$\Lambda(1405)$ and $\bar{K}N$ interaction in chiral dynamics

Tetsuo Hyodo

Tokyo Institute of Technology

supported by Global Center of Excellence Program
"Nanoscience and Quantum Physics"

2011, Sep 22nd

The Λ(1405) resonance

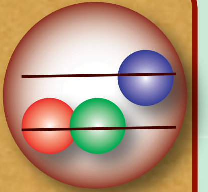
$$\Lambda(1405) : J^P = 1/2^-, I = 0$$

(PDG)

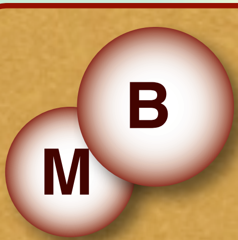
mass : 1406.5 ± 4.0 MeV, width : 50 ± 2 MeV

decay mode: $\Lambda(1405) \to (\pi\Sigma)_{I=0}$ **100%**

“naive” quark model
: p-wave ~1600 MeV?



N. Isgur, G. Karl, PRD18, 4187 (1978)



Coupled channel
multi-scattering

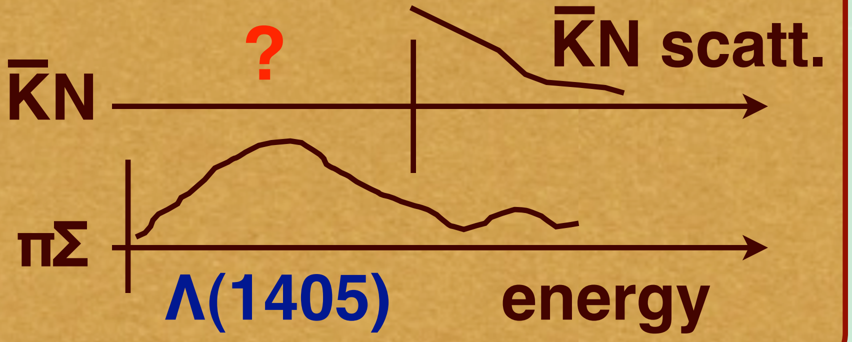
R.H. Dalitz, T.C. Wong,
G. Rajasekaran, PR153, 1617 (1967)

$\bar{K}N$ interaction below threshold

T. Hyodo, W. Weise, PRC 77, 035204 (2008)

--> $\bar{K}N$ potential, kaonic nuclei

J-PARC E15



Contents

- Λ(1405) in meson-baryon scattering

  T. Hyodo, D. Jido, arXiv:1104.4474, to appear in Prog. Part. Nucl. Phys.

  - Chiral SU(3) dynamics
  - Pole structure of Λ(1405)

- Toward realistic meson-baryon interaction

  - Constraint by accurate $\bar{K}N$ data

    Y. Ikeda, T. Hyodo, W. Weise, arXiv:1109.3005 [nucl-th]

  - Information of πΣ channel

    Y. Ikeda, T. Hyodo, D. Jido, H. Kamano, T. Sato, K. Yazaki,
    Prog. Theor. Phys. 125, 1205 (2011);
    T. Hyodo, M. Oka, Phys. Rev. C 83, 055202 (2011)

- Summary

Chiral unitary approach

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

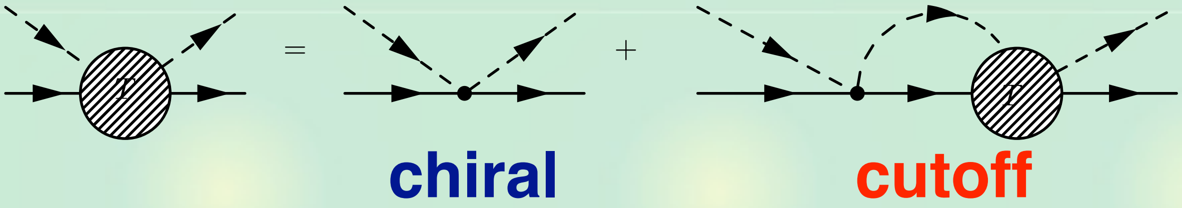
- Interaction <-- chiral symmetry

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)

