Chapter 5

Event selection in DIS

In this chapter, the ZEUS data acquisition flow is explained. The signature of a DIS event is described. Various methods employed to reconstruct the event kinematics are compared. The DIS event selection cuts and data selection utilizing the three level ZEUS trigger chain are presented.

5.1 Data acquisition flow

The ZEUS data acquisition uses a three level trigger system in order to reduce the huge volumes of data streaming from the detector. The HERA bunch crossing rate is high: every 96\,ns, a proton bunch collides with an electron bunch possibly giving an $e^-p$ interaction. On average, one in one hundred bunch crossings gives a detectable event. Therefore a fast readout is essential. The raw data coming from $\sim 250,000$ channels of the detector is approx. 0.5 Mb in size and, given that final event data is written out at speeds close to 1 Mb/sec, the total amount of data needs to be drastically reduced in early stages of data acquisition. Treated as a black box, the trigger chain effectively reduces the event rate from a 100 kHz input down to 5 Hz such that end storage facility can handle the data flow. The challenge is to identify the 5 most interesting events from hundreds of thousands of detectable collisions every second. At each level in the trigger chain, data volume is reduced, giving the system time to compute more characteristics of each accepted event at the next level of the trigger. Each subsequent level can therefore perform more sophisticated filtering of the data. The schematic description of the data flow and event rate reduction is given in Fig. 5.1.
Figure 5.1. Data acquisition flow at ZEUS. The left vertical scale depicts the event rate reduction at each trigger level.
5.1 Data acquisition flow

5.1.1 First level trigger

The first level trigger (FLT) is a hardware based trigger employing programmable logic to accept or reject events. It consists of component FLT’s, mostly local to each component, and the global first level trigger (GFLT). At first level trigger, all data are stored by the detector components locally, in hardware buffers. Because the trigger cannot take decisions within the time between two bunch crossings, the data are moved down a pipeline for a maximum delay of about $5 \mu s$ to allow a trigger decision to be taken. The individual component decisions use only a subset of the component’s entire data and are taken within $1 - 2.5 \mu s$. The component trigger decisions are then fed to the GFLT algorithm which combines the local decisions to make the global first level trigger decision. The output of the this global trigger arrives with a latency of $4.4 \mu s$.

The most important components are the CAL and the CTD. Typical information used by GFLT is the vertex position of the event, total transverse energy and energy sums in sections of the calorimeter. Events that have a signal in SRTD for which the timing is inconsistent with particles arriving from the event vertex are rejected as beam gas events. A NC DIS event is identified at the FLT level by tagging the scattered electron. The FLT reduces the event rate from 100 kHz to below 1 kHz by selecting events with large energy deposits in the calorimeter and good tracks from the CTD FLT.

For the current analysis, only those events are kept which, at the FLT level, passed at least one of the following criteria:

- an isolated electron identification (isolated EMC clusters in the calorimeter) with a minimum energy of $3.9 \text{ GeV}$ in at least one RCAL EMC cluster. (Near the beam pipe, this threshold is raised to $5 \text{ GeV}$.)

- an isolated electron identification (isolated EMC clusters in the calorimeter), with a minimum energy of $2 \text{ GeV}$ in at least one RCAL EMC cluster AND a track pointing to it.

- the total energy in the CAL EMC cells is larger than $20 \text{ GeV}$.

- for higher $Q^2$, the electron scatters at larger angles, crossing the BCAL. To keep those events, a cluster with minimum BCAL energy of $4.7 \text{ GeV}$ AND a reconstructed track pointing to this cluster are required.
For all the events, additional cuts on the timing information from C5, veto wall and SRTD were required such that background events like beam gas interaction and cosmics are rejected.

### 5.1.2 Second level trigger

All events accepted by GFLT are fully digitized and then copied to local component second level trigger (SLT) processors. The component SLT’s use the entire data from each component in order to send processed information to the global SLT (GSLT). The algorithms are more complex than the GFLT ones: objects like track momenta, event vertex and calorimeter clusters are reconstructed.

The ZEUS Global Tracking Trigger (GTT) Barrel Algorithm integrates track information from the CTD and MVD to obtain a global picture of the track topology in the barrel region (-1.5 < \(\eta\) < 1.5) of the ZEUS detector at the SLT stage. Algorithm processing is performed on a farm of Linux PCs and, to avoid unacceptable dead-time in the ZEUS readout system, must be completed within the strict requirements of the ZEUS trigger system. The GTT Barrel Algorithm greatly improves the vertex resolution and the track finding efficiency of the ZEUS SLT.

