Λ*N bound state based on chiral dynamics

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$\bar{K}$ in nuclei

- $\bar{K}N$ interaction is strongly attractive <-- Λ(1405).
  Formation of (deeply) bound kaonic nuclei?
  Y. Akaishi, T. Yamazaki, Phys. Rev. C65, 044005 (2002)
- Structure of the Λ(1405), kaon condensation, ...

The simplest $\bar{K}$-nucleus: $\bar{K}NN$ three-body system

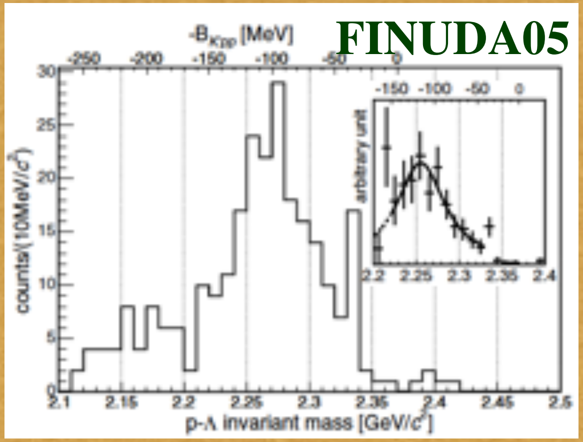
Theory: rigorous few-body calculations with realistic interactions

Yamazaki-Akaishi, Shevchenko, et al., Ikeda-Sato, Doté et al., Wycech-Green,

- System **bounds**
- Quantitative **difference**: uncertainties in $\bar{K}N$ int. at far below threshold

Experiment: some "evidences" in ΛN mass spectra

FINUDA, DISTO, OBELIX, etc.

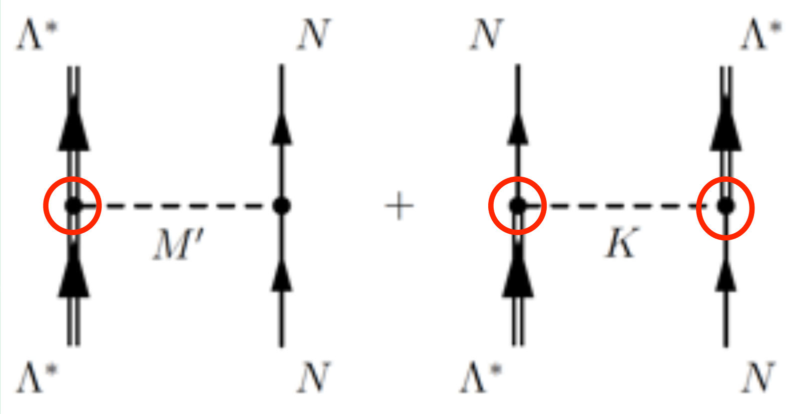


- **Interpretation** (πΣN?FSI?)

Λ* hypernuclei model

Regarding a $\bar{K}N(I=0)$ pair as the Λ*=Λ(1405), construct the "Λ*N potential" with the meson-exchange picture

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



<== Λ* structure seems to be surviving in $\bar{K}NN$ system.

T. Yamazaki, Y. Akaishi, Phys. Rev. C76, 045201 (2007),
A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A 804, 197 (2008); Phys. Rev. C 79, 014003 (2009)

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

To determine the coupling and make predictions, we need a framework to describe the Λ* <-- chiral unitary approach

Chiral unitary approach

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

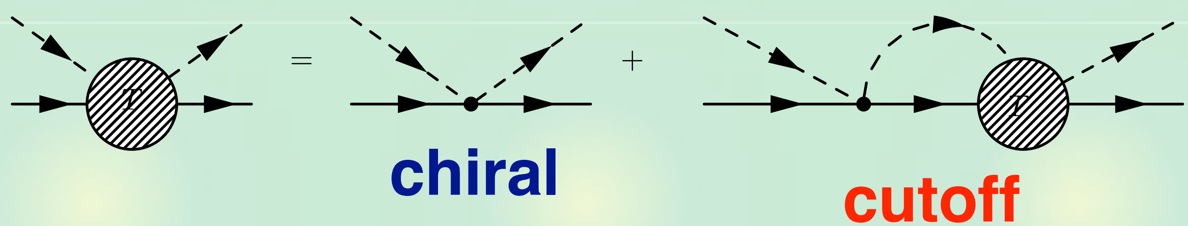
- Interaction <-- chiral symmetry

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

- Amplitude <-- unitarity in coupled channels

  R.H. Dalitz, T.C. Wong, G. Rajasekaran, Phys. Rev. 153, 1617 (1967)

