EXA2011

September 6, 2011

Coupled-channel properties of Λ(1405) and K^-pp production in pp collisions

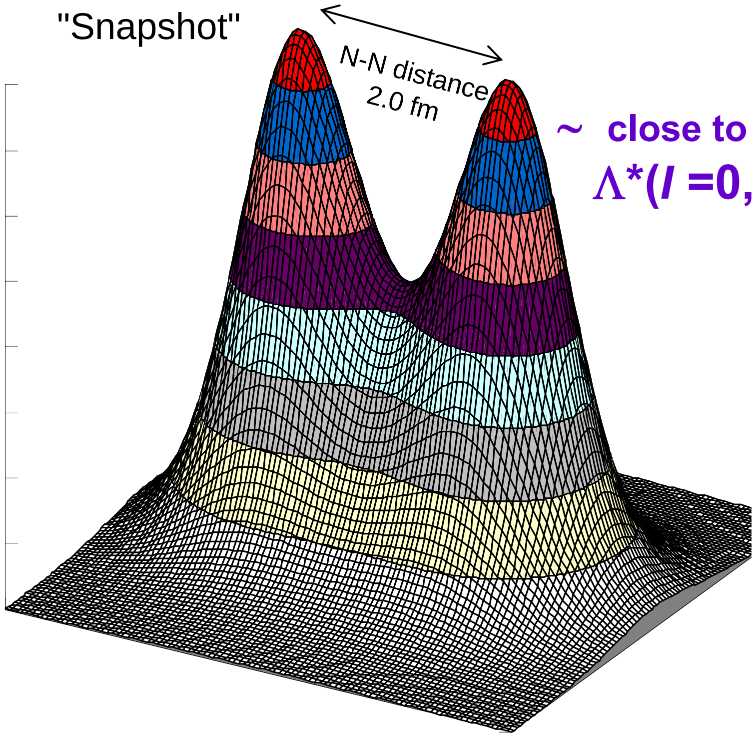
Khin Swe Myint ,

Yoshinori AKAISHI &Toshimitsu YAMAZAKI

K^- distribution in K^-pp

from an accurate three-body calculation

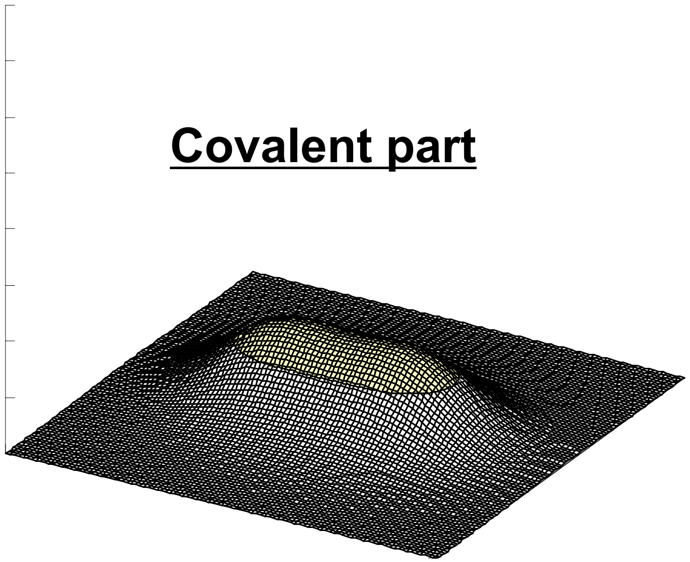
Phys. Rev. C 76 (2007) 045201



~ close to free
$\Lambda^*(I=0, K^-p)$

As is assumed and discussed by
A. Ivanov, P. Kienle et al.

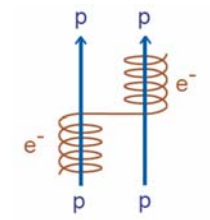
"Kaonic hydrogen molecule"

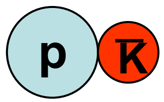


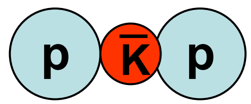
$$\Psi = \phi_a + \phi_b$$

The structure of K^-pp is virtually determined by $\Lambda^*=\Lambda(1405)$.

Heitler-London-Heisenberg picture of K^-pp







$\Lambda(1405)$

[MeV]

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

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

Covalent bonding

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

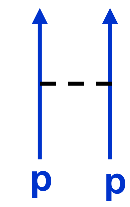
Exchange integral

K^-pp

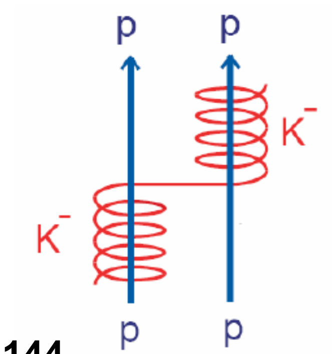
[MeV]

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

Virtual meson exchange



~4 times stronger

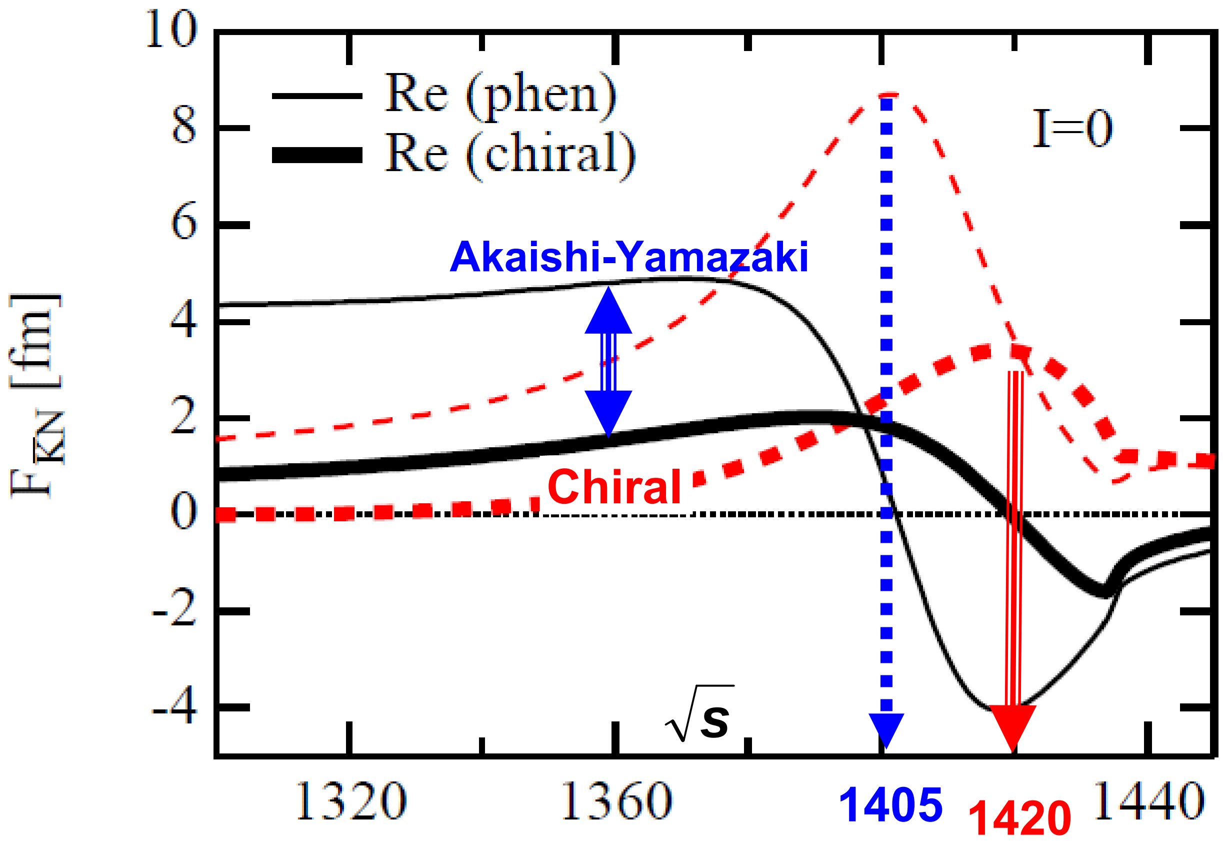


Real K^{bar} migrating
superstrong interaction

T. Yamazaki & Y. Akaishi,
Proc. Japan Academy, B 83 (2007) 144

$K^{bar}N$ scattering amplitude

T. Hyodo and W. Weise, Phys. Rev. C 77 (2008) 035204



Which is the Λ(1405) mass ?

