RECENT RESULTS ON MULTIPLICITY FROM ZEUS

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The hadronic final state has been investigated in inclusive neutral current deep inelastic ep scattering with the ZEUS detector at HERA. Multiplicity moments of charged particles were studied in the current region of the Breit frame. The mean charged multiplicity observed for inclusive deep inelastic scattering (DIS) events in the pseudorapidity region $|\eta_{\rm lab}| \le 1.75$ has been measured as a function of the total energy in the current region and as a function of its invariant mass, $M_{\rm eff}$, for both the current and target regions of the Breit frame.

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1 Introduction

The study of hadronization and correlations between final-state particles at HERA is an important testing ground for QCD and may serve as a rich source of information about phenomenological aspects of the hadronization. An example of the importance of the hadronization is demonstrated in Section 2 by comparing the data to the prediction of the Local Parton Hadron Duality (LPHD) hypothesis. Universality of the hadronization is discussed in Section 3, where ep data are compared to e^+e^- and pp results.

2 Measurement of multiplicity moments

The dominant source of particle production inside a jet is gluon splitting in the QCD cascade, where the presence of a gluon enhances the probability for emission of another gluon nearby in momentum space. This leads to inter-parton correlations and non-Poissonian statistics for the multiplicity distributions in restricted phase-space intervals where partons are counted.

In the Double Leading Log Approximation (DLLA), the normalised factorial moments of the multiplicity distributions of gluons which are restricted in transverse momentum $p_t < p_t^{\rm cut}$ are expected to have the following behaviour [1]:

$$F_q(p_t^{\rm cut}) \simeq 1 + \frac{q(q-1)}{6}\,\frac{\ln(p_t^{\rm cut}/Q_0)}{\ln(E/Q_0)}, \tag{1}$$

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where E is the initial energy of the outgoing quark that radiates the gluons. The maximum transverse momentum, $p_t^{\rm cut}$, and the p_t values are defined with respect to the direction of this quark.

Equation (1) indicates that there are positive correlations between partons, because the factorial moments are larger than unity. For small $p_t^{\rm cut}$ values, however, the correlations vanish due to the presence of an angular ordering of the partons in the jet. The existence of the angular ordering leads to the absence of branching processes with secondary gluon emission at small $p_t^{\rm cut}$. This ultimately leads to the suppression of the correlations in this phase-space region and to independent parton emission,[2] $F_q \simeq 1$ for $p_t^{\rm cut} = Q_0$.

The hypothesis of Local Parton-Hadron Duality (LPHD) [3] states that parton-level QCD predictions are applicable for sufficiently inclusive hadronic observables, without additional assumptions about hadronisation processes. Therefore, the hadronic spectra are proportional to those of partons if the cut-off Q_0 is sufficiently small. Allthough the theoretical formula (1) should be considered only as qualitative predictions when compared to the data using the LPHD hypothesis, one would expect that the factorial moments measured at HERA will approach 1 at suffeciently small $p_t^{\rm cut}$.

The multiplicity moments of order $q = 2, \ldots, 5$ as a function of $p_t^{\rm cut}$ are shown in Fig. 1 for the data at $Q^2 > 1000$ GeV^2 where Q^2 is the virtuality of the exchanged boson ($\langle Q^2 \rangle \simeq 2070$ GeV^2). One sees that as $p_t^{\rm cut}$ decreases below 1 GeV, the moments rise in contradiction to the LPHD hypothesis. Using DLLA theoretical calculations, on the other hand, the Monte Carlo models show the same trend as the data, although some differences in slopes are apparent.

To check if this disagreement can be explained by the contribution of the hadronization, the data was compared to a parton-level prediction of ARIADNE which was generated with cut-off Q_0=0.27 GeV^2. The ARIADNE predictions for partons decrease and approach unity for small p_t regions, in quite good agreement with equation 1. Thus this measurement is the first indication that perturbative QCD, in conjunction with the LPHD hypothesis, fails on a qualitative level to describe the hadronic multiplicities, and illustrates that contribution of the hadronization is important.

