but not protons) are shown. Comparison with the prediction for "standard jets" by Field and Feynman[10] again shows rather good agreement. In the region $z > 0.3$, the fastest and second-fastest charged hadrons carry $(21 \pm 1)\%$ and $(1.7 \pm 0.2)\%$ of the total momentum.

In summary, our investigation of electroproduced final states has shown good agreement with the quark-parton model. Comparison with other deep-inelastic processes suggests a common mechanism for hadron production. In addition, we find our data in agreement with the "standard jet" parametrization of Field and Feynman.

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Energy Dependence of the Spin-Spin Correlation Parameter $C_{LL} = (L,L;0,0)$ in p-p Elastic Scattering around $\theta_{\text{c.m.}}=90°$

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We have measured the spin-spin correlation parameter $C_{LL} = (L,L;0,0)$ in p-p elastic scattering around $\theta_{\text{c.m.}} = 90°$ from $p_{\text{lab}} = 1.0$ to 3.0 GeV/c. We observe a rapid energy dependence in C_{LL} and describe our interpretation of the results.

We have previously reported measurements of the total-cross-section difference, $\Delta\sigma_L$, for proton-proton scattering using a beam and a target that were both longitudinally polarized.[1,2] A striking energy dependence observed in $\Delta\sigma_L$ was interpreted as evidence for the formation of diproton resonances.[3] During the course of these measurements, we simultaneously measured the spin-spin correlation parameter $C_{LL} = (L,L;\ 0,0)$ in p-p elastic scattering for $70° \leq \theta_{\text{c.m.}} \leq 110°$ at $p_{\text{lab}} = 1.0$–3.0 GeV/c.[4] The experimental layout is shown in Fig. 1. Besides the longitudinally polarized beam and target described in earlier references, the apparatus consisted of a set of triggering scintillation counters, and an array of multiwire proportional chambers which were used to reconstruct the incident- and outgoing-proton trajectories. The detectors were positioned so that they would not interfere with $\Delta\sigma_L$ measurements, thus covering $\theta_{\text{c.m.}}$ near 90°.

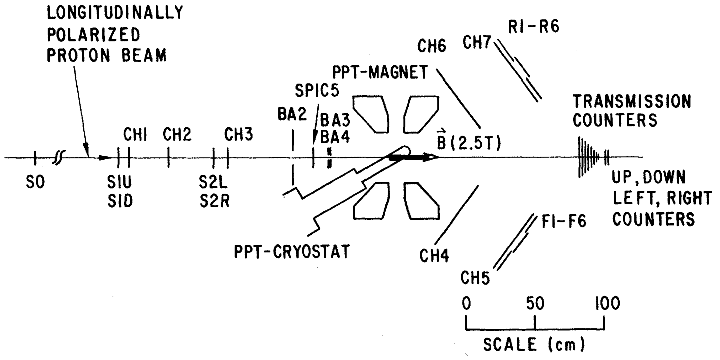

FIG. 1. Experimental setup for the $C_{LL}=(L, L; 0, 0)$ measurement. $S0$, $S1U$, $S1D$, $S2L$, $S2R$, $BA2$, $BA3$, $BA4$, $R1$–$R6$, and $F1$–$F6$ are scintillation counters. $CH1$ to $CH7$ are multiwire proportional chambers.

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

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

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 (beam direction); $I_0(\theta_{\text{c.m.}})$ is the spin-averaged differential cross section. The parameter

