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

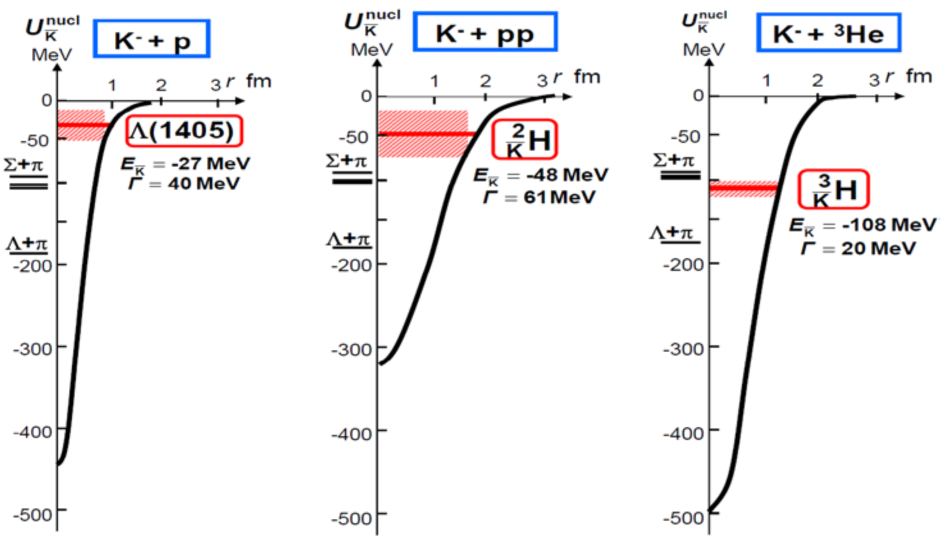
F. Sakuma, RIKEN

on behalf of the J-PARC E15 collaboration

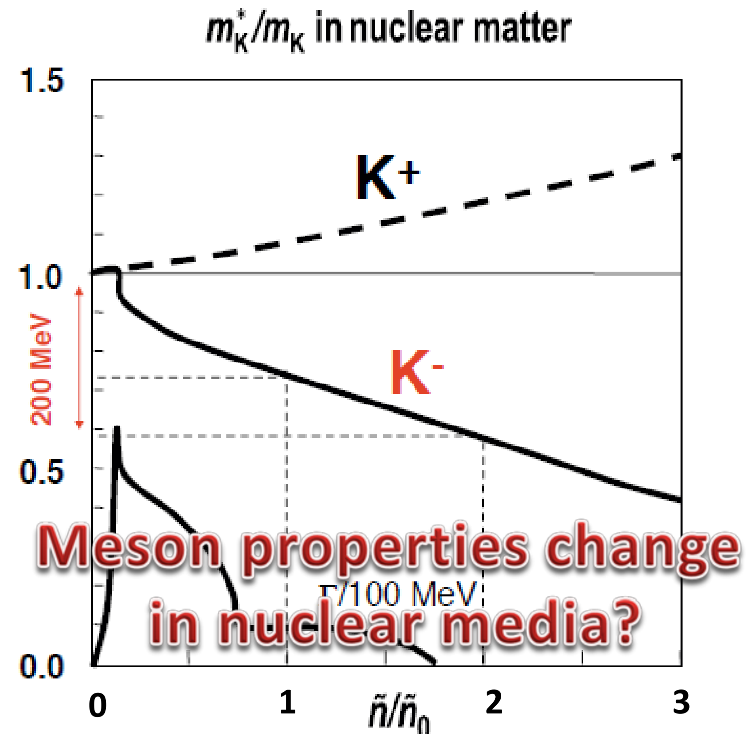
MENU2016, July 25-30, 2016, Kyoto

What are 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).

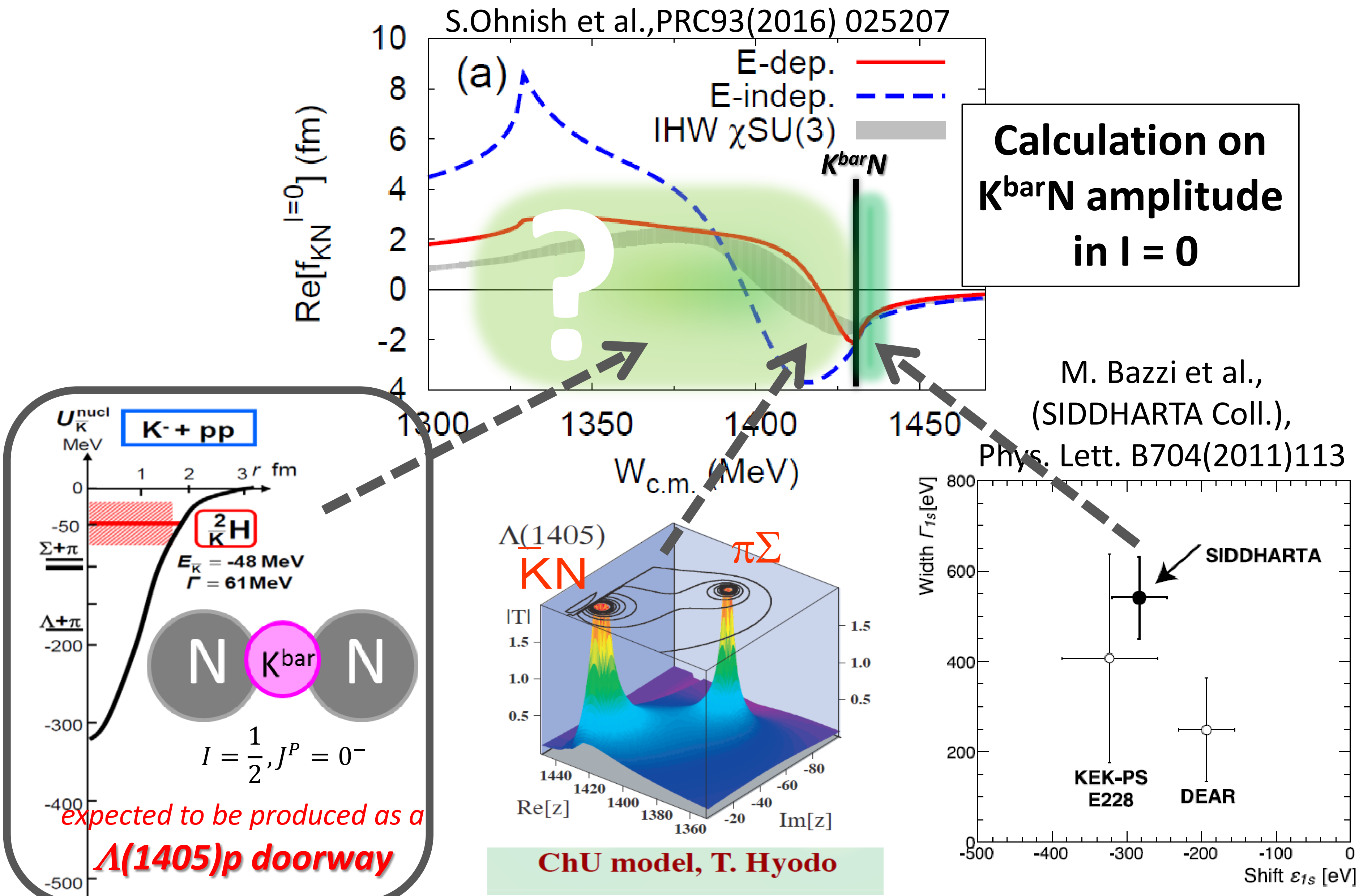


Meson properties change in nuclear media?

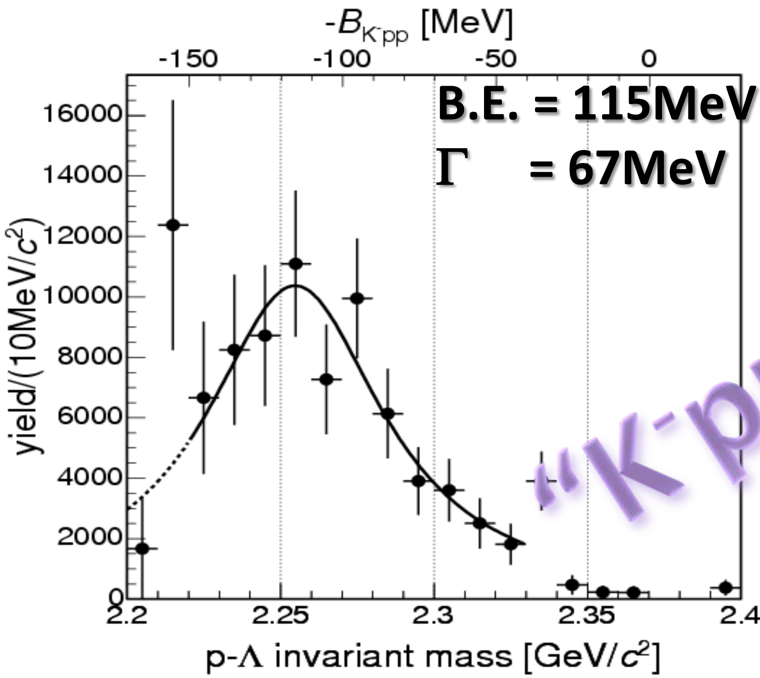
T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

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

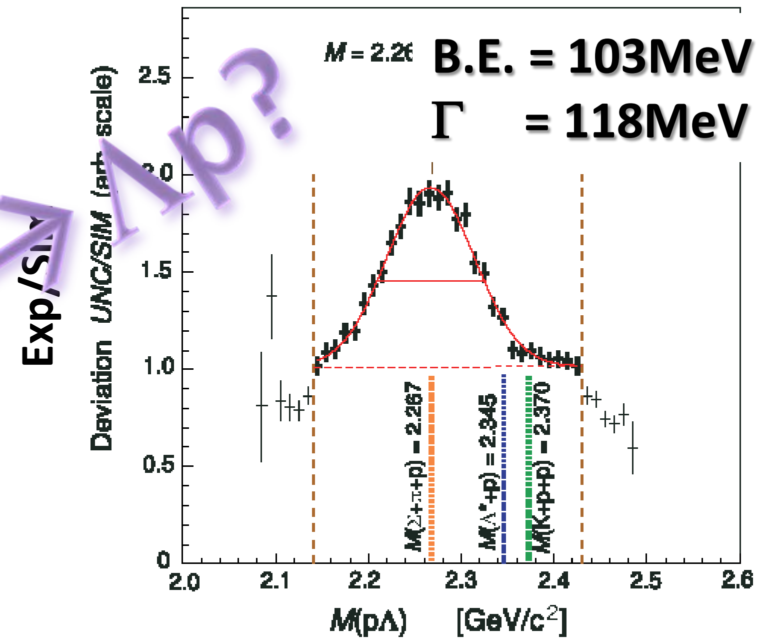
$K^{bar}N$ interaction - A good probe for low-energy QCD



Pioneering Experiments on $K^{bar}NN$



“K^-pp” → Λp?



FINUDA@DAΦNE

PRL**94**(2005)212303

^{6}Li+^{7}Li+^{12}C(*stopped* K^-, Λp)

DISTO@SATURNE

PRL**104**(2010)132502

p + p → (Λ + p) + K^+ @ 2.85GeV

2NA followed by FSI?
PRC74(2006)025206
PRC82(2010)034608 etc.

pp→p(N*)→p(ΛK^+)?
PRC92(2015)044002

vs. **K.Suzuki, HYP2015 talk**

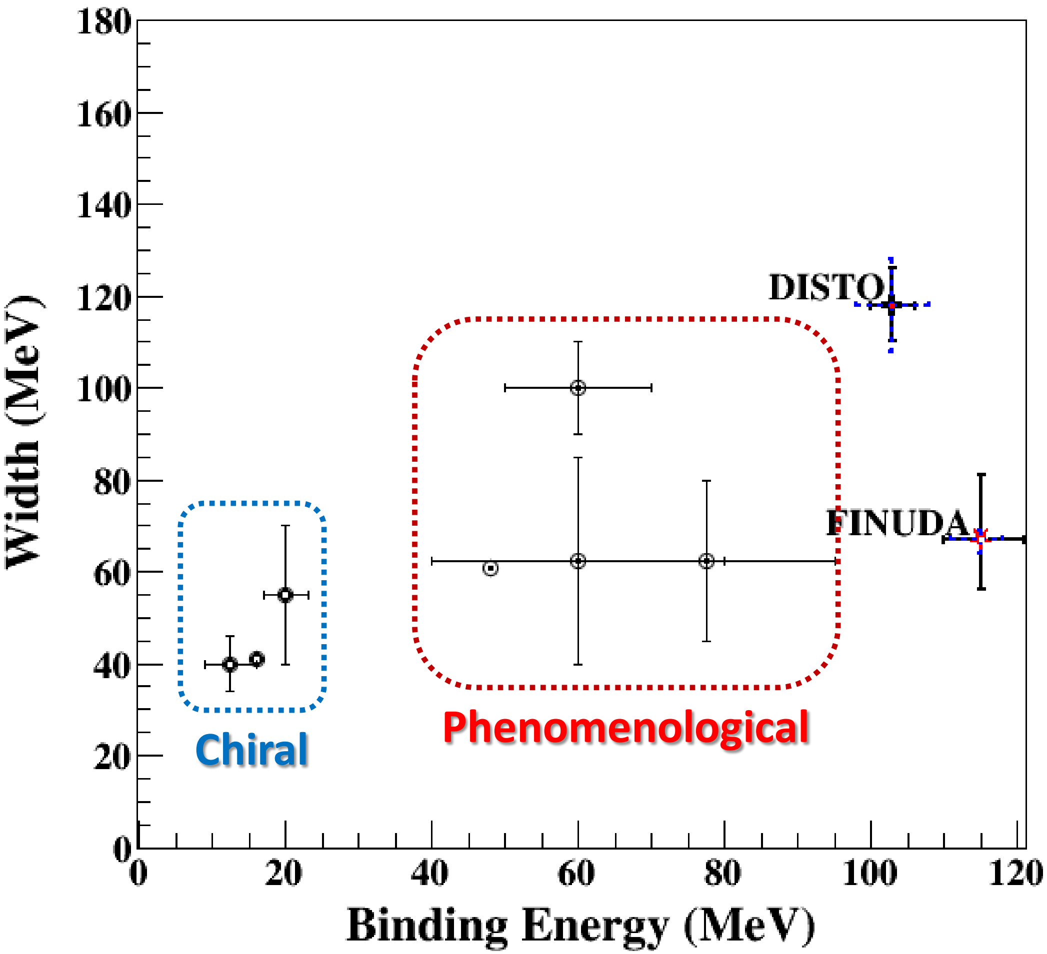
Theoretical Calculations on $K^{bar}NN$

$K^{bar}N$ 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 = *depending on $K^{bar}N$ interaction*

Dote, Tue. A-1

Comparison between Calcs. and Exps.



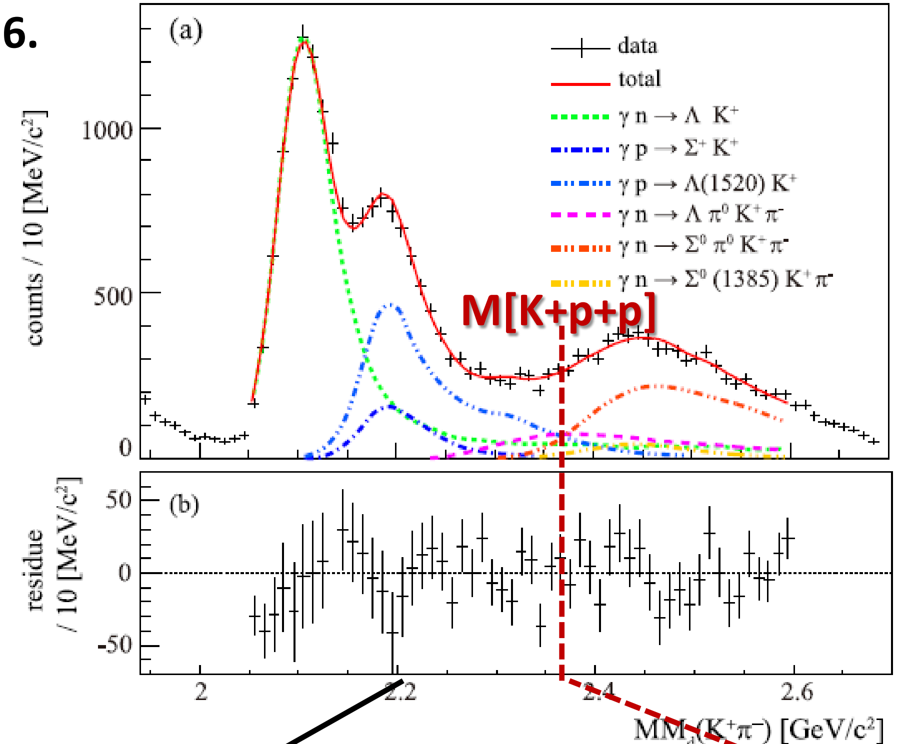
- **Binding energy**
  - Chiral:
    B.E. ~ 20MeV
  - Phenomenological:
    B.E. ~ 40-70MeV
  - Experiments ***(if $K^{bar}NN$)***:
    B.E. ~ 100MeV
- **Width**
  - almost agreement in Γ~40-100MeV
    - Theor.: mesonic decay
    - Exp.: non-mesonic decay

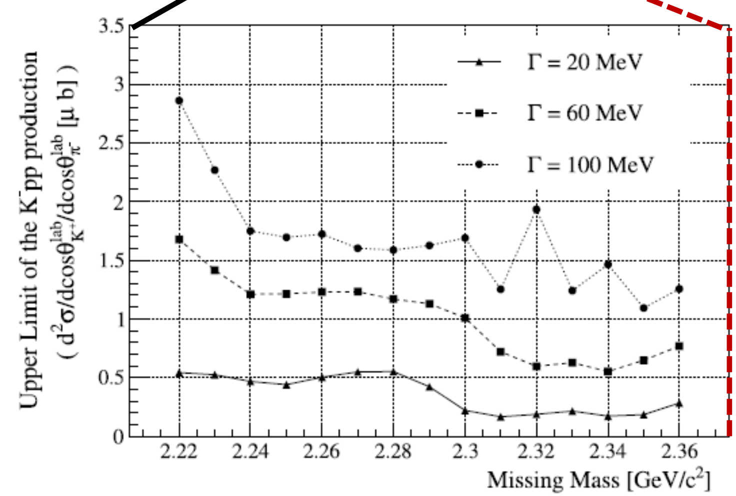
Recent Measurement at LEPS

A.O. Tokiyasu et al., Phys. Lett. B 728 (2014) 616.

- **Inclusive** $d(\gamma, K^+\pi^-)X$
  - E_γ = 1.5-2.4 GeV
  - $\cos\theta^{lab}_{K+/\pi-} > 0.95$
  - σ_{MM} ~ 10 MeV
- BG: $\gamma N \rightarrow K^+\pi^-\Lambda/\Sigma/\Lambda(1520)$
- **NO peak structure**
  - U.L.: 0.17-2.9 μb
    (= 1.5-26% CS of $\gamma d \rightarrow K^+\pi^- Y$)

→ LEPS2 (4π measurement)





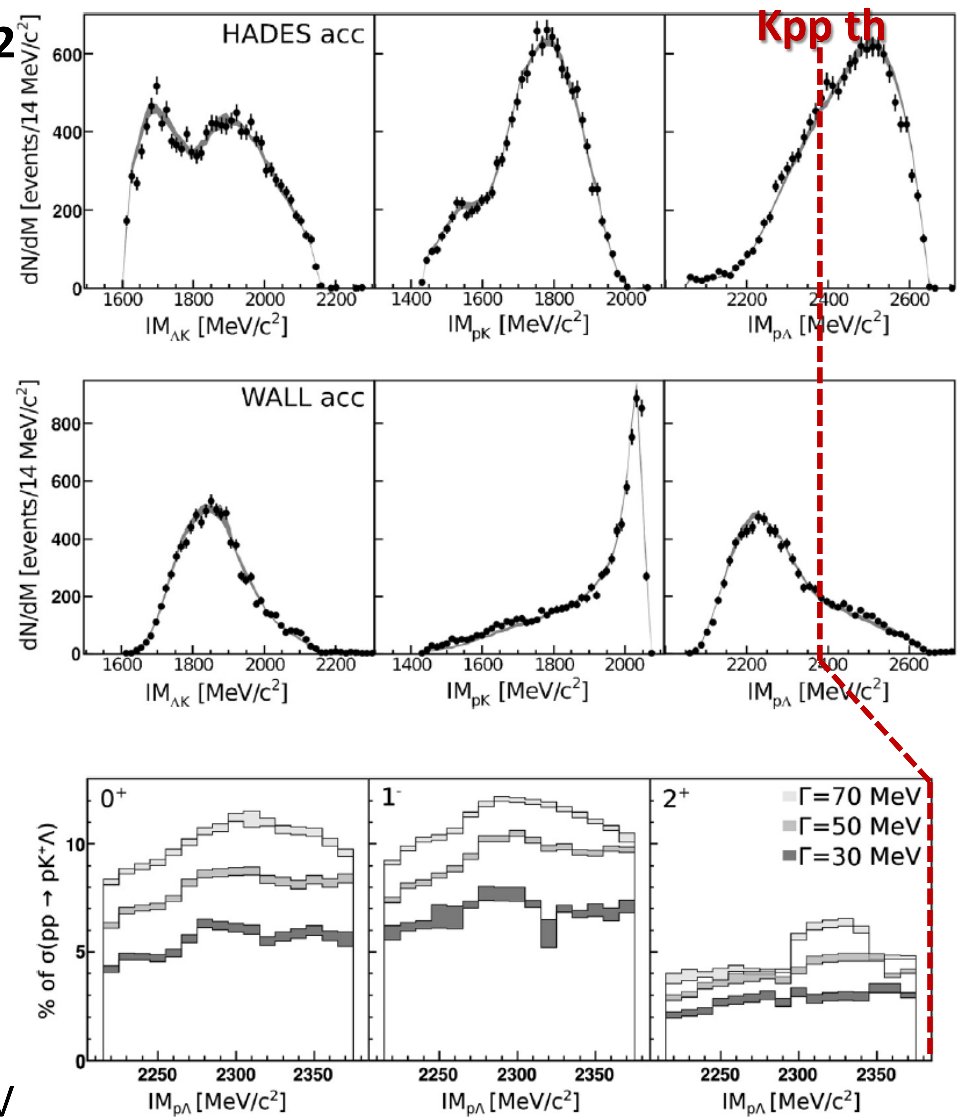
Recent Measurement at HADES

G. Agakishiev et al., Phys. Lett. B 742 (2015) 242

- **Exclusive** $pp \rightarrow p\Lambda K^+$
  - E = 3.5 GeV
- Bonn–Gatchina PWA
  - Well reproduces the data with N* resonances
    - $pp \rightarrow pN^* \rightarrow p\Lambda K^+$
- **NO peak structure**
  - U.L.: 0.7-4.2 μb (= 2-12% CS of $pp \rightarrow pK^+\Lambda$)
  - **$\Lambda(1405)$ production = 9.2 μb** PRC87(2013)025201

→ $\sigma(X = K^{bar}NN)/\sigma(\Lambda^*) <$ ~50%

vs. DISTO: $\sigma(X) > \sigma(\Lambda(1405))$ @ 2.85GeV



→ Combined analysis with COSY-TOF/DISTO/HOPI/HADES ($pp \rightarrow pK^+\Lambda$)

Brief Summary --- What We Have Learned? ---

- Theoretical approach to $K^{bar}NN$
  - Largely depends on $K^{bar}N$ interaction below the $K^{bar}N$ threshold
    - **Need feedback from $\Lambda(1405)$/"K-pp" experiments**

