Status of kaonic nucleus search experiment (E15) at J-PARC

RIKEN H. Outa

for E15 collabolation

- ✔ **Kaonic nuclear experiments**

- ✔ ***Present status* of the E15 experiment at J-PARC**

  Search for the K-pp bound state in the 3He(in-flight K-, n/p) reaction

  - **3He(in-flight K-, n) spectrum** — **Hashimoto**
  - **3He(in-flight K-, p) spectrum** — **Tokuda**
  - **Λp+n(missing) channel analysis** — **Sada**

J-PARC E15 collaboration

S. Ajimura[a], G. Beer[b], H. Bhang[c], M. Bragadireanu[e], P. Buehler[f], L. Busso[g,h], M. Cargnelli[f], S. Choi[c], C. Curceanu[d], S. Enomoto[i], D. Faso[g,h], H. Fujioka[j], Y. Fujiwara[k], T. Fukuda[l], C. Guaraldo[d], T. Hashimoto[k], R. S. Hayano[k], T. Hiraiwa[a], M. Iio[o], M. Iliescu[d], K. Inoue[i], Y. Ishiguro[j], T. Ishikawa[k], S. Ishimoto[o], T. Ishiwatari[f], K. Itahashi[n], M. Iwai[o], M. Iwasaki[m,n*], Y. Kato[n], S. Kawasaki[i], P. Kienle[p], H. Kou[m], Y. Ma[n], J. Marton[f], Y. Matsuda[q], Y. Mizoi[l], O. Morra[g], T. Nagae[j$], H. Noumi[a], H. Ohnishi[n], S. Okada[n], H. Outa[n], K. Piscicchia[d], M. Poli Lener[d], A. Romero Vidal[d], Y. Sada[j], A. Sakaguchi[i], F. Sakuma[n], M. Sato[n], A. Scordo[d], M. Sekimoto[o], H. Shi[k], D. Sirghi[d,e], F. Sirghi[d,e], K. Suzuki[f], S. Suzuki[o], T. Suzuki[k], K. Tanida[c], H. Tatsuno[d], M. Tokuda[m], D. Tomono[n], A. Toyoda[o], K. Tsukada[r], O. Vazquez Doce[d,s], E. Widmann[f], B. K. Weunschek[f], T. Yamaga[i], T. Yamazaki[k,n], H. Yim[t], Q. Zhang[n], and J. Zmeskal[f]

(a) Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan
(b) Department of Physics and Astronomy, University of Victoria, Victoria BC V8W 3P6, Canada
(c) Department of Physics, Seoul National University, Seoul, 151-742, South Korea
(d) Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy
(e) National Institute of Physics and Nuclear Engineering - IFIN HH, Romania
(f) Stefan-Meyer-Institut für subatomare Physik, A-1090 Vienna, Austria
(g) INFN Sezione di Torino, Torino, Italy
(h) Dipartimento di Fisica Generale, Universita' di Torino, Torino, Italy
(i) Department of Physics, Osaka University, Osaka, 560-0043, Japan
(j) Department of Physics, Kyoto University, Kyoto, 606-8502, Japan
(k) Department of Physics, The University of Tokyo, Tokyo, 113-0033, Japan
(l) Laboratory of Physics, Osaka Electro-Communication University, Osaka, 572-8530, Japan
(m) Department of Physics, Tokyo Institute of Technology, Tokyo, 152-8551, Japan
(n) RIKEN Nishina Center, RIKEN, Wako, 351-0198, Japan
(o) High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan
(p) Technische Universität München, D-85748, Garching, Germany
(q) Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, 153-8902, Japan
(r) Department of Physics, Tohoku University, Sendai, 980-8578, Japan
(s) Excellence Cluster Universe, Technische Universität München, D-85748, Garching, Germany
(t) Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, 139-706, South Korea

(*) Spokesperson
($) Co-Spokesperson

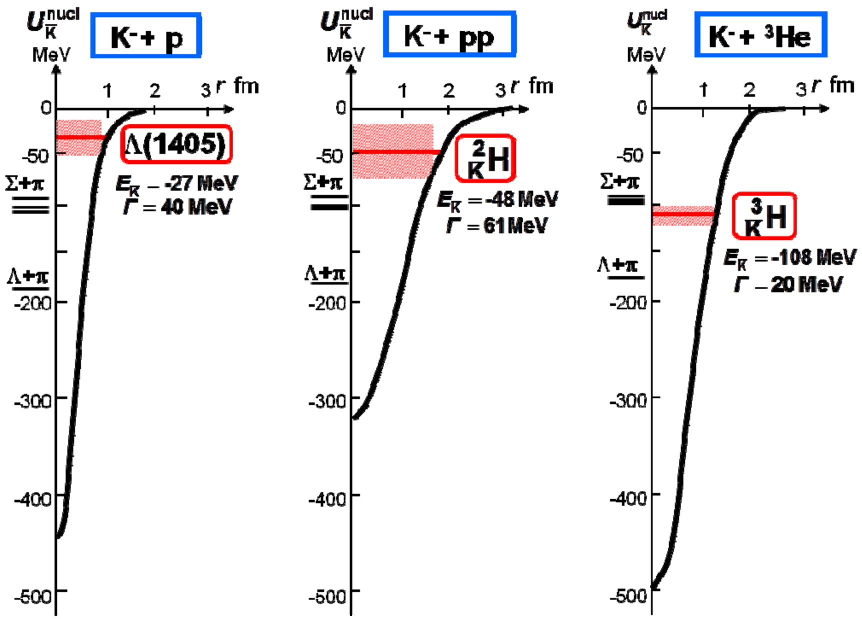
Introduction

Motivation :

What will happen when anti-kaon is embedded in nucleus?

✔ Does the simplest Kaonic nucleus “K-pp” exist?

✔ How deeply bound ?



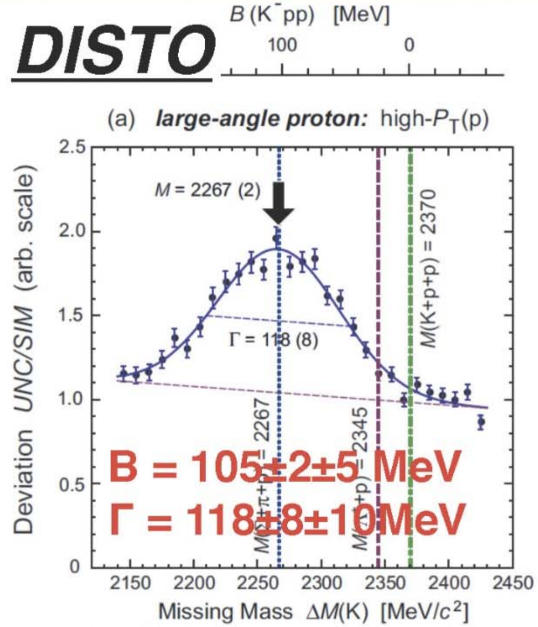
Y. Akaishi & T. Yamazaki, Phys. Rev. C65 (2002) 044005.

Y. Akaishi & T. Yamazaki, Phys. Lett. B535 (2002) 70.

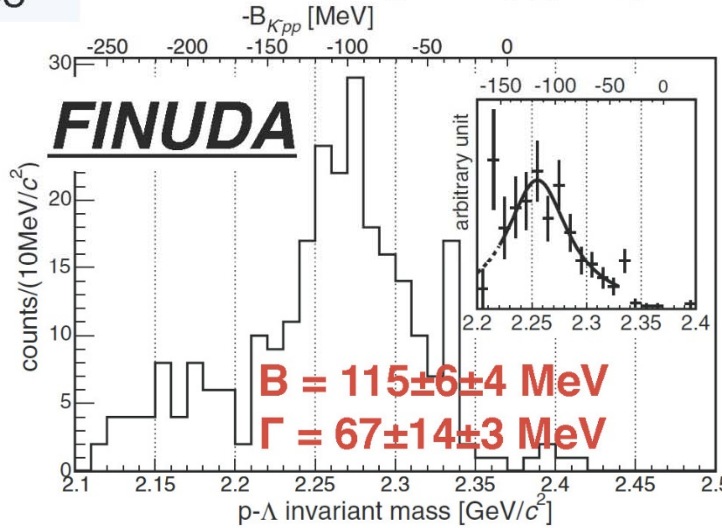
The simplest kaonic nuclei KbarNN

chiral & energy dependent	B.E.[MeV]	Γ[MeV]
N. Barnea, A. Gal, E.Z. Liverts(2012)	16	41
A. Dote, T. Hyodo, W. Weise(2008,09)	17-23	40-70
Y. Ikeda, H. Kamano, T. Sato(2010)	9-16	34-46

Λ(1405) ansatz	B.E.[MeV]	Γ[MeV]
T. Yamazaki, Y. Akaishi(2002)	48	61
N.V. Shevchenko, A. Gal, J. Mares(2007)	50-70	90-110
Y. Ikeda, T. Sato (2007,2009)	60-95	45-80
S. Wycech, A.M. Green (2009)	40-80	40-85

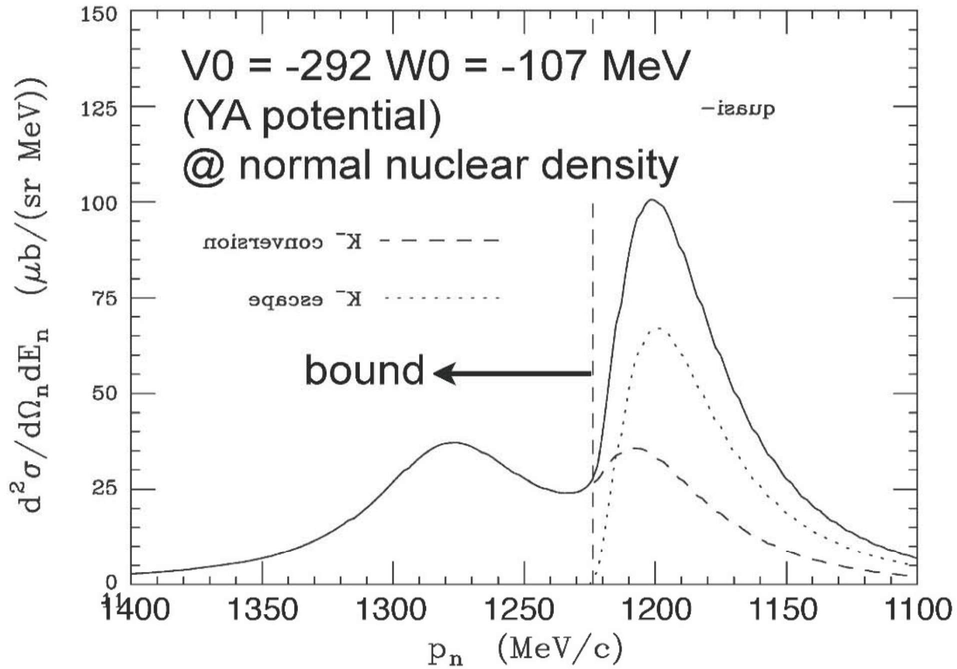


- **Many theoretical calculations**
- **Little experimental information**
- **bound or not? B.E. and width?**



Theoretical calculations on $^3He(K^-,n)$

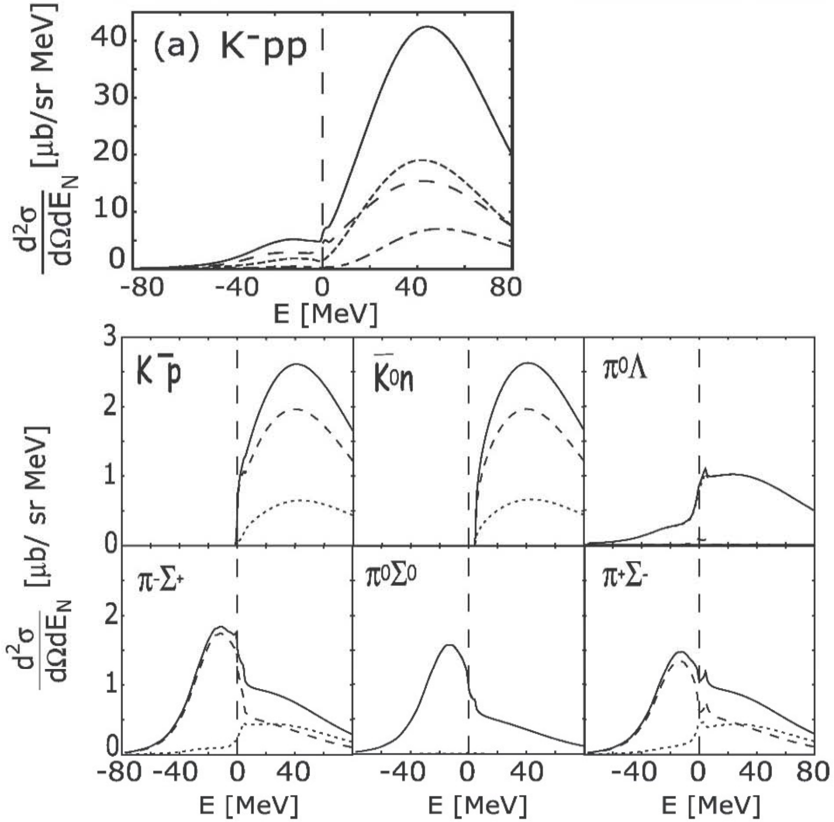
$K^- + {}^3He \rightarrow$ "K^-pp" $+ n$ @ P_K=1GeV/c, θ=0°



T.Koike and T.Harada. , PLB652 (2007) 262

cross section
may be > mb/sr

Easy to observe
If dσ/dΩ >1.0 mb/sr



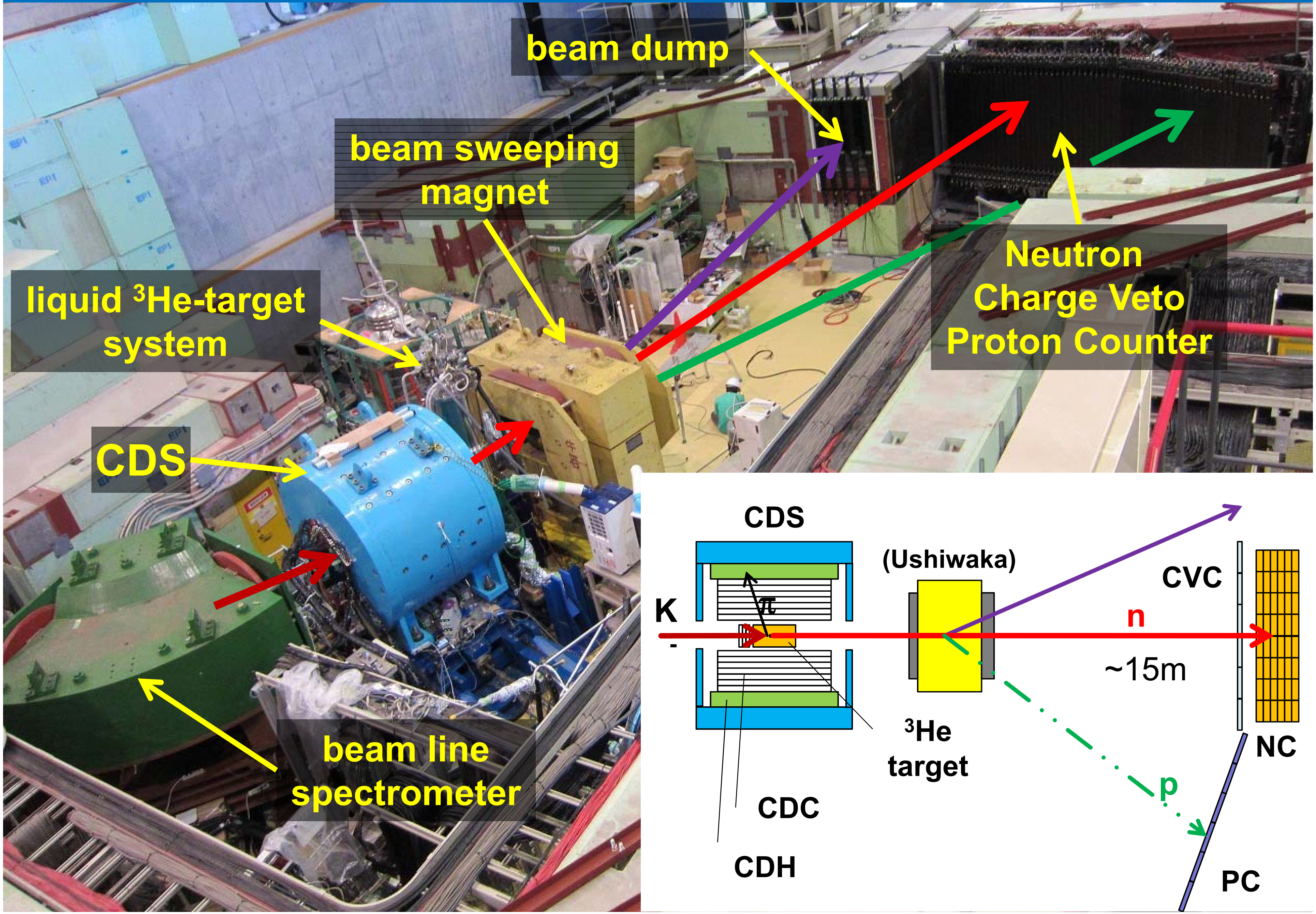
J. Yamagata-Sekihara et. al., Phys. Rev. C 80, 045204 (2009)

Σ tag may enhance the structure in bound region.

