Baryon–antibaryon interactions and bound-state possibility in a constituent quark model

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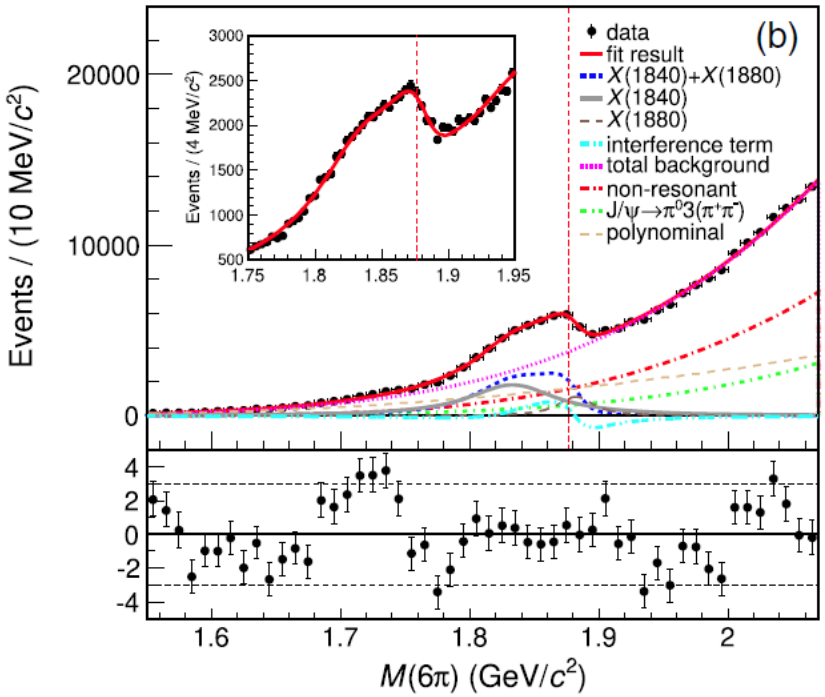
Introduction

$p\bar{p}$ bound state

$$J/\psi \to \gamma 3(\pi^+\pi^-)$$



M. Ablikim et al.(BESIII Collaboration)
Phys. Rev. Lett. 132, 151901(2024)

X(1840)

$$M = 1832.5 \pm 3.1 \pm 2.5 \text{ MeV}/c^2$$

$$\Gamma = 80.7 \pm 5.2 \pm 7.7 \text{ MeV}$$

X(1880)

$$M = 1882.1 \pm 1.7 \pm 0.7 \text{ MeV}/c^2$$

$$\Gamma = 30.7 \pm 5.5 \pm 2.4 \text{ MeV}$$

This indicates the existence of a $p\bar{p}$ bound state.

$q^3\bar{q}^3$ configuration

Calculating the color-color interaction of $q^3\bar{q}^3$ state is challenging because it is difficult to construct the color wave function when quarks and antiquarks are present together.

q^n : totally antisymmetric wave function.

$q^n\bar{q}^m$: antisymmetric for quarks and antiquarks, respectively.
Constructing a total color singlet requires an appropriate connection between the quark and antiquark color state.

Dibaryon case

For a dibaryon,

$$3 \otimes 3 \otimes 3 \otimes 3 \otimes 3 \otimes 3 = (\bar{3} \oplus 6) \otimes (\bar{3} \oplus 6) \otimes (\bar{3} \oplus 6)$$

$$= \cdots$$

$$= 1_{(m=5)} \oplus 8_{(m=16)} \oplus 10_{(m=10)} \oplus \overline{10}_{(m=5)} \oplus 27_{(m=9)} \oplus 35_{(m=5)} \oplus 28$$

too complicated

Let's consider the Young diagrams.

$$|C_1\rangle = \begin{array}{|c|c|}\hline 1&2\\\hline 3&4\\\hline 5&6\\\hline\end{array},\ |C_2\rangle = \begin{array}{|c|c|}\hline 1&3\\\hline 2&4\\\hline 5&6\\\hline\end{array},\ |C_3\rangle = \begin{array}{|c|c|}\hline 1&2\\\hline 3&5\\\hline 4&6\\\hline\end{array},\ |C_4\rangle = \begin{array}{|c|c|}\hline 1&3\\\hline 2&5\\\hline 4&6\\\hline\end{array},\ |C_5\rangle = \begin{array}{|c|c|}\hline 1&4\\\hline 2&5\\\hline 3&6\\\hline\end{array}.$$

We can represent the color state using the Young-Yamanouchi basis.

