Table 6: Some design parameters of the VXD

Inner cylinder radius + thickness	99mm + 1.2mm
Outer cylinder radius + thickness	159mm + 0.72mm
Total thickness	$1X_0$
Active radial length	36mm
Active wire length	1590mm
Angular acceptance	$8.6° - 165°$
Number of cells	120
Number of sense wires per cell	12
Lorentz angle	$5°$
Gas	pure dimethyl ether

3.3 ZEUS trigger and data acquisition system

The background event rate due to beam-gas, beam halo, cosmic rays and unwanted soft photoproduction events is 5 orders of magnitude higher than the event rate from interesting physics which is only a few Hz at the HERA design luminosity. The task of the ZEUS trigger and data acquisition system is to select and write out interesting events to tape at a rate not exceeding 5 events per second. This is accomplished by a three-level trigger system.[41] The overall architecture of the system is shown in Figure 21. The first level trigger(FLT) works on a subset of partially digitized data. It looks at every bunch crossing(about 10MHz) and brings the trigger rate down to $1kHz$. An accepted event is then completely digitized and sent to the second level trigger(SLT), which is a network of microprocessors. It examines the FLT selected events and reduce the trigger rate to below $100Hz$. The EVB(event builder) collects event data of the SLT selected events from all components and sends the assembled event data to the SGI computer farm of the third level trigger(TLT). At the TLT, a complete reconstruction is performed and selections are made thereupon. Events selected by the TLT are sent to the DESY IBM computer and eventually written to data cartridges.

In design and building of the ZEUS trigger system, the most challenging part was the first level trigger, which has to deal with $10.4MHz$ bunch crossing rate at HERA. In order to reach a FLT trigger decision at every bunch crossing, while the processing of each event takes about 50 bunch crossings, event data from each bunch crossing are stored and processed in a pipelined manner. The FLT consists of the component FLTs and the global FLT(GFLT).[42,43] The component FLTs perform preliminary reconstructions locally at component subdetectors, such as the CAL and the CTD, and send the results, called the component FLT data, to the GFLT. The GFLT combines the component FLTs data and performs logical operations to generate subtriggers. The GFLT decision is logical OR of 64 subtrigger decisions with programmable prescale factors. There is no global veto in the GFLT. The Veto Wall veto, for example, is optionally included in some subtriggers. While the available component FLT data are determined by the component hardware design, the GFLT is implemented as programmable electronics module and is quite flexible. For example, new subtriggers, such as an elastic J/ψ subtrigger and a ρ subtrigger, were tested and incorporated during the 1993 runs. If the GFLT accepts an event, all components stop the storage pipeline read-in, and read out the accepted event from the pipeline. The GFLT sends out pipeline-restart command after all components have finished reading out, which typically takes $15\mu s$.

At the design stage of the ZEUS trigger system, it was foreseen that the GFLT trigger rate might exceed $1kHz$ due to high trigger rate of the CAL-FLT based subtriggers. Since the CAL-FLT relies on energy sums without particle identification, it suffers from the proton beam induced background more than other components such as LUMI which tags e and γ in the electron beam direction, and muon chambers which do not respond to most of the events. The CTD-FLT cannot be used as an independent trigger since it provides only the number of tracks with no vertex or momentum information. The CAL-FLT is therefore limited to accepting events with large energy(excluding the forward beam pipe region), large transverse momentum or significant energy deposit in the electron

Figure 21: The ZEUS trigger and data acquisition system.

beam direction. It is difficult for the CAL-FLT to trigger on those events which deposit energy in the forward direction and have only moderate transverse energy. This shortcoming was addressed by adding the Fast Clear(FC)[44] which further processes the GFLT accepted events. The available processing time for the FC is $70\mu s$(timeout set by the GFLT) or the time interval between two successive GFLT accepted events($50\mu s$ on average for 2kHz GFLT acceptance rate), whichever is the shorter one. This is much longer than the processing time available to the CAL-FLT which is about $2.5\mu s$(limited by the length of the pipeline). The GFLT can alter its decision on an accepted event if the FC requests abort before the timeout($70\mu s$) and before the GFLT issues the next accept. The FC abort is a veto recommendation to the GFLT final decision. The GFLT endorses the FC abort recommendation if the event is accepted by the CAL-FLT based subtriggers alone. The FC was not in use in the 1993 runs, when proton beam current was less than 10% of its design value and the background could still be handled although with high energy thresholds.