At the SLT level, events are vetoed using timing obtained from the FCAL, RCAL or the upper and lower halves of the BCAL. Timings are calibrated such that a \(t = 0\) corresponds to collisions at the nominal interaction point. If the arrival time reported by RCAL, in absolute value, is larger than 8 ns or the time difference between FCAL and RCAL arrival times is larger than 8 ns, the event is vetoed as proton beam gas event. If the lower BCAL half reports a time delay longer than 10 ns w.r.t. the upper BCAL half, the event is vetoed as a cosmic event. A cut on \(\sum_{cells,i} E_{cells}^i - P^{cells}_{z,i} < 75 \text{GeV}\) is also required in order to further remove background and reduce rate.

The GSLT takes its decision after \(\approx 6 \text{ ms}\). The SLT reduces the event rate from 1 kHz to a typical 30-100 Hz.

For each event that passed the GSLT, the data of the event is sent to the event builder (EVB) where it is combined into a single record of ADAMO database tables[30]. This is also the data structure used in subsequent offline analysis. It is further distributed to the TLT processor nodes.
5.1 Third level trigger

The third level trigger (TLT) algorithms run on a farm of processors. Each workstation individually analyzes each single event with a custom simplified version of the offline reconstruction software and uses the full event information to calculate the event kinematics. Detailed tracking and jet finding algorithms are performed. Events that pass specific trigger criteria get a tag associated with these criteria added. These tags are known as the TLT flags and the pattern of these flags is used to select specific types of events. Typically, about 5 events pass the TLT criteria each second. The TLT accepted events are sent further to the event repository through a dedicated connection (FLINK) and to the online cluster for monitoring. During data taking, the ZEUS crew on shift monitors the trigger rates carefully for an optimal quality of data being recorded.

All data used in this analysis passed the TLT criteria, described by the following bit names:

- **TLT_HFL02**: a filter for charm mesons in DIS, it requires a DIS scattered electron OR a HFM trigger bit to be set. Essentially, the HFM trigger bits filter events with at least one loose charm meson candidate:
  - HFM01 tags events in which the decay $D^* \to K^- + \pi^+ + \pi_s^+$ has been loosely reconstructed ($1.65 < m(K, \pi) < 2.1 \text{ GeV} ; P_T(D^*) > 1.35 \text{ GeV} ; P_T(K, \pi) > 0.035 \text{ GeV}; P_T(\pi_s) > 0.1 \text{ GeV}$)
  - HMF02 and HFM03 are similar to HFM01 but tag the decays $D^* \to K^- + \pi^+ + \pi^- + \pi_s^+$ and $D^* \to K^0 + \pi^+ + \pi^- + \pi_s^+$ respectively
  - HFM04 tags the decay $D^0 \to K^- + \pi^+$. The $D^0$ candidate is reconstructed in the mass window $[1.6, 2.2] \text{ GeV}$ with the $P_T(D^0) > 2.8 \text{ GeV}$ and $P_T(K, \pi) > 0.7 \text{ GeV}$
  - HFM05 through HFM17 reconstruct other charm meson decay channels such as $D^0 \to K + 3\pi$ , $D^0 \to K^0 + 2\pi$ , $D^+$ and $D_s$ decays.

- **TLT_DIS03**: a medium $Q^2$ trigger, it requires an electron of at least 4 GeV, found by either SINISTRA or EM packages [31, 32]. For electrons scattered into the RCAL, a minimal radius around the beampipe of at least 35 cm is also required. Furthermore, $30 \text{ GeV} < E_{\text{total}} - p_Z$ is necessary as well as a combination of FLT and SLT bits (FLT 28,30,40,41,43,44,46,47 and SLT 1,2,3,4,5,6,7,8) to be on.
• TLT_SPP02: an inclusive DIS trigger. It requires $30 < E_{\text{total}} - p_Z < 100 \text{ GeV}$, an electron of at least $4 \text{ GeV}$ and excludes a region of $12 \times 12 \text{ cm}$ around the rear beampipe for the impact position of the electron (box cut).

### 5.1.4 Offline reconstruction

Typically, within a couple of days after acquisition, the data are reconstructed offline using not only the full event information but also calibration information regarding the status of the detector, such as calorimeter noise, MVD alignment, etc. so that corrections to event variables are performed for a more accurate measurement. The more CPU intensive parts of the reconstruction are implemented here rather than at TLT level. Samples of similar events are selected by associating each event with a specific code called a DST bit.

