Stopped K^- Physics with FINUDA

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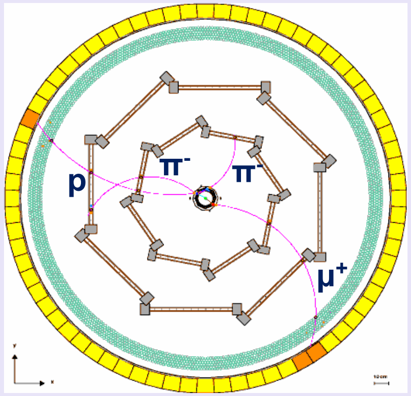
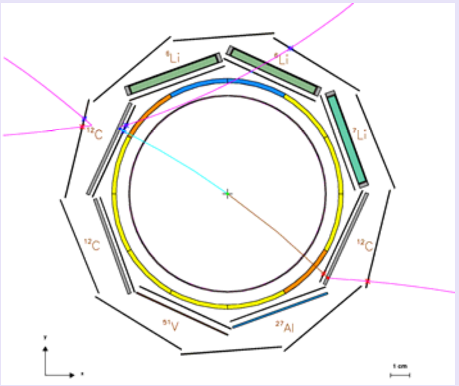
FINUDA collaboration



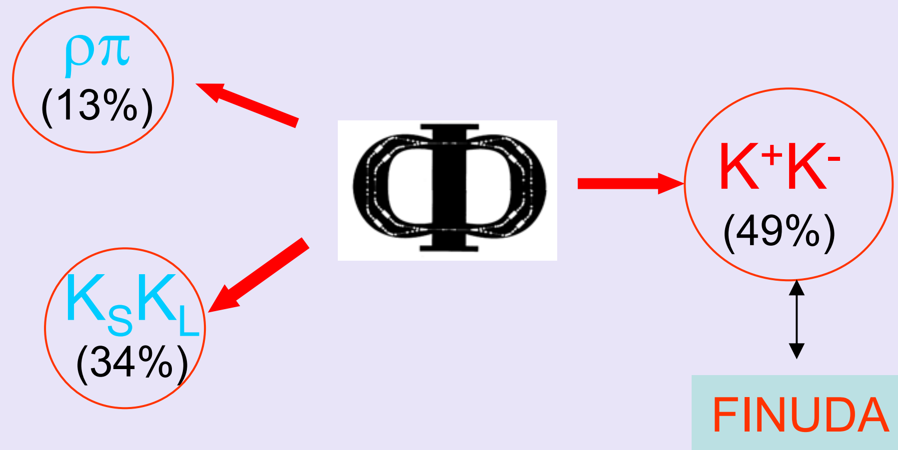


Stopped K^- Physics at DAΦNE

DAΦNE: e^+- e^- **collider**. Beam Energy **510 MeV**

$L \sim 7 \cdot 10^{31} cm^{-2} s^{-1} \longrightarrow 350\ \Phi\ s^{-1}$ (2004)

$L \sim \mathbf{1.2 \cdot 10^{32} cm^{-2} s^{-1}} \rightarrow 600\ \Phi\ s^{-1}$ (2007)



The **Φ** decay is a source of:

- neutral and charged kaons
- collinear and tagged
- low energy (~16 MeV)

$$e^+e^- \longrightarrow \Phi(1020) \longrightarrow K^+K^-$$

~16 MeV

The K^- can be stopped in thin targets (~ 0.2 ÷ 0.3 g cm^{-2}) to produce e.g. hypernuclei

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

Decay
(π,p,n)

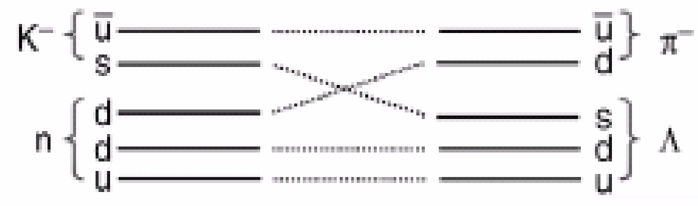
High resolution
spectroscopy

Physics topics (FINUDA @DAΦNE)

Strangeness Exchange reactions

$K^- + N \rightarrow Y(\Lambda/\Sigma) + \pi$

If Y remains bound a hypernucleus forms



❑ Hypernuclear spectroscopy

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

- Study of Λ-N and Σ-N interaction ▪Single particle models predictions
- Hypernuclear structure ▪ Study of Λ/Σ -nucleus potentials ▪astrophysical implications

❑ Hypernuclear decays

$\Lambda \rightarrow \pi N$ (**mesonic weak decay**) and $\Lambda N \rightarrow nN$, $\Lambda NN \rightarrow nNN$ (**non mesonic weak decay**)

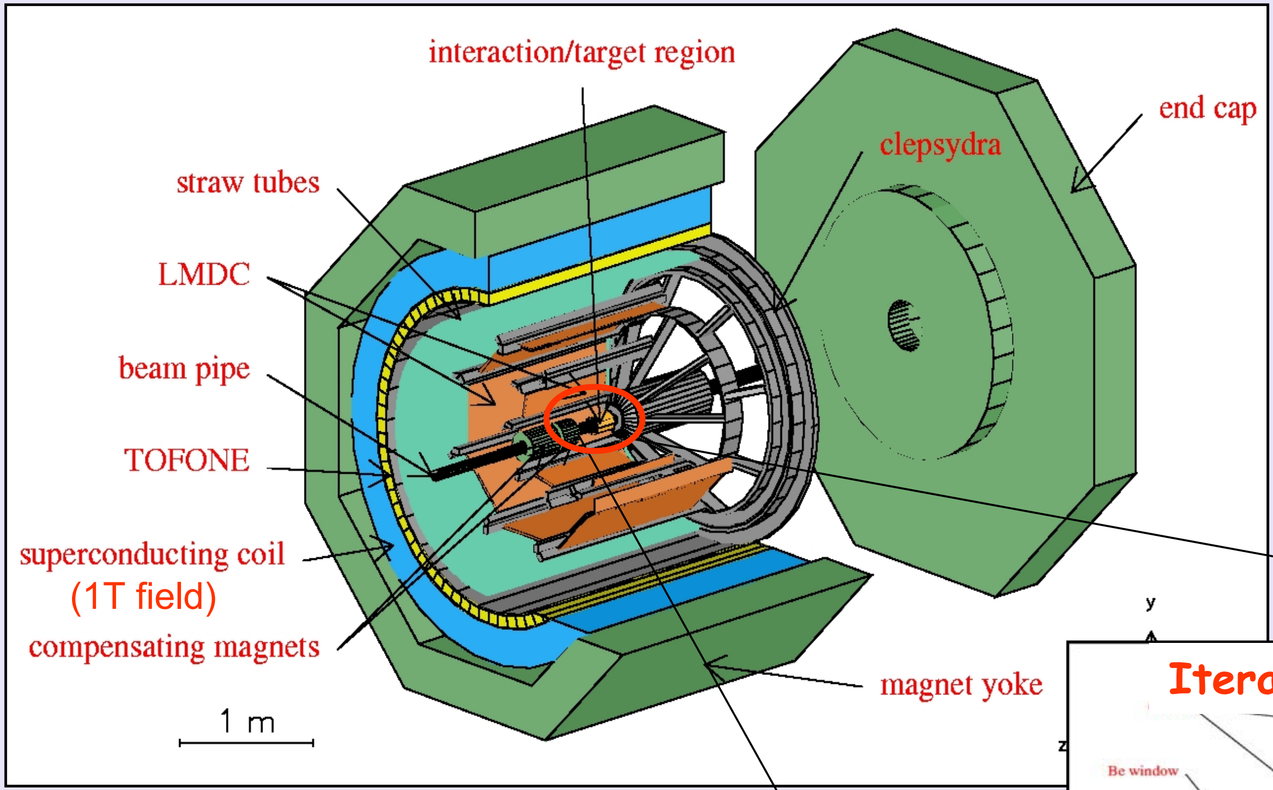
- baryon-baryon strangeness changing weak processes in nuclear matter
- mesons medium modifications • short range correlations •quark d.o.f.

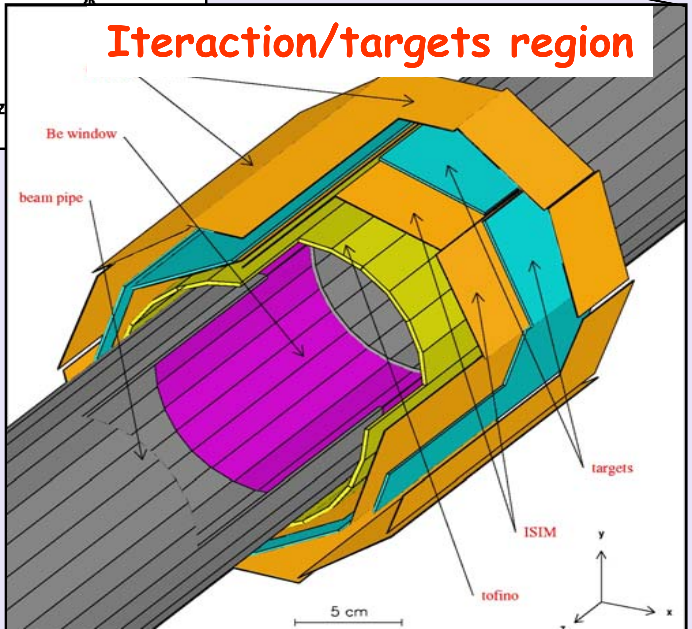
Physics topics (FINUDA @DAΦNE)

❑Search for:

- High N/Z (neutron rich) hypernuclei: $K^- + {}^{A}Z \rightarrow {}^{A}_{\Lambda}(Z-2) + \pi^+$ (${}^{6}_{\Lambda}H$, ${}^{7}_{\Lambda}H$…)
  Info on: neutron halo, low density Λ-n interaction, $\Lambda-\Sigma$ coupling
- (Deeply) bound kaonic clusters: **Λp,Λd**,...detection
  K^--A potential, K mass/condensation in nuclear matter, nuclear compressibility, chir.symm. rest.,
- Study of K^- multinucleon absorption (**Λp,Λd..**detection)
- Σ–hypernuclei
- rare decays
- K^+ charge exchange reactions

The FINUDA spectrometer

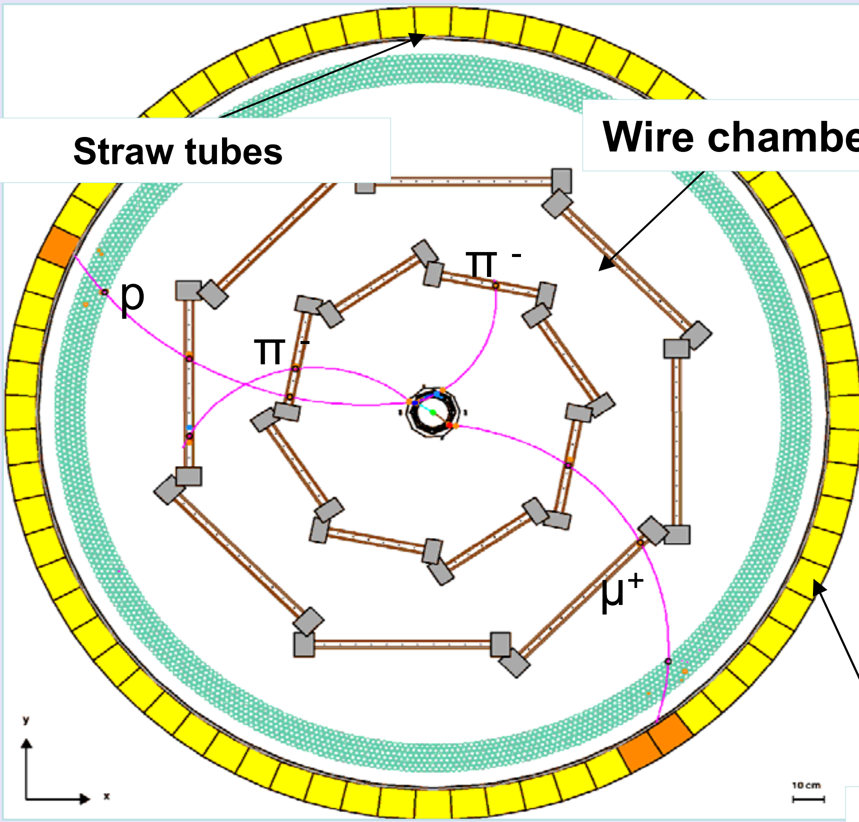




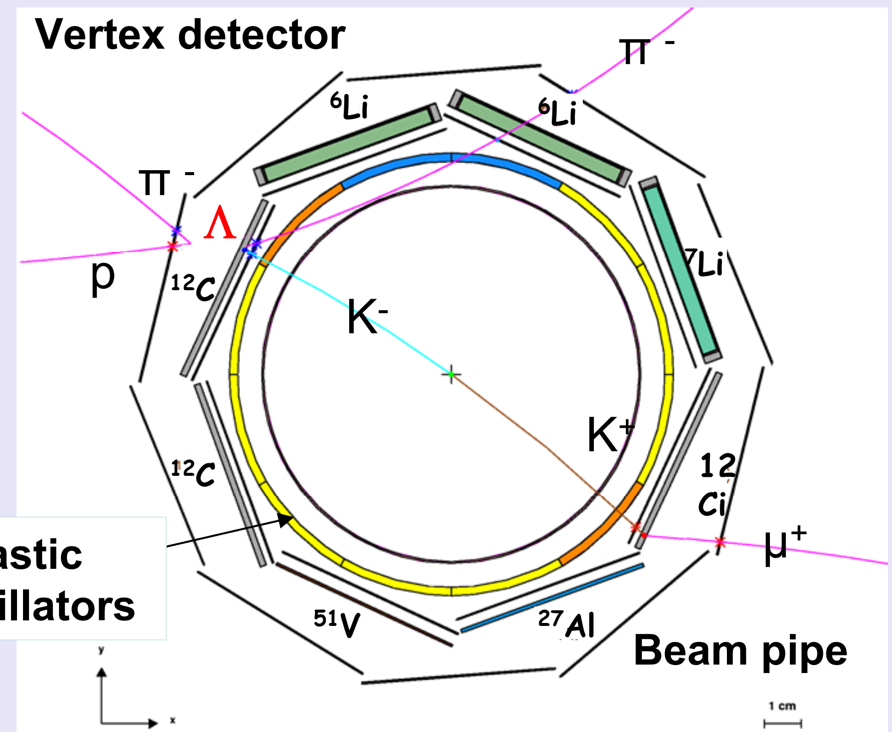
The FINUDA spectrometer

Second data taking
Average daily integrated luminosity ~ 7 pb-1
Total integrated luminosity 966 pb-1
1st data taking~250pb-1

FINUDA FRONTAL VIEW



VERTEX REGION

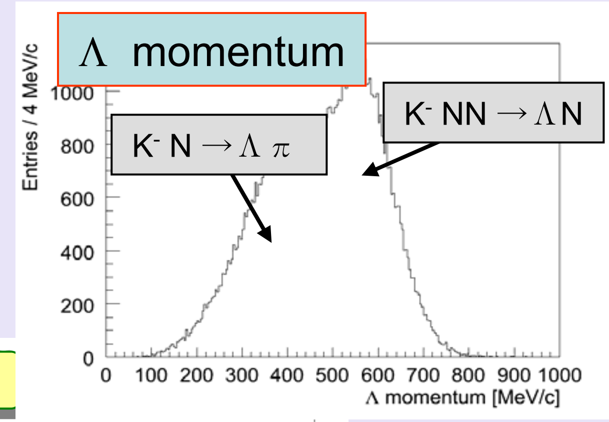


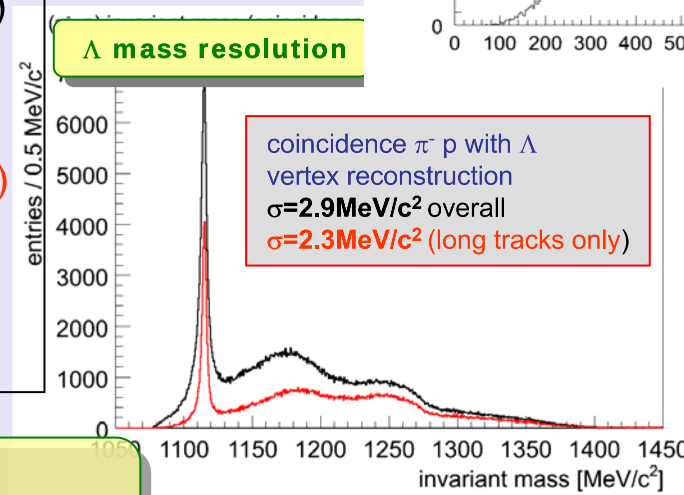
Tgts: 1st run: $2\times{}^{6}Li$, ^{7}Li, $3\times{}^{12}C$, ^{27}Al, ^{51}V

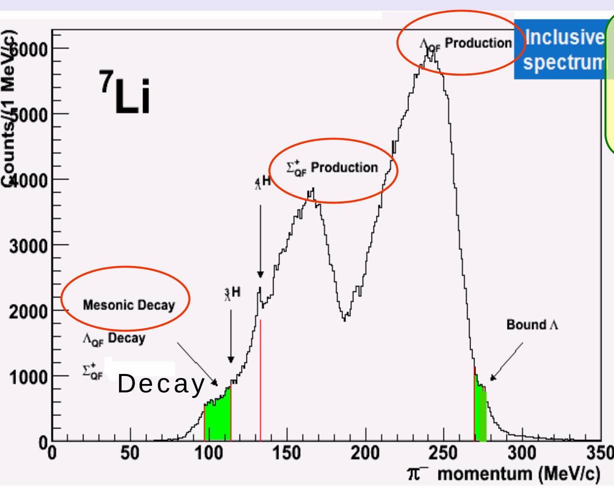
2nd run: $2\times{}^{6}Li$, $2\times{}^{7}Li$, ^{13}C, $2\times{}^{9}Be$, D_2O

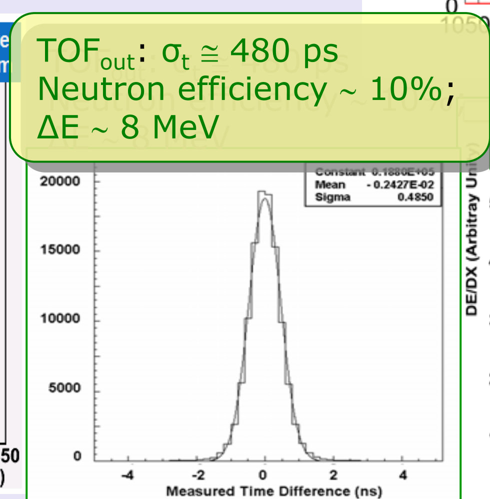
Detector performance

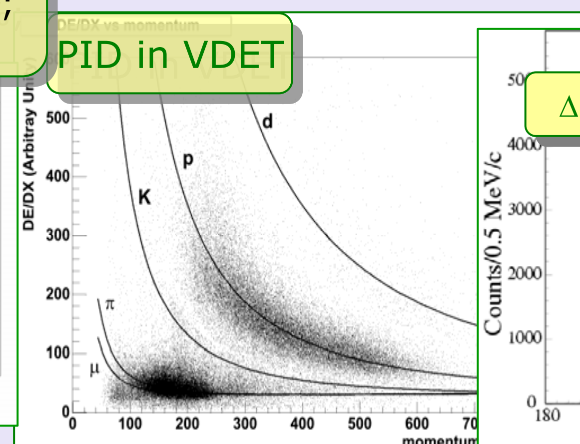
- ✓ Primary (K⁻) vertex identification (ISIM P.I.D.+ *x,y,z* resolution+K+tagging)
- ✓ secondary vertices (Λ decay…)
- ✓ high quality π, K, p, d, t … P.I.D. (d*E*/d*x*)
- ✓ High momentum resolution (6‰ FWHM) (tracker resolution + He bag + thin targets)
- ✓ Large momentum range
- ✓ Large acceptance (several particles in coinc.)
- ✓ Neutron detection (TOFONE) & T.O.F.
- ✓ Selective trigger based on fast scintillation detectors (TOFINO, TOFONE)

