Construction of a local $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential and composition of the $\Lambda(1405)$

Kenta Miyahara[a], Tetsuo Hyodo[b], Wolfram Weise[c]

[a]*Department of Physics, Kyoto Univ.*
[b]*Yukawa Institute for Theoretical Physics, Kyoto Univ.*
[c]*Physik-Department, Technische Univ. München*

2018, Jul. 13th

$\bar{K}$ meson and $\bar{K}N$ interaction

Two aspects of $K(\bar{K})$ meson

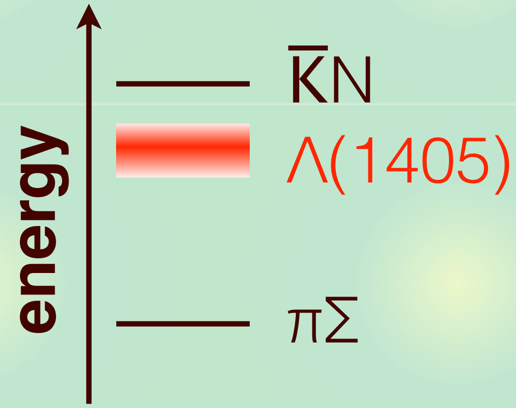
- **NG boson of chiral $SU(3)_R \otimes SU(3)_L$ —> $SU(3)_V$**
- **Massive by strange quark: $m_K \sim 496$ MeV**

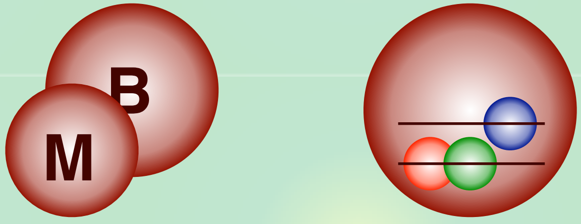
—> Spontaneous/explicit symmetry breaking

$\bar{K}N$ interaction ...

T. Hyodo, D. Jido, Prog. Part. Nucl. Phys. 67, 55 (2012)

- **is coupled with $\pi\Sigma$ channel**
- **generates $\Lambda(1405)$ below threshold**





molecule **three-quark**

- **is fundamental building block for $\bar{K}$-nuclei, $\bar{K}$-atoms, ...**

Kaonic nuclei : current status

Recent experiment for $\bar{K}NN$ (J-PARC E15, $^3He(K^-,\Lambda p)n$)

S. Ajimura, *et al.*, arXiv:1805.12275 [nucl-ex].

$$B = 47 \pm 3^{+3}_{-6}\ \mathrm{MeV}, \quad \Gamma = 115 \pm 7^{+10}_{-9}\ \mathrm{MeV}$$

Theoretical calculation with realistic $\bar{K}N$ interaction

- **Fit to K-p cross sections and branching ratios**
- **SIDDHARTRA constraint of Kaonic hydrogen**

[1] J. Revai, N.V. Shevchenko, Phys. Rev. C 90, 034004 (2014),
[2] S. Ohnishi, W. Horiuchi, T. Hoshino, K. Miyahara. T. Hyodo, PRC95, 065202 (2017).

	V^1 [1]	V^2 [1]	V^{Chiral} [1]	[2]
B [MeV]	53.3	47.4	32.2	25-28
$\Gamma_{\pi YN}$ [MeV]	64.8	49.8	48.6	31-59

- 2N **absorption (Γ_{YN}) is NOT included.**

Construction of $\bar{K}N$ potential

Local $\bar{K}N$ potential is useful for

- **extraction of the wave function of $\Lambda(1405)$**
- **application to few-body Kaonic nuclei/atoms**

Strategy

Fit to experimental data (chiral SU(3) EFT) [1]

equivalent amplitude

Single-channel complex $\bar{K}N$ potential [2] (used in $\bar{K}NN$ calculation)

