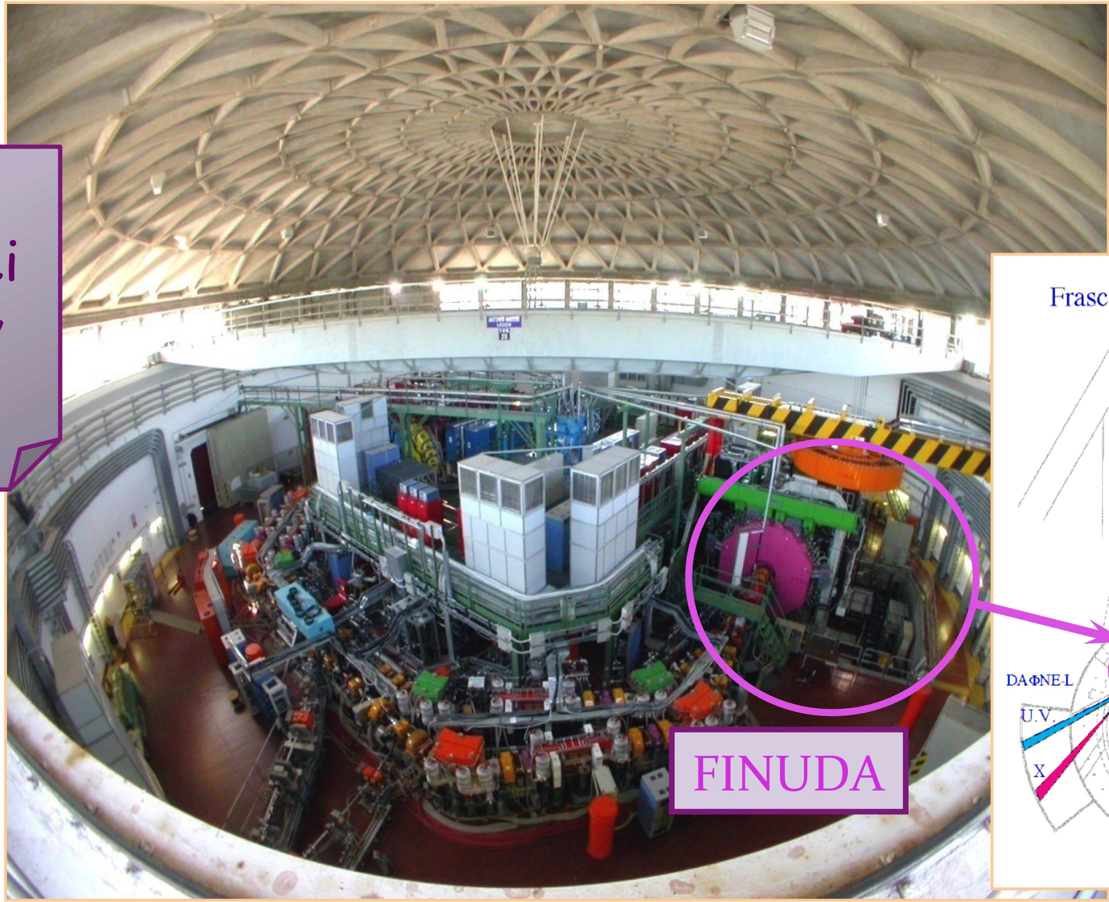
Overview

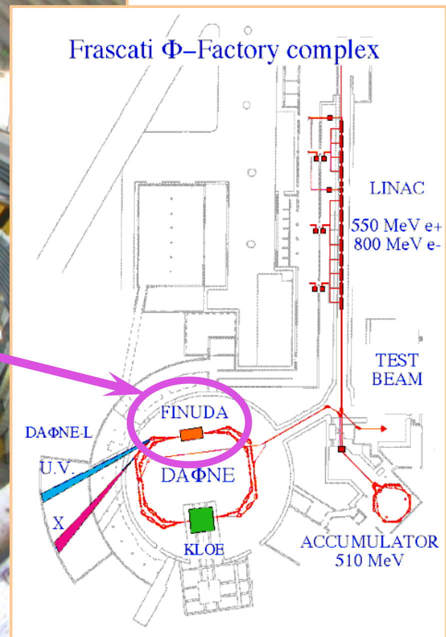
- FINUDA@DAΦNE
- FINUDA Scientific Program
- n-rich hypernuclei: physics motivations
- n-rich search results
  - ✓ $^{6}_{\Lambda}H$ observation
  - ✓ $^{9}_{\Lambda}He$ search

FINUDA: FIsica NUcleare a DAΦNE

The very first example of a *(hyper)nuclear physics* fixed-target experiment carried on at a *collider* (DAΦNE @ LNF)

Optimized to produce hypernuclei $^{A}_{\Lambda}Z$ in a completely new way





FINUDA: the Collaboration

Collaborating institutes

University of Victoria

Seoul National University

JINR Dubna

Bari University & INFN Bari
Brescia University & INFN Pavia
Pavia University & INFN Pavia
Torino Polytechnic & INFN Torino
Torino University & INFN Torino
Trieste University & INFN Trieste
L.N.F. / INFN Frascati

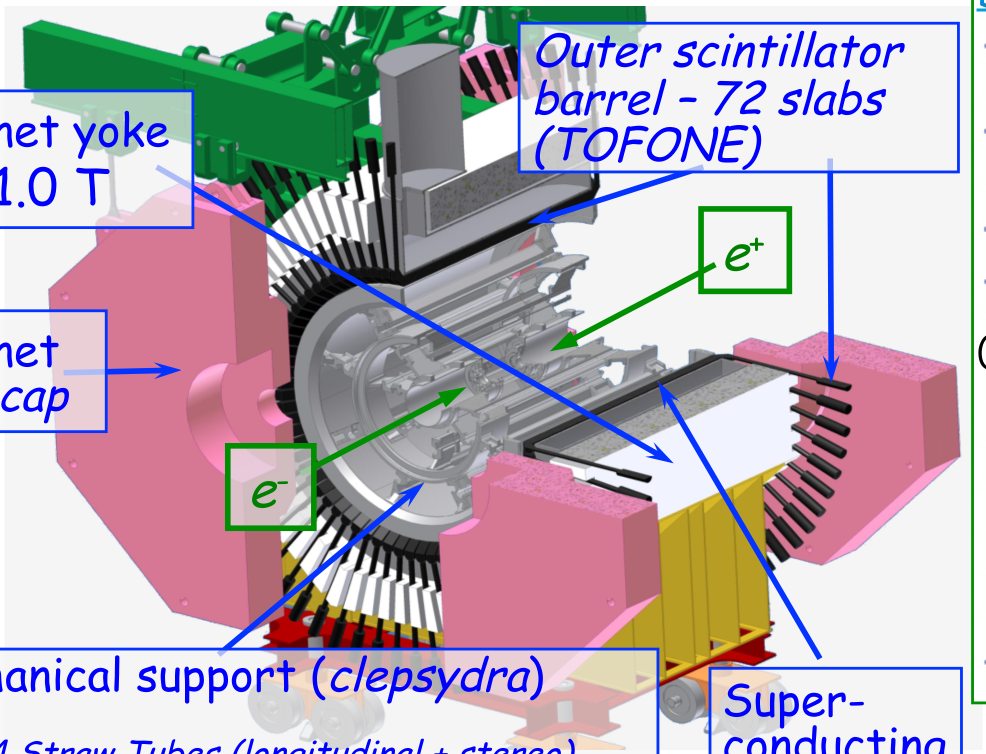
Kyoto, KEK, RIKEN

Teheran Shahid Beheshty University

Data takings

data taking	oct 2003 - jan 04	nov 2006 - jun 07
int. luminosity	220 pb^{-1}	960 pb^{-1}
daily luminosity	6 pb^{-1}	10 pb^{-1}
Total events (M)	30	200
Targets	^{6}Li (2), ^{7}Li (1), ^{12}C (3), ^{27}Al (1), ^{51}V (1)	^{6}Li (2), ^{7}Li (2), ^{9}Be (2), ^{13}C (1), D_2O (1)

The FINUDA detector



Mechanical support (*clepsydra*)
For:
- *2424 Straw Tubes (longitudinal + stereo)*
- *16 Low-Mass Drift Chambers (LMDC)*
- *18 μ-strip vertex detectors (ISIM/OSIM)*
- *Inner scintillator barrel – 12 slabs (TOFINO)*
- *8 Targets*

Detector capabilities:

- *Selective trigger* based on fast scintillation detectors (TOFINO, TOFONE)
- *precise* K^- *vertex identification* (~ 1 mm^3) (ISIM P.ID.+ *x,y,z* resolution + K^+ tagging)
- p, K, p, d, … P.ID. (OSIM and LMDC d*E*/d*x*)
- ***High momentum resolution***

(6‰ FWHM for π- @270 MeV/c for spectroscopy)

(1% FWHM for π- @270 MeV/c for decay study)

(6% FWHM for π- @110 MeV/c for decay study)

(2% FWHM for p @400 MeV/c for decay study)

(tracker resolution + He bag + thin targets)

- *Neutron detection* TOF (TOFONE-TOFINO)

Apparatus designed for a typical collider experiment:

- Cylindrical geometry
- large solid angle (~ 2π sr)
- multi-tracks analysis

Simultaneous study of formation and decay of strange hadronic systems by *full event reconstruction*

Hypernuclear Physics @FINUDA

$e^+ + e^- \rightarrow \phi(1020) \rightarrow K^+ + K^-$ (127 MeV/c)

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

Spectroscopy

${}^{A}_{\Lambda}Z \rightarrow {}^{A}(Z+1) + \pi^-$ Γ_{π^-} MWD

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

${}^{A}_{\Lambda}Z \rightarrow {}^{A-3}(Z-1) + p + n + n$ 2N induced Γ_{np}

} NMWD

FINUDA key features

- very thin targets (0.1 ÷ 0.3 g/cm^2)
  transparency ➥ "high" resolution spectroscopy

- different targets in the same run
  ➥ high degree of flexibility

- coincidence measurement with large acceptance
  complete event ➥ decay mode study

- simultaneous tracking of μ^+ from the K^+ decay
  $K^+ \rightarrow \mu^+ \nu_\mu$ ➥ energy and rate calibration

FINUDA Scientific Program

Main topics (.. not complete!):

Hypernuclear spectroscopy: PLB 622 (2005) 32: ${}^{12}_{\Lambda}C$
PLB 698 (2011) 219: ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{13}_{\Lambda}C$, ${}^{16}_{\Lambda}O$

Weak Decay: NPA 804 (2008) 151: NMWD ${}^{5}_{\Lambda}He$, ${}^{7}_{\Lambda}Li$, ${}^{12}_{\Lambda}C$
PLB 681 (2009) 139: MWD (${}^{5}_{\Lambda}He$,) ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{11}_{\Lambda}B$, ${}^{15}_{\Lambda}N$
PLB 685 (2010) 247: NMWD & 2N ${}^{5}_{\Lambda}He$, ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{11}_{\Lambda}B$, ${}^{12}_{\Lambda}C$, ${}^{13}_{\Lambda}C$, ${}^{15}_{\Lambda}N$, ${}^{16}_{\Lambda}O$
PLB 701 (2011) 556: NMWD & 2N ${}^{5}_{\Lambda}He$, ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{11}_{\Lambda}B$, ${}^{12}_{\Lambda}C$, ${}^{13}_{\Lambda}C$, ${}^{15}_{\Lambda}N$, ${}^{16}_{\Lambda}O$
NPA 881 (2012) 322 : (n, n, p) events from 2N

Rare Decays: NPA 835 (2010) 439; ${}^{4}_{\Lambda}He$, ${}^{5}_{\Lambda}He$ 2-body decays

Neutron-rich Hypernuclei: PLB 640 (2006) 145: upper limits ${}^{6}_{\Lambda}H$, ${}^{7}_{\Lambda}H$ and ${}^{12}_{\Lambda}Be$
PRL 108 (2012) 042501, NPA 881 (2012) 269: ${}^{6}_{\Lambda}H$ observation

Very interesting "by products":
- AKNC (PRL 94 (2005)212303, PLB 654 (2007) 80, PLB 669 (2008) 229)
- (K^0 K^+) on ${}^{7}Li$ at threshold (PLB 649 (2007) 25)
- multinucleon K- absorption on ${}^{6}Li$,${}^{12}C$ (NPA 775 (2006) 35)
- $A(K^-_{stop}, \pi^{+/-}\ \Sigma^{-/+})A'$ (PLB 704 (2011) 474)

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Search for light n-rich hypernuclei physics motivations

Hypernuclei with a large neutron excess (Dalitz et al., N. Cim. 30 (1963) 489, L. Majling, NPA 585 (1995) 211c, Y. Akaishi et al., Frascati Physics Series XVI (1999) 59.)

