# Kaon-nucleon dynamics and role of chiral symmetry

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# Kaon in nuclear and hadron physics

## Strange quark conveyer

$$K^+ \sim u\bar{s}, \quad K^0 \sim d\bar{s}, \quad \bar{K}^0 \sim \bar{d}s, \quad K^- \sim \bar{u}s,$$

Impurity in nuclear (ud-quark) systems
Kaon condensation, CFL phase, ... --> astrophysics

## Kaon-Nucleon interaction, kaons in nuclei

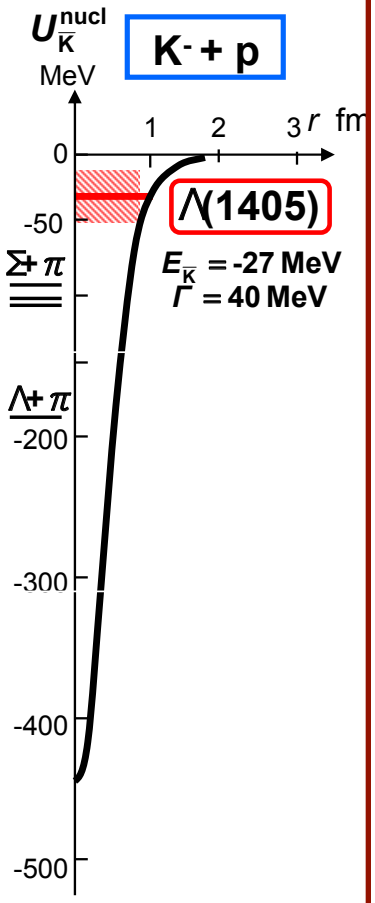
Λ(1405) quasi-bound state below $\bar{K}$N threshold
--> $\bar{K}$N(I=0) interaction is strongly attractive.
Deeply bound **kaonic nuclei** --> High density?

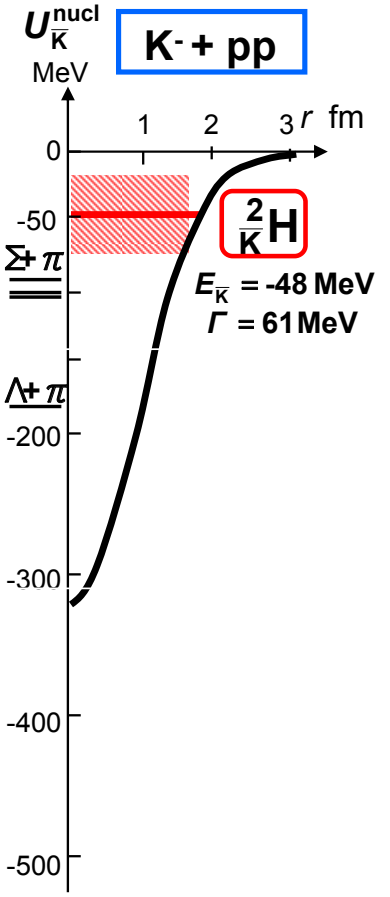
## Pseudoscalar meson : Flavor partner of π

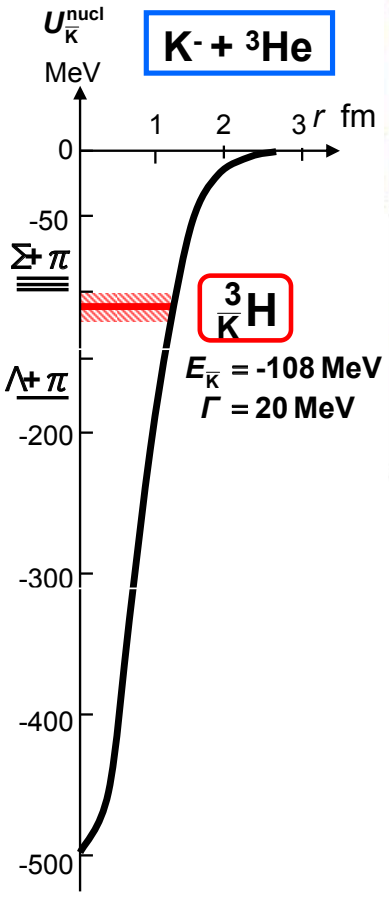
Nambu-Goldstone boson of **chiral symmetry** breaking

