PROCEEDINGS OF SCIENCE

Observation of events with an empty hemisphere in the Breit frame and differential cross-section measurement

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The Breit frame provides a natural reference frame to analyse electron–proton scattering events when the process of interest is plainly considered as a photon–hadron interaction. In the Breit frame, the photon runs on the z axis in the positive direction, and in the leading order picture the struck quark leaves the interaction on the z axis, too. Higher-order QCD corrections change that picture and at sufficiently low x, a rather spectacular event signature is predicted with no radiation in the forward direction but all emissions are expected to be found in the backward direction, from where the photon approaches. We report on a first observation of those empty current hemisphere events in electron–proton collisions at the HERA collider using data recorded with the H1 detector at a center-of-mass energy of 319 GeV. The large data sample corresponds to an integrated luminosity 351.1 pb^{-1} and allows for a differential cross-section measurement of these events. The data are compared to selected predictions from Monte Carlo event generators.

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1. Introduction

Neutral current (NC) deep inelastic scattering (DIS) process is one of the dominant processes produced at the unique electron[1]–proton collider HERA. It operated for about 15 years until 2007. The results [1] reported here are based on data taken by the H1 detector [2] in the years 2003-2007 corresponding to an integrated luminosity of 351.1 pb^{-1} at a centre-of-mass energy of 319 GeV.

The study is performed in the Breit frame where the virtual photon with momentum Q moves along the z axis and the proton fragments in the opposite direction as illustrated in Figure 1. In leading order (LO), the interaction corresponds to $\gamma^* + q \rightarrow q$. After the interaction, the struck quark q moves with momentum $Q/2$ in the current hemisphere, while the remnants of the proton are scattered into the target or fragmentation hemisphere. The current hemisphere is analogous to a single hemisphere of an $e^+e^- \rightarrow q\bar{q}$ process at an equivalent centre-of-mass energy of $\sqrt{s_{e^+e^-}} = Q$. In next-to-leading order (NLO) in QCD, two interacting processes $\gamma^*+q \rightarrow q+g$ and $\gamma^*+g \rightarrow q+\bar{q}$ produce two final-state parton balanced in the transverse plane having different configurations shown in the bottom row in Figure 1. The last configuration corresponds to the case where no final state appears in the current hemisphere [3]. An experimental study of the empty (current) hemisphere events (EHEs) is performed in Ref. [1] and reported here.

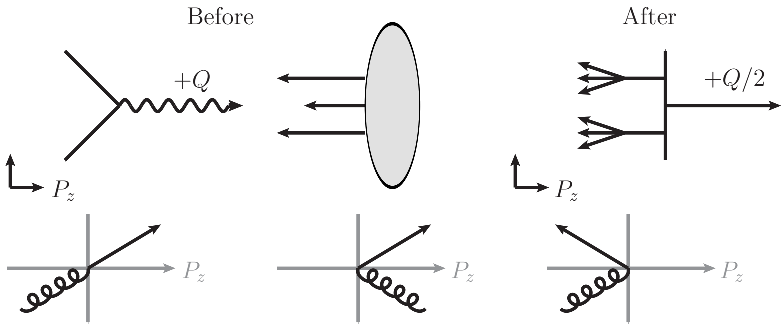

Figure 1: Parton configuration before and after the absorption of the virtual photon at leading-order (top) and after the interaction with the virtual photon at next-to-leading order (bottom) in the Breit frame.

2. Analysis and results

The NC DIS events are selected by requiring a scattered electron candidate with an energy exceeding 11 GeV, providing an efficient trigger in the electromagnetic calorimeter. The hadronic final state (HFS) is selected using a particle flow algorithm combing the tracking and calorimeter informations. The total longitudinal energy-momentum balance of all recorded final states is required to be twice of the initial electron beam energy in the range between 45 and 62 GeV, allowing to suppress efficiently events with hard initial state QED radiation and contributions from photoproduction background. The kinematic phase space used for the analysis corresponds to $150 < Q^2 < 15\,000\,\mathrm{GeV}^2$ and $0.14 < y < 0.7$ with Q^2 being the virtuality of the photon and y the inelasticity, respectively. The corresponding kinematic distribution for Bjorken x_{Bj}

[1]In this proceedings, we use the word electron generically for both electron and positron

is shown in Figure 2 comparing the NC DIS events and EHEs. The data are also compared with two expectations using simulated events from Djangoh 1.6 [4] and Rapgap 3.1 [5]. Both generators use LO matrix elements which include diagrams for boson-gluon fusion and QCD Compton processes. Higher order processes are included in Djangoh via the implementation of the Color Dipol Model in Ariadne [6], while in Rapgap they are included via parton showers in leading logarithm approximation. Higher order QED radiative effects are also included using Heracles [7]. The background contributions indicated in the figure from photoproduction, charged current and low-Q^2 NC DIS processes are small.