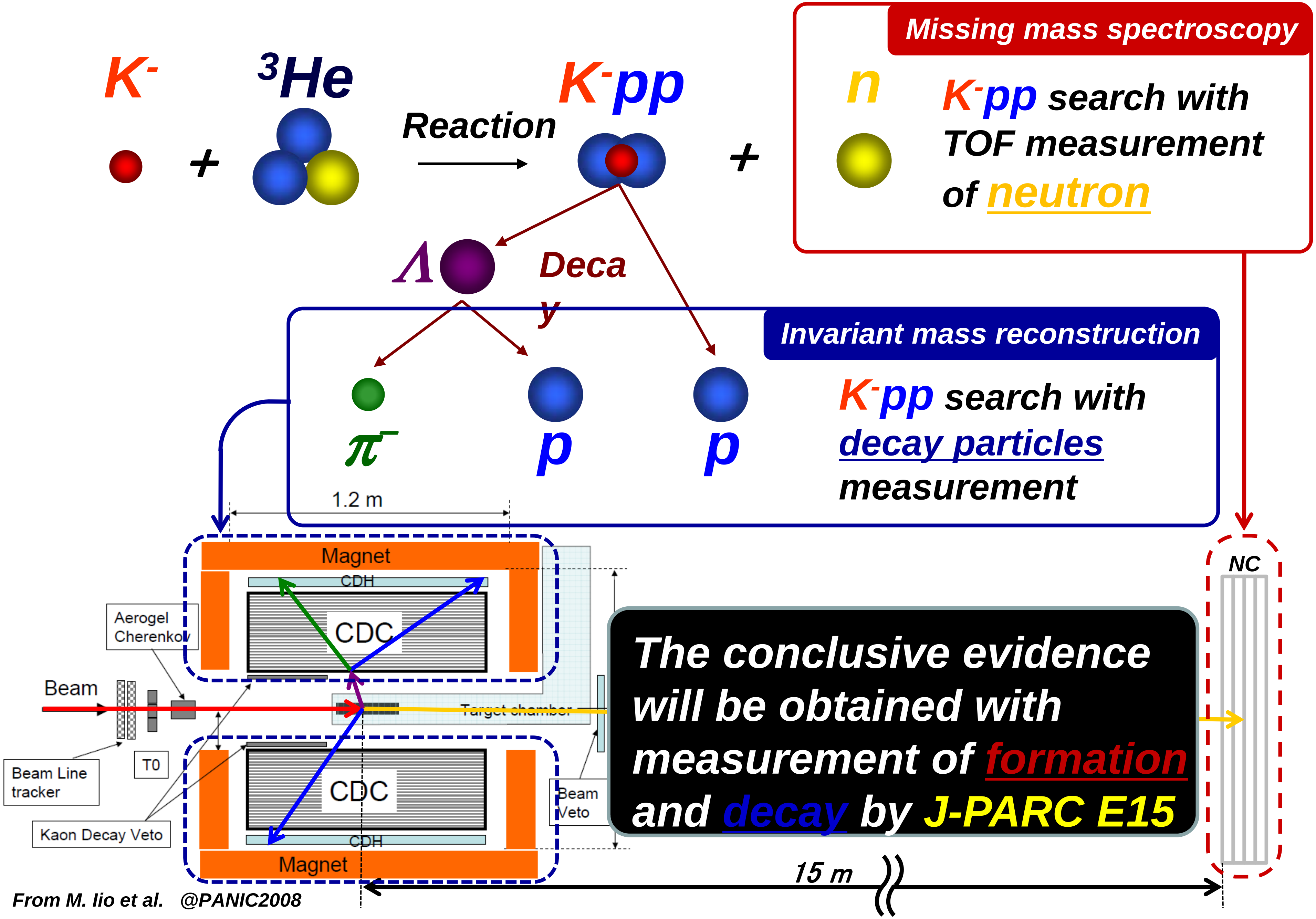
E15 Experiment

Setup &
Performance of detectors

K1.8BR spectrometer [Jun. 2012]



J-PARC E15 (Search for K⁻-pp deeply-bound kaonic nuclear state)



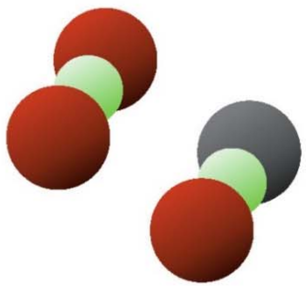
J-PARC E15 1st stage physics run

- Accumulated data
  - w/ liquid helium-3 target: ~1% of original proposal

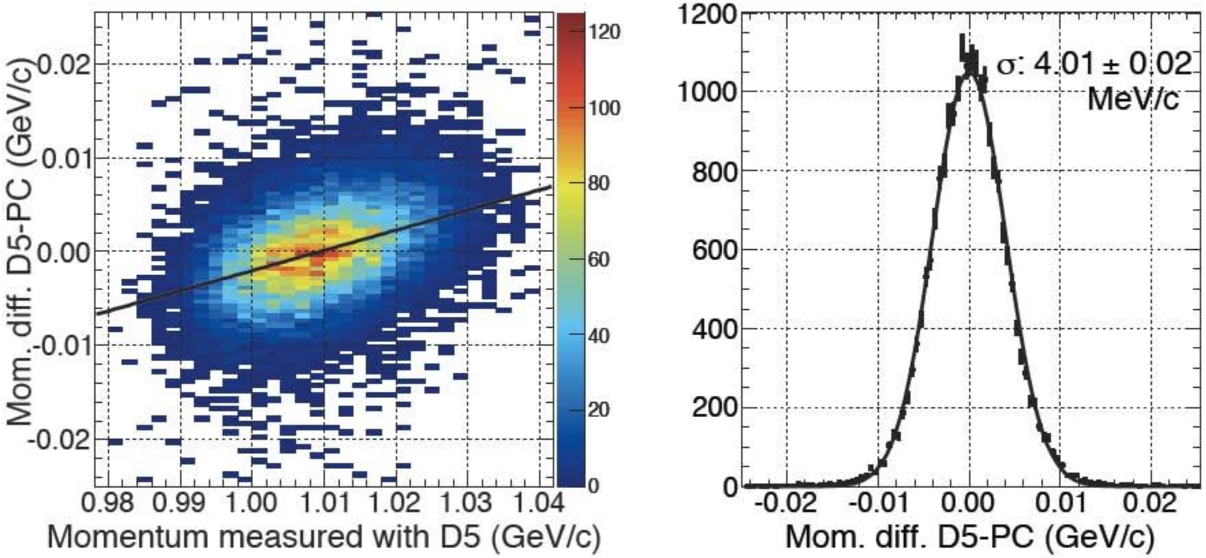
period	primary beam intensity	duration	Kaons on target
March, 2013	14.5 kW (18 Tppp, 6s cycle)	30 hours	0.9×10^9
May, 2013	24 kW (30 Tppp, 6s cycle)	88 hours	4.0×10^9

production target: Au 50% loss, spill length: ~2s, spill duty factor: ~45%

  - In total, 5×10^9 K- on target
  - empty target run, beam-through run, pion scattering run ...
- Expected physics output
  - ^{3}He(K–, n), [& Λpn]
  - ^{3}He(K–, p), [^{3}He(K–, d)]
  - multi-nucleon absorption, hyperon production etc...



Beam momentum reconstruction



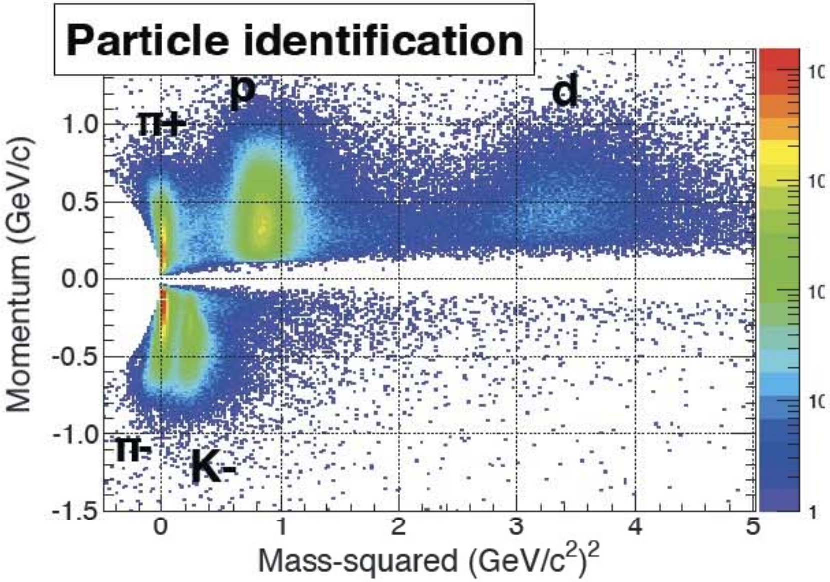
T0-PC resolution estimated with simulation: 3.4+-0.3 MeV/c

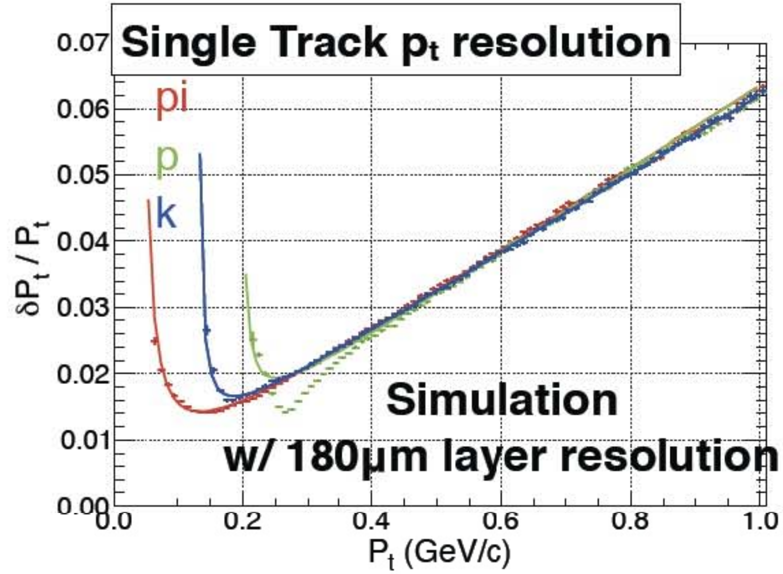
(Uncertainty in intrinsic timing resolution for protons)

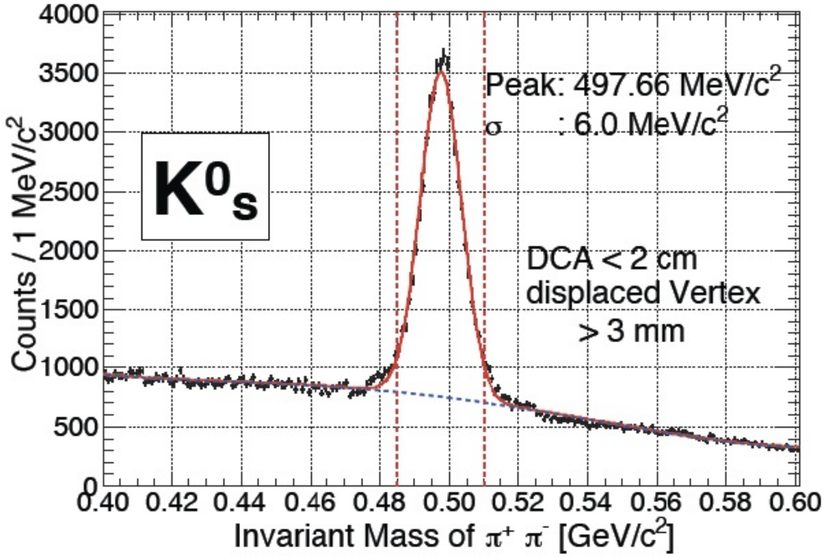
- **Beam momentum reconstruction**
  - **connect BLC1&2 tracks with 2nd order transfer matrix**
- **Proton beam through run**
  - **compare with forward TOF (T0-PC)**

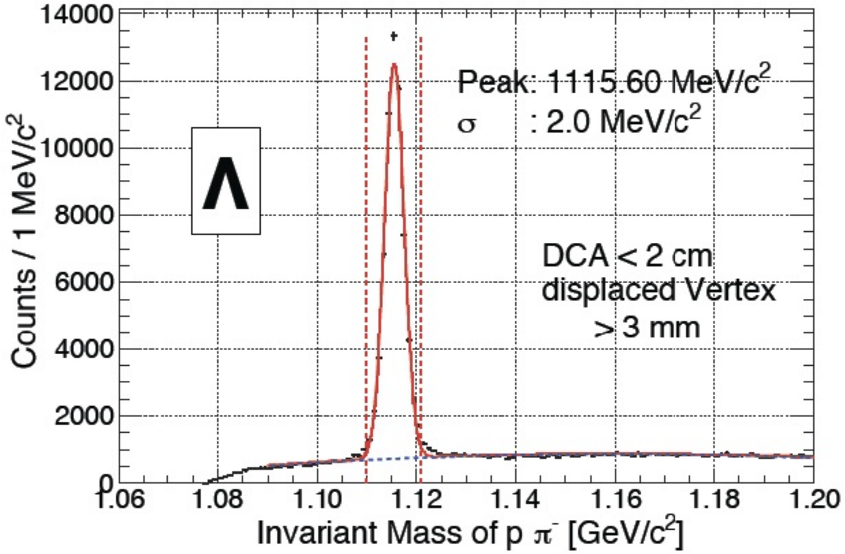
Beam momentum resolution 2.0±0.5 MeV/c

CDS performance

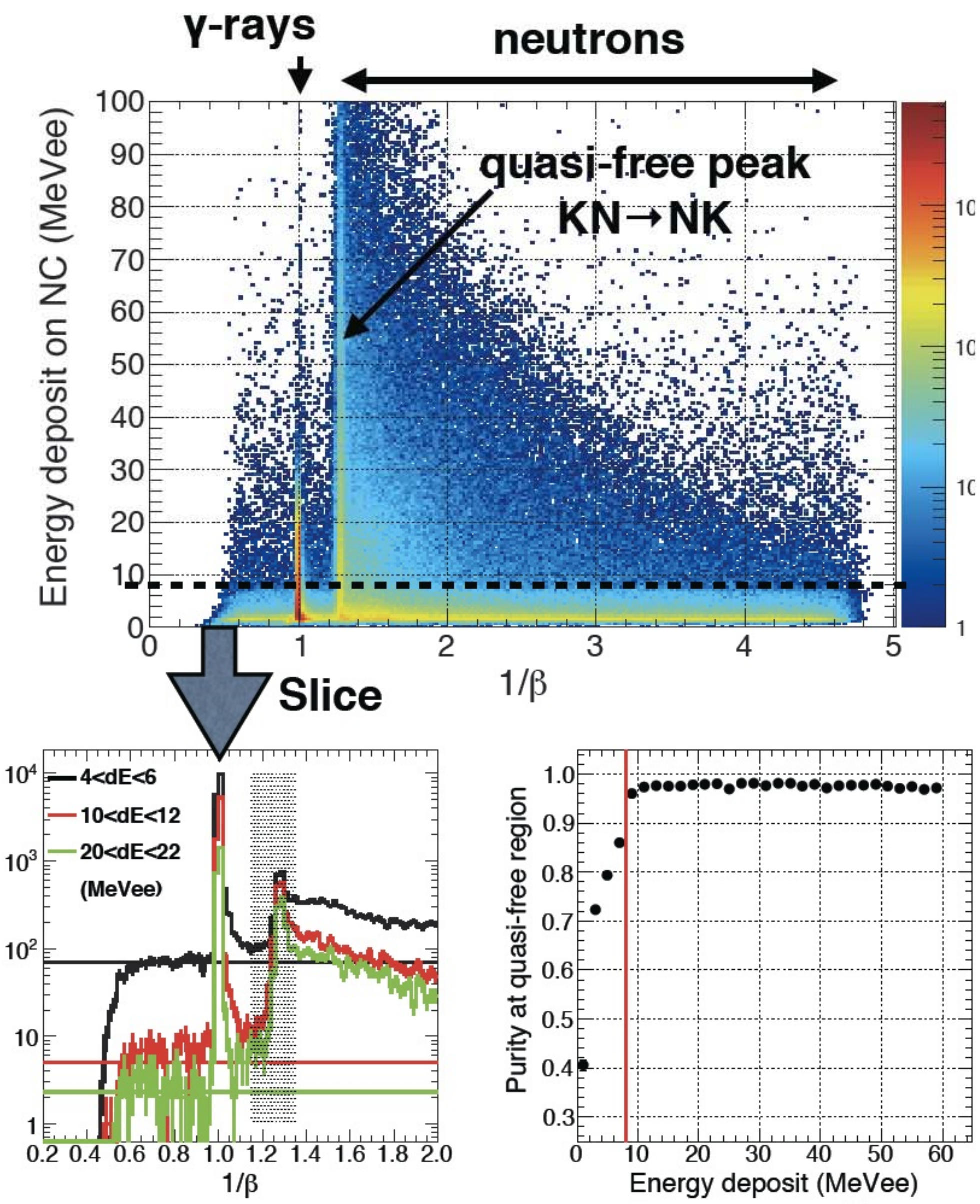


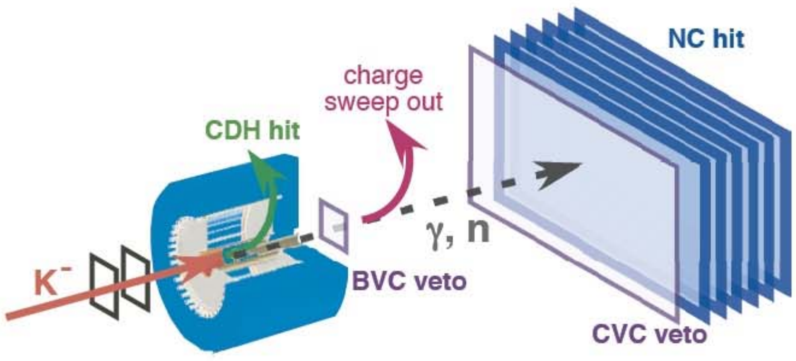






Neutron analysis

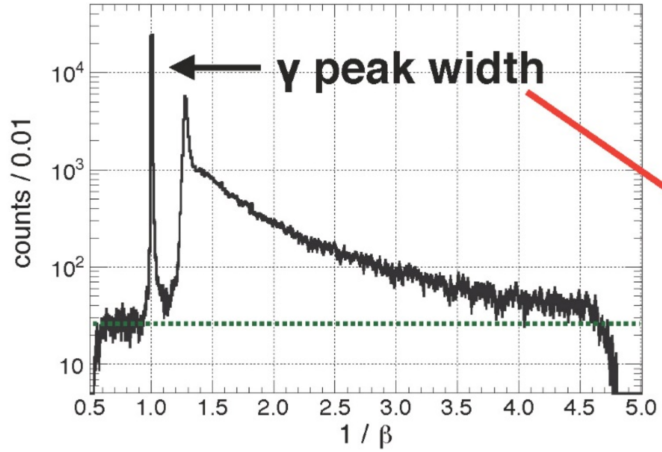


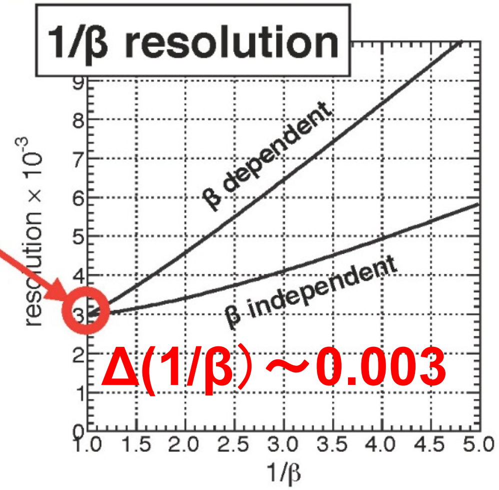


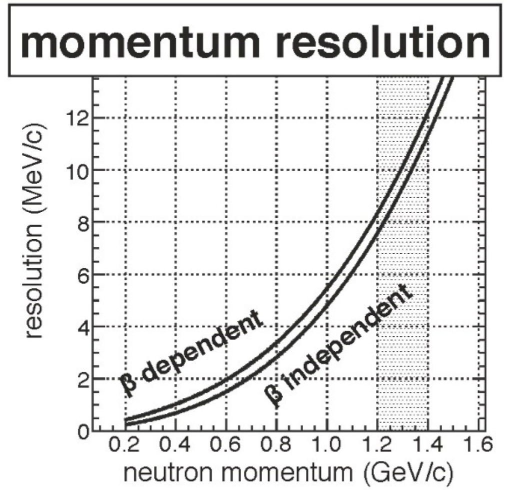
- **Neutral hit**
  - no hit on the BVC and CVC
  - first hit in the NC (timing-wise) was used to calculate 1/beta
- **Threshold on energy deposit**
  - reduce accidentals
  - online (discri) : ~0.5 MeVee
  - offline : 8 MeVee

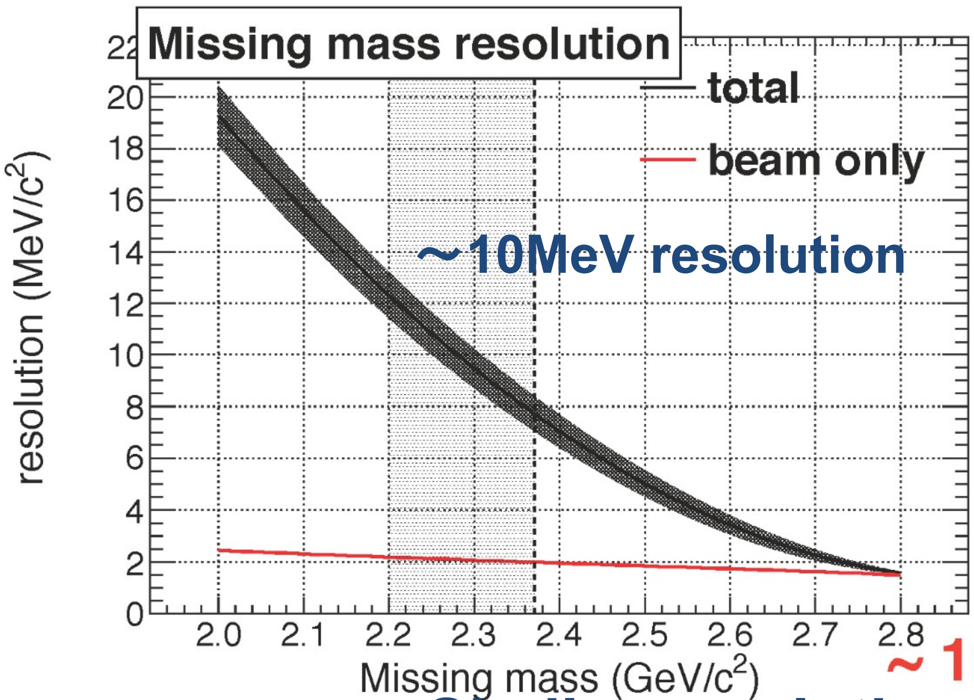
Efficiency = 23±4%

Missing mass resolution









$$\sigma_{\frac{1}{\beta}}\left(\frac{1}{\beta}\right) = \frac{1}{L_{vertex-NC}}\sqrt{\left(\frac{\sigma_z^{NC}}{\beta}\right)^2 + \left(\left(\frac{1}{\beta} - \frac{1}{\beta_{beam}}\right)\cdot\sigma_z^{vertex}\right)^2 + c^2\sigma_t^2}$$