# Deeply bound kaonic nuclei

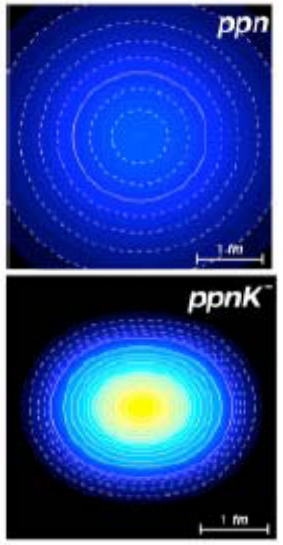
## $\bar{K}N$ potential




A. Dote et al.

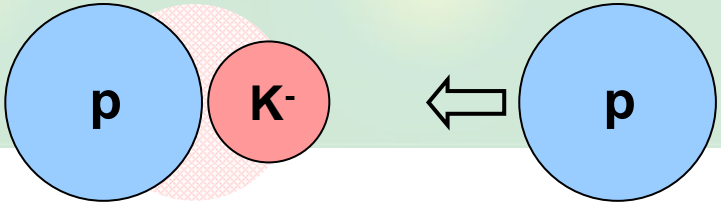


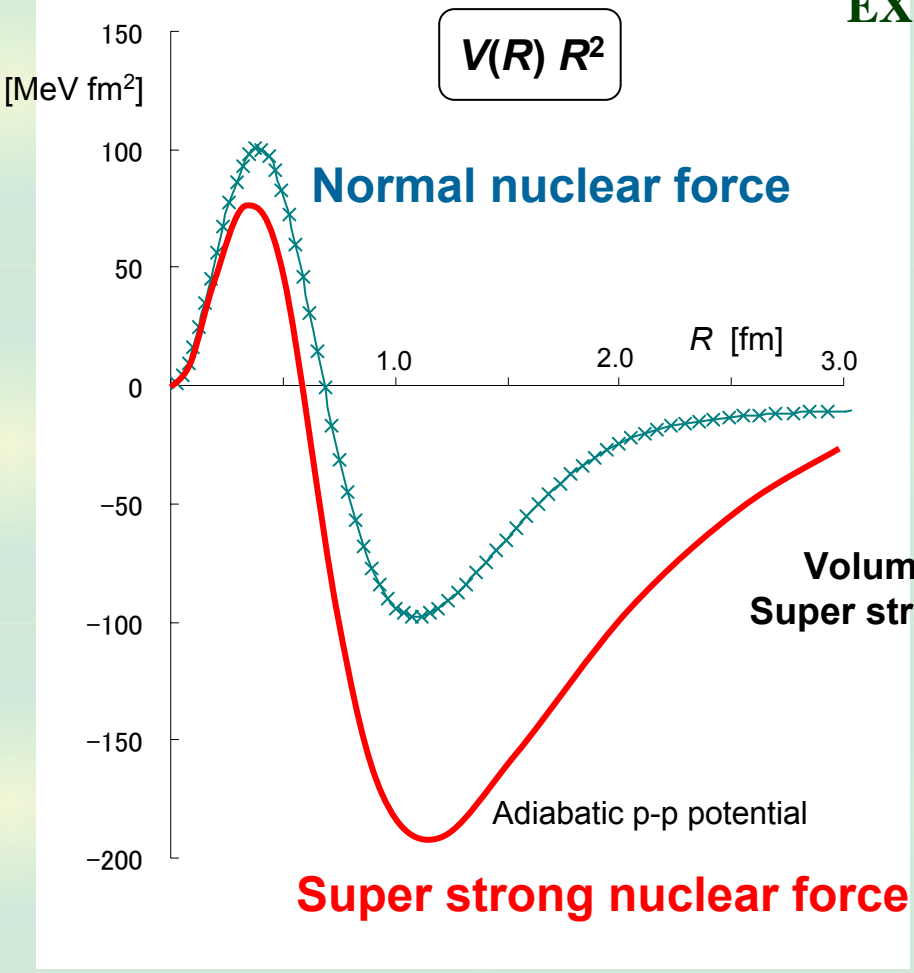

Shrinkage!

