Structure of the Λ(1405) and kaon-nucleon dynamics

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    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, Phys. Lett. B669, 133-138 (2008).
- Effective single-channel $\bar{K}N$ interaction

  T. Hyodo and W. Weise, Phys. Rev. C 77, 035204 (2008)
- On the $\bar{K}NN$ (strange dibaryon) system

Chiral dynamics

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

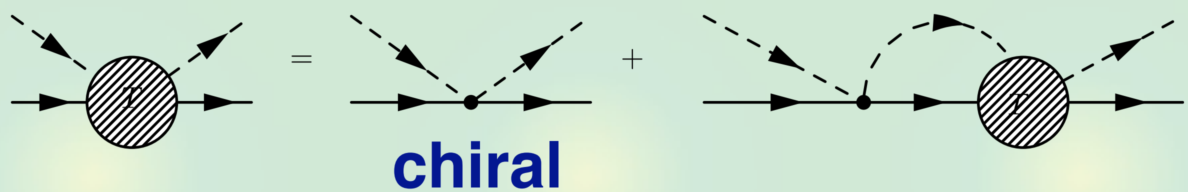
- Interaction <-- chiral symmetry

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, G. Rajasekaran, PR153, 1617 (1967)

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

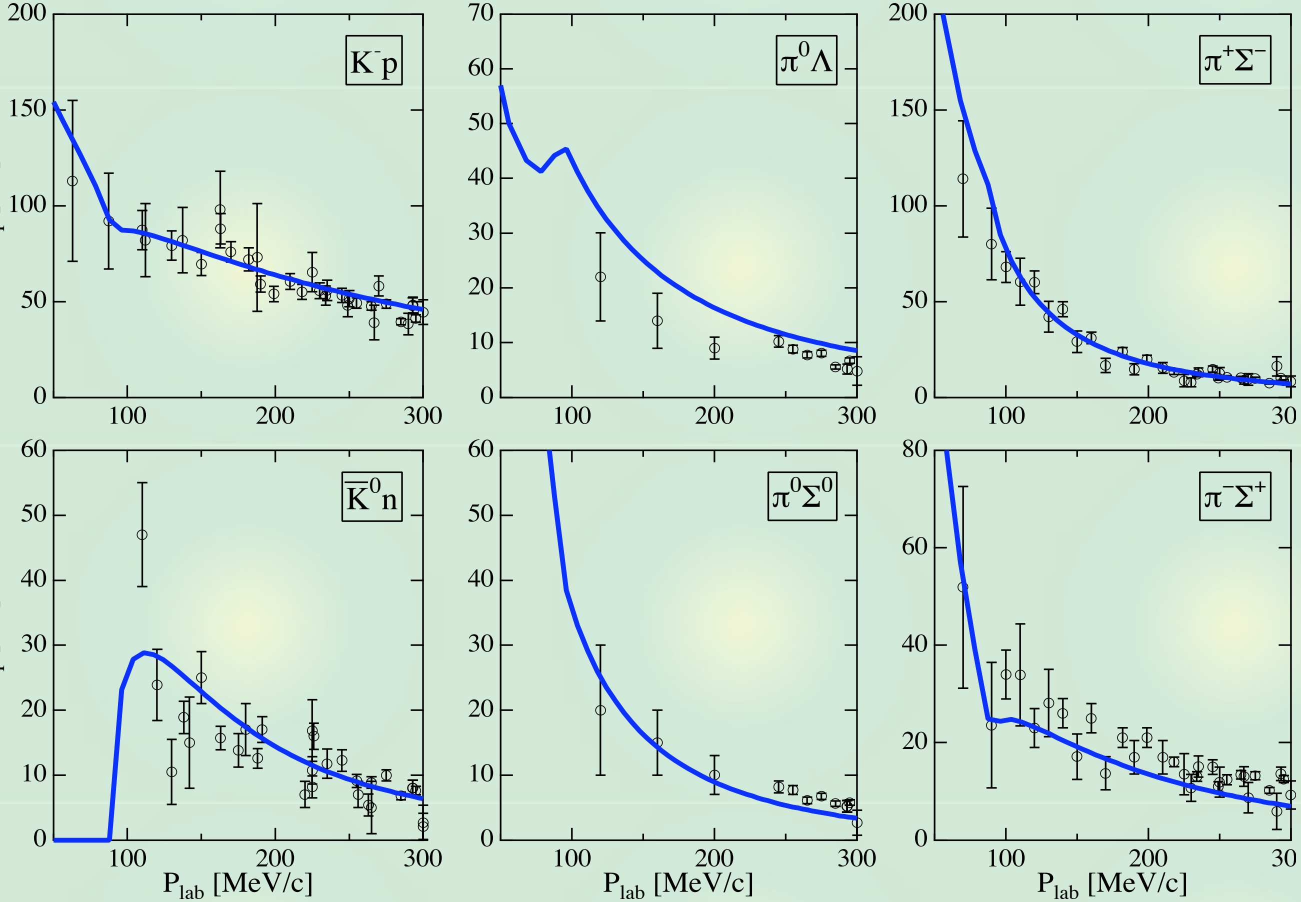


N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002), ... many others

works successfully, also in S=0 sector, meson-meson scattering sectors, systems including heavy quarks, ...

