Toward a realistic $\bar{K}N$-$\pi\Sigma$ interaction

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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

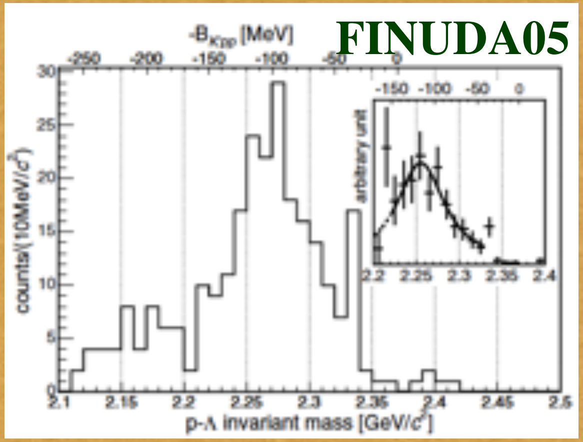
Theory: rigorous few-body calculations with realistic interactions

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

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

Experiment: some "evidences" in ΛN mass spectra

FINUDA, DISTO, etc.



- Interpretation (πΣN?FSI?)

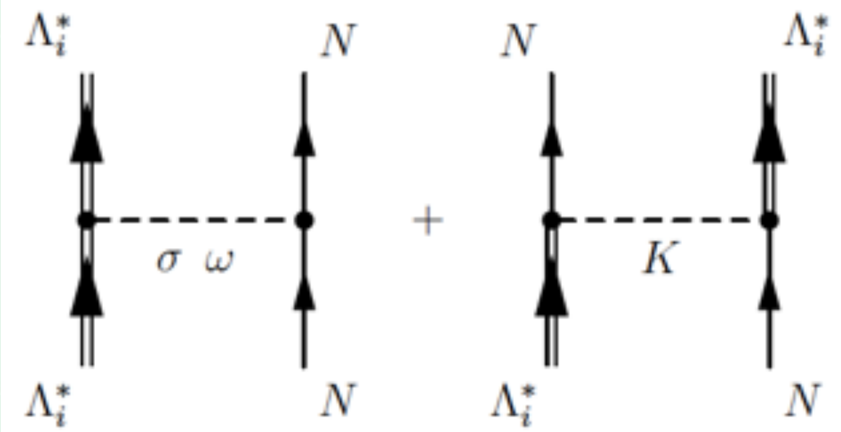
Contents

- Λ(1405) mass v.s. dibaryon($\bar{K}NN$) mass
  - in the Λ*N potential model
  - in the three-body $\bar{K}NN$-πΣN calculation
- Importance of the πΣ interaction
  - Threshold information of πΣ scattering
  - Determination of πΣ scattering length

Λ*N potential model

Λ*N potential --> Λ*N bound state

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



Λ* ~ KN quasi-bound state ==> important K exchange

If the Λ* is a shallowly bound KN system, then

The size of the Λ* increases.
Off-shellness of the exchanged K decreases.

--> enhances K exchange

Λ*N potential model: shallow Λ* leads to deep Λ*N

Three-body Faddeev calculation

A result of three-body coupled-channel calculation

Y. Ikeda and T. Sato, Phys. Rev. C76, 035203 (2007)

Model	$\bar{K}N$ (MeV)	$\pi\Sigma$ (MeV)	Scattering length (fm)	Resonance energy (MeV)
(a)	1095	1450	$-1.70 + i0.68$	$1419.8 - i29.4$
(f)	1160	1100	$-1.72 + i0.44$	$1405.8 - i25.2$

Model (A)
$-79.3 - i37.1$
$-63.3 - i22.2$

form factor Λ(1405) pole dibaryon pole

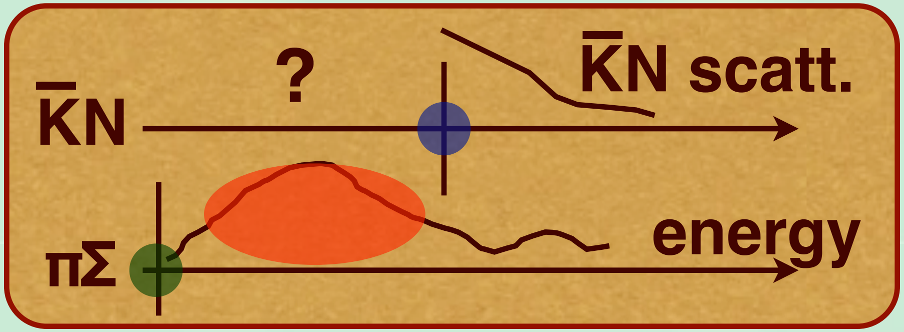
(a): shallow Λ*, deep dibaryon, strong πΣ interaction
(f): deep Λ*, shallow dibaryon, weak πΣ interaction

No simple correspondence in Λ* mass and dibaryon mass.
Strength of the πΣ interaction is important for ``deep” state?

