$K^{bar}NN$ bound state search at J-PARC E15

F. Sakuma, RIKEN

on behalf of the J-PARC E15 collaboration

RIKEN

RIKEN NiSHiNA CENTER

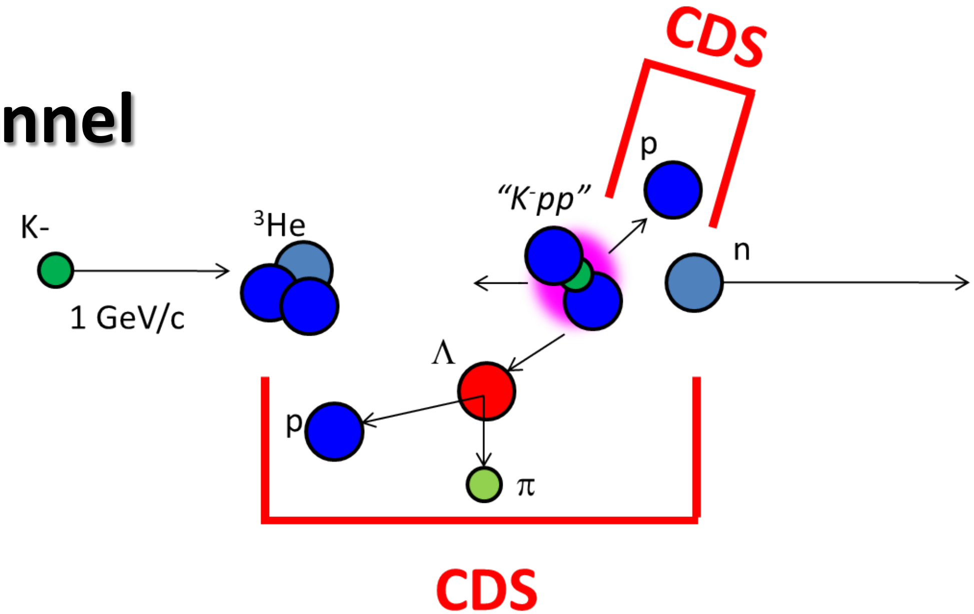
ASTRA: Advances and open problems in low-energy nuclear and hadronic STRAngeness physics,

ECT*, Trento, 23-27 October 2017

Outline of the Talk

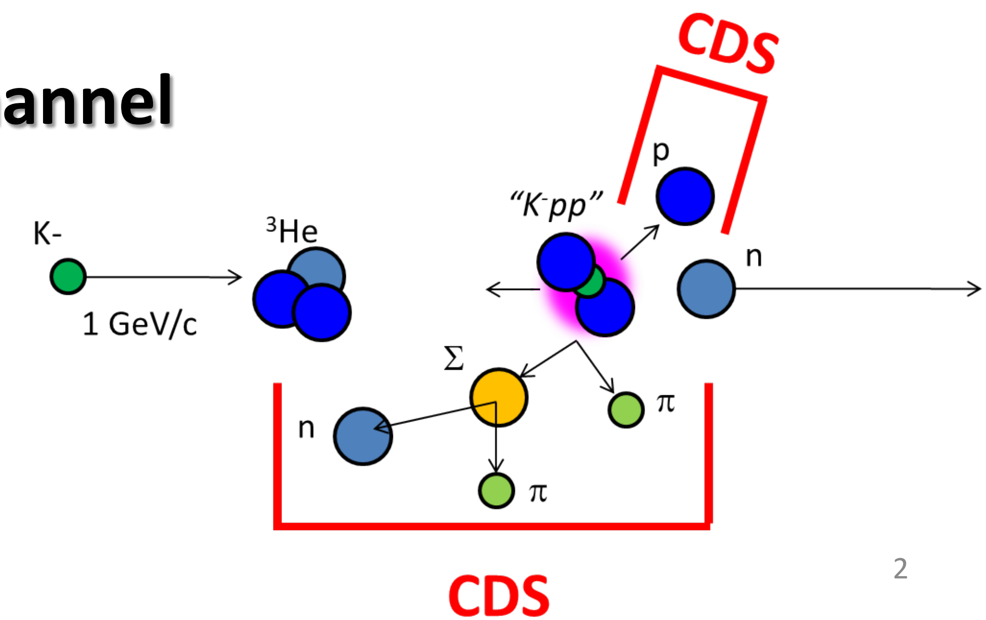
1. $K^{bar}NN$ search via Λp channel

→ Non-mesonic channel



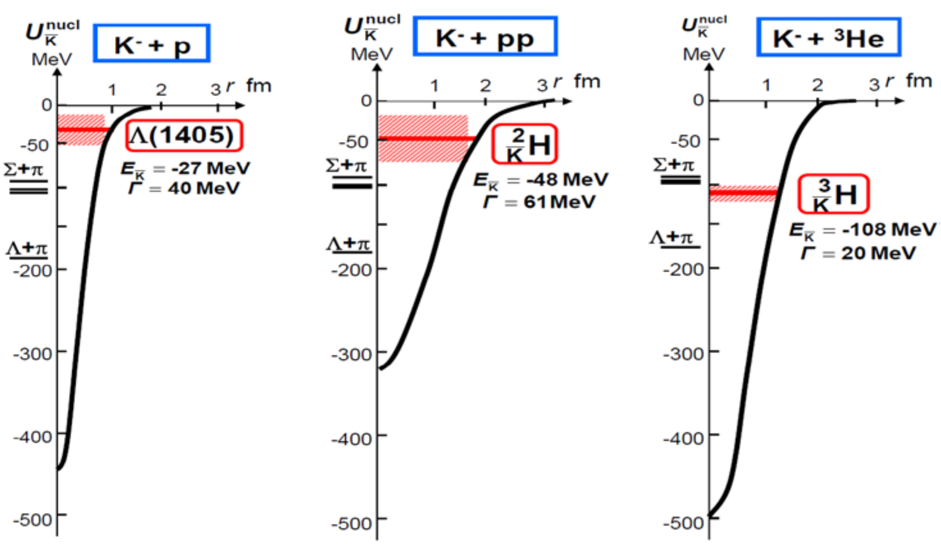
2. $K^{bar}NN$ search via $\pi\Sigma p$ channel

→ Mesonic channel

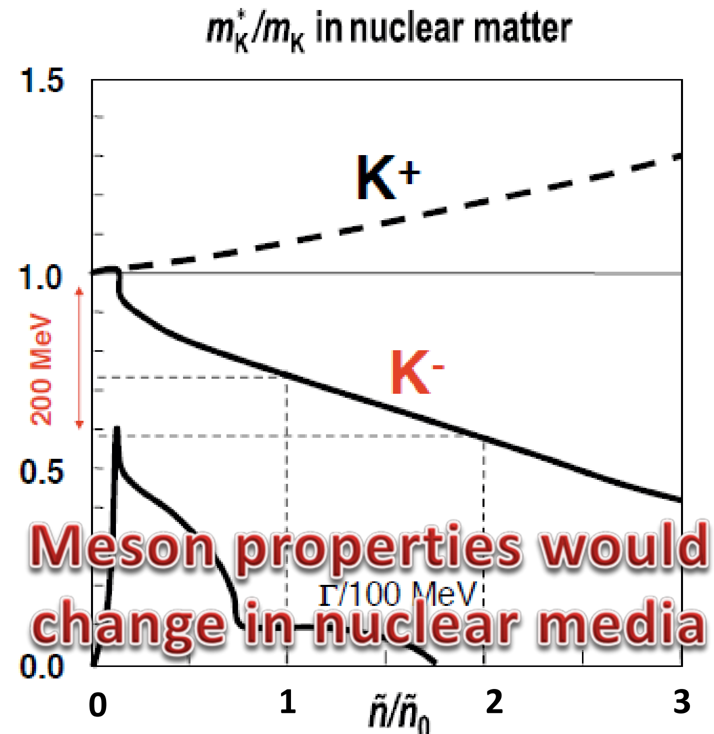


Kaonic Nuclei

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



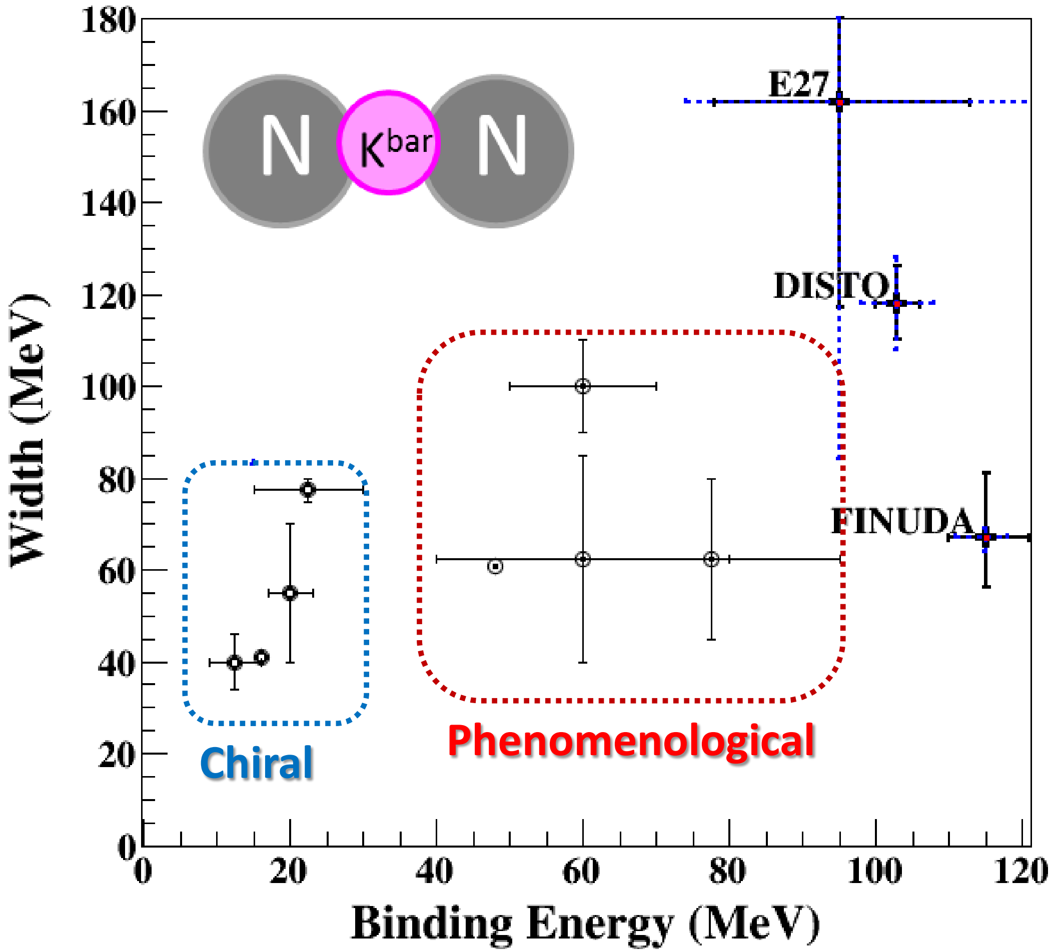
Y.Akaishi & T.Yamazaki, PLB535, 70(2002).



T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

Will provide new insight of low energy QCD

Present Status of $K^{bar}NN$



- **Binding energy**
  - Chiral:
    B.E. ~ 20MeV
  - Phenomenological:
    B.E. ~ 40-80MeV
  - FINUDA/DISTO/E27 *(if $K^{bar}NN$)*:
    B.E. ~ 100MeV
- **Width**
  - almost agreement in Γ~40-100MeV
    - Theor.: mesonic decay
    - Exp.: non-mesonic decay

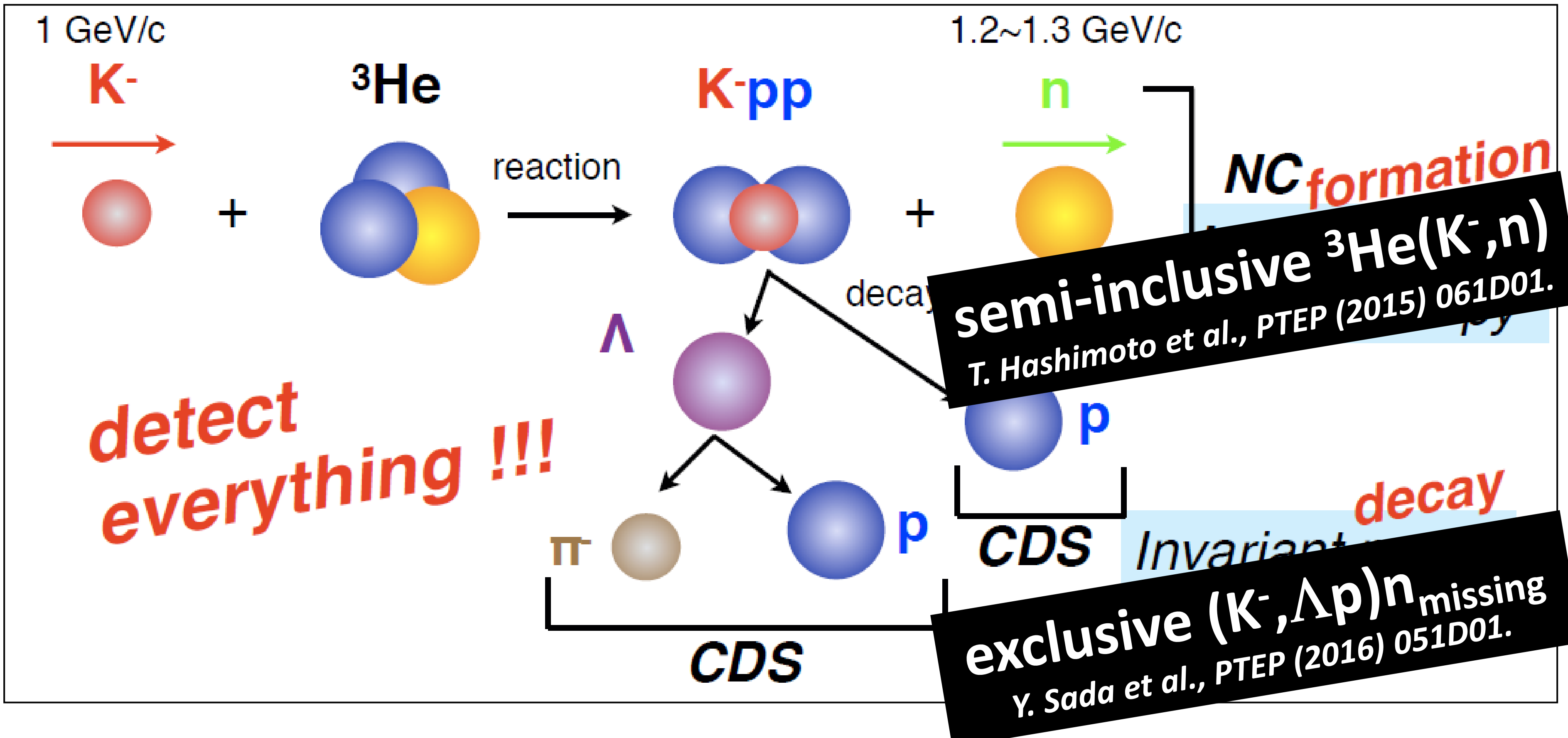
Upper limits were also obtained:

