$\bar{K}N$ and ΩN interactions in effective field theory

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- Introduction
- $\bar{K}N$ interaction
  - Chiral SU(3) dynamics (scattering amplitude)

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

  - Local $\bar{K}N(\text{-}\pi\Sigma\text{-}\pi\Lambda)$ potentials

    T. Hyodo, W. Weise, PRC 77, 035204 (2008);
    K. Miyahara. T. Hyodo, PRC93, 015201 (2016);
    K. Miyahara. T. Hyodo, W. Weise, PRC98, 025201 (2018)

- ΩN interaction
  - Potential (effect from inelastic channels)

    T. Sekihara, Y. Kamiya, T. Hyodo, PRC98, 015205 (2018)

Low-energy (s-wave) $\bar{K}N$ and ΩN interactions

$\bar{K}N$ interaction ($J = 1/2$)

$I = 0$ channel

- decays into $\pi\Sigma$
- $\Lambda(1405)$ resonance

$I = 1$ channel

- decays into $\pi\Sigma$ and $\pi\Lambda$

↑ ↑

Experimental data

ΩN interaction ($I = 1/2$)

$^5S_2$ channel

- decays into $\Sigma\Xi$ and $\Lambda\Xi$ in d-wave (small)

$^3S_1$ channel

- decays into $\Sigma\Xi$ and $\Lambda\Xi$ in s-wave (large)

↑

lattice QCD data

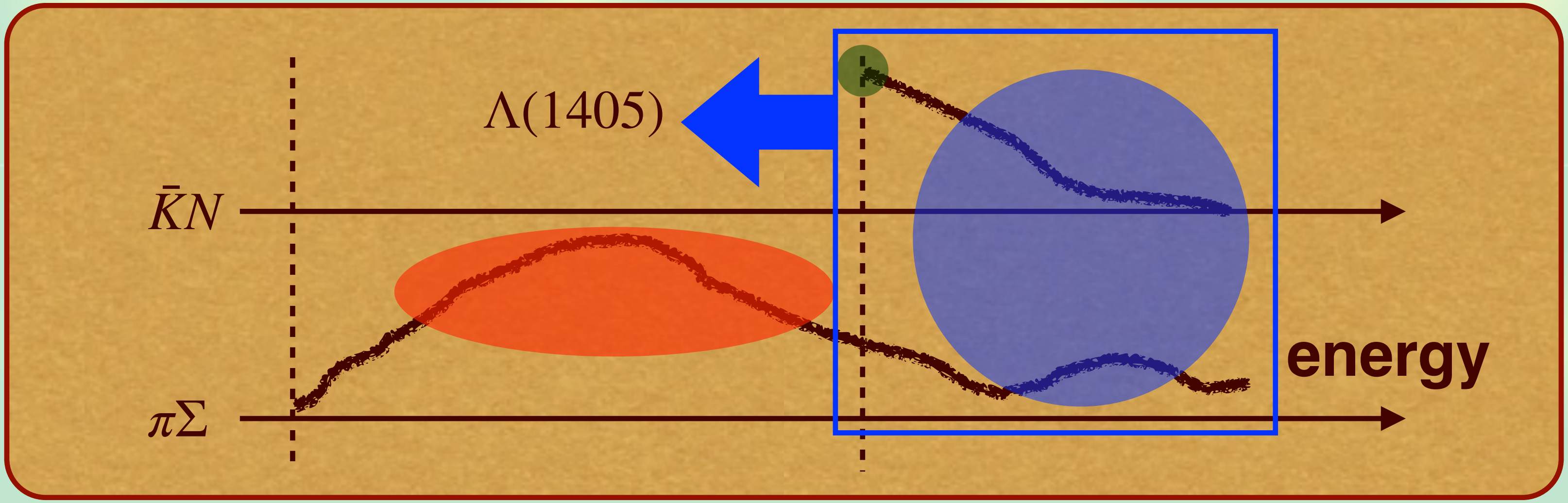
Strategy for $\bar{K}N$ interaction

Above the $\bar{K}N$ threshold: direct constraints

- $K^- p$ **total cross sections** (old data)
- $\bar{K}N$ **threshold branching ratios** (old data)
- $K^- p$ **scattering length** (new data: SIDDHARTA)

Below the $\bar{K}N$ threshold: indirect constraints

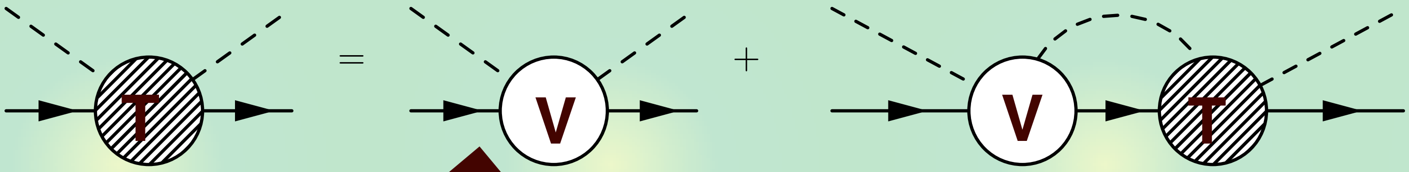
- $\pi\Sigma$ **mass spectra** (new data: LEPS, CLAS, HADES,…)

