Transverse Energy Flow at High Q^2 in H1

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A new measurement of the transverse energy flow at $Q^2 > 100$ GeV is presented including a comprehensive discussion of systematic effects. None of the standard Monte Carlo models satisfactorily describes the data. The mean transverse energy in the central rapidity region of the photon-proton centre of mass frame does not show the Q^2-independence expected from hadron-hadron collisions. Instead we find a clear increase of the transverse energy as a function of Q^2.

1 Introduction

The transverse energy flow (E_T flow) is a fundamental observable of the hadronic final state. It is sensitive to both perturbative QCD (pQCD) and fragmentation processes and has already proven to be an important discriminant for Monte Carlo models. The large amount of data collected by H1 over recent years now allows an investigation of energy flow over a considerably extended kinematic range, particularly at high Q^2 ($Q^2 > 100$ GeV^2) where a far more detailed measurement is now possible than previously reported [3]. On the other hand, it turns out that the transverse energy flow is more sensitive to systematic effects at high Q^2, compared to the low Q^2 domain. In order to benefit from the advantage in statistics it is therefore necessary to improve our understanding of systematic effects.

The LAr calorimeter is the main part of the H1 detector for this measurement. It covers a range in Θ from $4.4°$ to $150°$ (with respect to the proton direction), and it is used to measure the scattered positron and the particles of the hadronic final state. The backward calorimeters extends the Θ range for the hadronic final state up to $176°$. For the high Q^2 region the additional information about the scattered positron supplied by the central trackers is crucial to control systematic effects. See [2] for more details about the H1 detector.

The following results are based on data ($8.2pb^{-1}$) taken in 1996 with the H1 detector at HERA. Where necessary, low Q^2 results based on 1994 data that were originally presented elsewhere [1] are included.

2 Transverse Energy Flow

The E_T flow is presented in the hadronic center of mass system (hCMS). While in the laboratory frame (LAB) the transverse energy is dominated by kinematics, in the hCMS the transverse energy is produced by perturbative QCD radiation and fragmentation. The Lorentz transformation from the LAB into the hCMS therefore serves to isolate the physically interesting part. At high Q^2 this Lorentz transformation becomes a delicate step of the analysis. Any deviation from the true transformation produces an artificial contribution to the transverse energy seen in the hCMS. This is a more severe problem at high Q^2 since E_T increases with Q in the LAB but not in the hCMS. For this analysis the maximum E_T in the LAB is typically an order of magnitude larger than the the E_T in the hCMS (about 20 GeV compared to 2 GeV). In practice the transformation is calculated from the energy and direction of the scattered positron, and there are several sources of bias: energy resolution, calibration and QED radiation. Despite the good energy resolution of the H1 LAr calorimeter and the fact that the calibration uncertainty has been improved to the 1 % level, we are still affected by QED radiation. A change in the way E_T is calculated was therefore necessary. For a particle with energy E and angle Θ w.r.t. the incoming proton the transverse component is defined by $E_T = E \sin\Theta$. A deviation in the energy measurement of the scattered positron will result in an artificial component to the momentum of any particle in the hCMS. This component lies within the scattering plane[a] defined by the incoming proton and the scattered positron, as can be seen in Fig. 1. One can avoid this artificial momentum if only the component perpendicular to the scattering plane is taken into account. This component is given by

$$E_{\perp} = E_T |\sin\varphi^*| \frac{\pi}{2} \qquad (1)$$

Integrated over φ^* this is again equal to E_T given an isotropic distribution of the transverse energy around the proton. In general φ^* asymmetries are expected but detailed MC studies show that these do not have an important influence on the E_T flow.

This analysis consists of two parts. In the first part we present the E_T flow in 7 regions in x and Q^2 and compare them to 3 standard Monte Carlo models: ARIADNE 4.08, HERWIG 5.8 and LEPTO 6.5. The second part investigates the Q^2 dependence at fixed W.

[a] The H1 central tracker gives us a good knowledge about the direction of the scattered positron and since QED radiation is, in almost all cases, collinear with the incoming or outgoing positron a better determination of the angle rather than the energy of the scattered positron is obtained.

