First Commissioning Results for the Hera-B First Level Trigger

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Abstract

In order to filter rare B decays out of the immense data stream produced by the 920 GeV proton nucleon interactions at 10 MHz in Hera-B we developed a very fast track finder. Being Kalman filtering inspired it searches possible particle tracks through up to seven layers of tracking chambers. The trigger decision is based on the momenta and masses of track pairs. The implementation is a parallel and pipelined system of about 100 custom made hardware processors. This paper describes its first commissioning during the year 2000. As a result of the commissioning run in 2000 the functionality could be verified and the performance was estimated.

I. Requirements

Hera-B has been designed with the main goal to measure CP violation in the B system[1]. The B mesons are produced from reactions between 920 GeV protons with a fixed target among with a copious background. In order to obtain a sufficient number of Bs in average 4 interactions take place at a bunch crossing rate of 10 MHz. Since interesting events are rare (<1 Hz) a selective trigger system is a key element of Hera-B.

The rate of events transmitted from the Font End to the readout boards is limited to an average of 50 kHz. Hence the First Level Trigger (FLT) has to reduce the rate by three orders of magnitude. The length of the Front End pipelines is 128 slots which allows for a decision time of 10 μs (the rest of the pipeline is needed for the control systems). In order to limit the amount of detector channels the occupancies are allowed to reach up to 20 % at maximal interaction rate - which is the major challenge for the trigger and the other reconstruction systems.

The main event selection criteria used in the FLT are:

- leptons with large transverse momentum (p_T)
- pairs of leptons which form large invariant masses

In order to minimize the deadtime of the experiment the setup of the system cannot exceed a few minutes. Possible malfunctions must be detected during setup and problems must be traceable quickly. An overview about the electronics involved in Hera-B is given at this conference[2]. A more extensive overview of the First Level Trigger system can be obtained from[3].

II. Trigger Strategy

A fast and efficient way to implement the pattern recognition algorithm specified above is a Kalman Filter. It allows iterative processing and hence data required for the processing can be of local nature. Our specific implementation makes a few simplifications:

- No drift time but only hit information is used.

- Multiple scattering estimates for the track extrapolation are only used in the muon system.

- The tracks established during the iterative pattern recognition are not refit.

The algorithm as sketched in fig. 1 proceeds as follows:

1. An initial search region - a so called Region Of Interest (ROI) is formed by a processor using particle ID information from the muon system[5], the electro-magnetic calorimeter[6] or the high p_T hadron seeking pad chambers.

2. The search region is extrapolated to the next upstream chamber.

3. The ROI is projected simultaneously to all 3 stereo views of the chamber and the appropriate hits are extracted.

4. The hit patterns are overlayed and coincidences are found.

5. The coordinates of the found coincidences together with the so far best known point on the track are used to establish an updated ROI.

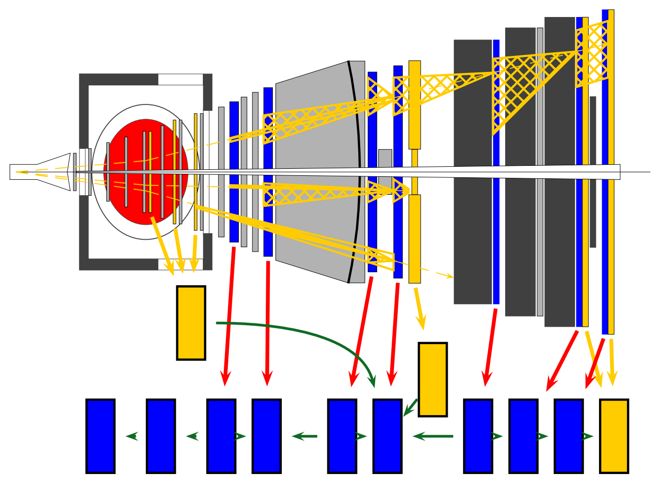
6. The updated ROI is sent to the next upstream chamber and the process is iterated starting from step 3 - till the last chamber is reached.

7. The kinematics of the found tracks is calculated assuming an origin at the main interaction point and track level cuts are applied.

8. All succeeding tracks are stored and all possible track pairs are processed in order to find the number of isolated tracks and the invariant masses of the pairs.

9. In case a sufficient number of isolated tracks of a certain class or a track pair with proper ID, charge and mass is found a positive trigger information is forwarded to the Hera-B Fast Control System - which is responsible to coordinate the readout of the experiment.

Figure 1: Schematic of the track finding algorithm.



III. Track Finder implementation

A. Hardware

Dedicated custom hardware processors based on massive use of EPLDs, ASICs and Look Up Tables are the core of the system. Approximately 100 such processors operate fully pipelined and in parallel. The processors are interconnected with 2 Gbit/s links[4] in order to communicate the process data and the detector data is received over many 500 Mbit/s optical fibers. All processors contain a MC86020 CPU as controller and are accessible by way of VME. All hardware is housed in 9u VME crates. The VME crates are controlled by Power PC computers running Lynx-OS. The setup and control processes are executed on PCs operated by Linux.