How it works? vs experimental data

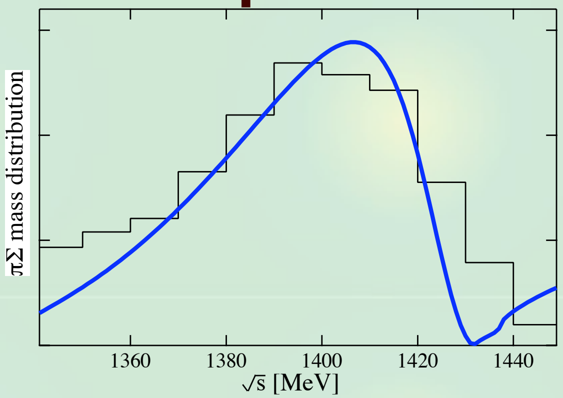
Total cross sections



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)

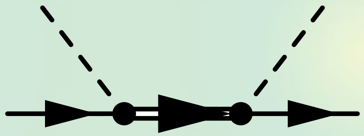
==> $\bar{K}N$ interaction in this framework

Two poles for one resonance

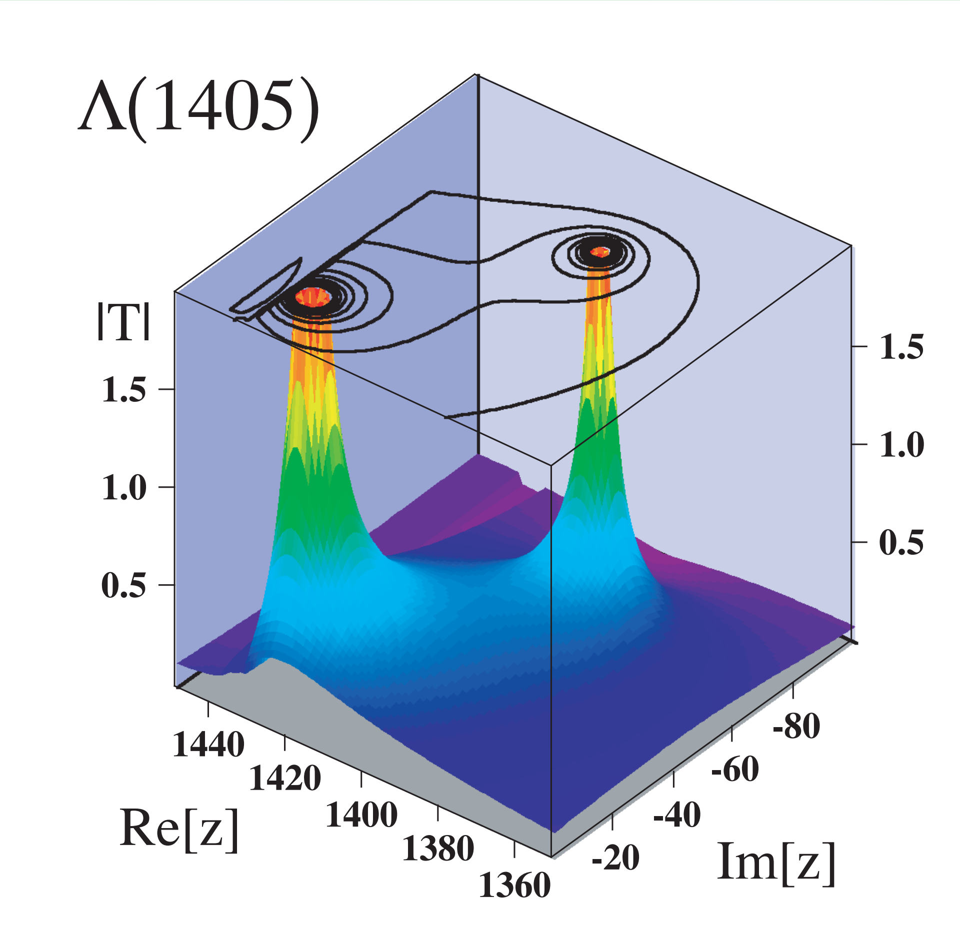
Poles of the amplitude in the complex plane : resonance

$$T_{ij}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - M_R + i\Gamma_R/2}$$

$$\sim$$



Real part	**Mass**
Imaginary part	**Width/2**
Residues	**Couplings**



Physical state: superposition

$$|\Lambda(1405)\rangle = a|\Lambda_1^*\rangle + b|\Lambda_2^*\rangle$$

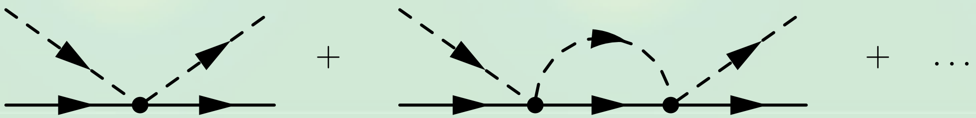
D. Jido, J.A. Oller, E. Oset, A. Ramos, U.G. Meissner, Nucl. Phys. A 723, 205 (2003);
T. Hyodo, W. Weise, Phys. Rev. C 77, 035204 (2008)

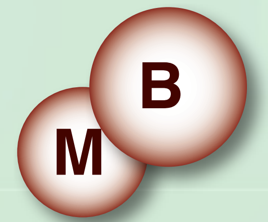
Dynamical state and CDD pole

Resonances in two-body scattering

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

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

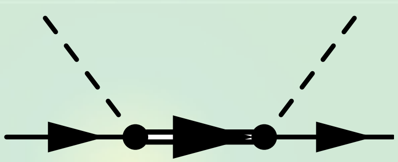


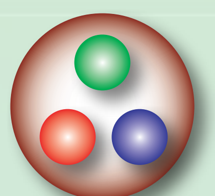


e.g.) Deuteron in NN, positronium in e^+e^-, (σ in π π), ...

