Λ(1405)pn Final State in the K$^-$ + ^{3}He reaction

-- in relation to the "K$^-$pp" bound state --

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on behalf of the J-PARC E15 collaboration

STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics

ECT*, Trento

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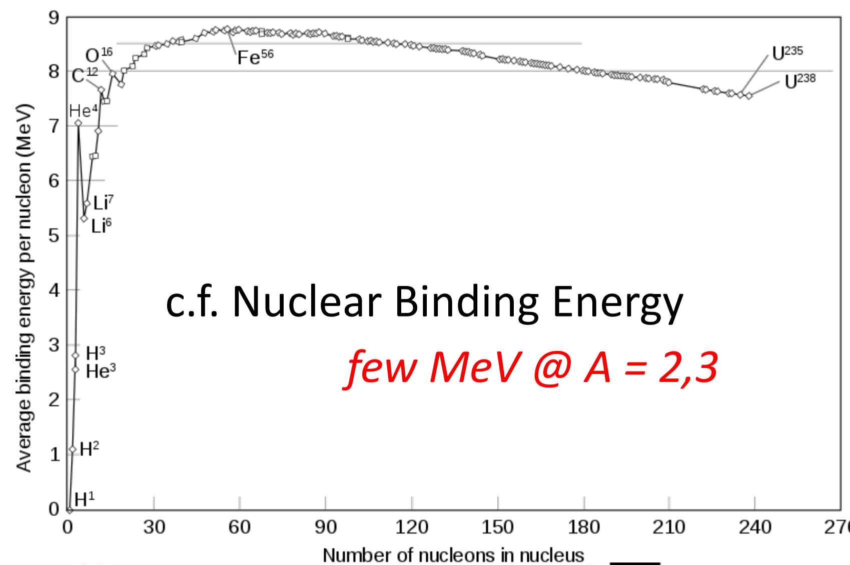
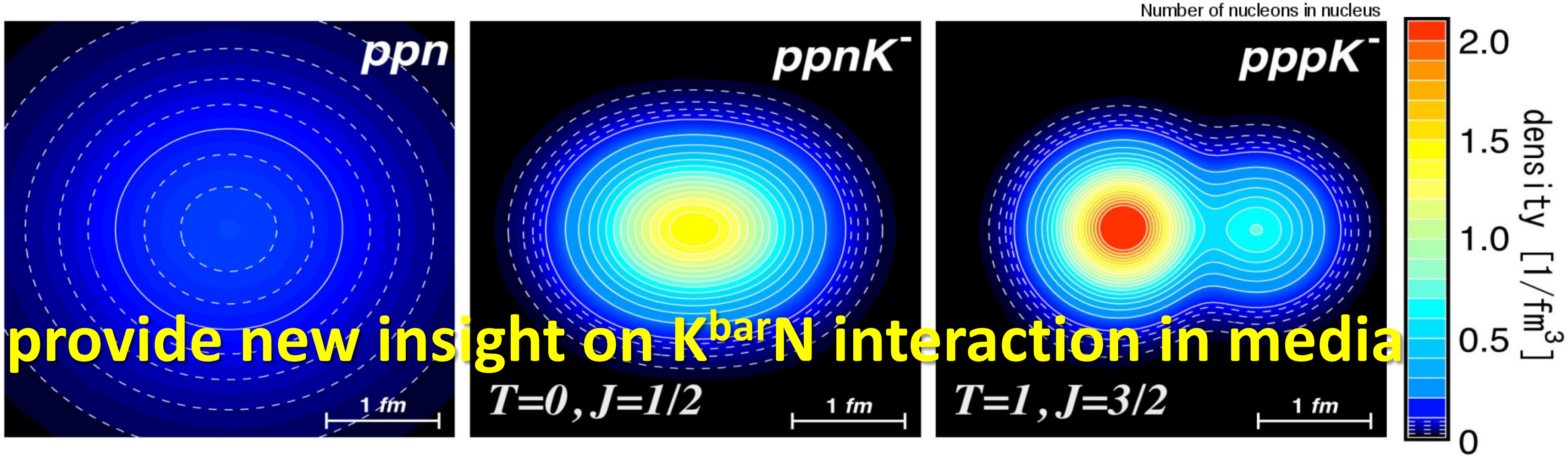
K^{bar}-Nuclear Bound State

Predicted from **attractive $K^{bar}N$ interaction in I=0**

Kaonic Nuclei	Binding Energy [MeV]	Width [MeV]
$\Lambda(1405) = K^-p$	27	40
K^-pp	48	61
K^-ppp	97	13
K^-ppn	118	21

Y.Akaishi and T.Yamazaki, PRC65(2002)044005.
A. Dote et al. PRC70(2004)044313. etc.





provide new insight on $K^{bar}N$ interaction in media

We observed the "K⁻pp" Bound-State

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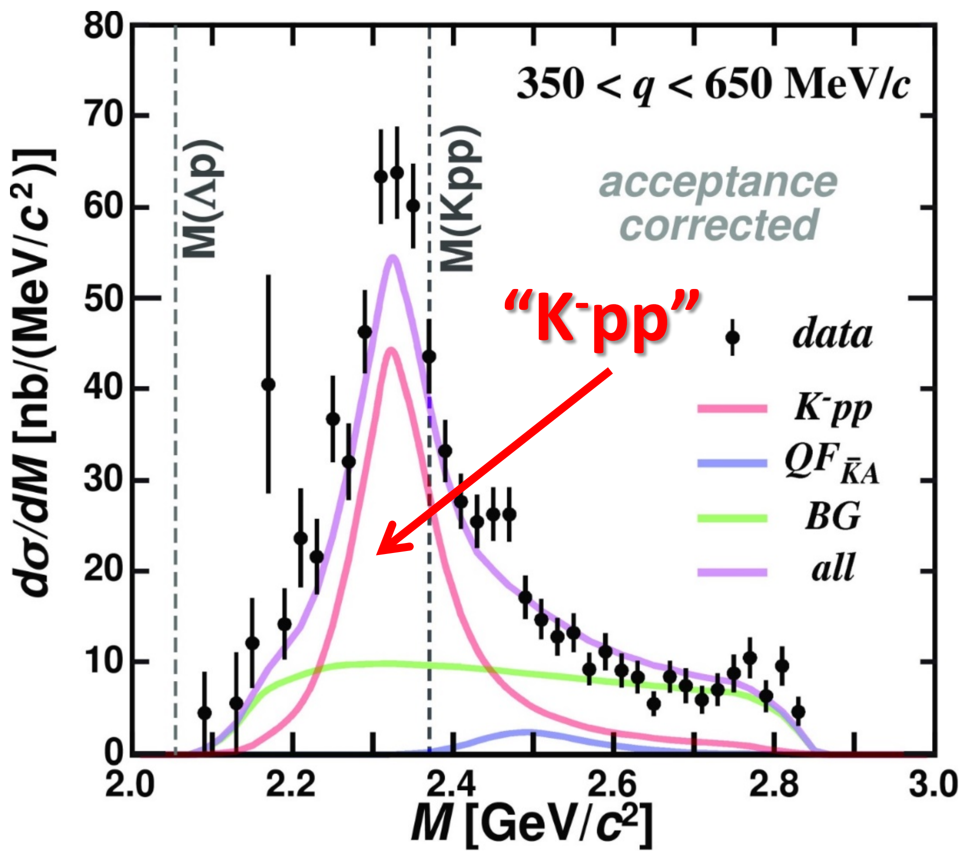
PLB789(2019)620.

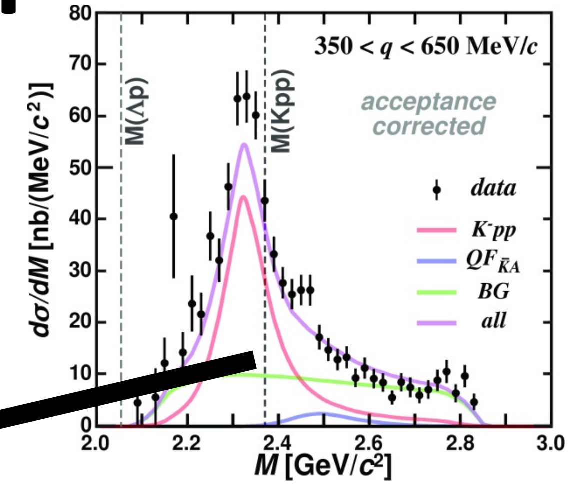
"$K^- pp$", a $\overline{K}$-meson nuclear bound state, observed in $^3\text{He}(K^-, \Lambda p)n$ reactions

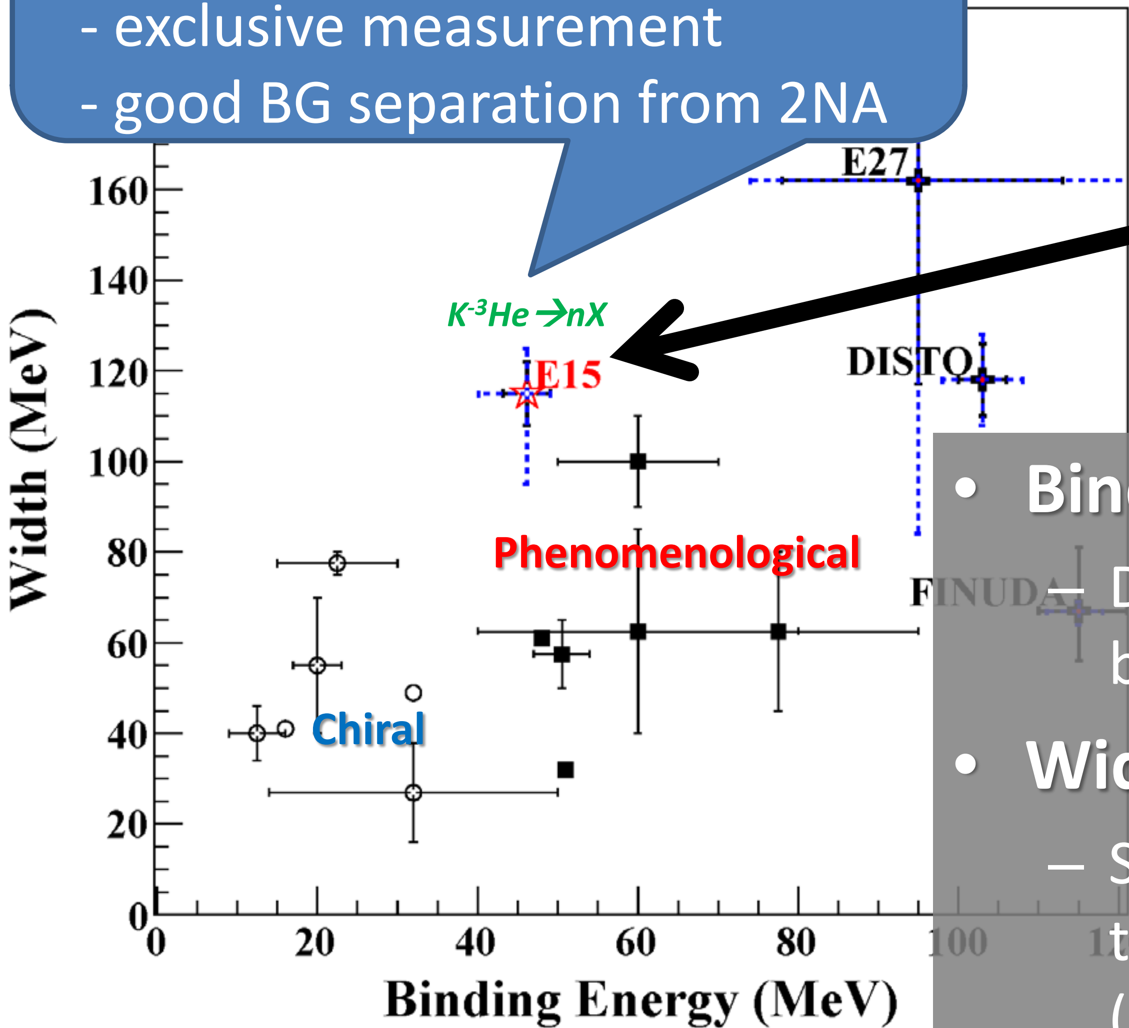


Observed "$K^{-}pp$"

the most reliable observation

- simple K- induced reaction
- exclusive measurement
- good BG separation from 2NA

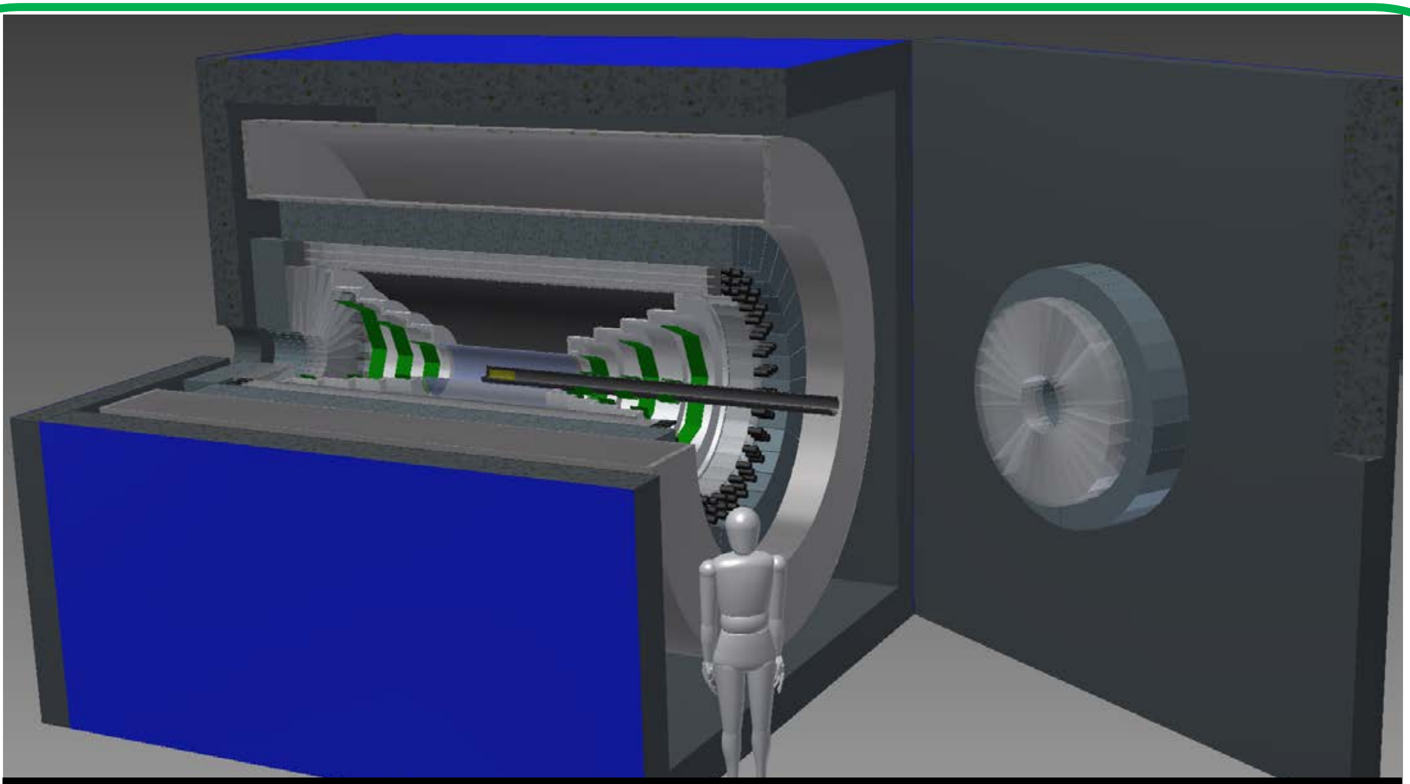




- **Binding energy: ~50 MeV**
  - Deeper than chiral-SU(3) based theoretical predictions
- **Width: ~100 MeV**
  - Seems to be larger than theoretical calculations (mesonic πY decays only)