Generalized optical potential

$$v_{ij} = g_i(k')U_{ij}\, g_j(k)$$
$$t_{ij} = g_i(k')T_{ij}(E)g_j(k)$$
$$\bar{G}_j = \left\langle g_j \middle| G_j^{(0)} \middle| g_j \right\rangle$$

Two-channel coupled equation

$$\begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix} = \begin{pmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{pmatrix} + \begin{pmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{pmatrix} \begin{pmatrix} G_1^{(0)} & 0 \\ 0 & G_2^{(0)} \end{pmatrix} \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix}$$

$$G_j^{(0)}(E) = \left(E_j - K_j + i\varepsilon\right)^{-1}$$
$$E = E_1 = E_2 - Q$$

$$v_{11}^{opt}(E) = v_{11} + v_{12}G_2(E)v_{21} \quad , \quad v_{12}^{opt}(E) = v_{12} + v_{12}G_2(E)v_{22}$$
$$v_{21}^{opt}(E) = v_{21} + v_{21}G_1(E)v_{11} \quad , \quad v_{22}^{opt}(E) = v_{22} + v_{21}G_1(E)v_{12}$$

$$G_j(E) = \left(E_j - K_j - v_{jj} + i\varepsilon\right)^{-1}$$

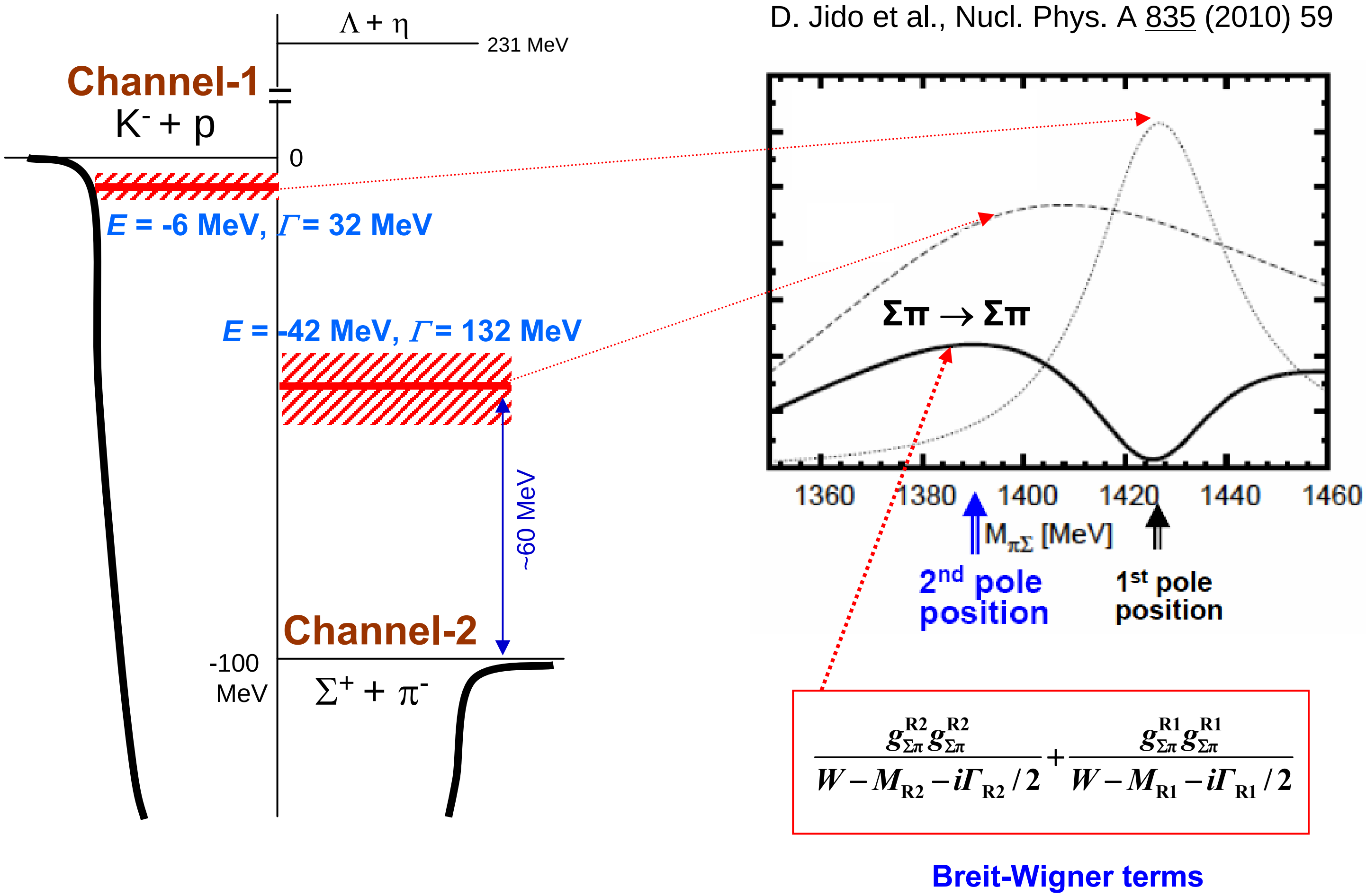
Solutions of 4 decoupled equations

$$t_{11}(E) = \frac{1}{1 - v_{11}^{opt}(E)G_1(E)} v_{11}^{opt}(E) \quad , \quad t_{12}(E) = \frac{1}{1 - v_{11}^{opt}(E)G_1(E)} v_{12}^{opt}(E)$$
$$t_{21}(E) = \frac{1}{1 - v_{22}^{opt}(E)G_2(E)} v_{21}^{opt}(E) \quad , \quad t_{22}(E) = \frac{1}{1 - v_{22}^{opt}(E)G_2(E)} v_{22}^{opt}(E)$$

$1 - v_{jj}^{opt}(E)\, G_j(E) = 0 \;\Rightarrow\;$ resonance / bound state

Double pole structure of Λ(1405)

D. Jido, J.A. Oller, E. Oset, A. Ramos & U.G. Meissner, Nucl. Phys. A 725 (2003) 181



$\Sigma\pi$ mass spectrum

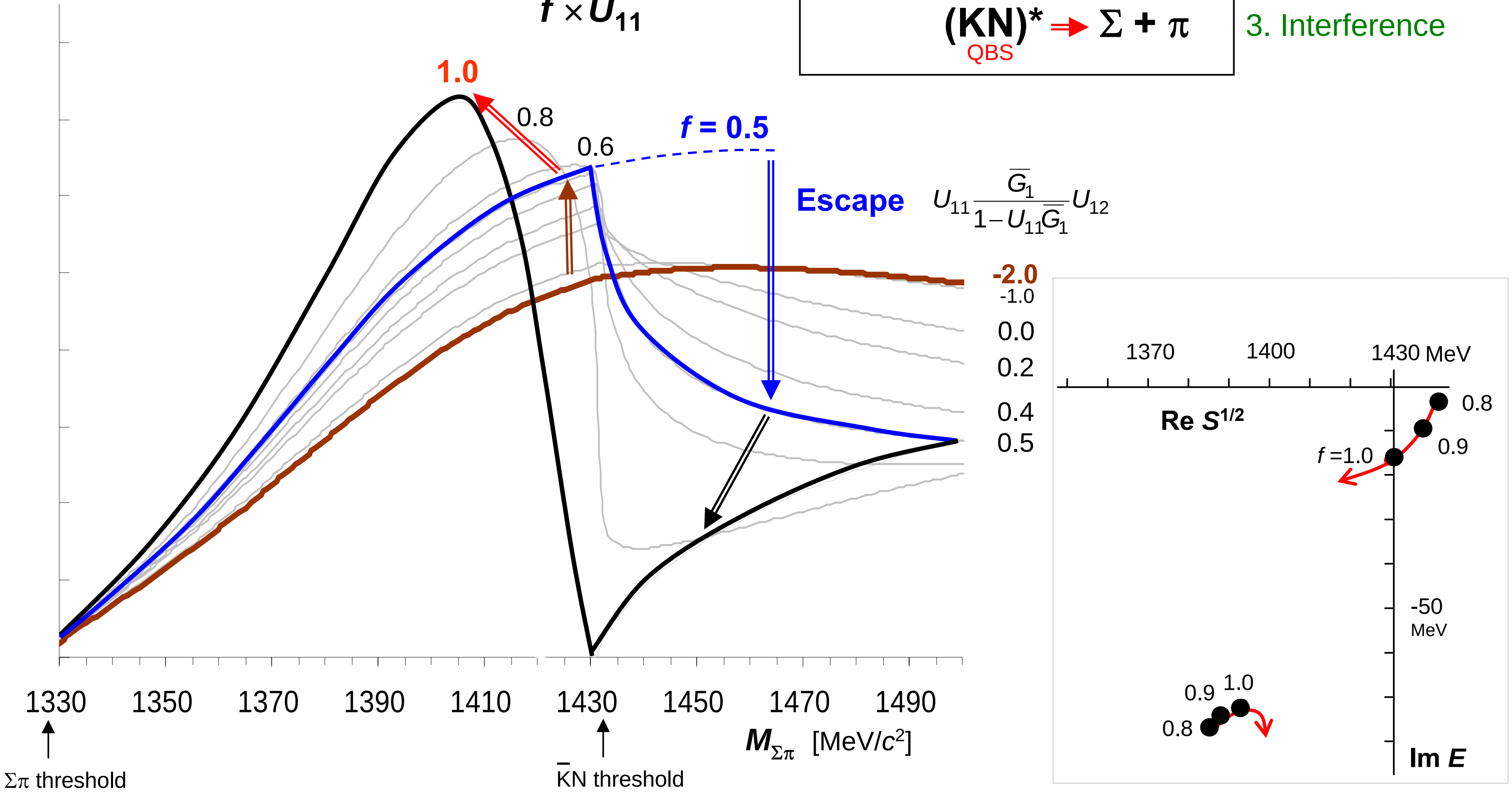
1; $\bar{K}N$
2; $\Sigma\pi$

$$U_{22}^{\text{opt}} = U_{22} + U_{21}\frac{\overline{G}_1}{1 - U_{11}\overline{G}_1}U_{12}$$

$$f \times U_{11}$$

$\Sigma + \pi \rightarrow \Sigma + \pi$
$\Sigma + \pi \rightarrow \bar{K} + N$
$\Sigma + \pi \rightarrow (KN)^*_{\text{QBS}} \rightarrow \Sigma + \pi$

