Study of KbarN interaction at J-PARC K1.8BR beam line

E15/E31 collaboration

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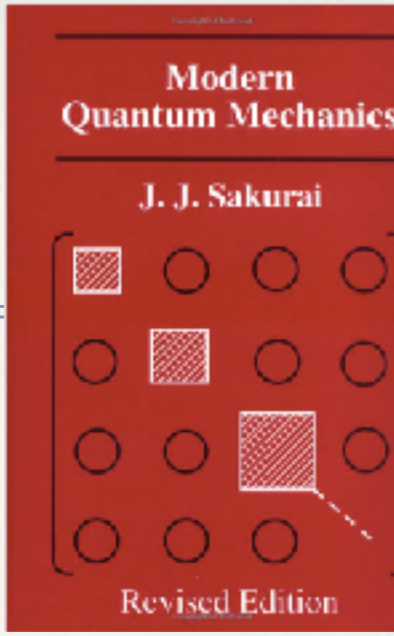
2016/12/02

Outline

- Physics motivation
  (personal understanding…)
- K1.8BR@J-PARC: E15/E31
  a brief history and current status
- Summary

Beginning of the story…

Editor of this book



POSSIBLE RESONANT STATE IN PION-HYPERON SCATTERING*

R. H. Dalitz and S. F. Tuan
Enrico Fermi Institute for Nuclear Studies and Department of Physics,
University of Chicago, Chicago, Illinois

(Received April 27, 1959)

With charge independence, it is convenient to describe the s-wave scattering processes of low-energy K^--proton collisions by two complex scattering lengths A_0 and A_1, one each for the $I=0$ and $I=1$ channels, related to the complex phase shifts δ_I by

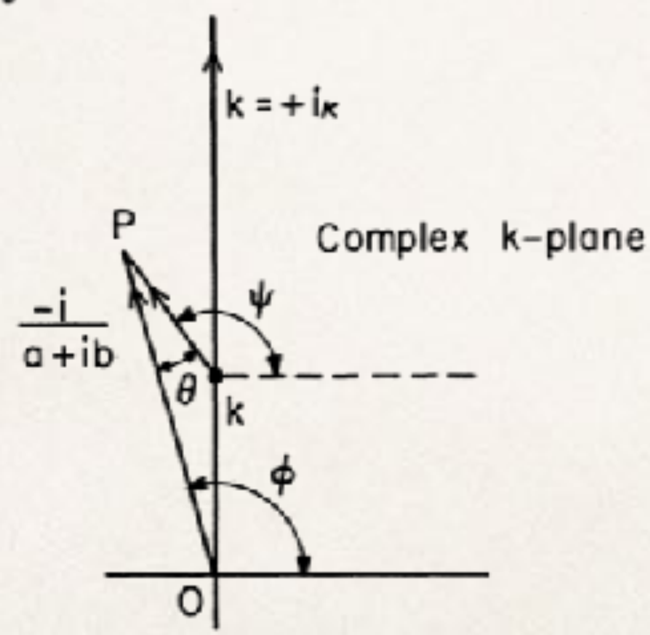


FIG. 1. The location of pole P on the complex k-plane.

low energies[4] has led to the following four solutions[5] for these amplitudes A_0 and A_1:

$$A_0 = (0.20 + 0.78i)\text{ f},\quad A_1 = (1.62 + 0.39i)\text{ f}, \qquad \text{(a+)}$$

$$A_0 = (1.88 + 0.82i)\text{ f},\quad A_1 = (0.40 + 0.41i)\text{ f}, \qquad \text{(b+)}$$

1, scattering length from K-p data;
2, derive $\pi\Sigma$ scattering amplitude;
3, predict the existence of **Λ**(1405).

Beginning of the story…

Particle Data Group, 2013th edition

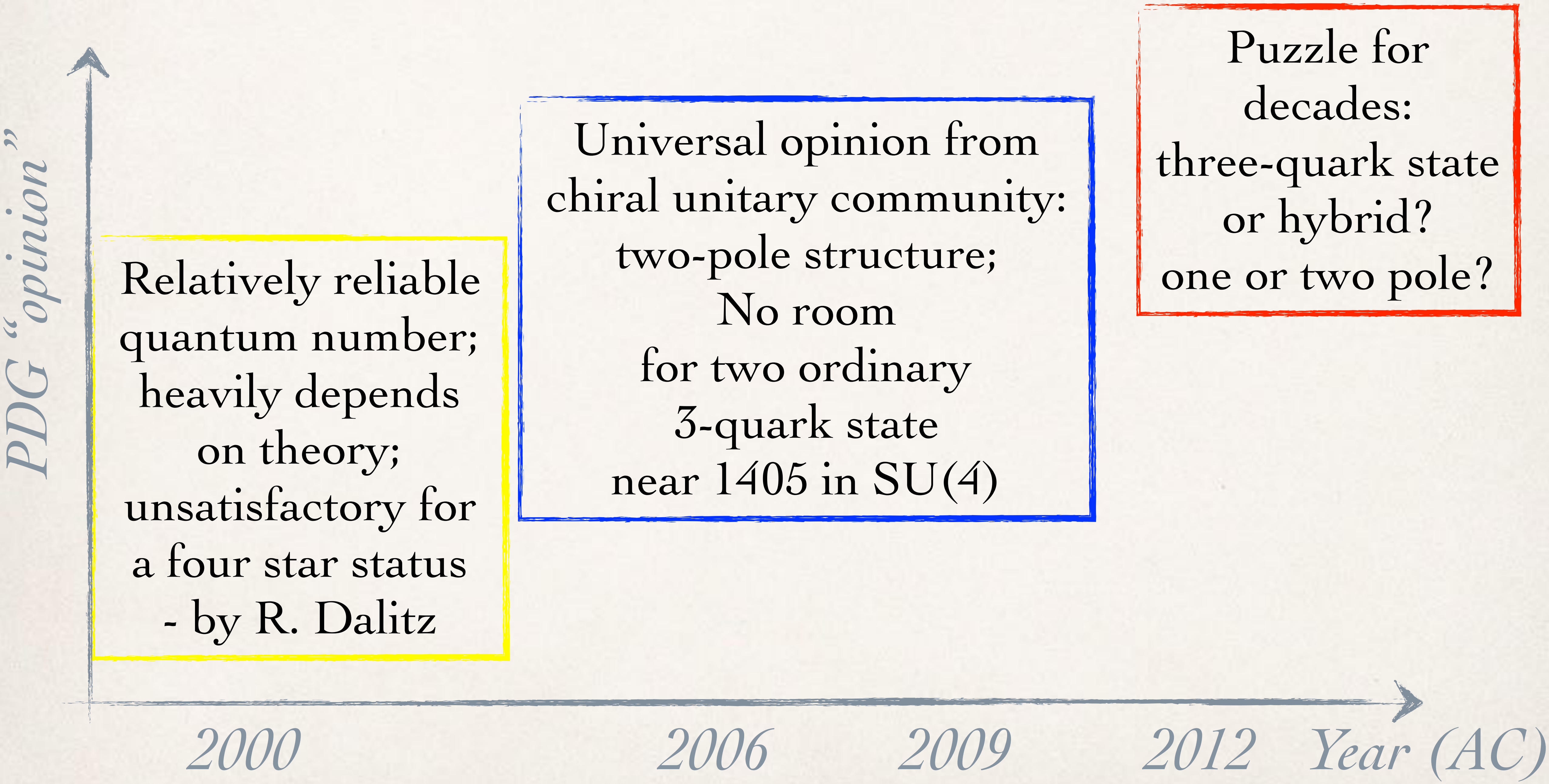
$\boxed{\Lambda(1405)\ 1/2^-}$ $I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗∗

The nature of the $\Lambda(1405)$ has been a puzzle for decades: three-quark state or hybrid; two poles or one. We cannot here survey the rather extensive literature. See, for example, CIEPLY 10, KISSLINGER 11, and SEKIHARA 11, for discussions and earlier references.

It seems to be the universal opinion of the chiral-unitary community that there are two poles in the 1400-MeV region. ZYCHOR 08 presents experimental evidence against the two-pole model, but this is disputed by GENG 07A. See also REVAI 09, which finds little basis for choosing between one- and two-pole models.

A single, ordinary three-quark $\Lambda(1405)$ fits nicely into a $J^P = 1/2^-$ SU(4) $\overline{4}$ multiplet, whose other members are the $\Lambda_c(2595)^+$, $\Xi_c(2790)^+$, and $\Xi_c(2790)^0$; see Fig. 1 of our note on "Charmed Baryons."

$\bar{K}N$ interaction: $\Lambda(1405)$



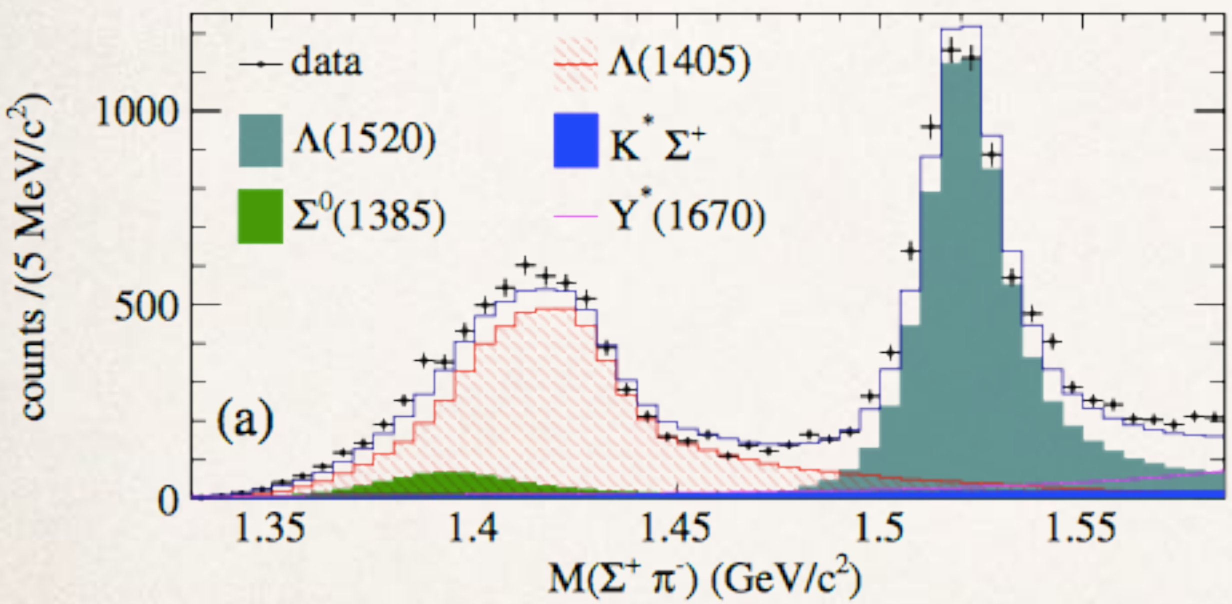
Motivation for E15&E31

- Investigate the nature of $\Lambda(1405)$:
  - Internal structure(E31) & binding energy(E15)
  - E31: d(K-, n)X, X=$\Lambda(1405)$->$\pi\Sigma$
  - E15: ^{3}He(K^-, n)X, X=K-pp->Λp

Internal structure of Λ(1405): E31

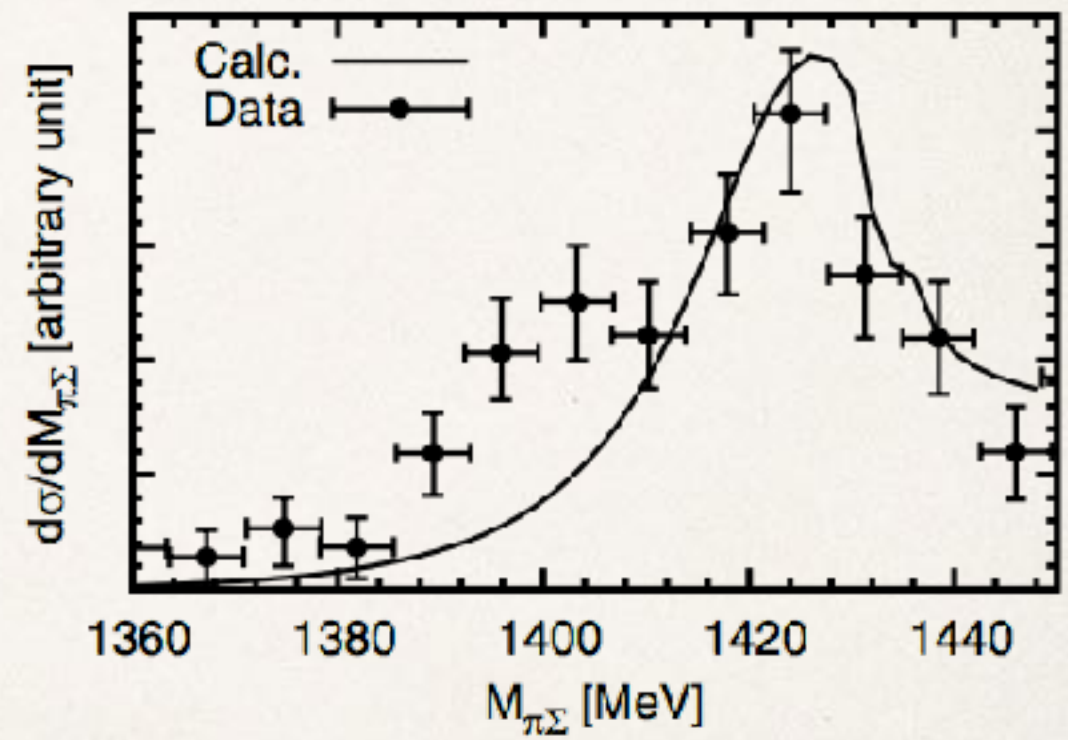
- Depending on the internal structure of Λ(1405), the spectral line shape of the $\pi\Sigma$ decay products may be changed for different production methods

$$\gamma + p \to K^+ + \Lambda(1405)$$



s-quark can locate at either baryon or meson sector

$$K^- + d \to \Lambda(1405) + n$$



s-quark sits inside K- meson

K. Moriya, *et al.*, Phys. Rev. Lett. 112, (2014), 082004
D. Jido, *et al.*, Eur. Phys. J. A 42, (2009), 257

Internal structure of Λ(1405): E31

$$K^- + d \to X + n$$

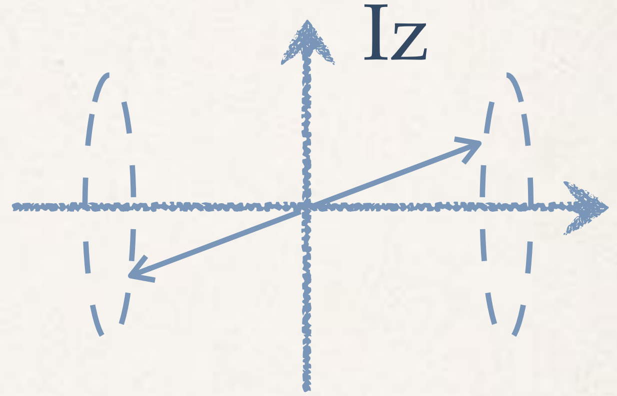
$$X \to \pi^0 + \Sigma^0$$ I = 0; Λ(1405)

$$\to \pi^+ + \Sigma^-$$

$$\to \pi^- + \Sigma^+$$

Mixed components

$$\to \pi^0 + \Lambda$$ I = 1; Σ(1385)



$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_{\mathrm{inv}}} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\,(T^{(0)}T^{(1)*}),$$

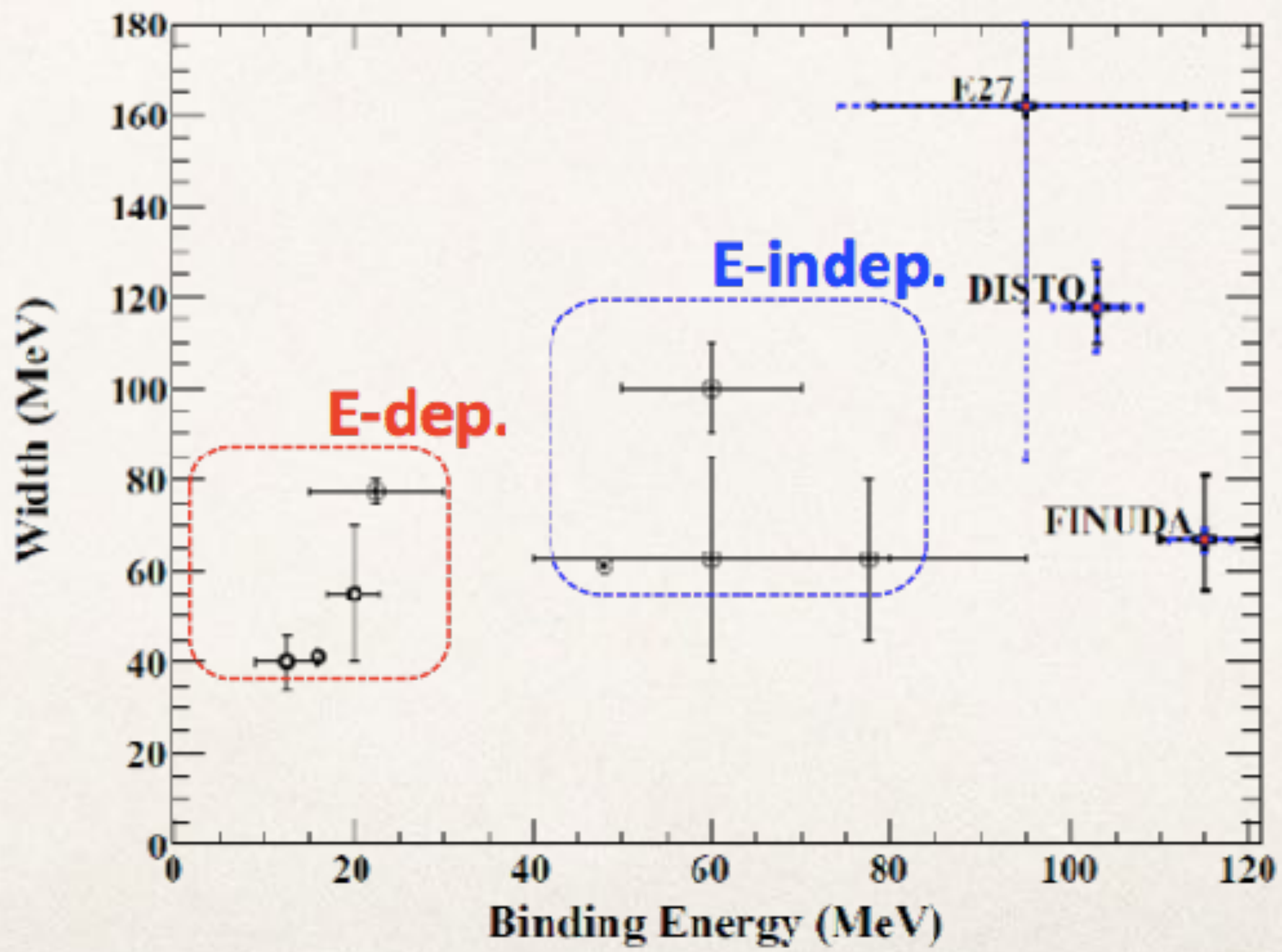
$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_{\mathrm{inv}}} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\,(T^{(0)}T^{(1)*}),$$

$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_{\mathrm{inv}}} \propto \frac{1}{3}|T^{(0)}|^2,$$

Y. Kamiya, *et al.*, Nucl. Phys. A 954 (2016) 41

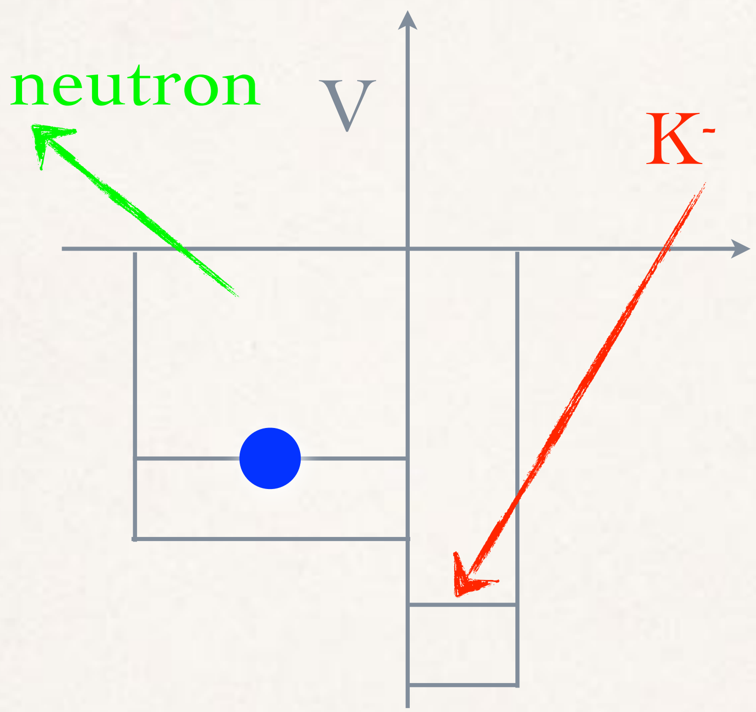
Binding energy of Λ(1405): E15

- $M_K + M_p = 1432$ MeV
- Single pole: B_{KN}=1432-$M_{\Lambda(1405)}$=27 MeV
- Double pole: B_{KN}=15MeV(Λ(1405)=|1390, 66i>+|1426, 16i>)



