特定領域研究「ストレンジネスで探るクォーク多体系」研究会
@熱海 2/27-28 (2009)

K^{bar}NN核の構造

(On the two resonance poles of K^{-}pp system)

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✓ Outline

- Introduction ($\bar{K}N$ interaction, The $\Lambda(1405)$, $K^{-}pp$ system)
- Analytic properties of $\bar{K}N$ amplitudes (The $\Lambda(1405)$)
- Coupled-channel formalism of three-body equations
- Results and discussion
- Summary

Introduction

✓ Introduction

K^bar N interaction in isospin I=0 channel

Strong attraction

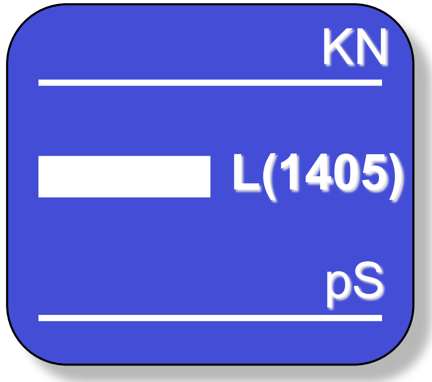
The L(1405) resonance

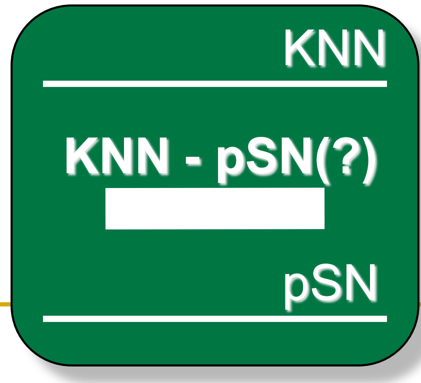
- Quasi-bound state of K^bar N state
- CDD pole coupling with meson-baryon
- Multi-quark state

K⁻pp system (N-Λ(1405) system)

K^bar NN – pYN coupled system

K^bar N - pS coupled system





✓ Introduction (The Λ(1405) and chiral dynamics)

✓ Coupled-channel chiral dynamics

Kaiser, Siegel, Weise, NPA594.

KN

L(1405)

pS

Chiral effective Lagrangian (up to O(q^2) terms)

↓

Pseudo-potential model $V_{ij} = -\frac{C_{ij}^{KSW}}{2F_\pi^2}\sqrt{\frac{M_i M_j}{s\epsilon_i\epsilon_j}}$

↓

S-wave resonance in $K^{bar}N$-$\pi\Sigma$ coupled-channel system

✓ Chiral unitary approach

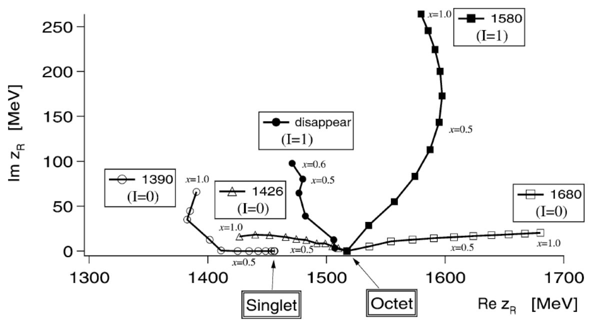
Oset, Ramos, NPA635.

Current algebra term (Weinberg-Tomozawa term) $V_{ij} = -\frac{C_{ij}^{OR}}{2F_\pi^2}(q_i^0 + q_j^0)$

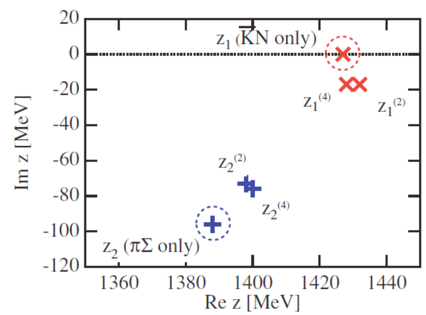
↓

Bethe-Salpeter equation with "on-shell factorization" → $V_{ij} = -\frac{C_{ij}^{OR}}{2F_\pi^2}(2\sqrt{s} - M_i - M_j)$

✓ Resonance pole of the Λ(1405) in chiral unitary approach



Jido et al., NPA725.



Hyodo, Weise, PRC77.