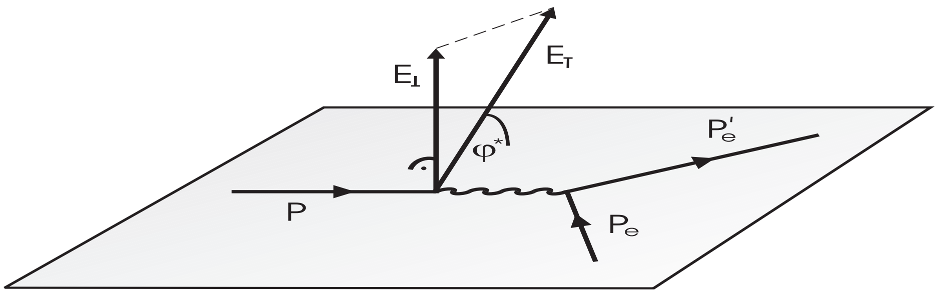

Figure 1: Component of the transverse energy perpendicular to the scattering plane. P Proton, P_e incoming positron, P'_e scattered positron.

The new measurements are shown in Fig. 2. The $<Q^2>$ covers a range from 175 GeV^2 to 2200 GeV^2. In the lowest Q^2 bin all MC models give similar predictions and describe well the energy flow. As Q^2 increases the models begin to differ and ARIADNE especially falls below the data. LEPTO slightly overshoots the E_T in all bins but describes the shape and its Q^2 and x dependence well. HERWIG follows the data closely in all but the highest $<W>$ bins.

Electron-proton scattering can be understood as a hadron-hadron process. The exchanged γ fluctuates into a hadronic object which then scatters at the proton. This picture is valid in the proton rest frame if the fluctuation time τ is large compared to the typical time of a strong interaction. In a previous publication H1 showed that this picture is not only valid in photoproduction but also in DIS [3]. For DIS, the estimate of the fluctuation time is $\tau = 1/(x\, m_P)$ [5] , where m_P is the mass of the proton. From hadron-hadron data, the central pseudorapidity range is expected to be insensitive to the structure of the colliding particles, which, for the virtual photon in DIS, is governed by Q^2 [4]. Both a similar level of $<E_T>$ and a similar W dependence compared to hadron-hadron collisions in the central pseudorapidity region was observed in our earlier publication. This is also true for the new analysis presented here although the improved statistics allow us to build a more precise picture of the Q^2 dependence. Since E_T depends on W we have selected data from a small range in W ($165 < W/GeV < 213$). We present the $<E_T>$ for two slices in η^*, the central bin ($-0.5 < \eta^* < 0.5$) and the fragmentation bin ($2 < \eta^* < 3$). The results are shown in Fig. 3. The transverse energy in the fragmentation bin and, significantly, in the central bin are seen to rise with Q^2. The Q^2 independence of the central bin clearly breaks down although x is still of the order of 10^{-2}, even at the highest Q^2 bin. The comparison with ARIADNE and LEPTO shows that a pQCD based Monte Carlo can describe the increase. However, none of these models satisfactorily follow the data; LEPTO