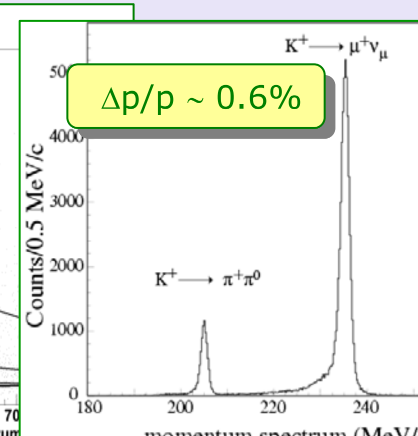












Weak decay of Λ hypernuclei

❑ Mesonic weak decay (as free decay):

- $\Lambda \rightarrow p\pi^-$ B.R. 63.9% ($\Gamma_{\pi-}$)
- $\Lambda \rightarrow n\pi^0$ B.R. 35.8% ($\Gamma_{\pi 0}$); *Not detectable by FINUDA*
- lifetime $\tau_{\Lambda\ free}$= 263 ps
- nucleons emitted with a momentum q~100MeV/c (Q~40MeV)

→ mesonic weak decay forbidden in (infinite) nuclear matter due to the Pauli blocking of the final state nucleon

→ allowed in light nuclei (π attraction by the medium, initial Λ momentum…, Pauli blocking less effective)

❑ Non Mesonic weak decay (dominant A≥12) Q~170 MeV

$\Lambda n \rightarrow nn$ (Γ_n) neutron induced decay

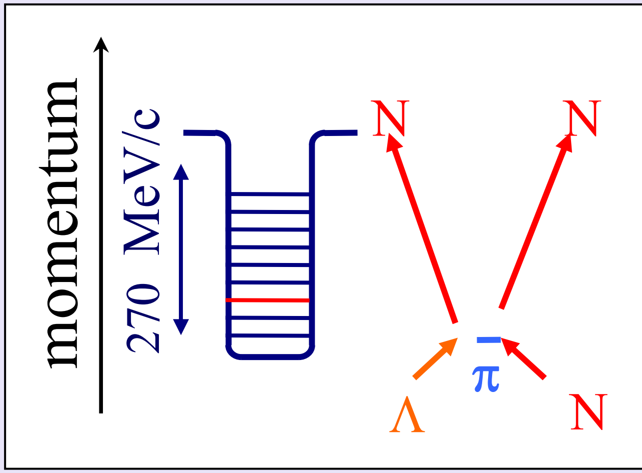
$\Lambda p \rightarrow np$ (Γ_p) proton induced decay

$\Lambda NN \rightarrow nNN$ (Γ_2) two-nucleon induced decay

$$\Gamma_T = \Gamma_M + \Gamma_{NM}$$

$$\Gamma_M = \Gamma_{\pi^-} + \Gamma_{\pi^0}$$

$$\Gamma_{NM} = \Gamma_n + \Gamma_p + \Gamma_2$$



NM Weak decay of Λ hypernuclei

NMWD: study of baryon-baryon weak interaction (and 3-baryons ΛNN int.)
Slightly affected by nuclear structure (mom. Tranfer ~400MeV/c), test of short range correlations, ΔI=1/2 rule, quark d.o.f., rare decays…

Strong disagreement between exp. and theory until recently

Γ_n/Γ_p puzzle: OPE: Γ_n/Γ_p ~0.1; EXP : Γ_n/Γ_p.~ 1

- Experimentally difficult
  -Hyp.nucleus identification (π)+ p/n detection necessary.
  High proton thresholds: low energy region missing (FSI and 2-N induced decays), model dependent data analysis→ Γ_n/Γ_p puzzle unsolved for several years
- Theory: OPE + kaons + heavier mesons exch.+ direct quark mechanisms

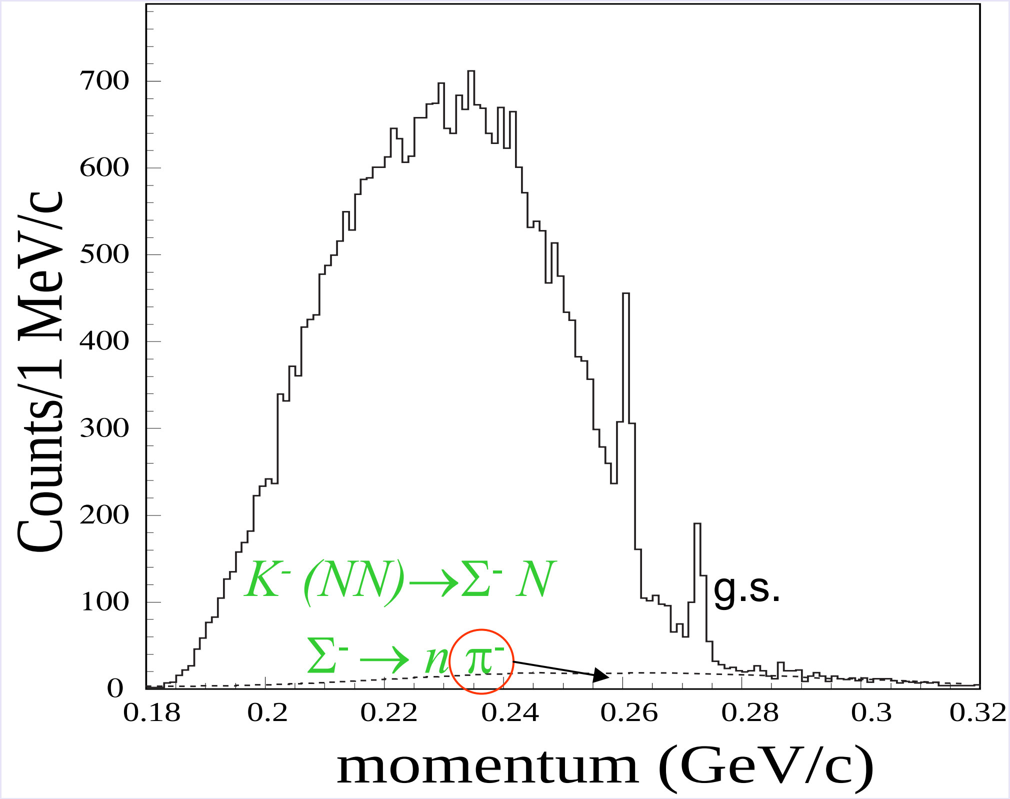
Γ_n/Γ_p puzzle solved in correlated p/n back-to-back kinematics +non-trivial data interpretation (no FSI, no 2N abs)

$^{12}_{\Lambda}$C: OME Γ_n/Γ_p ~0.4 [Garbarino,PRC69(04)]; EXP(KEK) : Γ_n/Γ_p.~ 0.4 [Kang,PRL96('06)]

Single proton spectra still incompatible with theor. predictions (Bauer et al,nucl-th/0602066)

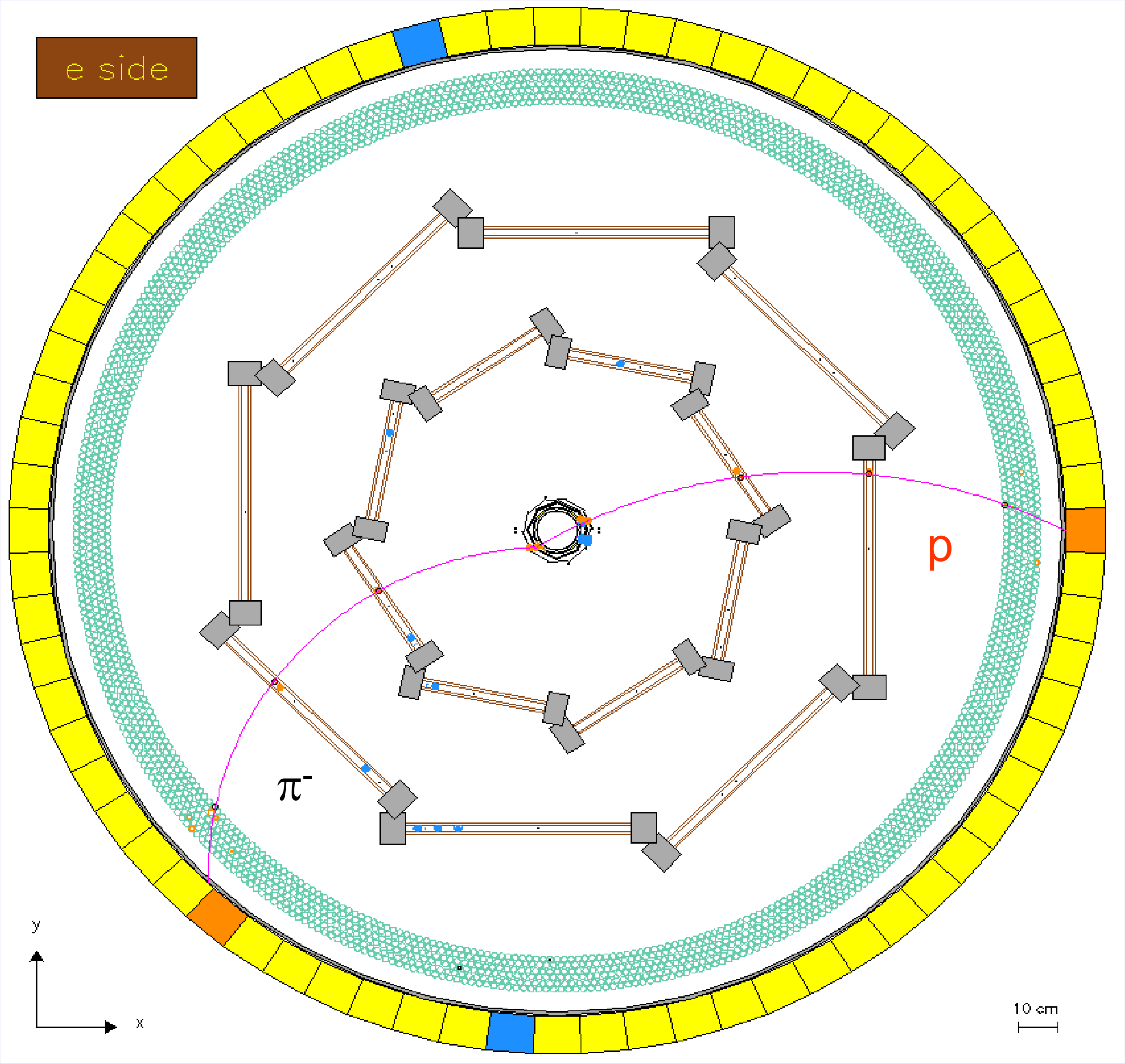
^{12}C (raw) excitation spectrum

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

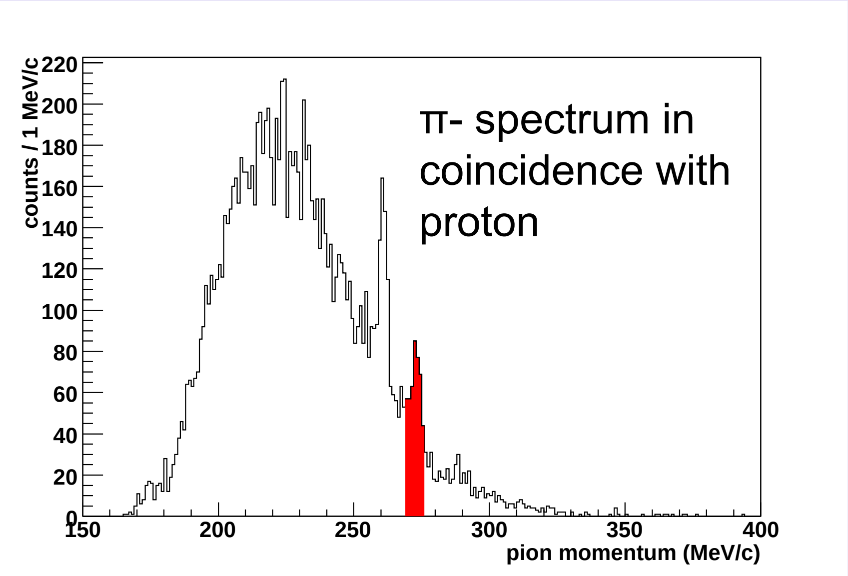


Inclusive spectrum of negative pions from ^{12}C targets. Hypernuclear peaks are visible even without any background subtraction

Proton induced NMWD in FINUDA

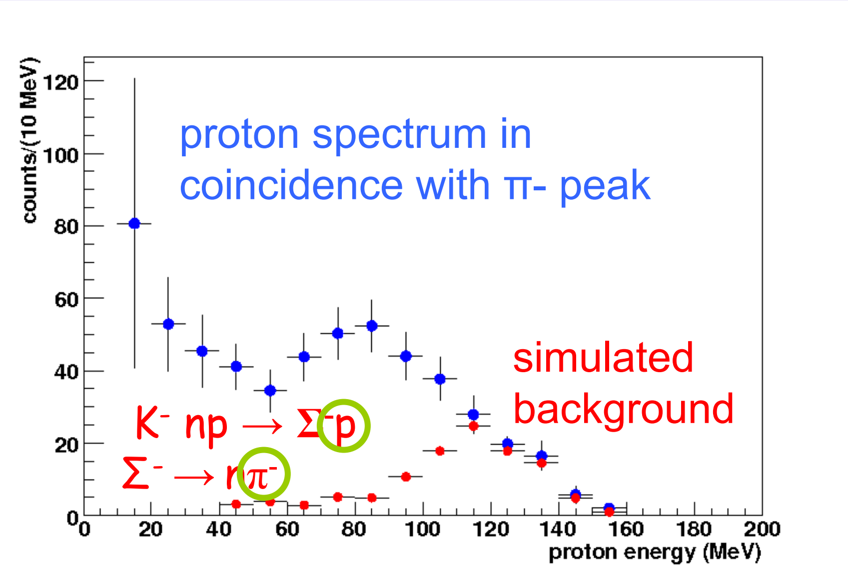


π- and proton spectra from $^{12}_{\Lambda}C$ NMWD

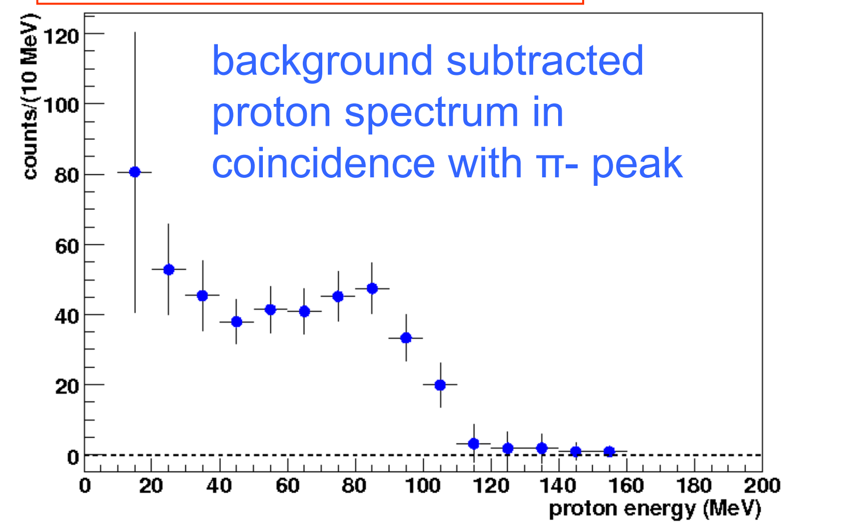


- Spectrum of negative pions for events with a proton detected in coincidence: red peak at 272 MeV/c ($^{12}_{\Lambda}C$ ground state)

Simulation of the background reaction
K- np → Σ-p followed by the decay **$\Sigma^- \rightarrow n\pi^-$**
Fermi momentum distribution for nucleons
selection criteria and quality cuts as for real data

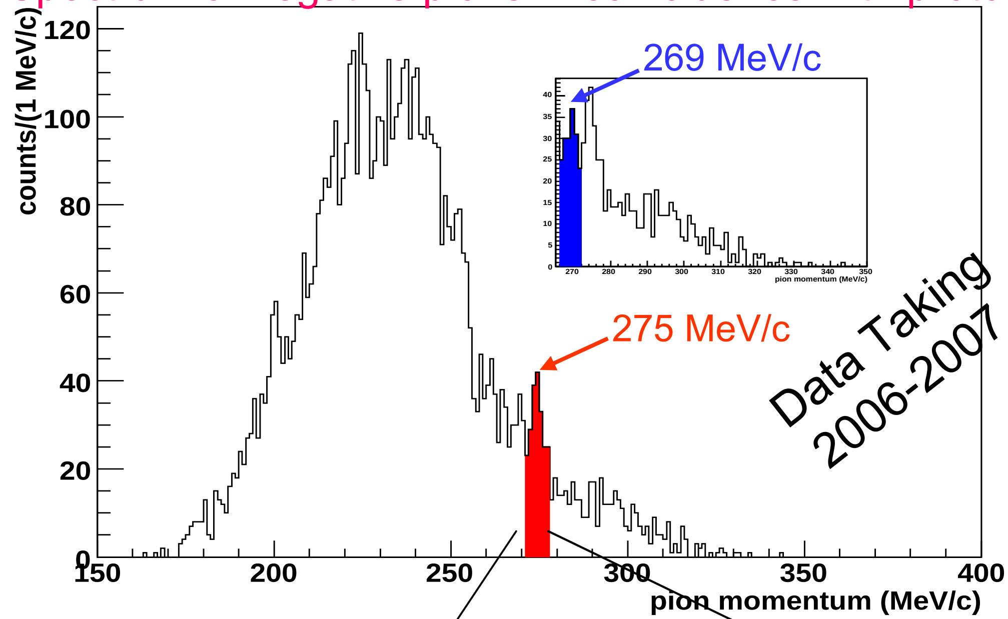


proton Thresh=15MeV



^{7}Li targets: NMWD of $^{7}_{\Lambda}$Li

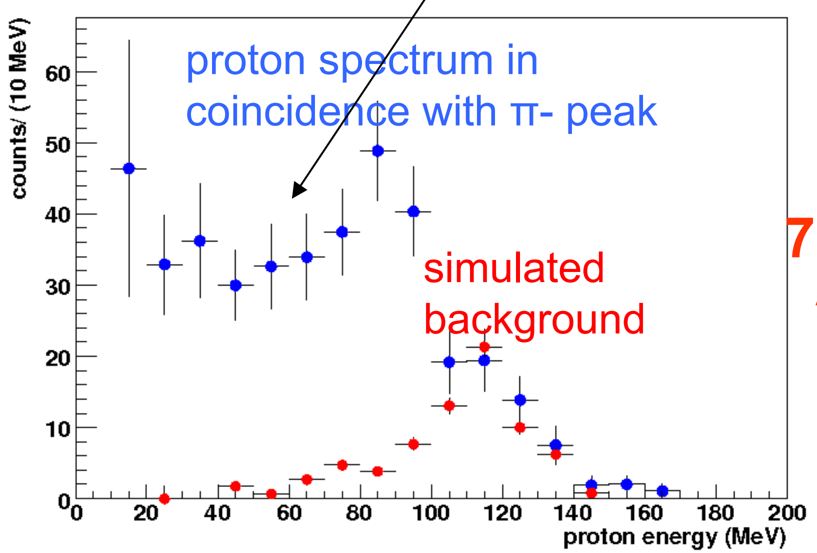
Spectrum of negative pions in coincidence with proton



