Kaonic nuclei studied via K^- induced reactions

Tadashi Hashimoto (JAEA)
for J-PARC E15 collaboration

Outline

- **Introduction**

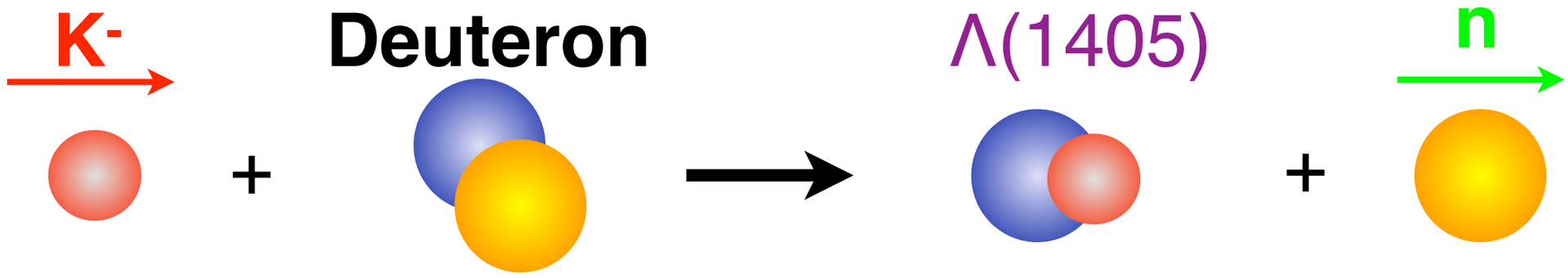
- **J-PARC E15^{1st}**
  - Two published papers
    - Semi-inclusive ^{3}He(K^{-},**n**)X & Exclusive ^{3}He(K^{-},**Λp**)n

- **J-PARC E15^{2nd}**
  - Preliminary results on the ^{3}He(K^{-},**Λp**)n channel

- **Summary and outlook**

Λ(1405) & "K⁻pp"

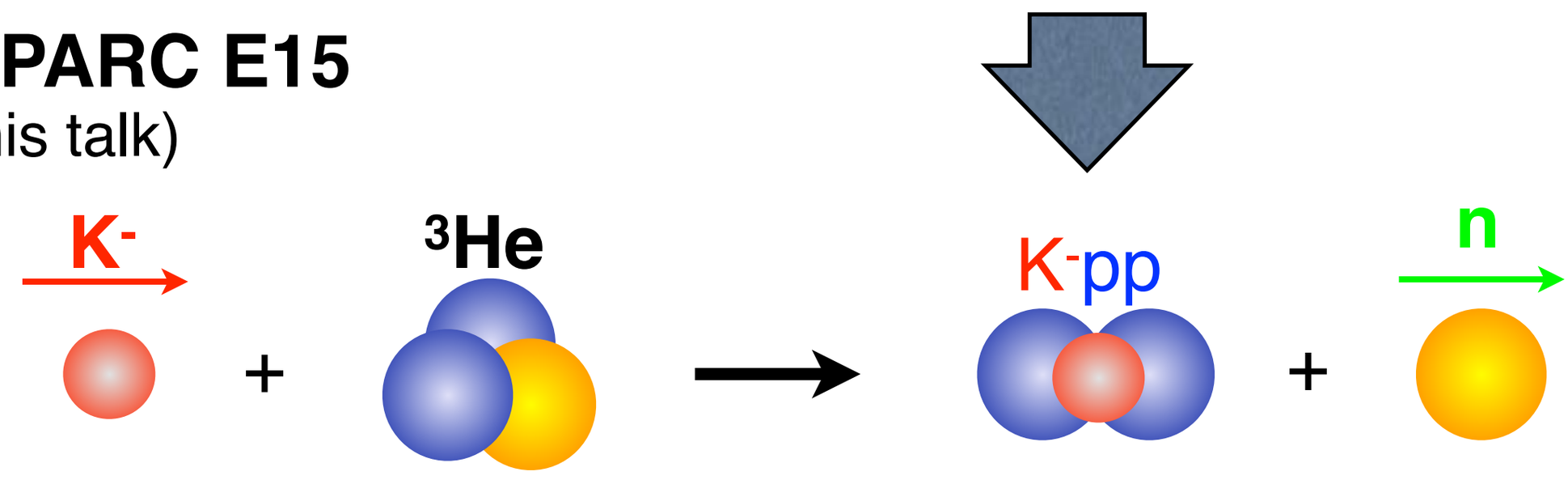
- **J-PARC E31**
  (previous talk)



K⁻p quasi-bound state?

B.E ($K^{bar}N$): 10 ~ 30 MeV >> B.E.(NN) ~ 2MeV

- **J-PARC E15**
  (this talk)

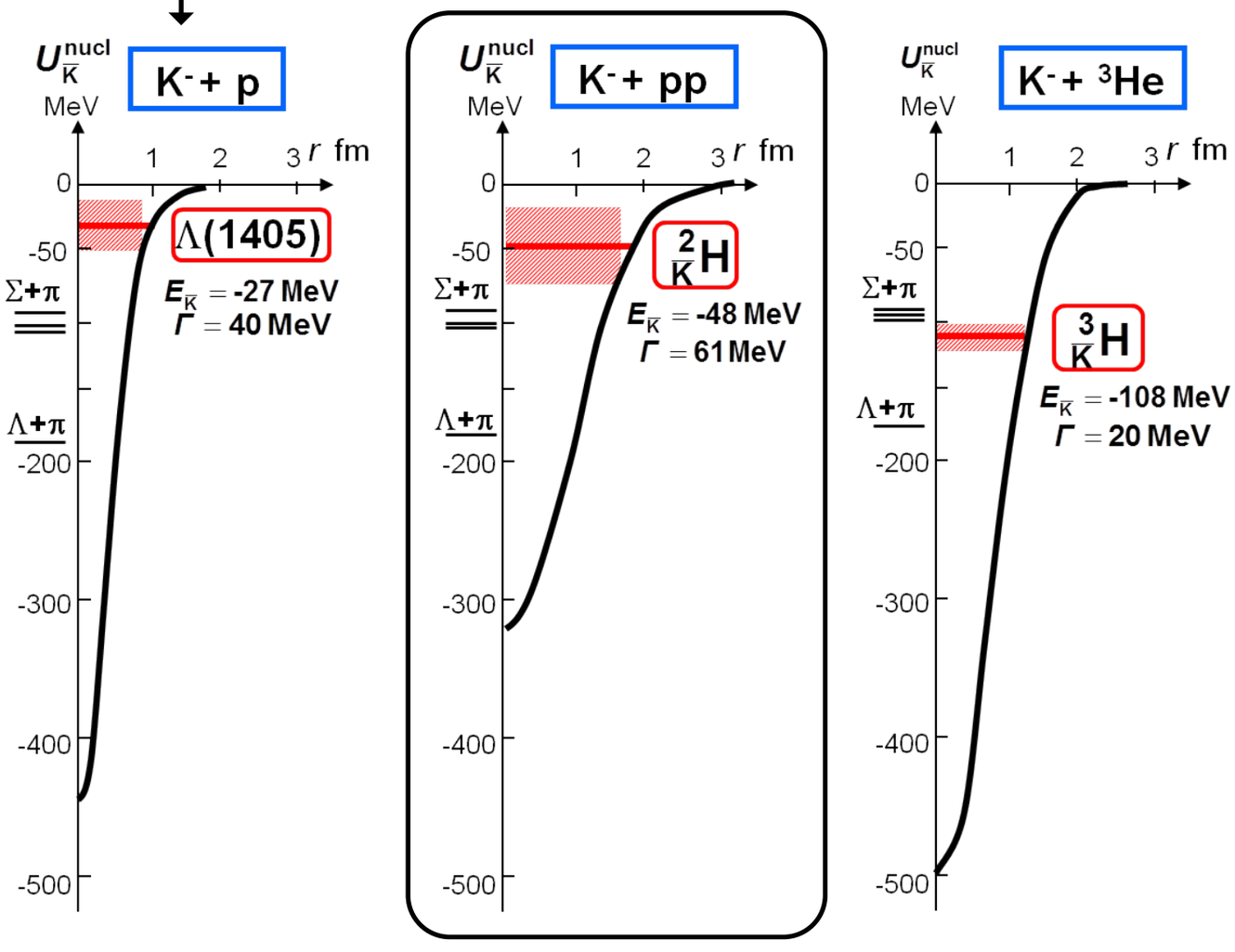


What happens?
Is there nuclear bound state?

Kaonic nuclear bound state

Could be a good probe for dense & cold QCD

Assumption

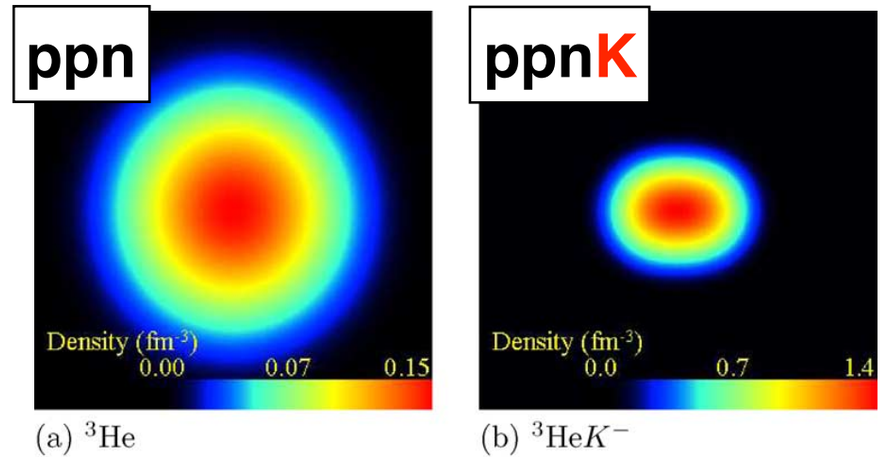


1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

the lightest kaonic nucleus

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

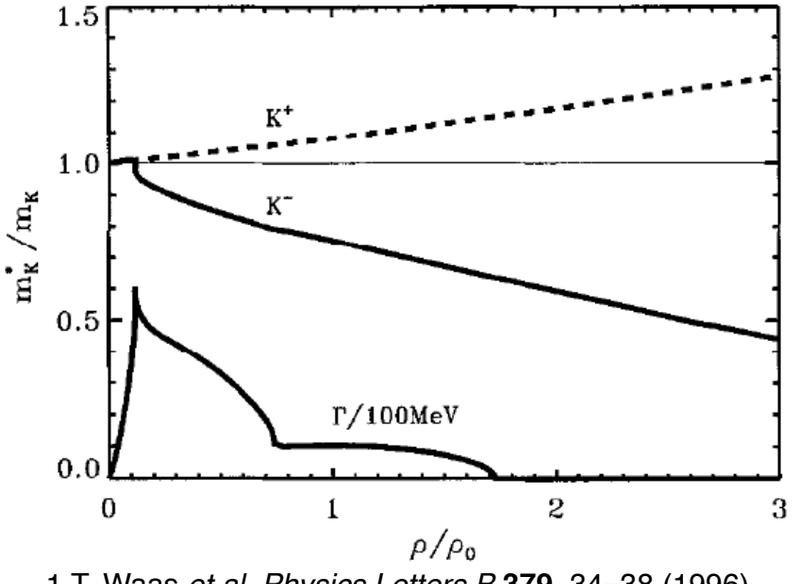
dense nuclei are predicted



(a) ^{3}He (b) ^{3}HeK^{-}

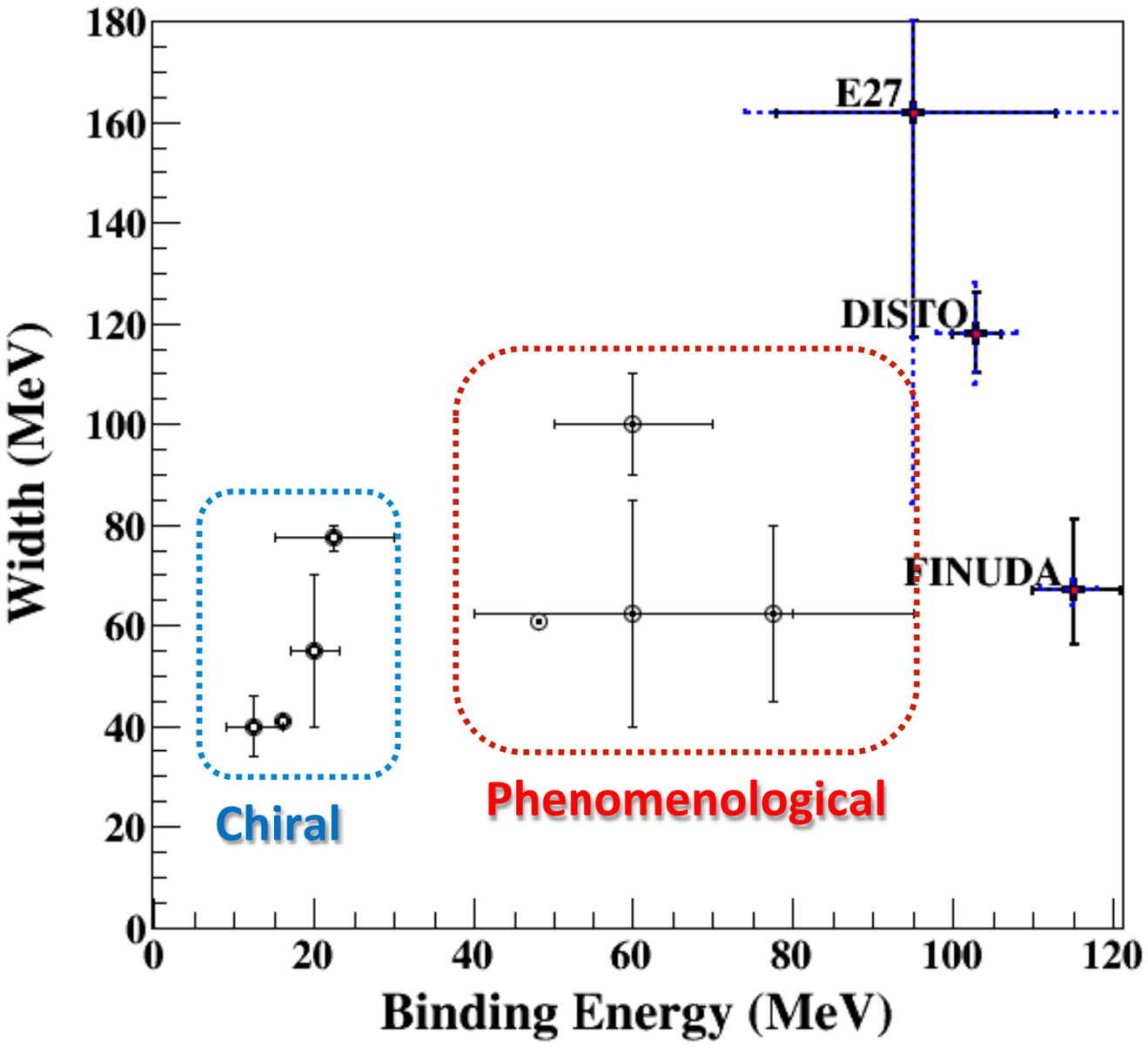
A. Dote, H. Horiuchi, Y. Akaishi and T. Yamazaki, Phys. Lett. B 590 (2004) 51

Kaon mass in nuclear medium?