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

Y. Akaishi
EXA08

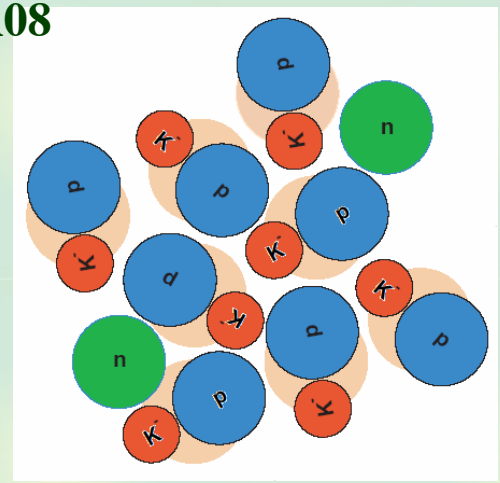
# Adiabatic p-p potential in K-pp



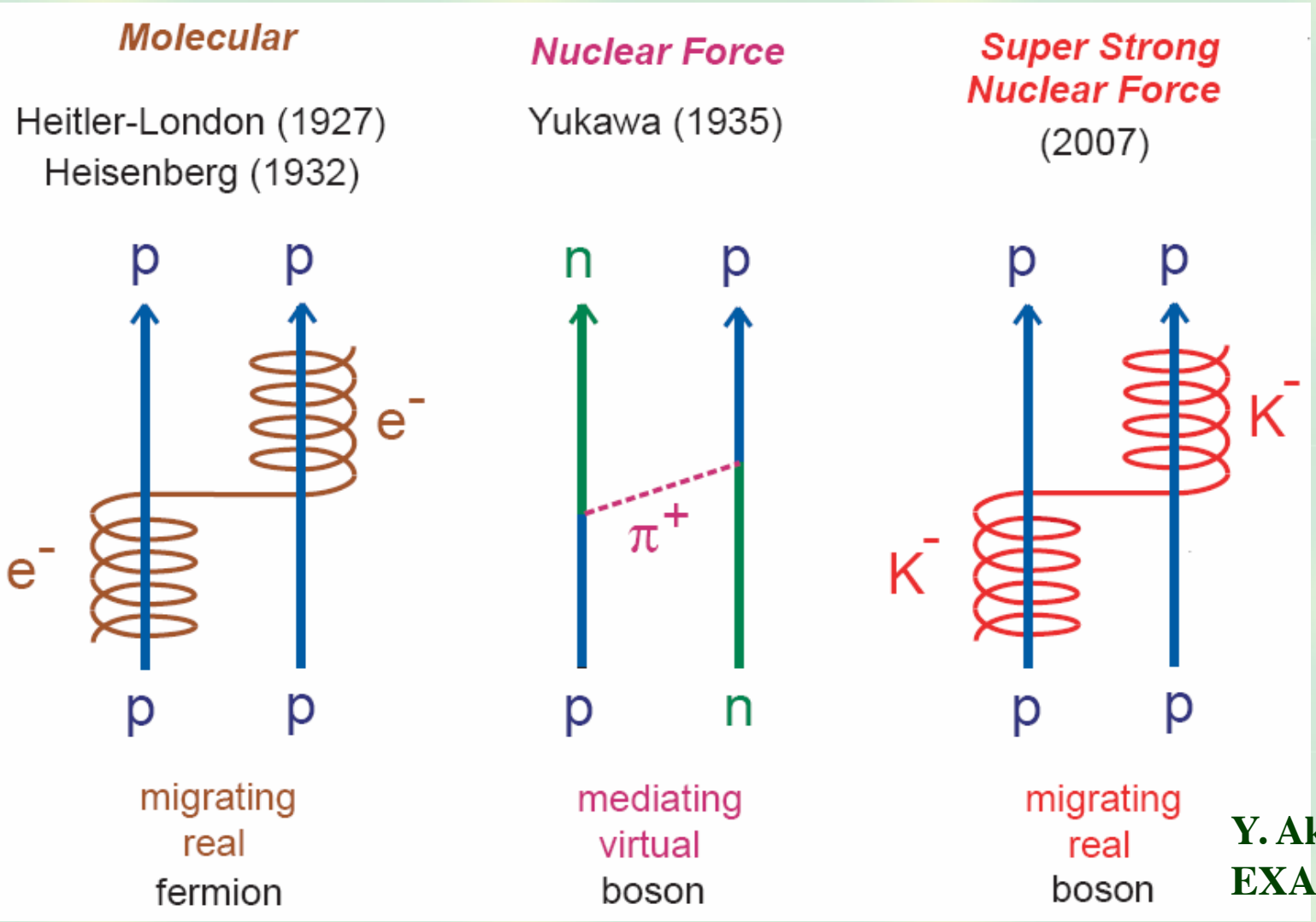

Super strong nuclear force

Y. Akaishi
EXA08



Volume integral ratio
Super strong / Normal ~ 4.1

# Deeply bound (few-body) kaonic nuclei




T. Yamazaki & Y. Akaishi,
Proc. Japan Academy, B 83 (2007) 144

# 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

# Chiral unitary approach

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

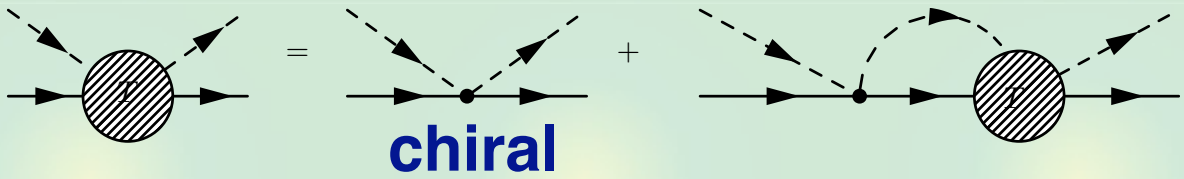
- Interaction <-- chiral symmetry

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)

