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

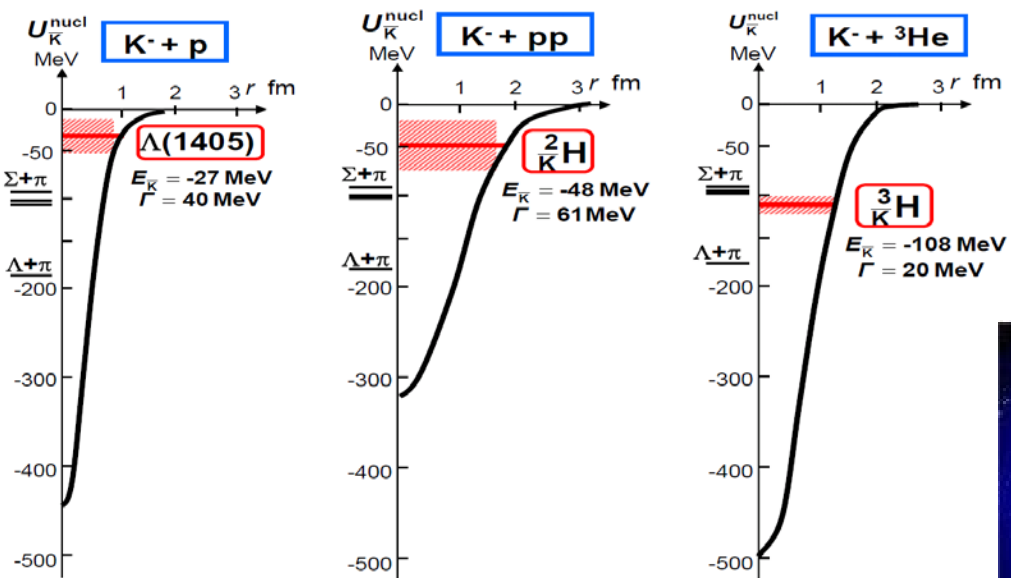
F. Sakuma, RIKEN
for the J-PARC E15 collaboration

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

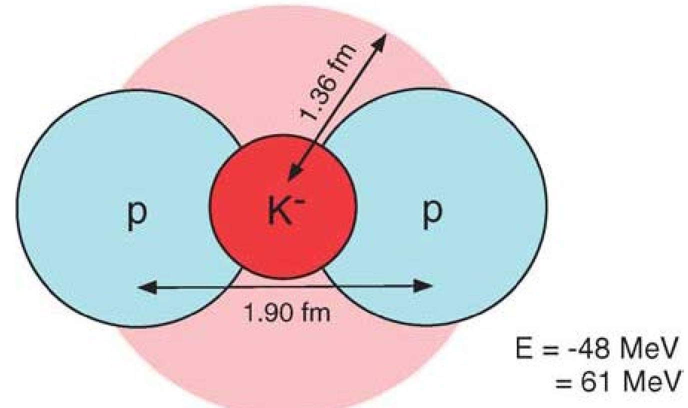
原子核媒質中のハドロン研究II J-PARC 2014 10/24-25

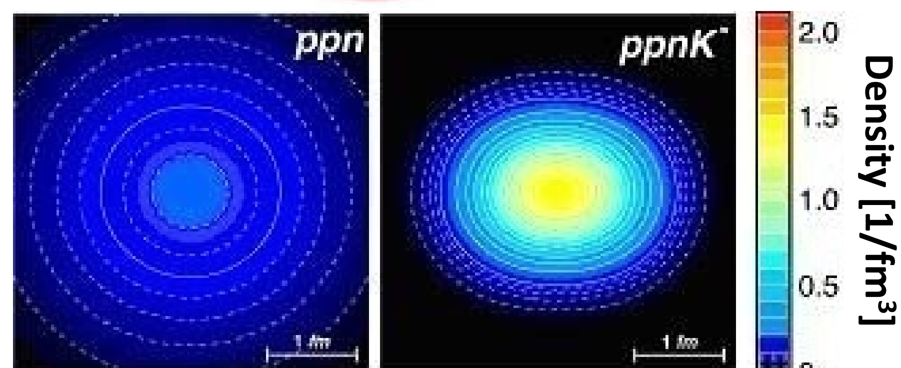
Kaonic Nuclei

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



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.

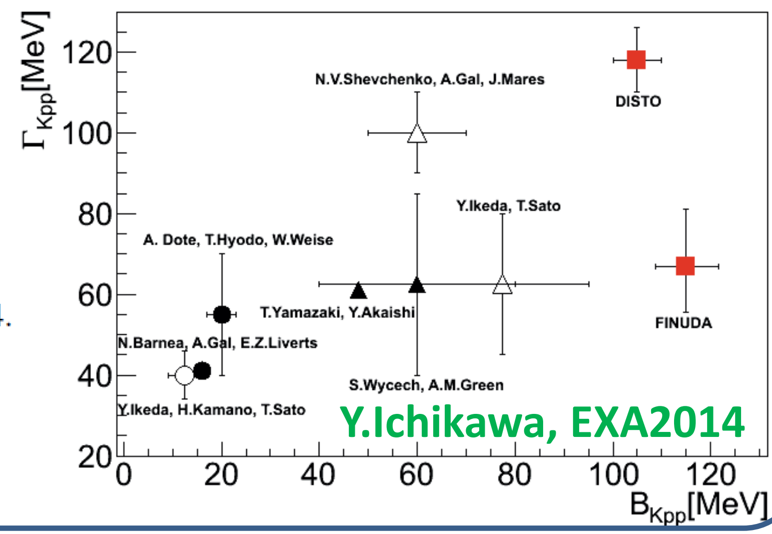
[9] Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. 124 (2010) 533.

[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.

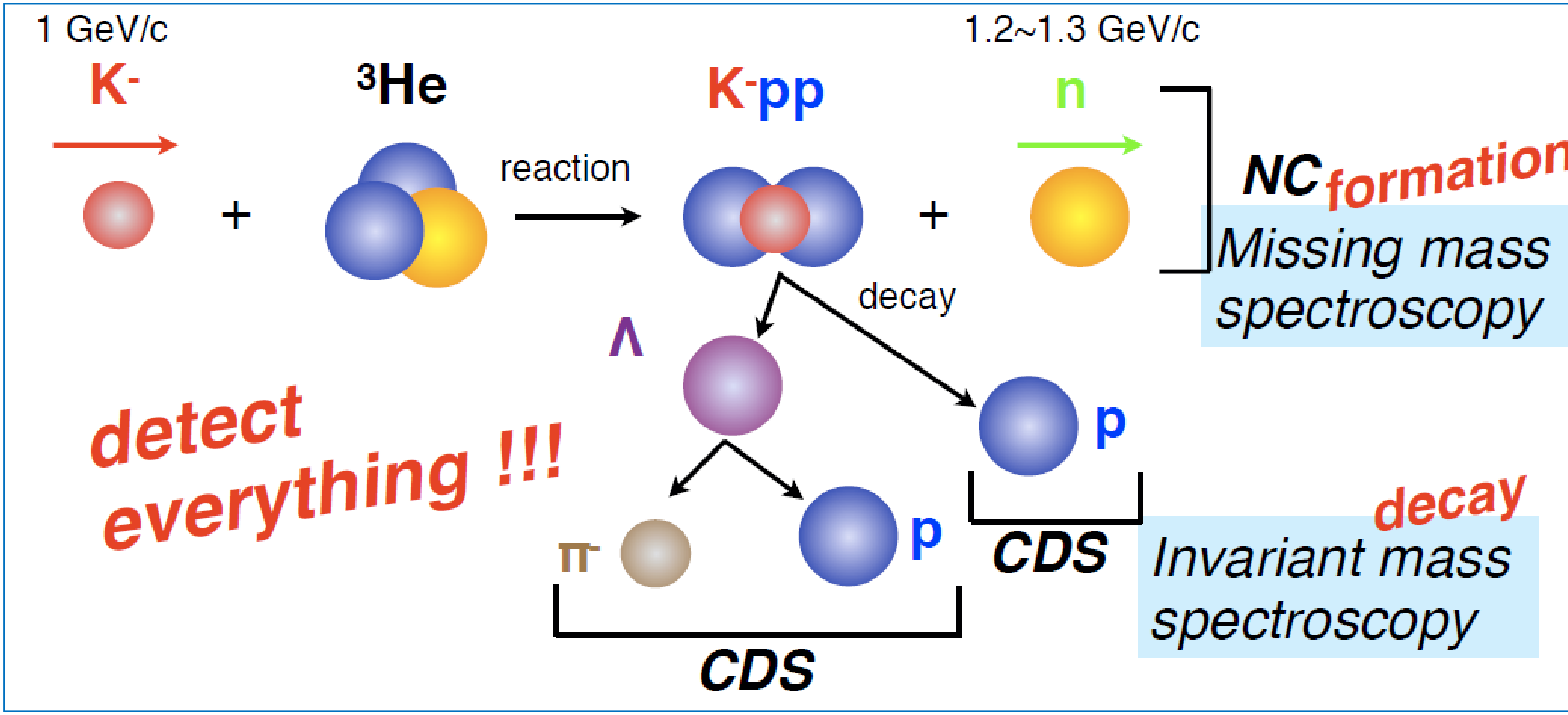


All theoretical studies predict existence of the K⁻pp

→ However, B.E. and Γ are controversial

Experimental Principle of E15

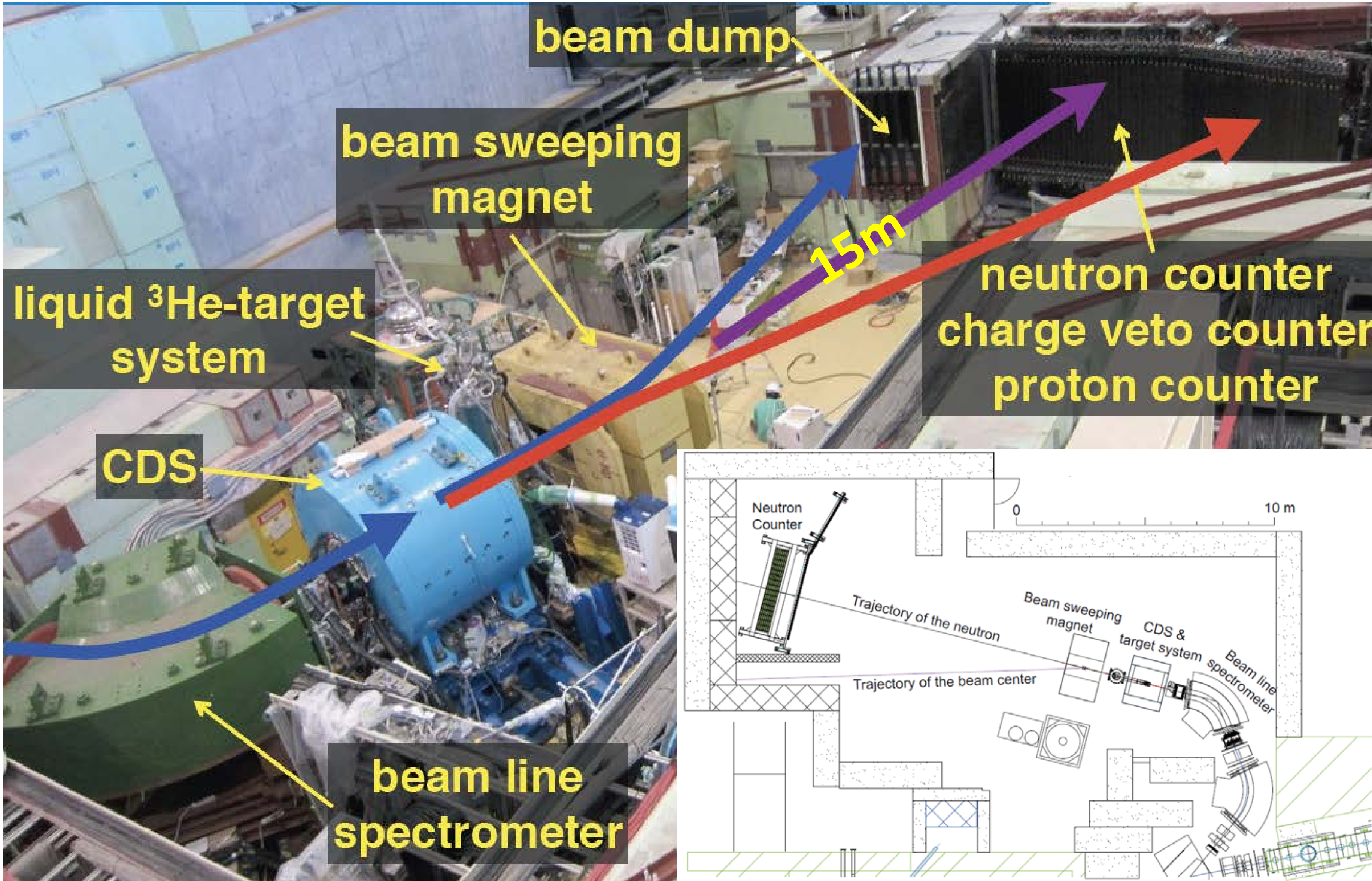
A search for the simplest kaonic nucleus, K^-pp, using ^{3}He(*in-flight* K^-,n) reaction