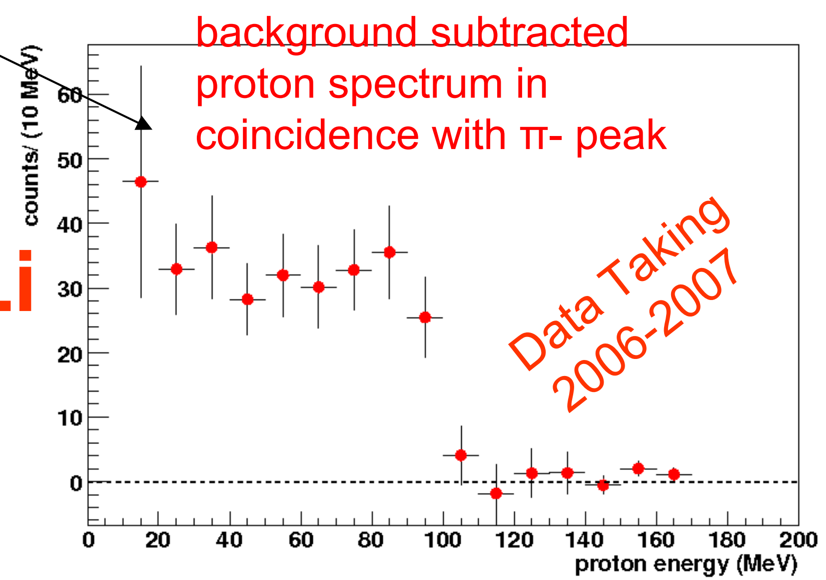
- when a K^- is stopped in a ^{7}Li target one can produce: $^{7}_{\Lambda}$Li, ($^{6}_{\Lambda}$He+p), **($^{5}_{\Lambda}$He+d)**, ($^{4}_{\Lambda}$He+t), ($^{3}_{\Lambda}$He+α).
- The red peak (275MeV/c) is consistent with

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

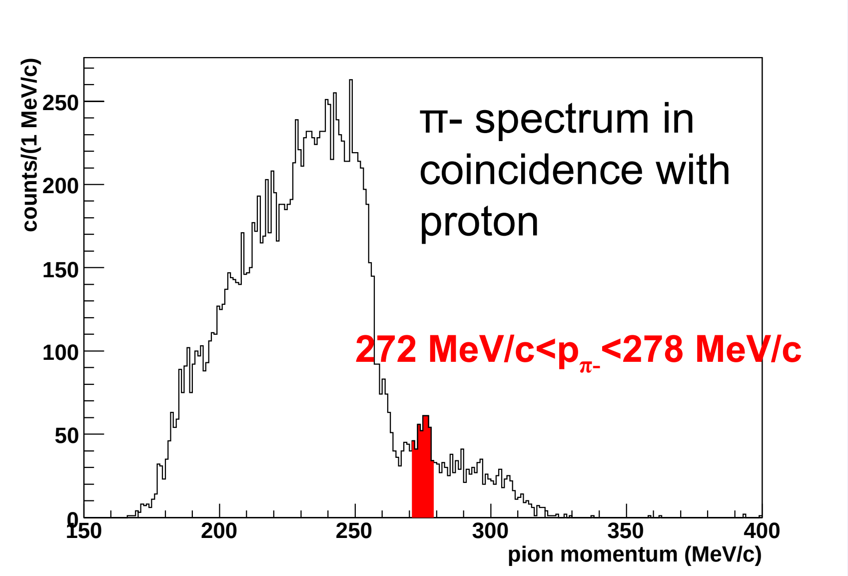
Simulated background: K- np → Σ^-p, $\Sigma^- \rightarrow n\pi^-$



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



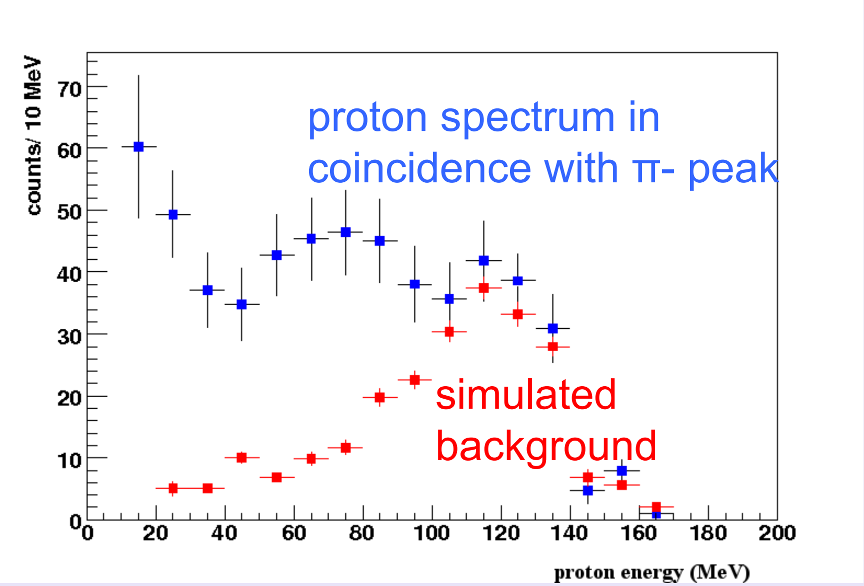
^{6}Li targets: NMWD of $^{5}_{\Lambda}$He

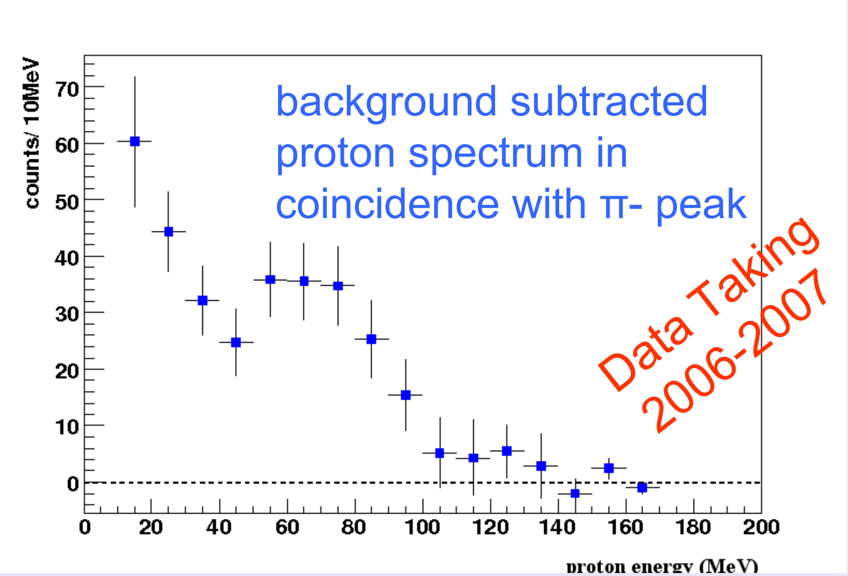


Spectrum of negative pions for events in coincidence with a proton:

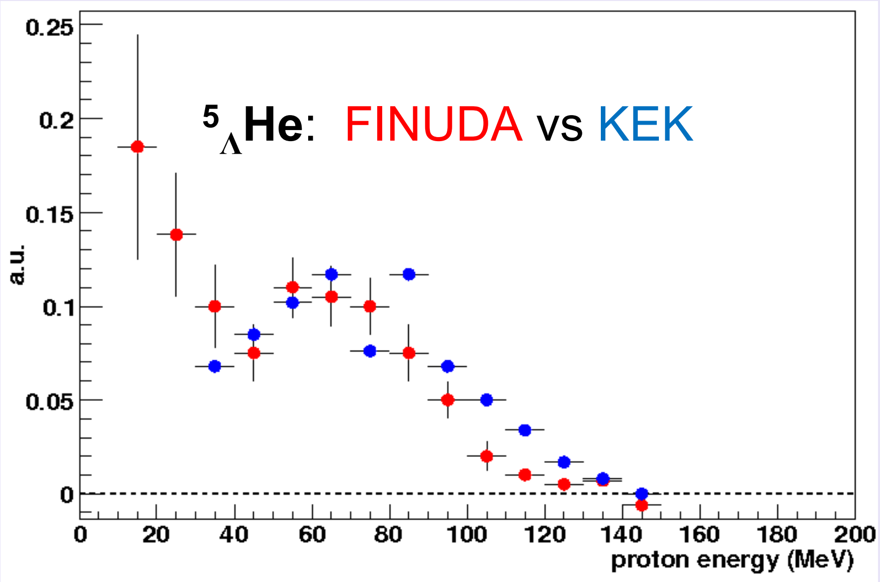
- A clear bump emerges at 275 MeV/c (ground state)
- The ground state of $^{6}_{\Lambda}$Li is proton unbound so it will immediately decay:

$$^{6}_{\Lambda}\mathrm{Li} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + p$$

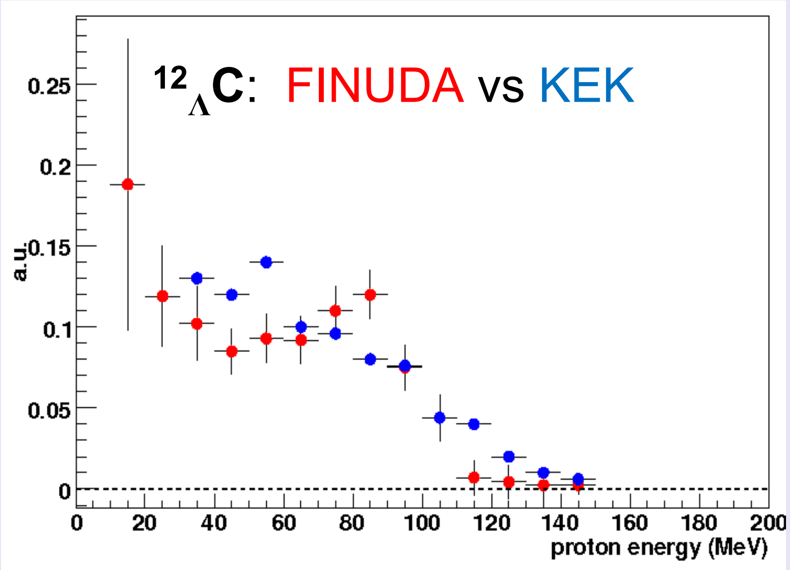




Comparison to other experimental data



FINUDA Collaboration, Nucl Phys. A (2008)



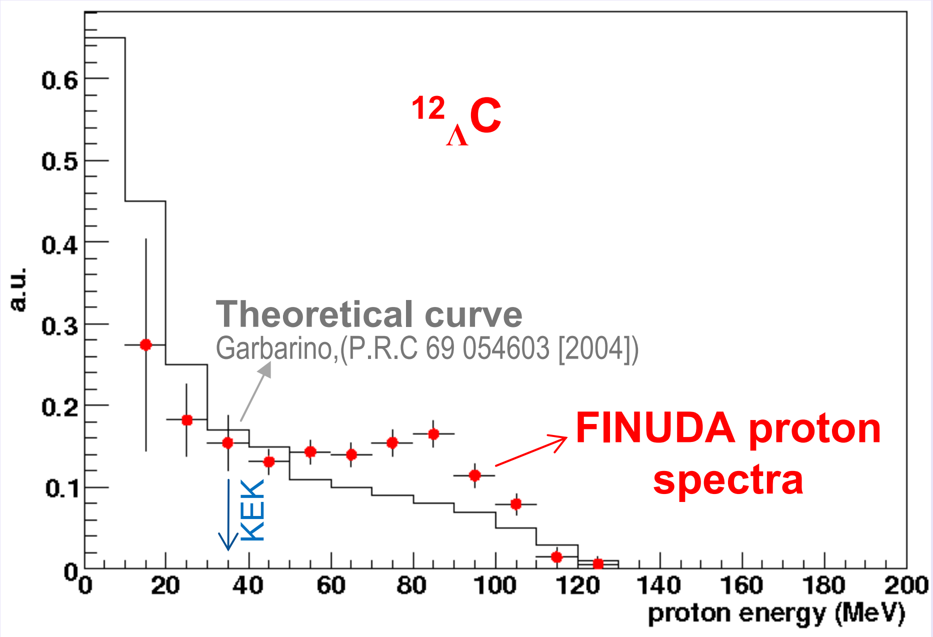
KEK: Phys. Lett. B 597 (2004) 249

Target	Hypernucleus	R_p
^{12}C	$^{12}_{\Lambda}$C	0.43±0.07
^{6}Li	$^{5}_{\Lambda}$He	0.28±0.09
^{7}Li	$^{7}_{\Lambda}$Li	0.37±0.09
^{7}Li	$^{5}_{\Lambda}$He	0.21±0.12
Mean of ^{6}Li and ^{7}Li values	$^{5}_{\Lambda}$He	0.25±0.07

- FINUDA provided for the first time data in an extended proton energy (and A) range where FSI and ΛNN decays dominate.
- Low energy behaviour similar in the 2 tgts
- disagreement between expts.

First direct measurement of R_p (proton yield per prompt hypernuclear π)

Comparison with theoretical calculations



- Kolmogorov-Smirnov test:

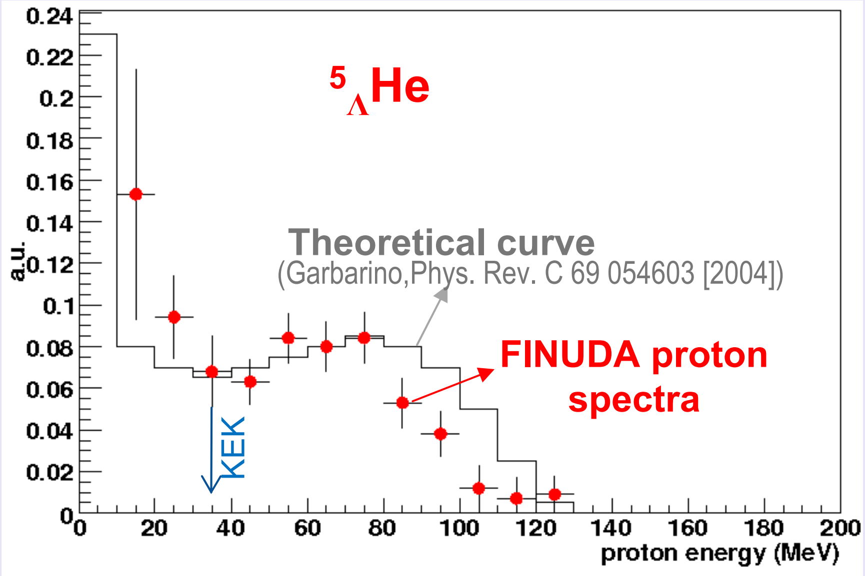
$^{12}{}_{\Lambda}$C: probability of P=0.5 at a confidence level of 5% → Low compatibility

$^{5}{}_{\Lambda}$He: probability of P=0.65 at a confidence level of 75%

Comparison with theoretical models not satisfactory

- New data important to constrain theories in low energy region

- $^{12}{}_{\Lambda}$C: the FSI and the contribution of the two-nucleons induced NMWD appear to be too strong to reproduce the data (low en. peak + excess smearing)



Neutron-rich hypernuclei

Hypernuclei with a large neutron excess have been theoretically predicted (L. Majling, *NPA 585 (1995) 211c*).

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

- **Hypernuclear physics**:

  ΛN interactions at low densities, the role of 3-body forces (Λ–Σ coupling)
- **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 (role of Σ).

  S. Balberg and A. Gal, Nucl. Phys. ***A 625****: 435, 1997.*

Neutron-rich hypernuclei

Production mechanisms (2 steps→low yield)

1) strangeness exchange+ charge exchange

$$K^- + p \rightarrow \Lambda + \pi^0$$
$$\hookrightarrow \pi^0 + p \rightarrow n + \pi^+$$
$$\pi^- + p \rightarrow \pi^0 + n$$
$$\hookrightarrow \pi^0 + p \rightarrow K^+ + \Lambda$$

2) strangeness exchange + Λ-Σ coupling

$$K^- + p \rightarrow \Sigma^- + \pi^+$$
$$\hookrightarrow \Sigma^- + p \rightarrow \Lambda + n$$
$$\pi^- + p \rightarrow \Sigma^- + K^+$$
$$\hookrightarrow \Sigma^- + p \rightarrow \Lambda + n$$

FINUDA(1st run):

Study of inclusive π^+ spectra

Backgrounds:

- $K^- + p \rightarrow \Sigma^+ + \pi^-$
  $\Sigma^+ \rightarrow \pi^+ + n$
  $(130 < p_\pi < 250 \text{ MeV/c})$
- $K^- + pp \rightarrow \Sigma^+ + n$
  $\Sigma^+ \rightarrow \pi^+ + n$
  $(100 < p_\pi < 320 \text{ MeV/c})$

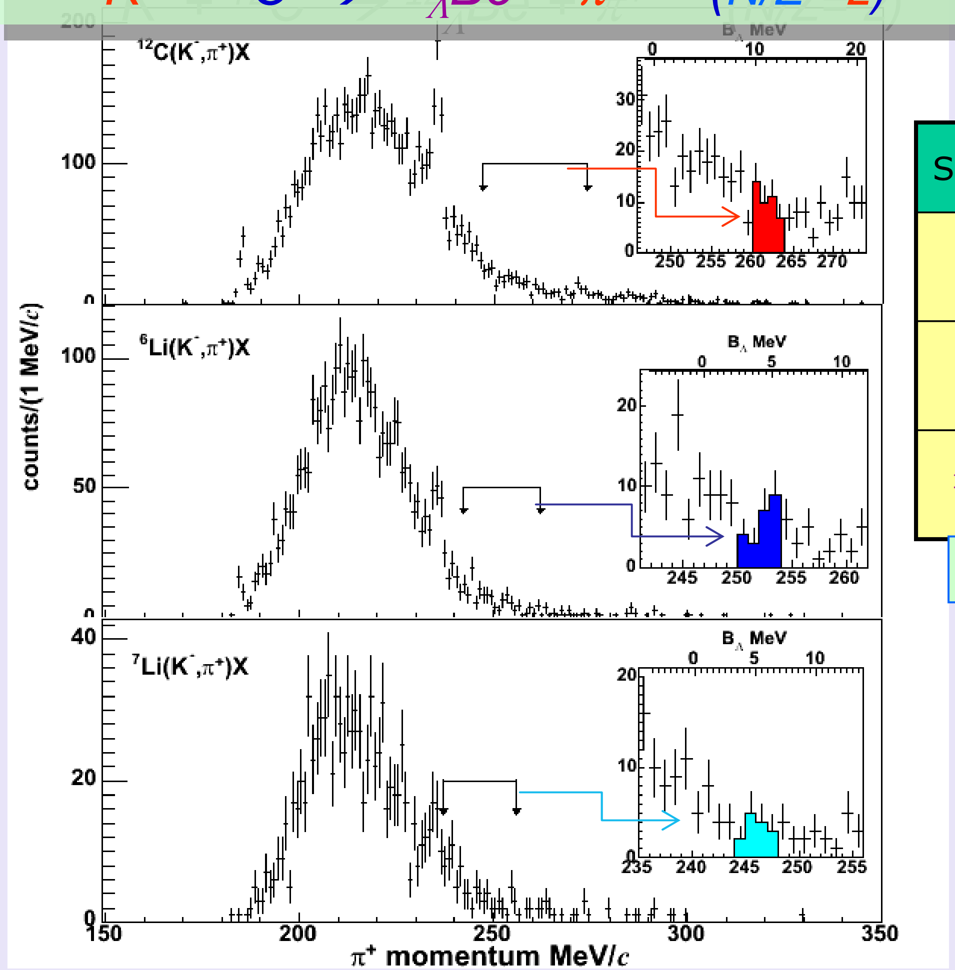
Selection on impact parameter to minimize background

Neutron-rich hypernuclei

$K^- + {}^6Li \rightarrow {}^6_\Lambda H + \pi^+$ (N/Z= 5) NEW

$K^- + {}^7Li \rightarrow {}^7_\Lambda H + \pi^+$ (N/Z= 6) NEW

$K^- + {}^{12}C \rightarrow {}^{12}_\Lambda Be + \pi^+$ (N/Z= 2)



1st data taking

Upper limits

System	FINUDA value 90% C.L.	From litterature
${}^6_\Lambda H$	$(2.5 \pm 0.4_{stat}{}^{+0.4}_{-0.1}{}_{syst}) \cdot 10^{-5}/K^-_{stop}$	-
${}^7_\Lambda H$	$(4.5 \pm 0.9_{stat}{}^{+0.4}_{-0.1}{}_{syst}) \cdot 10^{-5}/K^-_{stop}$	-
${}^{12}_\Lambda Be$	$(2.0 \pm 0.4_{stat}{}^{+0.3}_{-0.1}{}_{syst}) \cdot 10^{-5}/K^-_{stop}$	$6.1 \cdot 10^{-5}/K^-_{stop}$

