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Azimuthal Asymmetry in Inclusive Hadron Production by e^+e^- Annihilation*

R. F. Schwitters, A. M. Boyarski, M. Breidenbach, F. Bulos, G. J. Feldman, G. Hanson, D. L. Hartill, B. Jean-Marie, R. R. Larsen, D. Lüke,† V. Lüth, H. L. Lynch, C. C. Morehouse, J. M. Paterson, M. L. Perl, T. P. Pun, P. Rapidis, B. Richter, W. Tanenbaum, and F. Vannucci‡

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

F. M. Pierre,§ G. S. Abrams, W. Chinowsky, C. E. Friedberg, G. Goldhaber, J. A. Kadyk, A. M. Litke, B. A. Lulu, B. Sadoulet, G. H. Trilling, J. S. Whitaker, F. C. Winkelmann, and J. E. Wiss

Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720

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We have observed an azimuthal asymmetry in inclusive hadron production by e^+e^- annihilation at the center-of-mass energy $\sqrt{s} = 7.4$ GeV. The asymmetry is caused by the polarization of the circulating beams in the storage ring and allows separate determination of the transverse and longitudinal structure functions. We find that transverse production dominates for $x > 0.2$ where x is the scaling variable $2p/\sqrt{s}$.

The transverse beam polarization which is expected to arise in high-energy electron-positron storage rings[1] provides a convenient analyzer for studying the dynamics of electron-positron interactions. At SPEAR, significant beam polarization has been observed[2] at the c.m. energy $\sqrt{s} = 7.4$ GeV through the reaction $e^+e^- \to \mu^+\mu^-$. We report here measurements of inclusive hadron production (obtained simultaneously with these muon-pair data) which also show strong azimuthal-angle dependence, correlated with the initial-state polarization. The hadron azimuthal asymmetry is observed to have the same sign as μ-pair production, viz., hadrons are preferentially produced perpendicular to the polarization direction. This effect is momentum dependent; hadrons of low momenta show little polarization dependence, while the particles of highest momenta have azimuthal asymmetries comparable to muon pairs, which is the largest possible.

The beams are polarized with the electron (positron) spins predominantly aligned antiparallel (parallel) to the guide magnetic field of the storage ring. The dominant state formed by the annihilation of such polarized beams is that of a single, linearly polarized virtual photon. The general angular distribution for any final-state particle produced through annihilation has the following simple form[3]:

$$d\sigma/d\Omega = \sigma_T + \sigma_L + (\sigma_T - \sigma_L)\cos^2\theta + P^2(\sigma_T - \sigma_L)\sin^2\theta\cos 2\varphi. \tag{1}$$

θ is the polar angle of the produced particle measured with respect to the incident positron direction, φ is the azimuthal angle measured from the horizontal plane (the polarization direction is vertical), P is the magnitude of the polarization of each beam, and σ_T and σ_L contain the transverse and longitudinal structure functions which describe the energy and momentum dependence of the production process. Although σ_L and σ_T can, in principle, be determined from the $\cos^2\theta$ terms even in the absence of polarization, the finite polar-angle acceptance of the apparatus (50–130°) severely limits the precision achievable in this manner. The polarization-dependent term in Eq. (1) leads to an azimuthal dependence which can be used to separate the structure functions into transverse and longitudinal components with much greater accuracy even if the polar-angle acceptance of the experiment is limited to angles near 90°.

We have studied the structure functions for inclusive hadron production in data taken with the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory magnetic detector at SPEAR. By use of methods similar to those described by Augustin *et al.*,[4] hadron events were selected which had three or more visible prongs forming a vertex within the luminous region of the beams. Events containing a collinear ($\theta_{\rm coll} < 10°$) pair of particles identified as electrons were eliminated from the event samples; cosmic rays were rejected by time-of-flight criteria. A 6% background subtraction was made to account for beam-gas interactions. This subtraction was normalized to events with vertices outside the luminous region. Events from quantum-electrodynamic reactions $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to e^+e^-$ were recorded simultaneously with hadron data and were selected as by Augustin *et al.*[5] to monitor the luminosity and degree of beam polarization. The integrated luminosity for this data is 2300 nb^{-1}.

The azimuthal distribution for all hadron prongs with $x > 0.3$ ($x = 2p/\sqrt{s}$, p is the particle's momentum and $\sqrt{s}$ is the c.m. energy) and polar angles $53° < \theta < 127°$ is given in Fig. 1(a). A strong $\cos 2\varphi$ term, consistent with Eq. (1), is evident. Figure 1(b) shows the same distribution for events taken at $\sqrt{s} = 6.2$ GeV where the beam energy corresponds to a spin-depolarization resonance and the polarization is consequently expected to be small.[1] In this case, the data are uniformly distributed in φ, consistent with zero polarization. Additional evidence that we are observing polarization effects is obtained from the moments of $\cos(n\varphi)$ which are shown in Fig. 2 for the data of Fig. 1(a). Again, only the constant and $\cos 2\varphi$ moments are significantly different from zero. Possible detector biases would appear in higher moments, but do not seem to be present. The moments of $\sin(n\varphi)$ are consistent with zero.

The ratio of longitudinal to transverse structure functions was determined by a maximum-likelihood fit of Eq. (1) to the hadron data. The time-average value of P^2 used in the fits was determined by the quantum-electrodynamic reaction $e^+e^- \to \mu^+\mu^-$ to be 0.46 ± 0.05.