- flight length resolution
  → β dependence in 1/β resolution
- Intrinsic timing resolution
  → no β dependence in 1/β resolution
- Intrinsic resolution does not fully explain the γ peak width
  → add β (in)dependent contribution

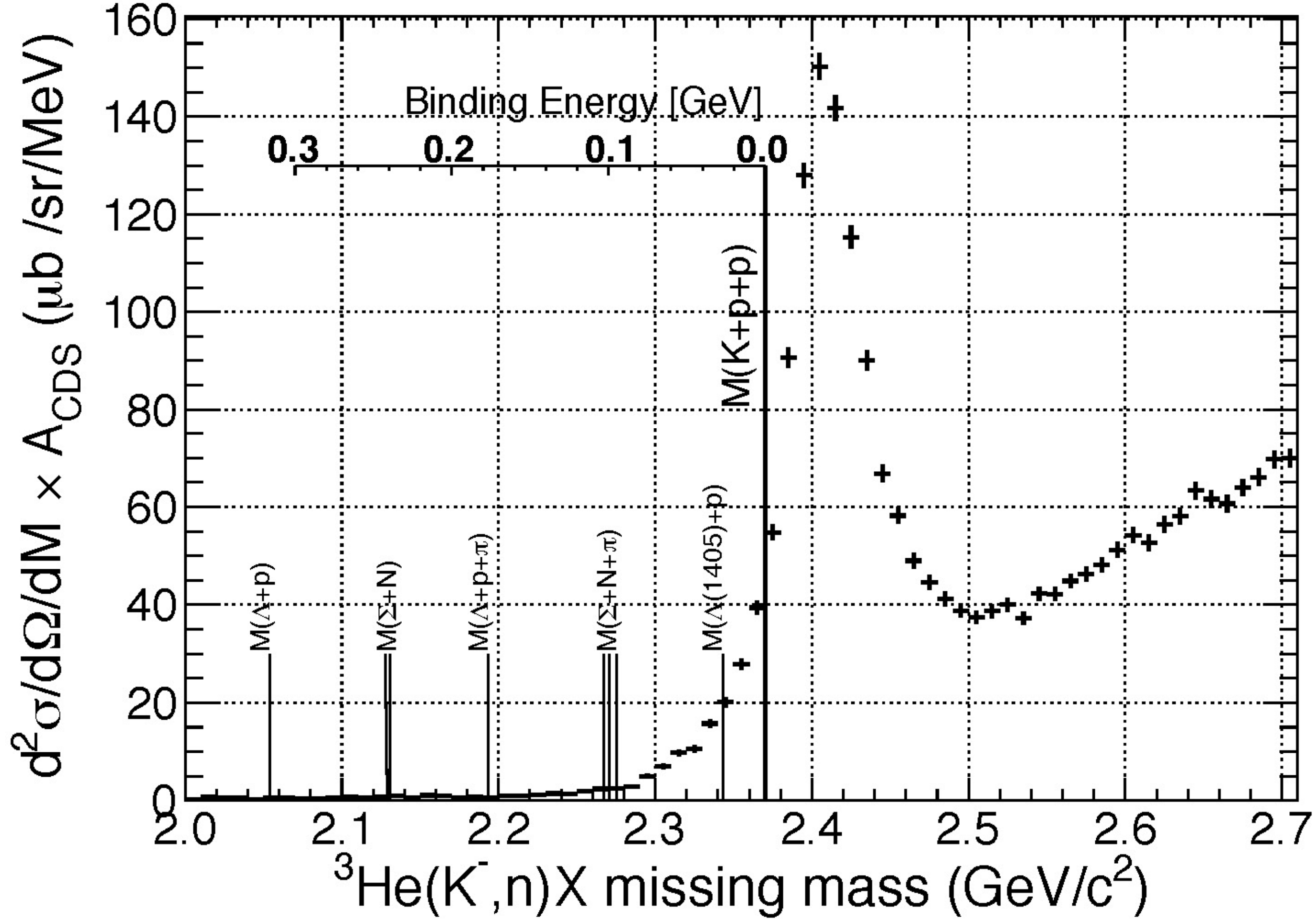
~ 10 MeV/c² resolution achieved !!

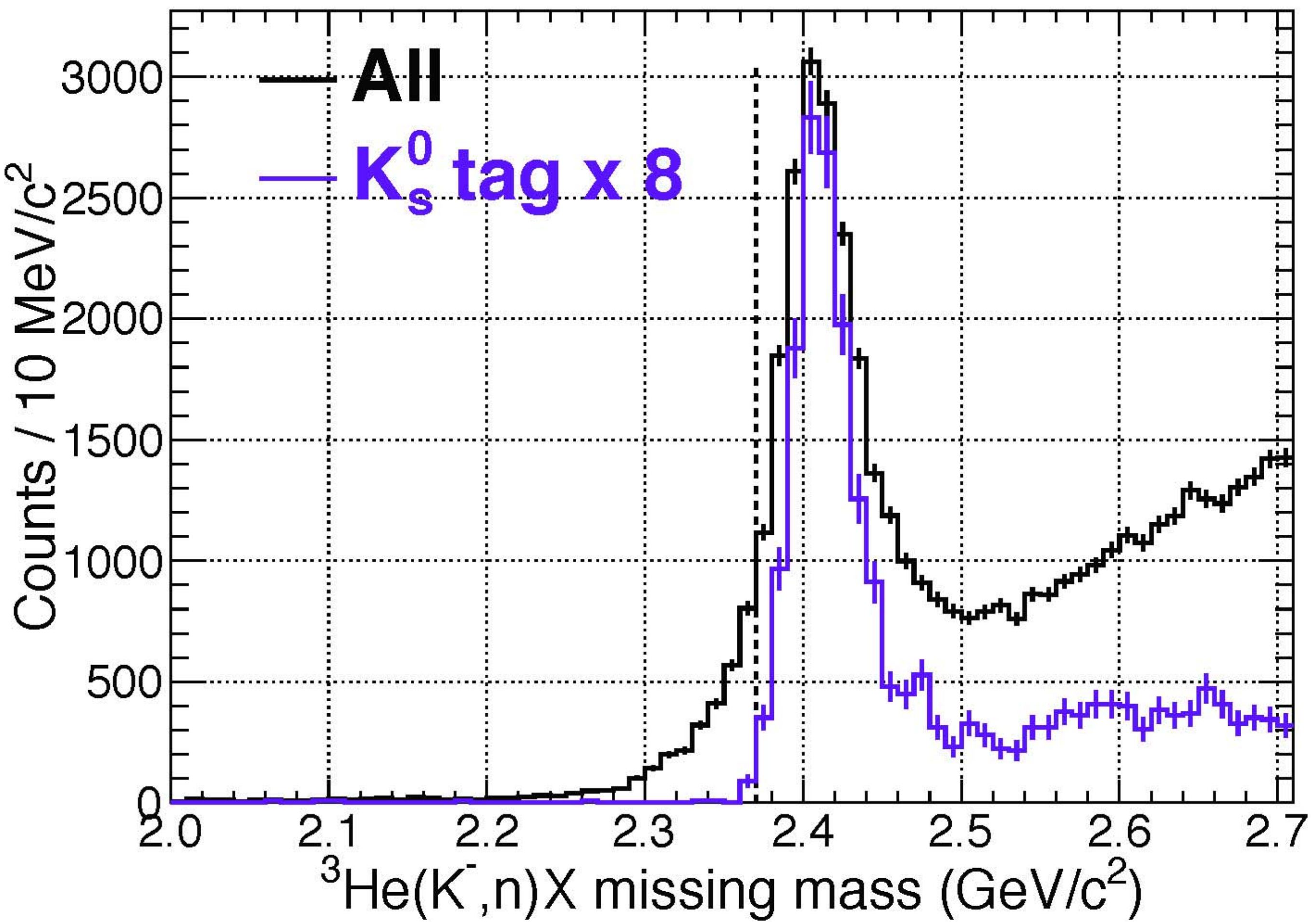
Similar resolution is expected also for proton

3He (K-, n) semi-inclusive spectrum

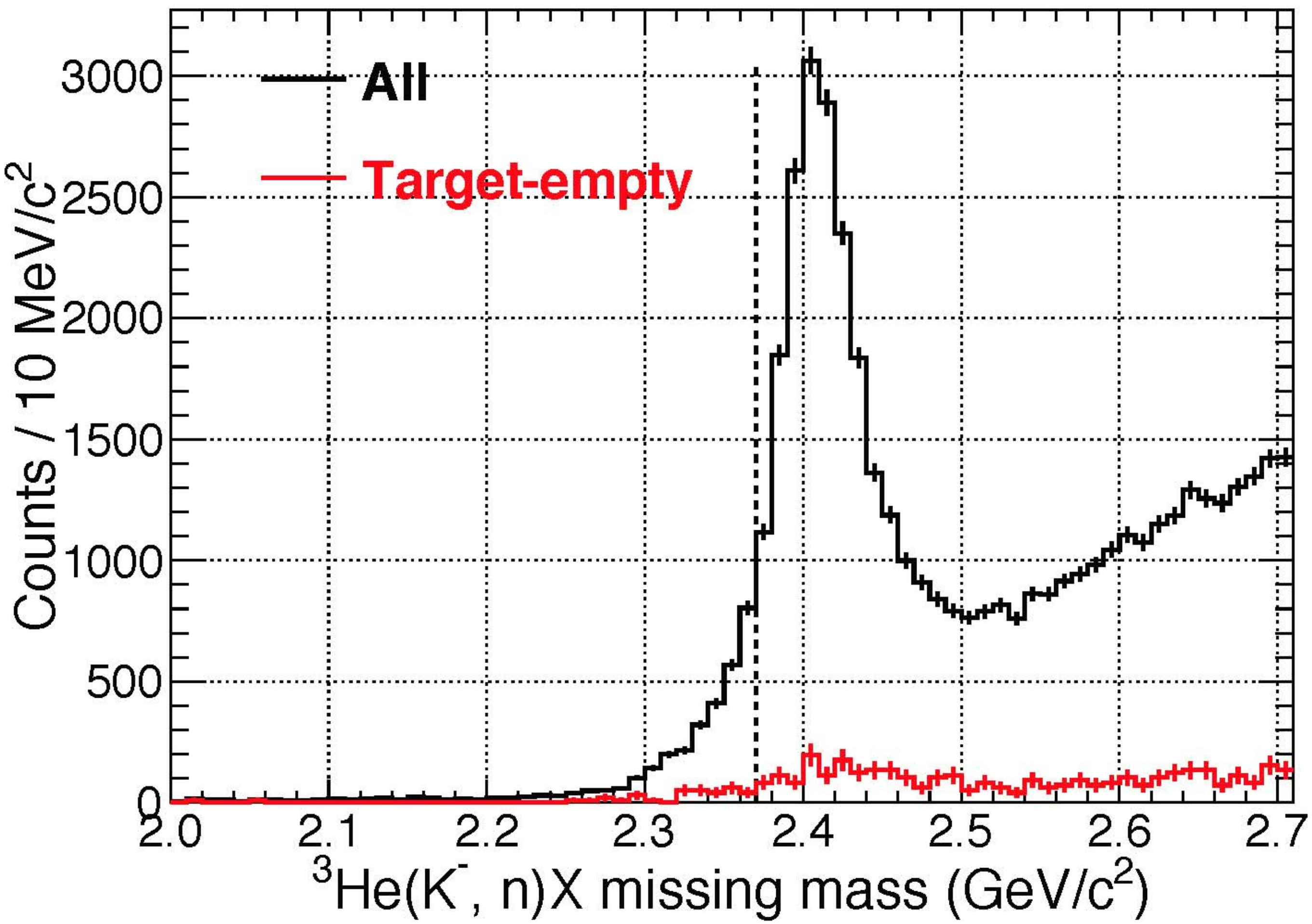
(Hashimoto)

3He (K-, n) semi-inclusive spectrum





Tail component in the bound region is NOT due to the detector resolution !!



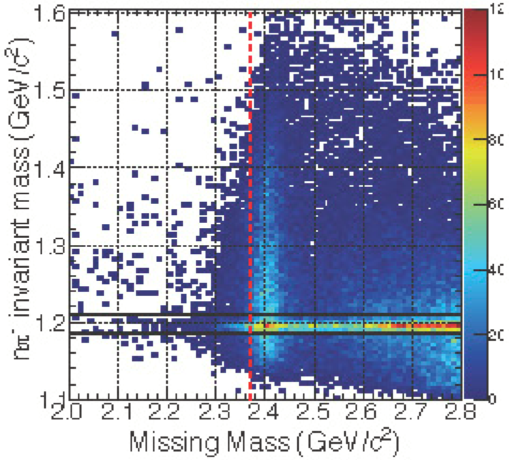
All
Target-empty
Counts / 10 MeV/c2
0
500
1000
1500
2000
2500
3000
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
3He(K-, n)X missing mass (GeV/c2)

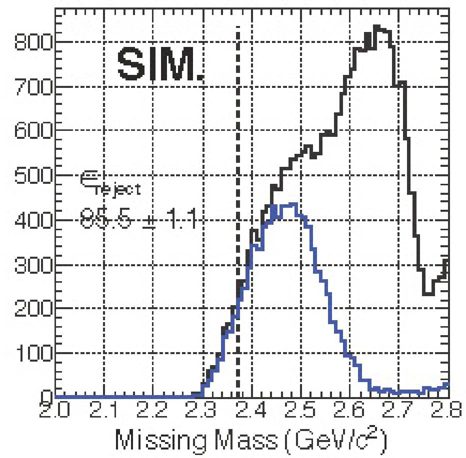
Possible fast neutrons

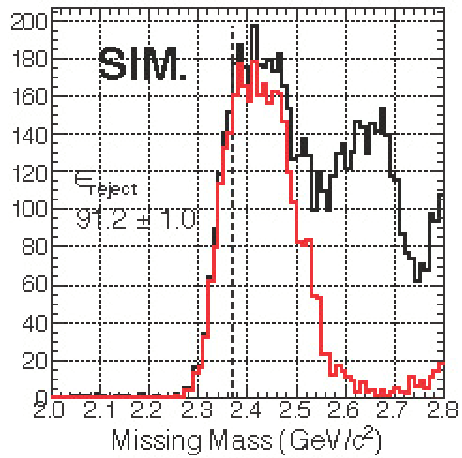
- Quasi-free nucleon process
  - fast neutrons from Σ decay
- Two-nucleon reaction process (2NR)
  - peak structure in non-mesonic branch
  - continuous distribution in mesonic branch (if uniform in phase space)
- Three-nucleon reaction process (3NR)
  - similar situation with mesonic 2NR

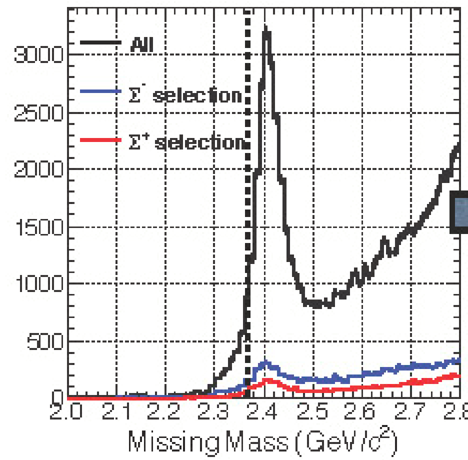
Possible fast neutrons - Σ decay -

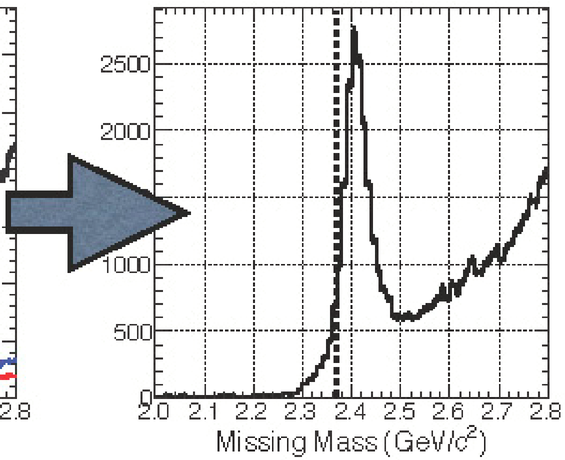
Can be removed by reconstructed Σ with a pion detected with the CDS



