Three-baryon forces in a quark model

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１. Introduction
２. Quark-Pauli effect (Kinematics)
３. Estimation of interaction kernel (Dynamics)
４. Summary

1. Introduction

Three-body force in the 3 baryon system

⇒ It is needed many physics category

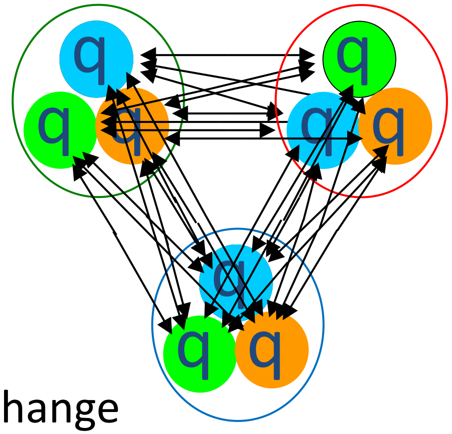
- Few-body system physics
- Nuclear matter physics
- Neutron star physics
- ……

Its origin is unclear

Theoretical approach

- 2π-exchange potential model (Fujita&Miyazawa)
- Phenomenological procedure
- Chiral effective-field theory
- Lattice QCD (HAL-QCD)
- ……

Approach by a quark model



9-quark 3-baryon system（3-cluster 9-body system）
⇒　Three-body force may be appearance
　　　of the constituent effects ?

- Kinematical：　quark-Pauli effect
- Dynamical：　appearance of *q*-*q* interaction through quark-exchange

Advantage of quark-model

- Systematical research in the unified model-framework
  from 1-baryon to few-baryons
- Separate estimation of the Pauli effect, each interaction…

Our final aim

- Understanding of 3-body baryon forces
  in the quark-model

Previous Research

- Toki, Suzuki, Hecht : PRC26 (1982) 736

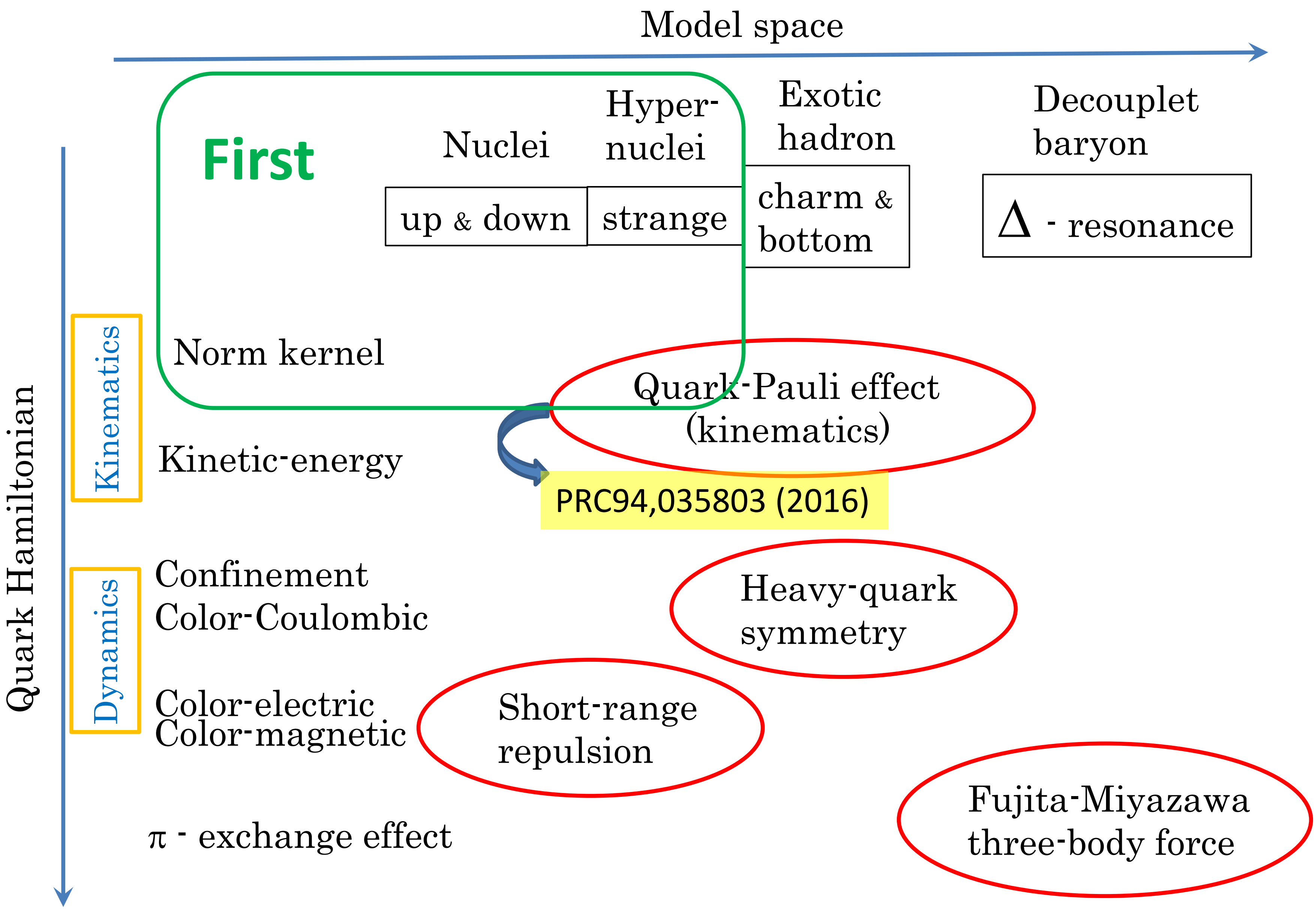
  quark-Pauli effect in the ^{3}He density by the RGM norm kernel
- Suzuki, Hecht : PRC29 (1984) 1586

  estimation of the FB interaction kernel in the NNN system
- Maltman : NPA439 (1985) 648

  contribution to charge form-factor from FB int. in the NNN and NNNN systems
- Takeuchi, Shimizu : PLB179 (1986) 197

  estimation of the norm and kinetic kernel in the ΛNN and ΛNNN systems
- Ohnishi, Kashiwa, Morita : PTEP2017 (2017) 073D04

  estimation of the 3-body force generated by the KMT interaction


Model space
First
Nuclei
Hyper-
nuclei
Exotic
hadron
Decouplet
baryon
up & down
strange
charm &
bottom
Δ - resonance
Quark Hamiltonian
Kinematics
Dynamics
Norm kernel
Kinetic-energy
Quark-Pauli effect
(kinematics)
PRC94,035803 (2016)
Confinement
Color-Coulombic
Heavy-quark
symmetry
Color-electric
Color-magnetic
Short-range
repulsion
π - exchange effect
Fujita-Miyazawa
three-body force

2. Quark-Pauli effect (Kinematics)

2-baryon wave function

$$\Psi_{B_1B_2}(1;2) = \frac{1}{\sqrt{2}}\left[\Phi_{B_1}(1)\Phi_{B_2}(2) - \Phi_{B_1}(2)\Phi_{B_2}(1)\right]$$

$$\langle \Psi_{B_1B_2}(1;2) | \Psi_{B_1B_2}(1;2) \rangle = 1$$

in terms of quark (6-quark wave function)

$$\Psi_{(3q)_1(3q)_2}(123;456) = \mathcal{A}\left\{\frac{1}{\sqrt{2}}\left[\Phi_{(3q)_1}(123)\Phi_{(3q)_2}(456) - \Phi_{(3q)_1}(456)\Phi_{(3q)_2}(123)\right]\right\}$$

Quark antisymmetrizer

$$\langle \Psi_{(3q)_1(3q)_2}(123;456) | \Psi_{(3q)_1(3q)_2}(123;456) \rangle = \mu$$

$\mu < 1$: Pauli repulsion

$\mu = 0$: complete Pauli-forbidden state

$\mu \sim 0$: almost Pauli-forbidden state

Quark-Pauli effects in three octet-baryons

C. N. and Y. Suzuki, PRC94,035803 (2016)

Estimation of the quark-Pauli effect in the $B_8 B_8 B_8$ systems through the eigen-value of the RGM norm-kernel

(no parameter)

Three-body baryonic repulsion originated from quark-kinematics

for Hyperon pazzlle

Does the quark-Pauli blocking effect play a prominent role to support the neutron star with 2-times solar-mass ?

