Suranaree University of Technology

Sawasdee Ka

10th., Oct., 2014

Theoretical Interpretation of J-PARC E27 Data

Khin Swe MYINT

Yoshinori AKAISHI and Toshimitsu YAMAZAKI

Study of kaonic nuclei by the d (π^+ , K^+) reaction at J-PARC

Ichikawa al,
XV International Conference on
Hadron Spectroscopy-Hadron 2013
Nara, Japan

Simplest kaonic nucleus K^- pp bound state is searched at

J-PARC K 1.8 beam line (J-PARC E27 experiment)

d (π^+ , K^+) X at the beam momentum 1.7 GeV/c

X strangeness (-1), singly charged, double baryon

K^- pp bound stae

quasi free Λ^* p, Σ^* p, Λ p, Σ^0 p

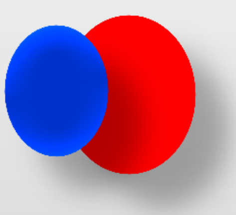
Anti Kaons $\bar{K}^0$, K^-

$\bar{d}\,s$, $\bar{u}\,s$

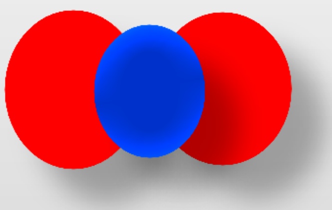
Strong attraction of $\bar{K}\,N$ in $I = 0$ channel

Λ^* or $\Lambda\,(1405)$

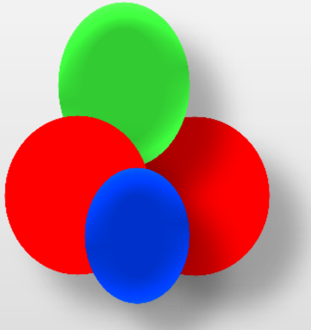
A resonace lies below the K^-p threshold and in the continuum region of $\pi^-\,\Sigma^+$



K^-p

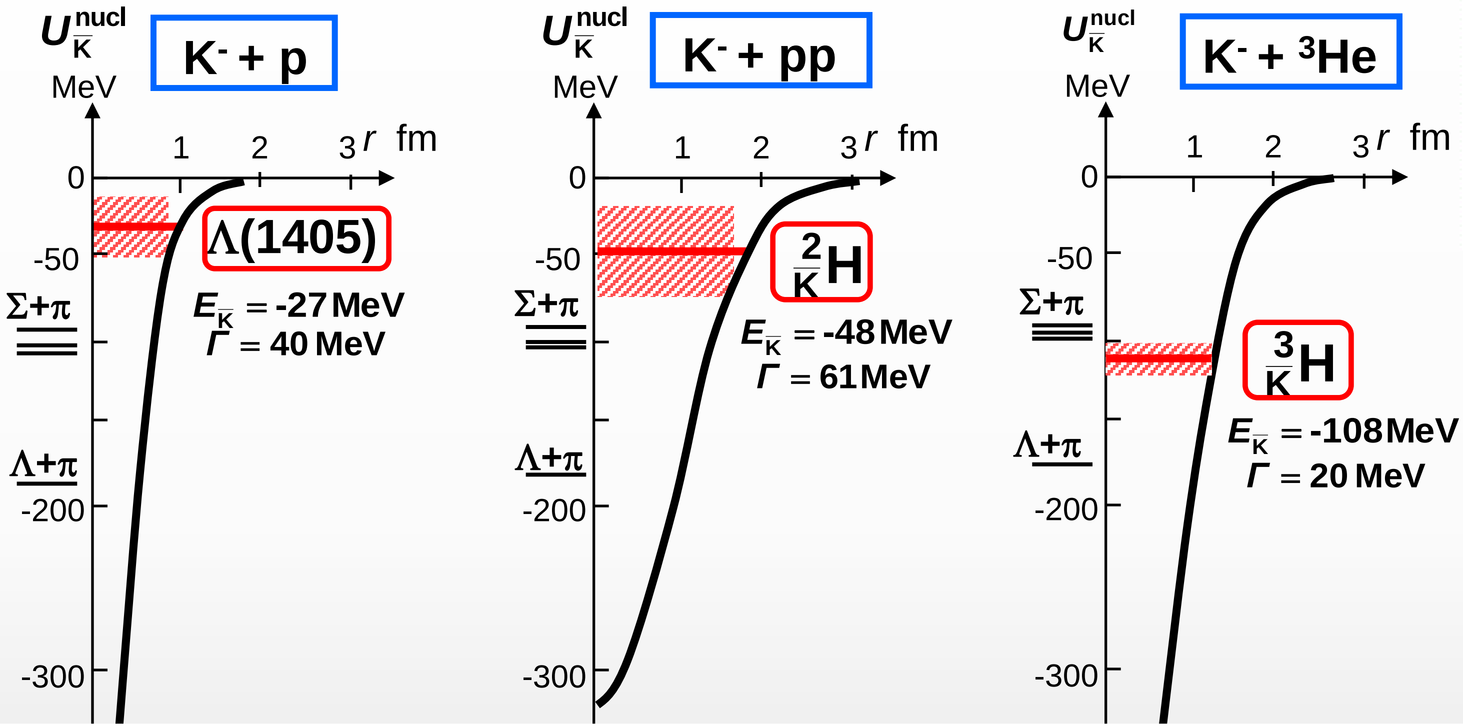


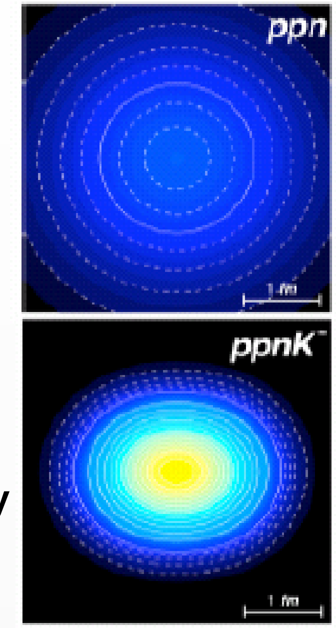
K^-pp



K^-ppn

"Λ(1405) Ansatz"





Shrinkage!