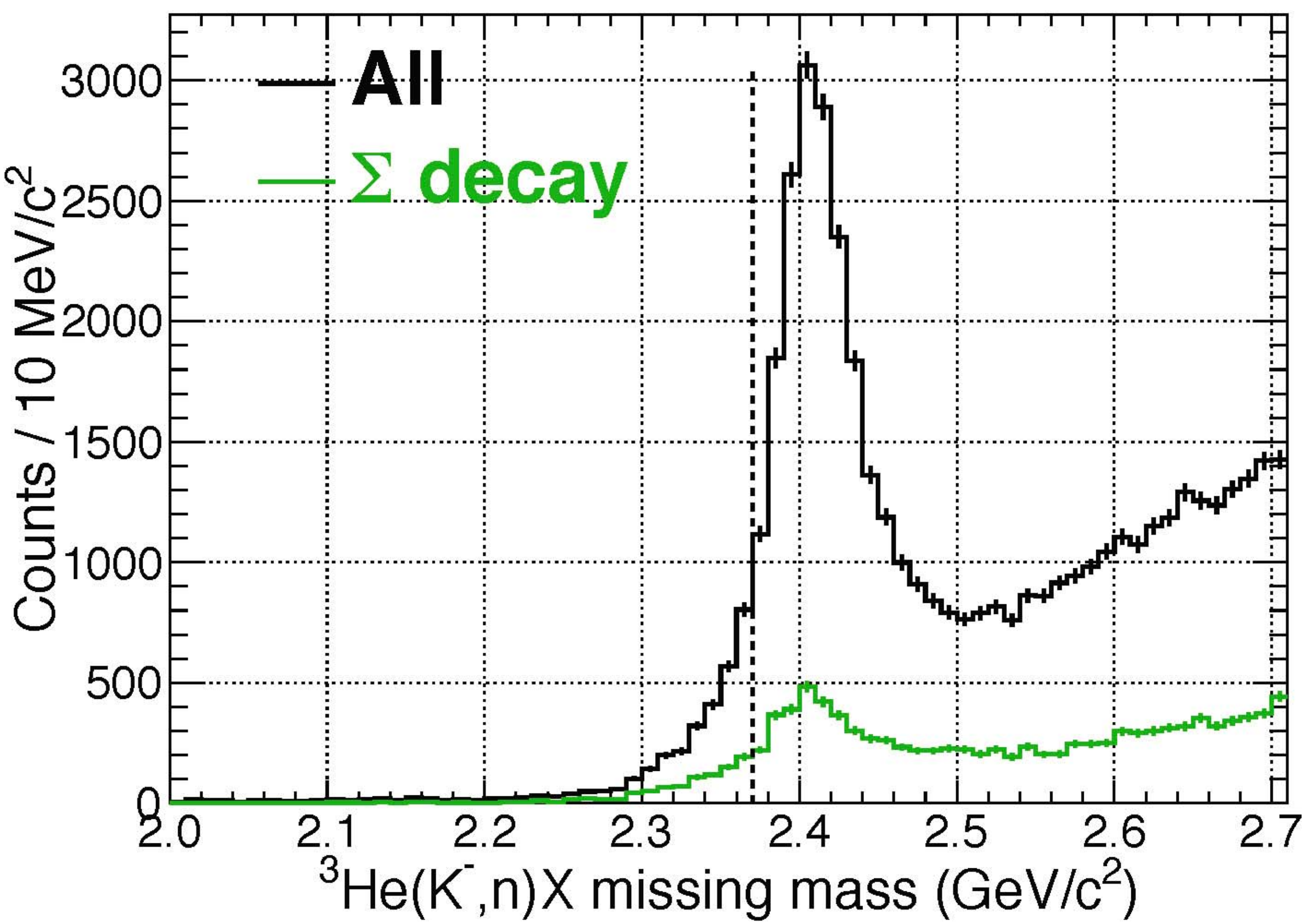




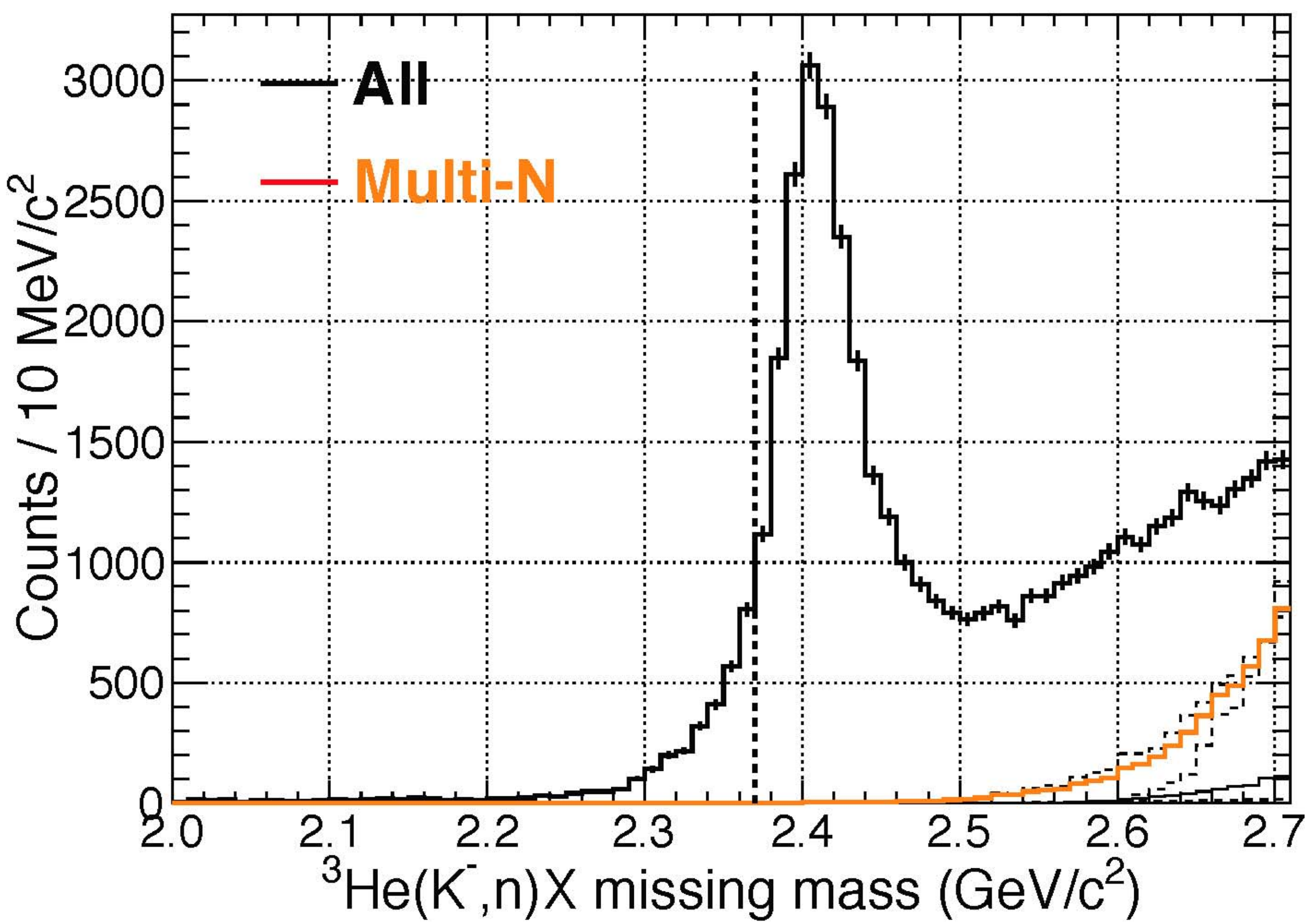




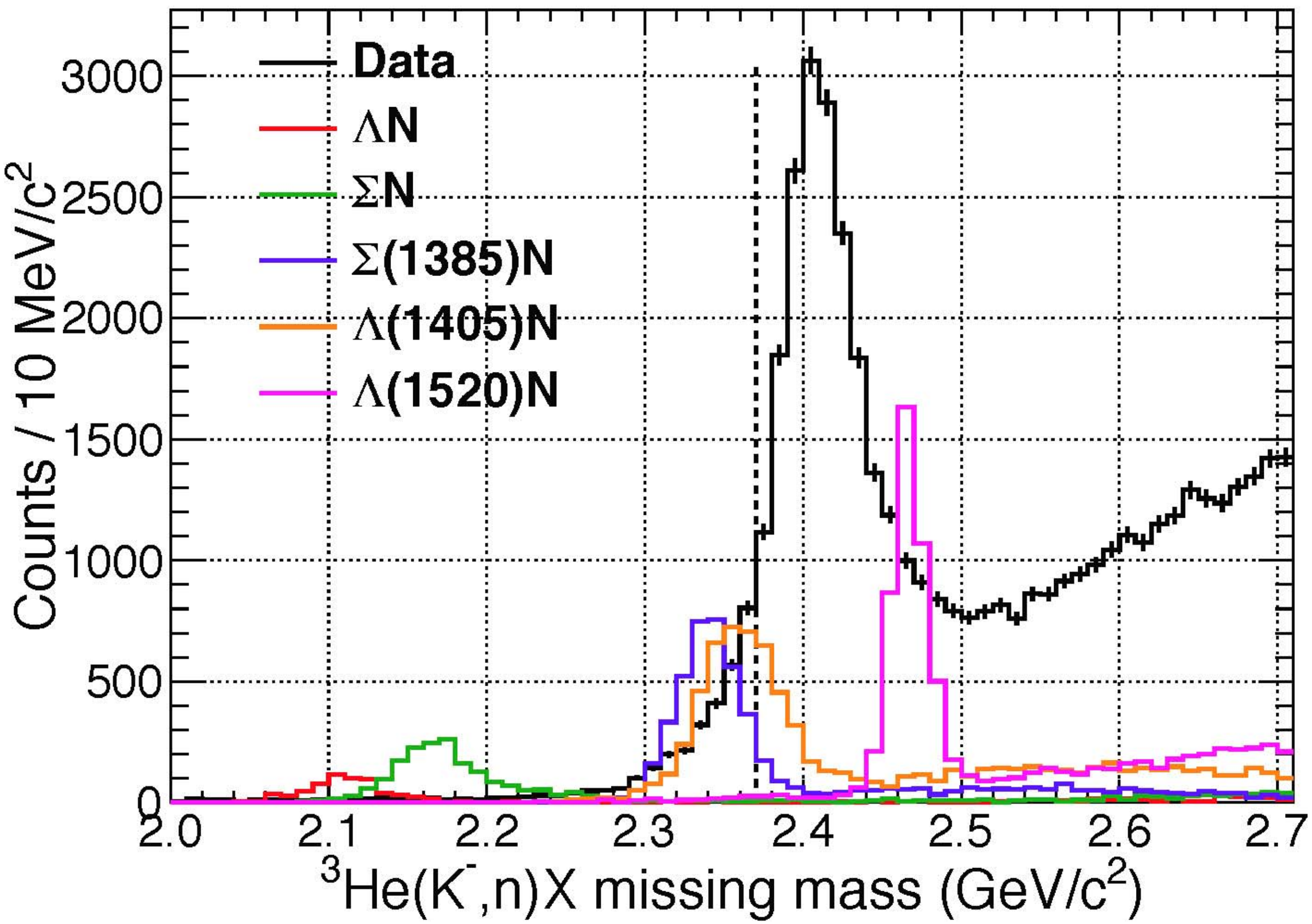
- 85~90% removed
- KN→NK contami in Σ selection
- Global shape did not change.



All
Σ decay
Counts / 10 MeV/c²
3000
2500
2000
1500
1000
500
0
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
³He(K⁻,n)X missing mass (GeV/c²)



All
Multi-N
Counts / 10 MeV/c^2
0
500
1000
1500
2000
2500
3000
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
^{3}He(K$^-$,n)X missing mass (GeV/c^2)


Data
ΛN
ΣN
Σ(1385)N
Λ(1405)N
Λ(1520)N
Counts / 10 MeV/c^2
^{3}He(K$^-$,n)X missing mass (GeV/c^2)
0
500
1000
1500
2000
2500
3000
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7

Possible fast neutrons

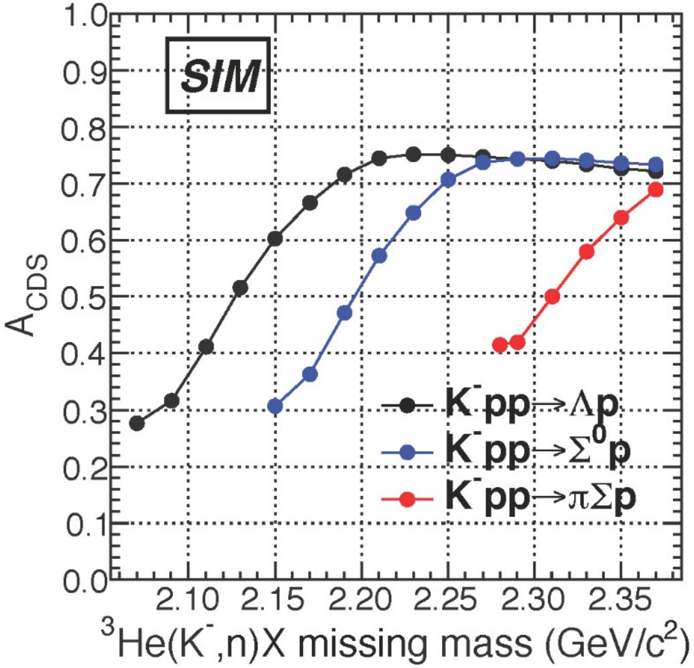
- **Quasi-free nucleon process**
  - fast neutrons from Σ decay   ~90% can be removed
- **Two-nucleon reaction process (2NR)**
  - peak structure in non-mesonic branch

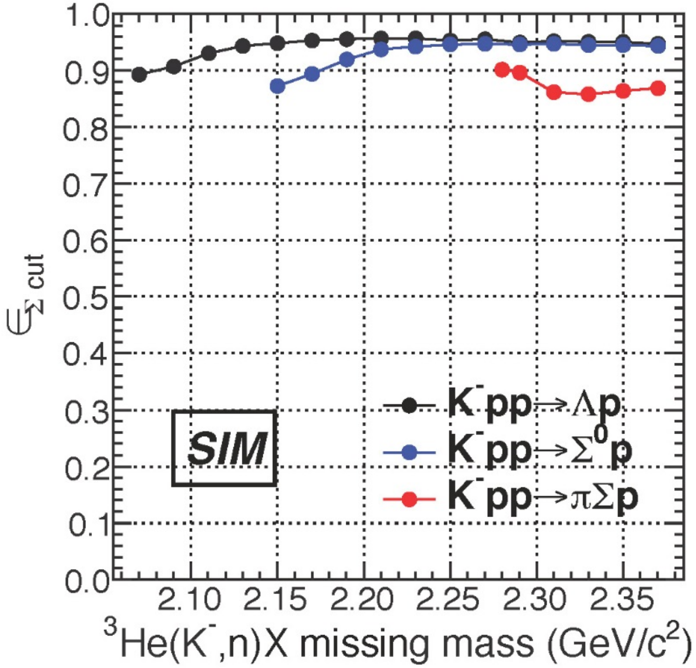
    ΛN,ΣN branch negligible   Y*N branch may contribute
  - continuous distribution in mesonic branch (if uniform in phase space)
- **Three-nucleon reaction process (3NR)**
  - similar situation with mesonic 2NR

    Mesonic 2NR & 3NR are negligible in the bound region

We can not explain the tail structure with ordinary processes
→evaluate the intensity of the excess

Intensity of the excess in K^{-}pp assumption





Upper limits for deep bound region

peak function + 2nd polynomial background

$$
\begin{aligned}
F(x; M_S, \Gamma) &= \int f(\tau) * g(x-\tau, \sigma_{MM}(\tau)) d\tau \\
f(x; M_S, \Gamma) &= \frac{d\sigma}{d\Omega}(\theta_{lab}=0) \cdot \left(\frac{1}{2\pi} \frac{\Gamma}{(x-M_s)^2 + \Gamma^2/4} \right) \cdot A_{cds}(x) \cdot \epsilon_{\Sigma \mathrm{cut}}(x) \\
g(x; \sigma) &= \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2} \right),
\end{aligned}
$$

$K^-pp \rightarrow \Lambda p$ decay only

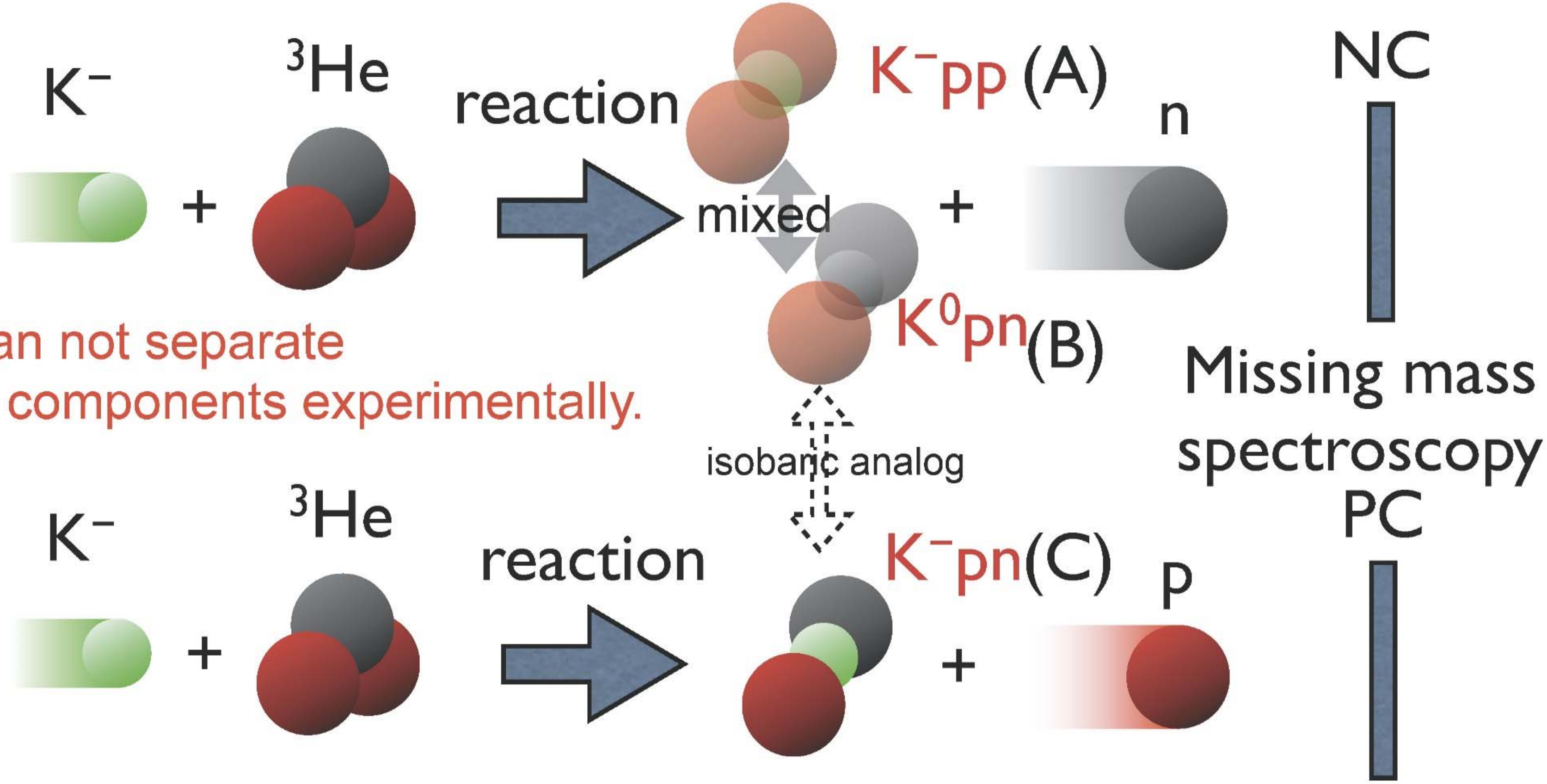
Fit region: 1.5~2.29 GeV/c^2
(2.29 GeV/c^2~
possible contribution
from Y*N branch of 2NR)

3He (K-, p) spectrum

(Tokuda)

J-PARC E15 experiment

A search for the simplest kaonic nucleus K^-pp



Can not separate
2 components experimentally.

To compare with both $^3He(K^-, n/p)$ reactions,
We can get the information of isospin dependence of reactions.