1. For the Young-Yamanouchi basis, the entries in each row and column are increasing.
2. From one basis, we can generate the remaining basis using the permutation property.

Dibaryon case

For a dibaryon,

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$$= \cdots$$

$$= 1_{(m=5)} \oplus 8_{(m=16)} \oplus 10_{(m=10)} \oplus \overline{10}_{(m=5)} \oplus 27_{(m=9)} \oplus 35_{(m=5)} \oplus 28$$

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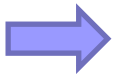
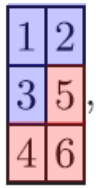


$|C_1\rangle =$ 

8-8

$|C_2\rangle =$ 

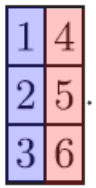
8-8

$|C_3\rangle =$ 

8-8

$|C_4\rangle =$ 

8-8

$|C_5\rangle =$ 

1-1

$$\lambda_i^c \lambda_j^c = 2(ij) - \frac{2}{3} I$$

$$\sum_{i<j} \lambda_i \lambda_j = \begin{pmatrix} -16 & 0 & 0 & 0 & 0 \\ 0 & -16 & 0 & 0 & 0 \\ 0 & 0 & -16 & 0 & 0 \\ 0 & 0 & 0 & -16 & 0 \\ 0 & 0 & 0 & 0 & -16 \end{pmatrix}$$

Conclusion: If we can construct the multiplet only using the fundamental representations (or antifundamental representations only), then we can easily calculate the color-color matrices.

Minimally Combined representation

Minimally combined representation

Minimally combined representation is useful way to obtain the color singlet basis of $q^n\bar{q}^n$ or $q^{n+3m}\bar{q}^n$.

How to construct.

Step 1: Separate quarks and antiquarks.

Step 2: Construct the irreducible representations of quarks using the product of fundamental representations. And do the same for antiquarks.

Step 3: Combine each irreducible representation of quarks with an irreducible representation of antiquarks of the same shape consisting of antifundamental representations.

Number of color basis

The number of color singlet basis of $q^n\bar{q}^n = \sum_Y d_Y^2$

where d_Y is a dimension of the corresponding Young diagram.

The summation is taken for all possible Young diagrams consisting n boxes satisfying the SU(3) symmetry.

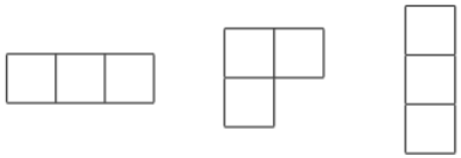
ex1) $q^2\bar{q}^2$

The possible Young diagrams : 

$d_{[2]} = 1, d_{[1,1]} = 1$

→ $\sum_Y d_Y^2 = 2$

ex2) $q^3\bar{q}^3$

The possible Young diagrams : 

$d_{[3]} = 1, d_{[2,1]} = 2, d_{[1,1,1]} = 1$

→ $\sum_Y d_Y^2 = 6$

Color basis of $q^3\bar{q}^3$

$$\mathbf{3}_1 \times \mathbf{3}_2 \times \mathbf{3}_3 \times \overline{\mathbf{3}}_4 \times \overline{\mathbf{3}}_5 \times \overline{\mathbf{3}}_6$$
$$= (\mathbf{1}_{123} + \mathbf{8}_{123} + \mathbf{8}_{123} + \mathbf{10}_{123}) \times (\mathbf{1}_{456} + \mathbf{8}_{456} + \mathbf{8}_{456} + \overline{\mathbf{10}}_{456})$$

