Few-body approach for structure of light kaonic nuclei

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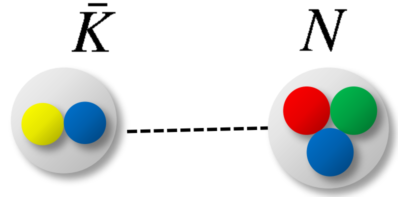
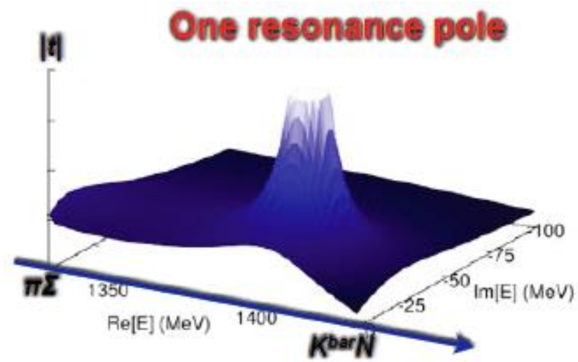
$K^{bar}N$ interaction



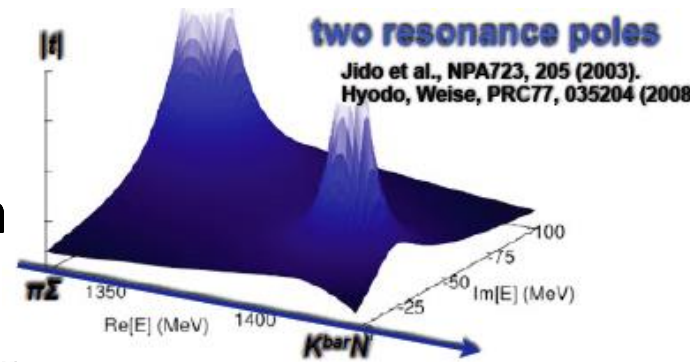
Dalitz, Wong, Tajasekaran, PR 153(1967)1617.



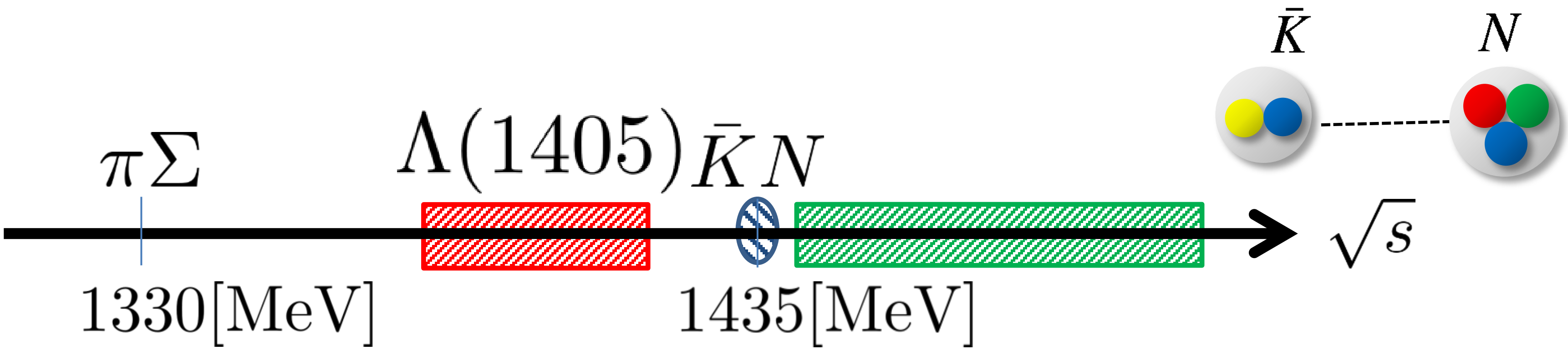
- Phenomenological $K^{bar}N$ interactions
  - Scattering length and flavor SU(3)
  - Strongly attractive
  - produce quasi-bound state of $K^{bar}N$, so-called Λ(1405)
- Chiral SU(3) symmetry

Kaiser, Siegel, Weise, NPA594(1995).

  - NG boson associated with spontaneous breaking of chiral SU(3) symmetry
  - Strongly attractive
  - Consistent with $K^{bar}N$ scattering data
  - Two poles,
    $K^{bar}N$ quasi-bound state → 1420MeV



Experimental constraint on $K^{bar}N$ interaction



above $K^{bar}N$ threshold energy: - $K^{-}p$ cross section

at/just-below KN threshold energy: - Branching ratio

- kaonic atom(new data by SIDDHARTA)

below the $K^{bar}N$ threshold energy:

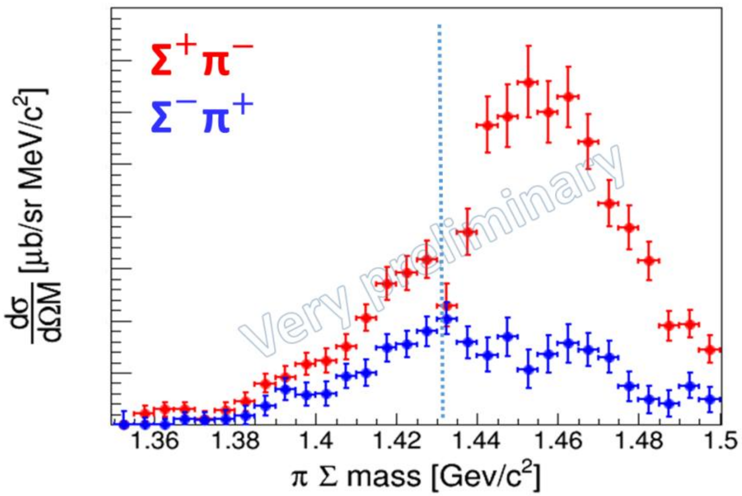
- So far, cannot perform $\pi\Sigma$ elastic scattering experimentally
  → large ambiguity still remains
- Few-body reaction ($K^{-}d \rightarrow \pi\Sigma n$)
- Few-body K-bound system (*KNN, KNNNN, KNNNN…..*)

J-PARC E31 experiment

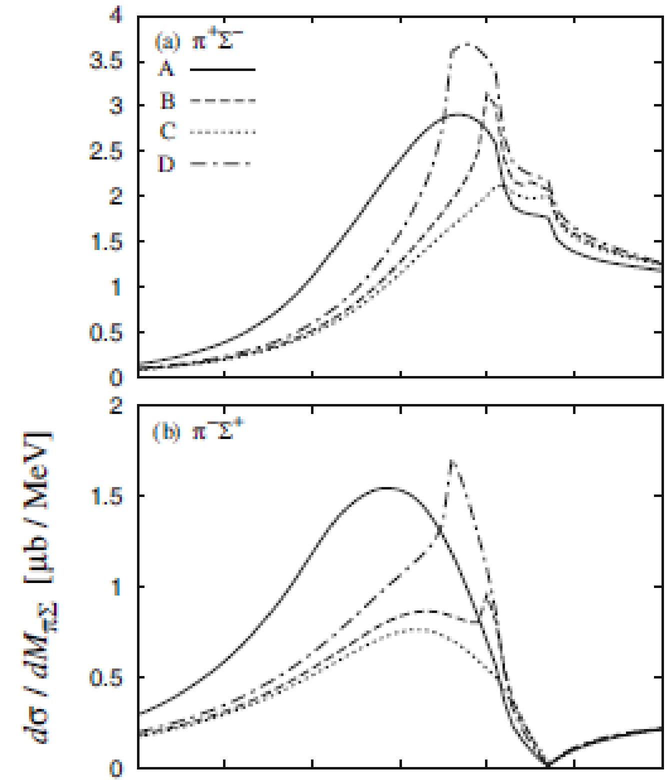
http://j-parc.jp/researcher/Hadron/en/pac_0907/pdf/Noumi.pdf

- ✓ $\Lambda(1405)$ production via the $K^{-}d \rightarrow \pi\Sigma n$. ($p_K$=1 GeV)
- ✓ We can access below the $K^{bar}N$ threshold.

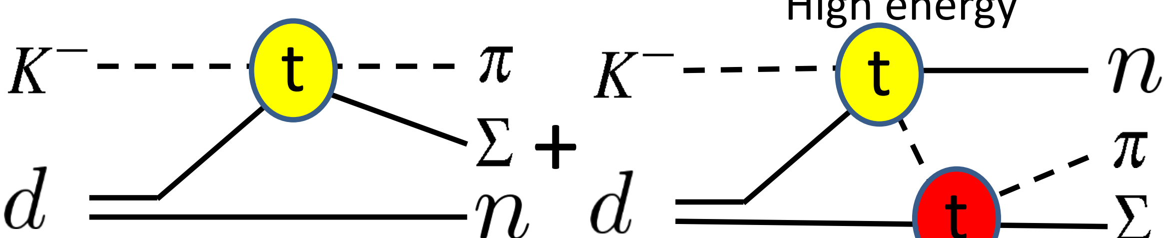
Kawasaki's slide in MENU2016



Jido, Oset, Sekihara, EPJA42, 257(2009).



High energy



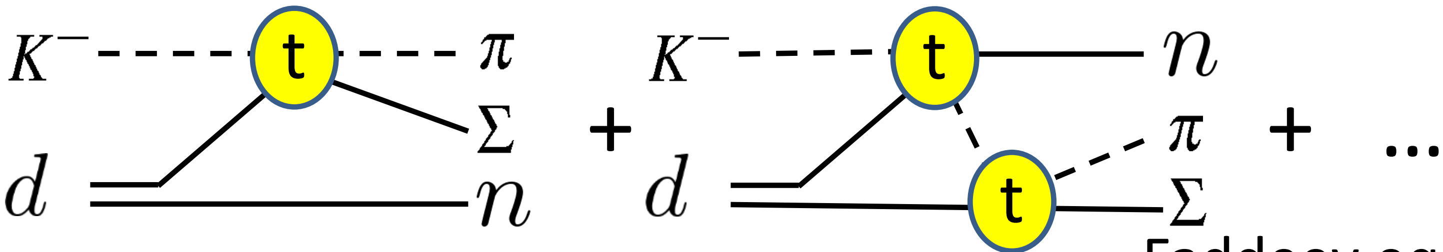
low energy

(p_K=800 MeV)

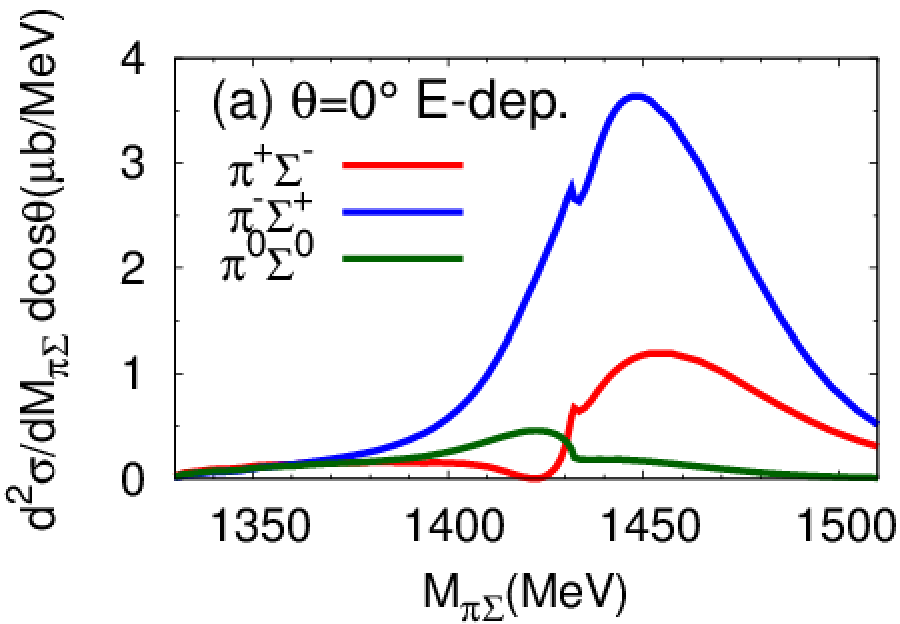
dominant for line shape

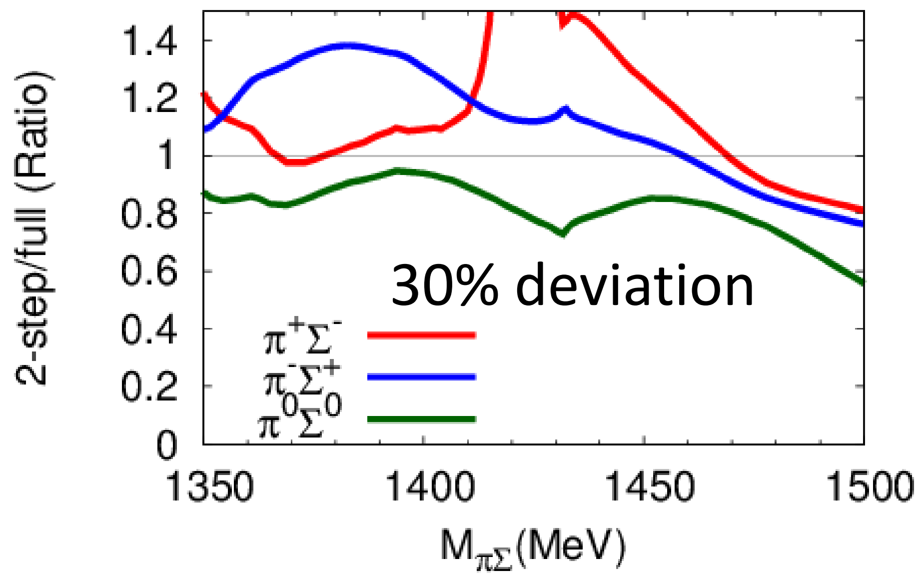
Full multiple scattering

SO, Y. Ikeda, T. Hyodo, W. Weise, Phys. Rev. C93, 025207 (2016).



