Experience with the ZEUS Trigger System

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The first three years' running experience of the ZEUS trigger system is reviewed. A three level trigger system was built to cope with the high frequency collisions and the high background rates. In 1994 the design performance was almost achieved at each level. The system is flexible enough to match the physics needs that change with increasing luminosity.

1. Introduction

To build a trigger system in the HERA environment is a challenging task. At HERA 820 GeV protons and about 30 GeV electrons (or positrons) collide with a 96 ns bunch crossing time. Such a high crossing frequency has not been experienced in other collider experiments.

The main backgrounds result from the interactions between the proton beam and machine elements or residual gas inside the beampipe. Due to the presence of synchrotron radiation from the electron beam, the vacuum condition is worse than in the case of proton-antiproton colliders.

The detector sees backgrounds in nearly 1 % of the beam crossings ($\sim$ 100kHz). These events are sometimes spectacular and very similar to the physics events.

The trigger system of a general purpose detector is required to handle a large variety of physics signatures. While keeping events which have a large energy deposit in the calorimeter, it should also have an acceptance for single muon events in order to catch W production and possible signs of new physics.

In the early stage of the experiment when the machine luminosity is still low, the requirements on the trigger are quite different from those at the design luminosity. At HERA the cross section of the very low Q^2 interactions (where the exchanged photon is almost real) is very large and the reaction rates are several hundred Hz at the design luminosity. The first few years are suited for the studies of these events, which means the requirements on the trigger change with time.

In order to satisfy various demands, the trigger system is needed to be sophisticated and flexible enough to select a variety of events and to handle the changes in requirements.

2. Structure of the ZEUS Trigger System

In order to cope with these difficulties mentioned in the previous section, ZEUS has chosen to use a three level trigger system[1].

At the first level trigger (FLT) data are processed in a pipelined manner. The decision is made 46 crossings, or $4.4\mu s$, after the crossing which caused the trigger. Until the decision arrives, the detector data are stored in either analogue or digital pipelines.

The subset of the data used for the FLT are first processed in each detector system with dedicated hardware processors, then sent to the global first level trigger box (GFLTB)[2], where the subdetector data are first aligned in time then combined with each other to make the final trigger decision.

One of the characteristics of the ZEUS FLT system is that almost all modifiable parameters to determine the trigger conditions are placed in the GFLTB. Detector components are continuously sending "trigger data" under the same conditions while defining the decision logic such as setting thresholds and making combinatorial logic is done at the GFLTB. The details of the GFLTB are described in the following section.

Once a trigger is issued from the GFLTB, each subdetector data acquisition system starts digitizing detector signals and buffering the event. By using the readout data, more precise trigger information is calculated and sent to the global second level trigger box (GSLTB)[2]. In the GSLTB data from each of the components are combined and finally the second level trigger (SLT) decision is made. The GSLTB, as well as most of detector SLTs, is implemented on a large INMOS transputer network where parallel processing is easily performed.

Upon receipt of a positive SLT decision, the data from each detector component are sent to local event buffers. The event builder (EVB)[3], which also consists of a transputer network, collects the data and combines it into an event. The event is sent to a processor station, part of a farm of 36 stations (30×SGI-4D/30S and 6×SGI-4D/25S) where the third level trigger(TLT)[4] is running, utilizing the complete event information from the whole detector.

The design output rate was set to 1kHz, 100Hz and 5Hz, for FLT, SLT and TLT, respectively. The design SLT output rate is already smaller than the physics rate, when HERA delivers the design luminosity of $1.5 \times 10^{31} cm^{-2} s^{-1}$. This means we already need to start selecting classes of physics events at the second level.

2.1. Global First Level Trigger Box

The logic of the detector FLT data is stable and independent of the runs to be taken. The logic definition for each run is set at the GFLTB where all data are combined. This centralisation makes it straightforward to control and modify trigger conditions.

As a consequence the GFLTB has to handle over 600 bits of data per crossing to take the final decision. The processing time assigned to the GFLT is 20 crossings or $1.92 \mu s$.