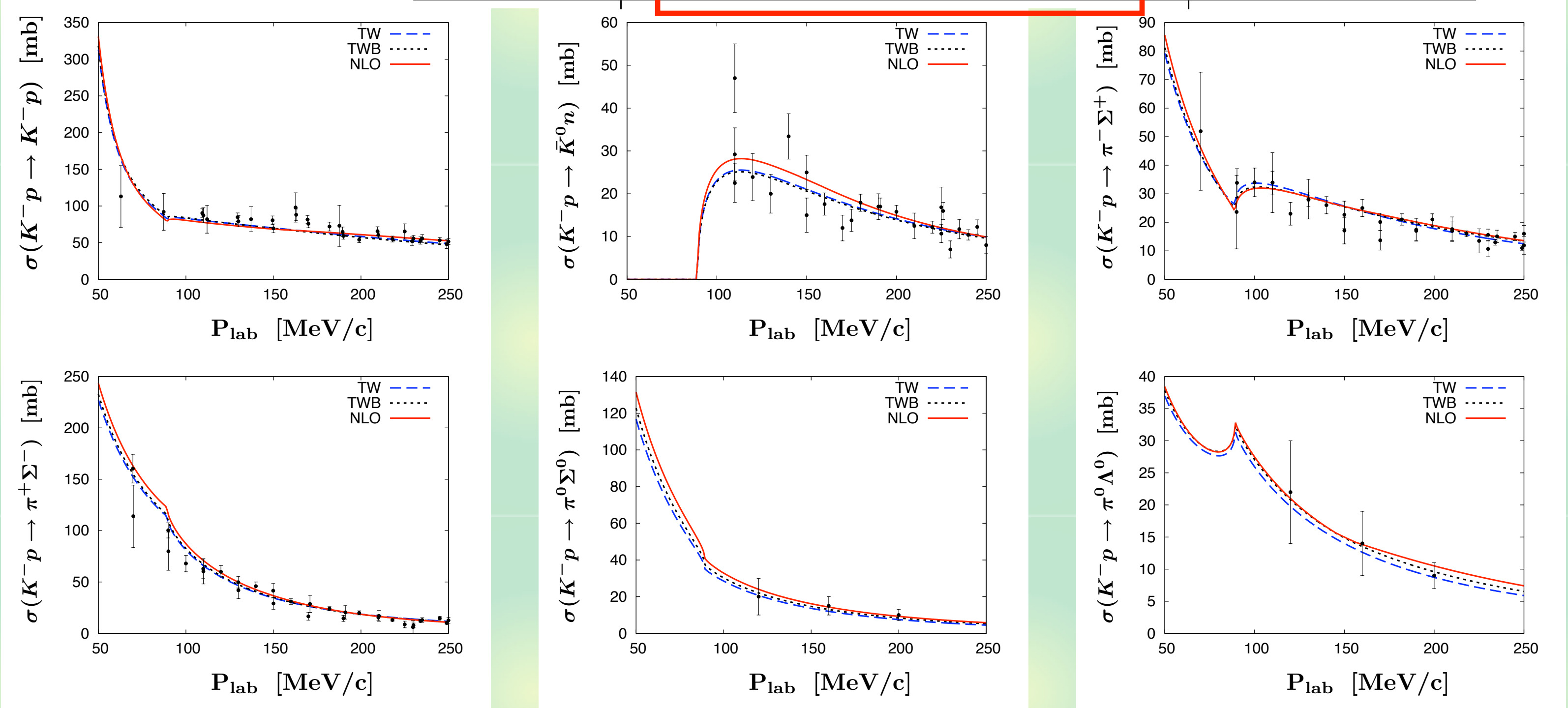
Coupled-channel real $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potential [3]

[1] Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011); NPA 881 98 (2012);
[2] K. Miyahara. T. Hyodo, Phys. Rev. C93, 015201 (2016);
[3] K. Miyahara, T. Hyodo, W. Weise, arXiv:1804.08269 [nucl-th].