Faddeev equations





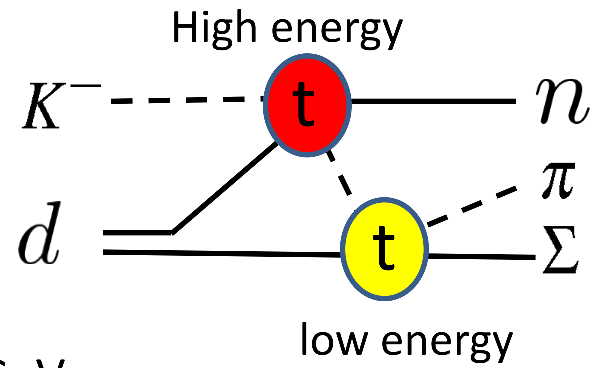
- 2-step calculation qualitatively reproduce the cross section obtained by full calculation
- Quantitative (Resonance parameters)

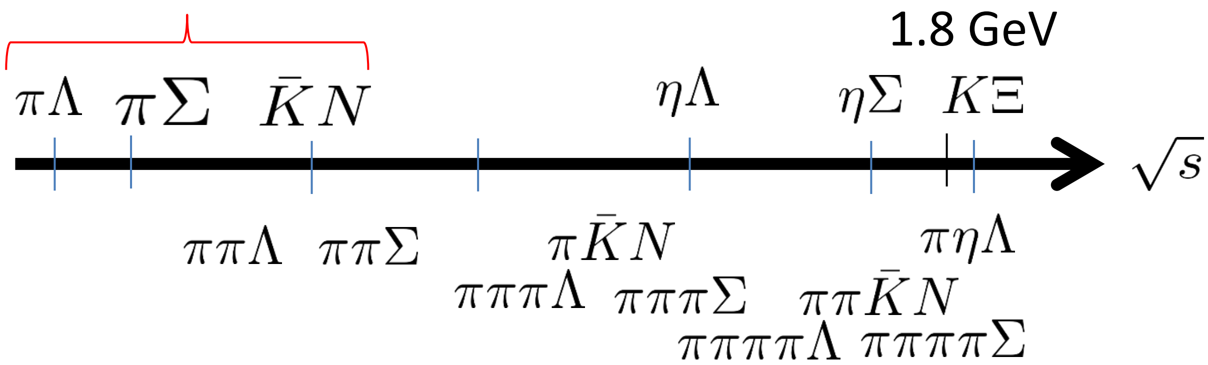
  → Faddeev calculation is necessary

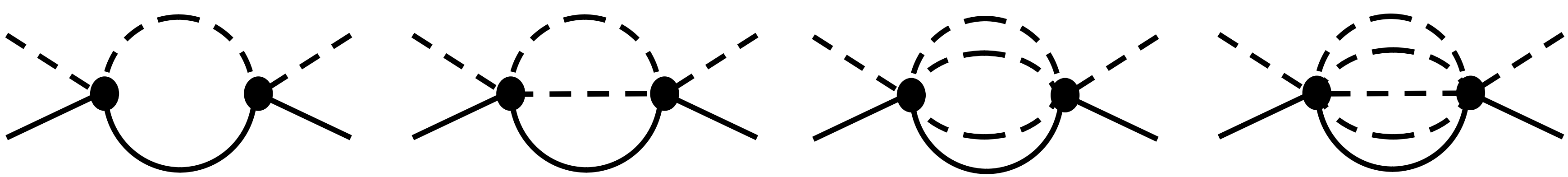
Magnitude of cross section

For the magnitude of the cross section,
high energy amplitude is important

H. Kamano and T.-S. H. Lee, arXiv:1608.03470[nucl-th].

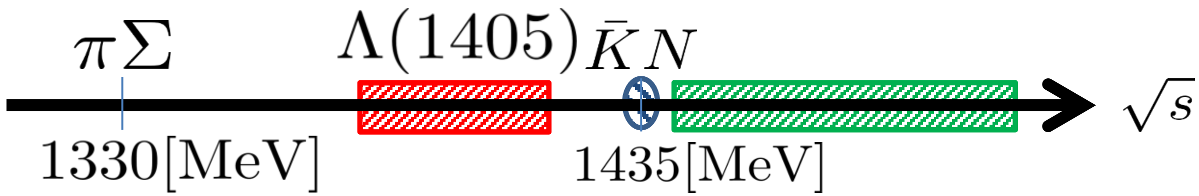




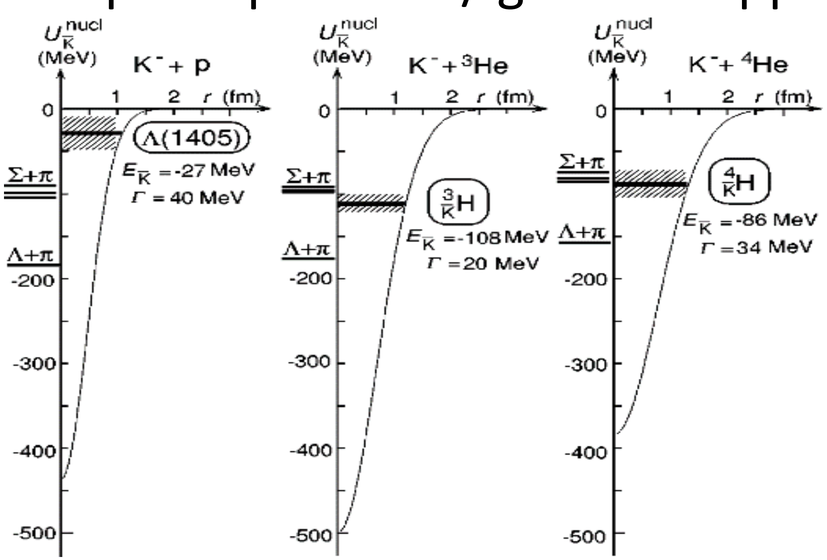


Kaonic nuclei

- Few-body K-bound system (*KNN, KNNNN, KNNNN.....*) is useful to study subthreshold $K^{bar}N$ interaction



- deeply bound and high density systems are proposed
  - ✓ phenomenological $\bar{K}N$ potential which reproduce the $\Lambda(1405)$ as $\bar{K}N$ quasi-bound state (strongly attractive in *I=0, L=0)*
  - ✓ optical potential/ g-matrix approach



Y. Akaishi, T. Yamazaki, PRC 65, 044005 (2002).

A. Dote, et. al., PLB590, 51(2004).

Strategy of this work

Y. Akaishi, T. Yamazaki, PRC 65, 044005 (2002).
Dote, et. al., PLB590, 51(2004).

AY-potential

- Phenomenological
- Energy independent

Many-body approximation

- Optical potential
- g-matrix interaction

Deeply binding and compressed systems

?

This works

SIDDHARTA pot.

- Chiral SU(3) dynamics
- Energy dependent

Miyahara, Hyodo,
PRC 93 (2016) 1, 015201.

Few-body approach

- Correlated Gaussian basis
- Stochastic variational method
- Three- to seven-body calc.

Varga, Suzuki,
Phys. Rev C52 (1995) 2885.

How structure of light nuclei is changed by injected kaon?

$K^{bar}N$ interactions

SIDDHARTA potential

K.Miyahara, T.Hyodo, PRC 93 (2016) 1, 015201.

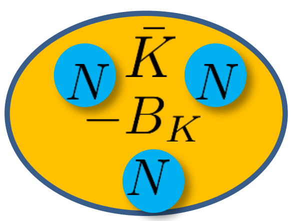
- Energy-dependent $K^{bar}N$ single-channel potential
- Chiral SU(3) dynamics using driving interaction at NLO
- Pole energy: 1424 - 26i and 1381 – 81i MeV

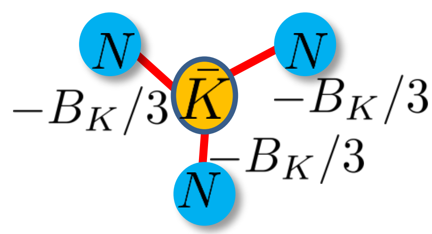
Y.Ikeda, T.Hyodo, W.Weise, NPA881 (2012) 98 .

- $K^{bar}N$ two-body energy in N-body systems are determined as:

$$\sqrt{s} = m_N + m_{\bar{K}} + \delta\sqrt{s} \quad , \qquad -B_K \equiv \langle\Psi|H|\Psi\rangle - \langle\Psi|H_N|\Psi\rangle \quad ,$$

$$\text{Type I:} \quad \delta\sqrt{s} = -B_K \quad , \qquad \text{Type II:} \quad \delta\sqrt{s} = -B_K/(N-1) \quad ,$$ for *N-body*





A. Dote, T. Hyodo, W. Weise, NPA804, 197 (2008).

Akaishi-Yamazaki (AY) potential

Akaishi, Yamazaki, PRC65, 04400(2002).

- Energy-independent
- Reproduce $\Lambda(1405)$ as $K^{bar}N$ quasi-bound state

Correlated Gaussian basis

Varga, Suzuki, Phys. Rev C52 (1995) 2885.
Varga, Suzuki, Comp. Pnys. Com. 106 (1997) 157.

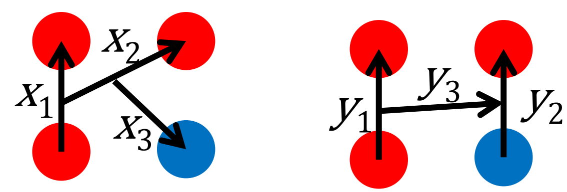
$$\Psi = \sum_{i=1}^{K} c_i \phi_i\,, \qquad \phi_i = \mathcal{A}\left\{e^{-\frac{1}{2}\tilde{\boldsymbol{x}}A_i\boldsymbol{x}} \chi_{iJM}\eta_{iTM_t}\right\}$$

A_i: $(N-1)\times(N-1)$ matrix (paramaters of coordinates) for *N-body*

$\boldsymbol{x} = \{\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_{N-1}\}$, χ_{iJM}: spin function, η_{iTM_t}: isospin function

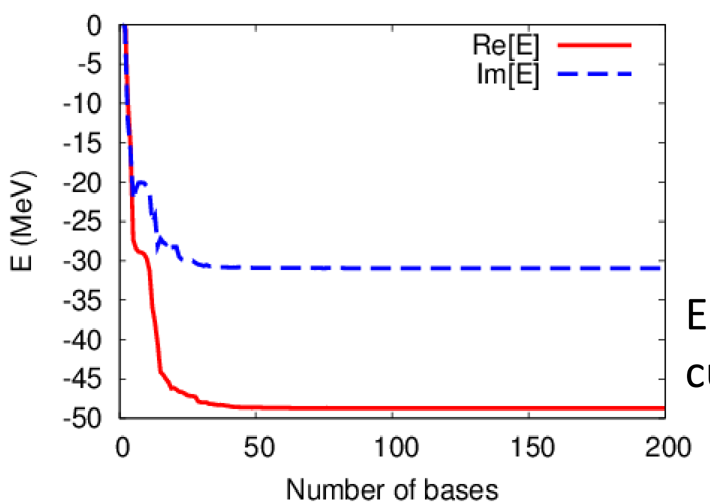
- Higher partial wave for each $\boldsymbol{x}_i$ are included by off-diagonal component of A_i.
- Matrix elements are analytically calculable for *N*-body systems
- Functional form of the correlated Gaussian remains unchanged under the coordinate transformation

$$\mathbf{y} = T\mathbf{x} \Rightarrow \tilde{\mathbf{y}}B\mathbf{y} = \tilde{\mathbf{x}}\tilde{T}BT\mathbf{x}$$



Stochastic variational method

- To obtain the well variational basis, we increase the basis size one-by-one by searching for the best variational parameter A_i among many random trials



Energy convergence curve for KNN

Structure of kaonic nuclei (N=3-5)

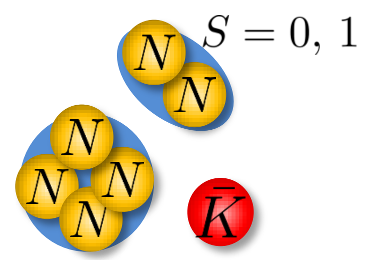
Model	SIDDHARTA Type I	SIDDHARTA Type II	AY
K^-pp-$\bar{K}^0pn$ $(J^\pi = 0^-)$			
B[MeV]	27.9	26.1	48.7
Γ[MeV]	30.9	59.3	61.9
${}^3\mathrm{He}K^-$-${}^3\mathrm{H}\bar{K}^0$ $(J^\pi = 1/2^-)$			
B[MeV]	45.3	49.7	72.6
Γ[MeV]	25.5	69.4	78.6
${}^4\mathrm{He}K^-$-${}^4\mathrm{H}\bar{K}^0$ $(J^\pi = 0^-)$			
B[MeV]	69.6	75.5	87.4
Γ[MeV]	28.0	74.5	87.2

