

Properties of the Hadronic Final State in Diffractive ep Scattering

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Abstract: Hadronic final states are analyzed with the ZEUS detector for deep inelastic diffractive scattering $ep \rightarrow eXp$, in which the virtual photon dissociates into a hadronic final state of mass $4 < M_X < 35$ GeV and the scattered proton, carrying more than 95% of the initial proton momentum, is detected in the Leading Proton Spectrometer. The event shape variables thrust and sphericity are studied as a function of M_X and compared to models of deep inelastic diffractive scattering as well as to measurements performed with e^+e^- collisions. The analysis is based on 0.9 pb^{-1} of data taking during 1994.

1 Introduction

Diffractive deep inelastic scattering (DIS) processes are most commonly ascribed to the t -channel exchange of a color singlet object with the quantum numbers of the vacuum, called the ‘‘Pomeron’’ (\mathbb{P}) [1, 2, 3]. The pomeron exchange picture has been successfully applied to diffractive processes in photo-production and hadronic reactions [4]. However it is not clear what the pomeron consists of and whether an appropriate formulation of diffractive dissociation in terms of quarks and gluons can be found. The diffractive DIS process $ep \rightarrow e'p'X$, where X represents the observed multihadronic final state with the invariant mass M_x , is characterized by the presence of a fast forward scattered proton (p').

The hadronic final state of mass M_X is analyzed in its center of mass system (cms), which in models based on \mathbb{P} exchange is equivalent to the cms of the virtual photon and the \mathbb{P} , here called the $\gamma^*\mathbb{P}$ cms.

Models with different \mathbb{P} structures lead to different topologies in the hadronic final state. A two-jet configuration is produced from a \mathbb{P} which predominately consists of quarks. A broadening of the jets in the events is expected due to a contribution from three-jet events originating from leading order gluon bremsstrahlung which is suppressed by a factor of α_s . For a \mathbb{P} with a predominantly gluonic structure, the final state contains three-jet events already at lowest order.

The event shape variable thrust T provides information on the topology of the hadronic final state which is related to the hadronic structure of the Pomeron. The thrust can be calculated as:

$$T = \max_{\vec{n}} \frac{\sum_i |\vec{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}, \quad (1)$$

where \vec{p}_i represents the momentum of the observed hadronic final state particle and the unit vector \vec{n} gives the orientation of the thrust axis. For very collimated 2 jet events, T takes on values close to 1, while spherical events results in T close to 0.5.

The thrust is analyzed in the γ^*IP cms. Boosting the system X into this frame gives access to the thrust angle (angle between the thrust axis and the γ^*IP -axis), which is a measure of the transverse momentum of the partons.

2 Kinematics and Event Selection

For the evaluation of M_X and the Lorentz transformation into the $\gamma^* IP$ cms, the sum of the four momenta of the particles in the observed hadronic final state X ($P_X = q + P_{IP}$) is needed. It is determined from the four momenta associated to the energy clusters found in the main calorimeter combined, when possible, with tracks reconstructed in the central tracking detector of the ZEUS apparatus [5].

The following kinematic range was defined for this analysis: $0.03 \leq y \leq 0.95$, $4 \text{ GeV}^2 < Q^2 < 90 \text{ GeV}^2$, $4 \text{ GeV} < M_X < 35 \text{ GeV}$ and $0.0003 < x_{IP} < 0.03$, to ensure a full containment of the hadronic final state.

The diffractive candidate events were selected by requiring a leading proton in the LPS [6] with more than 95% of the initial proton momentum, $x_L > 0.95$. A detailed description of the event selection can be found elsewhere [7].

3 Monte Carlo Generators

The diffractive hadronic final state was compared to predictions of various models based on two Monte Carlo (MC) generators: RIDI [8] and RAPGAP [9]. Since both generators are discussed extensively in these proceedings, only a short summary is given here.

3.1 RIDI

The MC generator RIDI (RIDI2.0) simulates the diffractive dissociation of virtual photons in ep interactions following the approach of Ryskin [8]. Diffractive dissociation is studied in the framework of the lowest orders (LLA) of perturbative QCD [10], in which the cross section is proportional to the square of the gluon structure function of the proton. The contribution of both transversely and longitudinally polarized photons is taken into account. The program simulates the dissociation of the photons in $q\bar{q}$ and $q\bar{q}g$ final states. Parton shower and fragmentation are done using JETSET [11].

