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

RIKEN H. Outa

for E15 collabolation

- ✔ **Kaonic nuclei**

- ✔ ***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**
    arXiv: [nucl-ex]1408.5637 submitted to PLB
  - (**— 3He(in-flight K-, p) spectrum** **Tokuda)**
  - **Λp+n(missing) channel analysis** **Sada**

J-PARC E15 collaboration

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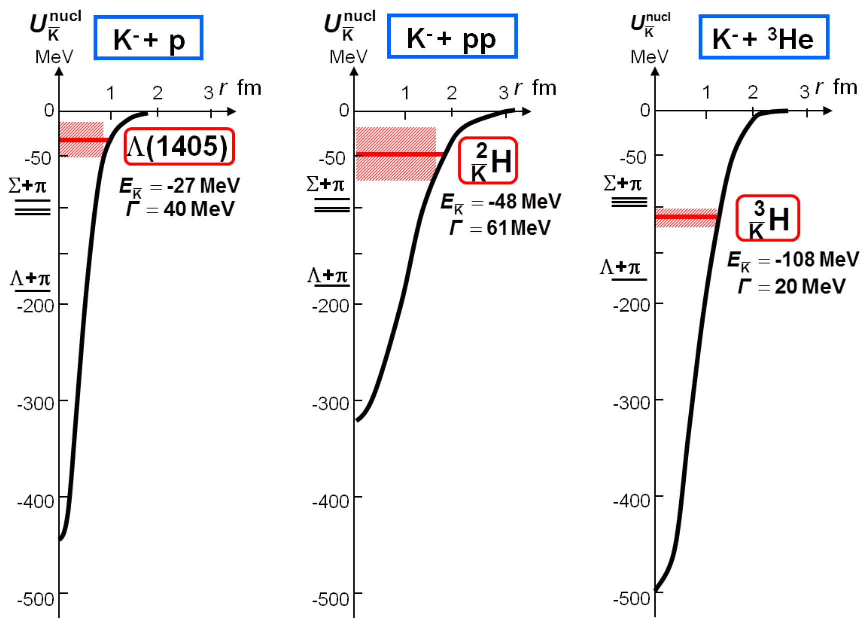
($) Co-Spokesperson

Introduction

Motivation :

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

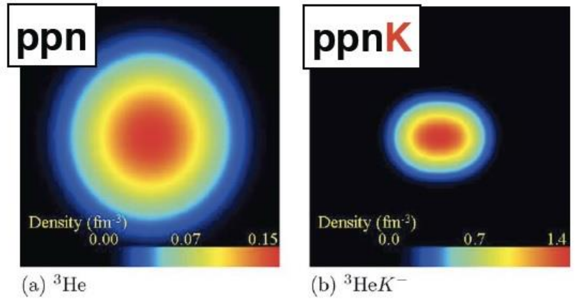
- ✔ **Does the simplest Kaonic nucleus "K-pp" exist?**
- ✔ **How deeply bound ?**



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

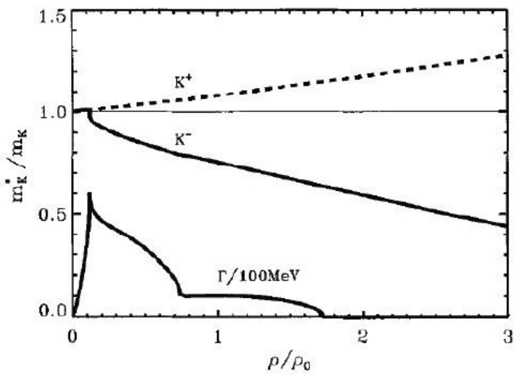
Y. Akaishi & T. Yamazaki, Phys. Lett. B535 (2002) 70.

dense nuclei are predicted



A. Dote, H. Horiuchi, Y. Akaishi and T. Yamazaki, Phys. Lett. B 590 (2004) 51

Kaon mass in nuclear medium?



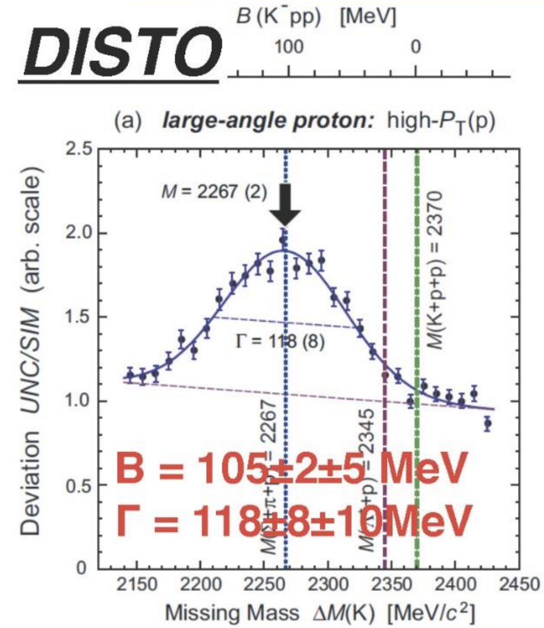
1.T. Waas *et al. Physics Letters B* **379,** 34–38 (1996).

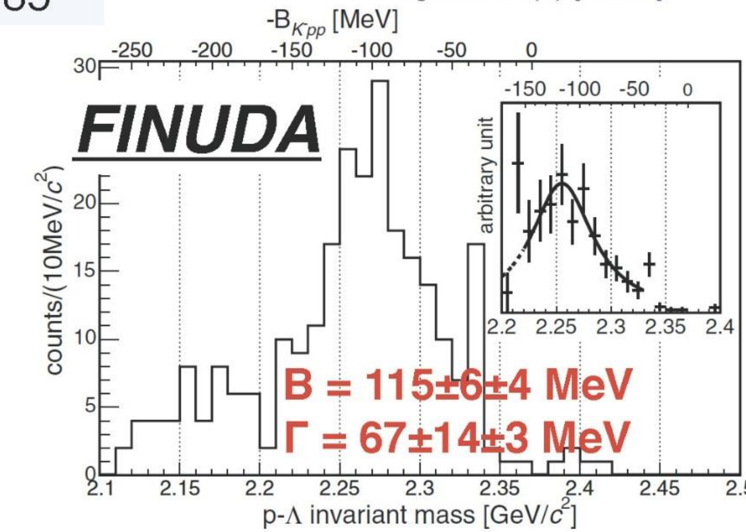
The simplest kaonic nuclei KbarNN

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

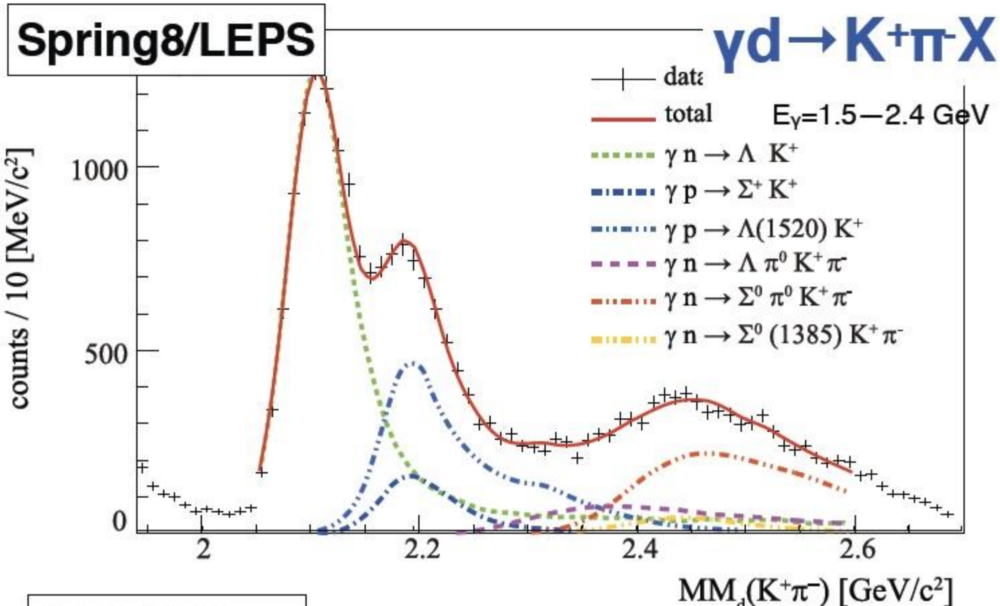
Λ(1405) ansatz	B.E.[MeV]	Γ[MeV]
T. Yamazaki, Y. Akaishi(2002)	48	61
N.V. Shevchenko, A. Gal, J. Mares(2007)	50-70	90-110
Y. Ikeda, T. Sato (2007,2009)	60-95	45-80
S. Wycech, A.M. Green (2009)	40-80	40-85

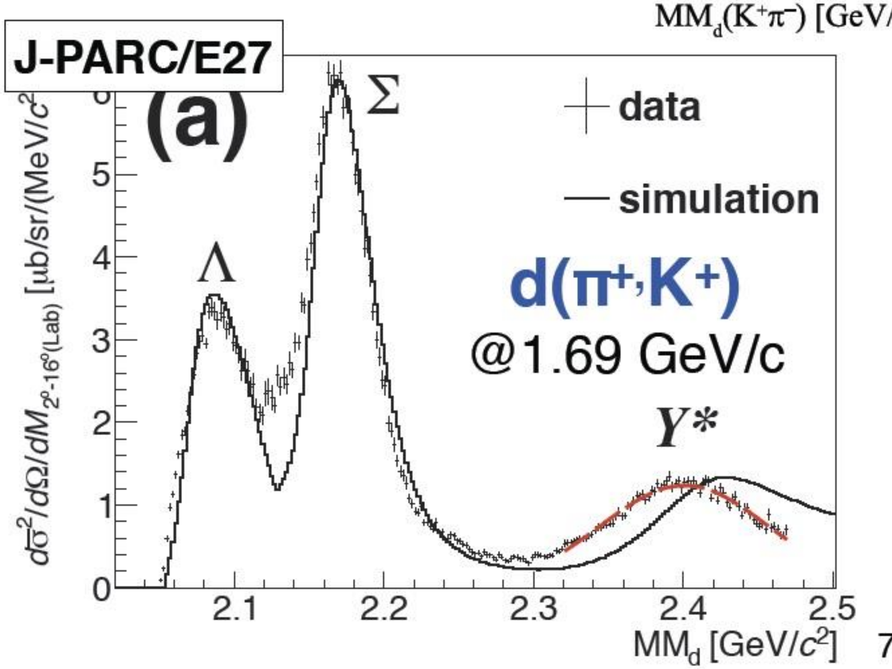
- **Many theoretical calculations**
- **Little experimental information**
- **bound or not? B.E. and width?**

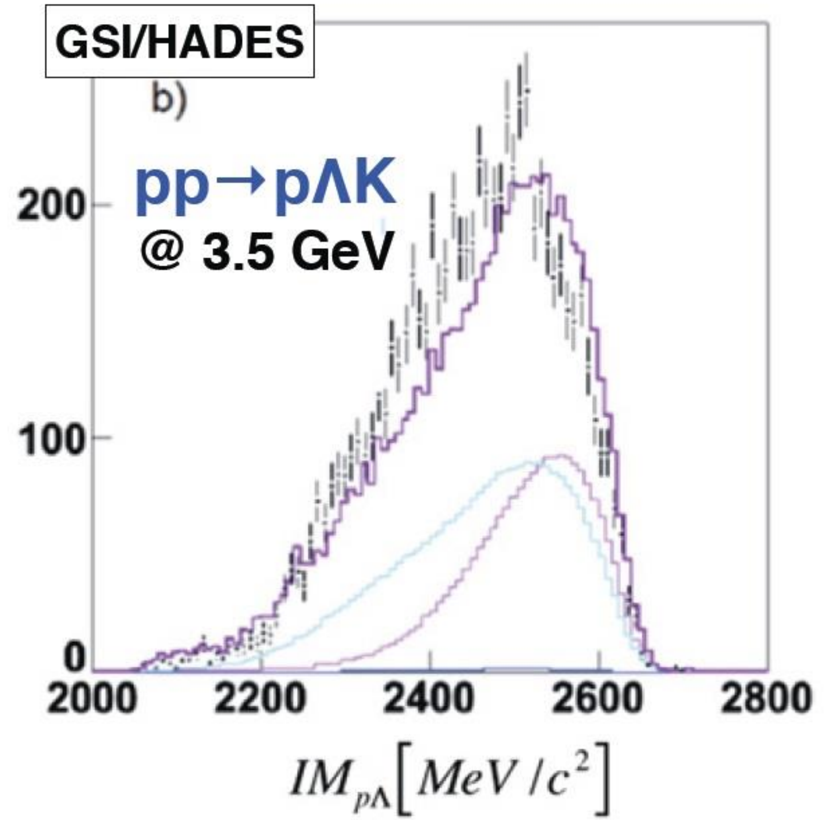




Experimental situation







talk by K. Lapidus

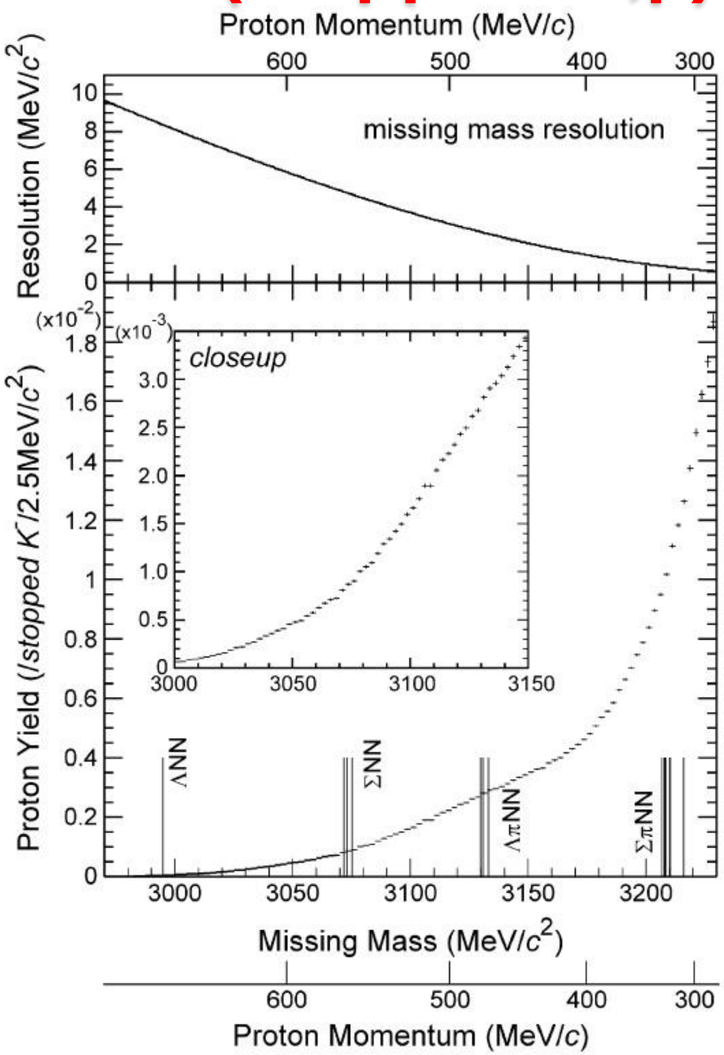
[1] A. O. Tokiyasu, et al., Phys. Lett. B 728, 616 (2014).