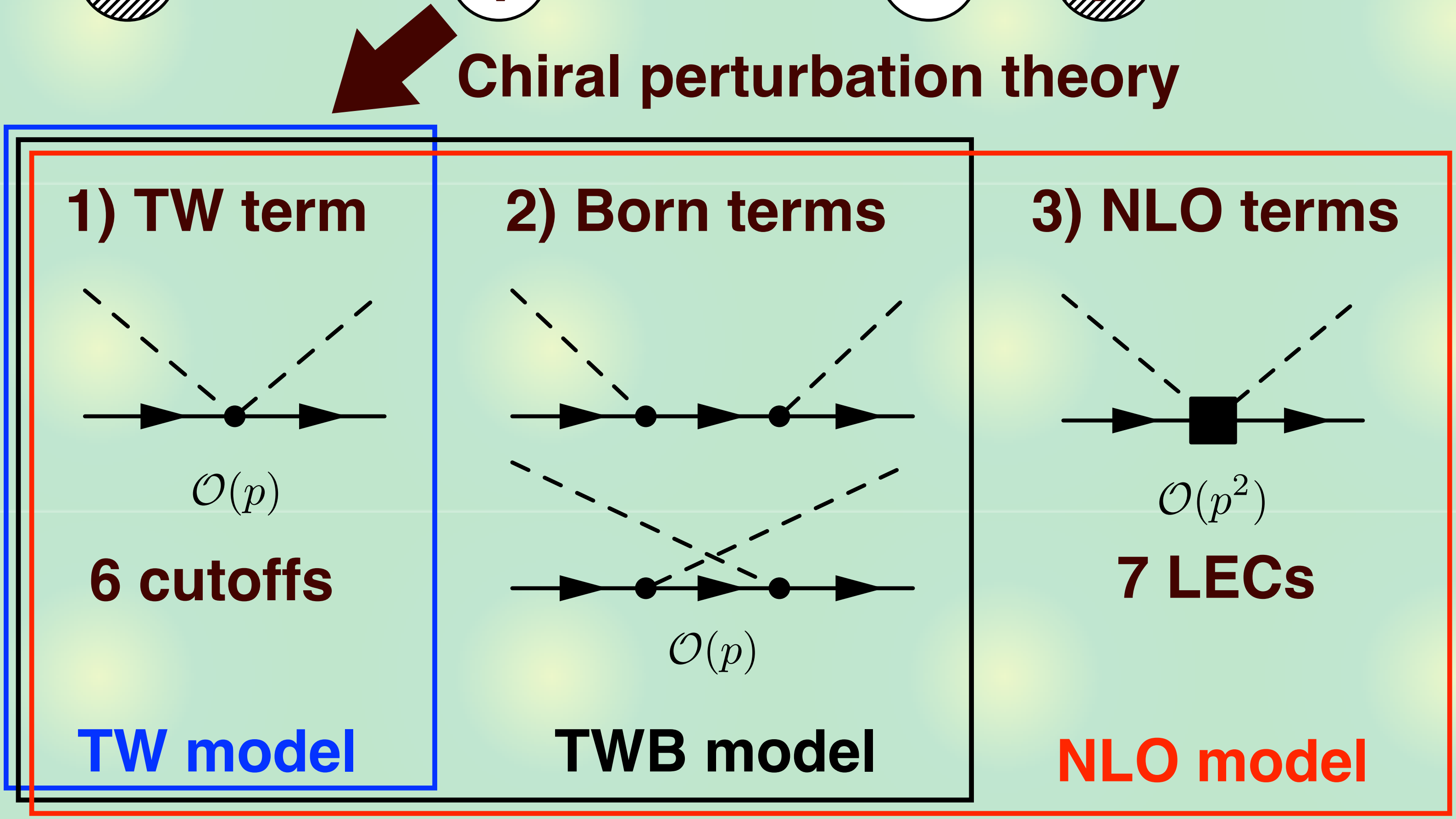


Construction of the realistic amplitude

Chiral SU(3) coupled-channels $(\bar{K}N, \pi\Sigma, \pi\Lambda, \eta\Lambda, \eta\Sigma, K\Xi)$ approach

