Experimental studies on the K^{bar}N interaction

- Recent Topics from J-PARC -

F. Sakuma, RIKEN

on behalf of the J-PARC

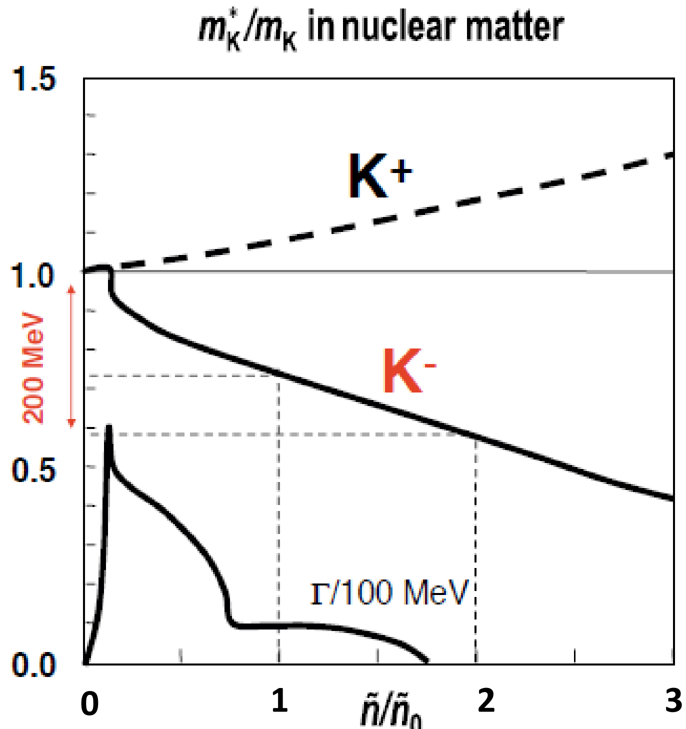
E15/E31/E57/E62 collaboration

SNP2017, Mar. 12-14, 2017, Osaka

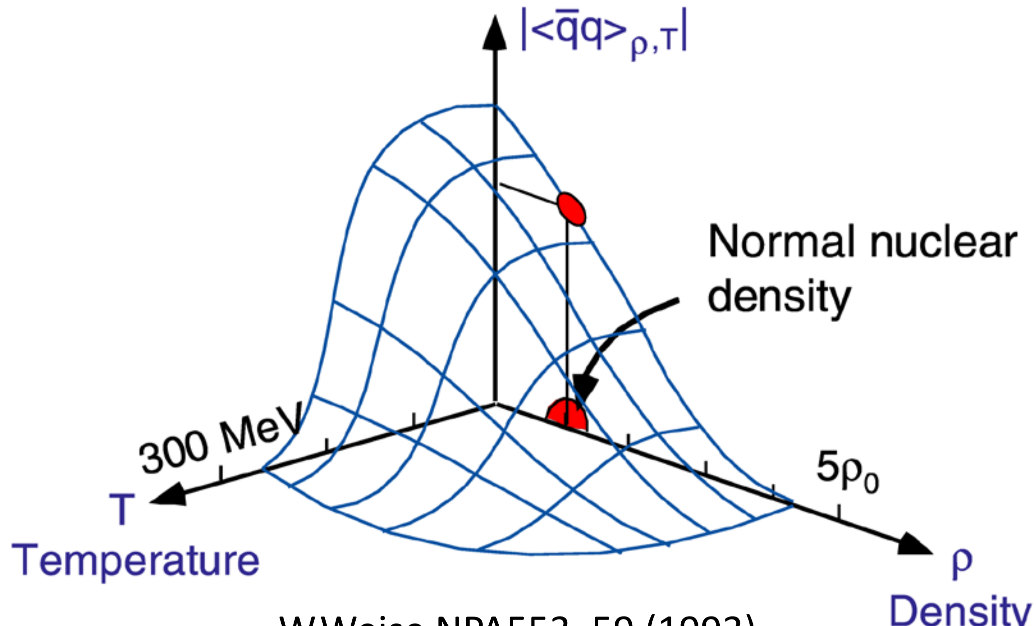
Physics Motivation

- **Meson properties change in nuclear media?**
- **$K^{bar}N$ interaction : attractive in I=0**

→ A good probe for low energy QCD



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

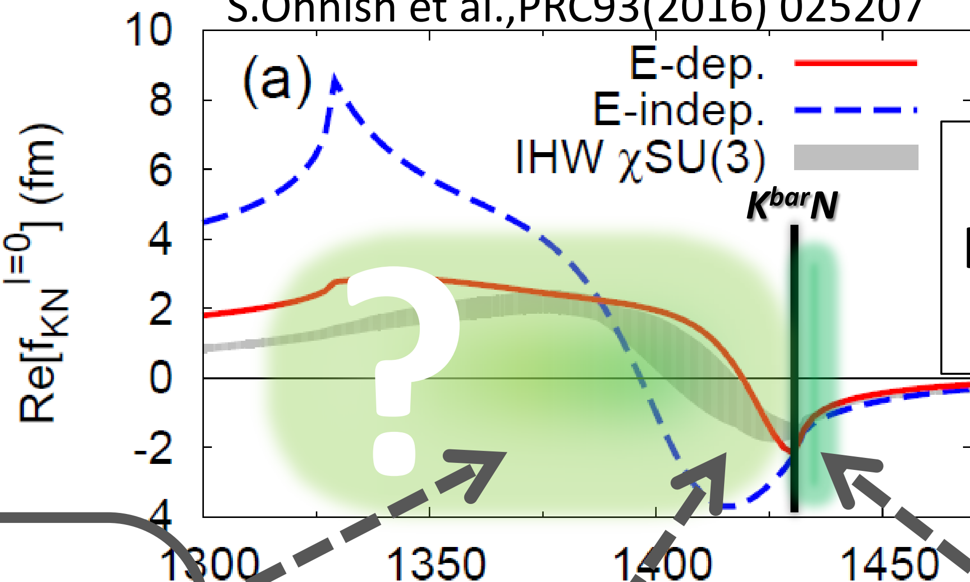


W.Weise NPA553, 59 (1993).

provide new insight on M-B interaction in media

Investigation of $K^{bar}N$ int. @ J-PARC

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



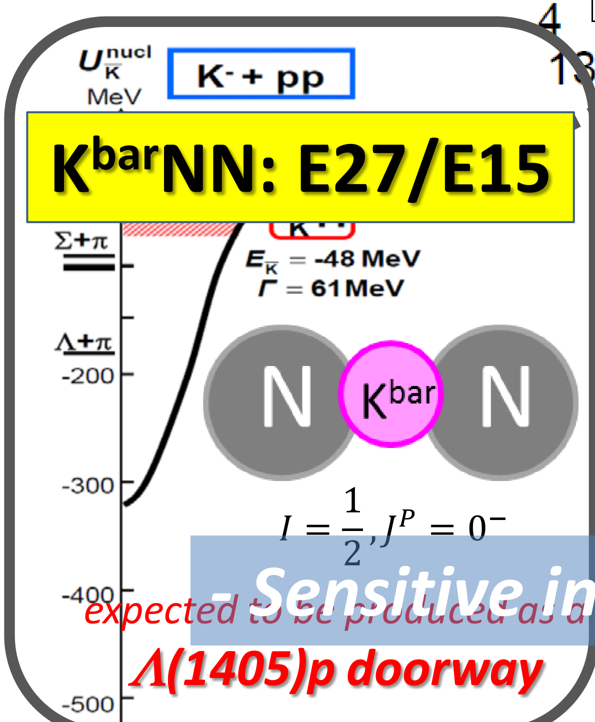
Calculation on $K^{bar}N$ amplitude in I = 0

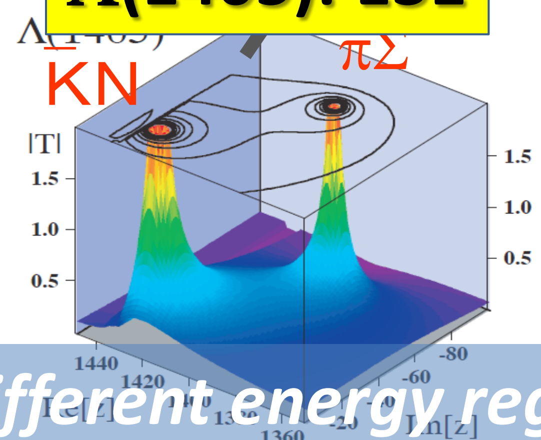
M. Bazzi et al., (SIDDHARTA Coll.), Phys. Lett. B704(2011)113

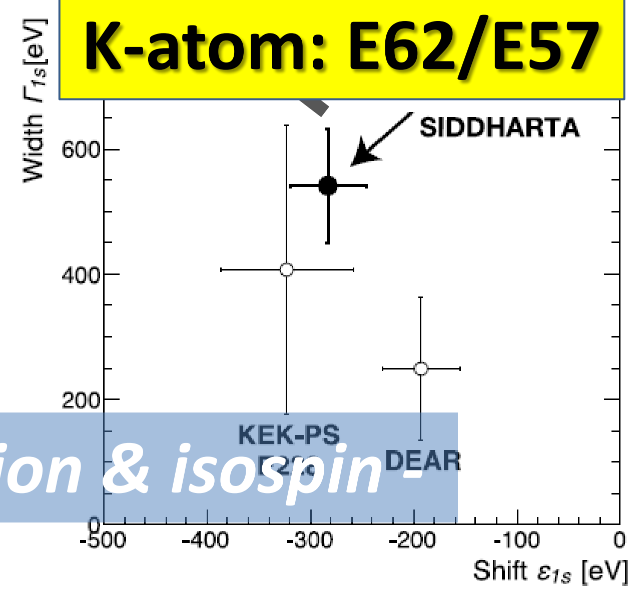
$K^{bar}NN$: E27/E15

Λ(1405): E31

K-atom: E62/E57







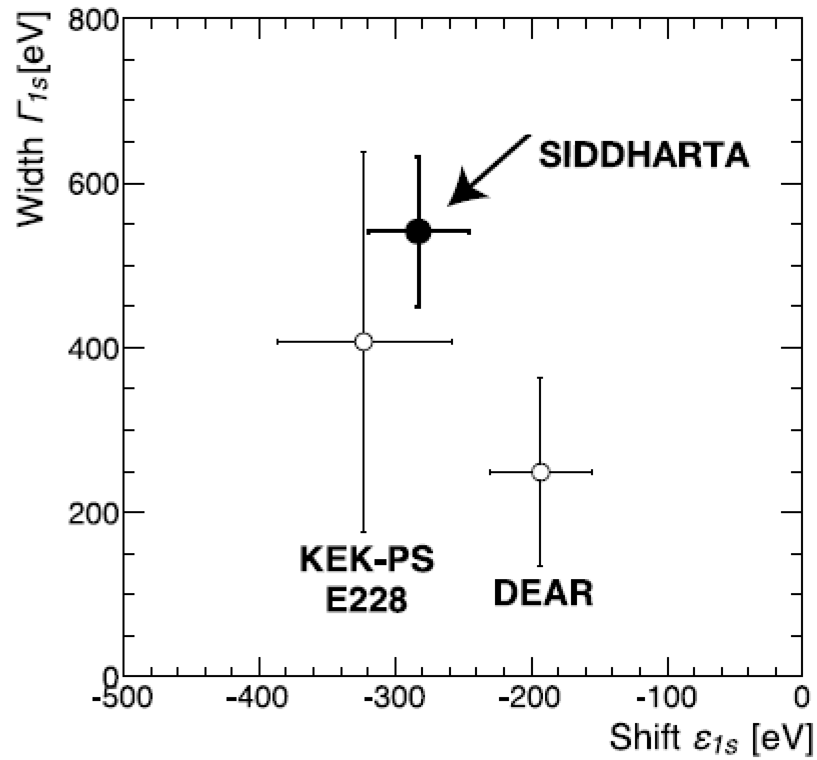
- Sensitive in different energy region & isospin -

① Kaonic-Atom Measurements

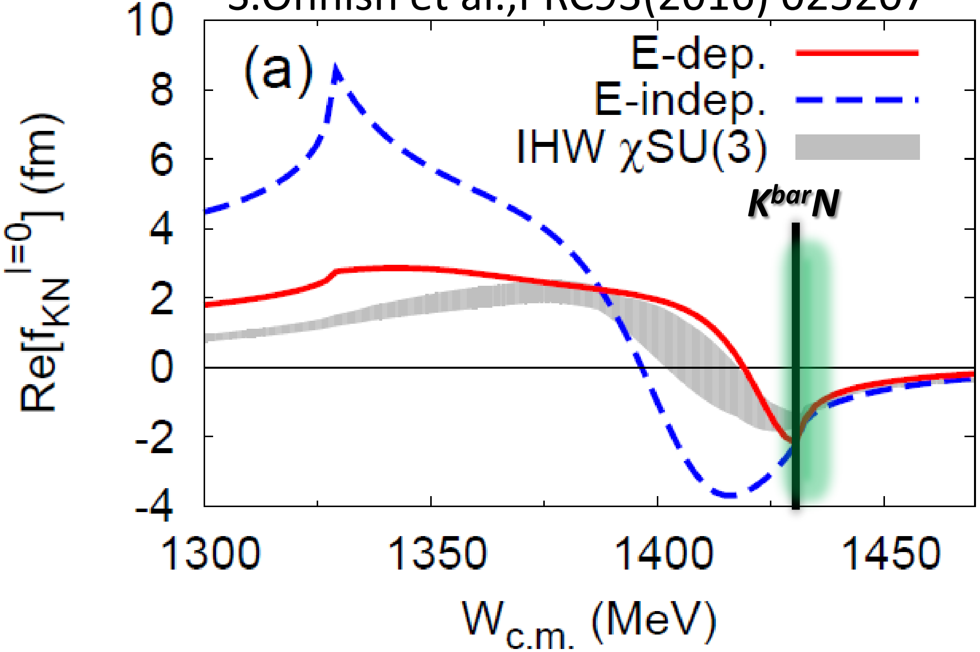
$K^{bar}N$ Interaction at the threshold

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

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



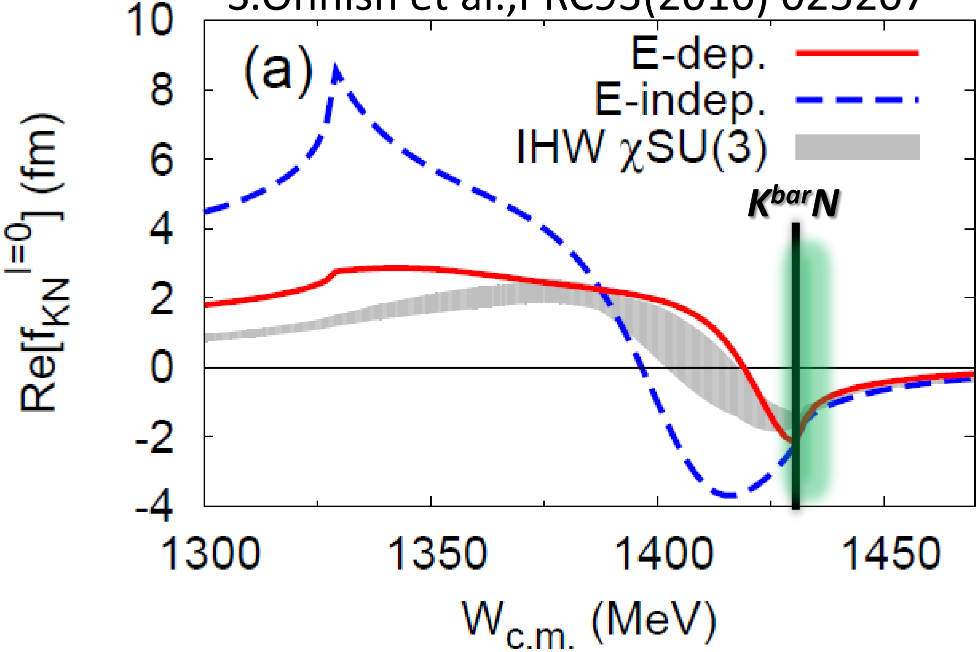
S.Ohnish et al.,PRC93(2016) 025207

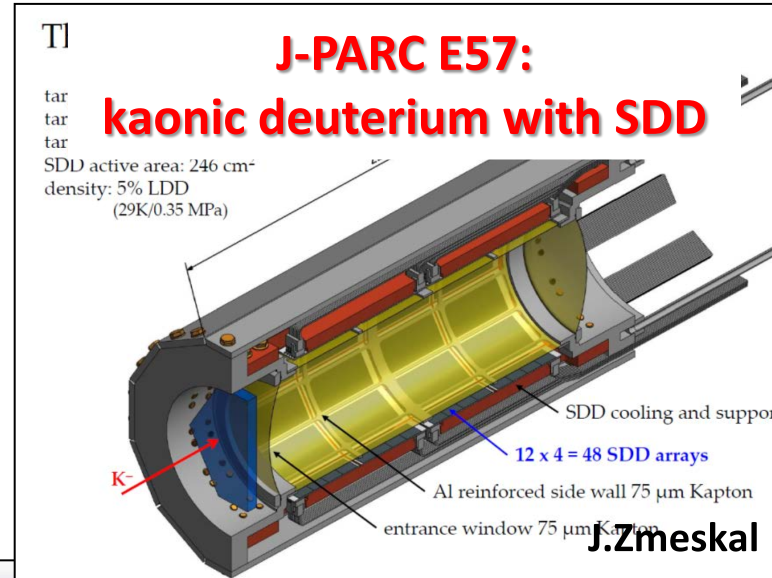


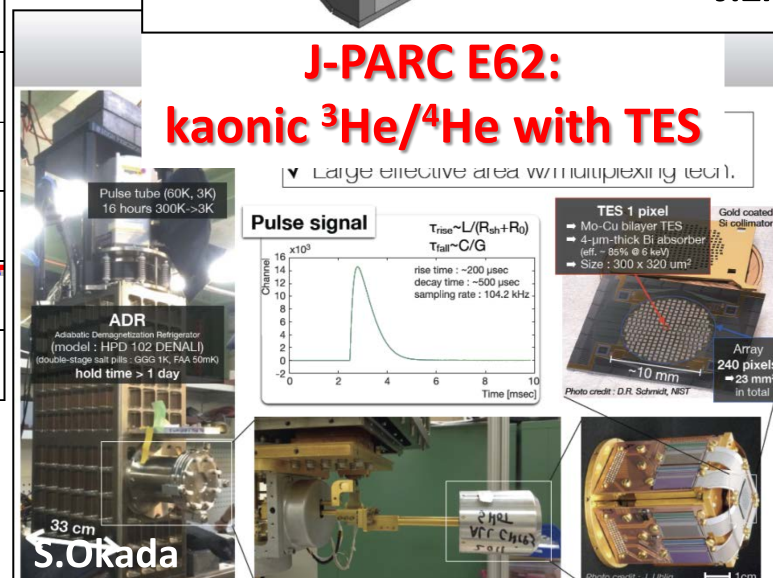
$K^{bar}N$ Interaction at the threshold

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

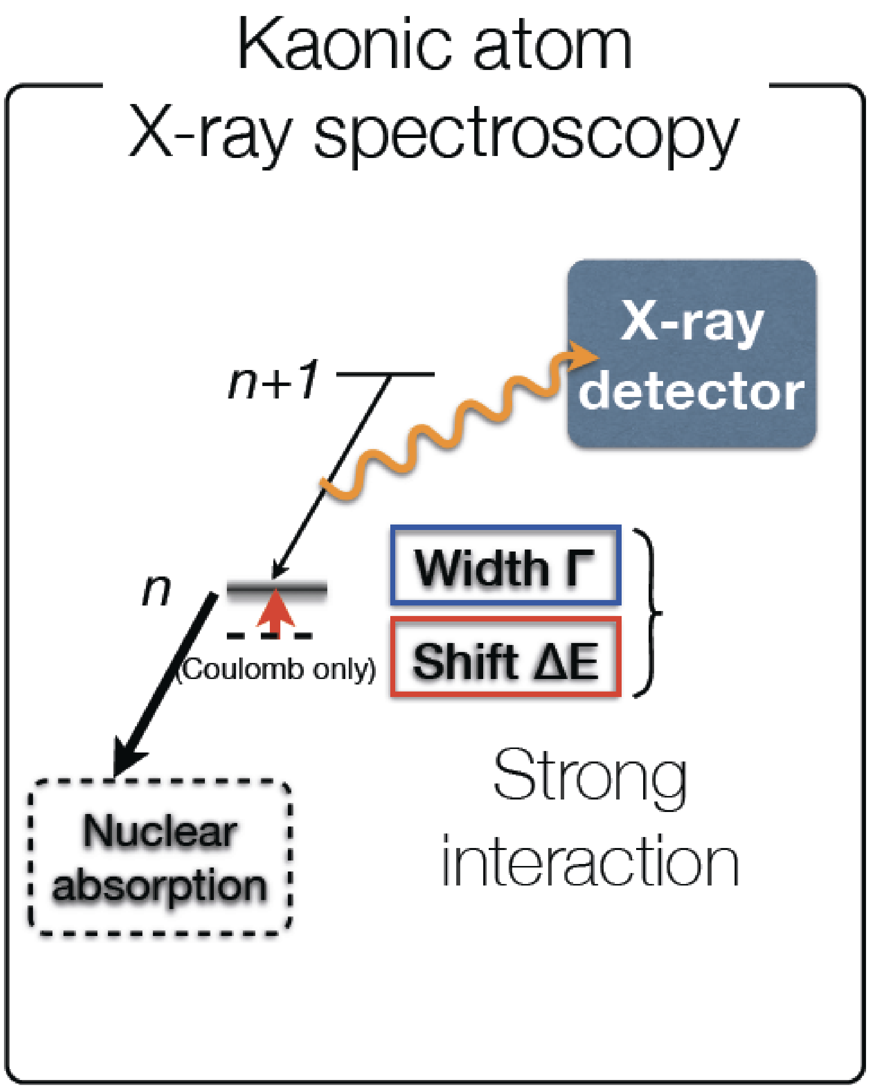
S.Ohnish et al.,PRC93(2016) 025207







$K^{bar}N$ Interaction via Kaonic-atoms



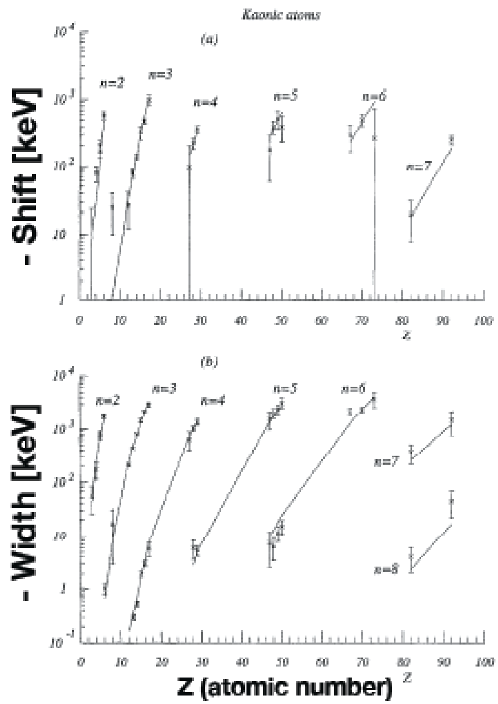
	E62	E57
Kaonic X-ray	**K-He** *3d-2p*	**K-d** *2p-1s*
Energy	~ 6 keV	~ 8 keV
Width	~ 2 eV	~ 1000 eV
Yield per stop-K	~ 7 % (Liquid He)	~ 0.1 % (0.05% of liq. D2 density)
X-ray detector	**TES**	**SDD**
FWHM resolution	~ 5 eV	~ 150 eV
Effective area	~ 0.2 cm^2	~ 200 cm^2
Physics	**K-nucleus potential** — K-N in nuclei —	**KN** (to disantangle I=0,1components) - KN in free space -

S.Okada, 21th J-PARC PAC

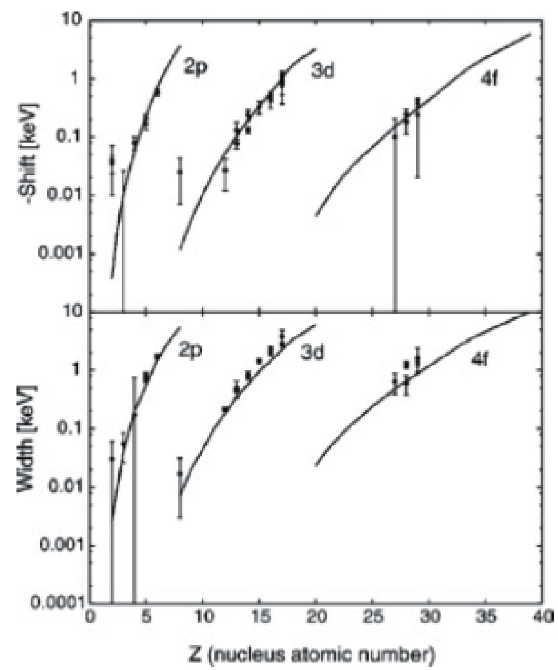
E62: K-nucleus Potential

Two theoretical approaches

Phenomenological Model
— **deep potential** —
typically 180 MeV deep



Chiral Unitary Model
— **shallow potential** —
typically 50 MeV deep



→ Closely related to **K⁻ nuclear cluster** study

→ **Current data quality is not good enough** to determine K-nucl. potential strength

S.Okada, 21th J-PARC PAC

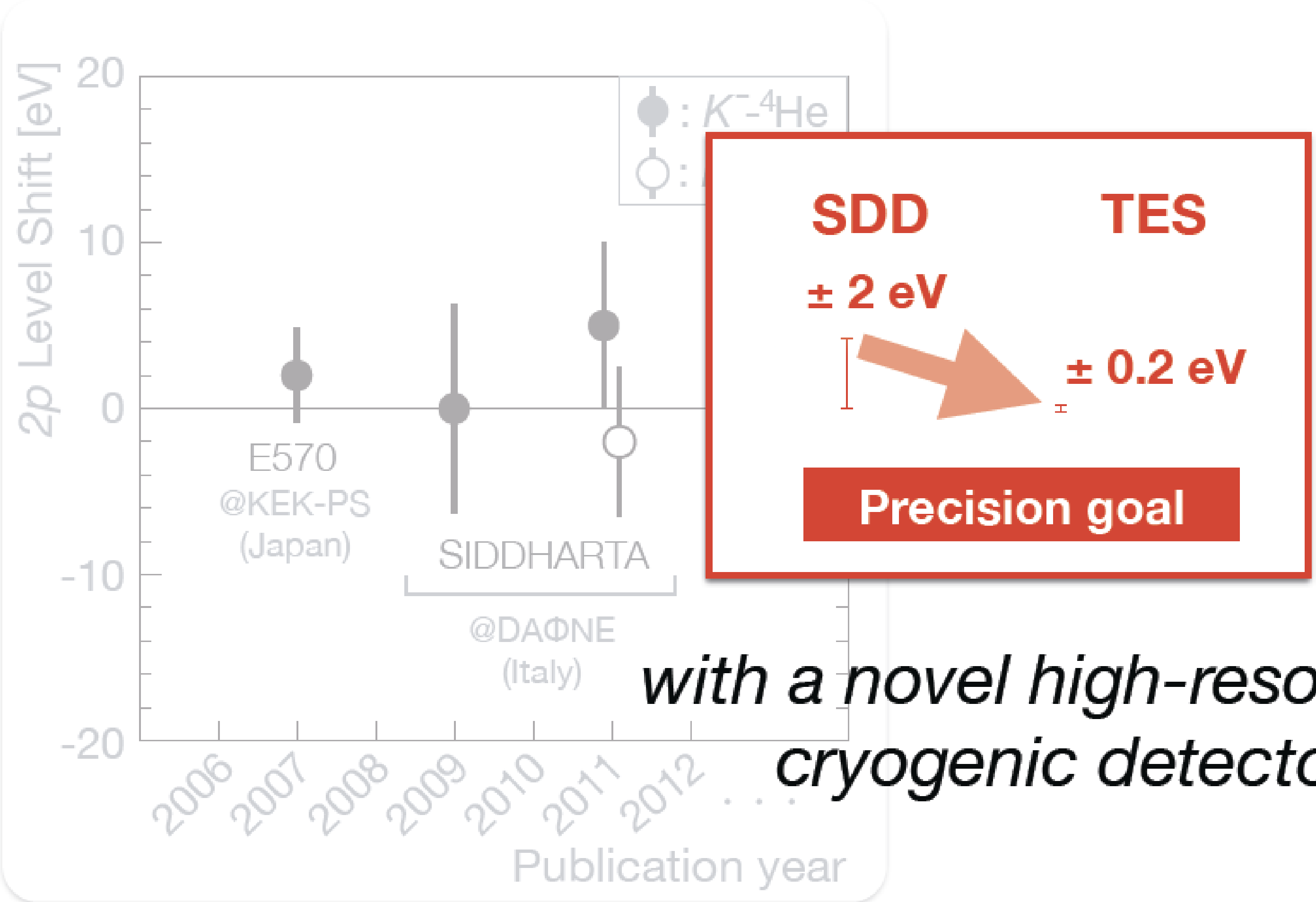
E62: $K^{3/4}$HeX with TES

S.Okada, 21th J-PARC PAC

Theo.