T. Hyodo, D. Jido, Prog. Part. Nucl. Phys., 67, (2012) 55-98

Binding energy of Λ(1405): E15



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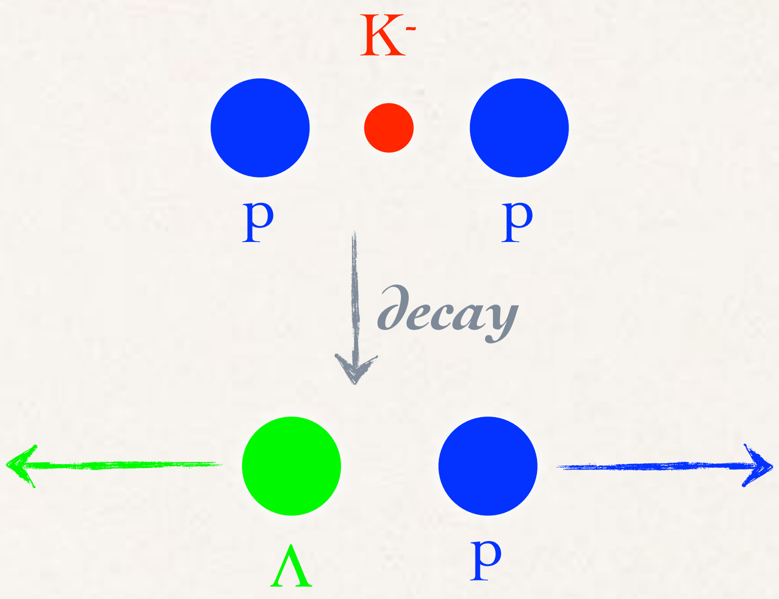
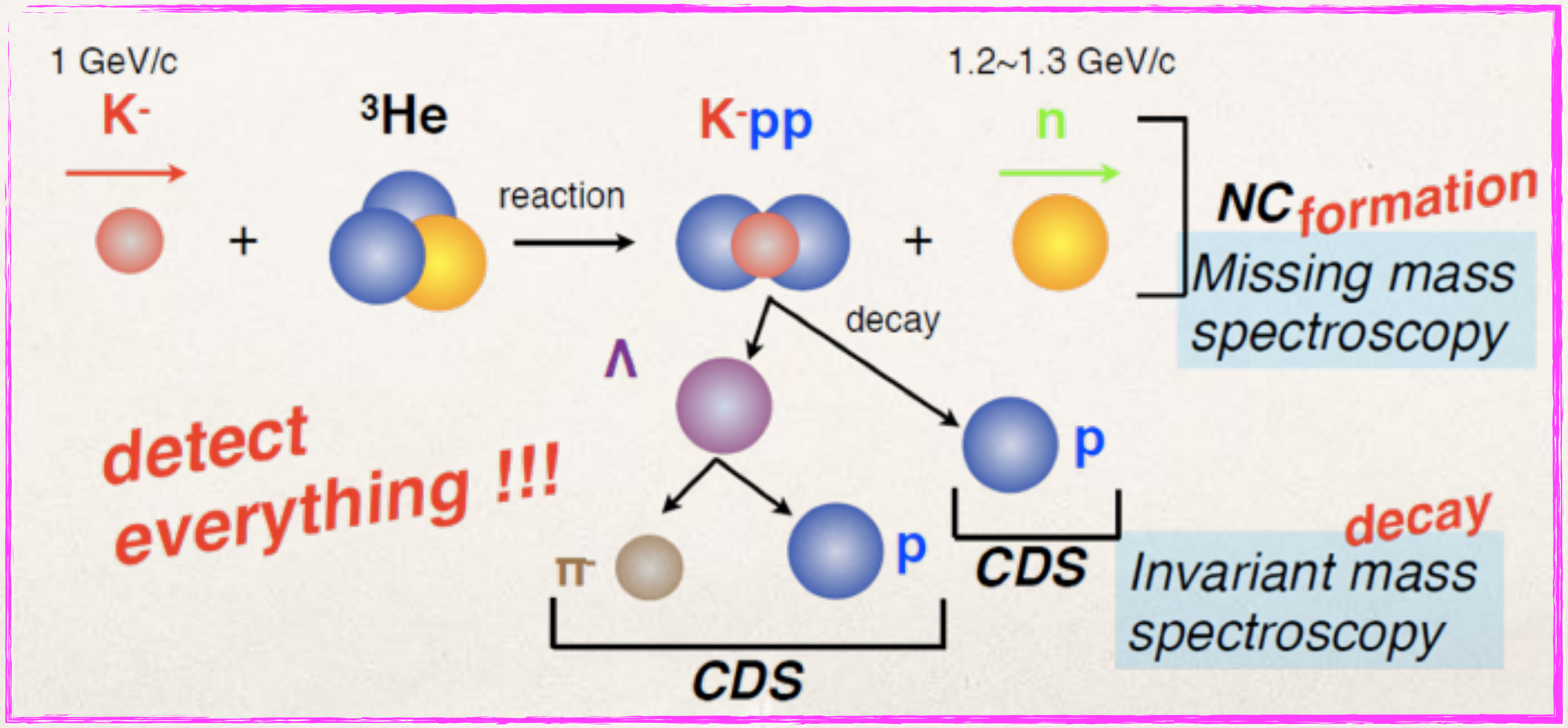
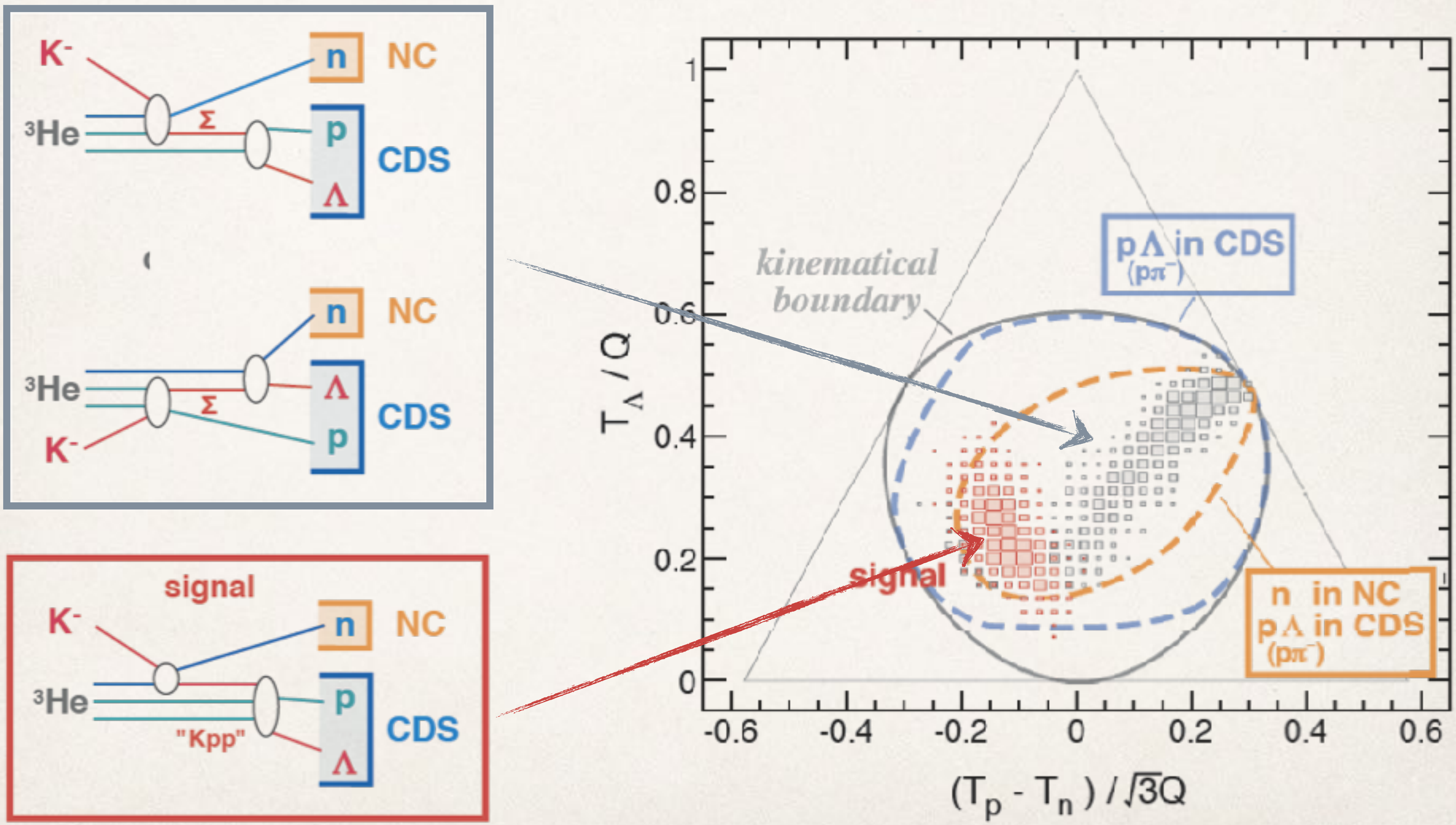




Binding energy of Λ(1405): E15



A brief history of E15/E31

Jan. 2007, stage-2 approval

Jan. 2009, completion of the beam-line spectrometer

Apr. 2010, completion of the cylindrical detector system (CDS)

Nov. 2010, completion of the 3He-target system

Delayed by Earth quake

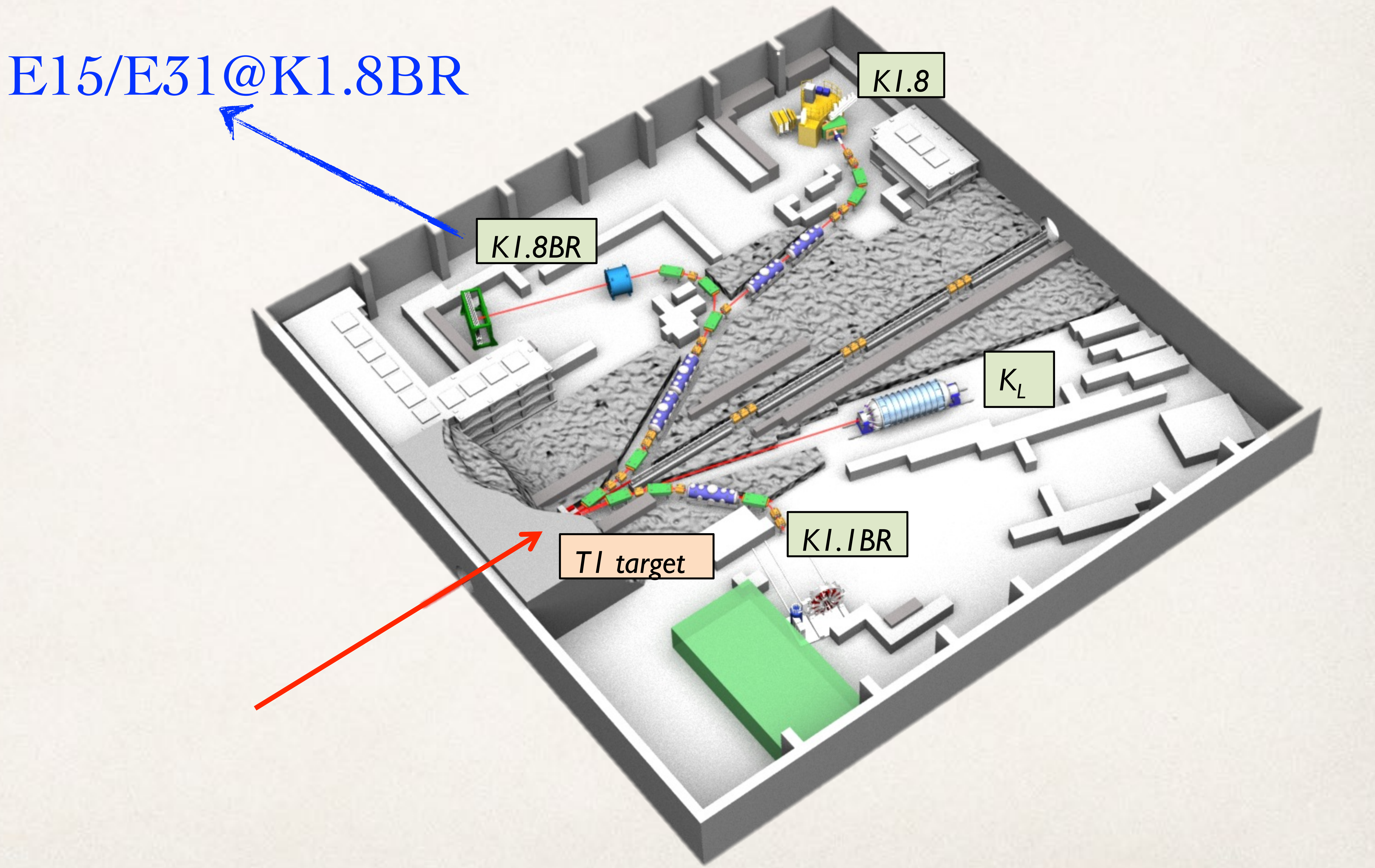
May. 2013, 1st-stage production run of E15

Accident on slow extraction

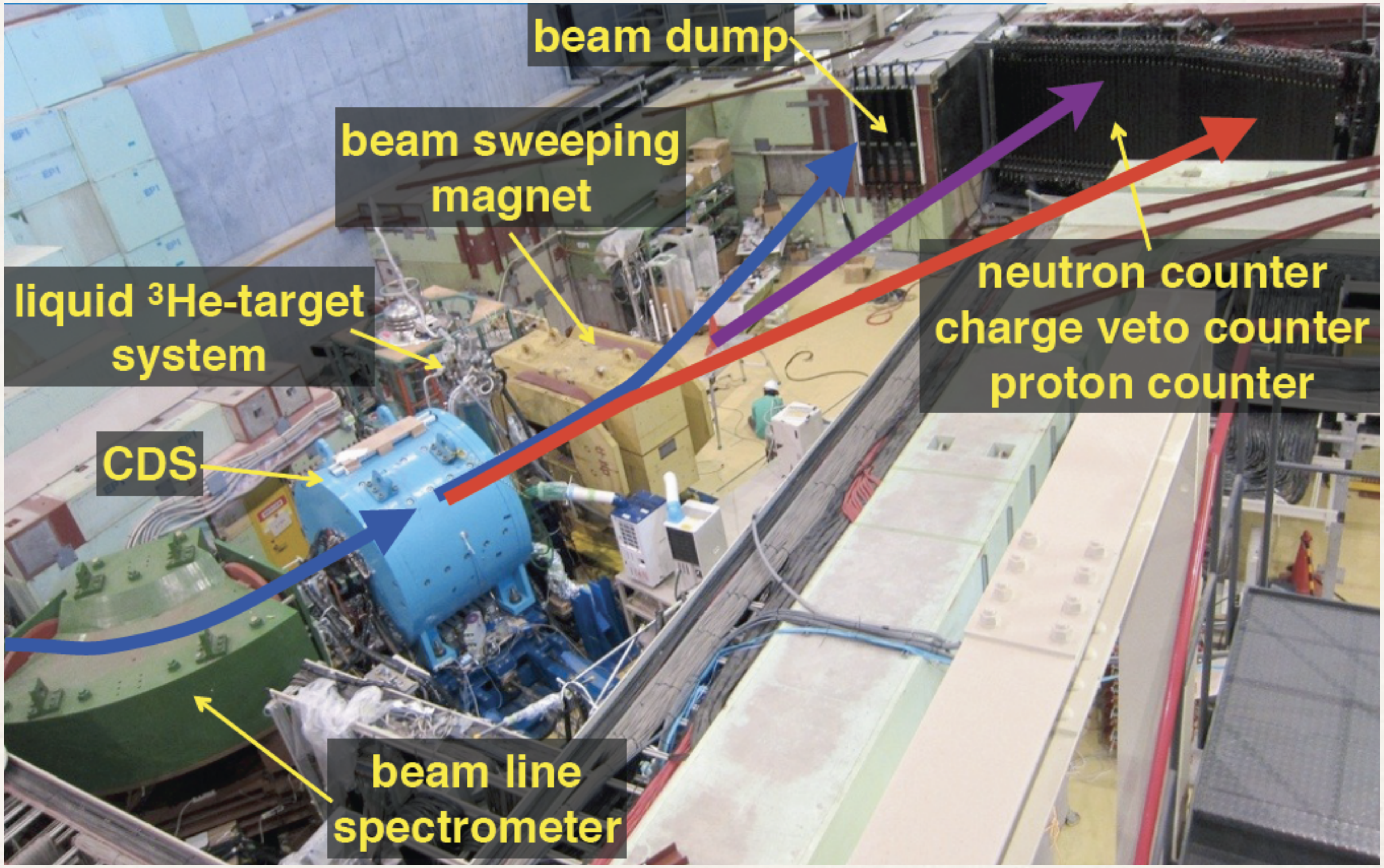
Nov. 2015, 2nd-stage production run of E15

Jun. 2016, 1st-stage production run of E31

Experimental setup for E15/E31

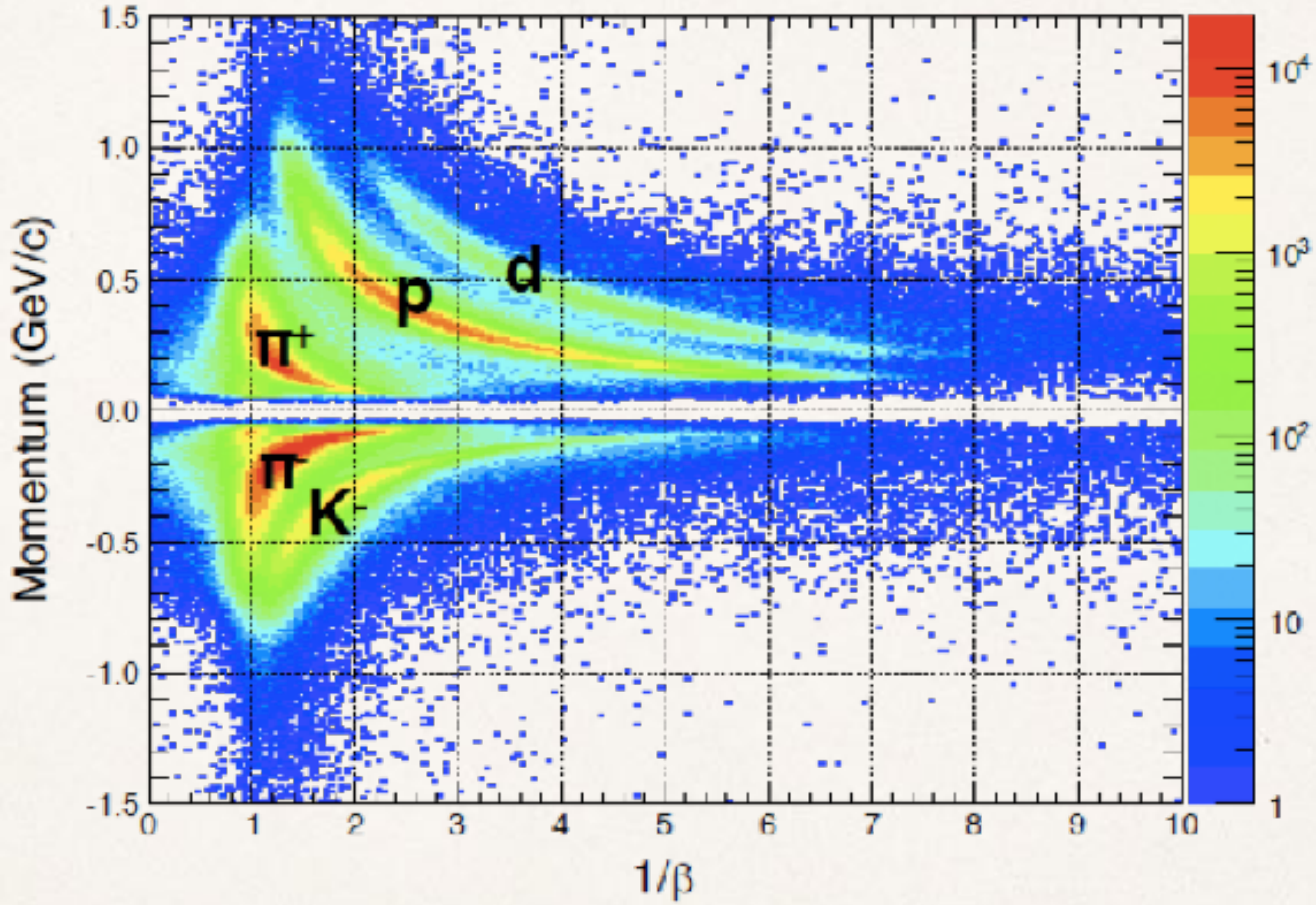


Experimental setup for E15/E31



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

Detector performance



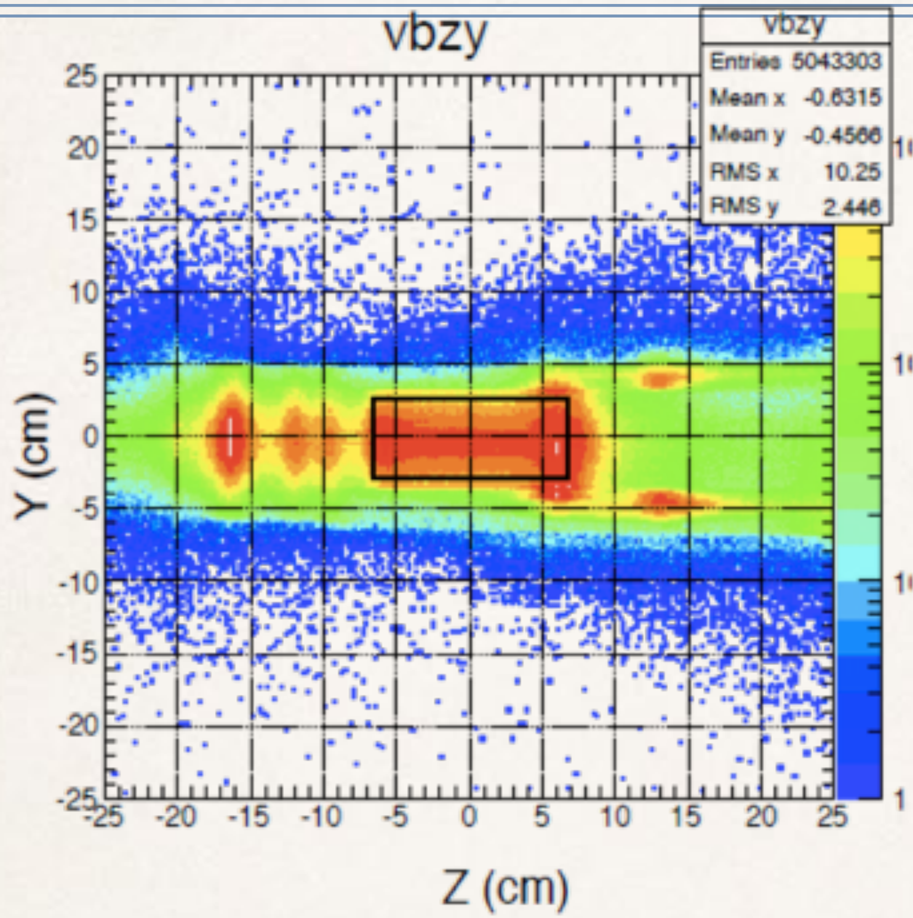
PID from Cylindrical Detection System

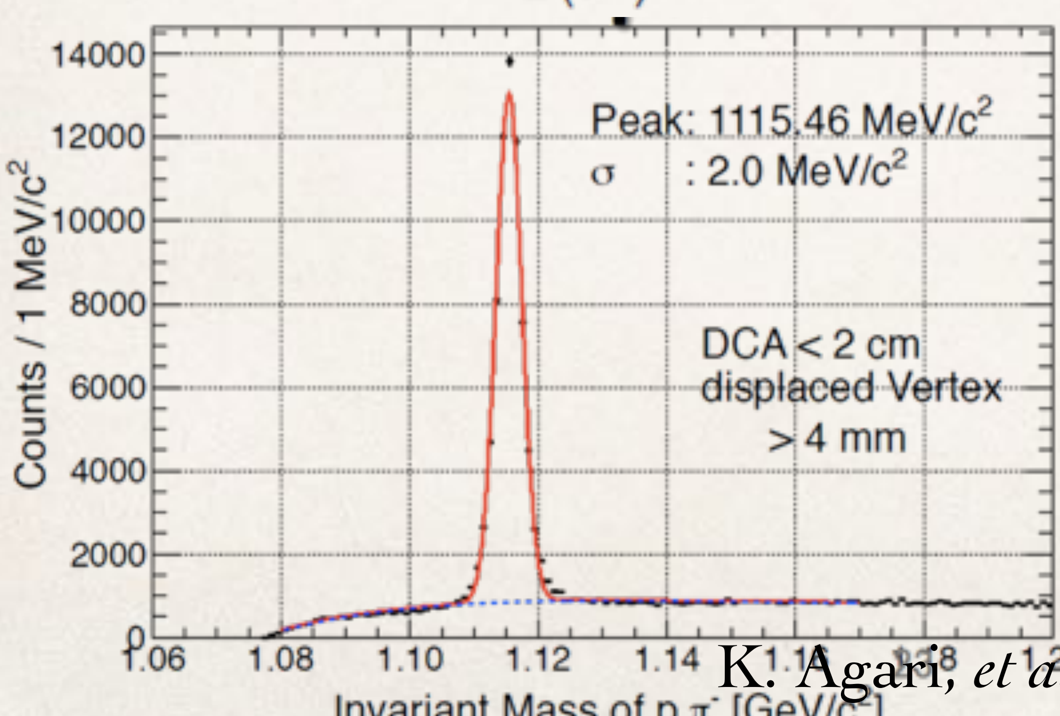
(15 layer, 1816 ch @ 0.7 T)

