The evaluation of the relativistic chiral nuclear force using the nucleon-nucleon scattering observables

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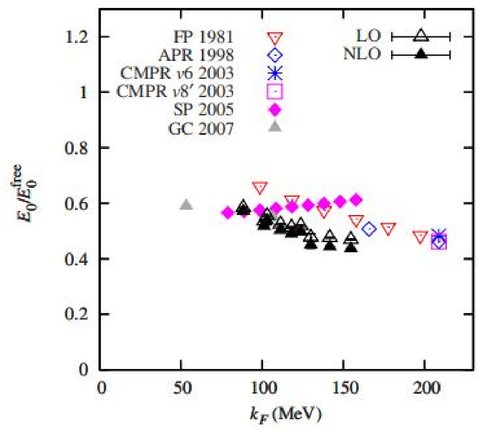
Introduction

Nuclear Force

Nuclear force is the interaction between nucleons. Studying nuclear force plays an important role in studying nuclear structure and nuclear reactions. It can be used for first principle calculations, etc.



This is from [1] and it is about the lattice simulation of many-nucleon systems.

Relativistic Chiral Nuclear Force

- The relativistic effects play an important role in the structure of nuclei. So it is necessary to construct a nuclear force theory within the framework of relativity. There are several advantages [2-3].

Relativistic Chiral Nuclear Force → Relativistic effect; Fewer parameters; Faster convergence

The the nucleon-nucleon scattering observables is More sensitive to nuclear force theory and there is abundant experimental data available.

In this study, we compare the Next-to-Next-to-Leading Order relativistic chiral nuclear force (N^2LO) with Next-to-Next-to-Next-to-Leading Order non-relativistic chiral nuclear force (NR-N^3LO).

Methods

- The total M-matrix of np scattering and pp scattering
- The relationship between M-matrix and S-matrix [4]

$$M(np) = M_N + M_{MM}$$

$$M(pp) = M_N + M_{C1} + M_{C2} + M_{MM} + M_{VP}$$

$$M_N(np) = \frac{1}{2ik}\sum Y_{L'm_s-m_s'}(\theta)C(L'SJ, m_s - m_s'm_s'm_s)\, i^{l-l'}(S^J_{l'sls} - \delta_{l'l})C(LSJ, 0\, m_s m_s)\sqrt{4\pi(2L+1)}$$

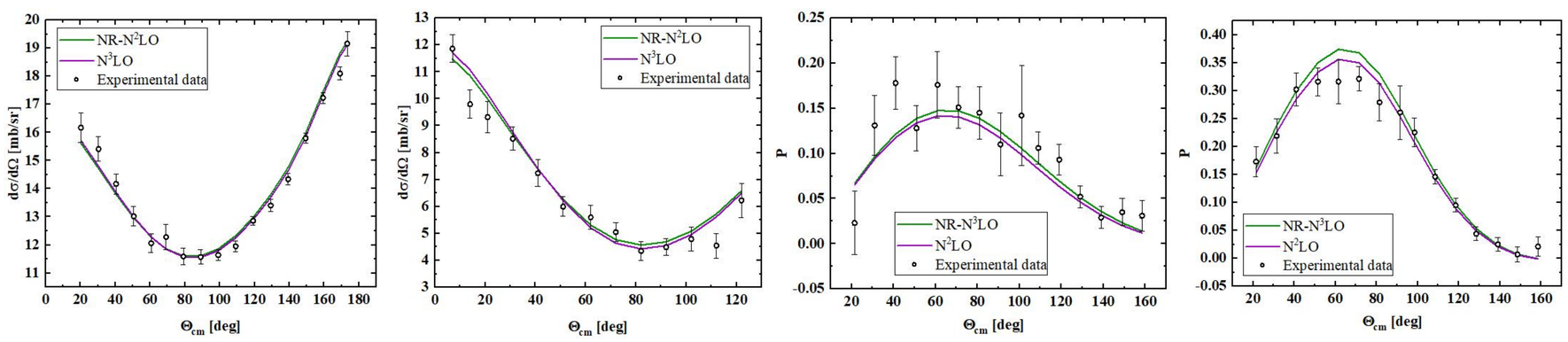
For $M_N(pp)$, there is a extra parameter 2.

