THE DØ UPGRADE FOR RUN II

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The DØ detector at the Fermilab is being upgraded to meet the demands imposed by high luminosity and shorter bunch spacings at the Tevatron. We describe the elements of the DØ upgrade which include the addition of a solenoidal field, the replacement of the tracking system with a silicon vertex detector, a scintillating fiber tracker and preshower detectors. Scintillation counters will be added to the central muon system. Plastic mini-drift tubes, pixel scintillation counters and thick shielding will make up the new forward muon system. The front end electronics for the existing calorimeter and the muon systems will be replaced. The trigger system will be replaced with a more sophisticated higher bandwidth system, and the data acquisition system will include modifications to the present system.

1 Introduction

In 1999 Fermilab will begin collider Run II, the first run with the Main Injector. Run II will produce an order of magnitude increase in the instantaneous and integrated luminosities to $2\text{x}10^{32}$ cm^{-2} s^{-1} and 2 fb^{-1}. In order to achieve this, the number of proton and antiproton bunches will increase from the present 6 to 36 (and eventually 108) corresponding to a decrease in the minimum bunch spacing from 2.5 μs to 396 (132) ns. With these bunch spacings, the average number of interactions per crossing is 5.2 (1.7) at this luminosity. These changes in the accelerator parameters require that a large amount of the present detector must be replaced to handle them. To meet these challenges, we have chosen to build on the excellent calorimetery and the large muon coverage of the present DØ and to take advantage of newer detector technologies to add a state-of-the-art magnetic tracking system[1]. The physics performance of the detector upgrades is discussed elsewhere in these proceedings[2].

A major element of the upgrade is replacement of the inner tracking systems with a solenoid magnet, silicon vertex detector, and scintillating fiber tracker. Central and forward preshower detectors improve the electron and photon identification. The muon system is augmented by the addition of scintillation counters to the central and forward regions, the replacement of the forward proportional drift tubes by plastic mini-drift tube planes, and thick forward shielding. New front-end electronics for the calorimeter and those muon detectors which are retained is required because of the decreased bunch

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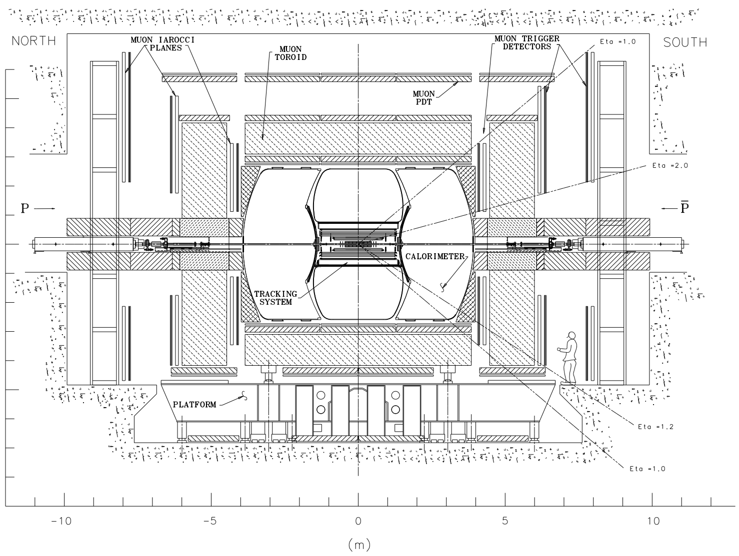

Figure 1: The DØ detector upgrade for Run II.

spacing. A fully pipelined trigger provides high rate capability. A side view of the complete upgrade detector is shown in Fig. 1.

1.1 Inner Tracking

A 2 Tesla field is provided by a 2.8m long superconducting solenoidal magnet built by the Toshiba Corp. Inside the tracking volume the value of $\sin\theta \times \int B_z\, dl$ along the trajectory of any particle reaching the solenoid is uniform to within 0.5%, despite the absence of a field-shaping iron return yoke. The magnet winding was recently completed.