Analytic properties of $K^{bar}N$ amplitudes

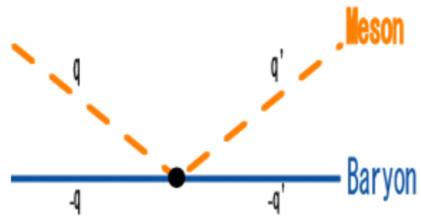
-- The $\Lambda(1405)$ --

✓ Model of $K^{bar}N$ interaction

Original:
Weinberg, PRL17 616 (66)
Tomozawa, Nuov. Cim. 46A 707 (66)
Chiral Lagrangian:
e.g., Bernard, Kaiser, Meissner IJMP E4 193 (95)

Weinberg-Tomozawa term

$$\mathcal{L}_{\mathcal{I}} = \frac{i}{8F_\pi^2} Tr[\bar{B}\gamma^\mu[\Gamma_\mu^2, B]]$$



$$\Gamma_\mu^2 = \Phi(\partial_\mu\Phi) - (\partial_\mu\Phi)\Phi$$

F: Meson field , B : Baryon field

Potential model (s-wave meson-baryon scattering)

$$V_{ij}(q,q') = -\frac{C_{ij}}{2F_\pi^2}\left(E_i(q)+\omega_i(q)-M_i+E_j(q')+\omega_j(q')-M_j\right)$$

Fixed with SU(3) symmetry → λ_{ij}

$$C_{ij} = \lambda_{ij}\frac{1}{2\pi^2\sqrt{\omega_i\omega_j}}$$

$$E_i(q)-M_i,\ E_j(q')-M_j \to 0$$
$$\omega_i(q),\ \omega_j(q') \to m_i,\ m_j$$

Energy-independent potential (E-indep.)

$$V_{ij}(q,q') \to V_{ij} = -\frac{C_{ij}}{2F_\pi^2}\left(m_i+m_j\right)$$

Lutz, PLB426 (98), Ikeda, Sato, PRC76 (07)

$$q, q' \to q_{\text{on-shell}}$$
$$E_i(q)+\omega_i(q),\ E_j(q')+\omega_j(q') \to E$$

Energy-dependent potential (E-dep.)

$$V_{ij}(q,q') \to V_{ij}(E) = -\frac{C_{ij}}{2F_\pi^2}\left(2E-M_i-M_j\right)$$

e.g., Oset, Ramos, NPA635 (98)

✓ Vertex form factors

Lippmann-Schwinger equation

$$T_{ij}(k,k';W) = V_{ij}(k,k') + \sum_m \int q^2 dq V_{im}(k,q) \frac{1}{E - E_m(q) - \omega_m(q) + i\varepsilon} T_{mj}(q,k';W)$$

