

Recent results of the K^{bar} NN search at J-PARC



F. Sakuma, RIKEN
on behalf of the J-PARC
E15 collaboration

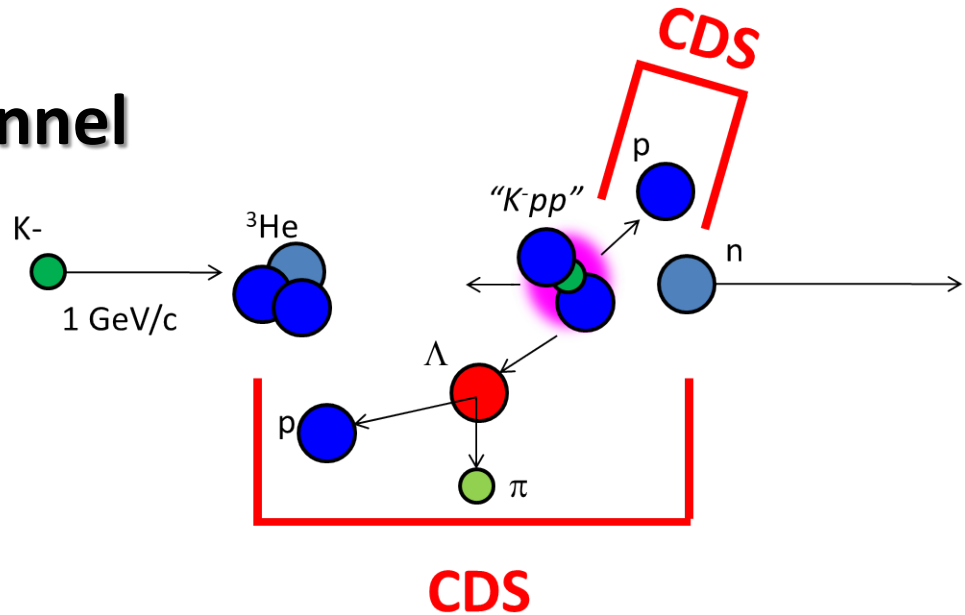


2017年度KEK理論センターJ-PARC分室活動総括研究会
J-PARC, 1-2 January 2018

Outline of the Talk

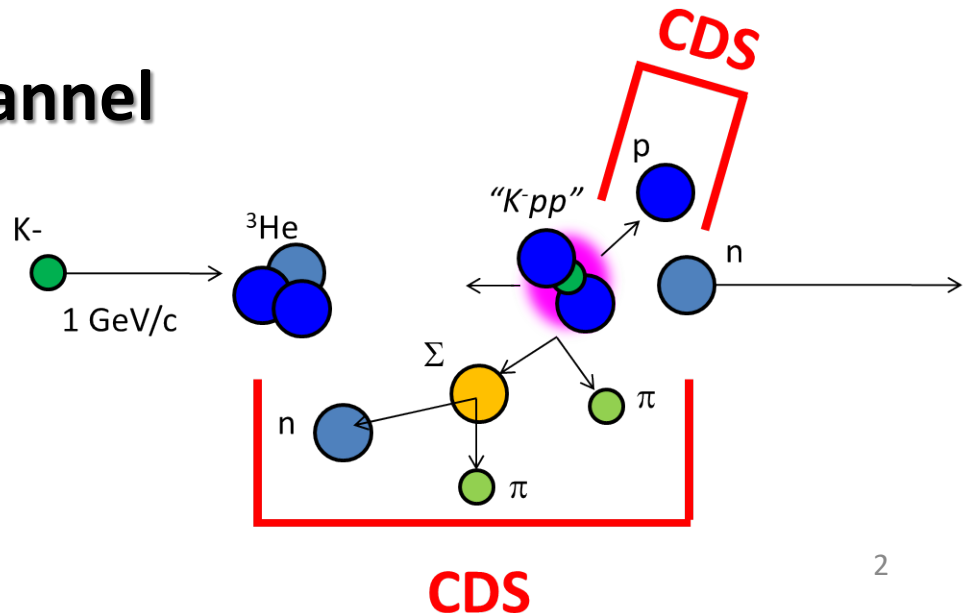
1. K^{bar} NN search via Λp channel

→ Non-mesonic channel



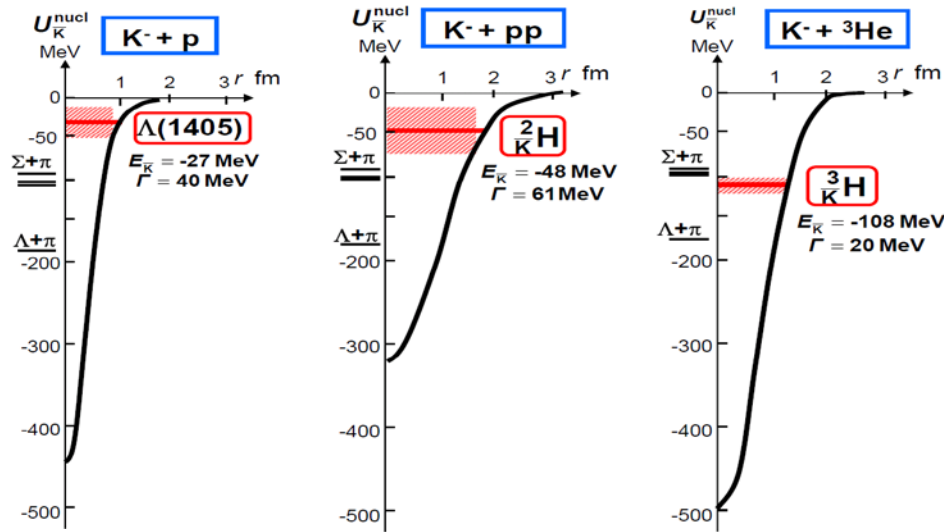
2. K^{bar} NN search via $\pi\Sigma p$ channel

→ Mesonic channel

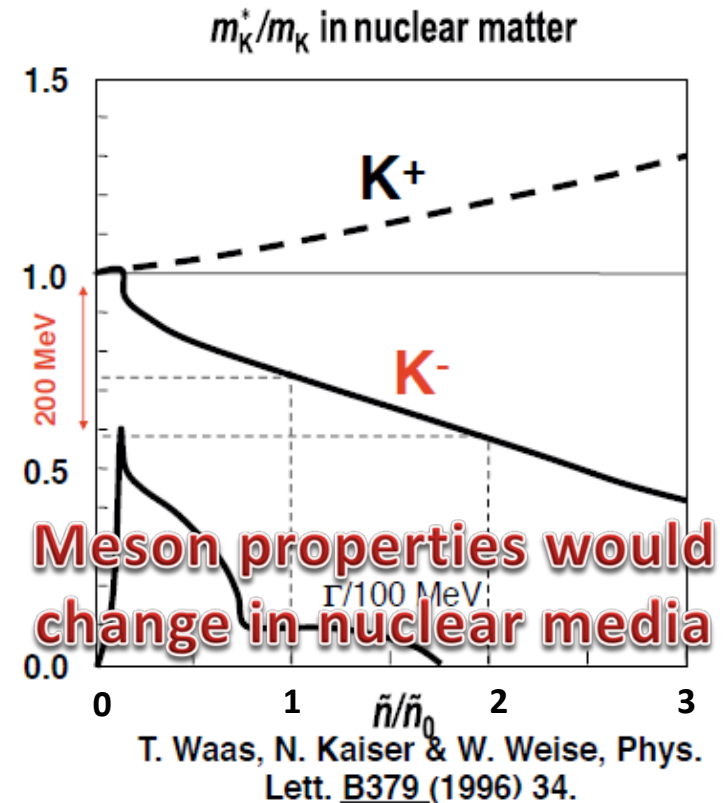


Kaonic Nuclei

- Bound states of nucleus and anti-kaon
- Predicted as a consequence of **attractive $K^{\text{bar}}N$ interaction in $l=0$**

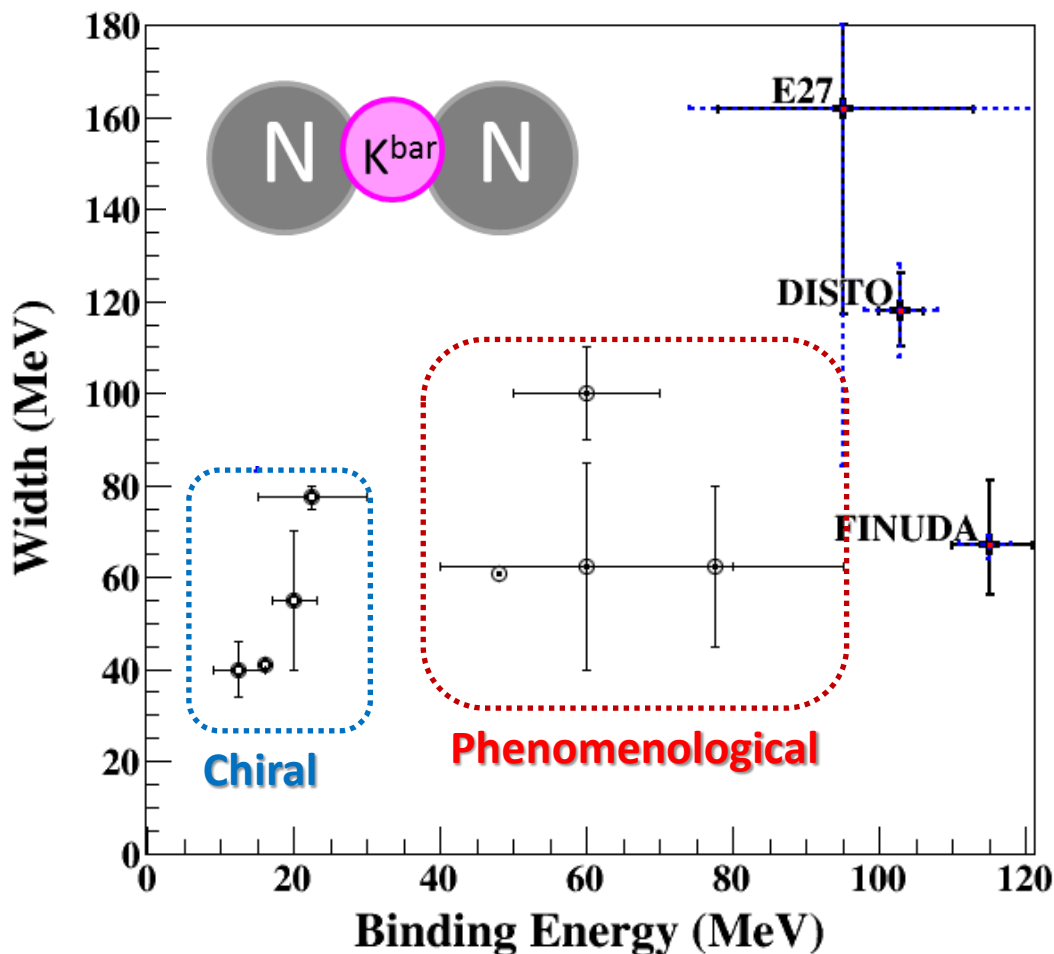


Y.Akaishi & T.Yamazaki, PLB535, 70(2002).



Will provide new insight of low energy QCD

Present Status of $\bar{K}NN$



Upper limits were also obtained:

- LEPS@SPRing8 [Inclusive $d(\gamma, K^+\pi)X$]
- HADES@GSI [Exclusive $pp \rightarrow p\Lambda K^+$]

- **Binding energy**

- Chiral:

B.E. $\sim 20\text{MeV}$

- Phenomenological:

B.E. $\sim 40\text{-}80\text{MeV}$

- FINUDA/DISTO/E27

(if $\bar{K}NN$):