- **LEPS@SPring8 [Inclusive d(γ, $K^+\pi^-$)X]**
- **HADES@GSI [Exclusive pp→pΛK^+]**

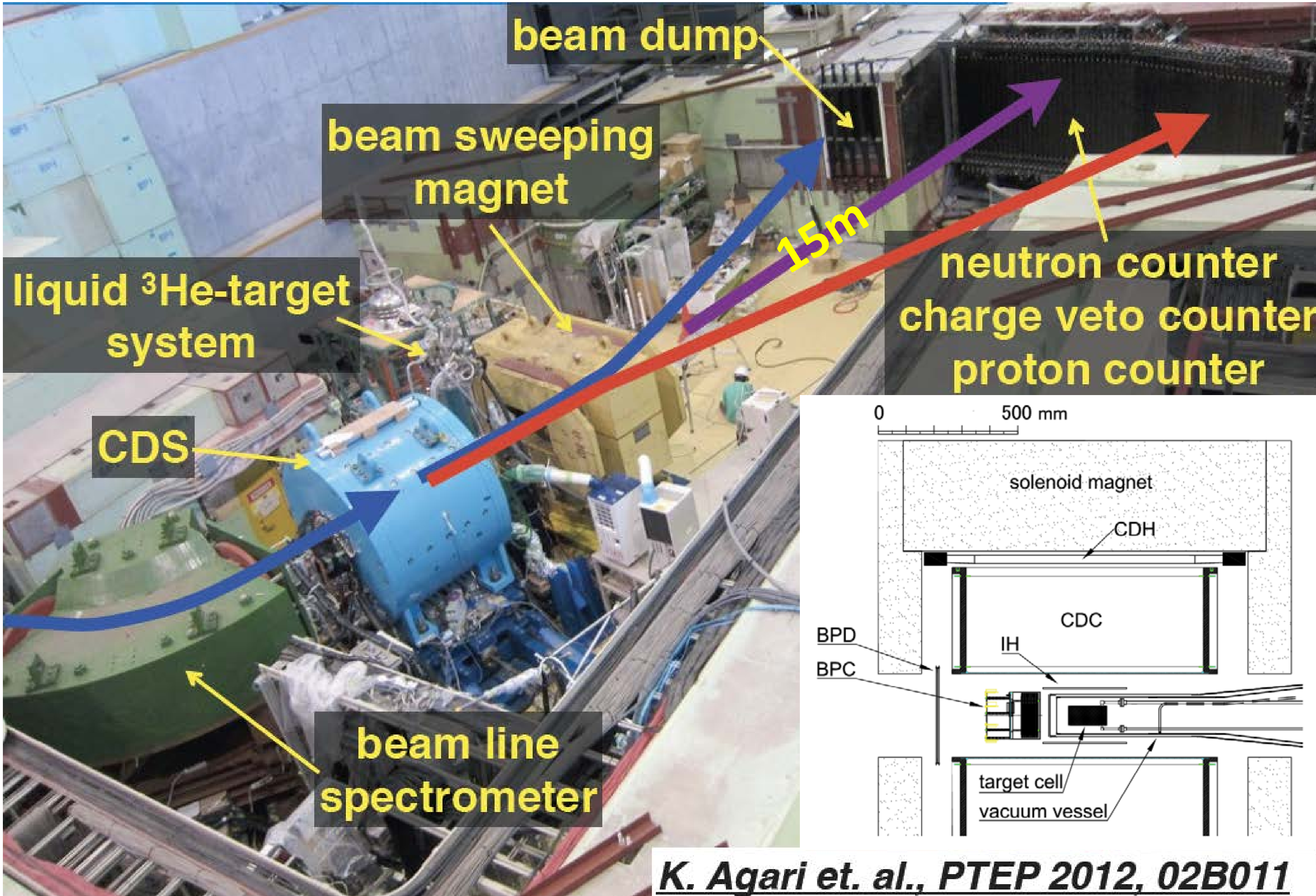
J-PARC E15 Experiment

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

☺ 2NA processes and Y decays can be discriminated kinematically



Experimental Setup for E15



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

Outline of the Talk

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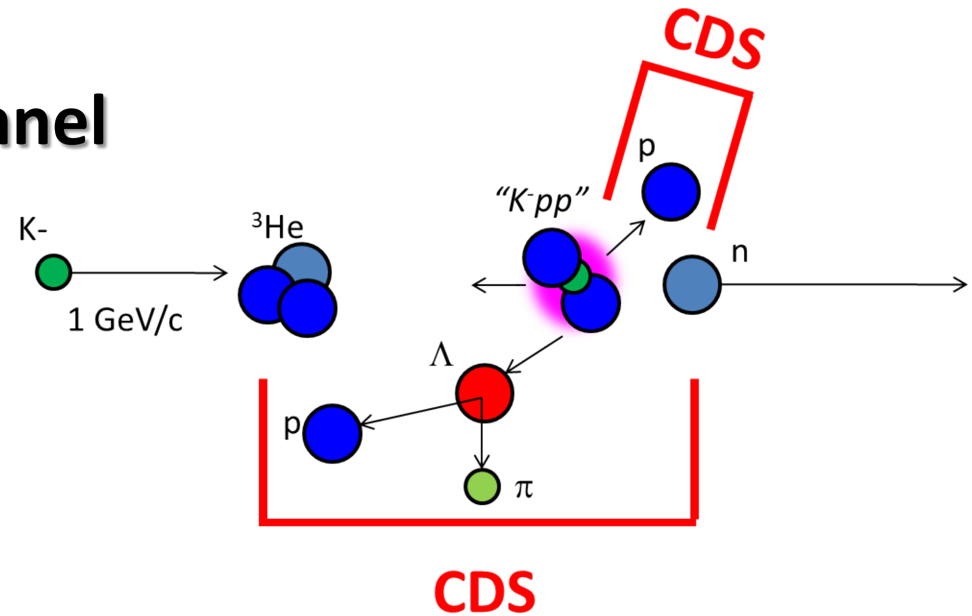
→ Non-mesonic channel



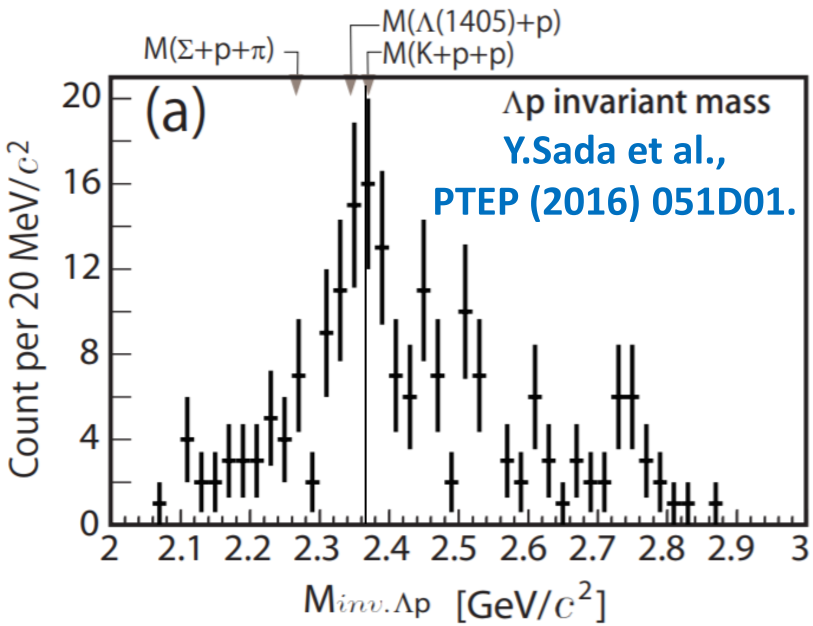
2. $K^{bar}NN$ seach via $\pi\Sigma p$ channel

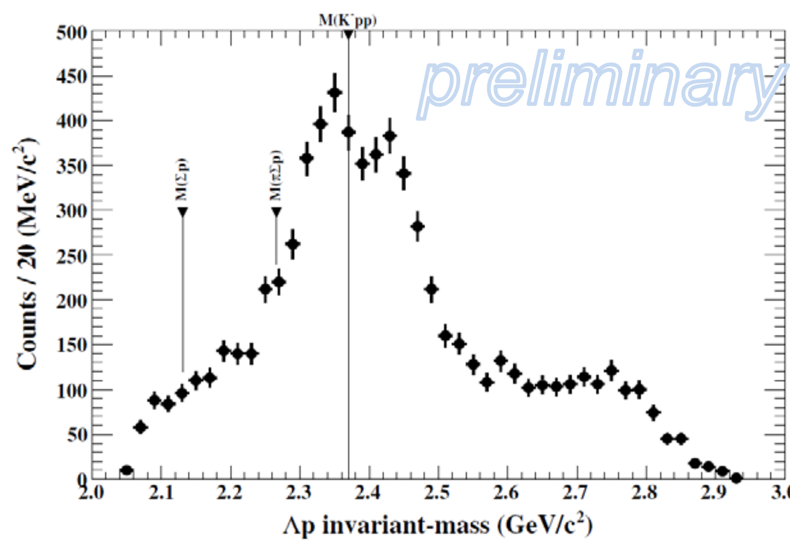
→ Mesonic channel

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

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

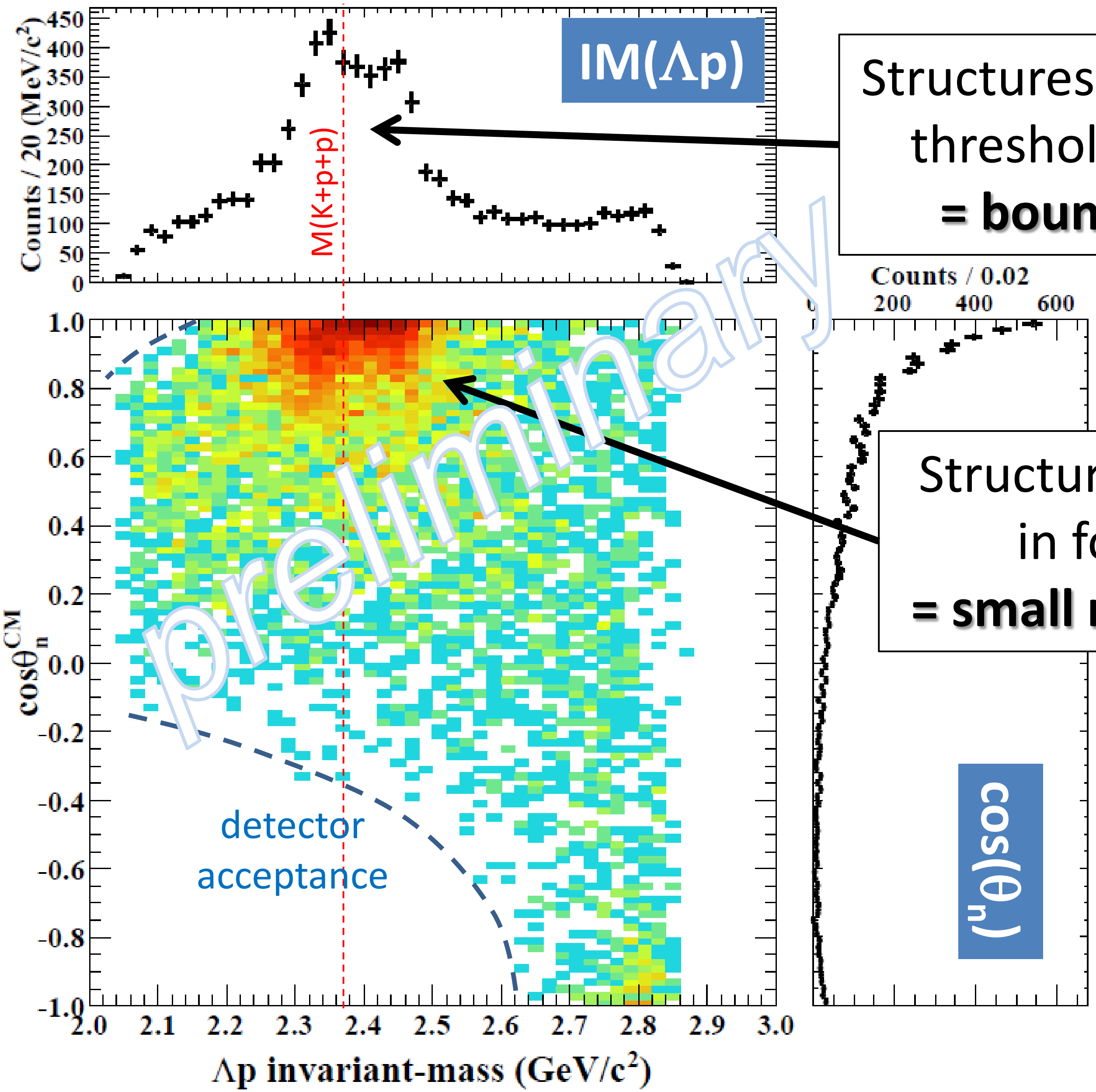
E15^{1st} → ***~30 times more data**** **E15^{2nd}**





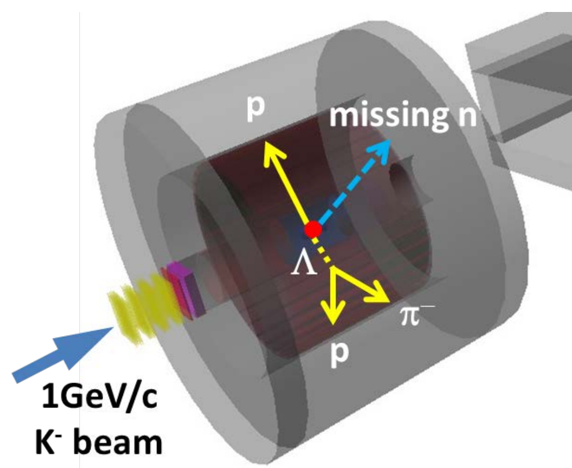
* dedicated trigger was introduced for $(K^-,\Lambda p)$

