JPS Meeting
September 25-28, 2015

3He(in-flight K-,n)反応を用いた 反K中間子束縛状態探索のための 水素・重水素標的を用いた素過程解析

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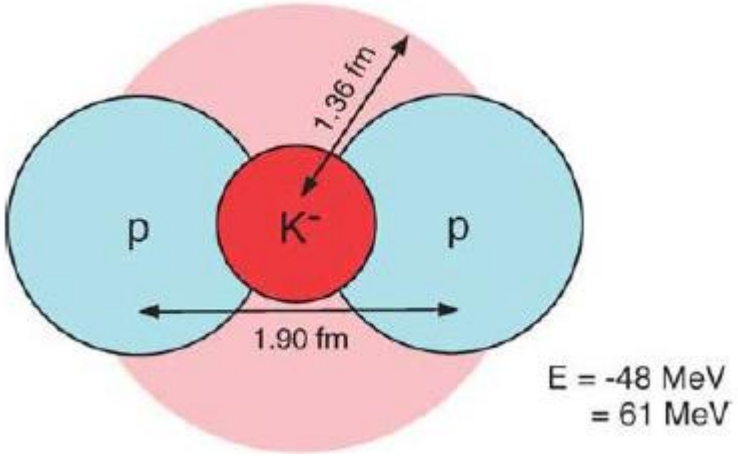
For the J-PARC E15 collaboration

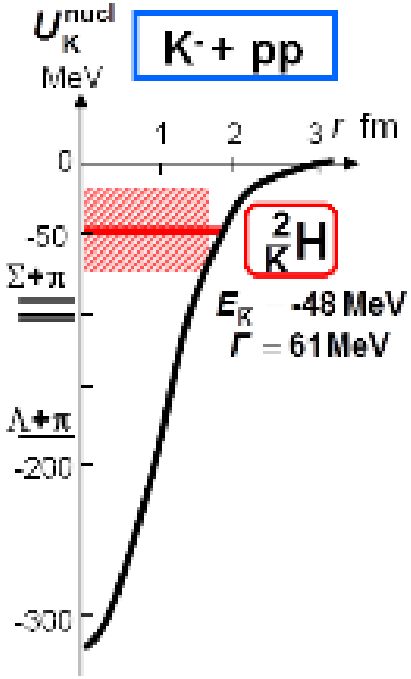
September 27, 2015

Kaonic nucleus

- **Bound state of $\bar{K}$ and Nucleus**
  - Result from strongly attractive $\bar{K}N$ interaction

- **$\bar{K}NN$ system**
  - The simplest kaonic nucleus

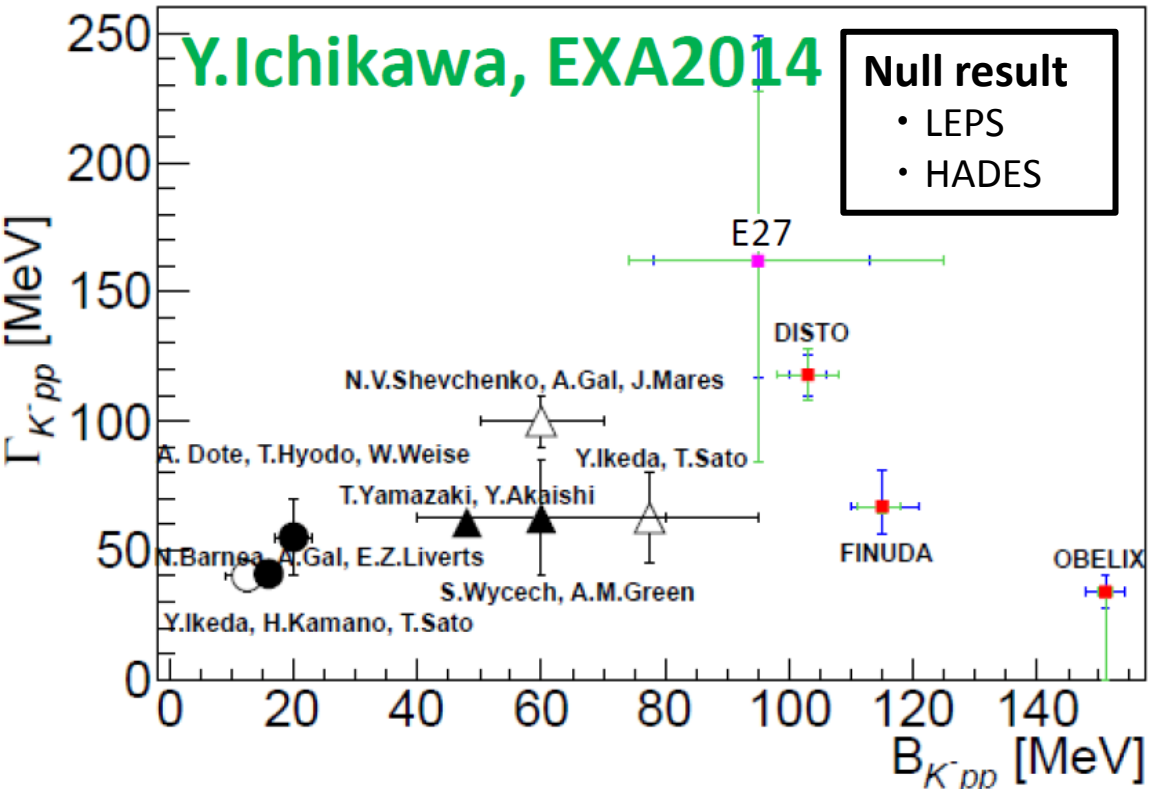




Y.Akaishi & T.Yamazaki, PLB535, 70(2002).

Recent status of $\bar{K}NN$

- There are many Theoretical/Experimental results.



Theoretical calculation

●/○	E-dependent Potential
▲/△	E-independent potential

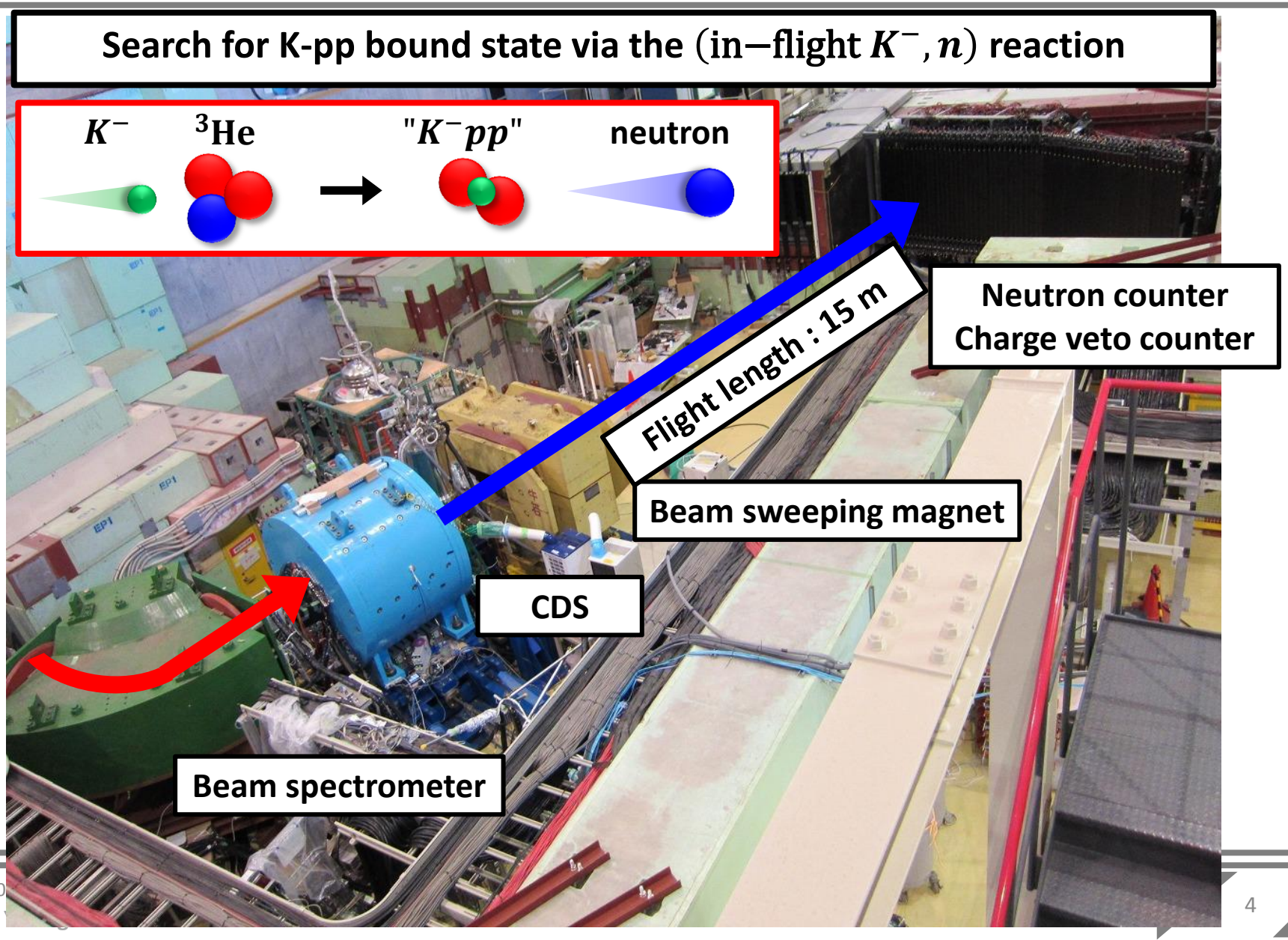
Experimental measurement

FINUDA	(stopped $K^-, \Lambda p$)
DISTO	$pp \to \Lambda p K^+$
J-PARC E27	$d(\pi^+, K^+)X, 2p$ coinsidence
OBELIX	$\bar{p}^4He \to \Lambda p n K^0 X$
LEPS	$\gamma d \to K^+ \pi^- X$
HADES	$pp \to \Lambda p K^+$

- $\bar{K}NN$ bound state is still unclear…

N. Barnea, A. Gal, E.Z. Liverts, Phys. Lett. B 712 (2012) 132.
A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A 804 (2008) 197;
A. Doté, T. Hyodo, W. Weise, Phys. Rev. C 79 (2009) 014003.
Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. 124 (2010) 533.
T. Yamazaki, Y. Akaishi, Phys. Lett. B 535 (2002) 70.
N.V. Shevchenko, A. Gal, J. Mareš, Phys. Rev. Lett. 98 (2007) 082301;
N.V. Shevchenko, A. Gal, J. Mareš, J. Revai, Phys. Rev. C 76 (2007) 044004.
Y. Ikeda, T. Sato, Phys. Rev. C 76 (2007) 035203;
Y. Ikeda, T. Sato, Phys. Rev. C 79 (2009) 035201.
S. Wycech, A.M. Green, Phys. Rev. C 79 (2009) 014001.

