Structure Observed in the Spin-Spin Correlation Parameter $C_{LL} = (L,L;0,0)$ in p-p Elastic Scattering around $\theta_{\text{c.m.}} = 90°$ in the Region $p_{\text{lab}} = 2.5-5.0$ GeV/c

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The spin-spin correlation parameter $C_{LL} = (L, L; 0, 0)$ has been measured for p-p elastic scattering around $\theta_{\text{c.m.}} = 90°$ up to $p_{\text{lab}} = 5$ GeV/c. An interesting energy dependence is observed in C_{LL} and the results are interpreted by comparison with other available data.

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We have previously reported the energy dependence of the spin-spin parameter $C_{LL} = (L, L; 0, 0)$ up to 3.0 GeV/c.[1] We interpreted the structure revealed in the above energy region in terms of the presence of a $^3F_3$ dibaryon resonance, and this interpretation has been confirmed by several phase-shift analyses.[2-4]

We searched for a possible structure beyond the energy region already investigated by using polarized beams from the Argonne National Laboratory zero-gradient synchrotron, and discuss here an experiment that measured C_{LL} in the incident-momentum range 2.75–5.0 GeV/c. The experiment was similar to that reported previously[1] in that it was performed with a simultaneous measurement of $\Delta\sigma_L(pp)$ and used a nearly identical setup. As before, data were obtained in the center-of-momentum angular range of ~65°–115° in order not to interfere with the $\Delta\sigma_L$ measurement. The experimental setup is shown schematically in Fig. 1. The spin of the vertically polarized beam from the zero-gradient synchrotron was precessed into the longitudinal direction by a combination of a solenoid and horizontally bending dipole located just upstream of the setup shown in Fig. 1. Beam particles traversing the entire length of the polarized target were selected in fast logic with use of scintillation counters. The beam intensity at the target was maintained near 10^5 protons/pulse. The beam polarization was monitored continuously during running by a liquid-hydrogen polarimeter located near the beginning of our beam line.[5] The target was composed of $K_2Cr_2O_7$-doped ethylene glycol and contained $(9.2 \pm 0.1)\%$ hydrogen by weight. Polarization was produced dynamically by microwave pumping and an NMR system monitored the polarization continuously during running. The direction of polarization was reversed every few hours to minimize systematic errors. Throughout the experiment the target polarization averaged near 85%.

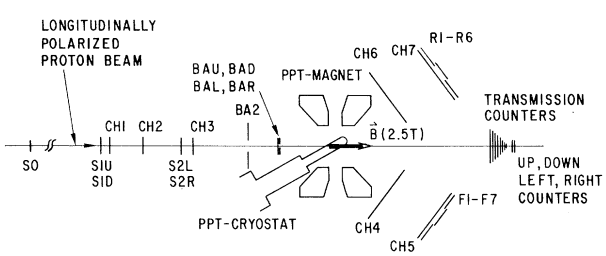

FIG. 1. Experimental setup. Scintillation counters: S0, S1U, S1D, S2L, S2R, BA2, BAU, BAD, BAL, BAR, R1–R6, F1–F7; multiwire proportional chambers: CH1–CH7.

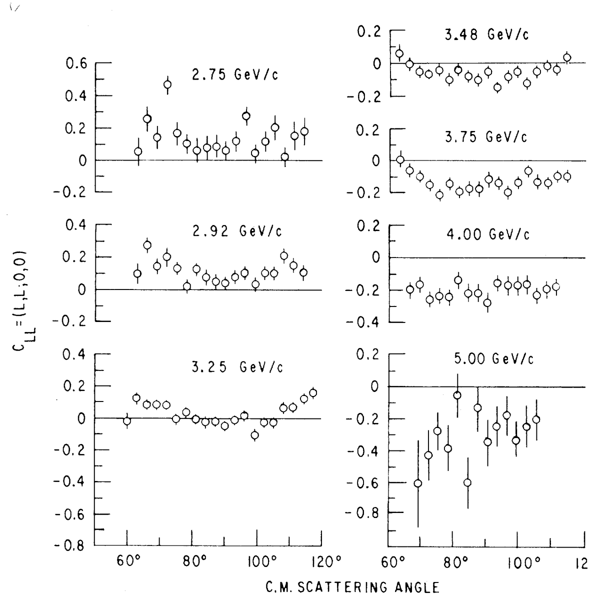

FIG. 2. $C_{LL} = (L, L; 0, 0)$ data from 2.75 to 5.00 GeV/c. The errors shown in the figure are due to counting statistics only. Systematic errors are estimated to be less than 5% of C_{LL} value.