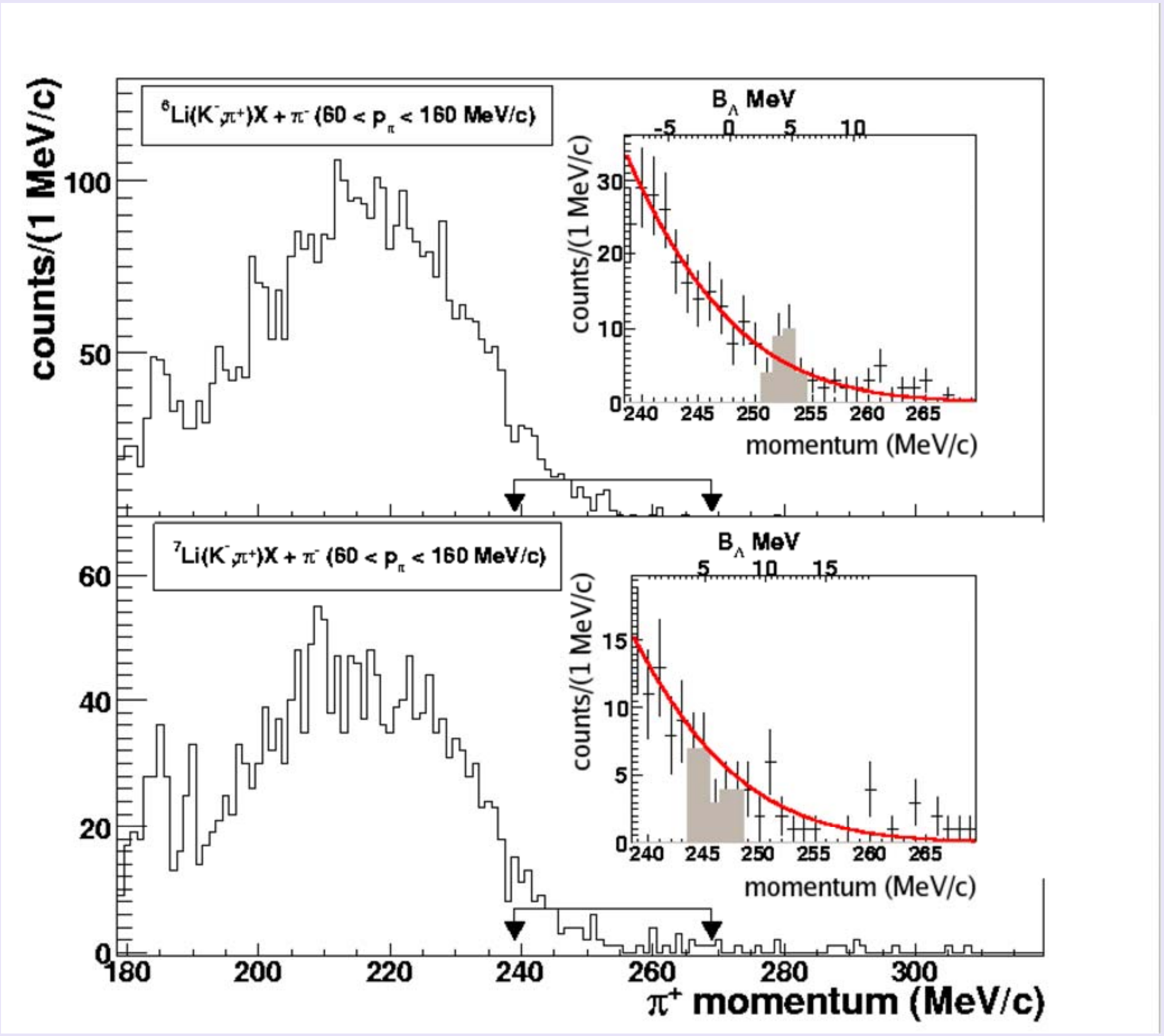
PLB 640 (2006)145

Neutron-rich hypernuclei

Data Taking
2006-2007
Work in progress

π+ spectra (production)
in coincidence with low-energy π- (mesonic decay)

Higher statistics allows to effectively suppress backgrounds by asking the presence of a mesonic decay π^-…
…statistical significance of a peak?



The search for (deeply) bound antikaon nuclear states

Theoretical predictions

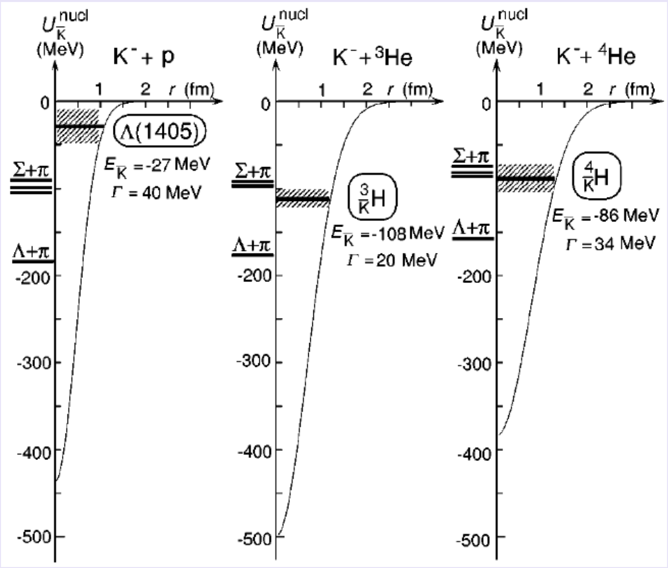
➢ First proposed by Wycech [NPA450(1986)]

➢ Akaishi & Yamazaki (PLB535(2002), PRC65(2002),PLB613(0205)

Strong attractive I=0 Kbar-N interaction (→ Λ(1405) as lightest Kbar-N bound state)

Nuclear K^- bound states formed on few body systems

- Strong(>100MeV) binding →Σπ channel closed →**narrow width** (→ expt.lly detectable!)
- nucleus shrinking (high nuclear density~$3\rho_0$)



Topics of interest: • K^--N interaction at varying ρ, •Λ(1405) properties in n.m.,• K^- in medium mass modification…

➢ Mares et al., NPA 770 (2006)

Sizeable binding energy (100-200 MeV), Γ>~50 MeV, possible only on heavier nuclei

➢ Weise et al, [arXiv:0801.1647]

K^--nuclear quasi-bound states can exist but $\Gamma \geq B_K$ especially if K-NN→Λ/ΣN channel into account

- Strongly debated subject
- Several theoretical papers but situation still unsettled (relevant region far below antiK-N threshold).

Experimental approaches

- **Missing mass spectroscopy**
  - **Energy** measurement of **recoiling particles** in the **A(K^-,N)X** reaction
    - KEK-PS E471 (K^-_{stop},N)
    - AGS E930 ($K^-_{in\text{-}flight}$,n) $^{15}{}_{K^-}O$: bound state at ~90 MeV
    - FINUDA (K^-_{stop})
    - KEK-PS E549 (K^-_{stop})

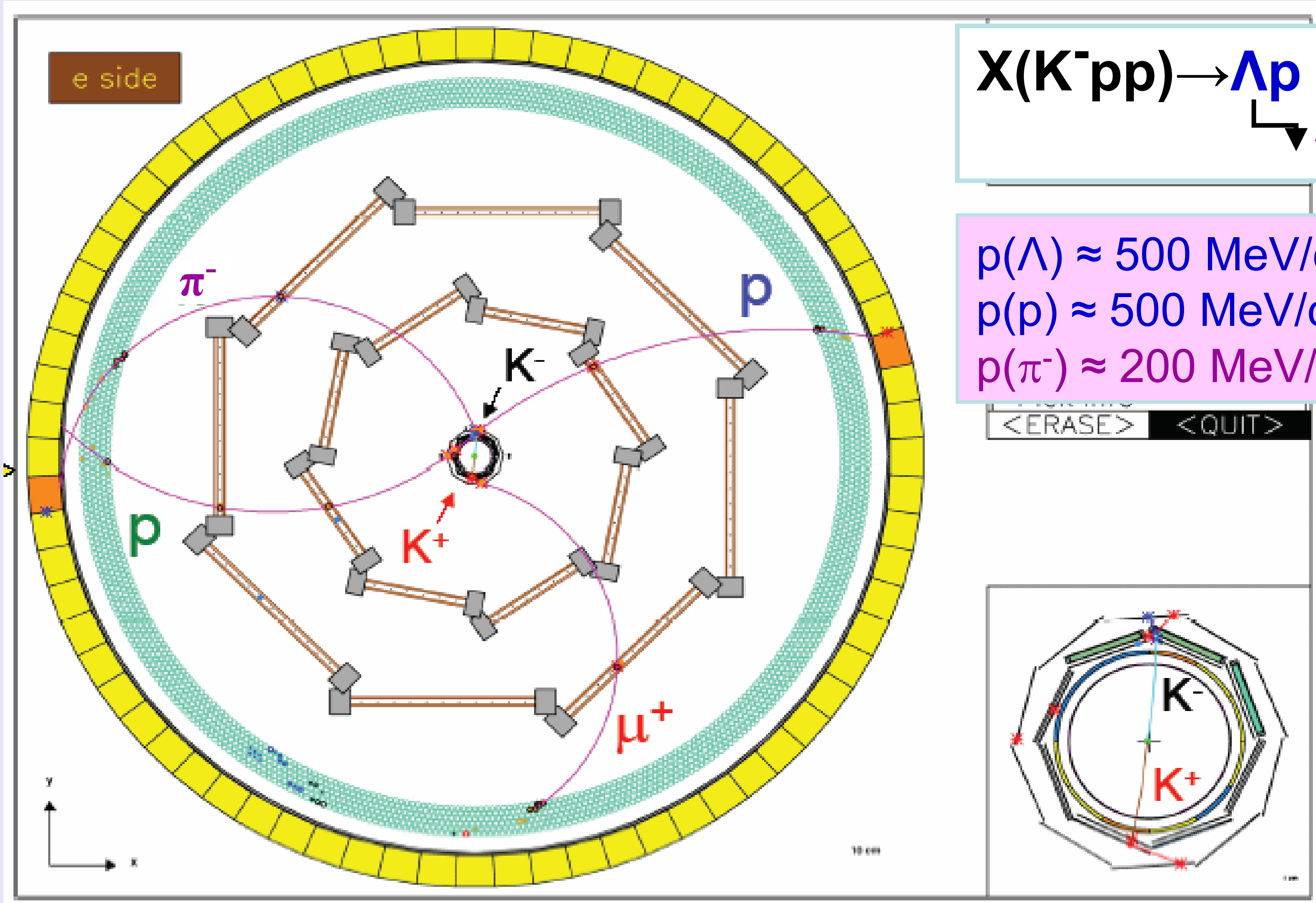
drawbacks:
sizeable backgrounds,
risk of fake signals

- **Invariant mass spectroscopy**
  - Detection of **decay products** of kaonic nuclear clusters (easier for light systems..)
    - **(K^-pp) → Λ + p**
    - **(K^-ppn) → Λ + d**
    - Typically (for stopped K^-)
      - $p_{p(\Lambda)}$ ~ 500 MeV/c
      - $p_{\pi(\Lambda)}$ < 200 MeV/c
      - p_p ~ 500 MeV/c
  - **Good p.i.d., low backround Λ-identification, angular correlations, high acceptance, high statistics are crucial items for this task**
    - FOPI (Ni-Ni heavy ion collisions) [see Hartmann's talk]
    - FINUDA (K^-_{stop})
    - OBELIX (p He)
    - KEK-PS E471-E549 ^{4}He (K^-_{stop},YN) [see Suzuki's talk]

drawbacks:
Collisional shift,
and broadening,
multinucleon abs. backgnds…

For an extensive review of the experimental situation see Iwasaki's talk.

K^-pp invariant mass studies with FINUDA



$X(K^-pp) \rightarrow \Lambda p$

$\quad \hookrightarrow \pi^- p$

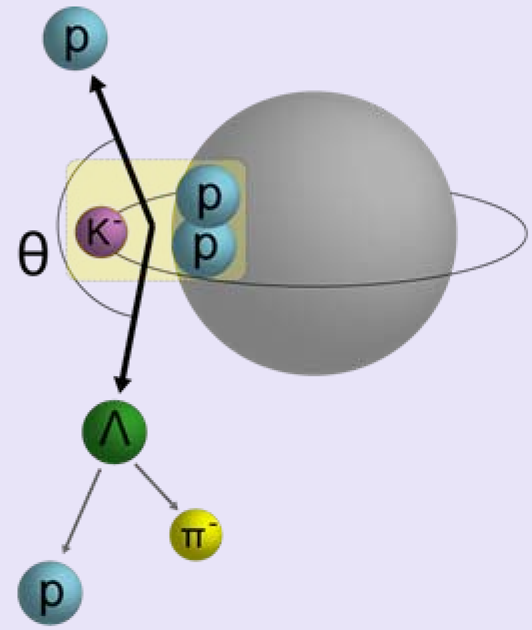
$p(\Lambda) \approx 500$ MeV/c
$p(p) \approx 500$ MeV/c
$p(\pi^-) \approx 200$ MeV/c

Search for the [K⁻pp] bound systems

[K-pp]: lightest possible bound state

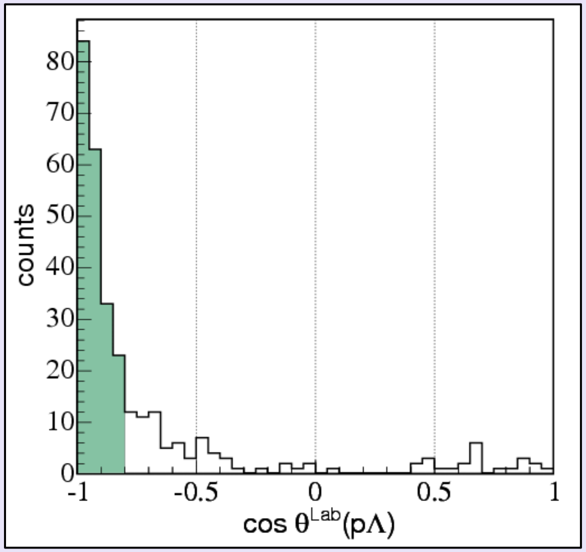
➢ Reaction under study
K- A→[K⁻pp]+A' via
possible [K⁻pp] decay to Λ-p

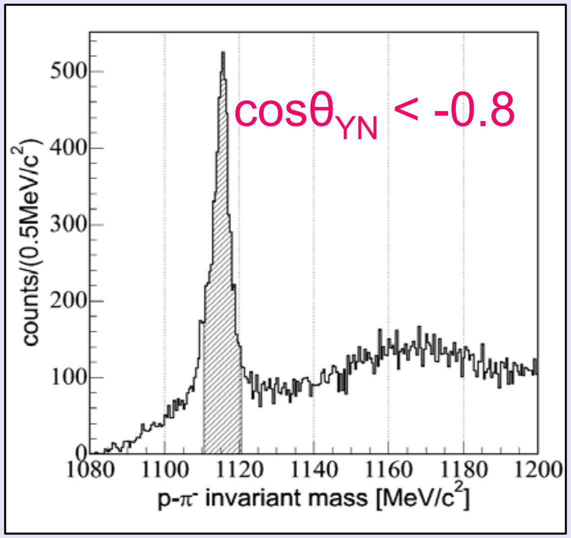
✓ *Λ recontruction*
✓ *study of* • ***Λ -p invariant mass***
and • ***Λ -p angular correlation***



➢ **Λ p emitted**
mostly back-to-back
(little FSI)

➢ Light targets only
(3x ^{12}C, 2x ^{6}Li, 1x ^{7}Li)





(Λp) invariant mass in FINUDA: observation of a possible [K^-pp]bound state

A bump is observed well below the K^-pp mass

- **Two nucleon absorption bckgnd**
  - **K^- + (pp) → Λp** q.f. peak expected at **2.34 GeV**
  - **K^- + (pp) → Σ^0p → Λγ p**
    Λp lower (~74 MeV) and broadened distribution; but **Λp/Σ^0p~4**[Katz,PRD1('70)]
- Magas et al [PRC74('06)]:
  K^- + (pp) → Λp + FSI (but b.t.b. correlation much broader)

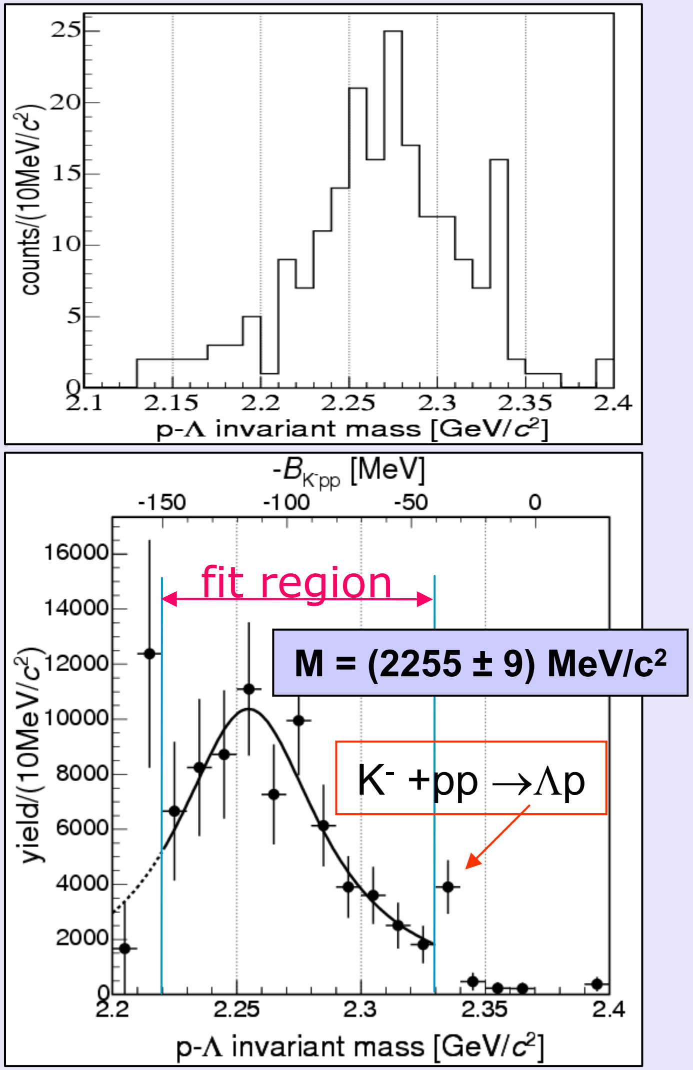
Kaon nuclear bound state formation

- **K^-(pp) → X → Λp**

B = 115$^{+6}_{-5}$ (stat)$^{+3}_{-4}$ (sys) MeV
Γ= 67$^{+14}_{-11}$(stat)$^{+2}_{-3}$ (sys) MeV

Akaishi-Yamazaki: **B=48MeV, Γ=61MeV**
Shevchenko,PRL98('07): **B=50-70MeV, Γ~100MeV**
Ivanov, nucl-th/0512037: **B=118 MeV, Γ~58MeV**

A dependence? Formation mechanism?