Formulation

9-quark 3-baryon wave-function

$$\Psi_{Sa}((0s)^9 : B_1B_2B_3) = \Psi^{(\mathrm{orb})}(B_1B_2B_3)\Psi^{(\mathrm{SF})}_{Sa}(B_1B_2B_3)\Psi^{(\mathrm{color})}(B_1B_2B_3)$$

$$|(0s)^9\rangle \sim \Psi^{(\mathrm{orb})}(B_1B_2B_3)$$

$$\Psi^{(\mathrm{color})}(B_1B_2B_3) = C(123)C(456)C(789)$$

We assume the color-singlet for 3q-cluster

$$\Psi^{(\mathrm{SF})}_{Sa}(B_1B_2B_3) = \sum_{S_{12}(\lambda_{12}\mu_{12})\rho_{12}(\lambda\mu)\rho} G(a_1a_2a_3, Sa; S_{12}(\lambda_{12}\mu_{12})\rho_{12}(\lambda\mu)\rho)$$
$$\times \left[[W^{[3]}(123)W^{[3]}(456)]_{S_{12}(\lambda_{12}\mu_{12})\rho_{12}} W^{[3]}(789)\right]_{S(\lambda\mu)\rho a}.$$

Eigen-value equation

$$\sum_{B_1'B_2'B_3'} \langle \Psi_{Sa}((0s)^9 : B_1B_2B_3)|\frac{1}{6}\mathcal{A}|\Psi_{Sa}((0s)^9 : B_1'B_2'B_3')\rangle C(Sa; B_1'B_2'B_3') = \mu_{Sa} C(Sa; B_1B_2B_3)$$

Antisymmetrizer

$\mu_{Sa} = 0$: Pauli forbidden state

$\mu_{Sa} \sim 0$: almost Pauli forbidden state

⇩

so much repulsive that μ_{Sa} is smaller

The degree to which 3-baryons are reluctant to overlap each other

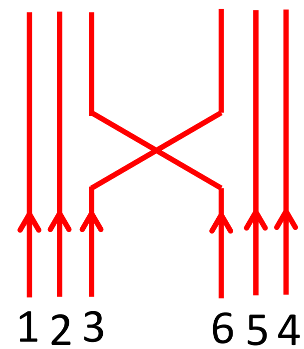
Antisymmetrizer

2-baryon system

Antisymmetrizer $\mathcal{A} = (1 - \mathcal{P})(1 - 9\, P_{36})$

baryon-exchange operator

quark -exchange operator



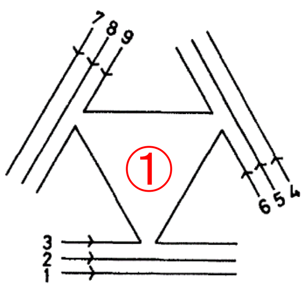
20 terms

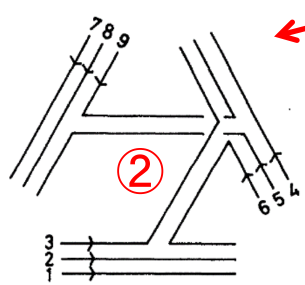
3-baryon system

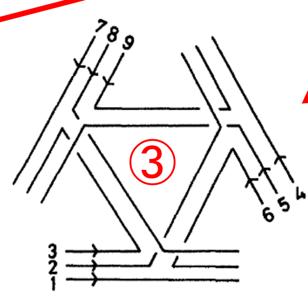
$$\begin{aligned}\mathcal{A} \;=\; & [1 \\ & -9\,(P_{36} + P_{69} + P_{93}) \\ & +27\,(P_{369} + P_{396}) \\ & +54\,(P_{36}P_{59} + P_{69}P_{83} + P_{93}P_{26})\,] \times \left[\sum_{\mathcal{P}=1}^{6} (-1)^{\pi(\mathcal{P})}\mathcal{P}\right] \\ & -216\, P_{26}P_{59}P_{83}\end{aligned}$$

D-term

2B-term







762 terms

Review of the B_8B_8 case

Almost Pauli forbidden state only in the 2-channel

ΣN(I=3/2) ^3S-state $\mu_{\mathrm{S}a} = 2/9$

They have the same flavor-SU(3) irreducible representation

Origin of repulsive Σ nuclear potential

ΞΞ (I=0) ^3S-state $\mu_{\mathrm{S}a} = 2/9$

Total Spin ½ case

Y	I	$B_8B_8B_8$	uncoupled	coupled
3	$\frac{1}{2}$	NNN	$\frac{100}{81}$	–
2	0	ΛNN	$\frac{25}{27}$	$0, \frac{100}{81}$
		ΣNN	$\frac{25}{81}$	
	1	ΛNN	$\frac{25}{27}$	$0, \frac{200}{243}, \frac{100}{81}$
		$\Sigma NN_{v=1}$	$\frac{50}{81}$	
		$\Sigma NN_{v=2}$	$\frac{125}{243}$	
	2	ΣNN	$\frac{4}{81}$	–
1	$\frac{1}{2}$	$\Xi NN_{v=1}$	$\frac{25}{27}$	$0, 0, 0, 0, \frac{200}{243}, \frac{100}{81}, \frac{130}{81}$
		$\Xi NN_{v=2}$	$\frac{35}{81}$	
		$\Lambda\Lambda N$	$\frac{5}{6}$	
		$\Sigma\Sigma N_{v=1}$	$\frac{85}{162}$	
		$\Sigma\Sigma N_{v=2}$	$\frac{35}{243}$	
		$\Sigma\Lambda N_{v=1}$	$\frac{5}{9}$	
		$\Sigma\Lambda N_{v=2}$	$\frac{20}{81}$	
	$\frac{3}{2}$	ΞNN	$\frac{10}{27}$	$0, 0, \frac{4}{81}, \frac{200}{243}, \frac{100}{81}$
		$\Sigma\Sigma N_{v=1}$	$\frac{73}{162}$	
		$\Sigma\Sigma N_{v=2}$	$\frac{235}{486}$	
		$\Sigma\Lambda N_{v=1}$	$\frac{5}{18}$	
		$\Sigma\Lambda N_{v=2}$	$\frac{85}{162}$	
	$\frac{5}{2}$	$\Sigma\Sigma N$	$\frac{4}{81}$	–

Y	I	$B_8B_8B_8$	uncoupled	coupled
0	0	$\Xi\Lambda N_{v=1}$	$\frac{5}{6}$	$0, 0, 0, \frac{200}{243}, \frac{130}{81}$
		$\Xi\Lambda N_{v=2}$	$\frac{55}{54}$	
		$\Xi\Sigma N_{v=1}$	$\frac{5}{54}$	
		$\Xi\Sigma N_{v=2}$	$\frac{55}{486}$	
		$\Sigma\Sigma\Lambda$	$\frac{10}{27}$	
	1	$\Xi\Lambda N_{v=1}$	$\frac{33}{54}$	$0, 0, 0, 0, 0, \frac{4}{81}, \frac{200}{243}, \frac{100}{81}, \frac{130}{81}$
		$\Xi\Lambda N_{v=2}$	$\frac{17}{162}$	
		$\Xi\Sigma N_{v=1}$	$\frac{11}{162}$	
		$\Xi\Sigma N_{v=2}$	$\frac{17}{27}$	
		$\Xi\Sigma N_{v=3}$	$\frac{673}{1458}$	
		$\Xi\Sigma N_{v=4}$	$\frac{295}{729}$	
		$\Sigma\Lambda\Lambda$	$\frac{4}{9}$	
		$\Sigma\Sigma\Lambda$	$\frac{23}{81}$	
		$\Sigma\Sigma\Sigma$	$\frac{19}{27}$	
	2	$\Xi\Sigma N_{v=1}$	$\frac{1}{3}$	$0, \frac{4}{81}, \frac{200}{243}, \frac{100}{81}$
		$\Xi\Sigma N_{v=2}$	$\frac{125}{243}$	
		$\Sigma\Sigma\Lambda$	$\frac{13}{27}$	
		$\Sigma\Sigma\Sigma$	$\frac{7}{9}$	