1. Decaying-st. pole
2. Threshold cusp
3. Interference



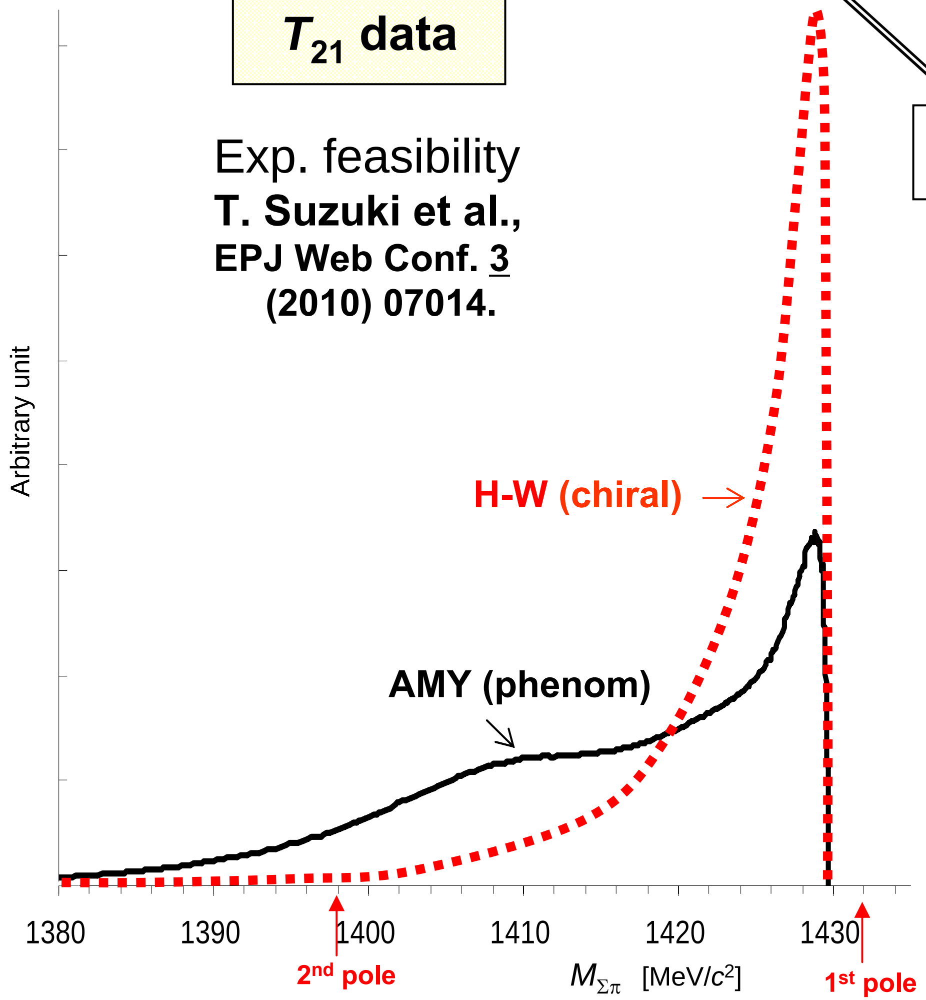
"Two-pole superposition" is not a proper explanation.

Stopped K^- on D

J. Esmaili, Y. Akaishi & T. Yamazaki,
Phys. Rev. C 83 (2011) 055207

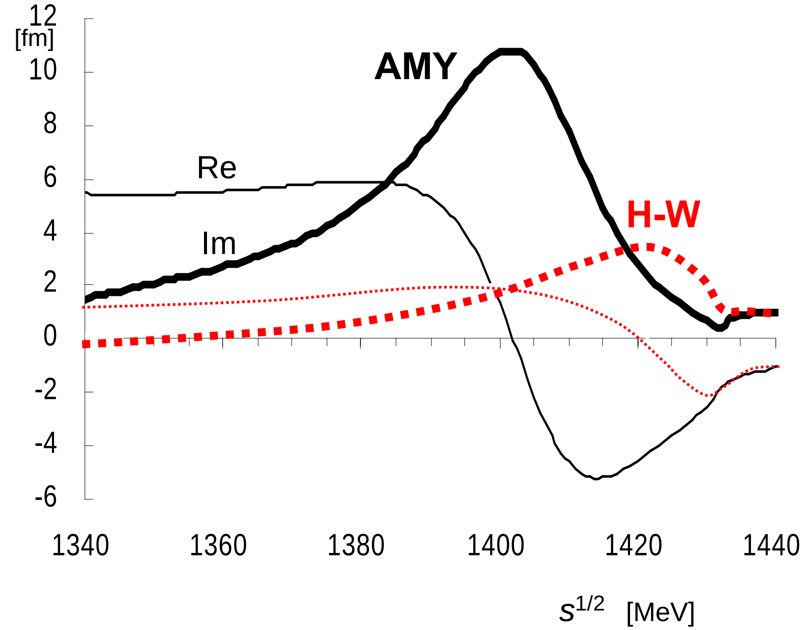
$\Sigma\pi$ invariant-mass spectrum

Projection with
$\rho(k)$ in D



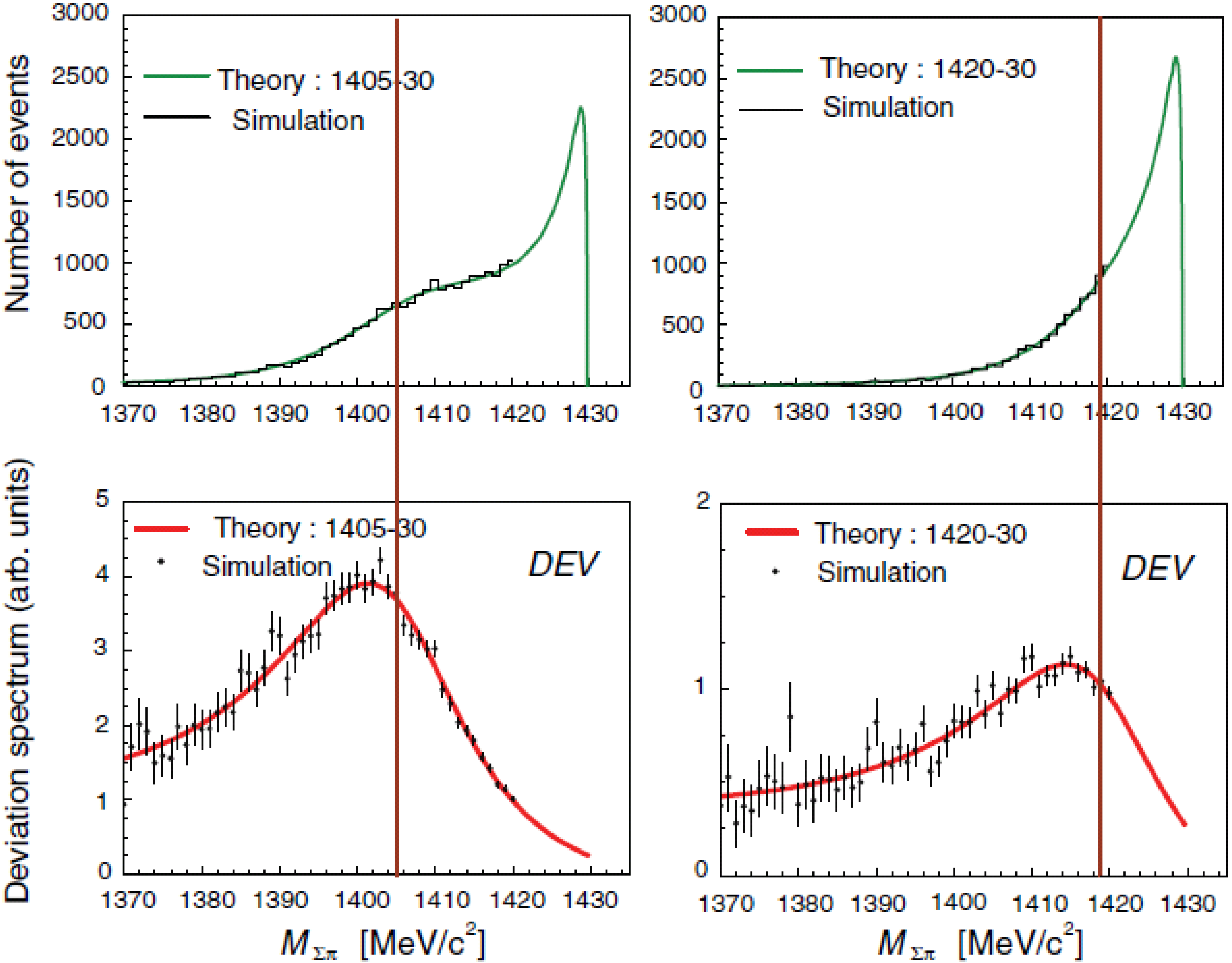
$$\left|T_{21}\right|^2 \, \mathrm{Im}\, G_2 = \mathrm{Im}\, T_{11}$$

