

Upgrading the DØ Fiber Tracker for TeV33*

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ABSTRACT

We have investigated upgrading the DØ fiber tracker for TeV33. It is expected that the inner layers of the fiber tracker being built for Tevatron collider Run 2 will suffer from high occupancy and potentially damaging radiation doses from the high luminosities projected for TeV33. We have studied eliminating the inner layers of the fiber tracker and increasing the number of outer layers. Results are presented on trigger performance for various fiber configurations.

I. INTRODUCTION

An exciting program of high- p_T physics in the era prior to LHC turn-on has been laid out in the TeV-2000 Report [1]. This physics program is predicated on increasing the integrated luminosity an order of magnitude beyond what is presently anticipated for Tevatron collider Run 2. Given the relatively short “window of opportunity” for achieving the goals of the TeV-2000 report, the TeV33 working group at Snowmass focused its attention on whether the detector demands for the TeV33 program could be met with relatively modest upgrades of the existing collider detectors [2]. In this paper we investigate upgrading the DØ fiber tracker to accommodate the higher luminosities expected for TeV33.

DØ is installing an entirely new central tracking system for Run 2, consisting of a Silicon Vertex Detector, a Fiber Tracker, and a 2 Tesla superconducting solenoid. The fiber tracker has 16 doublet layers of scintillating fibers, ranging in radius from 19.5 cm to 51.5 cm, configured as 8 axial doublet layers and 8 stereo doublet layers. The fiber diameter is 0.835 mm and the fibers are spaced on a 1 mm pitch, with the second layer of the doublet offset by 0.5 mm from the first layer. A total of $\sim 74,000$ fibers and associated readout channels will be deployed in the Run 2 fiber tracker.

It is expected that at TeV33 luminosities, the inner layers of the DØ fiber tracker will have such high occupancies that they will no longer be useful for triggering or track reconstruction. In addition, radiation damage to the inner layer will result in a factor of two loss in light yield after $\sim 10 \text{ fb}^{-1}$. We consider here the possibility of reconfiguring the fiber tracker with the following goals:

- Efficiently trigger on high- p_T charged particles,
- Minimize “fake triggers” from random hits,
- Maintain good momentum resolution,
- Provide robust pattern recognition capabilities,
- Reduce radiation damage to the fibers, and
- Capitalize on the investment in the Run 2 fiber tracker.

To achieve these goals, we have studied reconfiguring the Run 2 fiber tracker by eliminating the inner fiber layers and adding additional layers at the outer radii. Thus, the existing VLPC readout electronics and clear fiber plant would be retained, replacing some or all of the scintillating fiber cylinders. Note that the scintillating fiber cylinders are a relatively inexpensive component of the fiber tracker. In addition, it will probably be necessary to re-terminate at least some of the clear fiber bundles and it may also be necessary to develop new trigger electronics.

II. MODELING THE FIBER TRACKER

To allow fast simulation of fiber tracker design options, a simplified model was developed for the fiber tracker. The fibers were assumed to be the same length as in the Run 2 design, covering the region $|z| < 126 \text{ cm}$ (full coverage for $|\eta| < 1.6$). The efficiency of a fiber doublet layer was assumed to be 100%.

Two different geometries were considered. Geometry I consists of 6 - 12 fiber doublet layers evenly spaced in radius between 30 cm and 51.5 cm. Moving the innermost fiber layer from 20 cm to 30 cm provides room for some expansion of the silicon vertex detector, but probably does not leave room for any new detectors to be deployed. Although the inner radius has been increased relative to the Run 2 design, additional steps may be required to reduce the effects of radiation damage. One possibility is to split some of the inner fiber layers at $z = 0$ to reduce the attenuation of hits at the far end of the fiber. Geometry II is identical to Geometry I except the inner fiber radius is increased to 40 cm. Geometry II provides sufficient expansion room that one could consider adding a new detector between the silicon and fiber tracking detectors. One such possibility is the Microgap Chamber described in these proceedings [3].

A library of 6,000 Monte Carlo low- p_T interactions was used to simulate the pileup of many such interactions that occurs at high luminosity. Low- p_T non-diffractive inelastic interactions were generated using DTUJET [4] event generator, which is designed to reproduce the characteristics of minimum bias interactions. The number of low- p_T interactions in a beam crossing was generated from a Poisson distribution; the required number of DTUJET interactions were then randomly selected from the library. The z coordinate of each interaction was generated from a Gaussian distribution with $\sigma(z) = 20 \text{ cm}$. To further randomize the library of low- p_T interactions, each interaction was randomly

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rotated in ϕ , with all particles from the interaction rotated by the same amount. Charged particles were given circular orbits in r - ϕ space and fiber hits were recorded if the particle trajectory intersected a fiber layer. Low momentum charged particles that turned around before $r = 60$ cm were allowed to generate a second fiber hit. The effects of multiple scattering, energy loss, and photon conversions were neglected.

