E15: A Search for a deeply bound kaonic nuclear state by the in-flight $^3He(K^-,n)$ reaction at J-PARC

--- 2nd presentation ---

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M. Iwasaki

OUTLINE of the FIRST PAC presentation

- ***Physics motivation***
  - *theoretical background*
  - *experimental situation*
- ***Experimental procedure***
  - *in-flight* ^{3}He(K^{-}, n)
    - *missing-mass with neutron counter wall*
    - *invariant-mass with CDS*
- ***Beam request***
  - *~ one month @ 9 μA*

    5.5 weeks + 2 (for commissioning)

STAGE1 approval

FIFC presented by H. Ohnishi

Items to be addressed...

requested by previous PAC-report

- Relation with E549/E570 result

better understanding of the previous experiment

- Any change in strategy?

OBJECTIVE
of E549 + E570

1. Confirmation of S^0

2. $^4He(K^-_{stop}, n)$ spectroscopy

higher redundancies

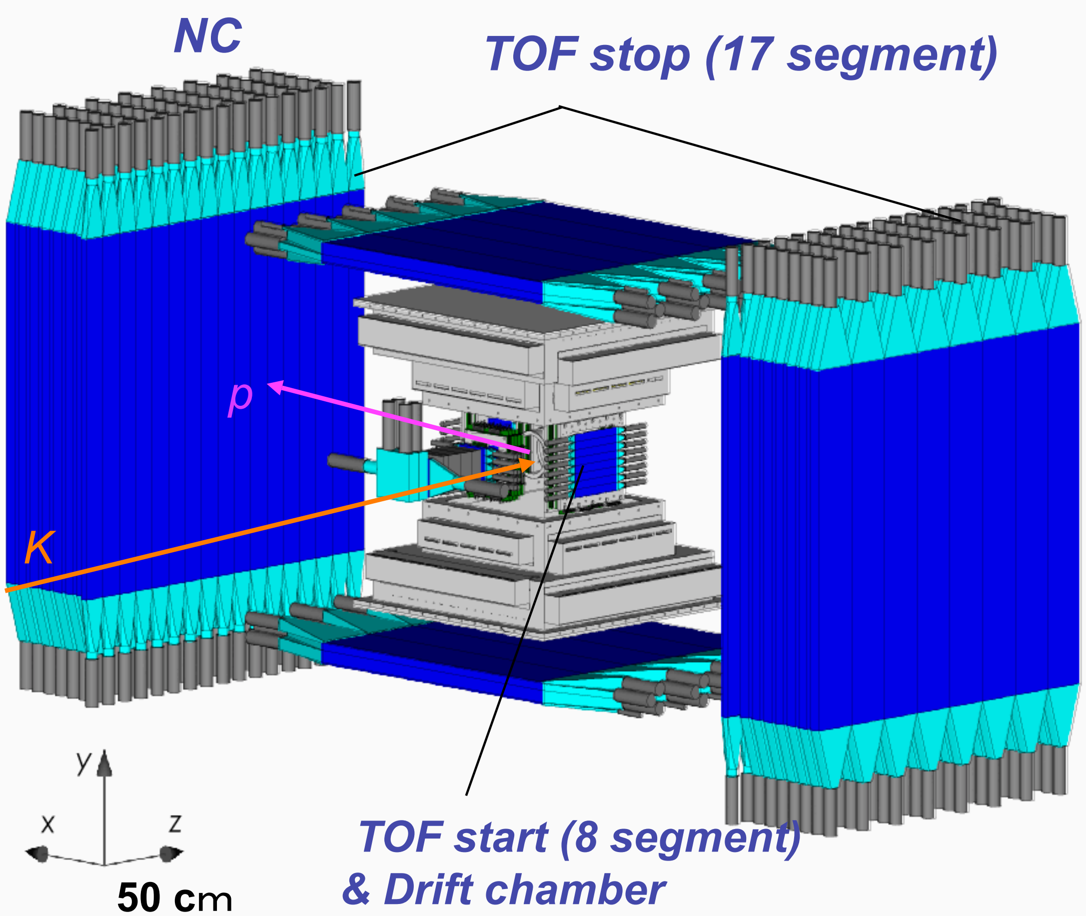
higher statistics P x 20 n x 6

better resolution P 300 -> 120 ps
n 300 -> 200 ps

inclusive for proton

E549/E570 Experimental Setup

12GeV PS K5   Data taking : 2005 May 25th – Jul. 1st



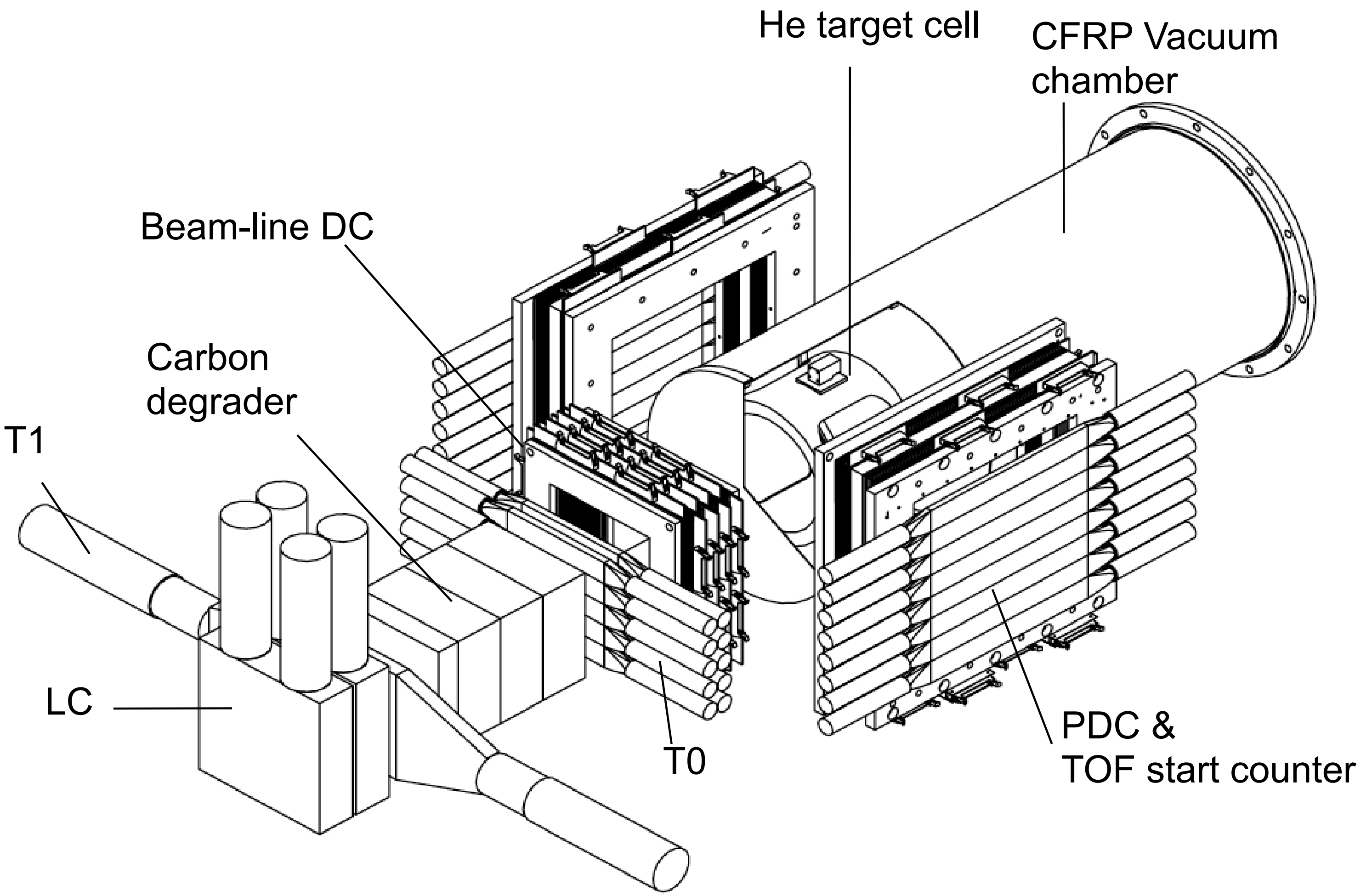
K^- momentum : 660 MeV/c
K- beam : 5K/spill
π^-/K^- ratio: ~200