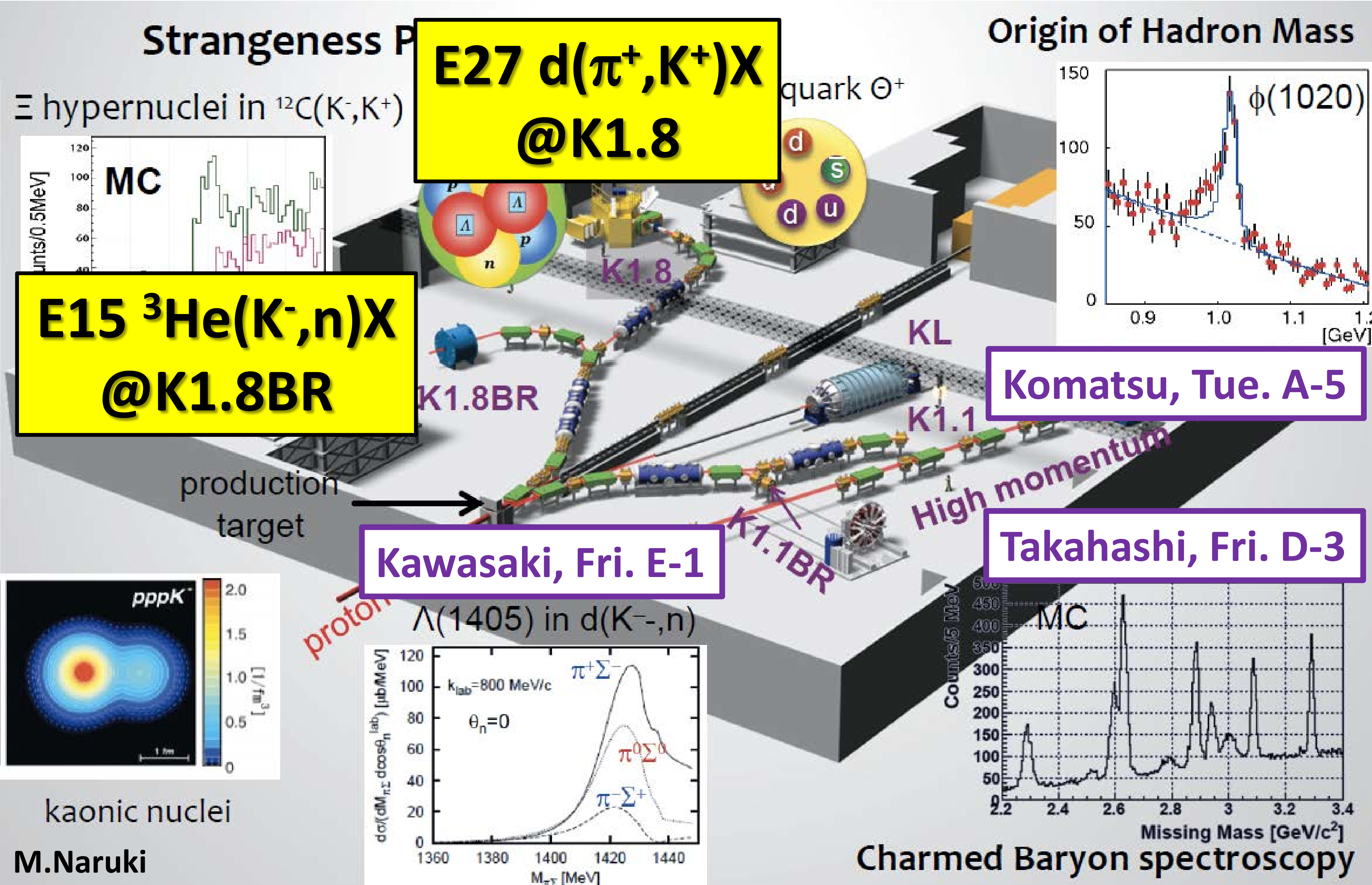
- Experimental approach to $K^{bar}NN$
  - Still controversial…
  - Have to hunt small/broad signal from large/widely distributed QF-BG

✓ **Exclusive measurement is crucial**

✓ **Other production channels are needed:**

π + A, $^{\text{in-flight}}K^-$ + A

K^{bar}NN Searches at J-PARC



M.Naruki

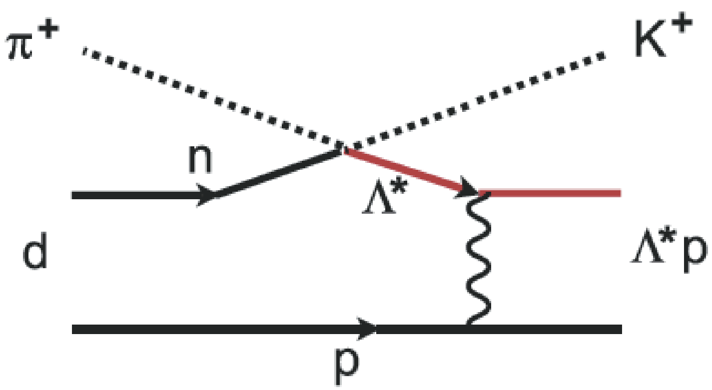
J-PARC E27 Experiment

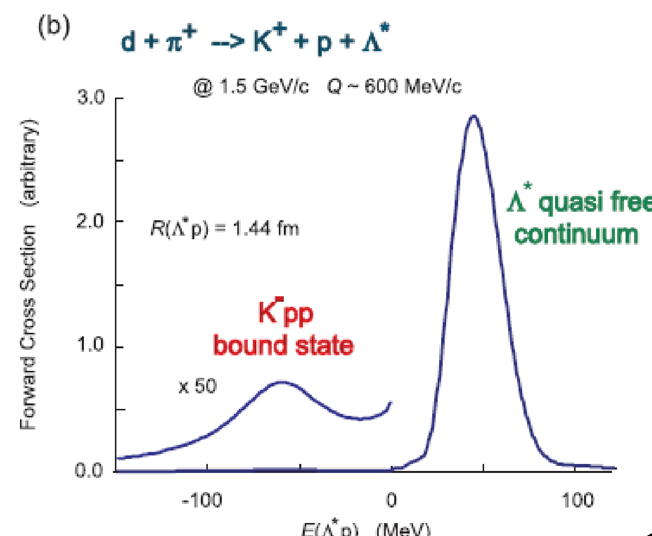
- d(π^+, K^+) reaction @ 1.69 GeV/c
  - **"K^-pp"** is expected to be produced as a **Λ(1405) doorway**

π^+ + "n" --> "Λ^*" + K^+

"Λ^*" + "p" --> bound K^-pp *minor* **~1%?**

--> quasi-free Λ^* *dominant*





Yamazaki & Akaishi, Phys. Rev. C 76 (2007) 045201.

E27: Publications

PTEP

Prog. Theor. Exp. Phys. **2014**, 101D03 (8 pages)
DOI: 10.1093/ptep/ptu128

inclusive $d(\pi^+,K^+)X$

Letter

Inclusive spectrum of the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c

Yudai Ichikawa[1,2,*], Tomofumi Nagae[1], Hyoungchan Bhang[3], Stefania Bufalino[4], Hiroyuki Ekawa[1,2], Petr Evtoukhovitch[5], Alessandro Feliciello[4], Hiroyuki Fujioka[1], Shoichi Hasegawa[2], Shuhei Hayakawa[6], Ryotaro Honda[7], Kenji Hosomi[2], Ken'ichi Imai[2], Shigeru Ishimoto[8], Changwoo Joo[3], Shunsuke Kanatsuki[1], Ryuta Kiuchi[8], Takeshi Koike[7], Harphool Kumawat[9], Yuki Matsumoto[7], Koji Miwa[7], Manabu Mor
Naruki[1], Masayuki Niiyama[1], Yuki Nozawa[1], Ryosuke Ota[6], Atsus
Hiroyuki Sako[2], Valentin Samoilov[5], Susumu Sato[2], Kotaro Shirot
Sugimura[2], Shoji Suzuki[8], Toshiyuki Takahashi[8], Tomonori N. Tak
Tamura[7], Toshiyuki Tanaka[6], Kiyoshi Tanida[3], Atsushi O. Tokiyasu
Tsamalaidze[5], Bidyut Roy[9], Mifuyu Ukai[7], Takeshi O. Yamamoto[7]

Performed in 2012

Y. Ichikawa et al., PTEP (2014) 101D03.
Y. Ichikawa et al., PTEP (2015) 021D01.

PTEP

Prog. Theor. Exp. Phys. **2015**, 021D01 (8 pages)
DOI: 10.1093/ptep/ptv002

exclusive $d(\pi^+,K^+)Yp$

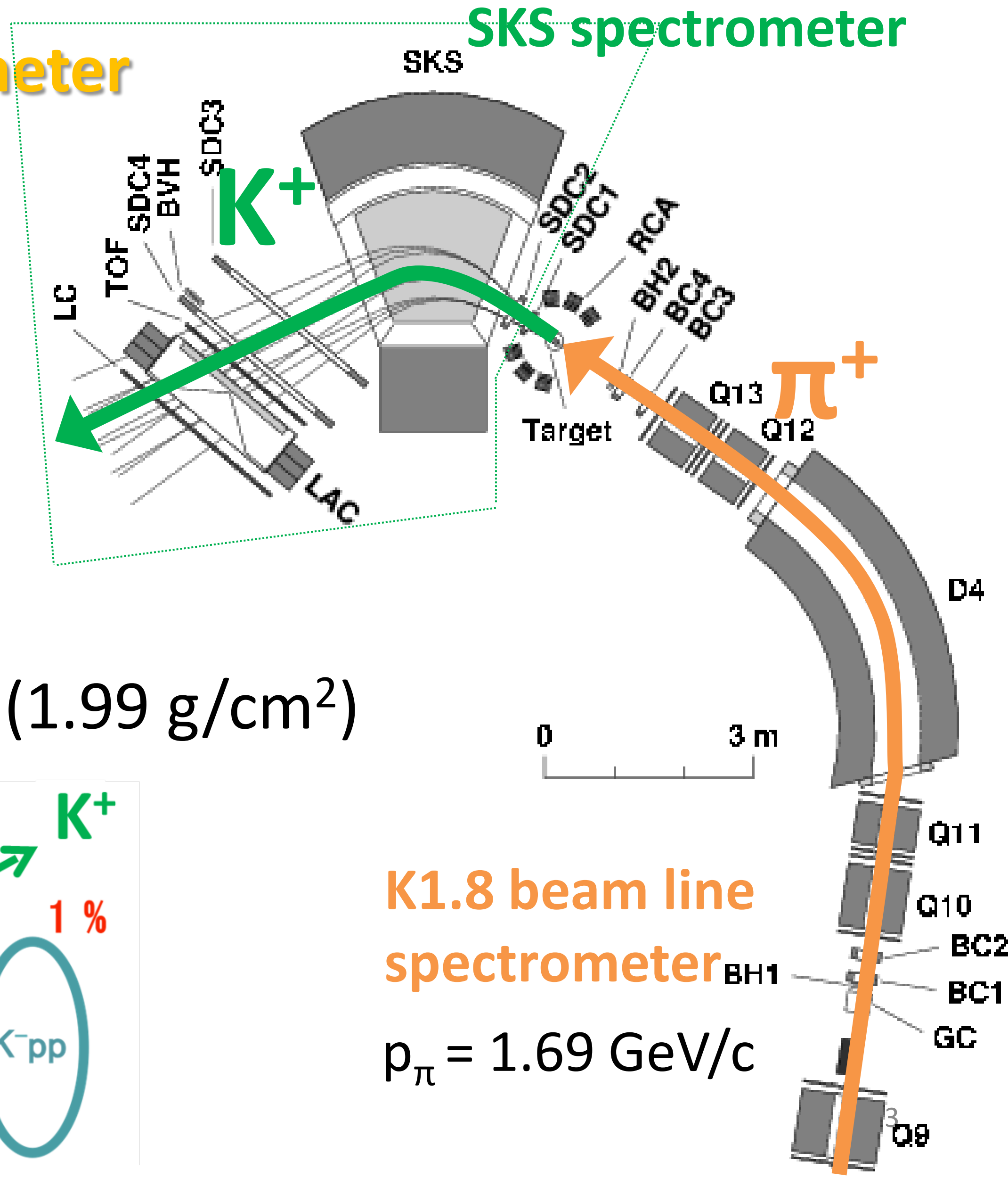
Letter

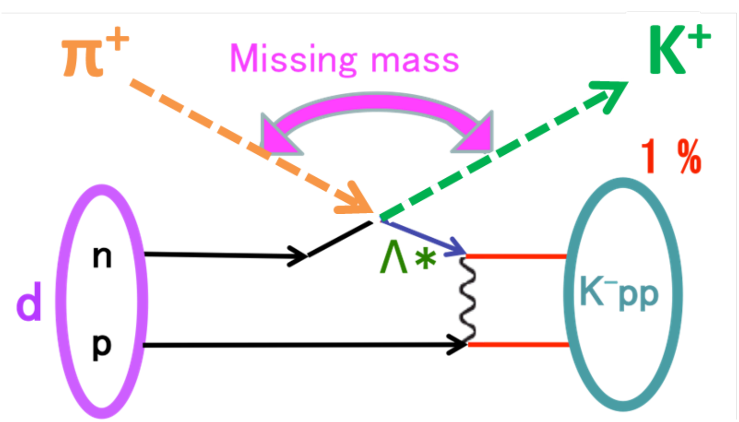
Observation of the "K^-pp"-like structure in the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c

Yudai Ichikawa[1,2], Tomofumi Nagae[1,*], Hiroyuki Fujioka[1], Hyoungchan Bhang[3], Stefania Bufalino[4], Hiroyuki Ekawa[1,2], Petr Evtoukhovitch[5], Alessandro Feliciello[4], Shoichi Hasegawa[2], Shuhei Hayakawa[6], Ryotaro Honda[7], Kenji Hosomi[2], Ken'ichi Imai[2], Shigeru Ishimoto[8], Changwoo Joo[3], Shunsuke Kanatsuki[1], Ryuta Kiuchi[2], Takeshi Koike[7], Harphool Kumawat[9], Yuki Matsumoto[7], Koji Miwa[7], Manabu Moritsu[10], Megumi Naruki[1], Masayuki Niiyama[1], Yuki Nozawa[1], Ryosuke Ota[6], Atsushi Sakaguchi[6], Hiroyuki Sako[2], Valentin Samoilov[5], Susumu Sato[2], Kotaro Shirotori[10], Hitoshi Sugimura[2], Shoji Suzuki[8], Toshiyuki Takahashi[8], Tomonori N. Takahashi[10], Hirokazu Tamura[7], Toshiyuki Tanaka[6], Kiyoshi Tanida[3], Atsushi O. Tokiyasu[10], Zviadi Tsamalaidze[5], Bidyut Roy[9], Mifuyu Ukai[7], Takeshi O. Yamamoto[7], and Seongbae Yang[3]

E27: Experimental Setup

- K1.8 beam line spectrometer
  - 1.69 GeV/c π^+
  - $\Delta p/p \sim 2\times10^{-3}$
- SKS spectrometer
  - 0.8-1.3 GeV/c K^+
  - $\Delta p/p \sim 2\times10^{-3}$
  - $\Delta\Omega \sim 100$ msr
- Target : liquid deuterium (1.99 g/cm^2)



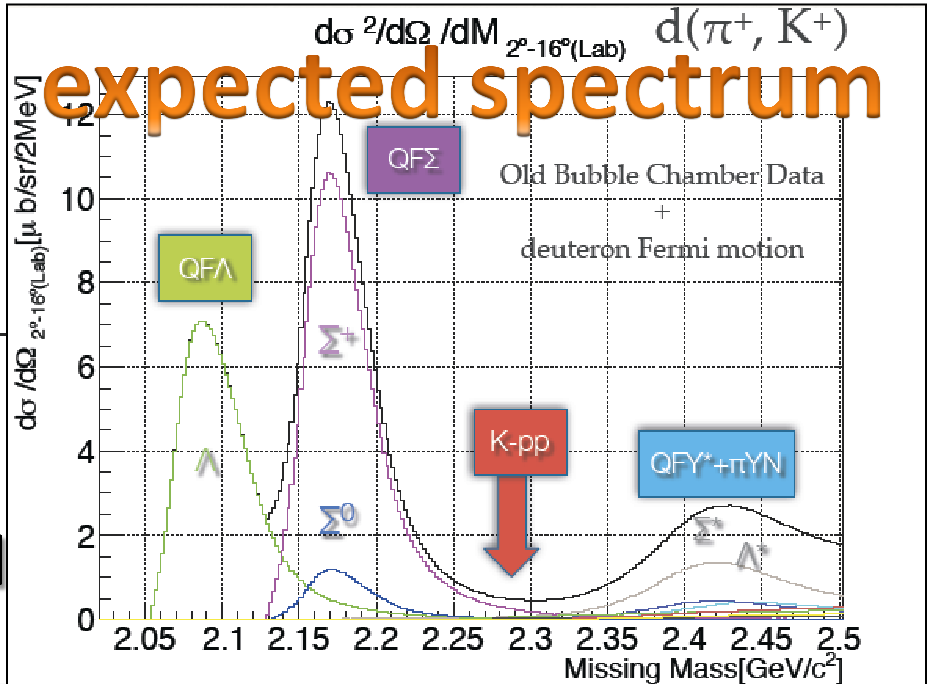


Y.Ichikawa

E27: Inclusive d(π^+,K^+)X

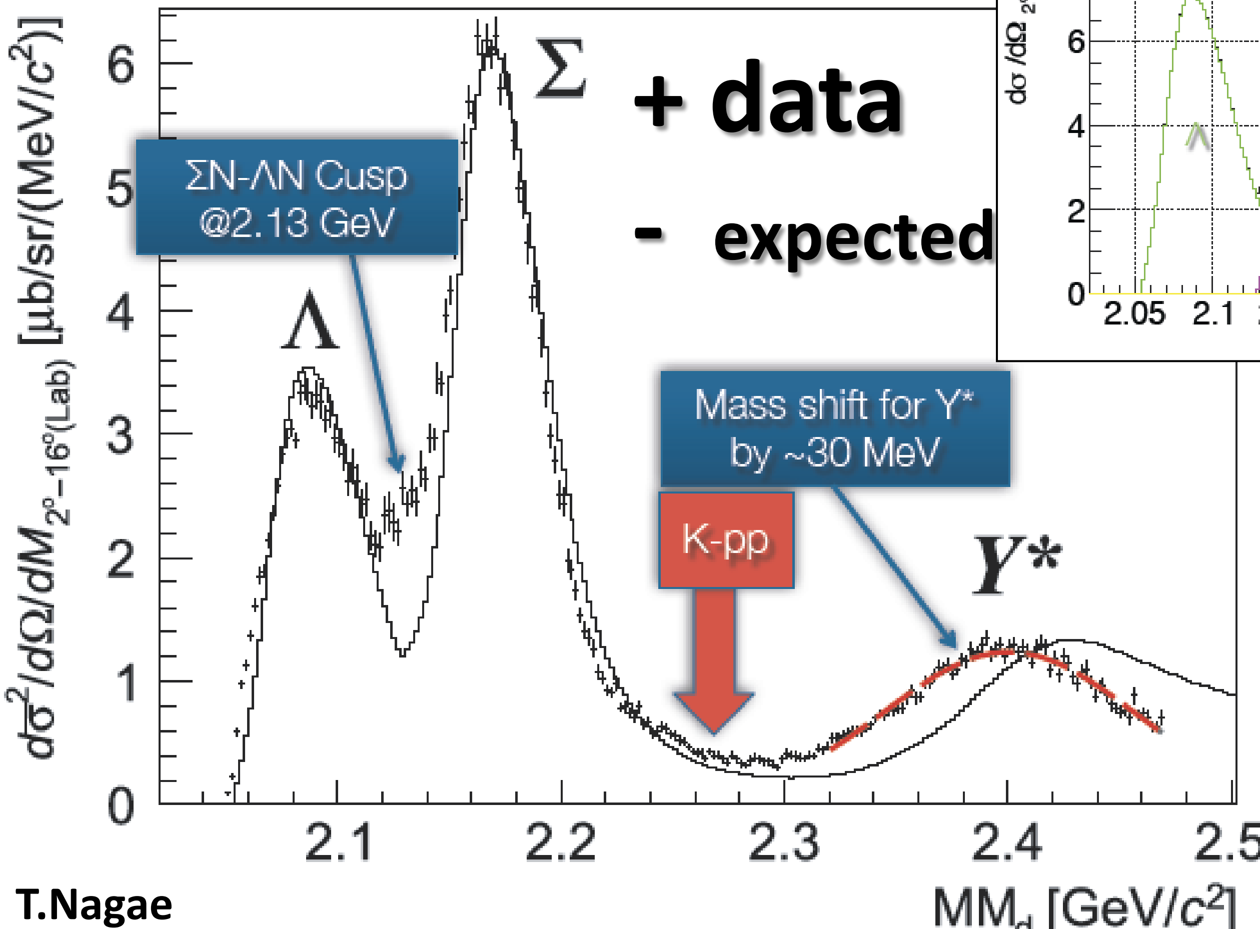
Y. Ichikawa et al., PTEP (2014) 101D03.

"K^-pp" signal is hidden by QF!?



+ data

- expected



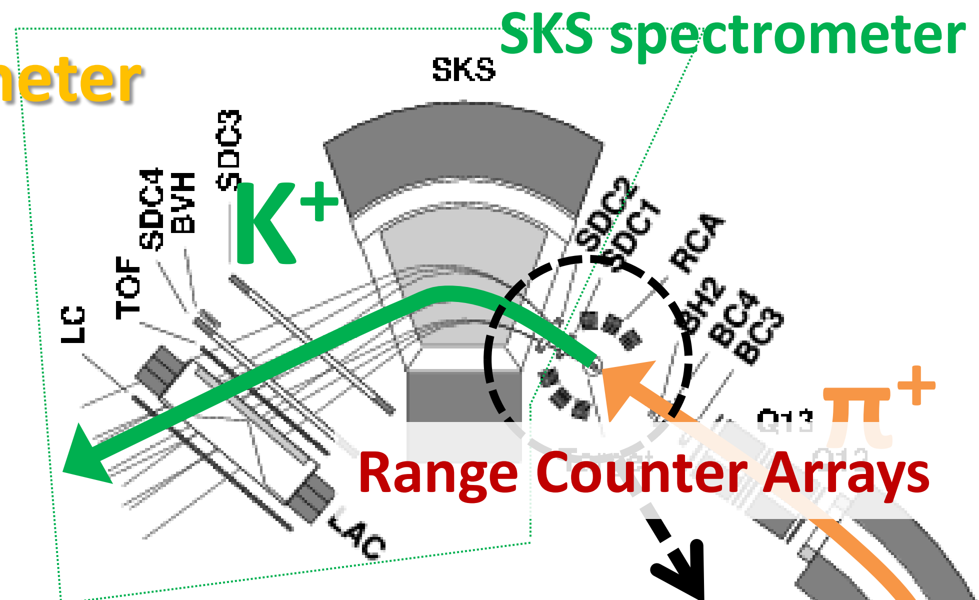
- ΣN-ΛN cusp
- Y* mass shift?