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

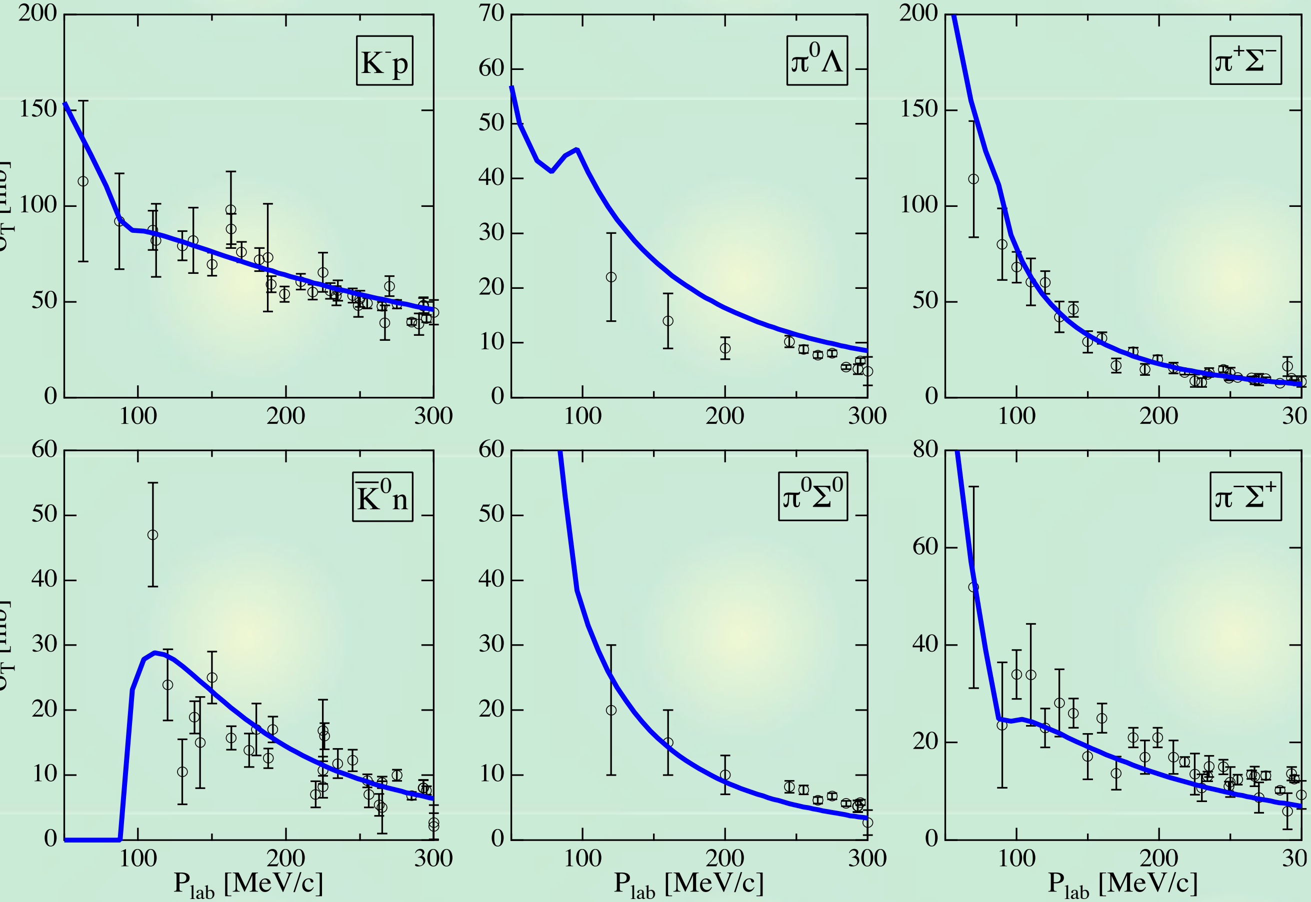


N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002), ... many others

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

$\bar{K}N$ scattering : comparison with data

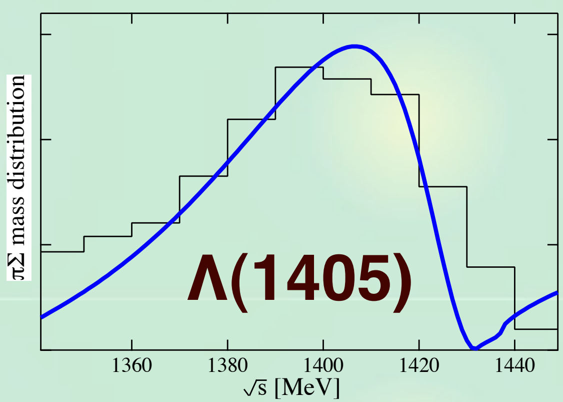
Total cross section of K-p scattering



Branching ratio

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

πΣ spectrum



<u>T. Hyodo, S.I. Nam, D. Jido, A. Hosaka, PRC68, 018201 (2003); PTP 112, 73 (2004)</u>

Good agreement with data above, at, and below $\bar{K}N$ threshold

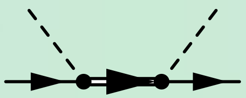
Λ(1405) mass, width, couplings: prediction of the model