Y	I	$B_8B_8B_8$	uncoupled	coupled
−1	$\frac{1}{2}$	$\Xi\Xi N_{v=1}$	$\frac{17}{81}$	$0, 0, 0, 0, \frac{4}{81}, \frac{200}{243}, \frac{130}{81}$
		$\Xi\Xi N_{v=2}$	$\frac{73}{81}$	
		$\Xi\Lambda\Lambda$	$\frac{1}{2}$	
		$\Xi\Sigma\Sigma_{v=1}$	$\frac{83}{162}$	
		$\Xi\Sigma\Sigma_{v=2}$	$\frac{17}{243}$	
		$\Xi\Sigma\Lambda_{v=1}$	$\frac{1}{36}$	
		$\Xi\Sigma\Lambda_{v=2}$	$\frac{83}{324}$	
	$\frac{3}{2}$	$\Xi\Xi N$	$\frac{34}{81}$	$0, 0, \frac{4}{81}, \frac{200}{243}, \frac{100}{81}$
		$\Xi\Sigma\Sigma_{v=1}$	$\frac{35}{162}$	
		$\Xi\Sigma\Sigma_{v=2}$	$\frac{253}{486}$	
		$\Xi\Sigma\Lambda_{v=1}$	$\frac{1}{3}$	
		$\Xi\Sigma\Lambda_{v=2}$	$\frac{50}{81}$	
	$\frac{5}{2}$	$\Xi\Sigma\Sigma$	$\frac{100}{81}$	–
−2	0	$\Xi\Xi\Lambda$	$\frac{1}{27}$	$0, \frac{4}{81}$
		$\Xi\Xi\Sigma$	$\frac{1}{81}$	
	1	$\Xi\Xi\Lambda$	$\frac{13}{27}$	$0, \frac{4}{81}, \frac{200}{243}$
		$\Xi\Xi\Sigma_{v=1}$	$\frac{26}{81}$	
		$\Xi\Xi\Sigma_{v=2}$	$\frac{17}{243}$	
	2	$\Xi\Xi\Sigma$	$\frac{100}{81}$	–
−3	$\frac{1}{2}$	$\Xi\Xi\Xi$	$\frac{4}{81}$	–

Λnn

$\Sigma^- nn$

$\Lambda\Lambda n$

$\Xi^- nn$

$\Sigma^-\Sigma^- n$

$\Xi^-\Xi^- n$

Total Spin ½ case

Y	I	$B_8B_8B_8$	uncoupled	coupled
3	$\frac{1}{2}$	NNN	$\frac{100}{81}$	–
2	0	ΛNN	$\frac{25}{27}$	$0\,,\ \frac{100}{81}$
		ΣNN	$\frac{25}{81}$	
	1	ΛNN	$\frac{25}{27}$	$0\,,\ \frac{200}{243}\,,\ \frac{100}{81}$
		$\Sigma NN_{v=1}$	$\frac{50}{81}$	
		$\Sigma NN_{v=2}$	$\frac{125}{243}$	
	2	ΣNN	$\frac{4}{81}$	–
1	$\frac{1}{2}$	$\Xi NN_{v=1}$	$\frac{25}{27}$	$0\,,\ 0\,,\ 0\,,\ 0\,,\ \frac{200}{243}\,,\ \frac{100}{81}\,,\ \frac{130}{81}$ [illegible]
		$\Xi NN_{v=2}$	$\frac{35}{81}$	
		$\Lambda\Lambda N$	$\frac{5}{6}$	
		$\Sigma\Sigma N_{v=1}$	$\frac{85}{162}$	
		$\Sigma\Sigma N_{v=2}$	$\frac{35}{243}$	
		$\Sigma\Lambda$ [illegible]	[illegible]	
		$\Sigma\Lambda$ [illegible]	[illegible]	
	$\frac{3}{2}$	ΞNN	$\frac{10}{27}$	$0\,,\ 0\,,\ \frac{4}{81}\,,\ \frac{200}{243}\,,\ \frac{100}{81}$
		$\Sigma\Sigma N_{v=1}$	$\frac{73}{162}$	
		$\Sigma\Sigma N_{v=2}$	$\frac{235}{486}$	
		$\Sigma\Lambda N_{v=1}$	$\frac{5}{18}$	
		$\Sigma\Lambda N_{v=2}$	$\frac{85}{162}$	
	$\frac{5}{2}$	$\Sigma\Sigma N$	$\frac{4}{81}$	–

Y	I	$B_8B_8B_8$	uncoupled	coupled
0	0	$\Xi\Lambda N_{v=1}$	$\frac{5}{6}$	$0\,,\ 0\,,\ 0\,,\ \frac{200}{243}\,,\ \frac{130}{81}$
		$\Xi\Lambda N_{v=2}$	$\frac{55}{54}$	
		$\Xi\Sigma N_{v=1}$	$\frac{5}{54}$	
		$\Xi\Sigma N_{v=2}$	$\frac{55}{486}$	
		$\Sigma\Sigma\Lambda$	$\frac{10}{27}$	
	1	$\Xi\Lambda N_{v=1}$	$\frac{33}{54}$	$0\,,\ 0\,,\ 0\,,\ 0\,,\ 0\,,\ \frac{4}{81}\,,\ \frac{200}{243}\,,\ \frac{100}{81}\,,\ \frac{130}{81}$
		$\Xi\Lambda N_{v=2}$	$\frac{17}{162}$	
		$\Xi\Sigma N_{v=1}$	$\frac{11}{162}$	
		$\Xi\Sigma N_{v=2}$	$\frac{17}{27}$	
		$\Xi\Sigma N_{v=3}$	$\frac{673}{1458}$	
		$\Xi\Sigma N_{v=4}$	$\frac{295}{729}$	
		[illegible]	[illegible]	
		[illegible]	[illegible]	
		$\Sigma\Sigma\Sigma$	$\frac{19}{27}$	
	2	$\Xi\Sigma N_{v=1}$	$\frac{1}{3}$	$0\,,\ \frac{4}{81}\,,\ \frac{200}{243}\,,\ \frac{100}{81}$
		$\Xi\Sigma N_{v=2}$	$\frac{125}{243}$	
		$\Sigma\Sigma\Lambda$	$\frac{13}{27}$	
		$\Sigma\Sigma\Sigma$	$\frac{7}{9}$	

Y	I	$B_8B_8B_8$	uncoupled	coupled
-1	$\frac{1}{2}$	$\Xi\Xi N_{v=1}$	$\frac{17}{81}$	$0\,,\ 0\,,\ 0\,,\ 0\,,\ \frac{4}{81}\,,\ \frac{200}{243}\,,\ \frac{130}{81}$
		$\Xi\Xi N_{v=2}$	$\frac{73}{81}$	
		$\Xi\Lambda\Lambda$	$\frac{1}{2}$	
		$\Xi\Sigma\Sigma_{v=1}$	$\frac{83}{162}$	
		$\Xi\Sigma\Sigma_{v=2}$	$\frac{17}{243}$	
		$\Xi\Sigma\Lambda_{v=1}$	$\frac{1}{36}$	
		$\Xi\Sigma\Lambda_{v=2}$	$\frac{83}{324}$	
	$\frac{3}{2}$	$\Xi\Xi N$	$\frac{34}{81}$	$0\,,\ 0\,,\ \frac{4}{81}\,,\ \frac{200}{243}\,,\ \frac{100}{81}$
		$\Xi\Sigma\Sigma_{v=1}$	$\frac{35}{162}$	
		$\Xi\Sigma\Sigma_{v=2}$	$\frac{253}{486}$	
		$\Xi\Sigma\Lambda_{v=1}$	$\frac{1}{3}$	
		$\Xi\Sigma\Lambda_{v=2}$	$\frac{50}{81}$	
	$\frac{5}{2}$	$\Xi\Sigma\Sigma$	$\frac{100}{81}$	–
-2	0	$\Xi\Xi\Lambda$	$\frac{1}{27}$	$0\,,\ \frac{4}{81}$
		$\Xi\Xi\Sigma$	$\frac{1}{81}$	
	1	$\Xi\Xi\Lambda$	$\frac{13}{27}$	$0\,,\ \frac{4}{81}\,,\ \frac{200}{243}$
		$\Xi\Xi\Sigma_{v=1}$	$\frac{26}{81}$	
		$\Xi\Xi\Sigma_{v=2}$	$\frac{17}{243}$	
	2	$\Xi\Xi\Sigma$	$\frac{100}{81}$	–
-3	$\frac{1}{2}$	$\Xi\Xi\Xi$	$\frac{4}{81}$	–