Lucite Cherenkov
: π/ K separation
Beam line DC
: K tracking

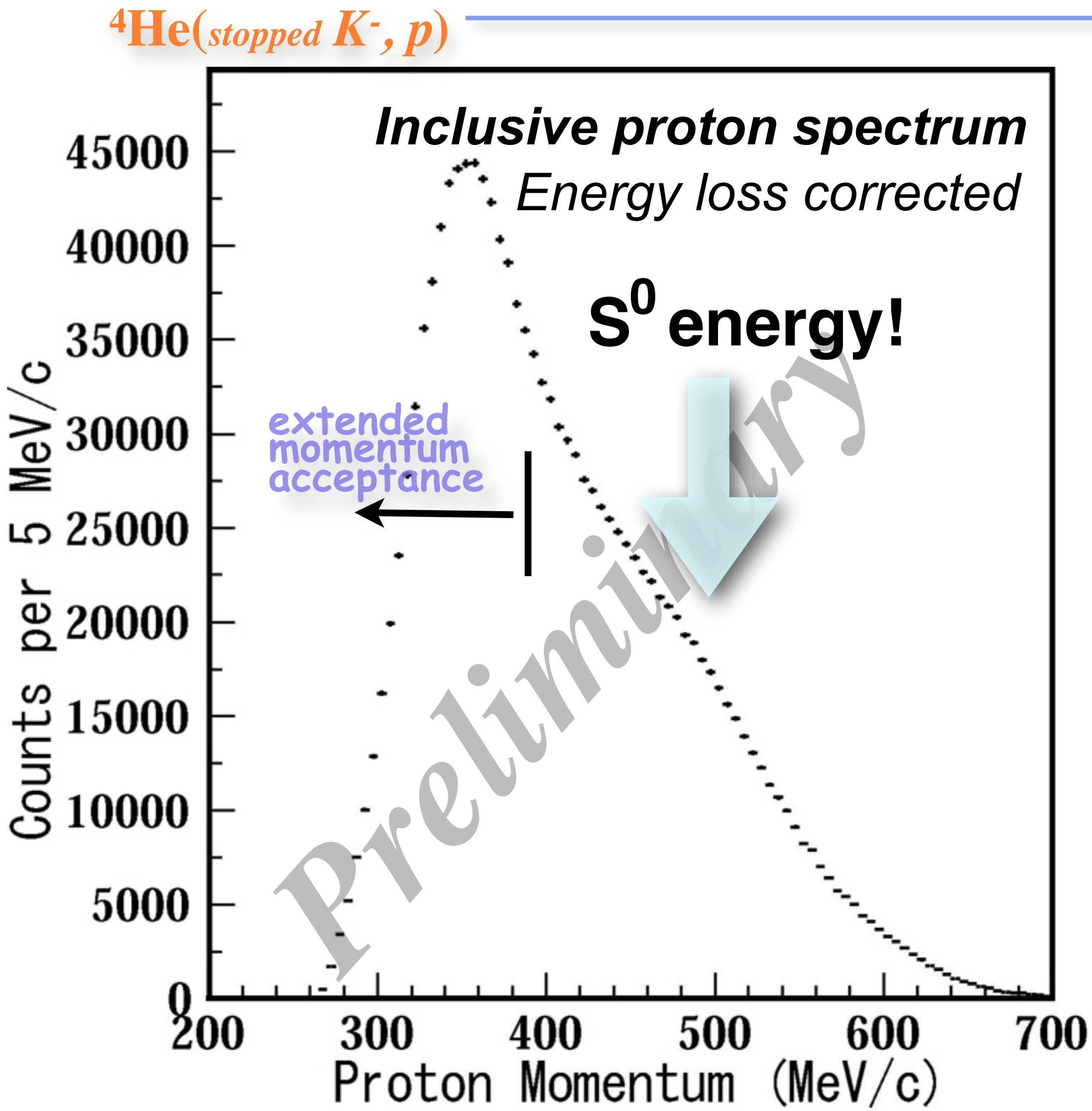
TOF counter
p : TOF path ~1.6m
n : TOF path > 2m

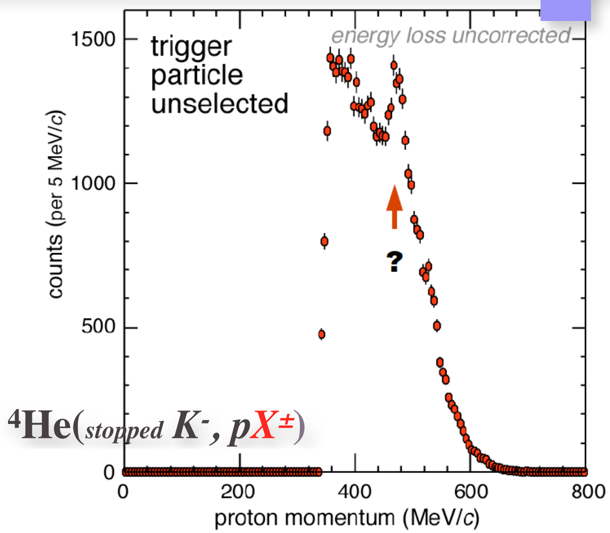
^{4}He(K^-_{stop} , p) inclusive measurement: (K × $TOF_{charged}$)

E549/E570 Experimental Setup - II



^{4}He(*stopped* K^-, *p*) proton inclusive spectrum

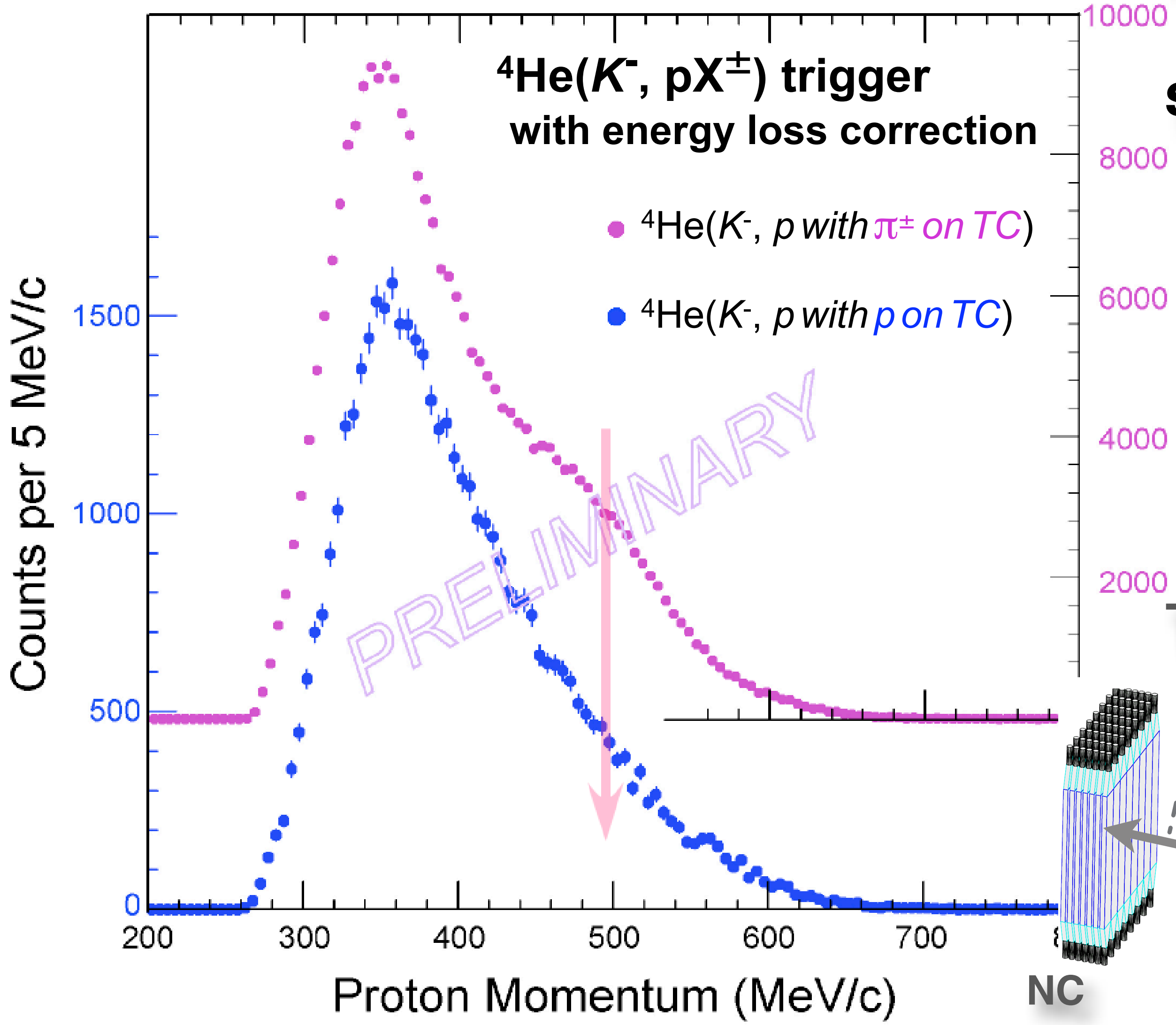




compared to E471

- higher redundancies
- higher statistics
- better resolution
- inclusive for proton
- wider mom. acceptance