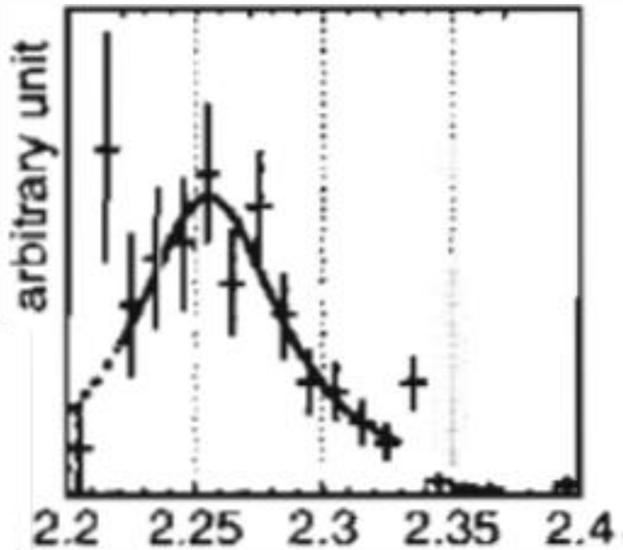
N.V. Shevchenko, A. Gal & J. Mares, Phys. Rev. Lett. 98 (2007) 082301
E = **-55~-70** MeV, Γ = **90~110** MeV
Y. Ikeda & T. Sato, Phys. Rev. C 76 (2007) 035203
E = **-80** MeV, Γ = **73** MeV
A. Dote, T. Hyodo & W. Weise, Phys. Rev. C 79 (2009) 014003
E = **-20**+-**3** MeV, Γ = **40~70** MeV

DAΦNE Conf. (1999)
Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005
T. Yamazaki & Y. Akaishi, Phys. Lett. B 535 (2002) 70

Experimental Observation of K$^-$ pp

FINUDA

M. Agnello et al., Phys. Rev. Lett. 94 (2005) 212303



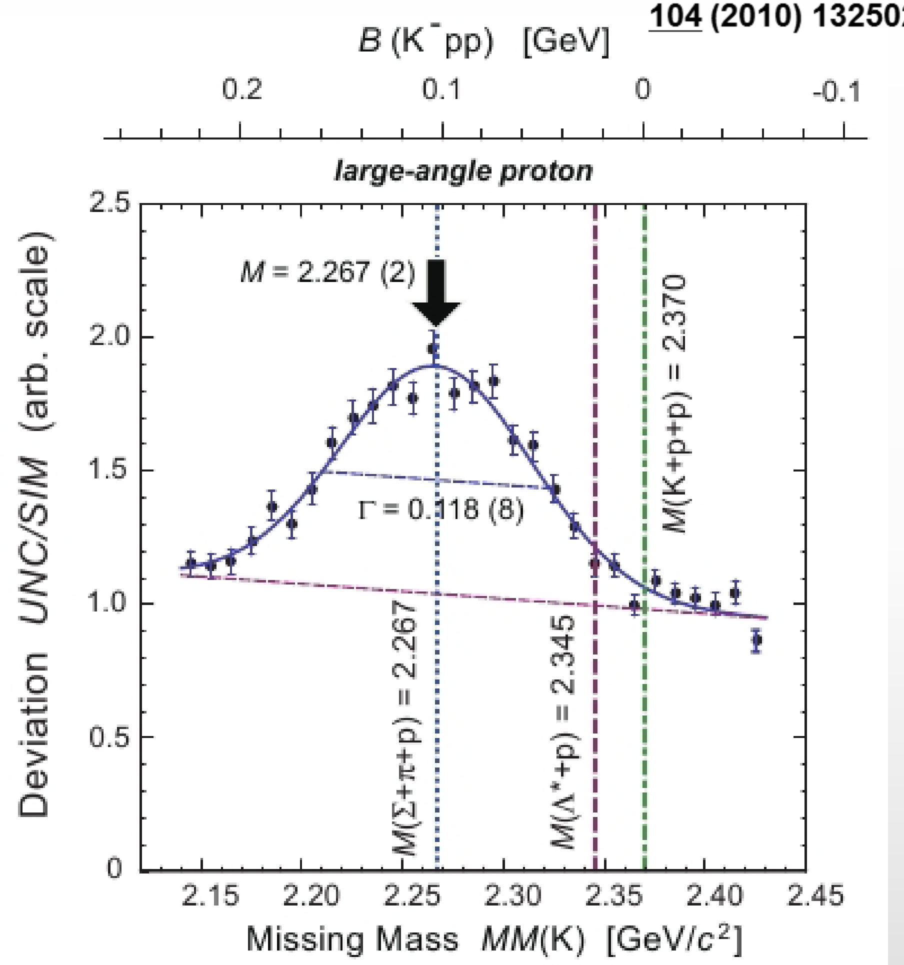
Stopped K$^-$ on ^{6}Li, ^{7}Li and ^{12}C targets and observed back to back Λp pairs

(B E, Γ)

