Recent results from the charge-exchange breakup reaction $dp \to \{pp\}_s n$ study at ANKE*

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A good understanding of the Nucleon–Nucleon interaction still remains one of the most important goals of nuclear and hadronic physics. Apart from their intrinsic importance for the study of nuclear forces, *NN* data are necessary ingredients in the modelling of meson production and other nuclear reactions at intermediate energies. It goes without saying therefore that any facility that could make significant contributions to this important database should do so.

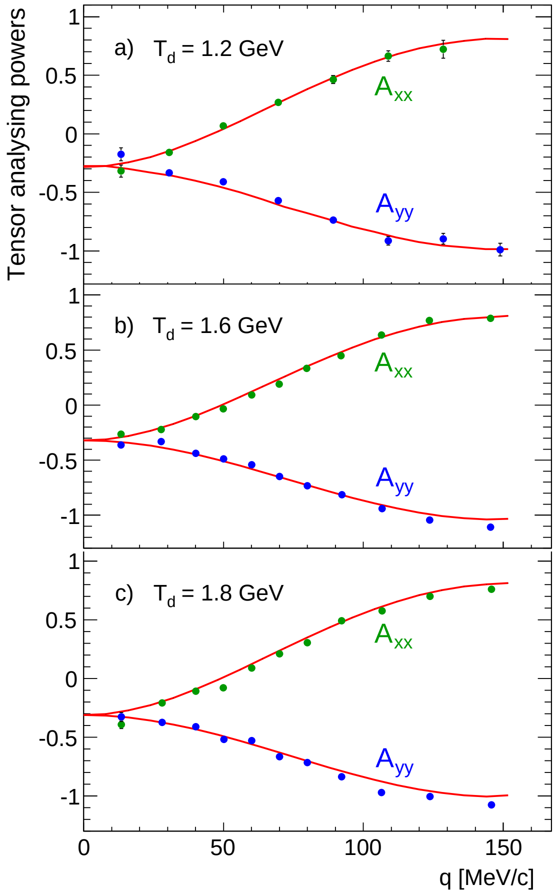

Fig. 1: Cartesian tensor analysing powers A_{xx} (green dots) and A_{yy} (blue dots) of the $dp \to \{pp\}_s n$ reaction at beam energies of $T_d = 1.2, 1.6$, and 1.8 GeV for low diproton excitation energy, $E_{pp} < 3$ MeV. The solid red curves are results of an impulse approximation calculation, where the input *np* amplitudes were taken from the SAID program at the appropriate energies.

The ANKE collaboration has embarked on a systematic programme to measure the differential cross section, analysing powers, and spin correlation coefficients of the $\vec{d}\vec{p} \to \{pp\}_s n$ deuteron charge–exchange breakup reaction. The aim is to deduce the energy dependence of the spin–dependent *np* elastic amplitudes. By selecting the two final protons with low excitation energy, typically $E_{pp} < 3$ MeV, the emerging diproton is dominantly in the $^1S_0$ state.

In impulse approximation the deuteron charge-exchange reaction can be considered as an $np \to pn$ scattering with a spectator proton. The spin dependence of the *np* charge-

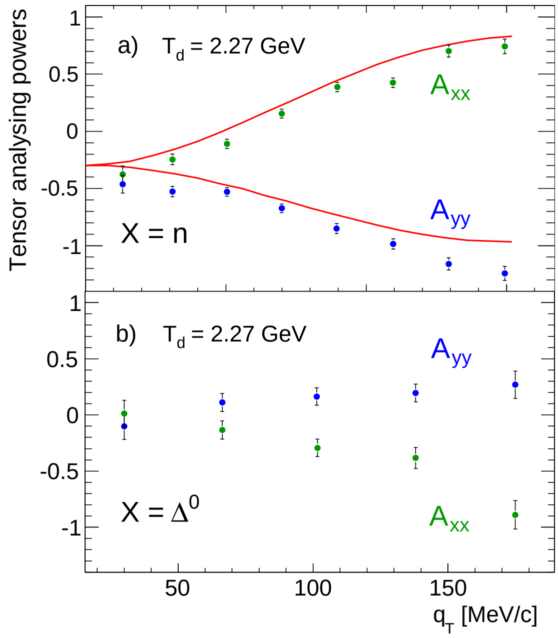

Fig. 2: Cartesian tensor analysing powers for the $dp \to \{pp\}_s X$ reaction at $T_d = 2.27$ GeV: with a neutron (a) or Δ^0 isobar (b) in the final state. In the Δ case the variable used is the transverse momentum transfer q_T. The red solid lines for the neutron are the results of an impulse approximation calculation.