Many of theoretical calculations predict **finite values** of $|\Delta E_{2p}| < 1$ eV (e.g., **~0.2 eV**)

Expt.



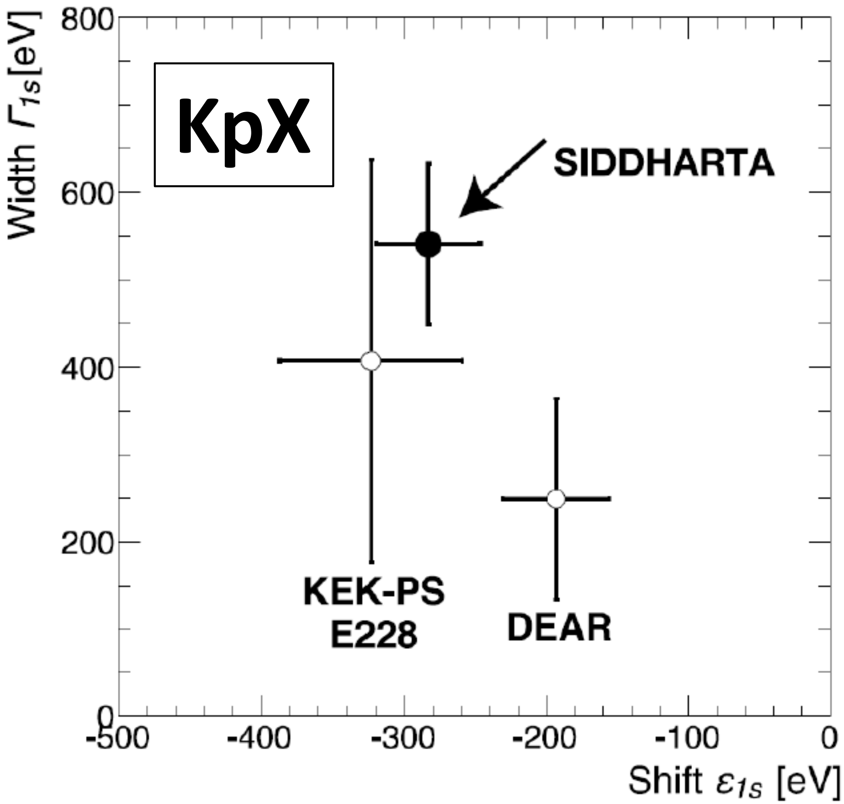
with a novel high-resolution cryogenic detector

E57: KdX Measurement

K-p scattering length

Precise measurement @ SIDDHARTA

- ✓ the strong-int. shift and width of the kaonic hydrogen 1s



K-d scattering length

NO experimental results

- ✓ due to the difficulty of the X-ray measurement
- ✓ missing information in the low-energy K^{bar}N int.

Scattering lengths

J.Zmeskal, 20th J-PARC PAC

Deser-type relation[1)] connect the observables shift ε_{1s} and width Γ_{1s} of the 1s state of K^-d to the real and imaginary part of the scattering length a_{K^-d}

$$\varepsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3 \mu_c^2 a_{K^-d} \boxed{(1 - 2\alpha\mu_c(\ln\alpha - 1)a_{K^-d})}$$

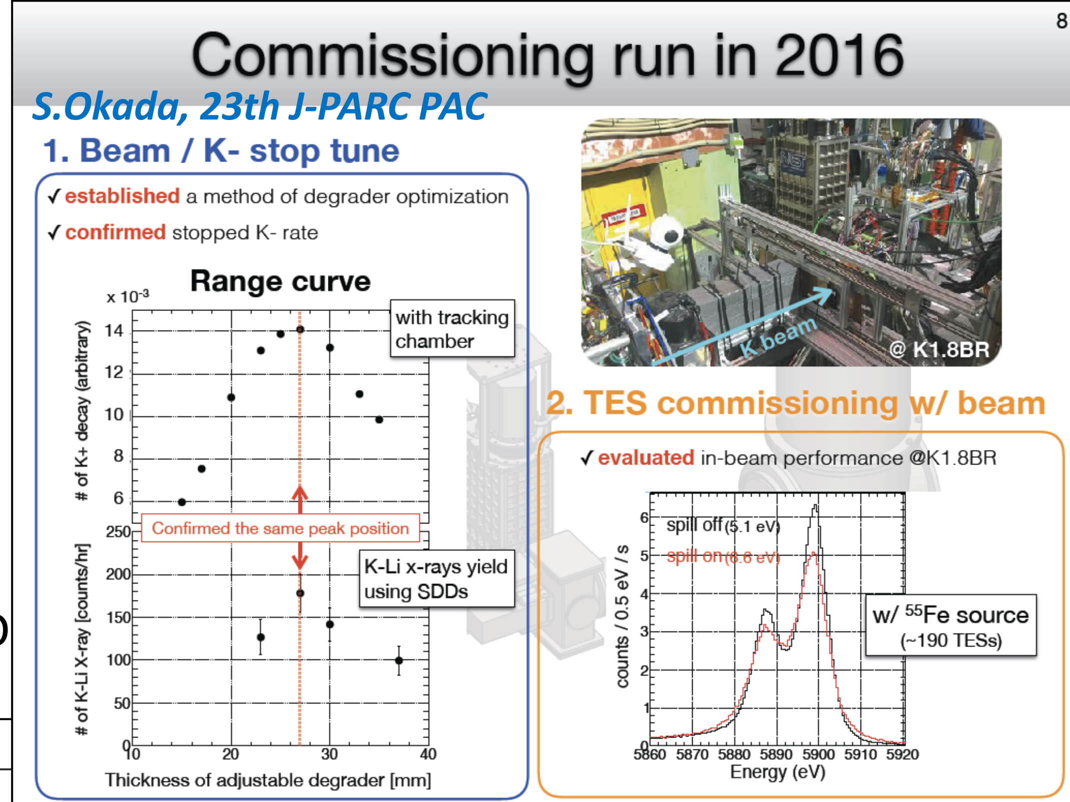
(μ_c reduced mass of the K$^-$p system, α fine-structure constant)

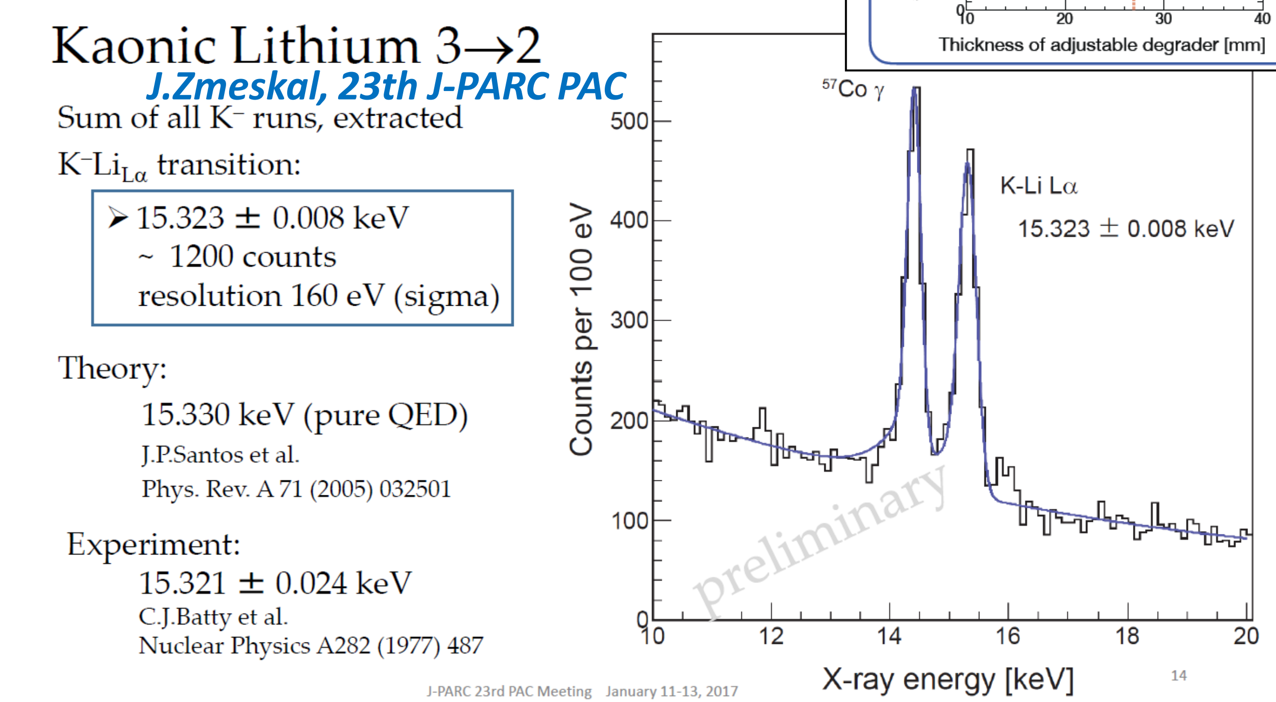
1) U.-G. Meißner, U.Raha, A.Rusetsky, Eur. Phys. J. C35 (2004) 349 next-to-leading order, including isospin breaking corrections

$$\boxed{\begin{aligned} a_{K^-p} &= \frac{1}{2}[a_0 + a_1] \\ a_{K^-n} &= a_1 \end{aligned}} \Leftarrow \boxed{a_{K^-d}}$$

Commissioning Runs

- **Successfully performed in 2016**
  - E62: TES under beam-condition
  - E57: K-Li Lα with prototype SDD





- **Scheduled in 2018**
  - E62: production
  - E57: start from K-p before K-d

② Λ(1405) Measurement

$K^{bar}N$ Interaction below the threshold

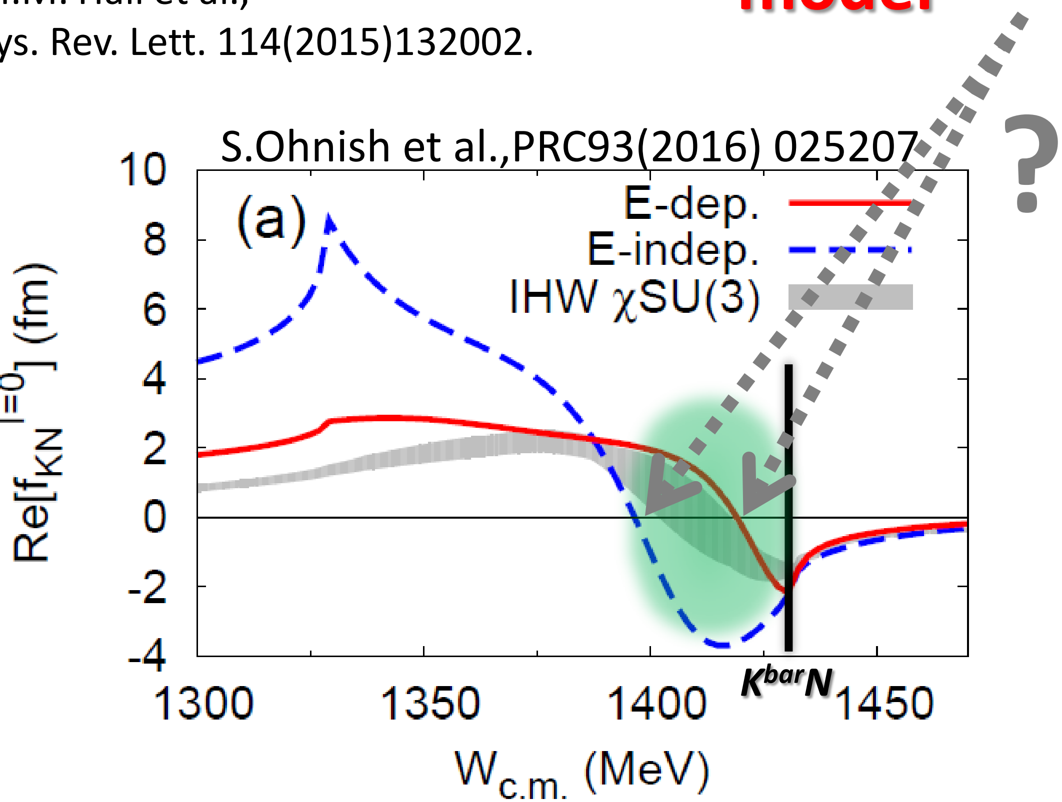
✓ $K^{bar}N$ int. plays an important role for $\Lambda(1405)$

- $J^P = \frac{1}{2}^-$ 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.

? $\Lambda(1405)$ or $\Lambda(1420)$

➢ **Depending on $K^{bar}N$ int. model**

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

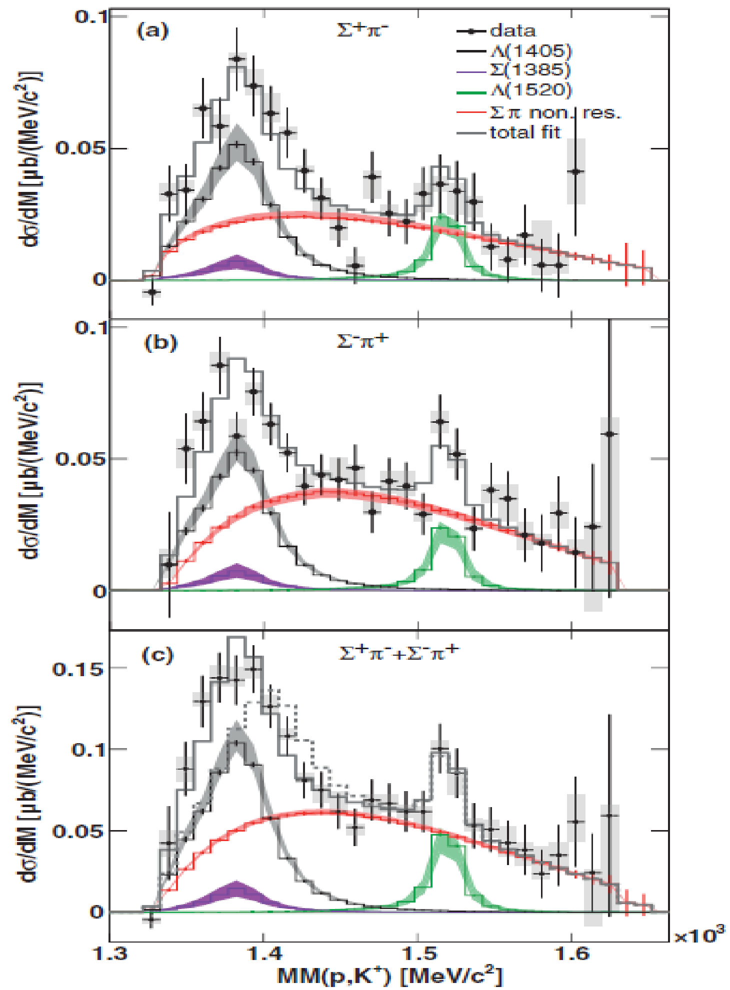


Spectral Shape of Λ(1405)?

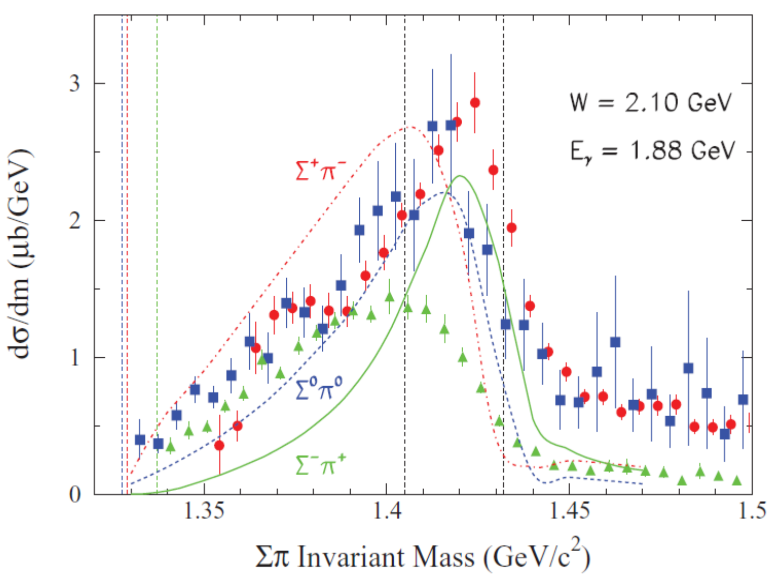
✓ γ/p-induced experiments

- **Spectral shape is still controversial**

$pp \to K^+ p\pi^-\Sigma^+, K^+ p\pi^+\Sigma^-$



$\gamma p \to K^+\pi^-\Sigma^+, K^+\pi^0\Sigma^0, K^+\pi^+\Sigma^-$

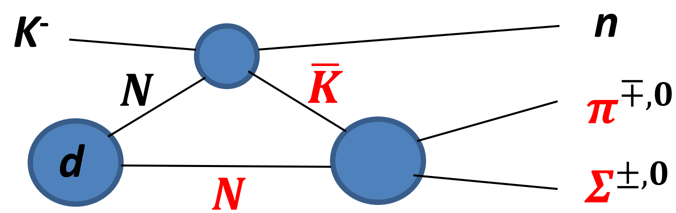


CLAS collaboration: PRC87, 035206

HADES collaboration: PRC87, 025201

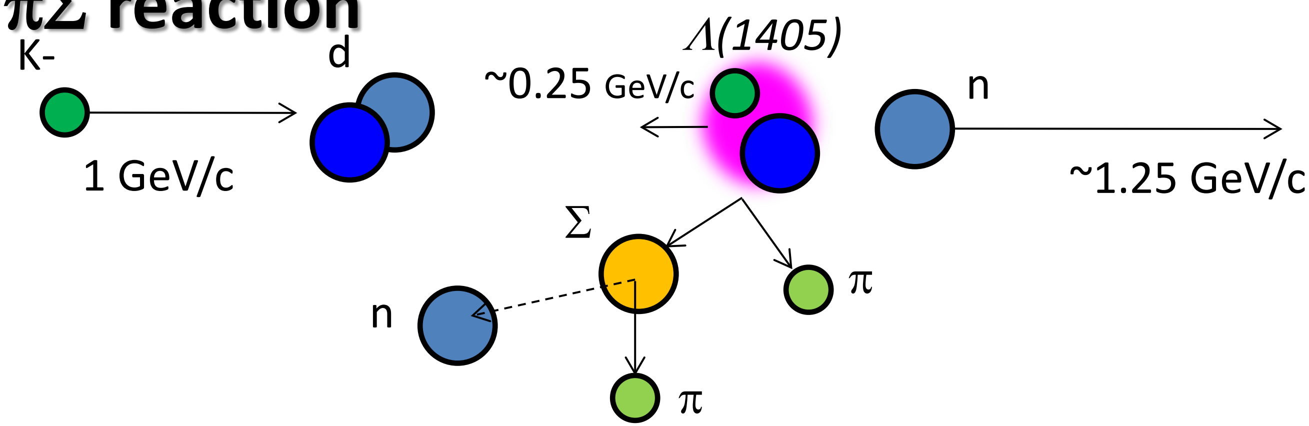
J-PARC E31 Experiment

Measurement of Λ(1405) line shape via $K^{bar}N \rightarrow \pi\Sigma$



Inoue

- d(K⁻,n)πΣ reactions at θ_n~0 degree to enhance **S-wave $K^{bar}N \rightarrow \pi\Sigma$ reaction**



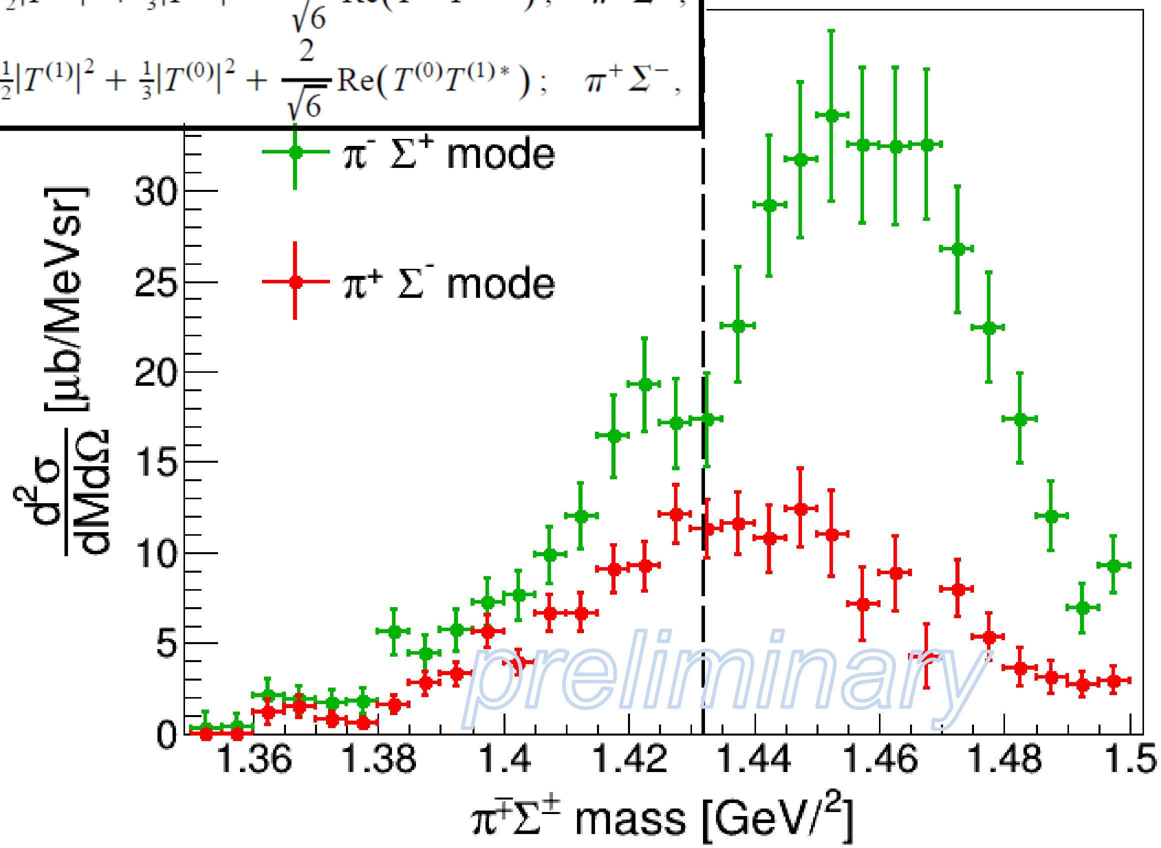
- Decomposition of I=0 and 1 amplitudes by identifying final state

Λ(1405)	**I = 0**	**S wave**	$\pi^{\pm}\Sigma^{\mp}, \pi^0\Sigma^0$
Σ(1385)	I = 1	P wave	$\pi^{\pm}\Sigma^{\mp}, \pi^0\Lambda$
Non-resonant	I = 0,1	S,P,D,…	

I = 0, 1 Mode ($\pi^{\pm}\Sigma^{\mp}$)

$$\tfrac{1}{2}|T^{(1)}|^2 + \tfrac{1}{3}|T^{(0)}|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}(T^{(0)}T^{(1)*})\,; \quad \pi^-\Sigma^+,$$

$$\tfrac{1}{2}|T^{(1)}|^2 + \tfrac{1}{3}|T^{(0)}|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}(T^{(0)}T^{(1)*})\,; \quad \pi^+\Sigma^-,$$

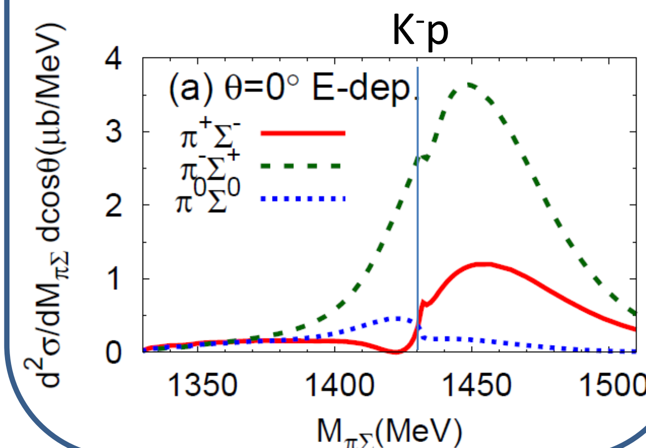


c.f.