$$|C_1\rangle = \left(\begin{array}{|c|}\hline 1 \\ \hline 2 \\ \hline 3 \\ \hline \end{array}, \begin{array}{|c|}\hline \bar{4} \\ \hline \bar{5} \\ \hline \bar{6} \\ \hline \end{array}\right), \quad |C_2\rangle = \left(\begin{array}{|c|c|}\hline 1 & 2 \\ \hline 3 \\ \cline{1-1} \end{array}, \begin{array}{|c|c|}\hline \bar{4} & \bar{5} \\ \hline \bar{6} \\ \cline{1-1} \end{array}\right), \quad |C_3\rangle = \left(\begin{array}{|c|c|}\hline 1 & 2 \\ \hline 3 \\ \cline{1-1} \end{array}, \begin{array}{|c|c|}\hline \bar{4} & \bar{6} \\ \hline \bar{5} \\ \cline{1-1} \end{array}\right),$$

$$|C_4\rangle = \left(\begin{array}{|c|c|}\hline 1 & 3 \\ \hline 2 \\ \cline{1-1} \end{array}, \begin{array}{|c|c|}\hline \bar{4} & \bar{5} \\ \hline \bar{6} \\ \cline{1-1} \end{array}\right), \quad |C_5\rangle = \left(\begin{array}{|c|c|}\hline 1 & 3 \\ \hline 2 \\ \cline{1-1} \end{array}, \begin{array}{|c|c|}\hline \bar{4} & \bar{6} \\ \hline \bar{5} \\ \cline{1-1} \end{array}\right), \quad |C_6\rangle = \left(\begin{array}{|c|c|c|}\hline 1 & 2 & 3 \\ \hline \end{array}, \begin{array}{|c|c|c|}\hline \bar{4} & \bar{5} & \bar{6} \\ \hline \end{array}\right)$$

There is an additional color basis from the decuplet-antidecuplet.

Color-color matrix of $q^3\bar{q}^3$

$$\lambda_1\lambda_2 = \begin{pmatrix} -\frac{8}{3} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{4}{3} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{4}{3} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{8}{3} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\frac{8}{3} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{4}{3} \end{pmatrix}, \quad \lambda_1\lambda_3 = \begin{pmatrix} -\frac{8}{3} & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{5}{3} & 0 & -\sqrt{3} & 0 & 0 \\ 0 & 0 & -\frac{5}{3} & 0 & -\sqrt{3} & 0 \\ 0 & -\sqrt{3} & 0 & \frac{1}{3} & 0 & 0 \\ 0 & 0 & -\sqrt{3} & 0 & \frac{1}{3} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{4}{3} \end{pmatrix}, \quad \lambda_1\lambda_4 = \begin{pmatrix} 0 & -\sqrt{2} & \sqrt{\frac{2}{3}} & \sqrt{\frac{2}{3}} & -\frac{\sqrt{2}}{3} & 0 \\ -\sqrt{2} & -\frac{5}{2} & \frac{5}{2\sqrt{3}} & \frac{5}{2\sqrt{3}} & -\frac{3}{2} & -\frac{\sqrt{5}}{3} \\ \sqrt{\frac{2}{3}} & \frac{5}{2\sqrt{3}} & -\frac{5}{6} & -\frac{3}{2} & -\frac{1}{2\sqrt{3}} & -\sqrt{\frac{5}{3}} \\ \sqrt{\frac{2}{3}} & \frac{5}{2\sqrt{3}} & -\frac{3}{2} & -\frac{5}{6} & -\frac{1}{2\sqrt{3}} & -\sqrt{\frac{5}{3}} \\ -\frac{\sqrt{2}}{3} & -\frac{3}{2} & -\frac{1}{2\sqrt{3}} & -\frac{1}{2\sqrt{3}} & -\frac{7}{6} & -\sqrt{5} \\ 0 & -\frac{\sqrt{5}}{3} & -\sqrt{\frac{5}{3}} & -\sqrt{\frac{5}{3}} & -\sqrt{5} & -\frac{8}{3} \end{pmatrix},$$

$$\vdots$$

$$\sum_{i<j} \lambda_i\lambda_j = \begin{pmatrix} -16 & 0 & 0 & 0 & 0 & 0 \\ 0 & -16 & 0 & 0 & 0 & 0 \\ 0 & 0 & -16 & 0 & 0 & 0 \\ 0 & 0 & 0 & -16 & 0 & 0 \\ 0 & 0 & 0 & 0 & -16 & 0 \\ 0 & 0 & 0 & 0 & 0 & -16 \end{pmatrix}$$

The sum of color-color matrices is the same as dibaryon.

