Brief Reports

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Spin transfer measurements for $pp \to pp$ at 647 MeV

M. W. McNaughton, B. E. Bonner, E. W. Hoffman, and O. B. van Dyck
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

C. L. Hollas and P. J. Riley
University of Texas, Austin, Texas 78712

K. H. McNaughton*
Case Western Reserve University, Cleveland, Ohio 44106

K. Imai and K. Toshioka
Argonne National Laboratory, Argonne, Illinois 60439

J. Roberts and S. E. Turpin
Rice University, Houston, Texas 77001

B. Aas and A. Rahbar
University of California/Los Angeles, Los Angeles, California 90024
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Measurements have been made of the spin depolarization parameters D_{NN}, D_{SS}, and D_{LS} ($27° \leq \theta_{\text{c.m.}} \leq 90°$) and the spin transfer parameters K_{NN}, K_{SS}, and K_{LS} ($56° \leq \theta_{\text{c.m.}} \leq 90°$) for $pp \to pp$ at 647 MeV. Typical uncertainties are about 0.03 compared with about 0.1 for previous data. Previous data are reviewed. The present data are in agreement with corrected previous data, and are in agreement with Arndt's phase-shift solutions.

[NUCLEAR REACTIONS $^1H(p,p,)^1H$, $E = 647$ MeV, measured D_{NN}, D_{SS}, D_{LS}, K_{NN}, K_{SS}, K_{LS}, $\theta = 27°$ to 90° c.m.]

I. INTRODUCTION

Recently there has been much interest in the nucleon-nucleon interaction at medium energies, especially following the discovery of energy-dependent structure near the pion production threshold. (For a comprehensive survey see Ref. 1.) Isovector phase-shift analyses[2,3] have found resonance-like structure in the $^1D_2$ and $^3F_3$ partial waves, as well as unexplained structure in either the $^3P_0$ or $^3P_2$ wave.[4] Explanations range from exotic dibaryon resonances[2,3,5–7] to conventional threshold effects.[8–15]

A first step in investigating this structure is to unambiguously determine the isovector (pp) elastic amplitudes. These are well determined below 600 MeV as a result of work at TRIUMF[16] and SIN.[17] At 800 MeV, we have recently measured 10 experimental parameters (Ref. 18 and references therein). Between these two energies ($600 \leq E \leq 800$ MeV) 12

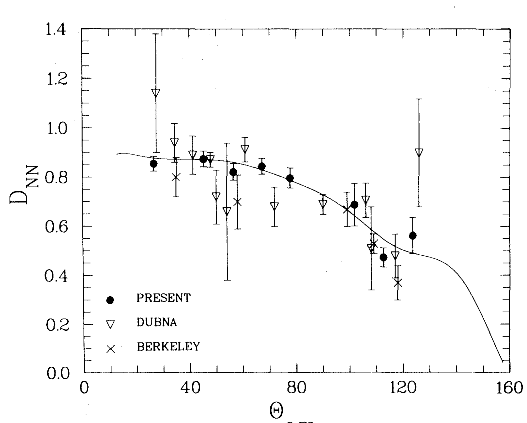

FIG. 1. D_{NN} vs $\theta_{\text{c.m.}}$ near 650 MeV, present and previous (Ref. 19) data compared with Arndt's phase-shift solution SF81. Data at the same angle have been averaged. Berkeley data (Ref. 36) are corrected as described in the text.

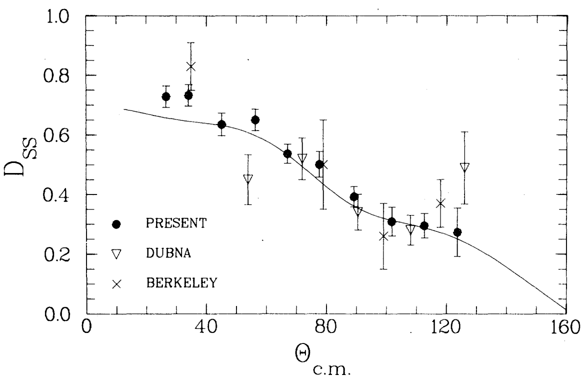

FIG. 2. D_{SS} vs $\theta_{c.m.}$ near 650 MeV, present and previous (Ref. 19) data compared with Arndt's phase-shift solution SF81. Data at the same angle have been averaged.

parameters have been measured, but most of these data are old (Dubna 1958 to 1970, and Berkeley 1970), are inconsistent and have large uncertainties. The early data are listed in Bystricky's compilation,[19] and discussed at the end of this paper. Recent data have been published for cross section,[20] analyzing power,[21,22] the spin correlation parameters A_{NN} (Ref. 22) and A_{LL} (Refs. 4 and 23), and the total cross section difference $\Delta\sigma_L$.[23]

We report here new measurements of the spin depolarization parameters D_{NN}, D_{SS}, and D_{LS} and the spin transfer parameters K_{NN}, K_{SS}, and K_{LS}. [Identity of particles implies $D(\theta)=K(\pi-\theta)$, so both D and K are plotted together in Figs. 1–3.]

