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# The DØ Upgrade Program and its Physics Potential

Michael Rijssenbeek
for the DØ Collaboration

*Fermi National Accelerator Laboratory*
*P.O. Box 500, Batavia, Illinois 60510*

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# THE DØ UPGRADE PROGRAM AND ITS PHYSICS POTENTIAL

Michael Rijssenbeek for the DØ Collaboration *
State University of New York at Stony Brook
Physics Department
Stony Brook, New York, 11794 †
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Abstract

The Fermilab Collider will be upgraded in a series of steps over the coming five years, with a 50-fold luminosity increase and shortening of the bunch crossing time from 3.5 $\mu$s to 400 ns. These changes in environment necessitate changes in several of the DØ detectors, their electronics and the triggers. In addition, we expect that with the large increase in accumulated luminosity and based upon the analysis of data from the first few runs, new physics opportunities shall be available. This evolution of the physics program in the era preceeding the SSC also affects the choices for the DØ upgrade. The upgraded detector which has been proposed and partially approved will be motivated and described.

## INTRODUCTION

The DØ detector is a large new general purpose collider detector at the Fermilab Tevatron. The detector, approved in 1984, has been operating since mid-1991 with cosmic rays and started its first $\bar{p}p$ run in May 1992. The DØ detector emphasizes the measurement of medium and high $p_T$ leptons and partons, combining full muon coverage with high density and hermetic calorimetry, finely segmented in depth (4 EM, 4 Hadronic), azimuth and $\eta$ ($.1 \times .1$; $.05 \times .05$ at shower maximum), down to 2 degrees from the beams.

Details of the DØ detector, its readout, the performance measured in extensive test beam studies, and initial running experience are given in other papers presented at this conference and references therein[1] .

Initial plans for the DØ upgrade, in prepa-

*The D0 collaboration: Universidad de los Andes - Bogota Colombia, University of Arizona, Brookhaven National Laboratory, Brown University, University of California - Riverside, Centro Brasiliero de Pesquisas Fisicas - Rio de Janeiro Brazil, CINVESTAV - Mexico City Mexico, Columbia University, Delhi University - Delhi India, Fermi National Accelerator Laboratory, Florida State University, University of Hawaii, University of Illinois - Chicago, Indiana University, Iowa State University, Lawrence Berkeley Laboratory, University of Maryland, University of Michigan, Michigan State University, Moscow State University - Russia, New York University, Northeastern University, Northern Illinois University, Northwestern University, University of Notre Dame, Panjab University - Chandigarh India, Institute for High Energy Physics - Protvino Russia, Purdue University, Rice University, University of Rochester, CEN - Saclay France, State University of New York - Stony Brook, Superconducting Supercollider Laboratory, Tata Institute of Fundamental Research - Bombay India, University of Texas - Arlington, Texas A&M University.

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ration for the Fermilab Main Injector, were made in the 1989 Breckenridge workshop[2] . The original idea of preserving the high $p_T$ physics capability of DØ evolved in subsequent years towards expanding the DØ physics capabilities with the inclusion of "low $p_T$" physics, i.e. inclusive and exclusive $b$ and $c$ physics.

The luminosity of the Tevatron collider has outgrown the DØ design expectation ($\mathcal{L}$=$10^{30}cm^{-2}s^{-1}$) already in this current run, and is projected to grow from $5 - 11 \times 10^{30}cm^{-2}s^{-1}$ in run Ib (Sep '94) and run II ('95) with 6×6 bunch operation, to $50 \times 10^{30}cm^{-2}s^{-1}$ with 36×36 bunch operation in the Main Injector era after 1997.

## THE DØ UPGRADE

The DØ upgrade program is designed to meet the challenges posed by the higher luminosity and shorter bunch spacing. The increased luminosity allows us to extend our present physics searches to higher masses. At the same time, we chose to extend our measurement capabilities towards lower $p_T$ physics, driven by growing interest in $b$ and $c$ physics.

At integrated rates equivalent to 300 $pb^{-1}$, at the end of run II, sense wires close to the beams will have collected around 1 C/cm, and all central drift chambers and transition radiation detectors, designed for driftlengths of 1.6-3.2 $\mu$s, will register multiple interactions from crossings occuring every 396 ns.