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

Present status

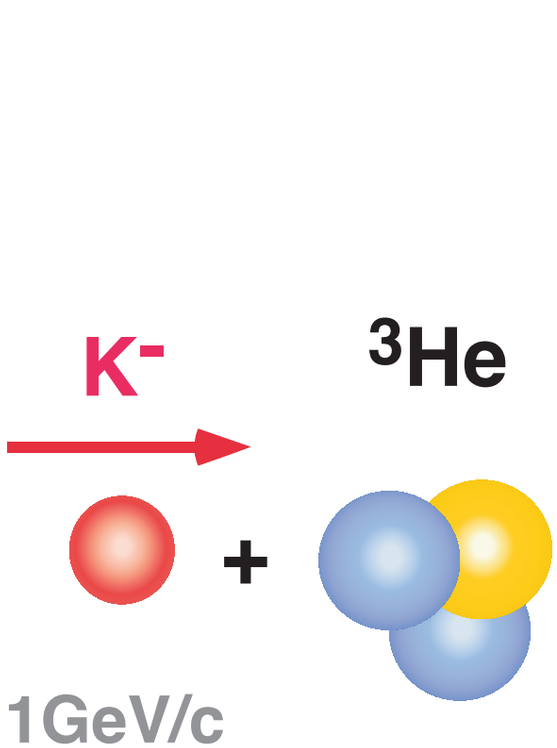


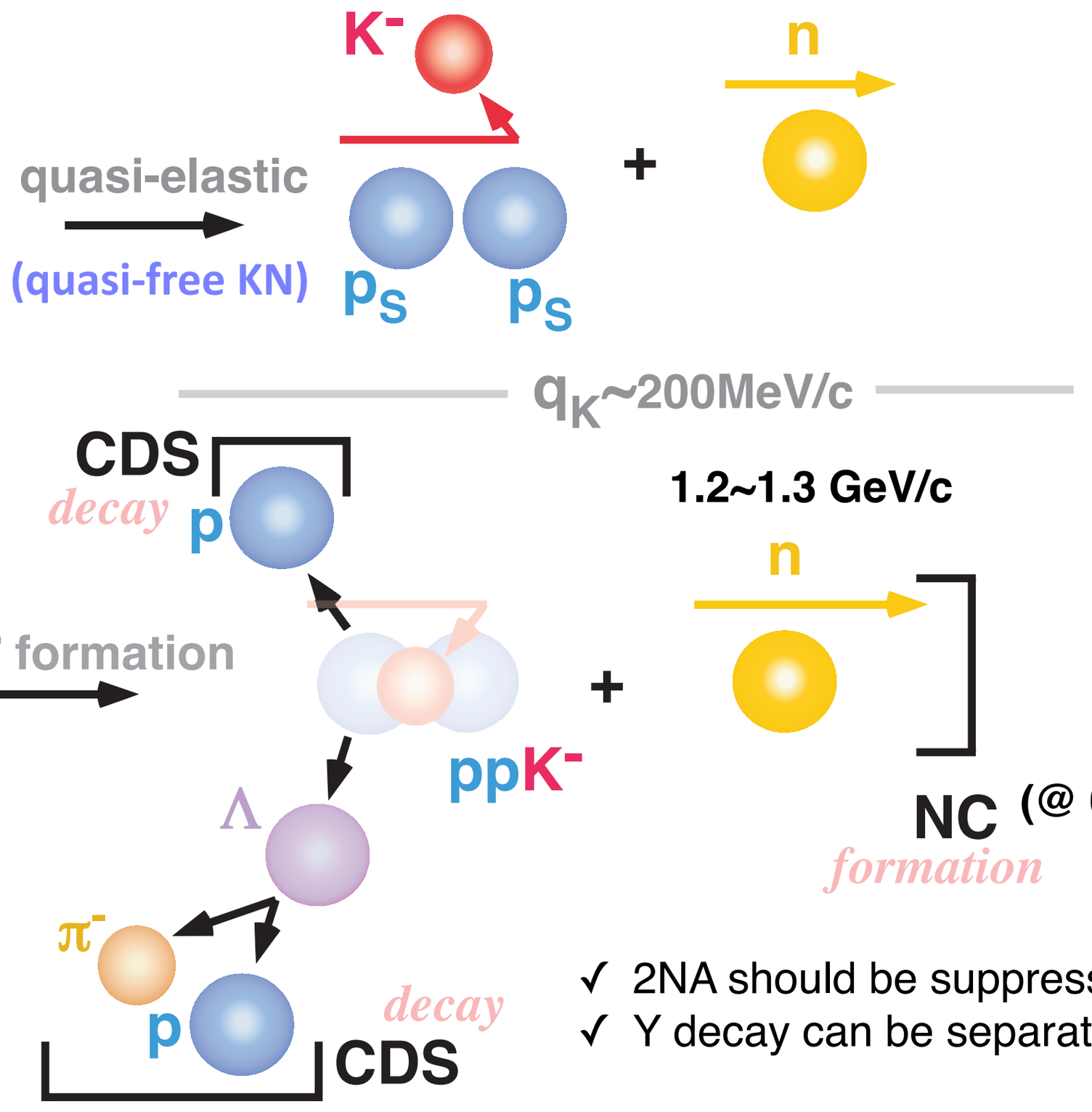
- **Experiment**
  - FINUDA $stop\text{-}K^-$
  - DISTO $pp \to \Lambda p K^+$
  - J-PARC E27 $d(\pi^+, K^+)X$
  - LEPS **NULL** $d(\gamma, \pi^- K^+)X$
  - HADES **NULL** $pp \to \Lambda p K^+$

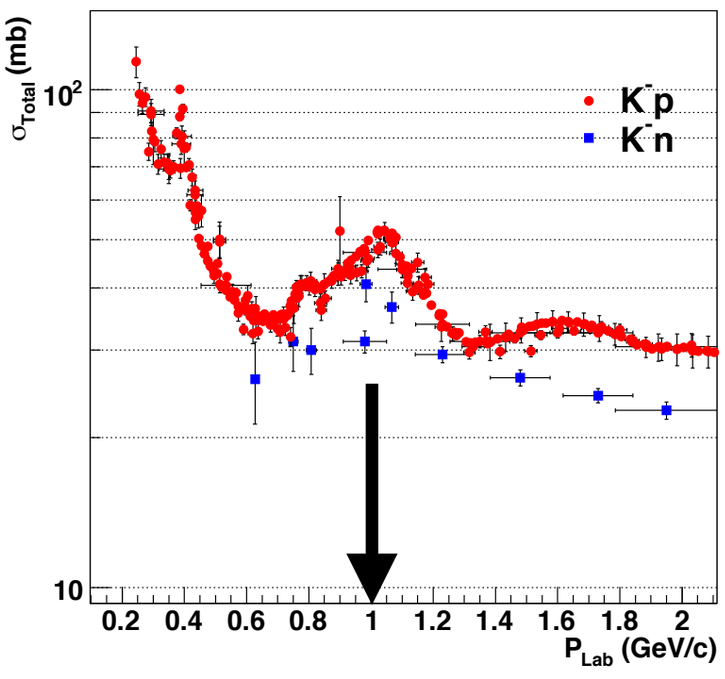
- **Few-body calc.**
  - B.E.& Γ depend on interaction model
    - **Chiral** (energy-dependent)
    - **Phenomenological** (energy-independent)

"K⁻pp" should be studied more

In-flight K^- reaction on ^3He

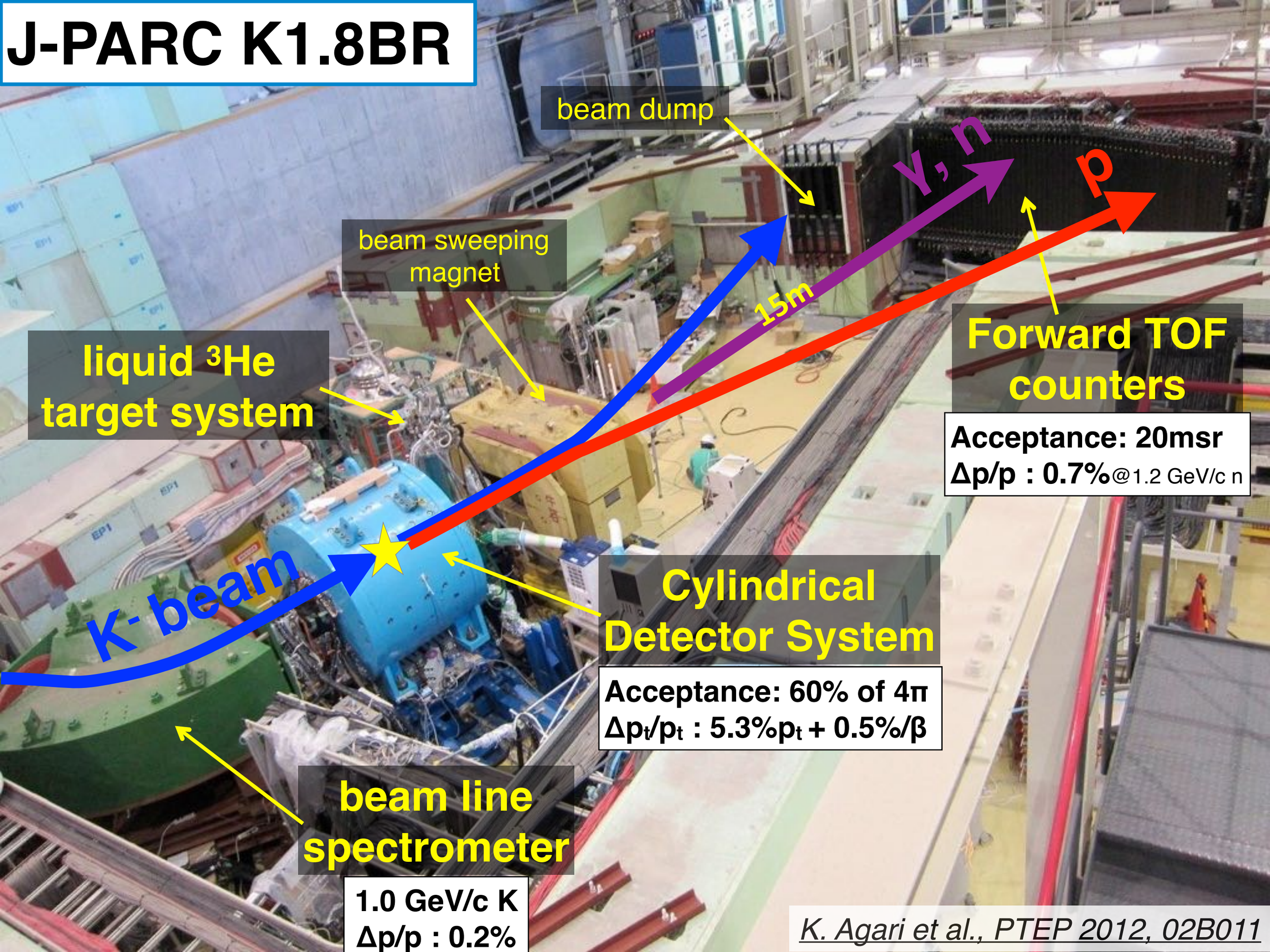






- ✓ 2NA should be suppressed
- ✓ Y decay can be separated

J-PARC K1.8BR



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

E15 1st

4 days in May, 2013

T. Hashimoto@EXA2017

Two papers from E15[1st]

PTEP

Prog. Theor. Exp. Phys. **2015**, 061D01 (11 pages)
DOI: 10.1093/ptep/ptv076

^{3}He(K$^-$, n) : semi-inclusive

Letter

Search for the deeply bound $K^- pp$ state from the semi-inclusive forward-neutron spectrum in the in-flight K^- reaction on helium-3

J-PARC E15 Collaboration
T. Hashimoto[1,*,†], S. Ajimura[2], G. Beer[3], H. Bha
M. Cargnelli[8], S. Choi[4], C. Curceanu[9], S. Enomo
Y. Fujiwara[1], T. Fukuda[11], C. Guaraldo[9], R. S. Ha
M. Iliescu[9], K. Inoue[13], Y. Ishiguro[10], T. Ishikawa
M. Iwai[12], M. Iwasaki[14,15], Y. Kato[14], S. Kawasa
J. Marton[8], Y. Matsuda[17], Y. Mizoi[11], O. Morra[6],
H. Ohnishi[14,2], S. Okada[14], H. Outa[14], K. Piscicc
A. Romero Vidal[9], Y. Sada[10], A. Sakaguchi[13], F.