J-PARC E15 experiment

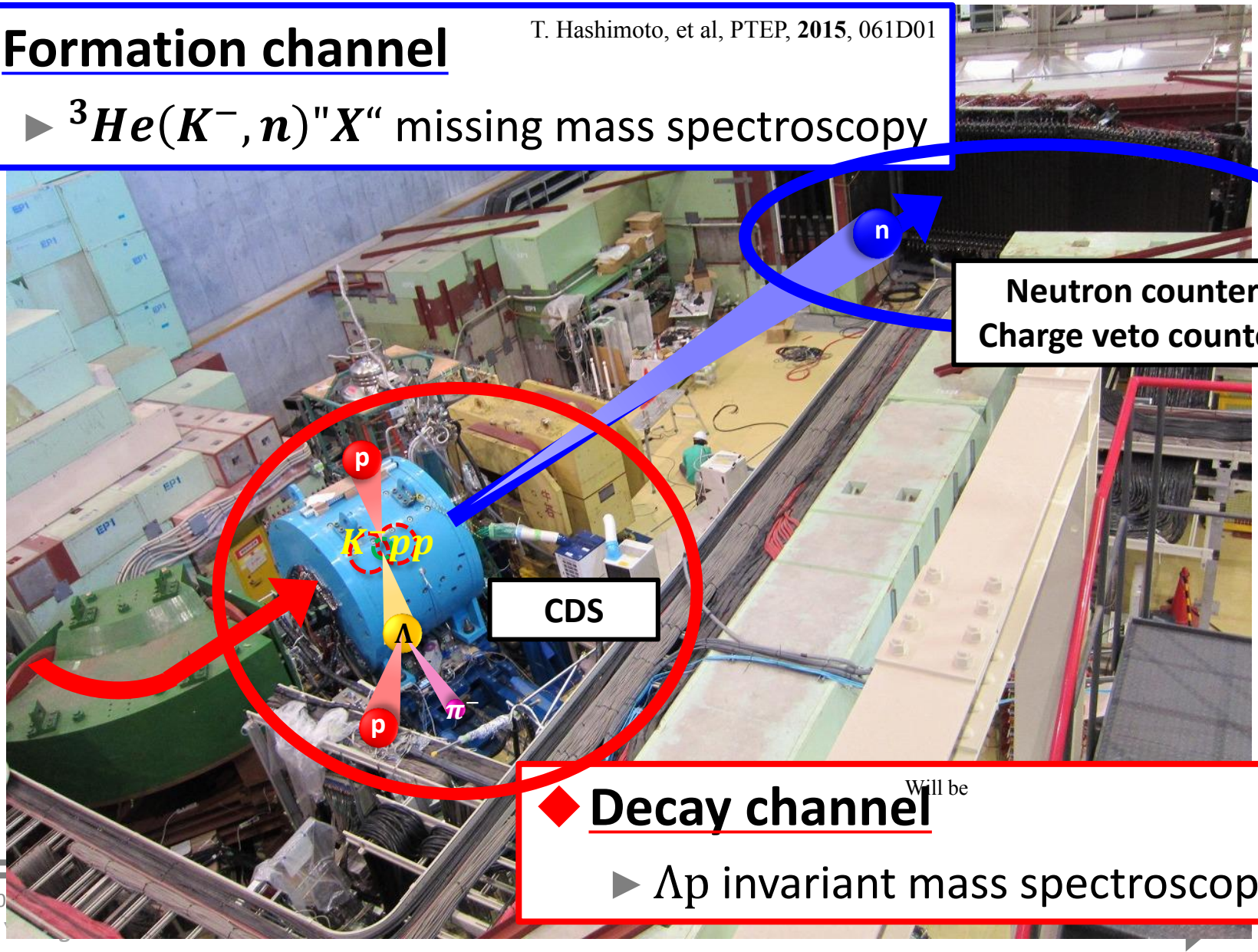


J-PARC E15 experiment

Formation channel

T. Hashimoto, et al, PTEP, **2015**, 061D01

- $^3He(K^-, n)$"X" missing mass spectroscopy



Decay channel

Will be

- Λp invariant mass spectroscopy

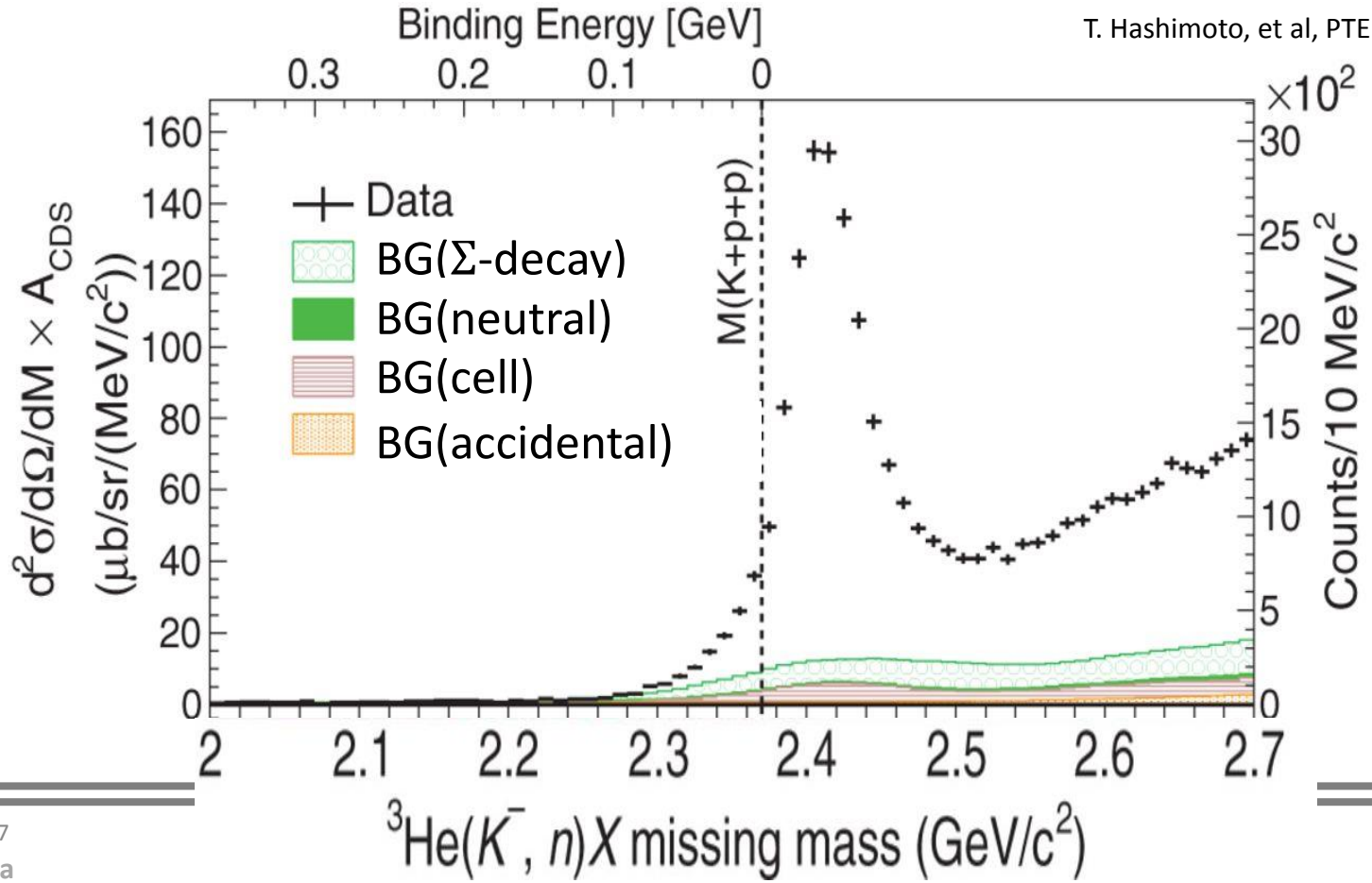
Result of E15-1st :: Formation channel

- At least one charged track in CDS is required.
- CDS acceptance (A_{CDS}) is not corrected.

Semi-Inclusive $^3He(K^-, n)X$ missing mass spectrum

- Sub-threshold excess is observed
- NO structure is observed in deeply-bound region

T. Hashimoto, et al, PTEP, **2015**, 061D01

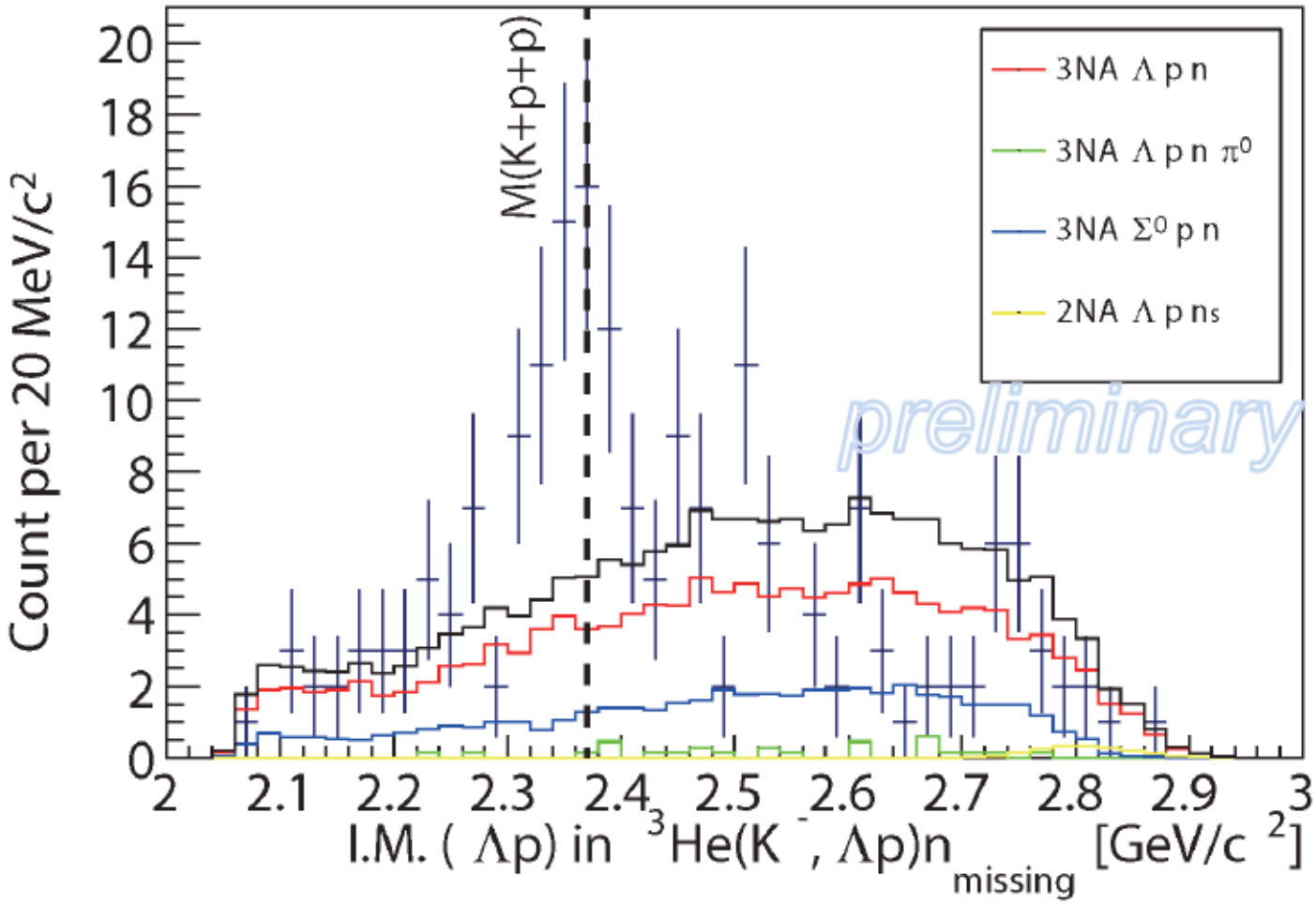


Result of E15-1st :: Decay channel

■ Missing neutron is selected in $MM(\Lambda p)$.

- Λp invariant mass spectrum in Λp"n" final state
  - Structure is observed below K-pp threshold.
    - $S = -1$ di-baryon state?

The result will be fixed quite soon.

