φ中間子工場におけるＫ中間子の深い束縛状態の探索（2）

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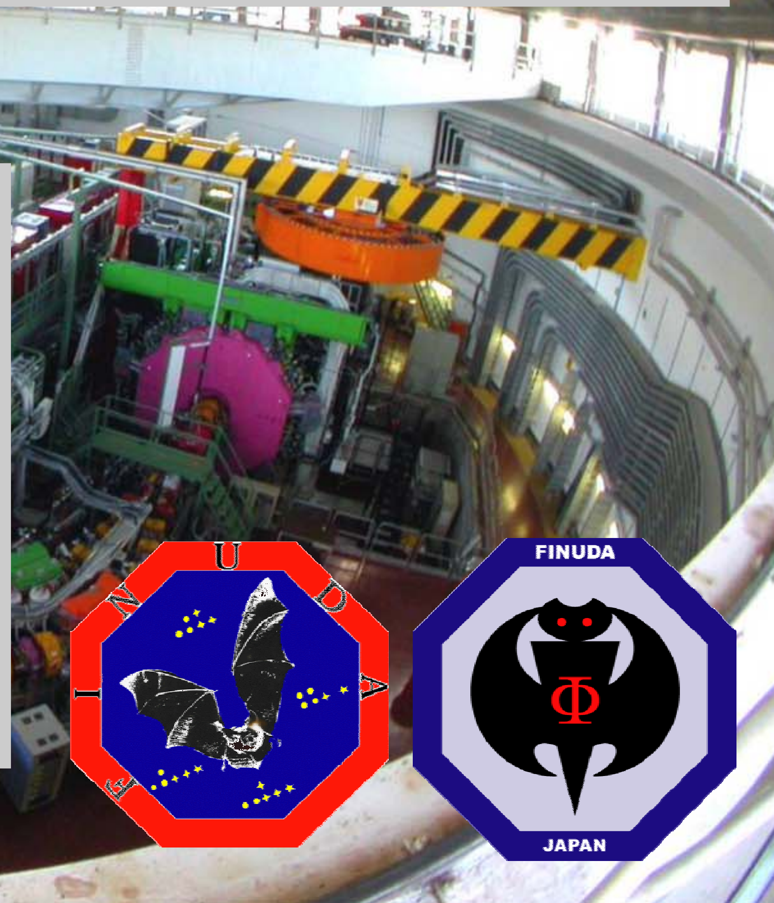
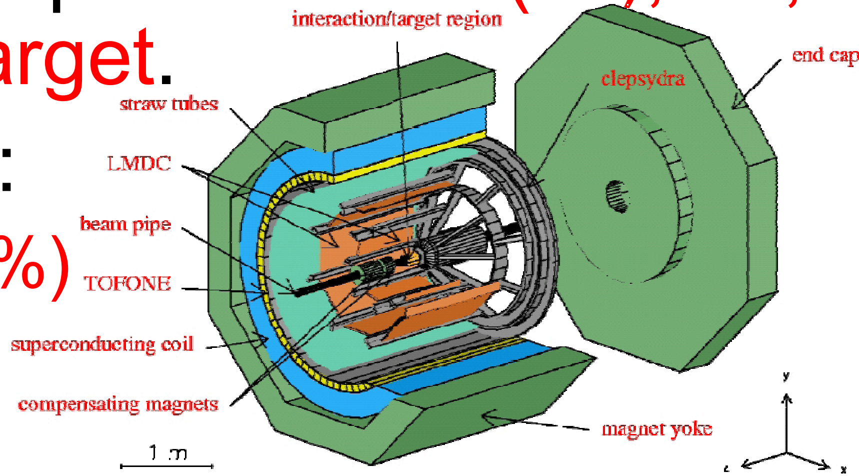


Overview of FINUDA experiment

- $K^{\pm}$ pair from φ decay stops inside ^{6}Li (x2), ^{7}Li, ^{12}C (x3), ^{27}Al and ^{51}V target.
- FINUDA spectrometer :



  - Large acceptance (~70%) → multi-tracking
  - Uniform magnetic field (B=1.0T) → momentum acceptance >120MeV/c
  - $\Delta p/p_{\mathrm{FWHM}}$ ~ 0.3% (0.6% now) for 275 MeV/c π^{-}.
  - PID for charged particles ($\pi^{\pm}$/p/d/t) with *dE/dx* and time-of-flight (TOF) information.
  - Neutron detection with two sets of scintillators.

Kaonic nuclei search with Λ tagging

Missing-mass spectroscopy

- Example:

$$^{6}\mathrm{Li} + K^- \rightarrow \begin{cases} K^- pppnn + n \\ K^- ppnnn + p \end{cases}$$

monoenergetic

KEK-PS E471/E549 (stopped K)
BNL-AGS E930/KEK-PS E548 (in-flight K)
FINUDA@DAΦNE (stopped K)

- A kaonic nucleus emits a hyperon in its decay.

Invariant-mass spectroscopy

- Example:

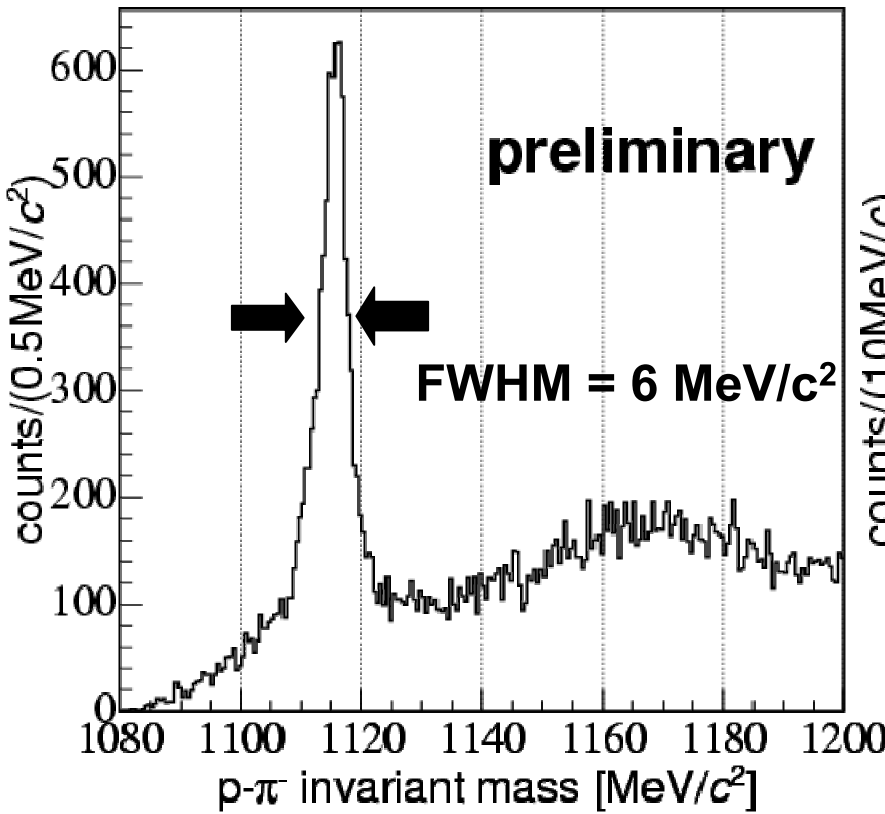
FINUDA@DAΦNE

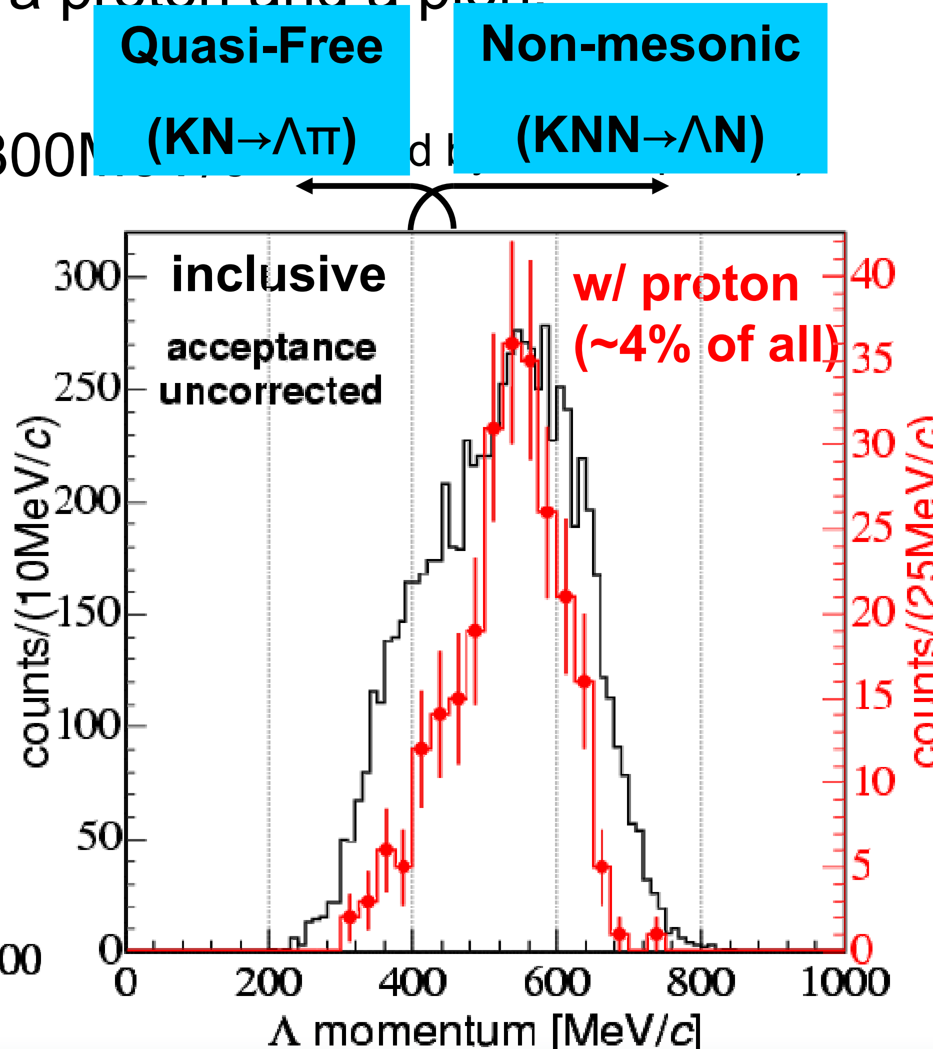
$$K^- pp \rightarrow \Lambda + p \quad , \quad K^- ppn \rightarrow \Lambda + d(p+n)$$

Λ detection is possible at FINUDA.

Λ tagging and momentum distribution

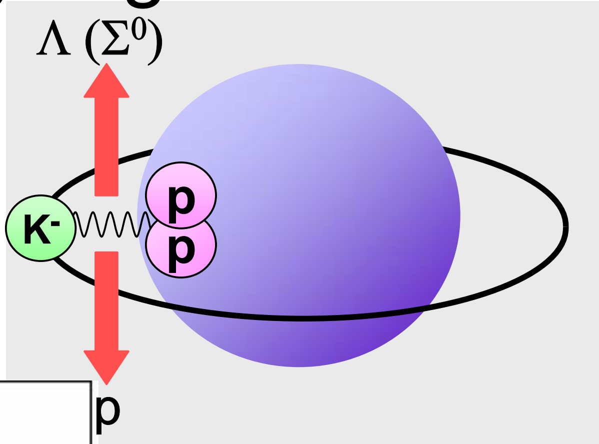
- Invariant mass spectrum of a proton and a pion
- Λ mass gate : ±5 MeV/c^2
- Momentum acceptance □ 300M





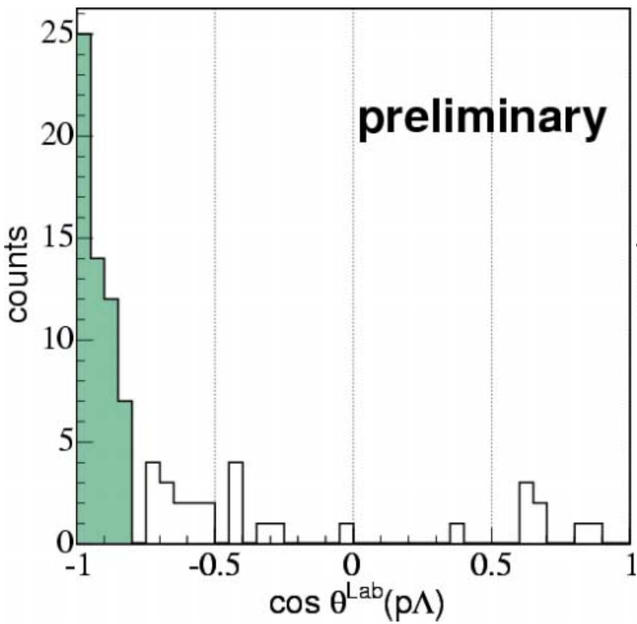
p+Λ : back-to-back correlation

- The proton and Λ has a strong angular correlation for every target.



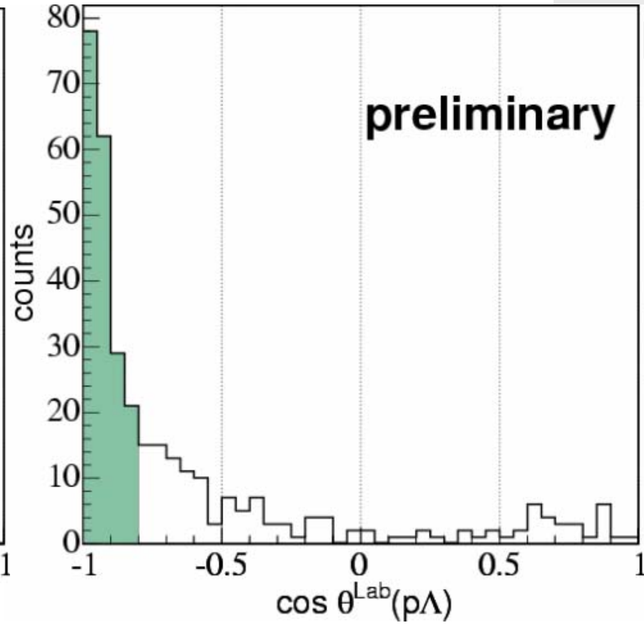
Light targets

(^{6}Li, ^{7}Li)