The Pauli principle does not apply to the Λ inside the nucleus + *extra binding energy (Λ "glue-like" role) ⇒ a larger number of neutrons can be bound with respect to ordinary nuclei.*

Hypernuclear physics:

ΛN interactions at low densities, the role of 3-body forces
nuclear core compression ($^{7}_{\Lambda}$Li vs ^{6}Li: H.Tamura et al., Phys.Rev. Lett. 84 (2000) 5963)
Λ extra binding energy

Neutron drip-line:

response of neutron halo on embedding of Λ hyperon, hypernuclear species with unstable nuclear core, extending the neutron drip line beyond the standard limits of n-rich nuclei
T. Yu. Tretyakova and D. E. Lanskoy, Nucl. Phys. ***A 691: 51c, 2001.***

Astrophysics:

Feedback with the astrophysics field: phenomena related to *high-density nuclear matter in neutron stars.*
S. Balberg and A. Gal, Nucl. Phys. ***A 625: 435, 1997.***

Search for light n-rich hypernuclei

Production reactions

(K^-_{stop}, π^+)

$K^- + p \rightarrow$ ~~$\Lambda+$~~π^0	~~π^0~~ $+ p \rightarrow n + \pi^+$	(2-step)	S-EX + C-EX
$K^- + p \rightarrow K^0 + n$	$K^0 + p \rightarrow \Lambda + \pi^+$	(2-step)	C-EX + S-EX
$K^- + p \rightarrow \Sigma^- + \pi^+$	$\Sigma^- + p \leftrightarrow n + \Lambda$	(1-step)	S-EX

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

${}^{9}_{\Lambda}$He (^{9}Be) U.L.=2.3 $10^{-4}/K^-_{stop}$; ${}^{12}_{\Lambda}$Be(^{12}C) U.L.=6.1 $10^{-5}/K^-_{stop}$;

${}^{16}_{\Lambda}$C(^{16}O) U.L.=6.2 $10^{-5}/K^-_{stop}$

T.Y.Tretyakova et al., Nucl. Phys. A 691 (2001) 51c (10^{-6}-$10^{-7}/K^-_{stop}$)

M. Agnello et al. Phys. Lett. B 640 (2006) 145

${}^{6}_{\Lambda}$H (^{6}Li) U.L.= (2.5 ± 1.4) $10^{-5}/K^-_{stop}$; ${}^{7}_{\Lambda}$H(^{7}Li) U.L.= (4.5± 1.4) $10^{-5}/K^-_{s}$;

${}^{12}_{\Lambda}$Be(^{12}C) U.L.= (2.0 ± 0.4) $10^{-5}/K^-_{stop}$;

(π^-, K^+)

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

P.K.Saha et al., PRL 94 (2005) 052502: ${}^{10}_{\Lambda}$Li (^{10}B) $d\sigma/d\Omega$ = 11.3±1.9 nb/sr

T.Y.Tretyakova et al., Phys. At. Nucl. 66 (2003) 1651

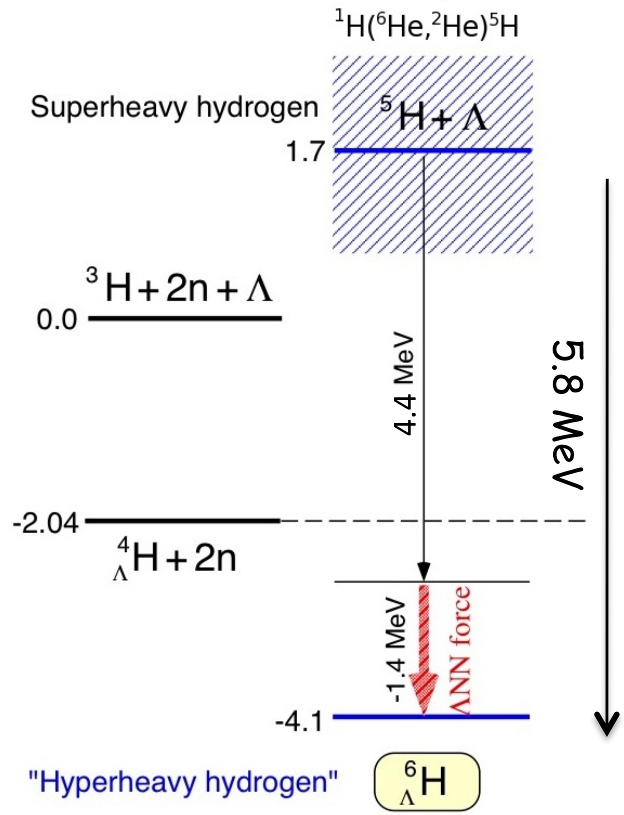
n-rich hypernuclei: $^{6}_{\Lambda}H$

Dalitz et al., N. Cim. 30 (1963) 489 (binding energy 4.2 MeV)

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	$^{5}_{\Lambda}$H (3.1) *n -1.8* xxx	♠ $^{6}_{\Lambda}$H (4.2) *2n -5* xxx	♠ $^{7}_{\Lambda}$H (5.2) 3n 0.4 xxx	

4.2 MeV

L. Majling, NPA 585 (1995) 211c
- binding energy
- prod. rate ~ 10^{-2} * hyp. prod. rate in (K^-_{stop}, π^-)



Y. Akaishi et al., AIP Conf. Proc. 1011 (2008) 277
K.S. Myint, et al., Few Body Sys. Suppl. 12 (2000) 383
Y. Akaishi et al., Frascati Phys. Series XVI (1999) 16

"coherent" Λ−Σ coupling in 0+ states
→ ΛNN three body force:
$B_{\Lambda NN}$ = 1.4 MeV, $\Delta E(0^+_{g.s.} - 1^+)$ = 2.4 MeV
model originally developed for $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He

${}^{6}_{\Lambda}H$ and ${}^{7}_{\Lambda}H$ (${}^{12}_{\Lambda}Be$) search with FINUDA

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

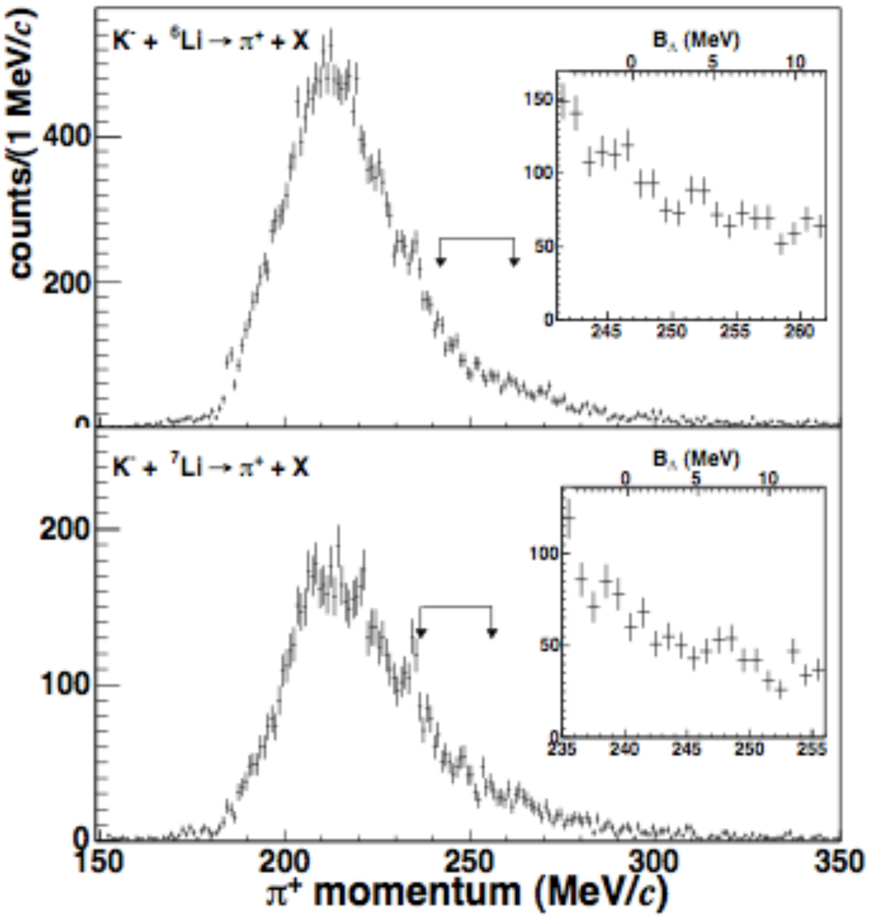
$K^{-}_{stop} + {}^{6}Li \rightarrow {}^{6}_{\Lambda}H + \pi^{+}$

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

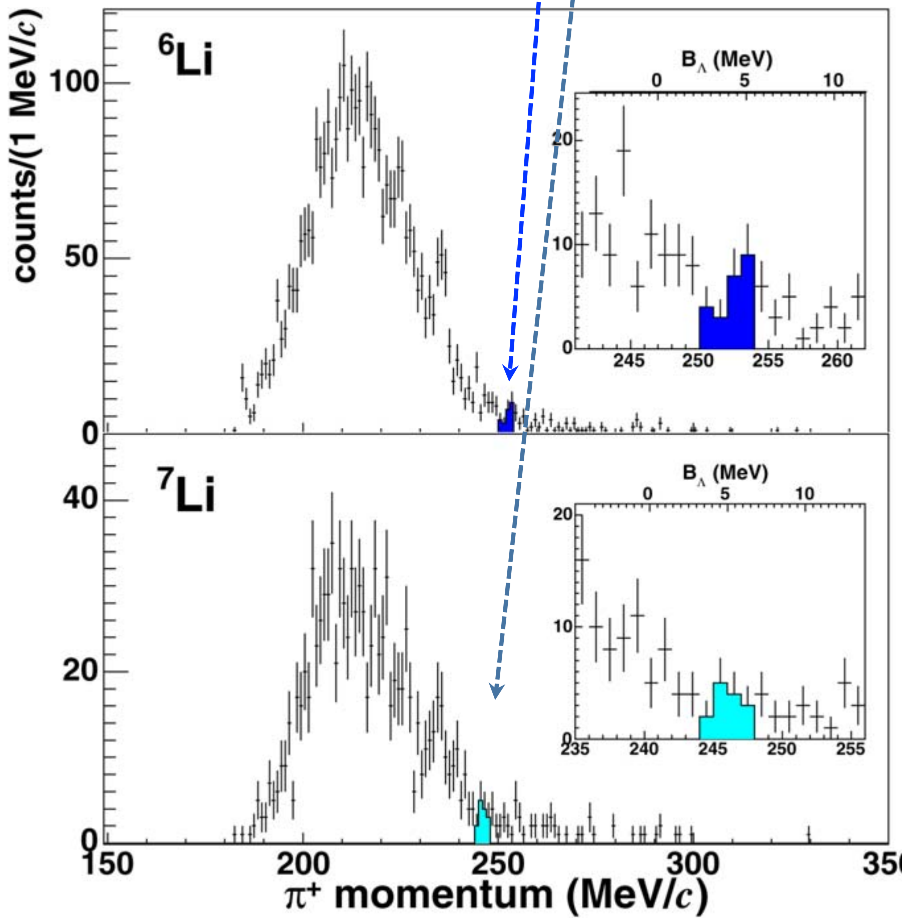
background:

- $K^{-} + p \rightarrow \Sigma^{+} + \pi^{-}$, $\Sigma^{+} \rightarrow n\,\pi^{+}$
- $K^{-} + pp \rightarrow \Sigma^{+} + n$, $\Sigma^{+} \rightarrow n\,\pi^{+}$

cut on K^{-}/π^{+} distance



raw inclusive spectrum



background subtracted spectrum

$R({}^{6}_{\Lambda}H)$ U.L.= $(2.5 \pm 1.4)\ 10^{-5}/K^{-}_{stop}$ 90% C.L.