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

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





e.g.) J/Ψ in e^+e^-, (ρ in π π), ...

Resonances in chiral unitary approach -> (a) dynamical?

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

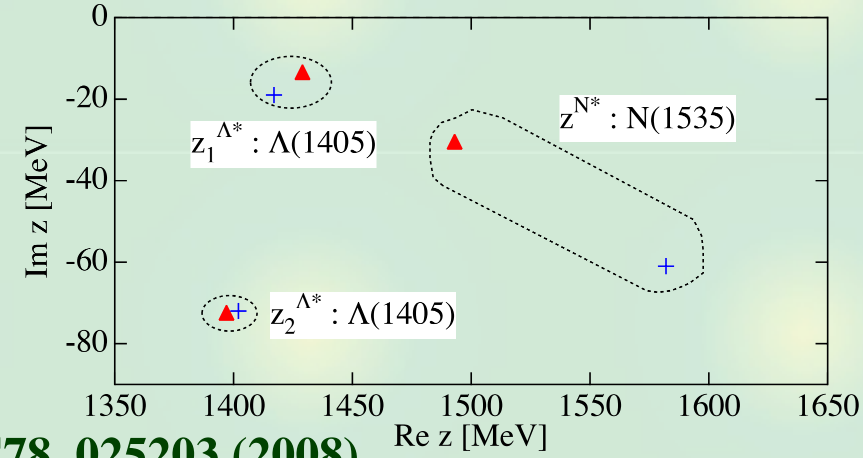
(1) Explicit resonance field in **V**

(2) Contracted resonance propagator in **V**

Defining "natural renormalization scheme",
we find **CDD pole contribution in G** (subtraction constant).

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

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



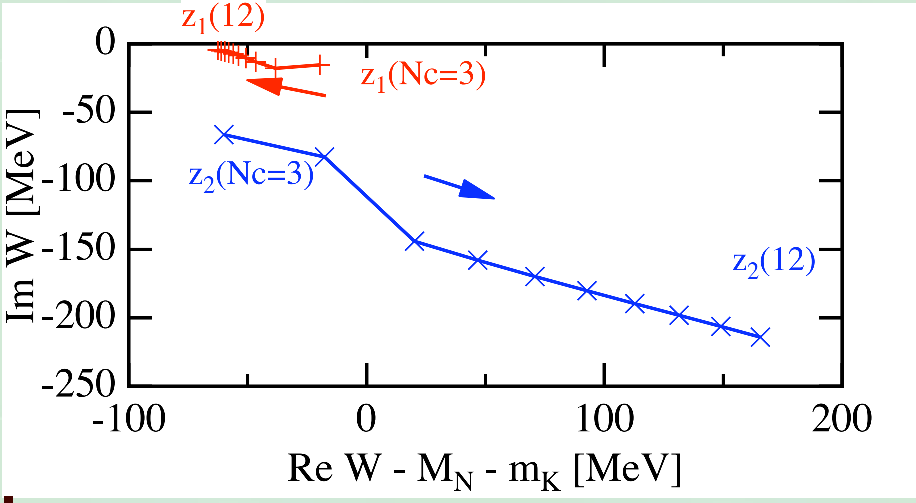
T. Hyodo, D. Jido, A. Hosaka, Phys. Rev. C78, 025203 (2008).

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

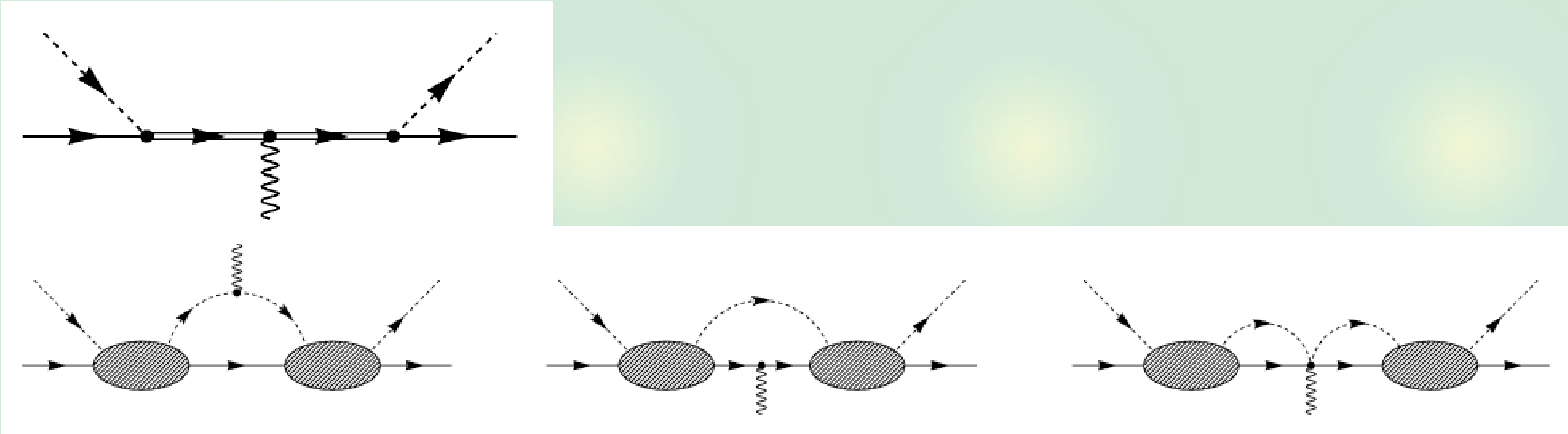
$$M_R \sim \mathcal{O}(N_c), \quad \Gamma_R \sim \mathcal{O}(1)$$