$$V_{ij}(q,q') \rightarrow V_{ij}(q,q') \times g_i(q) g_j(q')$$

$$g_i(q) = \left(\frac{\Lambda_i^2}{\Lambda_i^2 + q^2} \right)^2$$

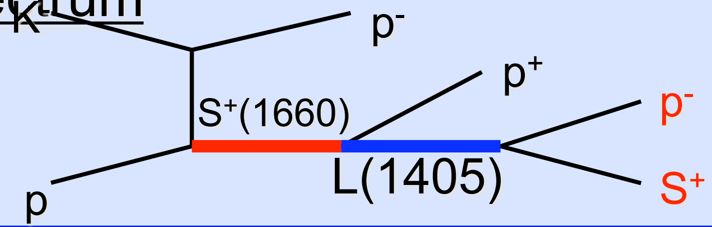
regularize loop integral

$\Lambda_{KN}, \ \Lambda_{\pi\Sigma} \ \Lambda_{\pi\Lambda} \ \cdots$ parameters

✓ Model of K^{bar}N interaction

Our parameters -> cutoff of dipole form factor

pS invariant mass spectrum

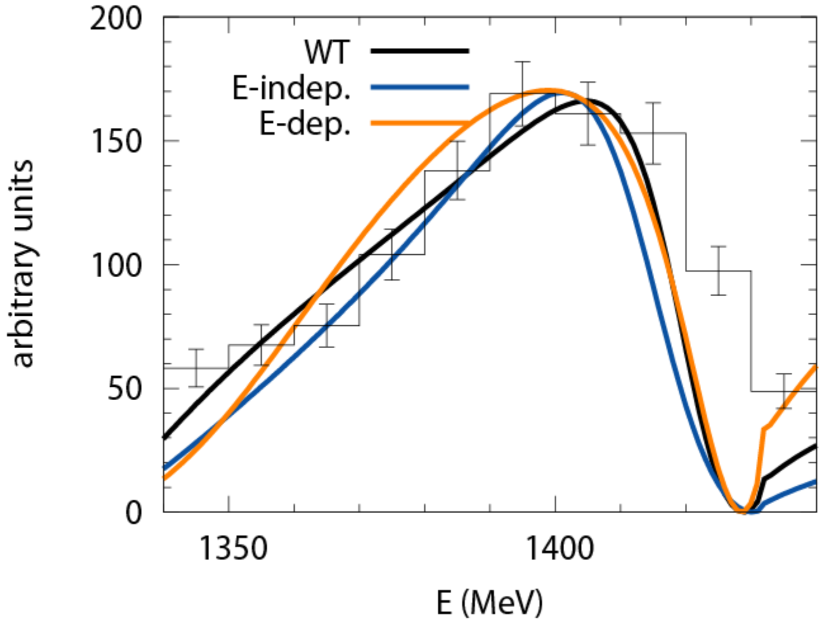


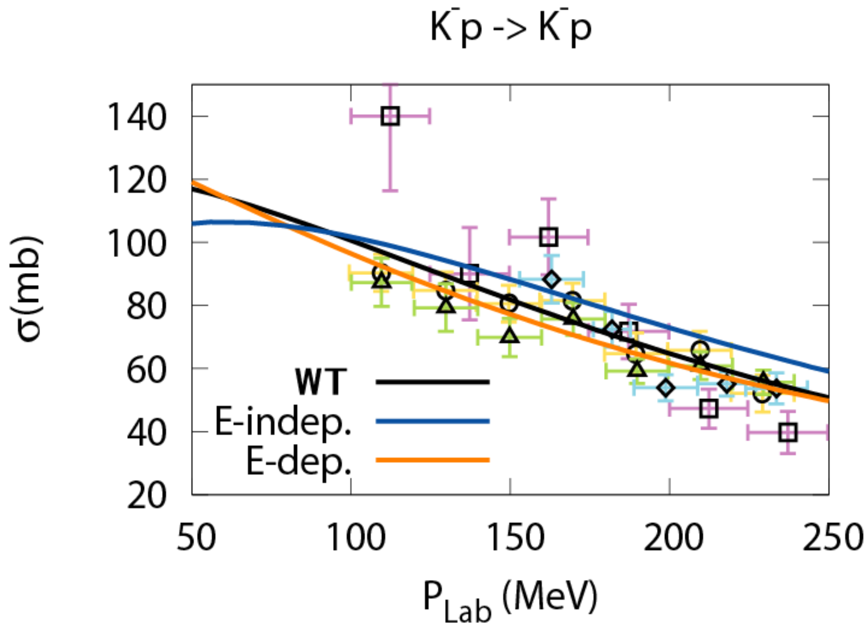
Hemingway (85)

with assumption

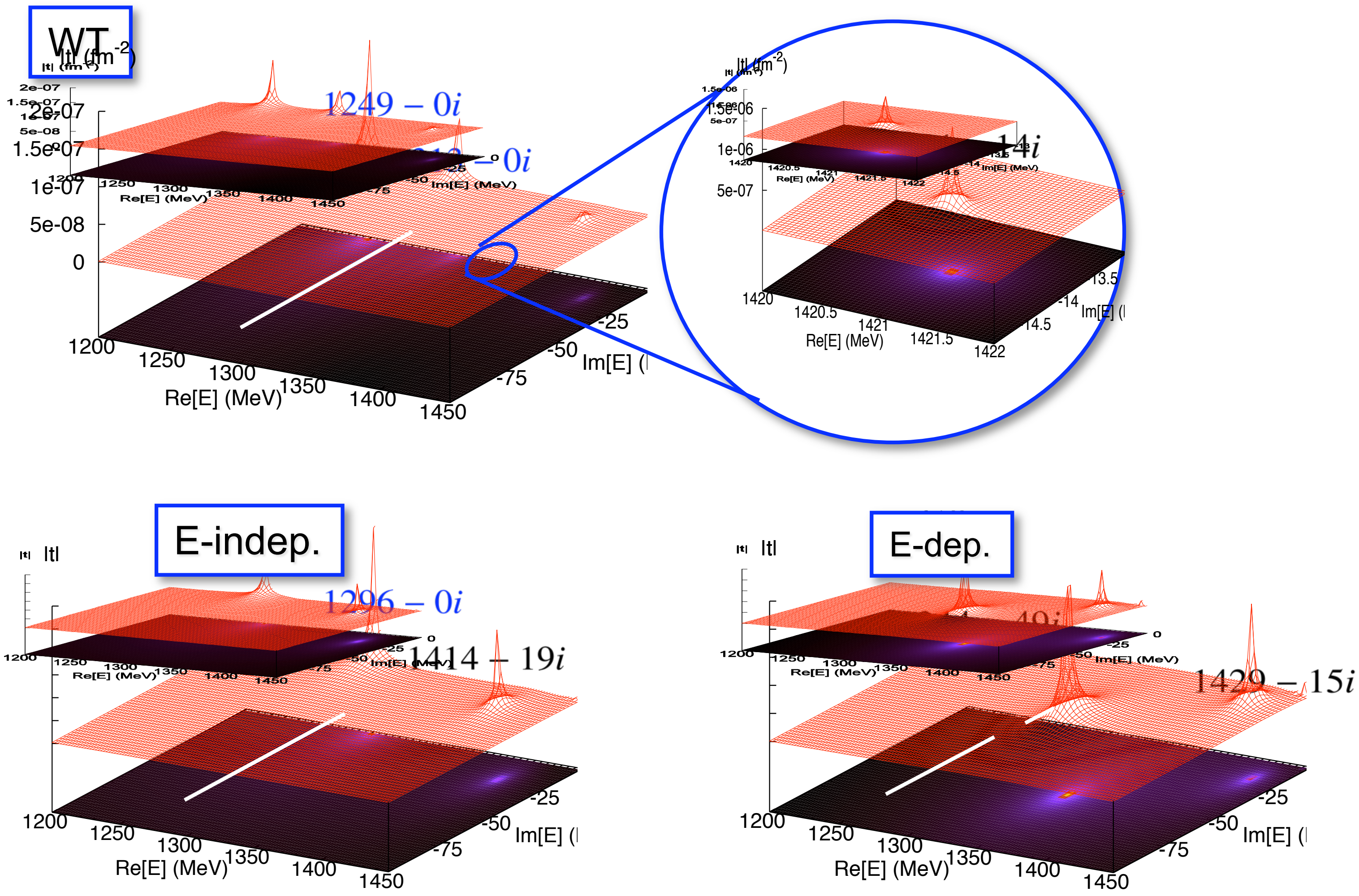
$$\frac{dN}{dE} \propto |t^{(I=0)}_{\pi\Sigma-\pi\Sigma}|^2 p_{c.m.}$$