Λnn

$\Sigma^- nn$

$\Lambda\Lambda n$

$\Xi^- nn$

$\Sigma^-\Sigma^- n$

$\Xi^-\Xi^- n$

Strong Pauli-repulsion

Total Spin 3/2 case

$\Sigma^-\Lambda n$

$\Xi^-\Sigma^- n$

$\Xi^-\Sigma^-\Lambda$

Y	I	$B_8B_8B_8$	uncoupled	coupled
2	0	ΛNN	$\frac{25}{27}$	–
	1	ΣNN	$\frac{35}{243}$	–
1	$\frac{1}{2}$	ΞNN	$\frac{50}{81}$	$\frac{35}{243}, \frac{5}{9}, \frac{25}{27}$
		$\Sigma\Sigma N$	$\frac{95}{243}$	
		$\Sigma\Lambda N$	$\frac{50}{81}$	
	$\frac{3}{2}$	$\Sigma\Sigma N$	$\frac{31}{486}$	$\frac{1}{27}, \frac{35}{243}$
		$\Sigma\Lambda N$	$\frac{19}{162}$	
0	0	$\Xi\Lambda N$	$\frac{20}{27}$	$\frac{35}{243}, \frac{5}{9}, \frac{35}{27}$
		$\Xi\Sigma N$	$\frac{140}{243}$	
		$\Sigma\Sigma\Sigma$	$\frac{55}{81}$	
	1	$\Xi\Lambda N$	$\frac{34}{81}$	$\frac{1}{27}, \frac{35}{243}, \frac{5}{9}, \frac{25}{27}$
		$\Xi\Sigma N_{v=1}$	$\frac{134}{729}$	
		$\Xi\Sigma N_{v=2}$	$\frac{565}{729}$	
		$\Sigma\Sigma\Lambda$	$\frac{23}{81}$	
	2	$\Xi\Sigma N$	$\frac{35}{243}$	–
-1	$\frac{1}{2}$	$\Xi\Xi N$	$\frac{14}{81}$	$\frac{1}{27}, \frac{35}{243}, \frac{5}{9}$
		$\Xi\Sigma\Sigma$	$\frac{95}{243}$	
		$\Xi\Sigma\Lambda$	$\frac{14}{81}$	
	$\frac{3}{2}$	$\Xi\Sigma\Sigma$	$\frac{355}{486}$	$\frac{35}{243}, \frac{25}{27}$
		$\Xi\Sigma\Lambda$	$\frac{55}{162}$	
-2	0	$\Xi\Xi\Lambda$	$\frac{1}{27}$	–
	1	$\Xi\Xi\Sigma$	$\frac{35}{243}$	–

Total Spin 3/2 case

Y	I	$B_8B_8B_8$	uncoupled	coupled
2	0	ΛNN	$\frac{25}{27}$	–
	1	ΣNN	$\frac{35}{243}$	–
1	$\frac{1}{2}$	ΞNN	$\frac{50}{81}$	$\frac{35}{243}, \frac{5}{9}, \frac{25}{27}$
		$\Sigma\Sigma N$	$\frac{95}{243}$	
		$\Sigma\Lambda N$	$\frac{50}{81}$	
	$\frac{3}{2}$	$\Sigma\Sigma N$	$\frac{31}{486}$	$\frac{1}{27}, \frac{35}{243}$
		$\Sigma\Lambda N$	$\frac{19}{162}$	
0	0	$\Xi\Lambda N$	$\frac{20}{27}$	$\frac{35}{243}, \frac{5}{9}, \frac{35}{27}$
		$\Xi\Sigma N$	$\frac{140}{243}$	
		$\Sigma\Sigma\Sigma$	$\frac{55}{81}$	
	1	$\Xi\Lambda N$	$\frac{34}{81}$	$\frac{1}{27}, \frac{35}{243}, \frac{5}{9}, \frac{25}{27}$
		$\Xi\Sigma N_{v=1}$	$\frac{134}{729}$	
		$\Xi\Sigma N_{v=2}$	$\frac{565}{729}$	
		$\Sigma\Sigma\Lambda$	$\frac{23}{81}$	
	2	$\Xi\Sigma N$	$\frac{35}{243}$	–
−1	$\frac{1}{2}$	$\Xi\Xi N$	$\frac{14}{81}$	$\frac{1}{27}, \frac{35}{243}, \frac{5}{9}$
		$\Xi\Sigma\Sigma$	$\frac{95}{243}$	
		$\Xi\Sigma\Lambda$	$\frac{14}{81}$	
	$\frac{3}{2}$	$\Xi\Sigma\Sigma$	$\frac{355}{486}$	$\frac{35}{243}, \frac{25}{27}$
		$\Xi\Sigma\Lambda$	$\frac{55}{162}$	
−2	0	$\Xi\Xi\Lambda$	$\frac{1}{27}$	–
	1	$\Xi\Xi\Sigma$	$\frac{35}{243}$	–

$\Sigma^-\Lambda n$

$\Xi^-\Sigma^- n$

$\Xi^-\Sigma^-\Lambda$

Strong Pauli-repulsion

Summary of quark-Pauli effect

- We investigated the quark-Pauli effects in the $B_8B_8B_8$ systems by estimating the eigenvalue of the RGM normalization kernel. (no parameter)

PRC94,035803 (2016)

- Almost Pauli-forbidden state

  Total spin 1/2

  $\Sigma NN(I=2) = \Sigma^- nn$, $\Sigma\Sigma N(5/2) = \Sigma^-\Sigma^- n$, $\Xi\Xi\Lambda - \Xi\Xi\Sigma(0)$, $\Xi\Xi\Xi(1/2)$

  Total spin 3/2

  $\Sigma NN(1)$, $\Sigma\Sigma N - \Sigma\Lambda N(3/2) = \Sigma^-\Lambda n$, $\Xi\Sigma N(2) = \Xi^-\Sigma^- n$, $\Xi\Xi\Lambda(0)$, $\Xi\Xi\Sigma(1)$

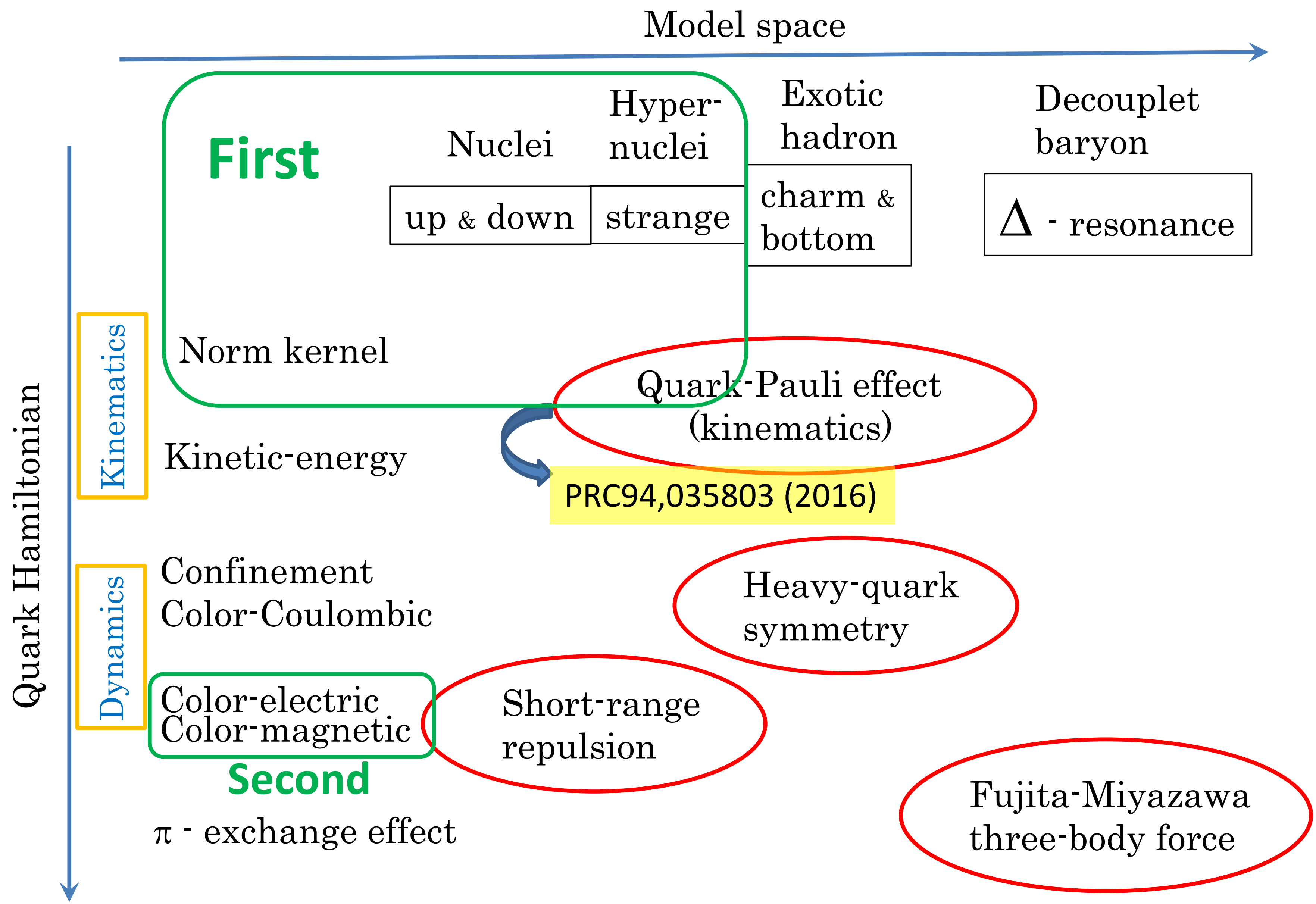
- The Pauli blocking effect is weak in the Λnn system