- two-nucleon absorption
- hyperon decays

CAN be discriminated kinematically

Experimental Setup



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

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 ^{3}He target*

Summary of E15 1st

Formation Channel

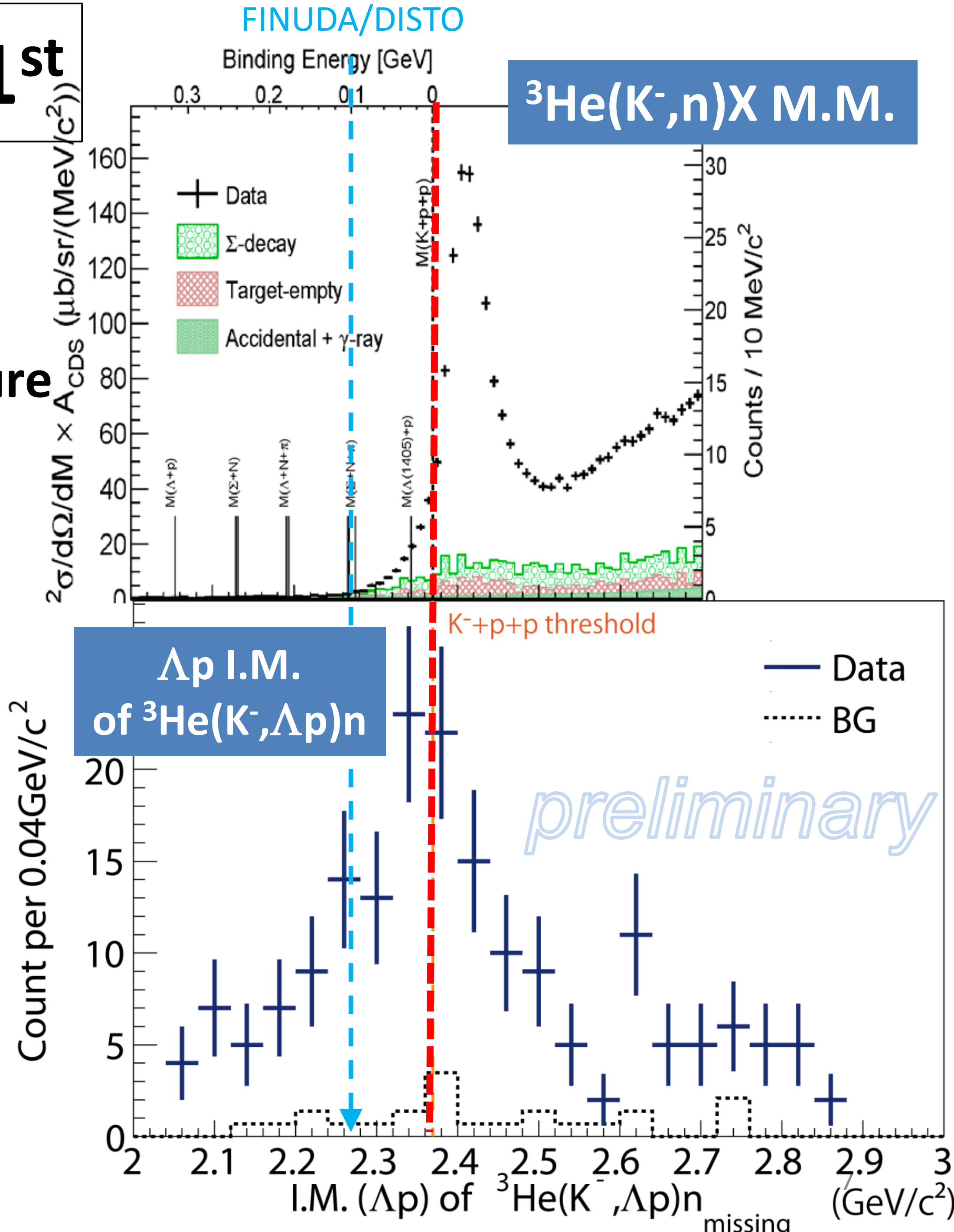
Semi-Inclusive $^{3}He(K^{-},n)X$

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

Decay Channel

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

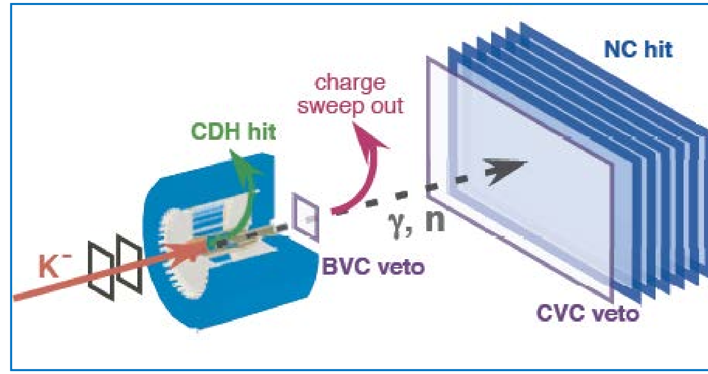
- ✓ **Hint of the excess around the threshold**
- ✓ Cannot be from 2NA of Λ*n (final state = Λpn)

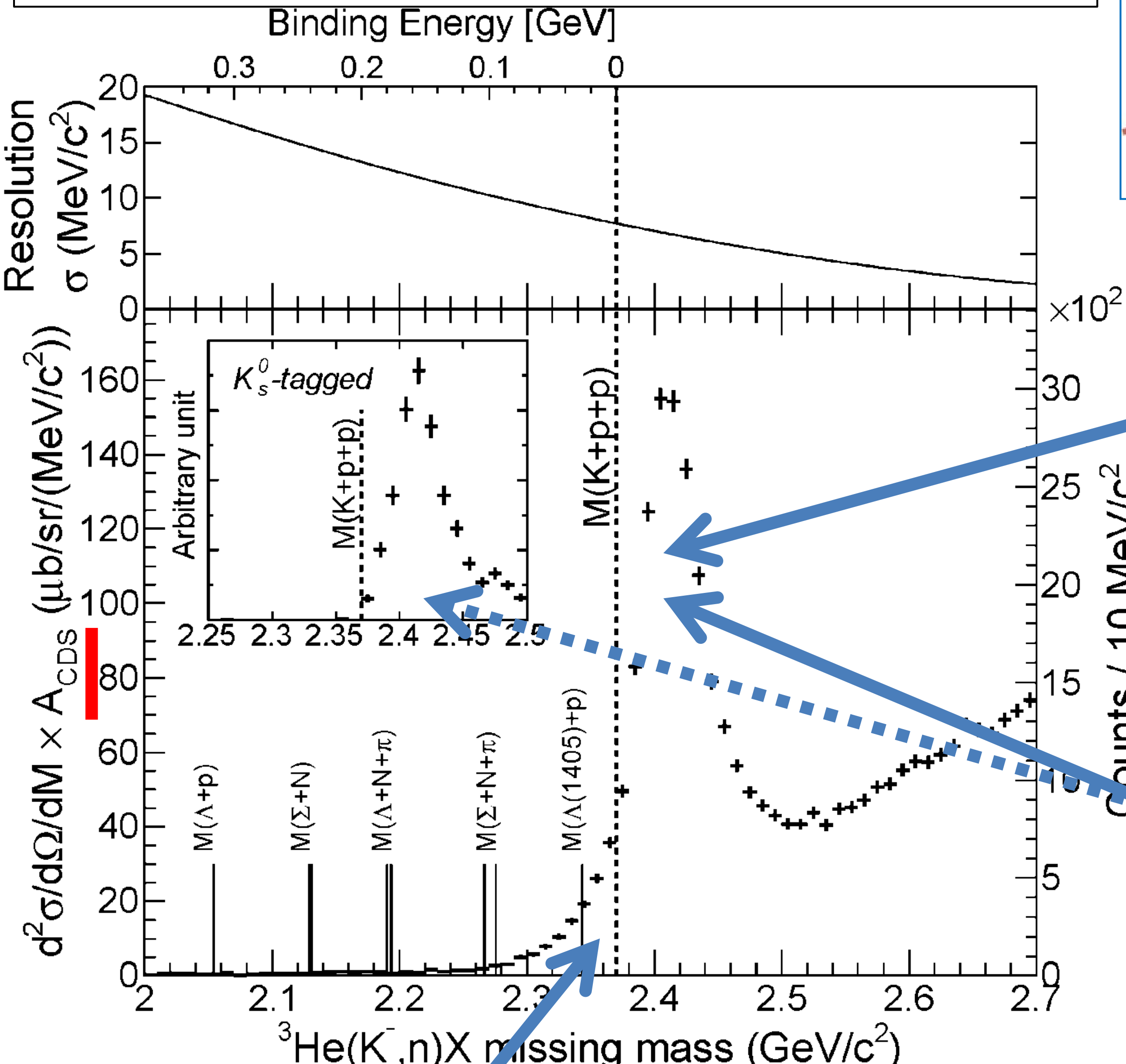


Formation Channel, Semi-Inclusive $^{3}He(K^{-},n)X$

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

Semi-Inclusive Spectrum





Quasi Elastic

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

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

and

Charge-Exchange

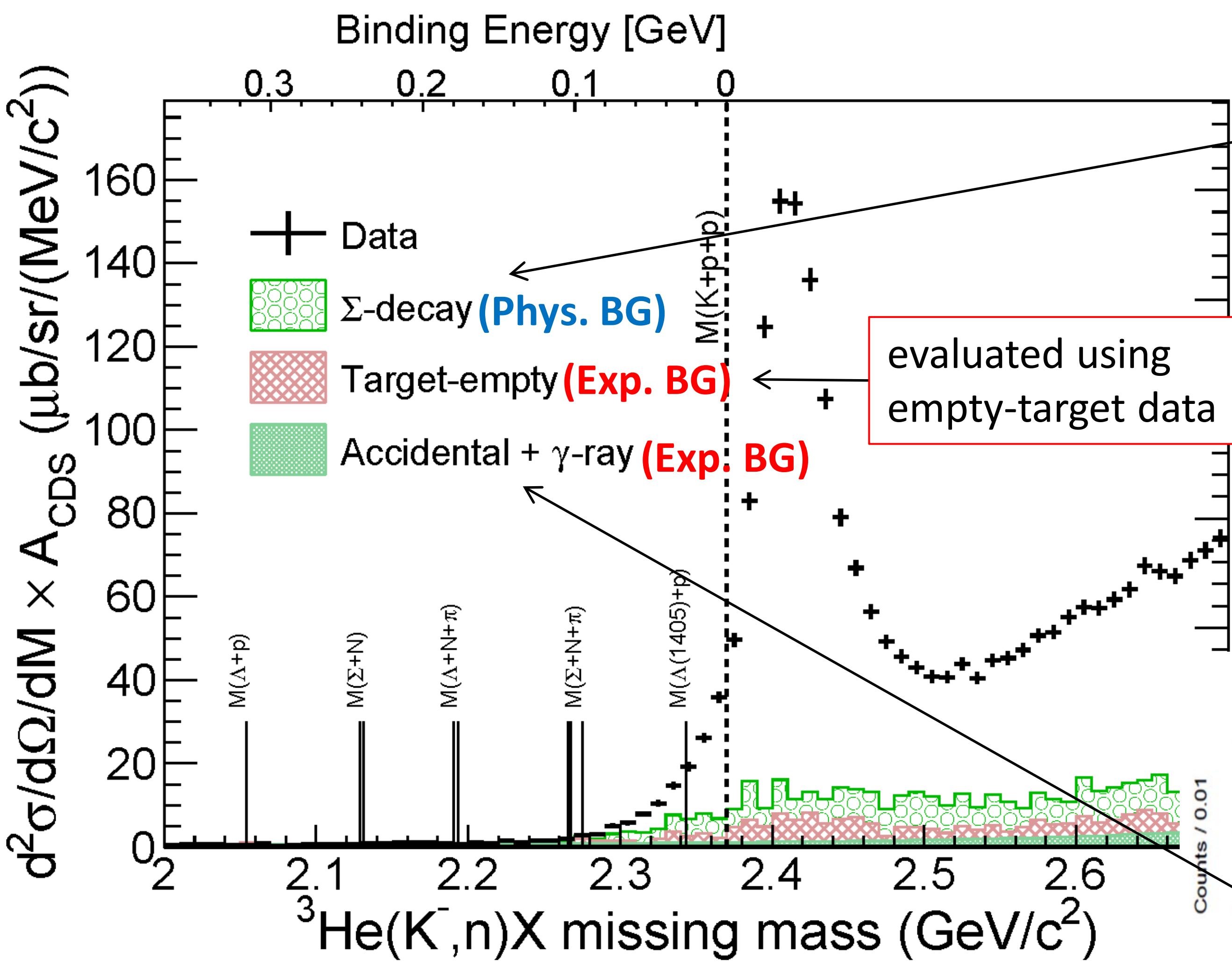
$K^- + {}^3He \rightarrow K^0 + n + d_s$

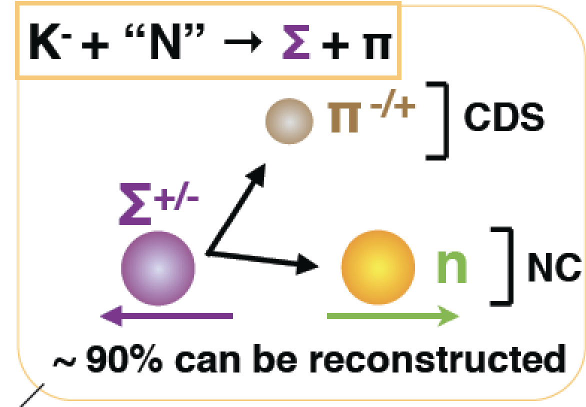
$K^0 \rightarrow \pi^+ + \pi^-$

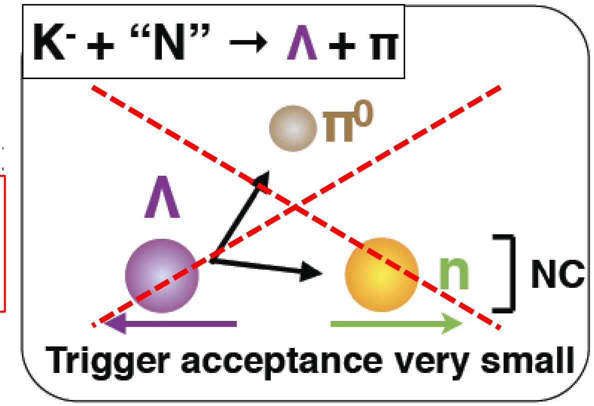
$d\sigma/d\Omega_{\theta=0deg}$ ~ 11mb/sr

The tail structure is not due to "the detector resolution"