II. EXPERIMENTAL METHOD

The experimental method used for the present data was almost identical to that for the 800-MeV work, and is described in detail in our previous paper.[18] Briefly, 647-MeV polarized protons from the LAMPF accelerator were focused onto a liquid hydrogen target, and both scattered and recoil protons were detected in multiwire drift chambers. The spin of the forward scattered or backward recoil proton (for D and K parameters, respectively) was analyzed in the carbon polarimeter Janus.[24] The spin of the beam protons was set in the N, S, or L directions by a combination of a 750-keV Wien filter and an 800-MeV spin precessor.[25]

The only significant difference between the present and previous[18] experimental procedures was in the monitoring of the beam polarization. In addition to using the beam line polarimeters,[26] the polarization magnitude was monitored every minute throughout the present experiment using the ion source quench ratio.[27] Thus for L spin both magnitude and direction of polarization were determined, while for N and S spin the magnitude was overdetermined. All measurements were consistent to within 1% throughout the experiment.

The inclusive carbon analyzing power, A_c (relevant to the carbon polarimeter), was obtained from a recent global fit to the world data.[28] As described previously[18] the uncertainty in A_c (typically ±2.5%) has been included as a point-to-point uncertainty in the data table. Overall normalization[18,27] is ±1%, which is negligible but could be included separately.

As previously,[18] the data are averaged over the ±3° laboratory acceptance of Janus. The angle quoted is the mean angle of the events, with about ±0.1° laboratory uncertainty. Data have been corrected for the finite azimuthal angular acceptance (maximum of 1% at 11° laboratory) and for small missettings in the direction of the beam polarization (maximum of −0.02 for D_{LS} at 35° laboratory).

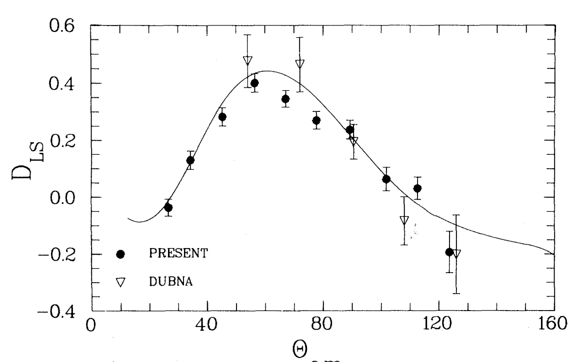

FIG. 3. D_{LS} vs $\theta_{c.m.}$ near 650 MeV, present and previous (Ref. 19) data compared with Arndt's phase-shift solution SF81.

III. DISCUSSION

The data are listed in Table I and plotted in Figs. 1–3 in comparison with previous data (600 to 670 MeV)[19] and with Arndt's[29] energy-dependent phase-shift solution SF81. (SF81 includes preliminary values of the present data.) Agreement is generally good. Unpublished single-energy phase shifts[30,31] have encountered ambiguities in the solution near 650 MeV. The present data resolve these ambiguities.

Finally, it is appropriate to review the older data in Bystricky's compilation,[19] and Arndt's[29] data set. These come from the series of measurements from 1958 to 1970 at Dubna, and Berkeley in 1970. It should be noted that the D_{NN} data of Ref. 32 are superceded by Ref. 33, and the D_{NN} data of Ref. 34 are renormalized in Ref. 35, footnote 2. The beam energy for the Dubna D_{NN} and D_{SS} data is variously listed at 635 or 640 MeV. Apparently the beam energy was 640 MeV, but there was 5-MeV energy loss in the glass wall of the liquid hydrogen target, giving 635

TABLE I. Spin depolarization and spin transfer parameters for $pp \rightarrow pp$ at 647 MeV.

θ_{lab}	$\theta_{c.m.}$	D_{NN}	ΔD_{NN}	D_{SS}	ΔD_{SS}	D_{LS}	ΔD_{LS}
11.5	26.6	0.855	0.030	0.729	0.036	−0.037	0.030
14.8	34.1			0.733	0.036	0.130	0.032
19.8	45.2	0.875	0.032	0.635	0.038	0.283	0.032
24.8	56.4	0.822	0.034	0.651	0.036	0.401	0.032
29.8	67.1	0.845	0.032	0.537	0.032	0.346	0.029
34.8	77.7	0.798	0.041	0.501	0.043	0.271	0.031
40.6	89.7			0.392	0.034	0.238	0.033
		K_{NN}	ΔK_{NN}	K_{SS}	ΔK_{SS}	K_{LS}	ΔK_{LS}
46.7	78.2	0.689	0.087	0.309	0.048	0.065	0.041
52.3	67.4	0.474	0.039	0.295	0.041	0.032	0.039
58.1	56.4	0.563	0.074	0.273	0.081	−0.193	0.073

MeV at target center. The most serious problem is with the Berkeley D_{NN} data.[36] Equation 3.4 (p. 18, Ref. 36) was derived by changing the sign of P_1 in the numerator but not in the denominator, and is therefore incorrect. The data have been rederived using the information in Table II of Ref. 36, but substituting recent values[22] for the *pp* analyzing power P_2. The corrected data (weighted average of 600 and 670 MeV) are plotted in Fig. 1, and are now in good agreement with other data and phase shifts.

In summary, the present work resolves ambiguities and discrepancies near 650 MeV. Data and phase-shift analyses are now consistent at this energy.

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*Present address: University of Texas, Austin, Tex. 78712.

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