3 Measurements of mean charged multiplicity

The measurements of multiplicities of charged particles at colliders have yielded insights into hadronization mechanisms. It has been found that charged particle multiplicities measured as a function of the centre-of-mass (cms) energy, $\sqrt{s}$, at e^+e^- [4, 5] colliders are the same as those measured at pp [6, 7] colliders as a function of $\sqrt{q_{\rm tot}^{\rm had}} = \sqrt{[(q_1^{\rm inc} - q_1^{\rm lead}) + (q_2^{\rm inc} - q_2^{\rm lead})]^2}$, where $q_{1,2}^{\rm inc}$ and $q_{1,2}^{\rm lead}$ are the four-momenta of the incoming protons and leading particles that escape down the beampipe, respectively. It is therefore interesting to study charged particle multiplicities in ep collisions. The charged particle multiplicities have been investigated in both the laboratory and the Breit frames. The current region of the Breit frame is analogous to a single hemisphere of e^+e^- annihilation. In $e^+e^- \to q\bar{q}$ the two quarks are produced with equal and opposite momenta, $\pm\sqrt{s_{ee}}/2$. The fragmentation of these quarks can be compared to that of the quark struck from the proton. This quark has an outgoing momentum $-Q/2$ in the Breit frame.Therefore, two times the multiplicity of the current region of the Breit frame is expected

[2]Note that this effect is similar to multiple photon bremsstrahlung in QED.