  ⇒ No quark-Pauli repulsion effectively works for Λ

No additional repulsion for Λ

- The Pauli blocking effect is strong in the $\Sigma^- nn$ system

  ⇒ The appearance of Σ^- is suppressed in the neutron star interior


Model space
Quark Hamiltonian
First
Nuclei
Hyper-nuclei
Exotic hadron
Decouplet baryon
up & down
strange
charm & bottom
Δ - resonance
Kinematics
Norm kernel
Quark-Pauli effect (kinematics)
Kinetic-energy
PRC94,035803 (2016)
Dynamics
Confinement
Color-Coulombic
Heavy-quark symmetry
Color-electric
Color-magnetic
Short-range repulsion
Second
π - exchange effect
Fujita-Miyazawa three-body force

Quark-Hamiltonian (only central forces)

$$
\begin{aligned}
H^{\mathrm{K+conf.+FB}} &= \sum_i \frac{1}{2m_i} \boldsymbol{p}_i^2 \\
\text{confinement} \quad & + \sum_{i<j} \left(\lambda_i^c \cdot \lambda_j^c \right) v_c(r_{ij}) \\
\text{Color-Coulombic} \quad & + \sum_{i<j} \frac{1}{4} \alpha_S \hbar c \left(\lambda_i^c \cdot \lambda_j^c \right) \frac{1}{r_{ij}} \\
\text{Color-electric} \quad & + \sum_{i<j} \frac{1}{4} \alpha_S \hbar c \left(\lambda_i^c \cdot \lambda_j^c \right) \left\{ -\frac{\pi \hbar^2}{2c^2} \left(\frac{1}{m_i^2} + \frac{1}{m_j^2} \right) \delta(r_{ij}) \right\} \\
\text{Color-magnetic} \quad & + \sum_{i<j} \frac{1}{4} \alpha_S \hbar c \left(\lambda_i^c \cdot \lambda_j^c \right) \left\{ -\frac{2\pi \hbar^2}{3 m_i m_j c^2} \delta(r_{ij}) \left(\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \right) \right\}
\end{aligned}
$$

We assume the flavor-SU(3) limit for quark-mass dependence

Set of $B_8 B_8 B_8$(isospin) states with the same irreducible expression in the flavor-SU(3) basis

[Spin 1/2]

- NNN(1/2) – ΞΣΣ(5/2) – ΞΞΣ(2)
  ($\Xi^-\Sigma^-\Sigma^-$, $\Xi^-\Xi^-\Sigma^-$)
- ΣNN(2) – ΣΣN(5/2) – ΞΞΞ(1/2)
  ($\Sigma^- nn$, $\Sigma^-\Sigma^- n$)

[Spin 3/2]

- ΣNN(1) – ΞΣN(2) – ΞΞΣ(1)
  ($\Xi^-\Sigma^- n$)

These have the same 3-body forces in the flavor-SU(3) limit.

3. Estimation of interaction kernel (Dynamics)

Resonating-group method (RGM) equation

3-baryon system

$$\left[-\frac{\hbar^2}{2\mu_1}\Delta_{R_{12}} - \frac{\hbar^2}{2\mu_2}\Delta_{R_{12-3}}\right]\chi(\vec{R}_{12},\vec{R}_{12-3}) + \int\int \underline{K(\vec{R}'_{12},\vec{R}'_{12-3};\vec{R}_{12},\vec{R}_{12-3})}\chi(\vec{R}'_{12},\vec{R}'_{12-3})d\vec{R}'_{12}d\vec{R}'_{12-3} = \varepsilon\chi(\vec{R}_{12},\vec{R}_{12-3})$$

Exchange RGM kernel
(non-local potential)

We investigate the qualitative feature of 3-baryon force by the estimation diagonal element $K(\vec{R}_{12},\vec{R}_{12-3};\vec{R}_{12},\vec{R}_{12-3})$

Diagonal exchange RGM kernel

$$K(\vec{R}_{12}, \vec{R}_{12-3}; \vec{R}_{12}, \vec{R}_{12-3})$$

$$= \frac{1}{3!}\Big\langle \phi(1,2,3)_{SI}\,\delta(\vec{R}_{12}-\vec{R}_a)\,\delta(\vec{R}_{12-3}-\vec{R}_b)$$

$$\times \Big| \textstyle\sum_{i<j} (\lambda_i \cdot \lambda_j)\ f(r_{ij}) \Big(\underline{\mathcal{A}} - \sum_{\mathcal{P}=1}^{6} (-1)^{\pi(\mathcal{P})}\mathcal{P}\Big) \Big| \phi(1,2,3)_{SI}\,\delta(\vec{R}_{12}-\vec{R}_a)\,\delta(\vec{R}_{12-3}-\vec{R}_b)\Big\rangle$$

antisymmetrizer $\mathcal{A} = [1$ D-term

$-9\,(P_{36}+P_{69}+P_{93})$ 2B-term

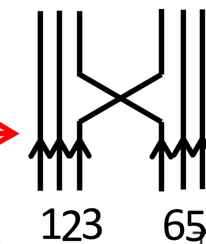
$+27\,(P_{369}+P_{396})$

$+54\,(P_{36}P_{59}+P_{69}P_{83}+P_{93}P_{26})] \times \Big[\sum_{\mathcal{P}=1}^{6}(-1)^{\pi(\mathcal{P})}\underline{\mathcal{P}}\Big]$

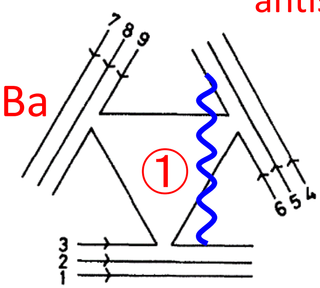
$-216\,P_{26}P_{59}P_{83}$

3-body effect !!

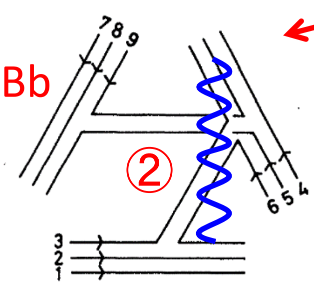
baryon-exchange operator

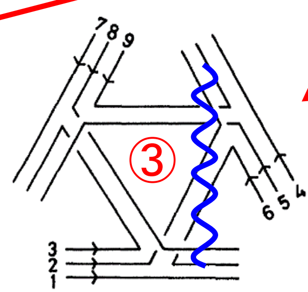


3Ba



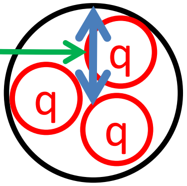
3Bb





3Bc

Parameter set { Width parameter $b = 0.6$ fm; Quark mass $mc^2 = 313$ MeV



Here, we investigate the qualitative feature of the 3-body effect in the following $B_8B_8B_8$ systems with S=1/2 by estimating the common diagonal RGM kernel.
The unit of the kernel is arbitrary.

NNN(I=1/2), ΛNN(I=0,1), ΣNN(I=2), ΞNN(I=3/2)

Λnn $\Sigma^- nn$ $\Xi^- nn$

The part of these RGM kernels is singular.

