

The latest results from J-PARC E15

F. Sakuma, RIKEN

on behalf of the J-PARC

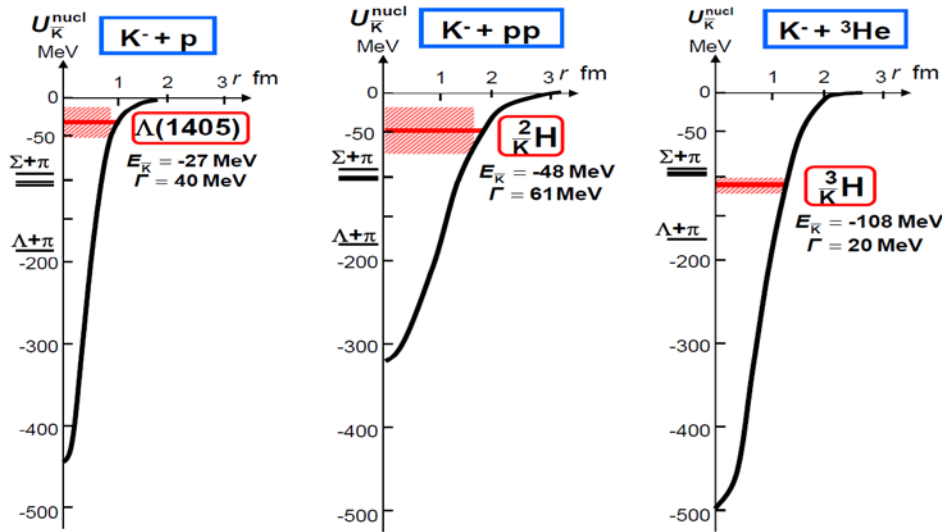
E15 collaboration



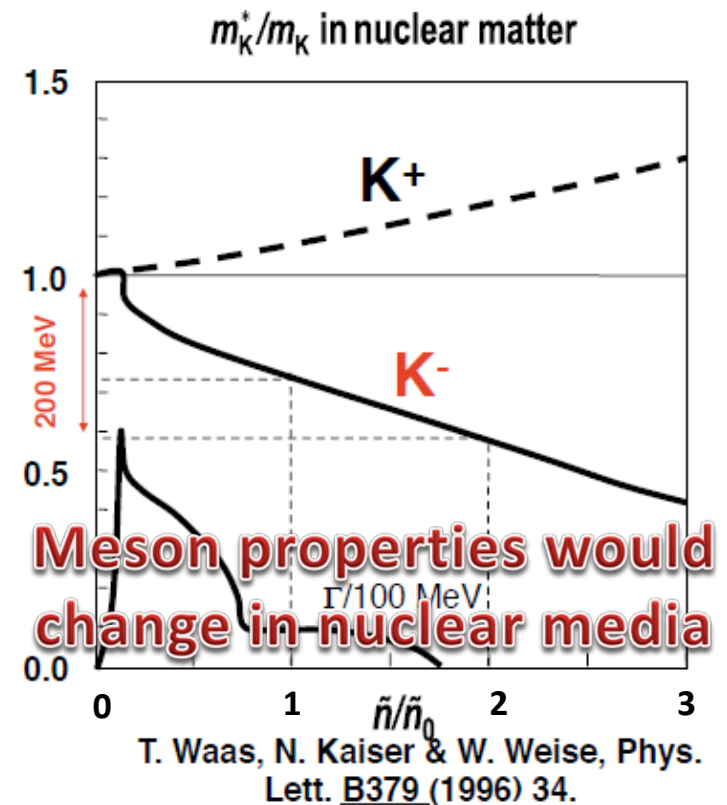
第6回「中性子星の核物質」研究会,
RIKEN, Wako, 1-3 December 2017

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).

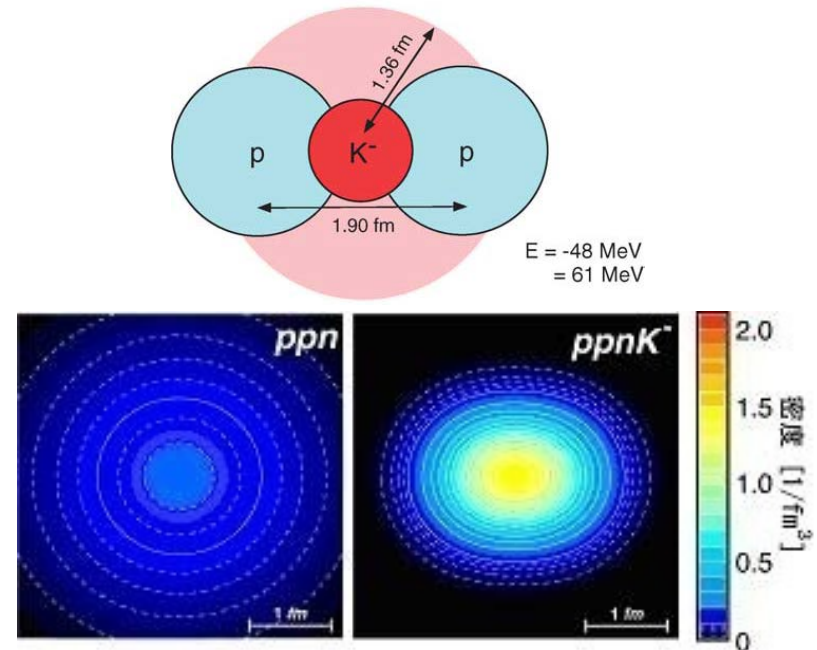


Will provide new insight of low energy QCD

Kaonic Nuclei

the density of kaonic nuclei is predicted to be
extreme high density

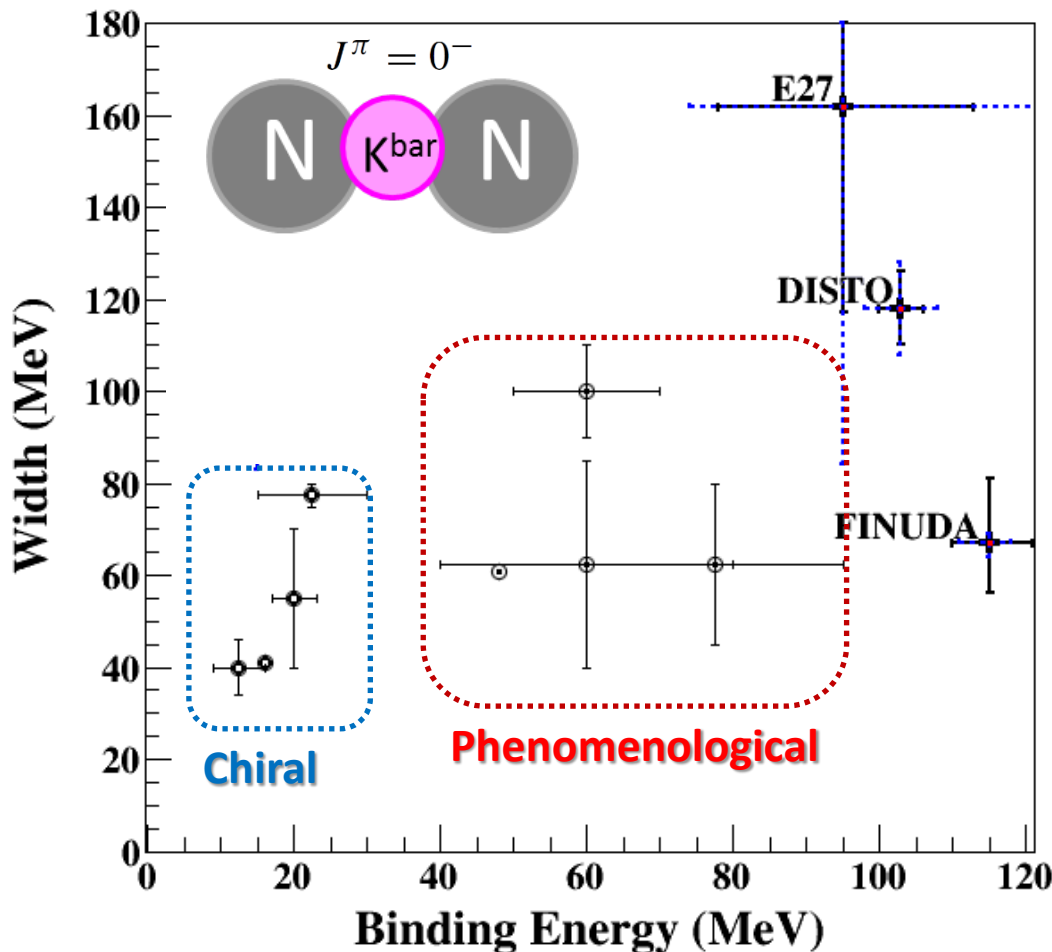
Kaonic Nuclei	Binding Energy [MeV]	Width [MeV]	Density
K ⁻ p	27	40	3.5ρ ₀
K ⁻ pp	48	61	3.1ρ ₀
K ⁻ ppp	97	13	9.2ρ ₀
K ⁻ ppn	118	21	8.8ρ ₀



T.Yamazaki, A.Dote, Y.Akaiishi PLB587,167(2004).

we will open new door to the condensed matter
physics, like the inside of neutron stars

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



- **Binding energy**

- Chiral:

- B.E. ~ 20MeV**

- Phenomenological:

- B.E. ~ 40-80MeV**

- FINUDA/DISTO/E27

- (if $K^{\text{bar}}NN$):**

- B.E. ~ 100MeV**

- **Width**

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

- Theor.: mesonic decay

- Exp.: non-mesonic decay

Upper limits were also obtained:

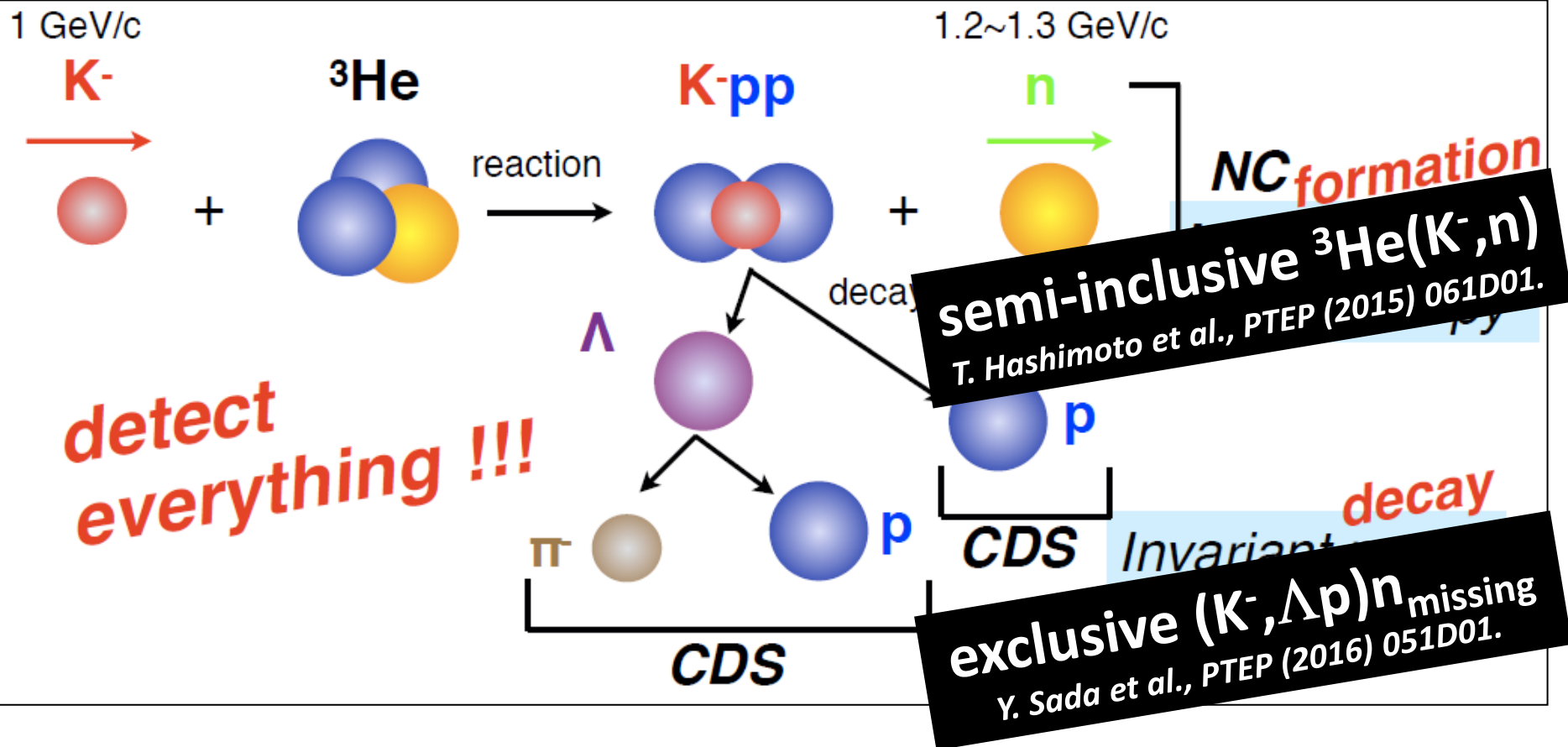
- LEPS@SPRing8 [Inclusive $d(\gamma, K^+\pi^-)X$]
- HADES@GSI [Exclusive $pp \rightarrow p\Lambda K^+$]

J-PARC E15 Experiment

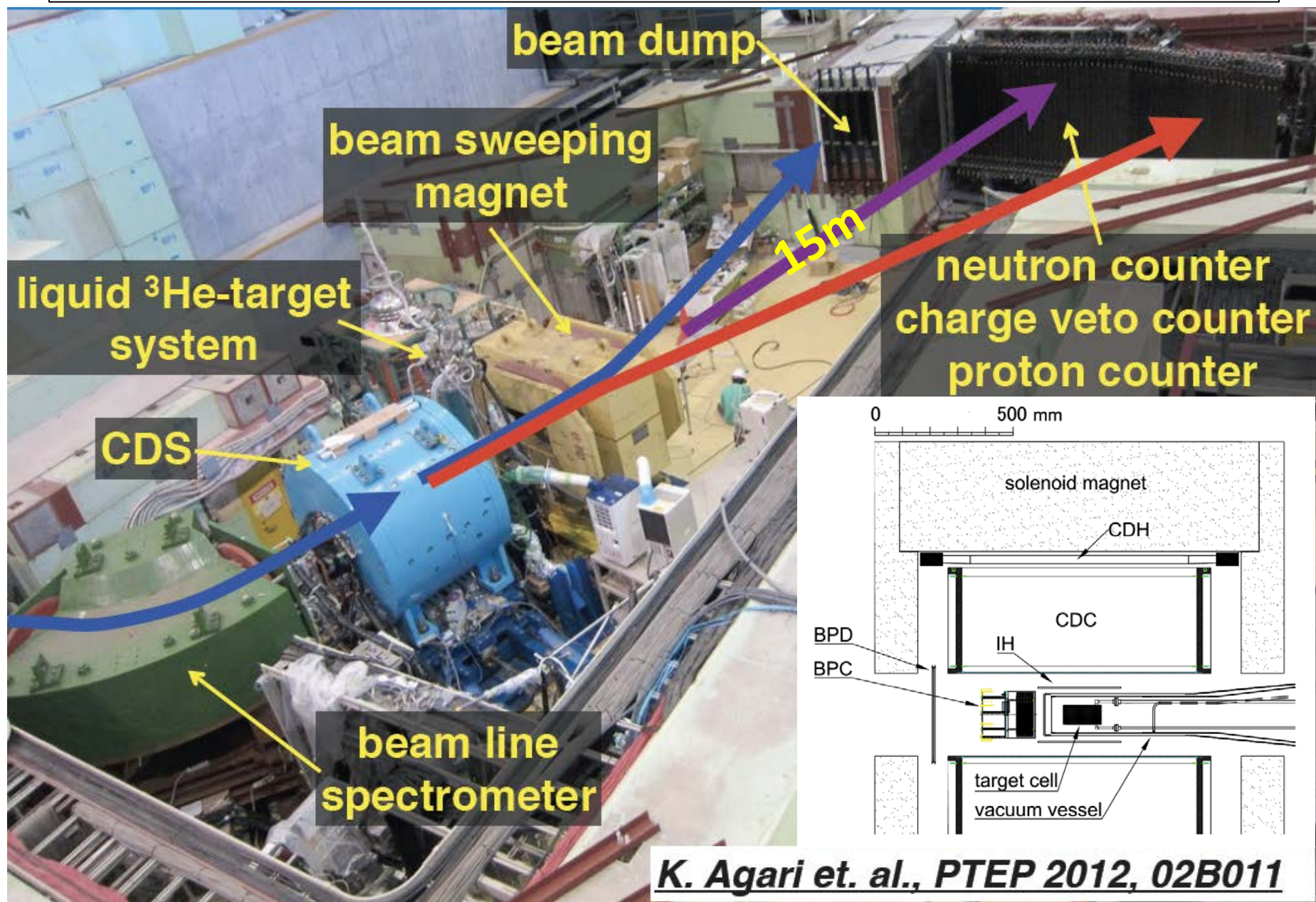
- ${}^3\text{He}(\text{in-flight } K^-, n)$ reaction @ 1.0 GeV/c



