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Longitudinal photon polarization in muon pair production at high x_F

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Muon pair production by pions has been studied in an apparatus optimized for detection at large x_F. Results, based on a small fraction of the data, are reported here for the virtual-photon polarization and the pion structure function. These results confirm our previous work and are consistent with a QCD model involving higher-twist effects at large x_F.

The dominant features of muon pair production in hadronic collisions are described by the Drell-Yan mechanism in which the muon pair is produced through a quark-antiquark annihilation.[1] Departures from this model may offer important clues to constituent interactions beyond the simple quark-parton model and thus provide further insight into the theory of quantum chromodynamics (QCD). Of particular interest is the polarization of the virtual photon that mediates the interaction $q\bar{q} \rightarrow \gamma^* \rightarrow \mu^+\mu^-$. Within the Drell-Yan picture, this photon is expected to be purely transverse, but in an earlier experiment by this collaboration a longitudinal component was observed for muon pairs carrying a large fraction of the available momentum.[2] This result was in agreement with a QCD prediction of higher-twist effects in muon pair production.[3] A similar experiment by Badier *et al.*[4] did not observe the longitudinal polarization.

This paper reports on initial results from a new experiment (Fermilab E-615) specifically designed to study the relevant kinematic region. The results discussed below were obtained from a test run of the new experiment and are reported now because they help clarify the contradictory experimental evidence for the effect.

The experiment was designed to have maximum acceptance at high x_F and to maintain good acceptance to large values of $|\cos\theta^*|$. These requirements correspond to detecting final-state muons close to the incident beam direction.

The notation used here follows that of Ref. 2. The kinematic variables characterizing the muon pair are its mass (M), its Feynman x (x_F), and its transverse momentum relative to the incident beam (p_T). The angles θ^* and ϕ^* describe the direction of the μ^+ in the rest frame of the pair. The momentum fractions of the quarks in the initial-state pion and nucleon are x_π and x_N.

The detector is described in detail in Ref. 5, but a brief summary is appropriate here. Figure 1 shows the apparatus. A π^- beam of 263 GeV was incident on a 1.7-absorption-length tungsten target. Following the target a large selection magnet ($\Delta p_T \sim 2.7$ GeV/c) focused high-mass pairs into the acceptance of a downstream spectrometer and swept away low-momentum secondaries. The aperture of the magnet was filled with 3.2 m of beryllium and 4.1 m of carbon. It was preceded and followed by 0.6 m of beryllium oxide. These 15 absorption lengths of shielding protected the downstream spectrometer from hadronic debris and the noninteracting component of the beam. At a given depth, the absorber was entirely uniform in a plane transverse to the beam.

The downstream magnetic spectrometer ($\Delta p_T \sim 0.80$ GeV/c) was equipped with nine planes of proportional chambers and 12 planes of drift chambers. Six planes of scintillation-counter hodoscopes were used for triggering. The momentum resolution of the system was $\sigma_p/p = 0.016p\%$ (p in GeV/c), the mass resolution was 2.5% at the Υ, and the x_F resolution was $\sim 3\%$ at $x_F \sim 1$.

The data reduction is described in detail elsewhere.[6] Analysis for this study was restricted to the mass region above 4.0 GeV/c^2 which contained a sample of 1322 events after the application of all selection criteria. Because of

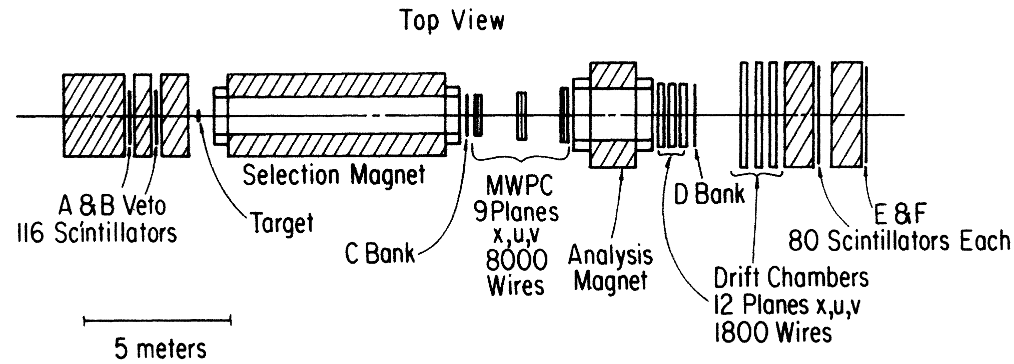

FIG. 1. Plane view of the detector.

the detector acceptance, this data sample is particularly rich in events at high x_F and is roughly equivalent to other recent measurements in the same kinematic region.[4]

The virtual-photon polarization manifests itself in the angular distribution $dN/d(\cos\theta^*)d\phi^*$ of the muon pair. Because of limited statistics and the good acceptance of our detector in $\cos\theta^*$ this work deals only distributions integrated over ϕ^*. In this case a purely transverse photon corresponds to a $1+\cos^2\theta^*$ angular distribution and a longitudinal photon to a $1-\cos^2\theta^*$ distribution. Thus the data will be parametrized by the form $1+\lambda\cos^2\theta^*$.