What kind of πΣ information?

Precise data at K̄N threshold

- threshold branching ratio
- K-p (possibly with K-n) scattering length <-- SIDDHARTA



More constraints in πΣ channel

- Precise data of πΣ spectrum
  exp.) CLAS, LEPS, HADES,...
  theory) reaction study for each experiment

- Any information at πΣ threshold
  scattering length, effective range,...

Threshold behavior of πΣ scattering

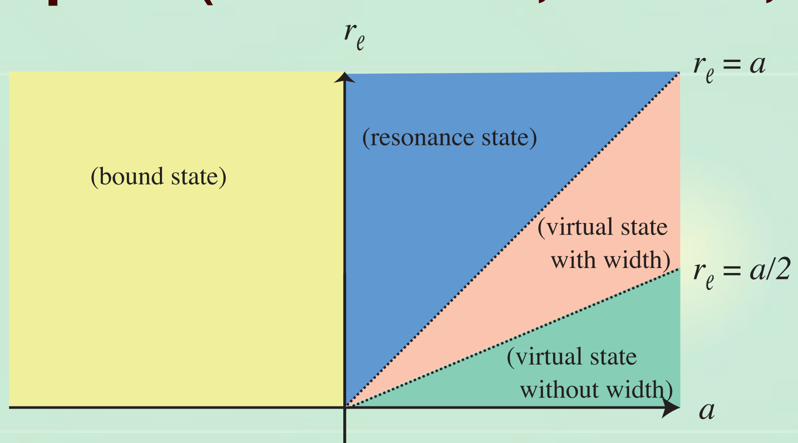
πΣ threshold information and $\bar{K}N$-πΣ amplitude

Y. Ikeda, T. Hyodo, D. Jido, H. Kamano, T. Sato, K. Yazaki, in preparation

Fix the $\bar{K}N(I=0)$ scattering length
--> various solutions for the sub-threshold amplitude

Model	A1a	A1b	B1 E-dep	B1 E-indep
parameter ($\pi\Sigma$)	$d_{\pi\Sigma} = -1.67$	$d_{\pi\Sigma} = -2.85$	$\Lambda_{\pi\Sigma} = 1005$ MeV	$\Lambda_{\pi\Sigma} = 1465$ MeV
parameter ($\bar{K}N$)	$d_{\bar{K}N} = -1.79$	$d_{\bar{K}N} = -2.05$	$\Lambda_{\bar{K}N} = 1188$ MeV	$\Lambda_{\bar{K}N} = 1086$ MeV
pole 1 [MeV]	$1422 - 16i$	$1425 - 11i$	$1422 - 22i$	$1423 - 29i$
pole 2 [MeV]	$1375 - 72i$ (R)	1321 (B)	$1349 - 54i$ (R)	1325 (V)
$a_{\pi\Sigma}$ [fm]	0.934	−2.30	1.44	5.50
r_e [fm]	5.02	5.89	3.96	0.458
$a_{\bar{K}N}$ [fm] (input)	$-1.70 + 0.68i$	$-1.70 + 0.68i$	$-1.70 + 0.68i$	$-1.70 + 0.68i$

- **πΣ scattering length + effective range**
  --> nature of the pole (resonance, virtual, or bound)



