Search for the Kaonic Bound State $K^{bar}NN$ via $^{3}He(K^{-}, \Lambda p/\pi\Sigma p)n$ Reactions

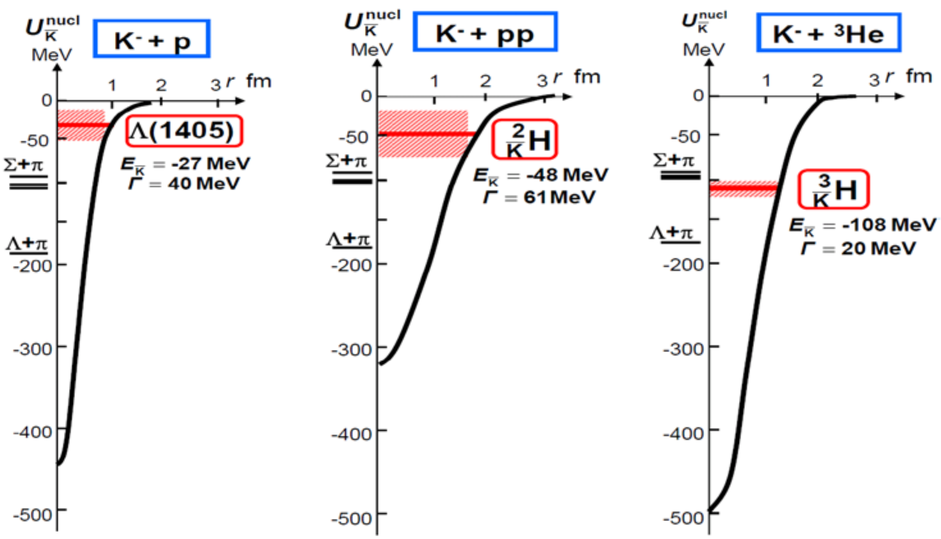
F. Sakuma, RIKEN

on behalf of the J-PARC E15 collaboration

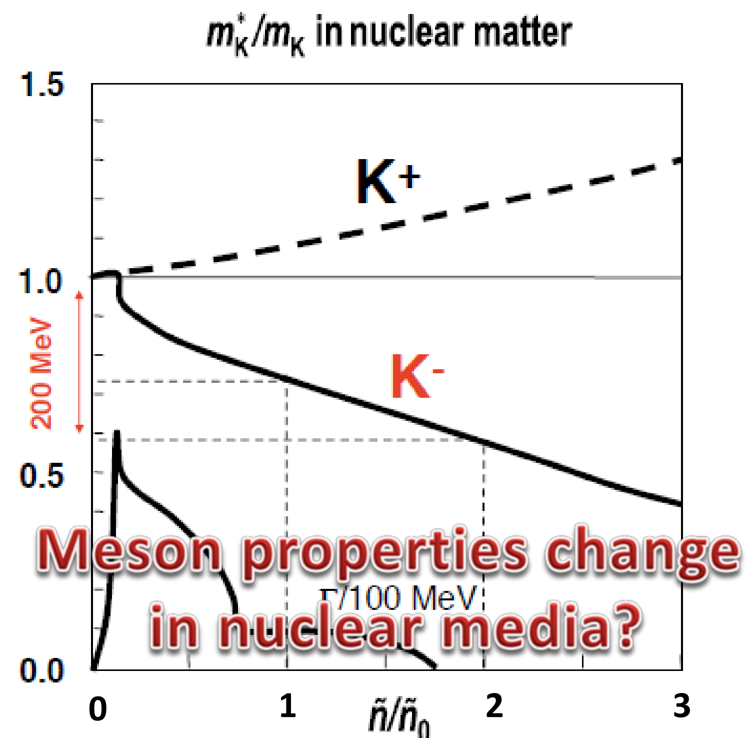
YKIS2018b Symposium "**Recent Developments in Quark-Hadron Sciences**"
June 11 - June 15, 2018, Yukawa Institute for Theoretical Physics, Kyoto University

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).

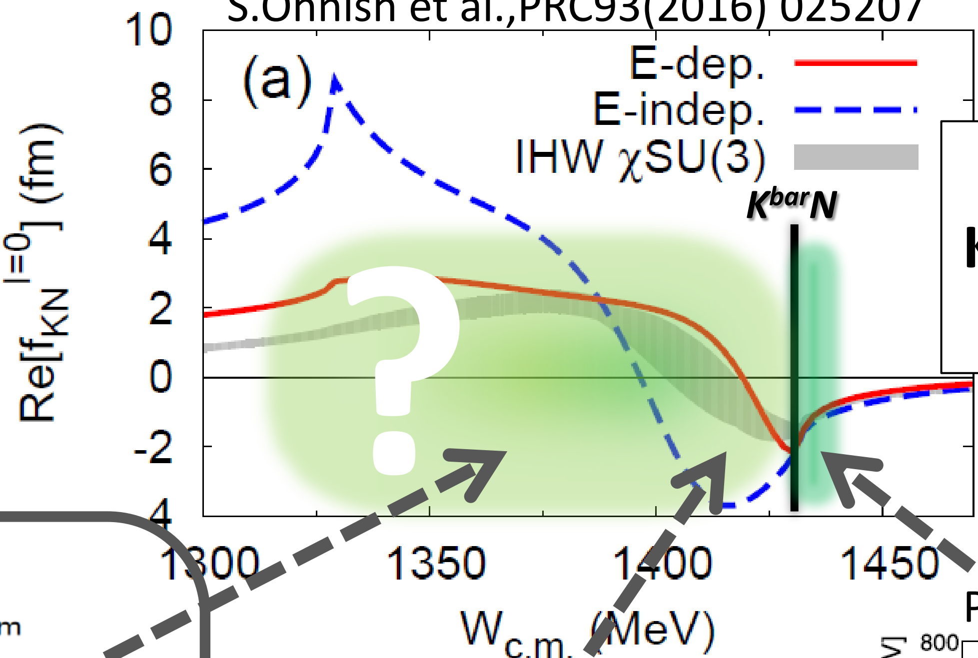


T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

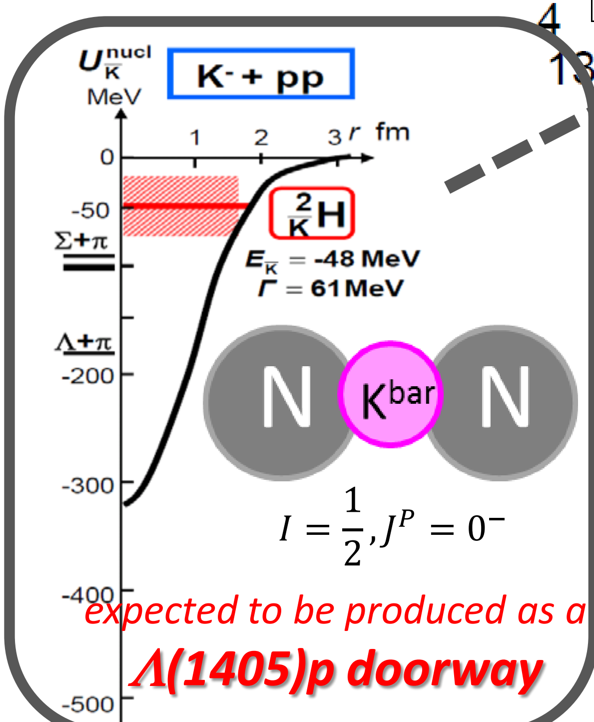
- Will provide new insight on $K^{bar}N$ interaction in media

$K^{bar}N$ interaction - A good probe for low-energy QCD

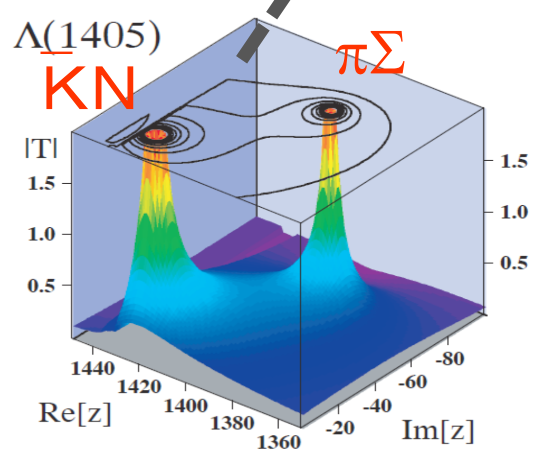
S.Ohnish et al.,PRC93(2016) 025207



Calculation on $K^{bar}N$ amplitude in I = 0

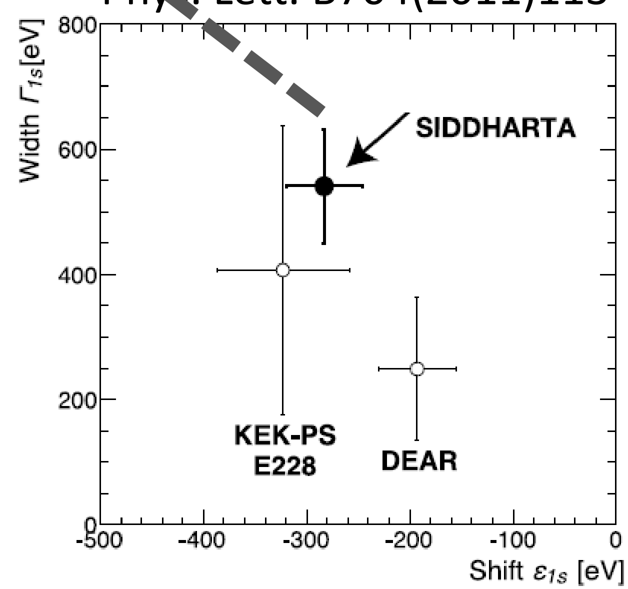


expected to be produced as a
Λ(1405)p doorway



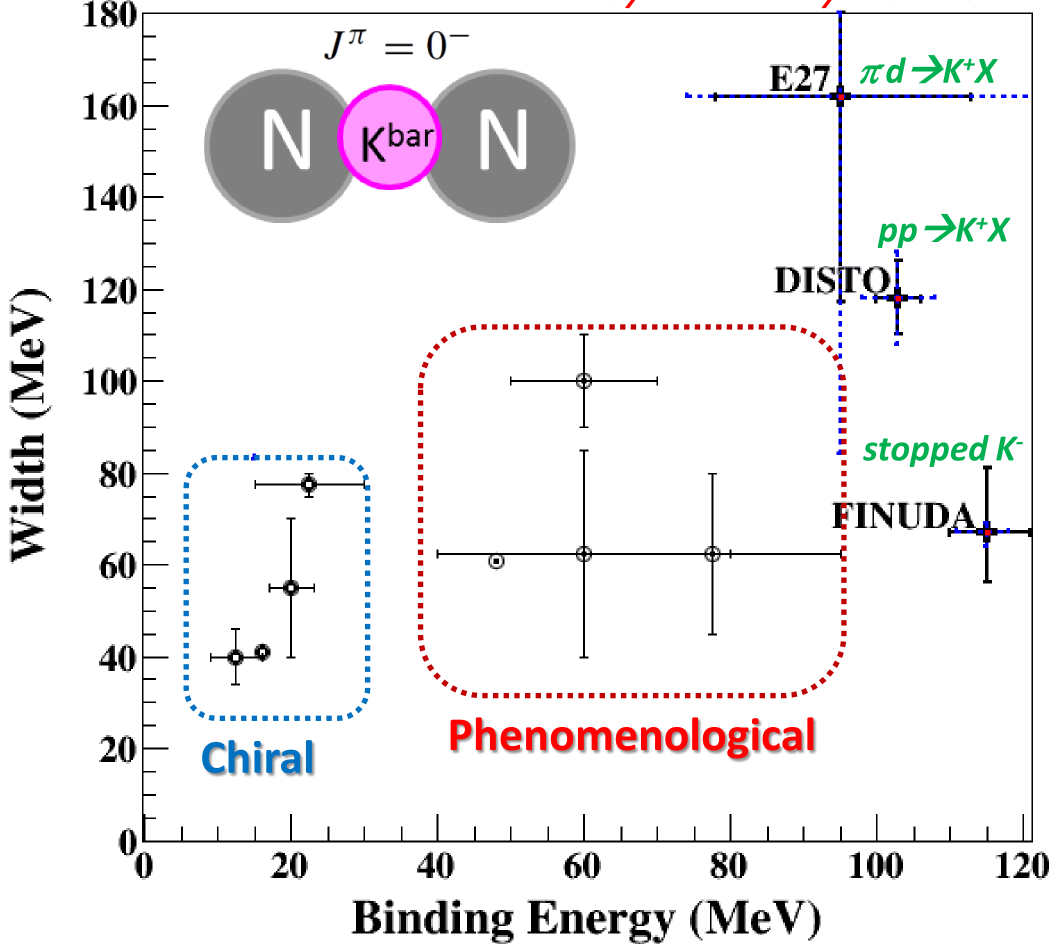
ChU model, T. Hyodo

M. Bazzi et al., (SIDDHARTA Coll.), Phys. Lett. B704(2011)113



Present Status of $K^{bar}NN$ = "$K^{-}pp$"

$K^{bar}NN$ is symbolically notated as "$K^{-}pp$" in this talk



Upper limits were also obtained:

- **LEPS@SPring8 [Inclusive $d(\gamma, K^{+}\pi^{-})X$]**
- **HADES@GSI [Exclusive $pp \rightarrow p\Lambda K^{+}$]**

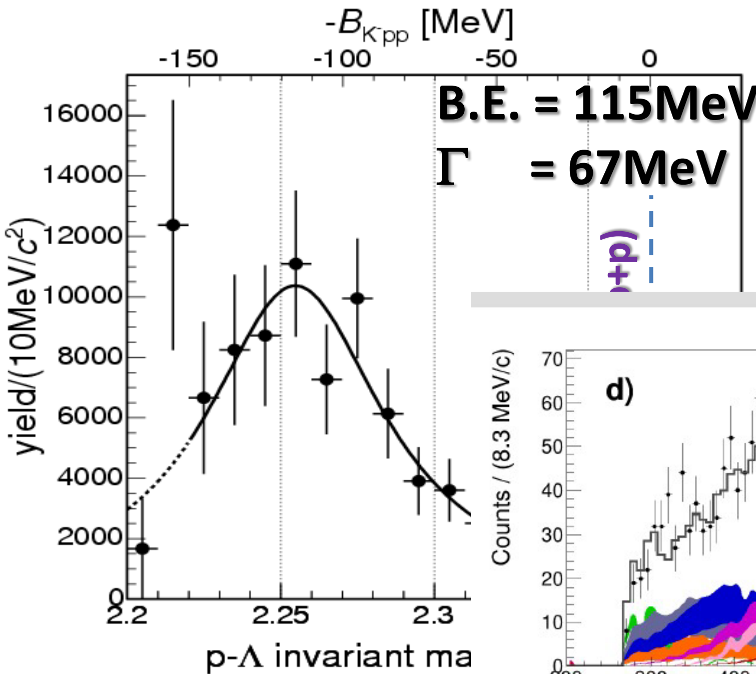
Theoretical Calculations on $K^{bar}NN$

$K^{bar}N$ int.	Chiral SU(3) (energy dependent)			Phenomenological (energy independent)			
Method	Variational		Faddeev	Variational		Faddeev	
	Barnea, Gal, Liverts	Dote, Hyodo, Weise	Ikeda, Kamano, Sato	Yamazaki, Akaishi	Wyceck, Green	Shevchenko, Gal, Mares	Ikeda, Sato
B (MeV)	**16**	**17-23**	**9-16**	**48**	**40-80**	**50-70**	**60-95**
Γ (MeV)	**41**	**40-70**	**34-46**	**61**	**40-85**	**90-110**	**45-80**

- **$K^{bar}N$ interaction model:**
  - Chiral SU(3) [energy dependent] → **B.E. ~ 20 MeV**
  - Phenomenological [energy independent] → **B.E. ~ 40-70 MeV**
- **Calculation method:**
  - Almost the same results

Strongly depending on $K^{bar}N$ interaction

"K$^-$pp" Search via Stopped-K$^-$



FINUDA@

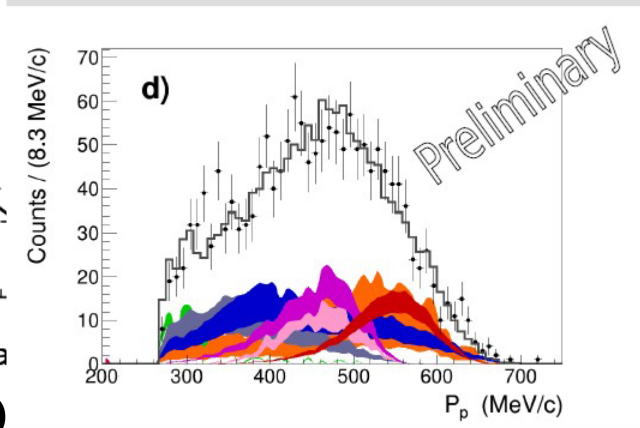
PRL**94**(2005)

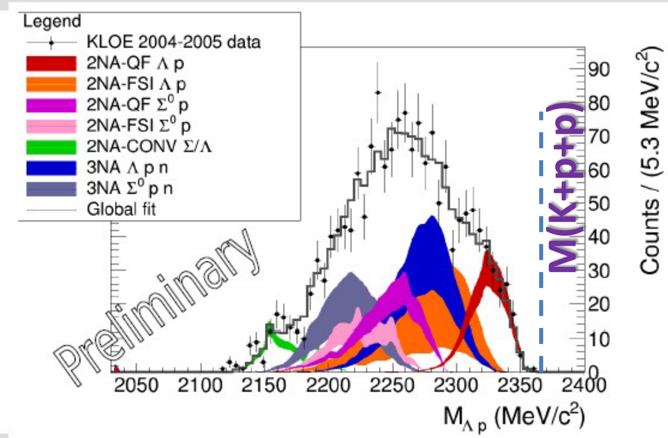
^{6}Li+^{7}Li+^{12}C(*stop*

AMADEUS@DAΦNE

R. Del Grande MESON2018

^{12}C(*stopped* K$^-$, Λp)





2NA followe

PRC74(2006)0252

PRC82(2010)0346

Simultaneous fit of:

- Λp invariant mass;
- angular correlation;
- proton momentum;
- Λ momentum.

Total reduced χ²:

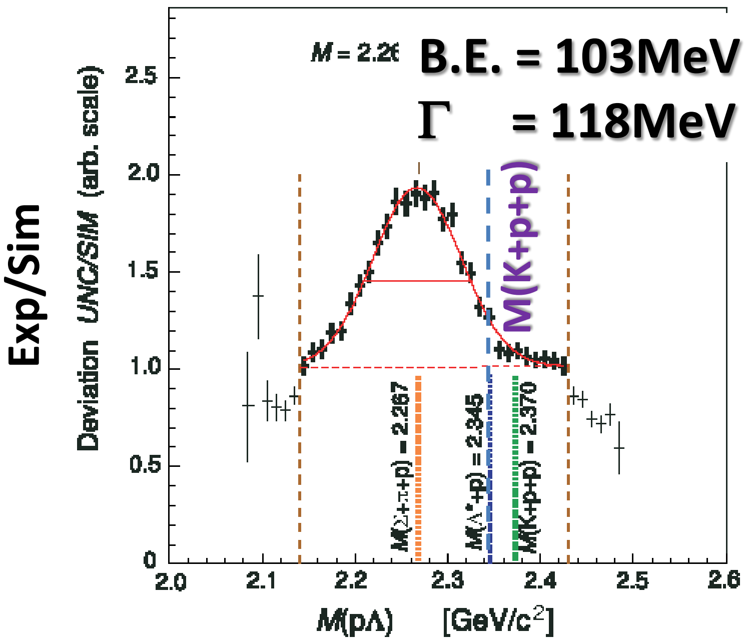
χ²/dof = 0.94

Process	Branching Ratio (%)
2NA-QF Λp	0.20 ± 0.04(stat.) ± 0.02(syst.)
2NA-FSI Λp	3.8 ± 2.3(stat.) ± 1.1(syst.)
2NA-QF Σ^{0}p	0.54 ± 0.20(stat.) $^{+0.20}_{-0.16}$(syst.)
2NA-FSI Σ^{0}p	5.4 ± 1.5(stat.) $^{+1.0}_{-2.7}$(syst.)
3NA Λpn	1.1 ± 0.3(stat.) ± 0.2(syst.)
3NA Σ^{0}pn	1.9 ± 0.7(stat.) $^{+0.8}_{-0.4}$(syst.)
2NA-Σ/Λconv	22 ± 4(stat.) $^{+1}_{-12}$(syst.)

Preliminary

Spectrum can be reproduced with 2NA/3NA!

"K^-pp" Search via pp Collision



DISTO@SATURNE

PRL**104**(2010)132502

$p + p \rightarrow (\Lambda + p) + K^+$ @ 2.85GeV

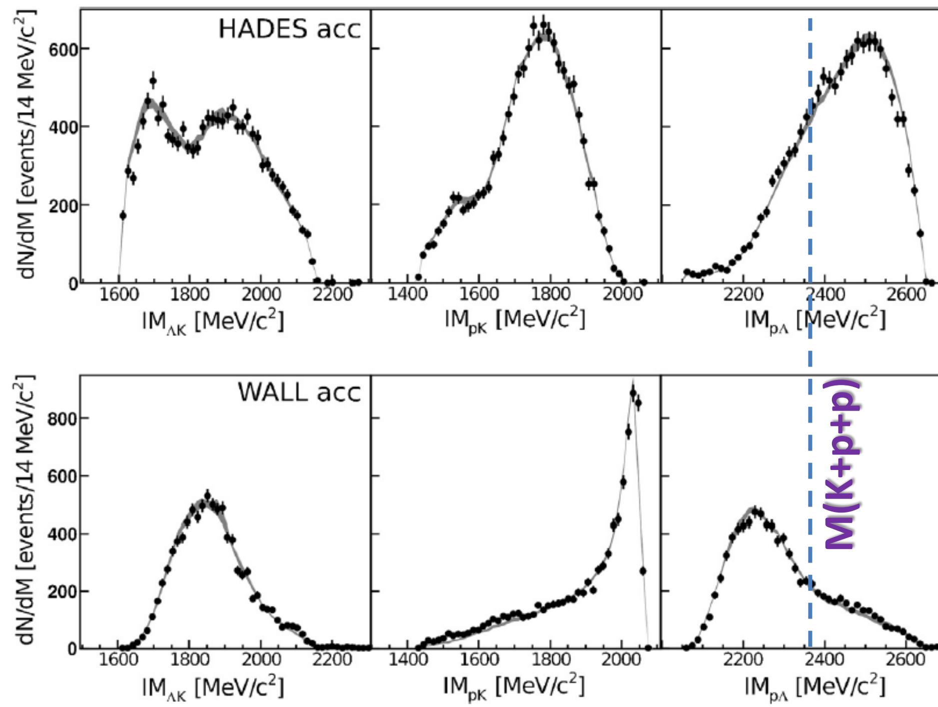
pp→p(N*)→p(ΛK+)?

