The HERA-B Level 1 Trigger

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Abstract

The HERA-B experiment at DESY, Germany, analyzes interactions of 920 GeV protons with a fixed target to measure CP violation. The described HERA-B First Level Trigger has to process, in real-time, about 10^5 channels of detector data which are read out every 96 ns. At a latency of at most 10 μs, it has to reduce the 10 MHz event rate by at least a factor of 200. To determine possible particle trajectories it applies a Kalman filter inspired track search method. The tracking can be initiated by one of three independently working pretrigger systems that also provide particle identification. The trigger decision is based on the momenta and masses of reconstructed track pairs.

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1 Introduction

The HERA-B detector is designed to observe CP violation in the B-meson system. The experiment, located at DESY, Hamburg, will initially investigate the decay $B^0 \rightarrow J/\psi\, K_S^0$, the so called Golden Decay. This will be followed by probing other B-decays. The trigger is highly specialized for finding J/ψ's coming from the detached vertex of a B, but it also needs to be flexible enough to incorporate future extensions of HERA-B's physics program [1] [2] [3].

Bottom mesons are produced by inserting thin wire targets into the halo of HERA's[2] 920 GeV proton beam. On average one in 10^6 interactions contains b quarks. In addition, the branching ratios of the rare decays of interest are of order 10^{-5}. In order produce a large number of B mesons the interaction rate[3] will be 40 MHz. The huge background, but also the large number of detector channels and high event rate, makes HERA-B triggering a special challenge.

Therefore, an efficient, highly selective trigger and a high bandwidth, low latency data acquisition system had to be built. The pipelined trigger system consists of four different levels. The First Level Trigger hardware consists of custom made electronics. All higher level triggers are implemented as commodity PC farms [4].

The initial trigger strategy of HERA-B aims to find J/ψ's from the Golden Decay already in the First Level Trigger (FLT). In 12 % of the cases a J/ψ decays into two leptons of opposite charge. The FLT uses this signature and looks for charged tracks in the field free region downstream of the magnet, see Fig. 1.

Extensions of the physics program may require to trigger on high-$\mathrm{p_T}$ hadrons. In such cases the First Level Trigger can demand that the event data contain hadrons with large transverse momentum [5].

2 Trigger Scheme

The J/ψ candidate is identified through two opposite charge electrons or muons having an invariant mass consistent with the mass of the J/ψ. The FLT reconstructs the lepton tracks, then, measuring the respective momenta and charge, it determines the dilepton invariant mass. The FLT starts from track seeds provided by a pretrigger. Its tracking algorithm utilizes detector data of the tracking chambers. For an overview of the connection between the FLT and the HERA-B detector, please, refer to Fig. 1.

In total there are three pretrigger systems. The muon pretrigger uses the hit information of the cathode pad chambers of the last two superlayers of the muon system. The electromagnetic calorimeter (ECAL) measures the energy that is deposited in its cells. The ECAL pretrigger electronics sums up the energy of all three by three cell arrays. The energy sum of these groups of nine cells are called cluster energy. Based on a programmable ECAL cluster energy threshold a pretrigger is generated. In addition to this energy threshold there is also the possibility to flag pretrigger candidates with energies above a second much higher cluster energy. ECAL trigger candidates with the higher cluster energy are assumed to be hard photons. This provides an extension to the di-lepton trigger scheme, since it allows triggering on photon decays as well.

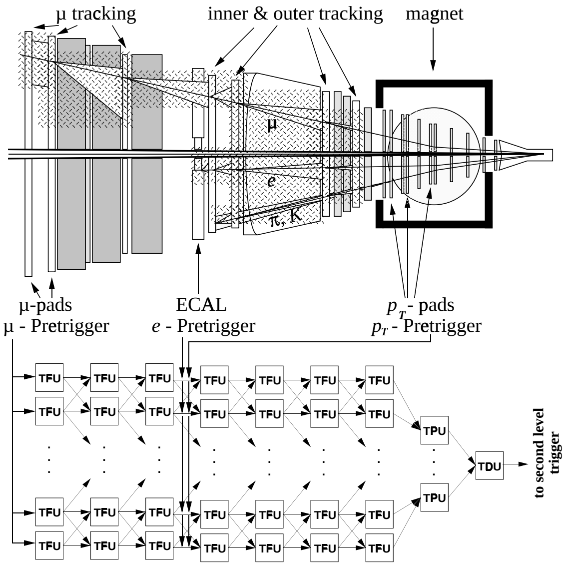

Figure 1: The First Level Trigger and its connection to HERA-B: The top sketch shows HERA-B (interaction region to the right), the bottom drawing shows the connection scheme of the FLT boards.

The third pretrigger type is directed at finding hadrons with large transverse momentum. The high-$\mathrm{p_T}$-pretrigger uses three layers of pad chambers located inside the magnet. This pretrigger can, for instance, trigger on the decay $B^0 \rightarrow \pi^+\pi^-$, or on hadrons from B_s decays and opens the door to study rare B decays [5].