60% of 4pi solid angle

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

Detector performance

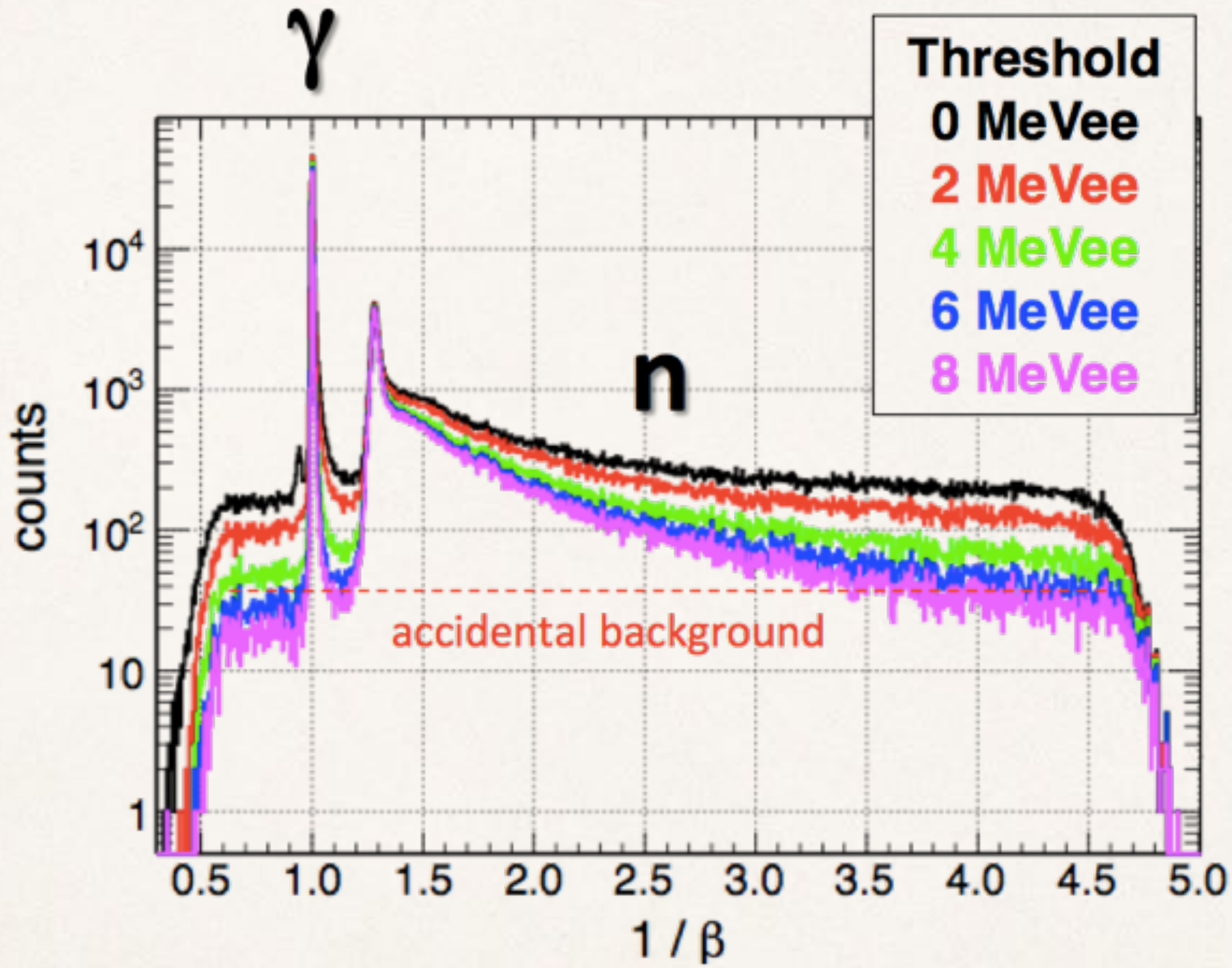




Designed resolution achieved!
(10 MeV/c^2 for K^-pp)

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

Detector performance



Time resolution ~160ps:

10 MeV/c^2 for 1GeV/c neutron

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

Analysis of $d(K^-, n)\pi^{\pm}\Sigma^{\mp}$ spectrum

$$\begin{aligned} \mathbf{Y} \quad &\rightarrow \boldsymbol{\pi}^+, \boldsymbol{\Sigma}^- \rightarrow \boldsymbol{\pi}^+\boldsymbol{\pi}^- \ \mathbf{n} \\ &\rightarrow \boldsymbol{\pi}^-, \boldsymbol{\Sigma}^+ \rightarrow \boldsymbol{\pi}^-\boldsymbol{\pi}^+ \ \mathbf{n} \end{aligned}$$

- Analysis procedure
  - $d(K^-, n)\pi^{\mp}\pi^{\pm}$"n“
    - n -> NC
    - $\pi^{\mp}\pi^{\pm}$ -> CDS
    - $d(K^-, \pi^{\mp}\pi^{\pm}n)$”n” identification
  - BG rejection in the $d(K^-, n)\pi^{\mp}\pi^{\pm}$"n“
    1. $K^-d \rightarrow (\pi\Sigma)_{\text{backward}}\, nfo_{\text{rward}}$ → Signal
    2. $K^-d \rightarrow K^0 n\, nsp_{\text{ectator}}$ → K^0 production (BG)
    3. $K^-d \rightarrow (\pi\Sigma)_{\text{forward}}\, n_{\text{spectator}}$ → Forward Σ production (BG)
  - $d(K^-, n)\pi^{\pm}\Sigma^{\mp}$ spectrum after the BG rejection
  - Decompose of $\Sigma^-\pi^+$ and $\Sigma^+\pi^-$

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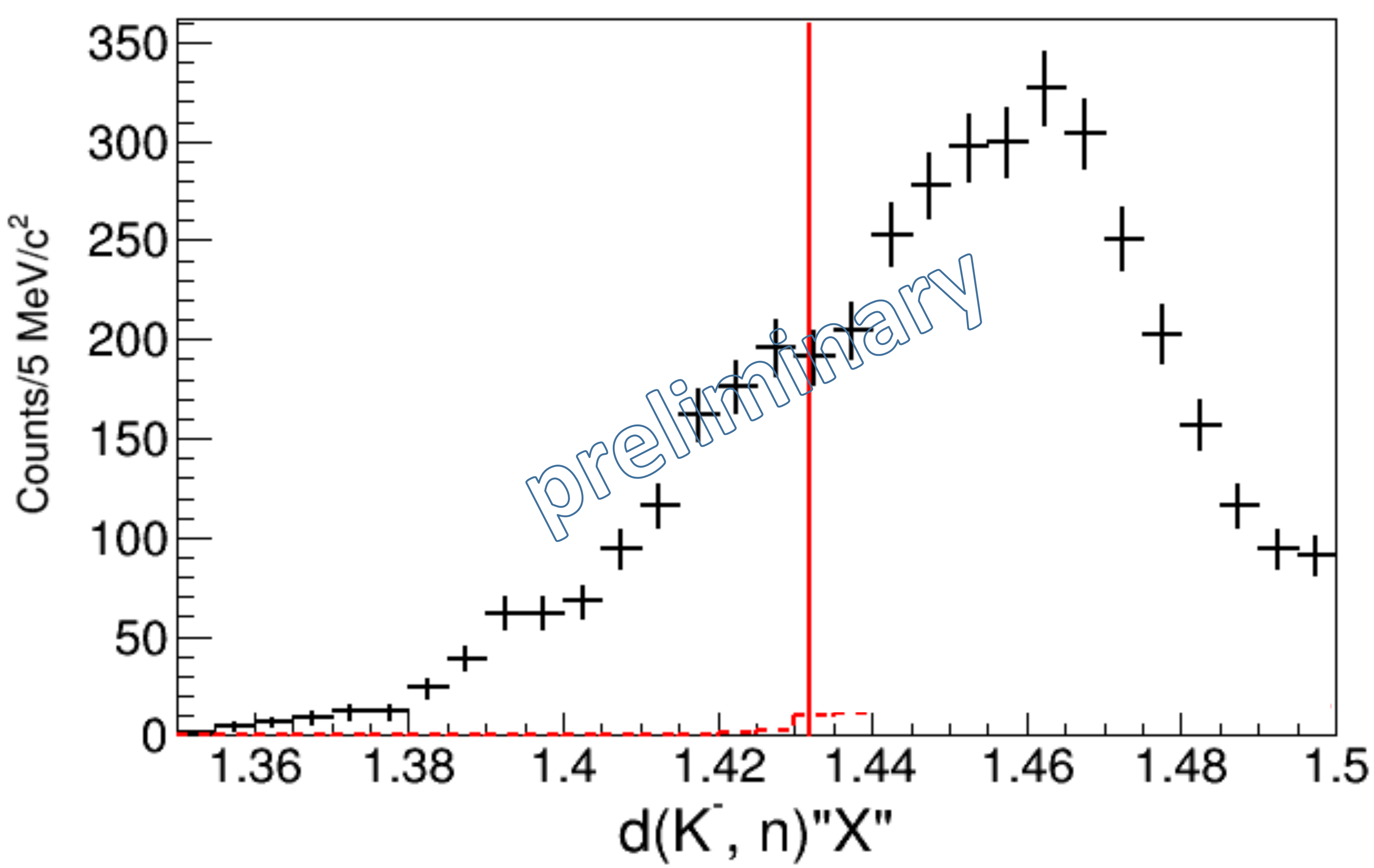
S. Kawasaki, *et al.*, MENU2016 proceeding

$d(K^-, n)\pi^{\pm}\Sigma^{\mp}$ spectrum



- The structures below and above the threshold

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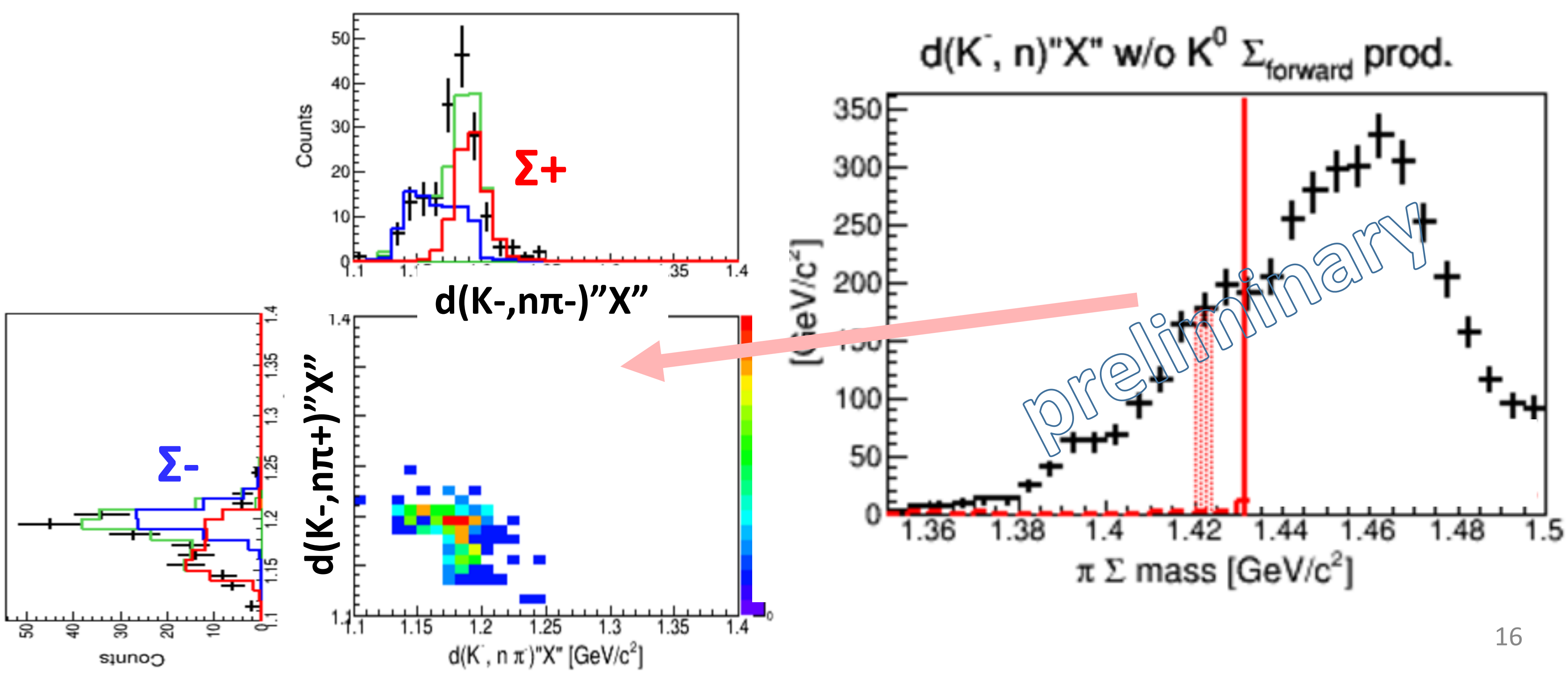
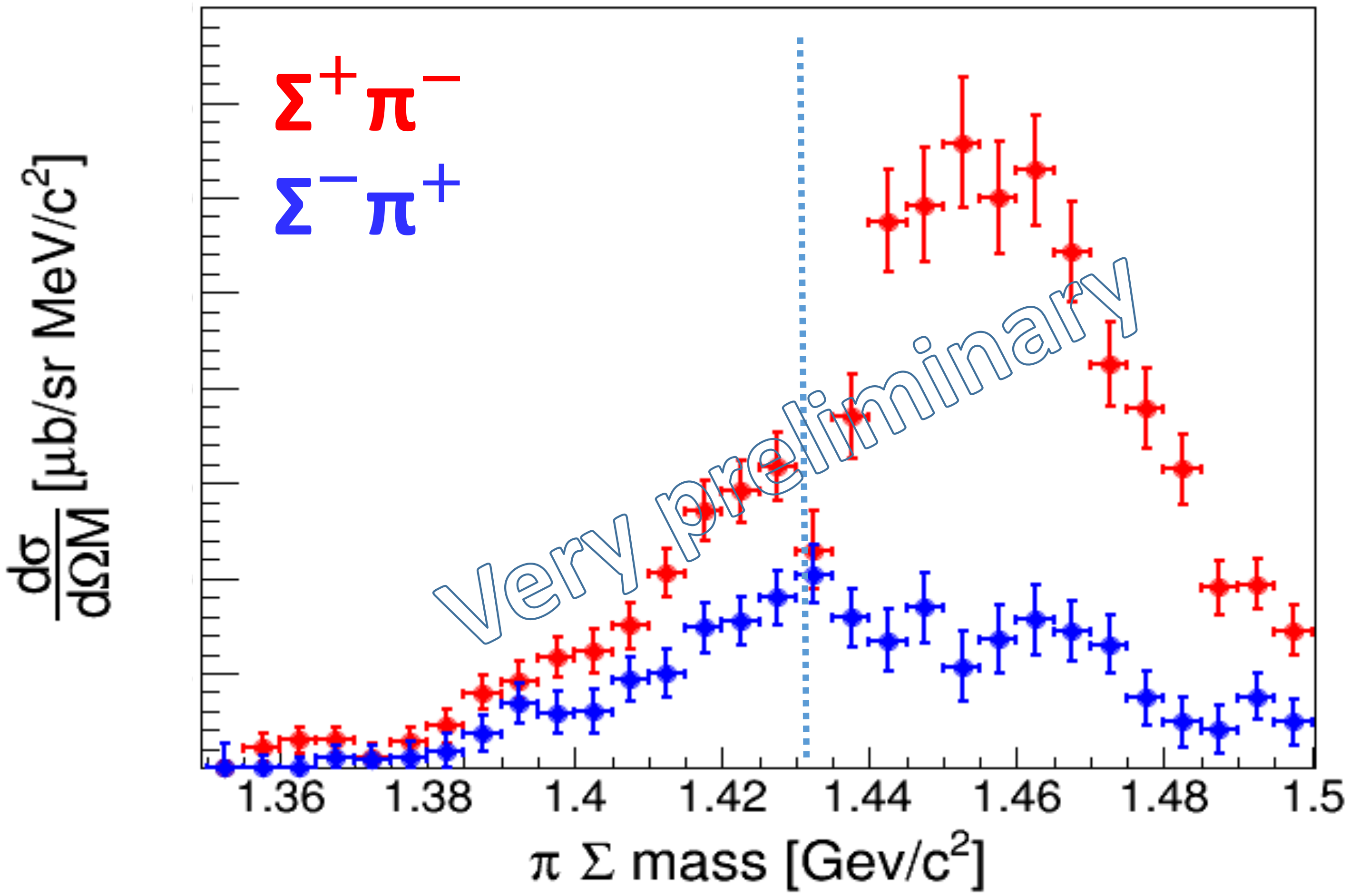
Decomposition into $\Sigma^{-}\pi^{+}$ and $\Sigma^{+}\pi^{-}$

- The d(K-,nπ)”X” distribution’s are fitted with the distribution of Σ+ and Σ- estimated by MC SIM (Template fitting)
  - Fitted bin by bin of the d(K-,n)”X”



Decomposed spectrum of $\Sigma^-\pi^+$ and $\Sigma^+\pi^-$

- w/ acceptance correction



- **The difference between two mode is due to the interference term of I =0 and I =1**