[2] Y. Ichikawa, T. Nagae, et al., arXiv nucl-ex, (2014).

[3] L. Fabbietti, et al., Nucl. Phys. A 914, 60 (2013).

KEK-PS E549

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



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

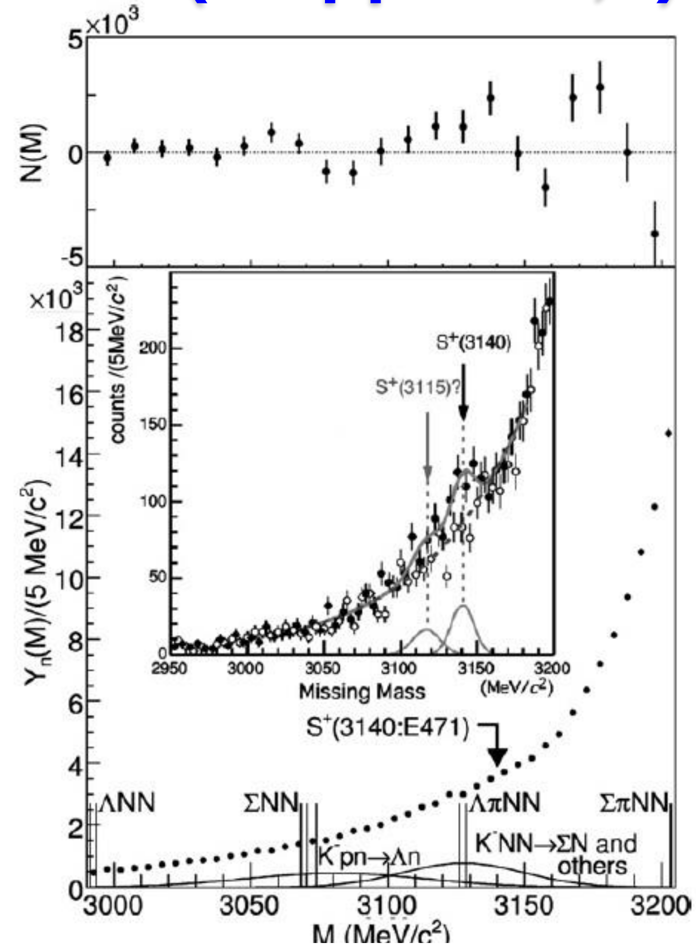


Fig. 5. The missing mass spectrum from the ^{4}He(K^{-}_{sto} … inclusive measurement. The systematic error of the or… cent relative error. The upper figure shows the overall … in the present experiment.

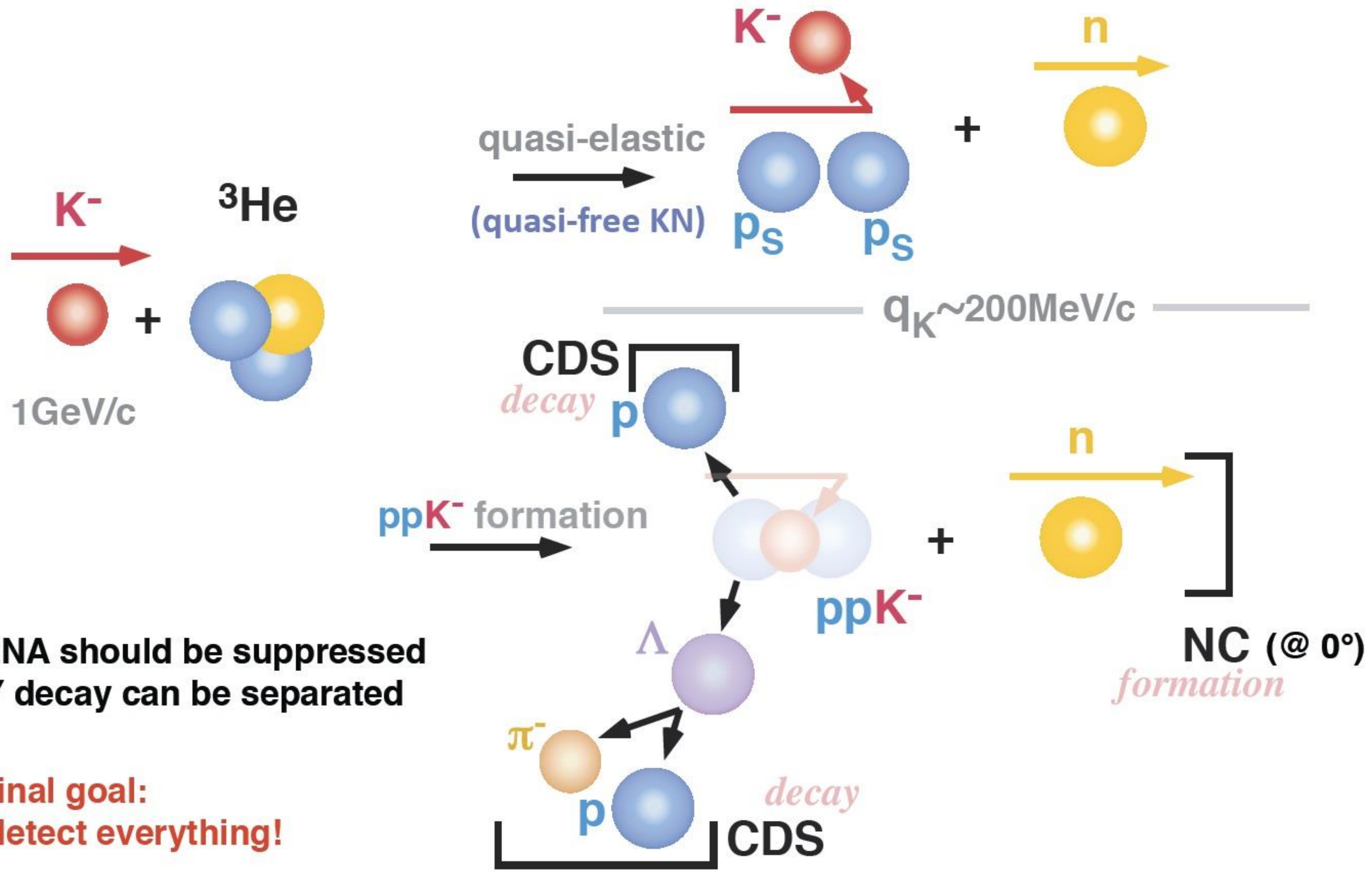
Error bar が見えないほどの高統計

Upper limits for the narrow deeply bound status

E15 Experiment

Setup &
Performance of detectors

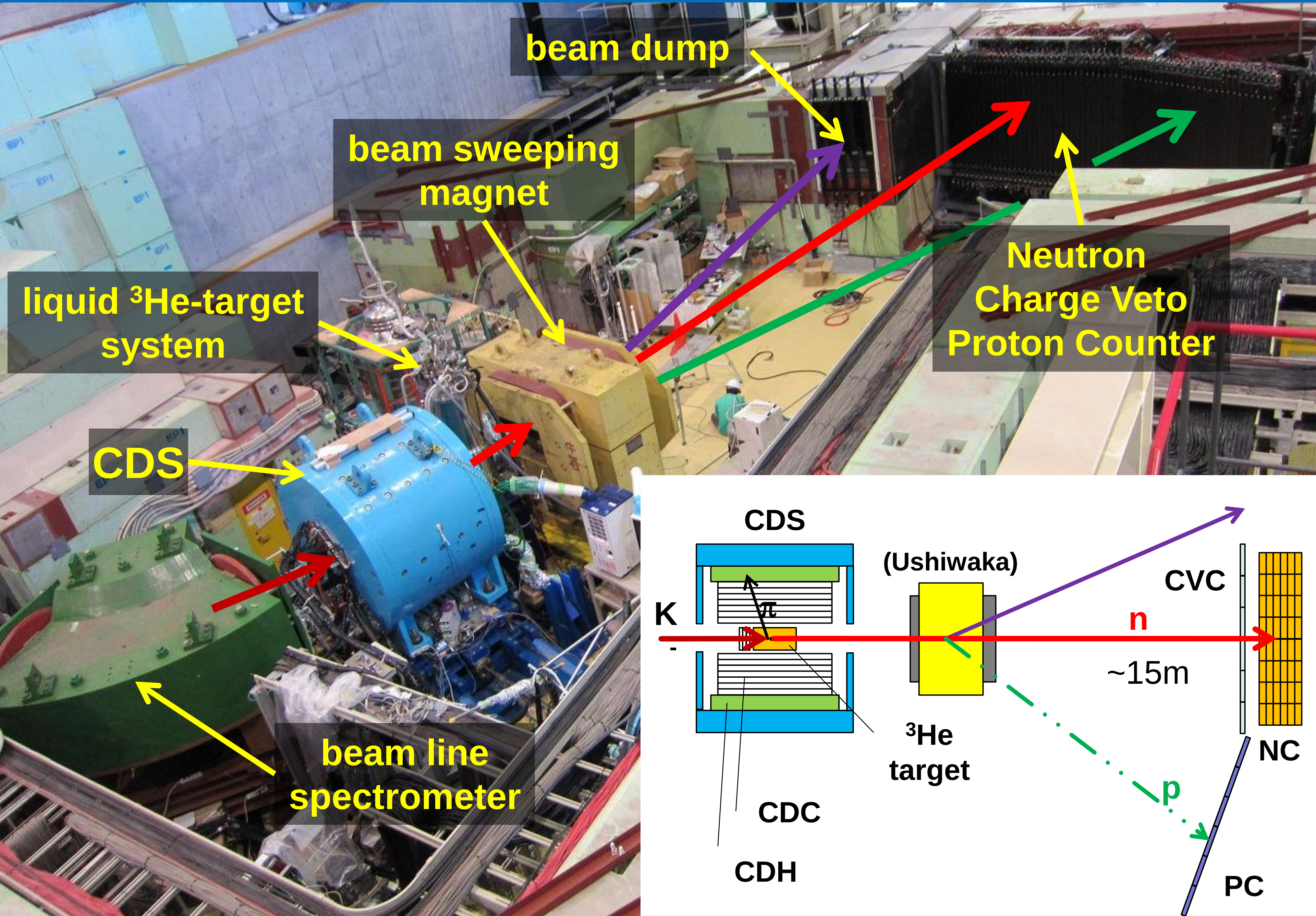
Inflight kaon reaction on ^{3}He



2NA should be suppressed
Y decay can be separated

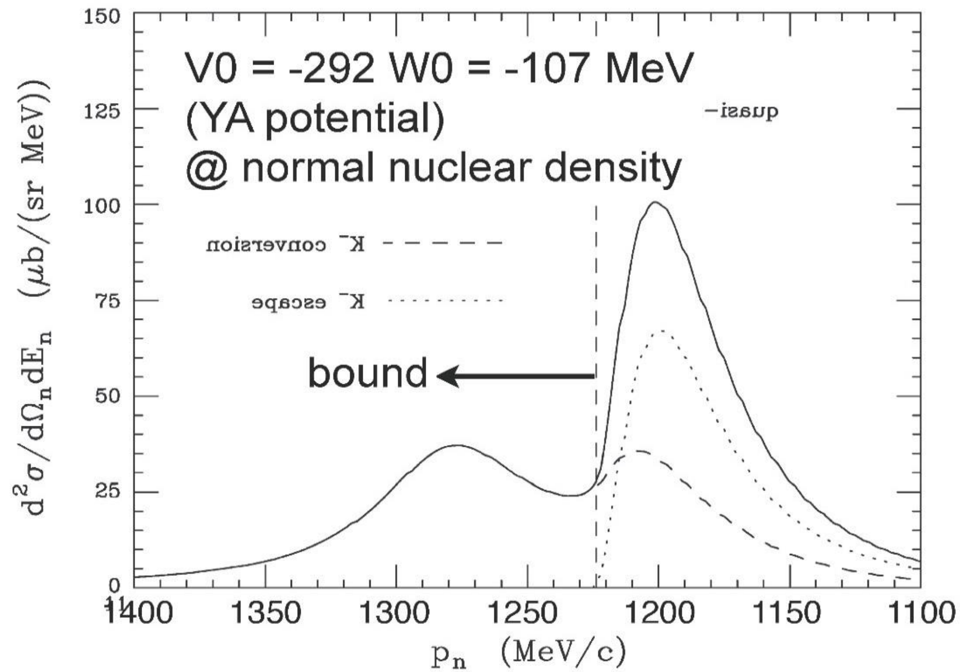
final goal:
detect everything!

