Measurement of Spin Parameters for a Decisive Clarification of the Structure Observed in the p-p System

I. P. Auer,[a] E. Colton,[b] W. R. Ditzler, D. Hill, R. Miller, H. Spinka, G. Theodosiou,[c] J.-J. Tavernier,[d] N. Tamura, K. Toshioka[e] D. Underwood, R. Wagner, and A. Yokosawa
Argonne National Laboratory, Argonne, Illinois 60439

and

P. Kroll and W. Jauch
Gesamthochschule Wuppertal, Federal Republic of Germany

(Received 10 June 1983)

Recent data are presented on spin-spin correlation parameters $C_{LL} = (L, L; 0, 0)$ and $C_{SL} = (S, L; 0, 0)$ at forward angles from 1.18 to 2.47 GeV/c incident momenta in proton-proton elastic scattering. Values for $\Delta\sigma_L$(inelastic) are derived and are shown to disagree with predictions of theoretical models attempting to describe p-p scattering without dibaryon resonances. Finally, the C_{LL} and C_{SL} data discriminate among various phase-shift solutions, and will lead to a clarification of the p-p phase shifts.

PACS numbers: 13.75.Cs, 14.20.Pt, 21.30.+y, 24.70.+s

A striking energy dependence has been observed in the difference between the proton-proton total cross sections, $\Delta\sigma_L^{\rm tot} = \sigma(\rightleftarrows) - \sigma(\rightrightarrows)$, for pure longitudinal spin states up to 3 GeV/c incident proton momentum.[1] These phenomena have stimulated both experimentalists and theorists to perform further studies of the nucleon-nucleon system; observables measured in the past were reexamined, and new measurements of various observables were undertaken.[2] Interpretations of various p-p experimental data include evidence for the existence of diproton resonances.[2] Phase-shift analyses in the p-p system have been performed by various authors.[3-5] Some of these results are consistent with the existence of diproton resonances.[3,4] Although the solutions are qualitatively similar, differences still exist. In the meantime, searches have been made for resonance poles; such poles have been found in $^1D_2$ and $^3F_3$ states.[4,6,7] We note that several authors attempt to explain existing experimental data without including dibaryon resonances.[8] In order to clarify the various interpretations, we carried out measurements of C_{LL} and C_{SL} at 1.18, 1.35, 1.49, 1.71, 2.00, 2.22, and 2.47 GeV/c at the Argonne zero-gradient synchroton. We chose to carry out these difficult measurements because (1) there are no $C_{LL} = (L, L; 0, 0)$ and $C_{SL} = (S, L; 0, 0)$ data in the forward region ($\theta_{\rm c.m.} \approx 30$ to $50°$) above 1.2 GeV/c incident proton momentum and these data are clearly needed to distinguish among phase-shift solutions (note that there exist ample data[9] in the region of $\theta_{\rm c.m.} \approx 60$ to $90°$ because of the simplicity of the experimental setup); and (ii) from C_{LL} data one can deduce values of $\Delta\sigma_L^{\rm in} = \Delta\sigma_L$(inelastic) and compare them with several theoretical predictions.

The experimental setup is similar to the one shown by Wagner[10]. Beam particles traversing the entire length of a polarized target of doped ethylene glycol held at 0.4 K[11] were selected in fast logic with the use of scintillation counters. Because of the complicated configuration of the polarized-target magnet, precise angular determination of the recoil protons by the proportional chambers placed inside of the magnet was difficult. To improve the situation, a large aperture analyzing magnet was used for the momentum determination of the forward-scattered particles. Events from free protons in the polarized target were selected by finding the momentum balance $\Delta p = p_{\rm measured} - p_{\rm free}$ for a given value of $\theta_{\rm c.m.}$, and by angle-angle correlations. After cuts were made on the momentum balance, a coplanarity distribution of angular-angular correlations was made which showed a clear elastic peak on a small background (less than 10%). While the beam polarization was reversed with every spill, the target polarization was reversed about every four runs. The beam polarization was monitored continuously during running by a liquid-hydrogen polarimeter[12] located near the beginning of our beam line. The systematic uncertainties, due principally to uncertainty in the beam and target polarizations, are estimated to be about 2.8%.

