Effective $\bar{K}N$ interaction

based on chiral SU(3) dynamics

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Introduction : importance of chiral symmetry

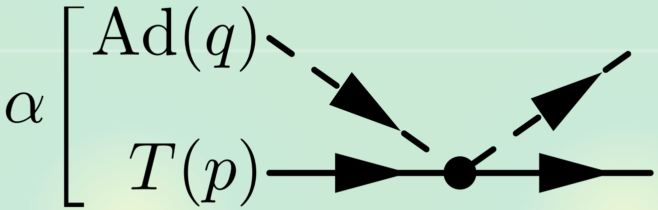
Chiral symmetry

- connects hadronic phenomena with underlying theory of QCD.
- dictates the low energy hadron-NG boson interaction (e.g. $\bar{K}N$ interaction).
- may give you a Nobel prize!

==> $\bar{K}N$ interaction in chiral SU(3) dynamics

Low energy theorem for s-wave interaction

Scattering of a target hadron (T) with the NG boson (Ad)



$$= \frac{1}{f^2}\frac{p\cdot q}{2M_T}\langle \boldsymbol{F}_T\cdot\boldsymbol{F}_{\mathrm{Ad}}\rangle_\alpha + \mathcal{O}\left(\left(\frac{m}{M_T}\right)^2\right)$$

s-wave : Weinberg-Tomozawa term

$$V_\alpha = -\frac{\omega}{2f^2}C_{\alpha,T}$$

$$C_{\alpha,T} \equiv -\langle 2\boldsymbol{F}_T\cdot\boldsymbol{F}_{\mathrm{Ad}}\rangle_\alpha = C_2(T) - C_2(\alpha) + 3 \quad (\text{for } N_f = 3)$$

coupling : pion decay constant
--> only flavor (group theoretical) structure is relevant
c.f. p-wave interaction ∈ axial charge g_A

The theorem well reproduces the πN scattering lengths

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

Chiral unitary approach

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

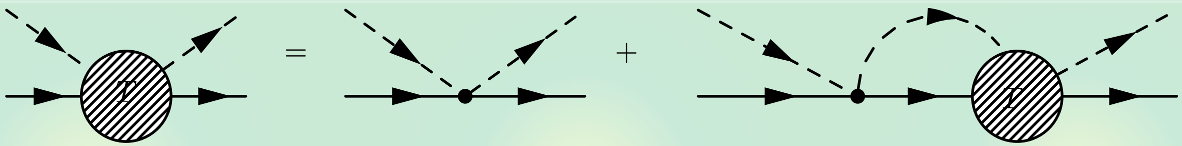
- **Interaction <-- chiral symmetry**

  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)