K1.8BR spectrometer [Jun. 2012]



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

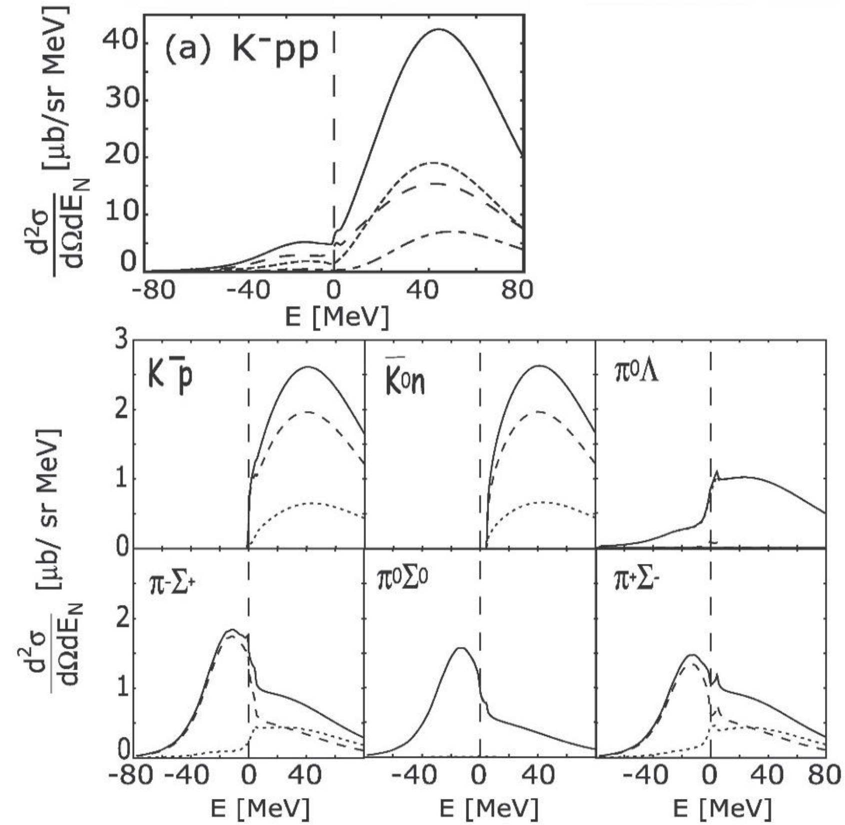
$K^- + {}^3He \rightarrow$ "K^-pp" + n @ P_K=1GeV/c, θ=0°



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

cross section
may be > mb/sr

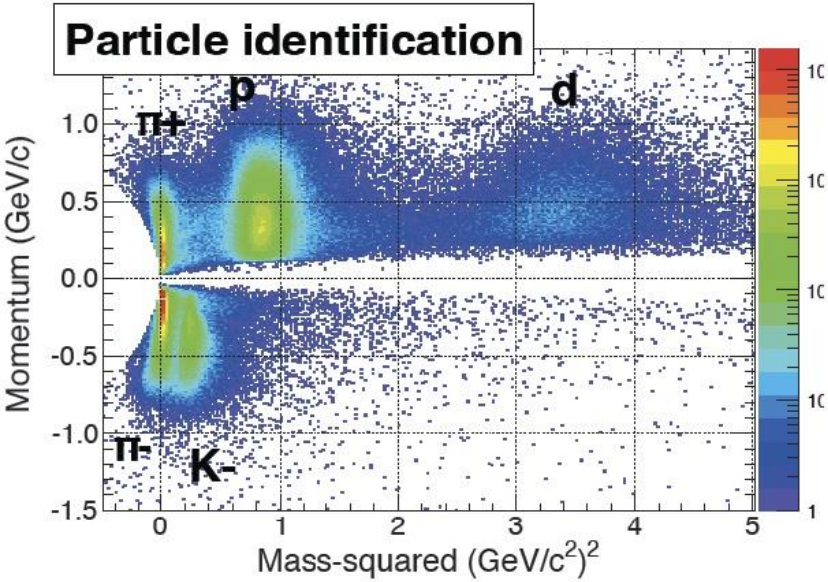
Easy to observe
If dσ/dΩ >1.0 mb/sr

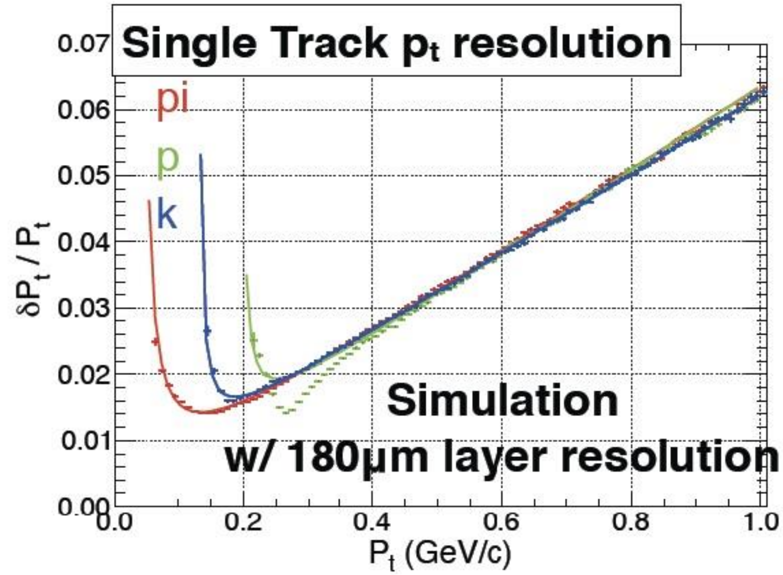


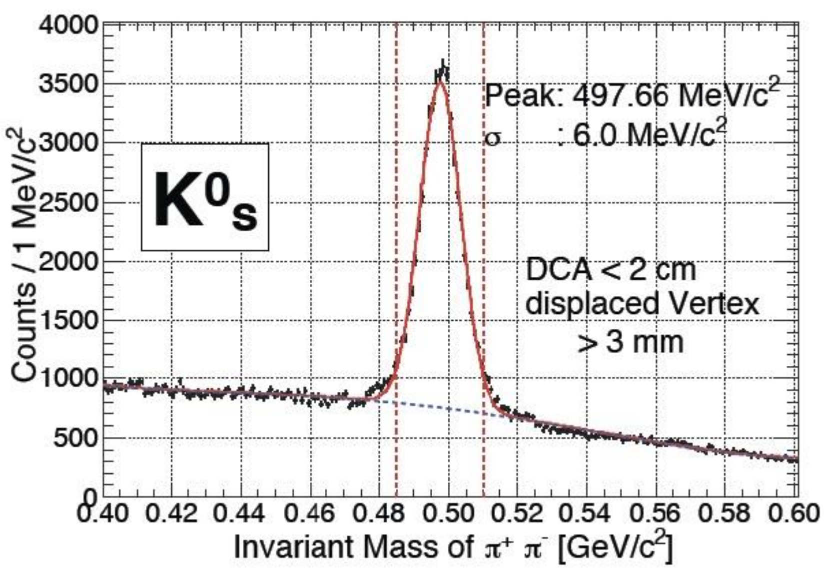
J. Yamagata-Sekihara et. al., Phys. Rev. C 80, 045204 (2009)

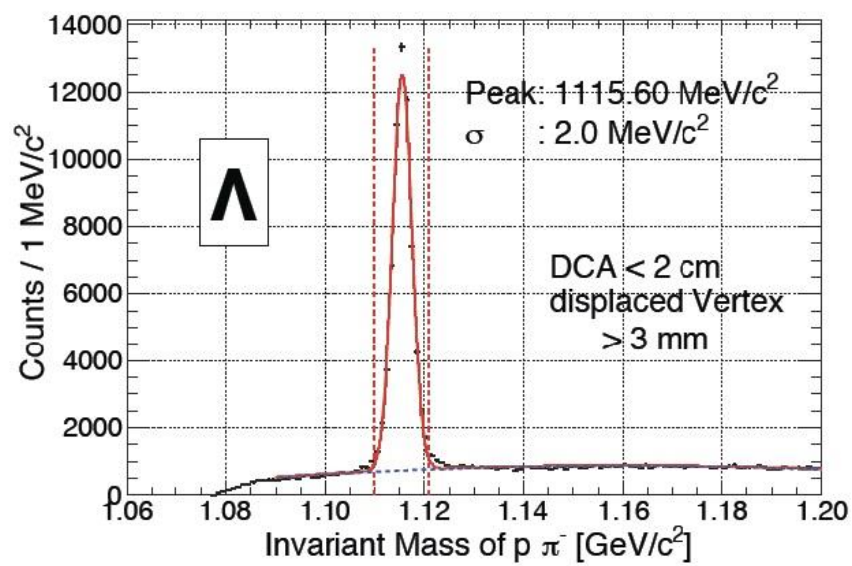
Σ tag may enhance the structure in bound region.

