J-PARC E15 実験における K中間子原子核探索の 最近の進展

F. Sakuma, RIKEN

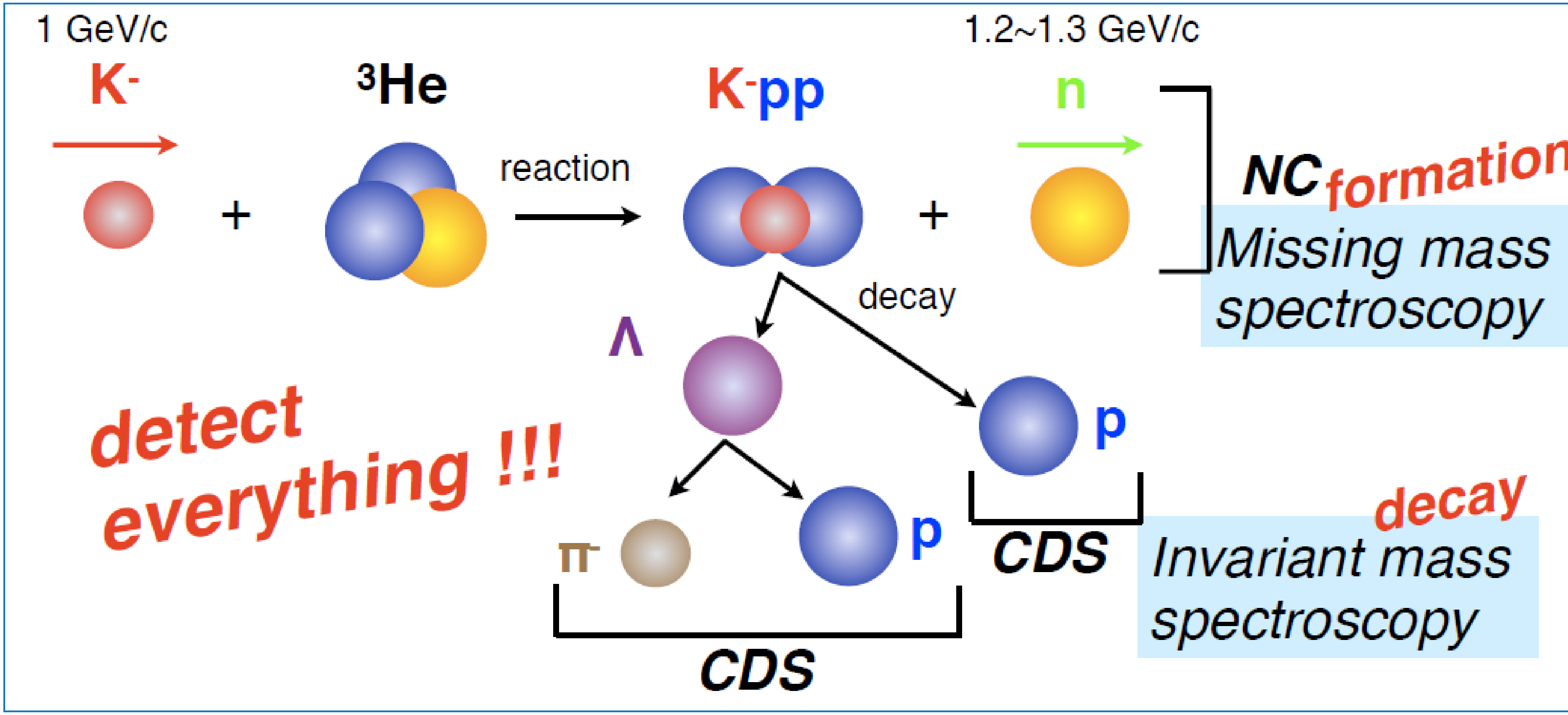
for the J-PARC E15 collaboration

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

「ストレンジネスを含む原子核の最近の展開」研究会　熱川ハイツ　2014 9/25-27

Experimental Principle of E15

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



- two-nucleon absorption
- hyperon decays

CAN be discriminated kinematically

E15 1st Stage Physics Run

- Production run of half the request (~15/30kW*week) was successfully accomplished.
  - ***~1% of the approved proposal (270kW*4weeks)***

	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*

- All detector systems worked well as designed.

Summary of E15 1st

Formation Channel

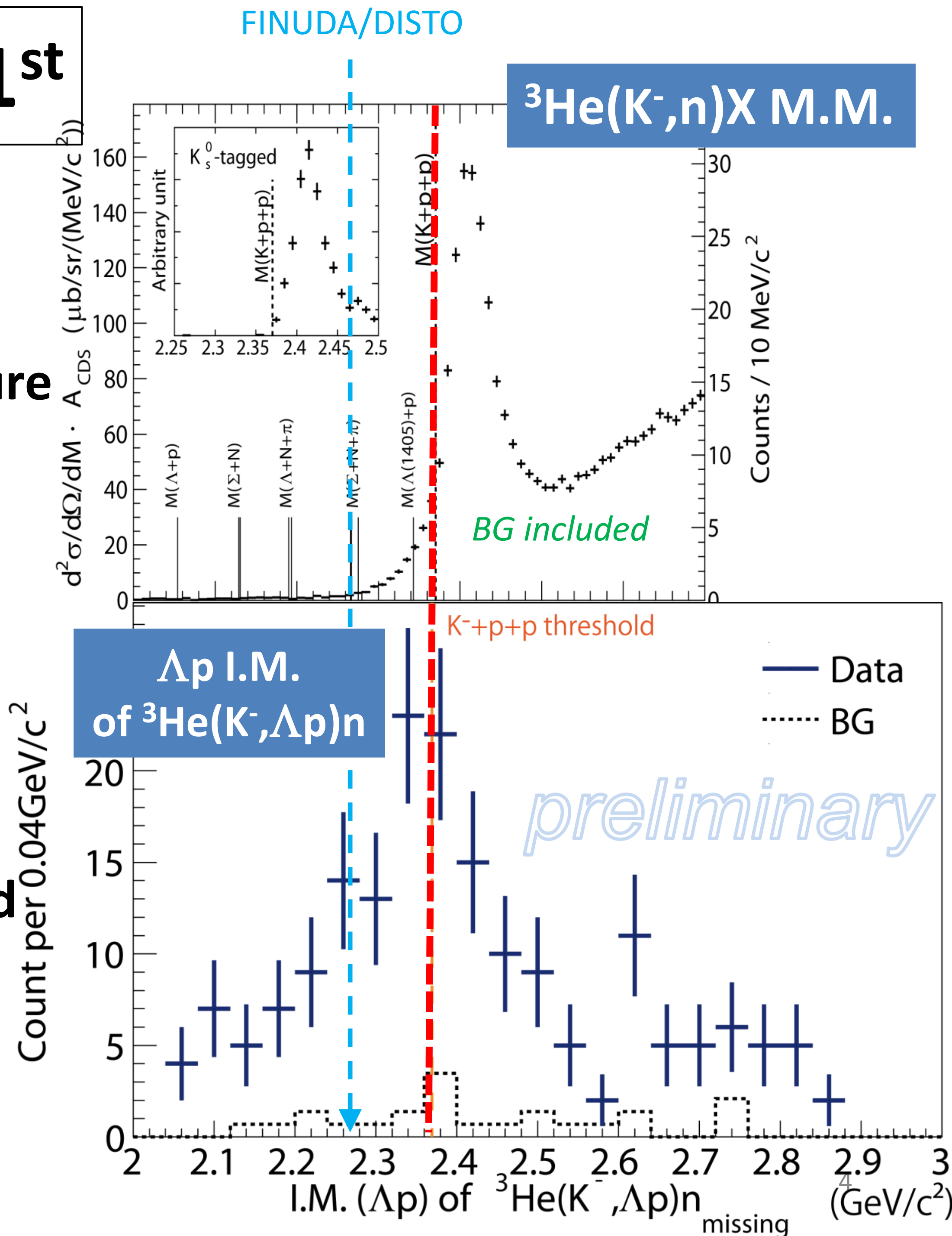
Semi-Inclusive $^3He(K^-,n)X$

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

Decay Channel

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

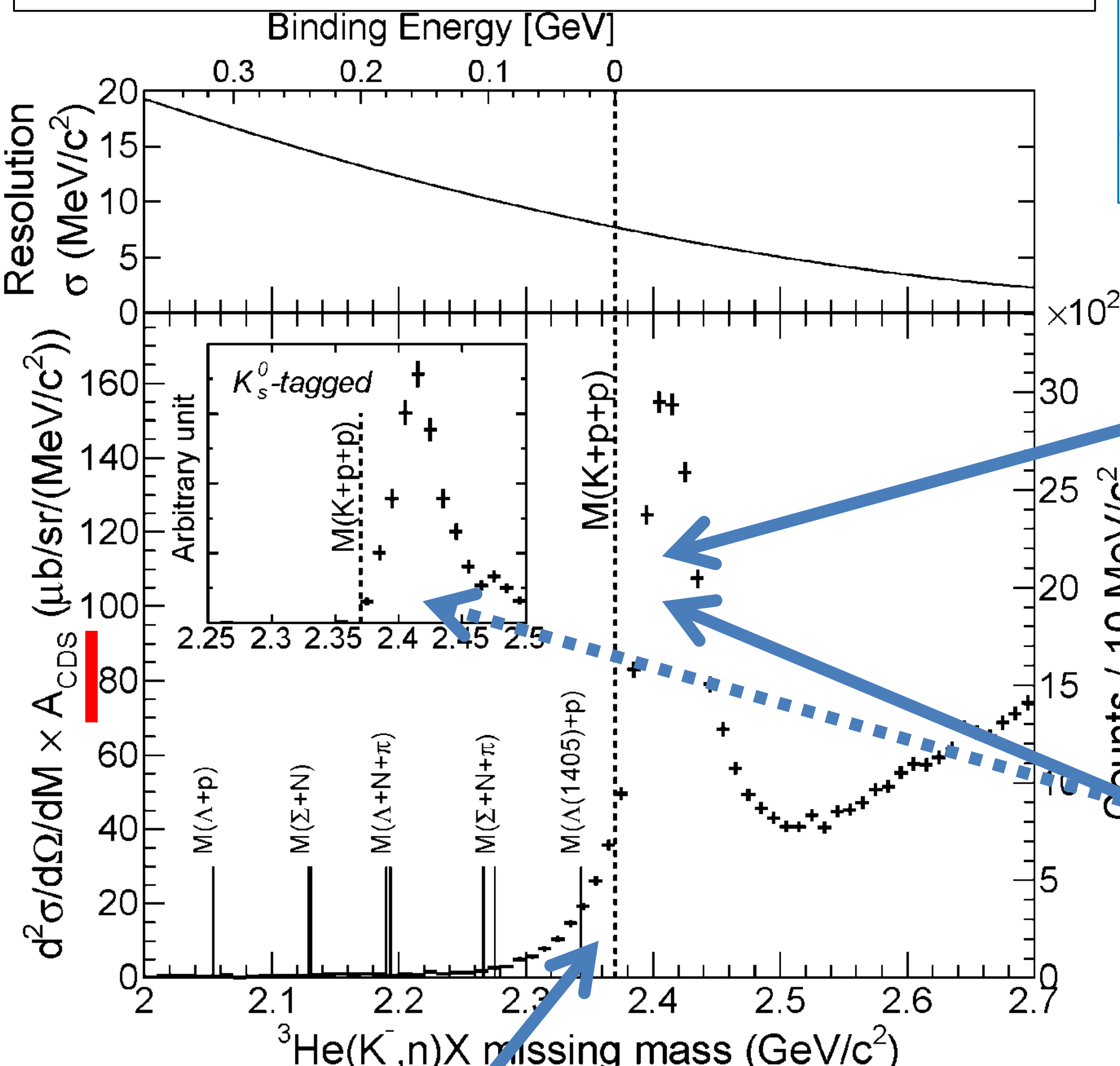
- ✓ **Excess around the threshold**
- ✓ Cannot be from 2NA of Λ^*n (final state = Λpn)