PTEP

Prog. Theor. Exp. Phys. **2016**, 051D01 (11 pages)
DOI: 10.1093/ptep/ptw040

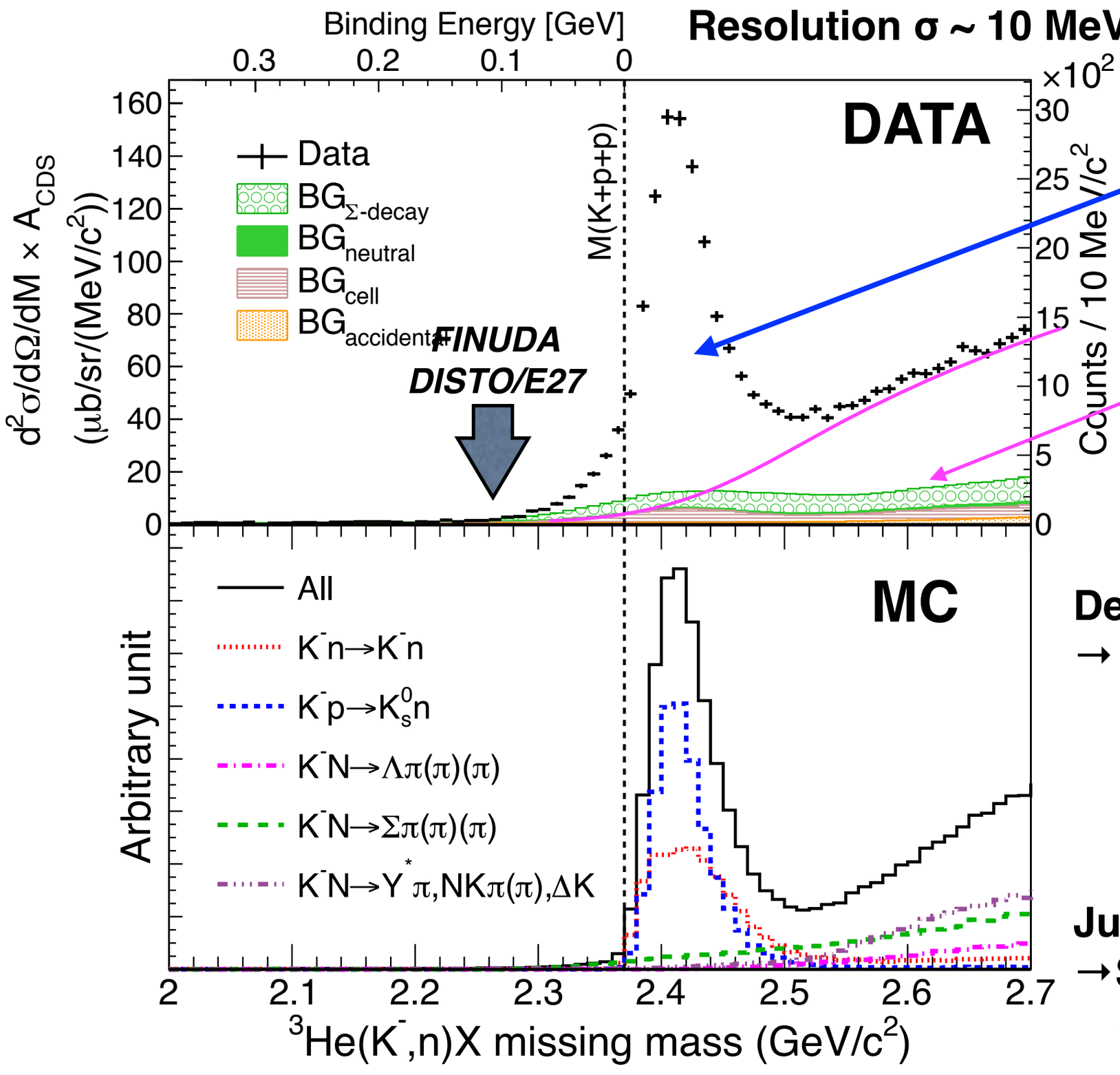
^{3}He(K$^-$, Λp)n : exclusive

Letter

Structure near the $K^- + p + p$ threshold in the in-flight ^{3}He$(K^-, \Lambda p)n$ reaction

J-PARC E15 Collaboration
Y. Sada[1,*], S. Ajimura[1], M. Bazzi[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], P. Buehler[6], L. Busso[7,9], M. Cargnelli[6], S. Choi[4], C. Curceanu[2], S. Enomoto[8], D. Faso[7,9], H. Fujioka[10], Y. Fujiwara[11], T. Fukuda[12], C. Guaraldo[2], T. Hashimoto[13], R. S. Hayano[11], T. Hiraiwa[1], M. Iio[8], M. Iliescu[2], K. Inoue[1], Y. Ishiguro[10], T. Ishikawa[11], S. Ishimoto[8], T. Ishiwatari[6], K. Itahashi[13], M. Iwai[8], M. Iwasaki[13,14], Y. Kato[13], S. Kawasaki[15], P. Kienle[†,16], H. Kou[14], Y. Ma[13], J. Marton[6], Y. Matsuda[17], Y. Mizoi[12], O. Morra[7], T. Nagae[10], H. Noumi[1], H. Ohnishi[13,1], S. Okada[13], H. Outa[13], K. Piscicchia[2], A. Romero Vidal[2], A. Sakaguchi[15], F. Sakuma[13], M. Sato[13], A. Scordo[2], M. Sekimoto[8], H. Shi[2], D. Sirghi[2,5], F. Sirghi[2,5], K. Suzuki[6], S. Suzuki[8], T. Suzuki[11], K. Tanida[18], H. Tatsuno[19], M. Tokuda[14], D. Tomono[1], A. Toyoda[8], K. Tsukada[20], O. Vazquez Doce[2,21], E. Widmann[6], B. K. Wuenschek[6], T. Yamaga[15], T. Yamazaki[11,13], H. Yim[22], Q. Zhang[13], and J. Zmeskal[6]

Forward neutron semi-inclusive spectrum



Quasi-elastic

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

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

Hyperon decay

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

$Y \rightarrow n + \pi$

Deep-bound region

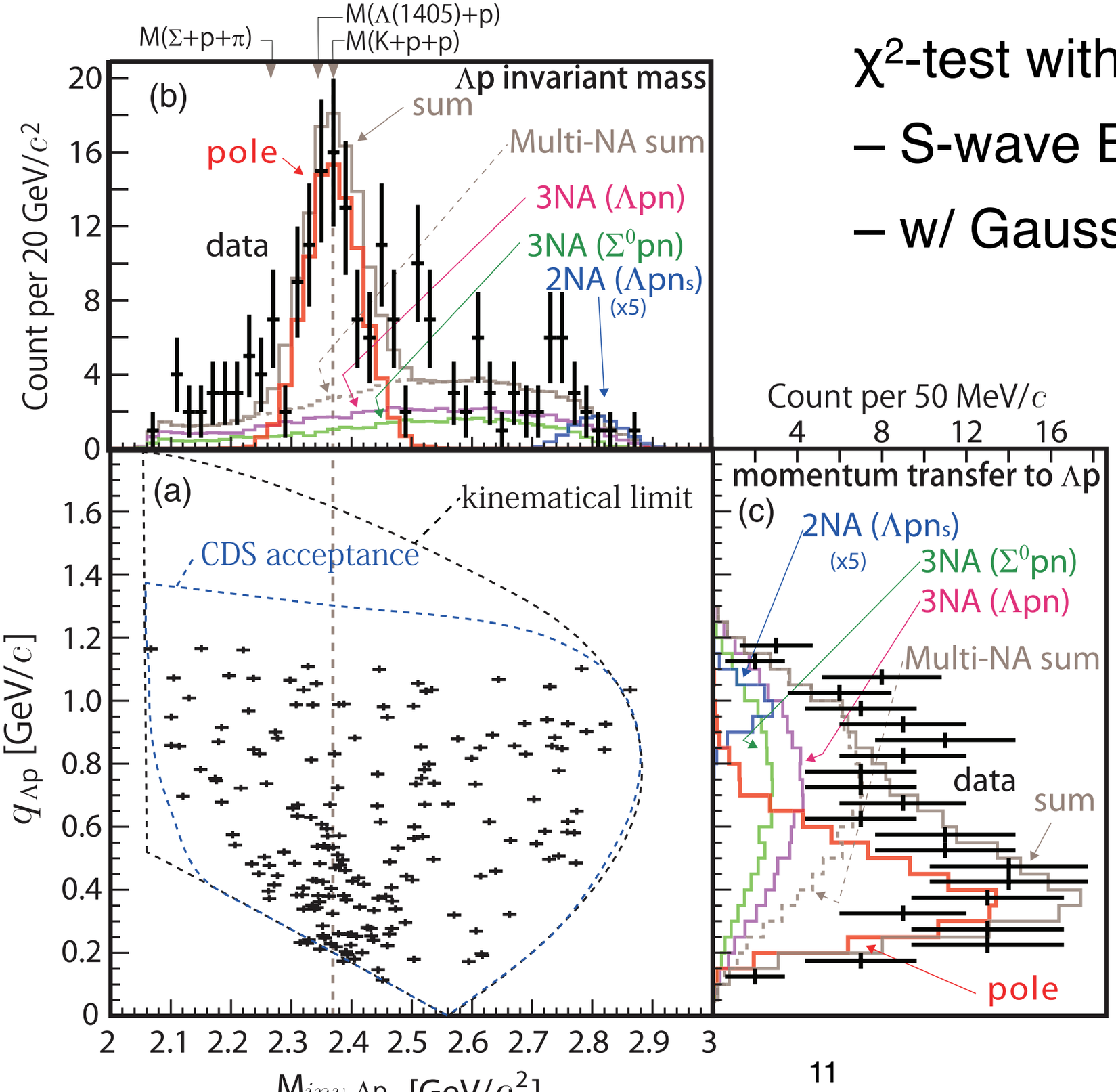
→ No significant peak
set upper limit:
a few hundreds ub/sr
= a few % of quasi-elastic K

Just below the threshold

→Significant yield ~ 1 mb/sr
should include quasi-free Λ(1405)

Λp invariant mass with a missing neutron

Resolution σ ~ 10 MeV/c² @ threshold



χ²-test with pole & 3NA(Ypn)

– S-wave Breit-Wigner pole

– w/ Gaussian form-factor

$$\frac{d^2\sigma}{dMdq} \propto \rho_3(\Lambda pn) \times \frac{(\Gamma_X/2)^2}{(M-M_X)^2+(\Gamma_X/2)^2} \times \left| exp\left(-\frac{q^2}{2Q_X^2}\right)\right|^2$$

$$M_X \sim 15 \text{ MeV}$$

$$\Gamma_X \sim 100 \text{ MeV}$$

$$Q_X \sim 400 \text{ MeV}$$

Compact state?