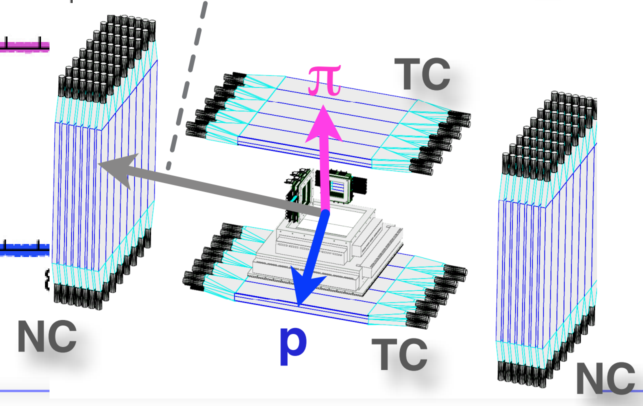
Proton spectrum by requesting X± on TC



same as E471

comparison with E471

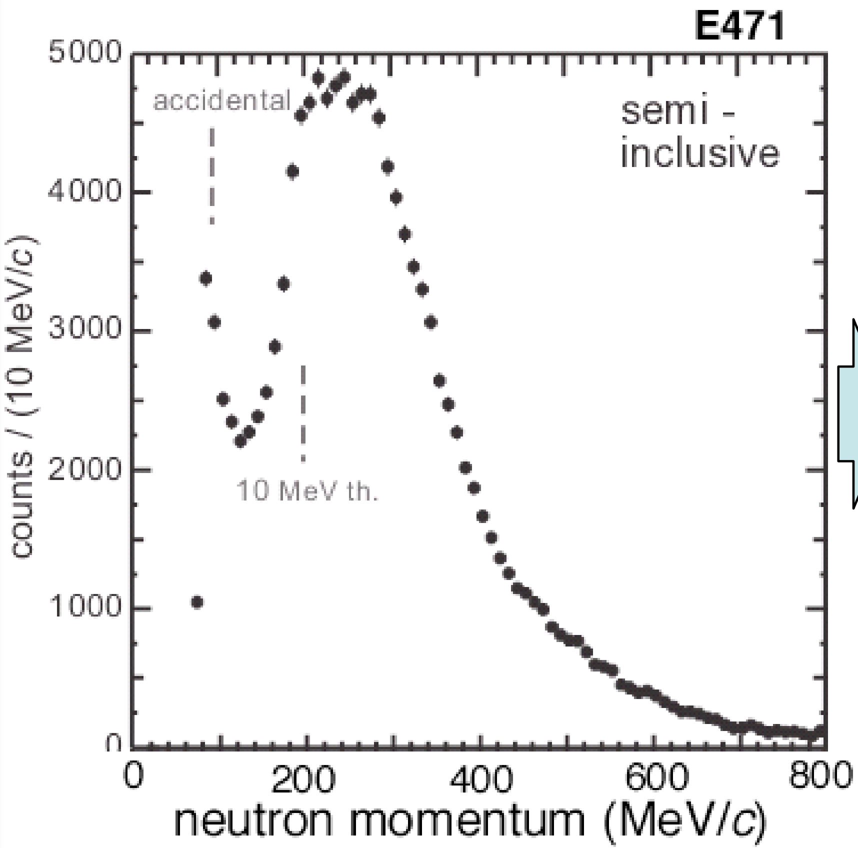
TOF measured p

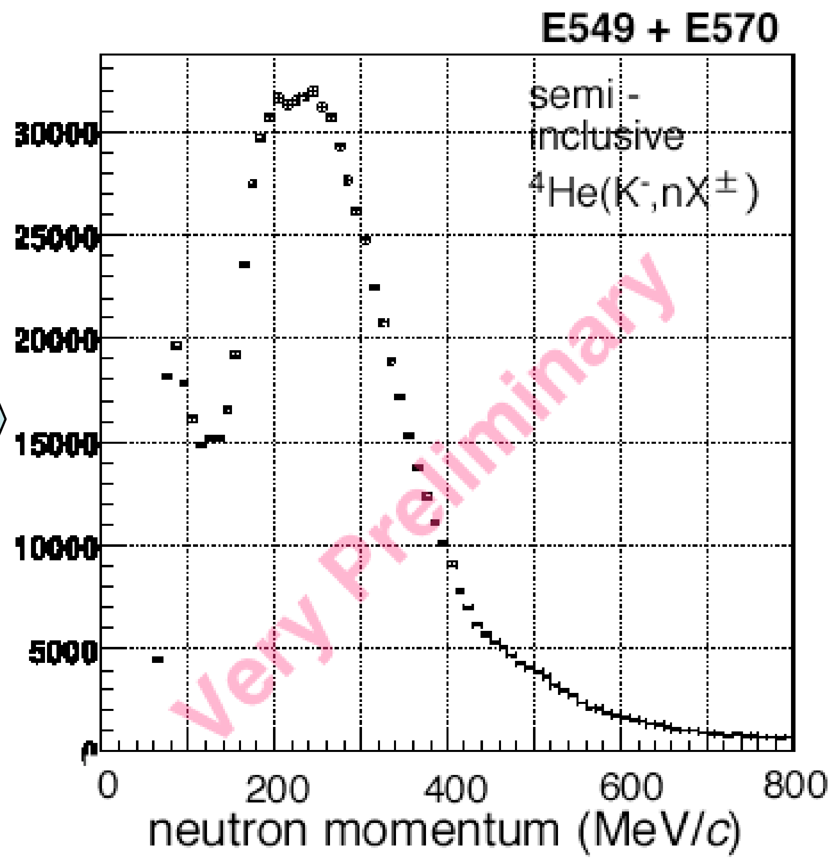


Neutron spectrum

No narrow peak in semi-inclusive spectrum
(~20MeV)

~ 6 times higher statistics
~30% better resolution





Why E471 gave Peak in proton spectrum?

already presented at ...

ECT* / HYP / JSPS / YKIS / KEK PS-PAC

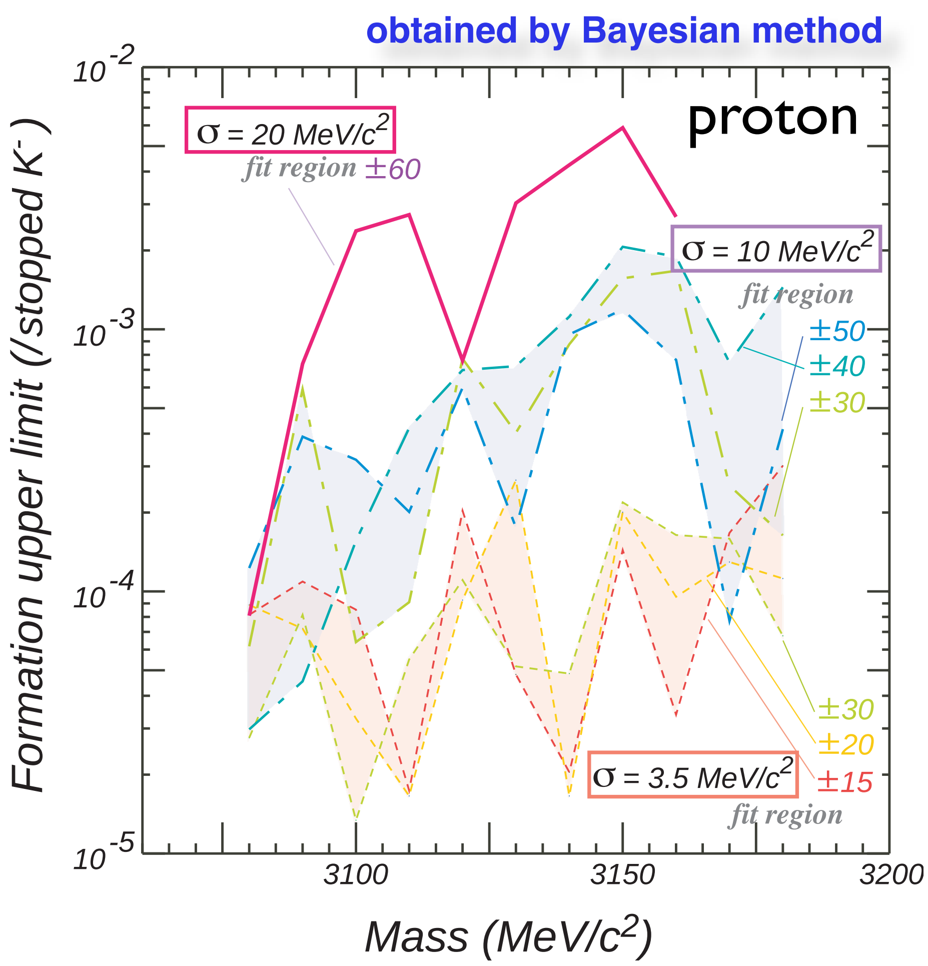
1. Peak in proton spectrum is likely an experimental artifact

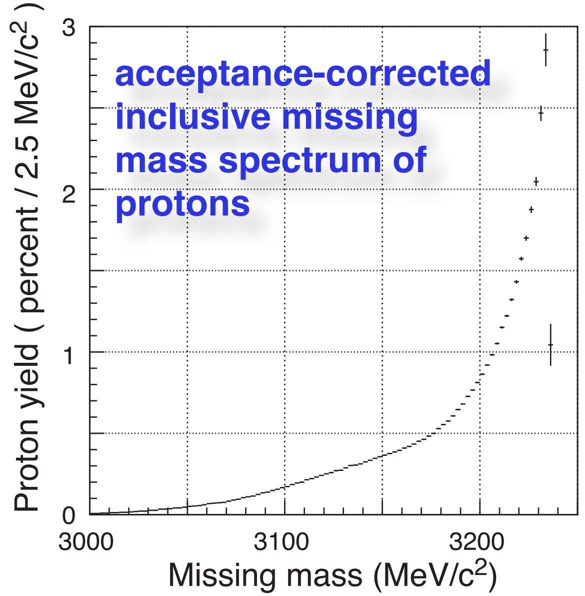
   due to PMT time response for huge pulses

2. E471 data re-analysis is impossible

3. No such effect is expected in neutron spectrum

Upper limit of peak formation yield





$\Gamma \sim 46 MeV/c^2$	$\lesssim 10^{-2}$
$\Gamma \sim 23 MeV/c^2$	$\lesssim 10^{-3}$
$\Gamma \sim 10 MeV/c^2$	$\lesssim 10^{-4}$

Narrow structure is excluded

Although...

