Kaon-Nucleon dynamics and role of chiral symmetry


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- Effective $\bar{K}N$ interaction

  T. Hyodo and W. Weise, Phys. Rev. C 77, 035204 (2008)
- Variational calculation for $\bar{K}NN$ system

  A. Doté, T. Hyodo and W. Weise, Nucl. Phys. A 804, 197 (2008); Phys. Rev. C 79, 014003 (2009)

  -> “Single-channel” approach
- Does chiral insist “shallow” state?
- Estimation in a schematic model

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

Chiral unitary approach

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

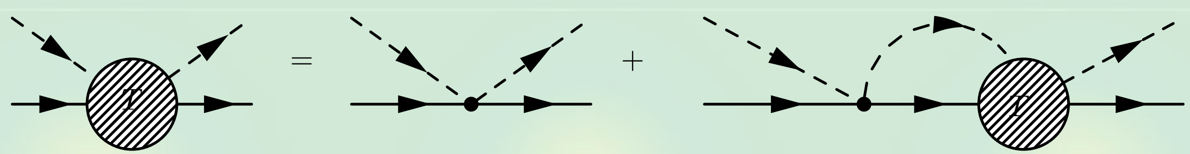
○ **Interaction <-- chiral symmetry**

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 and G. Rajasekaran, PR153, 1617 (1967)

