Latest results of a kaonic-nucleus search in J-PARC E15

Tadashi Hashimoto (RIKEN)
for the J-PARC E15 collaboration

- *"K^-pp"* searches and J-PARC E15
- Analysis status of $E15^{1st}$
  - semi-inclusive $^3He(K^-,n)$
  - exclusive $^3He(K^-,\Lambda p)n$

J-PARC E15 collaboration

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(*) Spokesperson
($) Co-Spokesperson

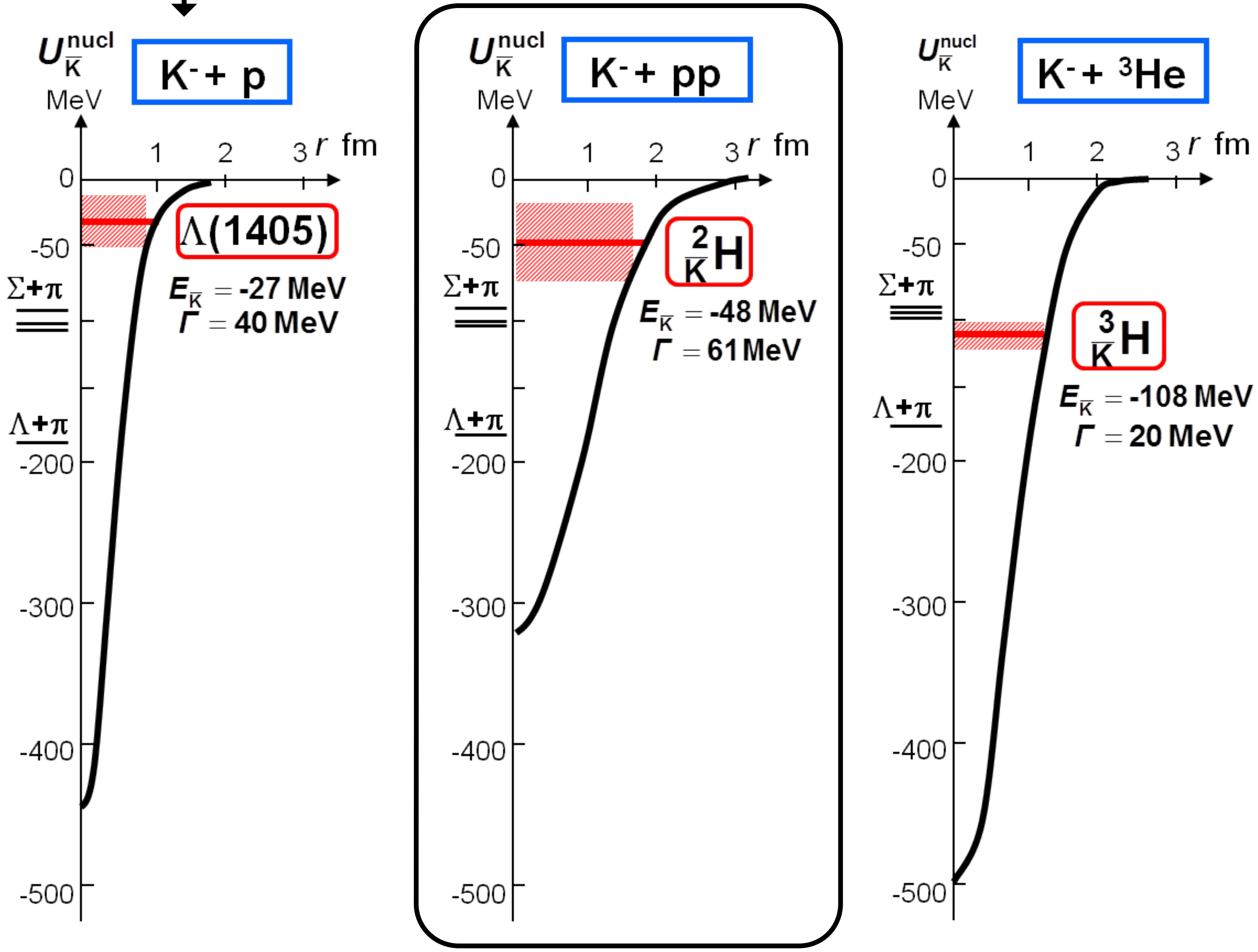
Kaonic nuclear bound state

Anti-kaon might be bound to a nucleus

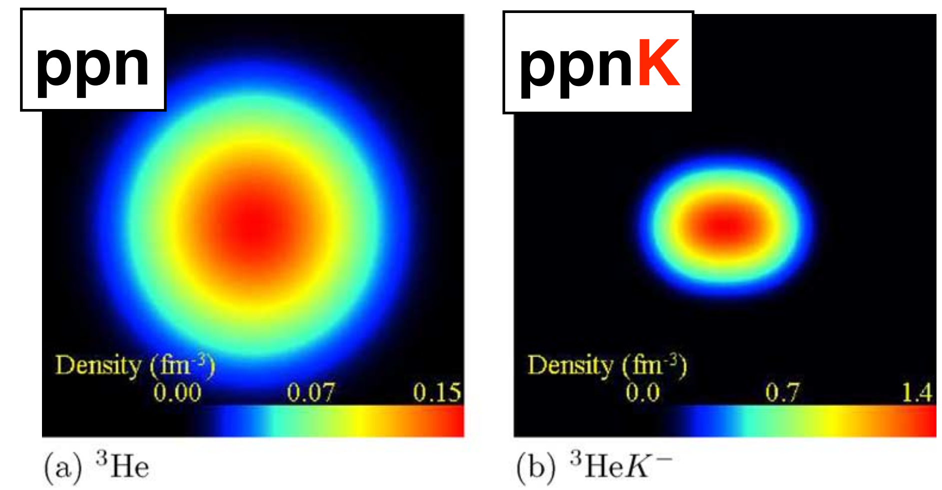
due to the strongly attractive K^bar N interaction in I=0

Assumption

1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

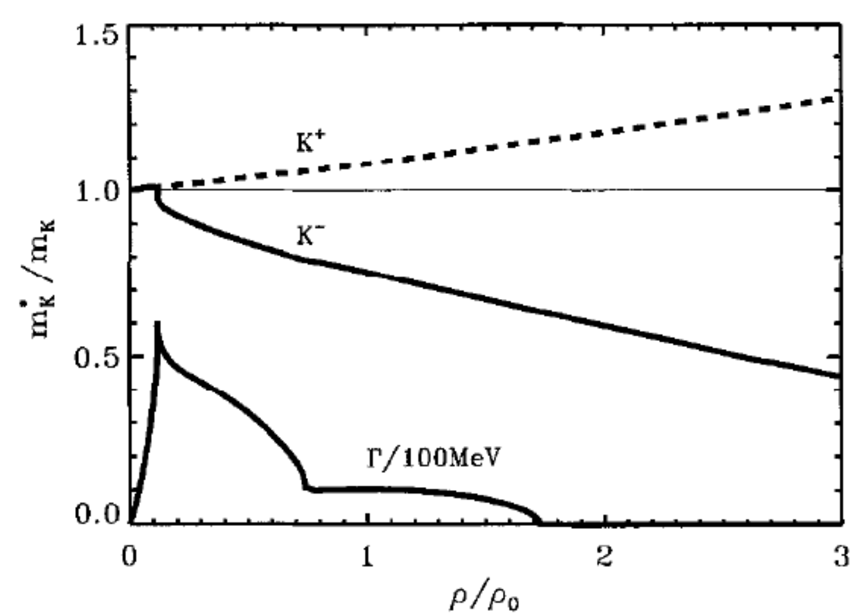


dense nuclei are predicted



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

Kaon mass in nuclear medium?

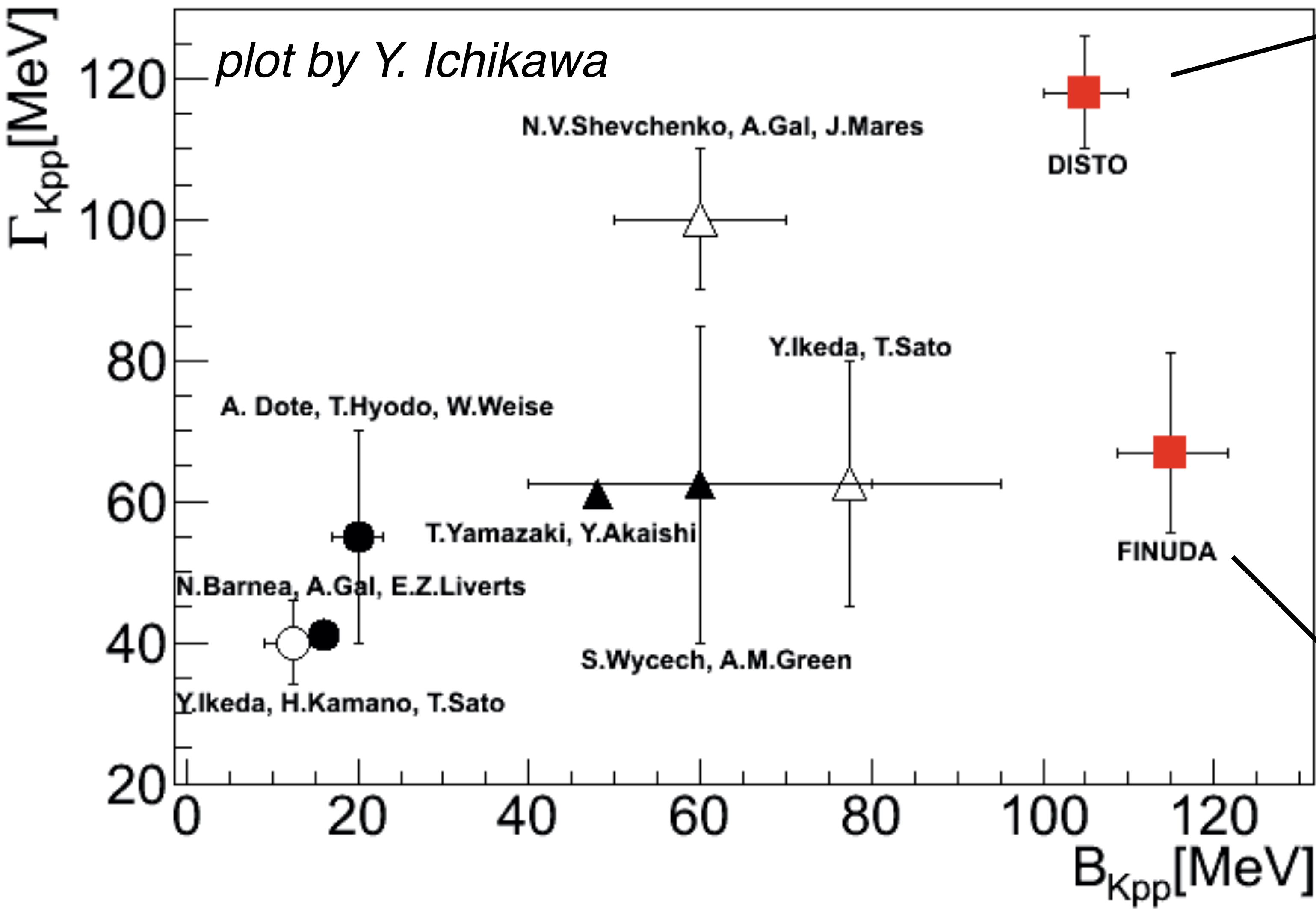


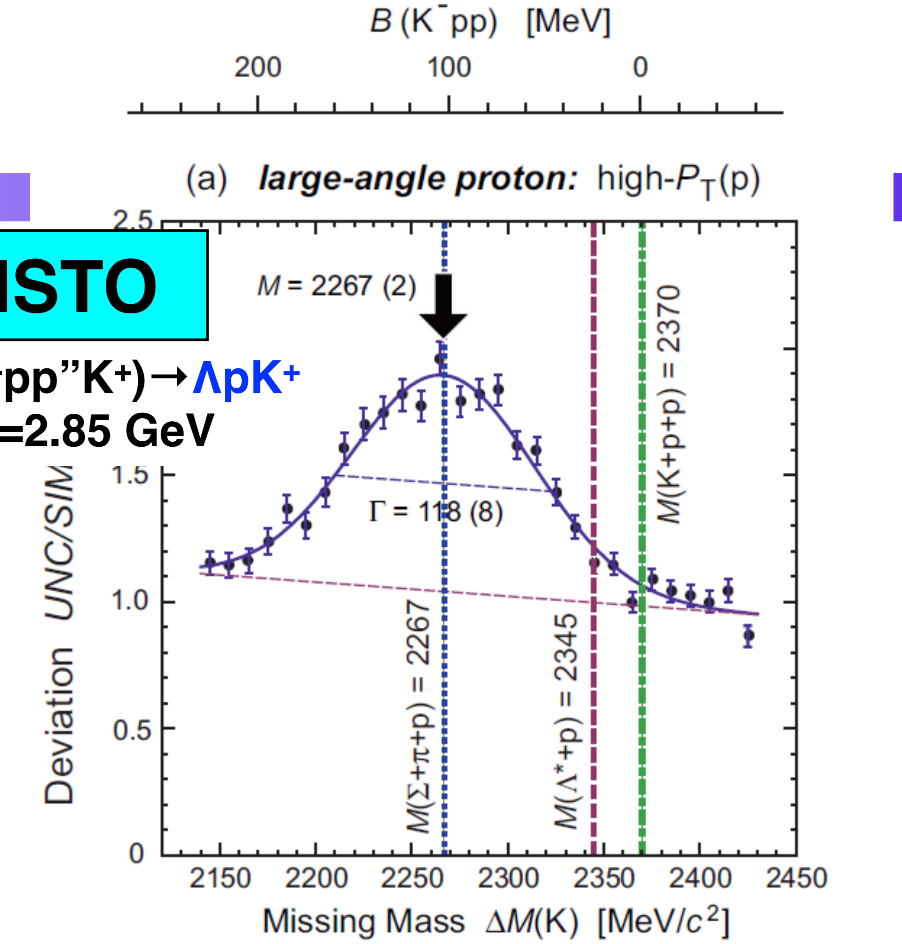
1.T. Waas *et al. Physics Letters B* **379,** 34–38 (1996).

the lightest kaonic nucleus

"K-pp" : $[K^{bar}(NN)_{I=1,S=0}]_{I=1/2}$, $J^{\pi}=0^-$

Current situation on “K⁻pp”





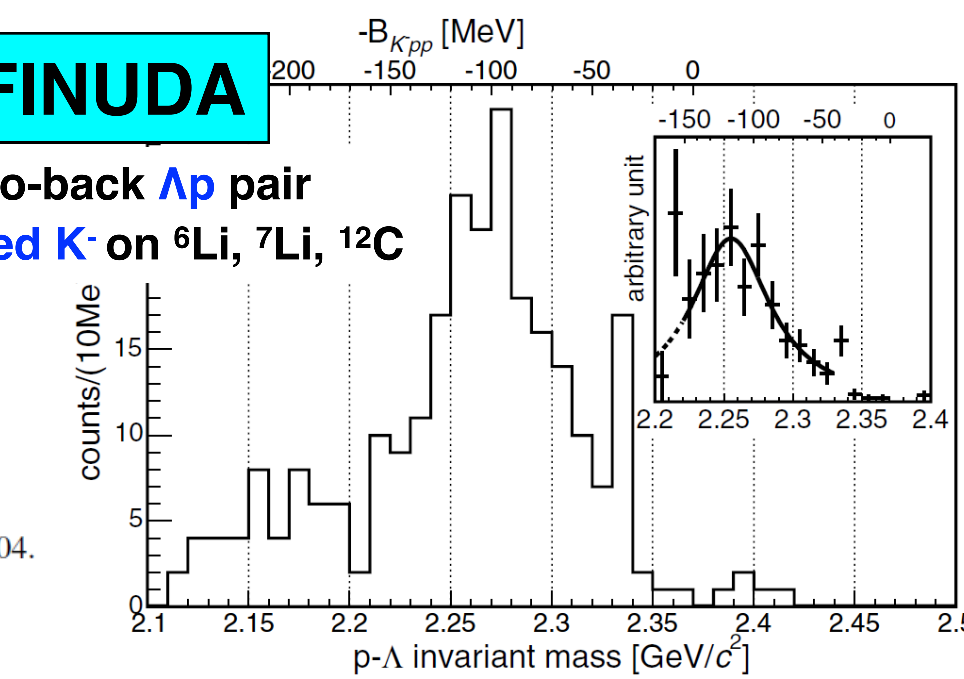
DISTO

pp→(“K⁻pp”K⁺)→ΛpK⁺
@T_p=2.85 GeV

T. Yamazaki *et al. Phys. Rev. Lett.* **104,** 132502 (2010).
P. Kienle *et al. Eur. Phys. J. A* **48,** 183 (2012).

FINUDA

back-to-back Λp pair
stopped K⁻ on ^{6}Li, ^{7}Li, ^{12}C



M. Agnello *et al. Phys. Rev. Lett.* **94,** 212303 (2005).

Theoretical value	K^{bar}–N interaction	Calculation method
●	Chiral base	Variation
○	Chiral base	Faddeev
▲	Phenomenological	Variation
△	Phenomenological	Faddeev

