

Recent results and future prospects of the K^{bar} NN search @ J-PARC E15

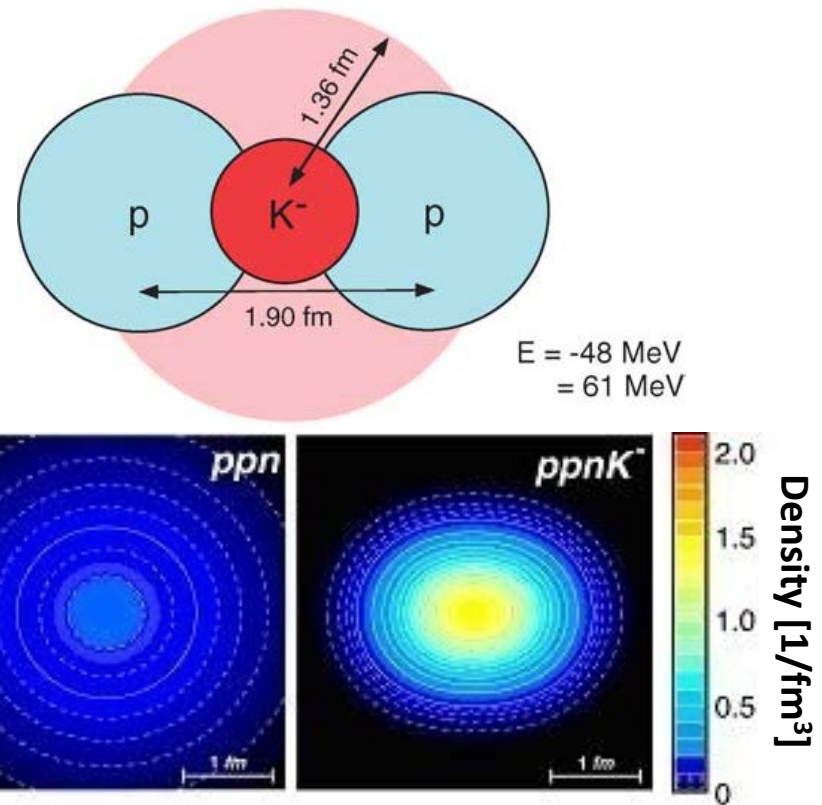
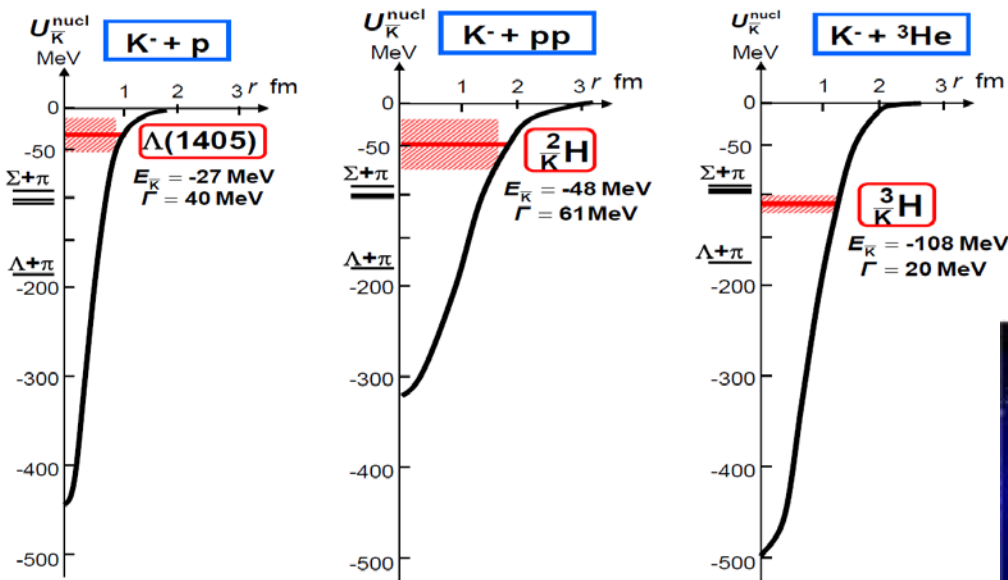
F. Sakuma, RIKEN

for the J-PARC E15 collaboration

- Results of the E15 1st physics run
- Future prospects of E15
- Summary

Kaonic Nuclei

Kaonic nucleus is a bound state of nucleus and anti-kaon ($K^{\text{bar}}\text{NN}$, $K^{\text{bar}}\text{NNN}$, $K^{\text{bar}}K^{\text{bar}}\text{NN}$, ...)



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

T.Yamazaki, A.Dote, Y.Akiaishi, PLB587, 167 (2004).

K⁻pp Bound State

K⁻pp : the simplest K^{bar} -nuclear state

Calculated $K^- pp$ binding energies B and widths Γ (in MeV).

A.Gal, NPA914(2013)270

	Chiral, energy dependent			Non-chiral, static calculations			
	var. [7]	var. [8]	Fad. [9]	var. [10]	Fad [11]	Fad [12]	var. [13]
B	16	17–23	9–16	48	50–70	60–95	40–80
Γ	41	40–70	34–46	61	90–110	45–80	40–85

[7] N. Barnea, A. Gal, E.Z. Liverts, Phys. Lett. B 712 (2012) 132.

[8] A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A 804 (2008) 197;
A. Doté, T. Hyodo, W. Weise, Phys. Rev. C 79 (2009) 014003.

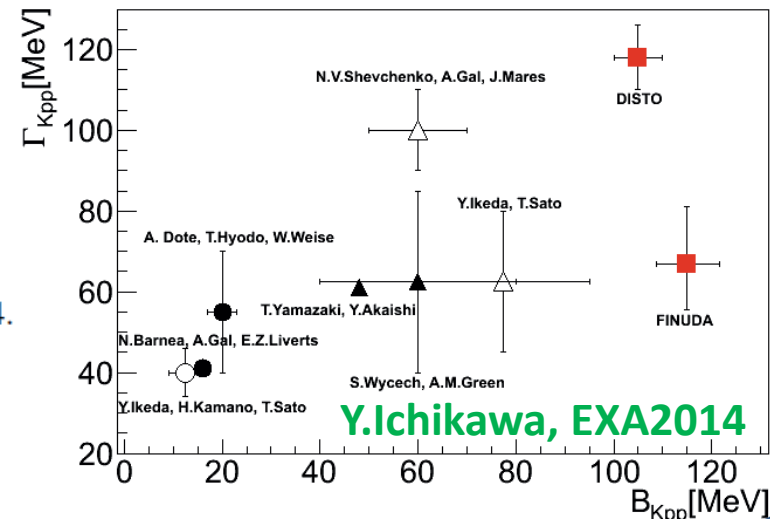
[9] Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. 124 (2010) 533.

[10] T. Yamazaki, Y. Akaishi, Phys. Lett. B 535 (2002) 70.

[11] 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.

[12] Y. Ikeda, T. Sato, Phys. Rev. C 76 (2007) 035203;
Y. Ikeda, T. Sato, Phys. Rev. C 79 (2009) 035201.

[13] S. Wycech, A.M. Green, Phys. Rev. C 79 (2009) 014001.

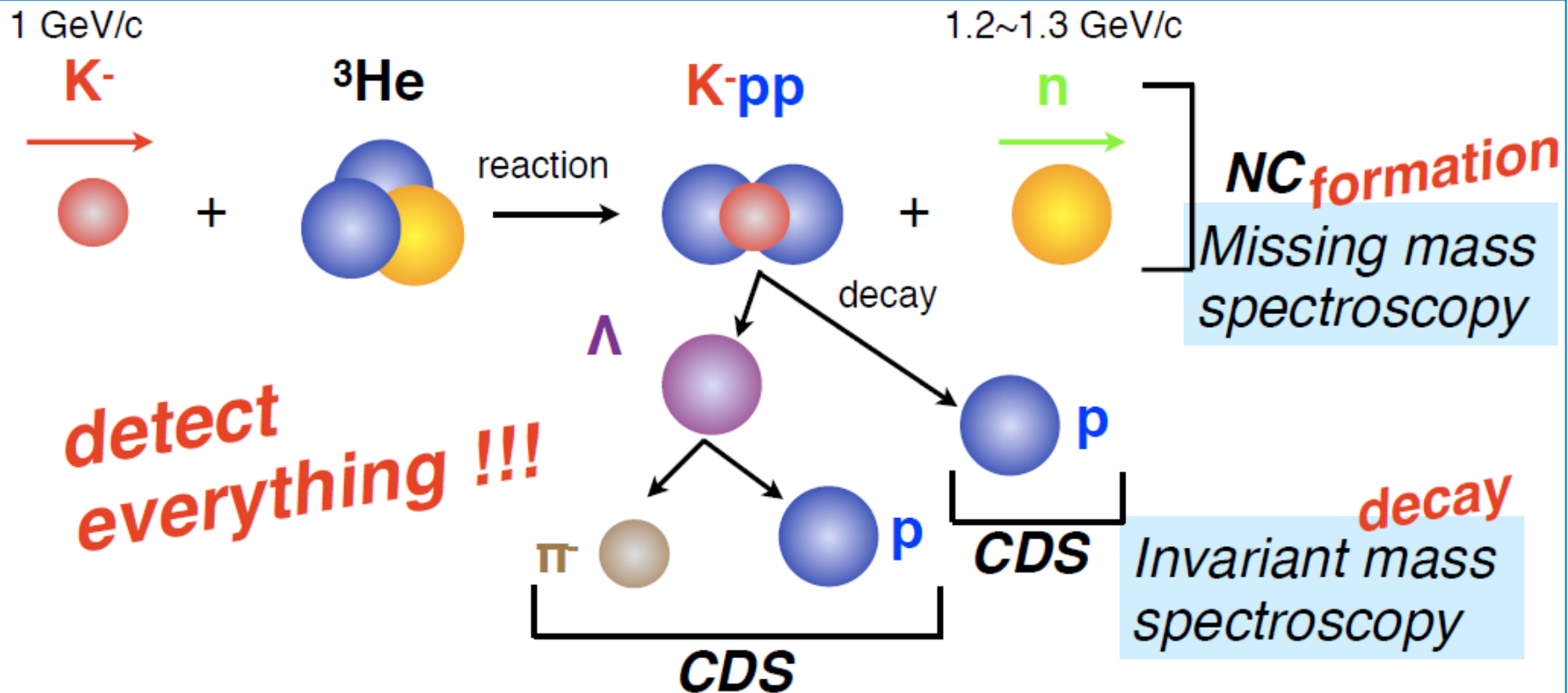


All theoretical studies predict existence of the K⁻pp

→ However, B.E. and Γ are controversial

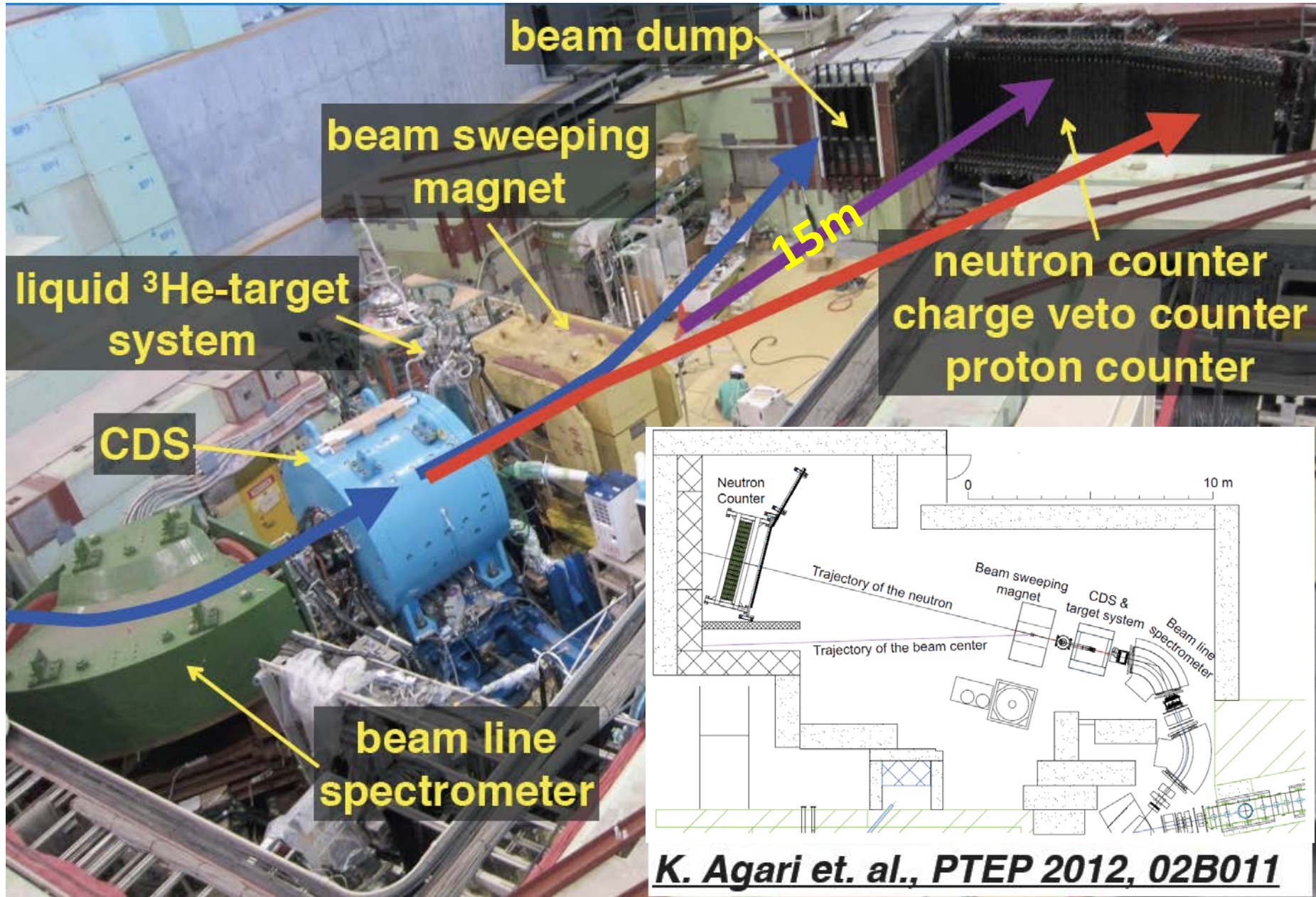
Experimental Principle of E15

A search for the simplest kaonic nucleus, K^-pp ,
using ${}^3\text{He}(\text{in-flight } K^-, n)$ reaction



- two-nucleon absorption
 - hyperon decays
- CAN be discriminated kinematically**

Experimental Setup



E15 1st Stage Physics-Run

- Production run of ***~1% of the approved proposal*** was successfully performed in 2013.
- All detector systems worked well as designed.

