Λ(1405) in chiral dynamics

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Introduction : Λ(1405) and $\bar{K}N$ dynamics

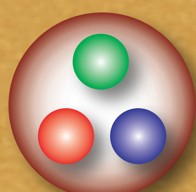
$\Lambda(1405) : J^P = 1/2^-, I = 0$

Mass : 1406.5 ± 4.0 MeV

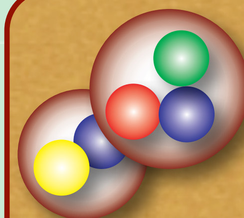
Width : 50 ± 2 MeV

Decay mode : $\Lambda(1405) \rightarrow (\pi\Sigma)_{I=0}$ **100%**

“naive” quark model
: p-wave
~1600 MeV?



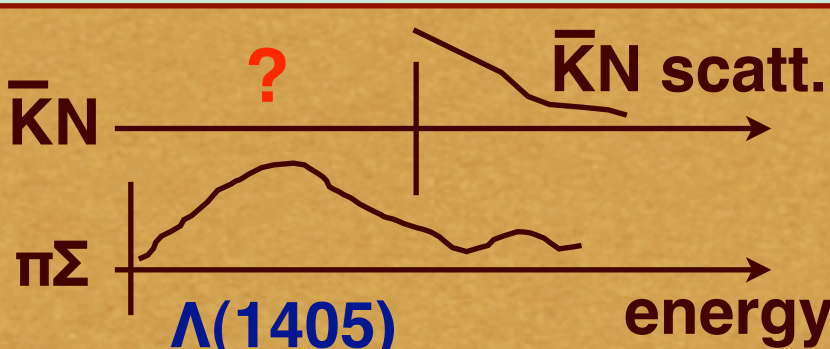
N. Isgur and G. Karl, PRD18, 4187 (1978)

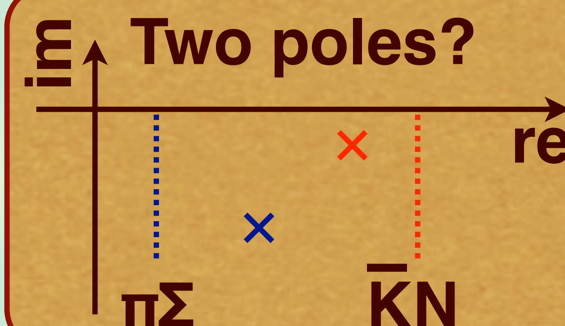


Coupled channel multi-scattering

R.H. Dalitz, T.C. Wong and G. Rajasekaran, PR153, 1617 (1967)

$\bar{K}N$ int. below threshold





Chiral unitary approach

S = -1, $\bar{K}N$ s-wave scattering : Λ(1405) in I=0

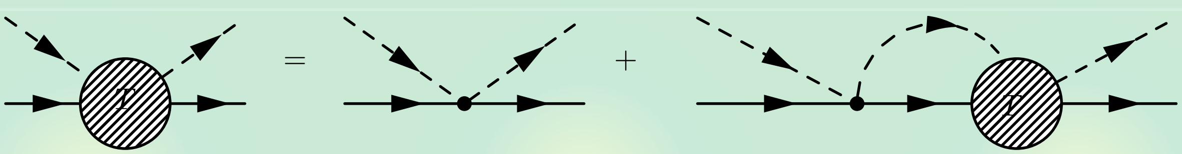
- ○ **Interaction <-- chiral symmetry**

Y. Tomozawa, Nuovo Cim. 46A, 707 (1966); S. Weinberg, Phys. Rev. Lett. 17, 616 (1966)

- ○ **Amplitude <-- unitarity (coupled channel)**

R.H. Dalitz, T.C. Wong and G. Rajasekaran, PR153, 1617 (1967)

$$T = \frac{1}{1 - VG} V$$



N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

works successfully, also in S=0, meson-meson scattering, heavy quark sectors, ...

Contents

Structure of Λ(1405) resonance

- Nc Behavior and quark structure

  T. Hyodo, D. Jido, L. Roca, Phys. Rev. D77, 056010 (2008).
  L. Roca, T. Hyodo, D. Jido, Nucl. Phys. A809, 65 (2008).

- Dynamical or CDD (genuine quark state) ? -> Jido-san's Talk

  T. Hyodo, D. Jido, A. Hosaka, Phys. Rev. C78, 025203 (2008).

- Electromagnetic properties -> Sekihara-san's Talk

  T. Sekihara, T. Hyodo, D. Jido, arXiv: 0803.4068 [nucl-th], Phys. Lett. B, in press

Phenomenology of $\bar{K}N$ interaction

- Construction of local $\bar{K}N$ potential

  T. Hyodo, W. Weise, Phys. Rev. C77, 035204 (2008).

- Application to three-body $\bar{K}NN$ system

  A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A804, 197 (2008)
  A. Doté, T. Hyodo, W. Weise, arXiv:0806.4917 [nucl-th]

Structure of dynamically generated resonances

Quark structure of resonances?

