Λ(1405) in chiral dynamics

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$\Lambda(1405)$ and $\bar{\mathrm{K}}\mathrm{N}$ dynamics

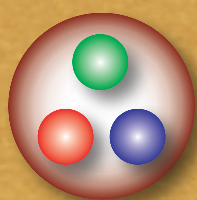
$\Lambda(1405) : J^P = 1/2^-, I = 0$

Mass : 1406.5 ± 4.0 MeV

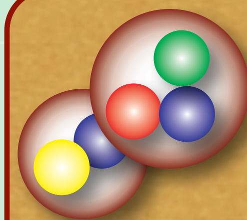
Width : 50 ± 2 MeV

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

"naive" quark model
: p-wave
~1600 MeV?



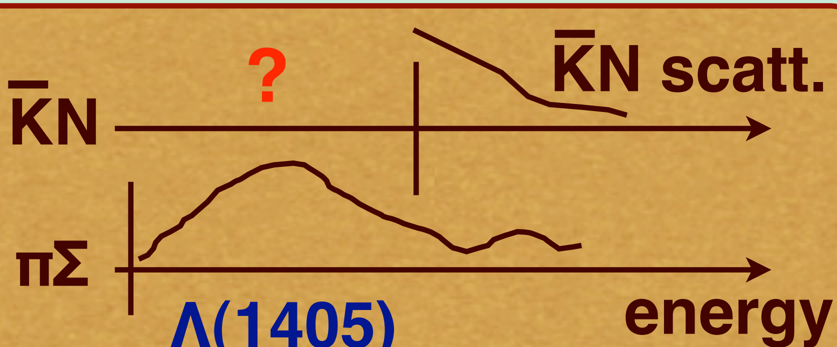
N. Isgur and G. Karl, PRD18, 4187 (1978)



Coupled channel multi-scattering

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

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



(deeply bound) kaonic nuclei
-->
exp. @ J-PARC

Chiral unitary approach

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

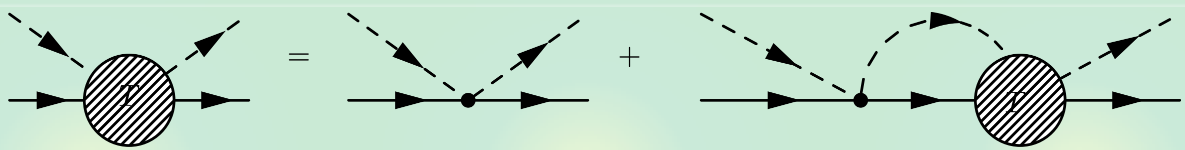
- ○ **Interaction <-- chiral symmetry**

  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)