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

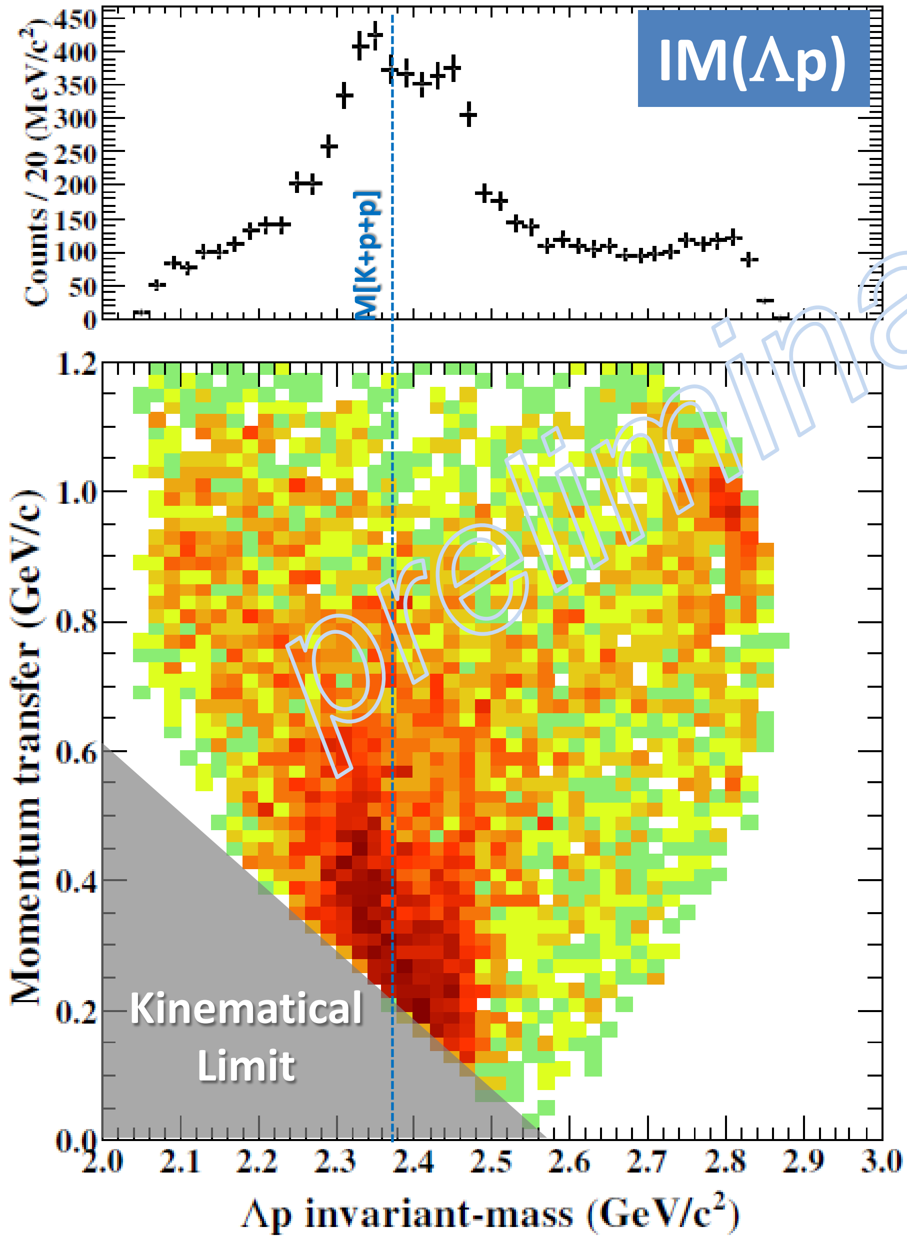


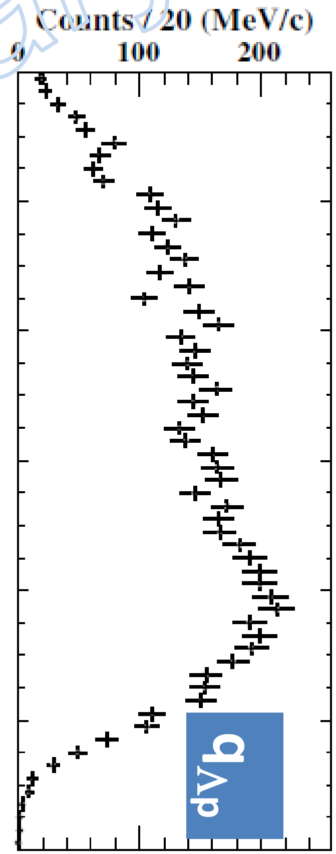
Structures around the Kpp threshold can be seen
= bound-state + QF

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



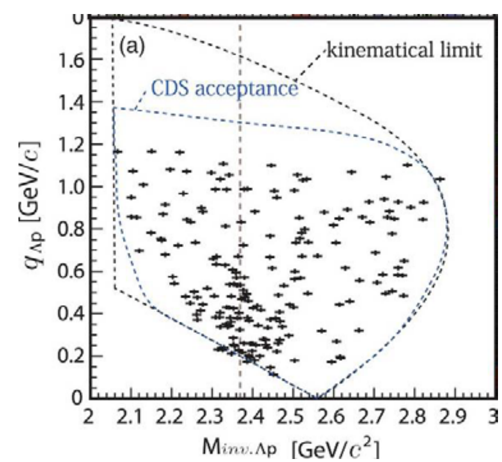
Momentum Transfer





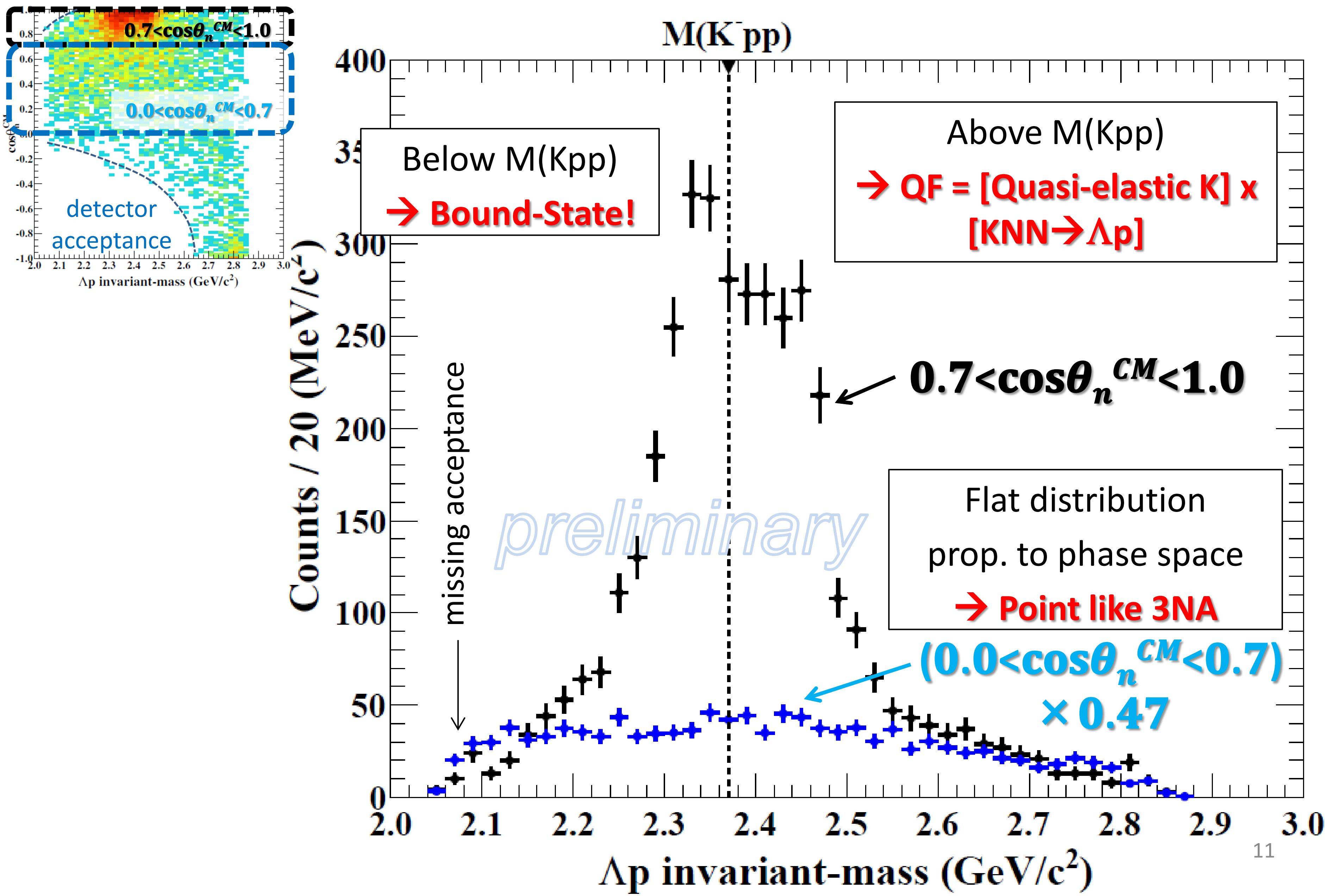
Momentum transfer ranges **from ~300 to ~600 MeV/c** for sub-threshold structure

c.f. E15^{1st}

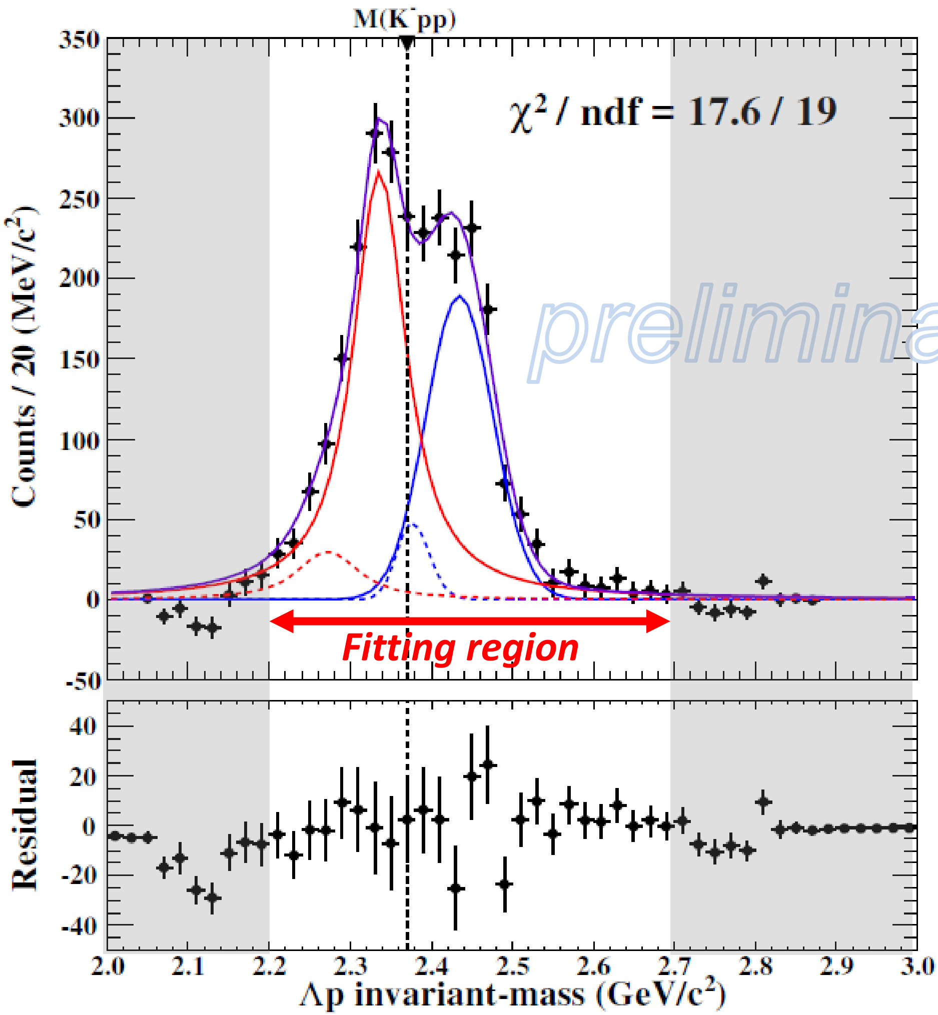


Consistent with E15^{1st}

Structures in Forward-n Region



Fitting with BW and Gaussian

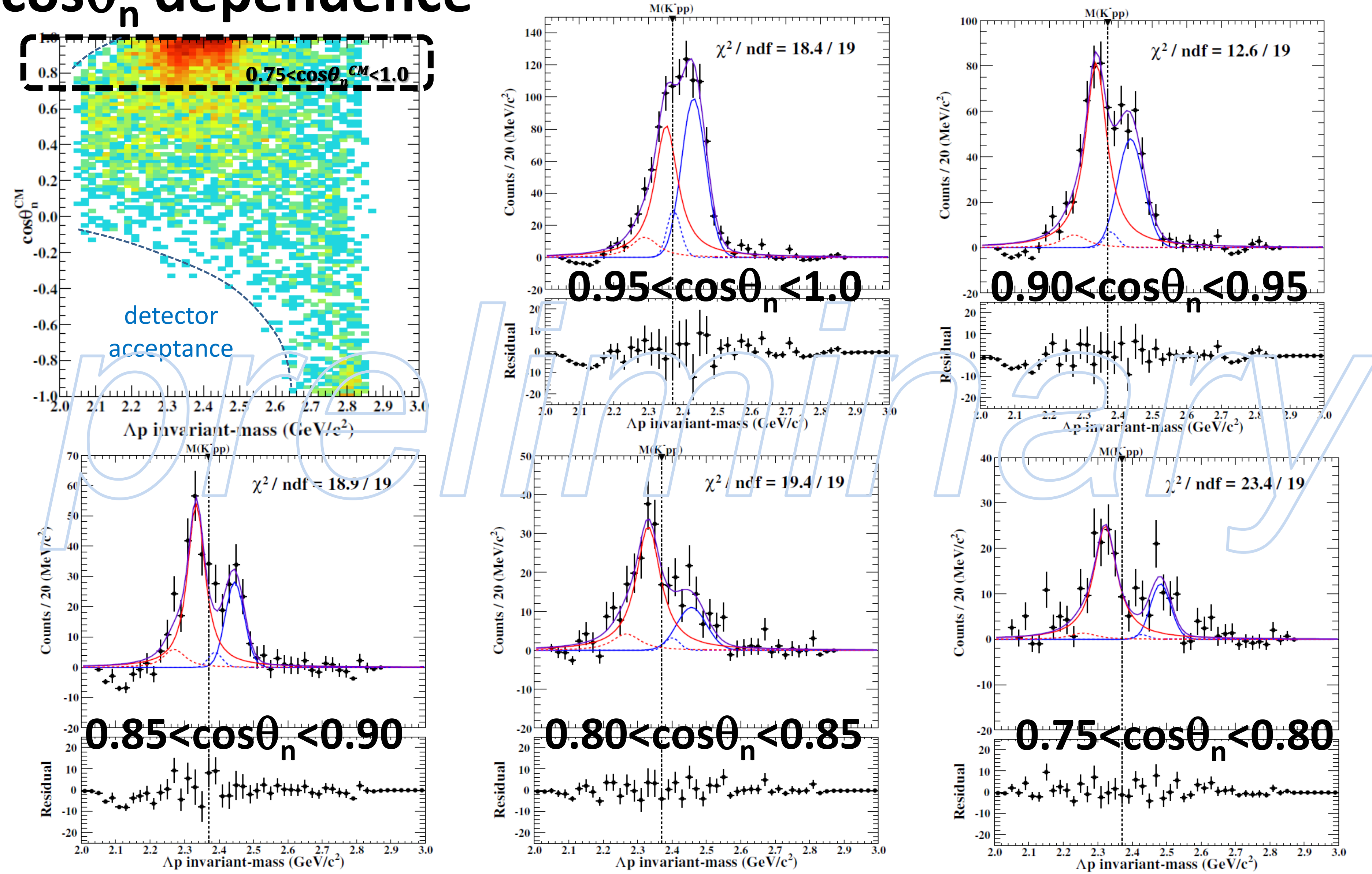


- Simple fitting after BG subtraction
  - **BS: Breit-Wigner**
  - QF: Gaussian
    ← Fermi-mom. Eff.
  - w/ Σ^0p contamination
    ← from MM(^{3}He(K$^-$,Λp)X)
- Fit values that reproduce the spectrum
  - B.E ~ 35 MeV/c^2
  - Γ ~ 75 MeV/c^2