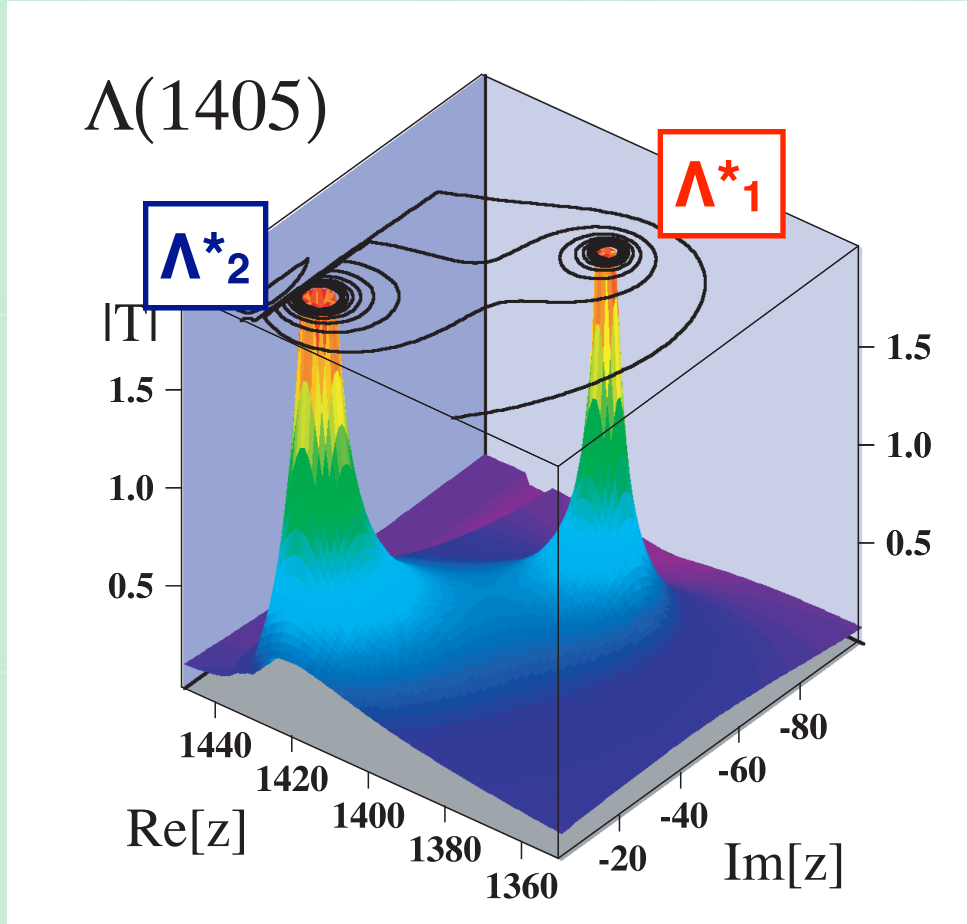
Two poles for one resonance

Poles of the amplitude in the complex plane: resonance

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)

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

$\sim$ 



Physical Λ* include two poles

$\bar{K}N$ bound state

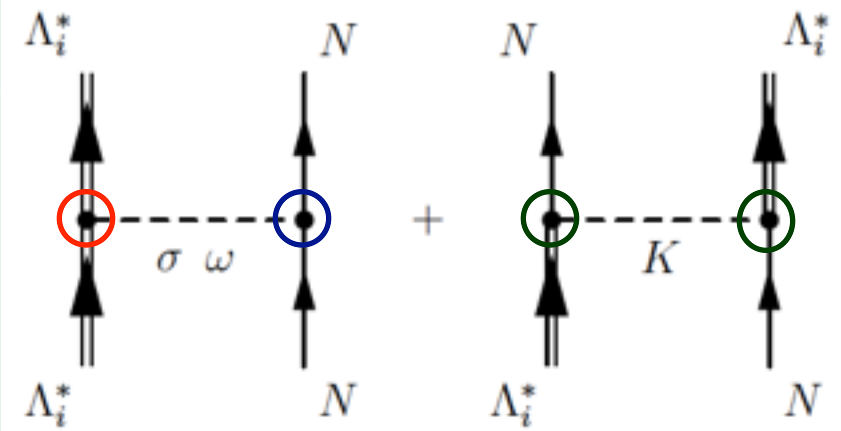
+ πΣ resonance

short summary
- Λ(1405): Λ^*_1, Λ^*_2
- Λ^*_i masses, widths, Λ^*_i-MB couplings predicted

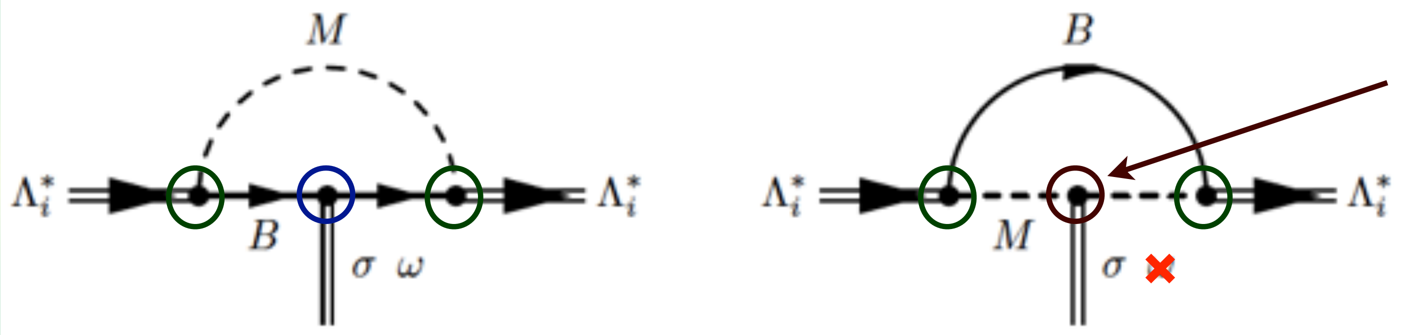
--> Λ* hypernuclei based on chiral dynamics

Λ*N potential with meson-exchange picture

$\Lambda^*_i N$ potential with one boson exchange (i=1,2)



- ○ NNσ, NNω couplings: Jülich (model A) YN potential
- ○ $\Lambda^*_i KN$ coupling: chiral unitary approach (pole residue)
- ○ $\Lambda^*_i\Lambda^*_i\sigma$, $\Lambda^*_i\Lambda^*_i\omega$, couplings
  --> estimated by microscopic MB=($\bar{K}N$,πΣ) couplings