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

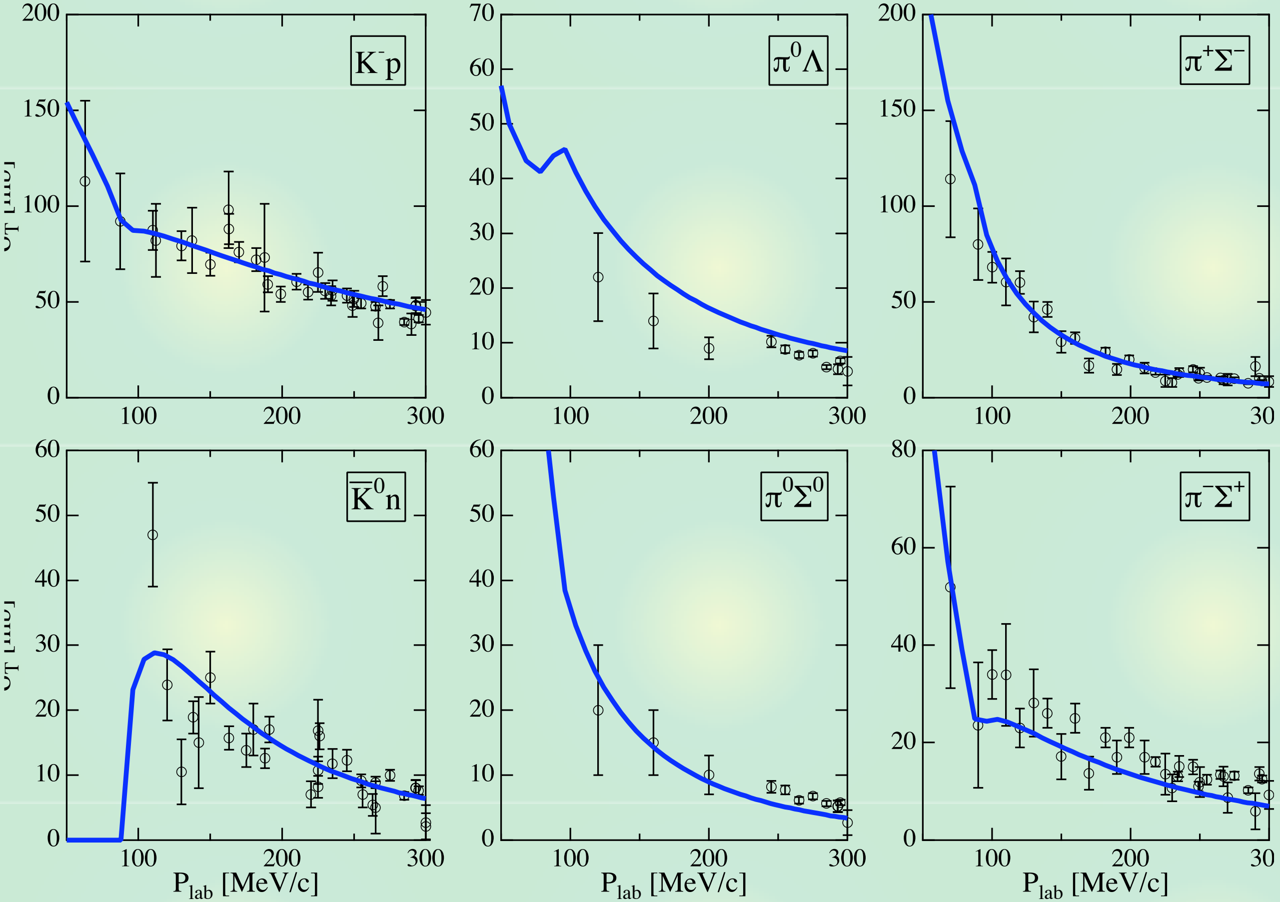


N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

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

How it works? vs experimental data

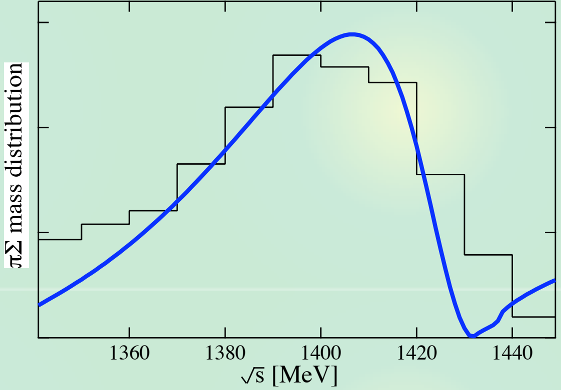
Total cross sections



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

Coupled-channel BS eq.
+ real valued interaction

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

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

few-body K-nuclei :
Doté-san's Talk

(exact transformation)

Single-channel BS eq.
+ complex interaction

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

$V^{\mathrm{eff}}(\sqrt{s})$

(with approximation)

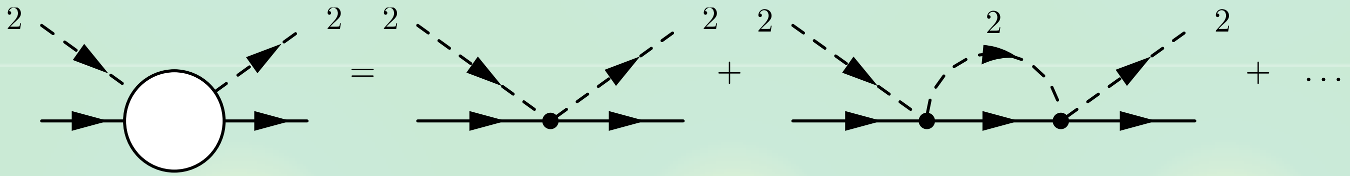
Schrödinger equation
+ local, complex, and
energy-dependent potential