$$115^{+6}_{-5},\ 67^{+14}_{-11}\ \mathrm{MeV}$$

DISTO

T. Yamazaki et al., Phys. Rev. Lett. 104 (2010) 132502



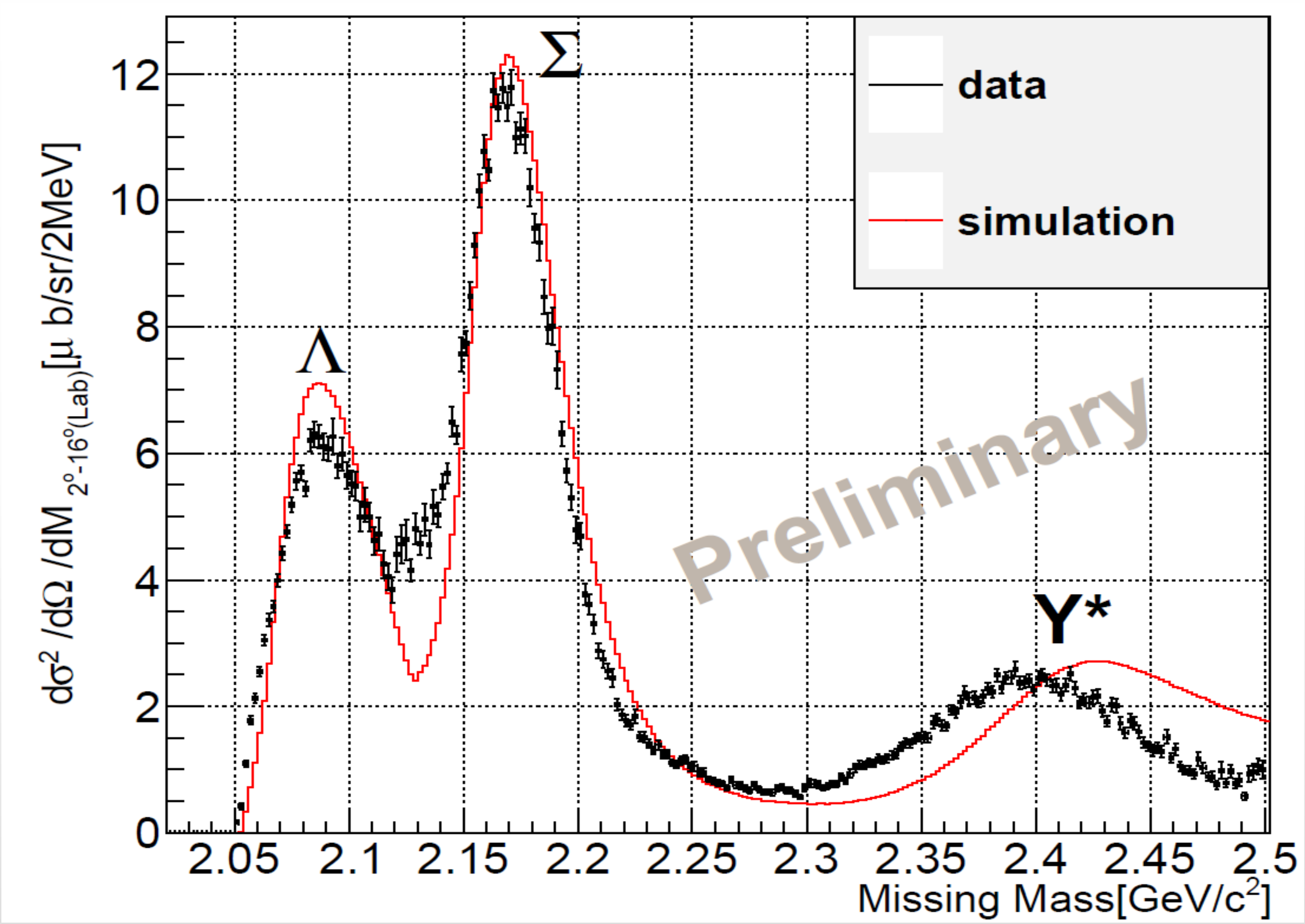
T_p = 2.85 GeV

$$p + p \rightarrow \Lambda + p + K^+$$

$$103^{+3}_{-3},\ 118^{+8}_{-8}\ \mathrm{MeV}$$

JPARC-E27 Inclusive spectrum

Y. Ichikawa et al., Proc. Science (Nara Conf. 2013)

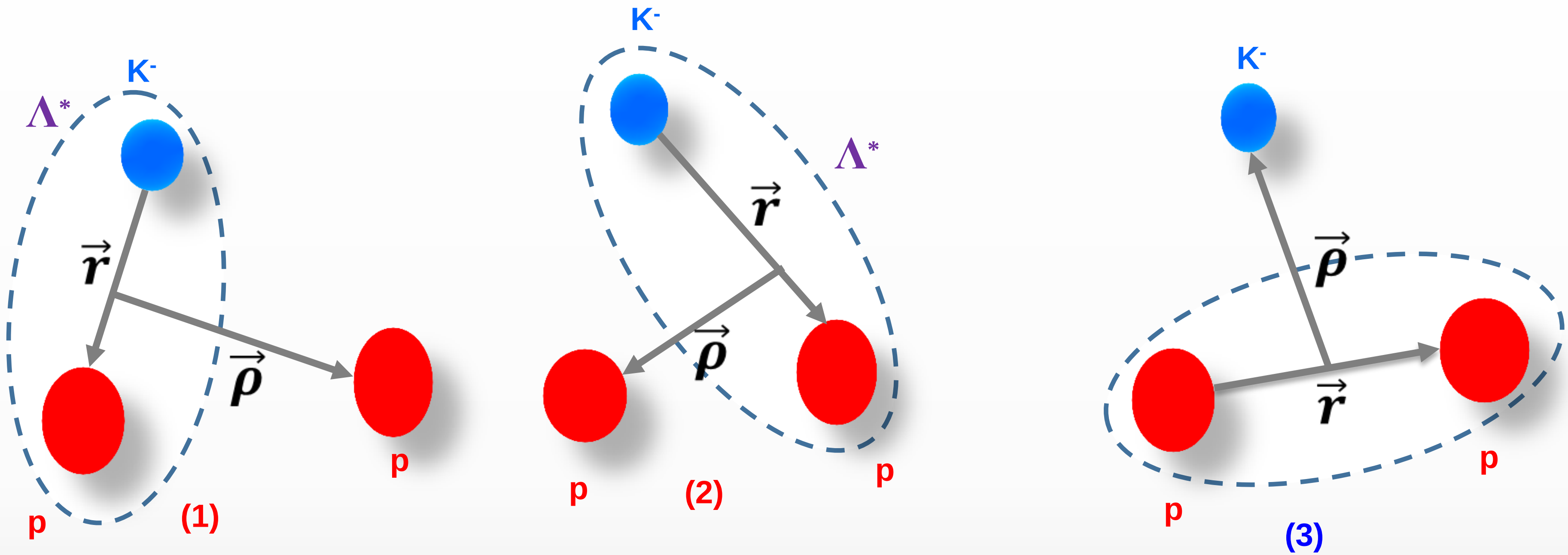


D (π^+ , K^+) X

X ⟶ strangeness (-1), single charged

K^- pp, Λ^* p, Σ^* p, Σ^0 p

Three-Body Coupled Channel Rearrangement Gaussian Basis Treatment



$$\psi(r,\rho) = \sum_{c=1}^{3} \sum_{i,j} \sum_{l,L} A_c^{i,j}\, r_c^{l+1}\, e^{-\left(\frac{r_c}{b_i}\right)^2}\, \rho_c^{L+1}\, e^{-\left(\frac{\rho_c}{d_j}\right)^2}$$

(1) and (2) are Λ^* – p structure, strong KN interaction. Major contribution

(3) is K-(pp) structure with p-p repulsive interaction

$$H \approx H_1 = \{T(\vec{r}) + V_{K^-p}(\vec{r})\} + \{T(\vec{\rho}) + V_{\Lambda^* p}(\vec{\rho})\}$$

$$H_{\Lambda^*} \qquad + \qquad H_{\Lambda^* p}$$

Variational wave function of K^-pp

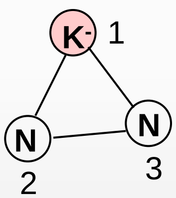
ATMS

Amalgamation of **T**wo-body correlations into **M**ultiple **S**cattering process

$$\psi = [\phi_{12} + \phi_{13}] \left| T = \frac{1}{2} \right\rangle$$

$$\Psi = \left[\left\{ f^{I=0}(r_{12}) \hat{P}_{12}^{I=0} + f^{I=1}(r_{12}) \hat{P}_{12}^{I=1} \right\} f_{\mathrm{NN}}(r_{23}) f(r_{31}) + f(r_{12}) f_{\mathrm{NN}}(r_{23}) \left\{ f^{I=0}(r_{31}) \hat{P}_{31}^{I=0} + f^{I=1}(r_{31}) \hat{P}_{31}^{I=1} \right\} \right] \left| T = 1/2 \right\rangle$$

$$\hat{P}_{12}^{I=0} = \frac{1 - \vec{\tau}_{\mathrm{K}} \vec{\tau}_{\mathrm{N}}}{4}, \quad \hat{P}_{12}^{I=1} = \frac{3 + \vec{\tau}_{\mathrm{K}} \vec{\tau}_{\mathrm{N}}}{4}$$



$$\left| T = 1/2 \right\rangle = \sqrt{\frac{3}{4}} \boxed{\left[\left(\bar{K}_1 N_2 \right)^{0,0} p_3 \right]} + \sqrt{\frac{1}{4}} \boxed{\left[-\sqrt{\frac{1}{3}} \left(\bar{K}_1 N_2 \right)^{1,0} p_3 + \sqrt{\frac{2}{3}} \left(\bar{K}_1 N_2 \right)^{1,1} n_3 \right]}$$