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

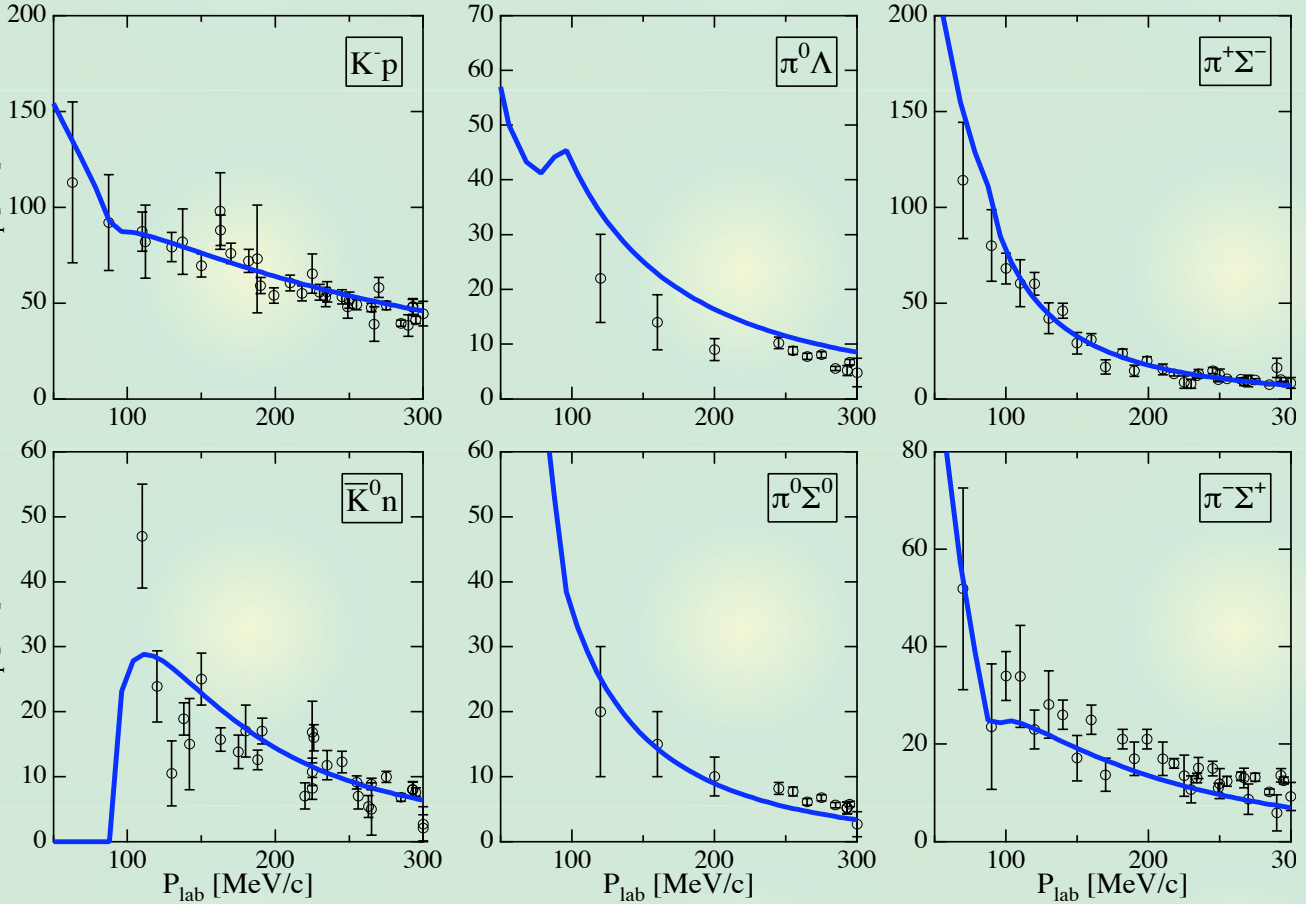



N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

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

# How it works? vs experimental data

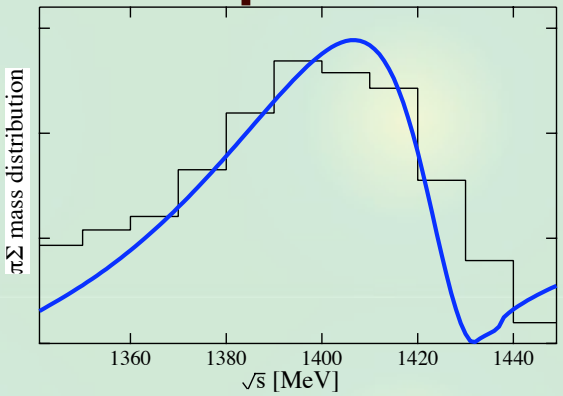
## Total cross sections




## 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

**Few-body kaonic nuclei in chiral dynamics**

**- single-channel $\bar{K}N$ potential**

**Construction of effective single-channel potential**

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

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

**2) Local potential in Schrödinger equation (approximate)**

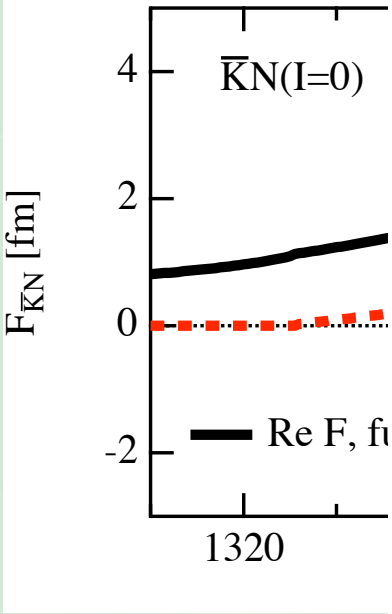
**--> $\bar{K}N$ interaction : attractive, but weaker than the phenomenological potential.**