2NA processes and Λ decays can be discriminated kinematically



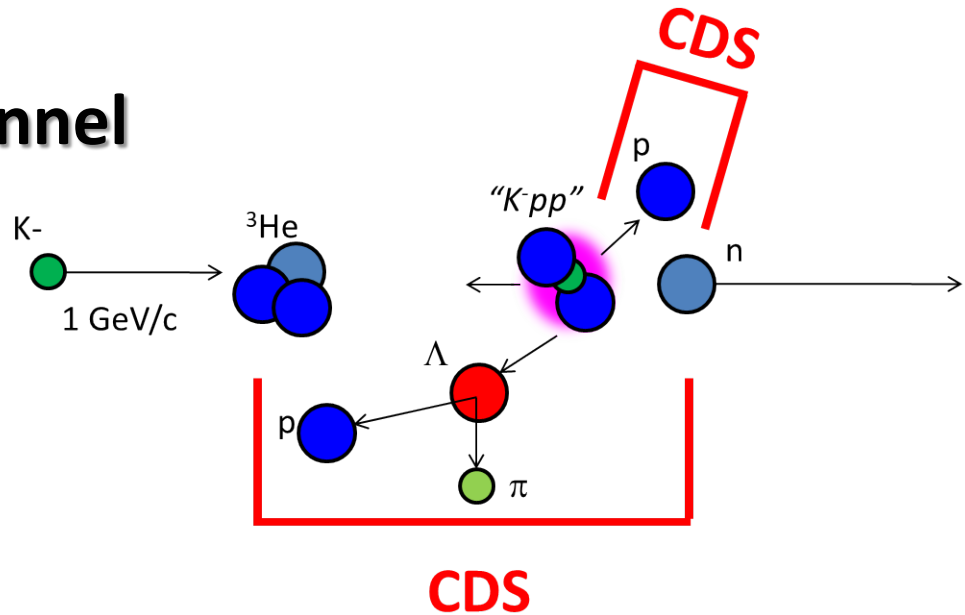
Experimental Setup for E15



Outline of the Talk

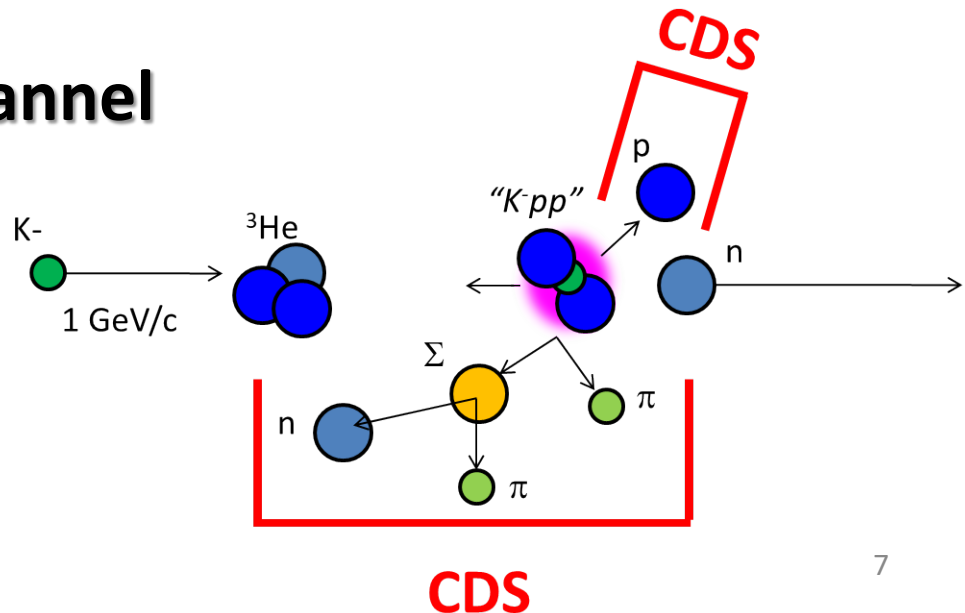
1. K^{bar} NN search via Λp channel

→ Non-mesonic channel



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

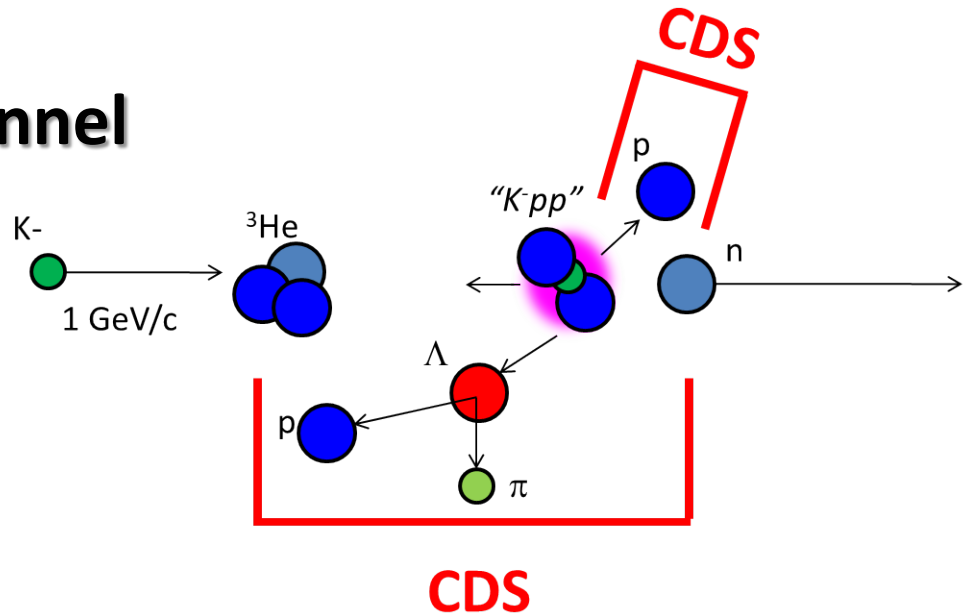
→ Mesonic channel



Outline of the Talk

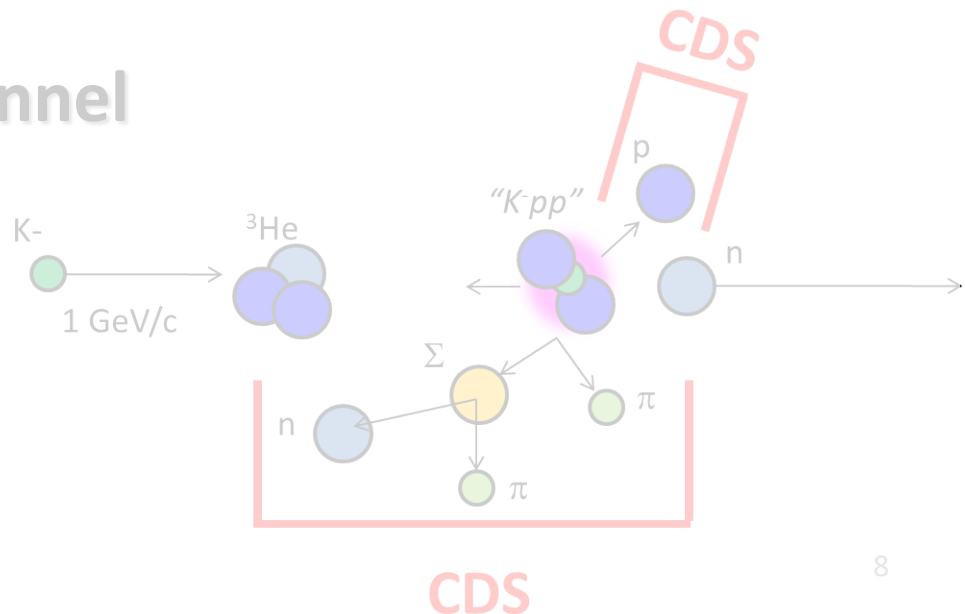
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2. K^{bar} NN search via $\pi\Sigma p$ channel

→ Mesonic channel



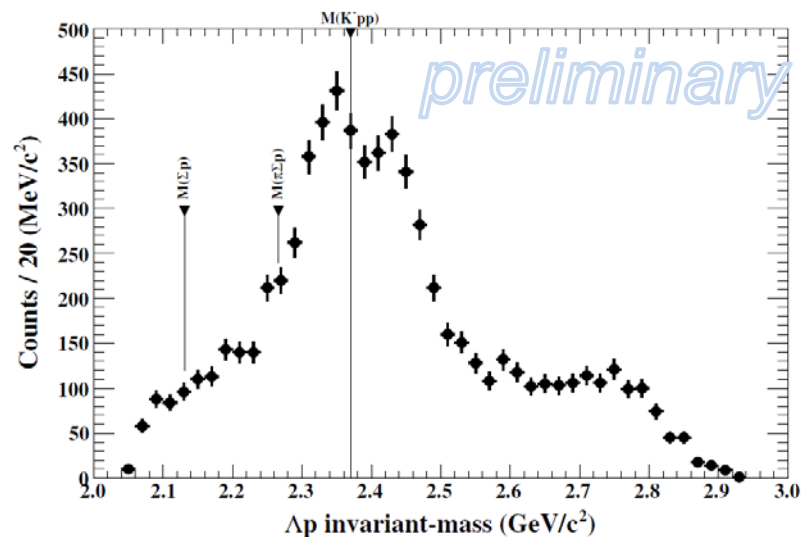
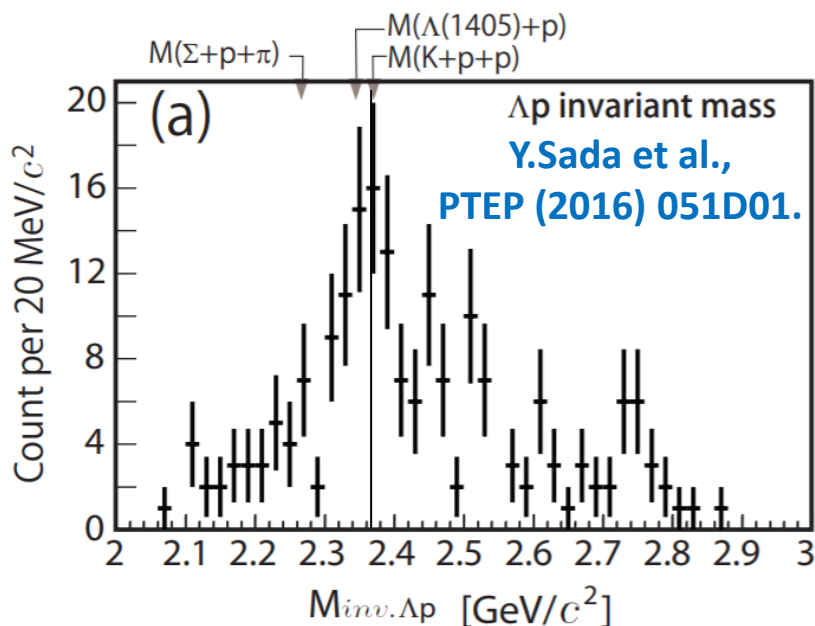
Exclusive ${}^3\text{He}(\text{K}^-, \Lambda p)\text{n}$ in E15-2nd