$\Lambda^* p$

Euler-Lagrange equation

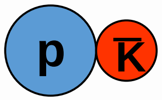
$$\delta_f \left\{ \langle \Psi | H | \Psi \rangle - \lambda \langle \Psi | \Psi \rangle \right\} = 0$$

$$v_{\bar{\mathrm{K}}\mathrm{N}}^{T=0}(r) = \{-595 - i83\}_{\mathrm{MeV}} \exp\left\{-(r/0.66_{\mathrm{fm}})^2\right\}$$

$$v_{\bar{\mathrm{K}}\mathrm{N}}^{T=1}(r) = \{-175 - i105\}_{\mathrm{MeV}} \exp\left\{-(r/0.66_{\mathrm{fm}})^2\right\}$$

$$v_{\mathrm{NN}}(r) = 2000_{\mathrm{MeV}} \exp\left\{-(r/0.447_{\mathrm{fm}})^2\right\} - 270_{\mathrm{MeV}} \exp\left\{-(r/0.942_{\mathrm{fm}})^2\right\} - 5_{\mathrm{MeV}} \exp\left\{-(r/2.5_{\mathrm{fm}})^2\right\}$$

Heitler-London-Heisenberg picture of K^-pp



$\Lambda(1405)$

[MeV]

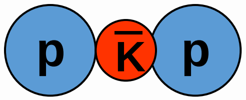
E	$-27.8 \quad -20.0i$
KE	115.3
PE	$\boxed{-143.1 \quad -20.0i}$

$$\sqrt{\frac{1}{2}}\,[\,\Lambda^* \; p + p \; \Lambda^*\,]$$

Covalent bonding

$$\left\langle \phi_a \middle| v_{K^-p} \middle| \phi_b \right\rangle + \left\langle \phi_b \middle| v_{K^-p} \middle| \phi_a \right\rangle$$

Exchange integral



K^-pp

[MeV]

E	-47.5	$-30.6i$
KE	167.0	
PE	-214.5	$-30.6i$
$\langle v_{NN} \rangle$	-19.0	
$\langle 2v_{KN}^{dir} \rangle$	$\boxed{-143.0}$	$\boxed{-23.3i}$
$\langle 2v_{KN}^{exc} \rangle$	$\boxed{-52.6}$	$-7.3i$

$\boxed{\Delta E = -20}$

$\Delta KE = 52$

$\Delta V_{NN} = -19$

33

$\Delta V^{exc} = -53$

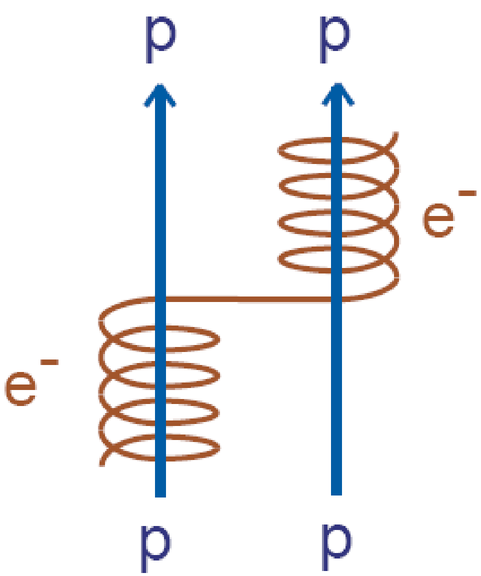
Real K^{bar} migrating superstrong interaction

Model: K^- pp production as a $\Lambda(1405)$ doorway state

Y. Akaishi, T. Yamazaki, M. Obu and M. Wada, Nucl. Phys. A 835 (2010) 67

Molecular

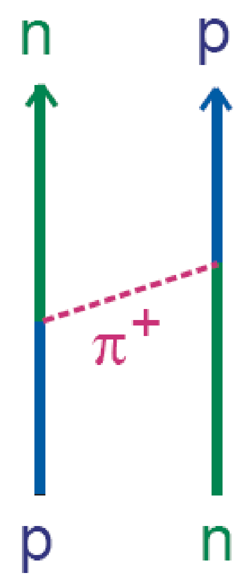
Heitler-London (1927)
Heisenberg (1932)



migrating
real
fermion

Nuclear Force

Yukawa (1935)



mediating
virtual
boson

Super Strong Nuclear Force

(2007)

Interaction between Λ^* and proton

$V_{\Lambda^* p}$ is constructed from three-body ATMS calculation

Amalgamation of Two-body correlations into Multiple Scattering process

DISTO

$$B_{K^- pp} = 105\ MeV, \quad \Gamma = 118\ MeV$$

$$B_{\Lambda^* p} = 105 - 27 = 78\ MeV$$

$$V_{\Lambda^* p} = (V_0 + iW_0)\left(\frac{r}{b}\right)^2 e^{-\frac{r}{b}}$$

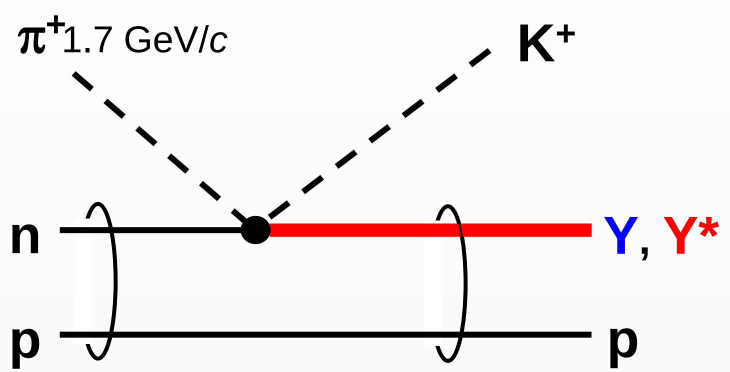
b = 0.3 fm

V_0 = -400 MeV

W_0 = -162 MeV

L= 0 E = - 78.0 - i 59.3 MeV

On the missing mass spectrum from D(π^+,K$^+$) E27 experiment



$$M_X^2 = (E_i - E_K)^2 - (p_\pi - p_K)^2$$

$$E_i = E_{\pi^+} + M_d$$

Differential cross section contains kinematical factor and spectral function S(E) where E is the missing mass variable