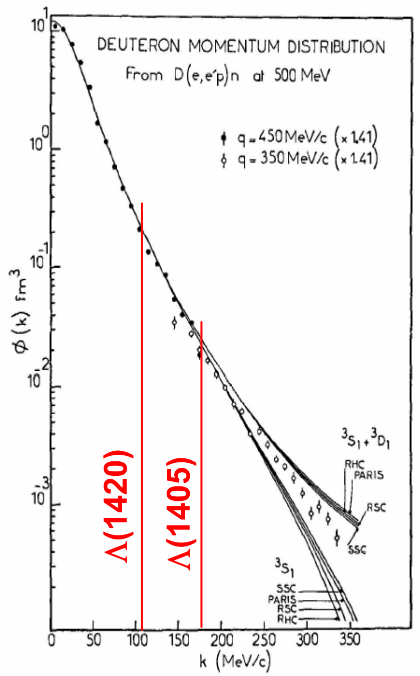
Scattering amplitude



T. Yamazaki, M. Maggiora, P. Kienle et al.,
Phys. Rev. Lett. 104 (2010) 132502

Deviation spectrum





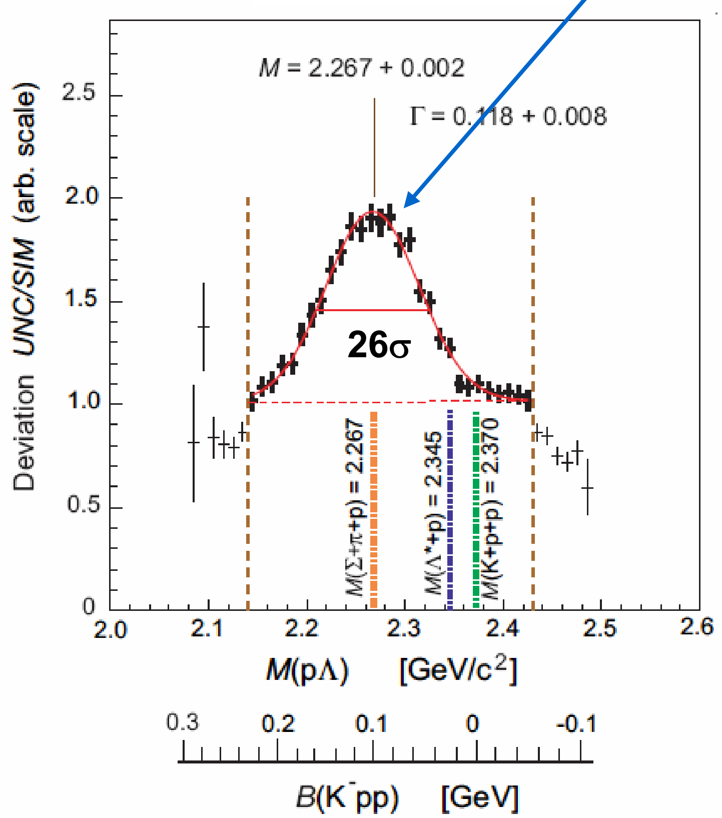
Simulation by J. Esmaili et al.

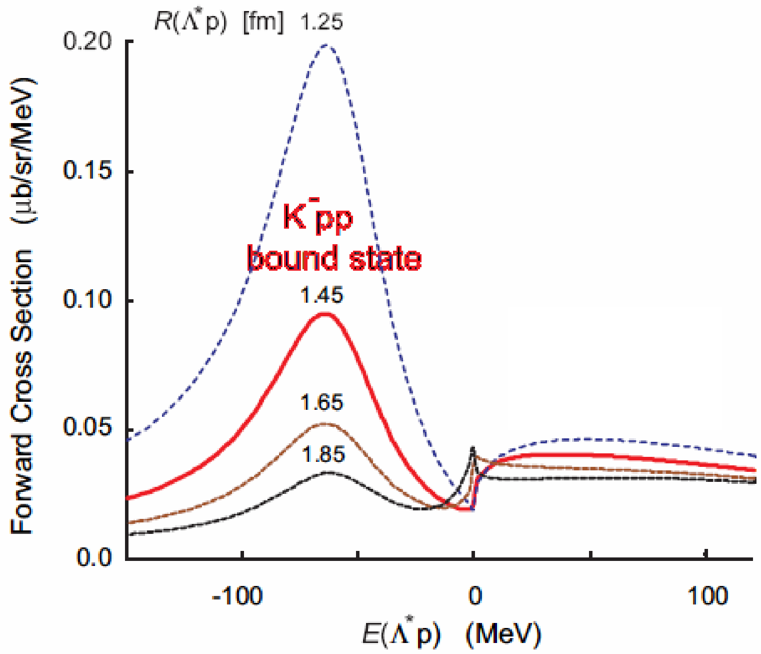
Experiment is awaited for the determination of 1405 MeV or 1420 MeV.

Λp invariant mass spectrum

T. Yamazaki, M. Maggiora, P. Kienle, K. Suzuki et al.,
Phys. Rev. Lett. 104 (2010) 132502

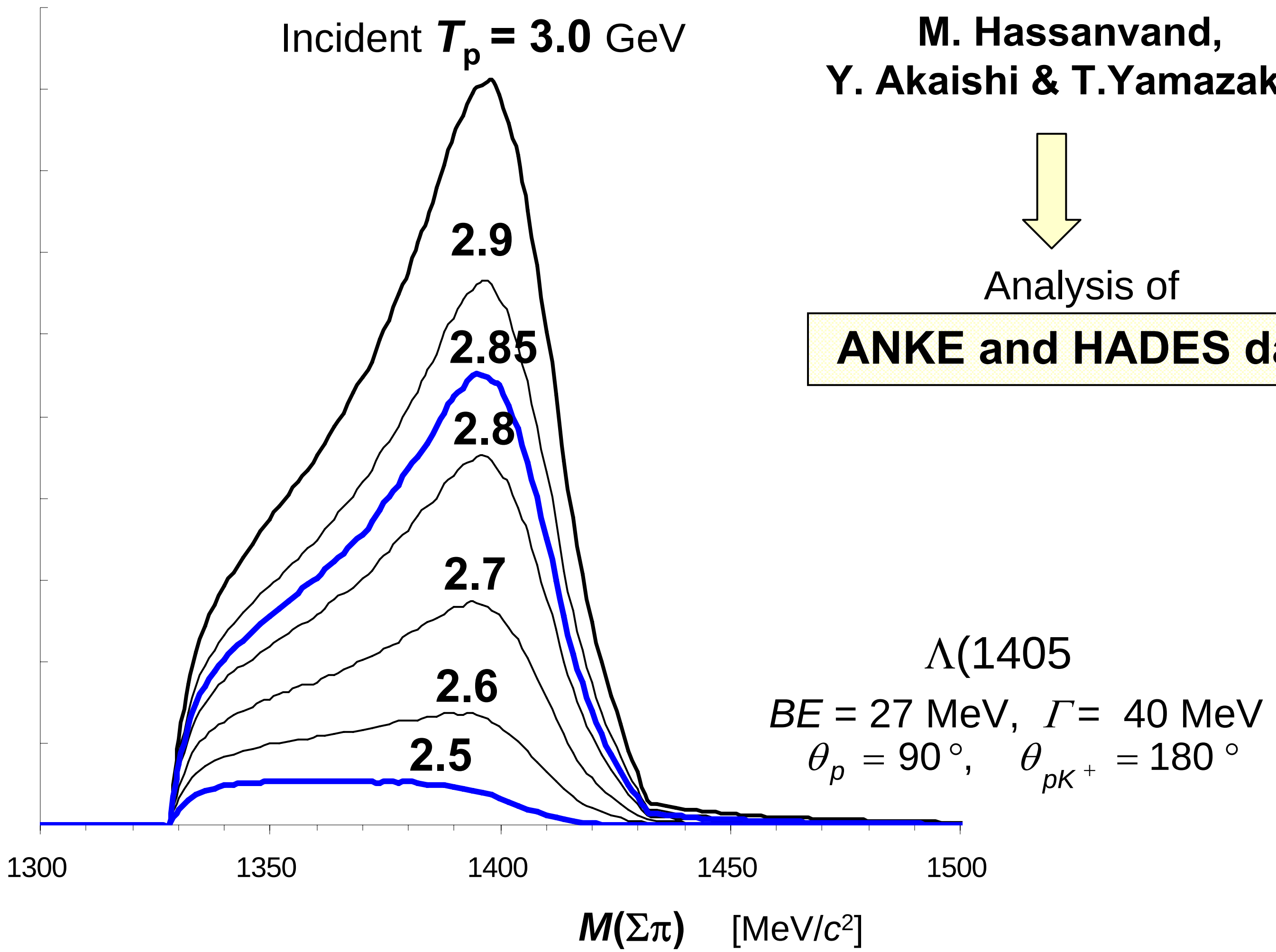
$$p + p \rightarrow K^{+} + \underbrace{\Lambda + p}_{X^{+}} \quad @\, T_p = 2.85\ \text{GeV}$$





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

$$p + p \rightarrow K^{+} + p + \Lambda^{*}$$
$$\hookrightarrow \Sigma^{0} + \pi^{0}$$