<-- known Nc scaling of $q\bar{q}$ meson

$$m \sim \mathcal{O}(1), \quad \Gamma \sim \mathcal{O}(1/N_c),$$

can be used to distinguish $q\bar{q}$ from others

e.g. ρ meson in ππ scattering

<-- originate from the contracted resonance propagator in higher order terms

J.A. Oller, E. Oset and J.R. Pelaez, Phys. Rev. D59, 074001 (1999)
G. Ecker, J. Gasser, A. Pich, and E. de Rafael, Nucl. Phys. B321, 311 (1989)

behavior in the large Nc limit

J.A. Oller and E. Oset, Phys. Rev. D60, 074023 (1999)

analysis of Nc scaling --> ρ ~ qq

J.R. Pelaez, Phys. Rev. Lett. 92, 102001 (2004)

Baryon resonances?

Nc scaling in the model

Introduce the Nc dependence into the model and study the behavior of resonance.

$$m \sim \mathcal{O}(1), \quad M \sim \mathcal{O}(N_c), \quad f \sim \mathcal{O}(\sqrt{N_c})$$

Leading order WT interaction has Nc dep.

$$V = -C\frac{\omega}{2f^2} \sim \mathcal{O}(1/N_c) \quad (\Leftarrow C \sim \mathcal{O}(1))$$

(for baryon and Nf > 2)

$$V = -C\frac{\omega}{2f^2}, \quad \underline{C \sim \mathcal{O}(N_c)} \quad \Rightarrow V \sim \mathcal{O}(1)$$

T. Hyodo, D. Jido and A. Hosaka, Phys. Rev. Lett. 97, 192002 (2006)
T. Hyodo, D. Jido and A. Hosaka, Phys. Rev. D75, 034002 (2007)

c.f. meson-meson scattering : $V_{\mathrm{LO}} \sim \mathcal{O}(1/N_c)$ **= trivial**
Nontrivial Nc dependence of the interaction is in NLO.

S = -1, I = 0 channel in Isospin basis

Coupling strengths with Nc dependence

$$
\begin{array}{cccccc}
 & & \bar{K}N & \pi\Sigma & \eta\Lambda & K\Xi \\
C^{I}_{ij}(N_c) = & & \left(\begin{array}{cccc}
\frac{1}{2}(3+N_c) & -\frac{\sqrt{3}}{2}\sqrt{-1+N_c} & \frac{\sqrt{3}}{2}\sqrt{3+N_c} & 0 \\
 & 4 & 0 & \frac{\sqrt{3+N_c}}{2} \\
 & & 0 & -\frac{3}{2}\sqrt{-1+N_c} \\
 & & & \frac{1}{2}(9-N_c)
\end{array}\right) & & &
\end{array}
$$

Off-diagonal couplings vanish at Nc -> ∞
--> single-channel problem in large Nc limit

Attractive interaction in $\bar{K}N$ -> $\bar{K}N$

KΞ -> KΞ : attractive -> repulsive for Nc > 9

In the large Nc limit

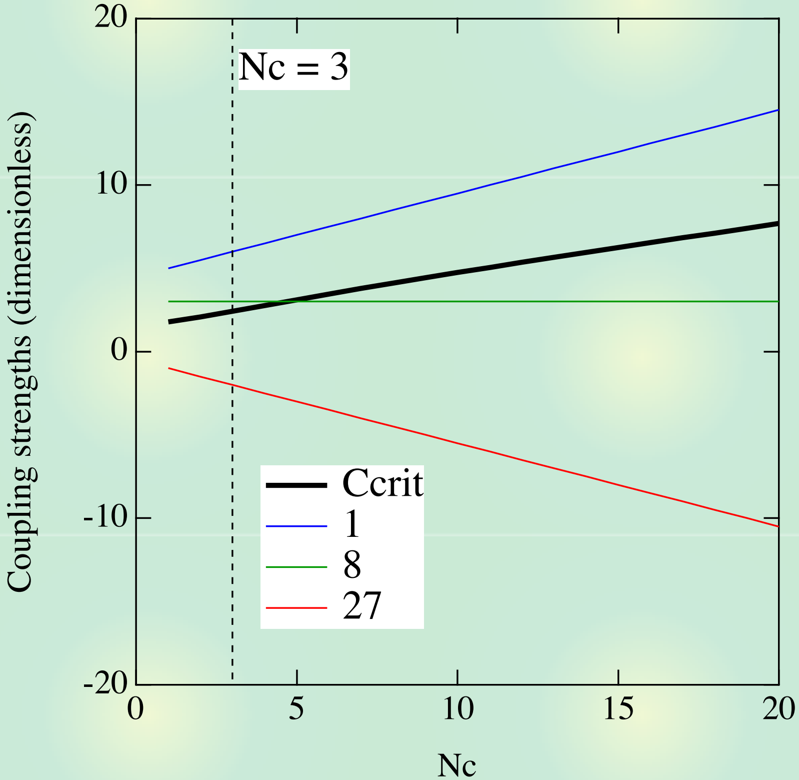
Attractive interaction in $\bar{K}$N(singlet) channels