PRC92(2015)044002

HADES@GSI

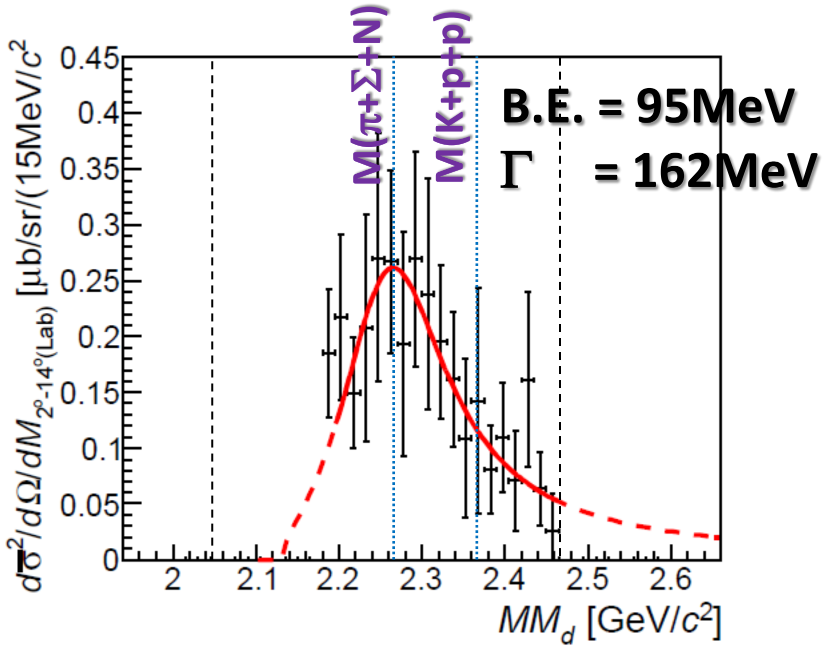
PLB**742**(2015)242

$p + p \rightarrow (\Lambda + p) + K^+$ @ 3.5GeV



Spectrum can be reproduced with N*'s

"K$^-$pp" Search via d(π^-,K$^+$)X



E27@J-PARC

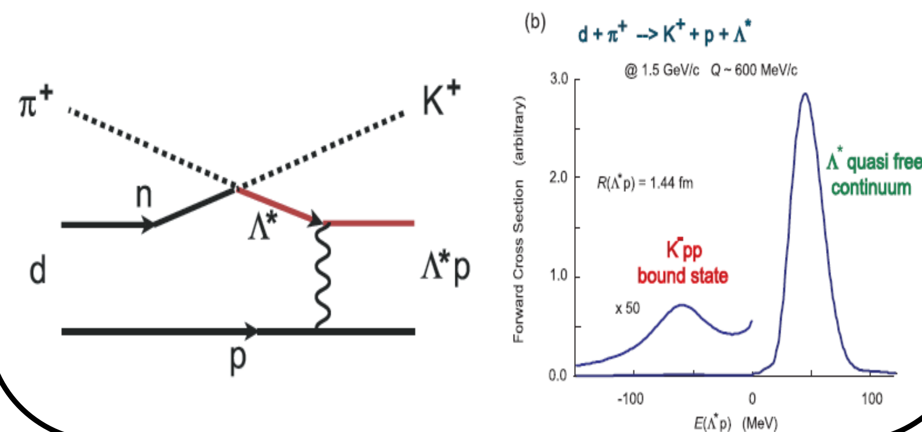
PTEP(2015)021D01.

d(π^-, K$^+$)Yp @ 1.69 GeV/c

π^+ + "n" --> "Λ^*" + K$^+$

"Λ^*" + "p" --> bound K$^-$pp *minor*

--> quasi-free Λ^* *dominant*

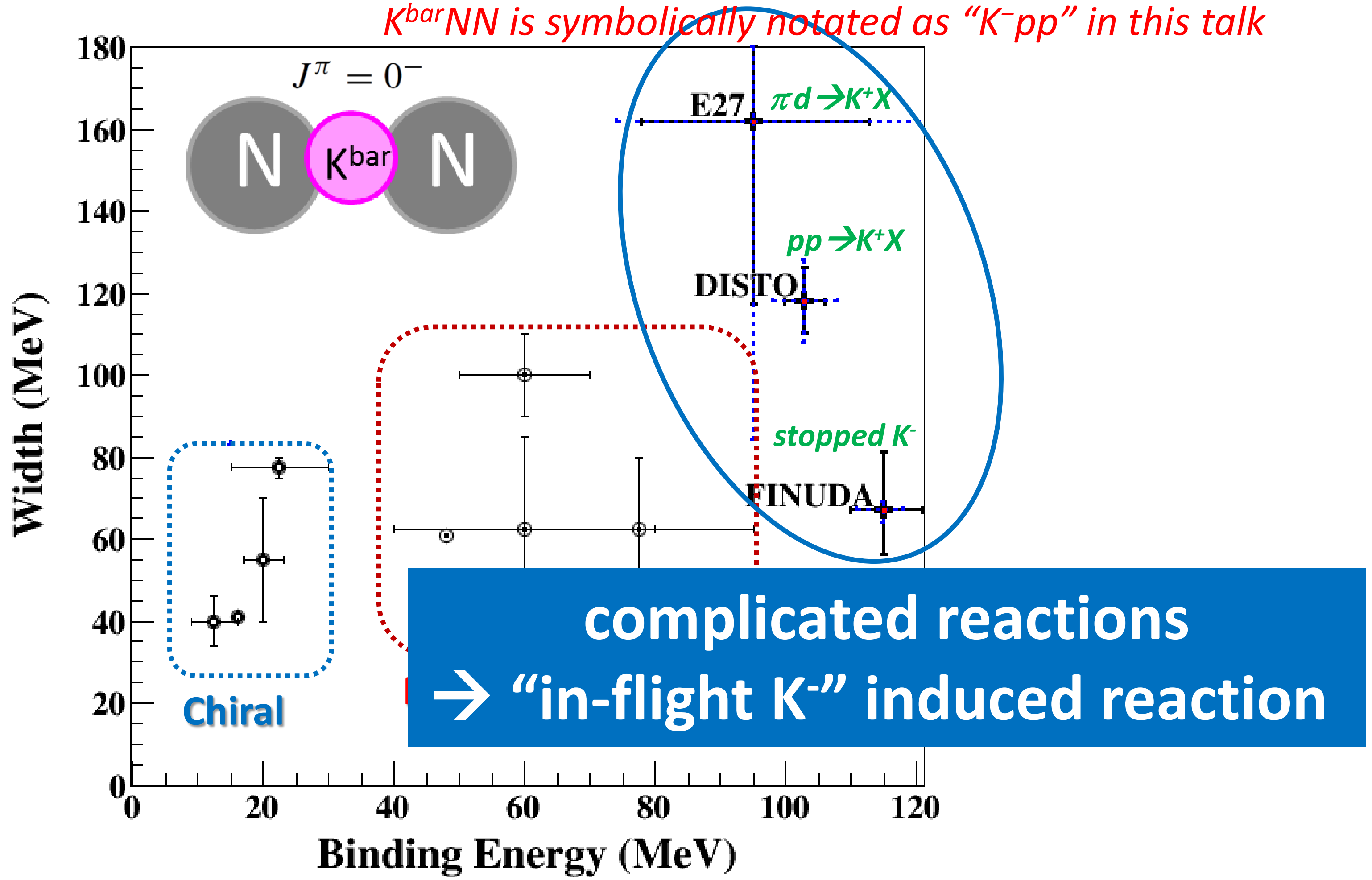


Yamazaki & Akaishi, PRC76(2007) 045201.

- Need more statistics
- Expect a new experiment with 4π detector @ J-PARC

Present Status of $K^{bar}NN$ = "K^-pp"

$K^{bar}NN$ is symbolically notated as "K^-pp" in this talk



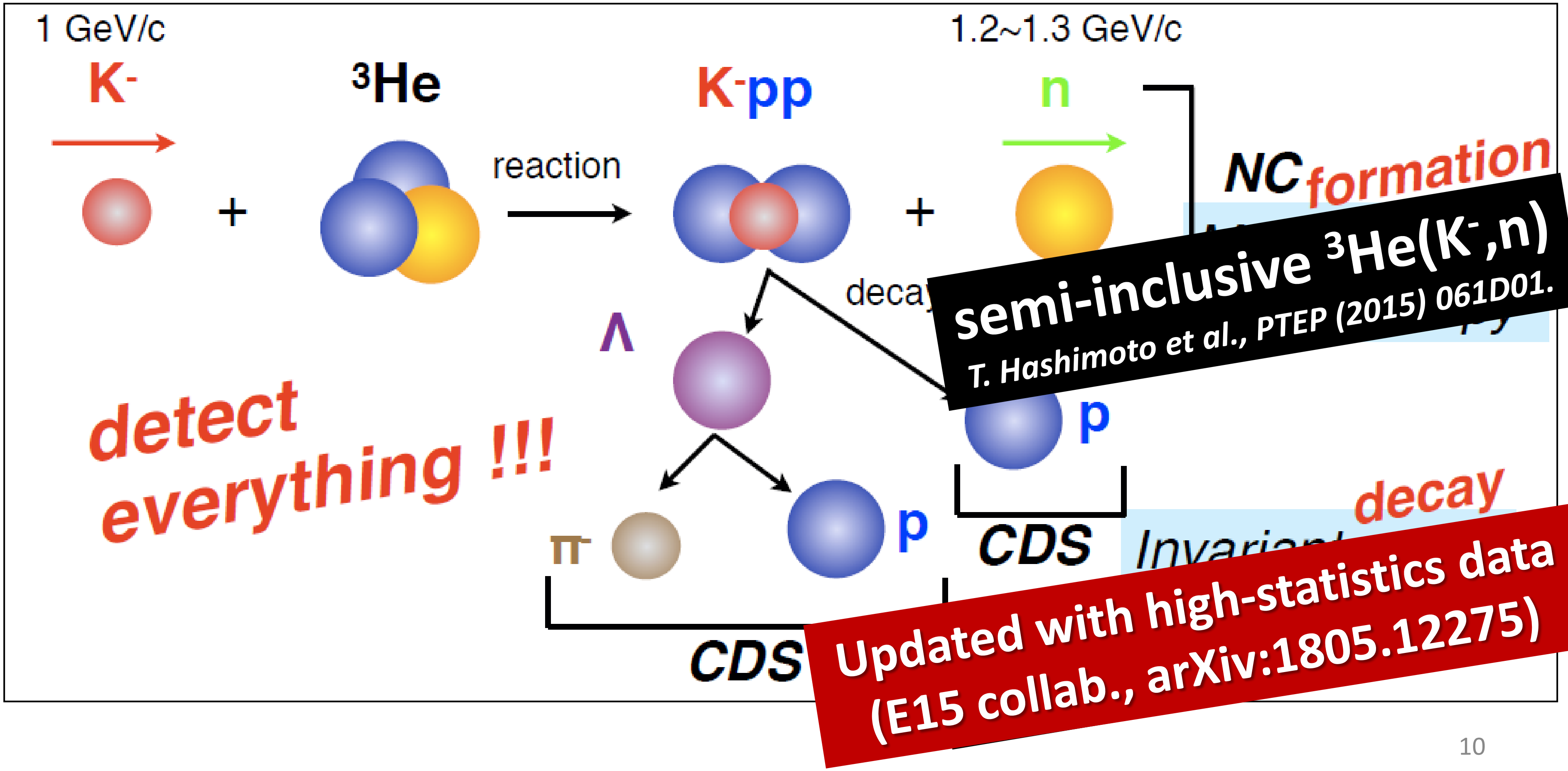
Upper limits were also obtained:

- **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



"K^-pp" in ^{3}He(K^-,Λp)n

"$K^- pp$", a $\overline{K}$-Meson Nuclear Bound State, Observed in ^{3}He$(K^-, \Lambda p)n$ Reactions

S. Ajimura[1], H. Asano[2], G. Beer[3], C. Berucci[4], H. Bhang[5], M. Bragadireanu[6], P. Buehler[4], L. Busso[7,8], M. Cargnelli[4], S. Choi[5], C. Curceanu[9], S. Enomoto[10], H. Fujioka[11], Y. Fujiwara[12], T. Fukuda[13], C. Guaraldo[9], T. Hashimoto[14], R. S. Hayano[12], T. Hiraiwa[1], M. Iio[10], M. Iliescu[9], K. Inoue[1], Y. Ishiguro[15], T. Ishikawa[12], S. Ishimoto[10], K. Itahashi[2], M. Iwasaki[2,11,*] K. Kanno[12], K. Kato[15], Y. Kato[2], S. Kawasaki[1], P. Kienle[16,†] H. Kou[11], Y. Ma[2], J. Marton[4], Y. Matsuda[12], Y. Mizoi[13], O. Morra[7], T. Nagae[15], H. Noumi[1], H. Ohnishi[17,2], S. Okada[2], H. Outa[2], K. Piscicchia[9], Y. Sada[1], A. Sakaguchi[1], F. Sakuma[2,‡] M. Sato[10], A. Scordo[9], M. Sekimoto[10], H. Shi[9], K. Shirotori[1], D. Sirghi[9,6], F. Sirghi[9,6], K. Suzuki[4], S. Suzuki[10], T. Suzuki[12], K. Tanida[14], H. Tatsuno[18], M. Tokuda[11], D. Tomono[1], A. Toyoda[10], K. Tsukada[17], O. Vazquez Doce[9,16], E. Widmann[4], T. Yamaga[2,1,§] T. Yamazaki[12,2], Q. Zhang[2], and J. Zmeskal[4]

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[11] *Tokyo Institute of Technology, Tokyo, 152-8551, Japan*
[12] *The University of Tokyo, Tokyo, 113-0033, Japan*
[13] *Osaka Electro-Communication University, Osaka, 572-8530, Japan*
[14] *Japan Atomic Energy Agency, Ibaraki 319-1195, Japan*
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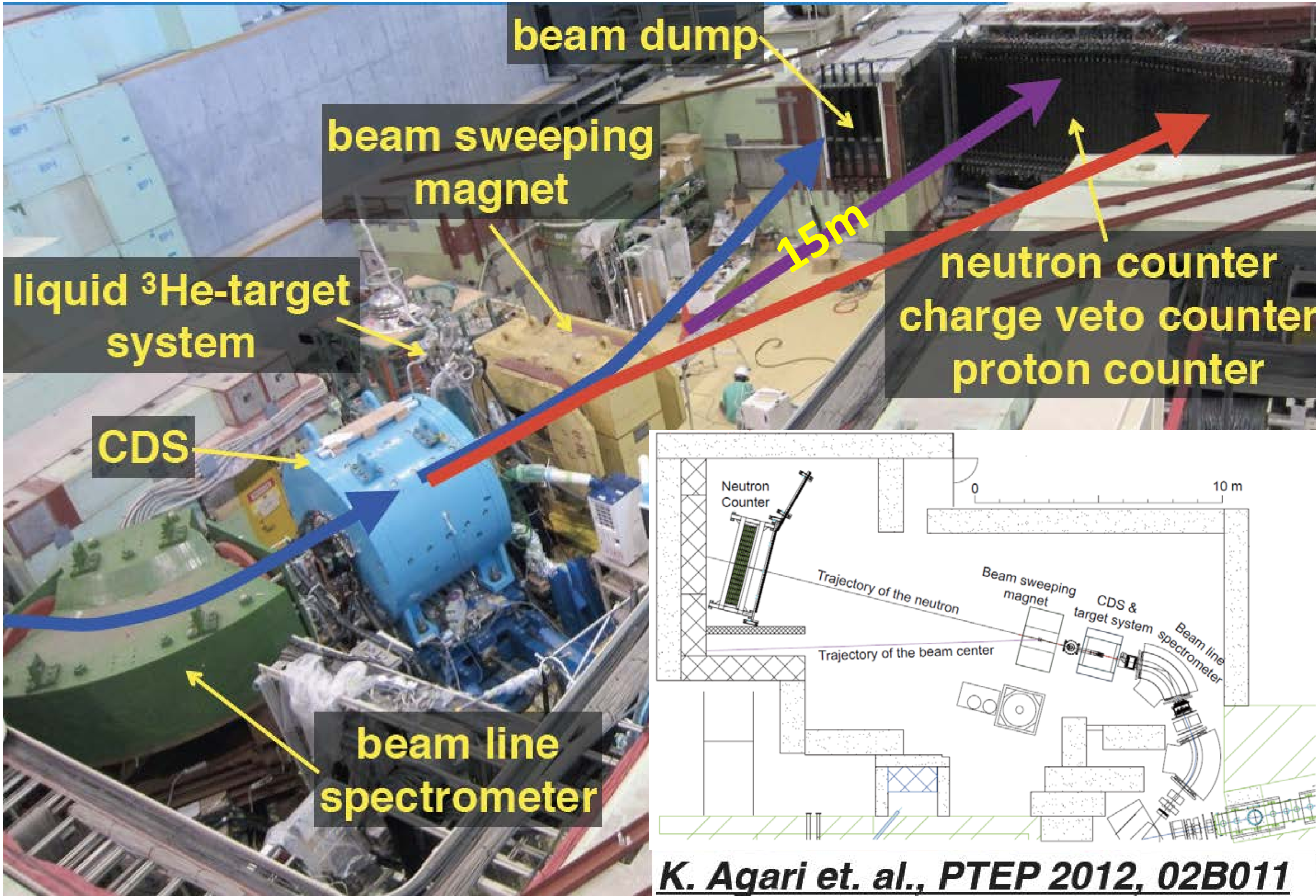
[16] *Technische Universität München, D-85748, Garching, Germany*
[17] *Tohoku University, Sendai, 982-0826, Japan and*
[18] *Lund University, Lund, 221 00, Sweden*

(J-PARC E15 Collaboration)

We observed a distinct resonance peak in the Λp invariant-mass spectrum of ^{3}He$(K^-, \Lambda p)n$, well below the mass threshold of $M(K^- pp)$. By selecting a relatively large momentum-transfer region $q = 350 \sim 650$ MeV/c, one can clearly separate the resonance peak from the quasi-free process, $\overline{K}N \to \overline{K}N$ followed by the non-resonant absorption by the two spectator-nucleons $\overline{K}NN \to \Lambda N$. We found that the simplest fit to the observed peak gives us a Breit-Wigner pole at $B_{Kpp} = 47 \pm 3\,(stat.)\,^{+3}_{-6}\,(sys.)$ MeV having a width $\Gamma_{Kpp} = 115 \pm 7\,(stat.)\,^{+10}_{-9}\,(sys.)$ MeV, and the S-wave Gaussian reaction form-factor parameter $Q_{Kpp} = 381 \pm 14\,(stat.)\,^{+57}_{-0}\,(sys.)$ MeV/c, as a new form of the nuclear bound system with strangeness – "$K^- pp$".

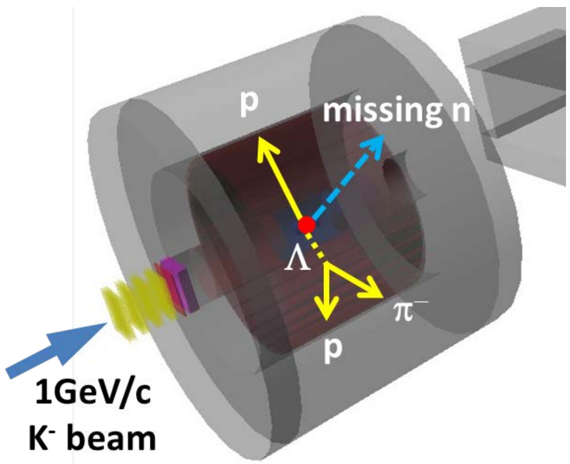
Since the prediction of the π-meson by Yukawa [1], there has been a long-standing question as to whether a mesonic nuclear bound state exists. Mesons are introduced as mediators between nucleons to confine them in vacuum one needs energy m to produce them. If a mesonic nuclear bound state exists, it will form a quantum state at an energy E_M below m whose binding energy $B_M = m - E_M$. Many mesons have been examined

Experimental Setup @ K1.8BR

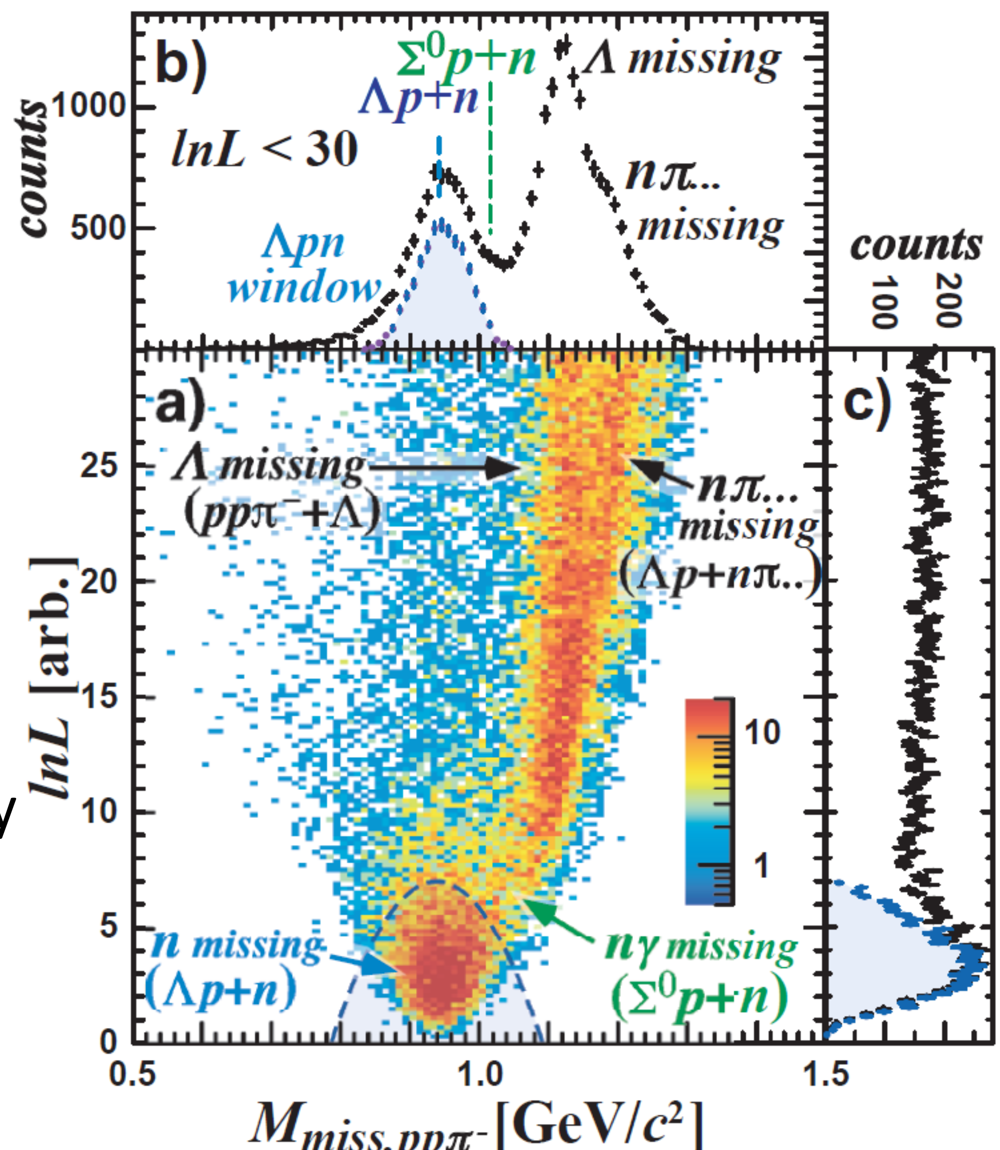


K. Agari et. al., PTEP 2012, 02B011

$^{3}He + K^{-} \rightarrow \Lambda\ p\ n$ Selection



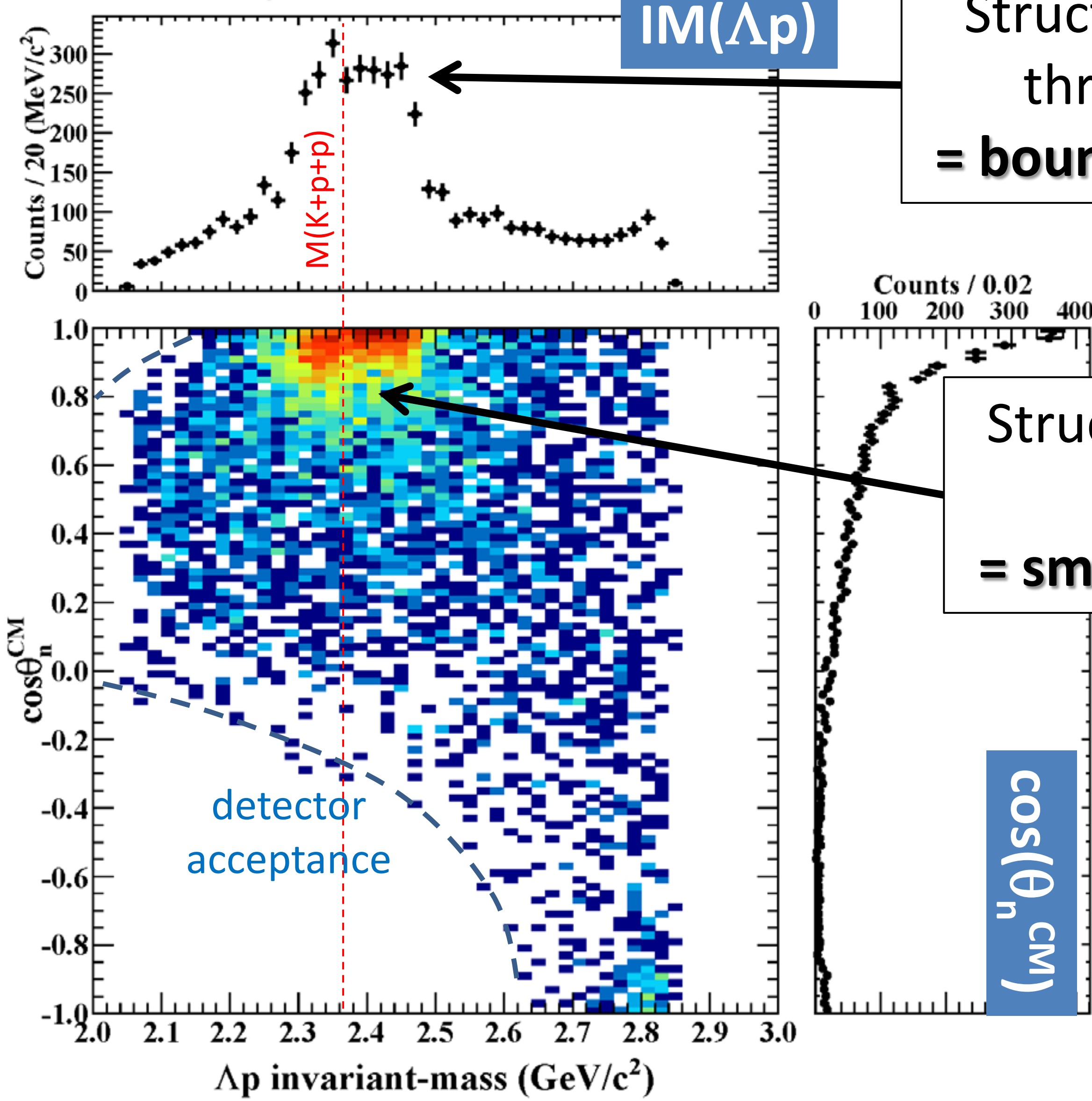
E15 collab., arXiv:1805.12275



- $\Lambda \rightarrow \pi^{-}p$ and p are detected with CDS
  - A missing neutron is identified by missing-mass of $^{3}He(K^{-},\Lambda p)n$
- Λpn_{miss} events are selected by log-likelihood method (*ln*L)
  - distance-of-closest-approach for each vertex
  - kinematical constraint