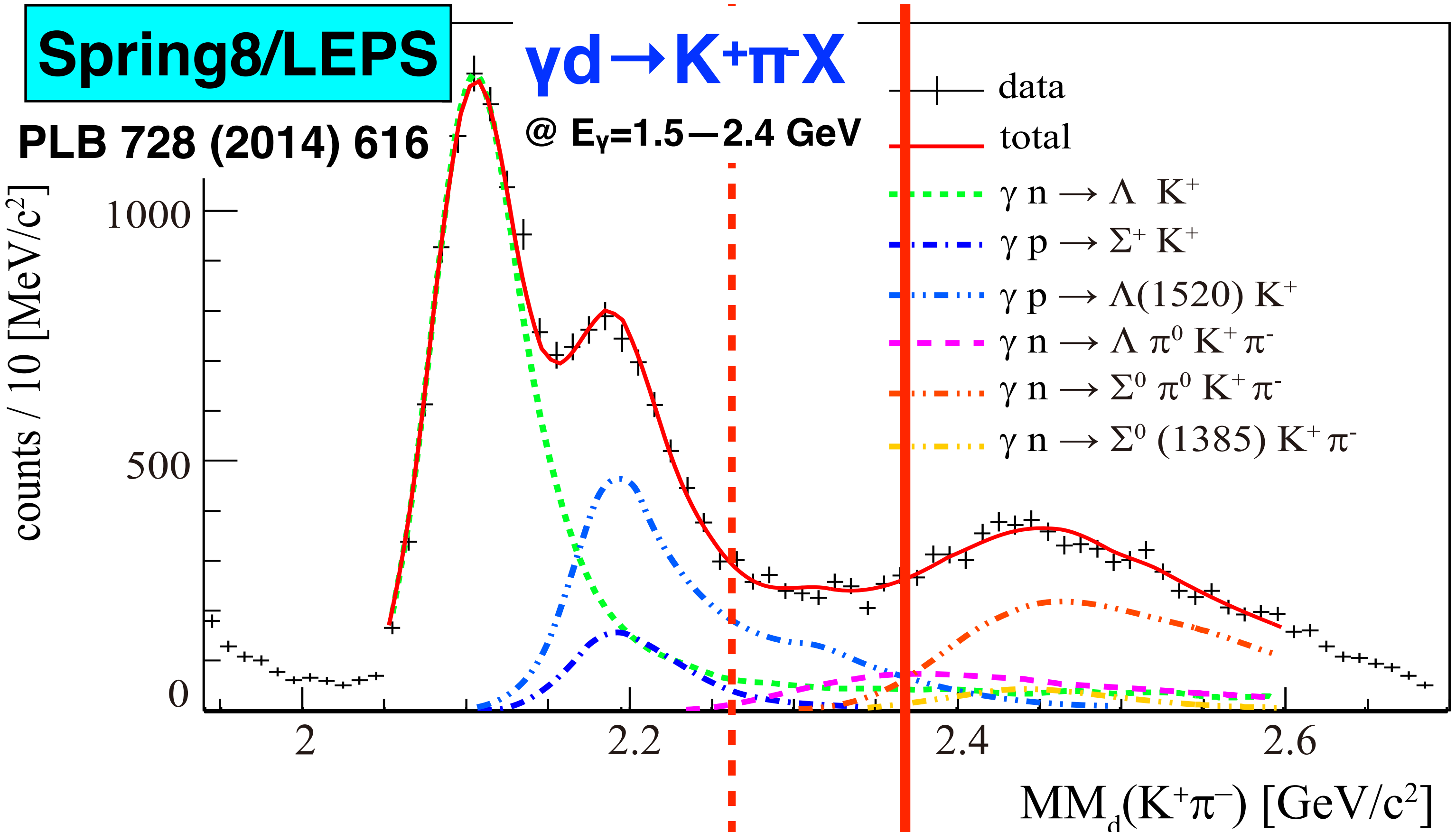
N. Barnea, A. Gal, E.Z. Liverts, Phys. Lett. B 712 (2012) 132.
A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A 804 (2008) 197;
A. Doté, T. Hyodo, W. Weise, Phys. Rev. C 79 (2009) 014003.
Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. 124 (2010) 533.
T. Yamazaki, Y. Akaishi, Phys. Lett. B 535 (2002) 70.
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.

+ Variety of few-body calculations
+ Two major experimental “observations” are still not understood well

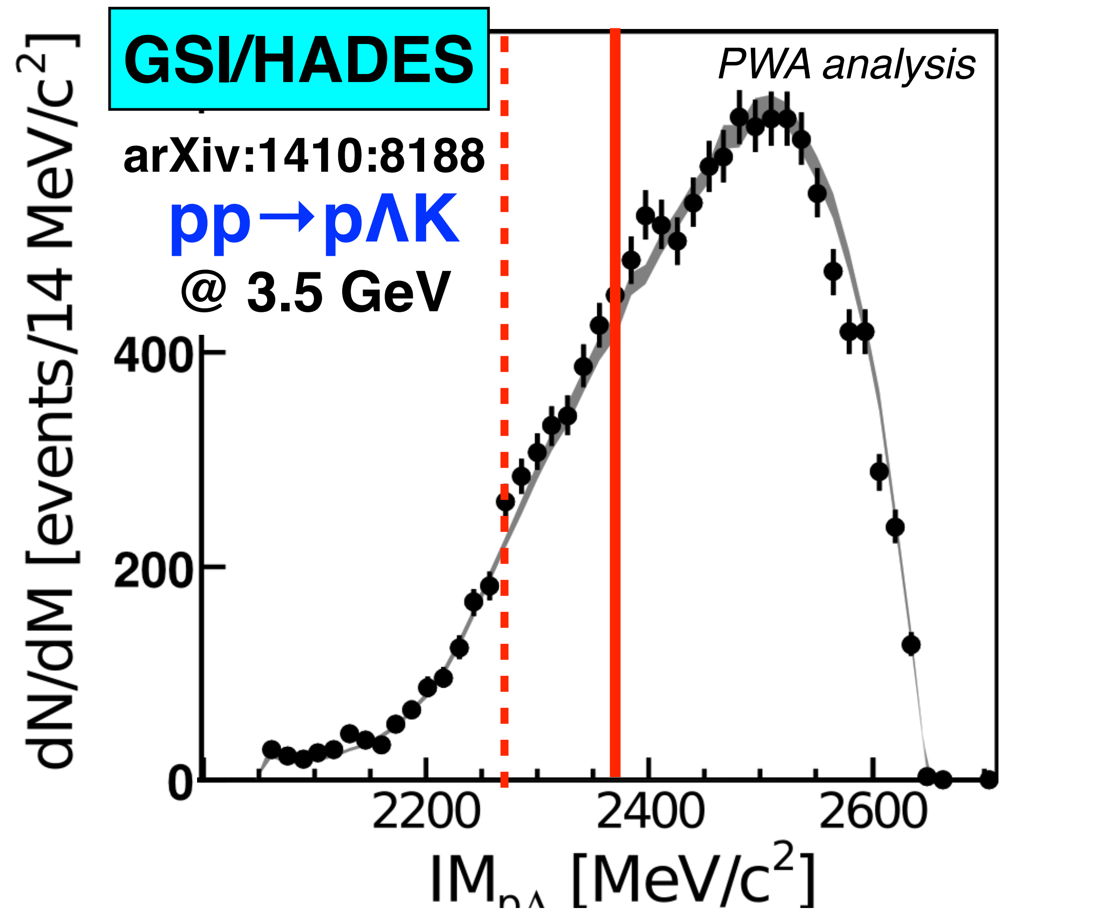
New experimental results

K-pp binding threshold (solid red line)
B.E. ~100 MeV (dashed red line)

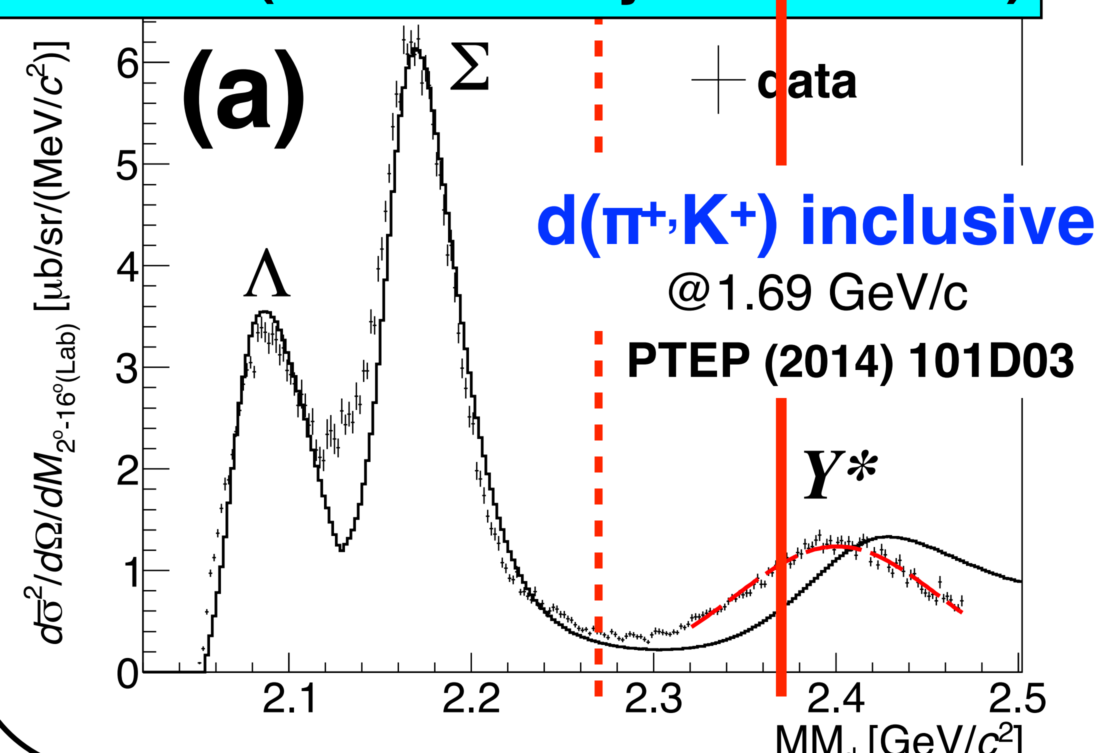
Spring8/LEPS

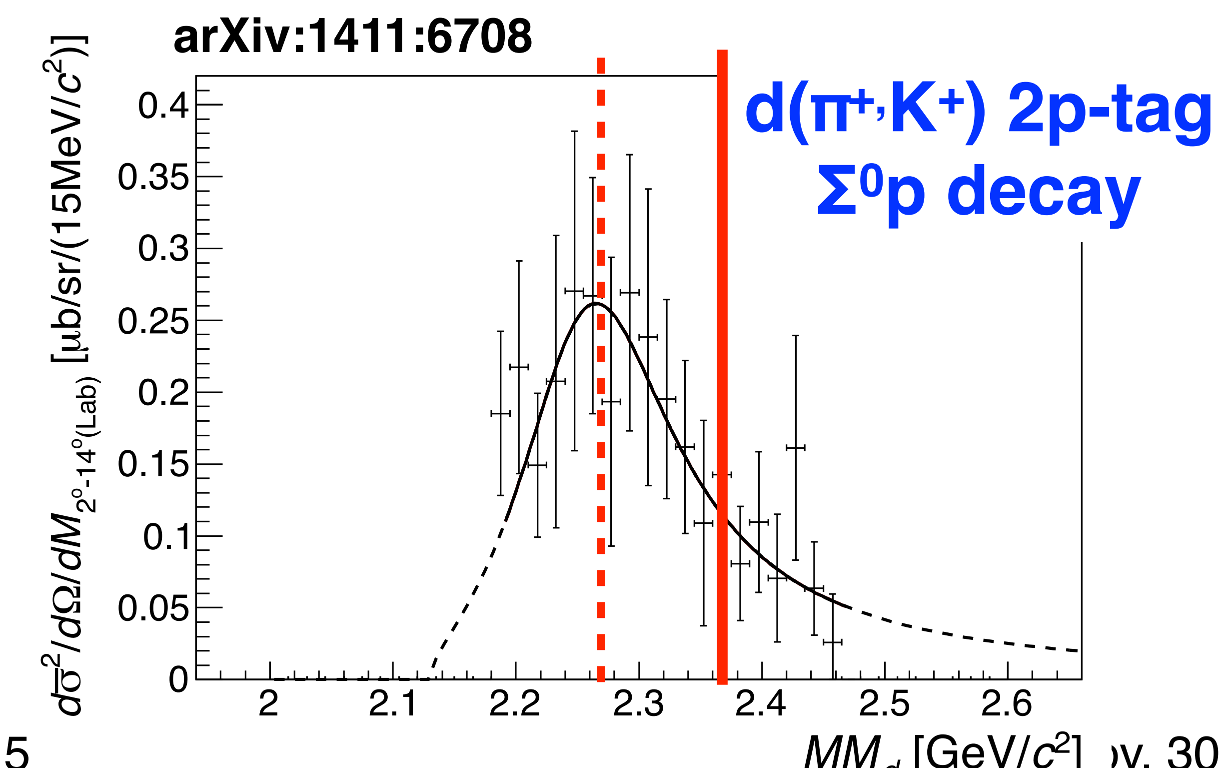


GSI/HADES

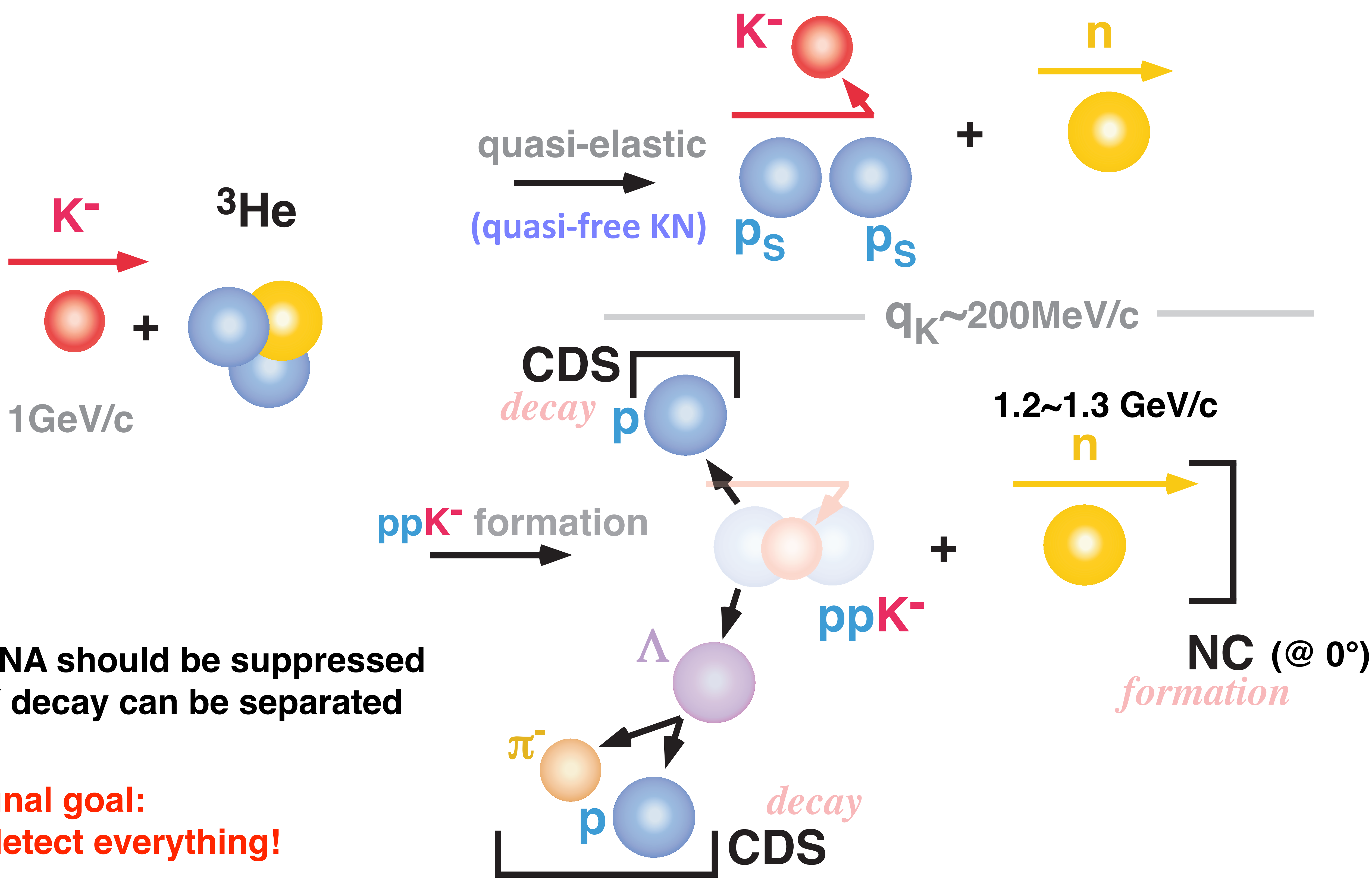


J-PARC/E27 (Next talk by Y. Ichikawa)





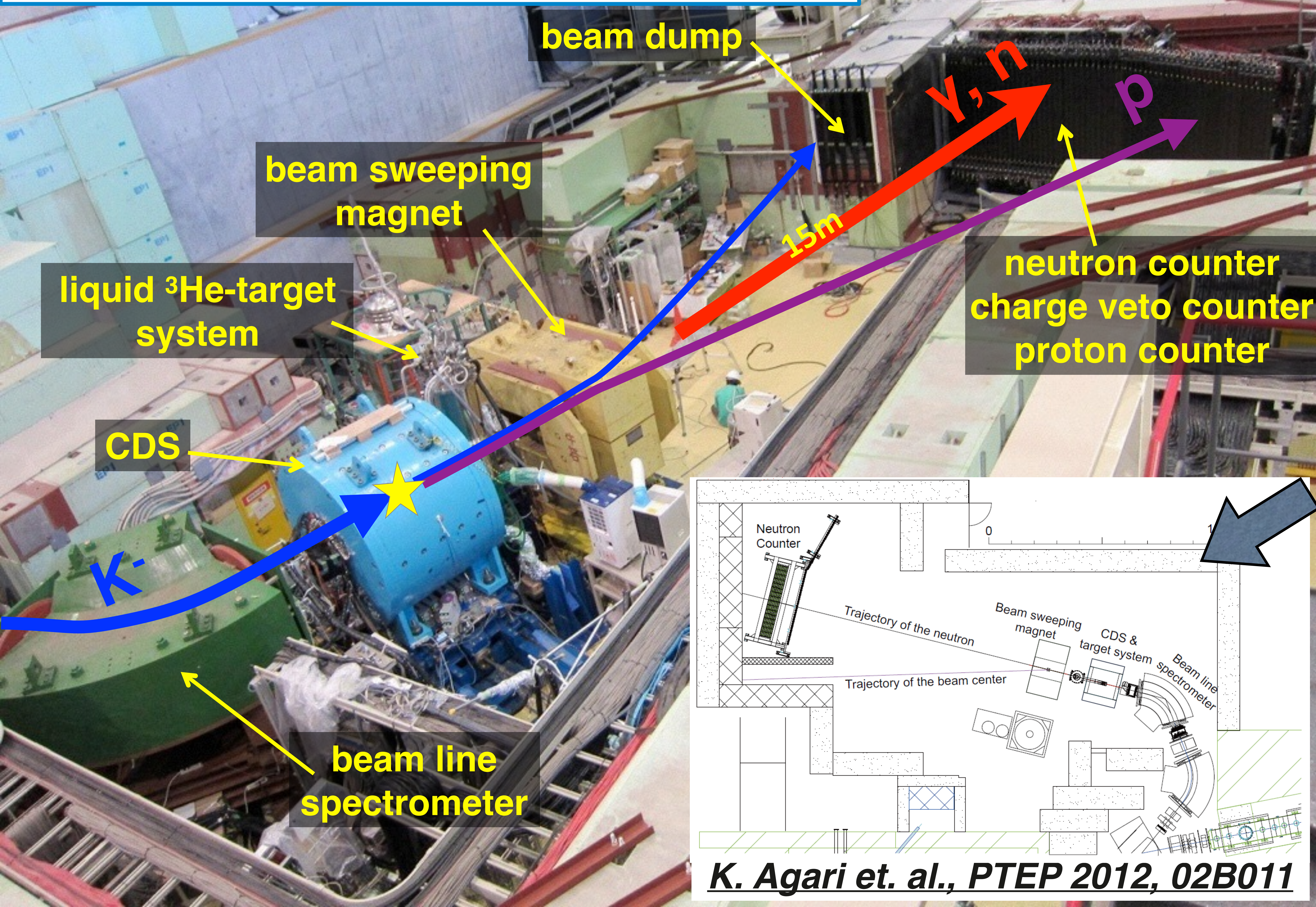
In-flight K^- reaction on ^3He



2NA should be suppressed
Y decay can be separated

final goal:
detect everything!