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

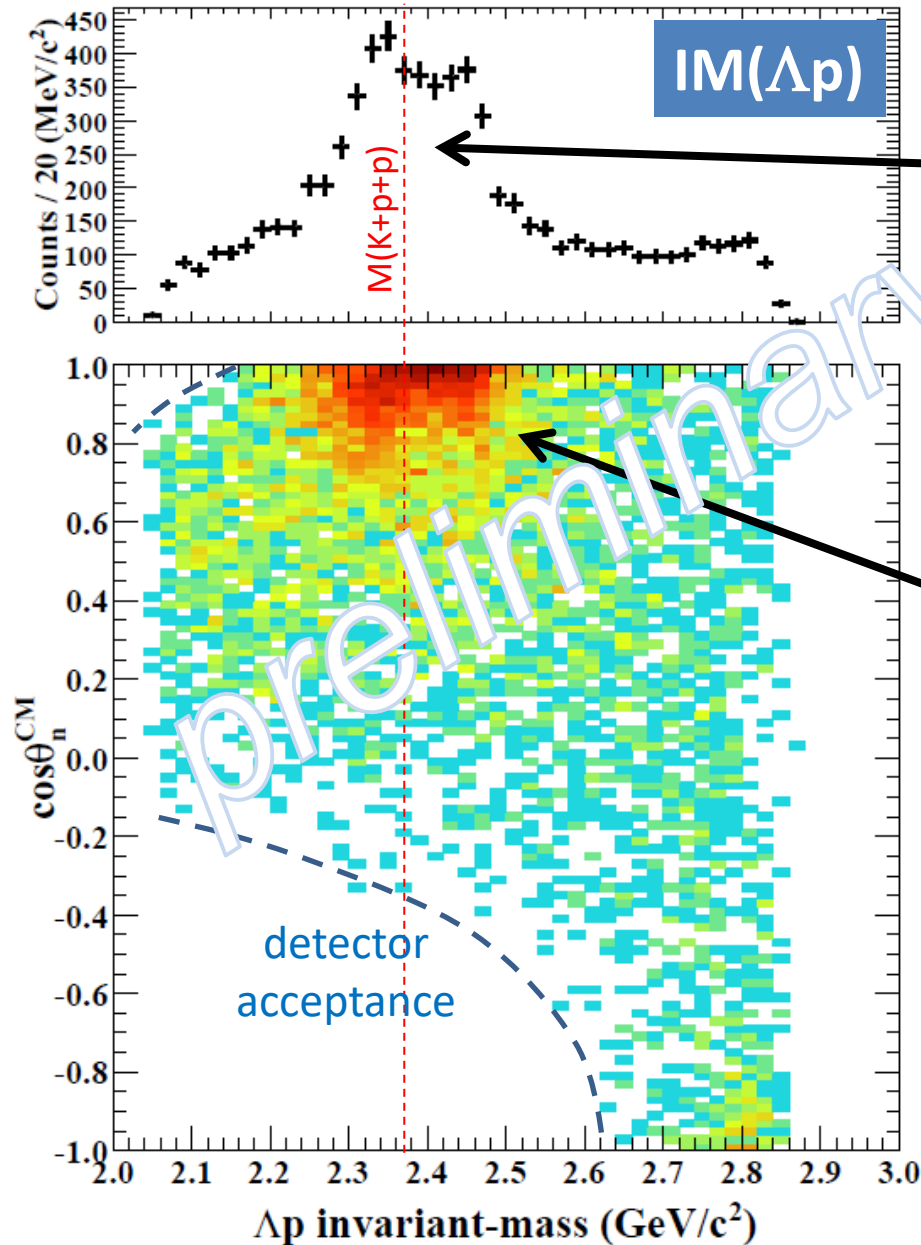
E15^{1st}

$\rightarrow \sim 30$ times more data*

E15^{2nd}



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

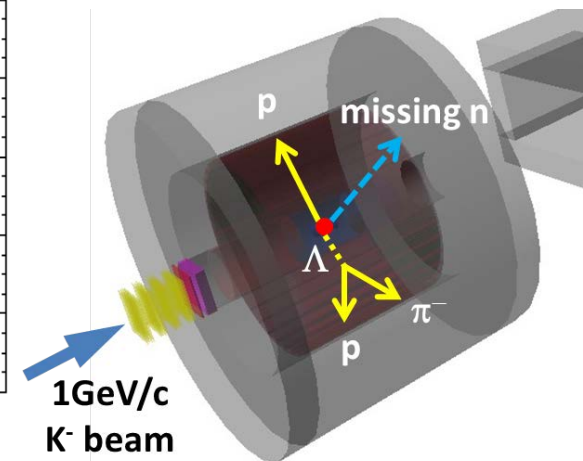


Structures around the Kpp threshold can be seen
= **bound-state + QF**

Counts / 0.02
200 400 600

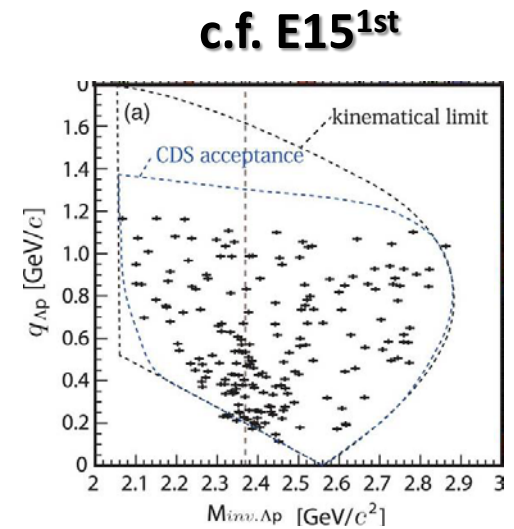
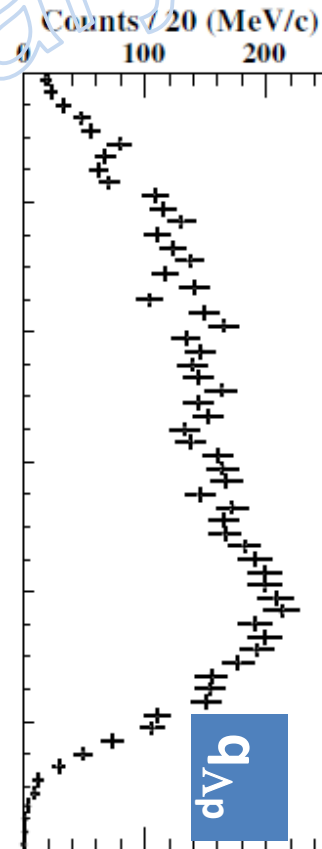
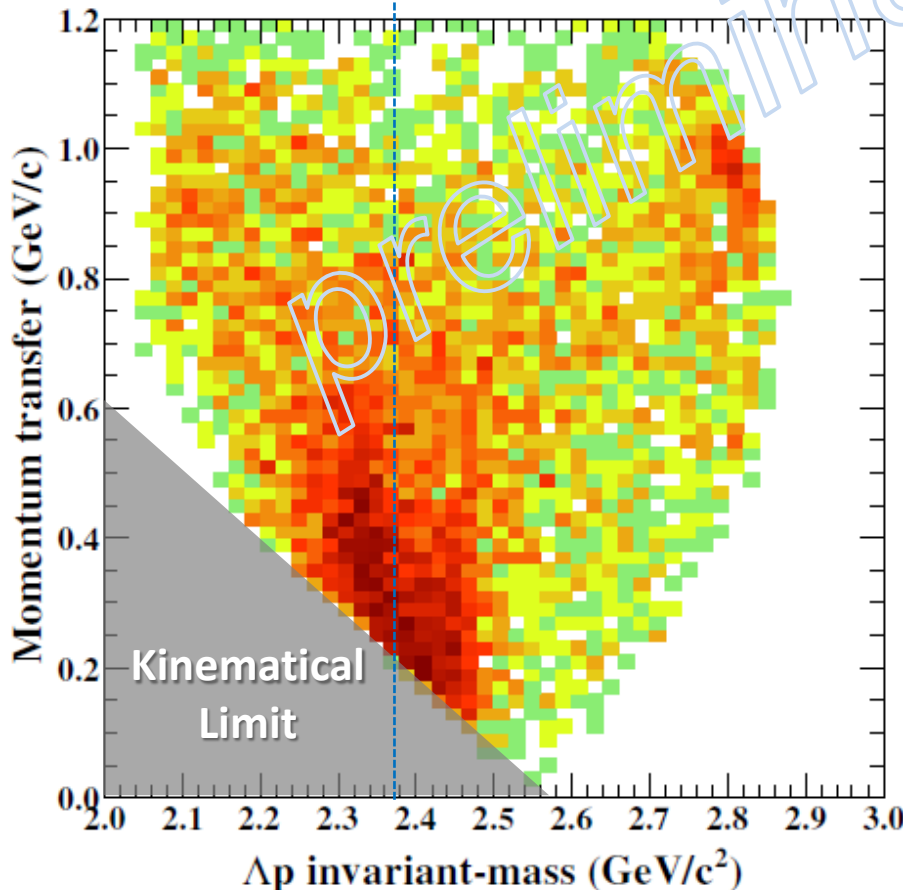
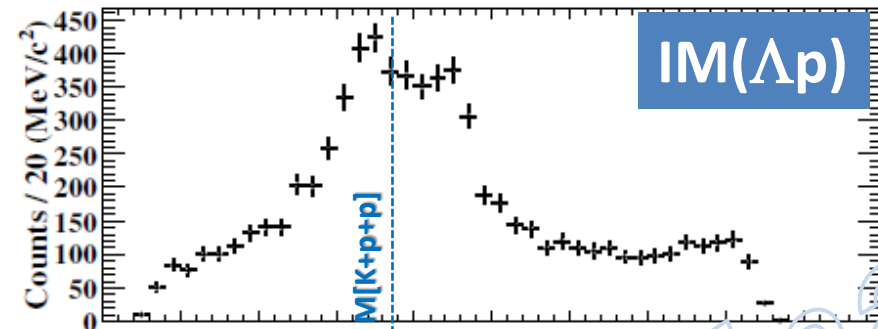
Structures are concentrated
in forward-n region
= **small momentum-transfer**

$\cos(\theta_n)$



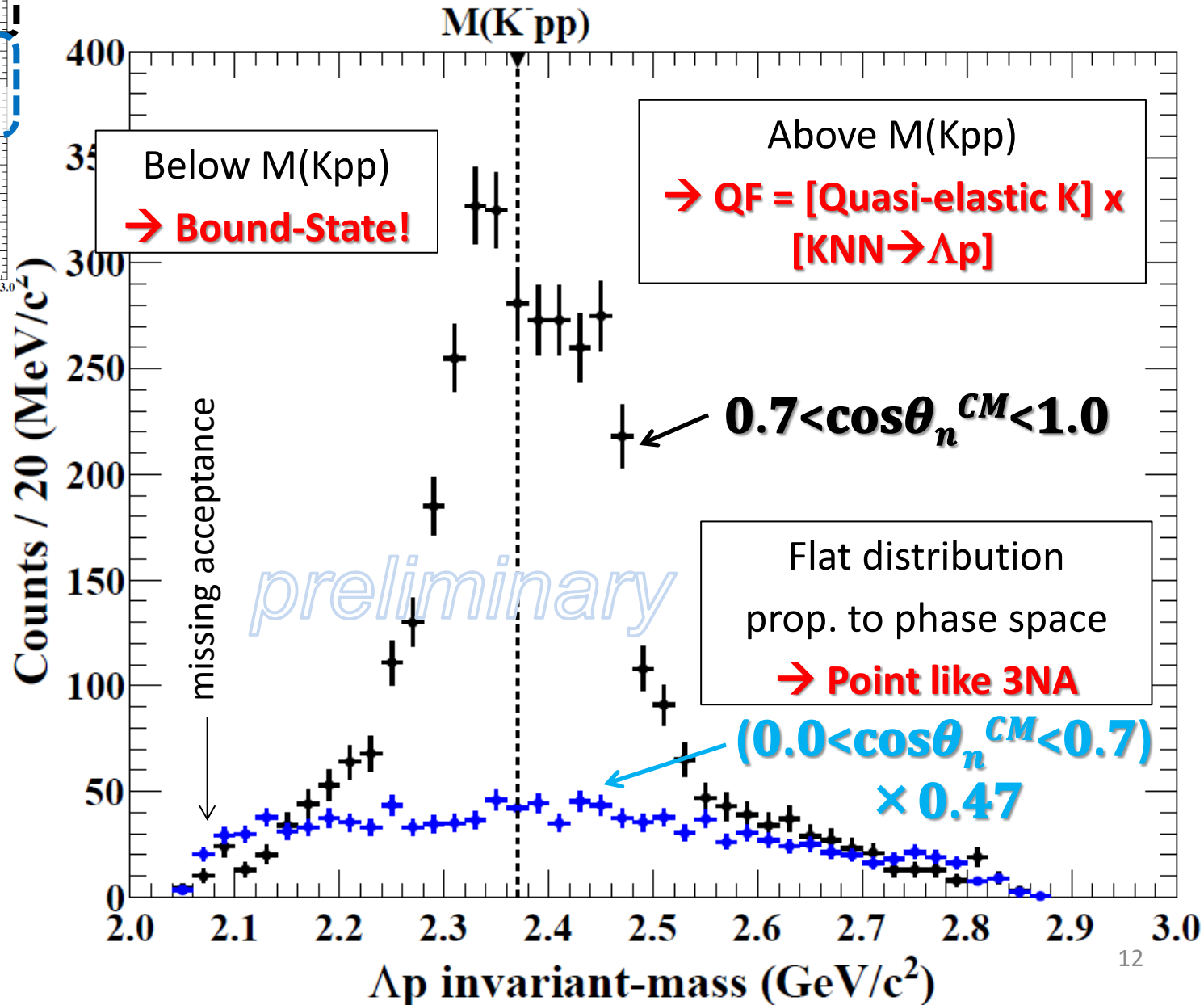
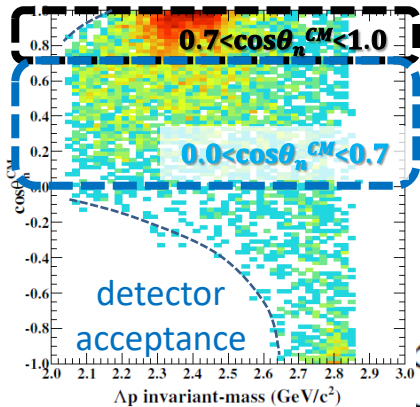
Momentum Transfer

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

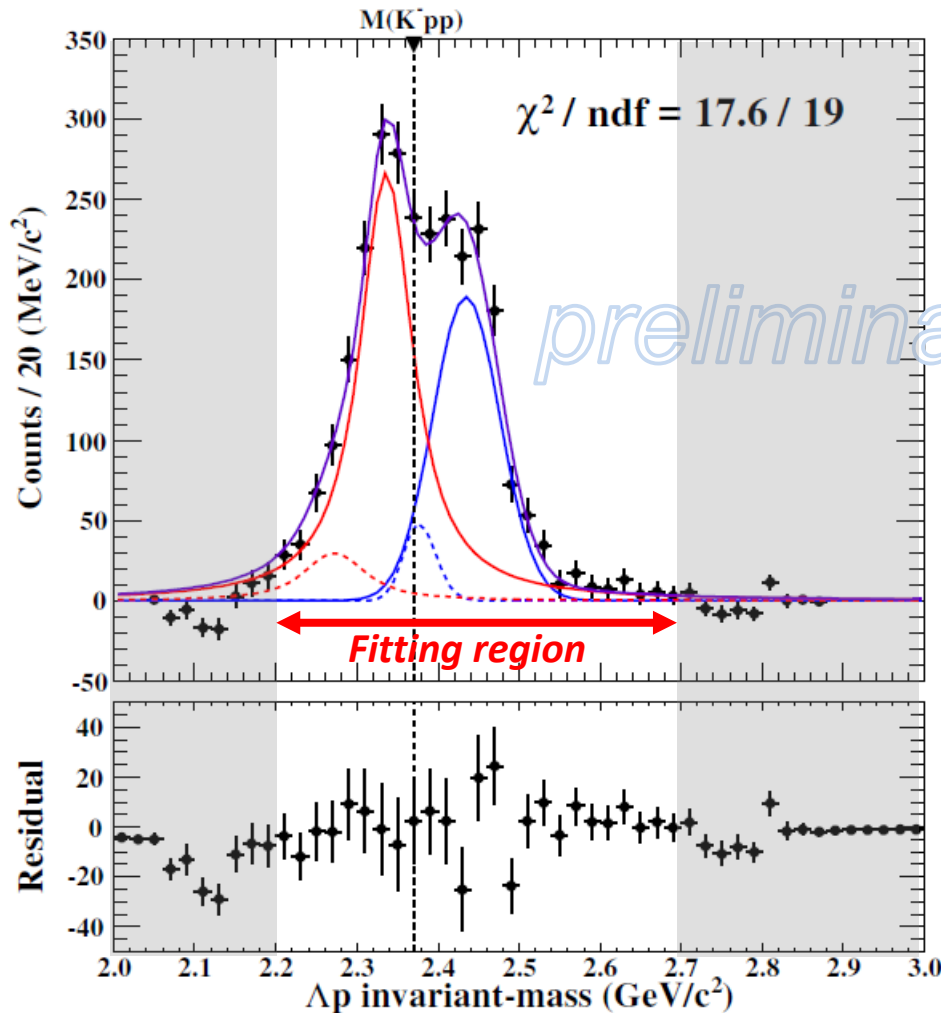


Consistent with E15^{1st}

Structures in Forward-n Region



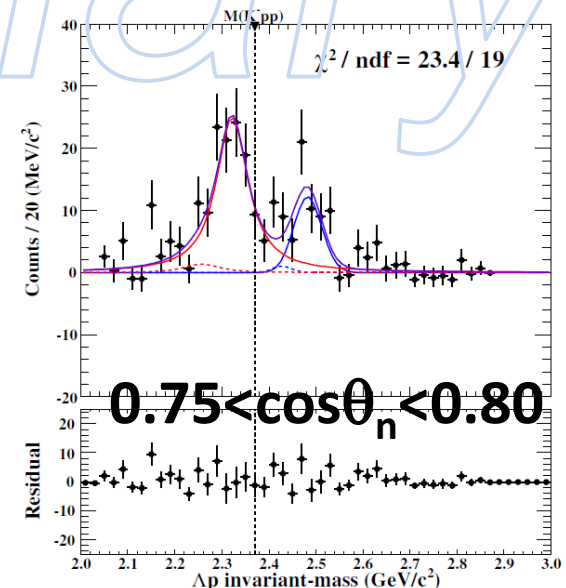
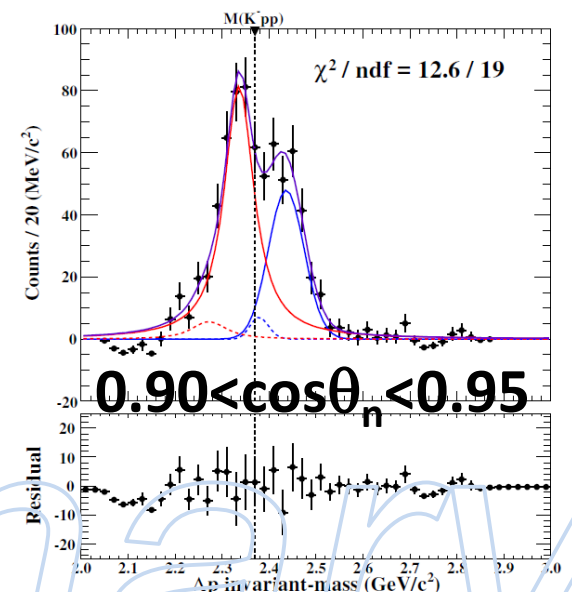
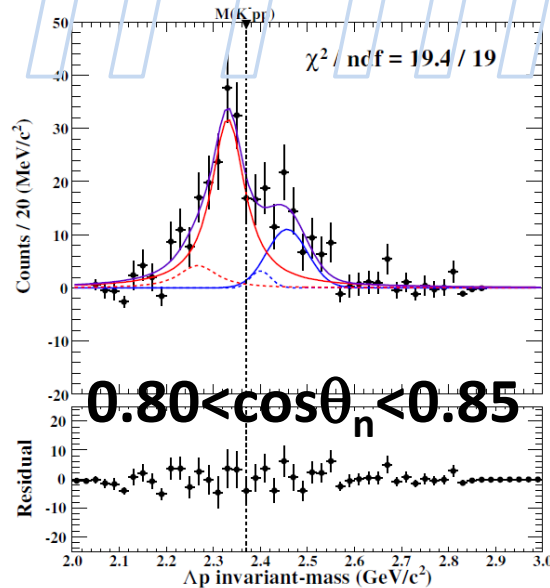
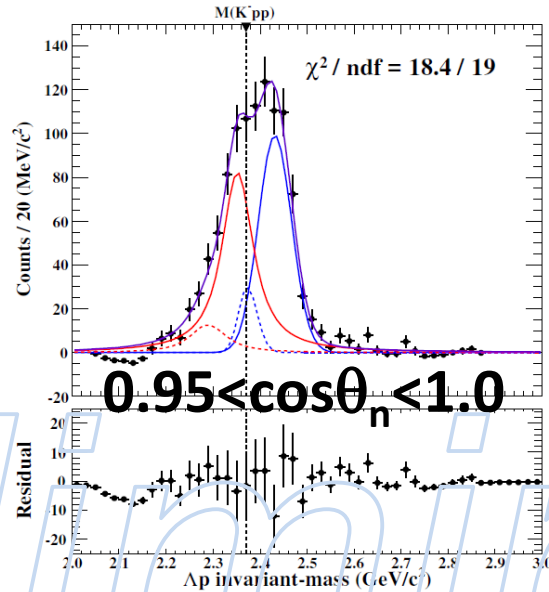
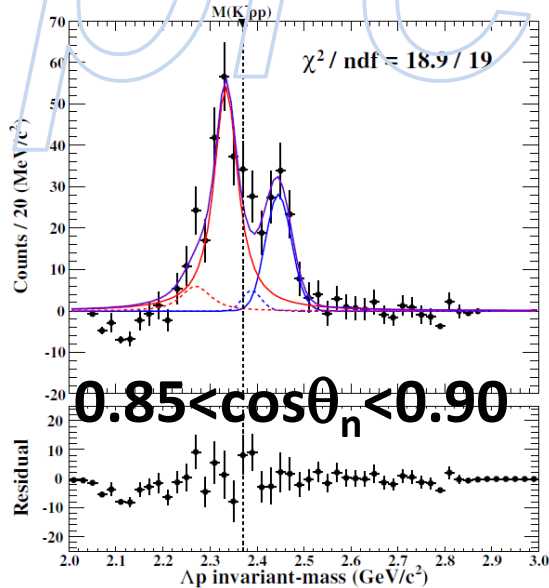
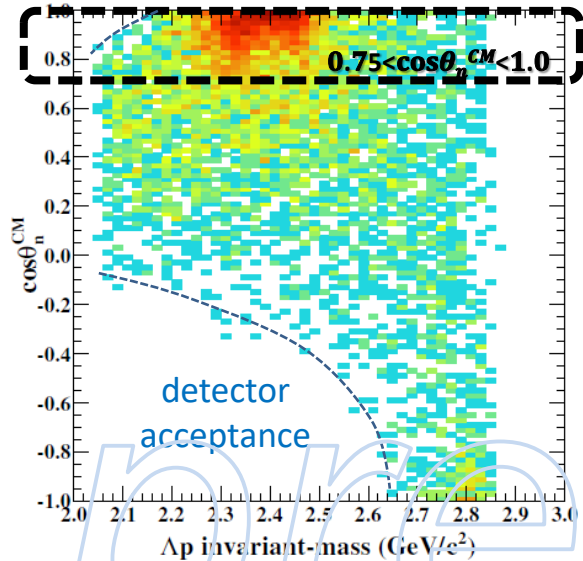
Fitting with BW and Gaussian