Faddeev calc. (AGS)

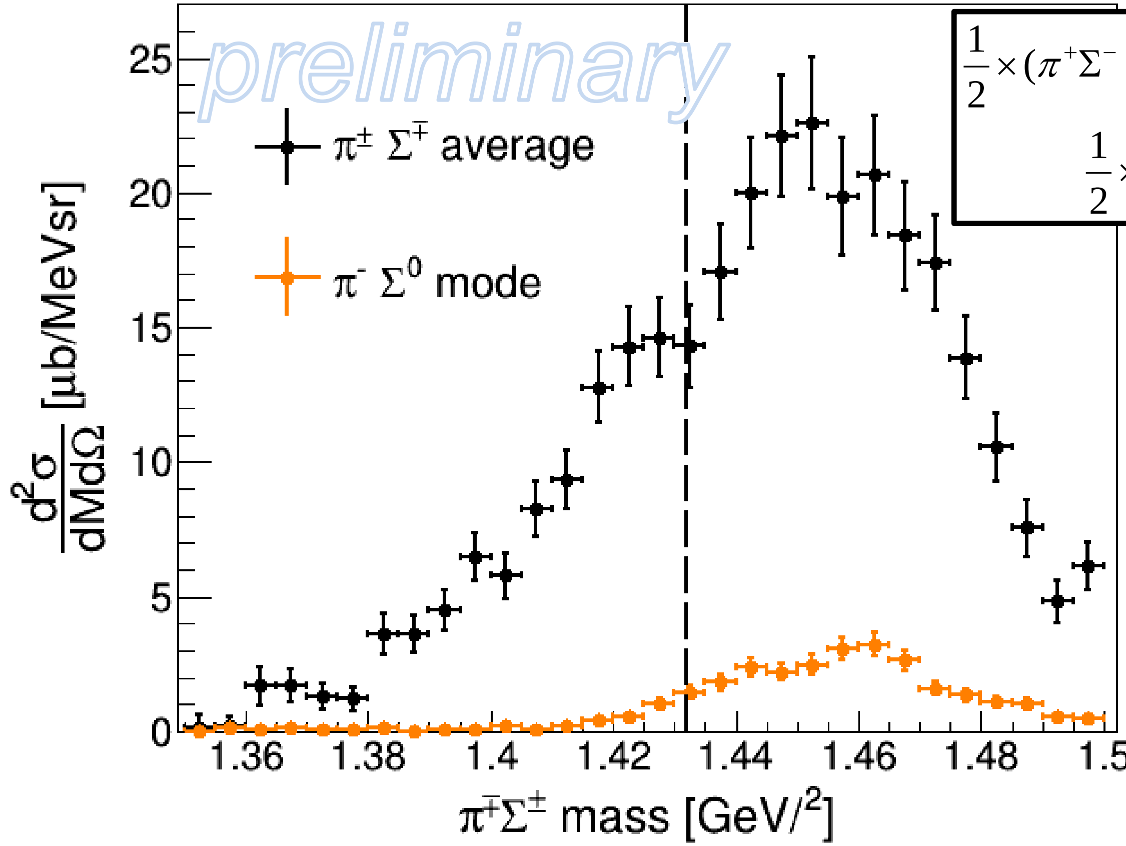
S.Ohnishi et al., PRC93(2016)025207

w/ angular dependence



- interference between the I = 0 and 1 terms of the $\pi\Sigma$ scattering amplitudes is observed

Comparison between
I = 0, 1 ($\pi^{\pm}\Sigma^{\mp}$) & I = 1 ($\pi^{-}\Sigma^{0}$)

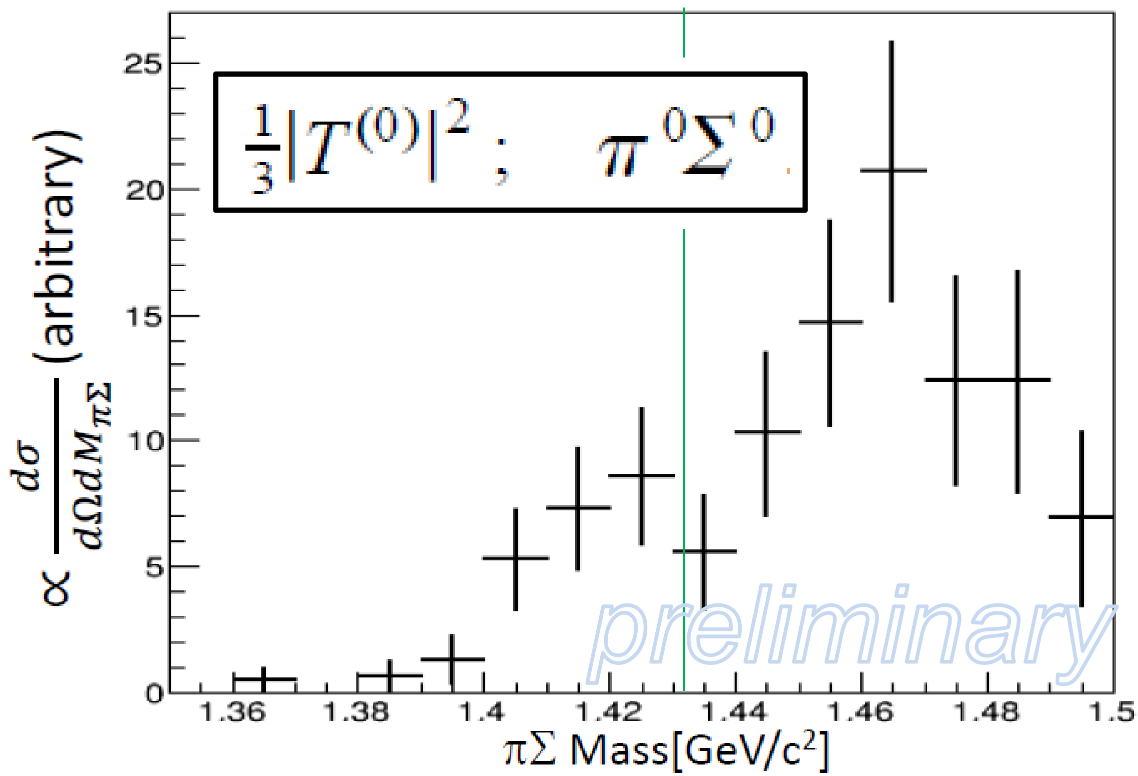


$$\frac{1}{2}\times(\pi^{+}\Sigma^{-}+\pi^{-}\Sigma^{+})=\frac{1}{2}\left|T^{(1)}\right|^{2}+\frac{1}{3}\left|T^{(0)}\right|^{2}$$

$$\frac{1}{2}\times(\pi^{-}\Sigma^{0})=\frac{1}{2}\left|T^{(1)}\right|^{2}$$

- I = 0 dominant below the threshold
  - $|T^{(0)}|^2/|T^{(1)}|^2 \sim 100$

I = 0 Mode ($\pi^0\Sigma^0$)

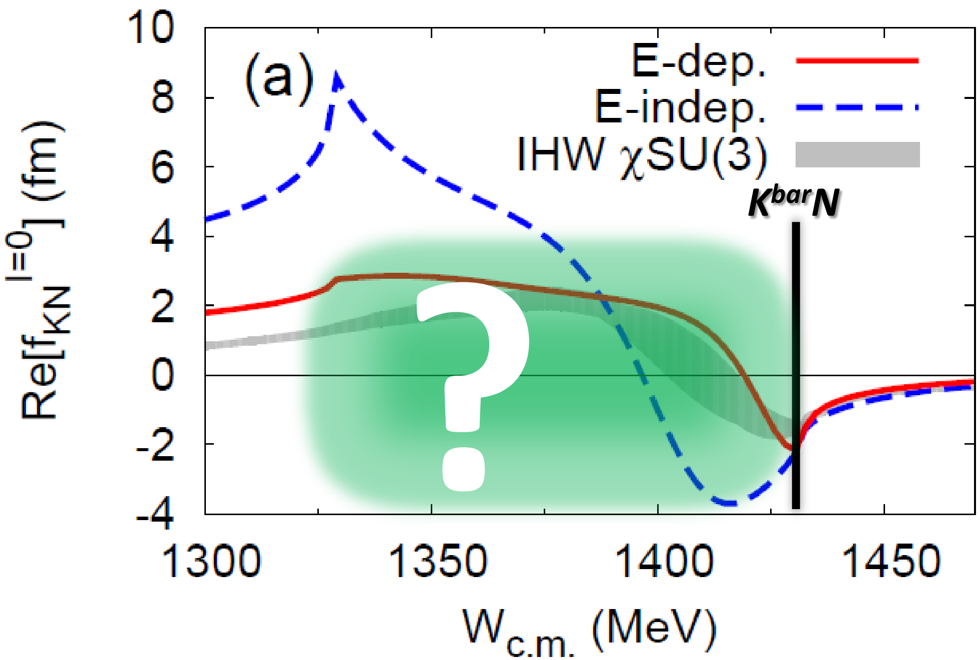


- The pure I = 0 channel is observed
- For further statistics:
  - **E31-2nd will be performed in May-Jun. 2017**

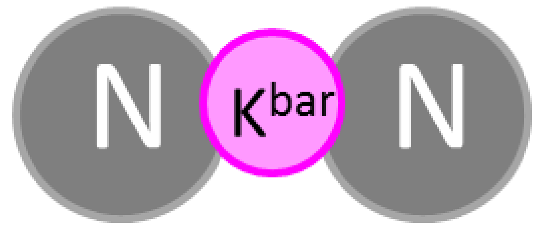
③ Kaonic-Nuclei Searches

Kaonic Nuclei

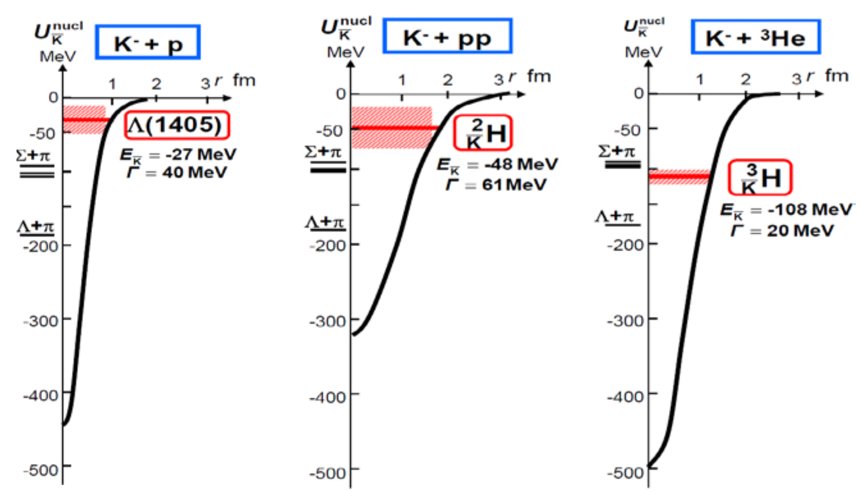
- **Bound states of nucleus and anti-kaon**
- Predicted as a consequence of **attractive $K^{bar}N$ interaction in I=0**



the simplest kaonic nuclei:



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



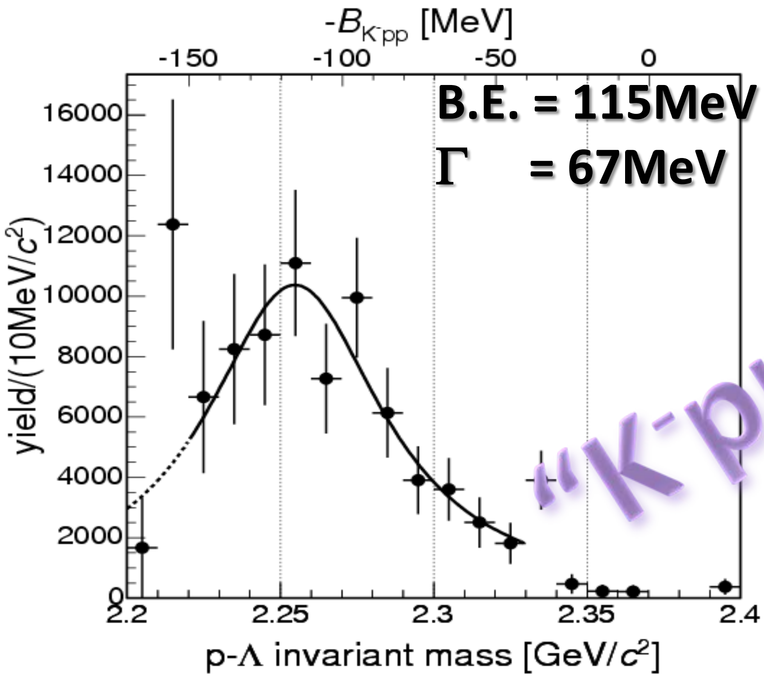
Y.Akaishi & T.Yamazaki, PLB535, 70(2002).

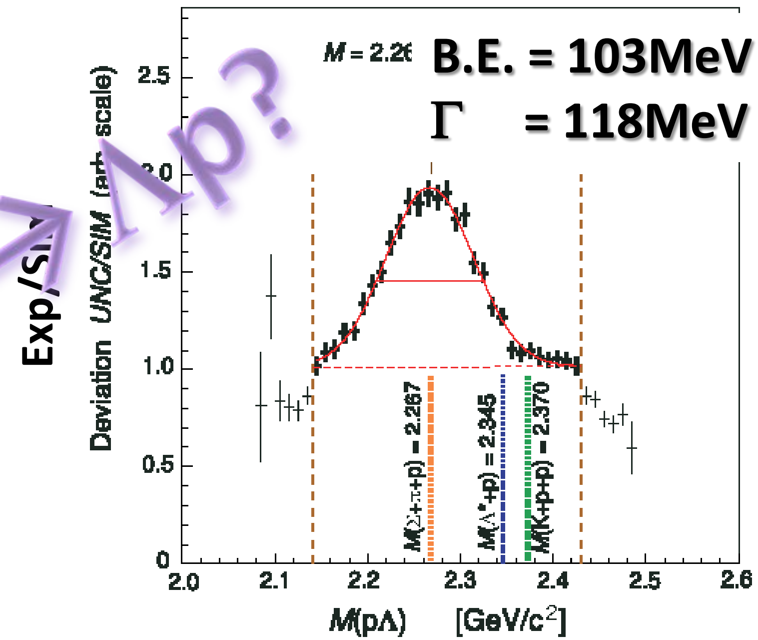
Theoretical Calculations on $K^{bar}NN$

$K^{bar}N$ 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*

Pioneering Experiments on K^{bar}NN





FINUDA@DAΦNE

PRL**94**(2005)212303

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

2NA followed by FSI?

PRC74(2006)025206

PRC82(2010)034608 etc.

DISTO@SATURNE

PRL**104**(2010)132502

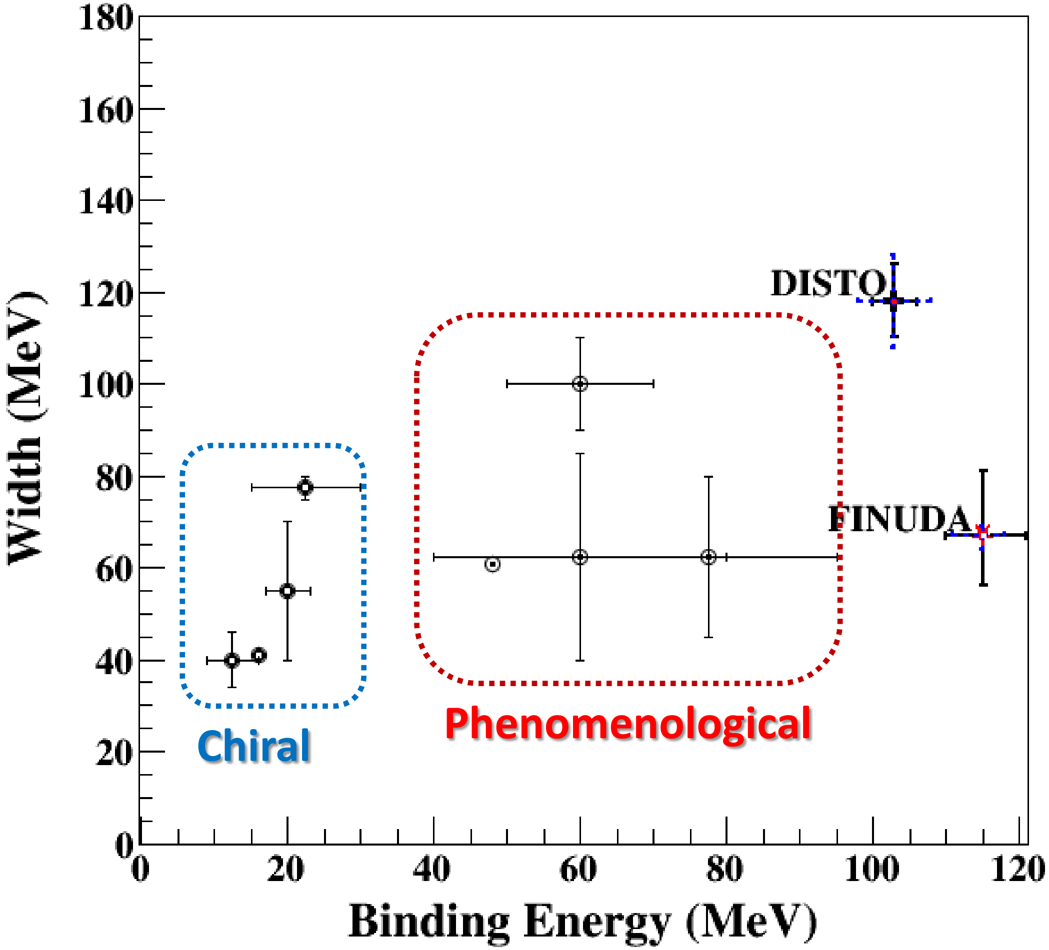
p + p → (Λ + p) + K$^+$ @ 2.85GeV

pp→p(N*)→p(ΛK$^+$)?

PRC92(2015)044002

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

Comparison between Calcs. and Exps.



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

Upper limits were also obtained:

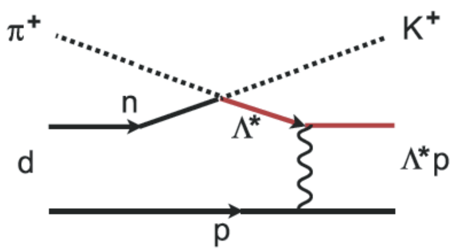
- **LEPS@SPring8 [Inclusive d(γ, $K^+\pi^-$)X]**
- **HADES@GSI [Exclusive pp→pΛK^+]**

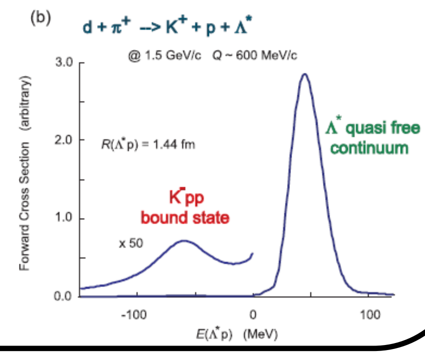
Recent Measurement at J-PARC E27

π^+ + "n" --> "Λ*" + K^+

"Λ*" + "p" --> bound K^-pp *minor*

--> quasi-free Λ* *dominant*





- **Exclusive** $\pi^+ d \rightarrow K^+ Y p$
  - $p_{\pi+}$ = 1.69 GeV/c
  - $\Delta p/p \sim 2\times10^{-3}$
  - $\Delta\Omega \sim 100$ msr
  - **final-state is identified by MM[d(π^+,K^+pp)X]**
- **Bump structure in $\Sigma^0 p$ decay mode:**
  - Mass

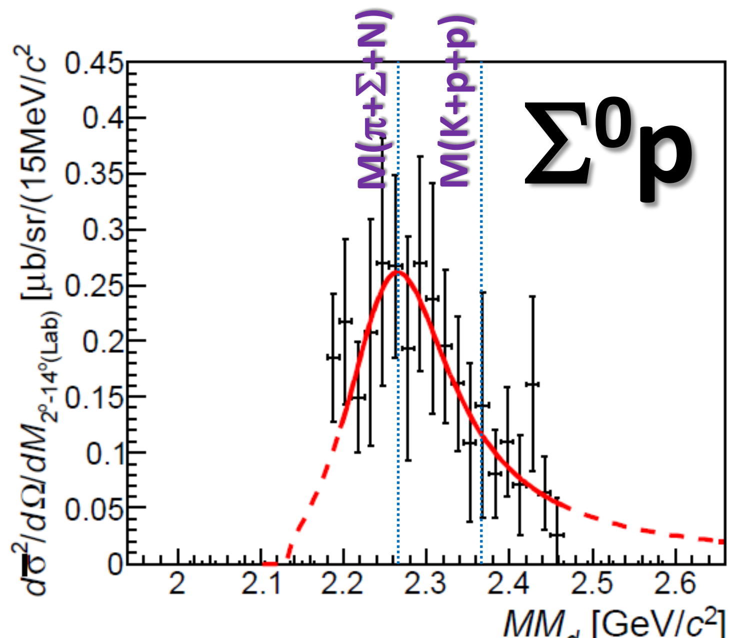
$$2275\ ^{+17}_{-18}\ (\mathrm{stat.})\ ^{+21}_{-30}\ (\mathrm{syst.})\ \mathrm{MeV}/c^2$$

  - Binding energy

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

  - Width

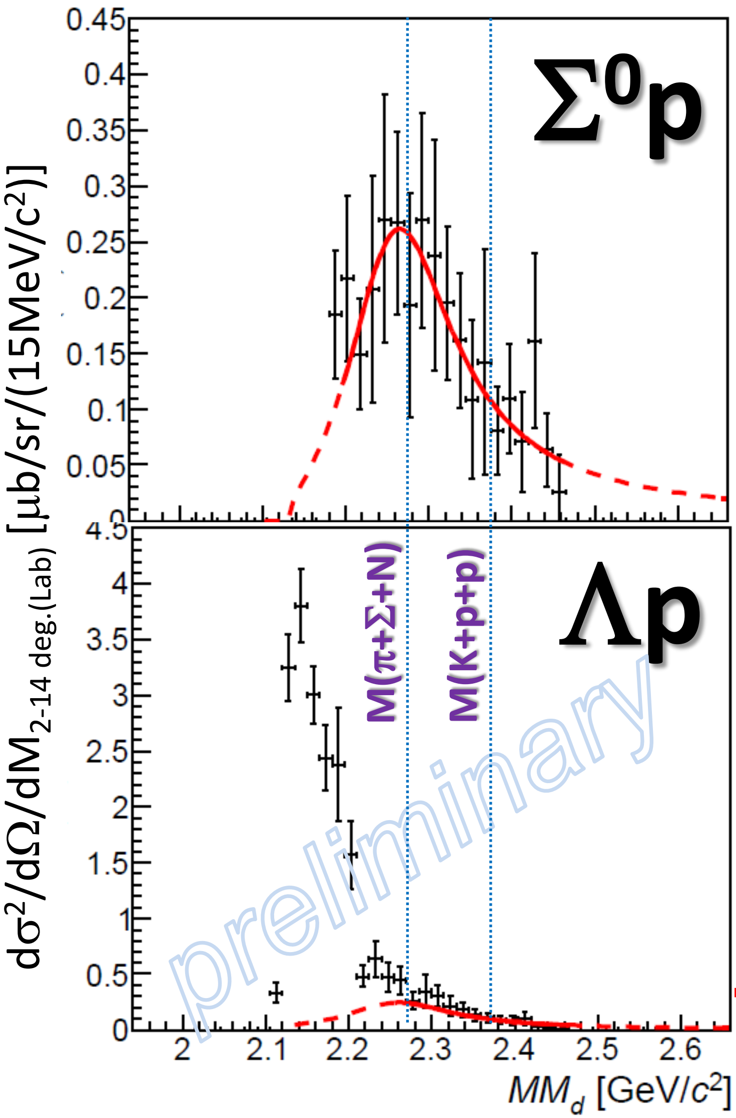
$$162\ ^{+87}_{-45}\ (\mathrm{stat.})\ ^{+66}_{-78}\ (\mathrm{syst.})\ \mathrm{MeV}$$



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

Recent Measurement at J-PARC E27

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



- **Decay branch:**

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

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

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

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

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

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

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

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

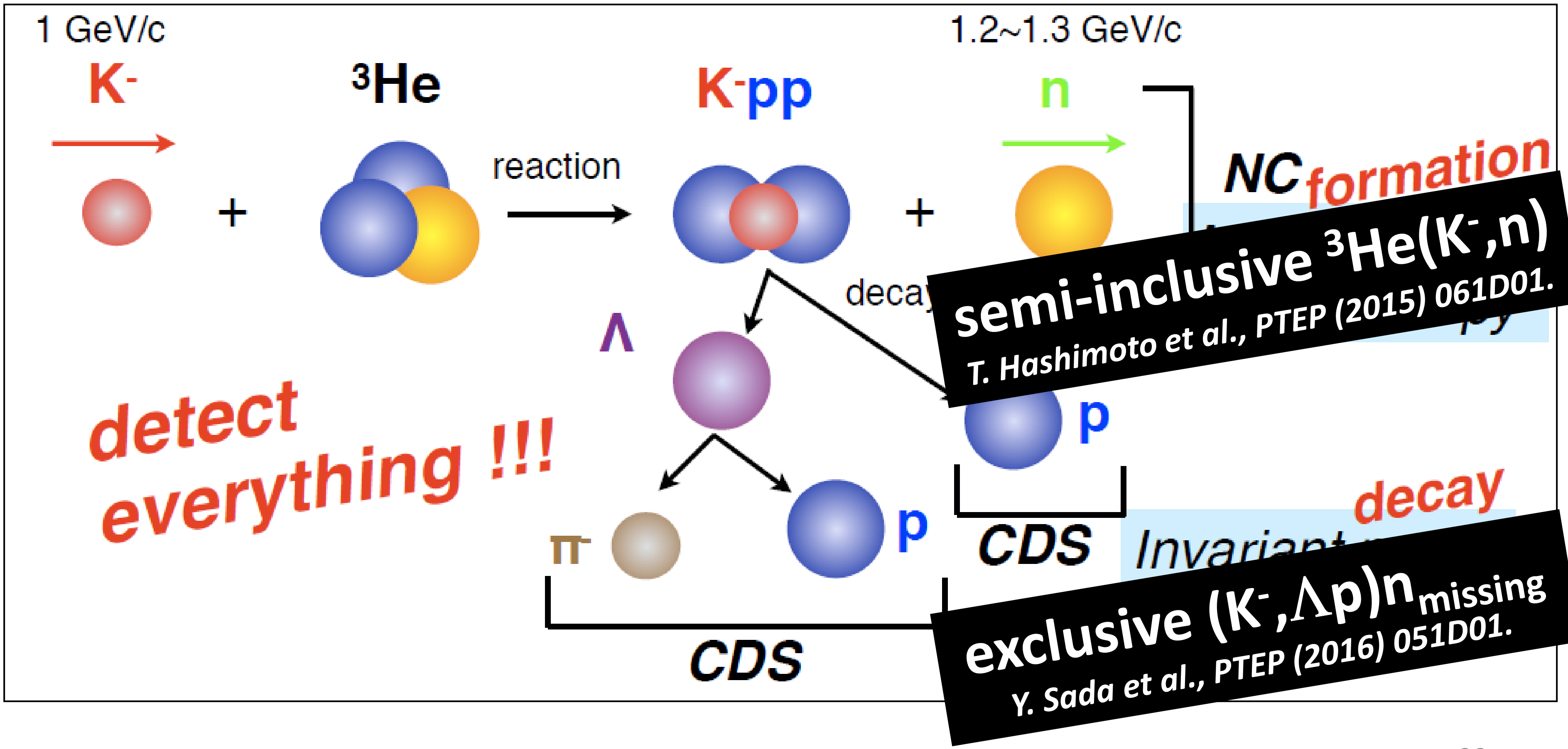
→ large prob. of Λ(1405)p→"K$^-$pp"