- Binding energies are similar values for Type I, II
- Binding energies for SIDDHARTA pot. are 20 MeV smaller than AY pot.
- Width of Type II is 2-3 times larger than Type I
- Binding energy for AY-potential is less than 100 MeV

Structure of $K^{bar}NNNNNN$ with $J^{\pi}=0^{-}$ and 1^{-}

	$^{6}\mathrm{Li}K^{-}$-$^{6}\mathrm{He}\bar{K}^{0}$ ($J^{\pi}=0^{-}$)		
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	68.7	77.0	102
Γ[MeV]	24.0	73.2	86.4

	$^{6}\mathrm{Li}K^{-}$-$^{6}\mathrm{He}\bar{K}^{0}$ ($J^{\pi}=1^{-}$)		
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	71.5	78.8	93.7
Γ[MeV]	26.3	74.0	86.7



	B[MeV]
$^{6}\mathrm{He}$ (0)	32.22
$^{6}\mathrm{Li}$ (1)	35.81

- 1^{-} state are ground state for SIDDHARTA potential, but the 0^{-} state is ground state for AY potential
- From the energy spectra of seven-body system, we may extract the information of KN interaction

Structure of K^{bar}NNNNNN with $J^{\pi}=0^{-}$ and 1^{-}

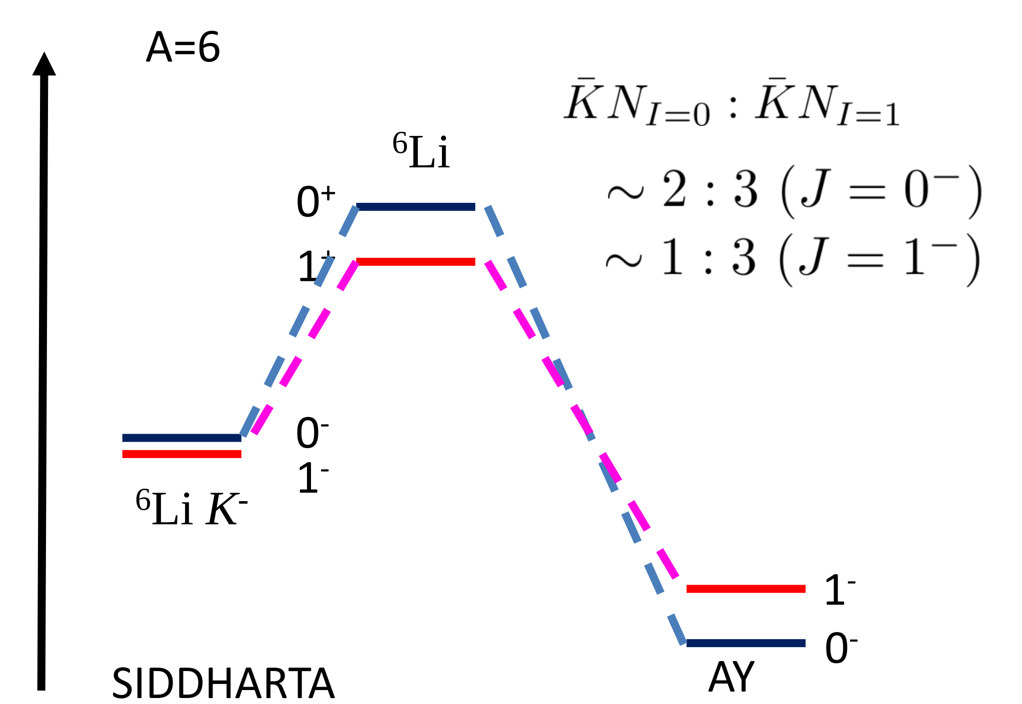
A=2

	NN	KNN
J=0	unbound	bound
J=1	bound (d)	unbound

$$\bar{K}N_{I=0} : \bar{K}N_{I=1}$$

$$\sim 3:1\ (J=0^{-})$$

$$\sim 1:3\ (J=1^{-})$$



- 1^{-} state are ground state for SIDDHARTA potential, but the 0^{-} state is ground state for AY potential
- From the energy spectra of seven-body system, we may extract the information of KN interaction

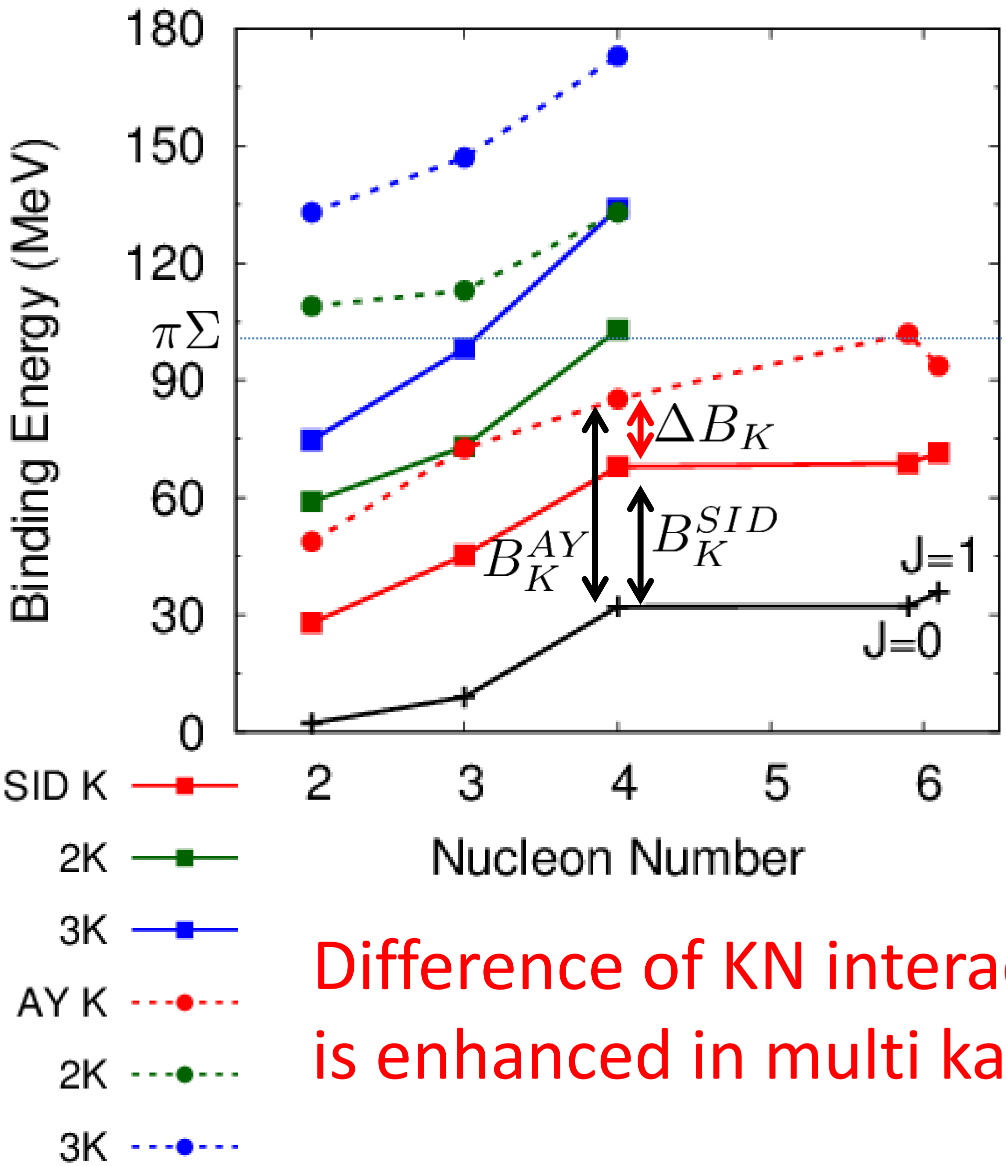
Summary

- We have investigated the structure of light kaonic nuclei, *$K^{bar}NN$, $K^{bar}NNN$, $K^{bar}NNNN$ and $K^{bar}NNNNNN$*
- Width largely depends how to deal with two-body energy in N-body systems, and it is around 25-30 MeV for Type I and 60-75 MeV for Type II
- B.E is not sensitive how to deal with two-body energy in N-body systems
- Difference between B.E. for SIDDHARTA and AY is $\Delta B_K \sim 20 \text{ MeV}$
- In the seven-body systems, $J^{\pi}=1^-$ and 0^- states are degenerate for SIDDHARTA potential, but 0^- state is ground state for AY potential

Future plan

- Channel-coupling between $K^{bar}N$- $\pi\Sigma$
- Kaonic atom (T. Hoshino, S.O, W. Horiuchi)

N and K number dependence of B.E.



$$B_K^{SID} \equiv B^{SID} - B_N \sim 34 \text{ MeV}$$
$$B_K^{AY} \equiv B^{AY} - B_N \sim 58 \text{ MeV}$$
$$\Delta B_K \equiv B^{AY} - B^{SID} \sim 24 \text{ MeV}$$
(averaged value)

$$B_{2K}^{SID} \sim 64 \text{ MeV}$$
$$B_{2K}^{AY} \sim 104 \text{ MeV}$$
$$\Delta B_{2K} \sim 40 \text{ MeV}$$

$$B_{3K}^{SID} \sim 88 \text{ MeV}$$
$$B_{3K}^{AY} \sim 137 \text{ MeV}$$
$$\Delta B_{3K} \sim 49 \text{ MeV}$$

Difference of KN interaction
is enhanced in multi kaonic nuclei

Structure of double kaonic nuclei

K^-K^-pp-$K^-\bar{K}^0pn$-$\bar{K}^0\bar{K}^0nn$ $(J^\pi = 0^+)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	59.0	54.8	109
Γ[MeV]	64.0	124	143

${}^3\mathrm{Li}K^-K^-$-${}^3\mathrm{He}K^-\bar{K}^0$-${}^3\mathrm{H}\bar{K}^0\bar{K}^0$ $(J^\pi = 1/2^+)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	73.1	72.8	113
Γ[MeV]	58.6	135	160

${}^4\mathrm{Li}K^-K^-$-${}^4\mathrm{He}K^-\bar{K}^0$-${}^4\mathrm{H}\bar{K}^0\bar{K}^0$ $(J^\pi = 0^+)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	103	111	133
Γ[MeV]	60.1	149	187

- Binding energies are similar values for Type I and II
- Width of Type II is 2 times larger than Type I
- Large decay width

Structure of triple kaonic nuclei

$K^-K^-K^-pp$-$K^-K^-\bar{K}^0pn$-$K^-\bar{K}^0\bar{K}^0nn$ $(J^\pi = 0^-)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	74.7	58.1	133
Γ[MeV]	112	163	205

${}^3\mathrm{Li}K^-K^-K^-$-${}^3\mathrm{He}K^-K^-\bar{K}^0$-${}^3\mathrm{H}K^-\bar{K}^0\bar{K}^0$-${}^3n\bar{K}^0\bar{K}^0\bar{K}^0$ $(J^\pi = 1/2^-)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	98.2	91.4	147
Γ[MeV]	97.9	190	245

${}^4\mathrm{Be}K^-K^-K^-$-${}^4\mathrm{Li}K^-K^-\bar{K}^0$-${}^4\mathrm{He}K^-\bar{K}^0\bar{K}^0$-${}^4\mathrm{H}\bar{K}^0\bar{K}^0\bar{K}^0$ $(J^\pi = 0^-)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	134	140	173
Γ[MeV]	96.4	219	294

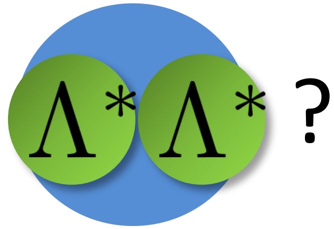
Λ(1405) in multi-kaonic nuclei

$$|[\bar{K}N]_{I=0}\rangle = \frac{1}{\sqrt{2}}[|K^-p\rangle - |\bar{K}^0 n\rangle]$$

K^-K^-pp-$K^-\bar{K}^0pn$-$\bar{K}^0\bar{K}^0nn$ ($J^\pi = 0^+$)			
Model	SIDDHARTA		AY
	Type I	Type II	
$P_{K^-K^-}$	0.35	0.35	0.34
$P_{K^-\bar{K}^0}$	0.37	0.36	0.36
$P_{\bar{K}^0\bar{K}^0}$	0.29	0.29	0.30

2Λ*

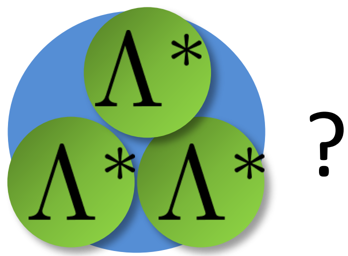
0.25
0.50
0.25



$^3\mathrm{Li}K^-K^-K^-$-$^3\mathrm{He}K^-K^-\bar{K}^0$-$^3\mathrm{H}K^-\bar{K}^0\bar{K}^0$-$^3n\bar{K}^0\bar{K}^0\bar{K}^0$ ($J^\pi = 1/2^-$)			
Model	SIDDHARTA		AY
	Type I	Type II	
$P_{K^-K^-K^-}$	0.02	0.01	0.05
$P_{K^-K^-\bar{K}^0}$	0.50	0.51	0.46
$P_{K^-\bar{K}^0\bar{K}^0}$	0.47	0.47	0.44
$P_{\bar{K}^0\bar{K}^0\bar{K}^0}$	0.01	0.01	0.05