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

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

Construction of the single channel interaction

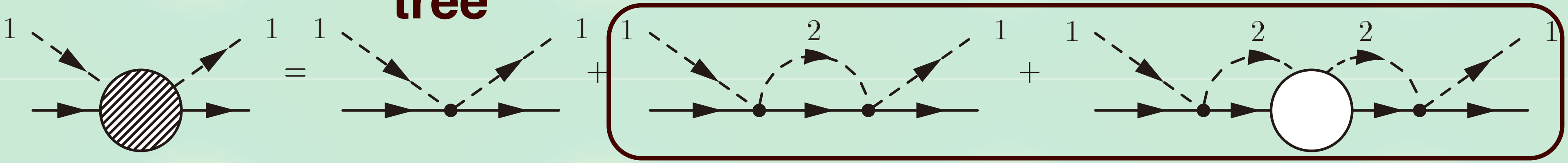
Channels 1 and 2 --> effective interaction in channel 1



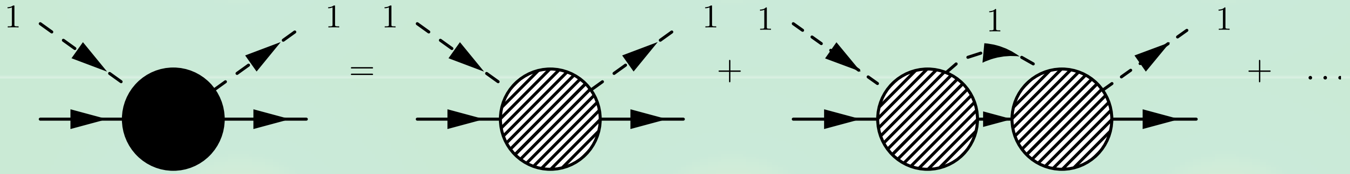
$$T_{22}^{\text{single}} = V_{22} + V_{22}G_2T_{22}^{\text{single}}$$

tree

effect of channel 2



$$V^{\text{eff}} = V_{11} + V_{12}G_2V_{21} + V_{12}G_2T_{22}^{\text{single}}G_2V_{21}$$