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

T.Nagae

J-PARC E15 Experiment

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



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

--- result of E15-1st in 2013 ---

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
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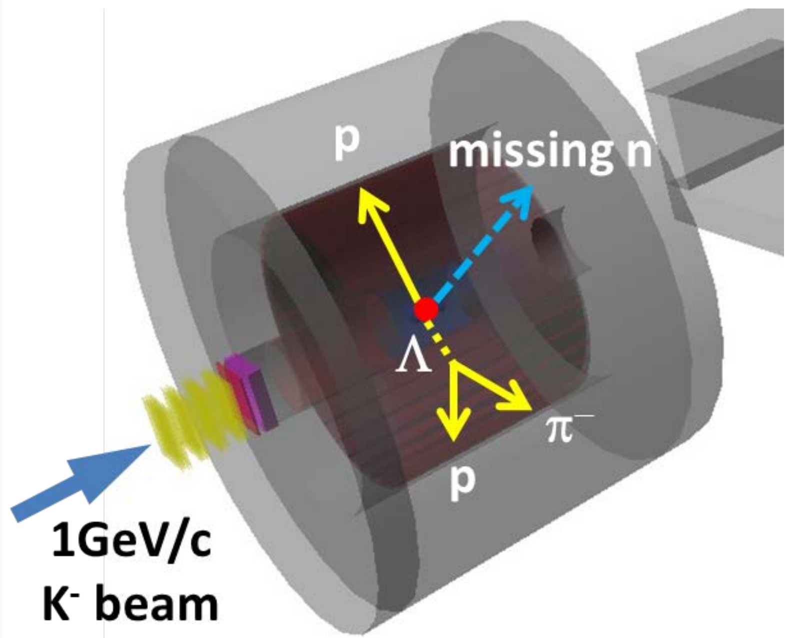
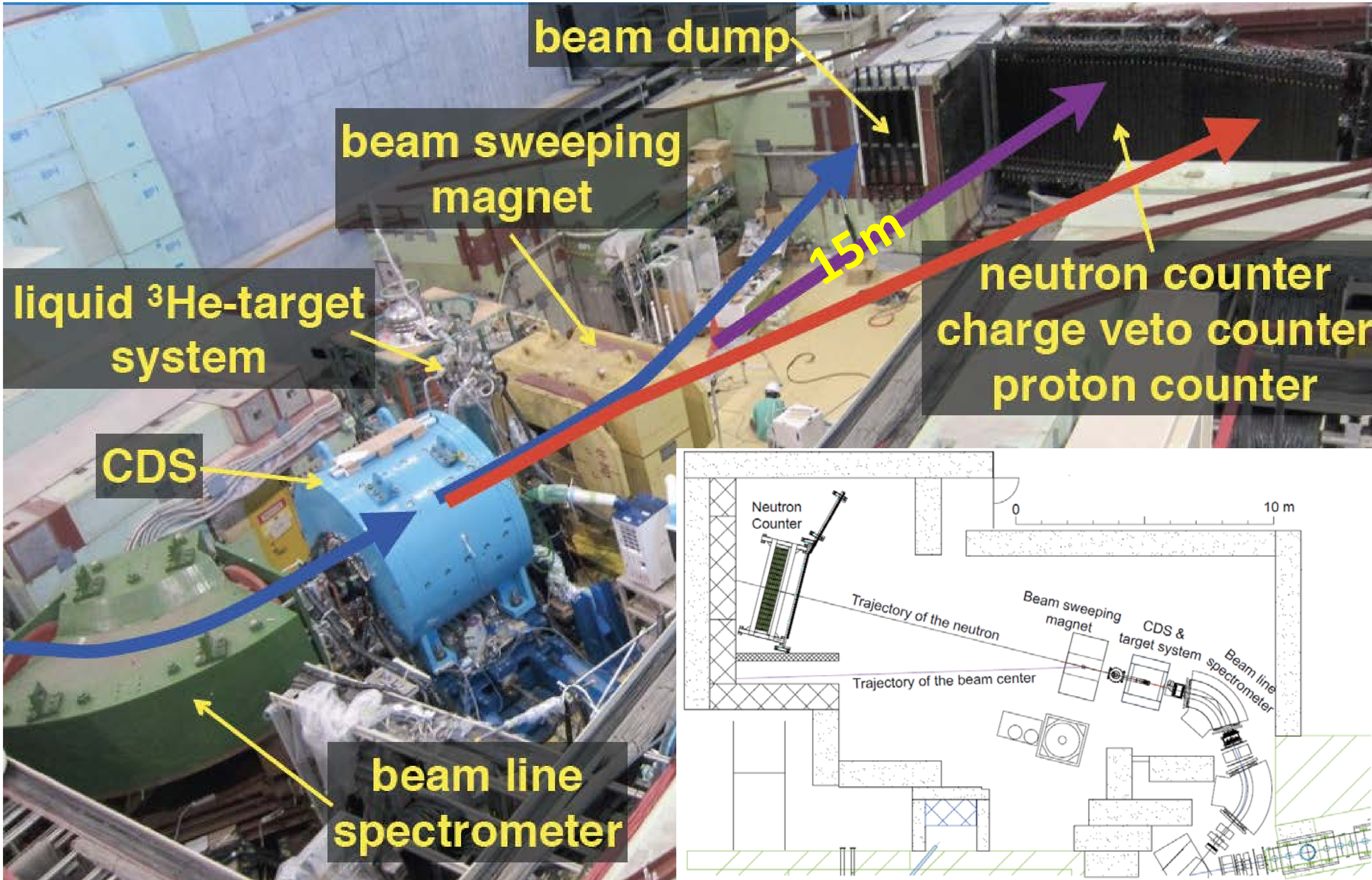


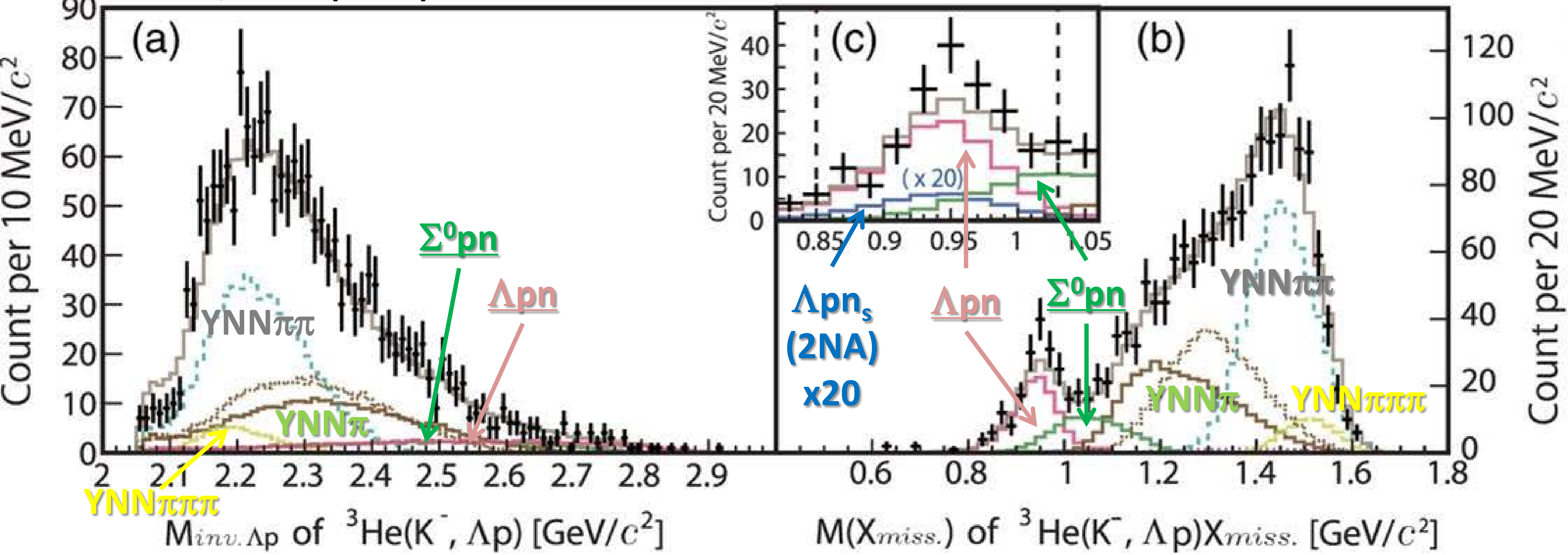
Experimental Setup



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

n-ID from Inclusive ^{3}He(K$^-$,Λp)X

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



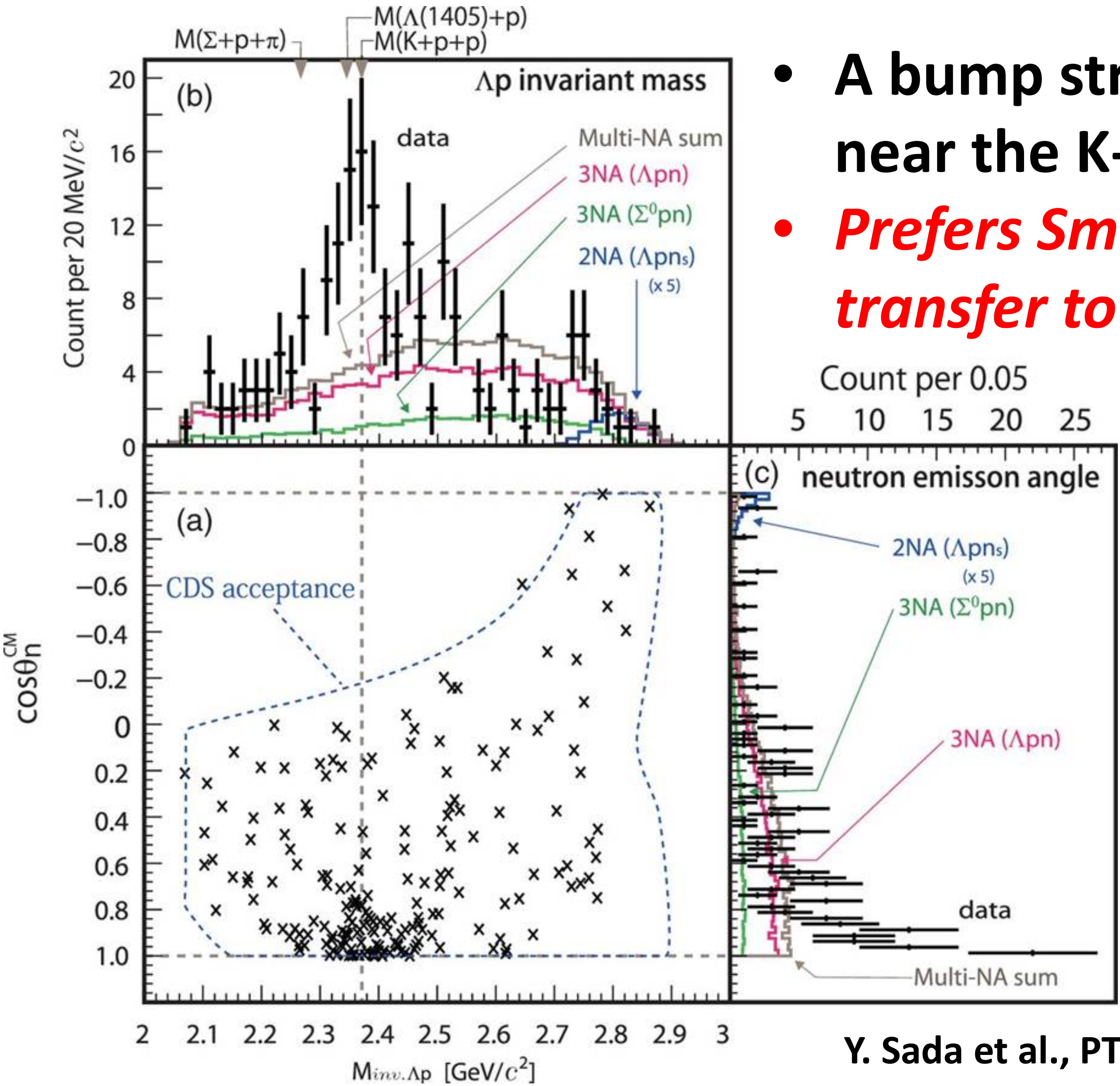
- Global fit both in Λp invariant- and missing-mass
  - σ ~ 10 MeV/c^2
  - w/ simulated spectra of 2NA/3NA

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

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

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

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



- **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?**
  - **…**

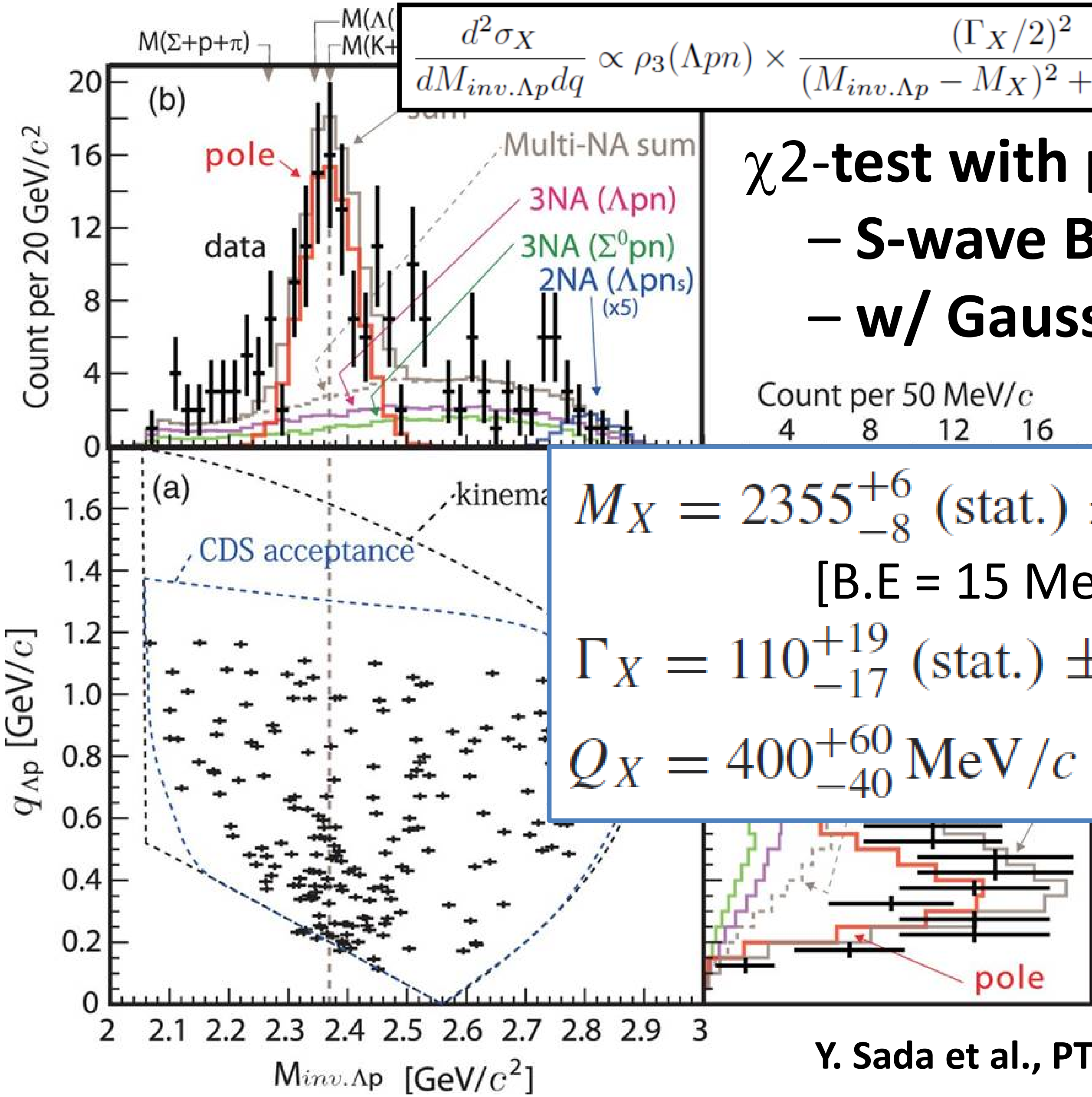
Y. Sada et al., PTEP (2016) 051D01.

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**



$$M_X = 2355^{+6}_{-8}\ (\text{stat.}) \pm 12\ (\text{syst.})\ \text{MeV}/c^2$$

[B.E = 15 MeV/c²]

$$\Gamma_X = 110^{+19}_{-17}\ (\text{stat.}) \pm 27\ (\text{syst.})\ \text{MeV}/c^2$$

$$Q_X = 400^{+60}_{-40}\ \text{MeV}/c$$

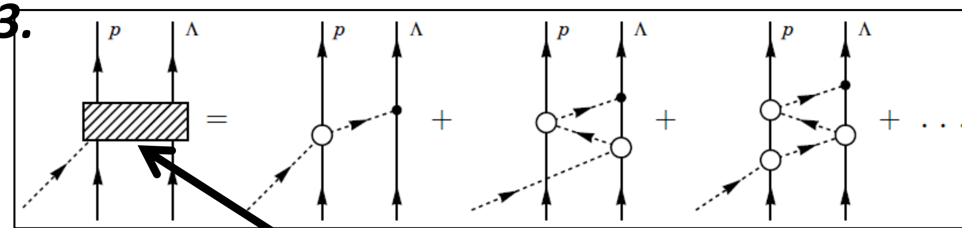
Y. Sada et al., PTEP (2016) 051D01.

A Theoretical Interpretation

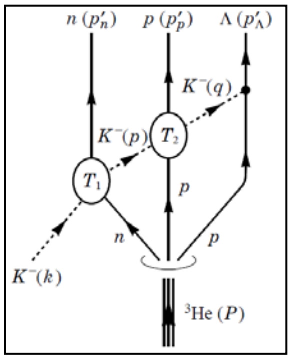
Sekihara, Oset, Ramos, PTEP(2016)123D03.

Chiral unitary approach

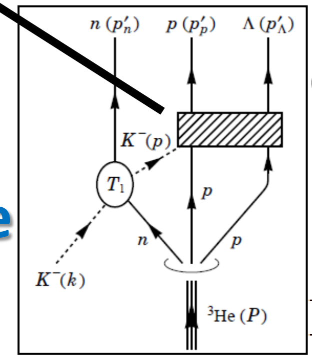
Sekihara



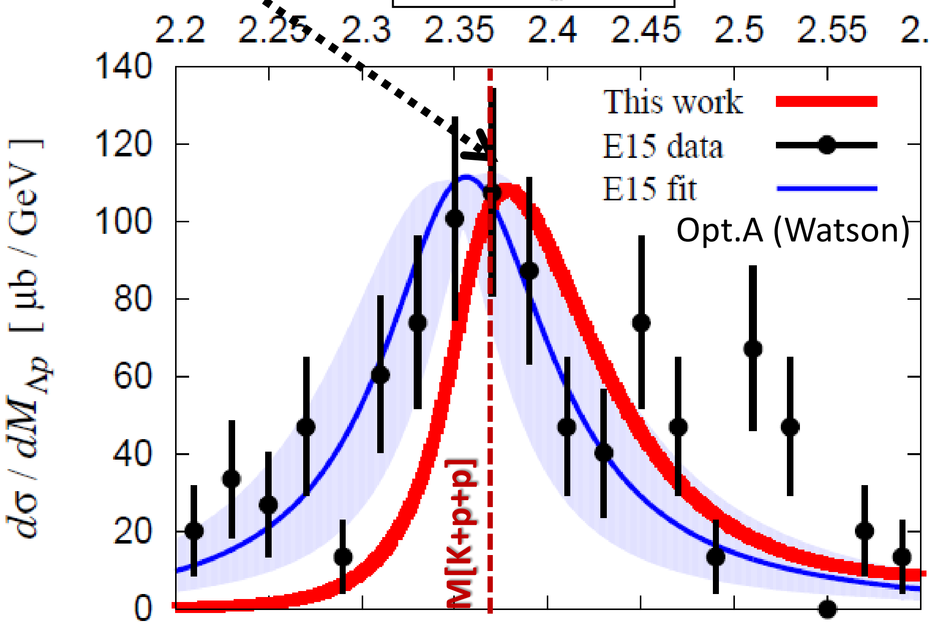
Uncorrelated Λ(1405)p state

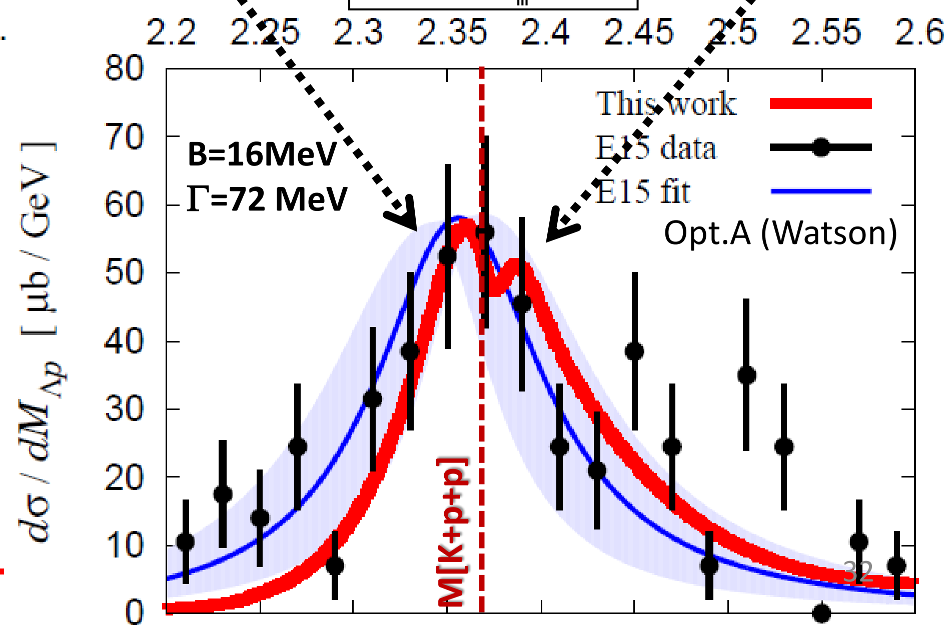


K^{bar}NN bound-state



quasi-elastic kaon scattering





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

E15-2nd Experiment

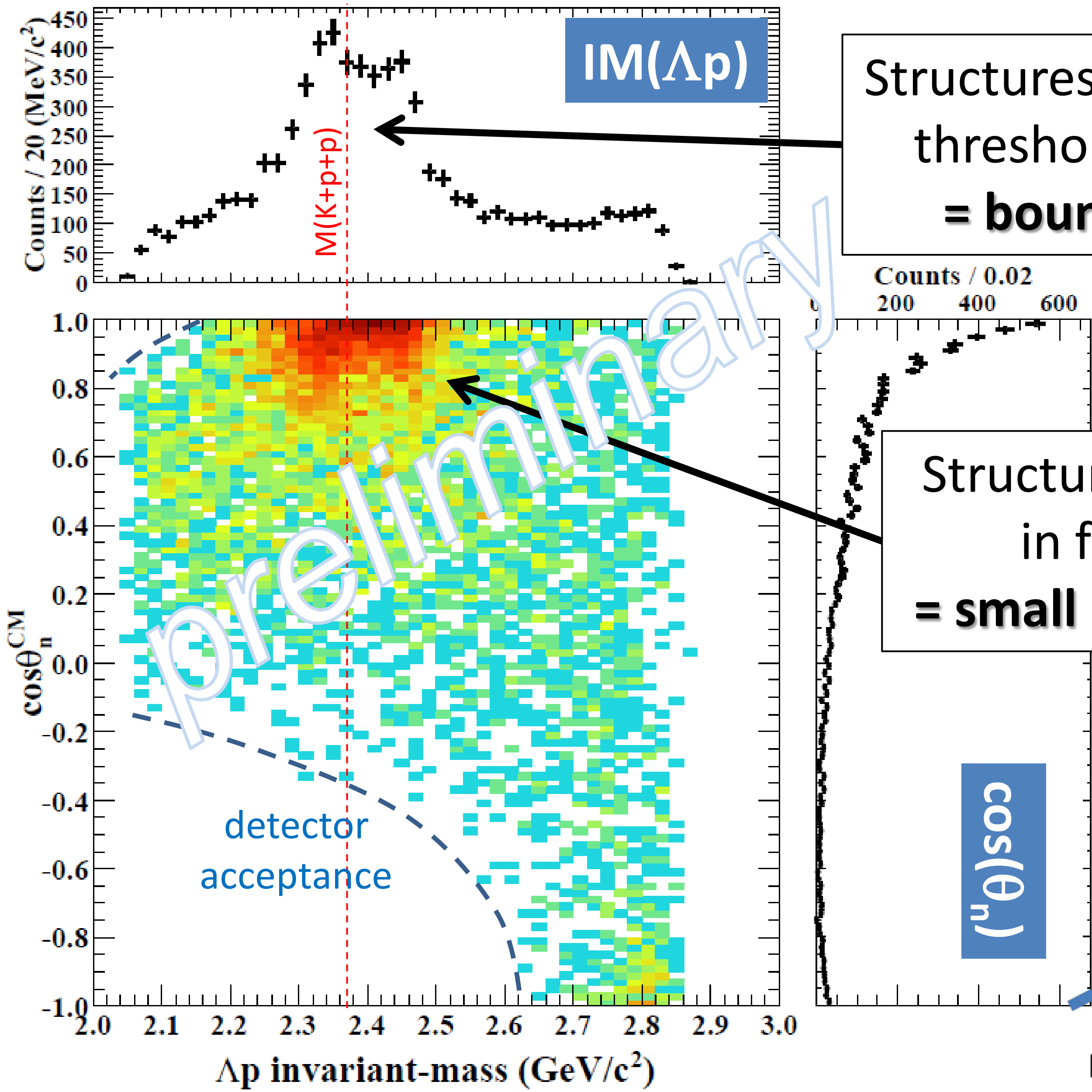
--- completed in Dec. 2015 ---

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

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

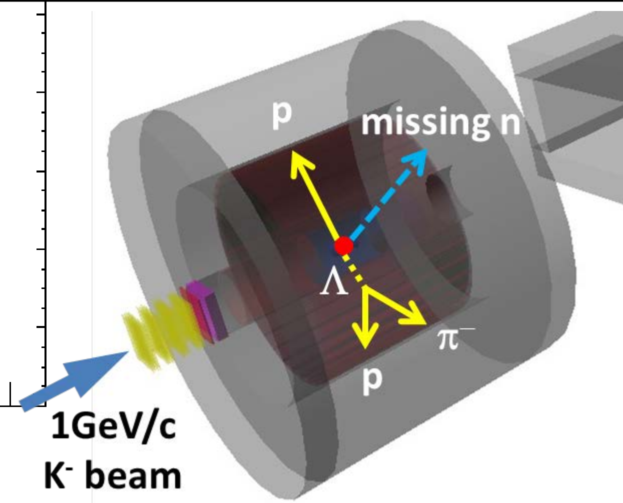
Will be published as "T.Yamaga et al., XXX (2017) XXX."

