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Partial Wave Analyses of the *pp* data alone and of the *np* data alone*

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Abstract

We present results of the Nijmegen partial-wave analyses of all *NN* scattering data below $T_{\text{lab}} = 500$ MeV. We have been able to extract for the first time the important *np* phase shifts for both $I = 0$ and $I = 1$ from the *np* scattering data alone. This allows us to study the charge independence breaking between the *pp* and *np* $I = 1$ phases. In our analyses we obtain for the *pp* data $\chi^2_{\text{min}}/N_{\text{df}} = 1.13$ and for the *np* data $\chi^2_{\text{min}}/N_{\text{df}} = 1.12$.

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I. INTRODUCTION

The last 15 years the Nijmegen group has been working on partial-wave analyses (PWA) of the NN-scattering data for energies below $T_{\rm lab} = 350$ MeV. In these analyses, the pp data furnish the $I = 1$ phase shifts [1] in the lower partial waves with $J \leq 4$. It has been customary to do these low energy PWA up to $T_{\rm lab} = 350$ MeV, despite of the fact that the inelasticities set in at $T_{\rm lab} \simeq 280$ MeV. It can be shown, however, that up to $T_{\rm lab} = 350$ MeV the inclusion of inelasticities in pp scattering improves the total $\chi^2 \simeq 1787$ with only about 1, so neglecting the inelasticities is totally warranted.

In the PWA of all the np data below $T_{\rm lab} = 350$ MeV, it has always been impossible to determine all important phase shifts, when only the np data were used. The standard procedure has therefore been to take the $I = 1$ phases (except the ${}^1S_0$) over from the pp analyses, with or without corrections for Coulomb, and np and $\pi^0\pi^\pm$ mass difference effects. The ${}^1S_0$ np phase shift was always searched for. It was found that there is a definite charge independence breaking in these ${}^1S_0$ phases. An attempt by us, to extract all the lower $I = 0$ and $I = 1$ phase shifts in an analysis of all np data below $T_{\rm lab} = 350$ MeV failed. However, it was possible to determine the np ${}^3P$ waves, when the higher partial waves were taken over from the pp analysis.

Recently, the Nijmegen group extended the pp PWA to energies so far above the pion production thresholds, that the inclusion of inelasticities was necessary. A preliminary version of such a PWA for all pp data with energies below $T_{\rm lab} = 500$ MeV has already been presented [2].

When the np PWA was extended to energies up to $T_{\rm lab} = 500$ MeV, it turned out to be possible to determine uniquely all the important partial waves. Comparing then with the analogous pp analysis gives indications for possible charge independence breaking effects in other waves besides the ${}^1S_0$ waves.

II. THE METHOD OF ANALYSIS

In the np as well as in the pp partial wave analyses, the various phases are obtained by solving the relativistic Schrödinger equation with a well-known long-range potential $V_{\rm L} = V_{\rm NUC} + V_{\rm EM}$ for $r \geq b = 1.4$ fm. This $V_{\rm L}$ contains the electromagnetic interaction (such as Coulomb, magnetic moment, and vacuum polarization), the OPEP tail, and the rest of the long range NN interaction as given by the Nijmegen potential [3].

For $r < b$ the short-range interaction is described by an energy-dependent, square-well potential

$$V_{\rm S} = V_{\rm R} - iV_{\rm I} \ .$$

For $V_{\rm R}$ we follow the same procedure as in the Nijmegen PWA and write

$$V_{\rm R} = \sum_{n=0}^{N} a_n (k^2)^n \ .$$

For the imaginary part of the potential we take

$$V_{\rm I} = (k^2 - k^2_{\rm thr})^n V \cdot \theta(E - E_{\rm thr}) \ .$$

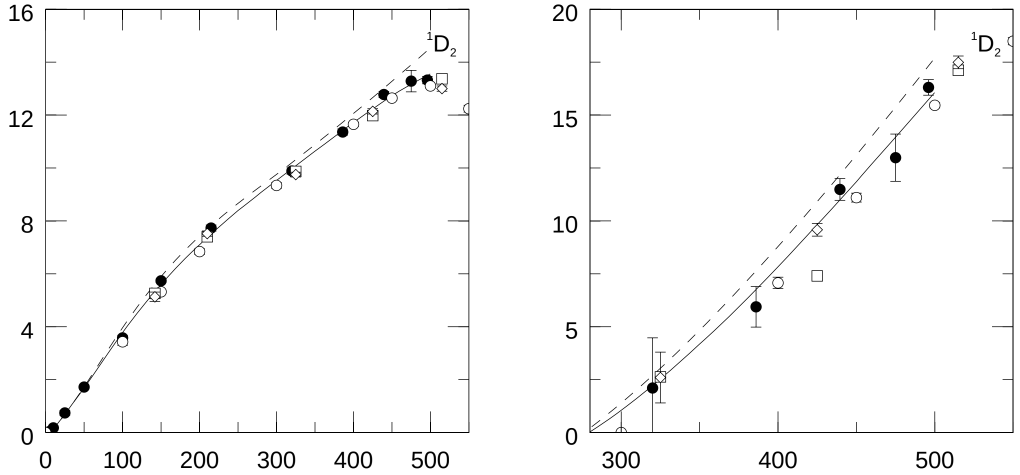

FIG. 1. Preliminary multienergy phase shifts and inelasticities in the $^1D_2$ partial wave in degrees vs. T_{lab} in MeV. Solid line: 0-500 MeV *pp* partial-wave analysis; dashed line: 0-500 MeV *np* partial-wave analysis. •: *pp* single-energy analyses; ○: Arndt *et al.* [4]; □: Dubois *et al.* [5]; ◇: Bugg *et al.* [6].

III. RESULTS

The results of our PWA can be summarized as follows. The phase parameters were parametrized with 36 parameters in the *pp* analysis and 38 parameters in the *np* analysis. We allowed for up to four parameters in the real part of the potential in each partial wave, which was found to be enough. The actual number of parameters per partial wave varies from four in the $^1S_0$ to one or none in the higher G waves. An imaginary part of the potential was only used in the $^1D_2$ and $^3F_3$ partial waves and in the *pp* PWA also in the coupled $^3P_2$-$^3F_2$ partial waves. As an example, Fig. 1 shows preliminary results for the $^1D_2$ partial wave. We reach $\chi^2_{\text{min}} = 3555.4$ for 3455 *pp* scattering data and $\chi^2_{\text{min}} = 4142.0$ for 3968 *np* scattering data.

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