The S-matrix needs to be processed with phase shift of C1, C2, MM and VP.

The detail formula of other terms of M-matrix can be found in Ref. [4-6]

Phase shift → S-matrix → M-matrix, Hoshizaki parameter → Observables

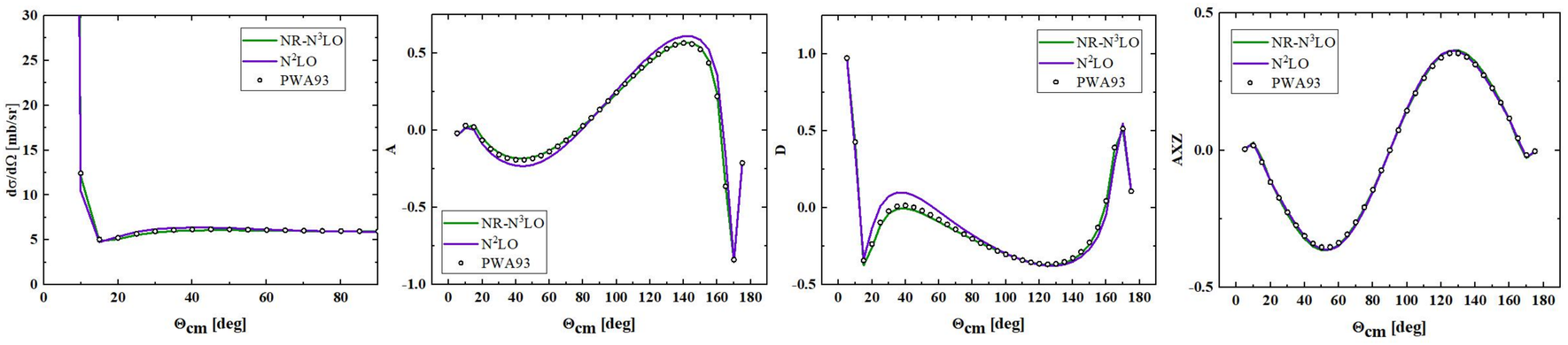
Results



✓ Here give the results of differential cross section at 50MeV and 89.5MeV and polarization at 40MeV and 80MeV.

Results of np Scattering

The average χ^2:
Differential Cross Sections
N^2LO : 1.379
NR-N^3LO : 1.343
Polarization
N^2LO : 1.394
NR-N^3LO : 1.107



✓ Here give the results of differential cross section, A, D and Azx at 70MeV. The terms of C2, VP and MM interactons are not taken into account here

Results of pp Scattering

The result of N^2LO is slightly worse than NR-N^3LO.

It needs to further add the terms of C2, VP and MM interactons to compare with the experimental data.

Summary

- ✓ For the result of np scattering, N^2LO is comparable with the NR-N^3LO and it can describe the observables well.
- ✓ For the result of pp scattering, N^2LO is slightly worse than NR-N^3LO when compared with the result of PWA93.
- ✓ The relativistic chiral nuclear force converges faster than the non-relativistic chiral nuclear force.

References

[1] E. Epelbaum et al, Rev. Mod. Phys. 81, 1773 (2009).
[2] Ren X L, Li K W, Geng L S, et al. Chinese Physics C, 2018, 42(1): 014103.
[3] Lu J X, Wang C X, Xiao Y, et al. Physical Review Letters, 2022, 128(14): 142002.
[4] J.R. Bergervoet, et al., Phys. Rev. C 38 (1988) 15.
[5] V.G.J. Stoks, et al., Phys. Rev. C 48 (1993) 792.
[6] Pérez R N, et al., Phys. Rev. C 88.064002(2013).
[7] Montgomery T, et al. Physical Review C, 1977, 16(2): 499.
[8] Scanlon J, et al. Nuclear Physics, 1963, 41: 401–423.
[9] Langsford A et al. . Nuclear Physics, 1965, 74(2): 241–260.