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





Chiral perturbation theory

1) TW term

$\mathcal{O}(p)$

6 cutoffs

TW model

2) Born terms

$\mathcal{O}(p)$

TWB model

3) NLO terms

$\mathcal{O}(p^2)$

7 LECs

NLO model

Best-fit results

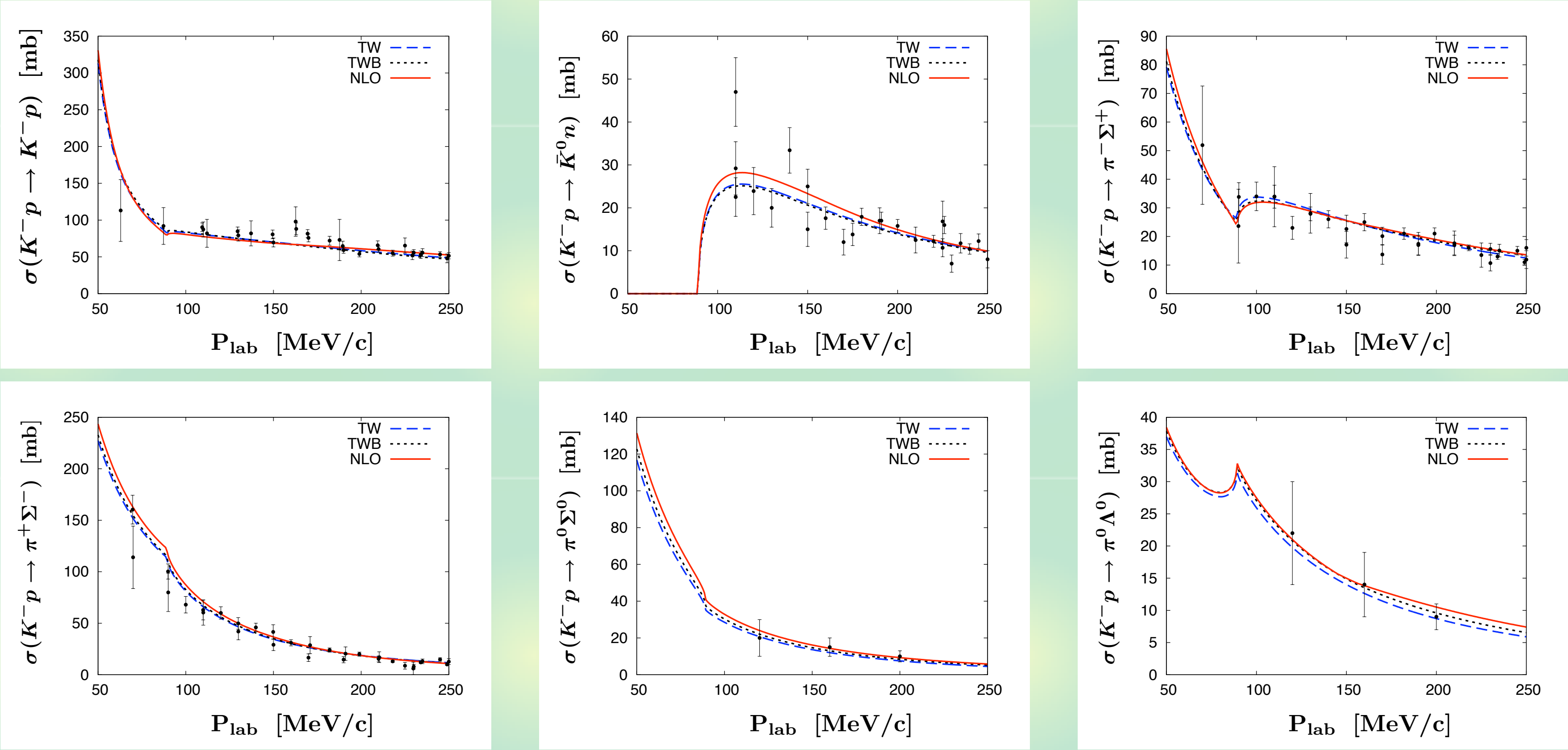
K-hydrogen

	TW	TWB	NLO	Experiment
ΔE [eV]	373	377	306	$283 \pm 36 \pm 6$ [10]
Γ [eV]	495	514	591	$541 \pm 89 \pm 22$ [10]
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	