3Λ*

0.125
0.375
0.375
0.125



Multi-Λ(1405) is not clustered in ground state of multi-KN systems

K^-K^-pp-$K^-\bar{K}^0pn$-$\bar{K}^0\bar{K}^0nn$ ($J^\pi = 0^+$)			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	59.0	54.8	109
Γ[MeV]	64.0	124	143
$B_{\bar{K}}$[MeV]	$122 + i51.4$	$119 + i98.7$	$166 + i94.5$
$\delta\sqrt{s}$[MeV]	$60.8 + i25.7$	$29.6 + i24.7$	
$P_{K^-K^-}$	0.35	0.35	0.34
$P_{K^-\bar{K}^0}$	0.37	0.36	0.36
$P_{\bar{K}^0\bar{K}^0}$	0.29	0.29	0.30

^{3}LiK^-K^--^{3}He$K^-\bar{K}^0$-^{3}H$\bar{K}^0\bar{K}^0$ ($J^\pi = 1/2^+$)			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	73.1	72.8	113
Γ[MeV]	58.6	135	160
$B_{\bar{K}}$[MeV]	$127 + i49.3$	$128 + i112$	$164 + i104$
$\delta\sqrt{s}$[MeV]	$63.4 + i24.7$	$21.4 + i18.6$	
$P_{K^-K^-}$	0.03	0.02	0.09
$P_{K^-\bar{K}^0}$	0.38	0.37	0.37
$P_{\bar{K}^0\bar{K}^0}$	0.60	0.61	0.55

^{4}LiK^-K^--^{4}He$K^-\bar{K}^0$-^{4}H$\bar{K}^0\bar{K}^0$ ($J^\pi = 1/2^+$)			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	103	111	133
Γ[MeV]	60.1	149	187
$B_{\bar{K}}$[MeV]	$130 + i48.0$	$141 + i118$	$159 + i119$
$\delta\sqrt{s}$[MeV]	$65.1 + i24.0$	$17.6 + i14.7$	
$P_{K^-K^-}$	0.05	0.04	0.11
$P_{K^-\bar{K}^0}$	0.90	0.92	0.78
$P_{\bar{K}^0\bar{K}^0}$	0.05	0.04	0.11

$K^-K^-K^-pp$-$K^-K^-\bar{K}^0pn$-$K^-\bar{K}^0\bar{K}^0nn$ $(J^\pi = 0^+)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	74.7	58.1	133
Γ[MeV]	112	163	205
$B_{\bar{K}}$[MeV]	$152 + i90.2$	$129 + i132$	$202 + i135$
$\delta\sqrt{s}$[MeV]	$50.7 + i30.1$	$21.5 + i22.0$	
$P_{K^-K^-}$	0.47	0.48	0.48
$P_{K^-\bar{K}^0}$	0.36	0.35	0.35
$P_{\bar{K}^0\bar{K}^0}$	0.17	0.17	0.17

${}^3\mathrm{Li}K^-K^-K^-$-${}^3\mathrm{He}K^-K^-\bar{K}^0$-${}^3\mathrm{H}K^-\bar{K}^0\bar{K}^0$-${}^3n\bar{K}^0\bar{K}^0\bar{K}^0$ $(J^\pi = 1/2^-)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	98.2	91.4	147
Γ[MeV]	97.9	190	245
$B_{\bar{K}}$[MeV]	$173 + i79.6$	$166 + i155$	$217 + i158$
$\delta\sqrt{s}$[MeV]	$57.7 + i26.5$	$18.5 + i17.2$	
$P_{K^-K^-K^-}$	0.02	0.01	0.05
$P_{K^-K^-\bar{K}^0}$	0.50	0.51	0.46
$P_{K^-\bar{K}^0\bar{K}^0}$	0.47	0.47	0.44
$P_{\bar{K}^0\bar{K}^0\bar{K}^0}$	0.01	0.01	0.05

${}^4\mathrm{Be}K^-K^-K^-$-${}^4\mathrm{Li}K^-K^-\bar{K}^0$-${}^4\mathrm{He}K^-\bar{K}^0\bar{K}^0$-${}^4\mathrm{H}\bar{K}^0\bar{K}^0\bar{K}^0$ $(J^\pi = 0^-)$			
Model	SIDDHARTA		AY
	Type I	Type II	
B[MeV]	134	140	173
Γ[MeV]	96.4	219	294
$B_{\bar{K}}$[MeV]	$185 + i75.3$	$195 + i171$	$219 + i189$
$\delta\sqrt{s}$[MeV]	$61.6 + i25.1$	$16.3 + i14.2$	
$P_{K^-K^-K^-}$	0.0007	0.0005	0.006
$P_{K^-K^-\bar{K}^0}$	0.06	0.05	0.12
$P_{K^-\bar{K}^0\bar{K}^0}$	0.91	0.92	0.79
$P_{\bar{K}^0\bar{K}^0\bar{K}^0}$	0.03	0.03	0.08

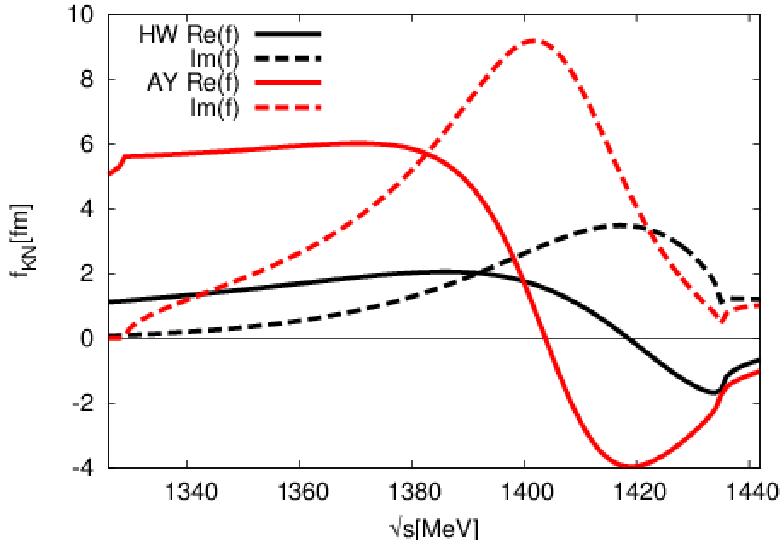
NN interaction

- AV4' potential: {1, σ.σ, τ.τ, σ.στ.τ}

R.B.Wiringa, S.C.Pieper, PRL89,182501 (2002).

	AV4'		Expt.
	B [MeV]	$\sqrt{\langle r^2 \rangle}$ [fm]	B [MeV]
^{2}H	2.24	2.02	2.22
^{3}H	8.99	1.67	8.48
^{4}He	32.11	1.39	28.30
^{6}He	32.22	2.66	29.27
^{6}Li	35.81	2.43	31.99

Pole position of Λ(1405) and energy dependence of potential



Hyodo, Weise, PRC77, 035204 (2008).

Phenomenological potential

Akaishi, Yamazaki, PRC65, 04400(2002).
Shevchenko, PRC85, 034001(2012).

Λ(1405), one pole
Energy independent

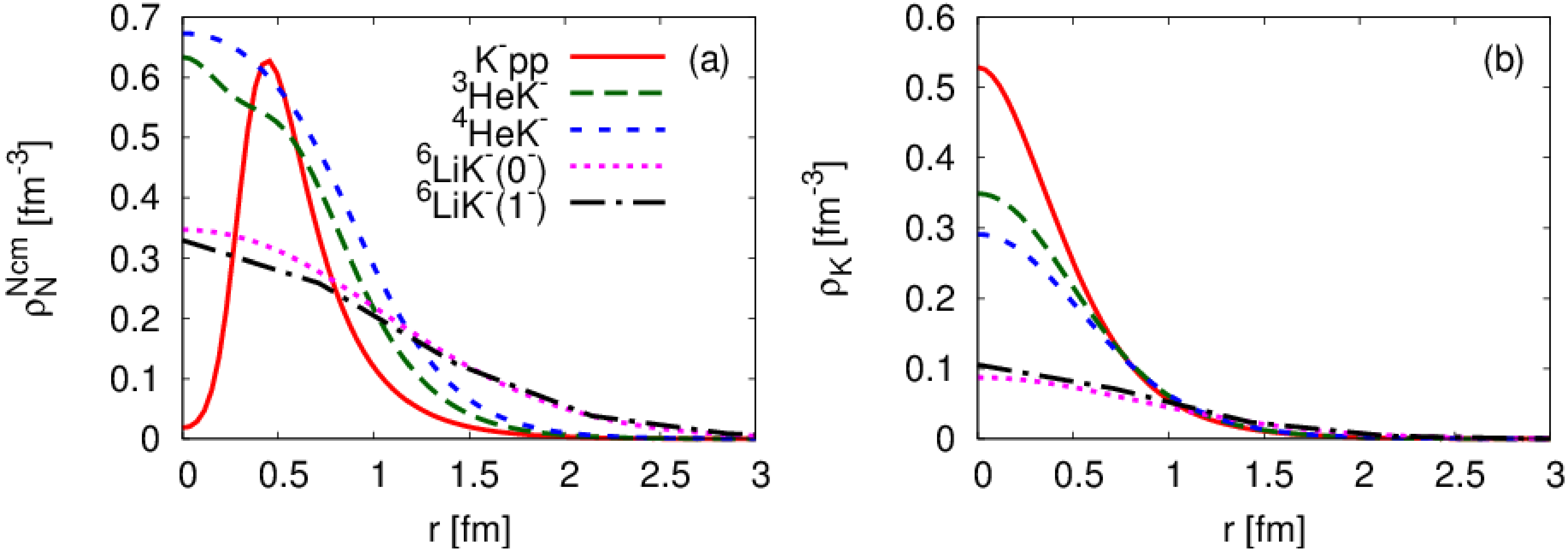
Chiral SU(3) dynamics

Kaiser, Siegel, Weise, NPA594, 325(1995).
Oset, Ramos, NPA635, 99(1998).
Hyodo, Jido, PPNP67, 55(2012).

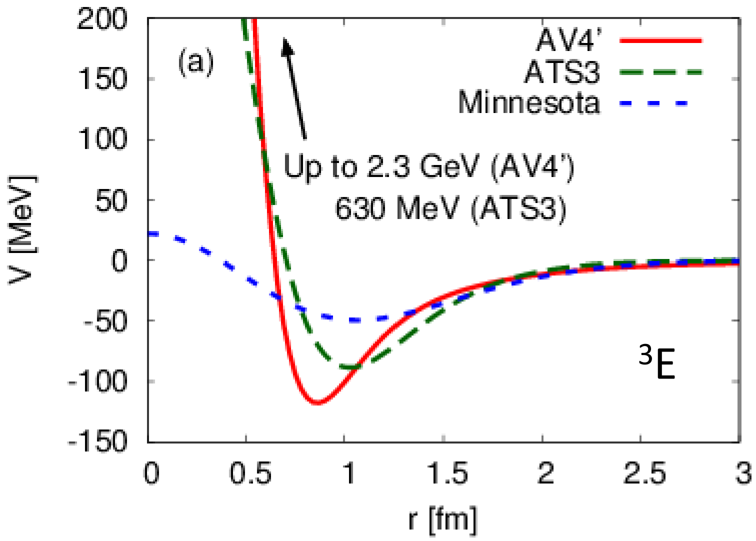
Λ(1420), two pole
Energy dependent

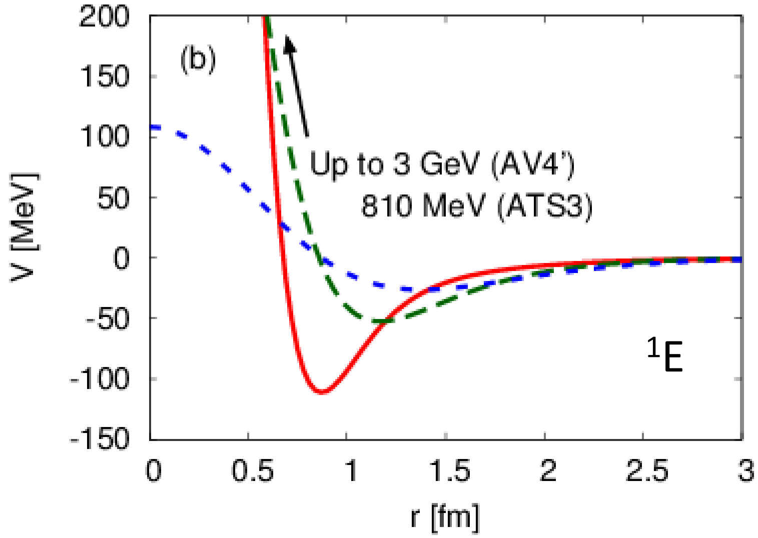
This difference is enhanced in kaon-nucleus quasi-bound states

