

# NUCLEON-NUCLEON AND FEW-BODY STUDIES

## A COMPLETE SET OF IN-PLANE SPIN-TRANSFER COEFFICIENTS FOR SMALL ANGLE pp ELASTIC SCATTERING AT 200 MeV

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Current potential models<sup>1</sup> of the nucleon-nucleon (NN) interaction can describe much of the low- and intermediate-energy NN scattering database with a  $\chi^2$  per datum fairly close to 1. In spite of these successes, however, there remains significant controversy over the value of one of the most fundamental parameters in such models, the pion-nucleon coupling constant  $g_\pi^2$ . Difficulties encountered initially in reproducing both the pp scattering data and the ground-state properties of the deuteron<sup>2</sup> led to speculation as to whether this coupling could be strongly charge-dependent.<sup>3</sup> Though later analyses of the NN (both pp and np) (Ref. 1) and  $\pi N$  (Ref. 4) data showed no clear signature for charge-dependence, the large value for  $g_{\pi^\pm}^2$  extracted in a recent study of the np cross section at back angles<sup>5</sup> has only served to muddy the waters further. An additional complication, and one whose severity is difficult to gauge, arises from the fact that those who model the interaction have generally employed different criteria for data selection, different conventions for renormalizing data sets, and have emphasized different energy ranges in their analysis. Thus, discrepancies at the few percent level for  $g_\pi^2$  remain, even when only pp scattering is considered.<sup>6,7</sup>

On the experimental side, while it is clear that some of the existing data must be in error (*e.g.*, when two measurements of nominally the same quantity differ by 4 or 5 standard deviations), it is also true that some of the most critical kinematic regimes remain relatively unexplored. Detailed analysis and simulations have shown<sup>7,8</sup> that precise knowledge of a specific set of spin observables, over the kinematic region where single pion exchange should dominate the hadronic interaction ( $q \sim 0.3\text{--}0.8 \text{ fm}^{-1}$ ), can provide significant constraints on the value of  $g_\pi^2$ . To identify these observables, we note that in a momentum-space representation, the first-order potential for the exchange of a pseudo-scalar particle takes the form:<sup>9</sup>

$$V_{ps}(q) = -\frac{g_{ps}^2}{4M_N^2} \frac{(\sigma_1 \cdot q)(\sigma_2 \cdot q)}{q^2 + m_{ps}^2}, \quad (1)$$

where  $M_N$  is the (average) nucleon mass and  $\sigma_k$  is the Pauli spin matrix for the  $k^{\text{th}}$  nucleon. By measuring an appropriate combination of spin-transfer observables, one can isolate that component of the NN interaction which exhibits a spin-longitudinal structure identical to that found in Eq. (1). Explicitly, this component – the “ $\delta$ ” amplitude in the

KMT formulation,<sup>10</sup> for example – can be expressed in the following model-independent manner:

$$|\delta|^2 = \frac{1}{4} \frac{d\sigma}{d\Omega} (1 - D_{nn} + D_{qq} - D_{ll}) . \quad (2)$$

In conjunction with the  $D_{NN'}$  data measured recently at IUCF,<sup>11</sup> the measurements described here constitute a robust set of high precision data that will allow us to map out the momentum-transfer dependence of the  $\delta$  amplitude in a regime where it is expected to be changing rapidly, due largely to single pion exchange.

Data for experiment E383 were acquired in three runs during 1995–96. Measurements of the lab-frame observables  $D_{LL'}$ ,  $D_{LS'}$ ,  $D_{SL'}$ , and  $D_{SS'}$  were completed at 5 angles ( $\theta_{lab} \approx 5^\circ, 7.5^\circ, 10^\circ, 12^\circ, \text{ and } 15^\circ$ ), at an average beam energy of 197.9 MeV. The basic measurement involved the scattering of protons, whose polarization vector had been precessed to lie in the (horizontal) reaction plane, from a thin CH<sub>2</sub> foil target. The higher-energy, forward-going protons were momentum analyzed with the K600 spectrometer and focal plane detectors, and their sideways polarization components determined using elastic scattering from natural carbon in the focal plane polarimeter (FPP). The low-energy recoil protons were detected with a thin (500  $\mu\text{m}$ ) stopping silicon microstrip detector located inside the scattering chamber. No coincidence requirement between the protons was imposed in hardware, so that a ‘singles’ analysis of the focal plane data, after suitable background subtraction, was possible. This detection scheme, developed during the  $D_{NN'}$  measurement,<sup>11</sup> is a very effective way to eliminate background.

Because the K600 is a horizontal-bending device, the in-plane polarization components of the scattered protons precess in the spectrometer’s magnetic field. Taking this into account, the measured FPP asymmetry (*i.e.*, the yield asymmetry between protons that scatter downward or upward in the FPP analyzer) can be expressed in the following form:

$$\epsilon_{FPP} = A_{FPP} (p_L \sin \alpha D_{LL'} + p_S \sin \alpha D_{SL'} + p_L \cos \alpha D_{LS'} + p_S \cos \alpha D_{SS'}) , \quad (3)$$

where  $p_L$  and  $p_S$  are, respectively, the longitudinal and sideways components of the beam polarization, and  $\alpha$  is the angle of spin-precession experienced by the scattered protons within the spectrometer. In order to isolate the individual spin-transfer coefficients, it is clear from Eq. (3) that one must be able to vary both the direction of the incident beam polarization and also the degree of spin precession for the outgoing protons. The former was effected through use of the two high-energy beamline solenoids, while the latter entailed making measurements under essentially identical conditions, but with the K600 in either its (usual) medium-dispersion configuration or in its newly developed low-dispersion mode of operation.<sup>12</sup> By pushing the ratio of field strengths in the two main K600 dipoles to the extremes of their acceptance limits for each configuration, changes in  $\alpha$  of close to 90° were achieved. The considerable effort required to switch from one configuration to the other, which involves moving the entire FPP apparatus, dictates that the needed data be taken over several different running periods.

