DØ UPGRADE FOR RUN II

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The DØ detector at The Fermilab Tevatron is undergoing a major upgrade to prepare for data taking with luminosities reaching 2×10^{32} cm^{-2} s^{-1}. The upgrade includes a new central tracking array, new muon detector components and electronic upgrades to many subsystems. The DØ upgraded detector will be operational for RUN II in spring 2000

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1 Introduction

The Fermilab $p\bar{p}$ collider remains the highest energy accelerator since mid 80's. He has delivered to CDF and DØ detectors an integrated luminosity of 120 pb^{-1}during the Run I period, between 1992 and 1996, at a peak luminosity up to 1.6×10^{31} cm^{-2} s^{-1}. The major studies encompass the top quark discovery, a precise measurement of the W mass, improved limits on tribosons anomalous coupling, improved limits on SUSY and more exotic particules masses and important tests of QCD in high $P_T$jets production and b quark production.

The next run in collider mode is scheduled to begin in spring 2000 with important improvements to the accelerator complex and to the DØ detector. By the end of the Run II, an integrated luminosity of several fb^{-1}is expected. The gain in luminosity by more than an order of magnitude coupled with the upgrade of the detector, will allow more precise measurements in the Standard Model domain and will increase the potential for new phenomena discovery.

2 The physics program

The physics program is the continuation of the Run I program with some shifts on the emphasis, due to the higher luminosity and to the better quality of the data. It is beyond the scope of this paper to present an exhaustive description of the physics program which will be undertaken [1]. A somewhat arbitrary choice of the "hottest" subjects are presented:

- Exploration of the mechanism of the electroweak symmetry breaking with a large sample of top and precise measurement of the EW parameters;
- Direct searches for new phenomena beyond the Standard Model;
- CP violation in the b-quark sector;
- Precise studies of QCD.

2.1 *Properties of the top quark*

- **$t\bar{t}$ production**. With a sample of over 1000 identified b-tagged events: measurement of M_{top} to $\pm$ 3 GeV; measurement of $\sigma_{t\bar{t}}$ to $\simeq$ 10%; detailled studies of top decays (branching ratios, FCNC, polarization of the W).

- **Single top production**. With a sample of $\simeq$ 400 events determine $\frac{\delta\sigma(t)}{\sigma(t)}$ to $\simeq$ 25% and $|V_{tb}|$ to 14%.

2.2 *Precise measurements of Electroweak parameters*

More than 1 500 000 events from $W \to e\nu$ decays and about the same number from $W \to \mu\nu$ will be available for analysis in each experiment. This large sample will permit the following measurements:

- $\delta(M_W) \simeq 40$ $\mathbf{MeV/c^2}$ (figure 1). This uncertainty combined with the LEP measurement and the uncertainty on the top mass measurement at the Tevatron will determine the mass of the Standard Model Higgs to a precision of $\delta M_H/M_H \simeq 40\%$ (figure 2)

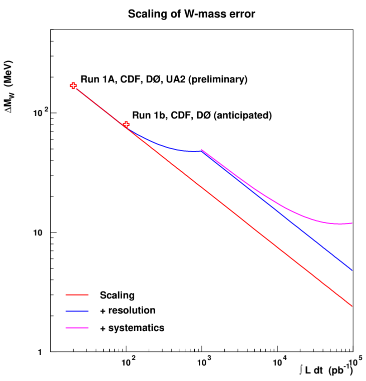

Figure 1. Uncertainty on the W mass measurement as a function of integrated luminosity

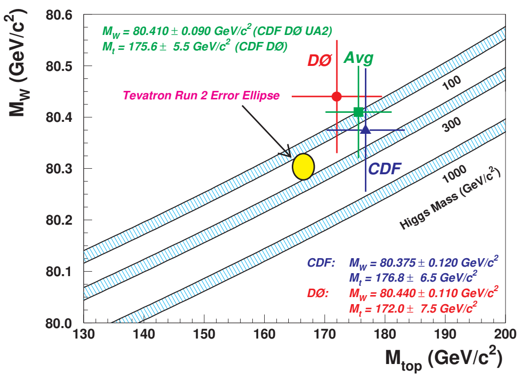

Figure 2. The measured W mass versus top mass in Run I. Theoritical predictions are shown for several values of Standard Model Higgs mass. The Run II error ellipse is shown at an arbitray position

- **W and Z charge asymmetry**: constraint on the choice of the set of parton density functions; measurement of $\delta(\sin^2\theta_W) \simeq 0.001$.

