Tracking at high luminosity with the Trip_t chip

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Abstract

The efficiency and fake rate of the Central Fiber Tracker deteriorate at high luminosity for a variety of reasons, including limitations of the electronics. New electronics was developed based on two custom chips: the "Trip" and the "Trip_t". In this note we quantify the improvements that can, and can not, be expected with the new electronics.

1 Introduction

The Central Fiber Tracker (CFT) was designed for operation at 132ns bunch crossing. Operation at 132ns has been abandoned, and the Tevatron will continue operating at 396ns. As a result, the triggered events are accompanied by several minimum bias collisions, and the resulting CFT occupancy is reaching 0.25 (0.13) for the CFT layer 1 (8) for jet triggers at a luminosity of $100 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$.[1] The effects on combinatorics, reconstruction time, VLPC gain, electronics, fake rate, efficiency, and the ability to reconstruct Ks's, has been documented in [2]. The purpose of this note is to explore options to improve tracking at high luminosity.

2 History

The front end of the CFT electronics presently in operation is mounted on "AFE I" boards. These boards have 8 Multi Chip Modules (MCM's), each with one "SVX" chip and 4 "SIFT" chips. The SIFT chips did not meet specifications at 132ns.[3] For this reason a new Trip chip and electronics was developed and tested.[4, 5, 6, 7, 8] We have enough Trip chip's in house to populate all AFE II boards. Then, 132ns operation was abandoned and the CFT will have to operate at high occupancy. For this reason, a second version of the Trip chip, called "Trip_t", is now under design to add the capability of measuring the arrival time of the first few photons and thereby provide a coarse measurement of the z-coordinate of the hit. The expected performance was obtained by measurements using the Trip chip.[9] It was found that the resolution of the z measurement is not limited by the noise of the chip, but rather by the statistics of the arrival time of the first few photons to the VLPC's.[6, 9] The measured resolution is 46cm (one standard deviation) for $n_{pe} = 8$ photo-electrons (and scales as $\propto n_{pe}^{-1/2}$). The design of the "AFE II" board, to accommodate the Trip or Trip_t chips, has been completed, the layout is in progress, and a batch of prototype boards will soon be built and tested during the 2004 fall shutdown.

Question: Should the AFE I boards of the present electronics be replaced by AFE II's? The purpose of this note is to provide the technical information necessary to arrive at a decision, and also explore other options to improve tracking at high luminosity. We do not address costs, manpower, logistics or the time required to build, debug, test, replace and commission the new electronics.

3 The SIFT chip at high occupancy

The performance of the SIFT/SVX chip combination at high occupancy has been investigated.[10] Here we summarize the salient feature. Typically, a MCM on AFE I firing discriminators at an occupancy of 30%, shifts the pedestals of SIFT-chip 1 by -1 photo-electron (pe), SIFT-chip 2 by -0.5pe, SIFT-chip 3 by +1pe, and SIFT-chip 4 by +4pe. This shift should be compared with the light yield of a track traversing perpendicularly the center of a fiber: ≈ 8pe. These shifts are not observed in stereo modules that have no firing discriminators.[10] Due to these shifts at high luminosity, some adc channels drop below threshold causing an inefficiency, and furthermore render the adc of limited use for more clever tracking algorithms.

Measurements have shown that the Trip chip decouples discriminator and analog channels,[8] therefore reducing the inefficiency due to pedestal shifts, and making the adc information useful for more clever tracking algorithms.

4 What the Trip chip will, and will not, achieve

The Trip or Trip_t chips will improve the following items with respect to the present electronics:

- Increases tracking efficiency at high luminosity or occupancy (because discriminator occupancy has little effect on the adc pedestals).
- Provides useful adc information that allows more clever tracking algorithms (to be discussed in Section 6).
- As luminosity increases, the VLPC efficiency and gain drop. With more stable adc output, the effect of this drop on efficiency will be reduced.
- Reconstruction time can be reduced (as discussed in Section 6).
- The Trip chip is simpler to operate. The SIFT chip has analog discriminator threshold and analog pedestal inputs which have to be constantly adjusted. The operation of the AFE I has been possible due to the heroic efforts of Jadwiga Warchol, Fred Borcherding, Jon Anderson, George Ginther, Mike Matulik, Paul Rubinov and others. All inputs to the Trip chip are digital, so the operation should be easier. System tests of the Trip chip have proven very stable in time.[8]
- With the adc information it is possible to apply a channel-by-channel correction offline if necessary.
- With the adc information it is even conceivable that refitting of the track is possible (using the χ_a^2 described in Section 6), thereby improving the p_T resolution.