KEK-PS 548: In-flight $^{12}C(K^{-},N)$

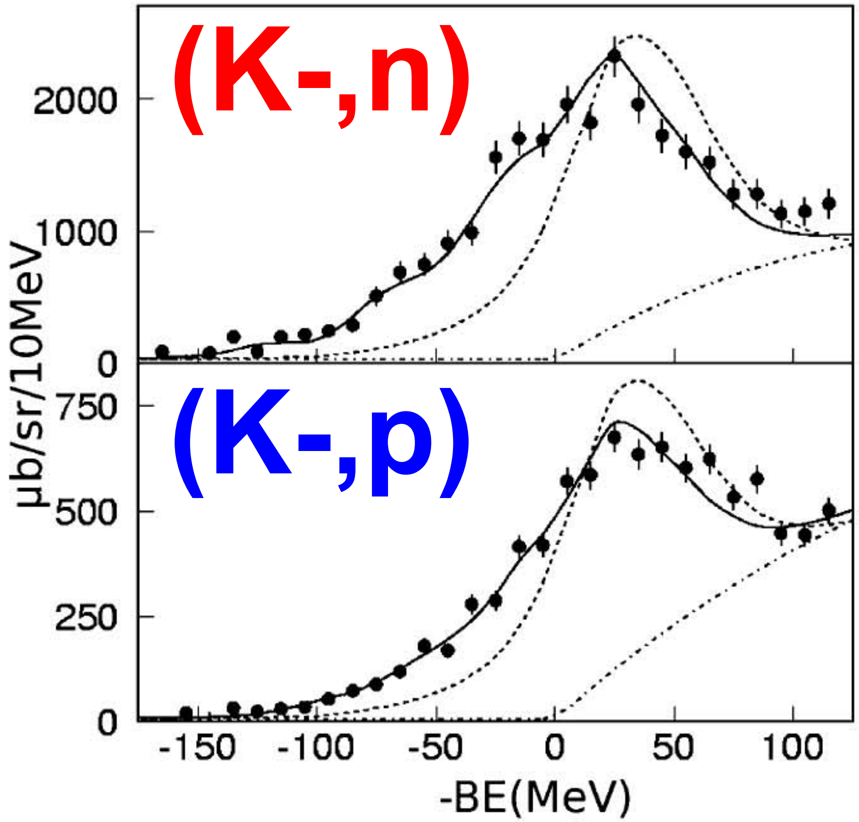
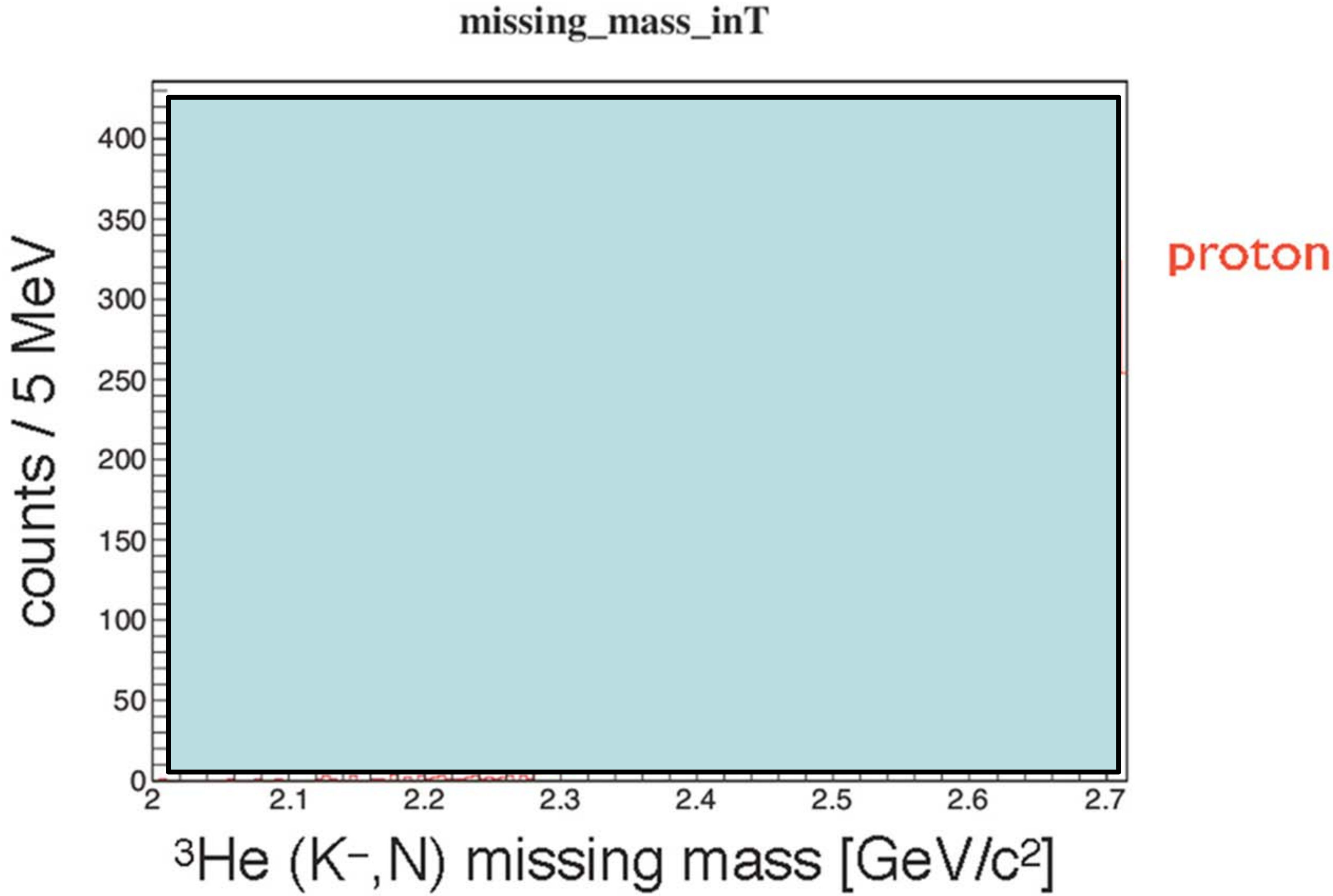
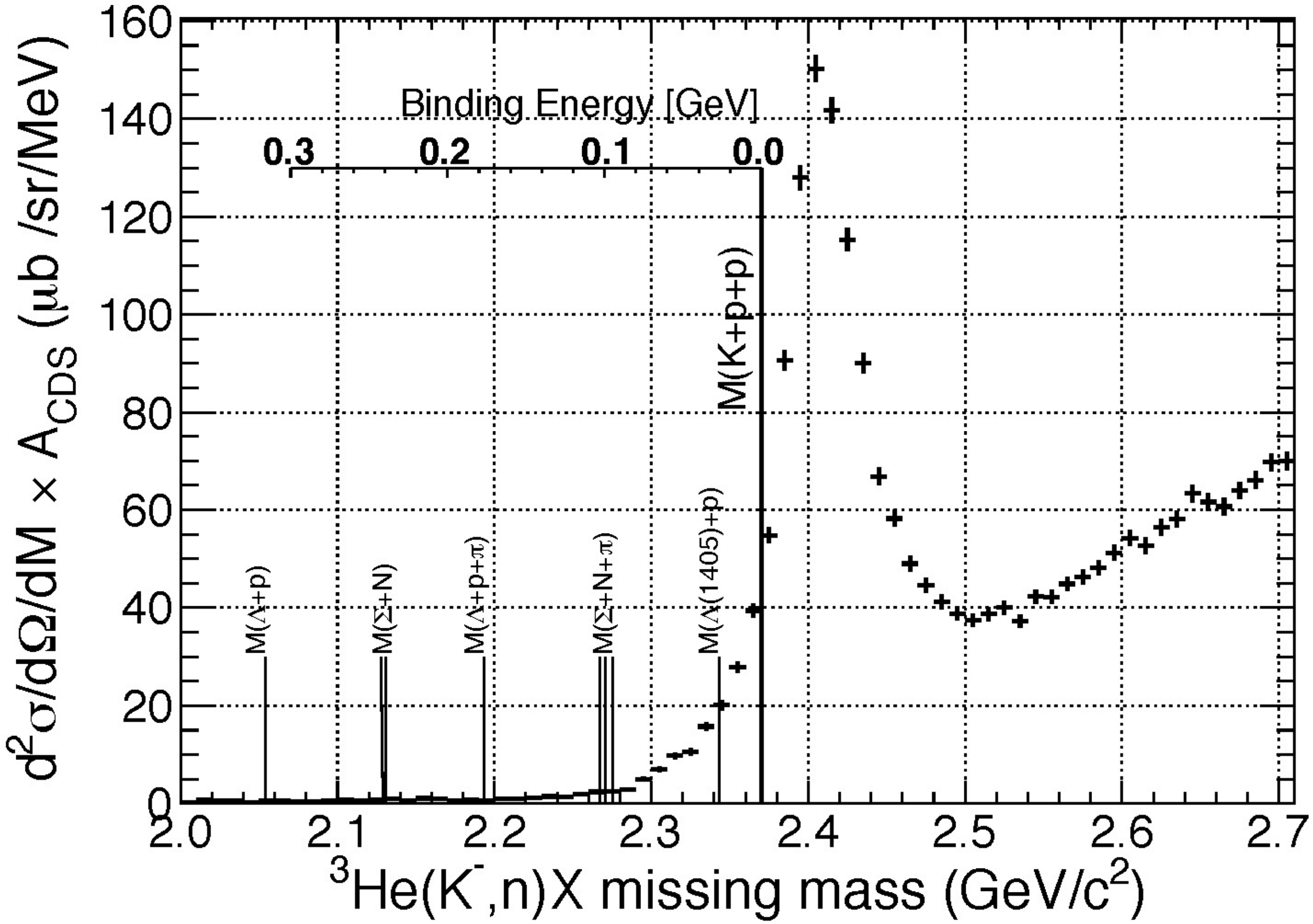


Fig. 1. Missing mass spectra of the $^{12}C(K^-,n)$ reaction (upper) and $^{12}C(K^-,p)$ reaction (lower). The solid curves represent the calculated best fit spectra for potentials with $Re(V)=-190$ MeV and $Im(V)=-40$ MeV (upper) and $Re(V)=-160$ MeV $Im(V)=-50$ MeV (lower). The dotted curves represent the calculated spectra for $Re(V)=-60$ MeV and $Im(V)=-60$ MeV. The dot-dashed curves represent a background process (see main text).

3He (K-, p) spectrum *(VERY preliminary!)*



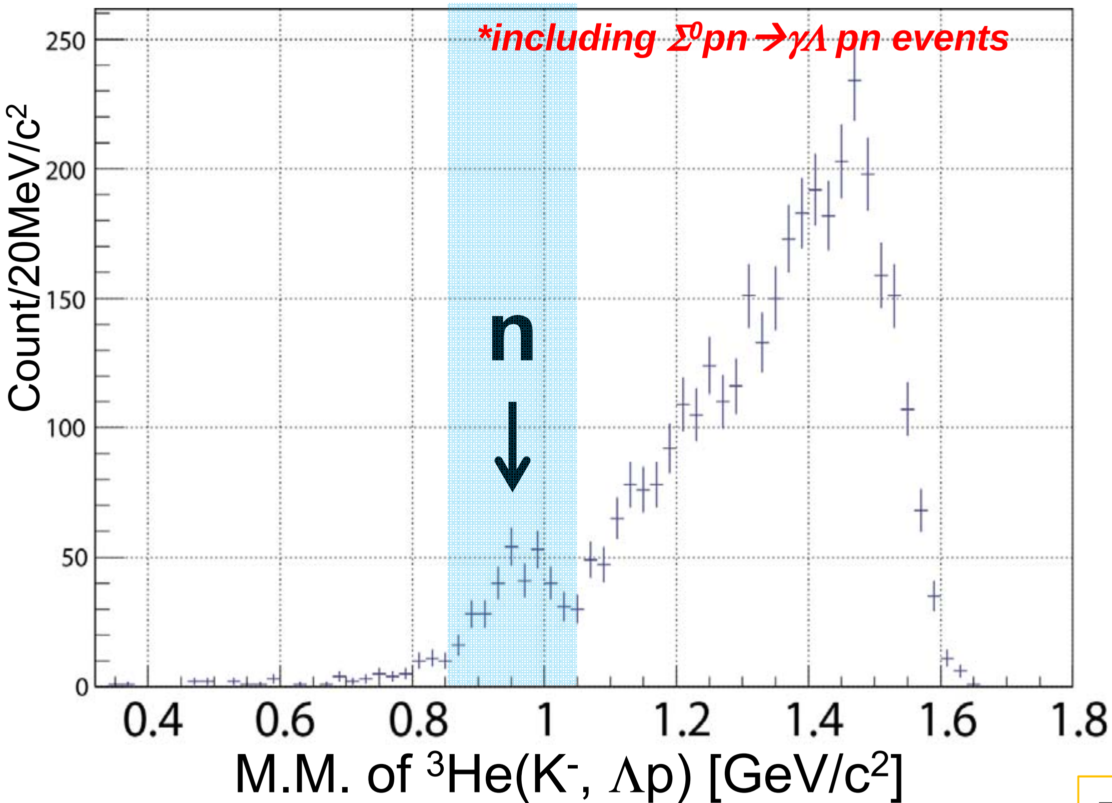
3He (K-, n) semi-inclusive spectrum

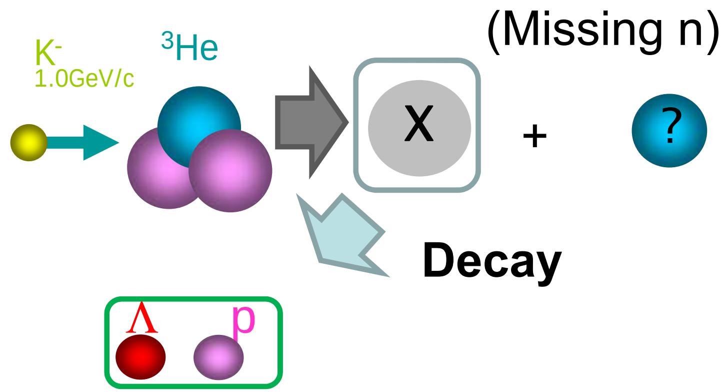


Λp n(missing) correlation

(Sada)

Missing Mass of $^3He(K^-, \Lambda p)$



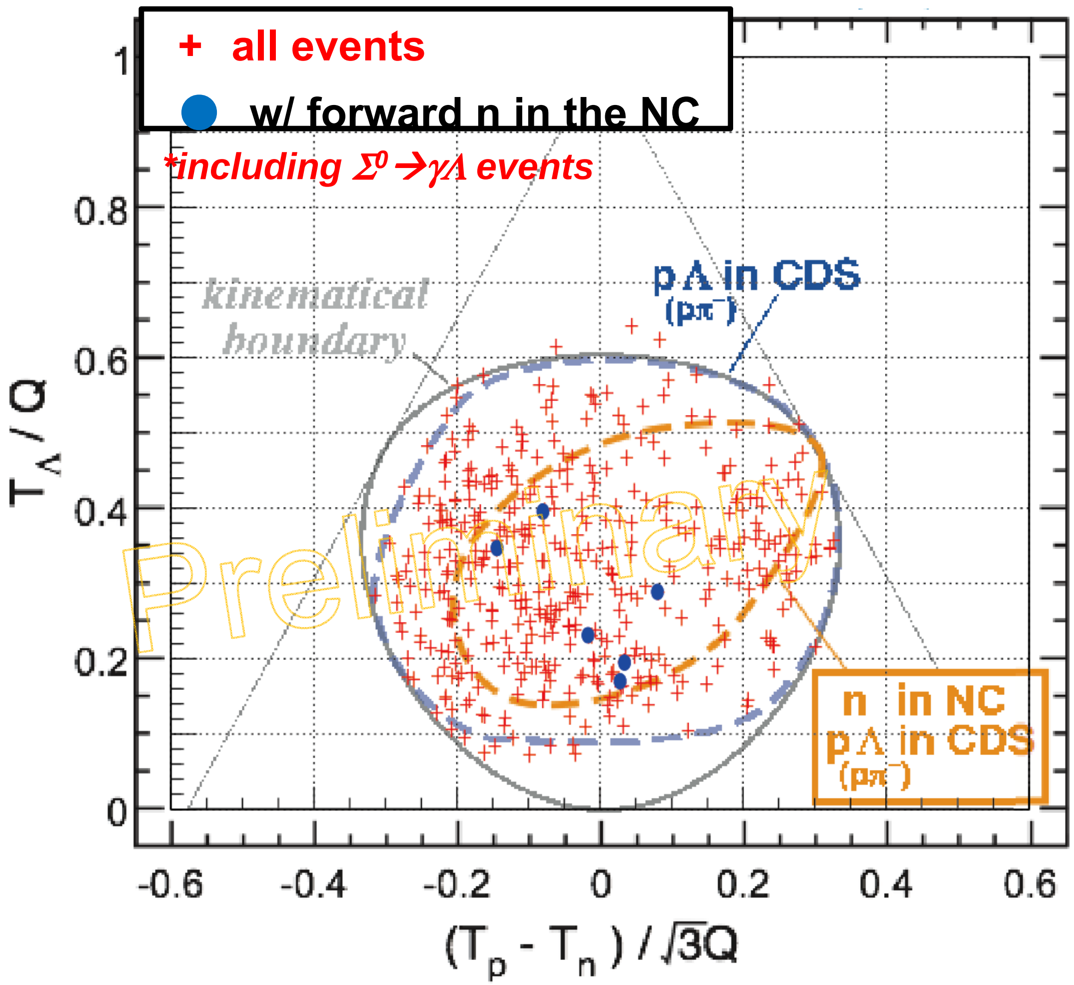


M. M. of ^{3}He (K-, Λp) [GeV/c^2]

- **Missing neutron can be identified.**

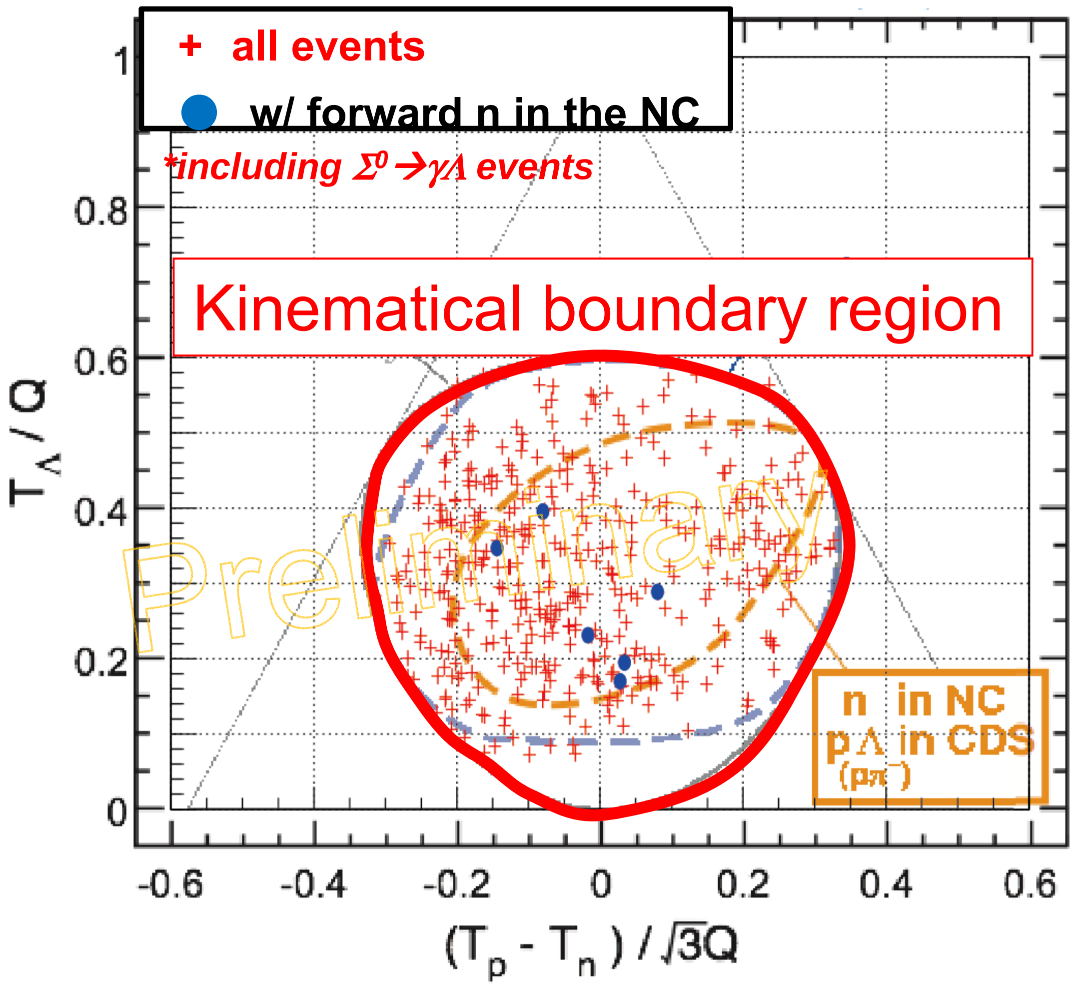
To study the origin of Λpn events,
Let us check Dalitz-plot in the next slide.