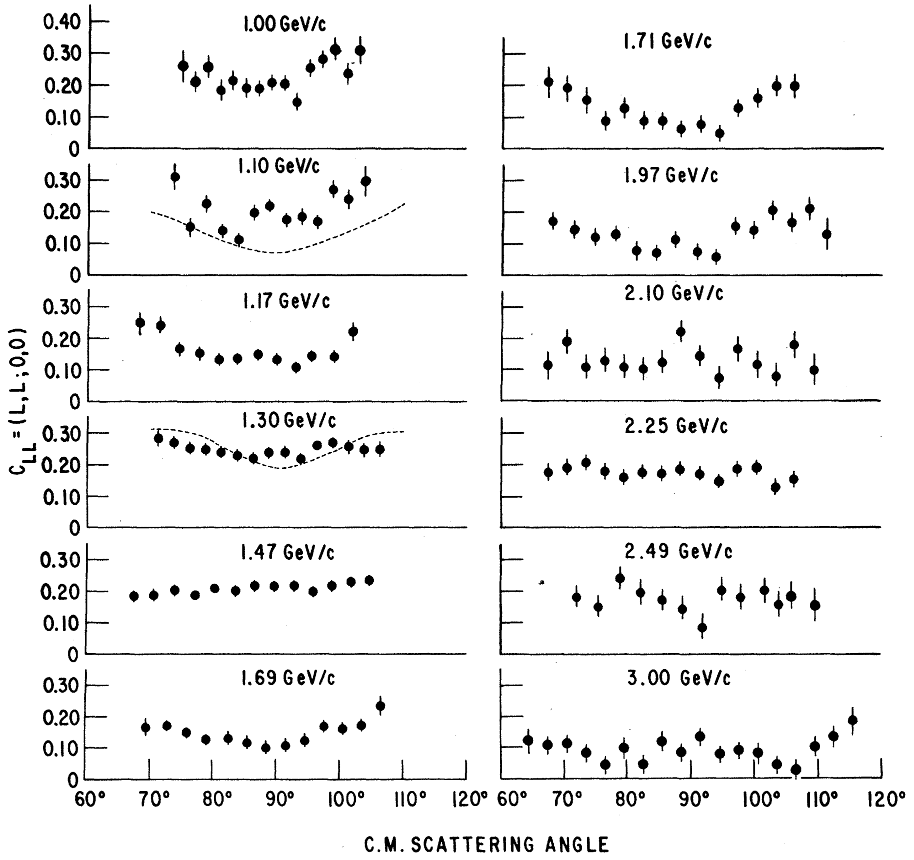

FIG. 2. $C_{LL}=(L, L;\ 0, 0)$ data from 1.0 to 3.0 GeV/c. The dashed curves are predictions from a phase-shift analysis by Hoshizaki (Ref. 5).

$C_{LL}(\theta_{\text{c.m.}})$ is then found to be

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

Figure 2 shows the angular dependence observed for the parameter C_{LL} at various incident-beam momenta. The errors shown are purely statistical, which dominate over systematic errors. The values of C_{LL} are all positive over the range covered, and are consistent with a symmetry about $\theta_{\text{c.m.}}=90°$ as expected for scattering of identical particles. Figure 2 also shows predicted curves from existing phase-shift solutions[5] for $p_{\text{lab}}=1.1$ and 1.3 GeV/c.

The values of C_{LL} at $\theta_{\text{c.m.}}=90°$ plotted versus the incident beam momentum are shown in Fig. 3. We observe a very interesting energy dependence. A way to study this structure is to define C_{LL} in terms of partial-wave amplitudes. In terms of s-channel helicity amplitudes, $\varphi_1=\langle ++|\varphi|++\rangle$, $\varphi_2=\langle --|\varphi|++\rangle$, $\varphi_3=\langle +-|\varphi|+-\rangle$, $\varphi_4=\langle +-|\varphi|-+\rangle$, and $\varphi_5=\langle ++|\varphi|+-\rangle$, we have

$$C_{LL}\,d\sigma/d\Omega=\tfrac{1}{2}[-|\varphi_1|^2-|\varphi_2|^2+|\varphi_3|^2+|\varphi_4|^2], \qquad (3)$$

where $d\sigma/d\Omega=\frac{1}{2}[|\varphi_1|^2+|\varphi_2|^2+|\varphi_3|^2+|\varphi_4|^2+4|\varphi_5|^2]$ is the spin-averaged differential cross section.