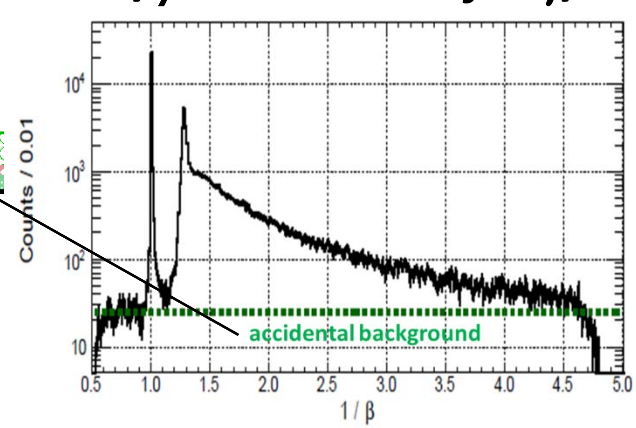
Background Evaluation



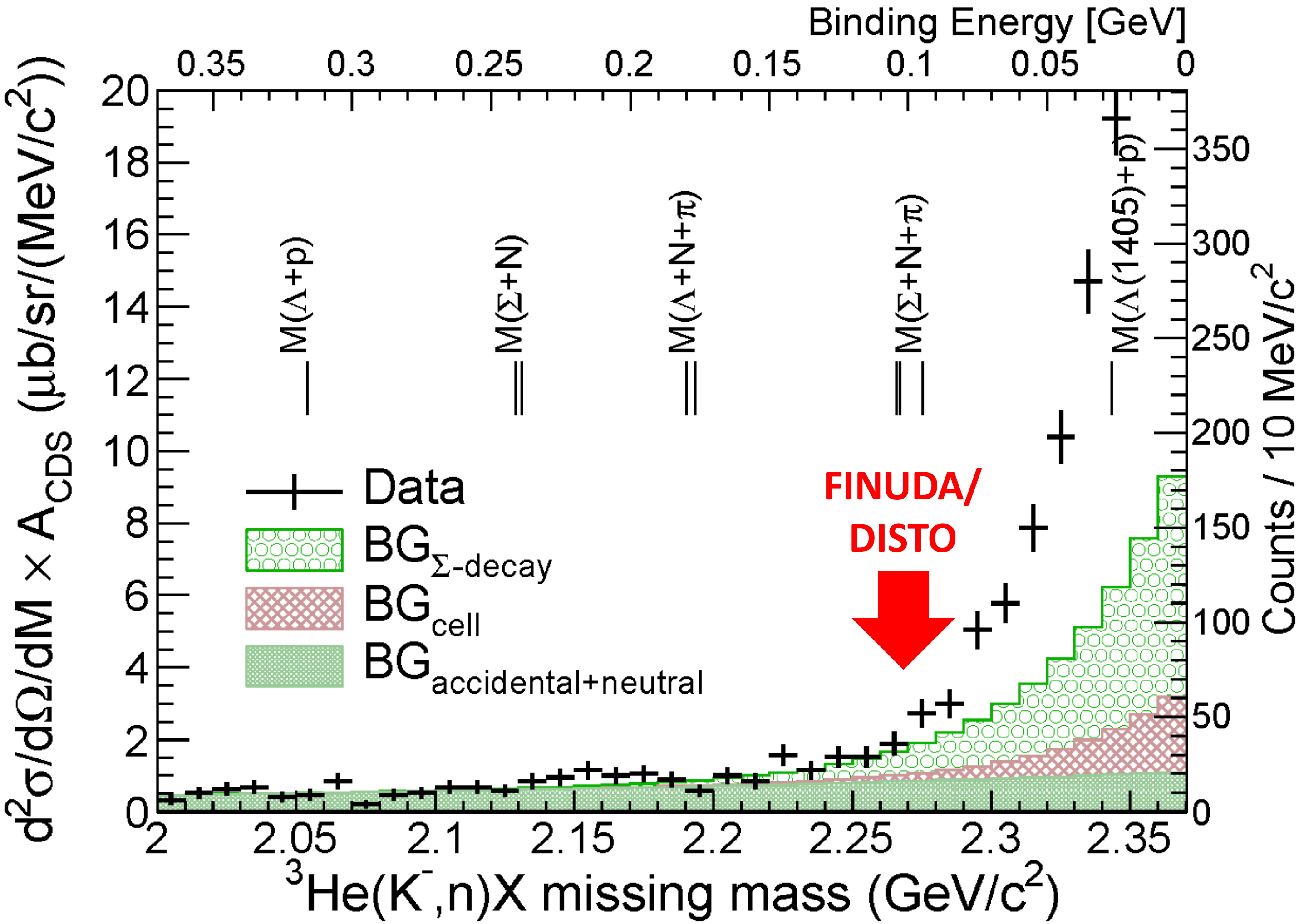




1/β distribution for γ/n

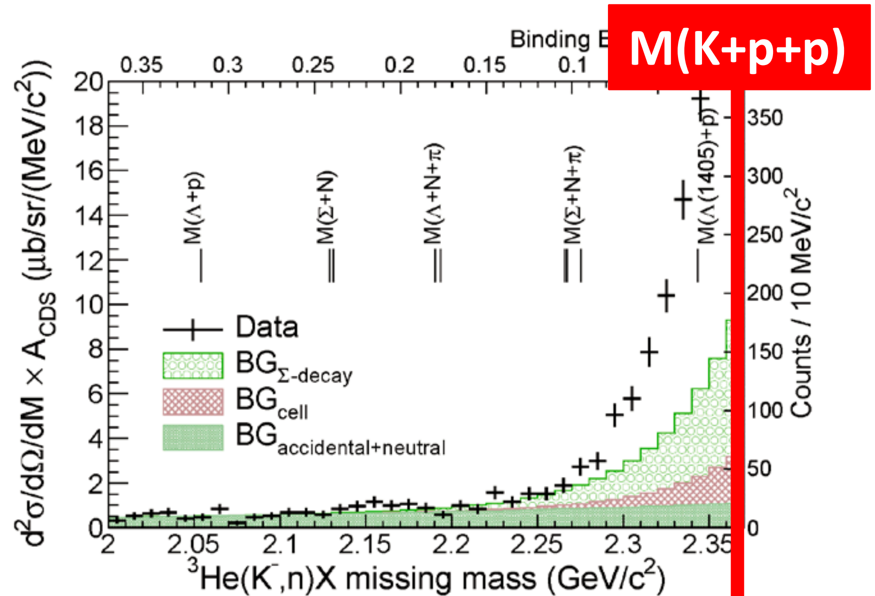


Spectrum below the Threshold



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

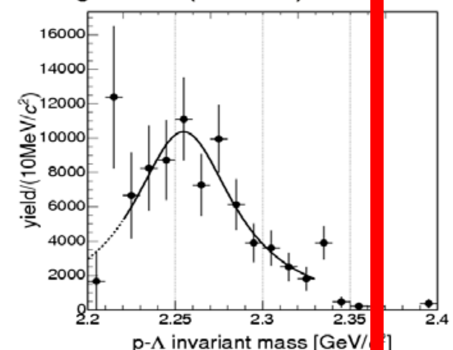
Comparison between E15 and Other Results