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



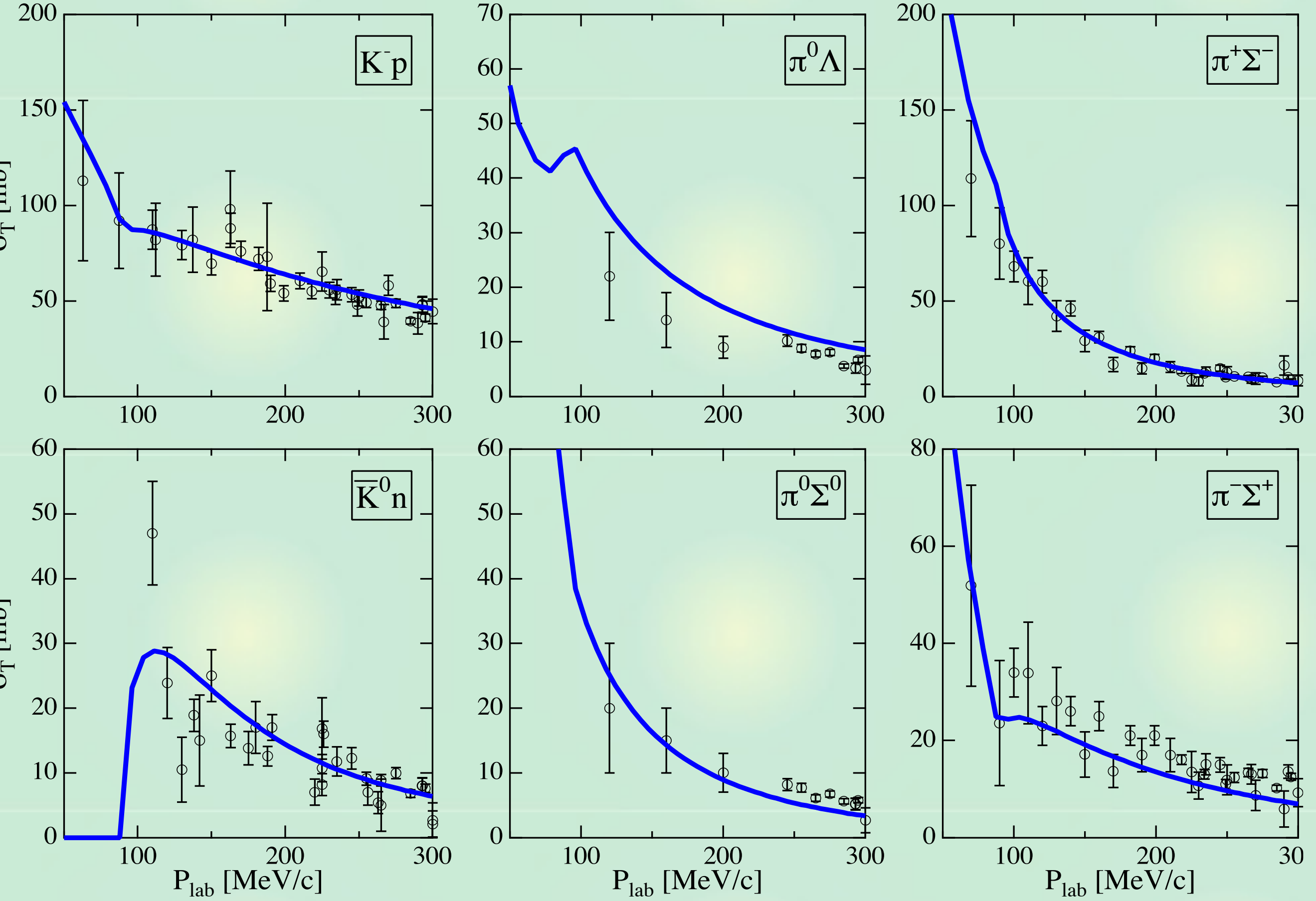
N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002), ... many others

It works successfully in various hadron scatterings.