CDS performance

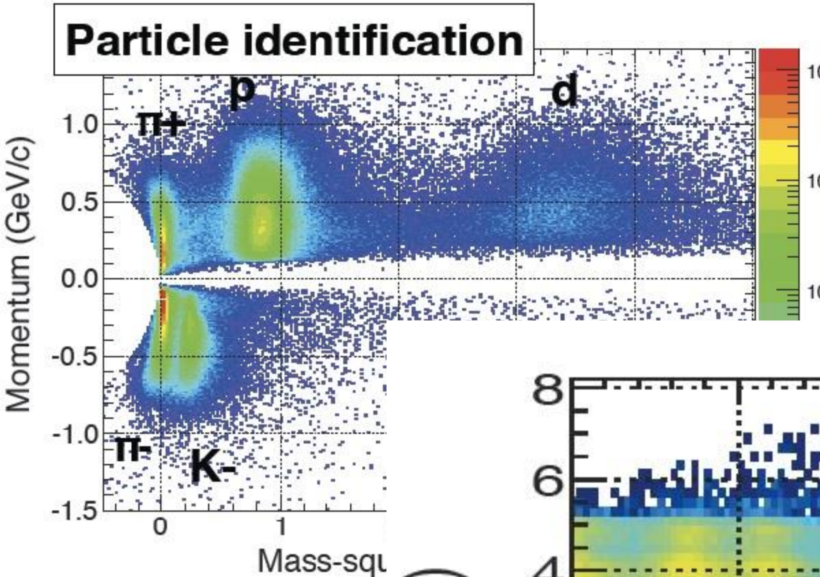


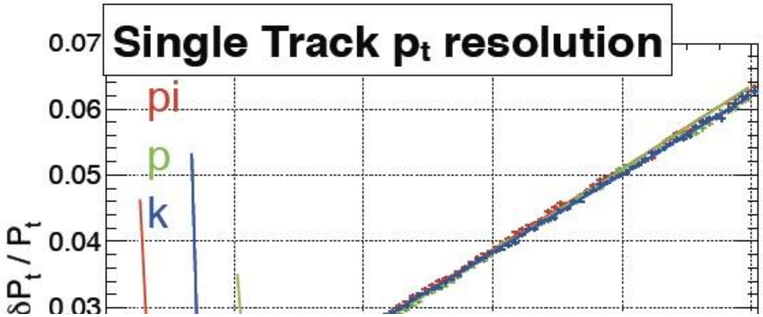


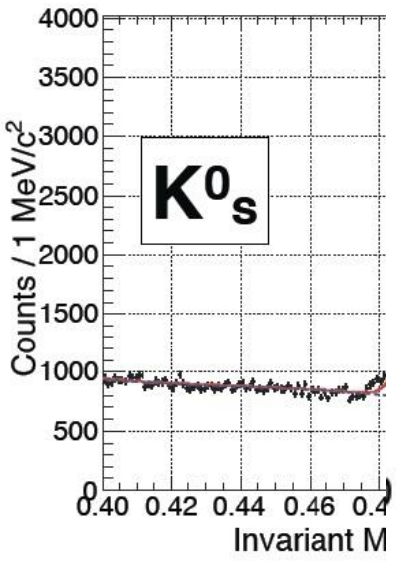


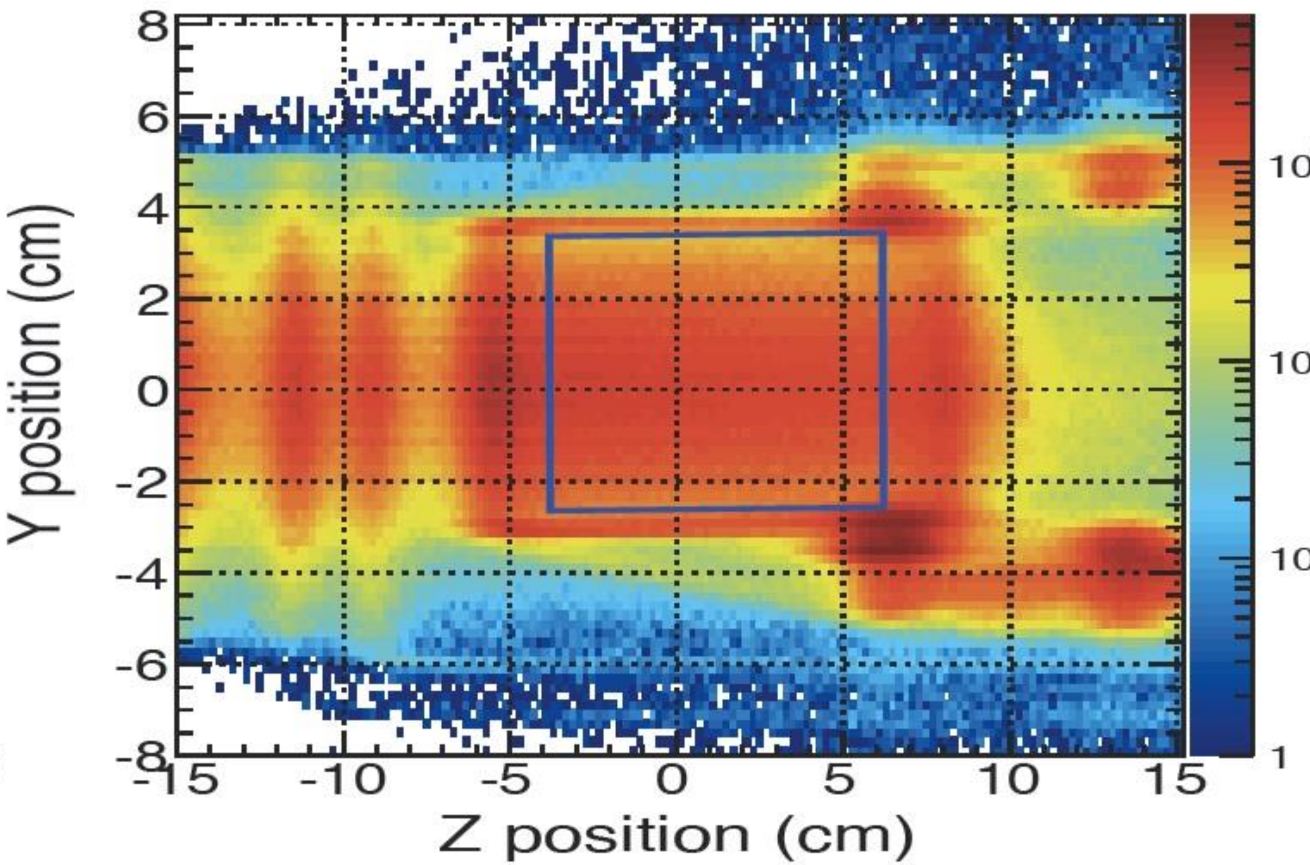


CDS performance

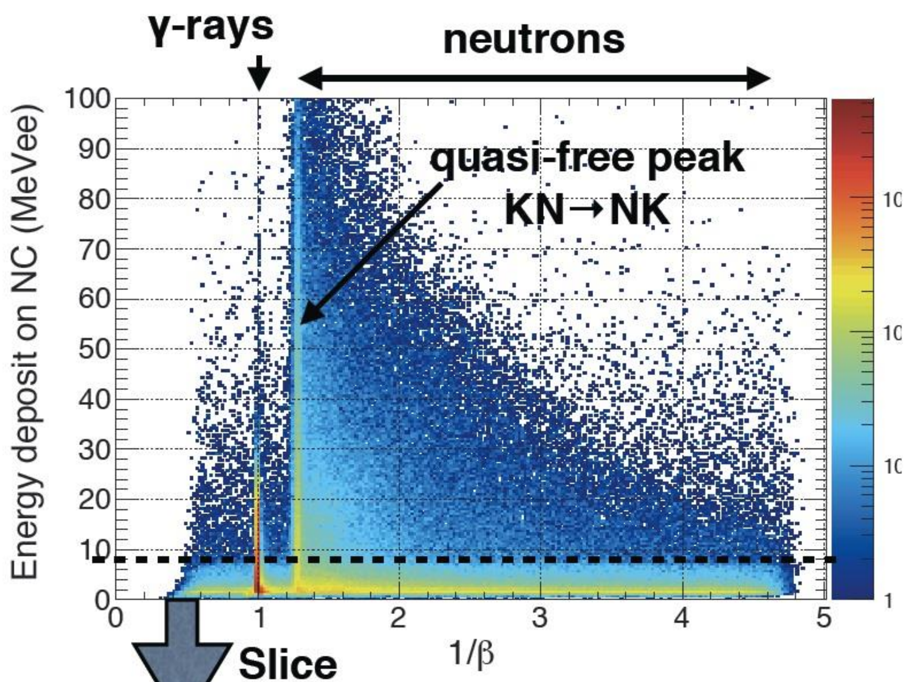


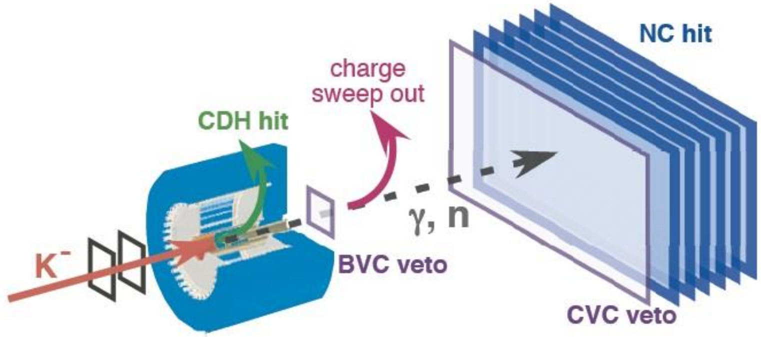


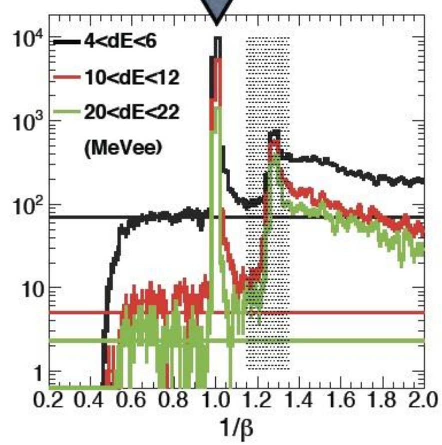


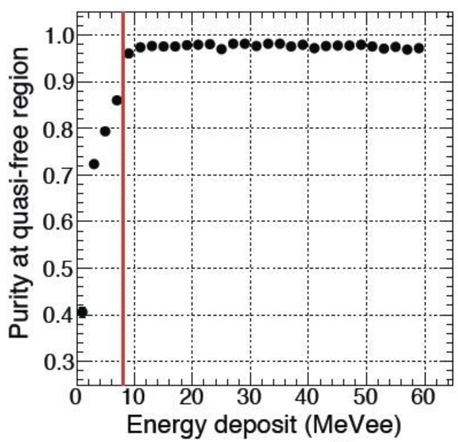


Neutron analysis









- **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**

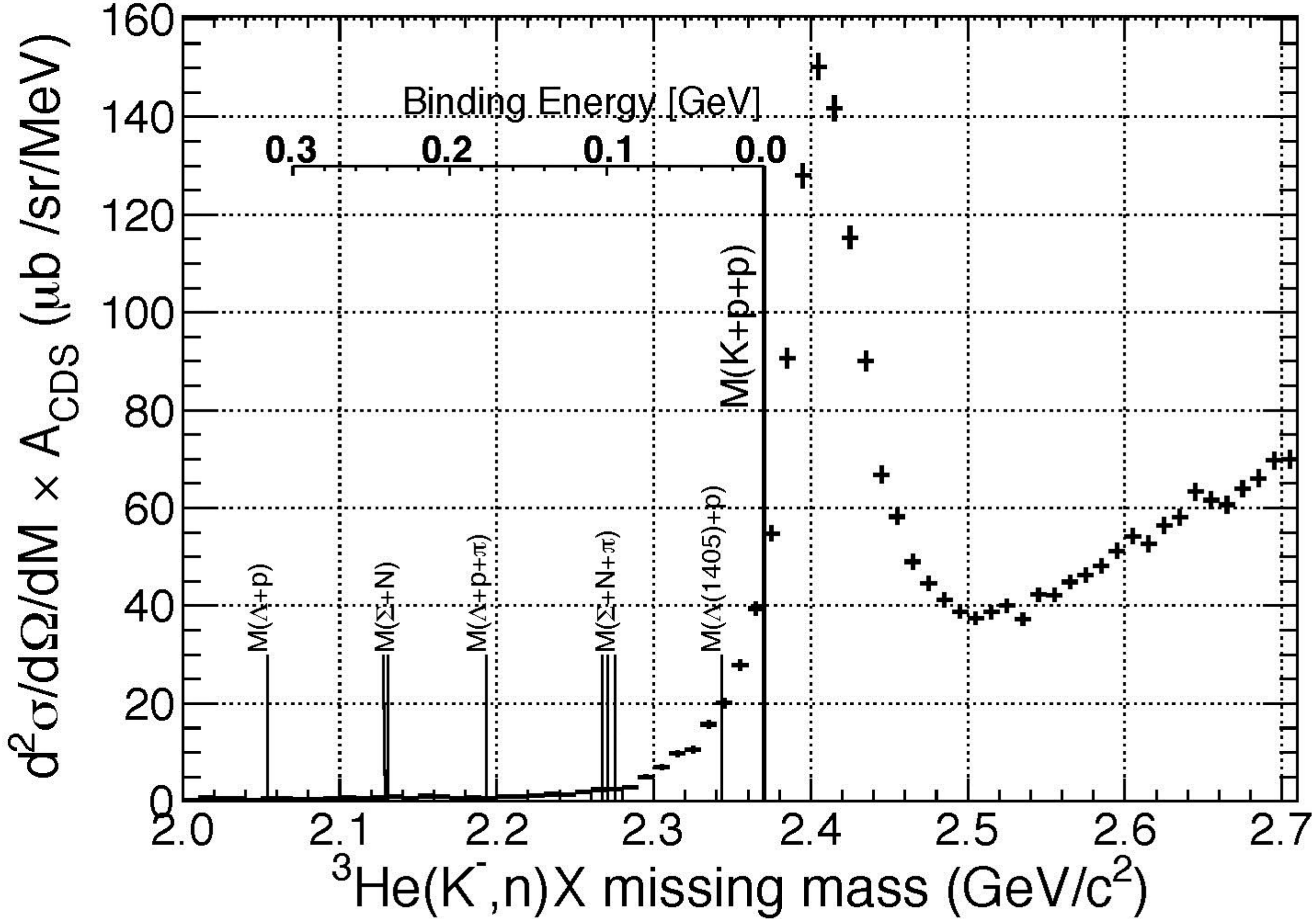
Efficiency = 23±4%

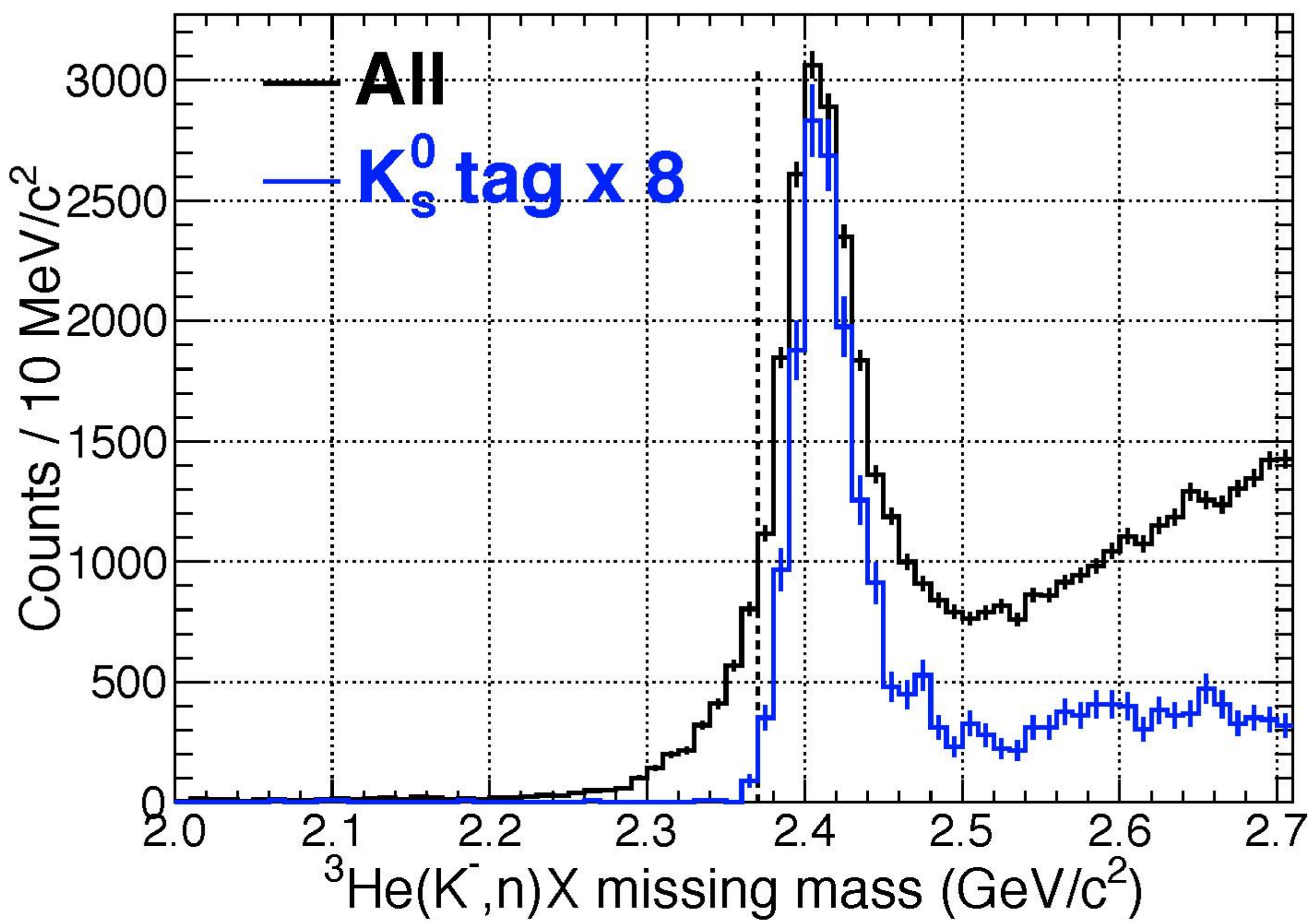
MM resolution ～10MeV

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

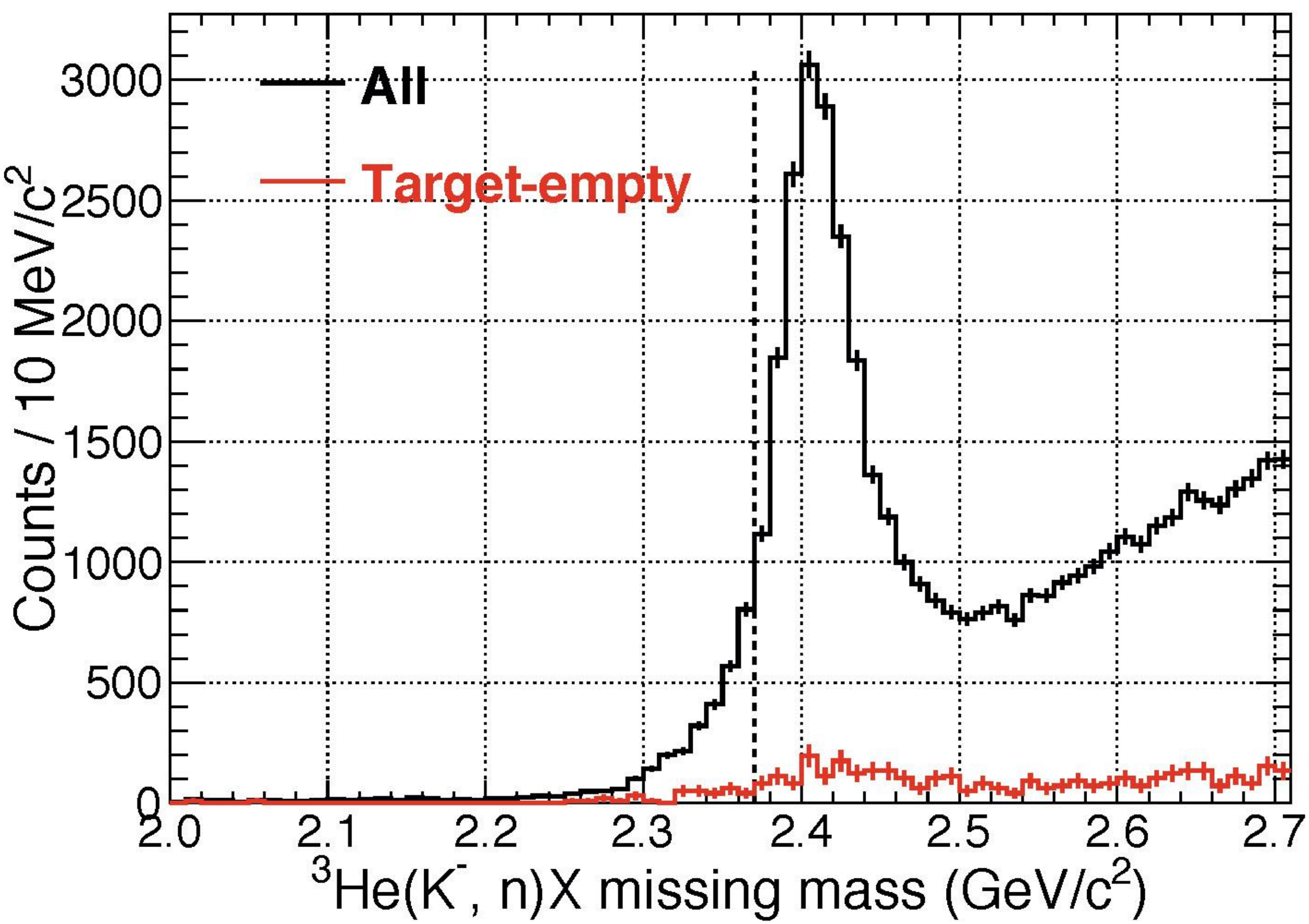
(Hashimoto)