The three pretriggers work in parallel and independently. If a suitable candidate is found, this information is passed on to the FLT. A demanding task of the FLT is to perform very fast online tracking. It uses a Kalman filter inspired method and reconstructs tracks in the field free region, see Fig. 1, using a subset of tracking chambers of the inner tracker (MSGCs), the outer tracker (honeycomb drift chambers), and the muon tracker (tube chambers, gas pixel

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[2] Hadron Elektron Ring Anlage = hadron electron ring facility

[3] several interactions occurring in *one* bunch crossing comprise one event

chambers) [3]. A hit in every trigger tracking layer is required; an electron, for example, has to be detected by 12 detector layers of four superlayers. A very high detector efficiency is therefore obligatory. Once tracks are reconstructed, their kinematical parameters and the invariant mass of track pairs are determined by the FLT and the trigger decision is derived from these measurements [6].

Using a complete detector and trigger simulation the trigger efficiency was determined. The reconstruction efficiency was found to be 35 % for the decay $J/\psi \rightarrow e^+e^-$, 55 % for $J/\psi \rightarrow \mu^+\mu^-$, and 28 % for $B^0 \rightarrow \pi^+\pi^-$ [7]. These values include the geometrical acceptance of the detector.

3 Hardware

3.1 Implementation

For the design of the FLT several constraints were taken into account. The FLT input rate is close to the proton bunch crossing rate of 10.4 MHz, its output rate should be at most 50 kHz, which is the allowed input rate of the Second Level Buffer. The Second Level Buffer stores all detector data for an event that has passed the FLT trigger criteria until the second level trigger process has decided on rejecting or keeping the event [4]. Therefore the nominal suppression of the FLT must be 200 for all combined trigger channels. Another requirement is that the data transfer to the FLT and pretrigger and decision making must be accomplished within a maximum latency of 10 μs. This limit is given by the depth of the memory pipeline, which is used for the intermediate storing of data by the detector front end electronics and the data buffers of the FLT itself. A large number of boards had to be designed and built, see Tab. 1.

Table 1: Overview of the custom made electronics boards of the FLT and pretrigger system. The FLT has to process over 10^5 detector channels which are read out every 96 ns.

	Optical Links	Link Boards	Pretrigger Boards	Interface Boards
ECAL	n/a	n/a	128	9
MUON	400	40	40	20
hi-p_T	1100	80	40	8
FLT	3400	200	80	n/a

The pretrigger electronics of the muon and high-p_T systems has a modular structure and consists of three types of boards: a Pretrigger Link Board, a Pretrigger Board, and a Pretrigger Message Generator. The Pretrigger Link Boards are located inside the Front End Driver crates very close to the detector. They transmit the digital data of the detectors to the Pretrigger Boards. In order to achieve this, the electronic signals are serialized by an Autobahn spanceiver[4], which is a 32 bit parallel to serial transceiver with an effective data rate of 800 Mbit/s. The serial electronic signal is converted to an optical signal by an optical transmitter board [8]. They are piggy back boards mounted onto the Pretrigger Link Boards, which can easily be replaced in case of failure. Each Link Board has six to eight of such optical links installed. The data are transmitted via a ≃60 meter long optical fiber to the Pretrigger Boards. Using optical signals assures a noiseless transmission and a clean ground separation. At the receiving end the optical signals are converted back to electrical signals by a piggy back transmitter module and are parallized back by another Autobahn spanceiver.

The Pretrigger Board uses the data to detect coincidences between two or three detector superlayers for the muon and the high-p_T system, respectively. The trigger algorithm is programmed into EPLDs[5]. This feature provides easy up-grade paths for changes in the physics program. If an appropriate trigger condition is fulfilled the parameters of the trigger seed are determined and are converted by a Pretrigger Message Generator to an 80 bit FLT message. The FLT messages contain the complete information of any given trigger candidate. The Pretrigger Message Generator sends it to an FLT Track Finding Unit (TFU) and the FLT processing is started. A detailed description of the pretrigger electronics of the muon system is given in reference [9] and an in depth description for the high-p_T pretrigger electronics can be found in these proceedings [10].

The electronics boards of the ECAL pretrigger are placed very close to the ECAL Front End Driver boards. The data are transmitted via copper cable to the Pretrigger Boards. Data processing and message generation is integrated into just one board. Up to 16 ECAL pretrigger boards are placed into one crate. Each crate has one interface board which sends ECAL trigger seeds to the TFUs. The interface board also arbitrates the message traffic coming from the Pretrigger Boards within one crate.

The TFU network has to process two orthogonal data streams. The pretrigger systems initiate a data flow from the TFUs associated with detector planes far from the target towards TFUs connected to detector planes close to the target (from left to right in Fig. 1). This data flow is heterogeneously distributed over the processing units and is asynchronous with respect to the bunch crossing rate of the experiment. The local data rate is a function of time, physics of the given event, and topology of the processor network. The

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[4] Motorola MC100SX1451

[5] electronic programmable logic device

Figure 2: The FLT Track Finding Unit: Ten such 9U VME boards are housed in each crate. In total 74 TFUs are needed.

second data stream is constant and synchronized by the bunch crossing clock of 10.4 MHz (from top to bottom in Fig. 1). The data is collected by detector Link Boards [11] and is sent via optical links to the TFUs using the same data transmission piggy back boards which have been described for the muon and the high-p_T pretrigger systems. The Link Boards are used to "map" the detector onto the FLT network.