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 :

$$|\langle r^2 \rangle_{\mathrm{E}}| = 0.33\ [\mathrm{fm}^2]$$

large (em) size of the Λ(1405) : c.f. -0.12 [fm²] for neutron
--> meson-baryon picture

T. Sekihara, T. Hyodo, D. Jido, Phys. Lett. B669, 133-138 (2008).

Summary 1 : Structure of Λ(1405)

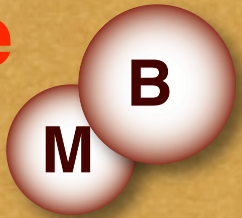
We study the structure of the Λ(1405)

- 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)

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



Effective interaction based on chiral SU(3) dynamics

Result of chiral dynamics --> single channel potential

few-body K-nuclei

Coupled-channel BS eq.
+ real valued interaction

$T_{ij}(\sqrt{s})$
$V_{ij}(\sqrt{s})$

(exact transformation)

Single-channel BS eq.
+ complex interaction

$T^{\mathrm{eff}}(\sqrt{s}) = T_{ii}(\sqrt{s})$
$V^{\mathrm{eff}}(\sqrt{s})$

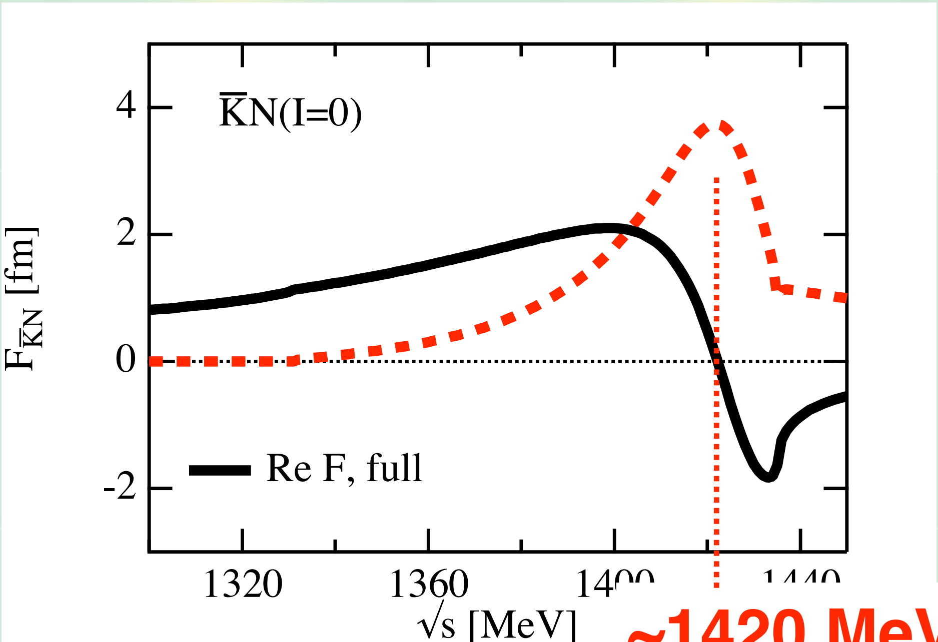
(with approximation)

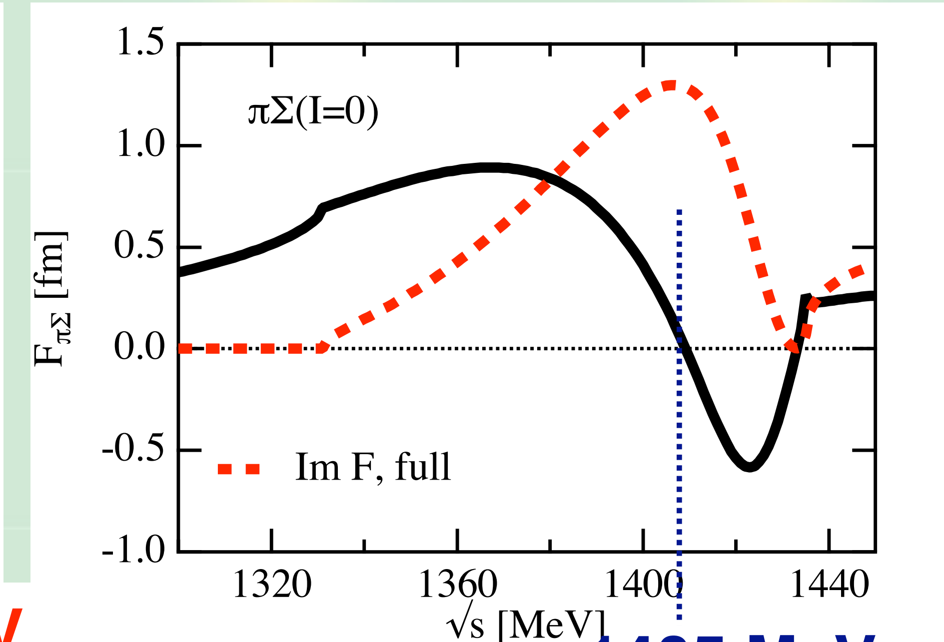
Schrödinger equation
+ local, complex, and
energy-dependent potential