The maximum drift time of the muon chambers at present is 0.7$\mu$s with the admixture of 5% $CF_4$. For the wide angle muon system the cosmics rate will be cut by extending the present $t_0$ scintillation shield on top to the bottom and sides of the detector. The shield will deliver a time stamp to muon hits.

Calorimeter signals are presently integrated and shaped to peak at 2.2$\mu$s after the interaction. With unipolar shaping this time is shortened to around 400 ns, and the noise introduced by the higher bandwidth will be lowered by a double JFET input stage. The baseline subtraction will be done with samples taken in between succesive trains of 12 bunches. We plan to use delay lines to allow time for the first level trigger decision. Prototypes have been built and work is underway for a realistic 5000 channel test.

Simulation work has been done for various shaping times and bunch intervals. A simulation for the $M_T(W)$ shows a small systematic shift of +80MeV for the 396ns bunch interval at $50 \times 10^{30}cm^{-2}s^{-1}$.

Trigger and DAQ upgrades are relatively straightforward, aiming at an expansion of bandwidth and throughput.

During run IIa, in 1995, an intermediate situation will exist for the tracking system; the full DØ tracking upgrade will be completed in time for run IIb, in 1997. For run II the present vertex drift chamber will be replaced with a smaller version of the full upgrade silicon and fiber detectors, whereas all other chambers will be operated with faster gas to reduce event overlap from different bunch crossings.

## CENTRAL TRACKING UPGRADE

The following sections describe the run III full DØ central tracking upgrade, shown in Figure 1. A 2 T solenoid surrounds the tracking region. The main parts, inner silicon detectors, outer scintillating fiber tracker, and preshower detector are described below.

### *Silicon system*

The silicon tracking is designed to give excellent secondary vertex tagging, excellent momentum resolution for tracks with $|\eta| < 2$, sign determination up to $|\eta|$=3 and $p_T \leq 50 GeV/c$, while covering the rather large spread in vertex position of $\sigma$=30 cm at the Tevatron. The