The silicon vertex detector is to be constructed of interleaved barrels and disks providing 3D tracking information to $|\eta| \leq 3$. A quarter view of the tracking system is shown in Fig. 2. The full barrel is made up of 7 barrel sections. Each 12 cm long barrel section consists of 4 layers. The innermost layer (layer 1) is located at a radius of 2.77 cm and the outer layer (layer 4) ends at a radius of 9.99 cm. Layers 1 and 3 use single sided detectors with 50 μm pitch strips that are aligned parallel to the beam direction, whereas layers 2 and 4 use double sided detectors with strips that are parallel to the beam on one side and make an angle of 2^o on the other side. The full length of the seven barrel sections is 84 cm. The $r\phi$ silicon strips provide a spatial resolution of approximately 10μm. At the ends of the barrel sections are located silicon disk detectors, each comprised of 12 double sided, 30^o stereo wedge detectors. There are a total of 16 disks, 12 (4) disks with an inner radius of 2.57 (9.5) cm and an outer radius of 9.96 (26) cm. The larger disks are located farthest from the interaction point. The silicon strips are AC-coupled (each strip has an integrated coupling capacitor and polysilicon bias resistor), which assure continued operation at high radiation doses. All the single sided detectors have been ordered, and a portion of the detectors have been received and probe tested. The readout is via SVX II chips (each of which has 128 channels, 32 stages of analog pipeline delay, and provides an 8 bit digitized signal) developed at Fermilab and LBL. The total number of silicon channels is about 800,000. The noise has been measured to have a standard deviation of $600e + 65e$/pF for a risetime of 105 ns. All the rad-hard SVX II chips were recently delivered and are under test. A modification of this design in which the number of barrels are reduced to six and the single sided silicon on the inner four barrels is replaced by double sided silicon with 90^o stereo strips on one of the sides is under consideration. The barrels and disks are mounted in a double-walled carbon fiber half-cylinder which provides a zero thermal expansion support. The silicon detector is cooled to maintain the silicon temperature below 10C.

The silicon vertex detector enables tagging of displaced vertices from heavy quark decay and separation of multiple interactions. The small angle stereo design provides $r - z$ resolution at the vertex of 0.4 mm allowing separation of primary vertices from multiple interactions. The design using large angle stereo strips would significantly improve the z-resolution.

The Central Fiber Tracker (CFT) surrounds the silicon detector and covers the central pseudorapidity region. It performs two main functions. First, with the silicon detector, the CFT enables track reconstruction and momentum measurement for all charged particles within $|\eta| \leq 2$. Second, it provides a list of track candidates above preset momentum thresholds for the Level 1 (hardware) trigger for tracks within $|\eta| \leq 1.6$. A total of about 74,000 multiclad scintillating fibers are arrayed in 8 concentric cylinders at radii of 19.5, 23.4, 28.1, 32.8, 37.5, 42.1, 48.8 and 51.5 cm. Each layer supports a "doublet" of fibers arrayed parallel to the beam axis, where the fibers in one layer of the doublet are offset from the fibers in the second layer of the doublet by half a fiber spacing. The fibers have a diameter of 835 μm with a 15 μm thick cladding. The inner fiber is also clad with a thin flouro-acrylic layer, which increases the light trapping significantly compared to single clad fibers. Every other layer, starting with the innermost layer, has an additional two doublets of small angle stereo fibers at $\pm\, 2^o$ to 3^o. Eleven meter clear multiclad

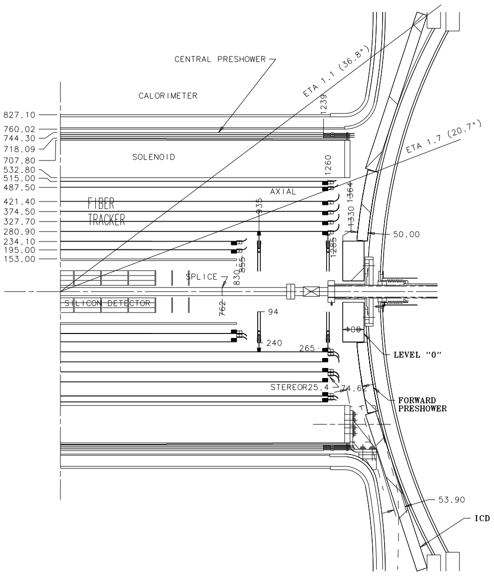

Figure 2: Detail of tracker.

fiber conducts the light to the Visible Light Photon Counter (VLPC) readout underneath the detector. The readout is also via SVX II. At $\eta = 0$, the resolution is approximately $\delta p_T/p_T = 8\%$ for $p_T = 50$ GeV/c.