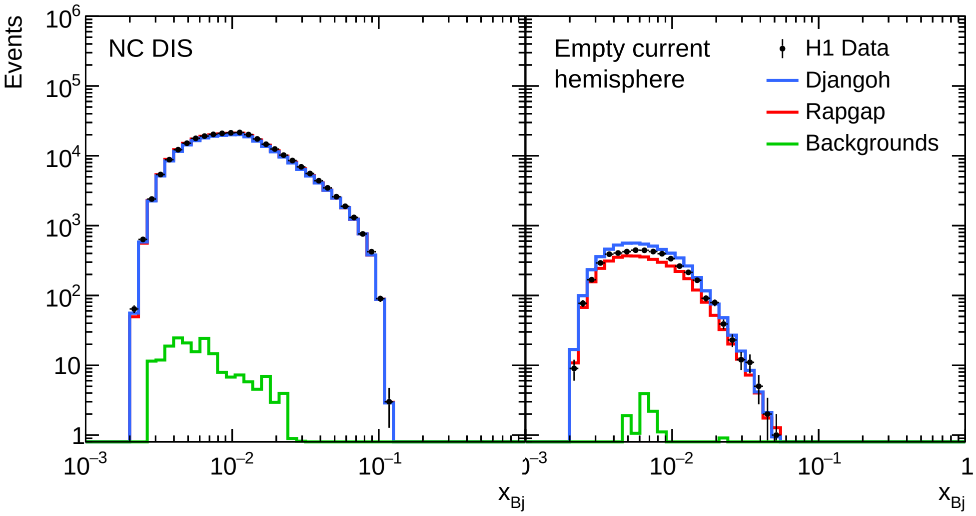

Figure 2: Event distributions after selection for NC DIS events (left) and events with an empty current hemisphere (right) as a function of $x_{\rm Bj}$ at the detector level in comparison with simulated samples from Djangoh and Rapgap.

It is interesting to look at the number of jets in the EHEs since according to the NLO prediction, two jets are expected. This is indeed observed in Figure 3, where the jets are defined in the Breit frame from all HFS objects using the k_t jet algorithm [8] with a distance parameter of $R = 1$ and the jets are required to have a transverse momentum greater than 7 GeV.

The data are then corrected for acceptance and resolution effects using a regularised matrix inversion algorithm as implemented in the TUnfold package [9]. The migration between the EHEs and non-EHEs is taken into account in the matrix, constructed from the average of the Djangoh and Rapgap simulations. The resulting fraction r of EHEs over the NC DIS events is

$$r = 0.0112 \pm 3.9\%_{\rm stat} \pm 4.5\%_{\rm syst} \pm 1.6\%_{\rm mod}\,, \qquad (1)$$

where the quoted relative uncertainties correspond to statistical, experimental systematic and model uncertainties. The experimental systematic uncertainties include those on the energy scale of the HFS objects, the energy resolution of the scattered electrons, and their angular resolutions. The model uncertainty covers the difference observed when using either Djangoh or Rapgap to construct the migration matrix.

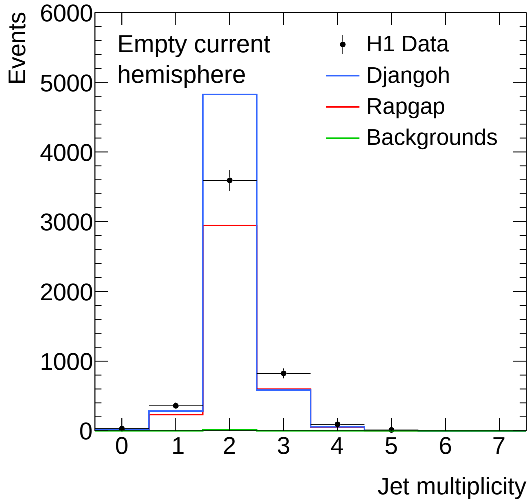

Figure 3: Number of jets in events with an empty current hemisphere with jets being defined in the Breit frame and exceeding a transverse momentum threshold of 7 GeV.