Fit to experiments: NLO chiral SU(3) dynamics

		TW	TWB	NLO	Experiment	
SIDDHARTA	ΔE [eV]	373	377	306	$283 \pm 36 \pm 6$	[10]
	Γ [eV]	495	514	591	$541 \pm 89 \pm 22$	[10]
Branching ratios	γ	2.36	2.36	2.37	2.36 ± 0.04	[11]
	R_n	0.20	0.19	0.19	0.189 ± 0.015	[11]
	R_c	0.66	0.66	0.66	0.664 ± 0.011	[11]
	χ^2/d.o.f	1.12	1.15	0.96		

cross sections



Y. Ikeda, T. Hyodo, W. Weise, PLB 706, 63 (2011); NPA 881 98 (2012)

Accurate description of all existing data (χ^2/d.o.f. ~ 1)

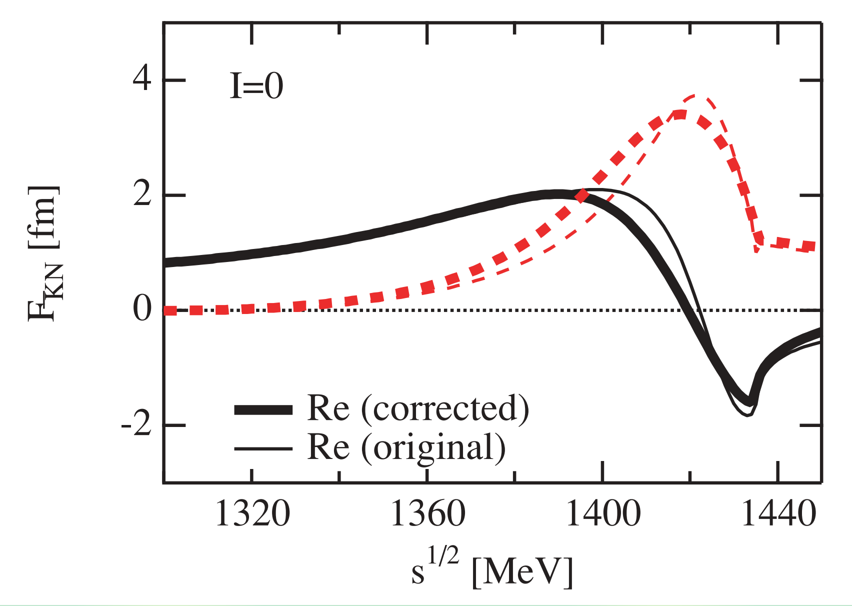
Construction of $\bar{K}N$ potential

Practical procedure for local $\bar{K}N$ potential

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

- **Chiral SU(3) :** thin lines
- **Potential : thick lines**

$U(W, r)$ **+ Schrödinger eq.**



r-dependence

- **single gaussian, range ~ 0.4 fm**

Potential strength

- **complex (absorption to lower energy $\pi\Sigma$ and $\pi\Lambda$)**
- **energy dependent (chiral + Feshbach projection)**