B.E. $\sim 100\text{MeV}$

- **Width**

- almost agreement in $\Gamma \sim 40\text{-}100\text{MeV}$

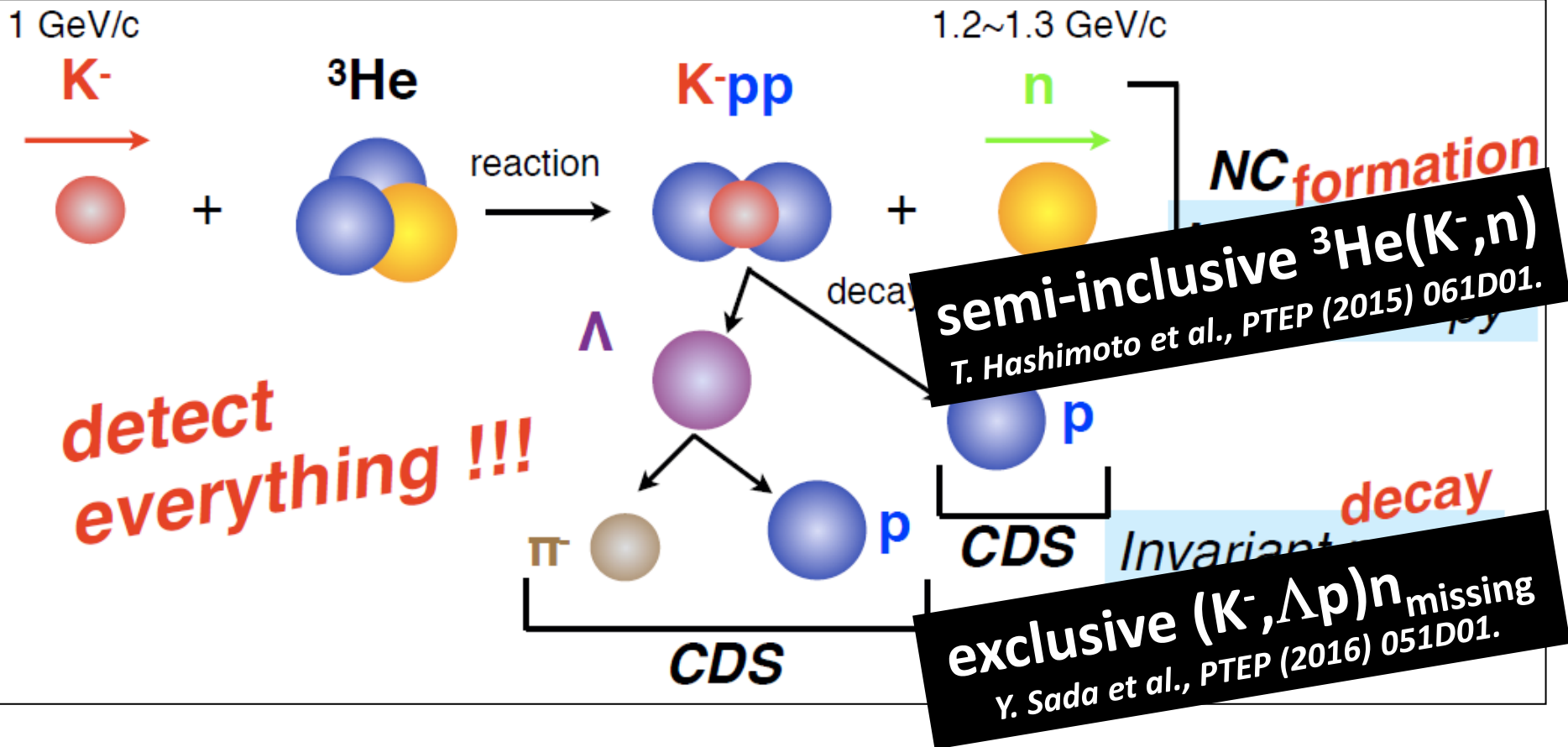
- Theor.: mesonic decay

- Exp.: non-mesonic decay

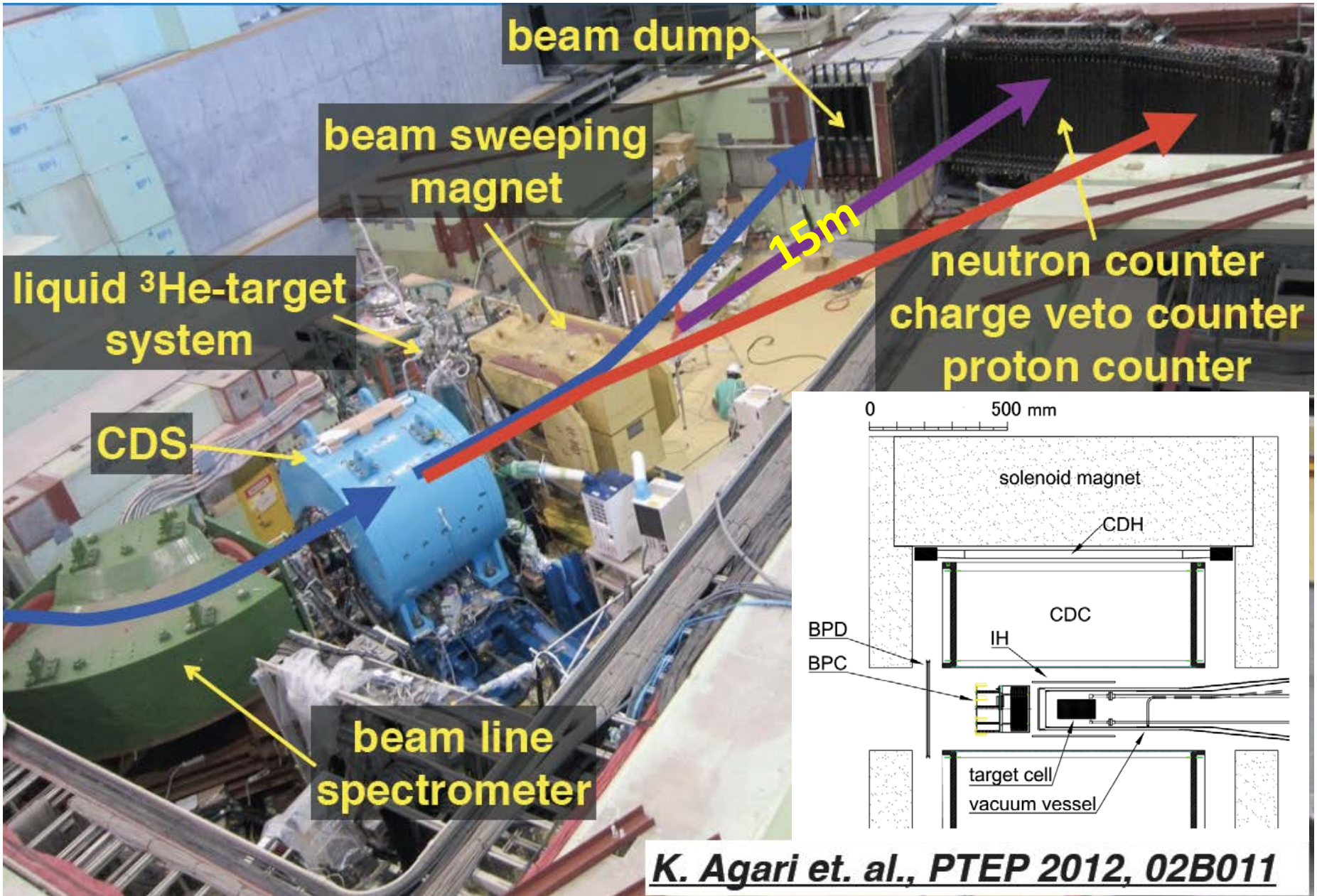
J-PARC E15 Experiment

- ${}^3\text{He}(\textit{in-flight} \text{ K}^-, \text{n})$ reaction @ 1.0 GeV/c

😊 2NA processes and Y decays can be discriminated kinematically



Experimental Setup for E15

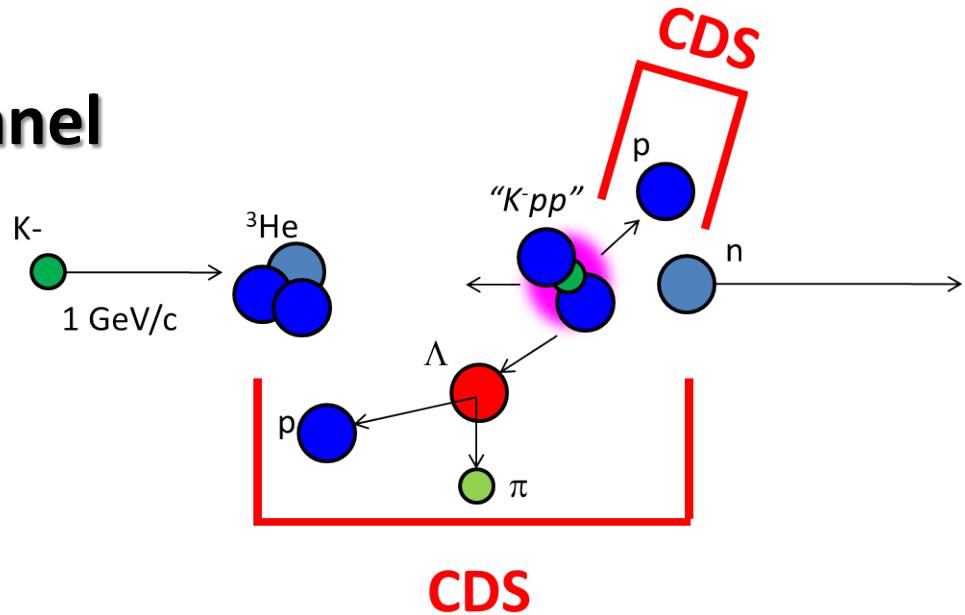


K. Aqari et. al., PTEP 2012, 02B011

Outline of the Talk

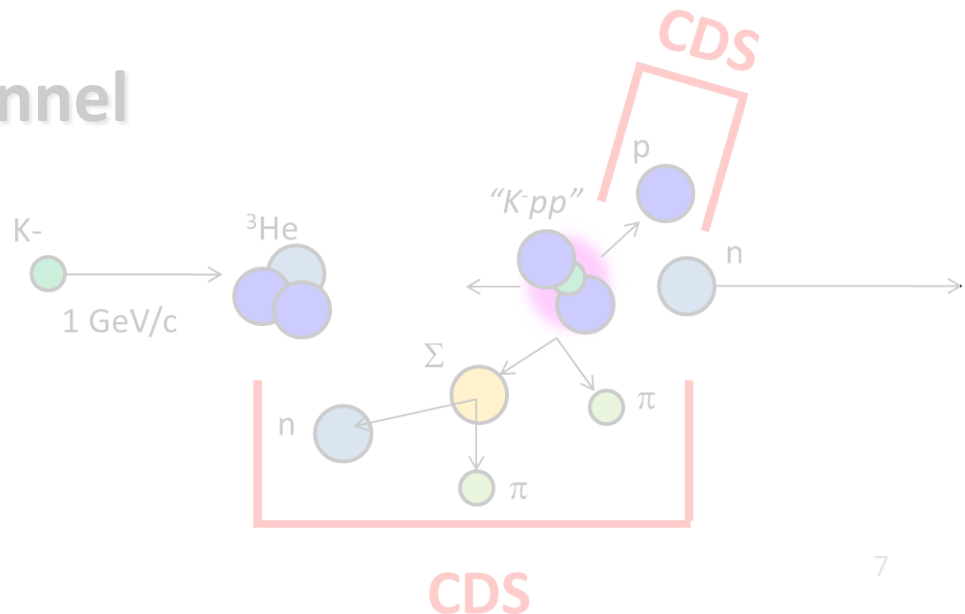
1. K^{bar} NN seach via Λp channel

→ Non-mesonic channel



2. K^{bar} NN seach via $\pi\Sigma p$ channel

→ Mesonic channel



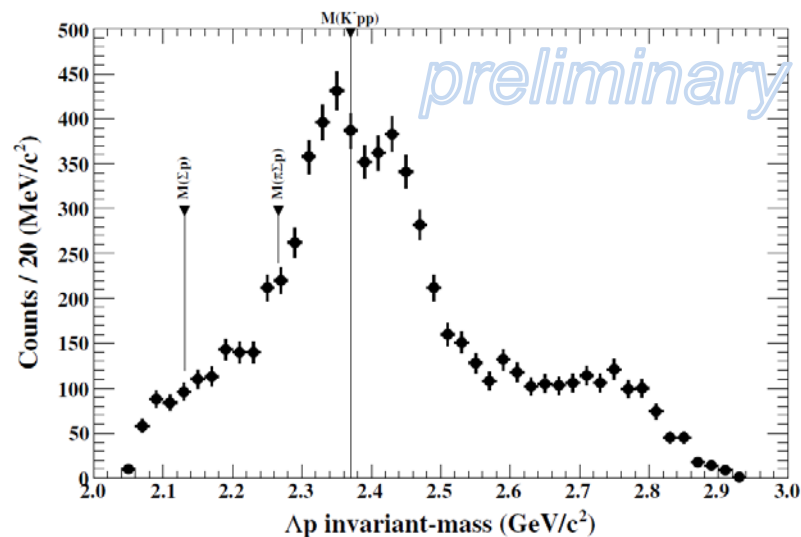
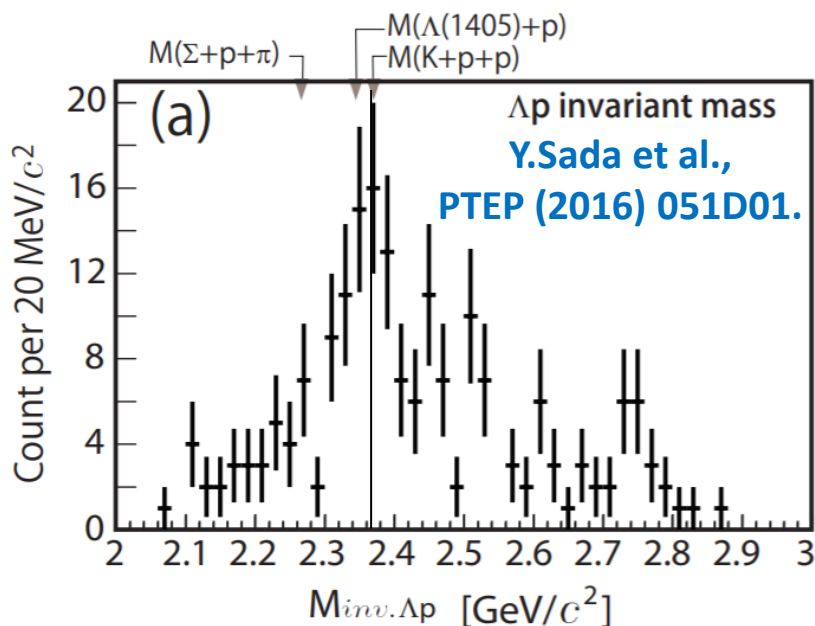
Exclusive ${}^3\text{He}(\text{K}^-, \Lambda p)\text{n}$ in E15-2nd

T.Yamaga's Ph.D work (Osaka-U)

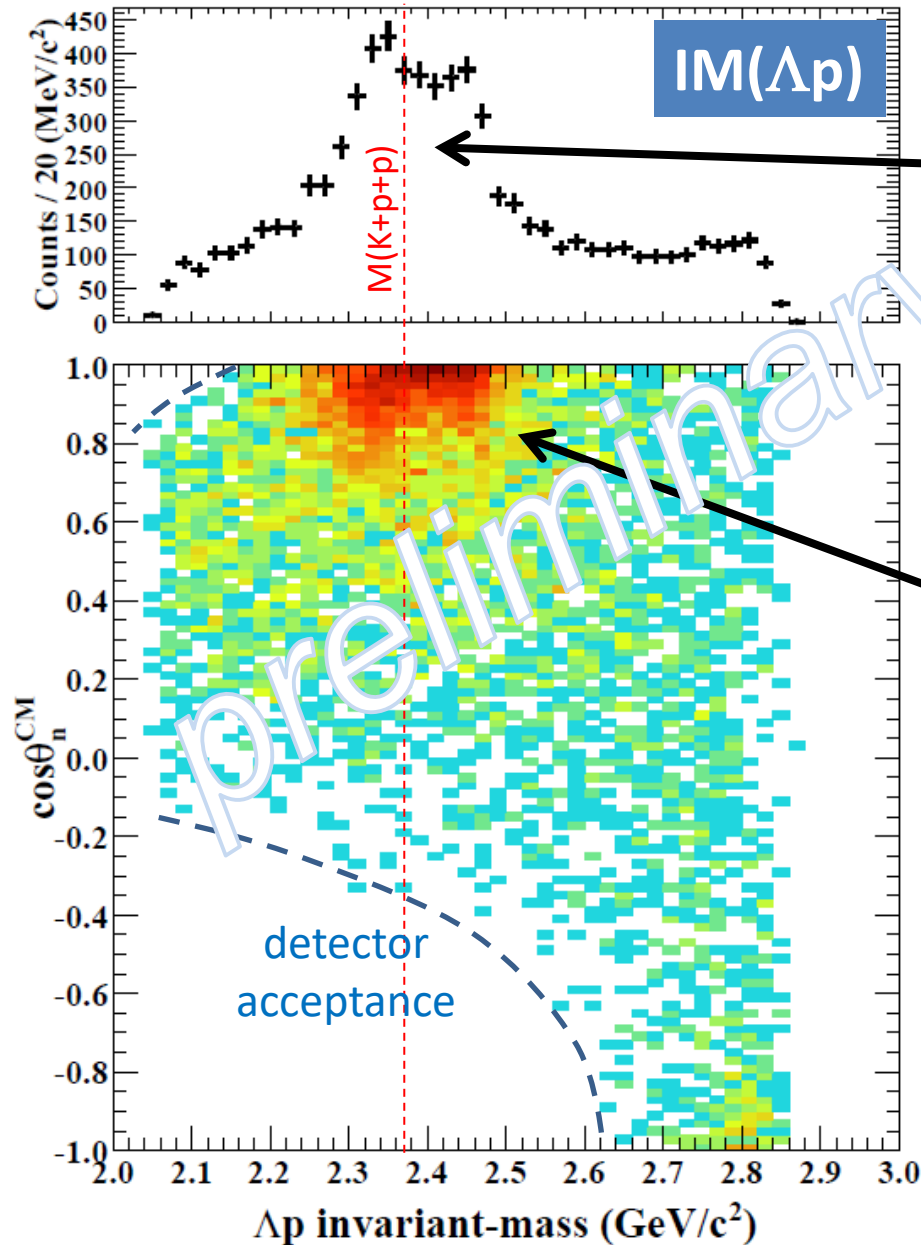
E15^{1st}

$\rightarrow \sim 30$ times more data*

E15^{2nd}



Exclusive ${}^3\text{He}(\text{K}^-, \Lambda p)n$ [E15-2nd]