preliminary

Sliced by Reaction Angle

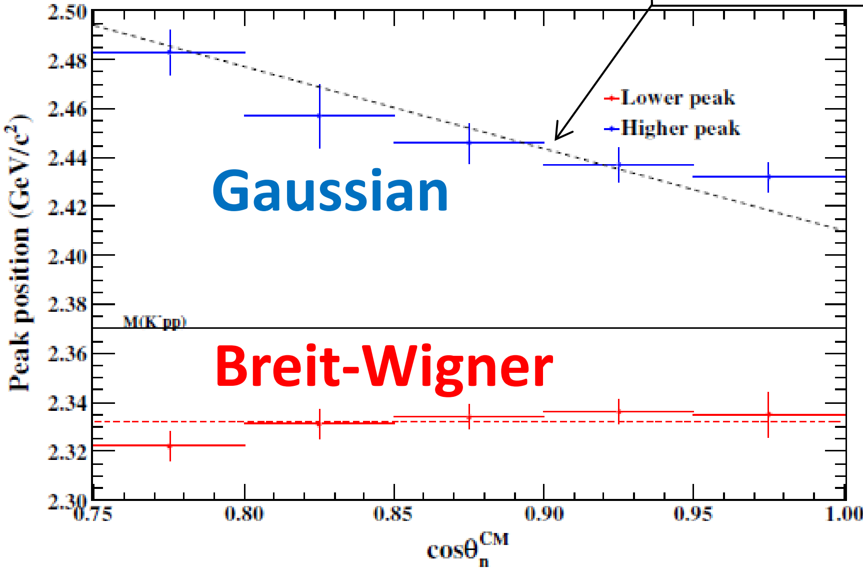
$\cos\theta_n$ dependence



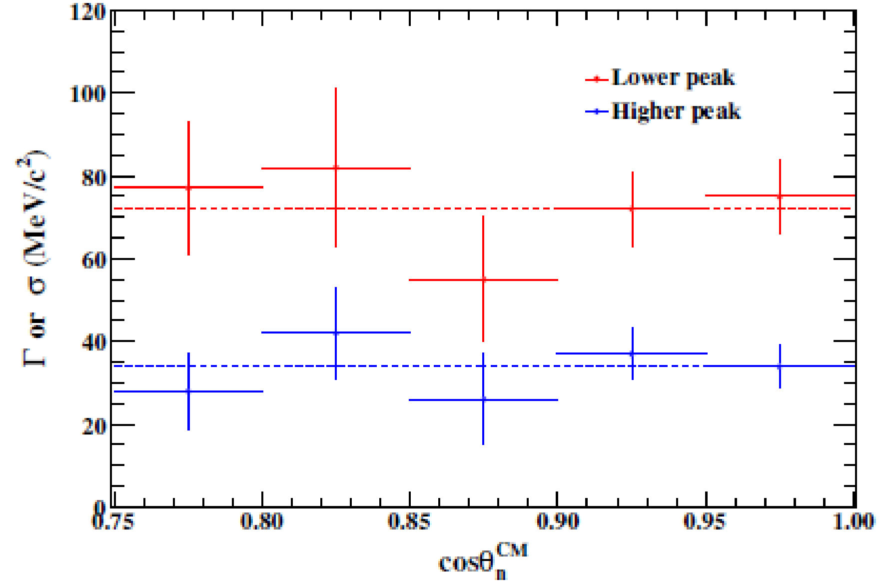
Reaction Angle Dependence

Peak position

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

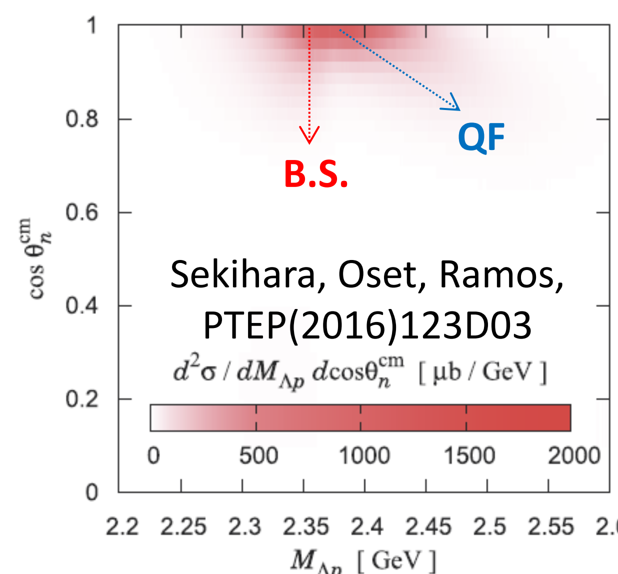


Width

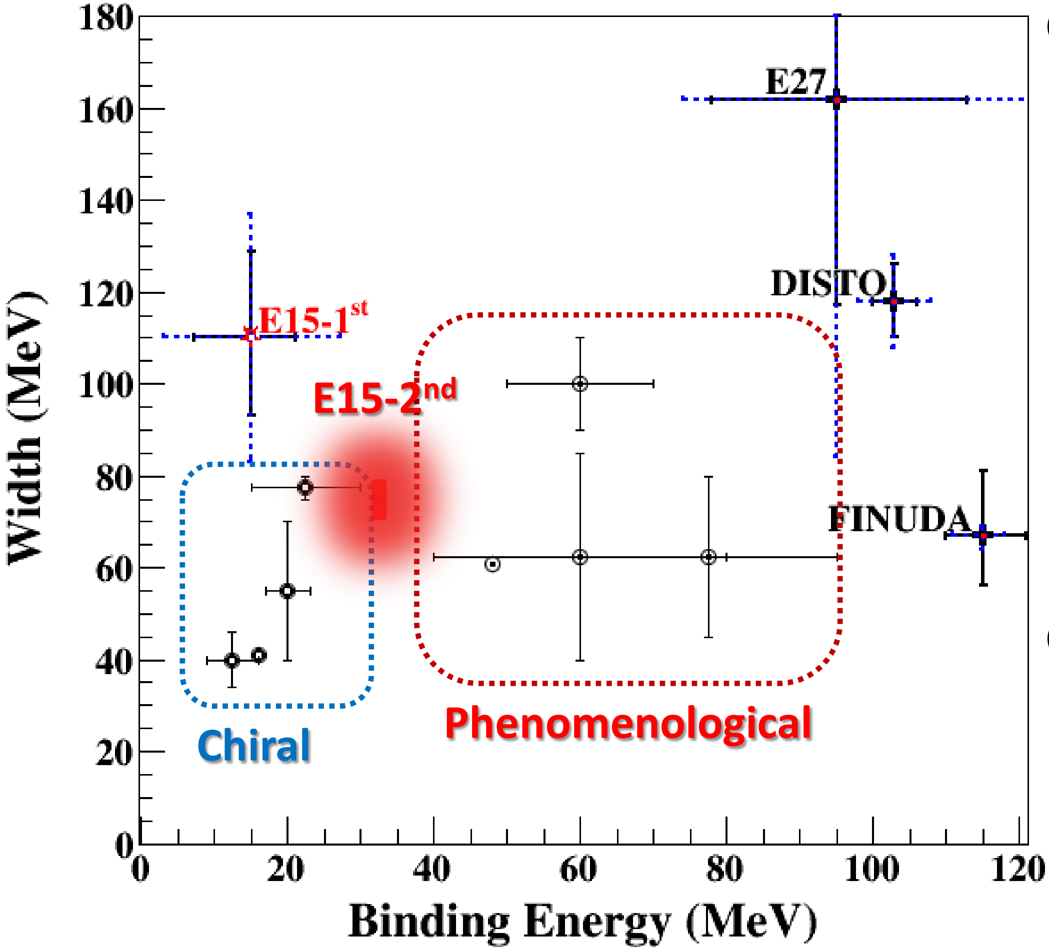


- **Above M(K⁻pp):**
  - **peak shift by recoil kaon energy**
- **Below M(K⁻pp):**
  - **peak is independent of $\cos\theta_n \sim q_{\Lambda p}$**

    → would be S=-1 di-baryon
- **Similar tendency as in a theoretical calculation**



Present Status of K^{bar}NN



- **Exp. <u>CANDIDATES</u>**
  - *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^{bar}N int.

<u>For further understanding:</u>

✓ **Λ(1405) production** → Λ*N doorway

✓ **πΣN decay channel** → new info. of K^{bar}NN

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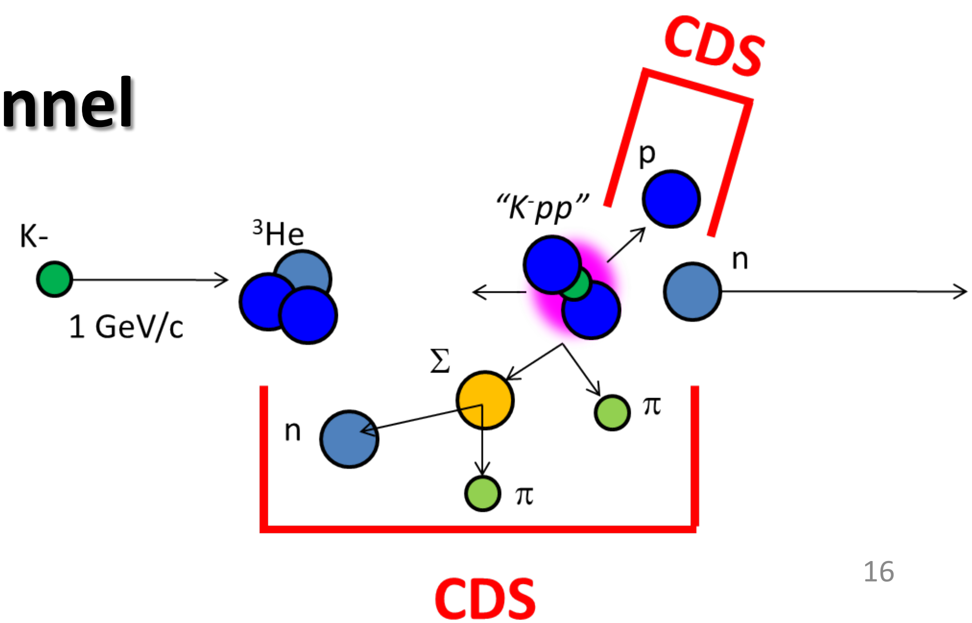
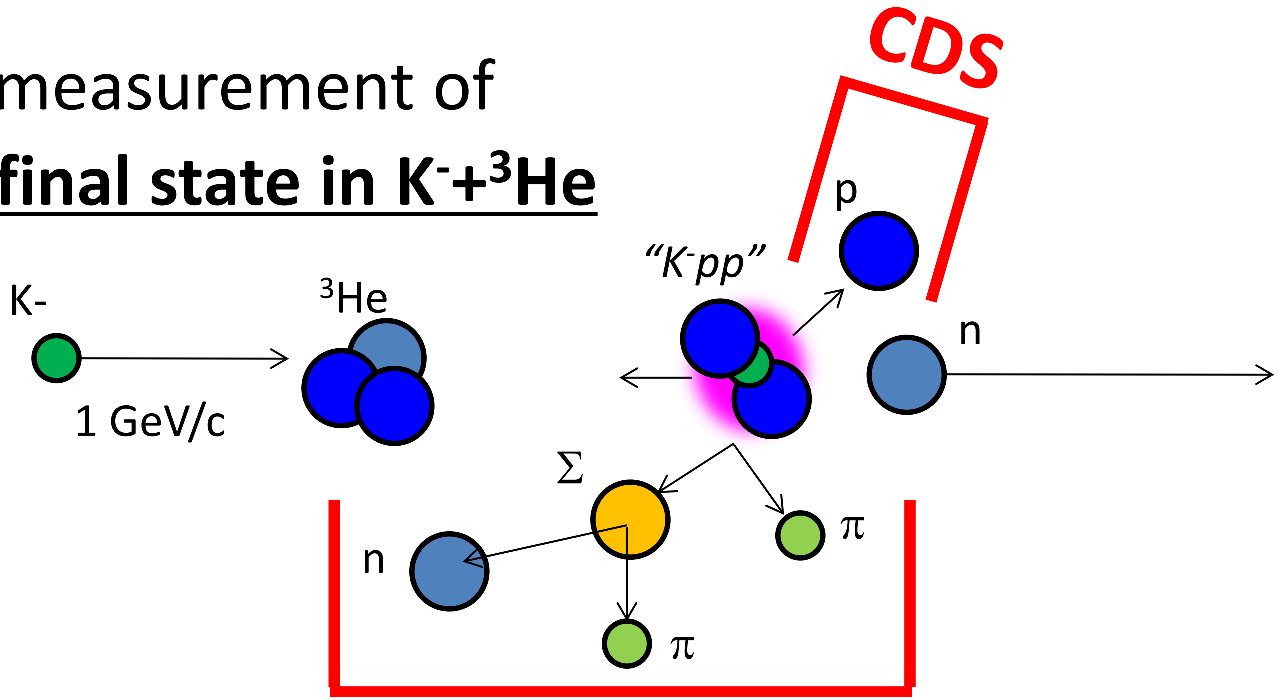
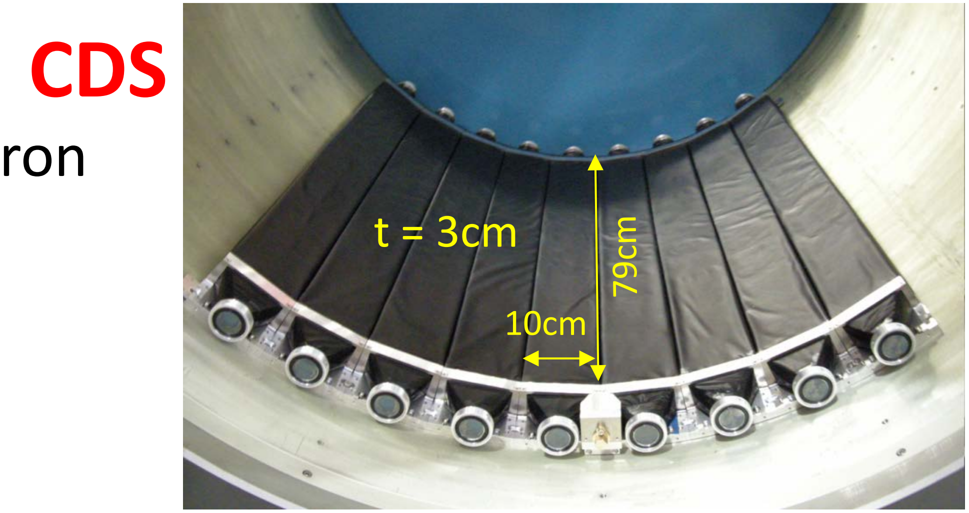