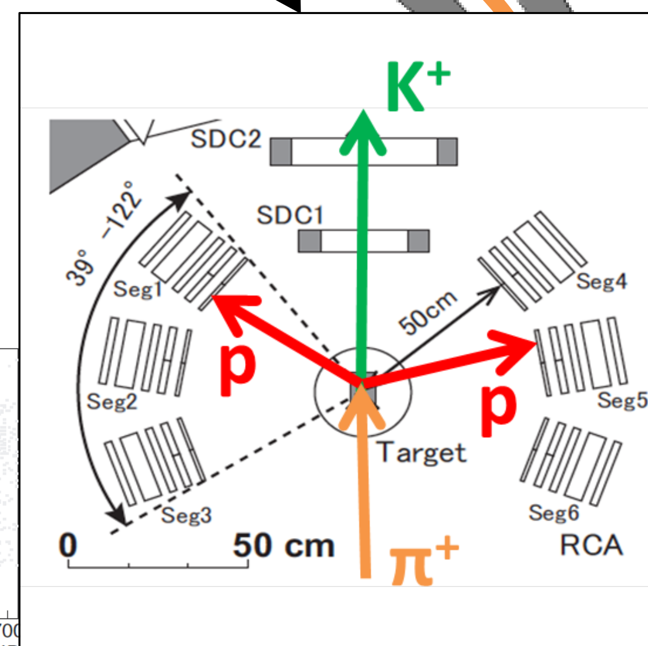
Ichikawa, Tue. A-1
Tokiyasu, Fri. E-1

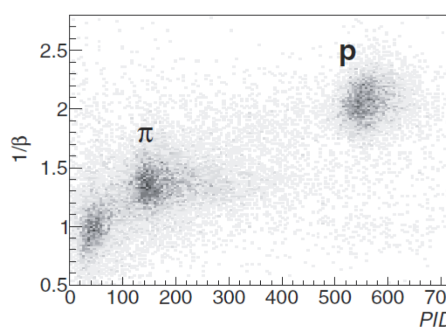
T.Nagae

E27: Experimental Setup

- **K1.8 beam line spectrometer**
  - 1.69 GeV/c π^+
  - $\Delta p/p \sim 2\times10^{-3}$
- **SKS spectrometer**
  - 0.8-1.3 GeV/c K^+
  - $\Delta p/p \sim 2\times10^{-3}$
  - $\Delta\Omega \sim 100$ msr
- Target : liquid deuterium (1.99 g/cm^2)
- **Range Counter Arrays (RCA)**
  - 5 layers of Plastic scinti.
  - 39-122 deg. (L+R)
  - 50 cm TOF







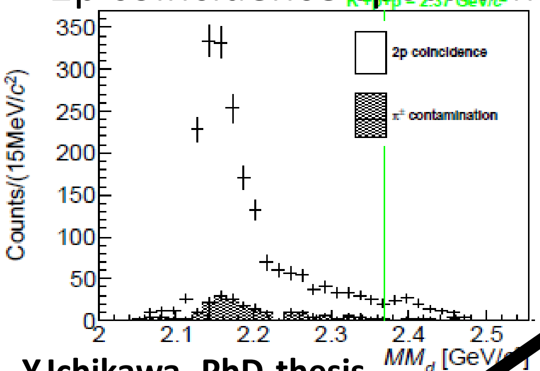
Y.Ichikawa

E27: Two-Proton Coincidence

Y. Ichikawa et al., PTEP (2015) 021D01.

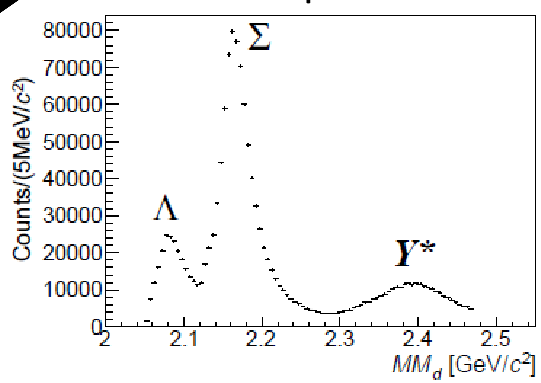
- p_p > 250 MeV/c
  - QFs are suppressed
- ΣN-ΛN cusp is clearly seen @ 2.13 GeV/c^2
- **Broad enhancement is observed @ 2.28 GeV/c^2**

< 2p coincidence spectrum >

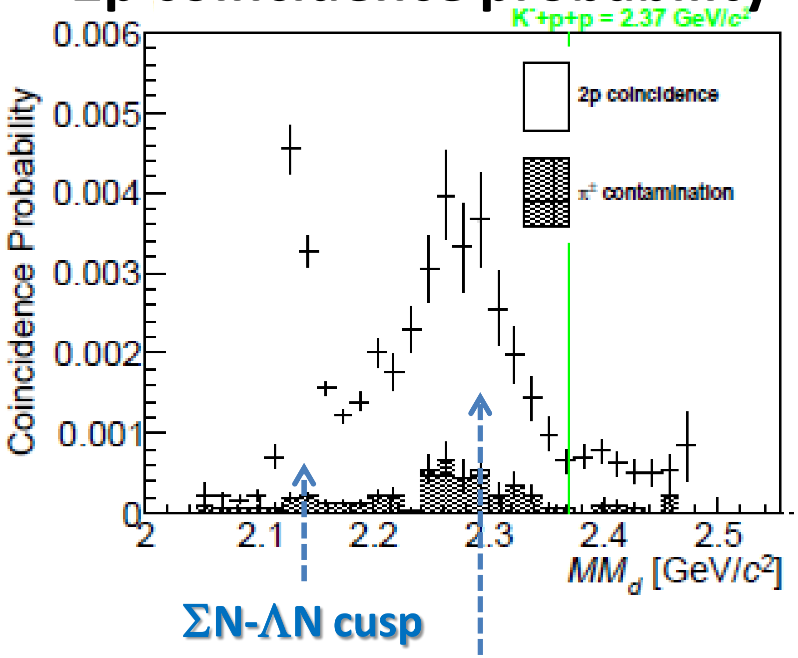


Y.Ichikawa, PhD-thesis. Kyoto-U (2015)

< Inclusive spectrum >



< 2p coincidence probability >

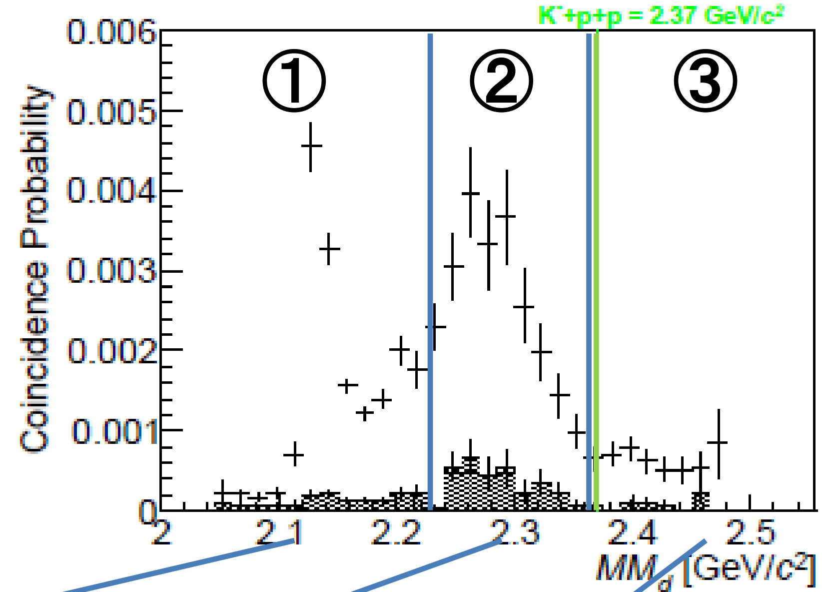


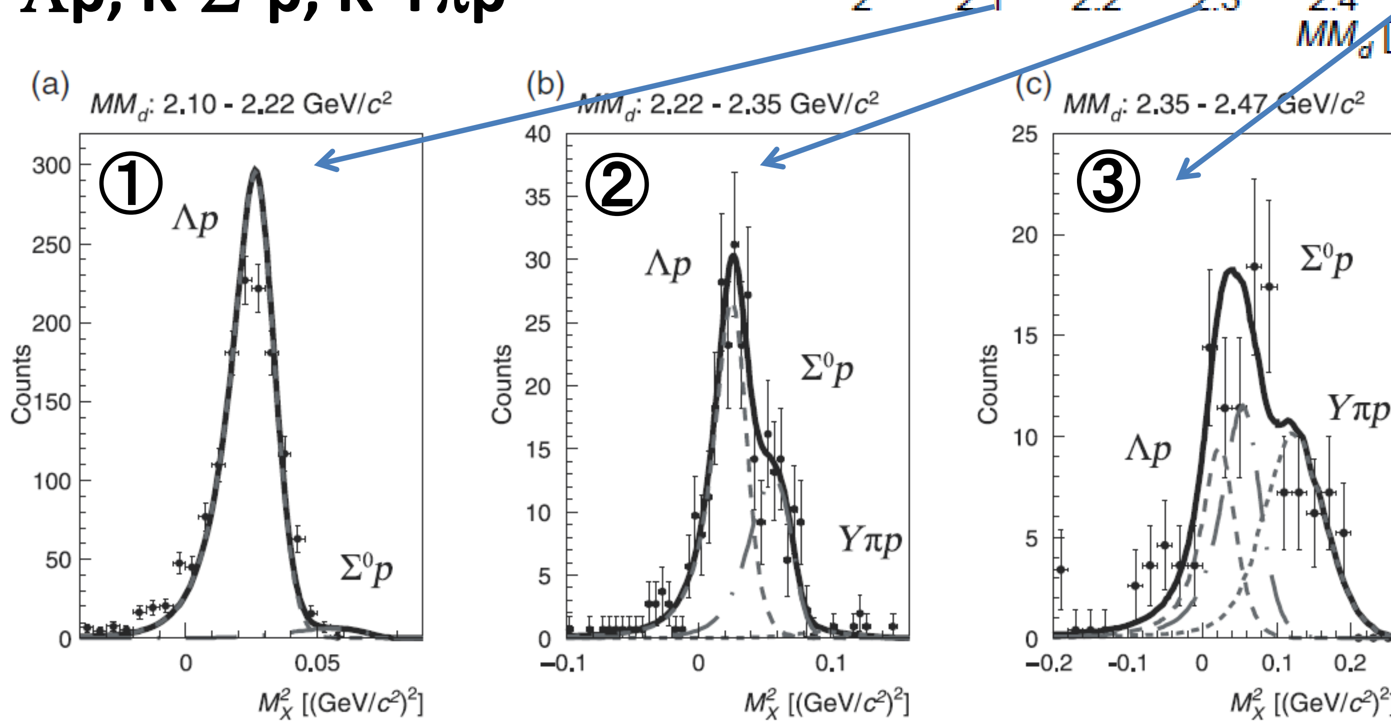
Y.Ichikawa

E27: Decay Mode Separation

Y. Ichikawa et al., PTEP (2015) 021D01.

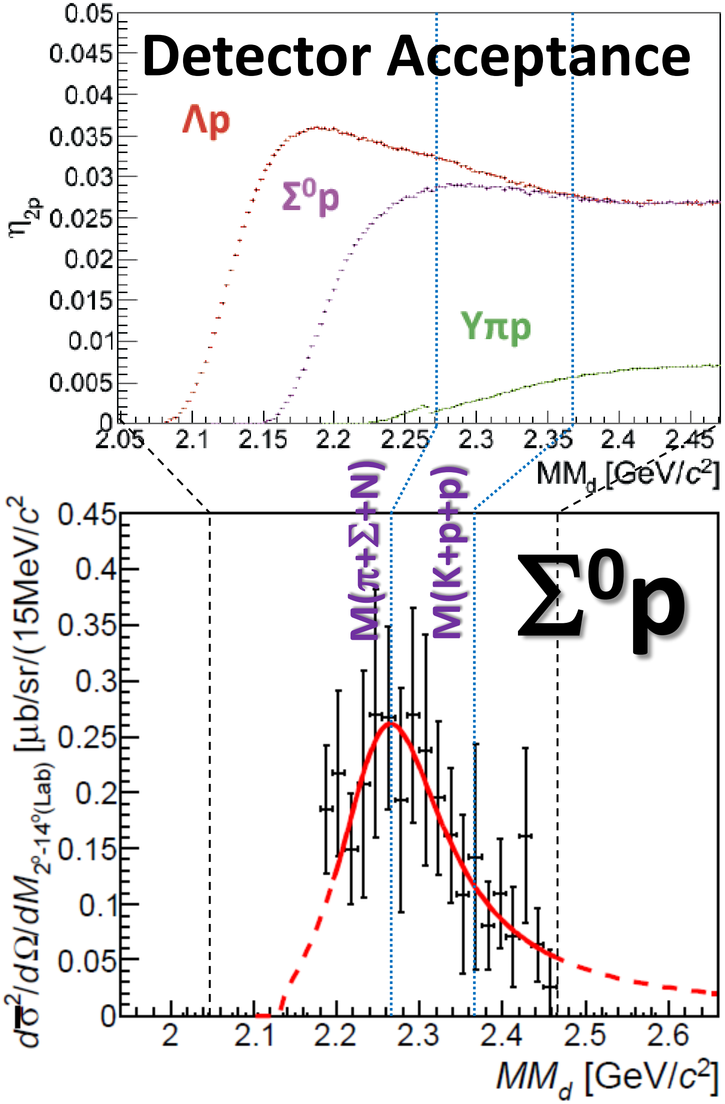
- Decay mode can be separated with **MM[d(π^+,K$^+$pp)X]**
  - two-protons in final state: **K$^+\Lambda$p, K$^+\Sigma^0$p, K$^+$Yπp**





E27: "K$^-$pp"-like Structure

Y. Ichikawa et al., PTEP (2015) 021D01.



- "K$^-$pp"-like structure in **Σ^0p** decay mode:
  - Mass

    Relativistic Breit-Wigner

    $$2275\ ^{+17}_{-18}\ (\text{stat.})\ ^{+21}_{-30}\ (\text{syst.})\ \text{MeV}/c^2$$
  - Binding energy

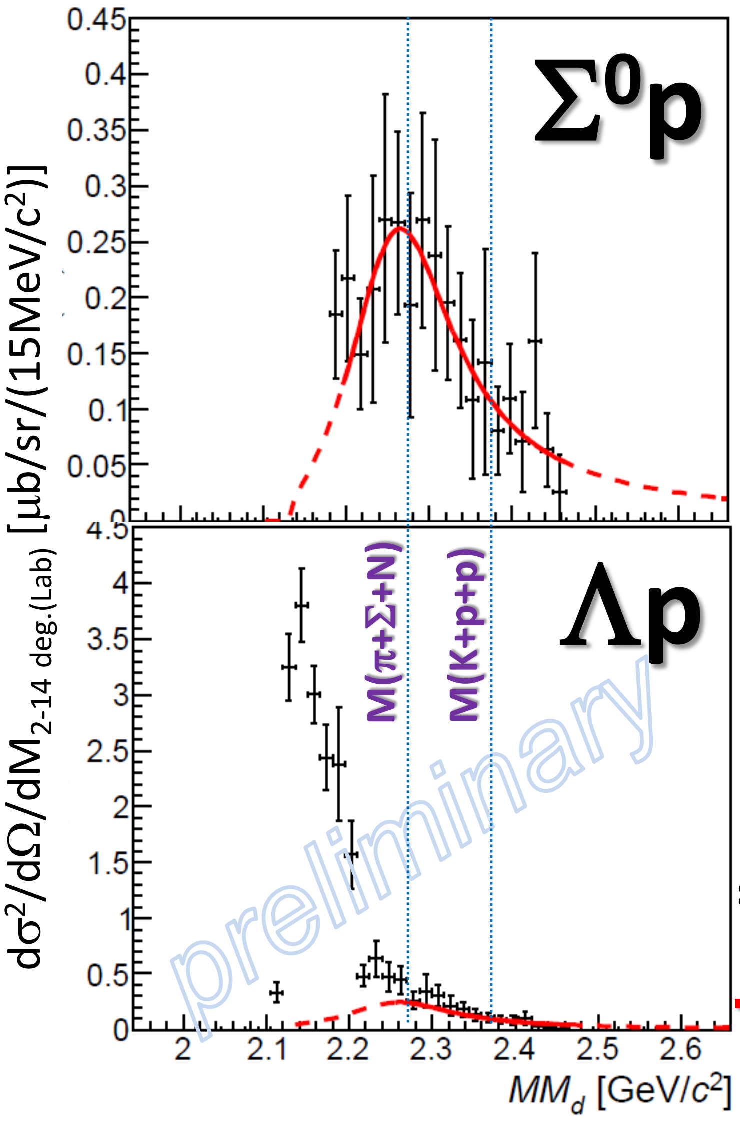
    $$95\ ^{+18}_{-17}\ (\text{stat.})\ ^{+30}_{-21}\ (\text{syst.})\ \text{MeV}$$
  - Width

    $$162\ ^{+87}_{-45}\ (\text{stat.})\ ^{+66}_{-78}\ (\text{syst.})\ \text{MeV}$$

T.Nagae

E27: "K$^-$pp"-like Structure

Y. Ichikawa et al., PTEP (2015) 021D01.



- Decay branch:

$$\Gamma_{\Lambda p}/\Gamma_{\Sigma^0 p} = 0.92\ ^{+0.16}_{-0.14}\ (\mathrm{stat.})\ ^{+0.60}_{-0.42}\ (\mathrm{syst.}).$$

Theor. Cal. on Y*N→YN : $\Gamma_{\Lambda p}/\Gamma_{\Sigma 0p}$ = 1.2

Sekihara, Jido, Kanda-En'yo PRC79(2009)062201(R).

- $d\sigma/d\Omega_{\text{"K-pp"}\to\Sigma 0p}$:

$$3.0 \pm 0.3\ (\mathrm{stat.})\ ^{+0.7}_{-1.1}\ (\mathrm{syst.})\ \mu b/sr$$

Y.Ichikawa, PhD-thesis. Kyoto-U (2015)

p(π$^-$,K^0)Λ(1405) @ 1.69GeV/c:
$d\sigma/d\Omega_{\Lambda(1405)}$=36.9μb/sr
BNL, NPB56(1973)15

= $(d\sigma/d\Omega_{\text{"K-pp"}\to Yp})$ / $(d\sigma/d\Omega_{\Lambda(1405)})$ ~ 7-8%

→ large prob. of Λ(1405)p→"K$^-$pp"

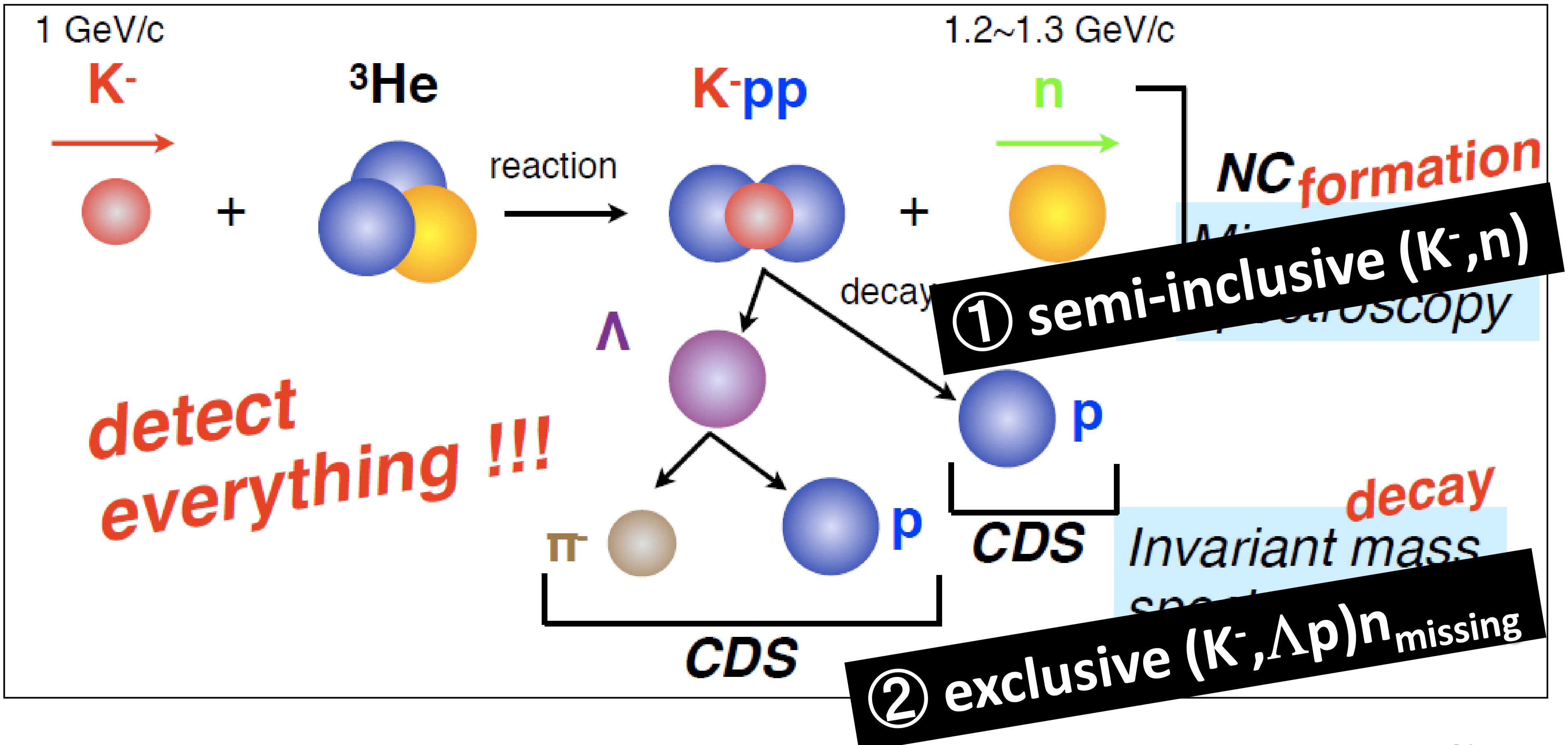
c.f., large prob. in DISTO, but < 50% in HADES

T.Nagae

J-PARC E15 Experiment
--- $K^{bar}NN$ via $^3He(K^-,n)$ ---

J-PARC E15 Experiment

- ^{3}He(*in-flight* K^{-},n) reaction @ 1.0 GeV/c
  - 2NA processes and Y decays can be discriminated kinematically



E15: Publications

Prog. Theor. Exp. Phys. **2015**, 061D01 (11 pages)
DOI: 10.1093/ptep/ptv076

inclusive ^{3}He(K^{-},n)X

Letter

Search for the deeply bound K^-pp state from the semi-inclusive forward-neutron spectrum in the in-flight K^- reaction on helium-3

J-PARC E15 Collaboration
T. Hashimoto[1,*,†], S. Ajimura[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], L. Busso[6,7]
M. Cargnelli[8], S. Choi[4], C. Curceanu[9], S. Enomoto[2], D. Faso[6,7], H.
Y. Fujiwara[1], T. Fukuda[11], C. Guaraldo[9], R. S. Hayano[1], T. Hiraiwa[2]
M. Iliescu[9], K. Inoue[13], Y. Ishiguro[10], T. Ishikawa[1], S. Ishimoto[12], K
M. Iwai[12], M. Iwasaki[14,15], Y. Kato[14], S. Kawasaki[13], P. Kienle[16,‡],
J. Marton[8], Y. Matsuda[17], Y. Mizoi[11], O. Morra[6], T. Nagae[10], H. No
H. Ohnishi[14,2], S. Okada[14], H. Outa[14], K. Piscicchia[9], M. Poli Lener
A. Romero Vidal[9], Y. Sada[10], A. Sakaguchi[13], F. Sakuma[14], M. Sato
M. Sekimoto[12], H. Shi[9], D. Sirghi[9,5], F. Sirghi[9,5], S. Suzuki[12], T. Su
H. Tatsuno[1], M. Tokuda[15], D. Tomono[10], A. Toyoda[12], K. Tsukada[18]
O. Vazquez Doce[9,19], E. Widmann[8], T. Yamaga[13], T. Yamazaki[1,14],
Q. Zhang[14], J. Zmeskal[8]

E15^{1st} experiment: Only 4days data-taking in 2013

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

exclusive ^{3}He(K^{-},Λp)n

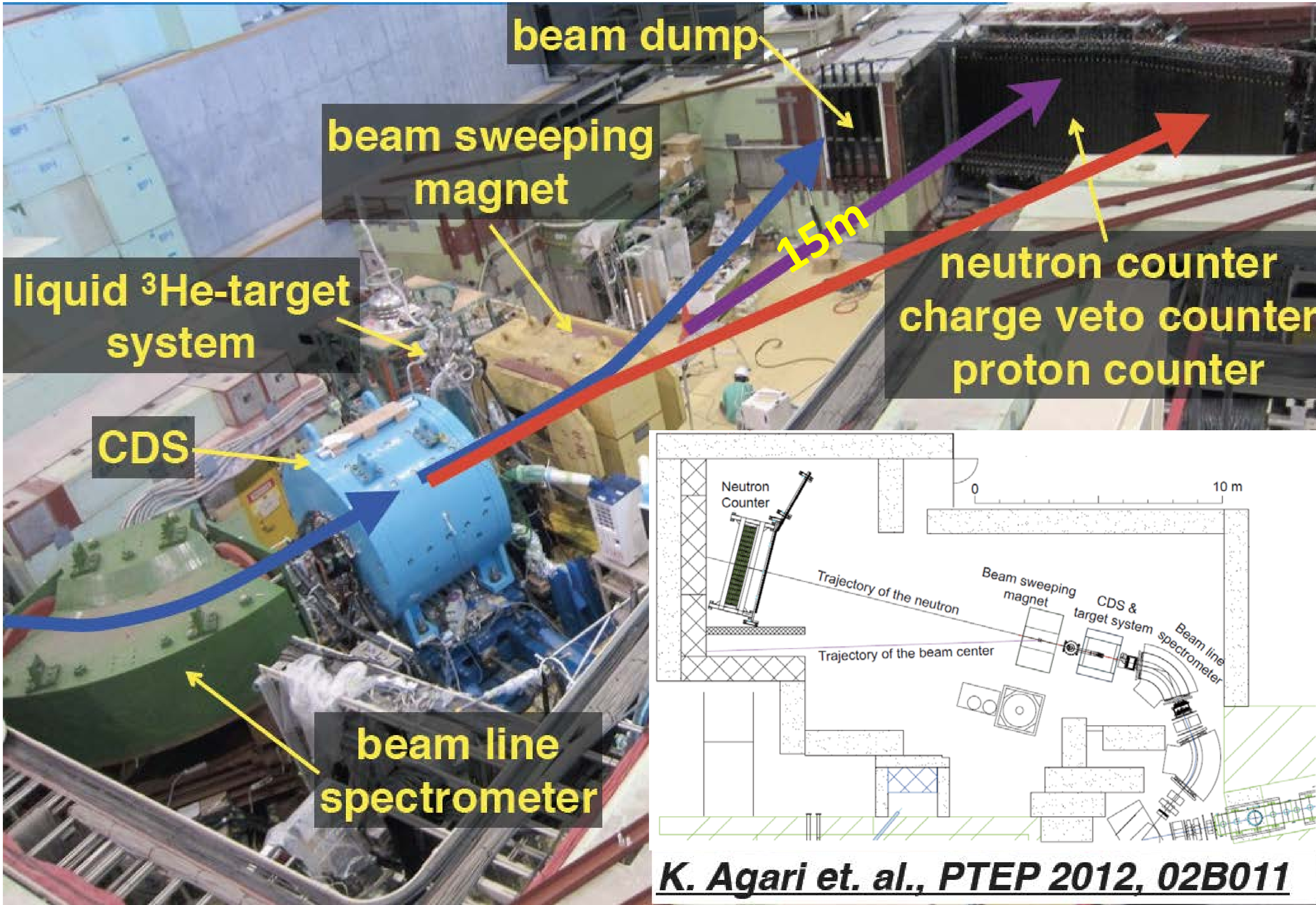
Letter

Structure near the $K^- + p + p$ threshold in the in-flight $^{3}\mathrm{He}(K^-, \Lambda p)n$ reaction