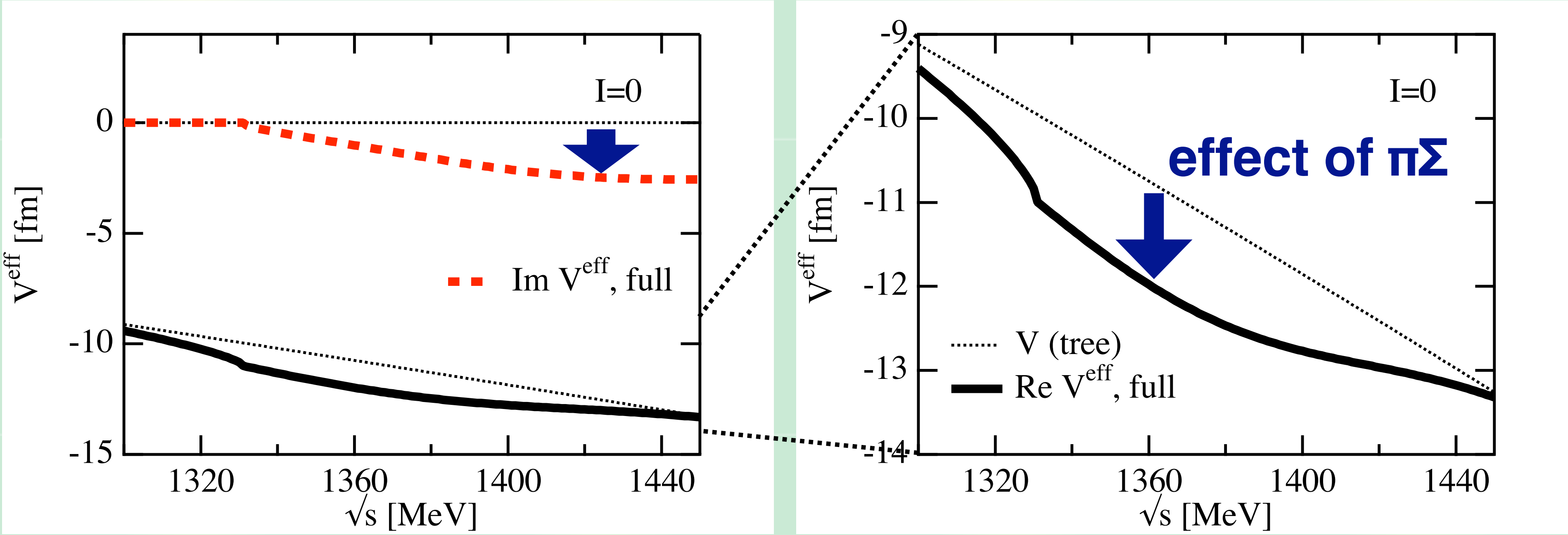


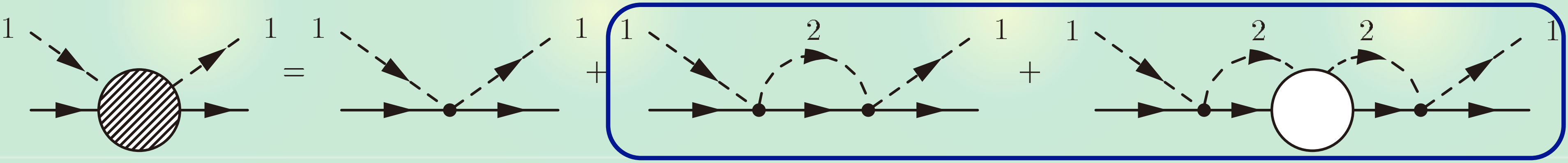
single channel

$$T_{11} = T^{\text{eff}} = V^{\text{eff}} + V^{\text{eff}}G_1T^{\text{eff}}$$

Equivalent to solving the coupled-channel equations

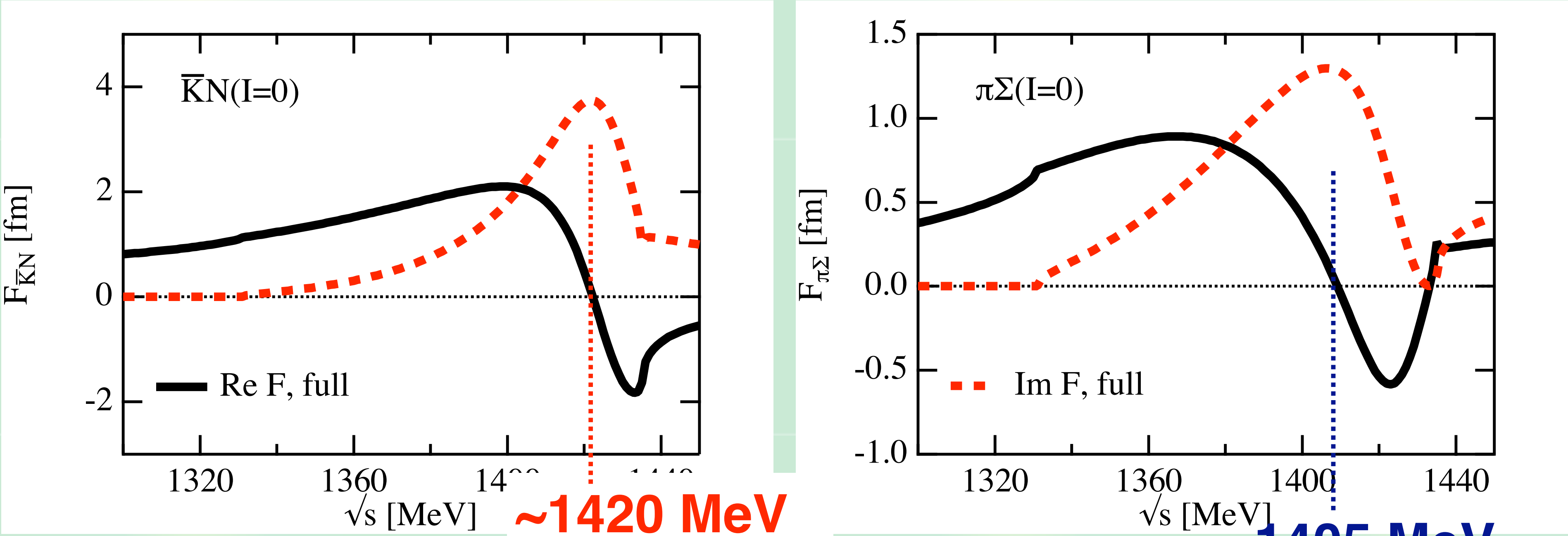
Single channel $\bar{K}N$ interaction with πΣ dynamics





- imaginary part <-- πΣ channel
- strength : not changed from the tree-level WT term
  ~1/2 of phenomenological (AY) potential

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



~1420 MeV (not a direct observable)

~1405 MeV (Experiment)

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

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

A note on the πΣ spectrum

Experimental spectrum has both signal and background (BG) components.