$K^- \, {}^3He \rightarrow \pi\Sigma pn$ @ E15

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





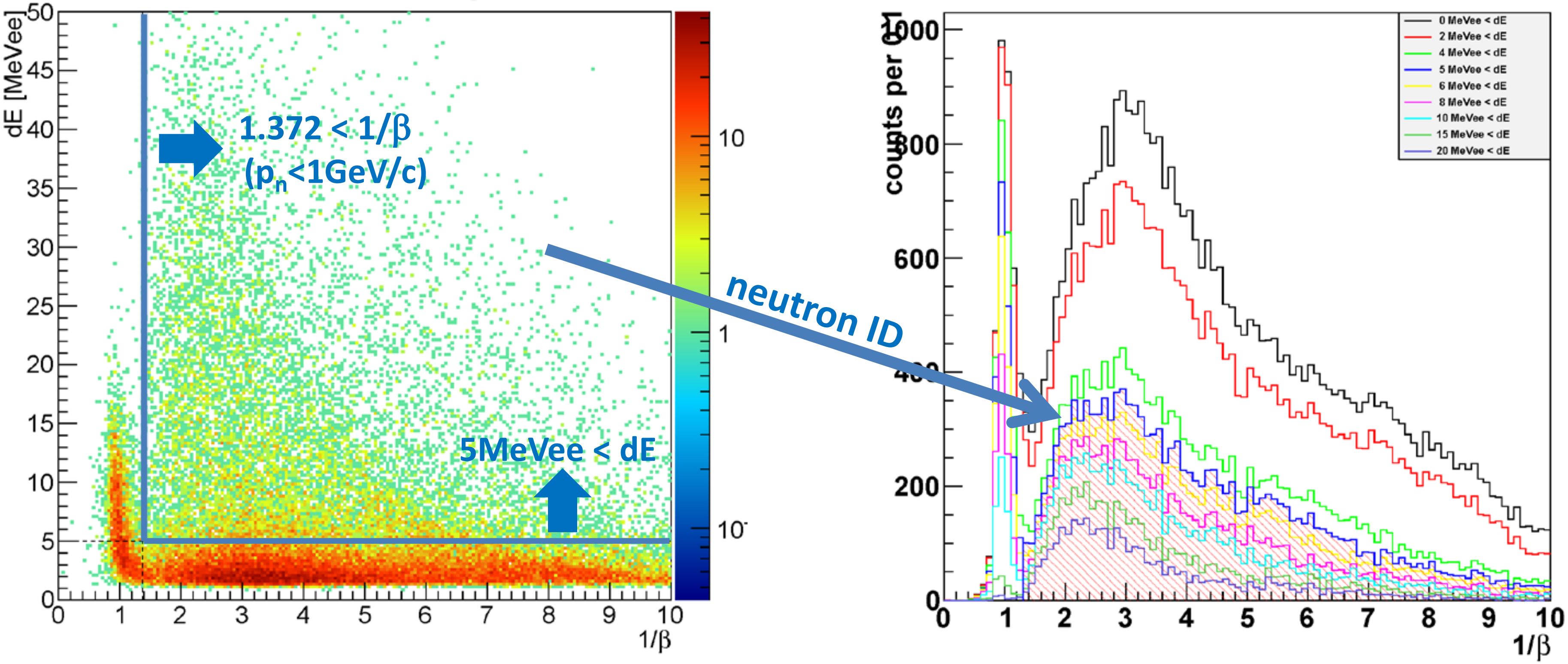
- **Experimental challenge** of neutron detection with thin scintillation counter (t=3cm)

  n detection efficiency ~ 3%

Neutron ID with CDS

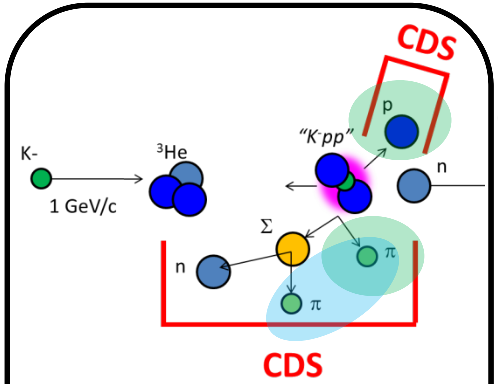
- $\pi^+\pi^-p$ events (3 tracks) in CDS with 4 CDH hits are selected
- a CDH hit with CDC-veto (outer-layer) is applied to identify the "neutral hit"

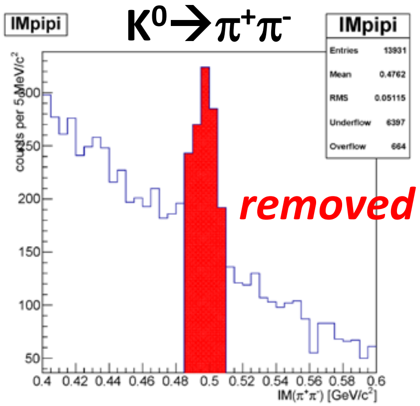
dE vs. 1/β **dE-cut dependence**

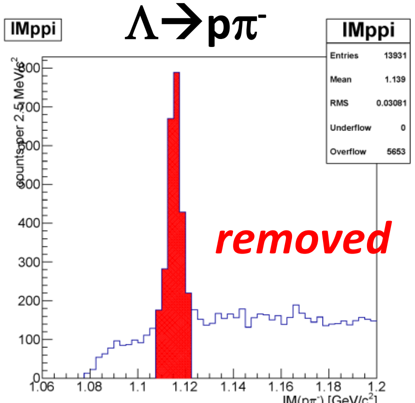


Neutron can be identified with CDS

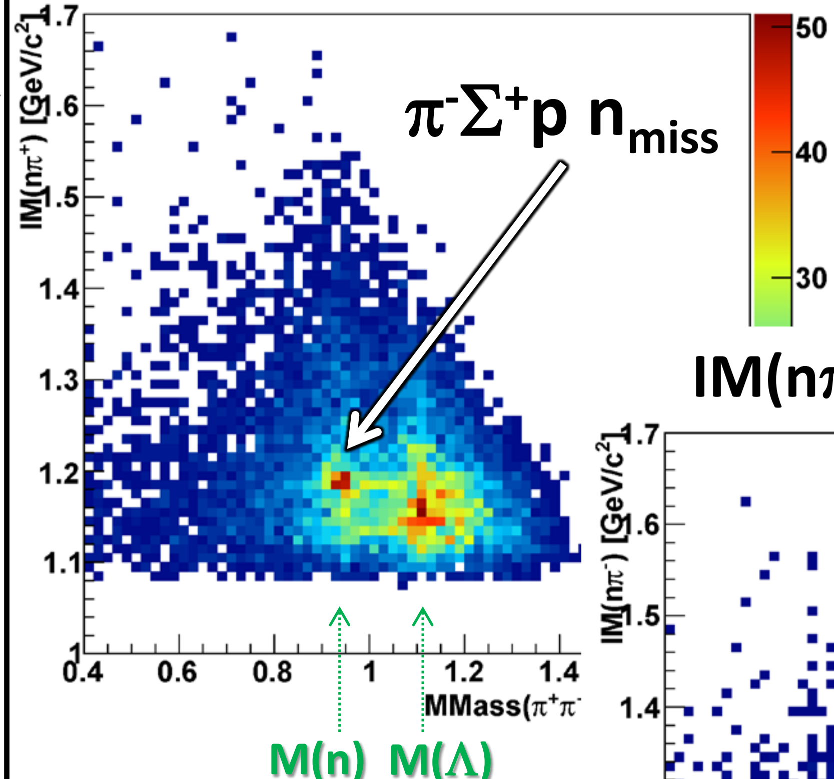
$\pi\Sigma pn$ Events

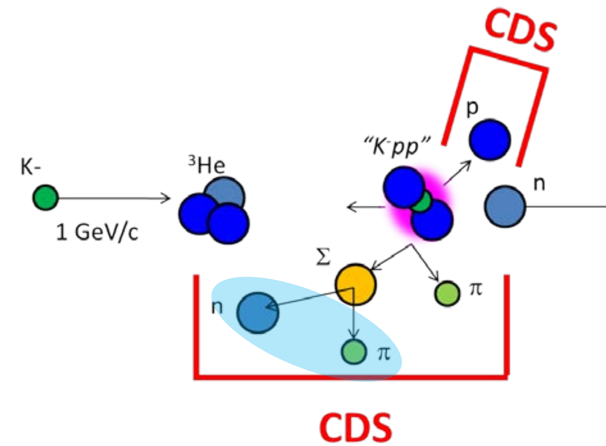




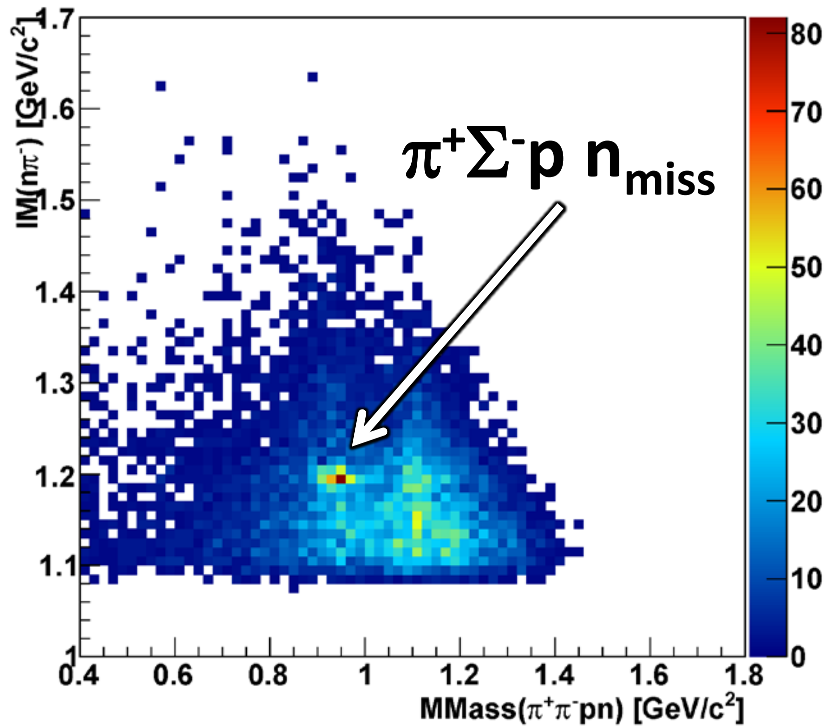


IM($n\pi^+$) vs MM($\pi^+\pi^-pn$)

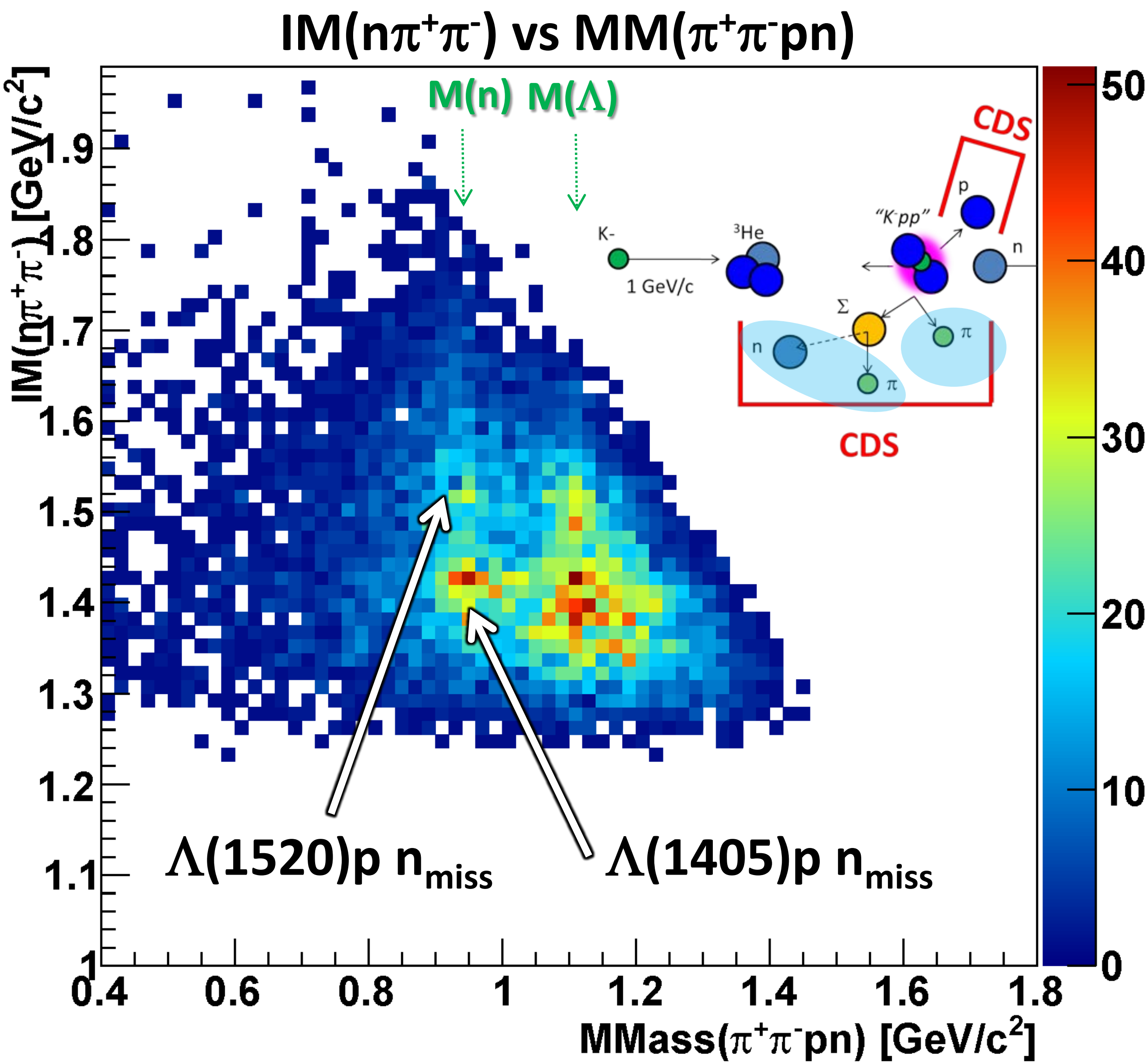




IM($n\pi^-$) vs MM($\pi^+\pi^-pn$)



Λ^*pn Events



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

Event Selection

Missing n:

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

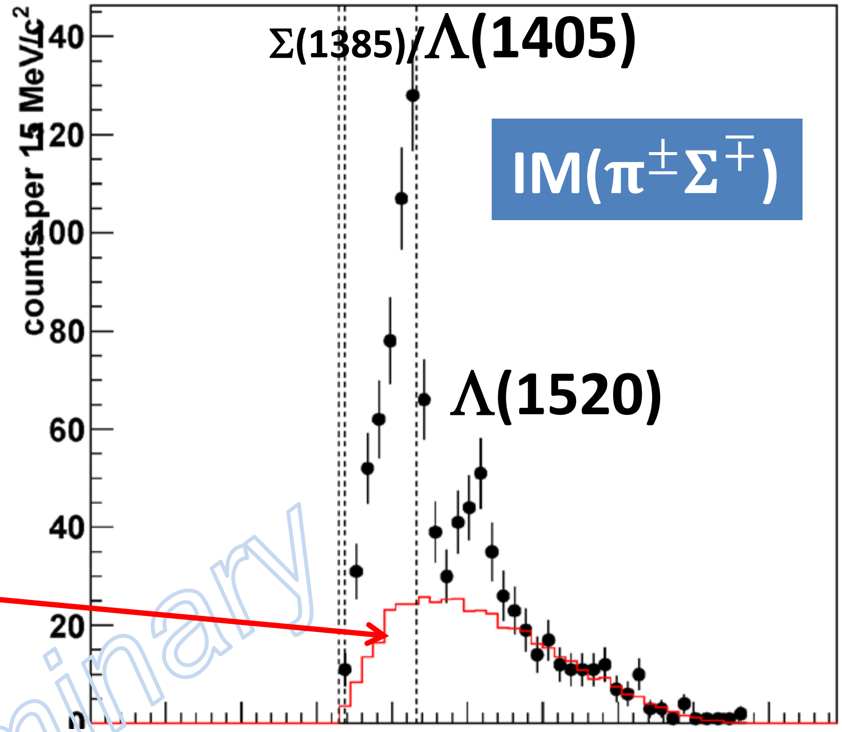
Σ mass:

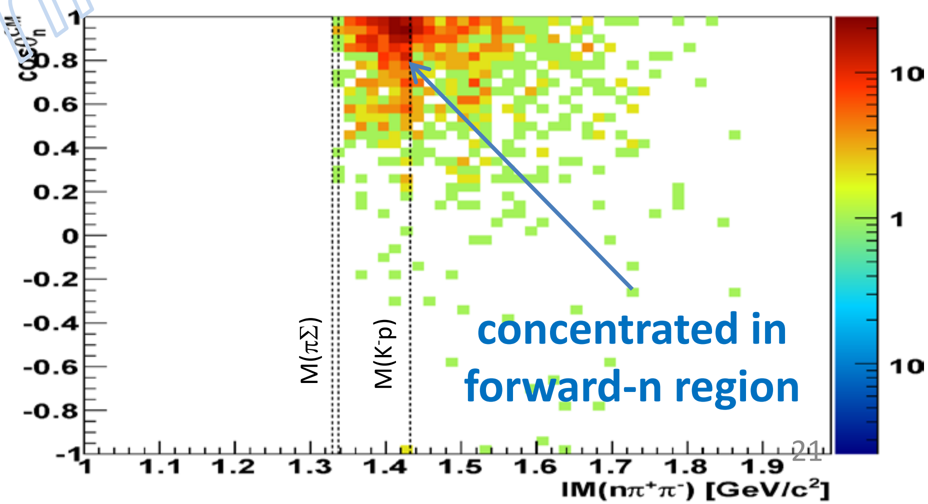
$1.18 < IM(n\pi^{-}) < 1.20$ GeV/c^2 for Σ^{-}

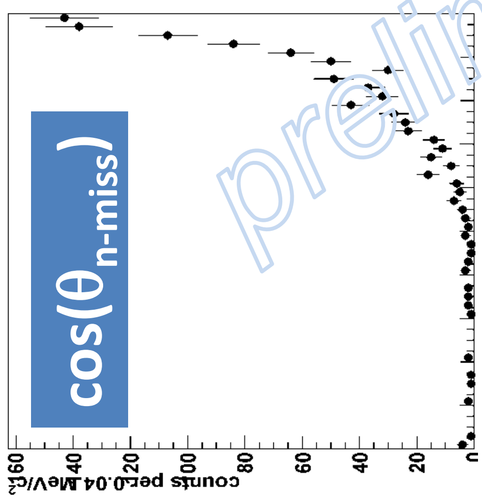
$1.19 < IM(n\pi^{+}) < 1.21$ GeV/c^2 for Σ^{+}

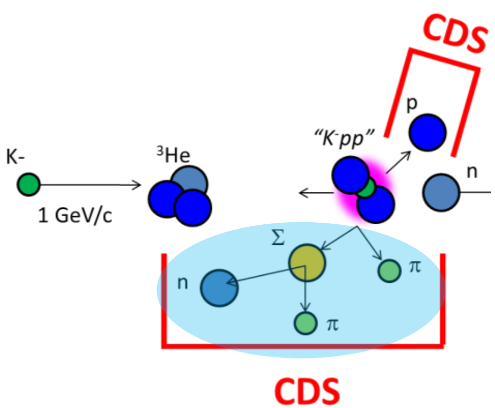
"Simple" PS-Background

$\boldsymbol{\pi^{\pm}\Sigma^{\mp}pn}$ phase-space with the detector acceptance



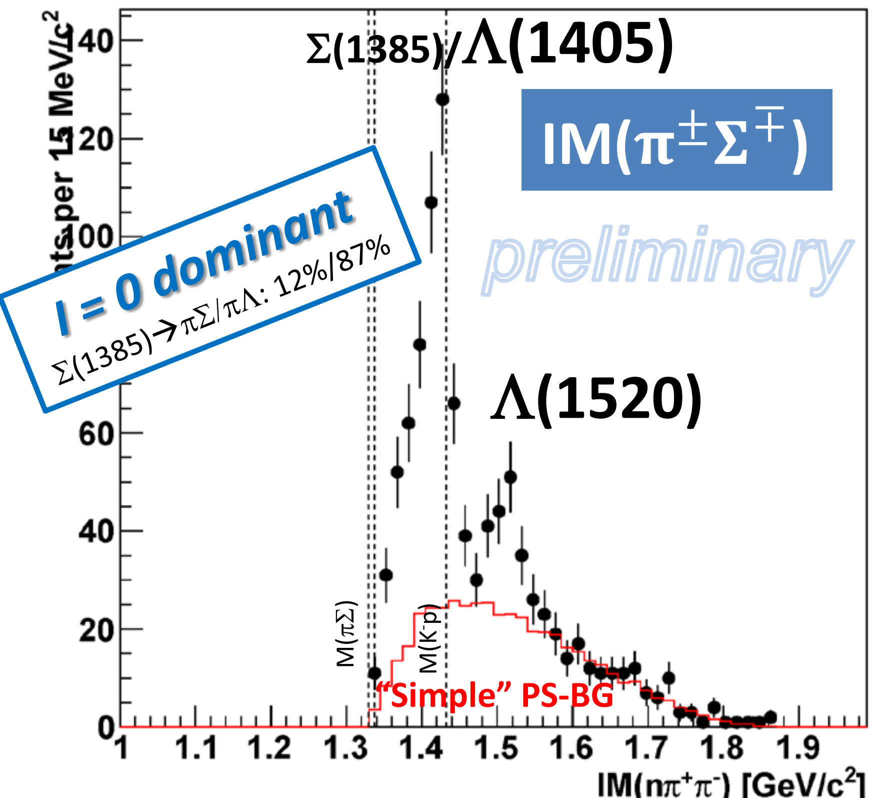




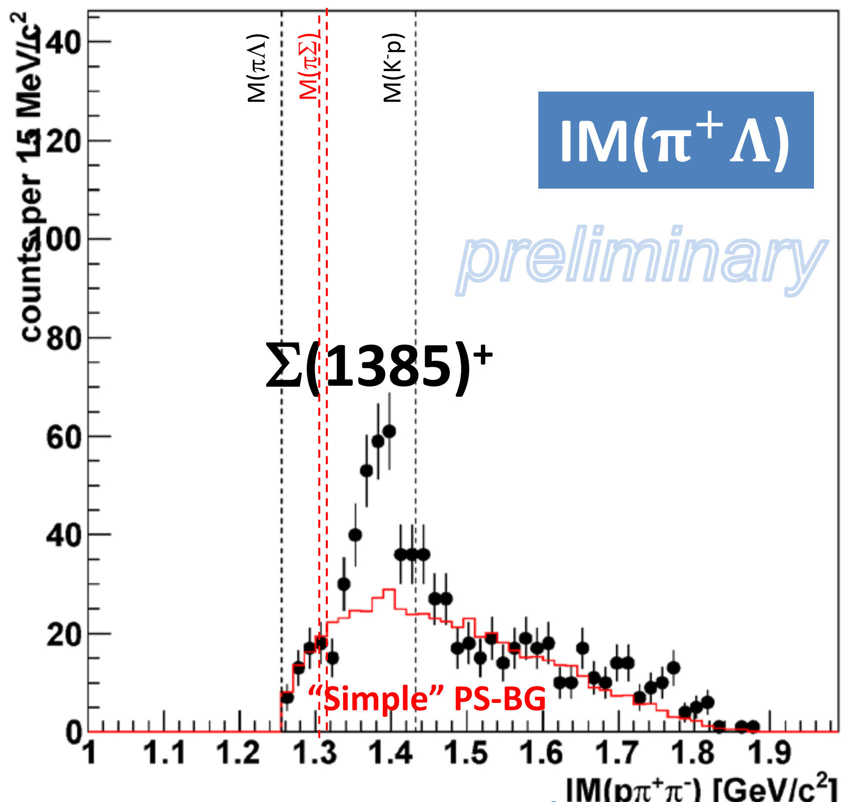


$(\pi^{\pm}\Sigma^{\mp})$p n_{miss} vs. $(\pi^{+}\Lambda)$n n_{miss}

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



I =0 and 1 mode

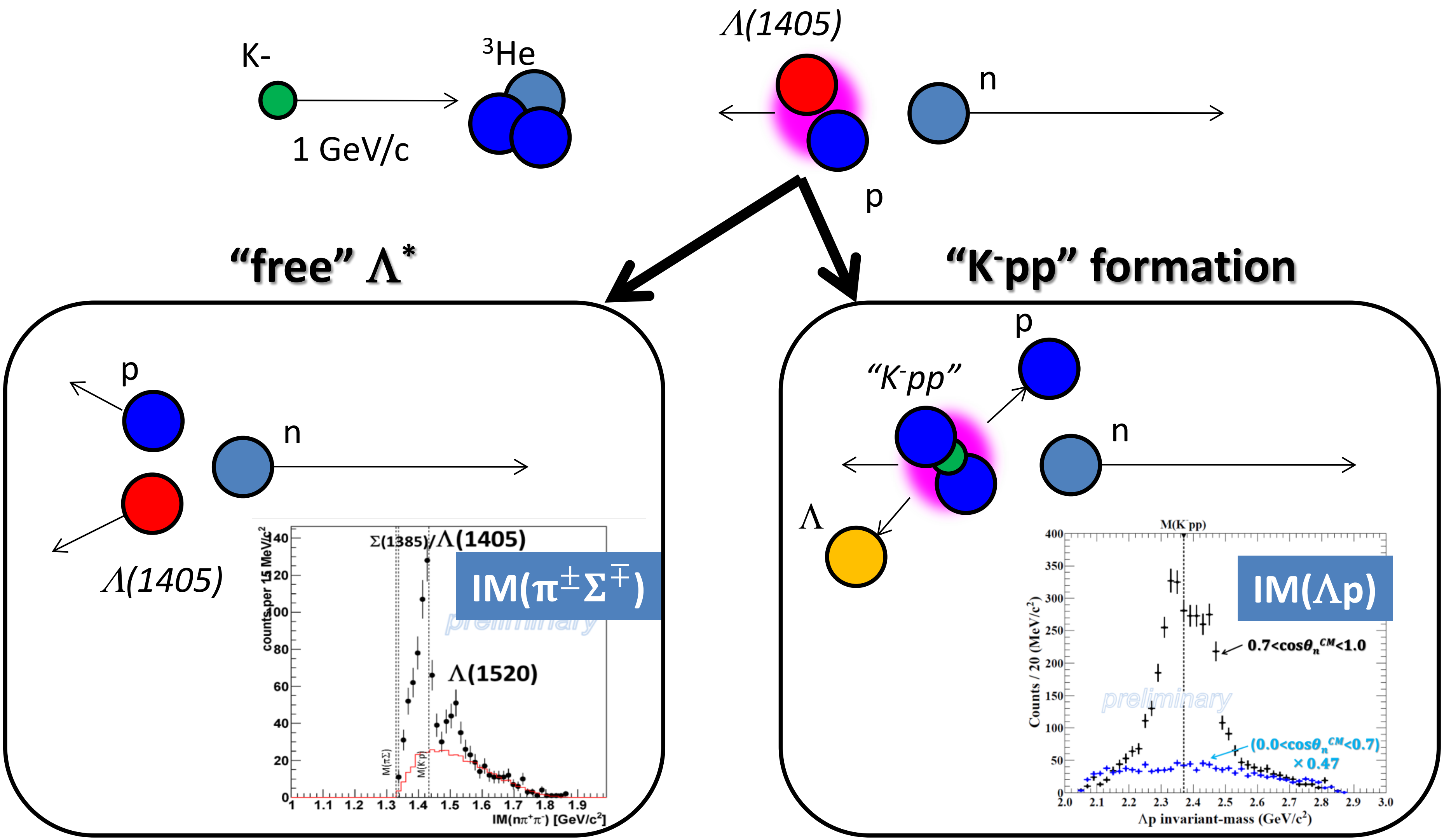


I = 1 mode

Discrimination of Λ(1405) and Σ(1385) is under way

→ Careful investigation of the backgrounds is needed

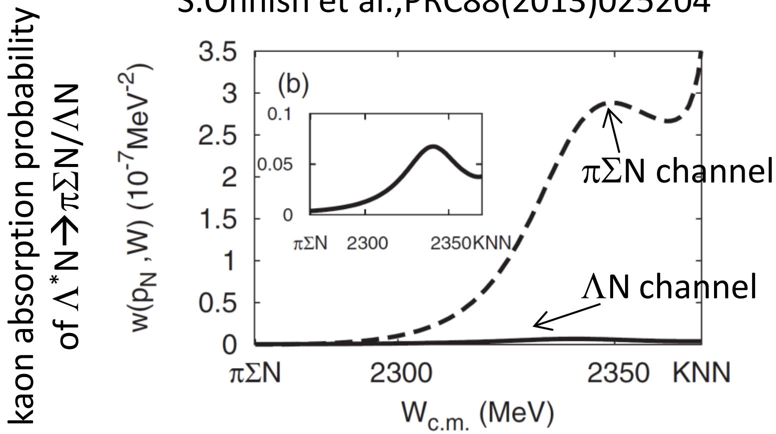
Production of Λ* and "K⁻pp"