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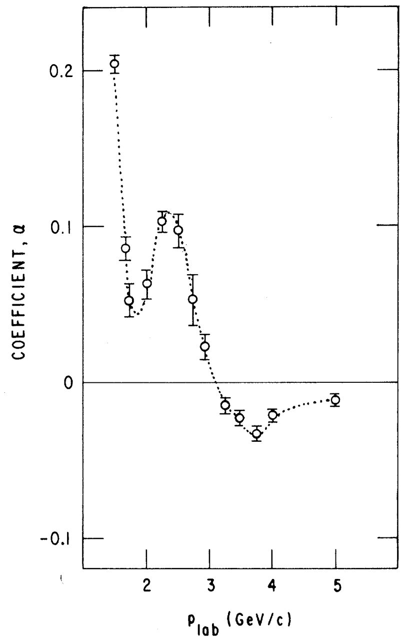

FIG. 3. $\alpha = k^2 C_{LL}\, d\sigma/d\Omega$ at $\theta_{\text{c.m.}} = 90°$ from the fit.

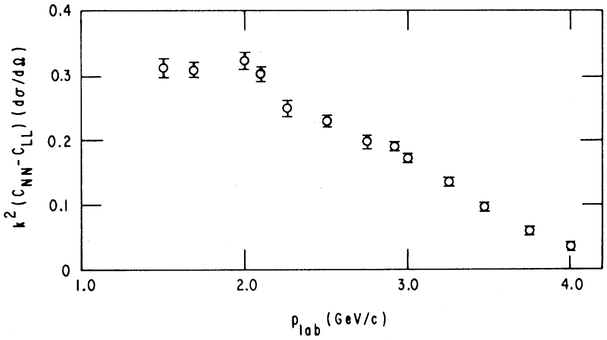

FIG. 4. $k^2(C_{NN} - C_{LL})\, d\sigma/d\Omega$ at $\theta_{\text{c.m.}} = 90°$.

The forward- and recoil-proton directions were measured by wire chambers CH4–CH7 and extrapolated through the field of the target magnet to give angles at the event vertex. Scintillation counters F1–F7 and R1–R6 were used in the trigger to demand a track in both arms. Elastic events were selected by using the polar-angle correlation from elastic kinematics together with a coplanarity cut.

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

$$\sigma^{\pm\pm}(\theta_{\text{c.m.}}) = \sigma_0(\theta_{\text{c.m.}})[1 + (\pm P_B)(\pm P_T) C_{LL}(\theta_{\text{c.m.}})], \qquad (1)$$

where P_B and P_T are the beam and target polarization, respectively, and + (−) refers to the spin state parallel (antiparallel) to the L direction of the beam; $\sigma_0(\theta_{\text{c.m.}})$ is the spin-averaged differential cross section. The parameter $C_{LL}(\theta_{\text{c.m.}})$ is then found to be

$$C_{LL}(\theta_{\text{c.m.}}) = \frac{1}{P_B P_T}\frac{(\sigma^{++} + \sigma^{--}) - (\sigma^{+-} + \sigma^{-+})}{(\sigma^{++} + \sigma^{--}) + (\sigma^{+-} + \sigma^{-+})}. \qquad (2)$$

Figure 2 shows the angular dependence observed for the parameter C_{LL} from 2.75 to 5.00 GeV/c incident-beam momenta. The errors shown are purely statistical and dominate over systematic errors (~8%). The values of C_{LL} are positive over the lower momentum range, but are negative at the higher momentum range.