SIDDHARTA

Branching ratios

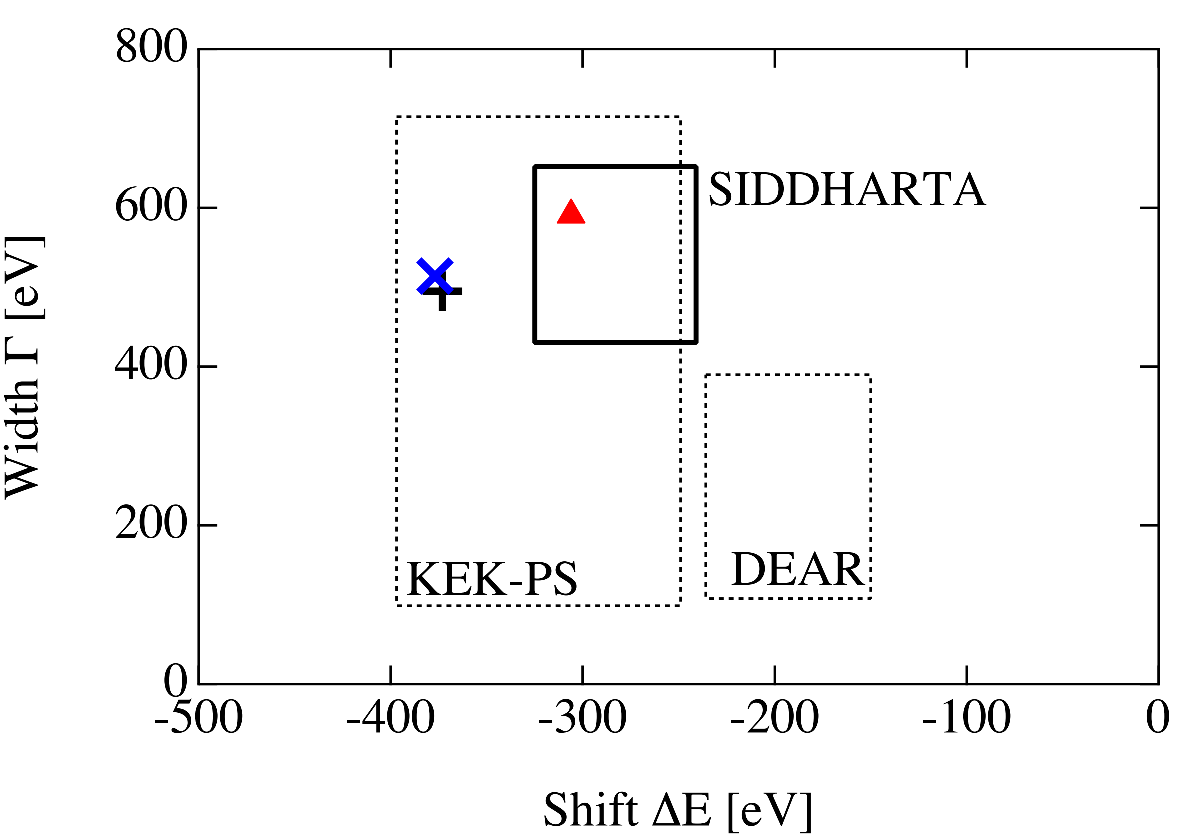
K^-p cross sections



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

Comparison with SIDDHARTA

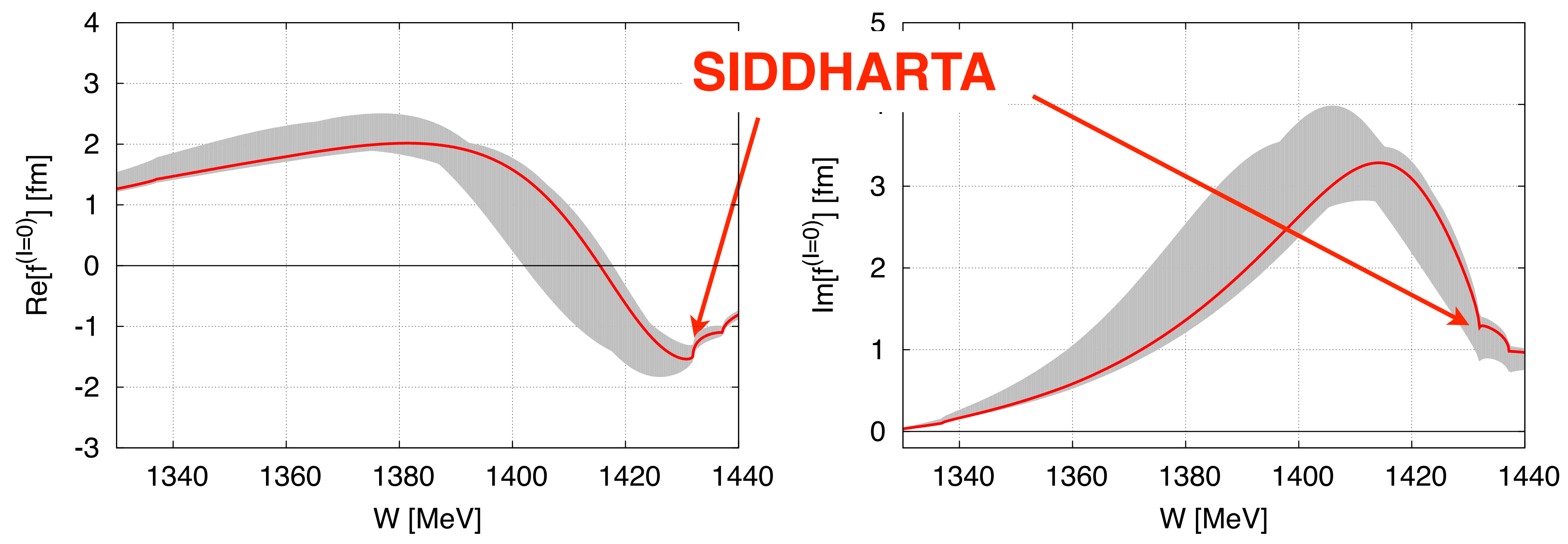
	TW	TWB	NLO
χ^2/d.o.f.	1.12	1.15	0.957



TW and TWB are reasonable, while best-fit requires NLO.

Subthreshold extrapolation

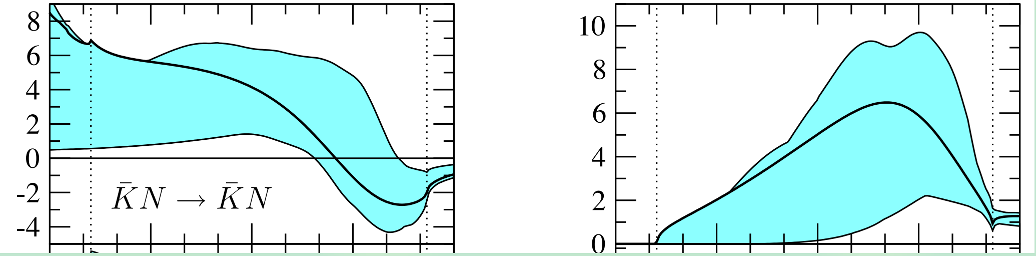
Uncertainty of $\bar{K}N \to \bar{K}N(I=0)$ amplitude below threshold