Reasonable on-shell scattering amplitude on real axis

Realistic $\bar{K}N$ potential

Problems of 2008 version

K. Miyahara, T. Hyodo, Phys. Rev. C93, 015201 (2016)

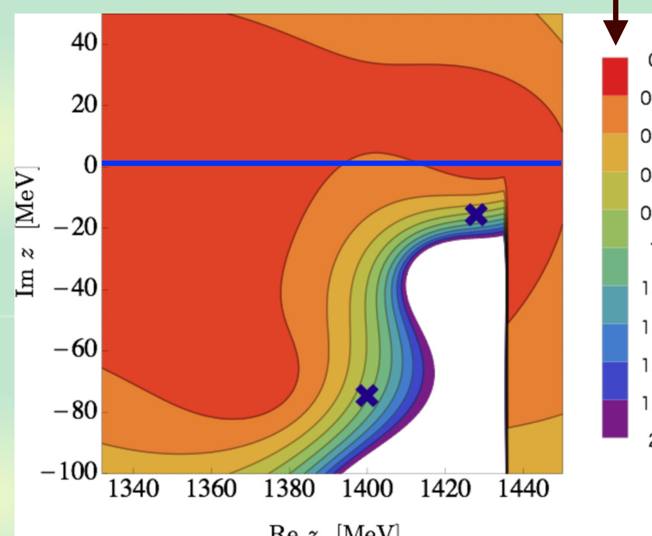
- Amplitude was not constrained by SIDDHARTA
- Pole structure of the amplitude was not reproduced.

original

Model	Pole position (MeV) $F^{\mathrm{Ch}}_{\bar{K}N}$	Pole position (MeV) $F_{\bar{K}N}$
ORB [68]	$1427-17i$, $1389-64i$	$1419-42i$
HNJH [66,67]	$1428-17i$, $1400-76i$	$1421-35i$
BNW [57,59]	$1434-18i$, $1388-49i$	$1404-46i$
BMN [58]	$1421-20i$, $1440-76i$	$1416-27i$

potential

deviation from original amplitude



- Deviation away from the real axis

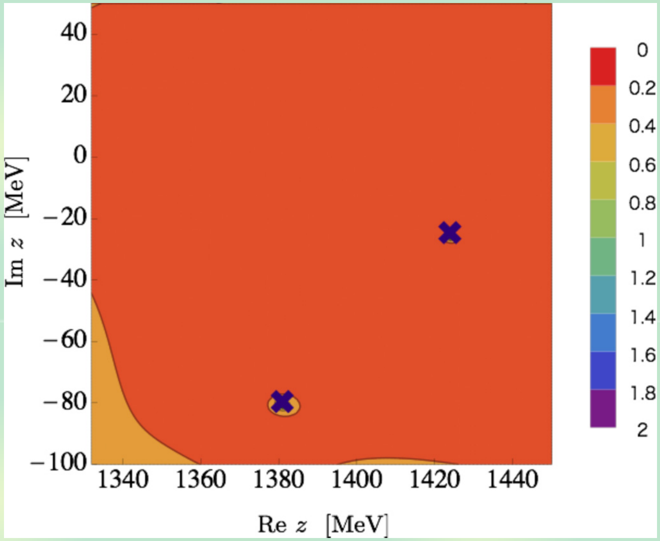
Description in the complex energy plane should be improved.

Realistic $\bar{K}N$ potential

New single-channel potential (Kyoto $\bar{K}N$ potential)

K. Miyahara, T. Hyodo, Phys. Rev. C93, 015201 (2016)

- **Chiral SU(3) at NLO with SIDDHARTA**
- **Improvement of construction**
  : pole positions in 1 MeV precision



Realistic potential : χ^2/d.o.f. ~ 1

- **applied to $\bar{K}$ few-body systems**

S. Ohnishi, W. Horiuchi, T. Hoshino, K. Miyahara. T. Hyodo, PRC95, 065202 (2017);
T. Hoshino, S. Ohnishi, W. Horiuchi, T. Hyodo, W. Weise, PRC96, 045204 (2017)