T. Hyodo, D. Jido, arXiv:1104.4474, to appear in Prog. Part. Nucl. Phys.

A simple model (1 parameter) v.s. experimental data

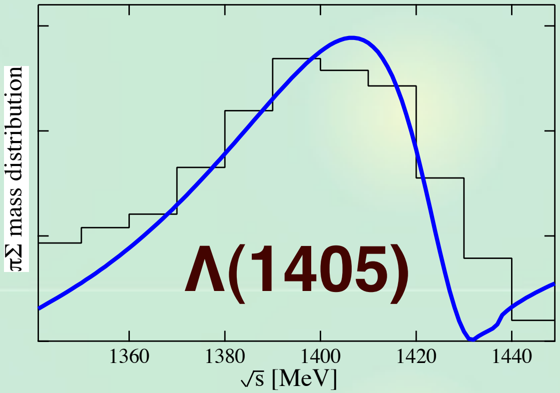
Total cross section of K-p scattering



Branching ratio

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

πΣ spectrum



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

Good agreement with data above, at, and below K̄N threshold

more quantitatively --> fine tuning, higher order terms,...

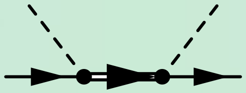
Pole structure in the complex energy plane

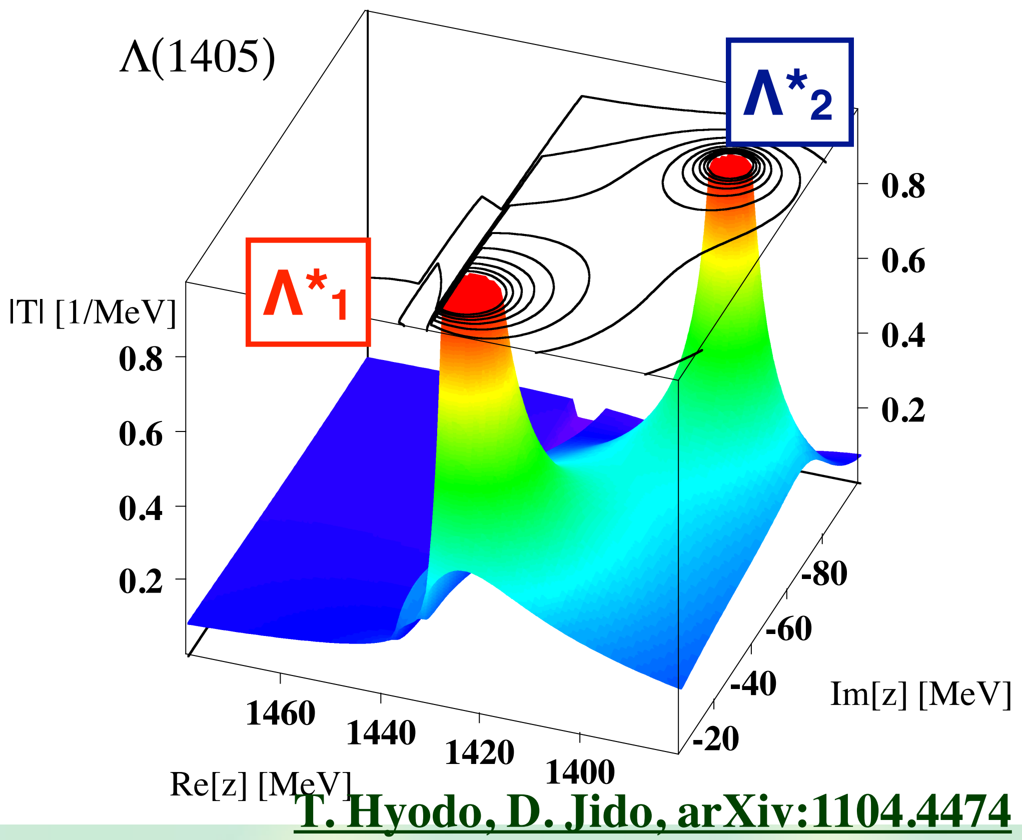
Resonance state ~ pole of the scattering amplitude

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

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

$\sim$





T. Hyodo, D. Jido, arXiv:1104.4474

Two poles for one resonance (bump structure) --> Superposition of two states ?