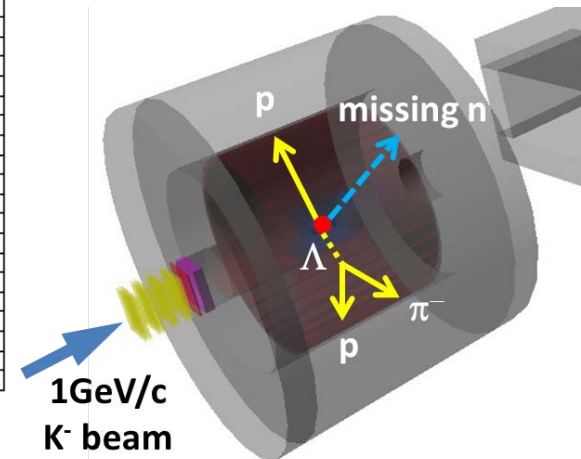


Structures around the Kpp threshold can be seen
= **bound-state + QF**

Counts / 0.02
200 400 600

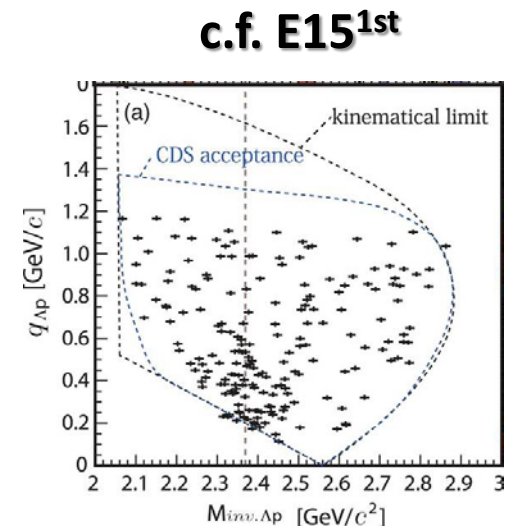
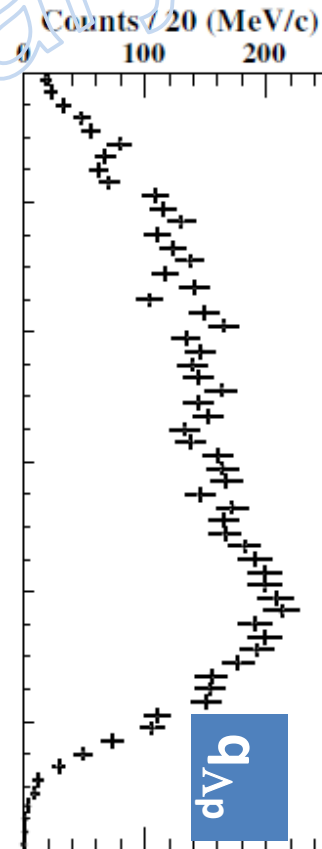
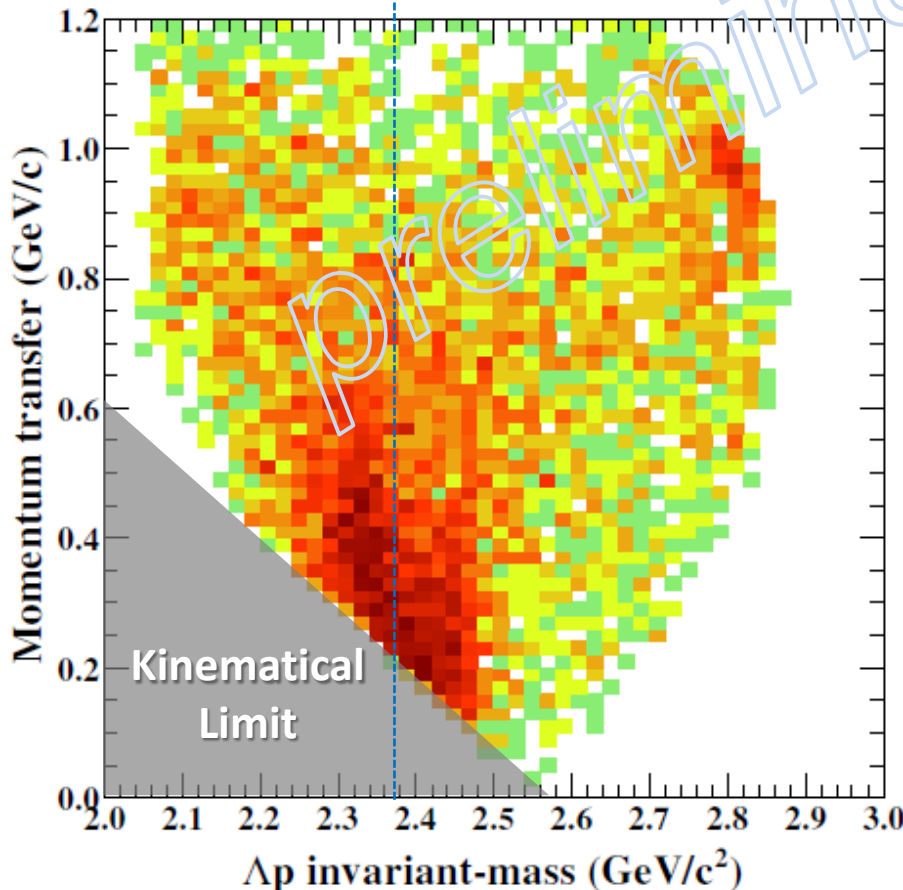
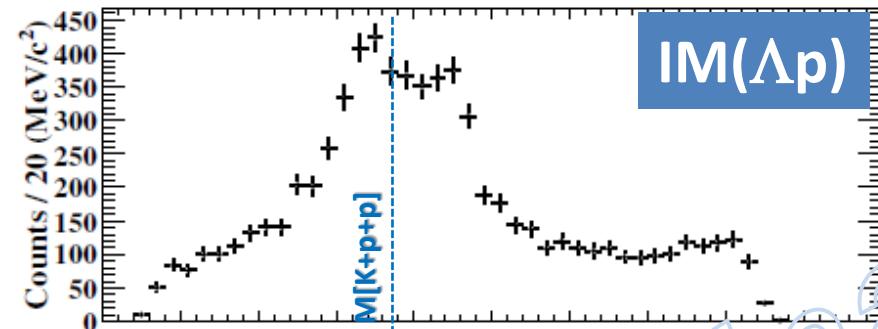
Structures are concentrated
in forward-n region
= **small momentum-transfer**

$\cos(\theta_n)$



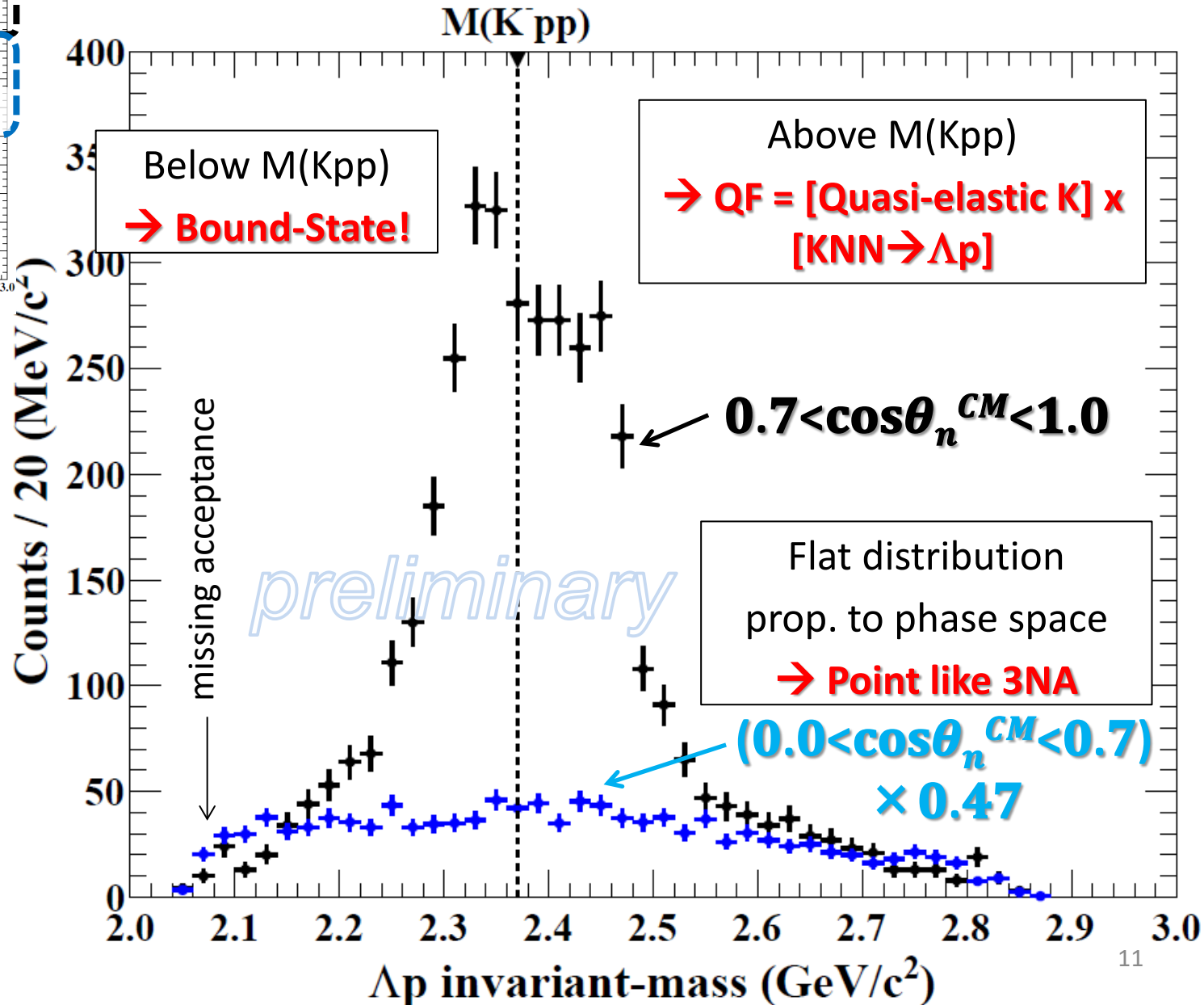
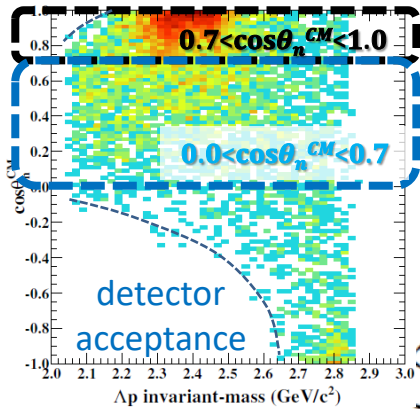
Momentum Transfer

Momentum transfer ranges
from ~ 300 to ~ 600 MeV/c
for sub-threshold structure

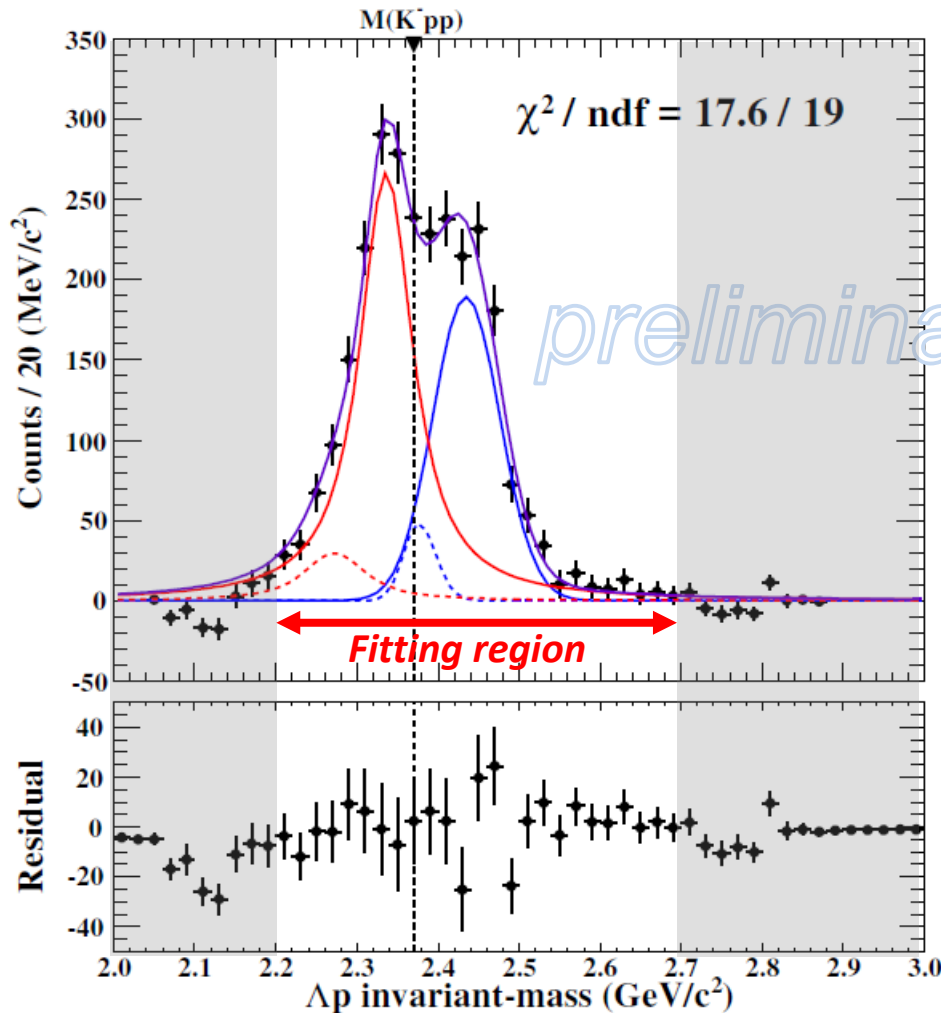


Consistent with E15^{1st}

Structures in Forward-n Region



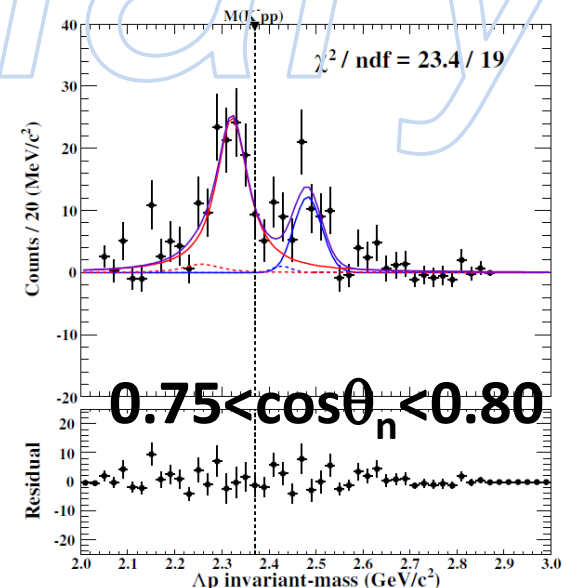
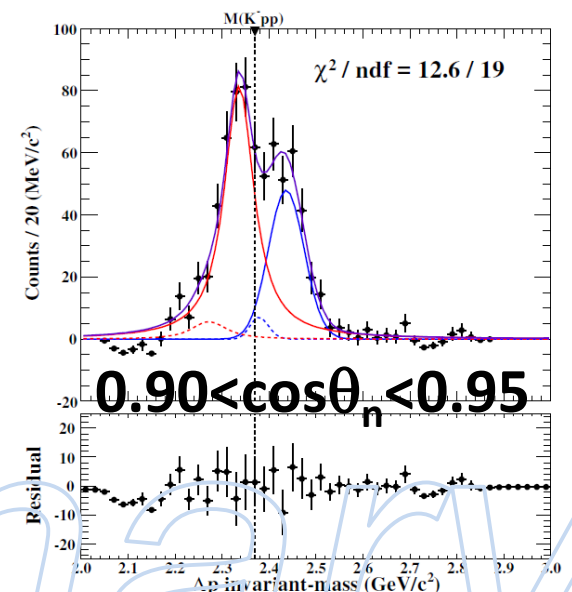
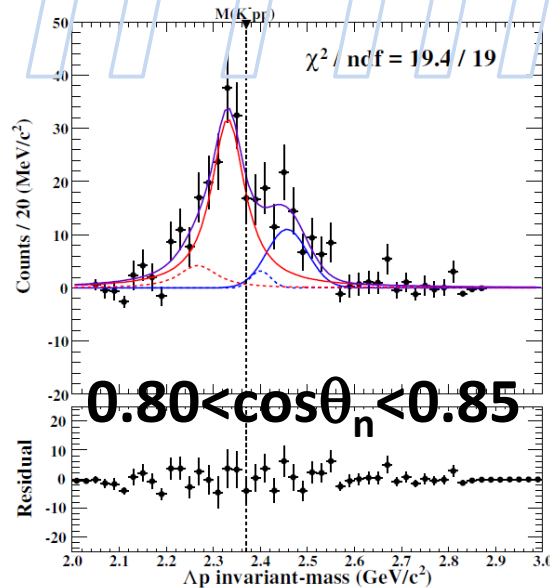
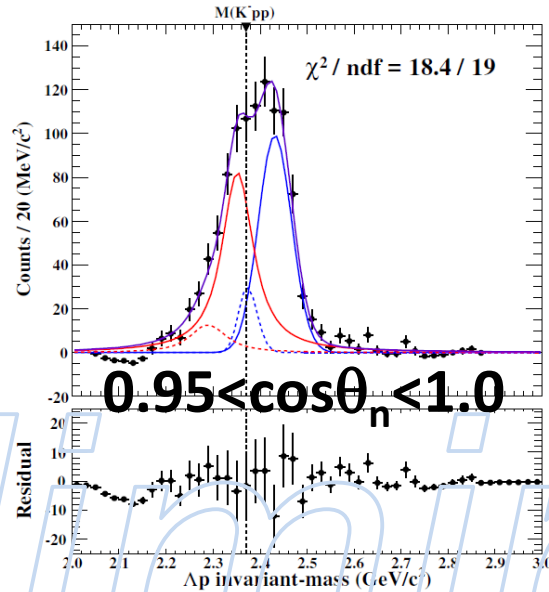
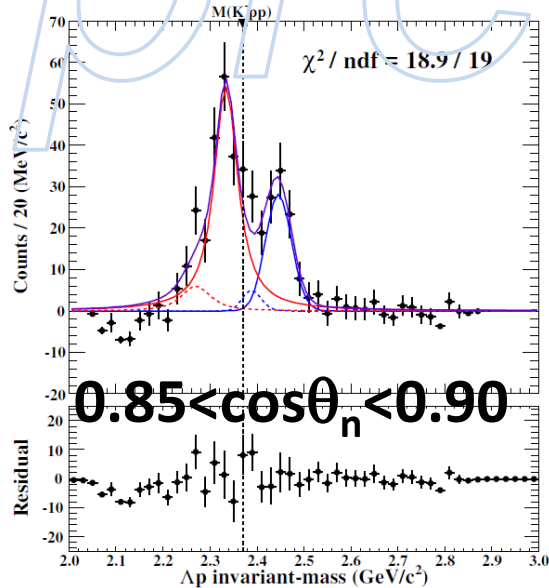
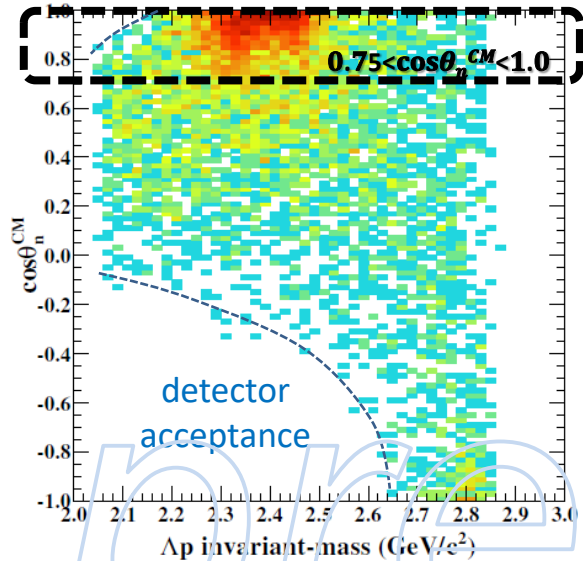
Fitting with BW and Gaussian