Heavy targets

(^{12}C, ^{27}Al, ^{51}V)



Origin of back-to-back p+Λ

Two-nucleon absorption

$$K^- + \text{``}pp\text{''} \rightarrow \mathbf{Y^*N} \rightarrow p + \Lambda$$

$$\rightarrow p + \Lambda + \gamma(\Sigma^0)$$

Via kaon-bound state (K⁻pp)

$$K^- + \text{``}pp\text{''} \rightarrow \mathbf{X} \rightarrow p + \Lambda$$

$$\rightarrow p + \Lambda + \gamma(\Sigma^0)$$

Origin of back-to-back p+Λ

Two-nucleon absorption

$$K^- + \text{“}pp\text{”} \to \mathbf{Y^*N} \to p + \Lambda$$

$$\to p + \Lambda + \gamma(\Sigma^0)$$

- (ΛN):(Σ^0N)=(9.4±2.6)%:(2.3±1.0)% for ^{4}He [*Katz et al.*]
- B.R. of Σ^0N decay was estimated as the average of those of Σ^+N and Σ^-N.

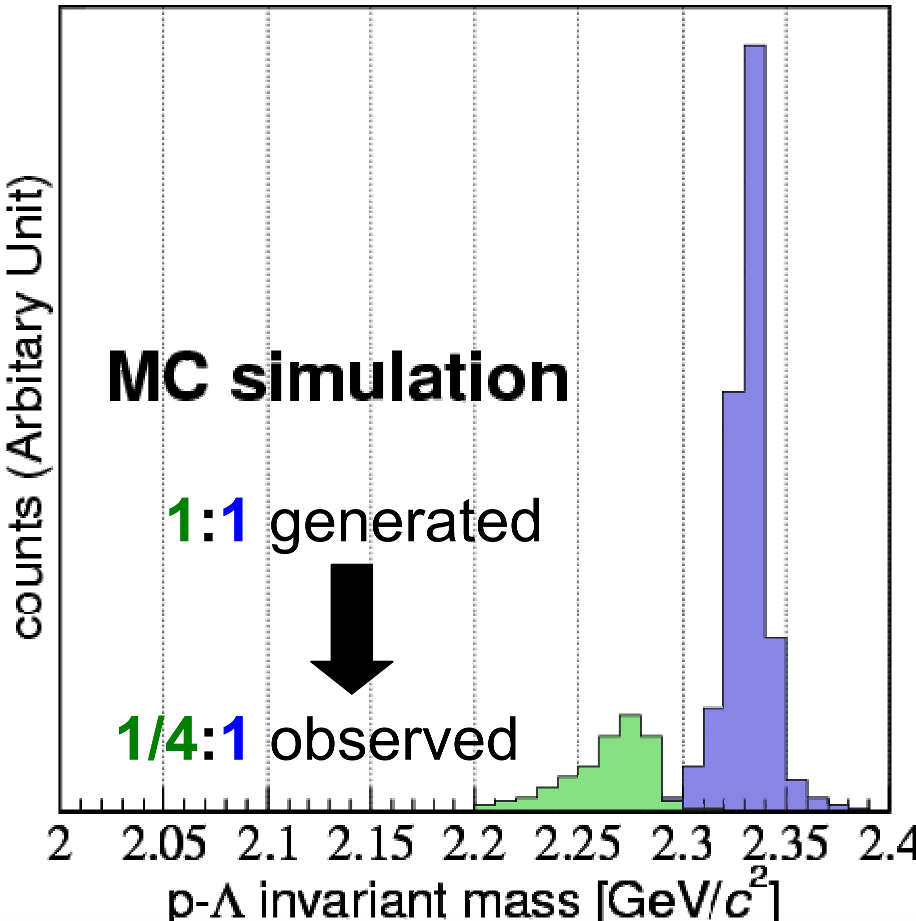
Two-nucleon absorption

p+Λ decay

- Almost same as the K^- + 2p mass (2.37 GeV/c^2)
- Reduced because of
  - the separation energy
  - The Fermi energy

