A New GTT Based Low Q² Neutral Current DIS D* Trigger For the ZEUS Experiment and MVD Track Residual Studies

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Abstract

This report details a new Global Tracking Trigger based low $Q^2 D^*$ trigger for the ZEUS experiment at HERA II. The trigger has both a higher efficiency and a lower rate than the trigger it replaces and has been designed for the high luminosity running expected at HERA II.

There is also a description of work undertaken with a view to improving the alignment of the ZEUS Microvertex Detector using physics tracking information.

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1 Introduction

The HERA collider at the DESY lab in Hamburg is the only proton-lepton collider in the world. It collides 920 GeV protons with 27.5 GeV electrons or positrons. The ZEUS detector is one of two general purpose experiments installed at HERA. It follows a broadly generic pattern for such detectors and a full description of its construction can be found elsewhere [1]. The components most relevant to this report are the Global Tracking Trigger (GTT) and the Microvertex Detector (MVD). These are described in more detail in this report.



Fig1: The ZEUS detector at HERA. The MVD with enlarged ladders and forward wheels are also shown.

Deep inelastic scattering (DIS) events at the HERA collider provide an excellent opportunity to study the characteristics of the charm and beauty quarks. Both of these heavy flavours are produced copiously at the HERA centre of mass energy (318 GeV). The production mechanisms of these quarks along with their cross-sections and contributions to the proton structure function f_2 can all be accurately measured in DIS due to the clean nature of such events and the relative ease with which they can be separated from background interactions. Such measurements are desirable as they lead to a deeper understanding of QCD which describes the strong force of nature.

1.1 Global Tracking Trigger

The ZEUS experiment utilises a three level trigger system. The first and second levels have global processors which evaluate the information provided by the individual component triggers for that level; they then decide if an event should be passed or dropped. The Global Tracking Trigger (GTT) is one such component trigger and its information is used in the global decision at the second level. As its name implies its decisions are made using tracking information from the event. However, unlike most other component triggers it uses information from several components in order to accept or reject an event. The Straw Tube Tracker (STT), Central Tracking Detector (CTD) and Silicon Microvertex Detector (MVD) are the relevant apparatus and when combined they are able to provide a much more accurate picture of the tracking characteristics of the event. Since it gives better information about the event it is expected that it will also be more able to distinguish between interesting physics events and background.

1.2 Silicon Microvertex Detector

The ZEUS MVD was installed inside the CTD in 2001. It has both forward and barrel regions but no rear region due to the asymmetry of collisions at HERA. The barrel region is made up of three superlayers, these are in turn are made from a total of 30 "ladders". Each ladder holds ten half-modules each composed of two single sided silicon strip detectors. The half-modules are orientated in such a way so that any particle traversing a ladder will pass through one r- ϕ and one r-z silicon detector. The silicon detectors have 512 strips with a readout pitch of $120 \,\mu m$. The forward region has a necessarily different structure. It consists of four wheels perpendicular to the HERA beam direction. The sensitive components of each wheel consist of two layers of fourteen trapezoidal sensors. The trapezoidal sensors have 480 strips with a readout pitch of 120 μm in the transverse and longitudinal planes.



Fig 2: Schematic of MVD forward wheels (left) and barrel cross section showing ladder positions (right)

2 GTT Trigger Study

2.1 Motivation

As the HERA II collider becomes better understood the luminosity delivered is becoming ever greater. This in itself is very good news as more luminosity leads to more interesting events to study. Unfortunately it also gives rise to possible problems in the trigger chain of the ZEUS experiment. For financial and technical reasons there is a limit to the rate at which events can be allowed through the three trigger levels. As the rates of interesting events increase these limits will eventually be exceeded unless the current triggers are tightened.

One expected change in the triggers is the rejection of lower Q^2 DIS events. This would undoubtedly reduce the rate of events but would also lead to the loss of interesting physics events. In order to avoid this loss it is necessary to design triggers that reclaim these lost interactions.

At present the heavy flavour physics group (HFL) has two GTT based triggers in operation, these are named GTT01 and GTT03. It is important that any new trigger not just duplicate the event selection of these but also fire on events that were missed by the existing algorithms. There is an existing GTT based neutral current DIS trigger named

GTT04, it was considered sensible to use this trigger as a starting point for any new trigger. The current incarnation of GTT04 has a logic that consists of a number of calorimeter energy deposit cuts as well as tracking cuts $0.143 < \Delta m < 0.148 GeV$.