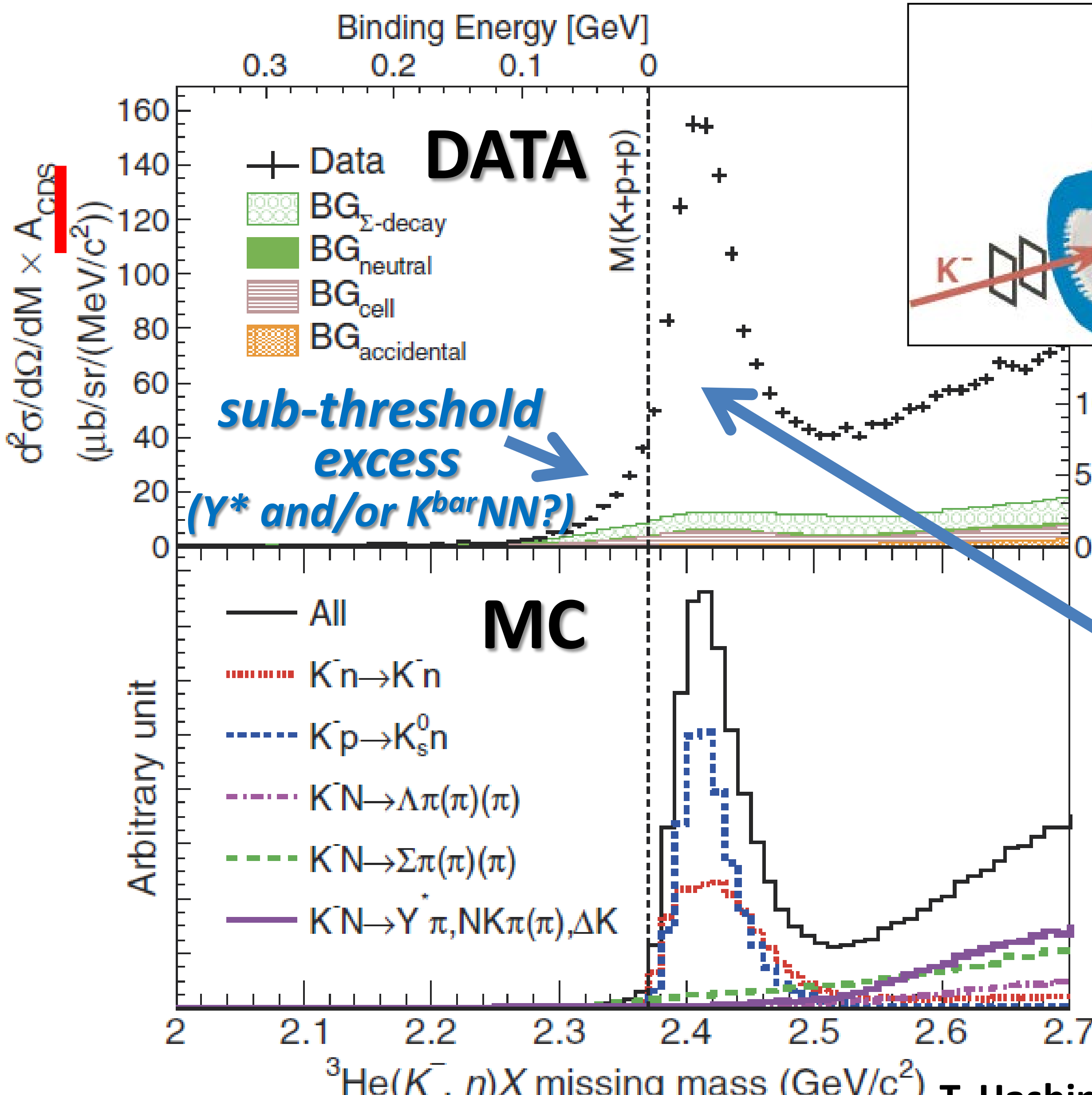
J-PARC E15 Collaboration
Y. Sada[1,*], S. Ajimura[1], M. Bazzi[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], P. Buehler[6], L. Busso[7,9], M. Cargnelli[6], S. Choi[4], C. Curceanu[2], S. Enomoto[8], D. Faso[7,9], H. Fujioka[10], Y. Fujiwara[11], T. Fukuda[12], C. Guaraldo[2], T. Hashimoto[13], R. S. Hayano[11], T. Hiraiwa[1], M. Iio[8], M. Iliescu[2], K. Inoue[1], Y. Ishiguro[10], T. Ishikawa[11], S. Ishimoto[8], T. Ishiwatari[6], K. Itahashi[13], M. Iwai[8], M. Iwasaki[13,14], Y. Kato[13], S. Kawasaki[15], P. Kienle[†,16], H. Kou[14], Y. Ma[13], J. Marton[6], Y. Matsuda[17], Y. Mizoi[12], O. Morra[7], T. Nagae[10], H. Noumi[1], H. Ohnishi[13,1], S. Okada[13], H. Outa[13], K. Piscicchia[2], A. Romero Vidal[2], A. Sakaguchi[15], F. Sakuma[13], M. Sato[13], A. Scordo[2], M. Sekimoto[8], H. Shi[2], D. Sirghi[2,5], F. Sirghi[2,5], K. Suzuki[6], S. Suzuki[8], T. Suzuki[11], K. Tanida[18], H. Tatsuno[19], M. Tokuda[14], D. Tomono[1], A. Toyoda[8], K. Tsukada[20], O. Vazquez Doce[2,21], E. Widmann[6], B. K. Wuenschek[6], T. Yamaga[15], T. Yamazaki[11,13], H. Yim[22], Q. Zhang[13], and J. Zmeskal[6]

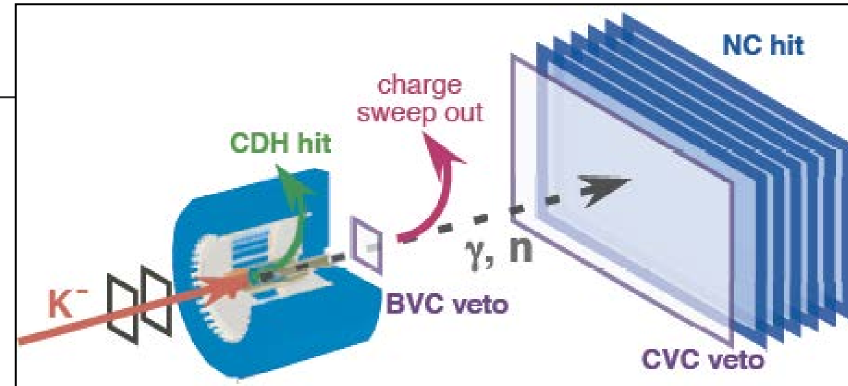
T. Hashimoto et al., PTEP (2015) 061D01.
Y. Sada et al., PTEP (2016) 051D01.

Experimental Setup



Semi-Inclusive $^{3}He(K^{-},n)X$





Quasi Elastic

$K^{-} + {}^{3}He \rightarrow K^{-} + \mathbf{n} + p_{s} + p_{s}$

$d\sigma/d\Omega_{\theta=0deg}$ ~ 6mb/sr

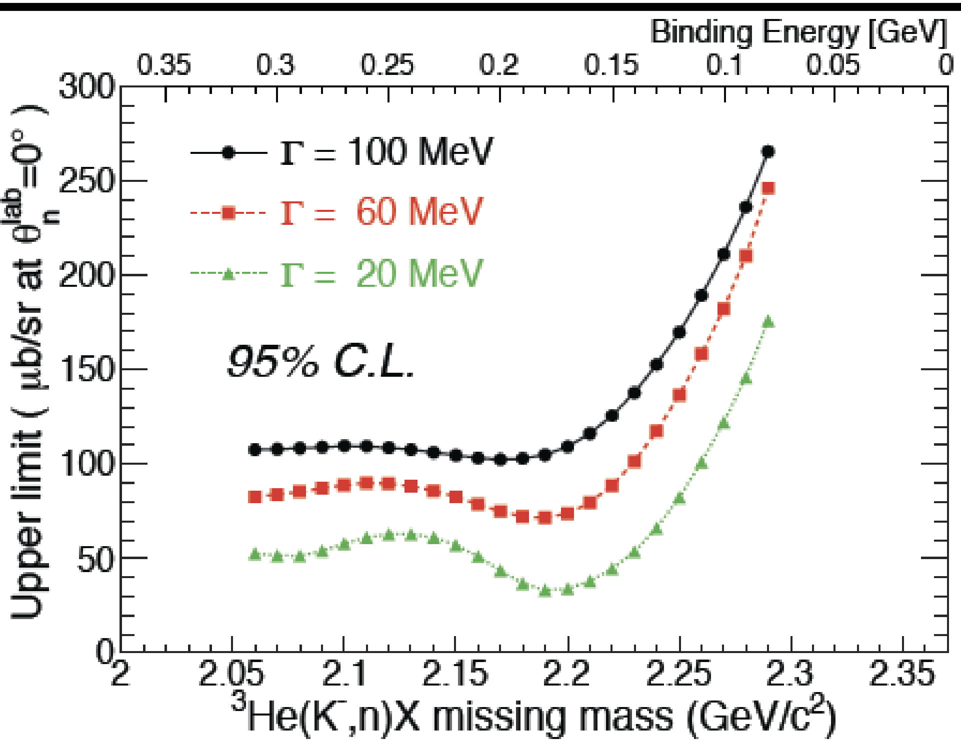
Charge-Exchange

$K^{-} + {}^{3}He \rightarrow K^{0} + \mathbf{n} + d_{s}$

$d\sigma/d\Omega_{\theta=0deg}$ ~ 11mb/sr

T. Hashimoto et al., PTEP (2015) 061D01.

Semi-Inclusive $^3He(K^-,n)X$



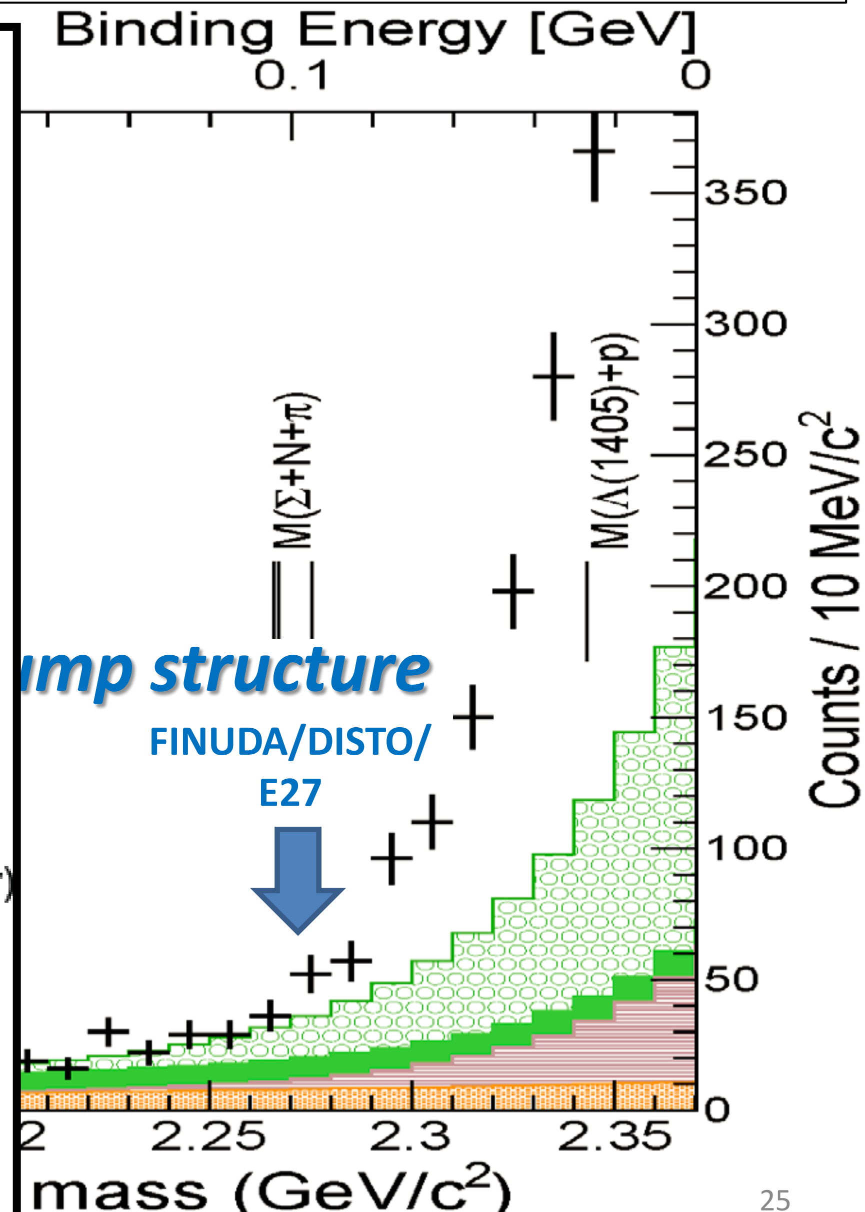
Assumptions

Intrinsic peak shape: Breit-Wigner

Decay mode: **$K^-pp \rightarrow \Lambda p$ 100%** (isotropic decay)

- **J-PARC E15 (U.L.)**
  30 ~ 300 μb/sr @ 0 deg.
  0.5 - 5% of quasi-elastic

smaller than usual hypernucleus sticking



T. Hashimoto et al., PTEP (2015) 061D01.

Exclusive $^3He(K^-,\Lambda p)n$

Y.Sada et al., PTEP (2016) 051D01.

PTEP

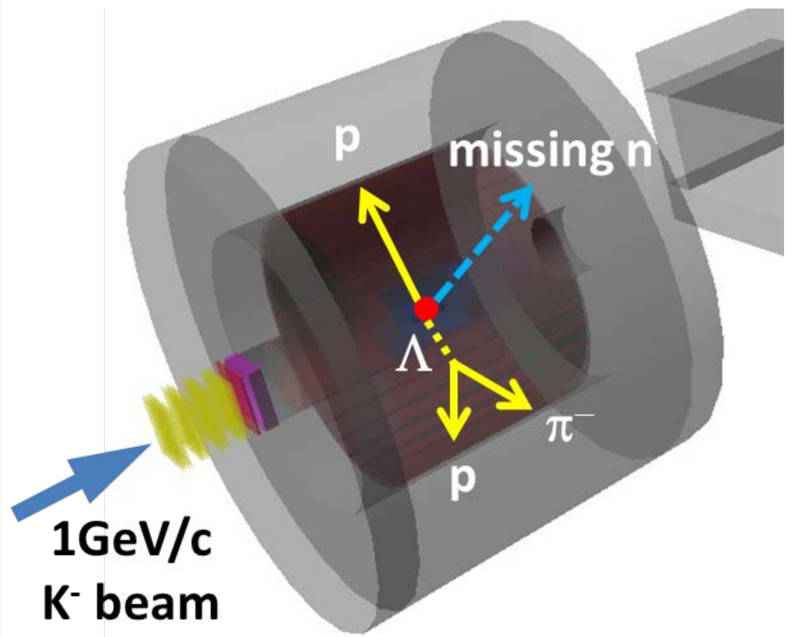
Prog. Theor. Exp. Phys. **2016**, 051D01 (11 pages)
DOI: 10.1093/ptep/ptw040

Letter

Structure near the $K^- + p + p$ threshold in the in-flight $^3\mathrm{He}(K^-, \Lambda p)n$ reaction

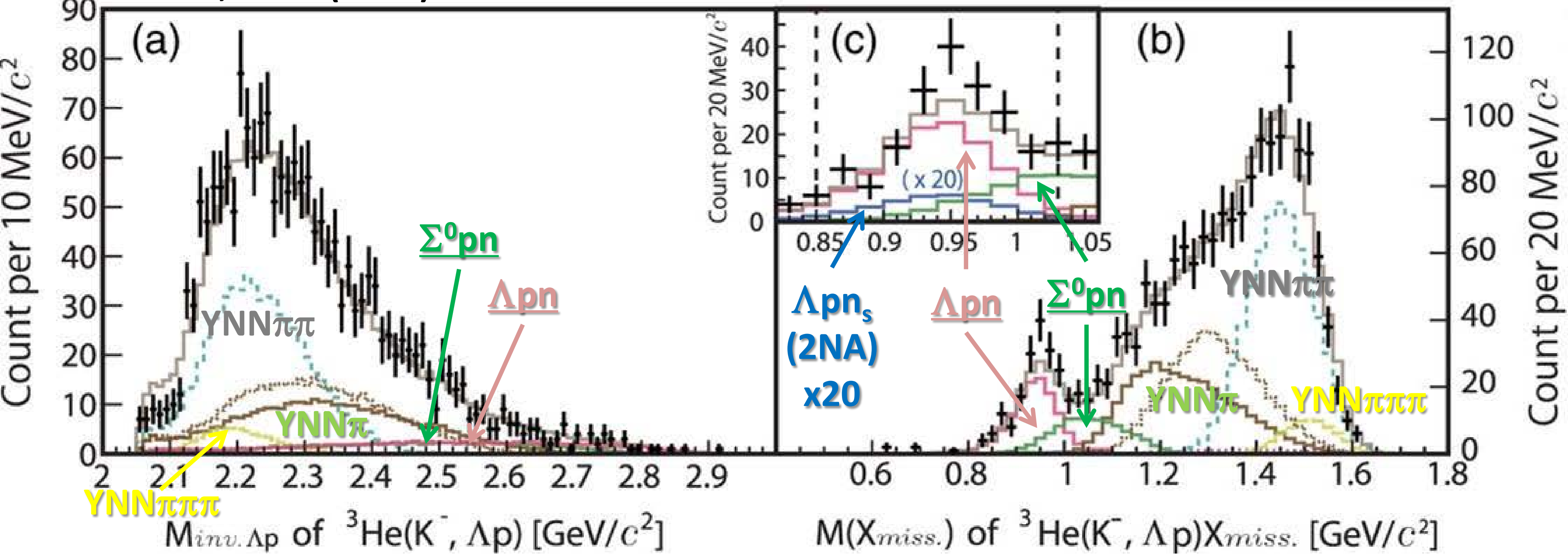
J-PARC E15 Collaboration

Y. Sada[1,*], S. Ajimura[1], M. Bazzi[2], G. Beer[3], H. Bhang[4], M. Bragadireanu[5], P. Buehler[6], L. Busso[7,9], M. Cargnelli[6], S. Choi[4], C. Curceanu[2], S. Enomoto[8], D. Faso[7,9], H. Fujioka[10], Y. Fujiwara[11], T. Fukuda[12], C. Guaraldo[2], T. Hashimoto[13], R. S. Hayano[11], T. Hiraiwa[1], M. Iio[8], M. Iliescu[2], K. Inoue[1], Y. Ishiguro[10], T. Ishikawa[11], S. Ishimoto[8], T. Ishiwatari[6], K. Itahashi[13], M. Iwai[8], M. Iwasaki[13,14], Y. Kato[13], S. Kawasaki[15], P. Kienle[†,16], H. Kou[14], Y. Ma[13], J. Marton[6], Y. Matsuda[17], Y. Mizoi[12], O. Morra[7], T. Nagae[10], H. Noumi[1], H. Ohnishi[13,1], S. Okada[13], H. Outa[13], K. Piscicchia[2], A. Romero Vidal[2], A. Sakaguchi[15], F. Sakuma[13], M. Sato[13], A. Scordo[2], M. Sekimoto[8], H. Shi[2], D. Sirghi[2,5], F. Sirghi[2,5], K. Suzuki[6], S. Suzuki[8], T. Suzuki[11], K. Tanida[18], H. Tatsuno[19], M. Tokuda[14], D. Tomono[1], A. Toyoda[8], K. Tsukada[20], O. Vazquez Doce[2,21], E. Widmann[6], B. K. Wuenschek[6], T. Yamaga[15], T. Yamazaki[11,13], H. Yim[22], Q. Zhang[13], and J. Zmeskal[6]



Inclusive ^{3}He(K$^-$,Λp)X

Y. Sada et al., PTEP (2016) 051D01.



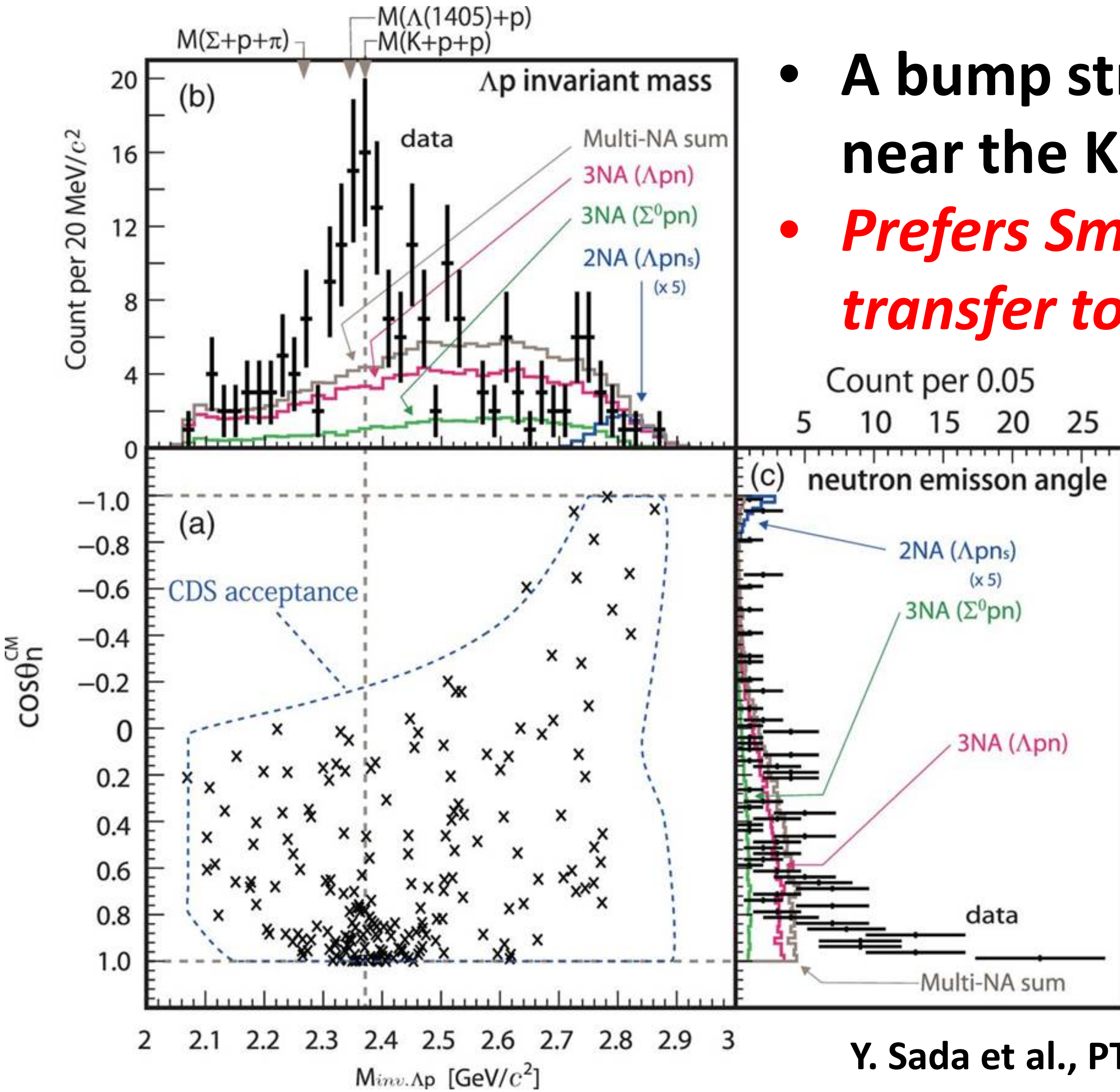
- Global fit both in Λp invariant- and missing-mass
  - σ ~ 10 MeV/c^2
  - w/ simulated spectra

c.f. 3NA(Λpn): $\dfrac{d^2\sigma_{3NA(\Lambda pn)}}{dT_n^{CM} d\cos\theta_n^{CM}} \propto \rho_3(\Lambda pn)$