J-PARC K1.8BR spectrometer



K. Agari et. al., PTEP 2012, 02B011

Summary of E15 1st

24 kW * 4-day data taking in May, 2013
~ 5.3 x 10^9 on ^{3}He
~ 1% of the approved proposal

Formation channel

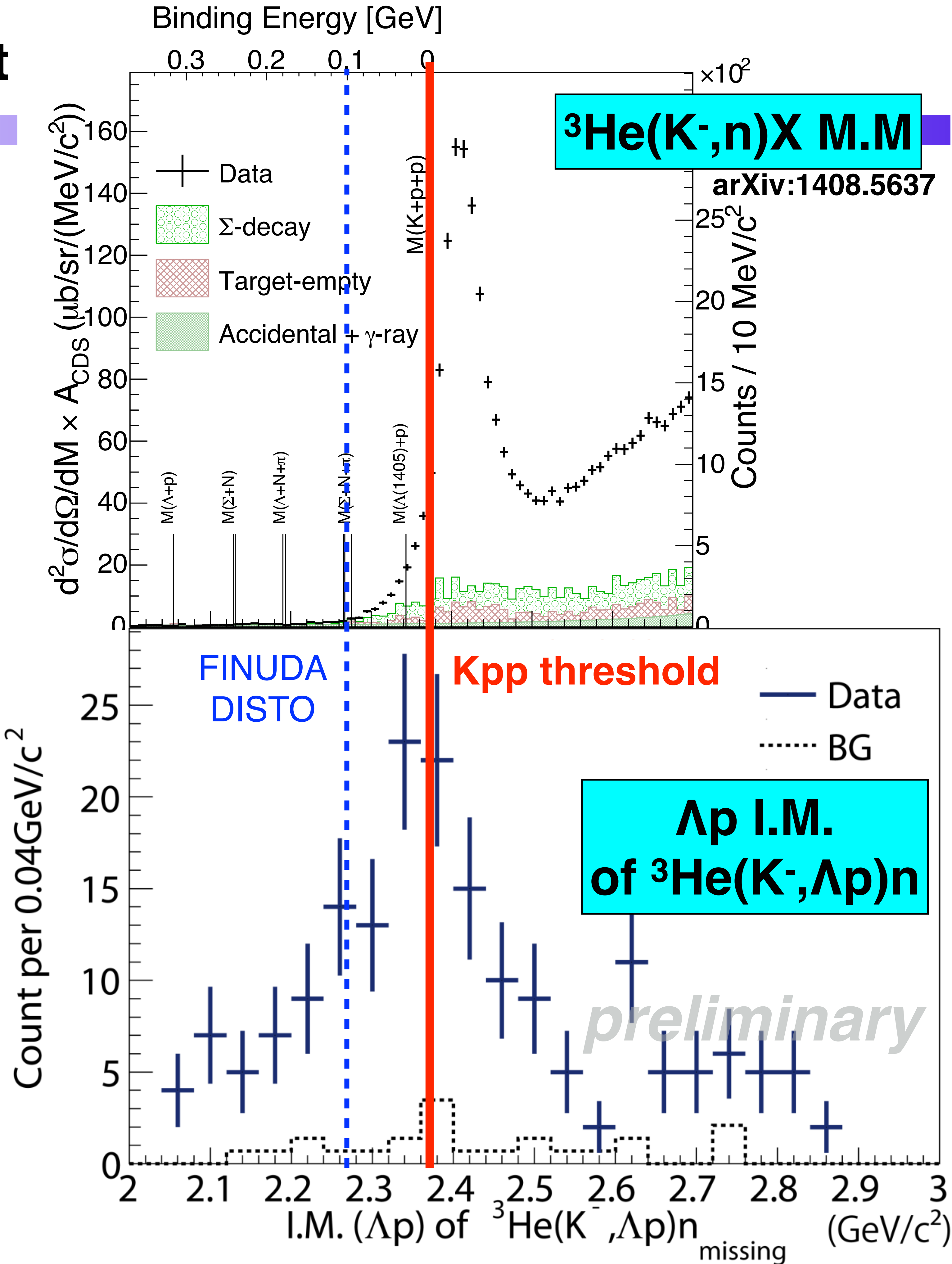
Semi-inclusive ^{3}He(K-,n)X

- **No significant bump structure** in the deeply bound region
- Excess below the threshold

Decay channel

Exclusive ^{3}He(K-,Λp)n

- Deviation from the simple Phase space
- Excess around the threshold ?



Formation channel
Semi-inclusive $^{3}He(K^{-}, n)$

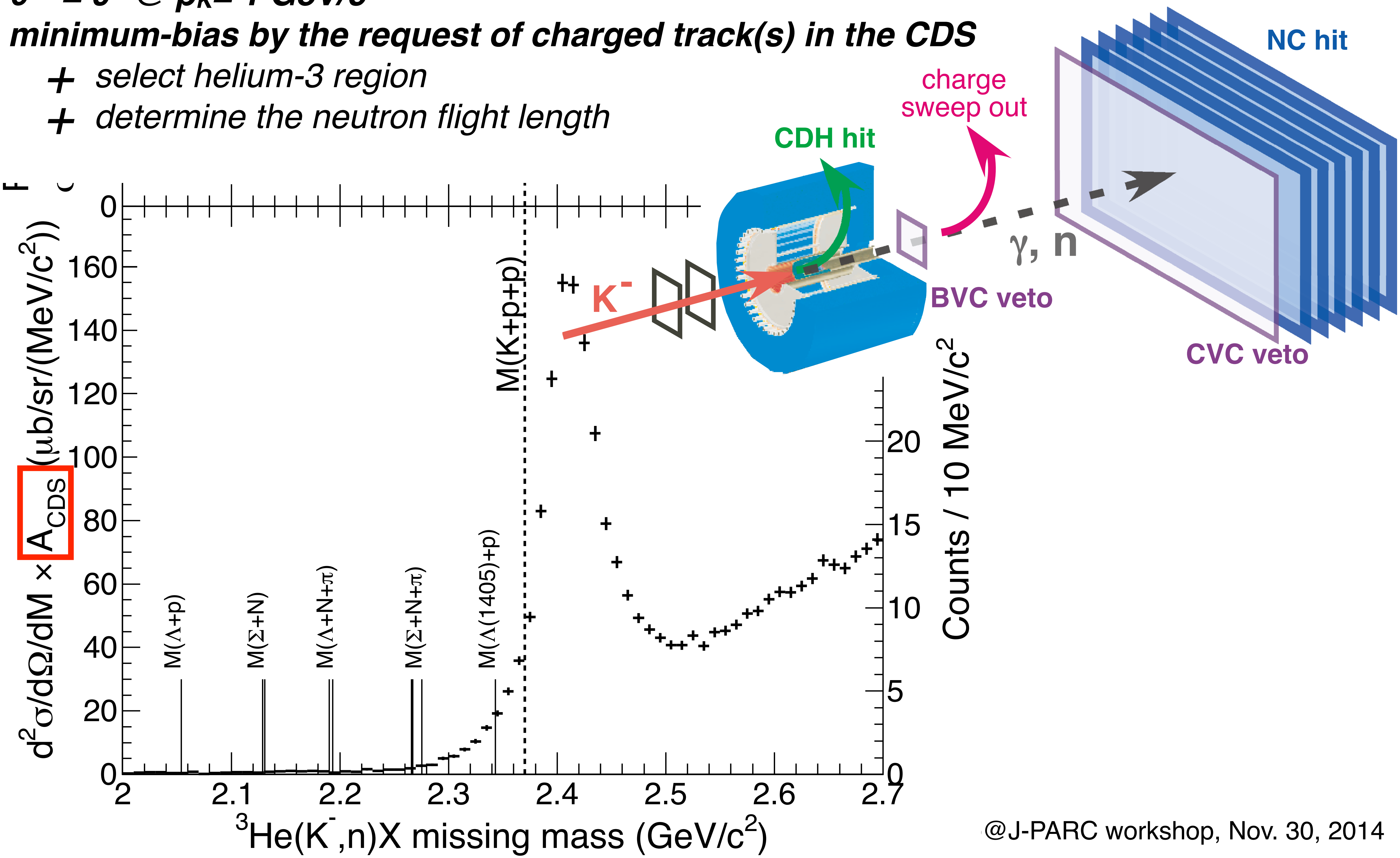
T. Hashimoto et al., arXiv:1408.5637

Semi-inclusive spectrum

θ^lab^= 0° @ p~K~= 1 GeV/c

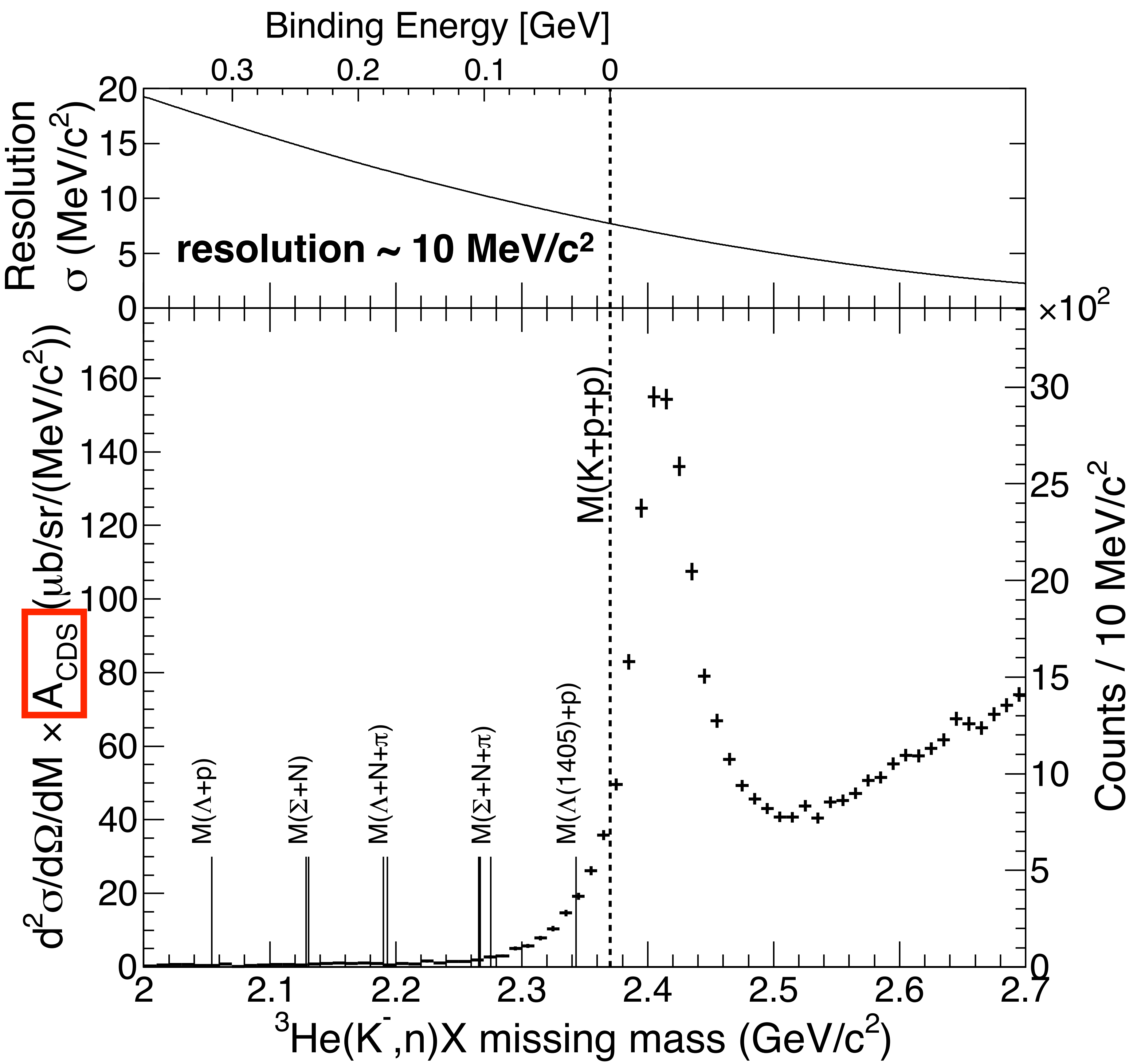
minimum-bias by the request of charged track(s) in the CDS