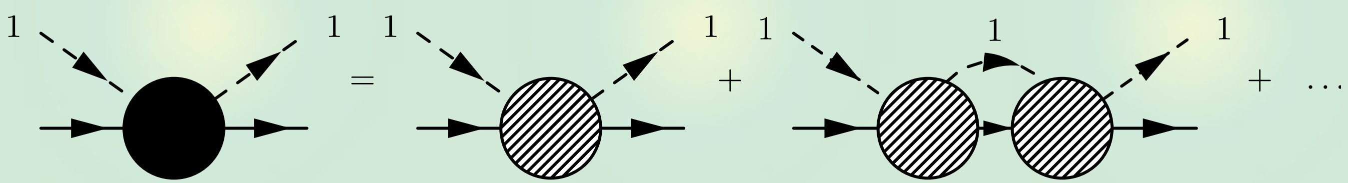
$f^{\mathrm{eff}}(\sqrt{s}) \sim T^{\mathrm{eff}}(\sqrt{s})$

$U^{\mathrm{eff}}(r, \sqrt{s})$

(Diagonal) scattering amplitude in $\bar{K}N$ and $\pi\Sigma$







Resonance in $\bar{K}N$ channel : at around 1420 MeV
<-- consequence of strong $\pi\Sigma$ dynamics (coupled-channel)

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

Origin of the two-pole structure

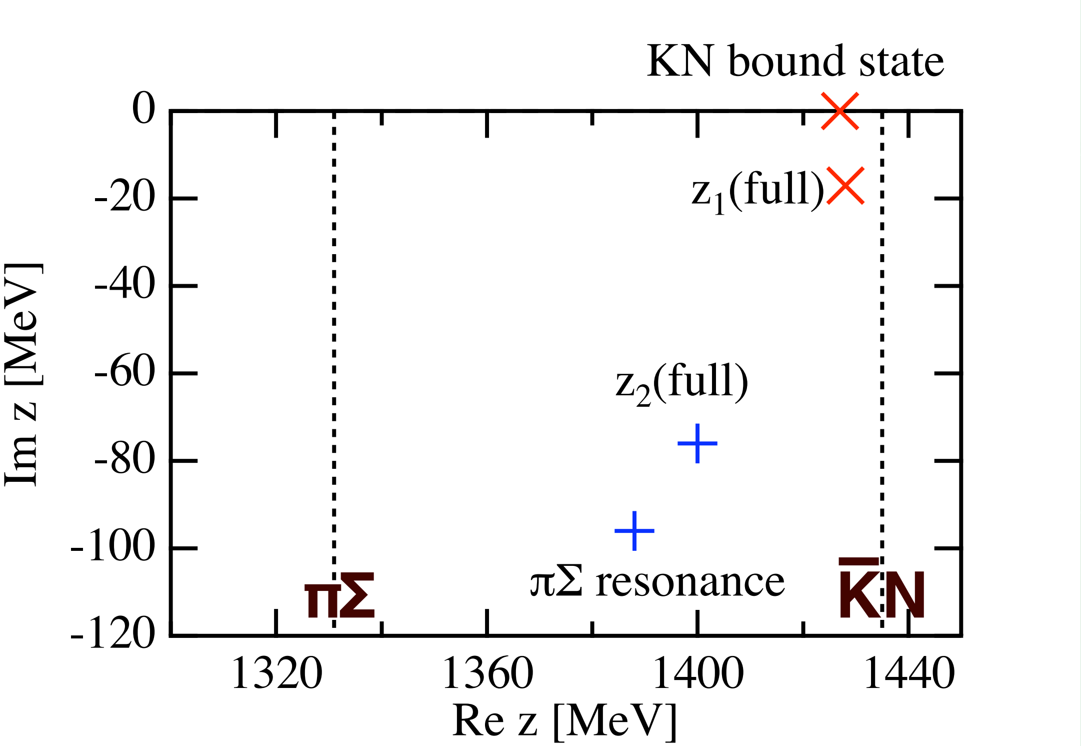
Chiral interaction

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

$$\begin{array}{cc} \bar{K}N & \pi\Sigma \end{array}$$

$$C_{ij} = \begin{pmatrix} 3 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & 4 \end{pmatrix}$$