To account for additional hits that are found in full GEANT simulations of the DØ Run 2 fiber tracker, additional “noise” hits were added to each beam crossing. On average, 11.3 noise hits were added to each fiber layer for each low- p_T interaction, with the actual number of noise hits in a layer generated from a Gaussian distribution. When combined with hits from the DTUJET interactions, the fiber occupancy at a luminosity of 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ with 146 bunches ranged from 10.1% at $r = 30$ cm to 4.8% at $r = 51.5$ cm.

Once a beam crossing is generated, an r - ϕ tracking trigger algorithm was simulated to see if the event would generate a trigger. For each fiber hit in the innermost layer, a search was made for hits in the outermost layer consistent with $p_T > 10$ GeV/c. For each such outer layer hit, the centers of the inner and outer fibers were used to define a circular trajectory passing through the origin. The intersection of the trajectory with each fiber layer was determined and a hit was searched for within a specified road size (0.5 mm and 1.0 mm were used in this study). The trigger condition was met if a hit along the trajectory was found in each layer of the fiber tracker.

III. RESULTS

Trigger rejection factors were calculated for a variety of fiber tracker designs. A higher rejection factor means the trigger is better at rejecting low- p_T interactions. Assuming that two of the three abort gaps are filled with beam, the Tevatron could store up to 146 bunches while maintaining the 132 ns bunch spacing of Run 2. If all 146 bunches are filled, beam-beam crossings would occur at a 7 MHz rate. Achieving a 7 kHz level 1 trigger rate would require a trigger rejection factor of 1000 from the combination of the tracking trigger and the calorimeter/muon triggers.

The cross section for QCD di-jet events producing a charged track with $p_T > 10$ GeV/c was estimated using ISAJET to be 7.0 ± 0.5 μb . Thus, at a luminosity of 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ the rate for real 10 GeV/c tracks is 7 kHz, limiting the maximum possible trigger rejection factor from a tracking trigger to ~ 1000 for 146 bunches. Note that the DTUJET event generator essentially never produces such high p_T tracks and the trigger rejection factors shown in this paper are intended to only represent the ability of the trigger to reject “fake tracks” that occur as the result of random association of fiber hits.

Three different trigger algorithms were simulated: a 1 mm trigger road with a 1 mm fiber pitch and a 0.5 mm trigger road with both 1 mm and 0.5 mm pitches. Note that since each doublet layer has two layers of fibers offset by 0.5 mm,

it is possible to segment the trigger more finely than the 1 mm fiber pitch. In principle, the trigger can be segmented with a ~ 0.25 mm pitch, although adjacent hits will cause some degradation in trigger performance. Thus, the 0.5 mm fiber pitch shows the effect of either using smaller diameter fibers or an indication of what might be achieved by making full use of the information in the fiber doublet.

Figures 1 and 2 show the trigger rejection factors for Geometry I (30 cm inner radius) and Geometry II (40 cm inner radius) at a luminosity of 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ (146 bunches). The error bars reflect the statistical error due to generating 20,000 events at each point. We see that Geometry II gives a higher trigger rejection factor for a small number of fiber layers, but as the number of layers increases Geometry I gives the better trigger rejection factor. We also see that tightening the trigger requirements, by narrowing the trigger road and/or reducing the fiber pitch in the trigger, substantially improves the rejection factor. The same trends were seen when the simulation was run with higher numbers of interactions per crossing except that at very high luminosity (2×10^{33} $\text{cm}^{-2}\text{s}^{-1}$ with 108 bunches) Geometry II was somewhat favored over Geometry I for up to 10-12 fiber layers. Even in this difficult environment, a trigger rejection of ~ 100 was achieved for 12 fiber layers with 0.5 mm fiber pitch and road size.

Some effort was made to understand the origin of the “fake tracks” that originate from noise hits and low- p_T tracks accidentally forming hit patterns consistent with high- p_T tracks. For cases where the trigger rejection was relatively low, the fake tracks were largely made up of random hits that were independent of each other. As the rejection was increased, either by increasing the number of layers and/or decreasing the fiber pitch and road size, the number of low- p_T tracks and noise hits used to make the fake track decreased significantly.

Single particle events were simulated to measure the trigger threshold curve for the above designs. The efficiencies were determined using 10 fiber layers, but the results are not expected to be very sensitive to the number of fiber layers. Figures 3 and 4 show the trigger efficiency as a function of the transverse momentum of the charged particle for Geometry I and Geometry II. Reducing the fiber pitch significantly sharpens the p_T threshold for both geometries. The thresholds were also somewhat sharper for Geometry I, which is expected given the longer lever arm in this geometry. In all cases, the transverse momentum where 50% efficiency is reached lies well below 10 GeV/c, with full efficiency reached at ~ 10 GeV/c.