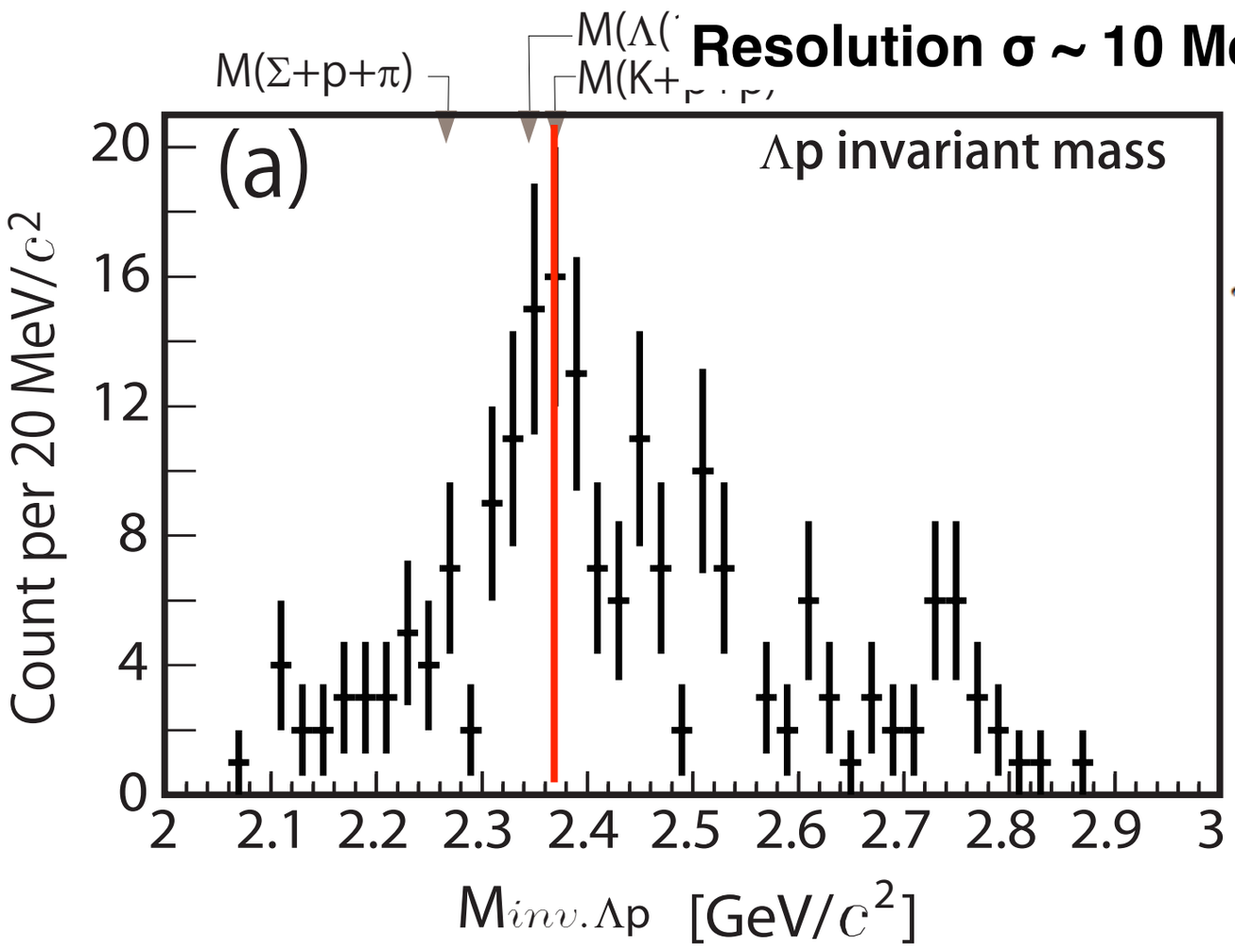
E15^{2nd}

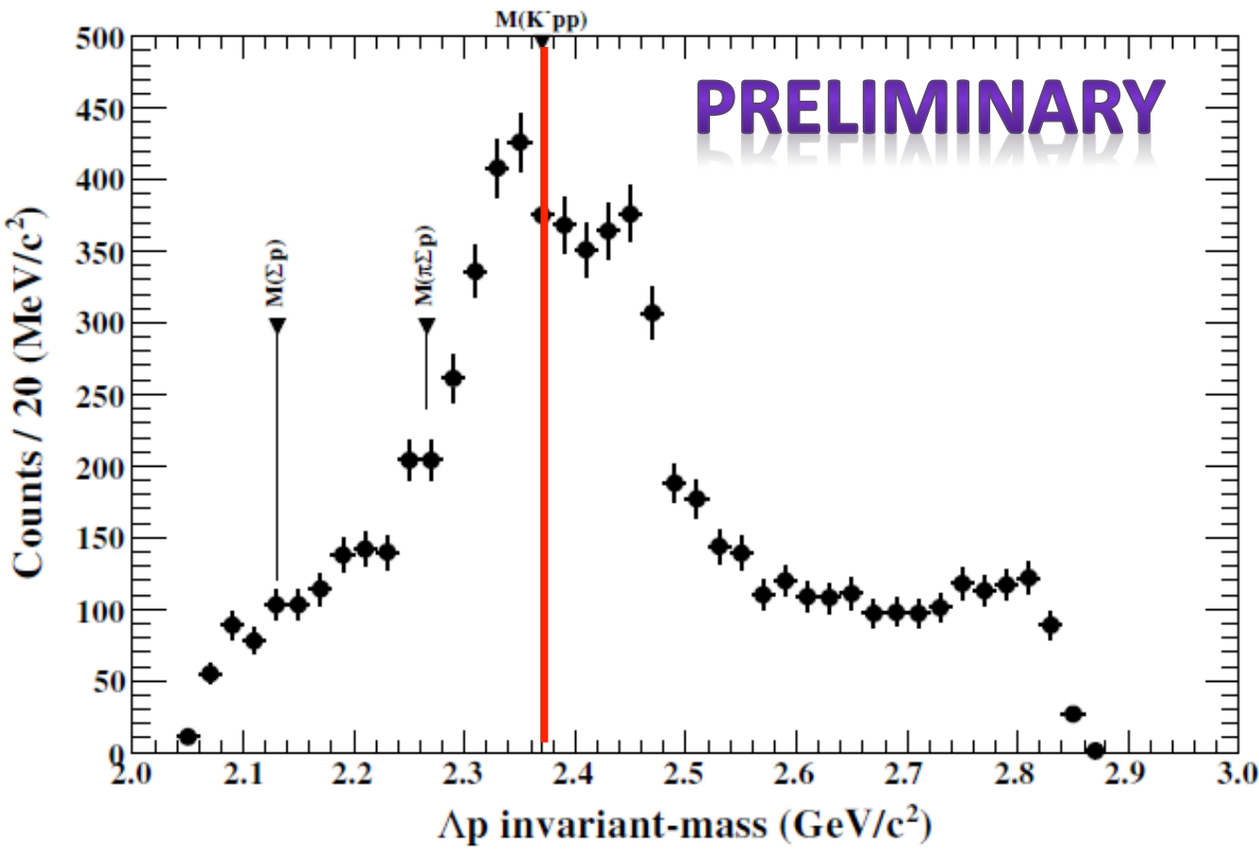
3 weeks in Nov.&Dec., 2015

Comparison between E15[1st] & E15[2nd]

1st → **2nd**

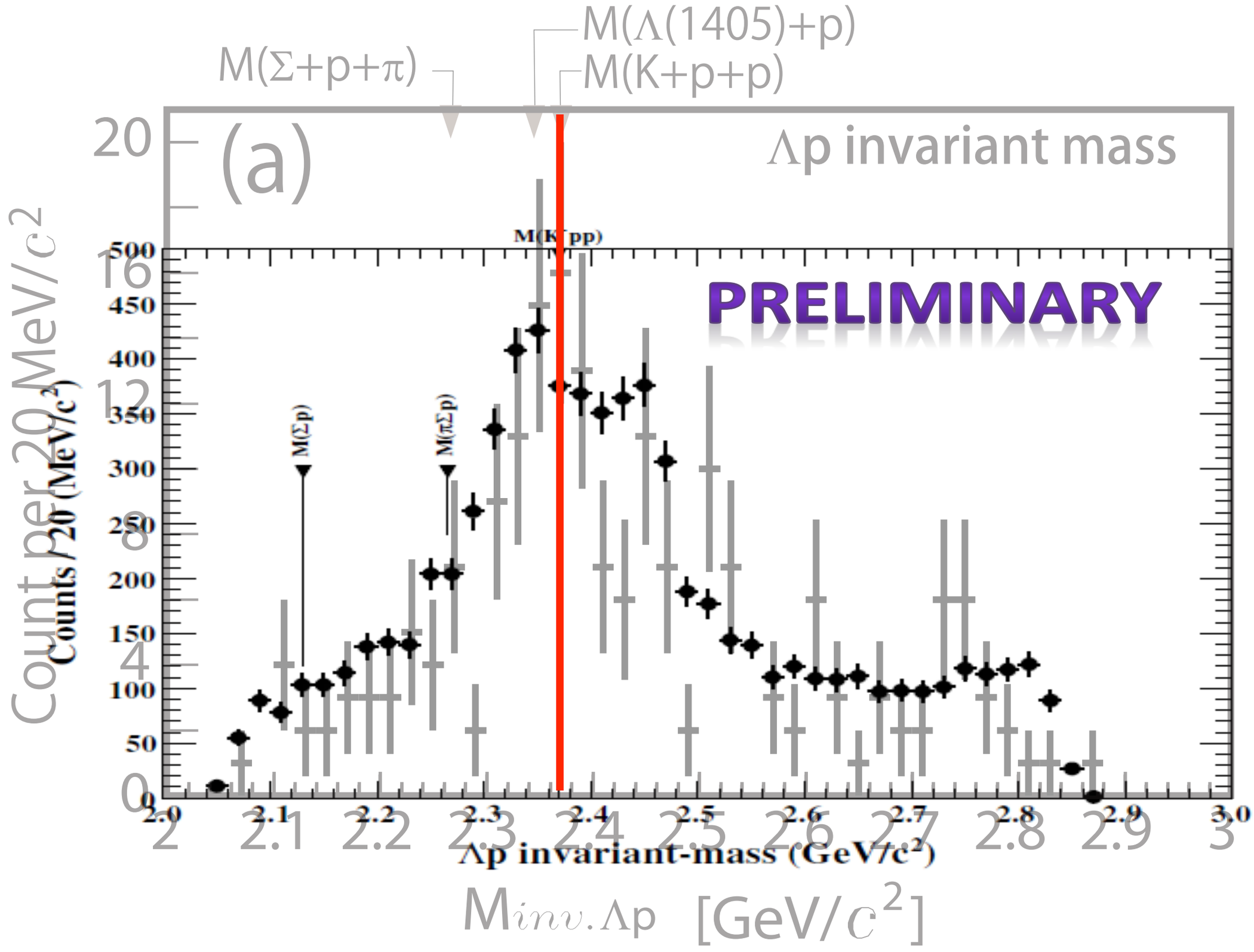
Resolution σ ~ 10 MeV/c² @ threshold



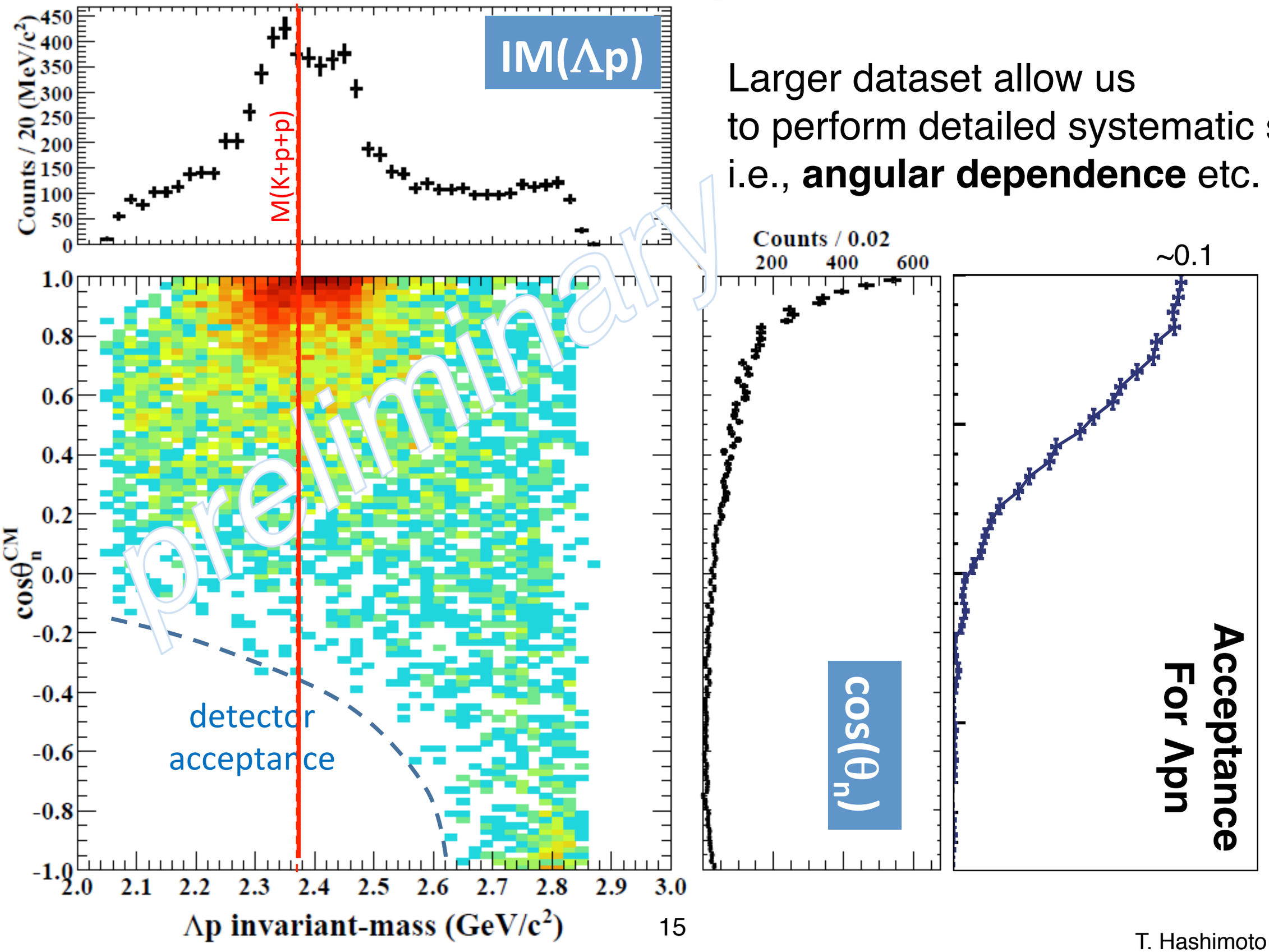


- **x 30 data for Λp(n) final state**
  - x 7 beam + dedicated trigger (requires > 3 hits on CDH)

Comparison between E15[1st] & E15[2nd]