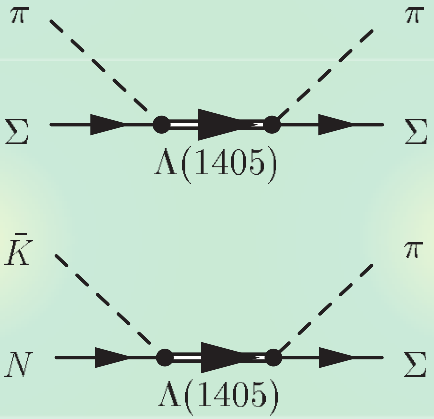
==> interference between signal and BG

To obtain pure I=0 component, all three charged states must be measured simultaneously (so far not yet done).

==> interference with other isospin components

To establish/exclude the existence of two poles, one has to study more than one reactions.

==> superposition of two amplitude
: relative weight in initial state
(initial state interaction is model dependent)



Why two poles? What is the difference?

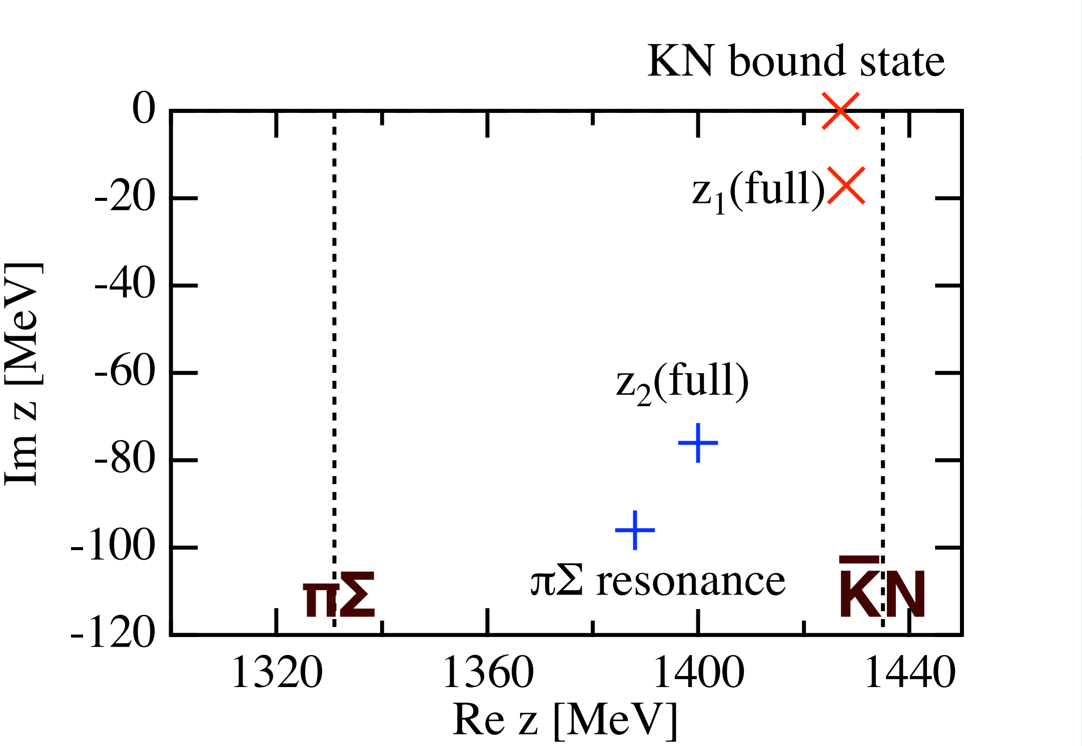
Origin of the two-pole structure

Chiral interaction

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

$$C_{ij} = \begin{array}{cc} \bar{K}N & \pi\Sigma \\ \left(\begin{array}{c} 3 \\ -\sqrt{\frac{3}{2}} \end{array}\right. & \left.\begin{array}{c} -\sqrt{\frac{3}{2}} \\ 4 \end{array}\right) \end{array}$$

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



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)