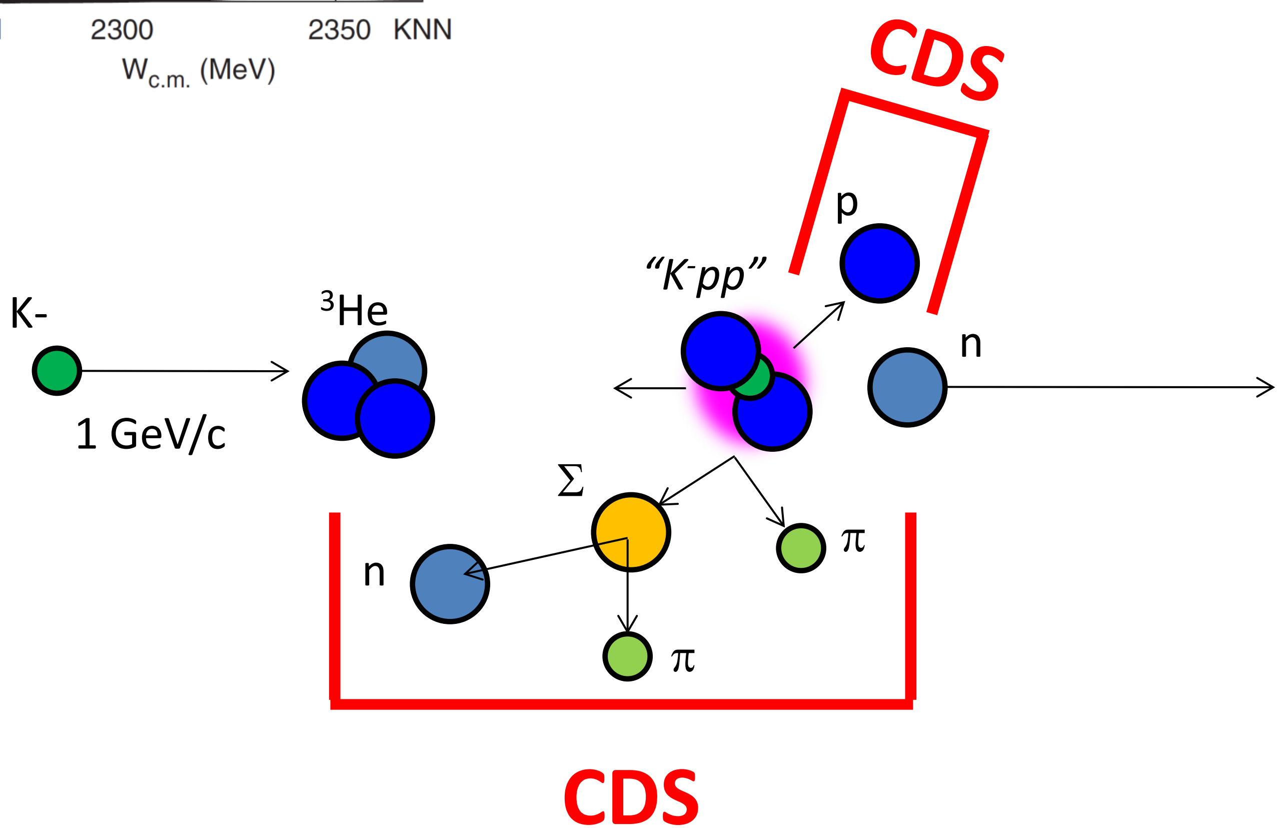
Comparison of each CS would give us important hints!

"K⁻pp"→πΣN Decay Channel

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



Theoretically,
πΣN decay is expected to be the dominant channel



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

Event Selection

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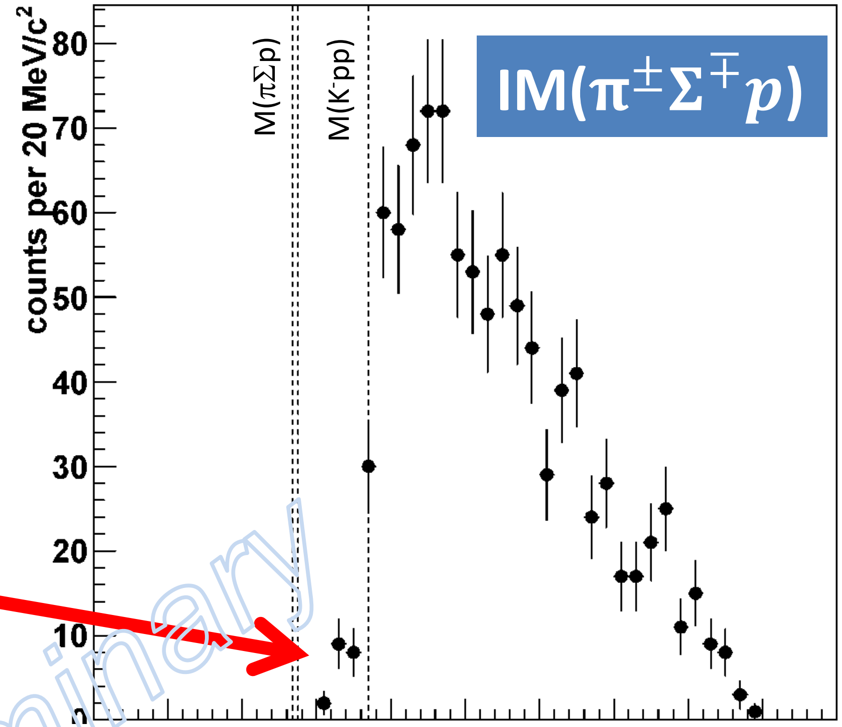
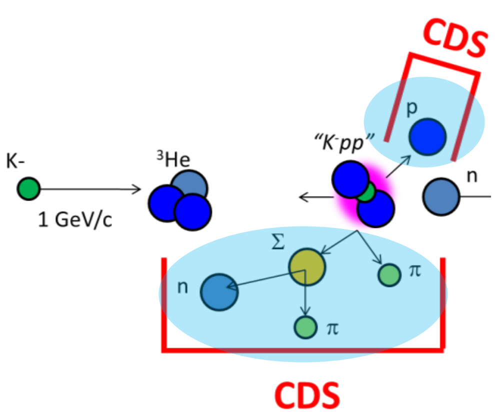
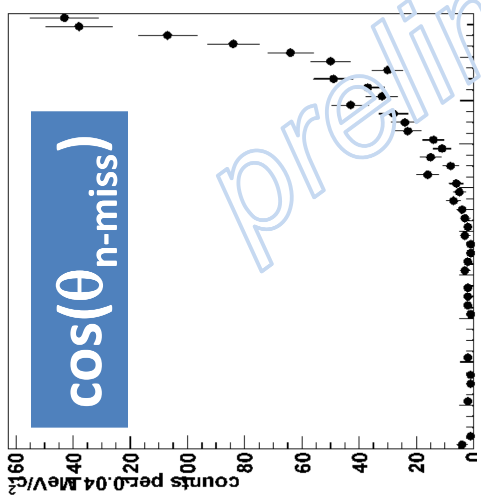
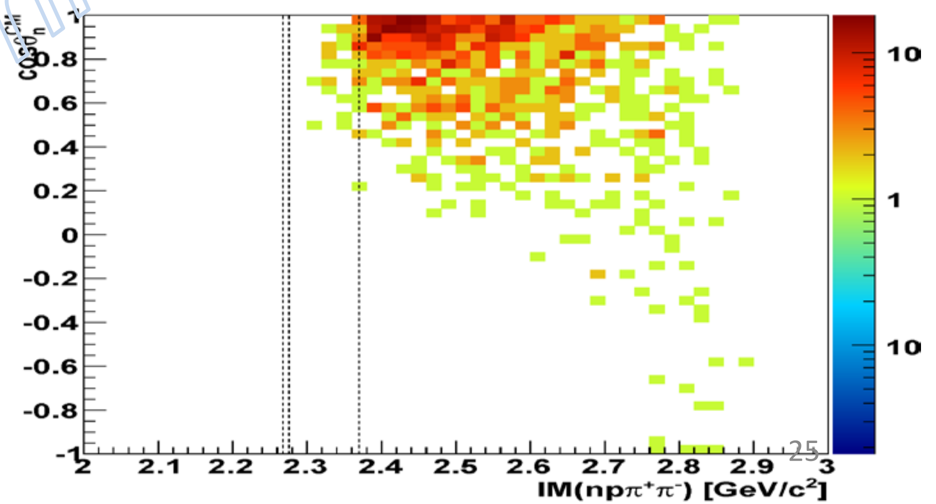


Subthreshold events seem to be suppressed!

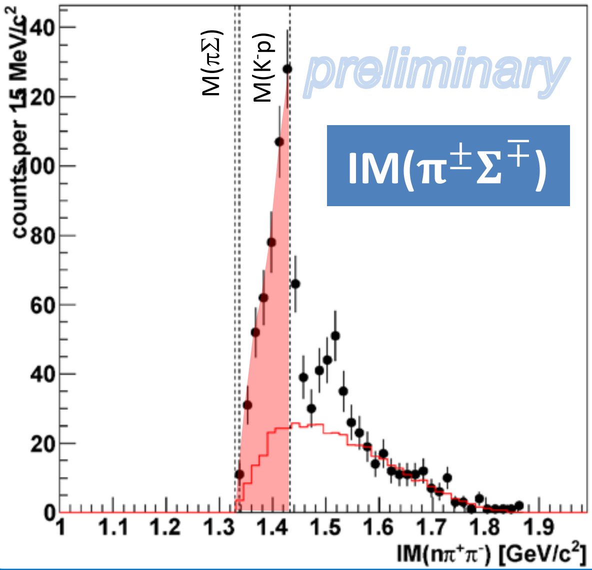


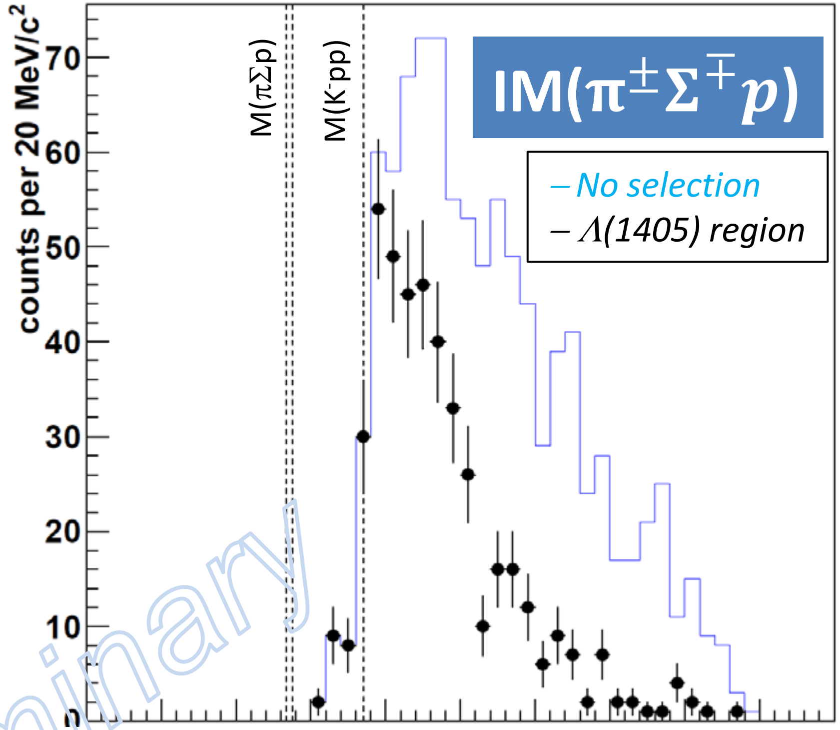


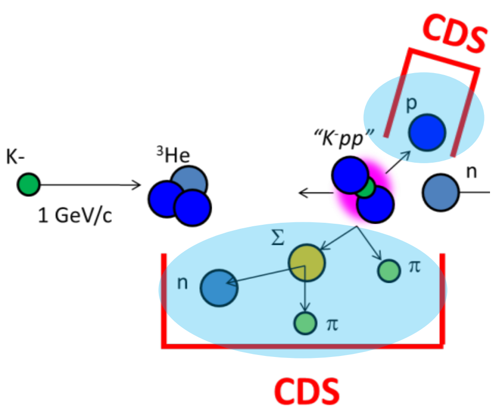


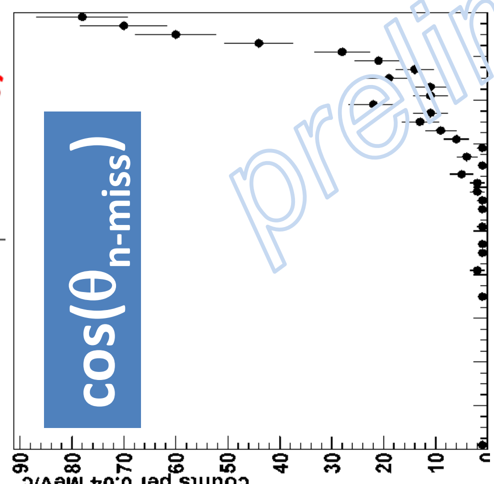
$\pi^{\pm}\Sigma^{\mp}p\ n_{miss}$ in $\Lambda(1405)$ Region

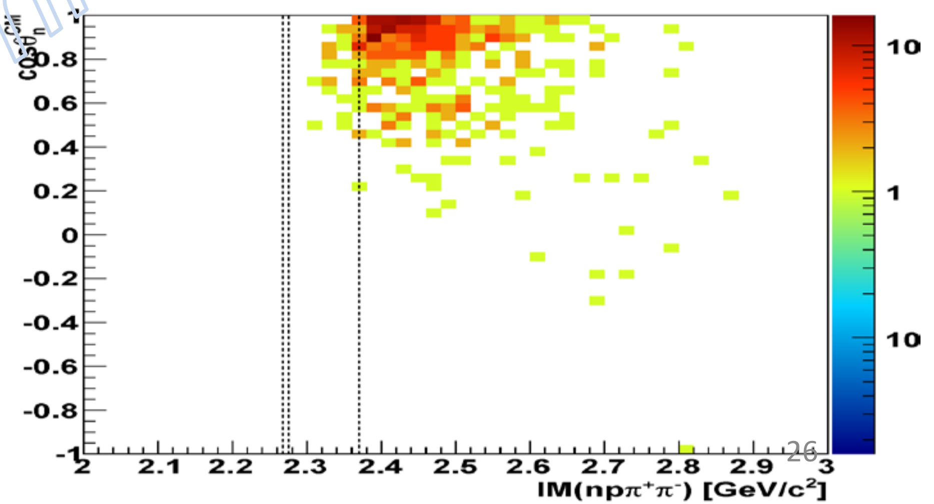
Λ(1405) region is selected
[IM($n\pi^{+}\pi^{-}$)<M($K^{-}p$)]







