First Results from the First Level of the H1 Fast Track Trigger

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***Abstract*— The H1 experiment at the electron-proton collider HERA has built a new Fast Track Trigger to increase the selectivity for exclusive final states and to cope with the higher background rates after the HERA luminosity upgrade. Hits measured in the central jet chamber of H1 are combined to track segments by performing 5×10^{12} mask comparisons per second using Content Addressable Memories (CAMs). These segments are collected and transmitted via 5 Gbit/s LVDS links to custom made Multi Purpose Boards and linked to tracks. The latency of the fully pipelined processing chain implemented in programmable logic (FPGAs) is 0.72 μs.**

During the summer 2004 running period, the FTT level one system delivered first physics triggers from which performance figures were extracted. A single hit efficiency of more than 95% was achieved, and first studies on the p_T resolution of tracks were performed using triggered ρ meson candidates.

***Index Terms*— Track trigger, online reconstruction, pattern recognition, H1, HERA.**

I. Introduction

THE HERA accelerator at DESY, where 920 GeV protons are collided with 27 GeV electrons (positrons) at a frequency of 10.4 MHz, has been recently upgraded. In order to enhance the selectivity for exclusive final states and to exploit thus the higher luminosity provided by the upgrade, the H1 experiment [1],[2] has built a new three level Fast Track Trigger (FTT) [3]. The FTT provides information with an increasing level of accuracy for the first three trigger levels of H1. The level one system discussed in this paper, replacing the old Drift Chamber r-ϕ trigger [4], has been commissioned in the summer of 2004. The higher levels will come into full operation during the 2004/2005 running period.

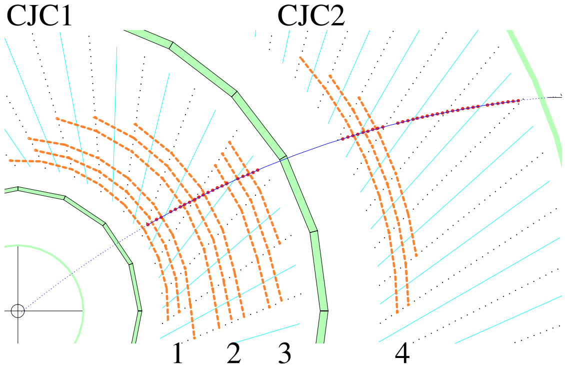

Fig. 1. r-ϕ view of a charged particle track passing through the central drift chamber of the H1 experiment. The four trigger layers consisting of three wires each are indicated by thick dashed lines.

II. The FTT Level One System

A. Digitisation and Hit Finding

The FTT trigger decisions are based on information from the Central Jet Chamber (CJC) of the H1 experiment. The analogue signals from both ends of selected wires arranged in four groups of three wire layers each (see figure 1) are tapped. The three inner layers are located in the CJC1 and have 30 azimuthal cells whereas the fourth layer is located in CJC2 and constituting of 60 cells. The information from five cells (15 wires) is collected on one of thirty Front End Modules (FEMs) (see figure 2 for an overview of the FTT level one data flow), where the signals are digitised with a 80 MHz sampling rate by 15 dual 10 bit ADCs (Analogue Devices AD9218-80). The digitised information is then processed by five FPGAs (Altera APEX 20K400E). Hits are identified by a Qt algorithm. The z-coordinate (along the