${}^{6}_{\Lambda}H$ search with FINUDA

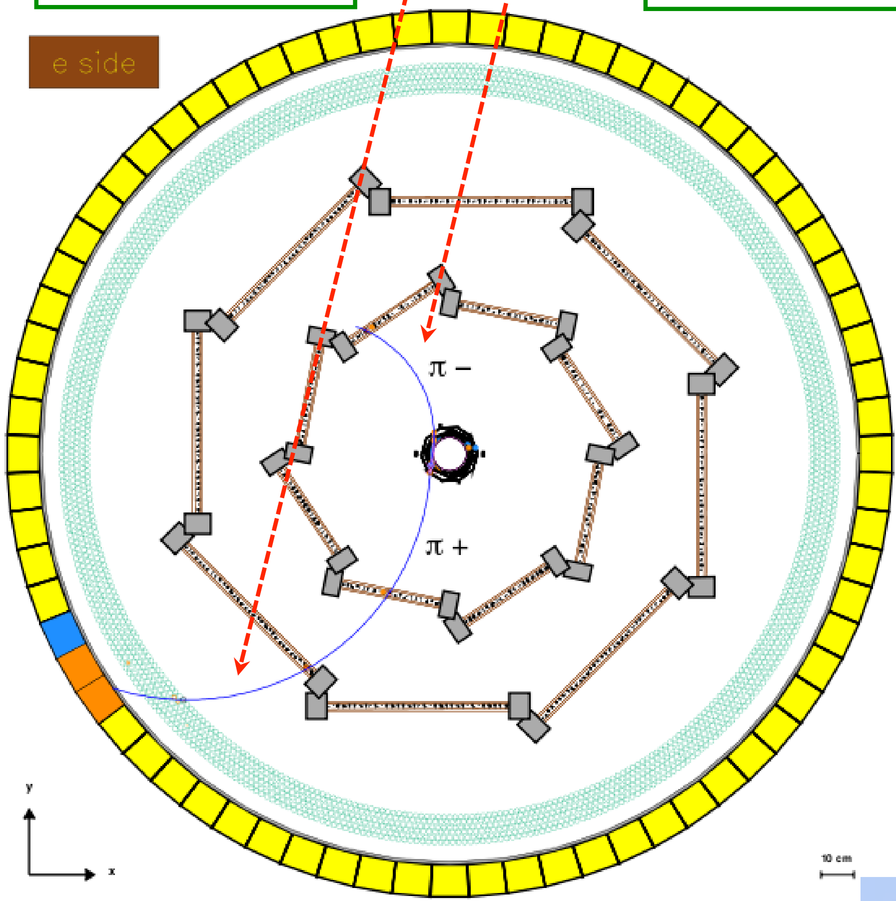
Coincidence measurement

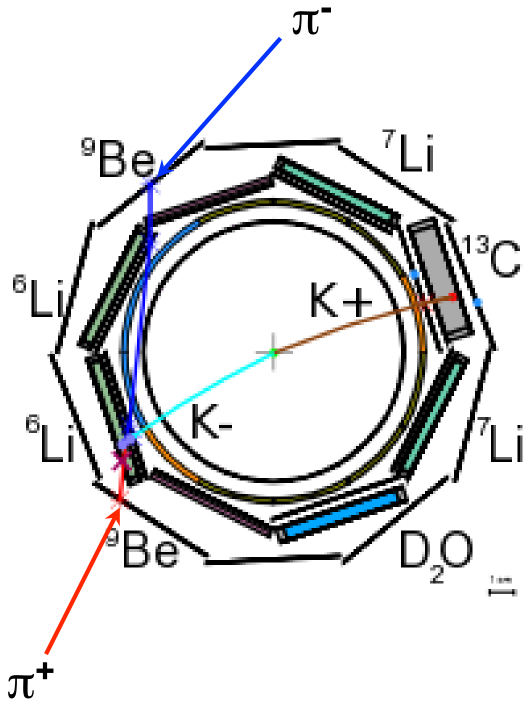
$K^{-}_{stop} + {}^{6}Li \rightarrow {}^{6}_{\Lambda}H + \pi^{+}$

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

D-CEX
~252 MeV/c

MWD
~134 MeV/c





$^{6}_{\Lambda}H$ search with FINUDA

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

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

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

independent 2-body reactions:
decay at rest

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

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

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

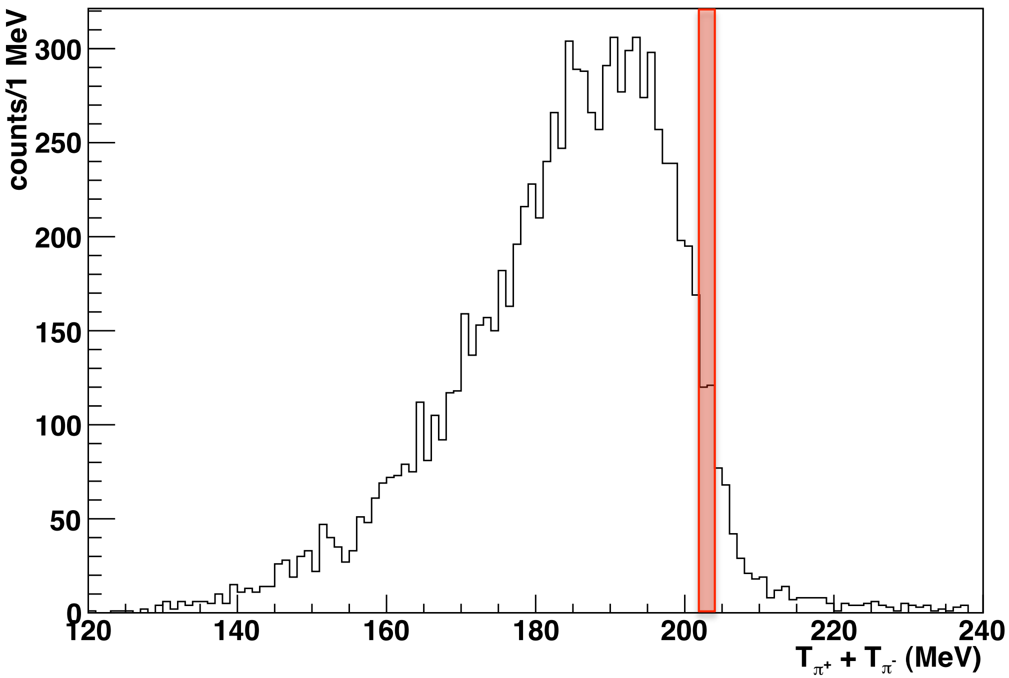
$$\sqrt{M^{2}({}^{6}_{\Lambda}H) + p^{2}(\pi^{+})} - M({}^{6}_{\Lambda}H)$$

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

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

$= 203.0 \pm 1.3$ **MeV** ($203.5 \div 203.3$ MeV with $B_{\Lambda} = 0 \div 6$ MeV)

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



selection:
$T(\pi^+)+T(\pi^-)$ = 202÷204 MeV

Finuda Coll. and A. Gal, NPA 881 (2012) 269.

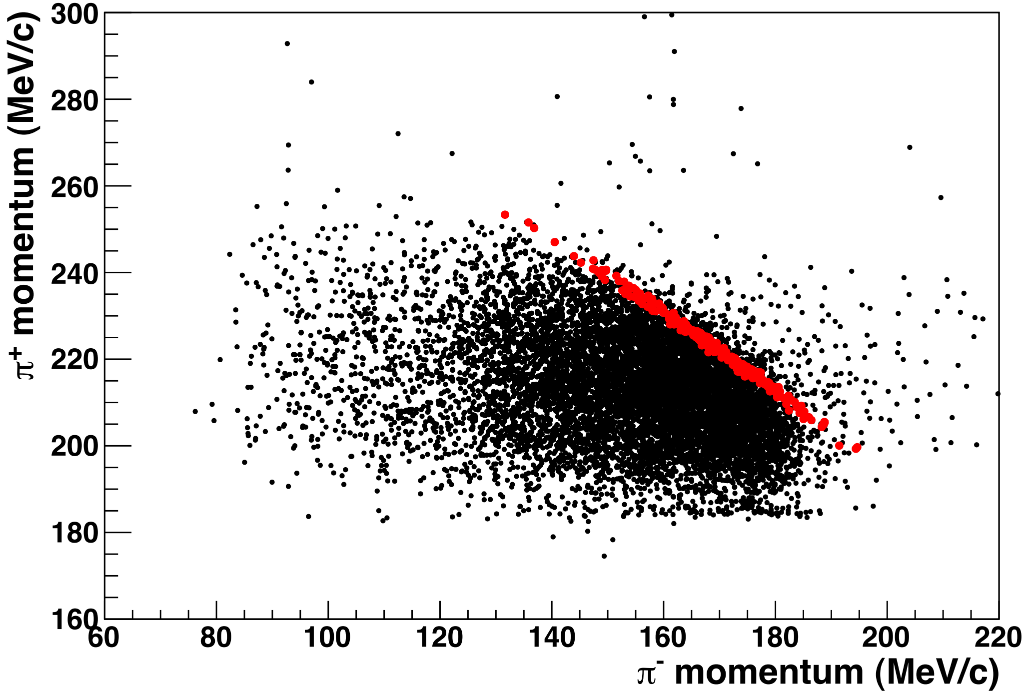
absolute energy scale:
μ+(235 MeV/c) from $K_{\mu 2}$
Δ_p< 0.12 MeV/c

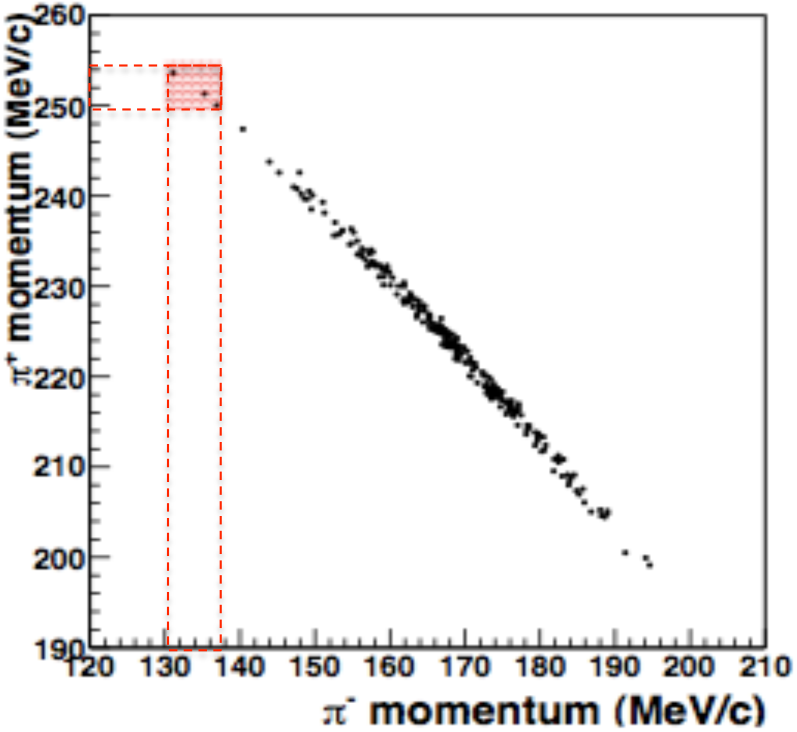
π-(132.8 MeV/c) from $^4{}_\Lambda H$
Δ_p< 0.2 MeV/c