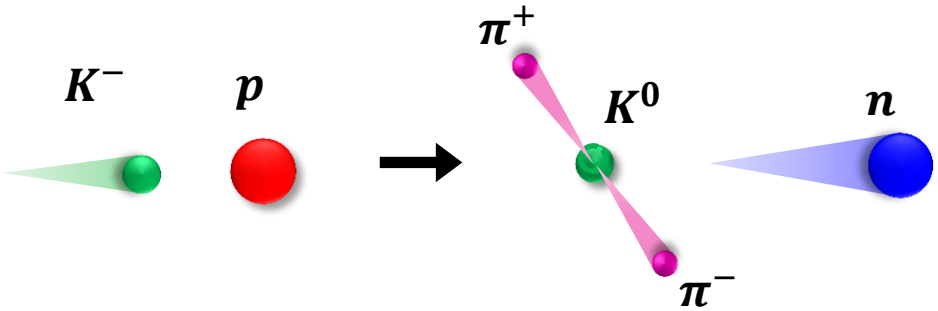


H2/D2 data analysis

- To investigate a contribution of elementary process
  - $p(K^-, n)$
  - $n(K^-, n)$
  - Comparison of the H2, D2 and 3He data

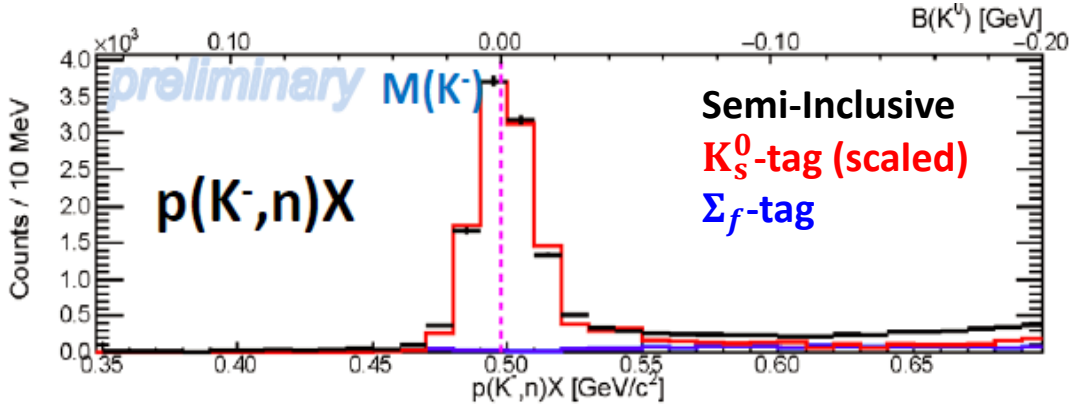
→ *Today's talk*

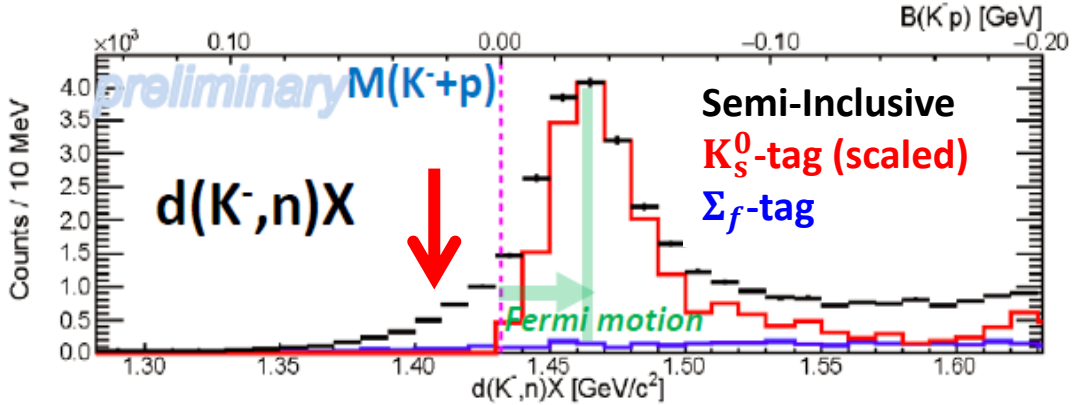
- To determined NC detection efficiency
  - $p + K^- \rightarrow n + K^0$ reaction



H2/D2 data analysis

- Semi-inclusive $p/d(K^-, n)"X"$ missing mass spectrum



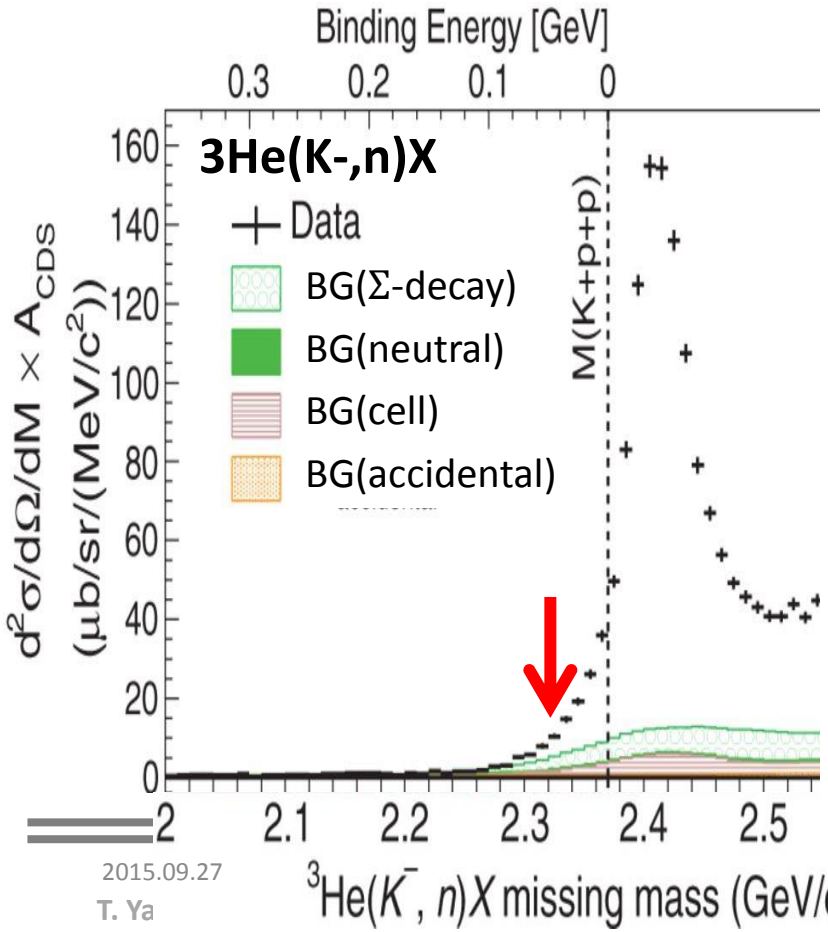


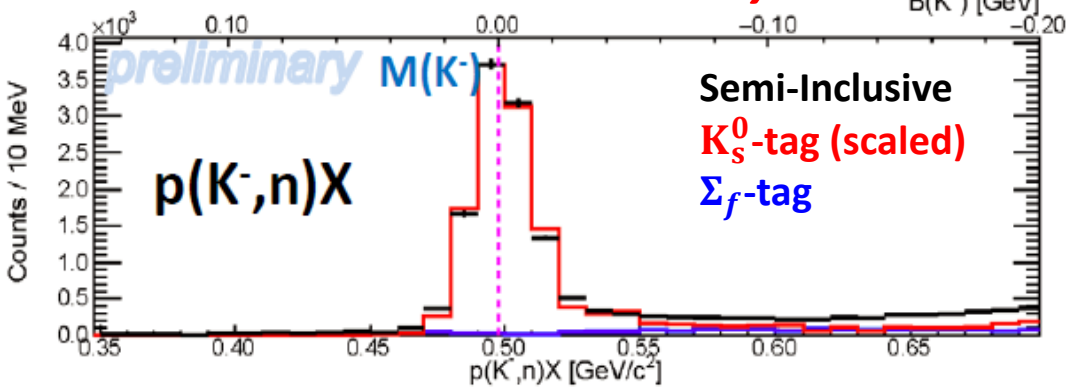
- $p(K^-, n)"X"$
  - Charge-exchange process is clearly observed.
- $d(K^-, n)"X"$
  - Excess below the K^-p threshold is observed.
  - $\Sigma(1385)/\Lambda(1405)$ contribution

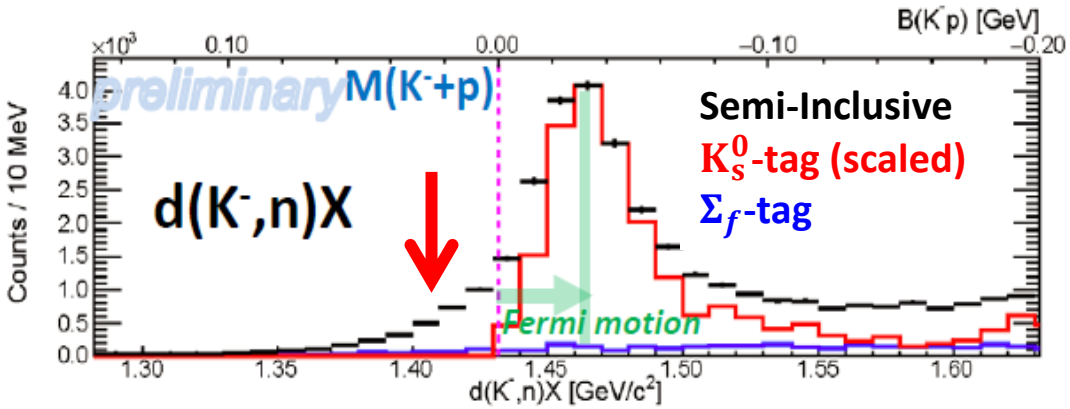
Comparison of the H2/D2 and 3He data

- **Semi-inclusive neutron missing mass spectrum**
  - **Sub-threshold excess in 3He is similar to that in D2.**
    - Y^* **production may contribute to the excess below the threshold.**

→ ***Exclusive analysis is desired.***







Summary

- **E15-1st result**
  - Excess below the threshold is observed in Formation/Decay channel analysis.
- **H2/D2 data analysis**
  - Comparison of H2/D2 and 3He data
  - Sub-threshold excess is observed in D2 data.
    - $\Sigma(1385)/\Lambda(1405)$ contribution
  - Excess in 3He comes from Y^*N contribution?
    - Exclusive analysis is desired.
    - Λpn, $\pi\Sigma Nn$
- ***The E15-2nd physics run will start this October.***
  - Exclusive analysis results with higher statistical data will be performed. (x10)

Thank you for your attention

~ The 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]

