HADRONIC FINAL STATES IN DEEP INELASTIC SCATTERING (DIS) AND PHOTO PRODUCTION AT HERA

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Deep inelastic data taken with the H1 and ZEUS detector at HERA are presented. The average charged multiplicity is compared to e^+e^-data in the Breit frame of reference. The first measurement of scaling violations of the fragmentation function at HERA is presented. Charged particle multiplicities and the transverse energy flow are compared to hadron-hadron interactions in the hadronic center of mass system. The difference in the W dependence of charged particle density in DIS and photo production data is discussed in terms of the AGK cutting rules. Finally a measurement of the transverse momentum spectra is presented and discussed in comparison to BFKL and DGLAP evolution schemes.

1 Introduction

The operation of the HERA e^+-p collider has vastly extended the kinematical range for studies of the hadronic final state of deep inelastic scattering (DIS). The event kinematics is determined by the four-momentum transfer $Q^2 = -q^2$ and the Bjorken scaling variable $x = Q^2/2P\cdot q$, with P the four momentum of the proton. The analyses presented hereafter are based on data taken in 1994.

2 Charged multiplicities

2.1 Breit frame

In the ep Breit frame the exchanged current is completely space-like. With the positive axis chosen to be the direction of the incoming proton, the negative z direction is referred to as current hemisphere of the interaction. The scaled longitudinal momentum x_p=$2p_{hadron}/Q$ can be directly compared to e^+e^-annihilation [a].

New results from H1 on the average charged multiplicity $< n >$ in the current hemisphere is shown in Figure 1 as a function of Q together with the results of the 1993 analysis from H1 [1] and ZEUS [2]. The solid curve is a parametrization of the average charged multiplicity from many e^+e^-experiments[3] as a function of $E^\star$. There is very good agreement between both HERA experiments and the e^+e^-experiments at high $Q(E^\star)$ which shows the universality of ftagmentation-functions. At low energies however the HERA data lie significantly below the e^+e^-data. The

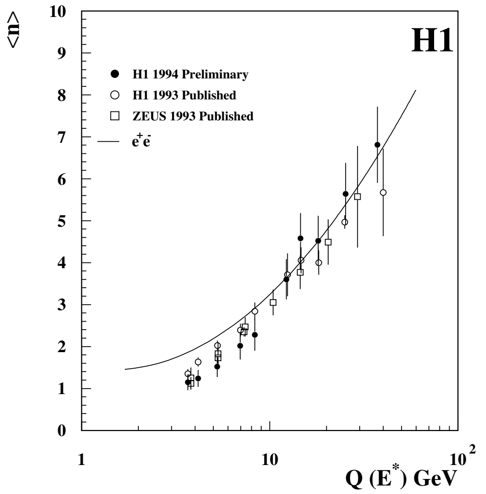

Figure 1: Average charged multiplicity in the current hemisphere of the Breit frame as a function of Q. The H1 measurements are shown in circles and the results from ZEUS 1993 as open squares. The curve is a fit to many e^+e^-results.

difference can be understood by contributions of higher order processes such as initial state gluon radiation and boson gluon fusion which are not present in e^+e^-experiments.

In QCD a scaling violation of the fragmentation function of the outgoing quark is expected since the gluon radiation increases with increasing Q. This leads to a softer particle spectrum and hence a depopulation at large x_p. The scaling violation at large x_p allows a measurement [4] of α_s as it was performed at LEP [5]. Figure 2 shows the first measurement of the scaling violation of the inclusive charged particle cross section at HERA. The Q^2 dependence varies for different x_p bins. Larger statistics at high x_p and high Q^2 is needed for a determination of α_s by such measurements.