FINUDA@DAΦNE

PRL**94**(2005)212303

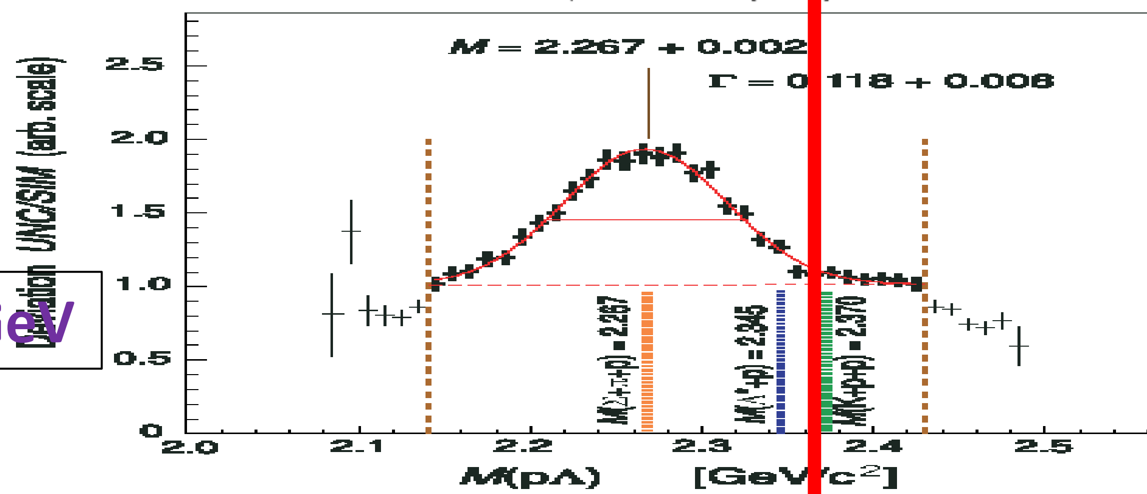
***A(stopped* K⁻, Λp)**



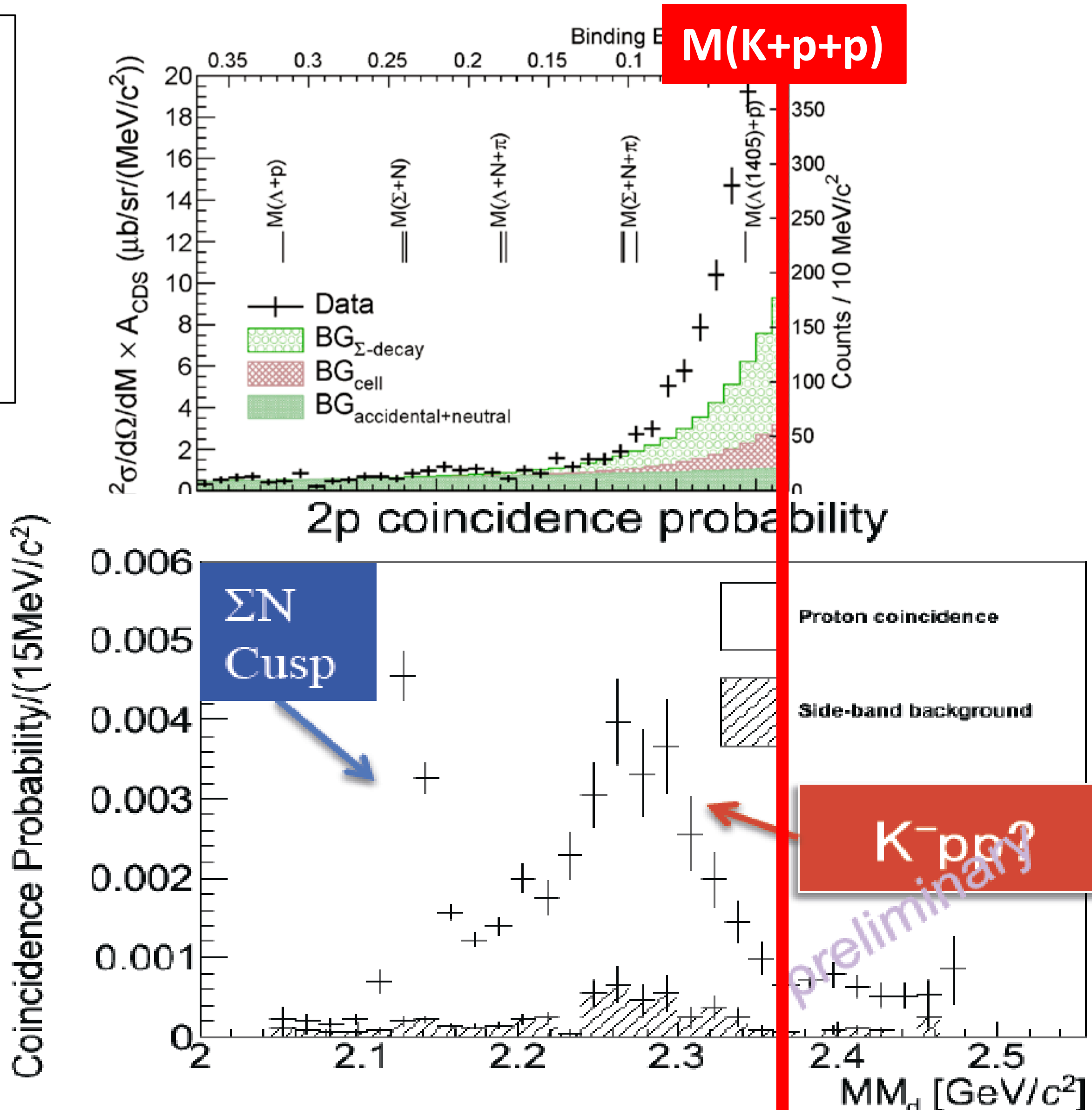
DISTO@SATURNE

PRL**104**(2010)132502

p + p → (Λ + p) + K⁺ @ 2.85GeV



Comparison between E15 and Other Results



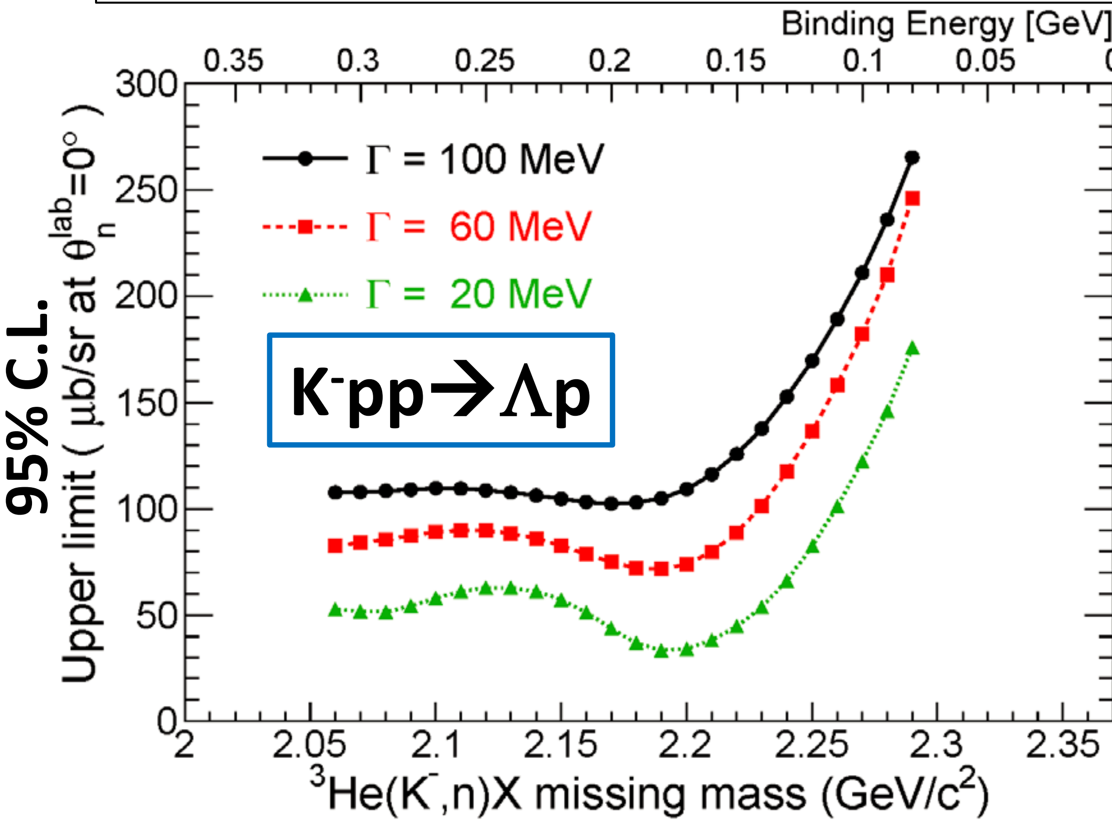
E27@J-PARC

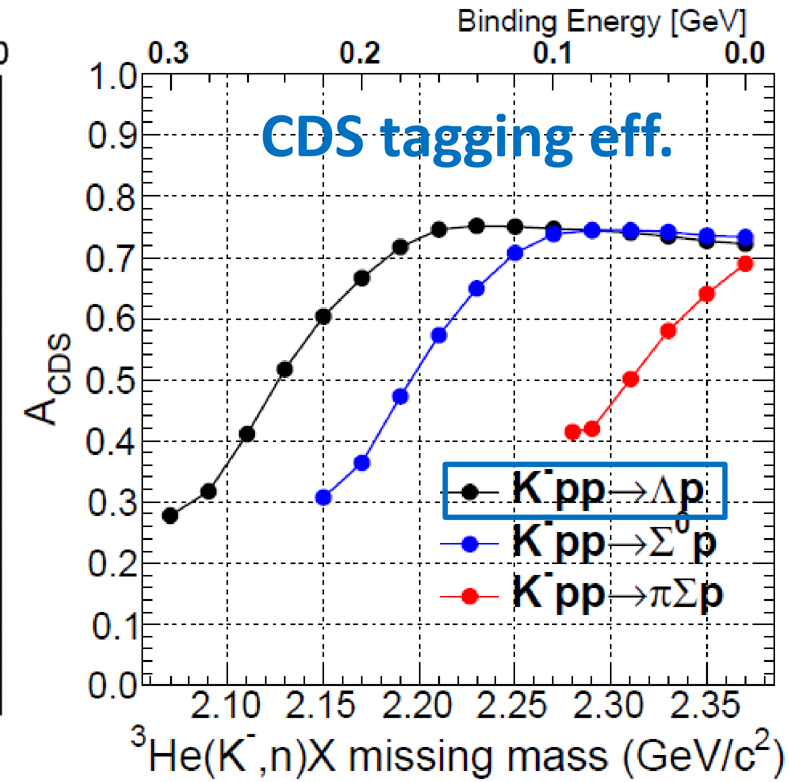
EXA2014 conference

d(π^+, K^+) @ 1.7GeV/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



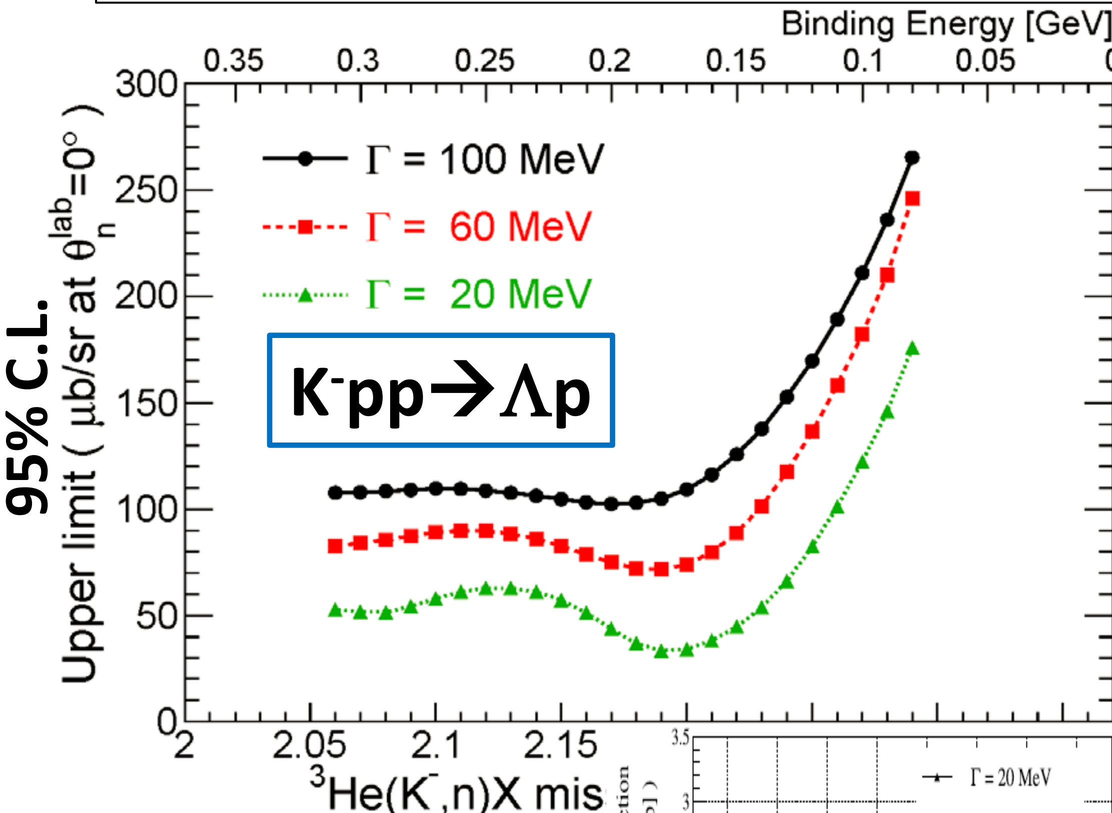


Assumptions

- K^-pp → Λp decay mode (isotropic decay)
- K^-pp shape = Breit-Wigner

U.L. depends on the decay mode

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

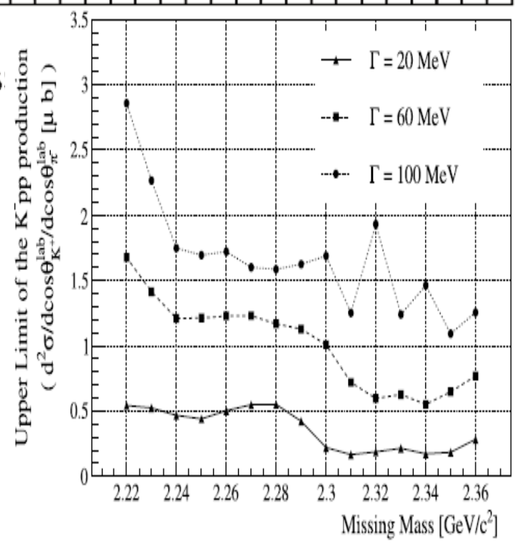


- **E15(K$^-$+^{3}He):**
  (UL) 0.5-5% of QF
- **FINUDA(stopped K$^-$):**
  ~0.1% of stopped K$^-$
- **DISTO(p+p):**
  larger than Λ* @ 2.85GeV
- **LEPS(γ+d)**
  (UL) 1.5-26% of γN→K$^+$π$^-$Y

LEPS@SPring-8

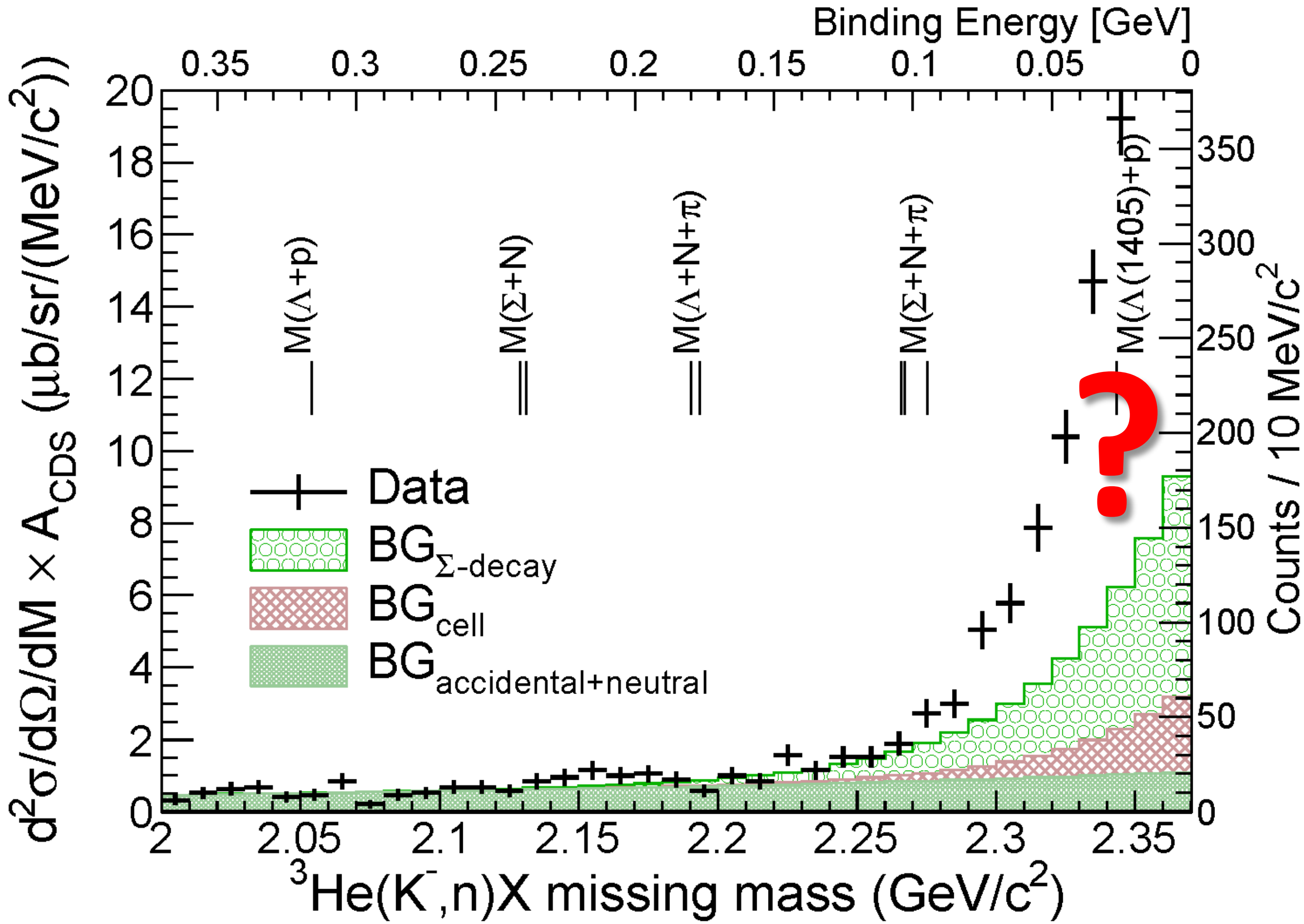
PLB**728**(2014)616

γ + d → K$^+$ + π$^-$ + X
@ 1.5-2.4GeV



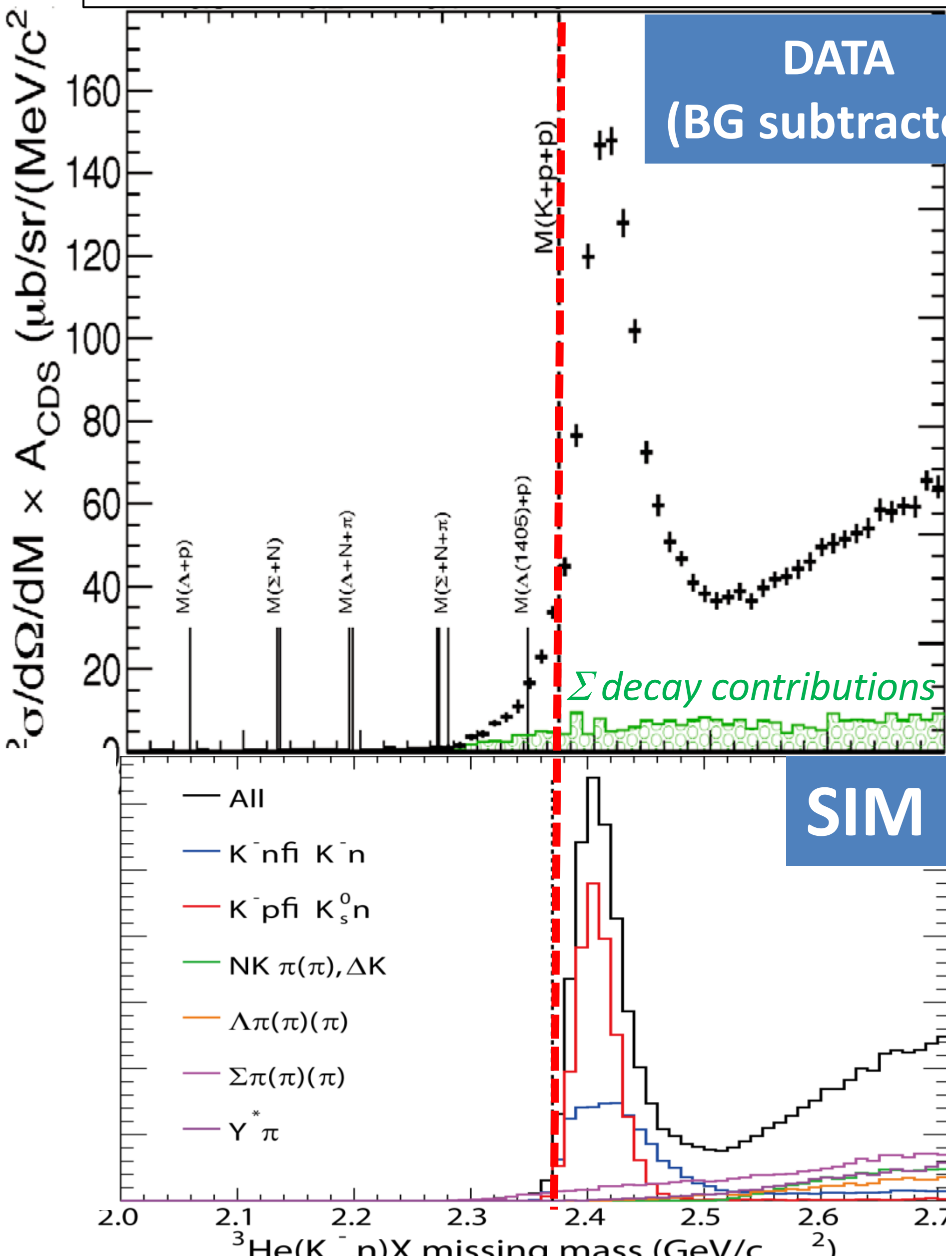
Upper limits (CS) can be directly compared with QF yield.

Spectrum below the Threshold



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

Excess = Elementary Processes?