Results of $^3He(K^-,\Lambda p)n$ [E15-2nd]

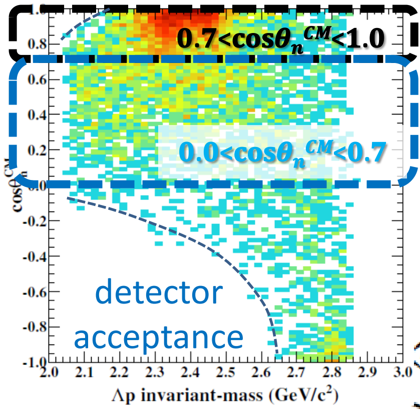


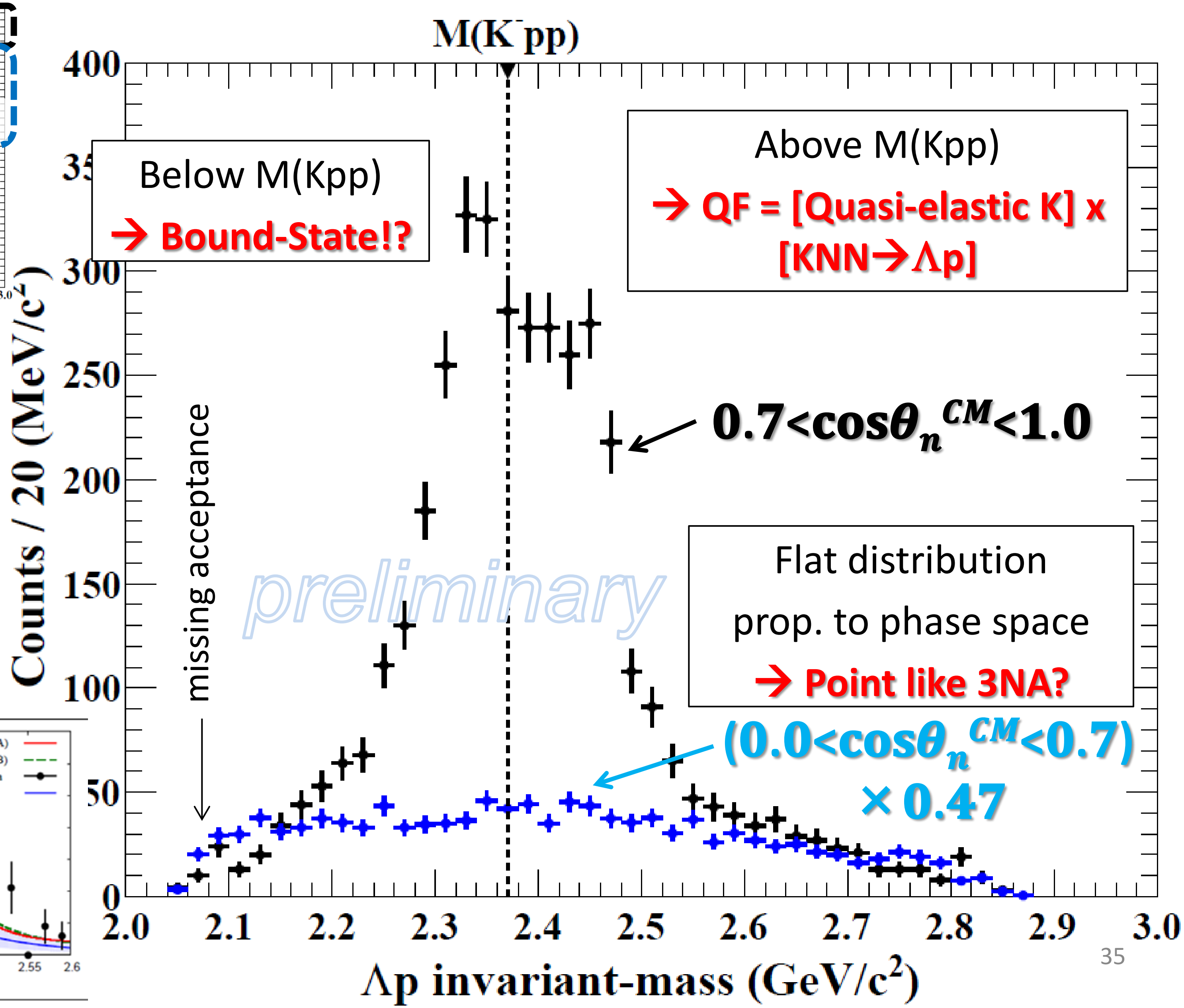
Structures around the Kpp threshold can be seen
= bound-state + QF

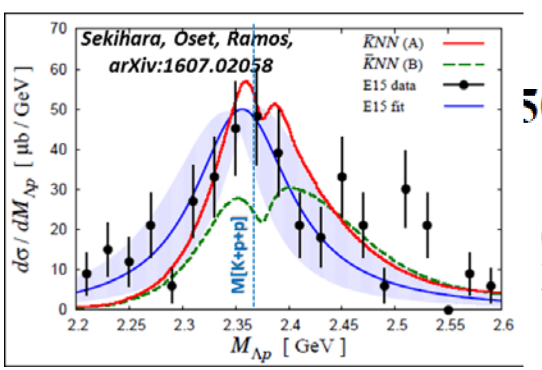
Structures are concentrated in forward-n region
= small momentum-transfer



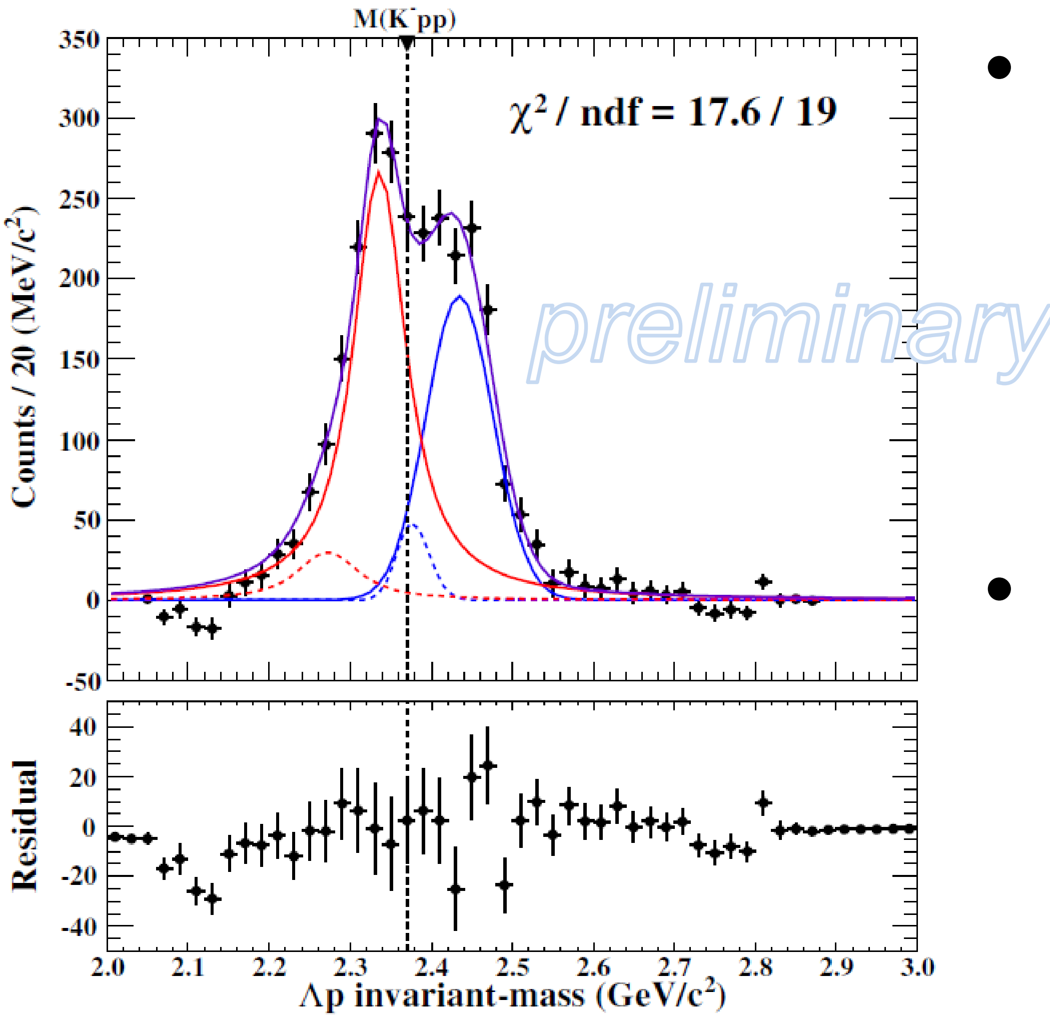
Results of ^{3}He(K^-,Λp)n [E15-2nd]







Results of ^{3}He(K$^-$,Λp)n [E15-2nd]

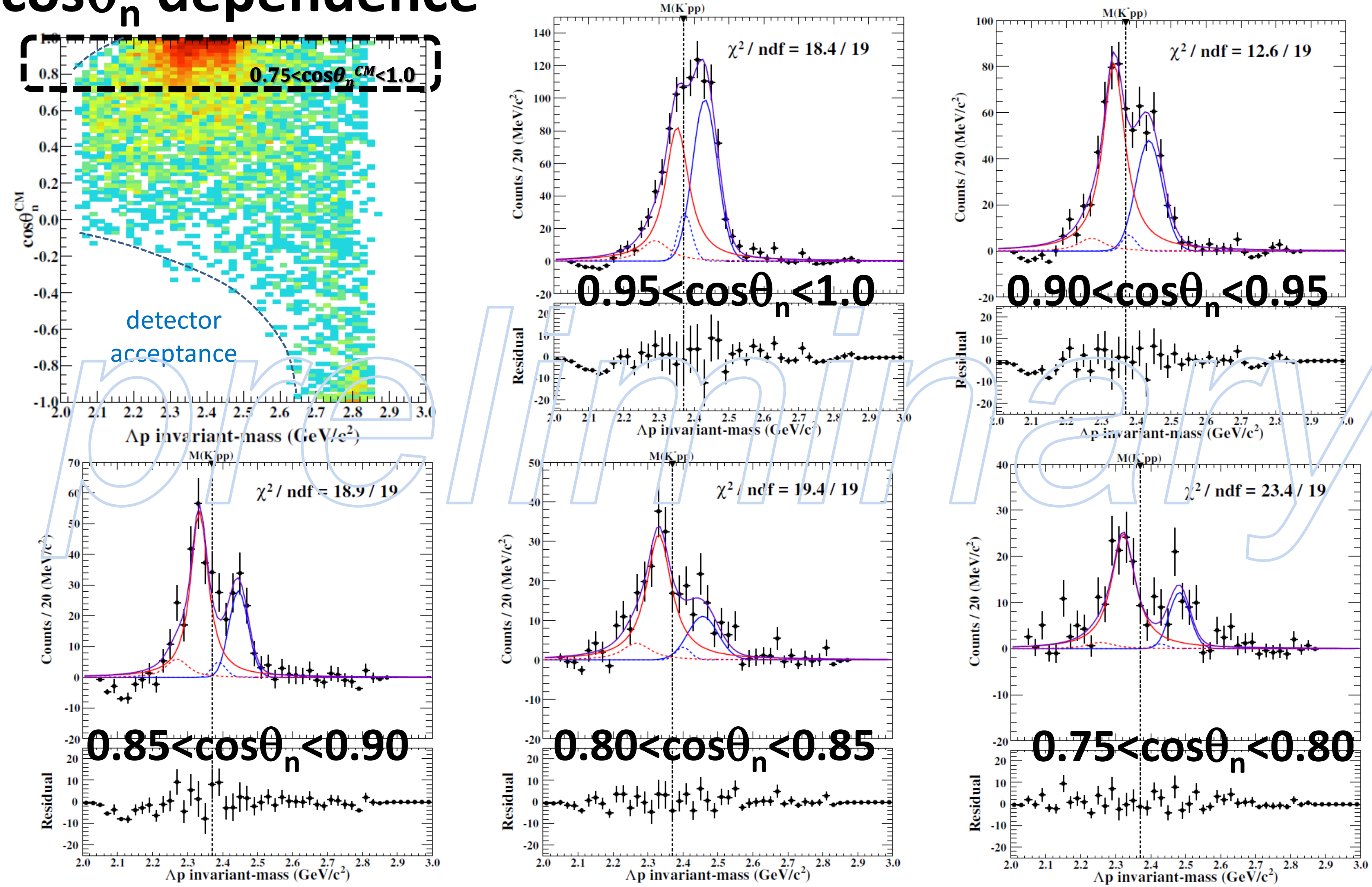


- Simple fitting w/o 3NA
  - **B.S.: Breit-Wigner**
  - QF: Gaussian ← Fermi-mom. Eff.
  - w/ Σ^0p contamination ← from MM(^{3}He(K$^-$,Λp)X)
- Well reproduce the spectrum
  - B.E ~ 34 MeV/c^2
  - Γ ~ 75 MeV/c^2

preliminary

Results of $^3He(K^-,\Lambda p)n$ [E15-2nd]

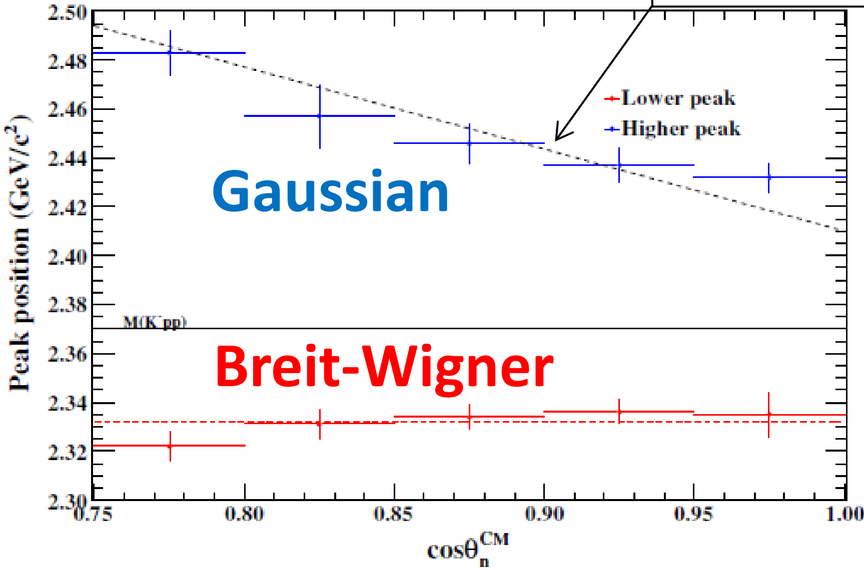
$\cos\theta_n$ dependence



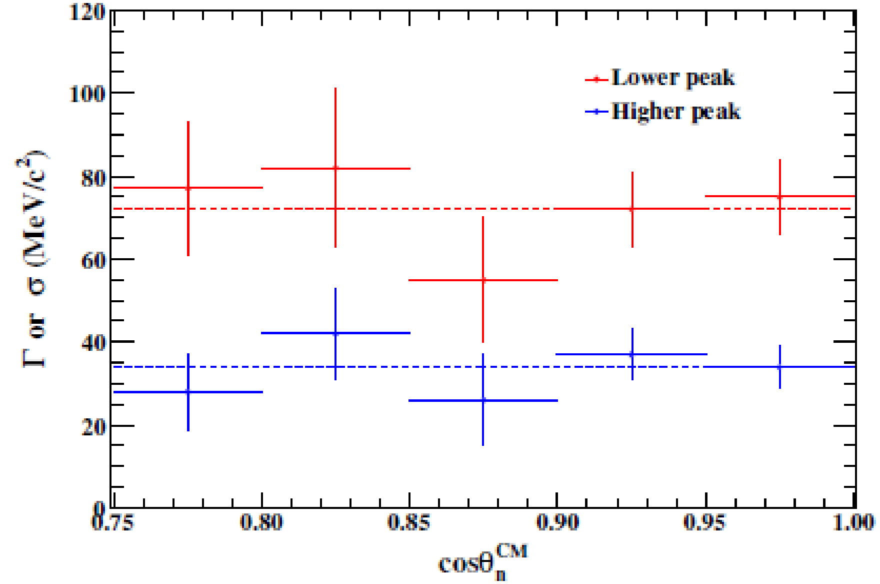
Results of $^{3}He(K^{-},\Lambda p)n$ [E15-2nd]

Peak position

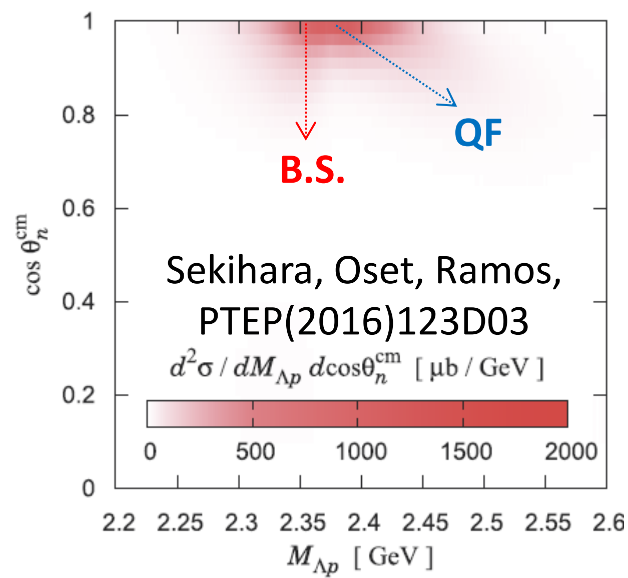
$$M_{QF} = M_{K^{-}pp} + \frac{q^2}{2M_{K^{-}}}$$



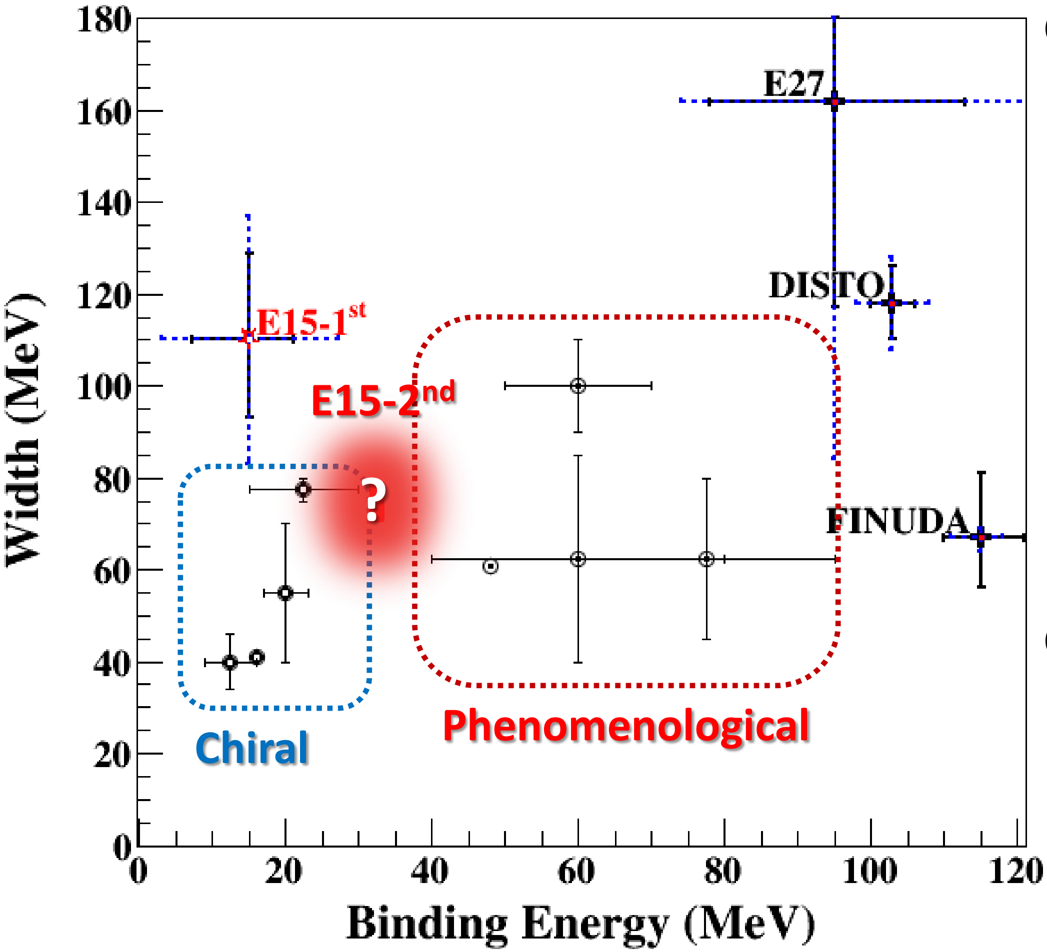
Width



- **Above M(K-pp):**
  - peak shift by recoil kaon energy
- **Below M(K-pp):**
  - peak is independent to $\cos\theta_n$ (~ momentum transfer)
- **Similar tendency as a theoretical calc.**



Present Status of K^{bar}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^{bar}N int.

For further understanding:

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

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

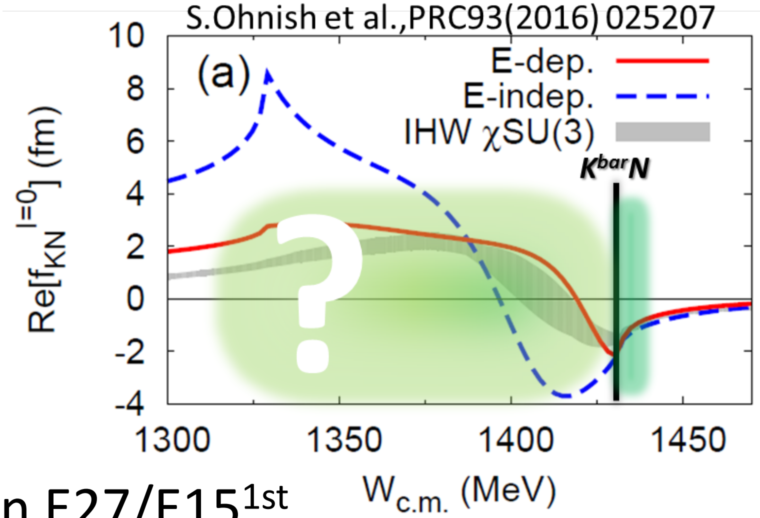
Summary

To investigate the $K^{bar}N$ interaction,
various experiments are proposed/conducting at J-PARC

- Sensitive in different energy region & isospin -

- **Kaonic-atom: E62/E57**
  - will start in 2018/2019
- **Λ(1405): E31**
  - 1st: analysis will be finalized
  - 2nd: will start in 2017
- **$K^{bar}NN$: E27/E15**
  - fruitful results were obtained in E27/E15 1st
  - analysis of E15 2nd data is going on
  - E15 3rd be discussed after analyzing new data

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



The Collaborations @ J-PARC K1.8BR

J-PARC E15/E31 collaboration

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J-PARC E57 collaboration (K-d)

J. Zmeskal[1] (spokesperson), M. Sato[2] (co-spokesperson), S. Ajimura[3], M. Bazzi[4], G. Beer[5], C. Berucci[1], H. Bhang[6], D. Bosnar[7], M. Bragadireanu[8], P. Buehler[1], L. Busso[9,10], M. Cargnelli[1], S. Choi[6], A. Clozza[4], C. Curceanu[4], A. D'uffizi[4], S. Enomoto[11], L. Fabbietti[12], D. Faso[9,10], C. Fiorini[13,14], H. Fujioka[15], F. Ghio[16], R. Golser[17], C. Guaraldo[4], T. Hashimoto[2], R.S. Hayano[18], T. Hiraiwa[3], M. Iio[11], M. Iliescu[4], K. Inoue[19], S. Ishimoto[11], T. Ishiwatari[20], K. Itahashi[2], M. Iwai[11], M. Iwasaki[2,21], S. Kawasaki[19], J. Lachner[17], P. Levi Sandri[4], Y. Ma[2], J. Marton[1], Y. Matsuda[22], Y. Mizoi[23], O. Morra[9], P. Moskal[24], T. Nagae[15], H. Noumi[3], H. Ohnishi[2], S. Okada[2], H. Outa[2], D. Pietreanu[8], K. Piscicchia[4,25], M. Poli Lener[4], A. Romero Vidal[26], Y. Sada[3], A. Sakaguchi[19], F. Sakuma[2], E. Sbardella[4], A. Scordo[4], M. Sekimoto[11], H. Shi[4], M. Silarski[4,24], D. Sirghi[4,8], F. Sirghi[4,8], K. Suzuki[1], S. Suzuki[11], T. Suzuki[18], K. Tanida[6], H. Tatsuno[11], M. Tokuda[21], A. Toyoda[11], I. Tucakovic[4], K. Tsukada[27], O. Vazquez Doce[12], E. Widmann[1], T. Yamaga[19], T. Yamazaki[2,18], Q. Zhang[2]