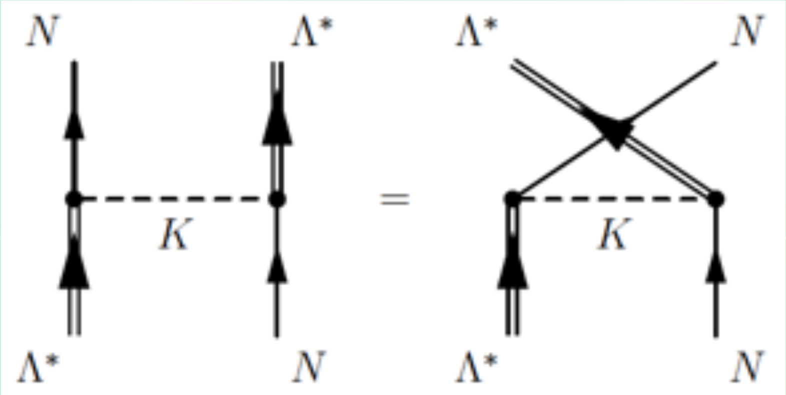
σ decay to ππ
$g_{K K \sigma} = 0$

Λ*N potential: K exchange

Λ*KN vertex: scalar type ($\Lambda^*=1/2^-$) --> attractive interaction

$$\mathcal{H}_{\Lambda^* NK} = g_{\Lambda^* NK}(\bar{\Lambda}^* \bar{K} N + \bar{N} K \Lambda^*)$$

Exchange factor



$$-\mathcal{P}_x \frac{1+\vec{\sigma}_{\Lambda^*}\cdot\vec{\sigma}_N}{2}$$

spin dependence
(P_x=1 for s-wave)

In total, S=0 (σσ=-3) attractive, S=1 (σσ=1) repulsive.

Mass difference of Λ* and N
--> effective K mass

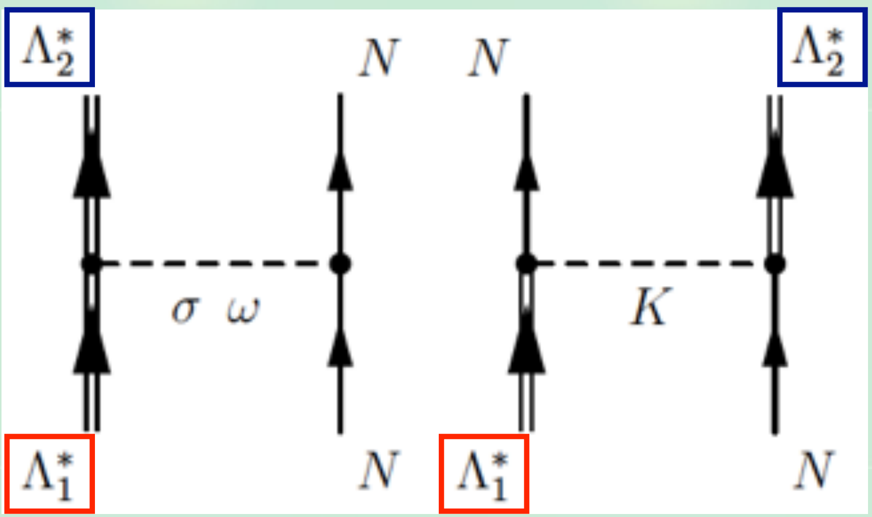
$$\tilde{m}_K = \sqrt{m_K^2 - (M_{\Lambda^*} - M_N)^2}$$

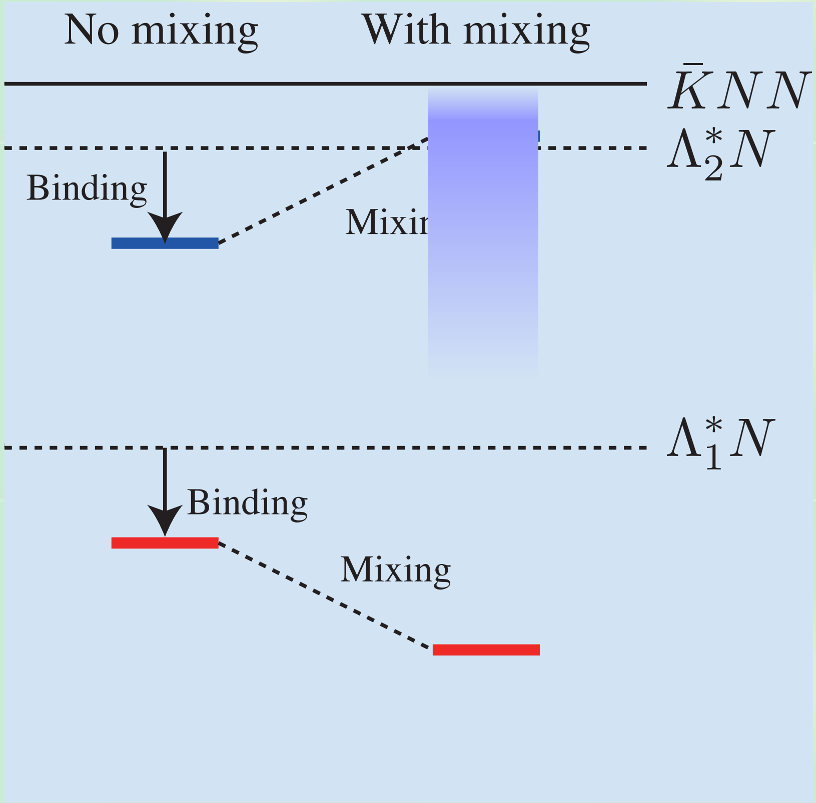
A. Arai, M. Oka, S. Yasui, Prog. Theor. Phys. 119, 103 (2008)

Λ*N potential: mixing interaction

Chiral unitary approach --> two Λ* states : Λ^*_1, Λ^*_2
With sufficient attraction,
two Λ*N bound states in B=2 system : $\Lambda^*_1 N$, $\Lambda^*_2 N$