B. Control software architecture

The Unix based processes are communicating by way of a message system based upon UDP-IP. The same message system is used to reach the controllers on the VME processors now based on a mail box protocol over VME. On top of the communication layer a standard set of control and monitor methods is implemented allowing high level access to the processors. These methods are used by the run setup and control processes as well as by dedicated test procedures.

C. System Verification

Initially every system component (typically boards) are completely verified in a stand alone mode prior to installation. For example each of track finding processors undergo a 1 week test which verifies every single off-chip signal in every process cycle in a dynamic fashion. This feature clearly had to be carefully designed into the boards.

The most important goal of the system setup is to verify the entire system functionality. This is achieved by comparing every intermediate processing result at each pipeline step of the hardware processors with the prediction of a simulation. The most important part is the operation of all processors in a synchronous single step mode – at a sufficient rate to map out the required parameter space of all tracks.

For speed reasons a simple serial operating of all processors is excluded. We implemented a system where the local controllers operate their processor in parallel to the others. Inter processor synchronization is ensured by dedicated messages clocking the system. In this way we are able to process events with 500 Hz allowing the emulation of a real time second in about one day. Detector data are inserted on the fly. The data can origin from previously recorded detector data or Monte Carlo generators.

In this way we were able to verify the functionality of the system except for the data input links since we are not able to write event data back to the front end - which we are clearly missing. The data inputs can only be checked by independent more static test procedures.

IV. Results

As a result of the commissioning run in the year 2000 we could verify the functionality of the FLT as track finder.

Figure 2: Hit track residuals

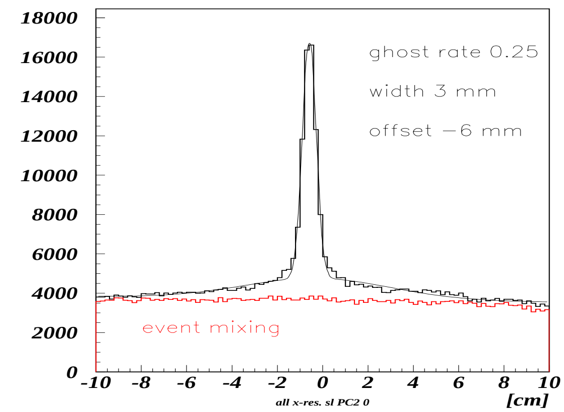
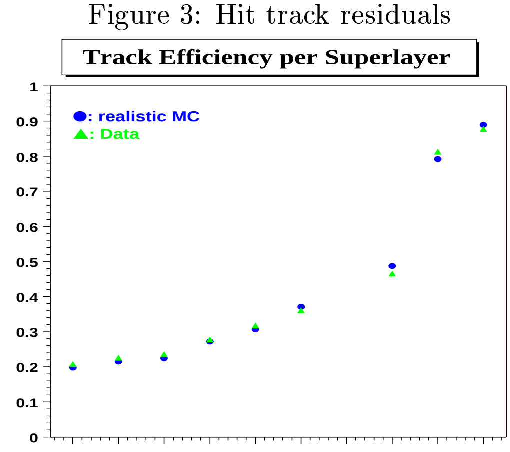


Figure 2 shows the distribution of the residuals between tracks found by the FLT and hits in a superlayer of the tracker which is not used in the FLT. A clear peak with the expected width is observed. The same plot can be produced using the simulation of the trigger algorithm on the recorded data. The non-flat background close to the peak can be explained by correlated hits in the tracking device. The flat underlying background is estimated using tracks from one event and his from an other event. The background level is consistent with a ghost rate of 25 %.

Figure 3: Hit track residuals



If one follows the tracking in the simulation step by step one can estimate the efficiency of the algorithm for each update. As a reference sample tracks which are decay products from identified J/ψs are used. Figure 3 represents this efficiency both for taken data and for a simulation on a realistic detector Monte Carlo. The two plots clearly agree. A decomposition of the efficiencies attributes about half of the inefficiency to detector cell inefficiencies and the other half to shortcomings in the algorithm of the FLT; these can (and are currently) clearly be improved by more careful adaption of the Look Up Table coding to the existing detector geometry.

V. Conclusion

We have designed, constructed and commissioned a deadtime-less level one track finder which concludes in about $10\,\mu s$. A key feature of all the hardware is built in self testing capabilities which allow for in situ system verification. An intense commissioning run of almost one year was still required to setup all the control and monitoring structures such that the system functionality could be verified - clearly to a large extend complicated by the ongoing commissioning of the tracking devices themselves. This is the first time a trigger system of a complexity comparable to the systems designed for the LHC experiments has been operated.

References

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