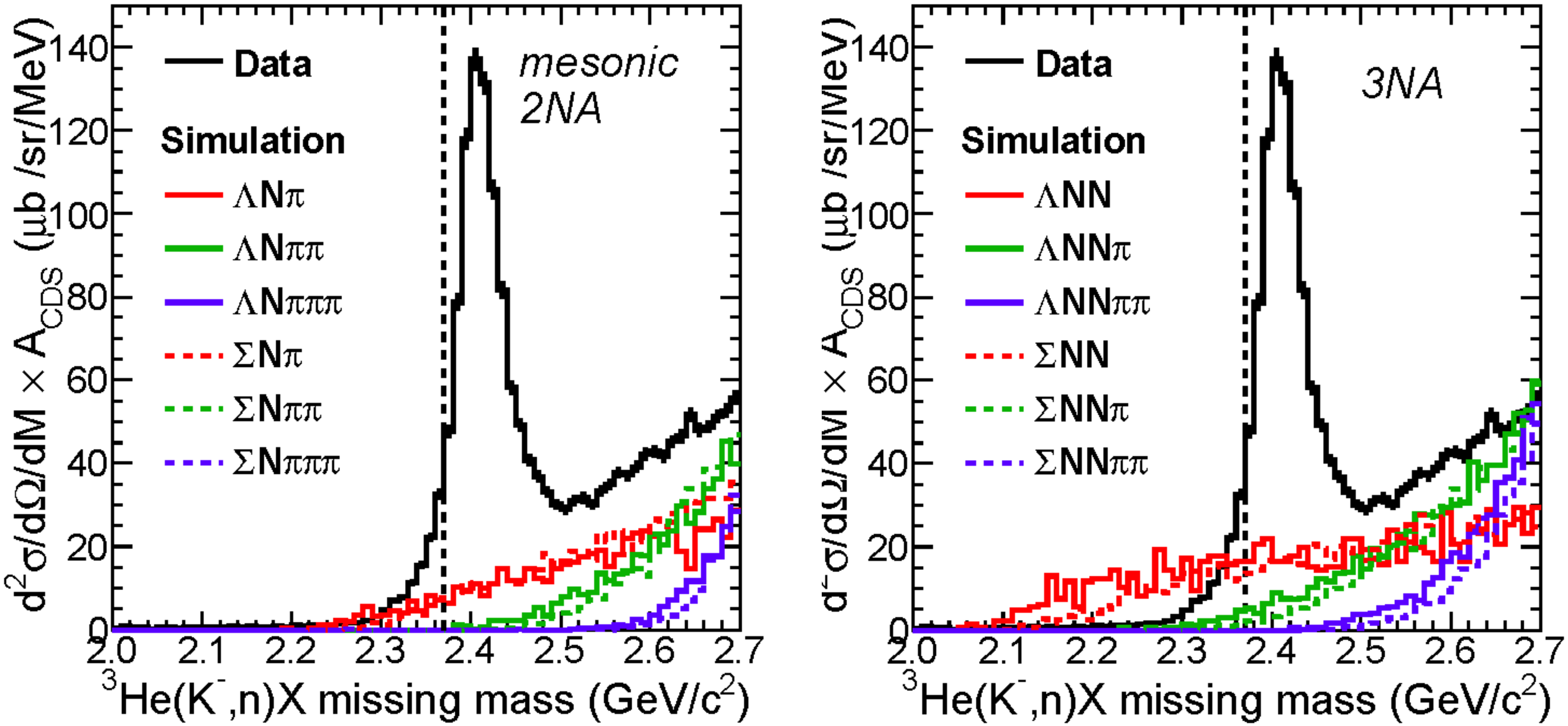
The tail structure is NOT reproduced by well known processes

would be attributed to the imaginary part of the attractive $K^{bar}N$

→ 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:
  - $\sigma_{tot} = 2*\sigma_{K\text{-}p} + \sigma_{K\text{-}n}$ (~150mb)

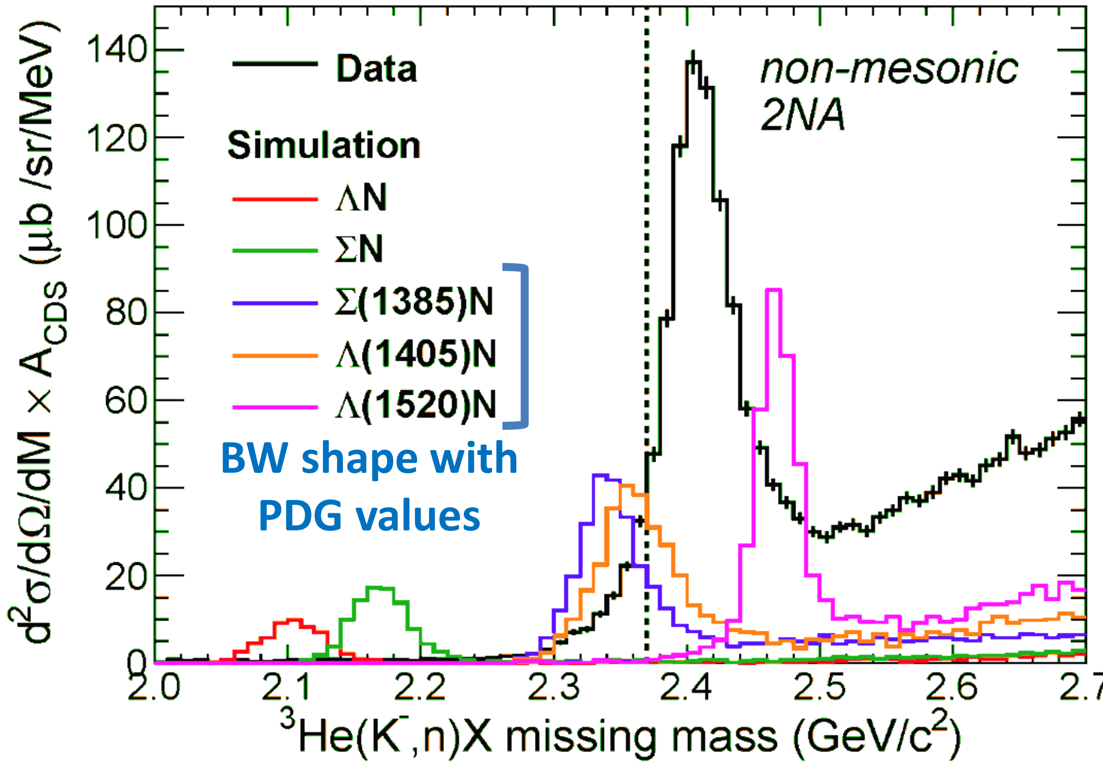
Excess = πΣN, πΣNN, etc?



Each process is simulated with unreasonably large CS of 100mb

➔ **contributions in the binding region are negligible**

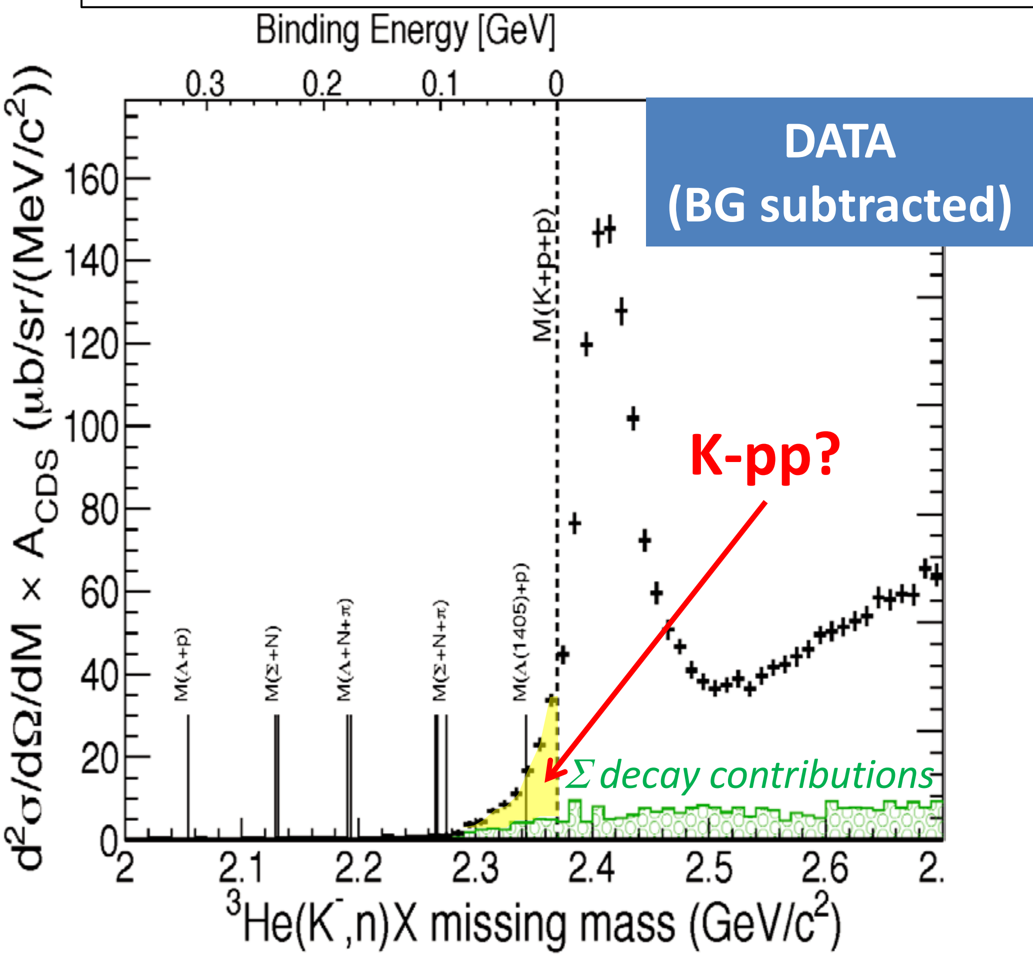
Excess = Λ^*N, etc?

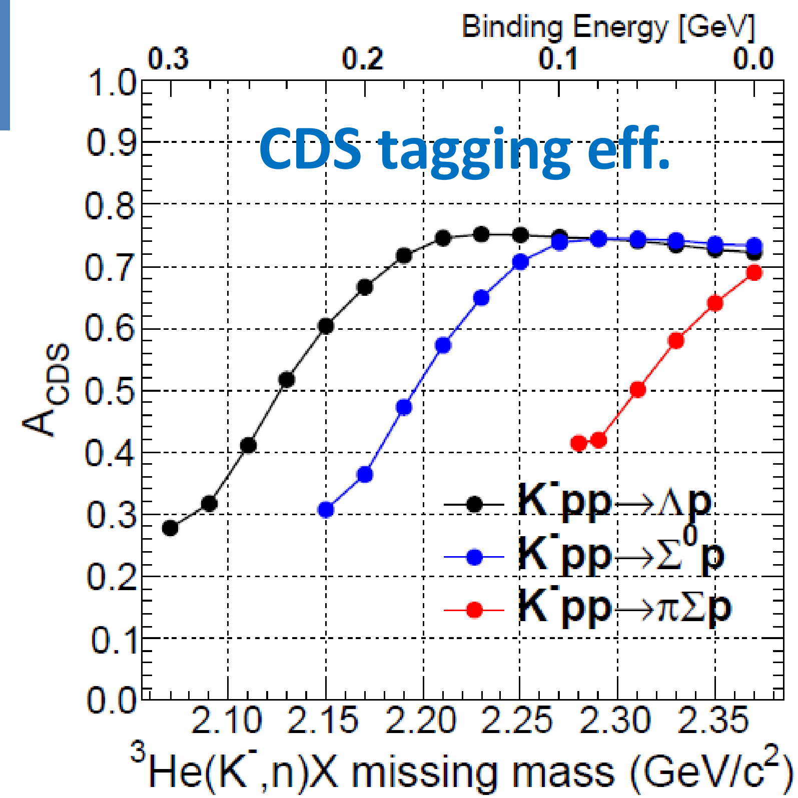


CS of each process : 20mb/sr @ 0 degrees

- **ΛN/ΣN branches are negligibly small** (consistent with KEK-PS E548)
- **Λ(1405)n branch seems to reproduce the excess**
  - Λ(1405) shape is "*simple BW with PDG values*"
  - need rather large CS of ~5mb/sr
- **For further study, exclusive measurement of πΣN is needed.**

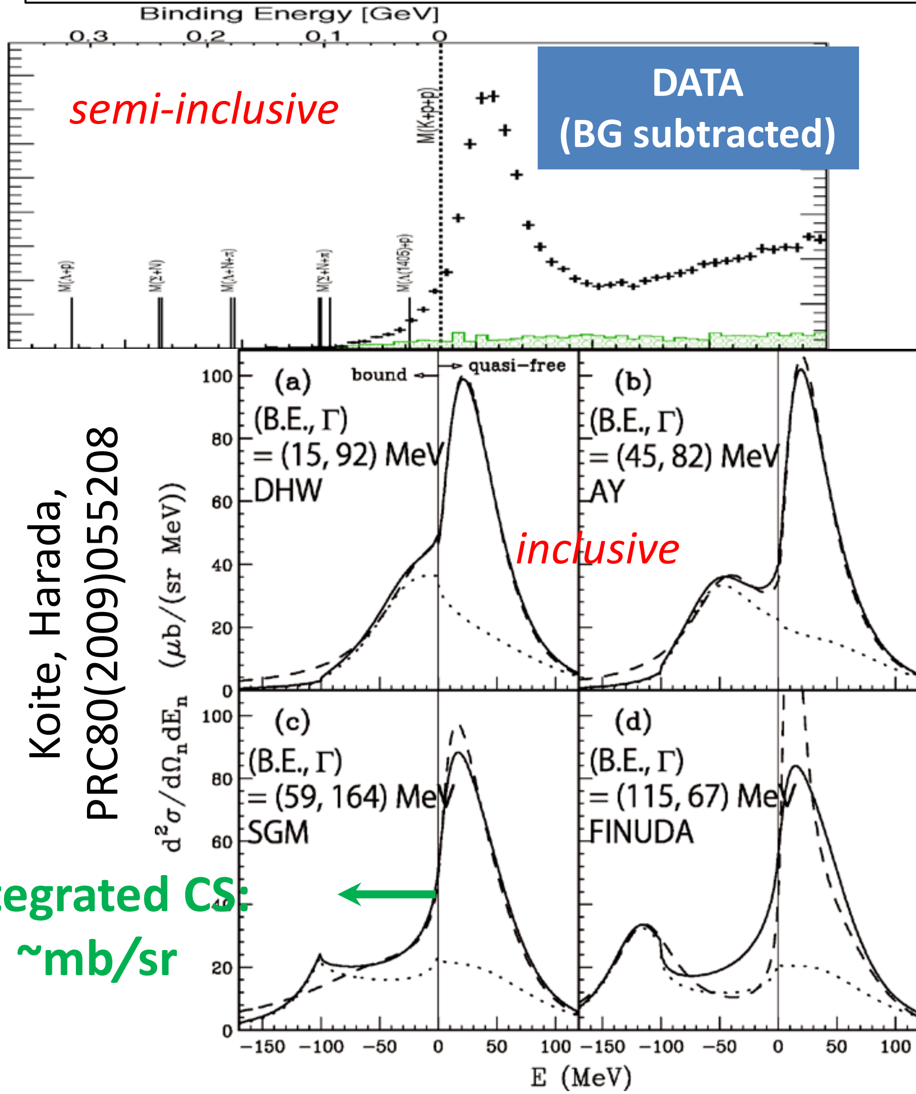
Excess = Loosely-Bound K^-pp?