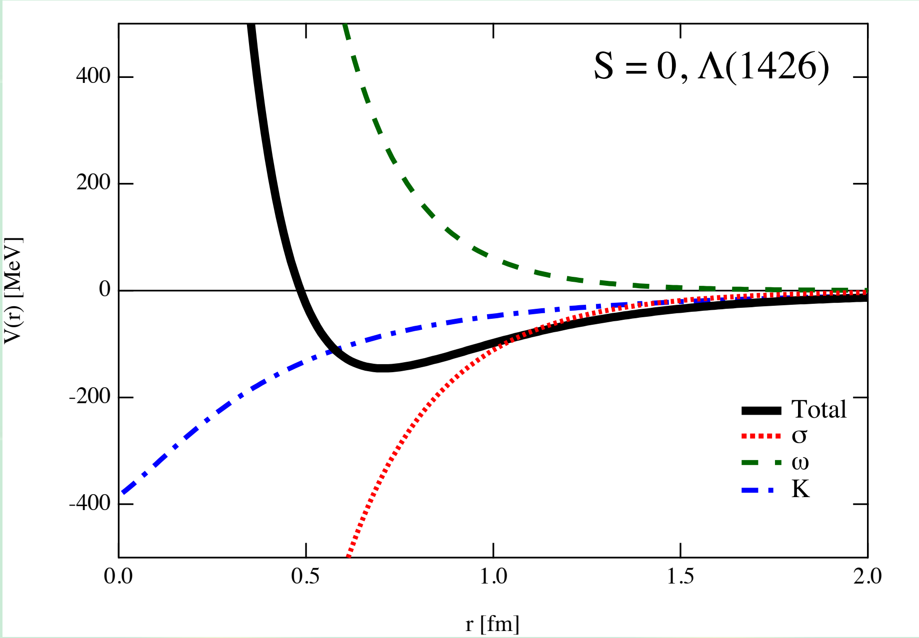
There can be the mixing of $\Lambda^*_1 N$ <--> $\Lambda^*_2 N$

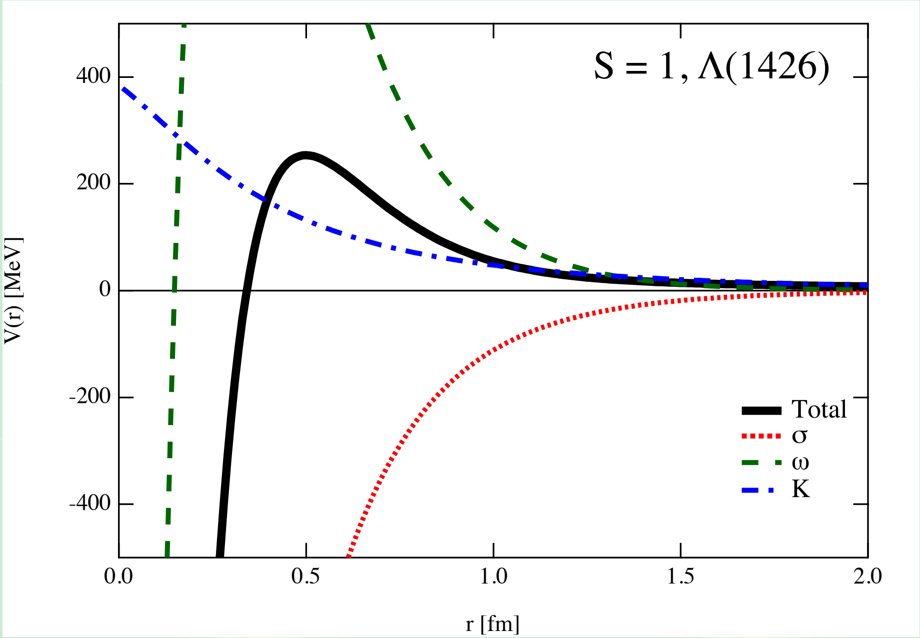




Λ*N potential: each contribution

Diagonal potentials for Λ^*_2N in S=0 and S=1, s-wave





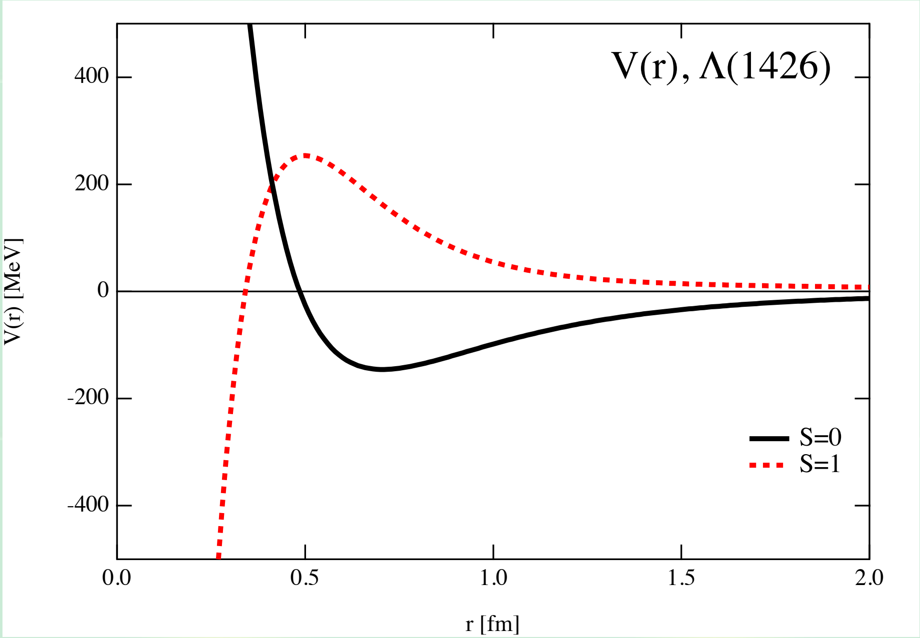
S=0: attractive pocket at intermediate range
<-- K exchange is attractive