	Primary-beam intensity	Secondary-kaon intensity	Duration	Kaons on target (w/ tgt selection)
March, 2013 (Run#47)	14.5 kW (18 Tppp, 6s)	80 k/spill	30 h	1.1×10^9
May, 2013 (Run#49c)	24 kW (30 Tppp, 6s)	140 k/spill	88 h	5.3×10^9

* production target: Au 50% loss, spill length: 2s, spill duty factor: ~45%, K/pi ratio: ~1/2

* ~70% of beam kaons hit the fiducial volume of ³He target

Summary of E15 1st

Formation Channel

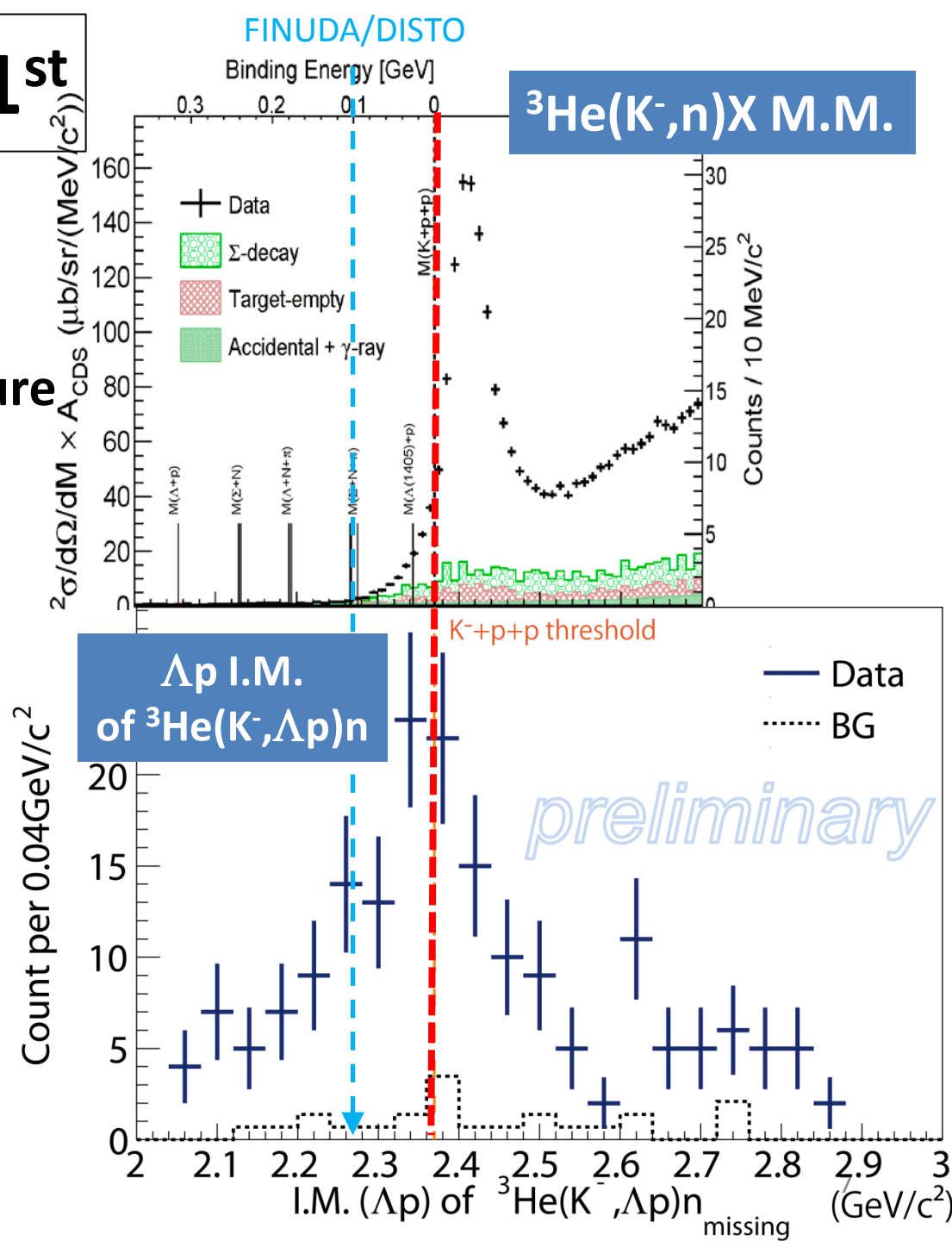
Semi-Inclusive $^3\text{He}(K^-,n)X$

- ✓ **No significant bump structure** in the deeply bound region
- ✓ **Excess below the threshold** attributed to 2NA of Λ^*n ?

Decay Channel

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

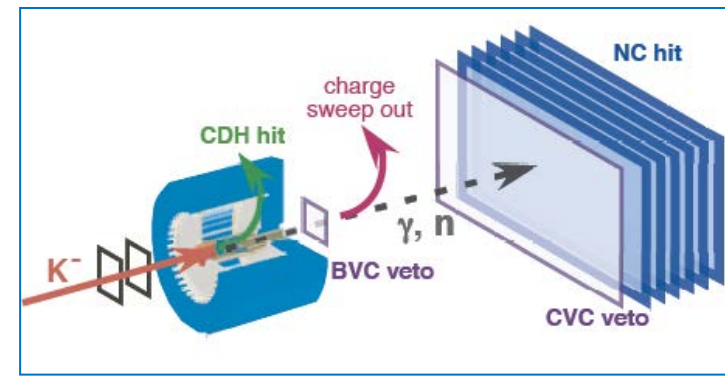
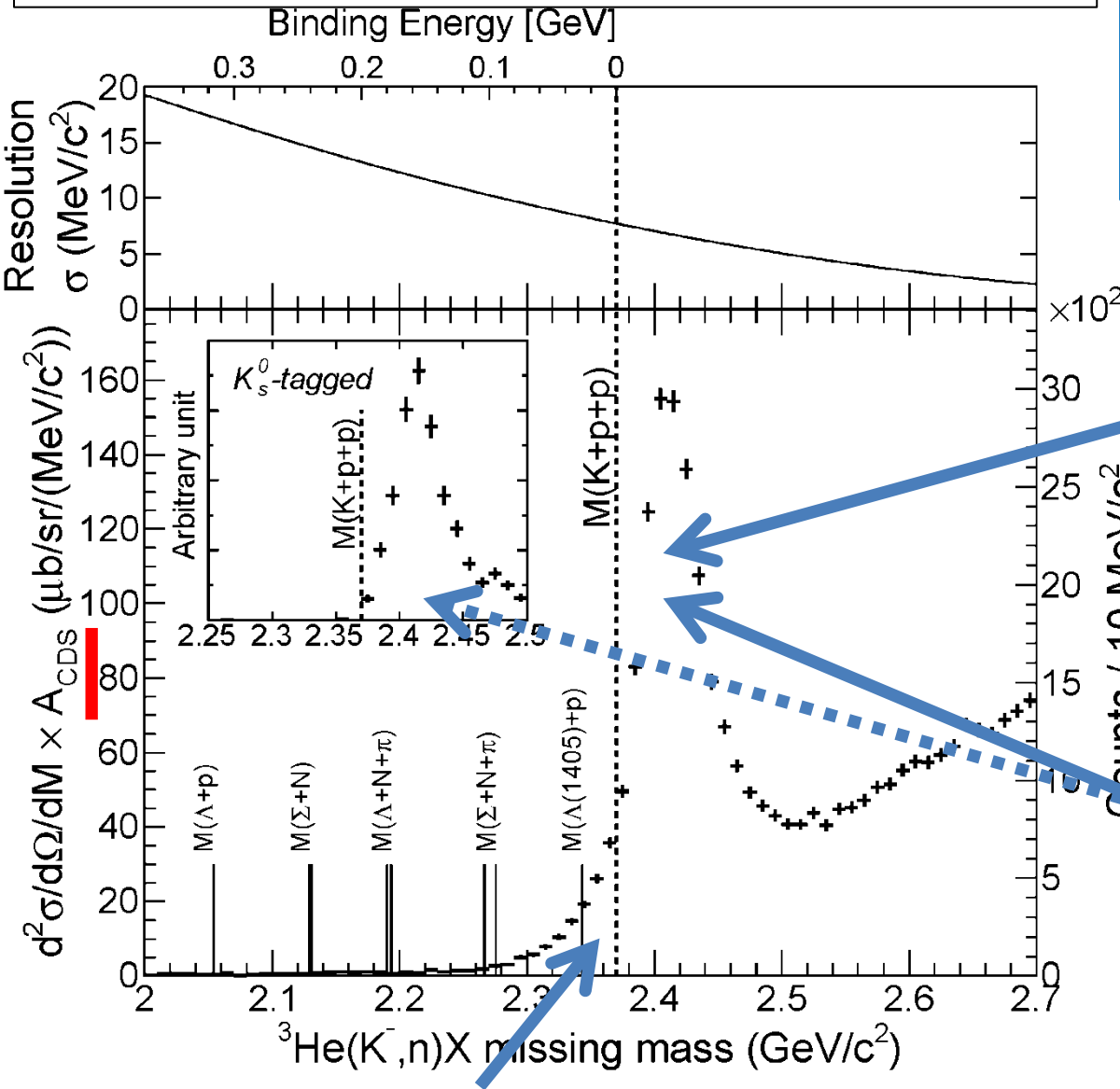
- ✓ **Hint of the excess around the threshold**
- ✓ **Cannot be from 2NA of Λ^*n** (final state = Λpn)



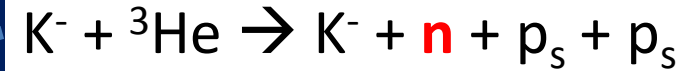
Formation Channel, Semi-Inclusive ${}^3\text{He}(\text{K}^-, \textcolor{red}{n})\text{X}$

T.Hashimoto et al., arXiv:1408.5637, submitted to PLB

Semi-Inclusive Spectrum



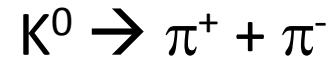
Quasi Elastic



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

and

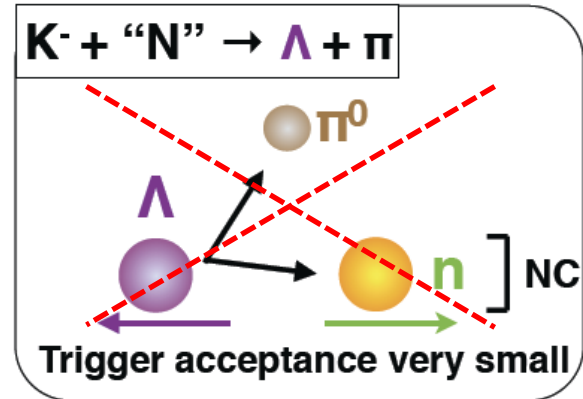
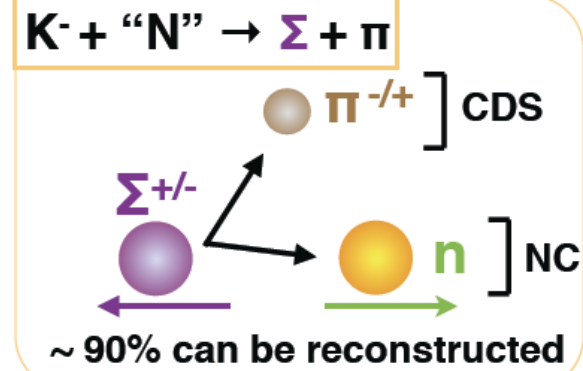
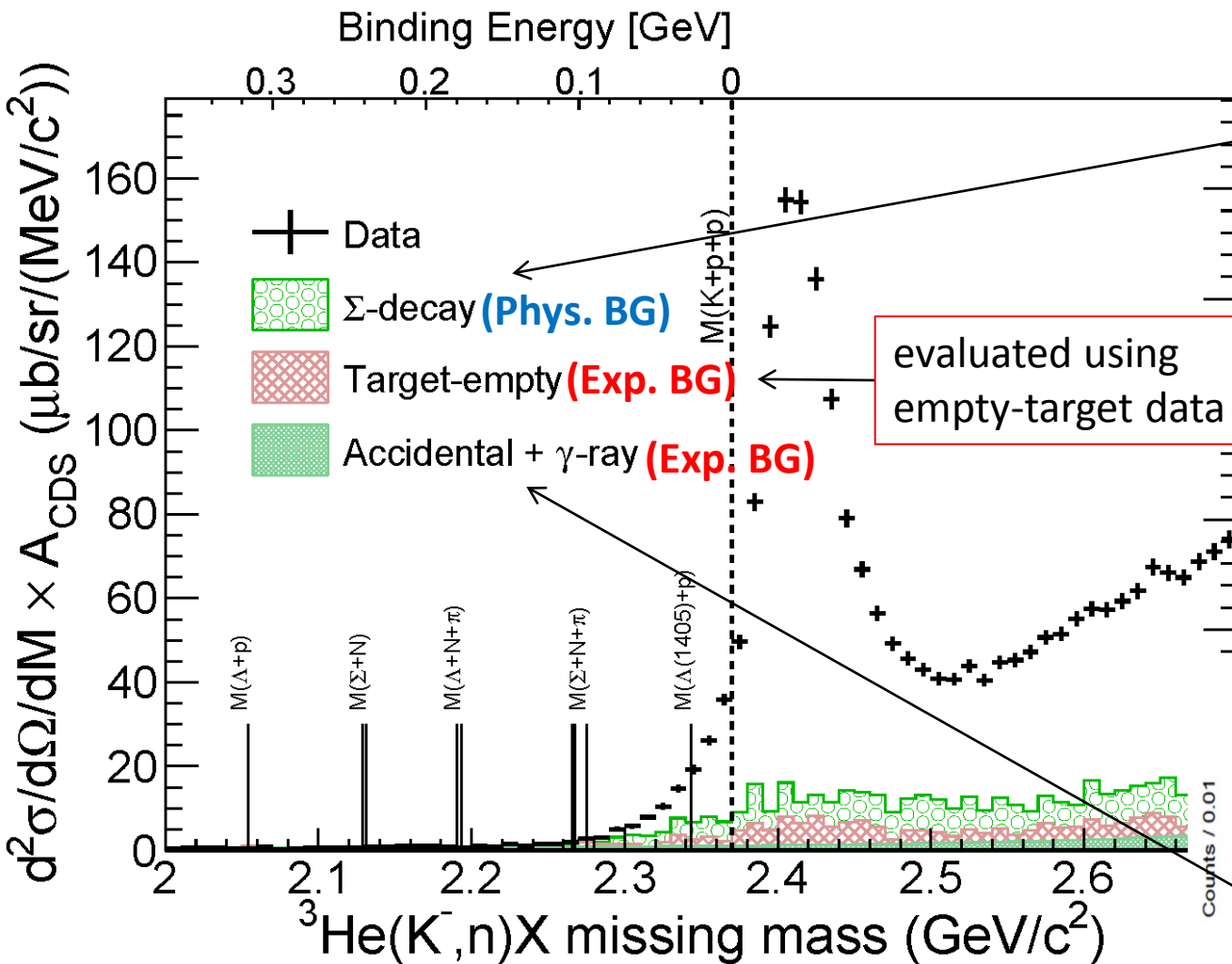
Charge-Exchange