[a] In e^+e^-: x_p=$2p_{hadron}/E^\star$ with $E^\star$ center of mass energy

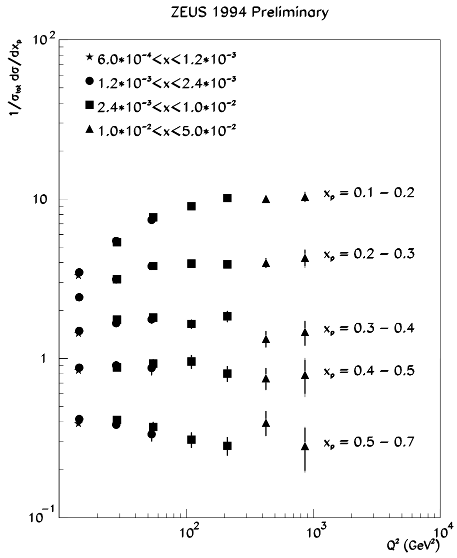

Figure 2: Scaled momentum cross section in the current hemisphere of the Breit frame.

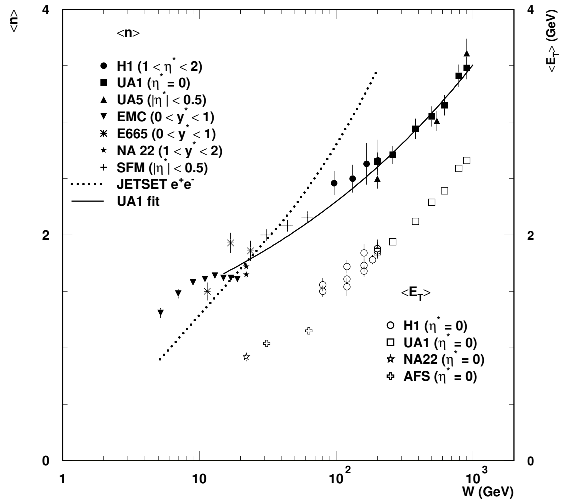

Figure 3: W dependence of mean charged particle density in DIS and hadron-hadron collisions (solid symbols, left scale) and the average transverse energy flow (open symbols, right scale), both per unit of (pseudo)rapidity .

2.2 Hadronic center-of-mass-system

The particle density and the transverse energy flow E_T are studied in the hadronic center-of-mass system (cms) and compared to other lepton-nucleon experiments. Figure 3 shows the mean charged particle multiplicity per unit of (pseudo)rapidity together with low energy DIS data and non single-diffractive hadron-hadron collisions (solid symbols) [6]. The HERA data interpolate nicely with the other DIS and hadron-hadron data and confirms the universality of the fragmentation process. The dotted curve is a prediction for the particle density from the JETSET generator for e^+e^- annihilation. It shows that the hadron density in the central rapidity region evolves much faster with W than in DIS and hadron-hadron data.
The open symbols show the mean transverse energy in the region $-0.5 < \eta^\star < 0.5$ where $\eta^\star$ is the pseudo rapidity in the cms. The comparison between $< n >$ and E_T demonstrates that the evolution with W is very similar. Hence the increase of the average E_T with energy can be rather attributed to an increase of the hadron multiplicity than to a rise of the mean transverse momentum of individual particles.

3 W dependence of charged particle densities in DIS and γ p

The measurements at HERA are particularly interesting in view of exploring the transition region between quasi real photoproduction ($Q^2 \simeq 0$) and deep inelastic scattering ($Q^2 > 0$) events. The virtual photon absorbtion cross section is strongly rising with W [7,8] whereas the total photoproduction cross section has a much weaker energy dependence [9]. In the framework of Reggeon Field Theory (RFT) [10] the CKMT [11] model describes the energy dependence of the virtual photon absorbtion cross section by one-pomeron exchange plus screening corrections which decrease as Q^2 increases and therefore give a stronger energy dependence for hard processes. The relation to charged particle production is made by Abramovskii, Gribov, and Kancheli [12] (AGK cutting rules), which predict a cancelation of the unitarity correction contributions in the inclusive particle cross section ($d\sigma_{ch}/d\eta$) in the central rapidity region at high energies: $\frac{d\sigma_{ch}}{d\eta} = \sigma^1 \cdot \frac{dN^1_{ch}}{d\eta}$, with $\frac{dN^1_{ch}}{d\eta}$ the charged particle density from one-Pomeron exchange and σ^1 the total cross section for one-Pomeron exchange.