Spares

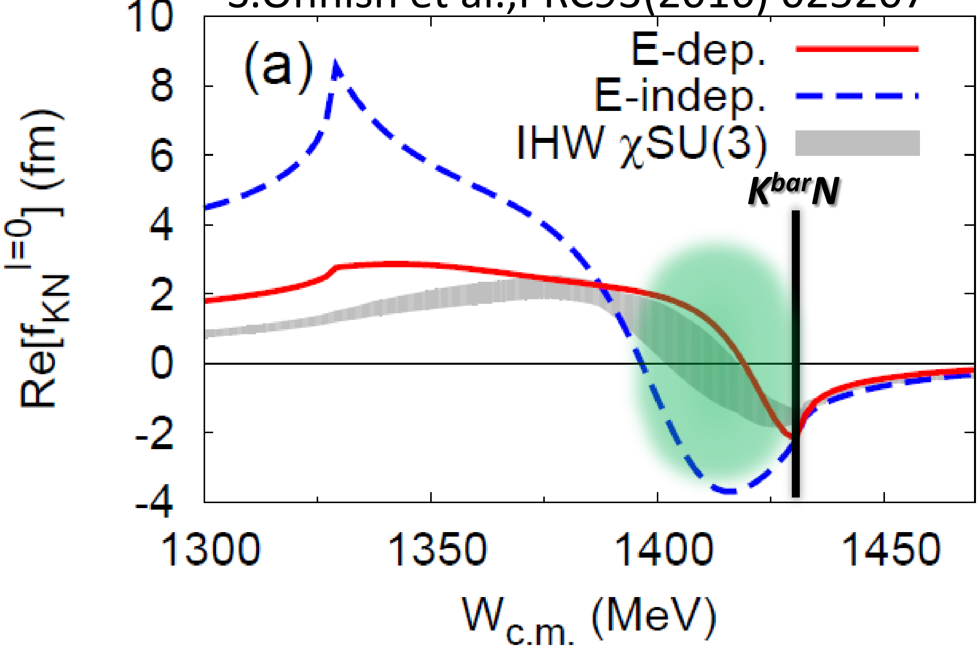
$K^{bar}N$ Interaction below the threshold

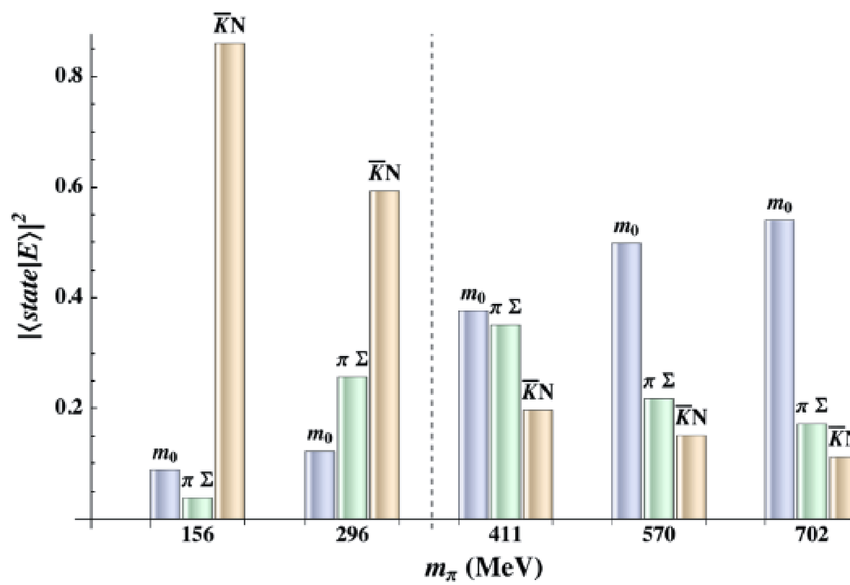
✓ $\Lambda(1405)$ plays an important role

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





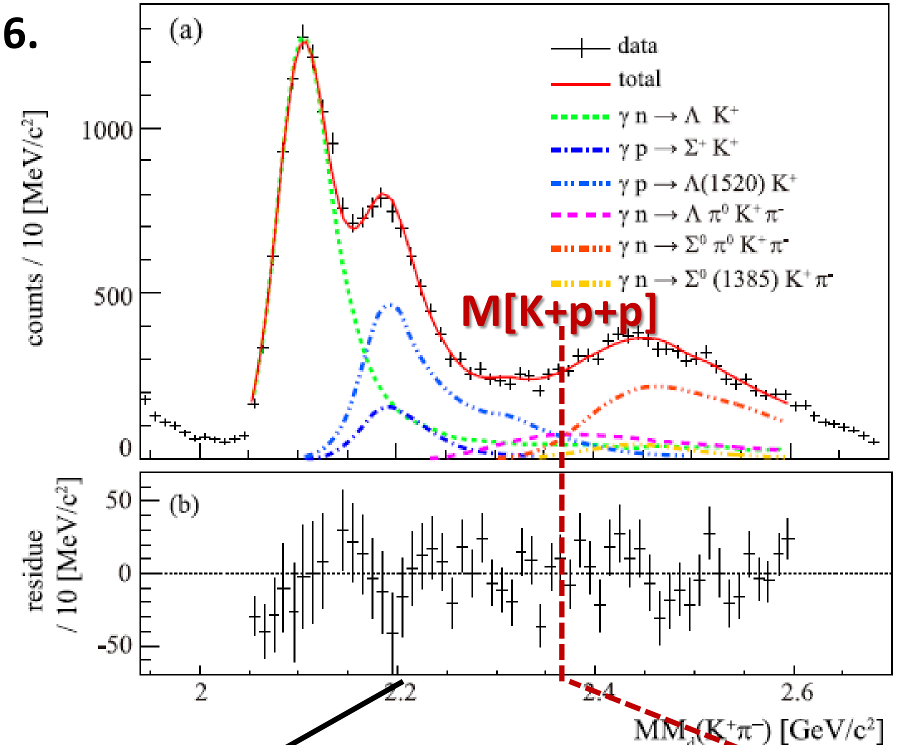
Recent Measurement at LEPS

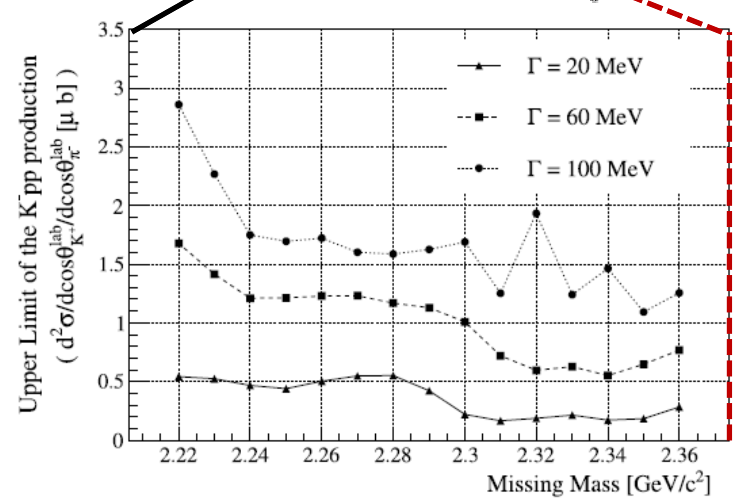
A.O. Tokiyasu et al., Phys. Lett. B 728 (2014) 616.

- **Inclusive** d(γ, $K^+\pi^-$)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)





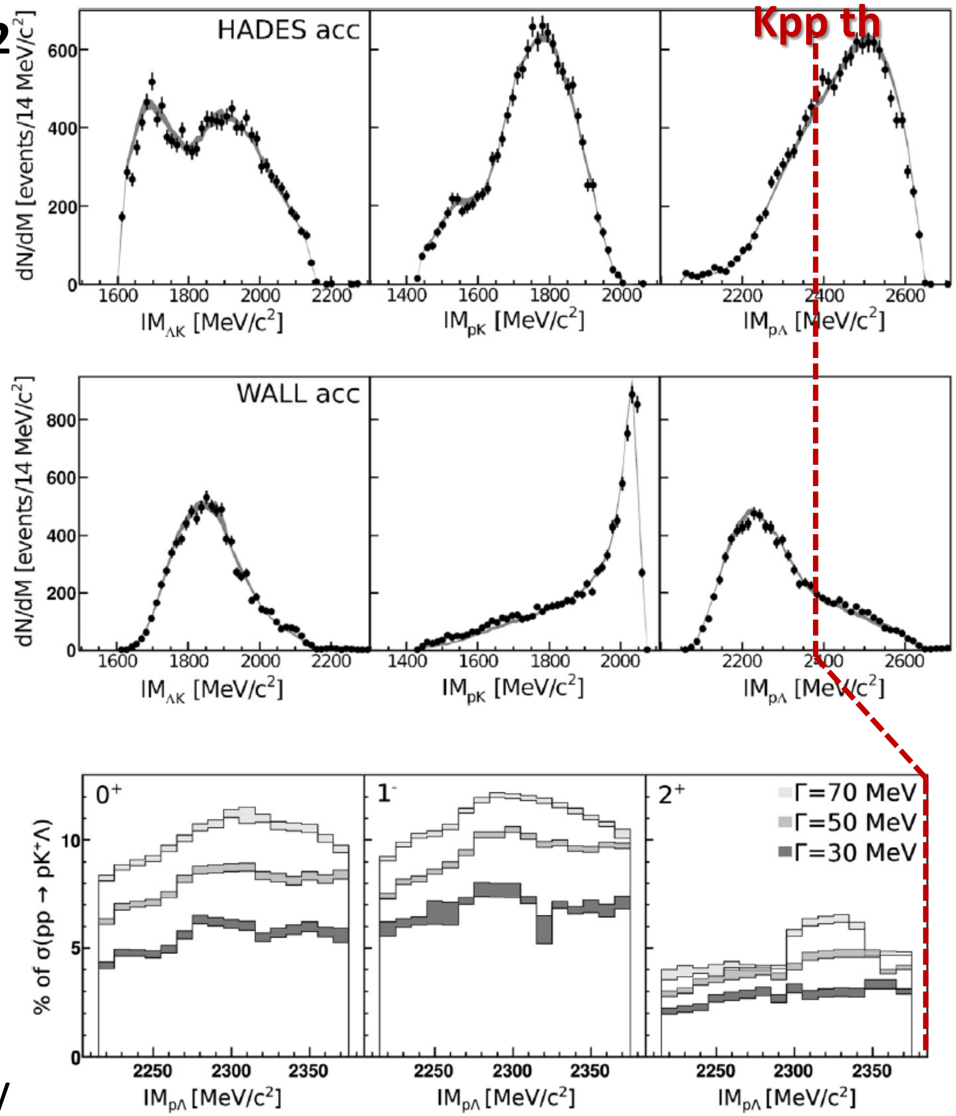
Recent Measurement at HADES

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

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

→ σ(X=K^{bar}NN)/σ(Λ*) < ~50%

vs. DISTO: σ(X) > σ(Λ(1405)) @ 2.85GeV



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

E15: Publications

PTEP

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

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M. Cargnelli[8], S. Choi[4], C. Curceanu[9], S. Enomoto[2], D. Faso[6,7], H.
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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

PTEP

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

exclusive ^{3}He(K^{-},Λp)n

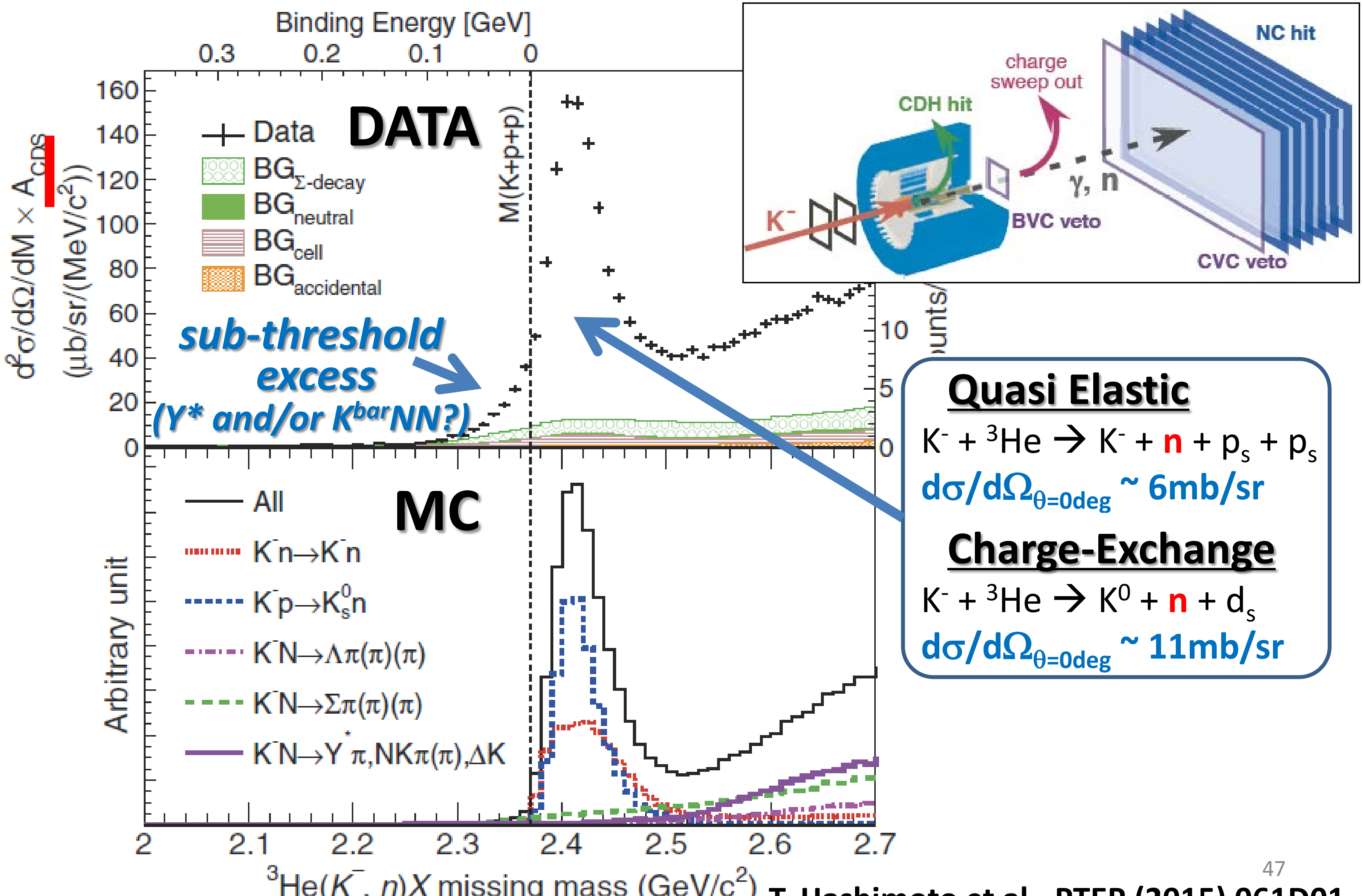
Letter

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.

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



Quasi Elastic

K$^-$ + ^{3}He → K$^-$ + **n** + p_s + p_s

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

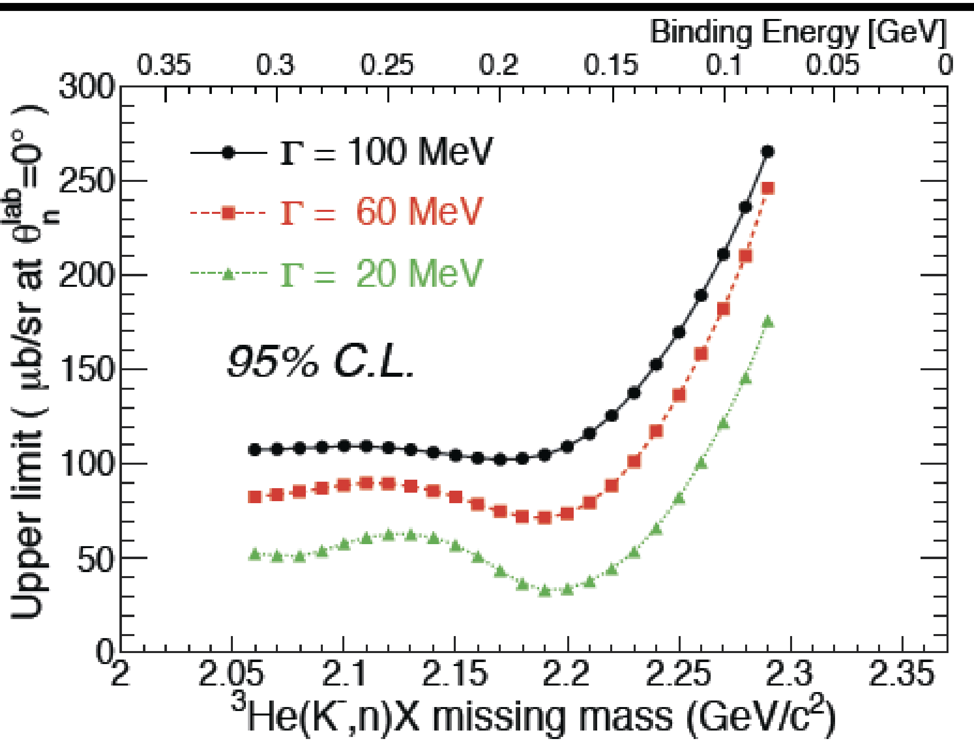
Charge-Exchange

K$^-$ + ^{3}He → K^0 + **n** + d_s

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

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

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



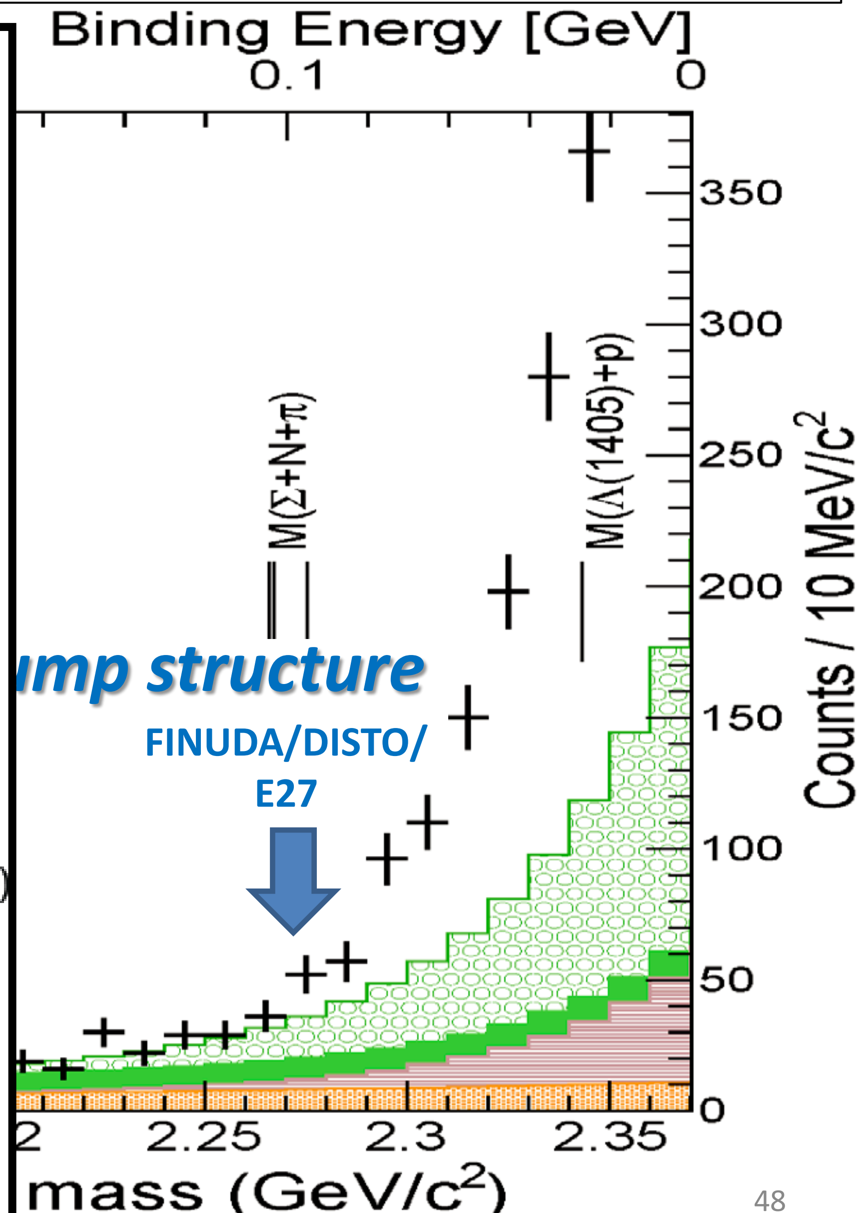
Assumptions

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



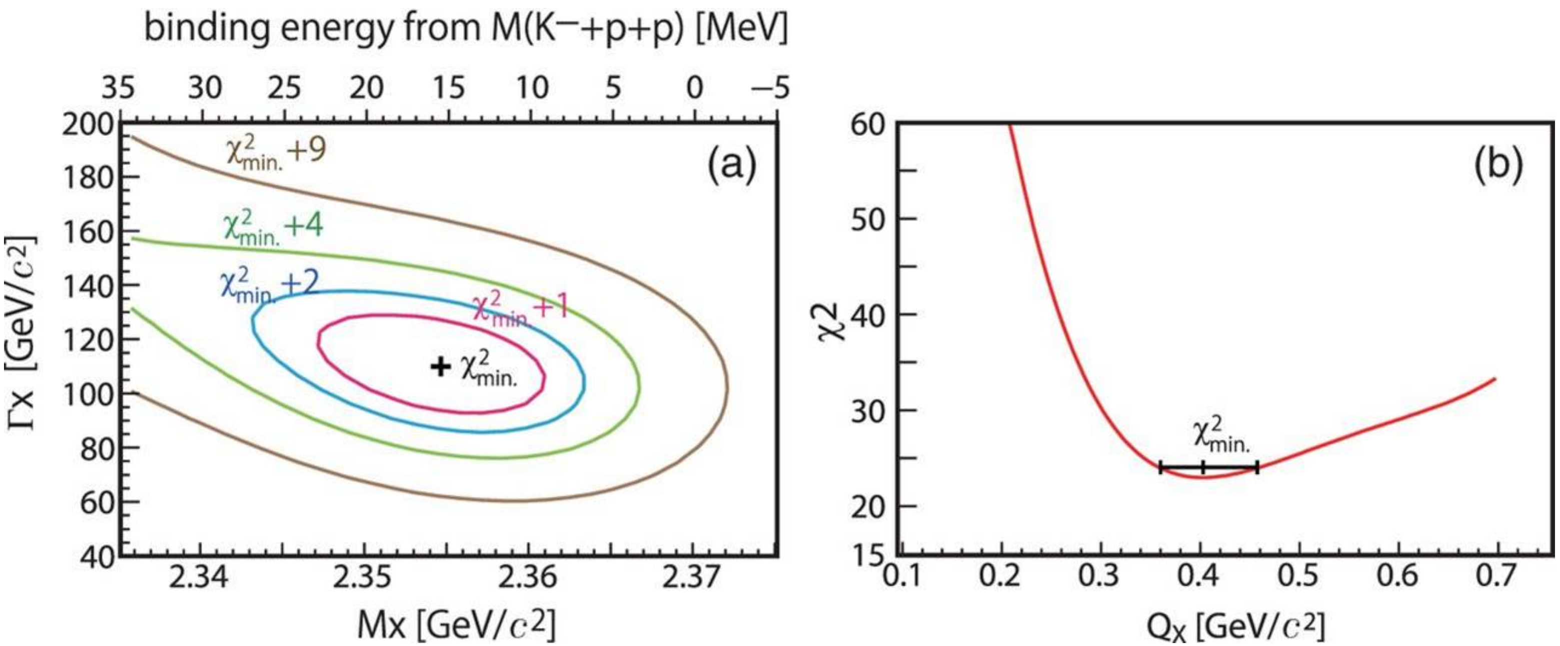
T. Hashimoto et al., PTEP (2015) 061D01.