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

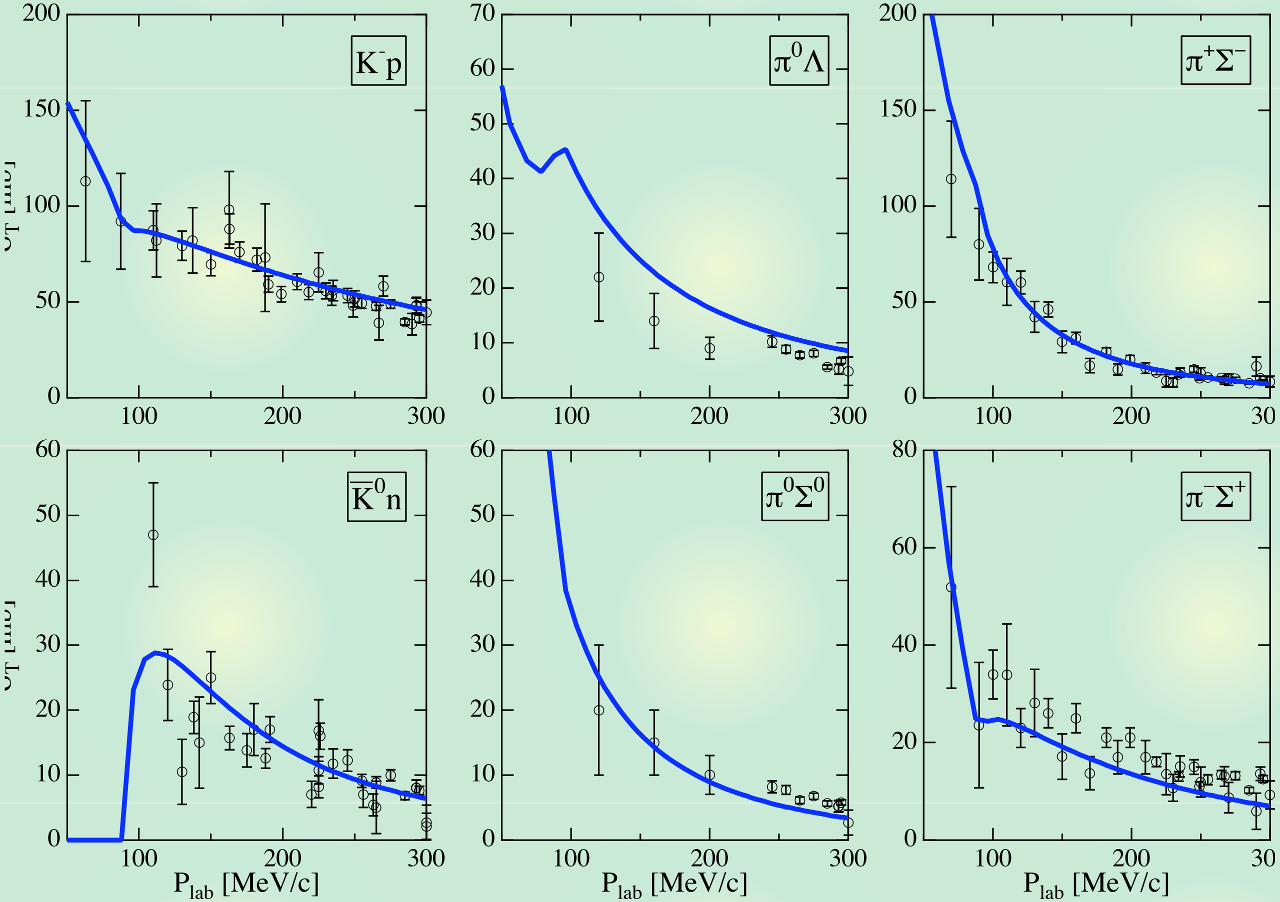


N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

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

Experimental data

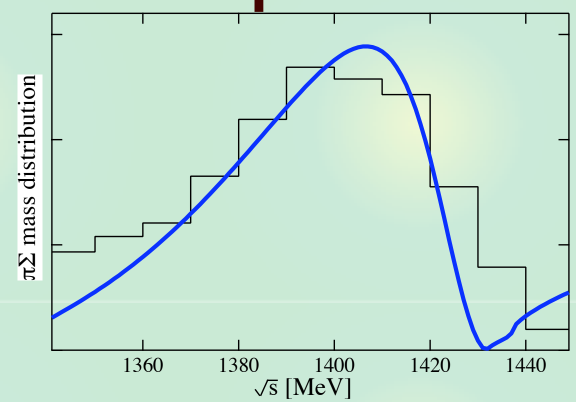
Total cross sections



threshold ratios

	γ	R_c	R_n
exp.	2.36	0.664	0.189
theo.	1.80	0.624	0.225

πΣ spectrum



T. Hyodo, S.I. Nam, D. Jido, A. Hosaka, Phys. Rev. C68, 018201 (2003),
T. Hyodo, S.I. Nam, D. Jido, A. Hosaka, Prog. Theor. Phys. 112, 73 (2004)

Contents

Structure of Λ(1405) resonance

- Dynamical or CDD (genuine quark state) ?