The photodetectors for the CFT must be capable of detecting single photons with high efficiency at high rates, and with a large gain. The VLPC's were developed jointly with Rockwell and have led to devices that have $> 70\%$ quantum efficiency, gains greater than 20,000 and very high rate capability, well in excess of the 10 MHz required for our application. To achieve this performance, the devices are run at cryogenic temperatures of 6-14K. The devices are produced in arrays of eight 1 mm pixels, with 1024 pixels mounted in a single cryogenic unit (cassette). We presently have over 20,000 pixels in hand, and have carried out extensive system tests on 3,000 channels. The double hit efficiency for cosmic ray tracks is better than 99.9%. The doublet position resolution is found to be about 100 μm.

The Central and Forward Preshower Detectors (CPS and FPS) will augment triggering on electrons in the regions $|\eta| \leq 1.3$ and $1.4 \leq |\eta| \leq 2.6$. These detectors will each use a similar technology: extruded triangular scintillator with wavelength shifting fiber (WLS) readout coupled to clear waveguide fiber

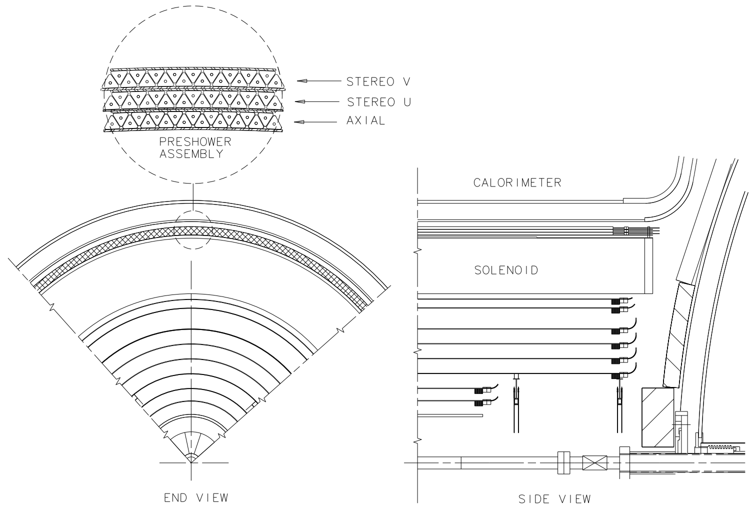

Figure 3: The central preshower detector.

which in turn couples to VLPC's.

In the central region the preshower (see Fig.3) is located after two radiation lengths of material made up of the solenoid and a lead radiator and before the calorimeter cryostat located at a radius of 72 cm. Three layers of scintillator provide axial and $\pm 23^o$ stereo information. The scintillator strips are about 2.6 m long, with the wavelength shifter fiber split at the center of the detector to double the effective segmentation along the beam direction. The total channel count is about 7,000. The center-to-center spacing of adjacent strips is about 7 mm, and each strip is optically isolated from its neighbors. The WLS fiber is coupled to 11 m of clear waveguide which brings the signal to the VLPC's.

Simulations of the CPS show that the information from the preshower detector will provide a factor of 3-5 reduction in the trigger rate by applying a pulse height cut and requiring coarse position-matching with tracks. Off-line, the early sampoling of the showers and the good position resolution of the detector will provide additional means for identifying electrons and therefore enhances the capability for tagging b-quark jets through their semileptonic decays.