The differential cross section for a particular spin direction of the beam and target, $I^{\pm\pm}$, is given by

$$I^{\pm\pm}(\theta_{\rm c.m.}) = I_0(\theta_{\rm c.m.})[1 + (\pm P_B)(\pm P_T)C_{XX}(\theta_{\rm c.m.})],$$

© 1983 The American Physical Society

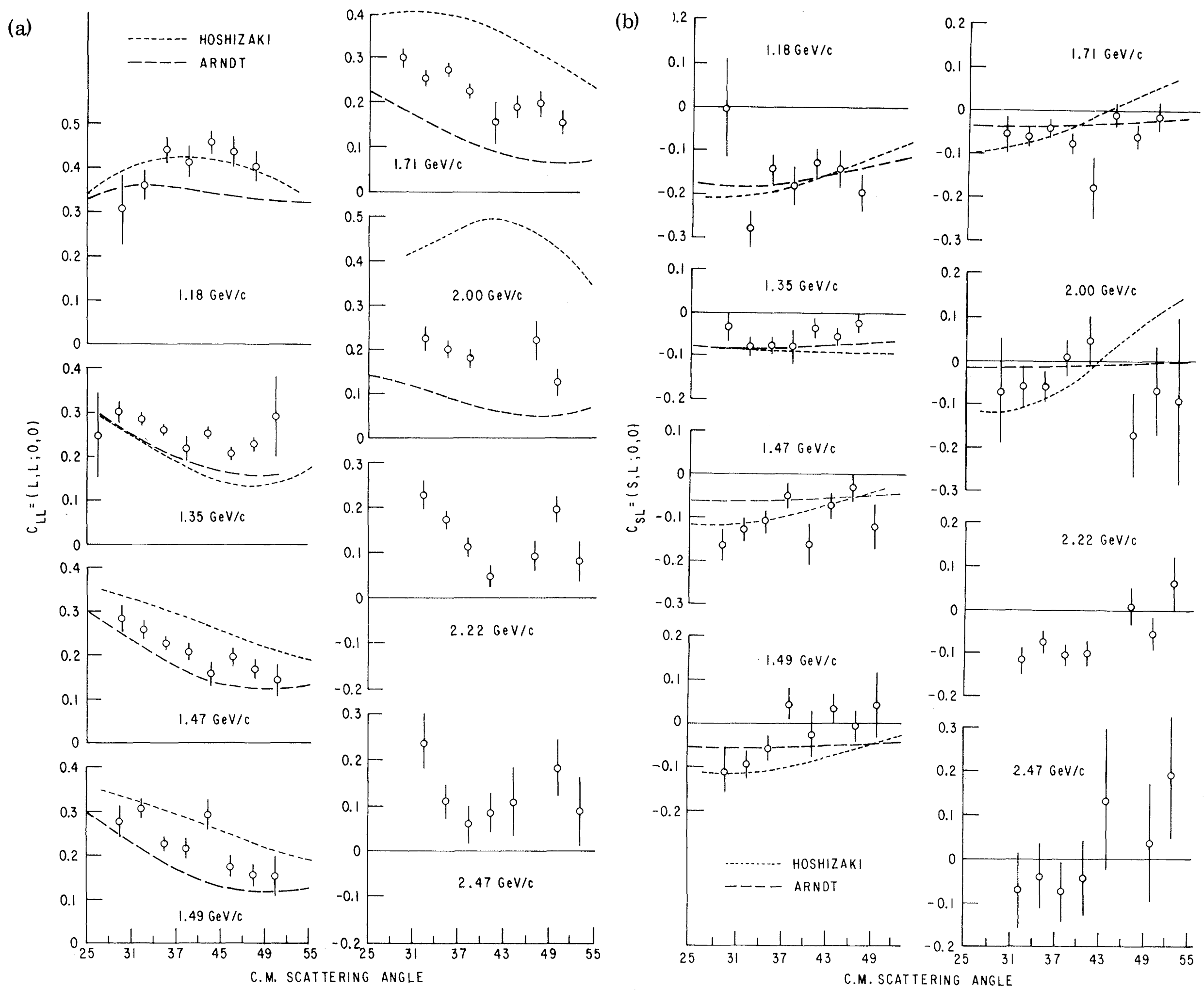

FIG. 1. (a) The measured spin-spin correlation parameter C_{LL}, together with the presently available phase-shift solutions from Refs. 3 and 4. (b) The measured spin-spin correlation parameter C_{SL}.