We need further understanding

- **Spin/Parity of the "K$^-$pp"**
  - *New 4π detector system is needed* ***← Future plan***

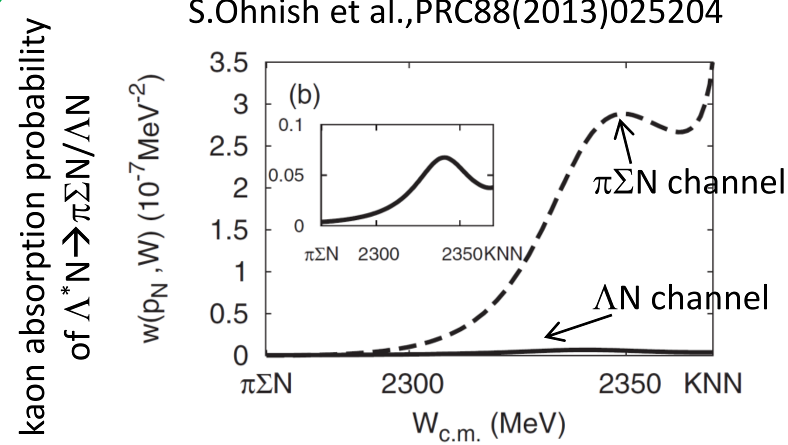


A new 4π detector with γ/n sensitive detectors

We need further understanding

- Spin/Parity of the “K^-pp”
  - *New 4π detector system is needed* ← ***Future plan***
- **Other decay channels**
  - **<u>πΣN mesonic decay</u>** is theoretically expected to be the dominant channel
    - Only YN non-mesonic decays were reported

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



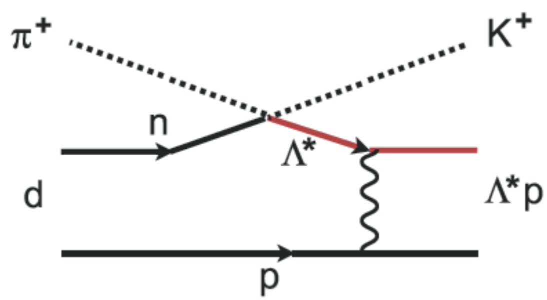
We need further understanding

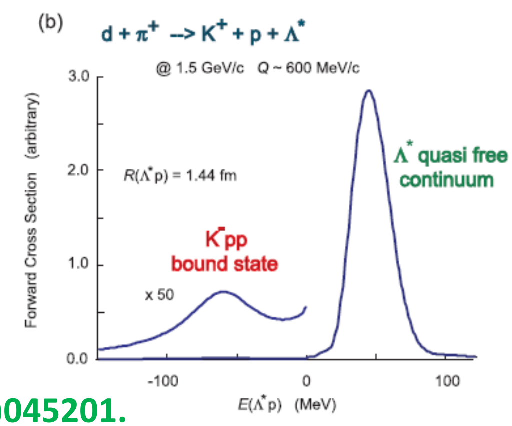
- Spin/
  – Nev … e plan
- Othe
  – πΣ … d to be
    the
    - C

π^+ + "n" --> "Λ^*" + K^+

"Λ^*" + "p" --> bound K^-pp *minor*

--> quasi-free Λ^* *dominant*





Yamazaki & Akaishi, PRC76(2007)045201.

- **Reaction mechanism**
  – Relation between **Λ(1405)** & "K^-pp"
    - Λ(1405) has been considered as **"K^-p"**
    - Theoretically, "K^-pp" is expected to be produced via **Λ(1405)+p→"K^-pp" door-way process**

We need further understanding

- Spin/
  - Ne … e plan
- Othe
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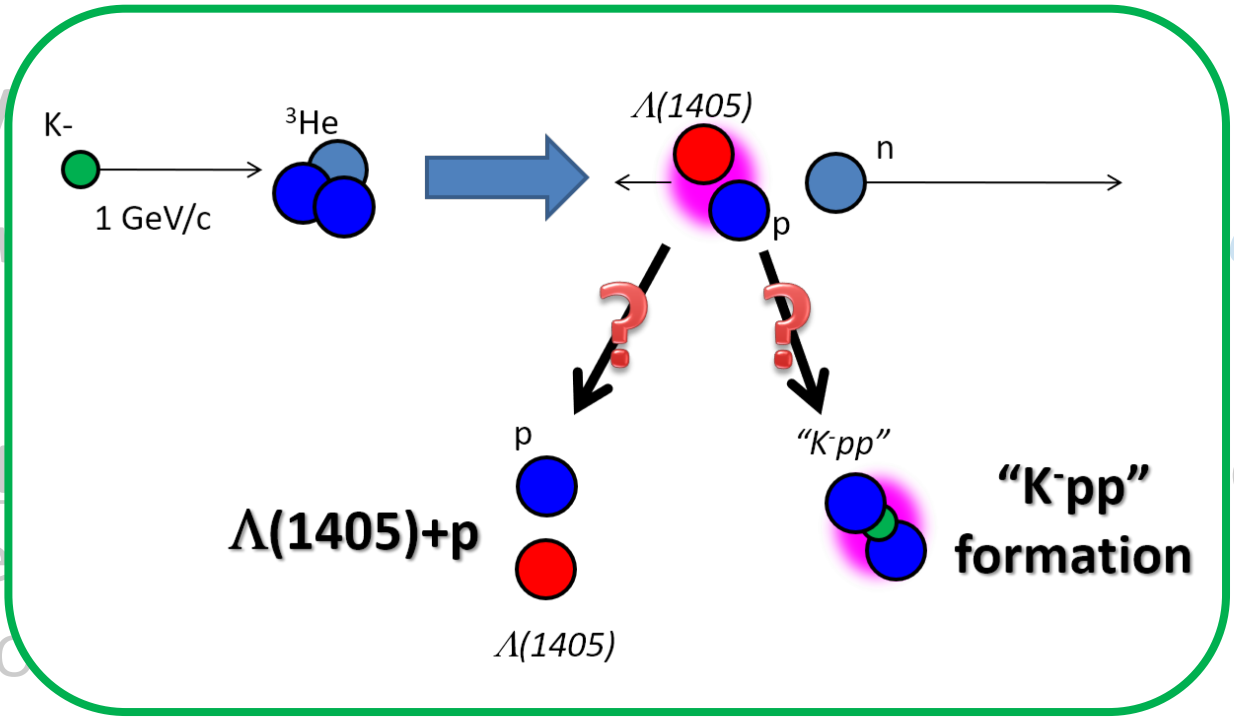
    - C



- **Reaction mechanism**
  - Relation between **Λ(1405)** & "K$^-$pp"
    - Λ(1405) has been considered as <u>**"K$^-$p"**</u>
    - Theoretically, "K$^-$pp" is expected to be produced via <u>**Λ(1405)+p→"K$^-$pp" door-way process**</u>

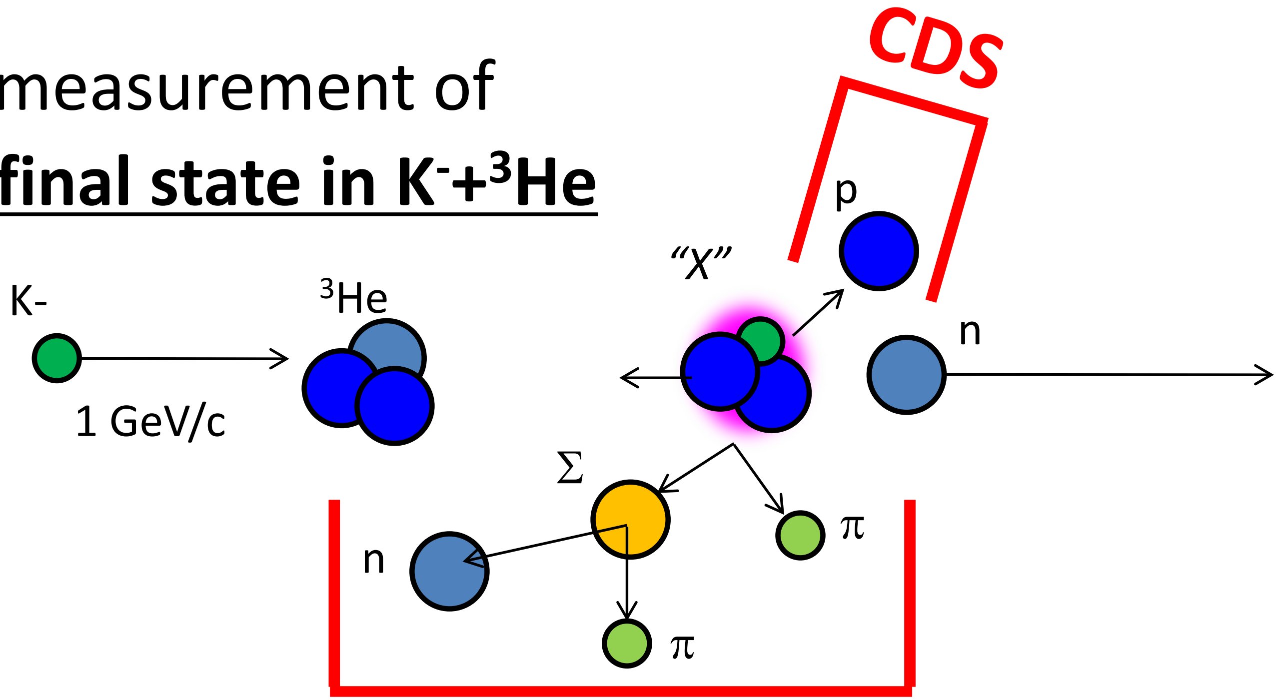
We need further understanding

- Spin/Parity of the "K$^-$pp"
  - *New 4π detector system is needed* ← ***Future plan***
- **Other decay channels**
  - **πΣN mesonic decay** is theoretically expected to be the dominant channel
    - Only YN non-mesonic decays were reported
- **Reaction mechanism**
  - Relation between Λ(1405) & "K$^-$pp"
    - Λ(1405) has been considered as **"K$^-$p"**
    - Theoretically, "K$^-$pp" is expected to be produced via **Λ(1405)+p→"K$^-$pp" door-way process**

K$^-$ 3He → πΣpn @ E15

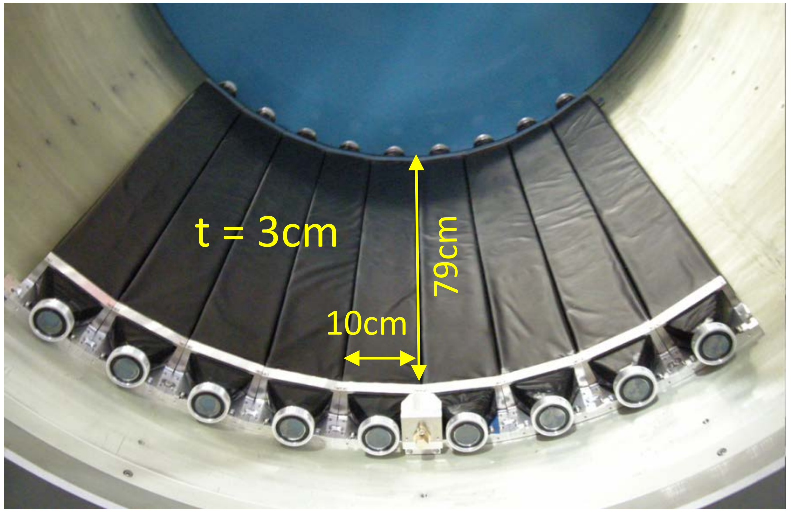
$K^{-}\ {}^{3}He \rightarrow \pi\Sigma pn$ Measurement

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



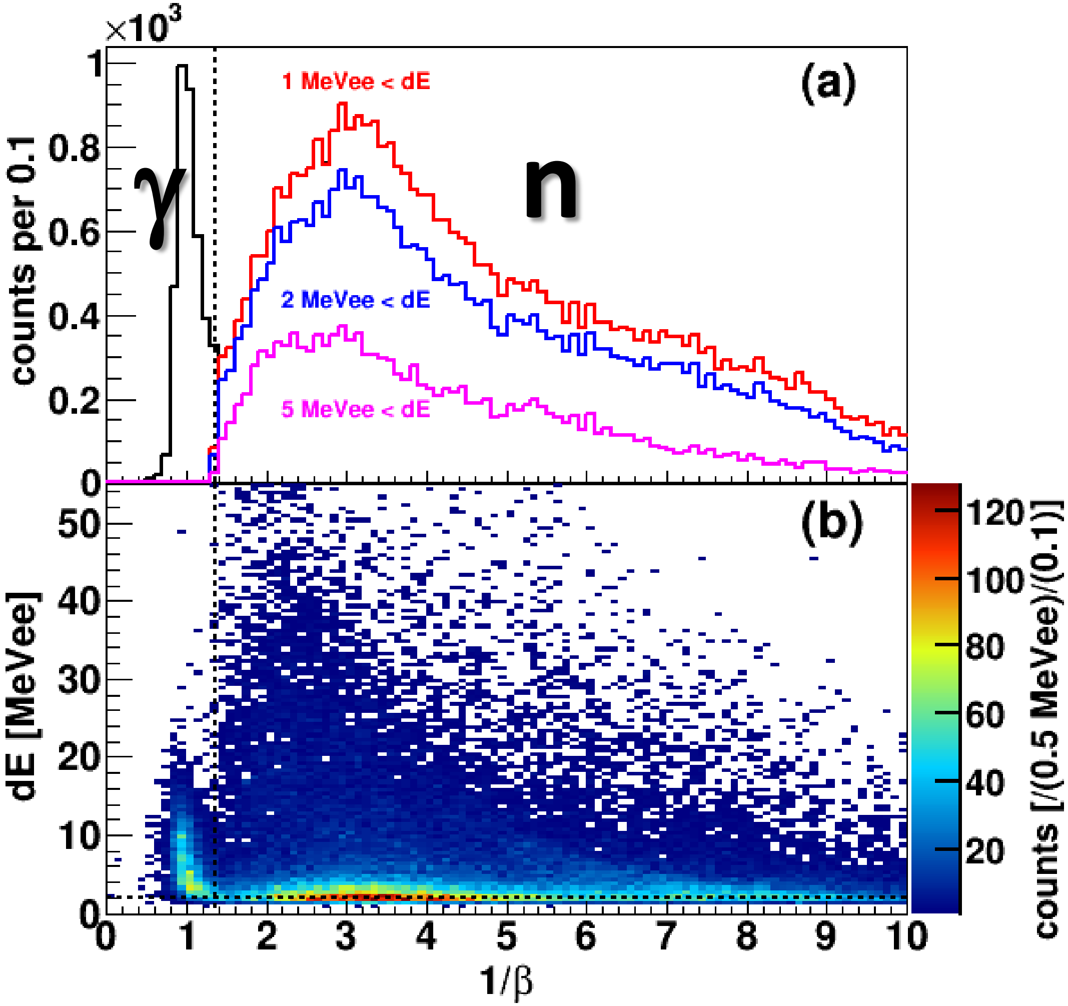
- <u>**Experimental challenge**</u> of neutron detection with thin scintillation counter (t=3cm)