Viet et al. (85)





✓ Resonance poles on $\bar{K}N$-physical, $\pi\Sigma$-unphysical sheet



- E-indep. potential model : One resonance pole (similar to WT)
- E-dep. potential model : Two resonance poles

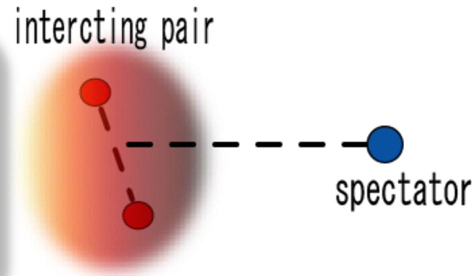
Coupled-channel formalism of three-body equations

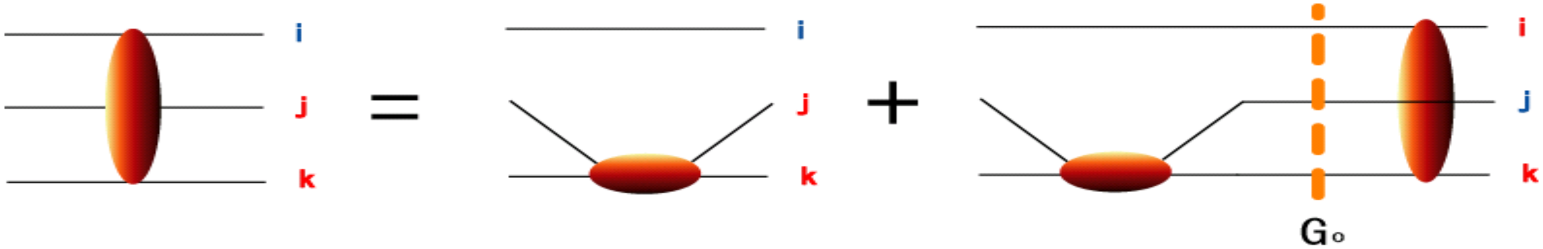
✓ Three-body equations

Faddeev Equations

$$T_i(W) = t_i(W, E(p_i)) + \sum_{j \neq i} t_i(W, E(p_i)) G_0(W) T_j(W)$$

$$t_i(W, E(p_i)) = v_i + v_i G_0(W) t_i(W, E(p_i))$$



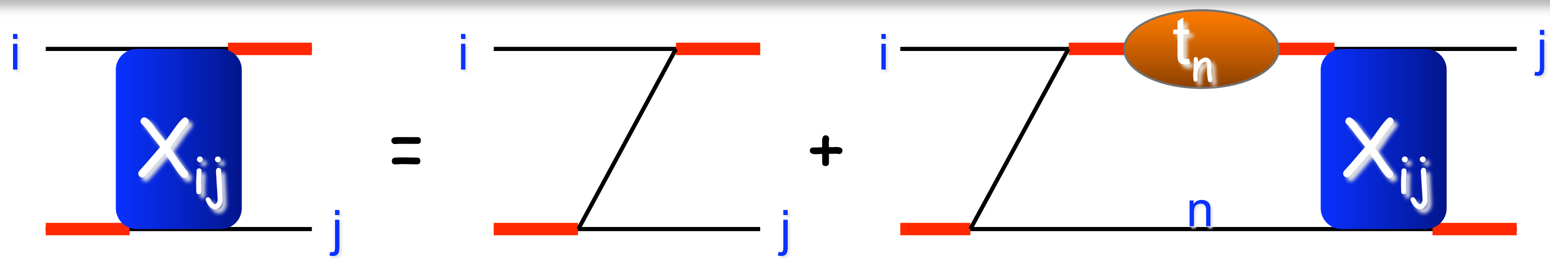


- W : 3-body scattering energy
- i(j) = 1, 2, 3 (Spectator particles)
- $T(W)=T_1(W)+T_2(W)+T_3(W)$ (T : 3-body amplitude)
- $t_i(W, E(p_i))$: 2-body t-matrix with spectator particle i
- $G_0(W)$: 3-body Green's function