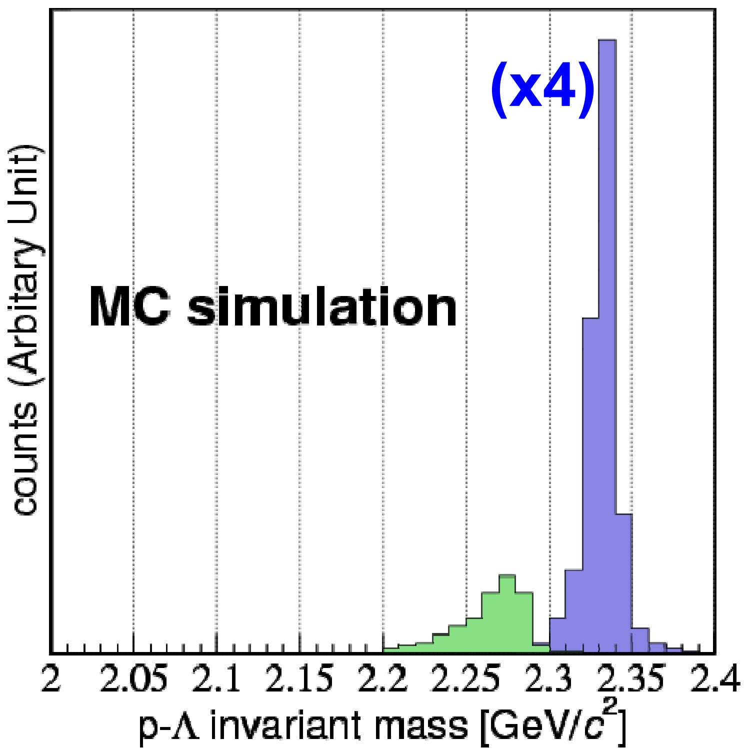
p+Σ^0 decay

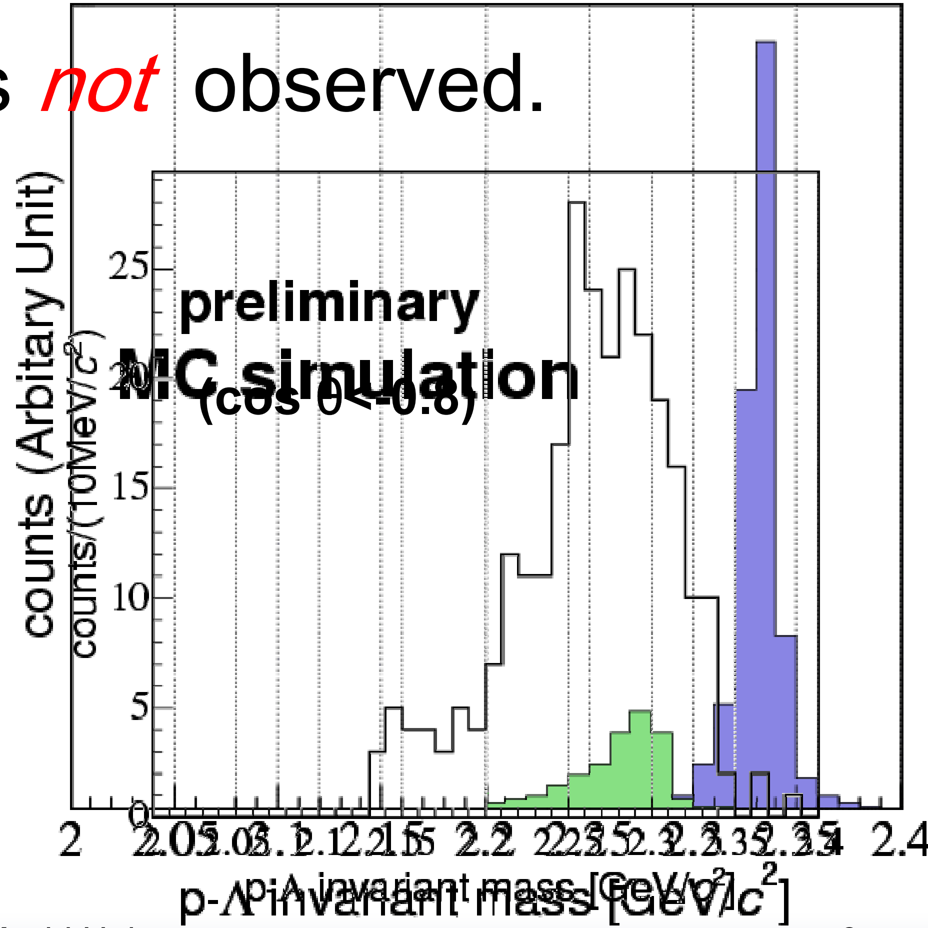
- Shifted due to missing γ energy, which is broadened from that in Σ^0 CMS (74MeV).



p-Λ invariant mass spectrum

- Assuming the Katz's B.R. (~4:1), the blue peak would be dominant.
- However, this peak is *not* observed.





Origin of back-to-back p+Λ

Two-nucleon absorption

$$K^- + \text{``}pp\text{''} \rightarrow \mathbf{Y^*N} \rightarrow p + \Lambda$$

$$\rightarrow p + \Lambda + \gamma(\Sigma^0)$$

Via kaon-bound state (K⁻pp)

$$K^- + \text{``}pp\text{''} \rightarrow \mathbf{X} \rightarrow p + \Lambda$$

$$\rightarrow p + \Lambda + \gamma(\Sigma^0)$$

Origin of back-to-back p+Λ

- We performed a Monte Carlo simulation with the actual acceptance considered.
- Input parameters :
  - Binding energy (B)
  - Width (Γ)

  } Lorentzian function

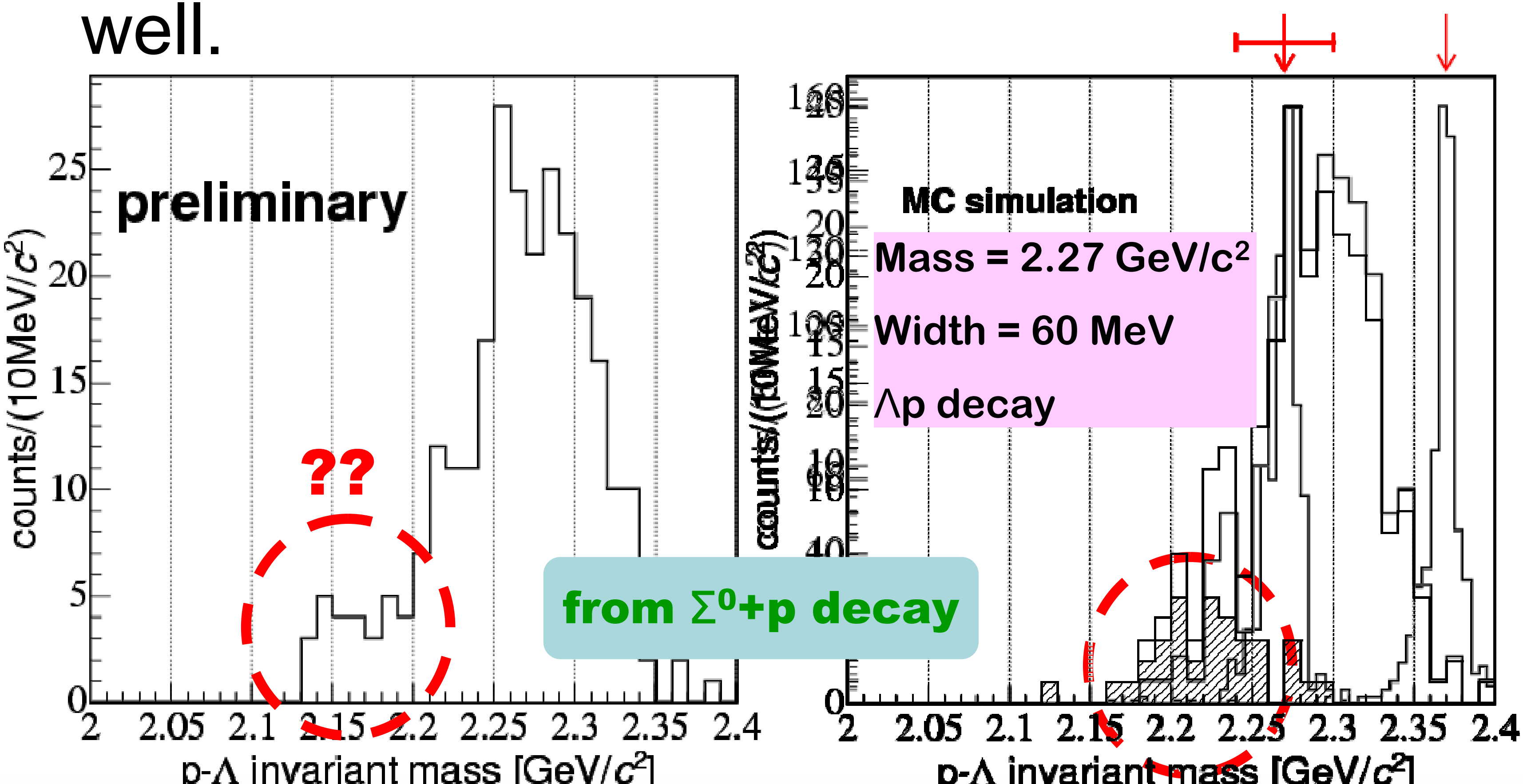
Via kaon-bound state (K^-pp)

$$K^- + \text{"}pp\text{"} \rightarrow \mathbf{X} \rightarrow p + \Lambda$$

$$\rightarrow p + \Lambda + \gamma(\Sigma^0)$$

Result of Monte Carlo simulations

- The distribution with B=100MeV and Γ=60MeV reproduces the spectrum fairly well.



Summary

- Assuming the existence of K^-pp with

  Binding Energy ~ 100 MeV

  Width □ 60 MeV

  the invariant mass spectrum appears to be reproduced.
- It is difficult to explain it only by two-nucleon absorption.
- The K^-pp system is fragmented for light-to-heavy targets.