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

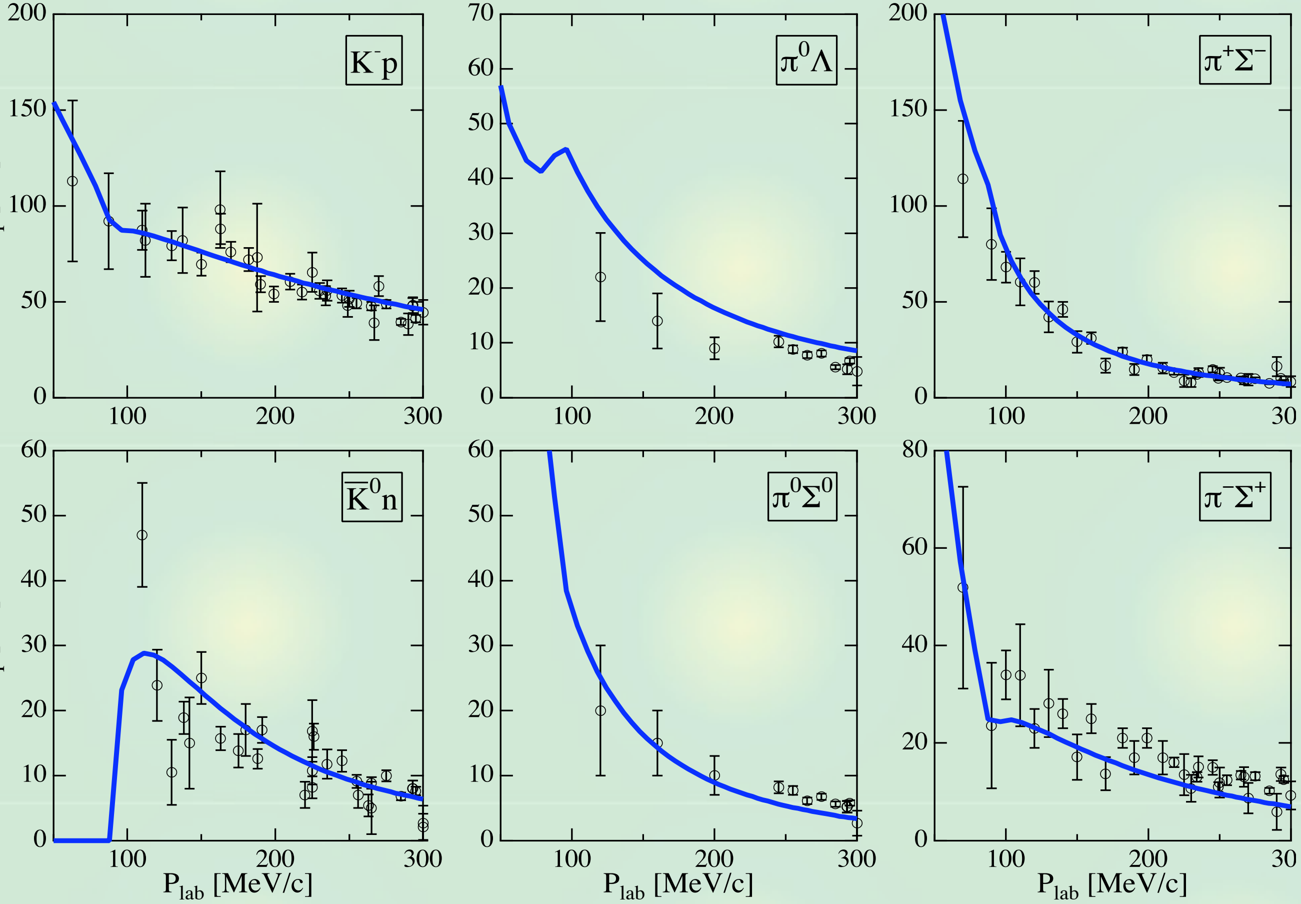


N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

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

How it works? vs experimental data

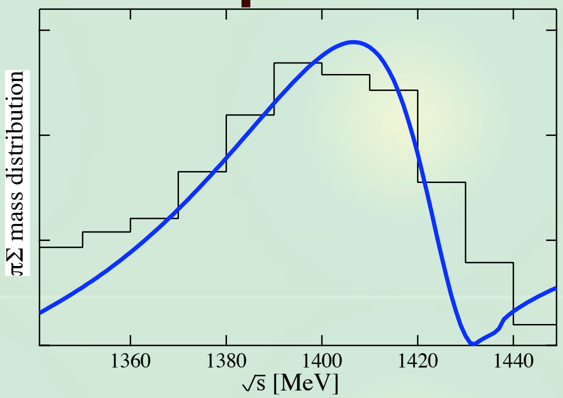
Total cross sections



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

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

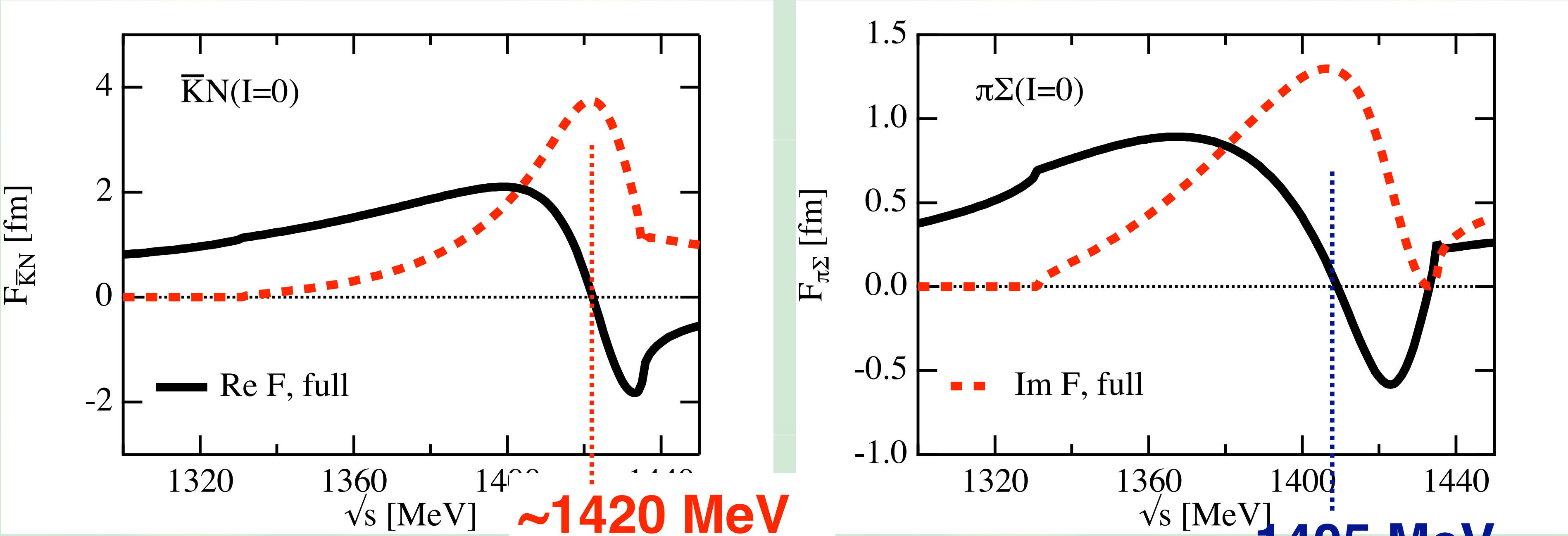
$$T^{\text{eff}}(\sqrt{s}) = T_{ii}(\sqrt{s})$$
$$V^{\text{eff}}(\sqrt{s})$$