FINUDA Coll., PRL 94(2005)212303

~ 200 events

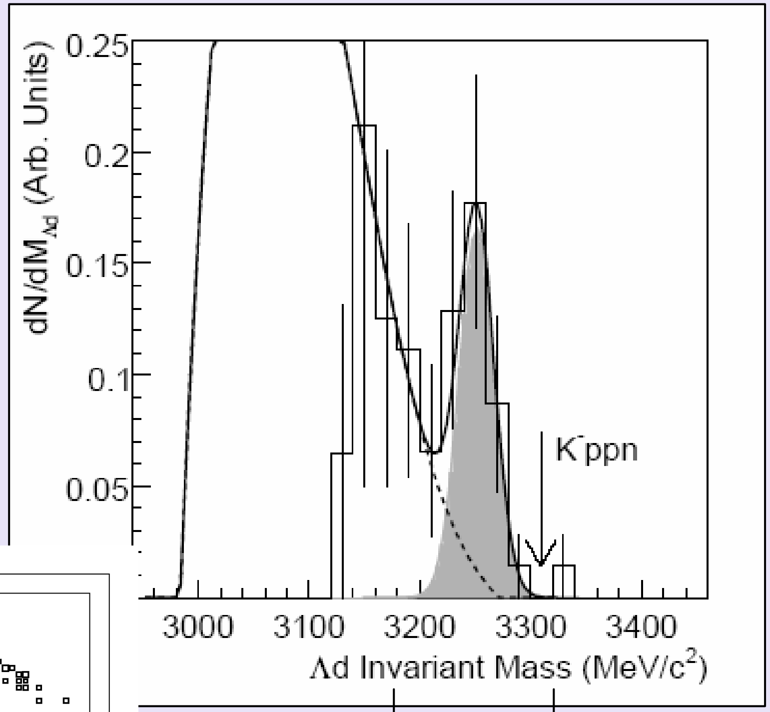
Acceptance correction

Study of ^{6}Li(K$^-$,Λd)X

Search for **[K$^-$ppn]** systems: study of Λd invariant mass

A.-Y, P.R.C.65(2002): B_{K^-}~108MeV, Γ_{pionic}~20 MeV

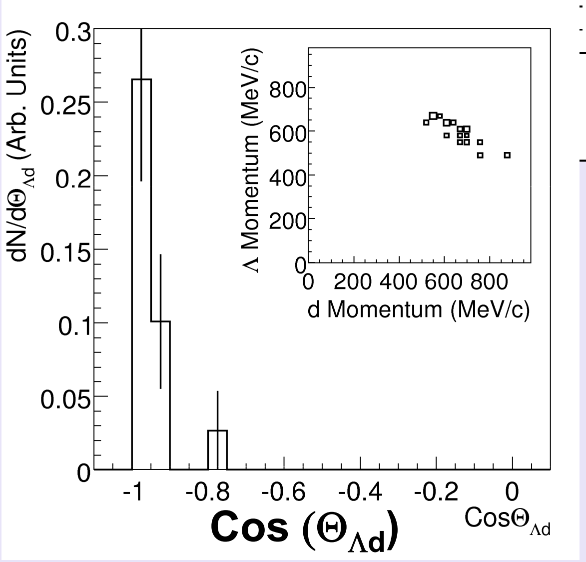
FINUDA Coll., PLB 654 (2007) 80



- Target: ^{6}Li (low background)
- ^{6}Li is a well known **[α+d]** cluster
- Bump observed at **$M_{\Lambda d}$= 3251** MeV (→B_K=58MeV), $\Gamma_{\Lambda d}$=37 MeV
  - 25 events in the peak, statistical significance 3.9σ

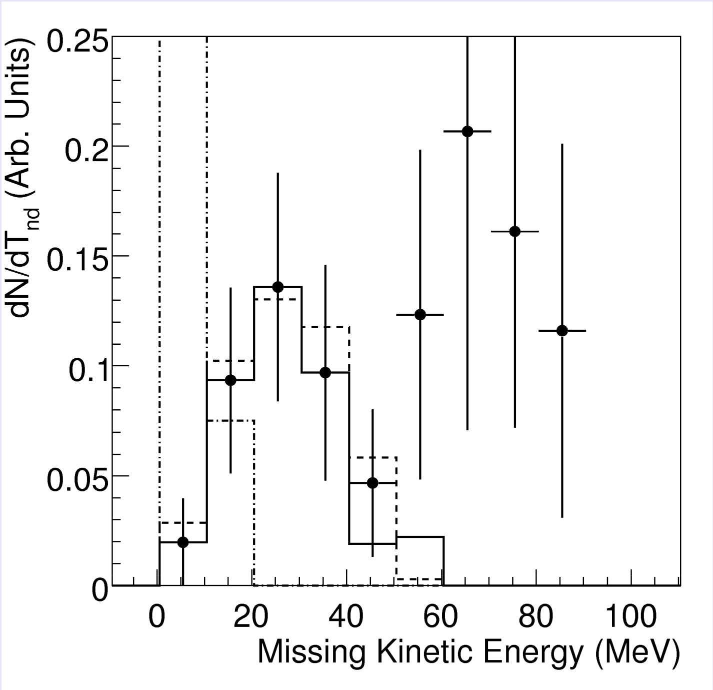
Yield=4.4*10^{-3}/stopped K$^-$

The events in the bump are strongly back-to-back correlated



Study of $^{6}Li(K^{-},\Lambda d)X$

- The shape of the missing kinetic energy distribution is reproduced only by the $^{6}Li(K^{-}_{stop}, \Lambda d)nd$ reaction channel, with:
  -- a **spectator deuteron** and
  -- a **neutron** carrying away the whole **residual energy**
  $K^{-}_{stop}\ {}^{6}Li \rightarrow \Lambda\ d\ n\ d_{spect}$



Study of $^6Li(K^-,\Lambda d)X$

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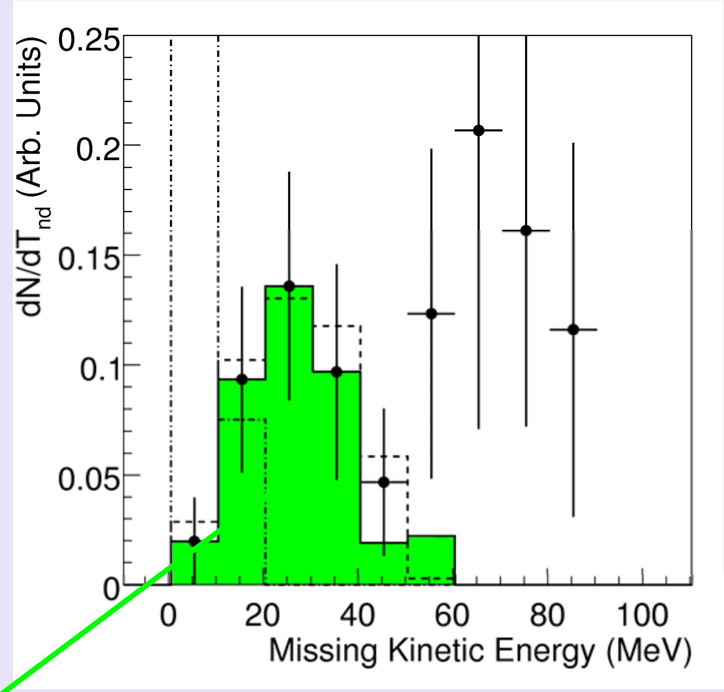

$^6Li(K^-_{stop}, \Lambda d)nd$ for events under the bump, $3220<M_{\Lambda d}<3280$ MeV/c^2

Study of ^{6}Li(K$^-$,Λd)X

- The shape of the missing kinetic energy distribution is reproduced only by the ^{6}Li(K$^-_{stop}$, Λd)nd reaction channel, with:
  - -- a **spectator deuteron** and
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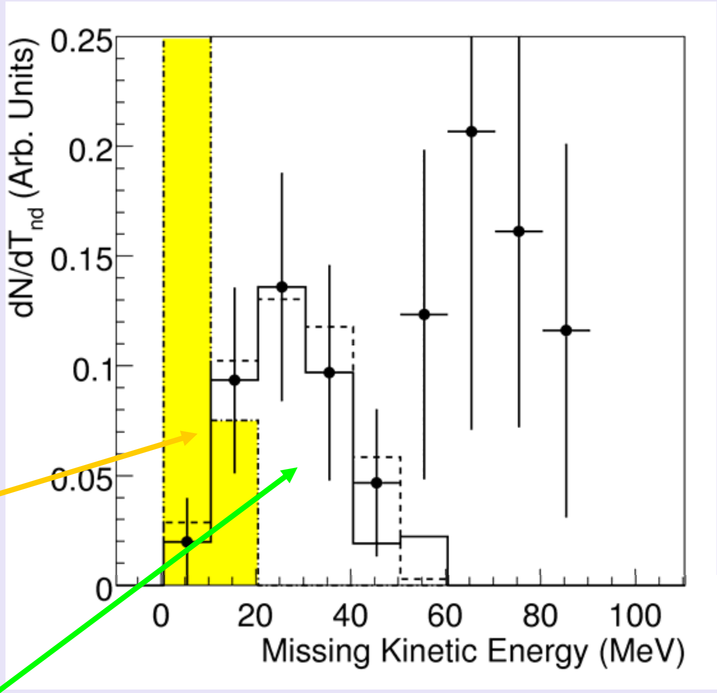

Simulation: ^{6}Li(K$^-_{stop}$, Λd) t

^{6}Li(K$^-_{stop}$, Λd)nd for events under the bump, $3220<M_{\Lambda d}<3280$ MeV/c^2

Study of $^6Li(K^-,\Lambda d)X$

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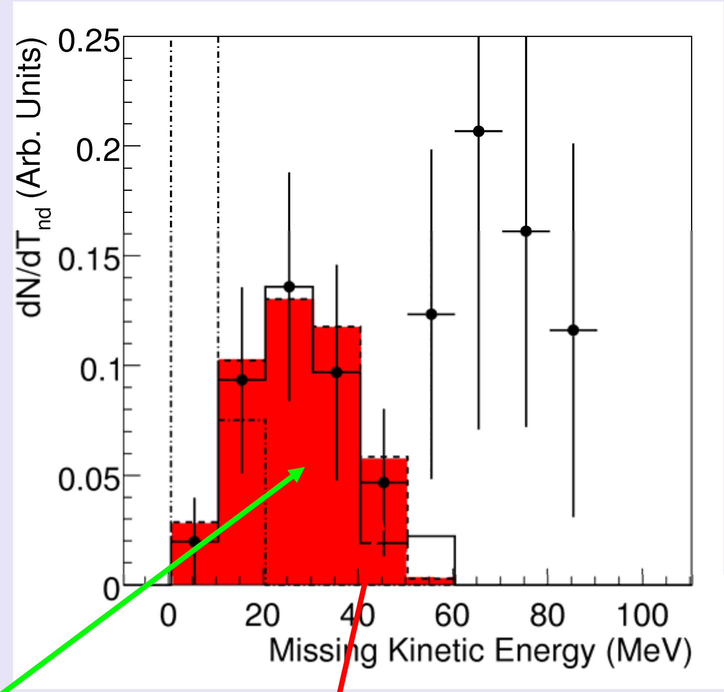


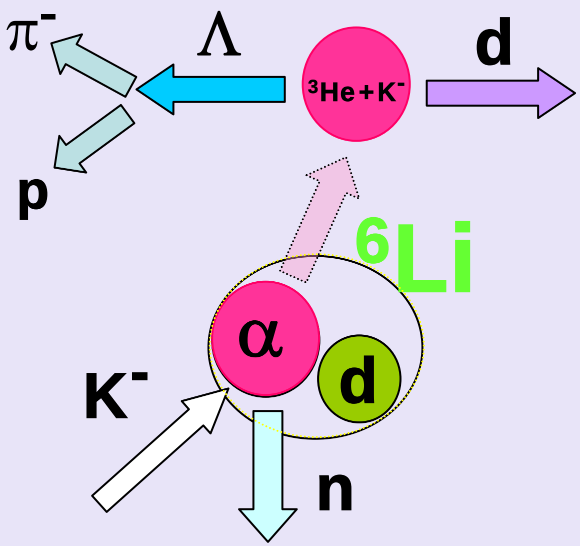
$^6Li(K^-_{stop}, \Lambda d)nd$ for events under the bump, $3220 < M_{\Lambda d} < 3280$ MeV/c^2

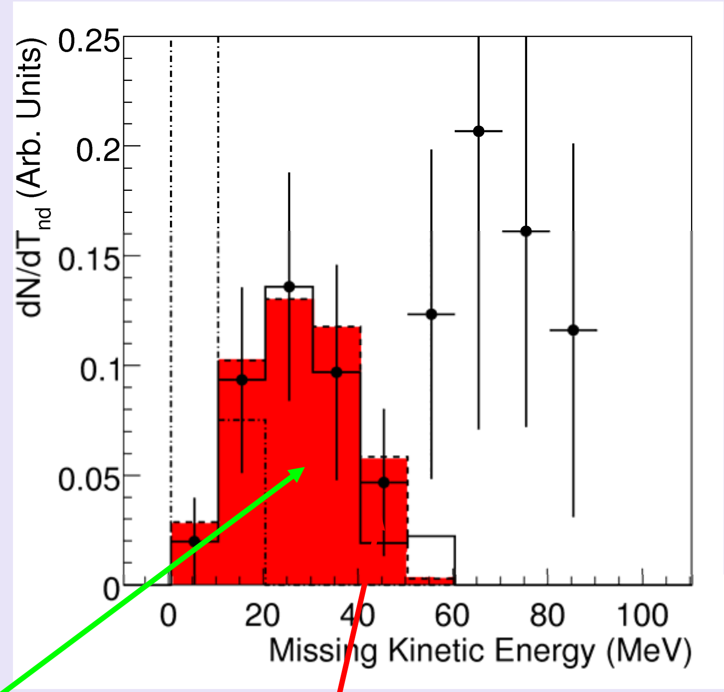
Simulation: $^6Li(K^-_{stop}, \Lambda d)nd$ for events with $3220 < M_{\Lambda d} < 3280$ MeV/c^2 and a spectator deuteron with $T_d < 3$ MeV

Study of $^{6}Li(K^{-},\Lambda d)X$

- The shape of the missing kinetic energy distribution is reproduced only by the $^{6}Li(K^{-}_{stop}, \Lambda d)nd$ reaction channel, with:
  - -- a **spectator deuteron** and
  - -- a **neutron** carrying away the whole **residual energy**

$K^{-}_{stop}\ ^{6}Li \rightarrow \Lambda\ d\ n\ d_{spect}$





$^{6}Li(K^{-}_{stop}, \Lambda d)nd$ for events under the bump, $3220<M_{\Lambda d}<3280$ MeV/c^2

Simulation: $^{6}Li(K^{-}_{stop}, \Lambda d)nd$ for events with $3220<M_{\Lambda d}<3280$ MeV/c^2 and a spectator deuteron with $T_d < 3$ MeV

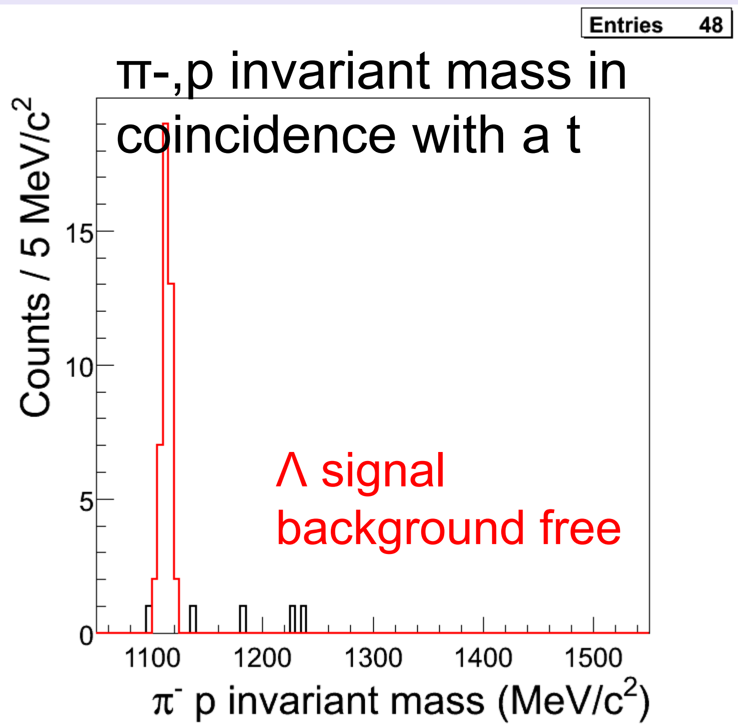
More statistics needed!...coming soon

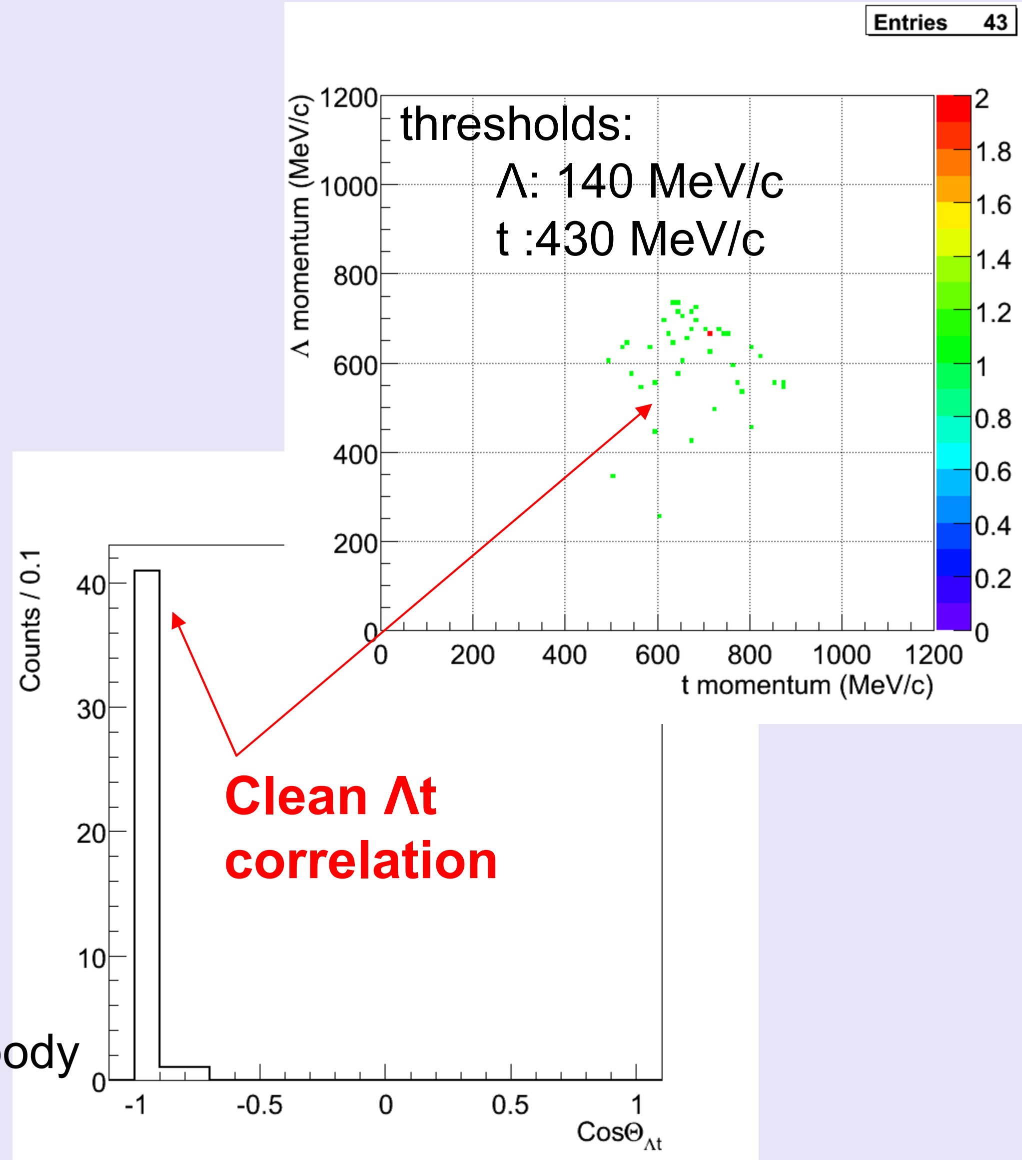
Data Taking
2006-2007

Study of A(K^-,Λt)X

- A = ^{6}Li,^{7}Li,^{9}Be

Yield~0.6*10^{-3}/stopped K^-





Step in understanding the role of multibody kaon absorption in nuclei

Summary-1

- ✓ The FINUDA spectrometer at DAΦNE has collected ~1.1 fb^{-1} of K^{-}_{stop} on several nuclear targets during 2 data taking periods.