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





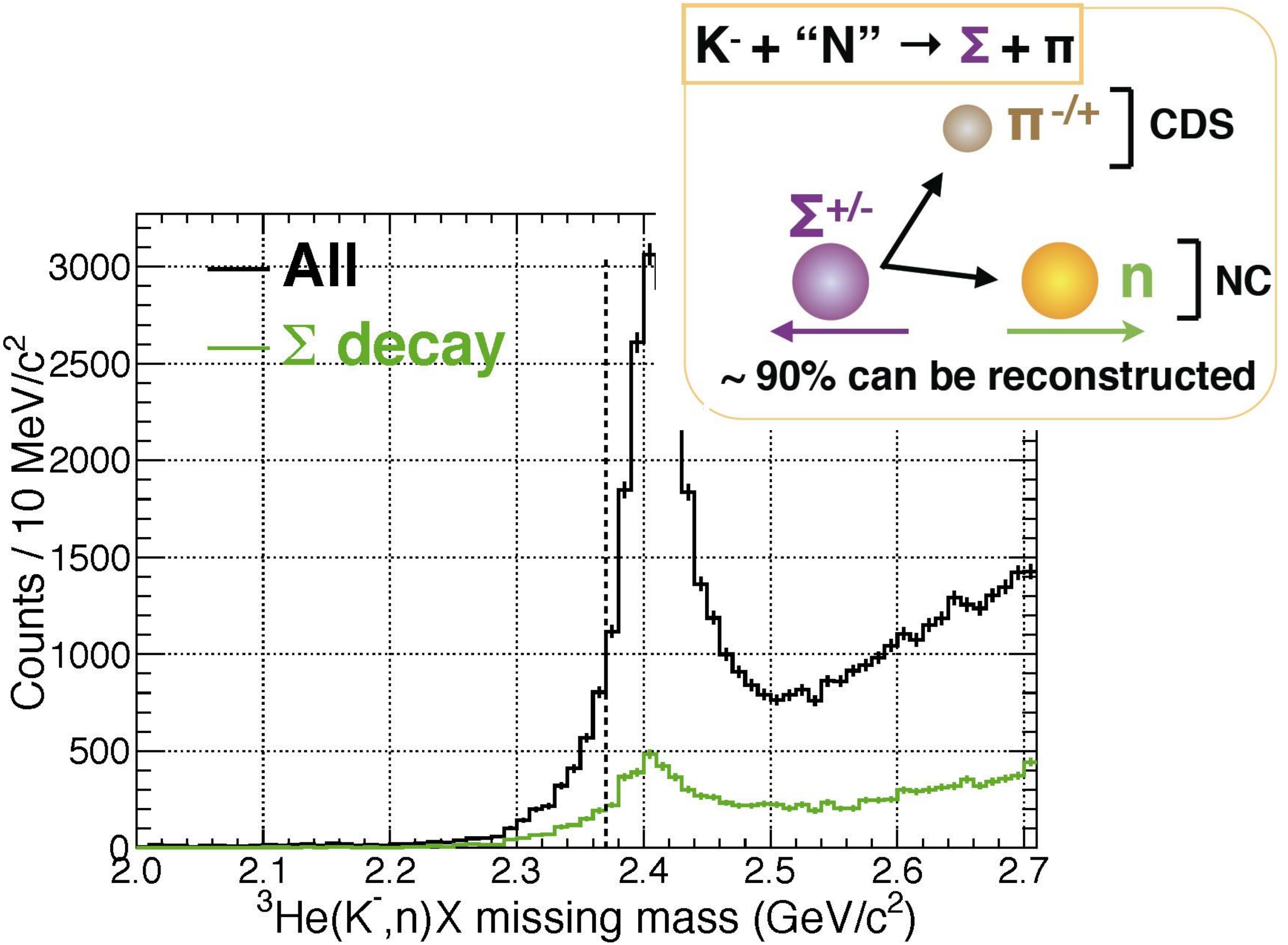
Tail component in the bound region is NOT due to the detector resolution !!



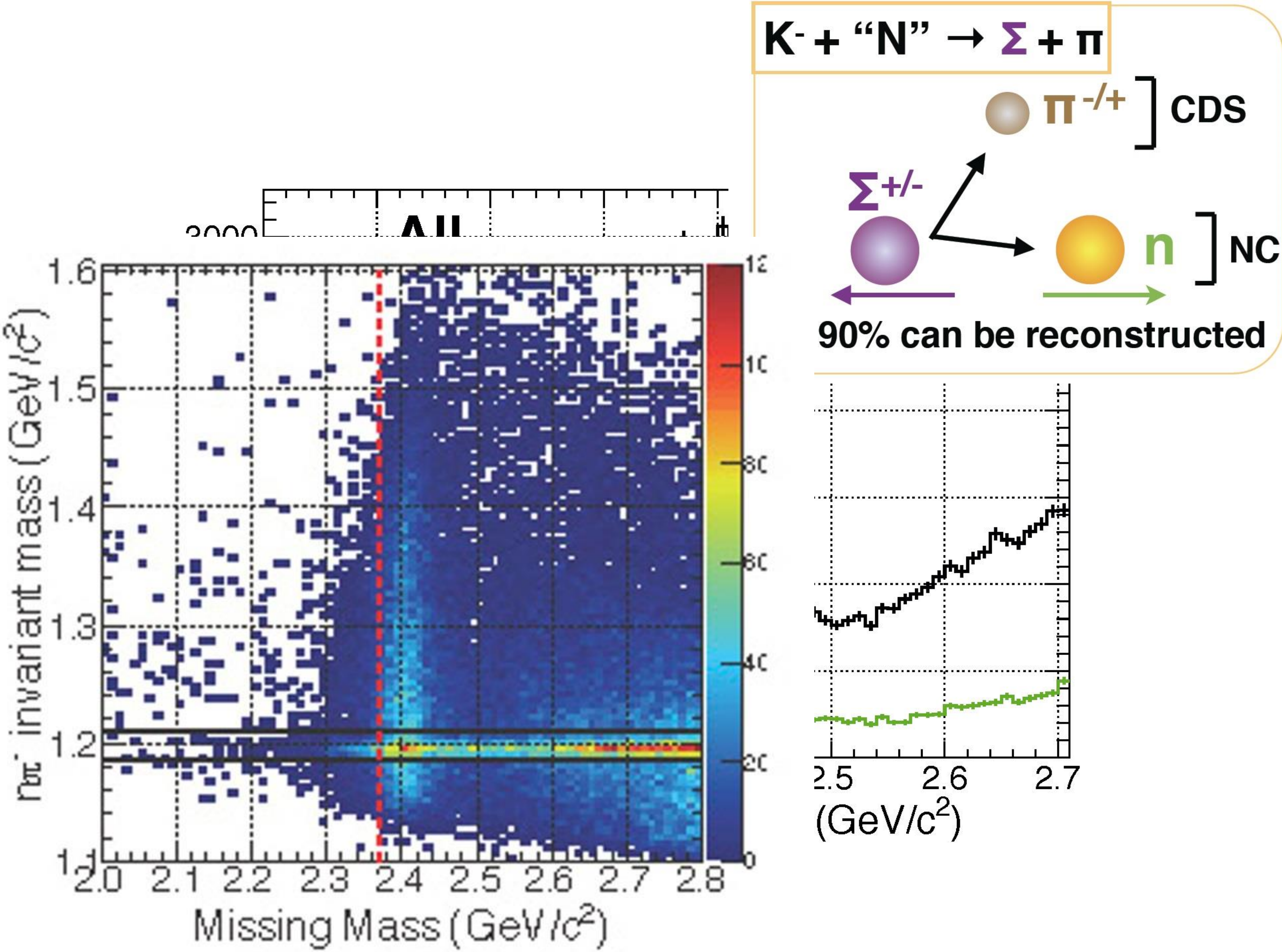
All
Target-empty
Counts / 10 MeV/c²
0
500
1000
1500
2000
2500
3000
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
³He(K⁻, n)X missing mass (GeV/c²)

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

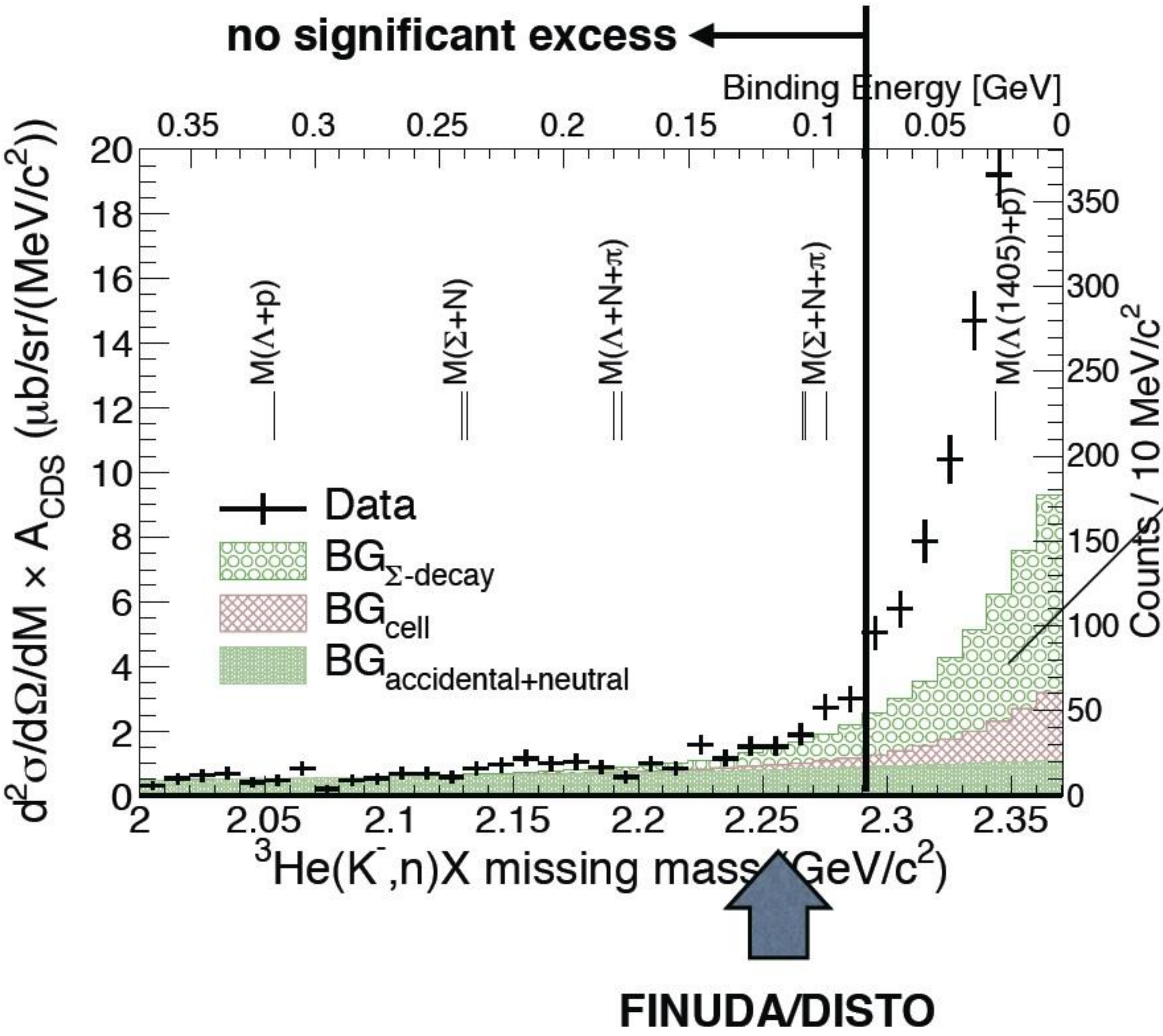


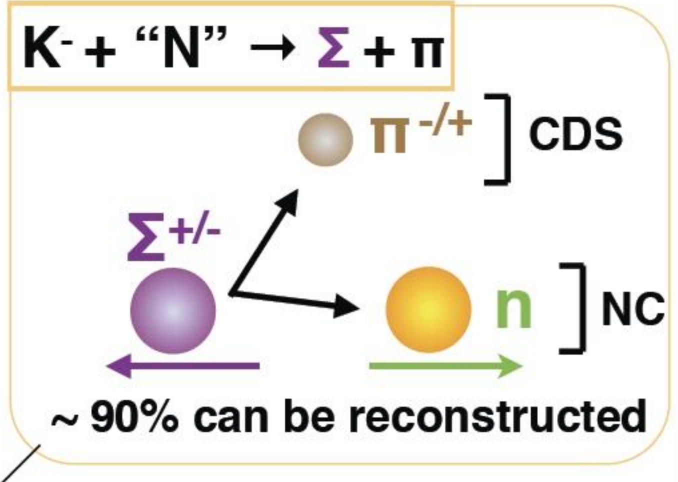
K- + "N" → Σ + π
π -/+
CDS
Σ+/-
n
NC
~ 90% can be reconstructed
All
Σ decay
Counts / 10 MeV/c2
3000
2500
2000
1500
1000
500
0
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
3He(K-,n)X missing mass (GeV/c2)