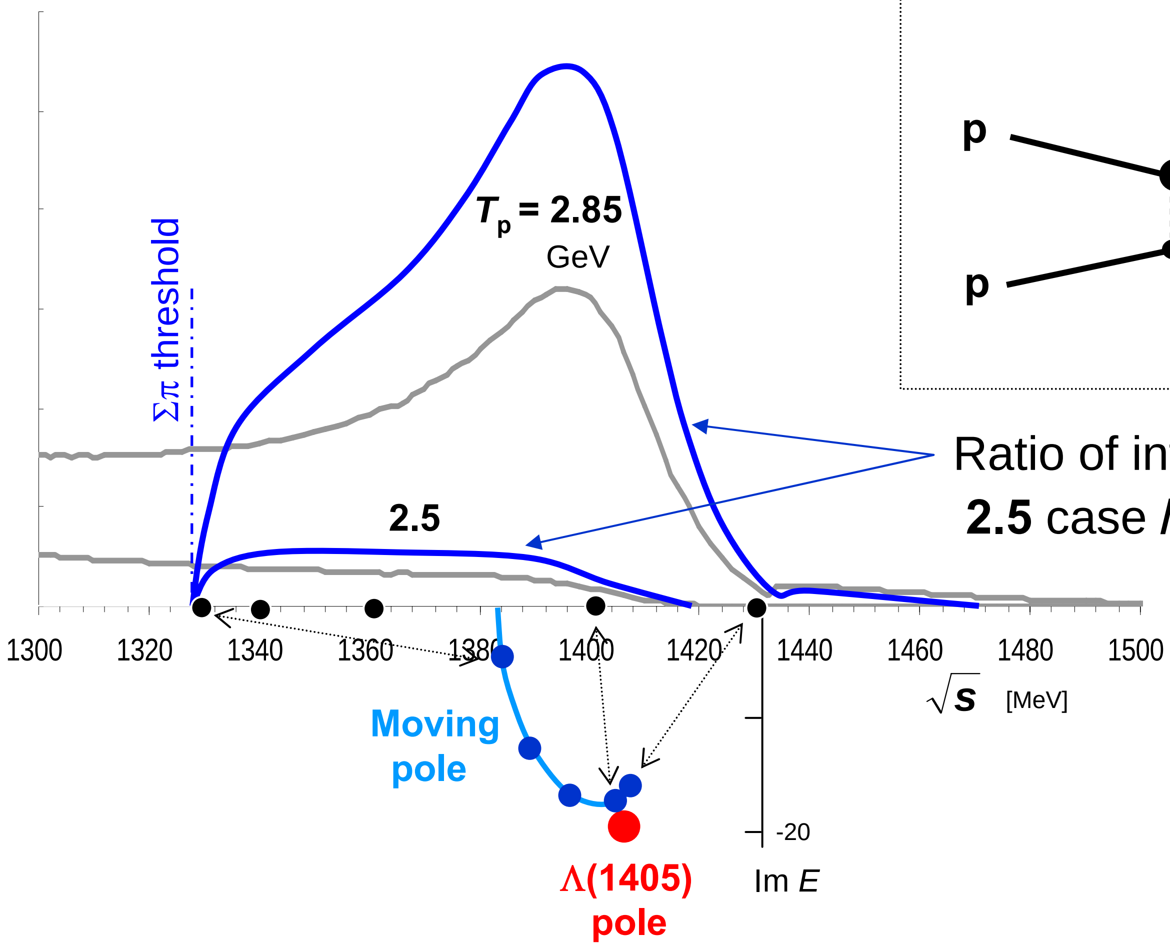
M. Hassanvand,
Y. Akaishi & T.Yamazaki

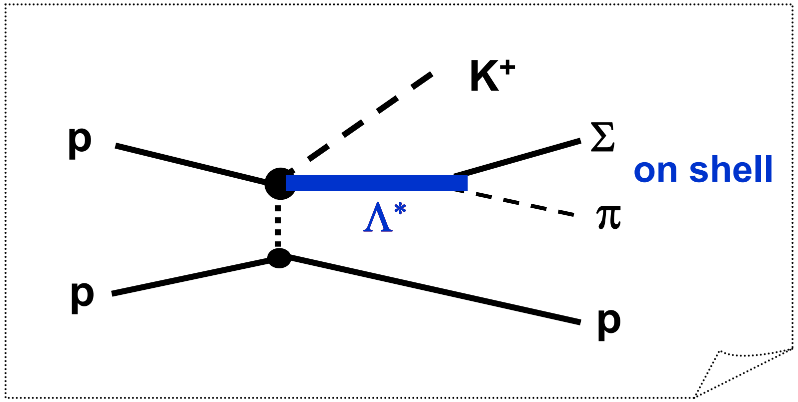
Analysis of

ANKE and HADES data

Decaying-state pole

Y. Akaishi, Khin Swe Myint & T. Yamazaki, Proc. Jpn. Acad. B 84 (2008) 264

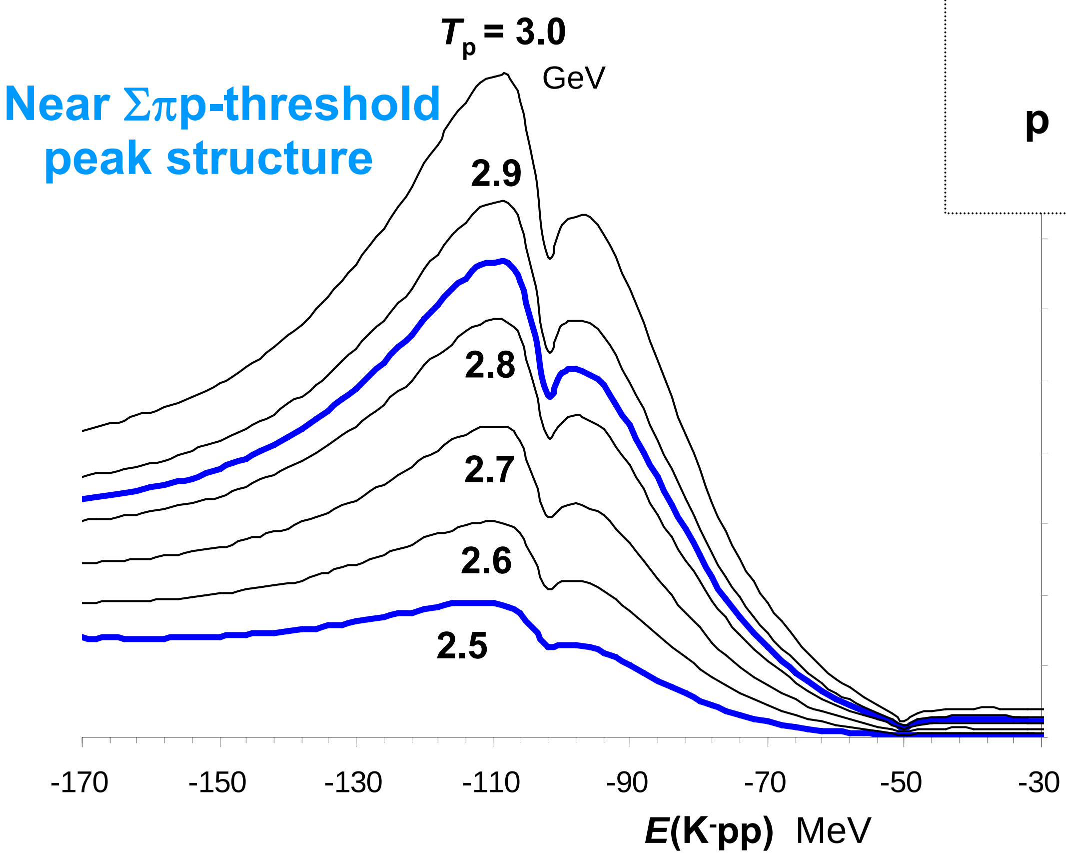


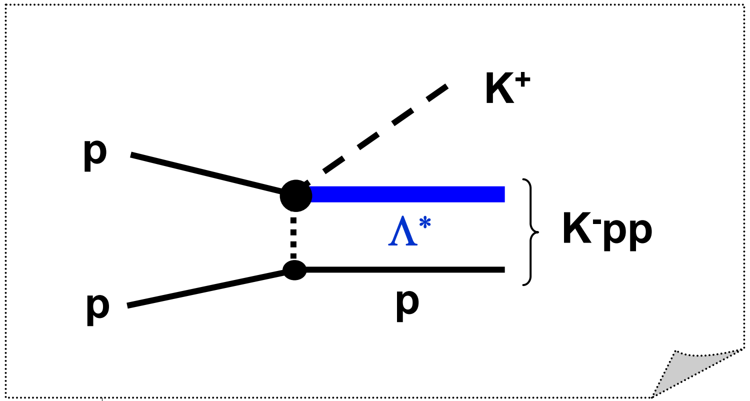


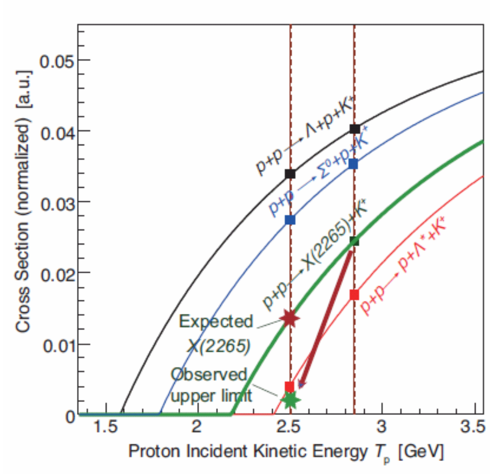
Ratio of integrated strengths
2.5 case / **2.85** case = **0.11**

Experimentally observed spectrum is not of "pole state" but of "decaying state".