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

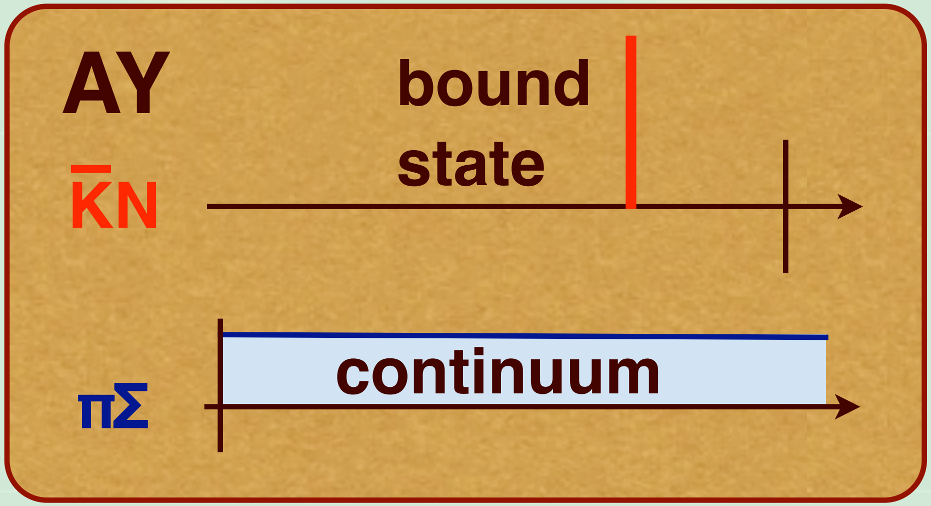


Very strong attraction in K̄N (higher energy) --> bound state
Strong attraction in πΣ (lower energy) --> resonance

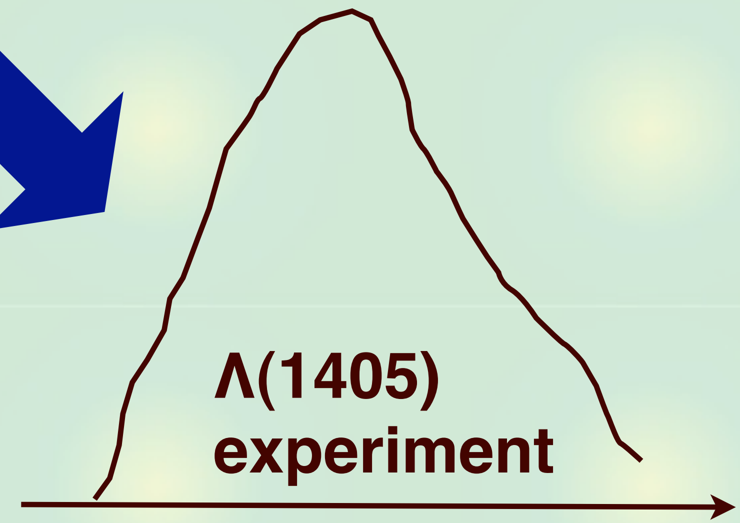
Two poles : natural consequence of chiral interaction
(pole position is model dependent)

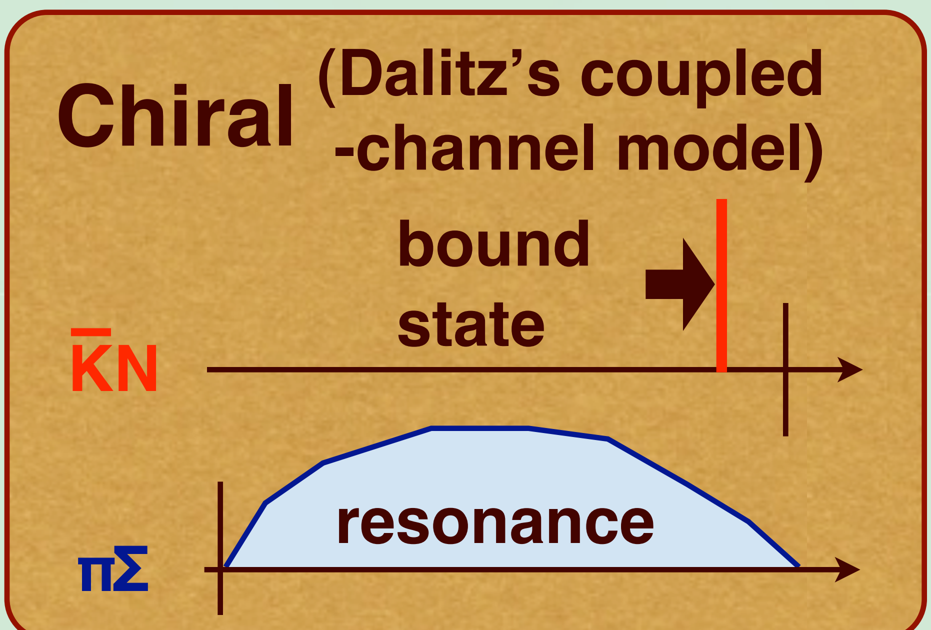
Effective single-channel KN interaction

Schematic illustration : AY vs Chiral



Feshbach resonance





Feshbach resonance on
resonating continuum

Summary 1 : $\bar{K}N$ interaction

We study the consequence of chiral SU(3) dynamics in $\bar{K}N$ phenomenology.