3.2 RAPGAP

RAPGAP [9] implements the Ingelman-Schlein approach of a partonic IP containing quarks and gluons. The parameterization of the IP structure function is based on fits to inclusive measurement of $F_2^{D(3)}$ from H1 1994 data [12]. Two fragmentation schemes are studied: 1: gluon radiation (figure 1b only) treated by ARIADNE (*RG ARI*) [13] according to the color

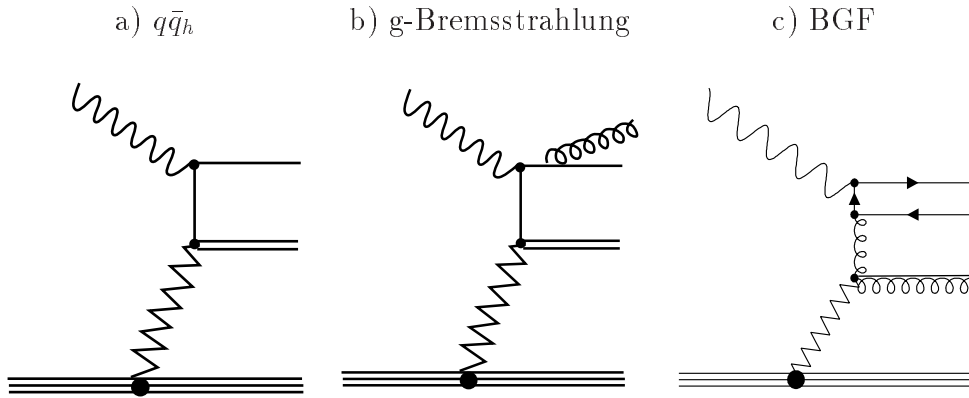


Figure 1: Feynman diagram of the 3 dominant processes contributing on parton level: a) the IP is a $q\bar{q}$ state; b) in addition a gluon is radiated off the quark line; c) boson gluon fusion (BGF) occurs at lowest order for a gluon dominated IP. The double lines indicate a hadronic object (IP remnant) as implemented in RAPGAP.

dipole model (CDM), 2: gluon radiation of the quark using matrix elements and parton showers (*RG MEPS*). The IP is treated as an extended color object, of which a remnant remains after the scattering, for which gluon radiation is suppressed.

For systematic studies, the contribution of the quark (*RG qqh*) (figure 1a and b) and the gluon (*RG BGF only*) (figure 1c) to the IP, and therefore to the hadronic final state, were separated.

Implemented in RAPGAP are further pQCD models containing a real $q\bar{q}$ final state (*RG-BLW qq*) [14] (figure 1a only) and a $q\bar{q}g$ final state (*RG-BW qqg*) [15] (figure 1c only), respectively. In the $q\bar{q}$ model, the IP is treated perturbatively, with the fixed transverse momentum k_t of the quark entering as a second hard scale. Both transverse and longitudinal polarized photons dissociate in a $q\bar{q}$ pair producing two jet events. In the $q\bar{q}g$ model, the perturbative IP enters through its gluonic structure function in the region of small β , producing three jet events.

3.2.1 Toy $q\bar{q}$ model

Inspired by the similarity between the event shape measurements in diffraction with the LPS and in e^+e^- collisions (figure 2), a simple $q\bar{q}$ toy model ($q\bar{q}$) was developed based on the RAPGAP generator. Every event RAPGAP generated was assumed to be a $q\bar{q}$ final state independent of the chosen structure function and gluon radiation was allowed from both q lines (figure 1a and b without the remnant suppression).