✓ Faddeev equations with separable potentials

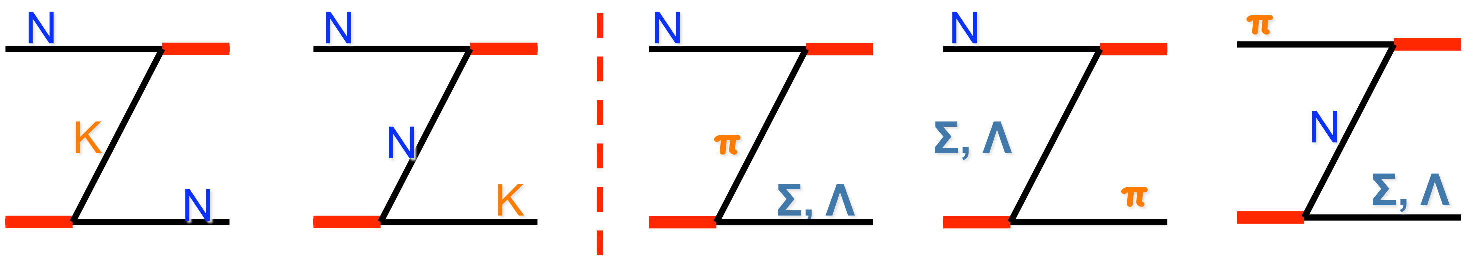
Alt-Grassberger-Sandhas(AGS) Equations

$$
\begin{aligned}
X_{ij}(\vec{p}_i,\vec{p}_j;W) &= (1-\delta_{ij})Z_{ij}(\vec{p}_i,\vec{p}_j;W) \\
&+ \sum_{n\neq i}\int d\vec{p}_n Z_{in}(\vec{p}_i,\vec{p}_n;W)\tau_n(\vec{p}_n;W)X_{nj}(\vec{p}_n,\vec{p}_j;W)
\end{aligned}
$$



- $Z(p_i,p_j;W)$: Particle exchange potentials
- $t(p_n;W)$: Isobar propagators

K^{bar}NN-pYN coupled-channel formalism



✓ Pole of the AGS amplitudes

$$X(W) = Z(W) + \underline{Z(W)\tau(W)}X(W)$$

Fredholm kernel

Formal solution for three-body amplitudes

$$X(W) = \sum_n \frac{|\phi_n(W)><\tilde{\phi}_n(W)|Z(W)}{1-\eta_n(W)}$$

Eigenvalue equation for Fredholm kernel

$$Z(W)\tau(W)|\phi_n(W)> = \eta_n(W)|\phi_n(W)>$$

$\eta_n(W_{pole}) = 1$ ➡ three-body resonance pole at W_{pole}

W_{pole} = -B –iG/2

Results and Discussion

✓ Energy-independent potential models

$$V_{ij}(q,q') \rightarrow V_{ij} = -\frac{C_{ij}}{2F_\pi^2}\left(m_i + m_j\right)$$

Lutz, PLB426 (98), Ikeda, Sato, PRC76 (07)

Fit ① : Scattering length given by Martin (Model Martin)

Martin (81)

$$a^{I=0}_{\bar{K}N} = -1.70 + i0.68 fm$$
$$a^{I=1}_{\bar{K}N} = 0.68 + i0.60 fm$$

→ $E_{\Lambda^*} = 1420 - i29 (MeV)$

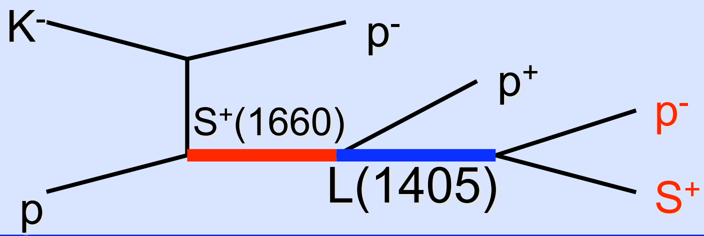
Fit ② : L(1405) pole position given by Dalitz (Model Dalitz)

Dalitz and Deloff (91)

$E_{\Lambda^*} = 1406 - i25 (MeV)$ → $a^{I=0}_{\bar{K}N} = -1.72 + i0.44 fm$

Fit ③ : pS invariant mass spectrum (Model Hemingway)

Hemingway (85)