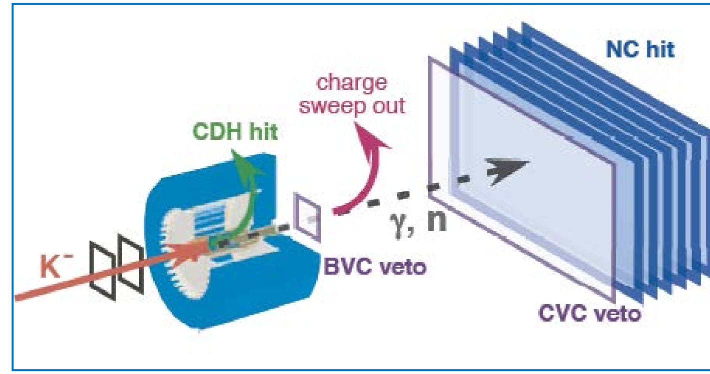


Formation Channel, Semi-Inclusive ^{3}He(K$^-$,n)X

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

Semi-Inclusive Spectrum





Quasi Elastic

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

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

and

Charge-Exchange

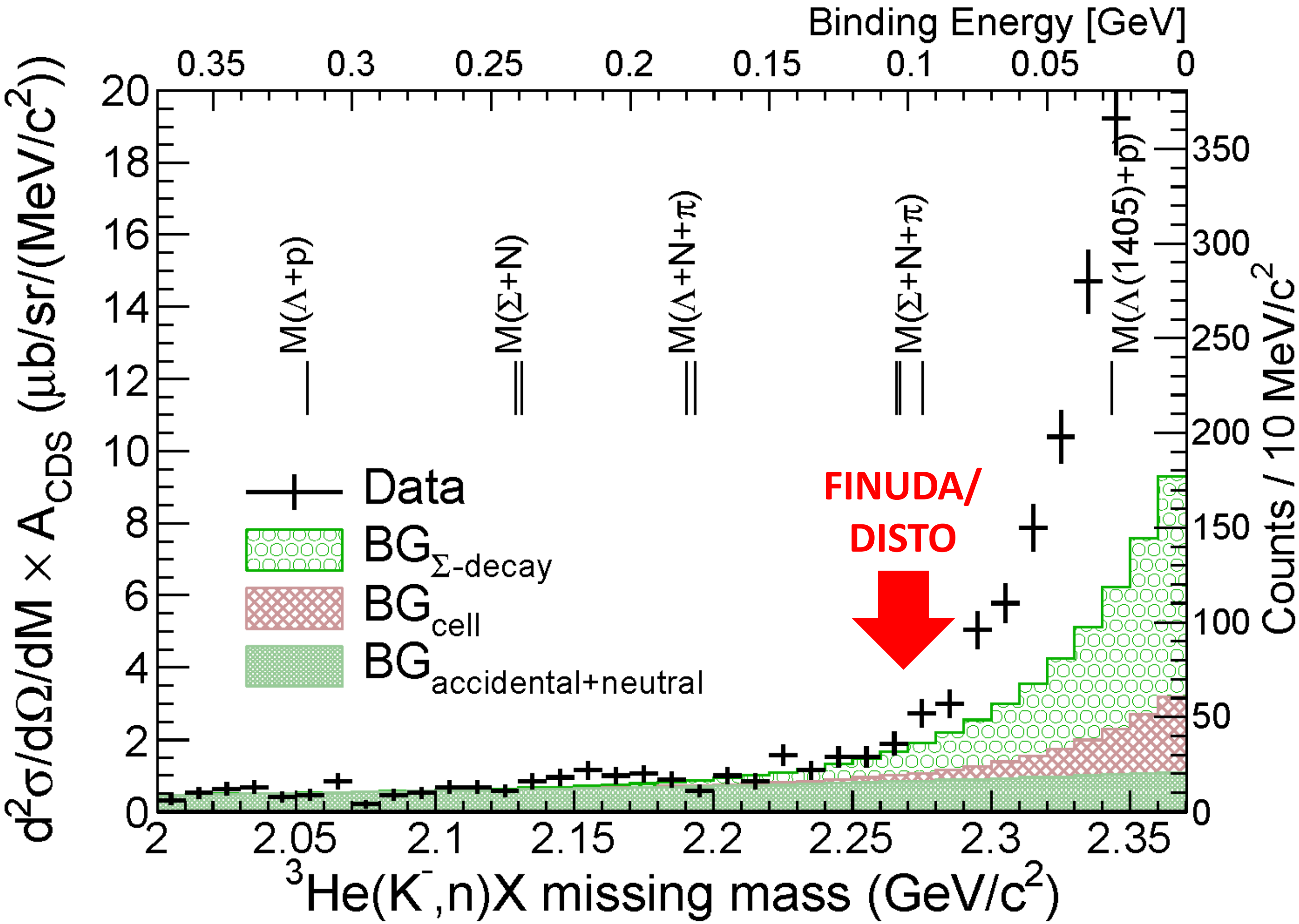
$K^- + {}^3He \rightarrow K^0 + \mathbf{n} + d_s$

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

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

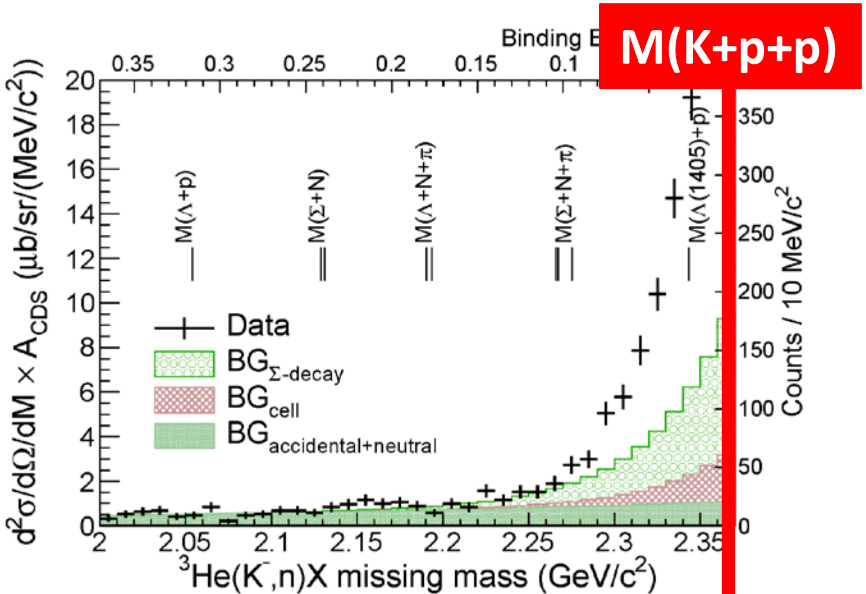
The tail structure is not due to “the detector resolution”

Spectrum below the Threshold



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

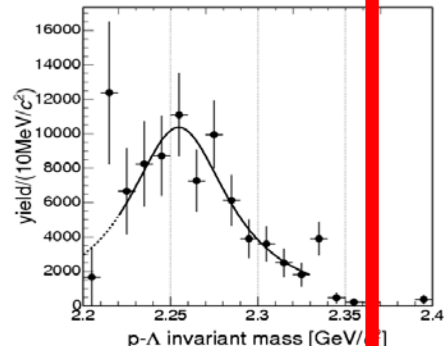
Comparison between E15 and Other Results



FINUDA@DAΦNE

PRL**94**(2005)212303

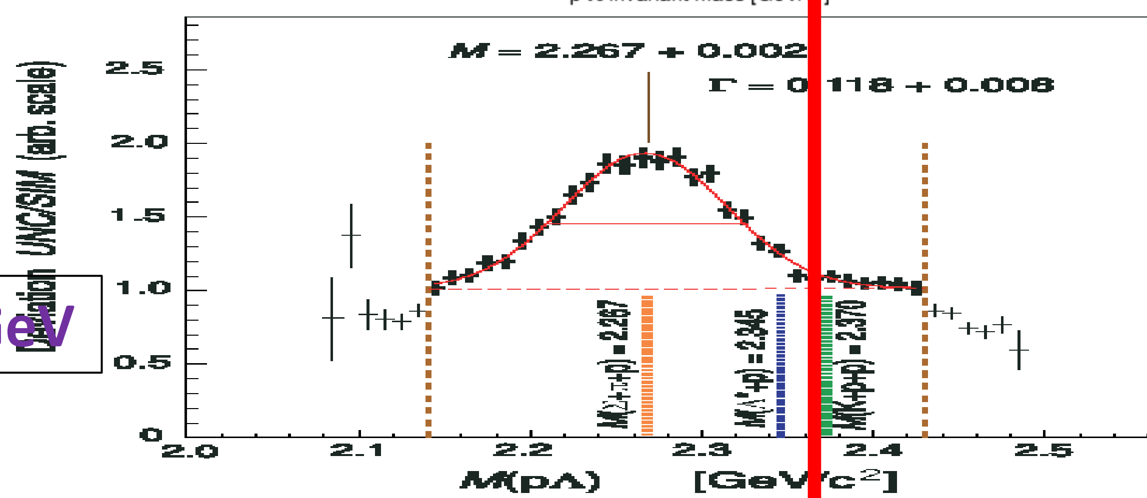
A(*stopped* K$^-$, Λp)