The ratio of longitudinal to transverse structure functions is presented in Fig. 3(a) for various values of the scaling variable x introduced previously. The errors are statistical only. No corrections for detector acceptance have been applied as they are estimated to be negligible. The quantity $(\sigma_T - \sigma_L)/(\sigma_T + \sigma_L)$ is given in Fig. 3(b). This quantity is the coefficient of $\cos^2\theta$ in the absence of polarization.

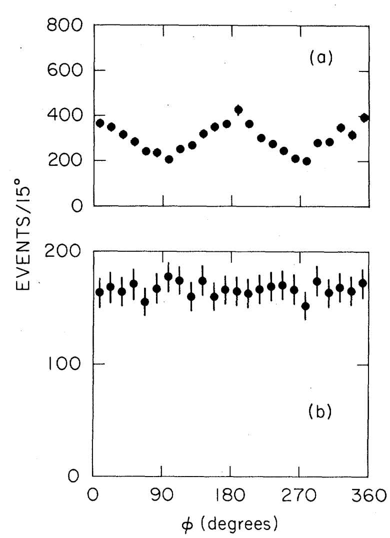

FIG. 1. Observed hadron yield for all particles with $x > 0.3$ per 15° of azimuthal angle (a) at $\sqrt{s} = 7.4$ GeV, and (b) at the spin-depolarization resonance at $\sqrt{s} = 6.2$ GeV. The angle $\varphi = 0$ is in the horizontal plane.

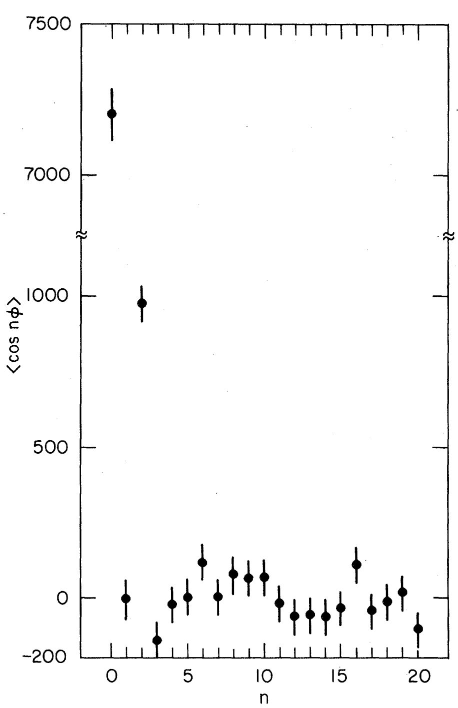

FIG. 2. The coefficients of $\cos(n\varphi)$ versus n in a Fourier expansion of the azimuthal distribution of the data of Fig. 1(a).

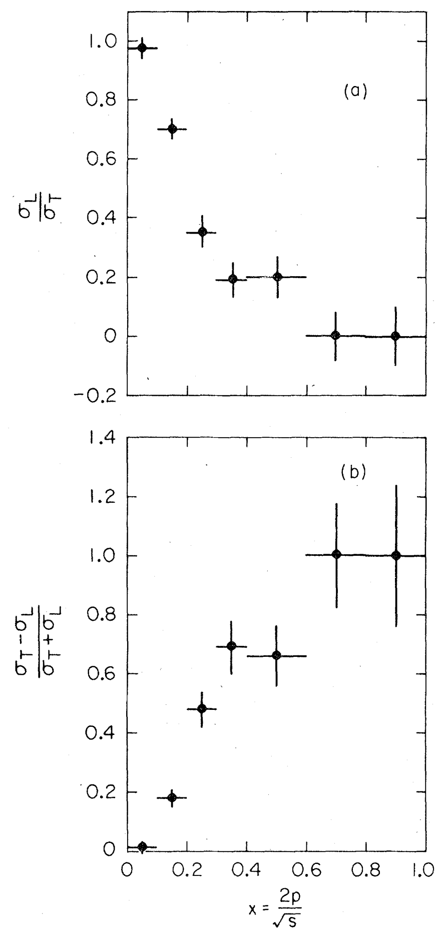

FIG. 3. (a) σ_L/σ_T versus x for the $\sqrt{s}=7.4$-GeV data. (b) $(\sigma_T-\sigma_L)/(\sigma_T+\sigma_L)$ versus x for the 7.4-GeV data.

The data presented in Fig. 3 clearly show the dominance of the transverse structure function as x increases. At low x there is roughly an equal mixture of transverse and longitudinal production while above $x=0.2$ hadrons are produced mainly through a transverse coupling. We expect the majority of hadrons to be pions, and so it is significant that they display the transverse coupling characteristic of the production of pairs of spin-$\frac{1}{2}$ particles. This is what is expected in the simple spin-$\frac{1}{2}$ parton model[6] where hadrons seen in the final state are emitted by the partons. In this model, the larger the x of the hadron, the closer the hadron direction is to the original parton direction, implying a value of σ_L/σ_T which decreases with x. While our results are consistent with the parton picture, this model is by no means required. For example the production of a pseudoscalar meson together with a state of natural spin and parity (excluding 0^+) will, in general, proceed through a transverse coupling.[7]

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†Fellow of Deutsche Forschungsgemeinschaft.

‡Permanent address: Institut de Physique Nucléaire, Orsay, France.

§Permanent address: Centre d'Etudes Nucléaires de Saclay, Gif-sur-Yvette, France.

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