Y (Λ / Σ) Y* (Λ* / Σ*)

$$S(E) = -\frac{1}{\pi}\, Im\left[\int dr\, dr' f^*(r') G^{(+)}(r',r)\, f(r)\right]$$

$$G^{(+)}(r',r) = \left\langle r' \middle| \frac{1}{E - H_{K^-pp} + i\varepsilon} \middle| r \right\rangle$$

$$f(r) = e^{iQr}\psi_i(r)$$

$$E - H_{K^-pp} = (E - H_{\Lambda^*}) - H_{\Lambda^* p}$$

$$G^{(+)}(r',r) = \left\langle r' \middle| \frac{1}{E' - H_{\Lambda^* p} + i\varepsilon} \middle| r \right\rangle$$

$$(E - H_{\Lambda^*}) \rightarrow E - B_{\Lambda^*} + i\,\frac{1}{2}\,\Gamma_{\Lambda^*}$$

Missing mass spectrum of Λ*-p system

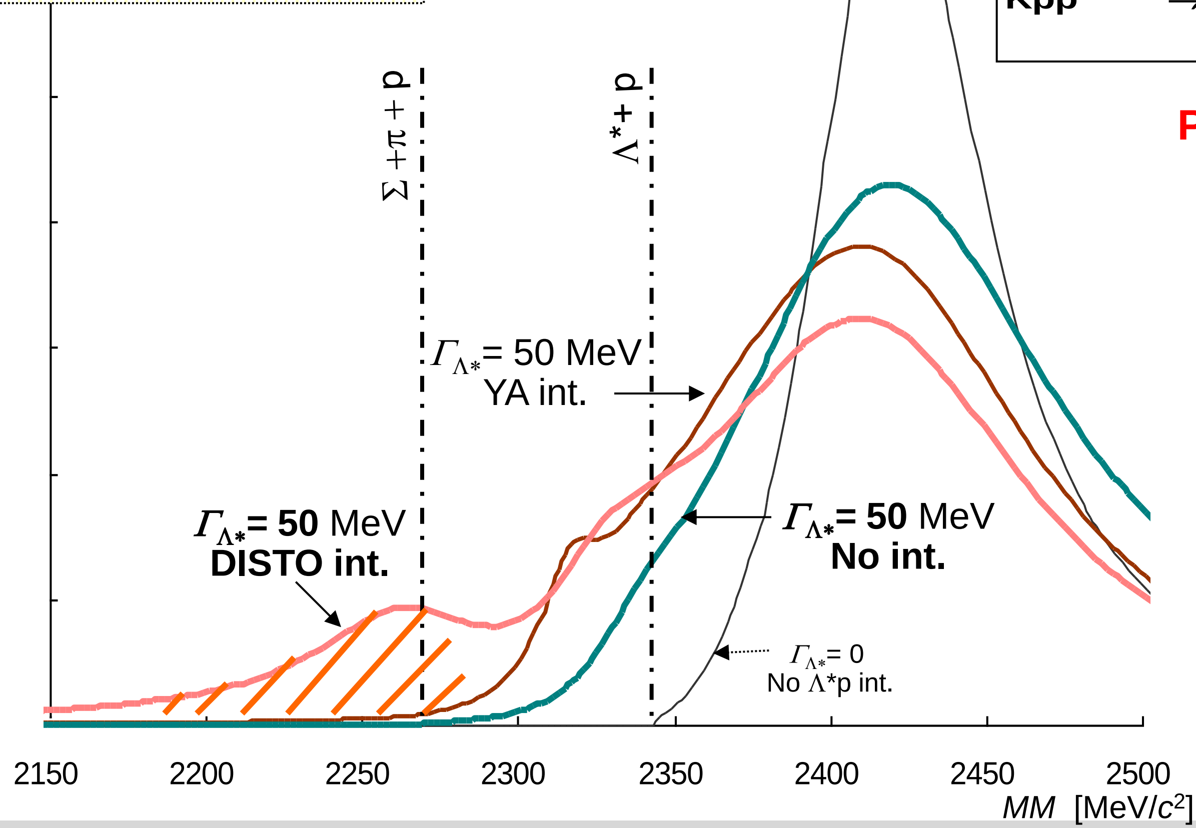
for E27@J-PARC

17%
YA → DISTO

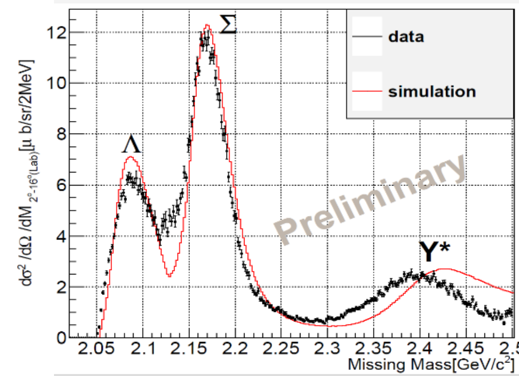
S. Maeda, Y. Akaishi & T. Yamazaki,
Proc. Jpn. Acad. B 89 (2013) 418

$$\Lambda \to p + \pi^-, \quad p_p = 100.5\ \mathrm{MeV}/c$$
$$\Sigma^+ \to p + \pi^0, \quad p_p = 189.0\ \mathrm{MeV}/c$$

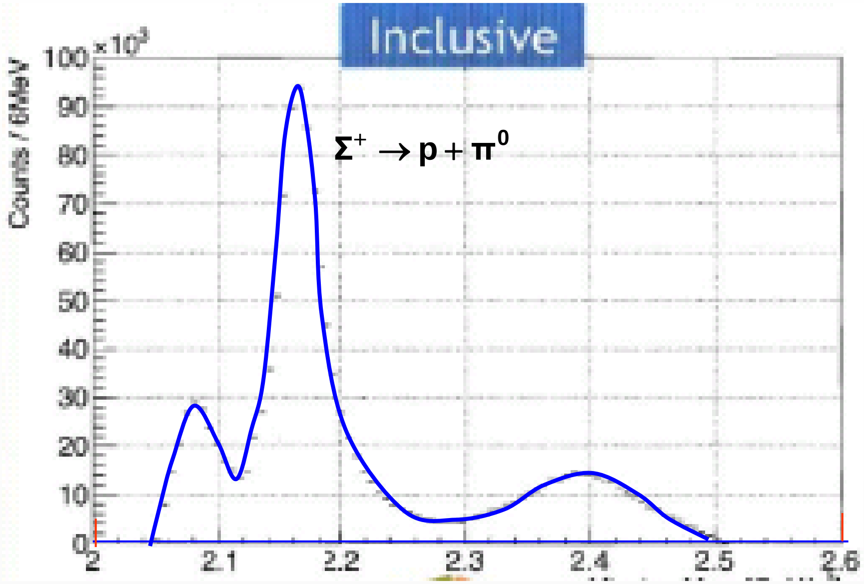
$$\Sigma^0 + p \to \Lambda + p, \quad p_p = 282.7\ \mathrm{MeV}/c$$
ΣN-ΛN conversion
$$Kpp^{DISTO} \to \Lambda + p, \quad p_p = 476.0\ \mathrm{MeV}/c$$
"K^-pp"= Λ*-p QBS



Proton (> 280 MeV/c)
coincidence
by T. Nagae et al.