4 MC Studies and Data Comparison

Figure 2 shows thrust T and sphericity S of the diffractive hadronic final state as a function of the invariant mass M_X [7] and compares them with results obtained in e^+e^- collisions [16] and the H1 large rapidity gap (LRG) analysis [17]. The results show that the hadronic final state becomes more collimated (larger $\langle T \rangle$, smaller $\langle S \rangle$) as M_X increases. This result is

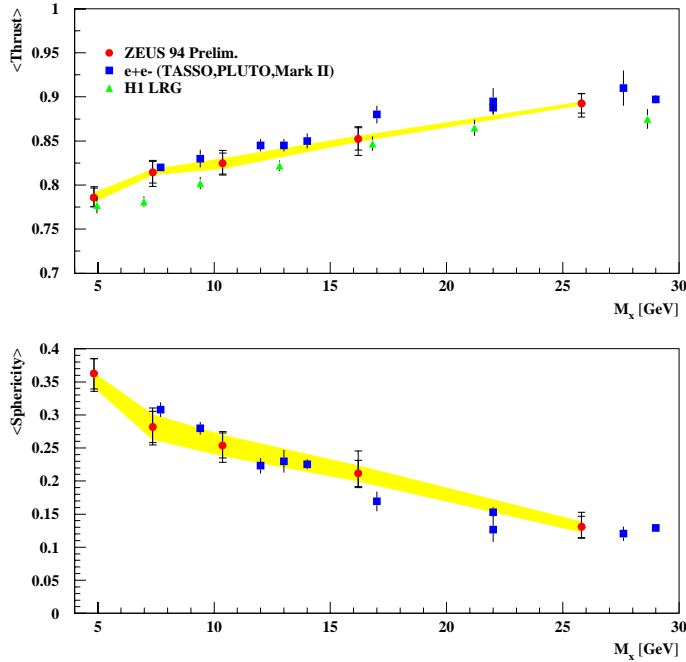


Figure 2: Average event shape variables thrust T (top) and sphericity S (bottom) as a function of the invariant mass M_X . The results are in good agreement with measurements from e^+e^- collisions. The large rapidity gap (LRG) results from H1 show events which are less collimated.

compatible with the measurements in e^+e^- annihilation at $\sqrt{s} = M_X$. On the contrary, the LRG thrust measurement by H1 obtains events less collimated, especially in the low M_X region.

In figure 3, we compare $\langle T \rangle$ with the predictions of various MC generators. Of the models studied, RAPGAP with the H1 fit 2 and the gluon radiation treated with ARIADNE (RG ARI) gives the best description of the data. The MEPS (RG MEPS) version on the other hand undershoots the results for most of the masses. Since the only difference between the two samples is the treatment of the radiated gluon, it appears that fragmentation is important for this measurement and different schemes can be distinguished in the thrust measurement. Since both samples contain a significant contribution of Boson Gluon Fusion (BGF) type events, we may conclude, that the BGF diagram is necessary to describe the diffractive hadronic final state.

In the bottom plot of figure 3, we compare $\langle T \rangle$ with pQCD based models. RIDI has difficulties reproducing the measurement in the low mass region. Since it contains both $q\bar{q}$ and $q\bar{q}g$ type events, one may conclude that more $q\bar{q}$ is needed at low masses. This may be confirmed by the other two models in this plots which are $q\bar{q}$ and $q\bar{q}g$ only: the $q\bar{q}$ model (RG-BLW qq) gives rise to a final state which is too collimated at high masses, while the $q\bar{q}g$ model (RG-BW qqg) produces events which are too spherical. An appropriate mixture could achieve a nice agreement with the data.

The top plot of figure 4 shows, how the different components of the RG H1 fit2 make up the total $\langle T \rangle$. We plot the contribution to $\langle T \rangle$ separately for the qq_h and for the BGF diagram, respectively. Please note, that one of the quarks in the qq_h component is treated as