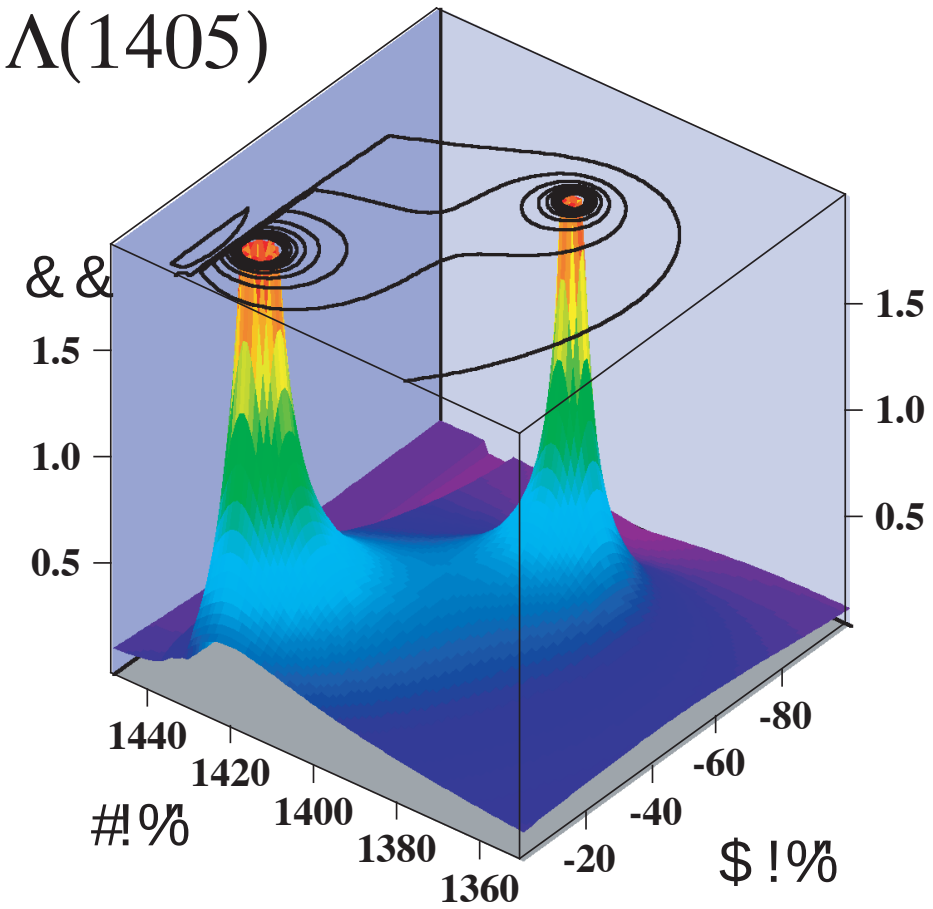
**Application to K-pp system : bound, but B ~ 20 MeV**

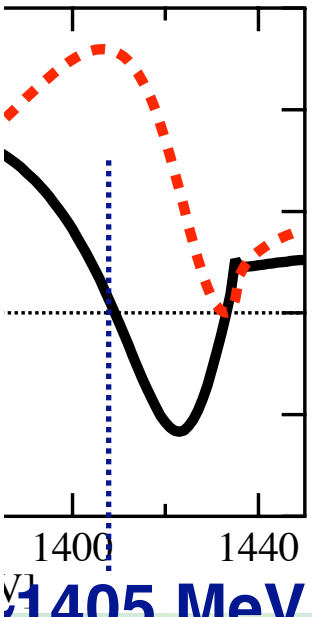
A. Doté, T. Hyodo and W. Weise,
Nucl. Phys. A 804, 197 (2008); Phys. Rev. C 79, 014003 (2009)