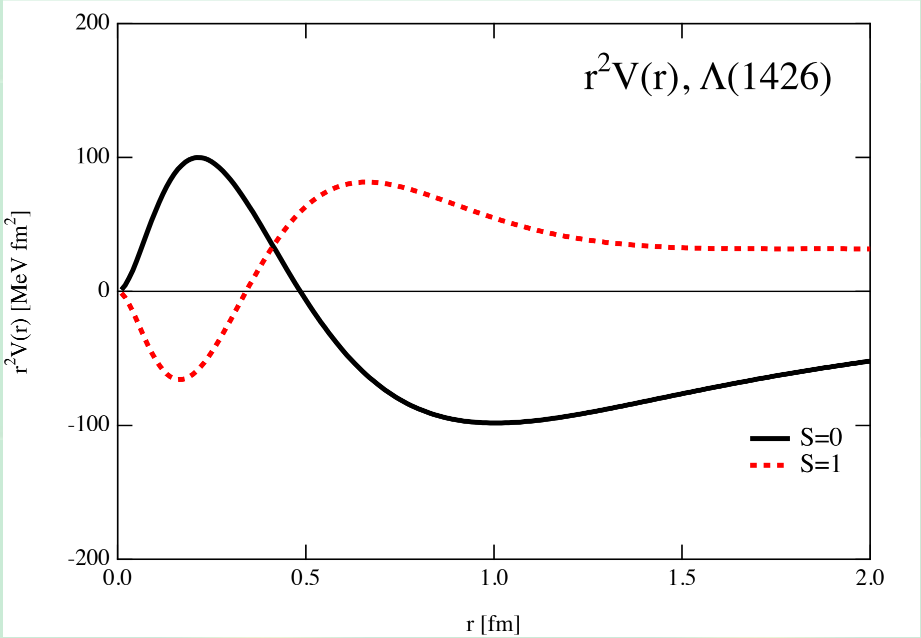
S=1: no intermediate attraction, but a short range dip
<-- K exchange is repulsive

Qualitatively similar potential for Λ^*_1N

Λ*N potential: volume integral

V(r) and $r^2V(r)$ for Λ^*_2N in S=0 and S=1





$$V(p=0) = \int d^3r V(r) = 4\pi \int_0^\infty dr\ r^2 V(r)$$

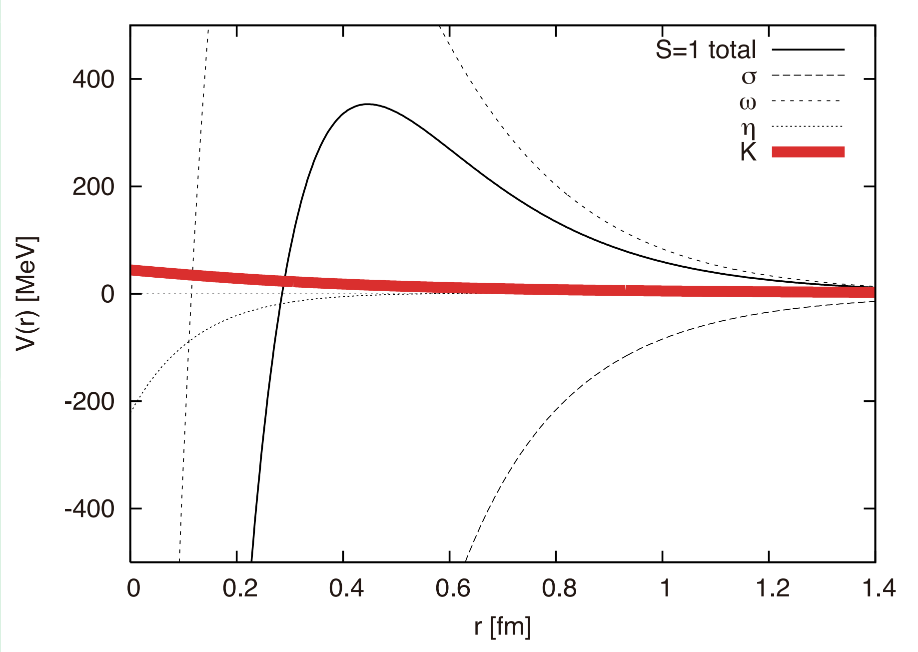
S=0: attractive pocket at intermediate range
--> volume integral is negative (attractive interaction)