- Simple fitting after BG subtraction
 - **BS: Breit-Wigner**
 - QF: Gaussian
 - w/ $\Sigma^0 p$ contamination
 - ← Fermi-mom. Eff.
 - ← from $MM(^3\text{He}(K^-, \Lambda p)X)$
- Fit values that reproduce the spectrum
 - B.E $\sim 35 \text{ MeV}/c^2$
 - $\Gamma \sim 75 \text{ MeV}/c^2$

Sliced by Reaction Angle

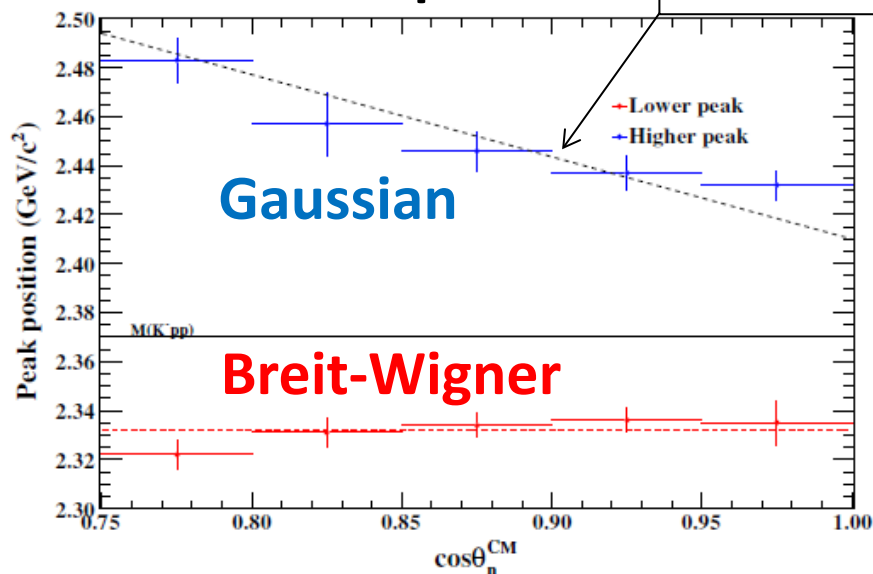
$\cos\theta_n$ dependence



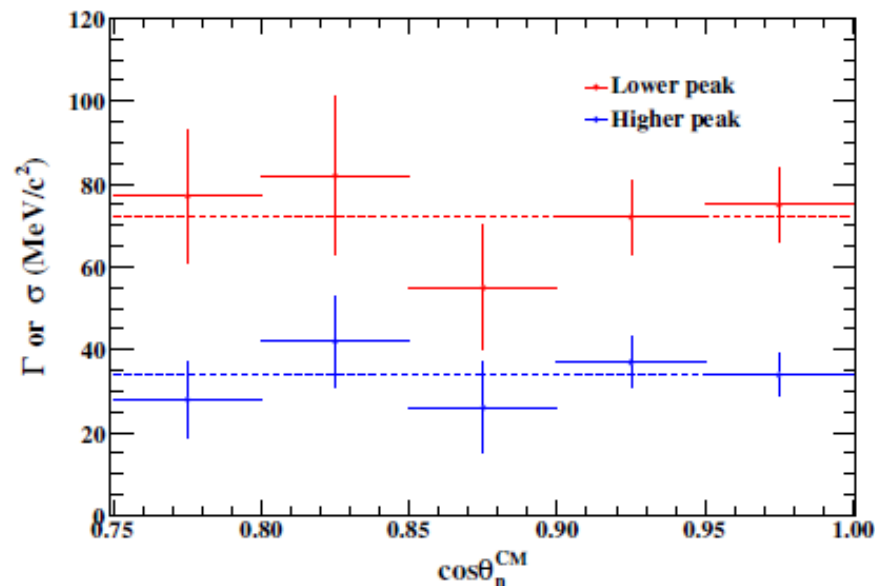
Reaction Angle Dependence

Peak position

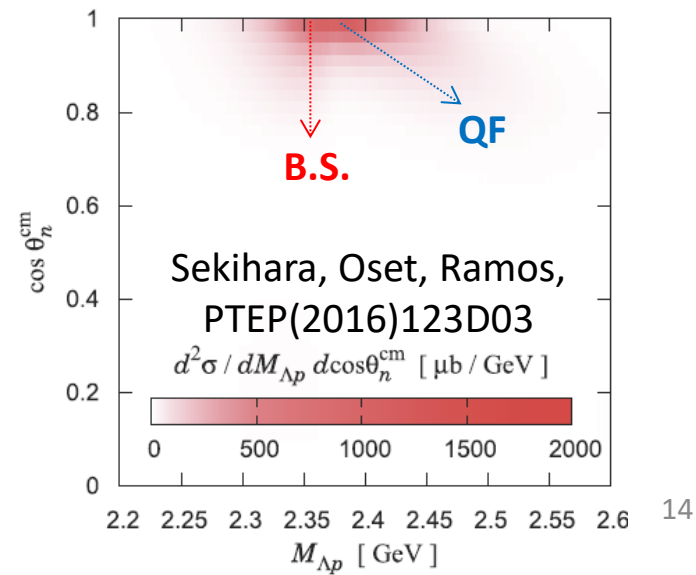
$$M_{QF} = M_{K^-pp} + \frac{q^2}{2M_{K^-}}$$



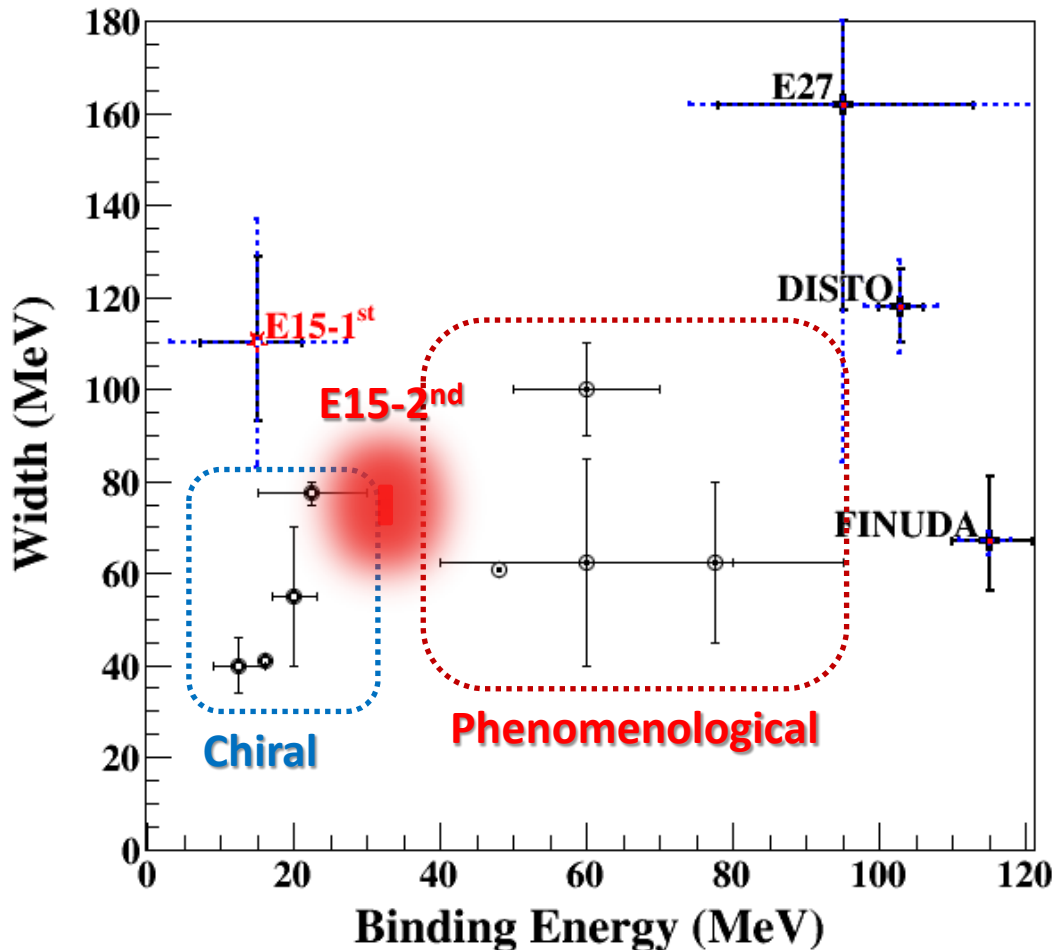
Width



- Above $M(K^-pp)$:
 - peak shift by recoil kaon energy
- Below $M(K^-pp)$:
 - peak is independent of $\cos\theta_n \sim q_{\Lambda p}$
 - would be $S=-1$ di-baryon
- Similar tendency as in a theoretical calculation



Present Status of $K^{\text{bar}}\text{NN}$



● Exp. CANDIDATES

– *Upper limit*

- LEPS/HADES

– *B.E. ~ 10-40 MeV*

- E15

– *B.E. ~ 100 MeV*

- FINUDA/DISTO/E27

● Theor. calculations.

- Difficult to reproduce deeply bound state using normal $K^{\text{bar}}\text{N}$ int.

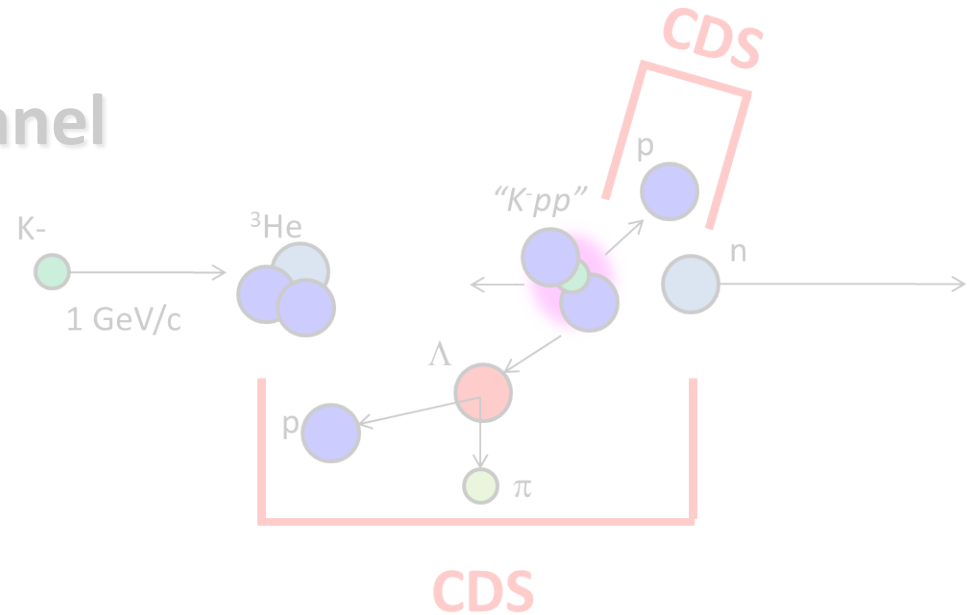
For further understanding:

- ✓ $\Lambda(1405)$ production → $\Lambda^*\text{N}$ doorway
- ✓ $\pi\Sigma\text{N}$ decay channel → new info. of $K^{\text{bar}}\text{NN}$

Outline of the Talk

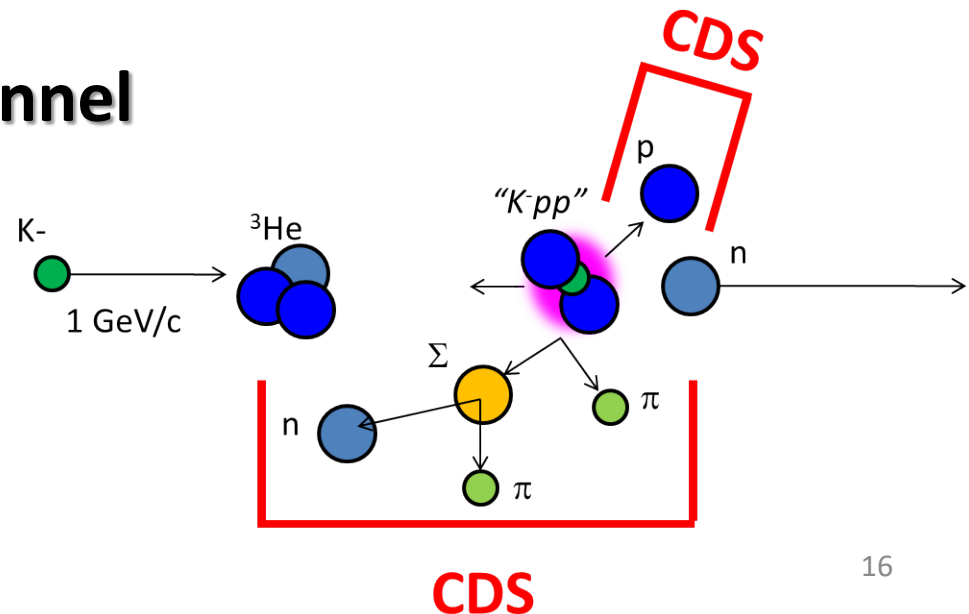
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→ Non-mesonic channel