where P_B and P_T are the beam and target polarization, respectively, ± refers to spin state, $I_0(\theta_{\mathrm{c.m.}})$ is the spin-averaged differential cross section, and C_{XX} represents C_{LL} or C_{SL}.

Figure 1 shows plots of the C_{LL} and C_{SL} data (the errors shown are purely statistical, which dominate our systematic errors) together with predictions from presently available phase-shift solutions.[3,4] Both solutions indicate the existence of diproton resonances in $^1D_2$ and $^3F_3$ states, but they are quantitatively different. A comparison[13] of the experimental values of C_{LL} and C_{SL} with phase-shift predictions shows better agreement with Refs. 3 and 4 than with Ref. 5. We hope that the new data will aid a convergence toward unique phase-shift solutions.

With use of C_{LL} data and dispersion relations, values of $\Delta\sigma_L^{\mathrm{in}}$ were calculated. The results are shown in Fig. 2 and compared with theoretical predictions which do not include diproton resonances. Extraction of $\Delta\sigma_L^{\mathrm{in}}$ was performed with use of (i) the C_{LL} data of this experiment, (ii) existing data[9] covering the angles near $\theta_{\mathrm{c.m.}} = 60-90°$, and (iii) the forward values obtained from dispersion relations.[14] We made a Legendre-polynomial expansion of $C_{LL}\, d\sigma/d\Omega$:

$$C_{LL}\frac{d\sigma}{d\Omega} = \sum_{i=0,2,\ldots}^{2J_{\max}} C_i P_i(\cos\theta).$$

We obtain $\Delta\sigma_L$(elastic) from the coefficient C_0, and then, by using $\Delta\sigma_L^{\mathrm{tot}}$ data,[1] we have

$$\Delta\sigma_L^{\mathrm{in}} = \Delta\sigma_L^{\mathrm{tot}} - \Delta\sigma_L(\mathrm{el}).$$

