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The Measurement of Azimuthal Asymmetries In Deep Inelastic Scattering

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Abstract

The distribution of the azimuthal angle for the charged hadrons has been studied in the hadronic centre-of-mass system for neutral current deep inelastic positron-proton scattering at HERA. Measurements of the dependence of the moments of this distribution on the transverse momenta of the charged hadrons are presented. Asymmetries that can be unambiguously attributed to perturbative QCD processes have been observed for the first time.

1 Introduction

Semi-inclusive processes in deep inelastic scattering (DIS) are of importance because they can be used to test the perturbative Quantum Chromodynamic (QCD) description of hadron production via parton fragmentation. An observable of particular interest is the distribution of the azimuthal angle, ϕ, (measured in the hadronic centre-of-mass frame, HCM) between the lepton scattering plane, defined by the incoming and outgoing lepton momenta, and the hadron production plane, defined by the exchanged virtual boson and an outgoing hadron .

Asymmetries in the ϕ distribution, i.e. terms proportional to $\cos\phi$ and $\cos 2\phi$ arise whenever a non-zero transverse momentum, in the HCM frame, is present in the scattering process. Consequently both non-perturbative and perturbative QCD effects [1–4] give rise to these asymmetries. The azimuthal dependence of parton production has the form

$$d\sigma/d\phi = A + B\cos\phi + C\cos 2\phi. \tag{1}$$

This form results from the polarisation of the exchanged virtual boson. The coefficients B and C depend on the helicities of the final-state parton(s), partonic transverse momenta and on colour coherence [3]. The $\cos 2\phi$ term is expected from interference of amplitudes arising from the $+1$ and -1 helicity components of the transversely-polarised part of the exchanged boson, whereas transverse/longitudinal interference gives rise to the $\cos\phi$ term. Terms in $\sin\phi$ and $\sin 2\phi$ are not expected for neutral current reactions.

The asymmetry that results from the intrinsic momentum of a quark in the proton is referred to as the non-perturbative asymmetry. Since the intrinsic momentum is small, this asymmetry should fall rapidly with increasing transverse momentum of the measured hadron and with increasing Q^2 [2], where $Q^2 \equiv -q^2$ is the negative square of the four-momentum of the virtual exchanged boson. In particular, the term C is small at high Q^2. The transverse momenta arising from the fragmentation itself does not contribute to the asymmetry but only smears the observed distribution [3].

In contrast, the asymmetry associated with leading-order terms in perturbative QCD calculations, the perturbative asymmetry, is weakly dependent on Q^2 and persists at high transverse momenta. The perturbative QCD contribution to terms B and C is large at leading order (LO) in α_s. The $\cos 2\phi$ term can be unambiguously attributed to perturbative QCD processes in the high Q^2 region under investigation.

The event kinematics of DIS are determined by Q^2, and one of the two Bjorken scaling variables $x = Q^2/2P{\cdot}q$ or $y = Q^2/xs$, where P is the four-momentum of the incoming proton and $\sqrt{s}$ is the positron-proton centre-of-mass energy. The kinematic region studied is $0.2 < y < 0.8$ and $0.01 < x < 0.1$, corresponding to a Q^2 range $180 < Q^2 < 7220$ GeV^2.

The form of Eq. 1 is expected to be maintained for single particle production [3, 4], since high-momentum hadrons are produced close to the direction of the parton. Note that in order to observe the $\cos\phi$ asymmetry, a selection procedure is required which consistently associates leading hadrons produced from either quarks or gluons [3, 4]. Since the gluon fragmentation function is 'softer' than that of the quarks, the hadron-quark correlation can be enhanced by selecting 'leading' charged particles. This was accomplished by cutting on the Lorentz-invariant variable $z_h(= P\cdot p_h/P\cdot q) > 0.2$, where p_h is the track or particle four-vector.

2 Results

Figure 1 shows the differential ϕ distributions of charged hadrons for four values of their minimum transverse momentum, p_c, in the HCM. The results obtained from the main analysis method [5] (full line) and a bin-by-bin correction method (points) are seen to agree. At low p_c, a clear $\cos\phi$ term is observed. As the value of p_c is increased a $\cos 2\phi$ term becomes evident.

Figure 2 shows the moments $\langle\cos\phi\rangle$ and $\langle\cos 2\phi\rangle$ as a function of p_c. The $\sin\phi$ term is consistent with zero independent of the value chosen for p_c, in agreement with expectation. The value of $\langle\cos\phi\rangle$ is negative and decreases in magnitude as p_c is increased. In contrast, the value of $\langle\cos 2\phi\rangle$ is positive and rises as p_c is increased. Figure 2 also compares the data with two LO QCD calculations. Both calculations were made with Q as the appropriate scale, with the Binnewies et al. LO fragmentation function [6] and with the CTEQ4 LO proton parton densities [7].