K$^-$pp missing mass spectrum





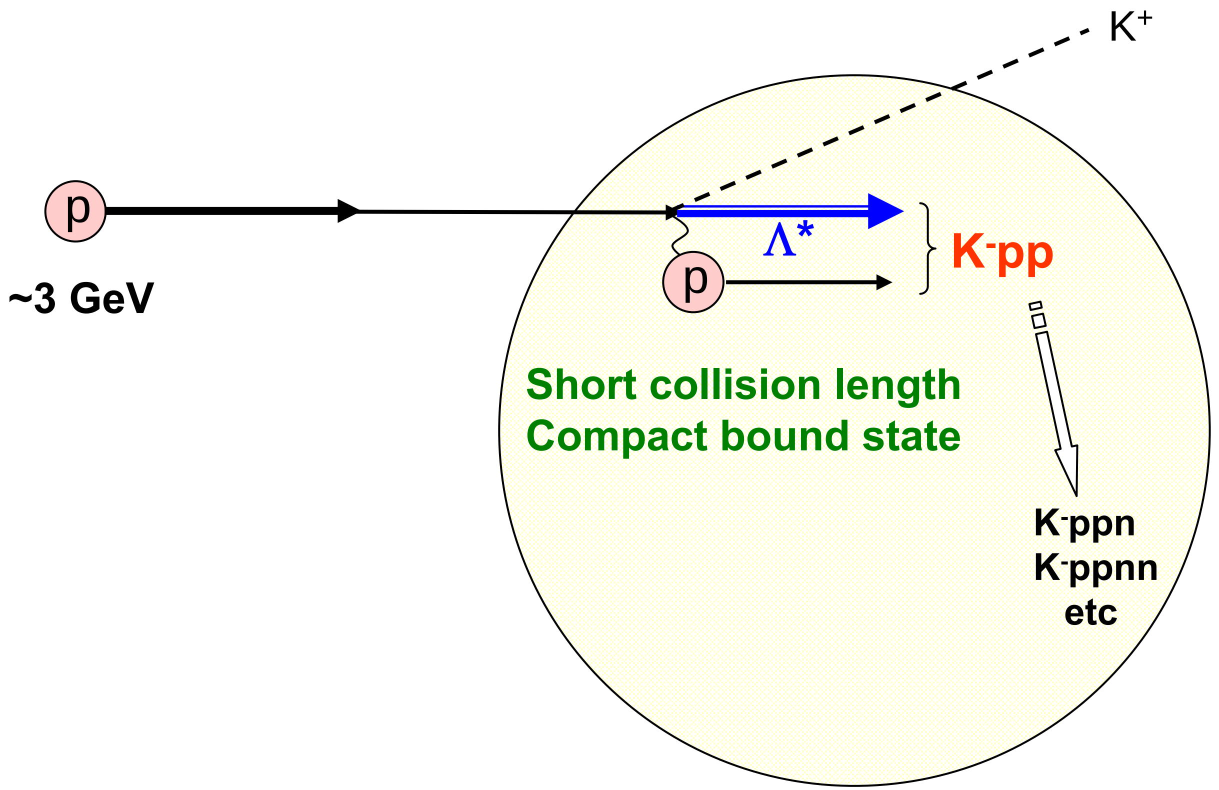


P. Kienle, M. Maggiora,
K. Suzuki, T. Yamazaki et al.,
arXiv:1102.0482 [nucl-ex]

T_p-dependence of K$^-$pp formation provides a useful information.

Doorway to “Kaonic Nuclear Clusters"

T. Yamazaki, Y. Akaishi & M. Hassanvand, Proc. Jpn. Acad. B 87 (2011) 362

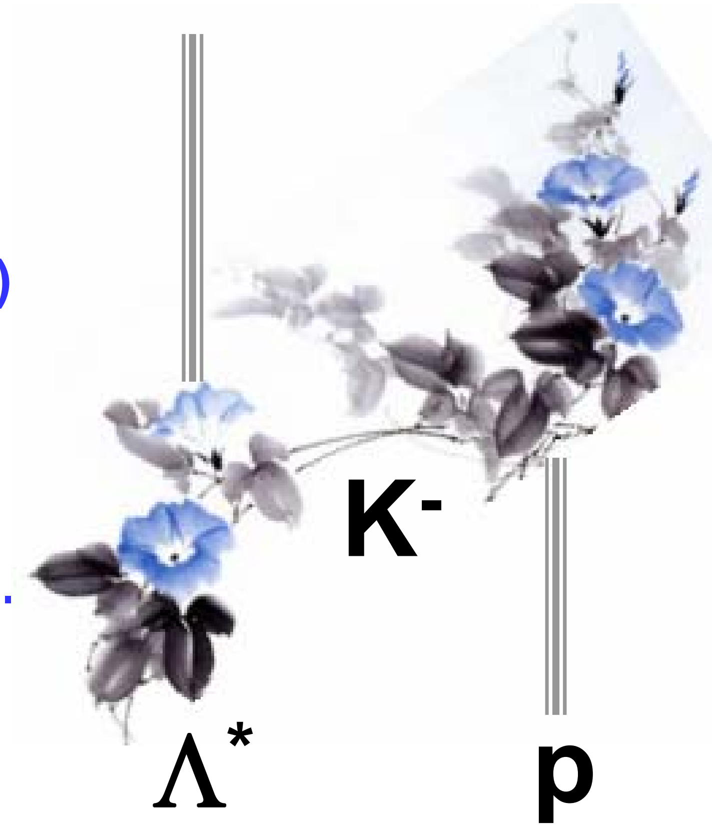


Conclusions

The $\Lambda(1405)$ plays an essential role in forming "K^{bar} Nuclear Clusters" (KNC)

Experimental information on $\Lambda(1405)$ is essentially important to establish the "super-strong nuclear force" (SSNF).

Incident-energy dependence of $K^{-}pp$ formation in pp collisions provides a useful information on the Λ*N's structure of KNC.

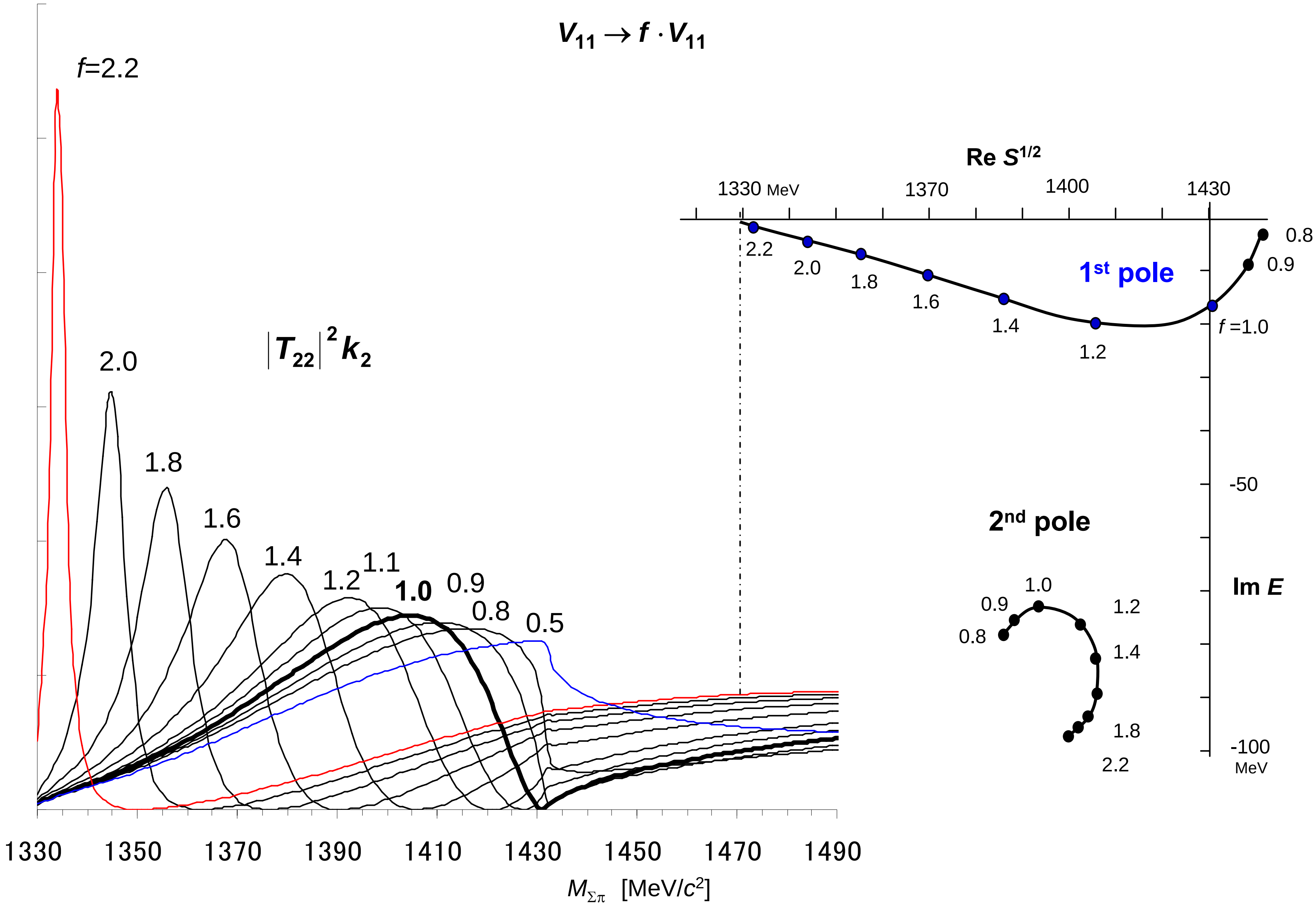


Acknowledgments

J. Esmaili, M. Hassanvand,
M. Obu, M. Wada, O. Morimatsu

Thank you very much!