Y. Kamiya, K. Miyahara, S. Ohnishi, Y. Ikeda, T. Hyodo, E. Oset, W. Weise, NPA 954, 41 (2016)

- **c.f. without SIDDHARTA**

R. Nissler, Doctoral Thesis (2007)



SIDDHARTA is essential for subthreshold extrapolation.

Construction of $\bar{K}N$ potential

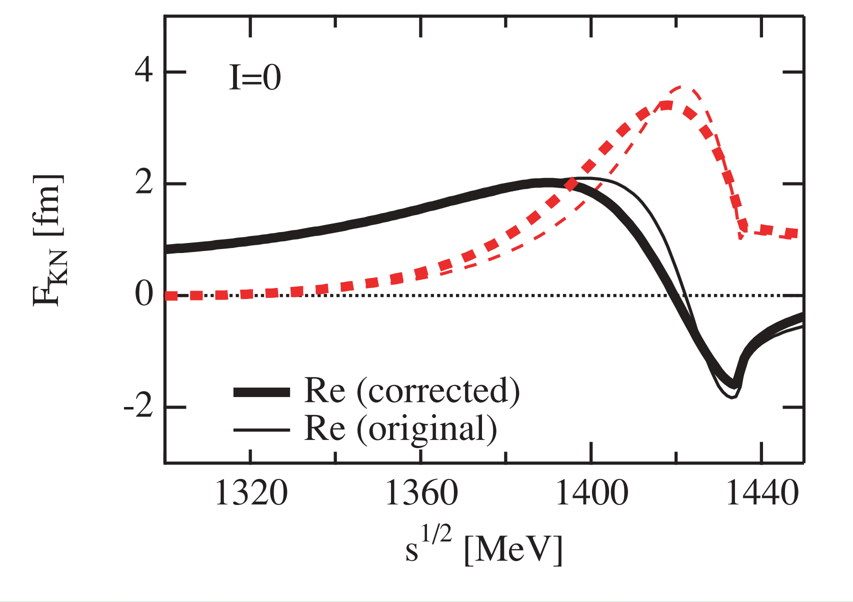
Local $\bar{K}N$ potential is useful for

- Extraction of the wave function of $\Lambda(1405)$
- Applications to few-body K-nuclei/atoms, correlation fn., ...