↓ (with approximation)

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

$$f^{\text{eff}}(\sqrt{s}) \sim T^{\text{eff}}(\sqrt{s})$$
$$U^{\text{eff}}(r, \sqrt{s})$$

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



~1420 MeV (not a direct observable)

~1405 MeV

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

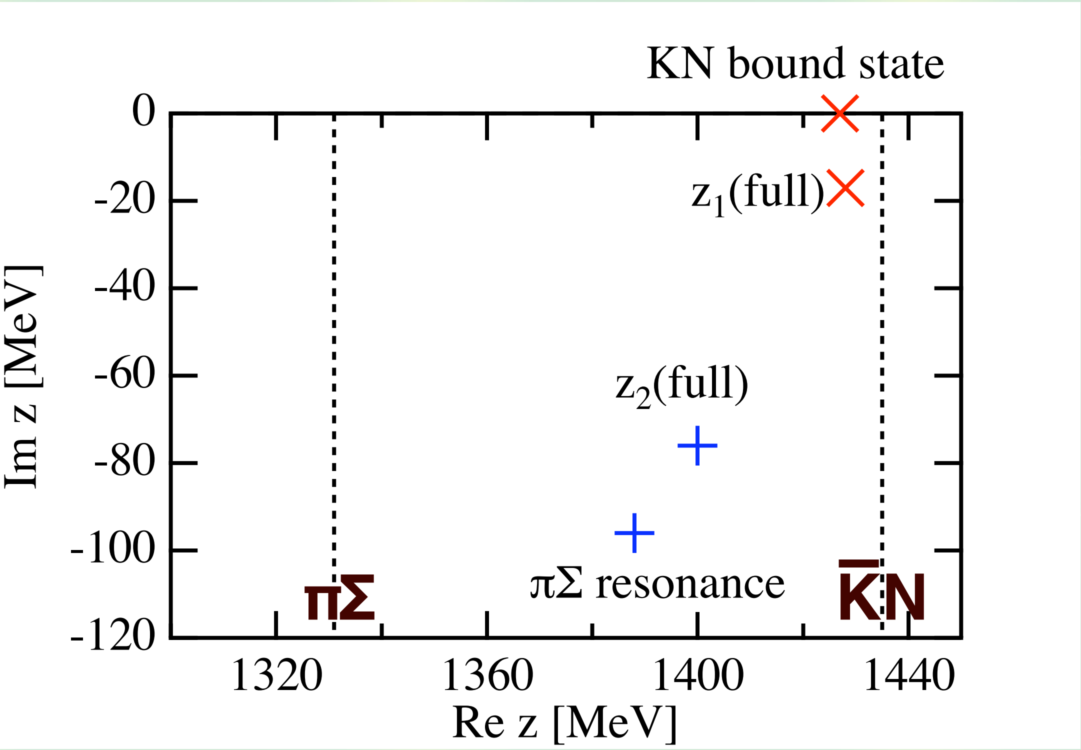
Chiral interaction

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

$\bar{K}N$ $\pi\Sigma$