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

- 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).

- Electromagnetic properties

  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

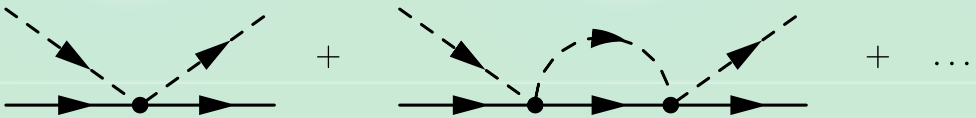
  A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A804, 197 (2008)
  A. Doté, T. Hyodo, W. Weise, arXiv:0806.4917 [nucl-th]

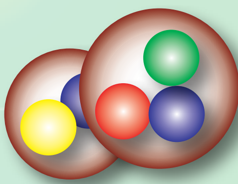
Dynamical state and CDD pole

Resonances in two-body scattering

- Knowledge of interaction (potential)
- Experimental data (cross section, phase shift,...)

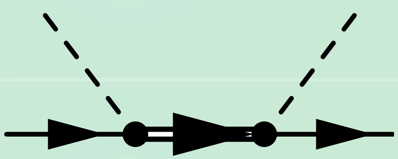
(a) dynamical state: molecule, quasi-bound, ...

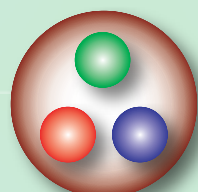




(b) CDD pole: elementary, independent, ...

L. Castillejo, R.H. Dalitz, F.J. Dyson, Phys. Rev. 101, 453 (1956)





Resonance in chiral unitary approach

-> (a) dynamical, but not always...

CDD pole contribution in chiral unitary approach

Amplitude in chiral unitary model

$$T = \frac{1}{\boxed{V^{-1}} - \boxed{G}}$$

V : interaction kernel (potential)

G : loop integral (Green's function)

Known CDD pole contribution

(1) Explicit resonance field in V

(2) Contracted resonance propagator in V

We point out the CDD pole contribution in the subtraction constant in G.

Analysis of phenomenological amplitude

N(1535) in πN scattering --> dynamical + CDD pole

Λ(1405) in $\bar{K}$N scattering --> mostly dynamical

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

Nc scaling in the model

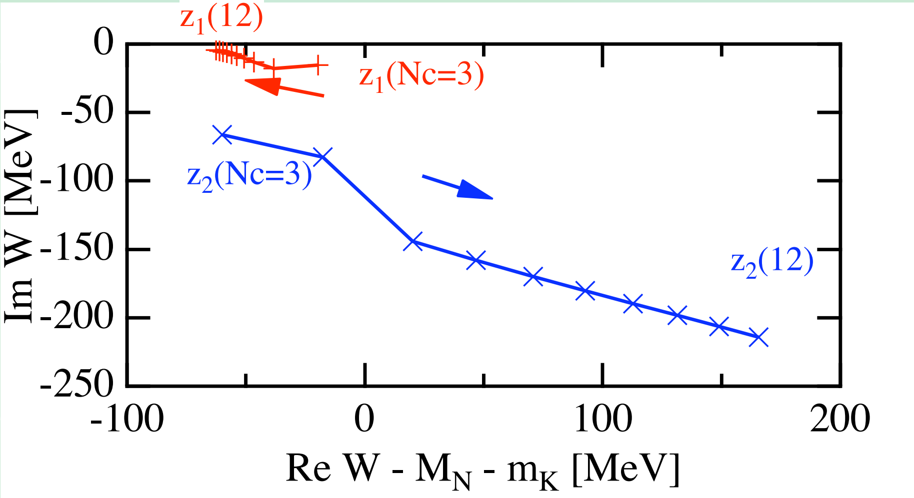
Nc : number of color in QCD
Hadron effective theory / quark structure