+ *select helium-3 region*
+ *determine the neutron flight length*



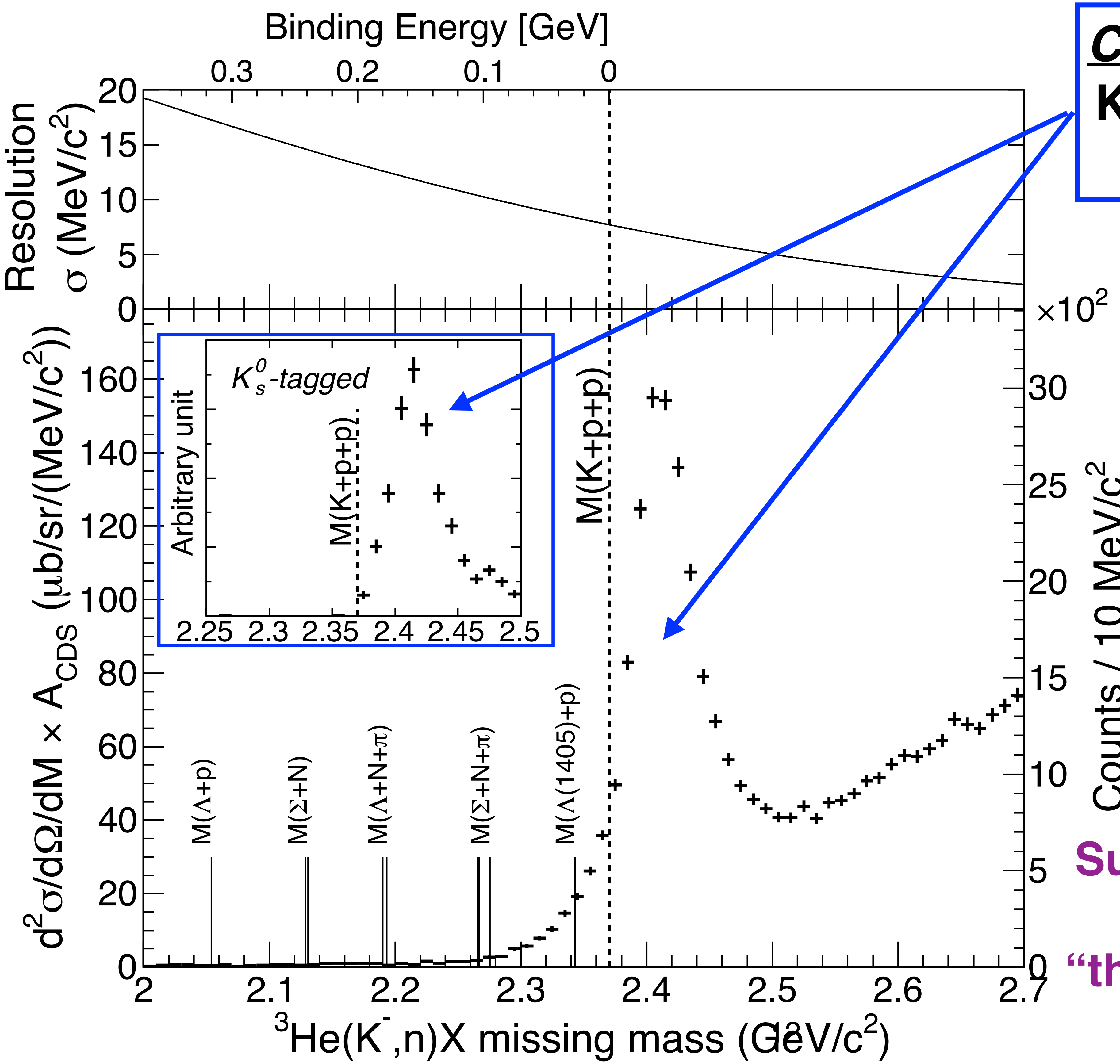
@J-PARC workshop, Nov. 30, 2014

Semi-inclusive spectrum



@J-PARC workshop, Nov. 30, 2014

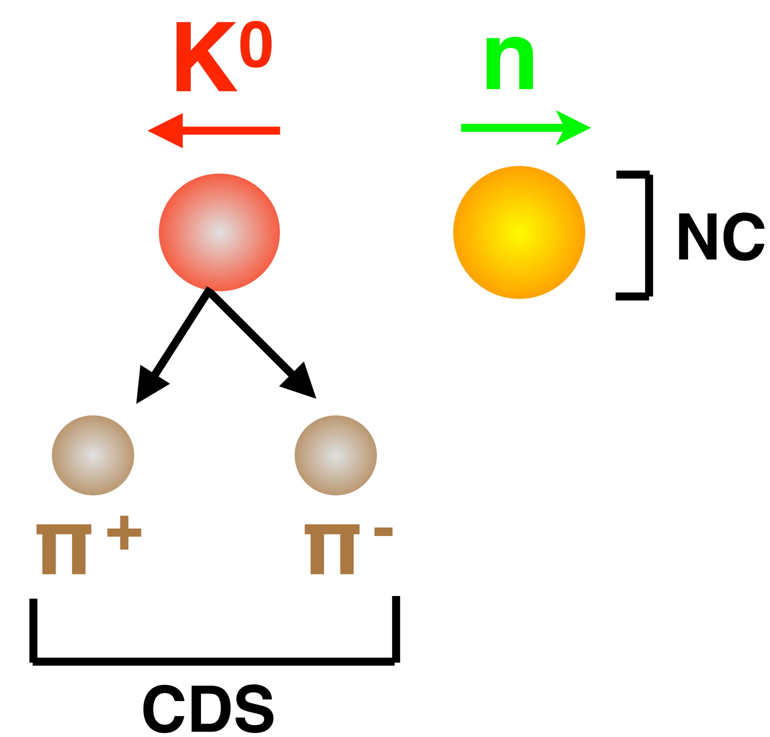
Semi-inclusive spectrum



Charge-exchange

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

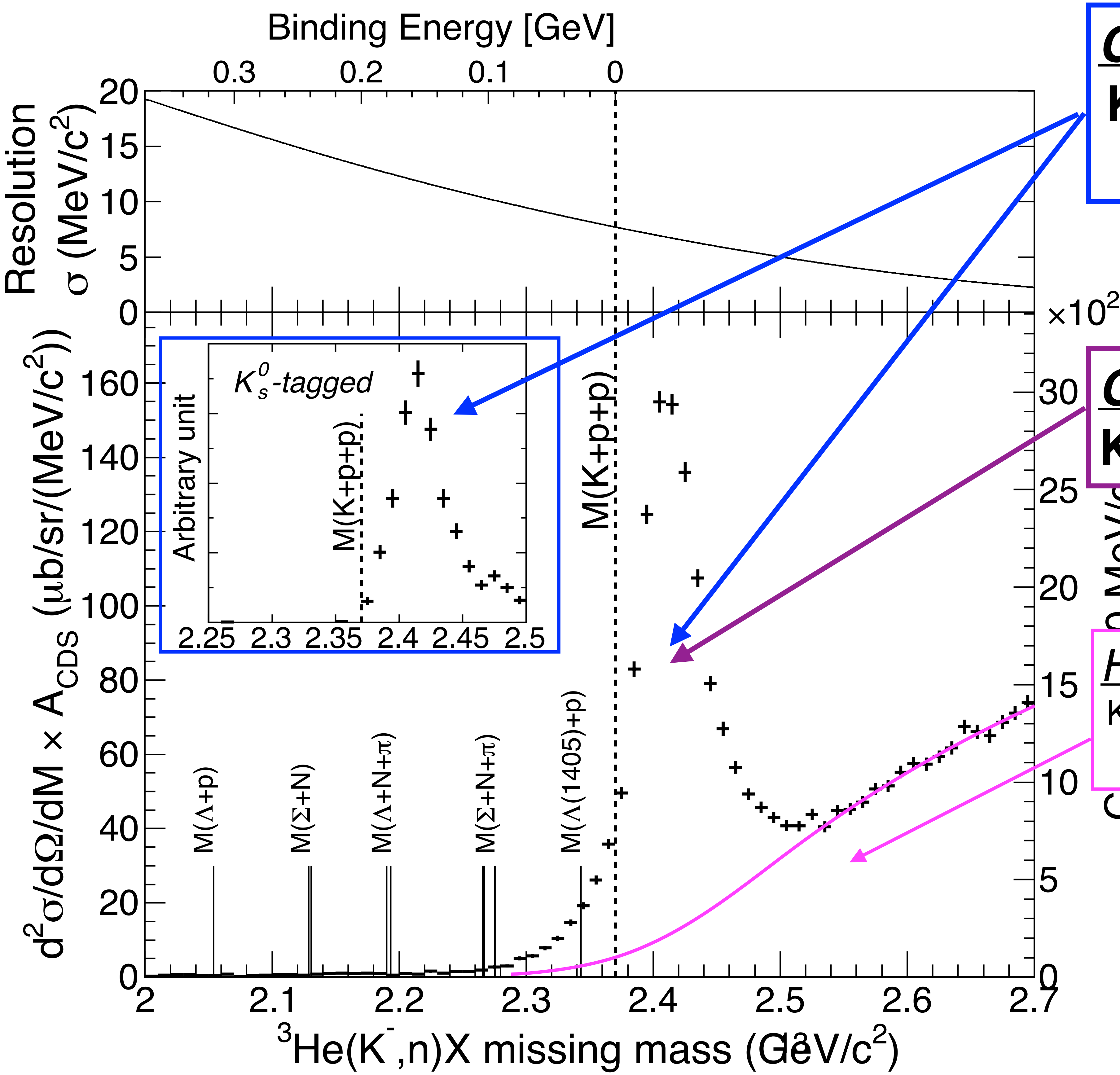
$K^0 \rightarrow \pi^+ + \pi^-$



Sub-threshold structure is not due to "the detector resolution"