Strategy

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

- Equivalence of the scattering amplitude



Thin: chiral SU(3)

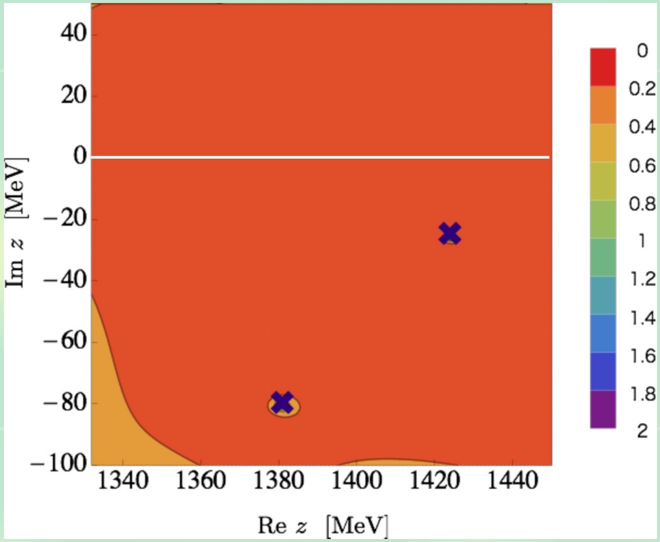
Thick: $V_{\rm local}(r, E)$
+ Schrödinger eq.

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
- Wave function: $\psi_{K^-p}(r), \psi_{\bar{K}^0n}(r)$



deviation

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

K. Miyahara. T. Hyodo, W. Weise, PRC98, 025201 (2018)

- Real-valued potential strengths
- Wave function: $\psi_{K^-p}(r), \psi_{\bar{K}^0n}(r), \psi_{\pi^+\Sigma^-}(r), \psi_{\pi^0\Sigma^0}(r), \psi_{\pi^-\Sigma^+}(r), \psi_{\pi^0\Lambda}(r)$

Realistic potentials $(\chi^2/\mathrm{d.o.f} \sim 1)$ are now available.

Summary: $\bar{K}N$ interaction

- $\bar{K}N$ interaction is studied with chiral EFT.
- All existing data (scattering + K-hydrogen) are reproduced with $\chi^2/\mathrm{d.o.f} \sim 1$.

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

- Realistic local potentials:

  basic construction method

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

  effective single $\bar{K}N$ channel potential

K. Miyahara. T. Hyodo, PRC93, 015201 (2016)

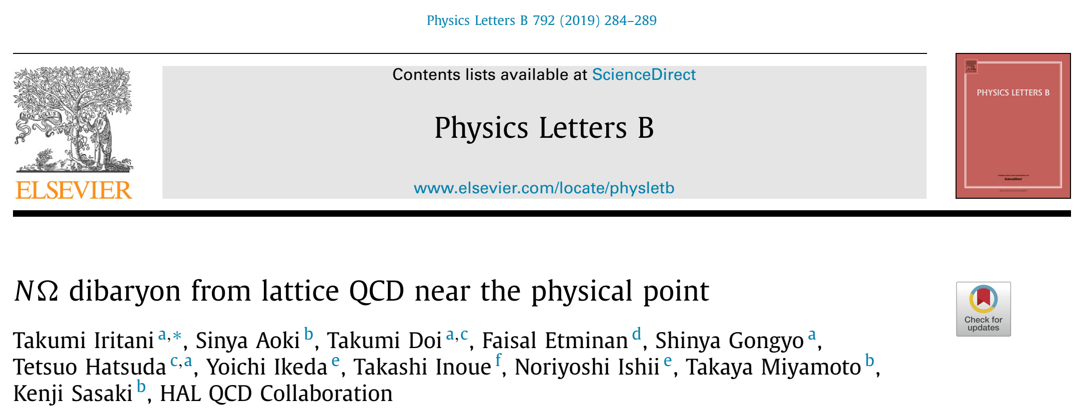
  coupled-channels potential $\bar{K}N$-$\pi\Sigma$-$\pi\Lambda$

K. Miyahara. T. Hyodo, W. Weise, PRC98, 025201 (2018)

ΩN interaction

Lattice QCD

T. Iritani, *et al.*, HAL QCD, Phys. Lett. B792, 284 (2019)



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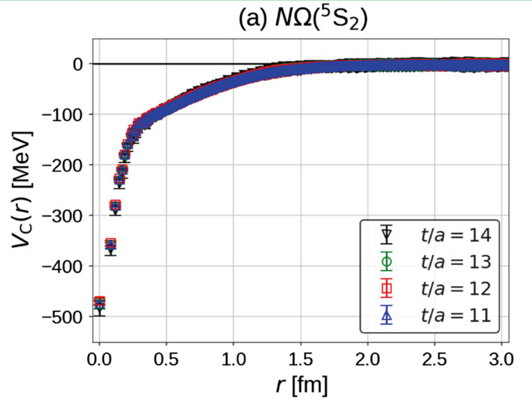
$N\Omega$ dibaryon from lattice QCD near the physical point

Takumi Iritani [a,*], Sinya Aoki [b], Takumi Doi [a,c], Faisal Etminan [d], Shinya Gongyo [a], Tetsuo Hatsuda [c,a], Yoichi Ikeda [e], Takashi Inoue [f], Noriyoshi Ishii [e], Takaya Miyamoto [b], Kenji Sasaki [b], HAL QCD Collaboration



Note:

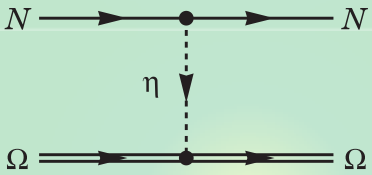
- **Effective single-channel framework (inelastic/d-wave ΩN channels are not explicitly included)**
- **Not exactly at physical point ($m_\pi \sim 146$ MeV)**
- **Physical origin (mechanism) of the potential?**

Effective field theory can fill this gap.