Figure 4 shows the measurement of the charged particle density $\rho(0)$ in the central rapidity region as a function of W for DIS data (open points) and photoproduction data (black points) together with low energy DIS [13] and hadron-hadron data [14], where the proton collision data are corrected for the elastic cross section. It is observed that the energy dependence for DIS data is much weaker. This is in agreement with the predictions from the AGK cutting rules since in this picture of a universal pomeron exchange $\rho(0)$ should only depend on σ_{tot}:

$$\rho(0) = \frac{1}{\sigma_{tot}}\frac{d\sigma_{ch}}{d\eta} \underset{\text{AGK}}{=} \frac{1}{\sigma_{tot}}\sigma^1\frac{dN^1_{ch}}{d\eta}.$$

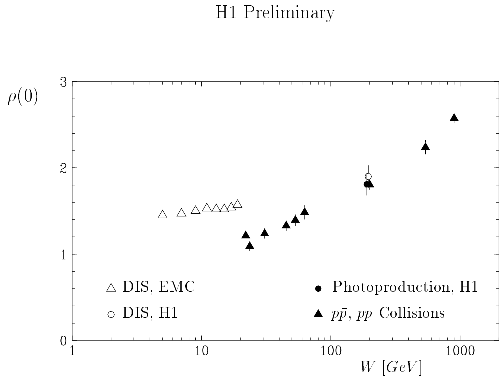

Figure 4: W dependence of charged particle density in the central rapidity region. Open symbols: DIS data, closed symbols: H1 photoproduction and hadron-hadron collisions

4 Transverse momentum spectra

At very low Bjorken x new dynamic features of QCD are expected to show up. Conventional DGLAP evolution equations [15] which sum up over leading $\log(Q^2/Q_0^2)$ are not expected to describe the data in detail [b]. In this region of very low x a better description is expected by the BFKL evolution [16] which sums over leading $\log(1/x)$. The leading log DGLAP resumation results in a strong ordering of the transverse momenta of the gluons in the parton cascade, whereas in the BFKL approximation the transverse momenta follow a random walk. As a consequence of the strong ordering less transverse energy is produced in the DGLAP evolution. Hence measurements of the hadronic final state can help to distinguish between the two approches. Indeed Monte Carlo

[b] Q_0^2 is the cut-off for the perturbative evolution

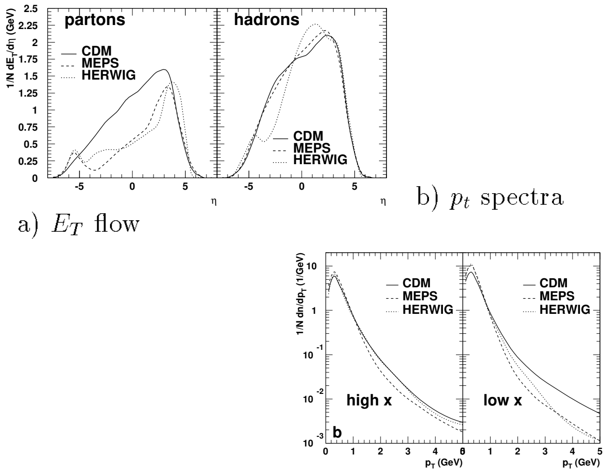

Figure 5: Monte Carlo studies: E_T flow on the parton and hadron level for DGLAP generators (MEPS and HERWIG) in comparison with the colour dipole model (CDM) (left side) as function of the pseudorapidity η in CMS. The right side shows the pt spectra for the three models for different x regions.