The Nc behavior is known from the general argument.
<-- introducing Nc dependence in the model,
analyze the resonance properties with respect to Nc

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

Nc scaling of (excited) qqq baryon

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

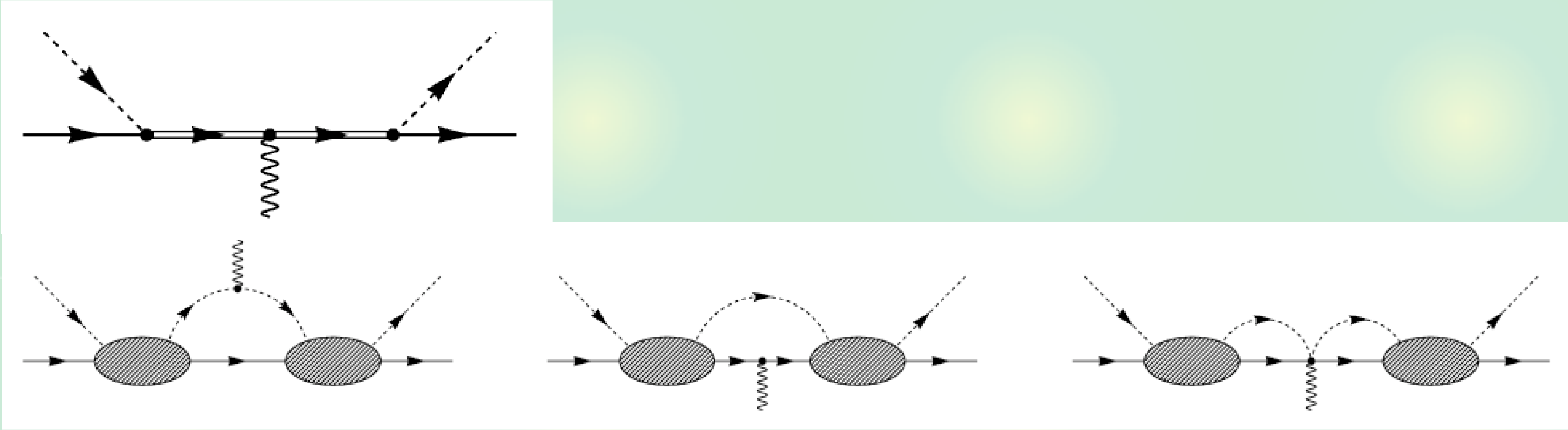


Result : $\Gamma_R \neq \mathcal{O}(1)$
~ non-qqq (i.e. dynamical) structure

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

Electromagnetic properties

Attaching photon to resonance
--> em properties : rms, form factors,...



result of mean squared radii :

$$< r^2 >_E = -2.193 \text{ fm}^2$$

large (em) size of the Λ(1405)
--> meson-baryon picture

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

Summary 1 : Structure of Λ(1405)

We study the structure of the Λ(1405)

- Dynamical or CDD?

  => dominance of the MB components

- Analysis of Nc scaling

  => non-qqq structure

- Electromagnetic properties

  => large e.m. size

Summary 1 : Structure of Λ(1405)

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- **Dynamical or CDD?**

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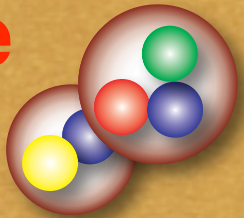
- **Analysis of Nc scaling**