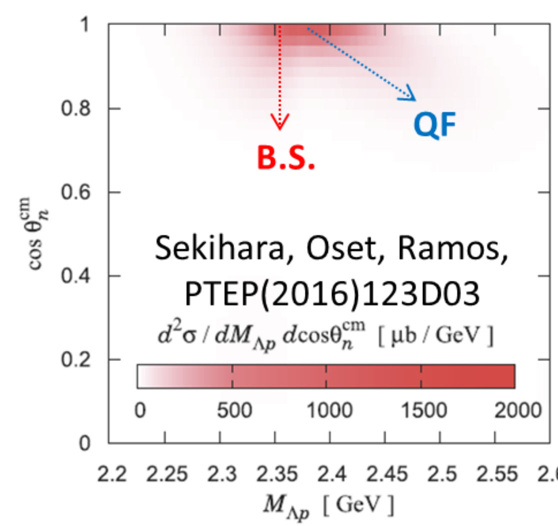
IM(Λp) vs. cos(θ_n^{CM})

E15 collab., arXiv:1805.12275



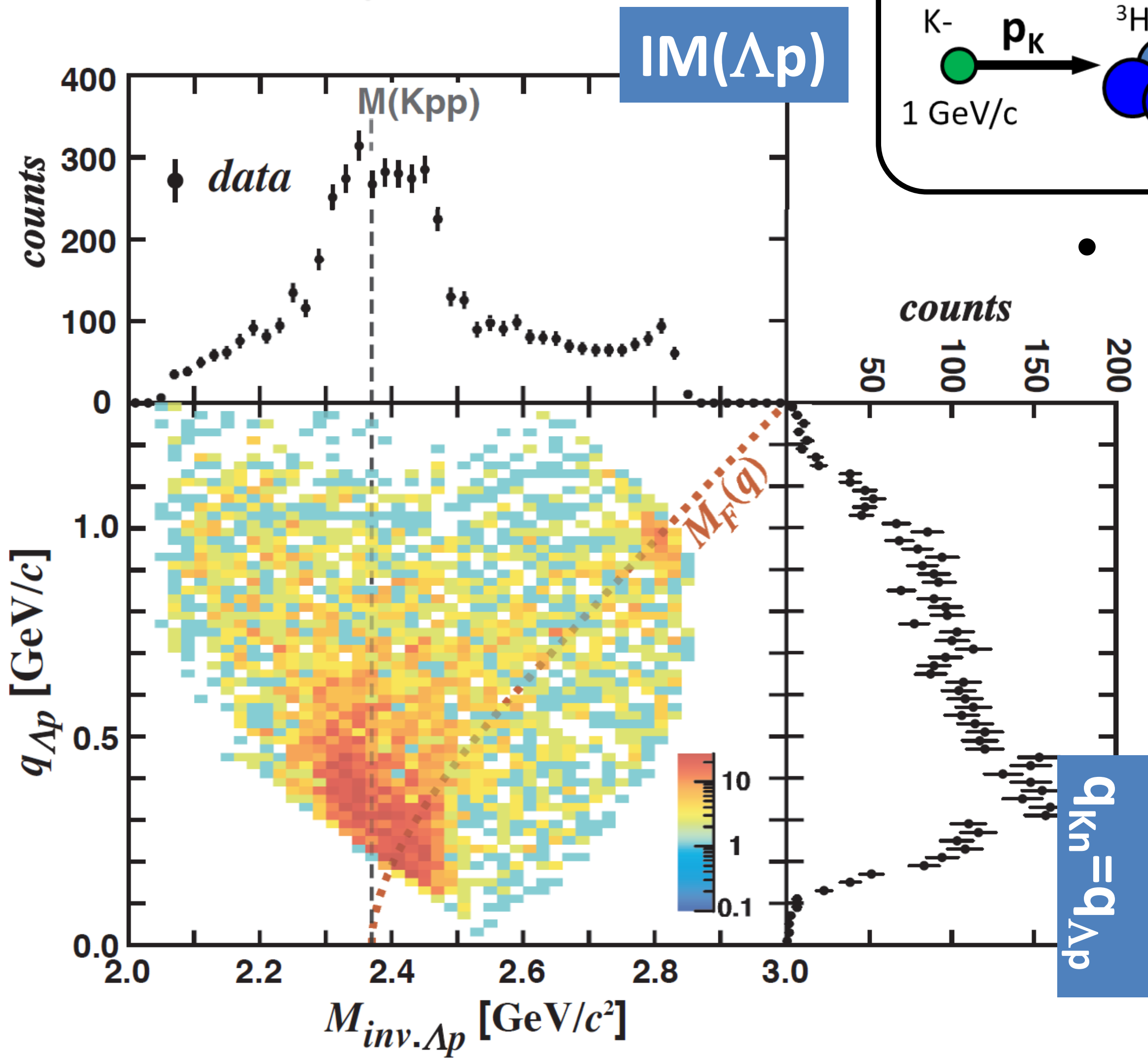
Structures around the K$^-$pp threshold can be seen
= bound-state + quasi-elastic

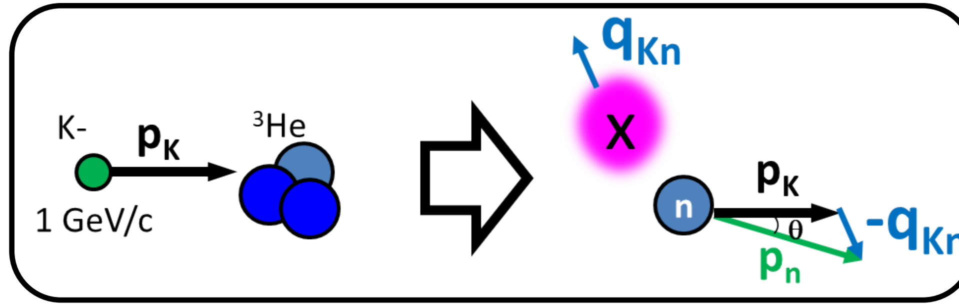
Structures are concentrated in forward-n region
= small momentum-transfer



IM(Λp) vs. Momentum Transfer q_{Kn}

E15 collab., arXiv:1805.12275

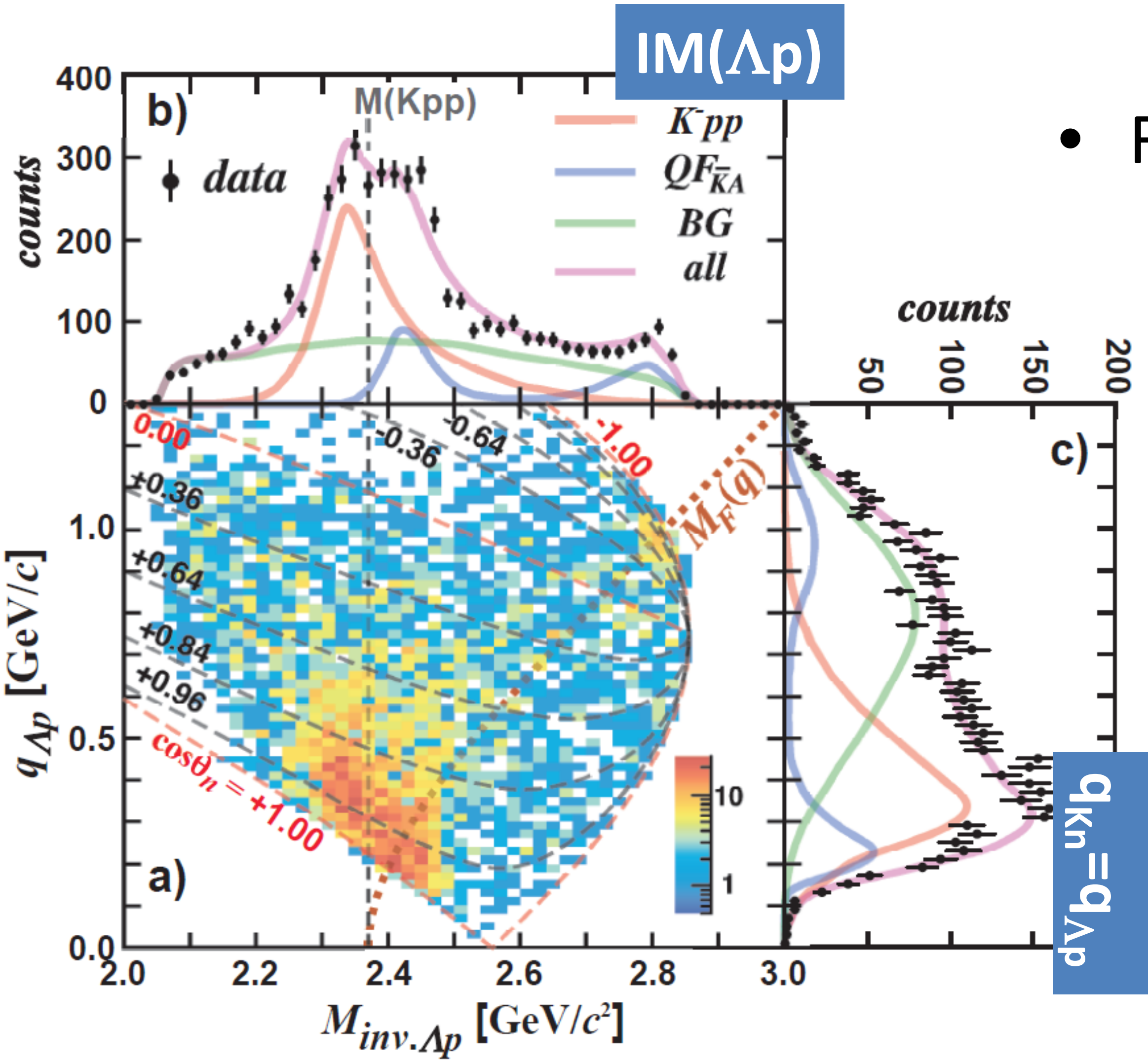




- Seems to consist of 3 components
  - **Bound state**
    - centroid NOT depend on q_{Kn}
  - **Qasi-elastic K^- abs.**
    - centroid depends on q_{Kn}
  - **Background**
    - Broad distribution

IM(Λp) vs. Momentum Transfer q_{Kn}

E15 collab., arXiv:1805.12275



- Fit with 3 components
  - **Bound state**
    - **centroid NOT depend on q_{Kn}**
    - BW*(Gauss form-factor)

$$f_{\{Kpp\}}(M,q) = \frac{A_{Kpp}\,(\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2}\, e^{-\left(\frac{q}{Q_{Kpp}}\right)^2},$$

  - **Qasi-elastic K^- abs.**
    - **centroid depends on q_{Kn}**
    - Followed by Λp conversion
  - **Background**
    - Broad distribution

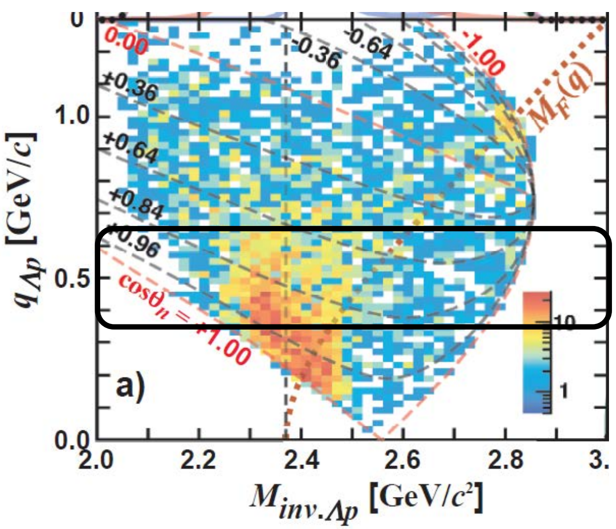
** We conduct the fitting in each 2D bin*

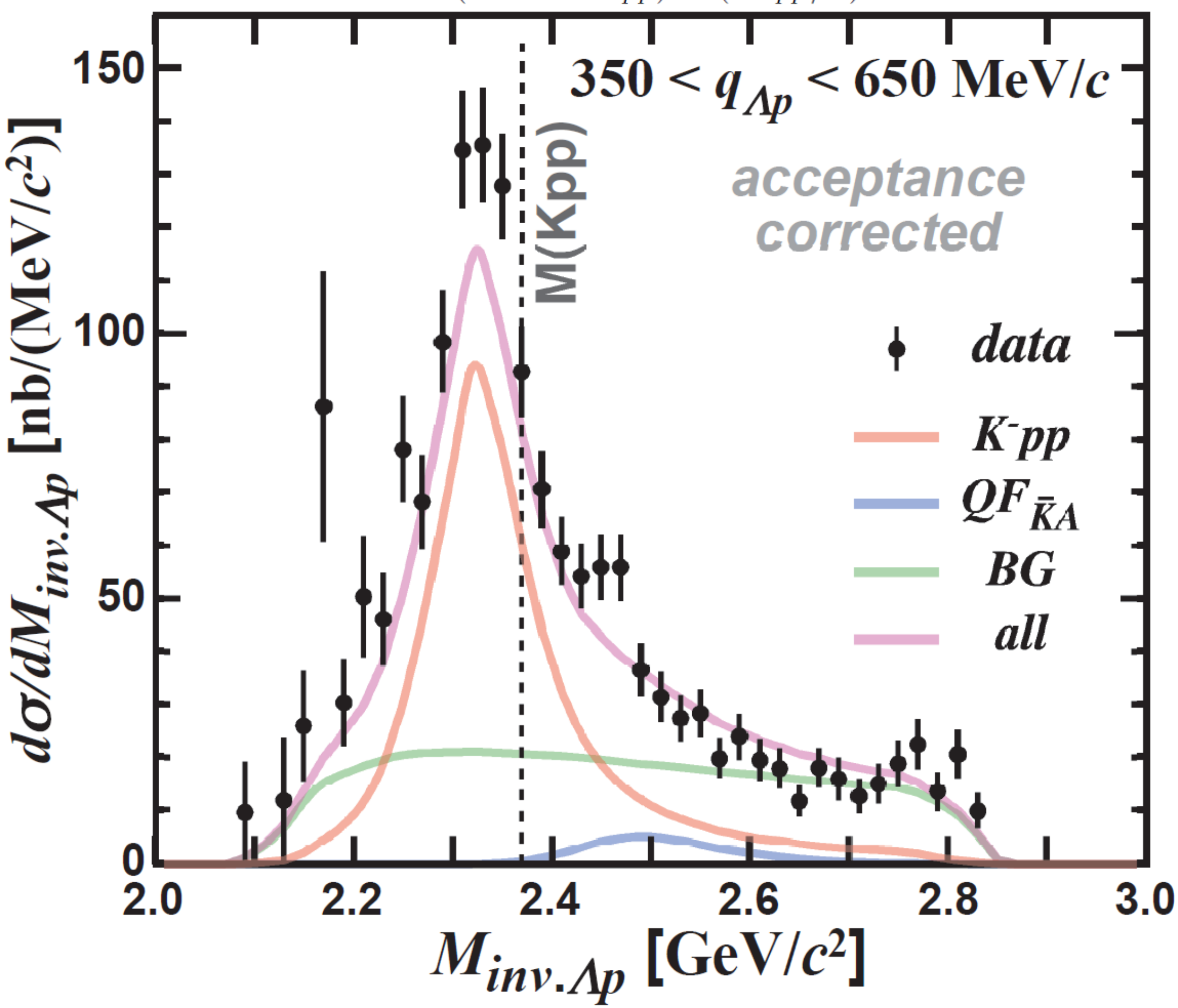
"K⁻pp" Bound-State

$$f_{\{Kpp\}}(M,q) = \frac{A_{Kpp}\ (\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2}\ e^{-\left(\frac{q}{Q_{Kpp}}\right)^2},$$

Select $0.35<q_{Kn}<0.65$ GeV/c

- BS and QF are well separated





E15 collab., arXiv:1805.12275

"K⁻pp" Bound-State

$$f_{\{Kpp\}}(M,q) = \frac{A_{Kpp}\,(\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2}\, e^{-\left(\frac{q}{Q_{Kpp}}\right)^2},$$

Fit values that reproduce the spectrum:

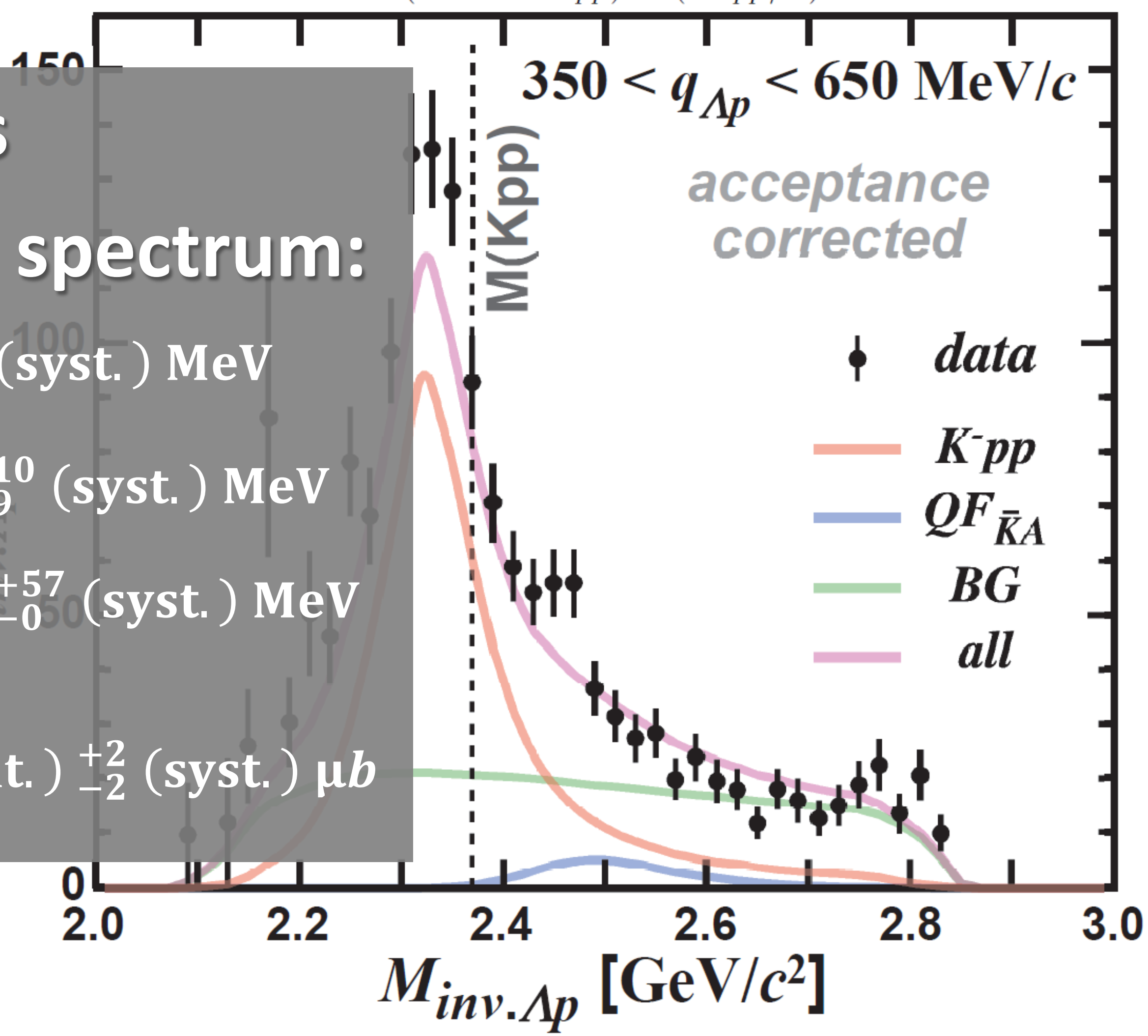
$B_{\text{"Kpp"}} = 47 \pm 3\,(\text{stat.})\,^{+3}_{-6}\,(\text{syst.})\ \text{MeV}$

$\Gamma_{\text{"Kpp"}} = 115 \pm 7\,(\text{stat.})\,^{+10}_{-9}\,(\text{syst.})\ \text{MeV}$

$Q_{\text{"Kpp"}} = 381 \pm 14\,(\text{stat.})\,^{+57}_{-0}\,(\text{syst.})\ \text{MeV}$

at below the $M(K^-pp)$

$\sigma_{\text{"Kpp"}} \cdot Br_{\Lambda p} = 15 \pm 1\,(\text{stat.})\,^{+2}_{-2}\,(\text{syst.})\ \mu b$

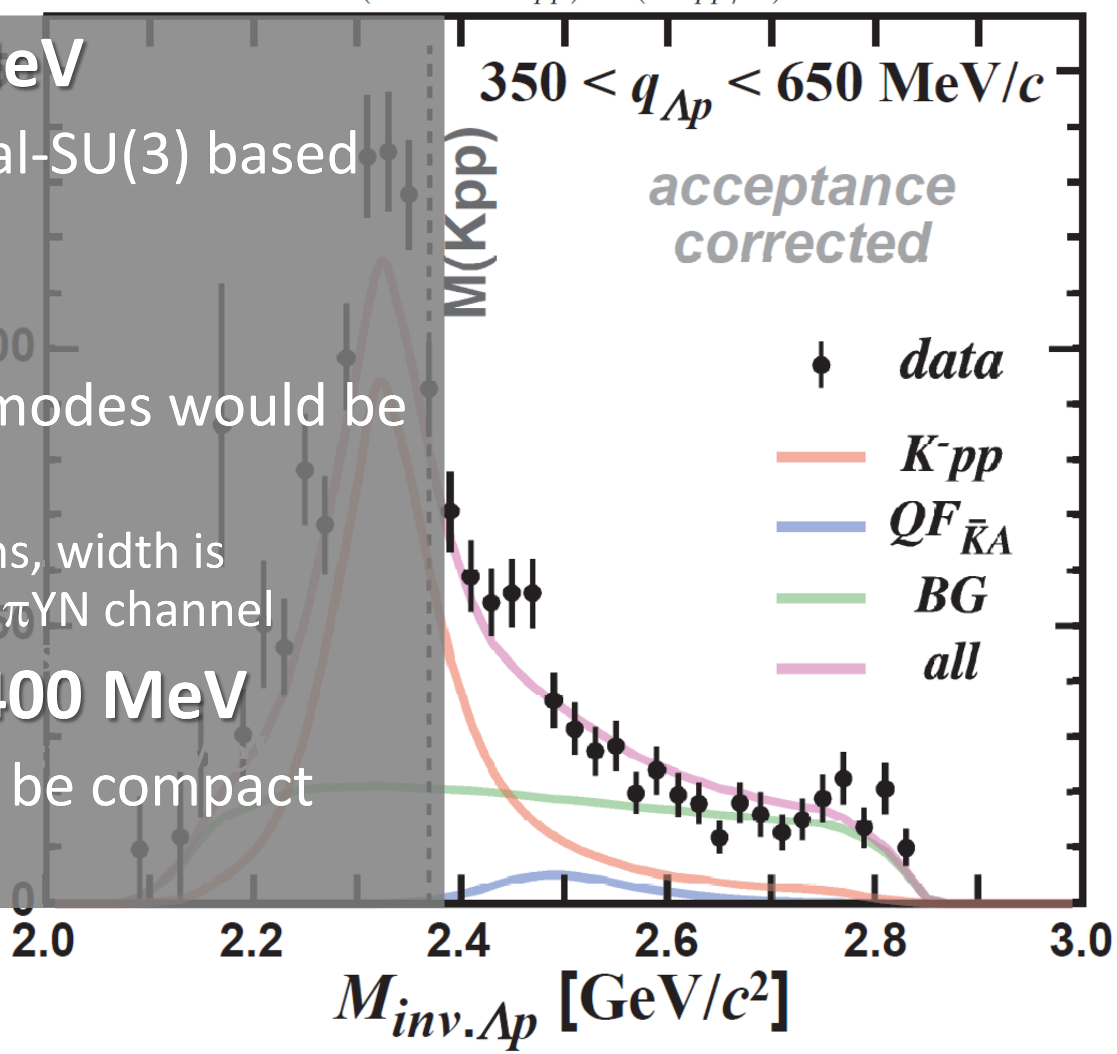


E15 collab., arXiv:1805.12275

“K⁻pp” Bound-State

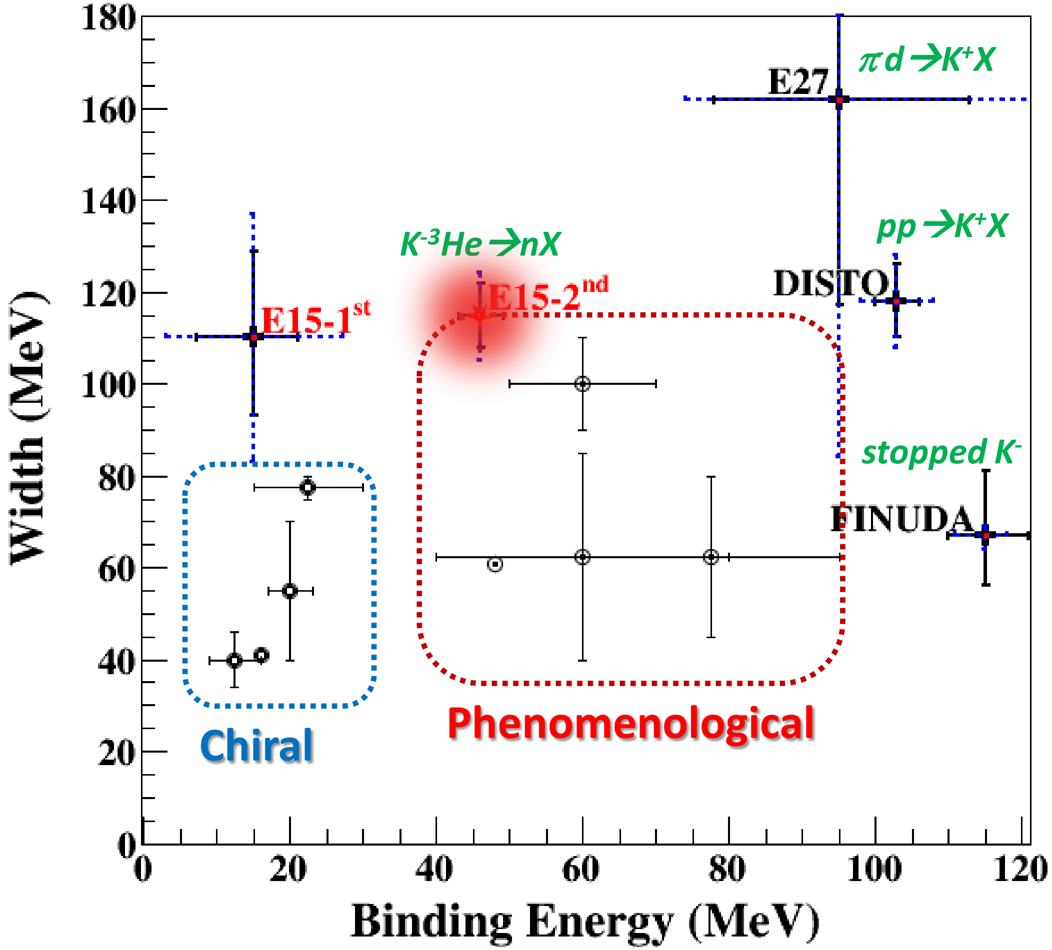
$$f_{\{Kpp\}}(M,q) = \frac{A_{Kpp}\,(\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2}\, e^{-\left(\frac{q}{Q_{Kpp}}\right)^2},$$