exchange amplitude in the cm system can be displayed in terms of five scalar amplitudes as:

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

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 spin–spin terms. In the $^1S_0$ limit of the impulse approximation, the $\vec{d}\vec{p} \to \{pp\}_s n$ observables are directly related to the *np* spin–dependent amplitudes through:

$$\begin{aligned} \frac{d^4\sigma}{dtd^3k} &= \tfrac{1}{3} I \left\{S^-(k,\tfrac{1}{2}q)\right\}^2, \\ I &= |\beta|^2 + |\gamma|^2 + |\varepsilon|^2 + |\delta|^2 R^2, \\ IA_y^d &= 0\,,\ IA_y^p = -2\mathrm{Im}(\beta^*\gamma)\,, \\ IA_{xx} &= |\beta|^2 + |\gamma|^2 + |\varepsilon|^2 - 2|\delta|^2 R^2, \\ IA_{yy} &= |\delta|^2 R^2 + |\varepsilon|^2 - 2|\beta|^2 - 2|\gamma|^2, \\ IC_{y,y} &= -2\mathrm{Re}(\varepsilon^*\delta)R,\ IC_{x,x} = -2\mathrm{Re}(\varepsilon^*\beta), \end{aligned}$$

where $R = \left\{S^+(k,\tfrac{1}{2}q)/S^-(k,\tfrac{1}{2}q)\right\}^2$ and $S^\pm$ are form factors that can be evaluated using low energy *NN* information. Here $\vec{k}$ is the *pp* relative momentum in the diproton and $\vec{q}$ the momentum transfer between the deuteron and diproton.

Although corrections due to final *P*- and higher *pp* waves have to be taken into account in the detailed analysis, it is clear that in the low E_{pp} limit a measurement of the differential cross section, A_{xx}, and A_{yy} would allow the extraction of $|\beta(q)|^2 + |\gamma(q)|^2$, $|\delta(q)|^2$, and $|\varepsilon(q)|^2$ over a range of values of q.

For the above to be the realistic objectives, the methodology has to be checked in energy regions where the np amplitudes are reasonably well known. An extended paper (*D. Chiladze et al., Eur. Phys. J. A 40 (2009) 23*) has recently been published with this in mind. The new ANKE results for the deuteron Cartesian tensor analysing powers A_{xx} and A_{yy} at three beam energies are shown in Fig. 1 as functions of the momentum transfer. The agreement between the experimental data and the impulse approximation predictions obtained using the reliable SAID np amplitudes as input at T_n = 600, 800, and 900 MeV, is very encouraging. This success provides a motivation for repeating these measurements at higher energies where the np input is far less certain.

The maximum deuteron energy available at COSY is $T_d \approx$ 2.3 GeV (1.15 GeV per nucleon) and the ANKE results for A_{xx} and A_{yy} near this energy are shown in Fig. 2a. The neutron–proton amplitudes are here not as well known and the deviations of the data from the predicted curves strongly suggest that there are deficiencies in the SAID values of the np amplitudes in this region.

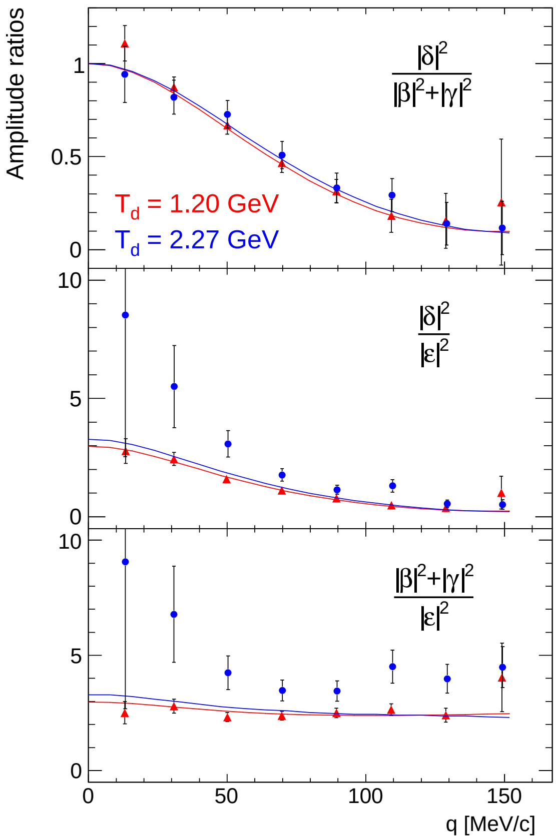

Fig. 3: Measured observable ratios as functions of q for two different beam energies. Solid lines are impulse approximation predictions.