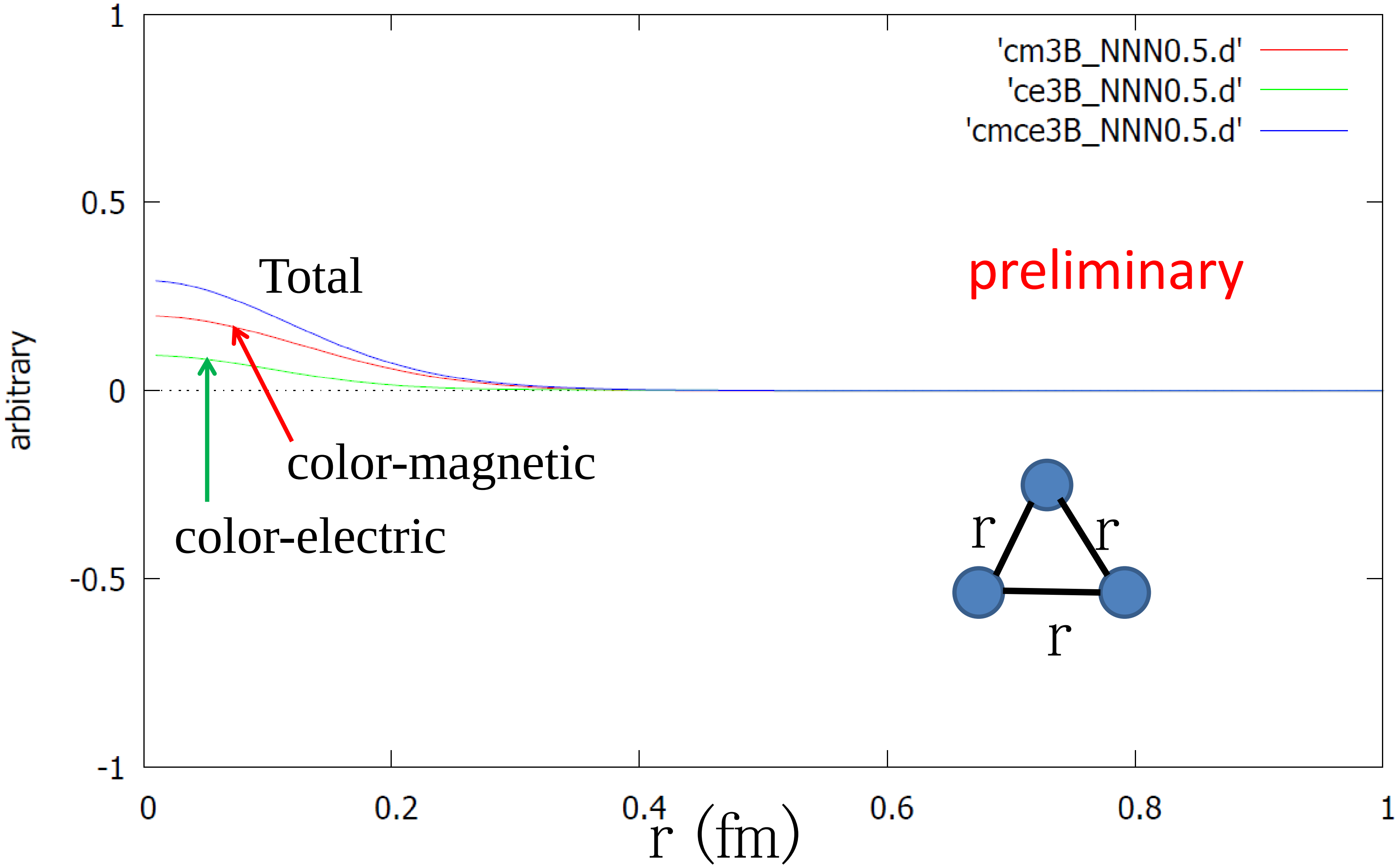
$$\left[-\frac{\hbar^2}{2\mu_1}\Delta_{R_{12}} - \frac{\hbar^2}{2\mu_2}\Delta_{R_{12-3}}\right]\chi(\vec{R}_{12},\vec{R}_{12-3}) + \int\int K(\vec{R}'_{12},\vec{R}'_{12-3};\vec{R}_{12},\vec{R}_{12-3})\chi(\vec{R}'_{12},\vec{R}'_{12-3})d\vec{R}'_{12}d\vec{R}'_{12-3} = \varepsilon\chi(\vec{R}_{12},\vec{R}_{12-3})$$

In fact, we may have to estimate this integral.

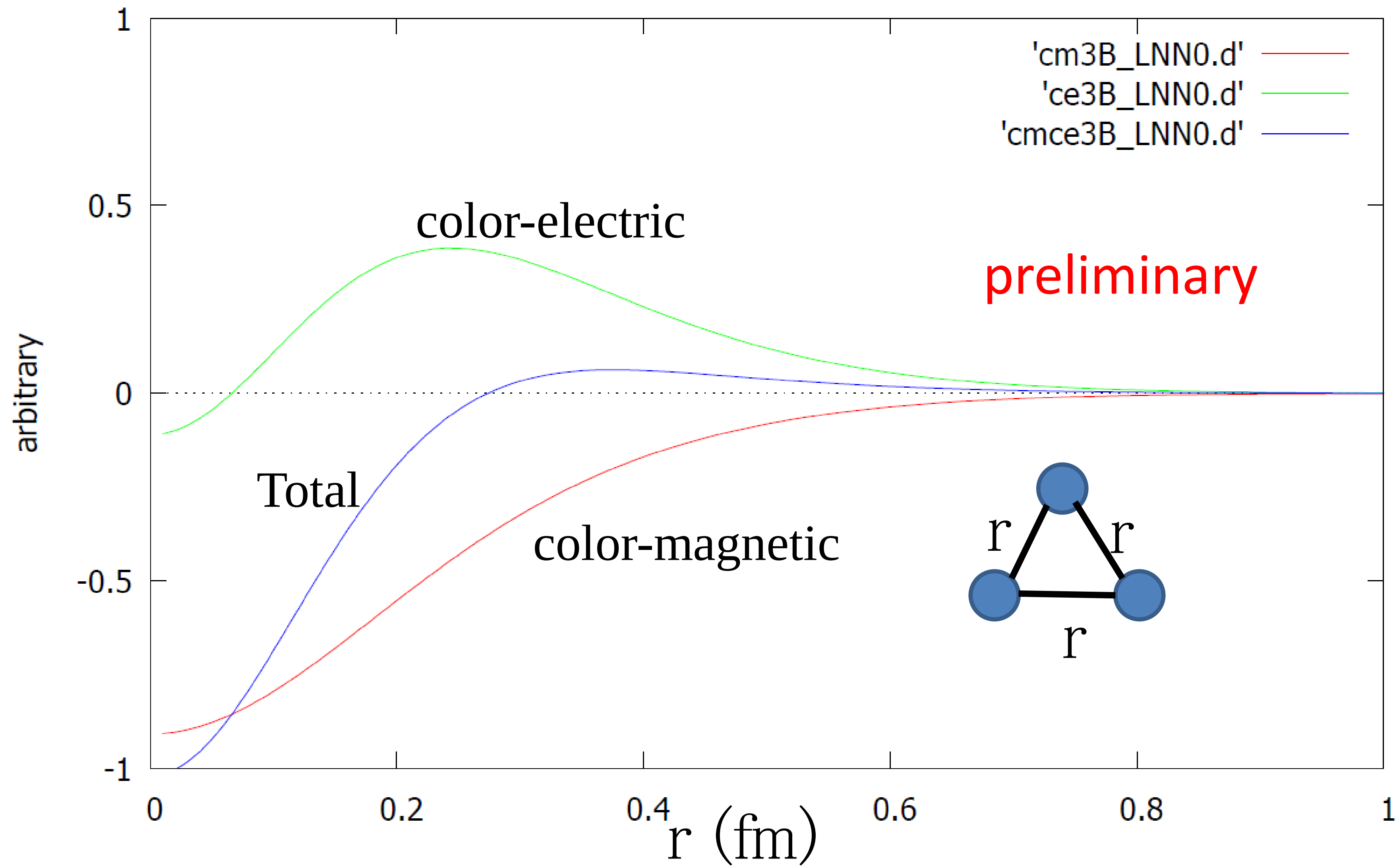
Possibly, large contribution !?

