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Relativistic effects in the 3N continuum and the A_y puzzle

H. Witała*[1], J. Golak[1], R. Skibiński[1], H. Kamada[2], W. Glöckle[3] and W. N. Polyzou[4]

[1] M. Smoluchowski Institute of Physics, Jagiellonian University, PL-30059 Kraków, Poland
[2] Department of Physics, Faculty of Engineering, Kyushu Institute of Technology, 1-1 Sensuicho Tobata, Kitakyushu 804-8550, Japan
[3] Institut für Theoretische Physik II, Ruhr-Universität Bochum, D-44780 Bochum, Germany
[4] Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242, USA

Abstract.
The three-nucleon (3N) Faddeev equation is solved in a Poincaré invariant model of the three-nucleon system. Two-body interactions are generated so that when they are added to the two-nucleon invariant mass operator (rest energy) the two-nucleon S matrix is identical to the non-relativistic S matrix with a CD Bonn interaction. Cluster properties of the three-nucleon S-matrix determine how these two-nucleon interactions are embedded in the three-nucleon mass operator. Differences in the predictions of the relativistic and corresponding non-relativistic models for elastic and breakup processes are investigated. Of special interest are the lowering of the A_y maximum in elastic nucleon-deuteron (Nd) scattering below ≈ 25 MeV caused by the Wigner spin rotations and the significant changes of the breakup cross sections in certain regions of the phase-space.

1 Introduction

The study of elastic and breakup Nd processes reveals cases where the non-relativistic description based on NN interactions only is insufficient to explain the data. These discrepancies generally increase with energy. Only in some cases the inclusion of certain types of 3N forces lead to an improvement. A relativistic treatment of the dynamics implies a different off-shell treatment of the NN interactions [1], leading to the possibility of additional effects beyond standard 3N forces. We refer to [2, 3, 4] for a detailed presentation and focus here on the A_y puzzle and pronounced relativistic effects in Nd breakup.

* *E-mail address:* witala@if.uj.edu.pl

2 Relativistic Faddeev equation

The 3N Faddeev equation is set up for a breakup operator and solved in momentum space and partial wave projected. In the relativistic case the equations have the same operator form as the non-relativistic equations. In the relativistic case Jacobi momenta are constructed using Lorentz boosts instead of Galilean boosts, the resolvents involve relativistic kinetic energies, the two-body interactions in the three-body problem appear inside of square roots in a manner dictated by S-matrix cluster properties, and the permutation operators include Wigner rotations [5] which are evaluated using the Balian-Brézin method [6].

3 Results

In Fig.1 we show relativistic effects for A_y at two low energies. Below ≈ 25 MeV the non-linear embedding of the two-body interaction in the three-body mass operator lowers the maximum of A_y by $\approx 2\%$ while the inclusion of Wigner spin rotations increase that lowering effect up to $\approx 10\%$. Above ≈ 25 MeV relativistic effects for A_y are negligible.

For the breakup cross section large relativistic effects are localized in specific regions of phase-space. They lead to a characteristic pattern of relativistic versus non relativistic cross section changes shown in Fig.2. At $E_N^{lab} = 200$ MeV those changes can be up to $\approx \pm 60\%$.

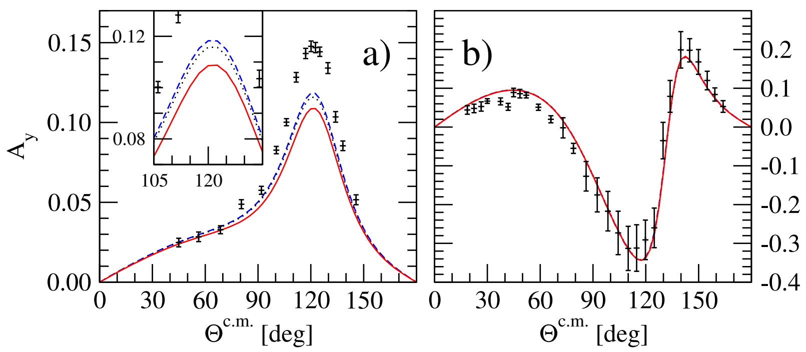

Figure 1. The nucleon analyzing power A_y in elastic Nd scattering at $E_{lab}^N = 8.5$ MeV (a) and 35 MeV (b). The dashed line is the non relativistic result obtained with the CD Bonn potential. The relativistic predictions are given by the dotted (without) and solid lines (with) Wigner rotations, respectively. The nd data in a) are from [7] and pd data in b) from [8].

4 Summary

An exactly Poincaré invariant formulation of three-nucleon scattering using realistic interactions leads to significant changes of the breakup cross section at higher energies and in certain regions of phase space [3, 4]. For the elastic scattering cross sections the small changes are restricted to backward angles [2]. For the low energy analyzing power A_y we found large relativistic effects of similar magnitude as in [9] but in opposite direction and that increases the discrepancy to the data. Therefore we expect that 3NF's in all their complexity [10] have to be taken into account.

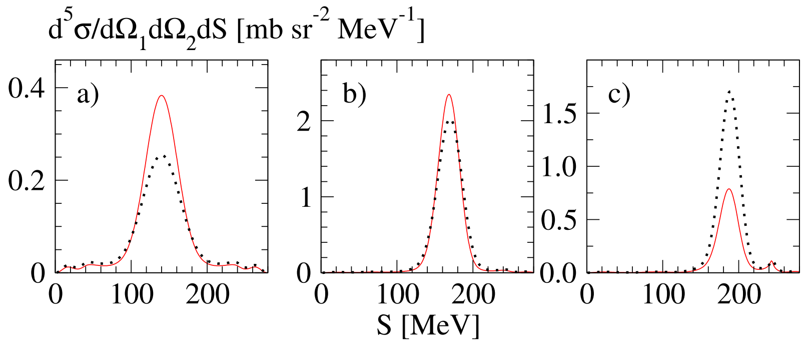

Figure 2. Cross sections for exclusive d(n,nn)p breakup at $E_{lab}^{n} = 200$ MeV at a fixed angle $\theta_2 = 37.5^o$ and varying θ_1: a) $\theta_1 = 37.5^o$, b) $\theta_1 = 47.5^o$, c) $\theta_1 = 57.5^o$. The non relativistic (relativistic) cross sections based on CD Bonn are shown by dashed (solid) lines, respectively.

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