$$C \sim N_c/2$$

Critical coupling strength (with Nc dep)

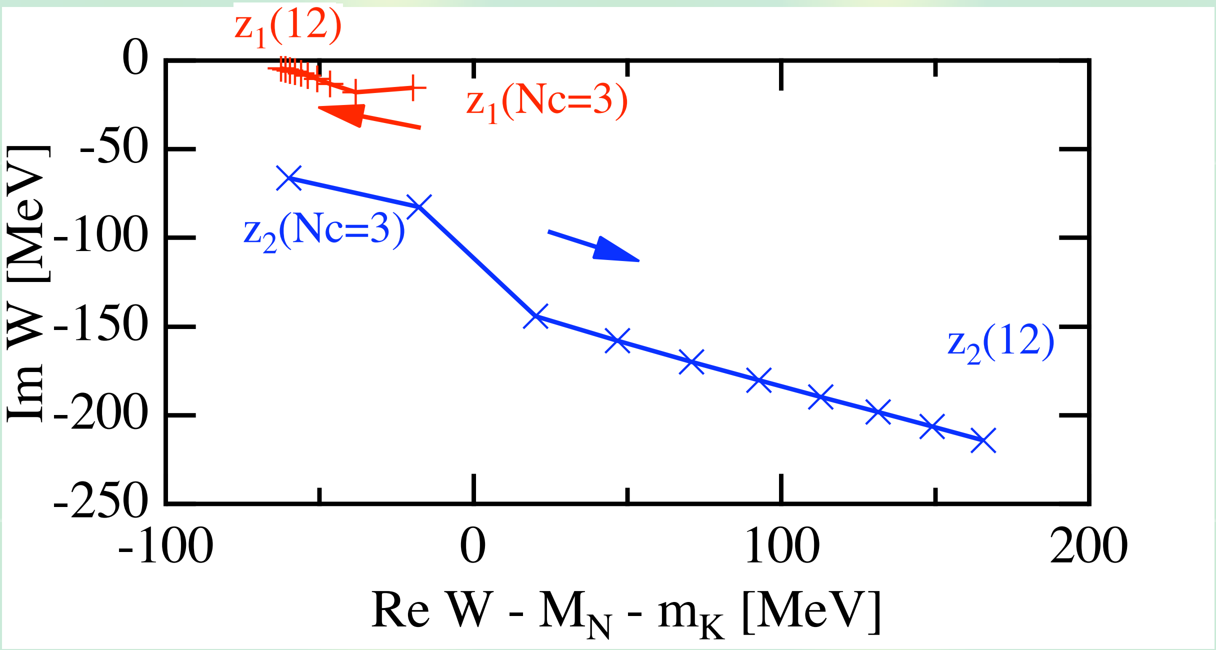
$$C_{\text{crit}}(N_c) = \frac{2[f(N_c)]^2}{m[-G(M_T(N_c)+m)]}$$

$$N_c/2 > C_{\text{crit}}(N_c)$$



Bound state in "1" or $\bar{K}$N channels

With SU(3) breaking : Pole trajectories around Nc = 3



1 bound state and 1 dissolving resonance

Nc scaling of (excited) qqq baryon

$$M_R \sim \mathcal{O}(N_c), \quad \Gamma_R \sim \mathcal{O}(1)$$

T.D. Cohen, D.C. Dakin, A. Nellore, Phys. Rev. D69, 056001 (2004)

$$\Gamma_R \neq \mathcal{O}(1)$$

~ non-qqq (i.e. dynamical) structure

Summary 1 : Nc behavior of Λ(1405)

We study the Nc scaling of the Λ(1405)

- Large Nc limit

  Existence of a bound state in "1" or $\bar{K}N$ channel even in the large Nc limit

- Behavior around Nc = 3

  1 bound state and 1 dissolving pole
  : signal of the non-qqq state.