N and K distribution



Dependence on NN interaction

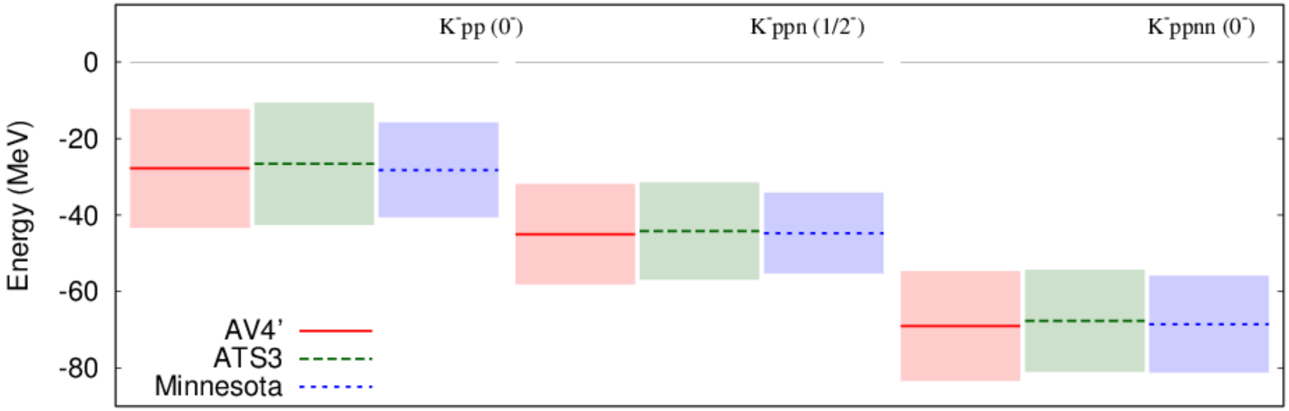




We investigate the *NN* interaction dependence by using AV4', ATS3, and Minnesota potential model, which well reproduce the binding energy of *s*-shell nuclei

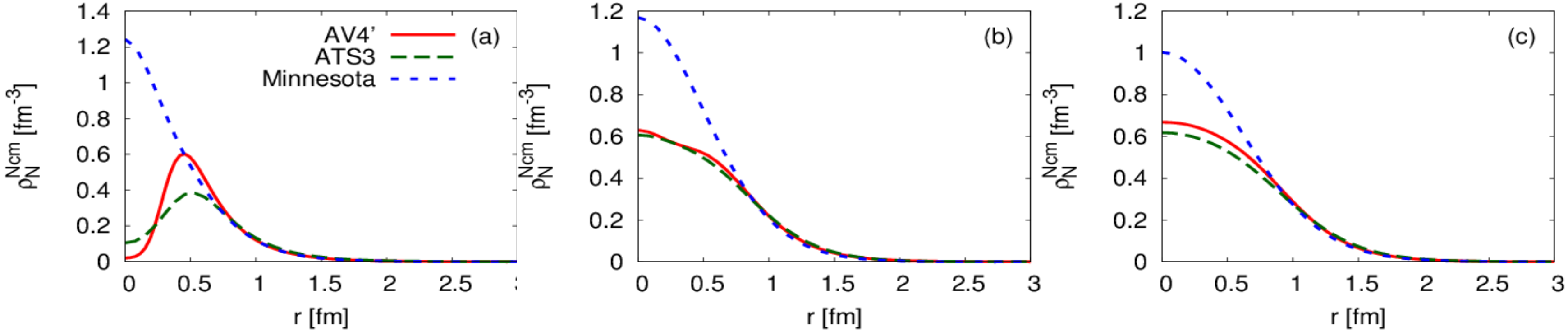
Dependence on NN interaction

Binding energy and decay width



- Binding energy and decay width are not sensitive to NN interaction model

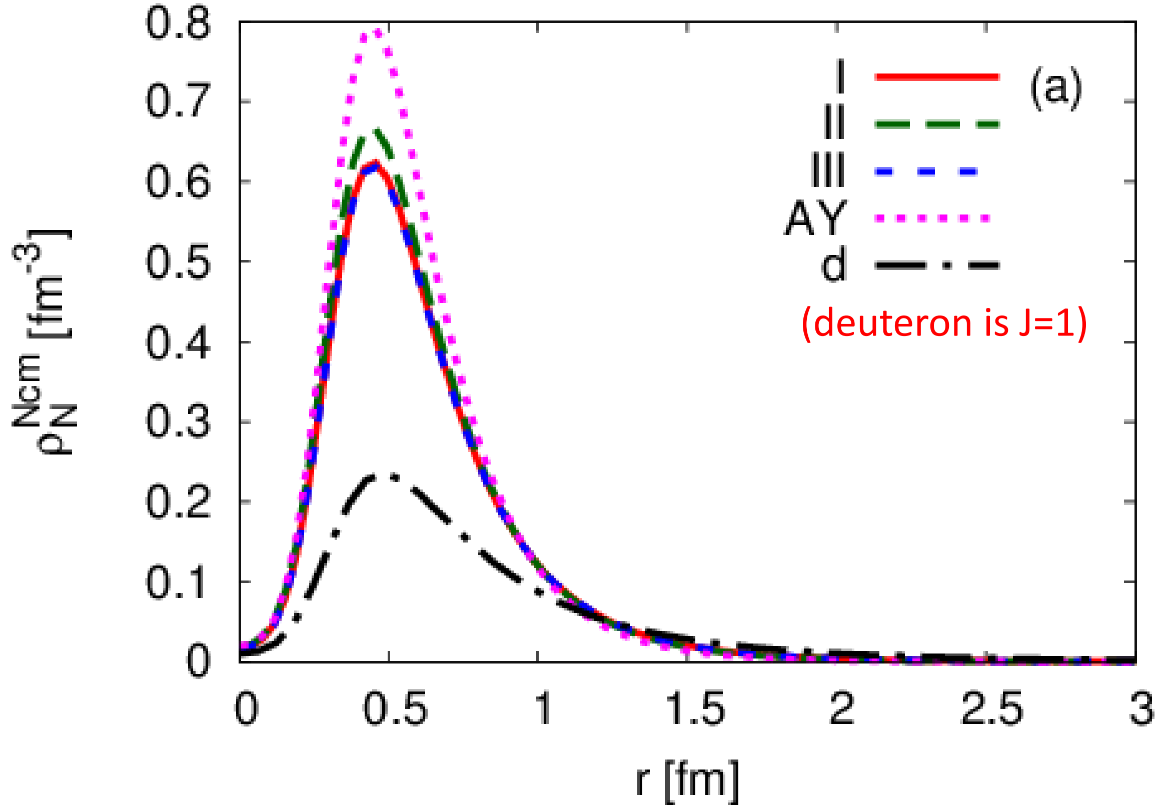
Nucleon distribution

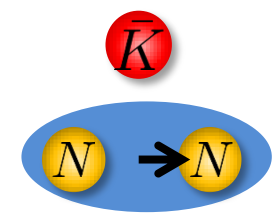


- AV4' and ATS3 potential with strong repulsive core produce similar density distribution, but the central density for Minnesota potential with soft core become high.

Density distribution of $K^{-}pp$-$K^{0bar}pn$

Nucleon distribution from C.M. of NN

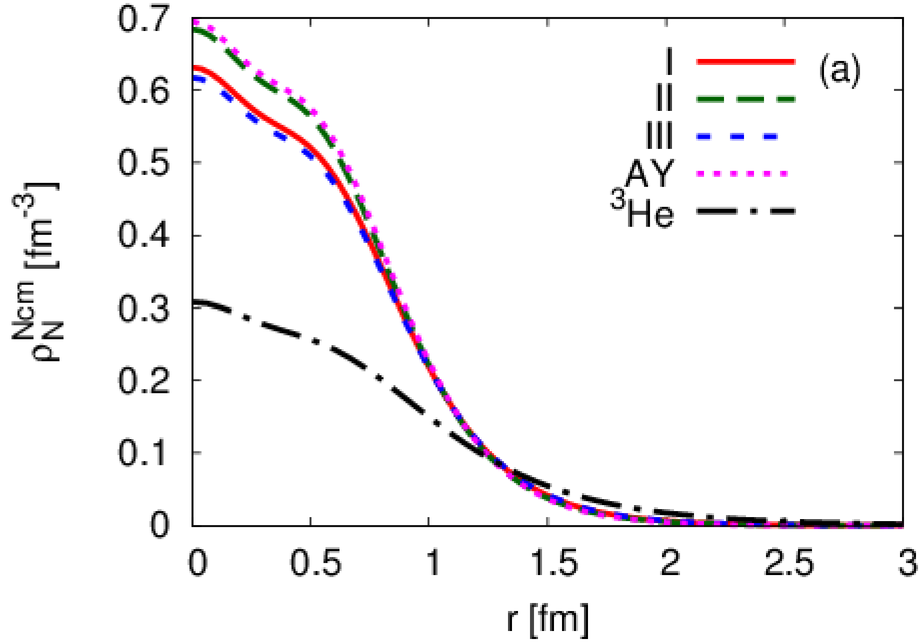


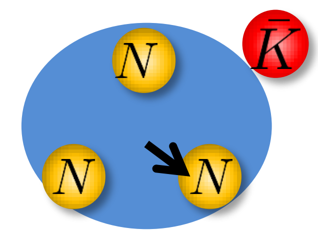


Central density for SIDDHARTA potential is slightly smaller than density for AY-potential

Density distribution of $K^{-}ppn$-$K^{0bar}pnn$

Nucleon distribution from C.M. of NNN



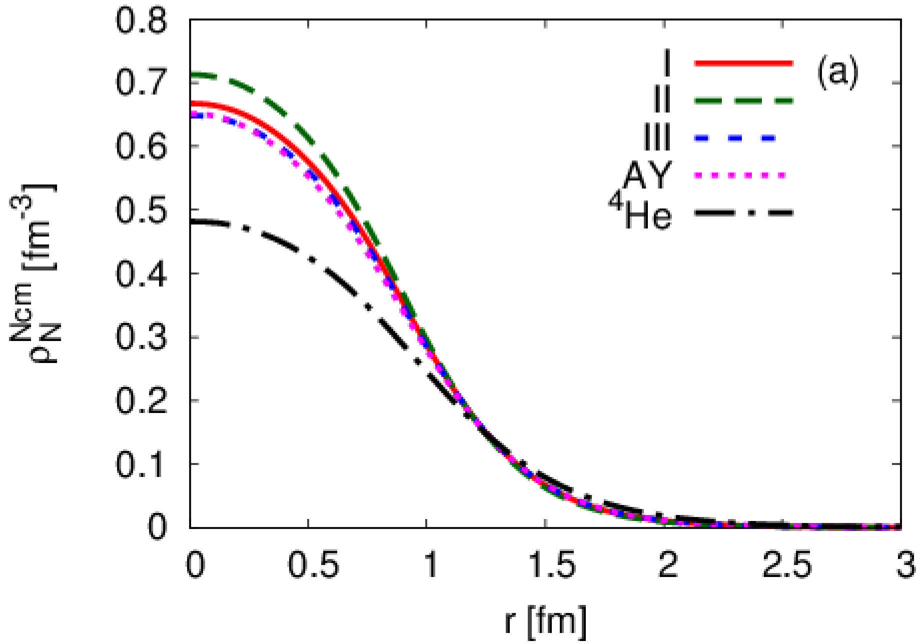


- Central nucleon density $\rho(0)$~0.6fm^{-3} is two times larger than ^{3}He, but smaller than the density $\rho(0)$=1.4 fm^{-3} predicted by g-matrix effective KN and NN interactions

Dote, et. al., PLB590, 51(2004).