Three-meson configuration: Color

We can obtain another color basis set changing the order of quarks and antiquarks.

$$
\begin{aligned}
&(3_1 \times \bar{3}_4) \times (3_2 \times \bar{3}_5) \times (3_3 \times \bar{3}_6) \\
&= (1+8)_{14} \times (1+8)_{25} \times (1+8)_{36} \\
&= [1(1_{14}1_{25}) + 8(1_{14}8_{25}) + 8(8_{14}1_{25}) + 1(8_{14}8_{25}) + 8(8_{14}8_{25}) + 8'(8_{14}8_{25}) \\
&\quad + 10(8_{14}8_{25}) + \overline{10}(8_{14}8_{25}) + 27(8_{14}8_{25})] \times (1+8)_{36}
\end{aligned}
$$

Here, we can determine six color singlet basis.

$$
\begin{aligned}
&|C_1'\rangle = 1_{14}1_{25}1_{36}, \quad |C_2'\rangle = 1_{1425}[8_{14}8_{25}]1_{36}, \quad |C_3'\rangle = 8_{1425}[1_{14}8_{25}]8_{36}, \\
&|C_4'\rangle = 8_{1425}[8_{14}1_{25}]8_{36}, \quad |C_5'\rangle = 8_{1425}[8_{14}8_{25}]8_{36}, \quad |C_6'\rangle = 8'_{1425}[8_{14}8_{25}]8_{36}.
\end{aligned}
$$

$$
|C'\rangle = U|C\rangle
$$

$$
U = \begin{pmatrix}
\frac{1}{3\sqrt{3}} & \frac{2\sqrt{2}}{3\sqrt{3}} & 0 & 0 & \frac{2\sqrt{2}}{3\sqrt{3}} & \frac{\sqrt{10}}{3\sqrt{3}} \\
-\frac{\sqrt{2}}{3\sqrt{3}} & \frac{2}{3\sqrt{3}} & 0 & 0 & -\frac{4}{3\sqrt{3}} & \frac{\sqrt{5}}{3\sqrt{3}} \\
-\frac{\sqrt{2}}{3\sqrt{3}} & -\frac{5}{6\sqrt{3}} & \frac{1}{2} & \frac{1}{2} & \frac{1}{6\sqrt{3}} & \frac{\sqrt{5}}{3\sqrt{3}} \\
-\frac{\sqrt{2}}{3\sqrt{3}} & -\frac{5}{6\sqrt{3}} & -\frac{1}{2} & -\frac{1}{2} & \frac{1}{6\sqrt{3}} & \frac{\sqrt{5}}{3\sqrt{3}} \\
\frac{5\sqrt{2}}{3\sqrt{21}} & -\frac{5}{6\sqrt{21}} & \frac{3}{2\sqrt{7}} & -\frac{3}{2\sqrt{7}} & -\frac{5}{6\sqrt{21}} & \frac{\sqrt{5}}{3\sqrt{21}} \\
\frac{\sqrt{10}}{\sqrt{21}} & -\frac{\sqrt{5}}{2\sqrt{21}} & -\frac{\sqrt{5}}{2\sqrt{7}} & \frac{\sqrt{5}}{2\sqrt{7}} & -\frac{\sqrt{5}}{2\sqrt{21}} & \frac{1}{\sqrt{21}}
\end{pmatrix}
$$

