



FAST TRACK TRIGGERING FOR THE CDF II DETECTOR

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In the upcoming Fermilab Tevatron collider run, $p\bar{p}$ collisions will occur at 132 ns intervals, and the CDF II trigger system requires that information about drift chamber tracks be provided within 2.2 μ s of every collision, so that tracking information can be used in conjunction with data from other detector components to trigger on physics objects with little background. We have developed a fast online track processor for locating high-momentum tracks in the chamber. The design is highly parallel, and is implemented in programmable logic devices. We describe the design of the system and performance tests.

The great majority of interesting physics signatures at CDF, the $p\bar{p}$ collider detector at Fermilab's Tevatron, will include charged-particle tracks. For events including top quarks, electroweak processes and "exotica" such as SUSY processes, these are typically lepton tracks with large transverse momentum (p_T), while for events with B decays these are typically low- p_T hadron tracks. These physics goals drive us to make fast triggering decisions based on tracking information, and having this information at the earliest stage of the trigger ("Level 1") allows us to make sophisticated decisions about which events to accept and which to reject at that stage.

For instance, tracks can be matched with primitives from the muon chambers and calorimeters (track stubs and clusters, respectively) to generate electron and muon triggers at Level 1. In CDF's Run 1, these triggers were generated from primitives only, leading to a large trigger rate from fakes and Main Ring backgrounds in the muon chambers. Alternatively, triggers can be generated exclusively from track information, with no other input, at Level 1. This could not be done in Run 1, which meant that there was no way to trigger on the presence of individual hadrons in an event. In the first example the trigger can be used to eliminate unwanted events, and in the second it can be used to capture a previously inaccessible class of events, all due to the availability of reconstructed tracks at Level 1.

However, tracks must be found very quickly if they are to be used at Level 1. The Tevatron will produce $p\bar{p}$ collisions every 132 ns, and tracks must be found for each event. Tracks need not be found within 132 ns; the collision data are stored in a pipeline for 5.5 μ s while the Level 1 decision is being made. But tracks must be found in less than 2.2 μ s to leave enough time to match them with primitives from the rest of the detector for use in the Level 1 decision. Finding tracks at this speed requires an extremely fast tracker, which is known as the XFT.

We have designed the XFT to find tracks with a minimum p_T of 1.5 GeV/c, to

maximize the acceptance for B decays. The track-finding efficiency is greater than 96% when the single-hit efficiency of the tracking chamber is greater than 92%, to give high efficiency for high- p_T physics. The momentum resolution $\delta p_T/p_T^2$ is better than 2%, allowing a lower threshold for high- p_T physics signatures; better knowledge of the track parameters gives us greater confidence in setting lower thresholds. The ϕ_0 resolution is better than 8 mrad, so that XFT tracks can be used as seeds for the Level 2 displaced-vertex trigger. The fake track rate is less than 50% at 10 GeV/c, to reduce the muon trigger rate. While this may seem to be a large fake rate, there are very few tracks of such large momentum, and they are always used in conjunction with primitives from other detectors.

CDF's Central Outer Tracker (COT), a drift chamber inside a 1.5 T solenoidal magnetic field, produces the input data for the XFT. 96 radial layers of sense wires are grouped into eight superlayers of 12 wires each; four superlayers are axial and four are stereo. The superlayers are broken into drift cells of 12 sense wires each, with a total of 2540 cells or 30240 readout channels. The cells are tilted at 35° from radial to compensate for the Lorentz angle, making the drift trajectories parallel to $\hat{\phi}$. The total drift time in the cell is less than 132 ns, so the drift is complete before the next $p\bar{p}$ collision.

To find tracks within the constraints of the Level 1 timing, the XFT uses parallel processing (all readout channels are processed simultaneously for a given event) and pipelining (multiple events can be processed simultaneously, each at a different step). There are three major steps in the track-finding algorithm. First, hits on the axial wires of the COT are found and classified. Hits are then grouped within each superlayer into segments. Finally, segments are grouped across superlayers, valid tracks are identified, and track parameters are calculated.