The Trip or Trip_t chips will **not** improve the following items with respect to the present electronics:

- The Central Track Trigger (CTT) efficiency and rejection will not improve because the SIFT chip has the same good discriminator performance that the Trip chip has.
- The occupancy will not be reduced significantly. The SIFT chip has an integration window of 240ns. The Trip chip can operate with a 50ns integration window. However we have found experimentally that most hits are in-time, so the occupancy is not significantly reduced by reducing the charge acquisition window. We believe that the occupancy is due to real hits from low p_T particles (loppers), and so, no electronics will be able to reduce the occupancy significantly. A marginal

reduction in occupancy can be achieved off-line as discussed in Section 6. Occupancy is an unsurmountable limitation of the CFT at 396ns operation, unless luminosity leveling is implemented.

5 Time measurement with the **Trip_t** chip

We have written a Monte Carlo to evaluate the efficiency and rejection provided by a time measurement with the Trip_t chip. The Monte Carlo trip_t_mc.C is included as an auxiliary file to this DØ note. To run the Monte Carlo, edit the file trip_t_mc.C to set the parameters of your choice, setup root, and enter "root trip_t_mc.C". The following are user settable parameters with the default values used for Figure 1 and Table 1. N=14 is the minimum number of required CFT hits, npe = 8.0 is the number of photo-electrons for a track traversing the axis of a fiber at $\eta = 0$, npePS=325.0 is the number of photo-electrons for an electron shower hitting the Pre-Shower detector at $\eta = 0$, PS is 1 (0) if the Pre-Shower detector is (is not) included in the tracking, eta is the pseudo-rapidity of the track, and chisq_cut=2.0 is the χ_z^2 per degree of freedom cut to separate real tracks from fake track candidates. To obtain more rejection of fakes at the expense of less efficiency for real tracks, reduce chisq_cut. We have assumed that half the CFT layers produce no useful z-measurement information (because the track does not traverse one fiber near its axis, but traverses two neighboring fibers far from their axis, sharing the low light yield between two fibers). As an example, the distribution of the χ_z^2 per degree of freedom for real and fake track candidates are shown in Figure 1 for $\eta = 1.3$ without the Pre-Shower detector included in the tracking. In Table 1 we show the efficiency and rejection provide by the Trip_t chip as a function of η with and without the Pre-Shower detector included in the tracking.

6 How can we use the **adc** and **tdc** information from the **Trip_t** chip?

The following is a list of ideas.

- Replace the present "across-the-board" 20-count adc cut (equivalent to 1 to 2 photo-electrons [1] depending on VLPC gain) by something more clever: *e.g.* off-line remove hits with less than 3.0 photo-electrons

[1] Above the 1 photo-electron on-line threshold.