- **Binding energy: ~50 MeV**
  - Much deeper than chiral-SU(3) based theoretical predictions
- **Width: ~100 MeV**
  - Non-meonic YN decay modes would be dominant
    - in theoretical calculations, width is evaluated with mesonic πYN channel
- **S-wave form factor: ~400 MeV**
  - $K^- + {}^3He$ reaction would be compact (~0.5 fm)



E15 collab., arXiv:1805.12275

Present Status of "K⁻pp"

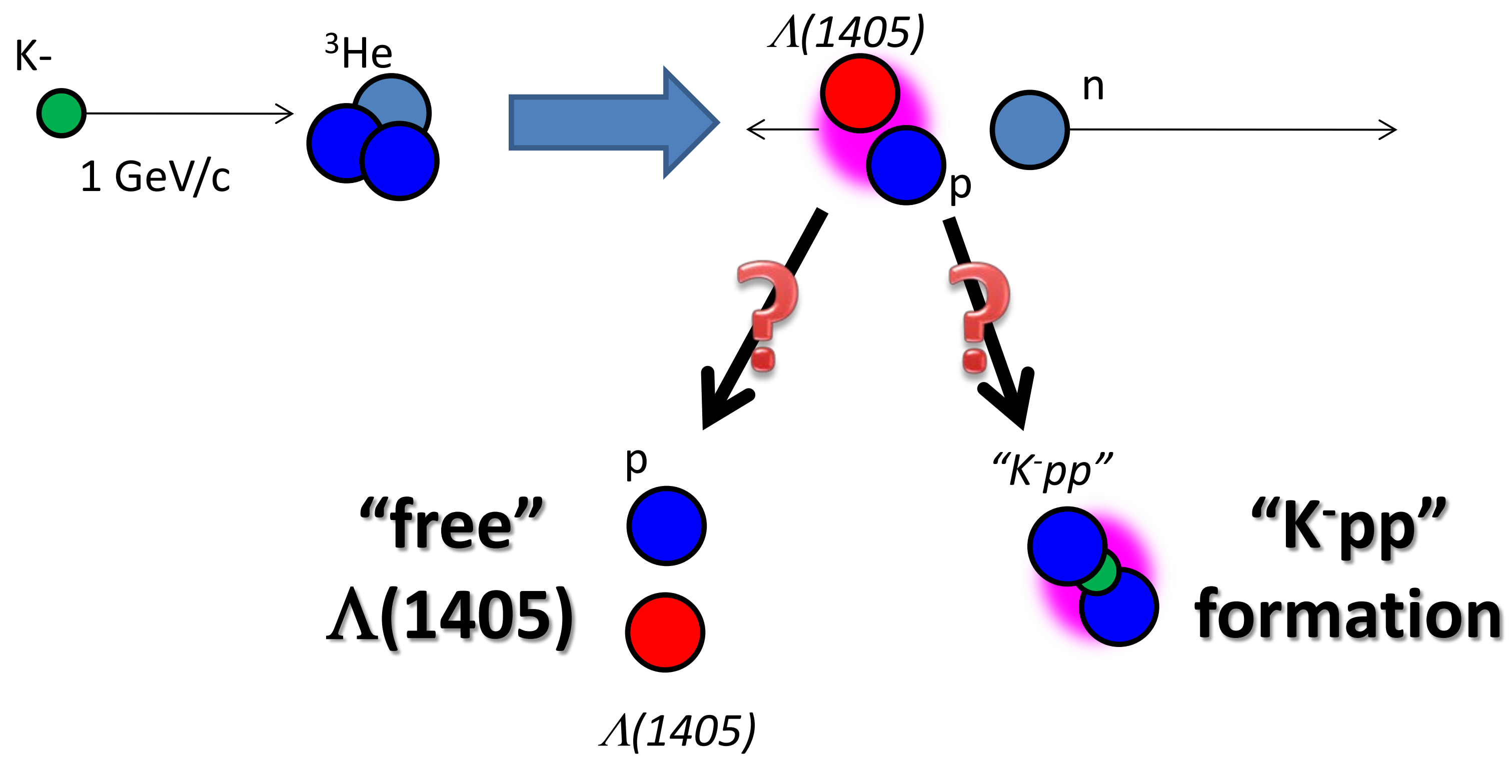


For further understandings:

✓ Λ(1405) production → Λ*N doorway

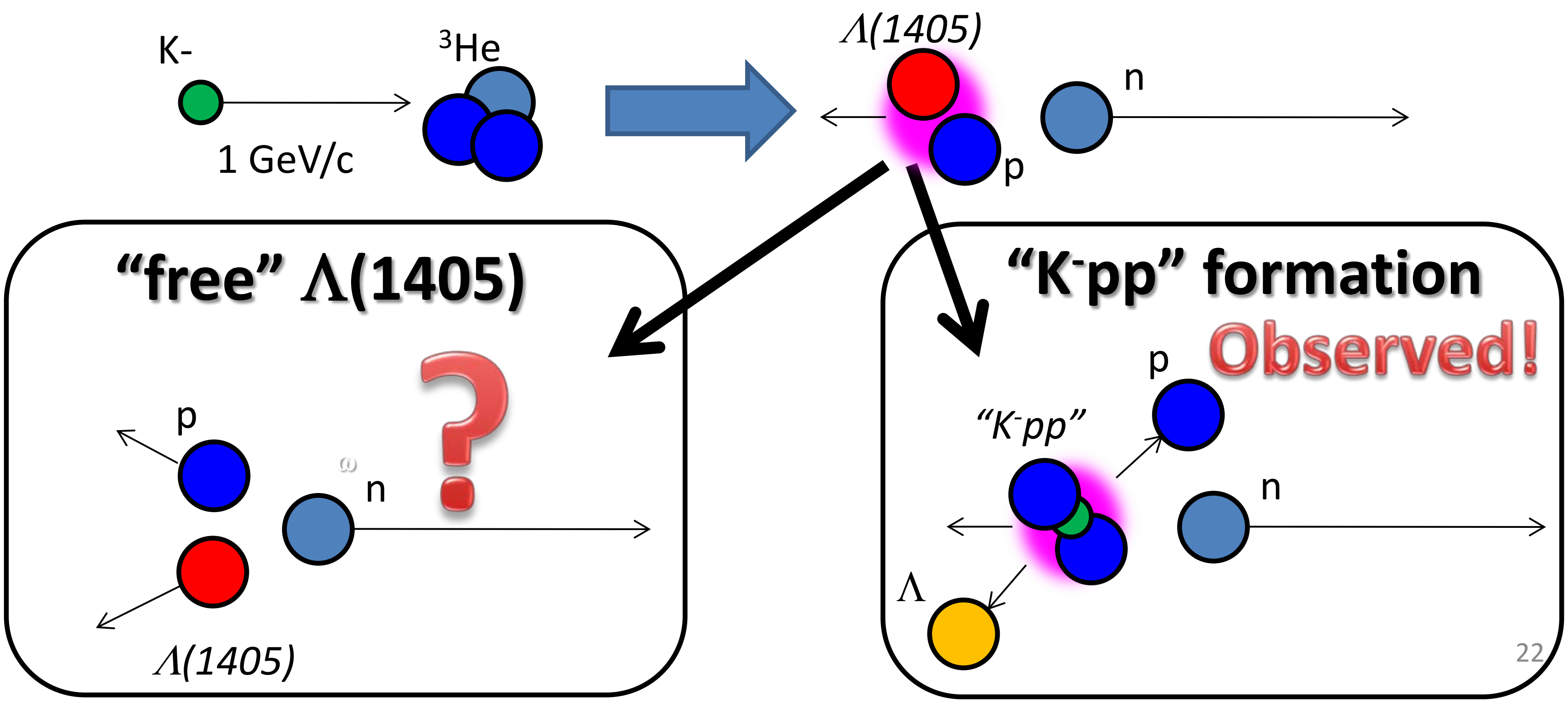
✓ πΣN decay channel → new info. of $K^{bar}NN$

Λ(1405) in ^{3}He(K$^-$,πΣp)n



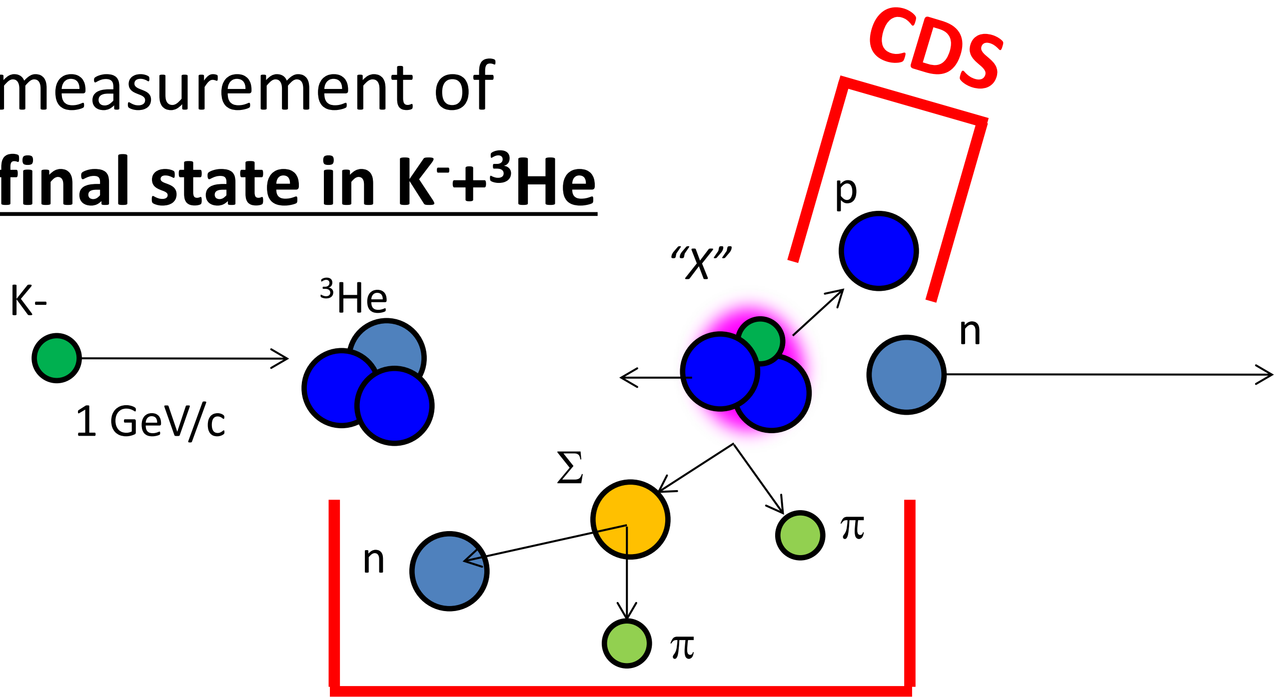
Λ(1405)p and "K⁻pp"

- Theoretically, "K^-pp" is expected to be produced via **Λ(1405)+p→"K^-pp" door-way process**
  - comparison between Λ(1405)p and "K^-pp" production would give us an important information

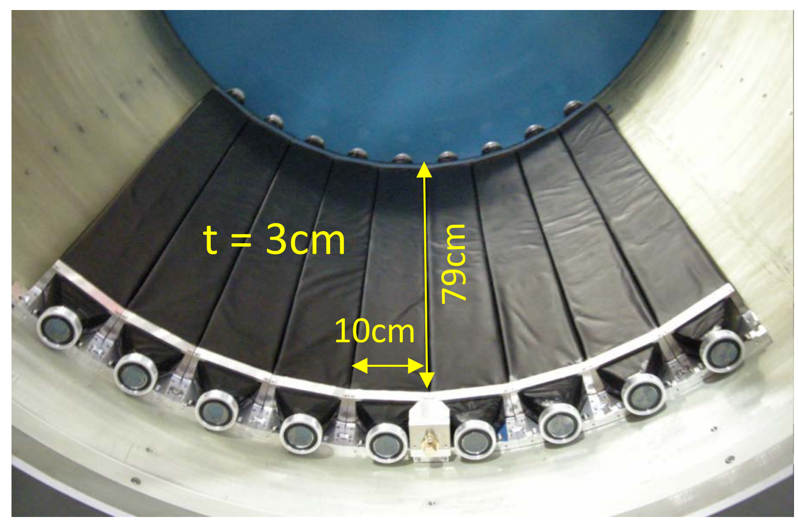


$K^- \, ^3He \rightarrow \pi\Sigma pn$ @ E15

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



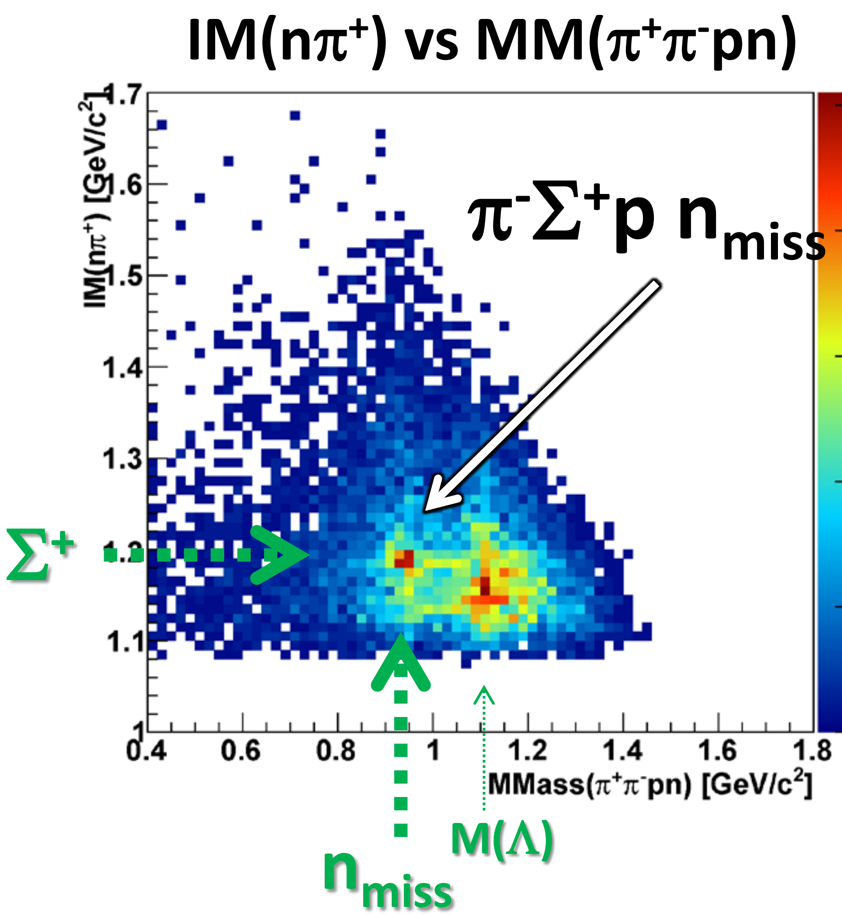
CDS



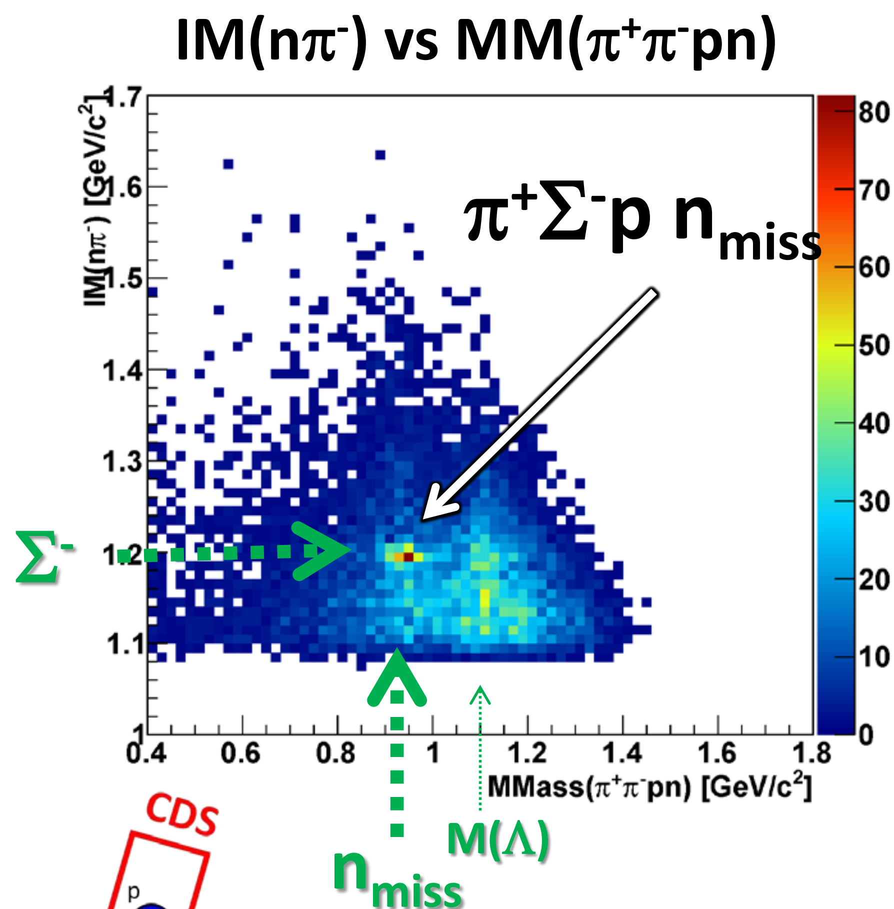
- **Experimental challenge** of neutron detection with thin scintillation counter (t=3cm)

  n detection efficiency ~ 3%

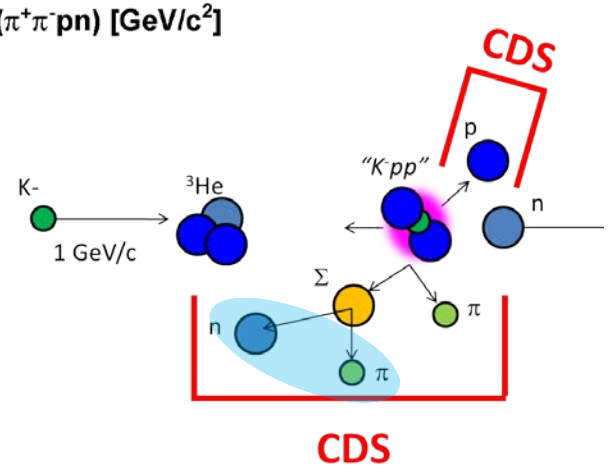
πΣpn Events



IM(nπ+) vs MM(π+π-pn)
π-Σ+p n_miss
Σ+
n_miss
M(Λ)
IM(nπ+) [GeV/c2]
MMass(π+π-pn) [GeV/c2]



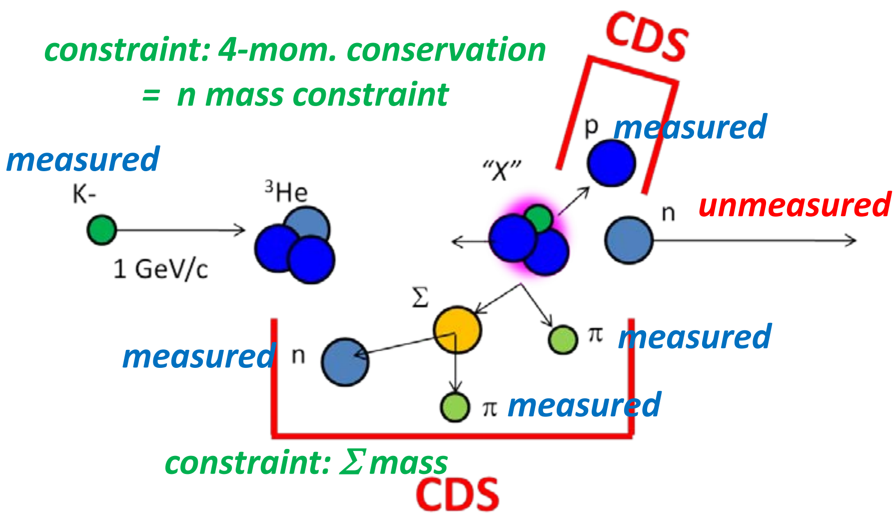
IM(nπ-) vs MM(π+π-pn)
π+Σ-p n_miss
Σ-
n_miss
M(Λ)
IM(nπ-) [GeV/c2]
MMass(π+π-pn) [GeV/c2]