  n detection efficiency ~ 3-10%



Neutron ID with CDS

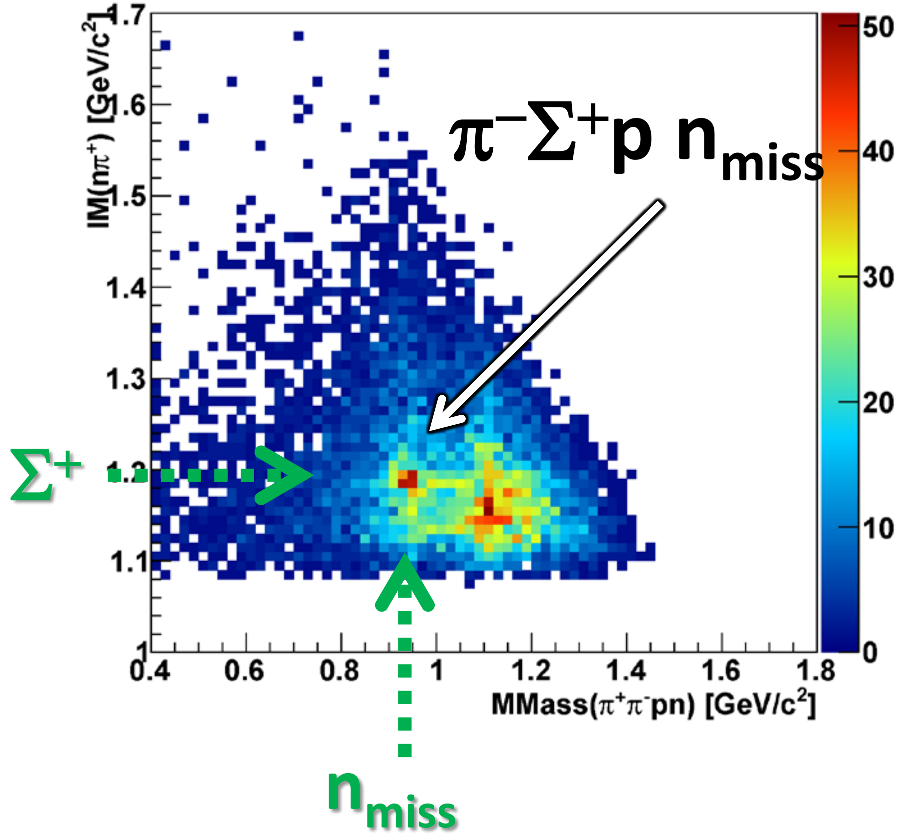
- $\pi^+\pi^-p$ events (3 tracks) in CDS with 4 CDH hits are selected
- a CDH hit with CDC-veto (outer-layer) is applied to assure the “neutral hit”



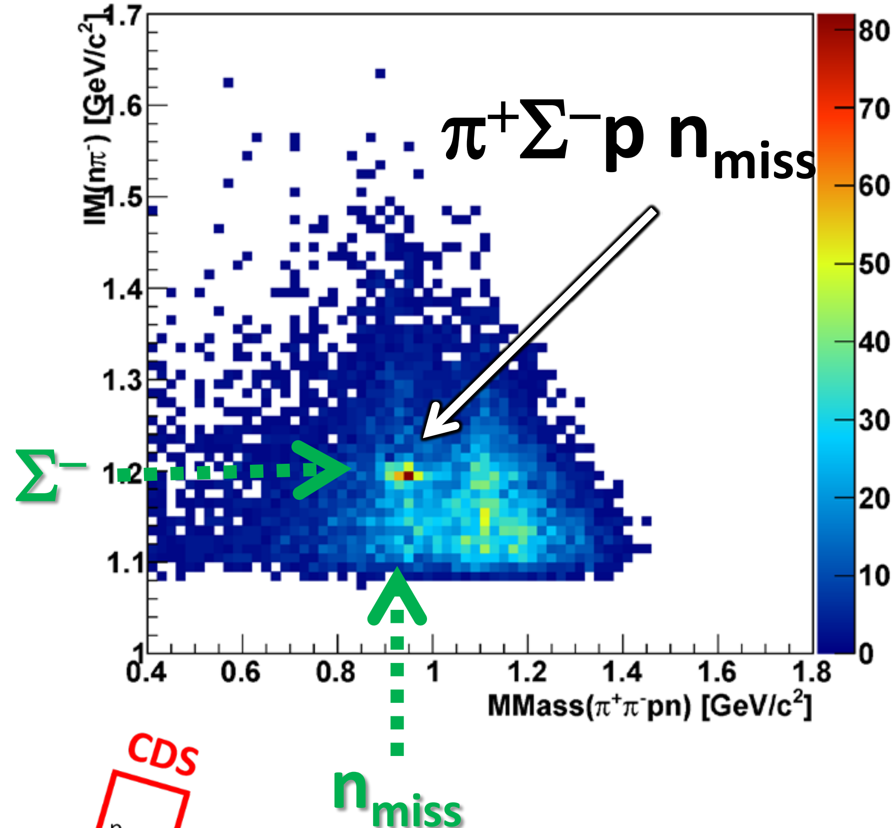
Neutron can be identified with CDS

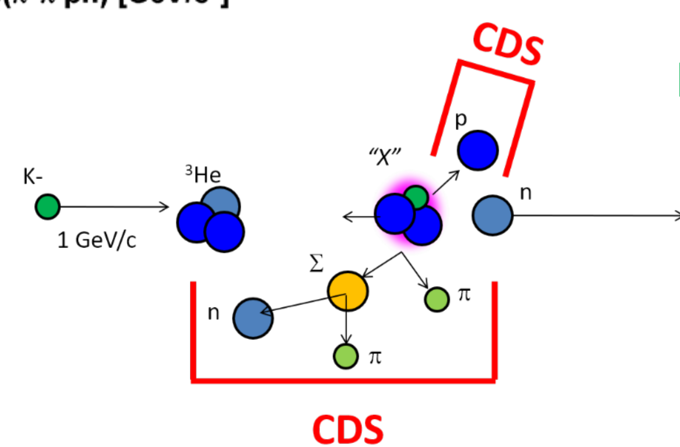
$\pi\Sigma pn$ Events

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



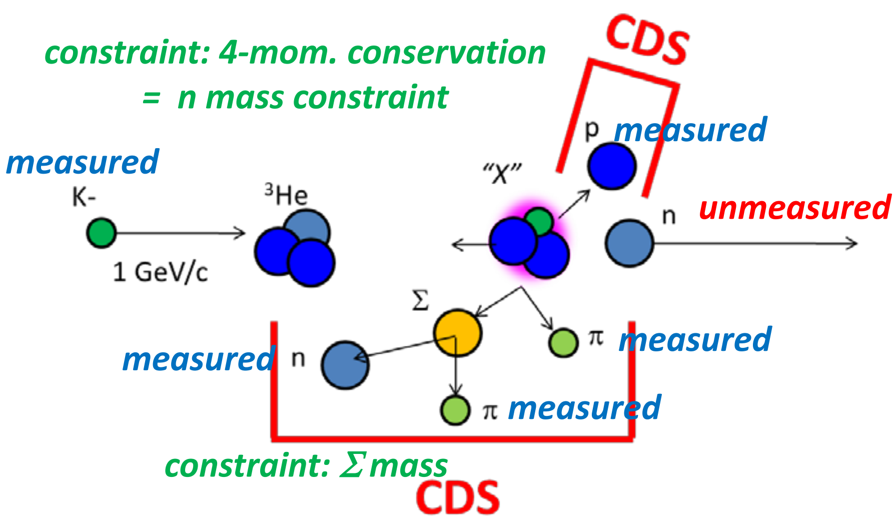
IM($n\pi^-$) vs MM($\pi^+\pi^-pn$)



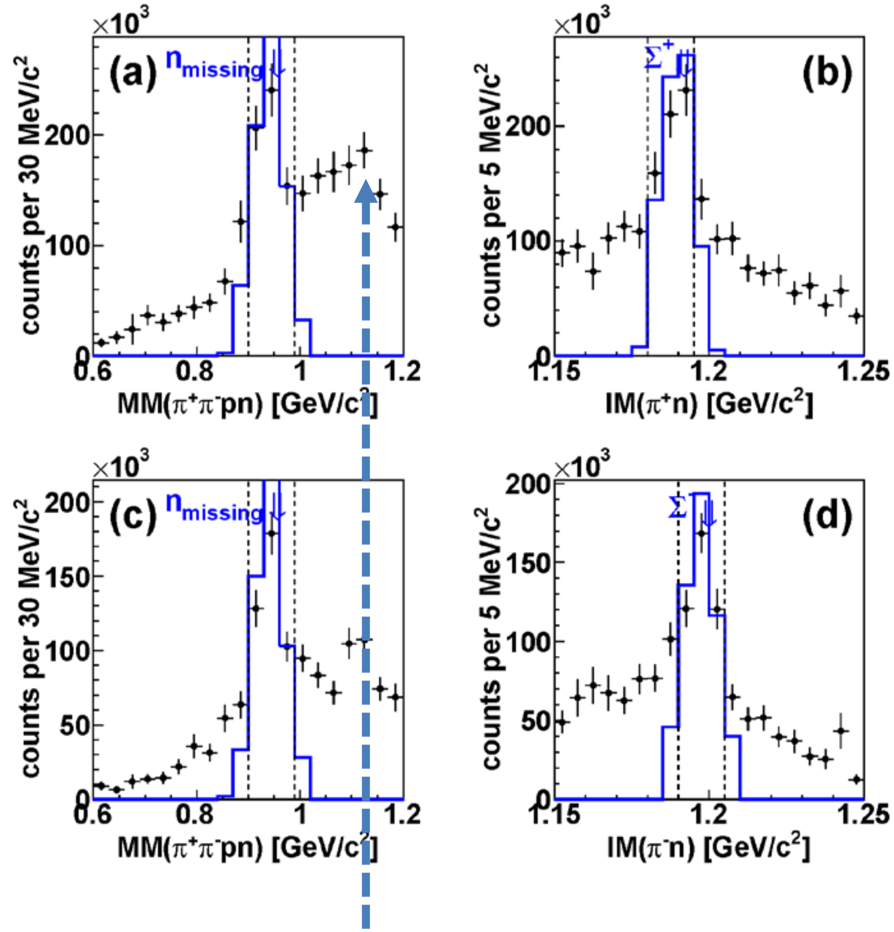


Selection of $\pi^{\pm}\Sigma^{\mp}pn$ Final State

- $\pi^{\pm}\Sigma^{\mp}$ events are separated using kinematical-fit
  - Constraints:
    - M($\Sigma \rightarrow n\pi$)
    - 4-momentum conservation
  - Event selection by χ^2 probability (0.01<p)



e.g. after acc/eff correction

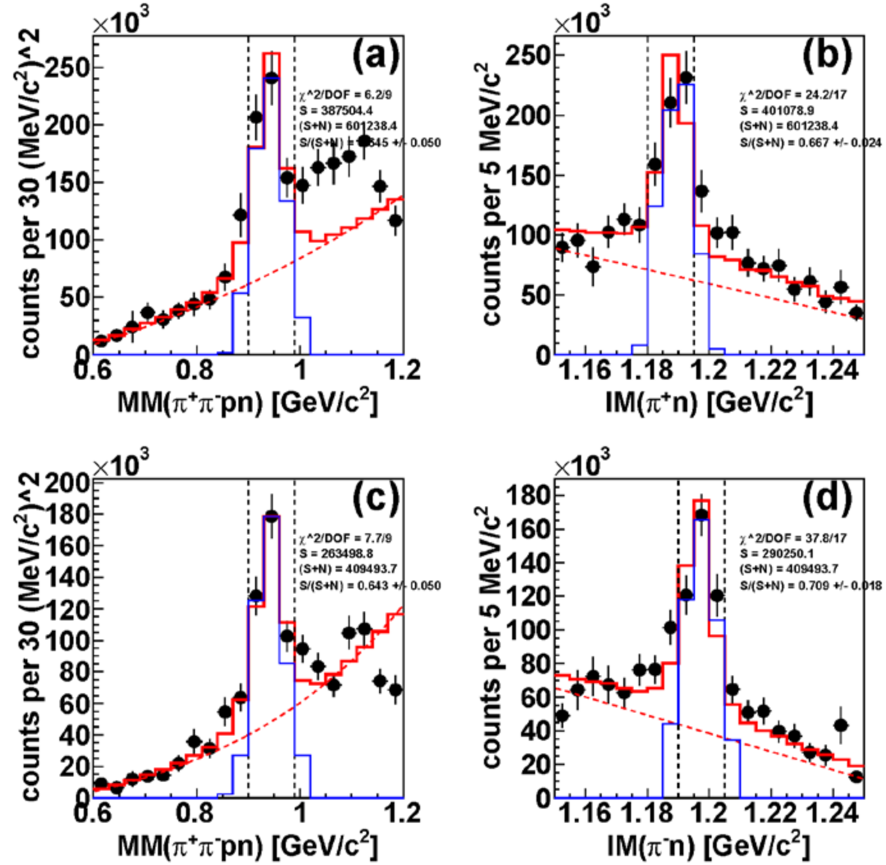


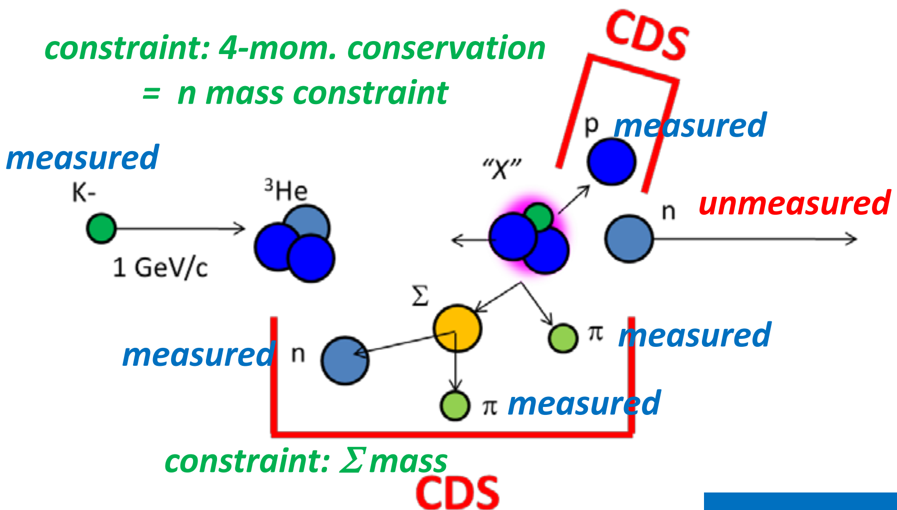
$\pi\pi pn\Lambda/\Sigma^0$ contribution can be seen