- 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

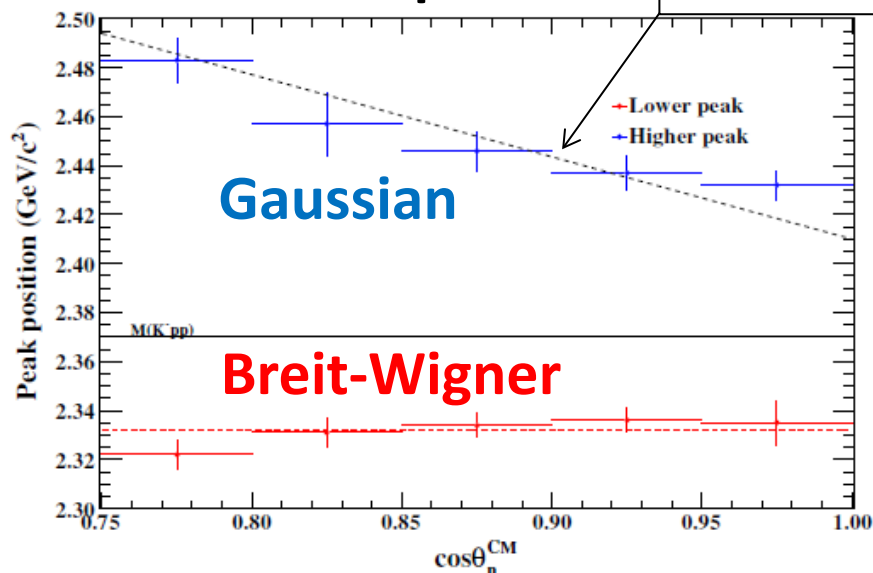
$\cos\theta_n$ dependence



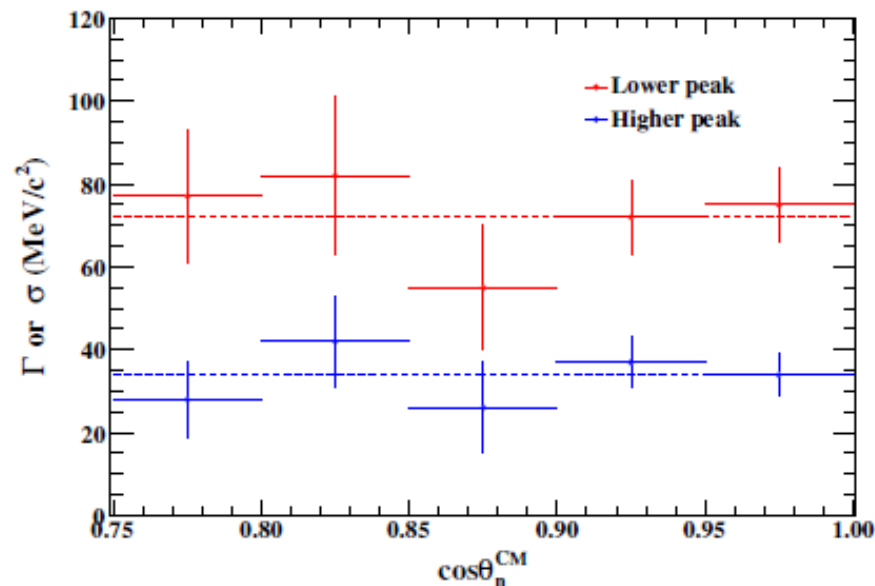
Reaction Angle Dependence

Peak position

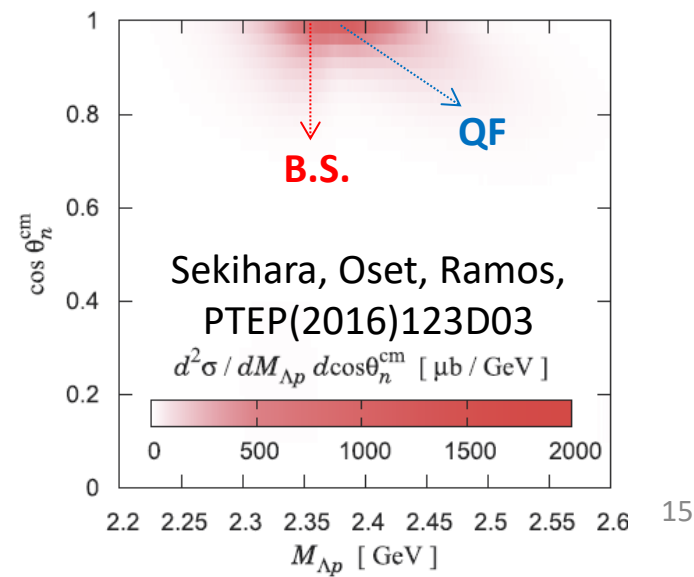
$$M_{QF} = M_{K^-pp} + \frac{q^2}{2M_{K^-}}$$



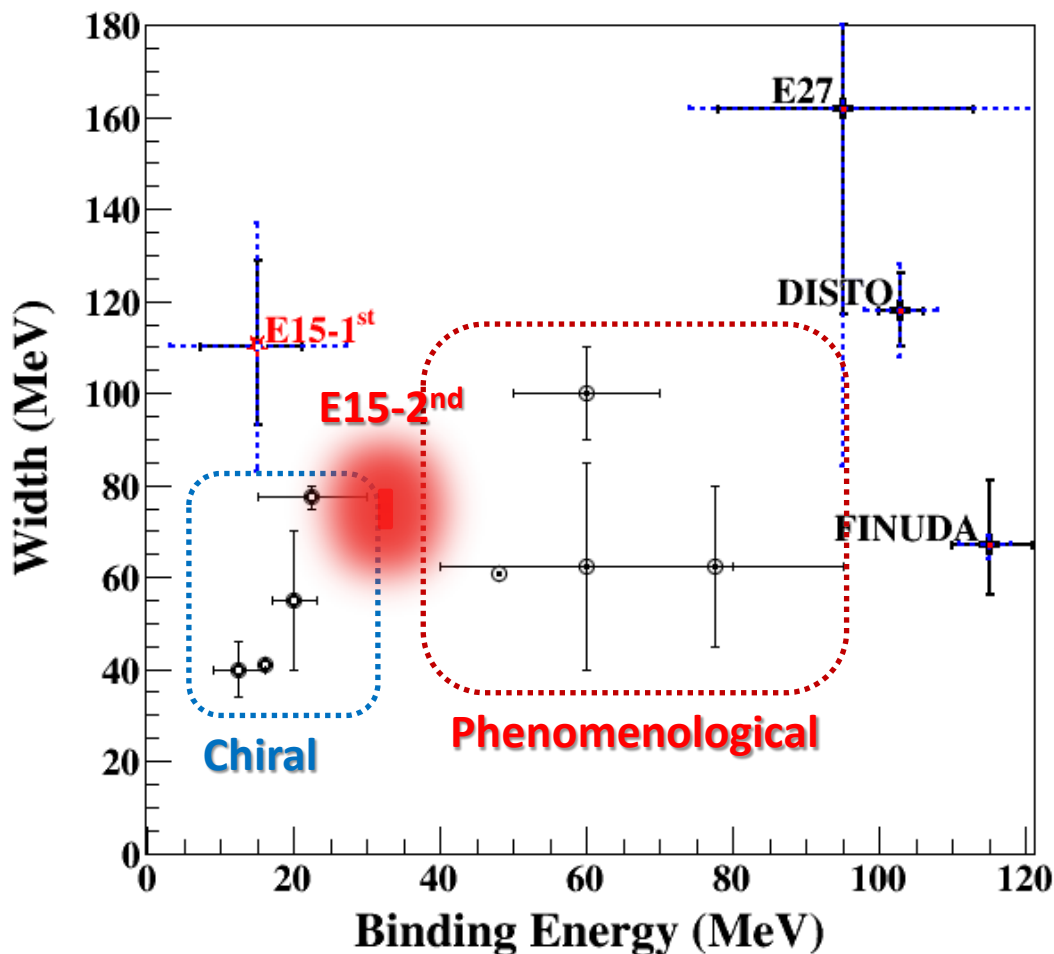
Width



- 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.

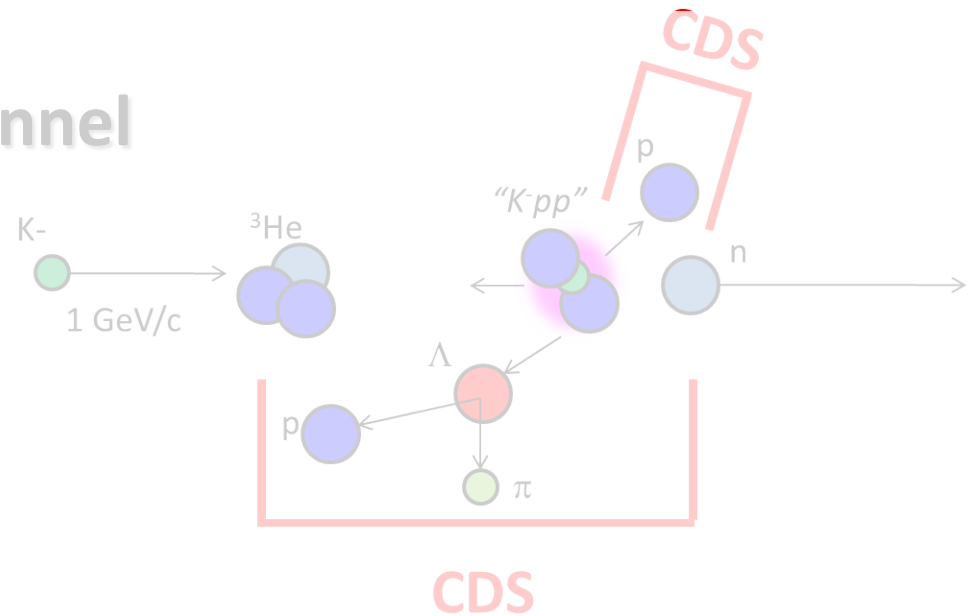
For further understanding:

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

Outline of the Talk

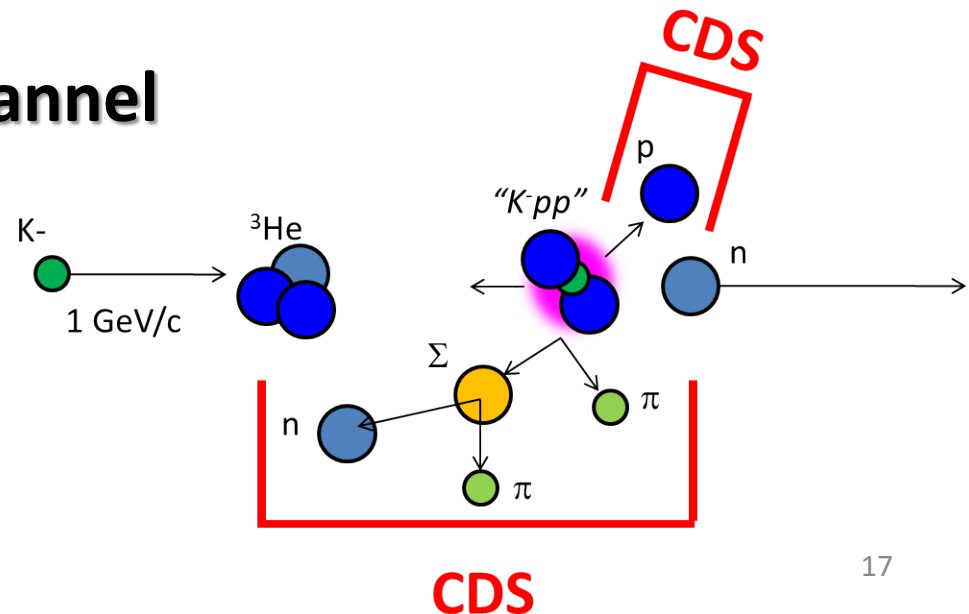
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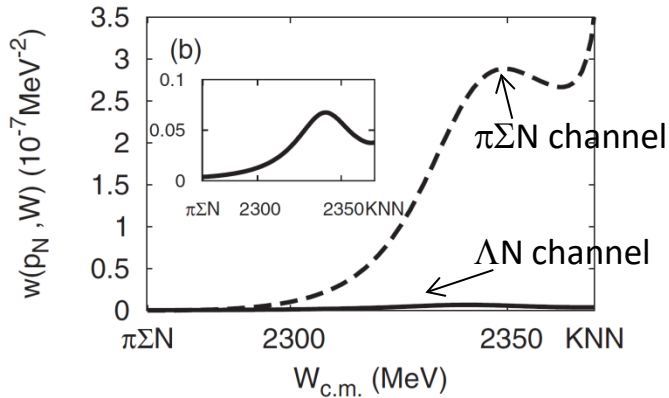
→ Mesonic channel