DISTO@SATURNE

PRL**104**(2010)132502

p + p → (Λ + p) + K$^+$ @ 2.85GeV

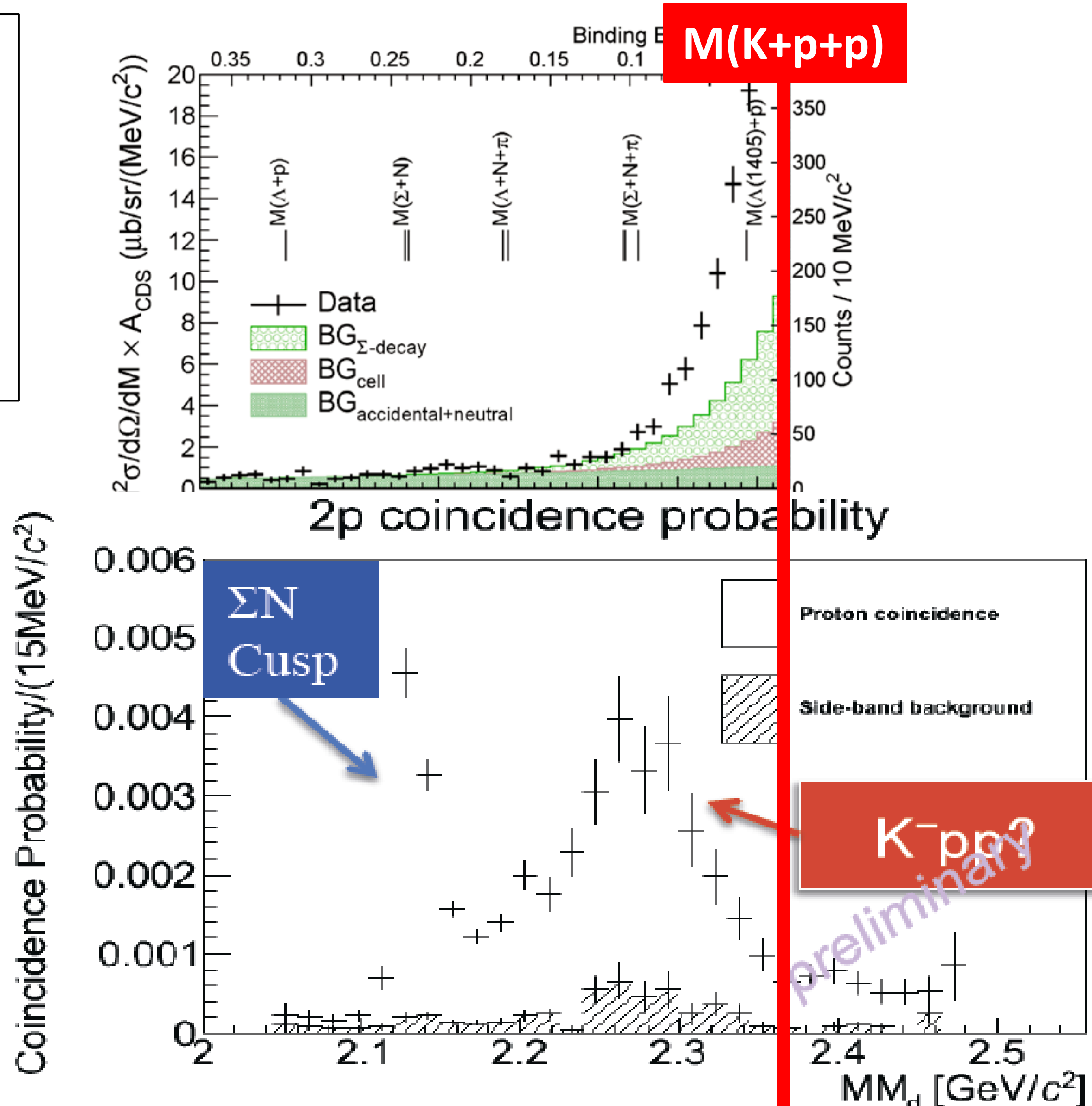


Comparison between E15 and Other Results

E27@J-PARC

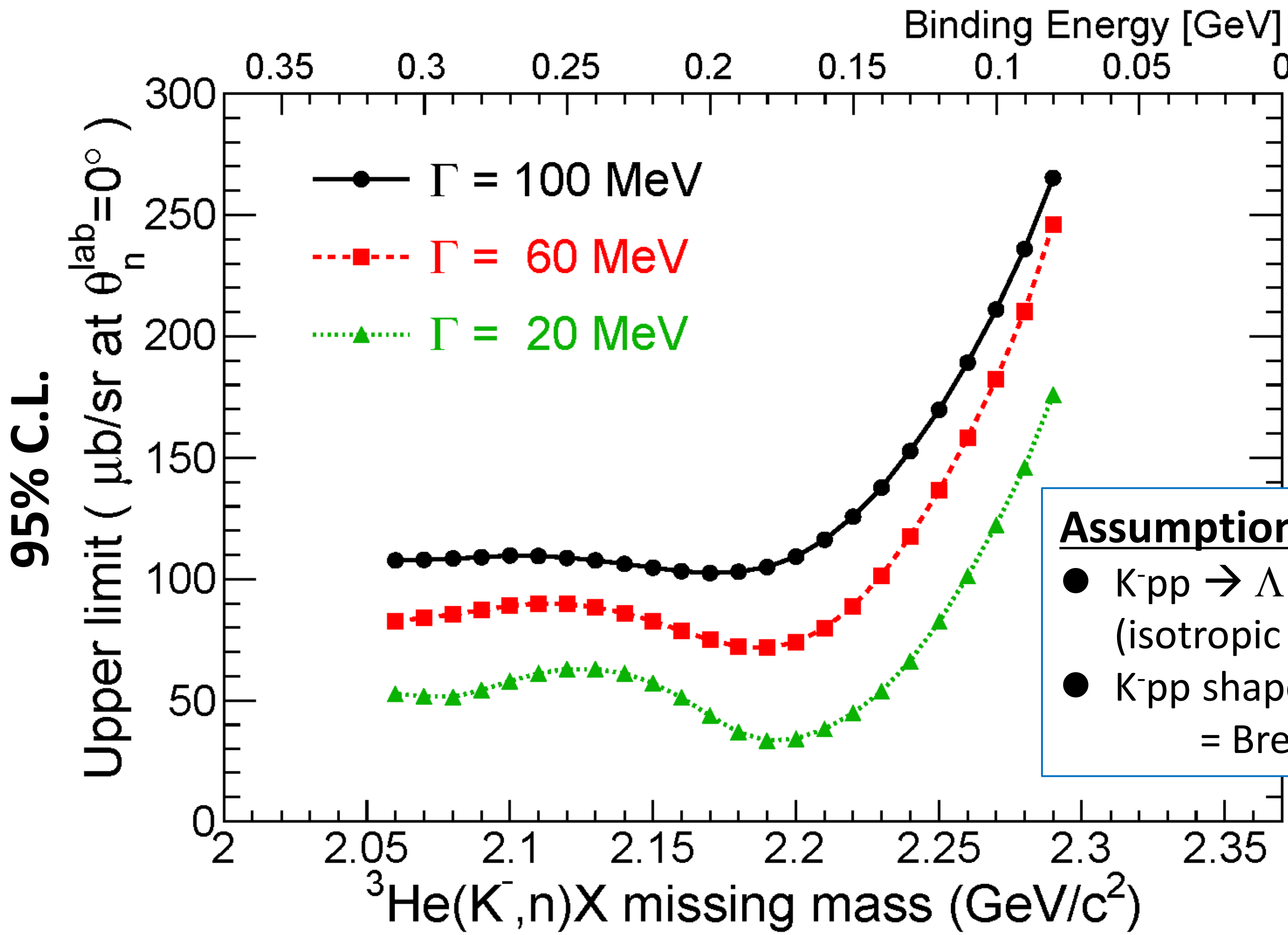
EXA2014 conference

d(π^+, K^+) @ 1.7GeV/c



- **Bump structure 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

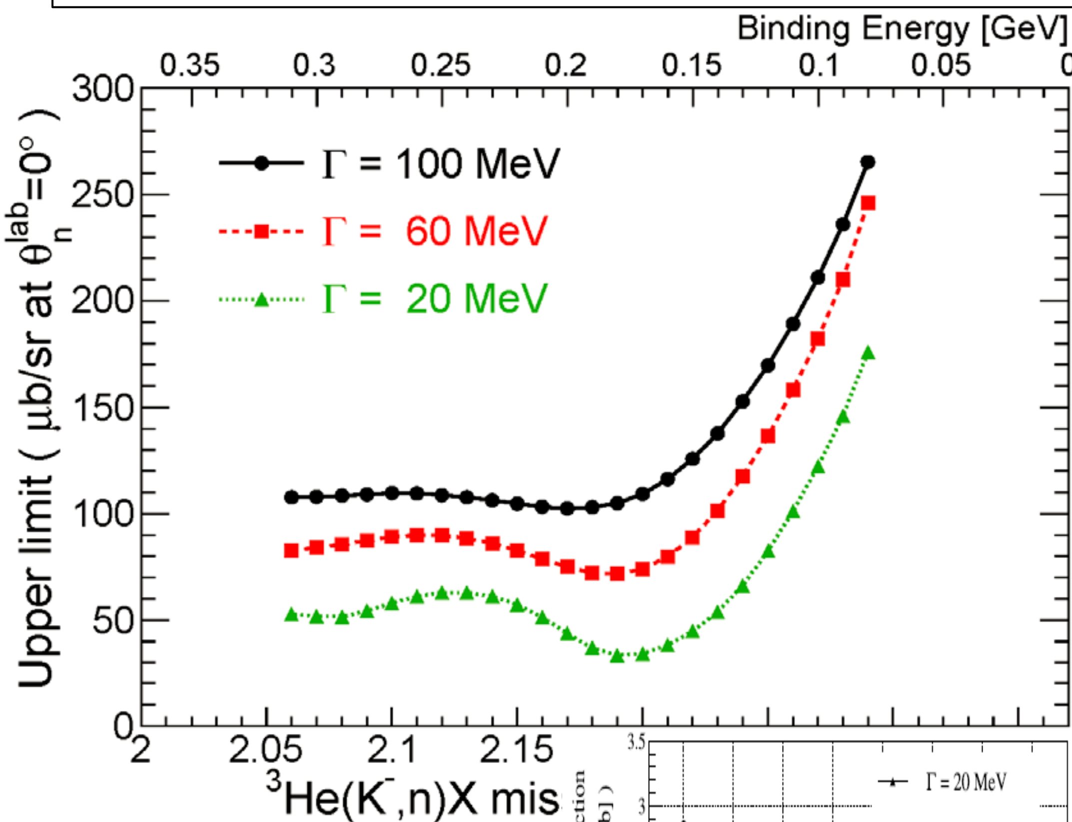


Assumptions

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

0.5 - 5% cross section of quasi-free K scattering

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

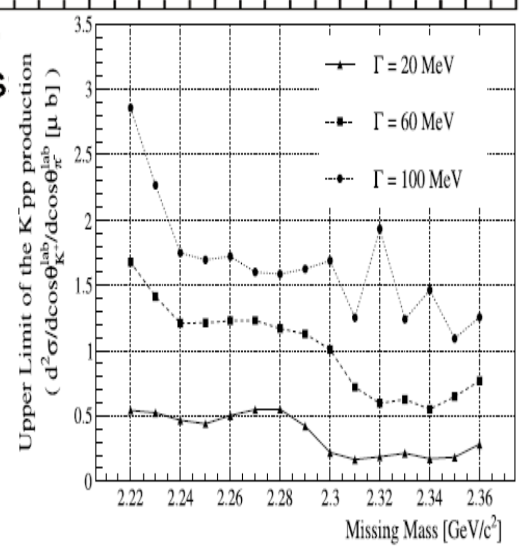


- **E15($K^{-}+{}^{3}He$):**
  (UL) 0.5-5% of QF
- **FINUDA(stopped K^{-}):**
  ~0.1% of stopped K^{-}
- **DISTO(p+p):**
  larger than Λ* @ 2.85GeV
- **LEPS(γ+d)**
  (UL) 1.5-26% of $\gamma N \rightarrow K^{+}\pi^{-}Y$

LEPS@SPring-8

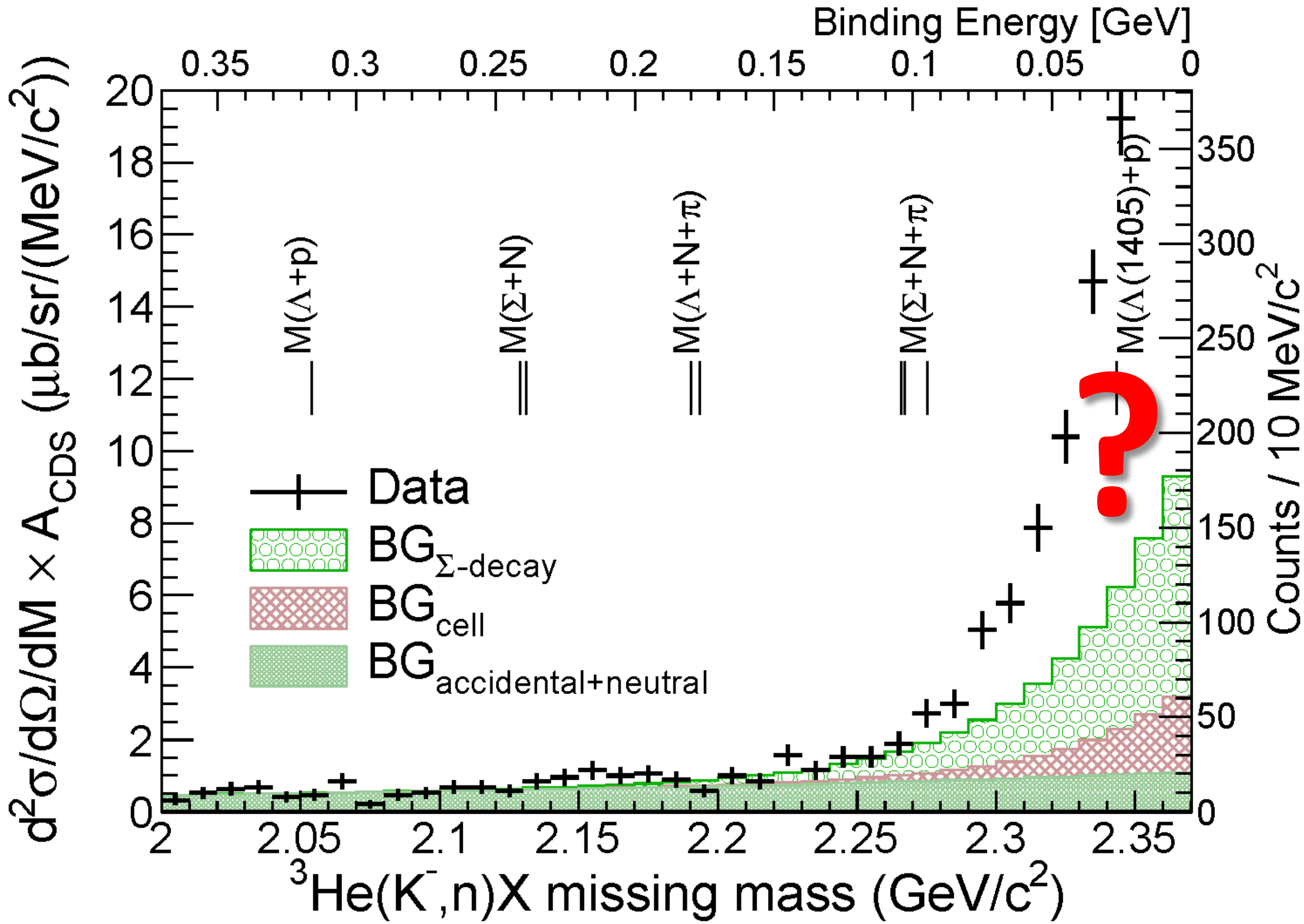
PLB**728**(2014)616

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



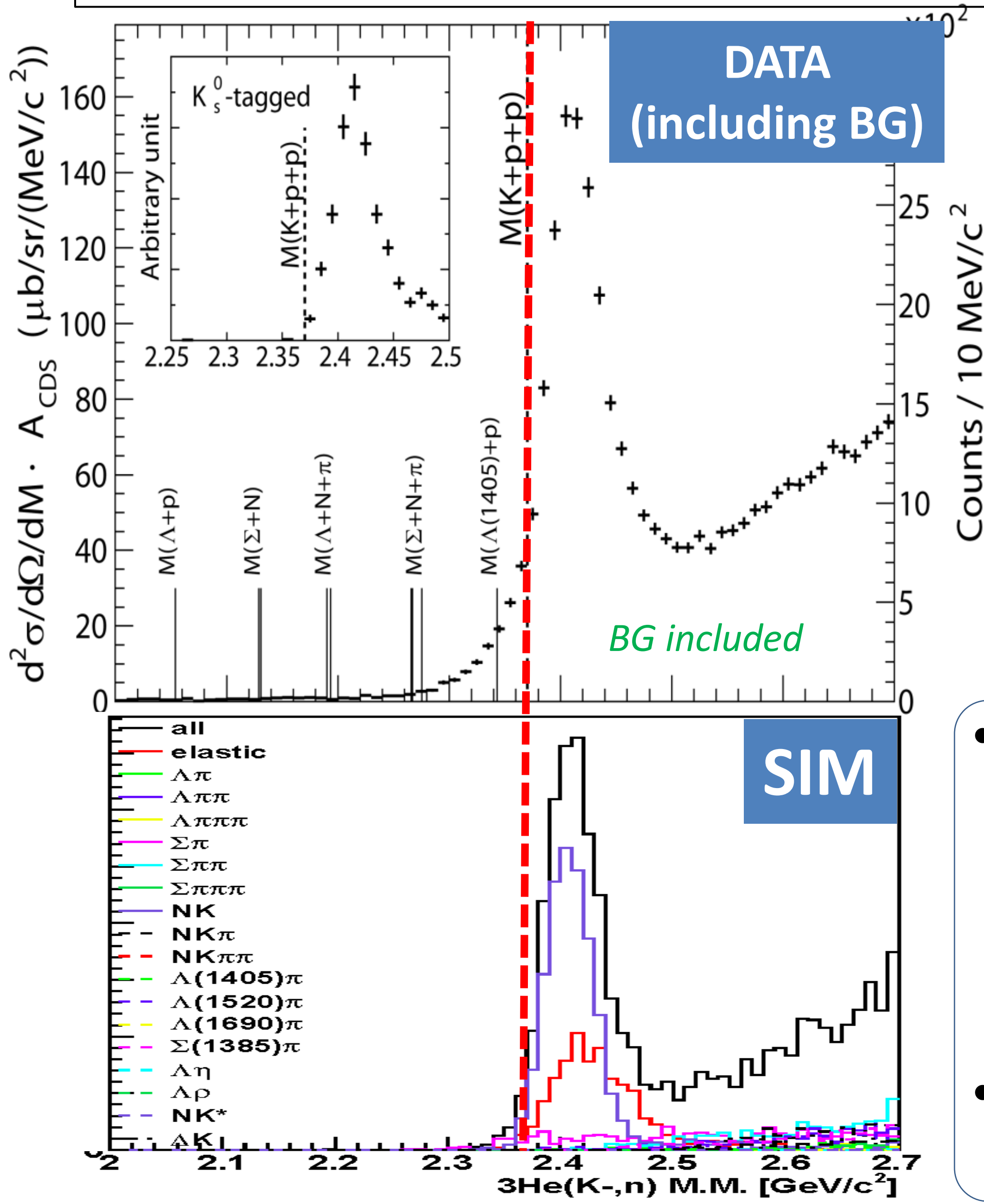
Need further more statistics to compare the stopped K^{-} experiment

Spectrum below the Threshold



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

Excess = Elementary Processes?