1. Do not have sensitivity for wider structure

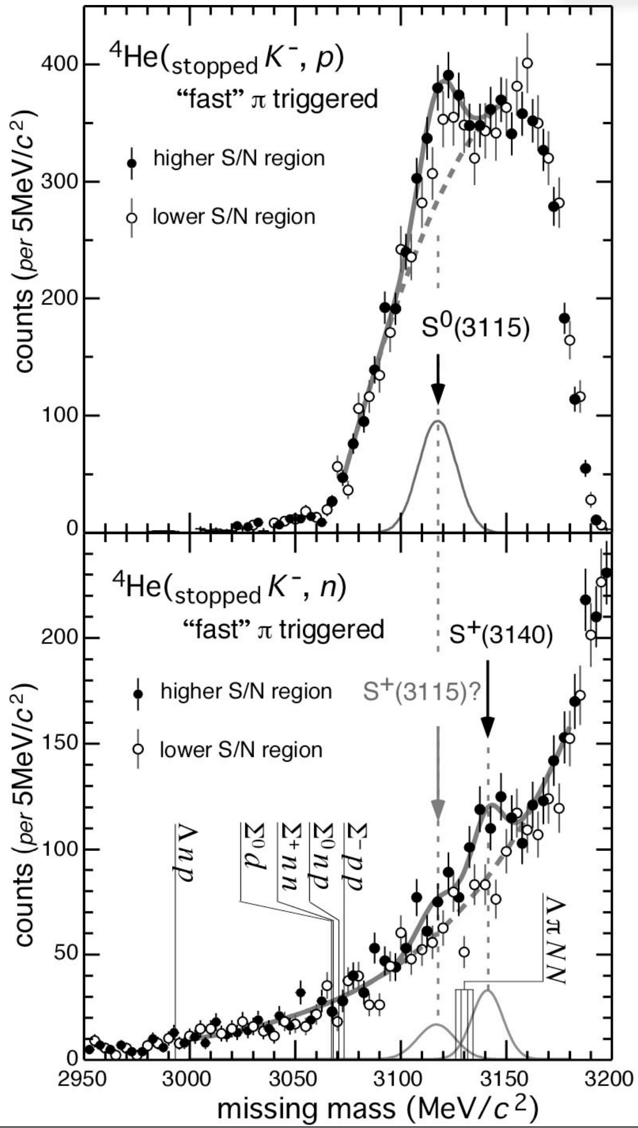
   poor S/N for stopped K reaction

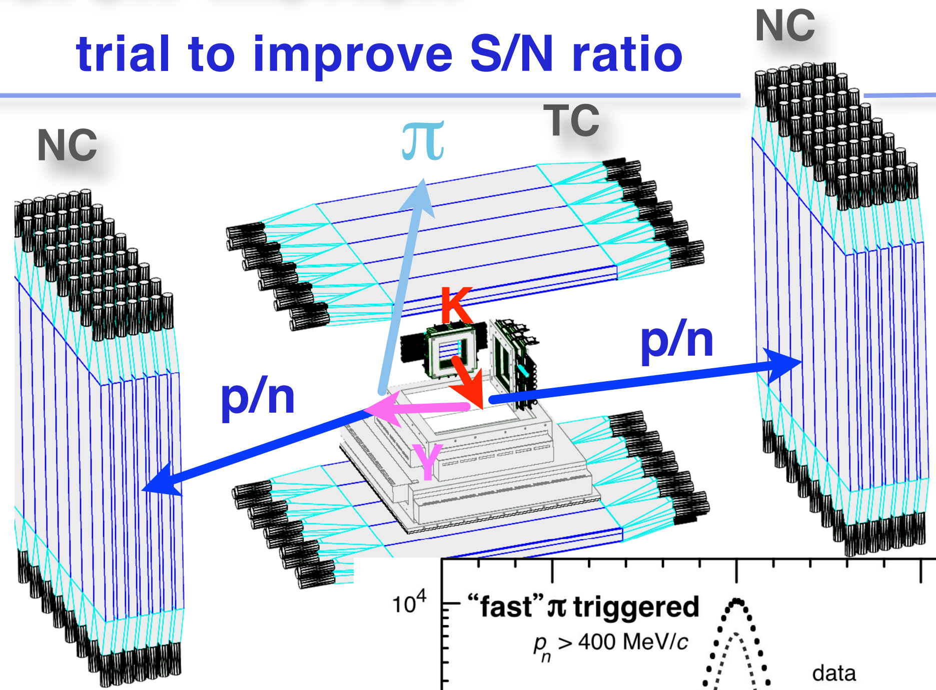
2. Study with decay particles recorded on TC

   in progress...