} systematic errors

σT (π+) = 0.96 MeV, σT (π−) = 0.84 MeV
σT_{exp} = 1.3 MeV
σT_{sys} = 0.17 MeV
σT = 1.3 MeV

uncertainty on T(π+) +T(π−) = 0.2 MeV
sensitivity of 30 keV per MeV of $B_\Lambda(^6{}_\Lambda H)$





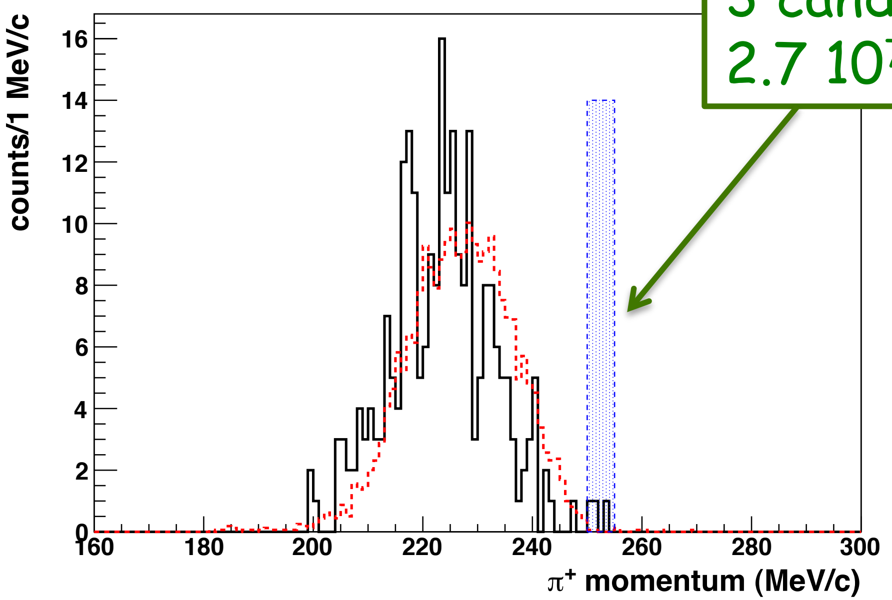
250÷255 MeV/c (σ_p= 1.1 MeV/c)

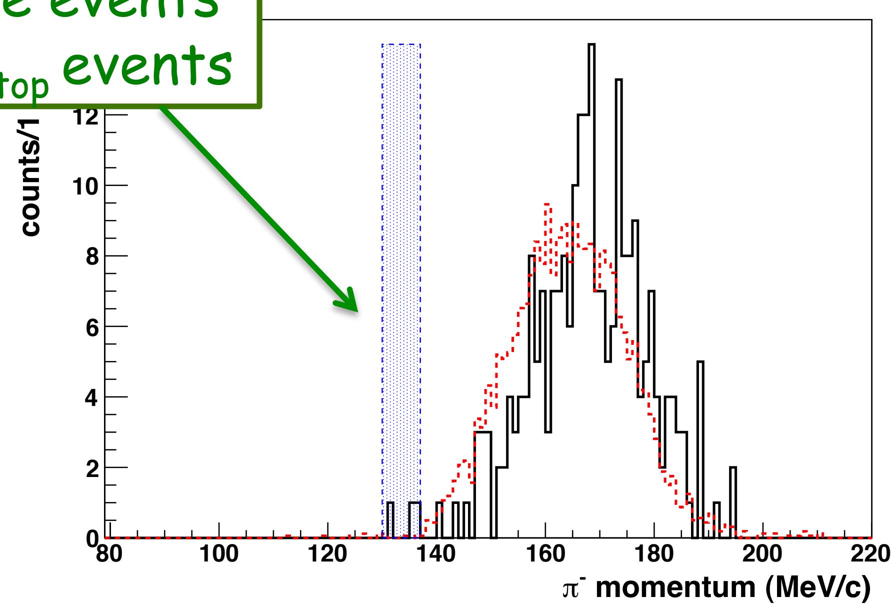
130÷137 MeV/c (σ_p= 1.2 MeV/c)

Finuda Coll. and A. Gal, NPA 881 (2012) 269.

blue bars: $p_{\pi+/\pi-}$ selection regions including ${}^{6}_{\Lambda}H$ lowest particle stability threshold ${}^{4}_{\Lambda}H$+2n ($p_{\pi+}$=251.9 MeV/c, $p_{\pi-}$=135.6 MeV/c) B_{Λ}=1.5÷6 MeV

3 candidate events
2.7 10^7 K^-_{stop} events





${}^{6}_{\Lambda}H/K^{-}_{stop}$ production rate

Background sources:

- fake coincidences: $\pi+(249\div255$ MeV/c$)$ & $\pi^{-}(130\div138$ MeV/c$)$ 0.27±0.27 ev.
- $K^{-}_{stop} + {}^{6}Li \rightarrow \Sigma^{+} + \pi^{-} + {}^{4}He + n$ (end point ~190 MeV/c)
  $\hookrightarrow n + \pi^{+}$ (end point ~282 MeV/c) 0.16±0.07 ev.
- $K^{-}_{stop} + {}^{6}Li \rightarrow {}^{4}_{\Lambda}H + n + n + \pi^{+}$ (end point ~252MeV/c)
  $\hookrightarrow {}^{4}He + \pi^{-}$ ($p(\pi^{-})$ = 133 MeV/c) negligible

${}^{6}_{\Lambda}H/K^{-}_{stop}$ production rate

Total background: BGD1 + BGD2 = 0.43 ± 0.28 events on ${}^{6}Li$

Poisson statistics: 3 events DO NOT belong to pure background: C.L.= 99%

$$R * BR(\pi-) = (3 - BGD1 - BGD2)\,(\varepsilon(\pi-))^{-1}\,(\varepsilon(\pi+))^{-1} / (n.\ K^{-}_{stop} \text{ on } {}^{6}Li)$$

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

H. Tamura, et al., PRC 40 (1989) R479
$BR(\pi-)\ {}^{4}_{\Lambda}H = 0.49$

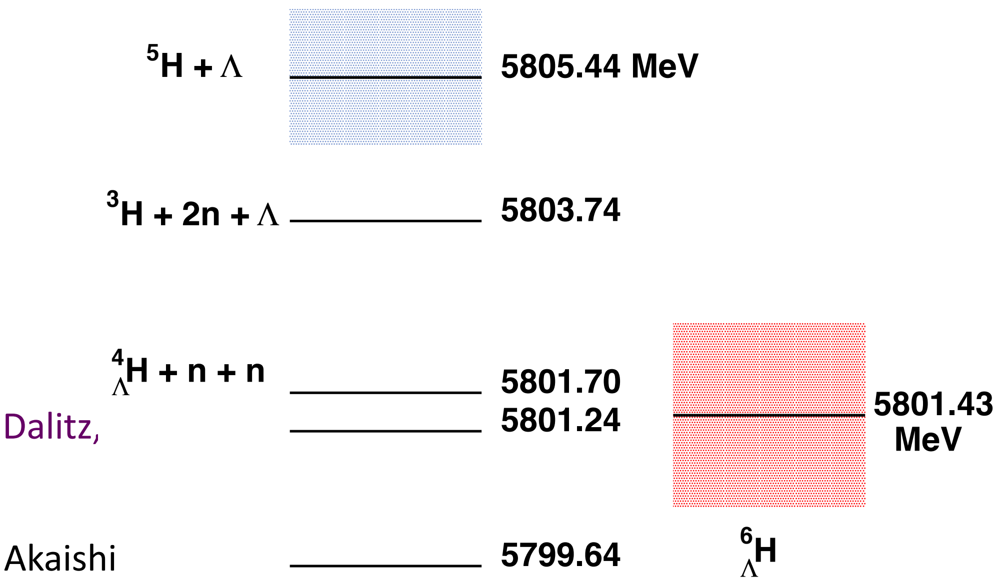
$$\mathbf{R = (5.9 \pm 4.0)\ 10^{-6}/K^{-}_{stop}}$$

$(2.5 \pm 0.4^{+0.4}_{-0.1})\ 10^{-5}/K^{-}_{stop}$
Agnello et al., *PLB 64(2006) 145*

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

kinematics

T_{tot} (MeV)	$p(\pi^+)$ (MeV/c)	$p(\pi^-)$ (MeV/c)	$M(^6_\Lambda H)$ formation (MeV/c²)	$M(^6_\Lambda H)$ decay (MeV/c²)
202.5±1.3	251.3±1.1	135.1±1.2	5802.33±0.96	5801.41±0.84
202.7±1.3	250.0±1.1	136.9±1.2	5803.45±0.96	5802.73±0.84
202.1±1.3	253.8±1.1	131.2±1.2	5799.97±0.96	5798.66±0.84



mean value = 5801.4±1.1

B_Λ = 4.0±1.1 MeV (^{5}He + Λ)

B_Λ = 5.8 MeV (^{5}He + Λ)
ΛNN force: 1.4 MeV

formation – decay = 0.98±0.74 MeV
→ excitation spectrum of $^6_\Lambda H$

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

discussion

Spin flip is forbidden in production at rest:

$K^{-}_{stop} + {}^{6}Li\ (L_i=0,\ S=1) \rightarrow {}^{6}_{\Lambda}H(L_f,\ S=1) + \pi^{+}$

$L_f = 0 \rightarrow {}^{6}_{\Lambda}H(1^{+}_{exc.})$ followed by :

(i) ${}^{6}_{\Lambda}H(1+exc.) \rightarrow \gamma + {}^{6}_{\Lambda}H(0+g.s.)$ (~ 10^{-13} s) M1

(ii) ${}^{6}_{\Lambda}H(0+g.s.) \rightarrow \pi- + {}^{6}He(0+g.s.)$ (~ 10^{-10} s)