In order to handle the large amount of data, modules with memory lookup tables (MLT) are employed. They are 340mm-deep 9U-modules with a VME interface and contain 32 16bit-MLTs. Every four bits have common inputs, so that there are 8 independent sets of MLTs. Feeding these data to each MLT input is complicated. To ease this complication, programmable gate arrays (Xilinx XC3020) are placed at the input of the MLT. Up to 64 bits of trigger data can be fed into gate arrays, where the delays of all data are controlled. Finally, 16 bits of data are output for the MLTs.

This logic reduces the work of physical cabling between the MLTs. Cabling between the MLTs is mostly unchanged during a one-year running period. The connection logic for programmable arrays is stored in read-only memories, which are updated when the new trigger requires a new connection between MLTs. This happens only a few times in one year of running. Run-to-run trigger changes are done by rewriting the logic in the MLTs.

The FLT logic is constructed from three layers of MLTs (Figure 1). The output of these MLT layers consists of 64 subtrigger slots which carry Yes/No information. A different trigger logic (subtrigger) can be assigned to each slot. Each slot can individually be enabled. Each slot also has a prescaler so that prescaling of the subtrigger can be done at this level. The final FLT decision is the logical OR of the 64 slots.

The definition of the subtrigger is done with a C-like logic definition language. When a trigger designer defines a new subtrigger, the online trigger database and offline simulation codes are updated at the same time by a software tool, so that consistency can be maintained at all times. For every run, one can assign different subtriggers to trigger slots, specify threshold values and choose prescale factors.

All subtrigger definitions used since 1992 are stored in a database. In total, more than 600 subtriggers have been generated, including triggers for various detector tests. In a typical physics run in 1994, 36 out of 64 trigger slots were used for

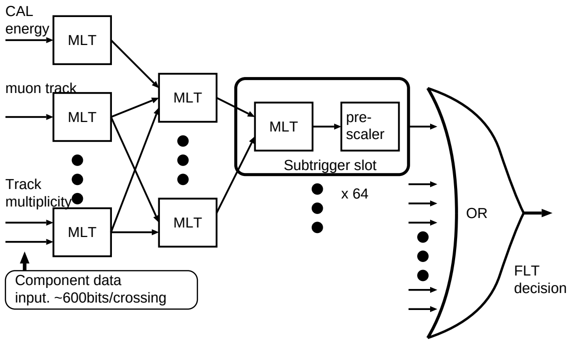

Figure 1. Schematic structure of the Global First Level Trigger Box.

physics, 8 for detector calibration and the rests for monitoring.

3. Running Condition in 1992-1994

Figure 2 shows the trigger rates of each trigger level for the three one-year running periods. The rates are plotted as a function of luminosity. The gradual increase of the HERA luminosity enables us to show each year's performance without too much overlap. Counting rates of small scintillating counters (C5 counters) are also plotted. The counters are located close to the beampipe and the rates are a good measure for the beam background condition.

As an example, this year's ZEUS data-taking during one positron fill is shown in figure 3. At the beginning of the fill the luminosity was $2.5 \times 10^{30} cm^{-2} s^{-1}$. The FLT rate at that time was more than 200Hz and the deadtime was just 1%. The run continued for 10 hours with occasional interruption due to HV trips in wire chambers.

We note the following:

- In 1994, the trigger system is almost running at the design specifications. The rate reduction by a factor of 10 at the SLT has been achieved. The FLT is running at up to 50% of the design rate. The data acquisition system has been proven to work with such high trigger rates. The TLT reduction factor was about four. This low reduction originates from the present physics requirements.