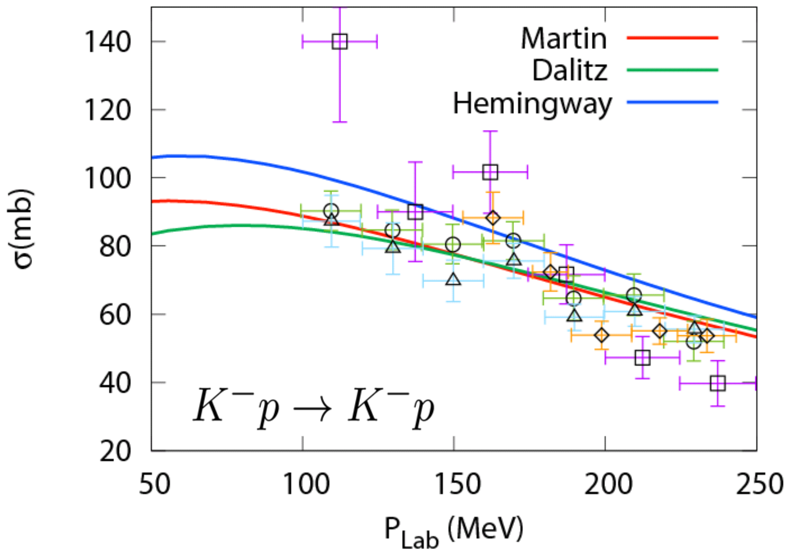


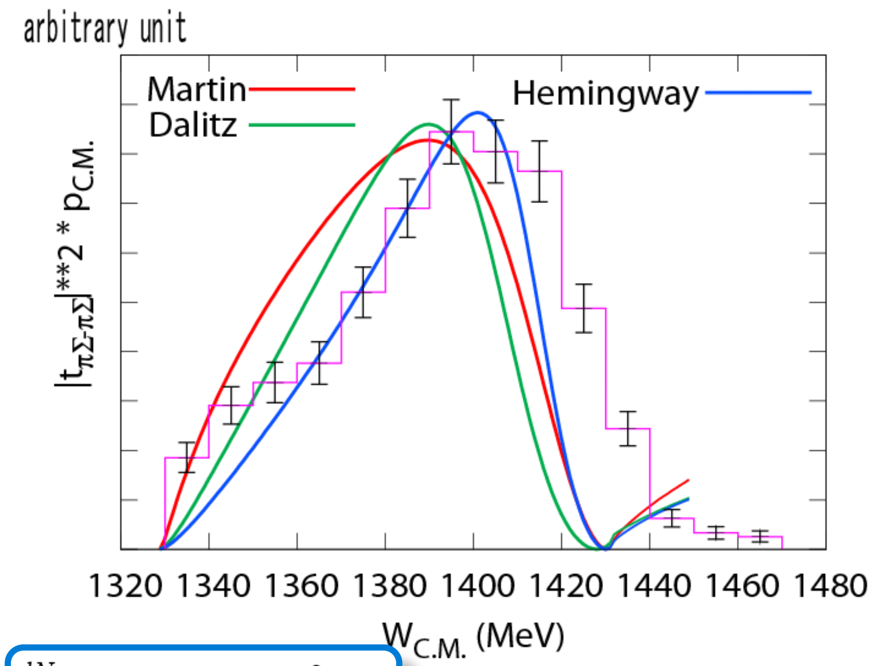
with assumption

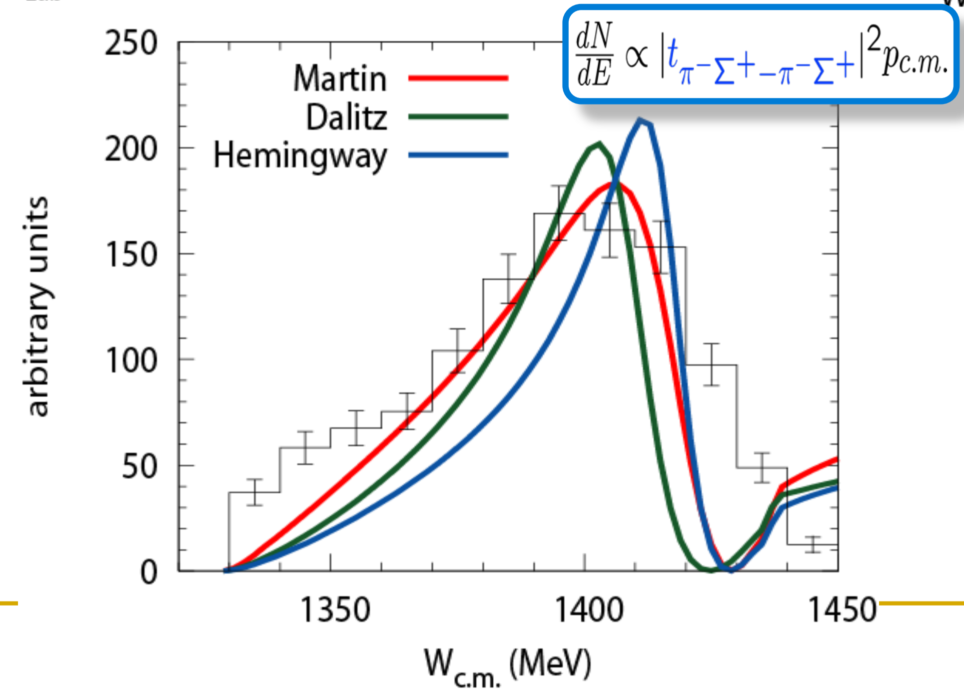
Viet et al. (85)