Strategy

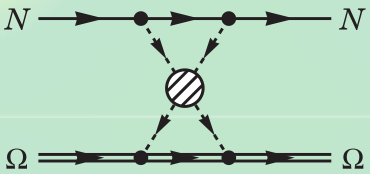
Long range part: known physical mechanisms

- A: one meson (η) exchange



(a)

- B: correlated two-meson exchanges

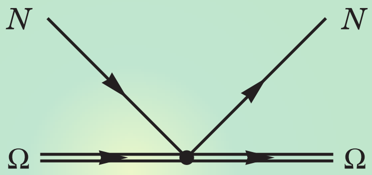


(b)

- determined by empirical information

Short range part

- C: contact term

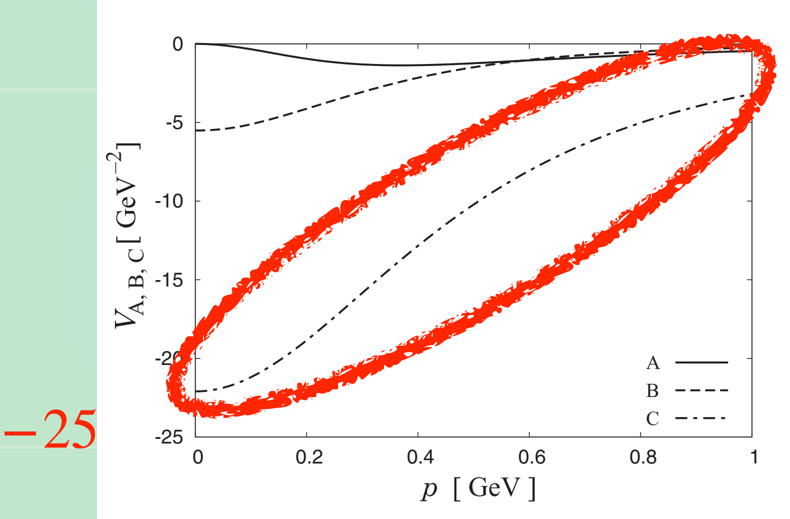


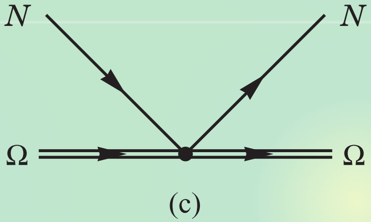
(c)

- determined by lattice QCD (scattering length@$m_\pi \sim 146$ MeV)

Mechanism of ΩN interaction

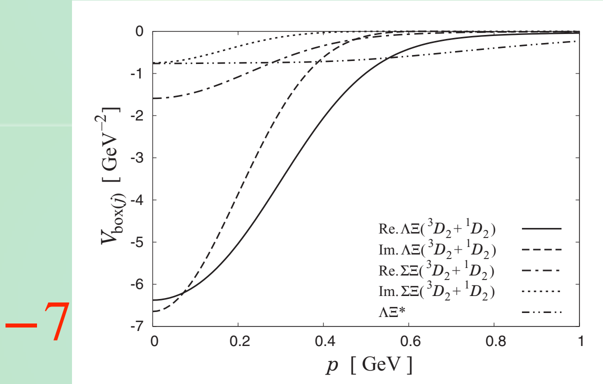
Non-local potential (in momentum space, $V(p,p)$)

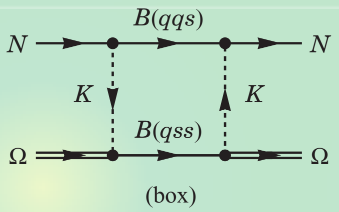




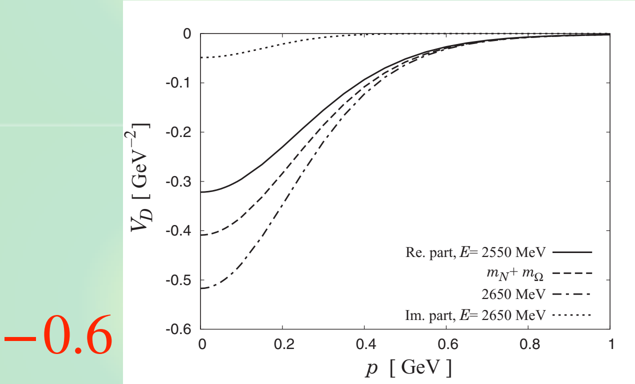
Strong short range attraction is needed.