  Residues of the would-be-bound-state
  : dominated by "1" or $\bar{K}N$
  : consistent with large Nc limit.

T. Hyodo, D. Jido, L. Roca, Phys. Rev. D77, 056010 (2008).
L. Roca, T. Hyodo, D. Jido, Nucl. Phys. A809, 65 (2008).

Effective interaction based on chiral SU(3) dynamics

Result of chiral dynamics --> single channel potential

Coupled-channel BS $T_{ij}(\sqrt{s})$
+ real interaction $V_{ij}(\sqrt{s})$

few-body K-nuclei

(exact)

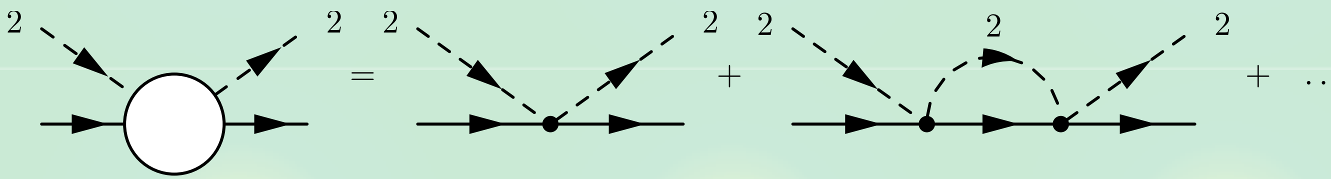
Single-channel BS $T^{\mathrm{eff}}(\sqrt{s}) = T_{ii}(\sqrt{s})$
+ complex interaction $V^{\mathrm{eff}}(\sqrt{s})$

(approximate)

Schrödinger equation $f^{\mathrm{eff}}(\sqrt{s}) \sim T^{\mathrm{eff}}(\sqrt{s})$
+ local potential
complex, energy-dependent $U^{\mathrm{eff}}(r, \sqrt{s})$

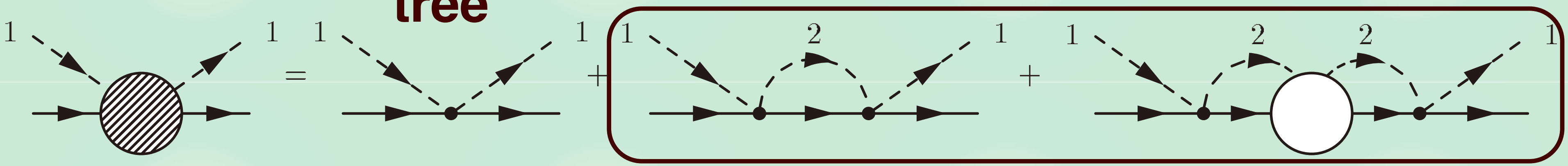
Construction of the single channel interaction

Channels 1 and 2 --> effective int. in 1

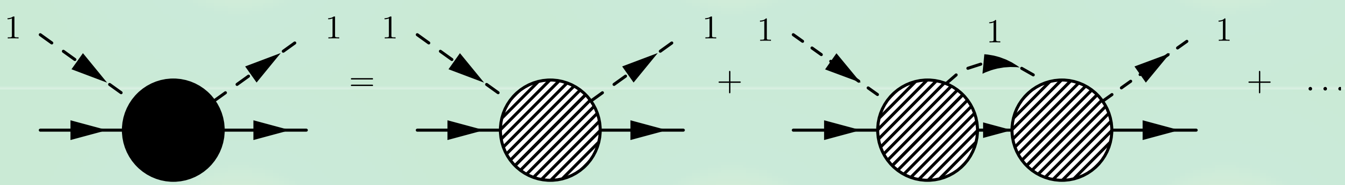


$$T_{22}^{\text{single}} = V_{22} + V_{22} G_2 T_{22}^{\text{single}}$$

tree **effect of channel 2**



$$V^{\text{eff}} = V_{11} + V_{12} G_2 V_{21} + V_{12} G_2 T_{22}^{\text{single}} G_2 V_{21}$$