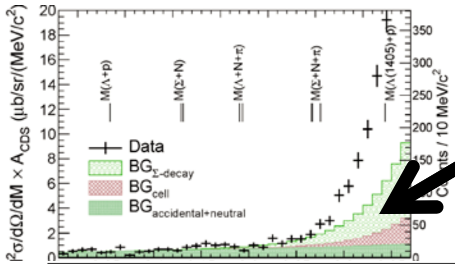
The tail structure is NOT reproduced by well known processes

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

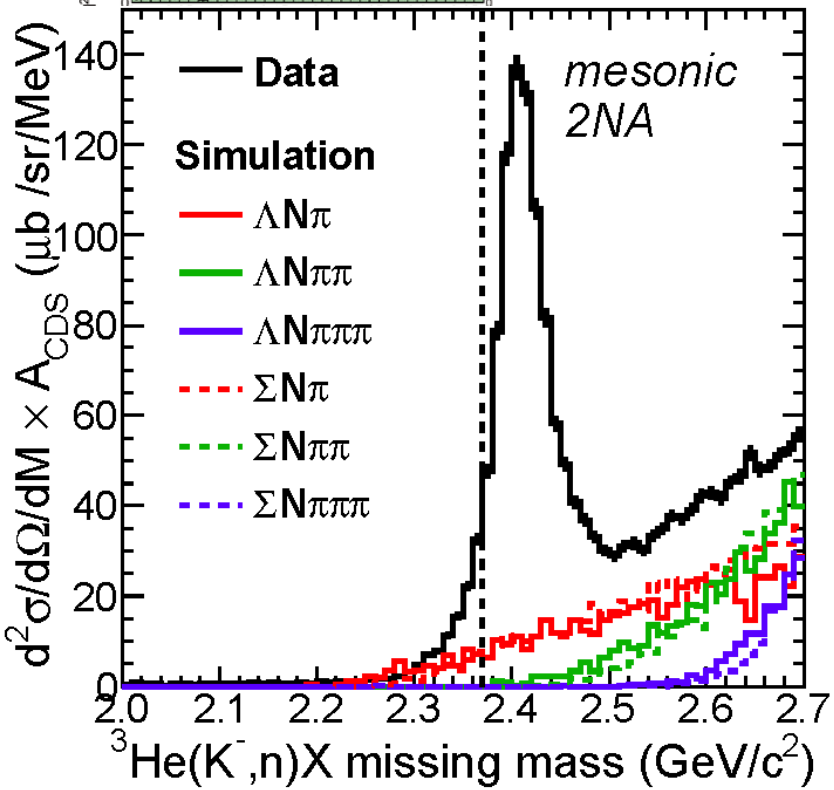
→ Multi-NA? K^-pp?

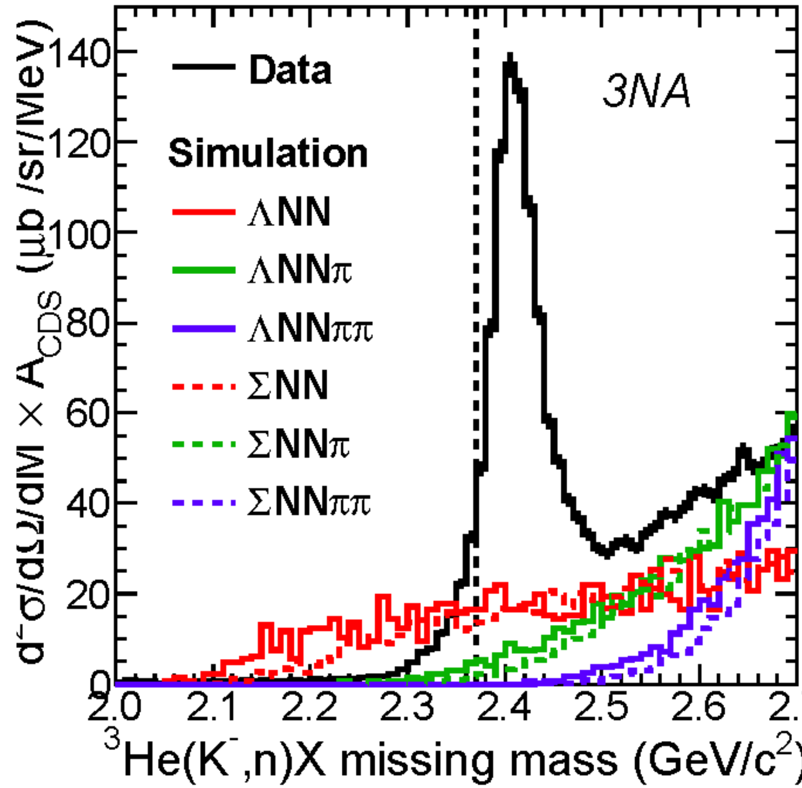
- Detector acceptance and all known K^-N interactions are considered:
  - Cross-section [CERN-HERA-83-02]
  - Fermi-motion
  - Angular distribution
- Simple assumptions:
  - $\sigma_{tot} = 2^*\sigma_{K\text{-}p} + \sigma_{K\text{-}n}$ (~150mb)

Excess = πΣN, πΣNN, etc?



BG from Σ-decay is subtracted in the spectra

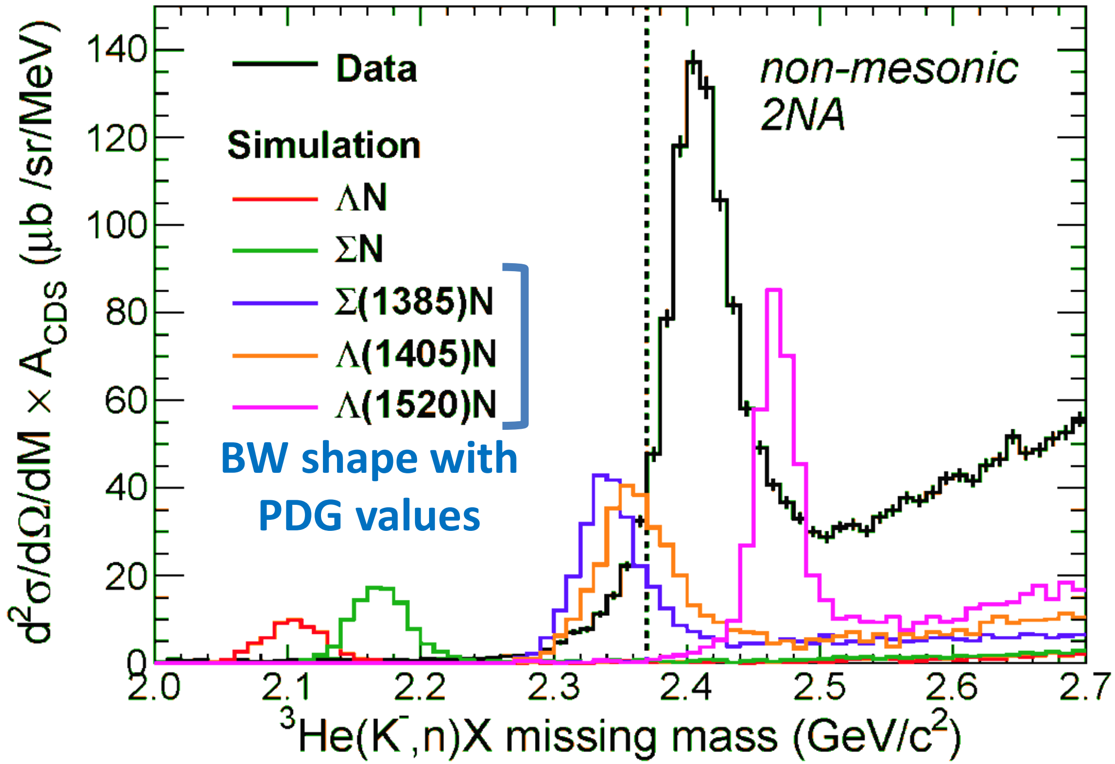




Each process is simulated with unreasonably large CS of 100mb

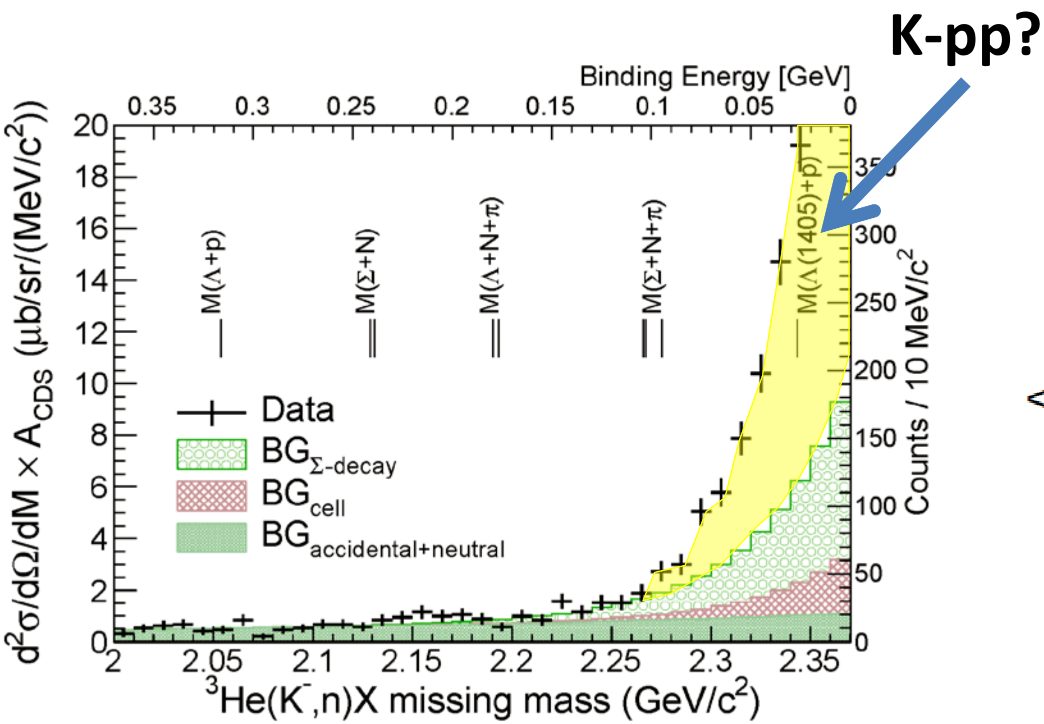
➔ **contributions in the binding region are negligible**

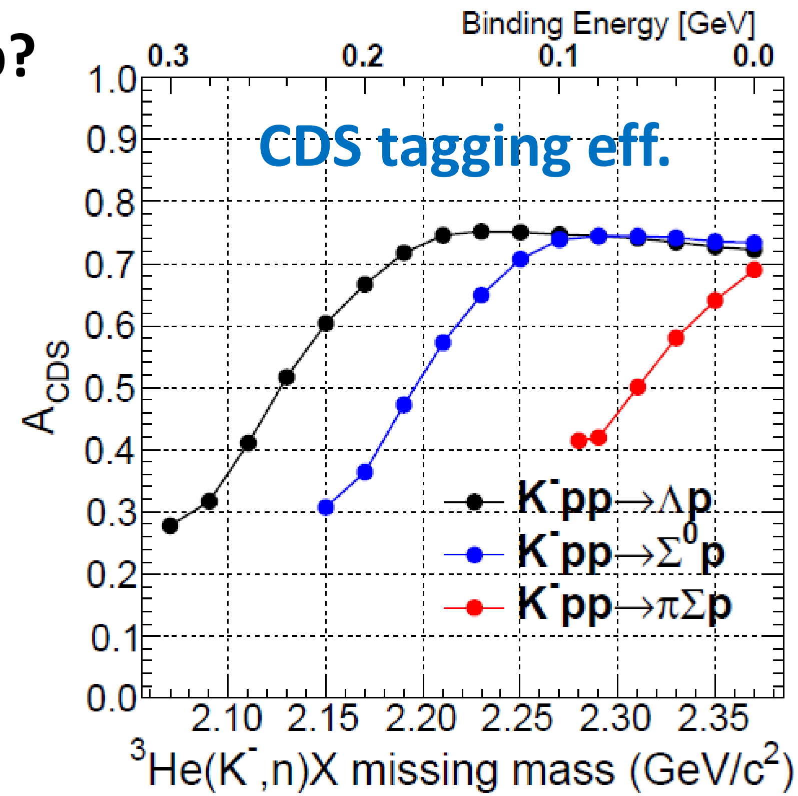
Excess = Λ^*N, etc?



- **ΛN/ΣN branches are negligibly small**
- **Λ(1405)n branches seems to reproduce the excess**
  - Λ(1405) shape is "*simple BW with PDG values*"
  - need rather large CS of ~5mb/sr
- **Exclusive measurement of πΣN is needed for further study**

Excess = Loosely-Bound $K^{-}pp$?





