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Jet correlations at HERA

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Measurements of jet correlations in ep collisions at a center-of-mass energy of $\sqrt{s} = 318$ GeV performed by the ZEUS experiment at HERA are presented. Events with a rapidity gap among the final-state jets in photoproduction are identified and used to study colour-singlet exchange processes. Several Monte Carlo models are considered for comparison with the measurements. In a separate study, jet angular correlation variables sensitive to the underlying gauge structure of the strong interactions are measured in three-jet events in photoproduction and neutral current deep inelastic scattering. The results are compared to leading order theoretical predictions assuming different underlying symmetry groups.

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1. Interjet energy flow in photoproduction at HERA

The dominant mechanism for dijet production in resolved photoproduction at HERA is the hard scattering between two partons from the initial incoming hadrons, interacting via a quark or gluon propagator. The colour connection between the two outgoing jets results in an energy flow that populates the rapidity region between them. An excess over the expected number of events with no energy in this rapidity region, called “rap-gap” events, can signify a colour-singlet exchange contribution, mediated by a pomeron-like object or an electroweak boson. The high transverse energy of the jets in the final state provides a perturbative scale at each end of the colour-singlet exchange, so that the cross section is fully calculable in perturbative QCD [1]. At HERA,

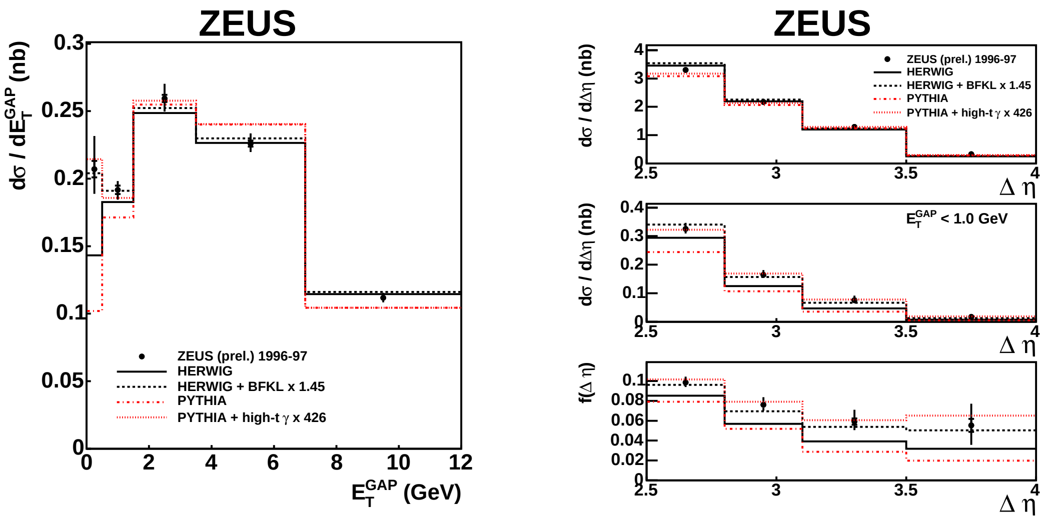

Figure 1: Differential cross section with respect to E_T^{GAP} (left). From top to bottom the total, rap-gap differential cross sections, and the gap fraction (right).

rapidity-gap events have been studied in the past by ZEUS [2] and H1 [3]. In the results presented here, problems relating to the infra-red safety of a gap definition were avoided by defining the gap in terms of E_T^{GAP}, the sum of the transverse energies of all the jets between the two highest E_T jets [1]. The total dijet differential cross section and that of events with $E_T^{GAP} < E_T^{CUT}$, in terms of the rapidity difference between the two highest E_T jets, $\Delta\eta$, were used to study the presence of a colour-singlet exchange contribution. The ratio of these two cross sections is called the gap fraction. If there were only coloured exchanges, the gap fraction would decay exponentially with increasing $\Delta\eta$, whereas if there were only colour-singlet exchanges, then this fraction should be constant for all $\Delta\eta$. Therefore, an excess over an exponential decay in the distribution of the gap fraction can be interpreted as a contribution from colour-singlet exchange processes. The data sample used in this analysis has a luminosity of 38.6 pb^{-1} and used data collected by ZEUS during the 96-97 running period. Several Monte Carlo models were considered for comparison with the data. PYTHIA and HERWIG were used with and without colour-singlet exchange, where the HERWIG model includes pomeron exchange and the PYTHIA model uses a high-t photon. Both PYTHIA and HERWIG were tuned to the E_T^{GAP} distribution of the data and the direct and resolved components were combined by fitting the models to kinematic distributions of the data.

Fig. 1 (left) shows the inclusive dijet differential cross section distribution with respect to E_T^{GAP}. HERWIG and PYTHIA were tuned to agree with the high E_T^{GAP} regions. As can be seen, without the colour-singlet exchange they fail to reproduce the measured values at low E_T^{GAP}, where a colour-singlet exchange contribution would become noticeable. A 3-4 % colour-singlet contribution to the MC models was found to provide good agreement with the data in all E_T^{GAP} regions. Using the scaling factors from Fig. 1 (left), several MC models were considered for comparison with the measured distributions of the inclusive dijet rap-gap cross section, defined as that for events with an $E_T^{GAP} < 1$ Gev, and the gap-fraction. Fig. 1 (right) shows that MC models with colour-singlet exchange describe the data distribution better, especially in the high $\Delta\eta$ region, where the colour-singlet exchange becomes significant. The figure shows that the predicted gap-fraction distribution for MC models without colour-singlet exchange falls off exponentially, whereas if a 3-4% colour-singlet exchange contribution is added, then the excess over the exponential decrease observed in the data is well reproduced.