2.2 Method

A good trigger should be able to reject background events (ie have a low rate). It should also have a very high efficiency at accepting the interesting events. In order to optimise these two aspects it is necessary to use two event samples. The first should be a sample of the type of interactions that you want to keep the second should consist of those that you wish to reject.

2.2.1 D* Sample Selection

A low Q^2 neutral current DIS D* sample was used to tune and evaluate the efficiency of the new trigger. A neutral current DIS trigger was used to tag the relevant events. The decay channel below was then used to tag the D* candidates.

$$D^{*\pm} \rightarrow D^0 + \pi_s^{\pm}$$

 $D^0 \rightarrow K^- + \pi^+ \text{ or } D^0 \rightarrow K^+ + \pi^-$

(where π_s^{\pm} indicates a slow pion produced when the D*[±] decays).

The following cuts were made on the sample in order to enrich the D* fraction as much as possible:

- $P_t(D^*) > 1.5 \text{ GeV}, |\eta(D^*)| < 1.5$

$$-P_t$$
 (K) > 0.4 GeV

$$-P_t(\pi) > 0.4 \text{ GeV}$$

- $P_t (\pi_s) > 0.12 \text{ GeV}$

It was also required that the mass of the reconstructed D^0 lies in the range 1.80 to 1.92 GeV. All events under the signal peak ($0.143 < \Delta m < 0.148 GeV$) were taken to be good D* candidates and used in the efficiency calculation. The final sample consisted of 1911 events.



Fig 3: The distribution of the mass difference $\Delta M = (M_{k\pi\pi_s} - M_{k\pi})$, for D^* candidates with $Q^2 < 10 \text{GeV}^2$.

2.2.2 Passthrough Sample

A representative sample of the events that you wish to reject is also required. For this study this "passthrough" sample consisted of any event that passed the calorimeter cuts of GTT04 but was passed through at the third level. This meant that the tracking cuts could be optimised to remove as much of the background events as possible whilst ignoring events already failing the calorimeter cuts. The passthrough sample consisted of ~85K events.

2.2.3 Variable Distributions



Fig 4: a) Distribution of the z position of the reconstructed primary vertex in D^* and passthrough events. The green distribution represents passthroughs that passed the original HFL07 trigger. b) The P_t sum of the two highest P_t tracks. c) The track multiplicity of the event. d) The number of event tracks fitted to the primary vertex.

The heavy flavour trigger GTT03 also has a cut on the P_t sum of the tracks associated to the vertex.



Fig 5: The P_t sum of all tracks that are used in the reconstruction of the primary vertex.

As can be seen this would be a good variable to cut on as the different samples are well separated.

2.3 New Trigger

After reviewing the various distributions and the cuts used in the other heavy flavour GTT based filters several changes were applied to GTT04. The cut on the sum of the two highest P_t tracks was removed along with the requirement on the z-position of the reconstructed vertex, The cut on the number of found tracks was loosened from five to three. Finally a cut on the vertex sum was introduced at 3 GeV. The efficiencies and rates of the original GTT04, the HFL trigger on which it is based and the modified GTT04 are shown in the table below. It can be seen that the modifications to the trigger produce a small increase in the efficiency over the original GTT04 logic. They also lead to large decrease in the amount of the passthrough sample kept.

Trigger	HFL07	GTT04	GTT04(mod)
% D*	96.0	94.2	96.8
% Passthrough	65.2	45.6	25.5

Fig 6: Percentages of D and passthrough samples that pass the three triggers HFL07, GTT04 and GTT04(mod).*

As mentioned previously in the text a successful trigger should also be able to reclaim events missed by existing triggers. Therefore it was also necessary to look at the correlated trigger rates for the three HFL GTT triggers. The results show that just 0.4% of the D* sample is rejected by all of the triggers but that this would increase to 3.9% if the modified GTT04 were to be removed. The results also indicate that more than half of the backgound events that pass the energy deposit cuts will be rejected by the three GTT triggers.

Trig Fired	01	03	04 (mod)	01 & 03	03 & 04	01 & 04	none	all
D* %	1.0	0.4	3.5	1.3	1.5	35.0	0.4	56.7
Pass %	14.5	1.7	2.0	1.2	0.7	14.5	58.3	6.9

Fig 7: Correlated trigger efficiencies and rates for the three HFL GTT based triggers.

2.4 Trigger Study Summary

In summary, the expected increase in the Q^2 cut in the ZEUS trigger chain will lead to a reduced rate but will also lead to interesting events being lost. In order to reclaim these events the GTT based heavy flavour neutral current DIS trigger, GTT04, has been modified. These modifications were tuned using a sample of low $Q^2 D^*$ and a sample of background events. The modified trigger both increases the efficiency and decreases the rate. The new trigger has now been implemented at the ZEUS second level trigger.