Analysis with hyperon motion

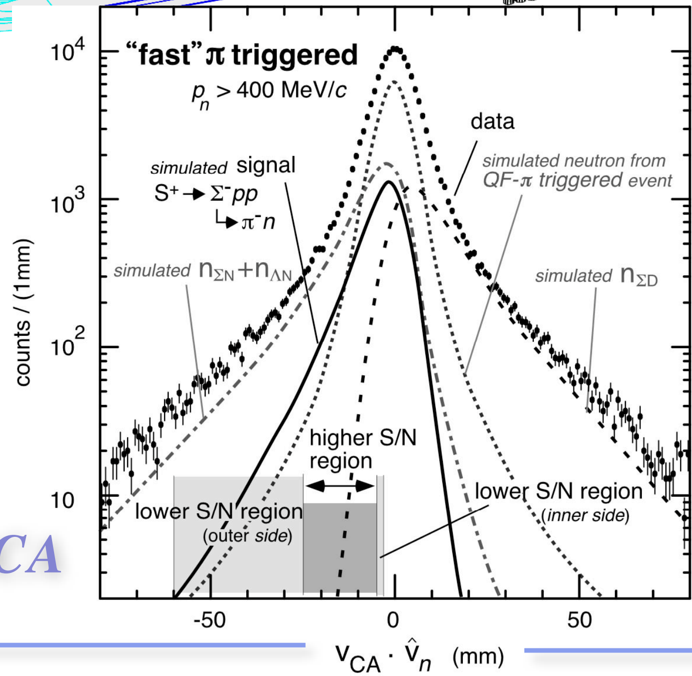
trial to improve S/N ratio



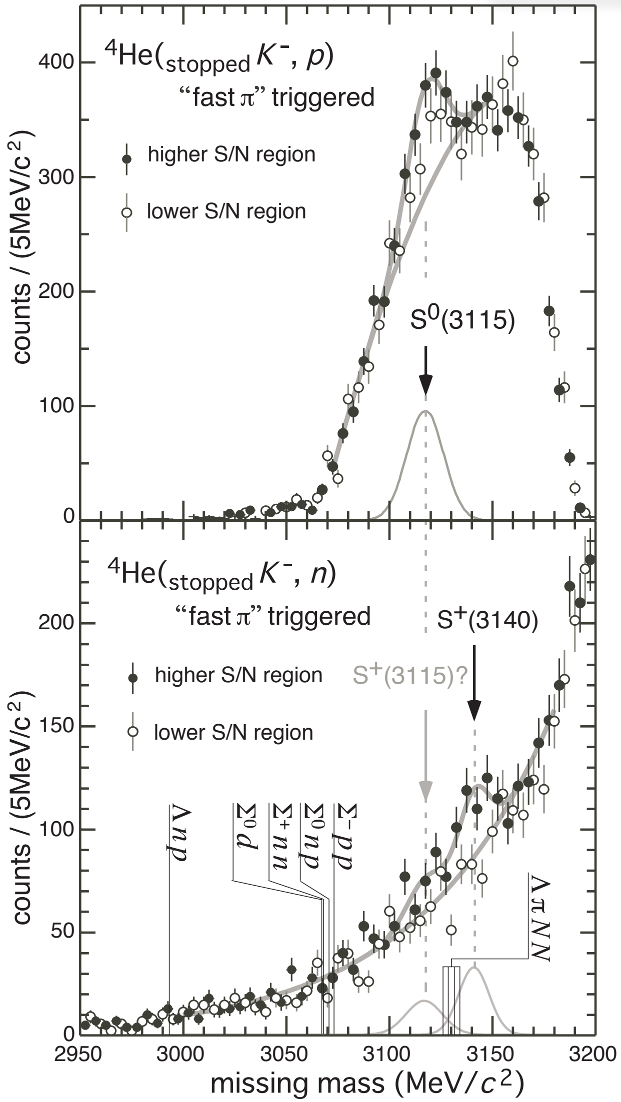


$v_{CA} \cdot \hat{v}_N$

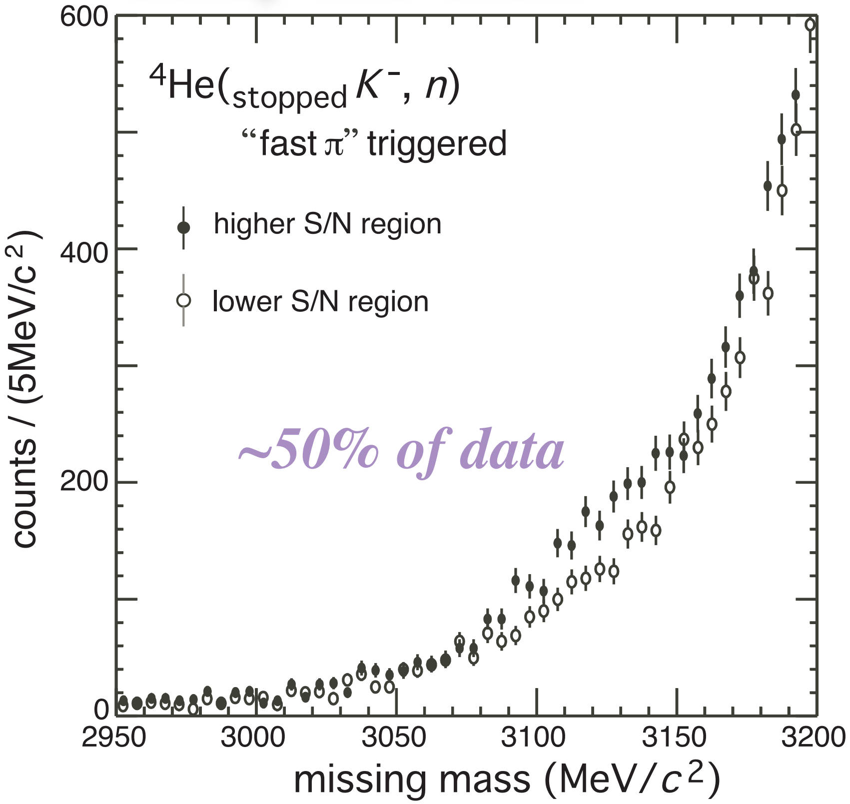
~ signed DCA



Analysis with hyperon motion - II



neutron spectrum of
side-band analysis
with Σ-backward
decay-like event



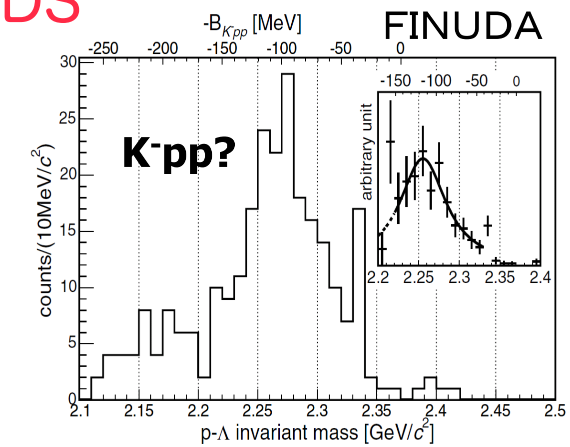
Perfect Exp. @ J-PARC

$$K^- + {}^3\mathrm{He} \rightarrow \langle K^- pp \rangle + n$$ neutron counter wall

$$\langle K^- pp \rangle \rightarrow \Lambda + p$$

$$\Lambda \rightarrow \pi^- + p$$

} CDS



1. In-flight method
   better S/N suppress QF-KNN background!
2. Exclusive
   detect both formation and decay
3. Most fundamental system
   avoid complex spectral structure

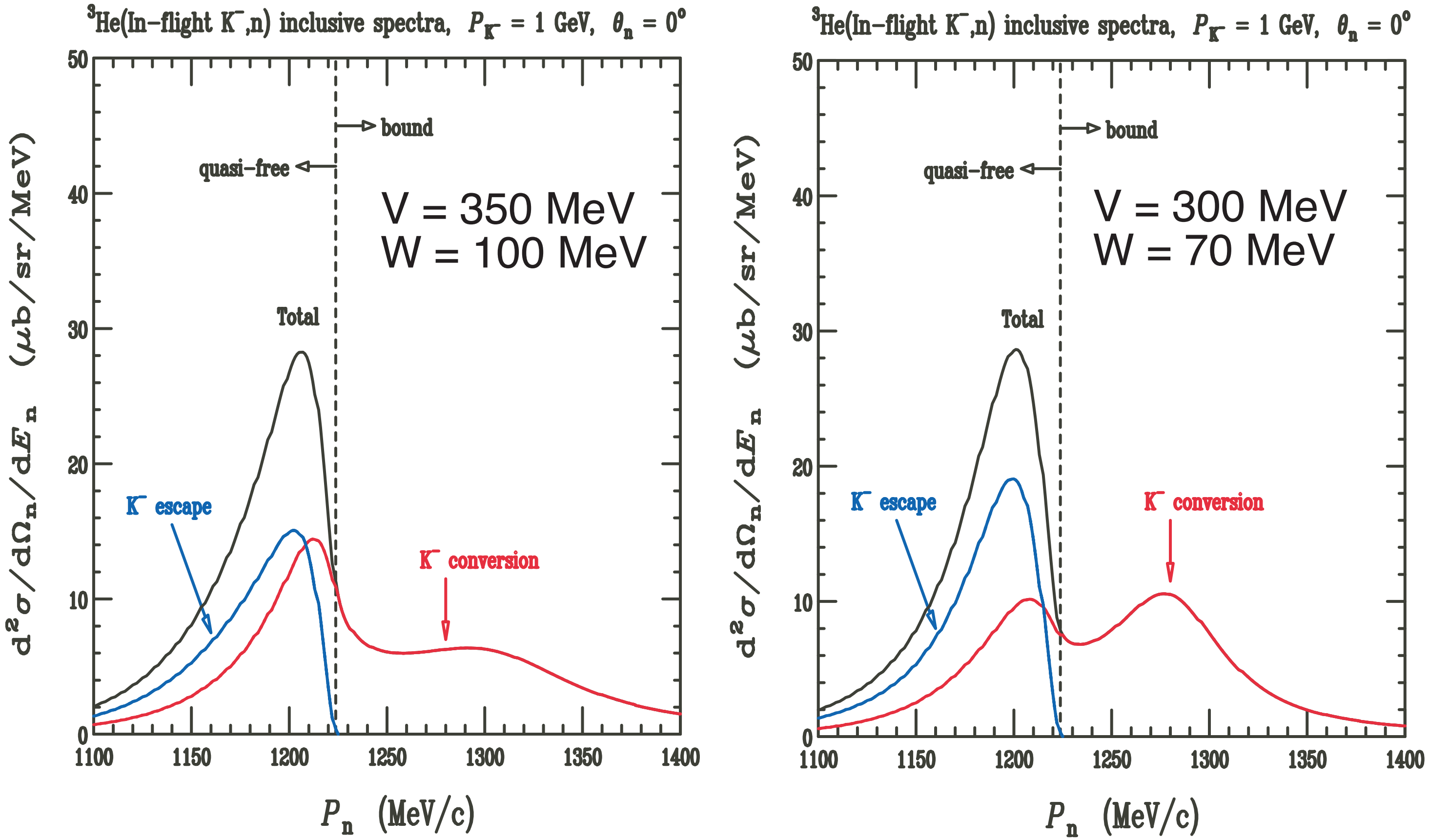
Recent theoretical progress

	method	**B.E.**	Γ
Akaishi, Yamazaki PLB**535** (2002) 70	ATMS	48 MeV	61 MeV
K. Swe Mynt, Akaishi APFB05	Gaussian base Rearrangement-channel		
Ivanov, Kinle, Marton, Widmann nucl-th/0512037	Field theoretic approach	115 MeV	28 MeV
Dote, Weise YKIS06	AMD		
Ikeda, Sato HYP06	Faddeev	55 MeV	40 MeV
Arai, Yasui, Oka JPS06-2	Λ* N model	87 MeV	
Shevchenko, Gal, Mares nucl-th/0610022	Faddeev	55-70 MeV	95-110 MeV

Kaon will be bound but wider in width

DWIA based spectral function

Koike & Harada



Signal is well separated from QF channel

Items to be addressed : answer

requested by previous PAC-report

- *Relation with E549/E570 result*

- *wider* ($\gtrsim$40 MeV/c^2) *structure is not excluded*
- *side-band S/N comparison gives enhancement*
- *stopped-K method: large background contamination*

- *Any change in strategy?*

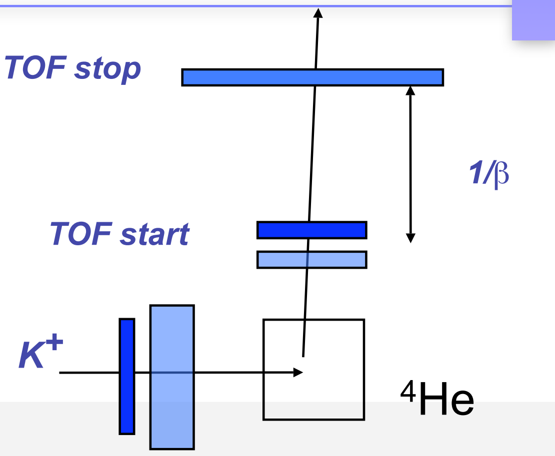
- *K^-pp is the simplest system (cf. FINUDA data)*
- *"background-free" spectroscopy*
  (formation & missing-mass)
- *no change in strategy for the search*

Thank you!

SPARE

TOF calibration with stopped K^+ events

ü4He(K^+_{stop} , $X^\pm$) reaction



mono-chromatic (1/β)

μ^+ ($K^+_{\mu 2}$: $K^+ \rightarrow \mu^+ \nu$,	63.43 %)
π^+ ($K^+_{\pi 2}$: $K^+ \rightarrow \pi^+ \pi^0$,	21.13 %)
e^+ (K^+_{e3} : $K^+ \rightarrow \pi^0 e^+ \nu$	4.87 %)

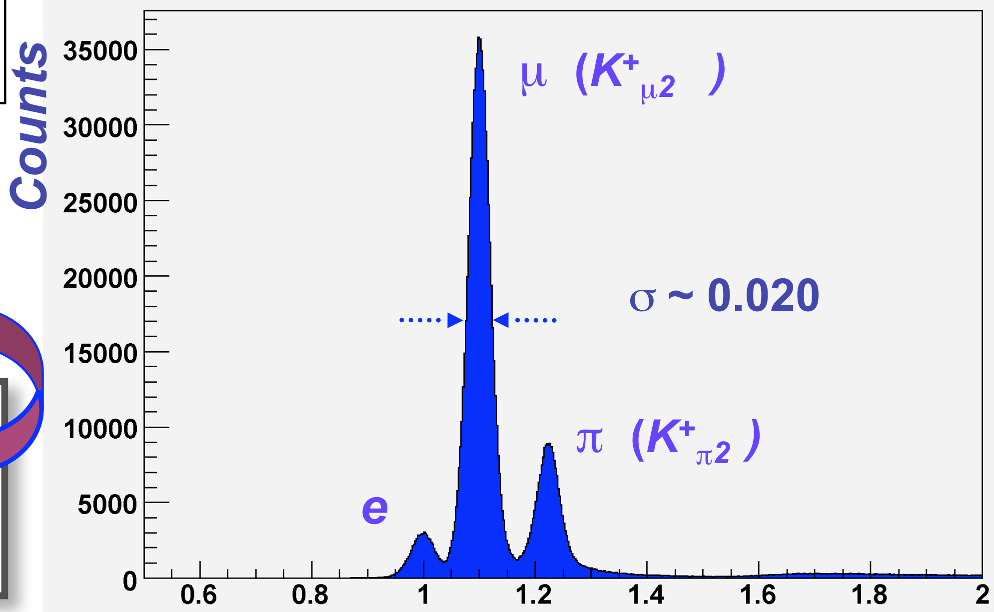
1/β 分解能

σ ~ 0.020 (Kμ2 peak width)