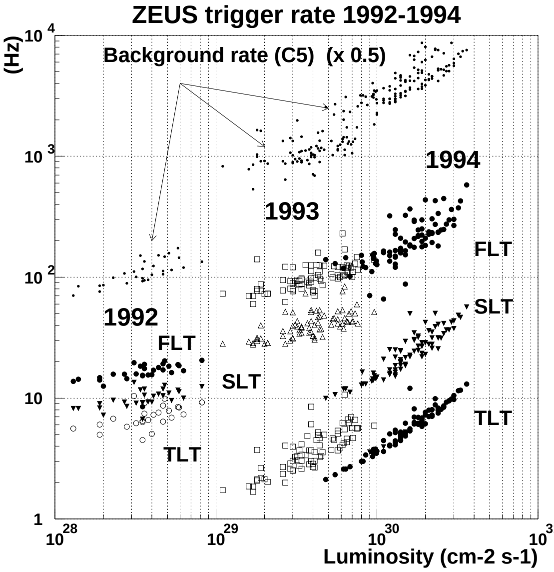

Figure 2. Trigger rates for each trigger level as a function of the HERA luminosity. Each point is corresponding to a data-taking run.

- The "bands" of the SLT and TLT rates seen in figure 2 are getting thinner every year. This means that the trigger rates are now almost a pure function of the luminosity and less sensitive to the background conditions which are varying from run to run. Note that the physics rates are already higher than the TLT output rate in 1993. The TLT output rate is determined by the decisions on which physics events we wish to archive on tape and not anymore by the background rate.

- The improvement from year to year is clearly seen. The reduction factor between the FLT and the SLT in one year is close to the one which has been achieved between the FLT and the TLT in the previous year. This is the result of our continuous effort to export previous year's TLT algorithms to the next year's SLT. In 1993, the background rejection with detector timing was

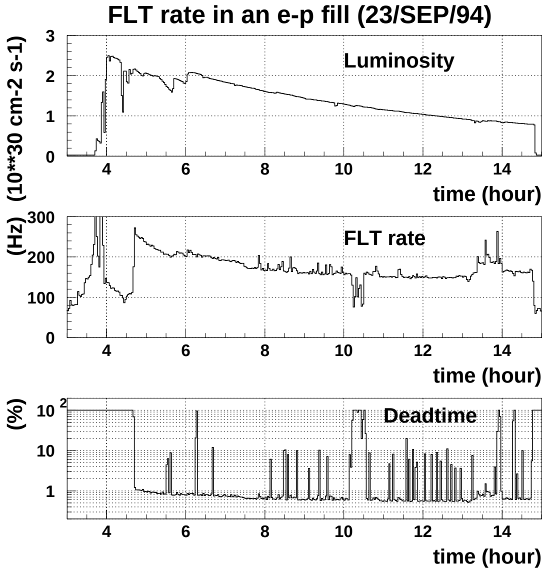

Figure 3. An example of the conditions during one positron fill.

moved from the TLT to the SLT and physics filters were moved in 1994. Both of these are discussed in the following sections.

- FLT rates in 1993 and in 1994 are on the same line so that it appears that no improvement was achieved. However, if the rate is compared with background rate, it turns out that the FLT rate was reduced by a factor two. Moreover, the acceptance of physics events was enlarged in 1994, although this is not visible in the figure. To keep the 1994 rate manageable considerable improvements were introduced. One example of this is the usage of a pattern recognition logic to find electrons. This is discussed in the subsequent section.

3.1. Background Rejection with Timing

The main source of background events is due to the proton beam. A large fraction of these events occur upstream of the interaction point. With a high probability detectors located on the proton beam side (rear detectors) suffer backgrounds coming from the back side, which cause hits with earlier times than those from physics events. By setting proper timing windows in the rear detector signals, a large fraction of the background can be rejected.

Since our main detector, the uranium-scintillator calorimeter (CAL), has a sub-nanosecond timing resolution, it is able to detect the beam background events which hit the rear CAL 12 nanosecond earlier than physics events originating from the interaction region. The detector is almost hermetic, which results in a high rejection efficiency.

In 1992 the background rejection with the CAL timing was done mainly offline and a conservative algorithm was installed at the TLT. In 1993, more stringent cuts were implemented both at the SLT and at the TLT. In 1994 the introduction of a small scintillator array at the rear CAL position allowed us to use timing already at the FLT.