Selection of $\pi^{\pm}\Sigma^{\mp}pn$ Final State

- $\pi^{\pm}\Sigma^{\mp}$ **events are separated using kinematical-fit**
  - Constraints:
    - M($\Sigma \rightarrow n\pi$)
    - 4-momentum conservation
  - Event selection by χ^2 probability (0.01<p)

e.g. after acc/eff correction



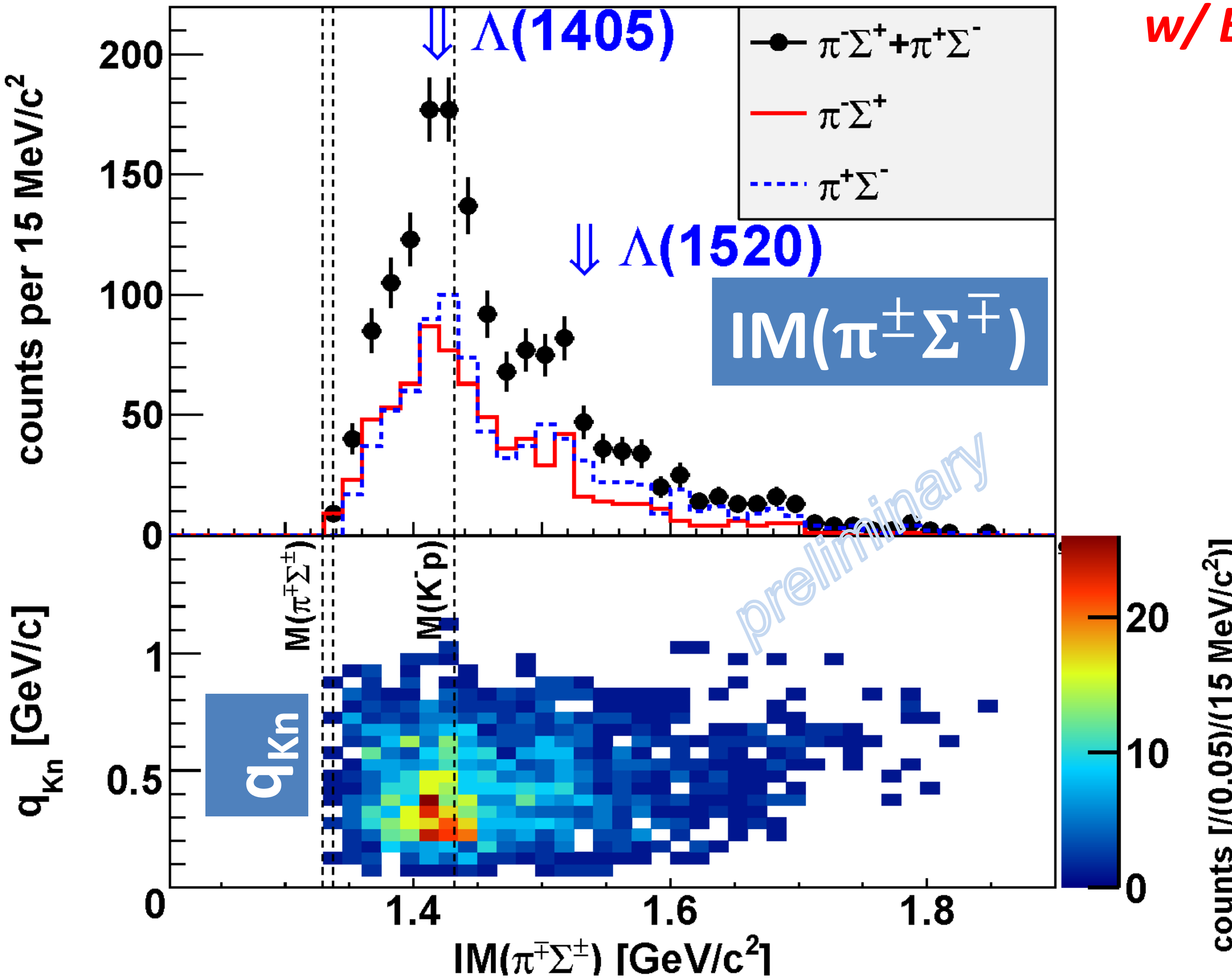


simple BG evaluation & subtraction

Now, we are trying to improve Exp. BG evaluation

IM($\pi^{\pm}\Sigma^{\mp}$) in $\pi^{\pm}\Sigma^{\mp}pn$ Final State

w/ Exp. BG



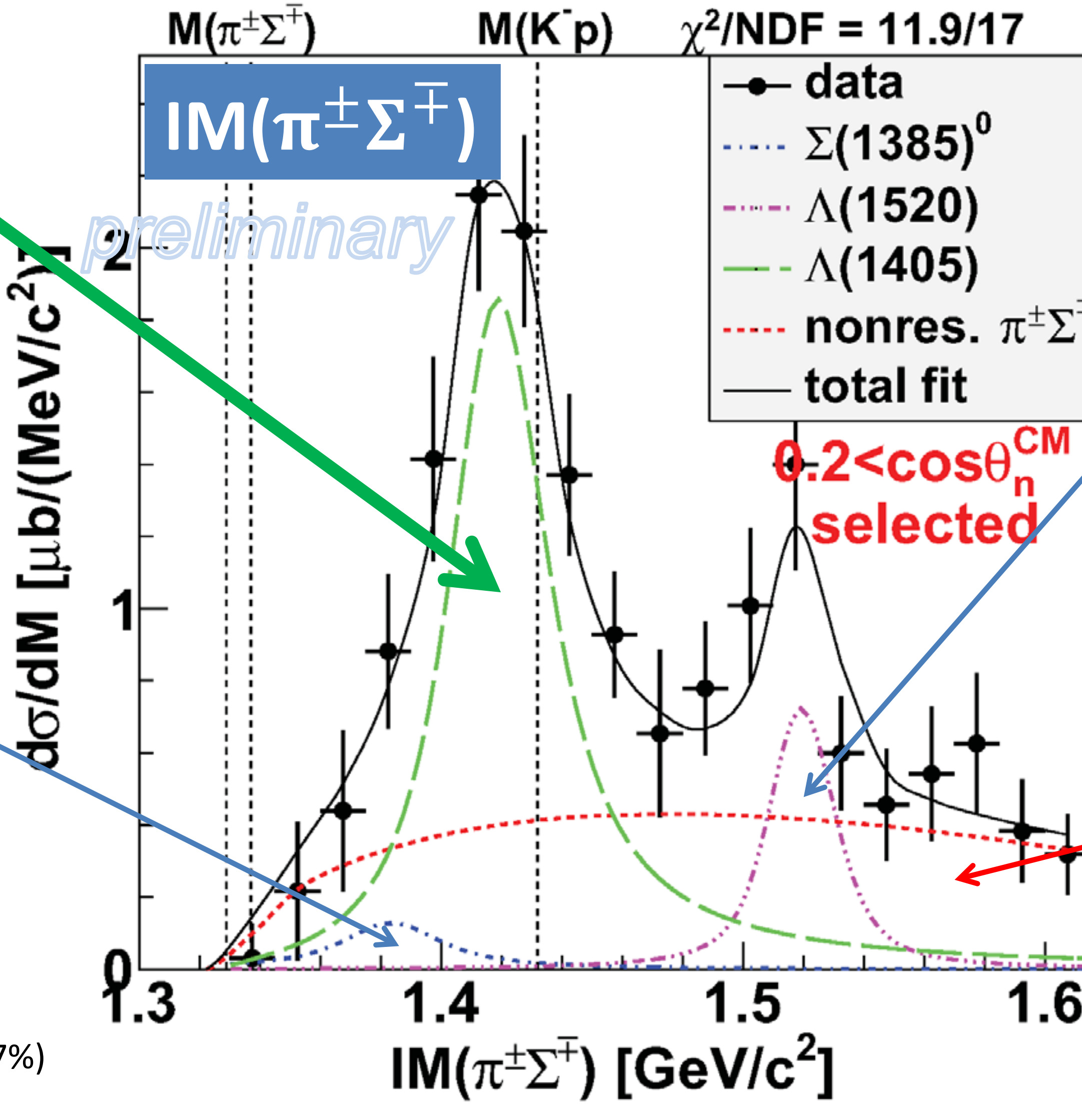
Λ(1405) can be clearly seen in low q_{Kn}

$Y^{*}pn$ Final State *w/ simple BG subt.*

$\Lambda(1405)$

~ 150 μb

Fit w/ Flatté formula:
Re(z) ~ 1420 MeV
-Im(z) ~ 15 MeV



$\Lambda(1520)$

~ 100 μb

$\pi\Sigma pn$ non-resonant

$\Sigma^0(1385)$

~ 20-100 μb

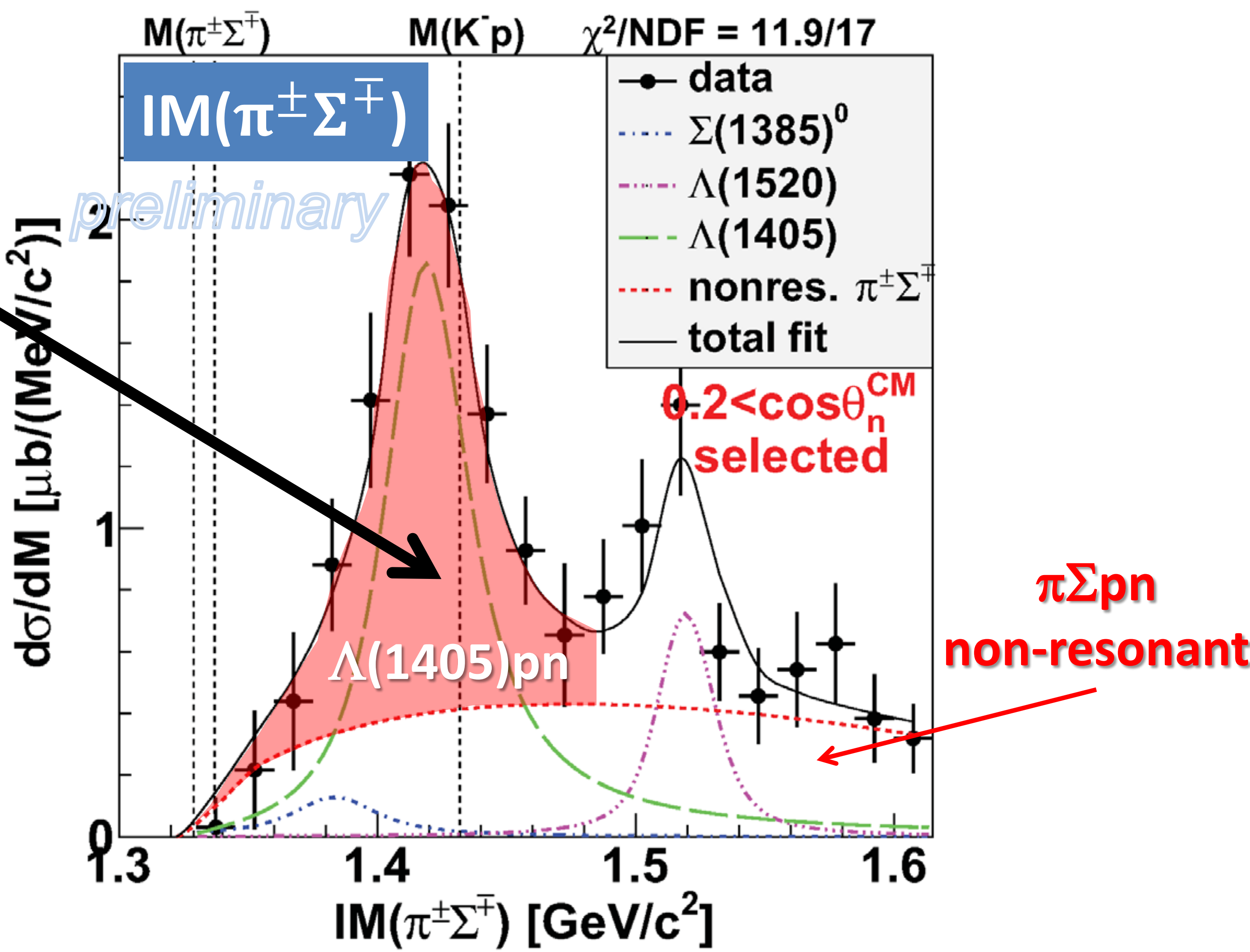
[evaluated from $\Sigma^{+/-}(1385) \rightarrow \pi^{+/-}\Lambda$ measurement]

($\Sigma(1385) \rightarrow \pi\Lambda/\pi\Sigma$: 87.0/11.7%)