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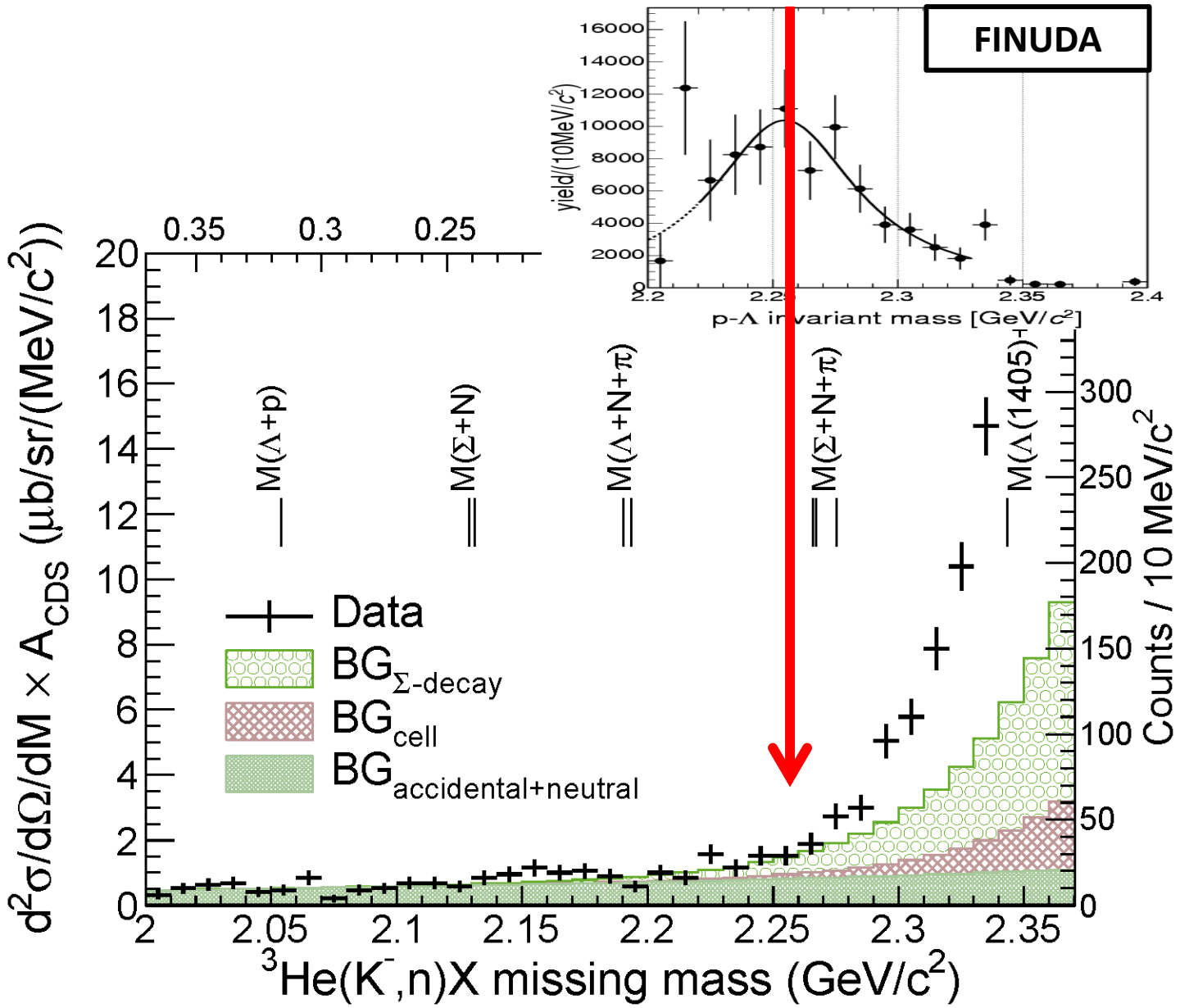
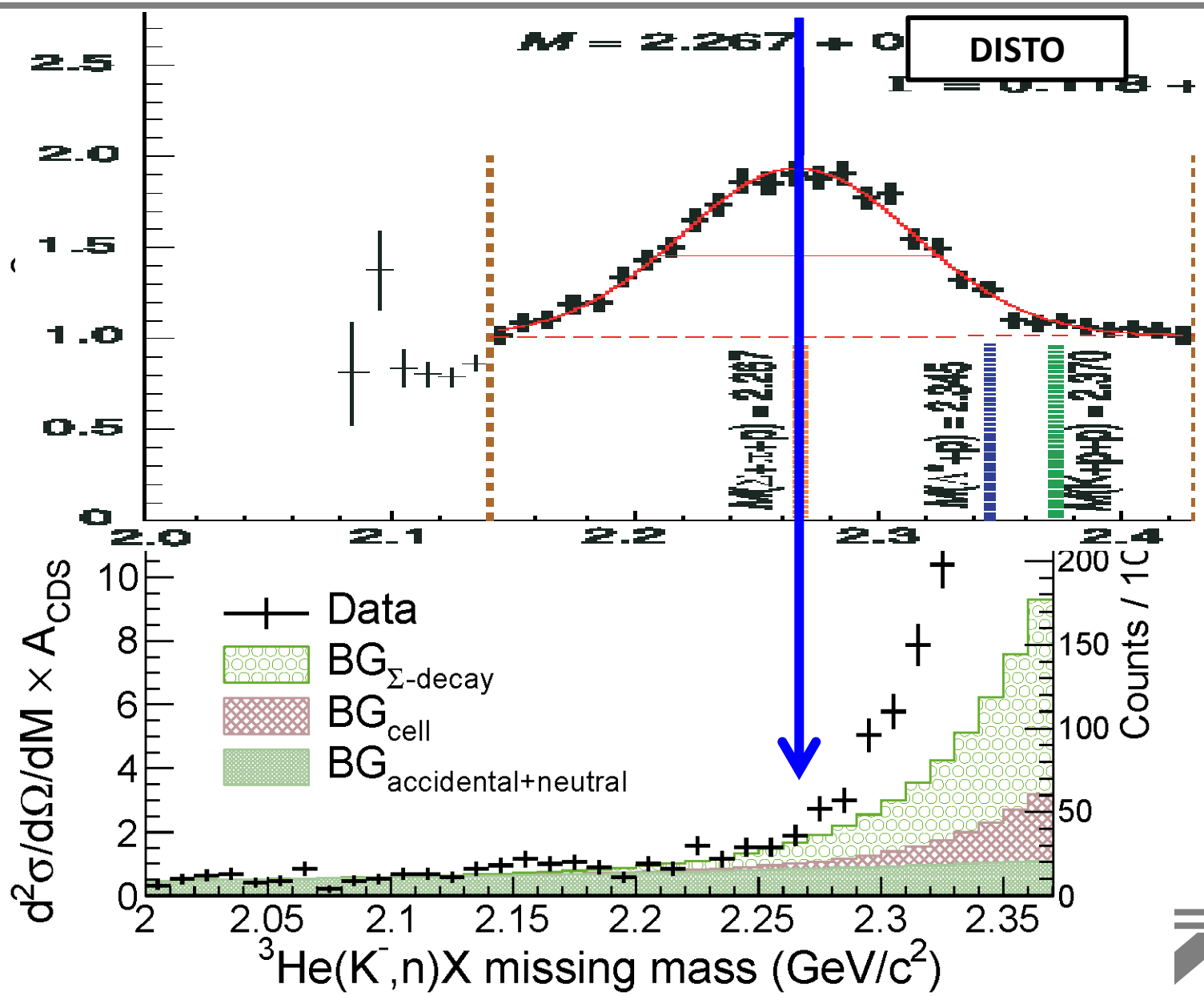
(*) Spokesperson
($) Co-Spokesperson