For proton…

Missing mass resolusoin
σ～3.5 MeV/c²
@Mass of S⁰

Twice improved



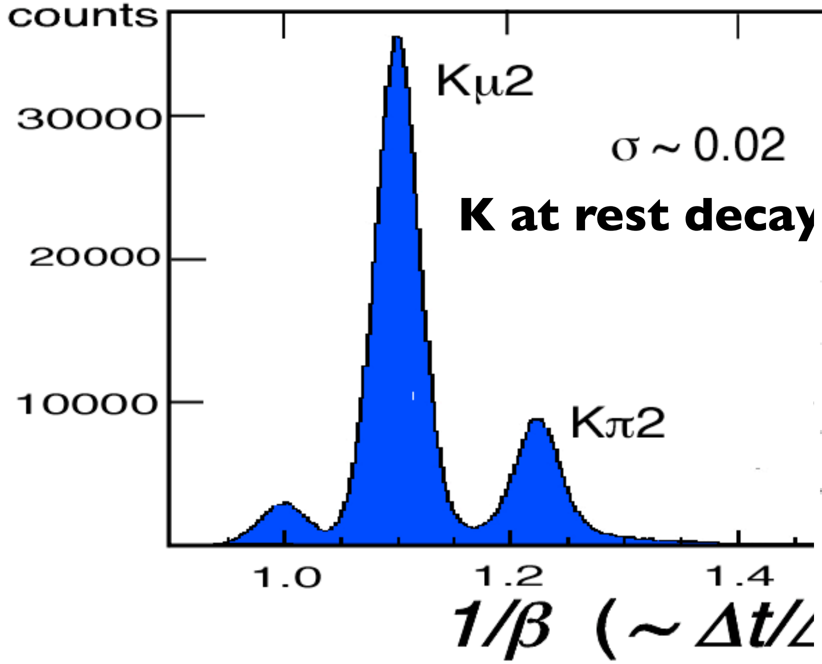
1/β distribution

Why E471 gives Peak in proton spectrum?

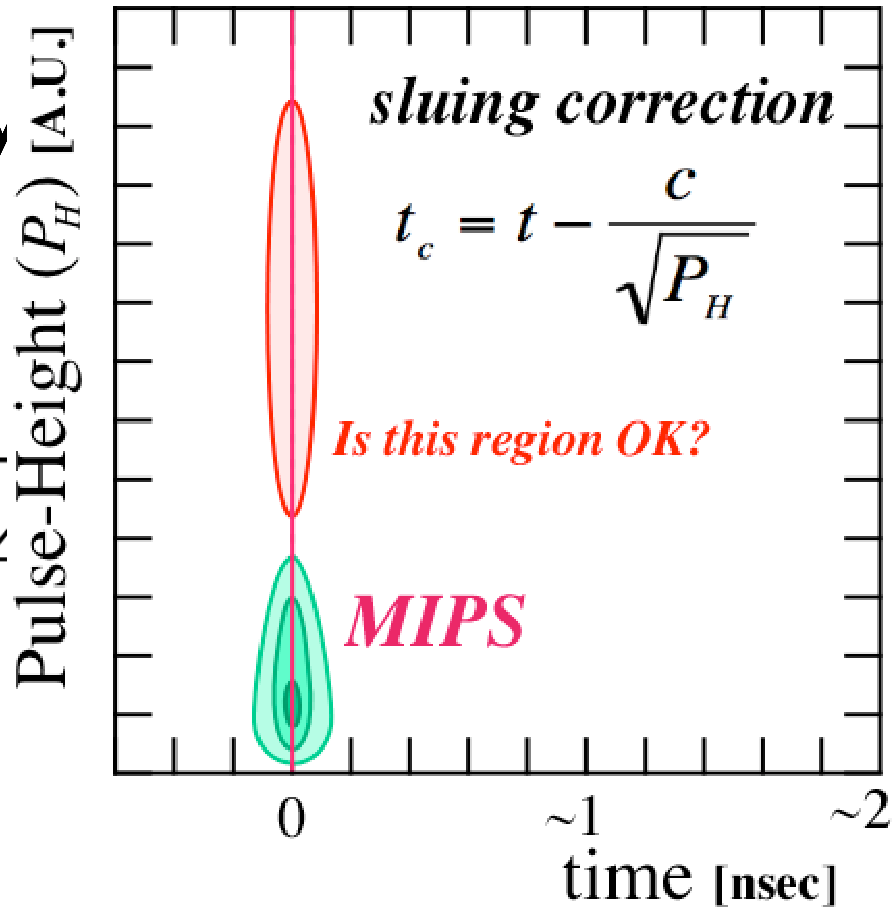
Why narrow peak in E471?

TOF analysis procedure

How actual signal from PMT looks like ...



Question is :

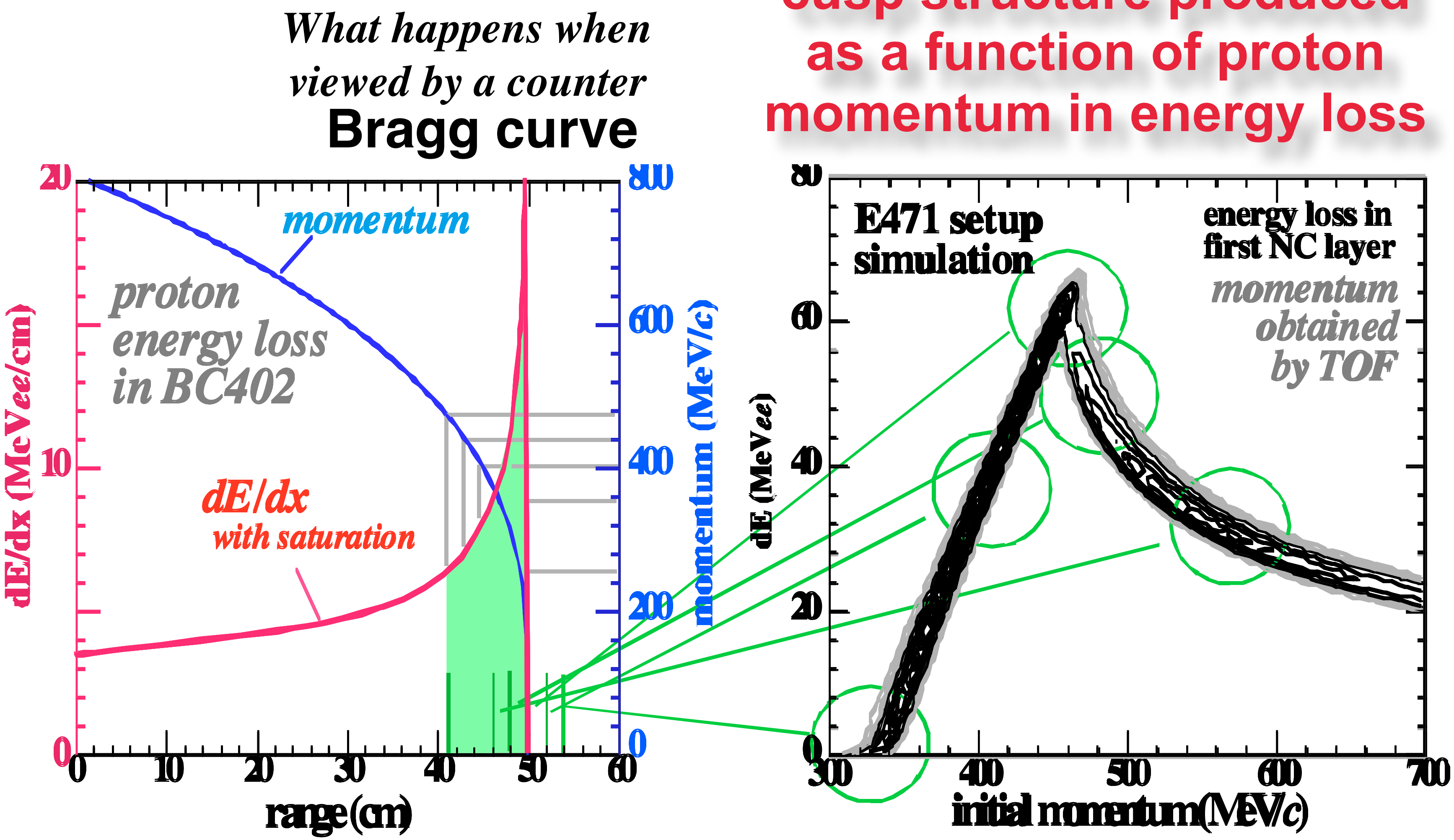


Slewing correction
needed ...
applied!

Very nice resolution achieved!