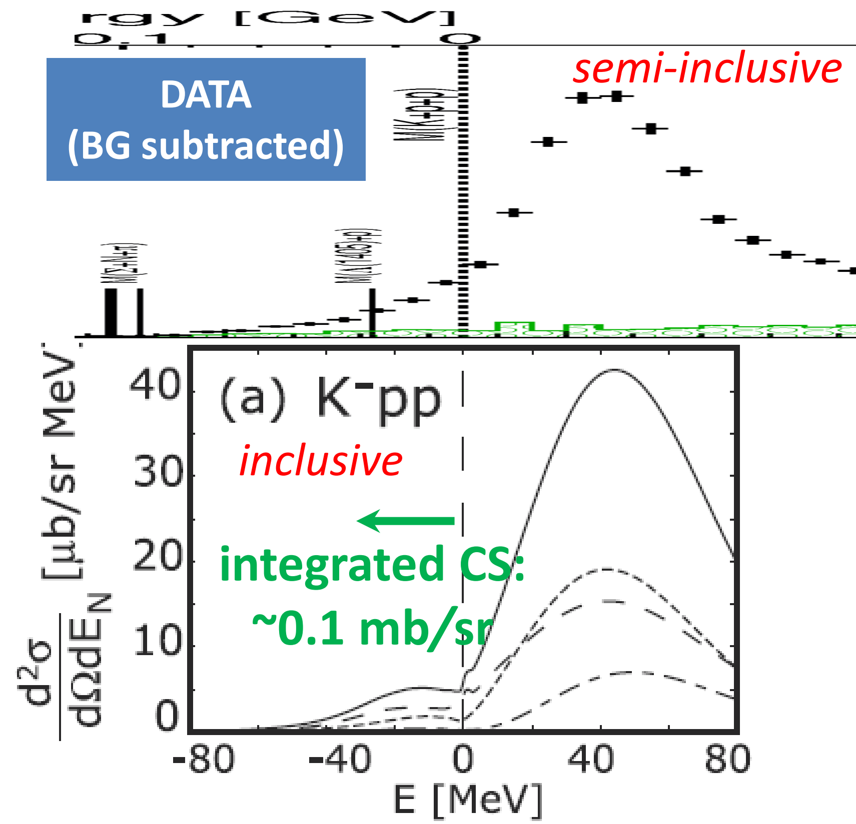


- The excess is **assumed** to be fully attributed to the bound K^-pp state
- **$d\sigma/d\Omega(\theta_{lab}=0^o)$ of the excess is ~ mb/sr** (Excess/QF < ~10%)

Comparison between E15 and Calc.



Koite, Harada, PRC80(2009)055208



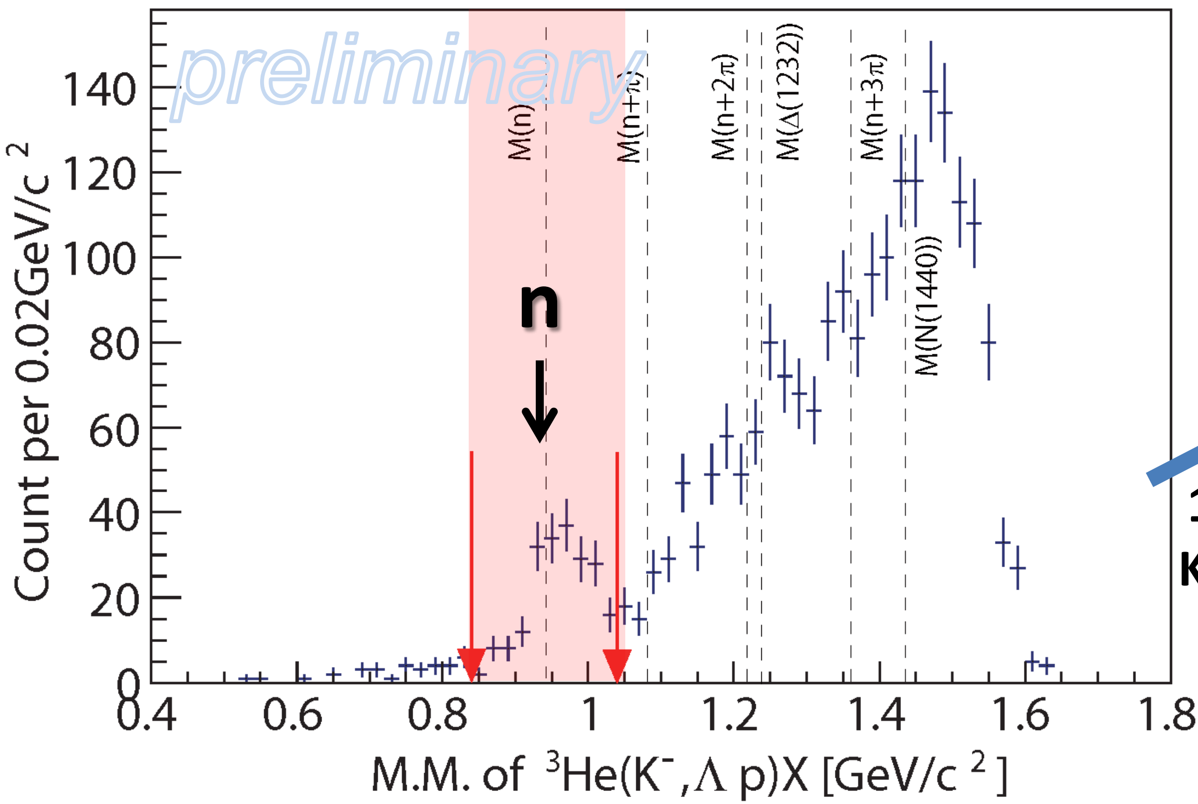
Yamagata-Sekihara, et al., PRC80(2009)045204

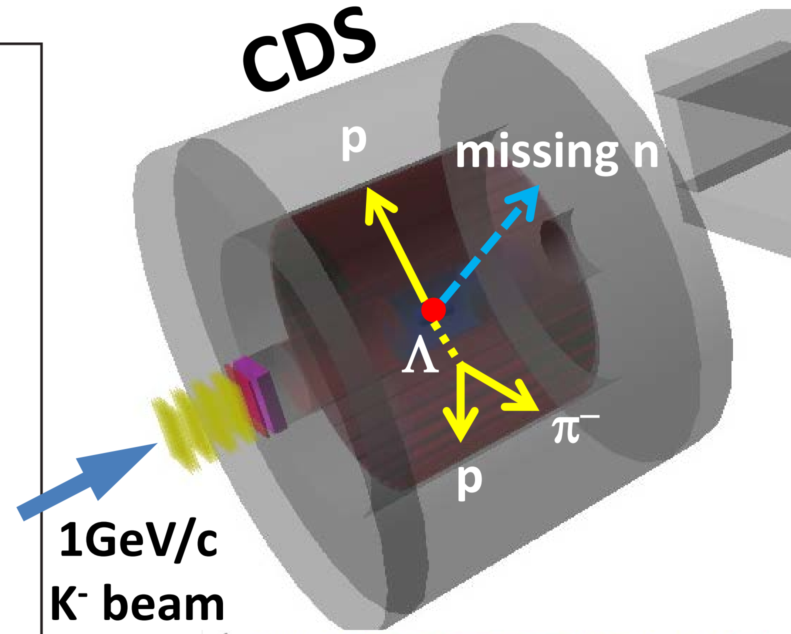
- CS is roughly consistent with KH
- Loosely-bound K-pp state ???

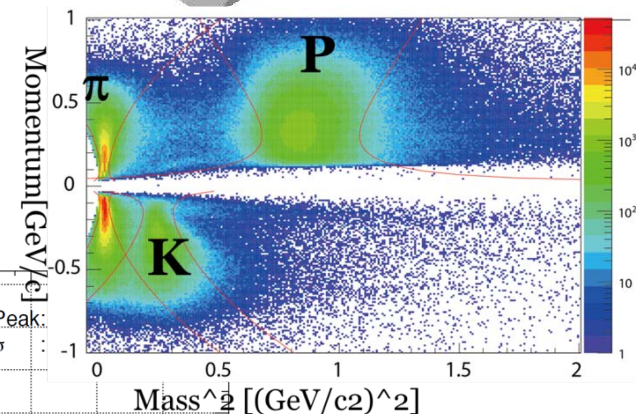
$\pi\Sigma N$ measurement is an important key

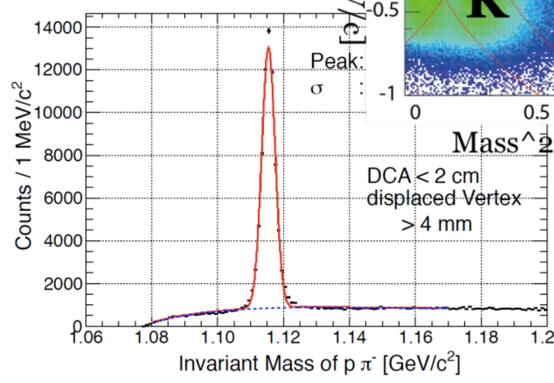
Decay Channel,
Exclusive ^{3}He(K^{-},Λp)n

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



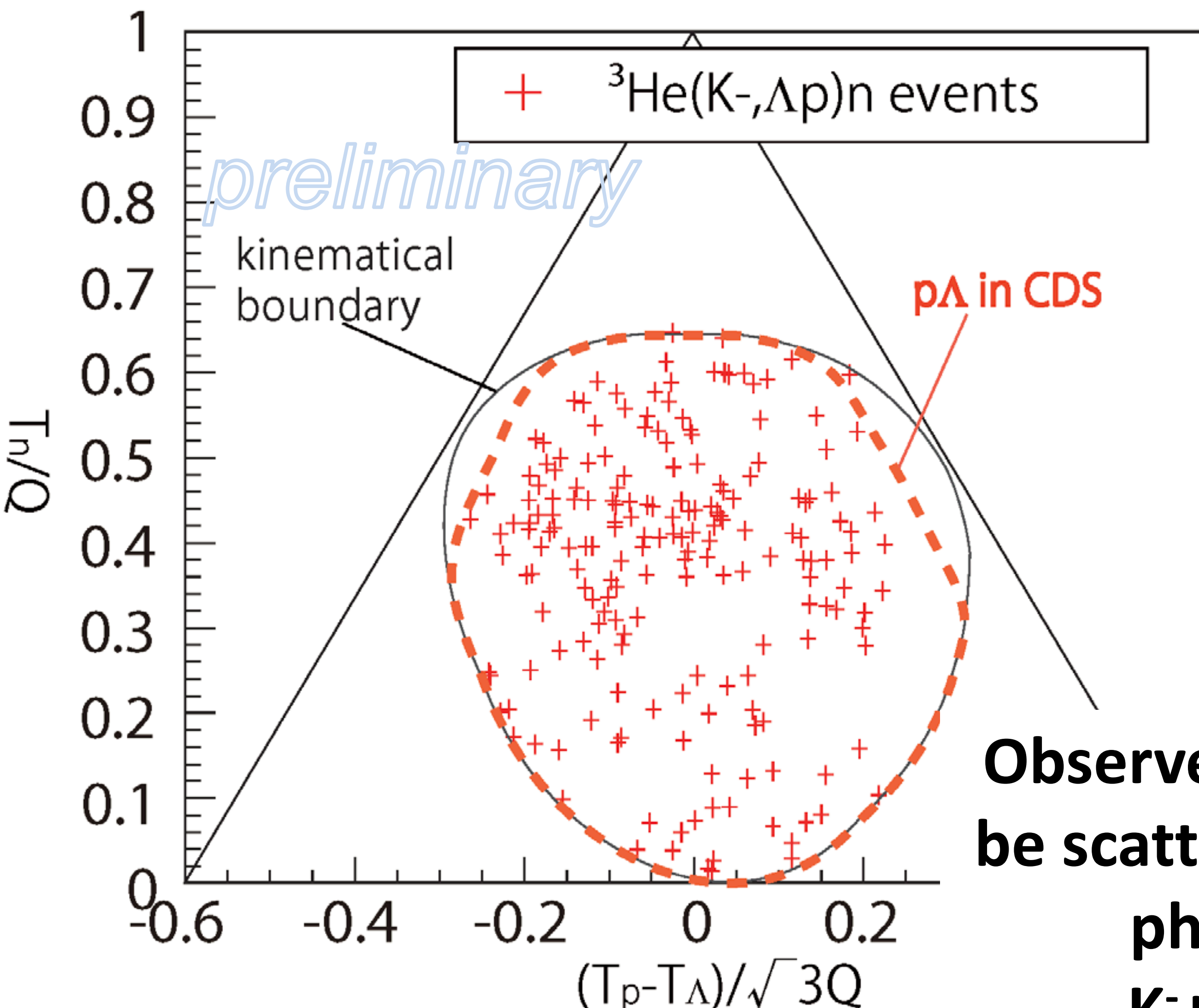






- $K^-{}^3He \rightarrow \Lambda(\Sigma^0)pn$ events can be identified exclusively
  - # of $\Lambda(\Sigma^0)pn$ events: ~190
    - Σ^0pn contamination: ~20%

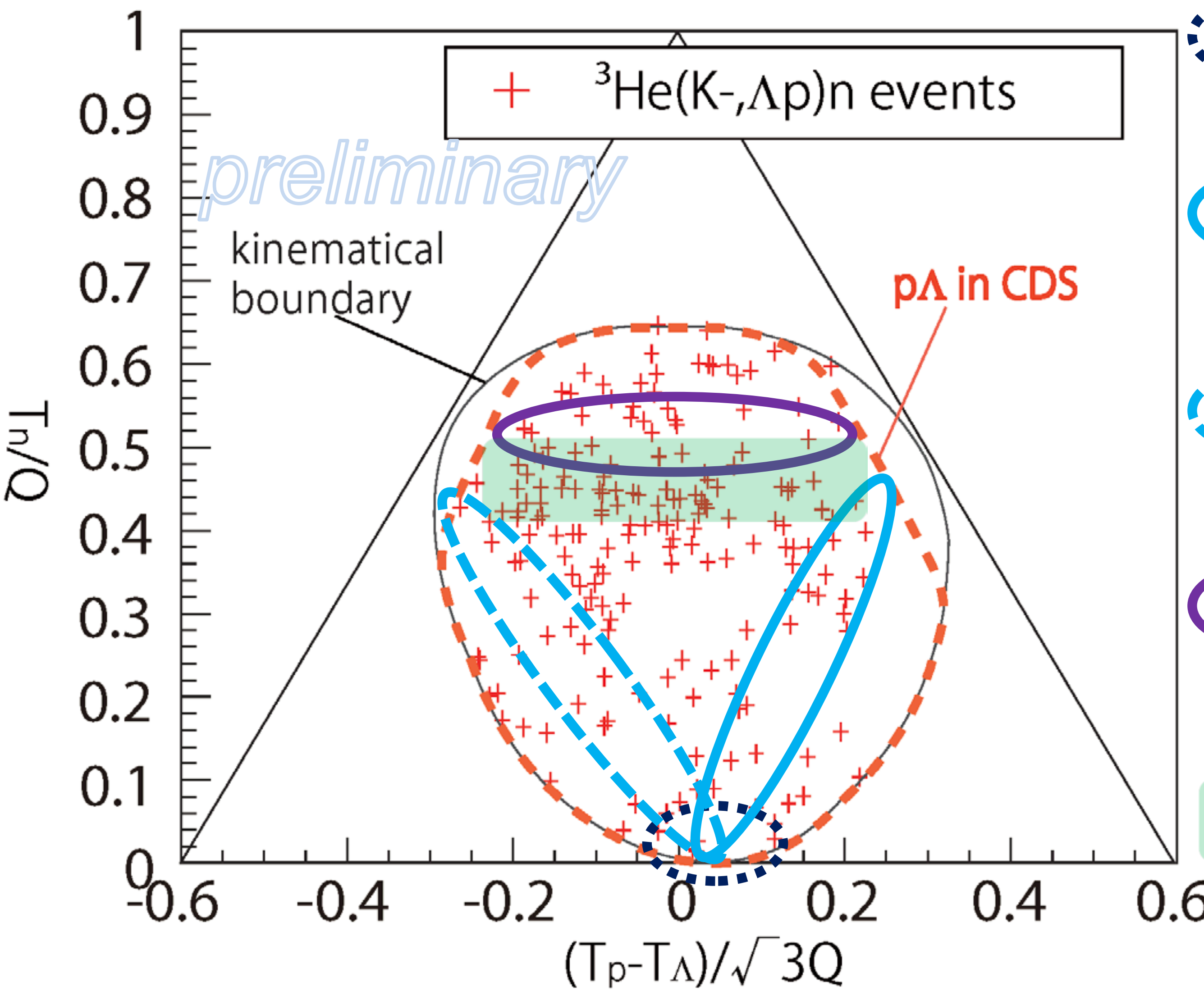
Dalitz plot



3NA:
e.g. $K^- {}^3He \rightarrow$ **Λpn**

Observed events seem to be scattered widely in the phase-space of $K^- + {}^3He \rightarrow \Lambda + p + n$