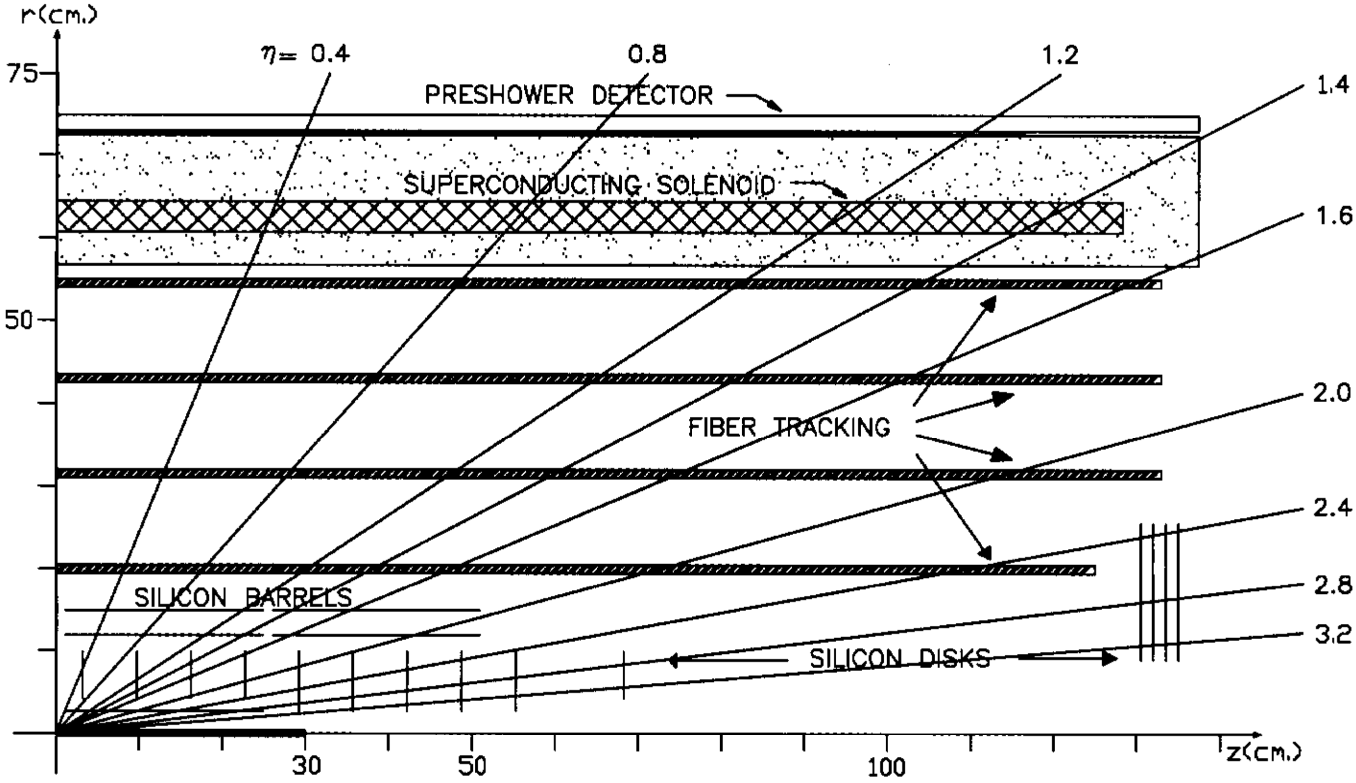


Figure 1. The Full DØ Central Tracking Upgrade.

central $\eta$ region is covered by two short inner barrels 2×25 cm long and one longer 2×51 cm outer barrel, all of single layer Si strips, at 25$\mu$m pitch with alternate strips read out. Each strip is 12 cm long and is read out at one end; two detectors mounted end to end form a 24 cm long "ladder" with 1 cm dead space for readout, support, connectors, and cooling at each end.

Disks are mounted between the innermost and middle barrels, $4.1 < r < 10cm$, and in the forward directions, $2.6 < r < 10cm$. The disks are constructed by grouping 12 wedge shaped double-sided detectors, with strips running on front and back with a 30° stereo angle. Readout is located at the outer edges, and circular cooling channels with water at sub-atmospheric pressure also serve as supports. Disks in the very forward directions are located in front of the end calorimeters and are single-sided for simplicity.

Disks and barrels are mounted in a lightweight tubular Al frame, suspended at each end. The frame and the water cooling/support system are in the prototyping stage.

The readout of the 800K channels of AC coupled, resistor or FET biased silicon strips is done with the SVX2 chip, a joint CDF/LBL/DØ development. Each 128 channel chip contains shaping, delay, and 7 bit A/D circuitry with subsequent multiplexing. Noise, at 12 pF input capacitance and 100 ns shaping, is low and allows a 20/1 S/N ratio.

The accuracy expected from the silicon system is around 12 $\mu$m per channel, with positioning systematics contributing around 20 $\mu$m.

*Scintillating fiber tracker*

The scintillating fiber system consists of four concentric barrel detectors in the space between silicon system and the coil, $20 < r <$

54$cm$.

Each fiber superlayer contains 8 layers of fibers arranged along $z, z, z, z, u, u, v, v$, where $u$ and $v$ have a 10° stereo angle with respect to the $z$ direction. Fibers are spaced by 870$\mu$m and adjacent layers are offset by 435$\mu$m. The doubled $z$ layer and the staggering improves efficiency and resolution. Support for a superlayer is formed by a thin and stiff carbon fiber cylinder. At the ends of the detector a transision is made from scintillating fibers to clear waveguide fibers that carry photons through the gap between the central and end calorimeters to the photo-detectors.

As photo-detectors we are testing the promising experimental Visible Light Photon Counters (VLPC) under development by Rockwell Inc. These semiconductor devices combine small size, low power, and high speed, with a very high QE$>$ 80% at $\lambda = 565nm$ and very low dark current ($\leq$ 5 kHz). Single, and multi-photon peaks are easily discernible in the VLPC pulse height spectrum. We expect upwards of 4 photo-electrons (near $z$=0) at the VPLC after a 6 m clear waveguide.

The VLPC operates at 7°K and thus has to be mounted in a liquid He cryostat. In the present design small cryostats, holding 8192 VLPC's each, will be mounted underneath the DØ calorimeters. Beam test data of a few hundred channels are being analyzed and a 2800 channel cosmic ray fiber test is in preparation.