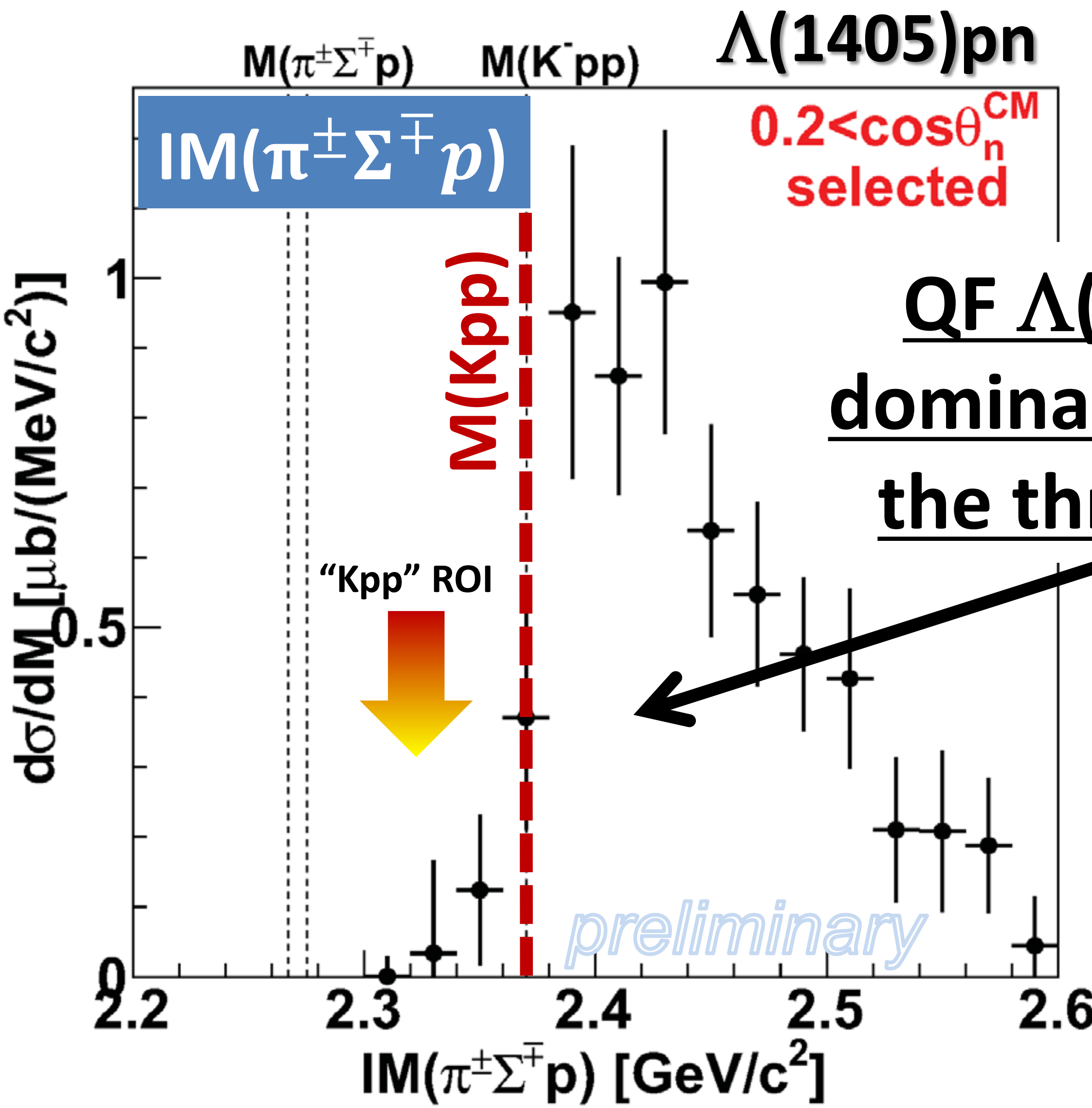
$\Lambda(1405)$pn Final State Selection

Select $\Lambda(1405)$pn final state

- Below $\Lambda(1520)$
- Small contribution from $\Sigma(1385)$



IM($\pi\Sigma$p) in Λ(1405)pn Final State



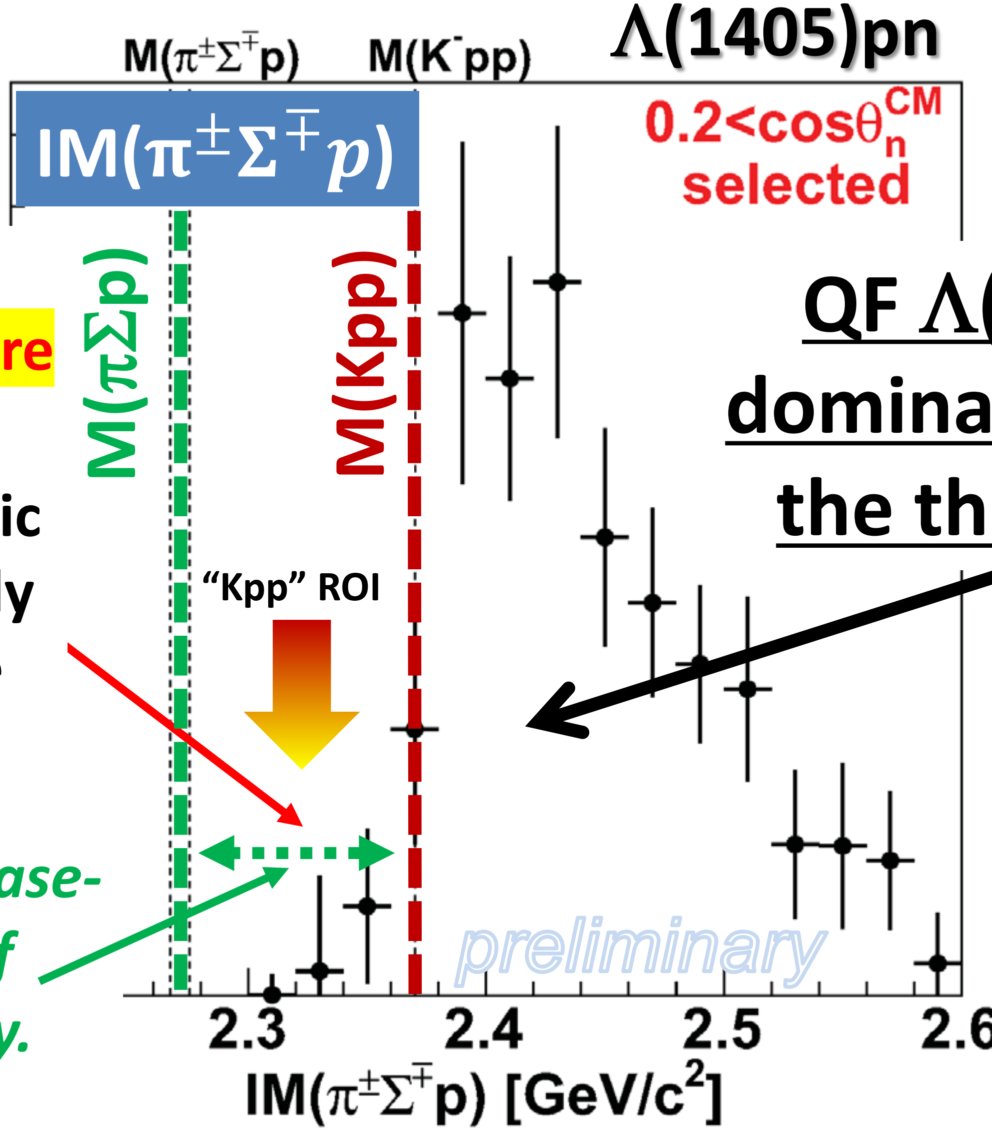
QF Λ(1405): dominant above the threshold

IM($\pi\Sigma$p) in Λ(1405)pn Final State

statistically,
NO significant structure

"Kpp"→$\pi\Sigma$N mesonic decay is theoretically expected to be the dominant channel

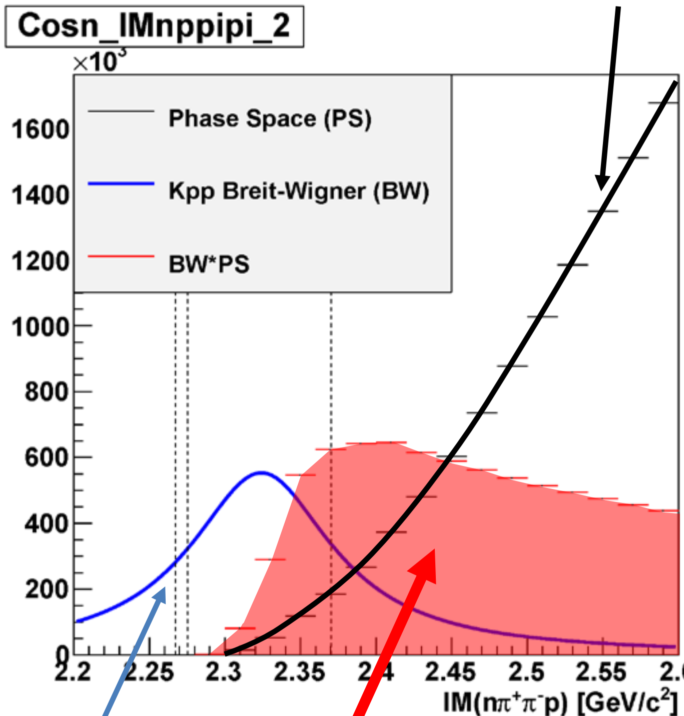
This will be due to phase-space limitation of "K⁻pp"→$\pi\Sigma$N decay.



QF Λ(1405):
dominant above the threshold

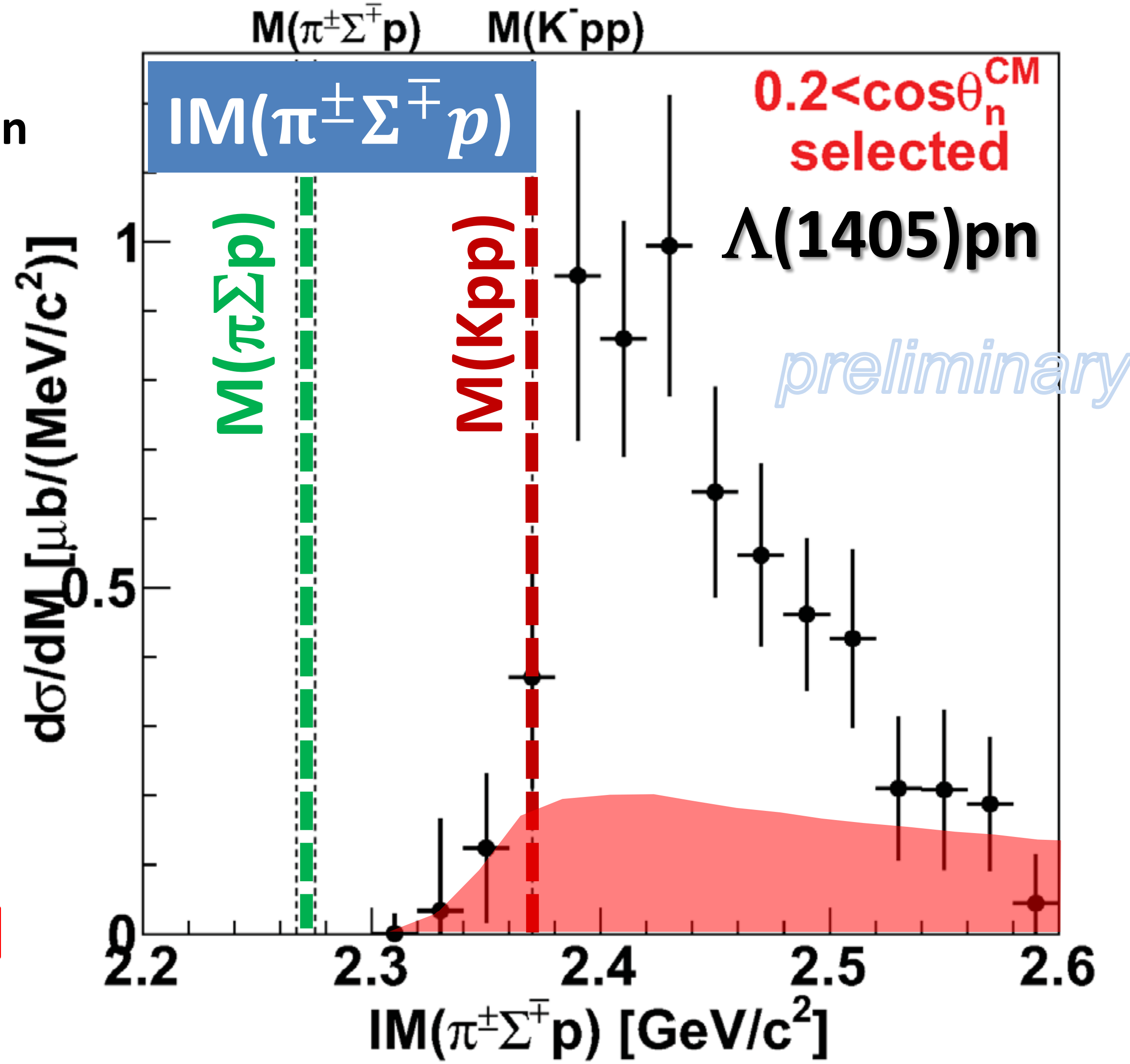
PS Limitation of "K^-pp"→$\pi\Sigma p$ Decay

Phase space of $\pi\Sigma pn$



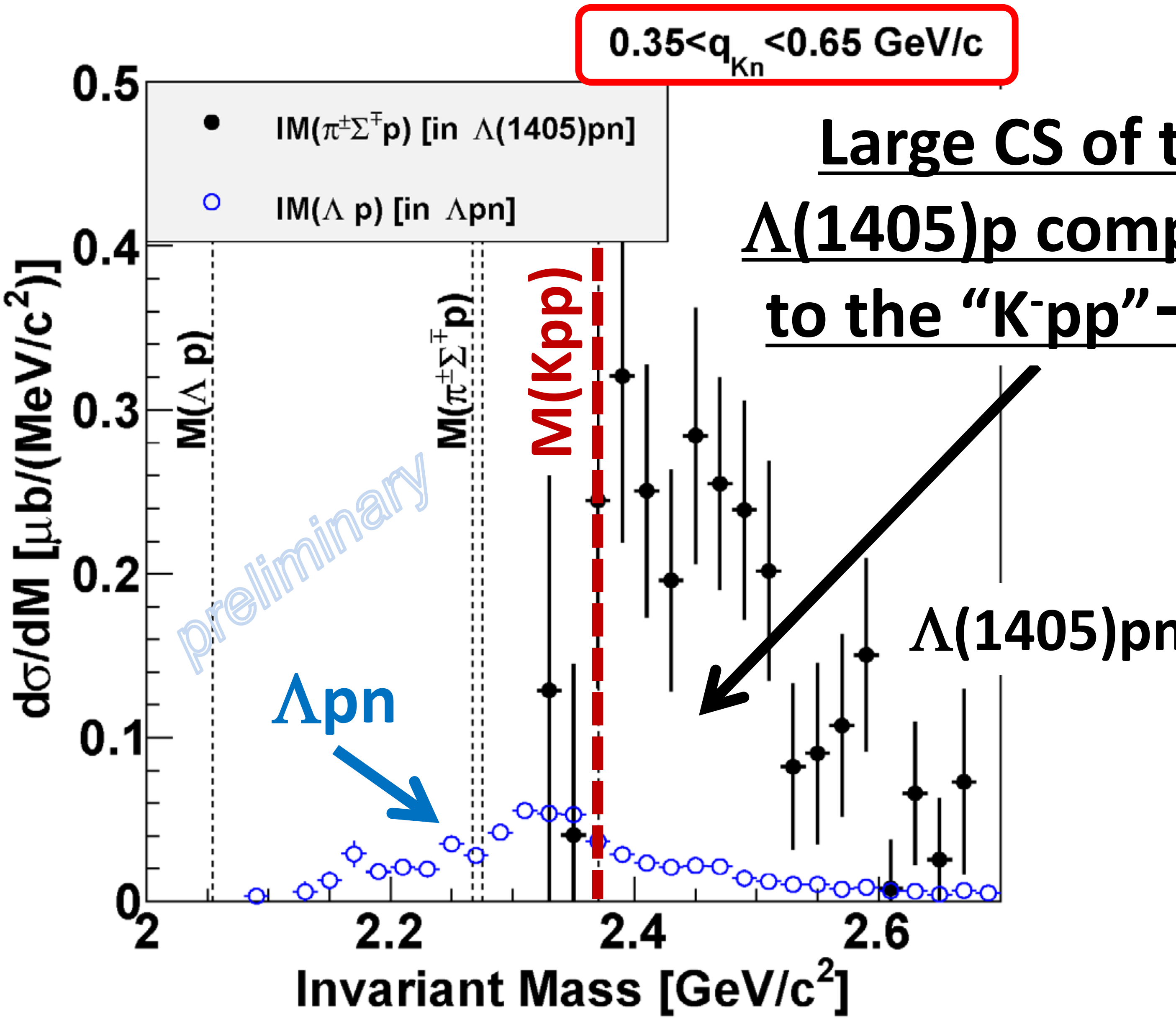
[BW] * [phase space]