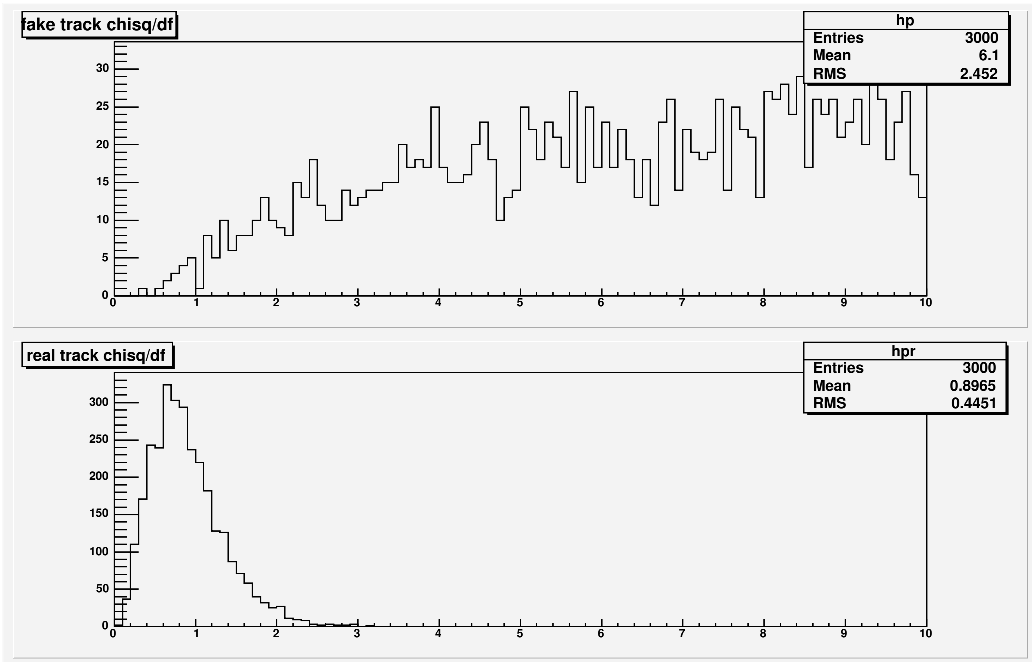

Figure 1: χ^2_z per degree of freedom for fake track candidates (top panel) and real tracks (bottom panel), from the tdc information of the Trip_t chip. $\eta = 1.3$, ≥ 14 CFT hits, and Pre-Shower detector not included in tracking. npe $= 8.0$ photo-electrons.

PS	eta	efficiency	rejection
yes	0.0	0.96	0.010
yes	0.5	0.96	0.009
yes	1.0	0.97	0.013
no	0.0	0.96	0.043
no	0.5	0.96	0.040
no	1.0	0.97	0.040
no	1.5	0.99	0.015

Table 1: Efficiency for real tracks and rejection factor for fake track candidates as a function of η, with and without the Pre-Shower detector included in the tracking. From the tdc information of the Trip_t chip. npe $= 8.0$ photo-electrons, $N = 14$ CFT hits, chisq_cut $= 2.0$.

unless they have a neighboring fiber hit with between 2.0 and 8.0 photo-electrons. The reason is as follows: A track going through the center of a fiber yields about 8 photo-electrons at $\eta = 0$ and 21 photo-electrons at $\eta = 1.6$. A track traversing two fibers of a doublet approximately shares these photo-electrons among the two fibers (because the track is offset).

- A cluster is formed by one hit fiber or two adjacent hit fibers in a doublet. Do not form clusters with two adjacent hit fibers if the two adc measurements are incompatible. For example, if two adjacent fibers have a sum of ≥ 30 photo-electrons, then these are two separate tracks and should not be clustered together.

  hit with ≥ 13 photo-electrons are two separate hits: two clusters should be made.

- Do not form clusters with two adjacent hit fibers if the two z measurements are incompatible. This separates hits at large positive η from hits with large negative η.

- Each time a hit is added to a track during off-line reconstruction, update a χ^2_a using the adc information of the cluster. The expected number of photo-electrons per doublet is $8.0/\sin(\theta_{\rm trk})$. The efficiency/rejection that can be obtained is discussed in Section 7.

- In the case of the Trip_t chip we can, during off-line track reconstruction, update a χ^2_z taking into account the z information of the hits provided by the Trip_t. Once the combined χ^2 from normal tracking, plus χ^2_a, plus χ^2_z surpasses a threshold the track candidate is declared fake and is dropped. Therefore the Trip or Trip_t chips can reduce the reconstruction time (roughly in proportion to the fake reduction factors in Tables 1 and 2).