Three-meson configuration: Spin

S=0

$$S_1=\begin{array}{|c|c|c|}\hline 1&2&3\\\hline 4&5&6\\\hline\end{array},\quad S_2=\begin{array}{|c|c|c|}\hline 1&2&4\\\hline 3&5&6\\\hline\end{array},\quad S_3=\begin{array}{|c|c|c|}\hline 1&3&4\\\hline 2&5&6\\\hline\end{array},\quad S_4=\begin{array}{|c|c|c|}\hline 1&2&5\\\hline 3&4&6\\\hline\end{array},\quad S_5=\begin{array}{|c|c|c|}\hline 1&3&5\\\hline 2&4&6\\\hline\end{array}.$$

$$S' = US$$

$$\begin{aligned}
S'_1 &= (14)_{S=0}(25)_{S=0}(36)_{S=0}\\
S'_2 &= (14)_{S=1}(25)_{S=1}(36)_{S=0}\\
S'_3 &= (14)_{S=1}(25)_{S=0}(36)_{S=1}\\
S'_4 &= (14)_{S=0}(25)_{S=1}(36)_{S=1}\\
S'_5 &= (14)_{S=1}(25)_{S=1}(36)_{S=1}
\end{aligned}$$

$$U = \begin{pmatrix}
\frac{1}{\sqrt{2}} & \frac{1}{4} & \frac{\sqrt{3}}{4} & \frac{\sqrt{3}}{4} & -\frac{1}{4}\\
-\frac{1}{\sqrt{6}} & -\frac{1}{4\sqrt{3}} & \frac{3}{4} & -\frac{1}{4} & -\frac{\sqrt{3}}{4}\\
-\frac{1}{\sqrt{6}} & \frac{5}{4\sqrt{3}} & \frac{1}{4} & \frac{1}{4} & \frac{\sqrt{3}}{4}\\
-\frac{1}{\sqrt{6}} & -\frac{1}{4\sqrt{3}} & -\frac{1}{4} & \frac{3}{4} & -\frac{\sqrt{3}}{4}\\
0 & \frac{\sqrt{\frac{3}{2}}}{2} & -\frac{1}{2\sqrt{2}} & -\frac{1}{2\sqrt{2}} & -\frac{\sqrt{\frac{3}{2}}}{2}
\end{pmatrix}$$

Results: Nucleon-antinucleon

Hamiltonian and Jacobi coordinate

$$H = \sum_{i=1}^{n}\left(m_i + \frac{\mathbf{p}_i^2}{2m_i}\right) - \frac{3}{4}\sum_{i<j}^{n}\frac{\lambda_i^c}{2}\frac{\lambda_j^c}{2}\left(V_{ij}^C + V_{ij}^{CS}\right) + \sum_{i<j<k}^{n}\left(AL_{ijk}^{C-C} + BL_{ijk}^{S-S} + CL_{ijk}^{C-S}\right),$$

$$V_{ij}^C = -\frac{\kappa}{r_{ij}} + \frac{r_{ij}}{a_0^2} - D,$$

$$V_{ij}^{CS} = \frac{\hbar^2 c^2 \kappa'}{m_i m_j c^4}\frac{e^{-(r_{ij})^2/(r_{0ij})^2}}{(r_{0ij})r_{ij}}\sigma_i \cdot \sigma_j .$$

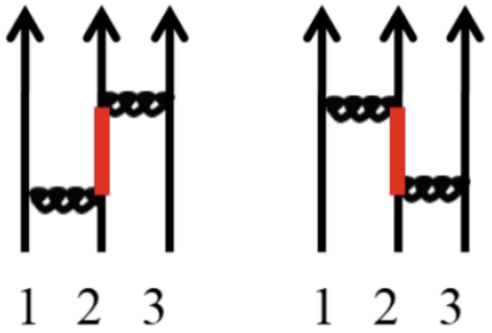
$$\vec{x}_1 = \frac{1}{\sqrt{2}}(\vec{r}_1 - \vec{r}_2)$$

$$\vec{x}_2 = \frac{1}{\sqrt{6}}(\vec{r}_1 + \vec{r}_2 - 2\vec{r}_3)$$

$$\vec{x}_3 = \frac{1}{\sqrt{2}}(\vec{r}_4 - \vec{r}_5)$$

$$\vec{x}_4 = \frac{1}{\sqrt{6}}(\vec{r}_4 + \vec{r}_5 - 2\vec{r}_6)$$

$$\vec{x}_5 = \frac{1}{\sqrt{6}}(\vec{r}_1 + \vec{r}_2 + \vec{r}_3 - \vec{r}_4 - \vec{r}_5 - \vec{r}_6)$$