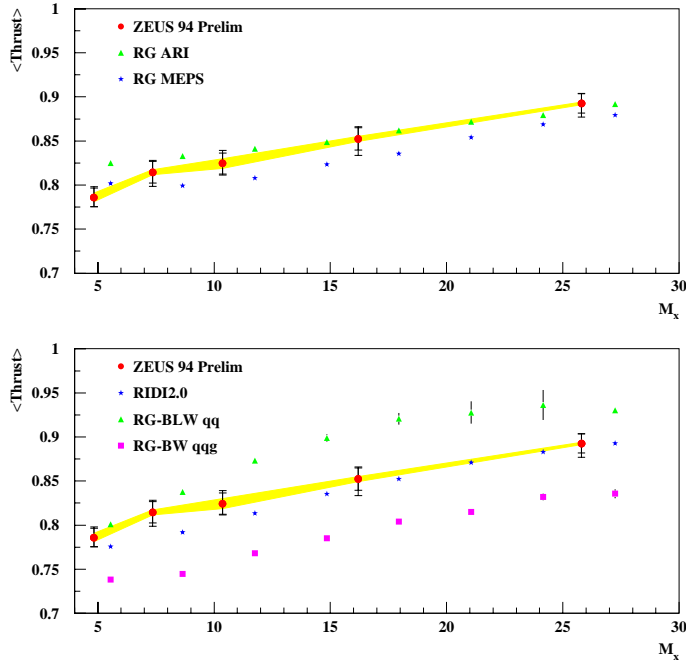


Figure 3: Average thrust $\langle T \rangle$ as a function of the invariant mass M_X compared to predictions of various MC generators. The best description of the data is given by RAPGAP in ARIADNE mode (top). Despite the good agreement with e^+e^- data, the $q\bar{q}$ model (RG-BLW qq) does not describe the data and produces too collimated events at higher masses (bottom).

the IP remnant (denoted by the subscript h) and therefore, gluon radiation is suppressed for this quark. We clearly see, that the qq_h alone produces final states more collimated than the data, while the BGF component alone generates events too spherical. However, with a very simple mixing, one can achieve a good description of the data. As an illustration, we mixed a sample with 35% BGF and 65% qq_h independent of M_X .

Triggered by the similarity of the hadronic final state event shape variables with results from e^+e^- collisions (which are $q\bar{q}$ dominated in this region of $\sqrt{s} = M_X$, see figure 2) and the disagreement with the qq_h component of RAPGAP (see figure 4), we created a toy model which generated final states similar to e^+e^- without altering the kinematics. This has the effect of removing the QCD suppression associated with the usual remnant treatment of the IP in RAPGAP. The result of this exercise is shown in the bottom plot of figure 4, which shows a nice agreement with the data. Adding extra k_T to the quarks to account for an angle between the thrust axis and the γ^*IP -axis does not change $\langle T \rangle$, since it just means a rotation of the event out of the γ^*IP direction.

To add a more dynamical measurement to the analysis, the angle between the thrust axis and the γ^*IP -axis can be measured. This angle can be transformed into a transverse momentum by multiplying by the total energy in one hemisphere of the event ($= \frac{M_X}{2}$). Since the hadronic final state becomes more collimated at higher masses it would be reasonable to assume that a two jet structure dominates. From the comparison of the $\langle T \rangle$ in diffraction with results from e^+e^- collisions and RAPGAP (RG-ARI), one can conclude that such a final state may be

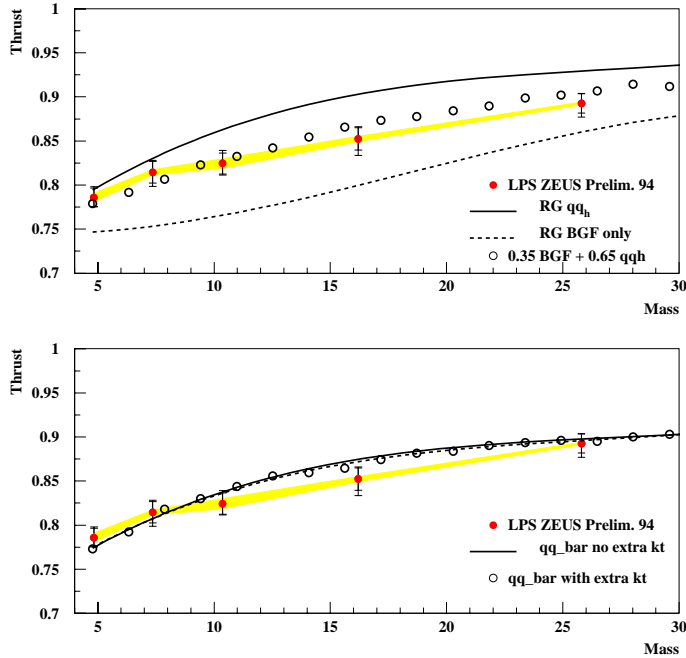


Figure 4: Average thrust $\langle T \rangle$ as a function of the invariant mass M_X compared to predictions of models containing only RAPGAP like qq_h events (top), RAPGAP BGF events (top) or e^+e^- like $q\bar{q}$ events (bottom).