We pay special attention to the data at $\theta_{\text{c.m.}} = 90°$ because (i) the number of scattering amplitudes involved is much smaller than at other angles since we have only three s-channel helicity amplitudes[6]: φ_1, φ_2, $\varphi_3 \equiv -\varphi_4$, and $\varphi_5 = 0$, and (ii) one can obtain lower statistical errors at $\theta_{\text{c.m.}} = 90°$ by using surrounding data and fitting these data with an expression given below.

Figure 3 shows the behavior of α, which is $k^2 C_{LL}\, d\sigma/d\Omega$ at $\theta_{\text{c.m.}} = 90°$, obtained from a fit by $k^2 C_{LL}\, d\sigma/d\Omega = \alpha + \beta \cos^2\theta_{\text{c.m.}}$ plotted versus the incident momenta.[7] This quantity is dimensionless and allows us to study the contributions of partial waves more directly. We observe two dips at $p_{\text{lab}} = 2.0$ and 3.75 GeV/c, and a rapid decrease around 2.75 GeV/c following a peak at 2.5 GeV/c.

We now attempt to interpret these structures by assuming them to be resonances in terms of the quantum numbers. We note that

$$k^2 C_{LL}\, d\sigma/d\Omega \approx -|\text{spin-singlet terms}|^2 - |\text{coupled triplet}|^2 + |\text{uncoupled and coupled triplet}|^2.$$

We observe no structure in the behavior of $k^2(C_{NN} - C_{LL})\, d\sigma/d\Omega$, which contains only coupled triplet terms, in the region of the incident momentum of 3.0–4.0 GeV/c as shown in Fig. 4 (parameter C_{NN} data are from Ref. 8). Therefore, the second dip seems to be due to a spin-singlet term; in a similar way, the first dip is attributed to a spin-singlet term, namely, ${}^1G_4$.[1,9] The contribution of spin-singlet partial waves to $k^2 C_{LL}\, d\sigma/d\Omega$ is written as follows:

$$k^2 C_{LL}(d\sigma/d\Omega)_{\text{spin-singlet}} = -|{}^1S_0 + 5P_2(\cos\theta)\,{}^1D_2 + 9P_4(\cos\theta)\,{}^1G_4 + 13P_6(\cos\theta)\,{}^1I_6 + \dots|^2, \qquad (3)$$

TABLE I. Resonance candidates.

	Mass (MeV)	Quantum state
Singlet		
$B_1^2(2.14)$	2.14–2.17	$^1D_2$
$B_1^2(2.43)$	2.43–2.50	$^1G_4$ [a]
$B_1^2(2.90)$	2.90 ± 0.10	$^1I_6$
Uncoupled triplet		
$B_1^2(2.22)$	2.20–2.25	$^3F_3$
$B_1^2(2.43)$	~2.43	Triplet $R_{J,J}$ [b]
$B_1^2(2.70)$	2.70 ± 0.10	Triplet $R_{J,J}$

[a]Ref. 1. [b]Ref. 12.

where $P_n(\cos\theta)$ is the Legendre polynomial of degree n. It is possible to attribute the second dip (mass $\approx 2900 \pm 100$ MeV) to a $^1I_6$ state because the dip around $\theta_{\rm c.m.} = 90°$ disappears at $\theta_{\rm c.m.} \approx 75°$, where $P_6(\cos\theta) = 0$.

The rapid energy dependence around 2.75 GeV/c as shown in Fig. 3 coincides with a similar behavior observed earlier in C_{NN} data,[8,10] and also coincides with a hint of a bump around 2.75 GeV/c in $\Delta\sigma_L$ preliminary data.[11] The structure also occurs in $k^2(1 + C_{LL})\,d\sigma/d\Omega$ versus the incident momenta, which contains only the triplet waves, but is absent on the curve of $k^2(C_{NN} - C_{LL})\,d\sigma/d\Omega$ versus the incident momenta, which contains only the coupled triplet. If the above structure is due to a resonance, the mass would be $\sim 2700 \pm 100$ MeV and due to an $R_{J,J}$ state.

In Table I we summarize the resonance candidates.

Finally, we note that the structure at a mass of the proposed 2.90-GeV singlet resonance coincides with a peak observed earlier in the forward differential cross section in the reaction $pp \to d\pi^+$ when plotted against incident proton momentum.[13]

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