Phys.Lett.B 862, 139278 (2025)

$$R = e^{-a_1 x_1^2 - a_2 x_2^2 - a_1 x_3^2 - a_2 x_4^2 - a_3 x_5^2}$$

Flavor, color, spin state(I=0,S=0)

$$F_1^A = (\begin{array}{|c|c|c|}\hline 1&2&3\\\hline\end{array}, \begin{array}{|c|c|c|}\hline \overline{4}&\overline{5}&\overline{6}\\\hline\end{array}),\ CS_1^A = \left(\begin{array}{|c|}\hline 1\\\hline 2\\\hline 3\\\hline\end{array}, \begin{array}{|c|}\hline \overline{4}\\\hline \overline{5}\\\hline \overline{6}\\\hline\end{array}\right)$$

$$F_1^B = (\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}),\ F_2^B = (\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}),$$

$$F_3^B = (\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}),\ F_4^B = (\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{6}\\\hline \overline{5}\\\cline{1-1}\end{array}),$$

$$CS_1^B = (\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}),\quad CS_2^B = (\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{6}\\\hline \overline{5}\\\cline{1-1}\end{array}),$$

$$CS_3^B = (\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}),\quad CS_4^B = (\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{6}\\\hline \overline{5}\\\cline{1-1}\end{array}),$$

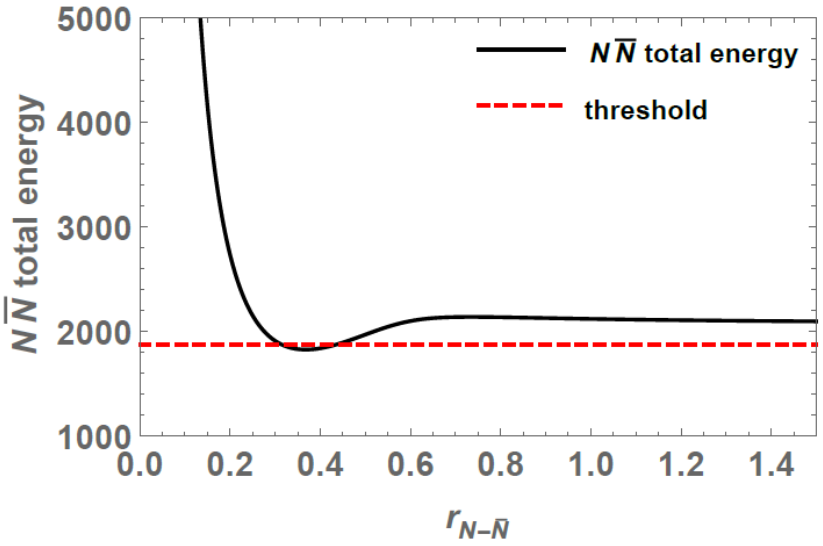
$$\psi_1 = F_1^A \otimes C_1 \otimes [(12)_{S=1}3]_{S=\frac{3}{2}}[(45)_{S=1}6]_{S=\frac{3}{2}}$$
$$\psi_2 = F_1^A \otimes (C_2 \sim C_5) \otimes [123]_{S=\frac{1}{2}}[456]_{S=\frac{1}{2}}$$
$$\psi_3 = (F_1^B \sim F_4^B) \otimes C_1 \otimes [123]_{S=\frac{1}{2}}[456]_{S=\frac{1}{2}}$$
$$\psi_4 = (F_1^B \sim F_4^B) \otimes (C_2 \sim C_5) \otimes [123]_{S=\frac{3}{2}}[456]_{S=\frac{3}{2}}$$
$$\psi_5 = (F_1^B \sim F_4^B) \otimes (C_2 \sim C_5) \otimes [123]_{S=\frac{1}{2}}[456]_{S=\frac{1}{2}}$$
$$\psi_6 = (F_1^B \sim F_4^B) \otimes C_6 \otimes [123]_{S=\frac{1}{2}}[456]_{S=\frac{1}{2}}$$