@J-PARC workshop, Nov. 30, 2014

Semi-inclusive spectrum



Charge-exchange

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

$K^0 \rightarrow \pi^+ + \pi^-$

$d\sigma/d\Omega_{\theta=0} \sim 11$ mb/sr

Quasi-elastic

$K^- + {}^3He \rightarrow K^- + 2p_s + n$

$d\sigma/d\Omega_{\theta=0} \sim 6$ mb/sr

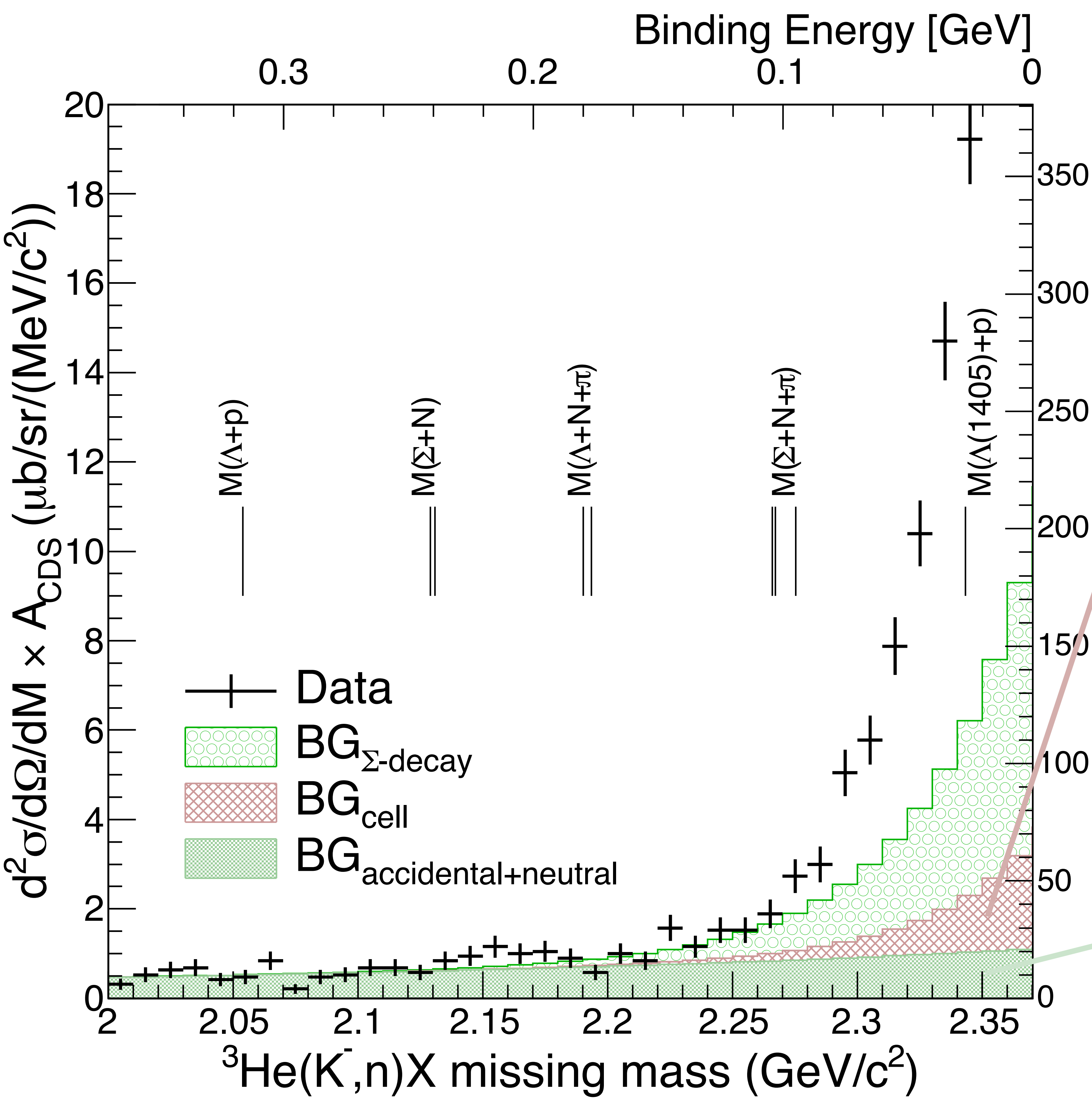
Hyperon decay

$K^- + {}^3He \rightarrow Y + \pi(\pi)(\pi) + 2N_s$

$Y \rightarrow n + \pi$

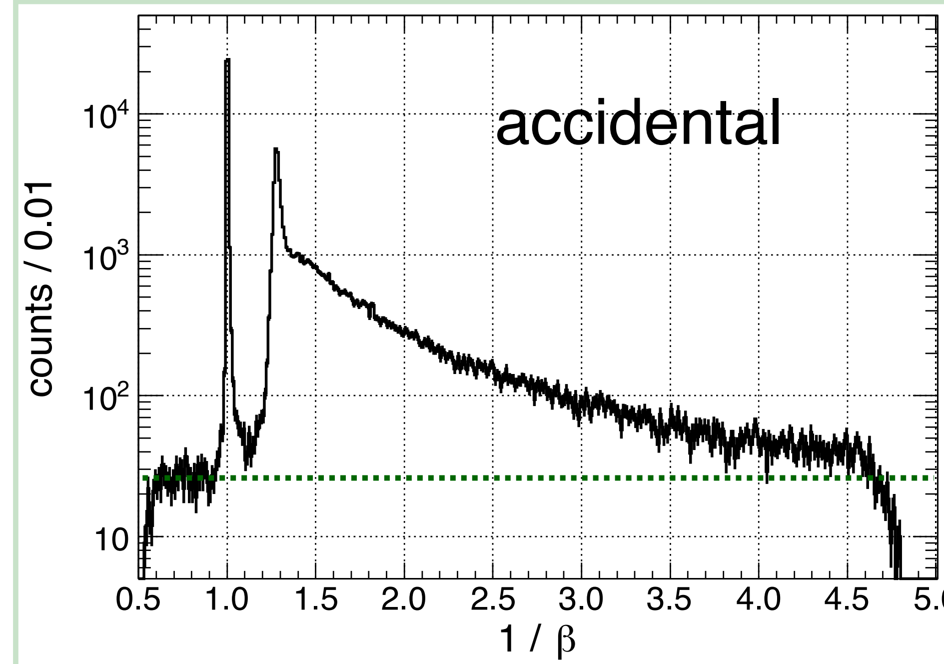
@J-PARC workshop, Nov. 30, 2014

Background evaluation



Close-up view in the bound region

evaluated using empty-target data



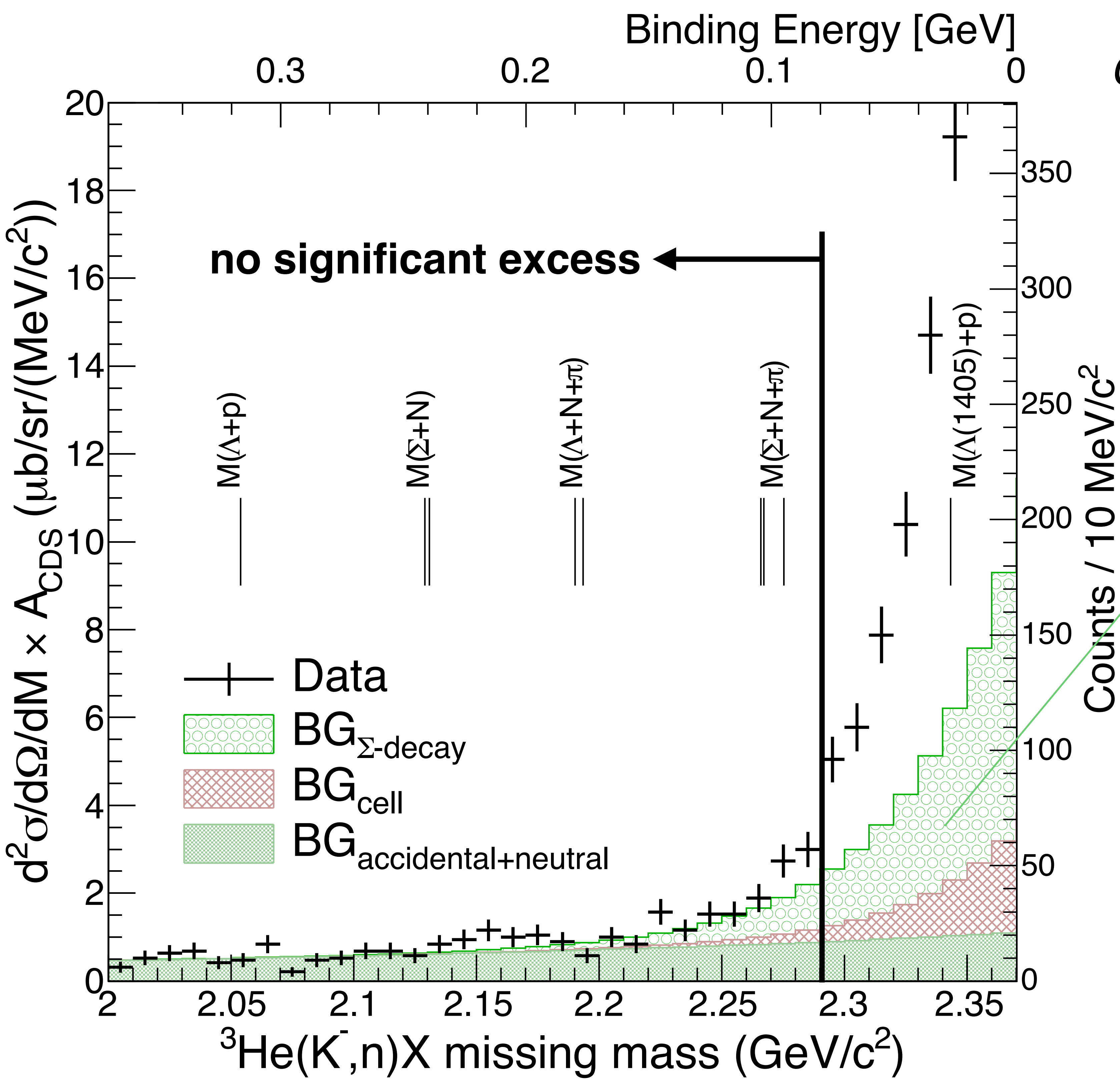
+

Y→Nπ^0, π^0→2γ

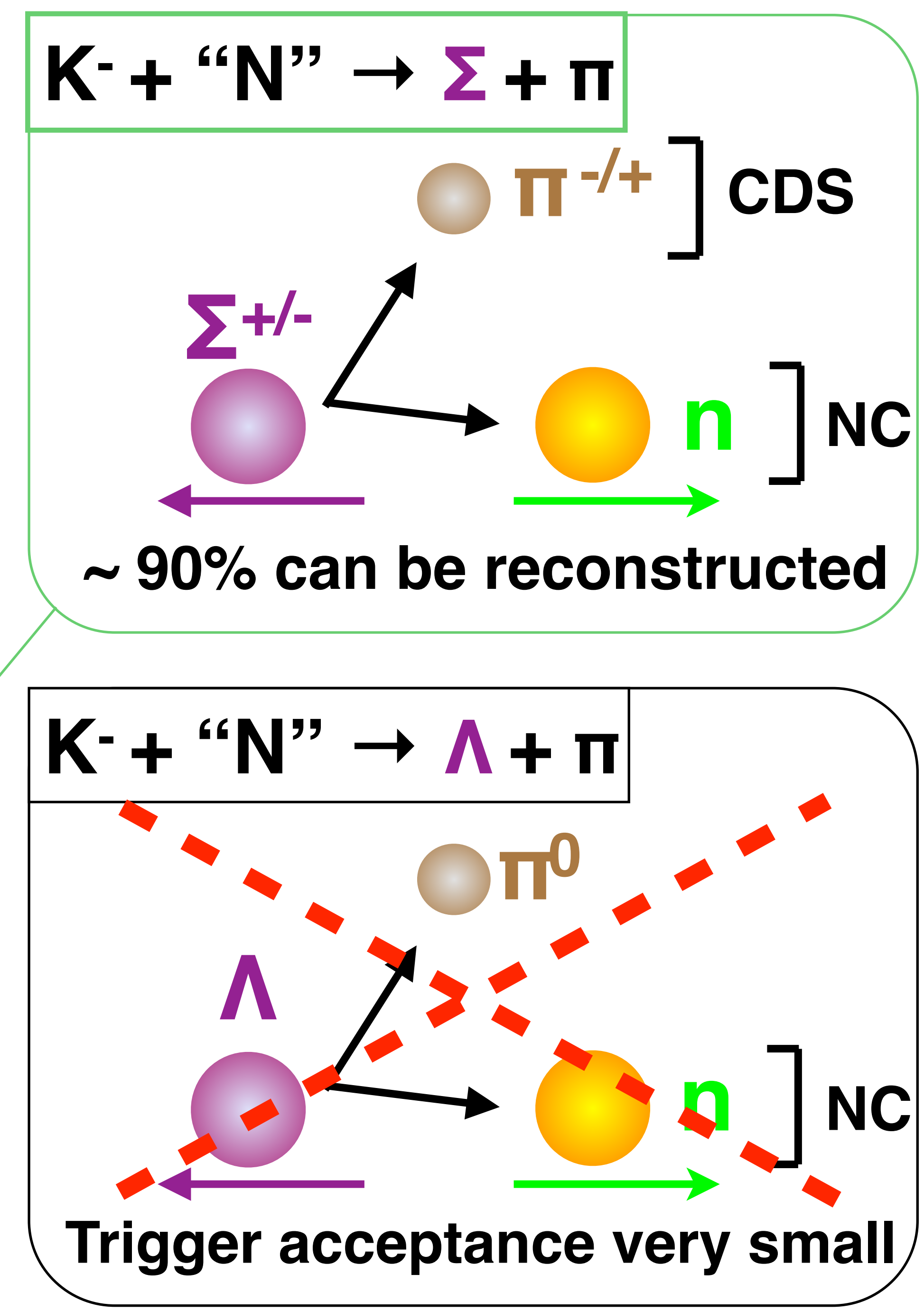
K_L decay&reaction in the NC

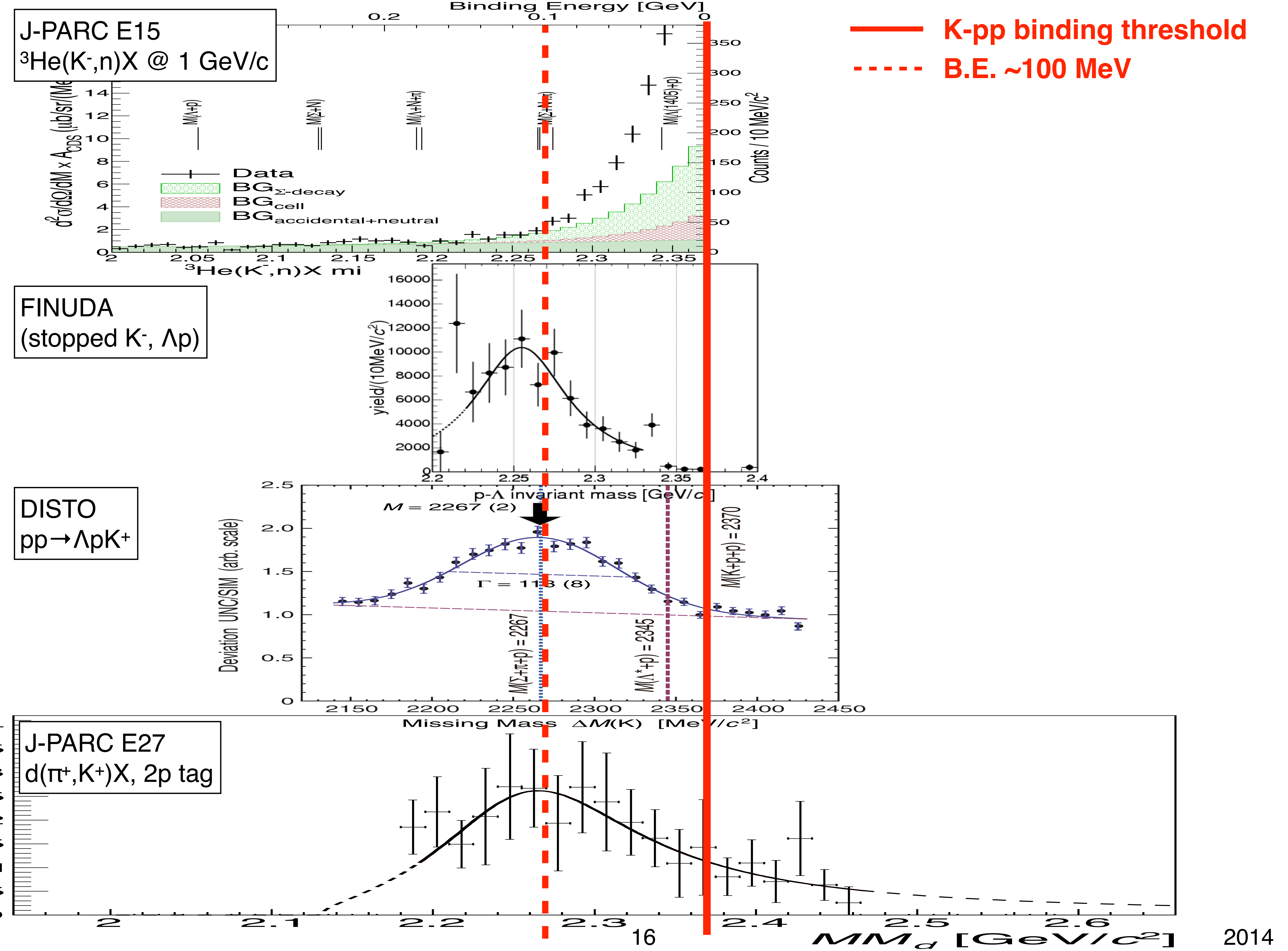
(evaluated with MC)

Background evaluation



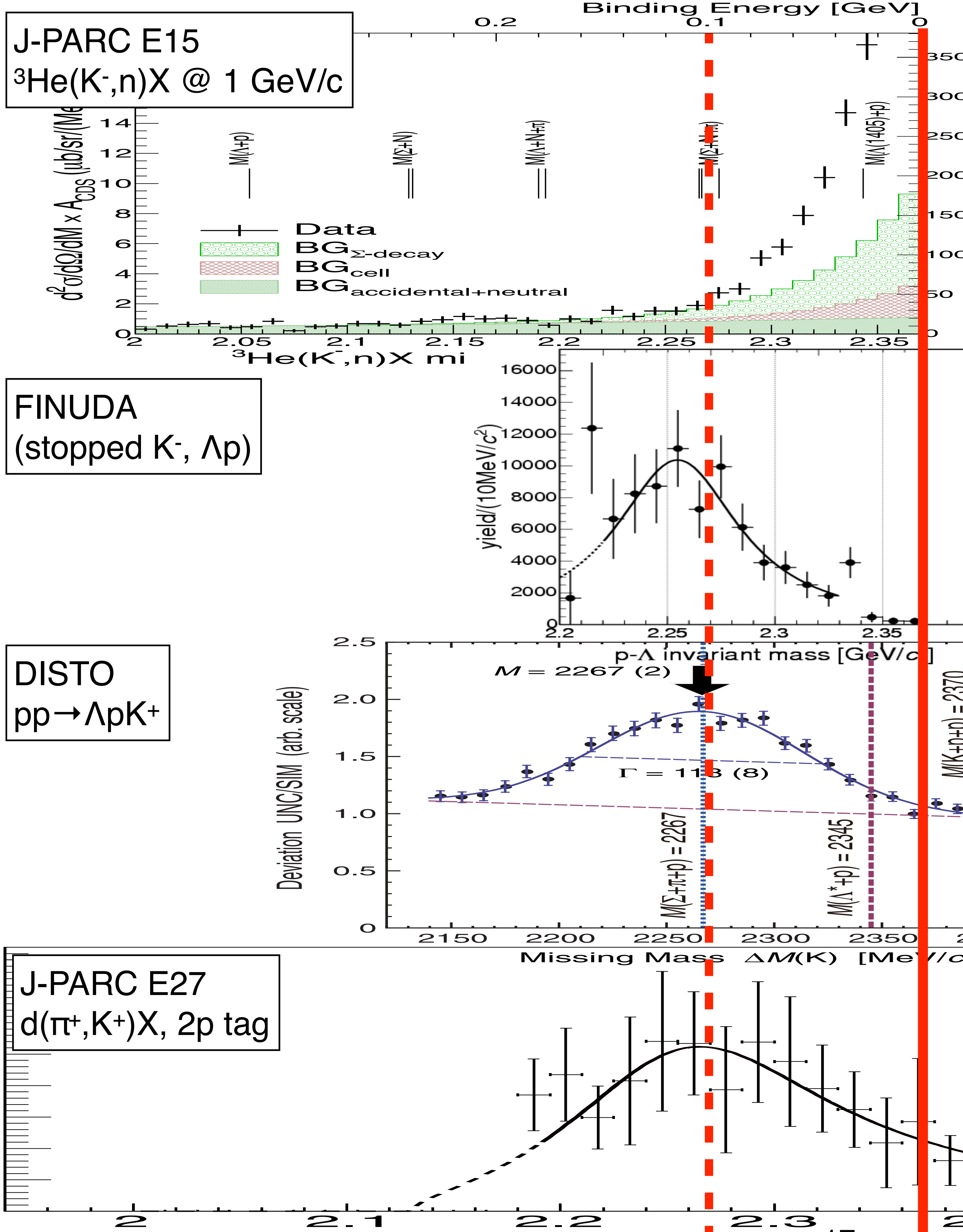
Close-up view in the bound region

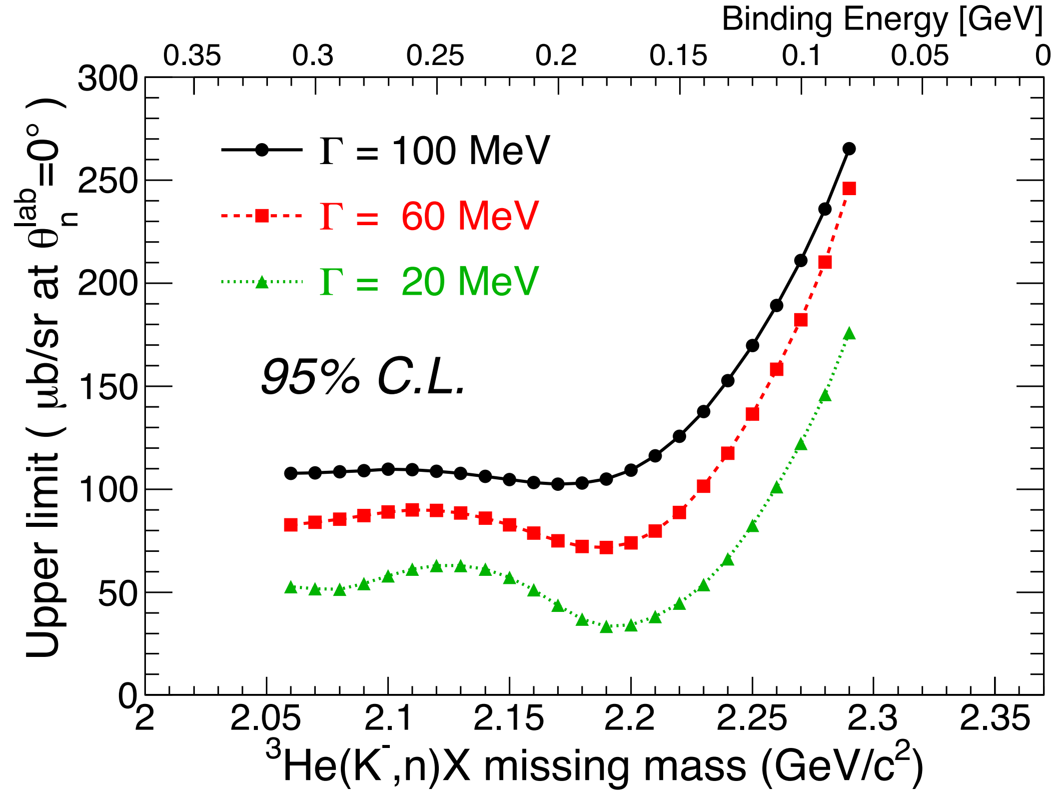




K-pp binding threshold
B.E. ~100 MeV
J-PARC E15
^{3}He(K$^-$,n)X @ 1 GeV/c
Binding Energy [GeV]
Data
BG$_{\Sigma\text{-decay}}$
BG$_{cell}$
BG$_{accidental+neutral}$
Counts / 10 MeV/c^2
^{3}He(K$^-$,n)X mi
FINUDA
(stopped K$^-$, Λp)
yield/(10MeV/c^2)
p-Λ invariant mass [GeV/c^2]
DISTO
pp→ΛpK$^+$
M = 2267 (2)
Γ = 118 (8)
Deviation UNC/SIM (arb. scale)
M(Σ+π+p) = 2267
M(Λ*+p) = 2345
M(K+p+p) = 2370
Missing Mass ΔM(K) [MeV/c^2]
J-PARC E27
d(π$^+$,K$^+$)X, 2p tag
MM_d [GeV/c^2]