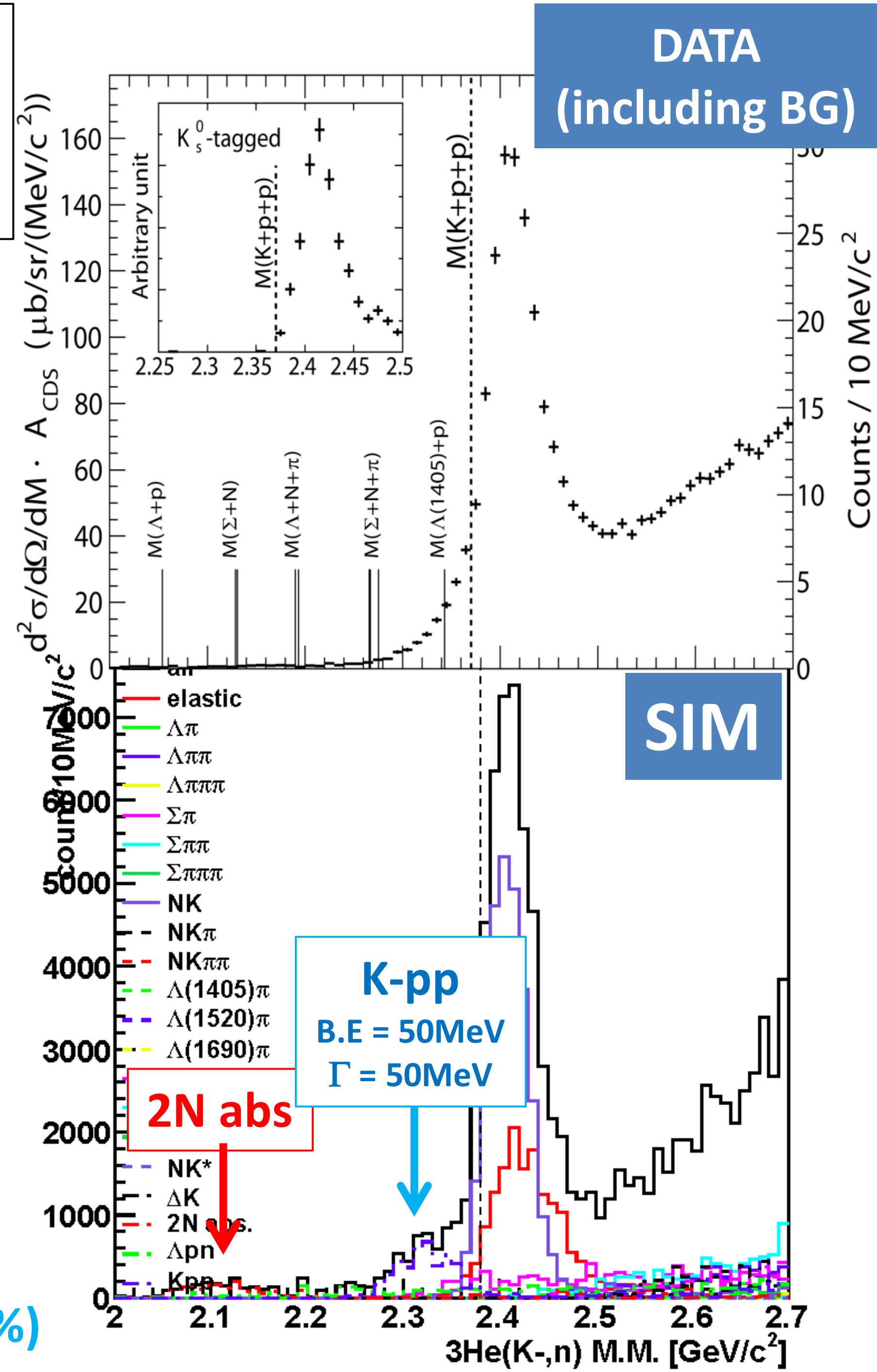
- The excess is **assumed** to be fully attributed to the bound $K^{-}pp$ state
- **$d\sigma/d\Omega(\theta_{lab}=0^{o})$ of the excess is ~ 1 mb/sr**

Excess = Loosely-Bound K^-pp?

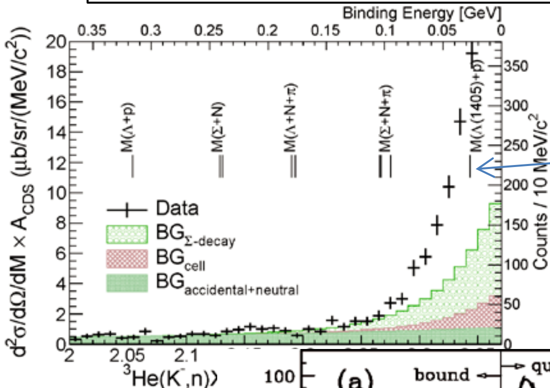
- Detector acceptance and all known K^-N interactions are considered:
  - Cross-section [CERN-HERA-83-02]
  - Fermi-motion
  - Angular distribution
- Simple assumptions:
  - $\sigma_{tot} = 2*\sigma_{K\text{-}p} + \sigma_{K\text{-}n}$ (~150mb)

+

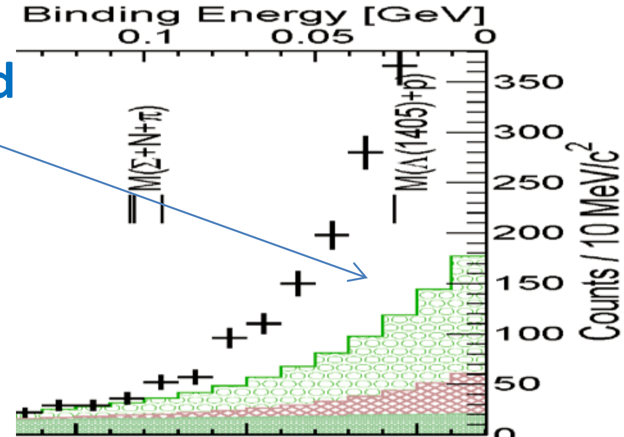
- Simple assumptions:
  - 2N abs.: $K^- \, {}^3He \rightarrow \Lambda \, n \, p_s$
    - $\sigma/d\Omega$=1mb/sr, isotropic
  - K^-pp prod.: $K^- \, {}^3He \rightarrow (K^-pp)n$
    - $d\sigma/d\Omega$=1mb/sr, isotropic
    - $K^-pp \rightarrow \Lambda p(25\%), \Sigma^0 p(25\%), \pi\Sigma p(50\%)$



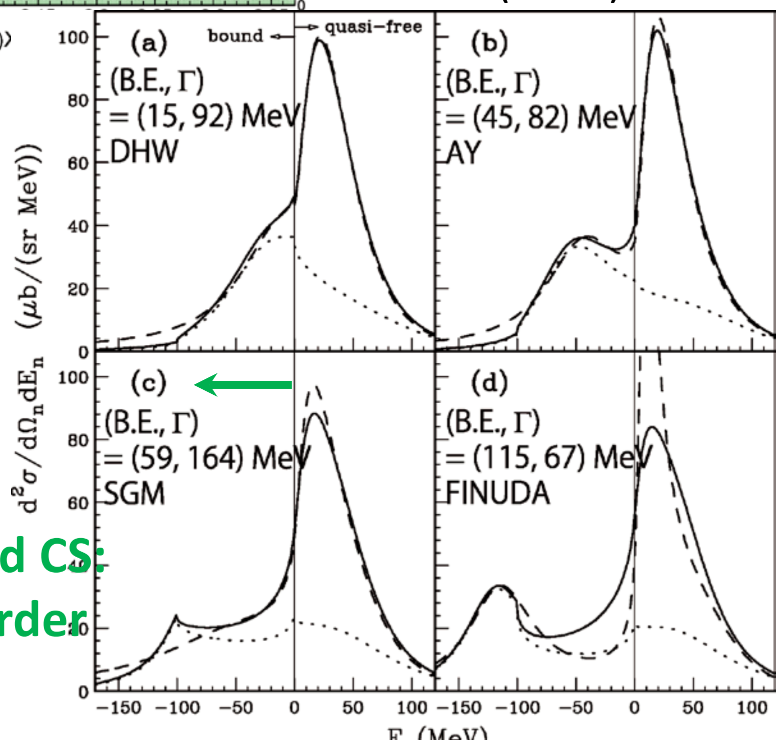
Comparison between E15 and Calc.



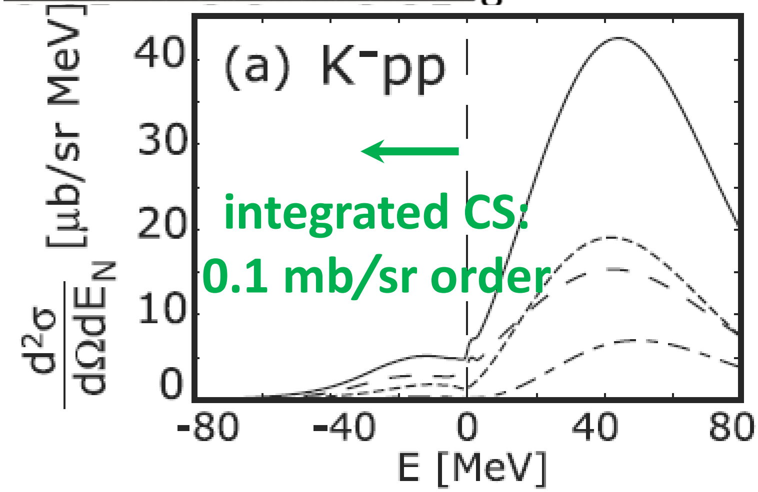
~ 1 mb/sr,
if excess is assumed to be K^-pp



Koite, Harada,
PRC80(2009)055208



integrated CS:
mb/sr order



integrated CS:
0.1 mb/sr order

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

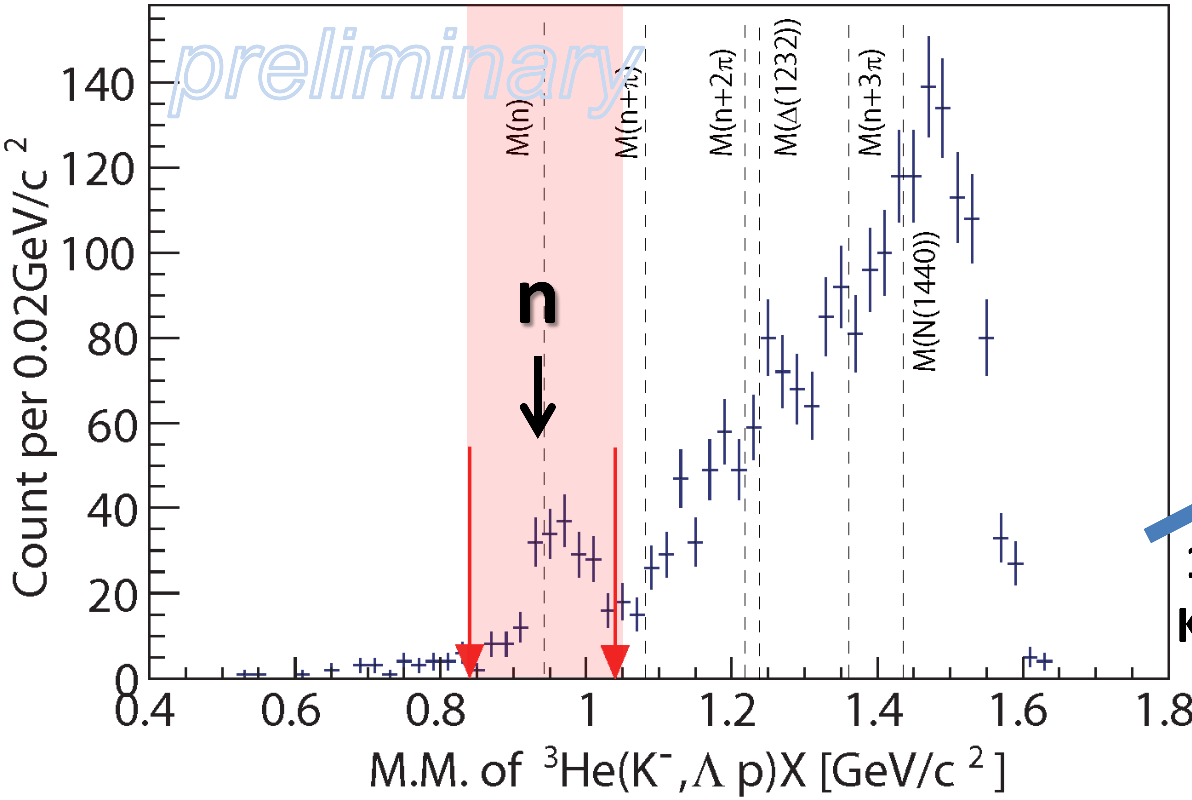
- CS is almost consistent with KH
- Loosely-bound K-pp state ???