$^3He(K^-, \Lambda pn)$ Result :Dalitz plot of Λpn



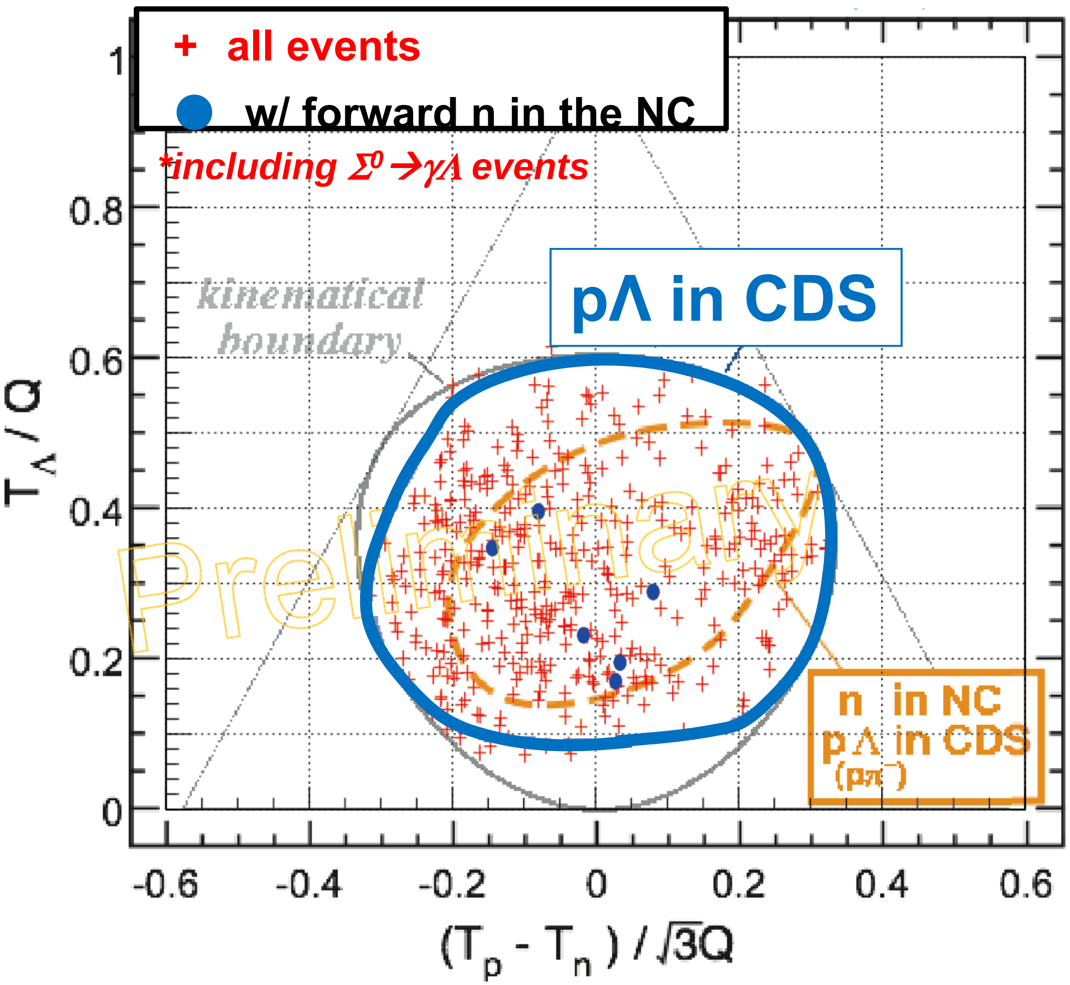
Selected **neutron missing** mass peak.

$^3He(K^-, \Lambda pn)$ Result :Dalitz plot of Λpn



Selected **neutron missing** mass peak.

^{3}He(K$^-$, Λpn) Result :Dalitz plot of Λpn

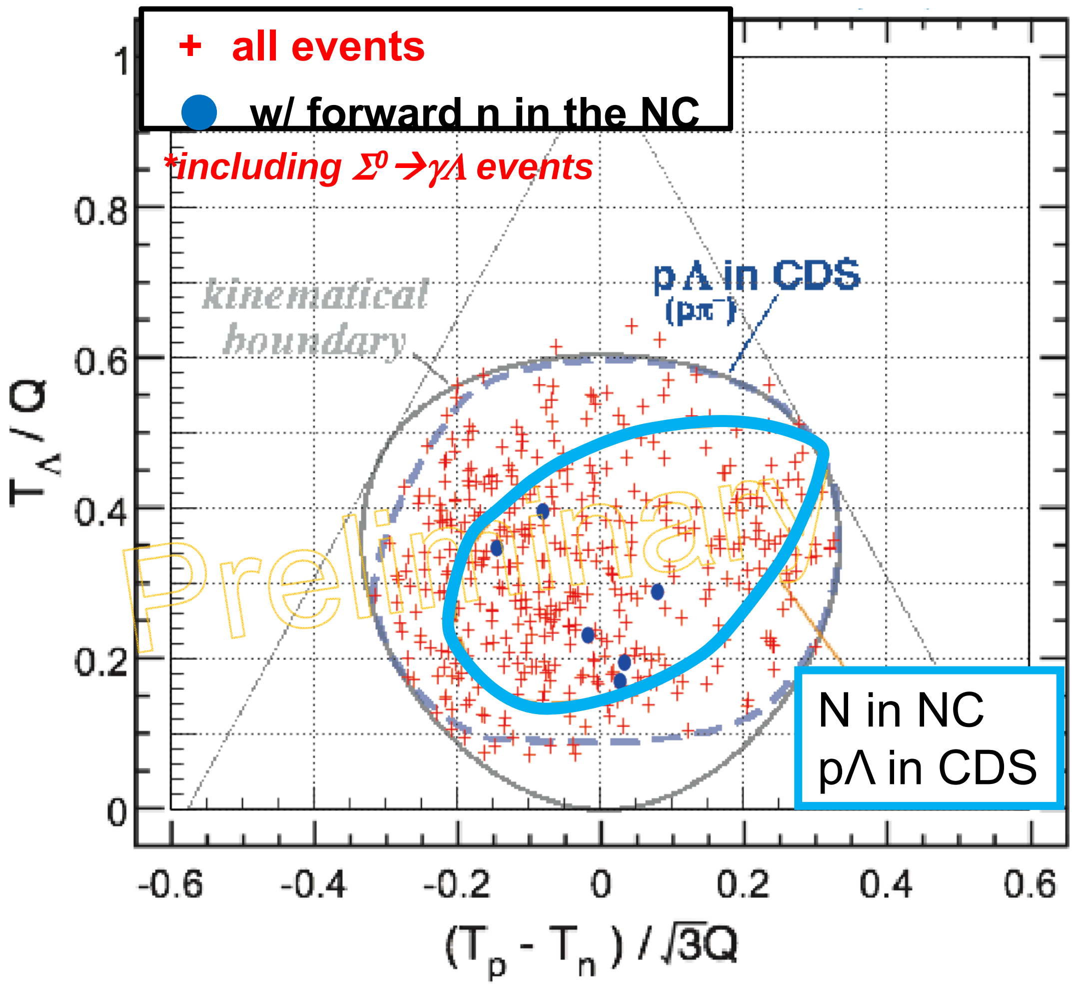


Selected **neutron missing** mass peak.

- Events are scattered widely in phase space.
- Multi-N absorption processes exist.

☑**It seems 3N-abs(Λpn) exists**

^{3}He(K$^-$, Λpn) Result :Dalitz plot of Λpn



Selected **neutron missing** mass peak.

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- **"Λpn" w/ forward n in the NC are a few events.**

☑We would like to carry out high statistical experiments !

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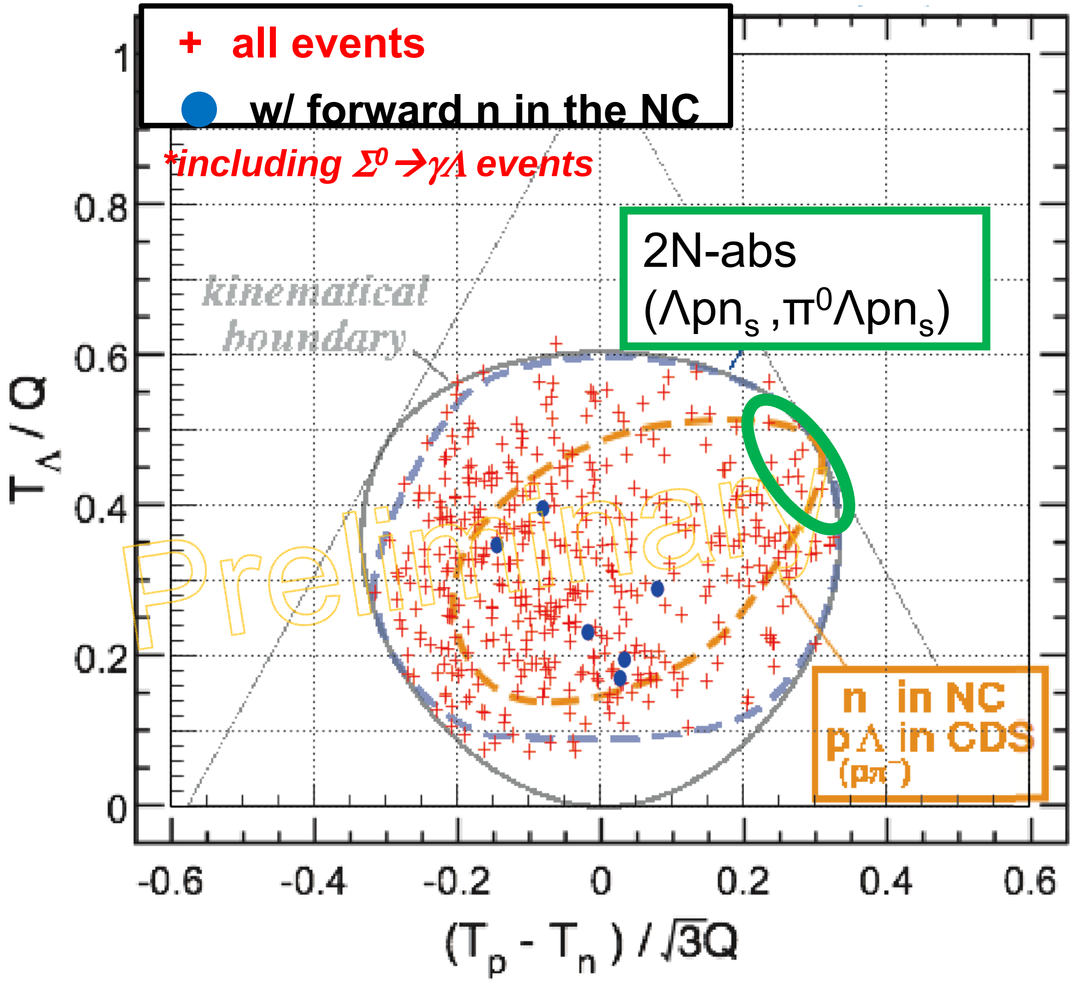

- Kinematical bound

Selected **neutron missing** mass peak.

- Events are scattered widely in phase space.
- Multi-N absorption processes exist.

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☑**2N-abs is very weak.**

- **"Λpn" w/ forward n in the NC are a few events.**

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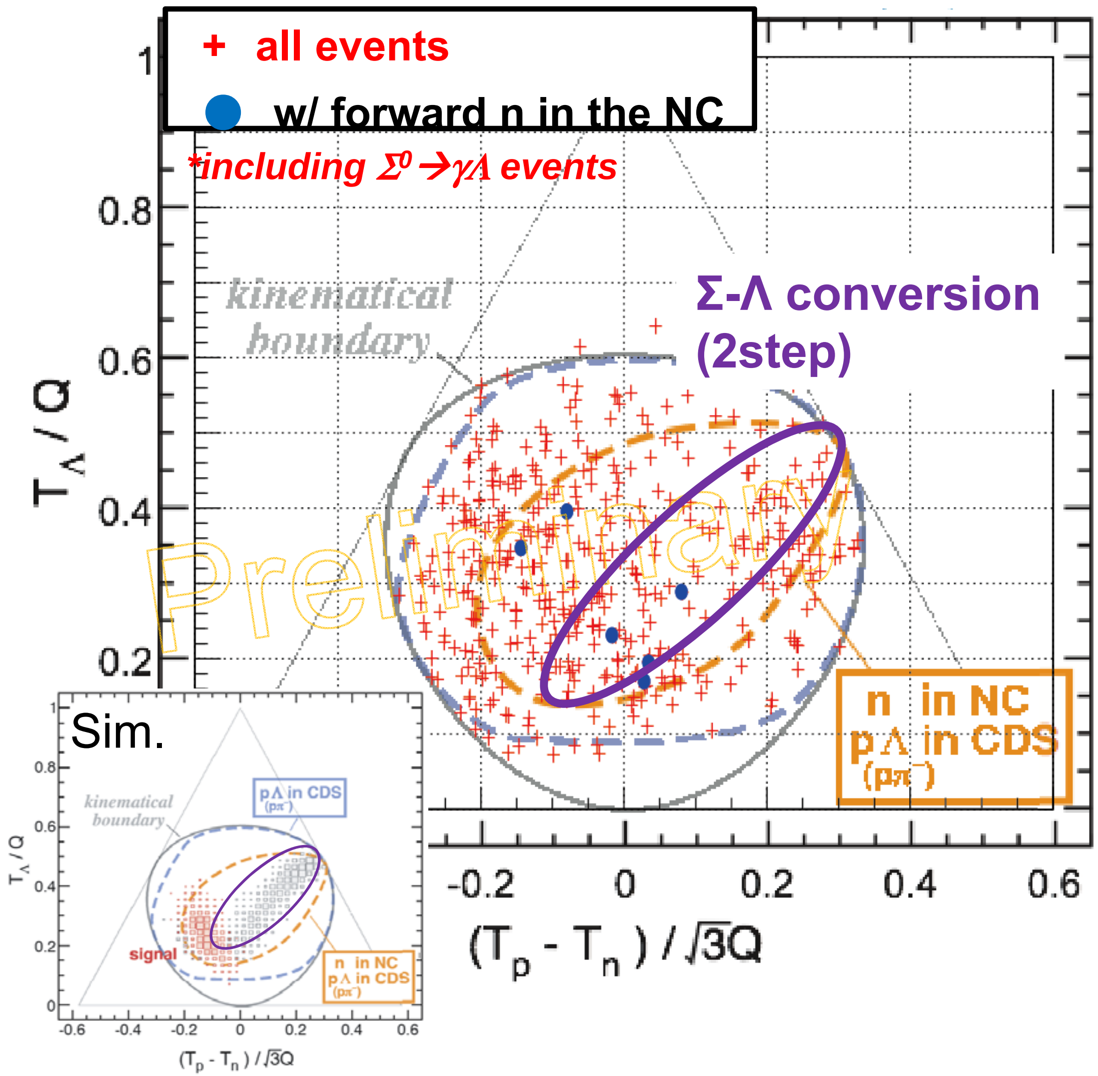
$^{3}He(K^{-}, \Lambda pn)$ Result :Dalitz plot of Λpn



Selected **neutron missing** mass peak.

- Events are scattered widely in phase space.
- Multi-N absorption processes exist.

☑It seems 3N-abs(Λpn) exists

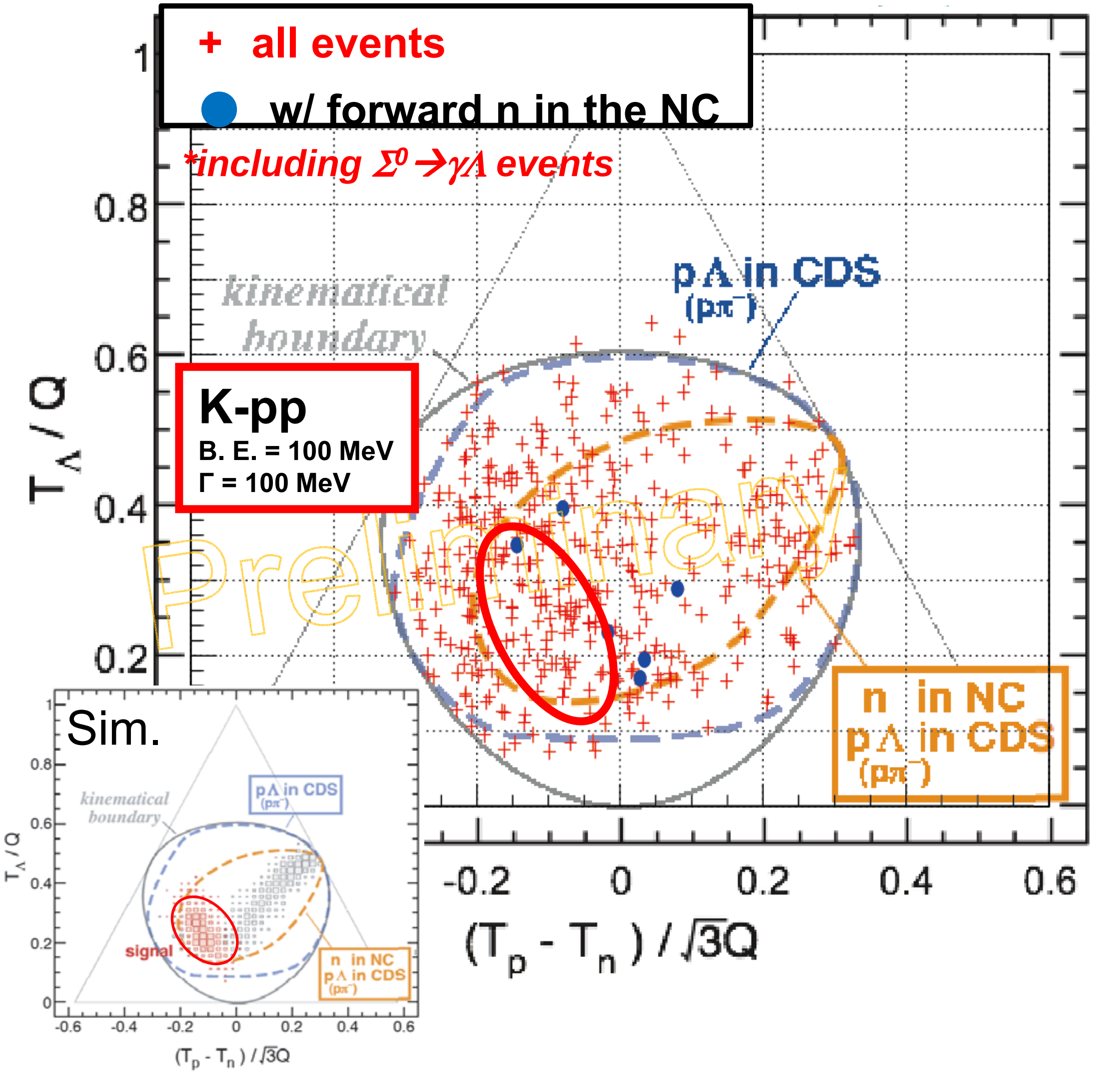
☑2N-abs is almost nothing.

☑ **can not see Σ-Λ conversion line?**

- **"Λpn" w/ forward n in the NC is a few events.**

☑We would like to carry out high statistical experiments !

$^3He(K^-, \Lambda pn)$ Result :Dalitz plot of Λpn



Finally,
will be confirmed in I. M. of Λp w/ missing n.

Selected **neutron missing** mass peak.

・Events are scattered widely in phase space.

・Multi-N absorption processes exist.

☑It seems 3N-abs(Λpn) exists

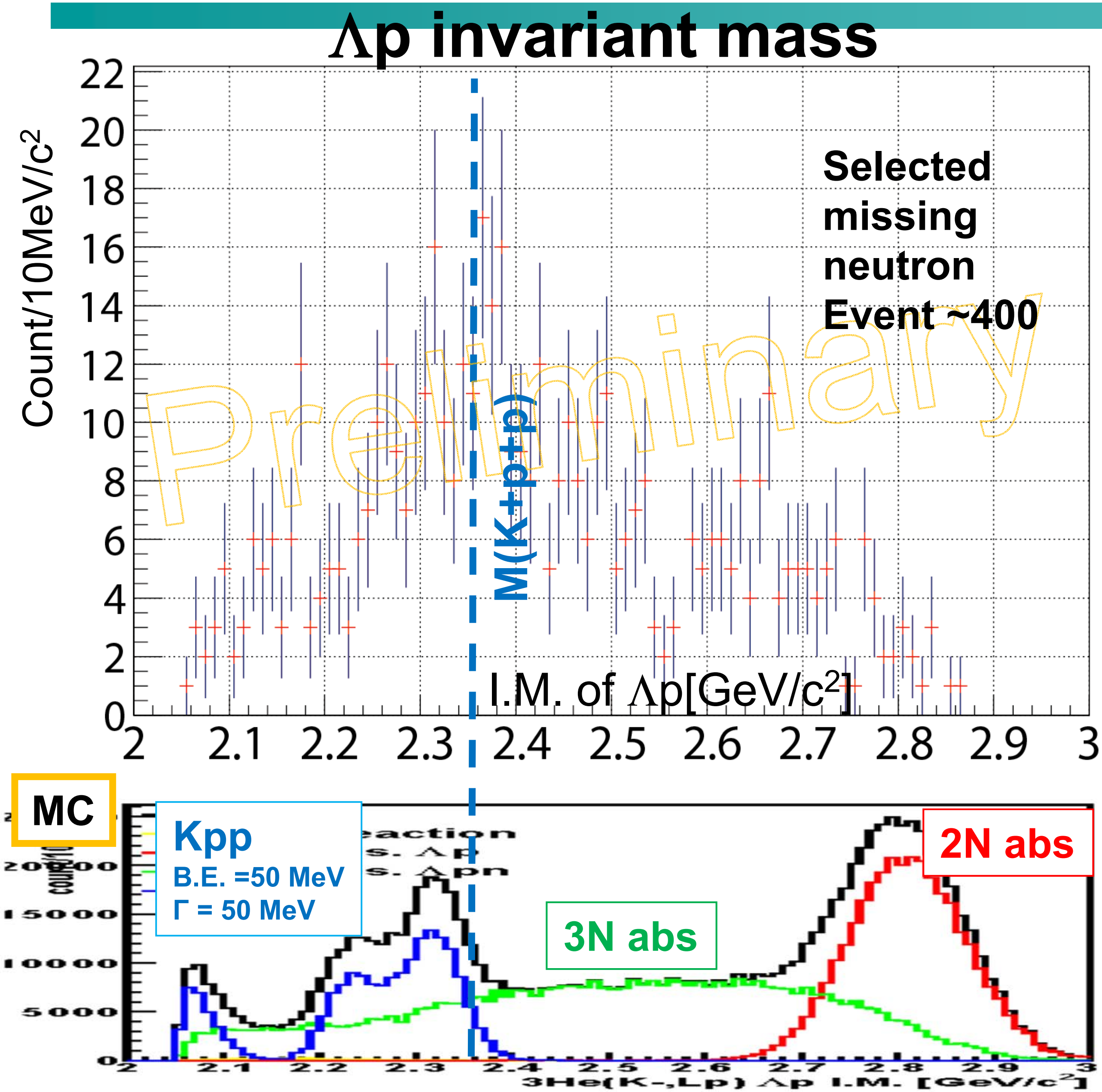
☑2N-abs is almost nothing.