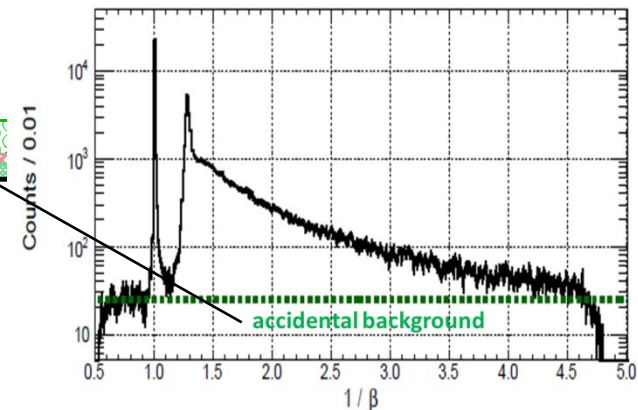
$$d\sigma/d\Omega_{\theta=0\text{deg}} \sim 11\text{mb/sr}$$

The tail structure is not due to “the detector resolution”

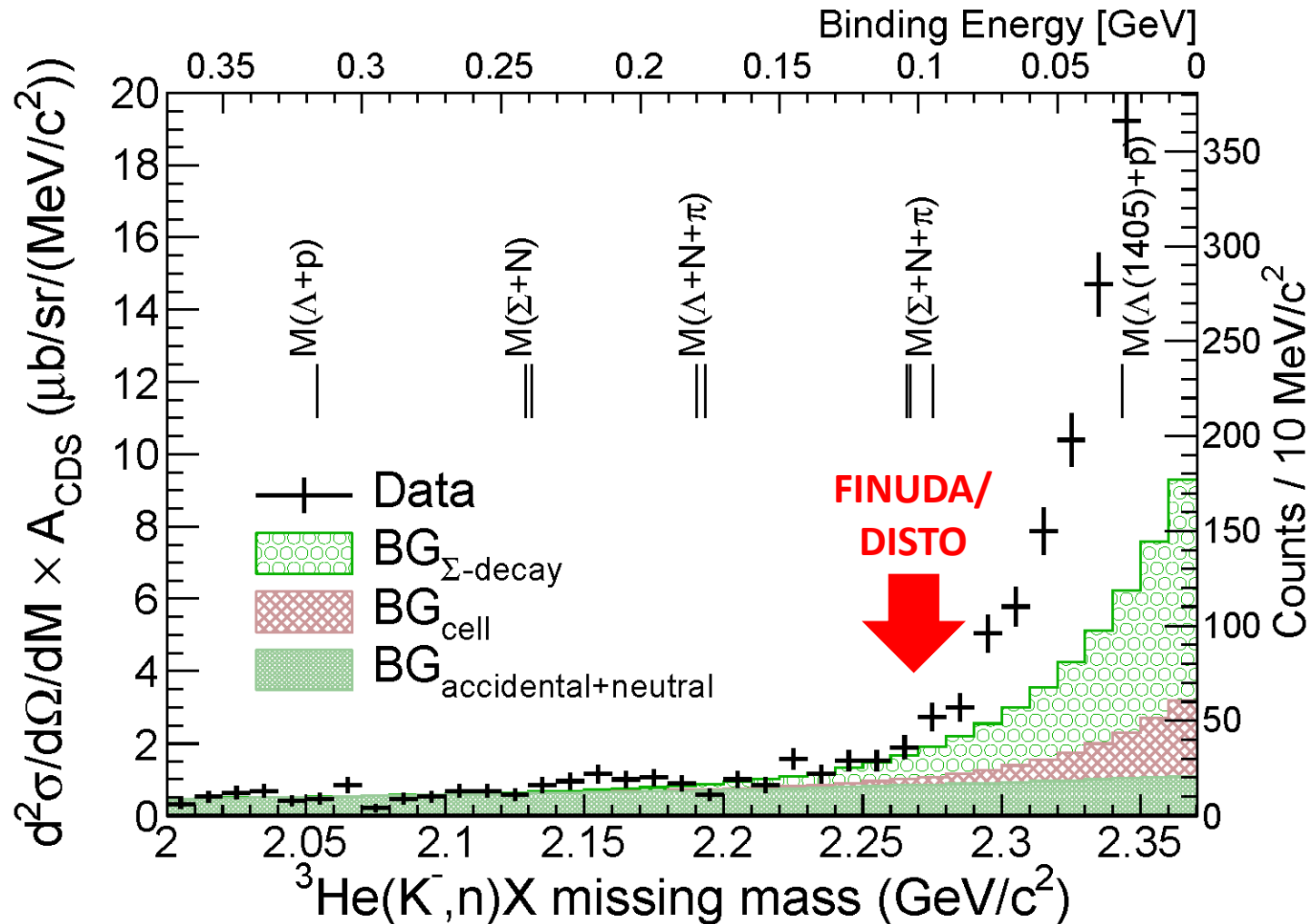
Background Evaluation



$1/\beta$ distribution for γ/n



Spectrum below the Threshold



- No significant bump-structure in the deep-binding region
- Statistically significant excess just below the threshold

Comparison between E15 and Other Results

FINUDA@DAΦNE

PRL94(2005)212303

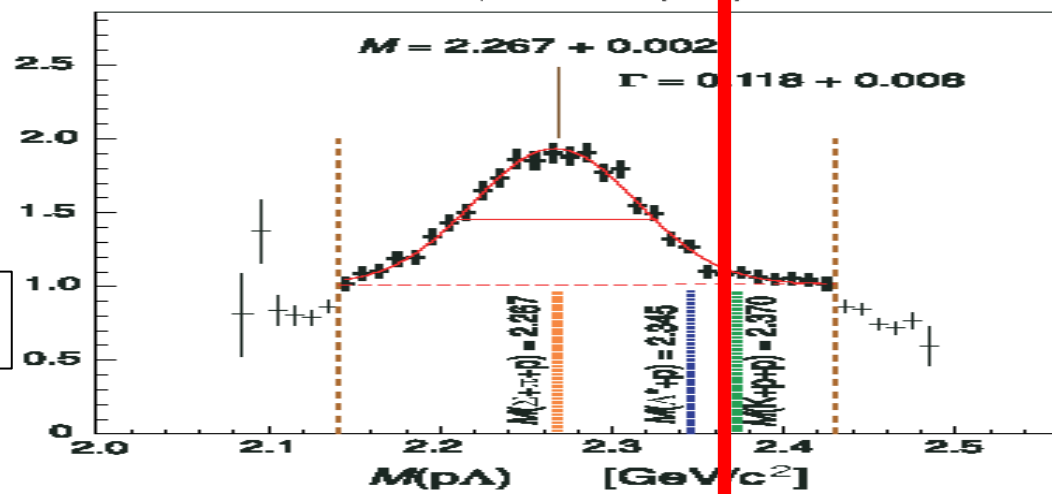
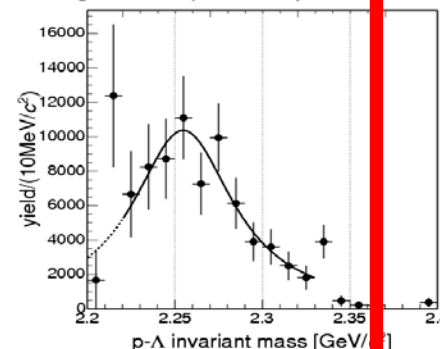
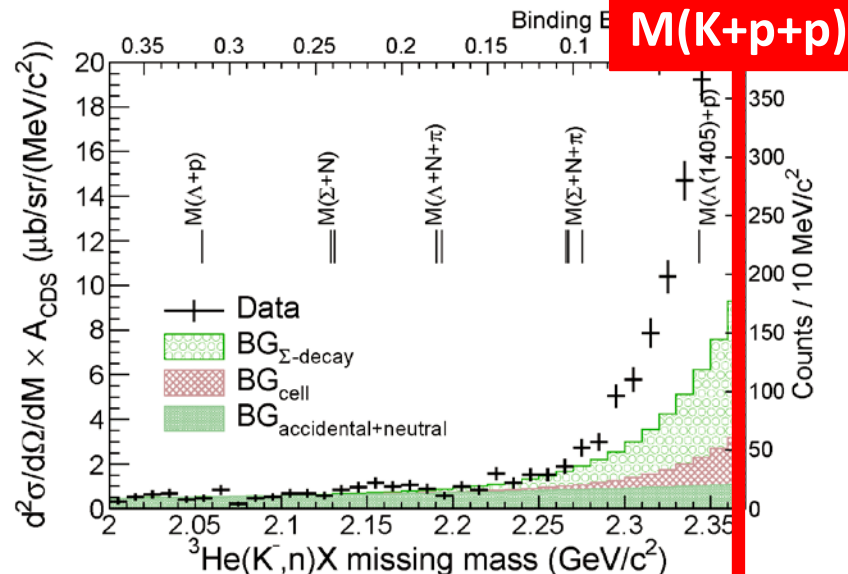
$A(\text{stopped } K^-, \Lambda p)$

DISTO@SATURNE

PRL104(2010)132502

$p + p \rightarrow (\Lambda + p) + K^+ @ 2.85 \text{ GeV}$

Deviation UNC/SIM (arb. scale)

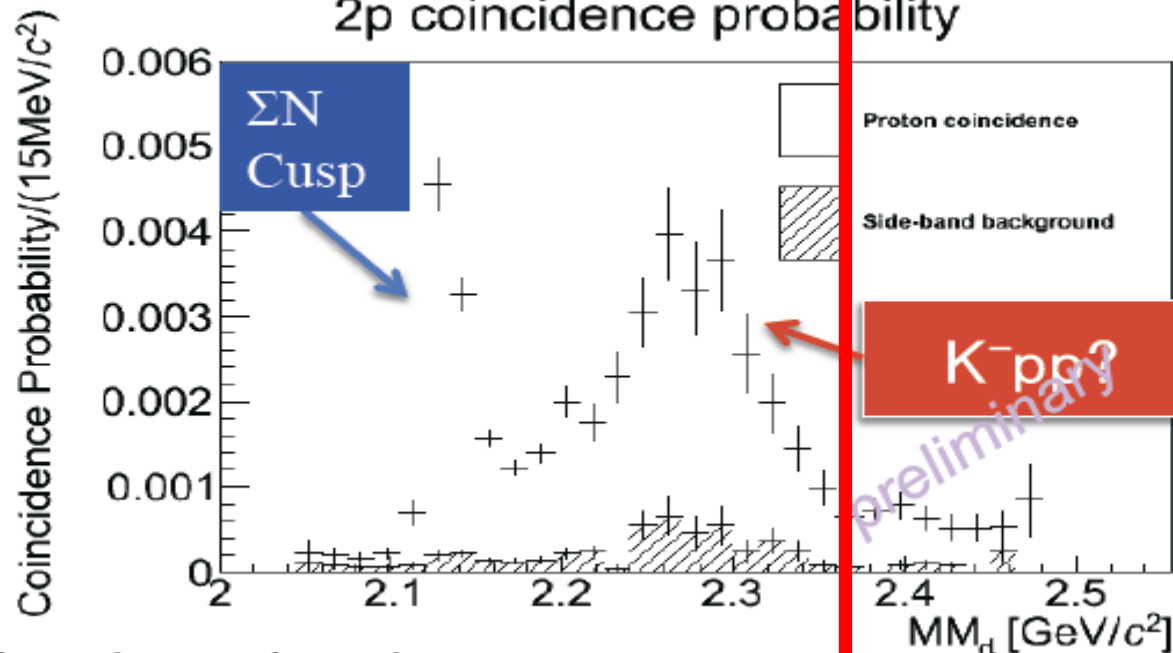
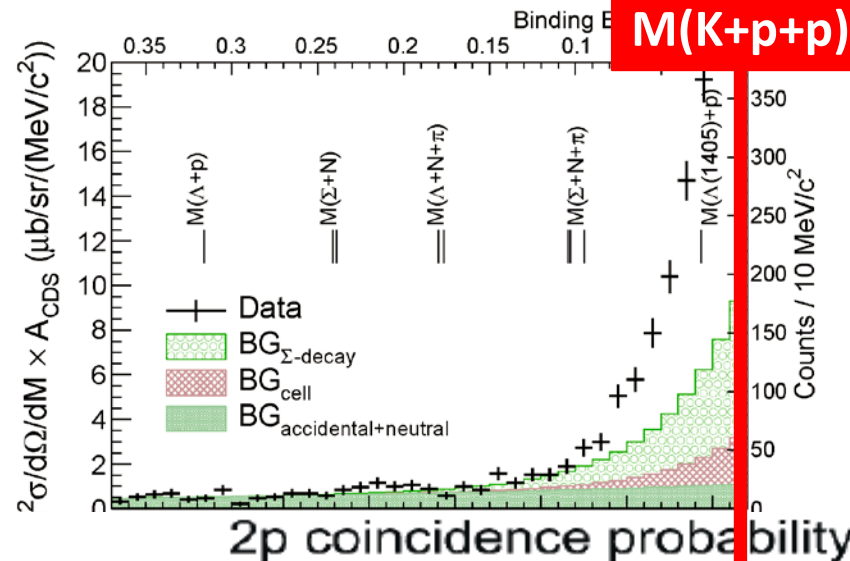