*Solenoid and Preshower detector*

R&D for the solenoid has started. The coil covers the $|\eta| < 1.6$ region. From present studies, and experience at KEK and HERA, we plan a 2 T coil with a $1X_0$ and 15 cm thickness. The present design uses a varying current density to provide good field uniformity near the ends. The absence of a return yoke presents no special problems. Forces, as presently calculated, are not excessive.

In order to correct for EM energy lost in the coil (note that the calorimeter cryostat walls present another $2X_0$), a preshower detector will be installed between coil and calorimeter cryostat, preceeded by a Pb radiator of an $\eta$ dependent thickness such as to keep the total thickness $2X_0$ uniformly for all $\eta$. The preshower detector will give additional electron identification power and pion rejection, complementing the $E/p$ matching power provided by the magnet.

The preshower detector consists of 6 layers of scintillating strips, 5mm wide and 3mm thick, organized as $z, z, u, u, v, v$ with $\pm 10°$ stereo. Strips are constructed by milling thin, deep isolating grooves in scintillating sheet. Readout is done with wave length shifting fibers, embedded in the scintillator and coupled to clear readout fibers at one detector end. To compensate for the cosec($\theta$) effect in light output, we plan to taper the scintillating sheet towards the ends. For readout, VLPC's are planned with 4 bit non-linear digitization. A hardware preshower electron trigger is under investigation.

*Simulation Studies*

Many simulations using GEANT and a realistic description of the upgraded detector have been performed[3] . Such studies show that the present hadronic resolution of $50\%/\sqrt{E}$ is preserved with the presence of the solenoid. For jets as low as 10 and 20 GeV $E_T$ the magnetic field has no influence on the $E_T$ resolution.

EM resolution in the central region worsens due to energy loss in the coil but can be restored completely using the strong correlations that exist between energy lost in the coil plus radiator and preshower energy, and between cryostat energy loss and the first EM layer energy. Using those correlations, the M($Z$) distribution measured by the Upgraded DØ appears indistinguishable from M($Z$) calculated for the present detector. $\not\!\!E_T$ resolution, as evidenced by the $M_T(W)$ distribution appears unaffected by field and coil.

Track finding and efficiency studies are underway. Preliminary studies indicate that efficiency is high and ambiguities quite low due to fine grained resolution in $r\phi$.

A vertex resolution study (Si barrels only) with $e$'s from $t \rightarrow e + X$ shows that secondary vertex tagging will perform well; the vertex resolution of 30 $\mu$m compares well with a typical 300 $\mu$m $B$ decay path. Momentum resolution varies as $(0.02 \oplus 0.005 p_T)$ for $|\eta| < 1.5$, roughly doubling towards $\eta = 3$. This performance predicts excellent mass resolution for exclusive decays as $B \rightarrow \Psi K_s^0 \rightarrow (\mu^+\mu^-)(\pi^+\pi^-)$.

Preliminary test beam results on $\pi^{\pm}/e$ rejection based on preshower energy agree well with GEANT simulations and with extrapolations of the successful UA2 preshower detector. After loose calorimeter EM shower shape and track-matching cuts, a 4 MIP preshower energy cut (for all three double layers) is highly efficient for electrons (99% for electrons from $W$, $Z$, or $t$; 88% for electrons from $b$ and $c$), while rejecting 97% of all remaining QCD fake electron candidates ($\pi^{\pm}\pi^0$ overlaps and early charge exchange reactions in the EM calorimeter). This complements and compares well with $E/p$ match requirements.

Conversion backgrounds have been studied, and appear to be very manageable due to the fine tracking resolution, the field, and the highly transparent detectors. In crossing 3 live detector layers, photons everywhere encounter less than $0.04X_0$ of material.

## PHYSICS WITH THE DØ UPGRADE

### *t, W, and Z physics*

The world average error (UA2 and CDF) on the $W$-mass is 270 MeV. Extrapolations from D0 test beam performance and reasonable assumptions about structure function uncertainties predict $\sigma(M(W)) \simeq 50 MeV$ for a $1 fb^{-1}$ event sample (Main Injector era).