Density distribution of K^-ppnn-K^{0bar}pnnn

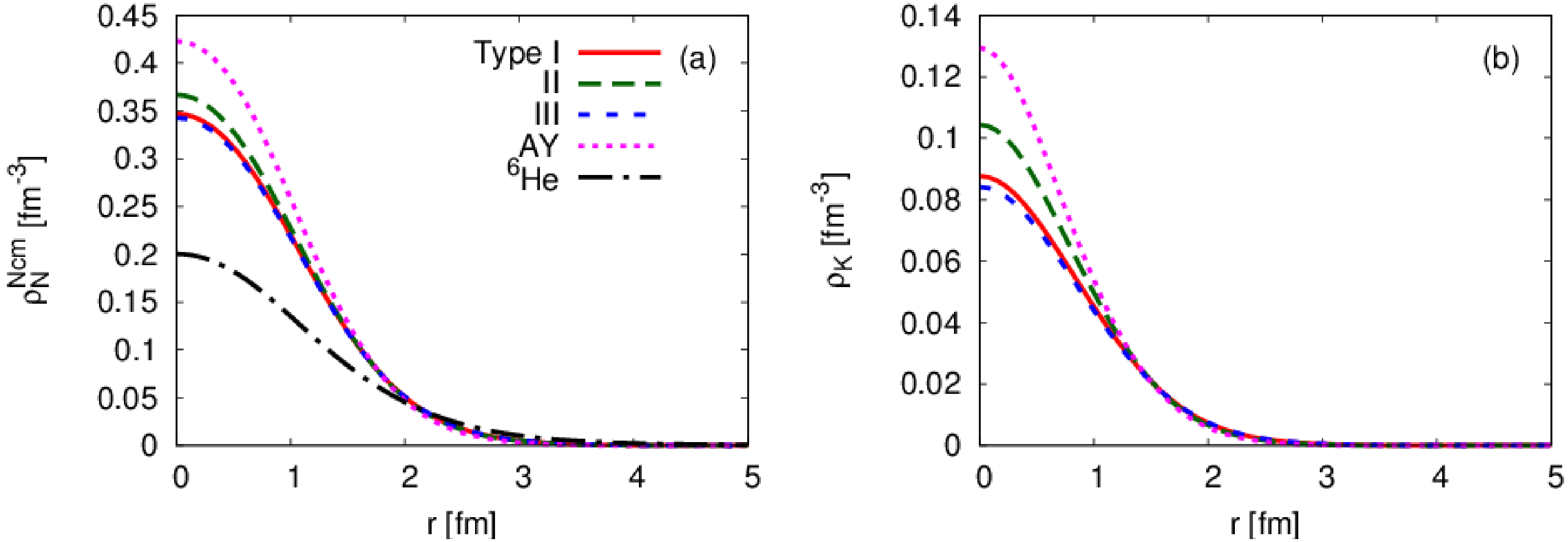
Nucleon distribution from C.M. of NNNN



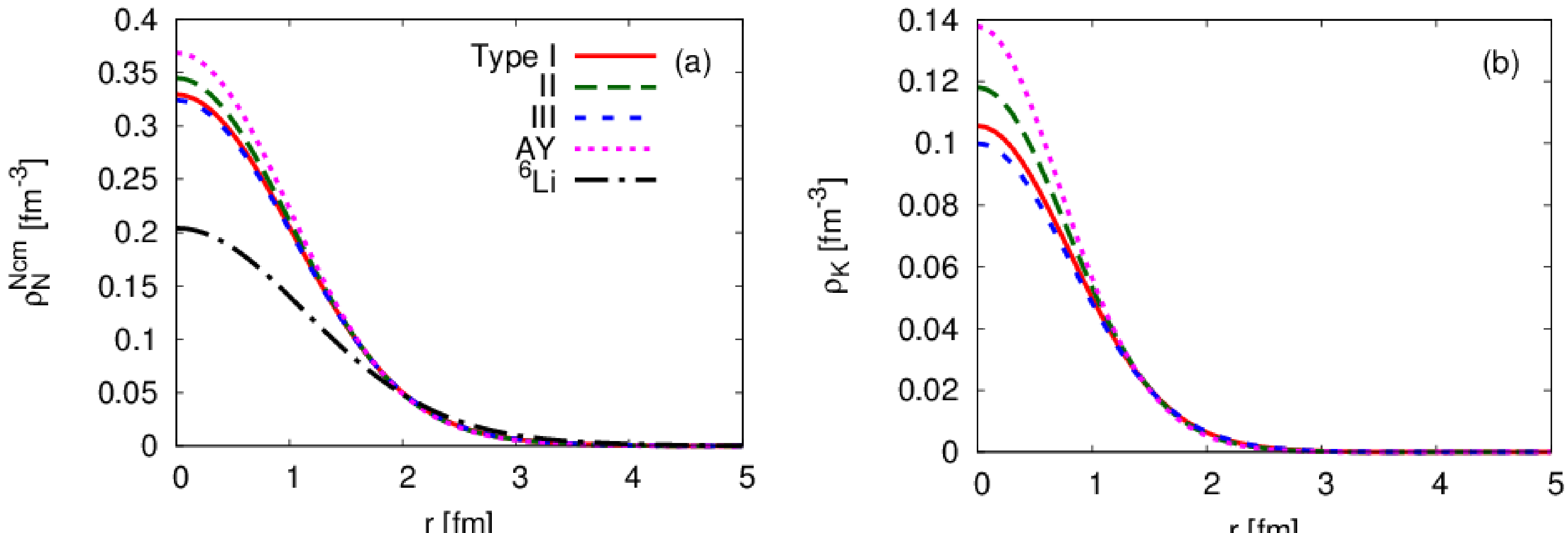
- Central nucleon density $\rho(0)$~0.7fm^{-3} is 1.5 times larger than ^{4}He

Density distribution of K^-pppnnn-K^{0bar}ppnnnn

J^π=0-

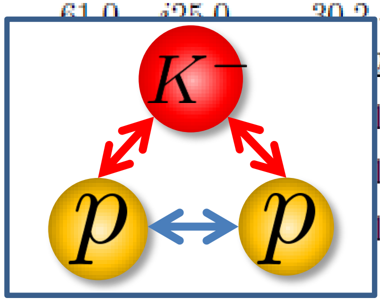


J^π=1-

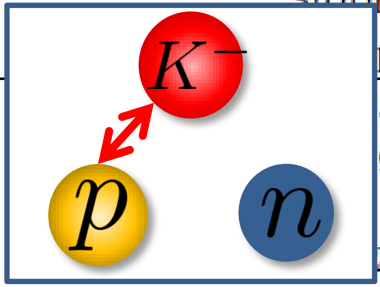


Structure of $K^{bar}NN$ with $J^{\pi}=0^{-}$

$K^{-}pp$-$\bar{K}^{0}pn$ ($J^{\pi}=0^{-}$)				
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	27.9	26.1	27.3	48.7
Γ[MeV]	30.9	59.3	30.5	61.9
$\delta\sqrt{s}$[MeV]	$-61.0 - i25.0$	$-30.2 - i23.7$	$-61.5 - i24.2$	
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	[illegible]	2.07	2.16	1.84
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	[illegible]	1.73	1.81	1.55
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	[illegible]	1.08	1.12	0.958
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	[illegible]	1.10	1.15	0.988



$K^{-}pn$-$\bar{K}^{0}nn$ ($J^{\pi}=0^{-}$)				
Model	SIDDHARTA			AY
	[illegible]	pe II	Type III	
B[MeV]	[illegible]	5.3	27.0	48.1
Γ[MeV]	[illegible]	9.4	31.0	61.6
$\delta\sqrt{s}$[MeV]	[illegible]	$- i23.8$	$-60.8 - i24.7$	
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	[illegible]	2.10	2.19	1.85
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	1.82	1.75	1.83	1.56
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.13	1.09	1.14	0.963
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.15	1.11	1.16	0.993



- Coulomb splitting is small (~0.5MeV)
- Binding energies are almost same between Type I, II, and III, but width of Type II is two times larger than Type I and III
- Binding energy for AY-potential is 48 MeV
- The radii for AY-potential become smaller than SIDDHARTA potential

Structure of $K^{bar}NNNN$ with $J^{\pi}=0^{-}$

${}^4\mathrm{Li}K^-$-${}^4\mathrm{He}\bar{K}^0$ ($J^\pi = 0^-$)				
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	67.9	72.7	61.6	85.2
Γ[MeV]	28.3	74.1	23.1	86.5
$\delta\sqrt{s}$[MeV]	$-67.6 - i23.0$	$-18.4 - i15.0$	$-77.0 - i19.2$	
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	1.98	1.91	2.01	2.07
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	1.83	1.72	1.90	1.81
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.22	1.18	1.24	1.27
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.22	1.12	1.28	1.14

${}^4\mathrm{He}K^-$-${}^4\mathrm{H}\bar{K}^0$ ($J^\pi = 0^-$)				
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	69.6	75.5	63.4	87.4
Γ[MeV]	28.0	74.5	23.0	87.2
$\delta\sqrt{s}$[MeV]	$-68.7 - i22.4$	$-19.1 - i14.9$	$-78.3 - i18.8$	
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	1.96	1.89	1.99	2.04
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	1.82	1.71	1.89	1.79
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.21	1.17	1.23	1.26
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.21	1.11	1.28	1.13

- Coulomb splitting is large (~2 MeV), since Coulomb effect is repulsive for ${}^4\mathrm{He}K^0$, but attractive for ${}^4\mathrm{He}K^-$
- Binding energy is about 60-75 MeV for SIDDHARTA potential
- width of Type II is three times larger than Type I and III
- Binding energy for AY-potential is about 86 MeV

Gamow vector

$$\langle\psi|\psi\rangle = \int dr\ |\psi(r)|^2 = 1,$$

$$_G\langle\psi|\psi\rangle_G = \int dr\ \psi(r)^2 = 1,$$

$$\langle r^2\rangle = \int dr\ r^2|\psi(r)|^2$$

$$\langle r^2\rangle_G = \int dr\ r^2\psi_G(r)^2$$

$$\langle r^2\rangle = \langle r^2\rangle_G = \frac{1}{2\kappa^2} \quad \text{(bound state).}$$

$$\langle r^2\rangle_G = \frac{1}{2\kappa^2 + 4i\kappa\gamma - 2\gamma^2} \quad \text{(quasibound state).}$$

Correlated Gaussian basis

Varga, Suzuki, Phys. Rev C52 (1995) 2885.
Varga, Suzuki, Comp. Pnys. Com. 106 (1997) 157.

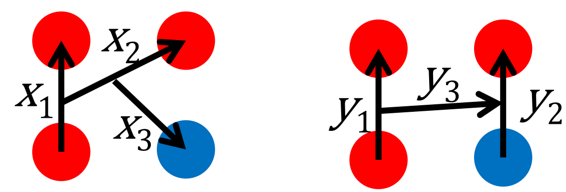
$$\Psi = \sum_{i=1}^{K} c_i \phi_i \,, \qquad \phi_i = \mathcal{A}\left\{ e^{-\frac{1}{2}\tilde{\boldsymbol{x}} A_i \boldsymbol{x}} \chi_{iJM} \eta_{iTM_t} \right\}$$

A_i: $(N-1) \times (N-1)$ matrix (paramaters of coordinates)

$\boldsymbol{x} = \{\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_{N-1}\}$, χ_{iJM}: spin function, η_{iTM_t}: isospin function

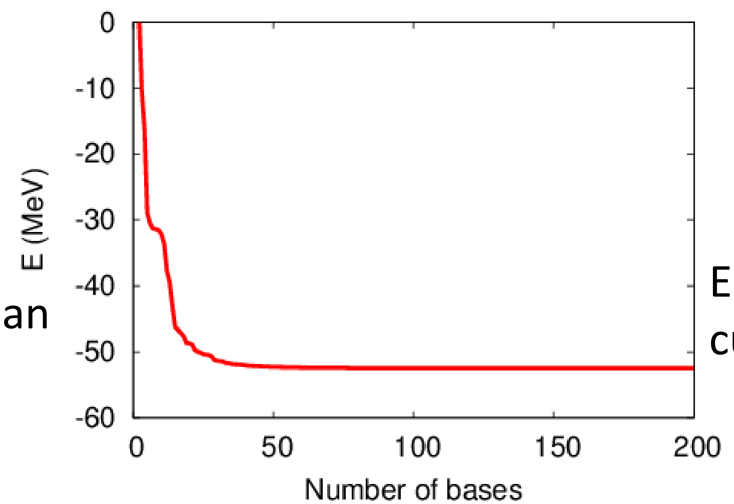
- Correlated Gaussian basis represent the total angular momentum *L=0,* but higher partial wave for each $\boldsymbol{x}_i$ are included by off-diagonal component of A_i.
- Matrix elements are analytically calculable for *N*-body systems
- Functional form of the correlated Gaussian remains unchanged under the coordinate transformation

$$\mathbf{y} = T\mathbf{x} \;\Rightarrow\; \tilde{\mathbf{y}} B \mathbf{y} = \tilde{\mathbf{x}} \tilde{T} B T \mathbf{x}$$



Stochastic variational method

- To obtain the well variational basis, we increase the basis size one-by-one by searching for the best variational parameter A_i among many random trials
- Diagonalize full complex Hamiltonian by using basis optimized for the real part of the Hamiltonian



Energy convergence curve for KNN

Correlated Gaussian basis

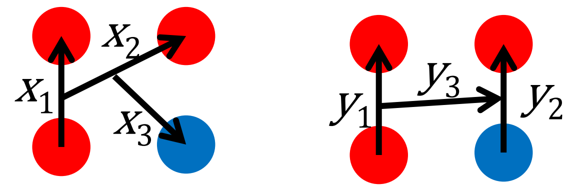
Varga, Suzuki, Phys. Rev C52 (1995) 2885.
Varga, Suzuki, Comp. Pnys. Com. 106 (1997) 157.

$$\Psi = \sum_{i=1}^{K} c_i \phi_i \,, \qquad \phi_i = \mathcal{A}\left\{ e^{-\frac{1}{2}\tilde{\boldsymbol{x}} A_i \boldsymbol{x}} \chi_{iJM} \eta_{iTM_t} \right\}$$

A_i: $(N-1) \times (N-1)$ matrix (paramaters of coordinates)
$\boldsymbol{x} = \{\boldsymbol{x}_1, \boldsymbol{x}_2, \dots, \boldsymbol{x}_{N-1}\}$, χ_{iJM}: spin function, η_{iTM_t}: isospin function

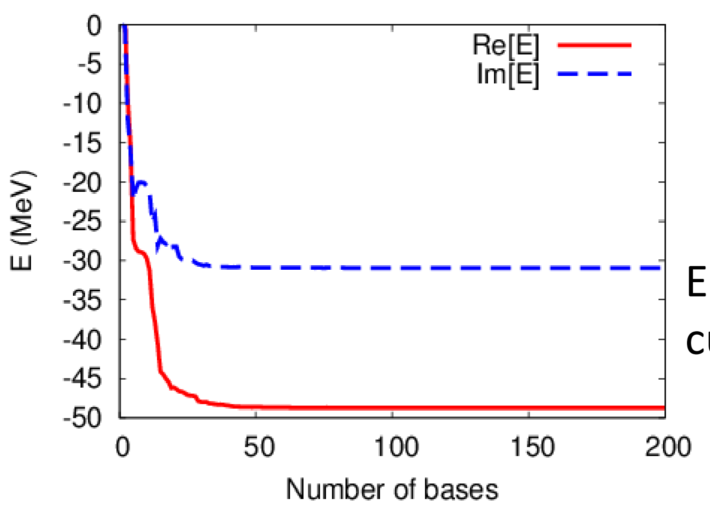
- Correlated Gaussian basis represent the total angular momentum *L=0,* but higher partial wave for each $\boldsymbol{x}_i$ are included by off-diagonal component of A_i.
- Matrix elements are analytically calculable for *N*-body systems
- Functional form of the correlated Gaussian remains unchanged under the coordinate transformation

$$\mathbf{y} = T\mathbf{x} \Rightarrow \tilde{\mathbf{y}} B \mathbf{y} = \tilde{\mathbf{x}} \tilde{T} B T \mathbf{x}$$



Stochastic variational method

- To obtain the well variational basis, we increase the basis size one-by-one by searching for the best variational parameter A_i among many random trials
- Diagonalize full complex Hamiltonia by using basis optimized for the real part of the Hamiltonian



Energy convergence curve for KNN

$K^{bar}N$ *interactions*

SIDDHARTA potential

K.Miyahara, T.Hyodo, PRC 93 (2016) 1, 015201.