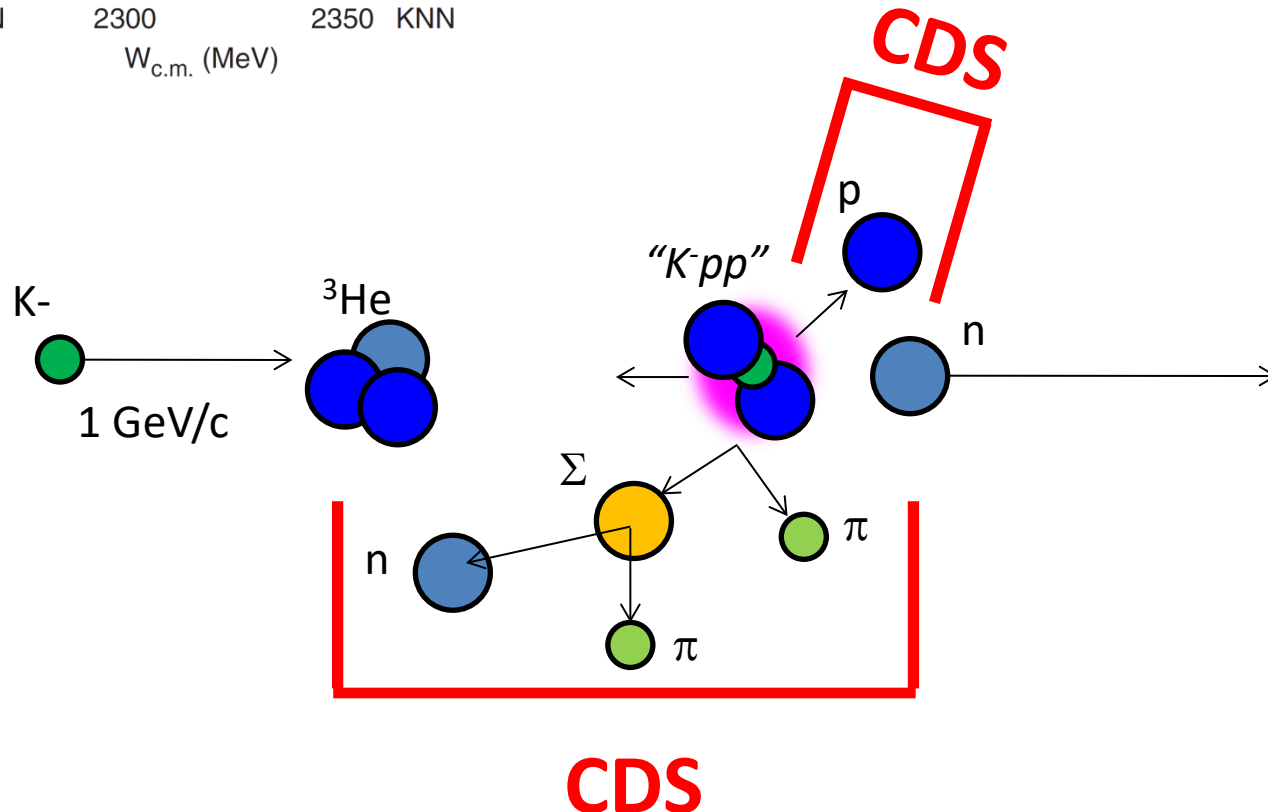
“K⁻pp” → $\pi\Sigma N$ Decay Channel

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

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

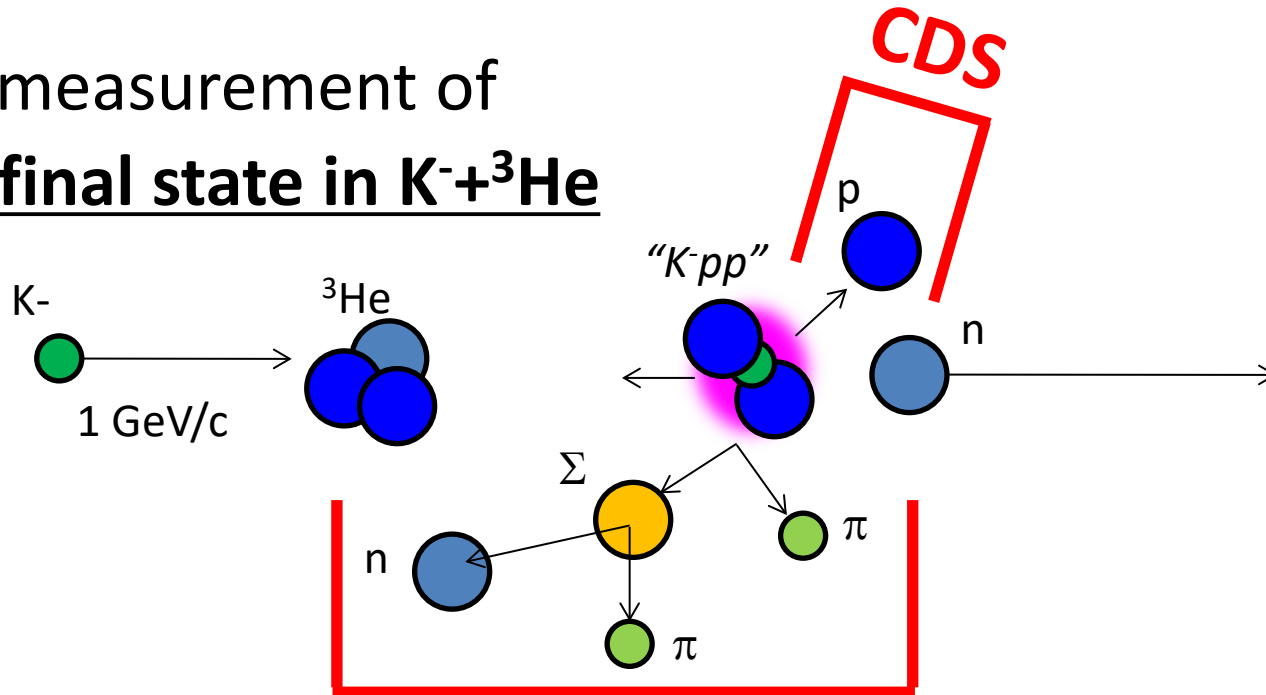


Theoretically,
 $\pi\Sigma N$ decay is expected to be
the dominant channel



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

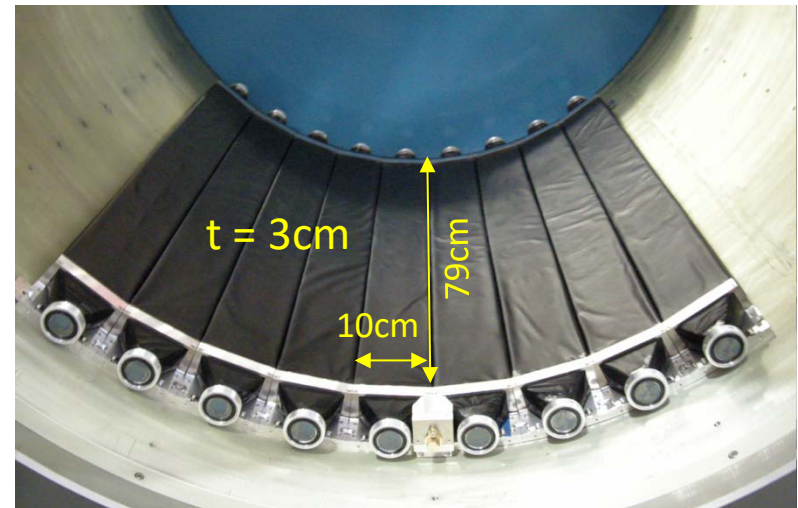
- Exclusive measurement of $\pi^\pm \Sigma^\mp pn$ final state in $K^- + {}^3\text{He}$



CDS

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

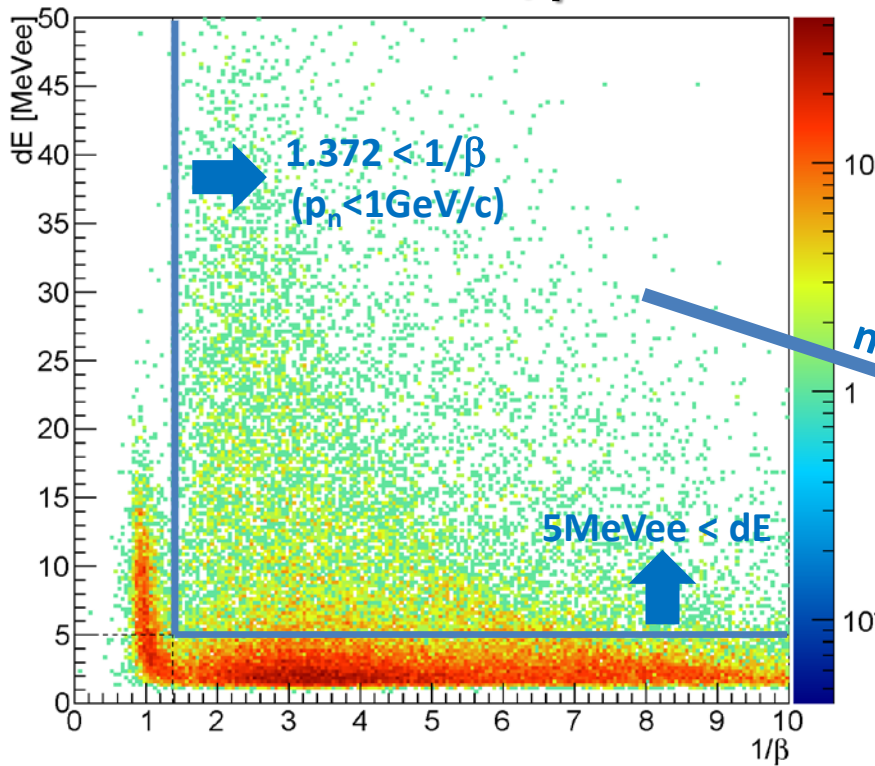
n detection efficiency $\sim 3\%$



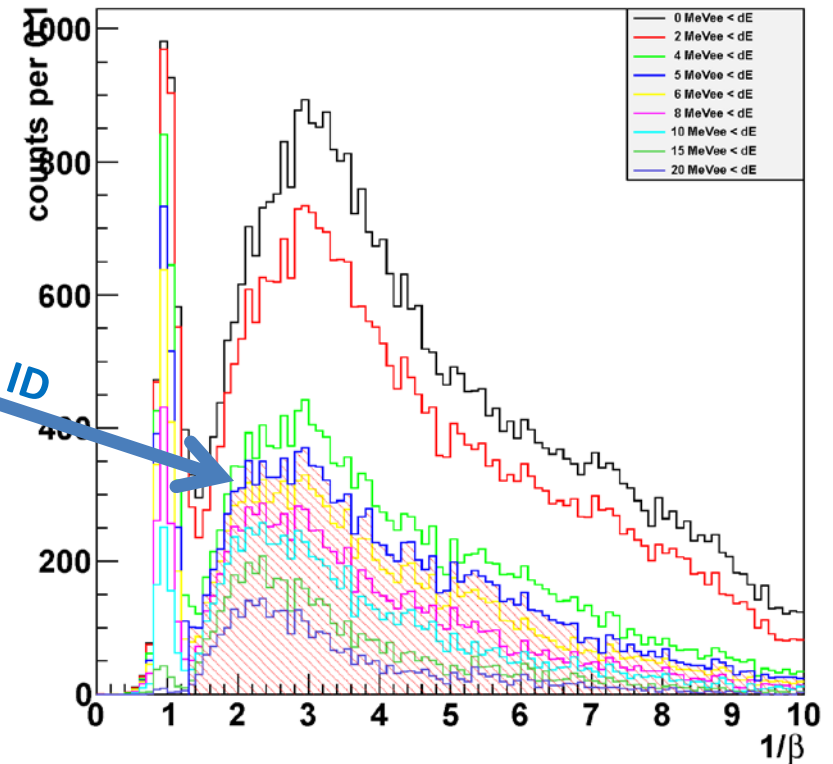
Neutron ID with CDS

- $\pi^+\pi^-p$ 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. $1/\beta$

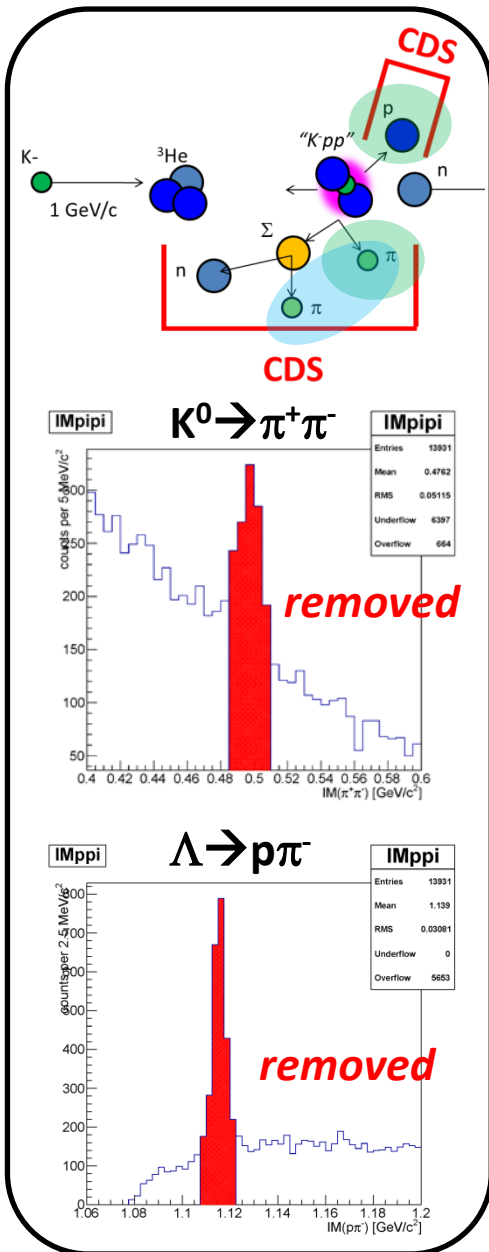


dE-cut dependence

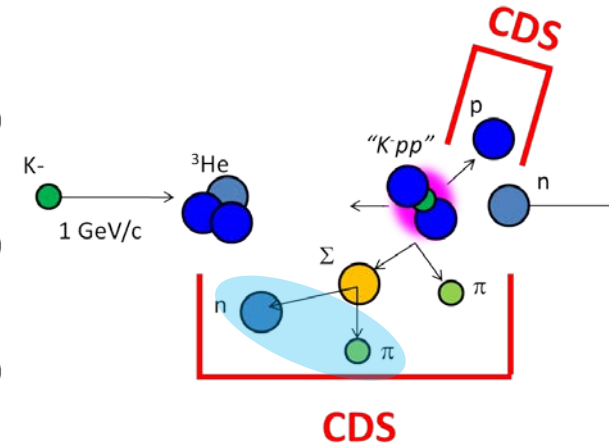
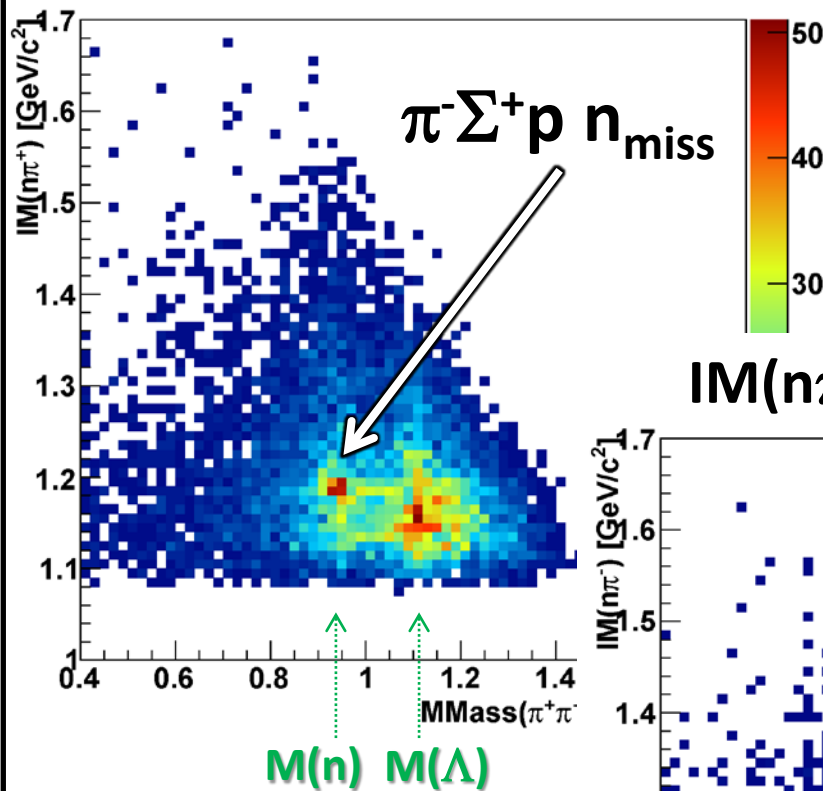