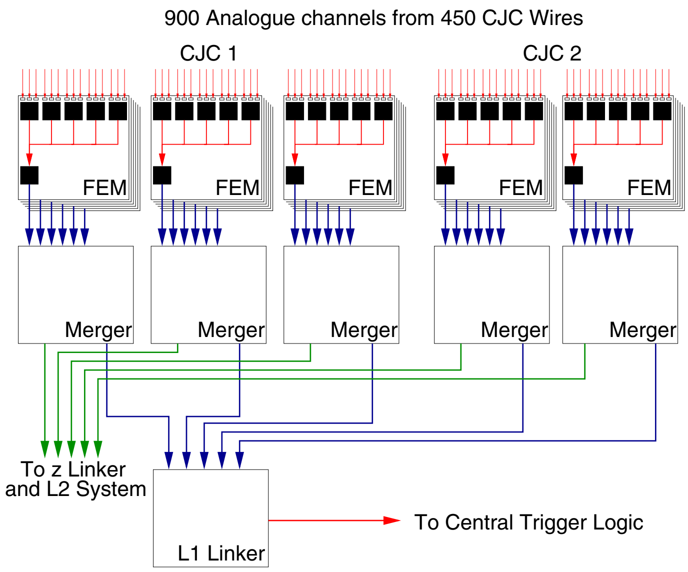

Fig. 2. Overview of the data flow in the FTT L1 system.

beam and chamber wire direction) is determined via charge division [5].

B. Track segment finding

The identified hits are filled into shift registers running at 20 MHz. For every HERA bunch crossing the shifted hit information is compared with up to 3072 masks per group of three wires. These comparisons are done in parallel, using Content Addressable Memories (CAMs) thus allowing for $5 \cdot 10^{12}$ mask lookups per second in the FTT system.

The pre-calculated, calibrated track curvature (κ) and azimuthal angle (ϕ) of the found track segments are collected and sent via a 5 Gbit/s Low Voltage Differential Signalling (LVDS) link to one of five *Merger cards*. The Merger cards are FTT Multipurpose Processing Boards (MPBs) [6] programmed to collect data from one trigger layer (CJC1) or one half layer (CJC2), respectively, and to forward the multiplexed data either to the *L1 Linker Card* or to the *L2 Linker card* depending on the input data and the operation mode.

C. Track segment linking

A dedicated MPB equipped with an Altera APEX 20K600EFC FPGA serves as L1 Linker card. Here the found segments are filled into 16×60 bin histograms representing the κ-ϕ plane for each layer. Tracks are identified as coincidences of at least two track segments from different layers. Based on the multiplicity, the transverse momenta and the topology of these tracks, trigger elements are generated and sent to the H1 central trigger logic. The trigger decision is available within the H1 level one latency of 22 HERA bunch crossings (2.112 μs); about 1 μs of this time is used up by the long drift times in the chamber. The track finding algorithm itself — after digitisation, but including internal transmission delays — takes 0.72 μs; see table I for details.

TABLE I
TIMING OF THE FTT LEVEL ONE ALGORITHM

Delay due to	*Delay* [μs]	*Cumulated* [μs]
Ionisation and drift in CJC	1.056	1.056
Analogue cable delay	0.180	1.236
FEM: Digitisation in ADCs	0.060	1.296
FEM: Hit finding	0.036	1.332
FEM: Segment finding	0.096	1.428
FEM: Data collection and multiplexing	0.086	1.514
Transmission to Merger	0.070	1.584
Merger: Multiplexing	0.086	1.671
Transmission to L1 Linker	0.060	1.731
L1 Linker: Receiving and sorting	0.077	1.808
L1 Linker: Linking	0.048	1.856
L1 Linker: Pipelining	0.096	1.952
L1 Linker: Trigger decision	0.067	2.019
Transmission to Central Trigger Logic	0.048	2.067
Latency of FTT logic only	—	0.722

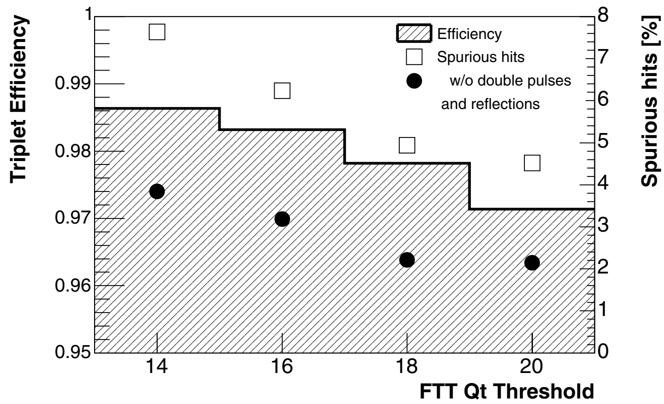

Fig. 3. Single hit efficiency as determined by the *triplet method* (histogram, left scale) and percentage of triplets with additional spurious hits on the middle wire before (open squares, right scale) and after removal of double pulses and signal reflections (filled circles, right scale).