DST bits 9,10 and 11 (tagging good NC events or events with a well reconstructed electron) were also required for all selected events. Bit 9 requires a scattered electron with an energy of at least $4 \text{ GeV}$ found by at least 4 of the electron finder packages, bit 10 filters events with a well reconstructed primary vertex and bit 11 requires $E - p_Z > 30 \text{ GeV}$.

### 5.2 Data from Hera II

After a long shutdown, HERA resumed operation in 2001. A summary of the luminosity recorded by ZEUS since 2002 until present day is given in Fig. 5.2. The luminosity values corresponding to different data taking periods are also given in Table 5.1. In the years 2002 and 2003 positrons were used. During the second half of 2004 and the entire 2005, electrons were used. This analysis uses a data sample of $127.35 \text{ pb}^{-1}$, corresponding to $129714544 \text{ e}^{-p}$ collisions recorded by ZEUS in 2005. In this thesis, the incoming/scattered lepton will be referred to as the electron. The following sections look at the selection criteria for obtaining a clean NC DIS sample. The quality of the selected events is scrutinized. All the runs have microvertex detector information available.

### 5.3 Event reconstruction

The final state of a DIS event consists of the scattered electron and the hadronic system. The hadronic system refers to all event attributes not related to the scat-
Figure 5.2. Integrated luminosity gated by ZEUS since 2002 until presently. Different positron/electron periods are plotted separately. The data set used in this analysis is shown as “04/05 e^− “.

A scattered electron: the jet, which is the result of the struck quark hadronizing, and the proton remnant. An event is determined in terms of kinematics by any two of the variables $Q^2$, $x$ and $y$, as explained in Chap. 2. Different methods are employed in order to compute the event kinematics: one can use only information from the hadronic system, scattered electron or a combination of the two.

<table>
<thead>
<tr>
<th>Period</th>
<th>Beams</th>
<th>Recorded luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 (MER)</td>
<td>$e^+p$</td>
<td>7.77 $pb^{-1}$</td>
</tr>
<tr>
<td>2007 (LER)</td>
<td>$e^+p$</td>
<td>13.18 $pb^{-1}$</td>
</tr>
<tr>
<td>2006/2007</td>
<td>$e^+p$</td>
<td>145.90 $pb^{-1}$</td>
</tr>
<tr>
<td>2006</td>
<td>$e^-p$</td>
<td>61.23 $pb^{-1}$</td>
</tr>
<tr>
<td>2004/2005</td>
<td>$e^-p$</td>
<td>152.26 $pb^{-1}$</td>
</tr>
<tr>
<td>2004</td>
<td>$e^+p$</td>
<td>43.74 $pb^{-1}$</td>
</tr>
<tr>
<td>2003</td>
<td>$e^+p$</td>
<td>2.87 $pb^{-1}$</td>
</tr>
<tr>
<td>2002/2003</td>
<td>$e^+p$</td>
<td>1.78 $pb^{-1}$</td>
</tr>
</tbody>
</table>

Table 5.1. A summary of different data taking periods and corresponding luminosities, as recorded by ZEUS. The top two entries (LER, MER = low and respectively medium energy runs) refer to periods for which the center of mass energy was altered. This analysis uses a sub-sample of 127 $pb^{-1}$ of the 2004/2005 data taking period.
5.3.1 Jacquet-Blondel method

The Jacquet-Blondel method uses only hadronic information to reconstruct the event kinematics. First, the following are defined:

\[
\delta_h = \sum_i^N (E_i - p_{z,i}) \tag{5.1}
\]

\[
p_{T,h}^2 = \left( \sum_i^N p_{x,i} \right)^2 + \left( \sum_i^N p_{y,i} \right)^2 \tag{5.2}
\]

where \( i \) runs over all calorimeter clusters not associated with the scattered electron. The polar angle \( \gamma_h \) of the struck quark, at leading order, is given by:

\[
\cos \gamma_h = \frac{p_{T,h}^2 - \delta_h^2}{p_{T,h}^2 + \delta_h^2} \tag{5.3}
\]