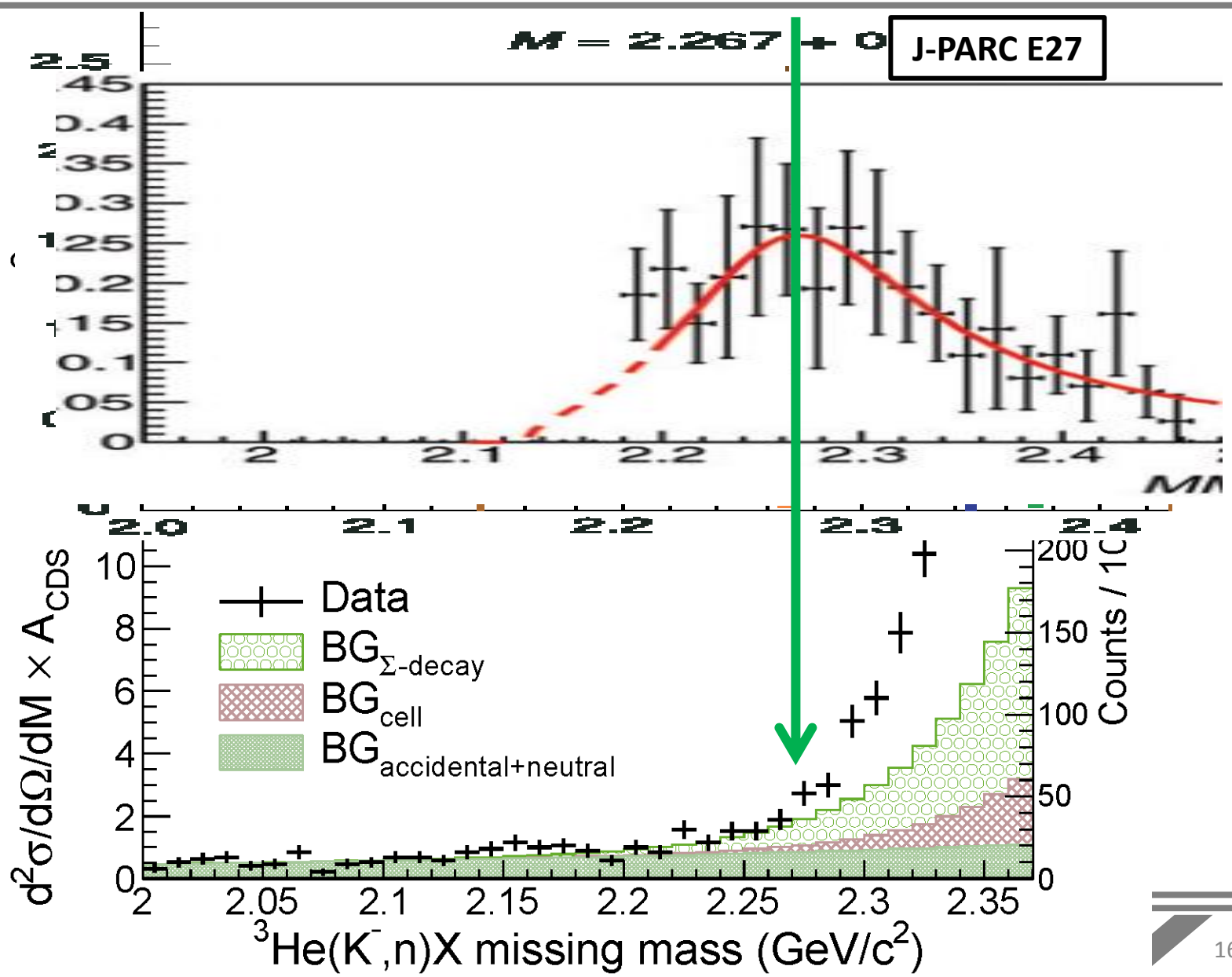
Deeply-bound region



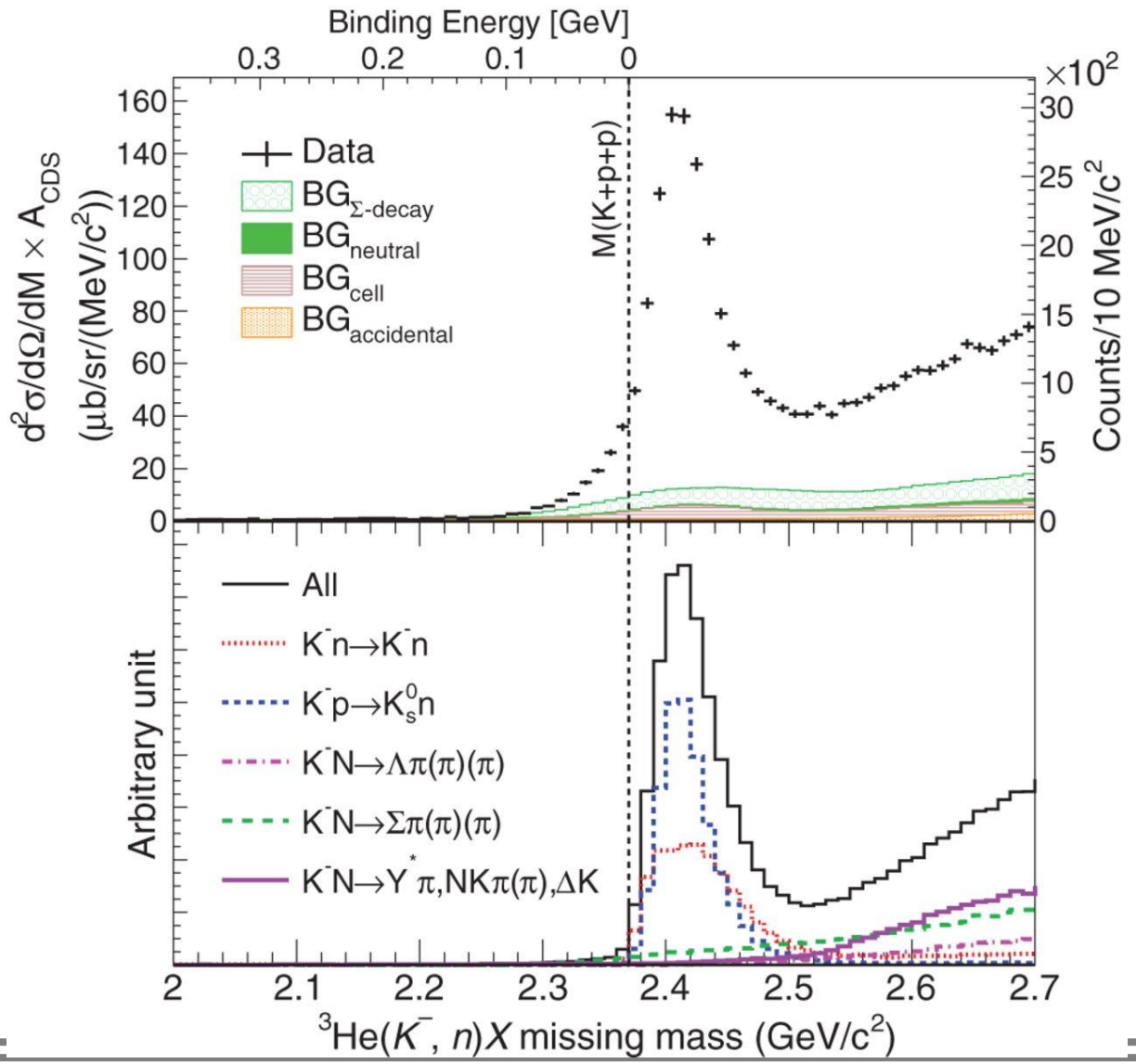
Deeply-bound region



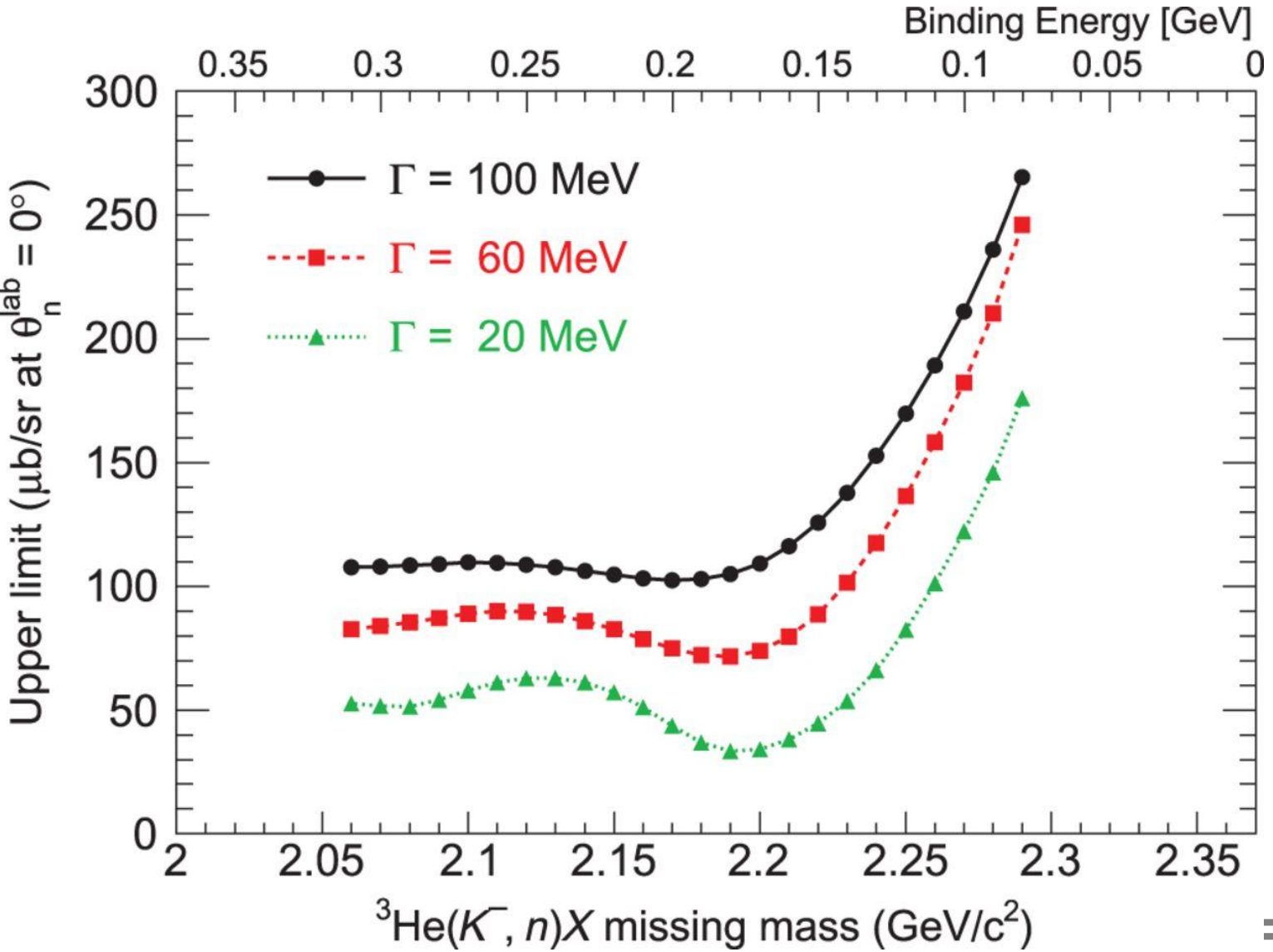
Deeply-bound region



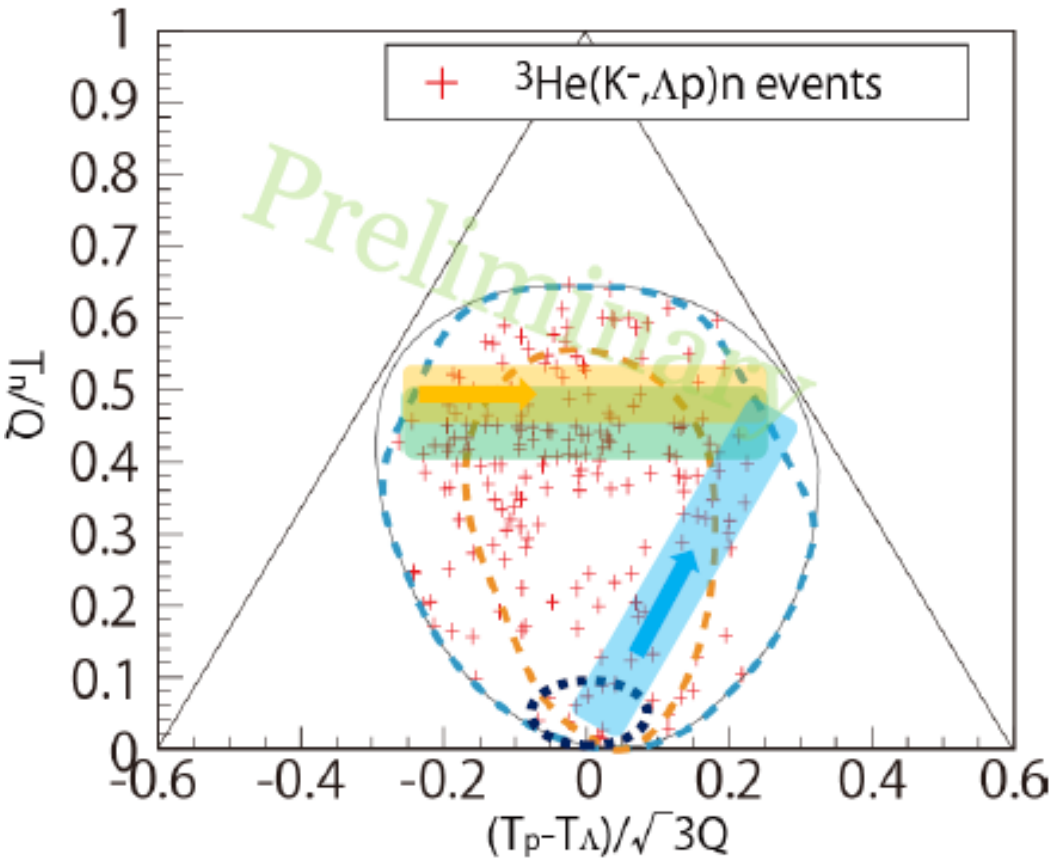
Semi-inclusive $^3He(K^-, n)"X"$ spectrum



Upper limit


Binding Energy [GeV]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Γ = 100 MeV
Γ = 60 MeV
Γ = 20 MeV
Upper limit (μb/sr at θ$_n^{lab}$ = 0°)
300
250
200
150
100
50
0
2
2.05
2.1
2.15
2.2
2.25
2.3
2.35
^{3}He(K^-, n)X missing mass (GeV/c^2)

Dalitz plot



Events are scattered widely in the phase-space of K$^-$+^{3}He->Λ+p+n

=>3NA is dominant!!

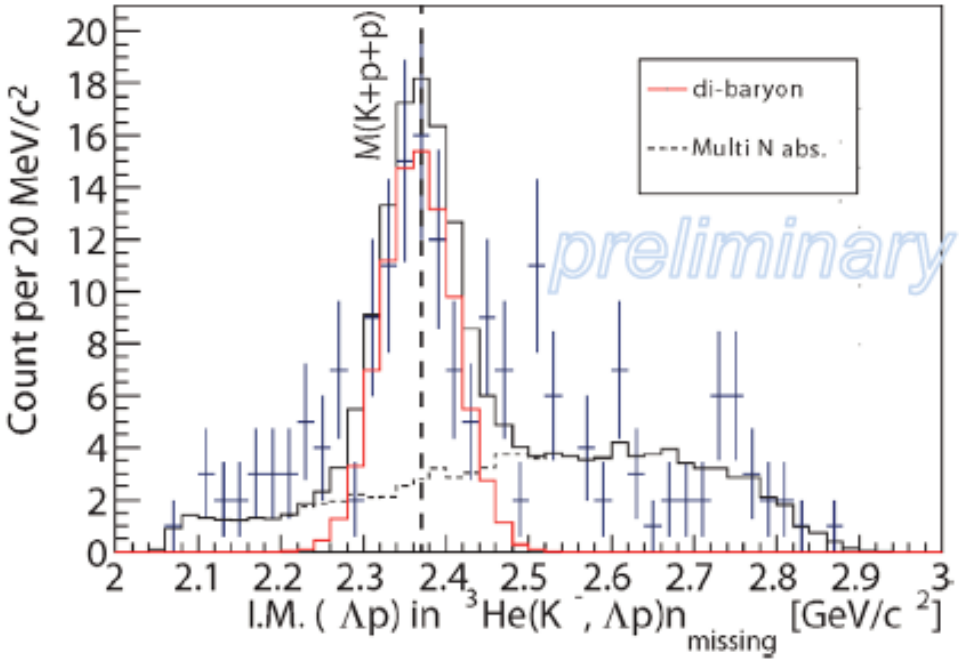
2NA:
e.g. K$^-$^{3}He→**Λpn$_s$**

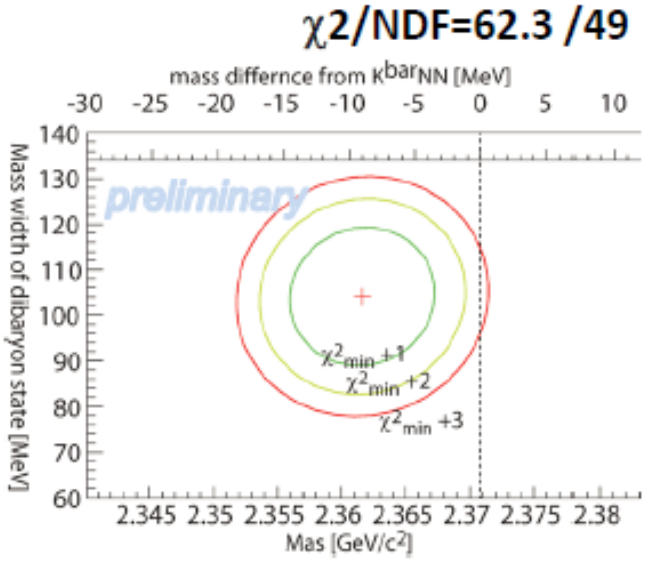
2NA+2step:
e.g. K$^-$^{3}He→Σ^0**p**n$_s$,
Σ^{0}n$_s$→**Λn**