The forward preshower detector (FPS) uses the same technology as the

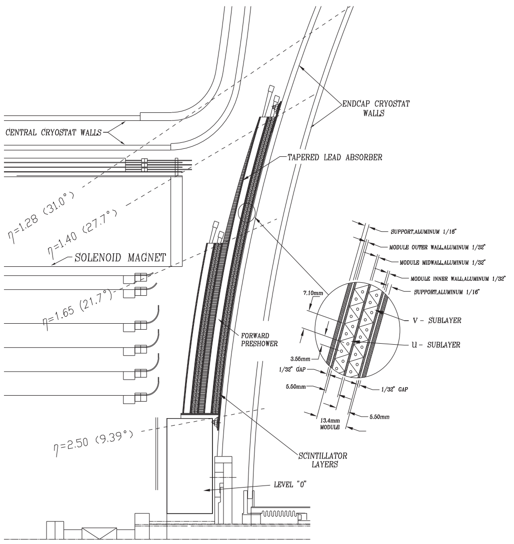

Figure 4: The forward preshower detector.

CPS, but the mechanical construction is quite different. This detector will cover the region from $|\eta| = 1.4$ to 2.5. It will be mounted on the face of the end calorimeter cryostat. The FPS will be segmented longitudinally into four structurally distinct layers, with each layer consisting of eight azimuthal wedges or modules. Each module subtends 45^o in ϕ, and will consist of both a u and a v scintillator sublayer. The central 22.5^o of each module will consist of active scintillator volume. The modules of successive layers are staggered to provide full azimuthal coverage. A lead converter ($2X_0$) is located between scintillator layers. The strip width will be about 8 mm, yielding a total channel count of 16,000.

Based on our studies, we expect this device to reduce the Level 1 trigger rate by factors of 2-4, as well as providing substantial improvements in offline electron identification and γ/π^0 separation.

1.2 The Calorimeter

The liquid argon calorimeter front-end electronics up to the digitizers will be replaced to accomodate the smaller bunch spacing and higher luminosities. The peak sampling time will be reduced to 400 ns from 2200 ns. An analog

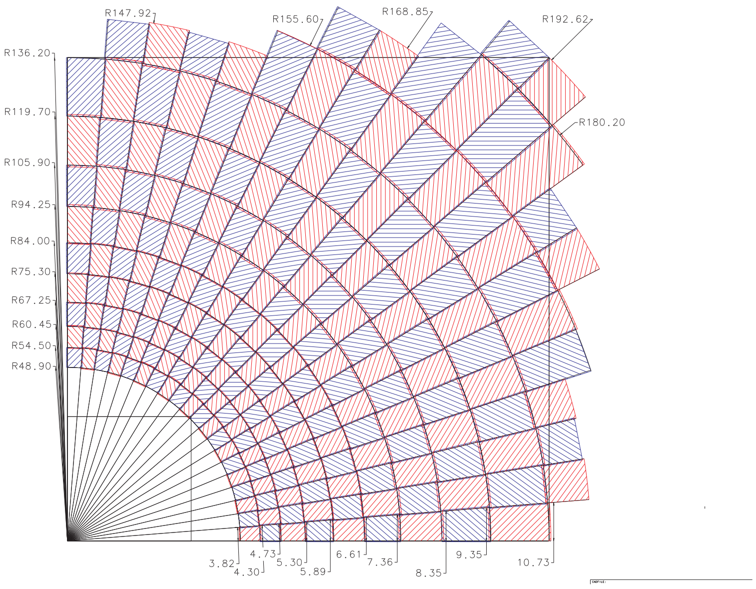

Figure 5: One quarter of the forward muon trigger detector.

pipeline, based on a switched capacitor array developed by LBL, provides a 48 deep analog pipeline to accomodate the trigger latency of about 4μs including cable delays. The signal shaping is unipolar.

In addition, the scintillator detector located in the region between the central and end calorimeter cryostats will be replaced because the present phototube readout will not work in the magnetic field that will be present in the upgraded detector.

1.3 The Muon System

In the central region, defined approximately as $|\eta| \leq 1$, the WAMUS drift chambers and "Cosmic Cap" scintillation counters will be retained with replacement of their electronics to accomodate the small bunch spacing. The coverage of the Cosmic Cap will be extended to the underside of the detector. In addition, 630 scintillation counters will be added to the space between the calorimeter and first layer of central muon drift chambers, to reject out-of-time backgrounds and to provide a ϕ match to CFT track candidates at the trigger level.