Comparison between E15 and Other Results

E27@J-PARC

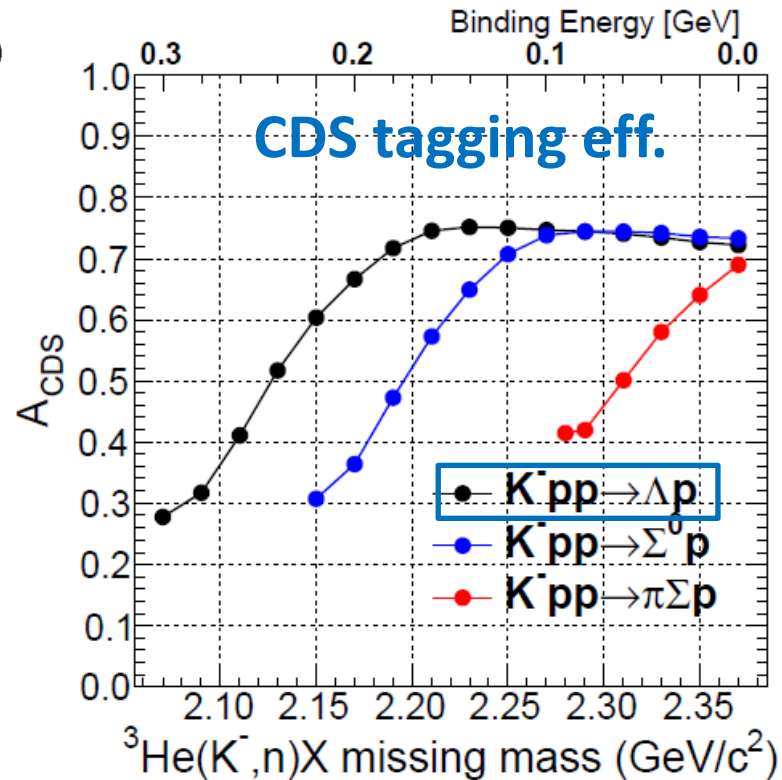
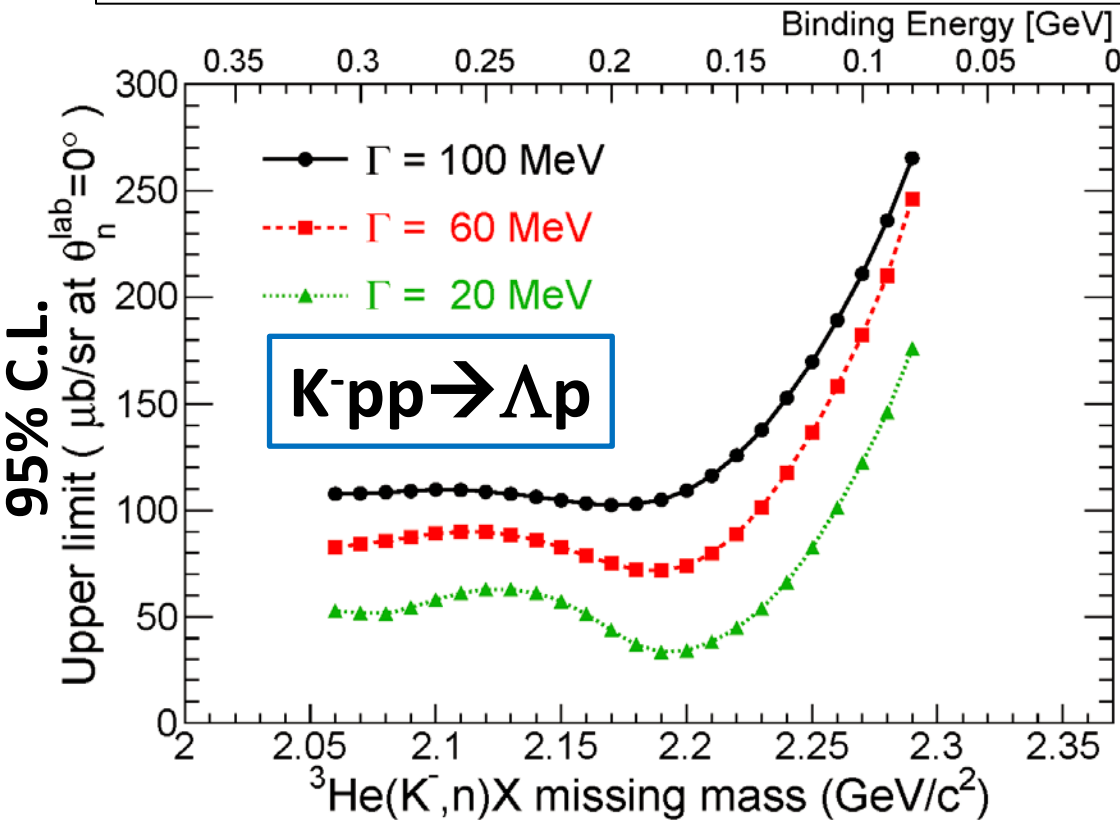
EXA2014 conference

$d(\pi^+, K^+) @ 1.7\text{GeV}/c$



- Bump structure in the deep-binding region reported from other experiments was NOT seen in E15
- Excess near the threshold can be seen only in E15

U.L. of the deeply-Bound K^-pp

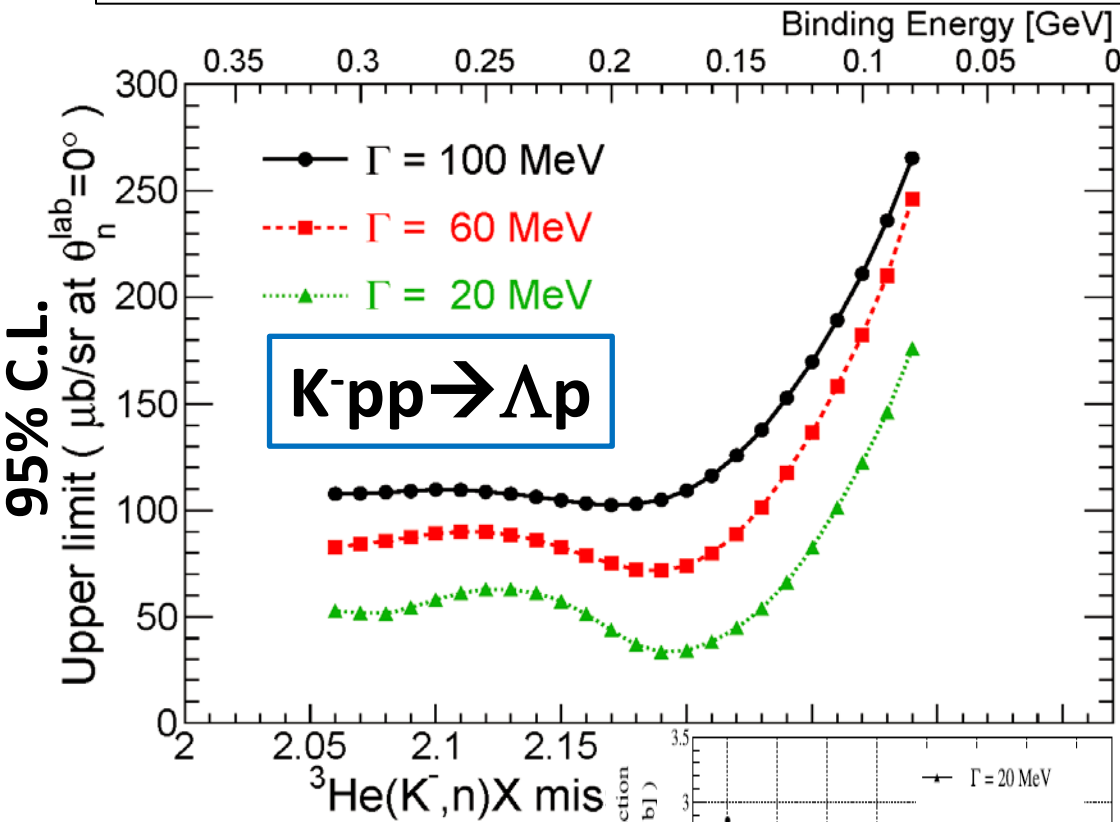


Assumptions

- $K^-pp \rightarrow \Lambda p$ decay mode (isotropic decay)
- K^-pp shape = Breit-Wigner

U.L. depends on the decay mode

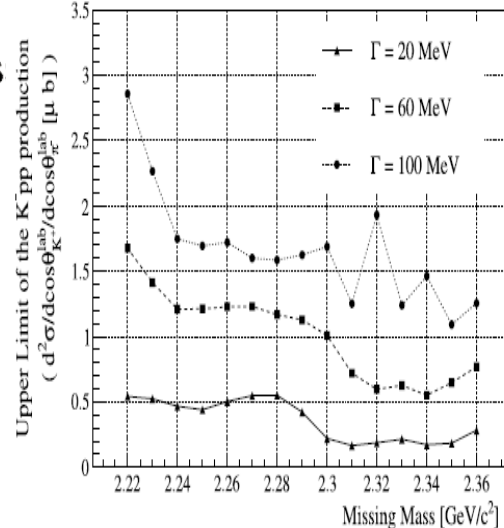
U.L. of the deeply-Bound K^-pp



LEPS@SPRing-8

PLB728(2014)616

$\gamma + d \rightarrow K^+ + \pi^- + X$
 @ 1.5-2.4 GeV



● **E15($K^-+^3\text{He}$):**

(UL) 0.5-5% of QF

● **FINUDA(stopped K^-):**

$\sim 0.1\%$ of stopped K^-

● **DISTO($p+p$):**

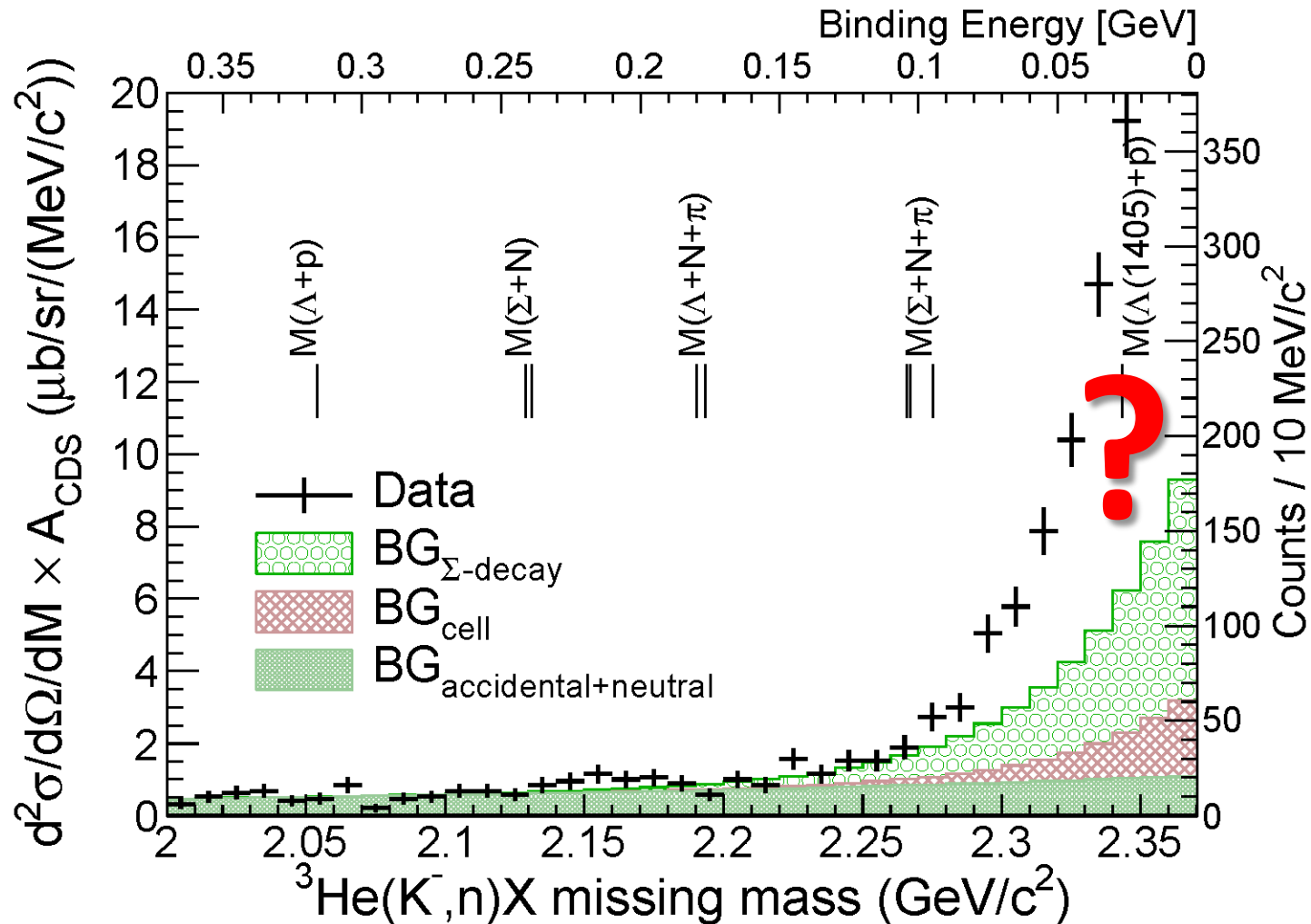
larger than Λ^* @ 2.85 GeV

● **LEPS($\gamma+d$)**

(UL) 1.5-26% of $\gamma N \rightarrow K^+ \pi^- Y$

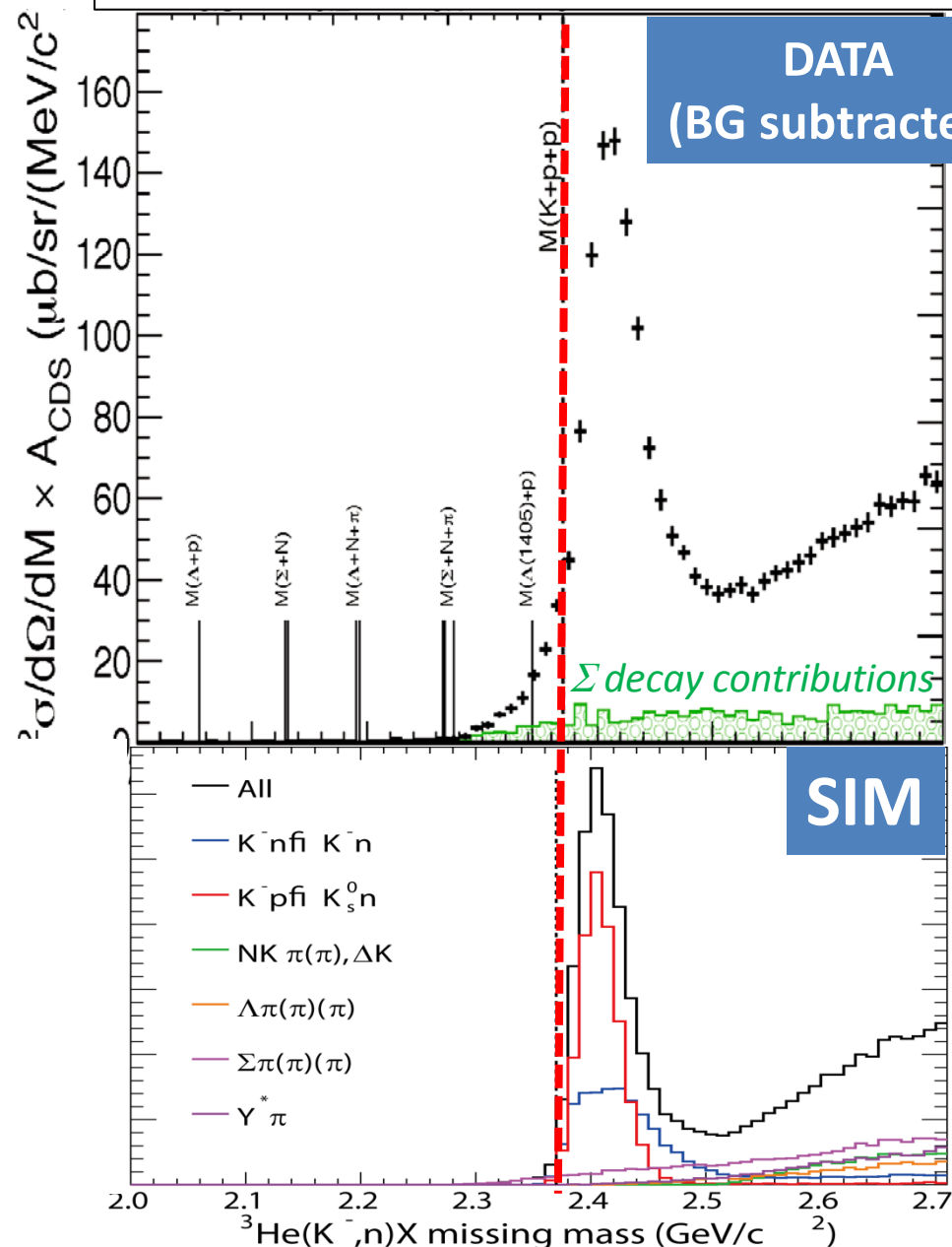
**Upper limits (CS) can
 be directly compared
 with QF yield.**

Spectrum below the Threshold



- No significant bump-structure in the deep-binding region
- Statistically significant excess just below the threshold

Excess = Elementary Processes?