Neutron can be identified with CDS

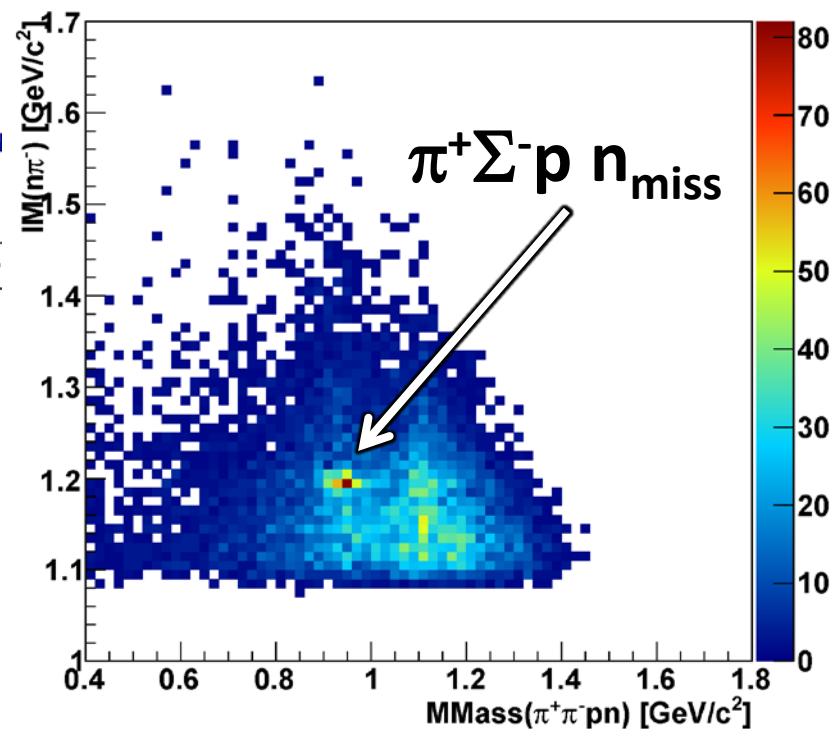
$\pi\Sigma pn$ Events



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

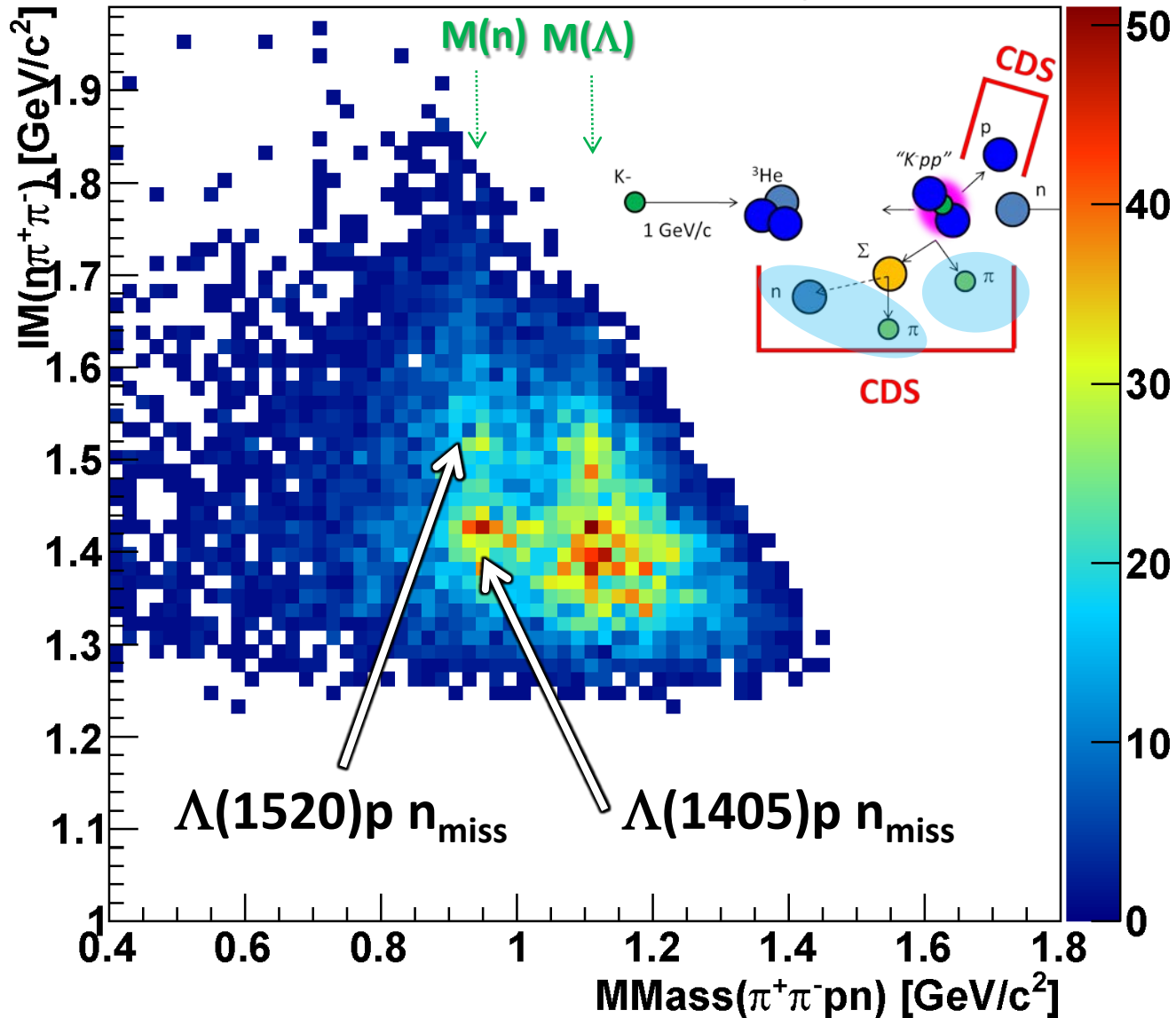


IM($n\pi^-$) vs MM($\pi^+\pi^-pn$)



Λ^* pn Events

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



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

Event Selection

Missing n:

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

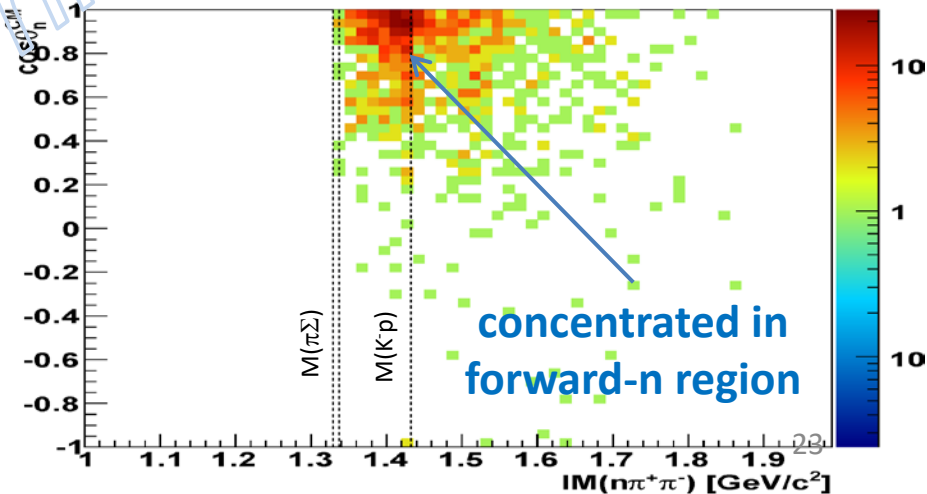
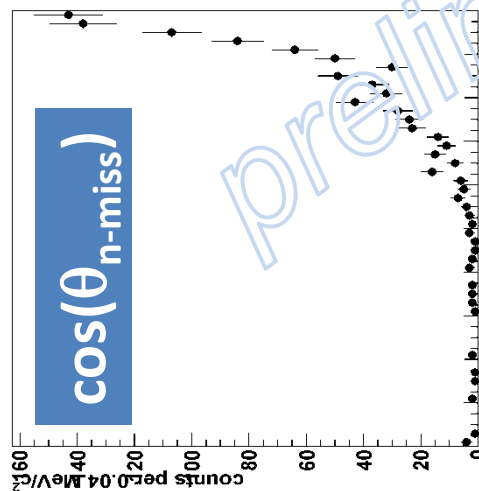
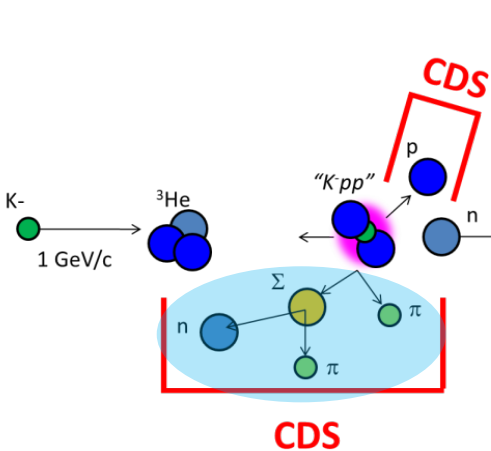
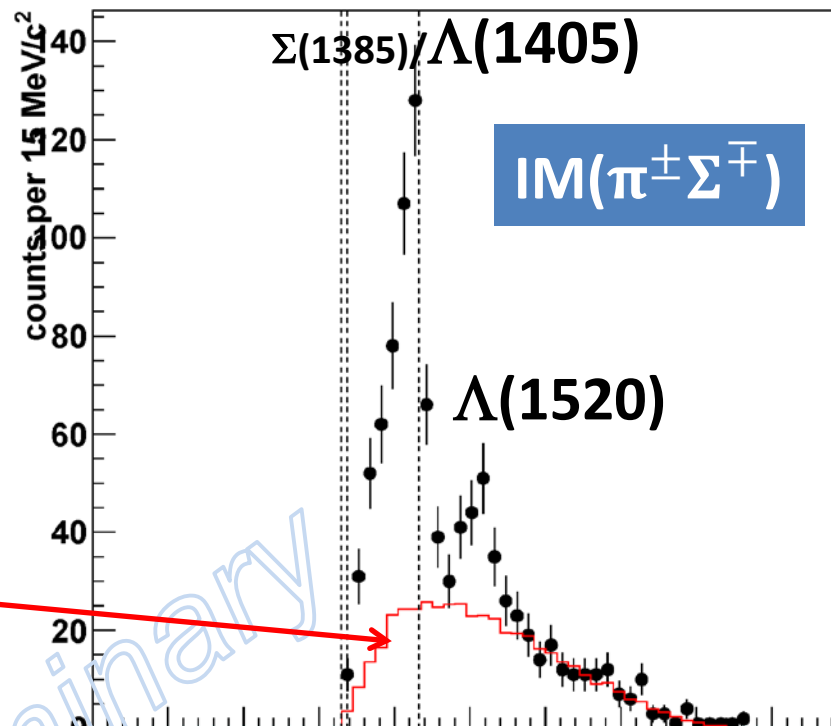
Σ mass:

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

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

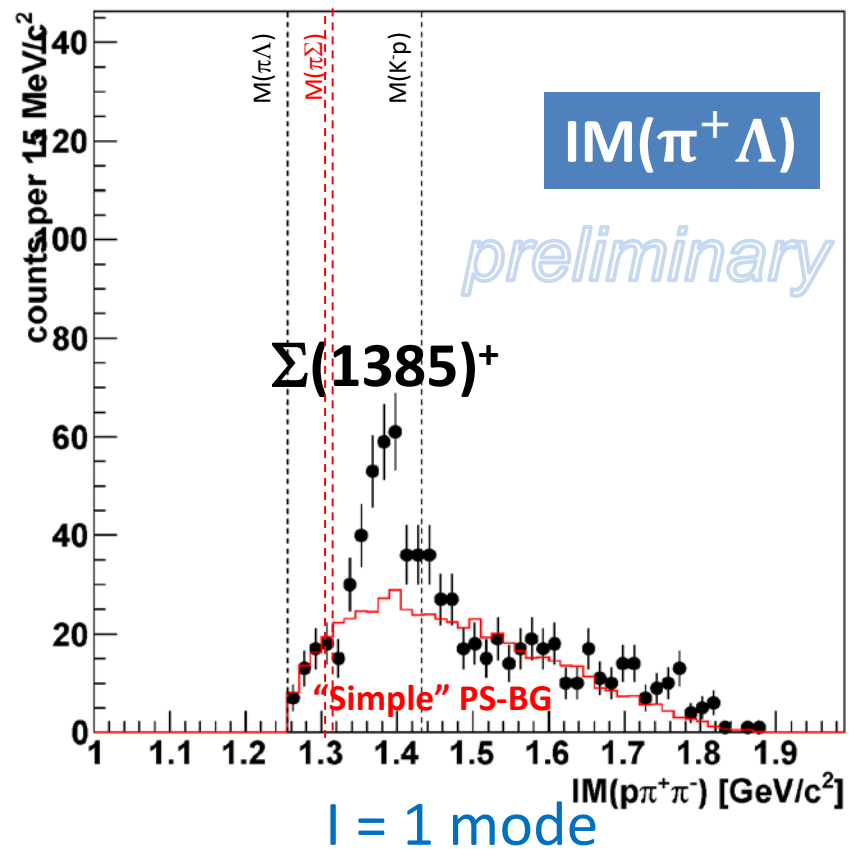
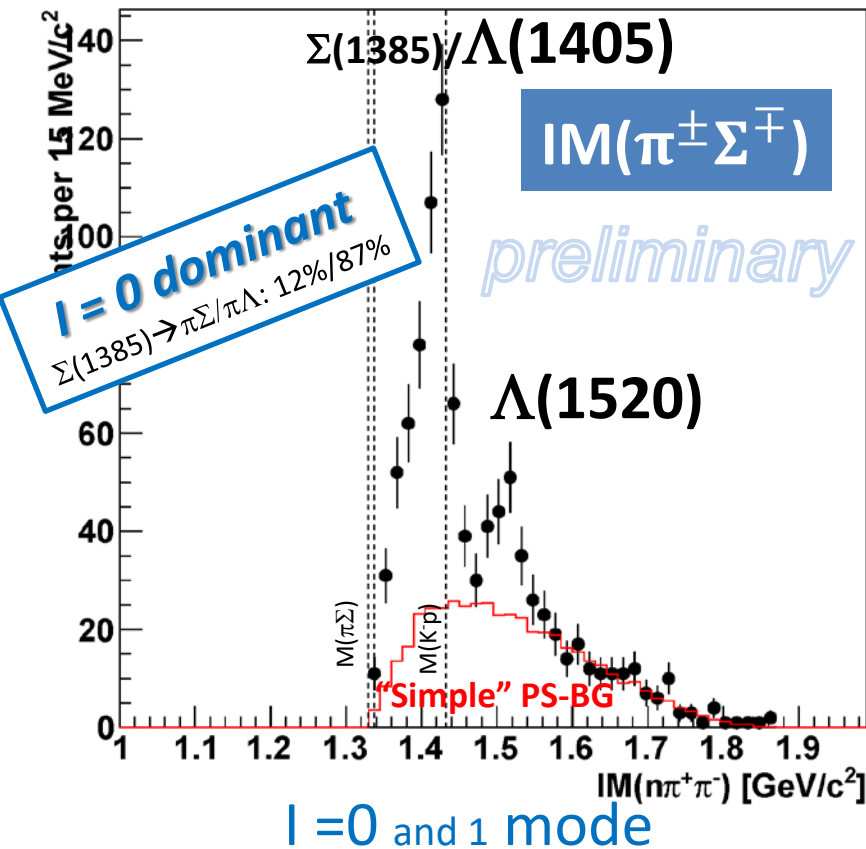
"Simple" PS-Background

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



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

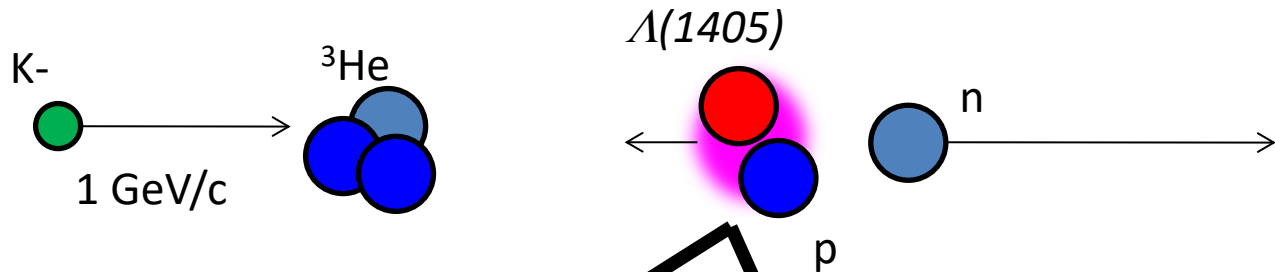
$\pi^+ \Lambda n n_{\text{miss}}$ final state was obtained as with $\pi^\pm \Sigma^\mp p n_{\text{miss}}$



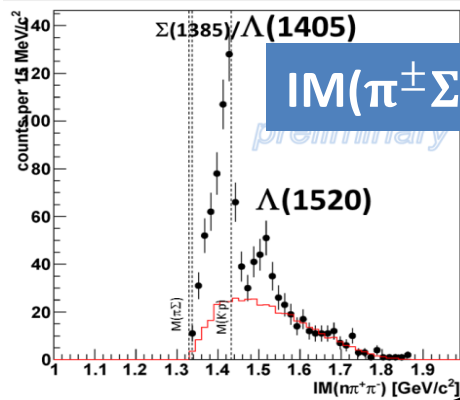
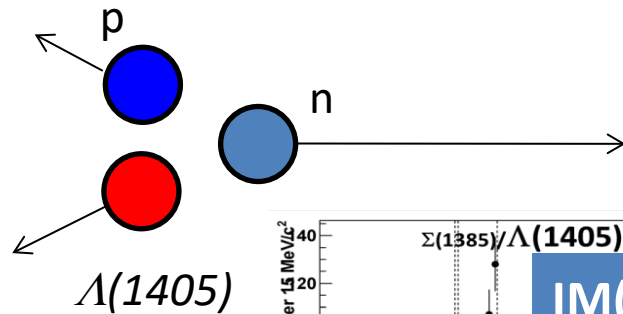
Discrimination of $\Lambda(1405)$ and $\Sigma(1385)$ is under way

→ Careful investigation of the backgrounds is needed

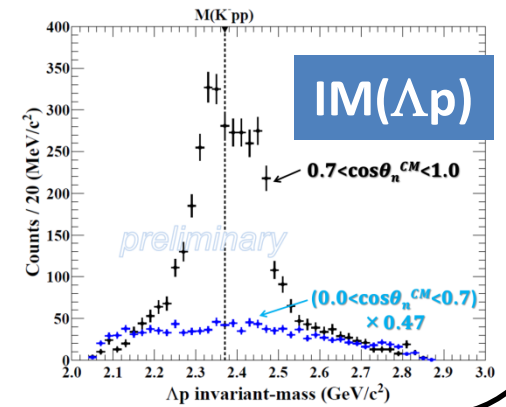
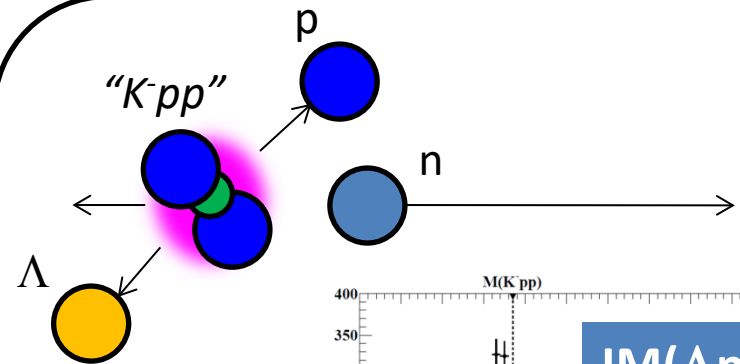
Production of Λ^* and “K-pp”



“free” Λ^*



“K-pp” formation



Comparison of each CS would give us important hints!