☑ can not see Σ-Λ conversion line?

・"Λpn" w/ forward n in the NC is a few events.

☑We would like to carry out high statistical experiments !

^{3}He(K$^-$, Λpn) Result



It seems that

☑2N abs is very weak.

☑3N abs may be dominant.

☑careful studies are in progress.

K-pp prod.: K- 3He □ K-pp n
ds/dW=1mb/sr (isotropic)
K-pp ->Lp(25%), S0p(25%), pSp(50%)

Summary of J-PARC E15 status

- ✔ J-PARC E15 1st stage physics run was performed.
  - — All the detector subsystems are working well with the good performance as designed
  - — Unfortunately stopped ay only 24KW*4 day running…

- ✔ Semi-inclusive 3He(K-,n) spectrum have tail component in the K-bound region which is hard to be explained by ordinary processes.

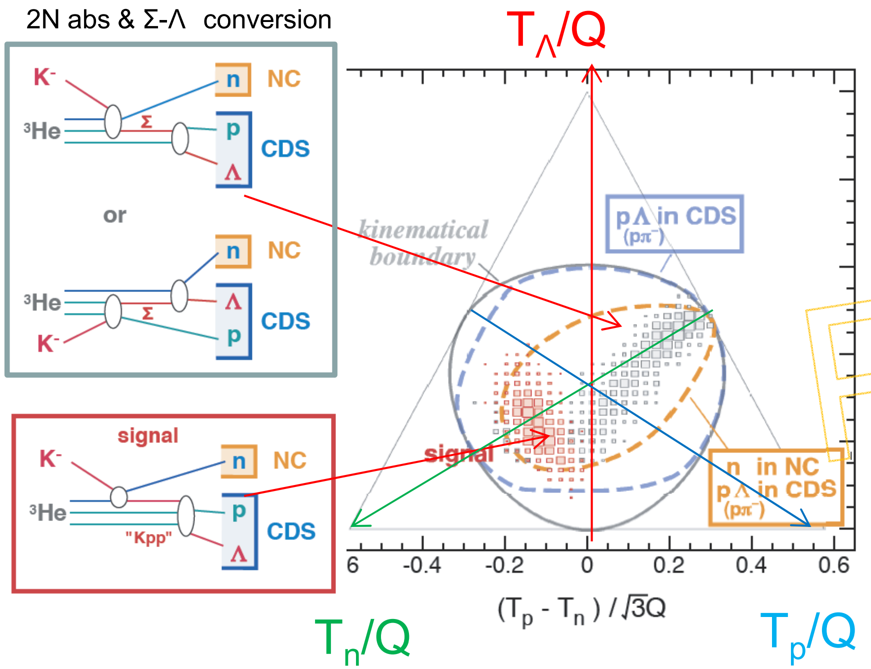
- ✔ 3He (K-,p) spectrum looks very similar to (K-,n)

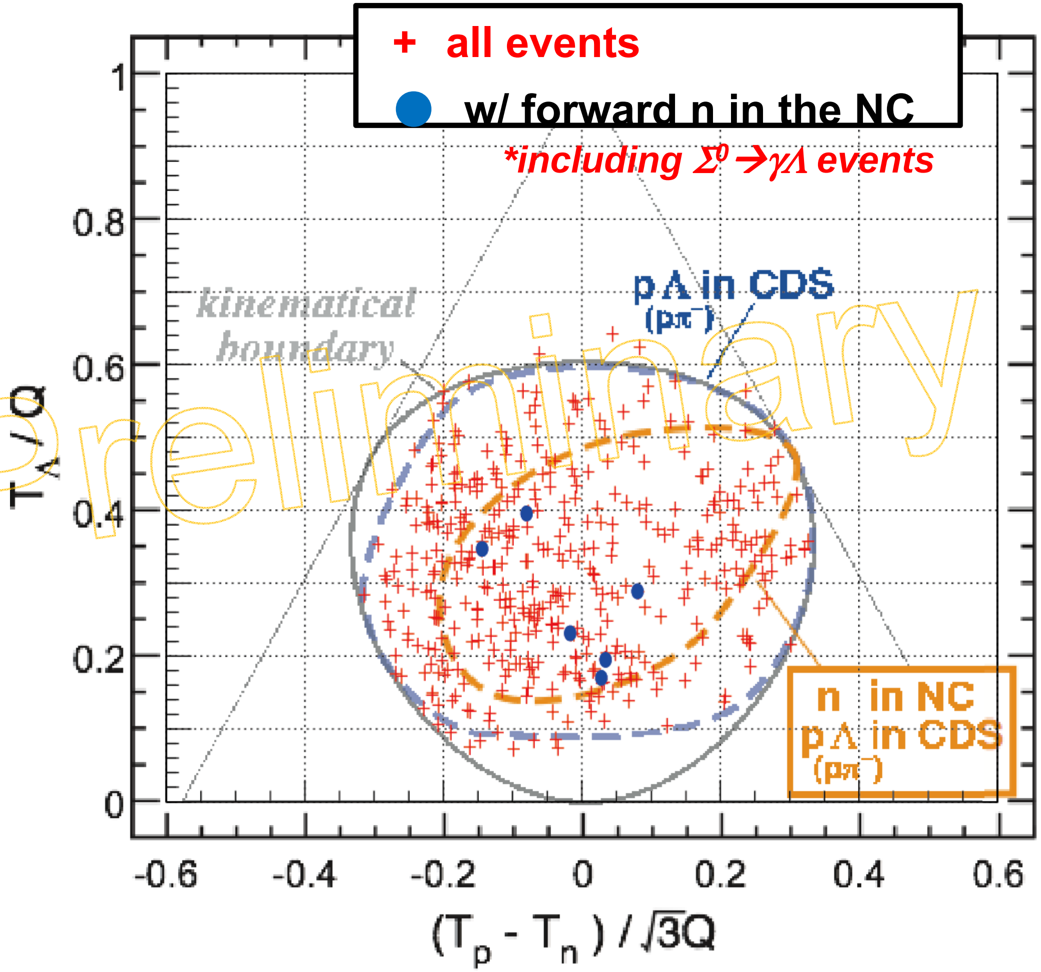
- ✔ Λ + p + n(missing) correlation analysis seems very interesting when the statistics is much improved in the future run.

SPARE SLIDES

Dalitz plot

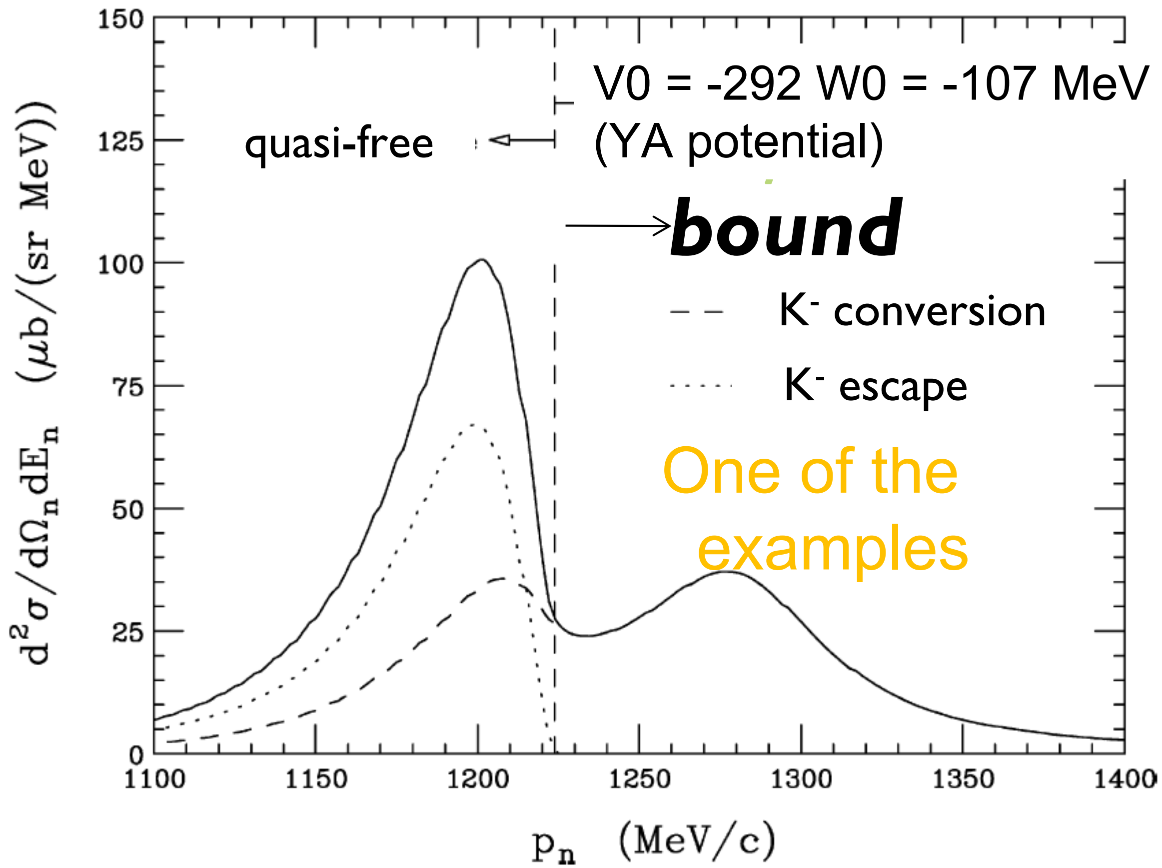
Dalitz plot of Λpn





Formation spectra : in-flight $^3He(K^-,n)$

$K^- + {}^3He \rightarrow$ "K^-pp" + n @ P_K=1GeV/c, $\theta=0^o$



Quasi-free peak
~1.2 GeV/c
Kpp peak >1.22GeV/c

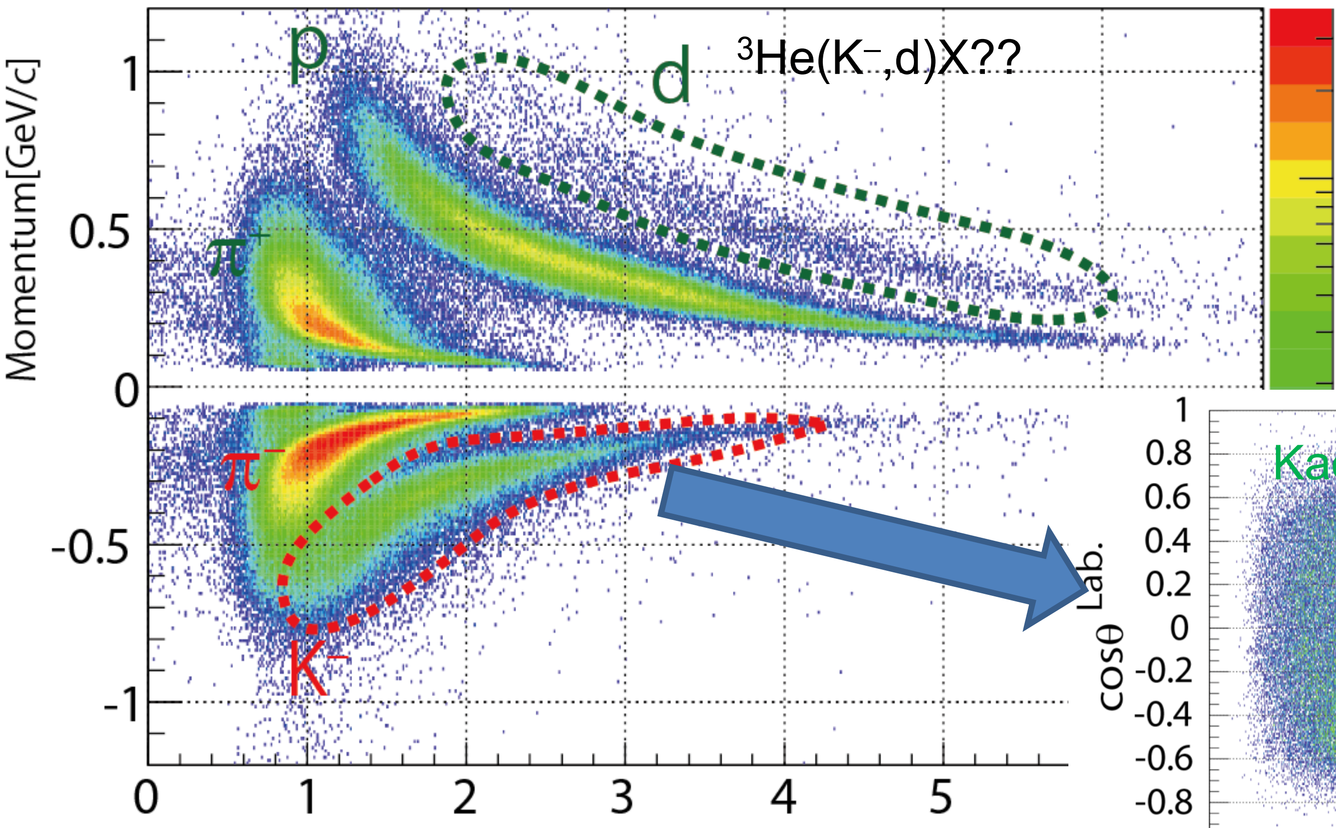
Easy to observe
If $d\sigma/d\Omega$ >1.0 mb/sr

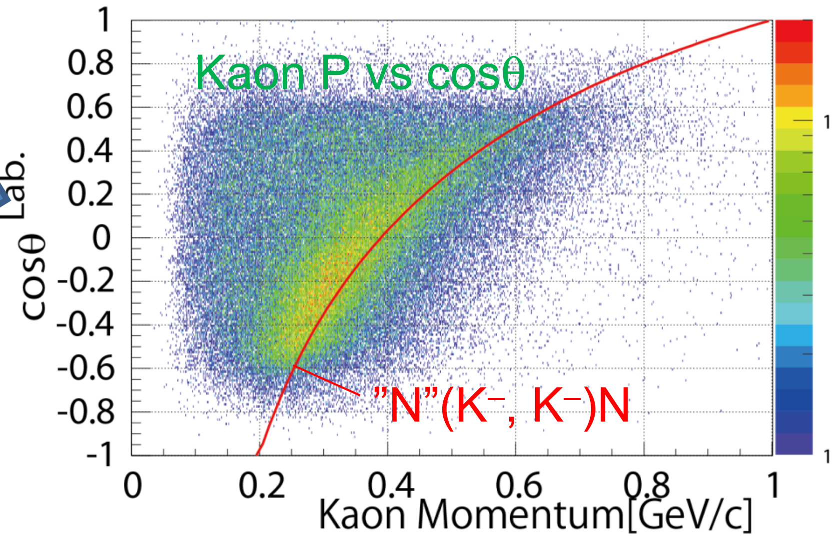
T.Koike and T.Harada., PLB652 (2007) 262

E15: PID for CDS

中性子検出効率

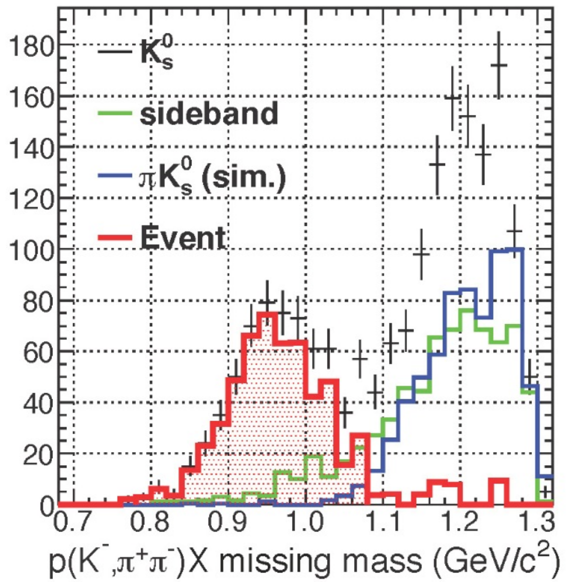
実測に利用

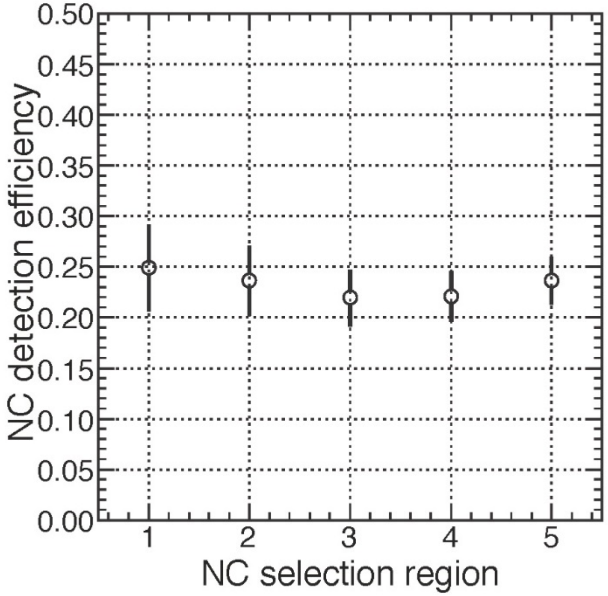




- PID for CDS (vertex in target volume)
- Cos θ means angle between beam K- and scattered particle
- Correlation of K- ‘s cos and momentum is clear => elastic scattering
- there is some deuteron events=> ^{3}He(K-,d)Λ reaction??