2. Study of colour dynamics in photoproduction and neutral current deep inelastic scattering at HERA

The essential feature of Quantum Chromodynamics (QCD) is the self-coupling of the gluons due to their colour charges. This feature is a consequence of the assumption made in QCD that the non-Abelian group SU(3) is the underlying symmetry describing the strong interactions. The group structure of the theory is characterized in the perturbative expansion of the cross section through the colour (or Casimir) factors, which are uniquely connected to the underlying symmetry group. At leading order in the perturbative calculations, the cross section for a three-jet final state resulting from initial *ep* scattering can be expressed as a sum of different colour configurations [5]. These are the partonic cross sections from the different types of processes times their respective combination of colour factors:

$$\sigma_{ep\to 3\text{jets}} = C_F^2 \cdot \sigma_A + C_F C_A \cdot \sigma_B + C_F T_F \cdot \sigma_C + T_F C_A \cdot \sigma_D \ . \tag{2.1}$$

In QCD, the Casimir factor giving the coupling strength of the $q \to qg$ vertex is $C_F = 4/3$, that of the triple-gluon vertex is $C_A = 3$, and that of the $q \to q\bar{q}$ vertex is $T_F = 1/2$. For a QED-like Abelian model, such as $U(1) \times U(1) \times U(1)$, the values are $C_F = 1, C_A = 0, T_F = 3$. The contribution from the triple-gluon vertex is zero in this case. Thus, variables which show a sensitivity to contributions from the different colour configurations are sensitive to the underlying symmetry group of the theory. They exhibit a distribution which is characteristic of a given group and their measurement can be used to determine the colour factors governing an interaction, thus providing a stringent test of QCD. In e^+e^- annihilation at LEP, similar studies have been carried out in the past using angular correlations in four-jet events from Z^0 hadronic decays [4]. At HERA, the effects of the different colour configurations arising from the underlying gauge structure manifest themselves in three-jet events in photoproduction and in neutral current DIS [5, 6]. The data used for the studies presented was taken by ZEUS in the 95-00 (for the photoproduction study) and 98-00 (for the DIS study) running periods. Some of the jet angular correlation variables that were devised are:

- α_{23}, defined as the angle between the two lowest transverse energy jets.

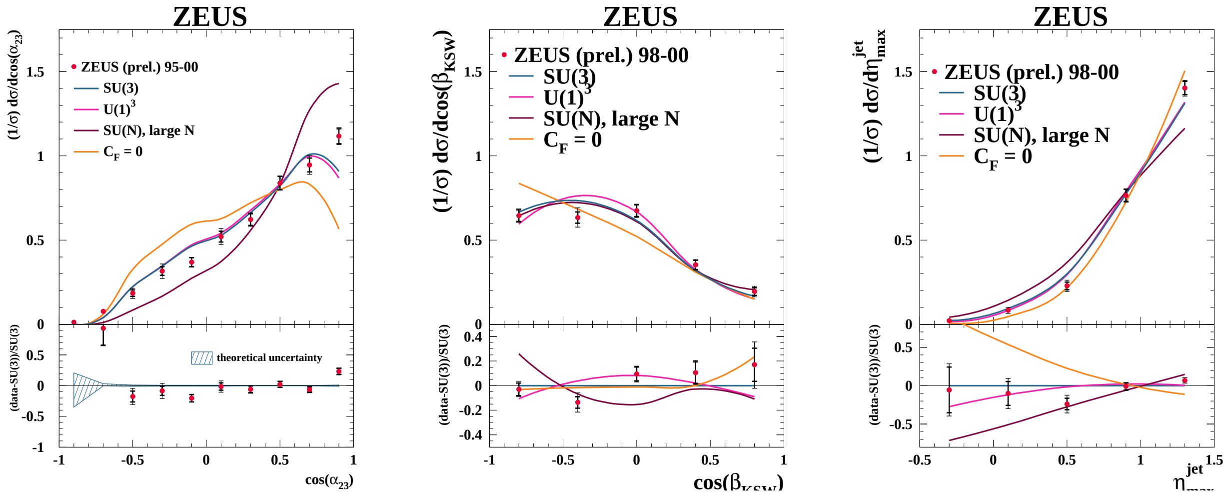

Figure 2: Angular correlation variables used to study group structure at HERA. In the photoproduction regime $\cos(\alpha_{23})$ (left) strongly disfavours SU(N) for large N . In the neutral current DIS regime: $\cos(\beta_{KSW})$ (center) and η^{jet}_{max} (right) distinguish between SU(3) and U(1)×U(1)×U(1).

- β_{KSW}, defined as

$$cos(\beta_{KSW}) = cos\left[\frac{1}{2}(\angle[(\vec{p}_1 \times \vec{p}_3),(\vec{p}_2 \times \vec{p}_B)] + \angle[(\vec{p}_1 \times \vec{p}_B),(\vec{p}_2 \times \vec{p}_3)])\right], \tag{2.2}$$

where $\vec{p}_i, i = 1,...,3$ is the momentum of jet i and $\vec{p}_B$ is a unit vector in the direction of the beam; the jets are ordered according to decreasing transverse energy;

- η^{jet}_{max}, the maximum pseudorapidity of the three jets with highest transverse energy.

Fig. 2 shows the distributions of the normalised differential cross sections for some of these angular correlation variables. The $\cos\alpha_{23}$ data distribution in photoproduction strongly disfavours a SU(N) (for large N) prediction, whereas in the DIS case, $\cos\beta_{KSW}$ shows a 10% difference between the distribution predicted by SU(3) and that of U(1)×U(1)×U(1). The measurements are found to be consistent with the admixture of colour configurations as predicted by SU(3).

References

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