The deficiencies of the SAID input np amplitudes at 1.135 GeV can be shown more explicitly by forming the following combinations of the observables:

$$
\begin{aligned}
(1-A_{yy})/(1+A_{xx}+A_{yy}) &\approx (|\beta|^2+|\gamma|^2)/|\varepsilon|^2\,,\\
(1-A_{xx})/(1+A_{xx}+A_{yy}) &\approx |\delta|^2/|\varepsilon|^2\,,\\
(1-A_{xx})/(1-A_{yy}) &\approx |\delta|^2/(|\beta|^2+|\gamma|^2)\,.
\end{aligned}
$$

The variation of these quantities with q are presented in Fig. 3 for the 1.2 and 2.27 GeV data. Whereas at the lower energy all the ratios are well described by the model, at the higher it is seen that it is only $|\delta|^2/(|\beta|^2+|\gamma|^2$ which is well understood. It seems that the SAID program currently overestimates the values of $|\varepsilon|$ at small q. This will become clearer when absolute values of the cross sections are extracted at 2.27 GeV.

The final goal is to go to even higher energies by using a proton beam (available up to 3 GeV at COSY) incident on a polarised deuterium target, $pd \to \{pp\}_s n$. This could be very fruitful because so little is known about the spin dependence of the np charge exchange reaction much above 1 GeV.

In order to determine the relative phases of the spin-spin amplitudes $(\beta,\delta,\varepsilon)$ it is necessary to determine the spin correlation parameters $C_{x,x}$ and $C_{y,y}$. A large amount of data was successfully obtained from the first double–polarised neutron–proton scattering experiment at ANKE (*cf.* Annual Report 2009). The *preliminary* results for the vector-vector spin correlation coefficients in the $\vec{d}\vec{p} \to \{pp\}_s n$ reaction at T_d = 1.2 GeV are shown in Fig 4, where they are seen to be in satisfactory agreement with impulse approximation predictions. The analysis of the higher energy data is in progress.

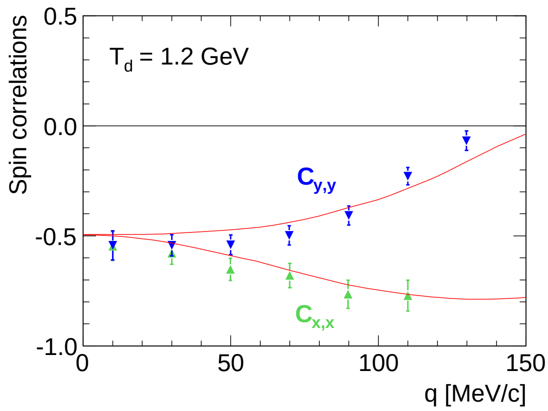

Fig. 4: Vector spin–correlation coefficients in $\vec{d}\vec{p} \to \{pp\}_s n$ reaction at $T_d = 1.2$ GeV. The red curves are the predictions of the impulse approximation calculation.

It was shown at Saclay that at $T_d = 2$ GeV the $\Delta(1232)$ isobar can be excited in the $\vec{d}p \to \{pp\}_s\Delta^0$ reaction and substantial tensor analysing powers were measured. In impulse approximation, these are also sensitive to a spin–transfer from the neutron to the proton in $np \to p\Delta^0$. The Δ^0 is seen clearly also in the ANKE charge-exchange breakup data at 1.6, 1.8, and 2.27 GeV. The values of A_{xx} and A_{yy} deduced at 2.27 GeV and shown in Fig. 2b are very different to those measured for the 'normal' neutron breakup with even changes of the signs. ANKE will therefore also provide useful information on the spin structure of Δ excitation in neutron–proton collisions.

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