The values of $C_{LL}(\theta_{\mathrm{c.m.}} = 0°)$ obtained from for-

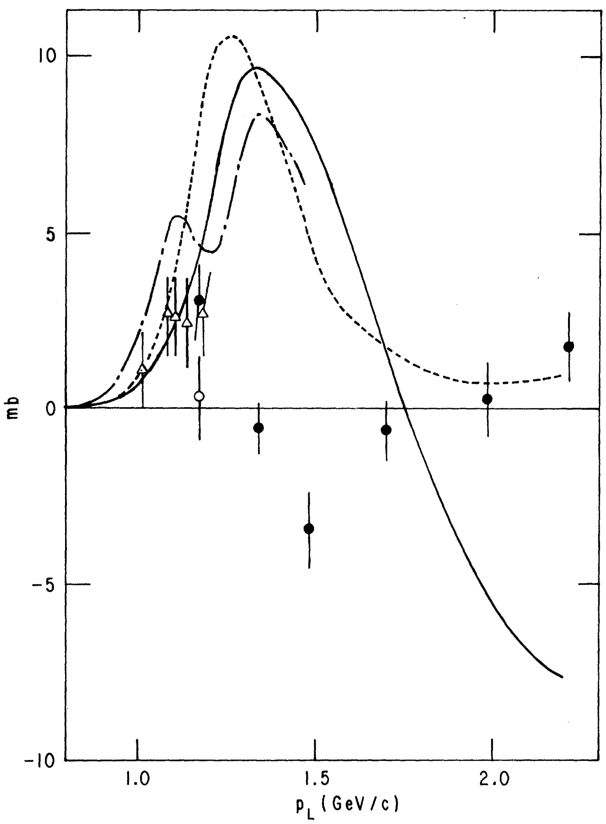

FIG. 2. $\Delta\sigma_L^{\mathrm{in}}$ vs incident proton momentum p_L. Closed circles: Our results for $\Delta\sigma_L^{\mathrm{in}}$; open circles: $\Delta\sigma_L^{\mathrm{in}} - \Delta\sigma_L$ ($pp \to \pi d$) at 1.18 GeV/c (Ref. 14); and triangles: $\Delta\sigma_L^{\mathrm{in}} - \Delta\sigma_L$ ($pp \to \pi d$) (Ref. 20). The solid, dashed, and dash-dotted lines are predictions of the integrated cross section $\Delta\sigma_L$ ($pp \to NN\pi$) from Refs. 15–17, respectively.

ward dispersion relations are compiled in Table I. We want to stress that the proton-proton forward amplitudes and therefore $C_{LL}(\theta_{\mathrm{c.m.}}=0°)$ are well determined from dispersion theory using precise measurements of σ_{tot}, $\Delta\sigma_L$, and $\Delta\sigma_T$ performed by various groups. The forward value of C_{LL} agrees well with the trend of the experimental data.

With the exception of the lower-energy region at 1.18 and 1.35 GeV/c, where the deuteron channel contributions are $\Delta\sigma_L(pp \to \pi^+ d) = 2.85 \pm 0.06$ mb[15] and about 1 mb, respectively, $\Delta\sigma_L^{\mathrm{in}}$ essentially equals $\Delta\sigma_L(pp \to NN\pi)$. This identification allows us to compare our results to various theoretical[16-19] predictions for the continuum channel (see Fig. 2). We also show the results of the Geneva group[20] at lower energies which are corrected for the πd channel.

The models that are based on π exchange fail

TABLE I. Values of C_{LL} at $\theta_{\mathrm{c.m.}}=0°$ by forward dispersion relations.

p_L GeV/c	C_{LL} ($\theta_{\mathrm{c.m.}}=0°$)
1.18	-0.148 ± 0.015
1.35	0.153 ± 0.015
1.49	0.223 ± 0.022
1.71	0.202 ± 0.020
2.00	0.180 ± 0.018
2.23	0.158 ± 0.016

dramatically except at very low energies. It seems that the triplet waves, which essentially contribute negatively to $\Delta\sigma_L^{\mathrm{in}}$, are underestimated whereas the singlet ones are more or less correct. This is supported by the observation that the inelasticity of the $^1D_2$ nucleon-nucleon wave is rather well reproduced by the models, in contrast to the triplet inelasticities.[17-19] We also note that the predicted bump in $\Delta\sigma_L^{\mathrm{in}}$ is similar in position and size to the peaks in the total NN cross sections $\Delta\sigma_T^{\mathrm{tot}}$ and $\Delta\sigma_L^{\mathrm{tot}}$, which are understood as being in the $^1D_2$ wave.

A recent measurement[21] of spin-spin correlation parameters for $pp \to np\pi^+$ at 1.47 GeV/c also seems to be inconsistent with the above-mentioned models. The model of Kloet and Silbar[17] disagrees with the A_{LL} values, and even the sign comes out wrong. On the other hand, the predictions for A_{NN} are fairly close to the data.

Thus, from the above results, we conclude that the standard models do not sufficiently describe the data around 1.5 GeV/c. We attribute that failure to the neglect of dibaryon resonances, in particular, contributions from the $^3F_3$ wave.[22] A simple estimate shows that the $^3F_3$ resonance can account for the discrepancy in $\Delta\sigma_L^{\mathrm{in}}$ shown in Fig. 2. Taking the parameters as obtained from elastic scattering, namely $\Gamma_{\mathrm{el}}/\Gamma_{\mathrm{tot}} = 0.15$, $\Gamma_{\mathrm{tot}} = 0.15$ GeV, and $M_{\mathrm{res}} = 2.25$ GeV, one obtains at resonance, i.e., at $P_{\mathrm{lab}} = 1.47$ GeV/c, a contribution of -11.6 mb to $\Delta\sigma_L^{\mathrm{in}}$. If we add the resonance and the theoretical prediction[16] incoherently, we have just the right magnitude to explain the difference.