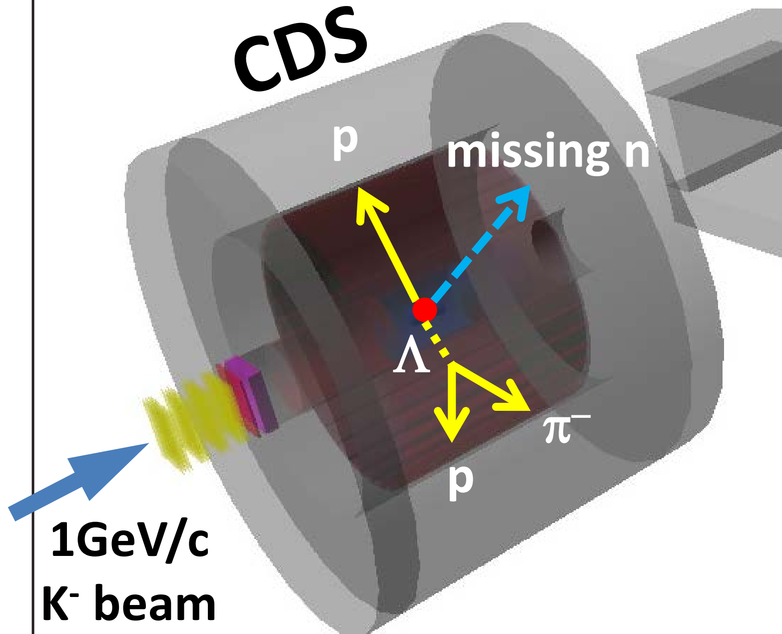
πΣN measurement is an important key

Decay Channel,

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

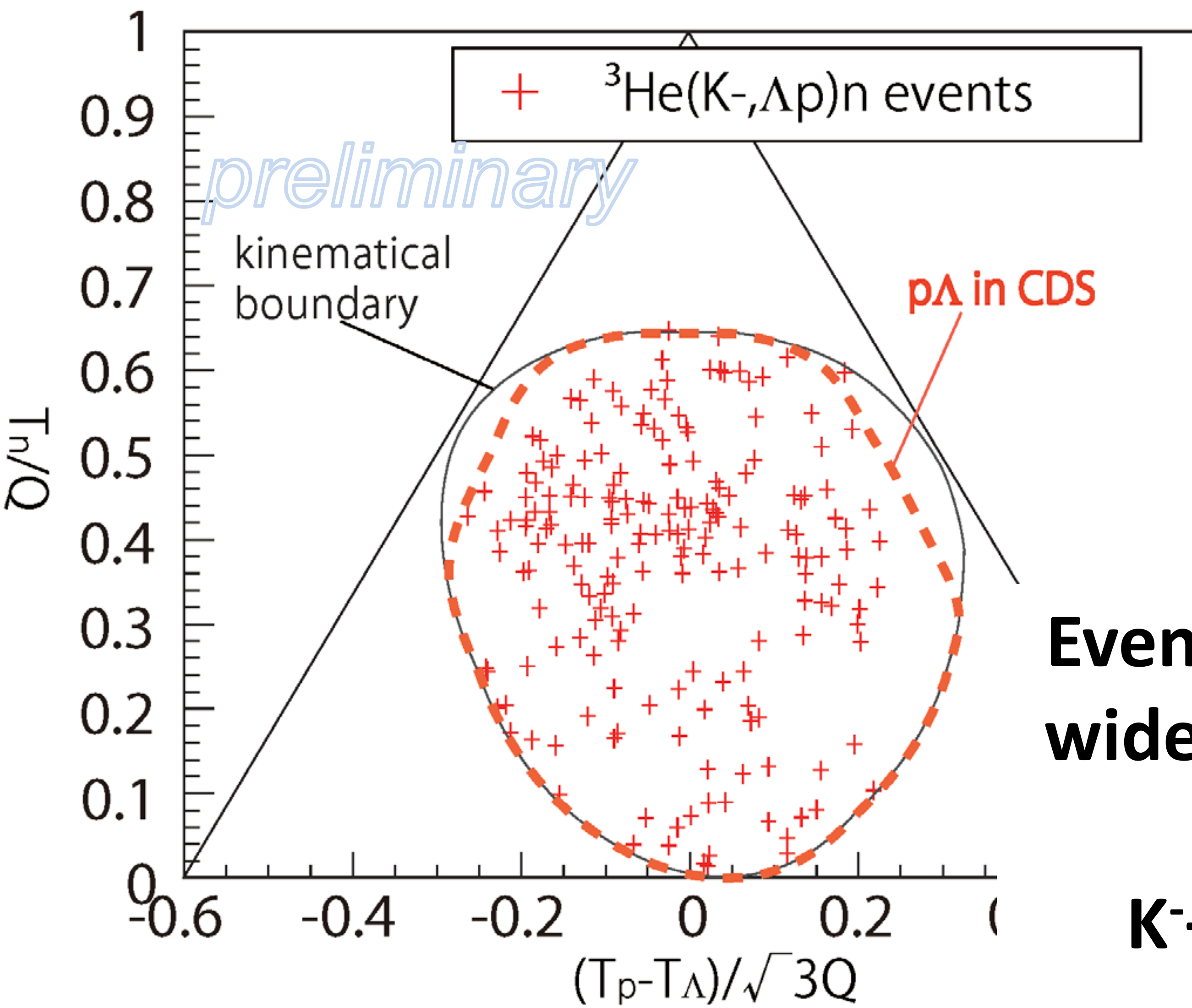
Exclusive $^3He(K^-,\Lambda p)n$ events





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

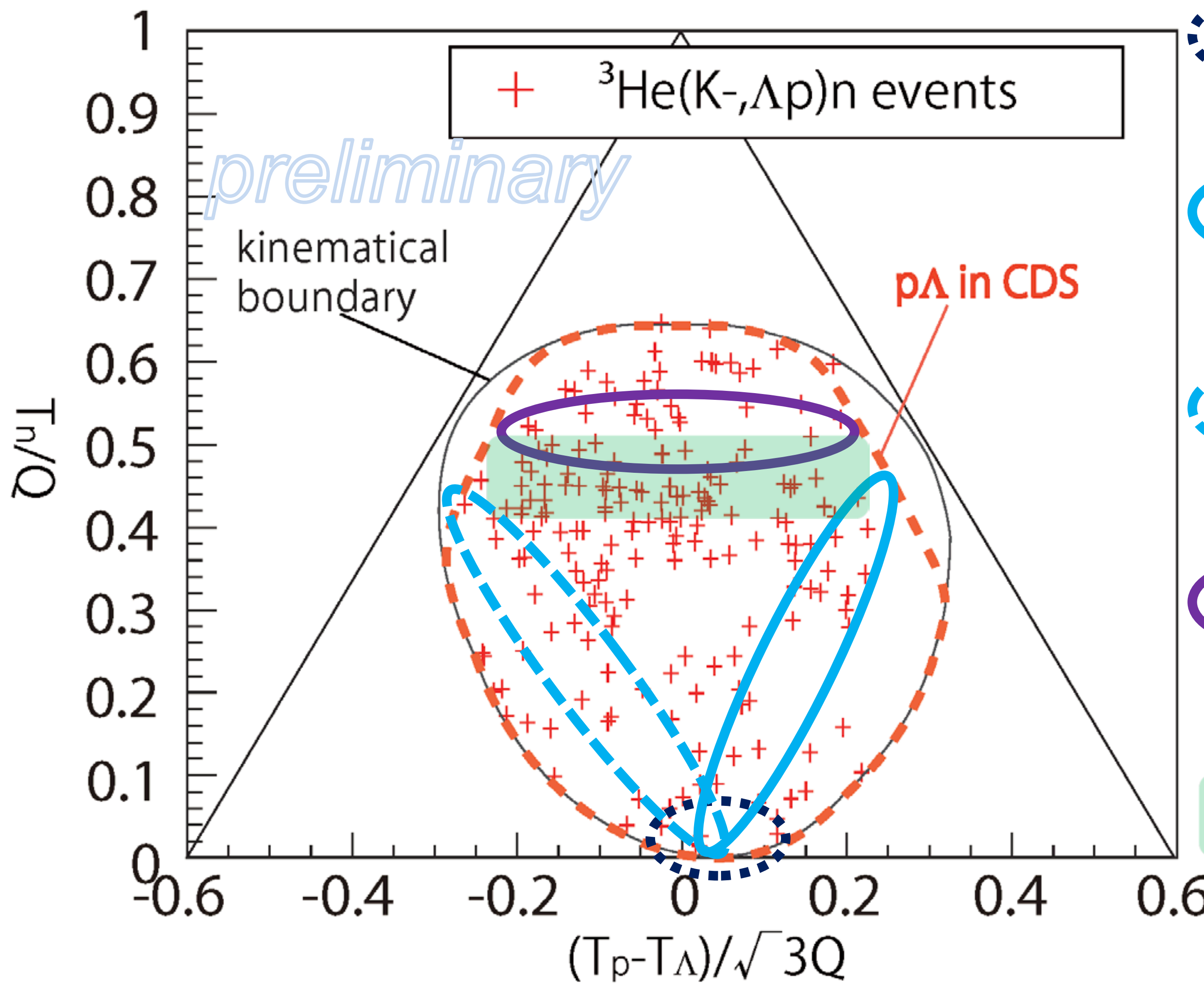
Dalitz plot



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

Events are scattered widely in the phase-space of $K^- + ^3He \rightarrow \Lambda + p + n$

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. $K^{-3}He \rightarrow \Lambda p n_s$,
$p n_s \rightarrow p n$

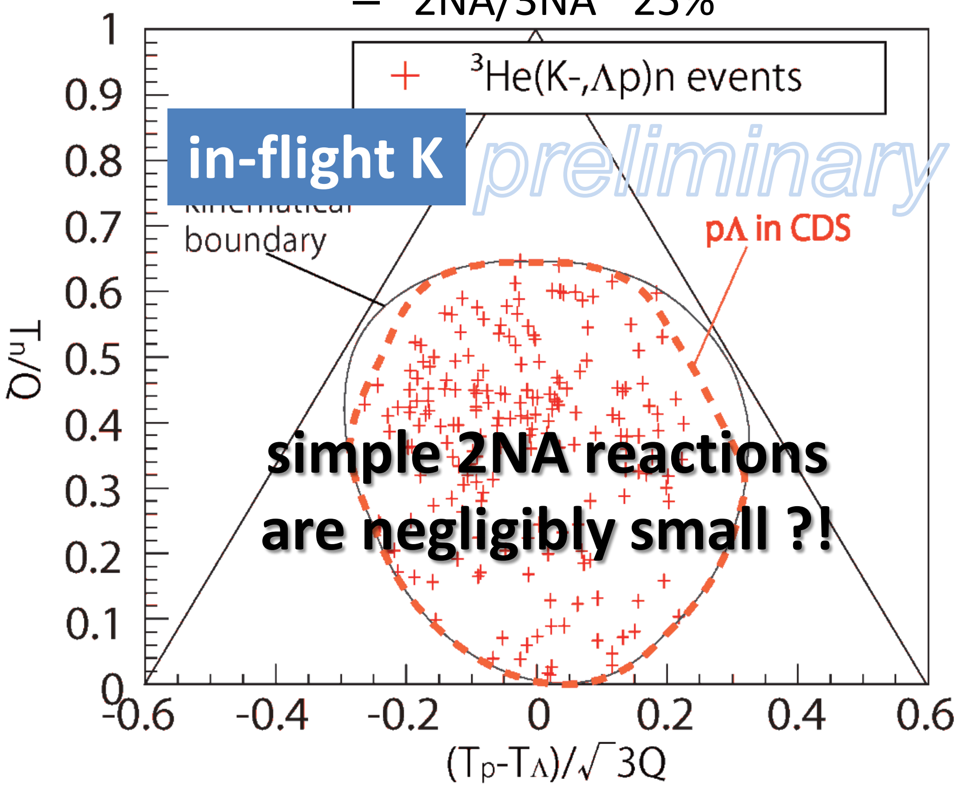
2NA+2step:
e.g. $K^{-3}He \rightarrow \Sigma^0 n p_s$,
$\Sigma^0 p_s \rightarrow \Lambda p$

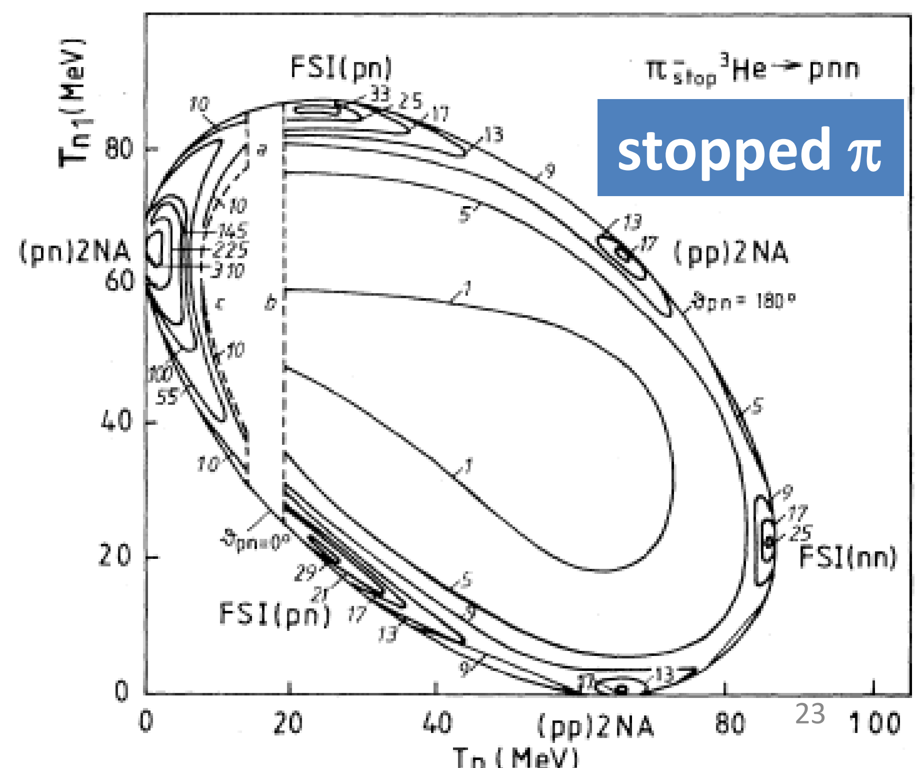
K^-pp form.:
$K^{-3}He \rightarrow (K^-pp)n$,
$K^-pp \rightarrow \Lambda p$