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

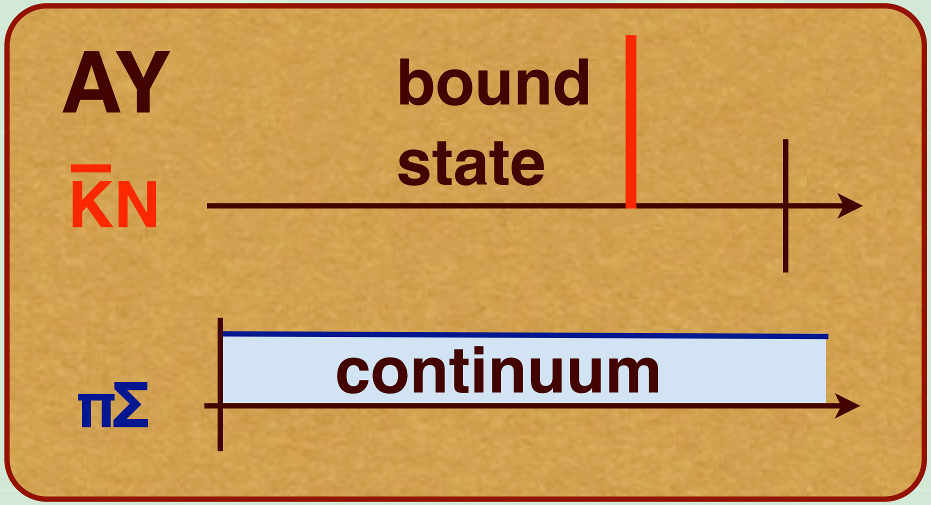
$$\omega_i \sim m_i, \quad 3.3m_\pi \sim m_K$$

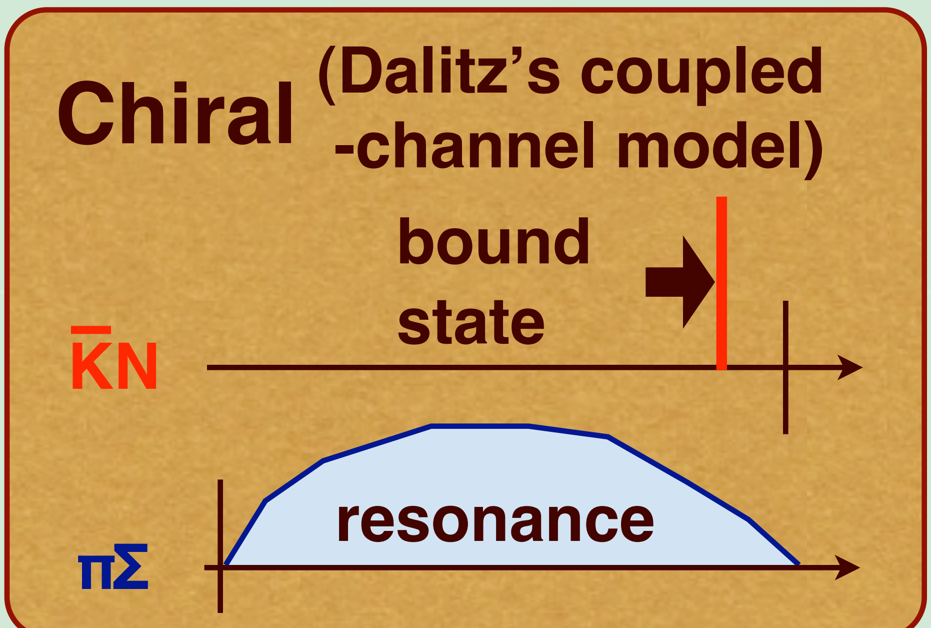


Very strong attraction in $\bar{K}N$ (higher energy) --> bound state
Strong attraction in $\pi\Sigma$ (lower energy) --> resonance

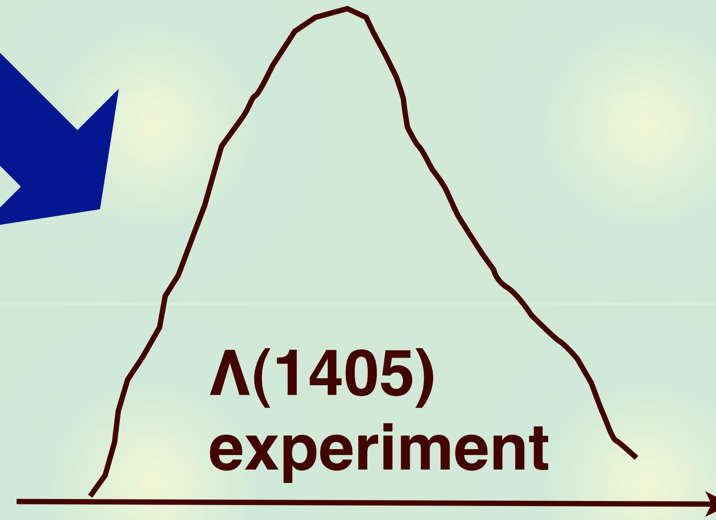
Two poles : natural consequence of chiral interaction
(pole position is model dependent)