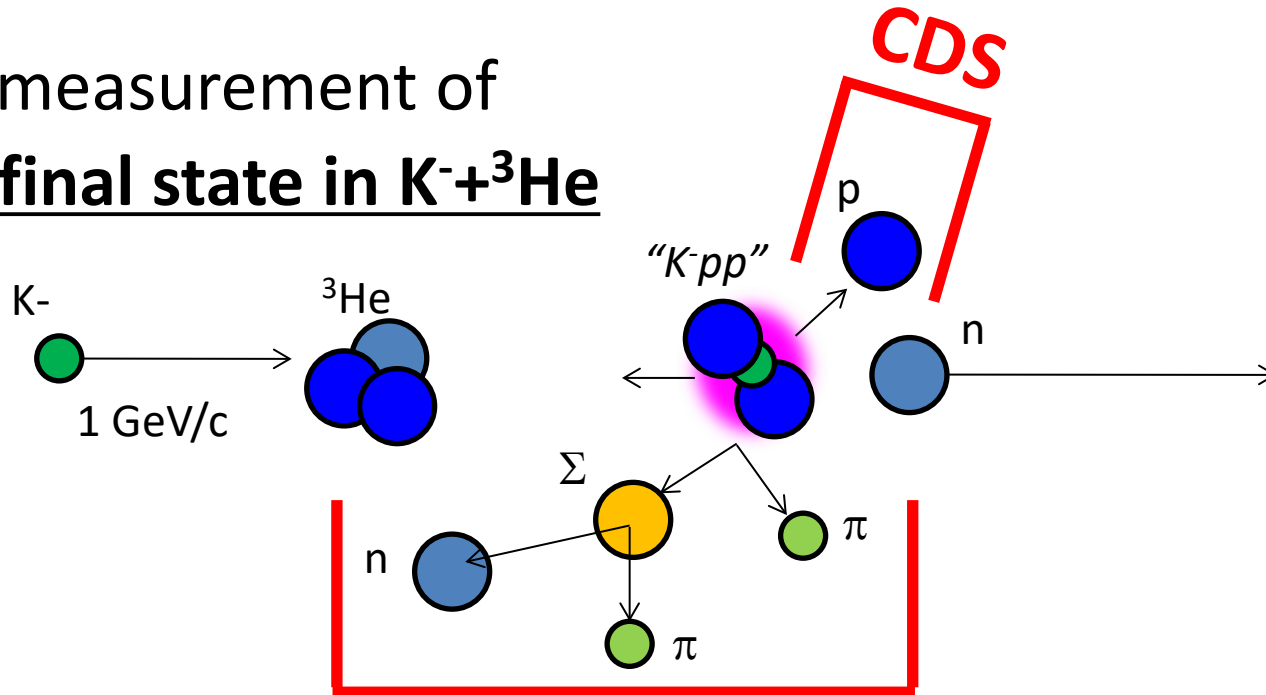
2. K^{bar} NN seach via $\pi\Sigma p$ channel

→ Mesonic channel



$K^- {}^3\text{He} \rightarrow \pi \Sigma pn$ @ E15

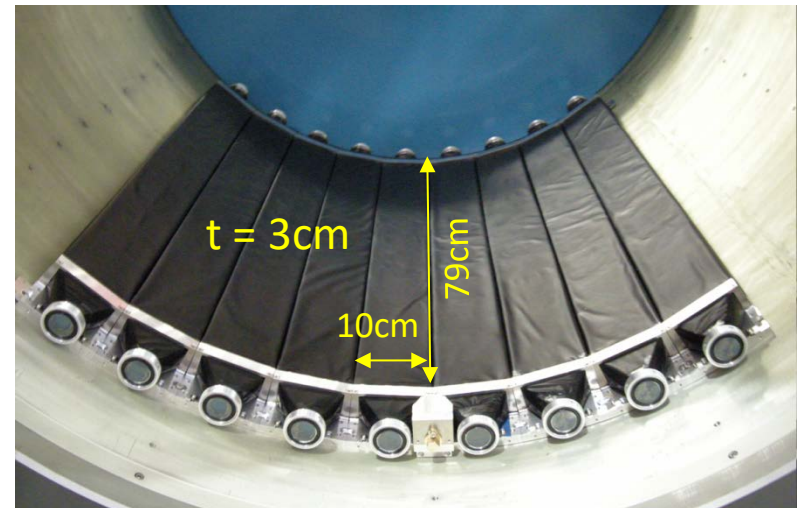
- Exclusive measurement of $\pi^\pm \Sigma^\mp pn$ final state in $K^- + {}^3\text{He}$



CDS

- Experimental challenge of neutron detection with thin scintillation counter ($t=3\text{cm}$)

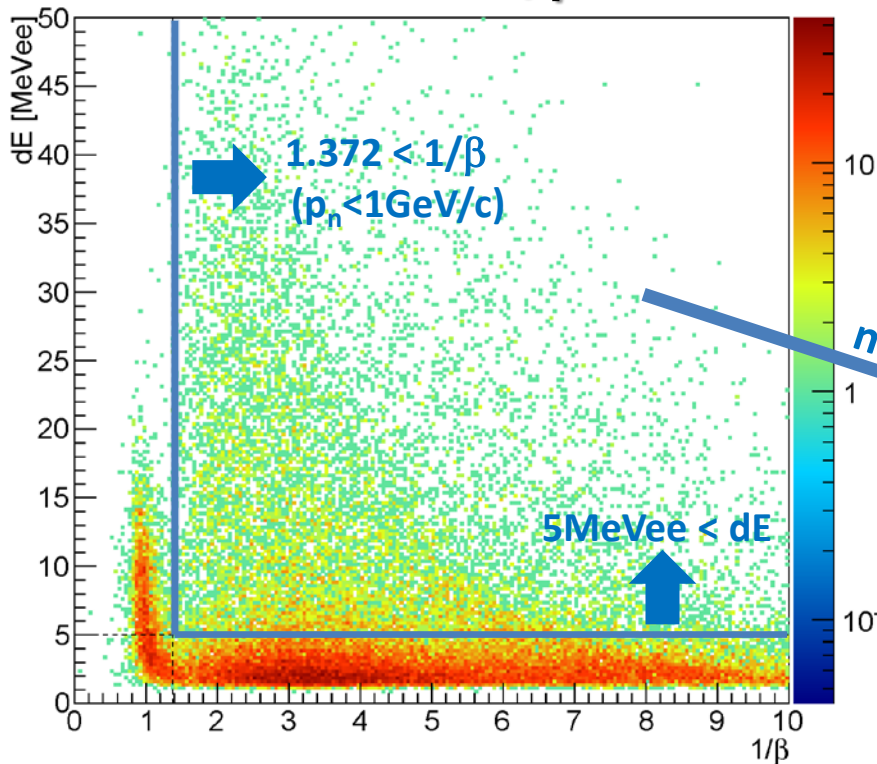
n detection efficiency $\sim 3\%$



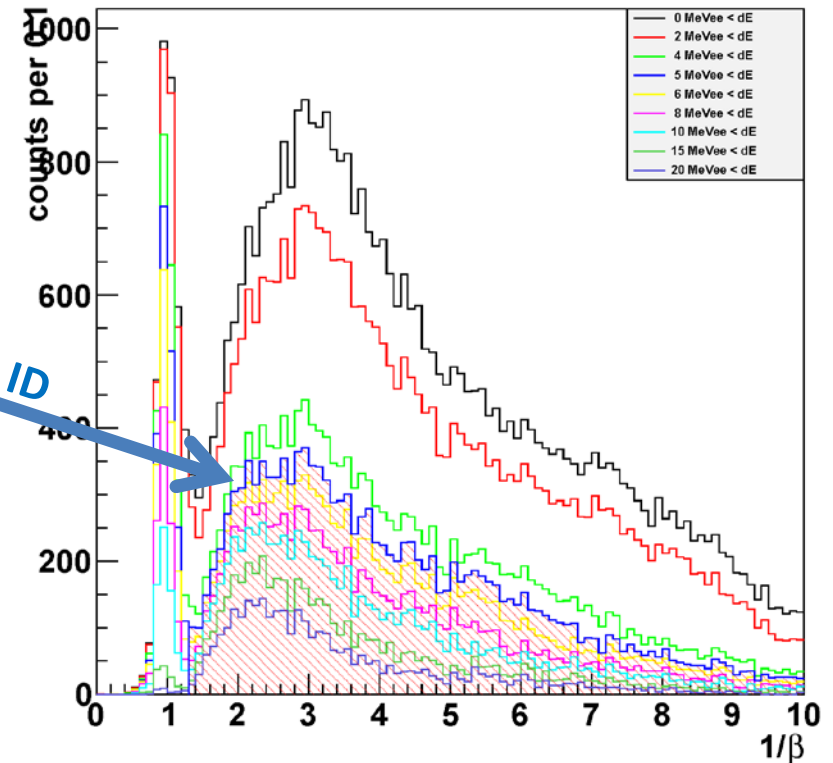
Neutron ID with CDS

- $\pi^+\pi^-p$ events (3 tracks) in CDS with 4 CDH hits are selected
- a CDH hit with CDC-veto (outer-layer) is applied to identify the “neutral hit”

dE vs. $1/\beta$

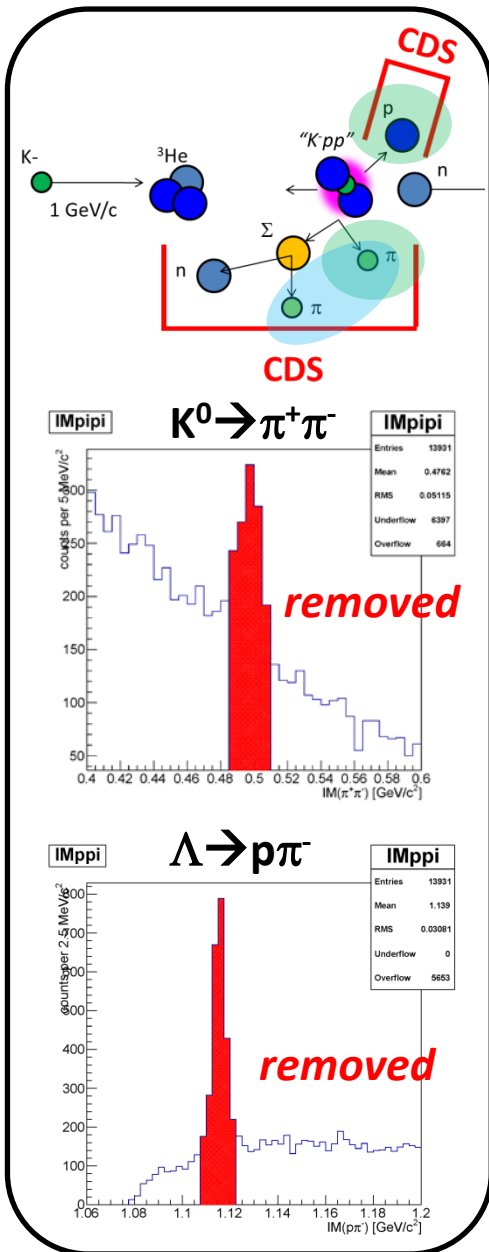


dE-cut dependence

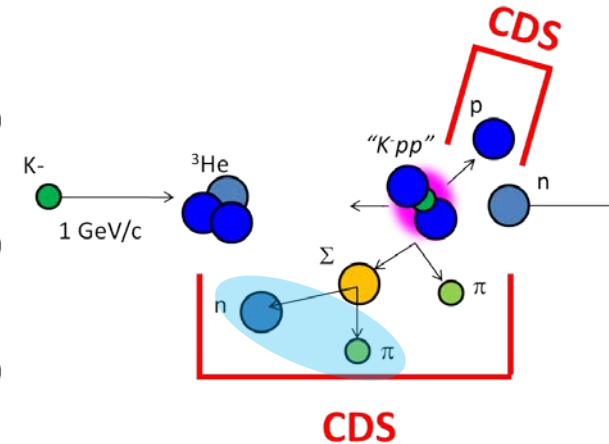
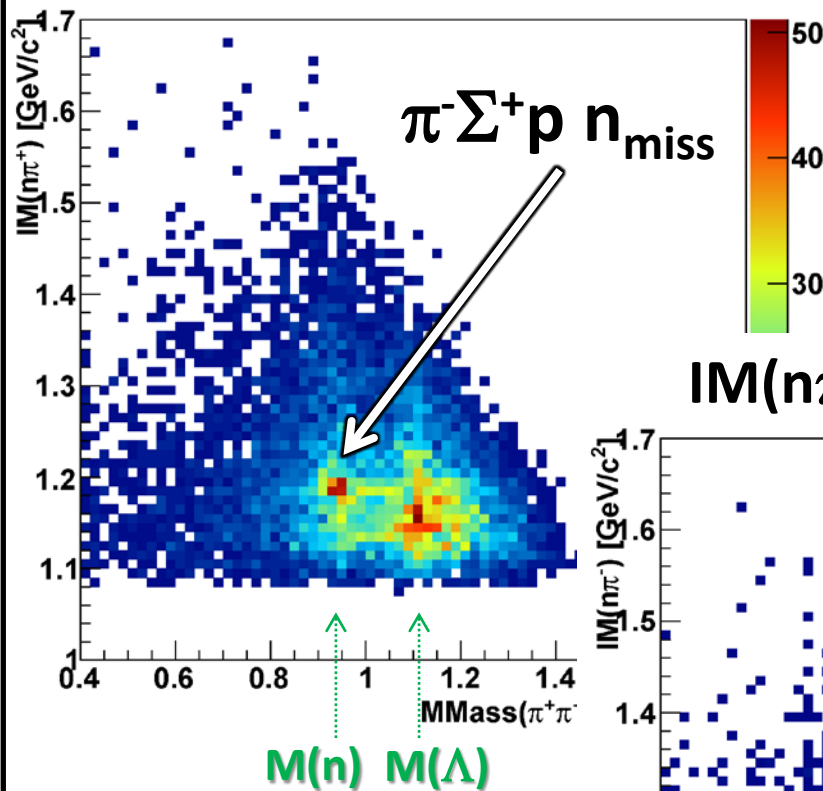


Neutron can be identified with CDS

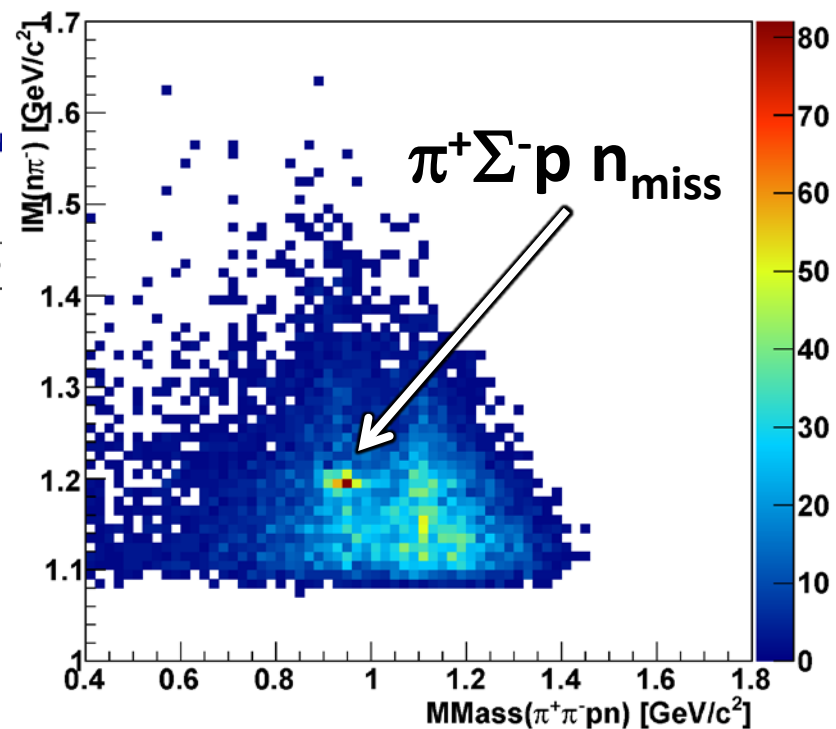
$\pi\Sigma pn$ Events



IM($n\pi^+$) vs MM($\pi^+\pi^-pn$)



IM($n\pi^-$) vs MM($\pi^+\pi^-pn$)



IM($n\pi^+\pi^-$) vs MM($\pi^+\pi^-pn$)



$\pi^\pm \Sigma^\mp p n_{\text{miss}}$ Final-State $[\text{IM}(\pi^\pm \Sigma^\mp)]$