Coincidence study



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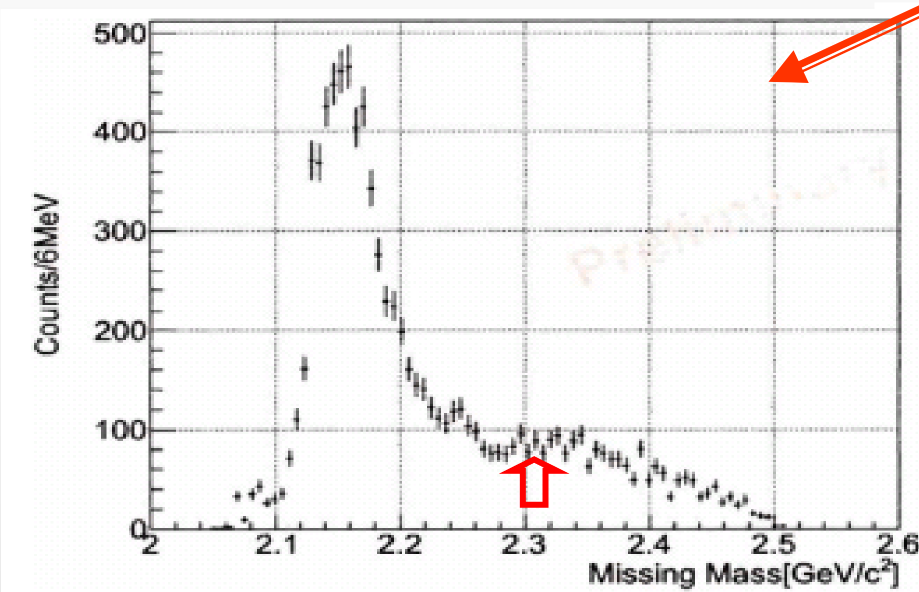
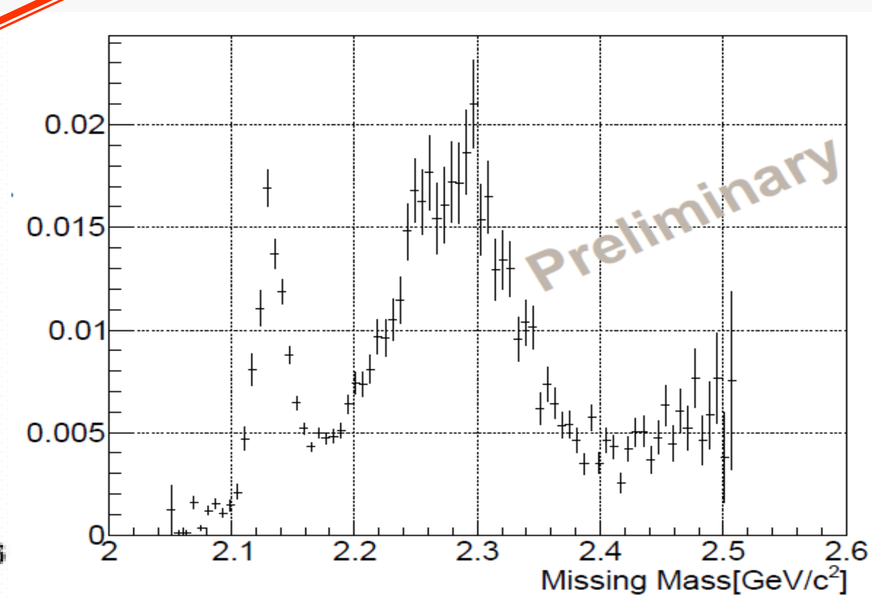
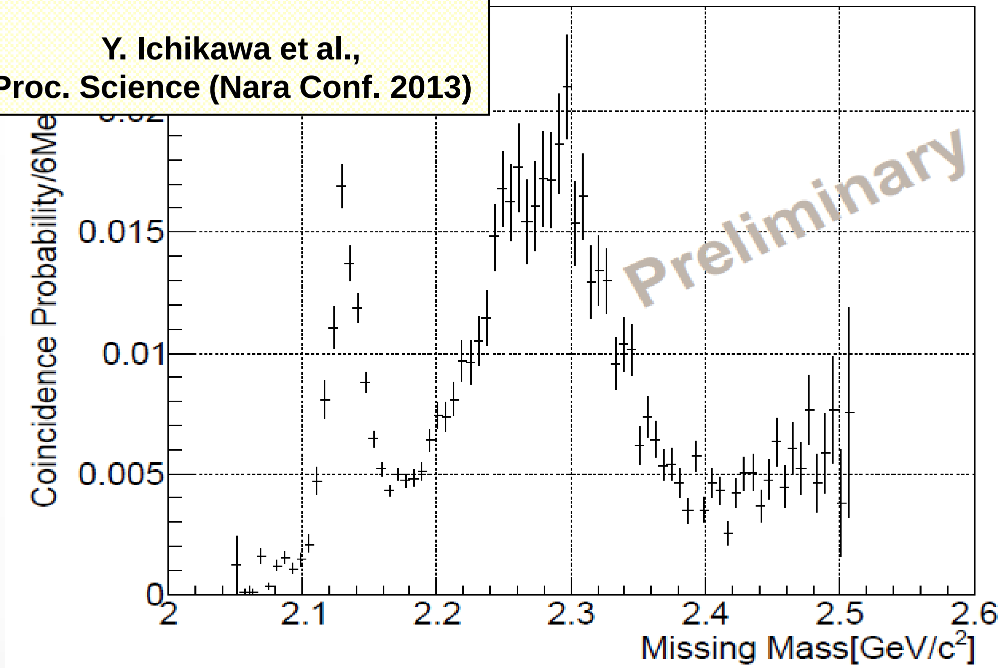




E27@J-PARC

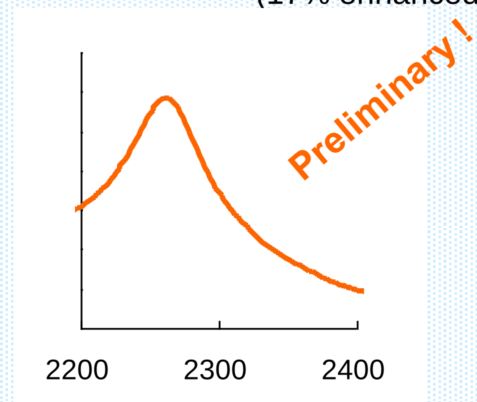
Y. Ichikawa et al.,
Proc. Science (Nara Conf. 2013)



K$^-$pp = Λ*-p

with real K^{bar} migration

(17% enhanced int.)



