Neutron–proton charge–exchange amplitude studies*

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An understanding of the NN interaction is fundamental to the whole of nuclear and hadronic physics. The database on proton–proton elastic scattering is enormous and the wealth of spin–dependent quantities measured by EDDA collaboration has allowed the extraction of NN phase shifts in the isospin $I = 1$ channel up to a beam energy of at least 2 GeV. The situation is far less advanced for the isoscalar channel where the much poorer neutron–proton data only permit the $I = 0$ phase shifts to be evaluated up to at most 1.3 GeV but with significant ambiguity above about 800 MeV.

The ANKE collaboration has been embarked on a systematic programme to measure the differential cross section and analysing powers of the $dp \to \{pp\}n$ reaction up to the maximum energy at COSY of 1.15 GeV per nucleon, with the aim of deducing information on the np amplitudes. Higher energies per nucleon will be achieved through the use of a proton beam and deuterium target. Spin correlations will also be studied with a polarised beam and target. However, for these to be valid objectives, the methodology has to be checked in a region where the np amplitudes are reasonably well known.

The charge–exchange amplitude of the elementary $np \to pn$ scattering may be written in terms of five scalar amplitudes in the cm system as

$$f_{np} = \alpha(q) + i\gamma(q)(\vec{\sigma}_1+\vec{\sigma}_2)\cdot\vec{n} + \beta(q)(\vec{\sigma}_1\cdot\mathbf{n})(\vec{\sigma}_2\cdot\vec{n}) + \delta(q)(\vec{\sigma}_1\cdot\vec{m})(\vec{\sigma}_2\cdot\vec{m}) + \varepsilon(q)(\vec{\sigma}_1\cdot\vec{l})(\vec{\sigma}_2\cdot\vec{l}),$$

where α is the spin–independent amplitude between the initial neutron and final proton, γ is a spin–orbit contribution, and β, δ, and ε are the spin–spin terms. The one–pion–exchange pole is contained purely in the δ amplitude and this gives rise to its very rapid variation with momentum transfer, which influences very strongly the deuteron charge–exchange observables.

Impulse approximation applied to $dp \to \{pp\}_{^1S_0}n$ then leads to the following predictions for the differential cross section and deuteron spherical analysing powers:

$$\begin{aligned}
\frac{d^4\sigma}{dt\,d^3k} &= I\left[S^-(k,\tfrac{1}{2}q)\right]^2\Big/3,\\
I\,it_{11} &= 0\,,\\
I\sqrt{2}t_{20} &= \left[|\beta(q)|^2+|\delta(q)|^2|\mathcal{R}|^2-2|\varepsilon(q)|^2+|\gamma(q)|^2\right],\\
I\,t_{22} &= \sqrt{3}\left[|\beta(q)|^2-|\delta(q)|^2|\mathcal{R}|^2+|\gamma(q)|^2\right]/2\,.
\end{aligned}$$

In this $^1S_0$ limit, a measurement of the differential cross section, t_{20}, and t_{22} would allow one to extract values of $|\beta(q)|^2+|\gamma(q)|^2$, $|\delta(q)|^2$, and $|\varepsilon(q)|^2$ for small values of the momentum transfer $\vec{q}$ between the initial proton and final neutron. However, even if a sharp cut of 1 MeV is placed upon E_{pp}, there still remain small contributions from proton–proton P–waves that dilute the analysing power signal. Such effects must be included in any analysis aimed at providing quantitative information on the neutron–proton amplitudes.

The variation of the cross section with momentum transfer can be found in Fig. 1 for $E_{pp} < 3$ MeV [1]. The impulse approximation describes well the dependence on this variable out to $q = 140$ MeV/c. It should be noted that no adjustment has been made to the model or the experimental data; the luminosity was evaluated independently using the quasi-free $np \to d\pi^0$ reaction.

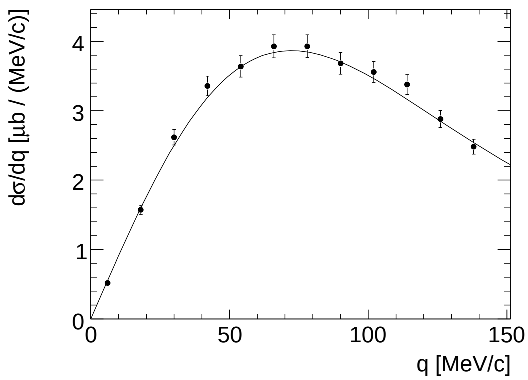

Fig. 1: Unpolarised differential cross section at $T_d = 1.17$ GeV for the $dp \to \{pp\}n$ reaction of $E_{pp} < 3$ MeV compared with the impulse approximation.

Our experimental values of the two tensor analysing powers are shown in Fig. 2 as a function of the momentum transfer.

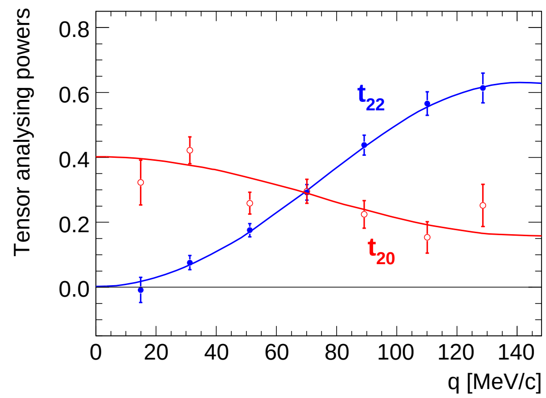

Fig. 2: Spherical tensor analysing powers t_{20} (open symbols) and t_{22} (closed) for the $\vec{d}p \to \{pp\}n$ reaction at $T_d/2 = 585$ MeV for $E_{pp} < 1$ MeV. The solid curves are the impulse approximation predictions.

The rapid rise of t_{22} with q is mainly a result of the fall in the $\delta(q)$ amplitude which, in a simple absorbed one–pion–exchange model, should vanish for $q \approx m_\pi c$. The much smoother variation of t_{20} is also expected, with a gentle decline from the forward value, once again being mainly driven by the fall in the $\delta(q)$ amplitude. All these features are well reproduced by the impulse approximation model using reliable np amplitudes.

Although all the experimental data agree with the impulse approximation model one could, invert the question. How well one could determine the amplitudes if there were no information available from the np phase shifts? Although the data reported here were obtained over short run, these are already sufficient to determine quite well the ratio of the $|\varepsilon(0)|/|\beta(0)|$ in the forward direction. Since little dilution of the t_{20} signal is expected at $q = 0$, all the data for $E_{pp} < 3$ MeV were fitted to a quadratic in q^2 for $q \leq 100$ MeV/c.

The value obtained at the origin gives $t_{20} = 0.37 \pm 0.02$, where the error is purely statistical. The uncertainty introduced by the beam polarisation would, however, contribute less than ± 0.01 to this. Since there is little or no dilution of the analysing power by the P-waves at $q = 0$, this result translates into an amplitude ratio of

$$|\varepsilon(0)|/|\beta(0)| = 0.61 \pm 0.03\,.$$

The proof–of–principle achieved here for the method suggests that measurements at higher energies will provide useful information in regions where the existing np database is far less reliable.

References:

[1] D. Chiladze et al., nucl-ex/0811.3288.

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