The experiment was designed to minimize sensitivity to most systematic errors, so the statistical uncertainty in each data point (typically  $\pm 0.01$ ) should be the dominant source of error. For these particular measurements, we are also aided by the fact that parity conservation forbids any induced in-plane polarization in the nuclear scattering, so that

a spin ‘flip’ at the ion source results in an exact reversal of the in-plane polarization at the K600 focal plane. This allows us to use a cross-ratio technique to calculate the FPP asymmetries, thereby cancelling most geometric or spin-dependent false asymmetries to all orders.<sup>13</sup> We also benefit from the recent precise determination of  $A_{FPP}$ , the effective analyzing power of the FPP, over the energy range of interest,<sup>14</sup> although we have carried out additional checks of this calibration, including several tests the FPP in its low dispersion location.

The presence of carbon in our primary target provides several other features useful for control or monitoring of systematic error. Perhaps most importantly, the location of the  $p + {}^1\text{H}$  peak relative to the discrete  $p + {}^{12}\text{C}$  states in the K600 focal plane allows us to determine the absolute scattering angle to within a few hundredths of a degree. Due to the strong angular dependence exhibited by some of these observables, this level of accuracy is crucial. Of all the  ${}^{12}\text{C}$  states, the elastic peak is of particular interest, in that the spin observables for this state must adhere to certain constraints,<sup>13</sup> which serves to further check the consistency of our analysis. Finally, we note that one complication for in-plane spin-transfer studies is that the precession of the scattered-proton polarization in the magnetic fields of the K600 must be accurately determined. Details on measurements we have carried out for this purpose are provided in another article in this report.<sup>15</sup>

In Fig. 1 we present our preliminary (on-line) results for all of the pp observables studied here. The error bars represent statistical uncertainties only. Based on our experience with analysis of previous pp measurements, we expect that the data points could move up or down by as much as 2-3 standard deviations in the final analysis, so it would be premature to make detailed comments on the implications of these data for particular models or phase-shift solutions at this time. On the other hand, we believe that the size of our final error bars (statistical plus systematic contributions) should not differ significantly from those shown here. If so, these data should provide a means of discriminating among different predictions, for example, for the observable  $D_{LL'}$ , which is expected<sup>7</sup> theoretically to be most sensitive to the value of  $g_{\pi}^2$ . Towards this end, analysis of the present forward-angle data (E383) is continuing, and measurements that will extend the data sets to larger angles (E397) have been scheduled for the summer of 1996.

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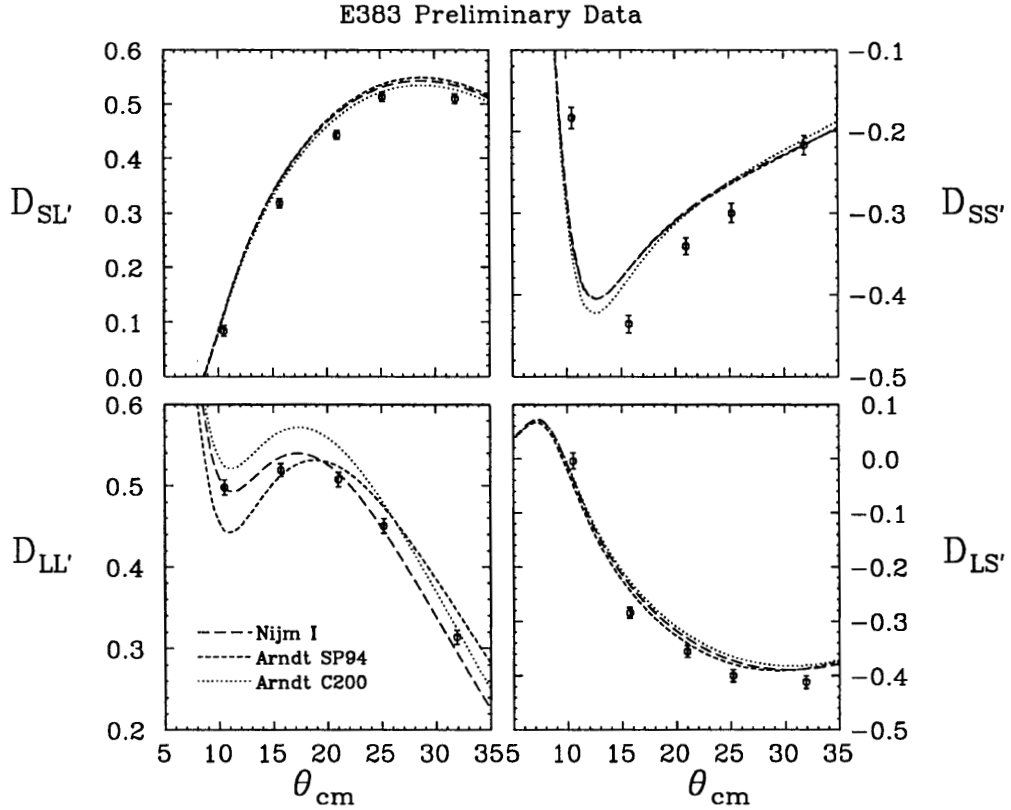


Figure 1. Preliminary results from analysis of experiment E383, and predictions from current potential models and partial-wave analyses. The long-dashed line represents the Nijmegen I potential, while the short-dashed and dotted lines correspond to Arndt's multi-energy (0-1.6 GeV) and local energy (175-225 MeV) phase shift solutions.

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