Schematic illustration : AY vs Chiral

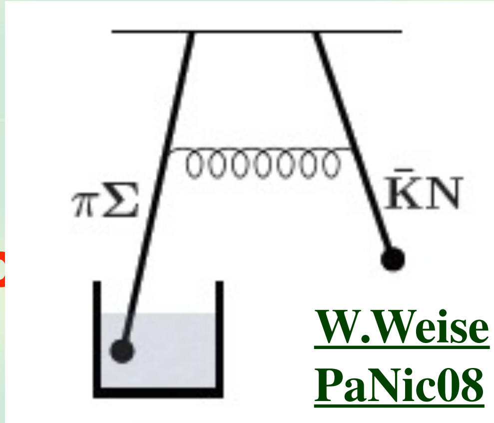




Feshbach resonance



Feshb… on
reson…



Summary 1 : $\bar{K}N$ "single-channel" approach

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 πΣ dynamics
- Two attractive interactions in $\bar{K}N$ and πΣ --> weaker effective $\bar{K}N$ interaction

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

- Application to K-pp system (without πΣN)

B.E. = 20 ± 3 MeV, Γ(πYN) = 40 ~ 70 MeV

A. Doté, T. Hyodo and W. Weise, Nucl. Phys. A 804, 197 (2008); Phys. Rev. C 79, 014003 (2009)

Three-body calculations for $\bar{K}NN$

Single-channel variational calculation (DHW)

B.E. = 20 ± 3 MeV, Γ(πYN) = 40 ~ 70 MeV

Coupled-channel Faddeev calculation (IS) using chiral interaction

Y. Ikeda and T. Sato, Phys. Rev. C 77, 035204 (2008)

B.E. ~ 79 MeV, Γ(πYN) ~ 74 MeV

Why are they so different?
Inconsistency in theoretical calculations?

- πΣN dynamics?
  (existence of another N when eliminating πΣ channel)

Y. Ikeda and T. Sato, arXiv:0809.1285 [nucl-th]

Does chiral insist “shallow” state?