When the amplitudes φ_1 through φ_5 are expanded in terms of partial-wave amplitudes, the spin-singlet partial waves, ${}^1S_0, {}^1D_2, {}^1G_4, \ldots$, appear in φ_1 and φ_2 with opposite signs, and the spin-triplet partial waves with $L=J=$ odd, i.e., ${}^3P_1, {}^3F_3, \ldots$, appear in φ_3 and φ_4 with opposite signs.

Figure 4(a) shows the quantity $k^2C_{LL}\,d\sigma/d\Omega$ at $\theta_{\text{c.m.}}=90°$ plotted with respect to the incident beam momentum, where k is the c.m. momentum.[6] This quantity is dimensionless and permits a study of the contributions of partial waves more directly. We observe a sharp dip at $p_{\text{lab}}=1.2$ GeV/c, a rapid decrease around 1.5 GeV/c and additional structure near $p_{\text{lab}}=2.0$ GeV/c.

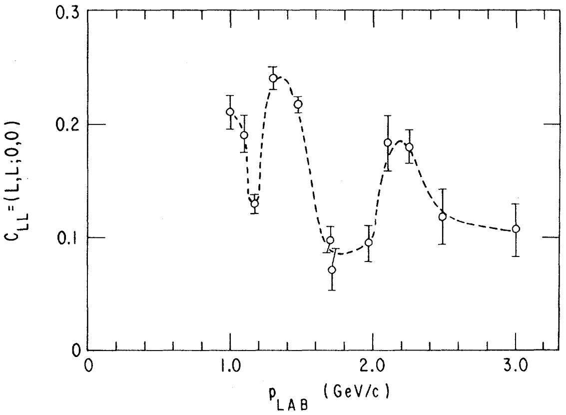

FIG. 3. C_{LL} at $\theta_{\text{c.m.}}\approx 90°$ vs p_{lab}. (Weighted averages of data at angles adjacent to 90°.) The dashed curve is only to guide the eye.