- **Neutron was identified by kinematics**
  - **^{3}He(K$^-$, Λp)n$_{missing}$**

– ***# of Λpn events: ~200***
– ***Σ^0pn contamination: ~20%***

Exclusive ^{3}He(K$^-$,Λp)n

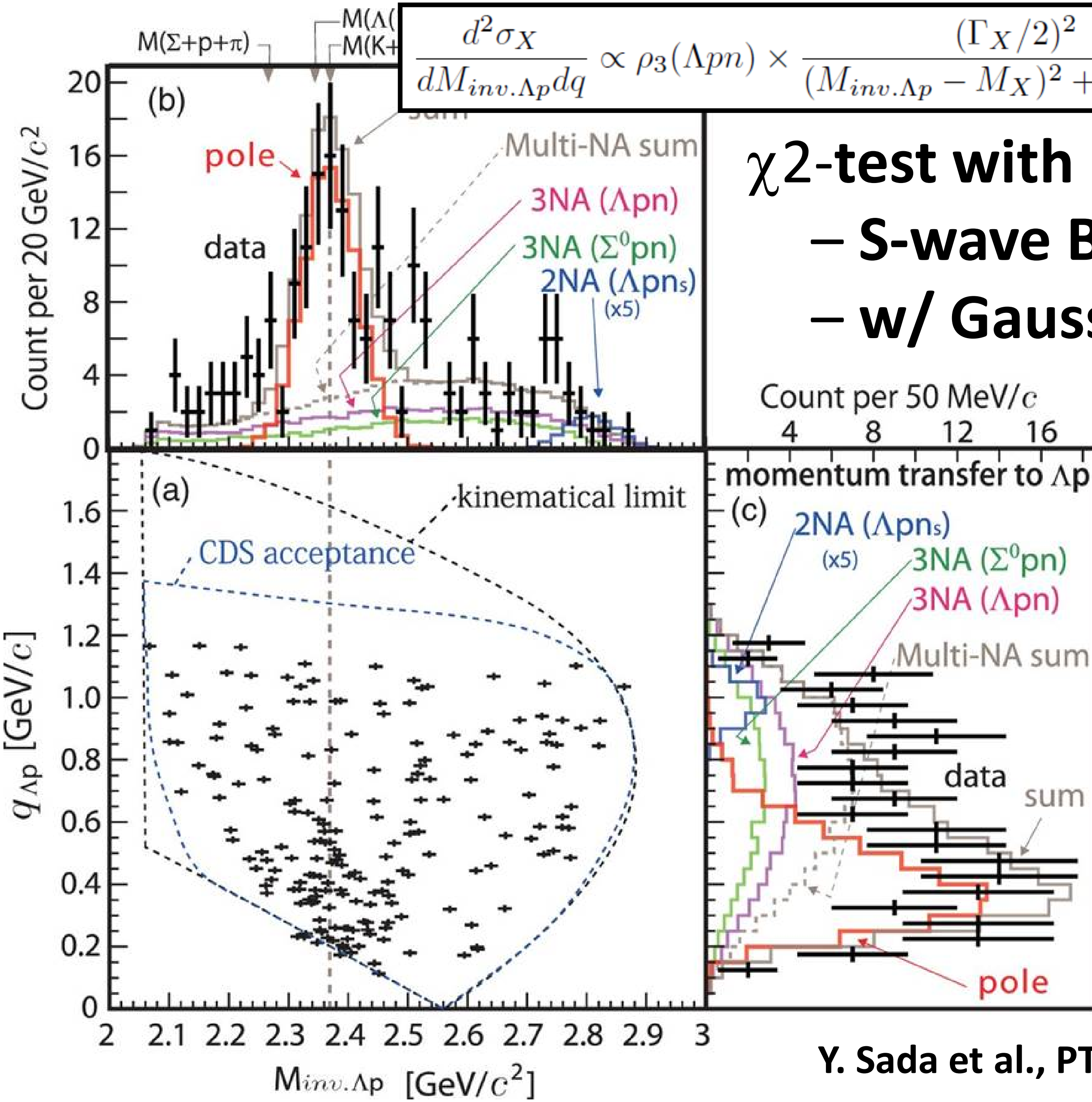


- **A bump structure exists near the K-pp threshold**
- ***Prefers Smaller momentum transfer to Λp** (0.8<cos$\theta^{CM}{}_n$)*
- **S=-1 dibaryon?**
  - **Λ*N?**
  - **K^{bar}NN?**
  - **…**

Y. Sada et al., PTEP (2016) 051D01.

Assuming a Breit-Wigner

$$\frac{d^2\sigma_X}{dM_{inv.\Lambda p}dq} \propto \rho_3(\Lambda pn) \times \frac{(\Gamma_X/2)^2}{(M_{inv.\Lambda p} - M_X)^2 + (\Gamma_X/2)^2} \times |\exp(-q^2/2Q_X^2)|^2,$$



$\chi 2$-**test with pole & 3NA(Ypn)**

- **S-wave Breit-Wigner pole**
- **w/ Gaussian form-factor**

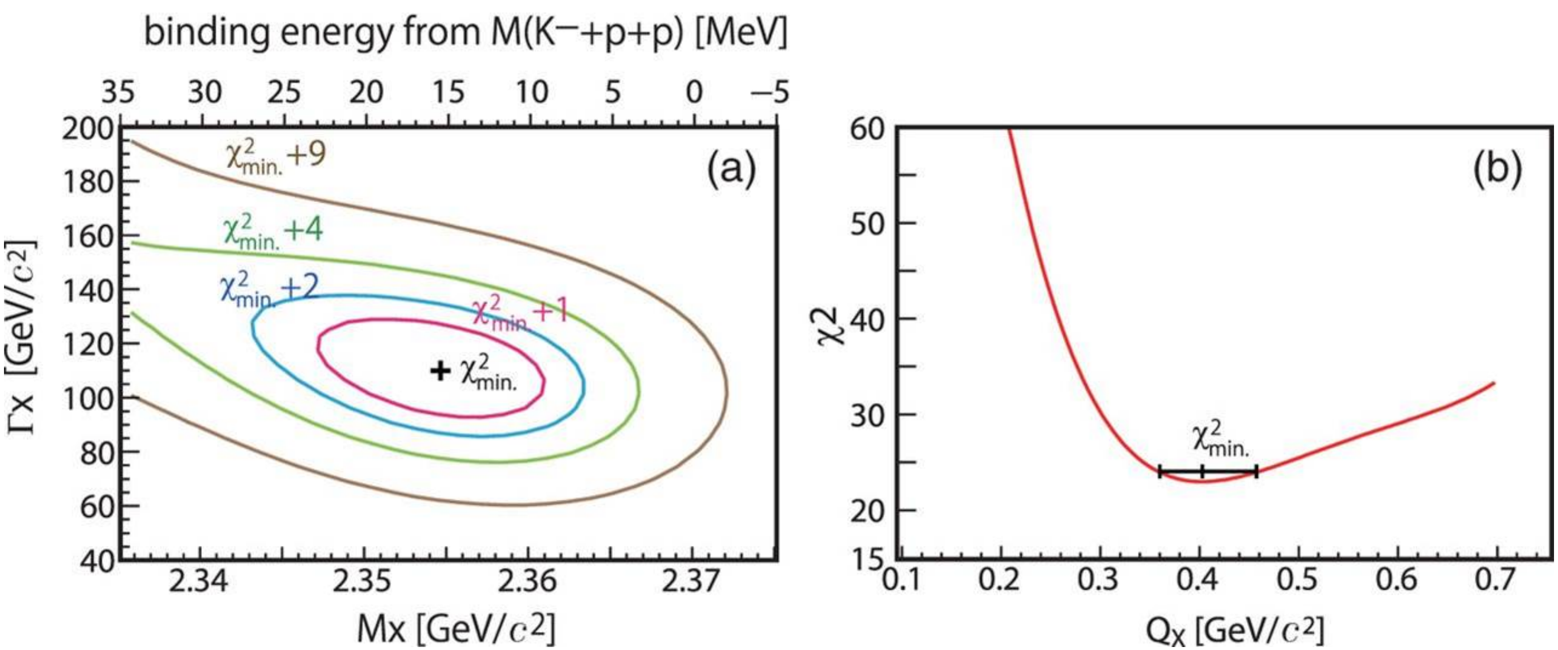
Y. Sada et al., PTEP (2016) 051D01.

Assuming a Breit-Wigner

Y. Sada et al., PTEP (2016) 051D01.

$$\frac{d^2\sigma_X}{dM_{inv.\Lambda p}dq} \propto \rho_3(\Lambda pn) \times \frac{(\Gamma_X/2)^2}{(M_{inv.\Lambda p} - M_X)^2 + (\Gamma_X/2)^2} \times |\exp(-q^2/2Q_X^2)|^2,$$

phase space Breit-Wigner form factor



B.E = 15^{+6}_{-8} (stat.) ± 12(syst.) MeV/c²

Γ = 110^{+19}_{-17}(stat.) ± 27(syst.) MeV/c²

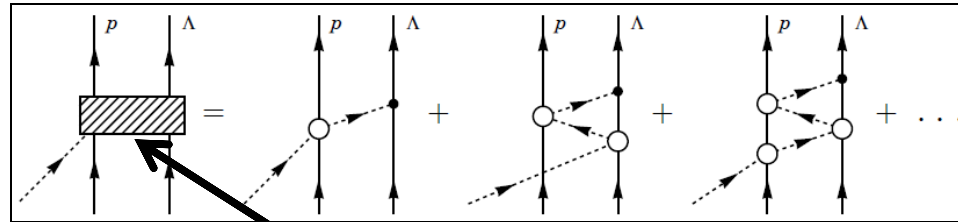
Q = 400^{+60}_{-40} MeV/c

A Theoretical Interpretation

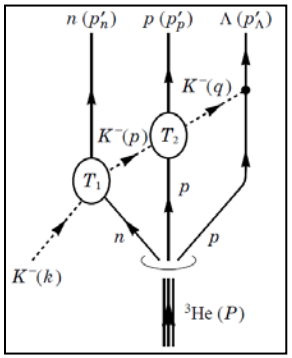
Sekihara, Oset, Ramos, arXiv:1607.02058

Chiral unitary approach

Sekihara, Tue. A-1

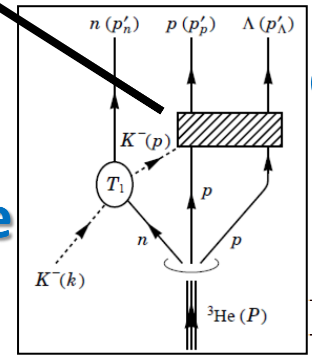


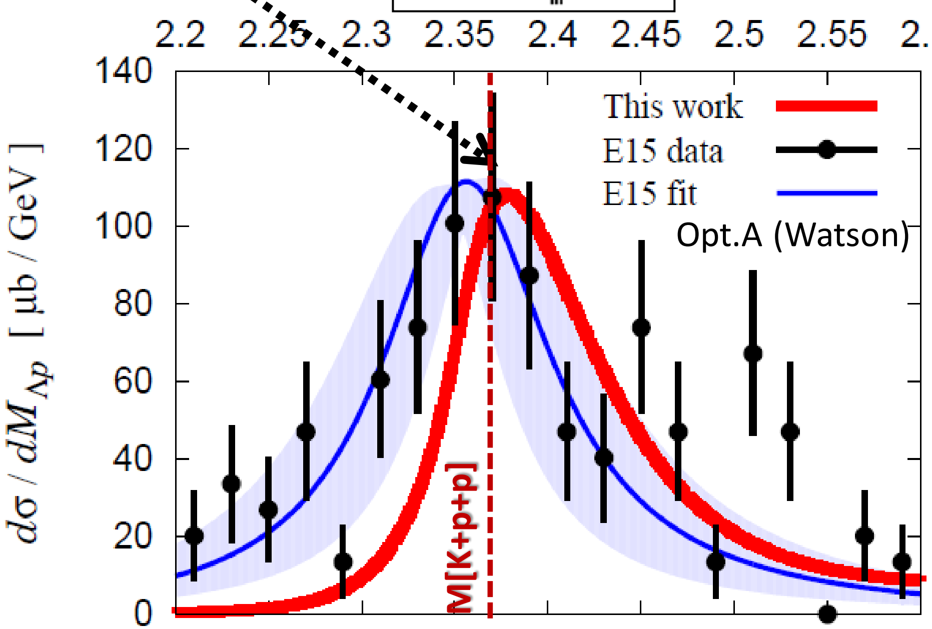
Uncorrelated Λ(1405)p state

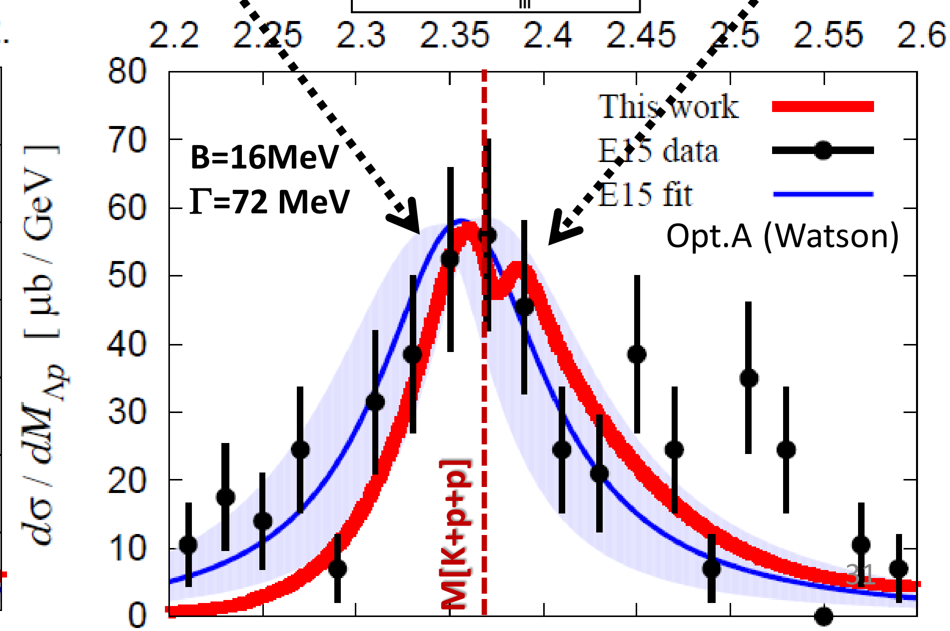


$K^{bar}NN$ bound-state

quasi-elastic kaon scattering







What is the structure observed in E15^{1st} data?

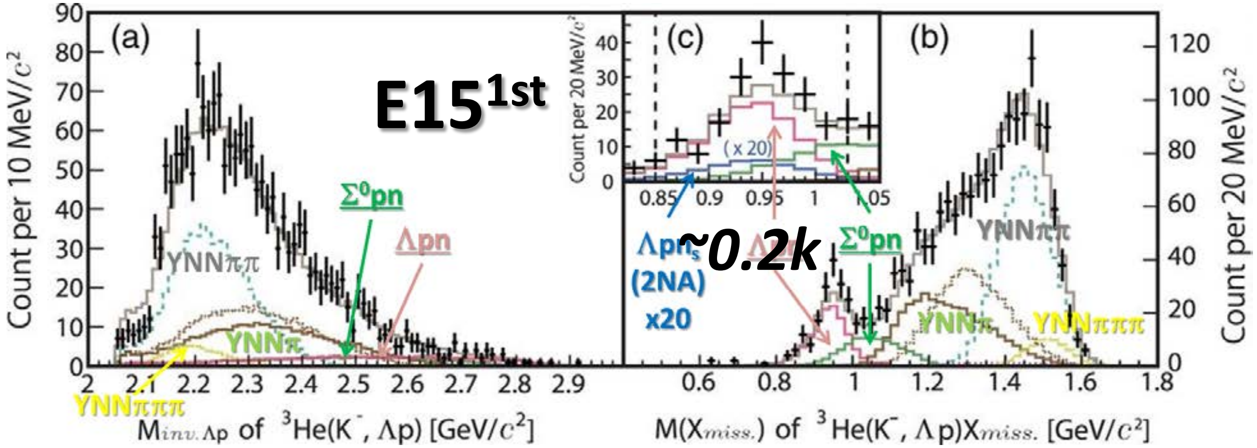
E15-2nd Experiment

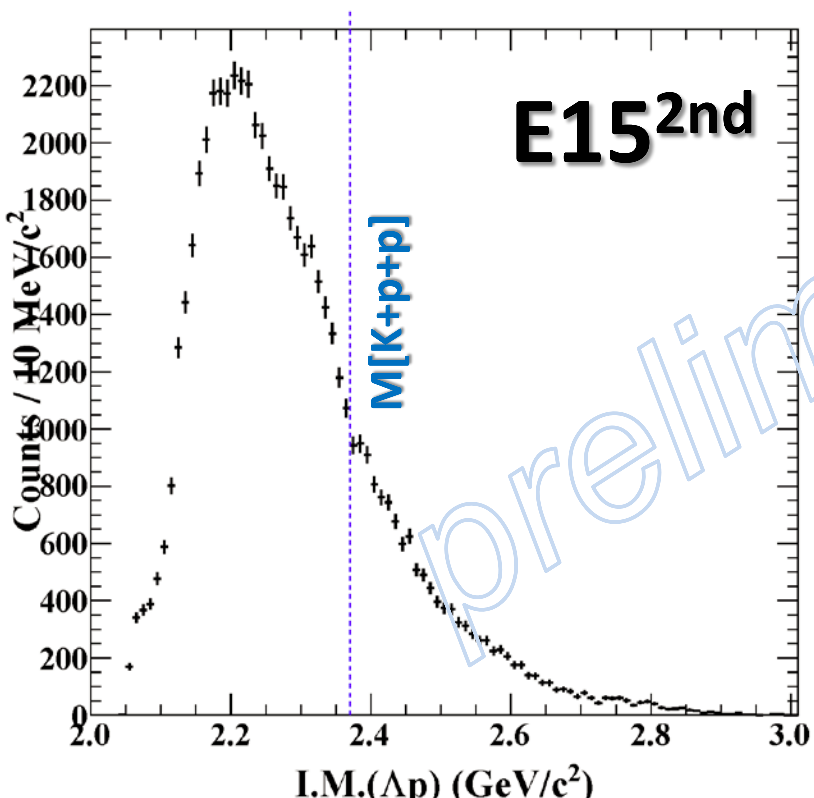
--- completed in Dec. 2015 ---

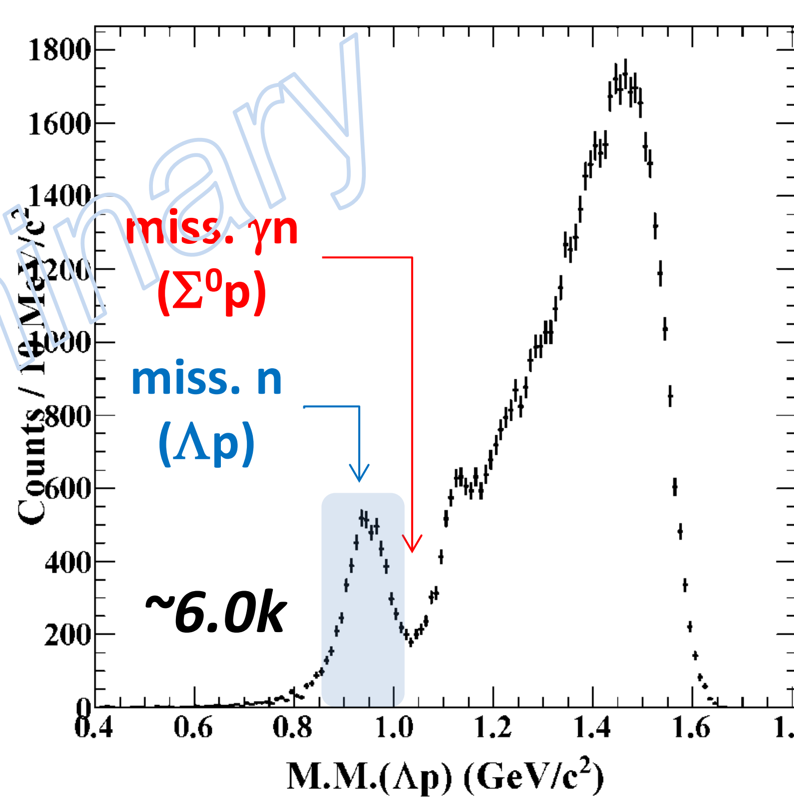
	E15-1st in 2013	E15-2nd in 2015
data-taking	4 days	3 weeks
(K-,n)	~7 times more data	
(K-,Λp)	~30 times more data*	

* dedicated trigger was introduced for (K-,Λp)