DISTO

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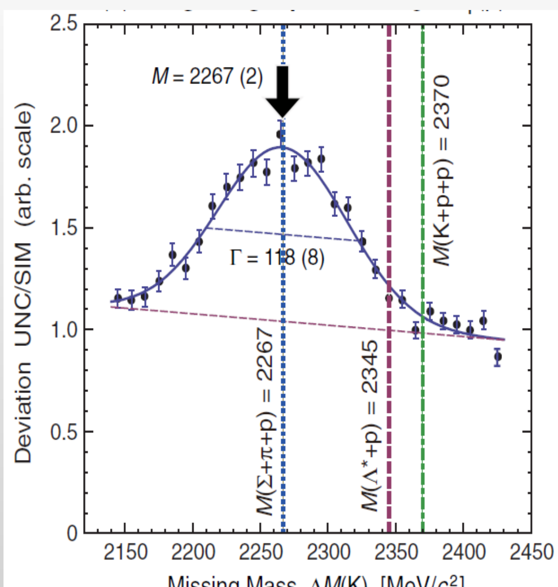
Phys. Rev. Lett.
104 (2010) 132502



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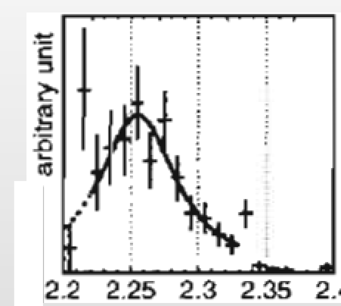

M. Agnello et al.,
Phys. Rev. Lett.
94 (2005) 212303

Inclusive spectrum

Y. Ichikawa et al., Proc. Science (Nara Conf. 2013)

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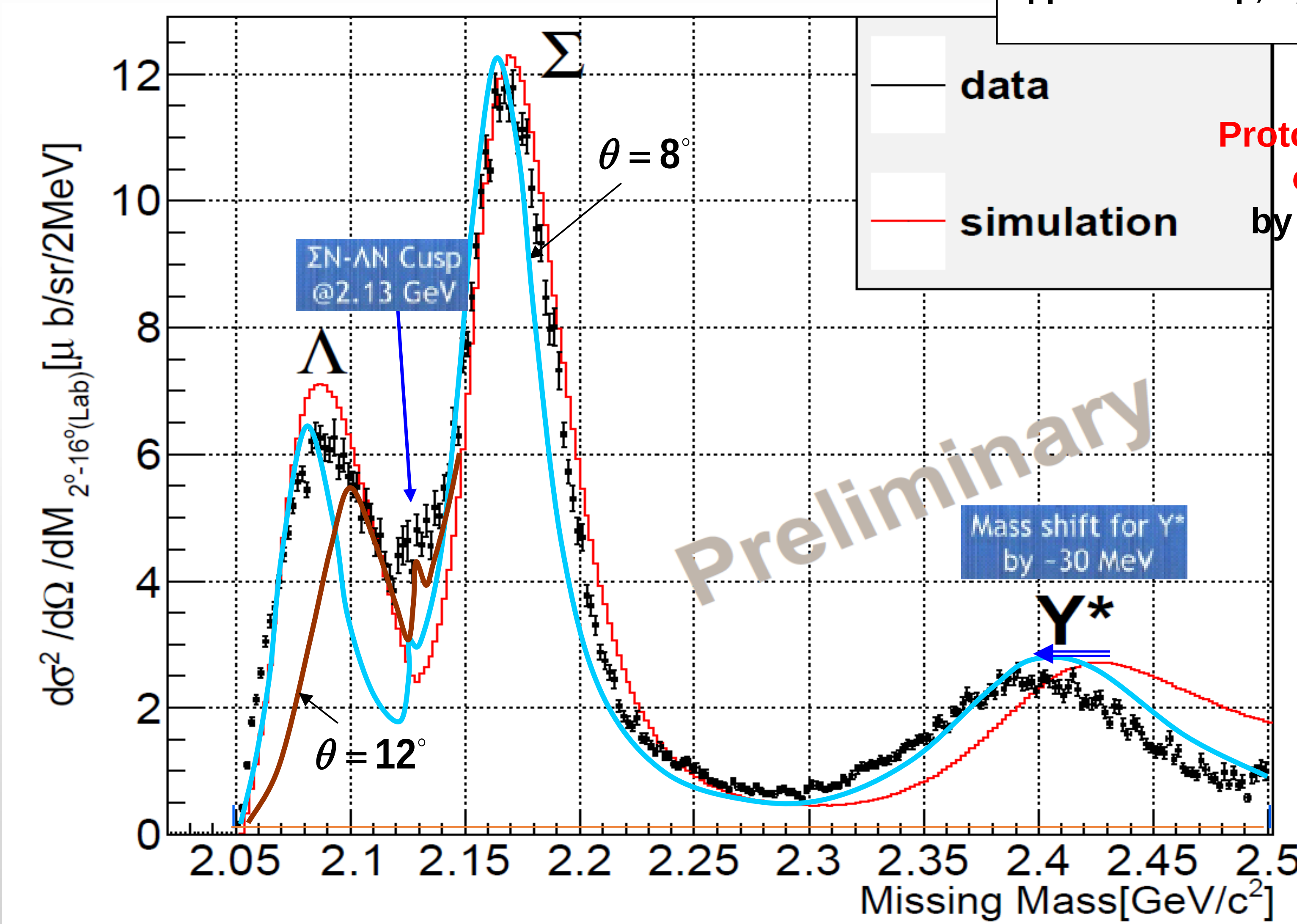
"K⁻pp"= Λ*-p QBS



Proton (> 280 MeV/*c*) coincidence

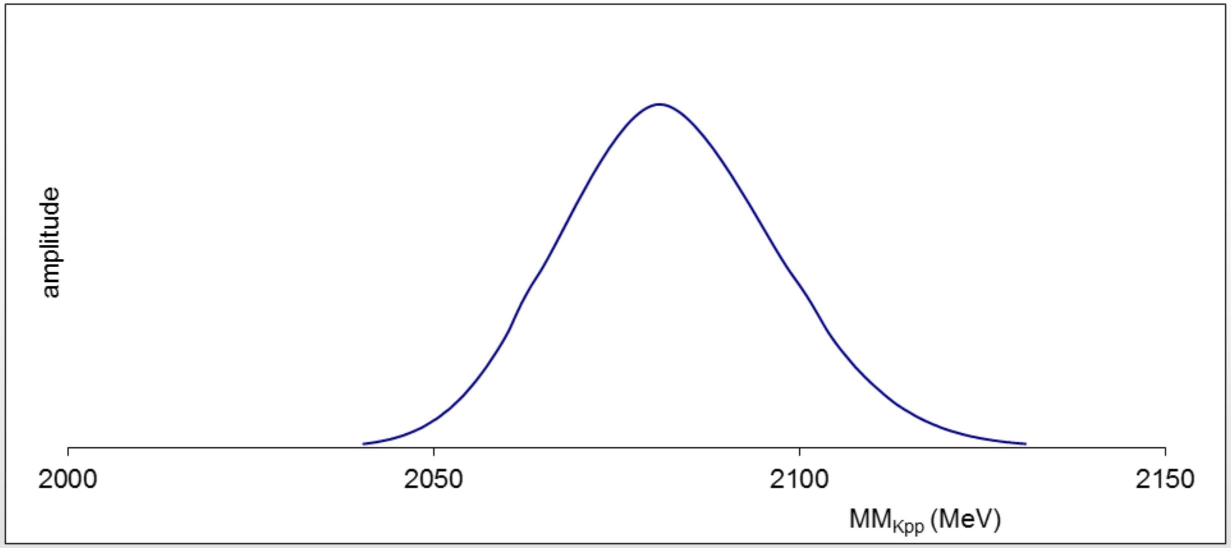
by T. Nagae et al.