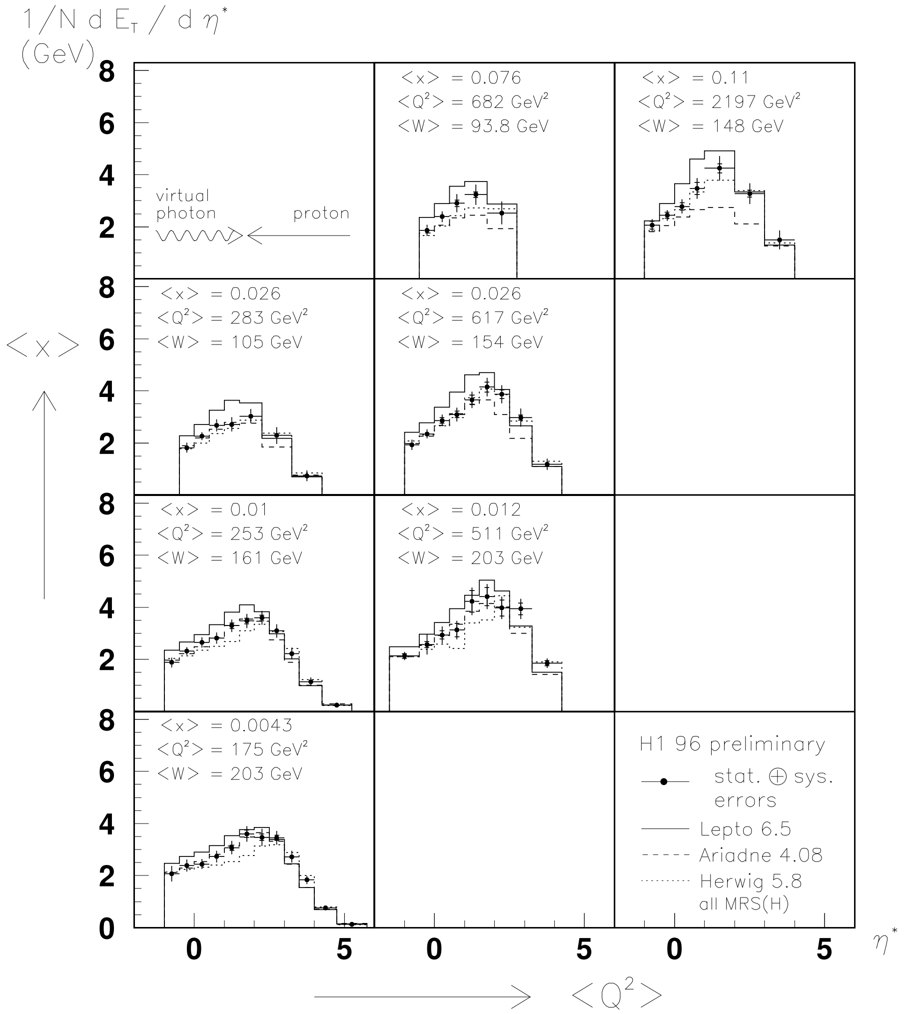

Figure 2: H1 preliminary results on the E_T flow in hCMS. Systematic errors are added in quadrature. The data is compared to 3 MC generators: Ariadne 4.08, Herwig 5.8 and Lepto 6.5. only events are selected with an energy of at least 0.5 GeV in the forward direction which is defined by $4.4° < \Theta < 15°$. This cut was introduced for the low Q^2 analysis in order to remove diffractive events. This allows a comparison with Monte Carlo models and pQCD calculations which is less dependent on model uncertainties of the diffractive process. At high Q^2 the influence of this cut is small but it is kept for the sake of consistency with our previous low Q^2 results.

shows a steeper increase in E_T with Q^2, while ARIADNE, despite giving an acceptable overall description, fails to describe the fragmentation region at the highest measured Q^2 point.

With the precision gained from higher statistics and better understanding of systematic effects a new measurement of the transverse energy flow has been presented. An increase in $<E_T>$ with Q^2 is seen in the central pseudorapidity bin. None of pQCD based Monte Carlo models can give a perfect description of the measurements.

References

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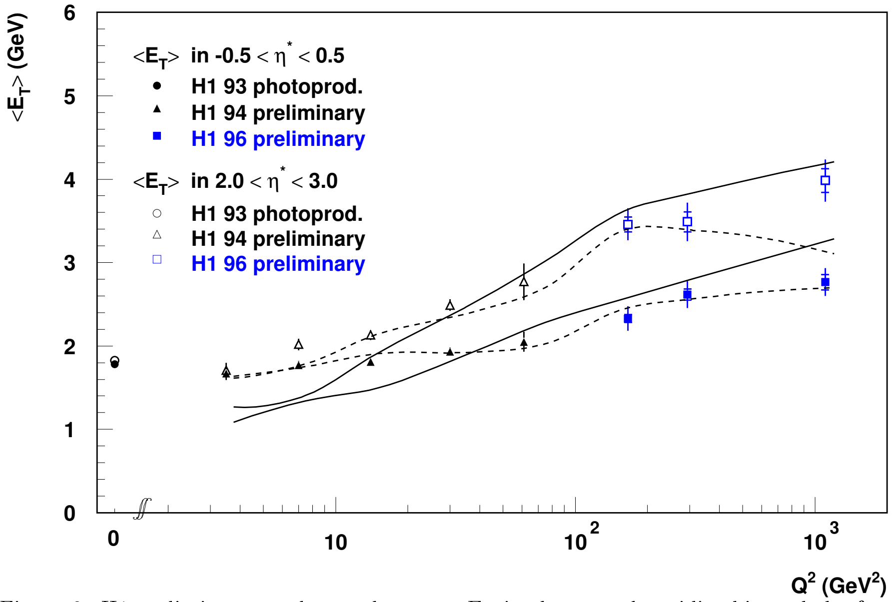

Figure 3: H1 preliminary results on the mean E_T in the central rapidity bin and the fragmentation region as a function of Q^2. 1994 data: only statistical errors included, 1996 data: statistical and systematic errors added in quadrature. Here the cut defined in the caption of Fig. 2 is not applied. Solid line: LEPTO 6.5, dashed line: ARIADNE 4.08.