Neutron detection efficiency



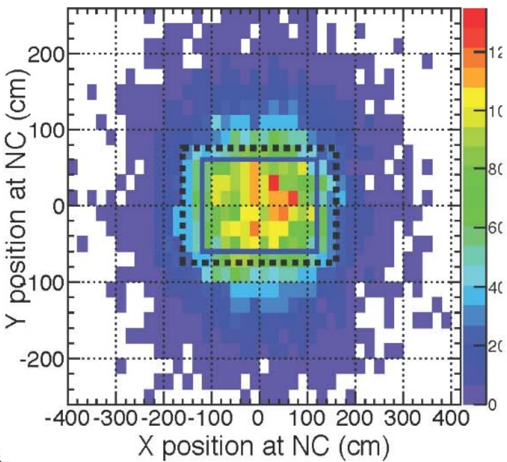


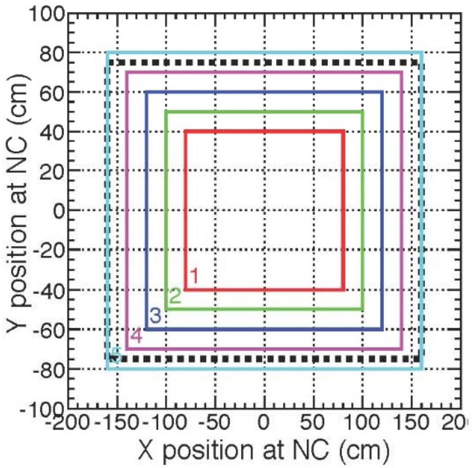
$$K^- + {}^3\mathrm{He} \rightarrow K_s^0 + n + d_s$$
$$K_s^0 \rightarrow \pi^+ + \pi^-$$

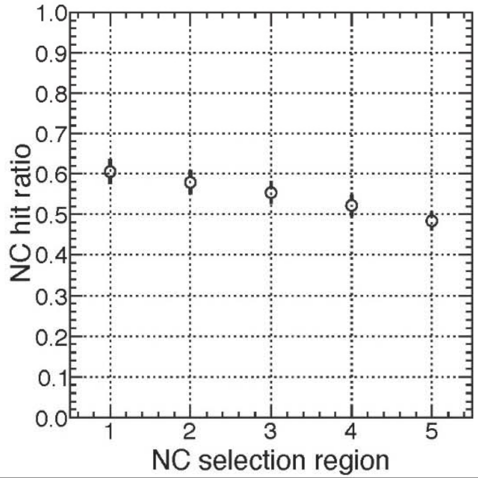
exclusive analysis
with KxCDH^{2hit} trigger data

estimate neutron flux
on the NC
from missing momentum

ε_{NC}= 23 +- 4 %



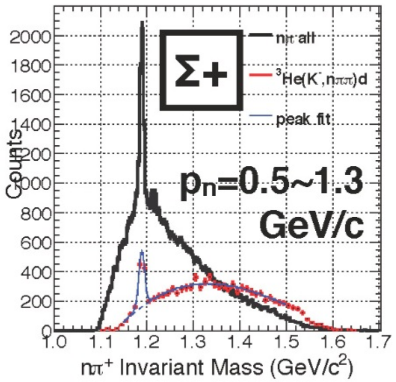


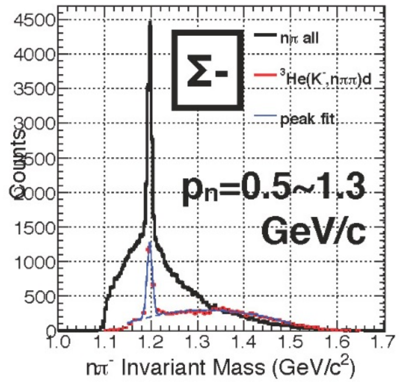


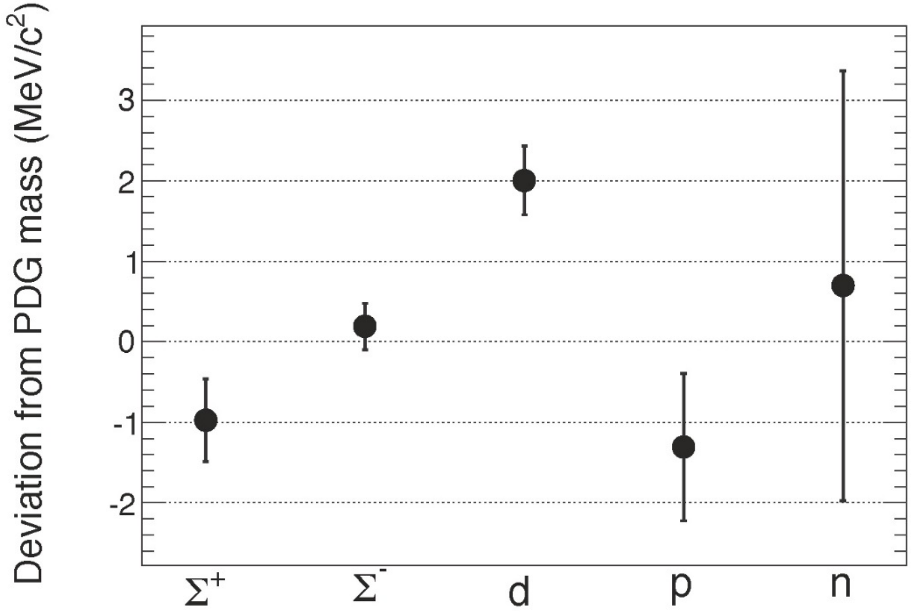
Simulation

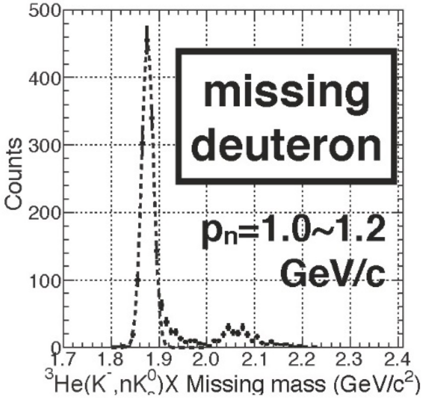
bad resolution
of missing mom.
↑
Fermi mom.

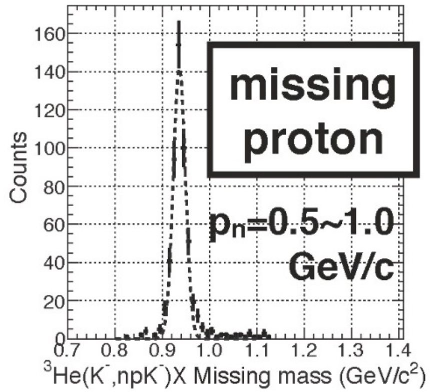
Missing mass scale

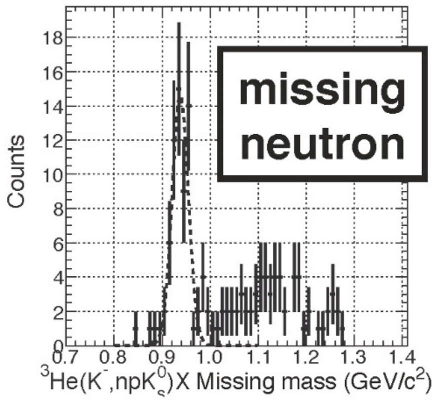












- **Known peaks were examined in combination with the CDS**
  - **covers wide range of neutron momentum**
- **Systematic error: 3 MeV/c^2**

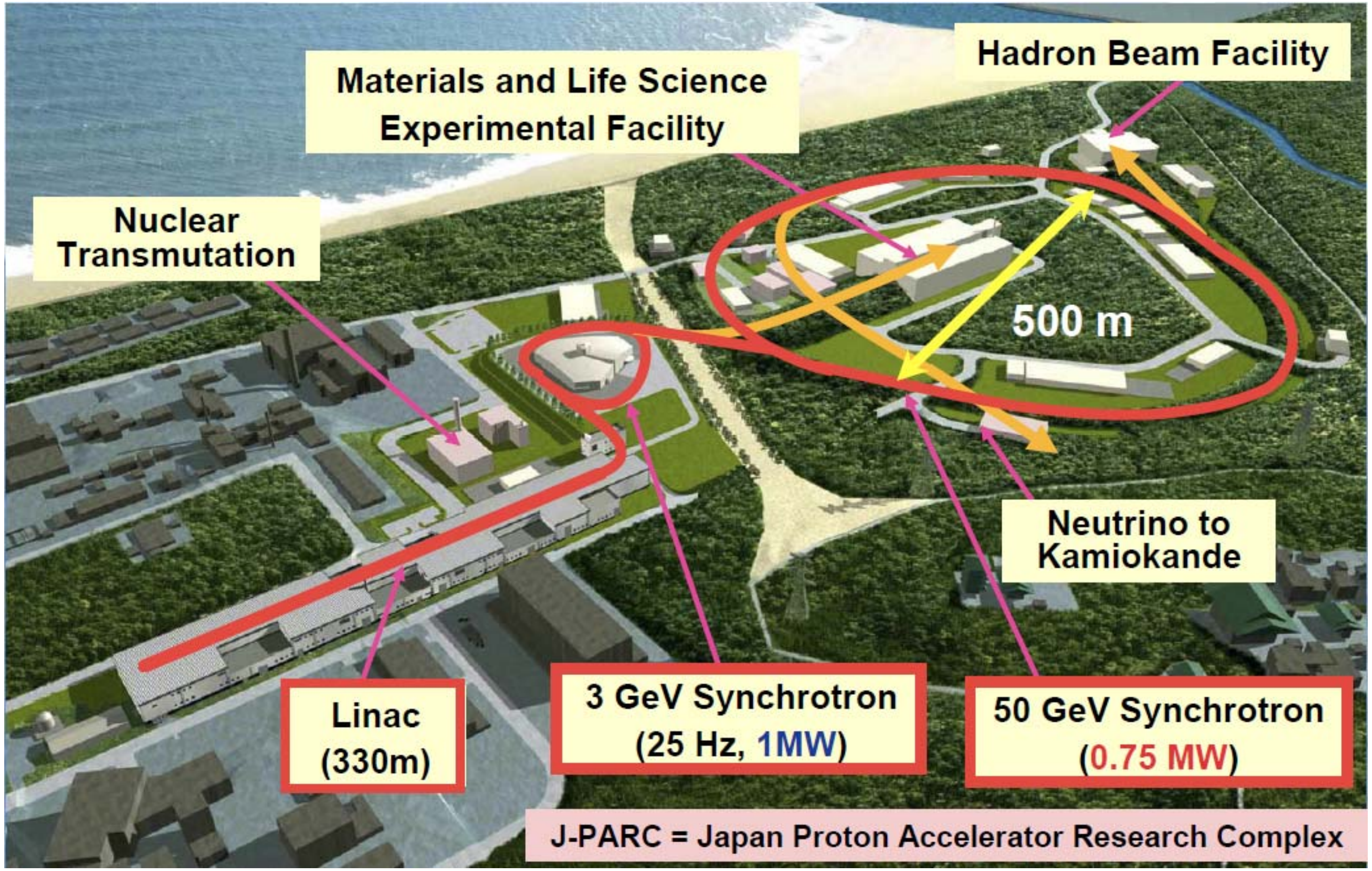
Normalization

	value	relative error (%)
Luminosity L (μb^{-1})	540	1.9
ϵ_{vertex}	0.98	2
$1 - f^{n}_{abs}$	0.946	1
ϵ_{NC}	0.23	16.5
$1 - \epsilon^{n}_{overveto}$	0.922	1.0
A_{NC} (msr)	22.1	1
ϵ_{DAQ}	0.815	0.9
ϵ_{trig}	0.983	0.1
total		16.9

- ε_{vertex} :
  - evaluated from CDC tracking efficiency
  - track multiplicities were considered.
- ε_{nabs} : neutron reaction loss before the NC
  - evaluated from ε_{NC}.
  - NC thickness ~ 36 g. Material between FF-NC ~ 7 g.
  - 20% systematic error assigned.
- A_{NC}: NC geometrical acceptance at the first layer.
  - Error from uncertainty in the relative position ~ 1 cm.

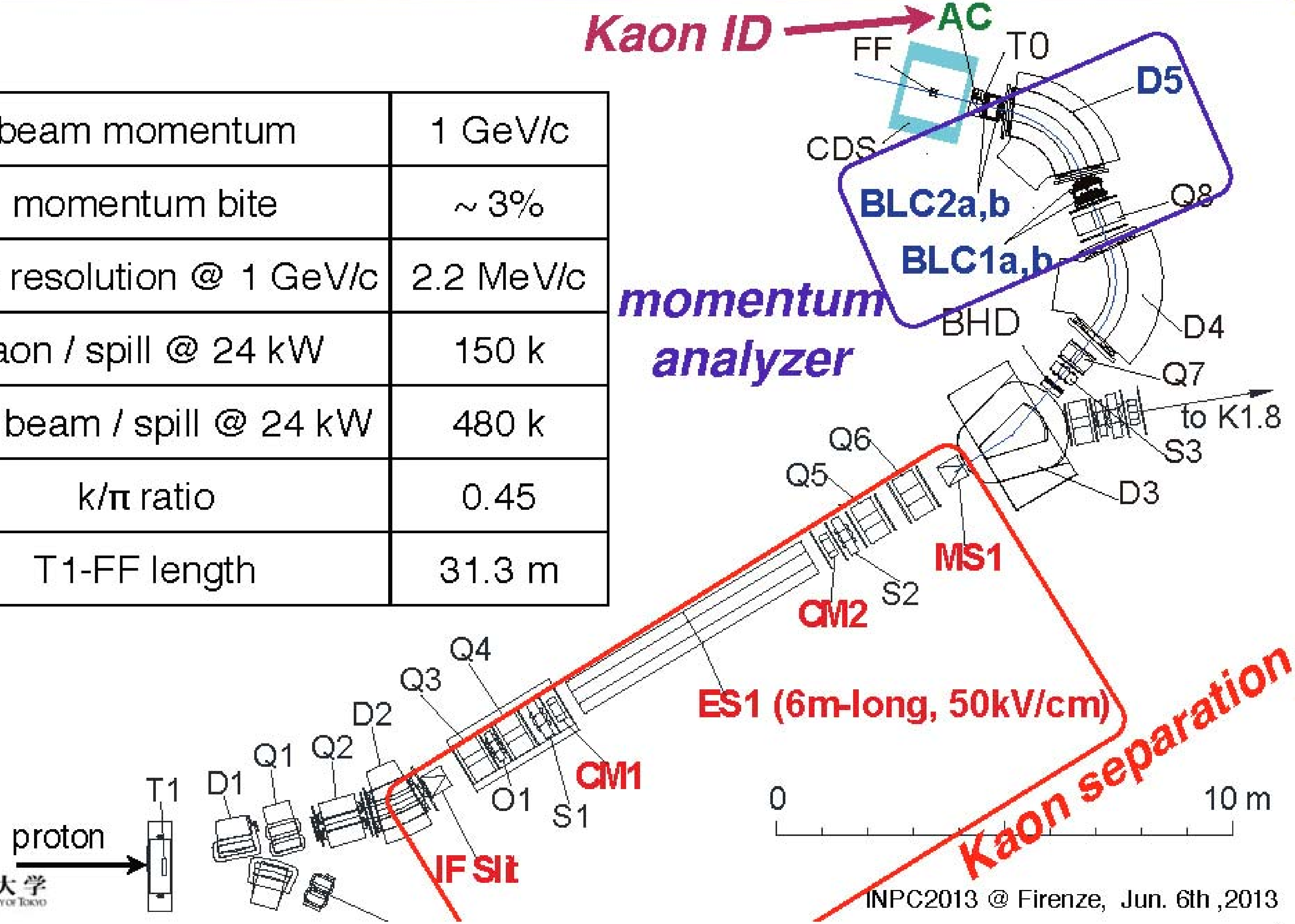
J-PARC

Locates in Tokai, Ibaraki



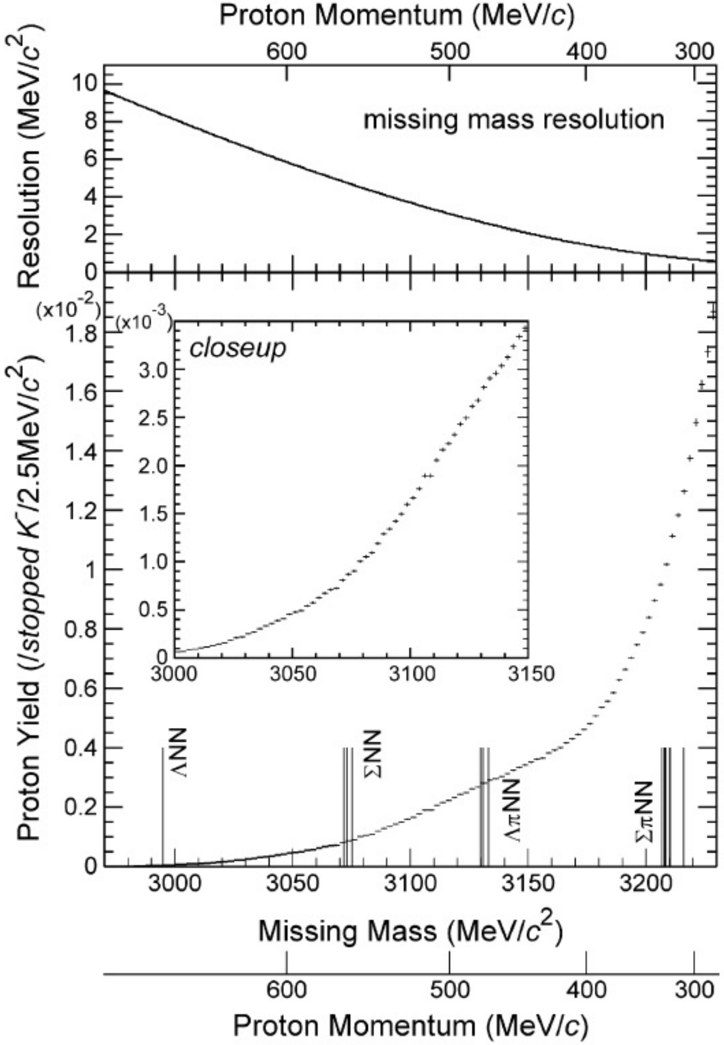
Kaon beam quality @ J-PARC K1.8BR

beam momentum	1 GeV/c
momentum bite	~ 3%
mom resolution @ 1 GeV/c	2.2 MeV/c
kaon / spill @ 24 kW	150 k
total beam / spill @ 24 kW	480 k
k/π ratio	0.45
T1-FF length	31.3 m

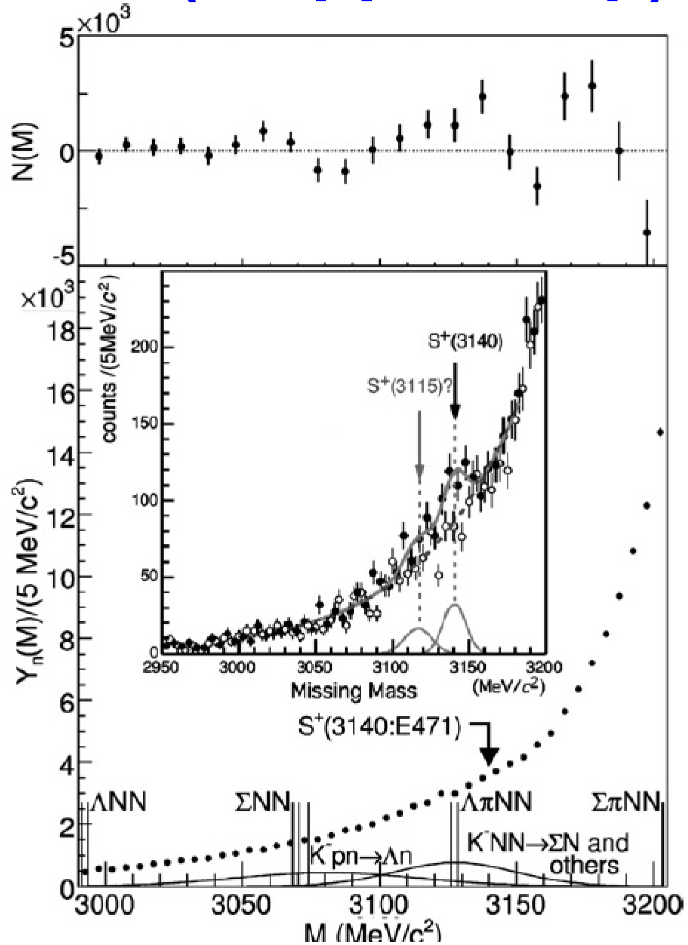


KEK-PS E549

^{4}He(stopped K^{-},p)



^{4}He(stopped K^{-},p)



Error bar が見えないほどの高統計

Fig. 5. The missing mass spectrum from the ^{4}He(K^{-}_{sto} … inclusive measurement. The systematic error of the or… cent relative error. The upper figure shows the overall … in the present experiment.

Upper limits for the narrow deeply bound status