2NA+2step:
e.g. K$^-$^{3}He→Σ^0**n**p$_s$,
Σ^{0}p$_s$→**Λp**

K$^-$pp form.:
K$^-$^{3}He→(K$^-$pp)**n**,
K$^-$pp→**Λp**

Assuming a Breit-Wigner

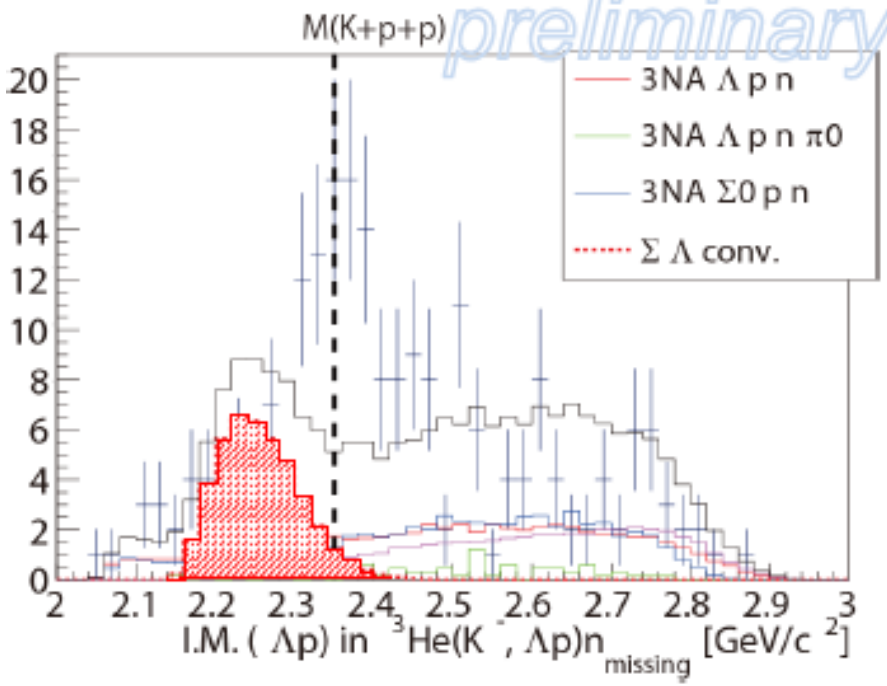




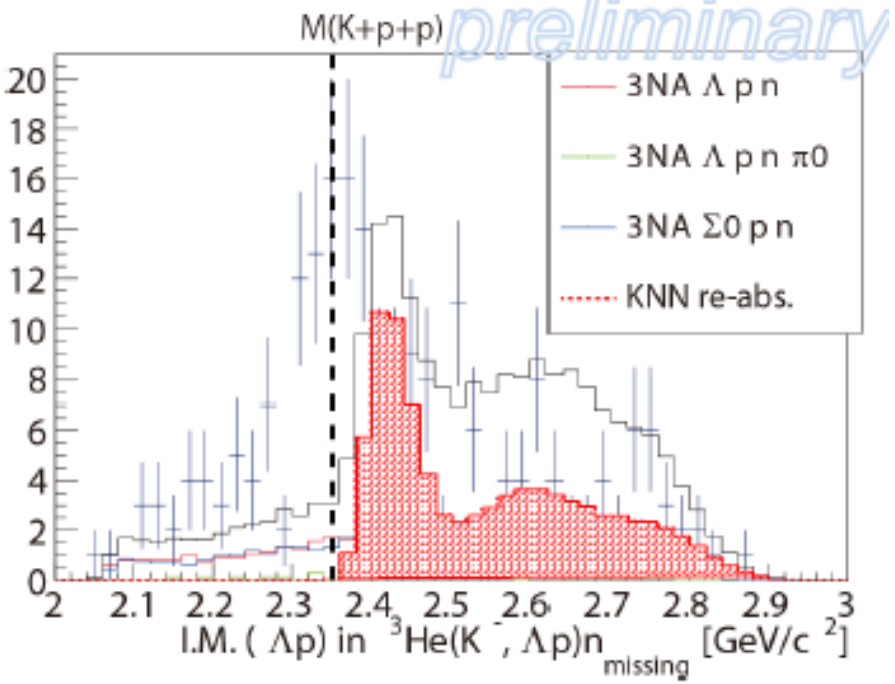
- χ^2-test with a Breit-Wigenr and 3NAs
  - assumption: isotropic Λp decay
  - parameters: Mass, Width, and Yield

2-step reaction

A) 2NA followed by Σ"N"→ΛN

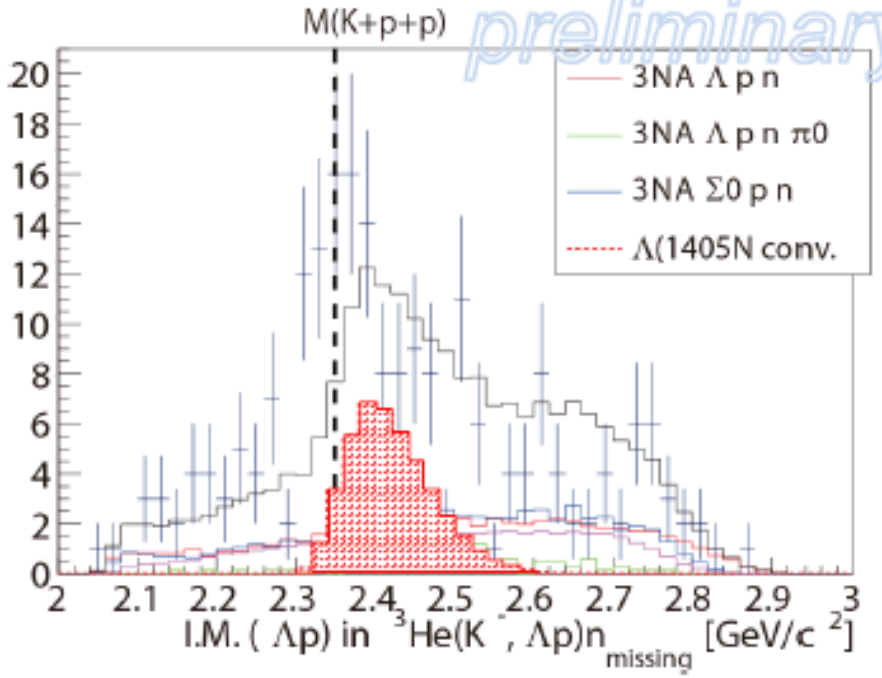


B) KN→KN followed by K"NN"→ ΛN



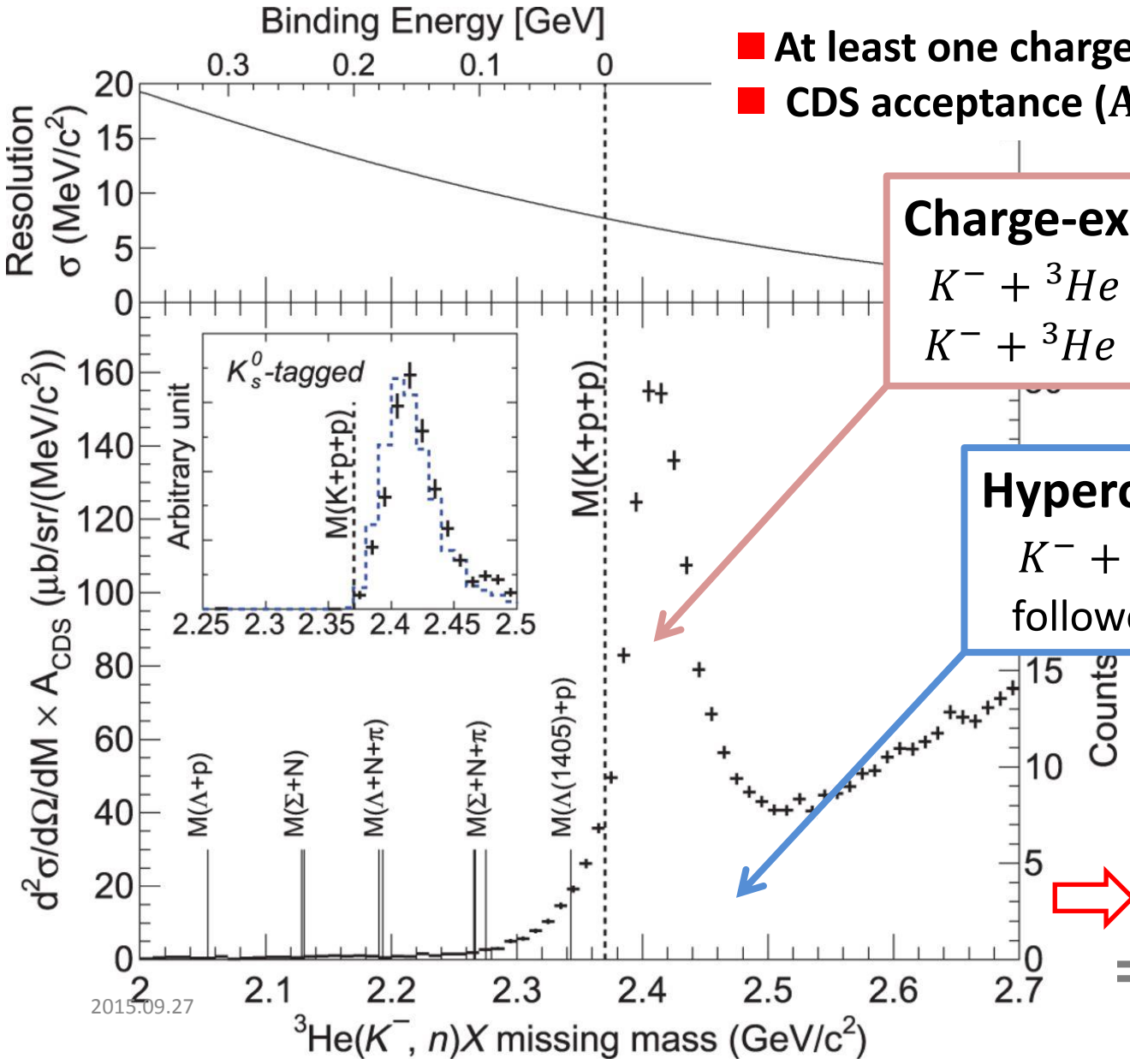
2-step reaction

C) 2NA followed by
$\Lambda(1405)$"N"→ΛN



- **The structure is NOT explained by any 2-step reactions**
- Other possibilities
  - ~~K^{-}"pp" → Λp cusp?~~
    - too broad (~100MeV/c^{2}) if the structure is attributed to the cusp
  - Shift of $\Lambda(1405)$? *~40MeV/c^{2}*
  - S=-1 di-baryon??

Semi-inclusive $^3He(K^-, n)$"X" spectrum



- At least one charged track in CDS is required.
- CDS acceptance (A_{CDS}) is not corrected.