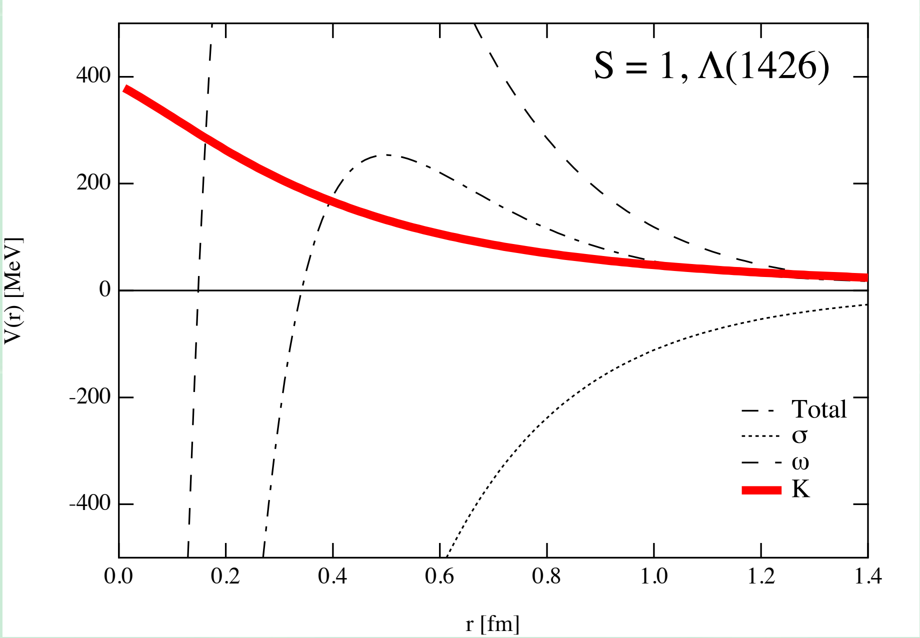
S=1: no intermediate attraction, but a short range dip
--> volume integral is positive (repulsive interaction)

Strength of K exchange

Comparison of K exchange term with the previous work

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





Coupling: decay of Λ* -> πΣ, Λ*=singlet, and flavor SU(3) symmetry

$$g^2_{\Lambda^* NK}/4\pi = 0.064$$

Coupling: residue of the pole of the generated resonance

$$g^2_{\Lambda^*_1 NK}/4\pi = 0.351, \quad g^2_{\Lambda^*_1 NK}/4\pi = 0.580$$

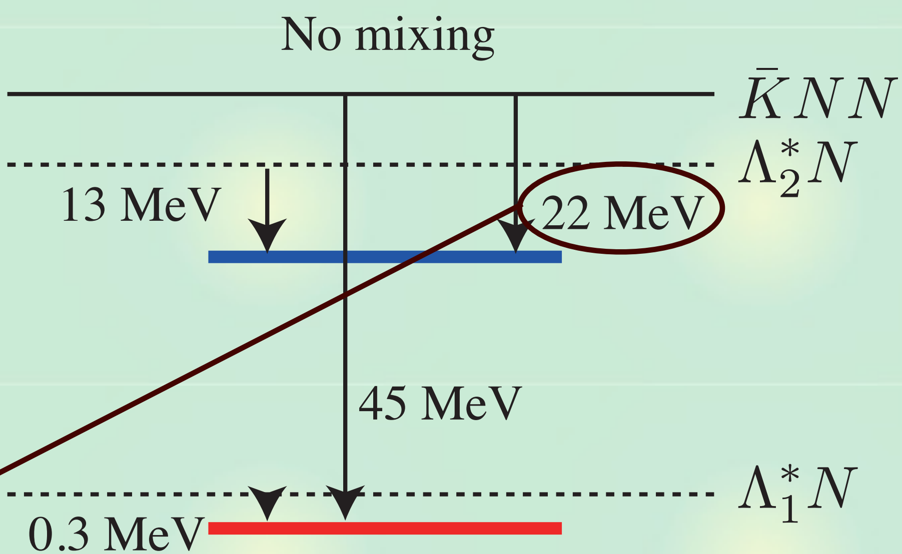
--> $\bar{K}$N bound state (large mixing of singlet and octet)

Λ*N bound states without mixing

Solve the schrödinger equation for the s-wave $\Lambda^*_i N$ potential without the mixing interaction.

- no physical bound states in S=1 channels (consistent with the analysis of the volume integral)
- for S=0 we obtain the bound states in both Λ^*_i