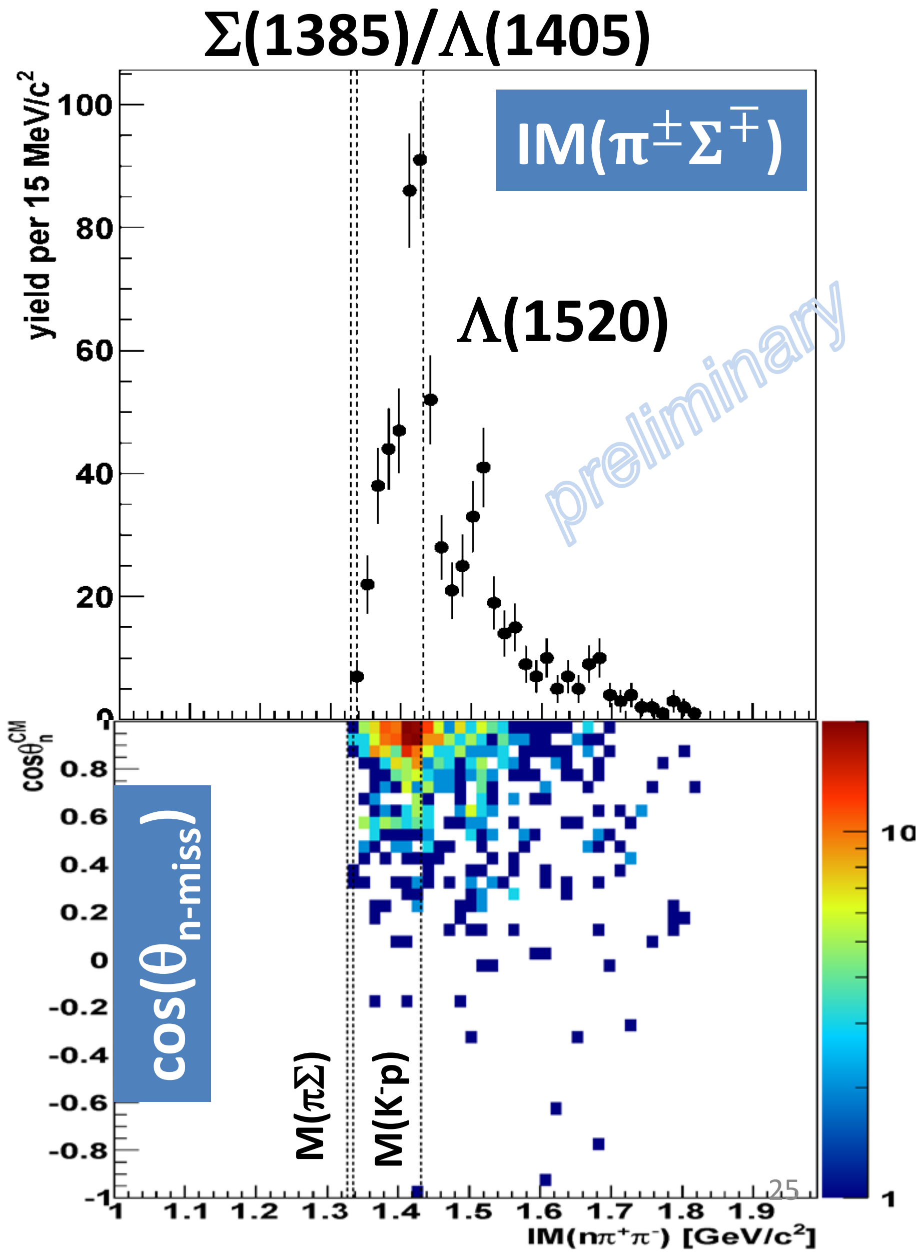


CDS
K-
1 GeV/c
3He
"K-pp"
p
n
Σ
π
n
π
CDS

IM(πΣ) vs. cos(θ_n^{CM})

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

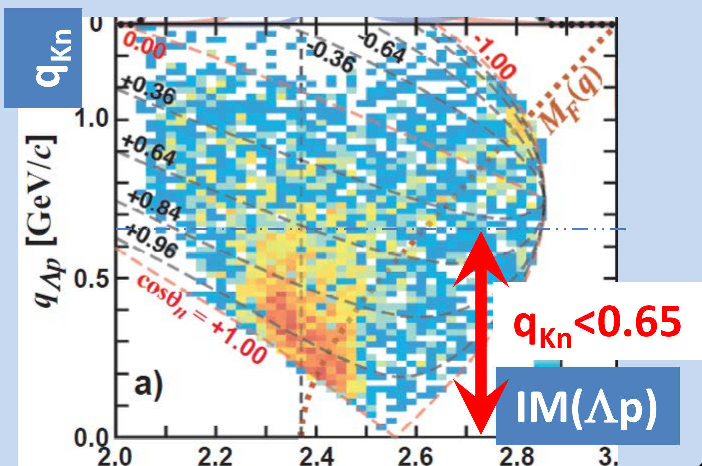


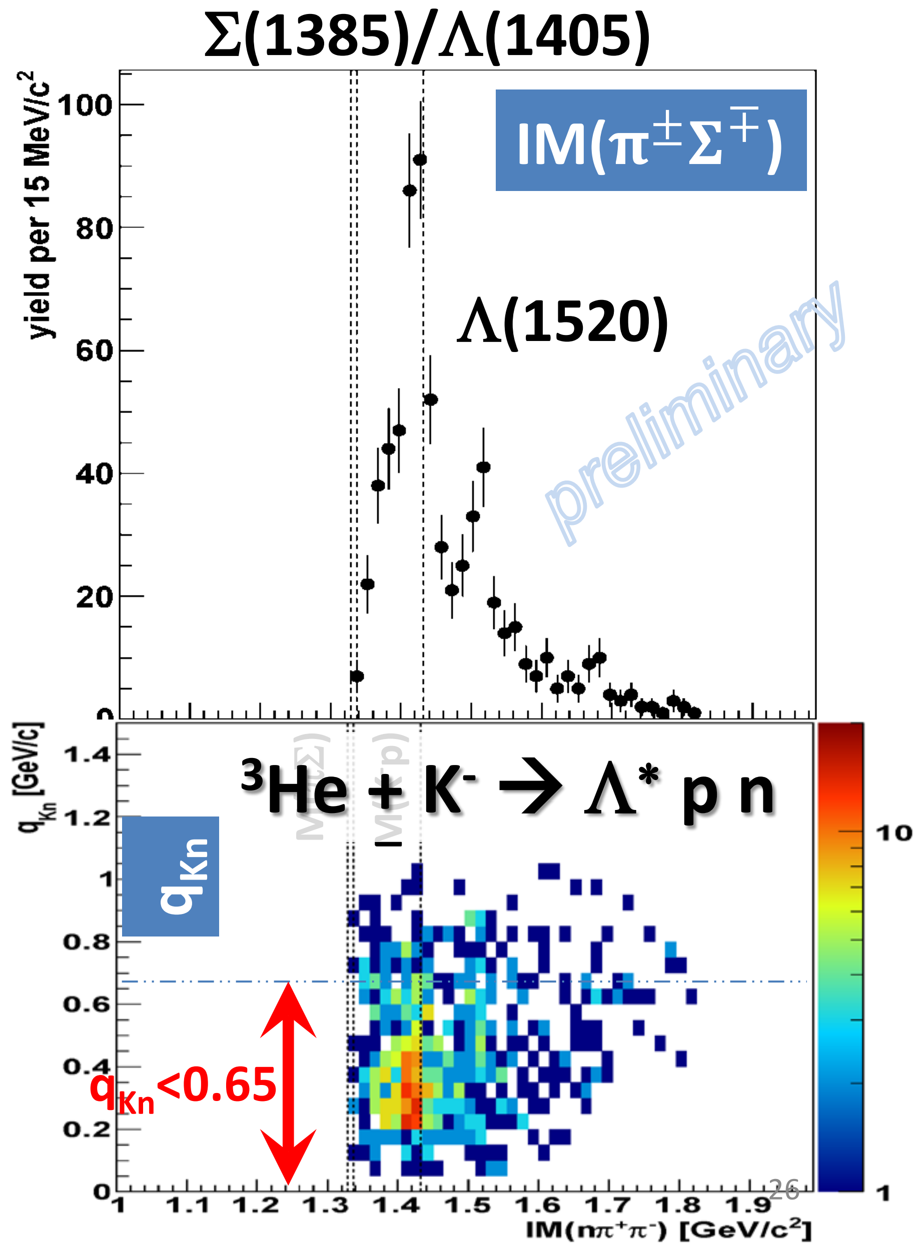


IM(πΣ) vs. Momentum Transfer q_{Kn}

- **To compare "K^-pp" and Λ^* production CS's, we select q_{Kn}<0.65 GeV/c region**
  - "K^-pp" and Λ^* signals can be seen in this region

***cf.* $^3He + K^- \rightarrow \Lambda\, p\, n$**





Y^* CS (q_{Kn}<0.65)

$\Lambda(1405)$

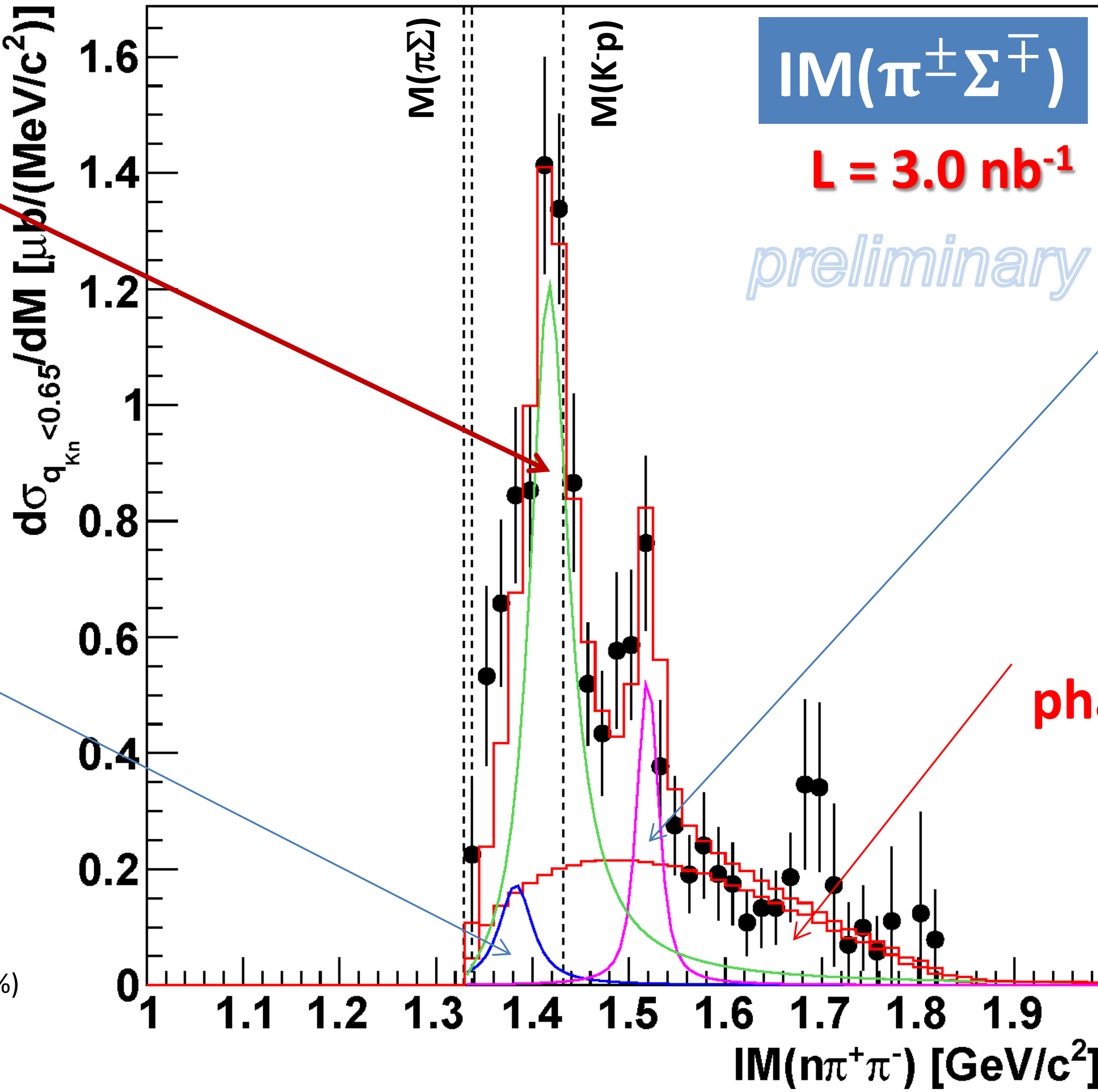
~ 130-140 μb

Flatté param.:

m_R ~ 1418 MeV/c

$g_{\pi\Sigma}$ ~ 1.9E-1

g_{KN} ~ 1.7E-2



$\Lambda(1520)$

~ 70 μb

$\Sigma^0(1385)$

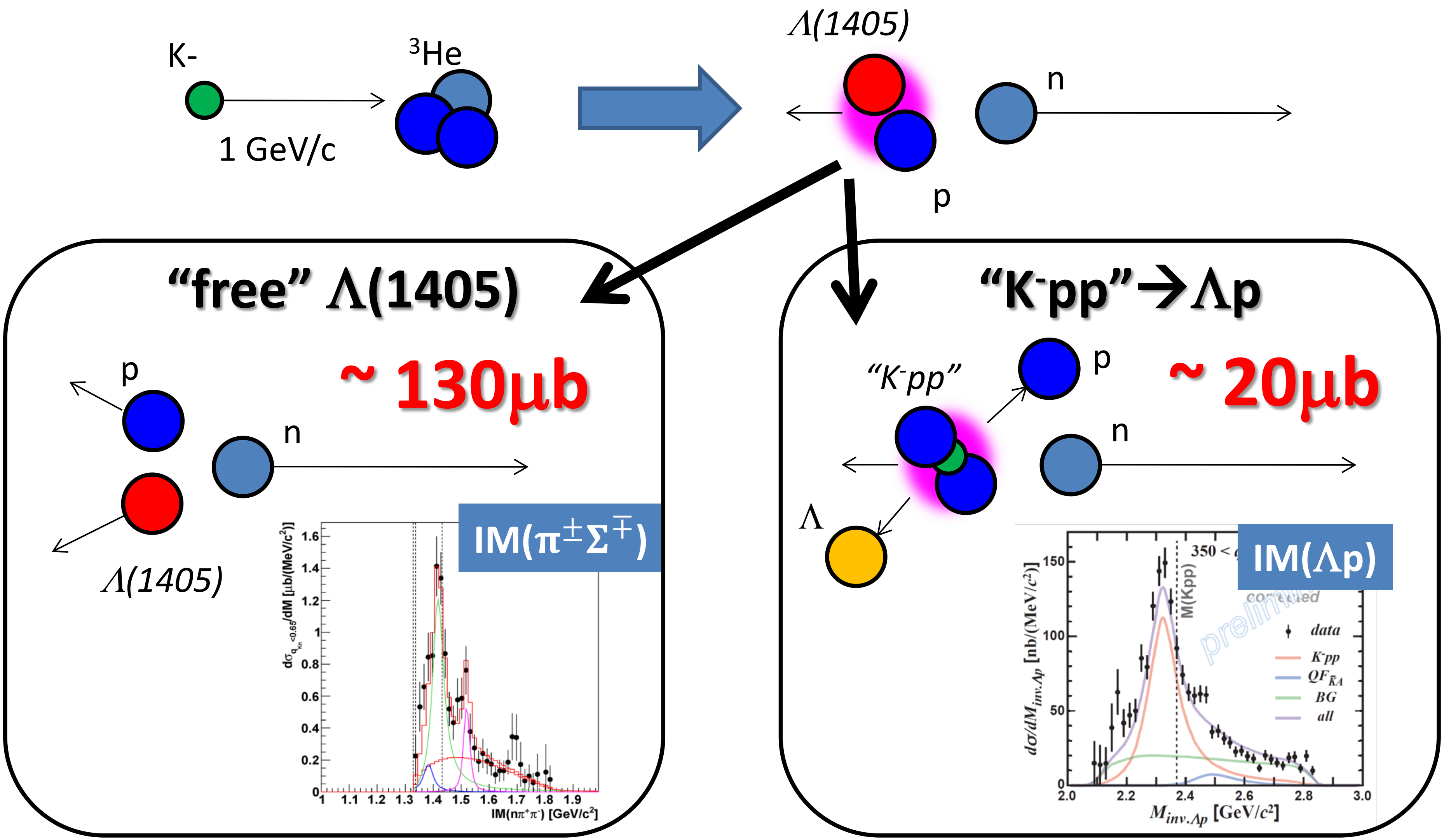
~ 40-80 μb

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

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

πΣpn phases-space

Production of $\Lambda(1405)$p and "K^-pp"



Large CS of Λ^* compared to "K^-pp" formation

“K^-pp” in ^{3}He(K^-,$\pi\Sigma$p)n

Search for “K^-pp” → $\pi\Sigma$N decay channel

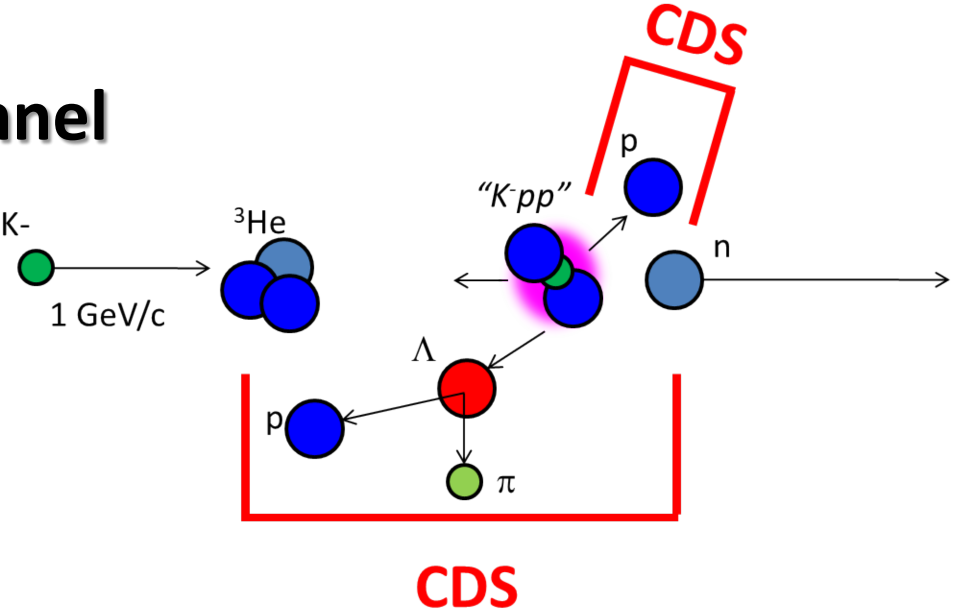
Two Decay Mode of "K⁻pp"

1. "K⁻pp" search via Λp channel

→ Non-mesonic channel

FINUDA/DISTO/E27/E15…

"K⁻pp" ($J^P = 0^-$) → $\Lambda(\frac{1}{2}^+)$ $p(\frac{1}{2}^+)$

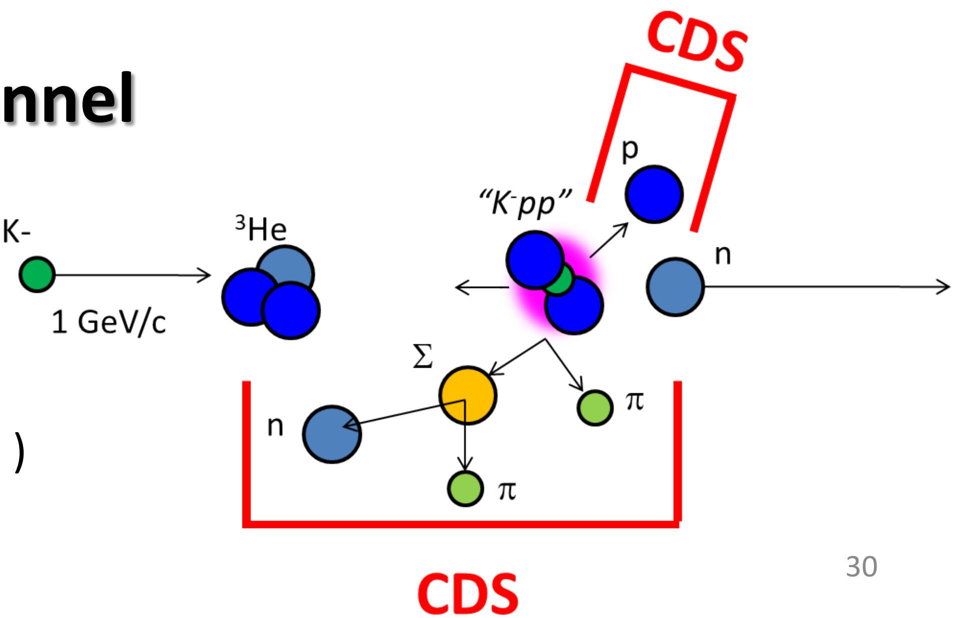


2. "K⁻pp" search via πΣp channel

→ Mesonic channel

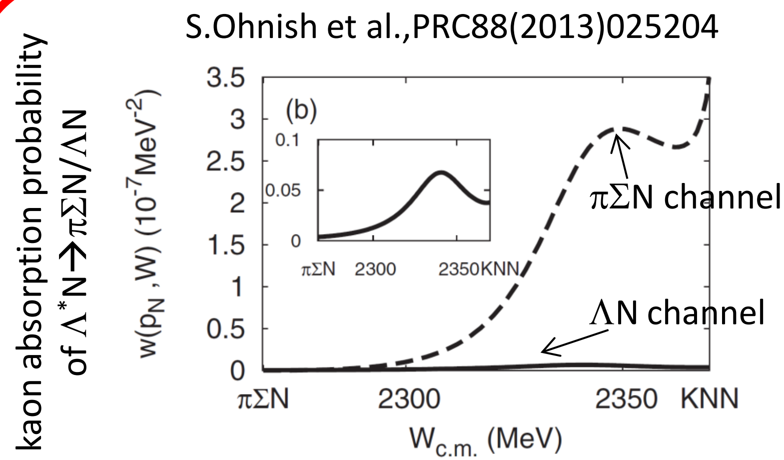
NO measurement so far

"K⁻pp" ($J^P = 0^-$) → $\pi(0^-)$ $\Sigma(\frac{1}{2}^+)$ $p(\frac{1}{2}^+)$



Two Decay Mode of “K⁻pp”

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



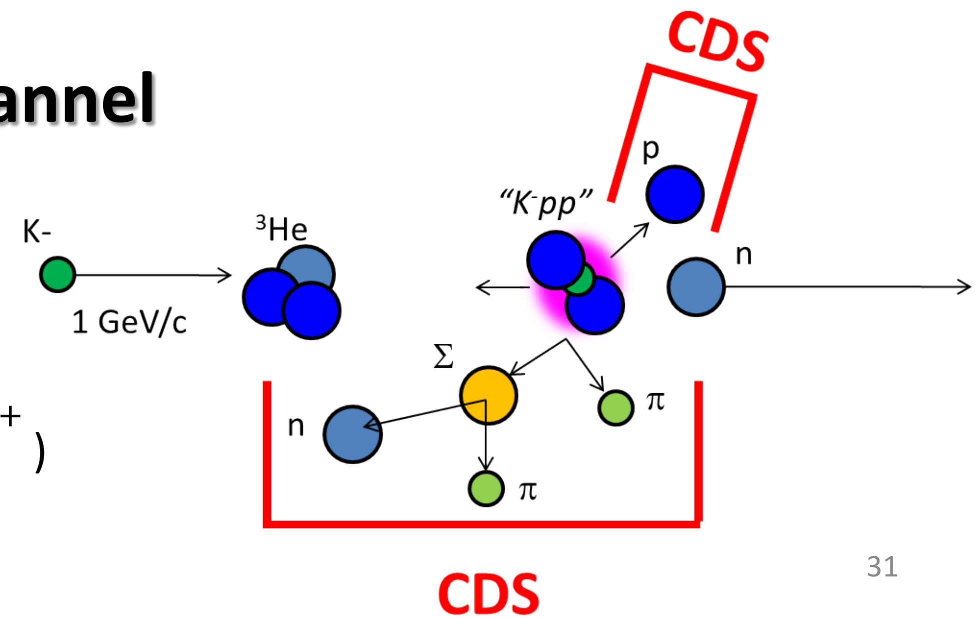
Theoretically, πΣN decay is expected to be the dominant channel