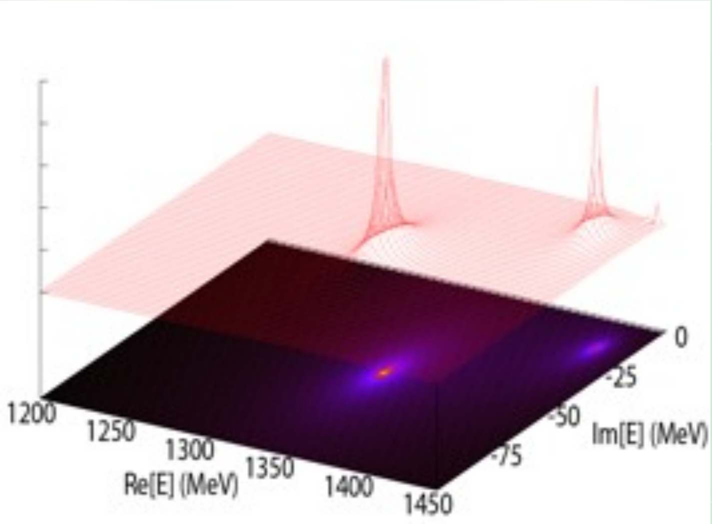
Two-pole structure for $\bar{K}NN$

Y. Ikeda, H. Kamano, T. Sato

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

“Chiral unitary like” model
: two poles in $\bar{K}N$-πΣ amplitude

Solving Faddeev equation, they find
two poles in **$\bar{K}NN$-πΣN amplitude**



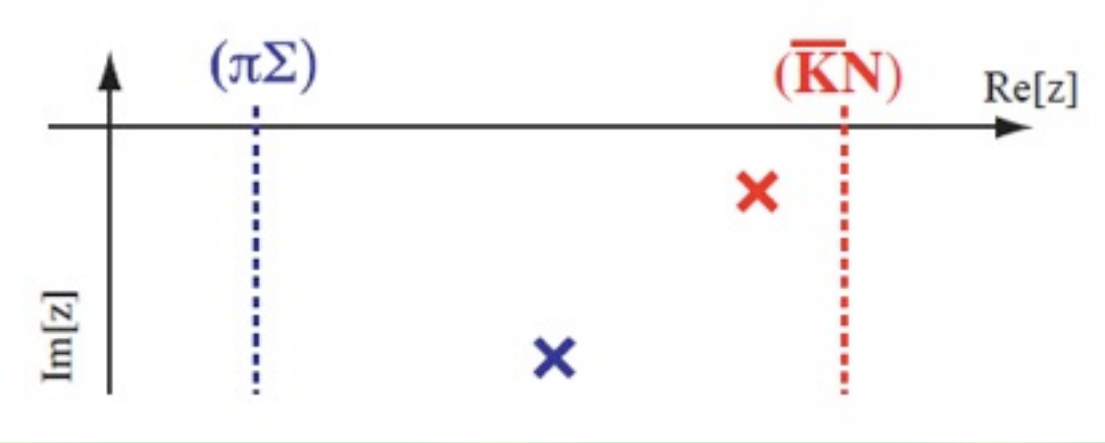
	pole I	pole II
$\bar{K}$- and N-exchanges in Z	$-14.5 - i28.7$	$-36.7 - i109.3$
$\bar{K}$-, N- and π-exchanges in Z	$-13.6 - i27.8$	$-45.8 - i104.0$
Full mechanism	$-13.7 - i29.0$	$-37.2 - i93.3$

--> Two poles for three-body system?

Two-pole structure for $\bar{K}NN$

Two poles in two-body scattering:

higher energy pole --> $\bar{K}N$ bound state
lower energy pole --> $\pi\Sigma$ resonance



If there are two poles in three-body system, "single-channel" approach of DHW focuses on the higher energy pole of $\bar{K}NN$, since the $\pi\Sigma N$ channel has been eliminated.

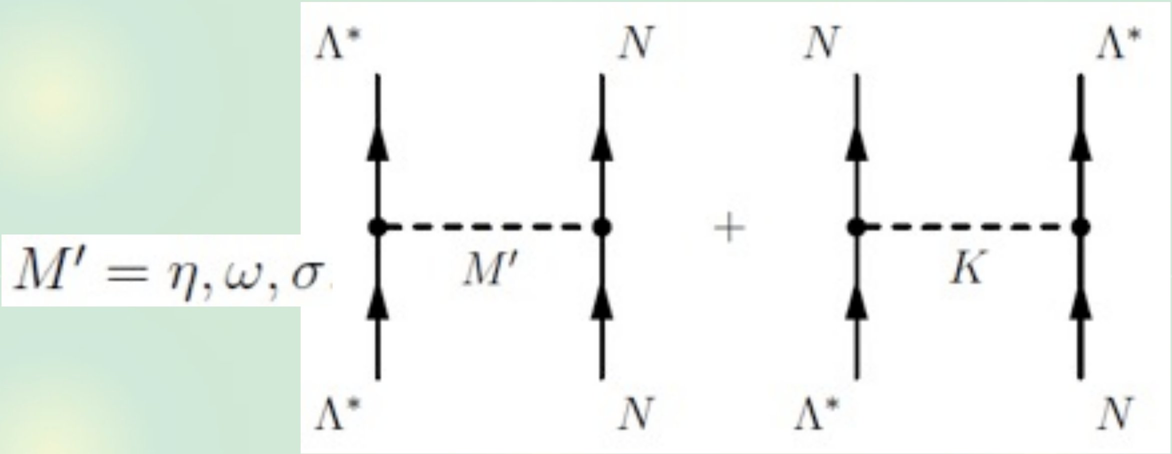
Then, where is the lower energy state in three-body system?

--> Schematic model calculation

Λ* hypernuclei model

Treating Λ(1405) as an elementary field,
construct "Λ*N potential" through meson exchange

A. Arai, M. Oka and S. Yasui, Prog. Theor. Phys. 119, 103 (2008)



This approach may be justified by the observation that the Λ* seems to be surviving in K-pp system.

Attractive interaction (mainly from σ exchange)
--> bound Λ*N, Λ*NN systems

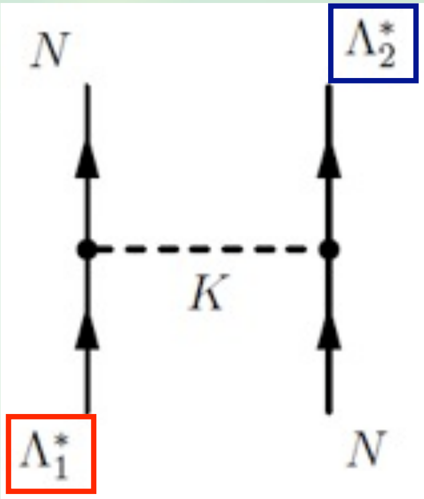
Λ* coupling constant : unknown (<-- FINUDA data).