3 MVD Track Residual Studies

3.1 Motivation

The ZEUS MVD has a design resolution of ~20 μm [2]. To achieve this resolution it is necessary to know the position of the MVD and its component sensors to a similarly high precision. The current method of alignment utilises a global fit of cosmic track residuals. A residual in this case is defined to be the distance between a hit on an MVD wafer and the intersection of the reconstructed track with that wafer. If the sensor positions are properly known and the track reconstruction adjusted accordingly these residuals will have a Gaussian distribution about zero. The width of this distribution gives an indication to how well aligned the sensors are. Cosmic muon tracks have been used in the past as they are well defined and have high transverse momenta. These characteristics lead to small systematic uncertainties in the track fitting algorithms used to define the track helix. One drawback of using such tracks is that they need to be taken during dedicated cosmic runs and hence the data set is extremely limited. Another problem is that the alignment procedure is really only effective for tracks that are incident on sensors at non-grazing angles, this means that cosmic muon tracks cannot be used to align near vertical sensors.



Fig 8: How MVD geometry is altered in a global fit in order to minimise residual distributions and improve alignment. Q and P represent the hit position and the reconstructed track intersection respectively.

Both of these limitations would be avoided if one were to use tracks found during physics events. The tracks would intersect all sensors at non-grazing angles as this is exactly how the MVD geometry was designed. The size of the data set would also be massively increased and hence the statistical errors correspondingly reduced. Unfortunately the residuals of physics tracks have never been studied with a view for use in an alignment program. It is not yet known if they have a Gaussian distribution or if the high track multiplicities found in HERA collisions would produce enough background to distort this distribution. Hence this study.

3.2 Method

In order to calculate a residual both the spatial position of the sensor hit and the track intersection with the sensor are required. Unfortunately these coordinates are non-trivial to obtain. The hit position is the simpler of the two as you only require the planar

geometry of the MVD sensor and the strip position of the hit. The track intersection with the sensor is not calculated as a matter of course in the event reconstruction and so it was necessary to use a custom made routine. Thankfully a suitable algorithm was used in the MVD data quality management and could be easily adapted. The program uses an iterative algorithm that is similar in nature to the Newton-Raphson method for finding a zero point [3].



Fig 9: The plane is intersected by the track at S_t (distance along the track). The algorithm used to numerically find the intersection is given in the text.

The sensor is assumed to be an infinite plane for the purposes of this algorithm. The steps involved in the algorithm are detailed below[3]:

1. The shortest distance between the origin and the plane is $d = \hat{n} \cdot c$.

2. The vector \vec{r}_0 is the position of the track at s = 0. This is the first estimate of the intersection. The direction of the track at s = 0 is given by the unit vector \hat{v}_0 . 3. An imaginary line from \vec{r}_0 to the plane in the direction of \hat{v}_0 can be drawn. The length of this line is:

$$d_{\vec{r}_0} = d - \frac{\hat{n} \cdot \vec{r}_0}{\hat{n} \cdot \vec{v}_0}$$

4. If $d_{\vec{i}_0}$ is small enough then the algorithm is stopped and $s_t = d_{\vec{i}_0}$.

5. Two different situations can appear:

i: When $d > \hat{n} \cdot \vec{r_0}$ (ie in fig. 9) then the current estimate for $s_t = s_0$ is 'below' the plane and the new estimate for s_t is $s_1 = s_0 + d_{\vec{r_0}}$.

ii. When $d < \hat{n} \cdot \vec{r_0}$ then the current estimate for $s_t = s_0$ is 'above' the plane and the new estimate for s_t is $s_1 = s_0 - d_{\vec{r_0}}$.

6. Subsequently a new position $\vec{r_1}$ and new direction $\hat{v_1}$ of the track can be

calculated and the algorithm returns to step 2 with $s_0 = s_1$, $\vec{r}_0 = \vec{r}_1$ and $\hat{v}_0 = \hat{v}_1$.

This algorithm will always converge if the sensor is not parallel to the track at the point of intersection.

3.3 Refining the Program

The coding of the algorithm is necessarily complicated as it uses reconstructed data from the event that is not really designed with the end user in mind. It was perhaps inevitable that this type of complicated program would require some refinements before it produced realistic results.



Fig 10: Residual distributions obtained from original code. A bug was later found relating the initial parameterisation of the helix.