**Why the interaction is weaker? --> structure of the $\Lambda(1405)$**

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




1405 MeV

**Resonance**

**<-- strong πΣ**

**Binding ene**

**Two poles with same quantum numbers**

**Different weights of the pole residues --> different spectra**

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

# Origin of the two-pole structure

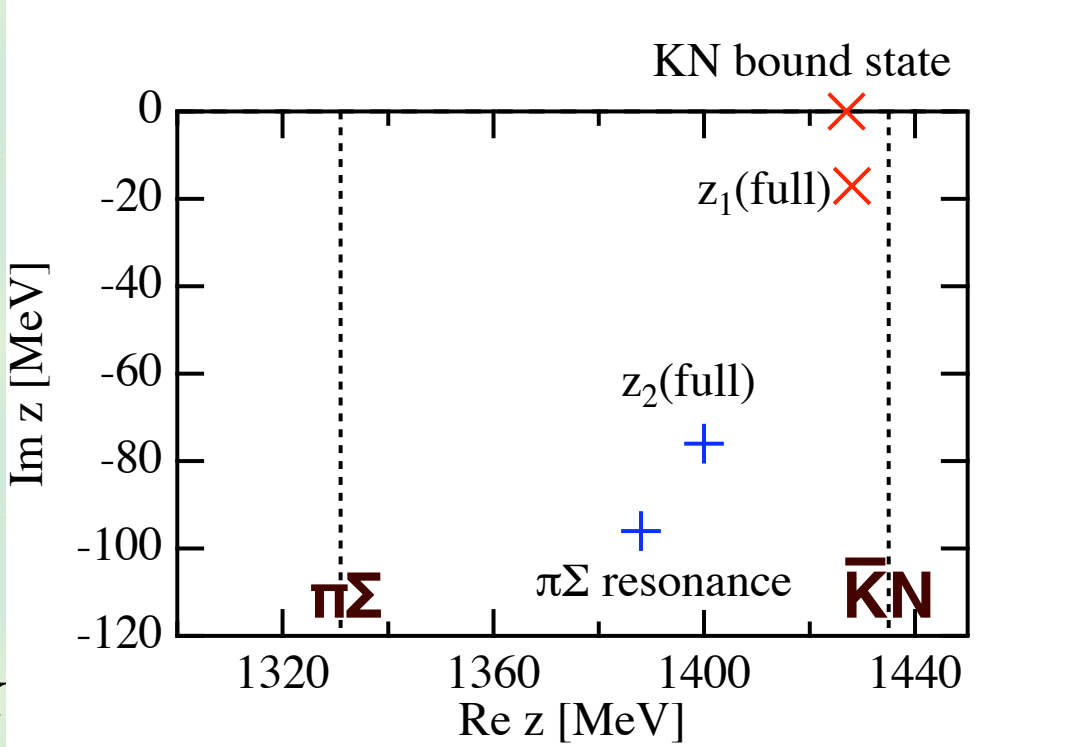
## Chiral interaction

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

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

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

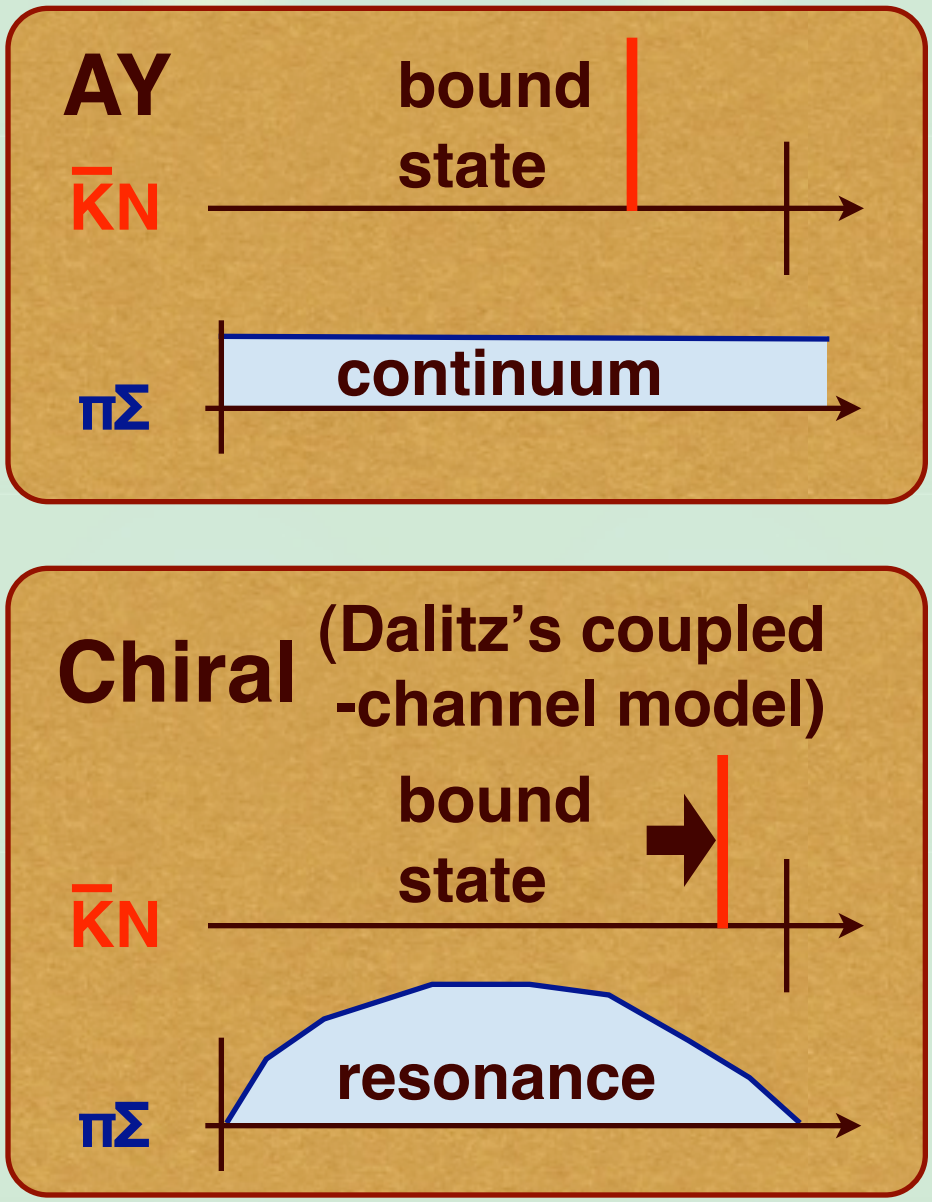
$$\omega_i \sim m_i, \quad 3.3m_\pi \sim m_K$$