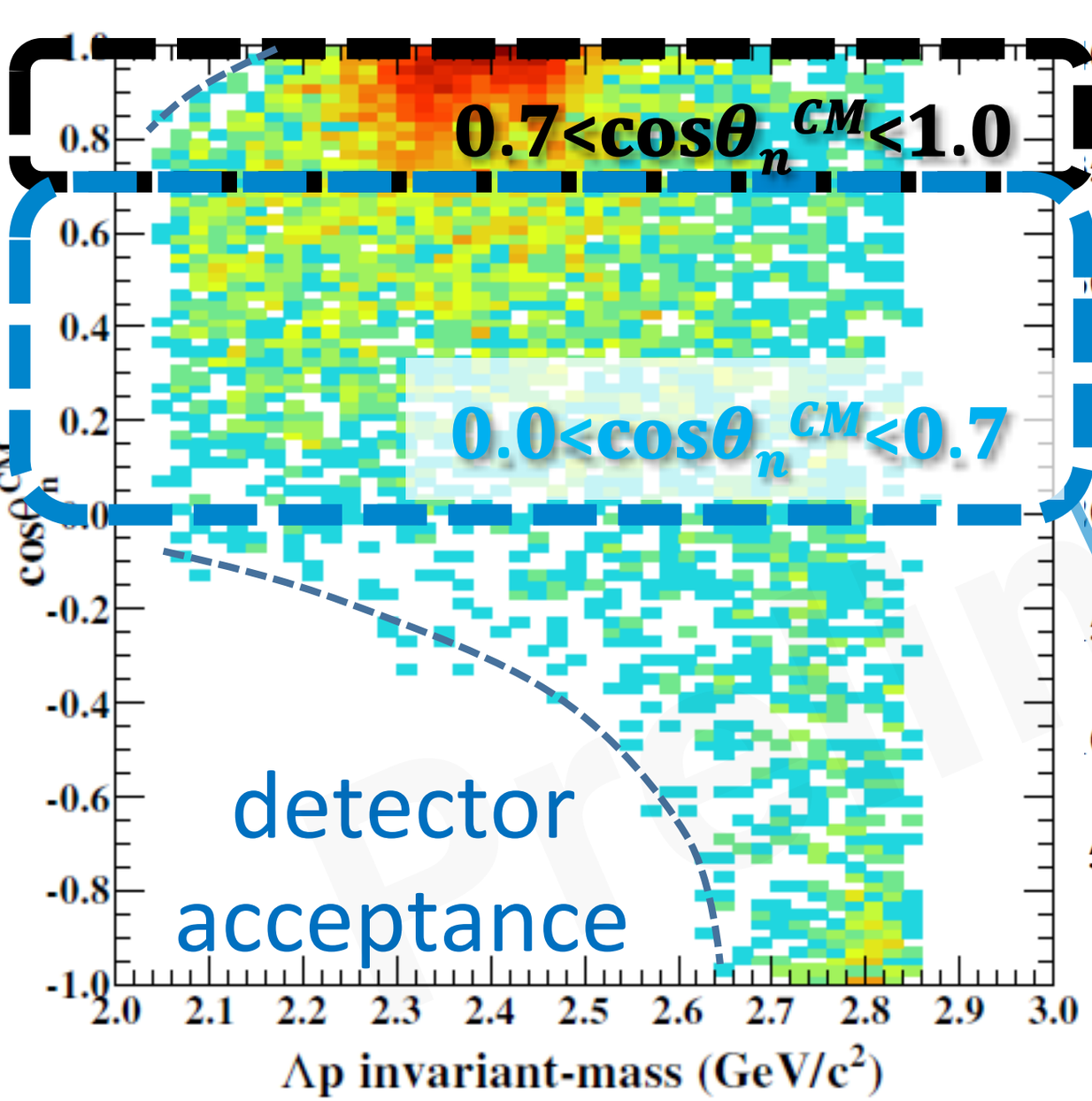


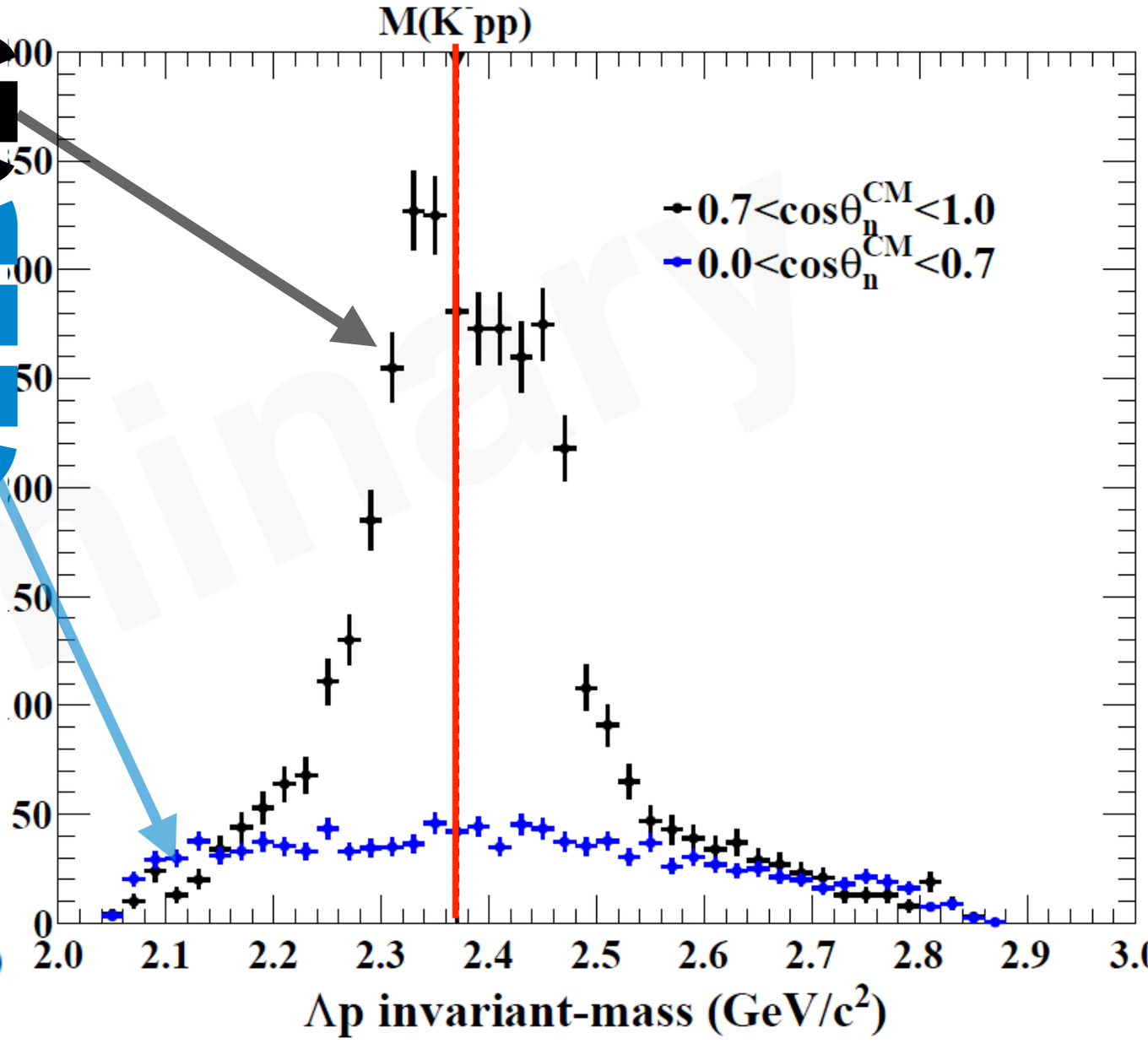
Reaction angle: $\cos\theta_n$



Larger dataset allow us
to perform detailed systematic study.
i.e., **angular dependence** etc.

Reaction angle dependence: $\cos\theta_n$





- **Structure around the threshold prefers the forward neutron**
- **Events widely spread to the phase space in the other region**
  - Point-like three nucleon absorption? 2 NA relatively weak.