7 Fake rejection using the adc information

Knowing the θ of a track we know the expected number of photo-electrons from a doublet cluster: $\mathsf{npe}/\sin\theta$. Then, each time a new cluster is attached to the track during track reconstruction, we can update χ^2_a using the adc information. To find the efficiency/rejection possible with this procedure, we have written a Monte Carlo program that is an auxiliary file to this D0 note: trip_mc.C. The results are shown in Figure 2 and Table 2 with the following parameters: $\mathsf{N} = 14$ is the minimum number of CFT hits required

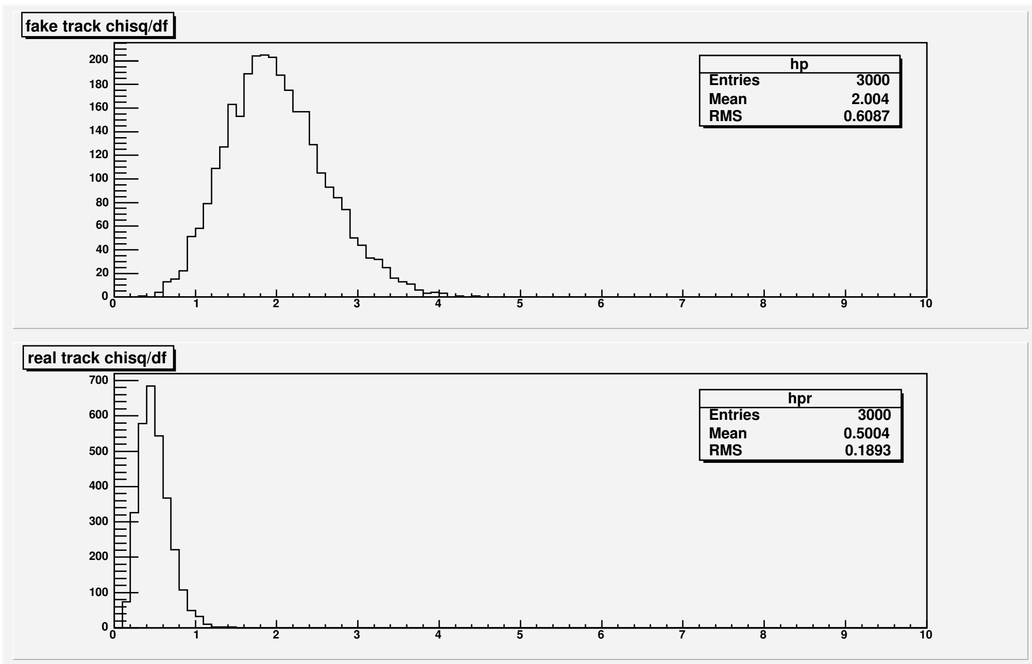

Figure 2: χ_a^2 per degree of freedom for fake track candidates (top panel) and real tracks (bottom panel), from adc information of the Trip or Trip_t chips. $\eta = 1.3$, ≥ 14 CFT hits. npe $= 10.0$ photo-electrons per doublet.

on track, npe $= 10.0$ is the mean number of photo-electrons per fiber doublet for $\theta = 90^0$, and chisq_cut $= 1.1$ to separate real tracks from fakes.

The conclusions regarding the use of the adc information are: (i) the rejection of fakes is very good; (ii) the rejection of fakes with adc information is better at $\eta = 0$, while the rejection of fakes with z information is better at large $|\eta|$, so the two are complementary.

The present SIFT/SVX electronics on AFE I has three limitations to use the adc information for facke track reduction: (i) The coupling of discriminator occupancy with the adc pedestal; (ii) the dynamic range is limited to $\approx$ 150fC, equivalent to about 18 photo-electrons, **per Tevatron superbunch**[11]; and (iii) the tick-to-tick variation of of pedestals.[10]

The Trip and Trip_t chips have an adc dynamic range of 300fC equivalent to about 36 photo-electrons at the maximum gain setting.[5]

eta	efficiency	rejection
0.0	0.99	0.001
0.5	0.99	0.003
1.0	0.99	0.038
1.5	0.99	0.015

Table 2: Efficiency for real tracks and rejection factor for fake track candidates as a function of η, from adc information of the Trip or Trip_t chips. npe = 10.0 photo-electrons per doublet, $N = 14$ CFT hits, chisq_cut = 1.1.

8 Other ideas to extend tracking to higher luminosities

- The CTT provides fast high-p_T tracking. Can these L1 and L2 tracks be passed on to L3 and to the off-line d0reco to speed up track reconstruction?
- Do high-p_T tracking generally, and only do low-p_T B-physics tracking for selected triggers.

References

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[11] "Saturation of the SVX Chip", P. Hasiakos and J. Estrada, DØ note 4495 (2004)