K^-NN system

Calculation by Akaishi-san

B	**Γ**	**[MeV]**	
48	61	$K^-pp \rightarrow \Lambda + p$	**[~100 MeV bound]**
(91	60)	← 17% stronger $\bar{K}N$ bare pot.+ relativistic effect (very small)	
~ 0		$K^-pn \rightarrow \Lambda + n$	
		$\rightarrow \Sigma^- + p$	
unbound		$K^-nn \rightarrow \Sigma^- + n$	

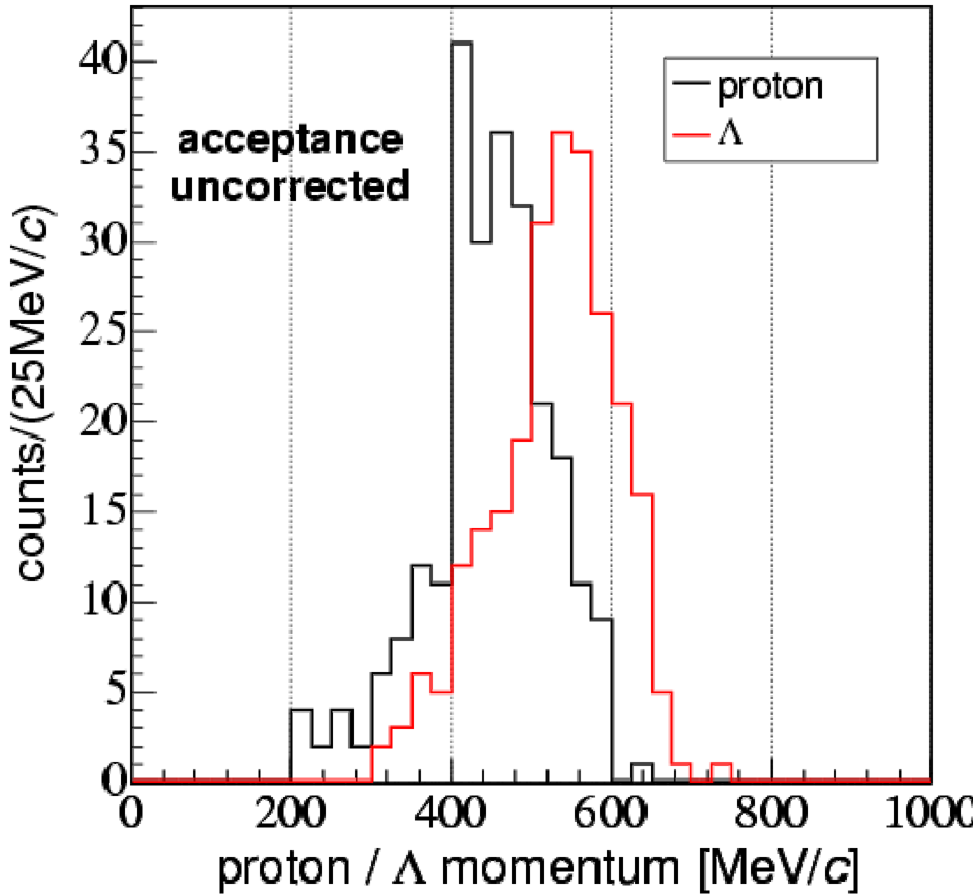
invariant mass spectroscopy ($\Lambda + p$, $\Lambda + n$)

K^-pn, K^-nn: **bound or not ?**

Σ^-: *emit a fast pion*

Isospin dependence of $\bar{K}N$ interaction

Proton and Λ momentum distribution



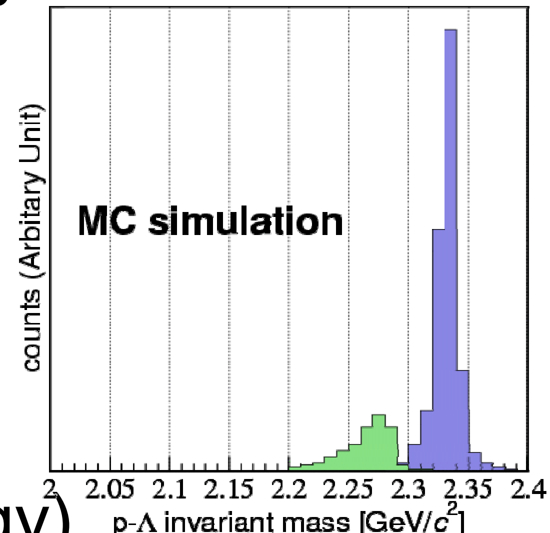
There is a divergence in the two spectra, because of the cut-off in slow π detection.

ΣN-ΛN conversion

- Katz's ΛN decay B.R. includes the ΣN-ΛN converted ΣN decay:

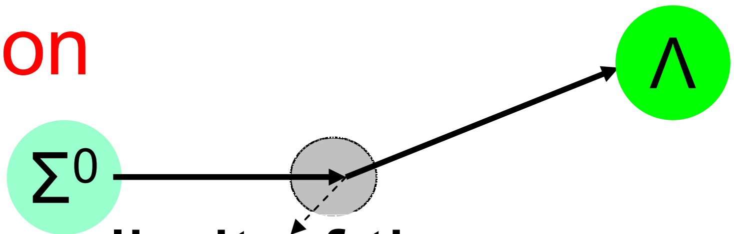
$$K^- + \text{``}pp\text{''} \rightarrow p + \Sigma^0 \,, \;\; \Sigma^0 N \rightarrow \Lambda N$$

- However, the final state particles (proton and Λ) has almost the same energy as that from ΛN decay, since we do not miss any γ.
- The resulting distribution lies around the blue peak, spread because of the recoiled nucleus (~20 MeV, smaller than the γ energy).