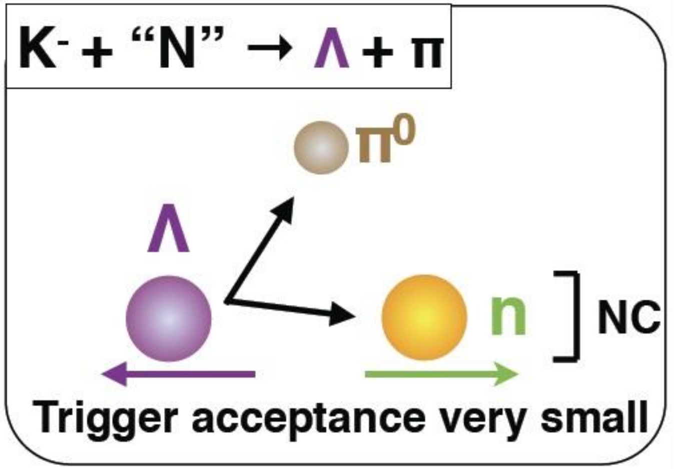


K- + "N" → Σ + π
π -/+
CDS
Σ+/-
n
NC
90% can be reconstructed
3000
All
nπ- invariant mass (GeV/c2)
Missing Mass (GeV/c2)
1.1
1.2
1.3
1.4
1.5
1.6
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
(GeV/c2)

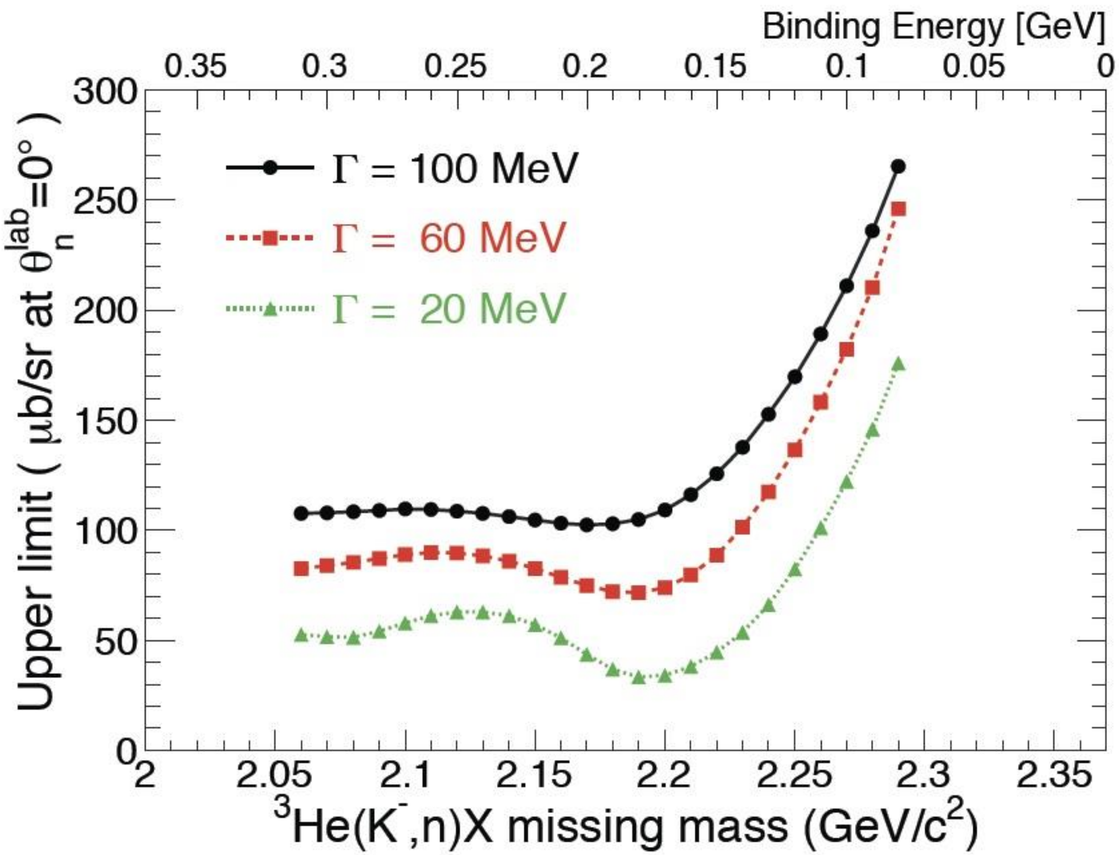
Background evaluation







Upper limits of the deeply bound $K^{-}pp$ production



Likelihood method
using estimated backgrounds

95% confidence level

Assumptions

Intrinsic peak shape:
Breit-Wigner
CDS tagging acceptance:
$K^-pp \rightarrow \Lambda p$ 100%
uniform angular distribution

The obtained upper limits are
0.5—5% cross section of quasi-free K scattering
one order of magnitude smaller than Koike&Harada prediction

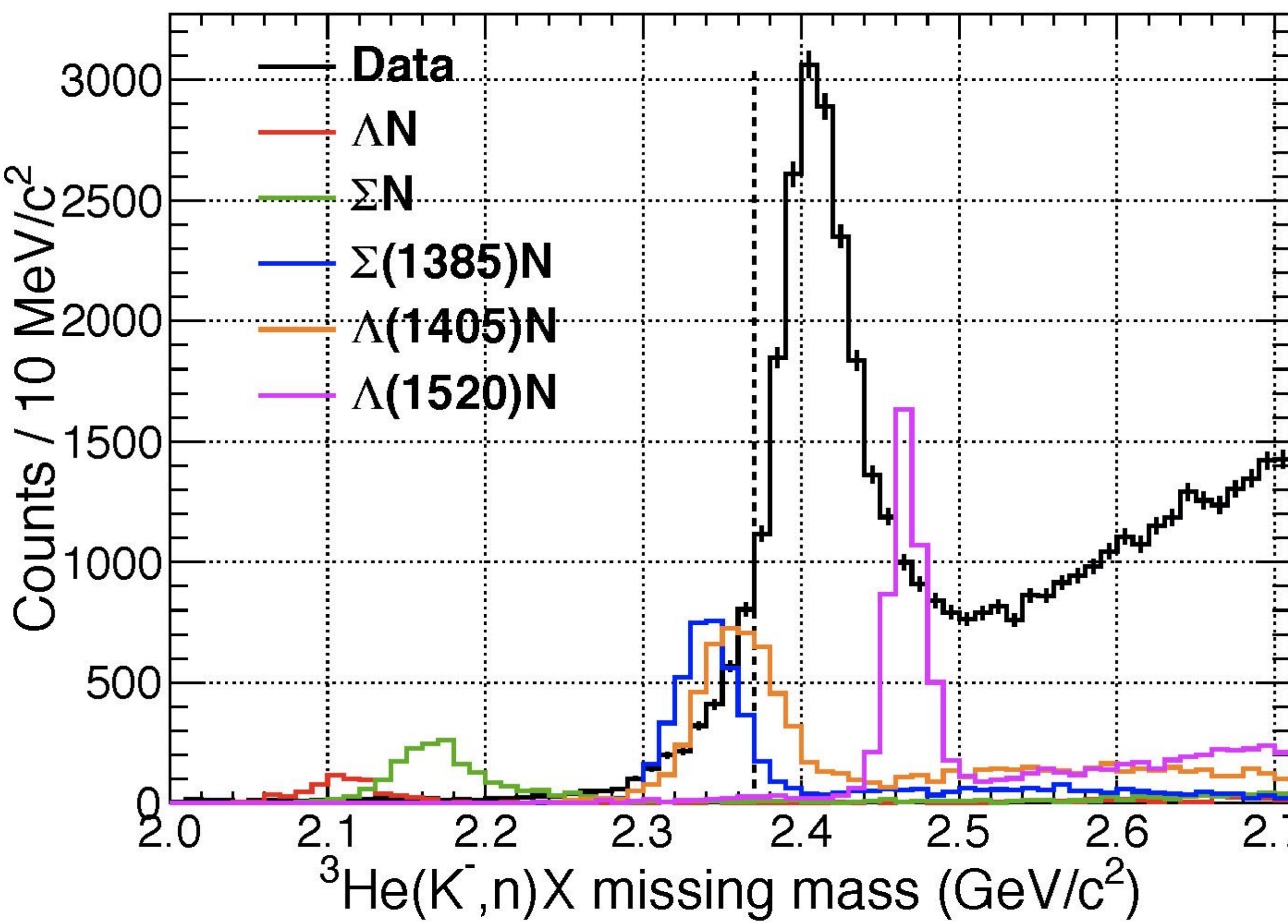
Possible fast neutrons

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

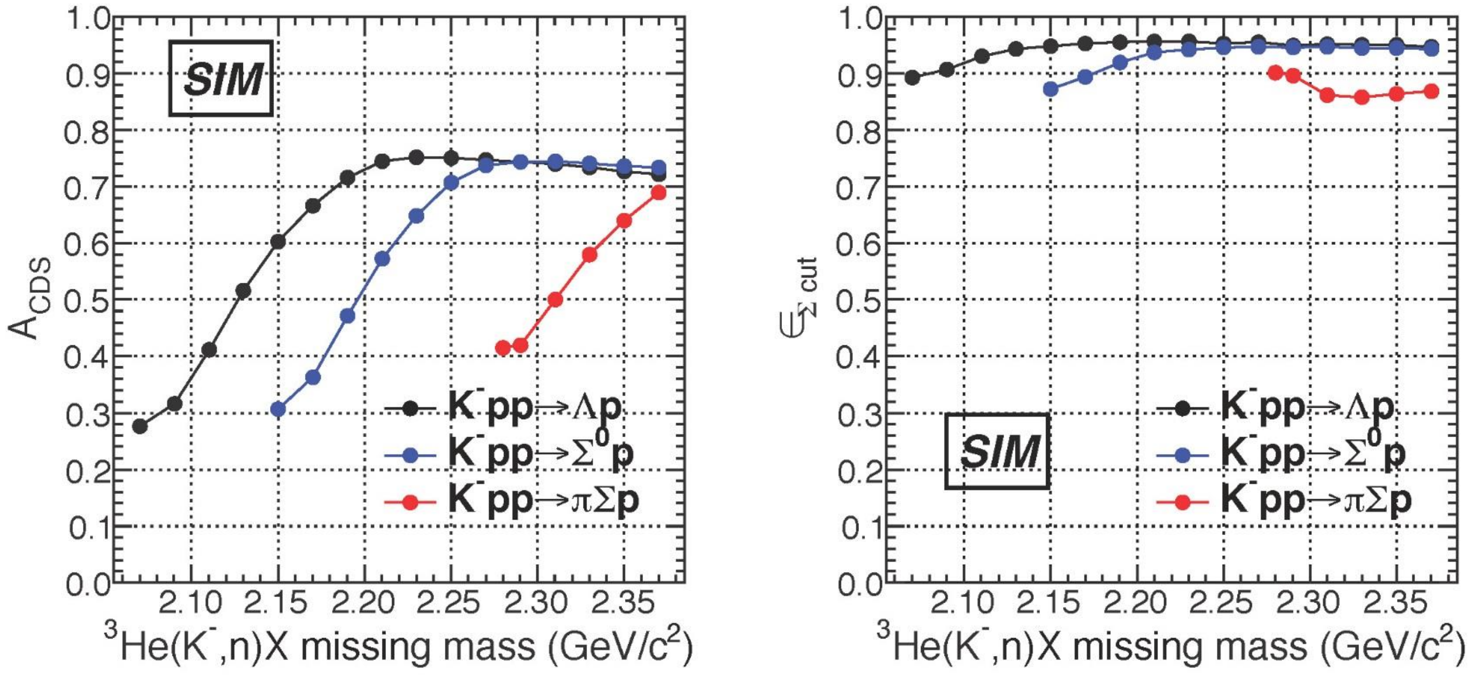
    ΛN,ΣN branch negligible Y*N branch may contribute
  - continuous distribution in mesonic branch (if uniform in phase space)
- **Three-nucleon reaction process (3NR)**
  - similar situation with mesonic 2NR

    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


Data
ΛN
ΣN
Σ(1385)N
Λ(1405)N
Λ(1520)N
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)