2. “K⁻pp” search via πΣp channel

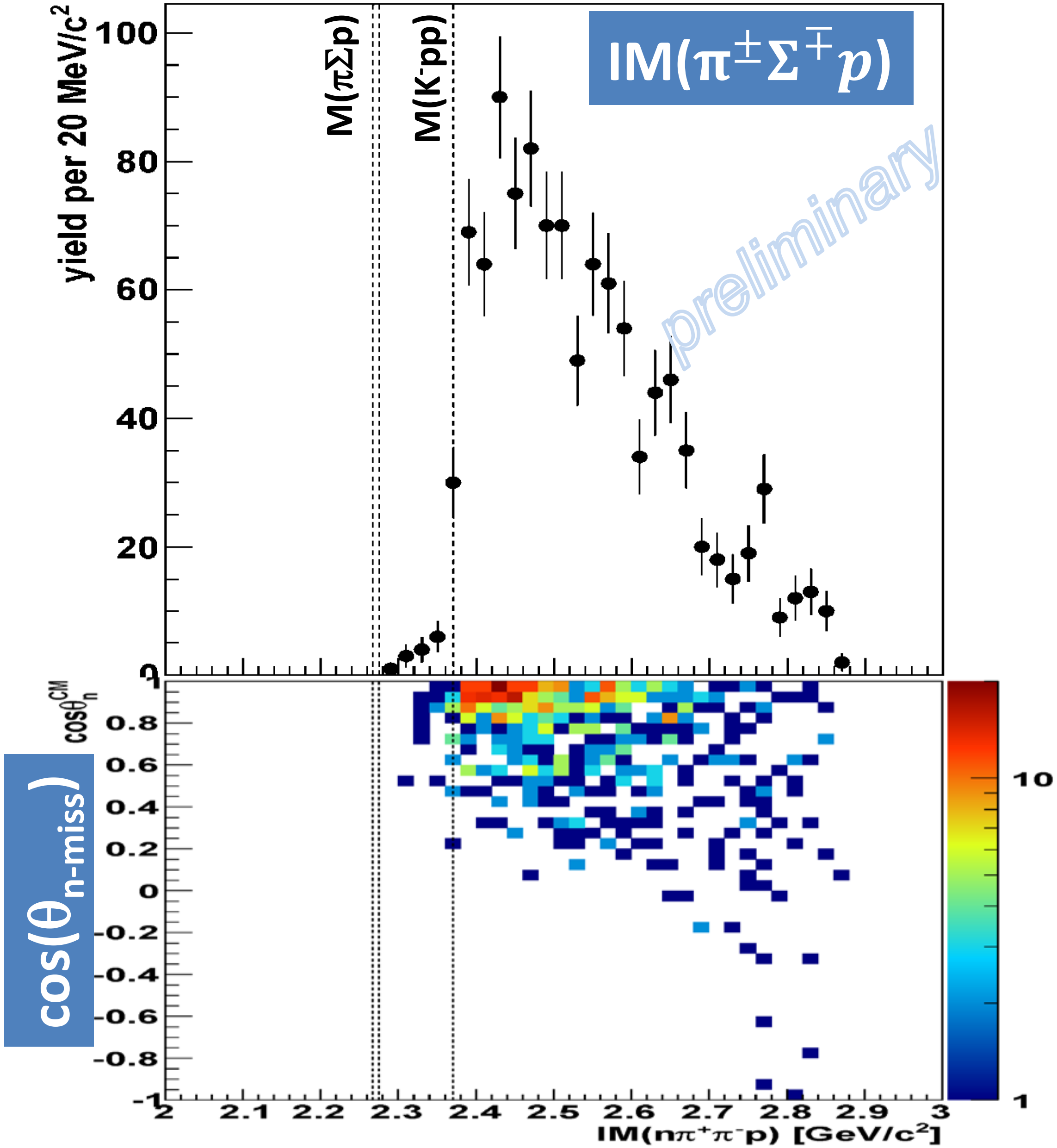
→ Mesonic channel

NO measurement so far

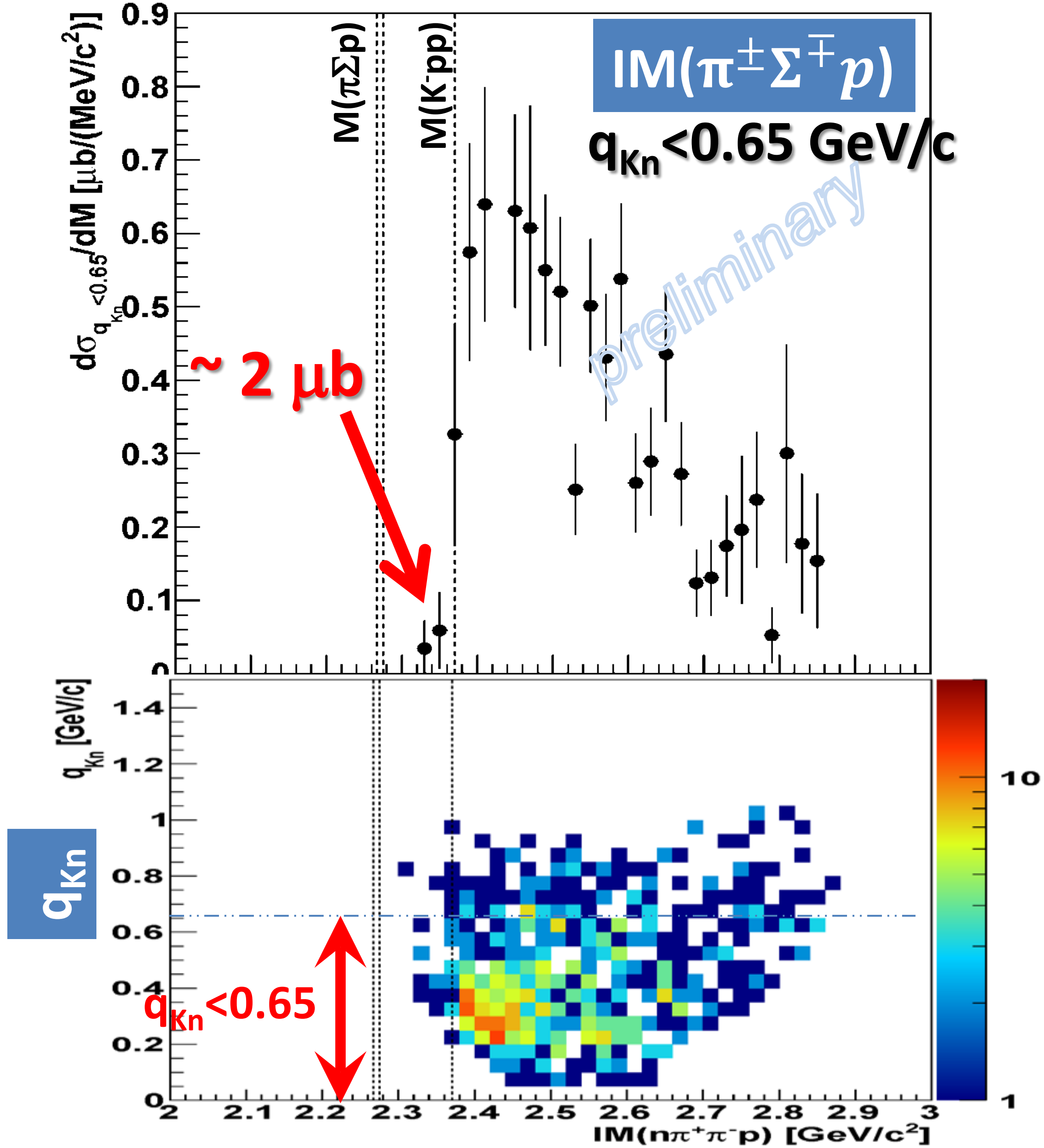
“K⁻pp” ($J^P = 0^-$) → π(0^-) Σ($\frac{1}{2}^+$) p($\frac{1}{2}^+$)

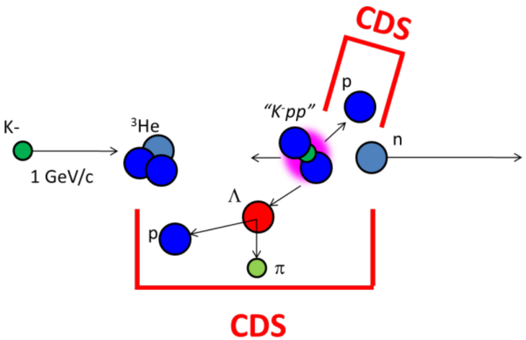


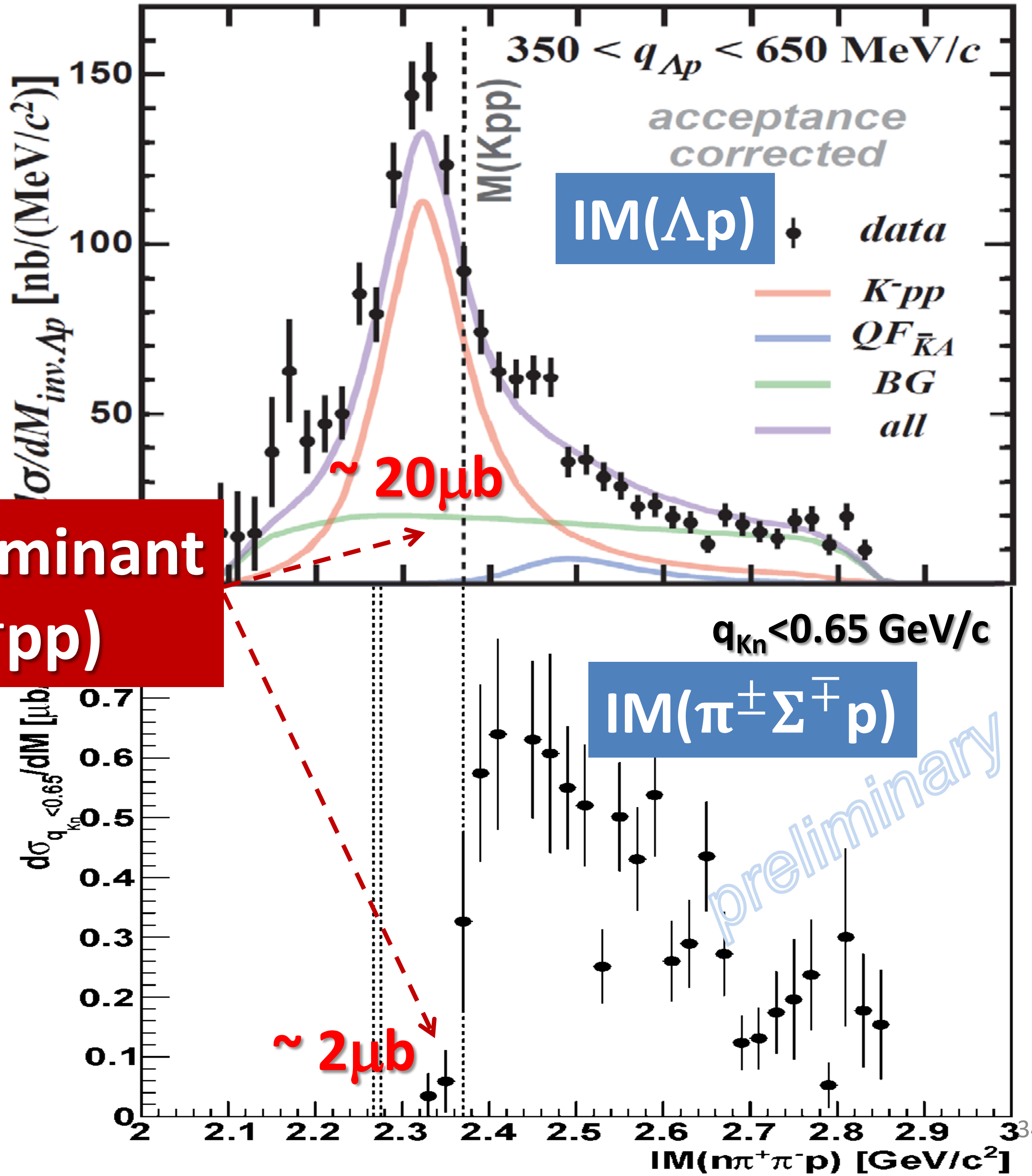
IM(πΣp) vs. cos(θ_n^{CM})



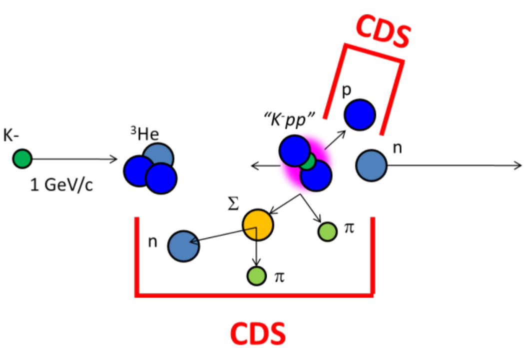
IM(πΣp) vs. Momentum Transfer q_{Kn}



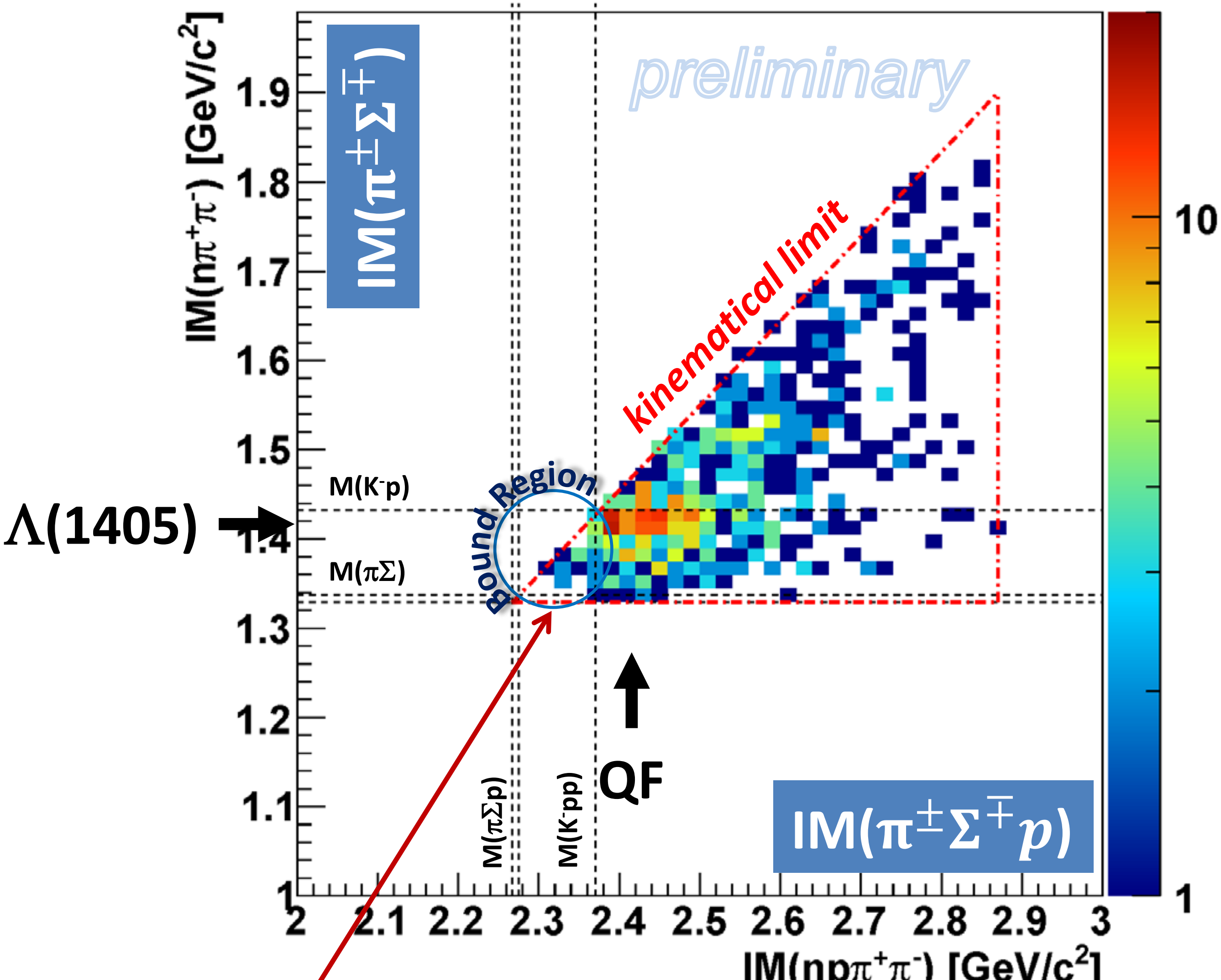


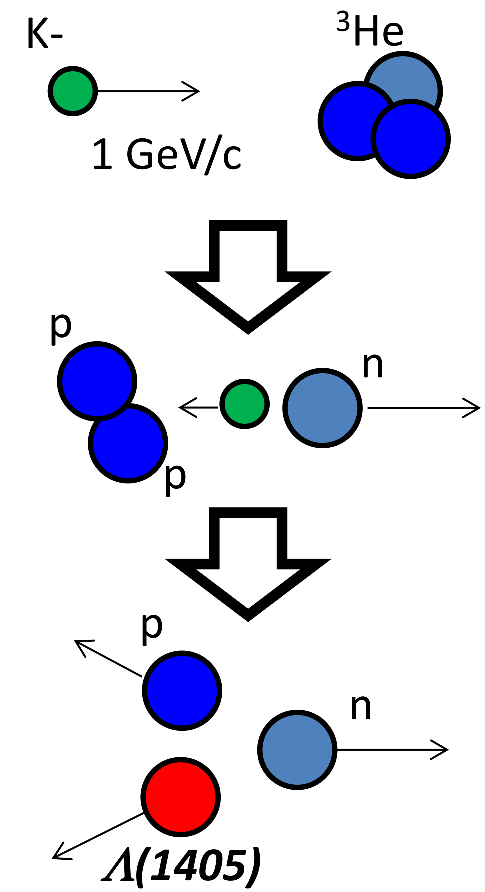


Λp decay is dominant below M(K⁻pp)



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



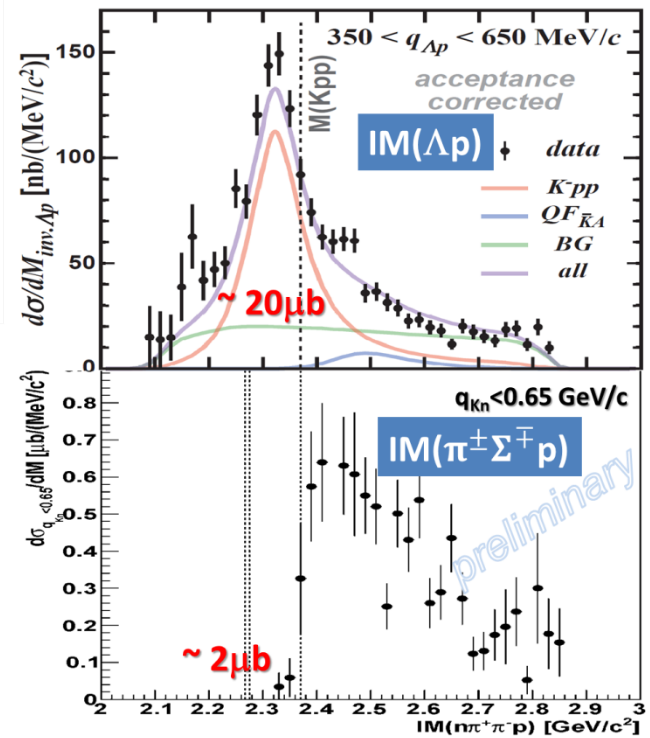


Small phase-space of "K$^-$pp"→$\pi\Sigma$N

Conclusions

- **We have observed a resonance peak below the K$^-$pp threshold in ^{3}He(K$^-$,Λp)n, "K$^-$pp"**
  - Binding energy: ~50 MeV
  - Width: ~100 MeV
  - S-wave form factor: ~400 MeV

  ← E15 collab., arXiv:1805.12275



- **Λ(1405) was clearly observed in $\pi^{\pm}\Sigma^{\mp}$p n_{miss} final state**
  - Large CS of Λ*compared to "K$^-$pp" formation

  ← need theoretical feedbacks

- **Weak structure below the K$^-$pp threshold is seen in IM($\pi^{\pm}\Sigma^{\mp}$p)**
  - Non-meonic YN decay modes would be dominant

  ← need further investigation of "K$^-$pp" → πΣN

What we have to do next

- **More quantitative studies of the "K^-pp"**
  - J^P
    - Angular distributions of "K^-pp"→Λp and Λ→$\pi^- p$ are consistent with S-wave, in current statistics
  - $\pi\Sigma p$ decay mode
    - Due to phase-space, or, detector acceptance(?)

- **Series of the kaonic nuclei searches:**
  - "K^-ppn" via [K^- + ^4He], "K^-ppnn/K^-pppnn" via [K^- + ^6Li], etc.
  - "K^-K^-pp" via [p^{bar} + ^3He annihilation]

We need a 4π detector system with γ/n sensitive detectors

Thank You!

J-PARC E15 Collaboration

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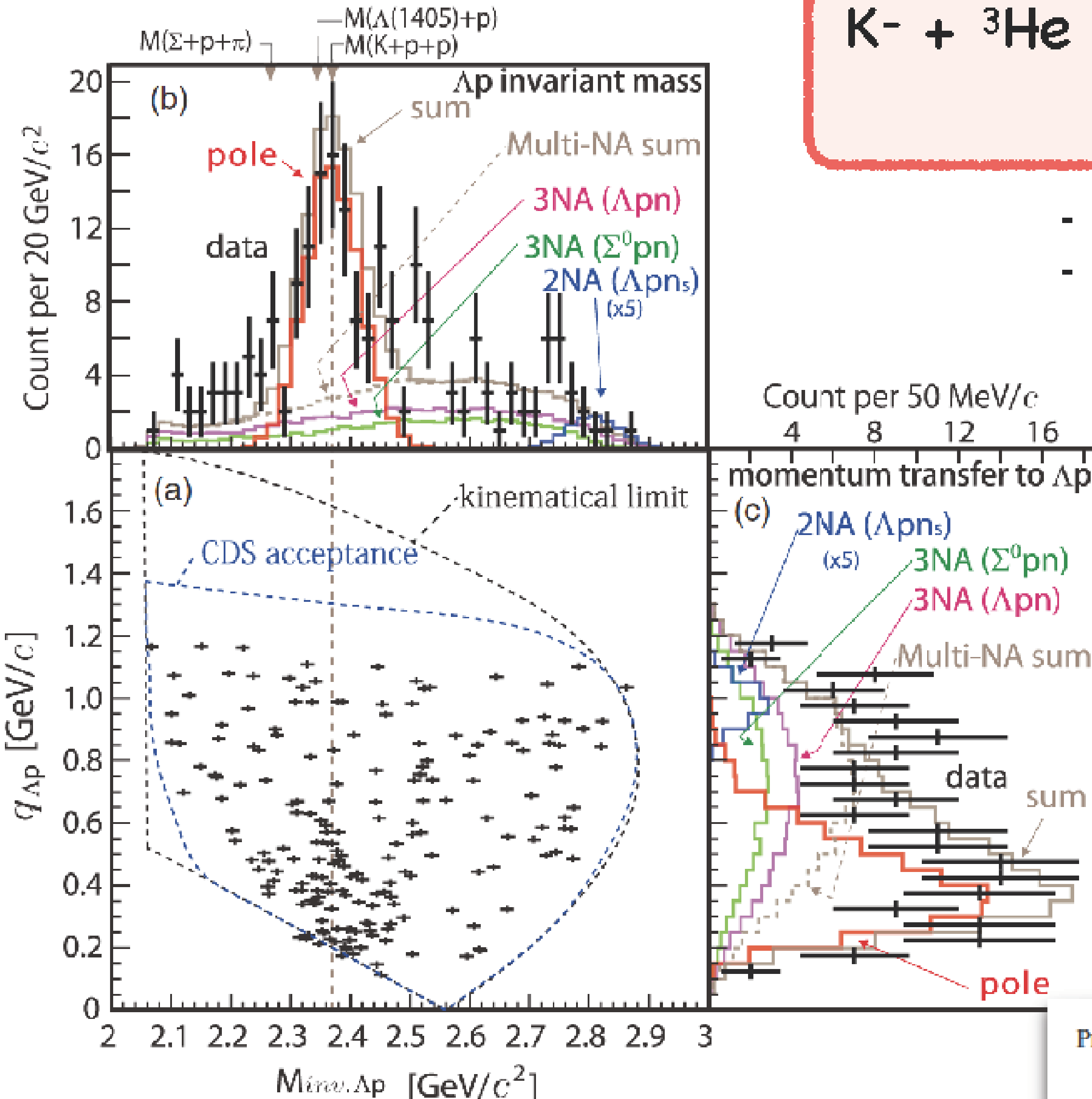
Spares

Forward $n_{mis.}$ + Λ p @ E15[1st]

Resolution σ ~ 10 MeV/c² @ threshold



$K^- + {}^3He \rightarrow (K^- p\, p) + n$

$\rightarrow (\Lambda + p) + n$

- s-wave Breit-Wigner pole
- w/ Gaussian form-factor

$$\frac{d^2\sigma}{dM\,dq} \propto \rho_3(\Lambda p n) \times \frac{(\Gamma_X/2)^2}{(M-M_X)^2+(\Gamma_X/2)^2} \times \left|exp\left(-\frac{q^2}{2Q_X^2}\right)\right|^2$$

$B_X \sim$ 15 MeV

$\Gamma_X \sim$ 100 MeV

$Q_X \sim$ 400 MeV

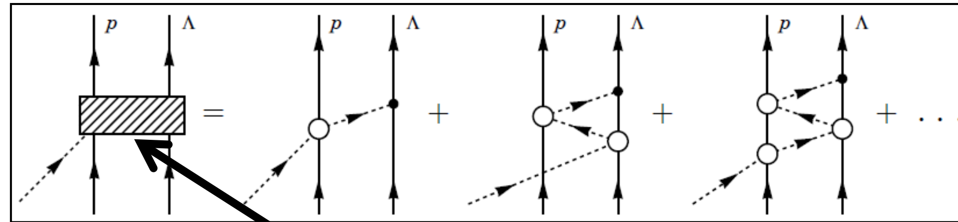
Compact state?