Event Selection

Missing n:

$$0.85 < \text{MM}(\pi^+ \pi^- p n) < 1.03 \text{ GeV}/c^2$$

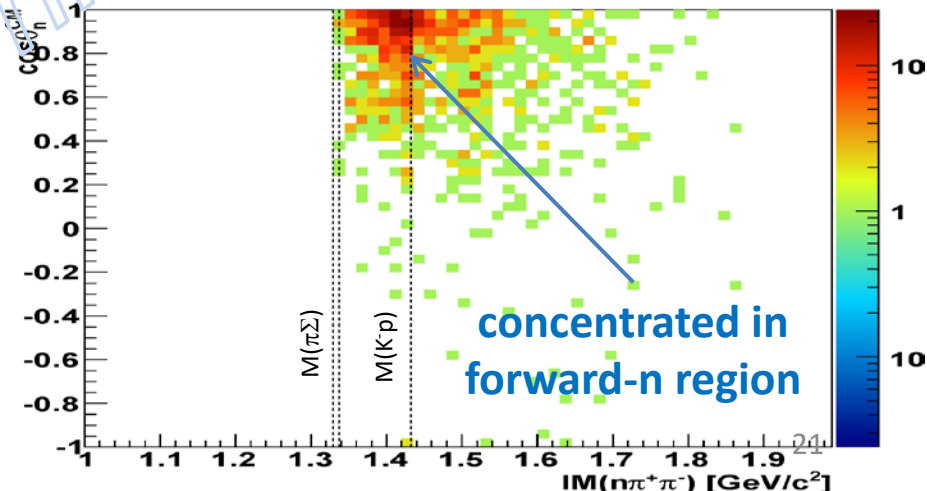
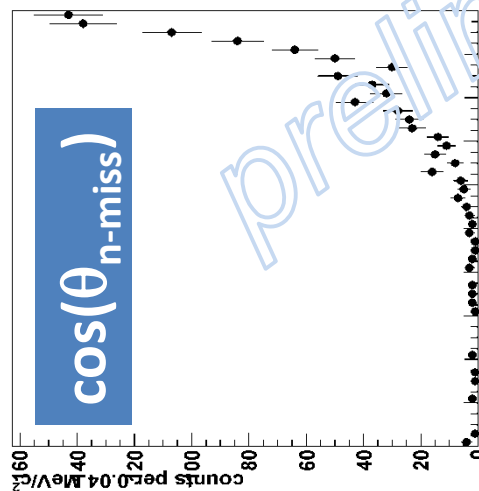
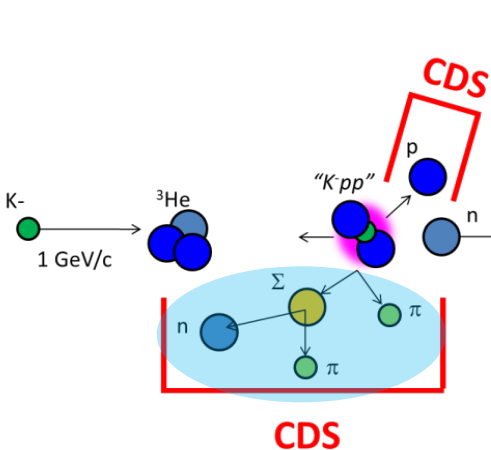
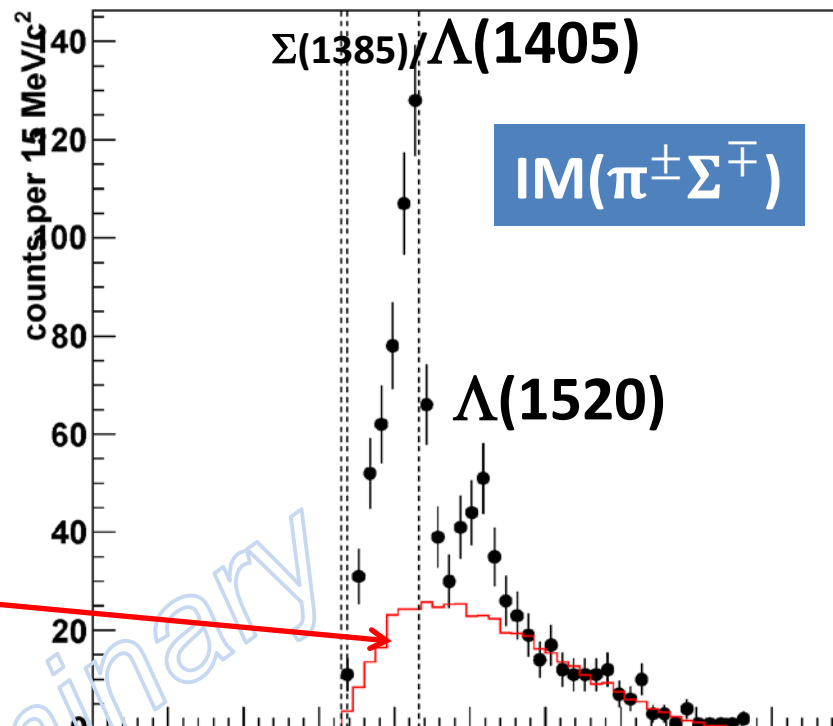
Σ mass:

$$1.18 < \text{IM}(n\pi^-) < 1.20 \text{ GeV}/c^2 \text{ for } \Sigma^-$$

$$1.19 < \text{IM}(n\pi^+) < 1.21 \text{ GeV}/c^2 \text{ for } \Sigma^+$$

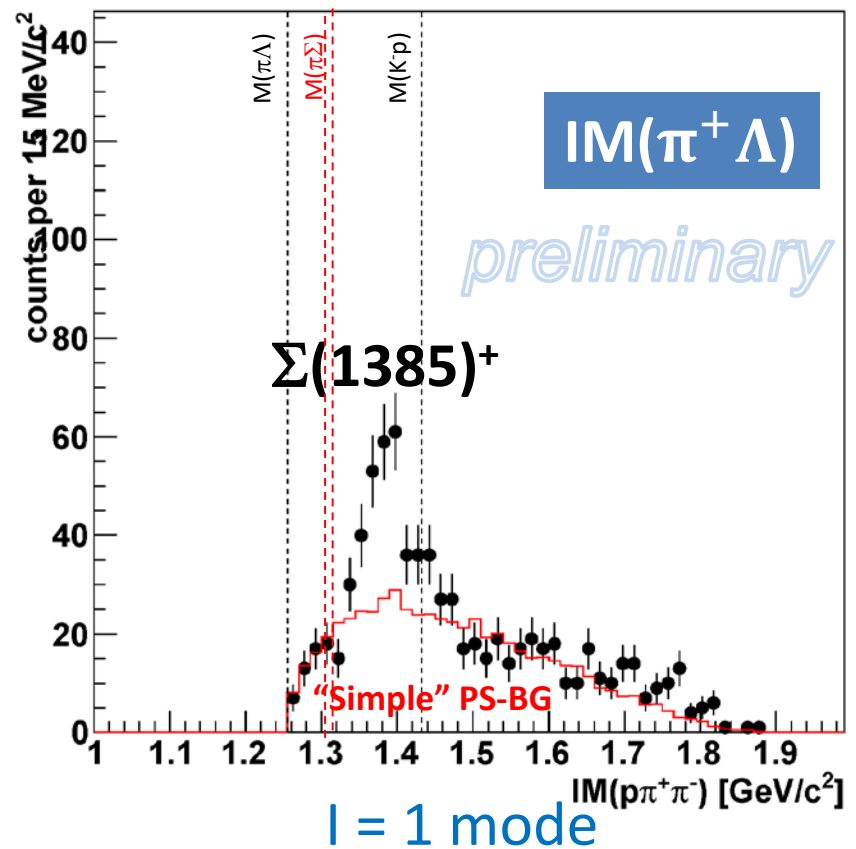
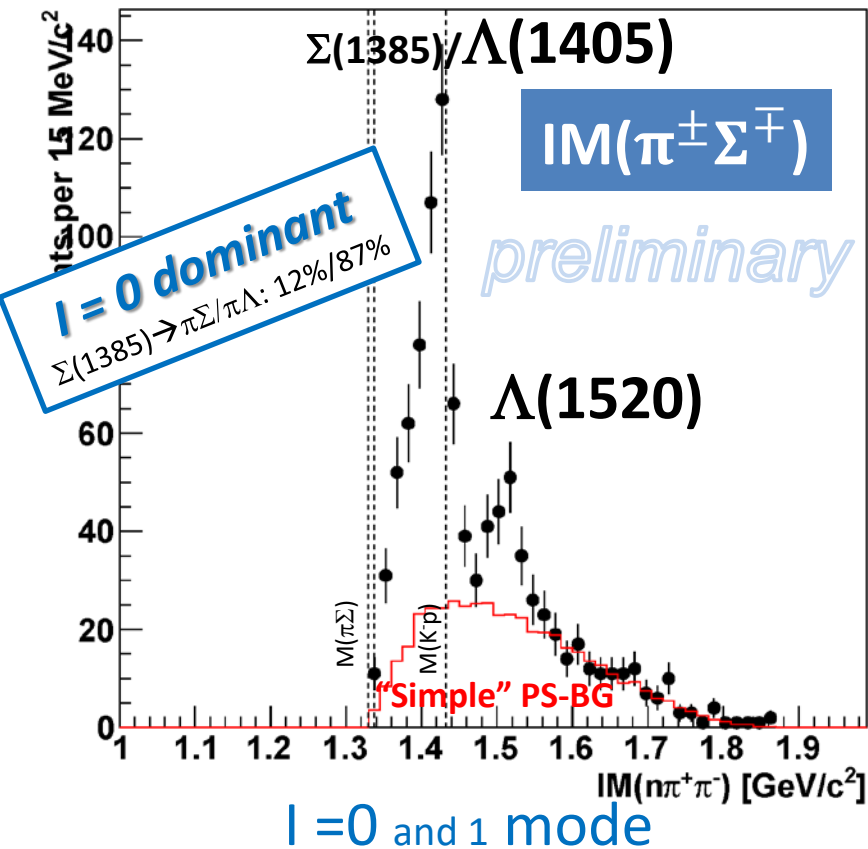
"Simple" PS-Background

$\pi^\pm \Sigma^\mp p n$ phase-space with the detector acceptance



$(\pi^\pm \Sigma^\mp) p n_{\text{miss}}$ vs. $(\pi^+ \Lambda) n n_{\text{miss}}$

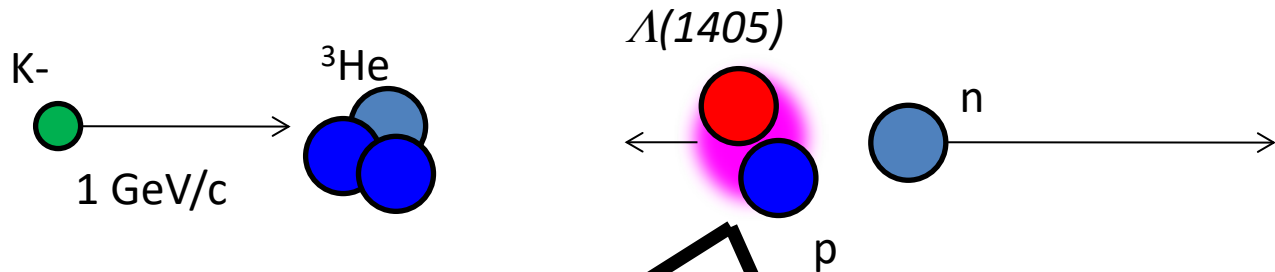
$\pi^+ \Lambda n n_{\text{miss}}$ final state was obtained as with $\pi^\pm \Sigma^\mp p n_{\text{miss}}$



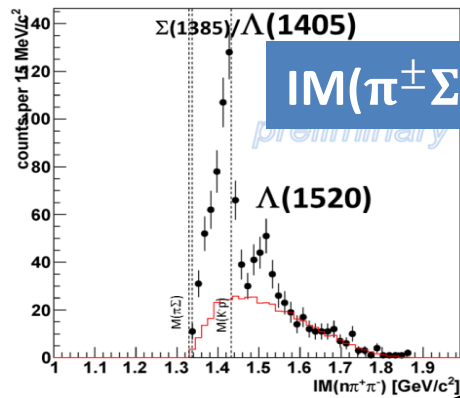
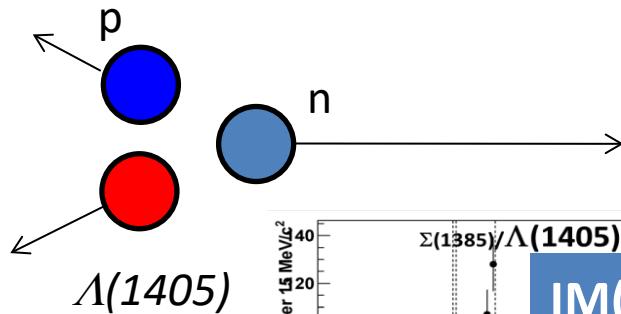
Discrimination of $\Lambda(1405)$ and $\Sigma(1385)$ is under way

→ Careful investigation of the backgrounds is needed

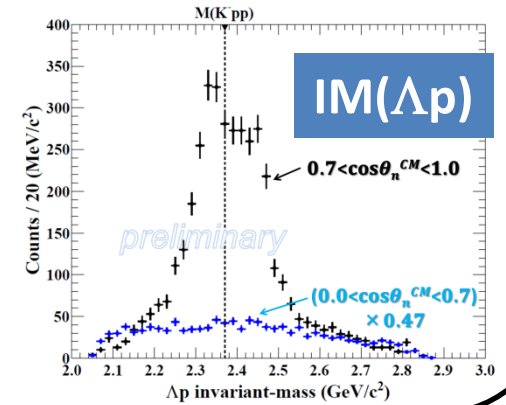
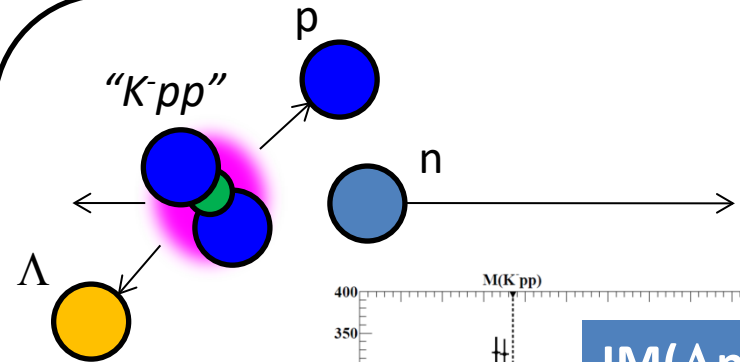
Production of Λ^* and “K-pp”



“free” Λ^*



“K-pp” formation

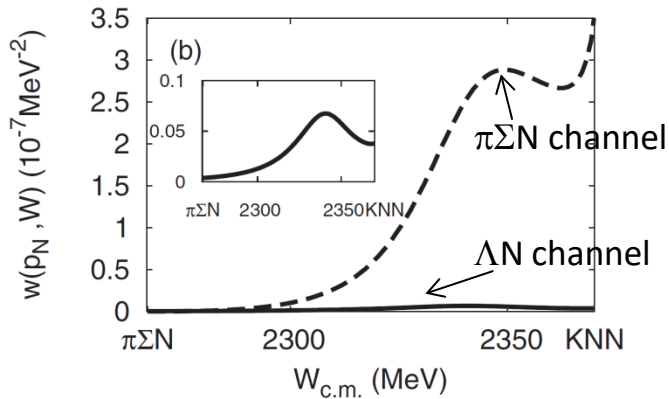


Comparison of each CS would give us important hints!