  => non-qqq structure

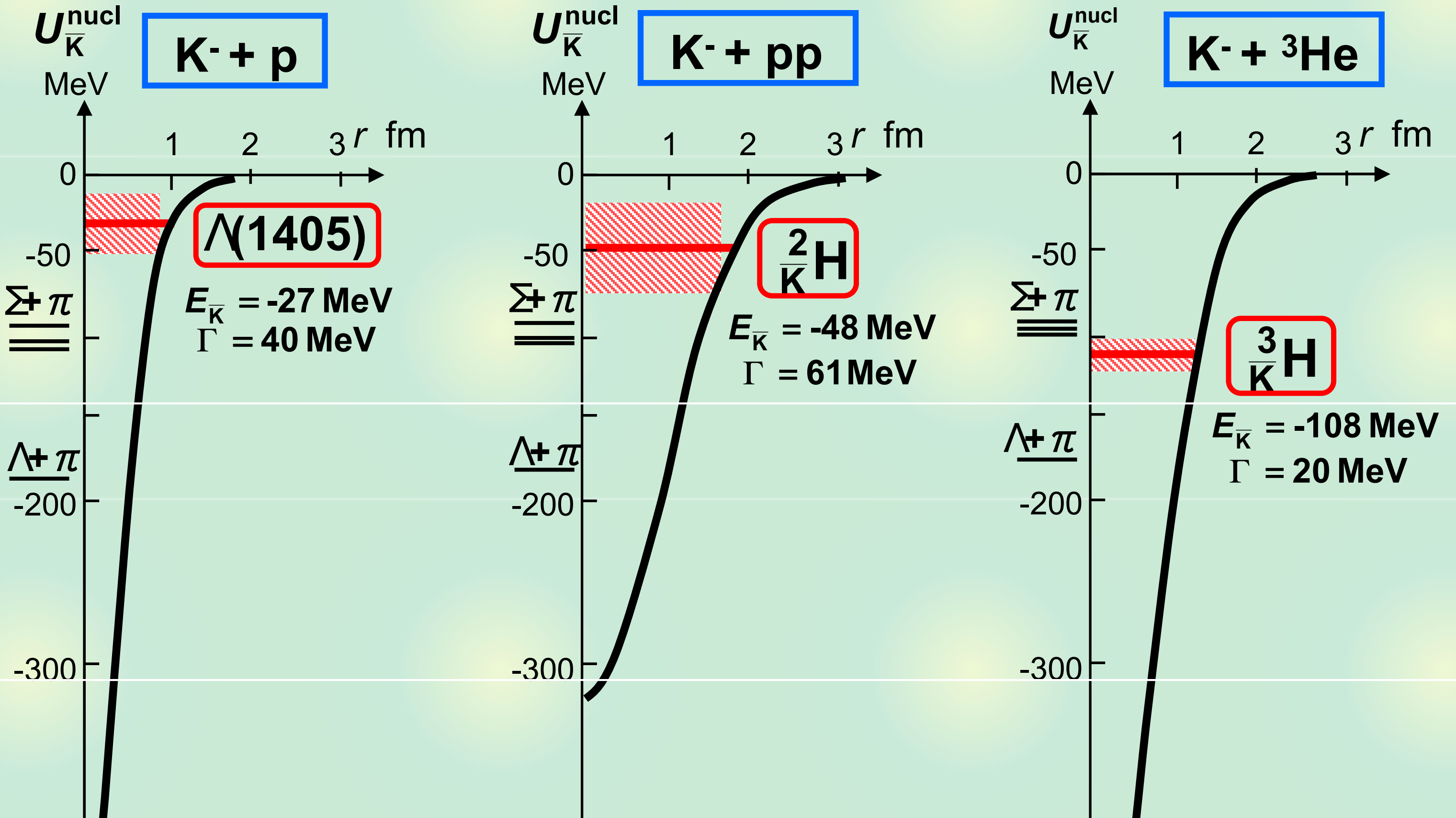
- **Electromagnetic properties**

  => large e.m. size

- **Independent analyses consistently support the meson-baryon molecule picture of the Λ(1405)**



Deeply bound (few-body) kaonic nuclei?



Potential is purely phenomenological.
What does chiral dynamics tell us about it?