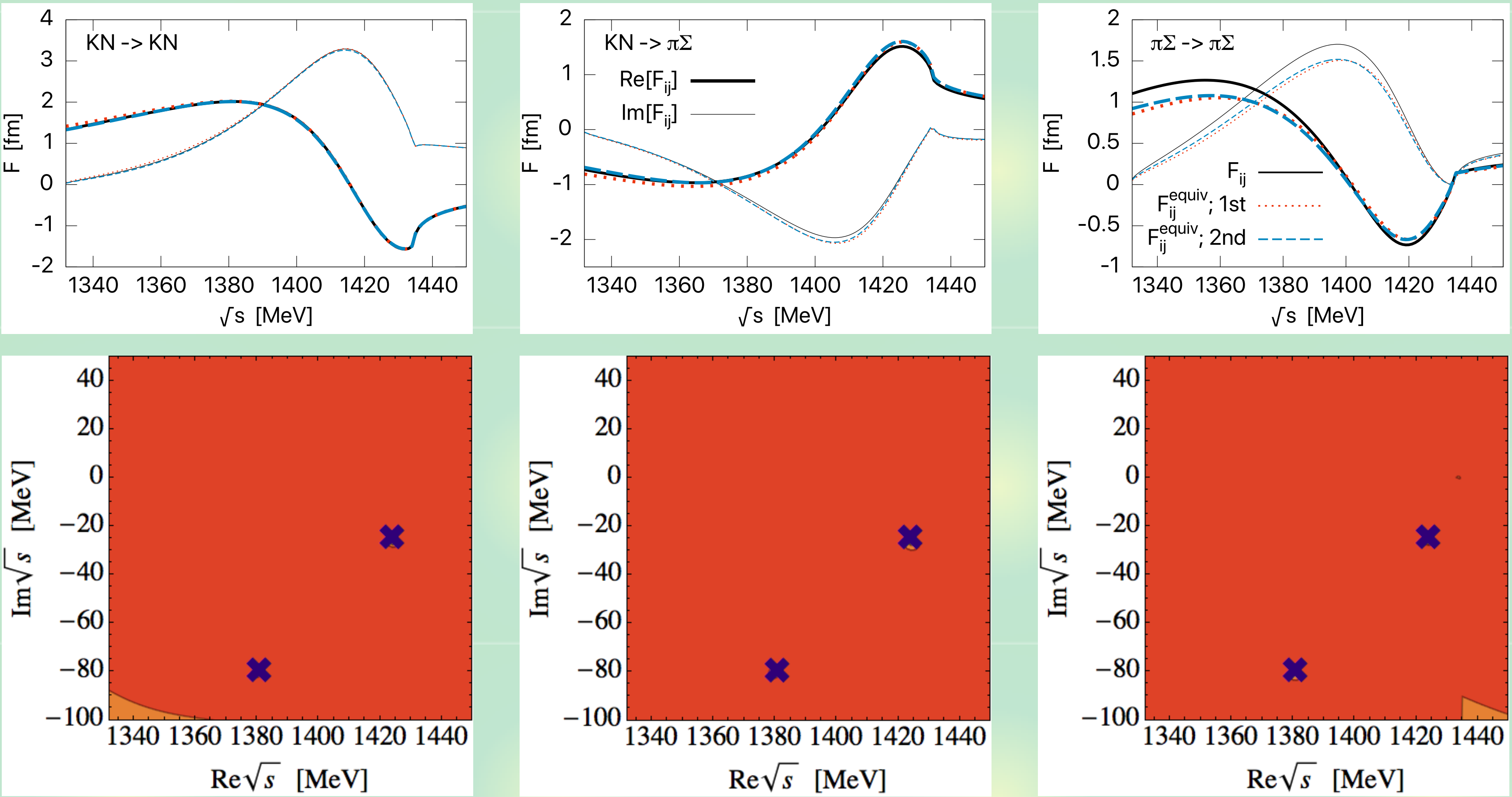
Note:

- **Energy dependence : 10th order polynomial in E**
- **$\pi\Sigma$, $\pi\Lambda$ are not explicit. Dynamics in few-body system?**