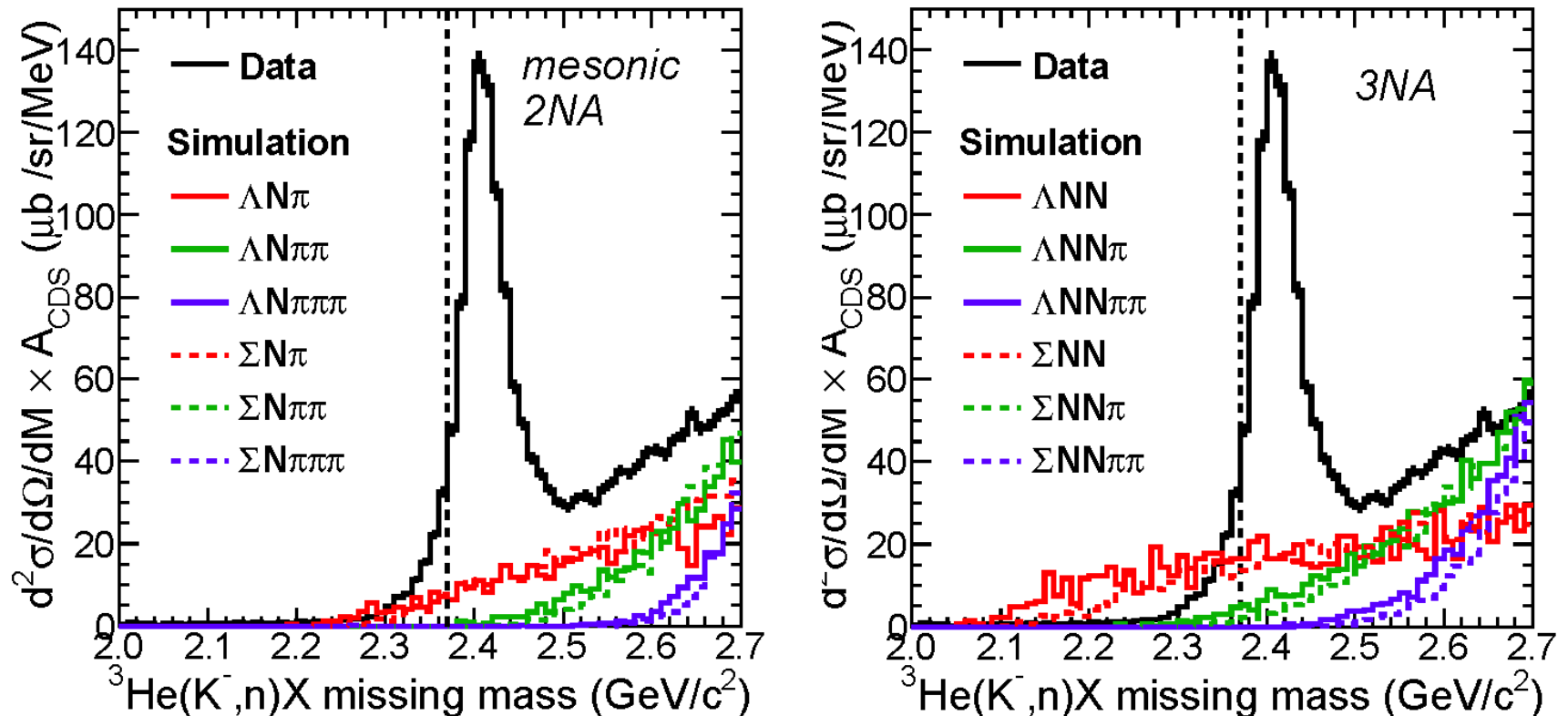
The tail structure is **NOT** reproduced by well known processes

would be attributed to the imaginary part of the attractive $K^{\text{bar}}n$

→ Multi-NA? K^-pp ?

- Detector acceptance and all known K-N interactions are taken in to account:
 - Cross-section [CERN-HERA-83-02]
 - Fermi-motion
 - Angular distribution
- Simple assumptions:
 - $\sigma_{\text{tot}} = 2 * \sigma_{K-p} + \sigma_{K-n} (\sim 150 \text{mb})$

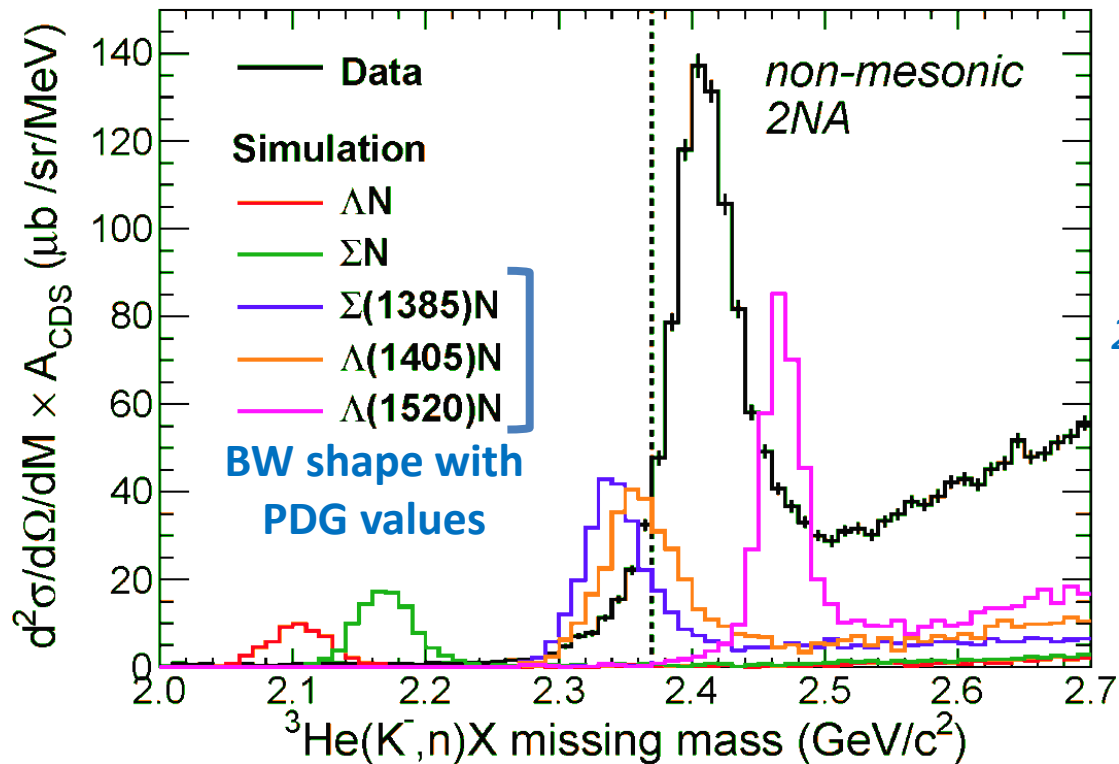
Excess = $\pi\Sigma N$, $\pi\Sigma NN$, etc?



Each process is simulated with unreasonably large CS of 100mb

➔ contributions in the binding region are negligible

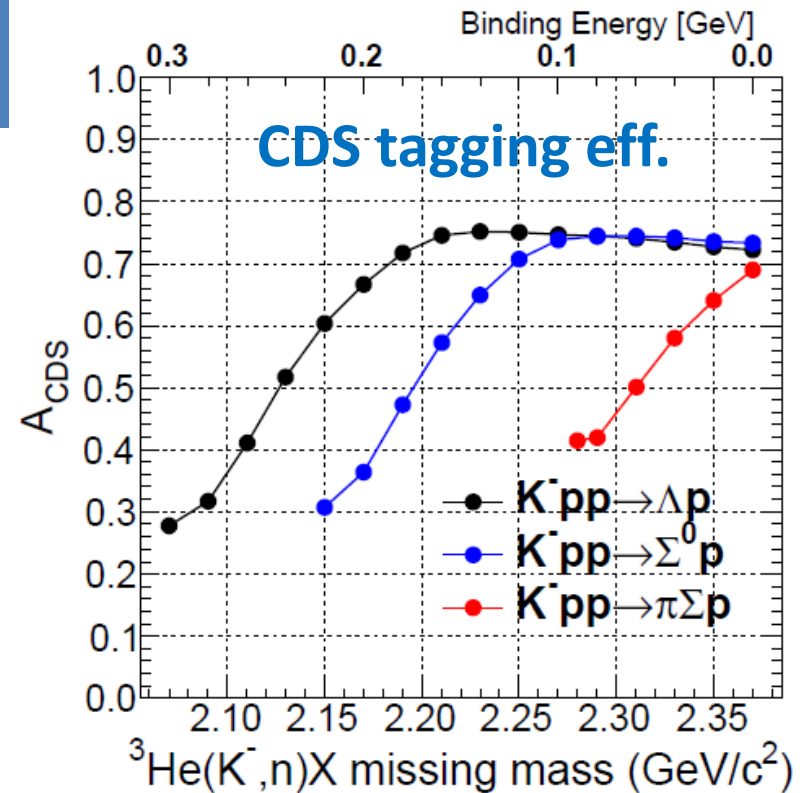
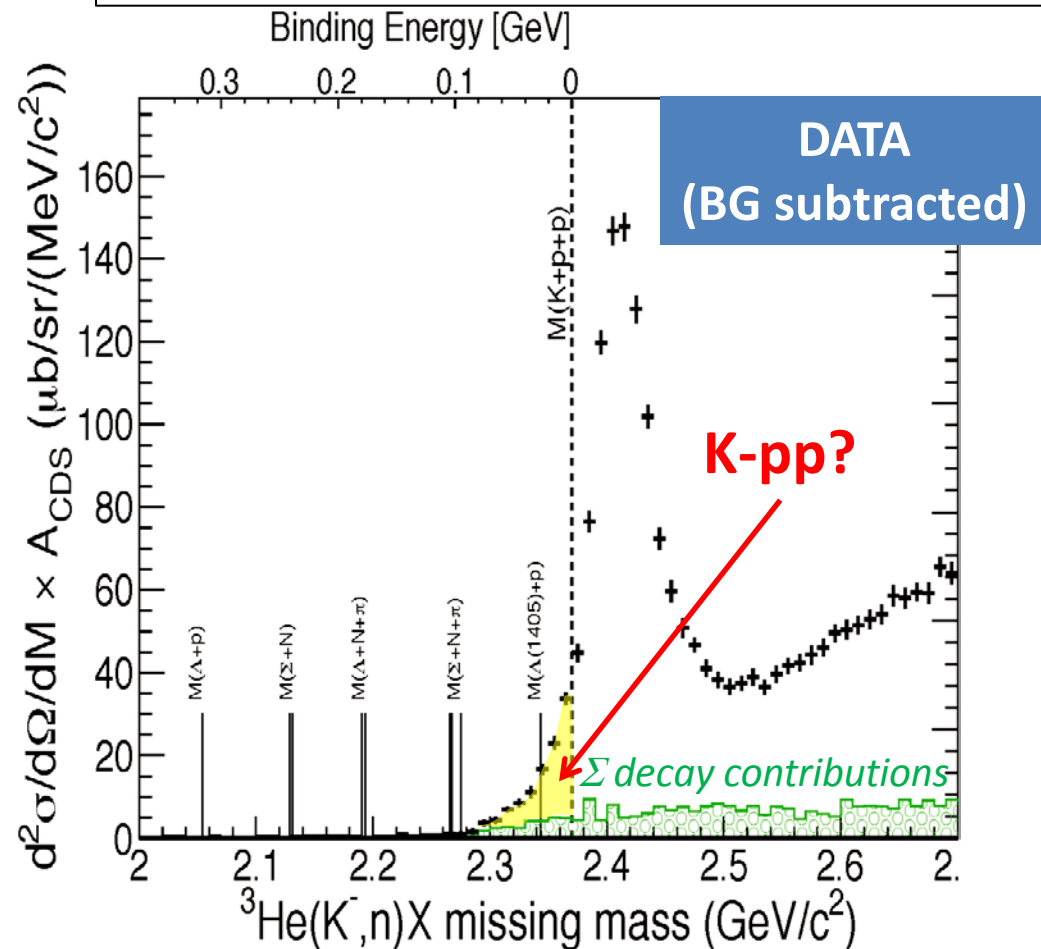
Excess = $\Lambda^* N$, etc?