The initial results were disappointing. The distributions were clearly not Gaussian. The

distribution widths were also extremely large, often resulting in residuals greater than the dimensions of the sensor. However these features had not been seen when this code had been put to similar uses. This was attributed to the fact that previously only integrated residuals over whole ladders had been looked at. After some searching a bug was found in the calling sequence of the iterative algorithm. It involved the incorrect transformation of the reconstructed vertex position between several coordinate systems. As the helix parameters are defined with respect to the vertex this obviously affected the residuals produced.



Fig 11: Improved distributions with the second generation of code. New problems found in the implementation of the intersection algorithm,

Once this bug was fixed new results were produced. These were once again disappointing. In this case both the r-ø and z-ø distributions have a tighter distribution and the z-ø distributions also have an almost Gaussian distribution. Unfortunately the r-ø distributions have a very strange double peak structure. This feature is more obvious in some ladders than others and the variation follows what you would expect if it were due to poorly aligned ladders, ie the vertically orientated ladders have much worse distributions.



Fig 12: Residuals from third iteration of code.

The third incarnation of the code gives far superior results. The distributions for both r- σ and z- σ hits are reasonably characterised by Gaussian. Even more telling, the peaks have a narrow width ($\sigma \approx 0.002$ cm). Considering that these results have very few track quality cuts and there is some obvious background in the tails these results are encouraging.

Unfortunately there are hints that the most recent results are not entirely correct. In the inner cylinder there seems to be an asymmetry between the occupancy of the inner and outer layer half modules (odd and even numbered). This seems to indicate the presence of another bug which is being investigated.



Fig 13: a) Hit occupancy for the barrel halfmodules. b) occupancy for the inner cylinder.

3.4 MVD Residual Study Summary

After several iterations of the analysis code reliable distributions for hit residuals have been obtained. In the process of refining the code bugs have been found in both the MVD data quality management code. The refined distributions are now at a stage that they can be used to begin design of an alignment procedure that would use ep collision events to improve the resolution of the MVD. The first stage of this design would be to refit the reconstructed tracks and vertices without the existing cosmic alignment and see what effect this has on the residual distributions. It would also be desirable to reduce the non-Gaussian characteristics present in the plots, for example the excesses in the central bins and tails of the distributions.

4 Future Directions

The D* trigger that was designed will be implemented later in the year and no more work is anticipated on this subject. However, that is not to say that it will not be used in any future analysis. Any analysis that requires triggering on low Q² NC DIS events would make good use of this trigger. The MVD residual study is undoubtedly the more interesting in terms of long term benefits. Once the initial studies have been completed it is anticipated that a similar global fit program as that used for the cosmics will be constructed. This will lead to an improvement in the resolution of the MVD and all associated tracking packages. In turn this will allow much more refined physics studies to be carried out. From a personal point of view it is intended to allow the inclusive tagging of heavy flavour events via impact parameters and an extraction of the $f_2^{b\overline{b}}$ structure function. It is hoped that analysis of this nature will make up the core of an eventual thesis.

References

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- [2] E.N. Koffeman et al., Nucl. Inst. Meth. A 453, 89 (2000);D. Dannheim et al., Nucl. Inst. Meth. A 505, 663 (2003).
- [3] E. Maddox, A Kalman filter track fit for the ZEUS Microvertex Detector, (2003) ZEUS-03-008.

Appendix – GTT04 Trigger Logic

The logic of the original GTT04 trigger was:

- FLT 28,30,34,35,36,37,39,40,41,42,43,44,51,52,53,54,62, 38,46,57,59 (same as HFL7)
- E REMC > 2.5 .or. E BEMC > 2.5 .or. E FHAC>10 .or. E FEMC > 10
- E pz + 2*Elumig > 27
- ET > 4 GeV (no inner two rings of FCAL)
- GTT tracking:
- -40 cm < zvtx < 80 cm
- no of vertex tracks >= 2 .and. no of found tracks >=5 .and.
 (no of found tracks >= 16 .or. sum of two highest pt tracks > 0.8).

The logic for the modified low Q^2 NC DIS trigger is:

- FLT 28,30,34,35,36,37,39,40,41,42,43,44,51,52,53,54,62, 38,46,57,59 (same as HFL7)
- E REMC > 2.5 .or. E BEMC > 2.5 .or. E FHAC>10 .or. E FEMC > 10
- E pz + 2*Elumig > 27
- ET > 4 GeV (no inner two rings of FCAL)
- GTT tracking:
- P_t sum of vertex tracks > 3 .and. no of vertex tracks >= 2 .and. no of found tracks >=3