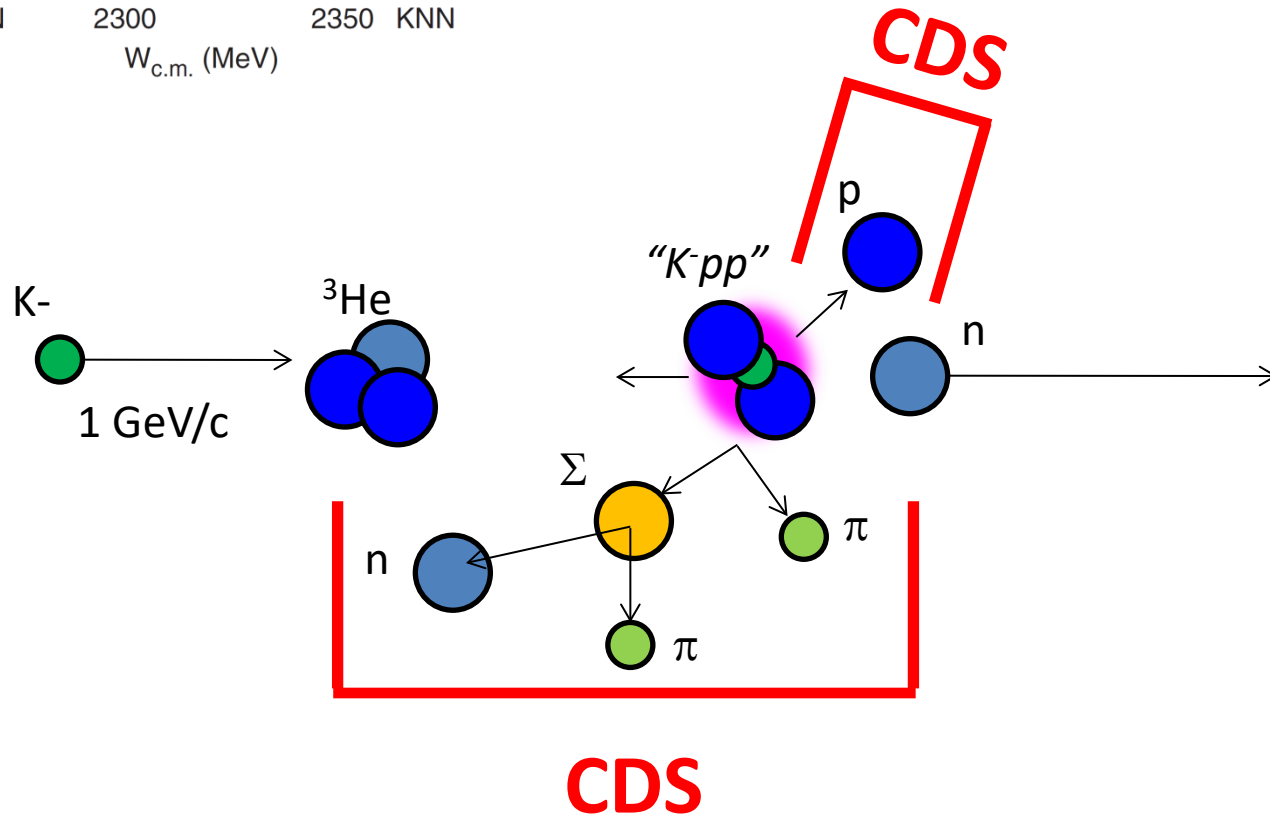
“K⁻pp” → $\pi\Sigma N$ Decay Channel

kaon absorption probability
of $\Lambda^* N \rightarrow \pi\Sigma N / \Lambda N$

S.Ohnish et al., PRC88(2013)025204



Theoretically,
 $\pi\Sigma N$ decay is expected to be
the dominant channel



$\pi^\pm \Sigma^\mp p n_{\text{miss}}$ Final-State $[\text{IM}(\pi^\pm \Sigma^\mp p)]$

Event Selection

Missing n:

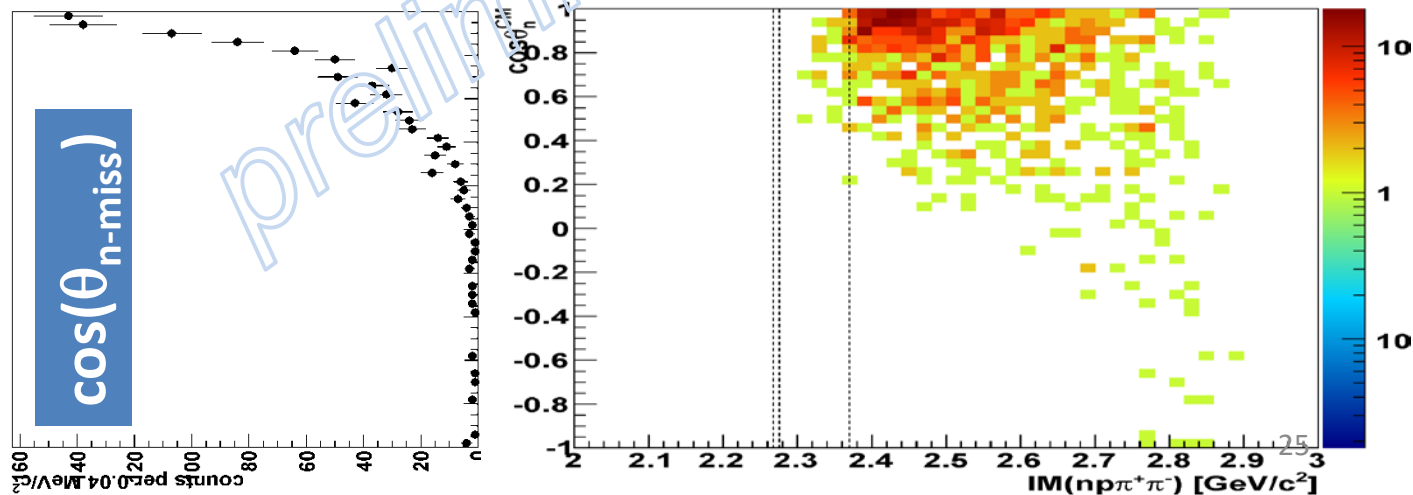
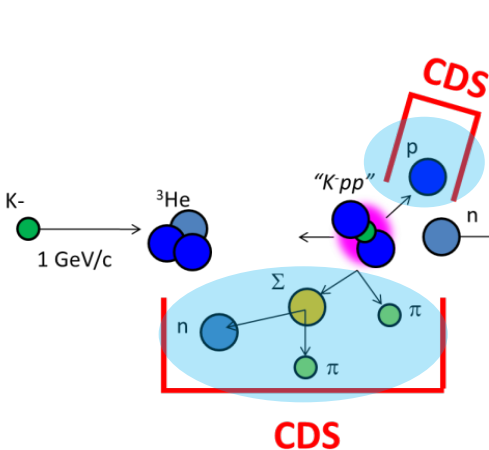
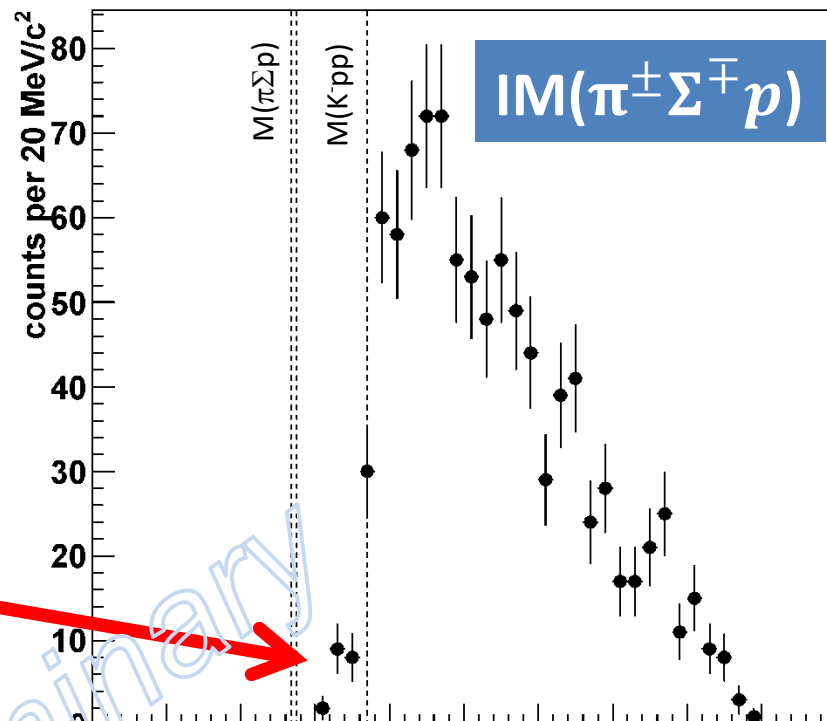
$$0.85 < \text{MM}(\pi^+ \pi^- p n) < 1.03 \text{ GeV}/c^2$$

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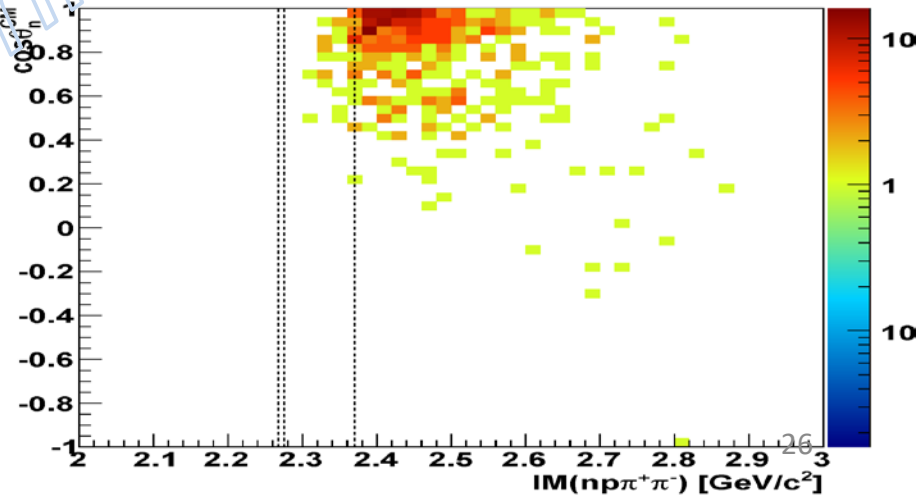
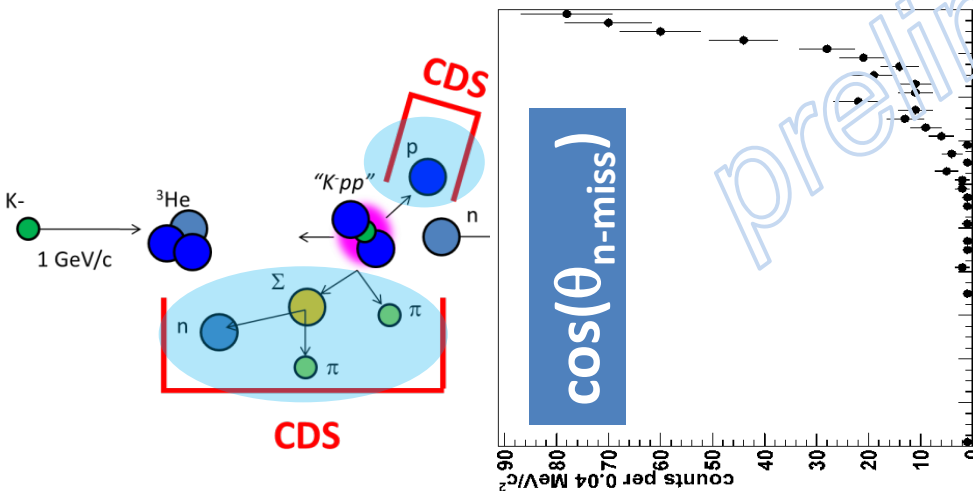
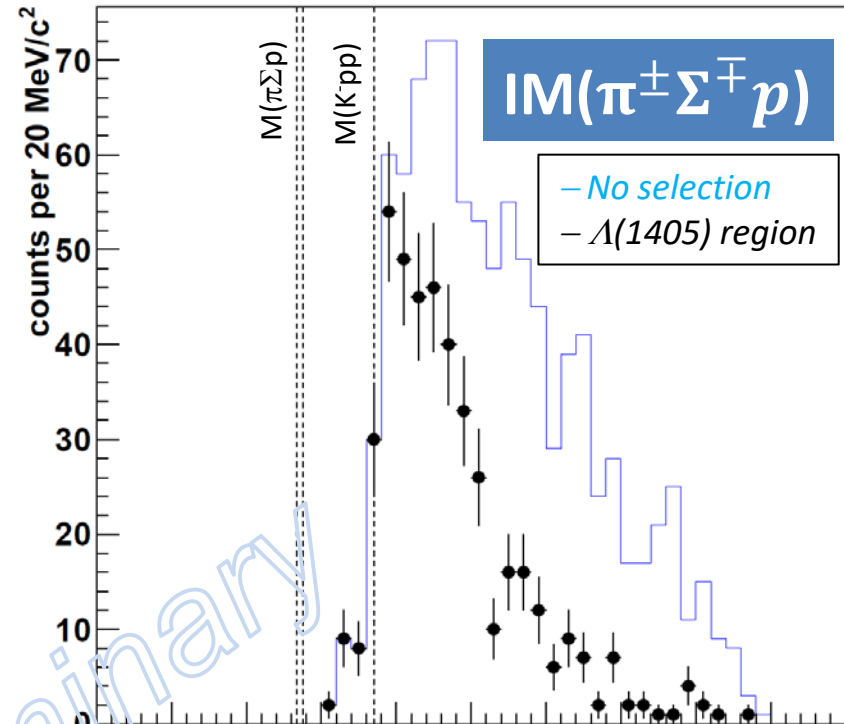
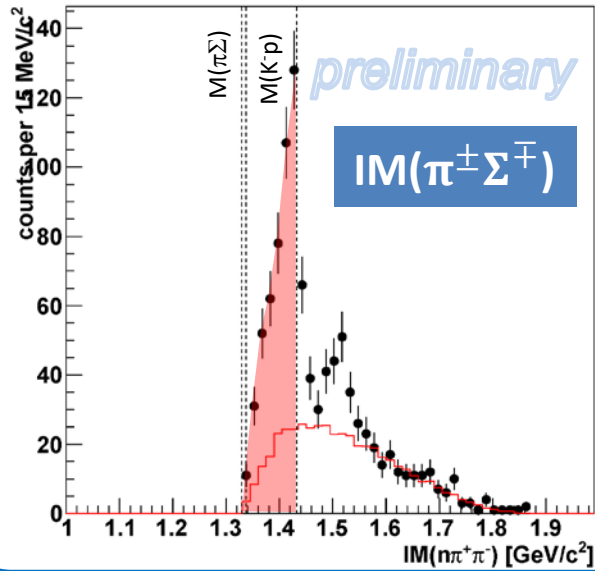
$$1.19 < \text{IM}(n\pi^+) < 1.21 \text{ GeV}/c^2 \text{ for } \Sigma^+$$

**Subthreshold events
seem to be suppressed!**



$\pi^\pm \Sigma^\mp p$ n_{miss} in $\Lambda(1405)$ Region

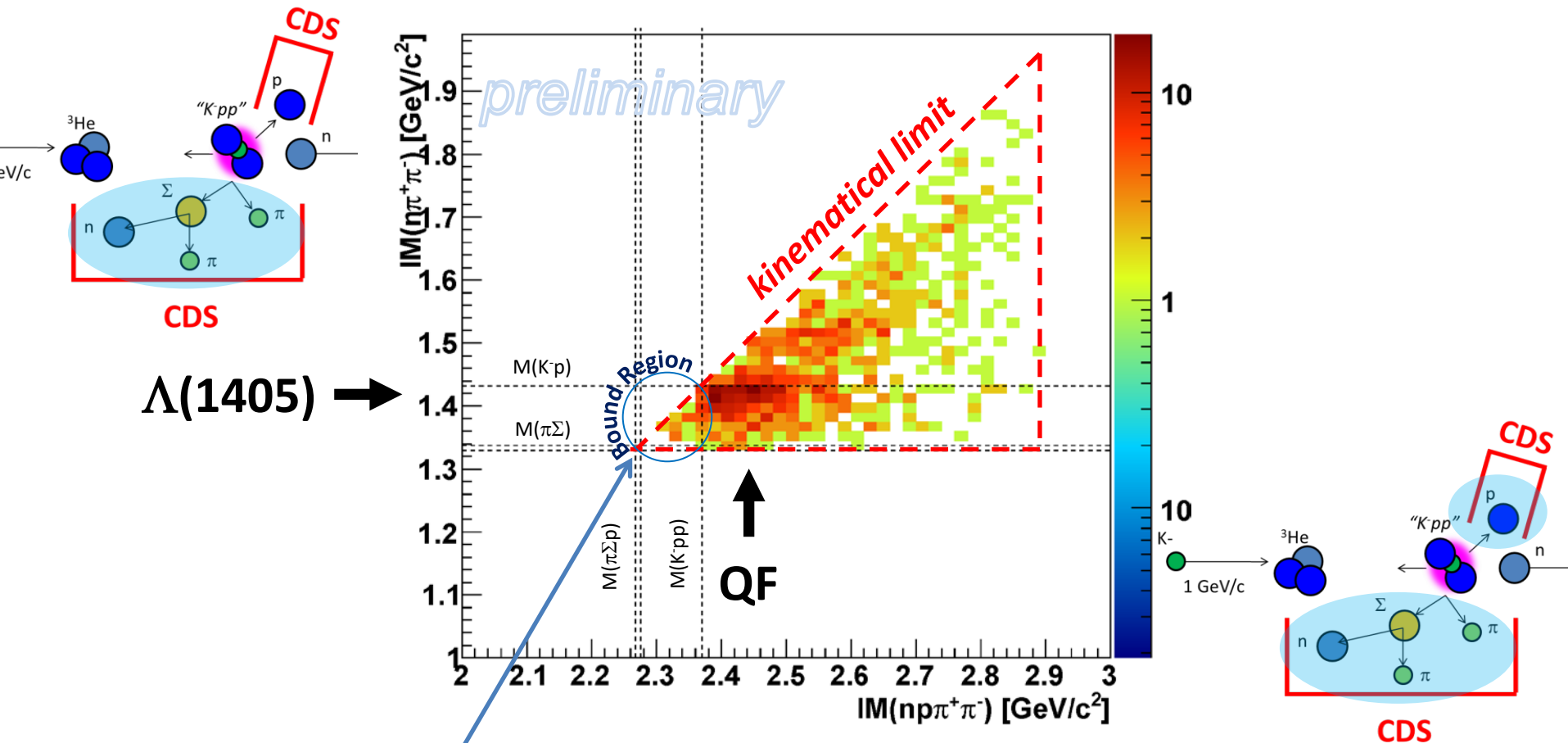
$\Lambda(1405)$ region is selected
[$\text{IM}(n\pi^+\pi^-) < \text{M}(K^-p)$]