Intensity of the excess in K⁻pp assumption



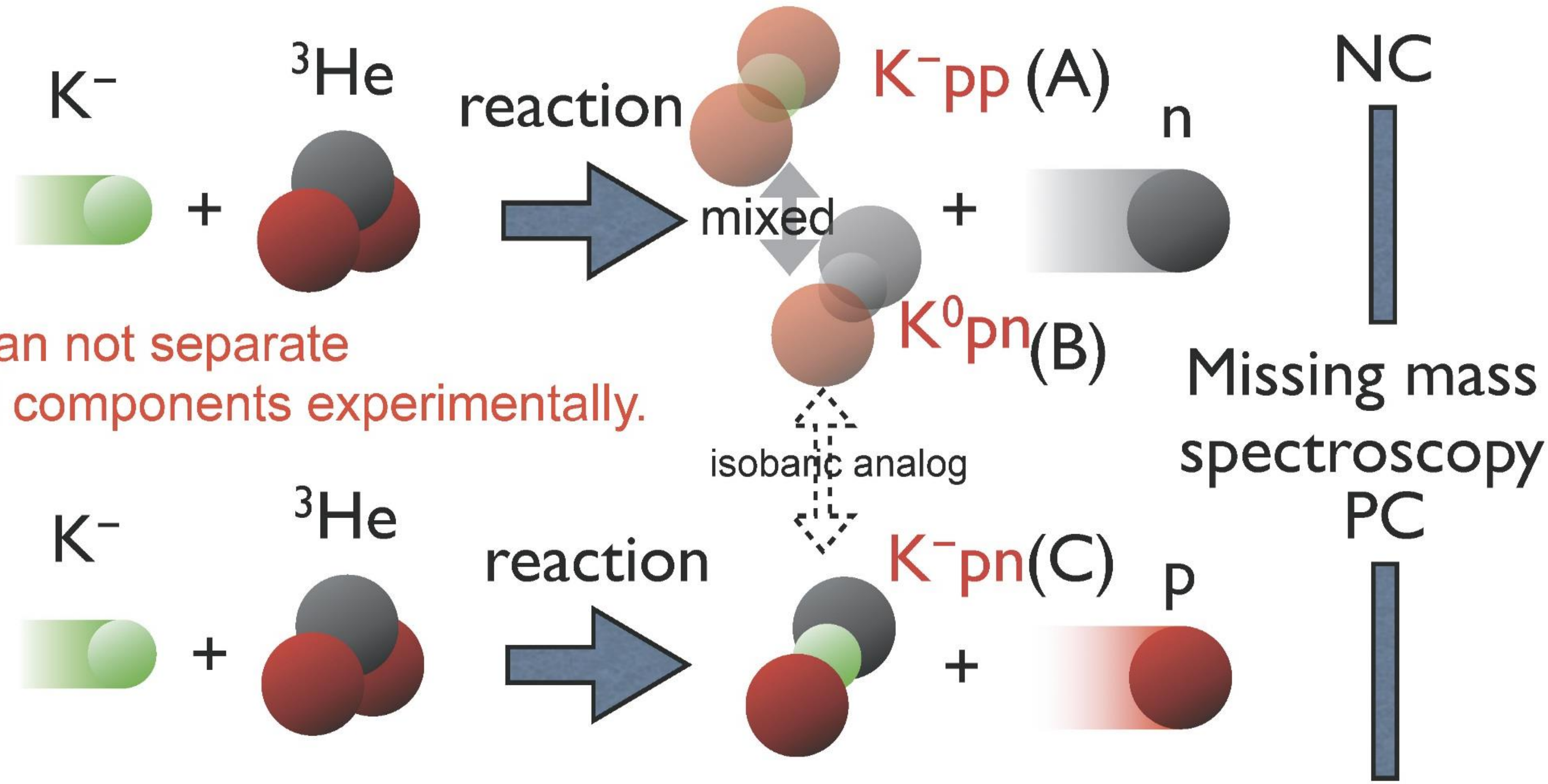
∼1 mb/sr in bound region
if we assume the decay to
Λp/Σ0p or πΣp

3He (K-, p) spectrum

(Tokuda)

J-PARC E15 experiment

A search for the simplest kaonic nucleus K^-pp



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

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

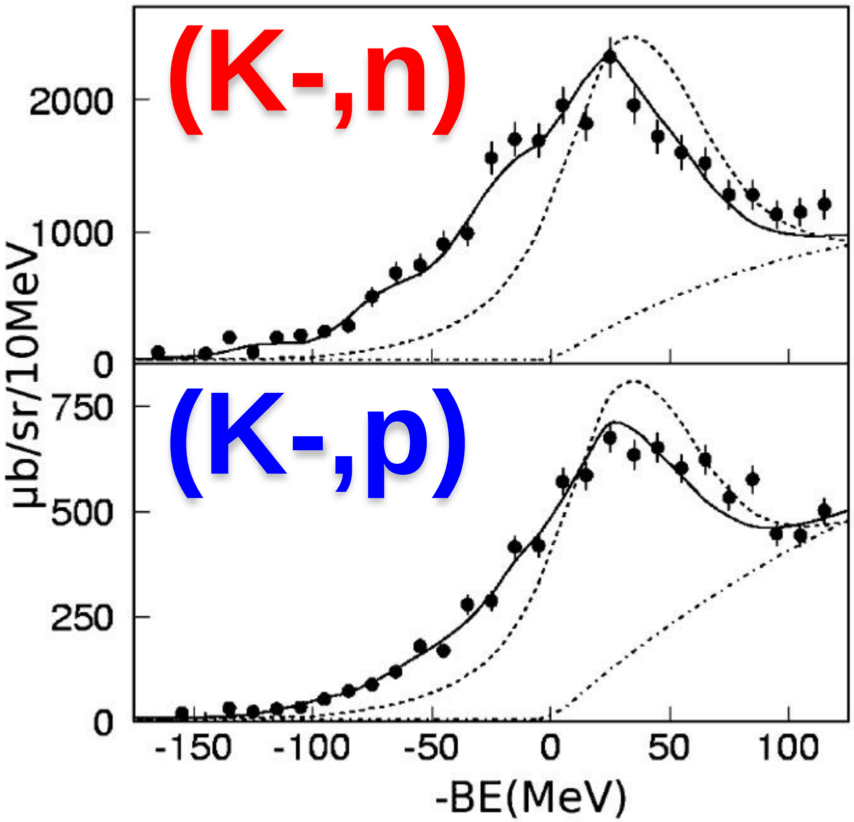


Fig. 1. Missing mass spectra of the $^{12}C(K^-,n)$ reaction (upper) and $^{12}C(K^-,p)$ reaction (lower). The solid curves represent the calculated best fit spectra for potentials with $Re(V)=-190$ MeV and $Im(V)=-40$ MeV (upper) and $Re(V)=-160$ MeV $Im(V)=-50$ MeV (lower). The dotted curves represent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

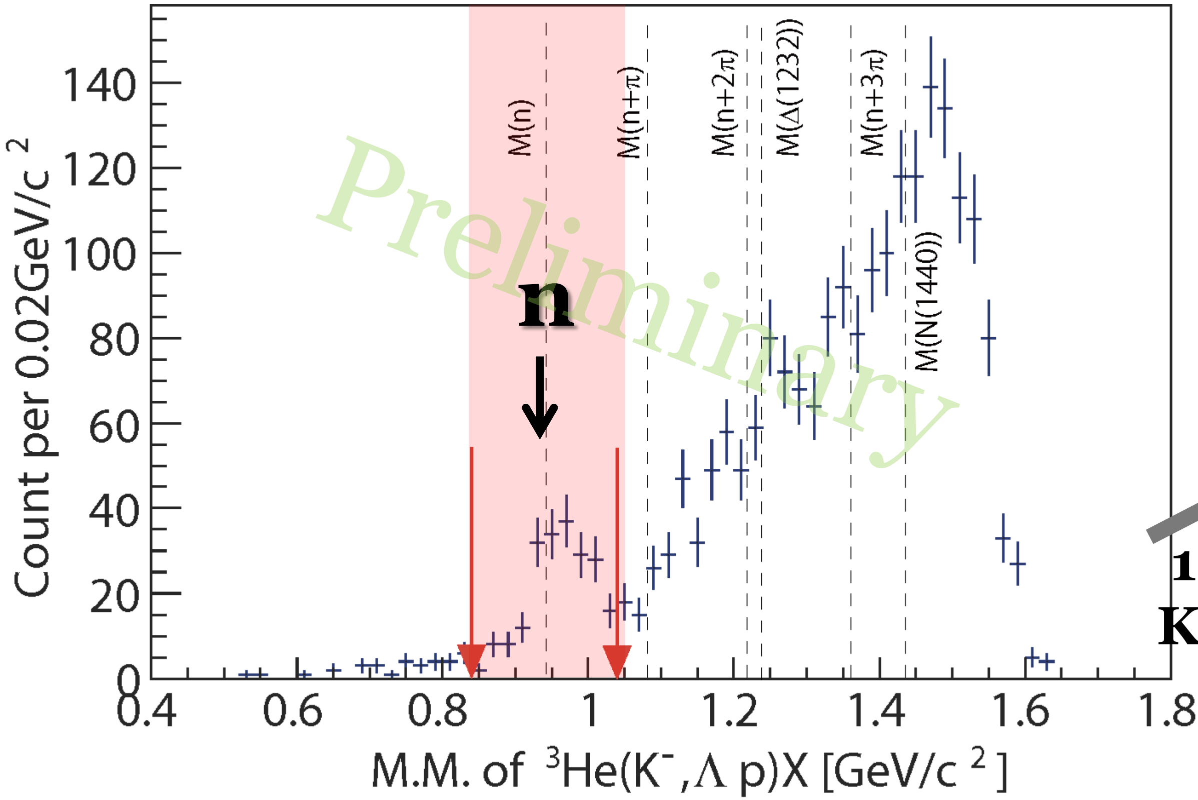
3He (K-, p) spectrum *(VERY preliminary!)*

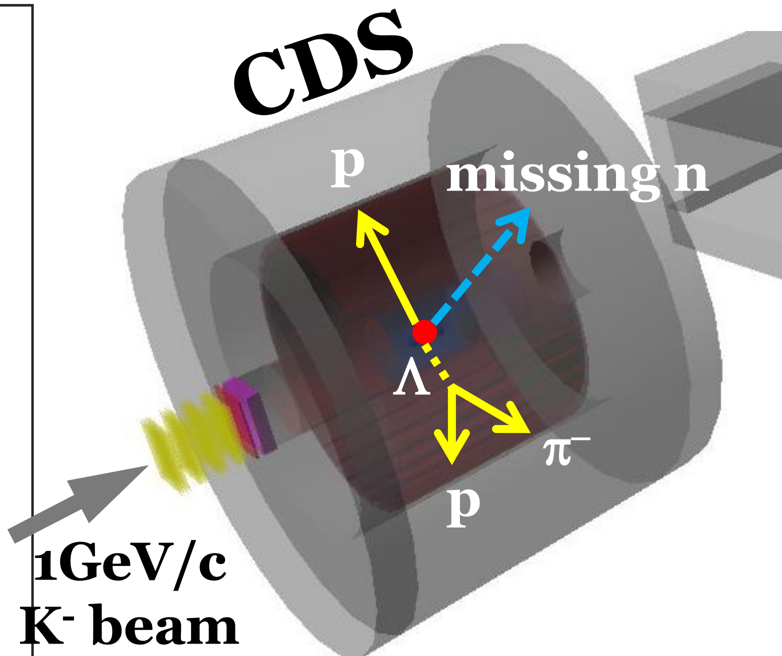
非公開

Λp n(missing) correlation

(Sada)

Exclusive $^3He(K^-,\Lambda p)n$ events

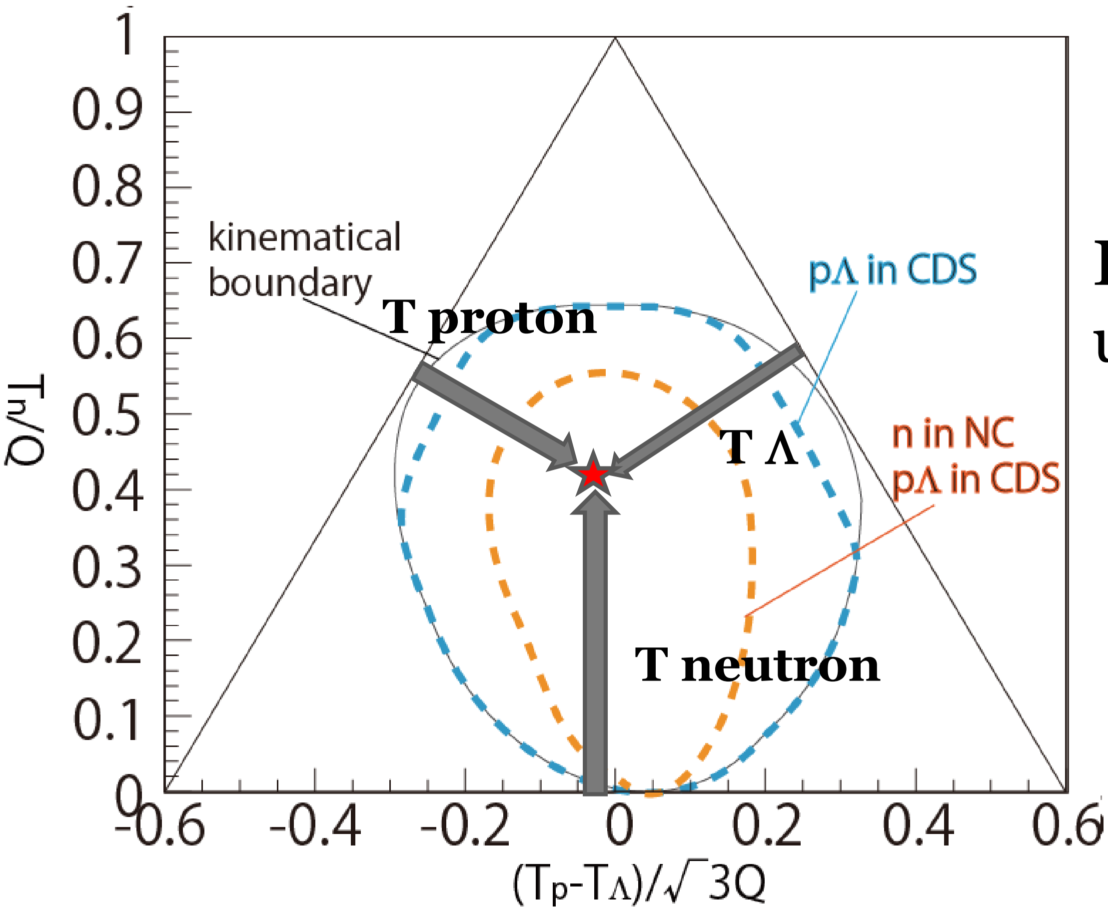




- $K^- {}^3He \rightarrow \Lambda(\Sigma^0)pn$ events can be identified exclusively
  - # of $\Lambda(\Sigma^0)pn$ events: ~190
    - $\Sigma^0 pn$ contamination: ~20%