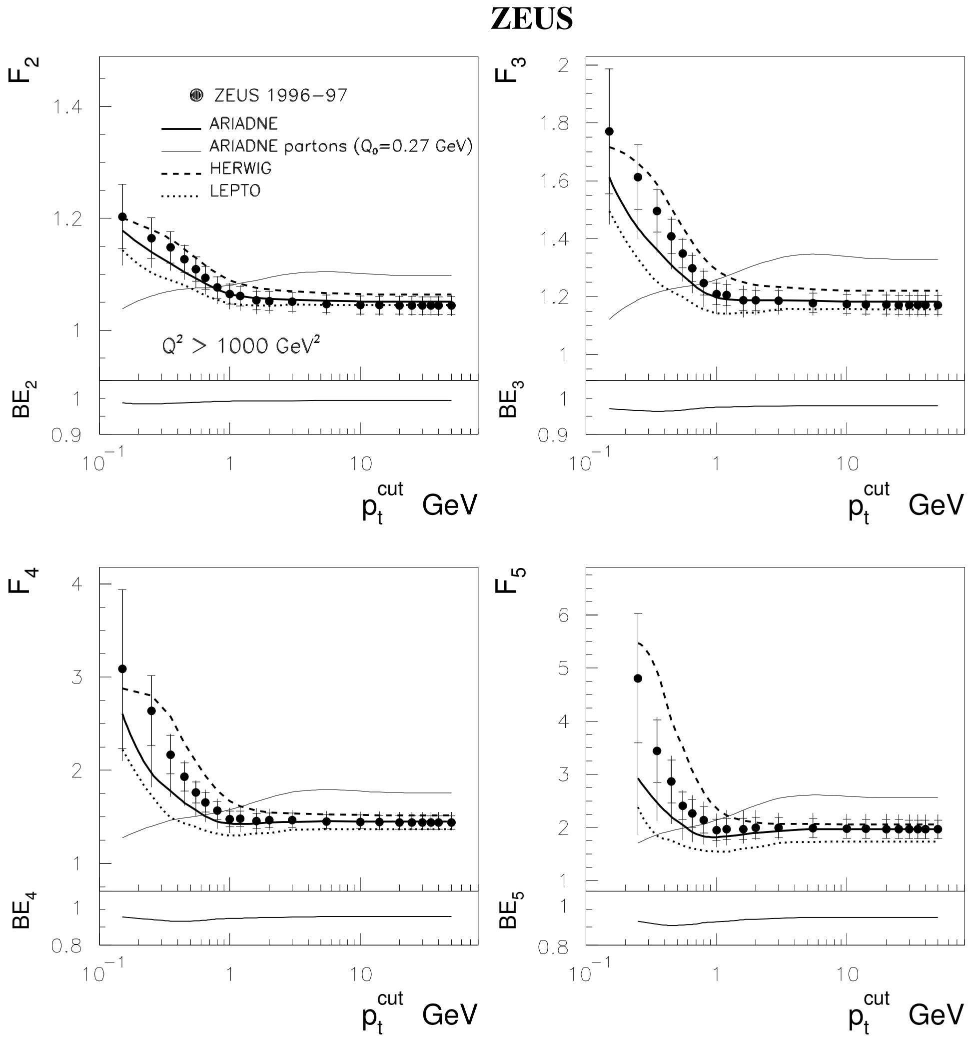

Fig. 1. Factorial moments for charged particles in the current region of the Breit frame as a function of $p_t^{\rm cut}$, compared to Monte Carlo models. The thin lines show the parton-level prediction and the thick solid lines are the hadron-level predictions of the same model. The dashed and dotted lines show the hadron-level predictions of HERWIG and LEPTO, respectively. The inner error bars are statistical uncertainties; the outer are statistical and systematic uncertainties added in quadrature. Shown under each plot are the Bose-Einstein (BE) correction factors for details see [2].

to have a dependence on Q similar to that of the total multiplicity in e^+e^- annihilation versus the energy $\sqrt{s_{ee}} = Q$. To take into account contributions from soft and hard QCD processes that lead to a decrease of the energy and the number of particles in the current region of the Breit

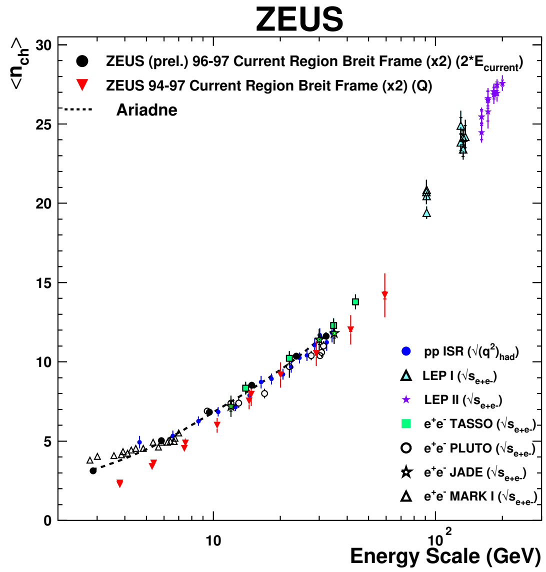

Fig. 2. Mean charged multiplicity, $\langle n_{\rm ch}\rangle$, in the current region of the Breit frame multiplied by 2 plotted versus $2E_{\rm current}$, where $E_{\rm current}$ is the sum of the energies of the particles in the current region (charged hadrons and neutrals). Also shown are the prediction from ARIADNE and other measurements from hadron-hadron, e^+e^-, and ep.

frame, $E_{\rm current}$ was used instead of $Q/2$, where $E_{\rm current}$ is the energy of all the particles in the current region of the Breit frame.

Figure 2 shows twice the measured mean charged multiplicity, $2\langle n_{\rm ch}\rangle$, in the current region of the Breit frame plotted versus $2E_{\rm current}$. Also shown are the prediction of ARIADNE and the measurements from e^+e^- and hadron-hadron (pp) experiments together with a previous ZEUS measurement [8] where $2\langle n_{ch}\rangle$ was measured as a function of Q. Both ZEUS measurements agree with the e^+e^- measurement for values of energy above 10 GeV. At low values of energy, the measurement of the mean charged multiplicity as a function of $2E_{\rm current}$ agrees better with e^+e^-, since the migrations of final state particles out of the current region are properly taken into account in $E_{\rm current}$.