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

Event Selection

Missing n:

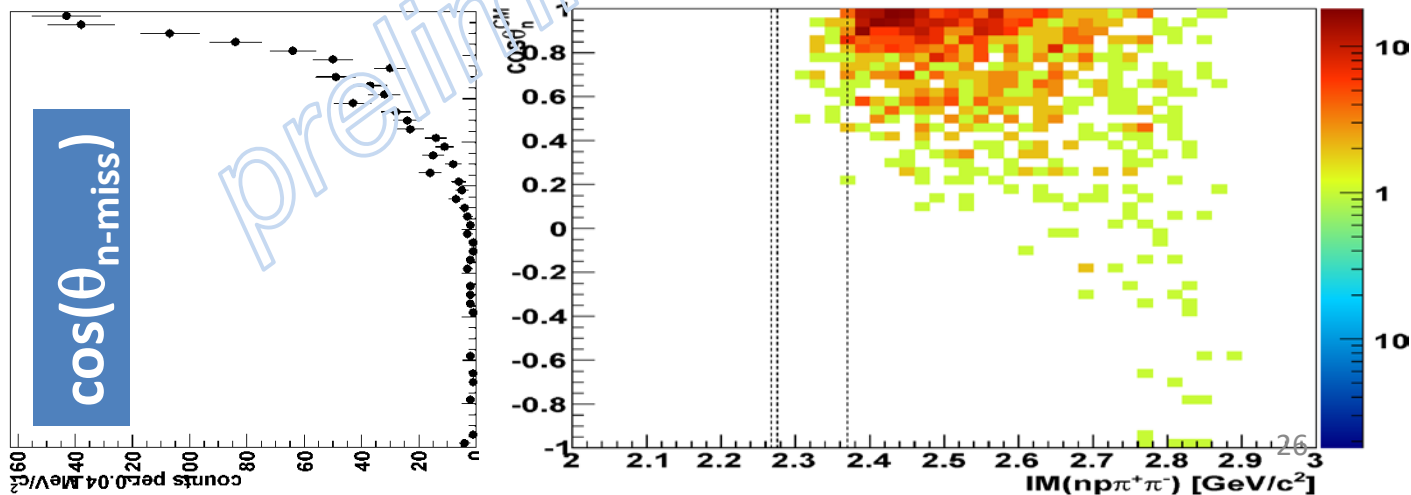
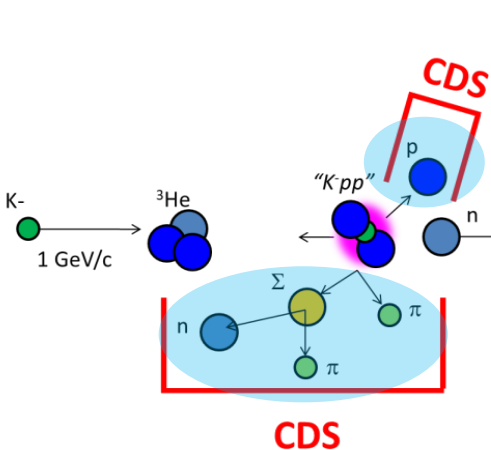
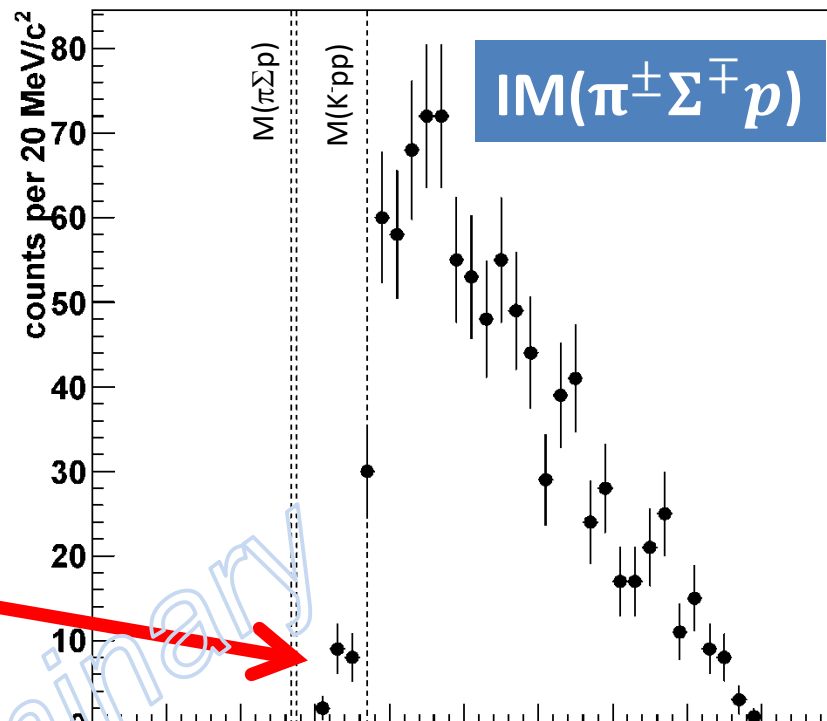
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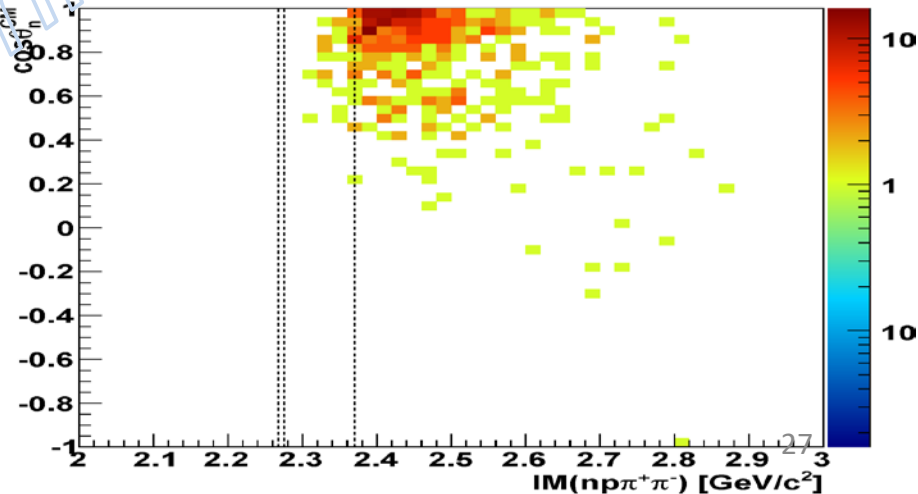
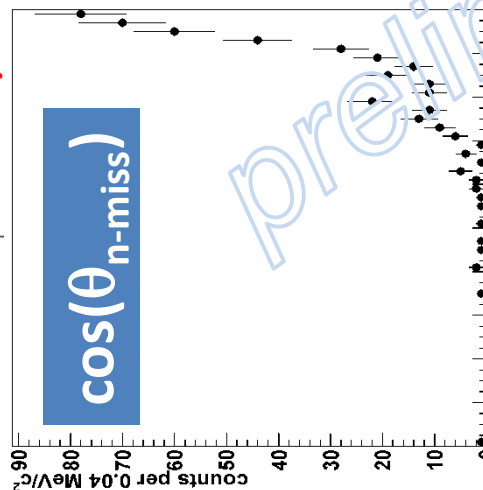
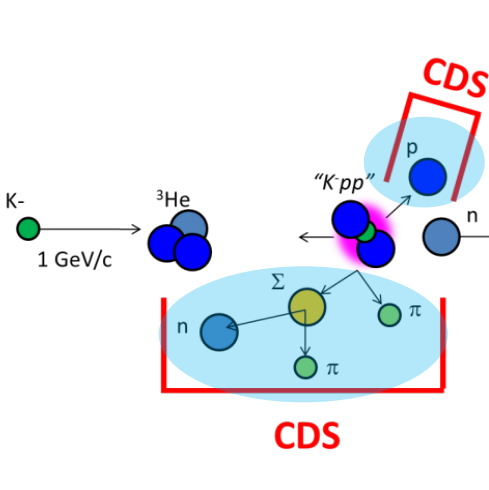
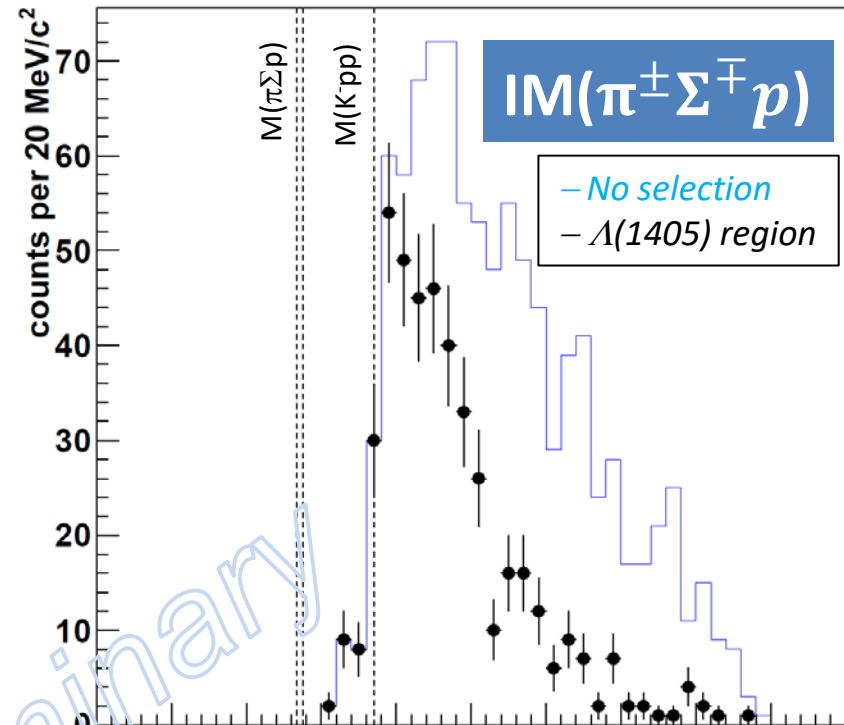
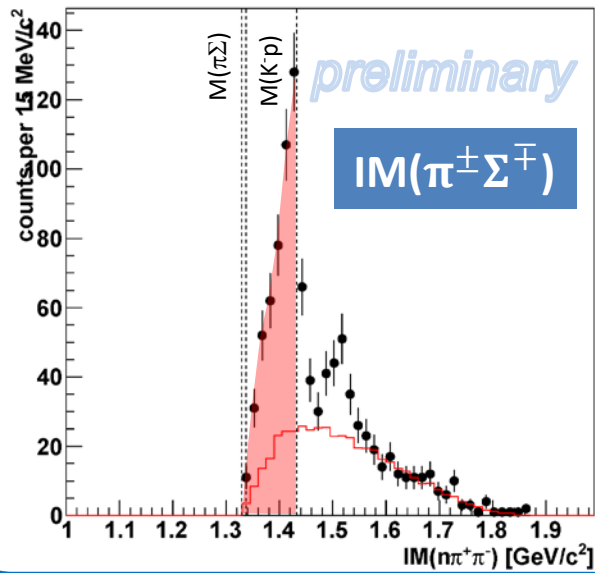
$$1.19 < \text{IM}(n\pi^+) < 1.21 \text{ GeV}/c^2 \text{ for } \Sigma^+$$

**Subthreshold events
seem to be suppressed!**



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

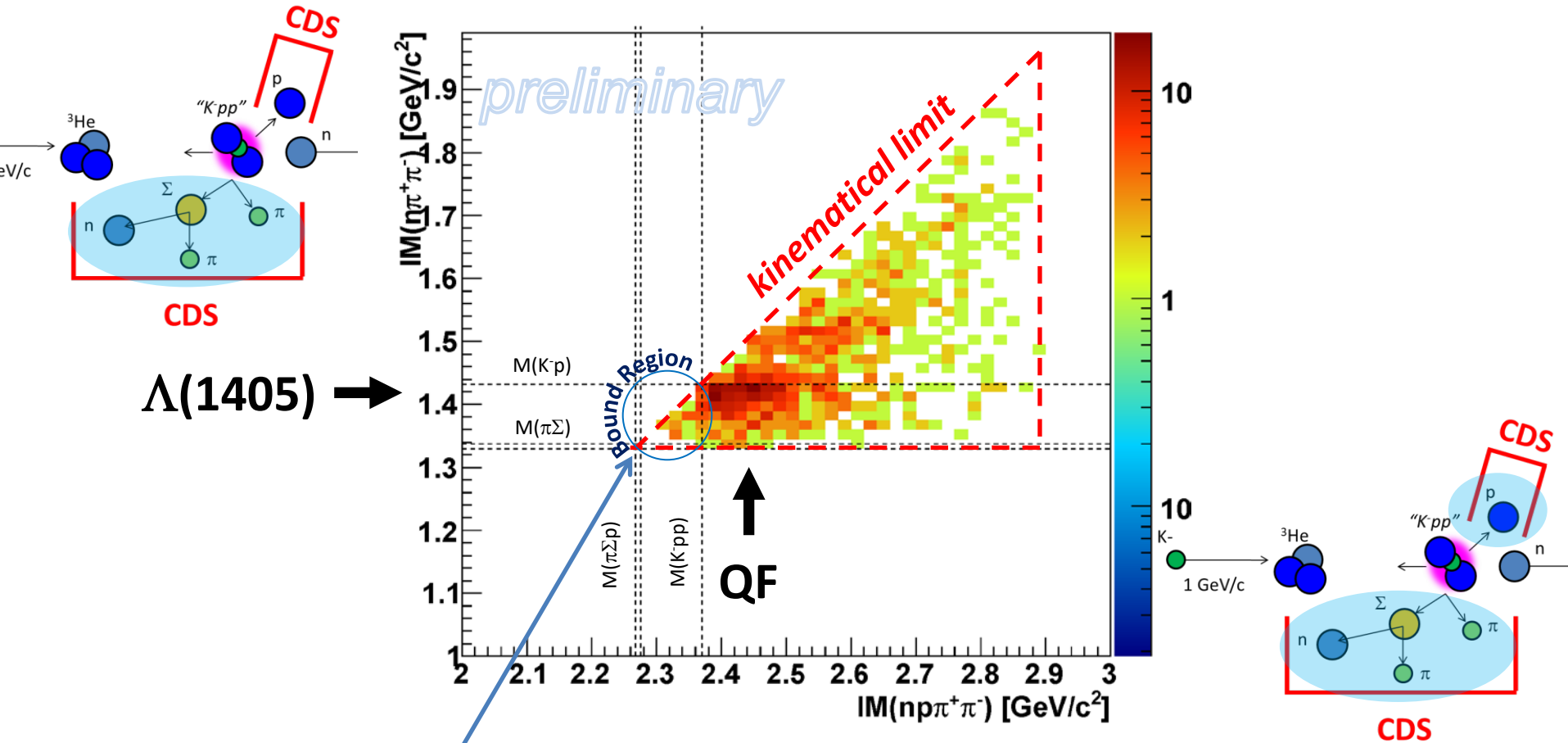
$\Lambda(1405)$ region is selected
[$\text{IM}(n\pi^+\pi^-) < \text{M}(K^-p)$]