The first step is performed by the XFT TDC Card (XTC), which is a mezzanine card to the TDC board that is used for data acquisition, and sees the same input signals. While the TDC measures hit arrival times to a precision of 1 ns, the XTC merely classifies the COT hits as "prompt" (drift time <44 ns) or "delayed" (longer drift time). Thus, the XTC is a two-bit TDC, in the non-pejorative sense of the term "two-bit." The lengths of the prompt and delayed windows can be modified at run time. This gives a very first pass at pattern recognition; particles passing close to sense wires will produce prompt hits, and those passing far from sense wires will produce delayed hits. There are a total of 168 XTC's in the system, each processing 96 inputs. The hit-classification circuitry is implemented in CPLD's, which have minimal channel-to-channel timing variations.

The prompt and delayed bits are determined within 132 ns of the COT hit arrival at the XTC, and the bits are then transmitted over 200 feet of cable from the detector to the CDF counting room, where they are captured by the XFT Finder system, 48 circuit boards distributed over three CDF readout crates. The Finder boards hold dictionaries of masks of prompt and delayed hits that represent segments of valid tracks (those that originate from the beamline and have sufficient p_T) passing through a given superlayer. The input bits are compared to the masks in

the dictionaries. If a set of inputs match with a given mask, a “pixel” is set for that mask. This pixel represents the ϕ position of the segment, plus slope information in the outermost two axial superlayers. (The slope of the segment indicates the charge of the particle, if it can be resolved.) The Finder system can allow for up to three missed hits per mask, increasing segment-finding efficiency (and fake rate) in regions with dead channels. The Finder dictionaries are implemented in a total of 336 FPGA’s, each of which holds the masks for four drift cells, or 48 sense wires. The number of valid masks ranges from 170 to 310, and increases with the radius of the superlayer. As some segments will cross the boundary between two Finder FPGA’s, information must be shared between chips to achieve full efficiency.

The Finder pixels are then transmitted to the XFT Linker system, 24 boards distributed among three crates that are adjacent to the Finder crates. The Linker compares the Finder pixels to a dictionary of masks that represent valid roads, much as the Finder did with the XTC hits. The segment ϕ positions and slopes from the Finder must match the mask at each superlayer. The circuitry is implemented in a total of 288 FPGA’s, each of which covers a 1.25° slice in ϕ . The total number of valid roads grows as $1/p_T(\min)$, and is equal to 2400 for $p_T(\min) = 1.5 \text{ GeV}/c$.

The use of FPGA’s in the Finder and Linker systems provides flexibility that is useful for testing and for unexpected running conditions. For instance, the Finder boards can be reconfigured to simply transmit known data from a RAM segment-finding circuitry on those boards, or to the Linkers to test the segment-linking circuitry. The mask dictionaries in the Finders and Linkers can be changed to search for tracks with smaller momentum, or to find cosmic-ray tracks.

The Linker identifies the track with the largest p_T in each ϕ slice, and reports its p_T , ϕ_0 , and charge to the extrapolation system (XTRP), which fans out the information to other parts of the trigger. XFT tracks are mapped onto electron and muon primitives, and passed to track-trigger circuitry (for low-multiplicity events), in time for the Level 1 decision. They are also sent to the vertex trigger and Level 2 processor for use in the Level 2 decision.

Installation and integration are underway at CDF. The Finder and Linker systems are in place, along with all the cables. We have tested communication among these systems extensively. Our installation of the complete XTC system awaits the delivery of more TDC’s; about half of the boards are now in place. The COT has just begun to take cosmic-ray data, and we have not had an opportunity to run the XFT at the same time. Instead, we have sent fake data through XTC inputs, and it was successfully passed through the entire chain, finally appearing in the output buffers of the Linker. A working system will be in place for CDF’s commissioning run in Fall 2000.

It has been a pleasure to build the XFT with my colleagues from The Ohio State University and Fermilab. I thank Jay Dittmann for his help in preparing this talk.