A Fast Track Trigger for the H1 Collaboration

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Abstract

The electron-proton collider HERA will be upgraded to provide higher luminosity in the year 2001. In order to enhance the physics output especially for exclusive channels, such as open heavy quark production, a low p_t Fast Track Trigger (FTT) with high resolution is build for the H1-Collaboration which reconstructs precisely all tracks measured in the central drift chamber in three dimensions within $25\,\mu$s. Curved tracks are reconstructed down to 100 MeV in a high track multiplicity environment with a momentum resolution of better than 5%. This complex and demanding task is tackled by a highly parallel track reconstruction algorithm. The first step identifies short track segments locally with a template matching technique using FPGAs. Segment linking using the CAM (content addressable memory) functionality of the Altera APEX 20Kx00E and track parameter optimisation using DSPs proceed in the second step within $20\,\mu$s. Finally, the derived physics quantities such as invariant masses are computed within some hundred μs using conventional processor boards. The full design is flexible and scalable with the capability to add information from other subtrigger systems.

Key words: HERA; H1; Track-Trigger; Drift Chamber; Pattern Recognition; CAM

Introduction

At the HERA accelerator at DESY collisions of 920 GeV protons and 27.6 GeV electrons (positrons) are studied. In the years 2000 and 2001 HERA will be upgraded to gain sensitivity for rare processes due to the anticipated increase in luminosity. Therefore, expected higher *ep* interaction and background rates will place a considerable strain on the H1 data acquisition [1] necessitating an upgrade of the existing trigger system. At HERA every 96 ns bunches of electrons and protons are collided. Reactions are triggered by a multi-stage triggering system (L1-L4) reducing the large input rate of $\mathcal{O}(1$ kHz) for processes with transverse momentum transfers $Q^2 > 1$ GeV^2 (DIS=deep inelastic scattering) to about 10 Hz. Events with $Q^2 > 100$ GeV^2 are triggered inclusively by calorimeter triggers with high efficiency also after the upgrade. However, exclusive final states – especially those containing heavy quarks – with low transverse momentum particles are more difficult to trigger because they cannot easily be discriminated against the bulk of inelastic DIS data. In order to maximise the available post-upgrade statistics for such processes, the H1 collaboration is building a Fast Track Trigger (FTT) [2] which shall supply information to the first three trigger levels of the H1 triggering system [3, 4] and will be capable of performing complex analysis such as fast track finding and invariant mass sums of charged particles within 25 and 100 μs, respectively. This report outlines the concept and design of such a FTT system.

Hit and Track Segment Finding at Level 1 (2.3 μs)

The FTT functionality is based on information of the H1 central jet chamber (CJC) which consists of two concentric drift chambers, the inner CJC1 and the outer CJC2, with 24 and 32 radial wire planes, respectively [5]. Trigger signals are built from four groups of three wire planes each, three of them inside CJC1 and one within CJC2 as shown in figure 1a. After amplification signals are digitised at 80 MHz using 8 bit linear FADCs and passed to a farm of Altera APEX 20K600E FPGAs. Hit data are next synchronised into shift registers, as shown in figure 1b. Track segments are defined by a three layer coincidence matching predefined patterns of vertex constrained tracks, which are basically characterised by straight lines. The search is realised by feeding the bit patterns from selected regions of the shift registers into parallel CAMs (content addressable memory), which are operated in a multiple match mode allowing for the possibility of more than one track segment within the same region. The output CAM addresses are fed to tag fields, which output the register positions. The track segment search is started using coarse hit information corresponding to a 20 MHz synchronisation and refined by restoring the original 80 MHz synchronisation. Finally track segment parameters are looked up from a list of refined valid masks which have been stored in SRAMs. In parallel with the first stage track segment finding, the z coordinate of the track segment is calculated using a charge division technique by analysing signals from both ends of wires. This information is then passed to the level 2 stage of the FTT using LVDS links.