*CS of each process :
20mb/sr @ 0 degrees*

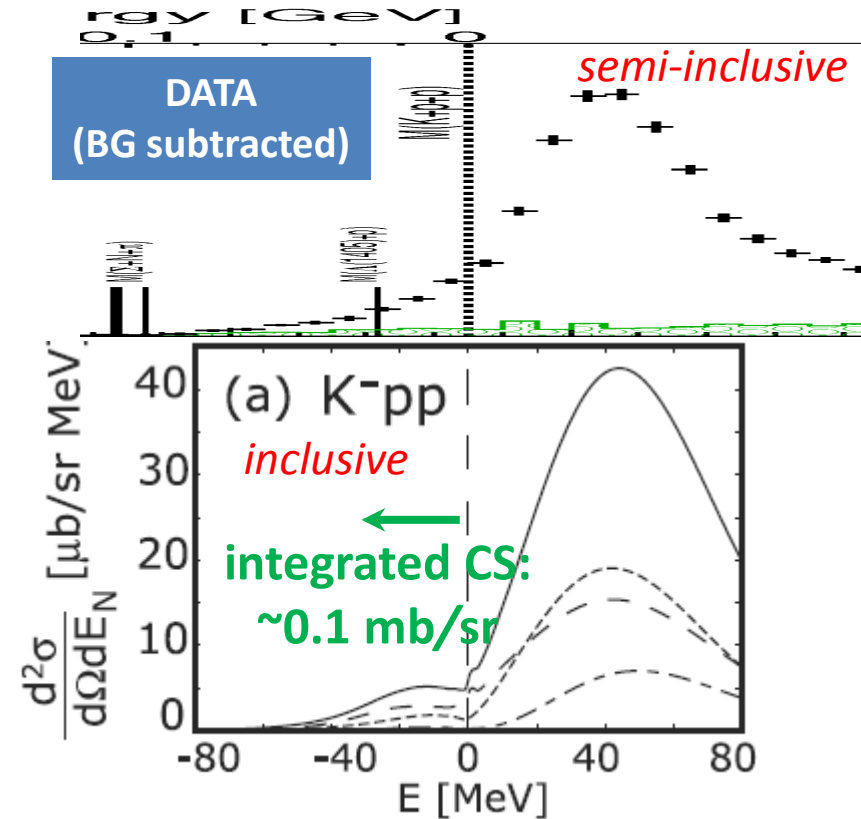
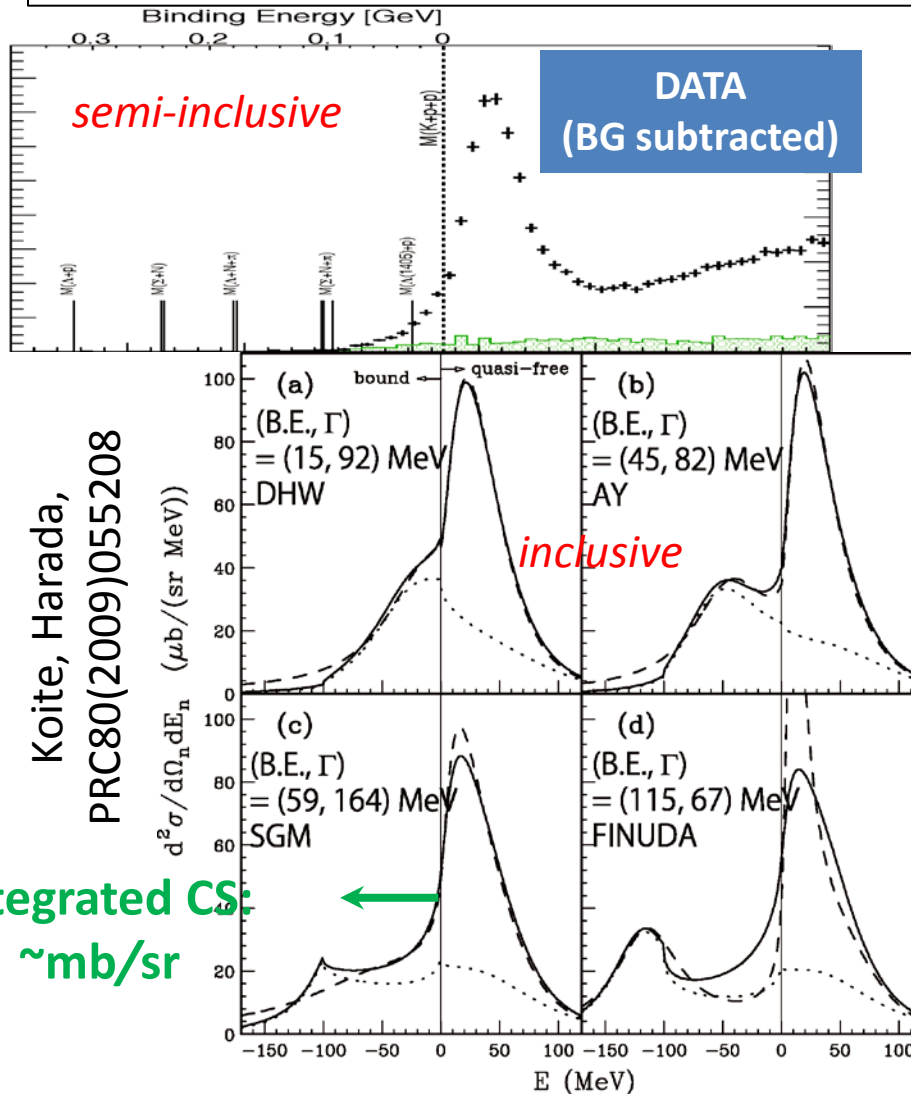
- $\Lambda N / \Sigma N$ branches are negligibly small (consistent with KEK-PS E548)
- $\Lambda(1405)n$ branch seems to reproduce the excess
 - $\Lambda(1405)$ shape is “simple BW with PDG values”
 - need rather large CS of $\sim 5\text{mb/sr}$
- For further study, exclusive measurement of $\pi \Sigma N$ is needed.

Excess = Loosely-Bound K⁻pp?



- The excess is **assumed** to be fully attributed to the bound K⁻pp state
- $d\sigma/d\Omega(\theta_{\text{lab}}=0^\circ)$ of the excess is $\sim \text{mb/sr}$ (Excess/QF < $\sim 10\%$)

Comparison between E15 and Calc.



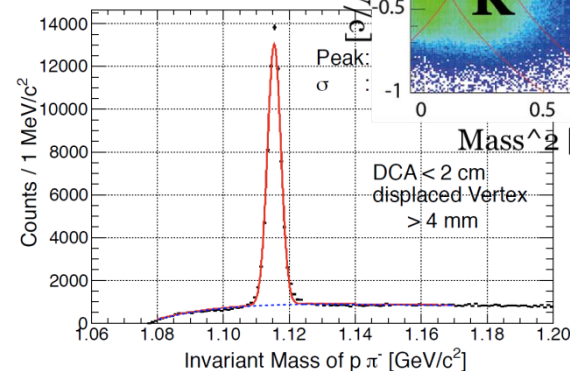
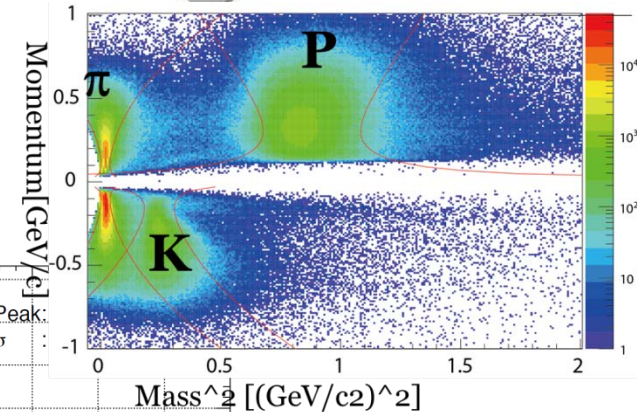
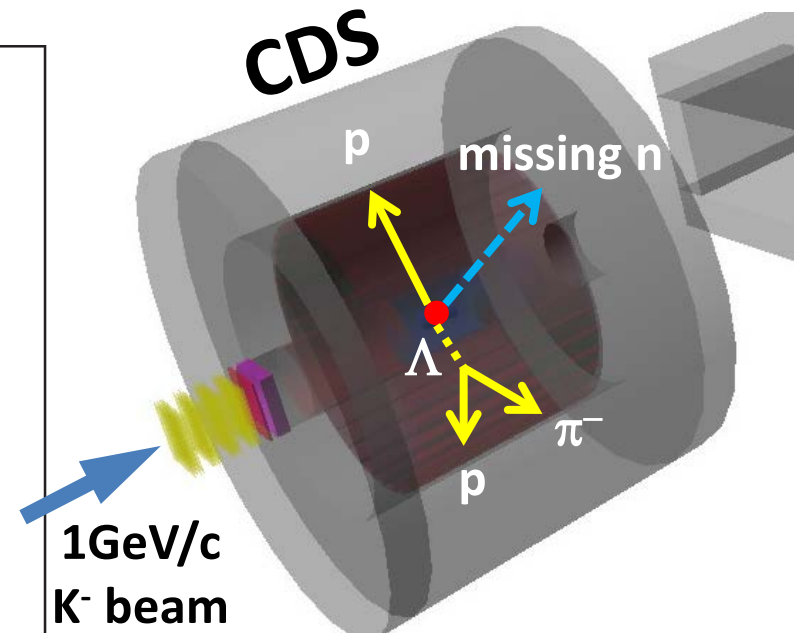
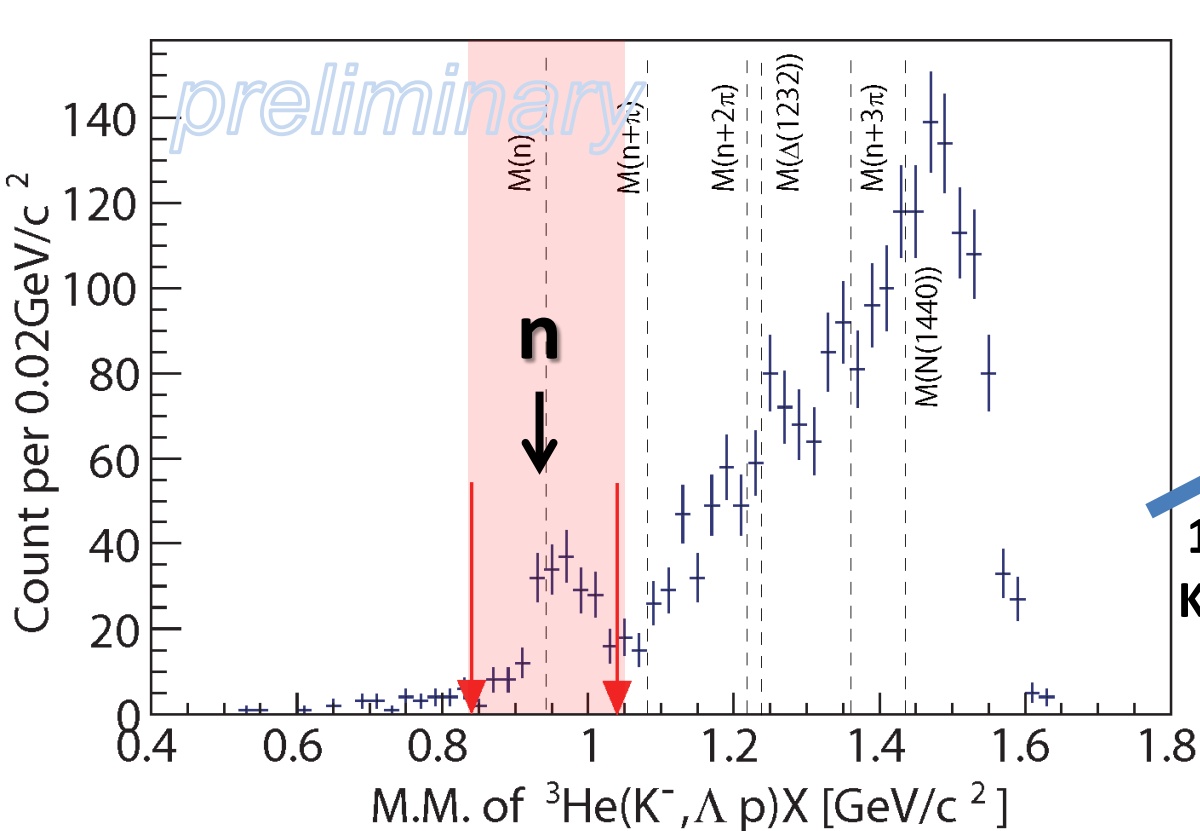
Yamagata-Sekihara, et al.,
PRC80(2009)045204

- CS is roughly consistent with KH
- Loosely-bound K-pp state ???

→ $\pi\Sigma N$ measurement
is an important key

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

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

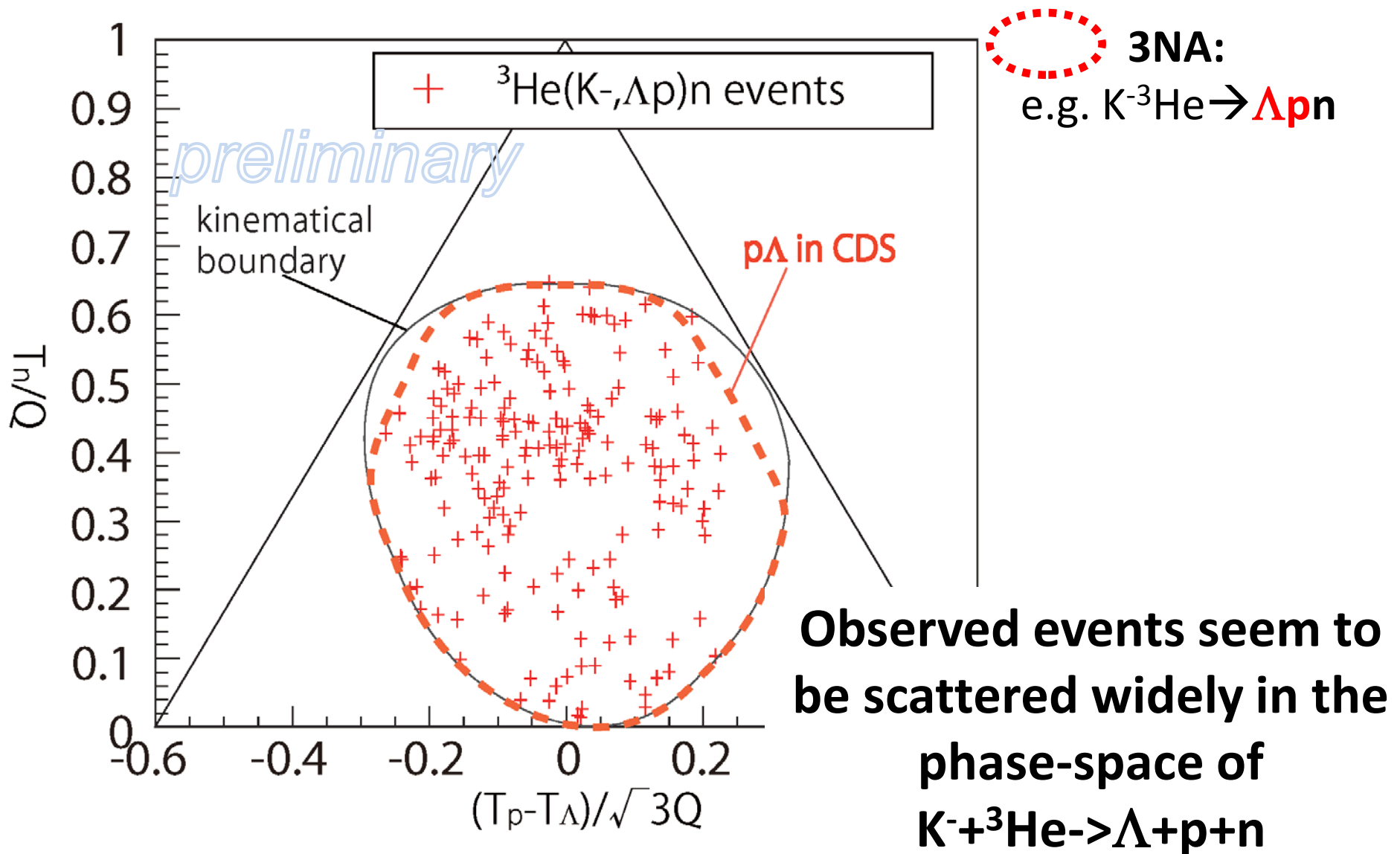


- $\text{K}-{}^3\text{He} \rightarrow \Lambda(\Sigma^0)pn$ events can be identified exclusively