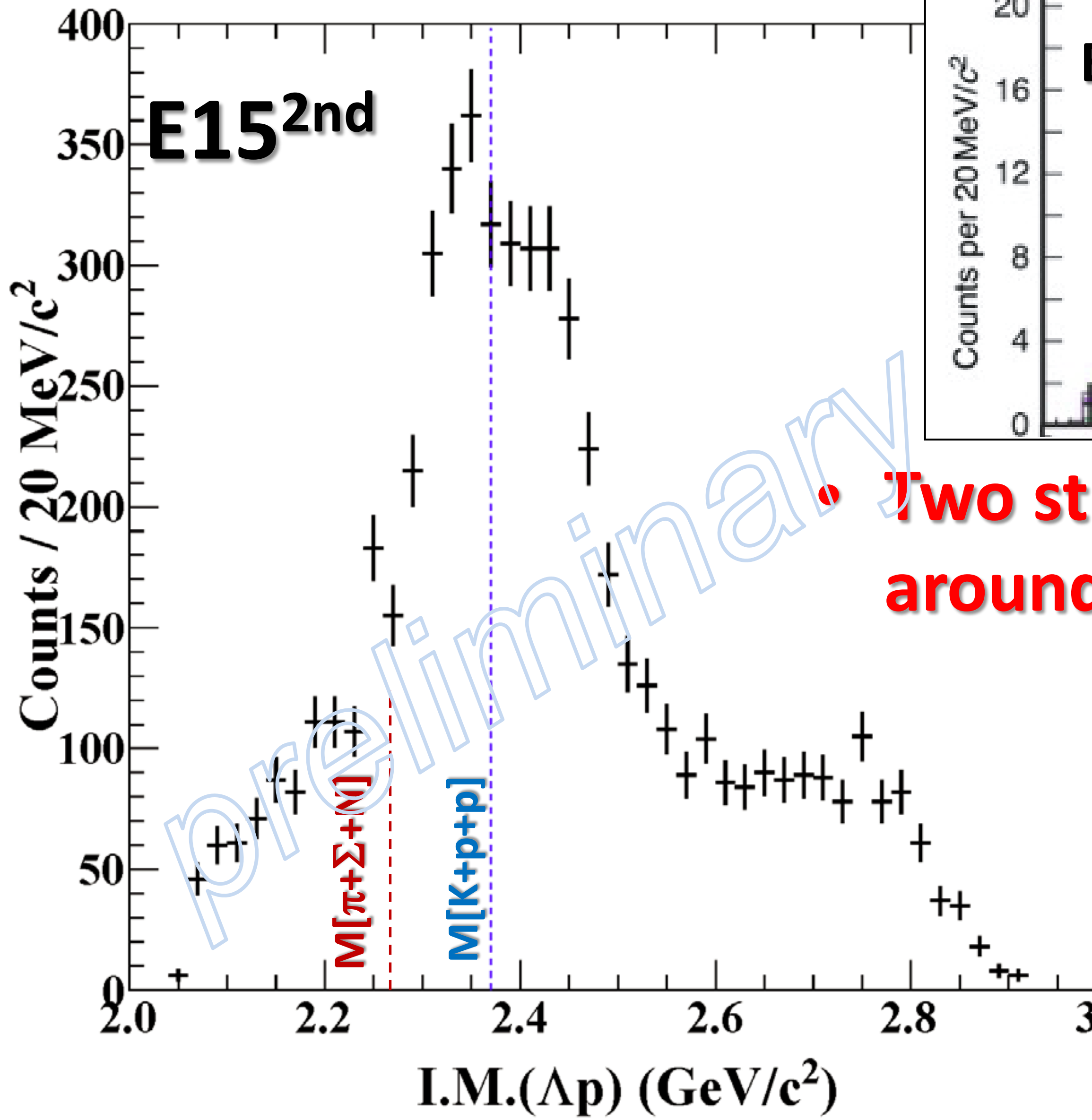
Inclusive ^{3}He(K$^-$,Λp)X

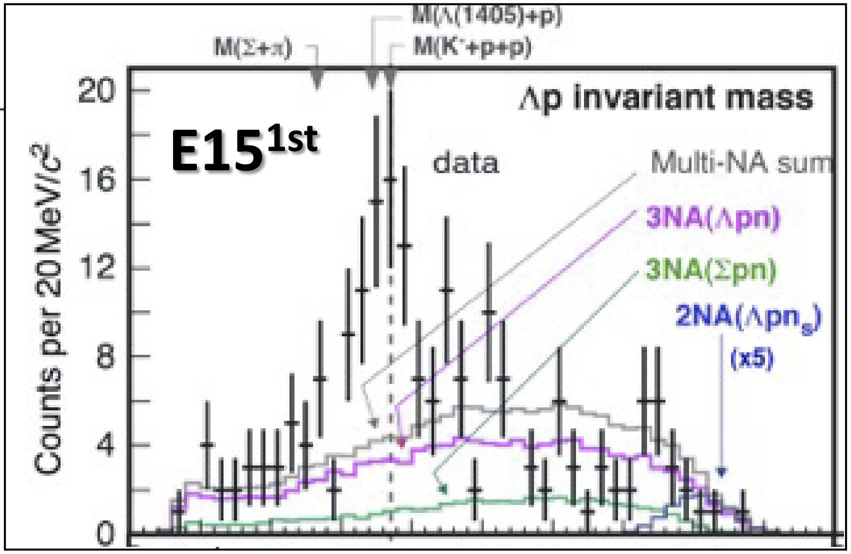




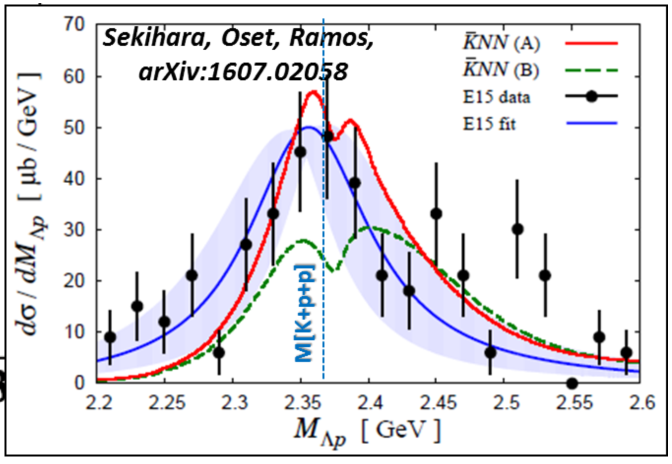


Exclusive $^3He(K^-,\Lambda p)n$

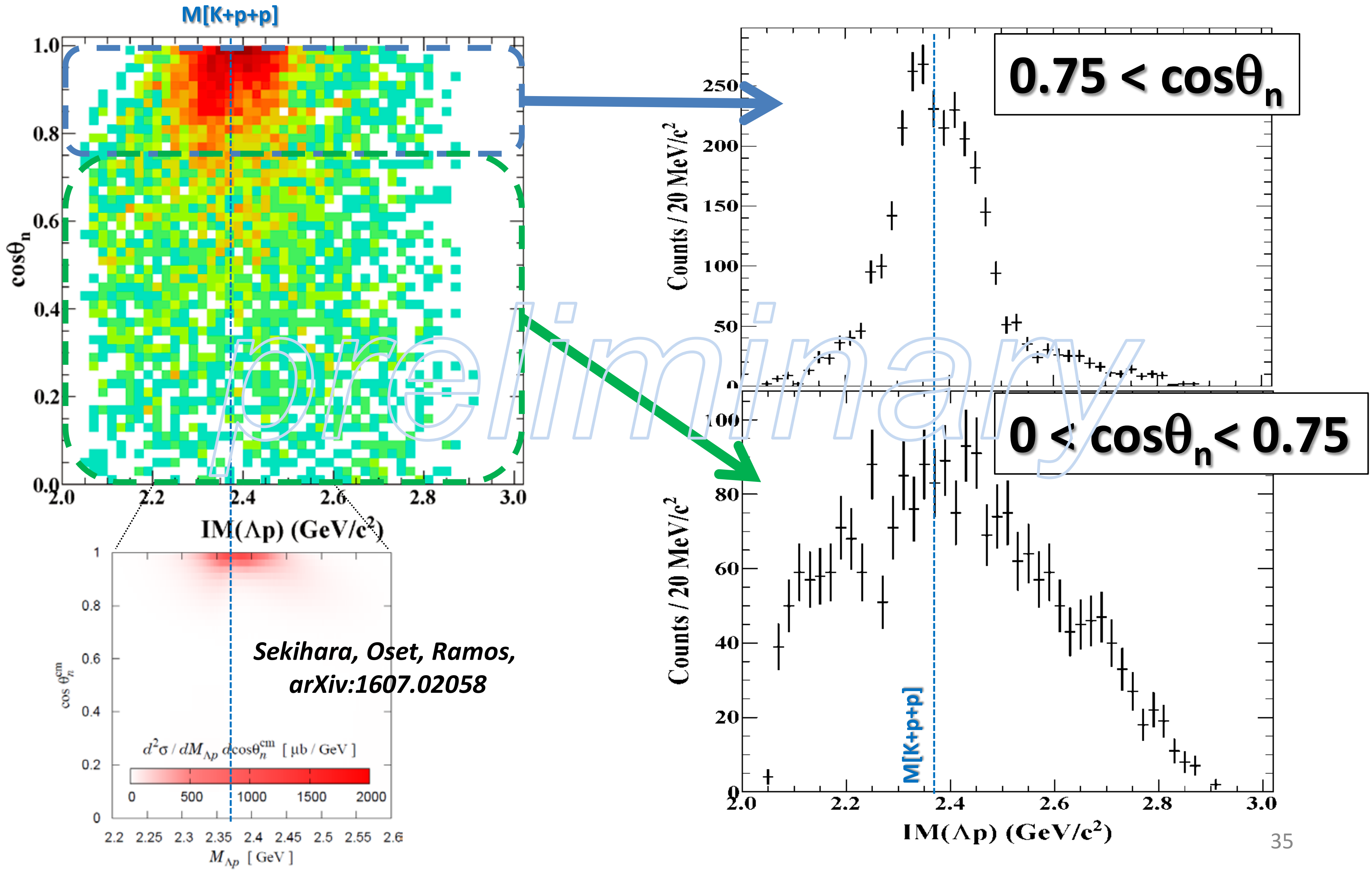




- Two structures are seen around M[K+p+p]!?



$^3He(K^-,\Lambda p)n$: Angular Dependence



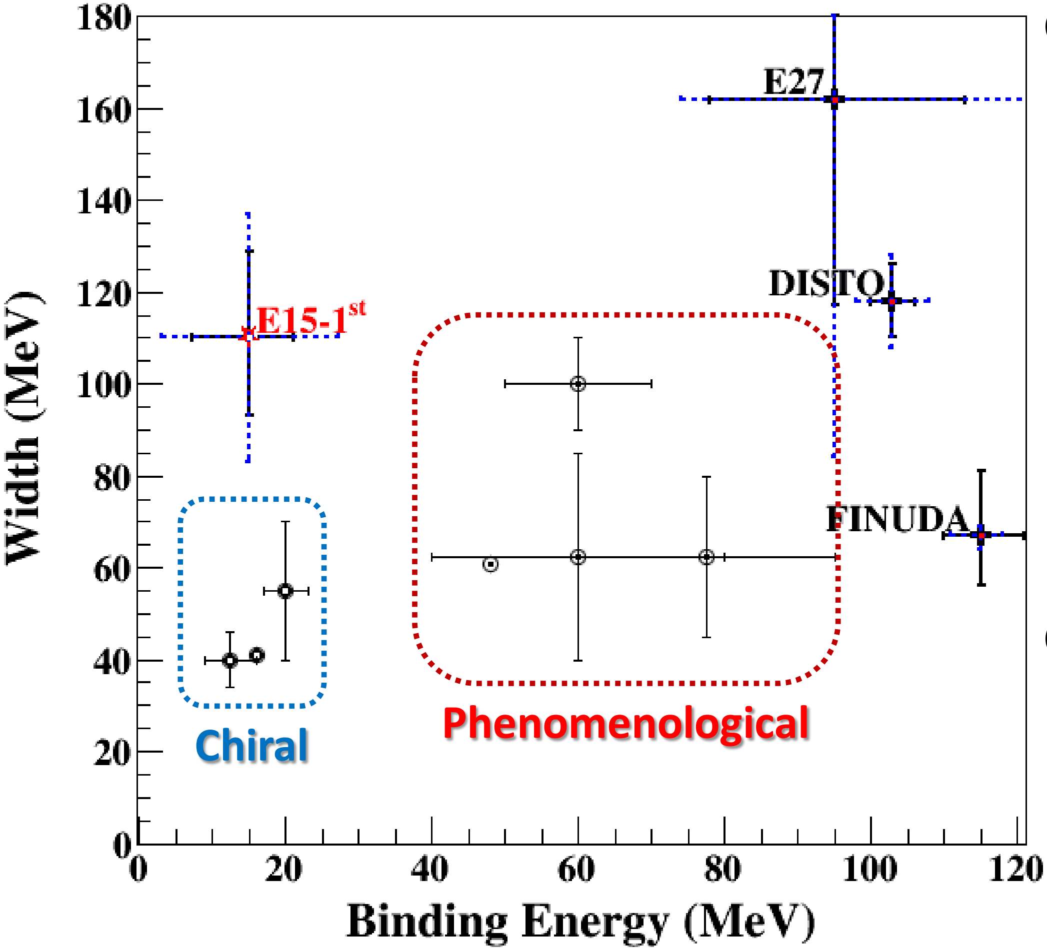
More detailed analysis will be shown in

Yamaga, Tue. A-1

- angular dependence, decay mode, etc.

Summary

Present Status of K^{bar}NN



- **Exp. <u>CANDIDATES</u>**

<u>Key measurements</u>

✓ **Λ(1405) production**

→ Λ*N doorway

✓ **πΣN decay channel**

→ new info. of K^{bar}NN

- **Theor. calculations.**
  - Difficult to reproduce deeply bound state w/ normal K^{bar}N int.

<u>K^{bar}NN or NOT? → Other Possibilities</u>

Y*N dibaryon? / πYN pion-assisted dibaryon? / Double-pole K^{bar}NN? / Partial restoration of Chiral symmetry?

Dote, Tue. A-1

K^{bar}NN searches @ J-PARC

- **E27: d(π^+,K^+)Yp @ 1.69 GeV/c**

  Y. Ichikawa et al., PTEP (2014) 101D03.
  Y. Ichikawa et al., PTEP (2015) 021D01.

  – "K-pp"-like structure was found in Σ^0p
    - B ~ 100 MeV/c^2
    - Γ ~ 160 MeV/c^2
    - $\Gamma(\Lambda p)/\Gamma(\Sigma^0 p)$ ~ 1

  - ***large prob. of Λ(1405)p → "K^-pp"***

- **E15: ^{3}He(K^-,Λp)n @ 1.0 GeV/c**

  T. Hashimoto et al., PTEP (2015) 061D01.
  Y. Sada et al., PTEP (2016) 051D01.

  – Structure around the threshold was fond in Λp

E15^1st^ results

- B ~ 15 MeV/c^2
- Γ ~ 110 MeV/c^2
- Q ~ 400 MeV/c

→

E15^2nd^ results

- ***Two structures !?***

Yamaga, Tue. A-1

Further theoretical inputs are welcome!

Thank You!

J-PARC E15 Collaboration

S. Ajimura[a], G. Beer[b], H. Bhang[c], M. Bragadireanu[e], P. Buehler[f], L. Busso[g,h], M. Cargnelli[f], S. Choi[c], C. Curceanu[d], S. Enomoto[i], D. Faso[g,h], H. Fujioka[j], Y. Fujiwara[k], T. Fukuda[l], C. Guaraldo[d], T. Hashimoto[k], R. S. Hayano[k], T. Hiraiwa[a], M. Iio[o], M. Iliescu[d], K. Inoue[i], Y. Ishiguro[j], T. Ishikawa[k], S. Ishimoto[o], T. Ishiwatari[f], K. Itahashi[n], M. Iwai[o], M. Iwasaki[m,n*], Y. Kato[n], S. Kawasaki[i], P. Kienle[p], H. Kou[m], Y. Ma[n], J. Marton[f], Y. Matsuda[q], Y. Mizoi[l], O. Morra[g], T. Nagae[j$], H. Noumi[a], H. Ohnishi[n], S. Okada[n], H. Outa[n], K. Piscicchia[d], M. Poli Lener[d], A. Romero Vidal[d], Y. Sada[j], A. Sakaguchi[i], F. Sakuma[n], M. Sato[n], A. Scordo[d], M. Sekimoto[o], H. Shi[k], D. Sirghi[d,e], F. Sirghi[d,e], K. Suzuki[f], S. Suzuki[o], T. Suzuki[k], K. Tanida[c], H. Tatsuno[d], M. Tokuda[m], D. Tomono[n], A. Toyoda[o], K. Tsukada[r], O. Vazquez Doce[d,s], E. Widmann[f], B. K. Weunschek[f], T. Yamaga[i], T. Yamazaki[k,n], H. Yim[t], Q. Zhang[n], and J. Zmeskal[f]

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(s) Excellence Cluster Universe, Technische Universität München, D-85748, Garching, Germany
(t) Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, 139-706, South Korea

(*) Spokesperson
($) Co-Spokesperson

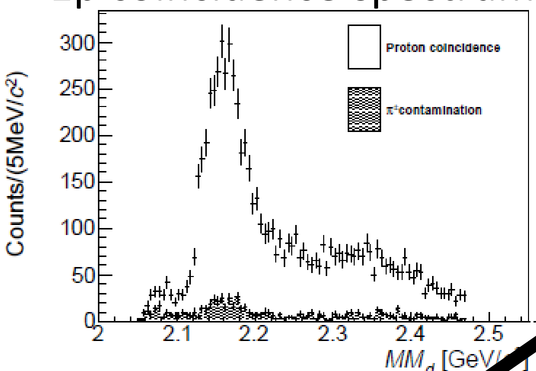
Spares

E27: One-Proton Coincidence

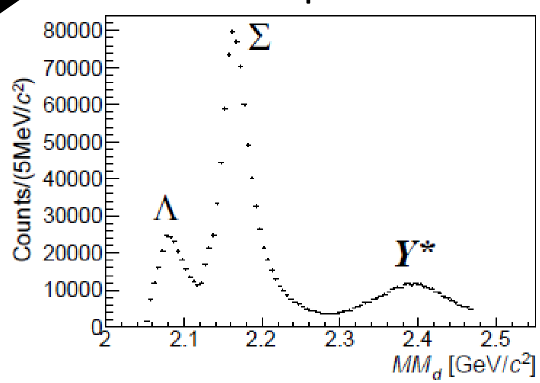
Y. Ichikawa et al., PTEP (2015) 021D01.

- p_p > 250 MeV/c
  - QFs are suppressed
- ΣN-ΛN cusp is clearly seen @ 2.13 GeV/c^2
- **Broad enhancement is observed @ 2.28 GeV/c^2**

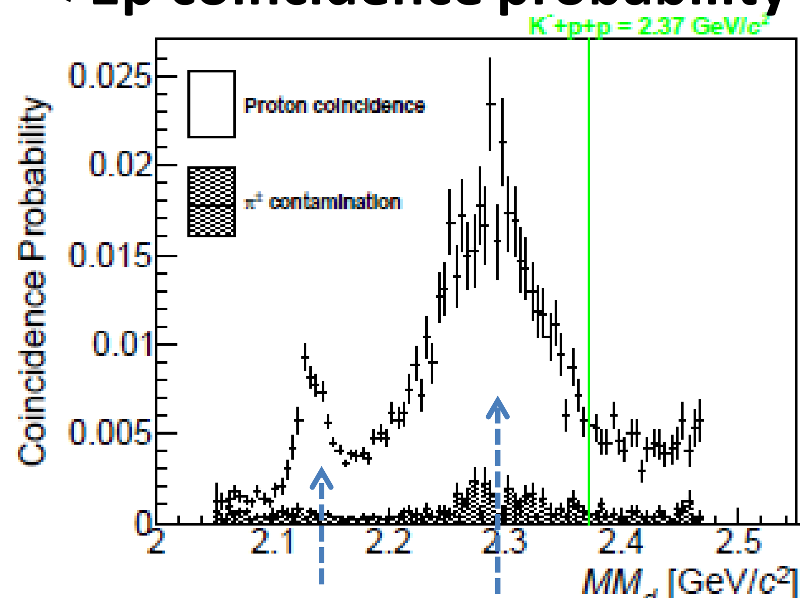
< 1p coincidence spectrum >



< Inclusive spectrum >



< 1p coincidence probability >

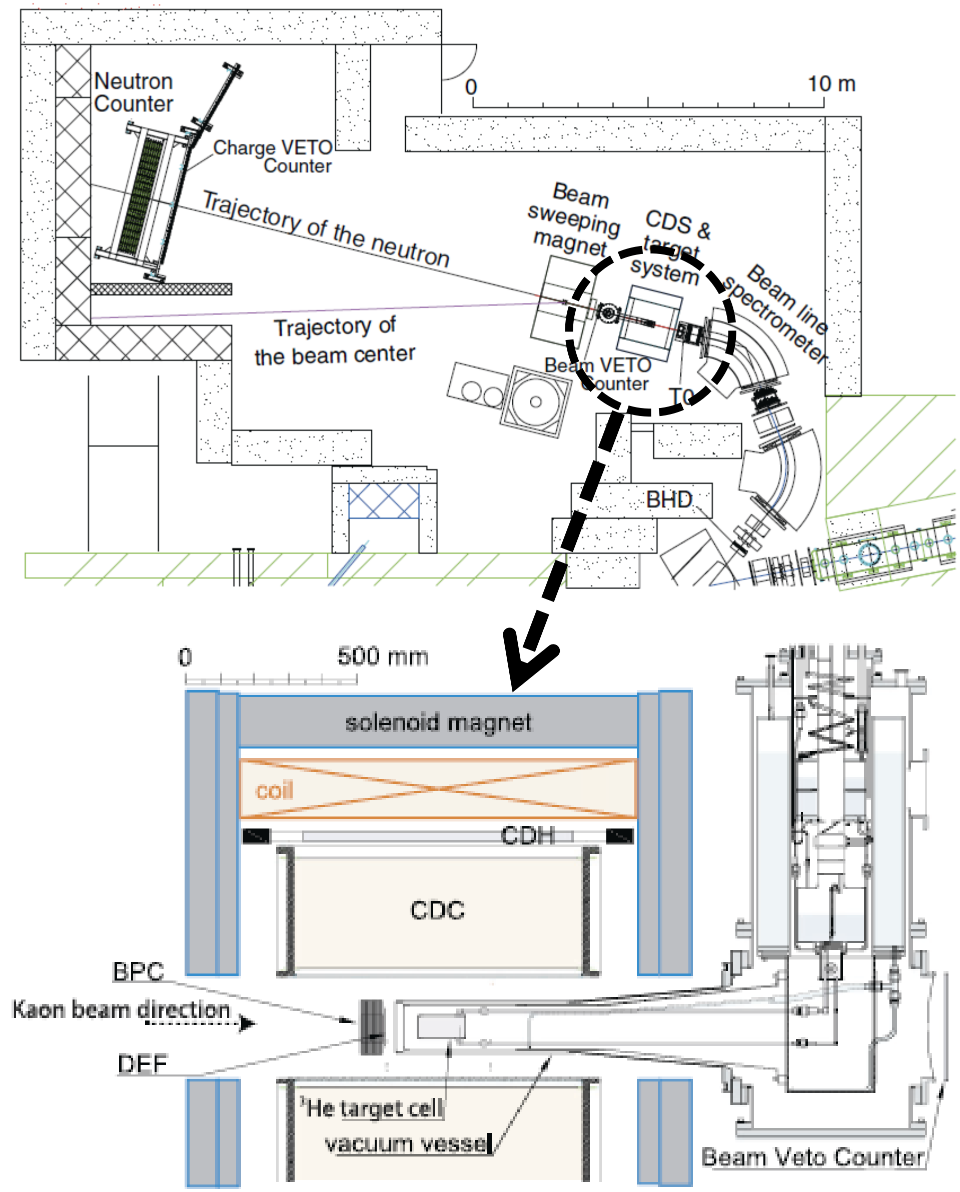


ΣN-ΛN cusp

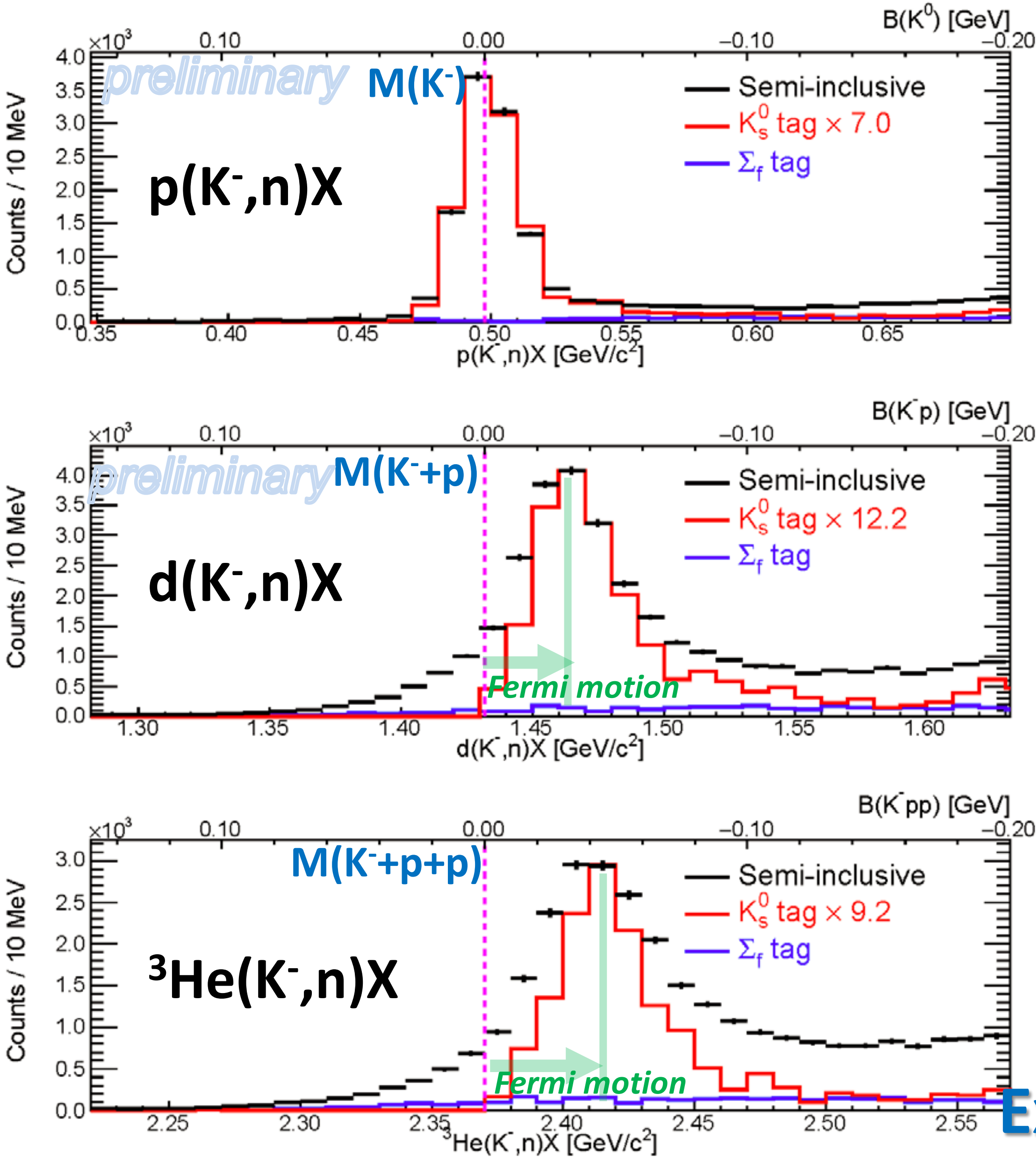
Broad bump

Experimental Setup

- **Beamline spectrometer**
  - 1.0 GeV/c K^-
  - $\Delta p/p$: 0.2%
- **Target System**
  - ~0.5l Liquid 3He @ 1.4K
    - $\rho = 0.081\ g/cm^3$
- **Cylindrical Detector System**
  - Acceptance: $54<\theta<126$ deg.
    - 59% of 4π
  - $\Delta p_t/p_t$: 5.3% p_t + 0.5%/β
- **Neutron Counter**
  - Acceptance: 20 msr
  - $\Delta p/p$ for 1.2GeV/c n: 0.7%



Subthreshold Excess?