We omit the singular term in this talk. preliminary

NNN(I = ½)

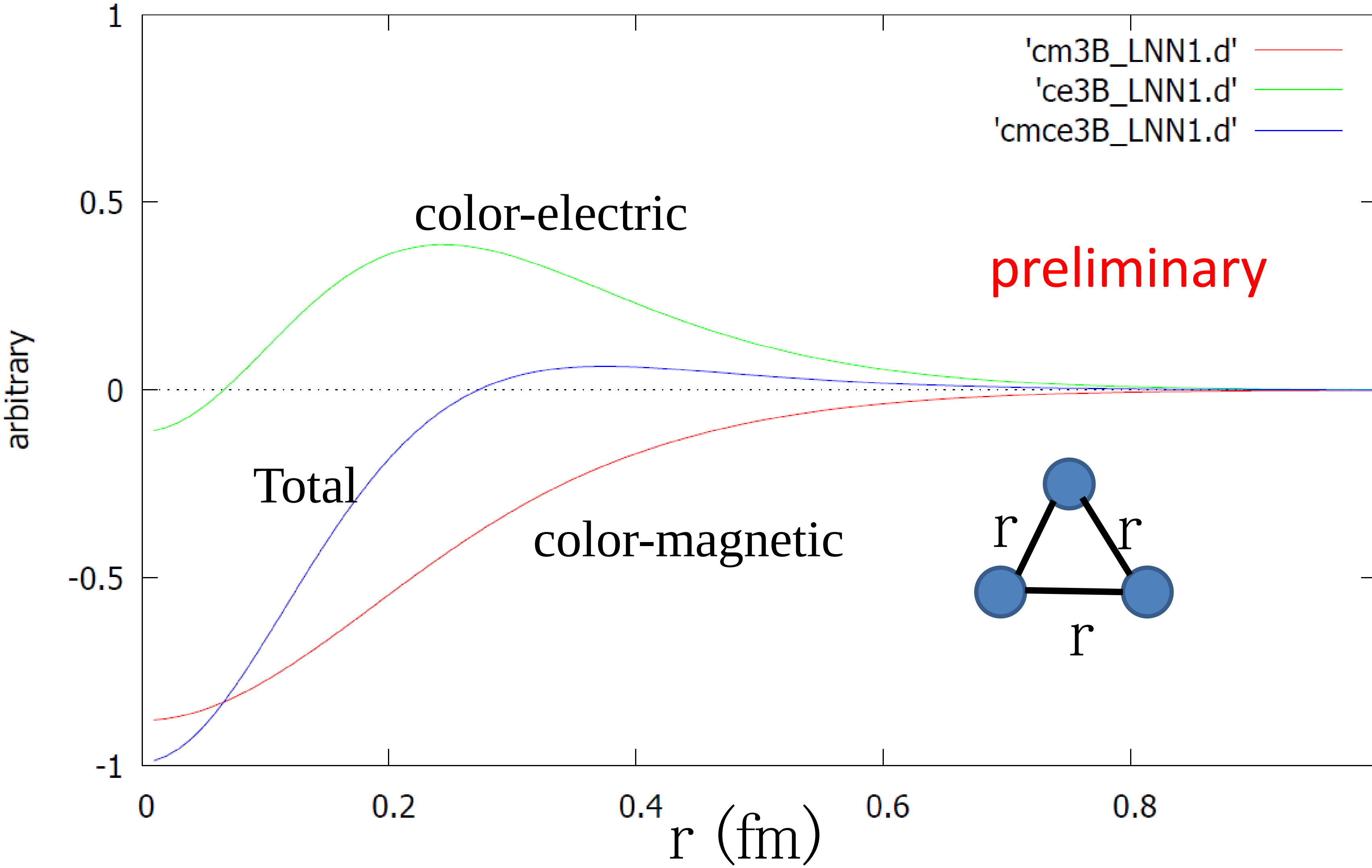

1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
arbitrary
r (fm)
'cm3B_NNN0.5.d'
'ce3B_NNN0.5.d'
'cmce3B_NNN0.5.d'
Total
preliminary
color-magnetic
color-electric
r
r
r

ΛNN(I = 0)

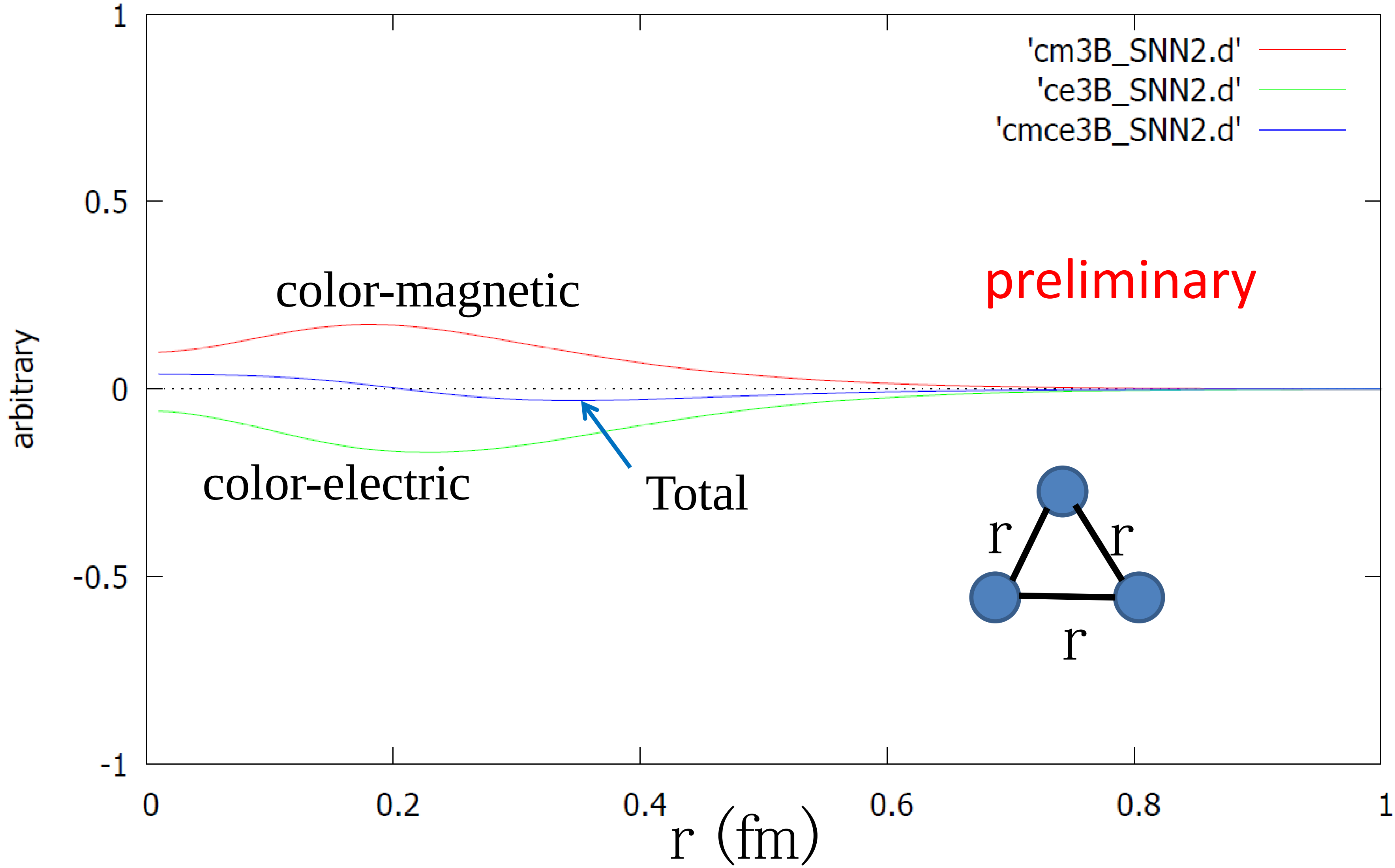


1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
arbitrary
r (fm)
'cm3B_LNN0.d'
'ce3B_LNN0.d'
'cmce3B_LNN0.d'
color-electric
preliminary
Total
color-magnetic
r
r
r