Why narrow peak in E471?

cusp structure produced as a function of proton momentum in energy loss

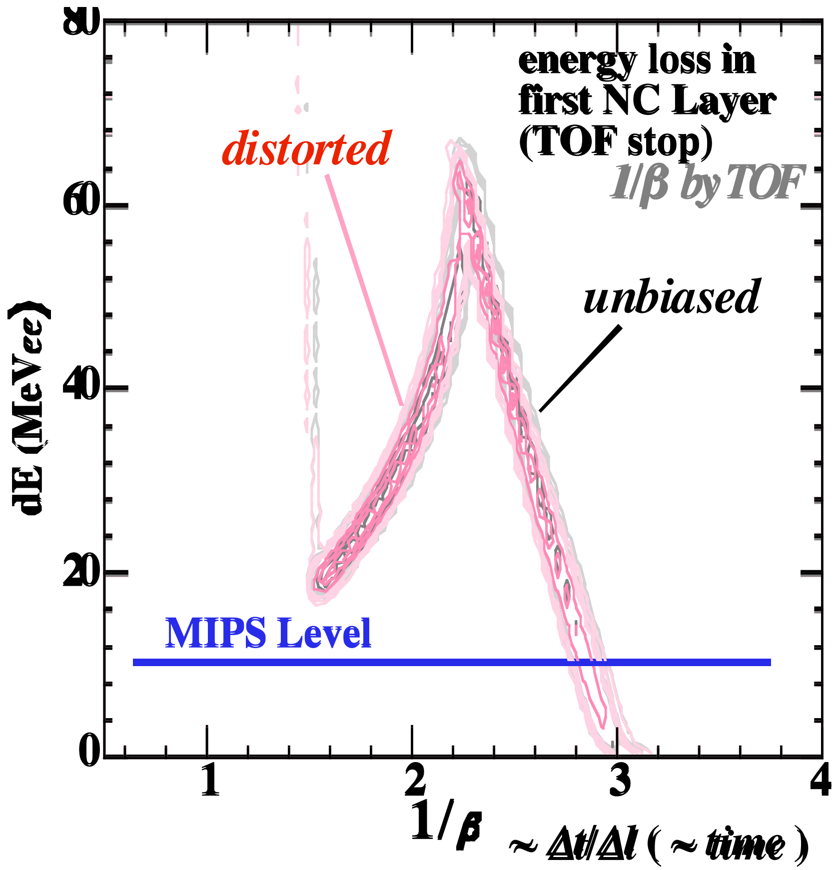


Why narrow peak in E471?

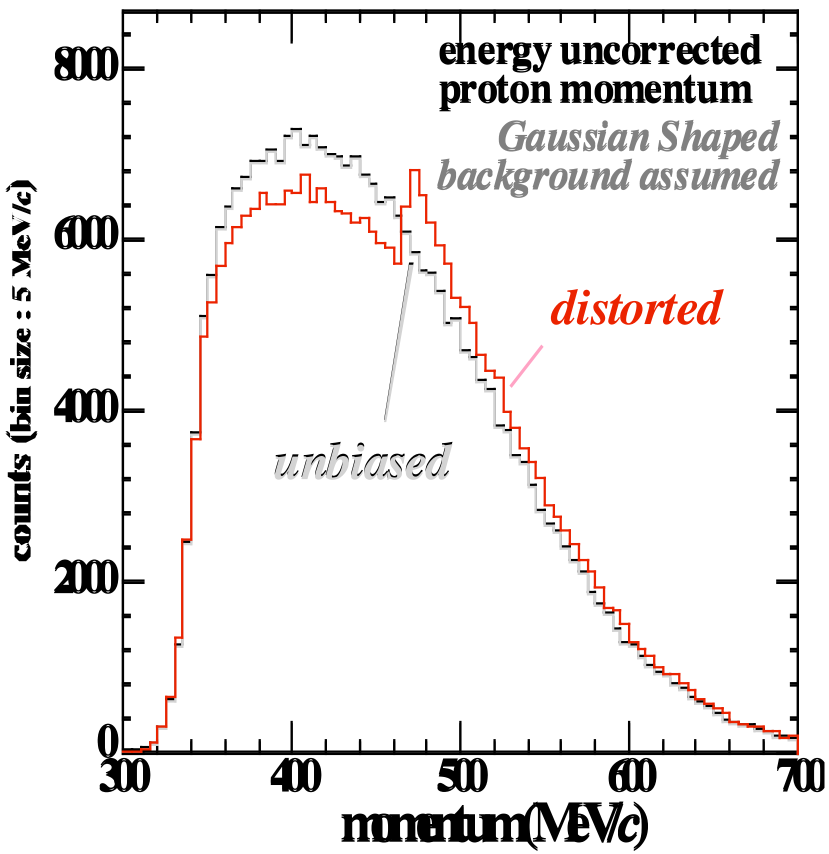
What happens if time correction is slightly imperfect?

Assuming distortion as small as
5 ps/MeVee

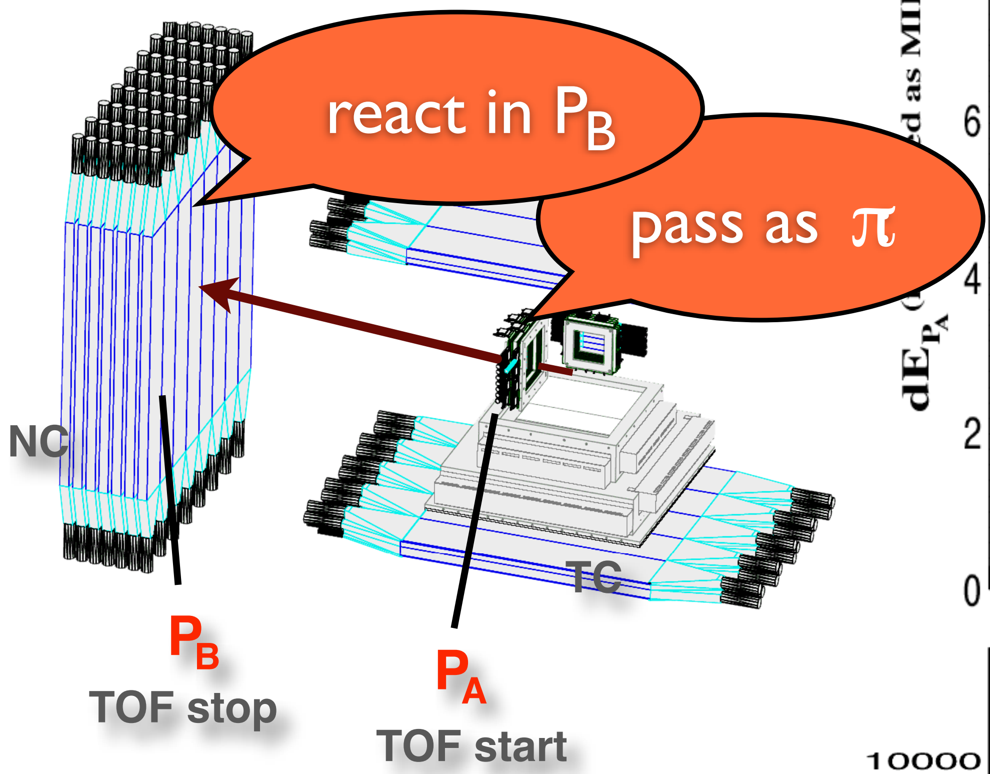
simulation

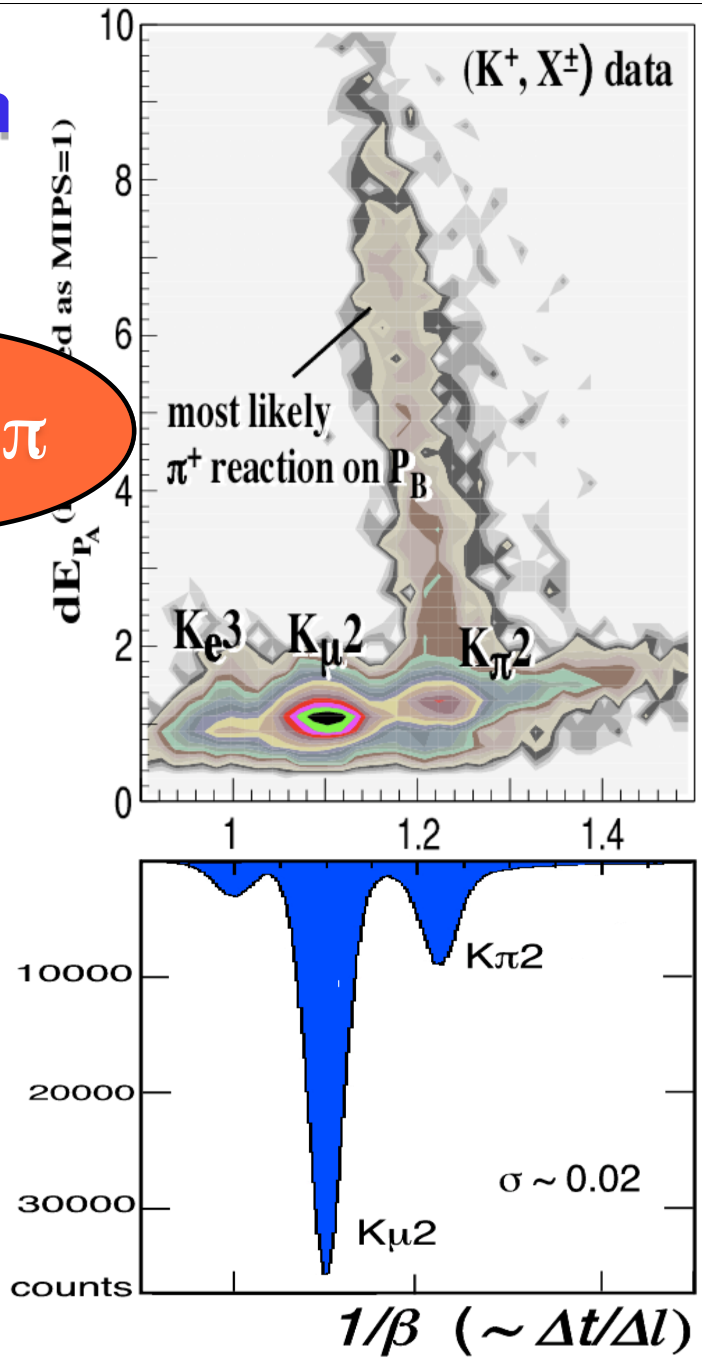


simulation



Why narrow peak in





data available only
in E549/E570

Why E471 gave Peak in proton spectrum?