- $K^-p \rightarrow K^0 + n_{fw}$

  well describes the spectrum

- $K^-d \rightarrow Y^* + n_{fw}$

  Y* production are seen as excess

  The main goal of E31

- $K^{-3}He \rightarrow Y^*N + n_{fw}$

  Y* production (and/or exotic production) are seen as excess

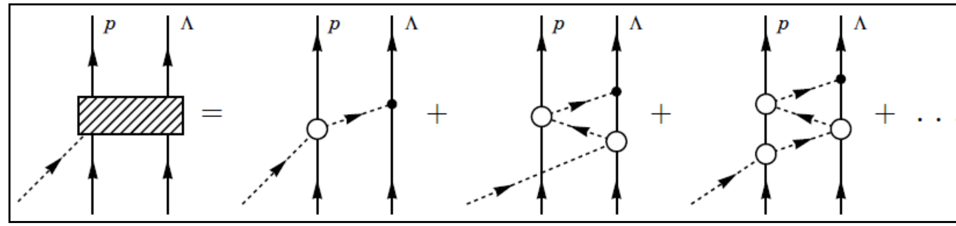
Exclusive analysis is crucial!

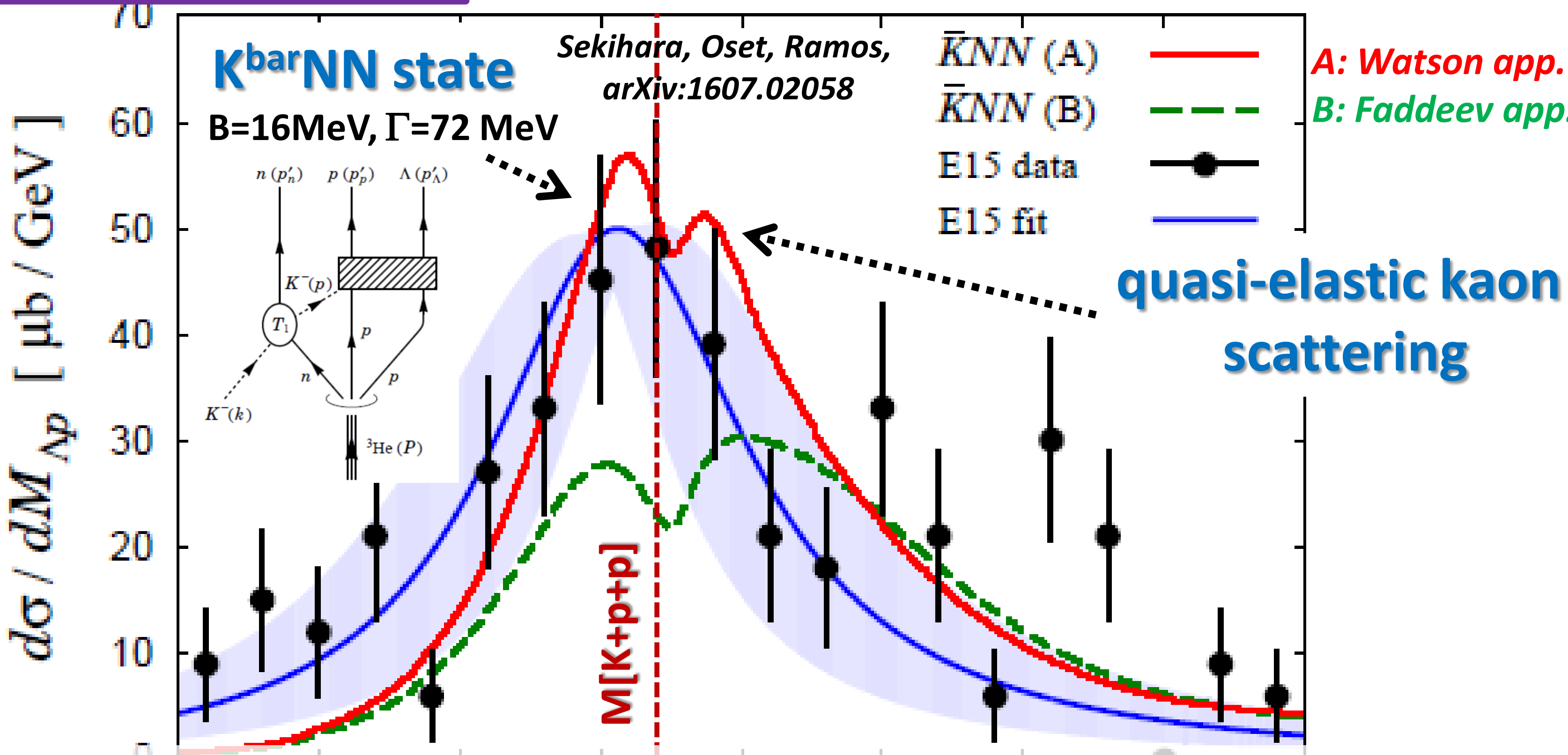
A Theoretical Interpretation

Sekihara, Oset, Ramos, arXiv:1607.02058

Chiral unitary approach

Sekihara, Tue. A-1



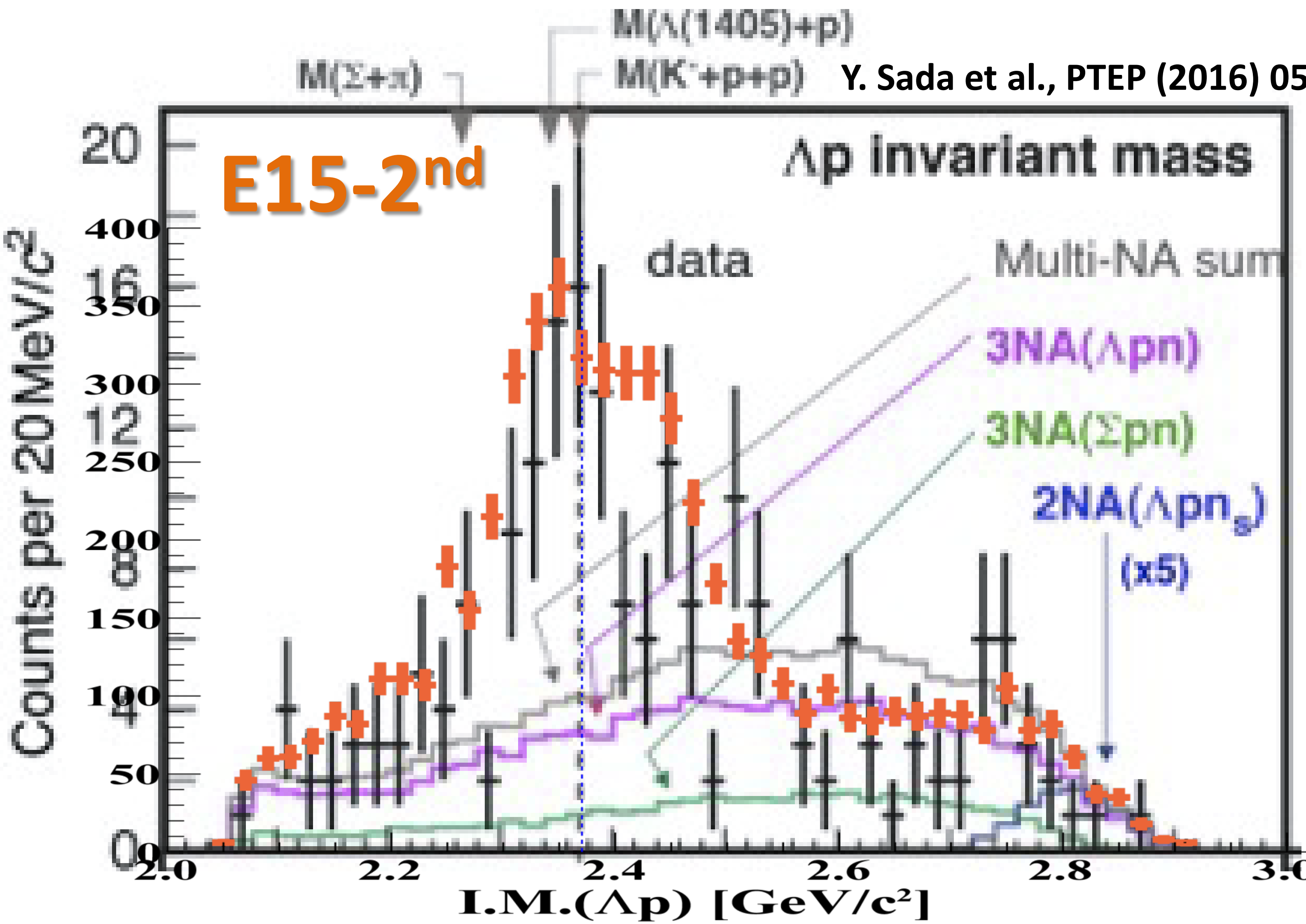


K^{bar}NN bound-state picture reproduces the data

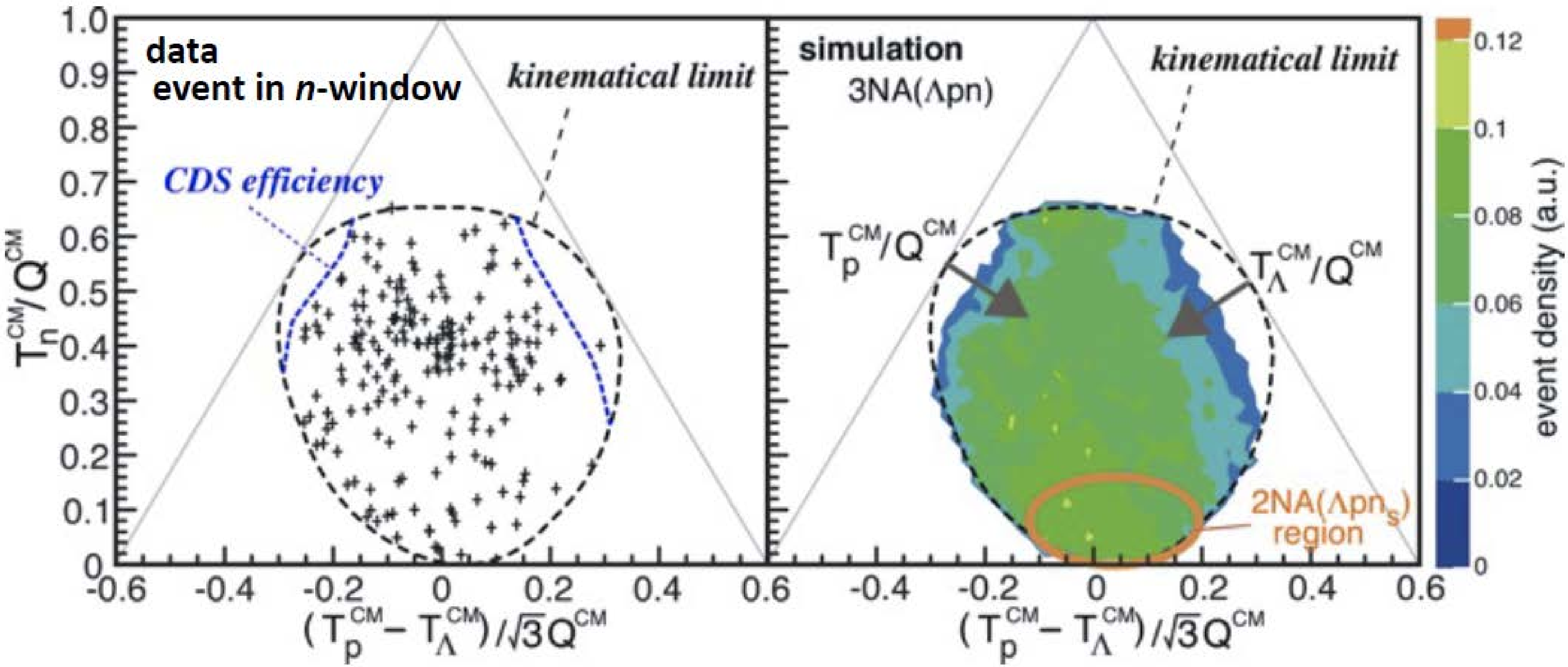
→ The data CANNOT be explained with uncorrelated Λ(1405)p

E15 1st vs 2nd

Y. Sada et al., PTEP (2016) 051D01.

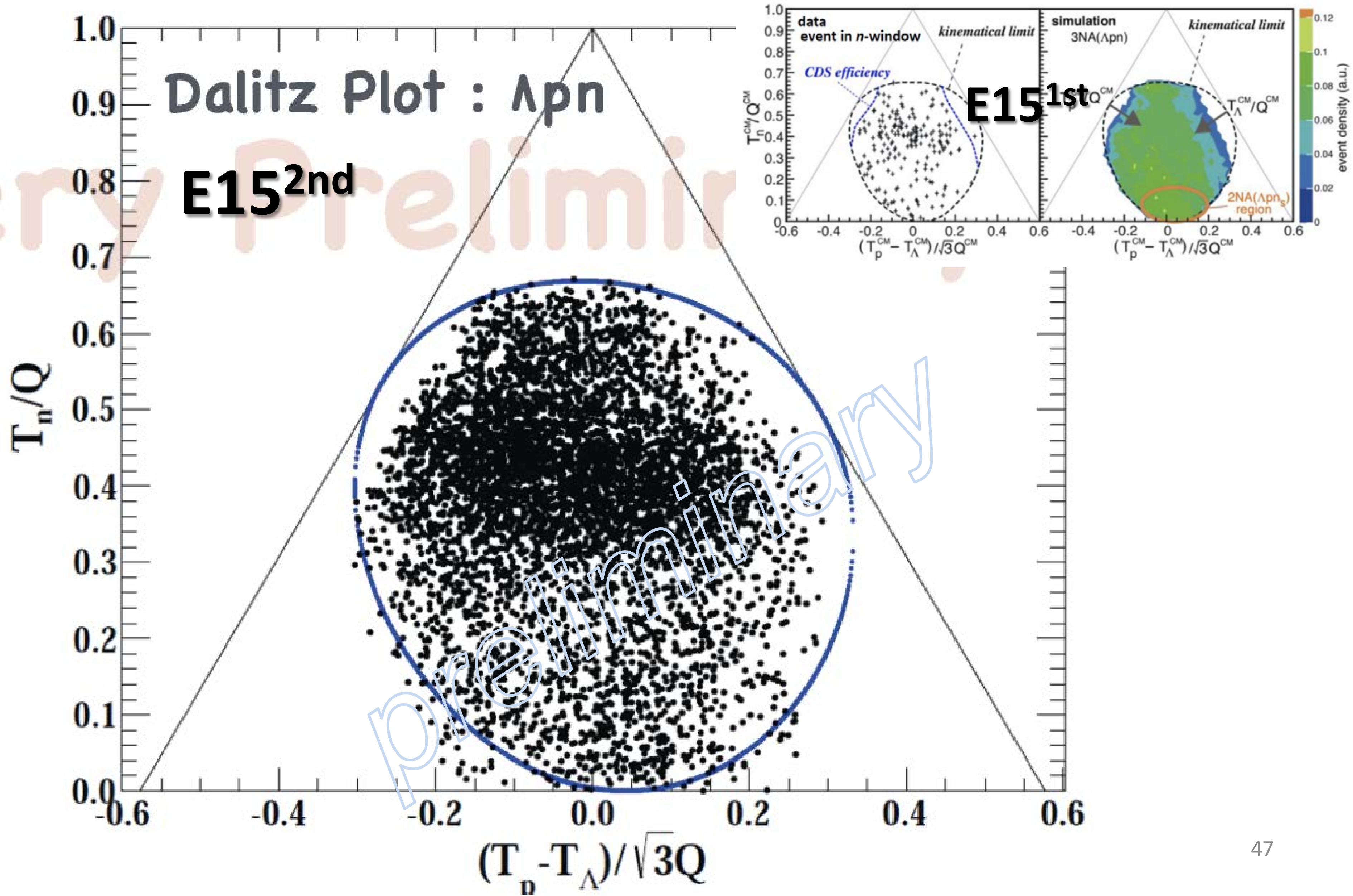


Exclusive $^3He(K^-,\Lambda p)n$



- The events widely distribute in the phase space
  - Contribution from 2NA processes seem to be small
- Event concentration is seen at $T^{CM}{}_n/Q^{CM}$~0.4

Exclusive $^3He(K^-,\Lambda p)n$



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

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

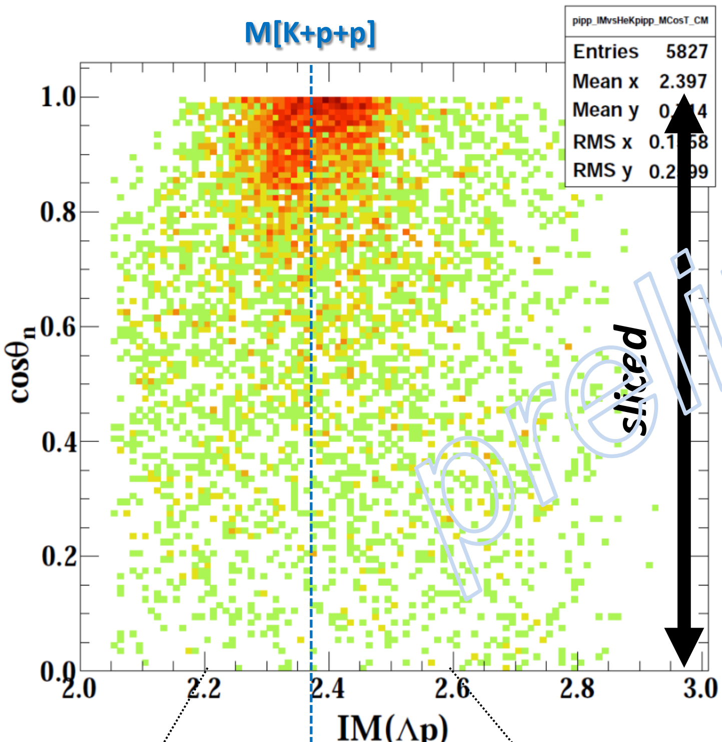
- **Λ(1405)N bound state** — T. Uchino et al., NPA868(2011)53.
  - loosely-bound system, I=1/2, $J^{\pi}=0^{-}$
  - various decay modes, $\Lambda N/\Sigma N/\pi\Sigma N$

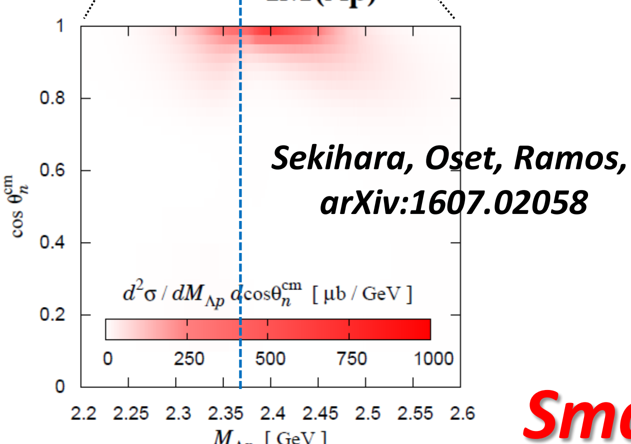
A structure near $\pi\Sigma N$ threshold

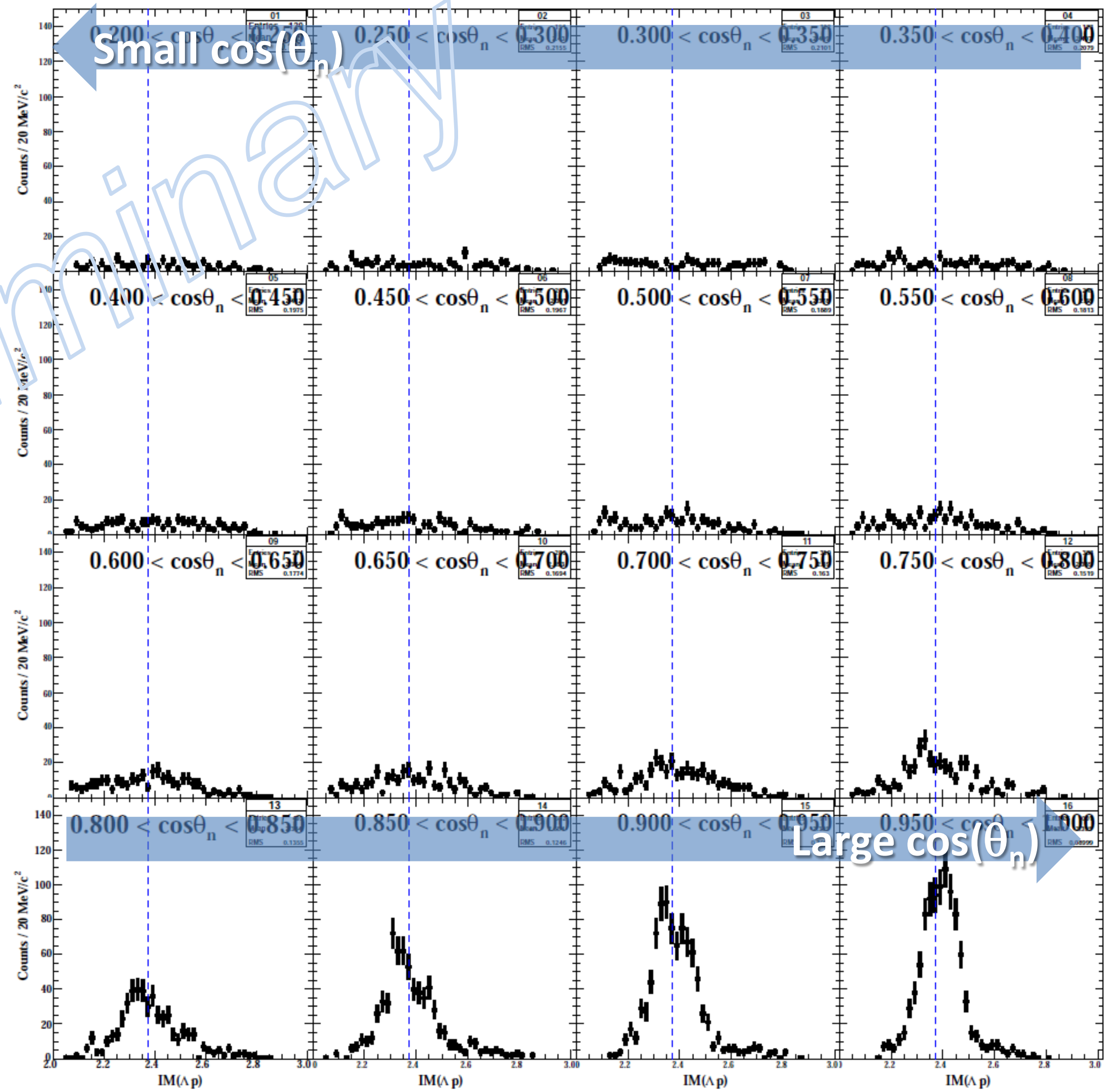
- **$\pi\Lambda N$-$\pi\Sigma N$ dibaryon** — H. Garcilazo, A. Gal, NPA897(2013)167.
  - structure near $\pi\Sigma N$ threshold
  - I=3/2, $J^{\pi}=2^{+}$ → no Λp decay (I=1/2)?
- **Double-pole $K^{bar}NN$** — A. Dote, T. Inoue, T. Myo, PTEP (2015) 043D02.
  - loosely-bound $K^{bar}NN$, &
  - broad resonance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