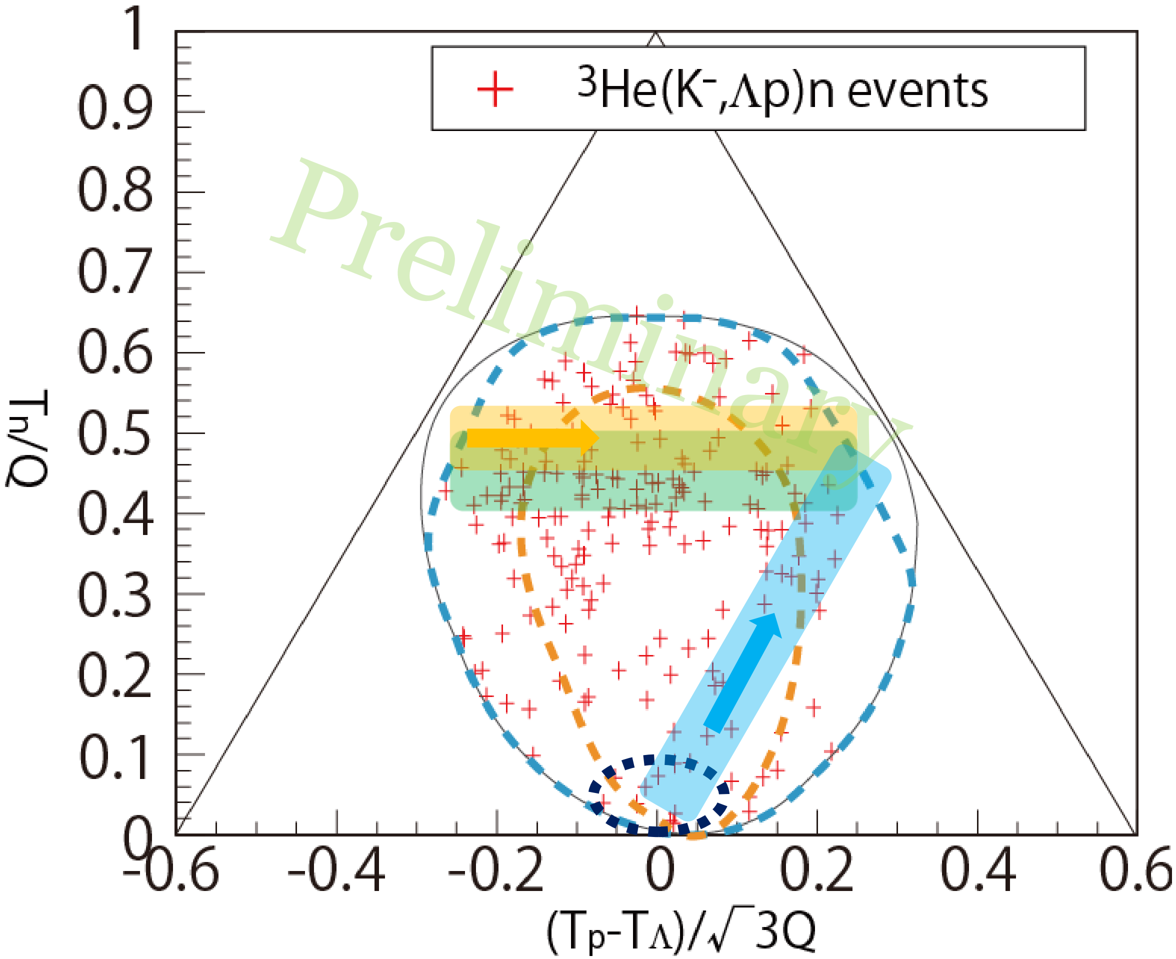
^{3}He(K$^-$,Λp)n: Dalitz plot

- To check Λpn events phase space distribution
  - To plot in this figure, kinematics is fixed.
  - Checking 3 nucleon absorption or 2 nucleon absorption



If events are distributed uniformly
=> 3NA is dominant

$^{3}He(K^{-},\Lambda p)n$: Dalitz plot



2NA:
e.g. $K^{-}{}^{3}He \rightarrow \Lambda p n_s$

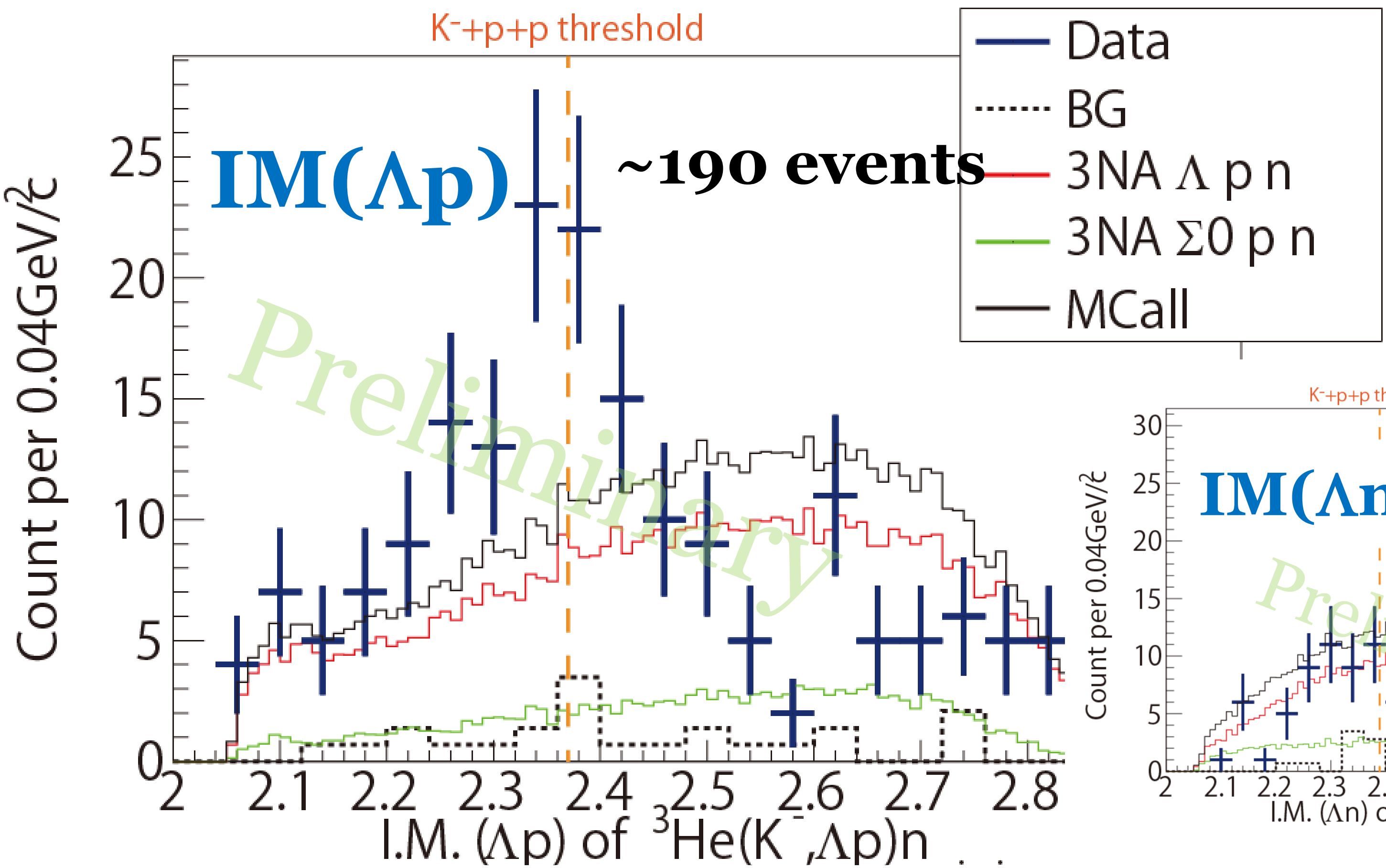
2NA+2step:
e.g. $K^{-}{}^{3}He \rightarrow \Sigma^{0} p n_s$,
$\Sigma^{0} n_s \rightarrow \Lambda n$

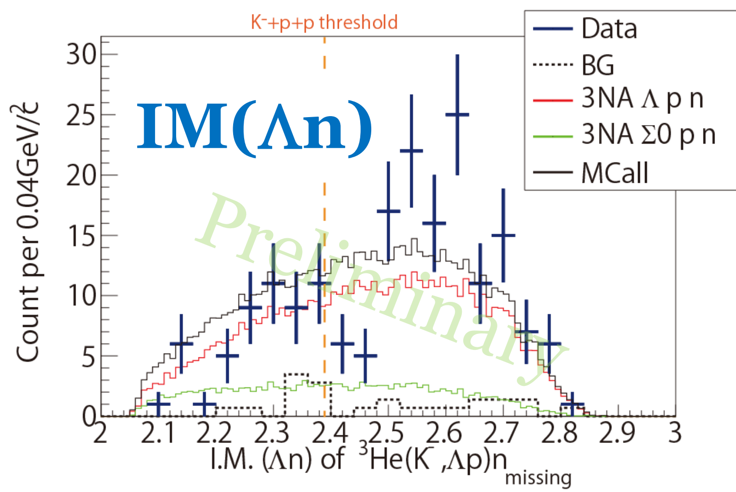
2NA+2step:
e.g. $K^{-}{}^{3}He \rightarrow \Sigma^{0} n p_s$,
$\Sigma^{0} p_s \rightarrow \Lambda p$

$K^{-}pp$ form.:
$K^{-}{}^{3}He \rightarrow (K^{-}pp) n$,
$K^{-}pp \rightarrow \Lambda p$

Events are scattered widely in the phase-space of $K^{-}+{}^{3}He \rightarrow \Lambda+p+n$
=>3NA is dominant!!

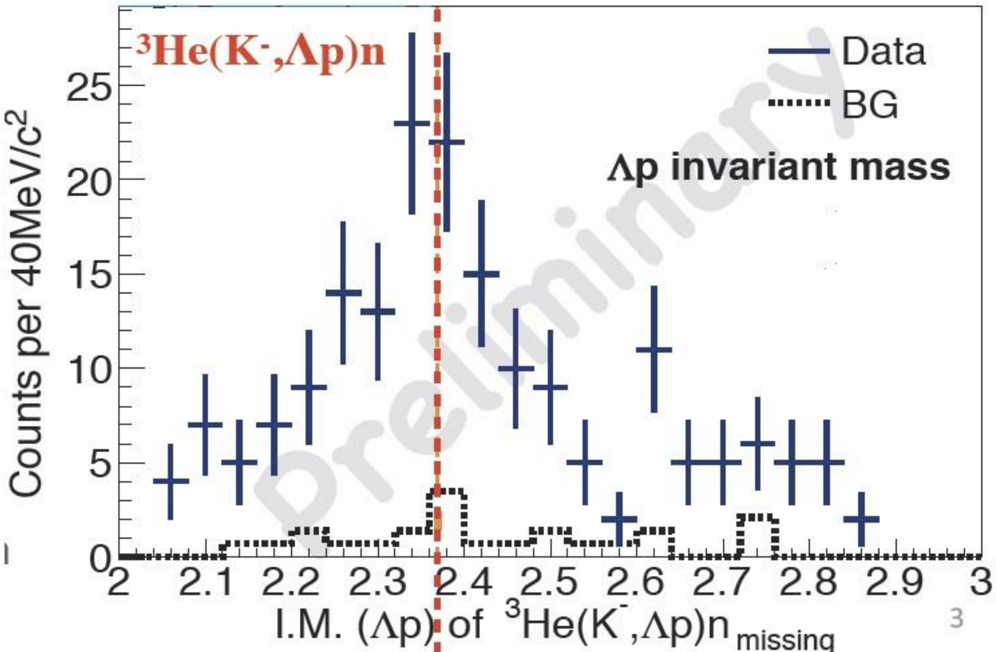
$^3He(K^-,\Lambda p)n$: Invariant Mass

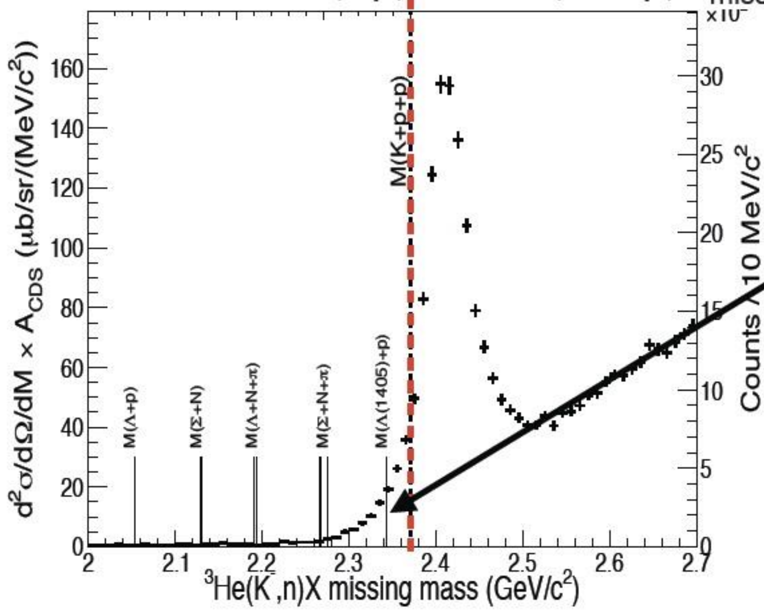




- **total CS : ~200 μb** (~ 0.1% of total cross section of $K^- {}^3He$)
  - **when phase-space distributions are assumed**
- **Excess around the threshold?**

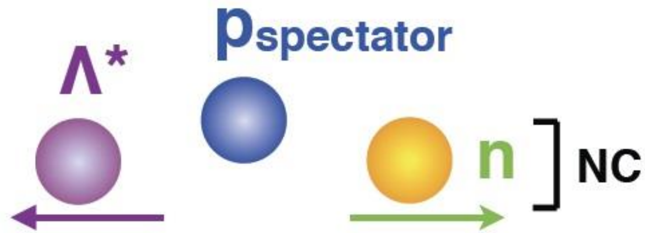
Structure just below the threshold





- **Exclusive Λp+n$_{missing}$**
  - cannot be explained by phase-space distribution
- **Semi-inclusive (K$^-$, n)**
  - multi-nucleon processes might contribute

$$K^- + {}^3\mathrm{He} \to Y^{(*)} + \boxed{N} + N_s.$$



we need further analysis including a comparison with the (K$^-$,p) channe

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 at only 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.**

- ✔ **Cross section< ~10^{-2} of K-QE at BK~100MeV**

- ✔ **3He (K-,p) spectrum looks <u>very similar to (K-,n)</u>**

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