Track Reconstruction and Trigger Information at Level 2 (20 μs)

The level 2 stage of the FTT is responsible for linking the track segments at the same $p_\perp$ and ϕ from the four groups of wire planes, for fitting the track parameters, and for forming a trigger decision by applying relatively simple trigger logic. For this purpose a generic level 2 FTT trigger card is being developed in collaboration with SCS [6]. That multi-purpose card implements several functions, which are described in the following. In a first stage input data taken from 30 level 1 cards are merged to a single 'linker' card. The linking is again realised using CAMs, which recognise similar $p_\perp$ and ϕ values in different layers and use a pre-clustering algorithm to find the optimal values for the overall track. Next, the linked tracks are passed to a 'fitter' card, which uses DSPs [1] to execute track fitting algorithms, improving the track parameter resolution considerably. The output from the fitter cards is then passed to 'decision' cards, where the final level 2 trigger signals are formed by e.g. calculating momentum sums or analysing event topologies. The track parameters themselves are passed onto the third FTT trigger level for further investigation.

Determination of Invariant Mass Sums on Level 3 ($\lesssim$ 100 μs)

The third stage of the FTT will perform detailed analysis on the full set of tracks extracted at level 2 to search for decays of rare particles like $D^* \to D^0\pi_{\rm slow} \to K\pi\pi_{\rm slow}$. To gain with respect to the total readout time of approximately 1 ms the final decisions should be available within around 100 μs of the interaction. Several single CPU VME-boards will be operated, each receiving the complete level 2 FTT information via a special interface card and hence analysing the same data to search for different event signatures. Studies have shown that one 500 MHz processor is sufficient to search for "golden decays" of D^* mesons. The efficiencies for triggering D^* mesons is found to be in excess of 80 % relative to a typical off-line selection, whilst keeping the corresponding trigger rates reasonably low.

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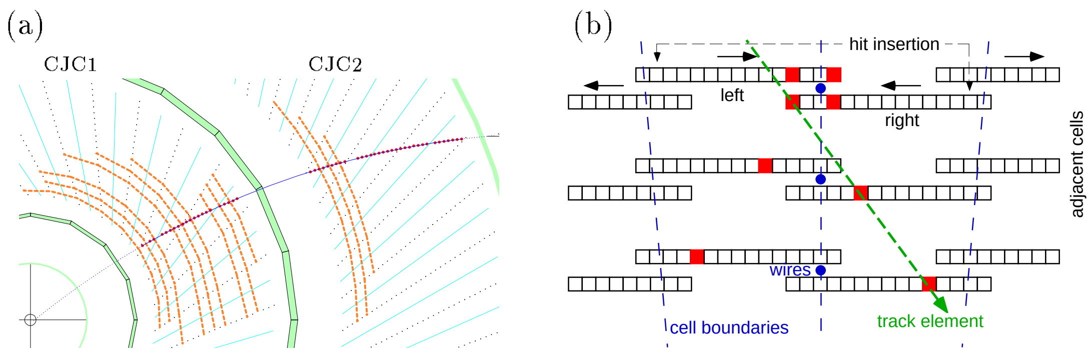

Fig. 1. (a) $r\phi$ view of the central drift chamber showing a track passing through. The position of the sense wires, the cathode planes and the chamber boundaries are also shown. The four groups of wire planes used by the FTT are indicated by the thick dashed lines. (b) Schematics showing the hit pattern recognition of track segments using shift registers at the first trigger level L1.

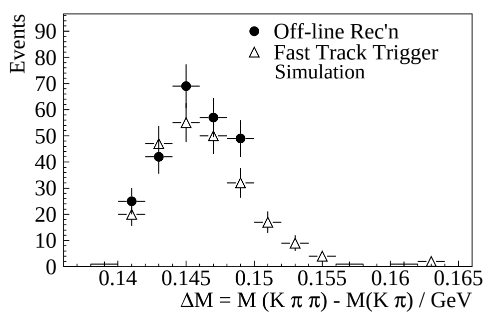

Fig. 2. Illustration of the expected $\Delta m = m(K\pi\pi_{\rm slow}) - m(K\pi)$ resolution of the proposed trigger. The solid circles show the Δm distribution of a sample of D^* candidates from DIS events collected by H1 in 1997, as reconstructed using the best available off-line analysis tools ($|m(K\pi) - m(D^0)|$ <0.08 GeV, Δm <0.15 GeV). The open triangles show the Δm distribution for the same sample of events with tracks reconstructed using the simulation of the proposed track trigger.