$$\frac{dN}{dE} \propto |t^{(I=0)}_{\pi\Sigma-\pi\Sigma}|^2 p_{c.m.}$$

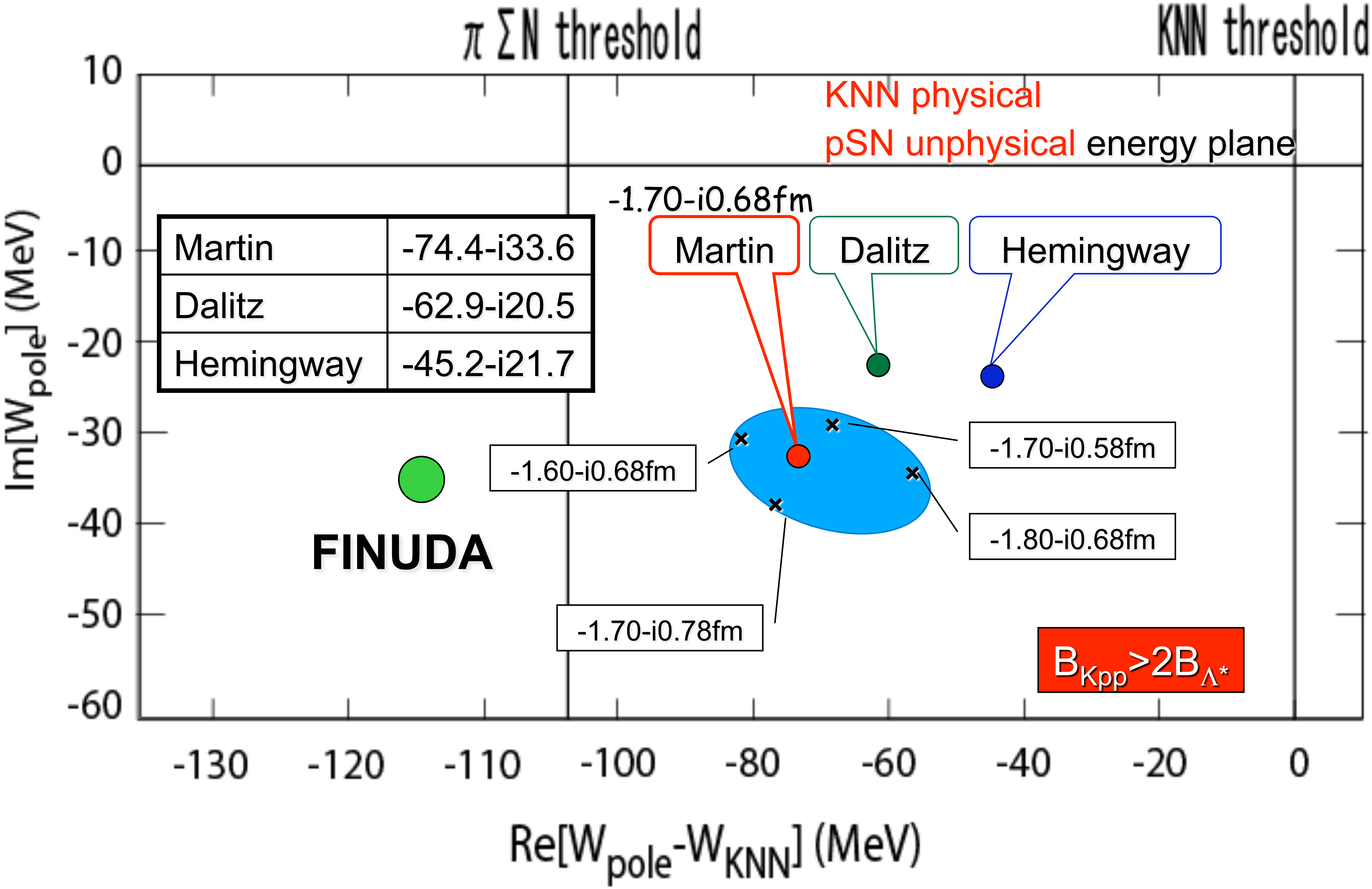
✓ Model of $K^{bar}N$ interaction







✓ Numerical results (pole position of $K^{-}pp$ system)