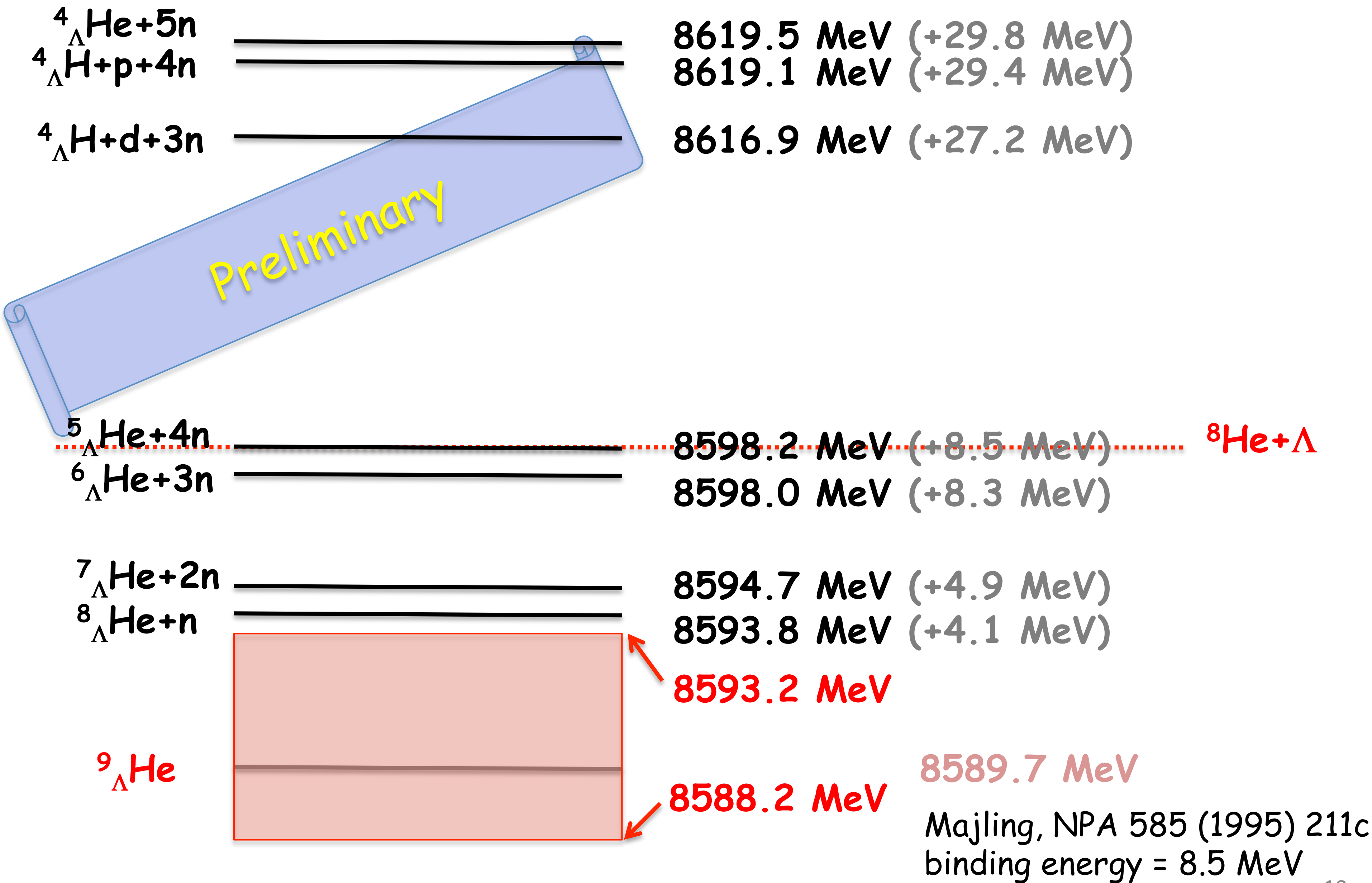
→ $B_{\Lambda}({}^{6}_{\Lambda}H) = (4.5 \pm 1.2)$ MeV vs ${}^{5}He+\Lambda$ from decay mass only

little neutron-excess effect compared to $B_{\Lambda}({}^{6}_{\Lambda}He) = (4.18 \pm 0.10)$ MeV

The excitation energy of the 1^{+} spin-flip state is identified with a systematic $\Delta M = 0.98 \pm 0.74$ MeV between values of ${}^{6}_{\Lambda}H$ mass derived separately from production and from decay. ΔM is consistent with the 1.04 MeV for the analogous spin-flip excitation in ${}^{4}_{\Lambda}H$, according to shell-model estimates.

An experiment to produce ${}^{6}_{\Lambda}H$ via the ($\pi-$, K+) reaction on ${}^{6}Li$ at 1.2 GeV/c was approved at J-PARC (E10) and should run soon. The expected energy resolution is 2.5 MeV FWHM, and the expected statistics is about 1–2 orders of magnitude higher than previous KEK experiments.

$^{9}_{\Lambda}$He search with FINUDA



${}^{9}_{\Lambda}He$ search with FINUDA

$K^-_{stop} + {}^{9}Be \rightarrow {}^{9}_{\Lambda}He + \pi^+$

${}^{9}_{\Lambda}He \rightarrow {}^{9}Li + \pi^-$
($\tau({}^{9}Li) \sim 178$ ms)

independent 2-body reactions:
decay at rest

Preliminary

$$M(K^-) + 5\,M(n) + 4\,M(p) - B({}^{9}Be) = M({}^{9}_{\Lambda}He) + T({}^{9}_{\Lambda}He) + M(\pi^+) + T(\pi^+)$$

$$M({}^{9}_{\Lambda}He) = 6\,M(n) + 3M(p) - B({}^{9}Li) + T({}^{9}Li) + M(\pi^-) + T(\pi^-)$$

$$\sqrt{M^2({}^{9}Li) + p^2(\pi^-)} - M({}^{9}Li)$$

$$\sqrt{M^2({}^{9}_{\Lambda}He) + p^2(\pi^+)} - M({}^{9}_{\Lambda}He)$$

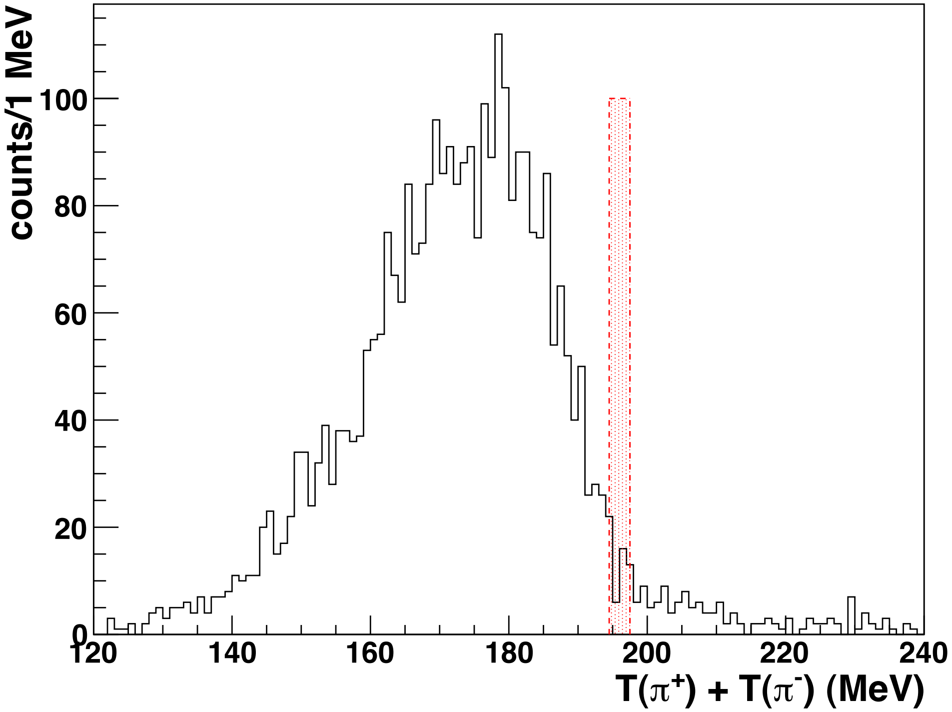
$$M({}^{9}_{\Lambda}He) = M({}^{8}He) + M(\Lambda) - B(\Lambda)$$

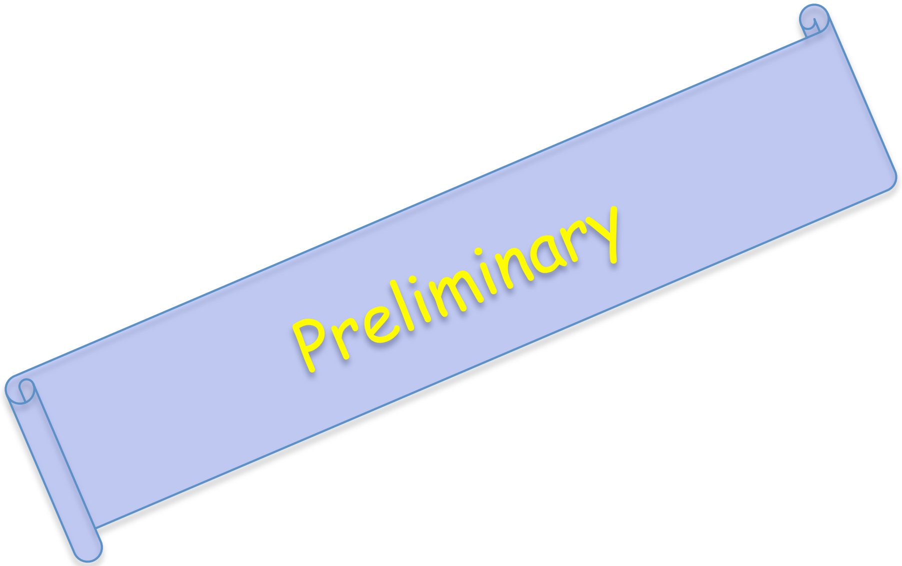
$$T(\pi^+) + T(\pi^-) = M(K^-) + M(p) - M(n) - B({}^{9}Be) + B({}^{9}Li) - T({}^{9}Li) - T({}^{9}_{\Lambda}He) - M(\pi^+) - M(\pi^-)$$

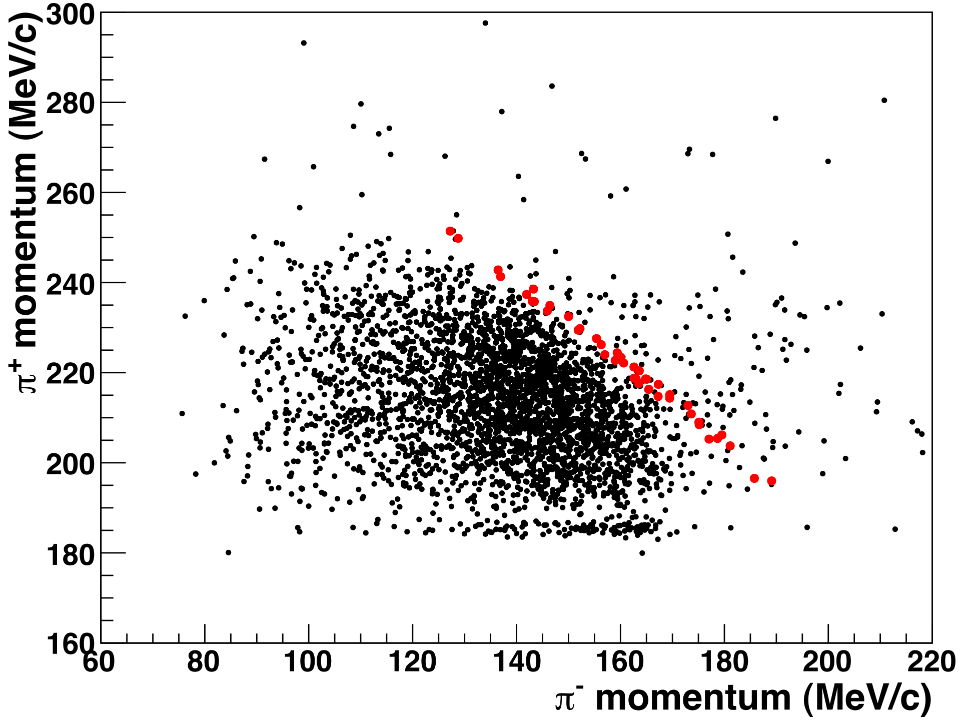
= **195.8 ± 1.3 MeV** (195.8÷195.7 MeV with B_Λ= 0÷10 MeV)