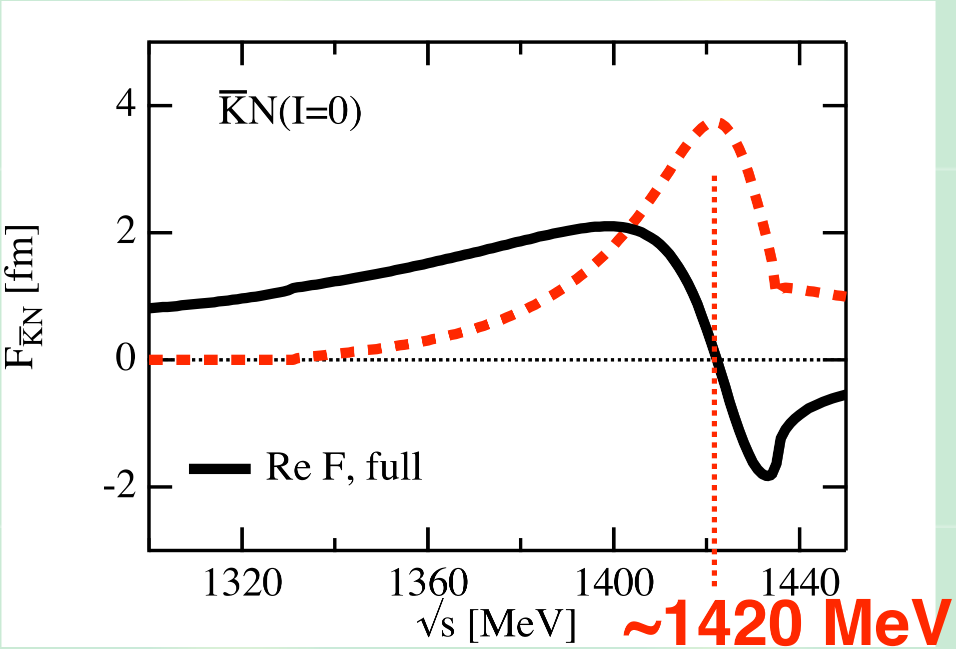


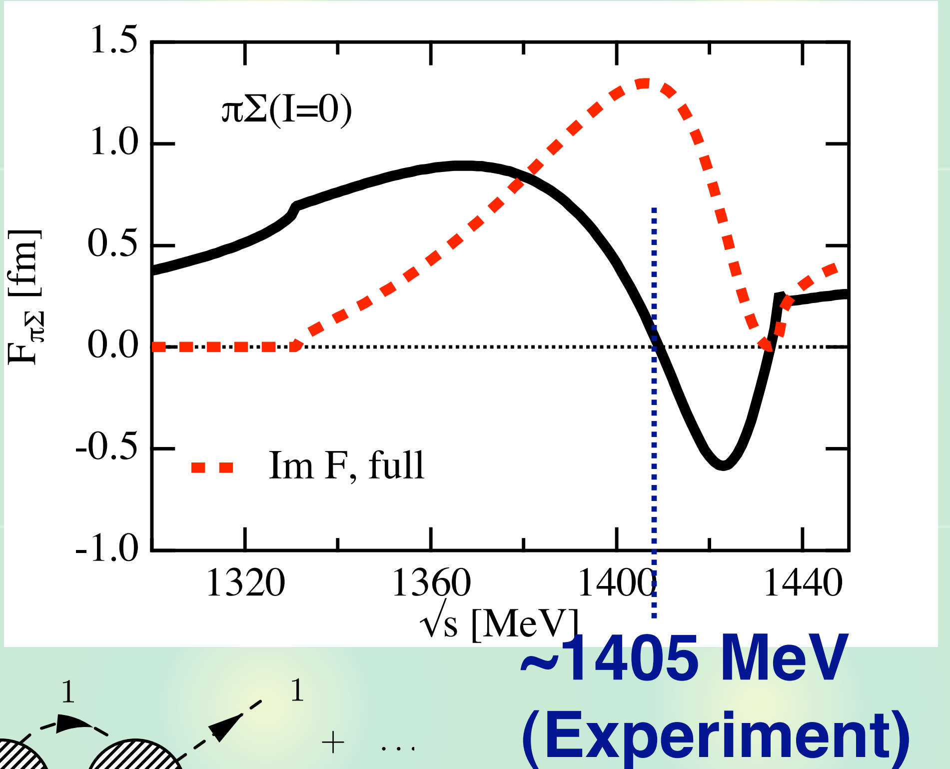
single channel

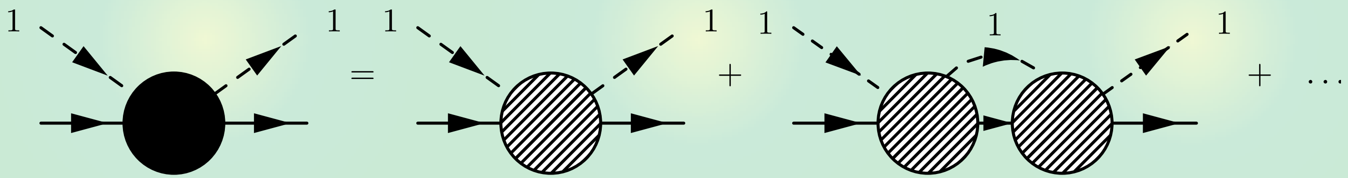
$$T_{11} = T^{\text{eff}} = V^{\text{eff}} + V^{\text{eff}} G_1 T^{\text{eff}}$$