Table 1. Event Samples at $1 fb^{-1}$.
50% $e$ and $\mu$ efficiency assumed.
M($t$) = 140 GeV.

| *reaction* | *events* |
|---|---|
| $t\bar{t} \rightarrow e + \mu + X$ | 530 |
| $t\bar{t} \rightarrow e + jets$ | 3200 |
| $W \rightarrow e\nu$ | $2.4 \times 10^6$ |
| $Z \rightarrow e^+e^-$ | $2.3 \times 10^5$ |
| $b\bar{b} \rightarrow X$ | $> 10^{10}$ |

The mass of the $t$, once discovered, will also be well measured ($\sigma(M(t)) \leq 5 GeV$), using the $t\bar{t} \rightarrow e + jets$ mode. Combining the $W$ (the $e$ and $\not\!p_T$combination with M($W$) constraint) with the nearest $b$-jet gives a nearly Gaussian distribution. Calibrating the mass scale with the $W \rightarrow jets$ decay (using the two non-$b$ jets to form a $W$), returns a M($t$) value within a few GeV from the starting value. This procedure relies on efficient $b$-tagging capability.

Measuring the $Z \rightarrow e^+e^-$ and $\mu^+\mu^-$ decay asymmetry, an independent measure of $\sin^2\theta_W^{ll}$ is obtained, differing from $\sin^2\theta^{\overline{MS}}$ in the M($t$) and M($H$) dependent radiative corrections. The estimated error on this quantity is 0.0009 for $10^5 Z \rightarrow e^+e^-$ decays.

The above three measurements give very powerful constraints on the Standard Model from a single experiment! Note that event samples at $1 fb^{-1}$ are huge (see Table 1.).

The precise measurement of $\Gamma_W$, via measurement of the leptonic cross section ratio of $W$ and $Z$, is sensitive to all decays of the $W$ and therefore to the inclusive $W \rightarrow t + X$ decay if the $t$-mass happens to lie below the

Table 2. Efficiencies for $b\bar{b} \rightarrow \Psi K_s^0$, $\Psi \rightarrow \mu\mu, K_s^0 \rightarrow \pi^+\pi^-$.

| *item* | |
|---|---|
| $B^0$ *per pair* | 0.75 |
| *Branching Ratio* | $2.5 \times 10^{-5}$ |
| $2\mu$ *trigger* | 0.06 |
| *Tracking Efficiency* | $(0.9)^4$ |
| $5\sigma$ *secondary vertex* | 0.7 |
| $K_s^0$ *containment* | 0.8 |

$W$-mass. At $1fb^{-1}$ a $\delta(\Gamma_W) \approx 25MeV$ is expected. Also, improved measures are expected for the $W$ EM moments, through measurement of $W\gamma$ production.

*B physics*

The FNAL $\bar{p}p$ collider with the Main Injector compares very well with dedicated $B$-factories. Production cross sections are large, and one is only (!) limited by the ability to trigger and store the events. For DØ, muon triggers are the natural choice. Using a $\mu$ to tag the $b$, one may study the $\bar{b}$ hadronization and decay modes. Several exclusive $B$ decay modes are sensitive to new physics and CKM parameters.

At $1fb^{-1}$, assuming the branching fractions and efficiencies listed in Table 2, DØ will collect 40K events of the type $b\bar{b} \rightarrow \Psi K_s^0(\Psi \rightarrow \mu\mu,\ K_s^0 \rightarrow \pi^+\pi^-)$.

$B_s$ mixing can be studied as a function of the precisely measured decaylength. At $1fb^{-1}$ we expect to find 2500 events of type $B_s \rightarrow D_s\pi\pi\pi, D_s \rightarrow \phi\pi$ (thus avoiding contamination from $B_d$). Studies show the ability to measure $x_s$ in the range between 10 and 20.

CP violation might be measurable in the $B$ decays to the CP eigenstate $\Psi K_s^0$. In addition to factors listed in Table 2, one has to account for wrong-sign tagging, smearing, and additional $\mu$ tagging. Studies indicate that DØ can measure $sin(2\beta)$ (Unitarity angle $\beta$ is expected to lie in the range 0.1-0.6) with an 0.15 error.

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