Kpp BW obtained with Λp



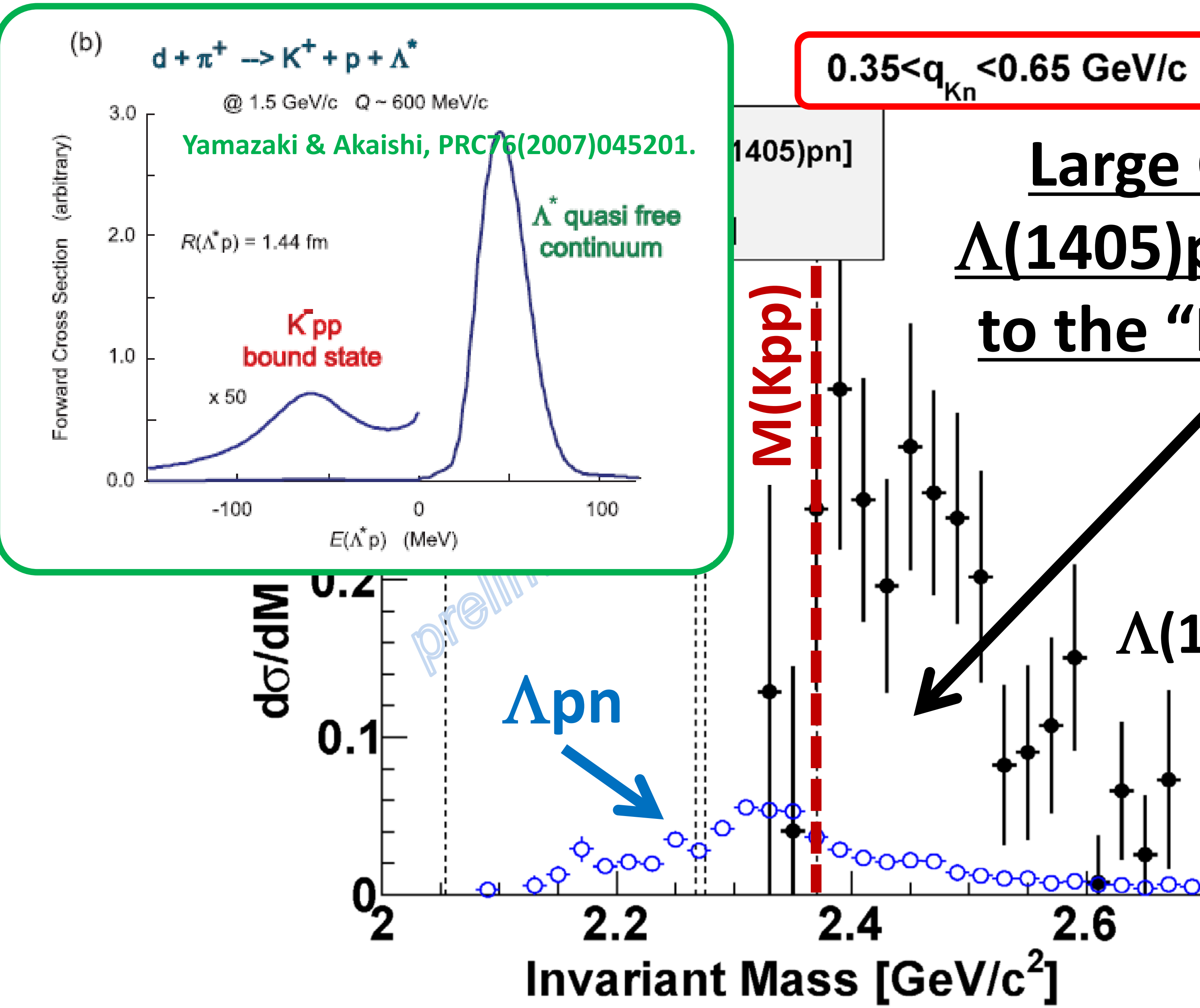
"K^-pp" spectrum would be found as a tail structure

Comparison of Λpn & Λ(1405)pn



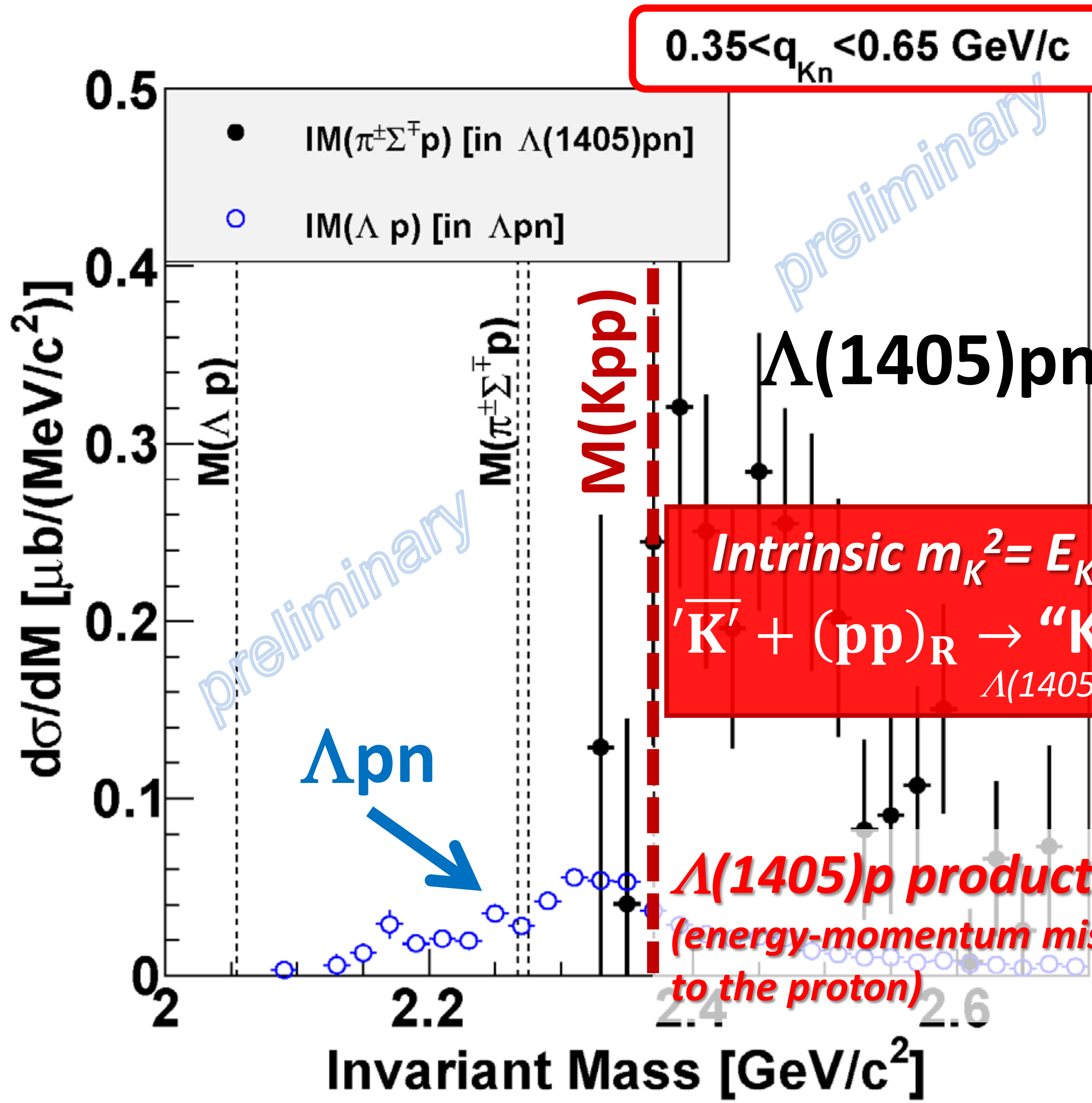
Large CS of the Λ(1405)p compared to the "K$^-$pp"→Λp

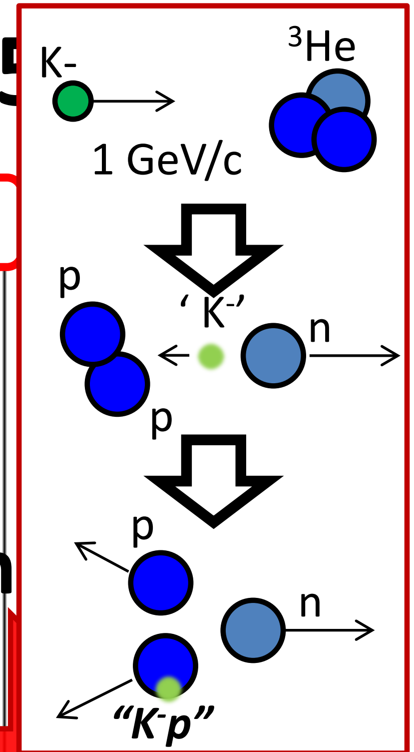
Comparison of Λpn & Λ(1405)pn



Large CS of the Λ(1405)p compared to the "K-pp"→Λp

Comparison of Λpn & Λ(1405





Intrinsic $m_K^2 = E_K^2 - q^2$

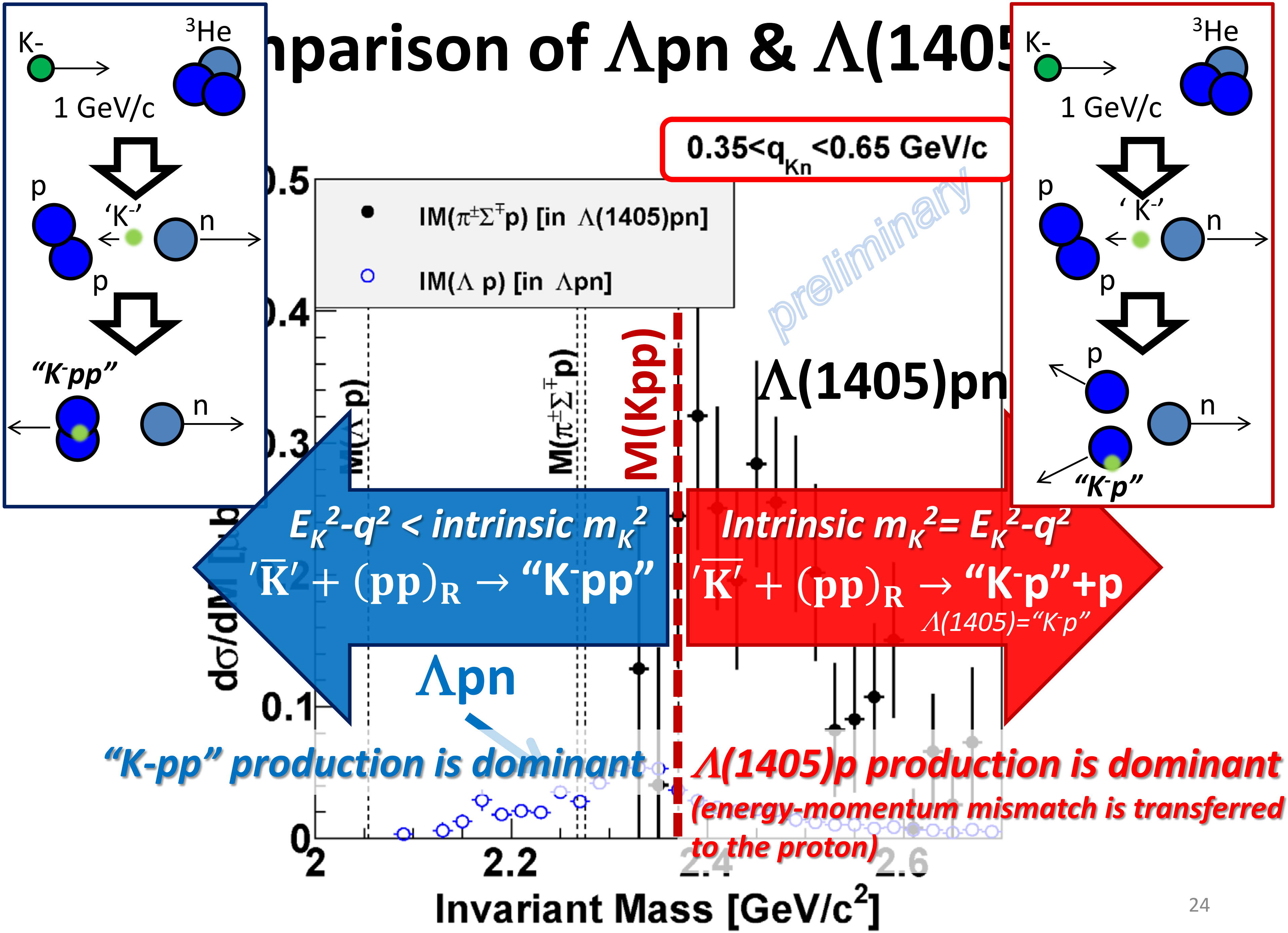
$'\overline{K}' + (pp)_R \rightarrow$ "K⁻p"+p

$\Lambda(1405)$="K⁻p"

Λ(1405)p production is dominant

(energy-momentum mismatch is transferred to the proton)

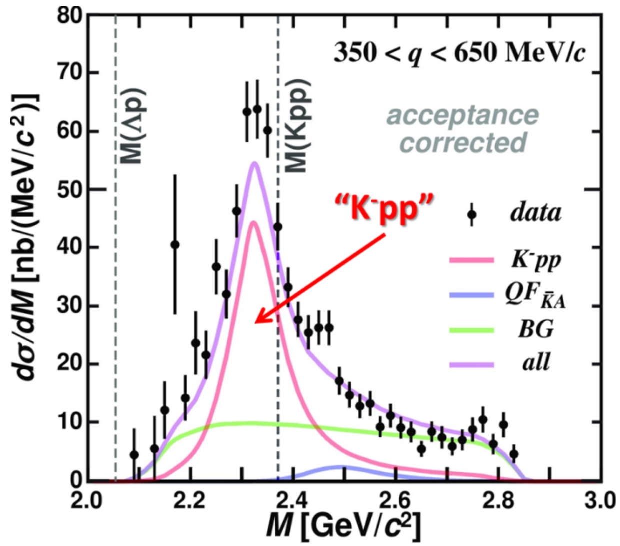
nparison of Λpn & Λ(1405



Summary

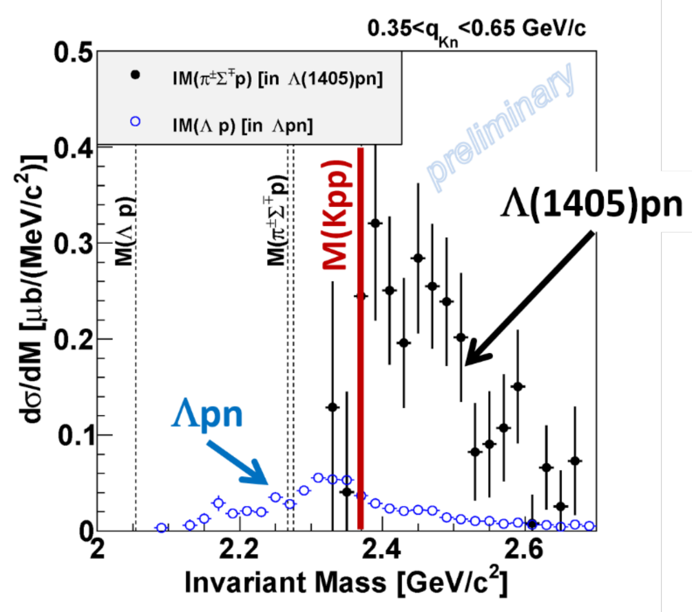
- **We observed the “$K^{-}pp$” bound state in $^{3}He(K^{-},\Lambda p)n$**
  - Binding energy: ~50 MeV
  - Width: ~100 MeV

← PLB789(2019)620.



- **We found large CS of the $\Lambda(1405)p$ formation compared to the “$K^{-}pp$”**
  - quite important information on the production mechanism of the “$K^{-}pp$”

← paper in preparation



Thank You!