One reason for the importance of the existence of diproton resonances is due to the fact that these resonances are predicted by a six-quark bag model.[23] It has been pointed out by Lomon[24] that medium- and long-range nucleon-nucleon interactions are relatively well understood, but short-range energy dependence due to quark structure effects should be taken into account.

We wish to acknowledge consultations with Dr. H. Kanada and Dr. H. Halpern, and the assistance of K. Byrum, R. Daly, O. Fletcher, W. Haberichter, R. Johnson, T. Kasprzyk, J. Kovach, R. Laverick, D. Primack, and A. Rask. We also express appreciation to the zero-gradient synchrotron operations staff.

[(a)]Present address: Bell Telephone Laboratories, Holmdel, N.J. 07733.

[(b)]Present address: Los Alamos National Laboratory, Los Alamos, N.M. 87544.

[(c)]Present address: University of Pennsylvania, Philadelphia, Pa. 19174.

[(d)]Present address: Saclay Nuclear Center, Saclay, F-91190 Gif-sur-Yvette, France.

[(e)]Present address: IBM Japan, Ltd., Tokyo, Japan.

[1]I. P. Auer *et al.*, Phys. Lett. 67B, 113 (1977), and 70B, 475 (1977), and Phys. Rev. Lett. 41, 354 (1978), and Phys. Rev. D 24, 2008 (1981).

[2]A. Yokosawa, Phys. Rep. 64, 47 (1980), and references therein.

[3]N. Hoshizaki, Prog. Theor. Phys. 61, 129 (1979).

[4]R. A. Arndt *et al.*, Phys. Rev. Lett. 46, 1111 (1981).

[5]Saclay-Geneva phase-shift analyses, private communication with F. Lehar.

[6]B. J. Edwards and G. H. Thomas, Phys. Rev. D 22, 2772 (1980).

[7]B. J. Edwards, Phys. Rev. D 23, 1978 (1981).

[8]For instance, W. M. Kloet and R. R. Silbar, Phys. Rev. Lett. 45, 970 (1980); W. M. Kloet and J. A. Tjon, Nucl. Phys. A392, 271 (1983), and Phys. Rev. C 27, 430 (1983), and references therein.

[9]I. P. Auer *et al.*, Phys. Rev. Lett. 41, 1436 (1978).

[10]R. G. Wagner, in *High Energy Spin Physics—1982*, edited by G. M. Bunce, AIP Conference Proceedings No. 95 (American Institute of Physics, New York, 1983), p. 214.

[11]I. P. Auer *et al.*, Phys. Rev. D 24, 1771 (1981).

[12]H. Spinka *et al.*, to be published.

[13]H. Kanada, private communication.

[14]W. Grein and P. Kroll, Nucl. Phys. A377, 505 (1982); tables of the forward amplitudes are published in P. Kroll, *Phenomenological Analyses of NN Scattering*, Physics Data Vol. 22-1 (Fachinformationszentrum, Karlsruhe, 1981).

[15]E. Aprile *et al.*, Ph.D. thesis, University of Geneva, 1983 (unpublished).

[16]A. König and P. Kroll, Nucl. Phys. A356, 345 (1981).

[17]W. M. Kloet and R. R. Silbar, Nucl. Phys. A364, 346 (1981).

[18]A. S. Rinat and R. S. Bhalerao, Weizmann Institute Report No. WIS-82/55 Nov.-Ph., 1982 (to be published).

[19]A. M. Green and M. E. Sainio, J. Phys. G 5, 503 (1979).

[20]E. Aprile *et al.*, to be published.

[21]T. S. Bhatia *et al.*, to be published.

[22]For instance, see K. Hidaka *et al.*, Phys. Lett. 70B, 479 (1977), and Ref. 2.

[23]A. Th. M. Aerts *et al.*, Phys. Rev. D 17, 260 (1978), and 21, 2653 (1980), and references therein.

[24]E. L. Lomon, Phys. Rev. D 26, 576 (1982), and references therein.