binding from	Λ*N th. [MeV]	K̄NN th. [MeV]
Λ^*_2 N	13.39	22.39
Λ^*_1 N	0.34	45.34

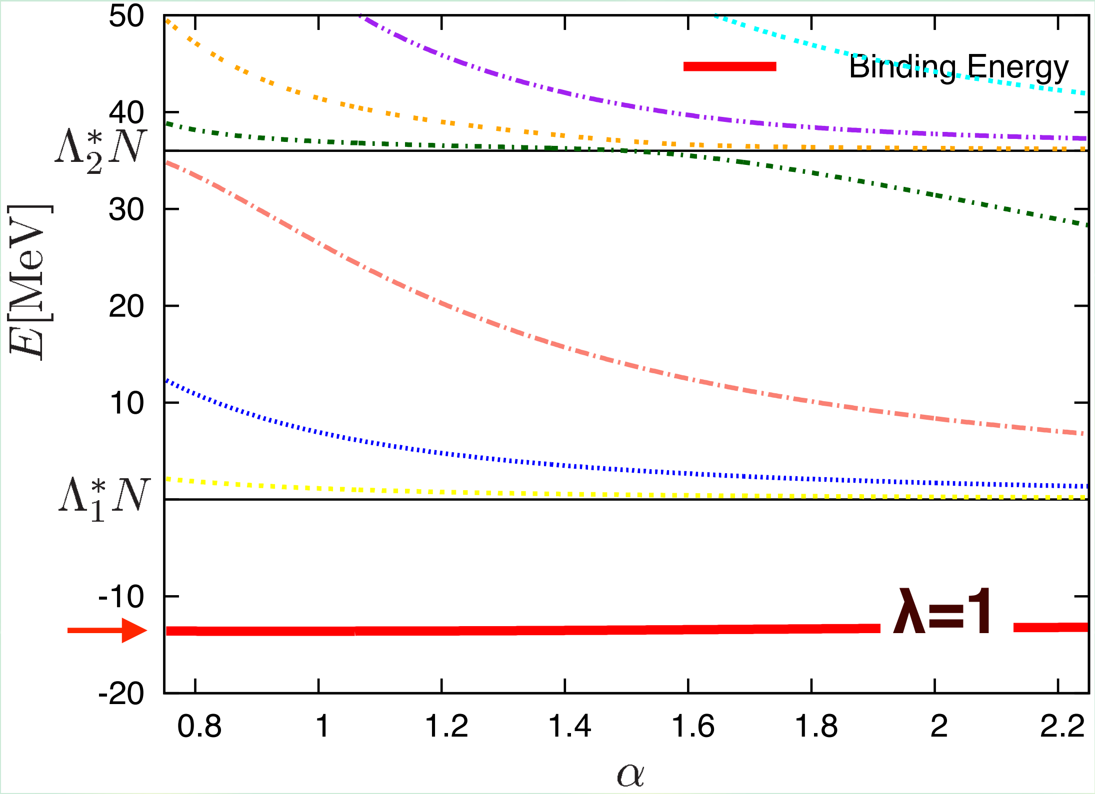


Similar value (20±3 MeV) in Dote-Hyodo-Weise.

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

Λ*N bound states with mixing

With mixing, the higher state becomes a resonance.
Real scaling method ≈ changing the box size.
λ: strength of the mixing interaction, physical for λ=1



The lower energy state bounds more.
The higher energy state disappears (above Λ^*_2N threshold?).

Summary

We study the Λ*N two-body system based on the Λ*N potential with chiral dynamics.

- **Chiral unitary model: two states Λ^*_1, Λ^*_2**
- **Both Λ^*_i generate bound states with N in spin S=0 channels, <-- K exchange**
- **With the mixing, the lower state bounds more, and the higher state dissolves.**

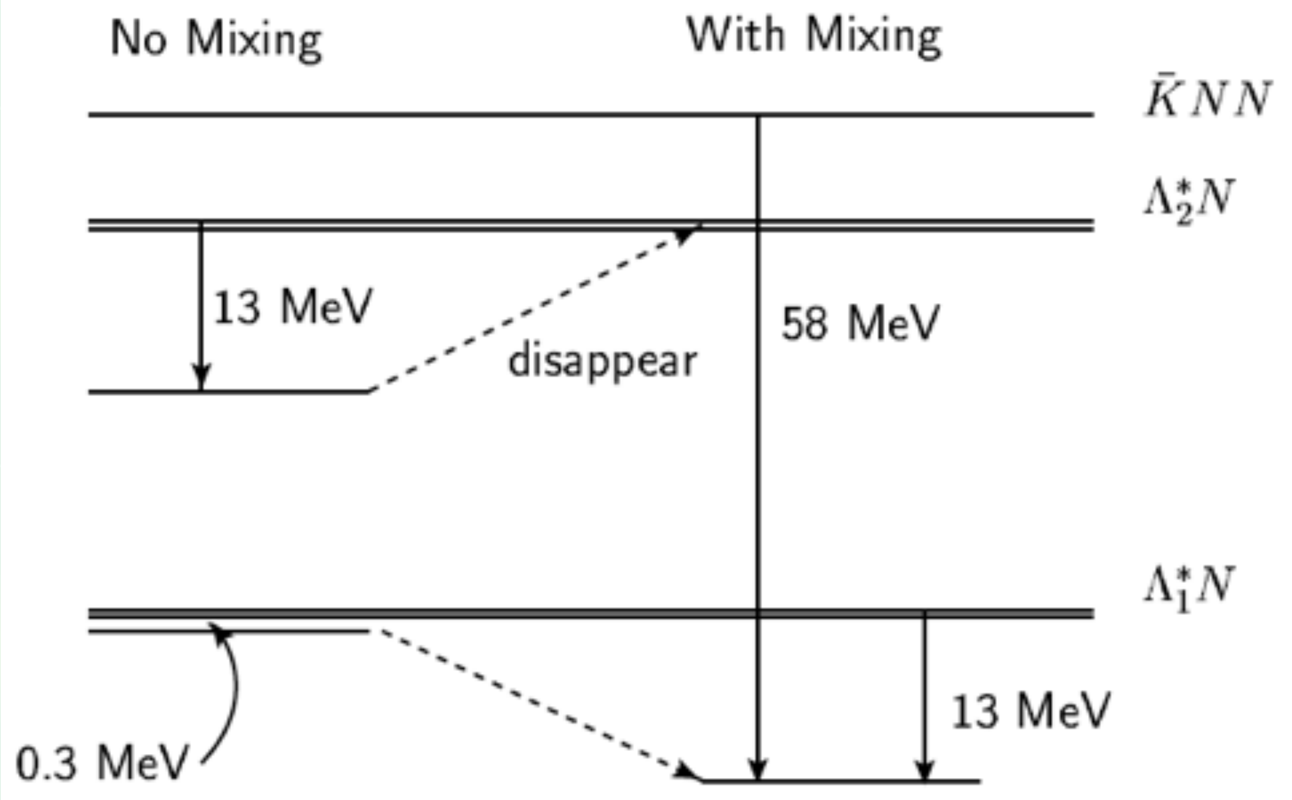
  mass of Λ*N ~ 2316-2322 MeV

  <-- strong mixing between Λ^*_1N - Λ^*_2N

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

Summary

taken from T. Uchino, Master thesis



- The Λ*N bound state decays into πΣN and YN.
- Disappeared state could be a very broad state.
- Physical Λ* (especially the lower one) has a finite width.
- Comparison with three-body calculation (Ikda et al)