The kinematic variables of the event are reconstructed as:

\[
y_{JB} = \frac{\delta_h}{2E_{e\text{beam}}} \tag{5.4}
\]

\[
Q_{JB}^2 = \frac{p_{T,h}^2}{1 - y_{JB}} \tag{5.5}
\]

where \( E_{e\text{beam}} \) is the nominal beam energy of the incoming electron. The hadronic \( x \) is obtained from \( Q^2 = sxy \). Because a large fraction of the hadronic system escapes undetected as it goes down the beampipe, the measured \( p_{T,h}^2 \) can be distorted. For this reason, the resolution of this method is somewhat poor, especially for low \( Q^2 \) and moderate \( x \). The Jacquet-Blondel method is mainly used in charge current interactions where there is no information available from the final state lepton: neutrino’s cross the ZEUS detector completely undetected.

5.3.2 Electron method

This method uses solely the measurement of the scattered electron. The kinematic variables are given by the following equations:

\[
y_e = 1 - \frac{E_e}{2E_{e\text{beam}}} (1 - \cos \theta_e) \tag{5.6}
\]
\[ Q_e^2 = 2E_e E_{beam} (1 + \cos \theta_e) \]  

(5.7)

where \( \theta_e \) and \( E_e \) are the angle and the energy of the scattered electron respectively. Both reconstructed variables depend on the accurate reconstruction of \( E_e \) and \( \theta_e \). Although the electron angle can be measured well with the help of the SRTD at low angles and by tracking at high angles, accurately determining the electron energy is problematic due to some amount of dead material in front of the calorimeter at low angles. At moderate \( x \), \( x \in [10^{-4}, 10^{-2}] \), this method has a poor resolution. A more detailed description of different reconstruction methods and their discriminative power for different regions of the phase-space can be found in previous ZEUS theses [33, 34].

### 5.3.3 Double angle method

This method relies on the angles of both the hadronic system and the scattered electron [35].

\[ y_{DA} = \frac{\sin \theta_e (1 - \cos \gamma_h)}{\sin \gamma_h + \sin \theta_e - \sin(\gamma_h - \theta_e)} \]  

(5.8)

\[ Q_{DA}^2 = 4E_e^2 \frac{\sin \gamma_h (1 + \cos \theta_e)}{\sin \gamma_h + \sin \theta_e - \sin(\gamma_h - \theta_e)} \]  

(5.9)

Neither \( y_{DA} \) nor \( Q_{DA}^2 \) depend on any measured energies. Since angles are in general more precisely measured than energies with the ZEUS detector, this method leads to accurate results in larger regions of the phase-space. These regions are characterized by substantial hadronic activity at large angles and a well measured electron track. These coincide with the region where charm can be measured well. The double angle method will therefore allow for an optimum reconstruction of the kinematic variables and so will be used in this thesis for the determination of the kinematics.

### 5.4 DIS selection

Present ZEUS analyses use a complex library of reconstruction software which translates the raw timed hits in the detector into physical objects, as explained in detail in previous chapters. Each event that has passed the trigger is reconstructed using programs from this library. The reconstructed events containing tracks, covariance
matrices and calorimeter energy deposits are written to the output. ROOT[36] is an object oriented data analysis framework which serves as an interface between the data and the particle reconstruction algorithms. All data used in this thesis have been processed within the Heavy Flavor analysis group at ZEUS in the form of ROOT files. This large data sample represents the raw data. A preselection is made from these events. First, events passing the criteria for deep inelastic scattering are selected. This is done using the following criteria:

DIS selection:

- $z$ position of the primary vertex: $-50 \text{ cm} < z < 50 \text{ cm}$. The $z$ position of the vertex is restricted to this range to ensure a high (and better understood) acceptance for the calorimeter as well as for the central trackers. Also, events for which the interaction point could not be reconstructed properly are rejected.

- Energy distribution in the calorimeter: $38 < \delta < 65 \text{ GeV}$, with $\delta = E - p_z$ and $E$ being the event total energy. For a perfectly contained and measured DIS event, it follows from energy and momentum conservation that $\delta = 2E_{\text{beam}} = 55 \text{ GeV}$. Particles escaping down the beam-pipe in the forward direction have energies almost equal to their momenta in the $z$ direction and therefore their contribution to $\delta$ is negligible. The same is not true in photo-production: the electron escapes the detector through the rear beam-pipe and therefore $E_e$ and $p_{ez}$ do not cancel, effectively lowering the measured $\delta$. This cut is therefore effective at removing photo-production background events while keeping DIS events.