- Resonance structure in $\bar{K}N$ appears at around 1420 MeV <-- strong $\pi\Sigma$ dynamics
- Two attractive interactions in $\bar{K}N$ and $\pi\Sigma$

  --> weaker effective $\bar{K}N$ interaction

  --> two poles for the $\Lambda(1405)$

  T. Hyodo and W. Weise, Phys. Rev. C 77, 035204 (2008)
- Application to K-pp system (without $\pi\Sigma N$)

  Doté-san's talk

Which channel is relevant?

Theoretical studies

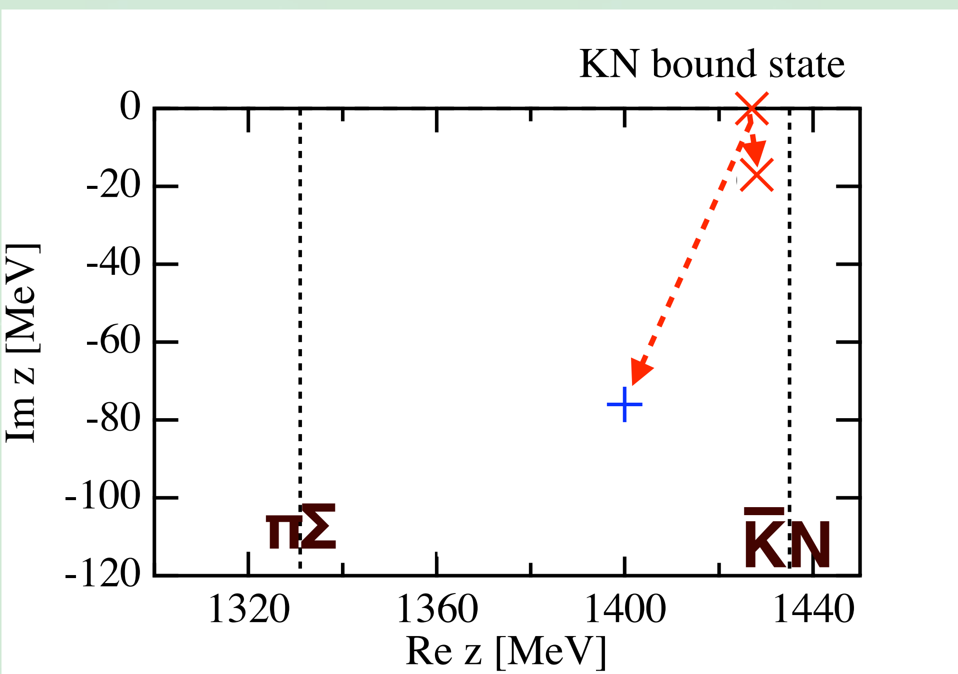
KNN - (πΣN) channels

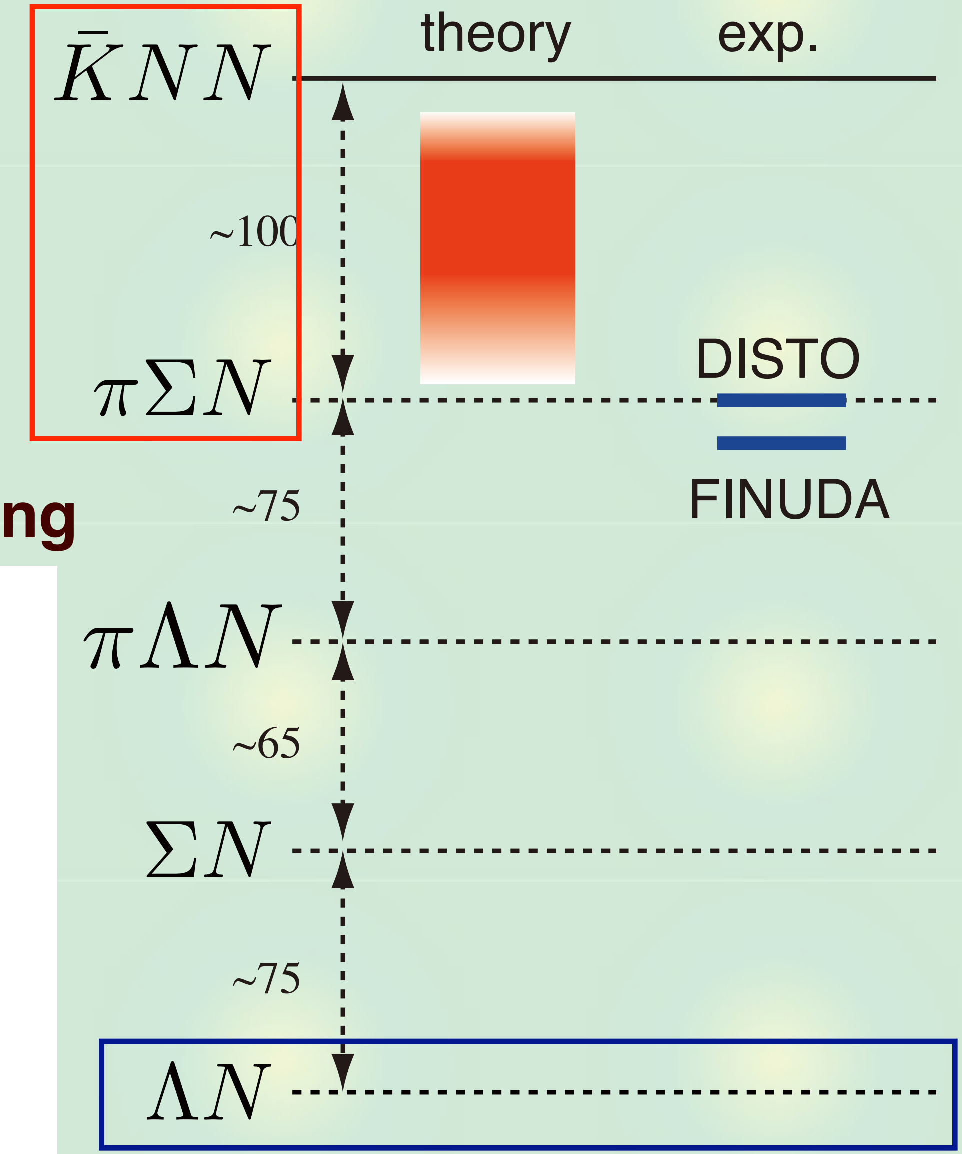
Experimental candidates

- energy ≦ πΣN

observed in ΛN inv. mass

effect of decay channel coupling





Λ*N state in chiral dynamics

Chiral dynamics --> two Λ* states : Λ^*_1, Λ^*_2

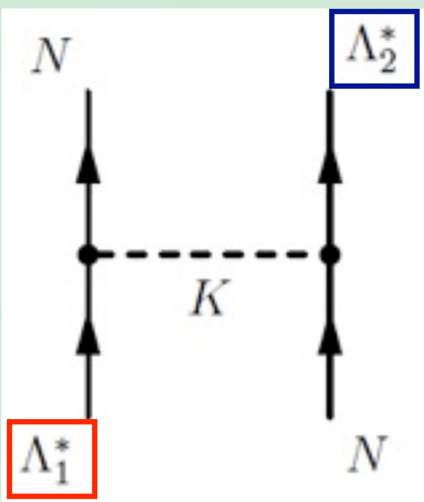