J-PARC E15 Collaboration

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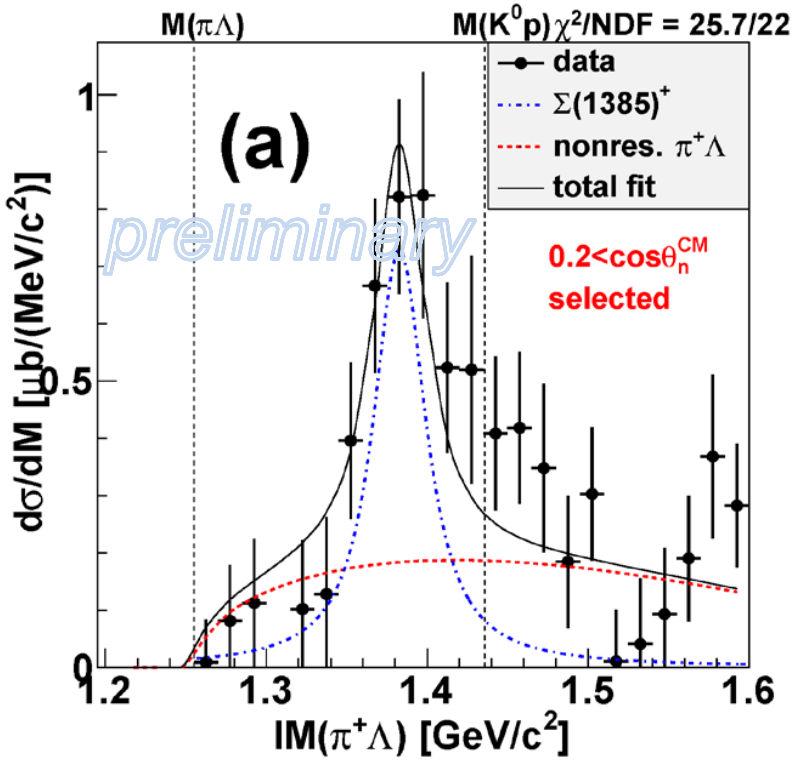
Spares

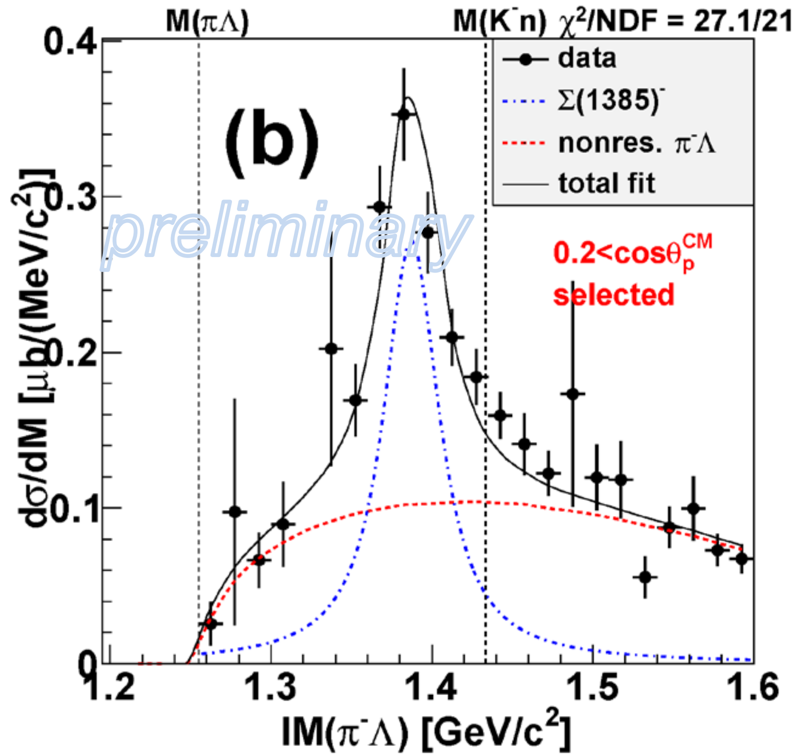
I=1 Channels, $\Sigma^{+/-}(1385)$

$\Sigma^+(1385)$ ~ 50 μb



in $\pi^+\Lambda$nn final state

$\Sigma^-(1385)$ ~ 20 μb



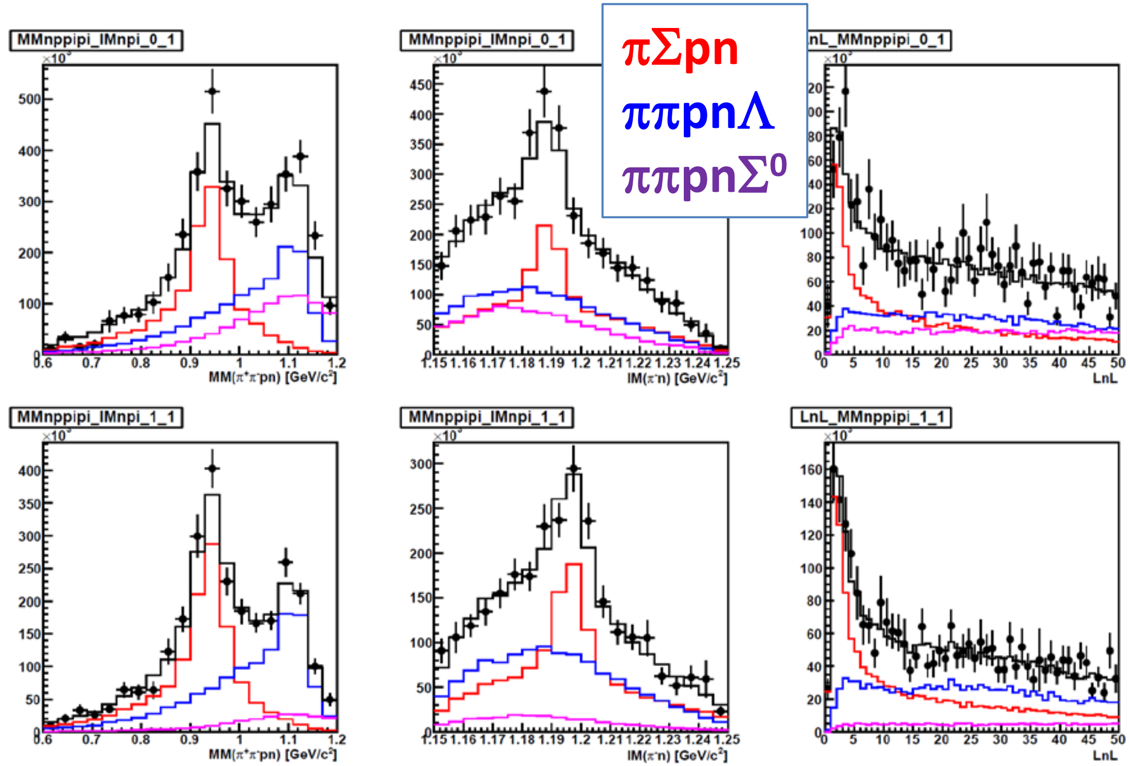
in $\pi^-\Lambda$pp final state

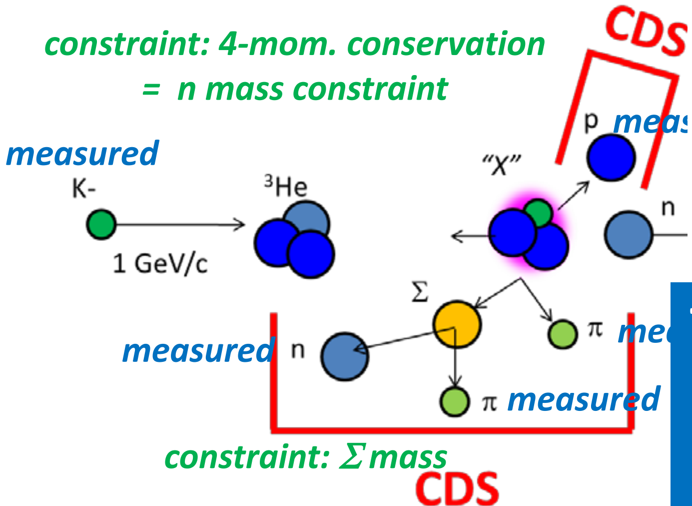
→ $\Sigma^0(1385)$ ~ 20-100 μb

Selection of $\pi^{\pm}\Sigma^{\mp}pn$ Final State

- $\pi^{\pm}\Sigma^{\mp}$ events are separated using kinematical-fit
  - Constraints:
    - M(Σ→nπ)
    - 4-momentum conserv
  - Event selection by χ^2 probability (0.01<p)

e.g. after acc/eff correction

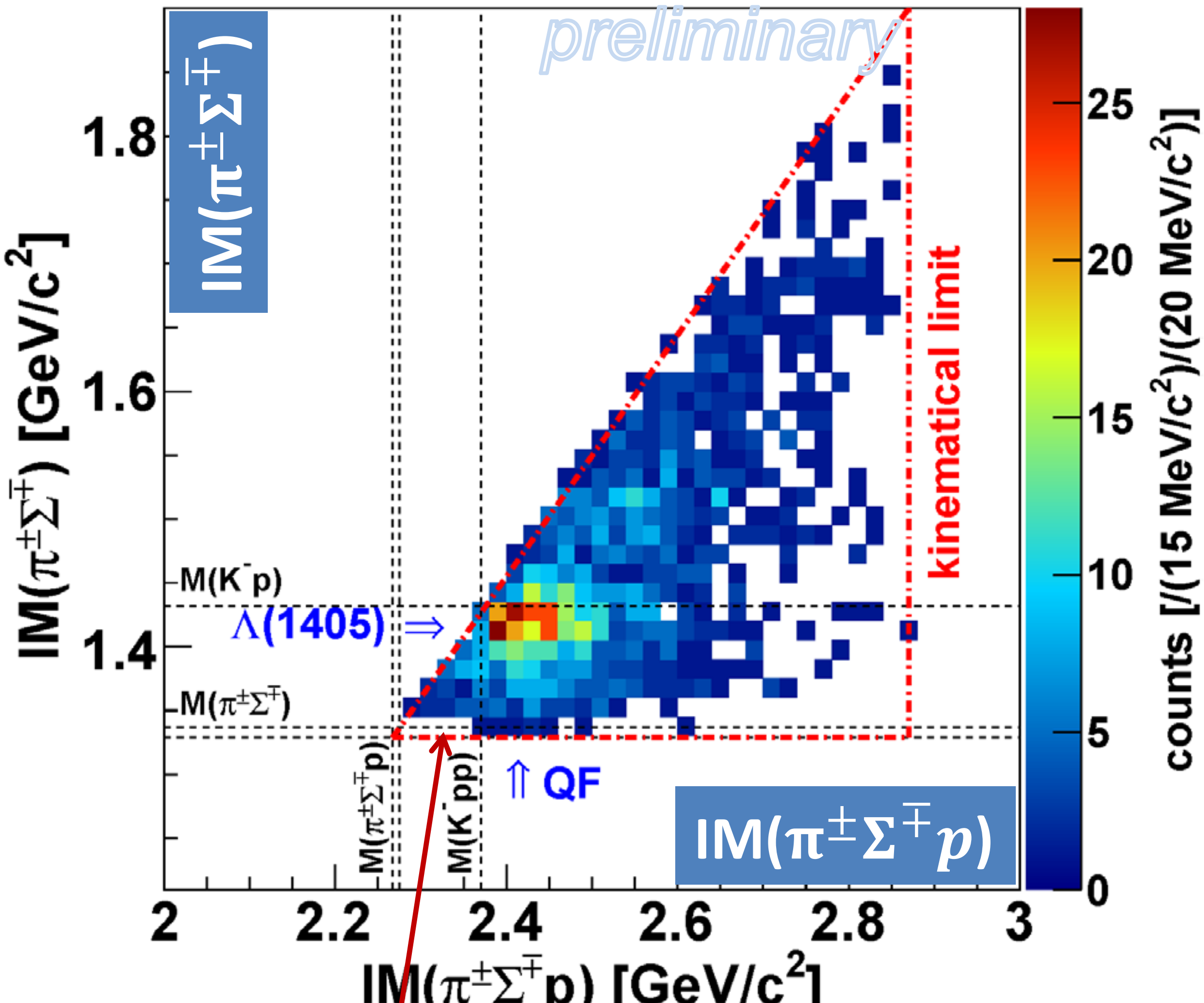


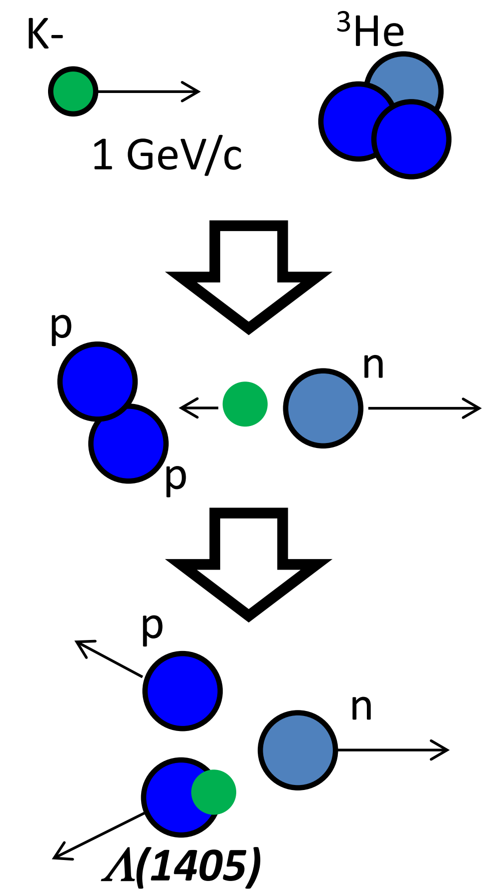


Trying to improve Exp. BG evaluation by introducing
- **new analysis cuts**
- **loglikelihood function with DCA**
- **global fit with signal & BG's**