Prog. Theor. Exp. Phys. 2016, 051D01 (11 pages)
DOI: 10.1093/ptep/ptw040

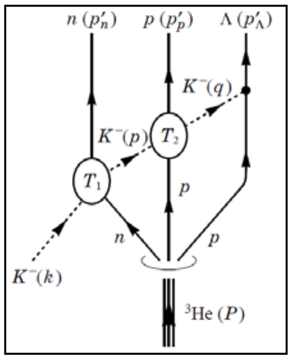
A Theoretical Interpretation of E15

Sekihara, Oset, Ramos, arXiv:1607.02058

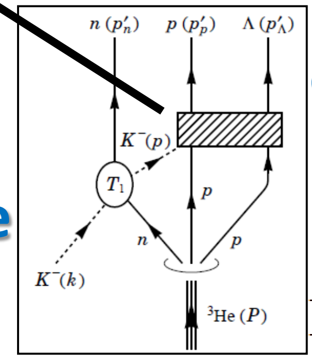
Chiral unitary approach



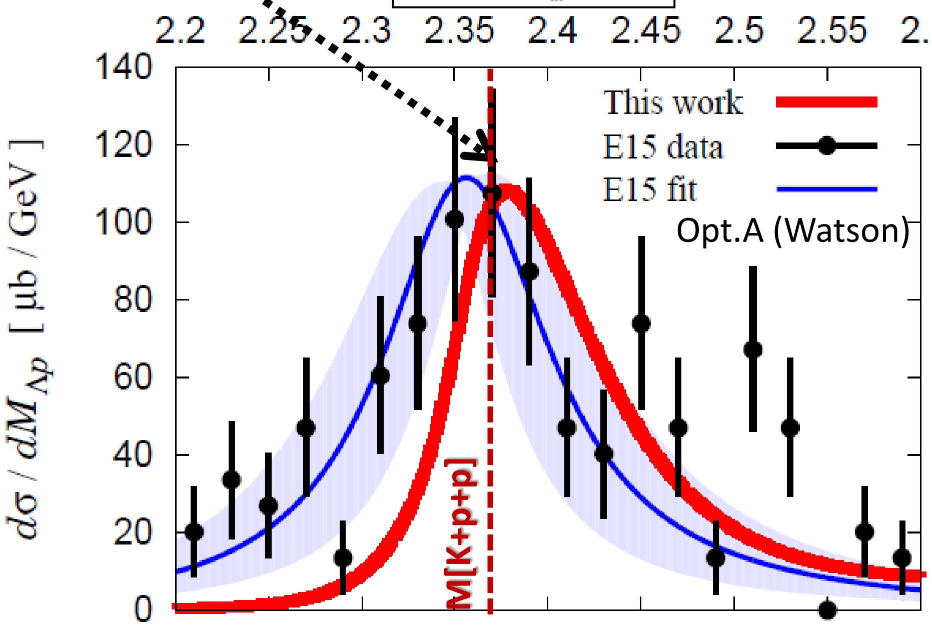
Uncorrelated Λ(1405)p state

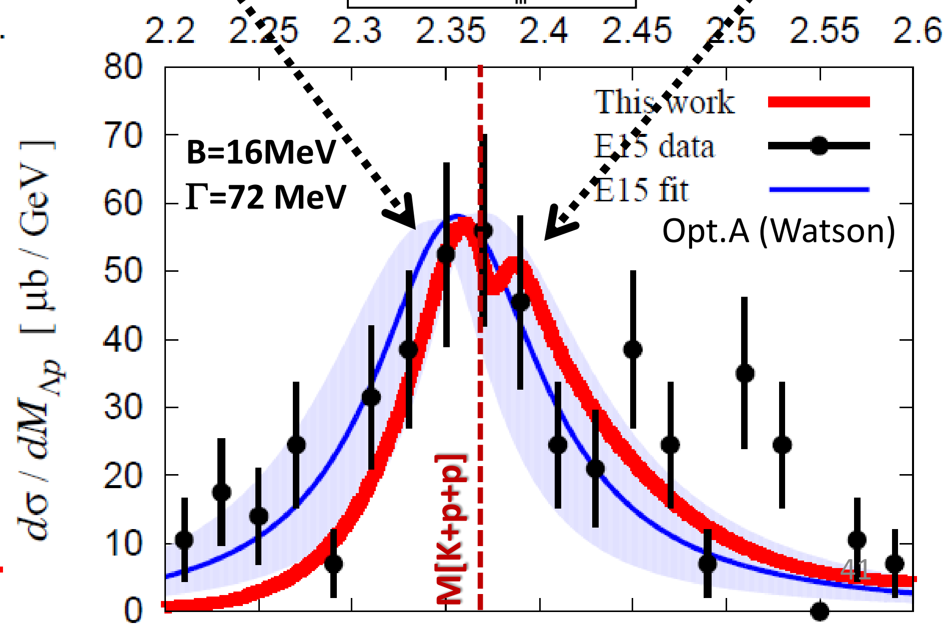


$K^{bar}NN$ bound-state



quasi-elastic kaon scattering





$K^{bar}NN$ or NOT? --- Other Possibilities

A structure near $K^{bar}NN$ threshold

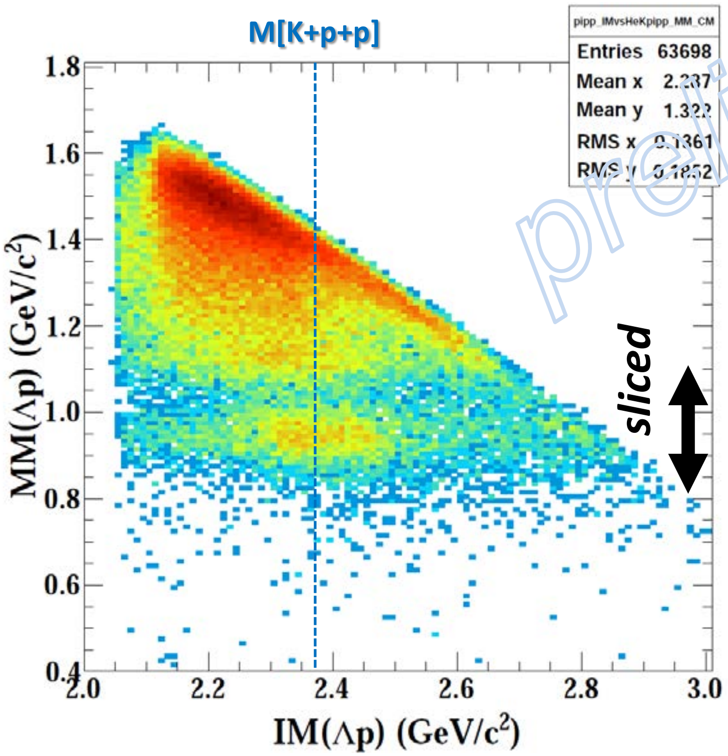
- **Λ(1405)N bound state** — T. Uchino et al., NPA868(2011)53.
  - loosely-bound system, I=1/2, $J^{\pi}=0^{-}$
  - various decay modes, ΛN/ΣN/$\pi\Sigma$N

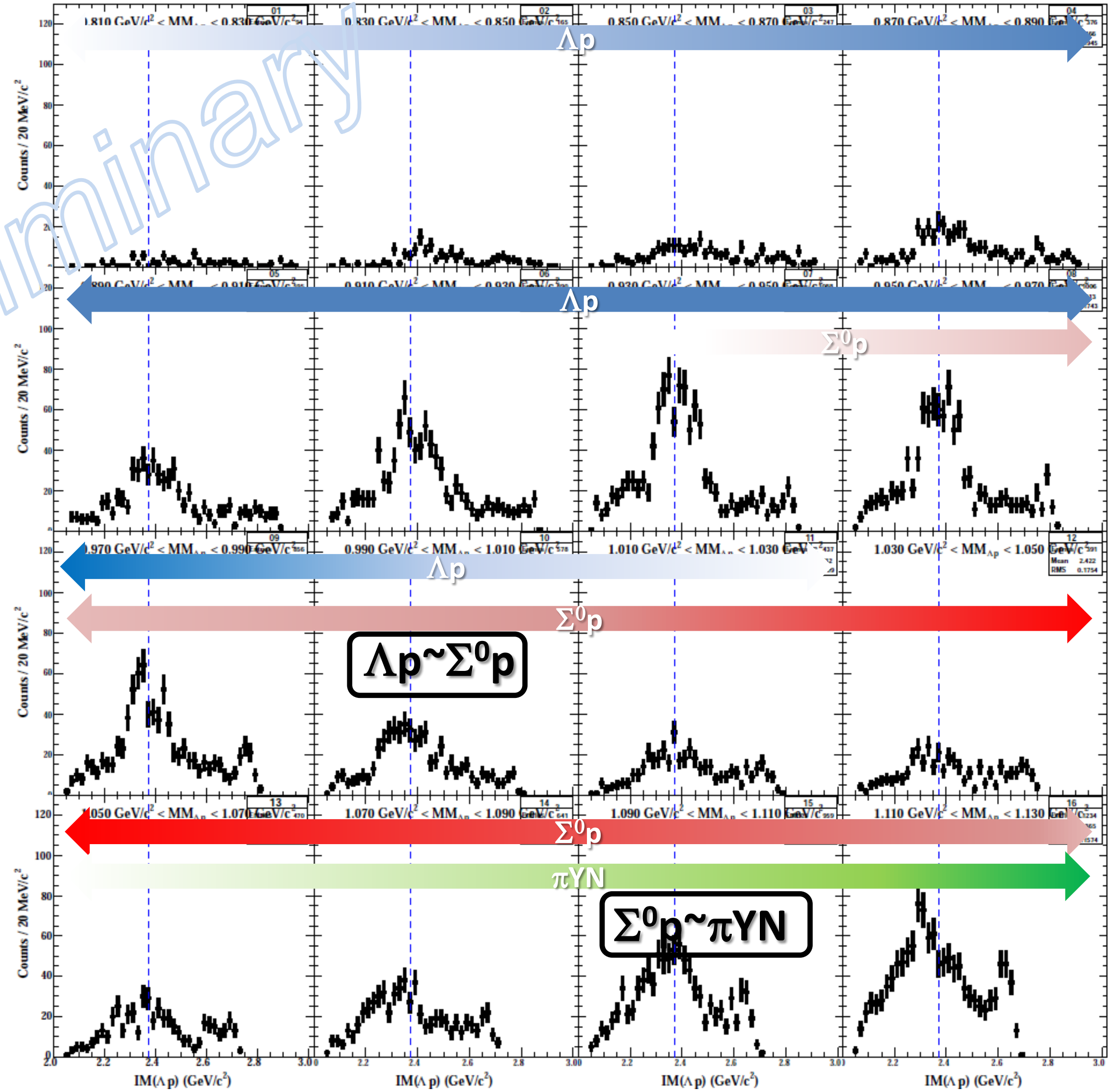
A structure near $\pi\Sigma$N threshold

- **$\pi\Lambda$N-$\pi\Sigma$N dibaryon** — H. Garcilazo, A. Gal, NPA897(2013)167.
  - structure near $\pi\Sigma$N threshold
  - I=3/2, $J^{\pi}=2^{+}$ → no Λp decay (I=1/2)?
- **Double-pole $K^{bar}NN$** — A. Dote, T. Inoue, T. Myo, PTEP (2015) 043D02.
  - loosely-bound $K^{bar}NN$, &
  - broad resonance near the $\pi\Sigma$N threshold → $\pi\Sigma$N decay
- **Partial restoration of Chiral symmetry**
  - enhancement of the $K^{bar}N$ interaction in dense nuclei

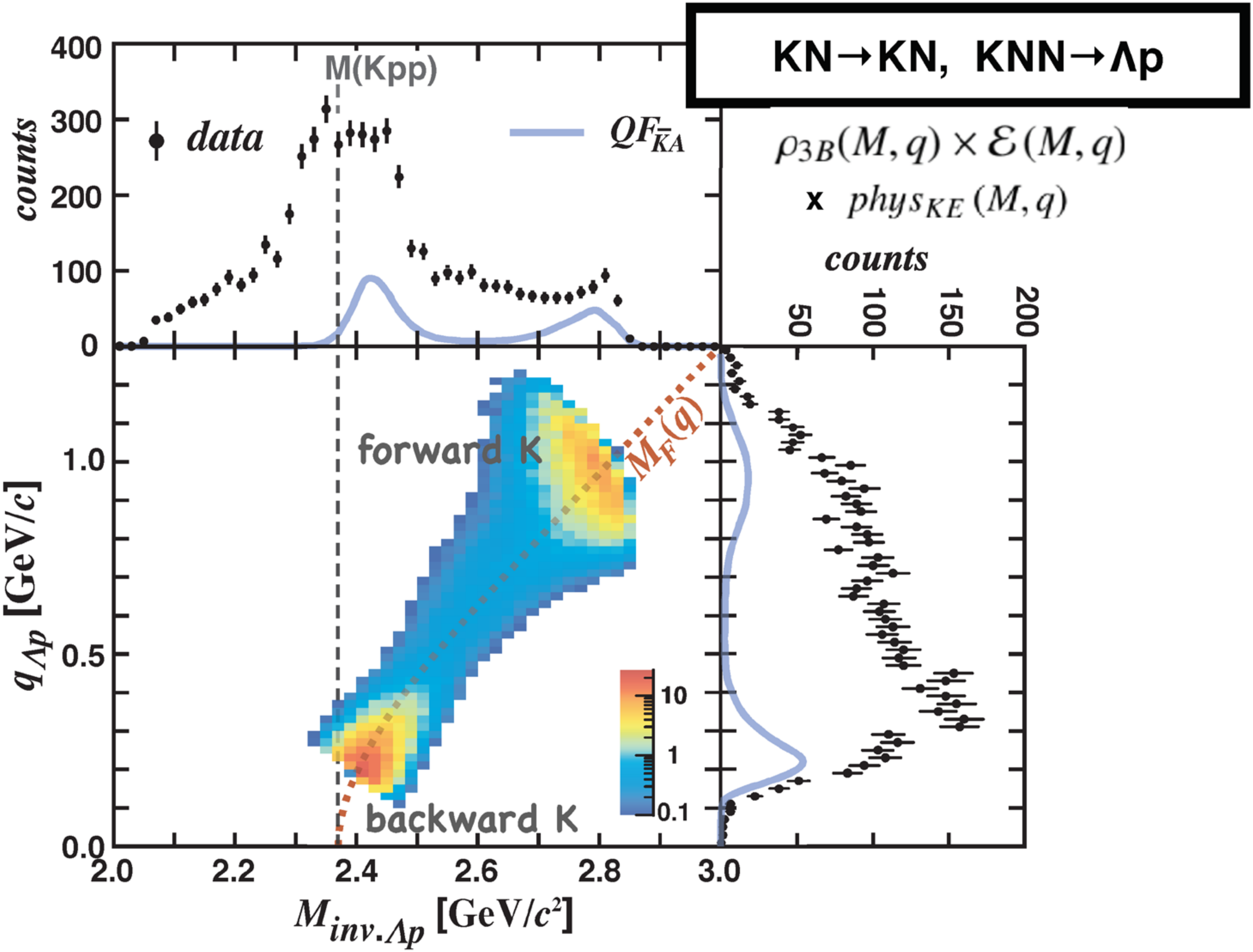
S. Maeda, Y. Akaishi, T. Yamazaki, Proc. Jpn. Acad., B89(2013)418.

^{3}He(K$^-$,Λp)n: Decay Channel

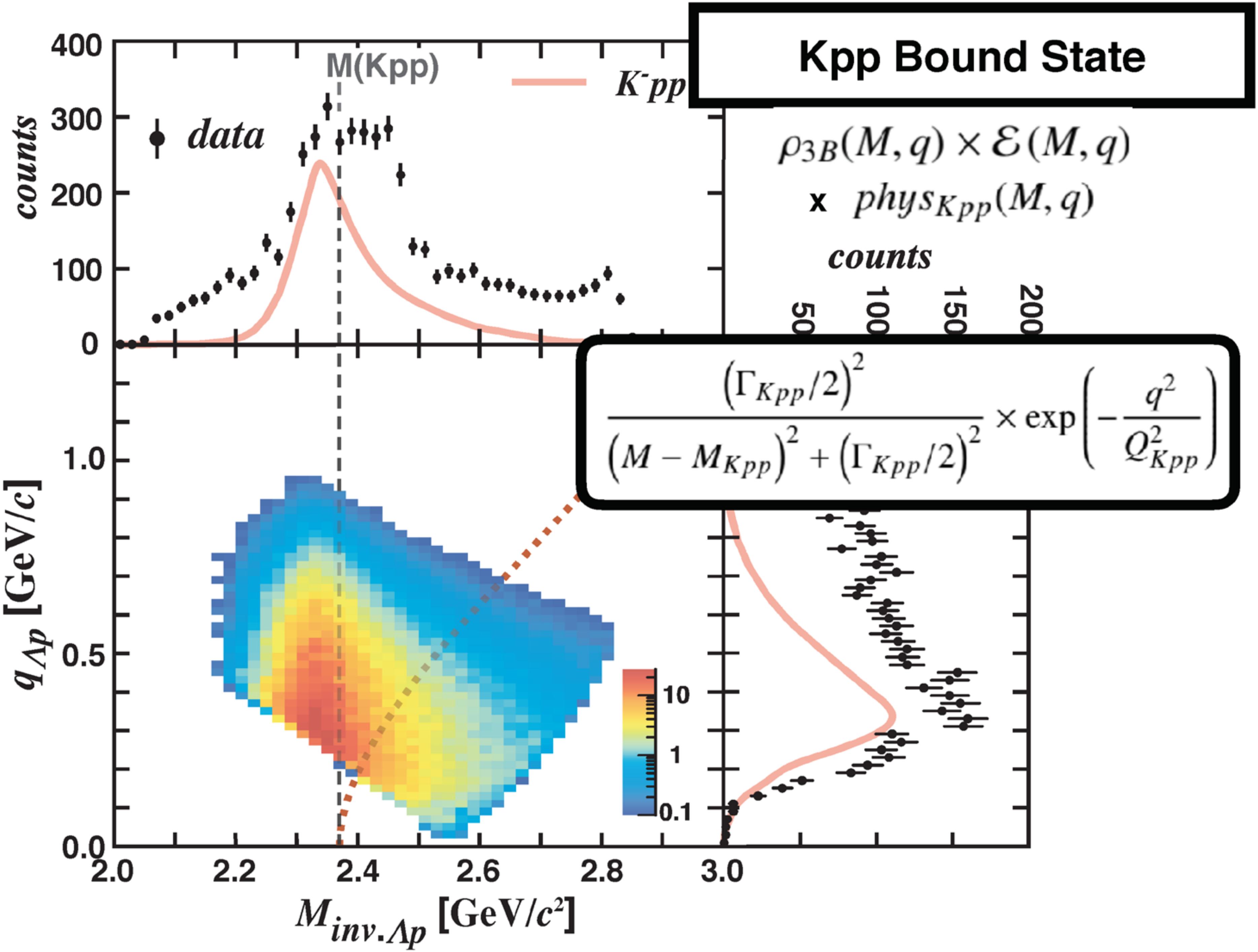




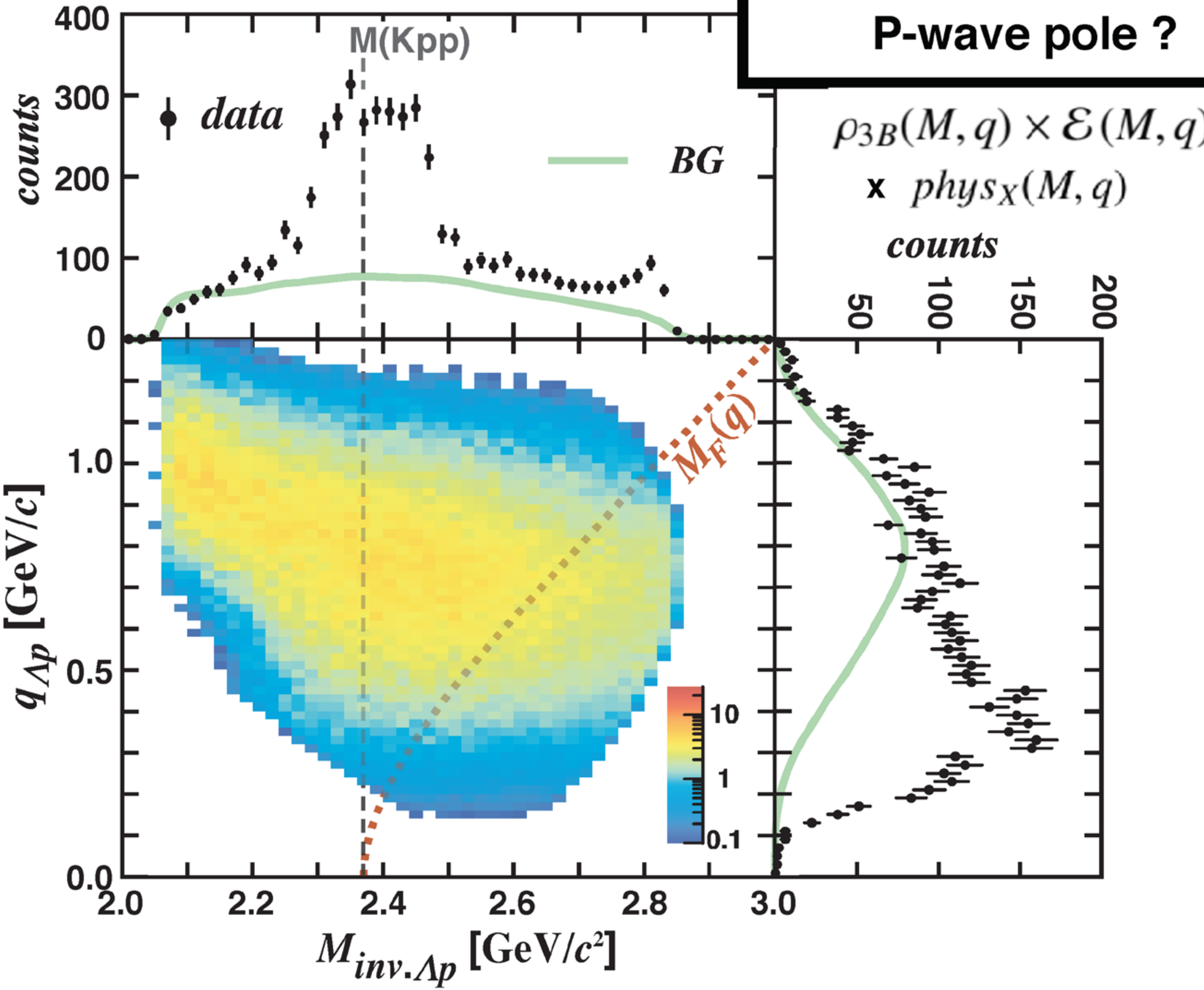
$\Gamma(\Lambda p) > \Gamma(\Sigma^0 p)$!?



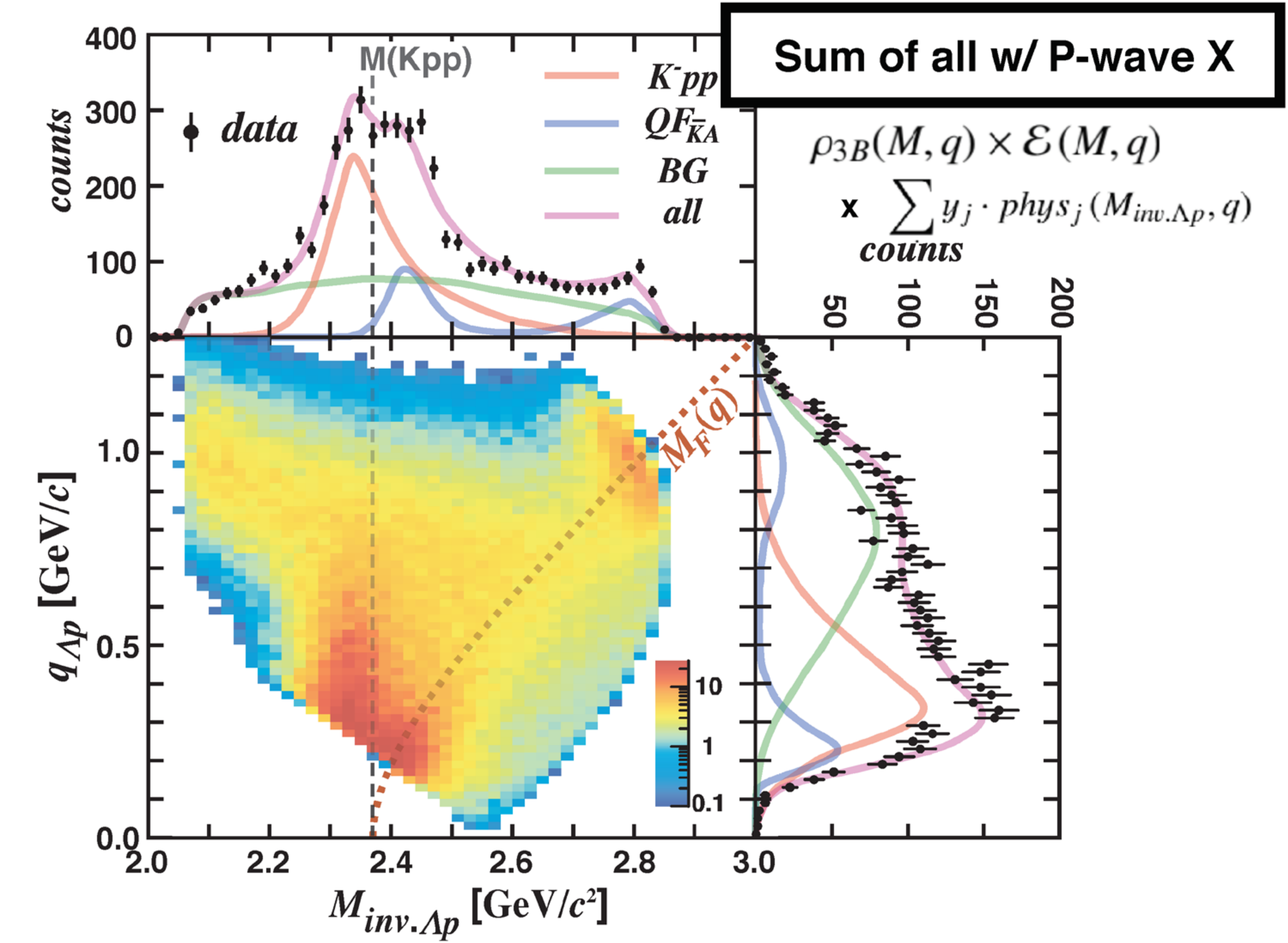
KN→KN, KNN→Λp
M(Kpp)
data
$QF_{\bar{K}A}$
counts
$\rho_{3B}(M,q) \times \mathcal{E}(M,q)$
x $phys_{KE}(M,q)$
counts
forward K
backward K
$M_F(q)$
$q_{\Lambda p}$ [GeV/c]
$M_{inv.\Lambda p}$ [GeV/c²]


Kpp Bound State
$\rho_{3B}(M,q) \times \mathcal{E}(M,q)$
x $phys_{Kpp}(M,q)$
$$\frac{(\Gamma_{Kpp}/2)^2}{(M-M_{Kpp})^2+(\Gamma_{Kpp}/2)^2} \times \exp\left(-\frac{q^2}{Q_{Kpp}^2}\right)$$
M(Kpp)
data
K^-pp
counts
$q_{\Lambda p}$ [GeV/c]
$M_{inv.\Lambda p}$ [GeV/c^2]

P-wave pole ?