Λ^*N state in chiral model

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

With sufficient attraction (σ exchange),
--> two Λ^*N bound states in B=2 system : Λ^*_1N, Λ^*_2N

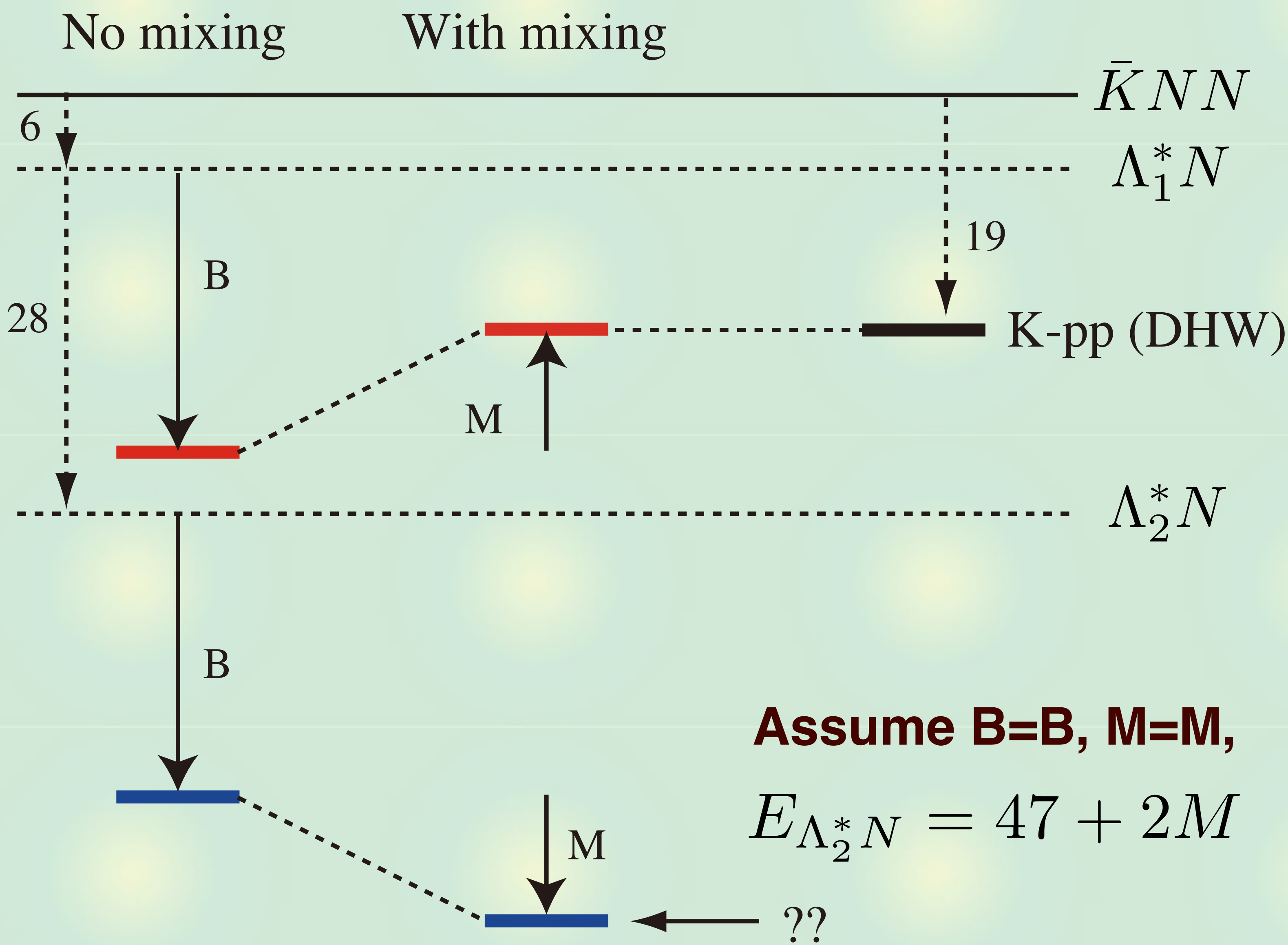
In addition, mixing of Λ^*_1N <--> Λ^*_2N : level repulsion



Λ^* coupling constant : unknown
We consider this model simulates the thee-body calculation
--> DHW result = Λ^*_1N

Estimation in a schematic model

Λ*N state in chiral model : result would be...