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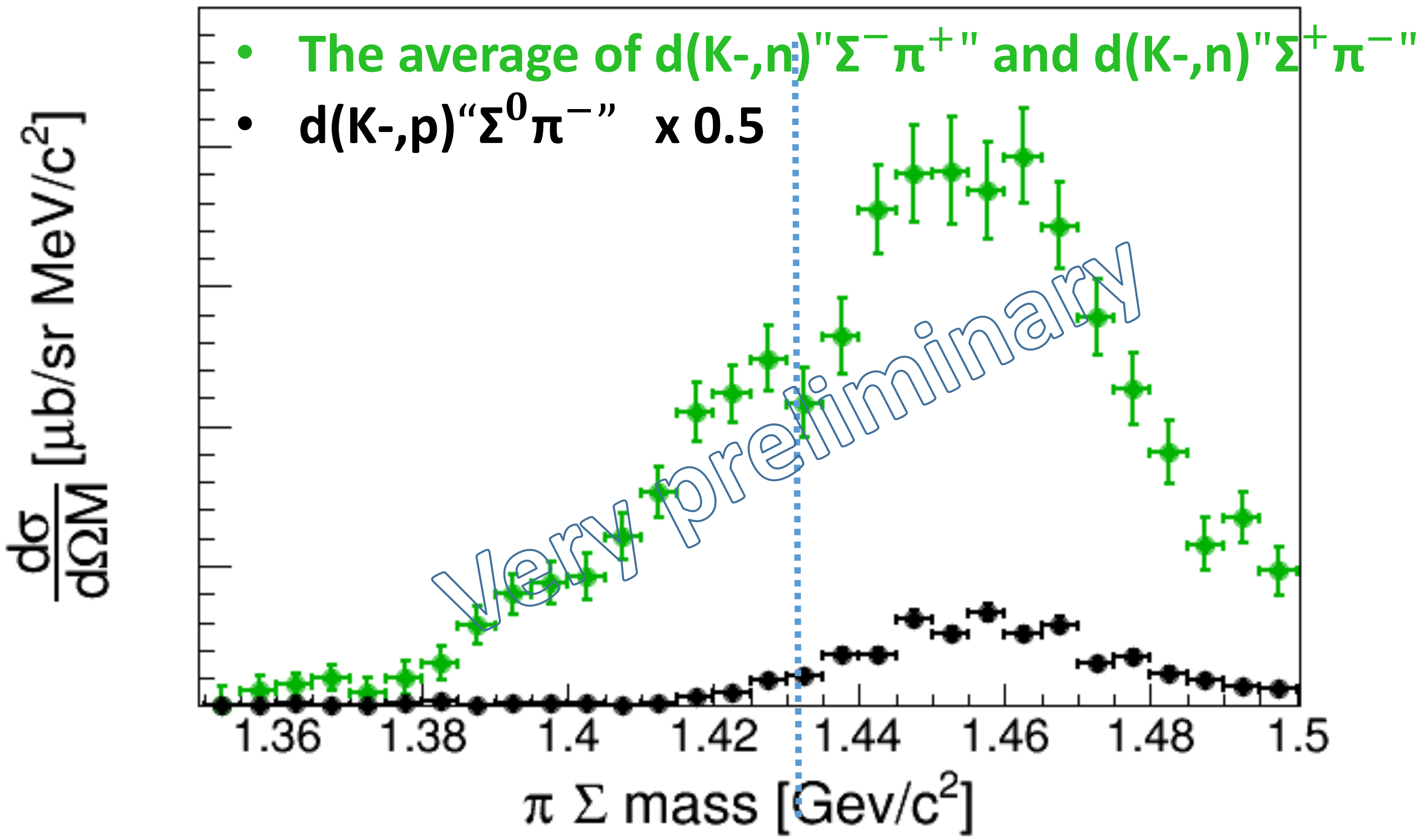
Suppression of I =1



$$\frac{1}{2}\times(\pi^+\Sigma^- + \pi^-\Sigma^+)$$
$$\sim\frac{1}{3}|f_{I=0}|^2 + \frac{1}{2}|f_{I=1}|^2$$

$$\frac{1}{2}\times(\pi^-\Sigma^0)\sim\frac{1}{2}|f_{I=1}|^2$$

Assuming the similarity of d(K-,n) and d(K-,p),
the amplitude of I =1 in the d(K-,n) reaction is expected to be suppressed below the threshold → the measurement of I =0 is waited for strongly

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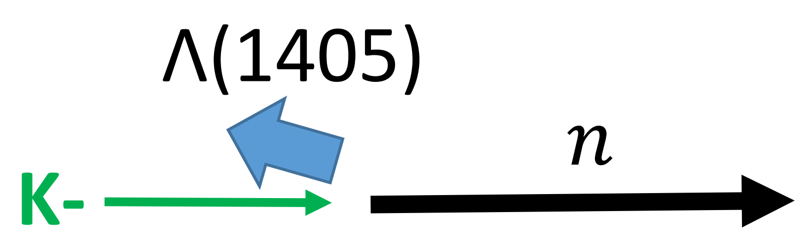
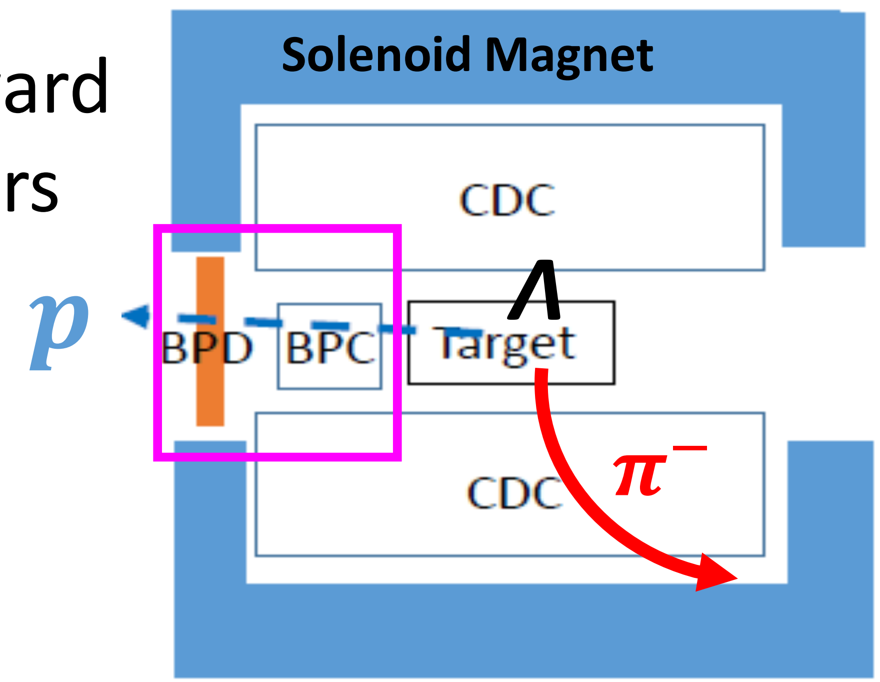
d(K-,n)"$\Sigma^0\pi^0$" analysis status

$$\pi^0\Sigma^0 \rightarrow \pi^0\, p\pi^-\gamma$$

- $\Lambda(1405)$ is recoiled backward

→ the decay proton emitted backward is detected by backward detectors





- Analysis procedure
  - **Reconstruction of Λ from $p\,\pi^-$**
  - **Separation of $\Lambda\,\pi^0\gamma$ by $d(K^-, n\,\Lambda)$"X" missing mass from $\Lambda\pi^0$or $\Lambda\pi^0\pi^0$**

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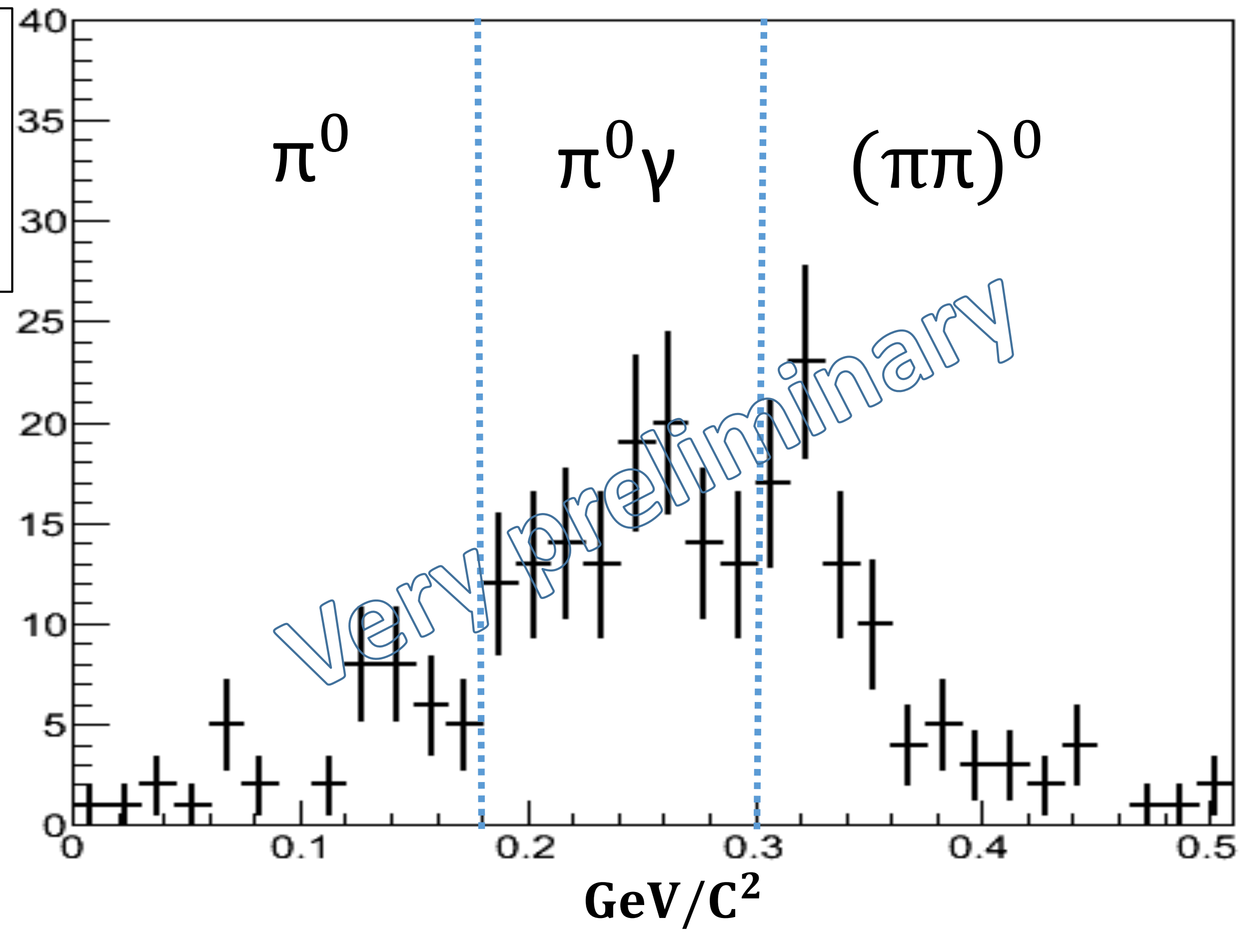
d(K-,nΛ)"X" missing mass

- π^0Λ (I =1)
- $\pi^0\Sigma^0$ -> $\pi^0\gamma$ Λ (I =0)
- $\pi^0\pi^0$Λ



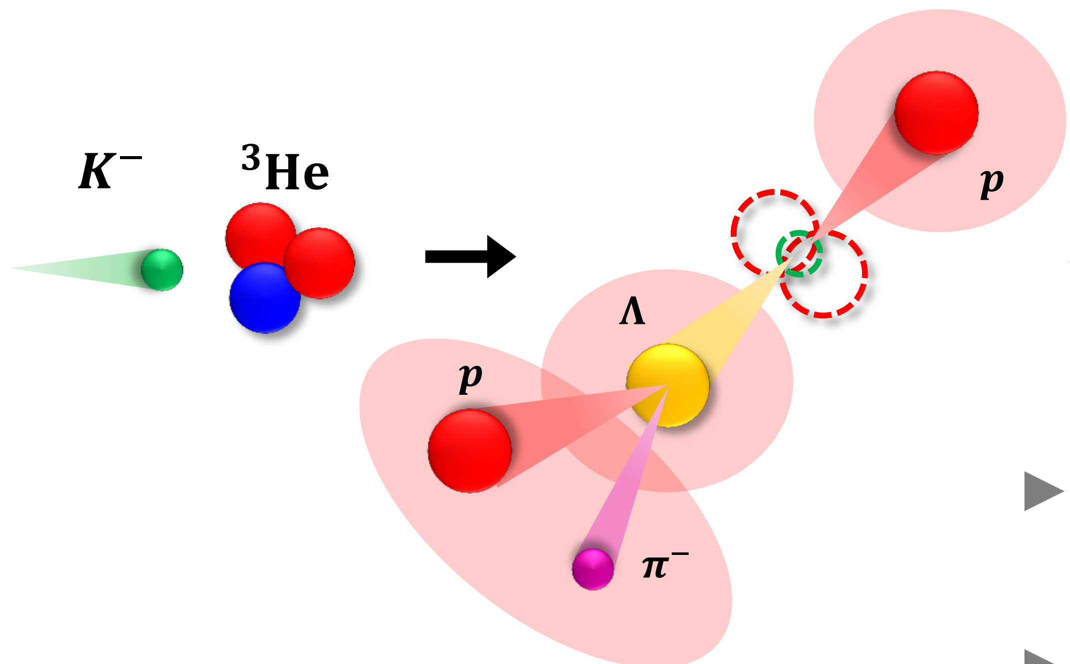
- Events in the region of $\pi^0\gamma$ is confirmed
- Events in the region of π^0 (I =1) is suppressed
- However we need more data for the d(K-,n)"$\Sigma^0\pi^0$" spectrum

Brief summary of E31

- Structure around 1420 was observed;
- Higher statistics are necessary for conclusion, especially pi0Sigma0 channel
- Next spring for 2nd round production of E31

Analysis Overview

- Λp invariant mass spectroscopy in $^{3}\mathrm{He}(K^{-},\Lambda p)"n"$ reaction



- ▶ πpp event selection
- ▶ Λ-Reconstruction
- ▶ Missing neutron selection

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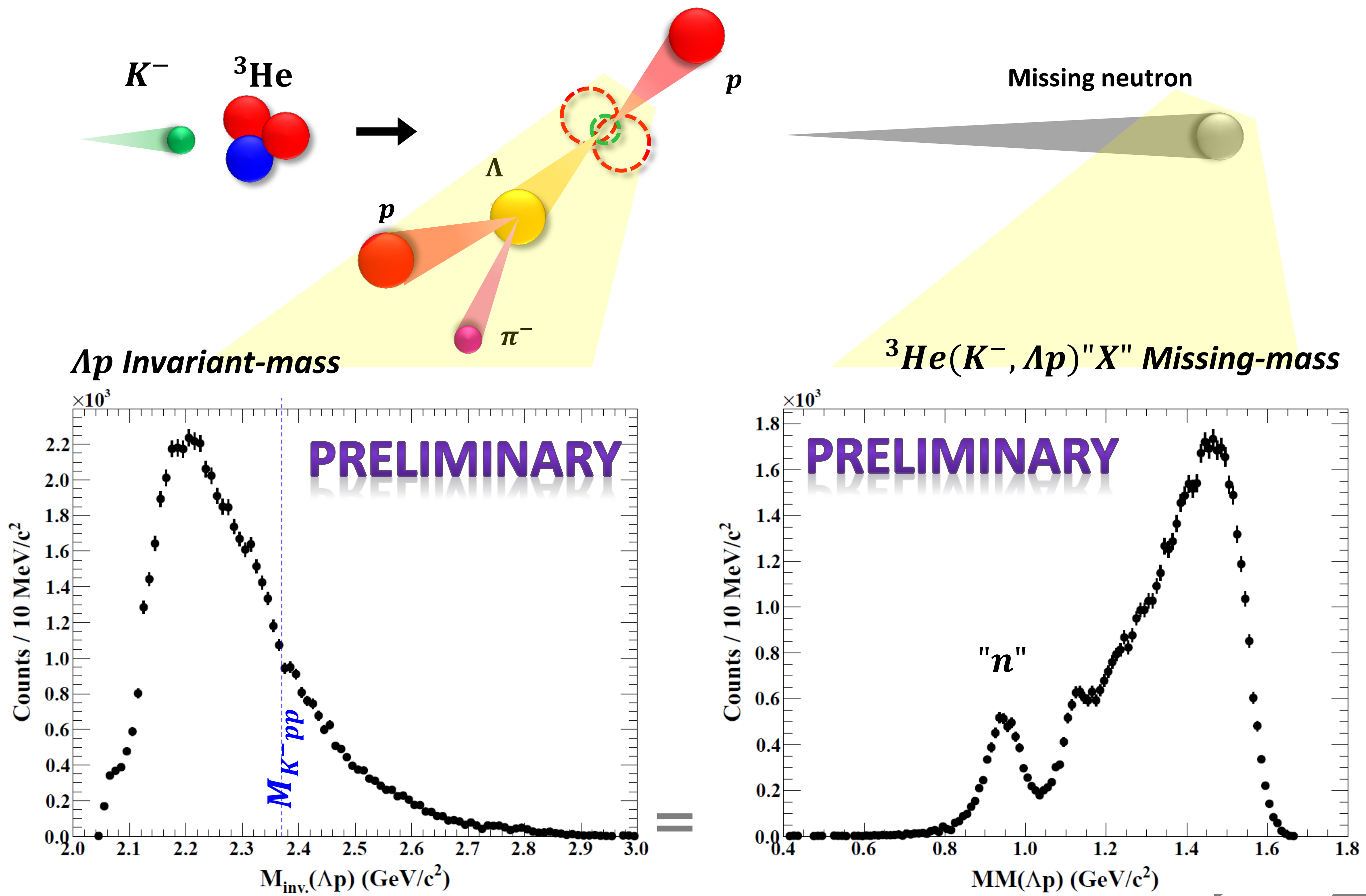
Analyzed Spectrum



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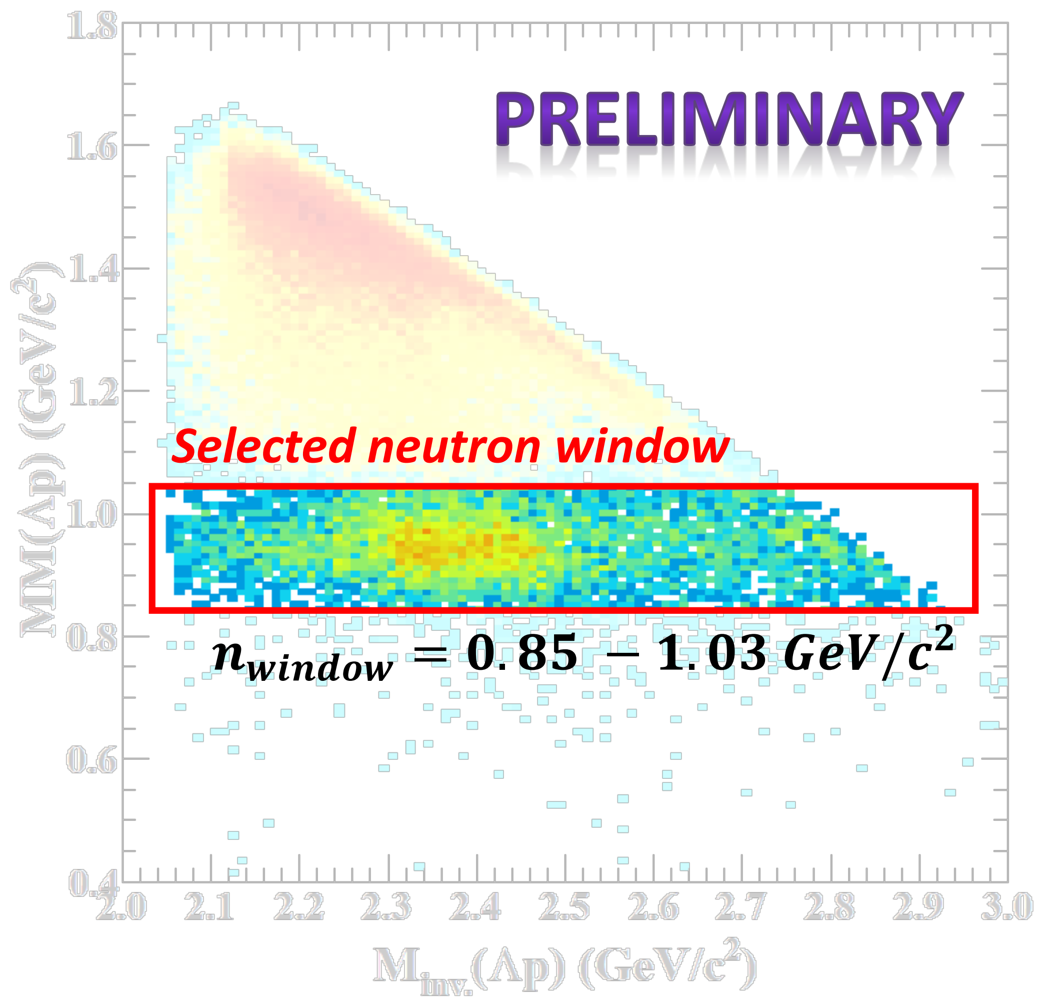
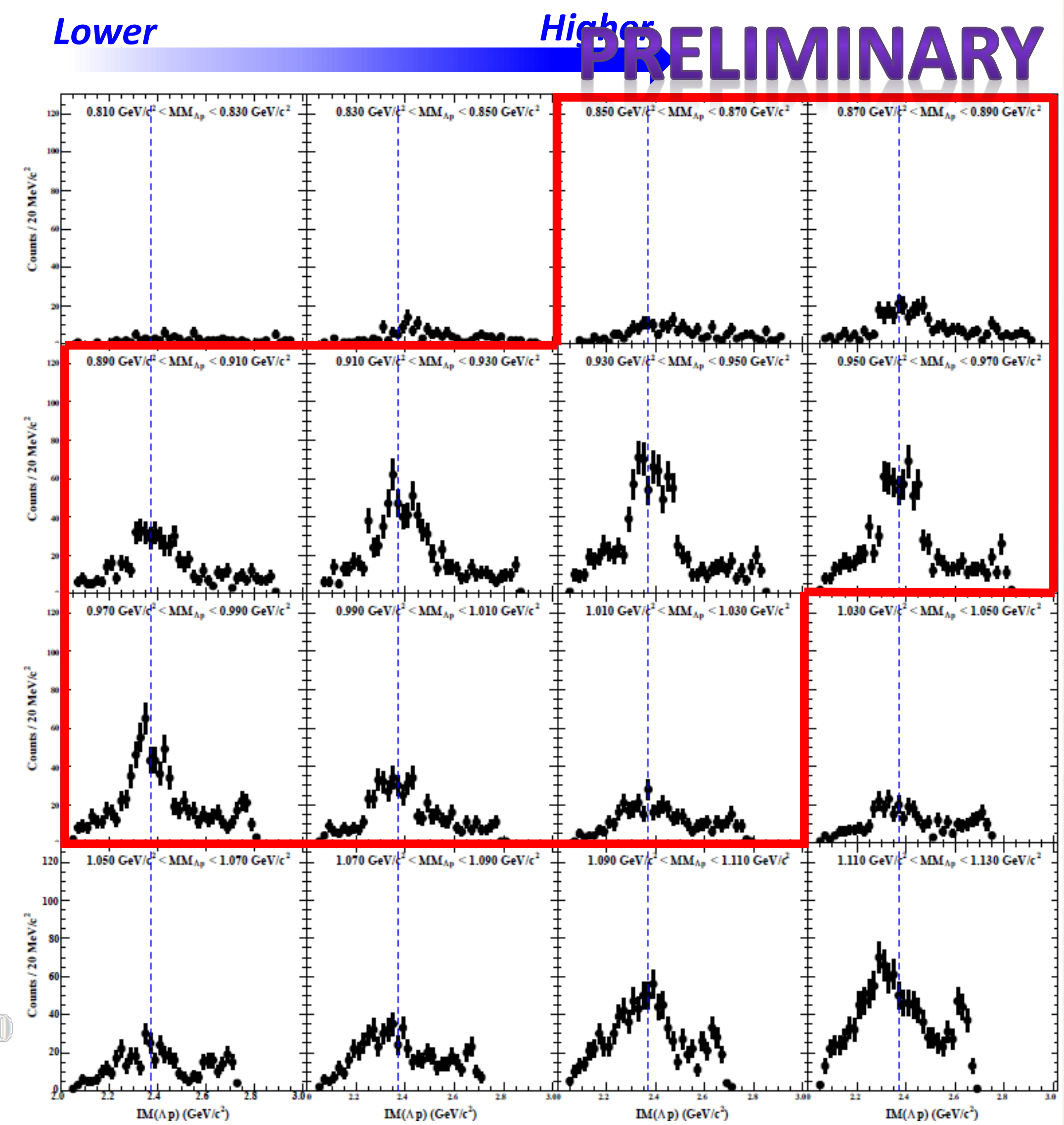
Neutron Window for Λpn Selection