III. PERFORMANCE

A. Hit finding efficiency

The single hit efficiency of the FTT as a function of the threshold was determined using the *triplet method*, i.e. asking whether there has been a hit on the middle wire of a group if there were hits on the outer two wires. This efficiency, determined for cosmic ray muons, lies well above 97% for *Qt*-thresholds safely above the noise level (see figure 3). The number of spurious hits is estimated by determining the percentage of additional hits on the middle wire if there is exactly one hit on each of the two outer wires. This percentage was found to be 4.5% for the threshold of 20, where the FTT was operated during 2004. About half of the spurious hits stem from double pulses caused by large charge depositions and reflections on the analogue cables. Simulation studies [7] have demonstrated that the requirement of three out of three hits for segment identification allows for running at noise levels of up to 10% without a significant degradation of the performance. Comparisons with the existing drift chamber readout also yield

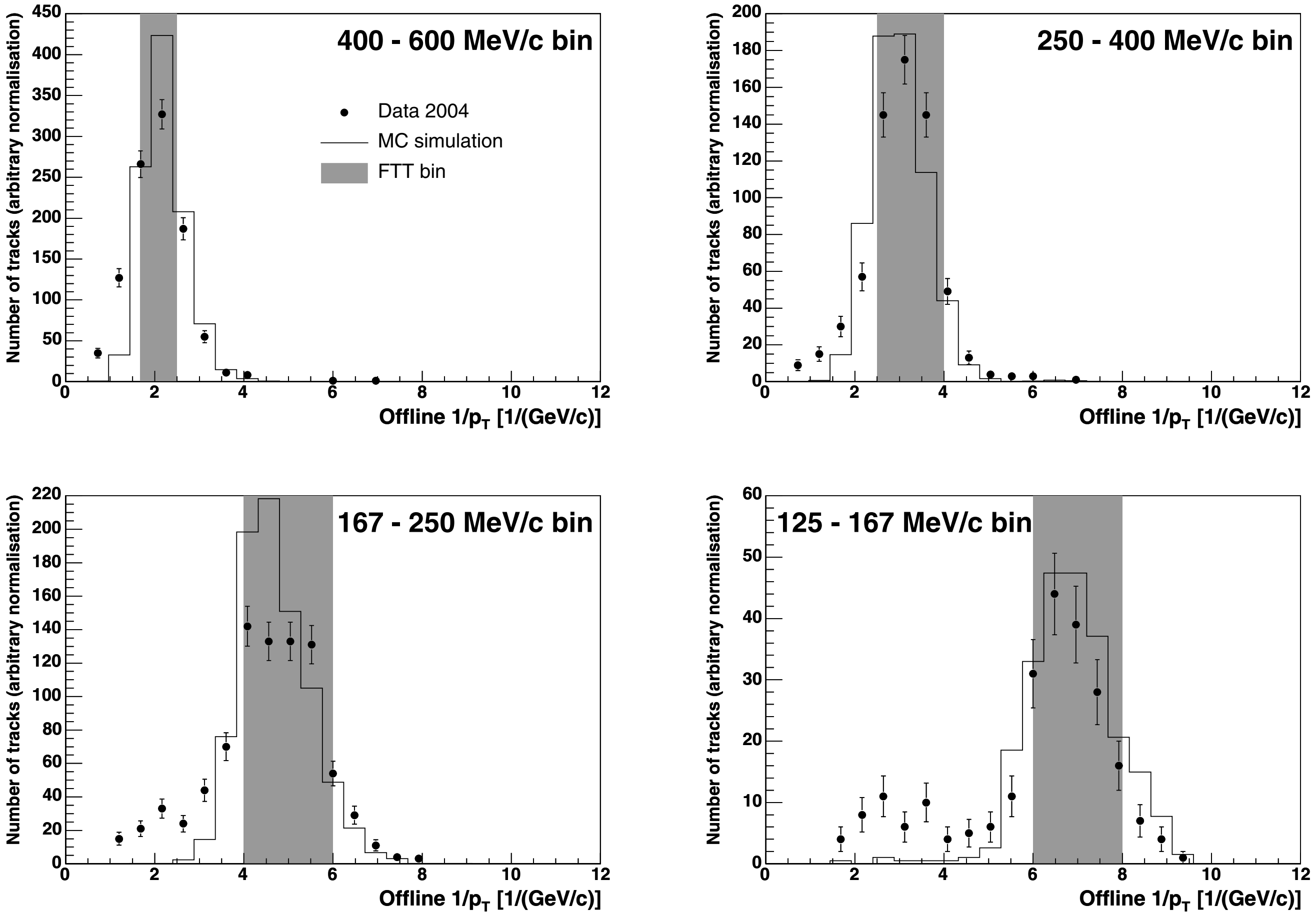

Fig. 4. Transverse momentum (p_T) resolution of the level one FTT: The offline reconstructed p_T of negatively charged tracks found in a FTT p_T trigger bin is plotted for four p_T trigger bins. The actual trigger bin is indicated by the grey shaded area. The open histograms show simulated elastic ρ meson production processed by the FTT simulation and normalised to the data.

single hit efficiencies of above 95%.

B. Track segment finding efficiency

The track finding efficiency in the 2004 running period was about 50%. This low efficiency is due to the fact that the links providing hit information from neighbouring cells to the segment finding algorithm were not in operation yet, thus leading to a loss of roughly half of the track segments.