Figure 2 shows that distributions in $\cos\theta^*$ for four regions of x_π. For consistency with model predictions, the t-channel (Gottfried-Jackson) reference frame is used to define $\cos\theta^*$. The solid curves indicate fits to the form $1+\lambda\cos^2\theta^*$ and the resulting values of λ are given in Table I. The results for the Collins-Soper reference frame[7] are also reported for comparison and are qualitatively similar. The variation of λ with x_π is shown in Fig. 3 and compared to the model prediction of Berger and Brodsky.[3]

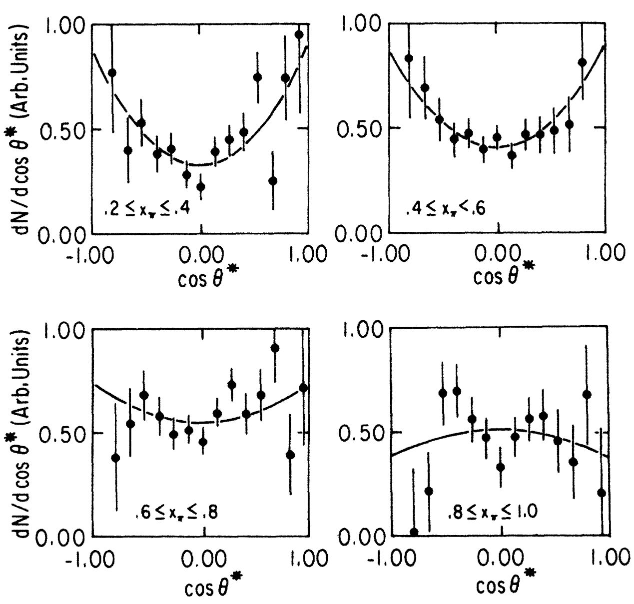

FIG. 2. Plots of $dN/d(\cos\theta^*)$ in four regions of x_π. Here $\cos\theta^*$ is defined in the t channel. Solid curve are fits to the form $A(1+\lambda\cos^2\theta^*)$.

The pion structure function $F(x_\pi)$ has also been determined from these data using the Drell-Yan-model relationship

$$x_\pi^2 x_N^2 d^2\sigma/dx_\pi dx_N \propto F(x_\pi)G(x_N) \ .$$

Here $G(x_N)$ is a nucleon structure function obtained from combining individual quark distributions parametrized by deep-inelastic scattering experiments.[8] If the pion structure function is fit to the form $F(x_\pi)\sim\sqrt{x_\pi}(1-x_\pi)^\beta$ we find $\beta=1.41\pm0.06\pm0.1$ (second error systematic) and $\chi^2=9$ for 13 degrees of freedom. This result is in good agreement with earlier determinations.[9] The data have also been fit to the form $F(x_\pi)\sim x_\pi[(1-x)^2+\gamma]$ as suggested by the Berger-Brodsky model. In this case we obtain $\gamma=0.0085\pm0.002\pm0.003$, and $\chi^2=15$ for 13 degrees of freedom. In the context of the model this value of γ corresponds to $\langle k_T^2\rangle=1.01\pm0.24\pm0.36$ $(\mathrm{GeV}/c)^2$. The systematic uncertainties in β and γ arise largely from uncertainty in the pion beam energy. The data and the latter fit are shown in Fig. 4.

These results serve to confirm our other observations of longitudinal virtual-photon polarization at high x,[2,10] with about the same statistical significance. At this level of precision they are consistent with the Berger-Brodsky

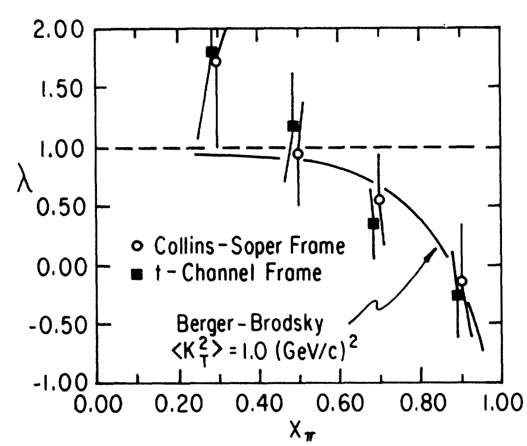

FIG. 3. Plot of λ vs x_π. Solid curve in the prediction from Ref. 3 with $\langle k_T^2\rangle=1.0$ $(\mathrm{GeV}/c)^2$, as was determined from the pion structure function fit, while the dashed line at $\lambda=1$ is the expectation of the Drell-Yan model.

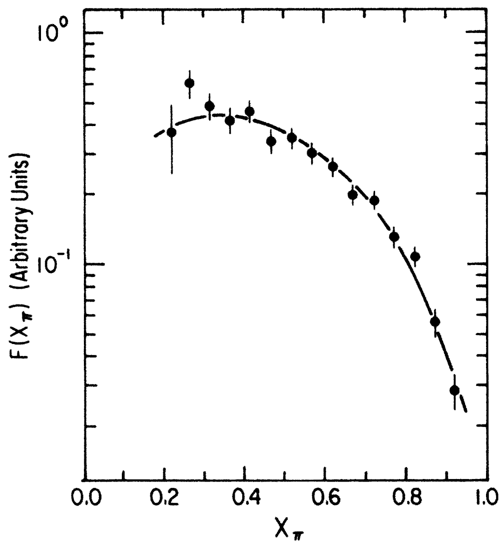

FIG. 4. The pion structure function, together with the fit described in the text.

TABLE I. Fits to $1+\lambda\cos^2\theta^*$ in four regions of x_π.

	Collins-Soper axis		Gottfried-Jackson axis	
x_π	λ	χ^2/DF	λ	χ^2/DF
0.2–0.4	1.72 ± 0.74	1.5	1.79 ± 0.63	1.5
0.4–0.6	0.95 ± 0.44	0.8	1.18 ± 0.46	0.3
0.6–0.8	0.55 ± 0.39	0.7	0.35 ± 0.31	1.2
0.8–1.0	-0.13 ± 0.49	1.0	-0.26 ± 0.37	1.2

model of a higher-twist QCD process.

The need for a more detailed measurement with better precision is clearly apparent. A sample 30 times larger is in hand and under analysis.

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