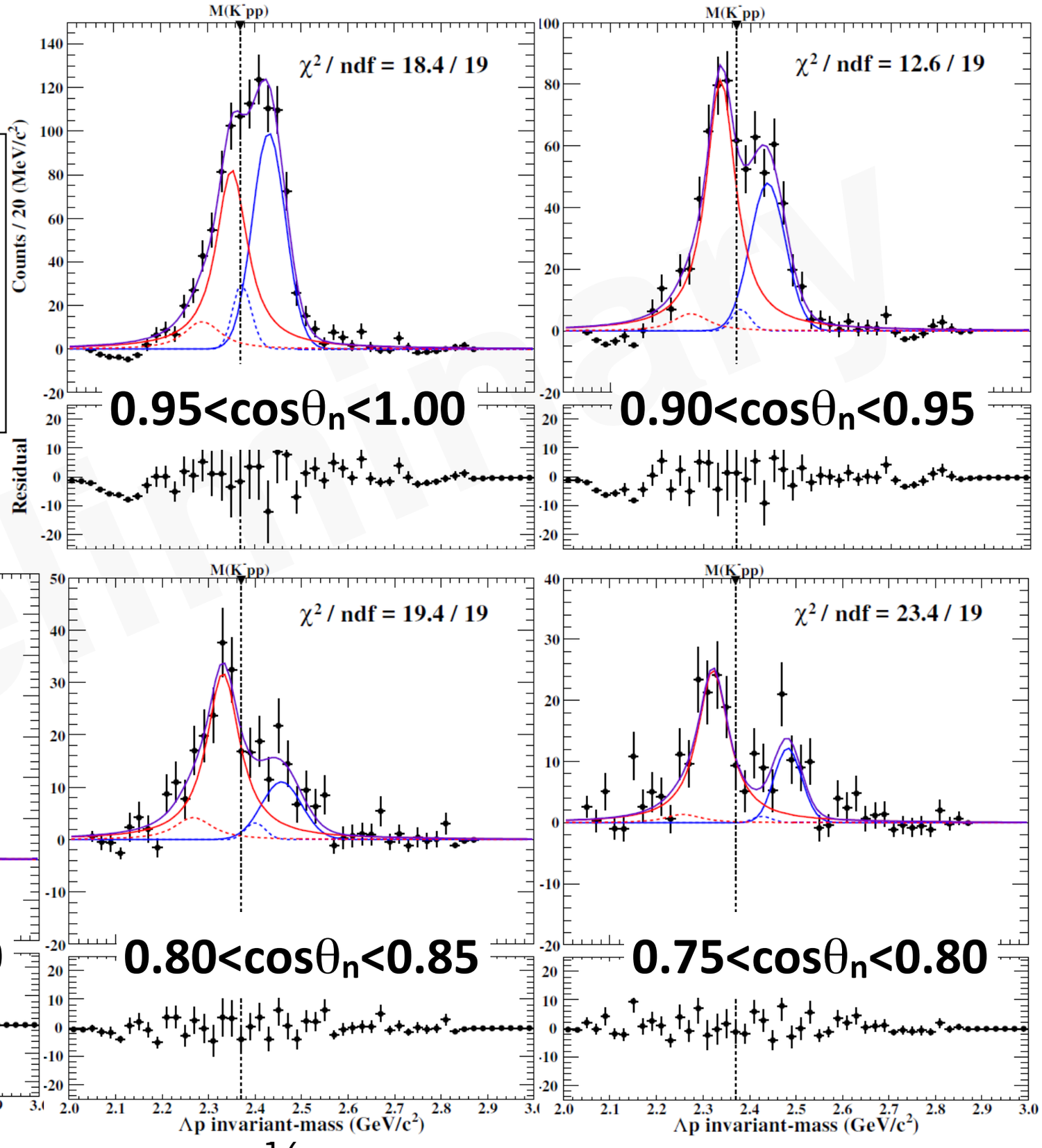
Slice by reaction angle: $\cos\theta_n$

Simple fitting w/o 3NA

B.S.: Breit-Wigner

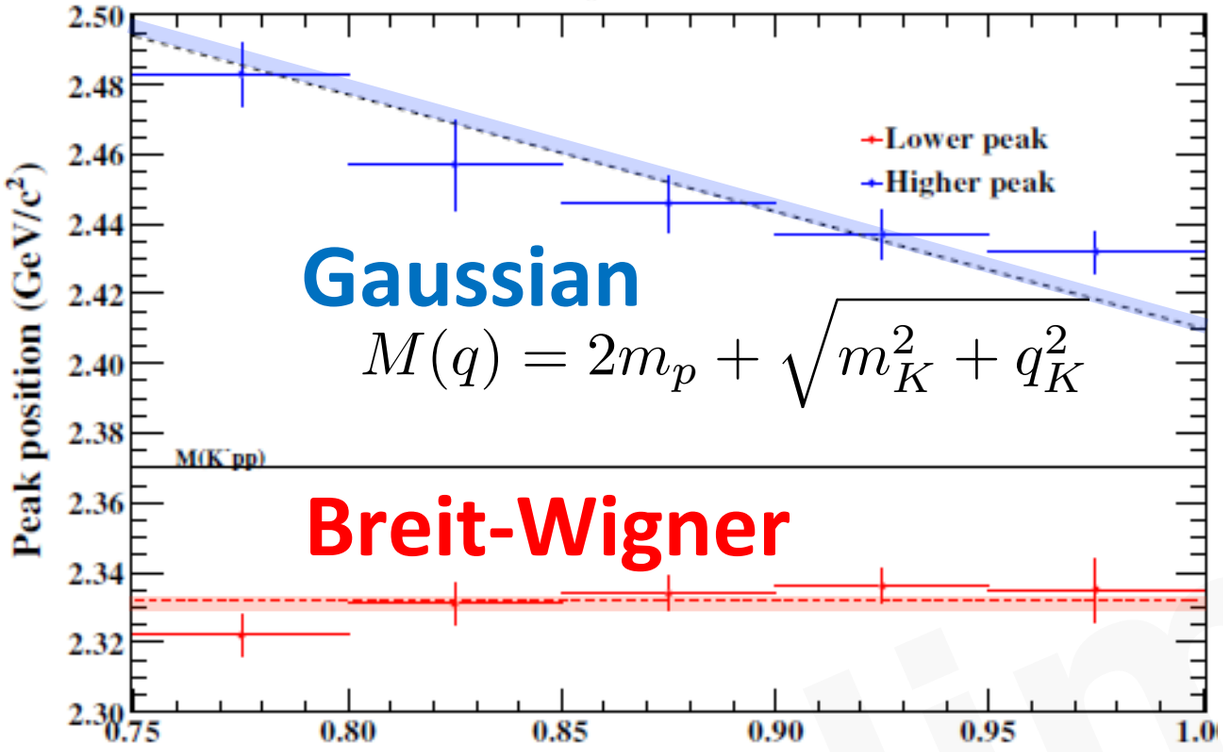
QF: Gaussian

w/ $\Sigma^0 p$ contamination

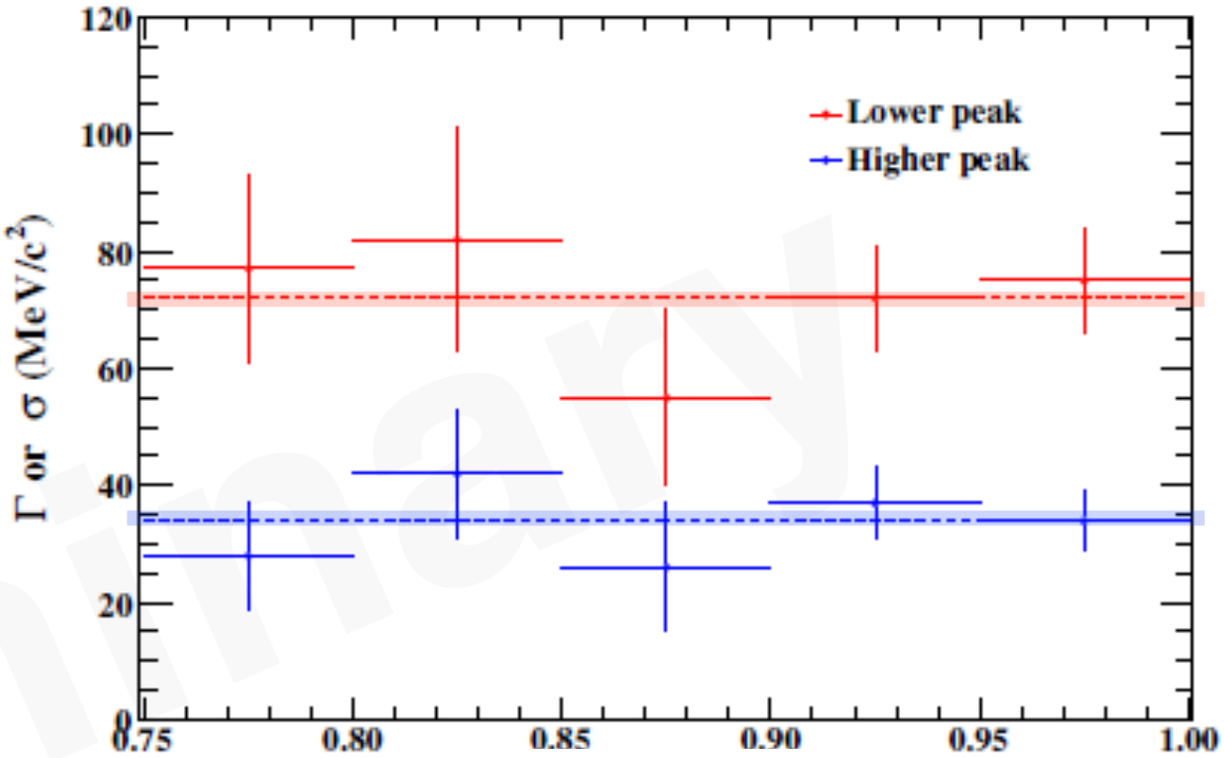


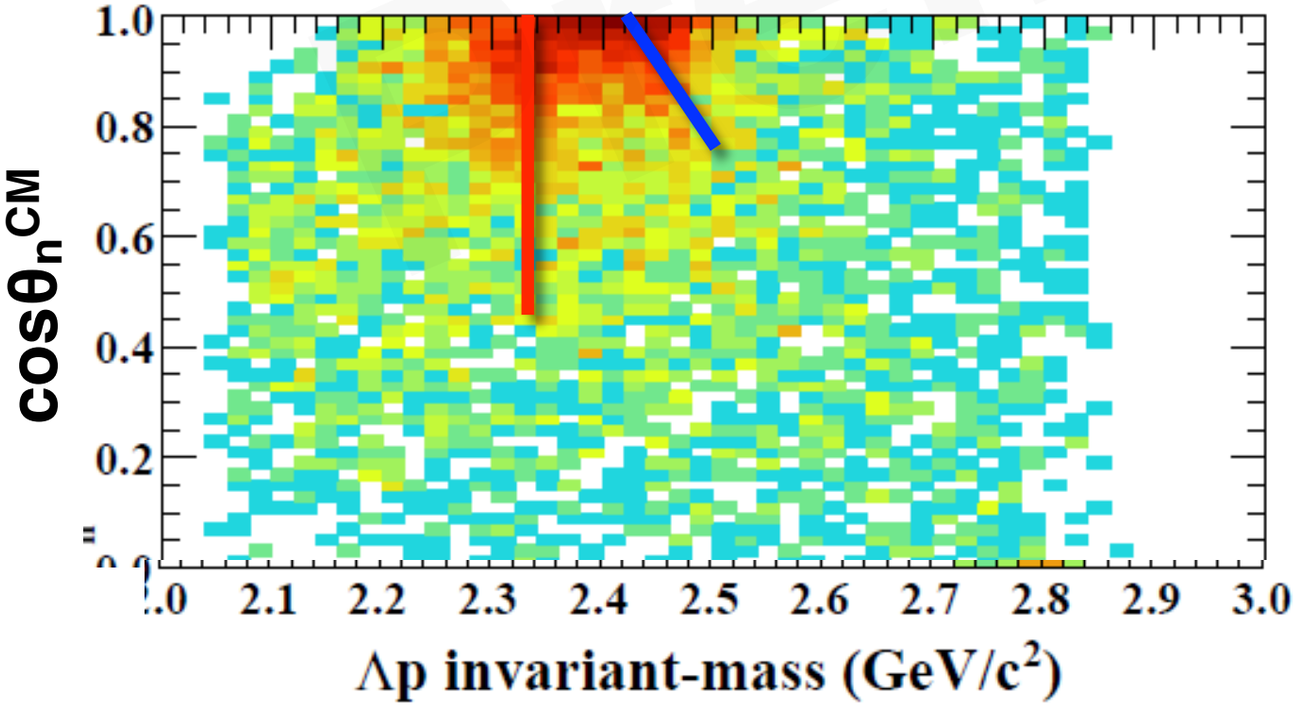
Two structures

Peak position



Width





Above M(K-pp): QE + IC

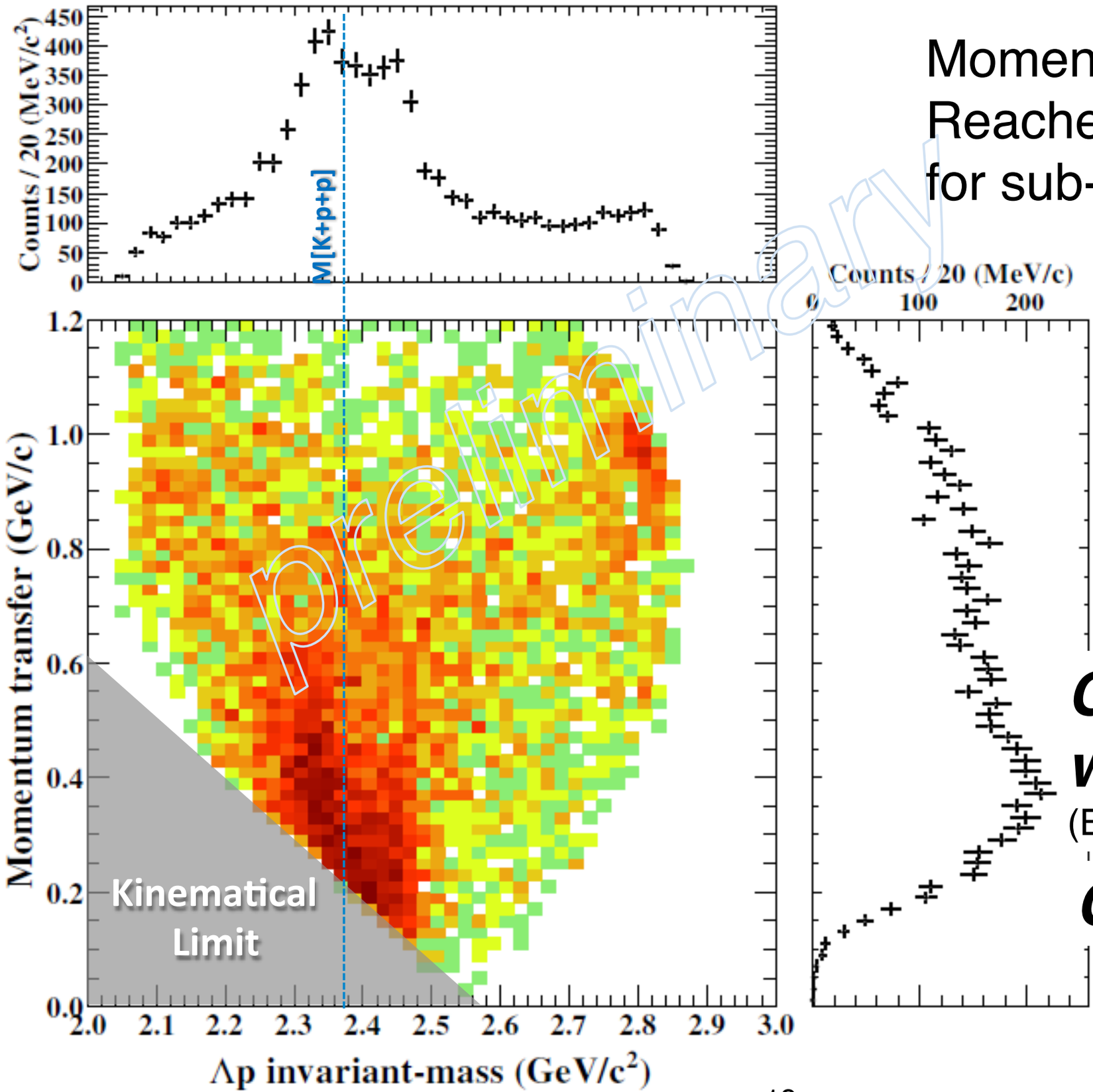
peak shift by recoil kaon energy

Below M(K-pp): Bound state!

peak is independent to $\cos\theta_n$

(~ momentum transfer)