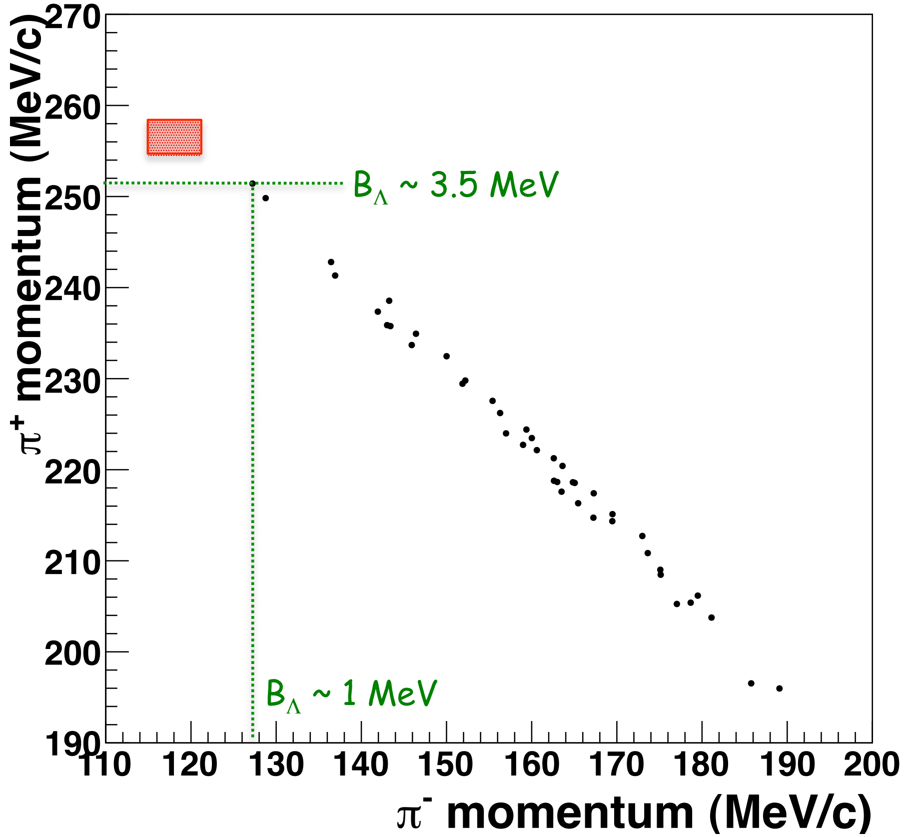
cut on $T(\pi^+) + T(\pi^-)$: 194.5÷197.5 MeV selection:

$T(\pi^+)+T(\pi^-) = 194.5 \div 197.5$ MeV





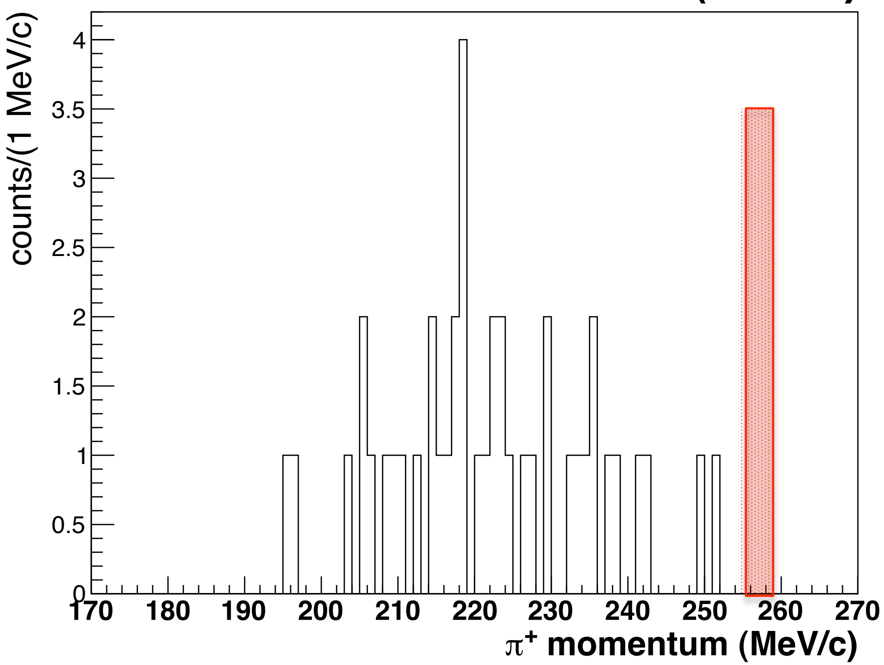


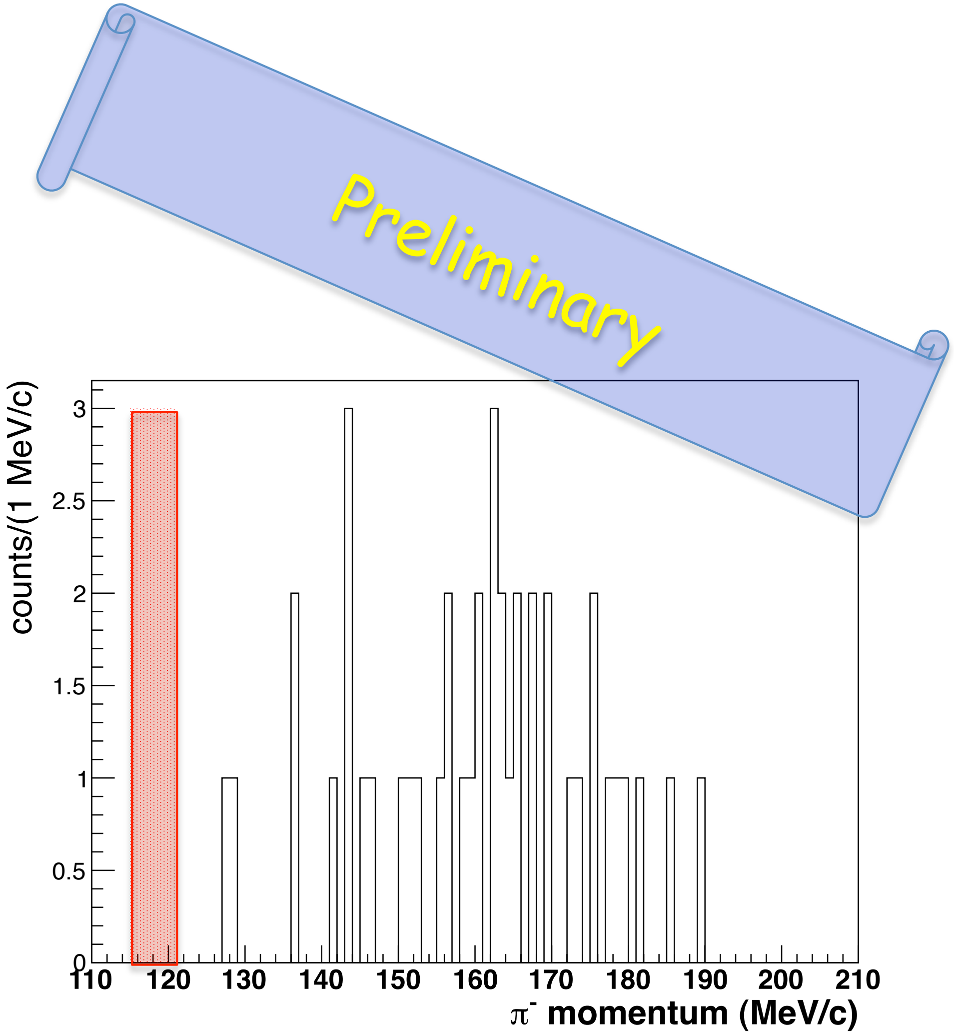


254.5÷258.5 MeV/c (σ_p= 1.1 MeV/c)

115÷121 MeV/c (σ_p= 1.2 MeV/c)

B_Λ = 5÷10 MeV





${}^{9}_{\Lambda}He/K^{-}_{stop}$ production rate

upper limit evaluation

Preliminary

- ✓ 0 observed events
- ✓ $\varepsilon(\pi-)$, $\varepsilon(\pi+)$
- ✓ n. K^{-}_{stop} on ^{9}Be (2.5 10^{7} K^{-}_{stop} events)

$$R * BR(\pi-) < 3\ 10^{-6} / (n.\ K^{-}_{stop}\ on\ {}^{9}Be)$$

$$BR(\pi-) = 0.32\ ({}^{5}_{\Lambda}He + 4\ spectator\ neutrons)$$

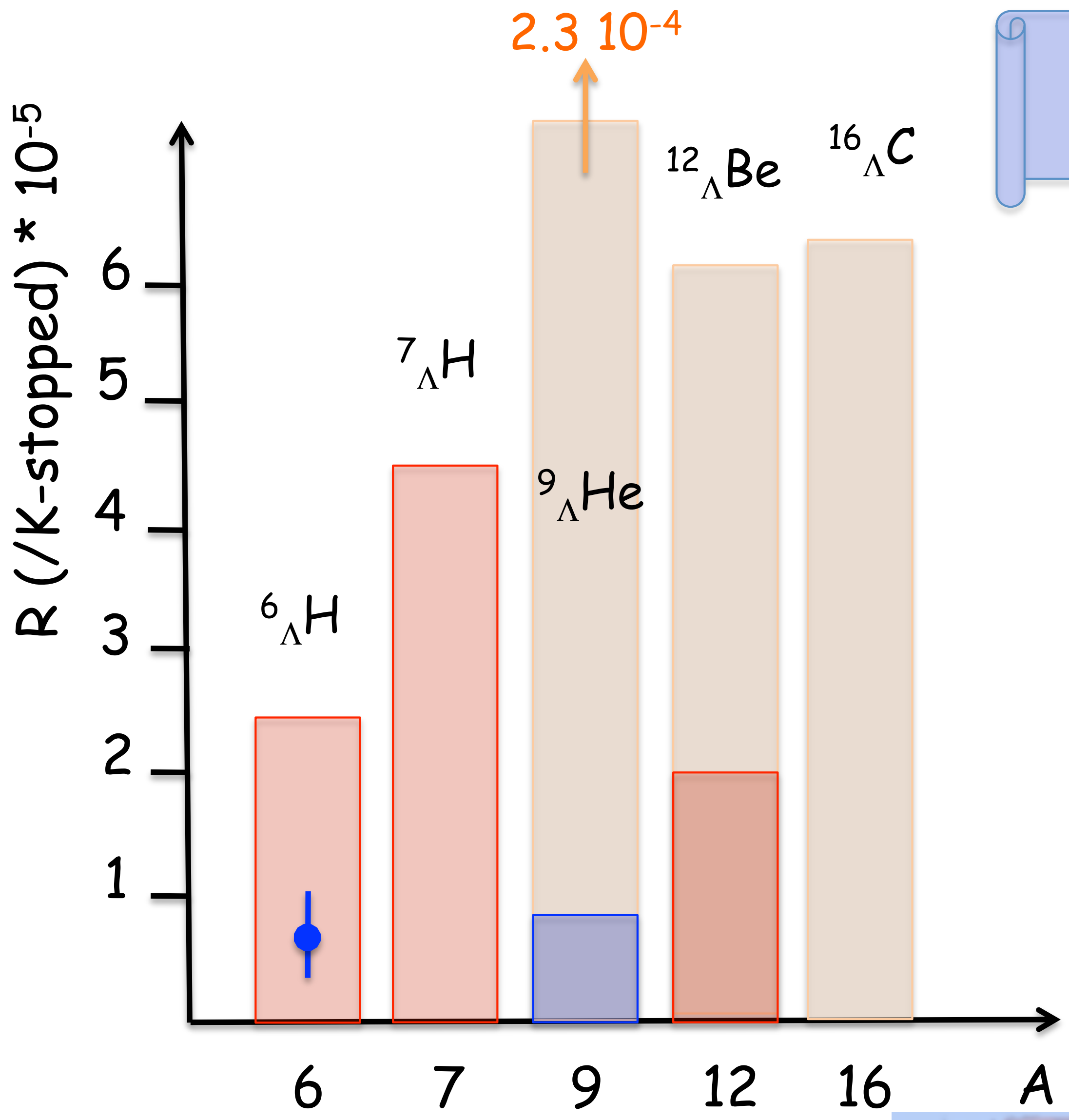
S. Kameoka, et al., NPA 754 (2005) 173c.
M.Agnello et al., PLB 681 (2009) 139.

$$\mathbf{R < 9\ 10^{-6} / (n.\ K^{-}_{stop}\ on\ {}^{9}Be)}$$

K.Kubota et al, NPA 602 (1996) 327.
${}^{9}_{\Lambda}He$ (^{9}Be) U.L.=2.3 $10^{-4}/K^{-}_{stop}$

Conclusions

(K^-_{stop}, π^+) production rate vs A



Preliminary

FINUDA: inclusive spectra

FINUDA: coincidence

KEK

full bars: U.L., 90% C.L.