Equivalent to the coupled-channel equations

Scattering amplitude in $\bar{K}N$ and $\pi\Sigma$







Resonance in $\bar{K}N$: around 1420 MeV

<-- strong πΣ dynamics (coupled-channel)

Binding energy : B = 15 MeV <--> 30 MeV

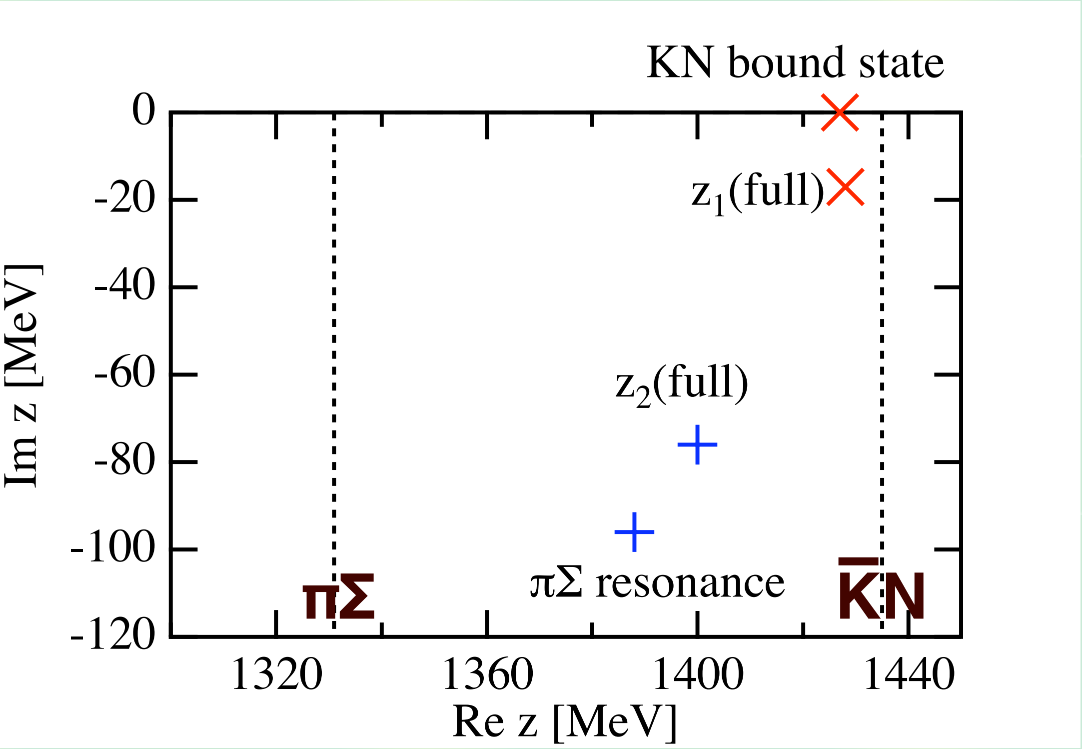
Origin of the two-pole structure

Chiral interaction

$$V_{ij} = -C_{ij}\frac{\omega_i + \omega_j}{4f^2}$$

$$C_{ij} = \begin{array}{cc} \bar{K}N & \pi\Sigma \\ \end{array}$$
$$C_{ij} = \begin{pmatrix} 3 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & 4 \end{pmatrix}$$

