Sinlget and triplet S wave N-N interaction phase shifts for finite size of quarks

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Introduction

Nucleon Nucleon (N-N) interaction is one of the most important phenomena that helps us in understanding various properties of nucleus. Progress has been made in understanding N-N interaction through Chiral Effective Field Theories [1]. Various relativistic and non-relativistic gluon exchange models have also been employed to understand N-N interaction [2, 3]. Attempts also have been made to study the N-N interaction using gluon exchange models where finite size of quarks are considered [3].

Phase shift analysis is one of the most important methods that sheds light in the case of scattering studies. Relativistic models have been successfully employed to understand the phase shifts for N-N interaction [4].

In this work, we study the effect of finite size effect of quarks on the phase shifts of N-N interaction. In constituent quark models, chiral symmetry breaking results in the quarks acquiring dynamic mass due to which the quarks have to be considered as virtual cloud around the quarks. In a typical one gluon exchange model, the delta function potential refers to zero range contact interactions. Consideration of zero range interactions between constituent quarks will reduce the interaction between the virtual clouds. Thus we need to employ a finite size effect for the quarks instead of considering a delta function based zero range interaction.

Theoretical Model

To get the scattering phase shifts we solve the radial Schrödinger equation for a particle with energy E and orbital angular momentum l given by,

$$\frac{d^2u_l}{dr^2} + \left[k^2 - \frac{l(l+1)}{r^2}\right] u_l = \frac{2\mu}{\hbar^2} V(r) u_l \quad (1)$$

In eq. (1), the potential $V(r) = V_{OGEP}$ is the one gluon exchange interaction potential given by

$$V_{OGEP} = \frac{\alpha_s}{4} \sum_{i<j} \left[\frac{1}{r_{ij}} - \frac{1}{m_q^2}\left(1 + \frac{2}{3}\boldsymbol{\sigma}_i.\boldsymbol{\sigma}_j\right) \delta^3(\boldsymbol{r}_i - \boldsymbol{r}_j)\right] \boldsymbol{\lambda}_i.\boldsymbol{\lambda}_j \quad (2)$$

In the above equation, $\boldsymbol{\lambda}_i$ and $\boldsymbol{\lambda}_j$ are the generators of the color SU(3) group for the i-th and the j-th quarks, $\boldsymbol{\sigma}_i$ and $\boldsymbol{\sigma}_j$ are the Pauli spin operators of the i-th and the j-th quarks and α_s is the strong coupling constant.

We replace the delta function in eq. (2) by Gaussian term,

$$\delta^3(\boldsymbol{r}_i - \boldsymbol{r}_j) = \frac{1}{\pi^{3/2} r_0^2} \exp(-\frac{r_{ij}^2}{r_0^2})$$

where r_0 represents the effective size of the quarks.

The S wave scattering phase shifts are calculated by phase function method [5] using the expression,

$$\delta_0'(k, r) = -\frac{V(r)}{k} \sin^2(kr). \quad (3)$$

Results and Discussions

The quark size parameter r_0 is taken to be 0.2 fm. FIG. (1) shows the phase shift for singlet channel and FIG. (2) gives the phase shift for triplet channel. The main two parameters α_s and quark mass have been adopted from

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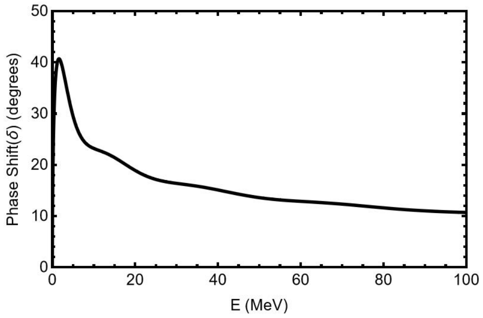

FIG. 1: Phase shifts for singlet ($^1S_0$) state.

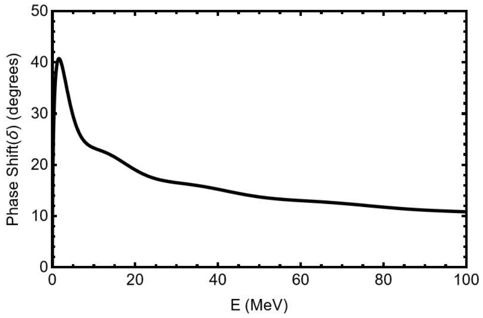

FIG. 2: Phase shifts for triplet ($^3S_1$) state.

previous literature [3]. The plots are in agreement with [4] except for the fact that there is a reduction in the short range repulsion.

We can attribute the reduction in repulsion to the smearing. Smearing results in a soft sphere scattering rather than a hard sphere scattering considered in the delta function potential case.

Conclusion and Remarks

We have probed the effect of changing the delta function potential to a finite size case in studying the N-N interaction phase shifts. There is a reduction in the short range repulsion due to the finite size effect.

Study of N-N interaction phase shifts for various finite sizes and also determination of scattering cross sections are in progress.

Acknowledgment

One of the authors (Nilakanthan V. K.) would like to thank the Mangalore Jesuit Educational Society (MJES) research grant (SAC/MRP/2024-25/05).

References

[1] Zhi-Wei Liu Z. W., Xiao Y., Lu J X., Geng L S., Mini-Proceedings Fourth International Workshop on the Extension Project for the J-PARC Hadron Experimental Facility (HEF-ex 2024),arxiv.org/2409.00366v1, pp 17, (2024).

[2] V.K. Nilakanthan, V.C. Shastry, S. Raghavendra and K.B. Vijaya Kumar, Eur. Phys. J. Plus, **134**: 517, (2019).

[3] V C Shastry and K B V Kumar, J. Phys. G: Nucl. Part. Phys. **46** 065101, (2019).

[4] K. B. Vijaya Kumar and S. B. Khadkikar, Nucl. Phys. A, **556**, 3, (1993).

[5] Kumar L., Khachi A. and Sastri O.S.K.S., J. Nucl. Phys. Mat. Sci. Rad. A. Vol. 9, No. 2 (2022), pp.215–221.