QF Λ-p production and Fermi motion

Deuteron momentum distribution $\rho_d(k_n) = N \times e^{-\frac{2}{a}k_n^2}$ where a = 0.1994 fm^{-1}

Neutron distribution is largest at $p_n = 0$ $\pi^+ + n \to K^+ + \Lambda$

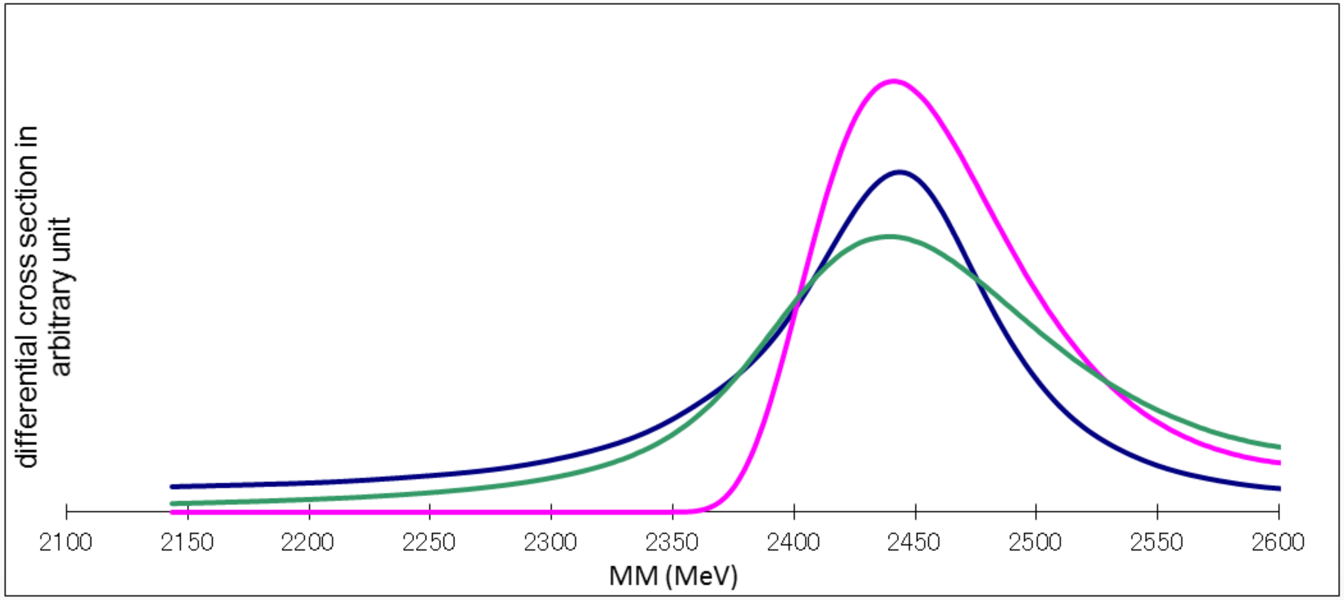
$$M_X^2 = (E_\pi + M_d - E_K)^2 - (p_\pi - p_K)^2$$



Peak position = 2080.94 MeV, level width = 35 MeV consistent with exp.

Λ peak is not a dynamical resonance

Quasi-free Λ^{*}p production



Peak position 2440 MeV, 40 MeV shift from E27 exp.

Blue curve: Fermi motion suppressed, $\Gamma_{\Lambda}{}^{*} = 50$ MeV $\Gamma_{width} = 100$ MeV

Pink curve: Fermi motion included, $\Gamma_{\Lambda}{}^{*} = 0$ $\Gamma_{fermi} = 90$ MeV

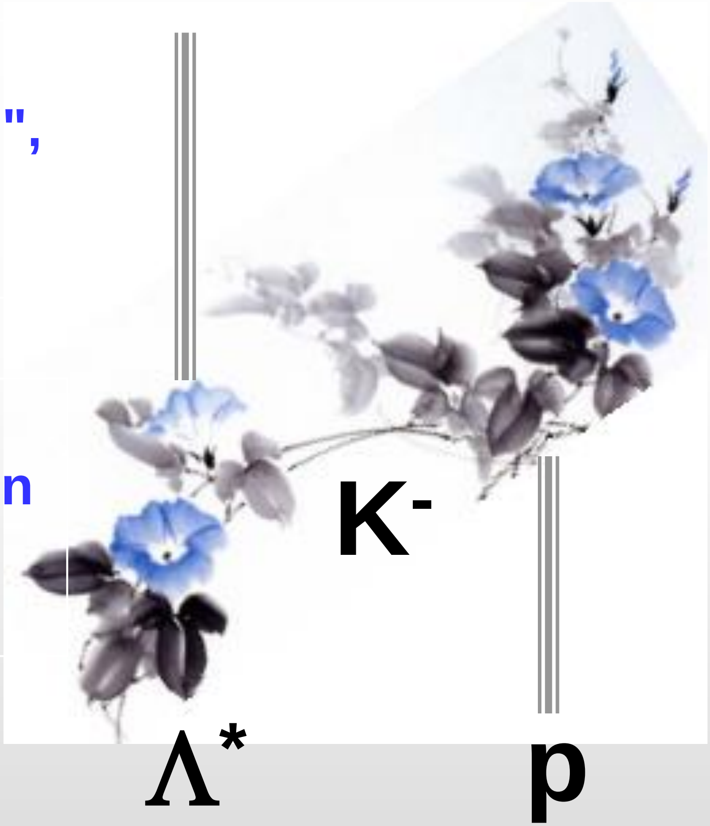
Green curve: Fermi motion included, $\Gamma_{\Lambda}{}^{*} = 50$ MeV $\Gamma_{total} = 140$ MeV

Concluding remarks

The $\Lambda^* = \Lambda(1405)$ plays an essential role in forming "anti-Kaonic Nuclear Clusters", the simplest one of which is

$$K^-pp = (K^-p)\text{–}p = \Lambda^*\text{–}p.$$

The Λ^*–p structure interacting with "super-strong force" due to K^{bar} migration provides a possible explanation of recent J-PARC data on K^-pp.



Thank you very much!