- ✓ Thanks to the performing FINUDA tracking and P.I.D and large acceptance several reaction channels were acquired and studied in coincidence.

- ✓ Data analysis of first data taking carried out successfully and first results from the analysis of second one are coming out. Selected topics were presented.

- ✓ Proton spectra from NMWD were measured for the first time down to 15 MeV, a crucial region for studying the role of FSI and 3-body decays. Comparison with theory unsatisfactory.

- ✓ Upper limit for the *Neutron Rich Hypernuclei* production established:
  - ✓ better than published for ${}_{\Lambda}^{12}Be$
  - ✓ measured for the first time for ${}_{\Lambda}^{6}H$ and ${}_{\Lambda}^{7}H$

Summary -2

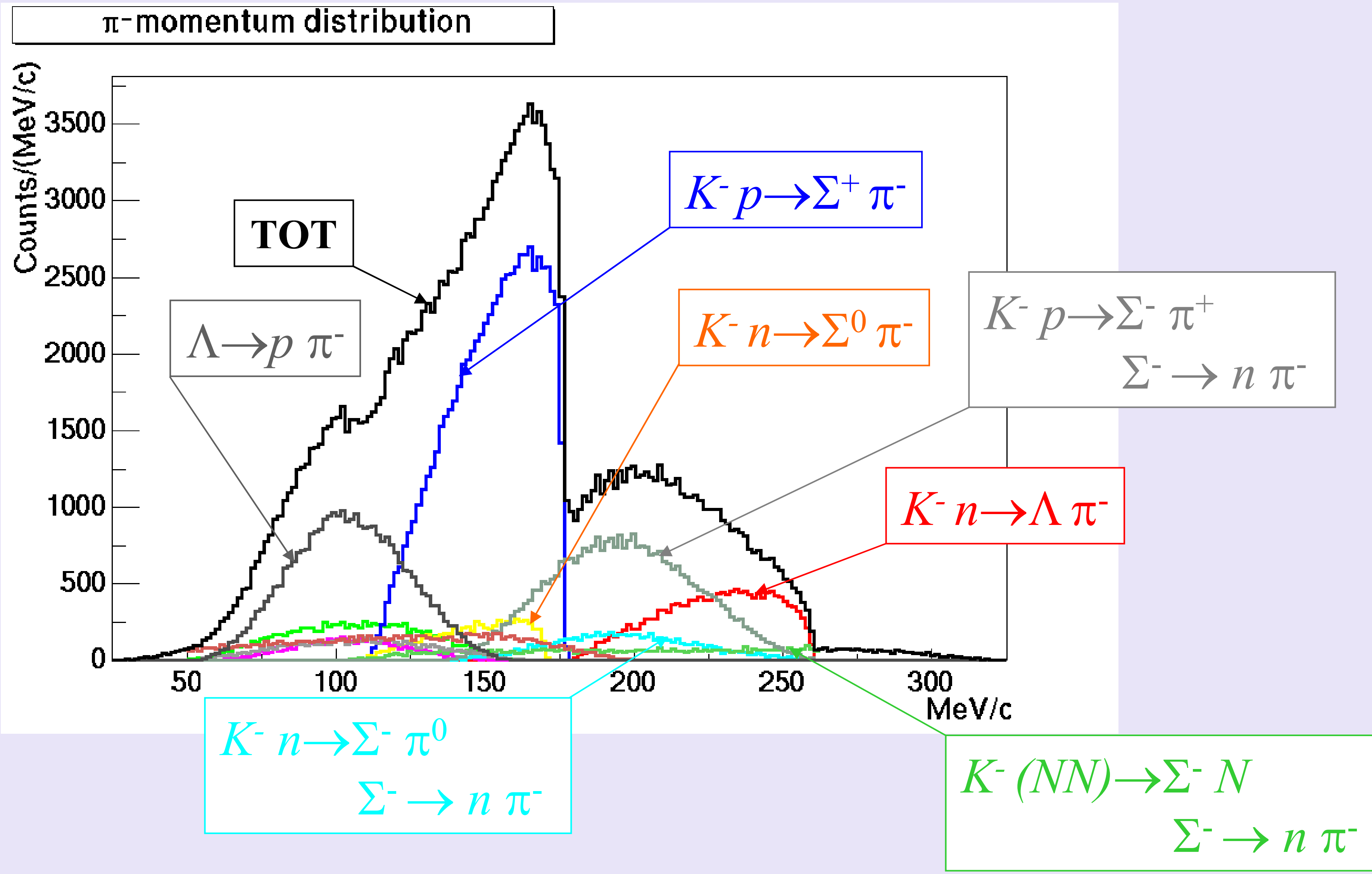
- ✓ Study of K^- multi-nucleon absorption performed via $A(K^-_{stop}, \Lambda\ p/d/t)X$; possible signals for $[K^-pp]$ and $[K^-ppn]$ bound clusters to be confirmed.

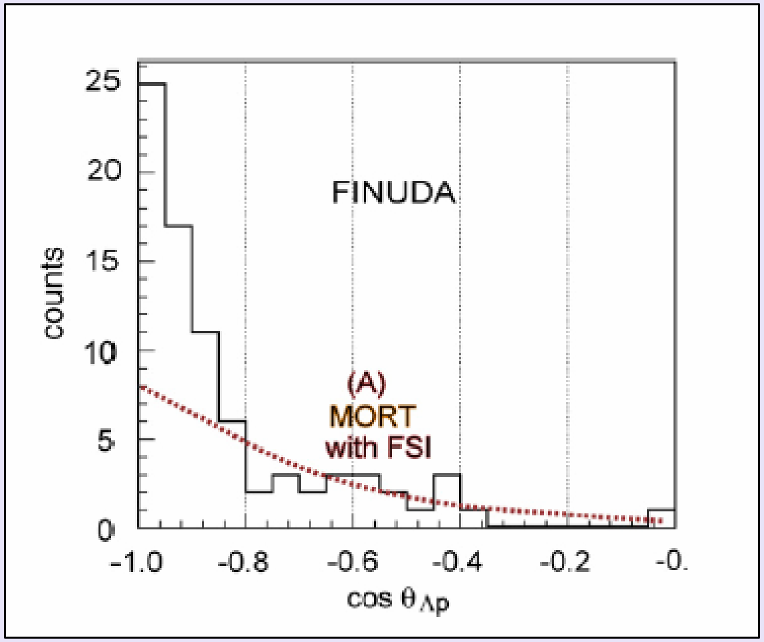
- ✓ **High statistics measurements** of $M_{\Lambda N/d}$, $\Theta_{\Lambda N/d}$, $p_{N/d}$, p_Λ distributions needed to clarify nature of signals and study A dependence, role of FSI and Fermi motion. Clear understanding of (background) multinucleon absorption processes crucial.

- ✓ Higher statistics data from 2nd run presently being analysed on ^6Li, ^7Li, ^9Be, ^{13}C, ^{16}O → single tgt analysis, correlation measurements, background subtraction, neutrons
- ✓ With high(er) statistics FINUDA could study excitation spectrum of spectroscopy nucleons and invariant mass of decay products simultaneously .

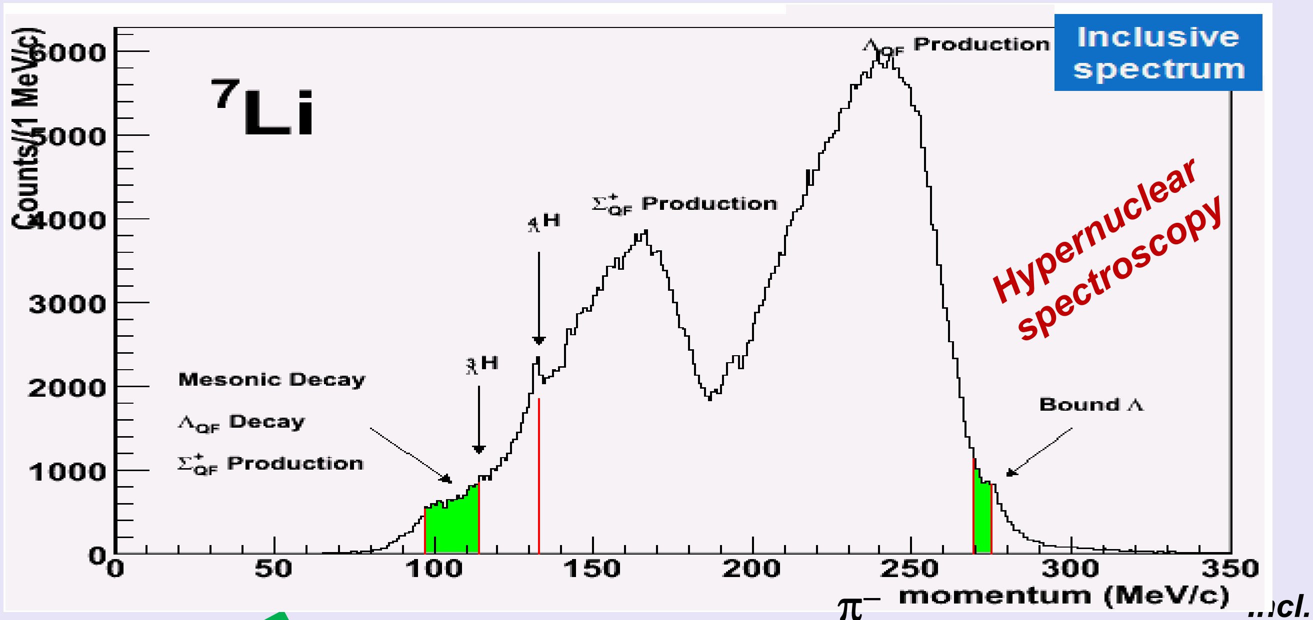
THANK YOU !

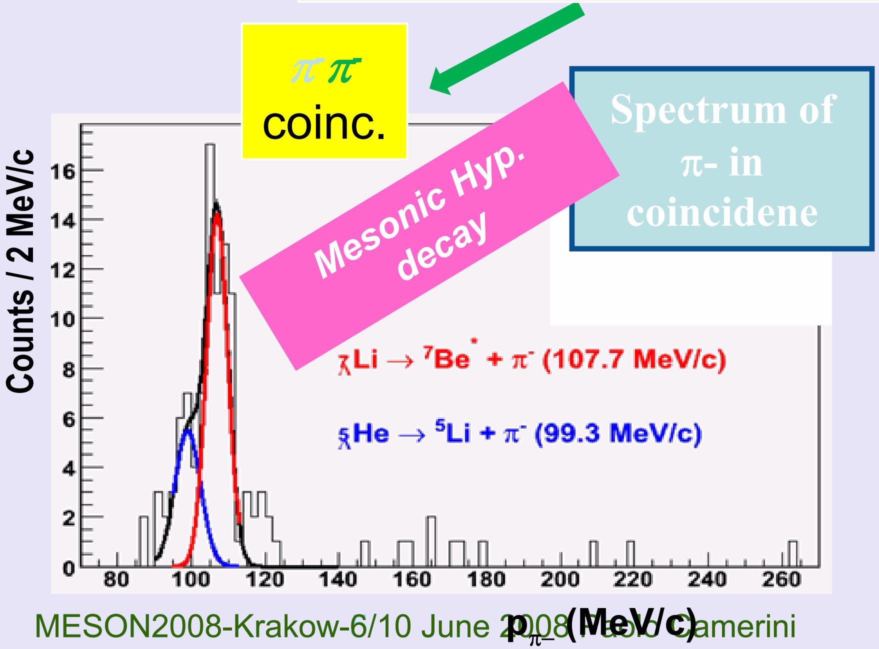
Background reactions: π ⁻ spectrum

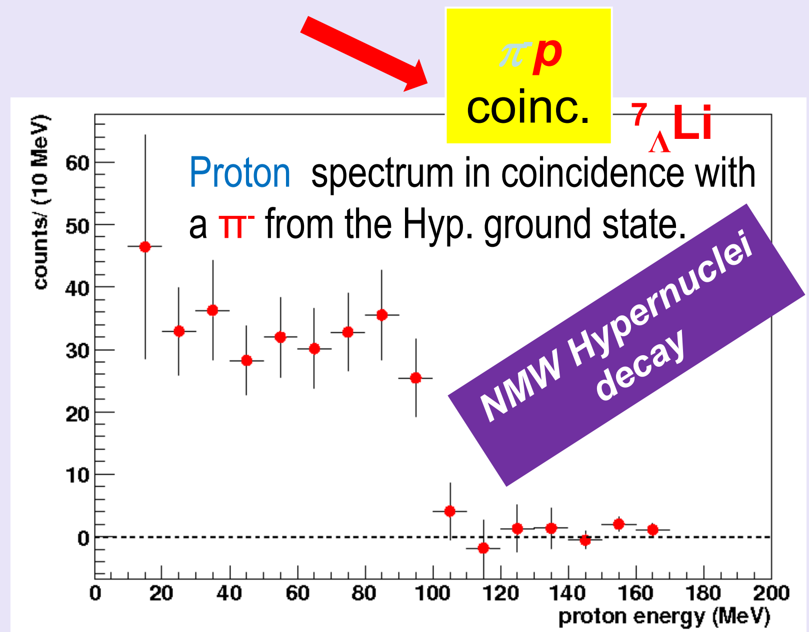



25
20
15
10
5
0
counts
FINUDA
(A)
MORT
with FSI
-1.0
-0.8
-0.6
-0.4
-0.2
-0.
cos θ Λp

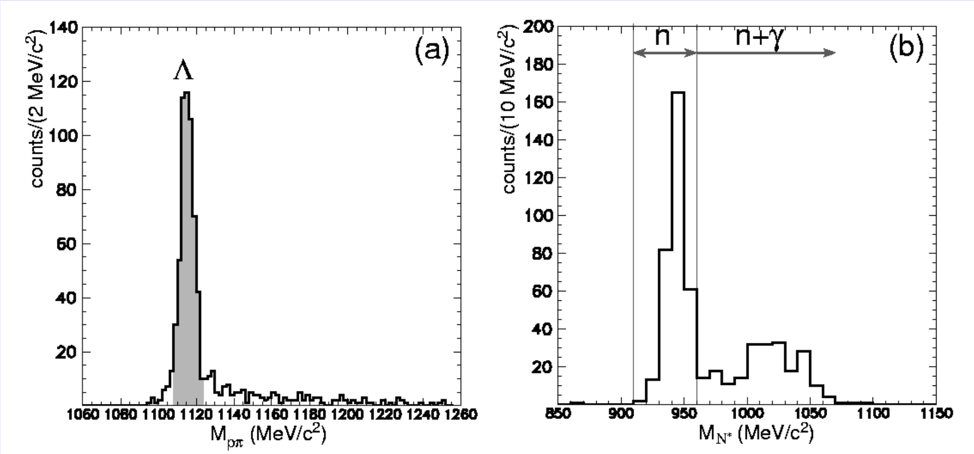
Hypernuclear Physics: FINUDA can simultaneously provide the full pattern: prompt π^-, and p and π^- from Hyp. decay and measure their spectra

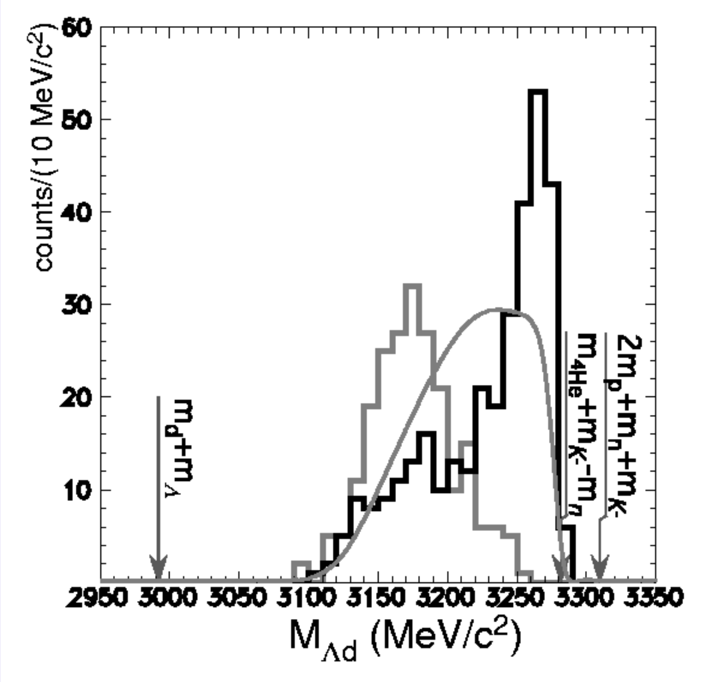






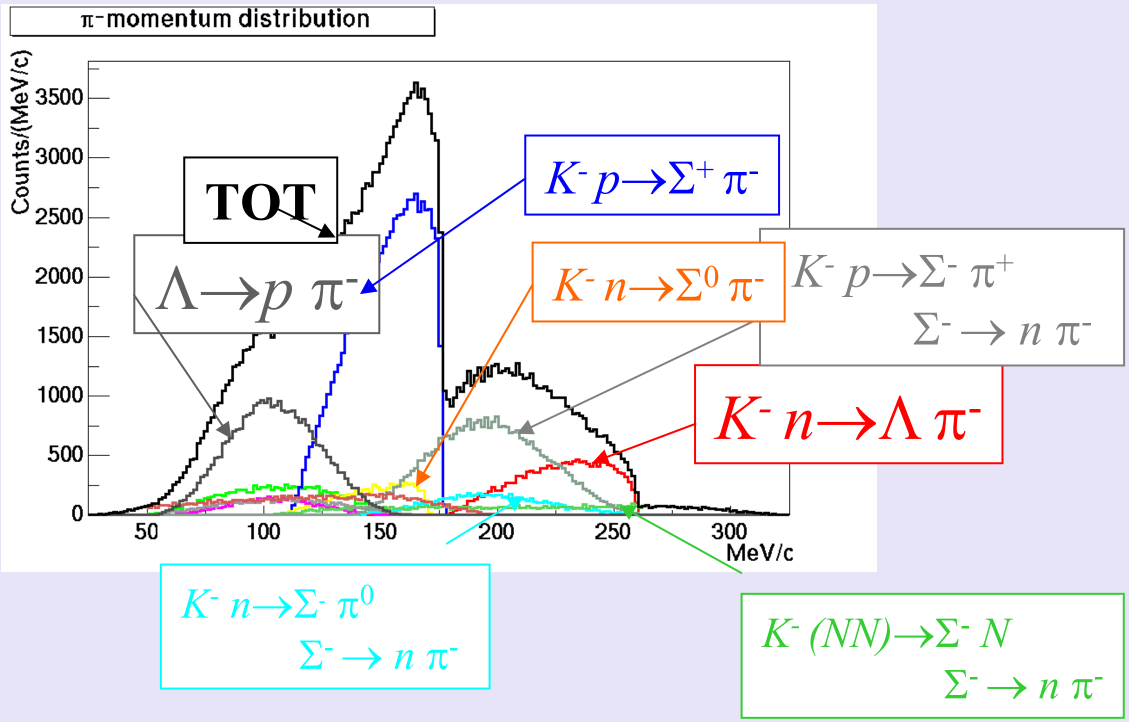
E549: Λd correlation from ^{4}He(K^-_{stop}, d)





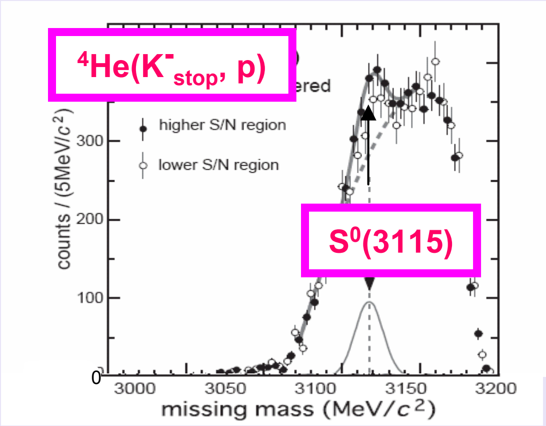
arXiv:0709.0996v1 [nucl-ex]