Exclusive ^{3}He(K$^-$,Λp)n

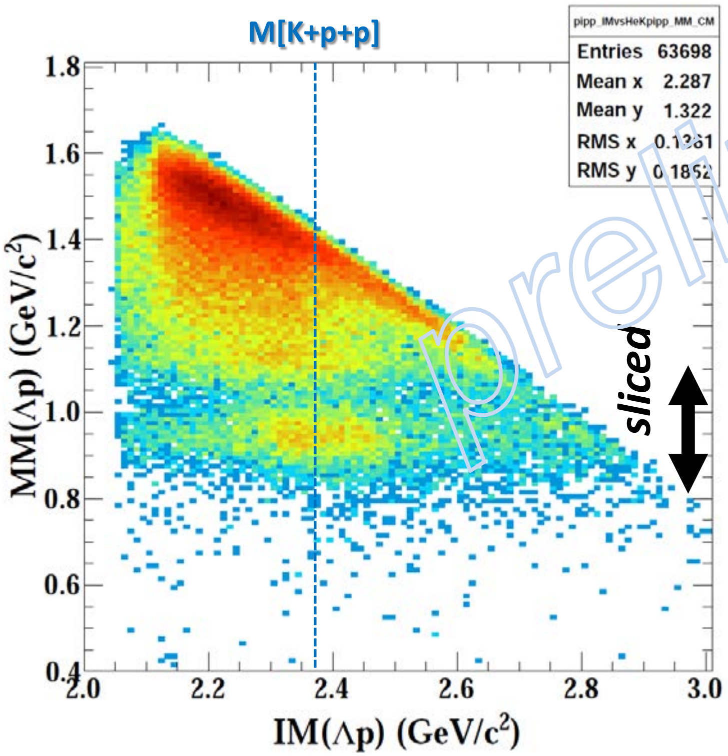


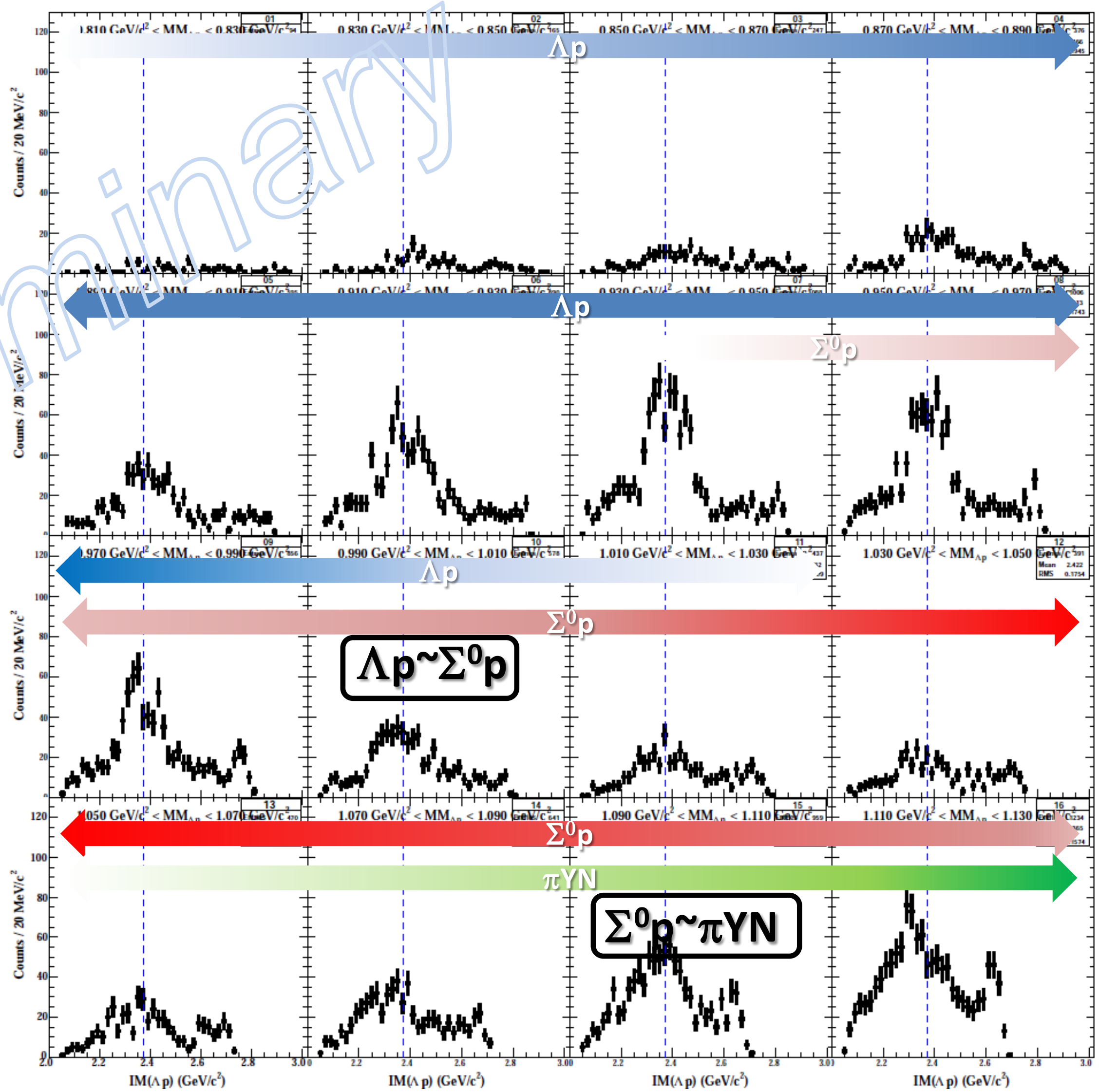




Smaller momentum transfer is preferred

^{3}He(K$^-$,Λp)n: Decay Channel





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

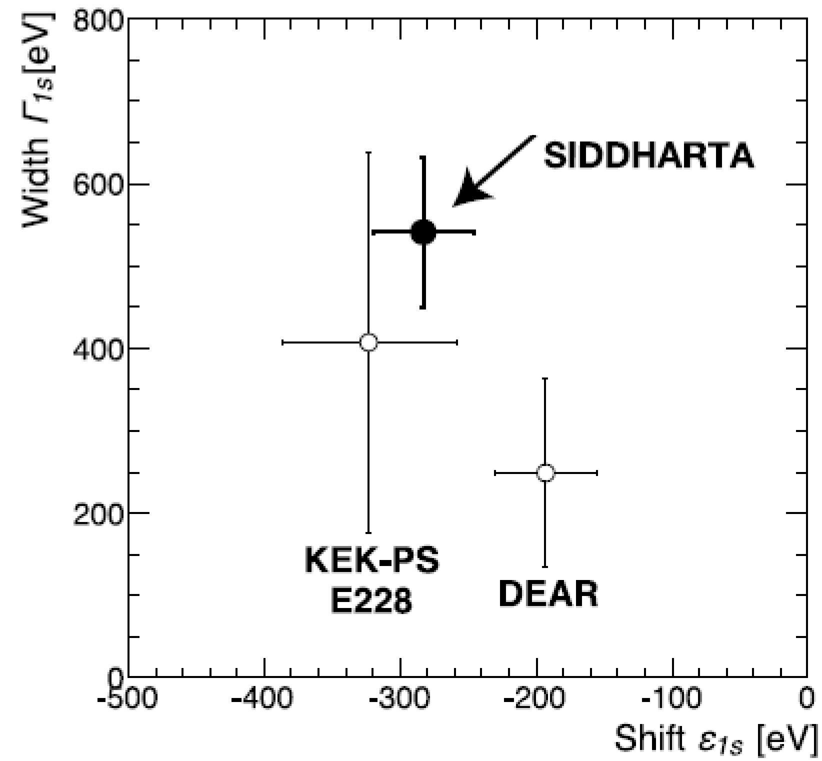
$K^{bar}N$ Interaction

A good probe for low energy QCD

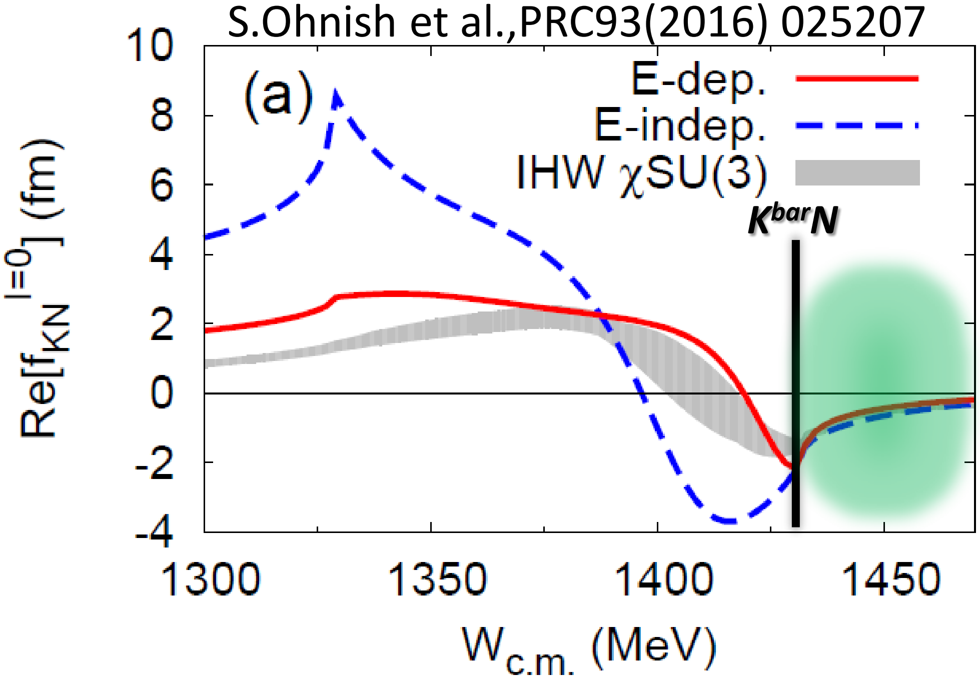
At the $K^{bar}N$ threshold:

- ✓ Low-energy K-p scattering
- ✓ Kaonic hydrogen X-ray

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



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



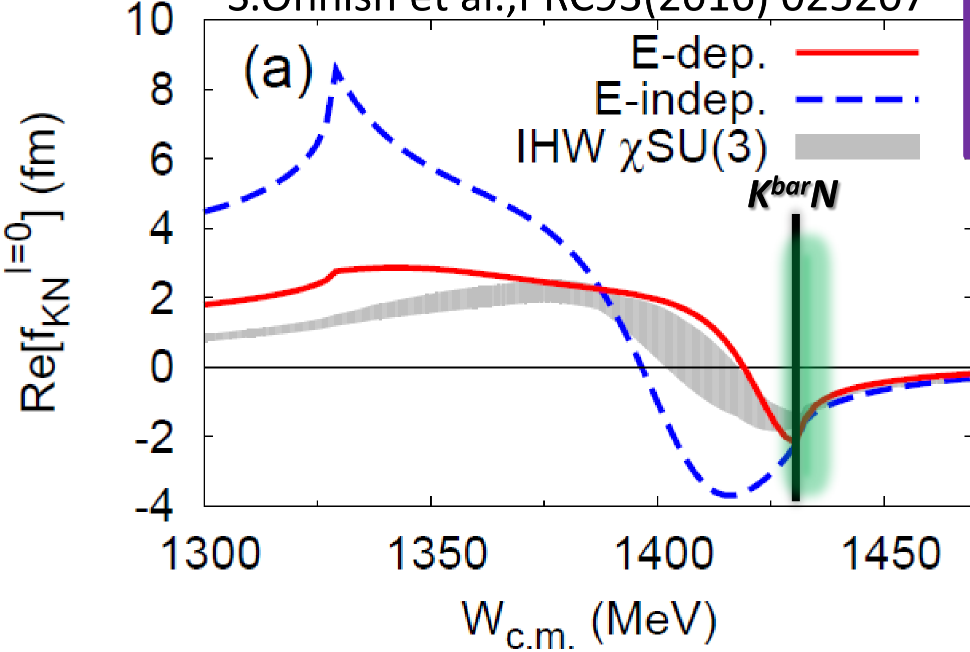
$K^{bar}N$ Interaction

A good probe for low energy QCD

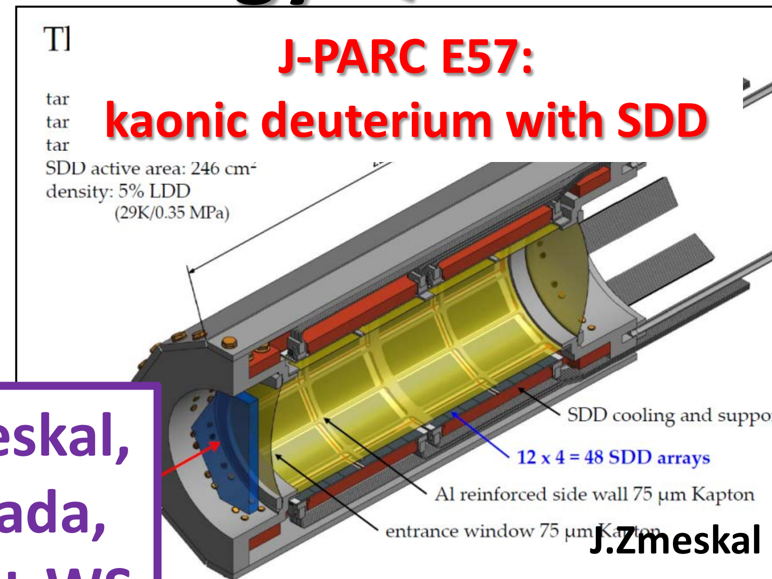
At the $K^{bar}N$ threshold:

- ✓ Low-energy K-p scattering
- ✓ Kaonic hydrogen X-ray
- ? **isospin dependent $K^{bar}N$**

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

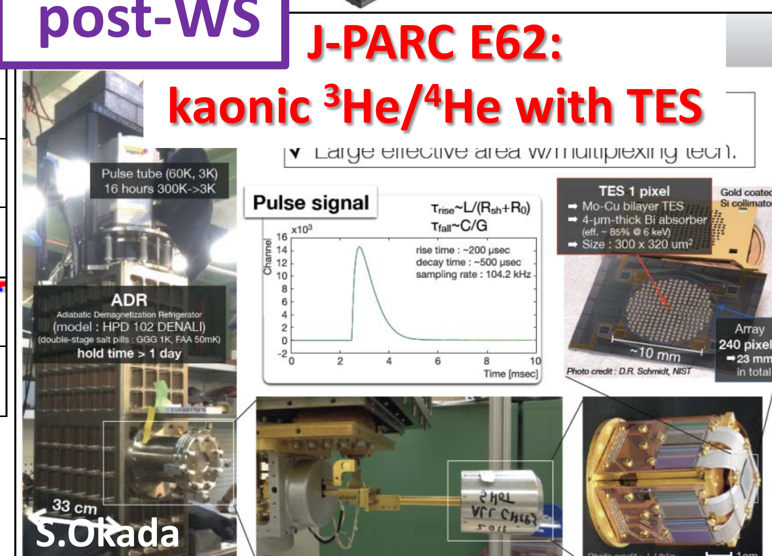


J-PARC E57:
kaonic deuterium with SDD



Zmeskal, Okada, post-WS

J-PARC E62:
kaonic ^{3}He/^{4}He with TES



$K^{bar}N$ Interaction

A good probe for low energy QCD

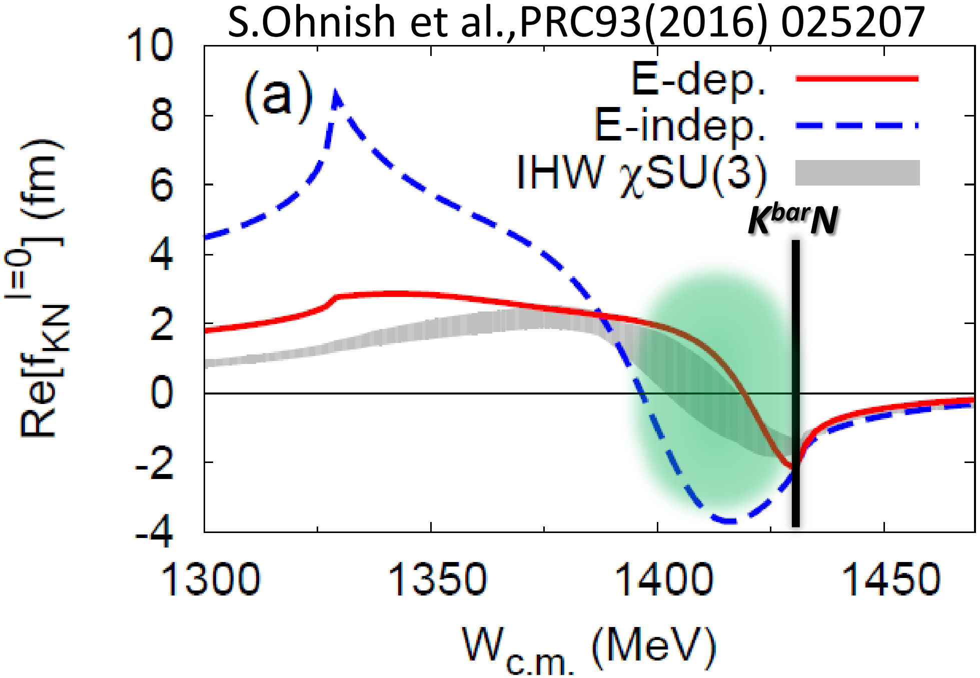
Below the $K^{bar}N$ threshold:

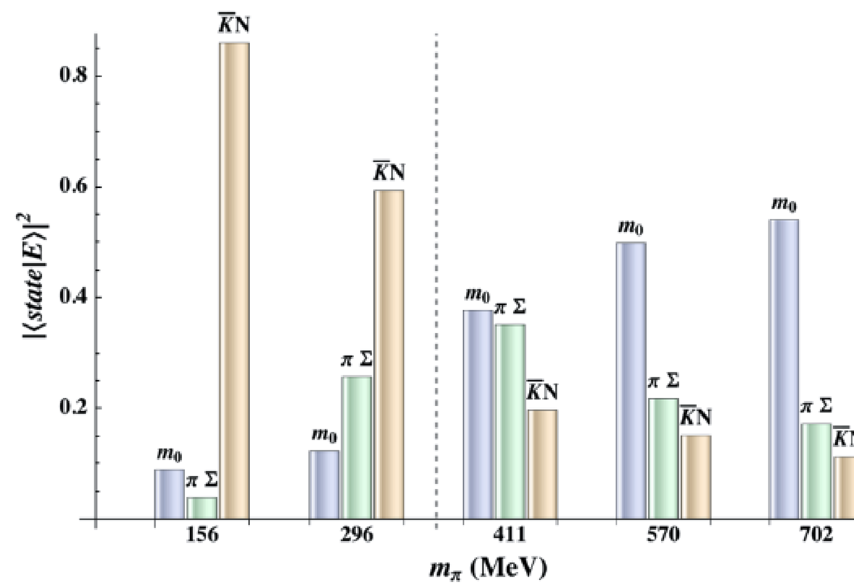
✓ $\Lambda(1405)$ plays an important role

- $J^P = \frac{1}{2}^-$ Moriya et al., (CLAS Coll.), Phys. Rev. Lett. 112(2014)082004.
- $K^{bar}N$ molecular from LQCD

J.M.M. Hall et al.,
Phys. Rev. Lett. 114(2015)132002.

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





$K^{bar}N$ Interaction

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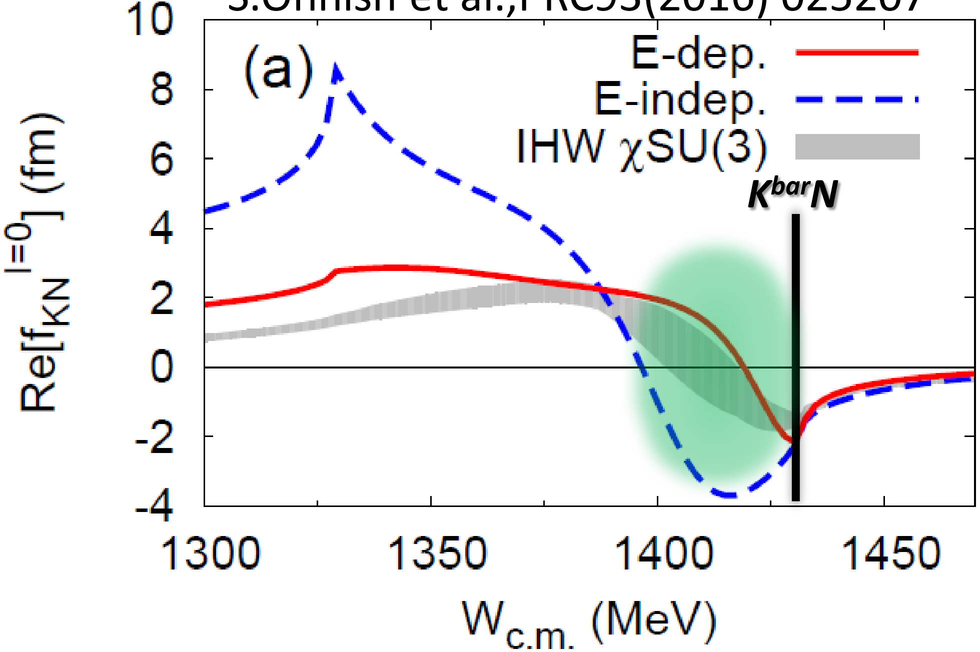
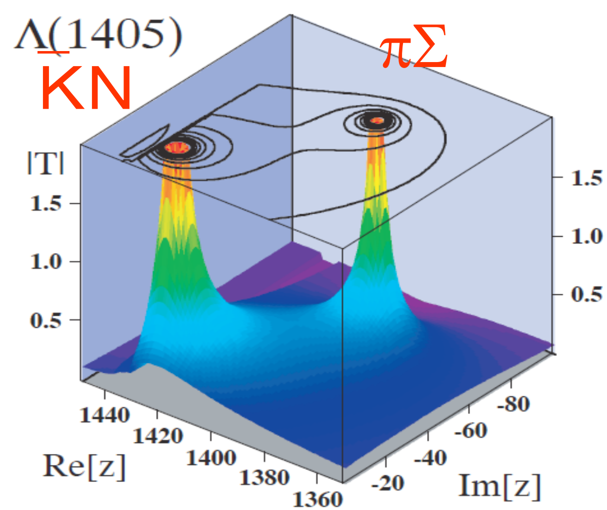
? Double pole structure

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





ChU model, T. Hyodo

K^{bar}N Interaction

A good probe for low energy QCD

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- K^{bar}N molecular from LQCD
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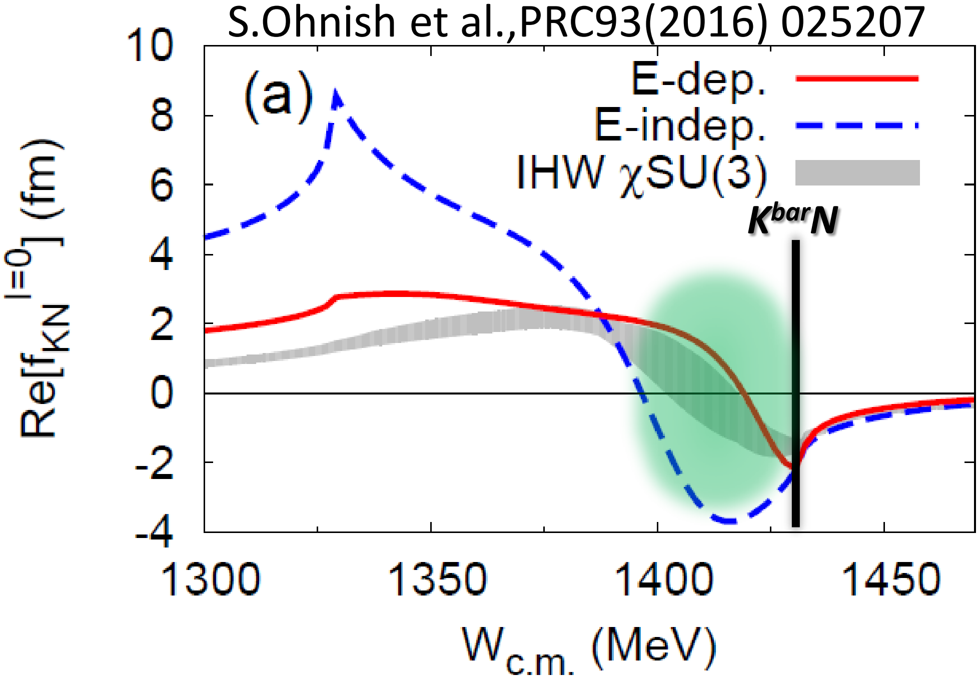
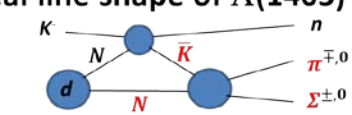
? **Double pole structure**

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

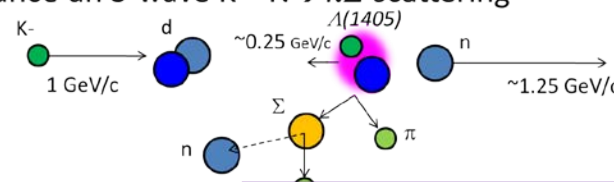


J-PARC E31: d(K-,n)Λ(1405)

aim to reveal line shape of Λ(1405) via K^{bar}N→$\pi\Sigma$



- employ d(K$^-$,n)$\pi\Sigma$ reactions at θ_n~0 deg., which is expected to enhance an S-wave K^{bar}N→$\pi\Sigma$ scattering



Kawasaki, Fri. E-1

$K^{bar}N$ Interaction

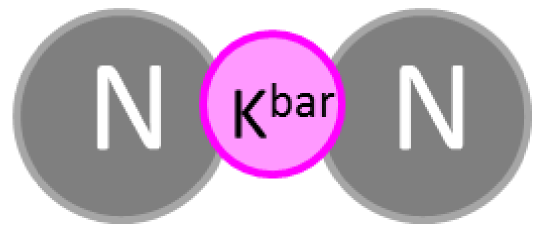
A good probe for low energy QCD

Below the $K^{bar}N$ threshold:

✓ $\Lambda(1405)$ plays an important role

? **Possible existence of "kaonic nuclei" → $K^{bar}NN$**

the simplest kaonic nuclei:



$$I = \frac{1}{2}, J^P = 0^-$$