studies of the transverse energy flow between the proton remnant and the current jet show that on the parton level DGLAP type monte carlo generators (MEPS [17], HERWIG [18]) produce less transverse energy between the current jet and the proton remnant than the colour dipole model CDM [19] [c](see Figure 5a)). This difference disappears however after hadronization; therefore the measurement of the transverse energy flow does not give a discrimination between the two types of models [20]. The p_t spectra should give a better handle to see whether the observed E_T is dominanted by parton radiation or by hadronization. Hadronization should typically produce a soft p_t spectra whereas the hard tail of the p_t distribution can be interpreted as parton radiation. Figure 5b) in fact shows that at low x where the differences between the models are expected to show up, the colour dipole model predicts a harder p_t spectrum. Figure 6 shows the measured charged particle transverse momentum spectra in the rapidity region $0.5. < \eta < 1.5$ for different bins in x and Q^2 [21]. The measured p_t spectra are compared to LEPTO and HERWIG, the DGLAP type models, and ARIADNE, which has no suppression of

[c] In the colour dipole model as implemented in ARIADNE, gluons are emitted similar to the BFKL ansatz with no ordering of the transverse momenta.

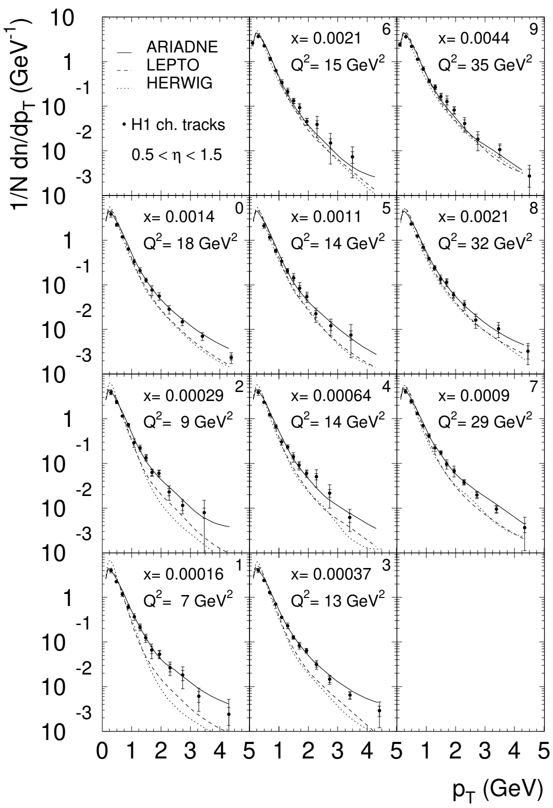

Figure 6: Charged particle transverse momentum spectra for different bins in x and Q^2 ($0.5 < \eta < 1.5$). The curves correspond to different models: ARIADNE(full line), LEPTO (dashed) and HERWIG(dotted)

gluon radiation. At large x and Q^2 all models give a good description of the data. At small x and Q^2 however the DGLAP-type models fall significantly below the data. This indicates that at small x there is more parton radiation present than predicted by the models based on leading log DGLAP parton showers. The data is well described by the colour dipole model ARIADNE.

5 Summary

Measurements of the hadronic final state in DIS at HERA were presented. The charged particle multiplicity in the Breit frame compares well with e^+e^-data at large Q^2, higher order processes lead to a depopulation at low x_p. In the hadronic center of mass system the charged particle multiplicity in the central rapidity region was shown to nicely agree with low energy DIS data and hadron-hadron collisions. This is in agreement with the universality of quark fragmentation. It was shown that the increase of mean E_T with energy mainly stems from an increase of the average charged multiplicity.

The difference of charged particle multiplicity in DIS and photoproduction was discussed in terms of the AGK model and shown to be consistent with the picture of a universal pomeron

The transverse momentum spectrum of charged particles in DIS was measured as function of x and Q^2 and compared to QCD models. At low x the DGLAP type models with suppressed gluon radiation produce a softer p_t spectra than the data. The observed p_t spectra indicate hard parton radiation which can be produced by the colour dipole model.

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