CONSIDERATIONS FOR TRACK PROCESSORS IN HIGH RATE COLLIDER EXPERIMENTS

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February 6, 1988

Abstract

A description of the CDF fast track-finding processor is given along with a brief discussion of the problems with tracking in the p-pbar environment.

Introduction

Dedicated, high-rate experiments at the Fermilab TEV I Collider offer a hope of eventually accumulating about 100 million bottom particle decays over the course of several years. To achieve this goal, high luminosities will be absolutely essential. At such luminosities, the interaction rate at the Collider could be as large as 2.5 MHz. Thus, rejection factors of roughly a million are needed at the trigger level in order to keep the number of events written to tape down to a reasonable level. The inclusion of high-precision, charged track information in the trigger can produce a large fraction of the needed rejection in several ways

1. At the first level of the trigger, it has been estimated from Monte Carlo studies (ref. [1]) that a trigger requiring an event to have at least one track with a transverse momentum (P_t) above 1 GeV/c and a total P_t greater than 10 GeV/c will reduce the primary interaction rate by a factor of 5.

2. Monte Carlo studies done by the Collider Detector Facility (CDF) group (ref. [2]) at the Fermilab Tevatron indicate that combining knowledge of track momenta with calorimetric information can reduce the fake electron trigger rates by a factor of $\sim 2 \times 10^2$. Matching the momentum of charged tracks to the energy of the shower reduces the rate by about another factor of 5.

3. Smart processors can use the tracking information to trigger on specific charged track event topologies.

To get the required information at the trigger level requires the development of a high-speed processor which can efficiently locate charged tracks from the tracking chamber data and accurately calculate the momentum of each track. In this paper, we will discuss the design of a track-finding system designed for use with the CDF central track chamber (CTC). Since the designs for such a tracking chamber are somewhat generic for many colliding beam detectors, we hope to elucidate some of the problems that must be faced in the development of track processors for any high-rate experiment at the Tevatron.

General Description

The Collider tracking environment is complicated by several sources of noise, all of which provide potential confusion for a track processor. These include beam related noise, high occupancy rates due to many low momentum tracks, after pulses from preamplifier electronics, etc. Modern drift chambers are designed to make it easier to reject random hits by arranging the sense wires into superlayers where each cell has multiple sense wires and every wire is equipped with multi-hit electronics. By looking at the correlation in timing between neighboring sense wires in a single cell, incorrect or ambiguous hits can be rejected from track finding and fitting. The CDF track chamber, for example, interleaves axial wire superlayers containing 12 wires in each cell, with stereo wire superlayers (for R-z measurements) containing 6 wires. The cells are tilted at a large angle with respect to a radial line from the origin. This ensures that any track with a transverse momentum above a few hundred MeV/c crosses the sense wire plane of a cell in such a way as to leave a "chevron" pattern of wire vs. time (see fig. 1) when the right-left ambiguity is correctly resolved.

The CDF track processor exploits the superlayer design by recording, on the processor, the wire location and time of every hit for 8 of the 12 wires in each axial cell of the CTC. Two stages of pattern recognition are then done to locate tracks. In the first stage, the device searches the data stored for each cell for wire-time patterns corresponding to the passage of a high P_t track through the cell (again, see fig. 1). A matched pattern constitutes a found track segment for the superlayer. In the second stage, the segments for each superlayer are evaluated to determine which set of them can be consistently linked together to form a single high P_t track.

The segment-finding stage is accomplished through the use of three types of printed circuit cards The first card, which is called the Time Memory, records timing information in RAM memory for the sense wires in each axial superlayer cell. The times of the hits are binned by an onboard clock which adjusts the storage address of the RAMs every 40 ns. Thus, for a typical drift velocity of 50 microns/ns, this time-binning gives an accuracy for the distance of the hit from a given wire of about 2 mm. The RAM memory has the capability of storing information for 16 such time bins, so that all hits from any part of

the 3.5 cm wide CTC cells will be recorded. Each Time Memory card stores hits for 8 axial cells.

After all drift times have been recorded, segments are located by the second card, a Mask Library, which addresses the Time Memory cards with a set of masks (the "chevron" pattern described above) representing the wire vs. time patterns expected for high P_t tracks passing through a cell. Simply put, if the times of the hits on a set of wires matches the times expected by a given mask for a sufficient number of wires, then a track segment is said to be "found". The location of the cell for which the match is found and the ID number of the matched mask are recorded on a third printed circuit card, a simple FIFO memory array. The ID number of the mask is defined to be the intergerized location, relative to the center of the cell, of the track segment which originally generated the mask. Hence, the cell location and the mask ID give the absolute azimuthal position of the track segment. Since all cells for a given superlayer are symmetric with respect to the CTC origin, any given mask is valid for all cells in that superlayer. We take advantage of this property by simultaneously sending a mask to all Time Memory cards for a given superlayer during the segment finding stage. In addition, we have one Mask Library for each superlayer so that all axial supercells can be simultaneously searched for track segments. In this way, the time needed for segment searching in a superlayer depends only on the number of wire-time patterns stored on the Mask Library card for that superlayer and is independent of the complexity of the event.