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

Effective interaction based on chiral SU(3) dynamics

Few-body kaonic nuclei in chiral dynamics

Result of chiral dynamics
--> single channel $\bar{K}N$ potential
--> few-body kaonic nuclei

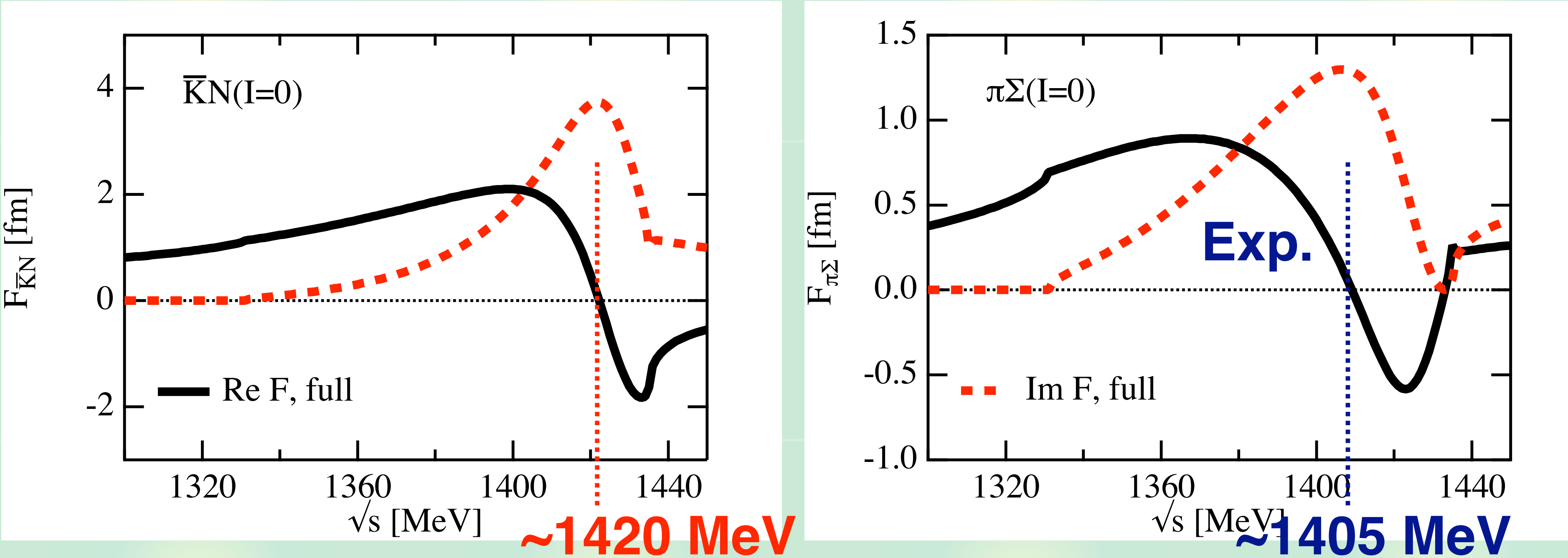
Construction of effective potential

1) Coupled-channel --> single $\bar{K}N$ channel BS equation
elimination of $\pi\Sigma$ channel
(exact)

2) Local potential in Schrödinger equation
(approximate)

We obtain the $\bar{K}N$ interaction weaker than the phenomenological one (factor ~1/2).

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



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

<-- strong $\pi\Sigma$ dynamics (coupled-channel)