Assume B=B, M=M,

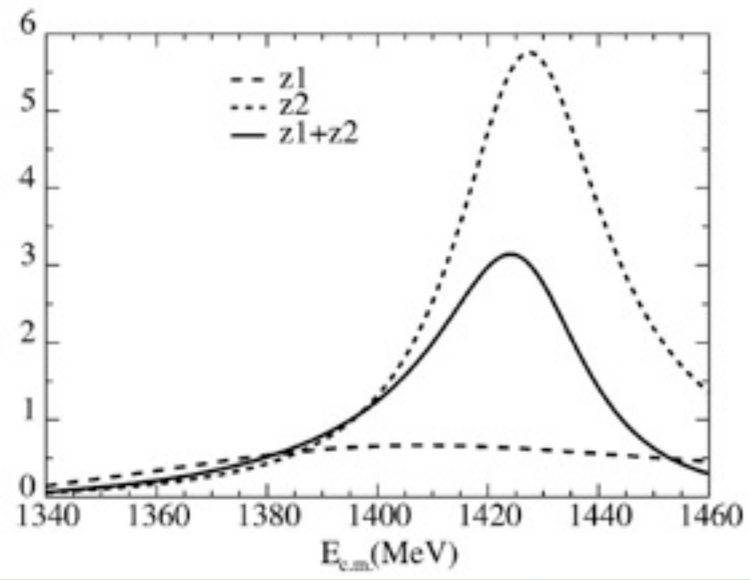
$$E_{\Lambda_2^* N} = 47 + 2M \quad [\mathrm{MeV}]$$

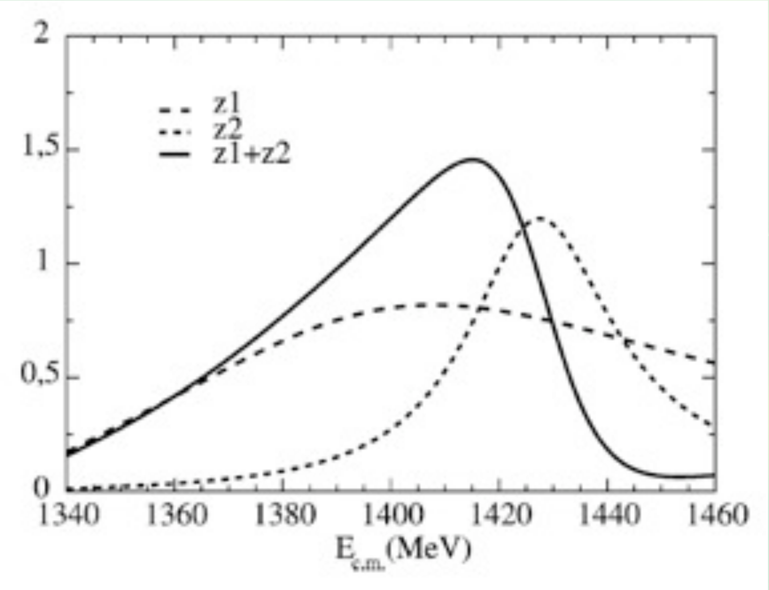
Λ*N state in chiral model

Chiral dynamics --> two Λ* states : Λ*₁, Λ*₂

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

$\bar{K}N$ πΣ





D. Jido, *et al*, Nucl. Phys. Rev. A725, 181 (2003)

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

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

Summary 2 : Coupled-channel approach

B=2 and S=-1 system in chiral dynamics

- Possibility of **two poles** for three-body $\bar{K}NN$ state in Faddeev approach.

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

- If this is the case, DHW result may corresponds to higher energy $\Lambda^*_1 N$ state.

  estimate of $\Lambda^*_2 N$ ~ 47 + 2M MeV?

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

- When the lower energy channel is strongly interacting, coupled-channel approach would be mandatory.