The storage capacity of the Mask Library cards is large enough so that all possible wire-time masks for tracks with P_t greater than about 3 GeV/c can be stored. The masks are generated from real CTC data which has been processed using the full CDF tracking software, so they include all effects expected from varying entry angles of the tracks into the cell, multiple scattering, propagation delays, etc. The number of masks needed depends on the P_t range for which tracking is desired. Figure 2 shows a Monte Carlo estimate of the number of masks needed as a function of P_t, assuming an intrinsic spatial resolution of 2 mm on the location of each hit. The masks are stored in RAM memory so that they can easily be modified, via FASTBUS, if a different P_t threshold is desired. From figure 2 we estimate that about 250 wire-time masks will be needed to locate tracks down to roughly 3 GeV/c in transverse momentum. In order to provide a fast segment search, we have designed the first three boards to operate as a pipelined processor using ECL technology. A search for all tracks down to about 3 GeV/c in P_t can be done in roughly 5 μ secs.

After the segment search is finished, the fourth card of the system, called a Linker card, reads in the data stored on the FIFO and links together those track segments from several superlayers which are consistent with coming from a single high P_t track. Consistency is measured by calculating the transverse momentum of a pair of segments in two different superlayers, then comparing this momentum to that calculated by pairing one of the

segments with yet another segment from a third superlayer. The momentum calculation is based on the fact that, if a track of transverse momentum P_t is produced at the origin with an azimuthal angle, ϕ_0 , then, in the small angle approximation, the orientation of the track at a radial distance R from the origin is given by the formula:

$$\phi_f = \phi_0 + \frac{.03BR}{2P_t}$$

where B is the magnetic field strength of the CDF solenoid and ϕ_f is the final phi position of the track. Hence, the Linker performs a subtraction of the absolute azimuthal positions of two track segments from different superlayers, places the results into a PROM lookup table to calculate a P_t, then enters that P_t value into a histogram stored in RAM memory. Since a calculation of P_t for all possible combinations would be too costly in terms of time, combinations are formed by pairing each segment from only two axial superlayers with all segments from the remaining three axial superlayers. A track which traverses all axial superlayers should have six entries in the histogram. All six should fall into a peak at a given value of P_t in the histogram indicating a successful link to form a single track. The present design demands that there be a least three segment pairings giving the same P_t measurements (within the known azimuthal resolution) before a track can be identified.

The transverse momentum of the entire linked track, as determined from an interpolation of the entries in the histogram, and the absolute azimuthal angle of the track at the outermost superlayer are stored on the Linker board. The polar angles of the found tracks can be determined by combining information from the track processor with ϕ-z measurements from a set of drift tubes which lie just outside the CTC. After the link search is finished, this tracking information is available for use by other trigger processors which attempt to link tracks to other detector elements (e.g. calorimeter clusters, muon detector hits, secondary vertex detectors, etc.). The information on found tracks and track segments is also read out as part of the output data stream for use in higher level triggers and to aid in pattern recognition during offline track reconstruction. The expected resolution of the processor is $\sim$ 1 mr in azimuthal positioning and $\sim 1\% \times P_t$ (GeV/c) for P_t values around 5 GeV/c. Monte Carlo simulations show that the average time for linking segments in Tevatron minimum bias events should be about 300 ns. The most complicated jet events may take up to as much as 100 μ secs.

There are several advantages to the segment search method for locating tracks. The most obvious is that only segments corresponding to nearly radial tracks will be found by the wire-time masks. Thus, there is a large rejection against information from low momentum tracks and random hits from all sources. This is especially true if the sense wire plane in each cell has a length and an angle with respect to the chamber radius which is fairly large. For such cases, the sense wire plane subtends a large angle in azimuth from the beam axis and therefore allows a good measurement of the momentum of the track

just from the indentification of the track segment. More wires in the sense wire plane also provide a higher efficiency for correct identification of a segment. All of this leads to another advantage; namely better performance by the linking card since the number of incorrectly identified segments is reduced. If the segments are sufficiently well-identified, then those segments seen in the outermost superlayers can be used directly in trigger processors which attempt to match charged tracks to calorimeter showers. Thus, an early level trigger decision can be made even before the segment linking stage is performed.

