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THE BTEV TRIGGERS AND DATA ACQUISITION SYSTEMS

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Representing the BTeV collaboration

A coherent and complete suite of triggers and data compression stages for the BTeV experiment has been designed and prototyped. Level 1 considers all crossings, finds primary vertices, and searches for detached tracks from these primary vertices using only the pixel vertex detector. Muons with a relatively high transverse momentum will also be identified at that stage. Level 1 runs on dedicated processors. Level 2 selects events based on the pixel and the forward tracking systems, and will run on a conventional processor farm. Level 3 will use the complete BTeV detector information to reduce the background by a factor of factor 2 to 5 and to reduce significantly the event size.

1. Introduction

BTeV is a recently approved experiment*aimed at precision studies of the electroweak interaction in B and Charm decays. The experiment will run at a peak luminosity of $2\,10^{32}$ cm^{-2} s^{-1}, corresponding to an average of two interactions per crossing, at a crossing rate of 7.6 MHz. For each such beam crossing, the probability to produce a $b\bar{b}$ pair will be $\approx 0.3\%$. The probability to produce a charm pair will be at least 5 times higher. Given this large data rate, the trigger and data acquisition system are crucial.

These systems are intimately connected. A significant fraction of the hardware performs both functions: since we have a multi-stage trigger, the event building proceeds as crossings are accepted or rejected. In this talk, I will summarize the concepts, and the algorithms for first two levels and will present some simulation results.

2. The Concept

BTeV will trigger on the most direct, reliable and distinctive features of Heavy Quark decays, that is, (i) relatively high transverse momentum ($P_t > 0.5$ GeV/c) tracks which either belong to no vertex or which belong to a secondary vertex, (ii) particle identification. A three-level approach is proposed:

- Level 1. All beam crossings will be processed. The aggregate data rate, after on-detector sparcification, coming into the system at this first stage will be

*K.A. Kulyatsev *et al* http://www-btev.fnal.gov/public_documents/btev_proposal

approximately 1.5 Tb/sec, given an average event size of $\approx$ 200 Kb. Only the information from the pixel vertex detector and the muon system will be considered at this stage. Only one percent of the incoming beam crossings will be selected, based on either the presence of a few relatively high P_t detached tracks or a stiff muon. Thus, a first pass at reconstructing all relevant tracks and vertices will be done on all beam crossings. We anticipate an average processing time of 150μs per crossing.

- Level 2. Based on the information obtained at Level 1, additional pixel hits and data from the first few forward tracking chambers, a more refined analysis of the track/vertex topology will be done. We anticipate a rejection factor of about 5 to 10, with a combined Level 1 & Level 2 efficiency of about 60%. The latency is again variable, with an average of 20 msec.

- Level 3. The event rate surviving Level 2 will be $\approx$ 15 to 20 kHz, corresponding to a data rate about a factor 5 too high to fit manage-ably into off-line data storage. We therefore plan to select relevant decay topologies by considering the complete information from the detector. In addition, data from the sub-detectors that are irrelevant to the selected heavy quark decay analysis will be dropped (For instance, information from the away side coming from the Cerenkov, e.m. calorimetry and muon systems). The average processing time should be less than $\approx$ 200 msec per event.

Note that these average latencies are noticeably higher than in previous collider experiments. Thus, large amount of buffering must take place. Also, the algorithms used at each level will be complex (e.g., we doing pattern recognition, momentum measurement, vertexing and particle i.d. in the triggers). This extreme reliance on our triggering algorithms demands high quality, robust and optimized event reconstruction software at the onset of the data taking. Finally, we do not plan to keep the Level 3 output data in mass storage: we will condense these data sets. Thus, the off-line reconstruction could be considered as a "Level 4" trigger, with a latency time of a few months.

3. Level 1 & 2 Trigger Algorithms and Implementation

3.1. *The Level 1 Pixel reconstruction*

The pixel detector is at the core of the BTeV tracking system. It is embedded in a 1.6 Tesla magnetic field. It consists of 31 stations distributed over 128 cm, centered at the I.P. Each station has 2 planes, arranged in orthogonal "views", (y, x). Each plane has over 500,000 pixels in a 10×10 cm area, with a square beam hole of 12×12 mm. Each pixel is $50 \times 400\mu$m in size. We will have pulse height information for each pixel, allowing to reach $\approx 7\mu$m resolution in the "high resolution" view. The relatively small "coarse" dimension greatly simplifies the pattern recognition by mitigating combinatorics at the early stages of track reconstruction.

Pixel planes are locally divided in two regions radially: the inner and outer regions. These region are disconnected. Inner hits are crucial to pin the track close to the vertex, and outer hits are needed to measure track slope and momenta. These track segments consist of only 3 stations, one missing hit being allowed in the "coarse" view. The inner and outer portion of the tracks are then matched at the second stage of the pattern recognition, and their momenta are already crudely determined ($\sigma_{\Delta P/P} \approx 6.5\%$).

Tracks rarely cross an azimuthal quadrant. Thus each quadrant can be reconstructed in parallel. The algorithm simplicity of the early stage of the track segment reconstruction allows us to use FPGA's at this stage (for example, a possible implementation would be based on the Xilinx Virtex XCVE400E, with a cycle time of 20 ns.) The inner/outer track segment matching, the track parameter calculations can be done on DSP's (on the 200 MHz TMS320C67X, for instance). The last phase consists of vertexing and counting the number of detached (in 3D) tracks which have a moderately high Pt.

3.2. *The Level 2*

The Level 2 algorithm will confirm the presence of the Heavy Quark decay in a given beam crossing, by improving both the accuracy of the distance of closest approach of the detached tracks to the previously identified primary vertex, and, to a lesser extent, the accuracy of the P_t determination. This will be accomplished by, sequentially: (i) Adding additional pixel hits on all Level 1 tracks. As explained above, these tracks are left incomplete (by design) at Level 1; (ii) Kalman filtering (e.g. fitting) the Level 1 tracks; (iii) Projecting these tracks to the first few forward tracking planes, and searching for matching hits and if successful, re-fitting the track; (iv) New pixel tracks are then searched for, using only "unused" pixel hits. The goal is to recover Level 1 tracking inefficiencies, particularly at low momentum. (iv)Based on the Level 1 primary vertex information, perform a completely new matching of tracks to vertices. We propose to implement this Level 2 algorithm on a farm of commercially available commodity computers, such as P.C.'s with Pentium III processors.

4. Simulation Results and Outlook

The most critical components of the challenging BTeV triggers have been simulated in detail. It has been shown that this trigger can be implemented on currently commercially available hardware. The Level 1 efficiency on signal events is ≈ 60 to 70%, with a rejection exceeding 100 to 1. A prototype of the Level 2 code has also been written, yielding a Level 2 efficiency of $\approx 85\%$ for a rejection factor of 5 to 1. The average running time for a Level 2 event was about 115 ms on a Pentium III 400 MHz processor. In the coming years, we will work on a detailed and complete technical design report for the BTeV detector, its trigger and data acquisition systems.