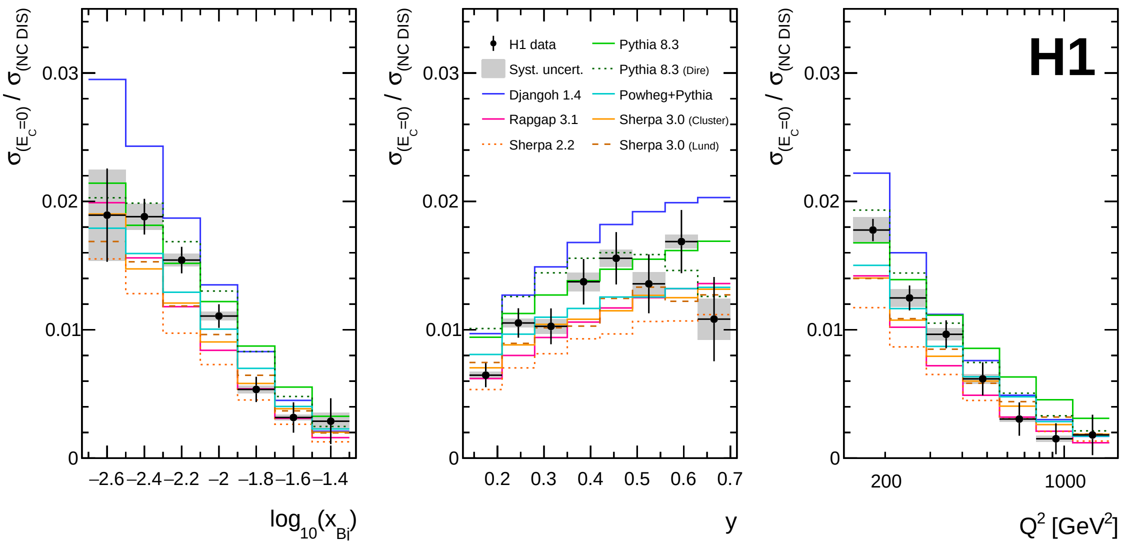

Figure 4: Ratios of differential cross sections of events with an empty current hemisphere in the Breit frame over those of neutral current DIS events as functions of x_{Bj}, y and Q^2, in comparison with different predictions. The vertical error bars represent the statistical uncertainties and the shaded area the total systematic uncertainties including model uncertainties.

Differential ratios as functions of x_{Bj}, y and Q^2 are also measured as shown in Figure 4, in comparison with various predictions from Djangoh 1.4, Rapgap 3.1, Sherpa 2.2 [10], Pythia 8.3 [11], Powheg+Pythia[12] and Sherpa 3.0. The predictions from Djangoh and Rapgap reasonably describe the overall shape of the data, while Djangoh (Rapgap) tends to over-predict (under-predict) the data in the normalisation. The predictions from Pythia 8.3 with default shower or with Dire parton shower both give a good description of the data. The predictions from Powheg+Pythia and Sherpa 3.0 are consistent with the data within uncertainties. The difference between using the cluster and using the Lund string fragmentation model as implemented in Sherpa 3.0 is relatively small. Sherpa 2.2 under-predicts the data in the entire x_{Bj} and y range.

3. Summary

Empty current hemisphere events in the Breit frame are observed for the first time using electron–proton collision data recorded by the H1 experiment corresponding to an integrated luminosity of 351.1 pb^{-1} at the centre-of-mass energy of 319 GeV. Despite the similarity between the deep-inelastic-scattering current hemisphere and one hemisphere in e^+e^- collisions, such empty events are absent in e^+e^- or pp collisions. The fraction of these events over the neutral current events in the phase space of $150 < Q^2 < 15\,000\,\mathrm{GeV}^2$ and $0.14 < y < 0.7$ is measured to be 0.0112 with a total uncertainty of 6.2%. The fraction is also measured differentially as functions of x_{Bj}, y and Q^2. These new measurements are valuable to improve and validate parton shower and hadronisation models.

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