The trigger seed of the pretriggers initiates the track finding chain by providing the initial measurements of the particle's location and direction. This information is used to determine a Region-of-Interest (RoI) for the tracking layer that is used by the TFU (Fig. 2). Each TFU is assigned to a fixed detector region. Even though the TFU network needs to store about $7 \cdot 10^4$ input bits every 96 ns, only a small subset of the data, 1.2 k bits, is stored by each TFU. Out of the 1.2 kbits only a maximum of 100 bits make up an RoI and are used for the individual measurement of a given TFU.

The detector input data rate for one TFU is 16 Gbit/s. In addition, the TFU also receives FLT messages from pretriggers or other TFUs. For short bursts it can receive up to 12 Gbit/s through this channel, see Tab. 2.

The core of the TFU is a "hit finder", which looks for triple coincidences from three layers of detector wires strung at three different orientations. Once a hit (triple coincidence) is found, this information is combined with previous measurements, the track candidate is extrapolated to the next tracking layer, and the RoI at the following layer is determined. The parameters of the RoI are also influenced by kinematical restrictions, multiple scattering, and the projectivity of the track. By each subsequent hit determination the track measurement is refined. Once the track is reconstructed in all FLT detector superlayers, it is used to determine the charge of the particle and its momentum. This calculation is performed by the Track Parameter Unit (TPU). The TPU is essentially a fast, look-up table based calculator. It also is able to reject duplicated tracks. They can, for example, be generated in overlap regions of different tracking systems. After the kinematical reconstruction the result is sent to the Trigger Decision Unit (TDU).

Table 2: FLT data throughput. One individual TFU can process up to 4 Gbit/s trigger candidate data, however it can buffer short bursts of up to 12 Gbit/s.

	detector input	candidate input	TFU output
single TFU	16 Gbit/s	12 Gbit/s	2 Gbit/s
entire FLT	1.2 Tbit/s		0.6 Tbit/s

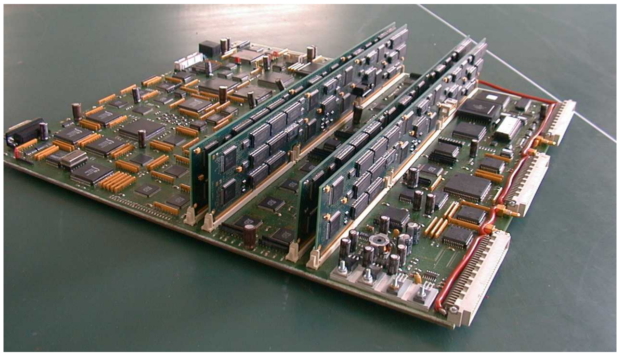

Figure 3: The FLT Trigger Decision Unit. Also visible four subcards which perform the calculation of all possible pair masses of a given event.

The primary function of the TDU, for a photo see Fig. 3, is to form the trigger decision. Typically the TDU will receive tracks from four different TPUs. Tracks that do not fulfill latency requirements are rejected. The remaining tracks are stored in a local message memory. A data processing unit combines tracks belonging to the same bunch crossing to determine their invariant mass. This is done for all possible track pairs. The final FLT decision is based on any combination of two tracks of a given particle ID, charge, momentum, transverse momentum, and invariant mass. In addition, triggers can be initiated based on count conditions, e.g. track multiplicities, according to particle ID of several combinations of one or two tracks.

In case of a positive FLT trigger decision the respective bunch crossing number is sent to the data acquisition system. The data acquisition distributes the trigger decision to all the Front End Drivers of the detector, which subsequently transfer the complete data set to the Second Level Buffer. The TDU also transfers the complete record the FLT tracks accompanied by the trigger type to the Second Level Buffer. The results of the FLT tracking are used as starting point for the higher level triggers and the measurment is subsequently refined under less stringent latency requirements.

3.2 Commissioning Status

At the time of the workshop the hardware of the complete system, including the respective pretrigger systems, had been designed, prototypes had been built and the series production was under way.

The electronics of sub-systems were tested by the developing groups, i.e. reliable inter board communication was established and board functionality checked. In addition, several system integration tests of components at the experiment had been performed. In those tests the operation of the interfaces between sub-systems was established.

The FLT without tracking had also been used to provide a physics trigger for the experiment. About a third of the pretrigger system of the ECAL had been installed and operated. Based on the multiplicity of the number of ECAL candidates a trigger was initiated. Data had been written to tape for offline analysis.

TFUs were operated in stand alone mode to establish their operation in the experiment. They were connected via Link Boards to the various trackers. It was shown that the data received by the TFU was identical to the data written to tape. The TFU was programmed to look for hits in a fixed RoI. Also this could be accomplished for the various detectors. The installation of all electronics board is on going and it is planned to complete the trigger by the end of this millennium.

4 Acknowledgments

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