Different πΣ spectra?
K-d --> πΣN reaction

Exp: O. Braun, et al., Nucl. Phys. B129, 715 (1977); J-PARC E31.
Theor: D. Jido, E. Oset, T. Sekihara, Eur. Phys. J. A42, 257 (2009); A47, 42 (2011)

Origin of the two-pole structure

Leading order chiral interaction for K̄N-πΣ channel

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

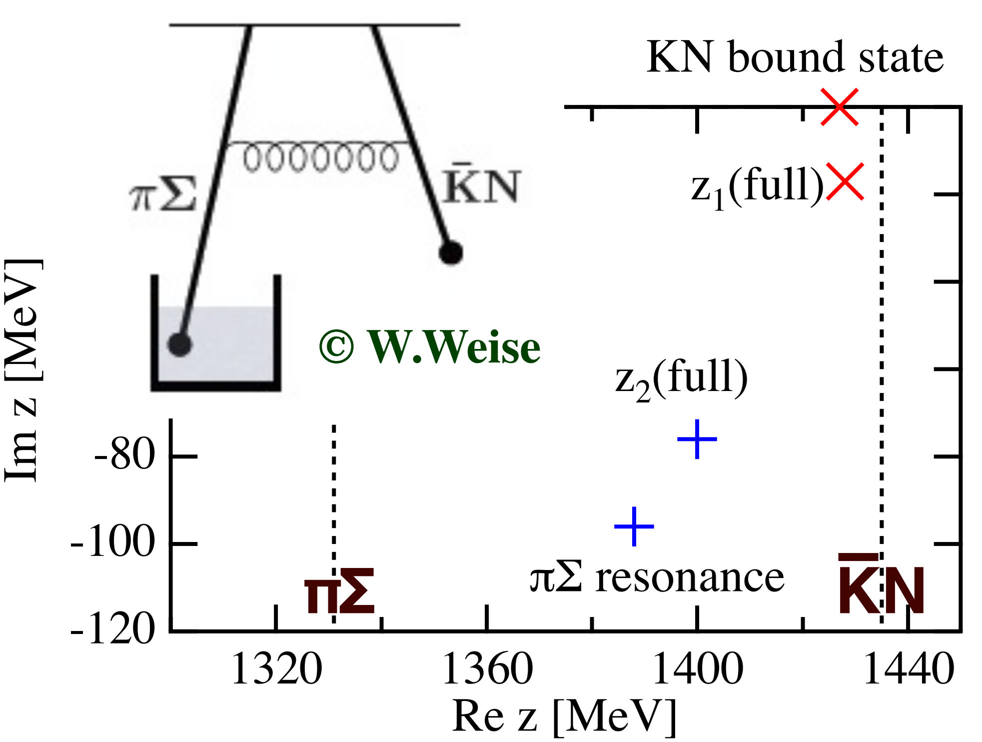
$$V_{ij} = -C_{ij}\frac{\omega_i + \omega_j}{4f^2}$$

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

at threshold

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

$$\Rightarrow V_{\bar{K}N} \sim 2.5V_{\pi\Sigma}$$



Very strong attraction in K̄N (higher energy) --> bound state

Strong attraction in πΣ (lower energy) --> resonance

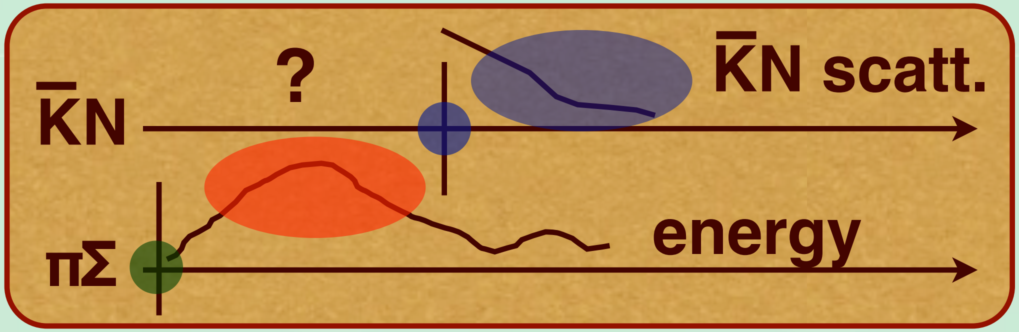
Model dependence? Effects from higher order terms?