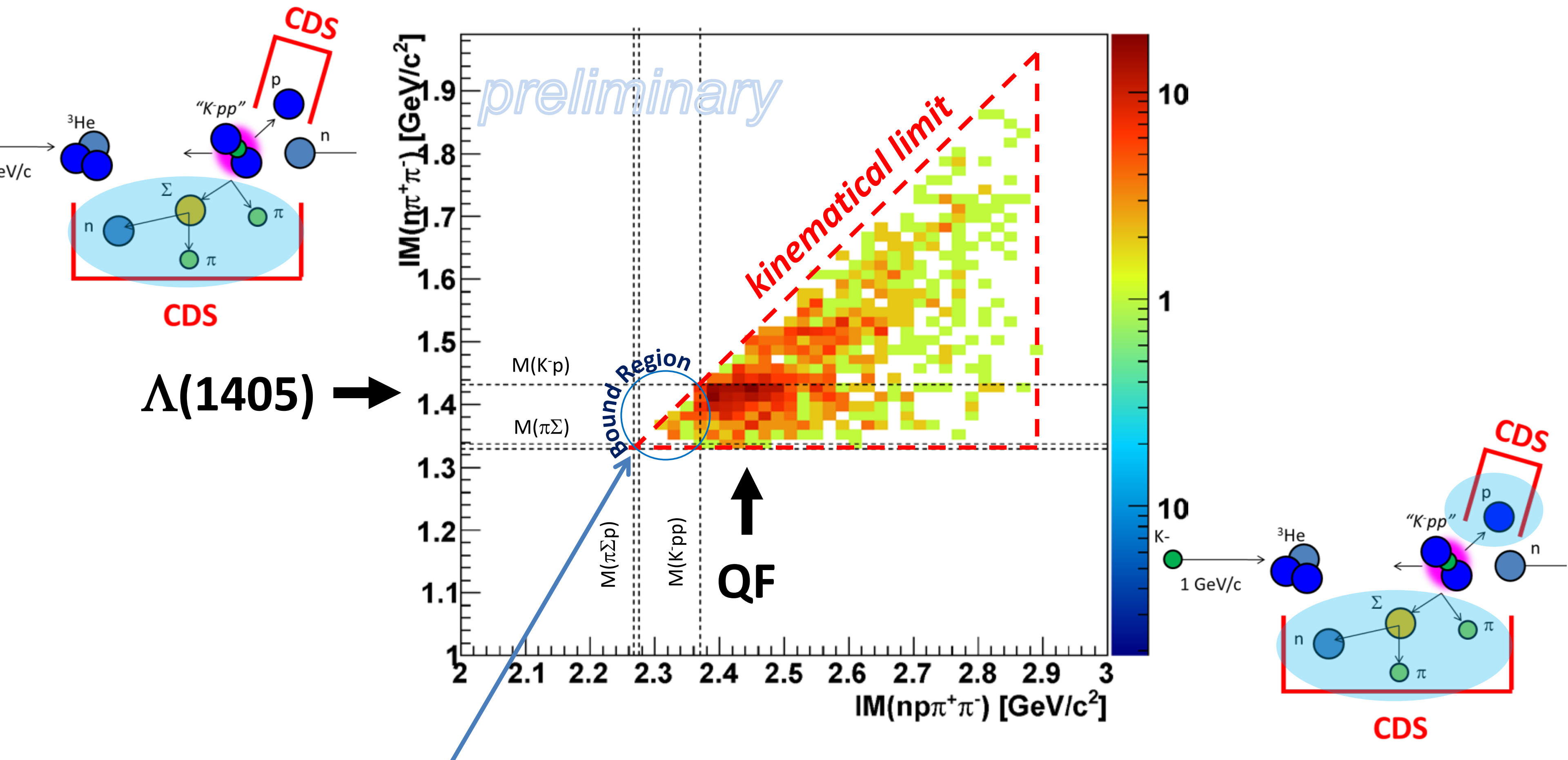




IM($\pi^{\pm}\Sigma^{\mp}$) vs. IM($\pi^{\pm}\Sigma^{\mp}p$)

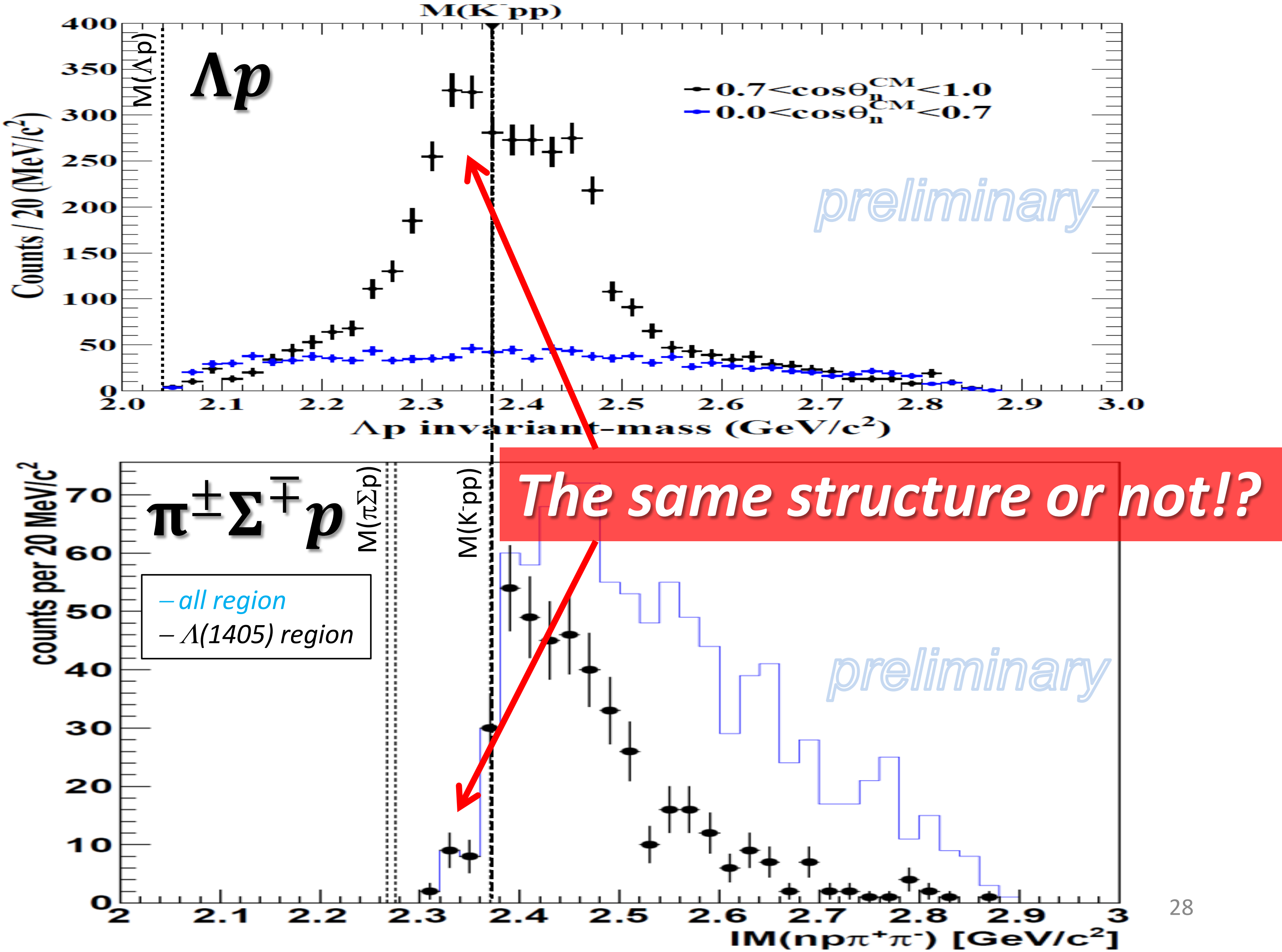
Λ(1405) and QF are strongly correlated

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



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

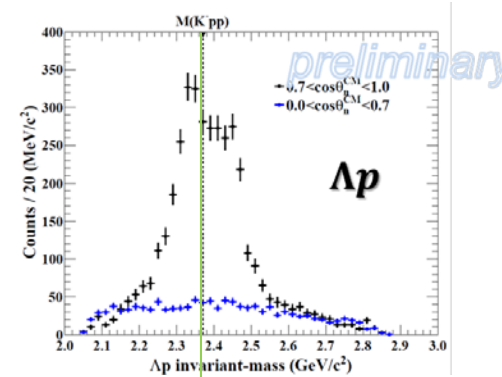
Λp vs. πΣp



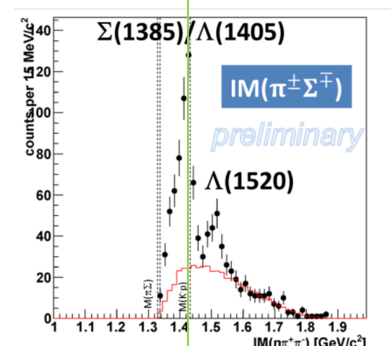
M(K⁻pp)
M(Λp)
Λp
0.7<cosΘn CM<1.0
0.0<cosΘn CM<0.7
preliminary
Counts / 20 (MeV/c²)
Λp invariant-mass (GeV/c²)
π±Σ∓p
M(πΣp)
M(K⁻pp)
– all region
– Λ(1405) region
preliminary
counts per 20 MeV/c²
IM(npπ⁺π⁻) [GeV/c²]
The same structure or not!?

Conclusion

- **Structures around the K^-pp threshold were found in $^3He(K^-,\Lambda p)n$**
  - above $M(K^-pp)$: K^-N quasi-free followed by $K^-N_sN_s \rightarrow \Lambda p$
  - below $M(K^-pp)$: would be S=-1 di-baryon decaying to Λp
    - $\Gamma(\Lambda(1405)) < \Gamma$(measured “di-baryon”)

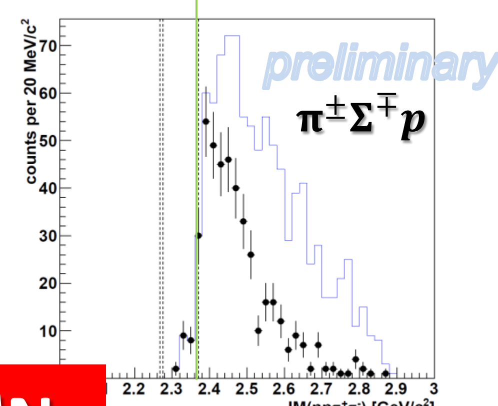


- **$\Lambda(1405)$ was clearly observed in $\pi^{\pm}\Sigma^{\mp}p\ n_{miss}$ final state**
  - Important hints of “K^-pp” production mechanism would be obtained



- **Weak structure below the K^-pp threshold was seen in $^3He(K^-,\pi^{\pm}\Sigma^{\mp}p)n$**
  - 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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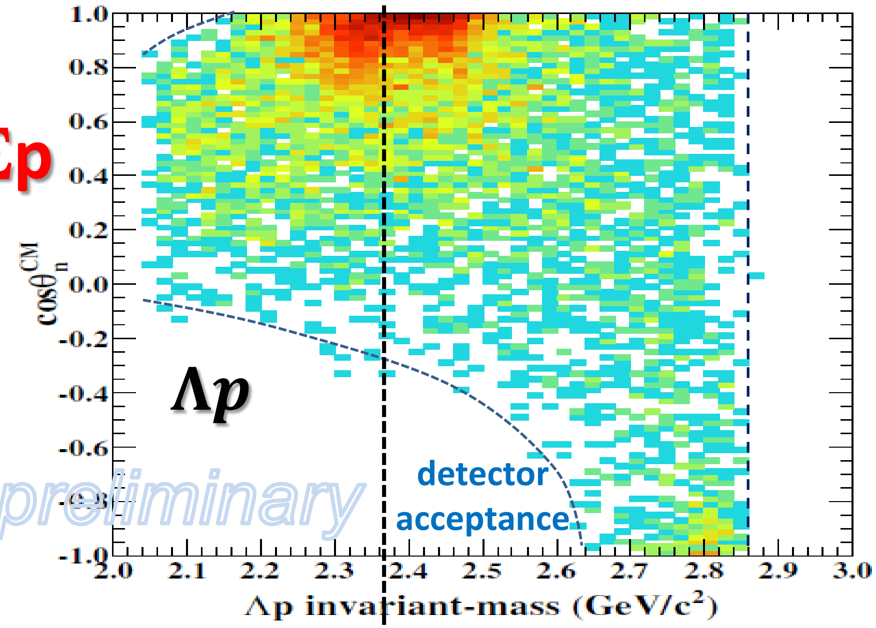
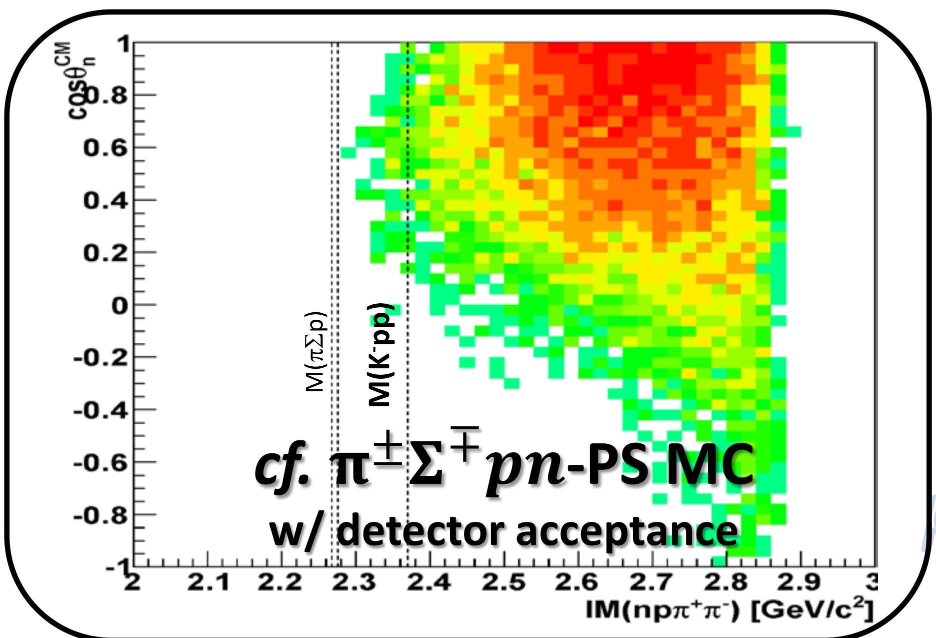
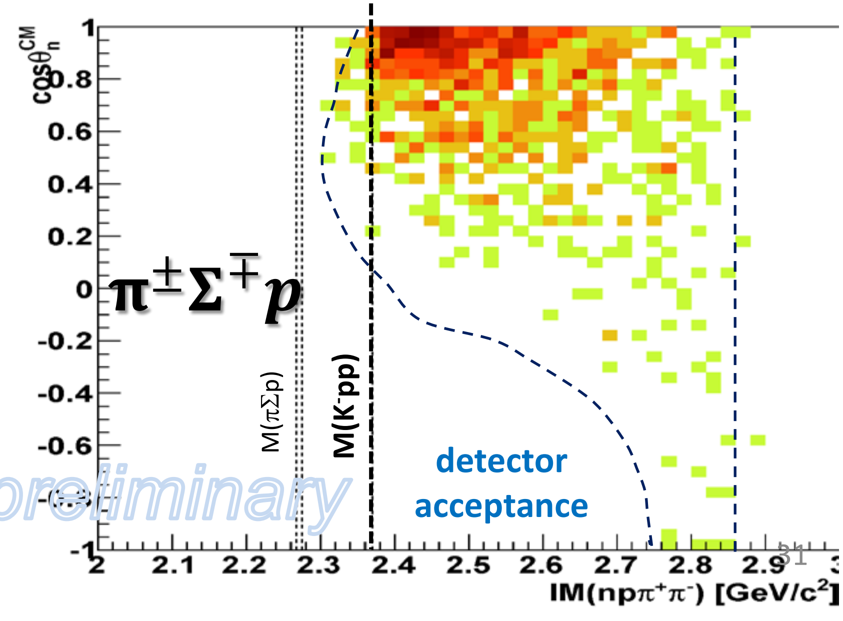
Λp vs. πΣp

- **Detector acceptance is different between Λp and πΣp**
  - At $\cos\theta_n$~1:
    - Λp: flat acceptance
    - πΣp: limited acceptance below the threshold







Acceptance of $K^{bar}NN$ Bound-State