The ultimate limitation on the minimum momentum detectable by a segment search track processor comes from the unwieldly large number of wire-time masks which result from attempts to match lower P_t segments. Much of the noise rejection from the segment search results from the relatively restricted phase space possible for radial tracks which enter the tracking chamber cell in the cases where the track segment is approximately straight. Allowing finite curvature across the superlayer increases not only the number of masks but creates "overlaps" between masks created at different momenta. At high momenta, the masks are determined primarily by the entry angle of the track into the cell and the point at which the track crosses the sense wire plane. Low momentum tracks increase the number of entry angles which must be represented by masks, and in some cases, provide non-unique combinations of entry angle and crossing point, thereby smearing the P_t resolution of the masks. This not only increases the number of possible mask matches to a given track segment, but the number of "ghost" segments which can be produced by accidental matching to data from very low momentum tracks. Since the ghost segments are matched at random places throughout the tracking chamber, the number of false tracks found is, in general, negligible. However, multiple mask matches to a given track segment and the fact that the number of tracks in minimum bias events increases roughly as $\frac{1}{P_t^5}$ means the segment linking time rises tremendously as the P_t limit falls below about 3 GeV/c. Thus, the ultimate P_t limit will be set by the amount of time available for segment linking.

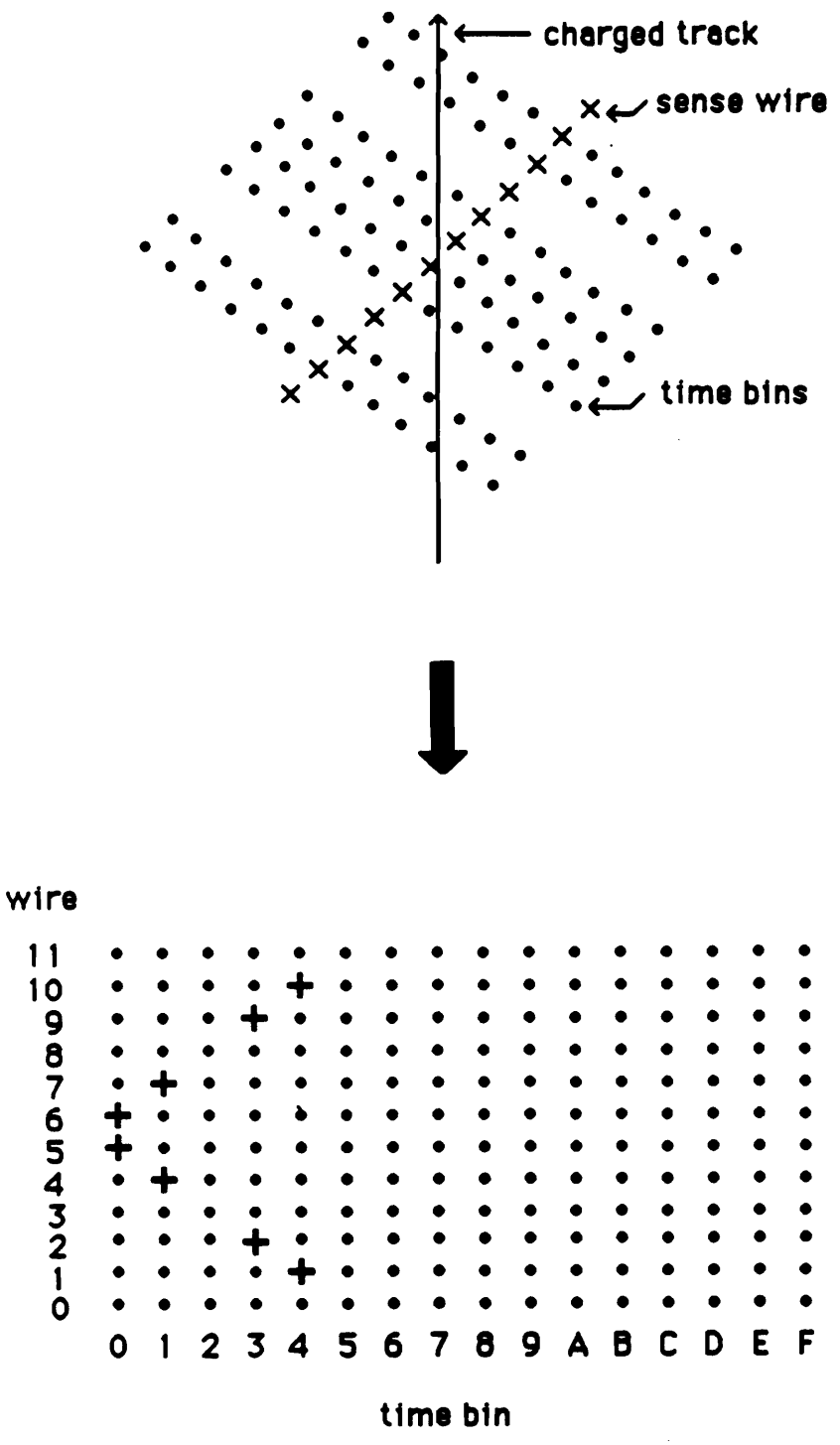
Conclusions

A segment finding track processor has been developed for use with the CDF Central Tracking Chamber. Resolutions of approximately 1 milliradian in azimuth and $\sim 1\% \times P_t$ for transverse momentum can be achieved for tracks above 3 GeV/c in P_t. Such segment finding processors are limited in their lower P_t cutoff for track finding by the amount of time available for linking of the segments. However, for lepton triggers, rejection factors of roughly 10^3 can be made by combining found segments from the outermost superlayers of the tracking chamber with information from other elements of the detector.

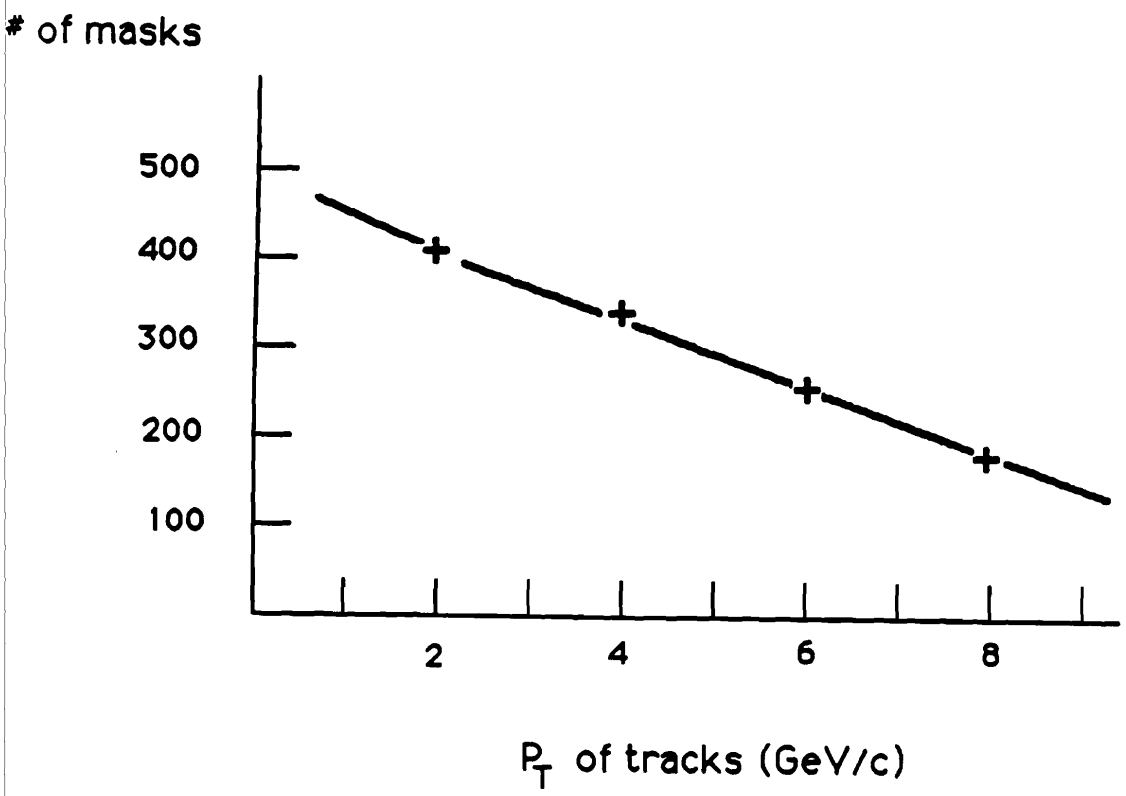
References

[1] R. Van Berg, R. Hughes, P. Karchin, N. S. Lockyer. *Proposal for a Bottom Collider Detector*. March 1987.

[2] Shlomit Tarem and James Bensinger. *Level Two Trigger Study Using CTC Information*. CDF Note No. 269. January 3, 1985.



1 Representation of wire-time pattern for a given mask



2 Number of masks vs. minimum P_t of found tracks