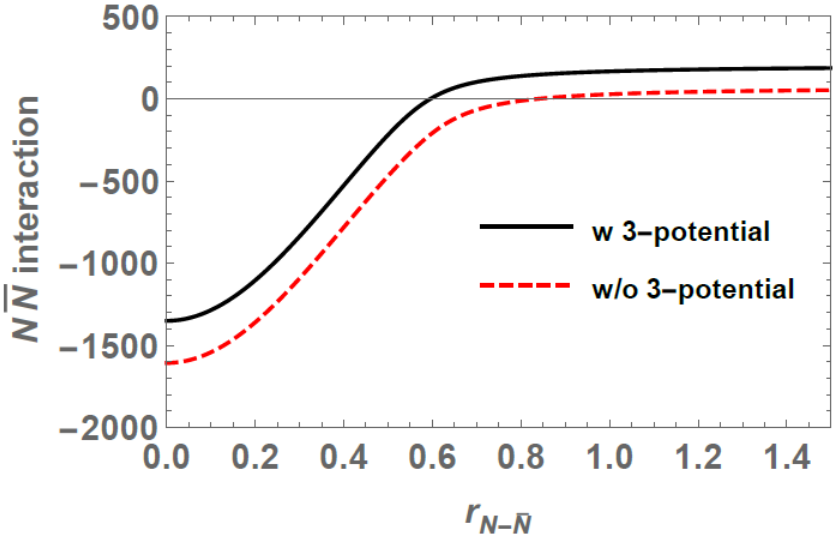
$$|C_1\rangle = \left(\begin{array}{|c|}\hline 1\\\hline 2\\\hline 3\\\hline\end{array}, \begin{array}{|c|}\hline \overline{4}\\\hline \overline{5}\\\hline \overline{6}\\\hline\end{array}\right),\ |C_2\rangle = \left(\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}\right),\ |C_3\rangle = \left(\begin{array}{|c|c|}\hline 1&2\\\hline 3\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{6}\\\hline \overline{5}\\\cline{1-1}\end{array}\right),$$

$$|C_4\rangle = \left(\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{5}\\\hline \overline{6}\\\cline{1-1}\end{array}\right),\ |C_5\rangle = \left(\begin{array}{|c|c|}\hline 1&3\\\hline 2\\\cline{1-1}\end{array}, \begin{array}{|c|c|}\hline \overline{4}&\overline{6}\\\hline \overline{5}\\\cline{1-1}\end{array}\right),\ |C_6\rangle = \left(\begin{array}{|c|c|c|}\hline 1&2&3\\\hline\end{array}, \begin{array}{|c|c|c|}\hline \overline{4}&\overline{5}&\overline{6}\\\hline\end{array}\right)$$

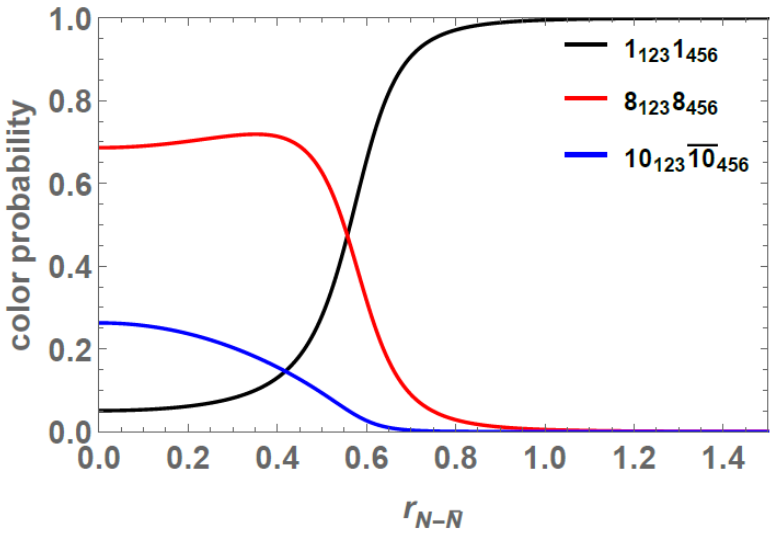
Results(I=0,S=0)