Experimental constraints for S=-1 MB scattering

K-p total cross sections (bubble chamber, large errors)

K̄N threshold observables

- threshold branching ratios (old but accurate)
- K-p scattering length <-- **SIDDHARTA exp.**



πΣ mass spectra

- new data is becoming available (LEPS, CLAS, HADES,...)
- normalization, reaction dependence,... <-- to be predicted?

πΣ threshold observables (so far no data)

Construction of the realistic amplitude

Systematic χ2 fitting with SIDDHARTA data

Y. Ikeda, T. Hyodo, W. Weise, arXiv:1109.3005 [nucl-th]

Interaction kernel: NLO ChPT

B. Borasoy, R. Nissler, W. Weise, Eur. Phys. J. A25, 79-96 (2005);
B. Borasoy, U.G. Meissner, R. Nissler, Phys. Rev. C74, 055201 (2006)

Parameters: 6 cutoffs (+ 7 low energy constants in NLO)

	TW	TWB	NLO	Experiment	
ΔE [eV]	373	377	306	$283 \pm 36 \pm 6$	[7]
Γ [eV]	495	514	591	$541 \pm 89 \pm 22$	[7]
γ	2.36	2.36	2.37	2.36 ± 0.04	[8]
R_n	0.20	0.19	0.19	0.189 ± 0.015	[8]
R_c	0.66	0.66	0.66	0.664 ± 0.011	[8]
χ^2/d.o.f	1.12	1.15	0.96		
pole positions	$1422 - 16i$	$1421 - 17i$	$1424 - 26i$		
[MeV]	$1384 - 90i$	$1385 - 105i$	$1381 - 81i$		

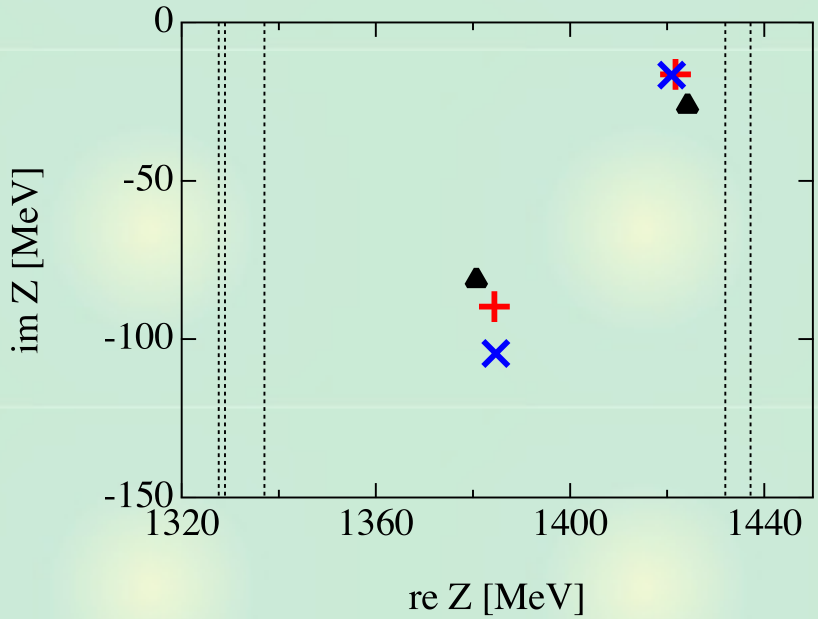
new!