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

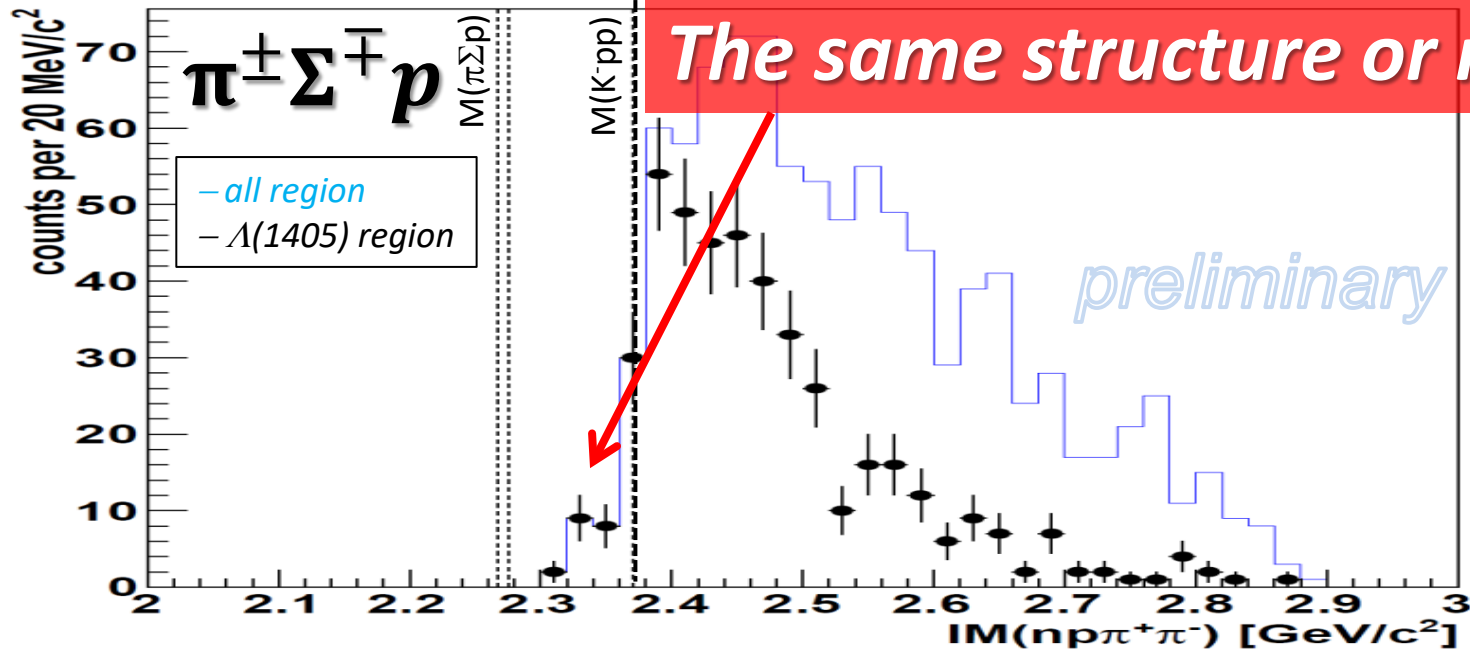
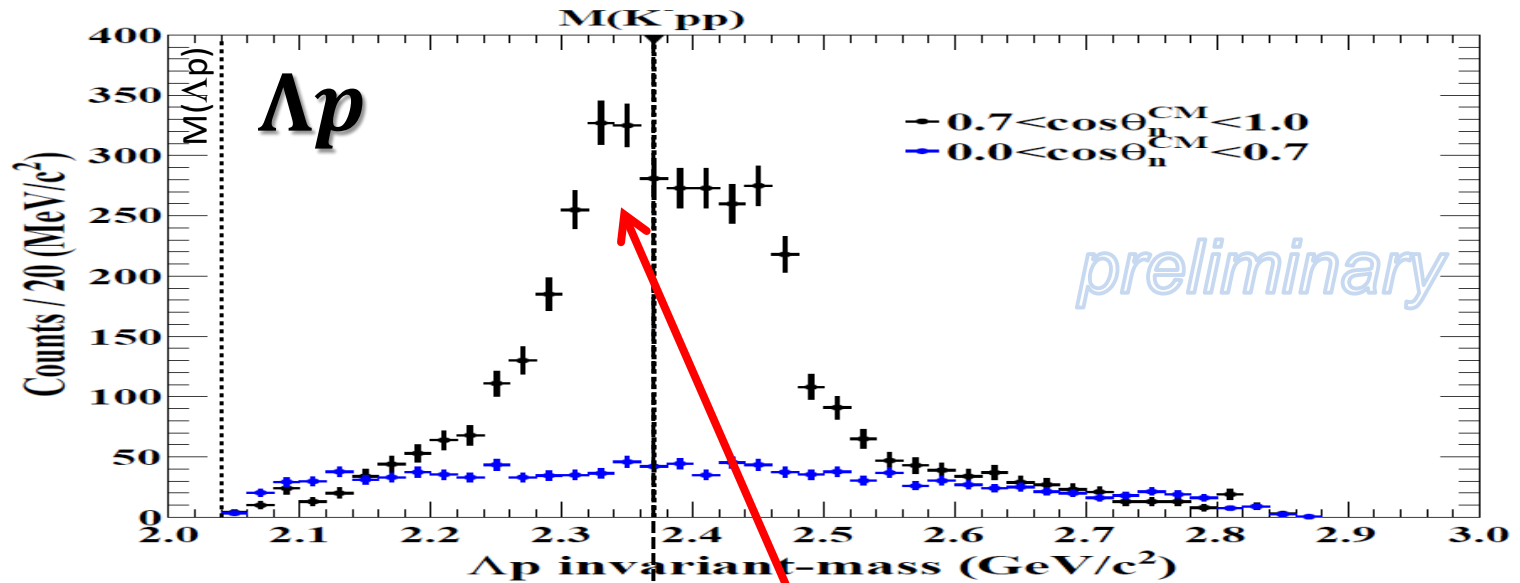
$\Lambda(1405)$ and QF are strongly correlated

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



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

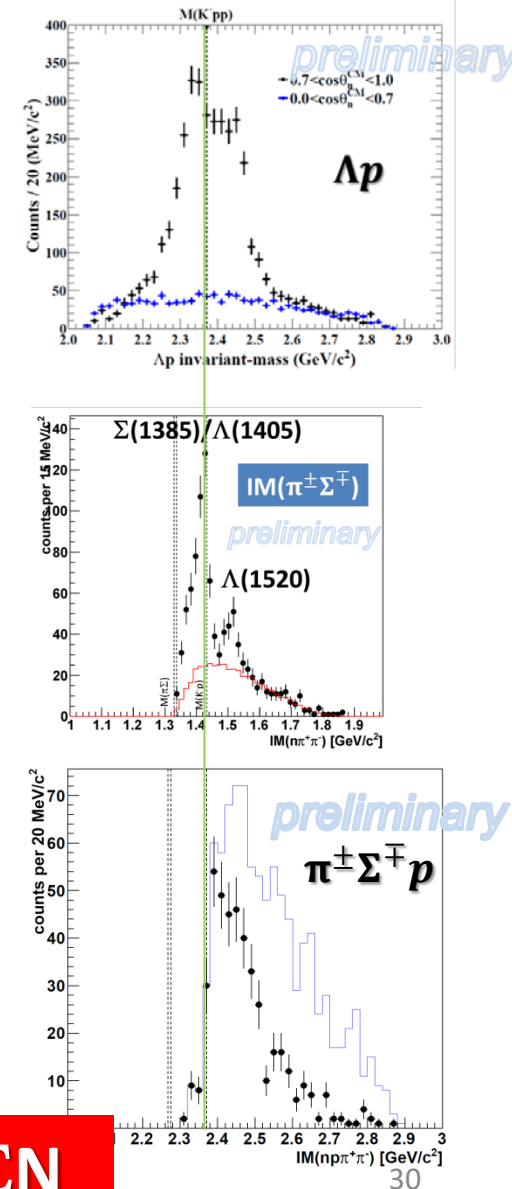
Λp vs. $\pi\Sigma p$



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 ” $\rightarrow \pi \Sigma N$

kaon in atoms/nuclei at DAFNE and J-PARC

-- Present status and future plans --

Dec.6-7, 2017, Wako, RIKEN

Place: Main building 2F room number 224-226

Dec.6 (Wed)

13:00-13:05	Masahiko Iwasaki (RIKEN):	Welcome address [5]
13:05-14:00	Catalina Curceanu (LNF-INFN):	SIDDHARTA2 and future [45+10]
14:00-14:40	Shinji Okada (RIKEN):	kaonic atoms at E62/E57 [30+10]
14:40-14:55	... Coffee break ...	
14:55-15:50	Tetsuo Hyodo (Kyoto):	$K^{\text{bar}}N$ interaction in chiral dynamics [45+10]
15:50-16:30	Kristian Piscicchia (LNF-INFN):	Λ^* at AMADEUS [30+10]
16:30-16:45	... Coffee break ...	
16:45-17:25	Hiroyuki Noumi (RCNP):	Λ^* at E31 [30+10]
17:25-17:55	Kiyoshi Tanida (JAEA):	polarization measurement of $\Lambda(1405)$ from Λ_c decay and spin structure of $\Lambda(1405)$ [20+10]
18:00-20:00	... Get-together party @ Main Cafeteria (party-fee:3,000JPY) ...	

Dec.7 (Thu)

10:00-10:55	Akinobu Dote (KEK):	$K^{\text{bar}}NN\cdot\pi\Sigma N\cdot\pi\Lambda N$ coupled channel system [45+10]
10:55-11:10	... Coffee break ...	
11:10-11:50	Raffaele Del Grande (LNF-INFN):	Λ_p at AMADEUS [30+10]
11:50-12:30	Oton Vazquez Doce (LNF-INFN):	$\Sigma^0 p$ at AMADEUS [30+10]
12:30-14:00	... Lunch ...	
14:00-14:40	Takumi Yamaga (RCNP):	Λ_{pn} at E15 [30+10]
14:40-15:20	Fuminori Sakuma (RIKEN):	$\pi\Sigma N$ at E15 [30+10]
15:20-15:40	... Coffee break ...	
15:40-16:20	Tadashi Hashimoto (JAEA):	(K^-, p) at E15 [30+10]
16:20-17:15	Takayasu Sekihara (JAEA):	reaction calculation of $K^{\text{bar}}NN$ [45+10]

The E15 Collaborations

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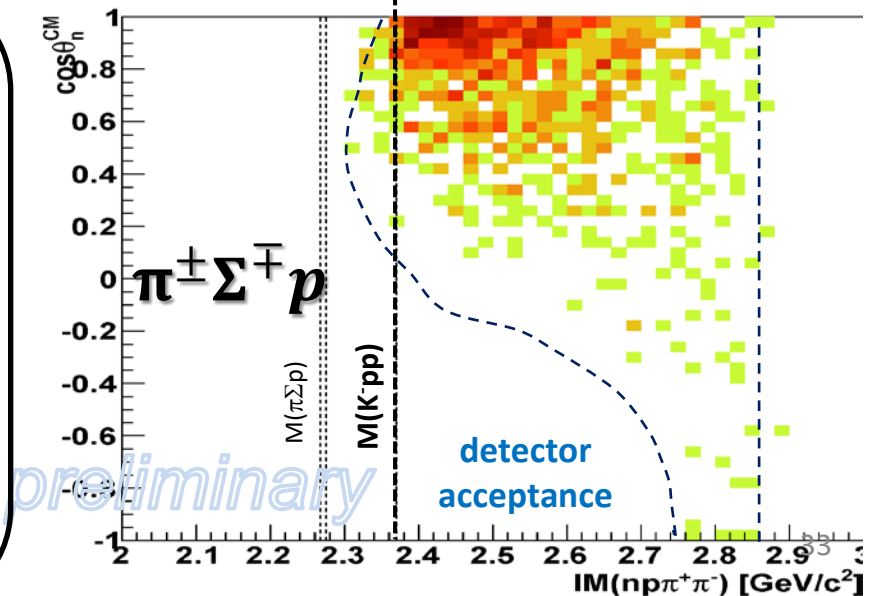
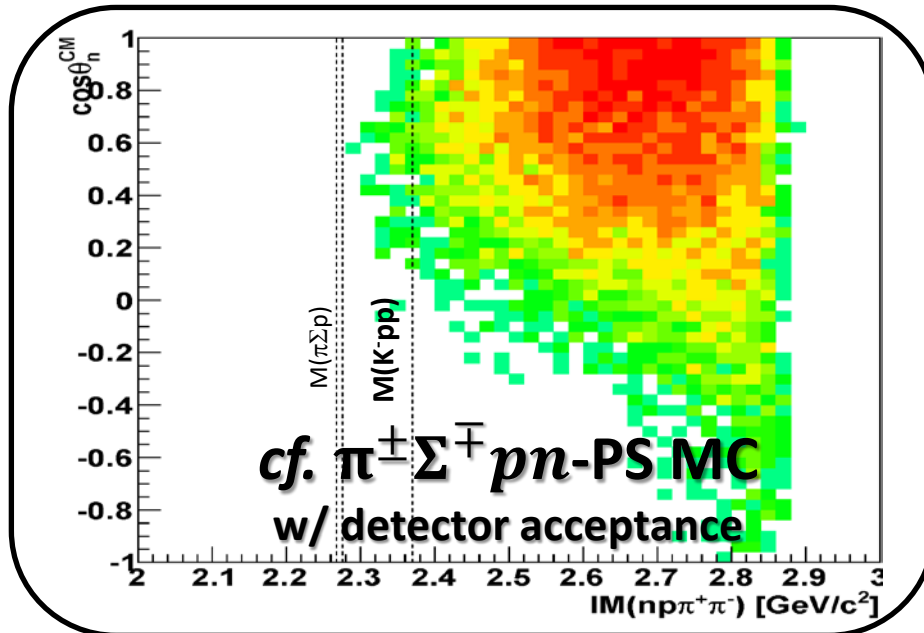
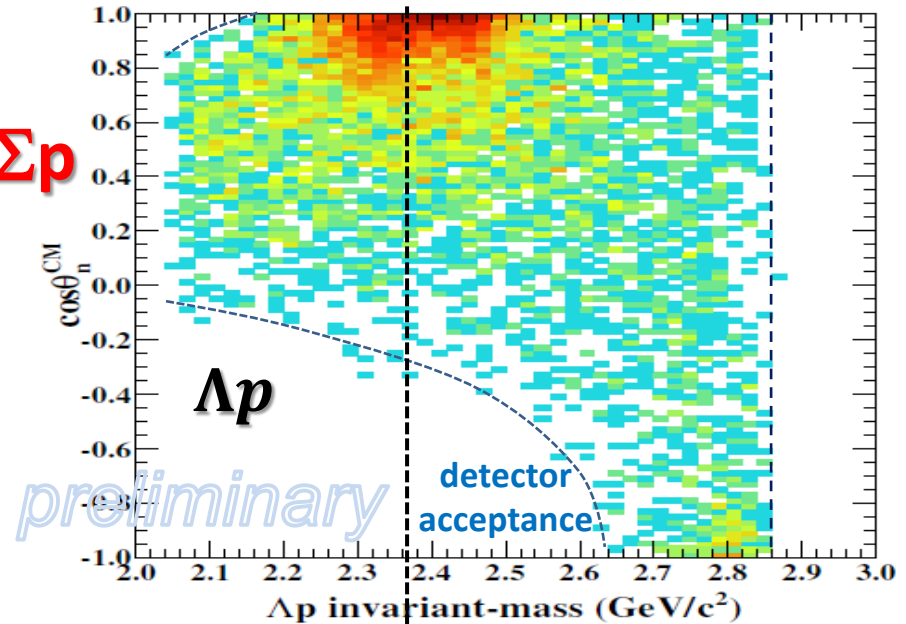
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- (v) Department of Chemical Physics, Lund University, Lund, 221 00, Sweden 

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