M(Kpp)
data
BG
counts
$\rho_{3B}(M,q) \times \mathcal{E}(M,q)$
x $phys_X(M,q)$
counts
$M_F(q)$
$q_{\Lambda p}$ [GeV/c]
$M_{inv.\Lambda p}$ [GeV/c^2]

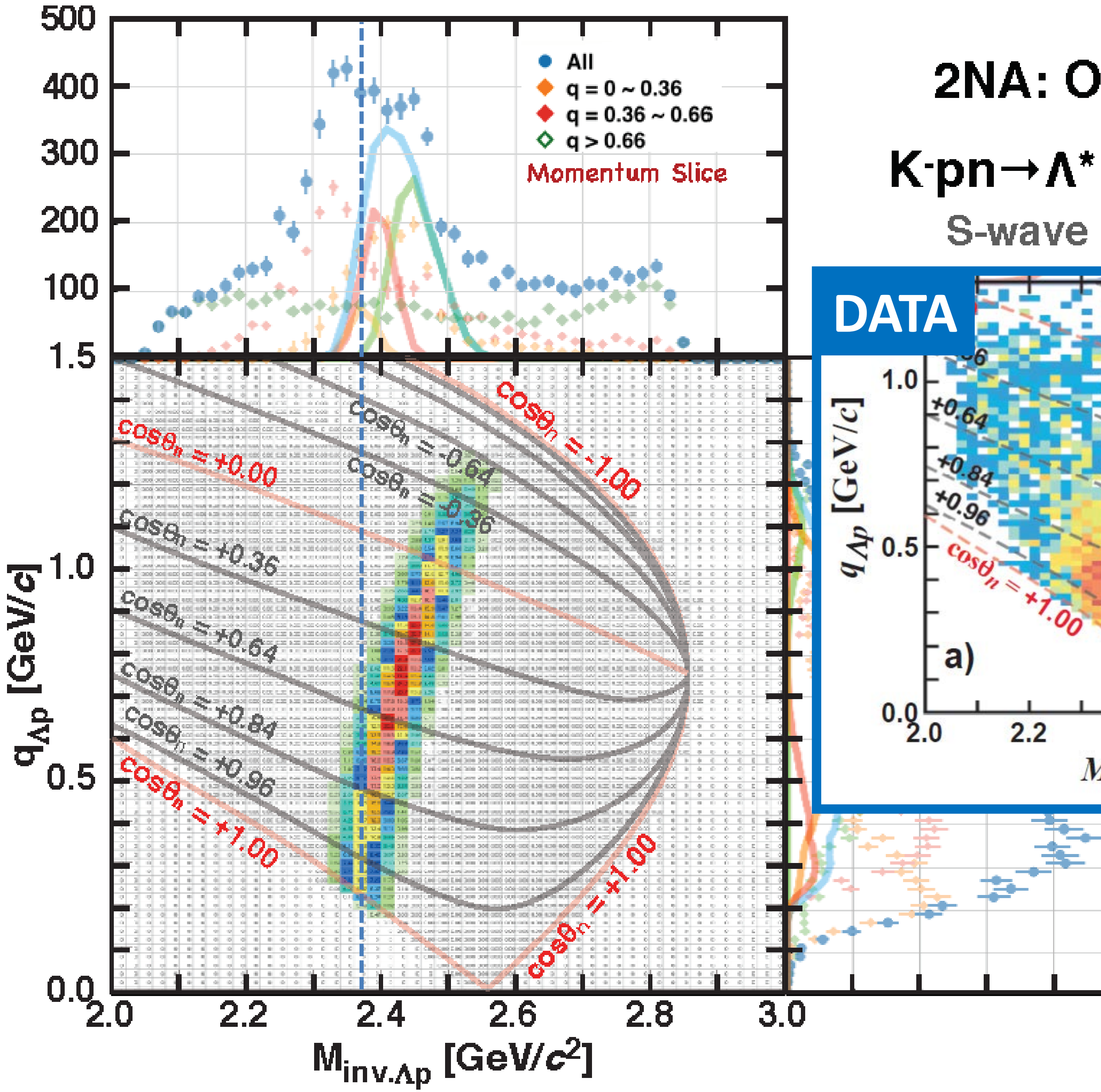


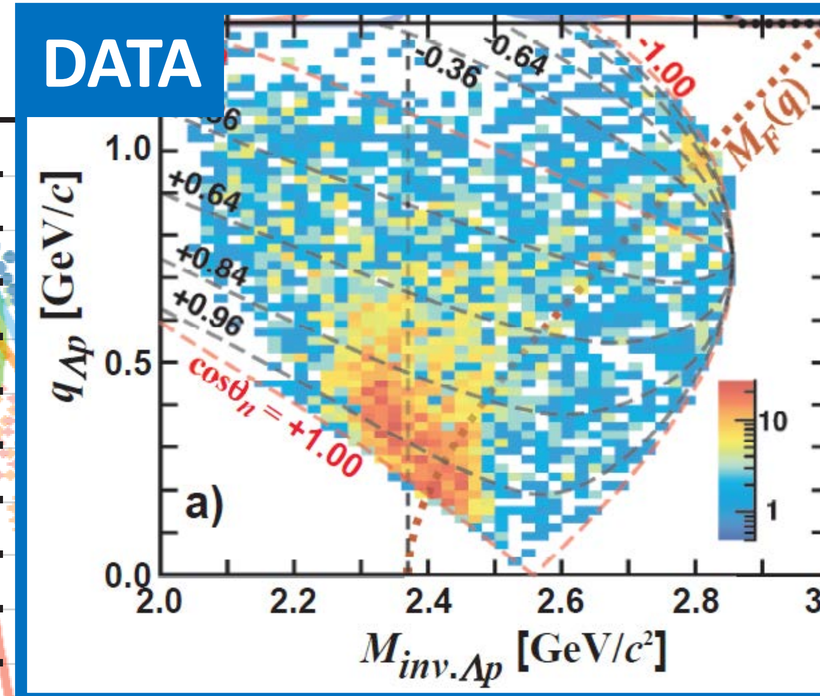
Sum of all w/ P-wave X
M(Kpp)
data
K⁻pp
QF$_{\bar{K}A}$
BG
all
counts
$\rho_{3B}(M,q) \times \mathcal{E}(M,q)$
x $\sum y_j \cdot phys_j(M_{inv.\Lambda p}, q)$
$M_F(q)$
$q_{\Lambda p}$ [GeV/c]
$M_{inv.\Lambda p}$ [GeV/c²]

2NA: On-shell Λ*

K⁻pn→Λ* n, Λ*p→Λp

S-wave



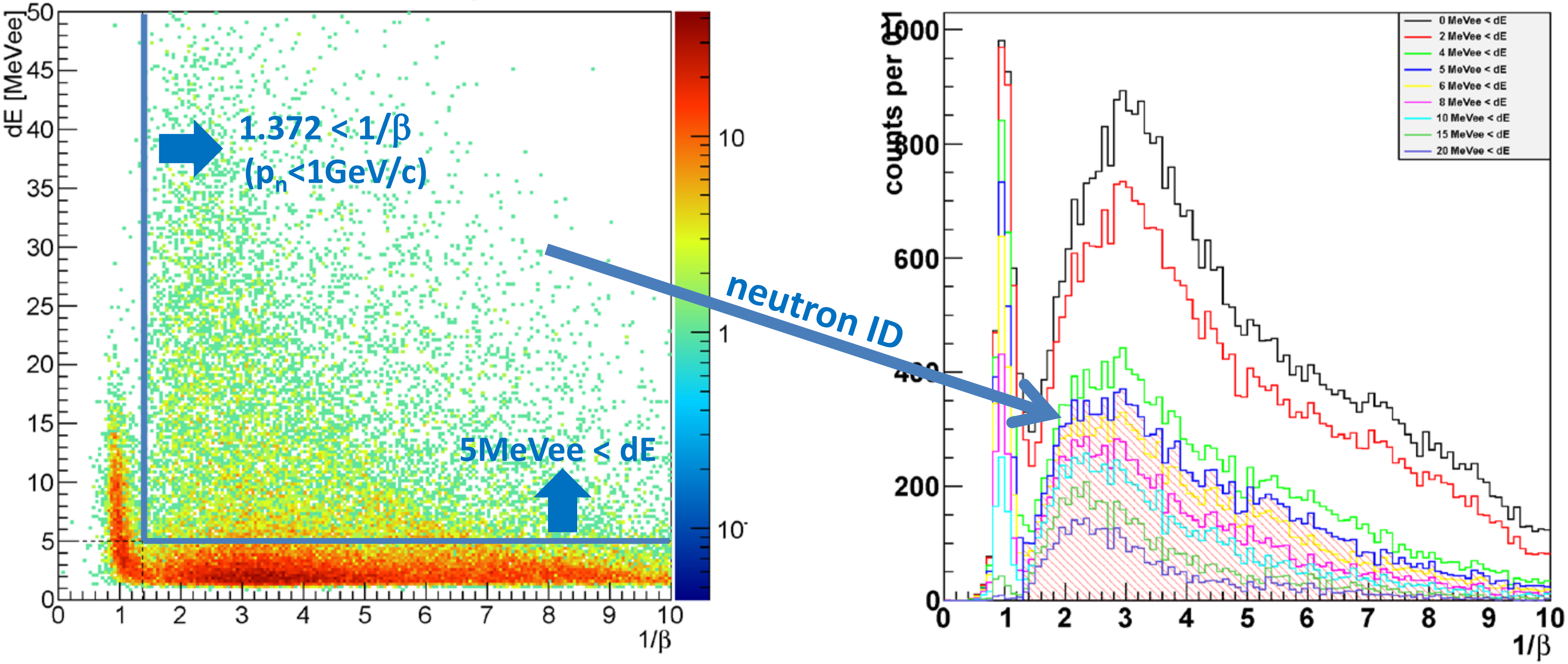


M_{Λ^*}=1420 MeV/c²

Neutron ID with CDS

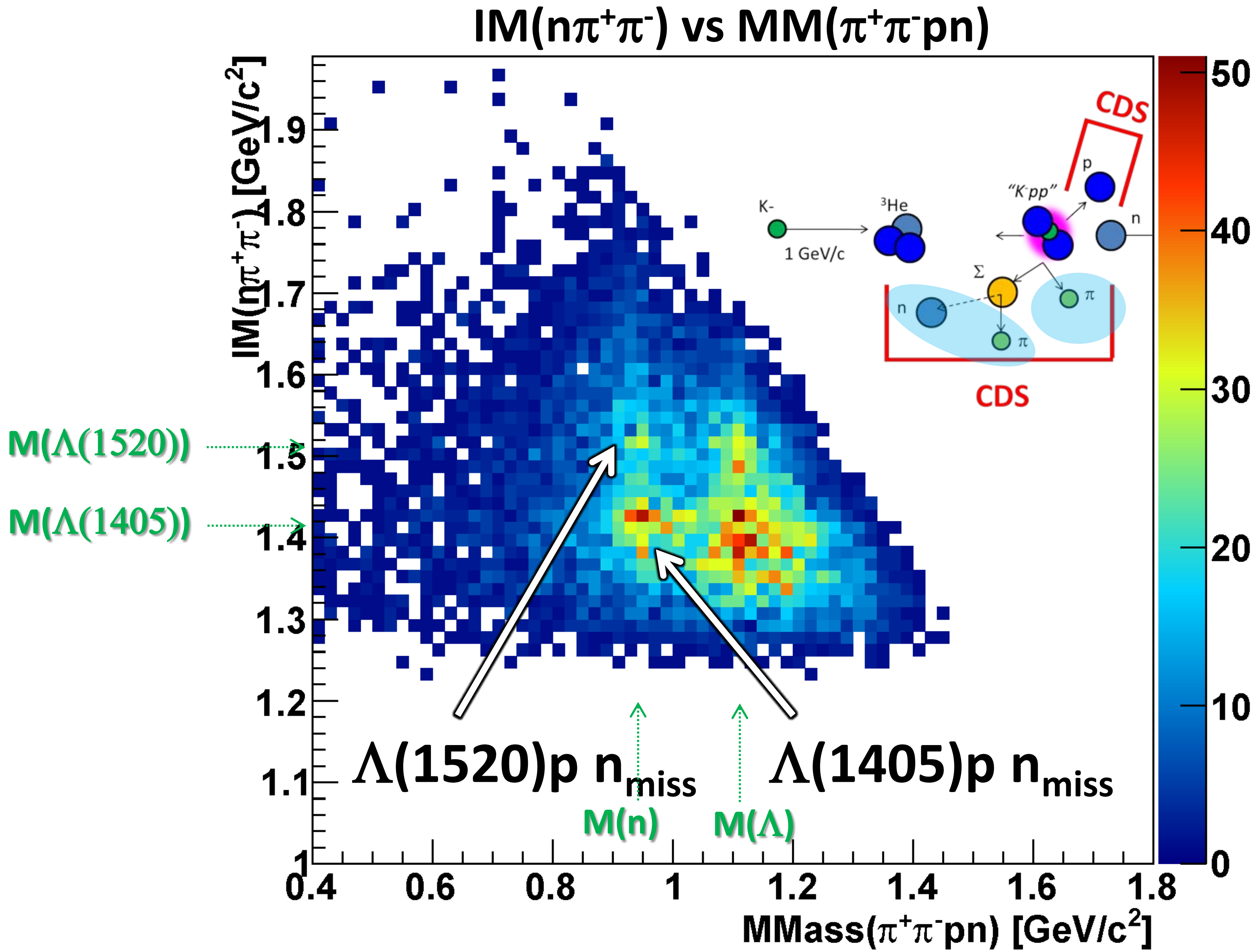
- $\pi^+\pi^-p$ events (3 tracks) in CDS with 4 CDH hits are selected
- a CDH hit with CDC-veto (outer-layer) is applied to identify the “neutral hit”

dE vs. 1/β **dE-cut dependence**

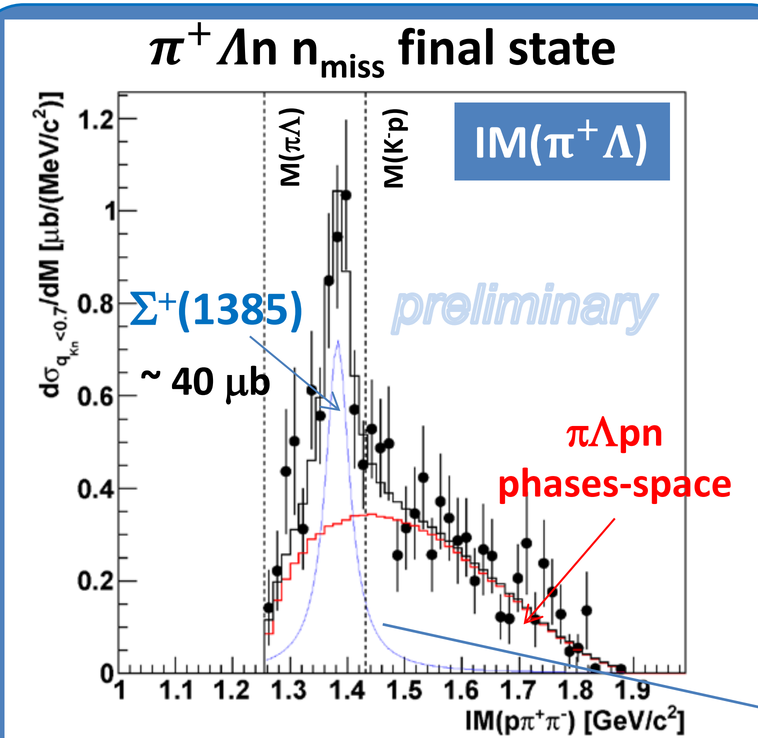


Neutron can be identified with CDS

Λ^*pn Events

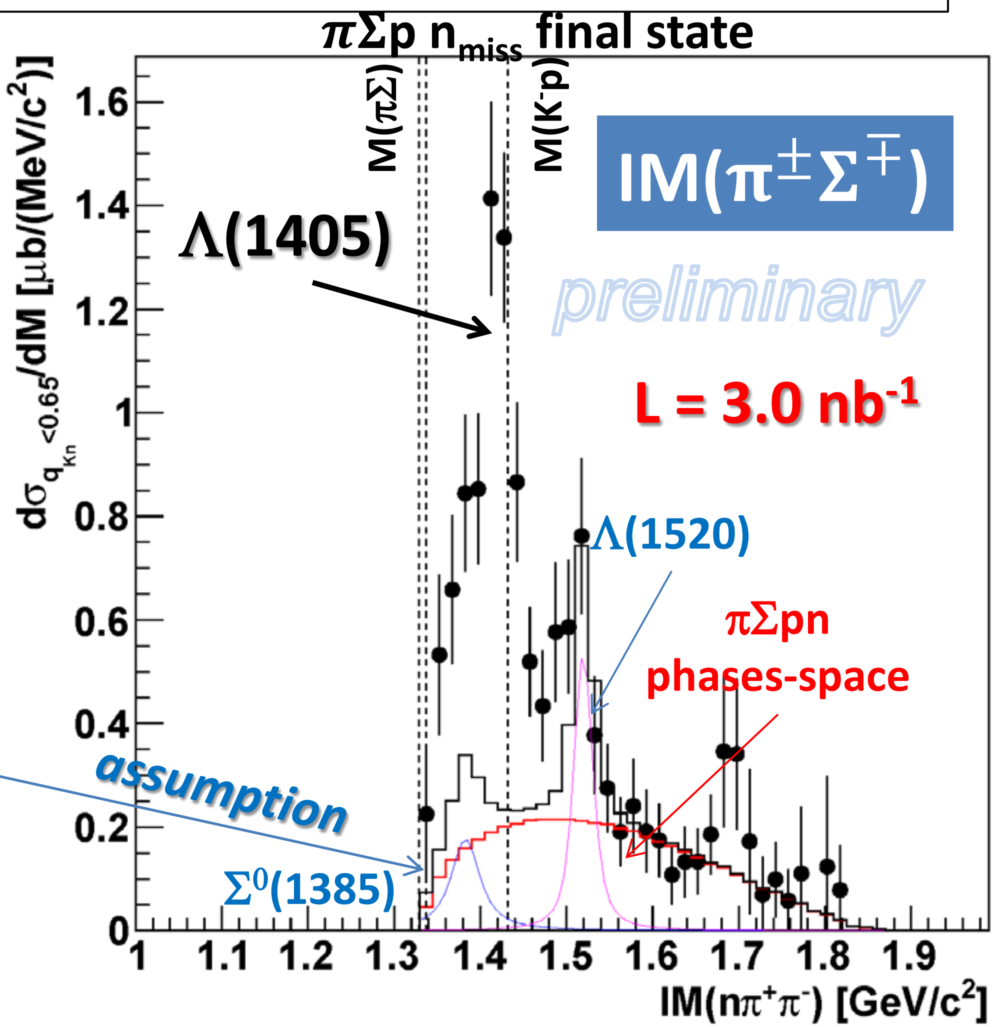


Y^* CS (q_{Kn}<0.65)



we assume Σ^0(1385) CS at 1.0 GeV/c to be:

$\sigma(\Sigma^{*0}) \sim 1\text{-}2*\sigma(\Sigma^{*+})$

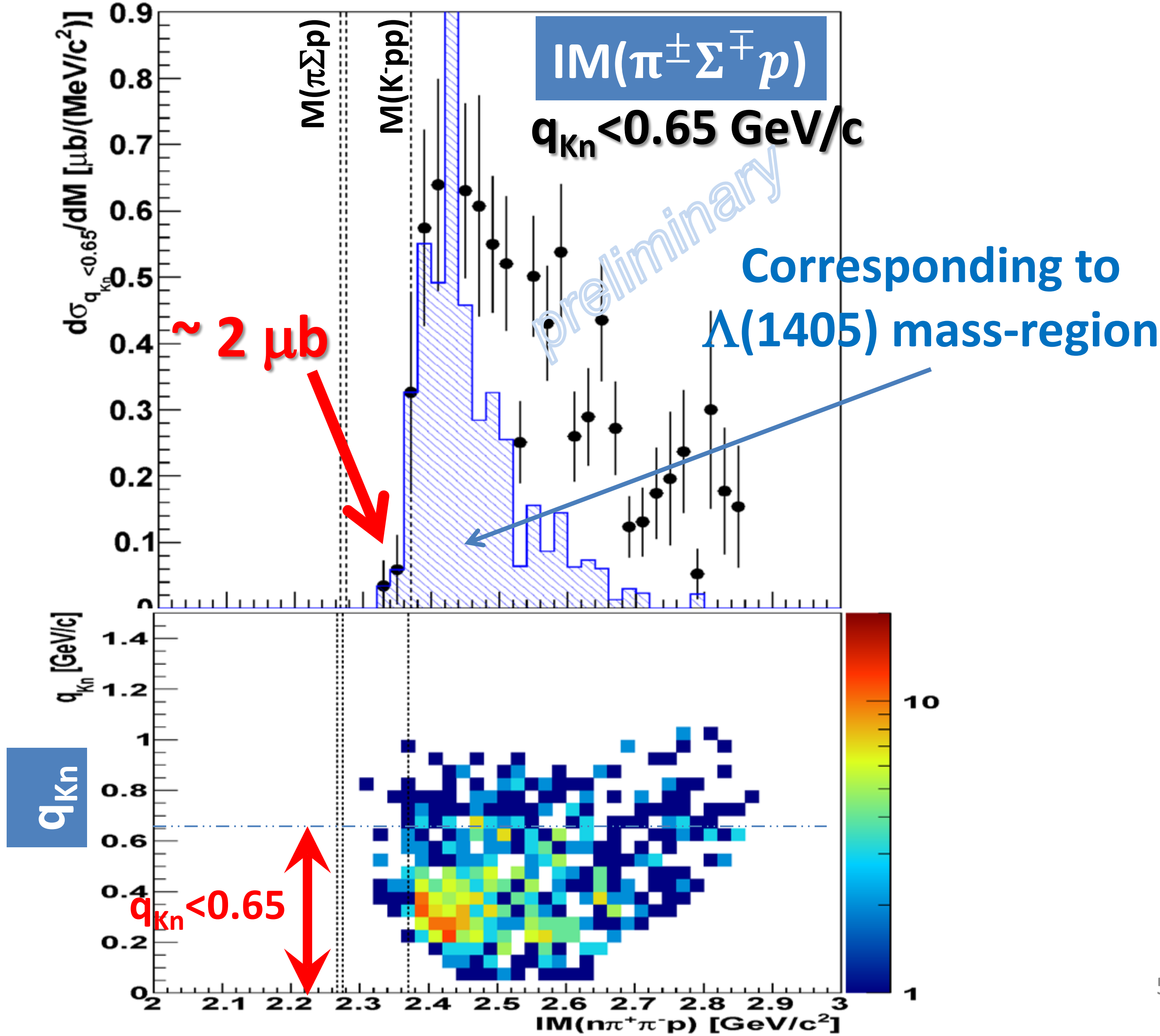


K^- + ^{3}He → **Σ^0(1385)** + p + n: ~ 40-80 μb (assumption)

K^- + ^{3}He → **Λ(1405)** + p + n: ~ 130 μb

K^- + ^{3}He → **Λ(1520)** + p + n: ~ 70 μb

IM($\pi\Sigma$p) vs. Momentum Transfer q_{Kn}



Detector Acceptance: 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