The input data to the Fast Clear are the EMC energy, HAC energy and tower address of each trigger tower, already digitized by the CAL-FLT. Since the arrival times of the particles are still unavailable at this stage, the FC does not act as a global veto trigger, but serves as a cleaner subtrigger for acceptance of DIS events. NC DIS events are recognized by isolated electrons within a certain kinematic region. CC DIS events have large missing transverse momentum. However, proton beam induced background events may also occasionally result in a large missing transverse momentum. The FC recognizes proton beam background events by an angle dependent cut on $R_f = (EMC - HAC)/(EMC + HAC)$ of the most energetic cluster, where EMC and HAC are energies in the EMC and HAC section of the cluster. The FC sends an abort recommendation to the GFLT if no isolated electron is found, and either the RCAL energy deposition is characteristic of the proton beam background or both the missing transverse momentum and $E - P_z$ are small.

The Fast Clear is a digital processor[44] designed and built by the Ohio State University group. The FC is essentially an unbuffered second level calorimeter trigger working in the time window(about $70\mu s$) set by the GFLT. The most critical requirement on the FC is the speed. The speed requirement is not compromised by the background rejection power of the FC. The strategy of the FC is to maximally make use of parallel and pipelined processing at a fast clock rate($60ns$). The design is implemented with ECL and CMOS logic. State-of-art programmable logic

Figure 22: Architecture of the Fast Clear processor.

array devices and micro-programmed controllers are used. The architecture of the FC is shown in Figure 22. The FC consists of 32 input cards for read-in and preprocessing the CAL-FLT data in parallel, 3 cluster cards for cluster finding in each calorimeter(FCAL, BCAL and RCAL) and 3 processor cards for cluster processing, and the trigger card for electron identification and trigger calculation. The CAL-FLT and the FC data are transferred to the EVB through a NIKHEF

2TP-VME transputer module. The author of this thesis designed and tested the processor card.

The second level trigger processor functions as an asynchronous pipeline, i.e. a series of parallel processors.[45] The SLT decisions are made in the order of events received. The SLT consists of the local SLTs and the GSLT(global SLT). At this stage, most of the digitized component data are available at the component event buffers. A network of transputers are used to process these data and transfer the results. Transputers are microprocessors with fast links with each other. The GSLT receives results from the component SLTs and combines the results to calculate the subtriggers and make the final decision. The GSLT decision is available about 5-7ms after the GFLT decision. Therefore each component should have a large buffer of about 15 events to store GFLT accepted events. During the 1993 runs, the SLT was only partially implemented. The GSLT rejects beam halo, beam-gas and cosmic muon events using the CAL timing information. More selective subtriggers will be implemented in the future to enhance background reduction. In comparison to the FLT, the SLT system is more flexible and allows for the addition of more processors, the addition and changing of algorithms and parallel execution on the processors. The GSLT decision is sent to the EVB(event builder).[47] If the GSLT decision is positive, the GFLT and GSLT trigger data are also sent to the EVB.

The EVB collects the component data, assembles the data into the final data format and sends the data to the TLT buffers. The EVB hardware is transputers. The TLT is a farm of SGI work stations. Events are processed in parallel by different work stations. The TLT code is written in fortran77. The code consists of a global veto and multiple branches of selective filters provided by the physics topical groups. The global veto rejects faked events from malfunction of the PMTs(5%), events with bad CAL time(15%), and cosmic and beam halo muons(5%). Then physics filters are applied to those events which pass the global veto cuts. The TLT accepts the logical OR of the various filters, each with a prescale factor. The prescale factors and cuts used in the physics filters are read in from data cards in the beginning of runs. In order to get a sample of minimum biased events, a small fraction of events at each level are accepted randomly. In 1993, the CTD track reconstruction at the TLT was still preliminary, with resolution in momentum far below that achieved in offline reconstruction, because calibration constants were not available online and more studies were needed in the first year of the CTD operation.

3.4 ZEUS detector simulation

When measuring a cross section, one tabulates the number of events in each bin of selected kinematic variables. In general, the observed number of events in each bin differs from the true distribution due to several reasons: (1) errors in bin assignment resulted from poor resolution in kinematic variables and energy loss in dead materials in front of the detector, (2) limited acceptance of the detector and and inefficiency of the triggers and filters, and (3) unwanted background events. A straightforward way to test whether an observed distribution has evolved from an assumed distribution is to compare real data and Monte Carlo data. One generates a sample of events according to the assumed distribution and pass the events through a simulated detector and triggers. Then the same set of programs used for reconstruction, event selection and analysis can be applied to the simulated events as if they were real data. The Monte Carlo method is extensively used in every stage of the experiment, from the detector and trigger design and event selection, to acceptance correction and error analysis. It also serves as an efficient and economical analysis and learning tool. In fact, more human and computer time are spent on simulated experiments than on real data in today's HEP experiments.

An observed event comes from a long and complicated series of reactions(for example, particle shower development in the calorimeter). If we can model the various elementary processes, the computer can build complex reaction chains for us. Simulation of the event production according to theoretical models is done by event generators which will be described in Chapter VI. More challenging and important is the detector and trigger simulation. An accurate simulation of