C. Transverse momentum reconstruction

The transverse momentum reconstruction of the level one FTT was tested by comparing tracks found in the full H1 offline reconstruction with the corresponding FTT tracks. In figure 4 the transverse momentum is shown as determined by the offline reconstruction for tracks found in four of the eight FTT p_T bins. Due to the low segment finding efficiency, most tracks are linked from only two segments (at design efficiency, an average of three segments per track is expected), leading to a smearing of thresholds. A comparison with a sample of simulated elastic ρ production events processed by the FTT simulation shows however that this effect is small and the FTT p_T reconstruction works as expected.

D. ρ production as a physics test case

Although most of the 2004 running period was used for commissioning and calibration, some FTT physics triggers were installed and delivered first performance results. Due to its high cross section and its specific track topology, the diffractive production of ρ mesons and their subsequent decay to two charged pions served as a test case for the FTT. Events with two oppositely charged tracks of at least 160 MeV/c transverse momentum were triggered. The track p_T spectrum and the mass of the FTT triggered ρ candidates as determined by the offline reconstruction are shown in figure 5. In addition, the FTT sample is compared to events triggered by the old drift chamber trigger (DCrϕ-trigger). This trigger has a transverse momentum threshold of 400 MeV/c and limited track counting capabilities. Because of the low average transverse momentum of the ρ decay particles at most one track above 400 MeV/c is expected. Therefore the trigger condition requires only one

