Partial-Wave Analyses of all Proton-Proton and Neutron-Proton Data Below 500 MeV*

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Abstract

In 1993 the Nijmegen group published the results of energy-dependent partial-wave analyses (PWAs) of the nucleon-nucleon (*NN*) scattering data for laboratory kinetic energies below $T_{lab} =$ 350 MeV (PWA93)[1]. In this talk some general aspects, but also the newest developments on the Nijmegen *NN* PWAs are reported. We have almost finished a new energy-dependent PWA and will discuss some typical aspects of this new PWA; where it differs from PWA93, but also what future developments might be, or should be.

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In order to learn about the NN interaction scattering experiments have been the primary source of experimental information for well over half a century. A substantial database of pp as well as np scattering data has been established. The available data cover a large range of energies, angles, and also different observables, see, e.g., Ref.[2]. The big question however is, what is it that we can learn about the NN interaction from all these data, and, how can we extract that knowledge from the data.

The NN interaction is far from trivial. We are dealing with the a strong as well as electromagnetic interaction, and nucleons are spin-half particles as well as isospin-half particles. This allows for a rich and complicated structure in the NN interaction that needs to get unraveled. Not only are we interested in a qualitatative description of the NN interaction and its characteristic properties, we also wish to establish a quantitatively sound description of the NN interaction.

The tool of choice to learn about the NN interaction has since day and age been the partial-wave analysis (PWA) of the data. In general one could describe the PWA as the tool that tries to extract as much information as possible about the NN interaction from the experimental scattering data (values plus uncertainties) in a preferably model-independent way, and express that information in phase shifts (again, values and uncertainties) and other relevant quantities, e.g. coupling constants.

Of course this definition is very general definition. It allows for various approaches to implement a PWA, and subsequently various NN PWAs do exist, see, e.g., Refs. [1, 3, 4].

In the Nijmegen energy-dependent NN PWA we try to exploit as much as possible what is "known" about the NN interaction and parametrize what is "unknown" in a phenomenological way. We have chosen to do so by using a boundary condition approach. For each partial wave the relativistic Schrödinger equation is solved for $r > b$, with the "known" long-range and intermediate-range interaction (strong and electromagnetic). For $r = b$ we introduce an energy-dependent boundary condition representing a phenomenological parametrization of the "unknown" short-range physics.

In 1993 we established this way an energy-dependent PWA of all pp and np data below $T_{lab} = 350$ MeV [1]. We have now almost finished a new PWA, up to 500 MeV. Below we will remark on some of the typical aspects of this new PWA; where it differs from PWA93, but also what future developments might be, or should be.

- The energy range of the PWA has been extended from 350 MeV to 500 MeV. This means that we have gone well above the pion-production threshold and consequently inelasticies start to become significant. We introduce them in selected waves by employing a complex energy-dependent boundary condition ar $r = b$. While this gives satisfactory results for now, a more physical guidance by allowing for physical mechanisms that generate inelasticities might be better. Not only for the waves where we could not introduce inelasticities now, but also if we wish to extend our PWA to even higher energies.

- The NN database has been enlarged. Not only with the data between 350 and 500 MeV, but also with many new data below 350 MeV[2]. Currently we use approximately 5000 pp and 5000 np data below 500 MeV. These numbers sound impressive and they do allow us to perform a PWA. But quantity does not equal quality. For example, the np data are much less accurate and varied than the pp data, and often suffer from systematic errors[5]. Many data, especially older, but also (very) recent data, are of mediocre quality. More and better data are needed in order to produce more reliable results. Also if we want to determine more precise values for coupling constants, or if we want to perform a quantitative study of small effects such as charge independence breaking.

- We have been able to extract uniquely all the important *np* phase parameters, $I = 1$ as well as $I = 0$, from the *np* data. Such a separate PWA of the *np* data[3], without any input from the $I = 1$ *pp* partial waves, is less model dependent, and, moreover, a comparison of the phase parameters from such an independent *np* PWA with the corresponding ones obtained from the *pp* data provides information about possible charge-independence breaking in the $I = 1$ *NN* waves.

- In PWA93 we used for the long-range interaction a modified version of the Nijm78 potential[6]. This has now been replaced by the One-Pion Exchange potential, and a chiral Two-Pion Exchange potential. As this long-range interaction is the result of a systematic expansion, it is, in principle, model independent and could be improved, if necessary, by taking higher orders into account. Using this long-range *NN* interaction we obtained a better fit to the data [7]. Moreover we were able to determine values for some of the low-energy coupling constants [8].

- *np* differential cross sections are notoriously difficult to measure. Hence the large number of sets of data that differ significantly from each other. Some, or even many of them, suffer from systematic errors. While we cannot deal with systematic errors in general, certain systematic uncertainties, however, can be treated. By taking the effects of relative normalization procedures into account we got an improved fit to the data[5]. Some data that we previously had to omit can now be included in a fit. Systematic effects will play a bigger role when experiments get more complicated and statistics get better. Properly handling systematic uncertainties in analyses will become more important. As that requires insight in experimental procedures, more cooperation with experimentalists is imperative.

We are currently in the exploratory phase, i.e. carefully studying the results of the new PWA and do some finetuning where deemed necessary. More details of the analyses and its results will be published in due time.

[1] V.G.J. Stoks, R.A.M. Klomp, M.C.M. Rentmeester, and J.J. de Swart, Phys. Rev. C **48**, 792 (1993).
[2] NN-OnLine, see `http://nn-online.org`
[3] R.A. Arndt, I.I. Strakovsky, R.L. Workman, Phys. Rev. C **62**, 034005 (2000).
[4] J. Bystricky, C. Lechanoine-Leluc, and F. Lehar, J. Phys. (Paris) **48**, 199 (1987).
[5] M.C.M. Rentmeester, R.G.E. Timmermans, and J.J. de Swart, Phys. Rev. C **64**, 034004 (2001).
[6] M.M. Nagels, T.A. Rijken, and J.J. de Swart, Phys. Rev. D **17**, 768 (1978).
[7] M.C.M. Rentmeester, R.G.E. Timmermans, J.L. Friar and J.J. de Swart, Phys. Rev. Lett. 82, 4992 (1999).
[8] M.C.M. Rentmeester, R.G.E. Timmermans, and J.J. de Swart, Phys. Rev. C **67**, 044001 (2003).