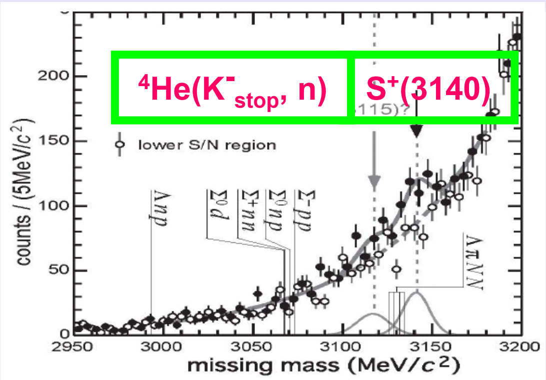
- K^- ^{4}He → Λ d (n)
- detected back-to-back d p pairs with π^- in coincidence
- Λ discriminated from Σ^0 (Λγ) event by missing mass
- Λ d peak at 3282 MeV/c^2 just below mass threshold
- interpreted as 3N absorption K^-ppn (n) → Λ d (n)
- accepted d p back-to-back only, spectra are shaped by the limited phase-space
- spectra are not corrected for the apparatus acceptance

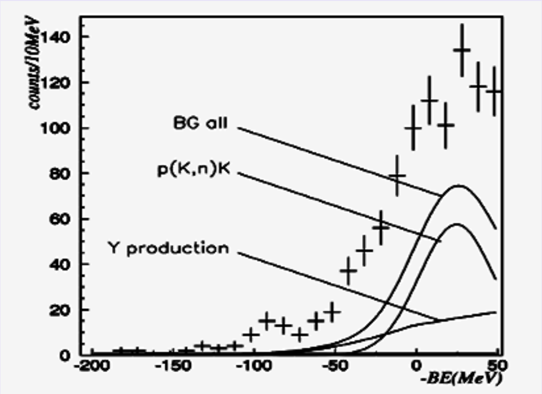

π⁻momentum distribution
Counts/(MeV/c)
3500
3000
2500
2000
1500
1000
500
0
50
100
150
200
250
300
MeV/c
TOT
$\Lambda \to p\ \pi^-$
$K^- p \to \Sigma^+ \pi^-$
$K^- n \to \Sigma^0 \pi^-$
$K^- p \to \Sigma^- \pi^+$
$\Sigma^- \to n\ \pi^-$
$K^- n \to \Lambda\ \pi^-$
$K^- n \to \Sigma^- \pi^0$
$\Sigma^- \to n\ \pi^-$
$K^- (NN) \to \Sigma^- N$
$\Sigma^- \to n\ \pi^-$

- Hunting K^- bound systems [K^-NNN] with (semi) inclusive reactions $^4He(K^-_{stop}, N)$ by KEK-PS E-471
  - Peak in the recoiling nucleon momentum at ~ 500 MeV/c, observed in coincidence with a fast π^-
    - Results compatible with the predictions by Akaishi-Yamazaki
  - $^4He(K^-_{stop}, p)$: withdrawn (M.Sato, PLB 659(2008)107)
  - $^4He(K^-_{stop}, n)$: currently under revision

- A further observation: E930@AGS
  - $^{16}O(K^-_{in\text{-}flight}, n)^{15}{}_K\text{-}O$



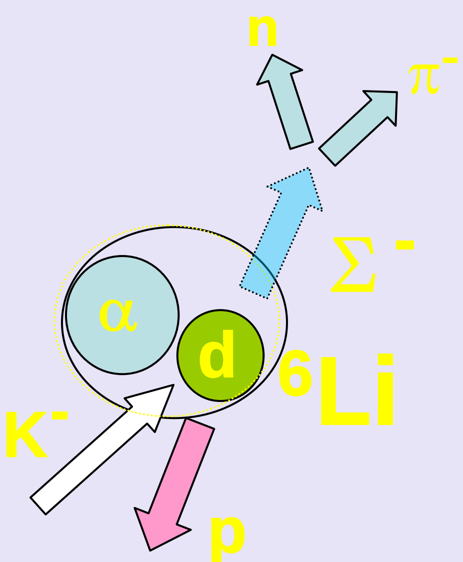




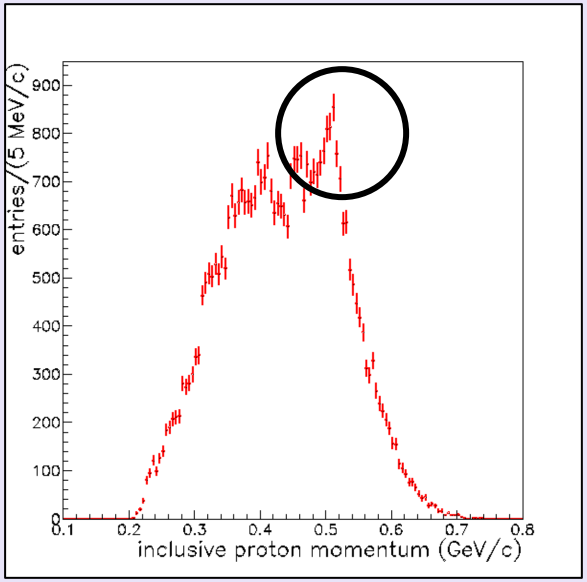
FINUDA: Study of the $^{6}Li(K^{-},p)X$ reaction

- Study of the proton missing mass:
  - Peak found at about 500 MeV/c
  - Interpretation: the proton peak is simply due to two nucleon absorption reaction:

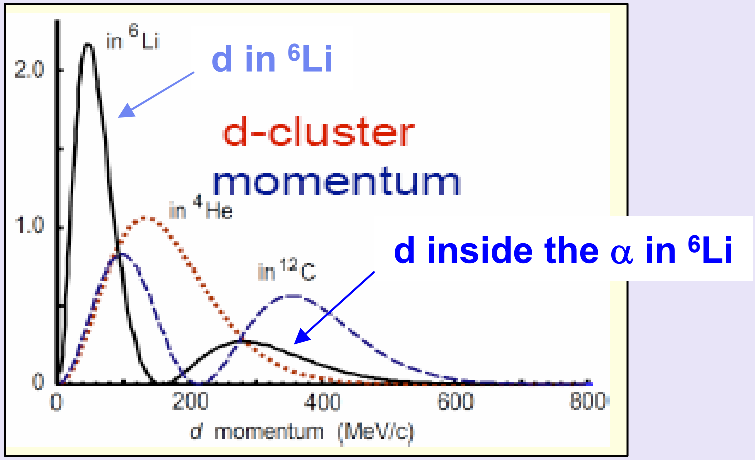
    K^{-}"d"$\rightarrow \Sigma^{-}+p$



  - Nothing exotic: simple reaction mechanism

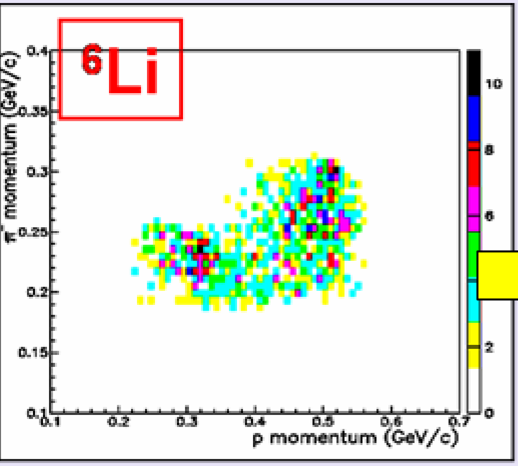


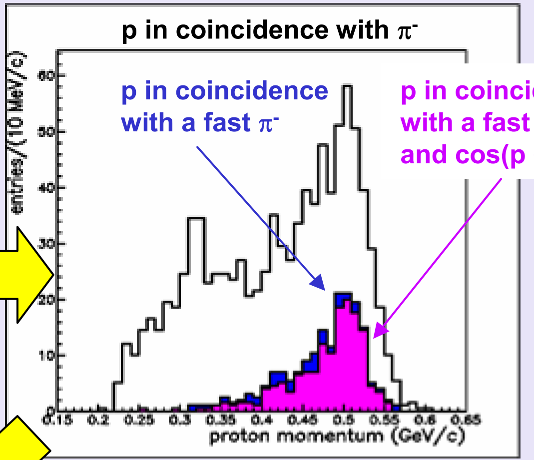
FINUDA Coll., NPA 775 (2006), 35

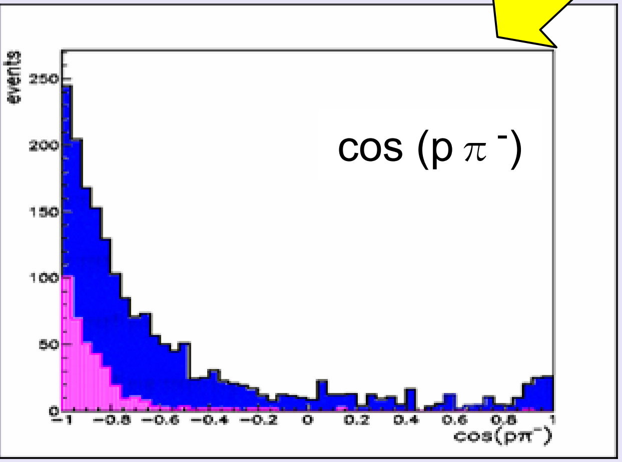


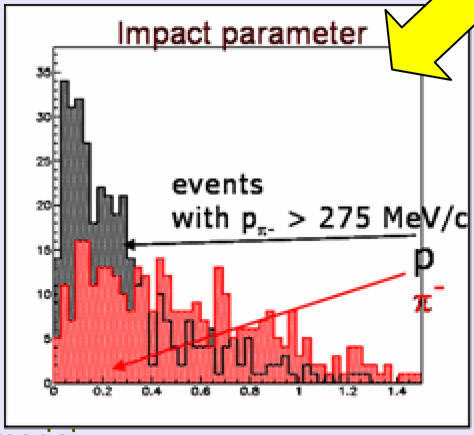
Yamazaki, Akaishi, NPA 792 (2007), 229

Semi-inclusive p spectra (in coincidence with a fast π^-)









- The Σ^- hyperon does not come from the decay of a [K^-NNN] cluster

Back-to-back angular correlation proper of a two-body reaction (isotropy expected from DBKS p π^-)

- capture rate K^- (np) $\rightarrow \Sigma^-$p:
  - 1.6%/stopped K^-
  - OK!

- The p and the high momentum π^- produced in two different vertices
  - The π^- comes from the decay of a Σ^- hyperon

No need to DBKS to explain the signal: agreement with the Oset-Toki expectations

Missing mass combined with π^- vs p momenta, cos(pπ^-), topological constraint …

…On the skeptical side…

- Akaishi-Yamazaki use a G-matrix treatment simplifying some absorption effects, and neglecting some couplings ($\pi\Sigma$, $\pi\Lambda$)

- Different theoretical approaches:
  - General attitude (Gal, Weise, Schaffner-Bielich, Wychech)
    - K^- -nuclear aggregates existence is not discarded, but
      - The potential is shallow
      - The expected widths are large
        - » Possible signals only from heavy systems
  - Microscopic chiral approach
    - Ramos, Oset NPA671 (2000) 481
      - Shallow nuclear potential, weak attractive KN interaction, fastly diluted (1405)
      - Small binding energy (30-40 MeV)
  - Density dependent potential
    - Mares et al. NPA770 (2006) 84
      - Sizeable binding energy (100-200 MeV), widths > 50 MeV but only on heavy nuclei
  - 3-body Faddeev calculations
    - Shevchenko et al. PRL98 (2007), 082301
      - Small binding energy (~50 MeV) and large width (~100 MeV)

- Alternative interpretations of observed signals
  - Magas et al. PRC74 (2006), 025206
  - Oset, Toki PRC74(2006), 015207

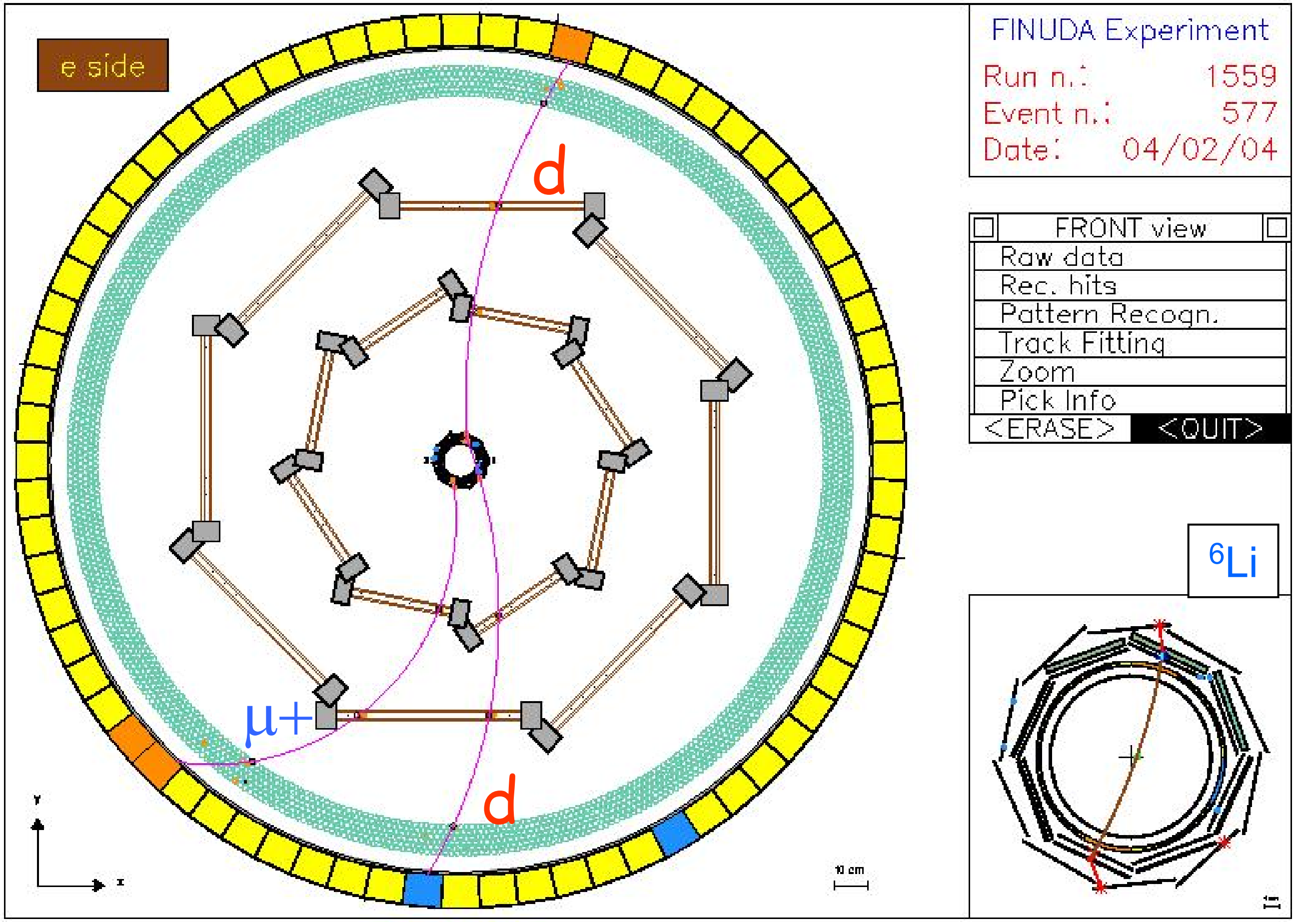
Hypernuclear rare decay

$$K^- + {}^6Li \rightarrow \pi^- + \begin{cases} {}^5_\Lambda He + p \\ {}^4_\Lambda He + p + n \\ {}^4_\Lambda H + p + p \end{cases}$$

Hyper-fragments production

$${}^4_\Lambda \mathrm{He} \rightarrow \begin{cases} d + d \\ p + t \\ d + p + n \end{cases}$$

p_d = 570 MeV/c
back to back topology



Hypernuclear rare decay

$$K^- + {}^6Li \rightarrow \pi^- + \begin{cases} {}^5_\Lambda He + p \\ {}^4_\Lambda He + p + n \\ {}^4_\Lambda H + p + p \end{cases}$$

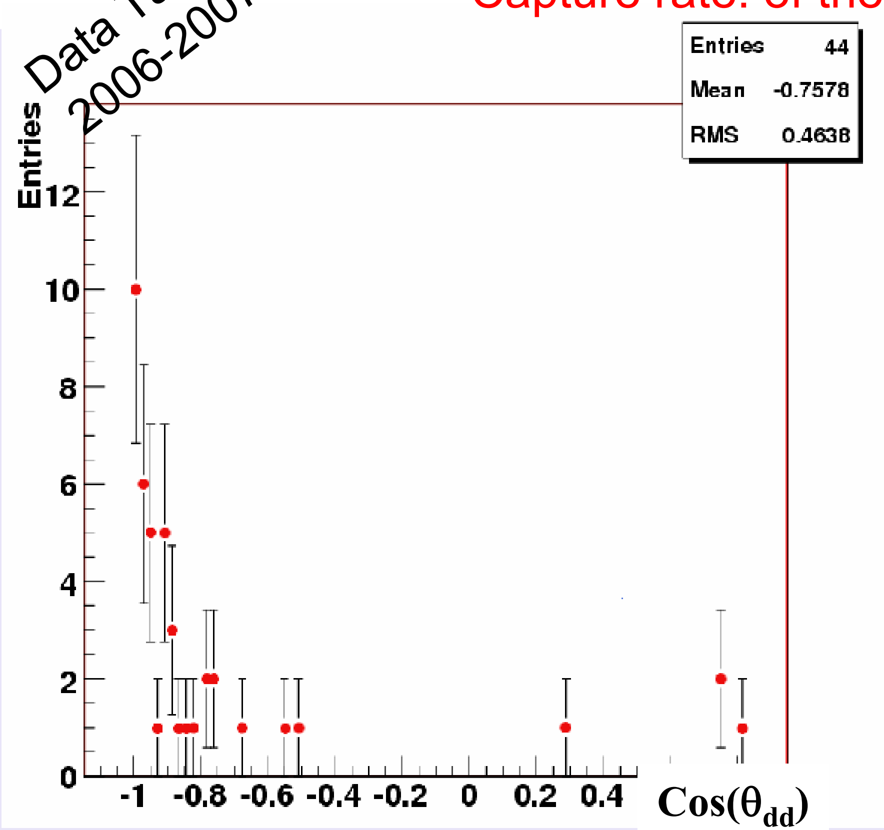
Hyper-fragments production

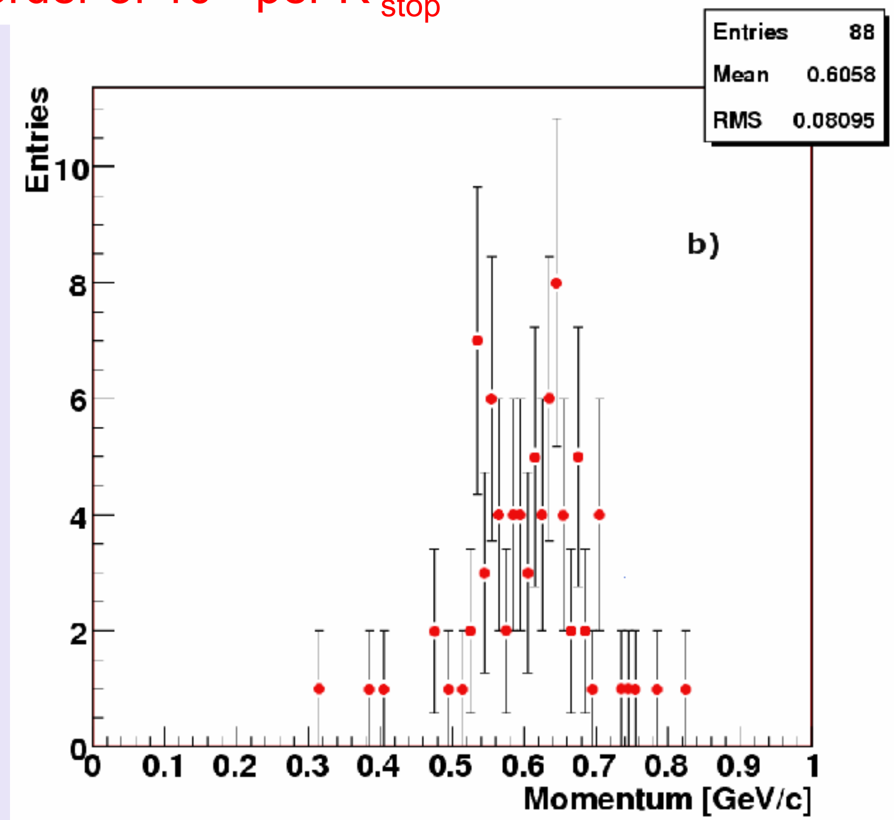
$${}^4_\Lambda He \rightarrow \begin{cases} d + d \\ p + t \\ d + p + n \end{cases}$$