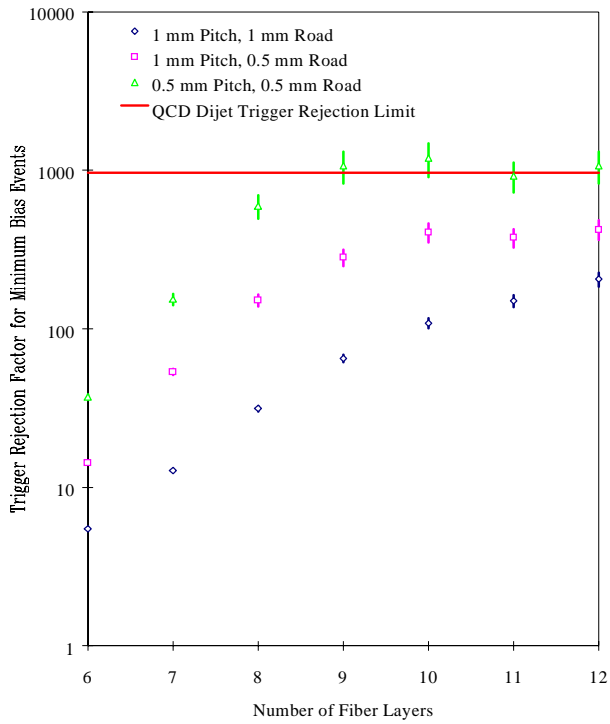


Figure 1: Trigger rejection factor for Geometry I (inner radius of 30 cm) as a function of the number of fiber layers for various trigger requirements. Also shown is the trigger rejection limit set by the rate for high- p_T tracks from QCD dijet events, which are not included in our model.

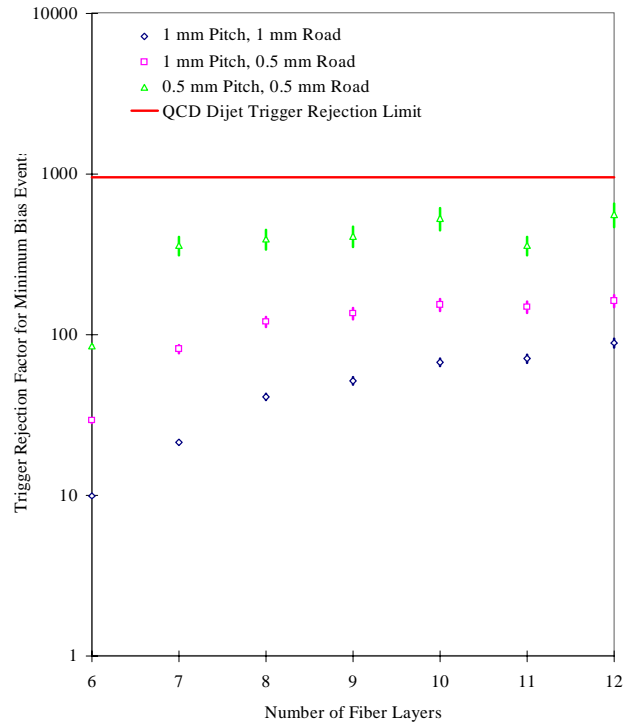


Figure 2: Trigger rejection factor for Geometry II (inner radius of 40 cm) as a function of the number of fiber layers for various trigger requirements. Also shown is the trigger rejection limit set by the rate for high- p_T tracks from QCD dijet events, which are not included in our model.

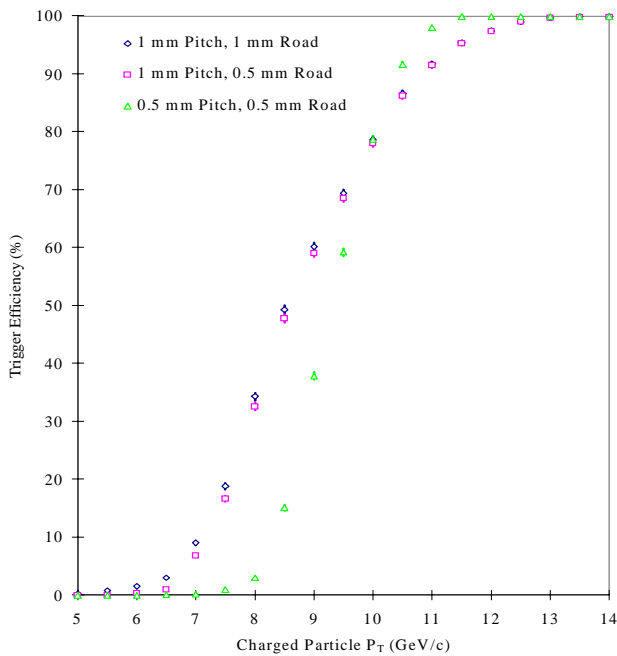


Figure 3: Trigger efficiency for Geometry I (inner radius of 30 cm) as a function of transverse momentum of the charged track for various trigger requirements.