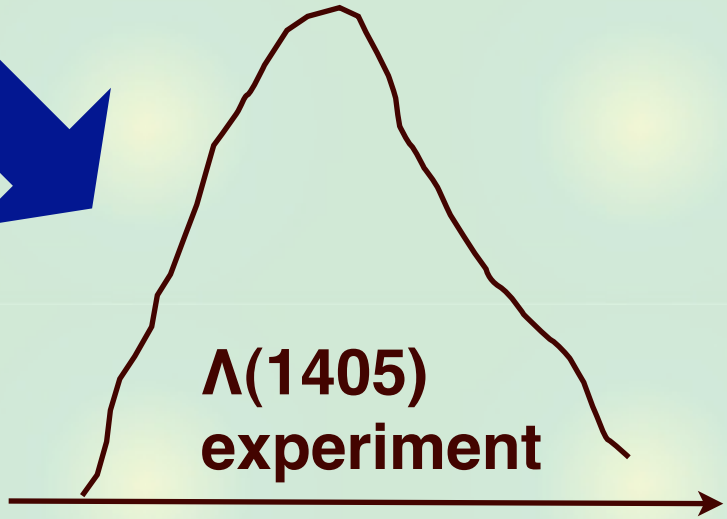

**Very strong attraction in $\bar{K}N$ (higher energy) --> bound state**
**Strong attraction in $\pi\Sigma$ (lower energy) --> resonance**

**Two attractive interactions --> Two states**
**$\pi\Sigma$ -> $\pi\Sigma$ attraction : chiral SU(3) symmetry**

# Schematic illustration : AY vs Chiral

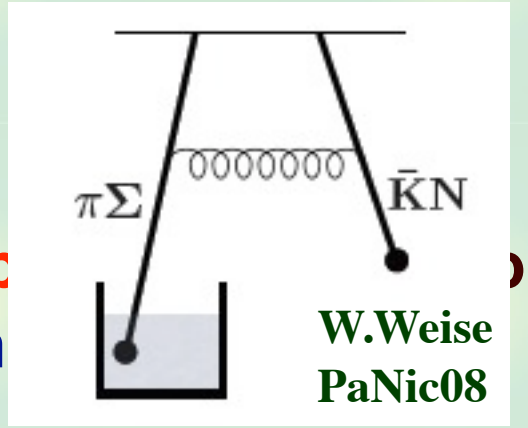



Feshbach resonance




Feshb…on

reson…



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

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

- Single-channel effective $\bar{K}N$ interaction is attractive and forms K-pp bound system.
- 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
- For deep binding region, $\pi\Sigma$ dynamics would play an important role.

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