$$|\Lambda(1405)\rangle = a|\Lambda_1^*\rangle + b|\Lambda_2^*\rangle$$

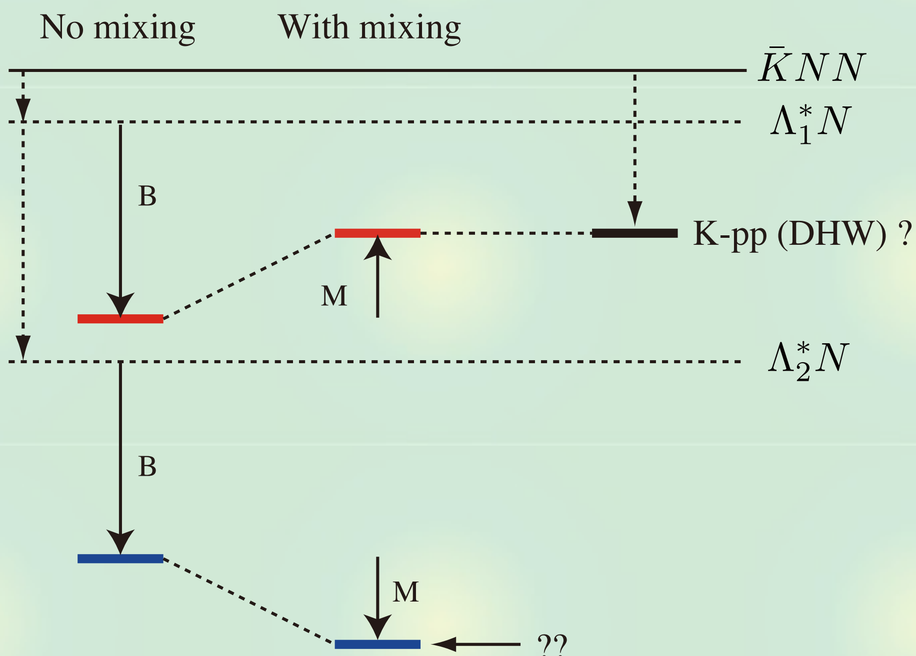
B=2 system : $\Lambda^*_1 N$, $\Lambda^*_2 N$?

$$|B=2, S=-1\rangle = a'|\Lambda_1^* N\rangle + b'|\Lambda_2^* N\rangle$$

Y. Ikeda, RCNP workshop, Dec. 25, 2008

mixing of $\Lambda^*_1 N$ <--> $\Lambda^*_2 N$





level repulsion --> $\Lambda^*_1 N$ becomes light?

T. Uchino, T. Hyodo, M. Oka, in preparation

Summary 2 : $\bar{K}$NN system

$\bar{K}$NN or strange dibaryon system

- To compare with observed candidates, we should choose relevant channel(s).

  importance of πΣN channel?

  actual decay into ΛN channel
  --> change the spectrum?

- If there are two states for Λ*(1405), there could be two states in KNN-πΣN system

  Mixing of two Λ*
  --> level repulsion?