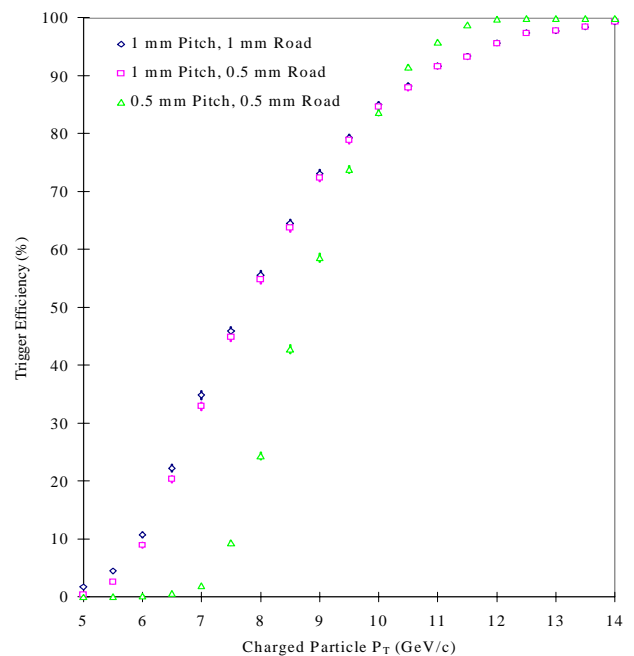


Figure 4: Trigger efficiency for Geometry II (inner radius of 40 cm) as a function of transverse momentum of the charged track for various trigger requirements.

IV. DISCUSSION

From the above modeling effort, it appears that an effective central tracking trigger can be achieved using 8 - 12 axial fiber layers at large radius with a trigger pitch and road size of 0.5 mm. Trigger rejection factors of ~ 1000 appear to be feasible at a luminosity of $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ with 146 bunches; even with luminosities as large as $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ it appears to be feasible to reach rejection factors of ~ 100 with 12 fiber layers.

The choice of an inner radius probably depends more on being able to withstand the radiation dose and space constraints than on trigger performance. While we did not study splitting the fibers at $z = 0$, it is an interesting alternative to reducing the trigger pitch since it also helps reduce the consequences of radiation damage in the scintillating fibers.

Unless the number of VLPC readout channels is significantly increased, we are skeptical that sufficient stereo layers could be added to provide the robust pattern recognition needed for 3-D tracking in the high occupancy environment at TeV33. The present Run II fiber tracker has equal numbers of axial and stereo fibers; merely providing robust 2-D tracking will require most, if not all, of the existing VLPC channels. Large numbers of "ghost" tracks may be a particularly vexing problem for 3-D tracking with small-angle stereo layers given the high occupancies at TeV33. We believe that 3-D tracking is much better suited to devices with very large channel counts. Pixel devices are particularly well suited for this task at TeV33. If the 3-D tracking devices have sufficient resolution in the z coordinate, it is not clear that much is gained by including stereo fiber layers.

The design presented here is also limited in its coverage, with full coverage extending over $|\eta| < 1.6$. The need for a forward tracking trigger covering the region $|\eta| > 1.6$ needs to be examined for TeV33. It may be desirable to supplement the fiber tracking trigger with a device designed specifically to provide a tracking trigger in the forward region.

In summary, it appears that an effective fiber tracking trigger can be constructed without increasing the channel count of the Run 2 fiber tracker. An optimal design would have 10-12 axial fiber doublet layers and have a trigger pitch and road size of 0.5 mm or less. The fiber tracking trigger has a reasonably sharp turn-on as the trigger threshold is passed, going from low efficiency to 100% efficiency over a $\pm 2 \text{ GeV}/c$ momentum range. Such a design will also provide accurate charged particle tracking in the bend plane for off-line momentum reconstruction. With an increase in the number of layers at large radius, the momentum resolution of the tracker should be no worse, and potentially somewhat better, than the Run 2 design. The redundancy in having a large number of layers is of great value in reducing the combinatorial backgrounds and providing robust pattern recognition. Eliminating the inner fiber layers reduces the

problems associated with radiation damage. Finally, by recycling much of the Run 2 fiber tracker, the cost should be minimized.

V: REFERENCES

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