$IM(\pi^\pm \Sigma^\mp) \text{ vs. } IM(\pi^\pm \Sigma^\mp p)$

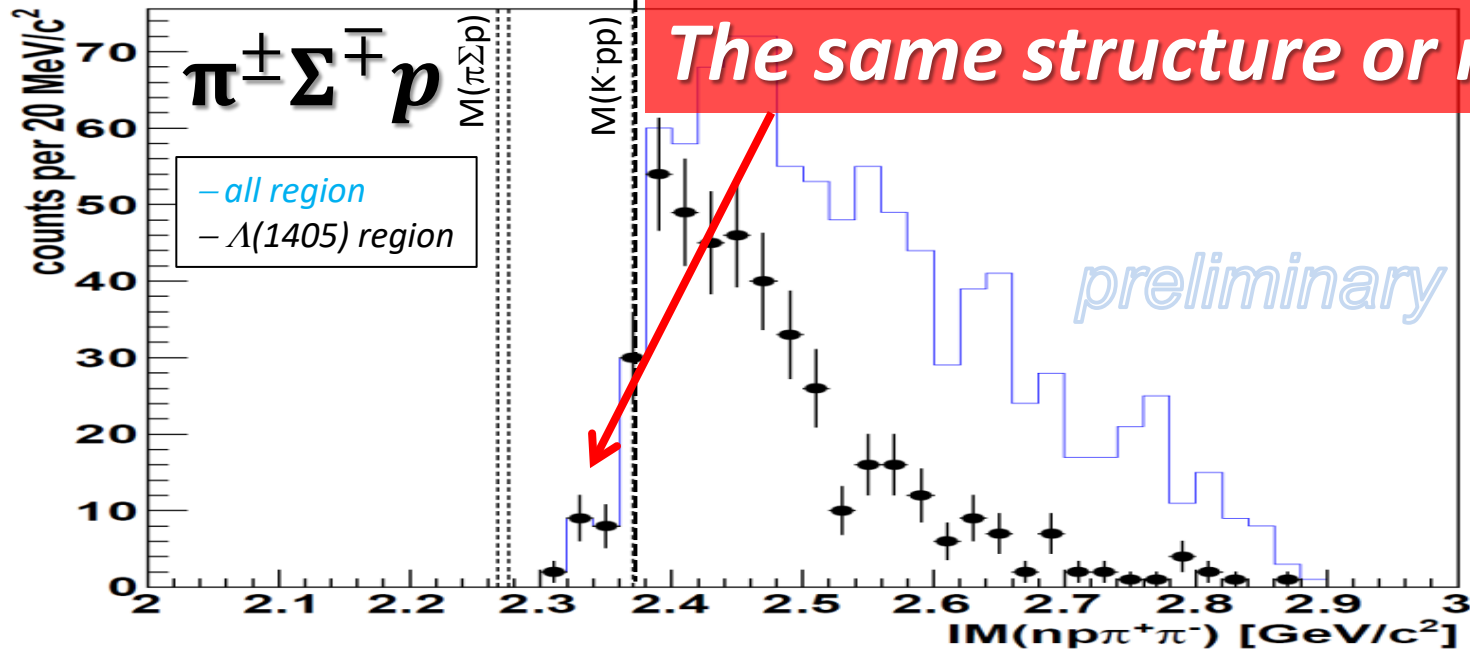
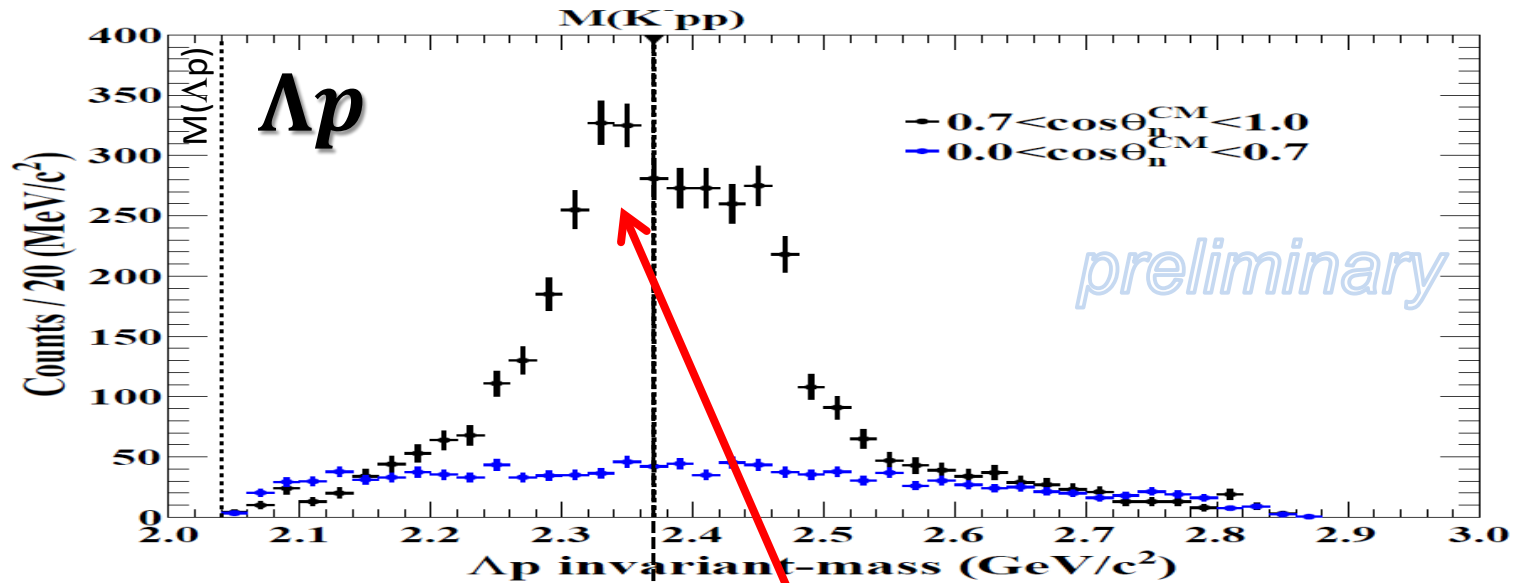
$\Lambda(1405)$ and QF are strongly correlated

= consistent with $K^- + N$ quasi-free followed by $K^- + N_s N_s \rightarrow \Lambda^* p$



small phase-space of " K^-pp " $\rightarrow$ $\pi\Sigma N$

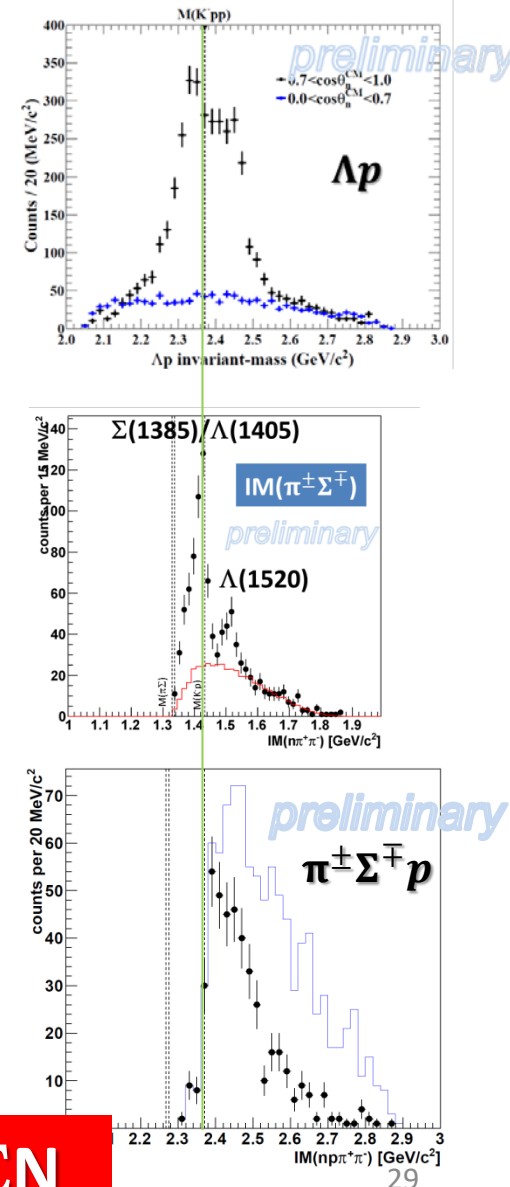
Λp vs. $\pi\Sigma p$



The same structure or not!?

Conclusion

- Structures around the K^-pp threshold were found in ${}^3\text{He}(K^-, \Lambda p)n$
 - above $M(K^-pp)$: K^-N quasi-free followed by $K^-N_s N_s \rightarrow \Lambda p$
 - below $M(K^-pp)$: would be $S=-1$ di-baryon decaying to Λp
 - $\Gamma(\Lambda(1405)) < \Gamma(\text{measured “di-baryon”})$
- $\Lambda(1405)$ was clearly observed in $\pi^\pm \Sigma^\mp p n_{\text{miss}}$ final state
 - Important hints of “ K^-pp ” production mechanism would be obtained
- Weak structure below the K^-pp threshold was seen in ${}^3\text{He}(K^-, \pi^\pm \Sigma^\mp p)n$
 - Suppression of “ K^-pp ” $\rightarrow \pi \Sigma N$ channel?
 - or
 - Limitation of detector acceptance / statistics?



need further investigation of “ K^-pp ” $\rightarrow \pi \Sigma N$

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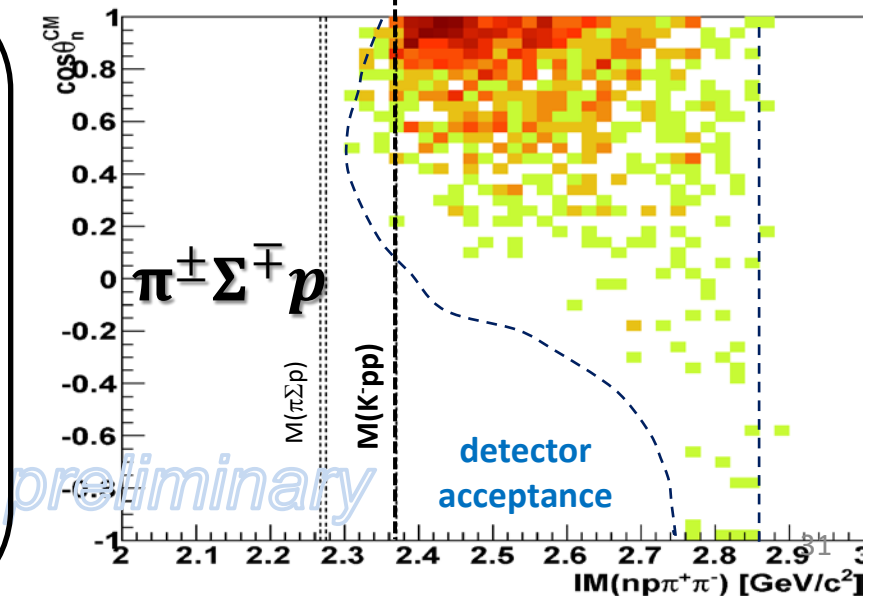
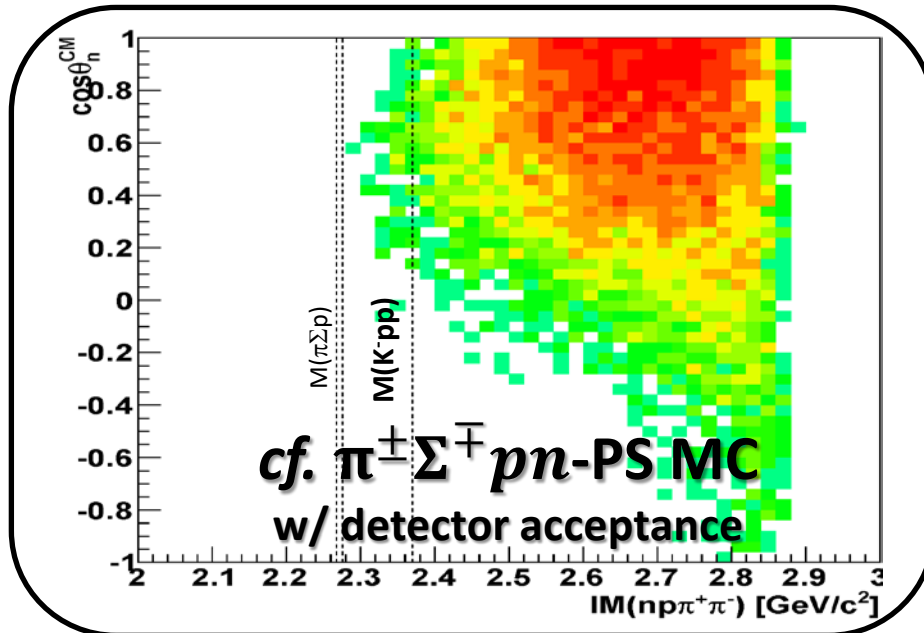
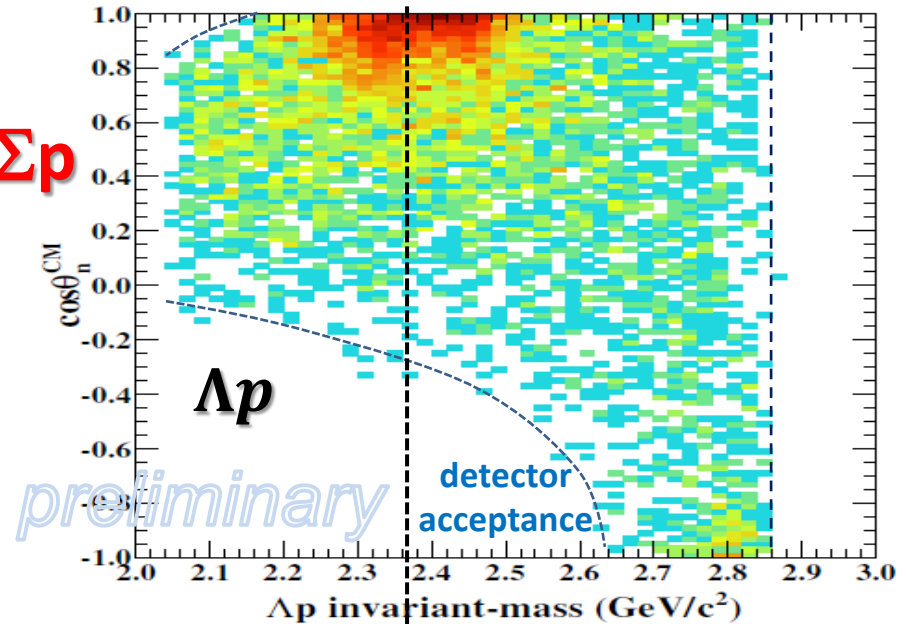
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Λp vs. $\pi\Sigma p$

- Detector acceptance is different between Λp and $\pi\Sigma p$

- At $\cos\theta_n \sim 1$:

- Λp : flat acceptance
- $\pi\Sigma p$: limited acceptance below the threshold



Acceptance of K^{bar} NN Bound-State