Σπ invariant-mass spectrum shape



Moving pole

Σπ single channel

Reference spectra

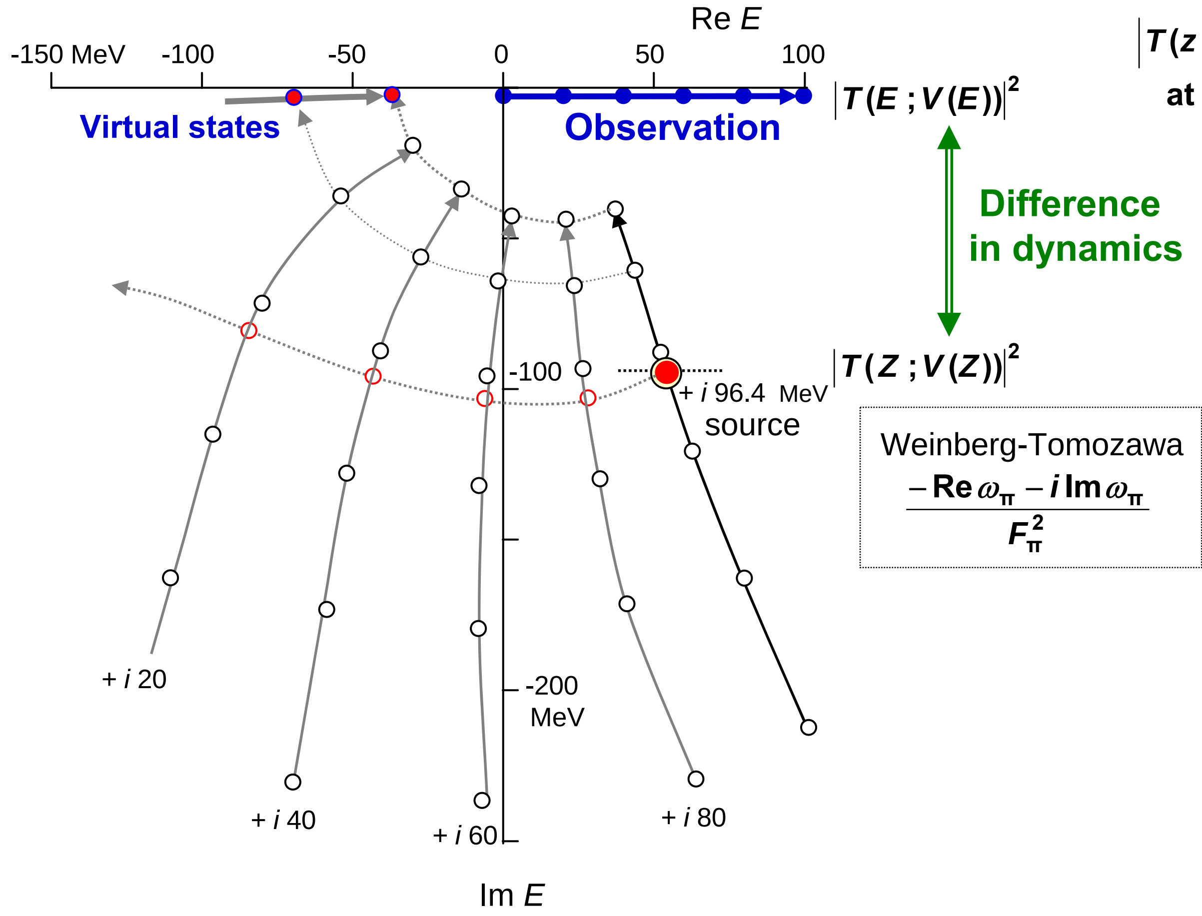
$$\left|T(z\,;V(Z^{\mathrm{ref}}))\right|^2$$

$$\omega_\pi = m_\pi + Z^{\mathrm{ref}}$$

Observed spectrum

$$\left|T(z\,;V(E^{\mathrm{obs}}))\right|^2$$

at z = E^{obs}



Weinberg-Tomozawa

$$\frac{-\mathrm{Re}\,\omega_\pi - i\,\mathrm{Im}\,\omega_\pi}{F_\pi^2}$$

Wpole/poleScut5.f

Decaying state and spectrum shape

Y. Akaishi, K.S. Myint &T. Yamazaki, Proc. Japan Academy, B 84 (2008) 264

Observed spectrum

Strength distribution of decaying states

$$S\,(E^{obs}) = S_{DS}(E^{obs}; E^{obs})$$

$$S_{DS}(E; E^{obs}) \equiv -\frac{1}{\pi}\mathrm{Im}\left\langle \frac{1}{E - H^{opt}(E^{obs}) + i\varepsilon} \right\rangle$$

Variable

Boundary condition

$$E^{obs} = E_{bc}^{(Q)} - Q$$

If S_{DS} ~ independent of E^{obs}

Intrinsic decaying state

$$S\,(E^{obs}) = S_{IDS}(E^{obs})$$

$$S_{IDS}(E) \equiv -\frac{1}{\pi}\mathrm{Im}\left\langle \frac{1}{E - H^{opt}(\mathrm{Re}\,\Xi_{IDS}) + i\varepsilon} \right\rangle$$