- Scattered electron: at least one candidate with probability larger than 0.9 according to the SINISTRA electron finder [31] and energy in the calorimeter of at least $10 \text{ GeV}$ is required. This electron is most likely to be the scattered electron.

- $y_e < 0.95$. This cut will remove fake candidates (such as neutral pions) mistaken for scattered electrons by the ZEUS reconstruction software.

- $y_{JB} > 0.02$. This cut is a convenience cut as in charm analysis well reconstructed tracks are required and thus reconstructable charm events will always pass this criterion. This cut is stronger than the cut used in inclusive DIS
5.4 DIS selection

Figure 5.3. This DIS event with $Q^2 \simeq 43 \text{GeV}^2$ was recorded in January 2005. The detector is seen in $r\phi$ view on the left and $z\theta$ view on the right. The interaction point (1) and the proton remnant (2) are marked on the right figure. Also an electron of 21 GeV is clearly seen in the calorimeter (3).

analyses. It removes events where the full hadronic system is contained near the beampipe in the proton direction.

- A restriction is made on the kinematic domain: $1 < Q_{DA}^2 < 1000 \text{GeV}^2$ and $0.03 < y_{DA} < 0.7$. For this, double angle variables are used.

This DIS selection is a standard selection for any ZEUS NC DIS analysis and therefore very well understood. In Fig. 5.3 and 5.4 two typical DIS events of $Q^2 \simeq 43 \text{GeV}$ and $Q^2 \sim 336 \text{GeV}$ are presented: the electron is found in the RCAL and the proton remnant flies in the forward direction, leaving energy deposits in the FCAL. In both figures, the calorimeter energy deposits associated with the scattered electron (3) and the proton remnant (2) are clearly visible. The interaction point is also explicitly labeled (1). In Fig. 5.4, the region around the interaction point has been enlarged (left figure). The beampipe and the first cylinder of barrel MVD ladders are visible. The primary interaction point (1) is pointed out, as well as a
two track secondary vertex (4).

For a subset of 240k events of raw data, the distributions in $E - p_z$, $Z$ vertex position, energy of the scattered electron, energy, the angle $\theta$ of the scattered electron, $\log_{10}(Q^2)$ and $\log_{10}(x)$ of the event are shown in Fig. 5.5. This is shown both excluding and including the DIS selection.

When searching for charm, it is necessary to identify the secondary vertices associated with the decay of the charm particle. For these vertices, high resolution is achieved if the tracks to be vertexed are well defined. This implies that a certain selection of “good” tracks should be performed for each event. Distributions of track characteristics such as momentum, number of MVD hits, $\eta$ and number of crossed superlayers in the CTD are presented in Fig. 5.6, after applying the DIS selection. The $\eta$ distribution is asymmetric, with more reconstructed tracks in the forward direction, due to the large proton boost along the positive $z$ axis. Well re-
5.4 DIS selection

Figure 5.5. Data plots: distributions of $E - P_z$, Z vertex position, the energy of the scattered electron as reported by the CAL, the angle $\theta$ of the scattered electron, $\log_{10}(Q^2)$ and $\log_{10}(x)$. The open squares represent distributions before the DIS selection is applied, the filled histograms are the distributions after DIS selection. The figures correspond to 240k events recorded during 4 runs in 2005.
Figure 5.6. Data plots. For all tracks, the following distributions are shown (from top left to bottom right): the number of hits in barrel MVD, MVD hits in the wheels, transverse momentum, pseudorapidity $\eta$ and the number of crossed superlayers in the CTD. The distributions represent the DIS selected data.
constructed CTD tracks, which crossed 5 superlayers and whose DCA $z$ coordinates were reconstructed within 10 cm around the origin of the coordinate system, are used to extract the barrel MVD efficiency shown in first plot of Fig. 5.6. About $\sim 90\%$ of all good tracks crossing the BMVD are associated hits in the MVD, as it can be inferred from Fig. 5.6. Both the pattern recognition software efficiency and the dead MVD channels influence this value. Also, there are tracks with more than 6 barrel hits ($3 r\phi + 3 rz$ hits, in 3 different cylinders), due to small overlaps of the edges of some neighboring ladders (see Fig. 3.14). In very rare cases, the maximum of 24 hits has been observed. For the forward MVD, the selected tracks do not always pass through the detector leading to an apparent loss in efficiency in Fig. 5.6. In Fig. 5.8 it is shown that tracks crossing at least 4 superlayers in the CTD have a corresponding polar angle larger than $\theta = 22^\circ$. For $\theta$ values around $19^\circ$, tracks will cross the first wheel of the FMVD and 2-3 CTD superlayers. This is valid for straight lines; low momentum helices can collect more hits in the FMVD and still cross few CTD superlayers. This analysis uses tracks within the pseudorapidity window $-1.6 < \eta(\text{track}) < 1.6$, corresponding to a polar angle range of $25.4^\circ < \theta < 154^\circ$. The large majority of the selected tracks will therefore leave at least 2 hits in the BMVD, ensuring a precise reconstruction of their position and momentum.