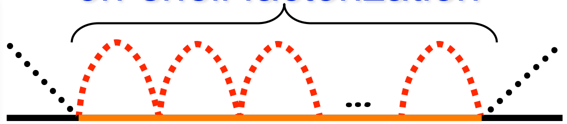


Martin	-74.4-i33.6
Dalitz	-62.9-i20.5
Hemingway	-45.2-i21.7

✓ K^-pp system in chiral unitary approach

$$V_{ij}(q,q') = -\frac{C_{ij}}{2F_\pi^2}\left(E_i(q)+\omega_i(q)-M_i+E_j(q')+\omega_j(q')-M_j\right)$$

on-shell factorization

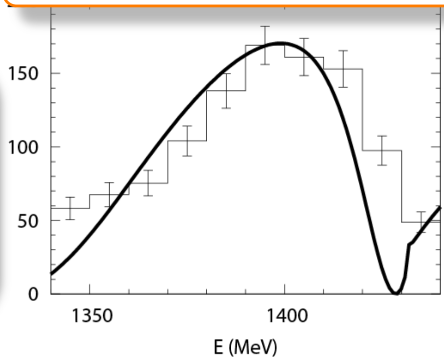


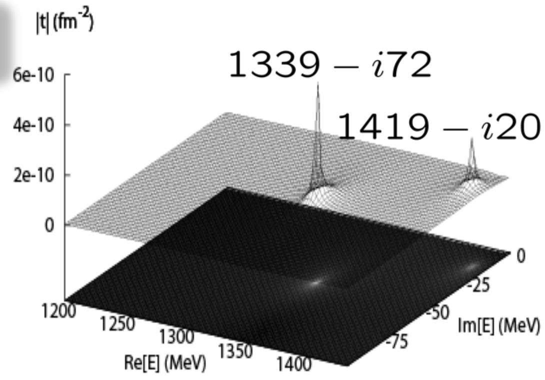
Energy-dependent potential (E-dep.)

$$V_{ij}(q,q') \to V_{ij}(E) = -\frac{C_{ij}}{2F_\pi^2}\left(2E-M_i-M_j\right)$$

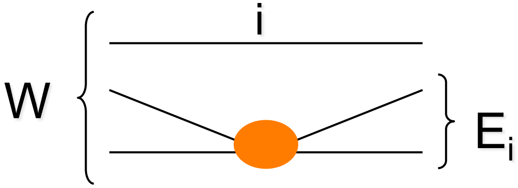
e.g., Oset, Ramos, NPA635, 99 (98)

$$\frac{dN}{dE} \propto |t^{(I=0)}_{\pi\Sigma-\pi\Sigma}|^2 p_{c.m.}$$





✓ Two-body scattering energy in three-body system



$$E_i = W - m_i - \frac{\vec{p}_i^{\,2}}{2\eta_i}$$

(Non-relativistic)

K^-pp pole positions $W_{pole} = -B - i\Gamma/2$

$-14.4 - i21.1$ MeV → Shallow bound state

$-70.7 - i139.3$ MeV

$B_{Kpp} \sim B_{\Lambda^*}$

e.g. Dote, Hyodo, Weise

✓ Summary

- The Λ(1405) and $K^{-}pp$ were studied.
- We constructed the model of $K^{bar}N$ interaction from WT term.
- Resonance pole in $\pi\Sigma$ channel is due to "on-shell factorization".
- We solved the Faddeev equations.

-- We found the resonance pole of $K^{-}pp$ system

on $K^{bar}NN$ physical and pYN unphysical sheet.

-- (-B, G) = (-45 ~ -80, 45 ~ 75)MeV

for energy-independent $K^{bar}N$ interaction. (deeply bound)

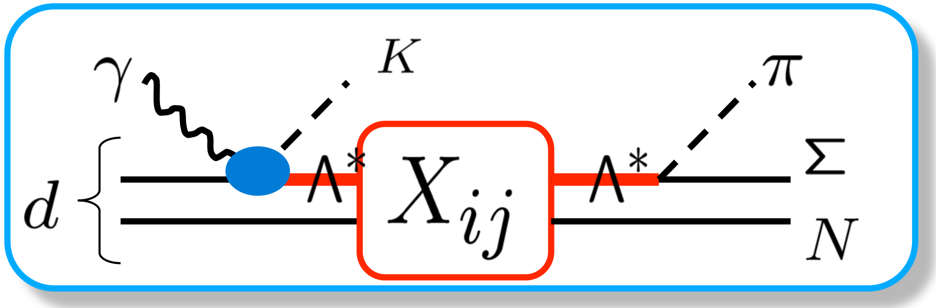
-- (-B, G) = (-14, 42) and (-71, 280)MeV

for energy-dependent $K^{bar}N$ interaction. (shallow bound)

✓ Future plan

Photo-production mechanism

$\gamma d \rightarrow K\pi\Sigma N$ reaction



This production mechanism is investigated

by LEPS and CLAS collaborations @SPring8, JLab.