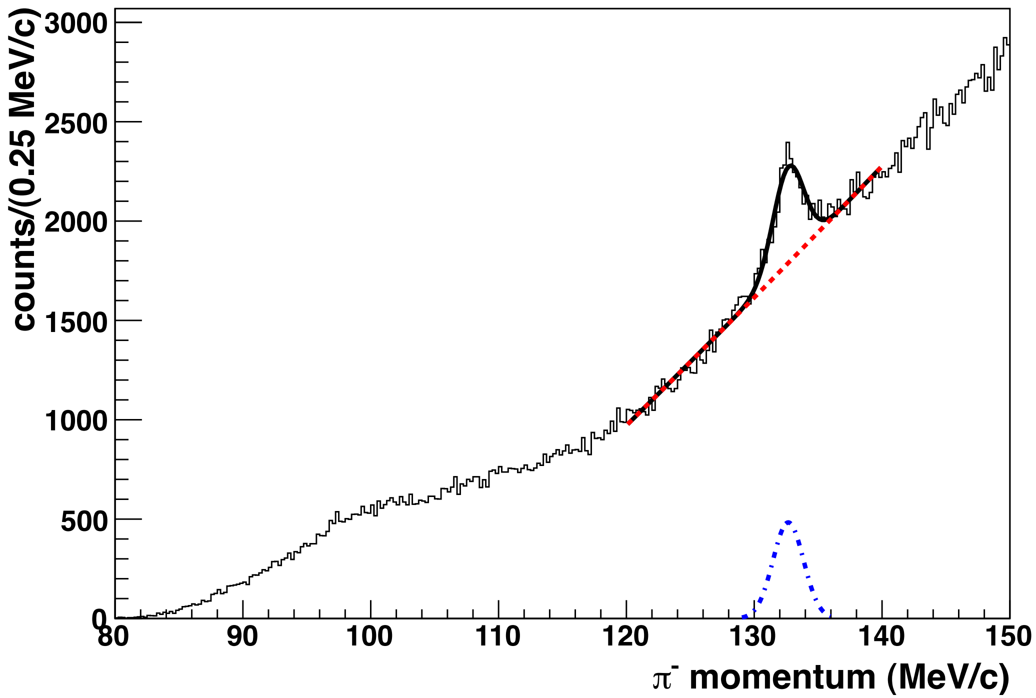
… no theoretical calculations A<12

… coincidence method limits

target	hypernucleus	2-b MWD daughter nucleus	lifetime	MWD 'model'	MWD 'model' BR($\pi-$)
${}^{6}Li$	${}^{6}_{\Lambda}H$	${}^{6}He$	801 ms	${}^{4}_{\Lambda}H$	0.49 H. Tamura, et al., PRC 40 (1989) R479
${}^{7}Li$	${}^{7}_{\Lambda}H$	${}^{7}He$	unstable	${}^{4}_{\Lambda}H$	0.49 H. Tamura, et al., PRC 40 (1989) R479
${}^{9}Be$	${}^{9}_{\Lambda}He$	${}^{9}Li$	178 ms	${}^{5}_{\Lambda}He$	0.323 FINUDA PLB 681 (2009) 139
${}^{12}C$	${}^{12}_{\Lambda}Be$	${}^{12}B$	20 ms	${}^{9}_{\Lambda}Be$	0.154 FINUDA PLB 681 (2009) 139
${}^{13}C$	${}^{13}_{\Lambda}Be$	${}^{13}B$	17.3 ms	${}^{9}_{\Lambda}Be$	0.154 FINUDA PLB 681 (2009) 139
${}^{16}O$	${}^{16}_{\Lambda}C$	${}^{16}N$	7.13 s	${}^{12}_{\Lambda}C$	0.099 Y.Sato et al., PRC 71 (2005) 025203

FINUDA low momentum π− resolution

production of ${}^{4}_{\Lambda}H$ hyperfragment on ${}^{6}Li$

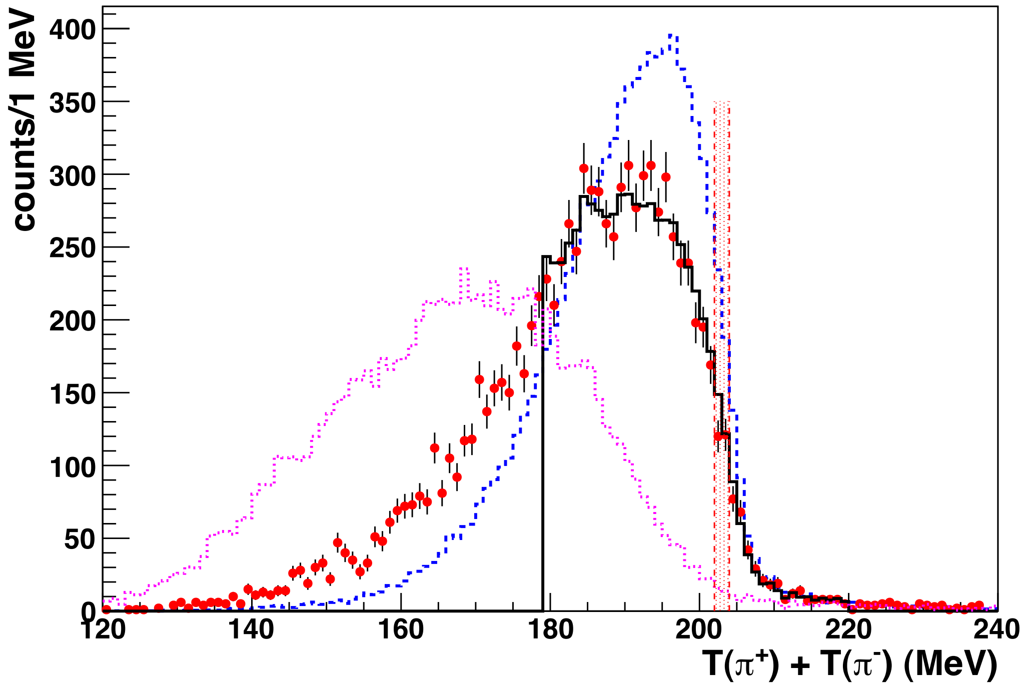


Background sources: Σ+ production and decay

$K^{-}_{stop} + {}^{6}Li \rightarrow \Sigma^{+} + \pi^{-} + {}^{4}He + n$

$\hookrightarrow n + \pi^{+}$

- quasi free approach: 0.743 ± 0.019
- 4-body interaction: 0.257 ± 0.017
- ${}^{4}He + n$ and "${}^{5}He$" final state



Finuda Coll. and A. Gal, NPA 881 (2012) 269.

n-rich hypernuclei: physics motivations

Hypernuclei with a large neutron excess (Dalitz et al., N. Cim. 30 (1963) 489, L. Majling, NPA 585 (1995) 211c, Y. Akaishi et al., Frascati Physics Series XVI (1999) 59.)

The Pauli principle does not apply to the Λ inside the nucleus + *extra binding energy (Λ "glue-like" role) ⇒ a larger number of neutrons can be bound with respect to ordinary nuclei.*

Hypernuclear physics:

ΛN interactions at low densities, the role of 3-body forces
nuclear core compression ($^{7}_{L}$Li vs ^{6}Li: H.Tamura et al., Phys.Rev. Lett. 84 (2000) 5963)
Λ extra binding energy

Neutron drip-line:

response of neutron halo on embedding of Λ hyperon, hypernuclear species with unstable nuclear core
T. Yu. Tretyakova and D. E. Lanskoy, Nucl. Phys. ***A 691: 51c, 2001.***

Astrophysics:

Feedback with the astrophysics field: phenomena related to *high-density nuclear matter in neutron stars.*
S. Balberg and A. Gal, Nucl. Phys. ***A 625: 435, 1997.***

Search for light n-rich hypernuclei

- Glue-like role of the Λ hyperon → existence of Hypernuclei with a N/Z ratio larger than normal nuclei → stabilizing action on unstable cores: $^{6}_{\Lambda}H$ (^{5}H)
Dalitz et al., N. Cim. 30 (1963) 489 ($^{6}_{\Lambda}He$, $^{7}_{\Lambda}Be$, $^{8}_{\Lambda}He$, $^{9}_{\Lambda}Be$ and $^{10}_{\Lambda}B$, emulsions)
L. Majling, NPA 585 (1995) 211c.
Y. Akaishi et al., Frascati Physics Series XVI (1999) 59.

- neutron-rich hypernuclei can go beyond the neutron drip line of ordinary nuclei

- n-halo systems: tool to study the strong interaction in a low density medium

- composition and equation of state of supernovae and neutron star cores sensitively depend on the hyperon content, mainly controlled by the depths of the hyperon–nucleus mean field potentials V_Y (ρ) at high densities ρ.

$^{9}_{\Lambda}He/K^{-}_{stop}$ production rate

upper limit evaluation

- ✓ 0 observed events
- ✓ $\varepsilon(\pi-)$, $\varepsilon(\pi+)$
- ✓ n. K^{-}_{stop} on ^{9}Be (2.5 10^{7} K^{-}_{stop} events)

$$R * BR(\pi-) < (1.6\pm1.4)\ 10^{-6}\ /\ (n.\ K^{-}_{stop}\ on\ ^{9}Be)$$

$$BR(\pi-) = 0.32\ (^{5}_{\Lambda}He + 4\ spectator\ neutrons)$$

S. Kameoka, et al., NPA 754 (2005) 173c.
M.Agnello et al., PLB 681 (2009) 139.

$$\mathbf{R < (5.0\pm4.1)\ 10^{-6}\ /\ (n.\ K^{-}_{stop}\ on\ ^{9}Be)\quad (90\%\ C.L.)}$$

K.Kubota et al, NPA 602 (1996) 327.
$^{9}_{\Lambda}He$ (^{9}Be) U.L.=2.3 $10^{-4}/K^{-}_{stop}$