Dalitz plot



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

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

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

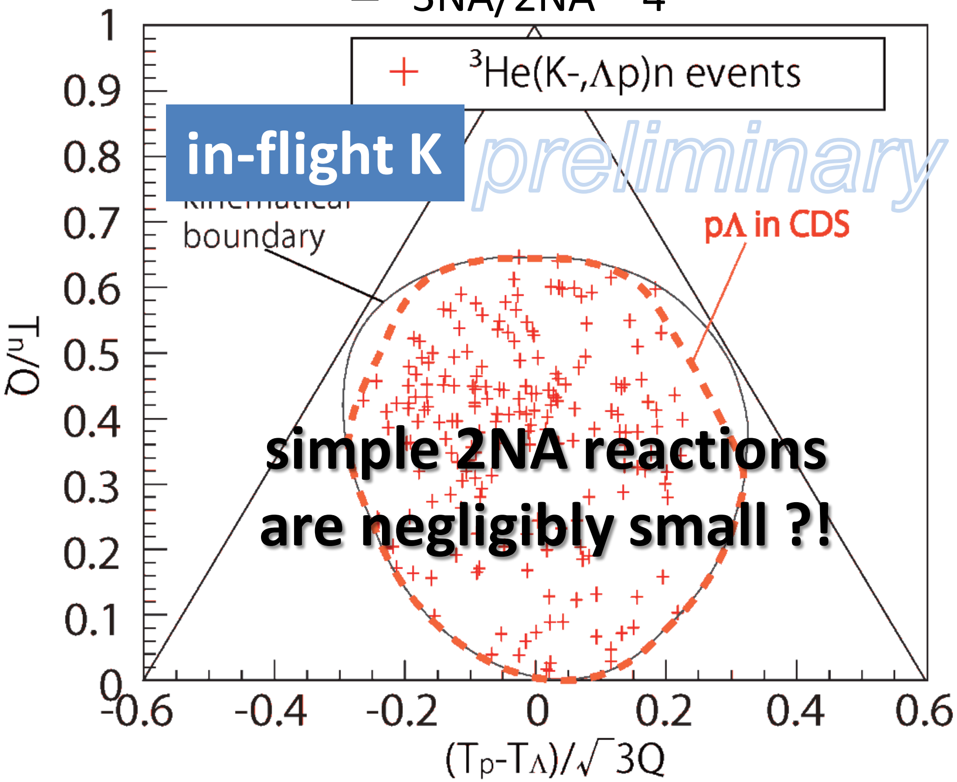
2NA+2step:
e.g. $K^-{}^3He \rightarrow \Sigma^0 n p_s$,
$\Sigma^0 p_s \rightarrow \Lambda p$

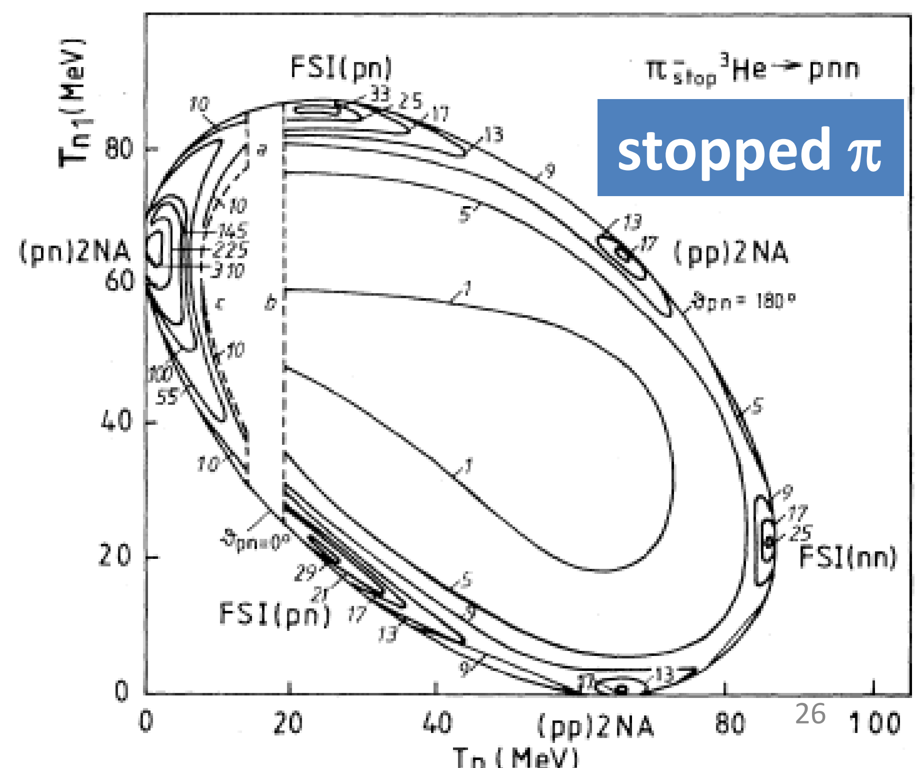
K^-pp form.:
$K^-{}^3He \rightarrow (K^-pp)n$,
$K^-pp \rightarrow \Lambda p$

K-induced vs π-induced

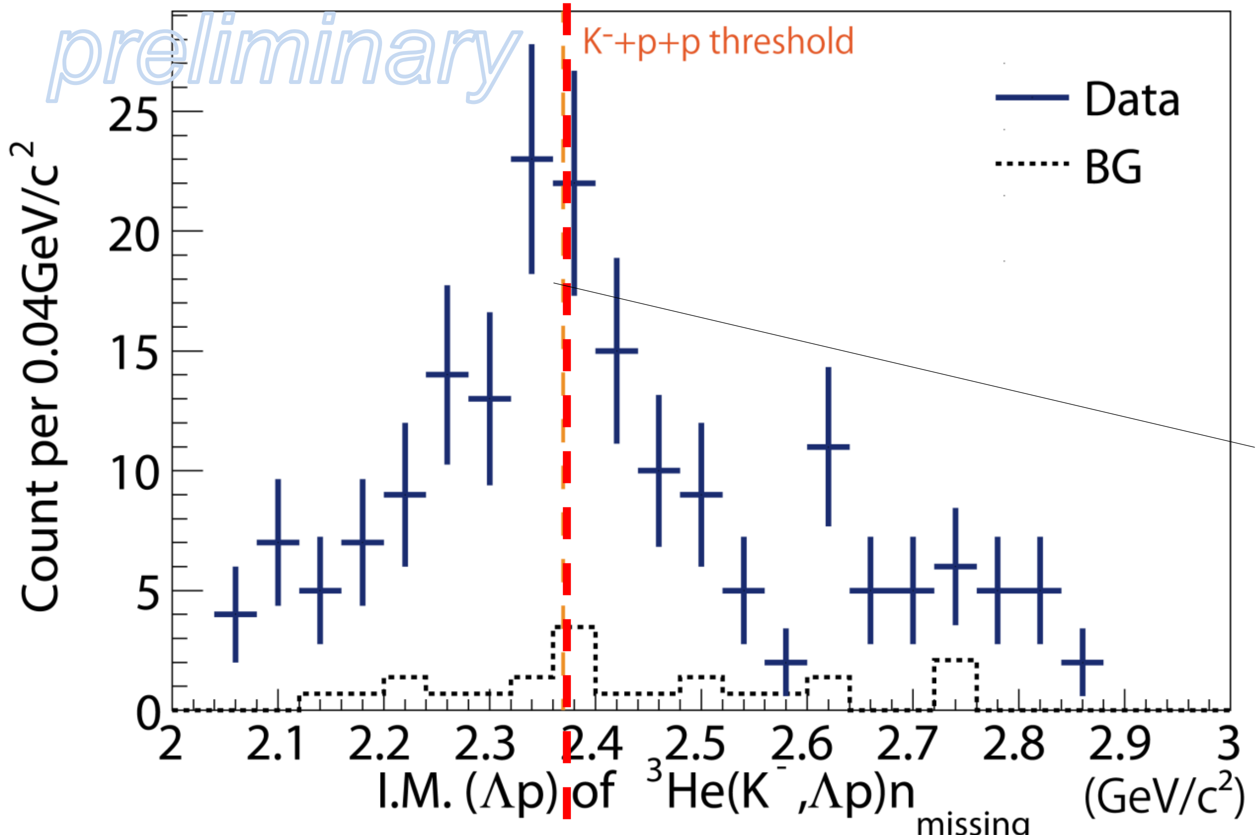
[1] D. Gotta, et al., PRC51. 496 (1995)
[2] P. Weber et al., NPA501 765 (1989)
[3] G. Backenstoss et al., PRL55. 2782 (1985)

- 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 ± 0.17mb (266 MeV/c)
  - 3nucleon absorption 3.7 ± 0.6 mb(220 MeV/c)
  - 3NA/2NA ~ 4



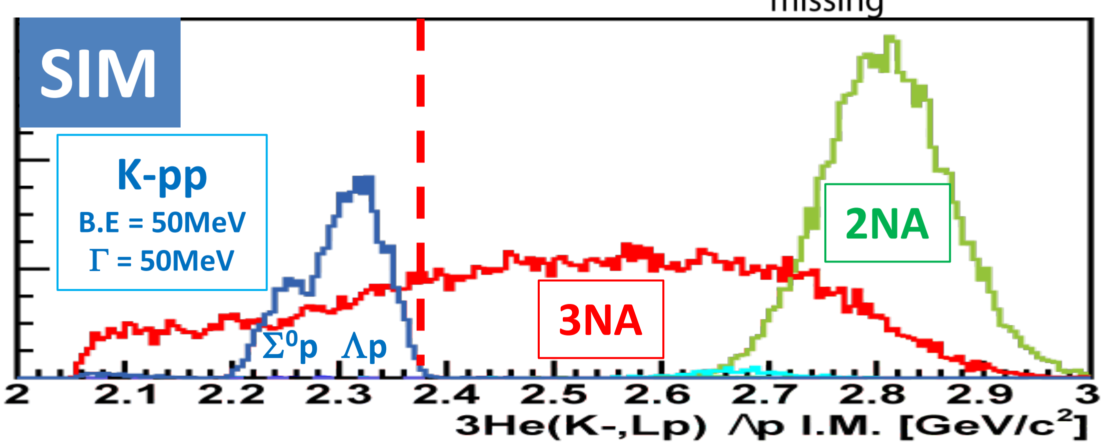


Λp Invariant Mass



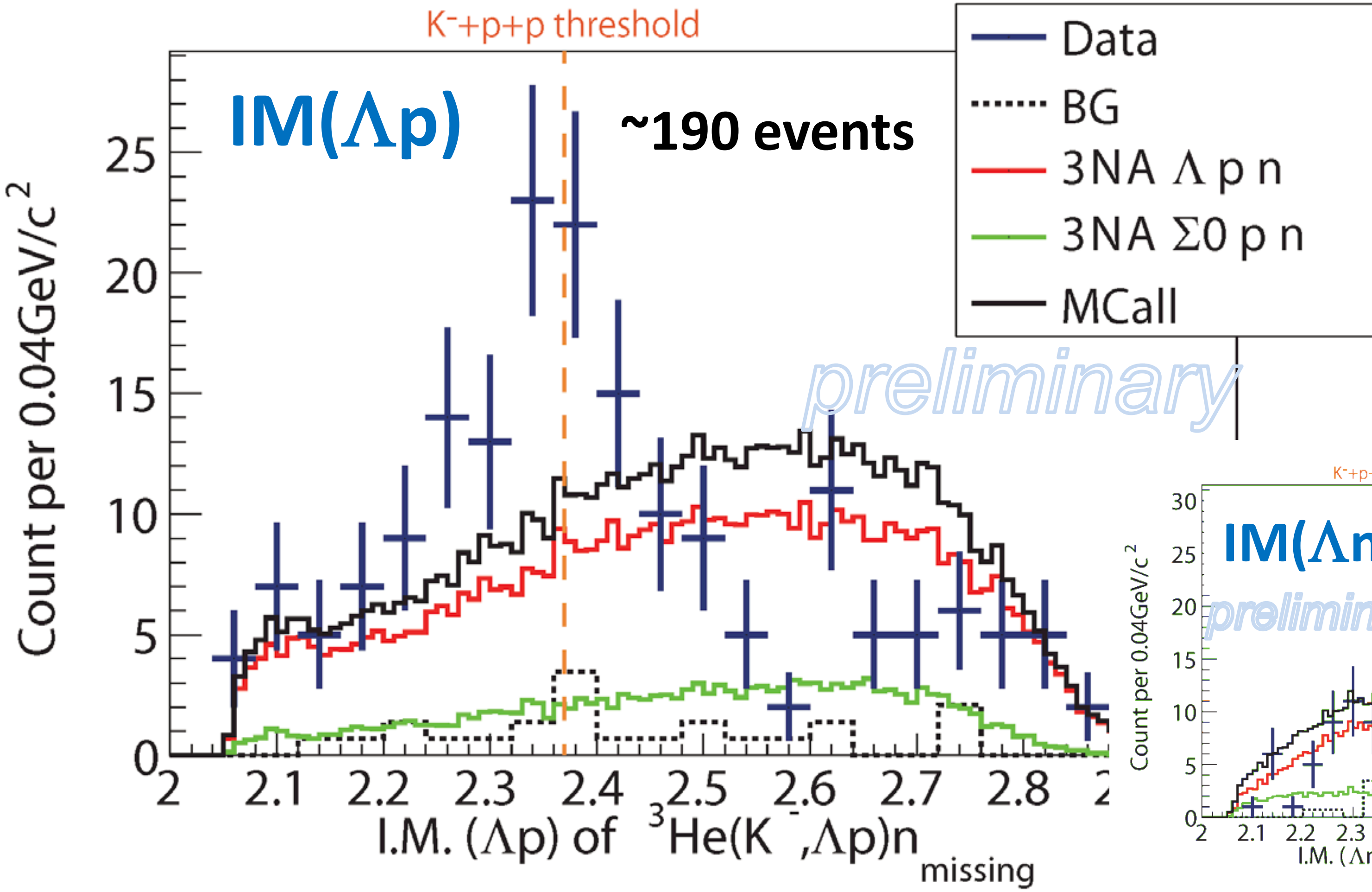
FS = Λ (Σ⁰) pn
→ cannot be from
*2NA of Λ*n*

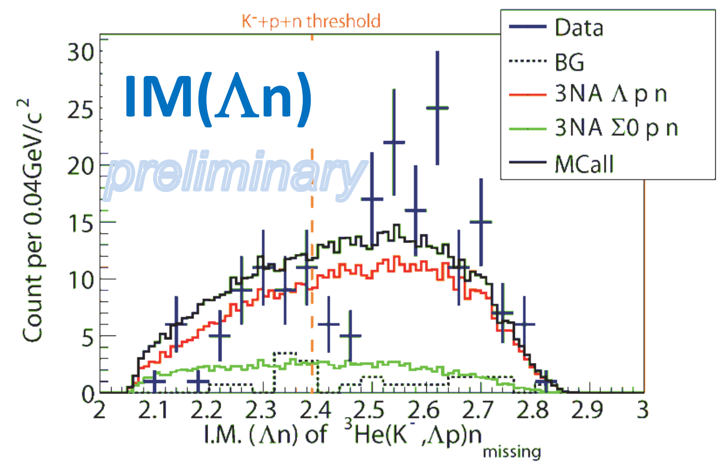
Excess around the threshold?