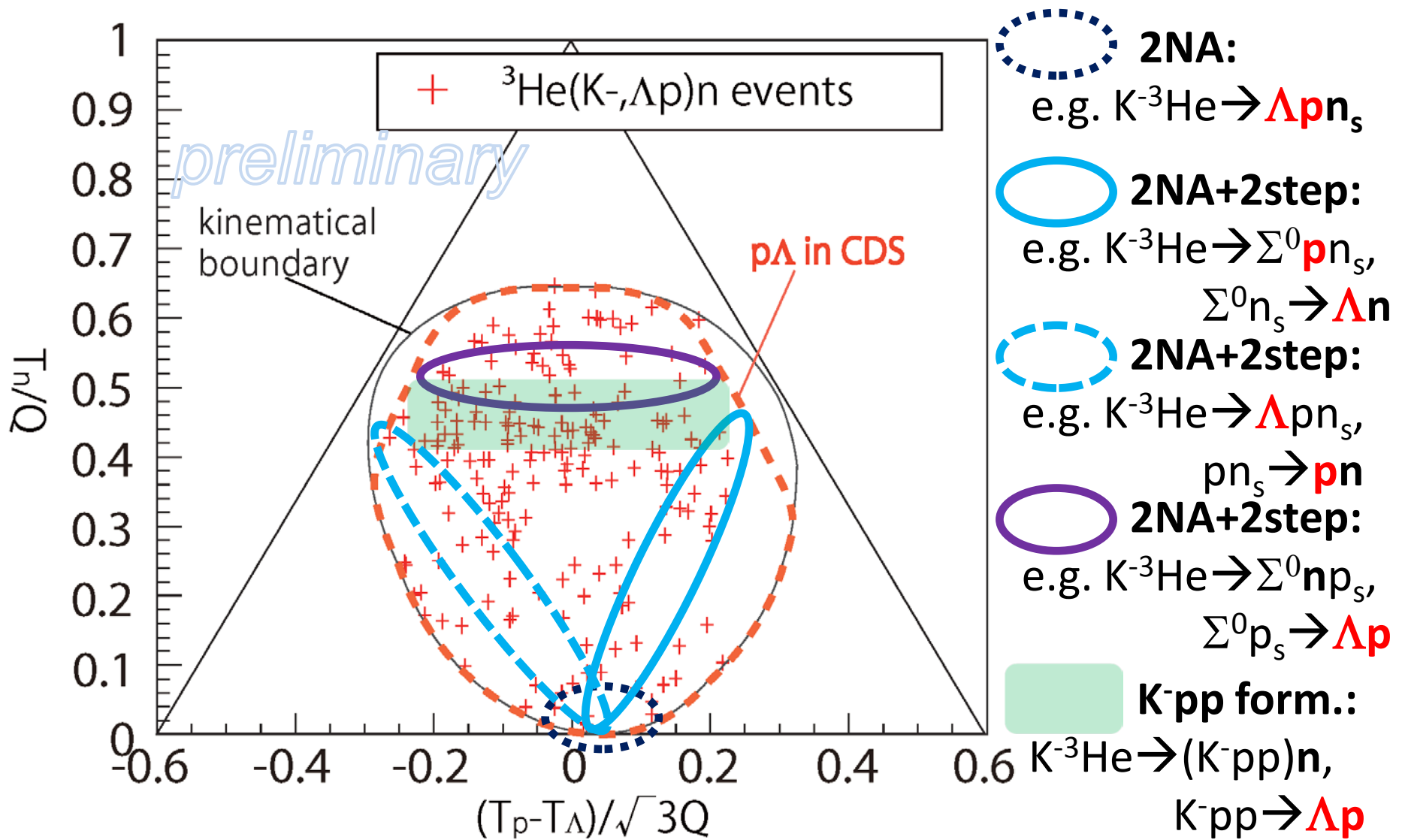
- # of $\Lambda(\Sigma^0)pn$ events: ~190

- Σ^0pn contamination: ~20%

Dalitz plot



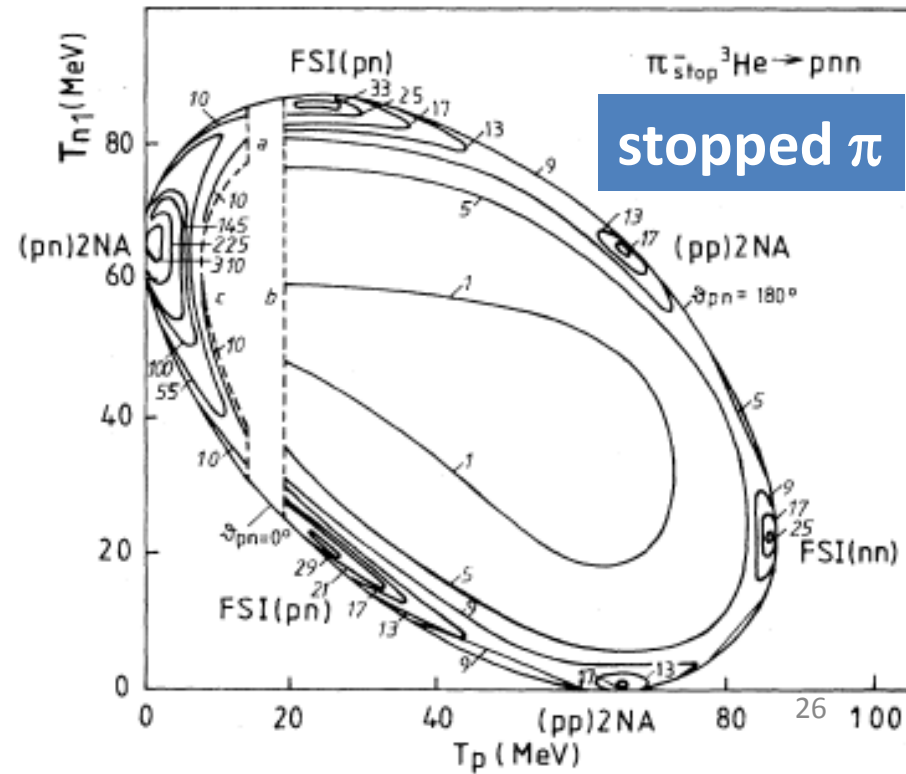
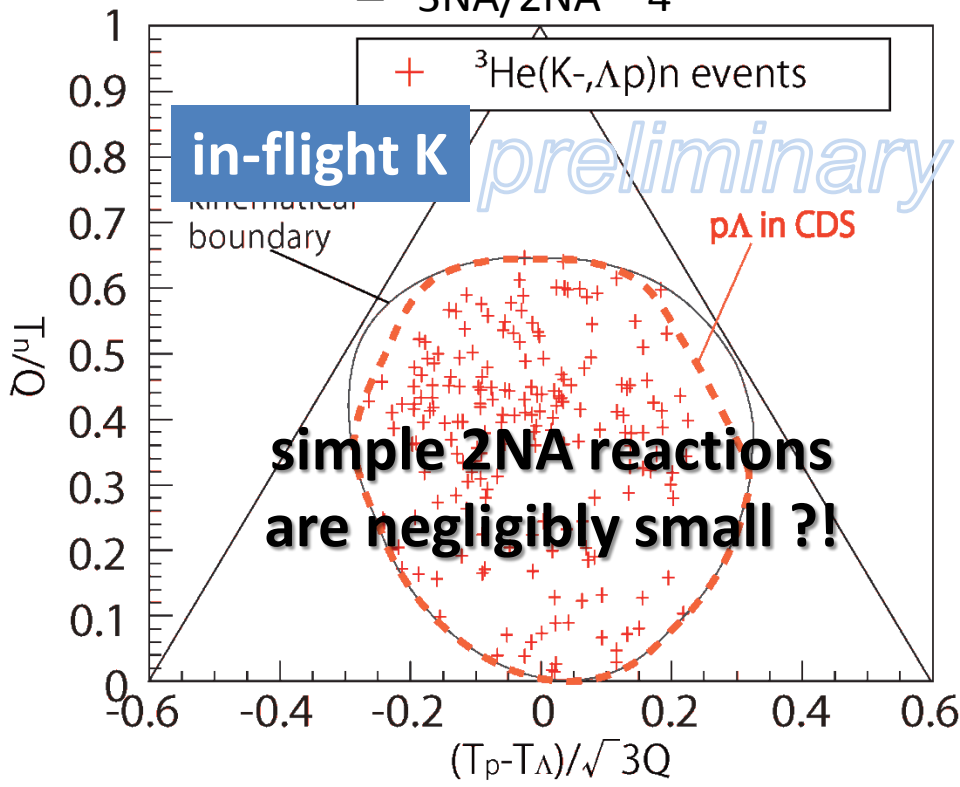
Dalitz plot



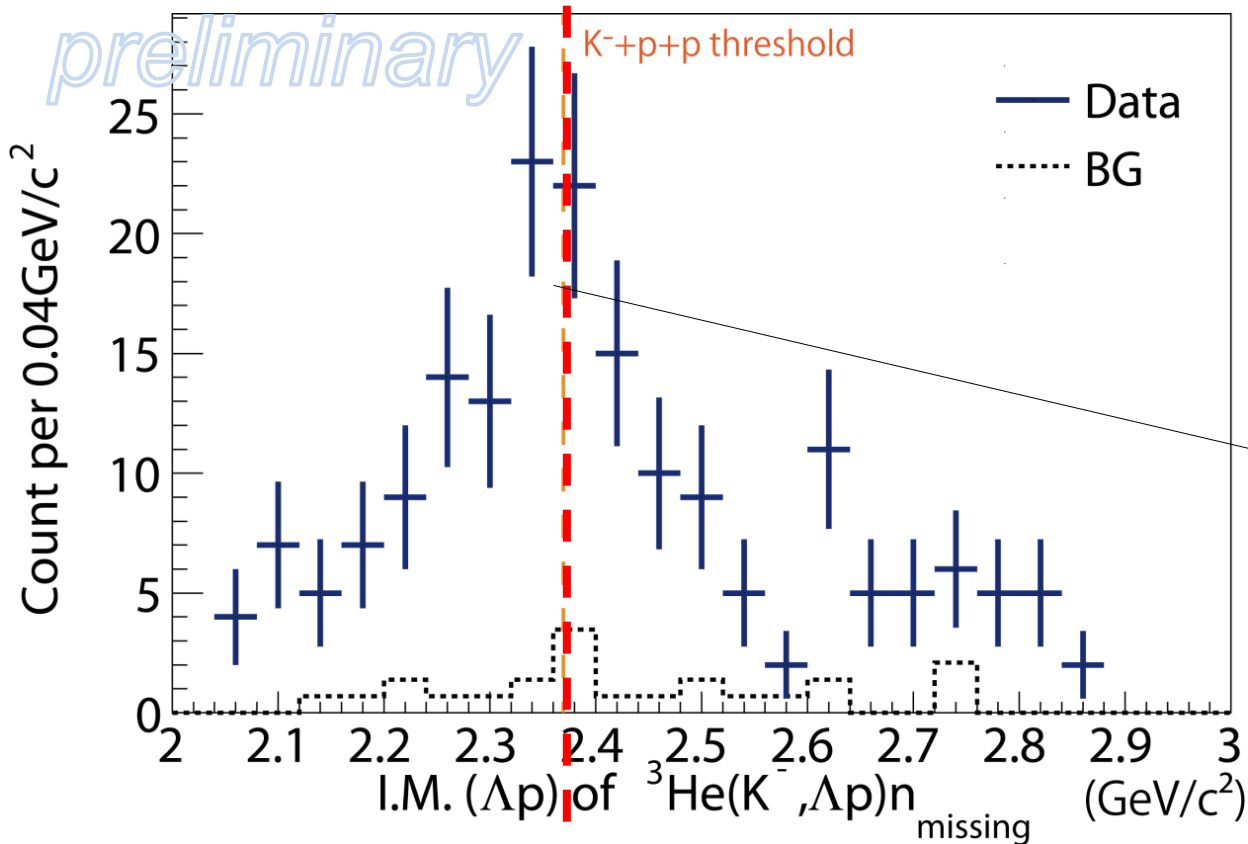
K-induced vs π -induced

- [1] D. Gotta, et al., PRC51. 496 (1995)
 [2] P. Weber et al., NPA501 765 (1989)
 [3] G. Backenstoss et al., PRL55. 2782 (1985)

- π^- stopped [1]
 - 2nucleon absorption & FSI (50%/ π_{stopped}) are clearly seen
 - 3nucleon absorption <3% / π_{stopped}
- π^- in-flight [2],[3]
 - 2nucleon absorption $0.85 \pm 0.17 \text{ mb}$ (266 MeV/c)
 - 3nucleon absorption $3.7 \pm 0.6 \text{ mb}$ (220 MeV/c)
 - $3\text{NA}/2\text{NA} \sim 4$