Coupled-channel potential

Coupled-channel $\bar{K}N$-$\pi\Sigma$ potential

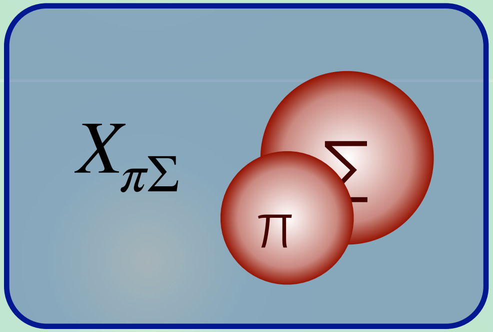
K. Miyahara, T. Hyodo, W. Weise, arXiv:1804.08269 [nucl-th]

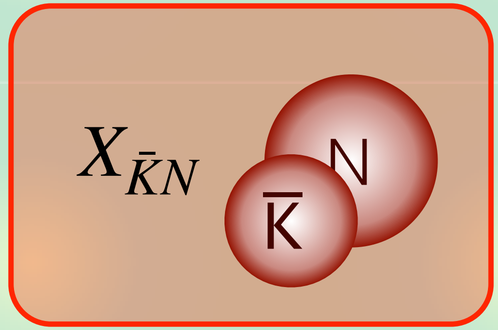


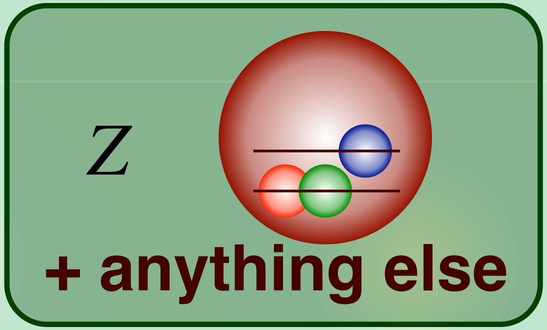
- Potential strengths are real.
- E-dependence : 1st/2nd order is sufficient.

Structure of Λ(1405)

Compositeness X: quantitative measure of structure ~ norm







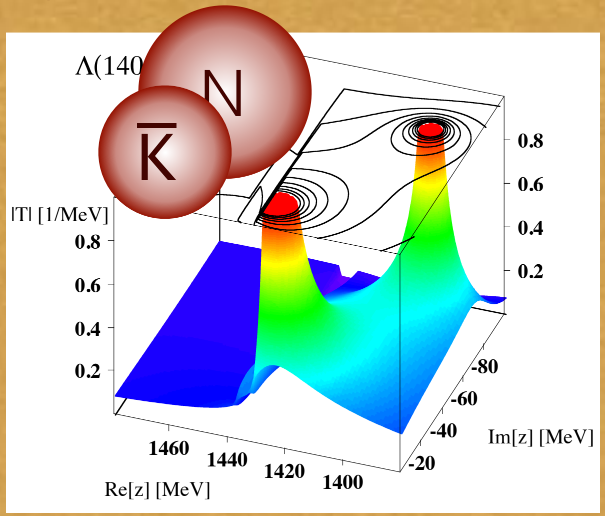
High-mass pole	$X_{\pi\Sigma}$	$X_{\bar{K}N}$	Z
Coupled channel	-0.04-0.23i	0.95-0.14i	0.08-0.37i
Single-channel	-	1.01-0.07i	-
Residue of pole	-0.19-0.22i	1.14+0.01i	0.05+0.21i

- **complex because of the unstable nature of** Λ(1405)
- $X_{\bar{K}N}$ **is consistent with each other**
- **Re** $X_{\bar{K}N}$ ~1, **Im** $X_{\bar{K}N}$ << 1 **—>** $\bar{K}N$ **dominance**

Summary

- Coupled-channel $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$ potentials based on NLO chiral SU(3) dynamics.

  - Realistic precision (χ^2/d.o.f. ~ 1)
  - Explicit treatment of πY channels
  - Simpler energy dependence
  - Compositeness: $\bar{K}N$ dominance of high-mass pole of $\Lambda(1405)$



K. Miyahara, T. Hyodo, W. Weise, arXiv:1804.08269 [nucl-th]