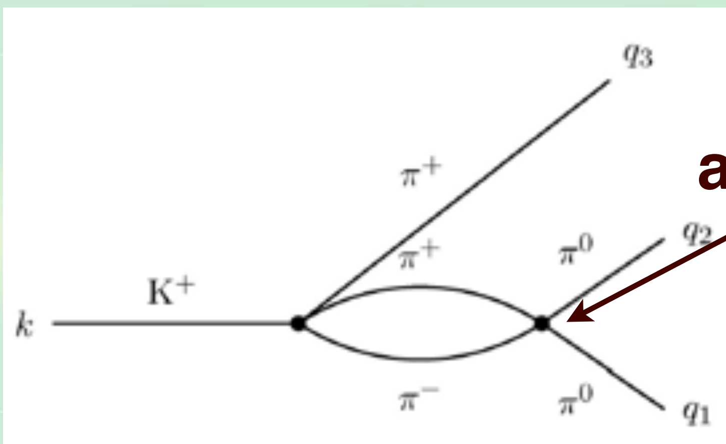
Determination of the scattering length

Extraction of hadron scattering length

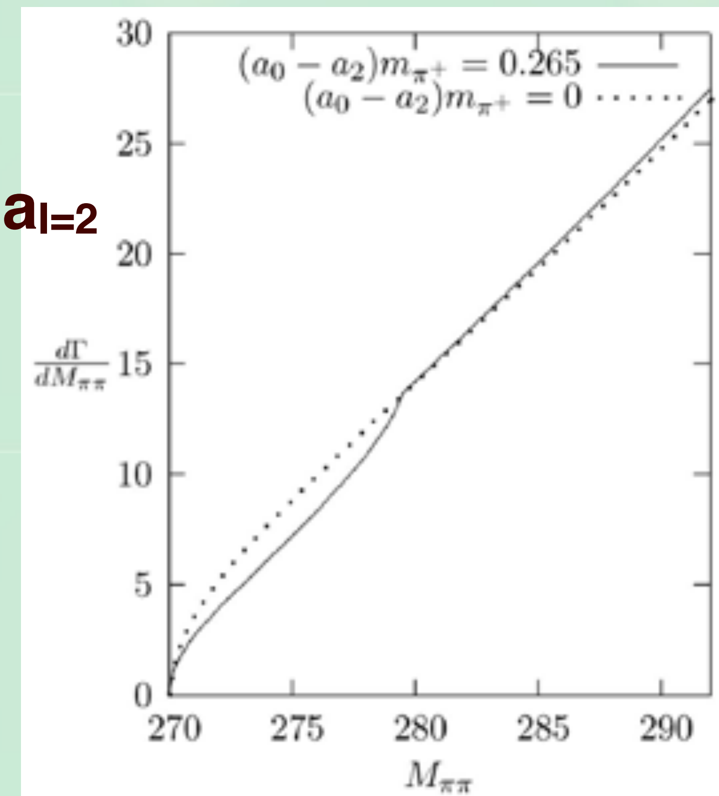
- shift and width of atomic state (c.f. Kaonic hydrogen)
- extrapolation of low energy phase shift
- final state interaction from heavy particle's decay

Cabibbo's method for π-π scattering length

N. Cabibbo, Phys. Rev. Lett. 93, 121801 (2004)



$a_{I=0} - a_{I=2}$

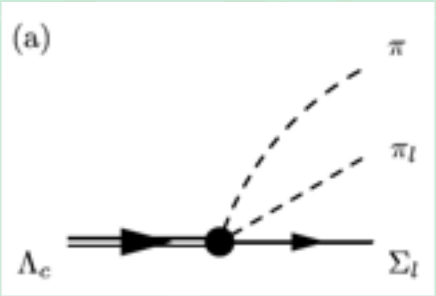


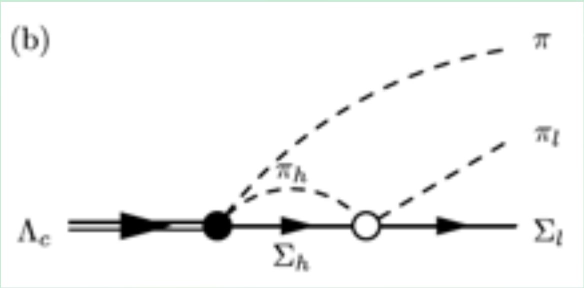
isospin violation
+ threshold cusp
+ amplitude interference
--> extraction of $a_{I=0} - a_{I=2}$