The forward muon system, defined approximately as $1 \leq |\eta| \leq 2$, has undergone a major revision. Due to aging, the forward region muon drift chambers will be replaced with plastic mini-drift tubes in an $r\phi$ geometry. The cells are square in cross section with a width of one cm. There will be three planes (A,B,C) on each end of the detector with (4,3,3) decks of tubes per layer. Three layers (A,B,C) of scintillation counters (see Fig. 5) in an $R-\phi$ geometry, with $\Delta\eta \times \Delta\phi = 0.1 \times 4.5\,\mathrm{deg}$, reject out-of-time background hits. A coincidence of hits in the three layers in conjunction with a track in the CFT forms the forward muon trigger. Lastly, the large flux of non-muon background particles, originating from collisions and scattered from the beampipe and low-β quadrupole magnets, has compelled the addition of a thick iron (50 cm) and polyethylene (15 cm) shield with a lead skin (5 cm) around the forward accelerator elements in the collision hall. This shield will reduce the background flux by a factor of 20-50.

1.4 The Trigger System and Data Acquisition

The upgrade trigger has three levels. Level 1 (L1) is a deadtimeless hardware trigger with inputs from the calorimeter (+ CFT), preshower, muon system (+CFT). The L1 trigger has a timescale of about 4μs. The L1 calorimeter trigger functionality remains unchanged from the present, using local energy deposition and global calorimetric characteristics to generate a trigger based on $\Delta\eta \times \Delta\phi = 0.8 \times 1.6$ trigger tiles and $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ trigger towers. The CFT and preshower track trigger is new, based on $r-\phi$ hit patterns in 4.5^o sectors with up to four distinct momentum thresholds. The CFT readout is picked off to provide fast signals for the trigger and loaded into field programmable gate arrays to form eight-fold coincidences from hits in the eight CFT layers. In the forward region, a L1 trigger will require a spatial match of preshower hits in each layer behind the converter lead with the corresponding track stubs in each layer before the lead. The muon L1 trigger uses the barrel scintillation counters, the cosmic ray veto scintillation counters, and the proportional drift tubes. The forward L1 muon region includes the pixel scintillation counters and the mini-drift tubes. The CFT is also an integral part of the L1 triggering scheme for both the central and forward regions.

The L2 trigger provides the capability to combine information from the various L1 triggers. As such, we want to preserve as much flexibility as possible in order to implement new algorithms as driven by the physics goals. The L2 trigger must complete its work in about 100 μs. The present architecture for the L2 trigger system consists of detector specific "pre-processors" that concentrate the raw data to form "objects" such as electrons, muons, jets, tracks, and secondary vertices. The time budget allocation between the pre-processors and the global stage based on our studies, indicates that the pre-processors have about 30-40 μs and the global processor has about 70 μs to complete its work. In this way we maintain the deadtime below 1%. The technologies for these processors include DSP's for the pre-processors, and an Alpha based RISC processor, being developed jointly by CDF and DØ, for the global stage. A global L2 processor then operates on these objects to provide the trigger. The L1 trigger must reduce the event rate to less than 10 khz. L2 reduces the rate to less than one khz.

The L3 trigger system remains essentially unchanged and consists of a farm of microprocessors, providing a further reduction in the trigger rate to about 10-20 Hz, which can be recorded on tape. We are considering proposals to further increase the amount of parallel paths for the data, in order to increase the potential bandwidth at L3. The combined effect is to reduce the raw inelastic event rate by a factor of about a 10^6.

2 Conclusions

The upgrade of the DØ detector for Run II is underway, and the upgrade has been approved by Fermilab. Conceptual designs for all subsystems have been completed and approved. Construction of many components is underway and is planned to be completed in 1999, in time for the first Main Injector run.

The upgrade of the DØ detector is a huge undertaking, and I thank all my colleagues for the opportunity to present the work of a very large number of people.

References

1. "The DØ Upgrade", DØ Note 2542, Fermilab-FN-639 (April 1995); "The DØ Upgrade: Forward Preshower, Muon System and Level 2 Trigger", DØ Note 2894, Fermilab-FN-641 (January 1996).
2. A. Byon, "Prospects for Top Physics at the Tevatron"; R. Brock, "Prospects for Electroweak Physics at the Tevatron"; M. Rijssenbeek, "Prospects for B Physics at the Tevatron", in these Proceedings.