K-induced vs π-induced

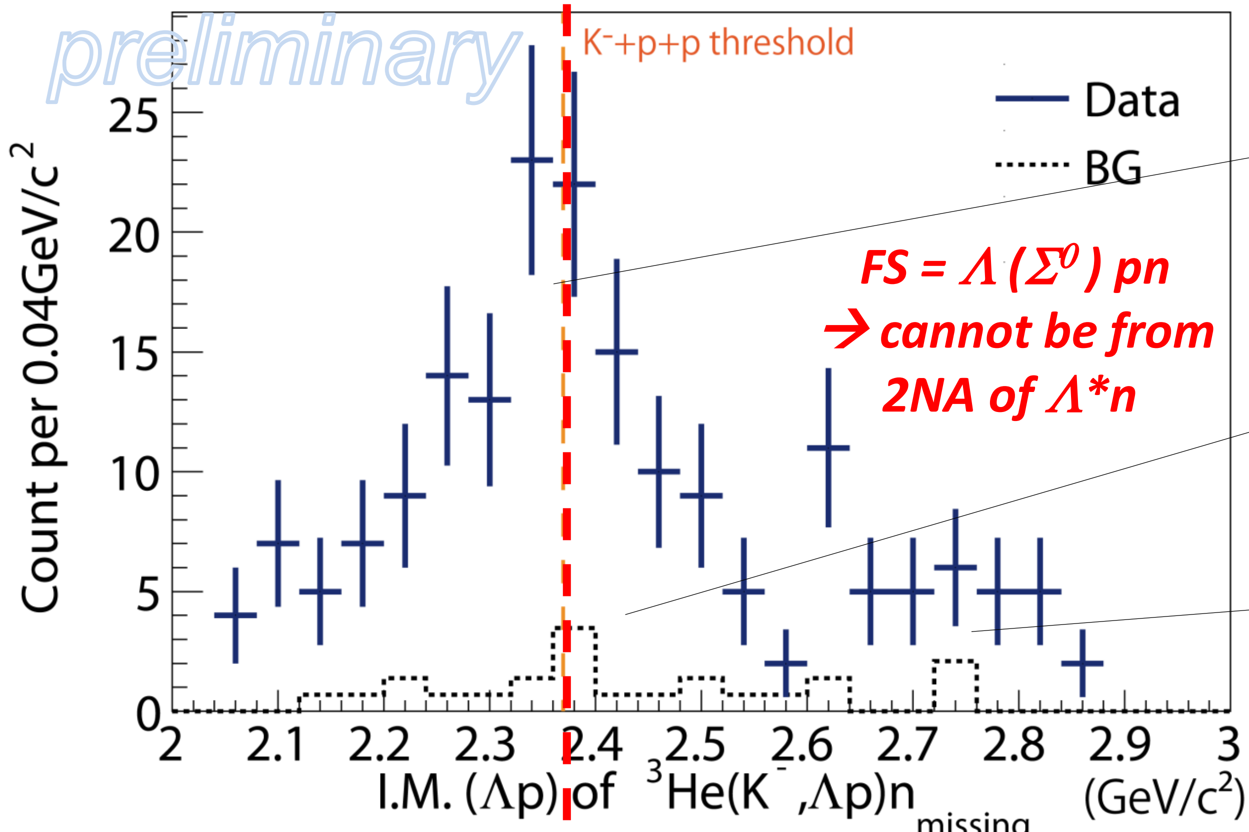
[1] D. Gotta, etal., Phys. Rev. C 51. 2 (1995)
[2] P. Weber etal., Nucl. Phys A501 (1989) 765-800
[3] G. Backenstoss etal., Phys. Rev. Lett 55. 25(1985)

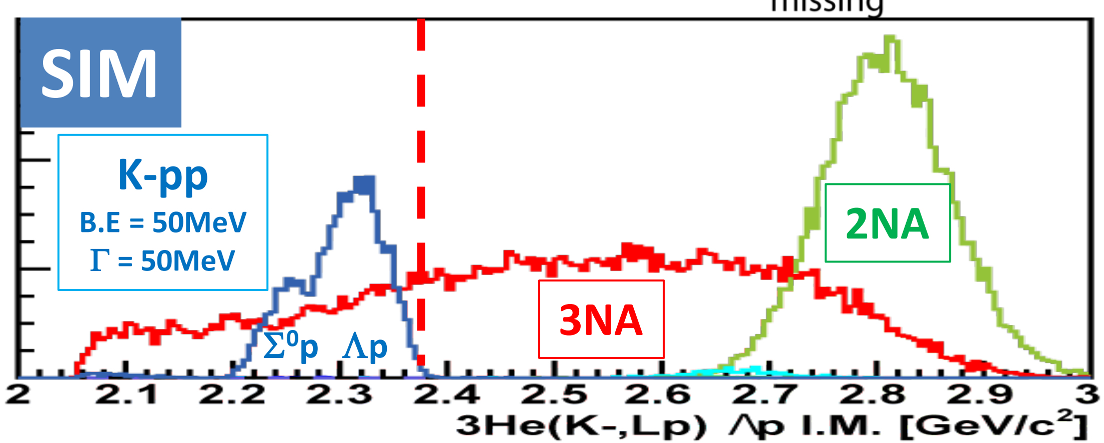
- π^- stopped [1]
  - 2nucleon absorption &FSI (50%/π_{stopped}) are clearly seen
  - 3nucleon absorption <3% /π_{stopped}
- π^- in-flight [2],[3]
  - 2nucleon absorption 0.85 ± 0.17mb (266 MeV/c)
  - 3nucleon absorption 3.7 ± 0.6 mb(220 MeV/c)
  - 2NA/3NA ~25%





Λp Invariant Mass

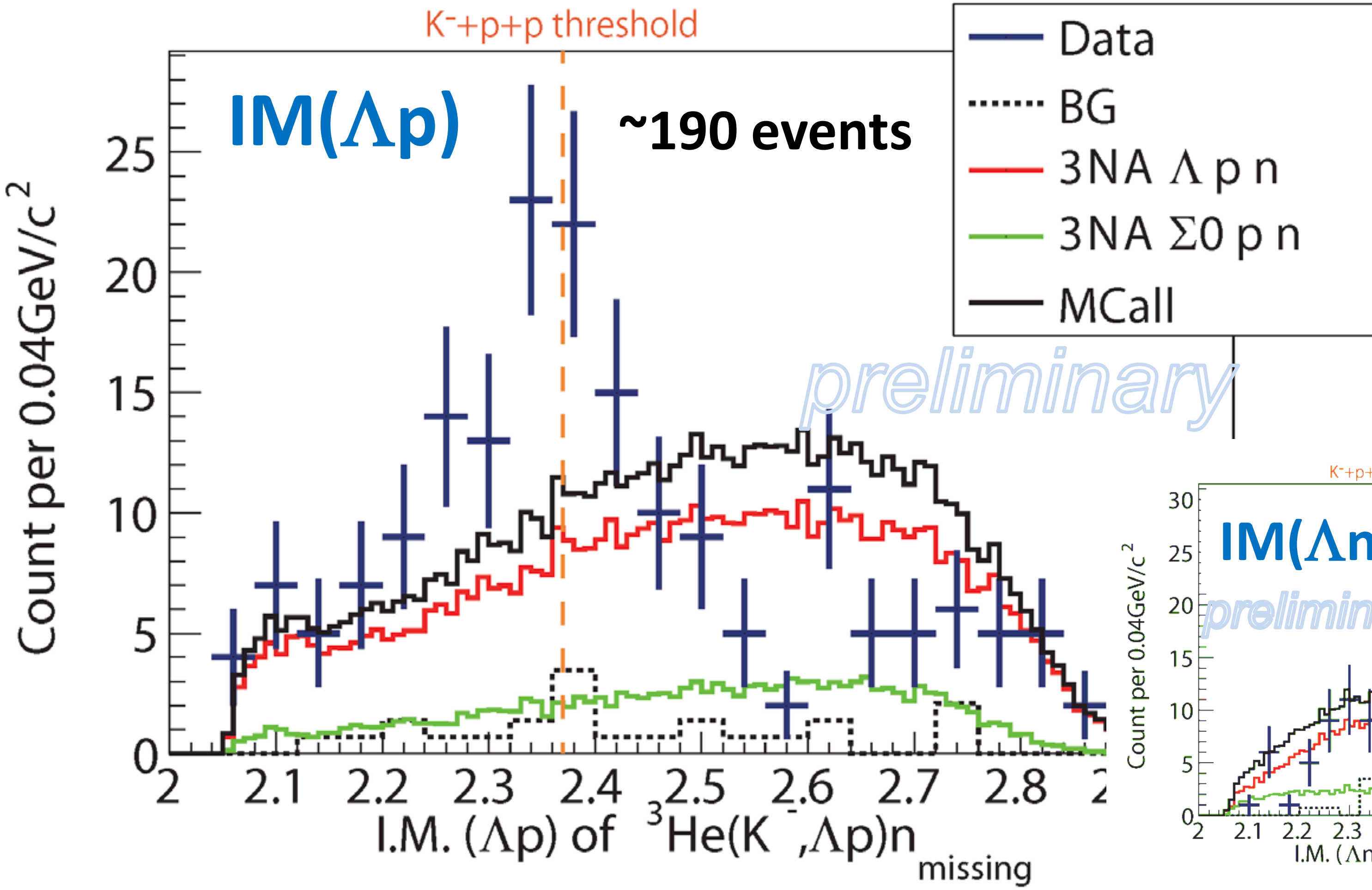


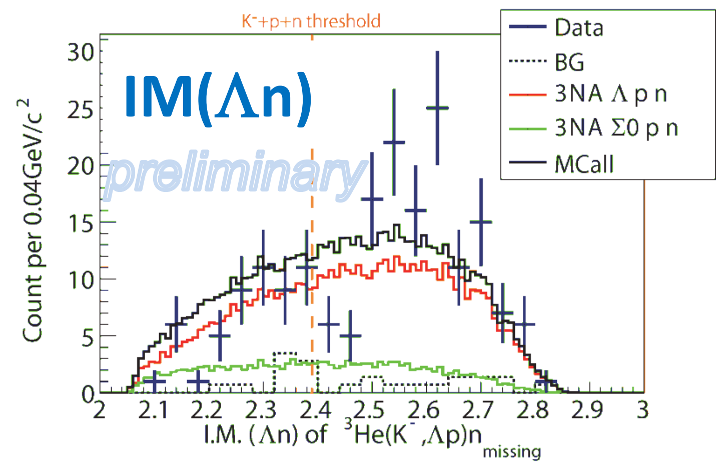


- Excess around the threshold?
- 3NA phase-space?
- 2NA contribution?