Comparison with phenomenological potential

Chiral interaction

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

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

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

$$C_{ij} = \left(\begin{array}{cc} 3 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & \boxed{4} \end{array}\right)$$

Phenomenological

Y. Akaishi, T. Yamazaki
Phys. Rev. C65, 044005 (2002)

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

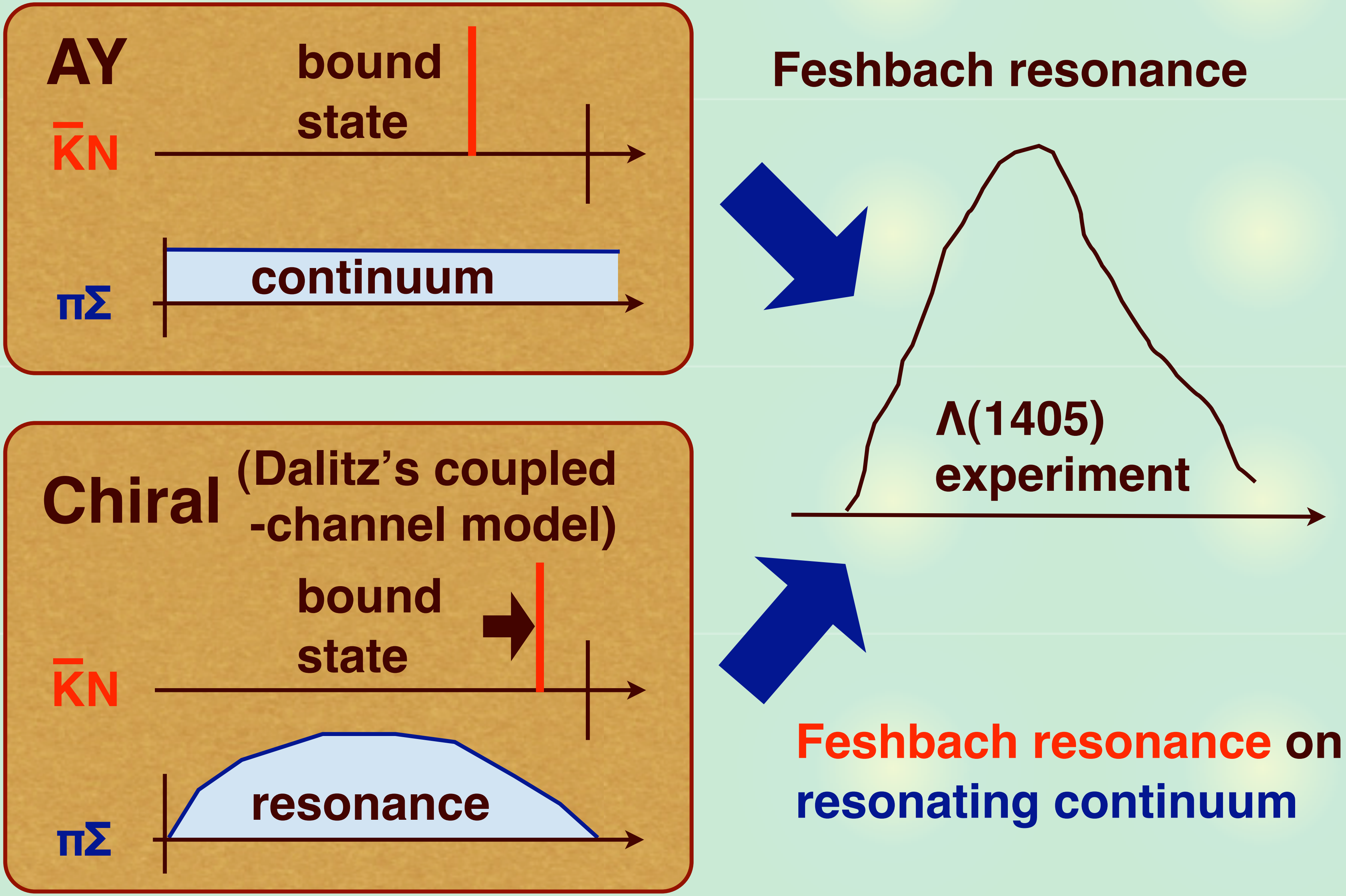
$$v_{ij}(r) \sim -\begin{pmatrix} 436 & 412 \\ 412 & \boxed{0} \end{pmatrix} g(r)$$