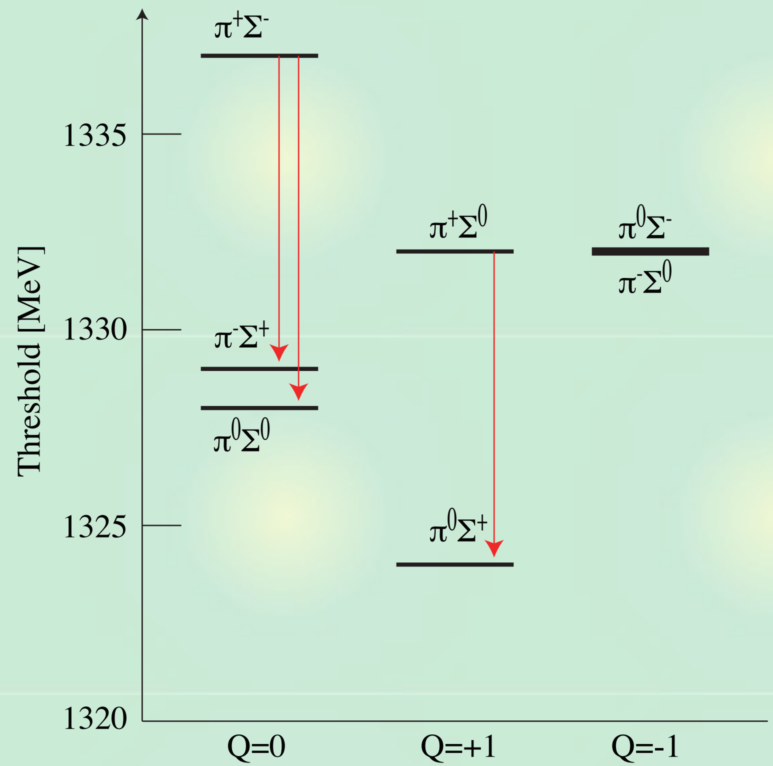
Determination of πΣ scattering length

Similar approach to πΣ spectrum in $\Lambda_c \to \pi (\pi\Sigma)$

T. Hyodo, M. Oka, work in progress







Σ^+(~uus) < Σ^0(~uds) < Σ^-(~dds)
--> complicated spectrum

To utilize threshold cusp, appreciable mass difference between $(\pi\Sigma)_h$ and $(\pi\Sigma)_l$ is necessary.

$$\pi^+\Sigma^- \to \pi^-\Sigma^+, \quad \pi^+\Sigma^- \to \pi^0\Sigma^0, \quad \pi^+\Sigma^0 \to \pi^0\Sigma^+,$$

Determination of πΣ scattering length

Three decay channels

$$\langle \pi^-\Sigma^+ |T| \pi^+\Sigma^- \rangle|_{\text{threshold}} = \frac{1}{3}a^0 - \frac{1}{2}a^1 + \frac{1}{6}a^2 \equiv a^{-+}$$

$$\langle \pi^0\Sigma^0 |T| \pi^+\Sigma^- \rangle|_{\text{threshold}} = \frac{1}{3}a^0 - \frac{1}{3}a^2 \equiv a^{00}$$

$$\langle \pi^0\Sigma^+ |T| \pi^+\Sigma^0 \rangle|_{\text{threshold}} = -\frac{1}{2}a^1 + \frac{1}{2}a^2 \equiv a^{0+}$$

mode	$\Lambda_c \to \pi(\pi\Sigma)_h$	$\Lambda_c \to \pi(\pi\Sigma)_l$
a^{-+}	1.7 ± 0.5 %	3.6 ± 1.0 %
a^{00}	1.7 ± 0.5 %	1.8 ± 0.8 %
a^{0+}	1.8 ± 0.8 %	not known

A lot of Λ_c in B decay (Belle, Babar) --> feasible?

Structure around the cusp in $(\pi\Sigma)_l$ + spectrum in $(\pi\Sigma)_h$
--> extraction of the scattering length