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

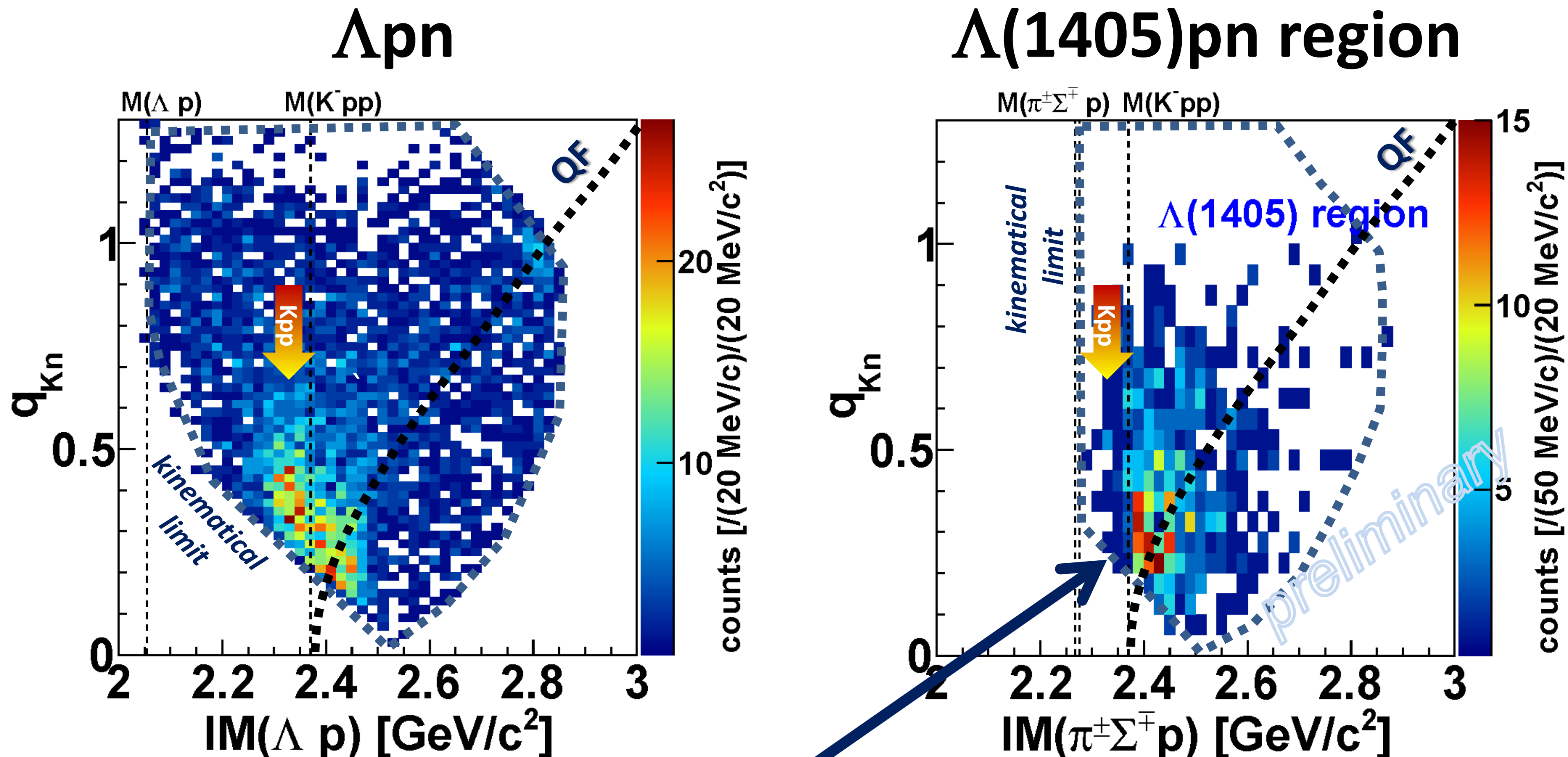
w/ Exp. BG





Small phase-space of "K⁻pp"→πΣN

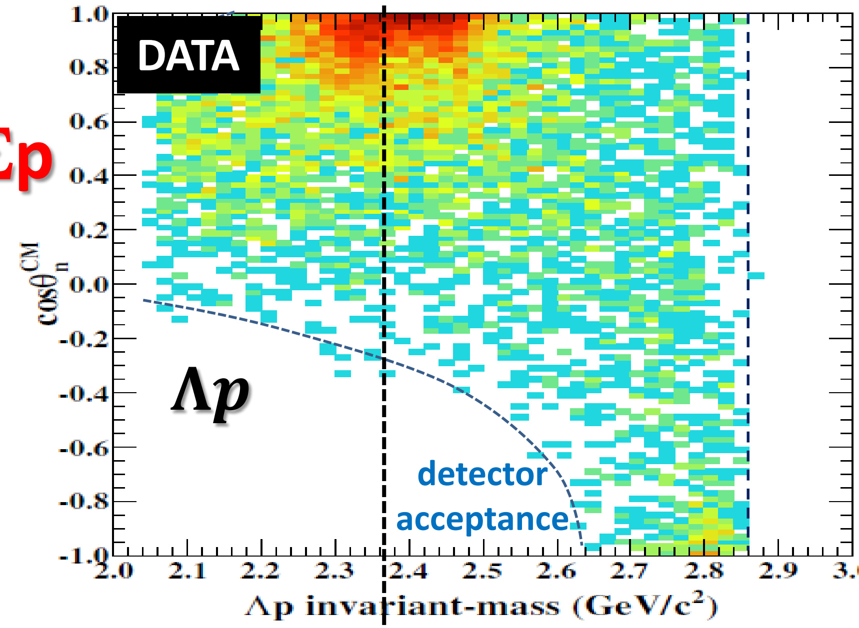
Comparison of Λpn & Λ(1405)pn

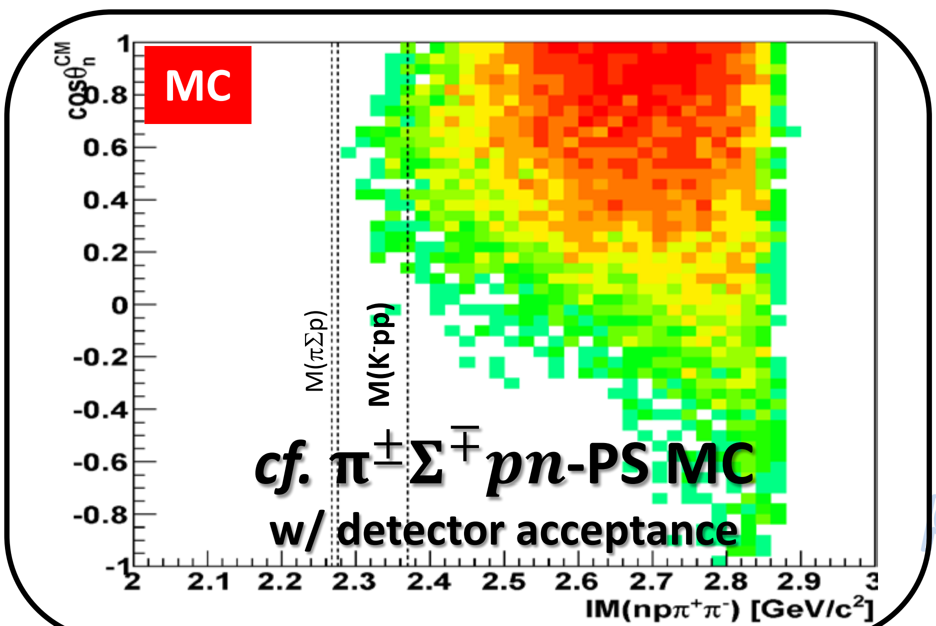


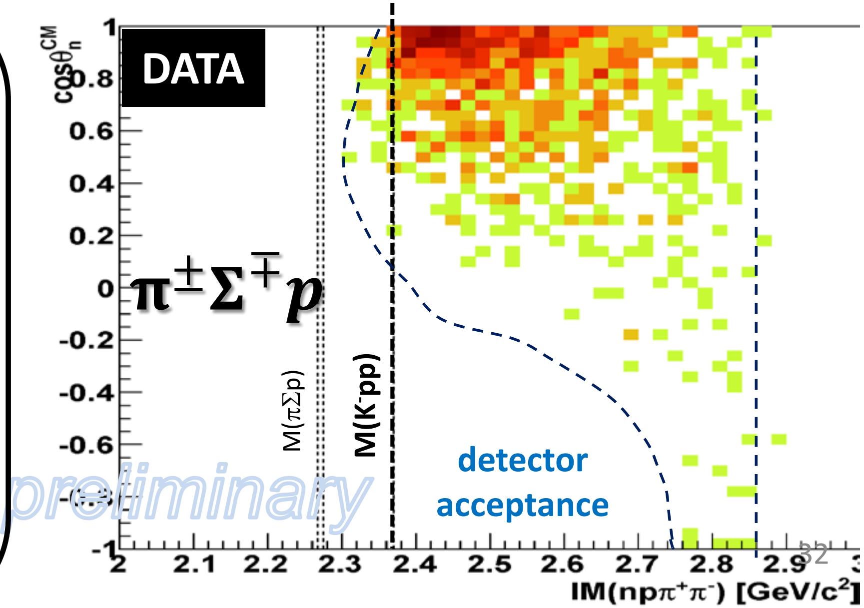
- **No clear structure below M(Kpp) in the IM(πΣp)**
- **QF followed by Λ(1405)p is dominant**

Detector Acceptance: Λp vs. $\pi\Sigma p$

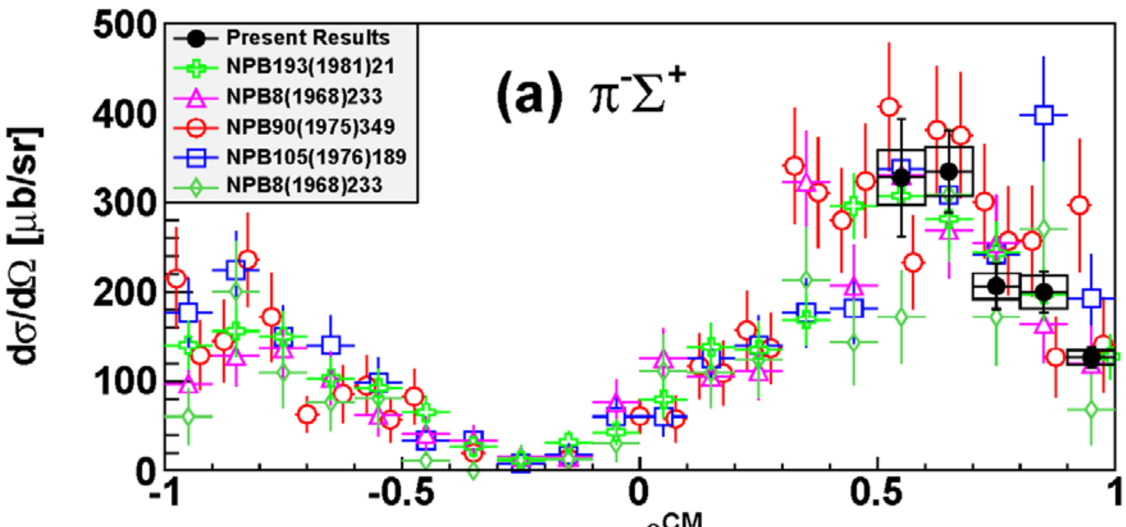
- **Detector acceptance is different between Λp and $\pi\Sigma p$**
  - At $\cos\theta_n$~1:
    - Λp: flat acceptance
    - $\pi\Sigma p$: limited acceptance below the threshold



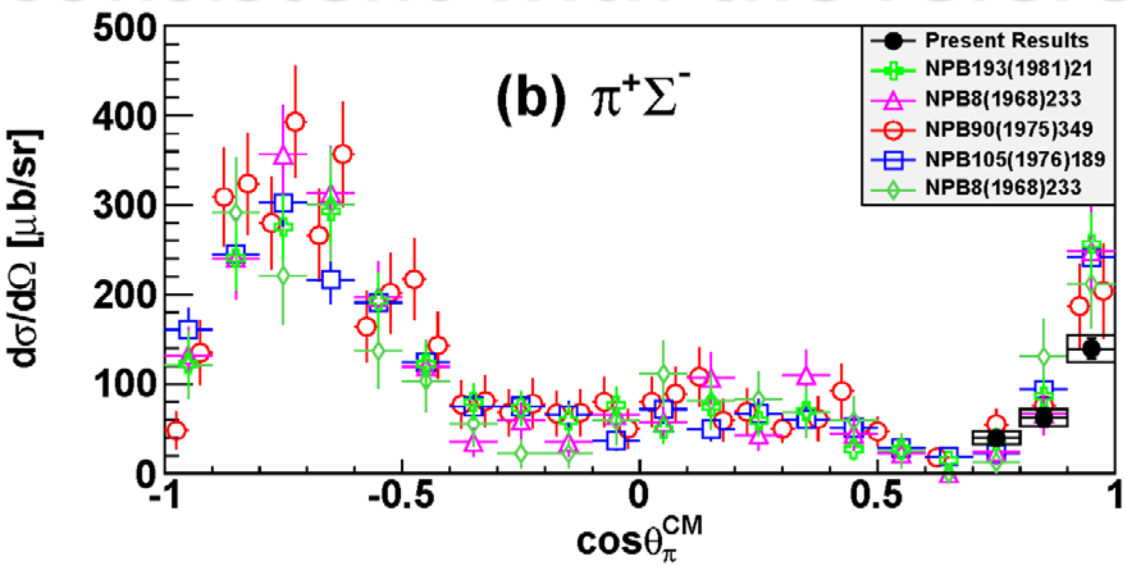




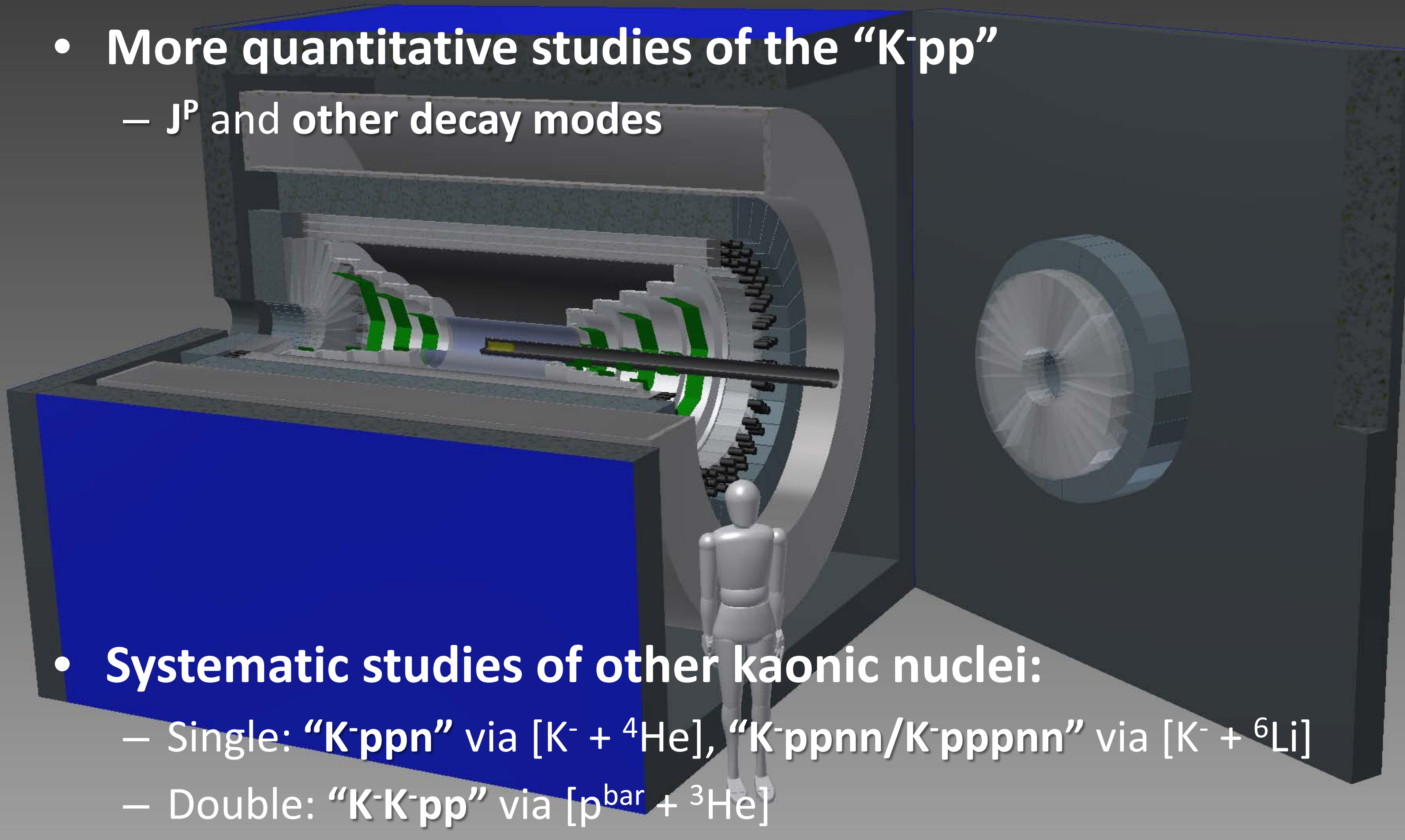
$K^-p \rightarrow \Sigma^+\pi^-/\Sigma^-\pi^+$ Cross Section



consistent with the references



Need further investigation



- **More quantitative studies of the "K^-pp"**
  - **J^P** and **other decay modes**
- **Systematic studies of other kaonic nuclei:**
  - Single: **"K^-ppn"** via [K^- + ^{4}He], **"K^-ppnn/K^-pppnn"** via [K^- + ^{6}Li]
  - Double: **"K^-K^-pp"** via [p^{bar} + ^{3}He]

A new 4π detector with γ/n sensitive detectors is required