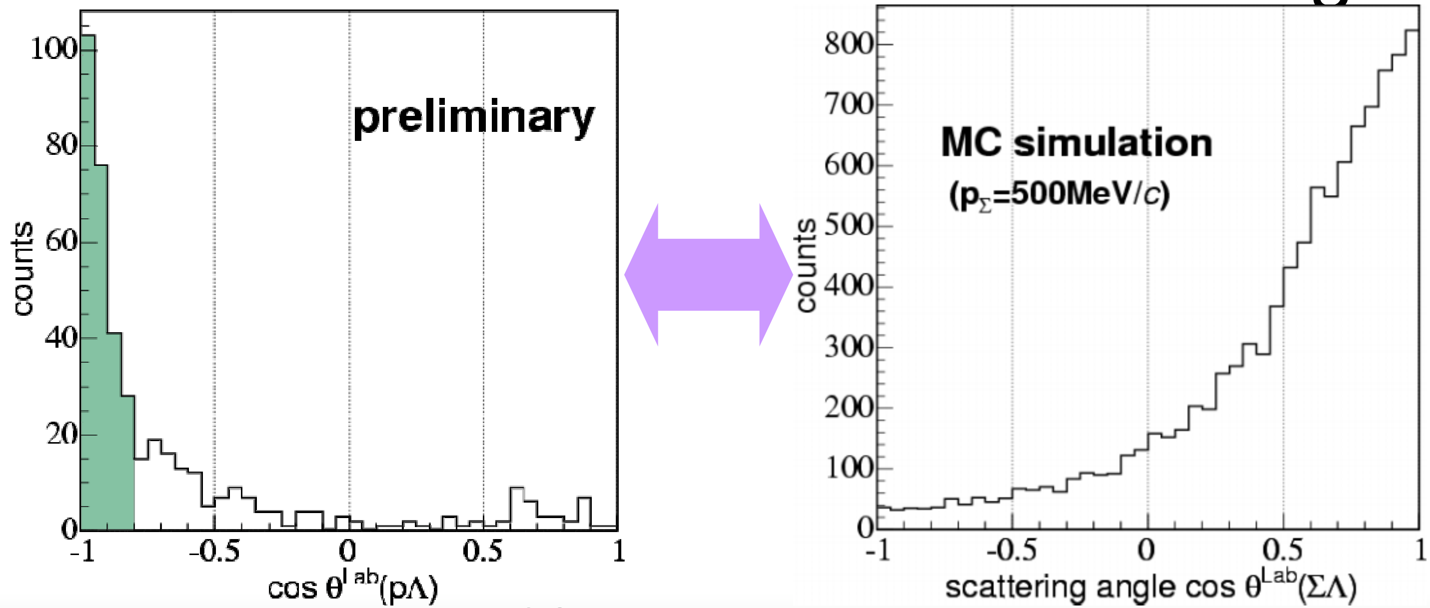


Possible contamination of conversion

- Forward-boosted Λ have higher momentum than initial Σ, depending on the scattering angle.

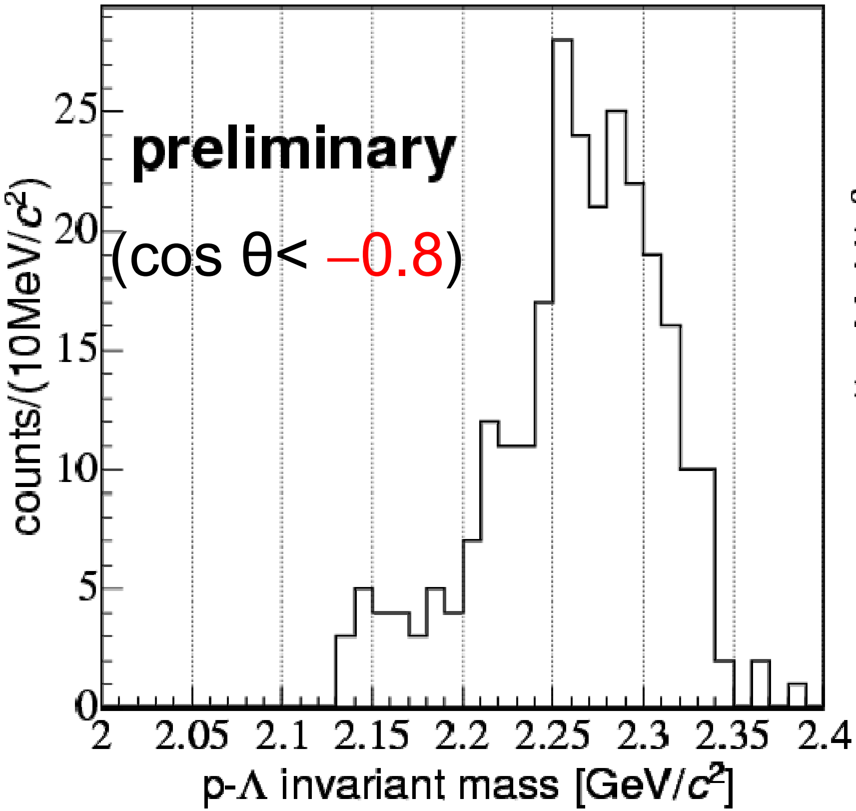


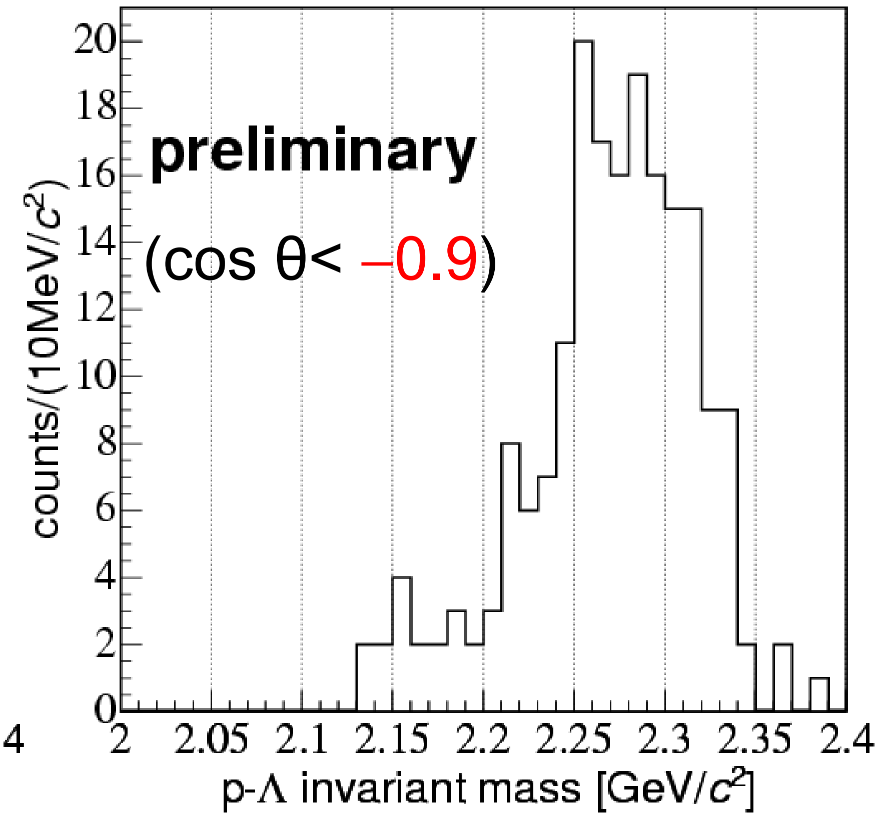
- We can estimate the upper limit of the contamination of the conversion/scattering.