Similarly to $\sqrt{s}$, $2E_{\rm current}$ constitutes not only the energy but also the invariant mass of the system. It is natural to use the invariant mass as a scale for comparison of the mean charged multiplicities in the current and target region of the Breit frame. However, while almost 95% of the hadronic system of the current region is measured in the ZEUS detector, only $\sim 25\%$ is detected in the case of the target region. The measurement here is performed for the visible charged multiplicity as a function of the visible invariant mass $M_{\rm eff}$, which was reconstructed

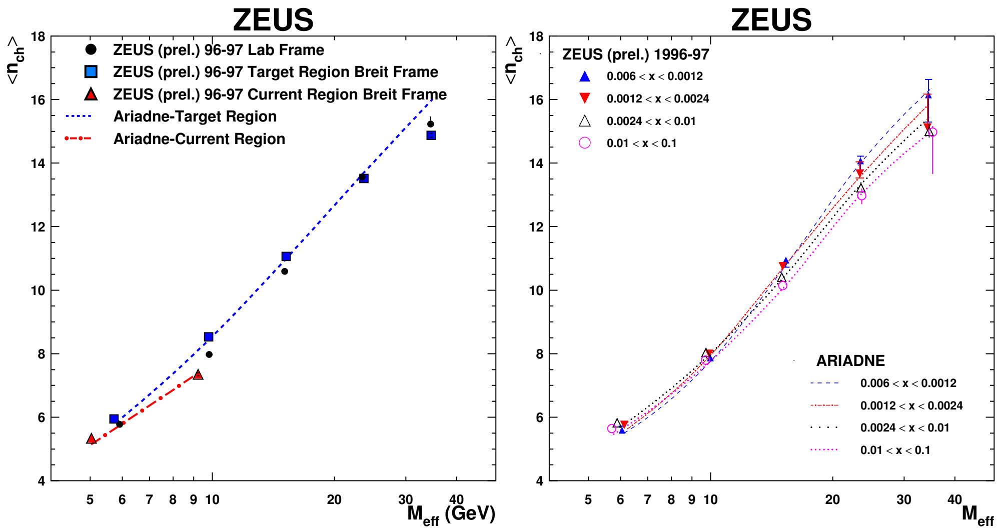

Fig. 3. (Left) $\langle n_{\rm ch} \rangle$ in the current and target regions of the Breit frame versus the $M_{\rm eff}$ of the respective (charged + neutral) particles together with the laboratory frame measurement (combined current+target). The predictions from ARIADNE for both regions of the Breit frame are also shown. (Right) $\langle n_{\rm ch} \rangle$ vs $M_{\rm eff}$ for different x regions together with predictions from ARIADNE.

from the energy and momenta of the hadrons as:

$$M_{\rm eff}^2 = (\sum_i E_i)^2 - (\sum_i P_{X_i})^2 - (\sum_i P_{Y_i})^2 - (\sum_i P_{Z_i})^2 \; , \tag{2}$$

where the sum runs over the calorimeter energy flow objects (EFOs) [9] in a pseudorapidity range $|\eta_{\rm lab}| < 1.75$; or hadrons of the system, in the case of hadron level MC.

Figure 3 (left) shows the measured $\langle n_{\rm ch} \rangle$ for the visible part of the current and target regions of the Breit frame versus $M_{\rm eff}$. The measurement shows approximately the same number of particles produced for the same $M_{\rm eff}$ in the visible part of the current and target regions. Because of the energy restrictions, the highest achievable $M_{\rm eff}$ in the current region is smaller than that for the target region. The predictions for each region of the Breit frame are also shown. ARIADNE describes the measurements for both the current and target regions of the Breit frame.

Since both the number of particles and $M_{\rm eff}$ are Lorentz boost invariant, the study of the total visible multiplicities is continued in the laboratory frame. The laboratory frame measurement (combined current+target) is also shown in Fig. 3 (left) as solid circles. ARIADNE describes the data, while LEPTO and LEPTO SCI which includes soft color interactions are above the data (not shown). Similar behaviour of ARIADNE and LEPTO has been observed in previous measurements [8]. A study of $\langle n_{\rm ch} \rangle$ as a function of $M_{\rm eff}$ in the laboratory frame for different x regions together with predictions from ARIADNEis shown in Figure 3 (right). A weak x dependence is observed both in data and MC. Comparing Fig. 3 with Fig. 2 one can see about 15% difference in the mean charged multiplicity between ep and e^+e^- (and pp) data for the same invariant mass. This observation is currently being investigated.

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