Charge-exchange/Quasi-elastic

$K^- + {}^3He \rightarrow K^0 + \boldsymbol{n} + d_{spec}$

$K^- + {}^3He \rightarrow K^- + \boldsymbol{n} + 2p_{spec}$

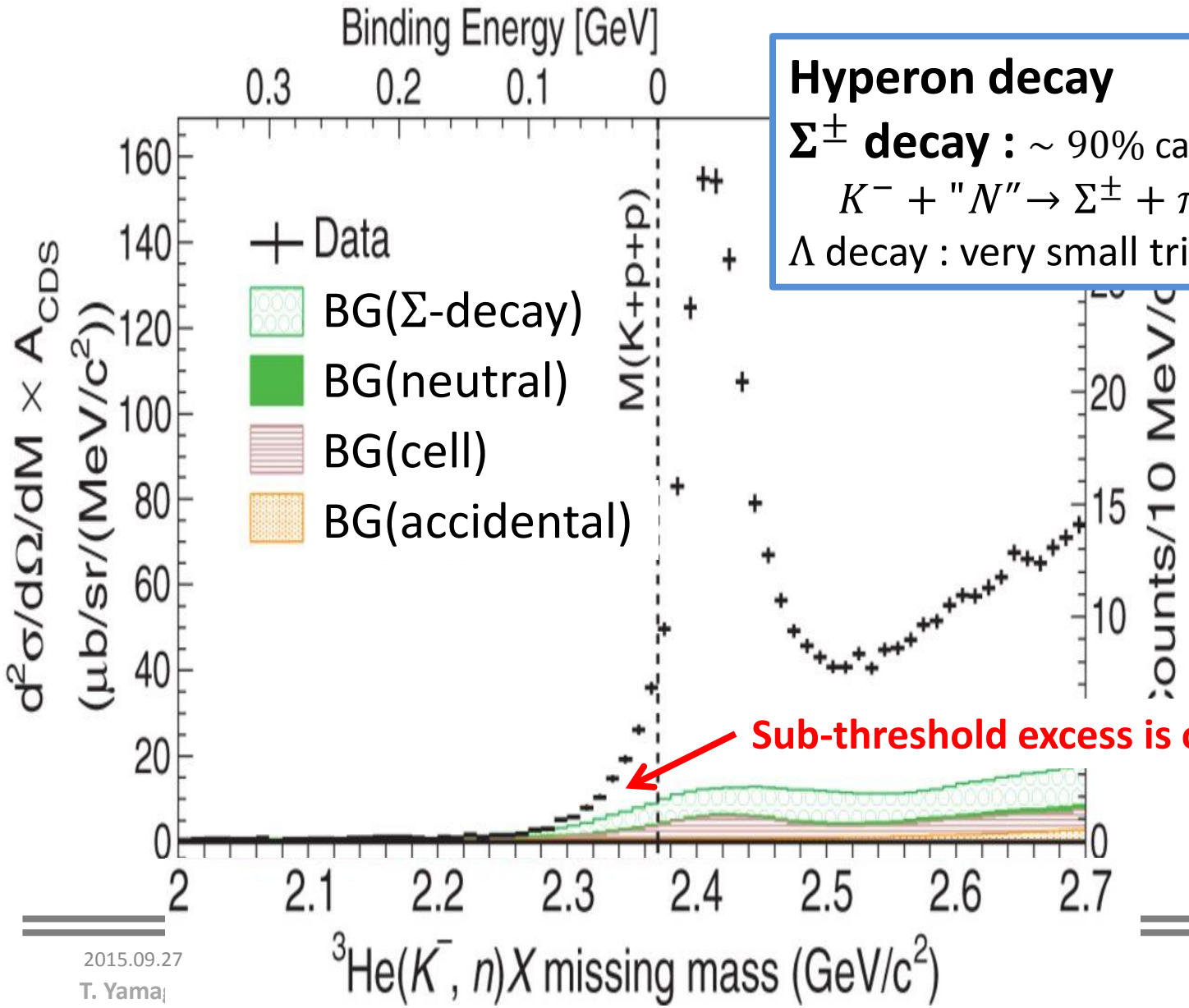
Hyperon decay

$K^- + {}^3He \rightarrow Y + \pi + 2N_{spec}$

followed by $Y \rightarrow \pi + \boldsymbol{n}$

⇨ **Evaluate the Background**

Semi-inclusive $^3He(K^-, n)"X"$ spectrum



Hyperon decay

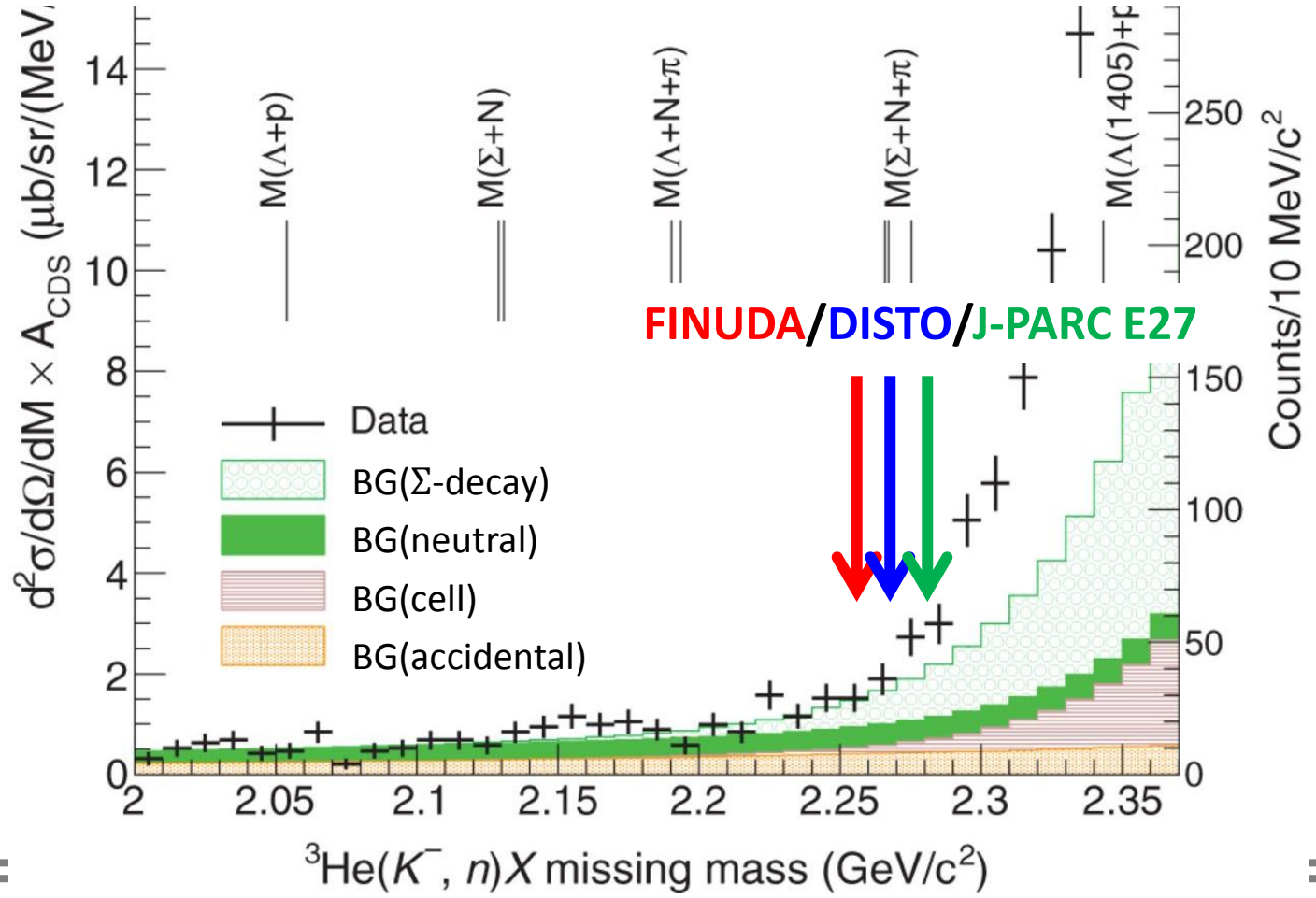
$\Sigma^{\pm}$ decay : $\sim 90\%$ can be reconstructed

$K^- + "N" \rightarrow \Sigma^{\pm} + \pi \rightarrow \boldsymbol{n} + \pi^{\pm} + \pi$

Λ decay : very small trigger acceptance

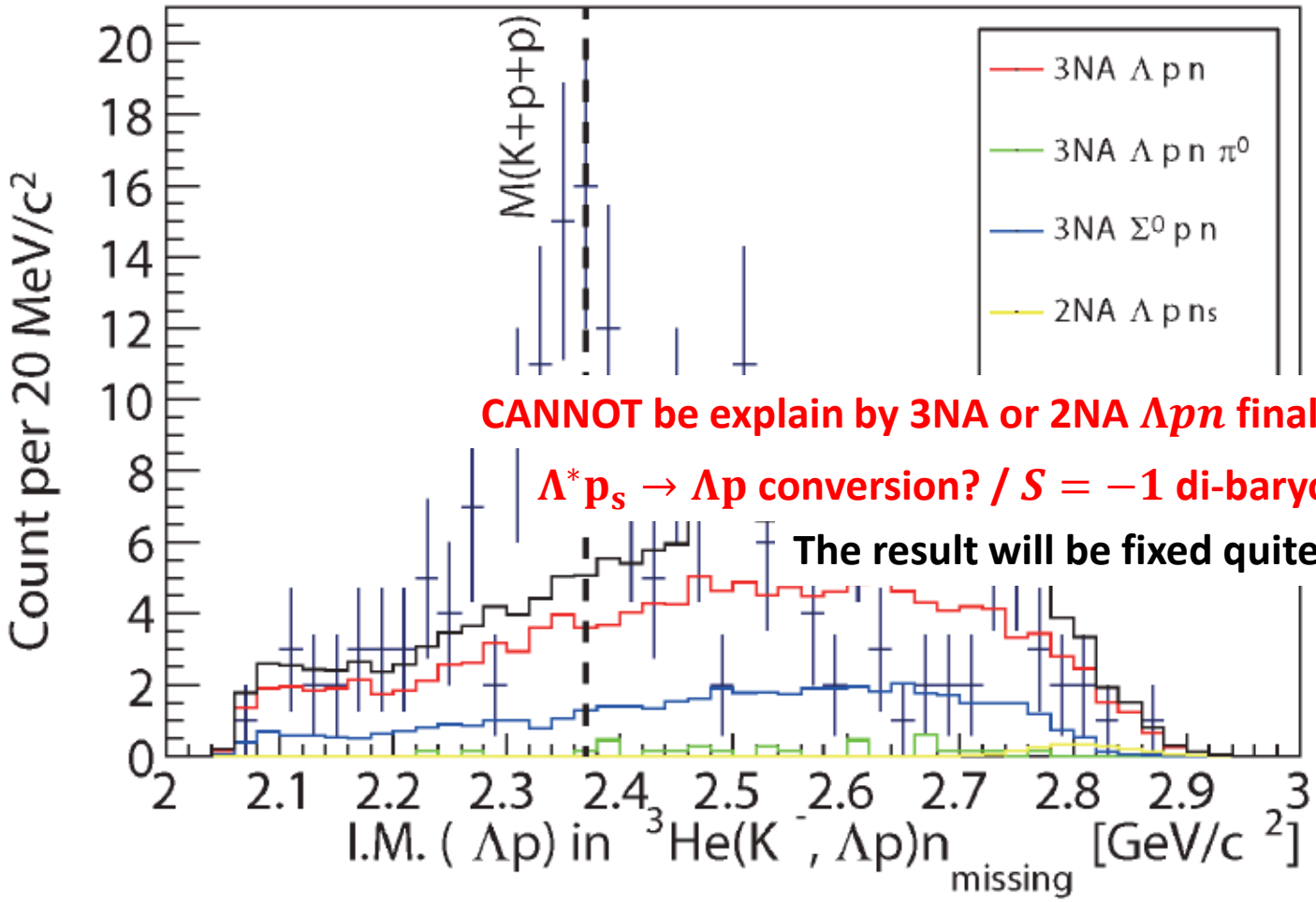
Comparison with other experiments

- **LEPS/SPring-8 and HADES/GSI also reported NO structure**



Λp invariant mass spectrum in $^3He(K^-, \Lambda p)$"n" reaction

- Missing neutron is selected in $MM(\Lambda p)$.



CANNOT be explain by 3NA or 2NA Λpn final state

$\Lambda^* p_s \rightarrow \Lambda p$ conversion? / $S = -1$ di-baryon state?

The result will be fixed quite soon.