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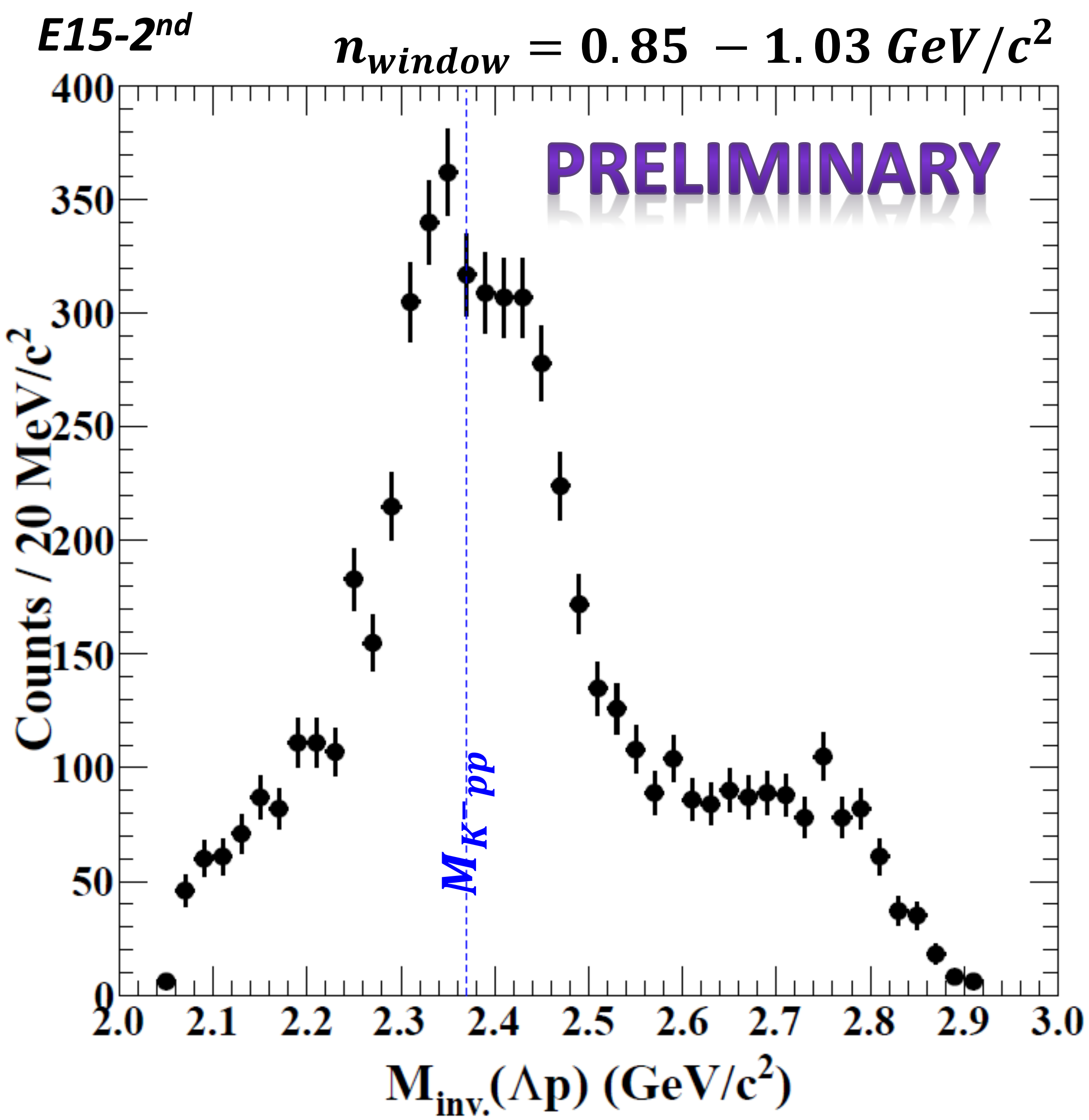
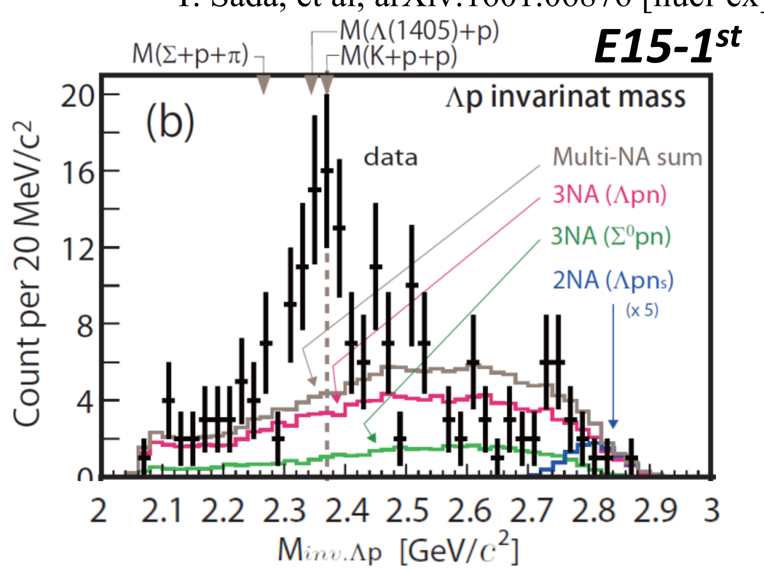
$IM(\Lambda p)$ in Λpn Final State



Y. Sada, et al, arXiv:1601.06876 [nucl-ex]



- **Consistent with the E15-1st result**
  - **With in statistics**
- **Structure around M_{K^-pp}**

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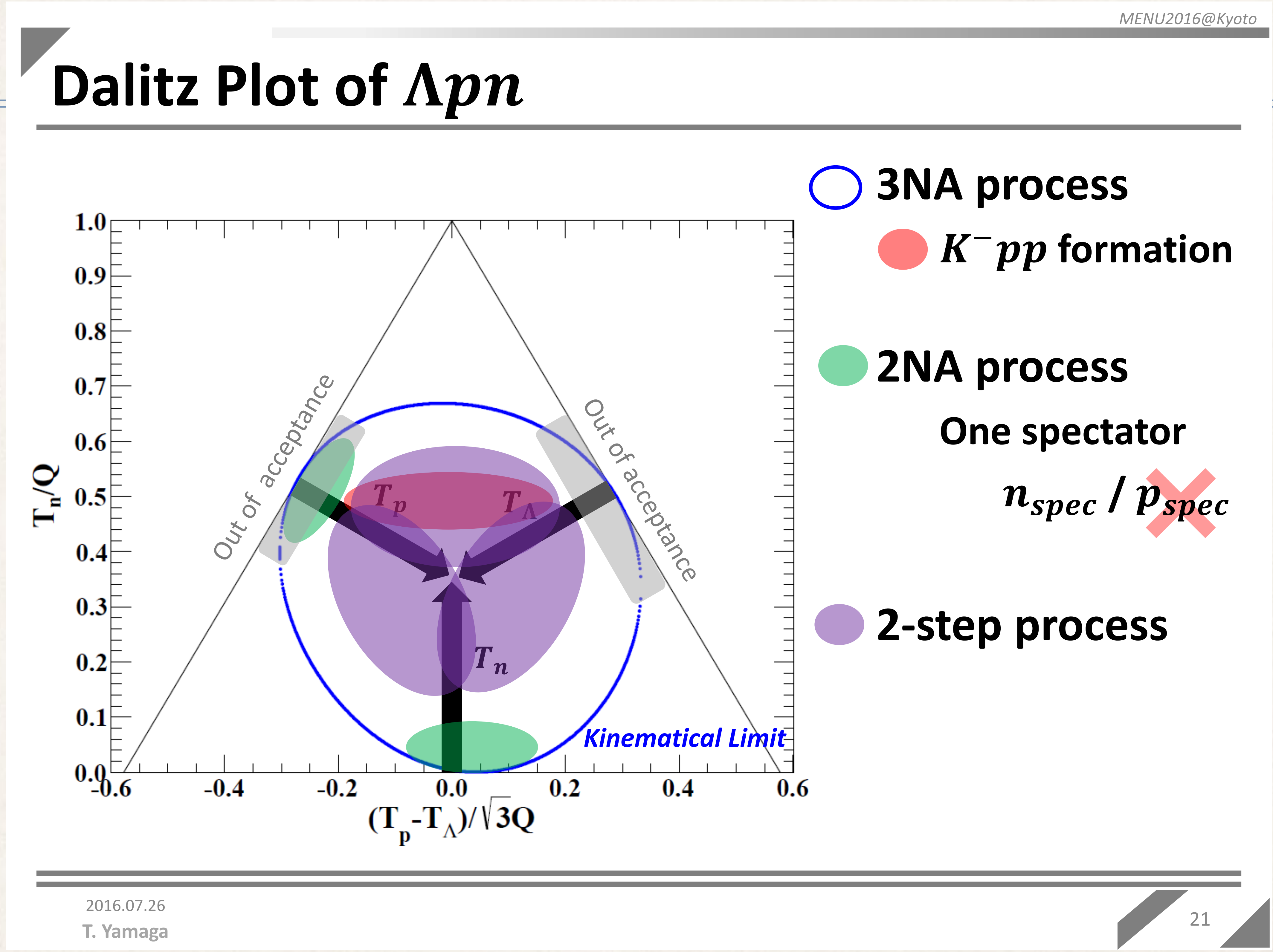

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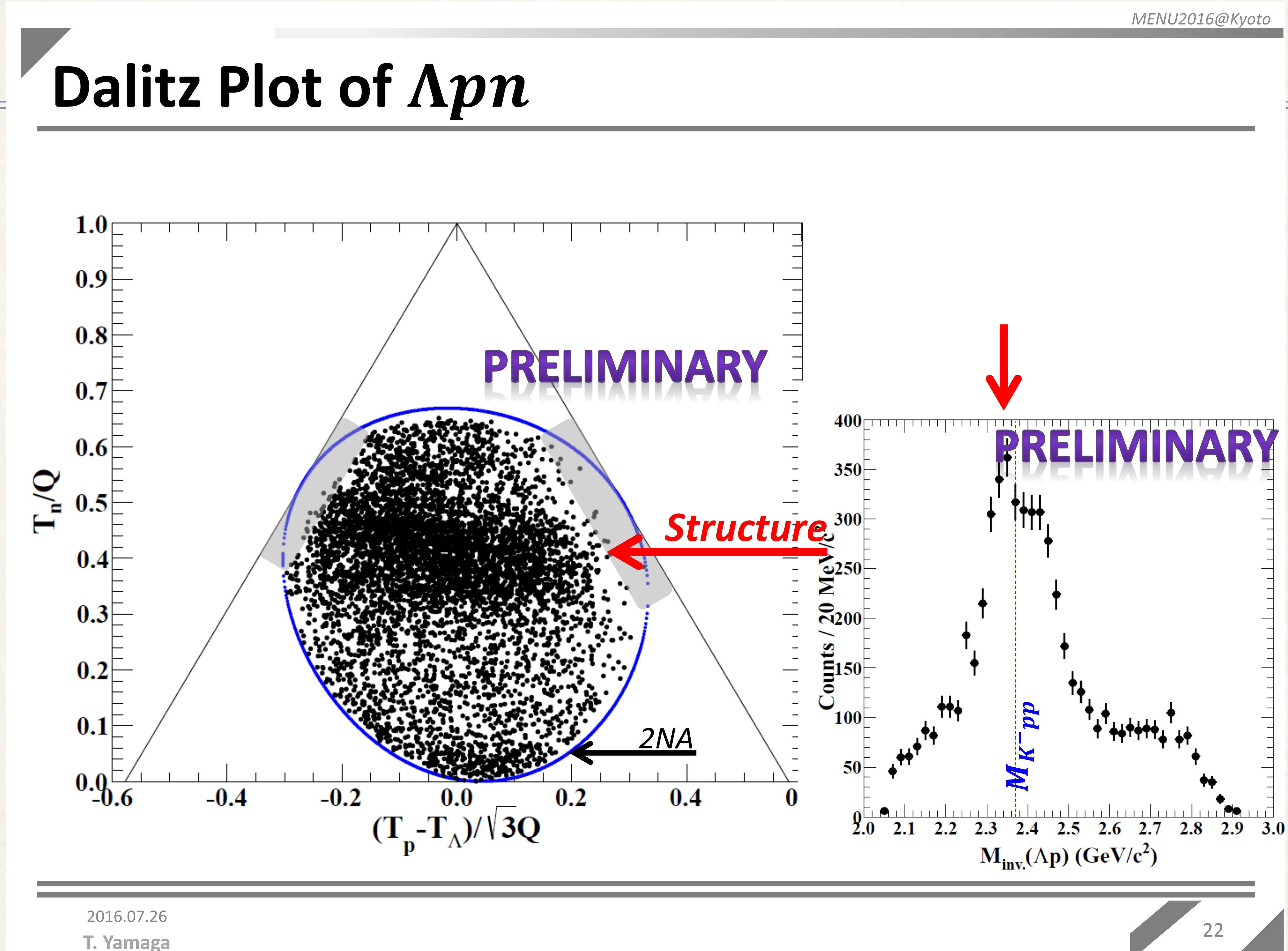

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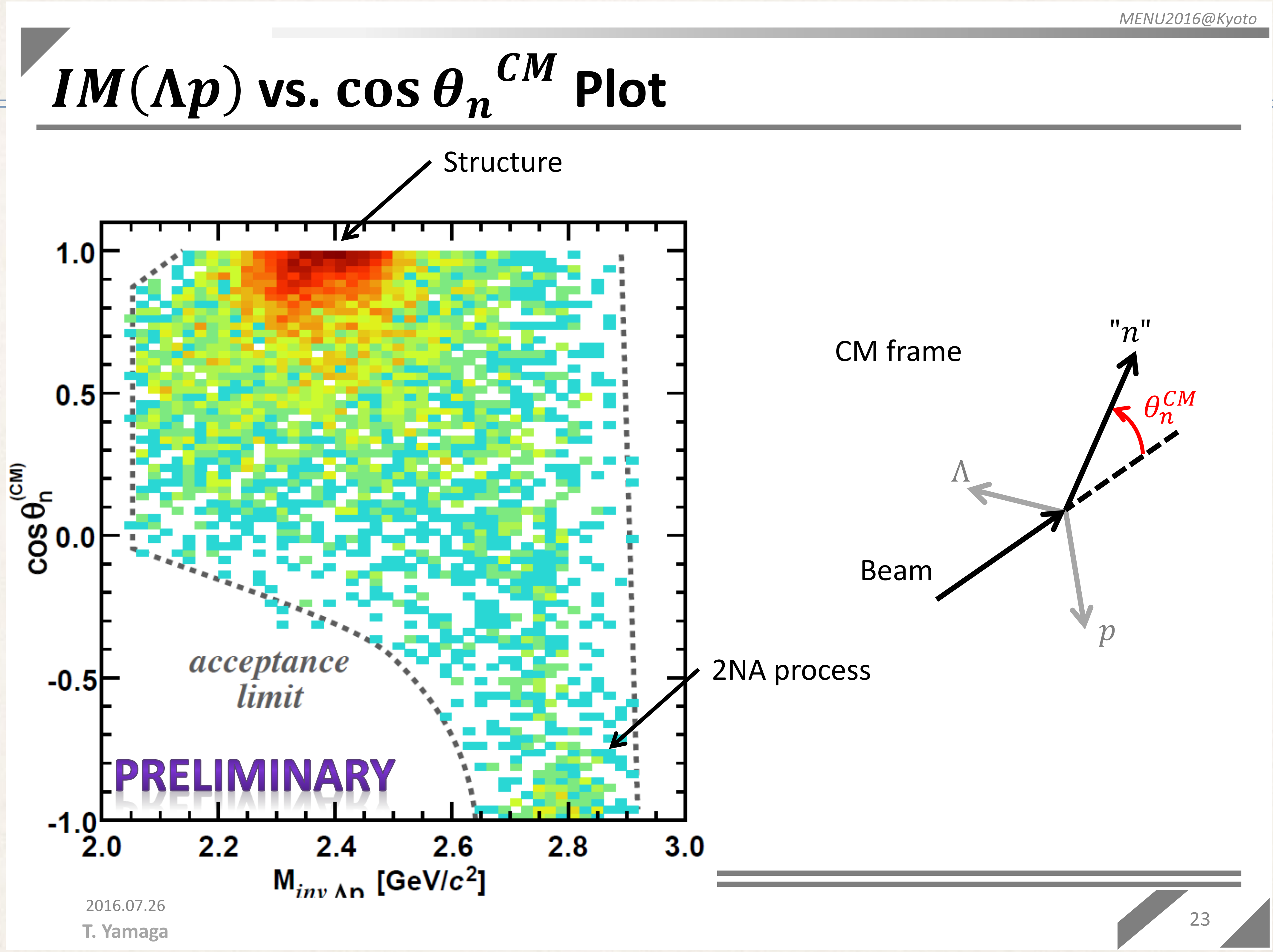

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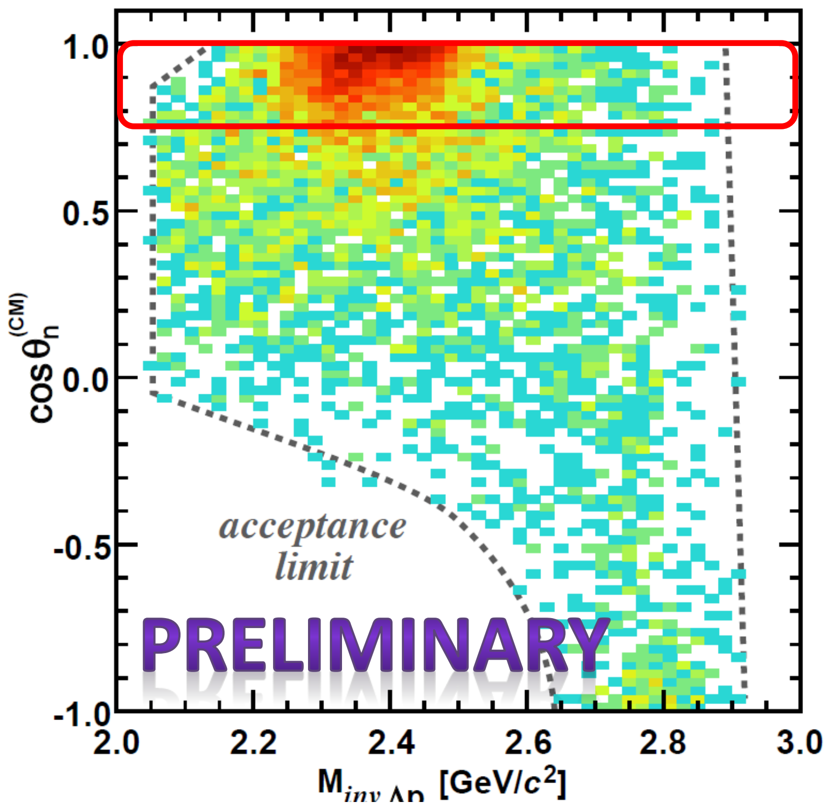
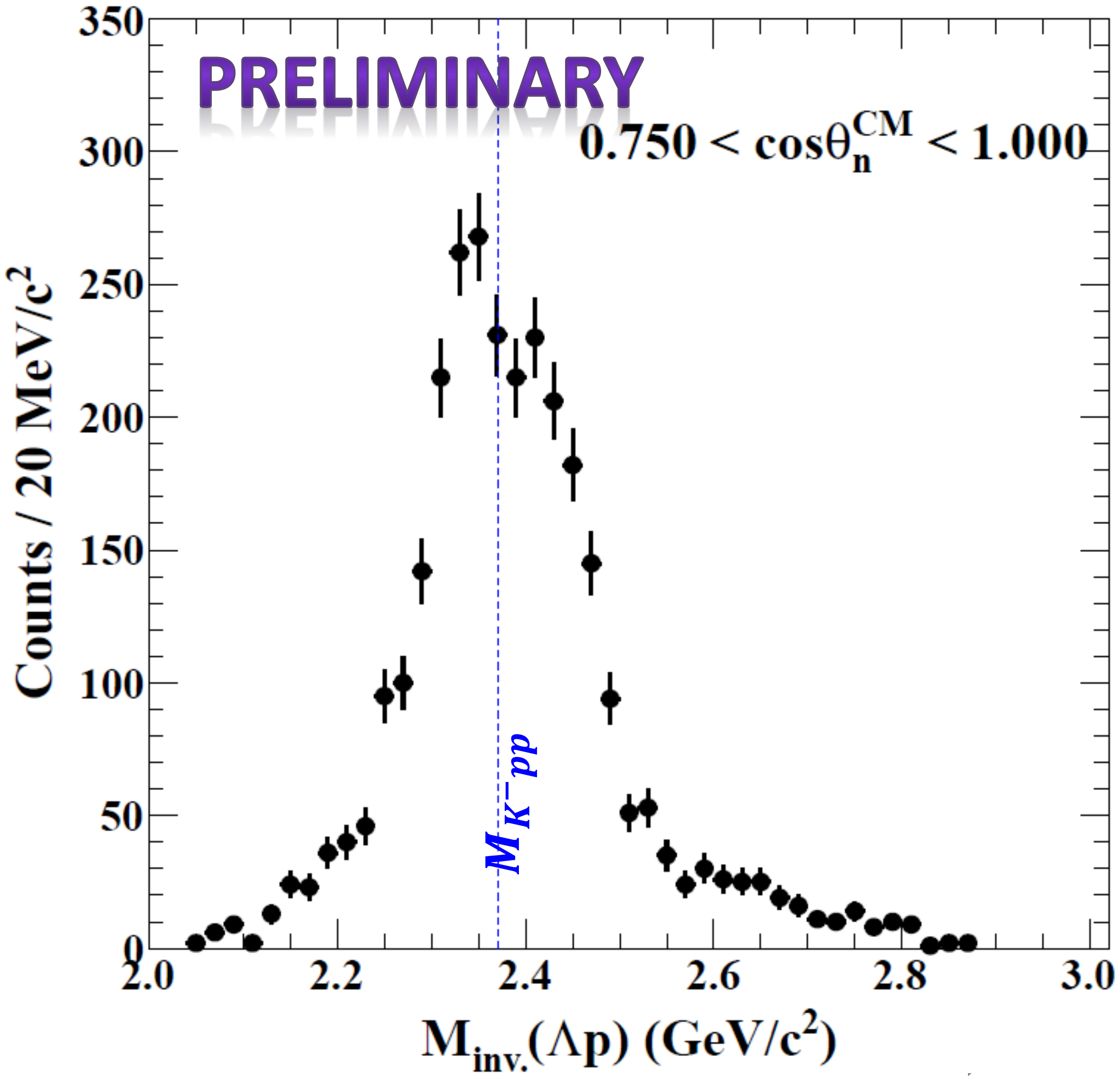
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