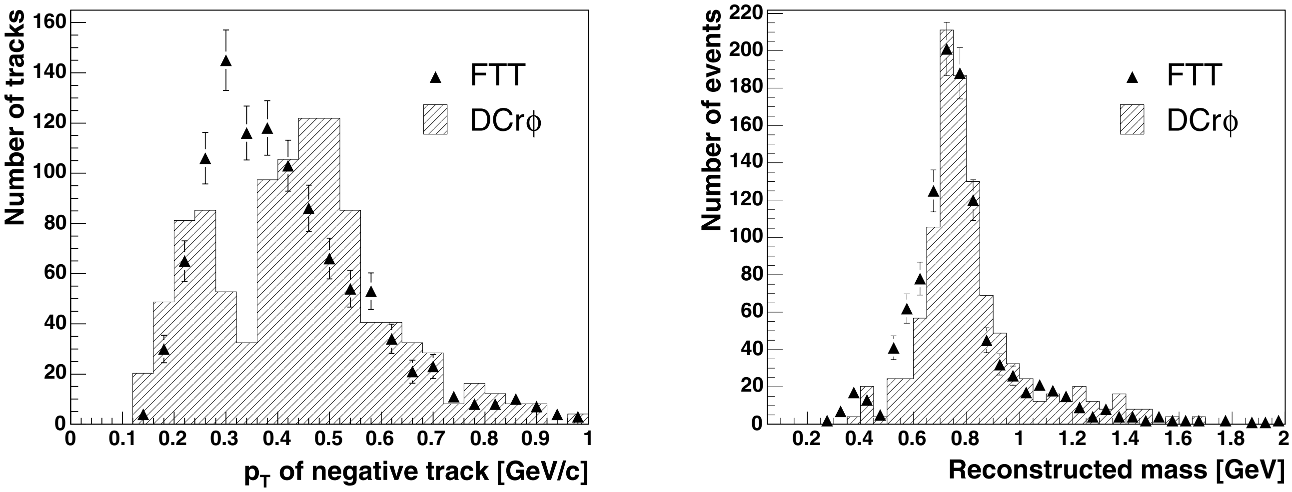

Fig. 5. The transverse momentum distribution for the negatively charged tracks and the offline reconstructed mass of triggered ρ meson candidates are shown for events triggered with the FTT and with the old drift chamber trigger (DCrϕ – normalised to the FTT histogram).

track seen by the trigger. The p_T distribution of the DCrϕ triggered events shows two peaks - one above 400 MeV/c, originating from tracks which fired the trigger and one at low momenta, originating from tracks not seen by the trigger. In contrast, the lower FTT threshold of 160 MeV/c does not cut significantly into the transverse momentum distribution of the decay tracks. As a result, the reconstructed invariant mass distribution of the FTT triggered events does not show a bias towards higher masses as opposed to the corresponding distribution for DCrϕ-triggered events.

IV. Conclusion and Outlook

The level one FTT system is in operation and delivering first trigger decisions. The digitisation and hit finding steps fulfil the specification whereas the segment finding step suffered from the missing links to the neighbour cells, effectively loosing half of the segments. The links will be in operation from the beginning of the next running period thus leading to an increased efficiency.

In addition, the FTT level two system will provide a full on-line track reconstruction in three dimensions with high precision. These tracks will be used by the level three system, consisting of a farm of commercial PowerPCs, to select events based on the calculation of invariant masses. The higher level systems, which are already installed, will be commissioned in the upcoming 2004/2005 running period.

References

[1] I. Abt *et al.*, "The H1 detector at HERA," *Nucl. Instrum. Meth.*, vol. A386, pp. 310–337, 1997.

[2] ——, "The tracking, calorimeter and muon detectors of the H1 experiment at HERA," *Nucl. Instrum. Meth.*, vol. A386, pp. 348–396, 1997.

[3] A. Baird *et al.*, "A fast high resolution track trigger for the H1 experiment," *IEEE Trans. Nucl. Sci.*, vol. 48, pp. 1276–1285, 2001.

[4] T. Wolff, "Development, construction and first results of a dead time free track finder as trigger for the H1 experiment at the HERA storage ring. (In German)," Ph.D. dissertation, ETH Zuerich, 1994, DISS-ETH-10408.

[5] A. Schoning, "A fast track trigger for the H1 collaboration," *Nucl. Instrum. Meth.*, vol. A518, pp. 542–543, 2004.

[6] D. Meer *et al.*, "A multifunctional processing board for the fast track trigger of the H1 experiment," *IEEE Trans. Nucl. Sci.*, vol. 49, pp. 357–361, 2002.

[7] H1 collaboration, "A Fast Track Trigger with high resolution for H1," 1999, proposal submitted to the Physics Research Committee, DESY internal report PRC 99/06 and addendum PRC 99/07.