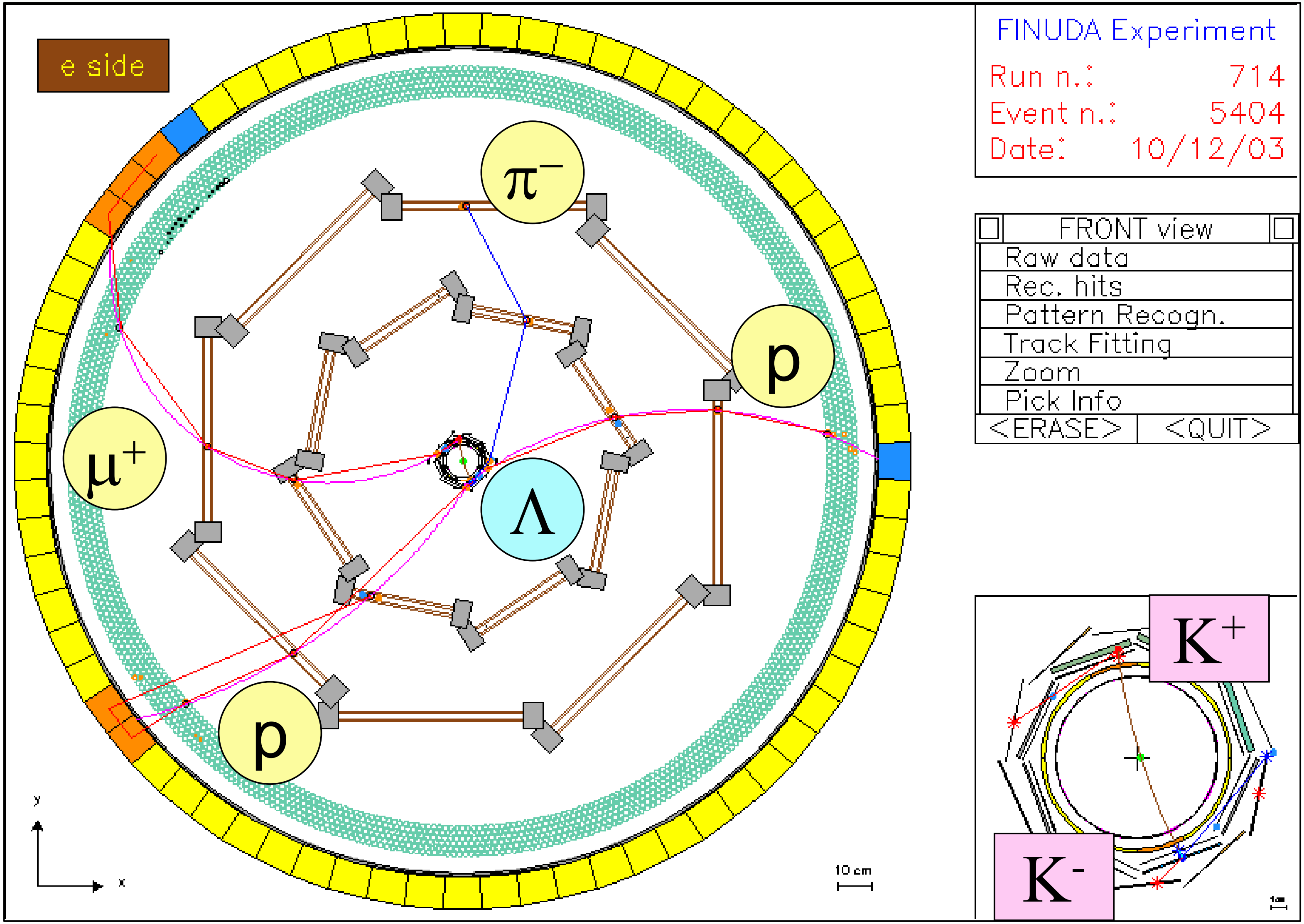
Invariant mass spectra w/ diff. cut

- Changing the cut condition does not affect the shape of the invariant mass spectrum.





Typical Event (K⁻pp and μ^+ from K^+)

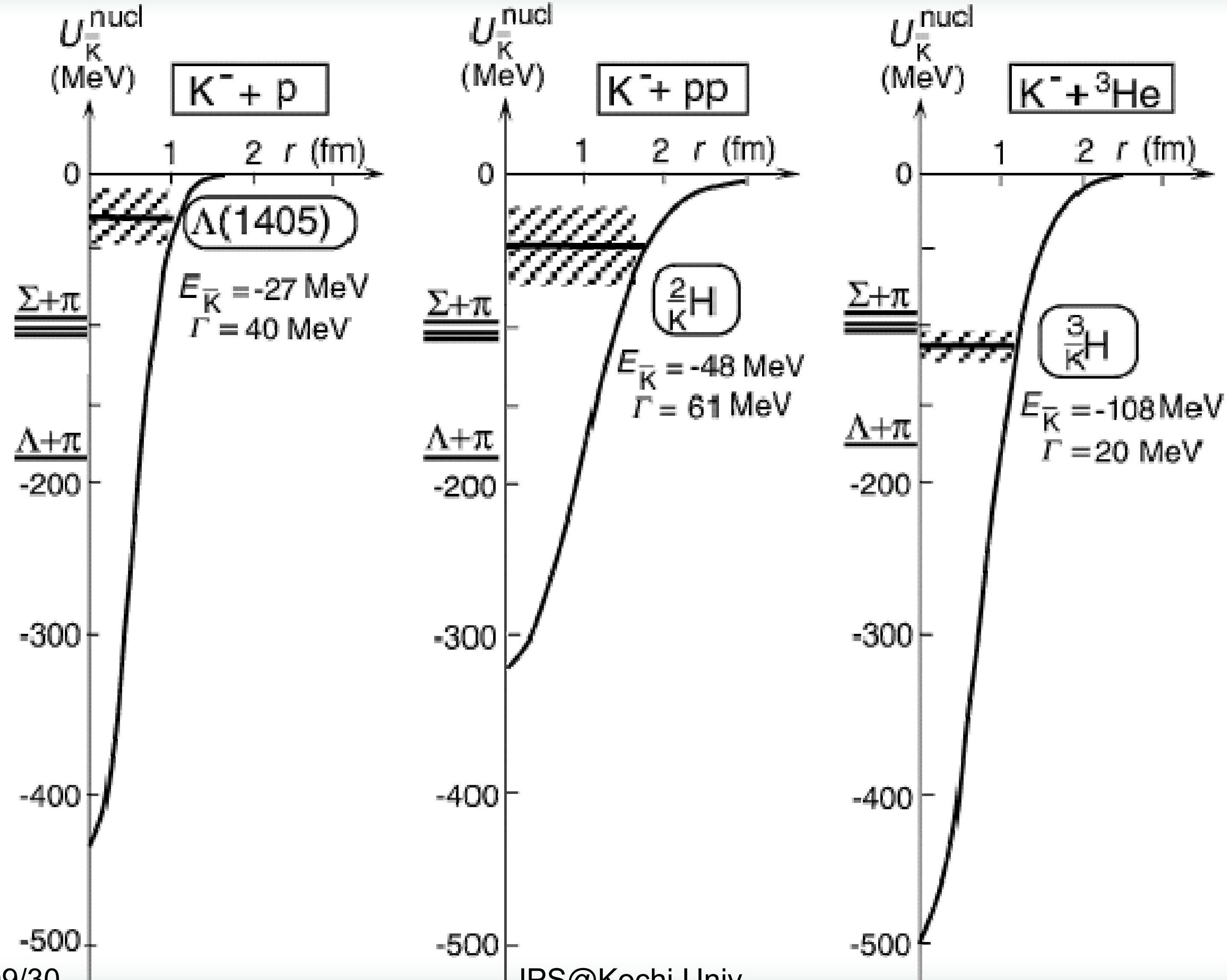


Perspective (Detailed)

- Missing-mass spectroscopy:
  using Auger neutron/(proton) process
  with ^{6}Li, ^{7}Li, (^{9}Be), (^{10}B), ^{12}C target.
- Invariant-mass spectroscopy:
  $$K^{-}ppn \rightarrow \Lambda + d(p+n)$$
  (already seen in $\cos\theta_{p\Lambda} > -0.8$ region?)
- Study of K^{-}NN system (isospin dependence)

- $d(K^{-},\pi^{-})K^{-}pp$ @J-PARC ?