Summary of results

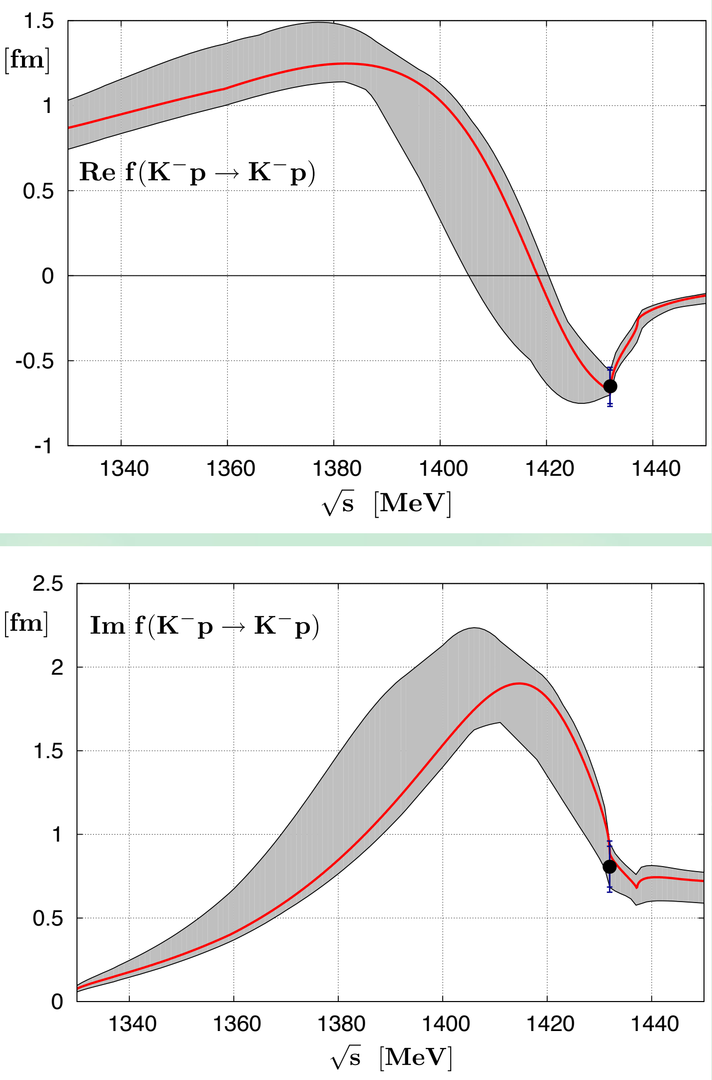
Results from three models

	WT	WTB	NLO
χ2/dof	1.12	1.15	0.957

Pole positions



NLO amplitude



Error analysis is now underway

Y. Ikeda, T. Hyodo, W. Weise, arXiv:1109.3005 [nucl-th]

πΣ threshold behavior

Effect of the πΣ threshold data for $\bar{K}$N-πΣ amplitude

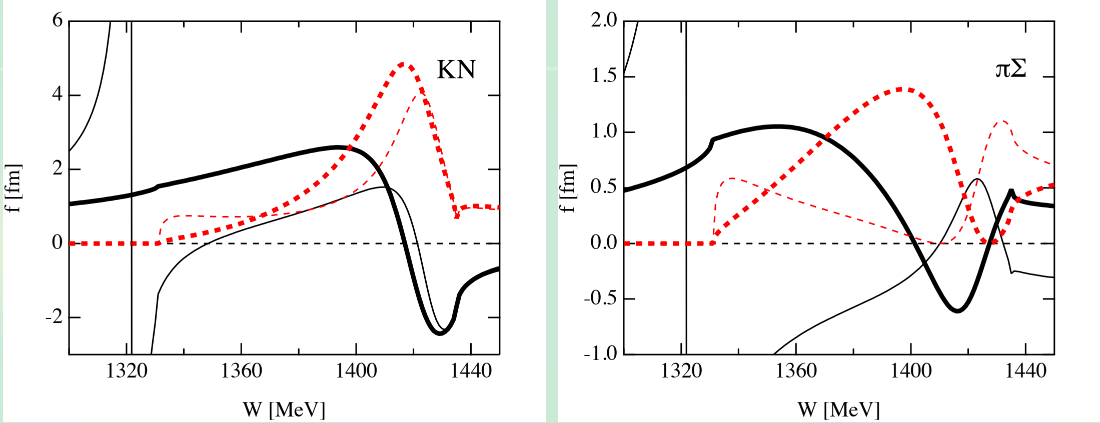
Y. Ikeda, T. Hyodo, D. Jido, H. Kamano, T. Sato, K. Yazaki, PTP 125, 1205 (2011)