3.2. Physics Filters

As previously mentioned, the physics rate is higher than the TLT output rate since 1993. In order to keep high efficiencies for interesting events, "physics filters " have been installed first in the TLT in 1993 then in the SLT in 1994.

As both have implemented the physics filters, the logical structure of the SLT and the TLT has become quite similar. At first, vetos like CAL timing rejection are applied to all events. Events which are not vetoed are then tested with filter algorithms. Several filters are defined by each of six physics groups. If one of the filters has a positive decision, the event is passed to the next level. In a manner similar to an FLT trigger slot, each filter can be prescaled individually, which allows each physics group to have monitoring filters for checking the efficiencies of the main triggers. In 1994 there were 27 filter algorithms in the SLT and 62 in the TLT.

The installation of the filters is performed in a close cooperation between the trigger group and the physics groups. The logic is defined by the physics groups and the coding is done by the trigger group. In case the logic requires sophisticated tools such as energy clustering, the development is done together.

The trigger group provides daily information on the trigger rate of each physics filter. The sharing of rates among the filters is determined by the physics groups.

This strategy has been very effective in ZEUS where, as typical for a general purpose detector, the physics topics are diverse and sometimes have contradictory requirements.

3.3. Pattern Recognition

To select interesting events, it is important to be able to identify jets and electrons. In 1994 a jet cluster algorithm and electron finders based on the CAL data were installed at the TLT. At the moment physics filters require the presence of those objects and the resulting physics filter rates have been significantly reduced. Since the kinematical variables of these objects are calculated, we can also make tighter cuts by imposing a certain kinematical range to them. This will be used to cope with future higher luminosity periods.

At the FLT, a pattern recognition logic to search for an isolated electron[5] has been implemented in the CAL trigger since 1993 and started being used in 1994. By requiring an isolated electron, the trigger rate for low-Q^2 deep inelastic events, where the scattered electrons enter in the rear CAL closest to the beampipe, was significantly reduced (Figure 4).

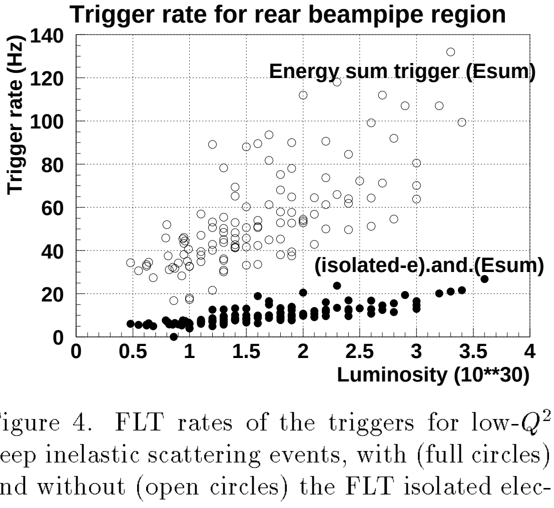

Figure 4. FLT rates of the triggers for low-Q^2 deep inelastic scattering events, with (full circles) and without (open circles) the FLT isolated electron finder.

4. Summary

The ZEUS trigger system has been running stably since the beginning of data taking in 1992. Adapting to the gradual increase of the HERA luminosity, the trigger system was gradually optimized. In 1994 the design performance was almost achieved.

The concentration of the logic definition of the first level trigger at the global trigger section has been successful. A trigger modification for a run using the trigger database is simple and a tool has been developed to keep consistency of logic through the frequent modification.

Due to the nature of the general purpose ZEUS detector, physics requests to the trigger system are diverse and sometimes in conflict. By introducing physics filters both at the second and the third level trigger and by allowing physics groups to define their own selection algorithms, the optimization of the triggers has been achieved quickly and efficiently.

The authors gratefully acknowledge the help of our ZEUS colleagues who work with us on the trigger system, as well as the ZEUS collaboration, which has provided the data we have presented in this report. We also thank the HERA machine group for providing us with a generous supply of beam-gas background to reject and much valuable physics to trigger on.

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