Assuming a Breit-Wigner

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

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

phase space Breit-Wigner form factor



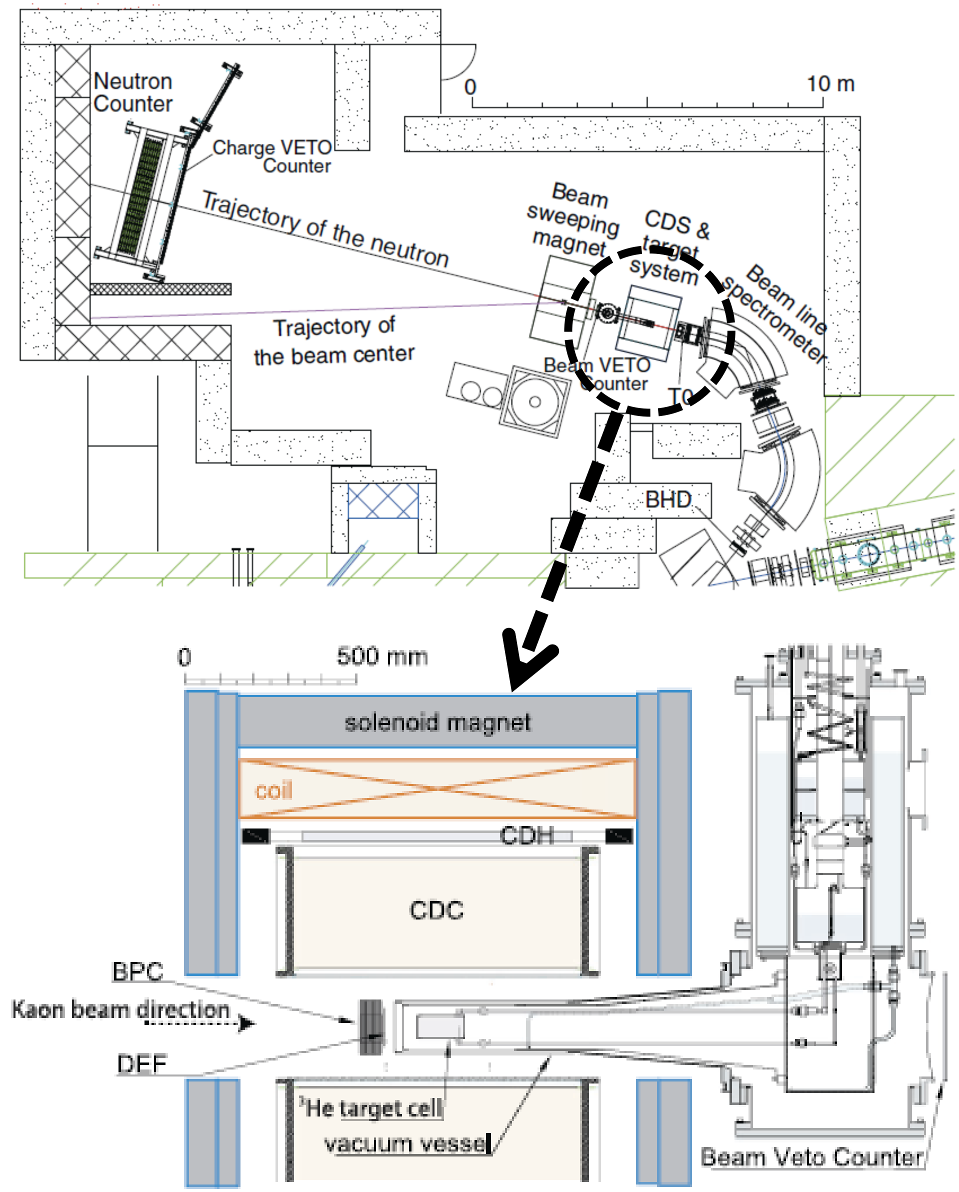
B.E = 15^{+6}_{-8} (stat.) ± 12(syst.) MeV/c²

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

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

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%

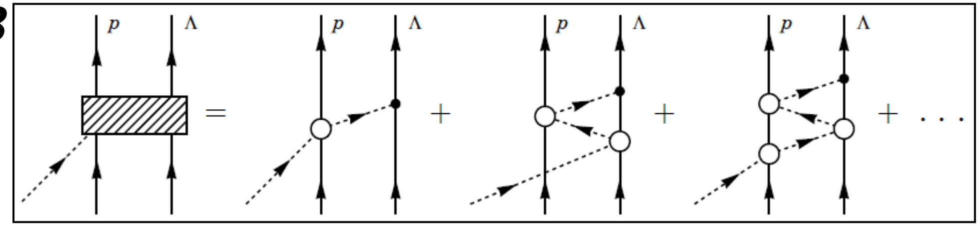


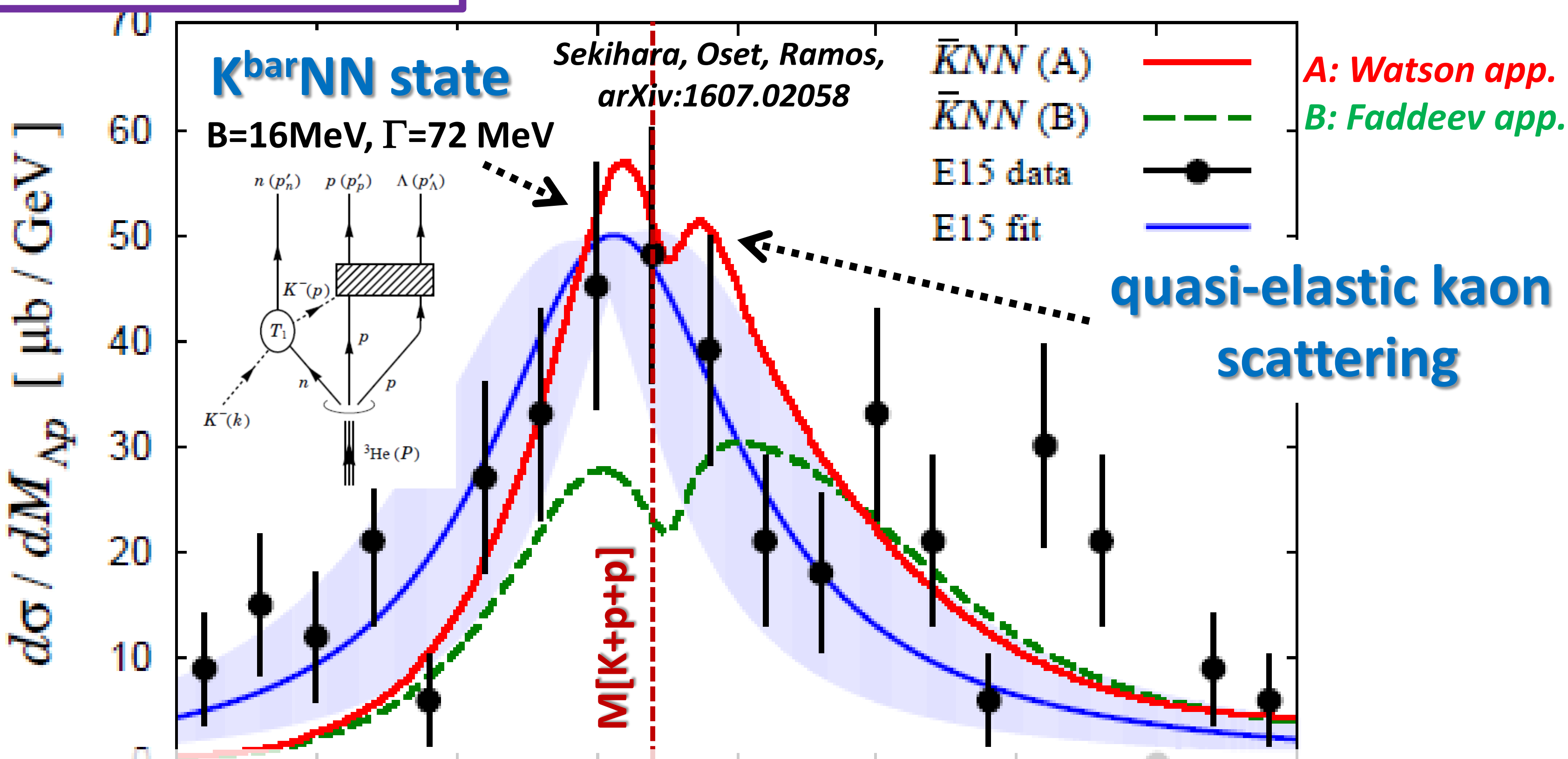
A Theoretical Interpretation

Sekihara, Oset, Ramos, arXiv:1607.02058

Chiral unitary approach

Sekihara, Tue. A-1



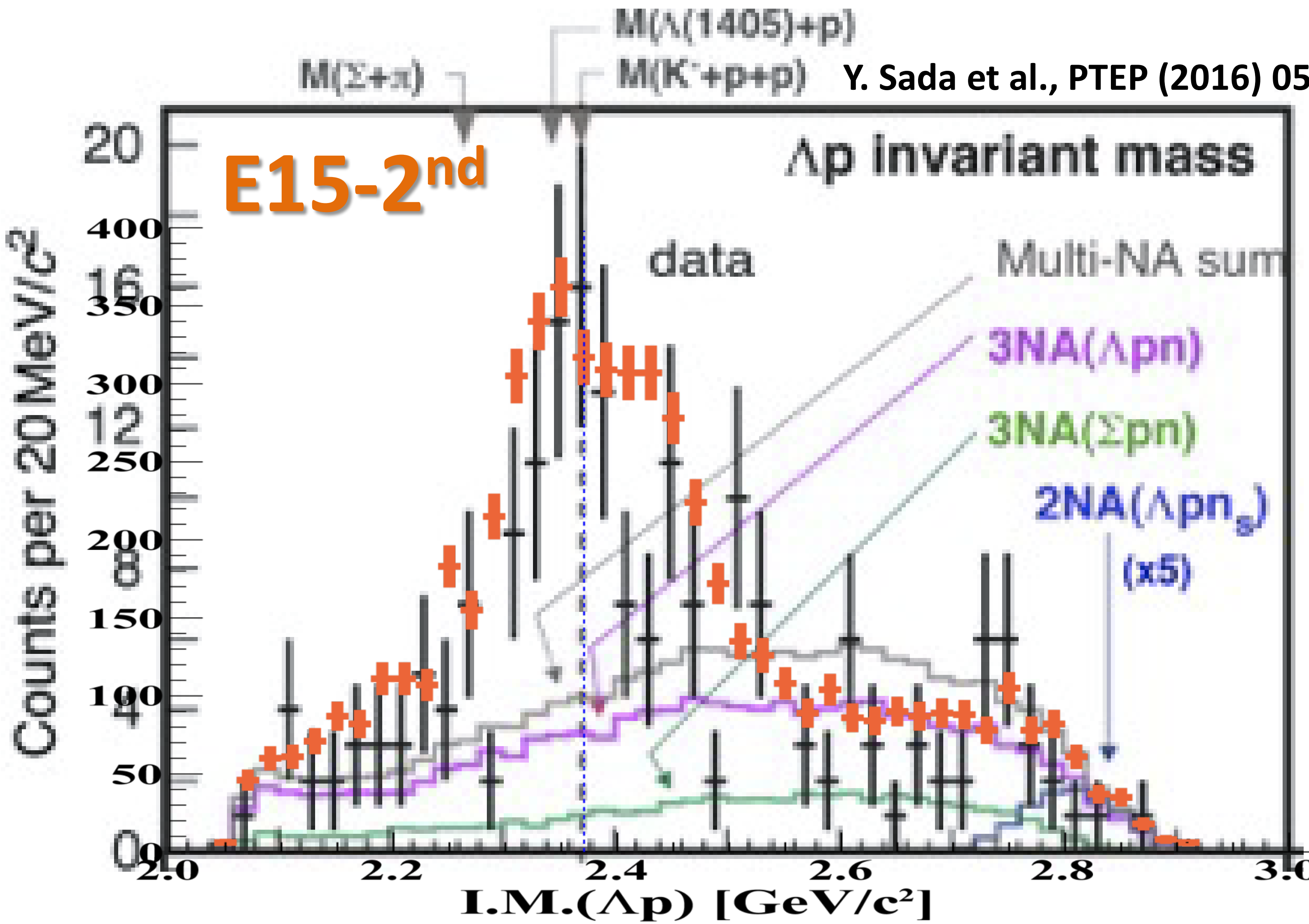


K^{bar}NN bound-state picture reproduces the data

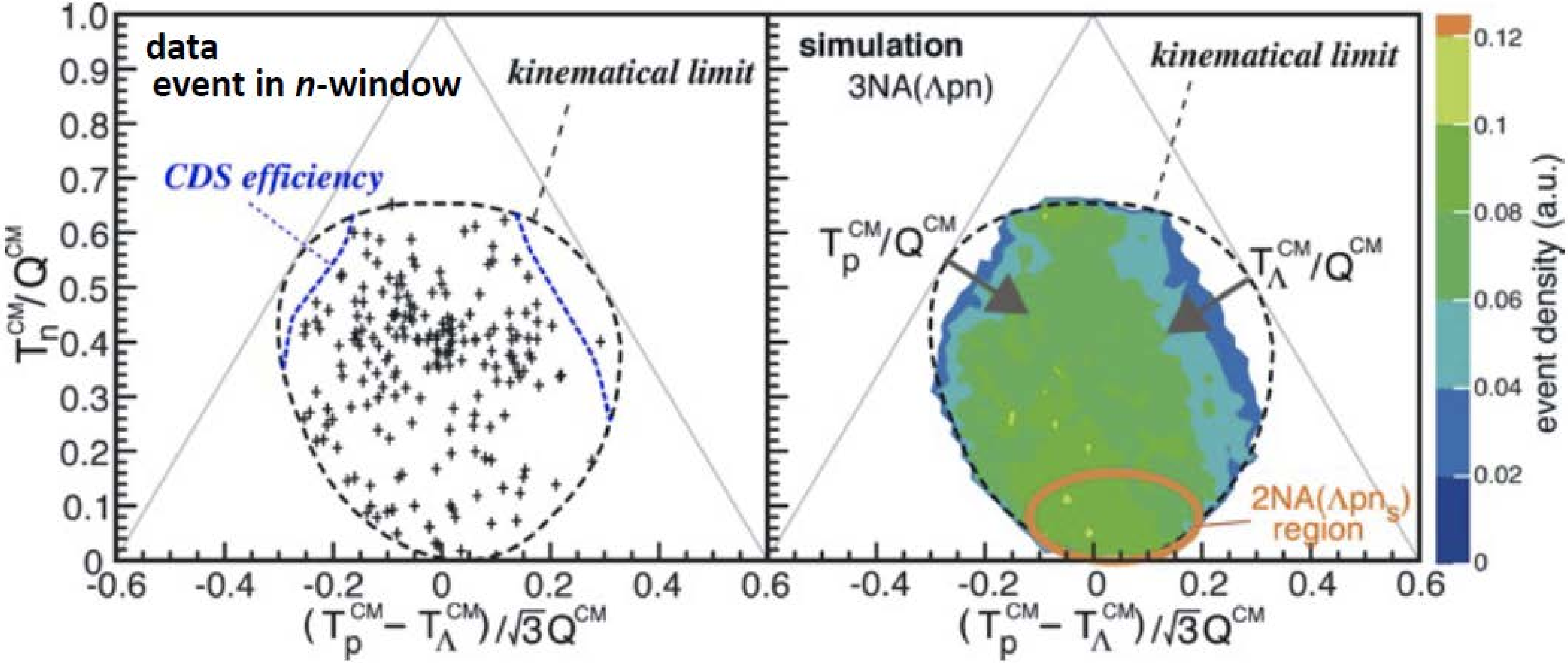
→ The data CANNOT be explained with uncorrelated Λ(1405)p

E15 1st vs 2nd

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

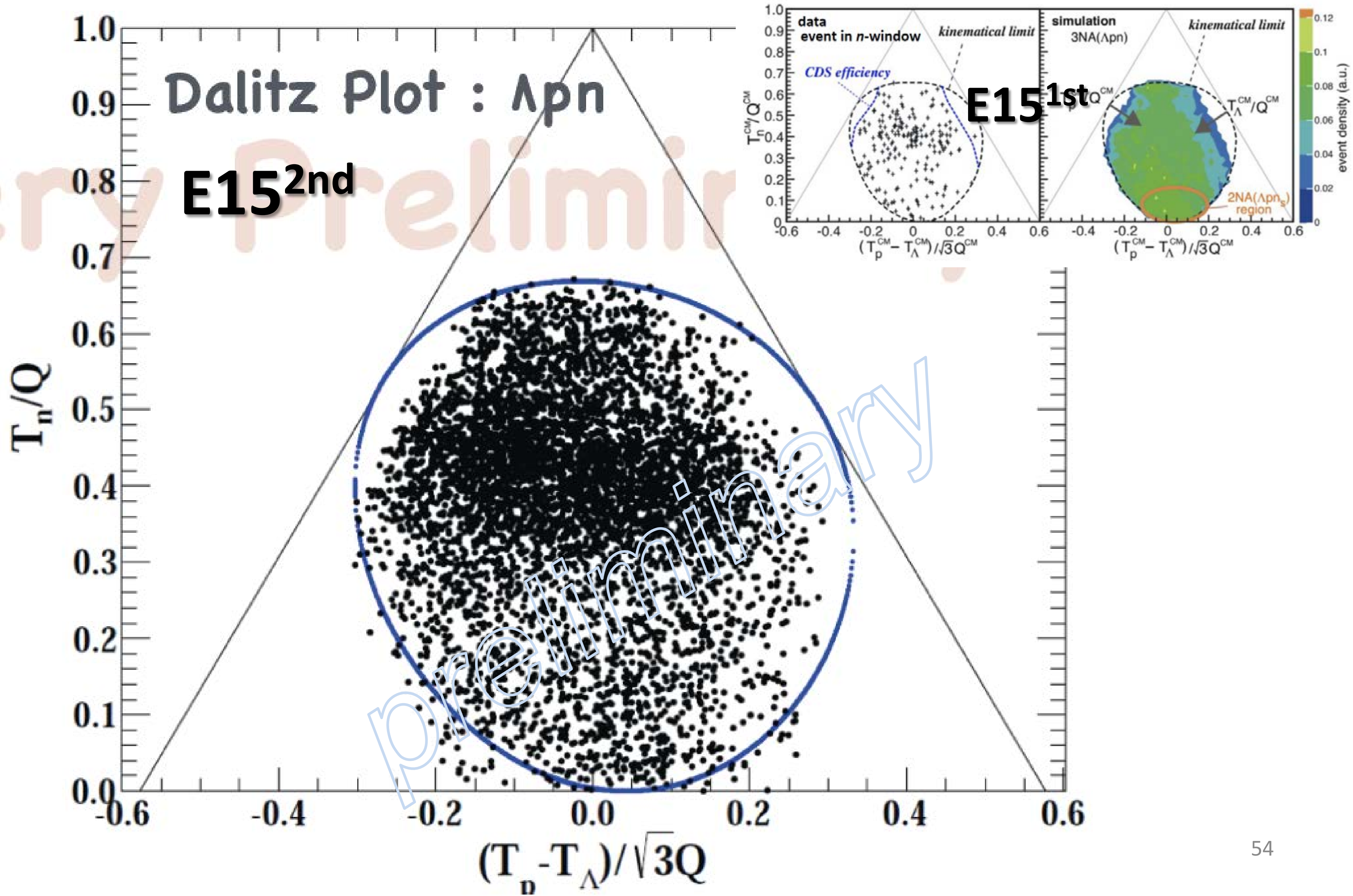


Exclusive $^3He(K^-,\Lambda p)n$



- 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

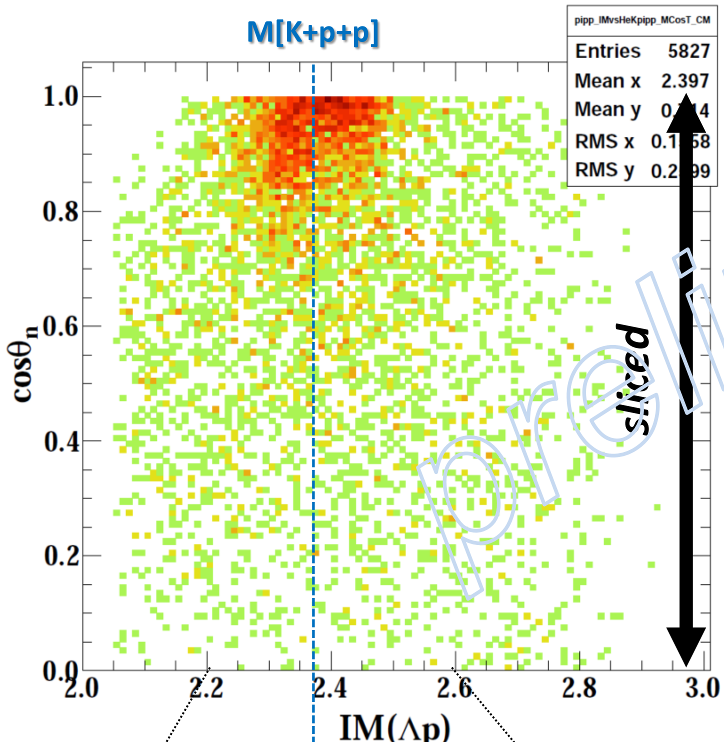
- **Λ(1405)N bound state** — T. Uchino et al., NPA868(2011)53.
  - loosely-bound system, I=1/2, $J^{\pi}=0^{-}$
  - various decay modes, $\Lambda N/\Sigma N/\pi\Sigma N$

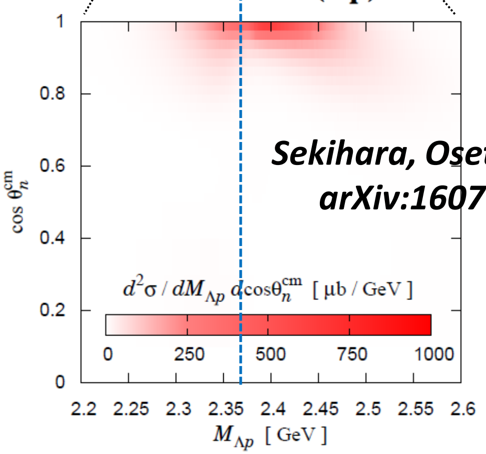
A structure near $\pi\Sigma N$ threshold

- **$\pi\Lambda N$-$\pi\Sigma N$ 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

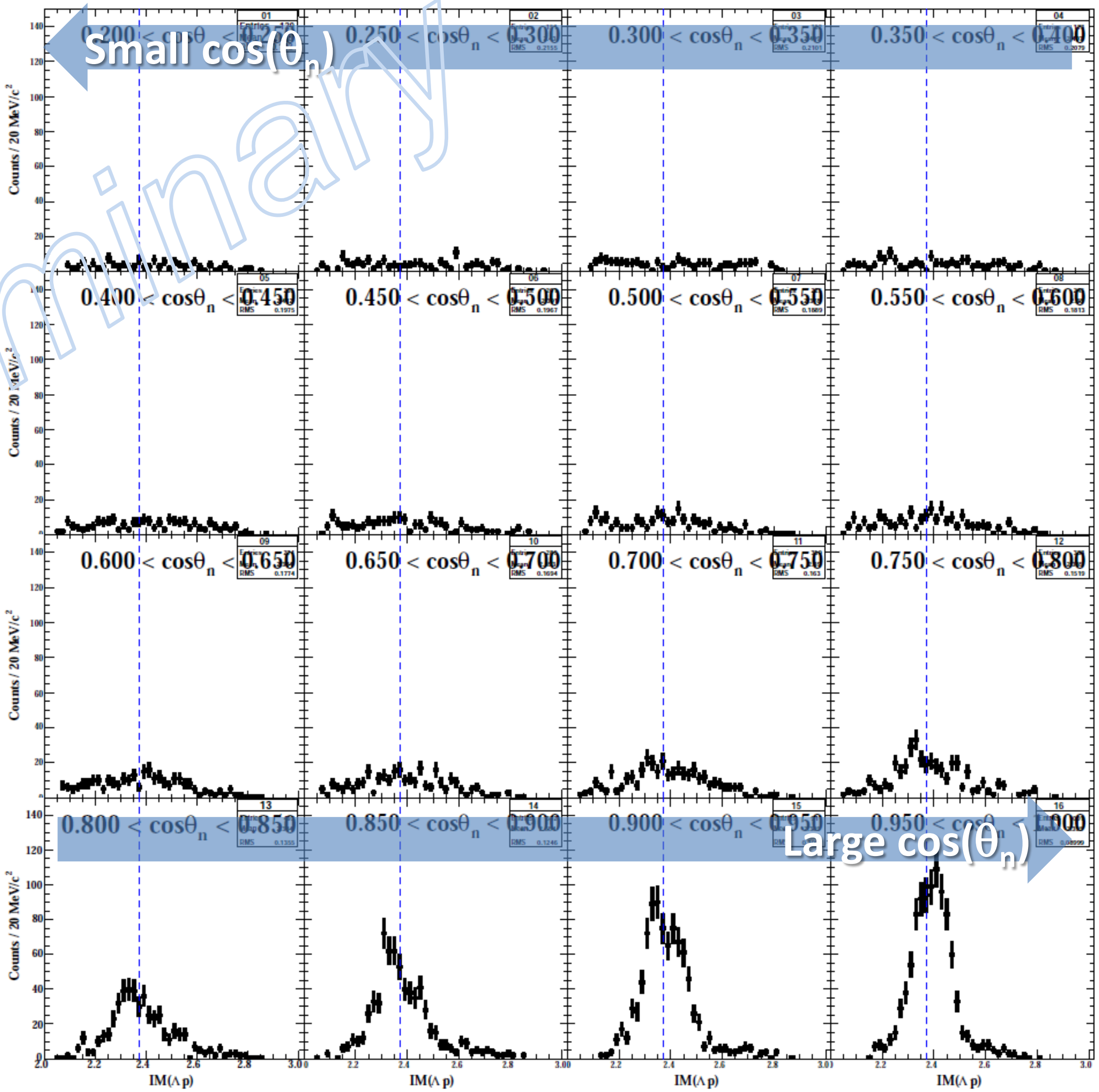
S. Maeda, Y. Akaishi, T. Yamazaki, Proc. Jpn. Acad., B89(2013)418.