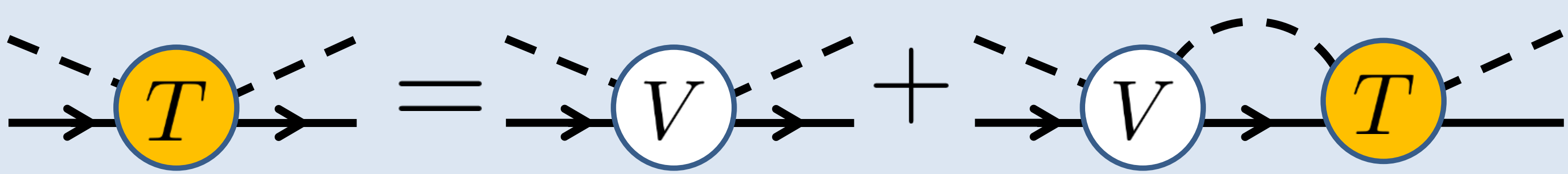
- Reproduce the scattering amplitude by chiral SU(3) dynamics using driving interaction at NLO
  Y.Ikeda, T.Hyodo, W.Weise, NPA881 (2012) 98 .

Chiral SU(3) dynamics

Description of *S=-1*, $K^{bar}N$ *s-wave* scattering

✓Interaction ← chiral symmetry

✓Amplitude ← unitarity in coupled channel



Kaiser, Siegel, Weise, NPA594, 325(1995).
Oset, Ramos, NPA635, 99(1998).
Hyodo, Jido, PPNP67, 55(2012).

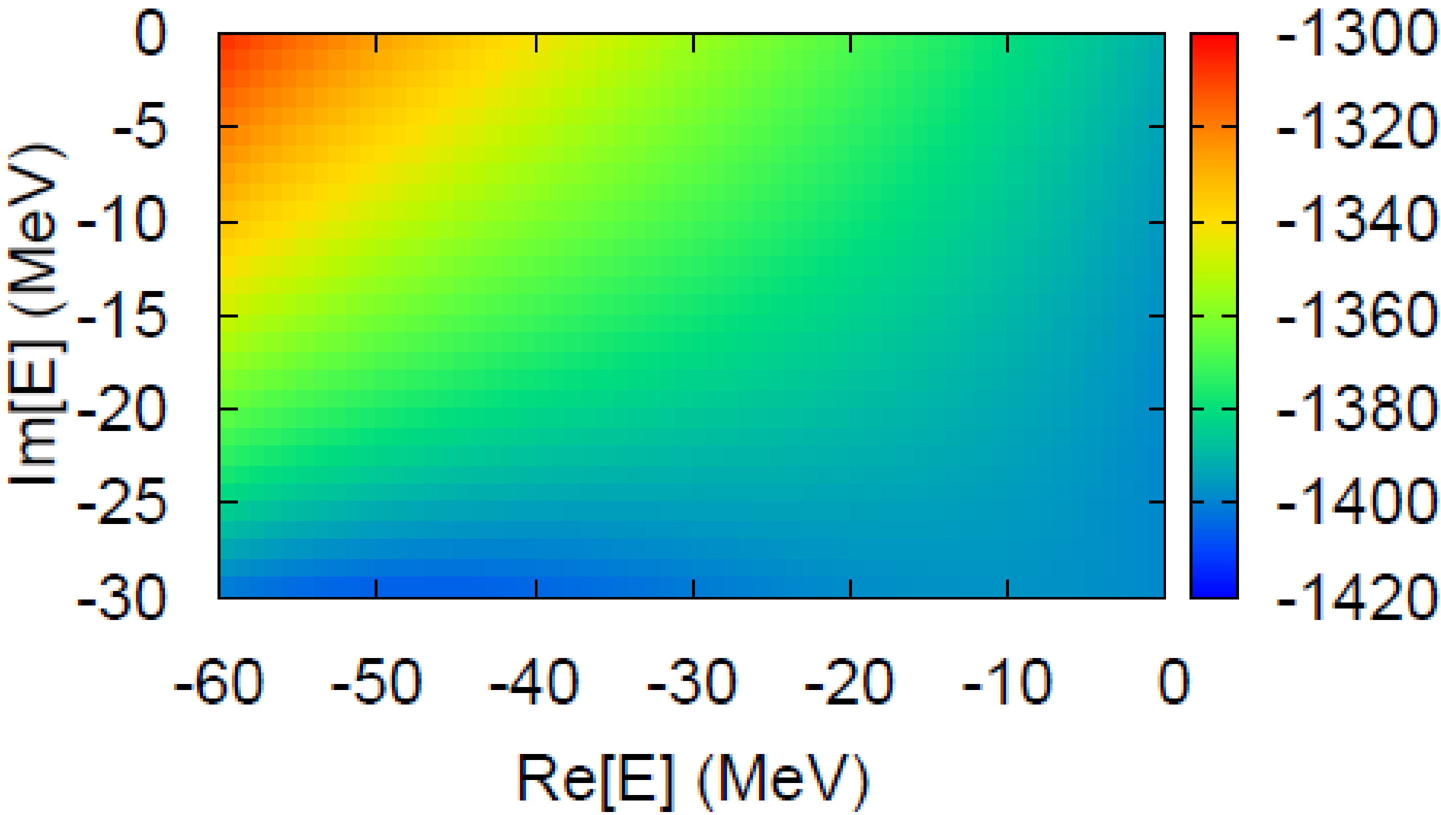


FIG. 1. (Color online) Strength of the $\bar{K}N$ potential $V_{\bar{K}N}^{I=0}(r=0,E)$ on the complex energy plane.

K^-pp-$\bar{K}^0pn$ ($J^\pi = 0^-$)				
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	27.9	26.1	27.3	48.7
Γ[MeV]	30.9	59.3	30.5	61.9
$B_{\bar{K}}$[MeV]	$61.0 + i25.0$	$60.4 + i47.4$	$60.1 + i24.7$	$77.7 + i41.8$
$\delta\sqrt{s}$[MeV]	$-61.0 - i25.0$	$-30.2 - i23.7$	$-61.5 - i24.2$	
P_{K^-}	0.65	0.65	0.65	0.64
$P_{\bar{K}^0}$	0.35	0.35	0.35	0.36
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	2.16	2.07	2.16	1.84
$\sqrt{\langle r^2_{\bar{K}N}\rangle}$ [fm]	1.80	1.73	1.81	1.55
$\sqrt{\langle r^2_N\rangle}$ [fm]	1.12	1.08	1.12	0.958
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.14	1.10	1.15	0.988
$\sqrt{\langle r^2_N\rangle_G}$ [fm]	$1.10 - i0.119$	$1.02 - i0.182$	$1.10 - i0.121$	$0.918 - i0.153$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.11 - i0.171$	$1.00 - i0.256$	$1.11 - i0.173$	$0.941 - i0.182$
$\langle T\rangle_G^{K^-}$ [MeV]	$117 + i28.8$	$124 + i53.1$	$116 + i28.7$	$102 + i31.4$
$\langle V\rangle_G^{K^-}$ [MeV]	$-113 - i33.7$	$-120 - i63.9$	$-112 - i33.7$	$-102 - i47.0$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$74.3 + i18.4$	$76.3 + i33.1$	$73.7 + i18.2$	$63.1 + i15.5$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-62.0 - i19.1$	$-64.3 - i35.6$	$-61.3 - i19.0$	$-48.6 - i21.6$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-44.1 - i9.76$	$-41.9 - i16.4$	$-43.9 - i9.50$	$-64.0 - i9.24$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-193 - i14.3$	$-201 - i27.2$	$-191 - i14.0$	$-186 - i26.0$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-8.67 - i1.19$	$-10.8 - i2.43$	$-8.52 - i1.20$	$-8.26 - i4.95$

	$K^{-}pn$-$\bar{K}^{0}nn$ ($J^{\pi}=0^{-}$)			
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	27.6	25.3	27.0	48.1
Γ[MeV]	31.6	59.4	31.0	61.6
$B_{\bar{K}}$[MeV]	$60.2+i25.6$	$58.7+i47.5$	$59.2+i25.1$	$76.3+i41.5$
$\delta\sqrt{s}$[MeV]	$-60.2-i25.6$	$-29.4-i23.8$	$-60.8-i24.7$	
P_{K^-}	0.38	0.38	0.38	0.37
$P_{\bar{K}^0}$	0.62	0.62	0.62	0.63
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	2.18	2.10	2.19	1.85
$\sqrt{\langle r^2_{\bar{K}N}\rangle}$ [fm]	1.82	1.75	1.83	1.56
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.13	1.09	1.14	0.963
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.15	1.11	1.16	0.993
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.11-i0.123$	$1.03-i0.187$	$1.11-i0.125$	$0.923-i0.155$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.11-i0.176$	$1.01-i0.263$	$1.12-i0.179$	$0.946-i0.185$
$\langle T\rangle_G^{K^-}$ [MeV]	$67.6+i20.6$	$81.4+i34.9$	$78.5+i19.4$	$65.3+i16.1$
$\langle V\rangle_G^{K^-}$ [MeV]	$-44.5-i10.2$	$-69.9-i38.0$	$-66.7-i20.4$	$-51.3-i22.6$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$112+i28.7$	$118+i52.2$	$111+i28.5$	$99.5+i30.8$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-107-i33.3$	$-112-i62.2$	$-106-i33.0$	$-97.3-i45.8$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-44.5-i10.2$	$-42.2-i16.7$	$-44.2-i9.93$	$-64.3-i9.40$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-194-i14.7$	$-201-i27.4$	$-192-i14.4$	$-186-i25.9$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-8.39-i1.14$	$-10.4-i2.34$	$-8.22-i1.15$	$-8.10-i4.86$

	$^3\mathrm{He}K^-$-$^3\mathrm{H}\bar{K}^0$ $(J^\pi = 1/2^-)$			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	45.3	49.7	42.0	72.6
Γ[MeV]	25.5	69.4	21.7	78.6
$B_{\bar{K}}$[MeV]	$70.4 + i20.7$	$78.4 + i55.9$	$64.8 + i17.5$	$94.3 + i51.9$
$\delta\sqrt{s}$[MeV]	$-70.4 - i20.7$	$-26.1 - i18.6$	$-75.7 - i18.2$	
P_{K^-}	0.53	0.53	0.53	0.51
$P_{\bar{K}^0}$	0.47	0.47	0.47	0.49
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	1.99	1.90	2.01	1.87
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	1.79	1.68	1.83	1.63
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.17	1.11	1.18	1.09
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.17	1.08	1.21	1.03
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.16 - i0.0539$	$1.09 - i0.0952$	$1.18 - i0.0575$	$1.07 - i0.124$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.15 - i0.115$	$1.02 - i0.196$	$1.19 - i0.118$	$0.996 - i0.176$
$\langle T\rangle^{K^-}_G$ [MeV]	$114 + i17.4$	$126 + i42.2$	$109 + i15.6$	$107 + i27.6$
$\langle V\rangle^{K^-}_G$ [MeV]	$-118 - i22.4$	$-135 - i54.0$	$-112 - i20.9$	$-114 - i44.6$
$\langle T\rangle^{\bar{K}^0}_G$ [MeV]	$103 + i15.9$	$113 + i39.8$	$98.6 + i13.7$	$101 + i26.1$
$\langle V\rangle^{\bar{K}^0}_G$ [MeV]	$-105 - i20.2$	$-118 - i50.0$	$-99.5 - i18.3$	$-107 - i42.1$
$\langle V\rangle^{K^-\bar{K}^0}_G$ [MeV]	$-39.0 - i3.56$	$-36.0 - i12.7$	$-37.6 - i1.05$	$-59.6 - i6.33$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-170 - i9.20$	$-188 - i26.6$	$-160 - i7.07$	$-189 - i26.3$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-22.8 - i3.58$	$-34.0 - i8.07$	$-20.8 - i3.80$	$-21.7 - i13.0$