Extrapolations with a given $\bar{K}$N(I=0) scattering length

--> uncertainty in subthreshold

Model	A1	A2	B E-dep	B 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)	$-1.70+0.68i$	$-1.70+0.68i$	$-1.70+0.68i$	$-1.70+0.68i$

subthreshold behavior



<-- πΣ scattering length, effective range

Determination of the πΣ scattering length

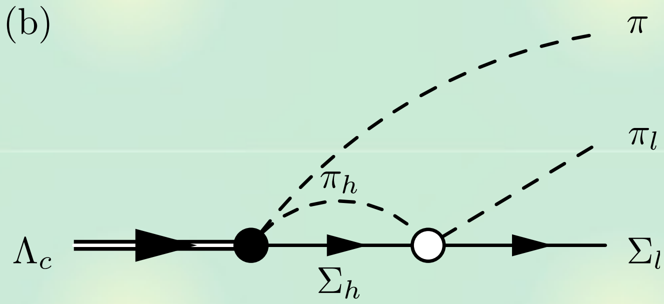
π π scattering length from K --> π π π decay

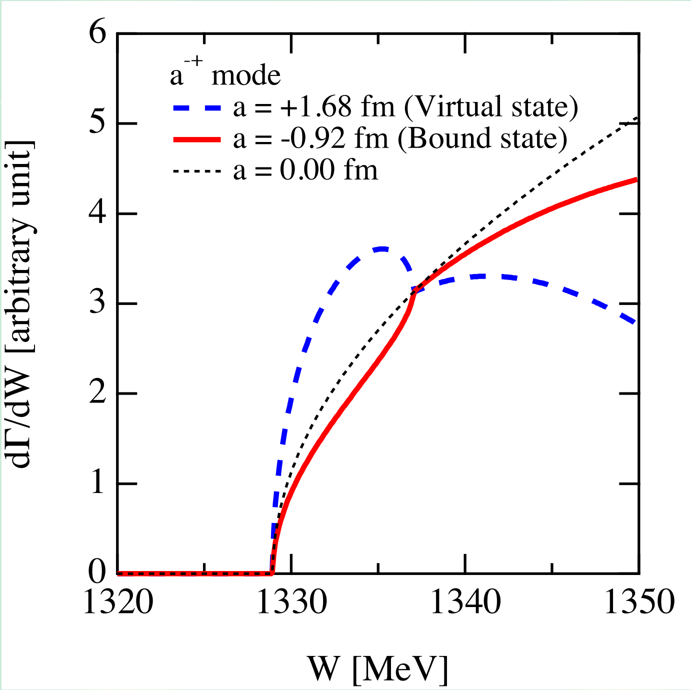
N. Cabibbo, Phys. Rev. Lett. 93, 121801 (2004);
NA48/2, J.R. Batley, *et al.*, Phys. Lett. B686, 101 (2010)

Analogy: πΣ scattering lengths from Λc --> π π Σ decays

T. Hyodo, M. Oka, Phys. Rev. C 83, 055202 (2011)

isospin violation
+ threshold cusp
+ amplitude interference





Expansion of the spectrum around cusp --> scattering length

Summary 1

We study the $\bar{K}N$-$\pi\Sigma$ interaction and Λ(1405) based on chiral SU(3) symmetry and unitarity

- **Λ(1405) is closely related to the $\bar{K}N$ interaction and $\bar{K}$ nuclei.**

  J-PARC E15, Y. Ikeda's Talk

- **Λ(1405) can be well described in chiral SU(3) dynamics.**

  T. Hyodo, D. Jido, arXiv:1104.4474, to appear in Prog. Part. Nucl. Phys.

- **Two poles for Λ(1405).**

  <-- attractive $\bar{K}N$ and $\pi\Sigma$ interactions

  J-PARC E31

Summary 2

Recent developments to construct a realistic meson-baryon interaction

- **New $\bar{K}N$ threshold data by SIDDAHRTA**

  - systematic χ2 analysis with NLO terms

  Y. Ikeda, T. Hyodo, W. Weise, arXiv:1109.3005 [nucl-th]

- **Threshold information of πΣ channel**

  - importance of πΣ threshold behavior

  Y. Ikeda, T. Hyodo, D. Jido, H. Kamano, T. Sato, K. Yazaki,
  Prog. Theor. Phys. 125, 1205 (2011)

  - scattering length from Λc decay

  T. Hyodo, M. Oka, Phys. Rev. C 83, 055202 (2011)