2014



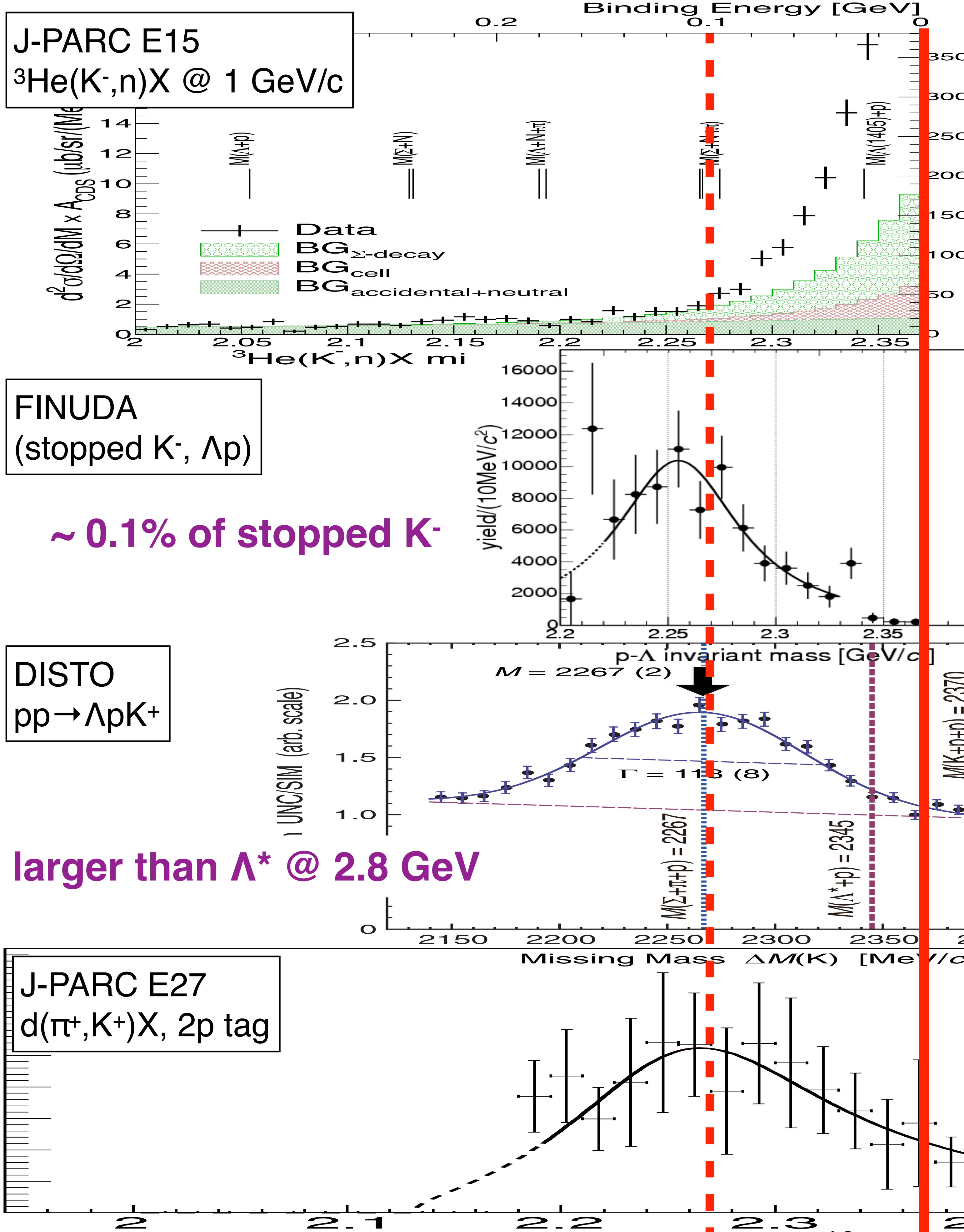


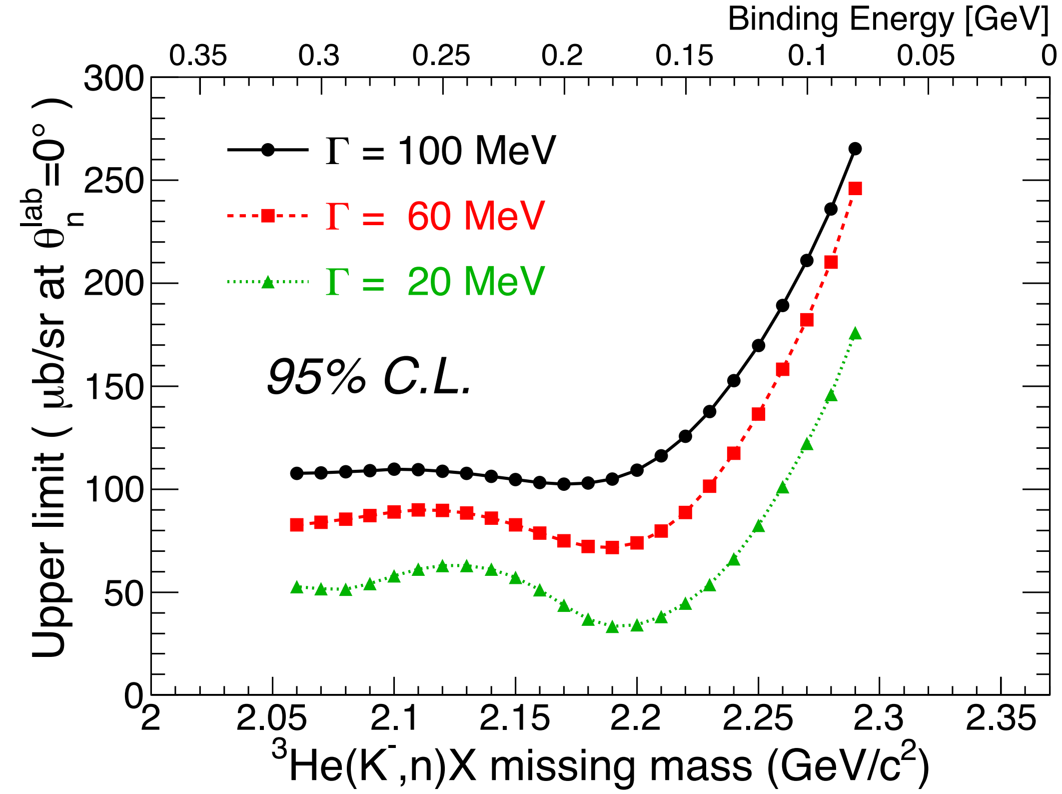
Assumptions

Intrinsic peak shape: Breit-Wigner

Decay mode: **$K^-pp \rightarrow \Lambda p$ 100%** (isotropic decay)

- **J-PARC E15 (U.L.)**
  30 ~ 300 μb/sr @ 0 deg.
  0.5 - 5% of quasi-elastic
  smaller than usual hypernucleus sticking





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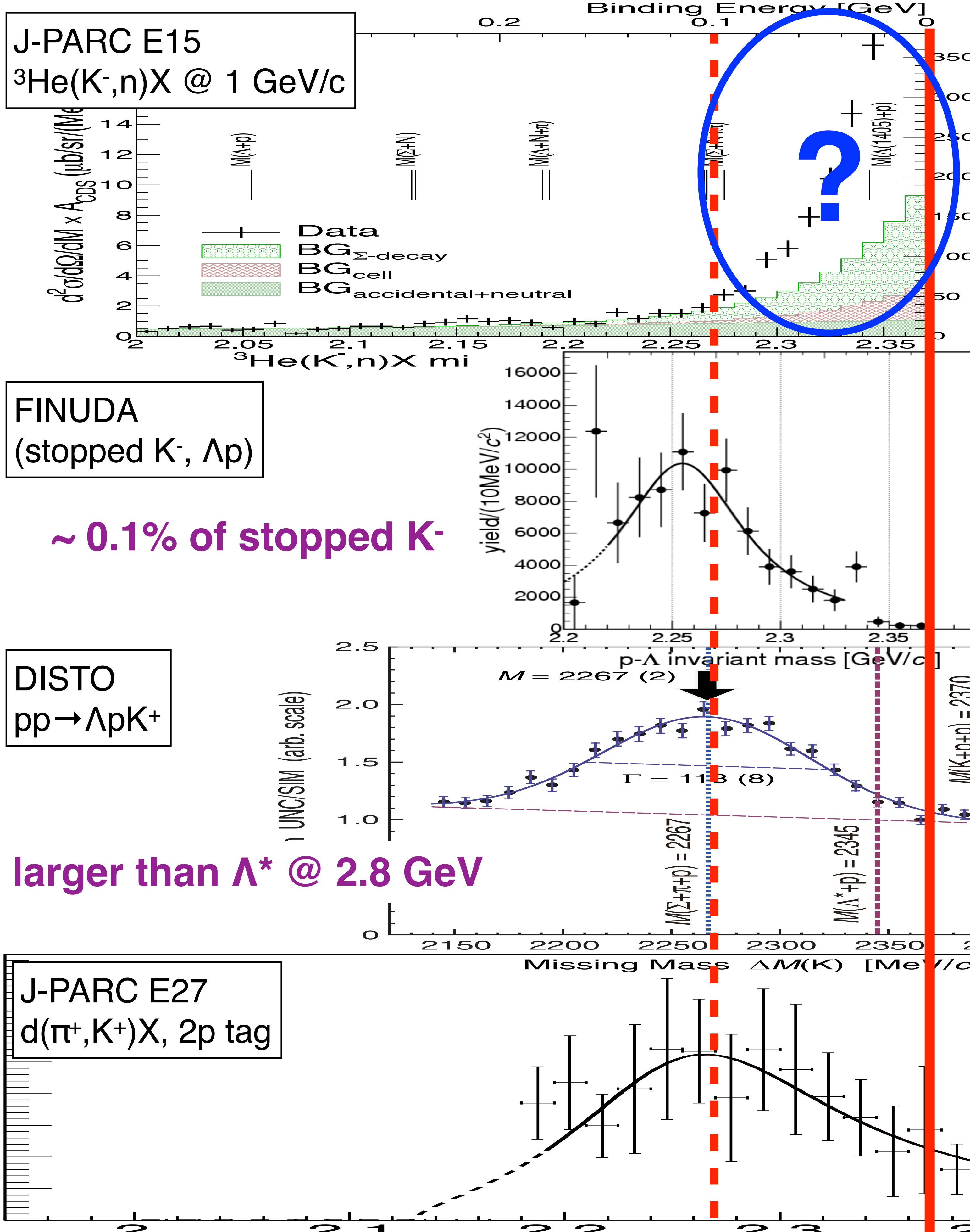
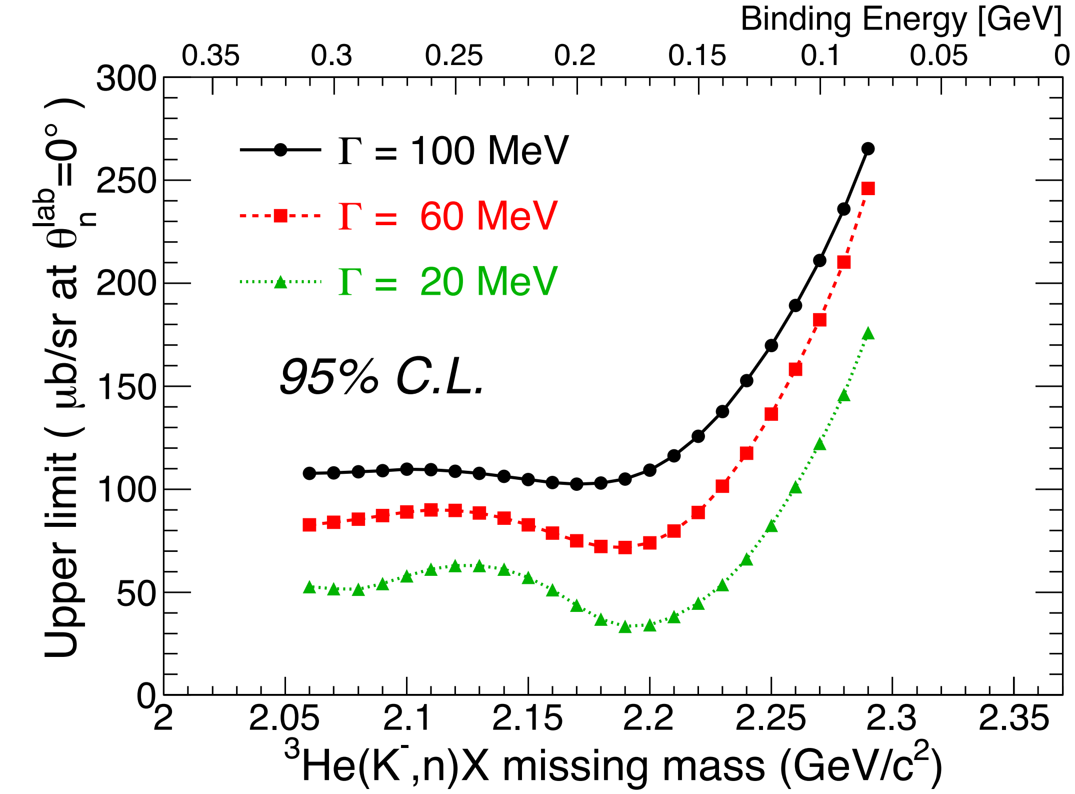
- **LEPS (γ+d) (U.L.)**
  1.5-26% of γN→K$^+$π$^-$Y
- **HADES (pp @ 3.5 GeV)**
  0.7-4.2 μb (Λ* ~ 10 μb)





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  1.5-26% of $\gamma N \to K^+\pi^- Y$

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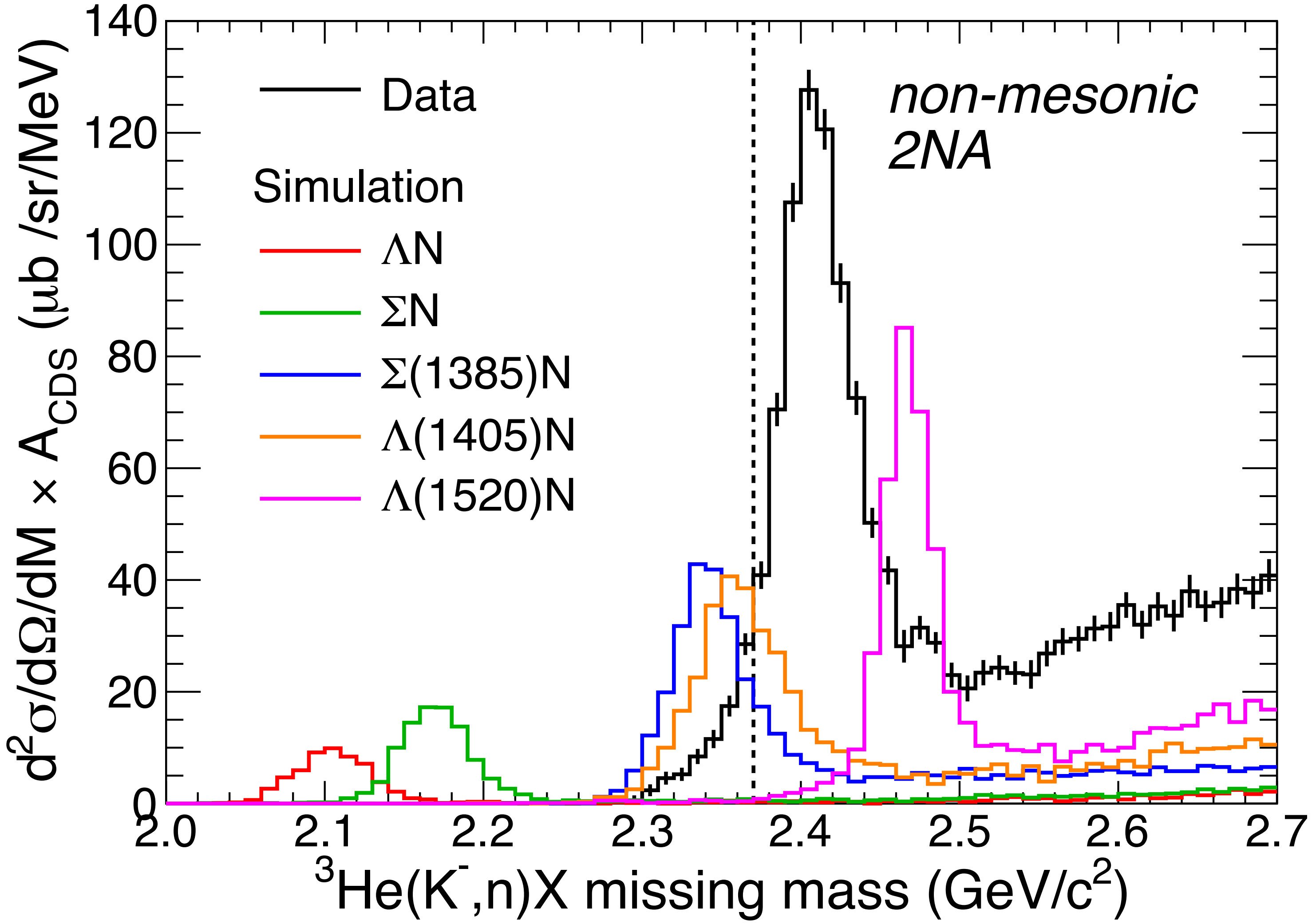
What is the origin of the excess?

naively understood by attractive & absorptive potential

other possibilities are…

1. non-mesonic two-nucleon absorption: Λ(1405)n branch

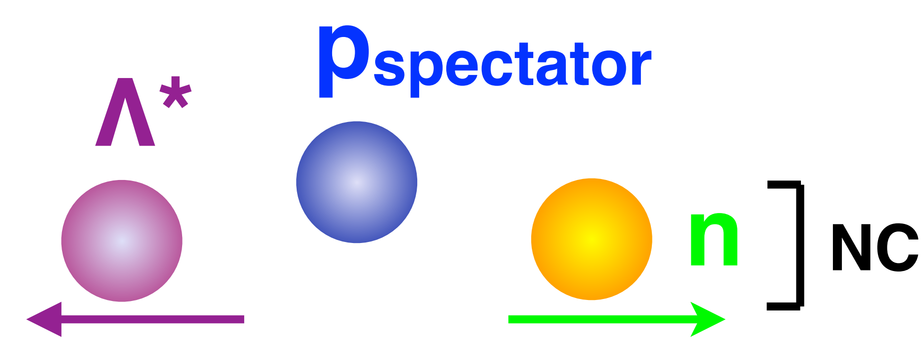
- rather large cross-section ~ 5 mb/sr needed
- U.L. 1 ~ 10% of Λ*n branch?



20 mb/sr @ θ=0

***Breit-Wigner** with PDG mass&width*

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



ΛN/ΣN branches are negligibly small

Λ(1520)n branch < 2 mb/sr

What is the origin of the excess?