5.5 The Monte Carlo simulation

Charm quarks are generated and fragmented into a $D$ meson. Charm decay was modelled through eight different decay modes. Transverse momentum cuts for the charm mesons were introduced in order to generate Monte Carlo events efficiently in the kinematic region required by the measurement, as summarized in Table 5.2.

For this analysis, the Monte Carlo programs HERWIG[37, 38] and PYTHIA[39], which implement leading order matrix elements followed by parton showers and hadronization, were used to model the final state. Direct and resolved events were generated separately and in proportion to the cross-sections. As input for the proton and photon parton distribution functions\(^1\), the CTEQ5L[40] and GRV-G LO[41] were used.

After generating the final state partons using the Monte Carlo generators, events are input into the detector simulation. The detector simulation is performed by the

\(^1\)The photon PDF’s are used for the generation of resolved events.
Table 5.2. Modelled decay channels in charm Monte Carlo and their \( P_T \) cuts at the generating level.

<table>
<thead>
<tr>
<th>Decay modes</th>
<th>( P_T ) cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+ )</td>
<td>1.25 GeV</td>
</tr>
<tr>
<td>( D^{*+} \rightarrow D_s^0 \pi_s^+ \rightarrow K^0 \pi^+ \pi^- \pi_s^+ )</td>
<td>1.35 GeV</td>
</tr>
<tr>
<td>( D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi^+ \pi^- \pi_s^+ )</td>
<td>2.3 GeV</td>
</tr>
<tr>
<td>( D^0 \rightarrow K^- \pi^+ )</td>
<td>2.6 GeV</td>
</tr>
<tr>
<td>( D_s^+ \rightarrow K^- K^+ \pi^+ )</td>
<td>1.7 GeV</td>
</tr>
<tr>
<td>( D^+ \rightarrow K^- \pi^+ \pi^+ )</td>
<td>2.8 GeV</td>
</tr>
<tr>
<td>( \Lambda_c \rightarrow p K^- \pi^+ )</td>
<td>2.8 GeV</td>
</tr>
</tbody>
</table>

MOZART program which is based on GEANT 3.13 package\[42\]. The MOZART program simulates the interaction between particles passing through different components and materials of the detector and outputs the simulated detector response. Trigger simulation is also included. The MC events are reconstructed in precisely the same way as the data and stored into similar ROOT ntuples. These ROOT files also contain information on the generated physics event: the truth variables. The simulated sample used in this analysis has an equivalent total luminosity of 295 \( \text{pb}^{-1} \).

In Fig. 5.7, comparisons are made between data and simulation for the distributions of DIS variables \( E - P_Z \), the primary vertex \( Z \) position, the scattered electron energy and angle, \( Q^2 \) of the event and Bjorken \( x \). The same reconstruction software was used both in data and in Monte Carlo. The histograms were area normalized\[2\]. The shape of all distributions is well described by the simulation. A shift of few \( \text{GeV} \) to higher values is seen in the energy of the scattered electron due to imperfections in the dead material description. This also reflects in the \( E - P_Z \) distribution.

\[2\] Luminosity normalization cannot be applied when comparing distributions of events because light flavor events were not included in the simulation.
Figure 5.7. Distributions of $E - P_Z$, the primary vertex $Z$ position, the energy and angle of scattered electron, $Q^2$ of the event and Bjorken $x$ are compared in data and simulated files. The histograms are area normalized. The shape is well described overall. A shift of $\sim 2\text{ GeV}$ in the scattered electron energy is seen, producing a similar effect on $E - P_Z$. 
Figure 5.8. The ZEUS detector and its tracking detectors. A polar angle of $\sim 19^\circ$ or smaller ensures one or more hits in the FMVD. A polar angle bigger than $22^\circ$ corresponds to 4 or more superlayers in the CTD.