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

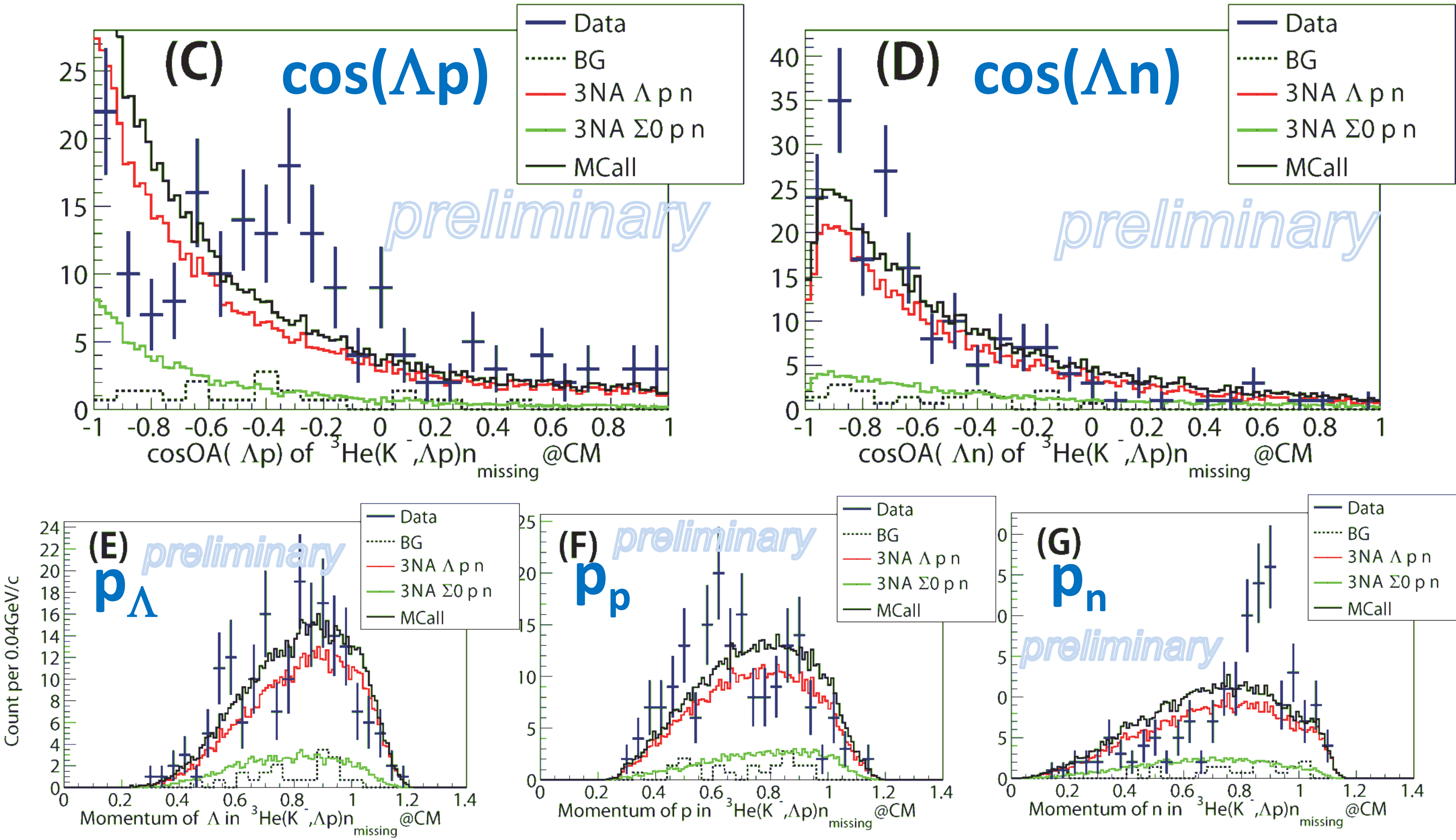
Comparison with Phase-Space





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

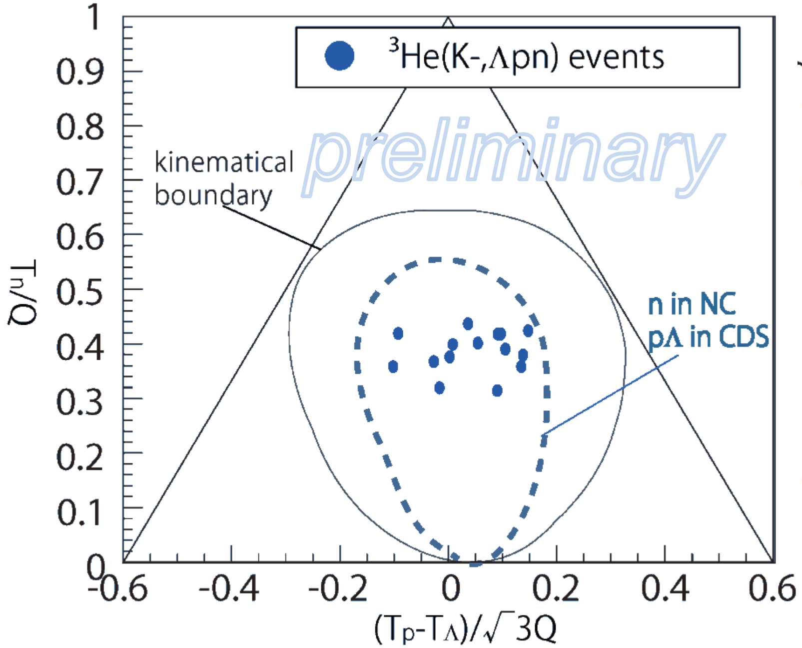
Comparison with Phase-Space

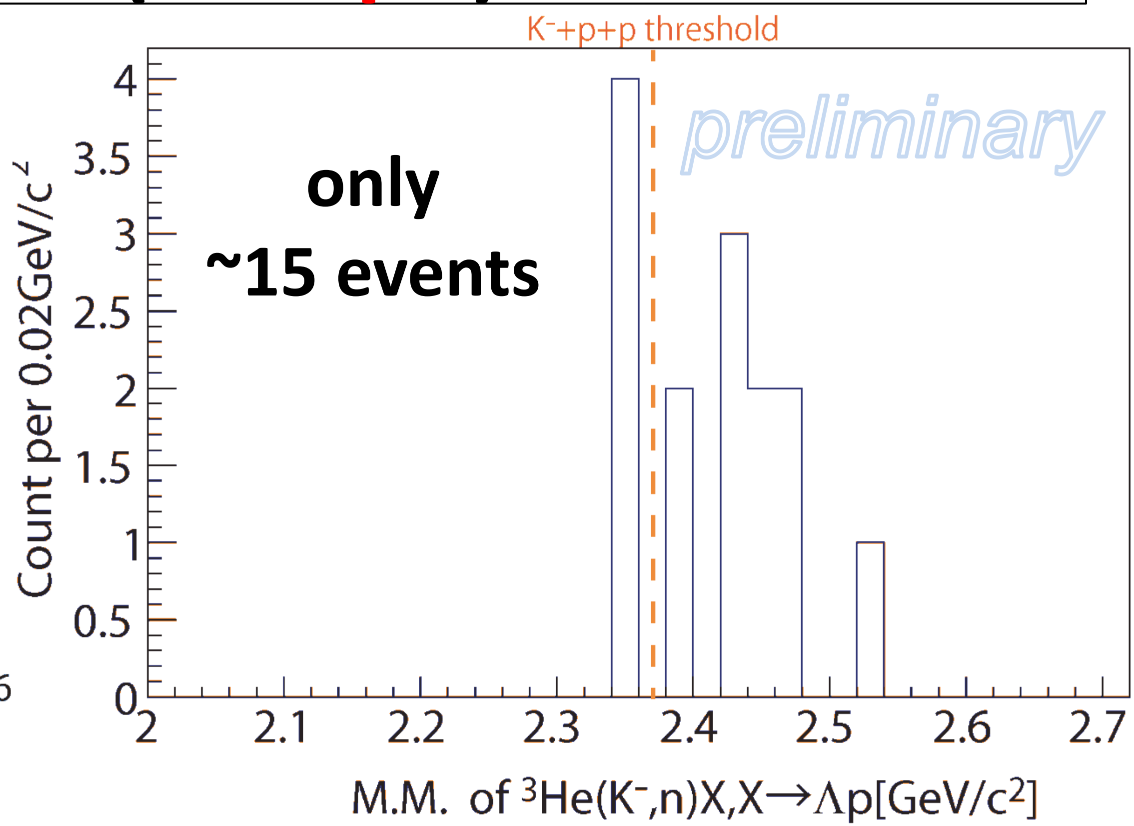


- **data cannot be reproduced by the phase-space?**

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 than x10~100 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

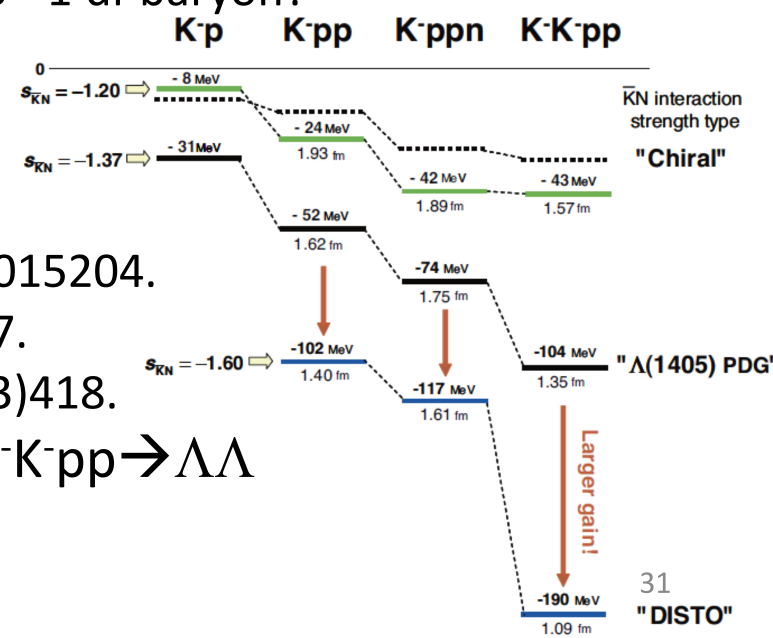
1. confirm the spectral shape of the Λp invariant-mass by the exclusive measurement of $^3He(K^-, \Lambda p)n$
2. explore the neutron spectrum at $\theta_{lab} = 0^o$ with the kinematically complete measurement of $^3He(K^-, \Lambda pn)$

➢ to extract more information on the $K^{bar}N$ interaction

何を測ればK⁻pp解決? (個人的感想)

- E15実験の統計を上げる
  - 主目的である^{3}He(K$^-$,Λpn)完遂
  - energy scan (p_K = 0.7~1.1 GeV/c)
    - Production = [FINUDA]　(K$^-$)+(pp)?
    - Production = [DISTO/E27] Λ*p?
- Decay Channel
  - これまでの実験は主にΛp-channel測定
  - πΣN/ΣN-channel測定が重要であろう
    - Molecular-state? / K-pp bound-state? / S=-1 di-baryon?
    - 理論計算は???
- もう1つK$^-$: K$^-$K$^-$pp
    - Hassanvand et. al.,Phys. Rev., **C84**(2011)015204.
    - Barnea et. al., Phys. Lett., **B712**(2012)137.
    - Maeda et. al., Proc. Jpn. Acad., B89(2013)418.
  - 実験例: p^{bar} + ^{3}He → (K$^-$K$^-$pp)+ K + K, K$^-$K$^-$pp→ΛΛ
- … ???

スピン/パリティー
重い核



Summary of E15 1st

Formation Channel

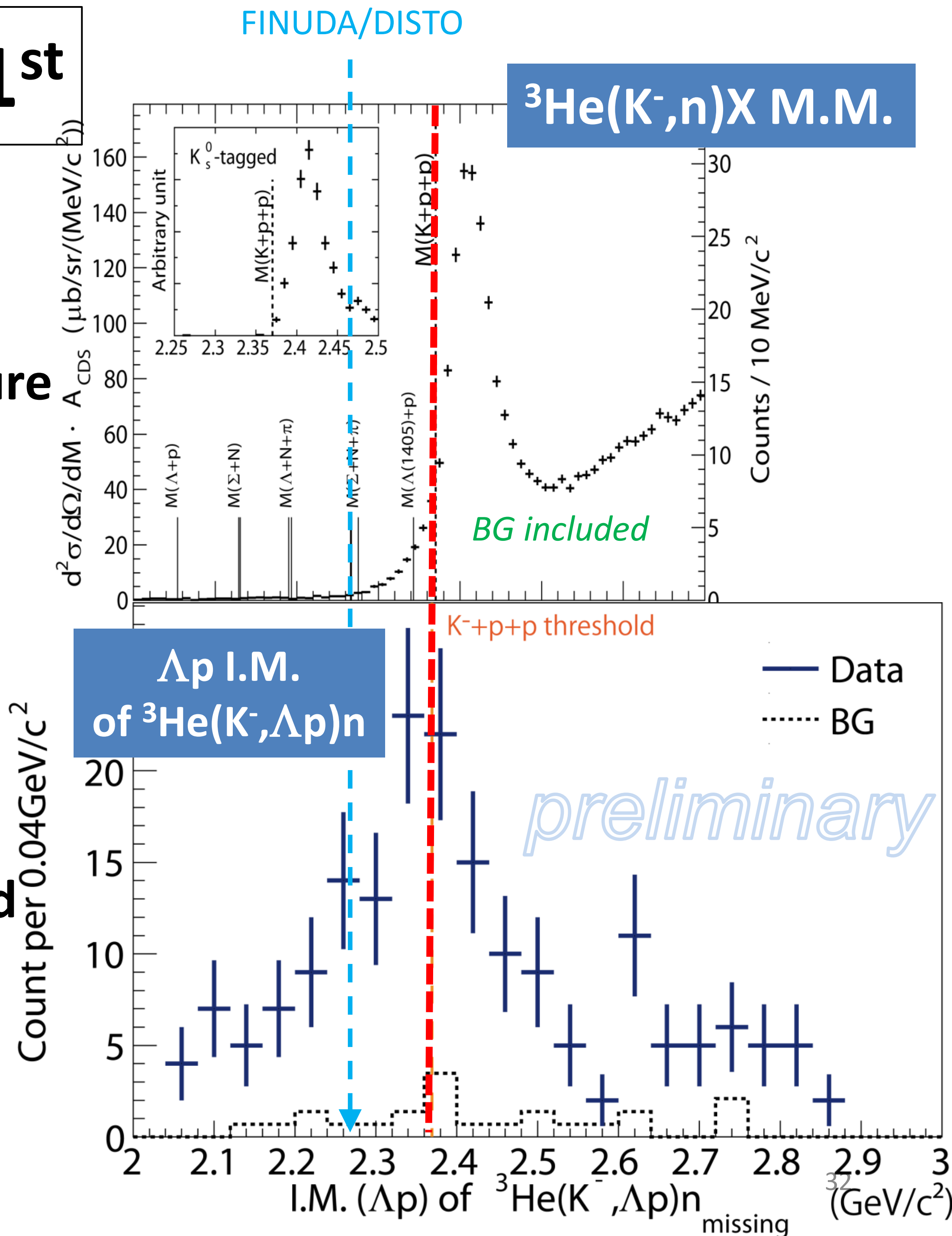
Semi-Inclusive ³He(K⁻,n)X

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

Decay Channel

Exclusive ³He(K⁻,Λp)n

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



The J-PARC E15 Collaboration

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