$$\omega_i \sim m_i, \quad 3.3 m_\pi \sim m_K$$

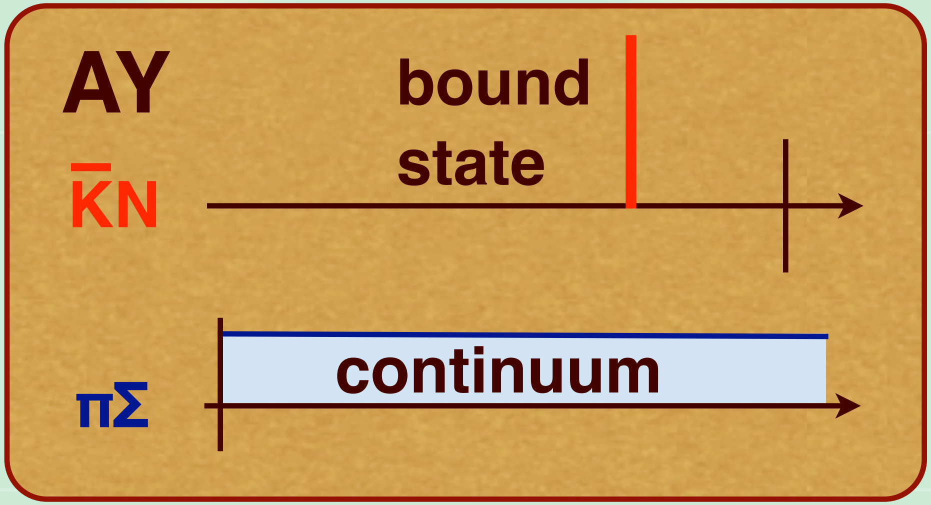


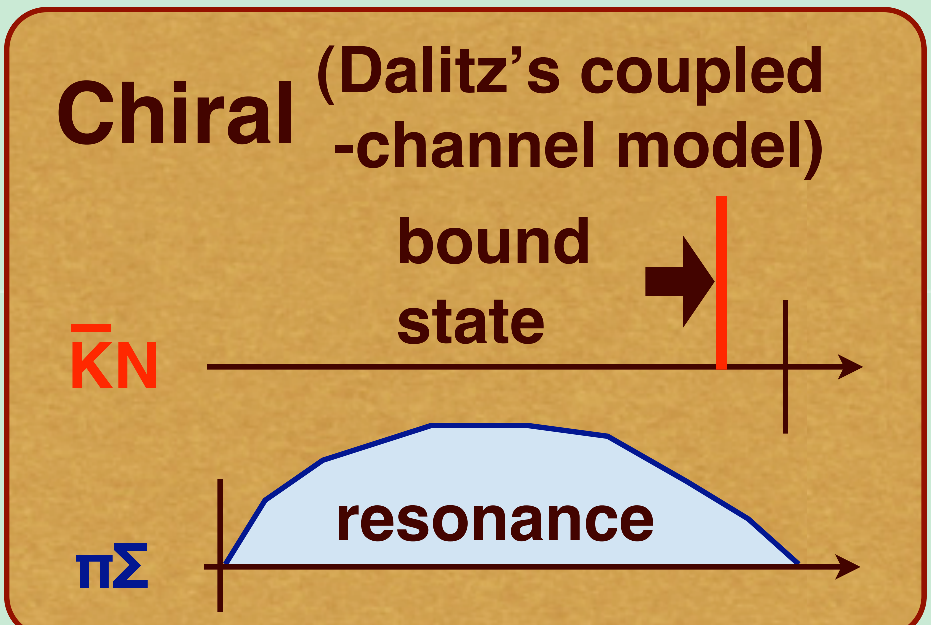
Very strong attraction in $\bar{K}N$ (higher energy) --> bound state
Strong attraction in $\pi\Sigma$ (lower energy) --> resonance

(model dependent)

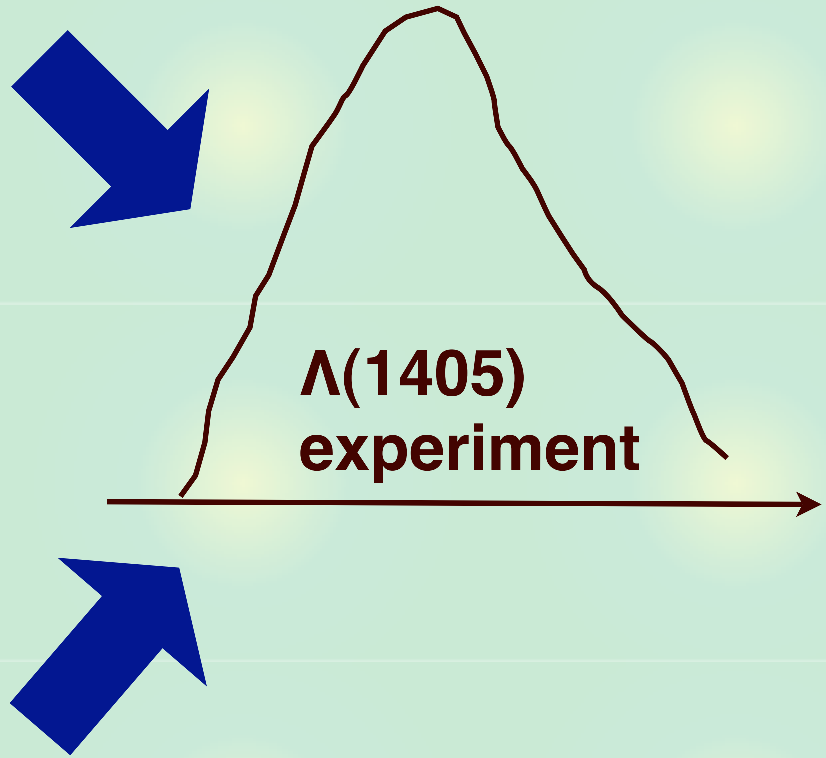
Two poles : natural consequence of chiral interaction