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

Two poles with same quantum numbers

Different weights of the pole residues --> different spectrum

D. Jido, J.A. Oller, E. Oset, A. Ramos, U.G. Meissner, Nucl. Phys. A 723, 205 (2003)

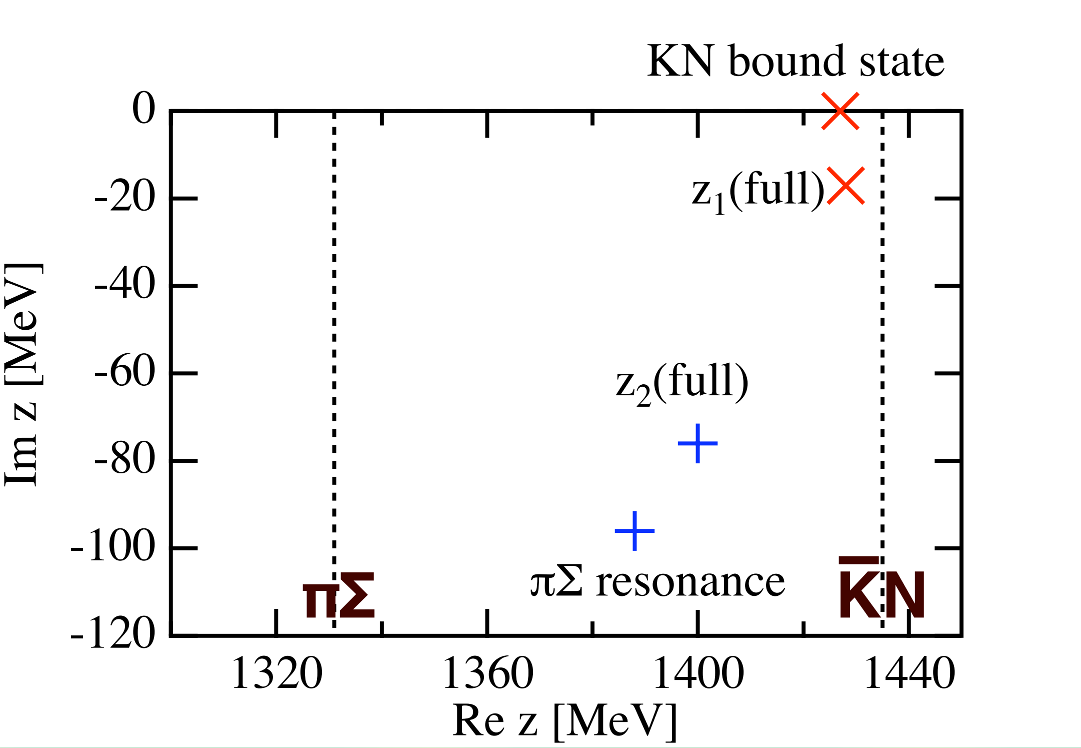
Origin of the two-pole structure

Chiral interaction

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

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

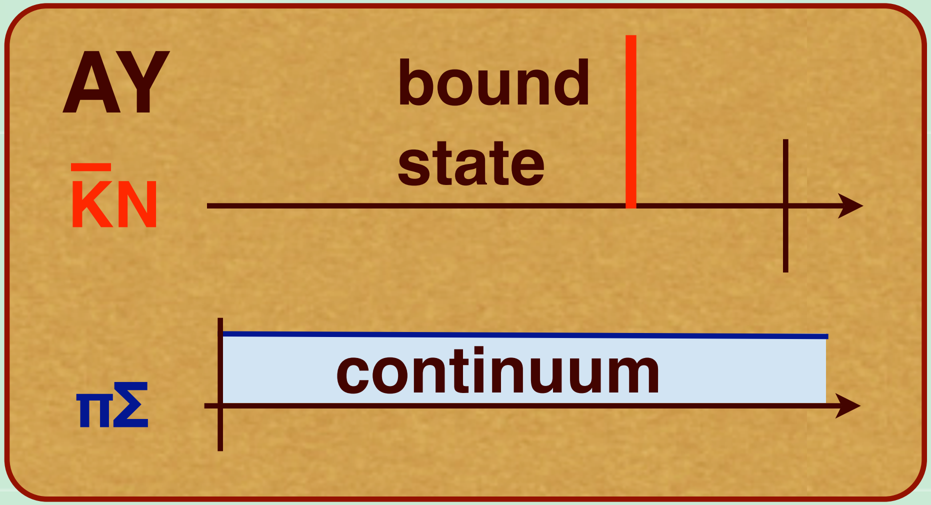
$$\omega_i \sim m_i, \quad 3.3m_\pi \sim m_K$$