1. Peak in proton spectrum is most likely experimental bias
2. E471 data re-analysis is impossible!
3. No such effect is expected in neutron spectrum

Decay particle study

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

$\rightarrow n + \pi^+$

$\rightarrow p + \pi^0$

$\Sigma^+ N \sim 1\%$

$K^- pp \rightarrow \Lambda(\Sigma 0)\ p$

$\rightarrow p + \pi^-$

$\rightarrow n + \pi^0$

$K^- pn \rightarrow \Lambda(\Sigma 0)\ n$

$\rightarrow p + \pi^-$

$\rightarrow n + \pi^0$

$\Lambda N \sim 12\%$

$K^- pn \rightarrow \Sigma^- p$

$\rightarrow n + \pi^-$

$\Sigma^- N \sim 4\%$

$K^- nn \rightarrow \Sigma^- n$

$\rightarrow n + \pi^-$

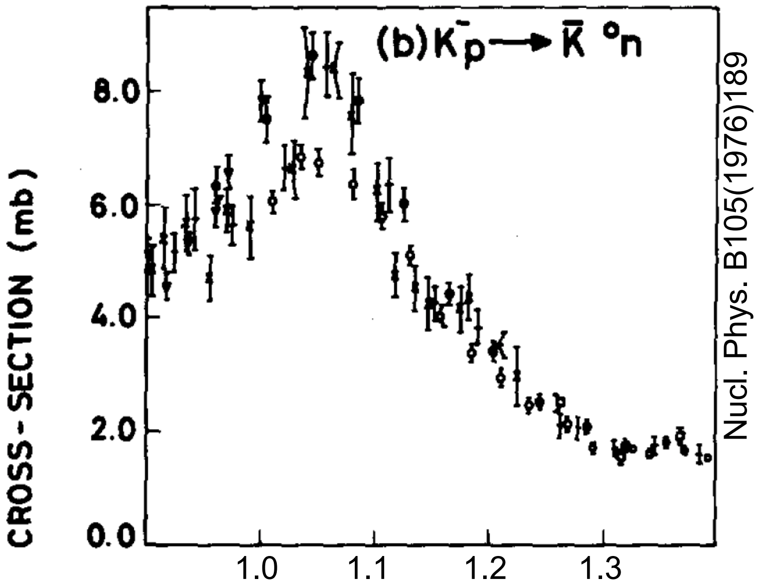
How to calibrate the neutron detector?

Absolute momentum scale calibration for Neutron counter

Charge exchange reaction, p(K^-,n),K_S^0 , will be used. (w/ CH2 target)

Large cross section with
1 GeV/c momentum K^- beam.

～ 6 mb



Known:

- incident K- beam momentum
- K_S^0 momentum measured by CDC

Reconstruct expect neutron momentum:

from K0 in CDC + incident K^- beam momentum

compare

Expected neutron momentum

Measured neutron momentum

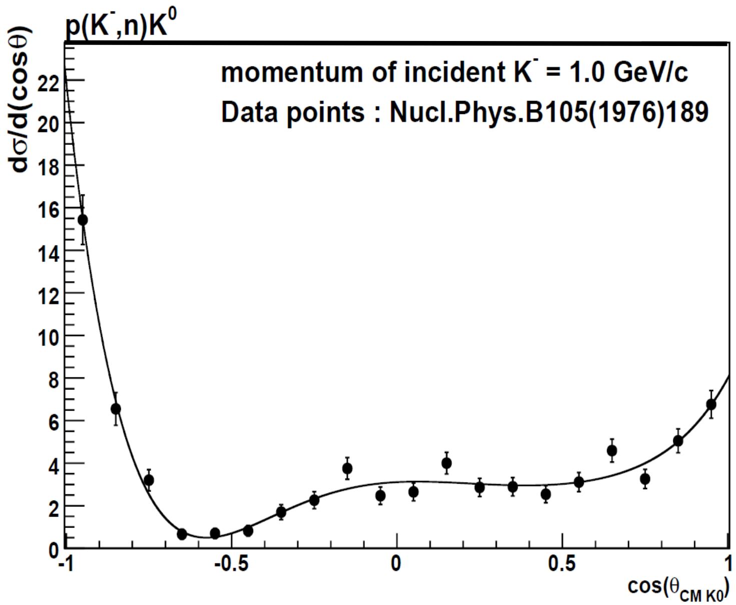
$p(K^-,n),K_S^0$ process in simulation

Differential cross section of the process :

Parameters given in
Nucl. Phys. B105(1976) 189 are used.

E15 detector simulation
(GEANT4 base)

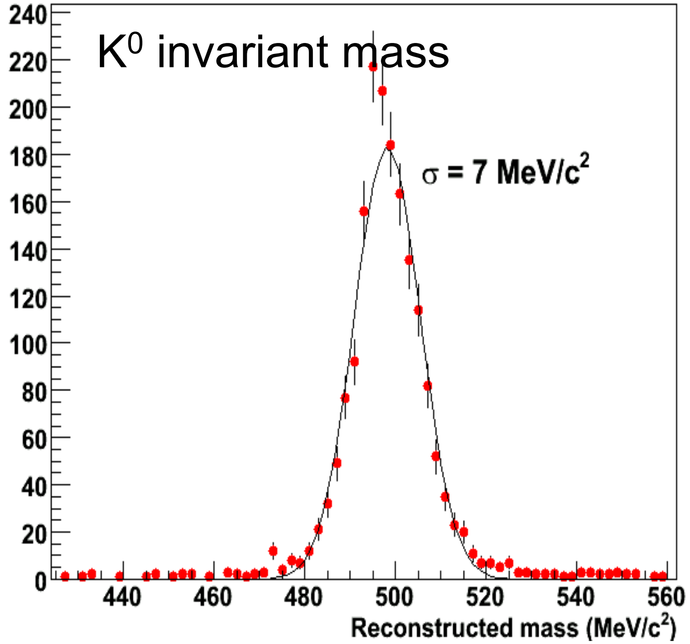
Expected number of interactions per hour



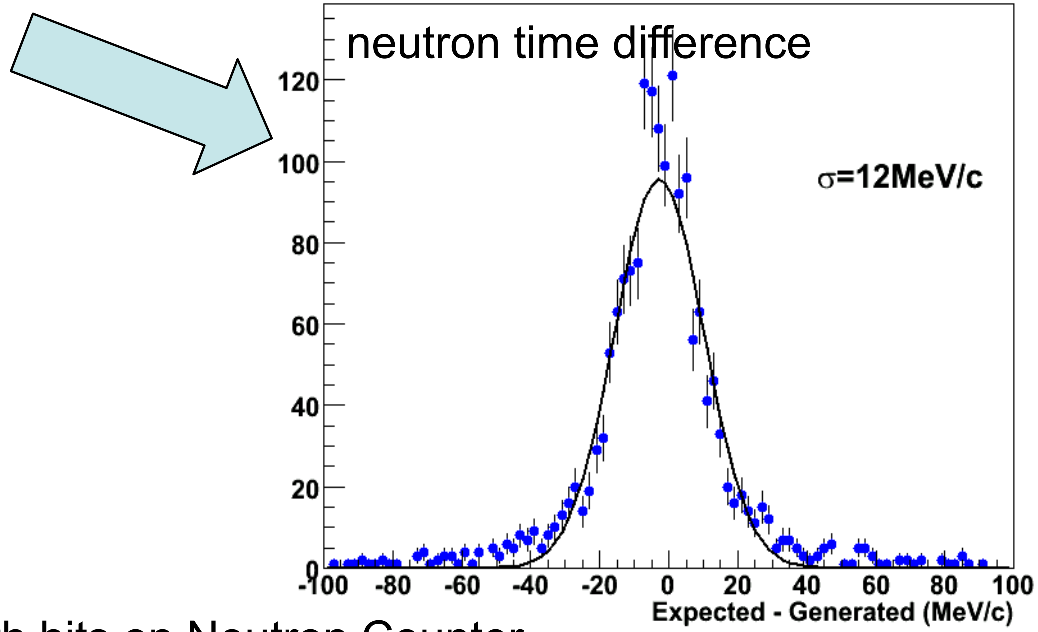
• Designed spill length of J-PARC PS @30 GeV operation	3.64s
• Number of spills per hour	989 spills
• Beam intensity	0.8Mk/spill
• Total cross section of the process, $p(K^-,n),K_S^0$,	6 mb
• CH_2 target 1g/cm^2	

Expected number of interaction = 4.1×10^5 interaction per hour

K_S^0 reconstruction



Calculate expected neutron momentum from reconstructed K_S^0 momentum and compared with generated "true" neutron momentum



Expected number of events with
K_S^0 reconstructed in CDC and with hits on Neutron Counter
(Neutron Counter efficiency = 30%; assumption)

4.3×10^{-3} event/interaction = 1.8×10^{3} events/hour