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Measurements of C_{NN} in Proton–Proton Scattering*

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The spin–spin correlation parameter C_{NN} for *p–p* scattering has been measured at 5 energies between 305 and 415 MeV. Measurements were made over the angular range of 50° to 90° in the c.m. system. A polarized beam, produced by scattering of the internal proton beam of the Chicago cyclotron, and the Argonne polarized proton target were used for the experiment. Results obtained for $C_{NN}(90°)$ are: 0.52±0.08 at 305 MeV, 0.48±0.08 at 330 MeV, 0.50±0.05 at 358 MeV, 0.46±0.06 at 386 MeV, and 0.42±0.04 at 415 MeV. Comparisons with other experimental results and with theoretical and phenomenological models will be made.

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The polarized beam was momentum analyzed by the fringing field of the cyclotron and focused in the experimental area by two quadrupole triplets. In a previous run the polarization of the beam was measured by the standard double scattering method. The value obtained for the beam polarization was $P_B = 0.535 \pm 0.025$. The polarization of the beam as it emerges from the cyclotron is directed vertically upwards. A solenoid magnet in the experimental area allows the polarization to be rotated either to the left or to the right into the horizontal plane. The polarized target polarization P_T is also directed horizontally and scatterings are observed in the vertical plane. Since the height of the polarized target above the floor was greater than the height of the beam, the beam was bent upwards through an angle of 9° by means of a bending magnet. The field of the polarized target magnet was such that it bent the beam down through 18°. In this arrangement the beam is horizontal as it passes through the polarized target. The target consisted of crystals of $La_2Mg_3(NO_3)_{12}\cdot 24H_2O$; the free protons were polarized by the dynamic nuclear orientation method[1] and the degree of polarization was measured with an NMR system.[2] Two banks of scintillation counters detected the scattered and recoil protons. Scatterings off the free protons of the *LMN* crystals were separated from scatterings off protons bound in the other nuclei by means of the angular correlation between the scattered and recoil protons.[3] Energy loss of the recoil protons in the target limited us to angles greater than 50° in the c.m. system.

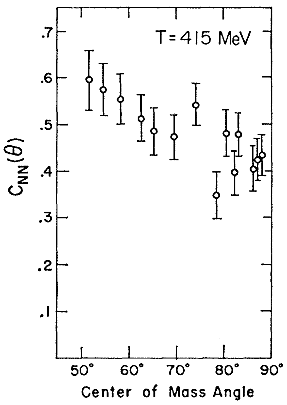

FIG. 1. Angular distribution of C_{NN} at 415 MeV.

Data were taken for the four possible combinations of left and right orientation of the beam polarization and left and right orientation of the target polarization. The rates at a given angle can be expressed as:

$$I(\theta) = I_0(\theta)[1 + (\pm P_B)P(\theta) + (\pm P_T)P(\theta) + (\pm P_B)(\pm P_T)C_{NN}(\theta)], \quad (1)$$

where $I_0(\theta)$ is the intensity observed with both target and beam unpolarized, and $P(\theta)$ is the polarization in *p–p* scattering. From the four rates one can compute three asymmetries:

$$\begin{aligned} \epsilon_1(\theta) &= P_B P(\theta), \\ \epsilon_2(\theta) &= P_T P(\theta), \\ \epsilon_3(\theta) &= P_B P_T C_{NN}(\theta). \end{aligned} \quad (2)$$

Thus, only one of P_B, P_T, and $P(\theta)$ need be known in

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[1] See, for example, C. D. Jeffries, *Dynamic Nuclear Orientation* (Interscience Publishers, Inc., New York, 1963).

[2] A. Moretti, S. Suwa, and A. Yokosawa, *Proceedings of the 2nd International Symposium on Polarization Phenomena of Nucleons*, Karlsruhe, p. 128 (Sept. 1965).

[3] The experimental details are similar to those discussed by S. Suwa, A. Yokosawa, N. E. Booth, R. J. Esterling, and R. E. Hill, Phys. Rev. Letters **15**, 560 (1965).

order to compute $C_{NN}(\theta)$. In fact, we have some information on all three: P_B, from our earlier measurement; P_T, from the NMR system; and $P(\theta)$, from other experiments.[4] In the analysis we assumed P_T to be unknown and used P_B as the standard. Values of $P(\theta)$ obtained from $\epsilon_1(\theta)$ were compared with earlier measurements and found to be in good agreement. Values of P_T obtained from the ratio of $\epsilon_2(\theta)$ to $\epsilon_1(\theta)$ were found to be in good agreement with values obtained from the NMR system. Data at lower energies were obtained by degrading the proton beam with CH_2.[5]

In Table I we give our results for $C_{NN}(90°)$. In the accompanying paper by Catillon *et al.* they are compared with earlier measurements[6–15] and with other results presented at this conference. Our results tend to be lower than some of the earlier measurements between 300 and 450 MeV. Another recent result, namely that of Coignet *et al.* obtained with a polarized target,[13] is also lower than an interpolation between the older results. Our results are in excellent agreement with predictions of the phase-shift analysis of Kazarinov *et al.*[16] and of the potential model of Hamada and Johnston.[17]

Table I. $C_{NN}(90°)$.

T, MeV	$C_{NN}(90°)$
415	0.42 ± 0.04
386	0.46 ± 0.06
358	0.50 ± 0.05
330	0.48 ± 0.08
305	0.52 ± 0.08

Figure 1 shows the angular distribution of $C_{NN}(\theta)$ at $T=415$ MeV. Notice the trend for C_{NN} to be larger at smaller angles. At 575 MeV, the angular distribution over the same angular range appears flatter,[13] while at 680 MeV, the trend is the opposite, with $C_{NN}(\theta)$ being smaller at smaller angles.[15] Below 415 MeV our angular distributions become flatter.

One of the predictions of $M(12)$ symmetry is $C_{NN}(90°)=2D(90°)-1$, where $D(\theta)$ is the Wolfenstein depolarization parameter.[18] Roth *et al.*[19] measured $D(90°)$ at 430 MeV and obtained 0.67 ± 0.10. Thus, $2D(90°)-1=0.34\pm0.20$ which can be compared with our value of $C_{NN}(90°)=0.42\pm0.04$ at 415 MeV.

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[4] A convenient summary of the data may be found in R. Wilson, *The Nucleon–Nucleon Interaction: Experimental and Phenomenological Aspects* (Interscience Publishers, Inc., New York, 1963).

[5] There is evidence, both experimental and theoretical, that degrading does not change the beam polarization; see E. Heiberg, U. Kruse, J. Marshall, L. Marshall, and F. Solmitz, Phys. Rev. **97,** 250 (1955); and L. Wolfenstein, *ibid.* **75,** 1664 (1949).

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