▶ Structure enhanced

◆ $0.75 < \cos\theta_n^{CM} < 1.0$

▶ **Structure** + 3NA + 2 step



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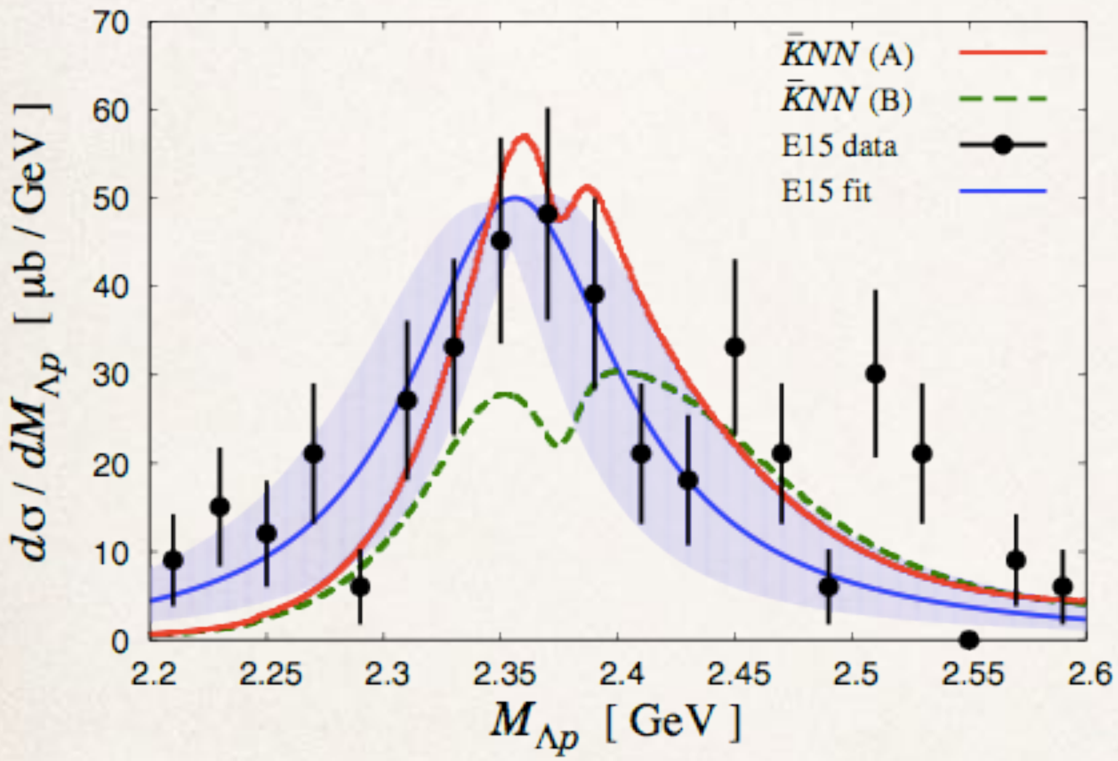
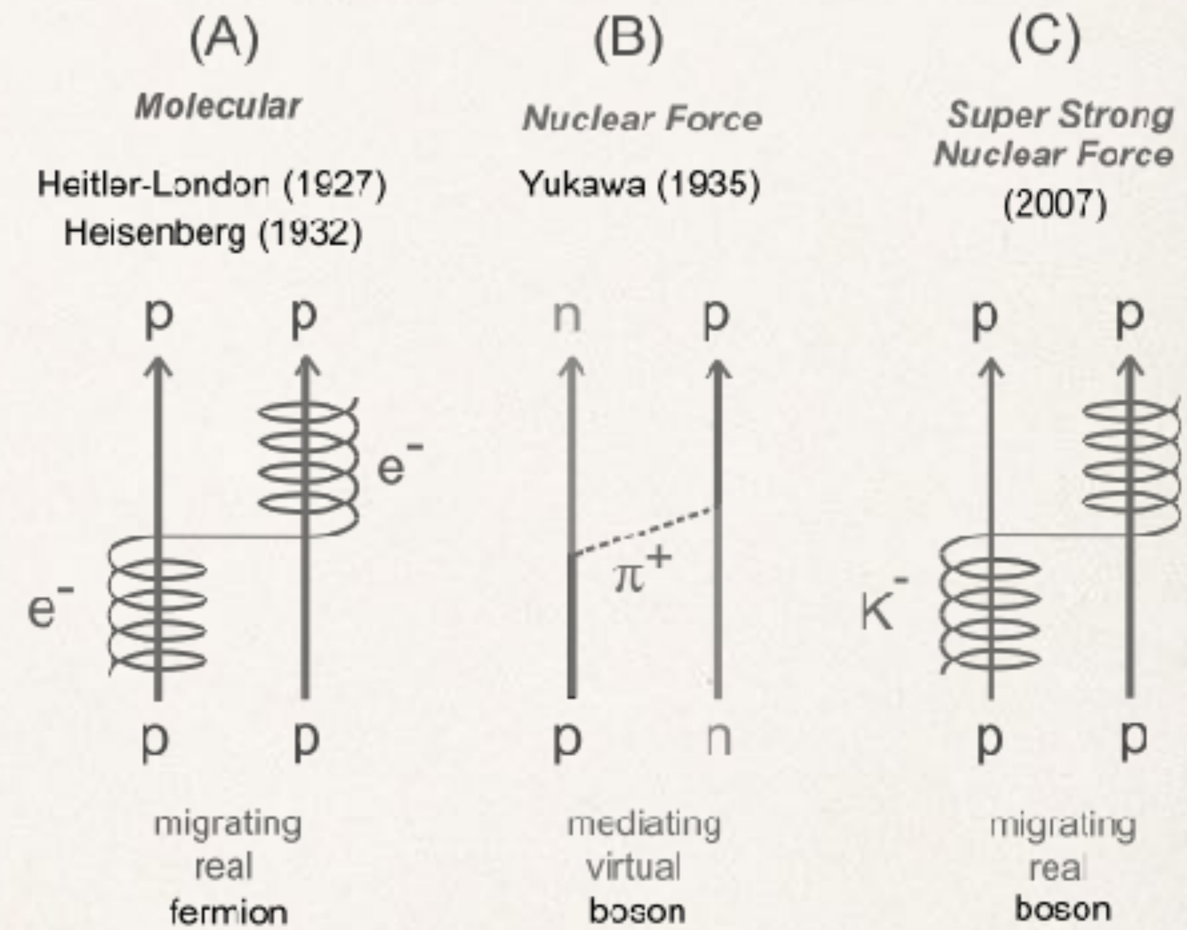
Brief summary of E15





T. Yamazaki, *et al.*, Proc. Jpn. Acad., Ser. B 83, 144
T. Sekihara, *et al.*, arXiv:1607.02058

Thank you for your attention

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

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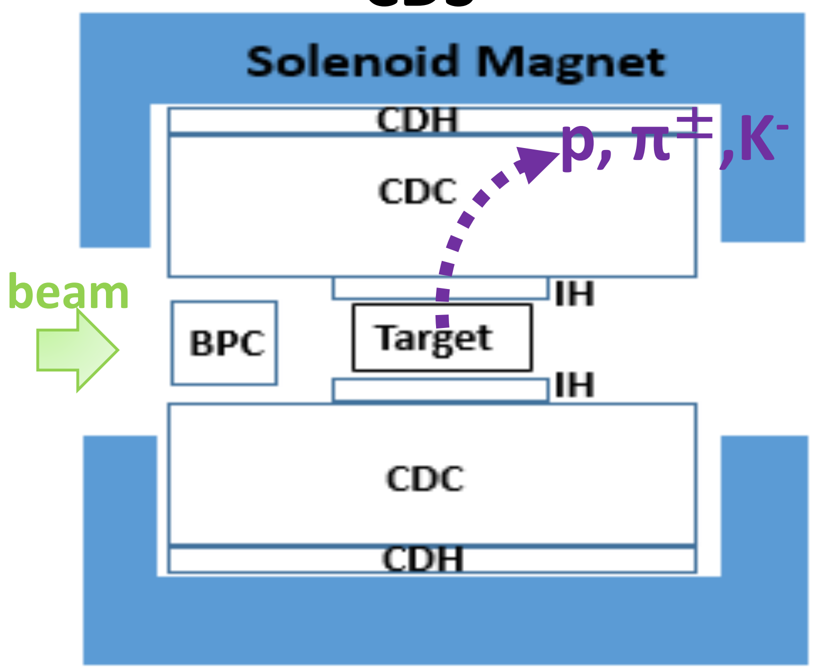
(*) Spokesperson
($) Co-Spokesperson

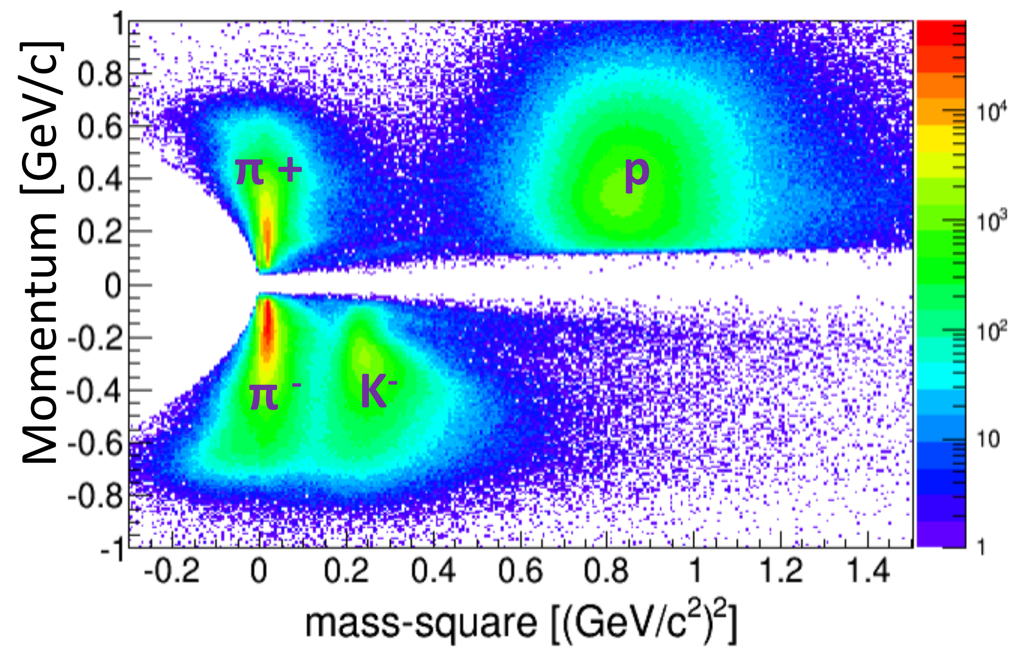
backup

- Cylindrical detector system (CDS)

CDS

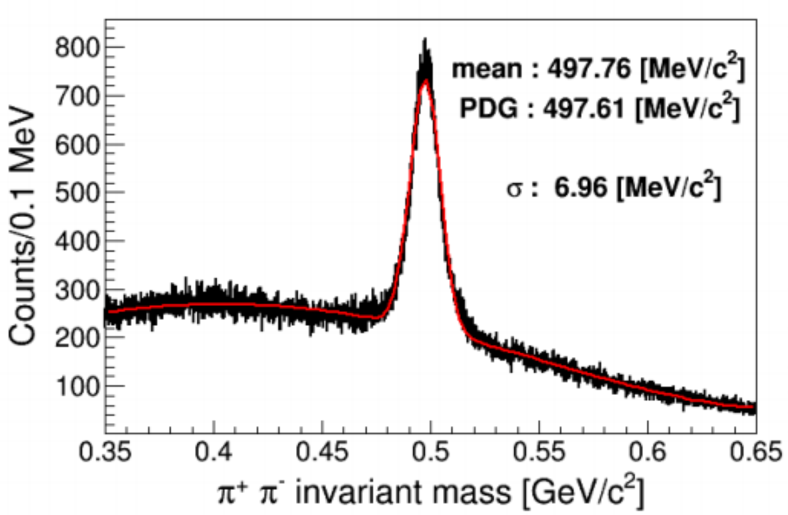


Particle identification



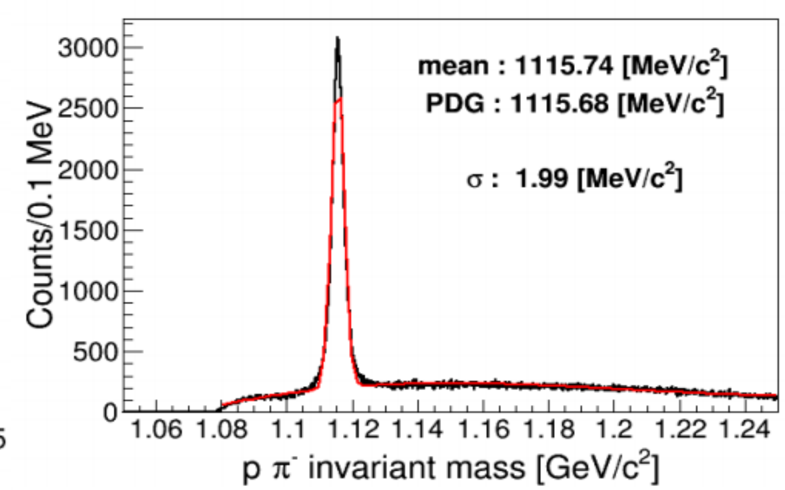
K^0s reconstruction

CDS $\pi^+ \pi^-$ IM

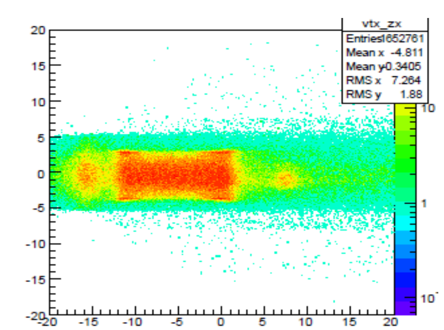


Λ reconstruction

CDS p π^- IM



Vertex position



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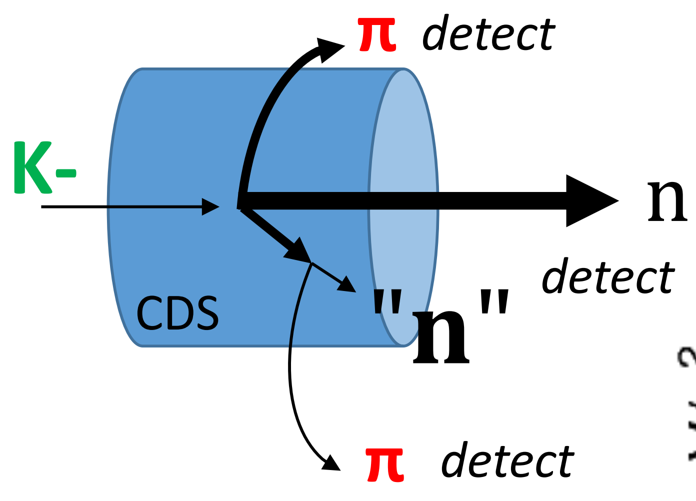
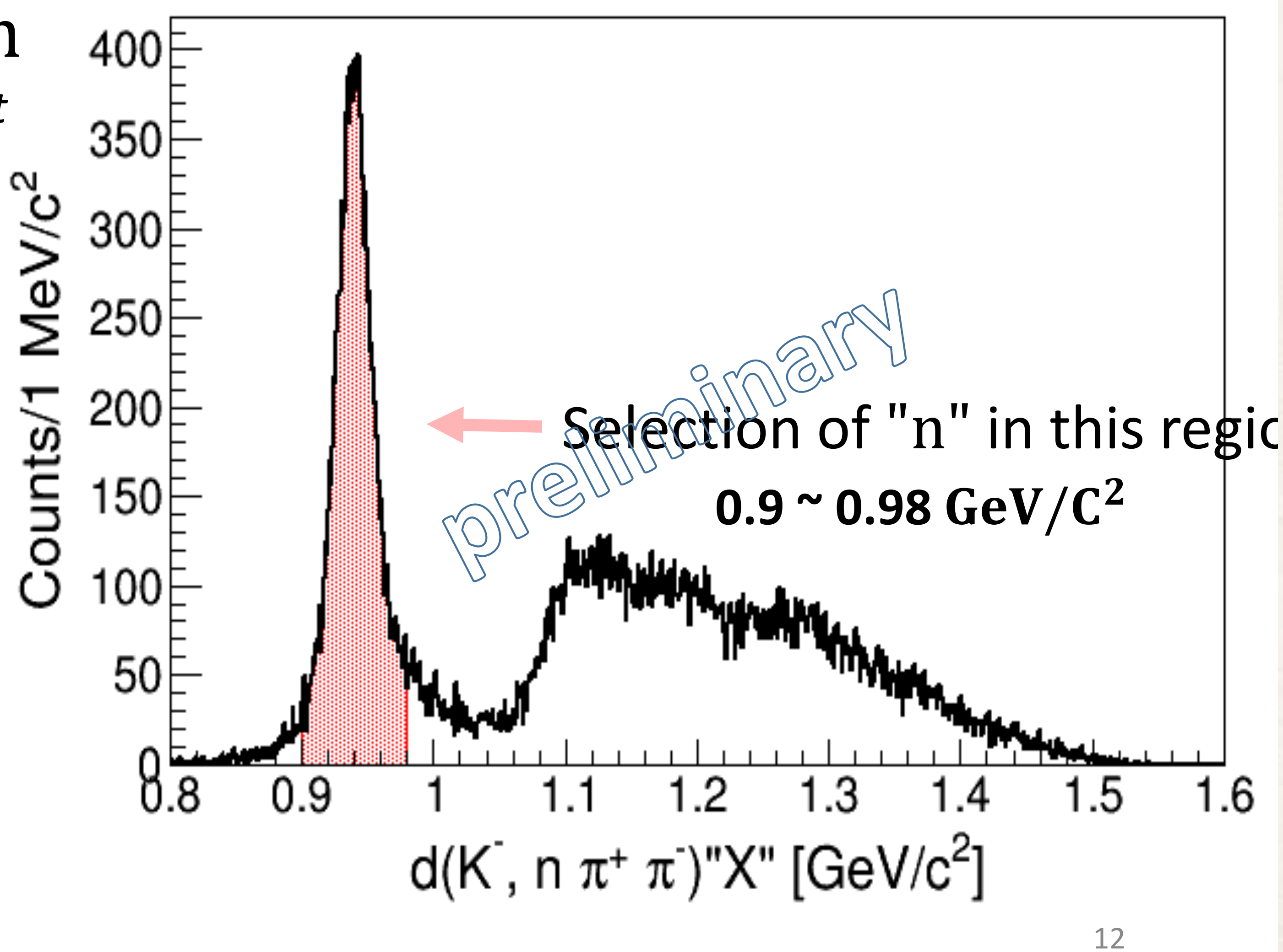
$d(K^-, \pi^{\mp}\pi^{\pm}n)$"n" identification