$$r_{N-\overline{N}} = \frac{1}{3}(\vec{r}_1 + \vec{r}_2 + \vec{r}_3 - \vec{r}_4 - \vec{r}_5 - \vec{r}_6)$$





$$V^{B\overline{B}} = H_C^{B\overline{B}} + H_{CS}^{B\overline{B}} - (H_C^B + H_{CS}^B + H_C^{\overline{B}} + H_{CS}^{\overline{B}})$$



There is a possible bound state for I=0, S=0.

Future Plan

$q^2Q\bar{q}^2\bar{Q}(I=0)$

$$F_1^A = \left(\begin{array}{|c|c|}\hline 1 & 2 \\ \hline\end{array}, \boxed{3}, \begin{array}{|c|c|}\hline \bar{4} & \bar{5} \\ \hline\end{array}, \boxed{\bar{6}}\right), \quad CS_1^A = \left(\begin{array}{|c|}\hline 1 \\ \hline 2 \\ \hline\end{array}, \boxed{3}, \begin{array}{|c|}\hline \bar{4} \\ \hline \bar{5} \\ \hline\end{array}, \boxed{\bar{6}}\right)$$

$$F_1^B = \left(\begin{array}{|c|}\hline 1 \\ \hline 2 \\ \hline\end{array}, \boxed{3}, \begin{array}{|c|}\hline \bar{4} \\ \hline \bar{5} \\ \hline\end{array}, \boxed{\bar{6}}\right), \quad CS_1^B = \left(\begin{array}{|c|c|}\hline 1 & 2 \\ \hline\end{array}, \boxed{3}, \begin{array}{|c|c|}\hline \bar{4} & \bar{5} \\ \hline\end{array}, \boxed{\bar{6}}\right)$$

$\Lambda_c\bar{\Lambda}_c$ or $\Lambda\bar{\Lambda}$

Future Plan

$q^6\bar{q}^3$

$$C_1 = \left(\begin{array}{|c|c|}\hline 1 & 2 \\ \hline 3 & 4 \\ \hline 5 & 6 \\ \hline \end{array} , \begin{array}{|c|}\hline \overline{7} \\ \hline \overline{8} \\ \hline \overline{9} \\ \hline \end{array} \right), \cdots$$

$$C_6 = \left(\begin{array}{|c|c|c|}\hline 1 & 2 & 3 \\ \hline 4 & 5 \\ \cline{1-2} 6 \\ \cline{1-1} \end{array} , \begin{array}{|c|c|}\hline \overline{7} & \overline{8} \\ \hline \overline{9} \\ \cline{1-1} \end{array} \right), C_7 = \left(\begin{array}{|c|c|c|}\hline 1 & 2 & 3 \\ \hline 4 & 5 \\ \cline{1-2} 6 \\ \cline{1-1} \end{array} , \begin{array}{|c|c|}\hline \overline{7} & \overline{9} \\ \hline \overline{8} \\ \cline{1-1} \end{array} \right), \cdots$$

$$C_{38} = \left(\begin{array}{|c|c|c|c|}\hline 1 & 2 & 3 & 4 \\ \hline 5 \\ \cline{1-1} 6 \\ \cline{1-1} \end{array} , \begin{array}{|c|c|c|}\hline \overline{7} & \overline{8} & \overline{9} \\ \hline \end{array} \right), \cdots$$

There are $(5 \times 1 + 16 \times 2 + 10 \times 1) = 47$ color singlet basis.

$NN\bar{N}$

Summary

- We have investigated the nucleon-antinucleon state using baryon-antibaryon configuration in a constituent quark model.
- There is a possibility of bound state for I=0,S=0.
- Nucleon-antinucleon state shows very attractive interaction at short distance.

Thank you