produced either by a $q\bar{q}$ state or by introducing extra gluon from a BGF type contribution to a state which contains a \mathbb{P} remnant which escapes detection. Using the thrust angle to measure the transverse momentum of the event with respect to the γ^*P -axis can help distinguish the two classes of events.

Figure 5 shows how different the prediction of this angle are for various models. Our $q\bar{q}$ toy model has an adjustable transverse momentum and can therefore be brought in agreement with any measured angle.

It needs to be stressed here that the toy model is not meant to be a prediction. It's purpose is to describe the data well enough to correct them for detector effects in a model independent way. However, it's an interesting exercise to reproduce the diffractive final state by taking a diffractive parameterization of the cross section and adding e^+e^- fragmentation.

5 Conclusions

The ZEUS Leading Proton Spectrometer (LPS) was used to tag the diffractively scattered proton and the hadronic final state was investigated in terms of the event shape variable thrust. The average thrust $\langle T \rangle$ shows a strong similarity to thrust measurement performed in e^+e^- collisions at $\sqrt{s} = M_X$.

The results were compared to various MC models, most of which are implemented in the RAPGAP framework. Of the models studied, the Ingelman-Schlein kind of approach as implemented

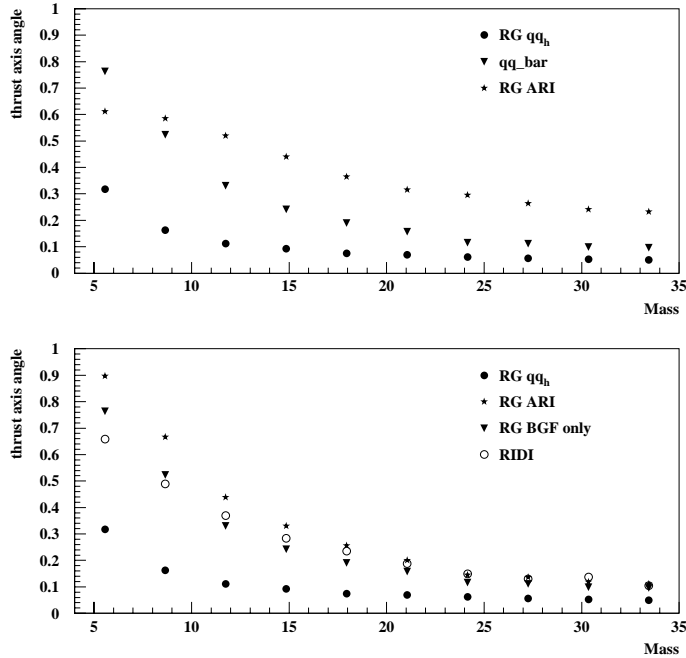


Figure 5: Average thrust angle (angle between thrust axis and the $\gamma^* IP$ -axis) as a function of the invariant mass M_X predicted by various MC models.

in RAPGAP with a IP composed out of quarks and gluons seems to give the best description of the data. Differences in the fragmentation scheme can be distinguished using the thrust. None of the so far available pQCD based models integrated in RAPGAP nor the RIDI model give a completely satisfactory description of the thrust measurement.

Based on the comparison with e^+e^- measurements, one might assume a simple $q\bar{q}$ model (without IP remnant) may be a good candidate. This was confirmed by applying a toy model based on RAPGAP generating only $q\bar{q}$ with gluon radiation from both quark lines.

Since the transverse momentum of the gluons and quarks in the hadronic final state is predicted to be different, a variable to distinguish a $q\bar{q}$ dominated event from a gluon dominated one is the thrust angle. Predictions for various models were shown, which span a wide range of the thrust angle. This suggests a promising area for future measurements

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