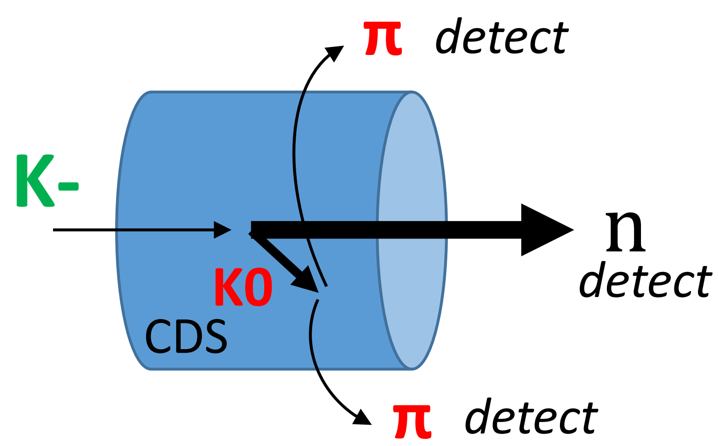


$d(K^-, \pi^{\mp}\pi^{\pm}n)$"X" missing mass

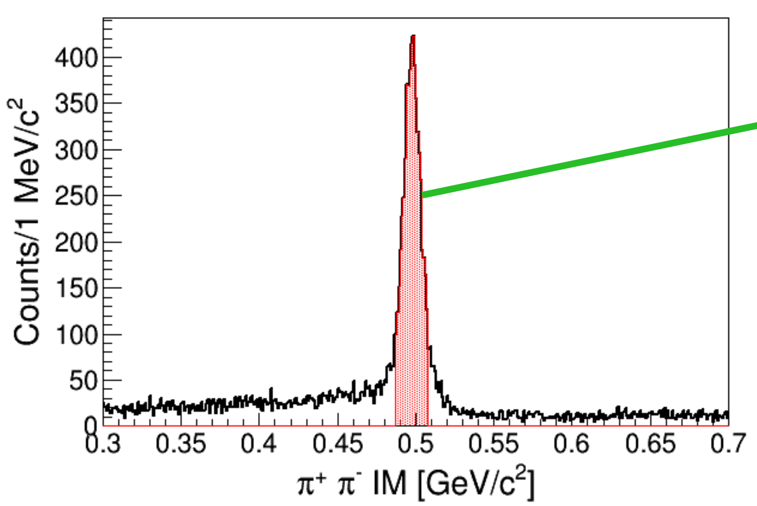


BG : $K^- d \rightarrow K^0 n\, n_{spectator}$

Charge exchange : $K^- p \rightarrow \overline{K^0} n$

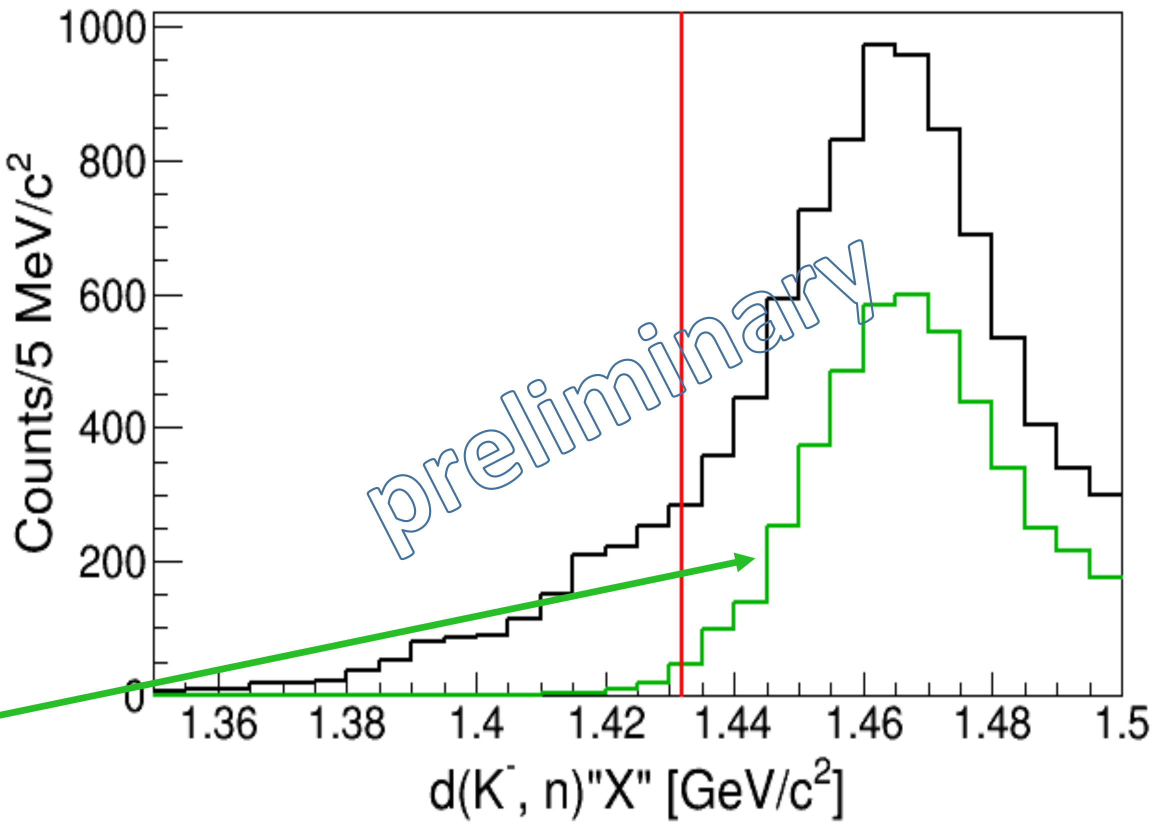


Invariant mass ($\pi^- \pi^+$)



K0 event is reconstructed

$d(K^-, n)\pi^{\mp}\pi^{\pm}$"n" **missing mass**



- **Missing mass resolution ~ 10 MeV/c^2 at KN threshold**
- **the tail below threshold cannot be explained by detector resolution**

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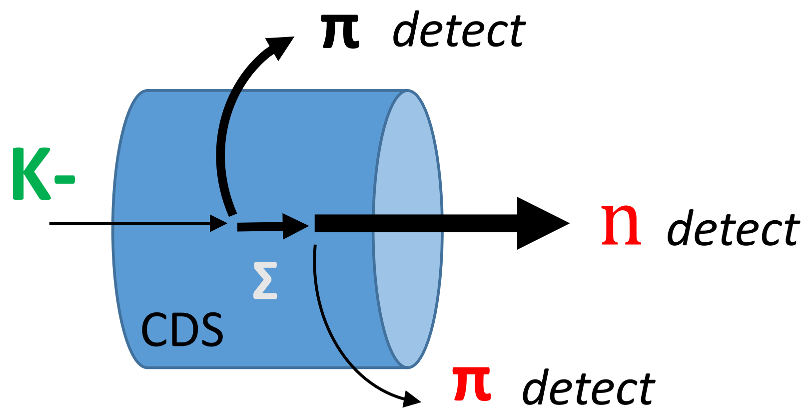
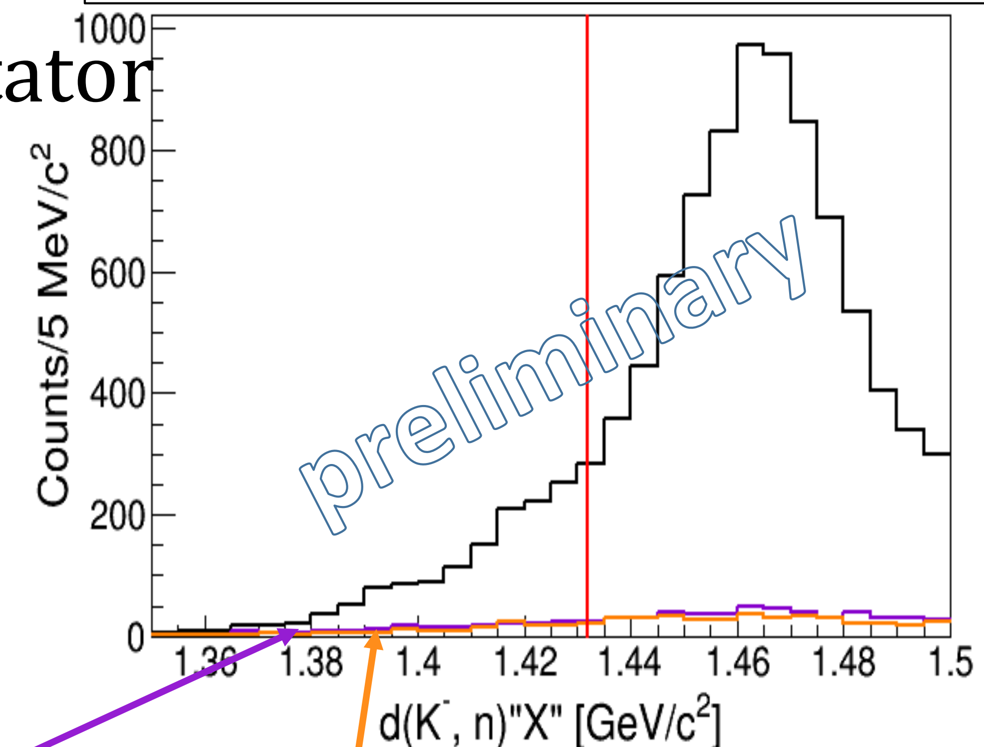
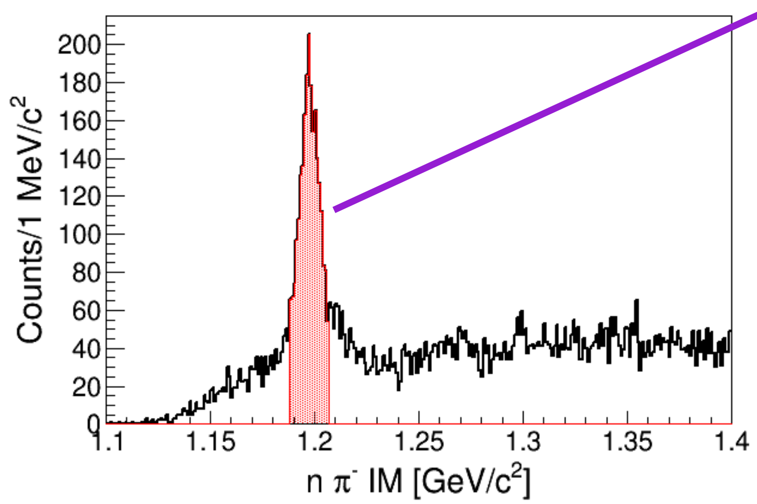
BG : $K^{-}d \to \pi\Sigma\, n_{spectator}$



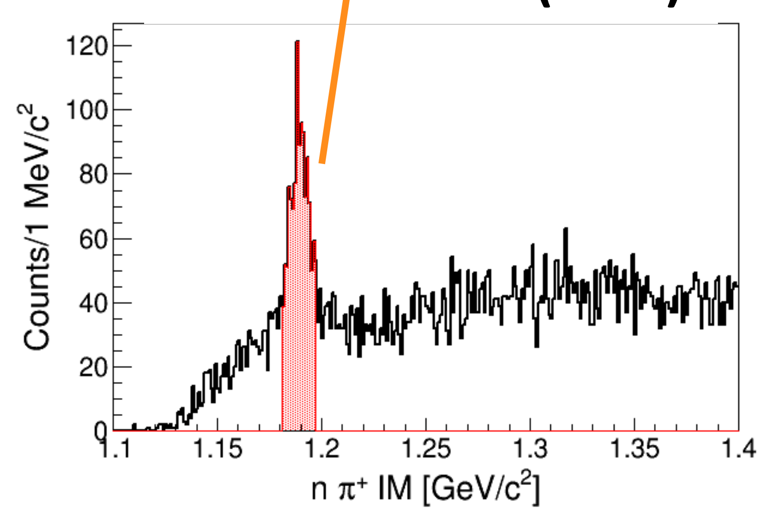
$d(K^{-}, n)\pi^{\mp}\pi^{\pm}$"n" **missing mass**



Invariant mass ($\pi^{-}n$)



Invariant mass ($\pi^{+}n$)



- **Neutron from Σ event is reconstructed**
- **The contribution of this reaction is small**

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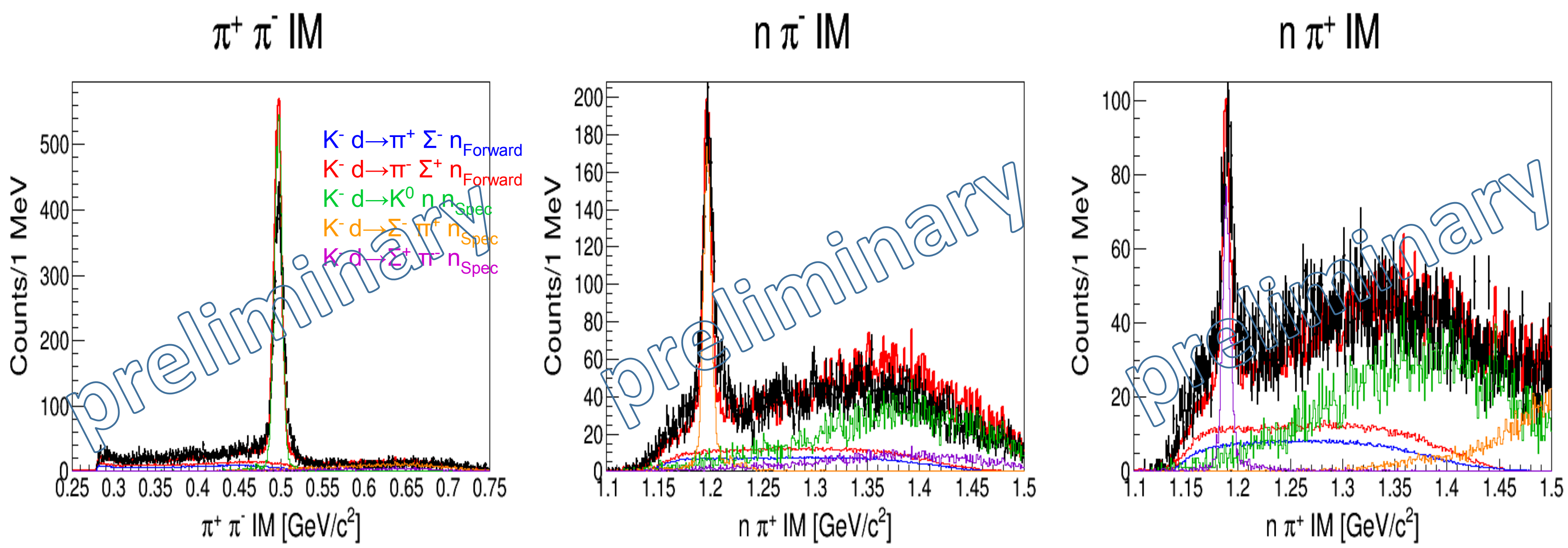
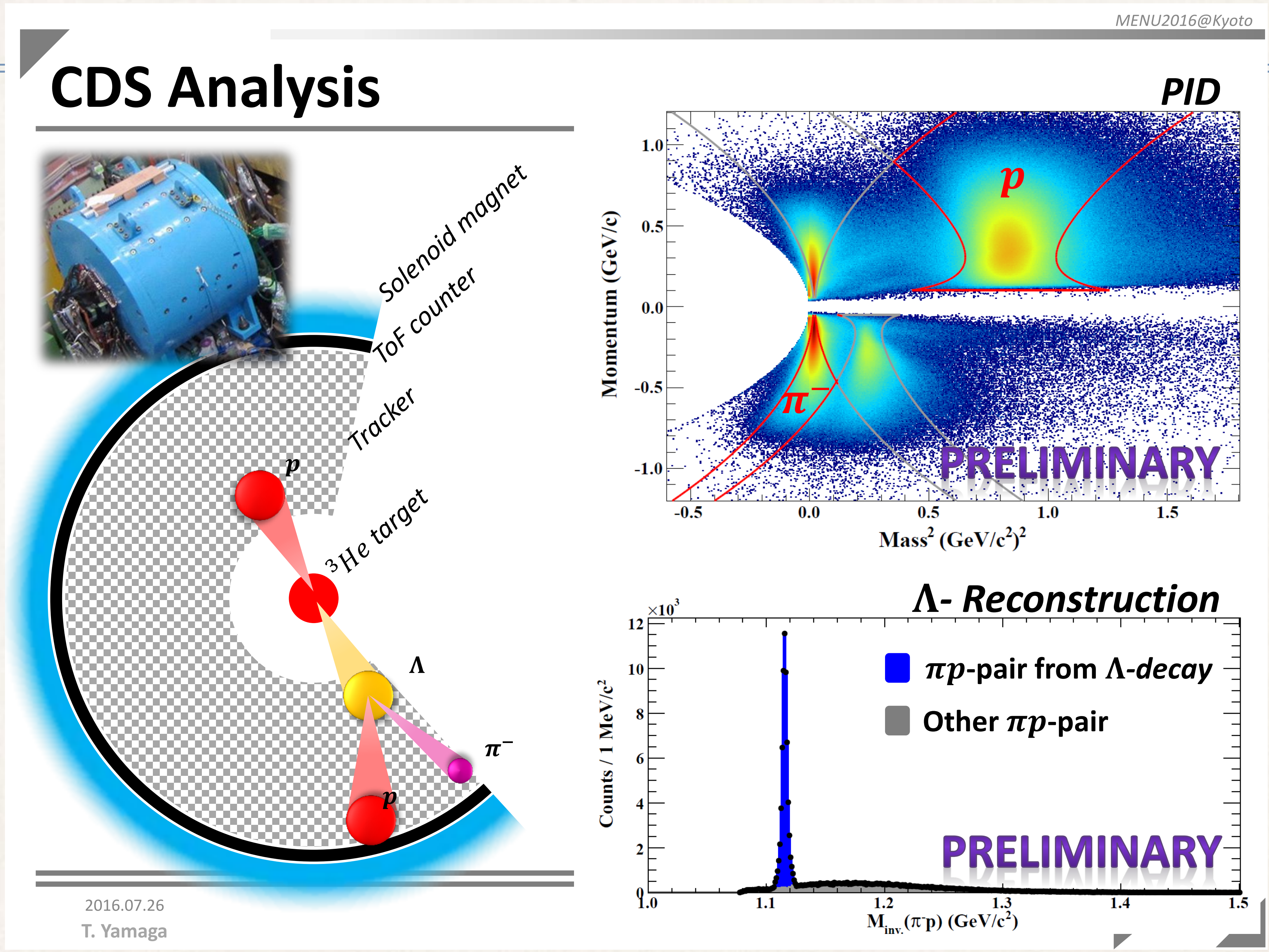
Decompose of signal and BG

- Fitting of invariant ($\pi^-\pi^+$), (n π^+) and (n π^-) by SIM

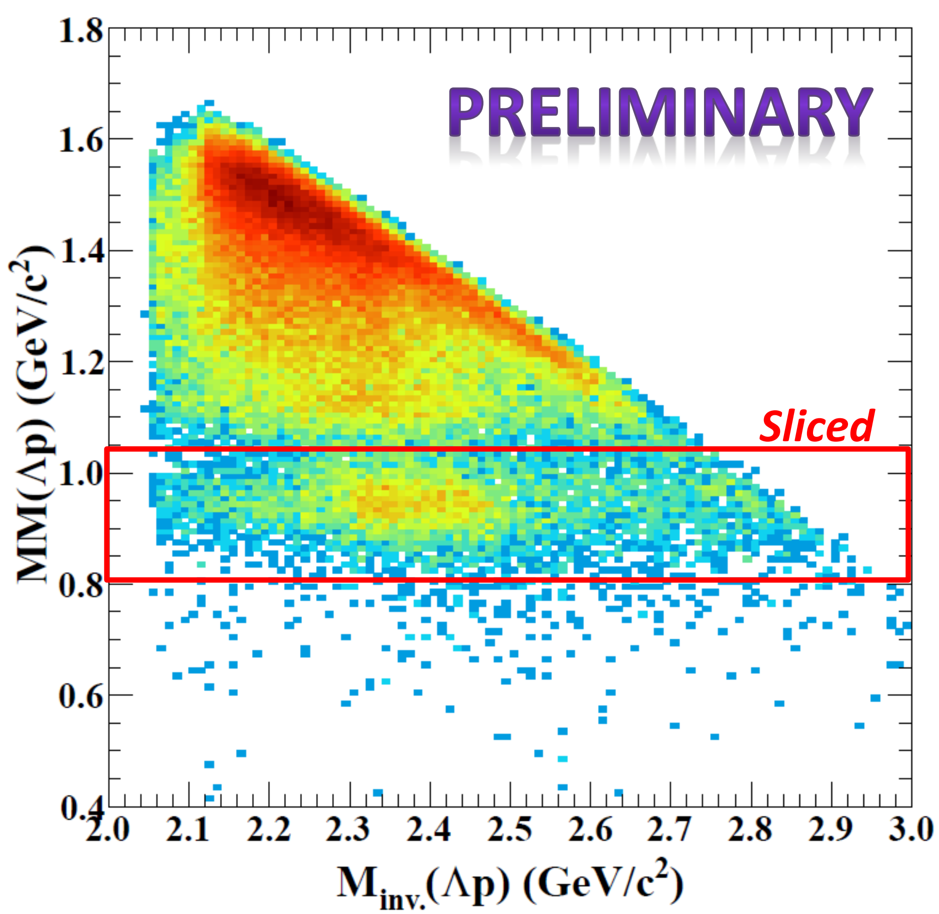
Invariant mass ($\pi^-\pi^+$) **Invariant mass (π^-n)** **Invariant mass (π^+n)**