First, we examine whether the rapid decrease

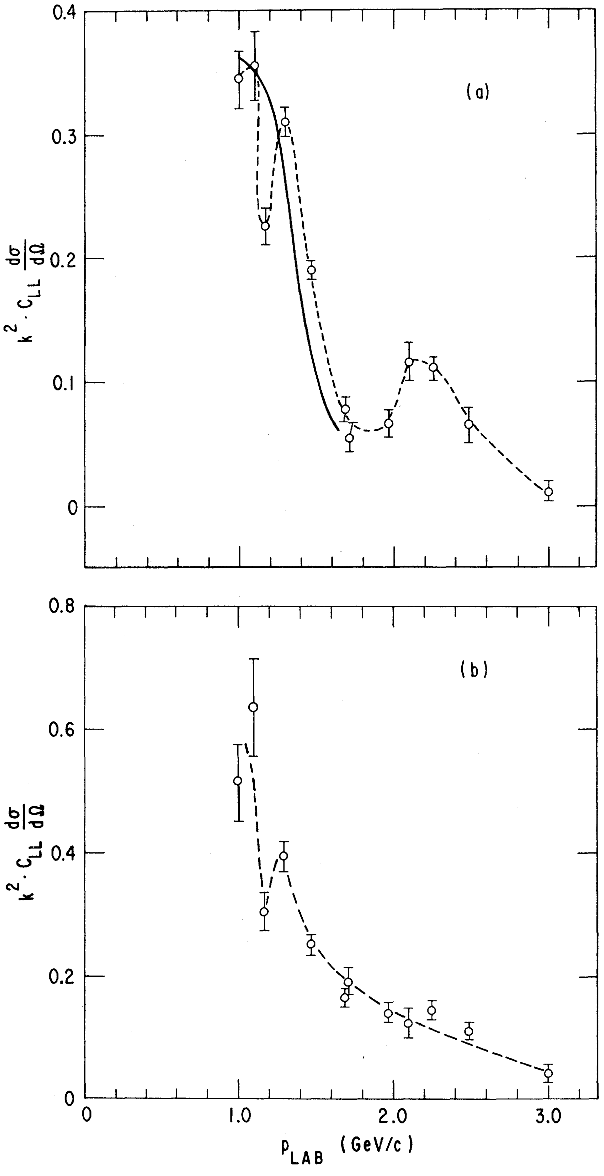

FIG. 4. (a) $k^2C_{LL}\,d\sigma/d\Omega$ at $\theta_{\text{c.m.}}\approx 90°$ vs p_{lab}. The dashed curve is only to guide the eye. The solid curve is the contribution of the ${}^3F_3$ resonance over a smooth background. (b) $k^2C_{LL}\,d\sigma/d\Omega$ at $\theta_{\text{c.m.}}\approx 74°$ vs p_{lab}. The dashed curve is only to guide the eye.

in Figs. 3 and 4(a) near $p_{\text{lab}} = 1.5$ GeV/c is consistent with the partial wave ${}^3F_3$ having a resonant behavior.[3] Equation (3) can be expressed in terms of ${}^3F_3$ and interfering partial waves as

$$[k^2 C_{LL}\, d\sigma/d\Omega]_{90^\circ} = |-\tfrac{7}{8}\,{}^3F_3 + A|^2 + \dots, \tag{4}$$

where A is the sum of other partial waves and the value can be estimated from the results of a phase-shift analysis.[5] By substituting these values and the ${}^3F_3$ resonance at 2260-MeV mass with a 200-MeV width and with an elasticity of 0.2 into Eq. (4), we find the same amount of rapid decrease as shown in Fig. 4(a).

Next, we discuss the structure observed around $p_{\text{lab}} = 2$ GeV/c as shown in Fig. 4(a). Combining these data with $\Delta\sigma_L$ and $\Delta\sigma_T$ (measured with a transversely polarized beam and target) data,[2,7] we speculate that there exists a resonantlike structure due to a spin singlet state. We pursue the argument that this resonantlike behavior is very likely due to the ${}^1G_4$ partial wave by studying the C_{LL} data. The contribution of spin-singlet partial waves to $k^2 C_{LL}\, d\sigma/d\Omega$ is written as follows:

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

where $P_n(\cos\theta)$ is the Legendre polynomial of degree n. The contribution of the ${}^1G_4$ wave should vanish at $\theta_{\text{c.m.}} = 70.1^\circ$ because $P_4(\cos\theta)$ becomes zero, and indeed we see no structure around 2 GeV/c as shown in Fig. 4(b), in which the values of $k^2 C_{LL}\, d\sigma/d\Omega$ are plotted at $\theta_{\text{c.m.}} = 74^\circ$ as a function of p_{lab}. (Data at $\theta_{\text{c.m.}} = 70^\circ$ exhibit similar behavior as in Fig. 4(b); however, there exist fewer data points.)

Finally, we discuss the sharp dip observed at 1.17 GeV/c as shown in Figs. 4(a) and 4(b). We consider this due to a spin-singlet wave, because peaks also appear both in $\Delta\sigma_L$ and $\Delta\sigma_T$.[2,7] In particular, one can argue that they are due to the ${}^1D_2$ wave, because it is the only wave that couples to the S-wave $N\Delta$ state, which is responsible for the rapid increase of the pp total cross section near 1.2 GeV/c. It has been shown[5] that the ${}^1D_2$ state could exhibit resonantlike behavior around this momentum. We also point out that a bump has been observed in the total cross section of $pp \to \pi d$ in the same energy range,[8] which has been interpreted in terms of the final-state interaction between one of the nucleons and a pion, forming $\Delta(1236)$ in the intermediate state.

In conclusion, the measurement of the spin-spin correlation parameter C_{LL} in pp elastic scattering near $\theta_{\text{c.m.}} = 90^\circ$ has revealed rich structure in $p_{\text{lab}} = 1.0$ to 3.0 GeV/c, which is consistent with the presence of ${}^3F_3$, and possibly ${}^1G_4$ and ${}^1D_2$ resonances.

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