Schematic illustration : AY vs Chiral



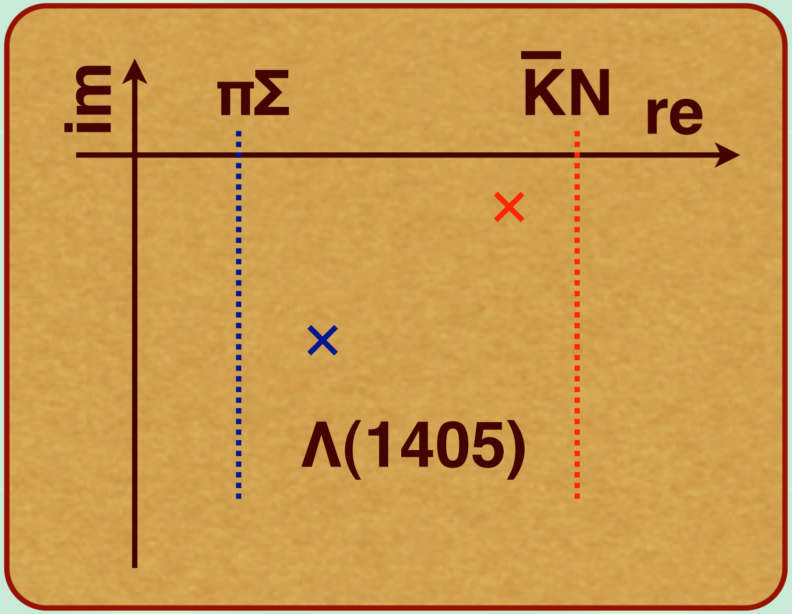


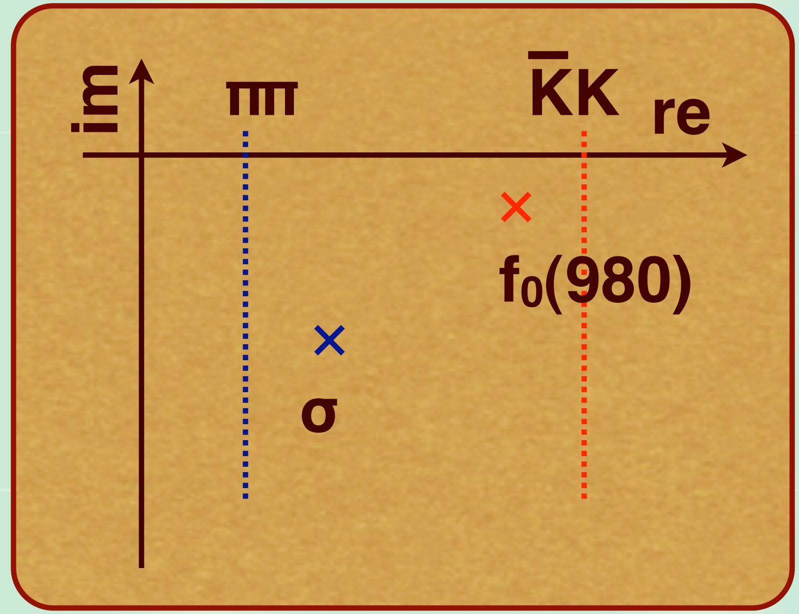
Feshbach resonance



Feshbach resonance on resonating continuum

Correspondence?





Σ ~ “I=1” ~ π,   N ~ “I=1/2” ~ K

Correspondence between two poles of Λ(1405) <=> σ and f_0(980)

Summary 2 : $\bar{K}N$ interaction

We derive the single-channel local potential based on chiral SU(3) dynamics.

- Resonance structure in $\bar{K}N$ appears at around 1420 MeV <-- strong πΣ dynamics
- Less attractive (~1/2) interactions than the phenomenological interaction

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

- Application to K-pp system

$$\text{B.E.} = 19 \pm 3 \text{ MeV}$$
$$\Gamma(\pi YN) = 40 \sim 70 \text{ MeV}$$

A. Doté, T. Hyodo and W. Weise, Nucl. Phys. A 804, 197 (2008), arXiv: 0806.4917 [nucl-th]