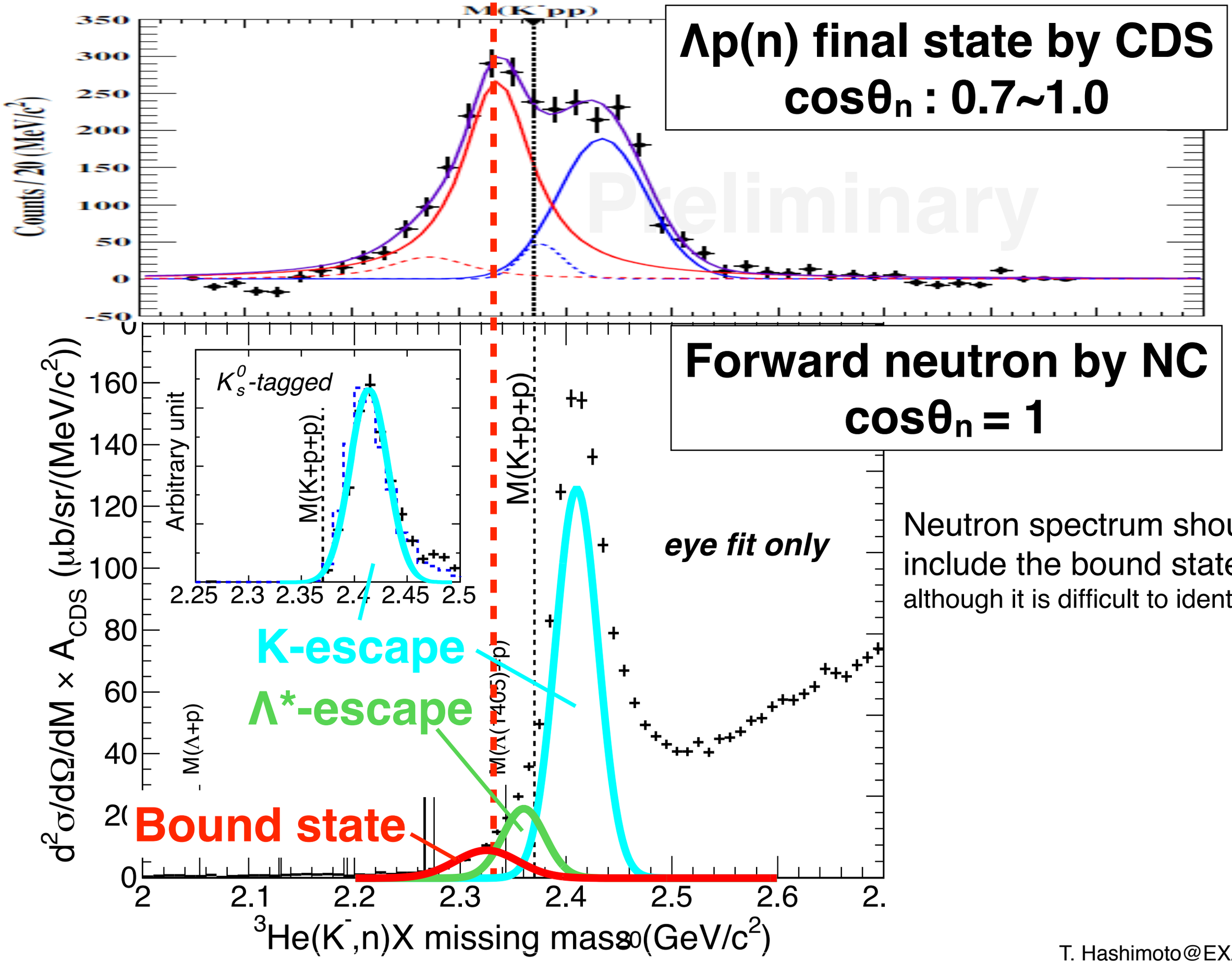
Momentum transfer



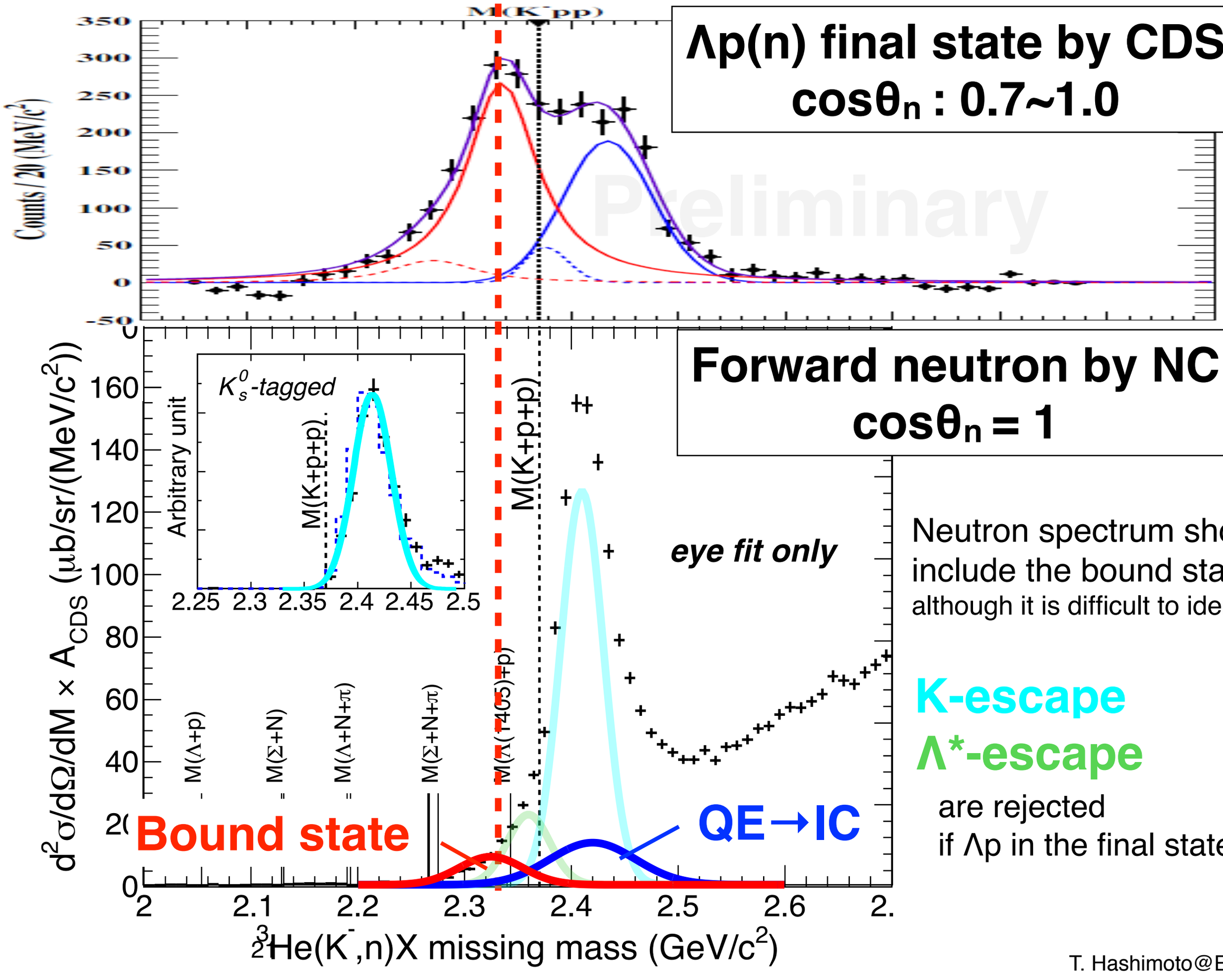
Momentum transfer
Reaches **~ 600 MeV/c**
for sub-threshold structure

Consistent with E15[1st]
(E15[1st] includes unbound region)

Compact state !?



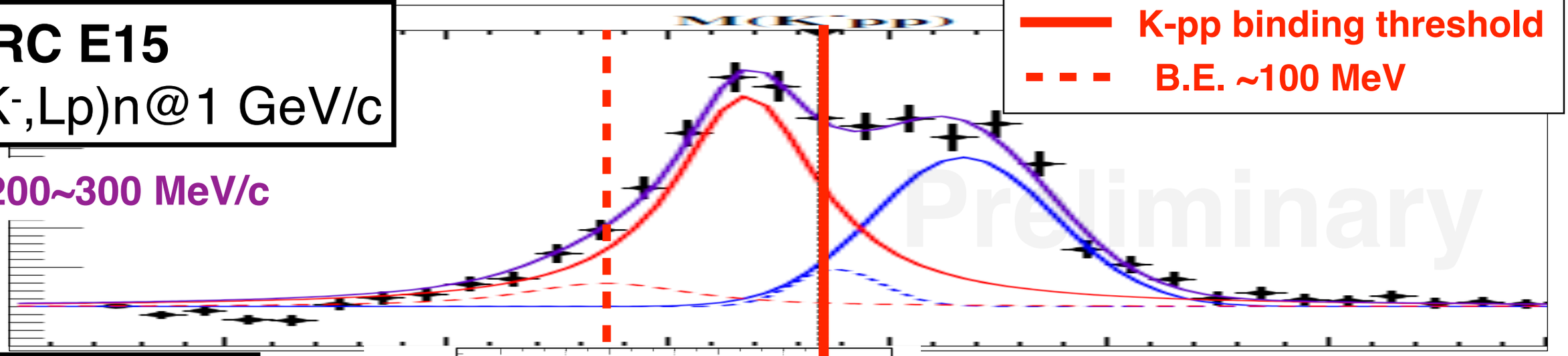
T. Hashimoto@EXA2017



T. Hashimoto@EXA2017

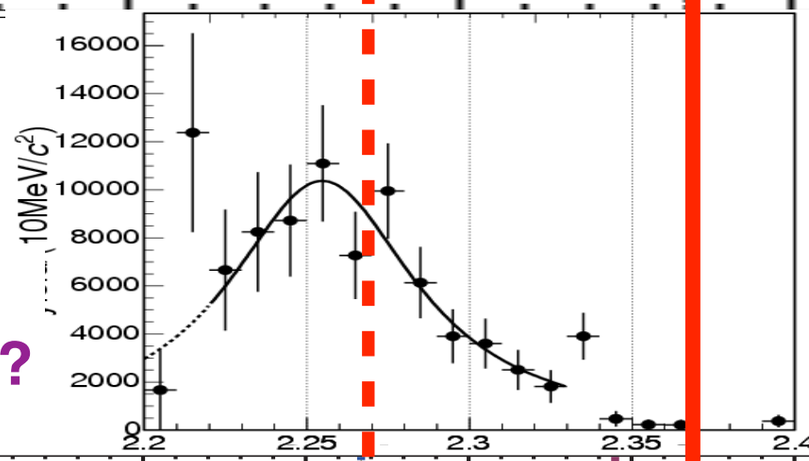
J-PARC E15
^{3}He(K$^-$,Lp)n@1 GeV/c

q_K: 200~300 MeV/c



FINUDA
(stopped K$^-$, Λp)

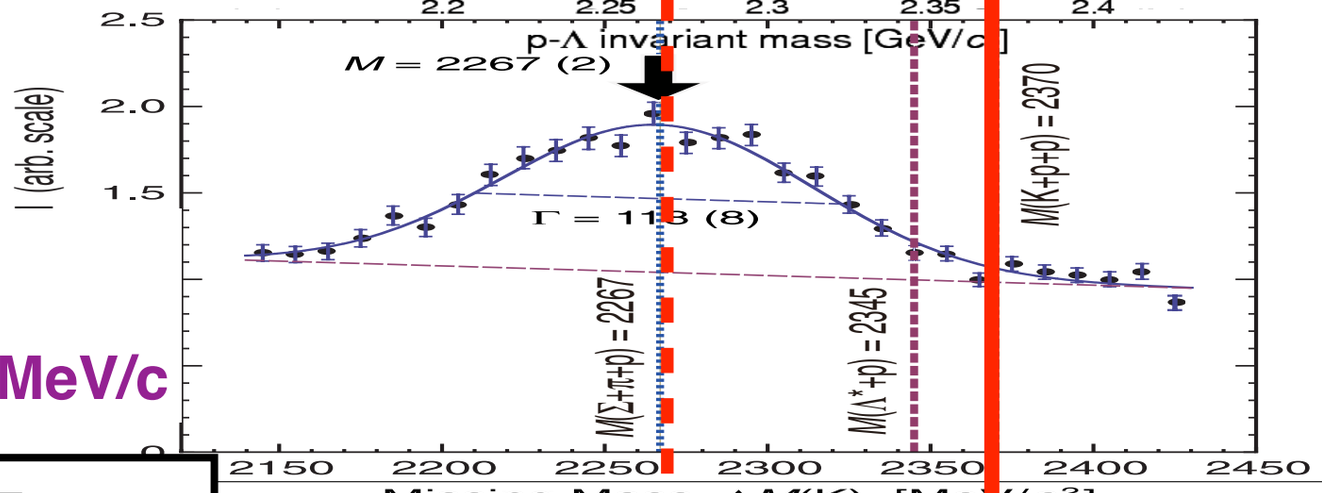
~ 0.1% of stopped K$^-$
Background from 2NA?



DISTO
pp→ΛpK$^+$

N* -> ΛK+?
(Double resonance)

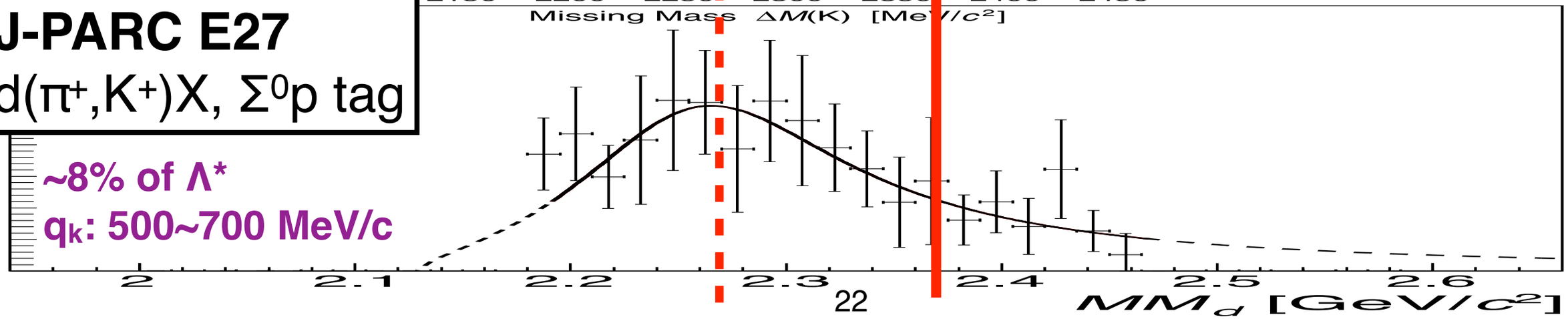
q_K: 300~400 MeV/c



J-PARC E27
d(π$^+$,K$^+$)X, Σ^{0}p tag

~8% of Λ*

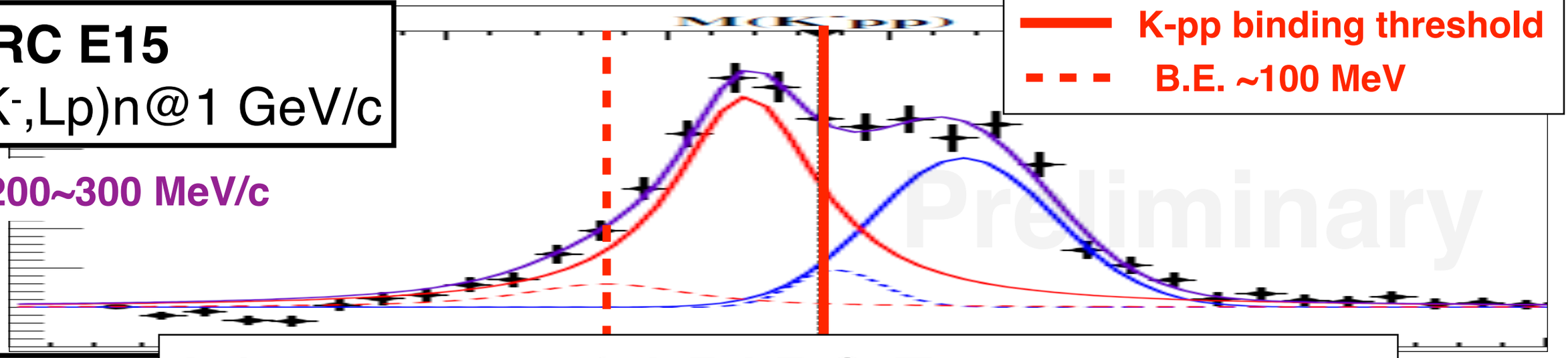
q_K: 500~700 MeV/c



XA2017

J-PARC E15
^{3}He(K$^-$,Lp)n@1 GeV/c

q_k: 200~300 MeV/c



FINUDA
(stopped K$^-$,

~ 0.1% of st
Backgroun

DISTO
pp→ΛpK$^+$

N* -> ΛK+?
(Double resonance)
q_k: 300~400

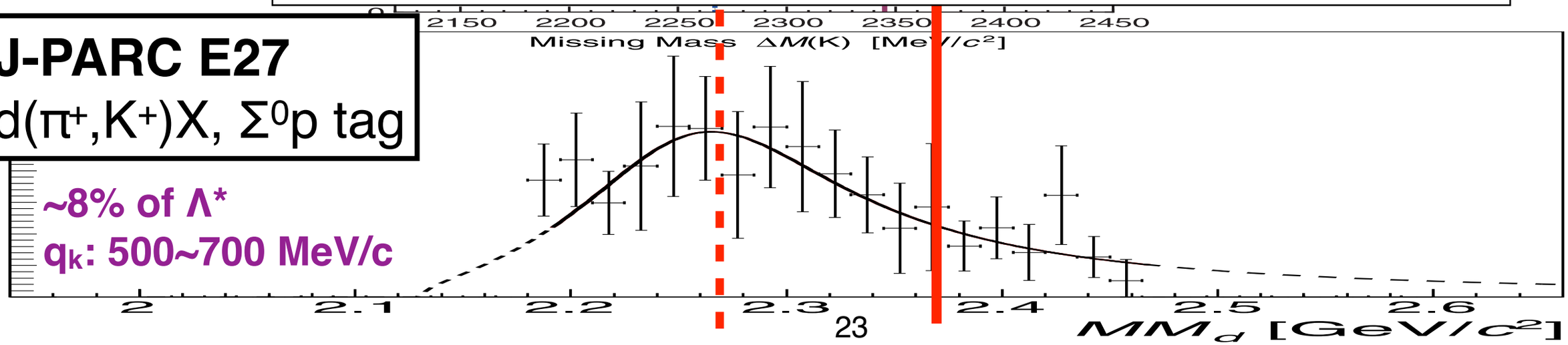
Advantages of J-PARC E15

- lowest momentum transfer
- Well identified final state
- Less background expected
- Good statistics