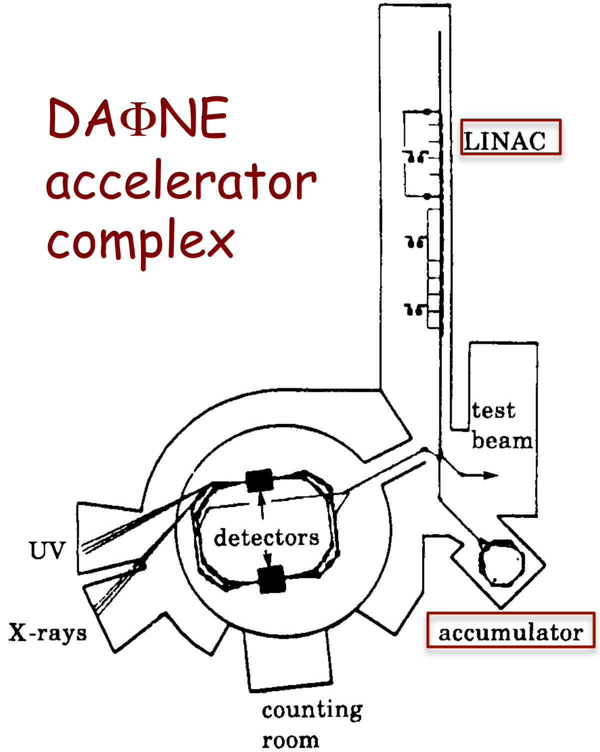
FINUDA: FIsica NUcleare a DAΦNE

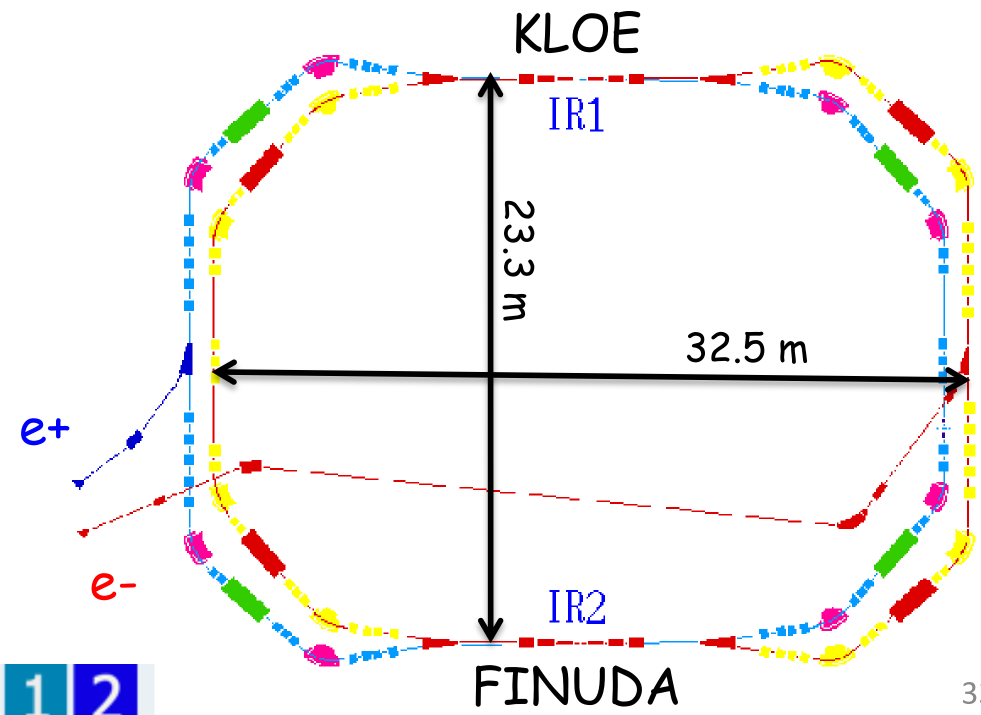
DAΦNE

Double Annular Φ-factory for Nice Experiments

Energy (GeV)	0.51
Luminosity (cm-2 s-1)	10^{32}
Beam Hor. Dim. at IP (mm)	2.11
Beam Vert. Dim. at IP (mm)	0.021
R.M.S. Bunch length (mm)	30
Crossing angle (mrad)	25
Collision frequency (MHz)	380.44
Bunches/ring	120
Max number of particles/bunch	9.0 10^{10}
Max total mean current (A)	5.5

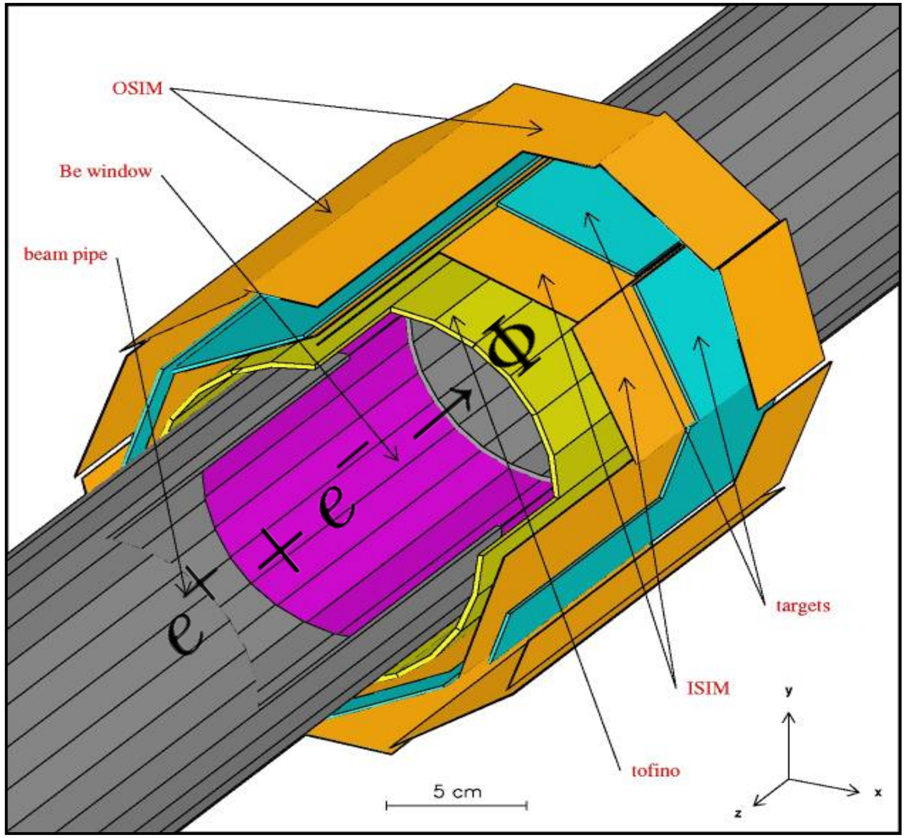
DAΦNE accelerator complex

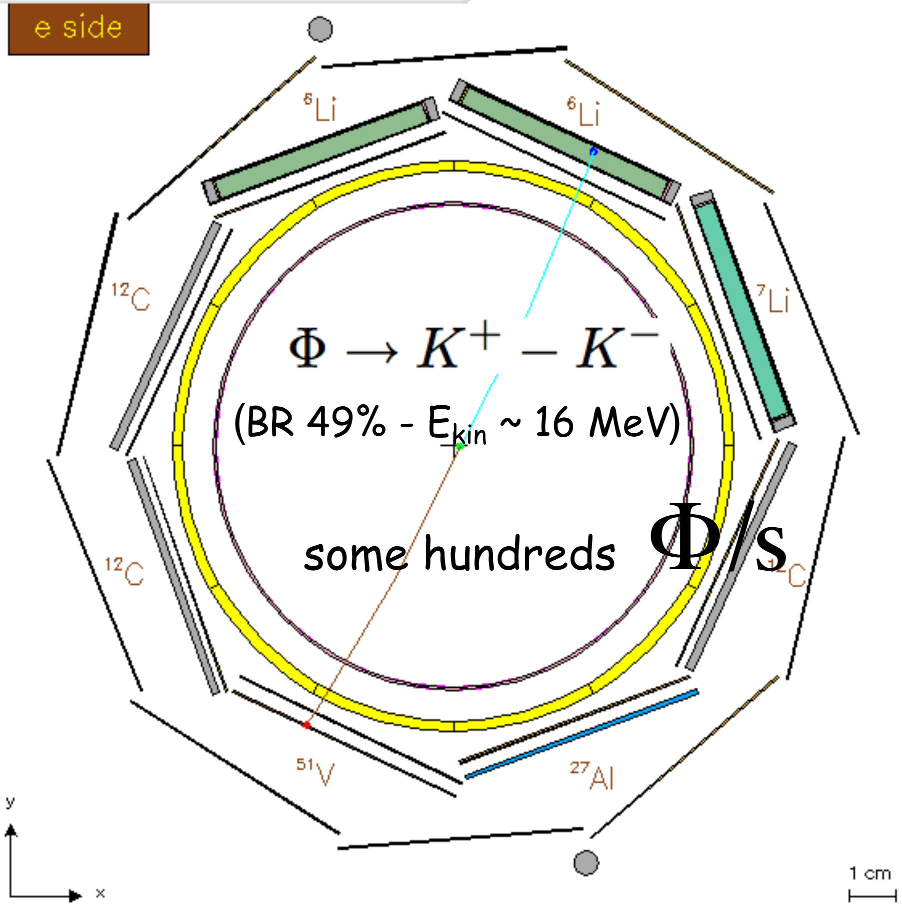


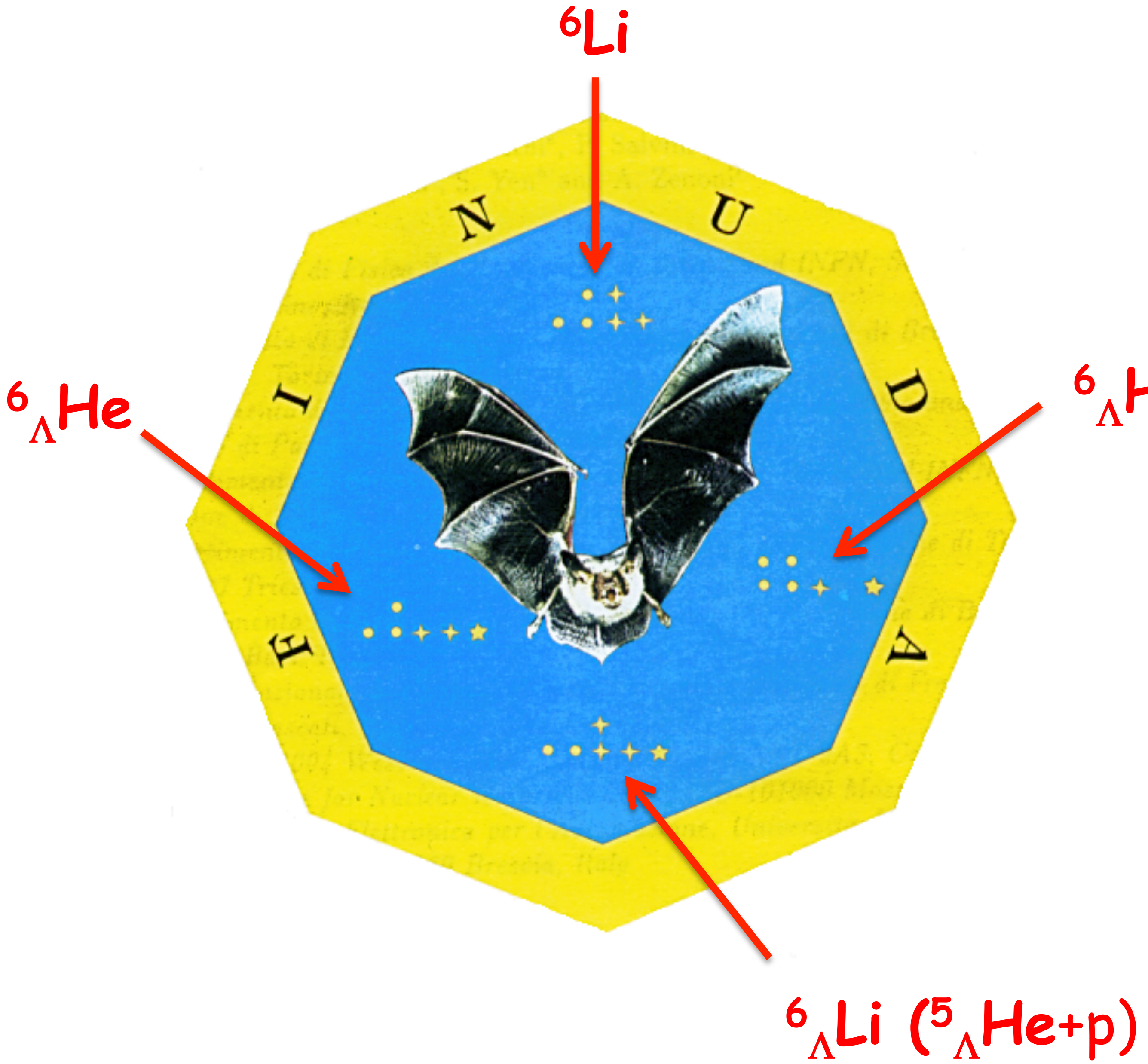


The FINUDA interaction region

target region
- 12 scintillators (TOFINO)
- 8 silicon microstrips layer (ISIM)
- 8 targets
- 10 silicon microstrip layer (OSIM)






^{6}Li
F I N U D A
$^{6}_{\Lambda}He$
$^{6}_{\Lambda}H$
$^{6}_{\Lambda}Li$ ($^{5}_{\Lambda}He$+p)