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

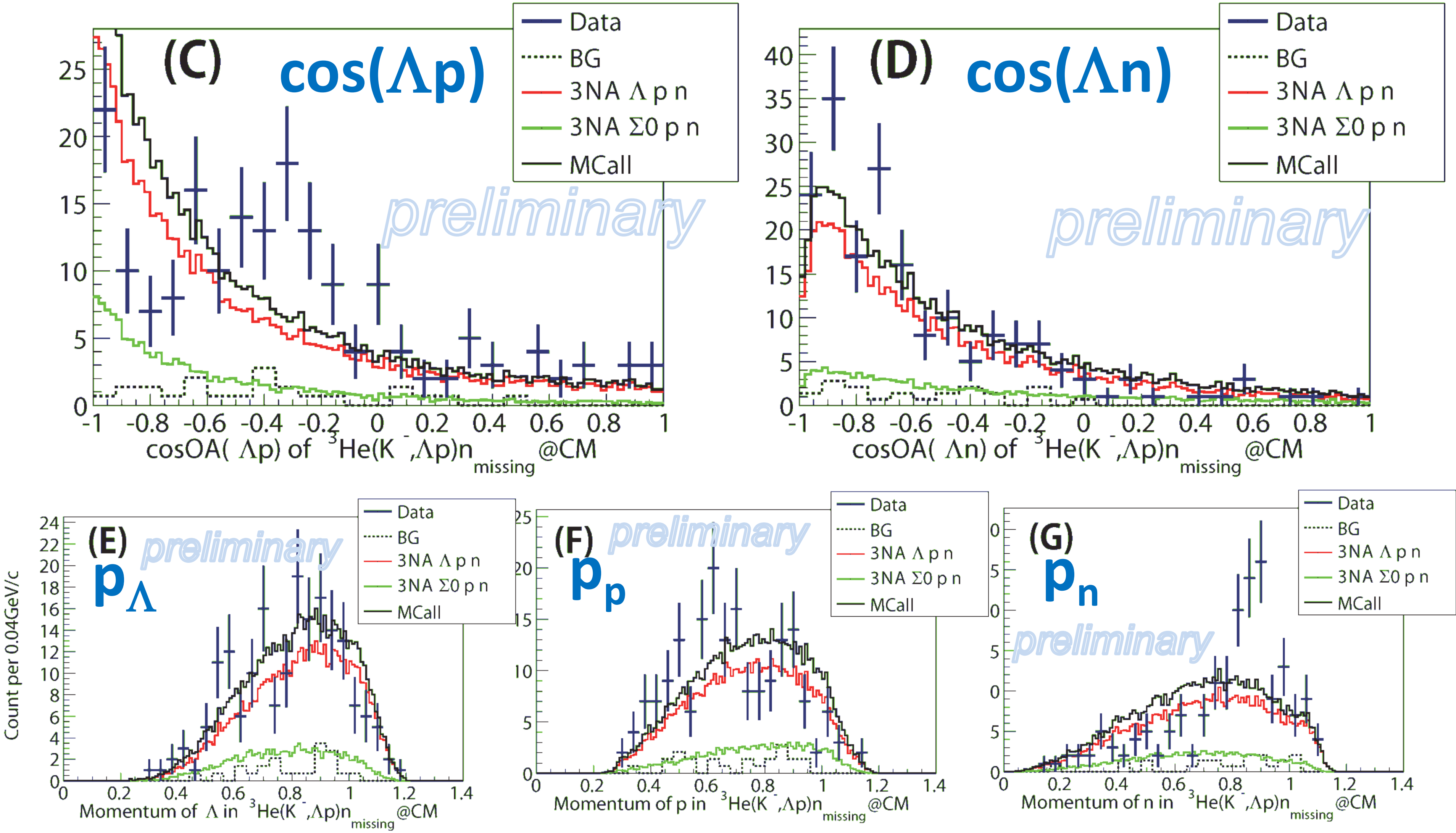
Comparison with Phase-Space





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

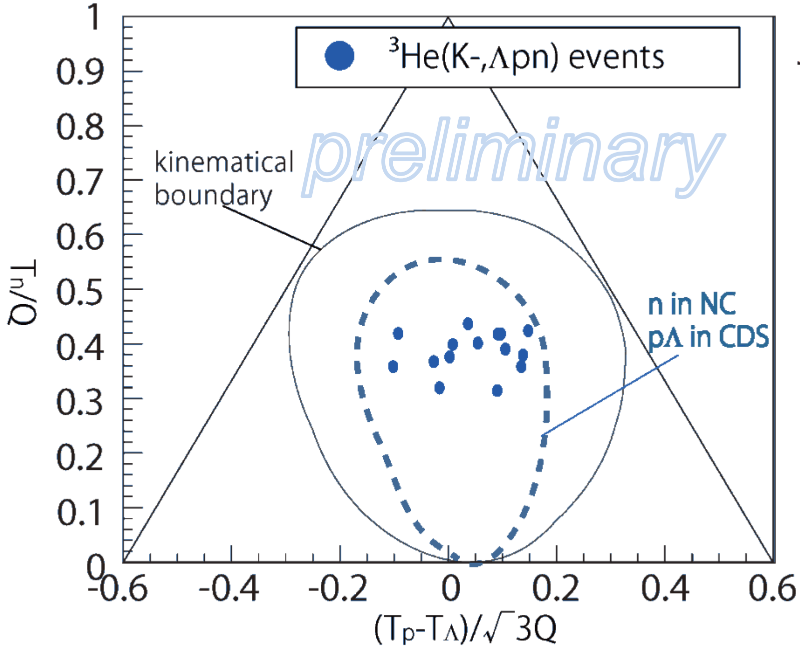
Comparison with Phase-Space

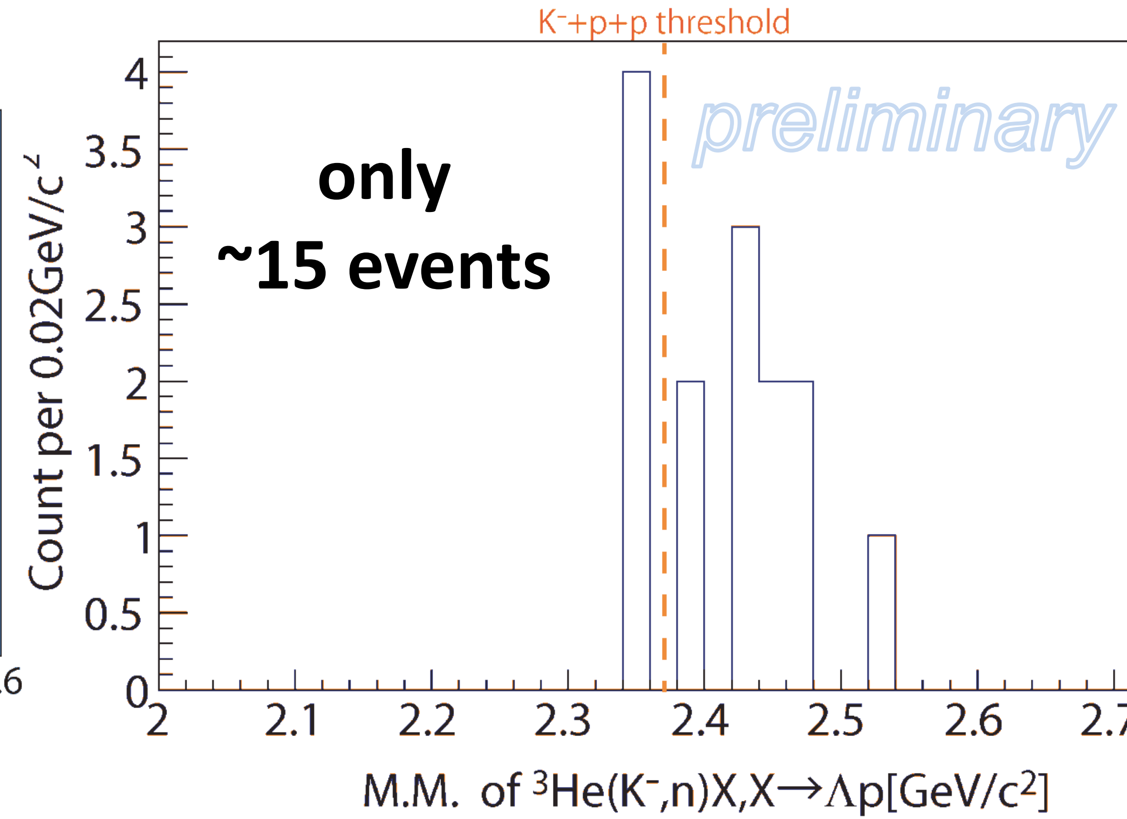


- data cannot be reproduced by the phase-space?

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

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





- Minimum momentum transfer of the $^3He(K^-,n)$ 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 $^3He(K^-,n)X$ reaction
2. confirm the spectral shape of the Λp invariant-mass by the exclusive measurement of $^3He(K^-,\Lambda p)n$
3. explore the neutron spectrum at $\theta_{lab}=0^O$ with the kinematically complete measurement of $^3He(K^-,\Lambda pn)$

Summary of E15 1st

Formation Channel

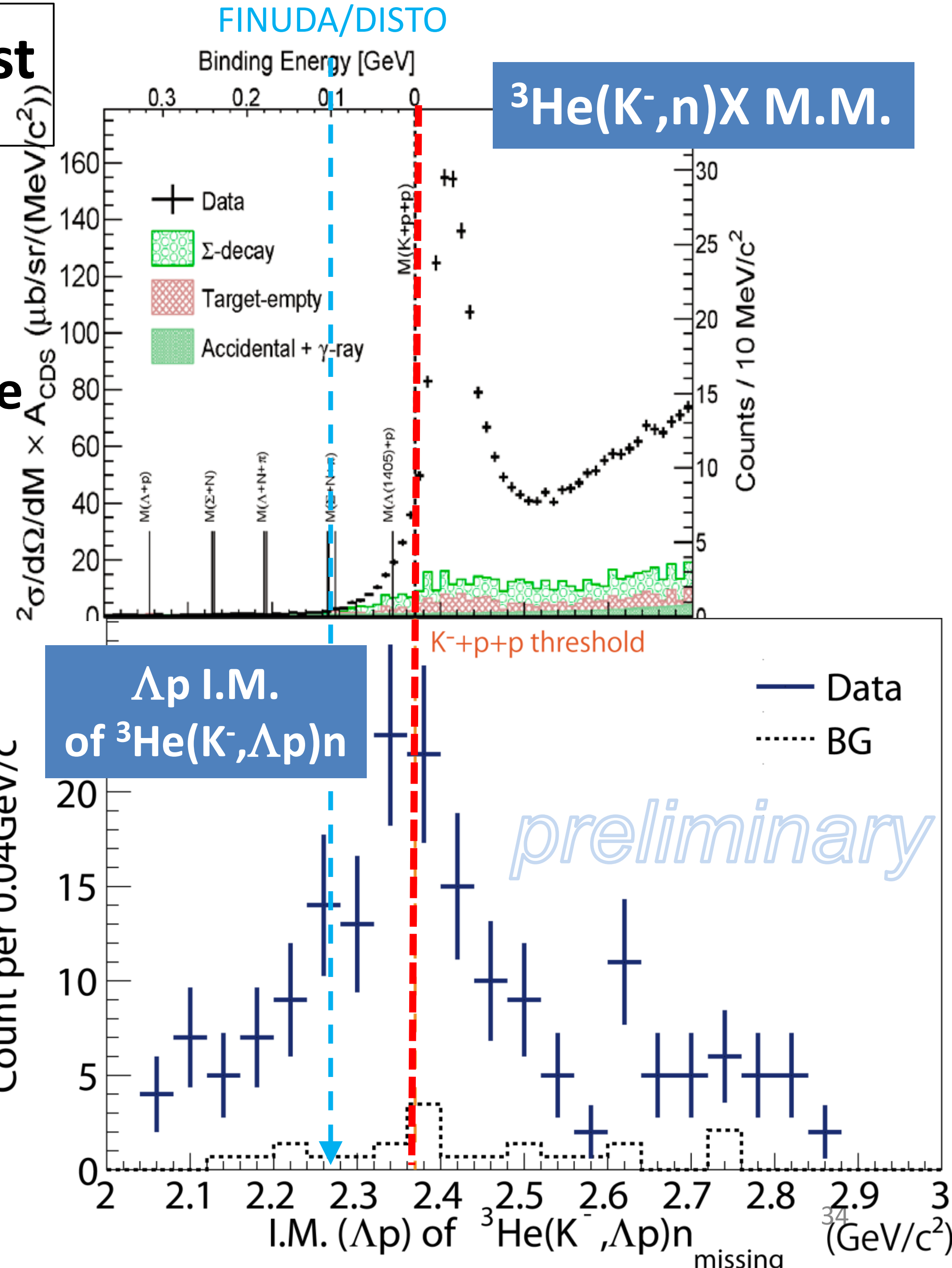
Semi-Inclusive $^3He(K^-,n)X$

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

Decay Channel

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

- ✓ **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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