Non-strange channel: K$^+$Λ(Y) >> K$^+$K$^-$N

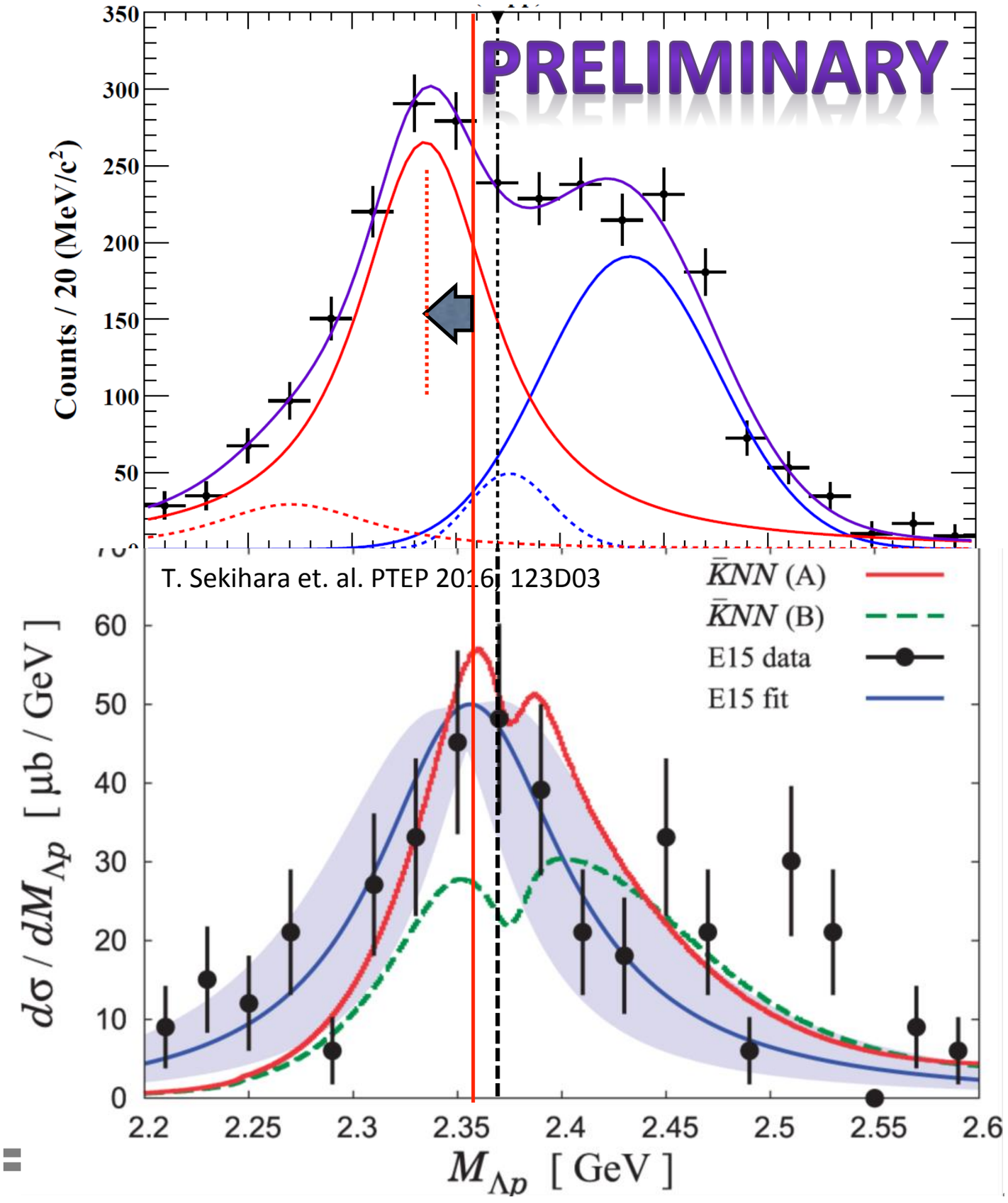
J-PARC E27
d(π$^+$,K$^+$)X, Σ^{0}p tag

~8% of Λ*
q_k: 500~700 MeV/c



XA2017

Comparison with a theoretical spectrum

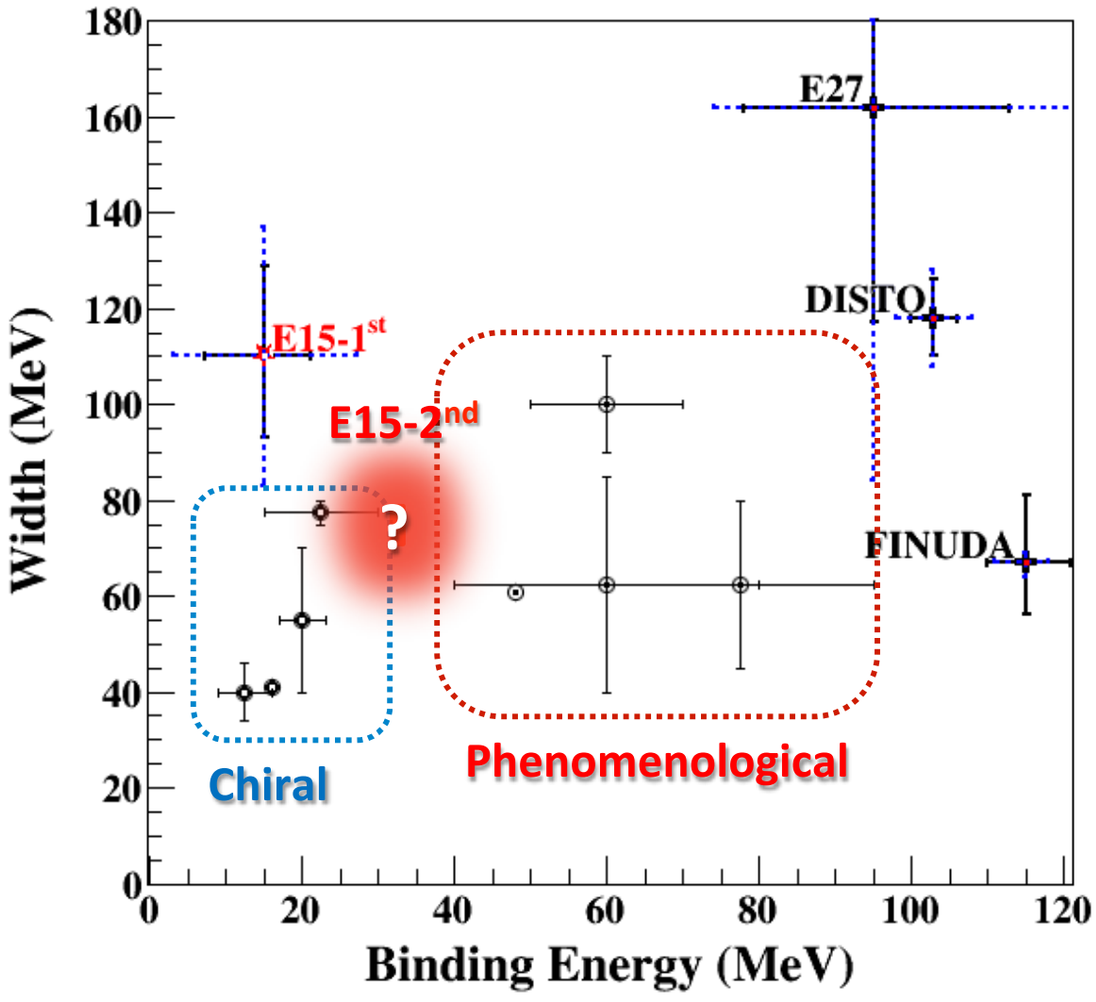


- Qualitatively rather good agreement
  - Two peak structure
  - “Kpp” + “QE+IC”
- Binding energy is much deeper in our experiment
- Details of the theoretical calculation → *next talk*

Summary

- **J-PARC E15: "K⁻pp" search in the ^{3}He(K⁻,n) reaction**

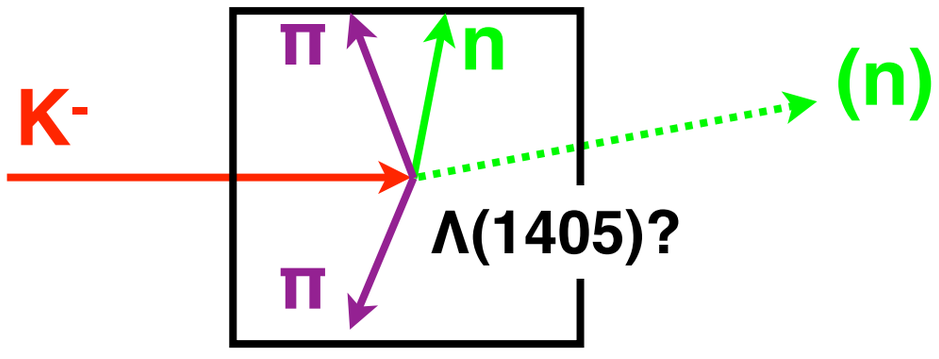
- **Λp spectrum with a larger data set obtained in 2015**
  - Above the M(K⁻pp) threshold
    - Peak shifts against $\cos\theta_n$ / q_K
    - Quasi-elastic + Internal conversion
  - Below the M(K⁻pp) threshold
    - q_K-independent peak → bound state !
    - Could be a compact state
      ← momentum transfer distribution
  - Consistent with
    forward neutron spectrum

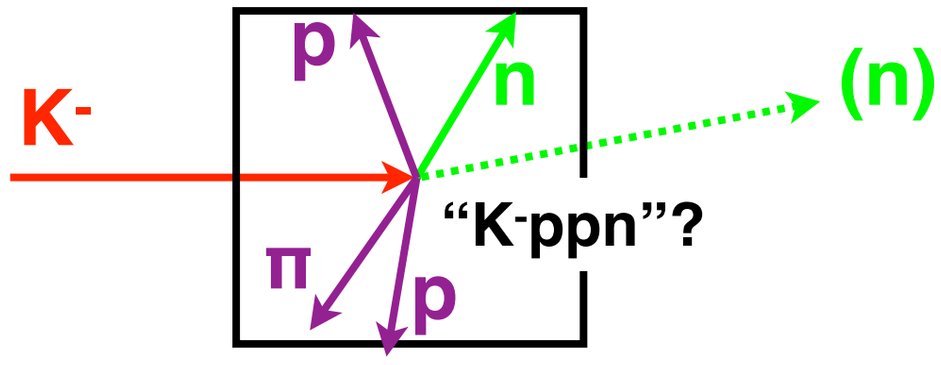


Outlook

- **Further analysis with the E15^{2nd} dataset**
  - Differential cross sections
  - Forward proton channel (K^-pn)

- **Considering major detector upgrade**
  - Neutron counter in the CDS
    - Λ(1405) / K^-ppn with large angular acceptance





- **Kaonic atom X-ray measurements** (from Jun. 2018)
  - E62: K^- $^{3/4}$He with TES → talk by S. Okada
  - E57: K^-d with SDDs → poster by C. Trippl

J-PARC E15 collaboration

S. Ajimura[a], G. Beer[b], C. Berucci[e], H. Bhang[c], M. Bragadireanu[d], P. Buehler[e], L. Busso[f,g], M. Cargnelli[e], S. Choi[c], C. Curceanu[h], S. Enomoto[n], D. Faso[f,g], H. Fujioka[j], Y. Fujiwara[k], T. Fukuda[l], C. Guaraldo[h], T. Hashimoto[m], R. S. Hayano[k], T. Hiraiwa[a], M. Iio[n], M. Iliescu[h], K. Inoue[a], Y. Ishiguro[j], T. Ishikawa[k], S. Ishimoto[n], T. Ishiwatari[e], K. Itahashi[m], M. Iwai[n], M. Iwasaki[o,m*], K. Kanno[k], K. Kato[j], Y. Kato[m], S. Kawasaki[i], P. Kienle[p], T. Kim[o], H. Kou[o], Y. Ma[m], J. Marton[e], Y. Matsuda[q], Y. Mizoi[l], O. Morra[f], T. Nagae[j†], H. Noumi[a], H. Ohnishi[m,a], S. Okada[m], H. Outa[m], K. Piscicchia[h], A. Romero Vidal[h], Y. Sada[a], A. Sakaguchi[i], F. Sakuma[m], M. Sato[m], A. Scordo[h], M. Sekimoto[n], H. Shi[h], K. Shirotori[a], D. Sirghi[h,d], F. Sirghi[h,d], K. Suzuki[e], S. Suzuki[n], T. Suzuki[k], K. Tanida[u], H. Tatsuno[v], M. Tokuda[o], D. Tomono[a], A. Toyoda[n], K. Tsukada[r], O. Vazquez Doce[h,s], E. Widmann[e], B. K. Wuenschek[e], T. Yamaga[i], T. Yamazaki[k,m], H. Yim[t], Q. Zhang[m], and J. Zmeskal[e]
(J-PARC E15 Collaboration)

Thank you for your attention !