Theoretical calculations



Old experimental data（1）

TABLE III. Branching ratios for K^- absorption at rest.

Reaction	Events/(stopping K^-) (%)
$K^- He^4 \rightarrow \Sigma^+ \pi^- H^3$	9.3±2.3
$\rightarrow \Sigma^+ \pi^- dn$	1.9±0.7
$\rightarrow \Sigma^+ \pi^- pnn$	1.6±0.6
$\rightarrow \Sigma^+ \pi^0 nnn$	3.2±1.0
$\rightarrow \Sigma^+ \quad nnn$	1.0±0.4
Total $\Sigma^+ = (17.0 \pm 2.7)\%$	
$K^- He^4 \rightarrow \Sigma^- \pi^+ H^3$	4.2±1.2
$\rightarrow \Sigma^- \pi^+ dn$	1.6±0.6
$\rightarrow \Sigma^- \pi^+ pnn$	1.4±0.5
$\rightarrow \Sigma^- \pi^0 He^3$	1.0±0.5
$\rightarrow \Sigma^- \pi^0 pd$	1.0±0.5
$\rightarrow \Sigma^- \pi^0 ppn$	1.0±0.4
$\rightarrow \Sigma^- \quad pd$	1.6±0.6
$\rightarrow \Sigma^- \quad ppn$	2.0±0.7
Total $\Sigma^- = (13.8 \pm 1.8)\%$	
$K^- He^4 \rightarrow \pi^- \Lambda \ He^3$	11.2±2.7
$\rightarrow \pi^- \Lambda \ pd$	10.9±2.6
$\rightarrow \pi^- \Lambda \ ppn$	9.5±2.4
$\rightarrow \pi^- \Sigma^0 He^3$	0.9±0.6
$\rightarrow \pi^- \Sigma^0 (pd, ppn)$	0.3±0.3
$\rightarrow \pi^0 \Lambda (\Sigma^0)(pnn)$	22.5±4.2
$\rightarrow \Lambda \ (\Sigma^0) \quad (pnn)$	11.7±2.4
$\rightarrow \pi^+ \Lambda \ (\Sigma^0) nnn$	2.1±0.7
Total $\Lambda \ (\Sigma^0) = (69.2 \pm 6.6)\%$	
Total $= \Lambda + \Sigma = (100_{-7}^{+0})\%$	

Σ^+ 1.0±0.4 %

Σ^- 3.6±0.9 %

Λ 9.4±2.6 %

Σ^0 2.3±1.0 %

PRD 1 (1970) 1267

Old experimental data (2)

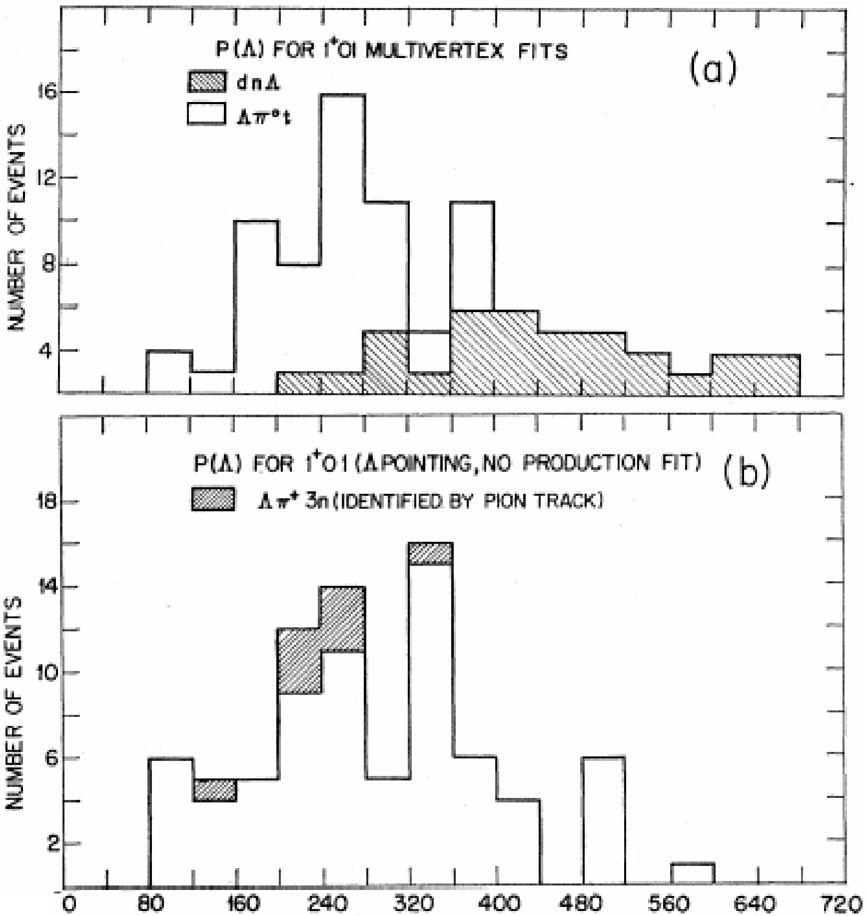
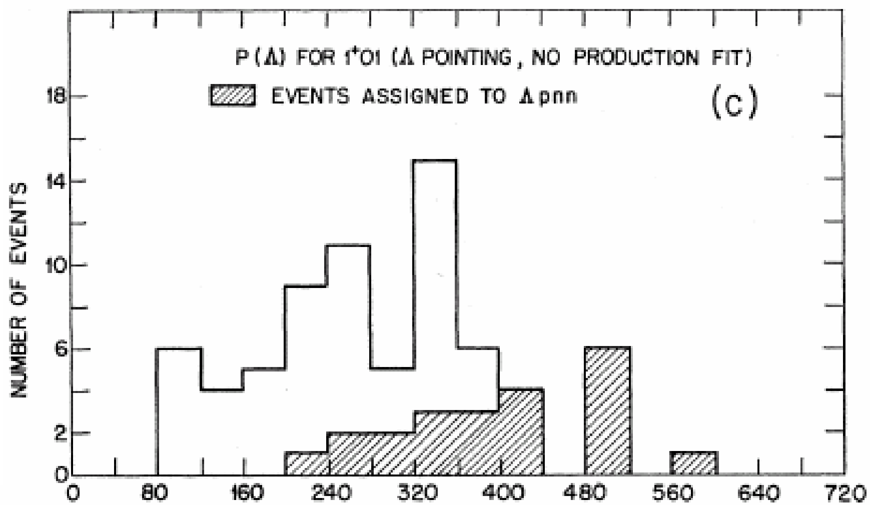


Fig. 2. Fitted Λ momentum for events with a Λ plus one visible positive prong at production is shown in (a) for events giving a multivertex kinematic fit. The $\pi^+\Lambda(\Sigma^0)nnn$ events are removed by identification of the positive prong as a pion as shown in (b). The remaining events which give only a fit to the Λ and no production fit are assigned to $\Lambda(pnn)$ (shaded in graph) or $\pi^0\Lambda(pnn)$ in (c) using the spectrum of (a) as a guide.



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