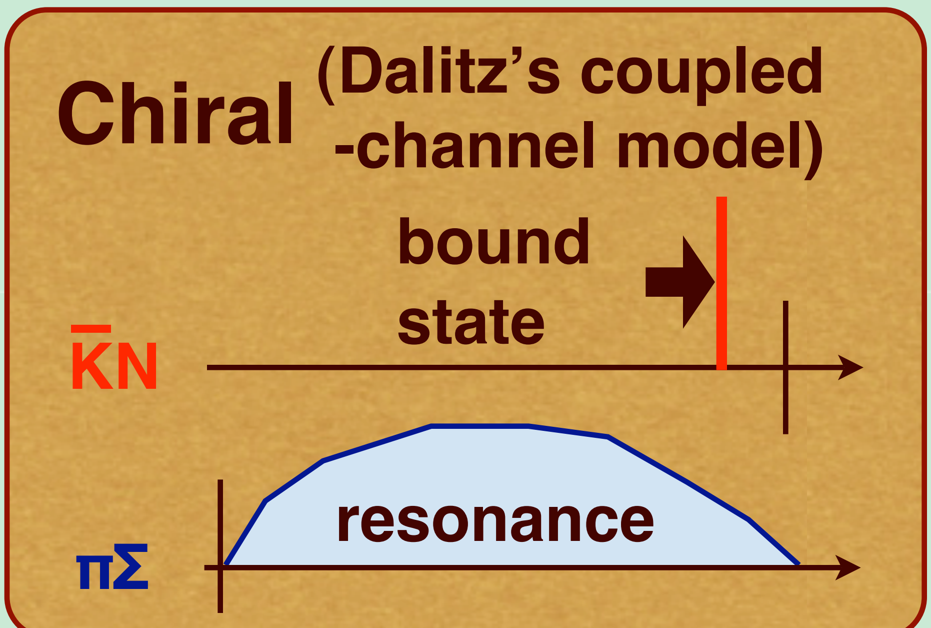


Very strong attraction in $\bar{K}N$ (higher energy) --> bound state
Strong attraction in πΣ (lower energy) --> resonance

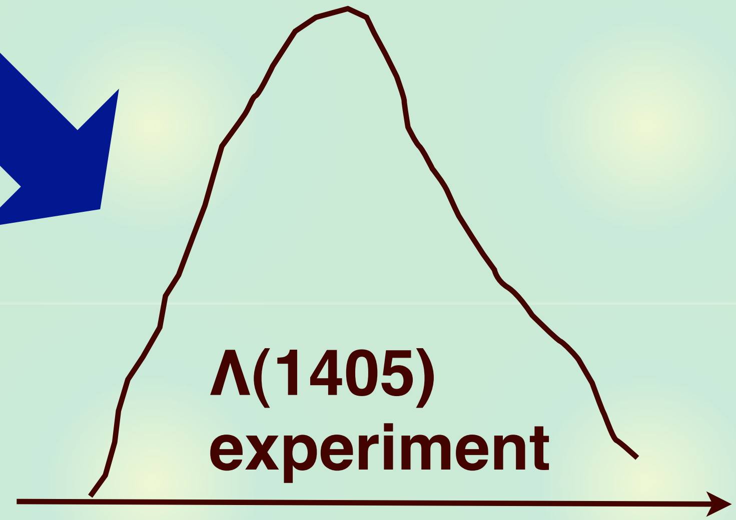
Two attractive interaction --> Two states
πΣ -> πΣ attraction : chiral (SU(3)) symmetry

Schematic illustration : AY vs Chiral





Feshbach resonance



Feshbach resonance on resonating continuum

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 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]