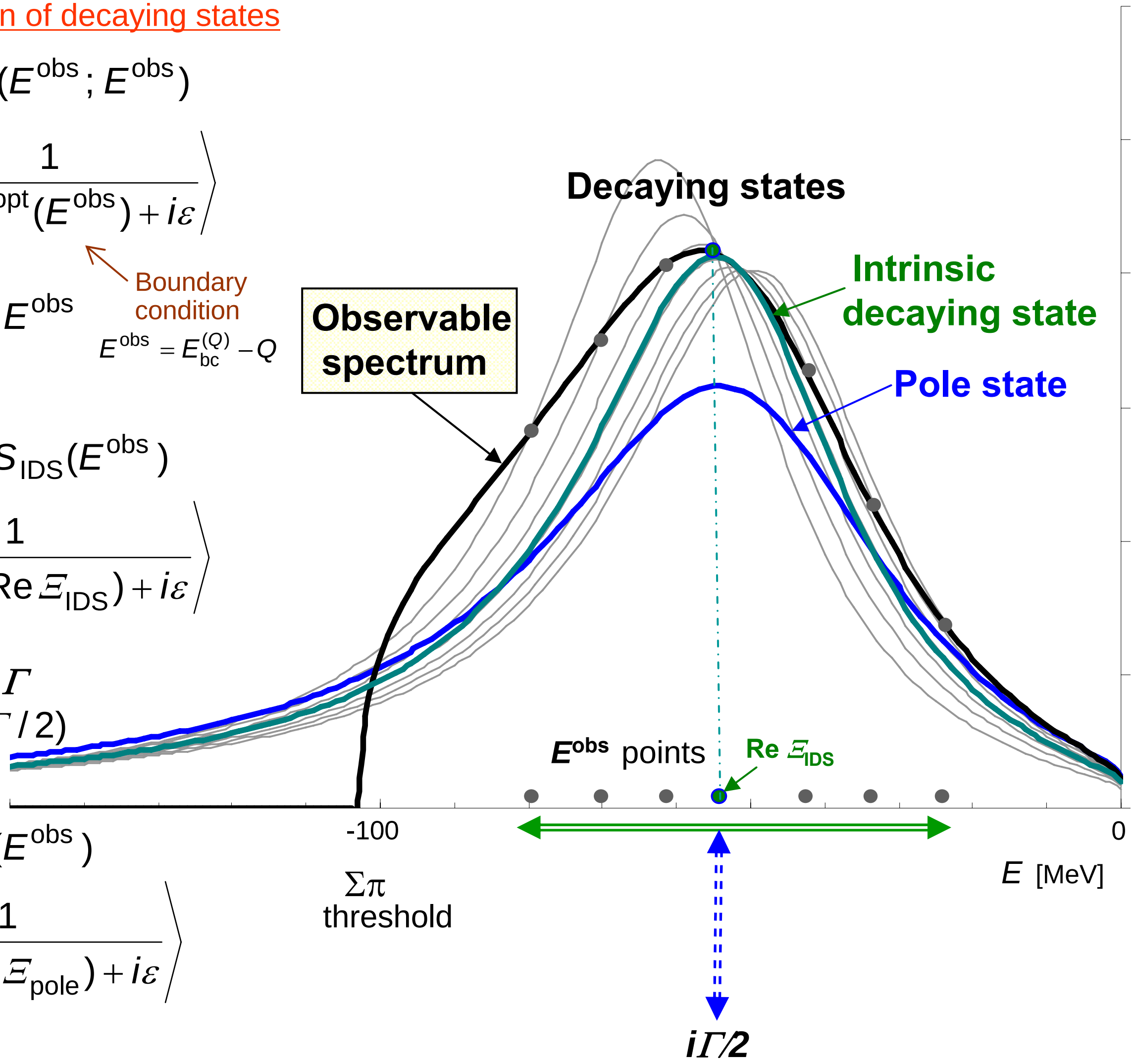
If S_{IDS} ~ independent of Γ

$\mathrm{Re}\,\Xi_{IDS} + i\,(0 \sim \Gamma/2)$

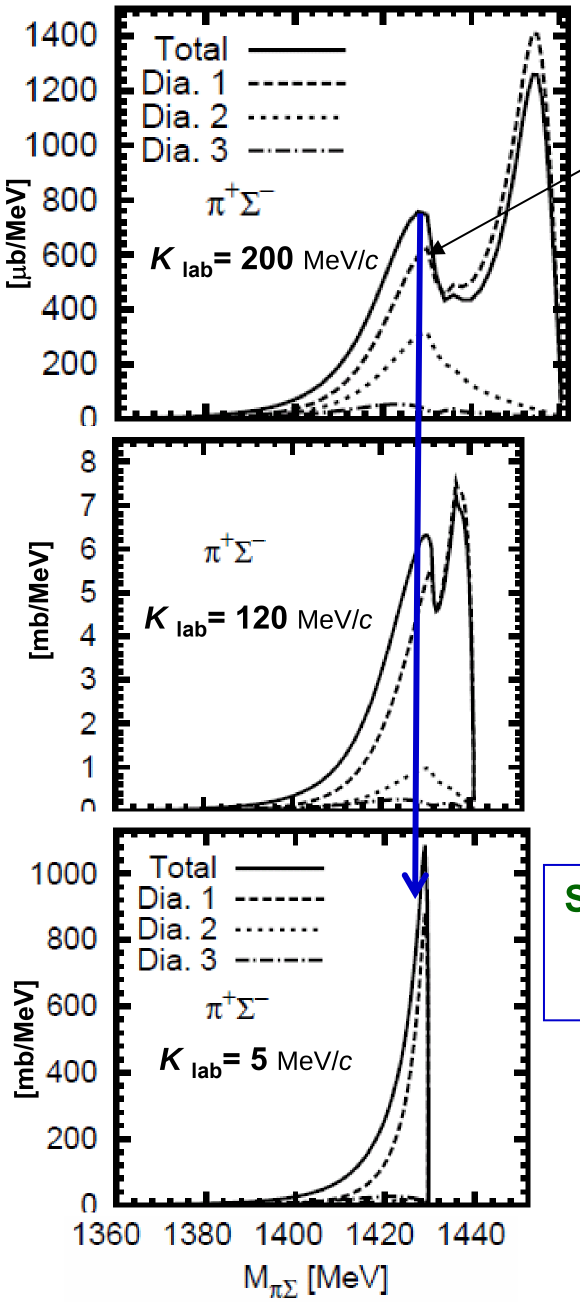
Pole state

$$S\,(E^{obs}) = S_{pole}(E^{obs})$$

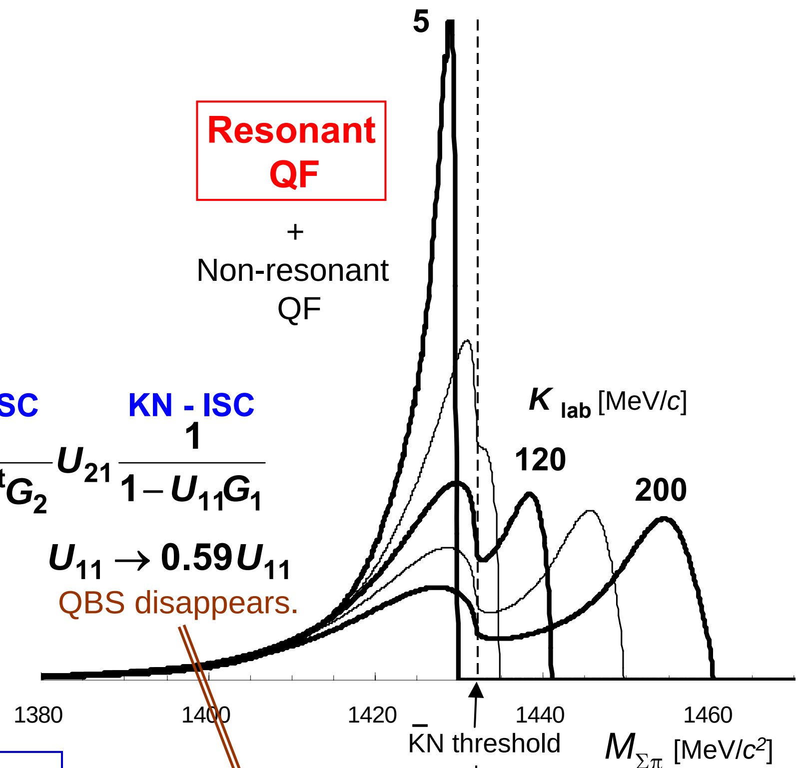
$$S_{pole}(E) \equiv -\frac{1}{\pi}\mathrm{Im}\left\langle \frac{1}{E - H^{opt}(\Xi_{pole}) + i\varepsilon} \right\rangle$$



Low-momentum K^-+D reaction



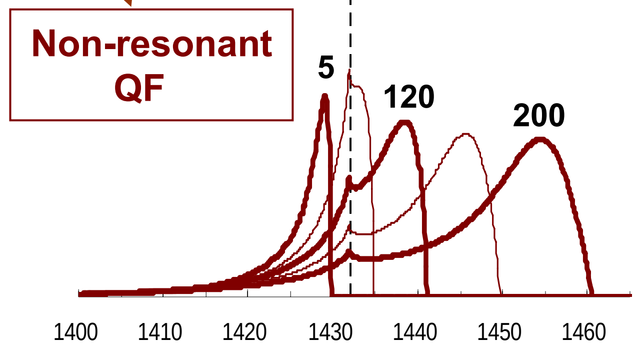
This peak structure
Is produced by
a threshold effect
and has nothing to do with
any resonances.



$$T_{21} = \underbrace{\frac{1}{1-U_{22}^{\rm opt}G_2}}_{\Sigma\pi\text{ - FSC}} U_{21} \underbrace{\frac{1}{1-U_{11}G_1}}_{\bar{K}N\text{ - ISC}}$$

$$U_{11} \to 0.59\,U_{11}$$

QBS disappears.



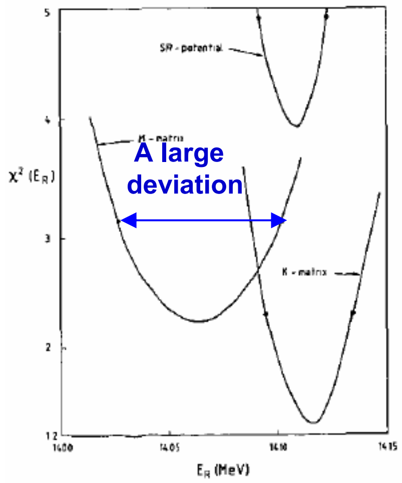
Stopped kaon does ~~not~~ provide
a good set up to learn
about $\Lambda(1405)$.

D. Jido, E. Oset & T. Sekihara,
Eur. Phys. J. A 42 (2009) 257

The PDG value of $\Lambda(1405)$

Mass	1406.5 ± 4.0 MeV
Width	50 ± 2 MeV

R.H. Dalitz and A. Deloff, J. Phys. G 17 (1991) 289

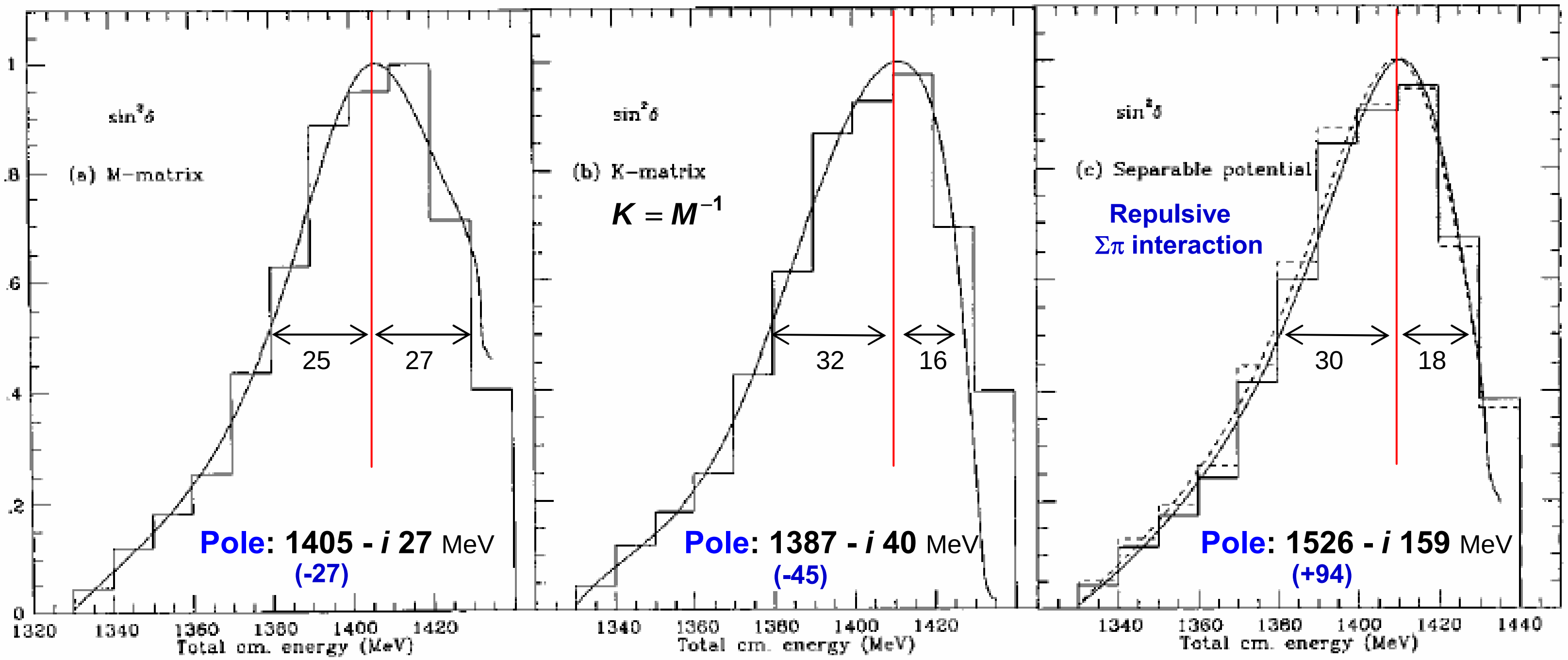


Constraint :
a = -1.54 + i 0.74 fm

$$\sigma_{\rm tot} = \frac{4\pi}{k^2}\sin^2\delta\ ,\quad \sin^2\delta_{\rm R} = \frac{\Gamma^2/4}{(E-E_{\rm R})^2+\Gamma^2/4}$$

$$\boxed{\delta_{\rm R} = \frac{\pi}{2}\ \text{ at } E_{\rm R}}$$

E_R=1406 MeV $\qquad$ E_R=1411 MeV $\qquad$ E_R=1410 MeV



Dalitz's strong preference!