	$^4\mathrm{Li}K^-$-$^4\mathrm{He}\bar{K}^0$ ($J^\pi = 0^-$)			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	67.9	72.7	61.6	85.2
Γ[MeV]	28.3	74.1	23.1	86.5
$B_{\bar{K}}$[MeV]	$67.6 + i23.0$	$73.5 + i59.9$	$57.6 + i17.5$	$85.2 + i55.2$
$\delta\sqrt{s}$[MeV]	$-67.6 - i23.0$	$-18.4 - i15.0$	$-77.0 - i19.2$	
P_{K^-}	0.08	0.06	0.07	0.16
$P_{\bar{K}^0}$	0.92	0.94	0.93	0.84
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	1.98	1.91	2.01	2.07
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	1.83	1.72	1.90	1.81
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.22	1.18	1.24	1.27
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.22	1.12	1.28	1.14
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.21 - i0.0324$	$1.17 - i0.0627$	$1.24 - i0.0431$	$1.26 - i0.125$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.19 - i0.123$	$1.05 - i0.201$	$1.26 - i0.139$	$1.09 - i0.210$
$\langle T\rangle^{K^-}_G$ [MeV]	$32.6 + i6.75$	$26.7 + i16.2$	$30.7 + i1.60$	$50.3 + i7.22$
$\langle V\rangle^{K^-}_G$ [MeV]	$-25.1 - i6.74$	$-20.0 - i15.9$	$-23.2 - i2.51$	$-42.3 - i12.0$
$\langle T\rangle^{\bar{K}^0}_G$ [MeV]	$214 + i27.8$	$240 + i66.0$	$200 + i27.6$	$183 + i52.7$
$\langle V\rangle^{\bar{K}^0}_G$ [MeV]	$-265 - i38.4$	$-300 - i94.3$	$-245 - i38.5$	$-232 - i88.3$
$\langle V\rangle^{K^-\bar{K}^0}_G$ [MeV]	$-24.8 - i3.66$	$-20.2 - i9.13$	$-23.9 + i0.218$	$-43.9 - i2.82$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-132 - i7.68$	$-136 - i20.4$	$-118 - i4.57$	$-158 - i22.1$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-46.6 - i6.49$	$-67.2 - i16.7$	$-39.1 - i7.00$	$-35.3 - i21.2$

	$^4\mathrm{He}K^-$-$^4\mathrm{H}\bar{K}^0$ $(J^\pi = 0^-)$			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	69.6	75.5	63.4	87.4
Γ[MeV]	28.0	74.5	23.0	87.2
$B_{\bar{K}}$[MeV]	$68.7 + i22.4$	$76.4 + i59.7$	$58.8 + i17.1$	$86.5 + i55.6$
$\delta\sqrt{s}$[MeV]	$-68.7 - i22.4$	$-19.1 - i14.9$	$-78.3 - i18.8$	
P_{K^-}	0.93	0.94	0.93	0.86
$P_{\bar{K}^0}$	0.07	0.06	0.07	0.14
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	1.96	1.89	1.99	2.04
$\sqrt{\langle r^2_{\bar{K}N}\rangle}$ [fm]	1.82	1.71	1.89	1.79
$\sqrt{\langle r^2_N\rangle}$ [fm]	1.21	1.17	1.23	1.26
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.21	1.11	1.28	1.13
$\sqrt{\langle r^2_N\rangle_G}$ [fm]	$1.21 - i0.0338$	$1.16 - i0.0633$	$1.23 - i0.0441$	$1.24 - i0.120$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.19 - i0.120$	$1.04 - i0.196$	$1.26 - i0.136$	$1.13 - i0.208$
$\langle T\rangle^{K^-}_G$ [MeV]	$216 + i28.1$	$244 + i66.6$	$202 + i27.9$	$188 + i53.4$
$\langle V\rangle^{K^-}_G$ [MeV]	$-269 - i39.1$	$-306 - i95.7$	$-250 - i39.3$	$-241 - i90.0$
$\langle T\rangle^{\bar{K}^0}_G$ [MeV]	$30.5 + i5.50$	$25.1 + i14.7$	$28.6 + i0.588$	$47.0 + i6.54$
$\langle V\rangle^{\bar{K}^0}_G$ [MeV]	$-23.0 - i5.54$	$-18.5 - i14.2$	$-21.2 - i1.63$	$-38.7 - i10.9$
$\langle V\rangle^{K^-\bar{K}^0}_G$ [MeV]	$-24.4 - i3.00$	$-19.9 - i8.71$	$-23.2 + i0.893$	$-42.7 + i2.64$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-130 - i7.27$	$-136 - i20.3$	$-117 - i4.18$	$-157 - i21.9$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-46.7 - i6.72$	$-68.5 - i17.0$	$-39.5 - i7.35$	$-36.1 - i21.7$

	$^6\mathrm{Be}K^-$-$^6\mathrm{Li}\bar{K}^0$ $(J^\pi = 0^-)$			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	68.0	76.9	62.7	101
Γ[MeV]	23.9	73.4	19.5	86.4
$B_{\bar{K}}$[MeV]	$75.0 + i18.3$	$87.6 + i59.5$	$65.8 + i13.4$	$113 + i56.5$
$\delta\sqrt{s}$[MeV]	$-75.0 - i18.3$	$-14.6 - i9.92$	$-85.0 - i15.0$	
P_{K^-}	0.73	0.75	0.73	0.65
$P_{\bar{K}^0}$	0.27	0.25	0.27	0.35
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	2.85	2.83	2.87	2.57
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	2.56	2.47	2.59	2.29
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.85	1.83	1.86	1.67
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.54	1.48	1.66	1.44
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.85 - i0.0179$	$1.82 - i0.0329$	$1.86 - i0.0148$	$1.66 - i0.0728$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.62 - i0.0764$	$1.50 - i0.117$	$1.65 - i0.0886$	$1.42 - i0.167$
$\langle T\rangle_G^{K^-}$ [MeV]	$185 + i18.9$	$210 + i46.1$	$177 + i19.7$	$181 + i30.6$
$\langle V\rangle_G^{K^-}$ [MeV]	$-220 - i28.1$	$-257 - i67.6$	$-210 - i30.6$	$-221 - i57.4$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$80.4 + i4.38$	$76.8 + i24.1$	$75.8 - i2.32$	$107 + i15.3$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-84.4 - i7.14$	$-82.8 - i29.5$	$-79.6 + i0.994$	$-117 - i29.1$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-29.3 + i0.0277$	$-24.7 - i9.71$	$-26.5 + i4.52$	$-51.9 - i2.69$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-137 - i6.30$	$-152 - i23.4$	$-123 - i3.17$	$-178 - i24.8$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-31.3 - i5.64$	$-51.3 - i13.3$	$-28.5 - i6.59$	$-30.7 - i18.4$

	$^{6}\mathrm{Li}K^{-}$-$^{6}\mathrm{He}\bar{K}^{0}$ $(J^{\pi}=0^{-})$			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	68.7	77.0	63.2	102
Γ[MeV]	24.0	73.2	19.4	86.4
$B_{\bar{K}}$[MeV]	$74.4+i18.6$	$86.2+i59.6$	$65.0+i13.5$	$111+i56.5$
$\delta\sqrt{s}$[MeV]	$-74.4-i18.6$	$-14.4-i9.93$	$-84.5-i15.1$	
P_{K^-}	0.36	0.35	0.36	0.39
$P_{\bar{K}^0}$	0.64	0.65	0.64	0.61
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	2.83	2.80	2.85	2.57
$\sqrt{\langle r^2_{\bar{K}N}\rangle}$ [fm]	2.54	2.46	2.58	2.28
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.83	1.81	1.84	1.66
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.63	1.53	1.66	1.44
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.83-i0.0200$	$1.80-i0.0346$	$1.84-i0.0195$	$1.66-i0.0722$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.62-i0.0756$	$1.49-i0.119$	$1.65-i0.0880$	$1.42-i0.167$
$\langle T\rangle_G^{K^-}$ [MeV]	$101+i7.71$	$104+i26.5$	$96.4+i3.10$	$117+i18.1$
$\langle V\rangle_G^{K^-}$ [MeV]	$-111-i11.7$	$-117-i34.4$	$-105-i8.02$	$-131-i33.8$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$165+i15.9$	$184+i43.8$	$158+i14.5$	$171+i27.7$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-194-i23.6$	$-221-i62.5$	$-184-i23.4$	$-206-i52.4$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-30.1-i0.369$	$-25.6-i9.99$	$-27.4+i4.14$	$-52.3-i2.82$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-139-i6.56$	$-154-i23.8$	$-125-i3.36$	$-178-i24.9$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-30.8-i5.46$	$-49.7-i12.9$	$-27.8-i6.37$	$-30.5-i18.3$

	$^6\mathrm{Be}K^-$-$^6\mathrm{Li}\bar{K}^0$ $(J^\pi = 1^-)$			
Model		SIDDHARTA		AY
	Type I	Type II	Type III	
B[MeV]	69.5	75.6	63.4	91.0
Γ[MeV]	26.7	73.5	21.8	86.2
$B_{\bar{K}}$[MeV]	$69.1 + i21.8$	$76.8 + i60.7$	$59.1 + i16.1$	$93.8 + i56.1$
$\delta\sqrt{s}$[MeV]	$-69.1 - i21.8$	$-12.8 - i10.1$	$-79.4 - i18.3$	
P_{K^-}	0.07	0.06	0.06	0.14
$P_{\bar{K}^0}$	0.93	0.94	0.94	0.86
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	3.00	2.97	3.01	2.87
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	2.57	2.50	2.61	2.41
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.94	1.92	1.95	1.85
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.55	1.48	1.59	1.41
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.94 - i0.0147$	$1.91 - i0.0163$	$1.95 - i0.0212$	$1.84 - i0.0690$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.54 - i0.0809$	$1.43 - i0.136$	$1.58 - i0.0880$	$1.38 - i0.143$
$\langle T\rangle_G^{K^-}$ [MeV]	$30.7 + i5.41$	$25.0 + i16.0$	$28.6 + i0.0899$	$52.3 + i7.93$
$\langle V\rangle_G^{K^-}$ [MeV]	$-23.7 - i5.54$	$-18.8 - i15.5$	$-21.7 - i1.27$	$-44.7 - i13.1$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$237 + i23.6$	$261 + i58.1$	$225 + i23.0$	$215 + i40.5$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-290 - i34.1$	$-324 - i86.3$	$-273 - i34.0$	$-272 - i74.9$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-23.0 - i2.73$	$-18.5 - i8.93$	$-21.8 + i1.28$	$-42.0 - i3.56$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-122 - i6.85$	$-129 - i20.1$	$-110 - i3.70$	$-155 - i21.7$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-43.8 - i6.51$	$-64.5 - i16.7$	$-37.3 - i7.21$	$-35.8 - i21.5$

	$^6\mathrm{Li}K^-$-$^6\mathrm{He}\bar{K}^0$ $(J^\pi = 1^-)$			
Model	SIDDHARTA			AY
	Type I	Type II	Type III	
B[MeV]	71.5	78.8	65.5	93.7
Γ[MeV]	26.3	74.0	21.7	86.7
$B_{\bar{K}}$[MeV]	$70.6 + i21.0$	$80.2 + i60.5$	$60.7 + i15.7$	$95.7 + i56.3$
$\delta\sqrt{s}$[MeV]	$-70.6 - i21.0$	$-13.4 - i10.1$	$-81.0 - i17.8$	
P_{K^-}	0.94	0.95	0.94	0.87
$P_{\bar{K}^0}$	0.06	0.05	0.06	0.13
$\sqrt{\langle r^2_{NN}\rangle}$ [fm]	2.99	2.96	3.00	2.85
$\sqrt{\langle r^2_{KN}\rangle}$ [fm]	2.56	2.49	2.60	2.40
$\sqrt{\langle r^2_{N}\rangle}$ [fm]	1.94	1.91	1.94	1.85
$\sqrt{\langle r^2_{\bar{K}}\rangle}$ [fm]	1.55	1.47	1.59	1.41
$\sqrt{\langle r^2_{N}\rangle_G}$ [fm]	$1.93 - i0.0150$	$1.91 - i0.0155$	$1.94 - i0.0216$	$1.84 - i0.0680$
$\sqrt{\langle r^2_{\bar{K}}\rangle_G}$ [fm]	$1.53 - i0.0791$	$1.42 - i0.131$	$1.58 - i0.0865$	$1.37 - i0.141$
$\langle T\rangle_G^{K^-}$ [MeV]	$238 + i23.7$	$264 + i58.6$	$227 + i23.2$	$219 + i41.0$
$\langle V\rangle_G^{K^-}$ [MeV]	$-294 - i34.5$	$-331 - i87.5$	$-278 - i34.7$	$-279 - i76.3$
$\langle T\rangle_G^{\bar{K}^0}$ [MeV]	$29.0 + i4.23$	$23.6 + i14.7$	$26.8 - i0.890$	$49.3 + i7.21$
$\langle V\rangle_G^{\bar{K}^0}$ [MeV]	$-21.9 - i4.46$	$-17.6 - i14.2$	$-20.0 - i0.454$	$-41.7 - i12.0$
$\langle V\rangle_G^{K^-\bar{K}^0}$ [MeV]	$-22.6 - i2.04$	$-18.2 - i8.57$	$-21.2 + i1.98$	$-41.1 - i3.36$
$\langle V^{I=0}_{\bar{K}N}\rangle$ [MeV]	$-120 - i6.39$	$-129 - i20.0$	$-108 - i3.27$	$-154 - i21.5$
$\langle V^{I=1}_{\bar{K}N}\rangle$ [MeV]	$-43.7 - i6.75$	$-65.6 - i17.0$	$-37.5 - i7.61$	$-36.4 - i21.9$