The calculation from ZEUS (based on the calculation of Chay et al. [3]) includes an estimation of the non-perturbative contribution, from intrinsic k_T and hadronisation p_T, and integrates over the whole kinematic

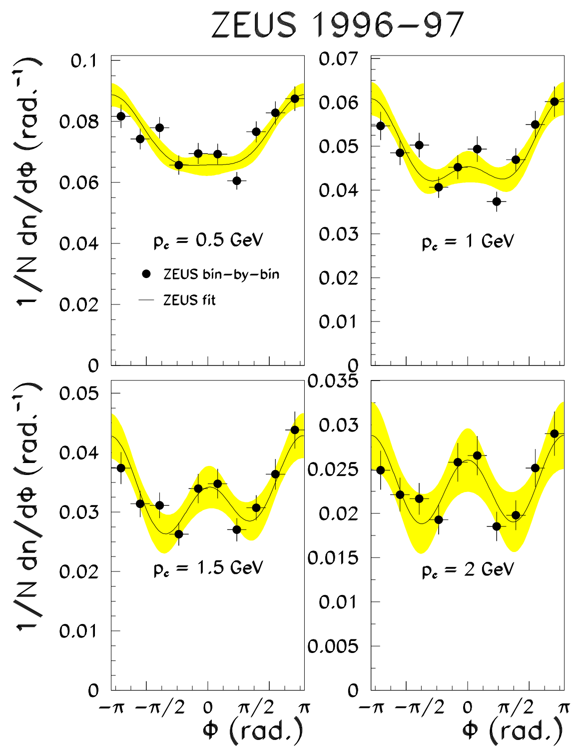

Figure 1: The differential ϕ distributions obtained for four values of the transverse momentum cut, p_c, in the hadronic centre-of-mass frame in the kinematic region $0.01 < x < 0.1$ and $0.2 < y < 0.8$ for charged hadrons with $0.2 < z_h < 1.0$. The full line (with accompanying statistical error band) is the result obtained from the main analysis. The data points were corrected using a bin-by-bin procedure (only statistical errors are shown).

range. The results of Ahmed & Gehrmann are purely at leading order in α_s and are evaluated at the mean values $\langle x \rangle = 0.022$ and $\langle Q^2 \rangle = 750$ GeV^2 of the data. The different implementations account for the observed difference in the two predictions; using $\langle x \rangle$ and $\langle Q^2 \rangle$ in the ZEUS perturbative calculation leads to agreement with the Ahmed & Gehrmann calculation.

3 Conclusions

The azimuthal asymmetries in the deep inelastic electroproduction of single particles have been measured at HERA in the HCM. For hadrons produced at large transverse momenta, the measured value for $\langle \cos\phi \rangle$ is negative and is in agreement with QCD predictions. The moment $\langle \cos 2\phi \rangle$ has been measured here for the first time and is non-zero and positive. It increases as a function of the minimum particle transverse momentum, as expected from QCD. Since the non-perturbative contribution to $\langle \cos 2\phi \rangle$ is predicted to be negligible, this measurement provides clear evidence for a perturbative QCD contribution to the azimuthal asymmetry.

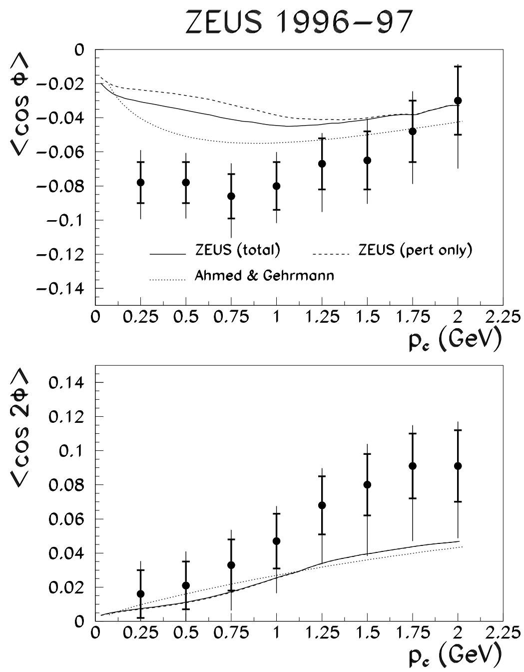

Figure 2: The values of $\langle\cos\phi\rangle$ and $\langle\cos 2\phi\rangle$ are shown as a function of p_c in the kinematic region $0.01 < x < 0.1$ and $0.2 < y < 0.8$ for charged hadrons with $0.2 < z_h < 1.0$. The inner error bars represent the statistical errors, the outer are statistical and systematic errors added in quadrature. The lines are the LO predictions from ZEUS with perturbative and non-perturbative contributions (full line), ZEUS with the perturbative contribution only (dashed line) and Ahmed & Gehrmann (dotted line – see text for discussion). For the case of $\langle\cos 2\phi\rangle$, the ZEUS total and perturbative predictions are almost identical.

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