Absence of πΣ diagonal coupling
--> strong (×2) attractive interaction in $\bar{K}$N

πΣ -> πΣ attraction : required by flavor SU(3) symmetry
- same feature in Dalitz's coupled-channel model

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

Schematic illustration : AY vs Chiral



AY

$\bar{K}N$ bound state

$\pi\Sigma$ continuum

Chiral (Dalitz's coupled -channel model)

$\bar{K}N$ bound state

$\pi\Sigma$ resonance

Feshbach resonance

Λ(1405) experiment

Feshbach resonance on resonating continuum

Three-body calculation, DISTO result

Variational calculation for the K-pp system

Single-channel chiral $\bar{K}N$ potential + realistic NN potential

πΣN channel is eliminated

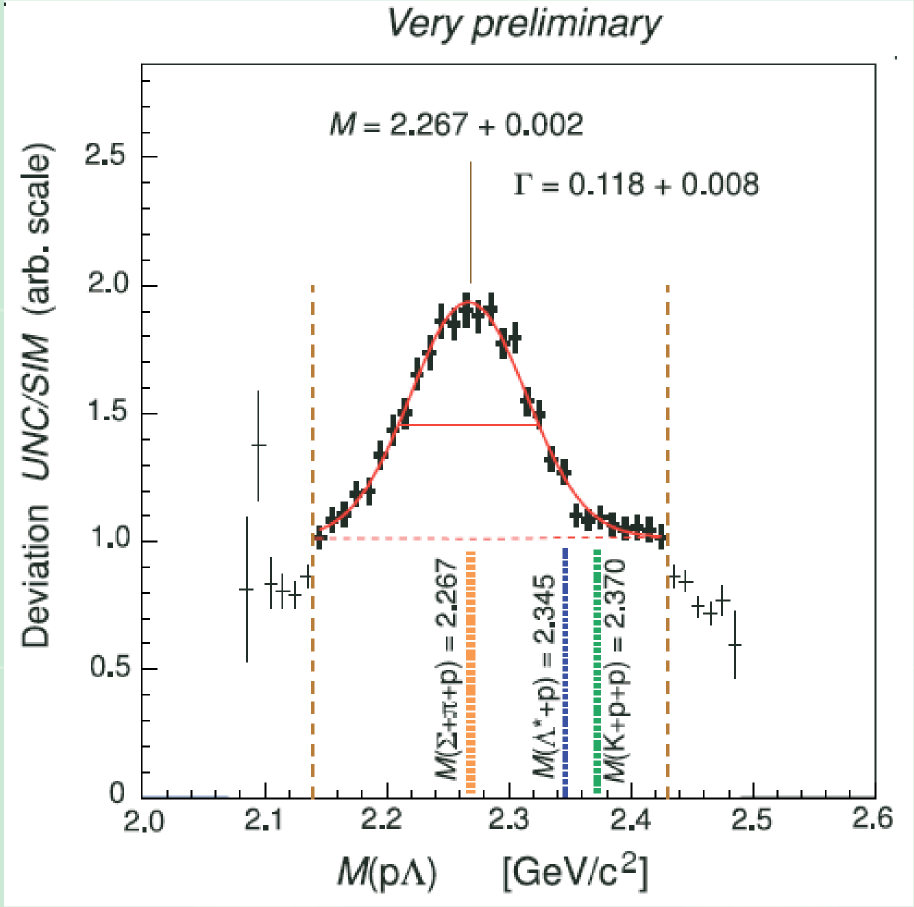
B.E. = 20 ± 3 MeV
Γ(πYN) = 40 ~ 70 MeV

inconsistent with DISTO data?

yes, if the peak is dominated by the $\bar{K}NN$ component

peak on top of πΣN th.
chiral s-wave interaction
--> Strong πΣ attraction

T. Yamazaki *et al*, arXiv:0810.5182 [nucl-ex]



Important role of πΣN component ?

Summary : $\bar{K}N$ 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 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);
arXiv: 0806.4917 [nucl-th], Phys. Rev. C, in press

Conservative conclusion

- Both AY/chiral potentials reproduce existing experimental data, but have different subthreshold behavior.
  => Present experimental database is not sufficient to constrain the $\bar{K}N$ interaction at (far) below threshold.
- So we need accurate data of
  - $\bar{K}N$ scattering lengths,
  - Spectrum of $\pi\Sigma$ (in different reactions, different channels, ...) ...