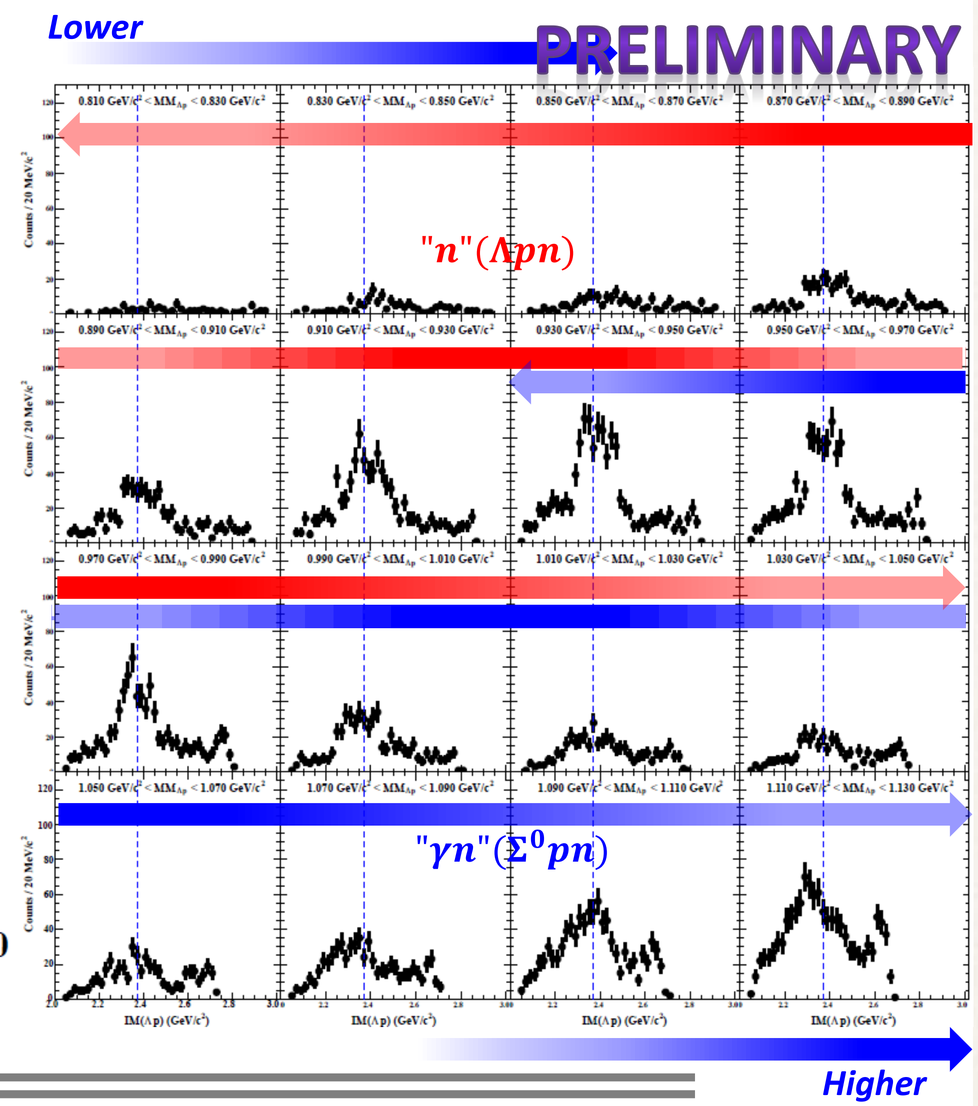


- SIM seem to reproduce the data well

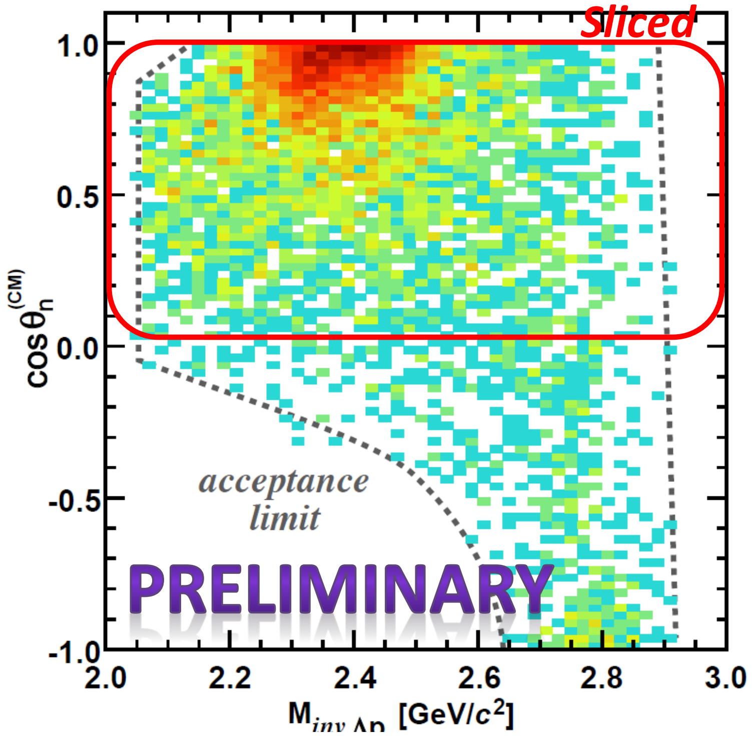

MENU2016@Kyoto
CDS Analysis
Solenoid magnet
ToF counter
Tracker
^3He target
p
Λ
π^-
p
PID
Momentum (GeV/c)
Mass^2 (GeV/c^2)^2
PRELIMINARY
Λ- Reconstruction
×10^3
Counts / 1 MeV/c^2
πp-pair from Λ-decay
Other πp-pair
$M_{inv.}(\pi^- p)$ (GeV/c^2)
PRELIMINARY
2016.07.26
T. Yamaga

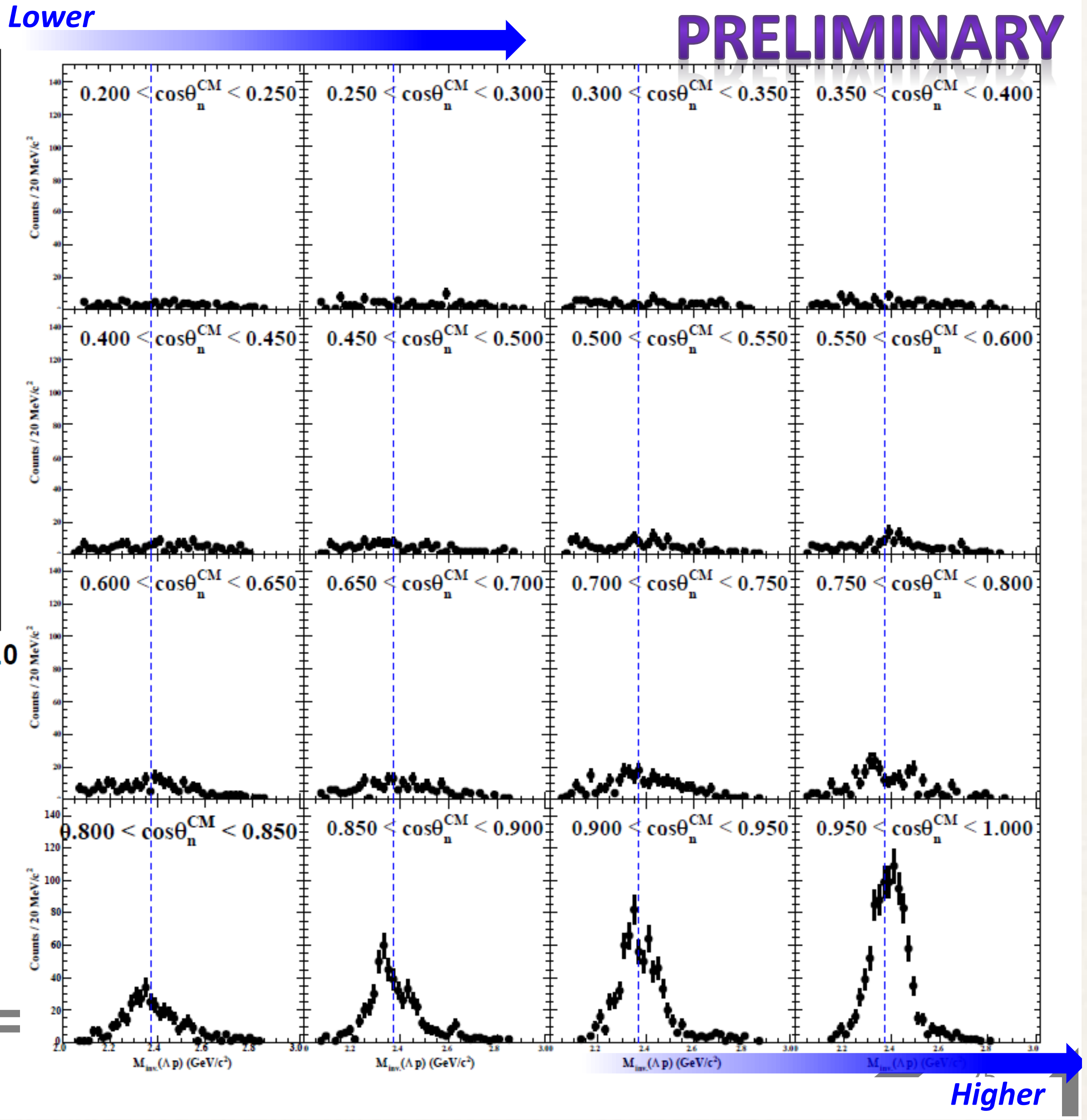
$MM(\Lambda p)$ Slice around "n" Region



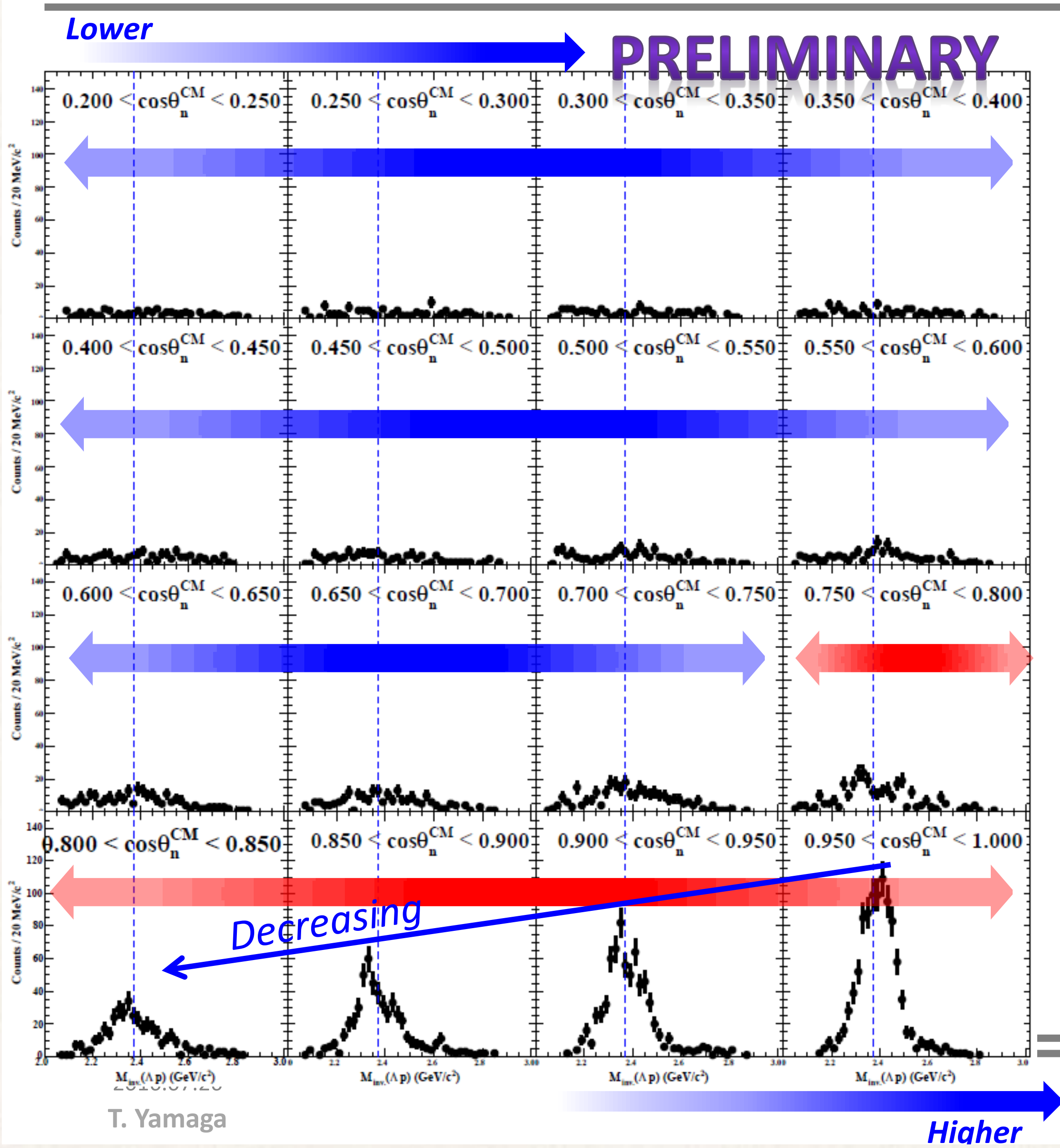


$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



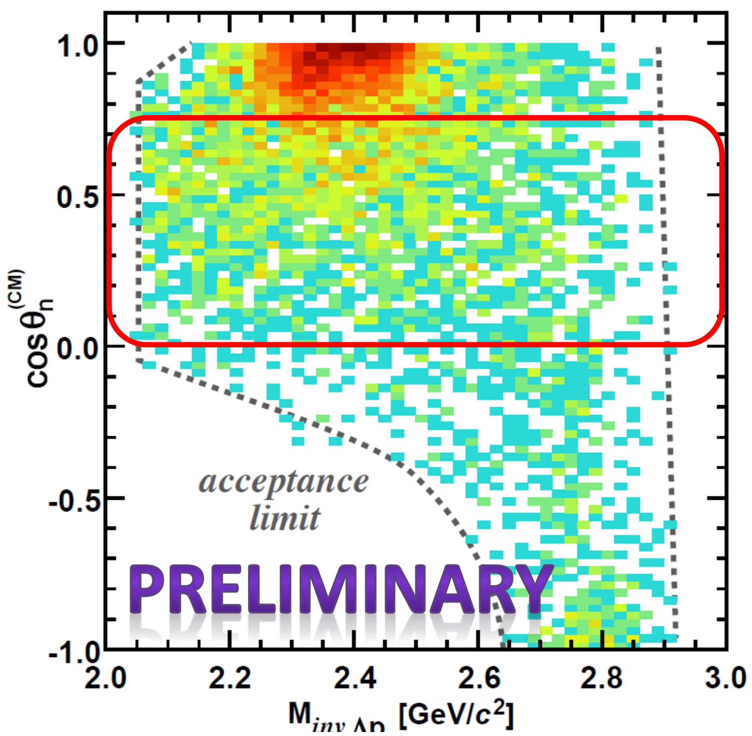


$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



- **Lower Region**
  - No structure
  - Small event
- **Higher Region**
  - Structure observed

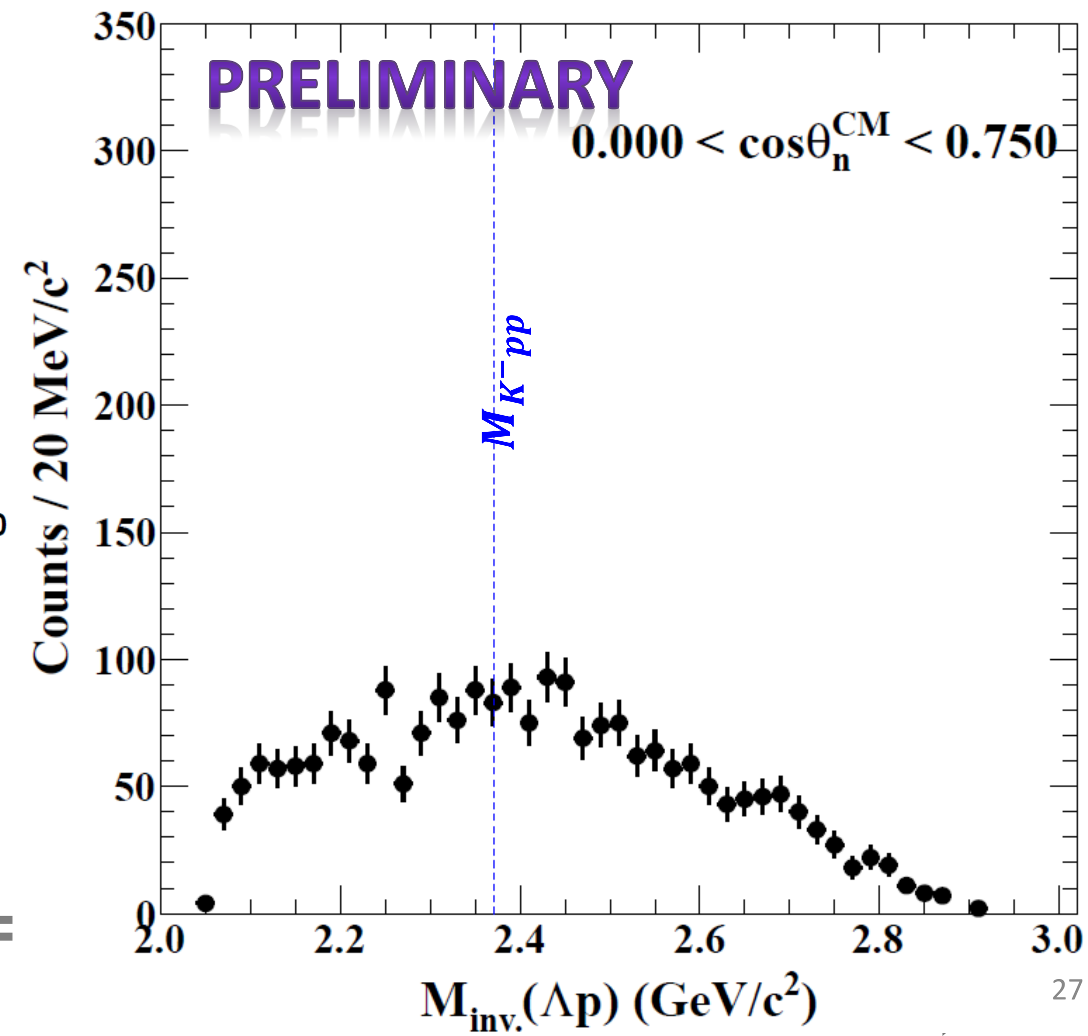
$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$



- ▶ No Structure

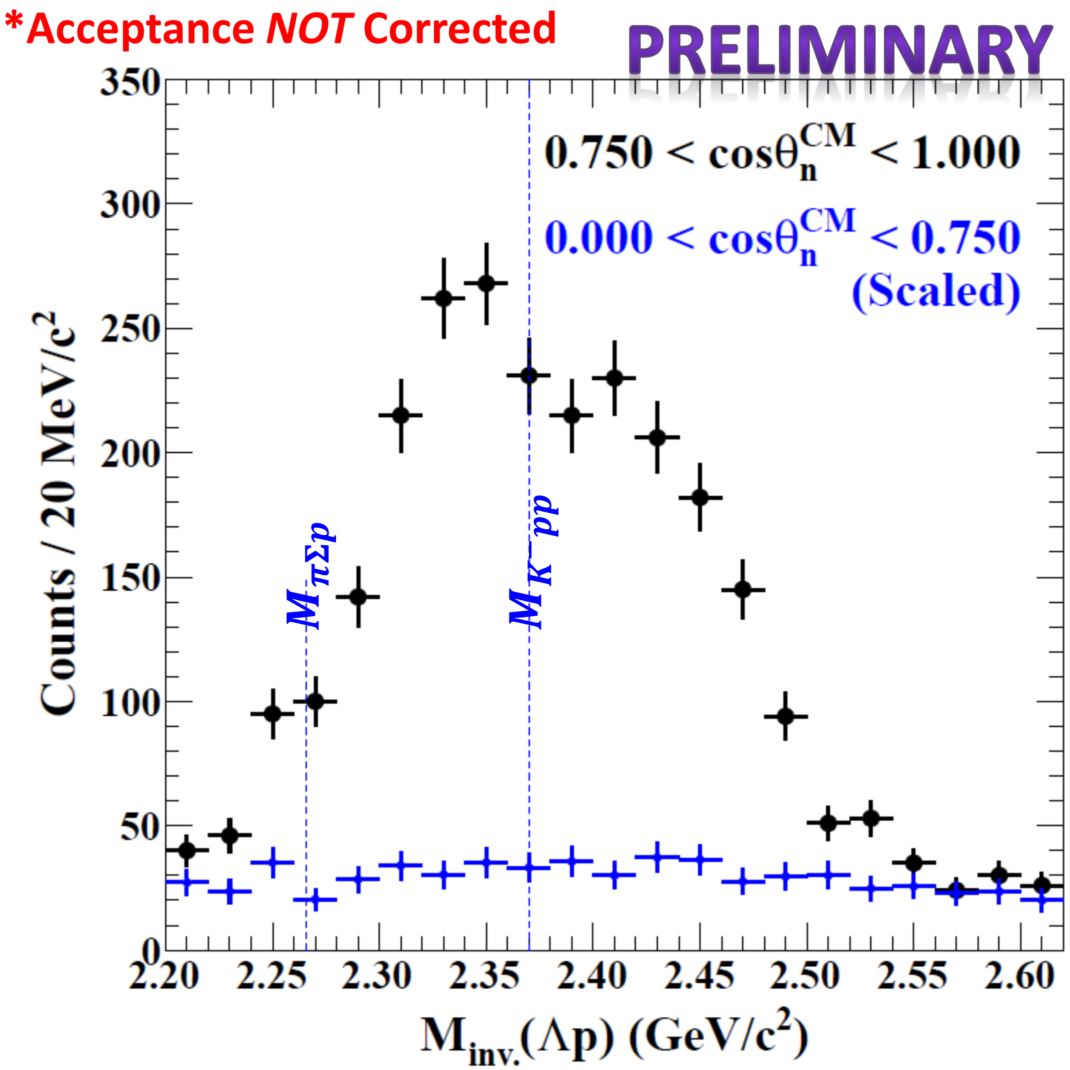
◆ $0.0 < \cos\theta_n^{CM} < 0.75$

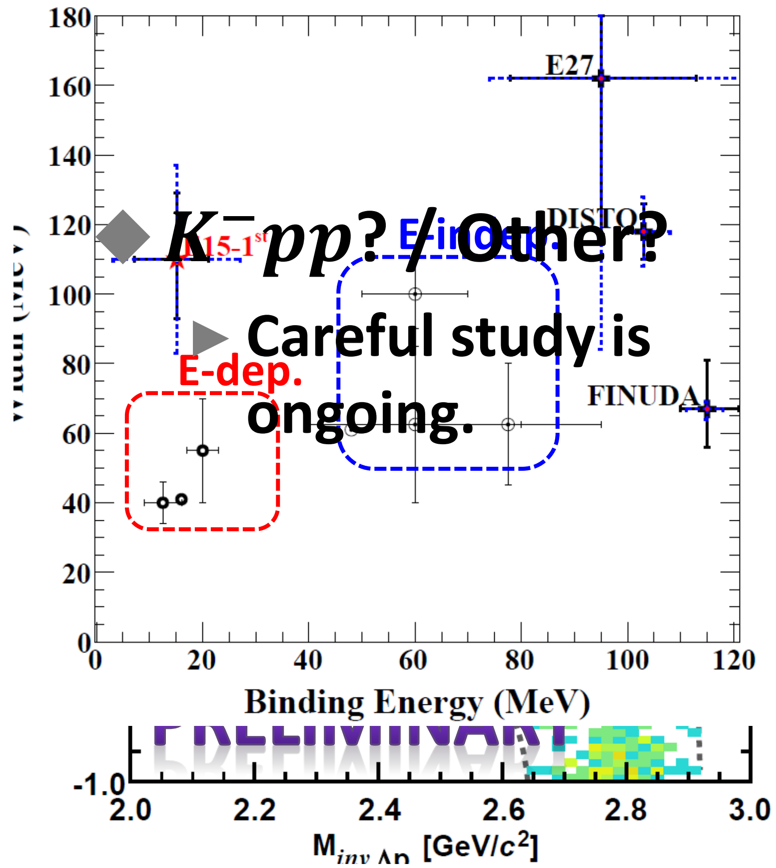
- ▶ 3NA + 2 step



$\cos\theta_n{}^{CM}$ Sliced $IM(\Lambda p)$

*Acceptance *NOT* Corrected





- $K^- pp$? / Other?
  - Careful study is ongoing.