naively understood by attractive & absorptive potential

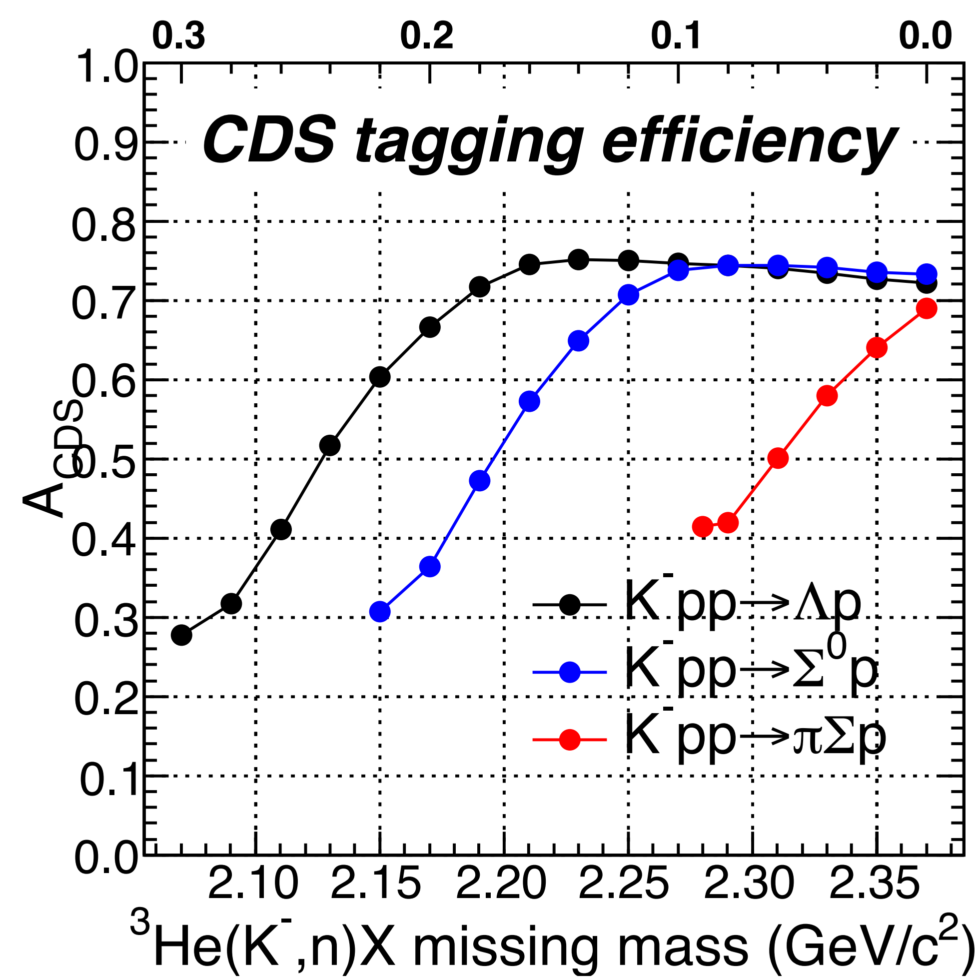
other possibilities are…

1. non-mesonic two-nucleon absorption: Λ(1405)n branch

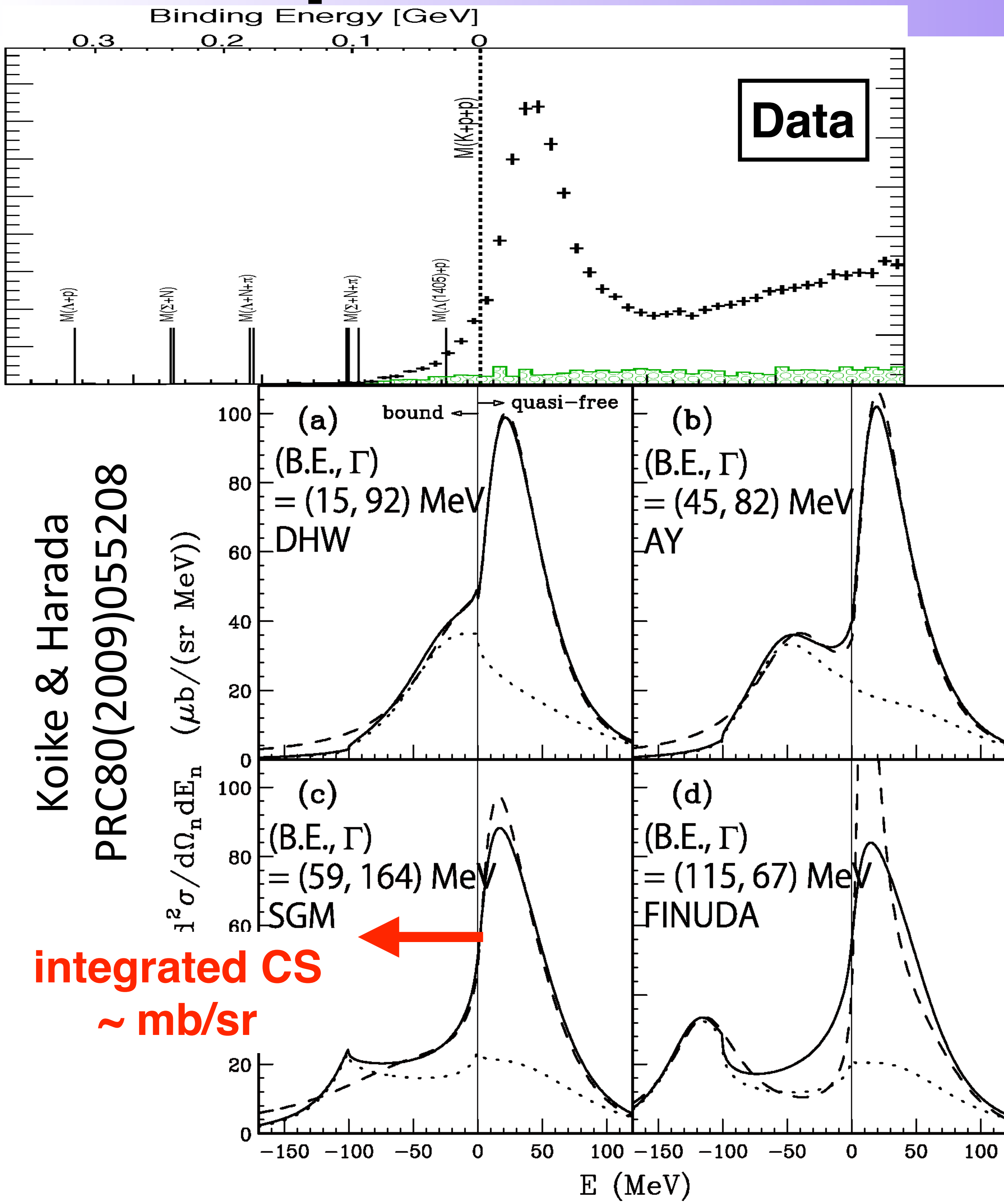
- rather large cross-section ~ 5 mb/sr needed
- U.L. 1 ~ 10% of Λ*n branch?

2. Loosely-bound "*K^-pp*" state

- The excess corresponds to 1~2 mb/sr
  - ~ 10% of quasi-elastic peak
- Assumptions
  - Fully attributed to the K^-pp state
  - isotropic decay $K^-pp \rightarrow \Lambda p/\Sigma p/\pi\Sigma p$

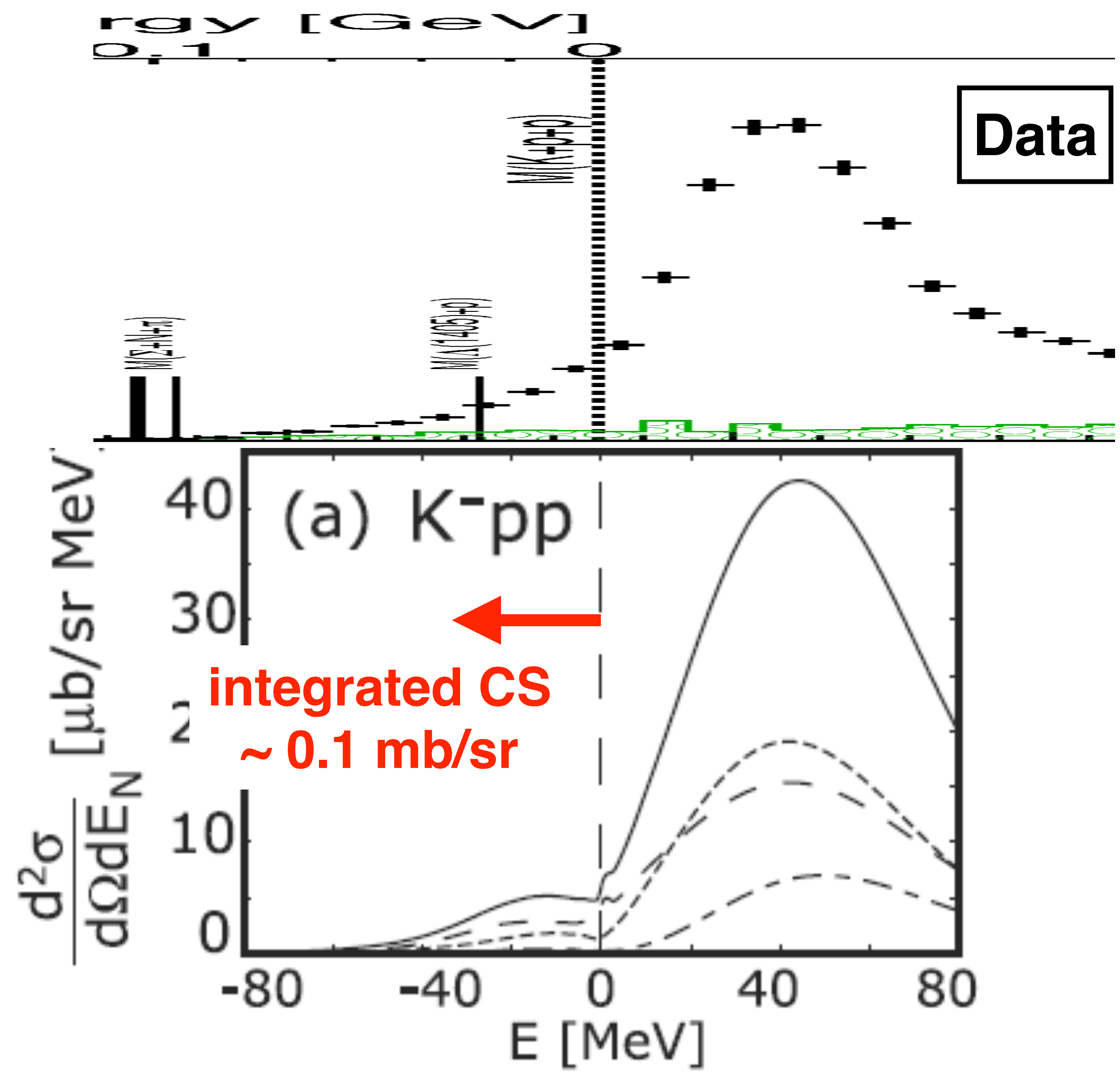


Comparison with theoretical spectra



Koike & Harada
PRC80(2009)055208

theoretical spectral functions are ***inclusive***



Yamagata-Sekihara, et al.,
PRC80(2009)045204

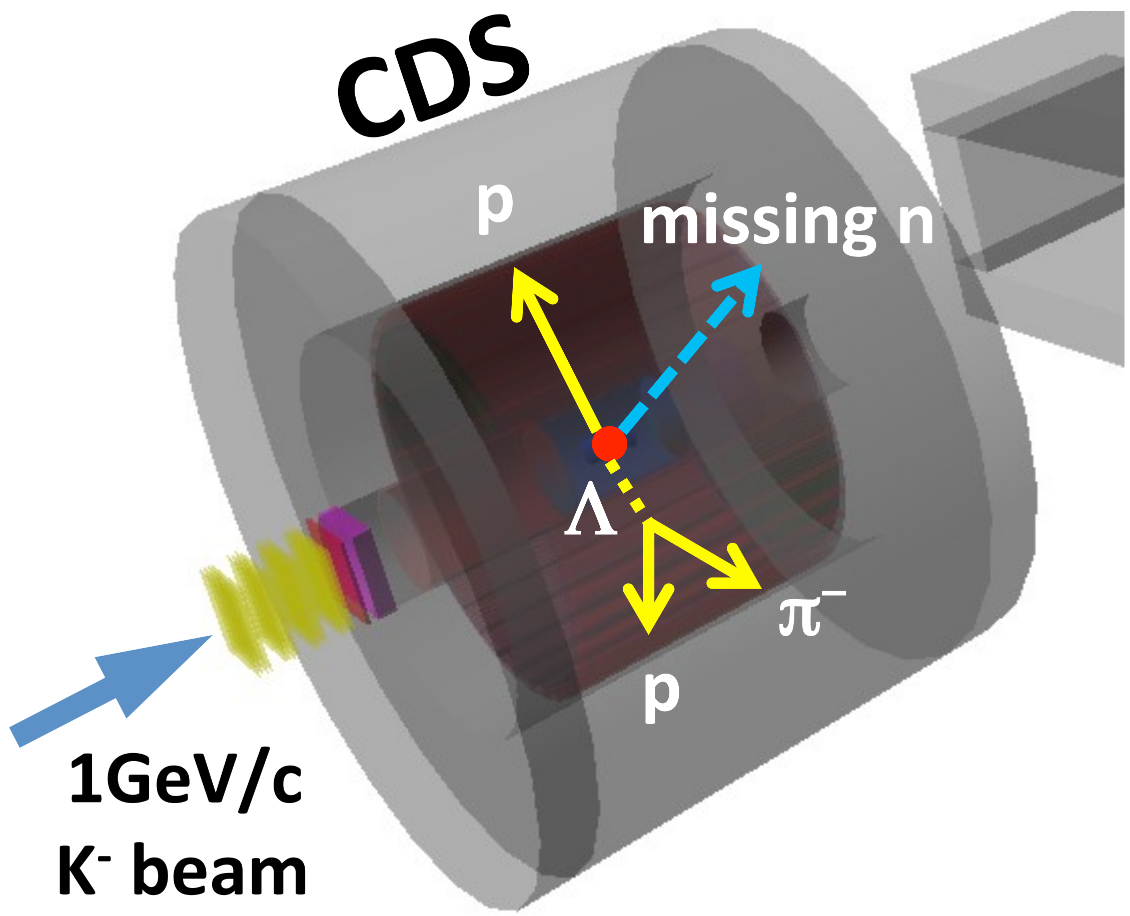
CS is roughly consistent with Koike&Harada

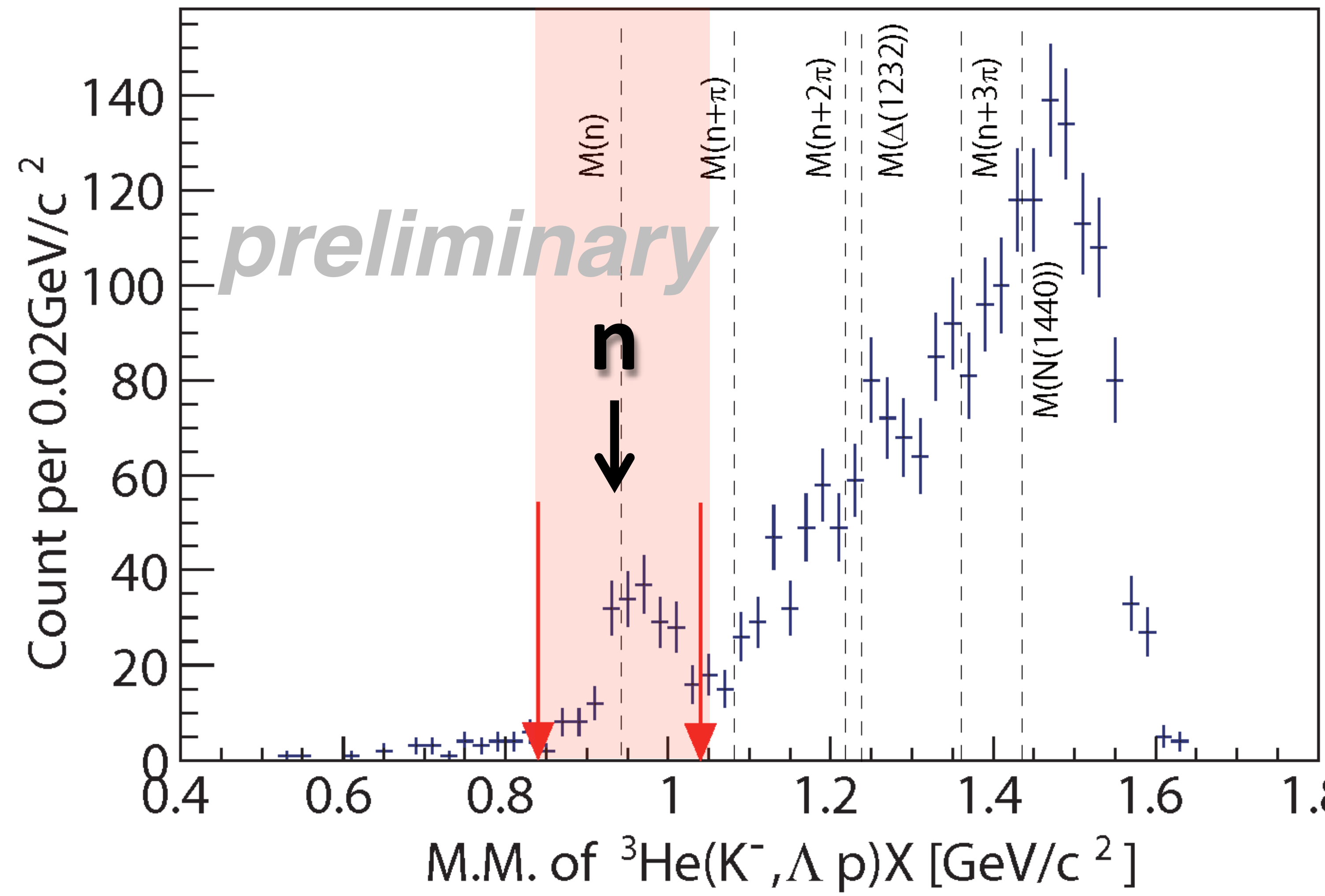
Exclusive measurement (πΣN) is an important key for further study

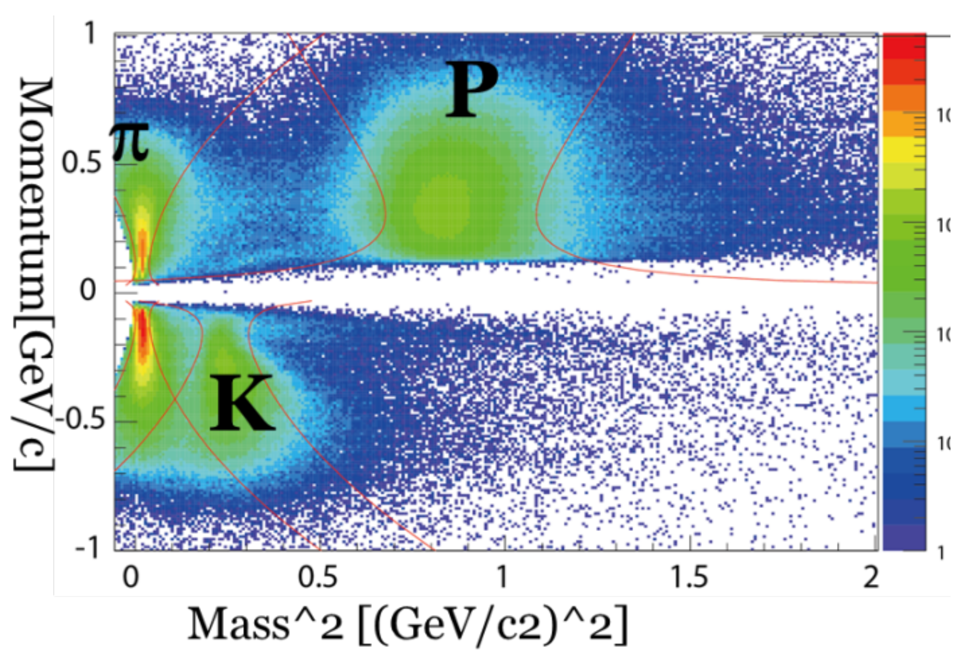
Decay channel
Exclusive $^{3}He(K^{-}, \Lambda p)n$