p_d = 570 MeV/c
back to back topology

Data Taking 2006-2007

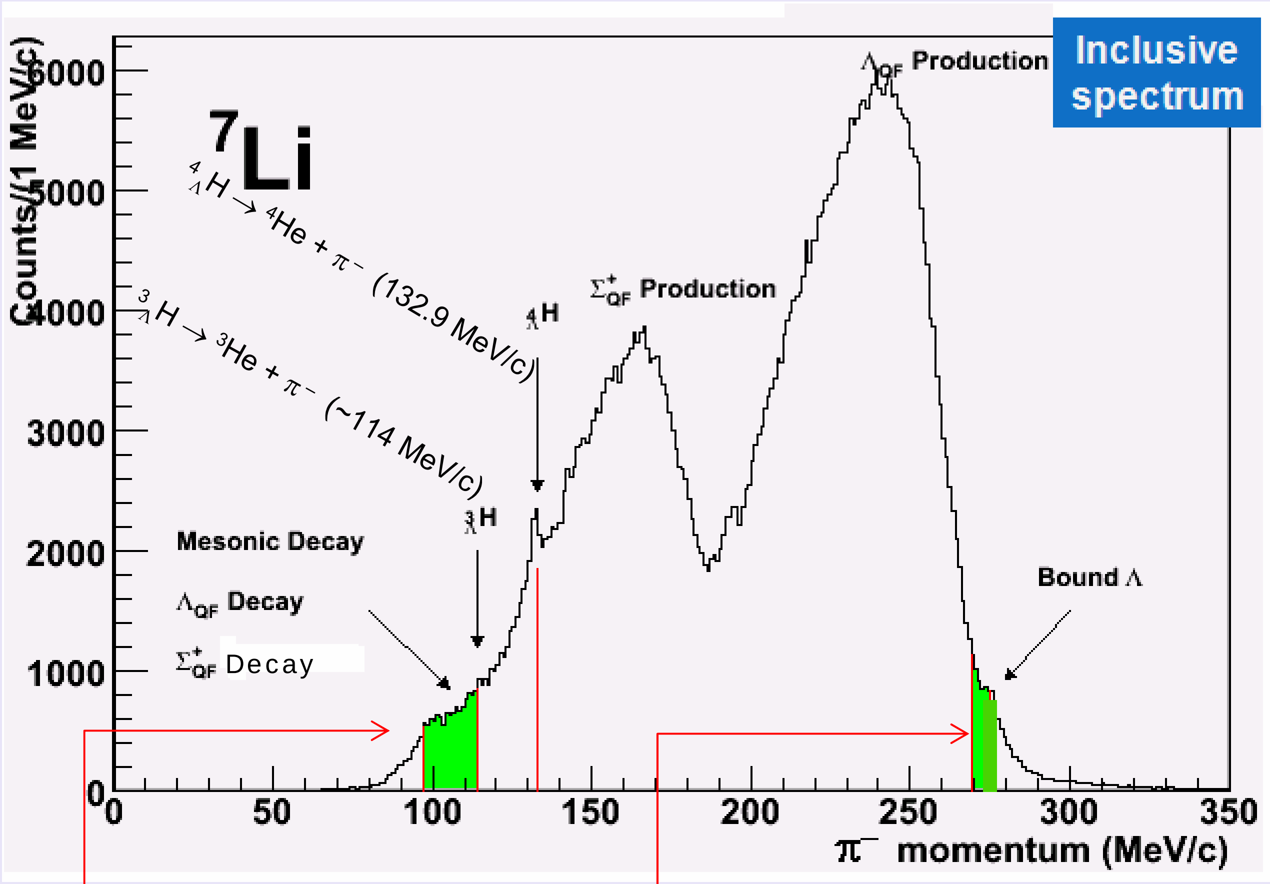
Capture rate: of the order of 10^{-5} per K^-_{stop}





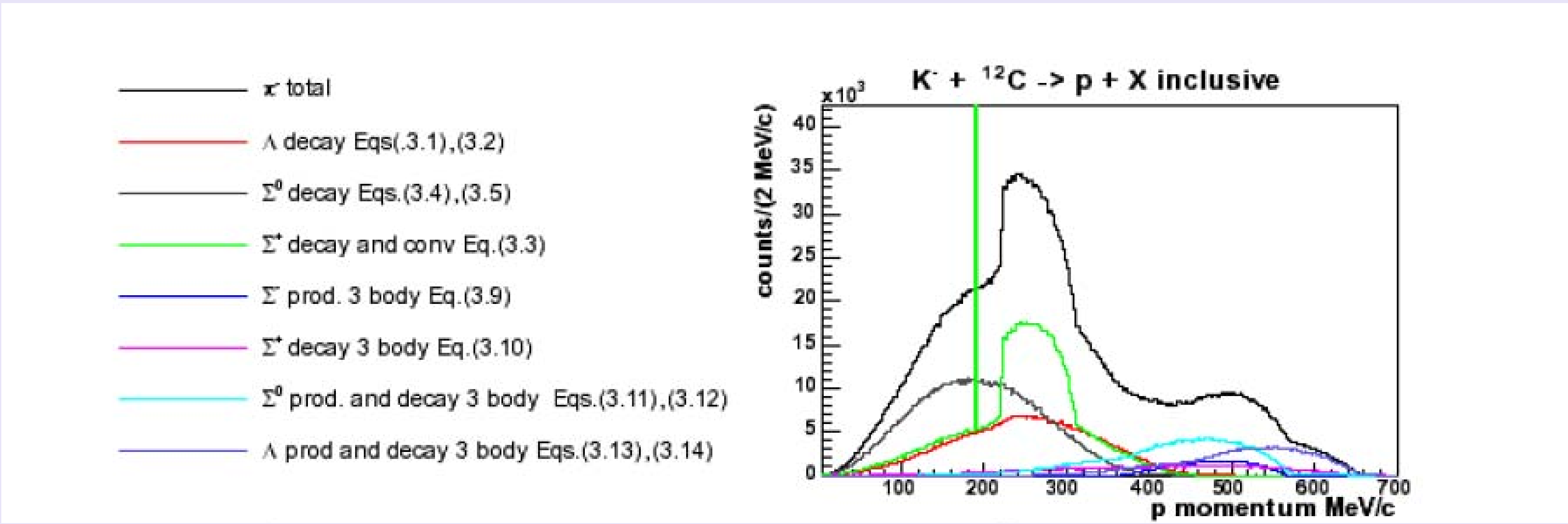
FINUDA and $^{7}_{\Lambda}Li$ - $^{5}_{\Lambda}He$

Production and Mesonic Decay



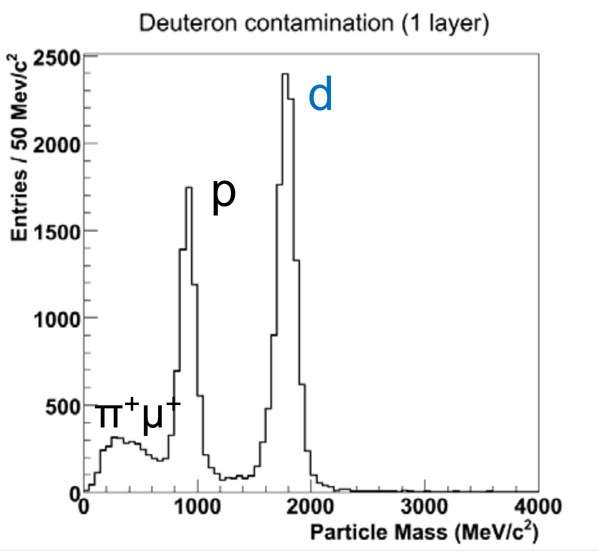
Detection of prompt π^- in coincidence with

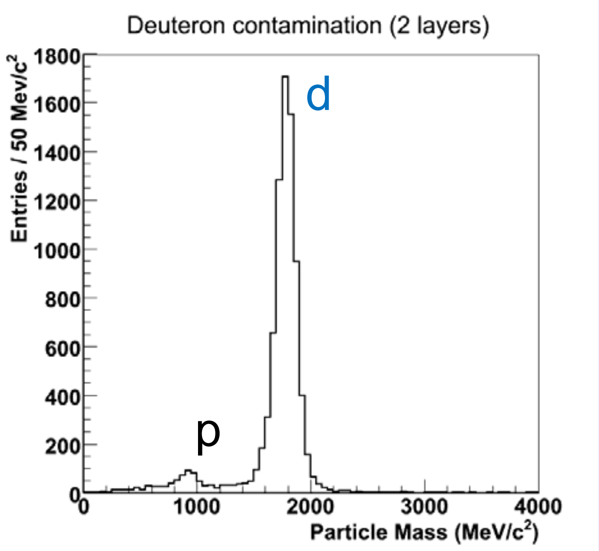
π^- of low momentum from mesonic decay of the hypernucleus levels

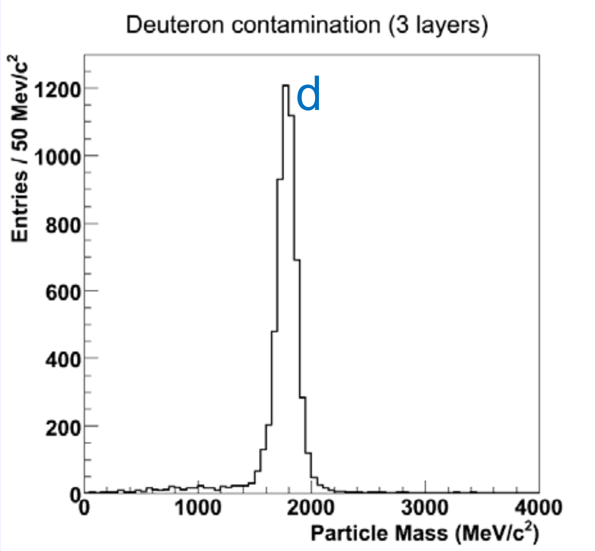

π⁻ total
Λ decay Eqs(.3.1),(3.2)
Σ⁰ decay Eqs.(3.4),(3.5)
Σ⁺ decay and conv Eq.(3.3)
Σ⁻ prod. 3 body Eq.(3.9)
Σ⁺ decay 3 body Eq.(3.10)
Σ⁰ prod. and decay 3 body Eqs.(3.11),(3.12)
Λ prod and decay 3 body Eqs.(3.13),(3.14)
K⁻ + ¹²C -> p + X inclusive
x10³
counts/(2 MeV/c)
0
5
10
15
20
25
30
35
40
100
200
300
400
500
600
700
p momentum MeV/c

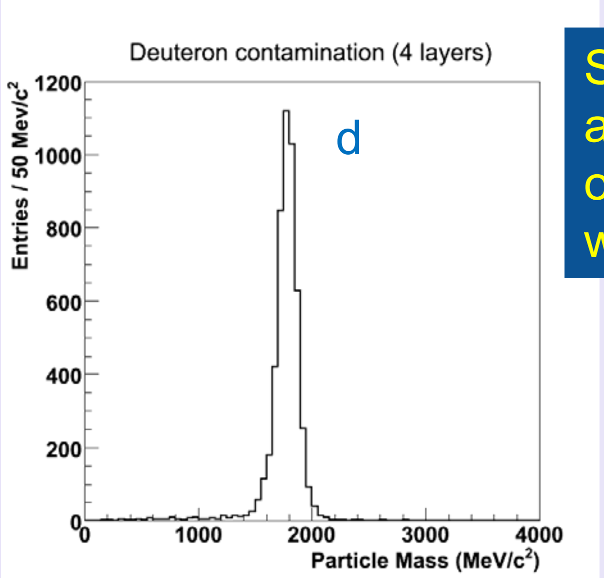
Progress in Particle Identification

Contamination in deuteron selection , as example





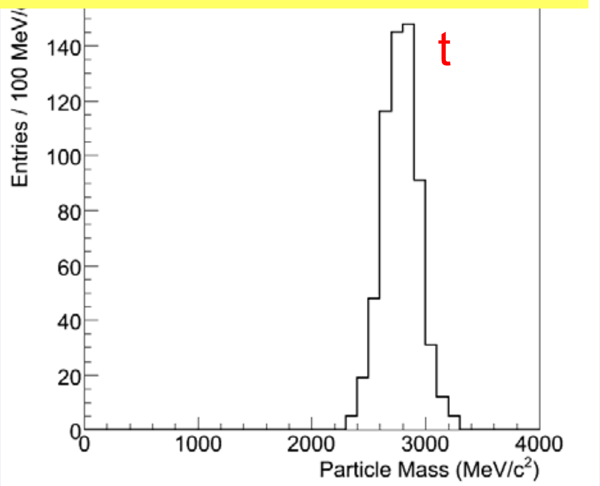




Suppression of *MIP* and p contamination on d and t discrimination with 3 and 4 layers !

Ratio p/d~xxx/1

Contamination in triton selection



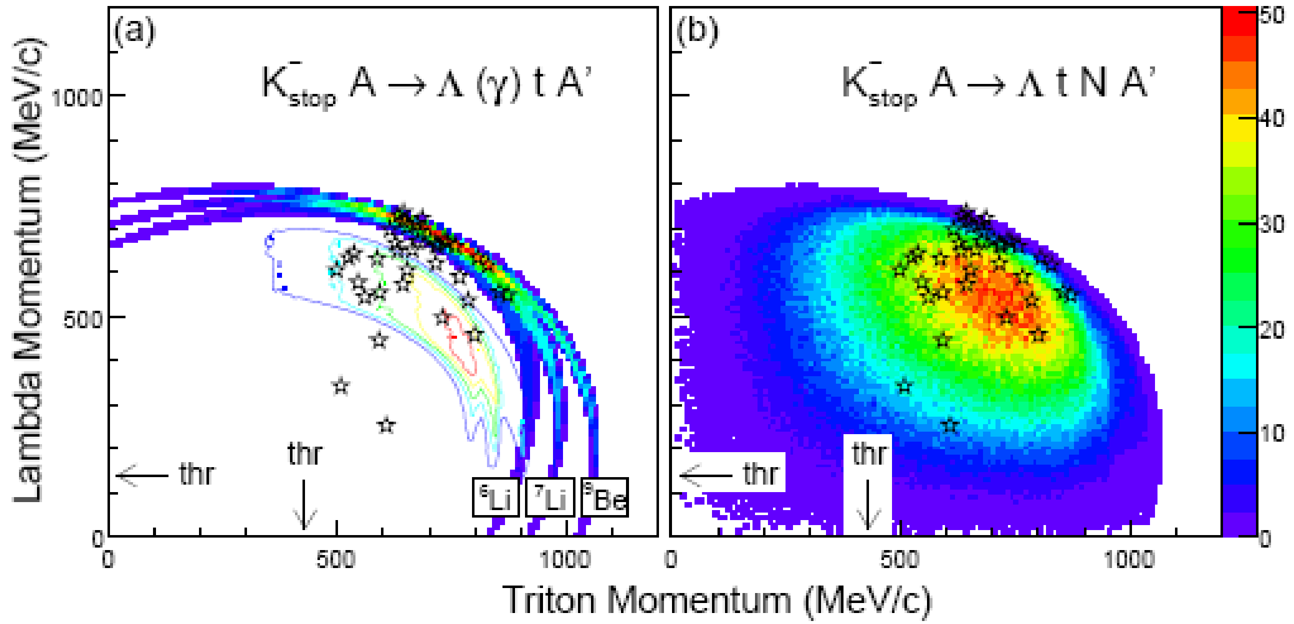


Fig. 3. p_Λ vs p_t plots for the direct reactions (a) $K^-_{stop}A \to \Lambda(\gamma)tA'$ and (b) $K^-_{stop}A \to \Lambda tN A'$, where the notation A' represents a bound system of nucleons and N a single nucleon. The experimental data are represented by stars. In (a), the phase space distribution for the $K^-_{stop}A \to \Lambda tA'$ reaction is represented by a diffusion plot; instead, the contour plot shows the $K^-_{stop}A \to \Lambda\gamma tA'$ phase space where the $\Lambda\gamma$ pairs are the product of Σ^0 decays.

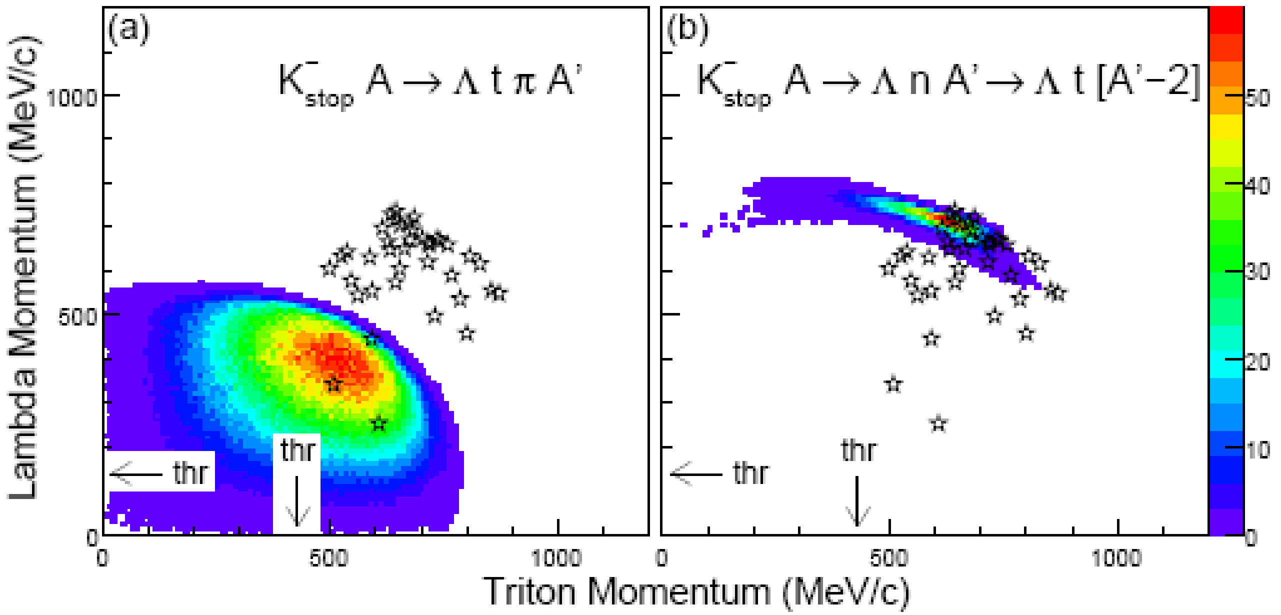


Fig. 4. Diffusion plots of p_Λ vs p_t for the multistep reactions (a) an on-shell pion is produced in the final state $K^-_{stop}A \to \Lambda t \pi A'$ and (b) a pick-up reaction $NA' \to t[A'-2]$ produces the final triton in $K^-_{stop}A \to \Lambda t[A'-2]$, where the notation $[A'-2]$ represents a bound system of nucleons and N a single nucleon. The experimental data are represented by stars.