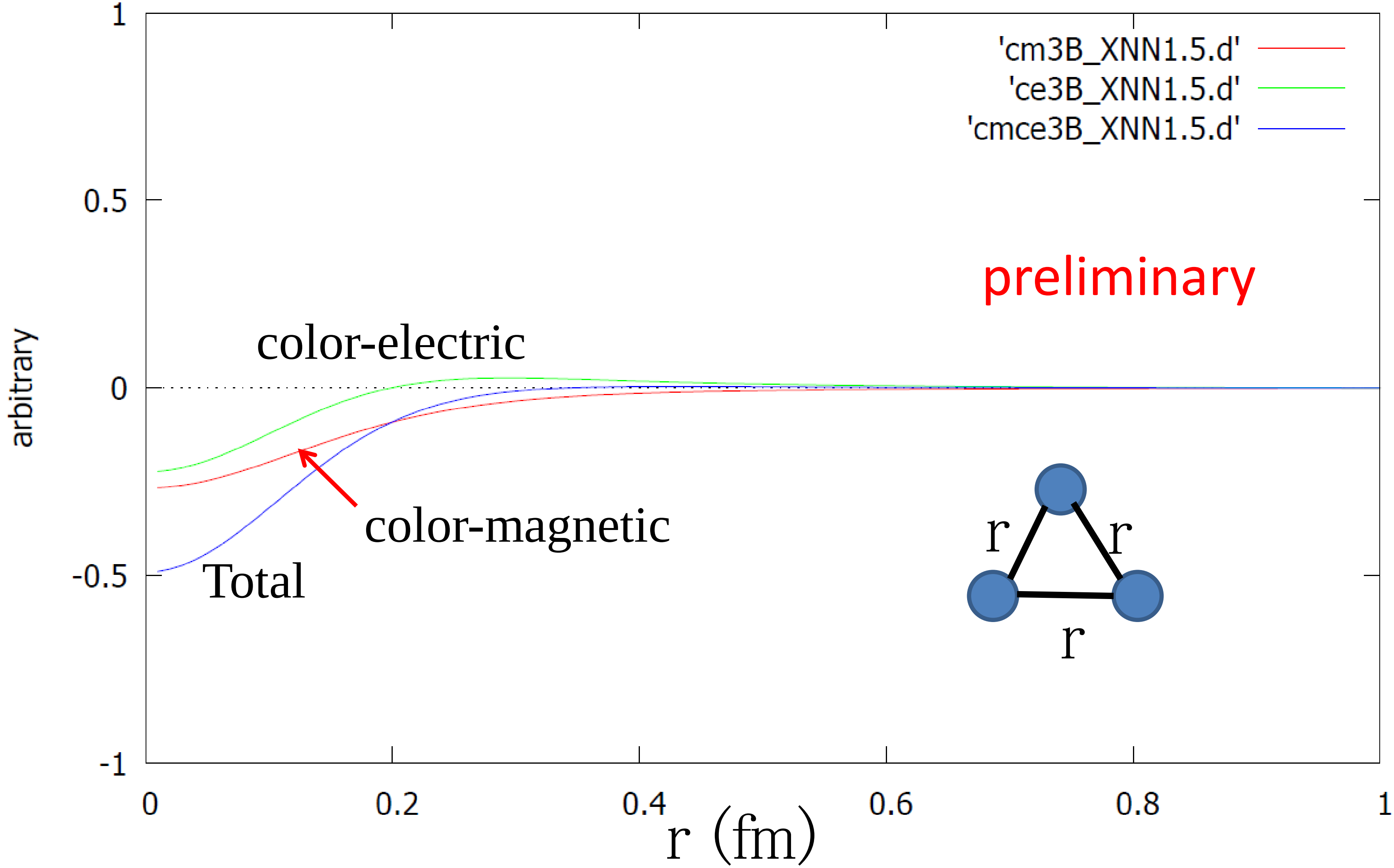
$\Lambda NN(I = 1)$ [Λnn]



$\Sigma NN(I = 2)$ $[\Sigma^{-}nn]$

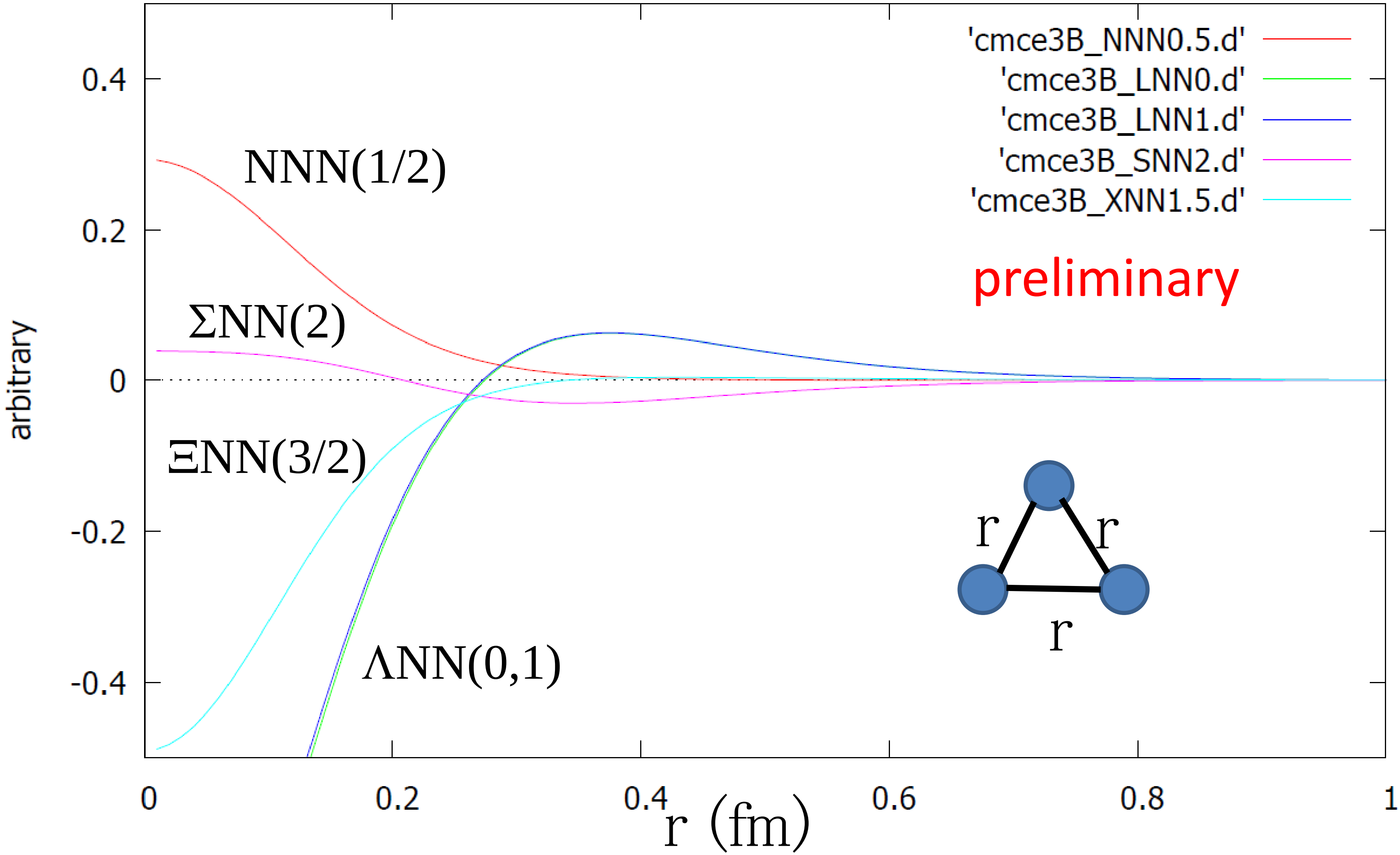


ΞNN(I = 3/2) [Ξ⁻nn]



1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
arbitrary
'cm3B_XNN1.5.d'
'ce3B_XNN1.5.d'
'cmce3B_XNN1.5.d'
preliminary
color-electric
color-magnetic
Total
r
r
r
r (fm)

Total



0.4
0.2
0
-0.2
-0.4
arbitrary
0
0.2
0.4
0.6
0.8
1
r (fm)
'cmce3B_NNN0.5.d'
'cmce3B_LNN0.d'
'cmce3B_LNN1.d'
'cmce3B_SNN2.d'
'cmce3B_XNN1.5.d'
preliminary
NNN(1/2)
ΣNN(2)
ΞNN(3/2)
ΛNN(0,1)
r
r
r

Summary & Future

- We investigated the 3-body effect generated from the color-electric and color-magnetic interactions in the $B_8B_8B_8$ systems by estimating the diagonal RGM kernel.

- The dependence on $B_8B_8B_8$ systems (preliminary)

  NNN(1/2) (also $\Xi\Sigma\Sigma(5/2)$, $\Xi\Xi\Sigma(2)$) : repulsive

  ΛNN(0), Λnn : repulsive at medium and attractive at short-range

  $\Sigma^- nn$, (also $\Sigma^-\Sigma^- n$, $\Xi\Xi\Xi(1/2)$)

  : attractive at medium and repulsive at short-range

  $\Xi^- nn$: attractive

$$\int\int K(\vec{R}'_{12}, \vec{R}'_{12-3}; \vec{R}_{12}, \vec{R}_{12-3})\chi(\vec{R}'_{12}, \vec{R}'_{12-3})d\vec{R}'_{12}d\vec{R}'_{12-3}$$

Future

- Estimation of effective potential
- Estimation of the other terms
- Including flavor-symmetry breaking

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