$\Sigma\Xi$ and $\Lambda\Xi$ channels





d-wave ΩN channels



Diagonal (contact) >> $\Sigma\Xi$ and $\Lambda\Xi$ >> d-wave ΩN

Quasi-bound state

Scattering length and quasi-bound state

m_π	V_{strong}	V_C	a **[fm]**	B **[MeV]**	Γ **[MeV]**
146	**real**	**off**	**7.4 (input)**		
146	**comp**	**off**	**4.1-3.1i**		
phys	**real**	**off**		**0.3**	**0**
phys	**comp**	**off**	**5.3-4.3i**	**0.1**	**1.5**
phys	**comp**	**on**		**1.0**	**2.0**

- **HAL QCD final:** $a \sim 5.3$ fm **@** $m_\pi \sim 146$ MeV
- m_π **extrapolation: binding decreases**
- $\mathrm{Im}\ V_{\mathrm{strong}}$ **: dispersive repulsive shift**
- V_{C} **: binding increases** ~ 1 MeV

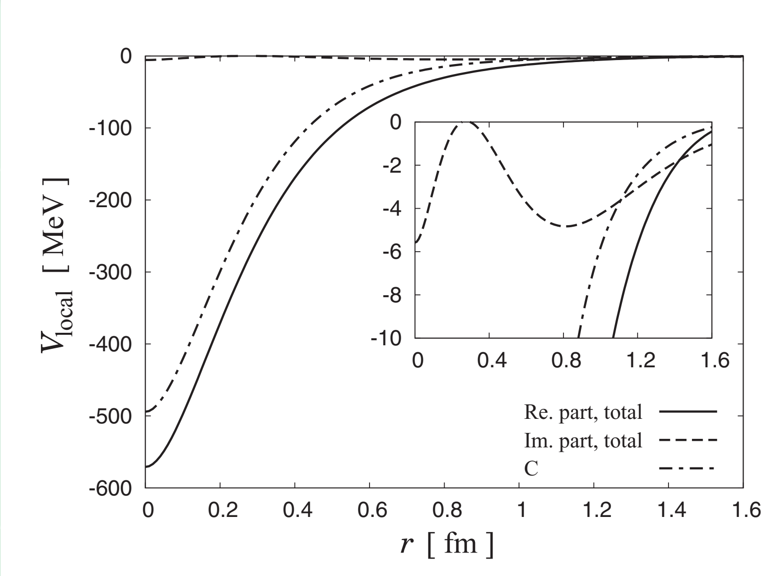
Equivalent local potential

Equivalent local potential

- superposition of Yukawa fns

$$V_{\mathrm{local}}(r) = \mathrm{F.T.} \sum_{n=1}^{9} \frac{C_n}{q^2 + m_n^2} \left(\frac{\Lambda^2}{\Lambda^2 + q^2} \right)^2$$

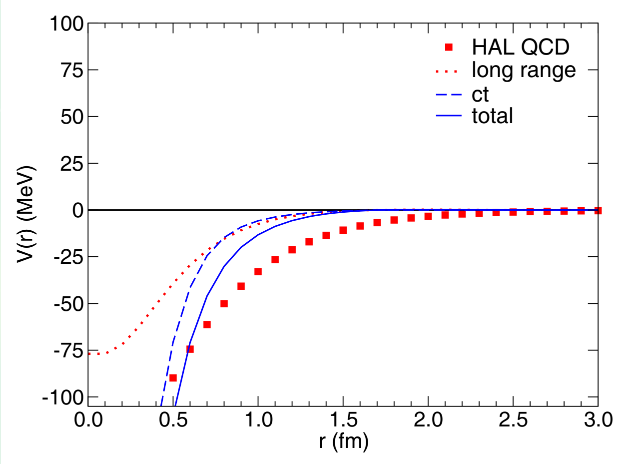
- fit nonlocal potential with C_n



Comparison with HAL QCD potential

J. Haidenbauer, U.G. Meissner, Eur. Phys. J. A55, 70 (2019)

- long-range tail?



Summary: ΩN interaction

- $\Omega N(J=2)$ **interaction is studied.**

  long range: known meson exchanges

  short range: contact term <— lattice QCD

- **Strong short-range attraction is needed on top of meson exchanges.**

- $\Sigma\Xi$ **and** $\Lambda\Xi$ **channels give small imaginary part (absorption) of the potential.**

- $\Omega^{-}p$ **quasi-bound state (with Coulomb)**

  $B \sim 1$ MeV, $\Gamma \sim 2$ MeV

T. Sekihara, Y. Kamiya, T. Hyodo, PRC98, 015205 (2018)