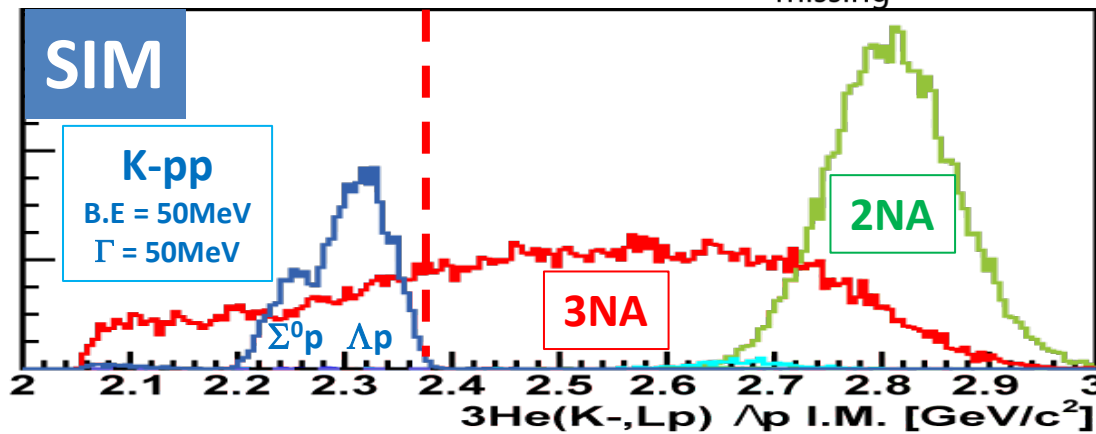


Λp Invariant Mass



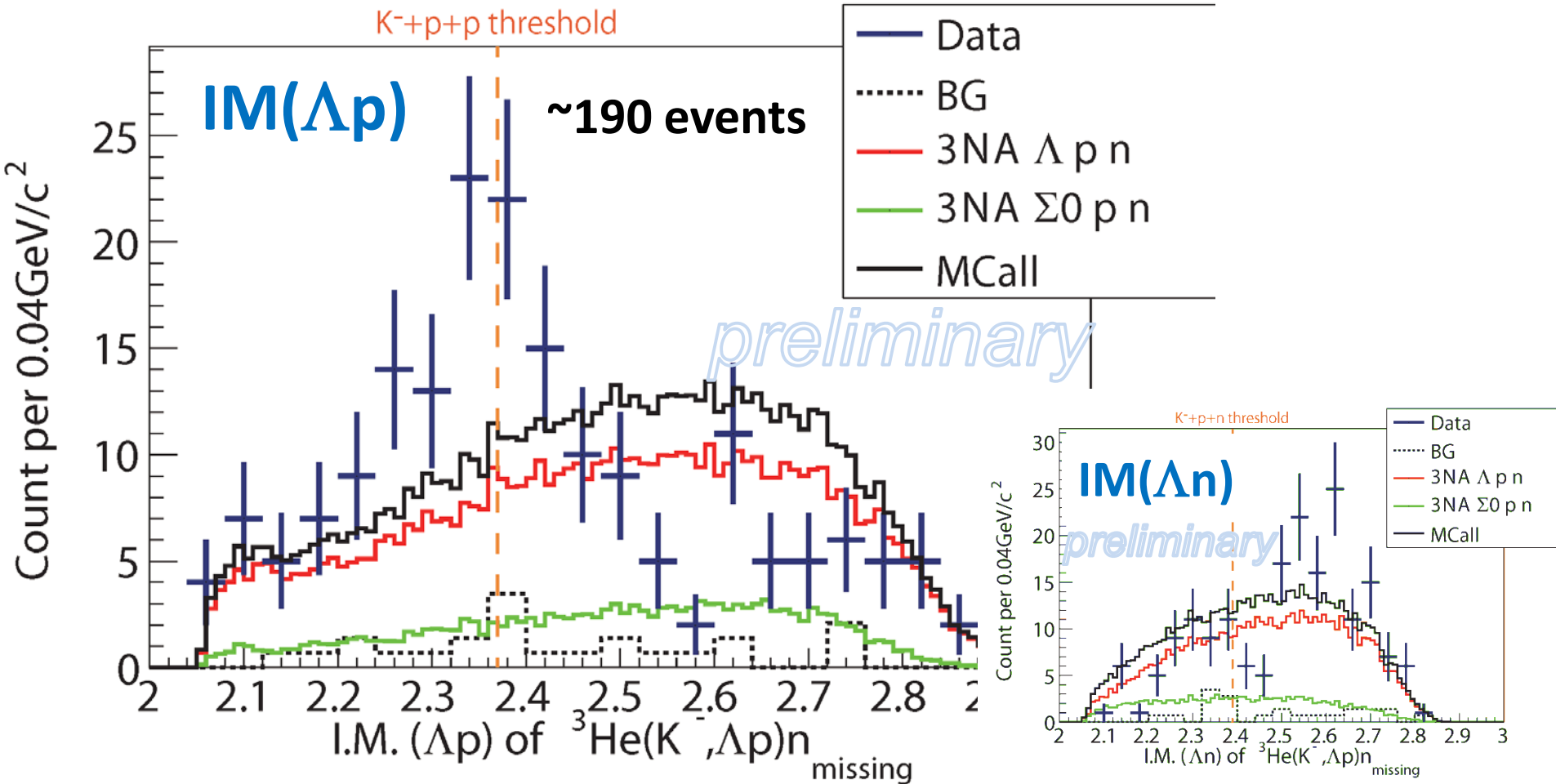
*FS = $\Lambda (\Sigma^0) pn$
 $\rightarrow$ cannot be from
 2NA of $\Lambda^* n$*

**Excess around the
threshold?**



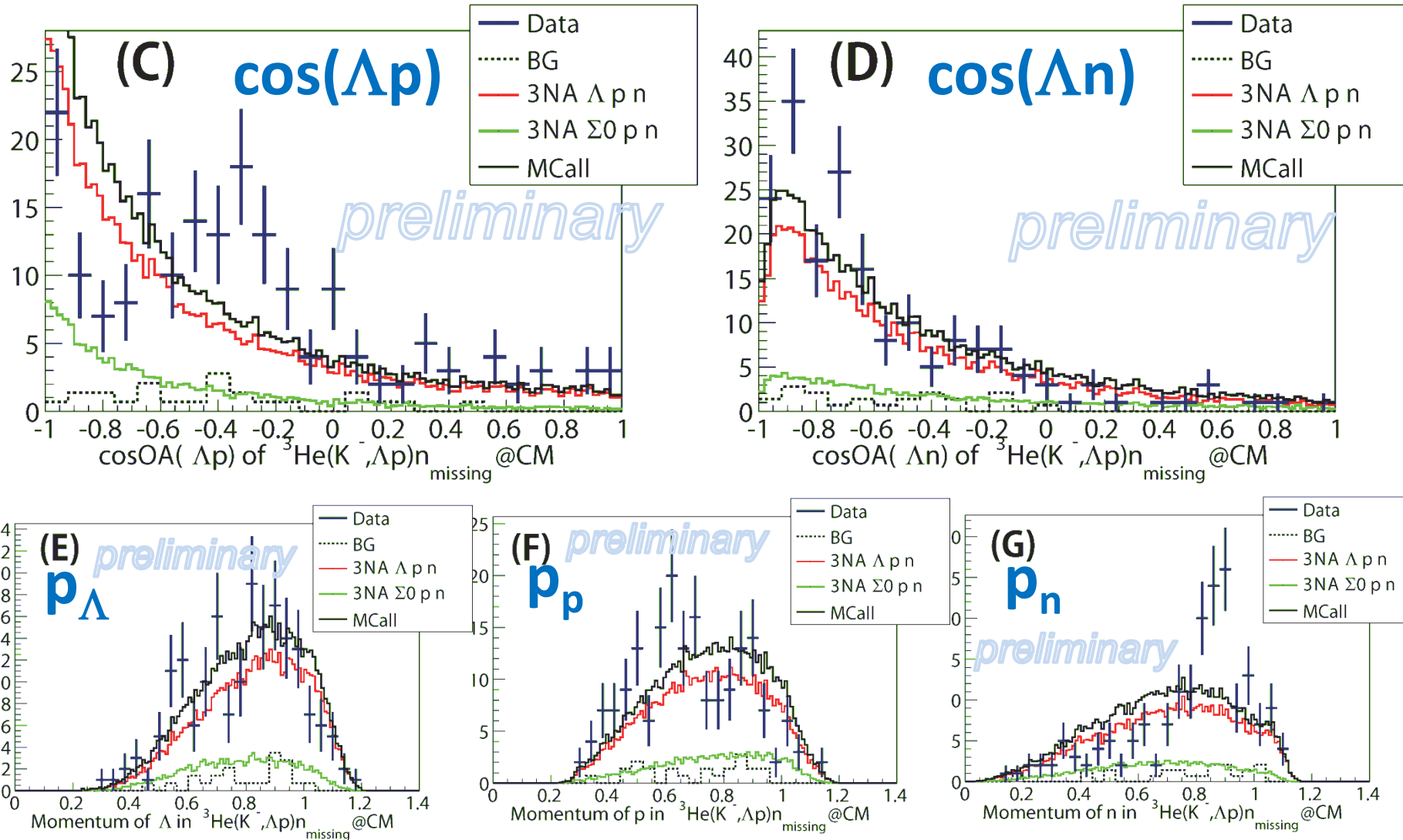
***Further study is
ongoing, such as
contribution from
2NA+2step.***

Comparison with Phase-Space



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

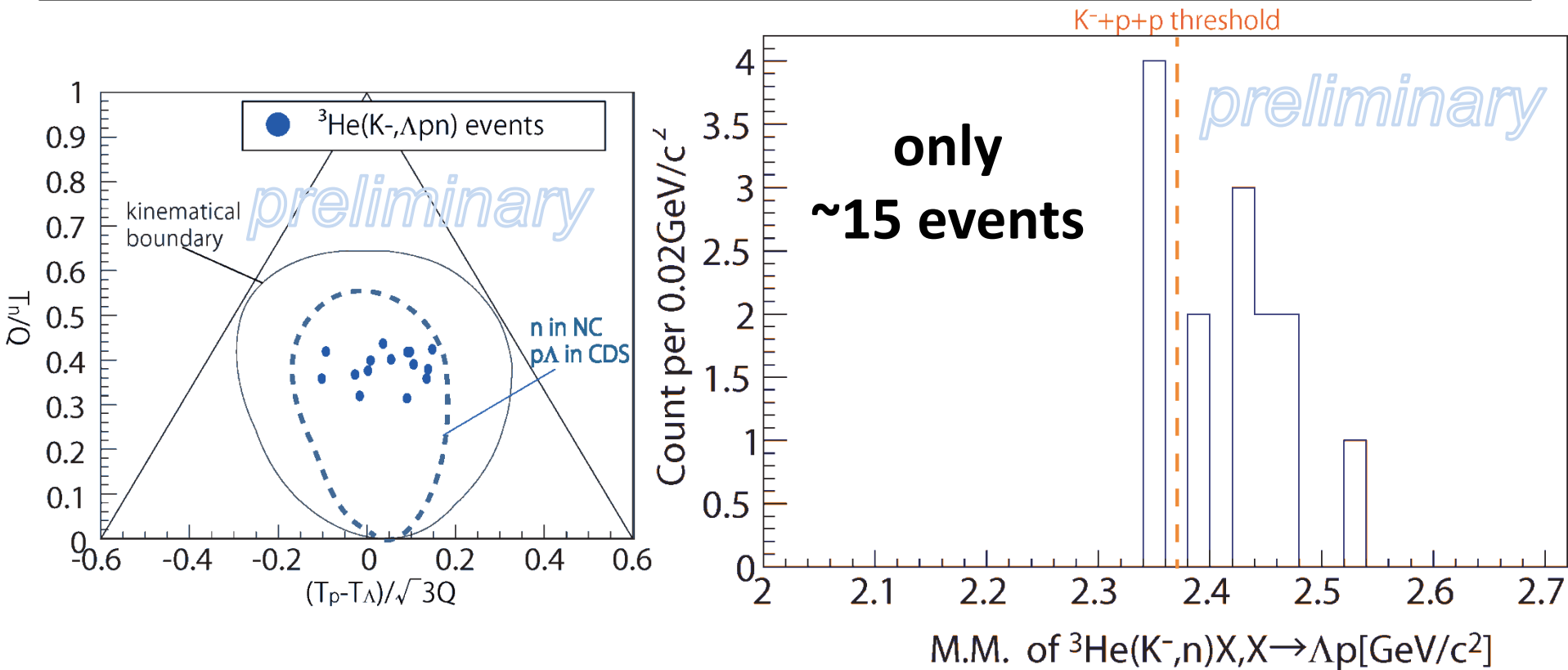
Comparison with Phase-Space



- data cannot be reproduced by the phase-space? ²⁹

**Formation + Decay Channel,
Kinematically Complete $^3\text{He}(\text{K}^-, \Lambda \text{pn})$**

Kinematically-complete measurement of $^3\text{He}(\text{K}^-, \Lambda \text{pn})$



- Minimum momentum transfer of the $^3\text{He}(\text{K}^-, n)$ reaction
→ would enhance the $S=-1$ di-baryon production
- **More beam time is required**

Future Prospects of E15

E15 2nd stage (approved)

May, 2013
(Run#49c)

24 kW
(30 Tppp, 6s)

140 k/spill

88 h

5.1×10^9

x10

E15^{2nd}: 50×10^9 kaons on target in 2015

The goal of the E15^{2nd}

1. derive $\pi\Sigma N$ decay information in ${}^3\text{He}(K^-, n)X$ reaction
2. confirm the spectral shape of the Λp invariant-mass by the exclusive measurement of ${}^3\text{He}(K^-, \Lambda p)n$
3. explore the neutron spectrum at $\theta_{\text{lab}}=0^\circ$ with the kinematically complete measurement of ${}^3\text{He}(K^-, \Lambda pn)$

Summary of E15 1st

Formation Channel

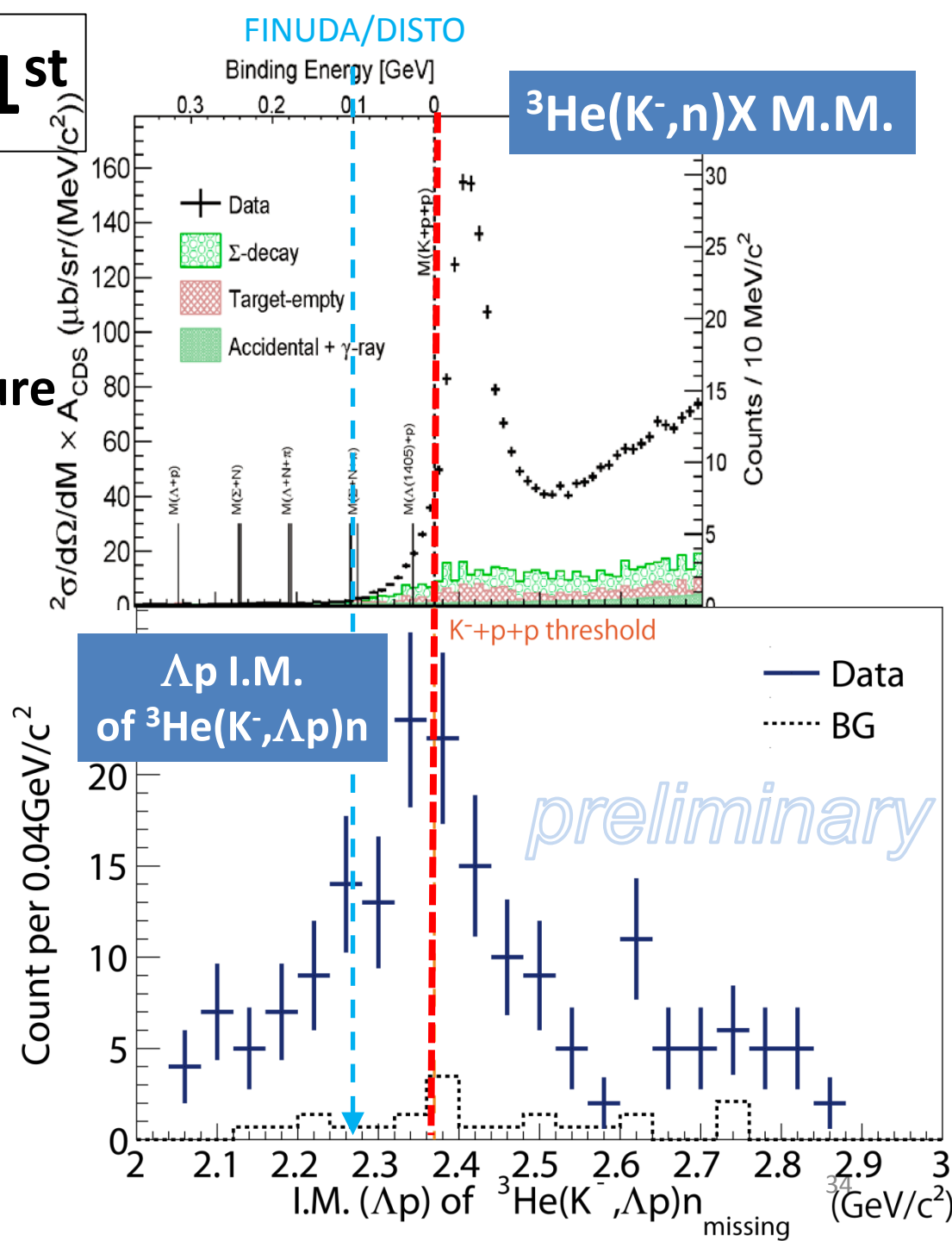
Semi-Inclusive $^3\text{He}(K^-,n)X$

- ✓ **No significant bump structure** in the deeply bound region
- ✓ **Excess below the threshold** attributed to 2NA of Λ^*n ?

Decay Channel

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

- ✓ **Hint of the excess around the threshold**
- ✓ **Cannot be from 2NA of Λ^*n** (final state = Λpn)



The J-PARC E15 Collaboration

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