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



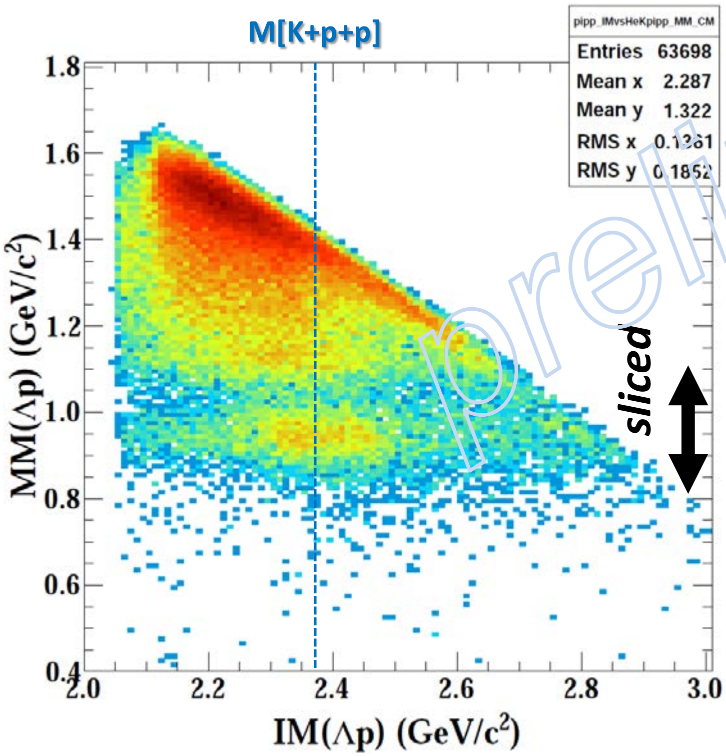


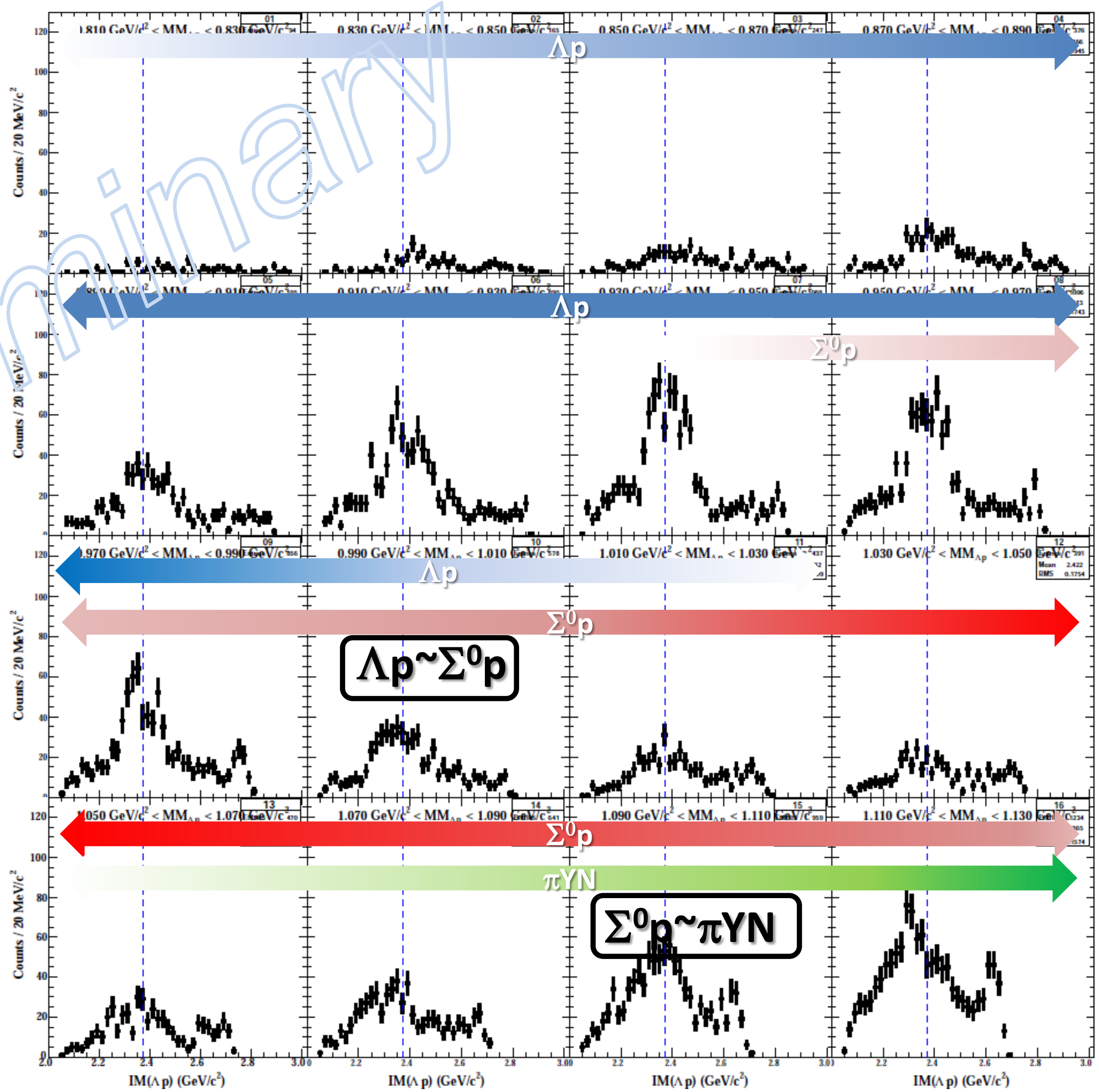
Sekihara, Oset, Ramos, arXiv:1607.02058



Smaller momentum transfer is preferred

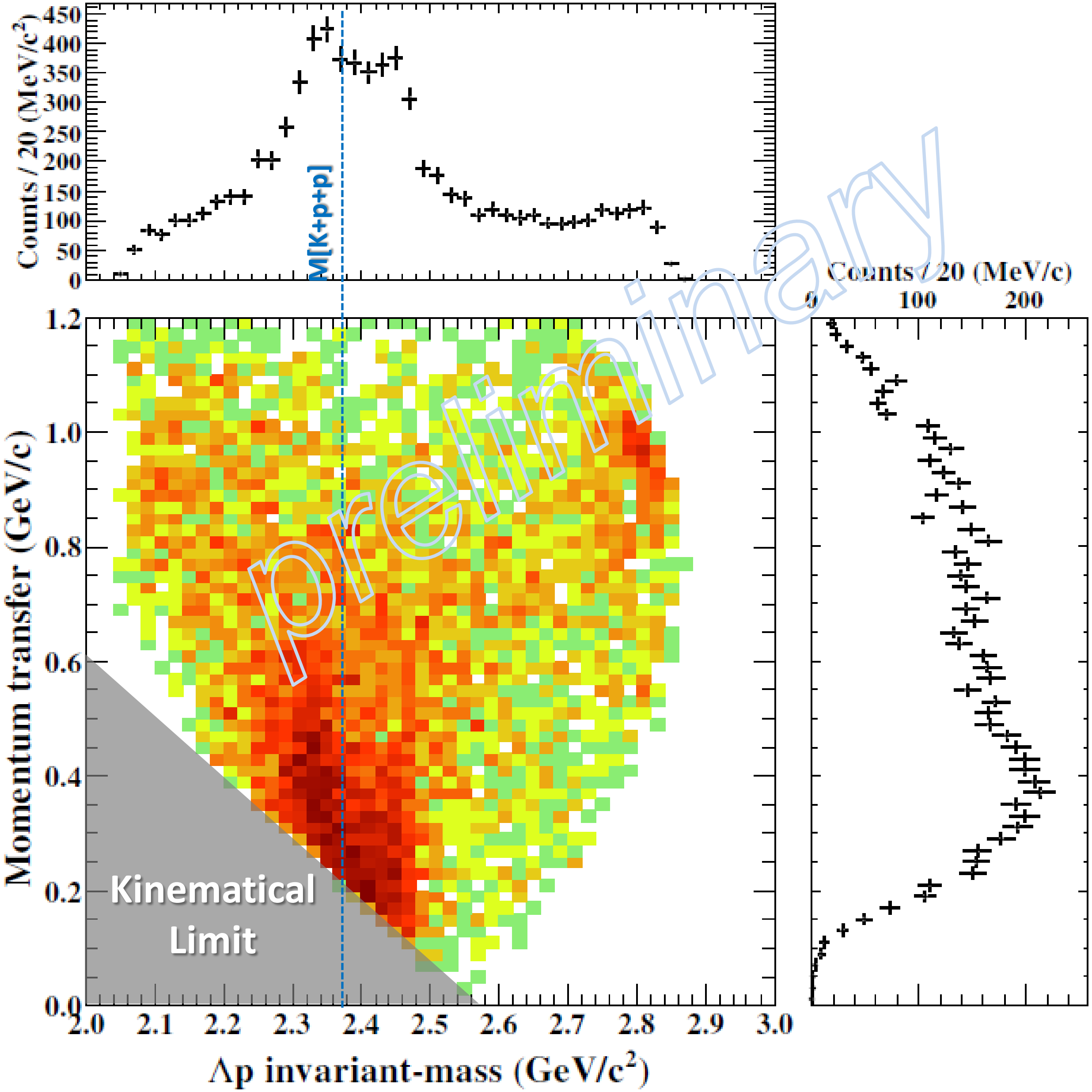
^{3}He(K$^-$,Λp)n: Decay Channel





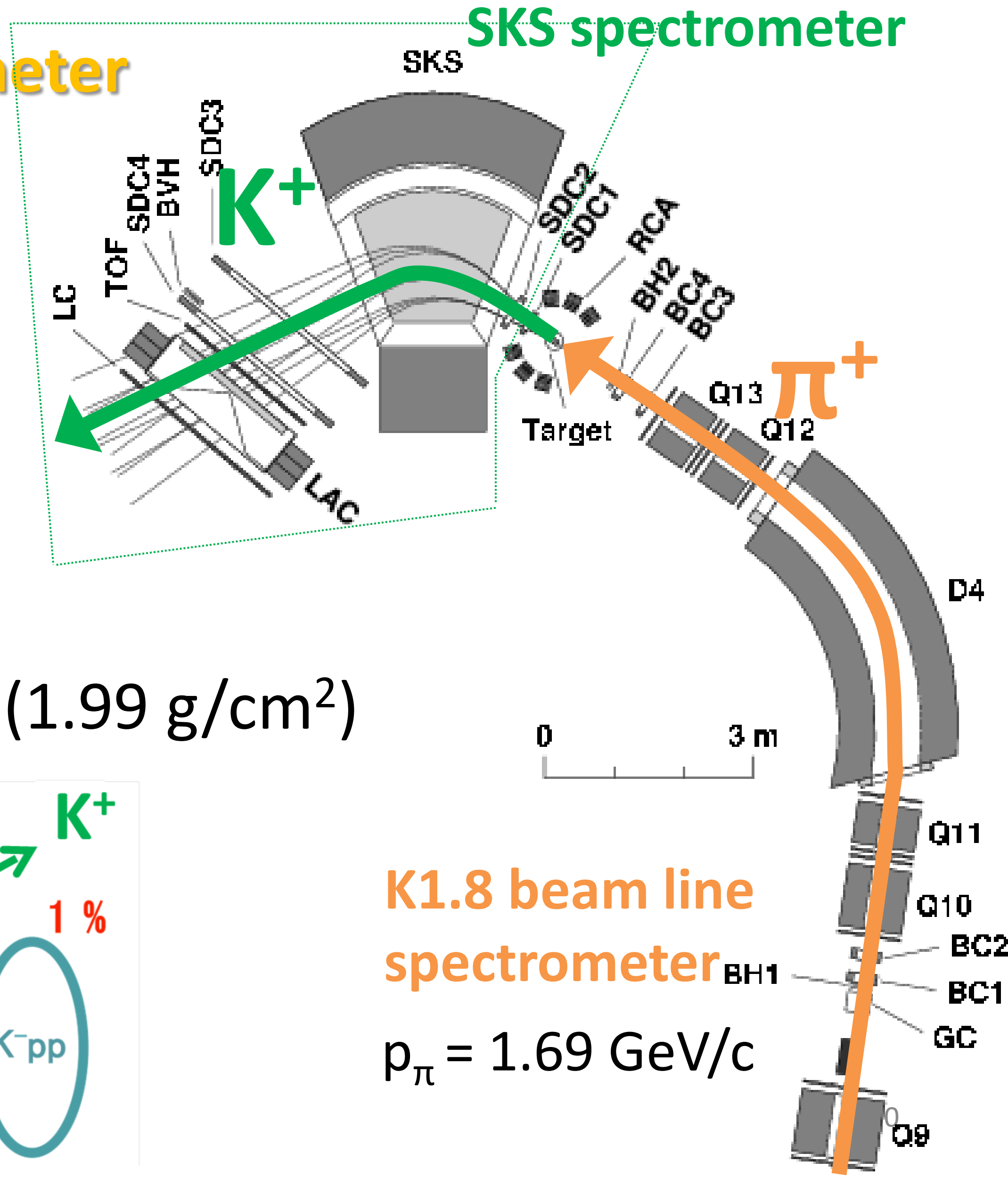
$\Gamma(\Lambda p) > \Gamma(\Sigma^0 p)$!?

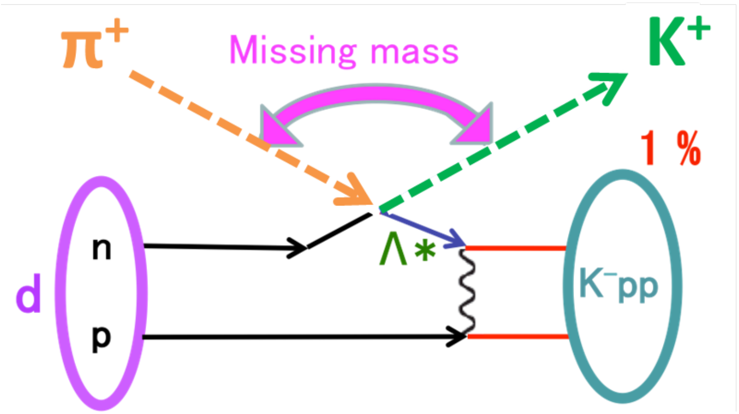
$^{3}He(K^{-},\Lambda p)n$: q-dependence



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)



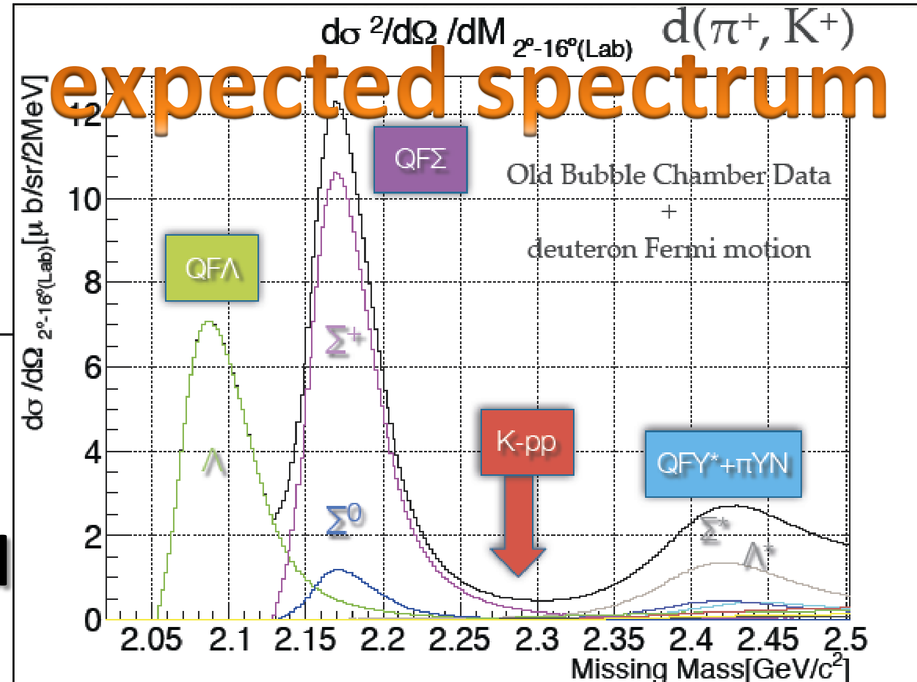


Y.Ichikawa

E27: Inclusive d(π^+,K$^+$)X

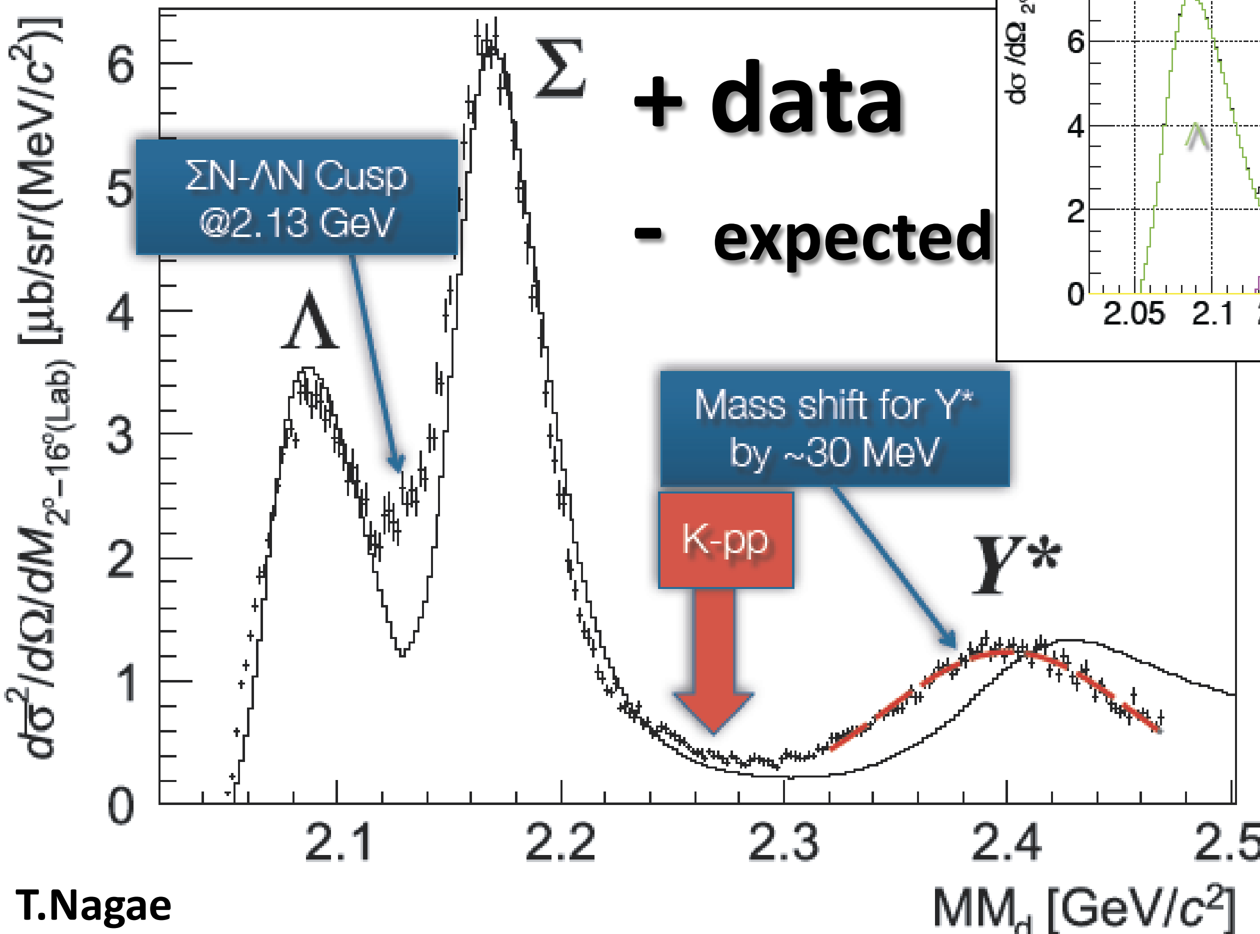
Y. Ichikawa et al., PTEP (2014) 101D03.

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



+ data

- expected



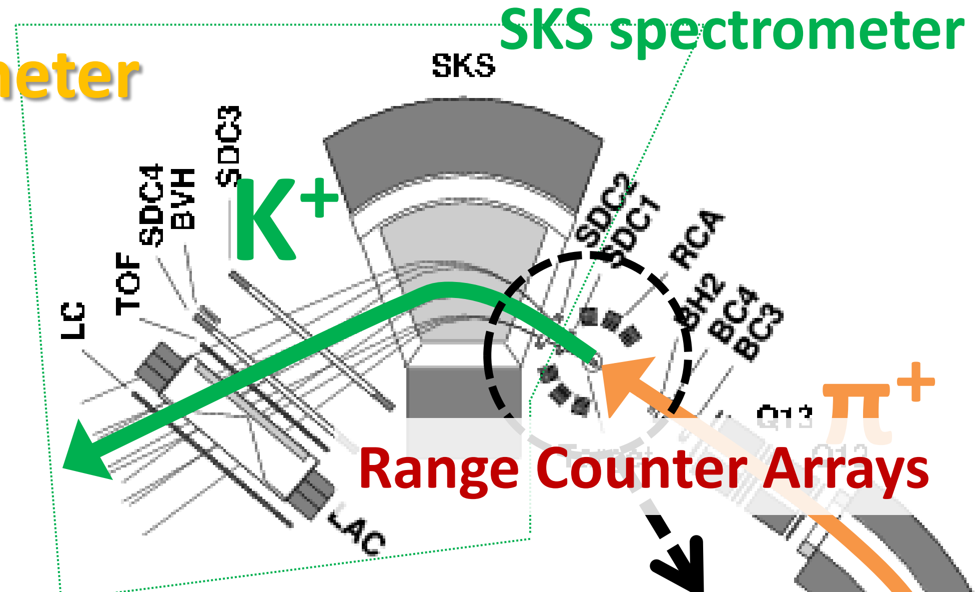
- ΣN-ΛN cusp
- Y* mass shift?

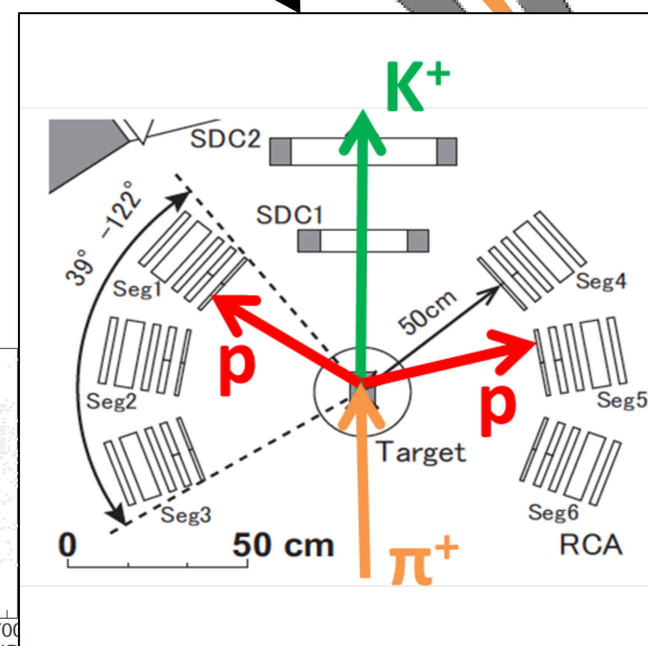
Ichikawa, Tue. A-1
Tokiyasu, Fri. E-1

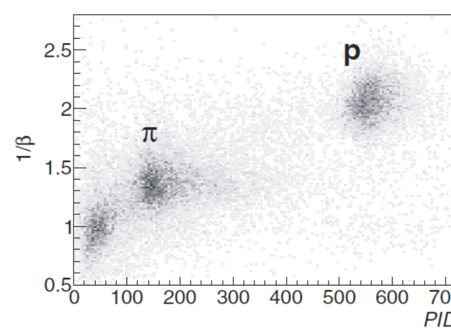
T.Nagae

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







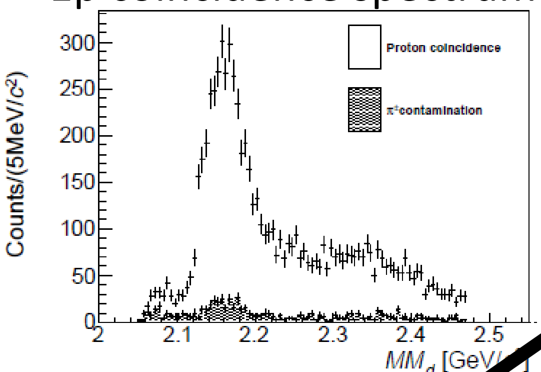
Y.Ichikawa

E27: One-Proton Coincidence

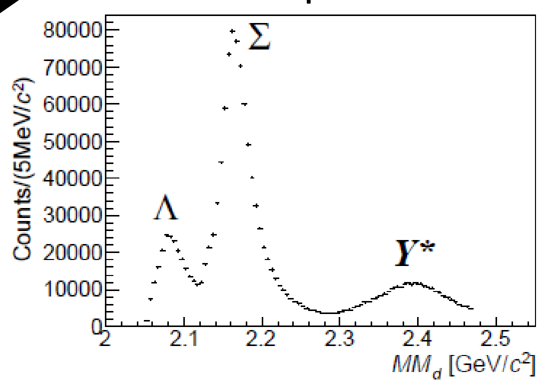
- $p_p > 250$ MeV/c
  - QFs are suppressed
- ΣN-ΛN cusp is clearly seen @ 2.13 GeV/c^2
- **Broad enhancement is observed @ 2.28 GeV/c^2**

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

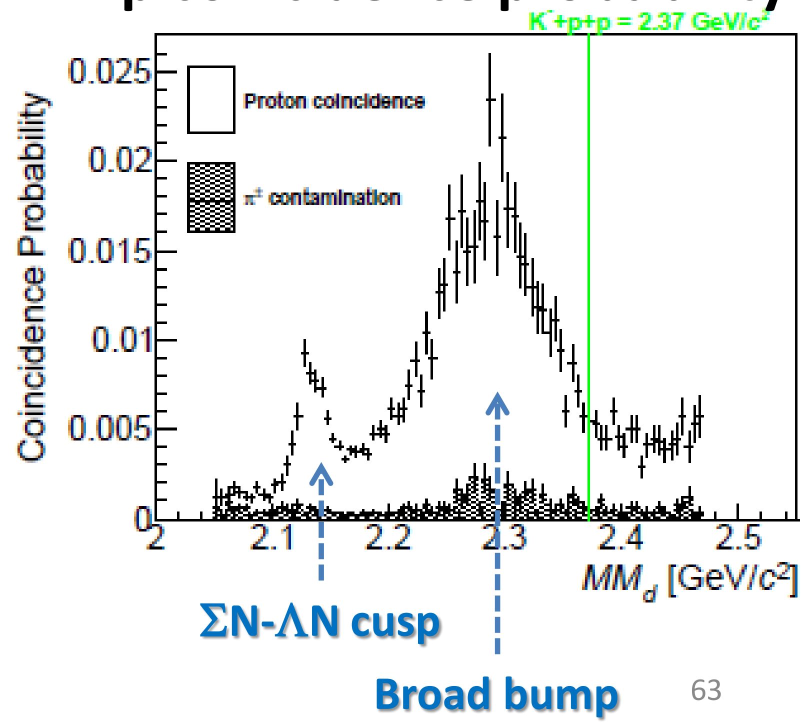
< 1p coincidence spectrum >



< Inclusive spectrum >



< 1p coincidence probability >

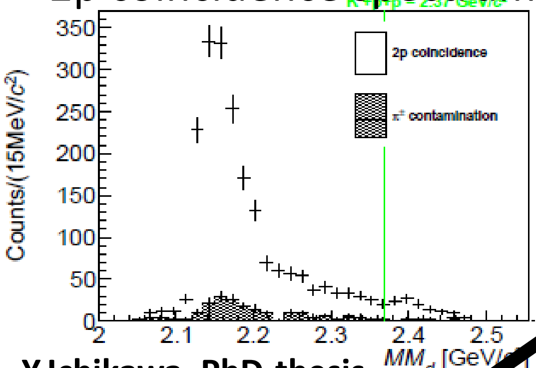


E27: Two-Proton Coincidence

- 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**

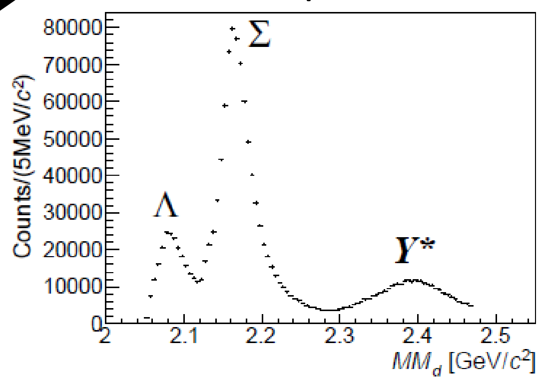
Y. Ichikawa et al., PTEP (2015) 021D01.

< 2p coincidence spectrum >



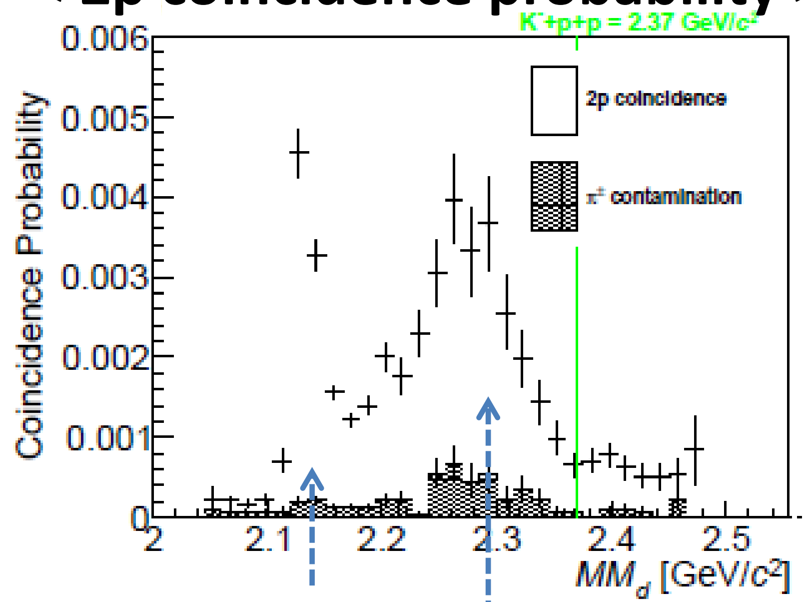
Y.Ichikawa, PhD-thesis. Kyoto-U (2015)

< Inclusive spectrum >



=

< 2p coincidence probability >



ΣN-ΛN cusp

Broad bump

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**