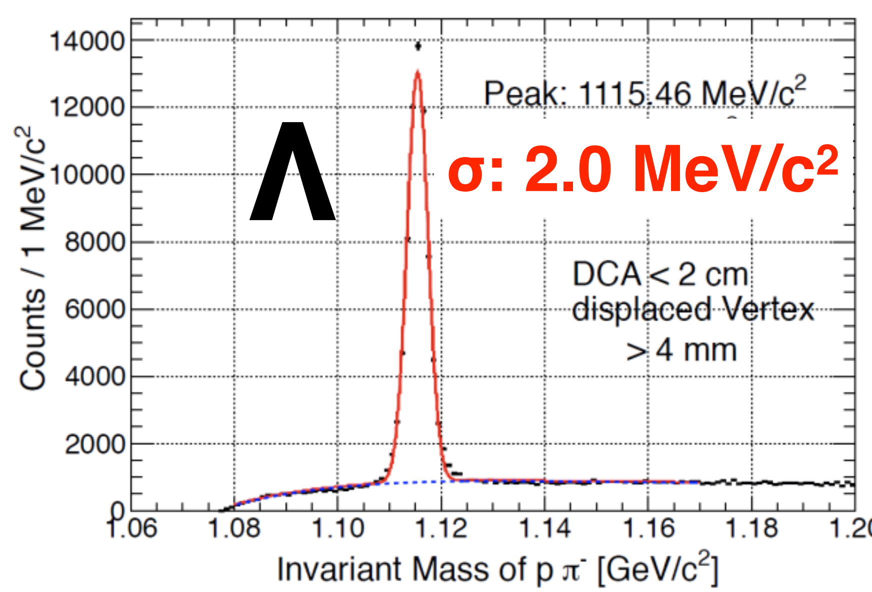
Updated results will be presented @ PAC meeting (Dec. 4th)

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









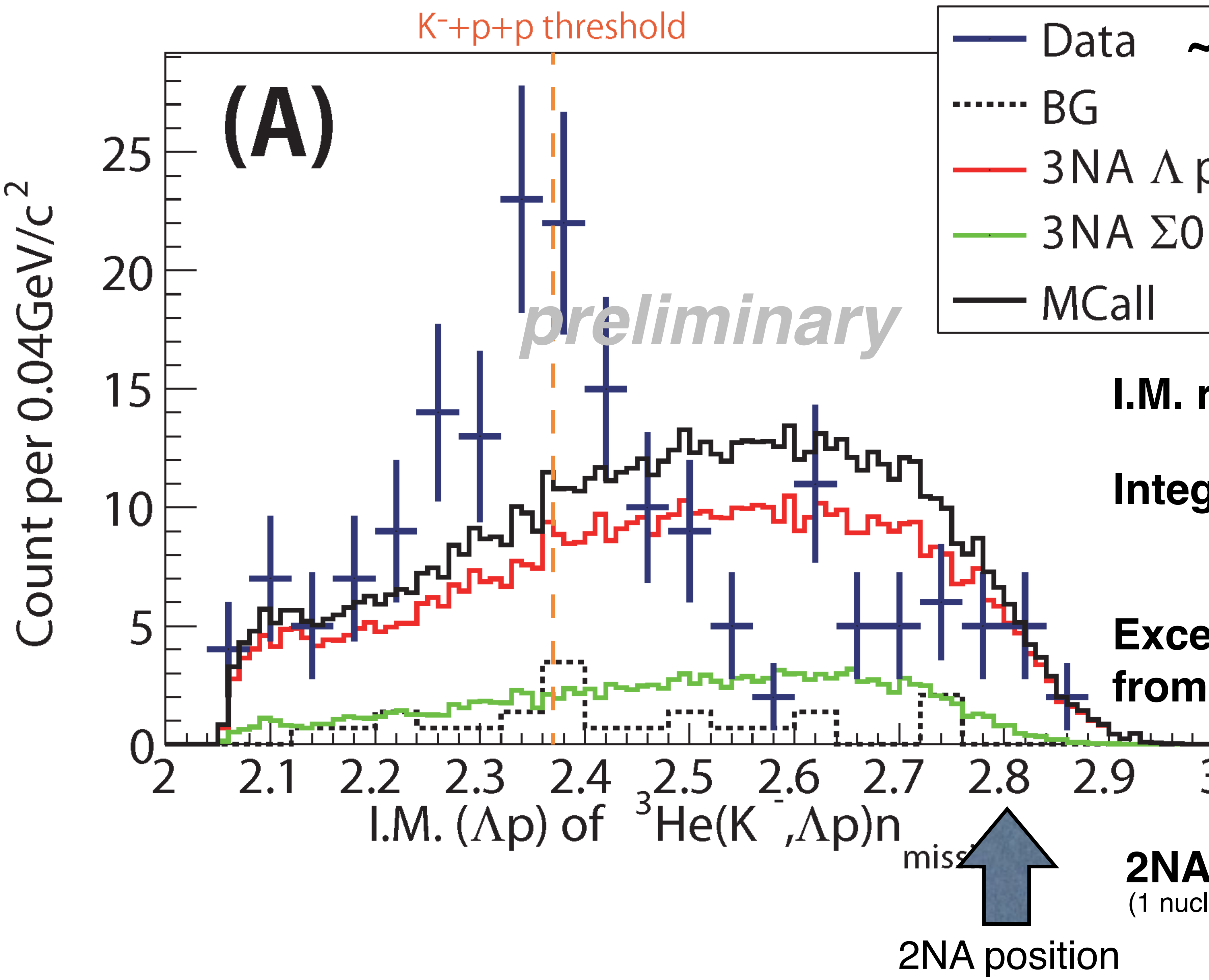
K^- ^3He → Λpn events can be identified

(~20% Σ^0pn contamination)

$\Sigma^0 \to \Lambda\gamma$

T. Hashimoto@J-PARC workshop, Nov. 30, 2014

Λp invariant mass



~ 200 events

MC (Phase-Space)

I.M. resolution ~ 10 MeV/c^2

Integrated CS: ~200 μb

~0.1% of total CS of $K^{-3}He$

Excess around the threshold from the phase-space distribution

*cannot be from 2NA of Λ*n*

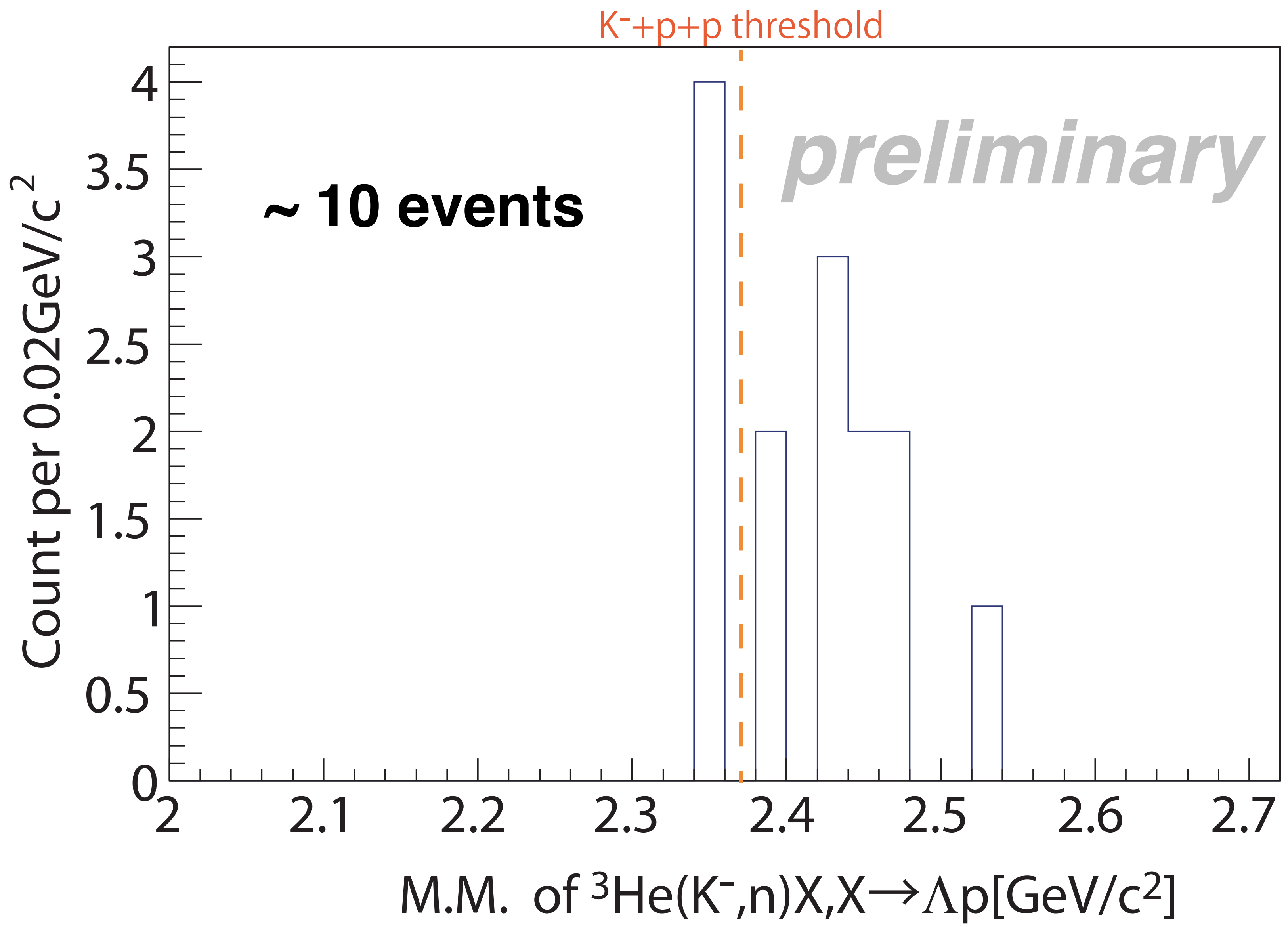
2NA reactions are not prominent
(1 nucleon is a spectator)

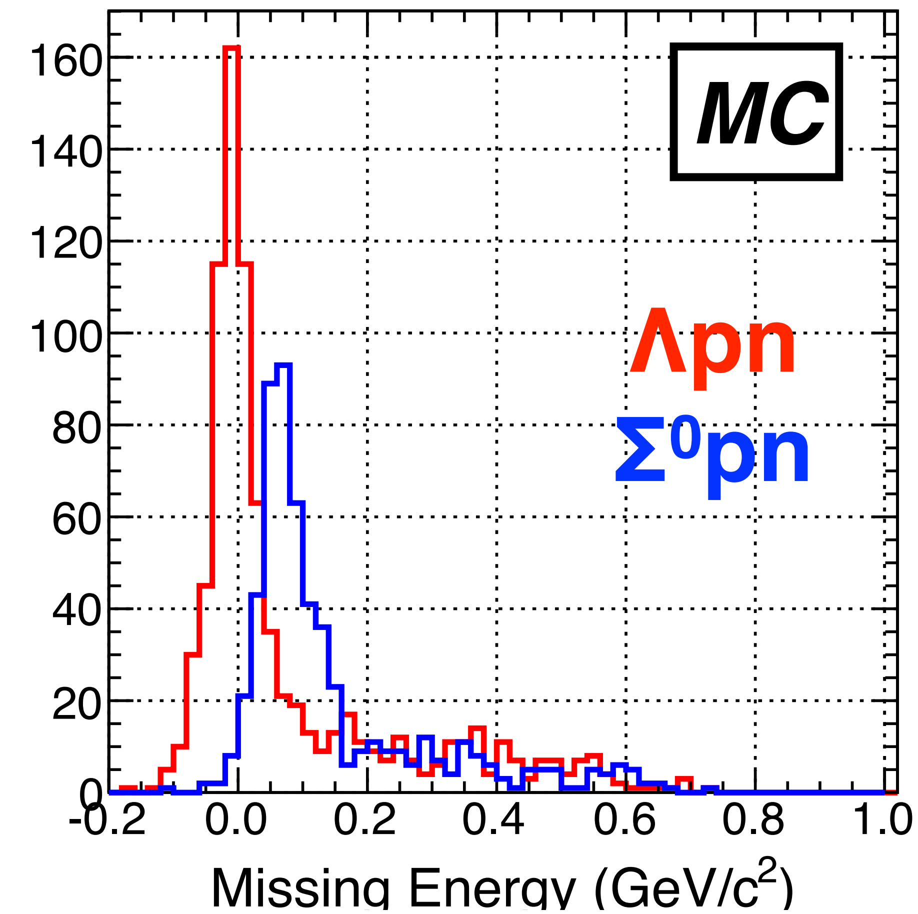
Further study is ongoing:

improved event selection, contribution from 2NA + 2step.

Λpn kinematically complete measurement

Our final goal. But…





Λp/Σ⁰p could be separated

We definitely need more beam !!

Outlook - E15^{2nd} & near future plan@K1.8BR

- **Calibration run with H2-target**
- **E31 pilot run with D2-target**
  - confirm the d(K^-, n)Λ(1405) reaction by tagging the charged decay modes
- **E15 2nd-stage physics run ← already approved !**
  - x10 statistics, ~10% of full proposal
  - Exclusive analysis of **πΣN** decay
  - Kinematically complete measurement of ^{3}He(K^-,**Λpn**)
- **E17: K^-He x-ray measurement with TES** *status report @ PAC meeting by S. Okada*
  - TES: novel cryogenic detector, ~5 eV FWHM@6 keV
  - Feasibility test was successfully performed at PSI by HEATES collaboration
- **K^-d x-ray measurement with SDDs** *talk by J. Zmeskal on Dec. 1*

2015

2016 ~ ?

These experiments provide crucial information on the K^{bar}N interaction

Summary of E15 1st

24 kW * 4-day data taking in May, 2013
~ 5.3 x 10^9 on ^3He
~ 1% of the approved proposal

Formation channel

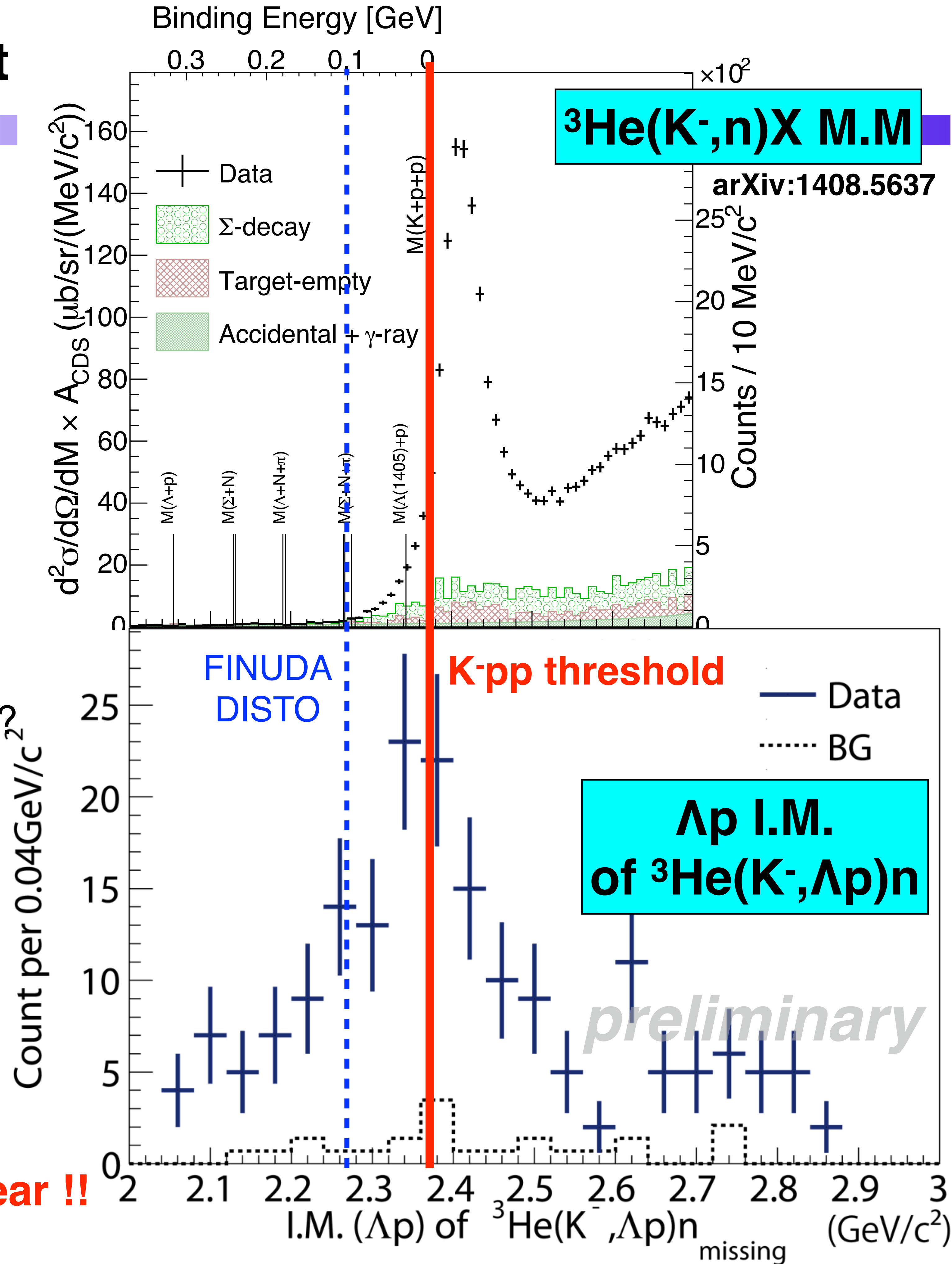
Semi-inclusive $^3He(K^-,n)X$

+ **No significant bump structure** in the deeply bound region
+ Excess below the threshold
  2NΛ of Λ*n ? loosely-bound K-pp?

Decay channel

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

+ Deviation from the simple Phase space
+ Excess around the threshold ?



x10 statistics data will come next year !!