Λp invariant mass spectrum in $^3He(K^-, \Lambda p)$"n" reaction

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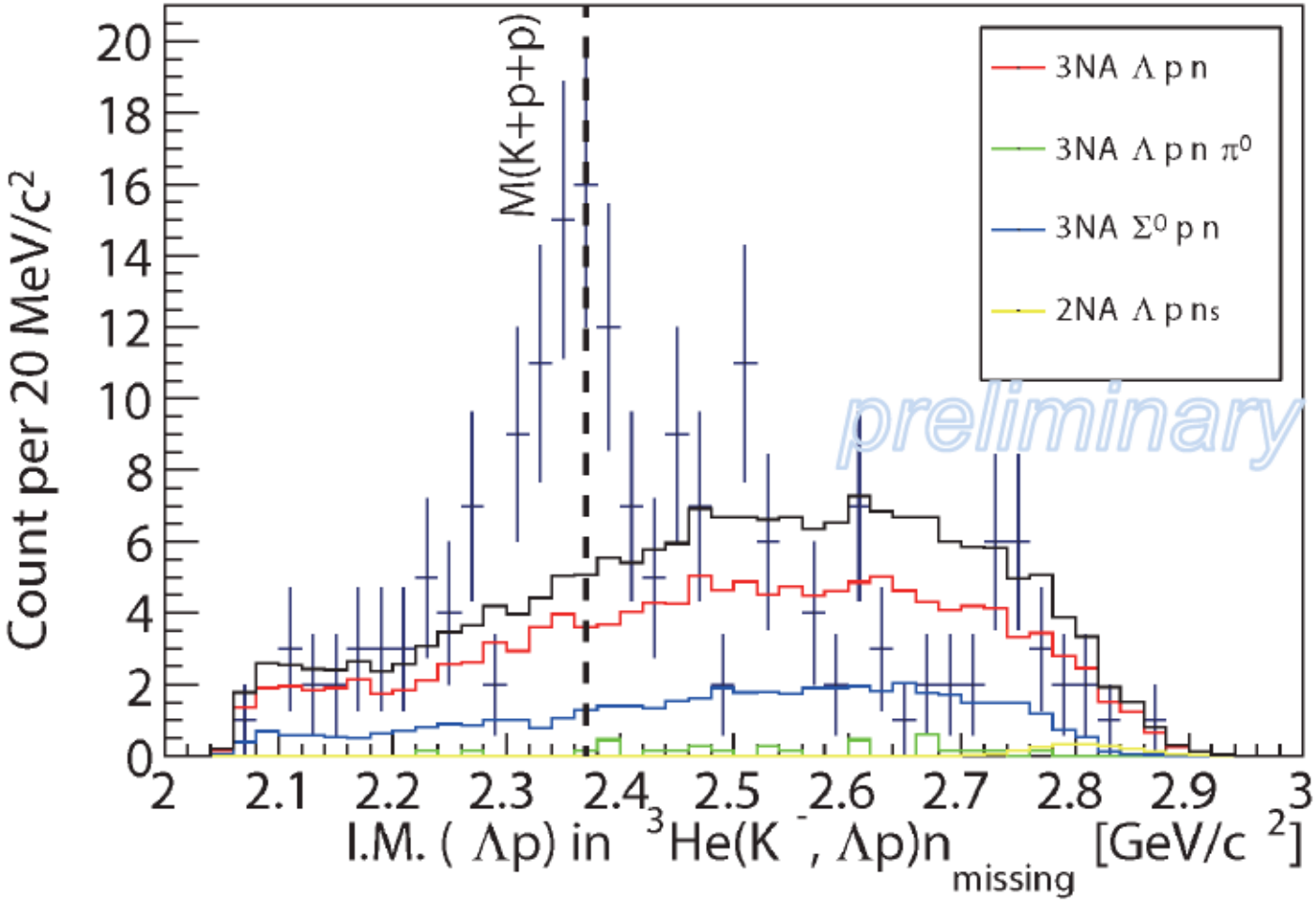
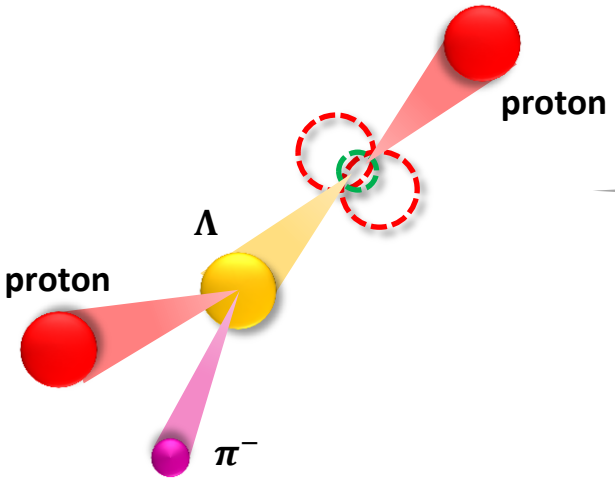
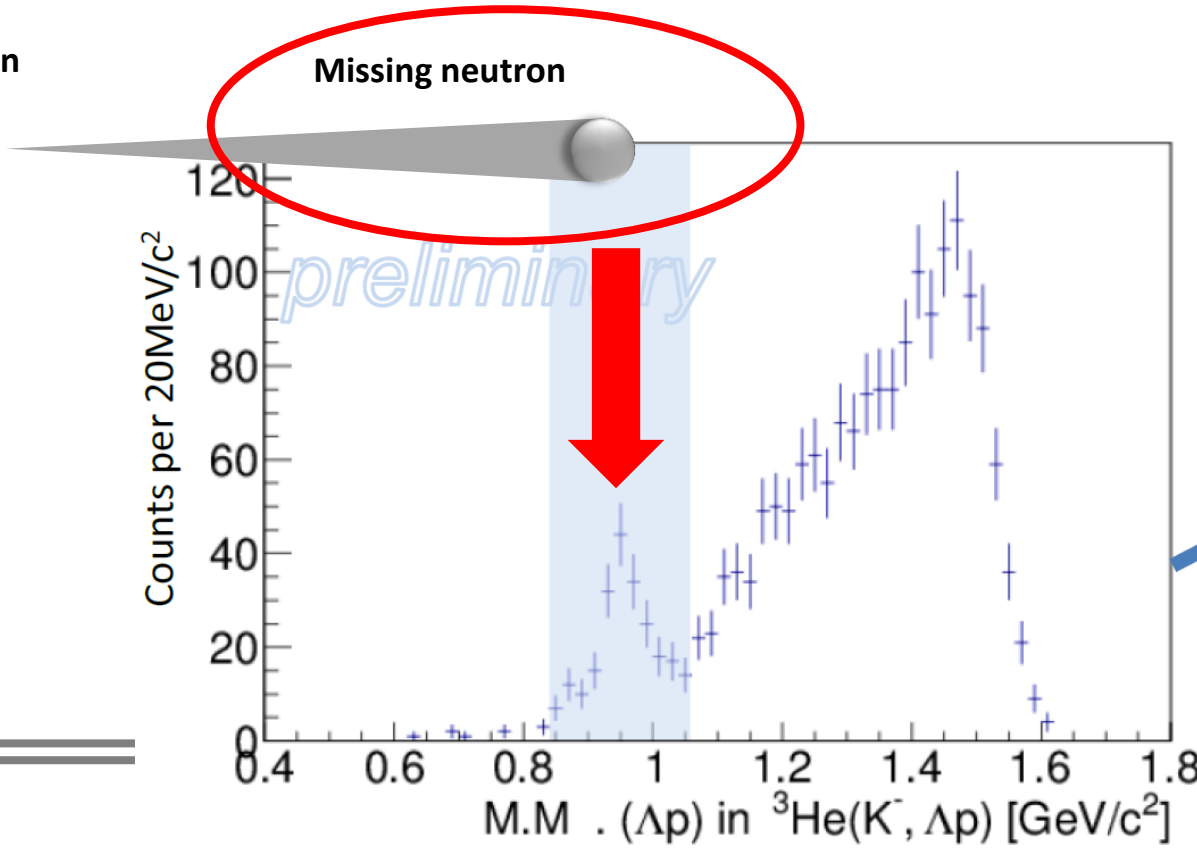


Decay channel analysis

- **Λp invariant mass spectroscopy in $^3He(K^-, \Lambda p)$"n" reaction**
  - **Select missing neutron in MM(Λp)**





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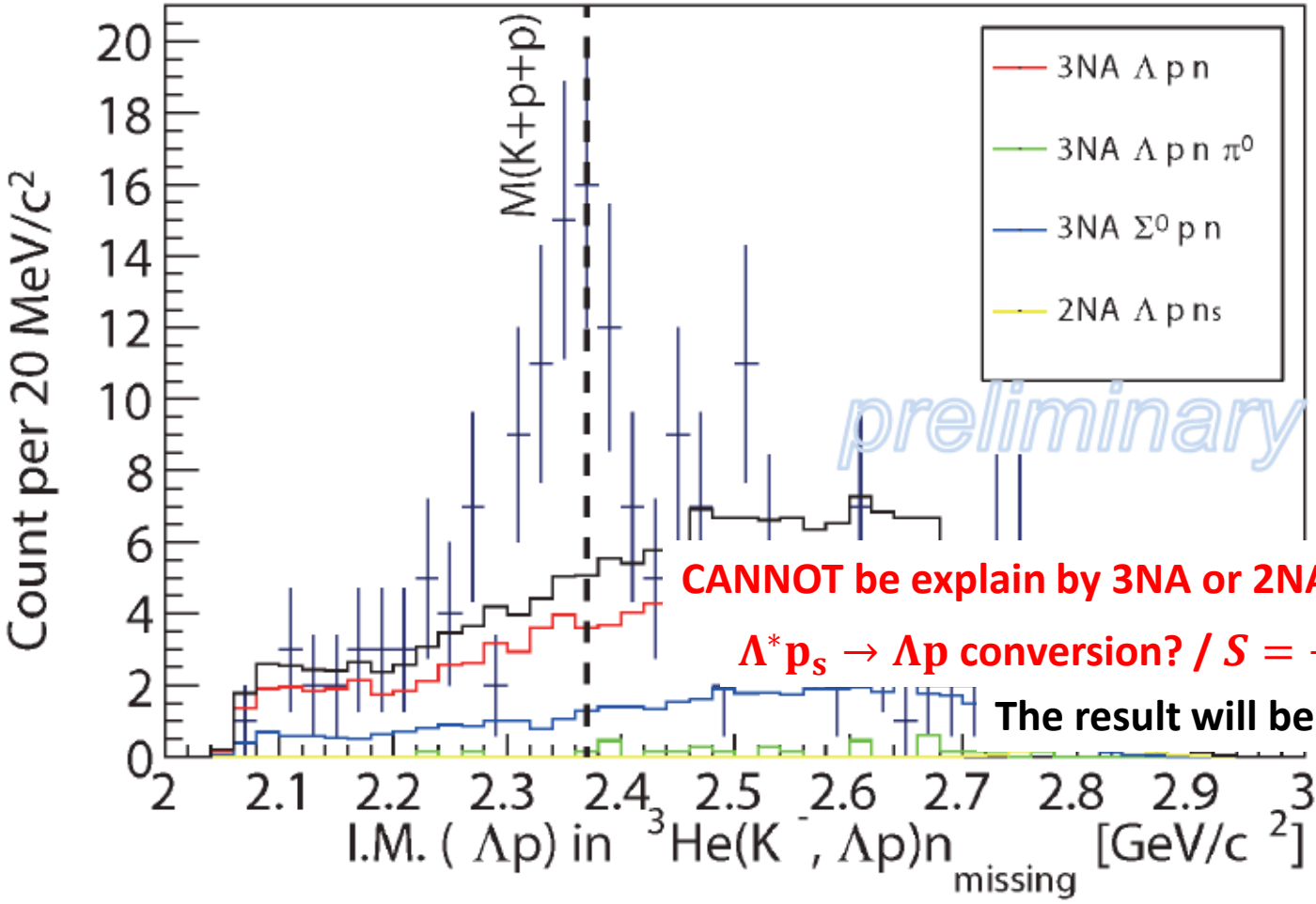


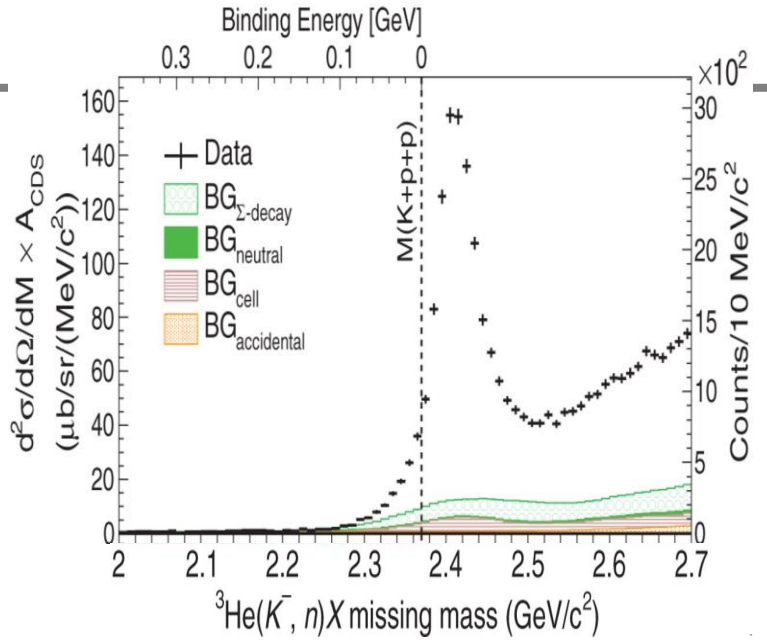
CANNOT be explain by 3NA or 2NA Λpn final state

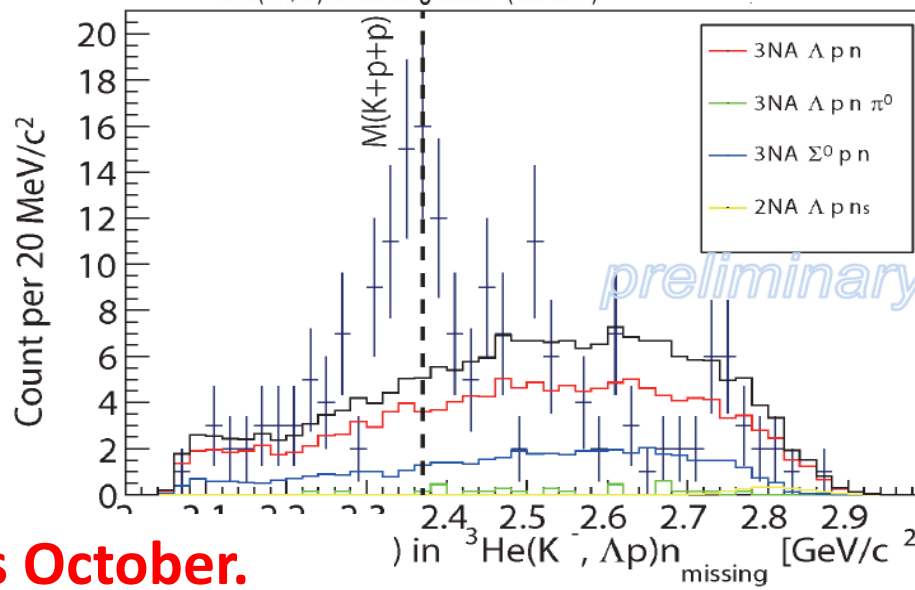
$\Lambda^* p_s \rightarrow \Lambda p$ conversion? / $S = -1$ di-baryon state?

The result will be fixed quite soon.

Summary

- **Formation channel**
  - $^3He(K^-, n)$"X" missing mass spectrum
    - Excess below the threshold is observed.
    - NO structure in deeply-bound region
- **Decay channel**
  - Λp invariant mass spectrum
    - Structure is observed below K-pp threshold.





The experiment will resume this October.

Result of E15-1st

- **Formation channel**
  - $^3He(K^-, n)$"X" missing mass spectrum
    - Excess below the threshold is observed.
    - NO structure in deeply-bound region
- **Decay channel**
  - Λp invariant mass spectrum
    - Structure is observed below K-pp threshold.