Three unknown scattering lengths, two constraints

$$a^{-+} - a^{00} = a^{0+}$$

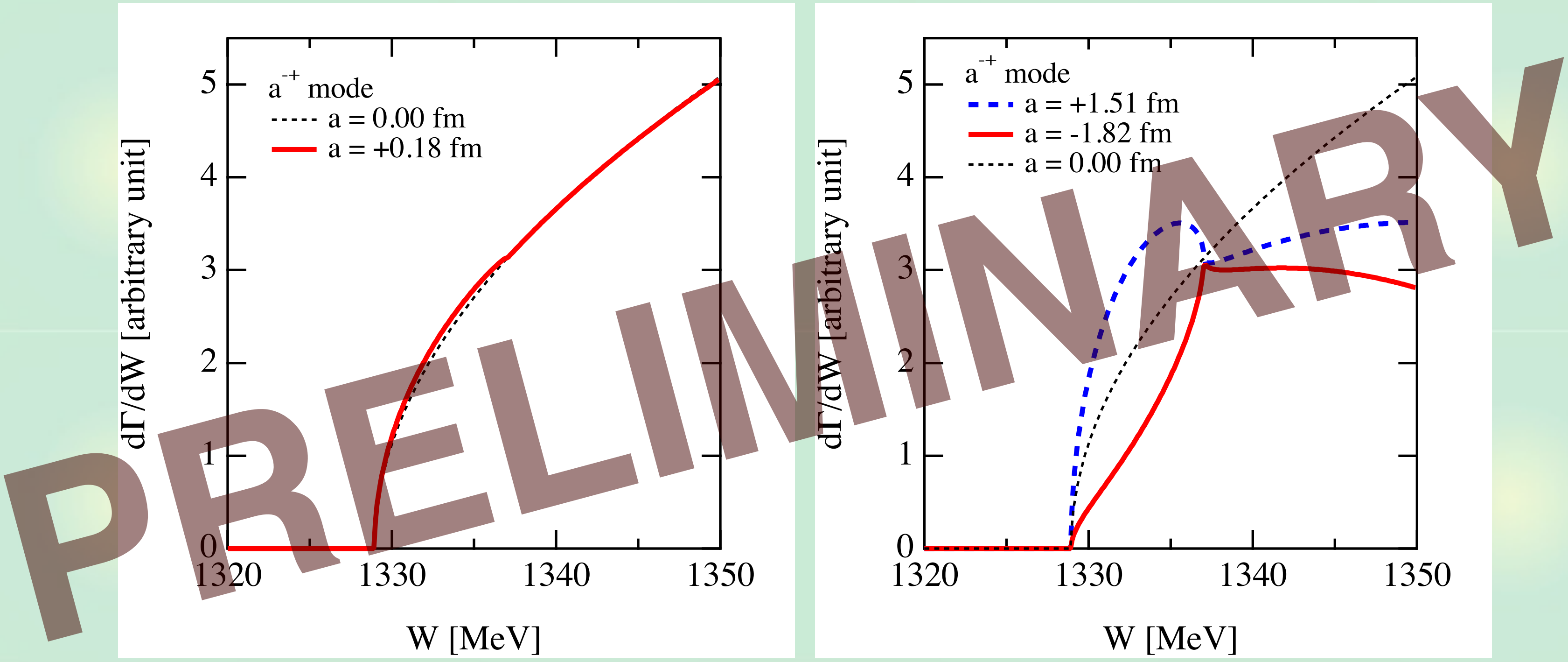
I=2 scattering length: lattice QCD --> Y. Ikeda's talk

Determination of πΣ scattering length

Expansion of the decay spectrum --> scattering length

$$|\mathcal{M}|^2 = \begin{cases} A + B|\delta| + C|\delta|^2 + \mathcal{O}(|\delta|^3) & \text{for} \quad W > W_{th} \\ A' + B'\delta + C'\delta^2 + \mathcal{O}(\delta^3) & \text{for} \quad W < W_{th} \end{cases}$$

$$|a| = \frac{|B'|}{2m_h\sqrt{A}|M_0^{h(0)}|}, \qquad \frac{a}{|a|} = \frac{M_0^{(0)}}{|M_0^{(0)}|} \cdot \frac{M_0^{h(0)}}{|M_0^{h(0)}|} \cdot \frac{B'}{|B'|}$$



Summary

We emphasize the importance of the πΣ interaction for the $\bar{K}N$-πΣ physics

- **No simple connection between Λ(1405) mass and strange dibaryon mass.**
- **πΣ threshold data is important for the amplitude in the ``deep" region.**

  Y. Ikeda, T. Hyodo, D. Jido, H. Kamano, T. Sato, K. Yazaki, in preparation
- **πΣ scattering length can be extracted from the Λ_c decay. Lattice QCD will help to complete the constraints.**

  T. Hyodo, M. Oka, in preparation;
  Y. Ikeda, HAL QCD collaboration, in preparation.