- **Trilinear gauge bosons coupling**: Improved limits on anomalous couplings by a factor $\simeq 5 - 15$ for WWγ and by $\simeq 10 - 100$ for ZZγ compared to Run I.

2.3 *Search for new phenomena*

- **SUSY**
  Run II will allow the exploration of a large fraction of the MSSM parameter

phase space for charginos ($\chi^{\pm}$), neutralinos (χ^0), squarks ($\tilde{q}$) and gluinos ($\tilde{g}$). The most promising signals include $\chi^{\pm}$ in trilepton final state, $\tilde{g}$ in missing p_T+ jets. The mass reach is: $M_{\chi^{\pm}} \simeq 220$ GeV/c^2; $M_{\tilde{g}} \simeq 400$ GeV/c^2

- **Exotic phenomena**
  Search for W'Z', leptoquarks, technicolor, charged Higgs from top decay, compositness,..with mass limits improved by a factor 1.5-2 compared to RUN I

2.4 Properties of the b-quark

CDF has already demonstrated in Run I that precision B physics (spectroscopy, decays, lifetime, mixing, etc) can be done successfully at the Tevatron.

The copious production of the various species of b hadrons will allow a variety of B physics topics to be studied [2] (QCD tests, study of the B_c system, observation of rare decay modes, B_s mixing, CP violation). The main focus will certainly be the search for CP violation and establishing CKM constraints: $\sin(2\beta)$ will be measured with a precision better than ± 0.14; from fully reconstructed B_s decays, a value up to $x_s \simeq 20$ could be reached.

2.5 Properties of QCD

Precision studies will be made with new probes in new regions of phase space. Measurements of parton distributions, Drell-Yan production of W and Z accompanied by jets and non-pertubative phenomena such as rapidity gaps and diffractive scattering will be of continued importance with large sample of data.

3 Upgrade of the accelerators

To meet the required increase in luminosity, an upgrade of the Fermilab accelerator complex is underway [3]. In Run II, the plan is to deliver an instantaneous luminosity of 2×10^{32} cm^{-2} s^{-1}. For the TeV33 project, an increase of a factor 5 in instantaneous luminosity is foreseen.

The key to increase the luminosity is to increase the number of antiprotons. This goal is achieved by replacing the existing Main Ring with a new accelerator, the **Main Injector**, and adding a new antiproton storage ring, the **Recycler**, within a new common tunnel adjacent to that of the Tevatron. This will result in an overall increase both in bunch population and in the number of bunches available for $p\bar{p}$ collisions.

- **The Main Injector** is a large aperture, rapid cycling, 120 GeV proton synchrotron designed specifically to replace the present Main Ring in its two main functions: production of $\bar{p}$'s and injection into the Tevatron. In addition the Main Injector will provide an extracted 120 GeV beam containing 3×10^{13} protons with a 2.9 second cycle time.

- **The Recycler** is a permanent-magnet, 8 GeV storage ring which will provide a factor of $\simeq 2$ increase in luminosity beyond that projected with the Main Injector alone.

Additional changes include:

- an increase in beam energy from 900 GeV to the nominal 1 TeV;
- an increase in the number of bunches from 6 to 36, together with a decrease in the crossing time from 3400 to 396 ns and later to 132 ns (with a 108 bunches against 108 bunches operation).

The main Tevatron parameters for Run II are compared to the ones in Run I in table 1.

	Run IB	Run II	units
Protons/bunch	2.32×10^{11}	2.70×10^{11}	
Antiprotons/bunch	5.50×10^{10}	7.50×10^{10}	
Total Antiprotons	3.30×10^{11}	1.98×10^{12}	
Energy/beam	900	1000	GeV
Number of bunches	6 + 6	36 + 36	
Antiprotons stacking	0.6×10^{11}	2×10^{11}	per hour
Typical Luminosity	1.6×10^{31}	2.0×10^{32}	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Integrated Luminosity	3.2	41.0	pb^{-1}per week
Bunch spacing	3500	$396 \rightarrow 132$	ns
Interactions per crossing	2.7	$5.8 \rightarrow 2.0$	

Table 1. Tevatron running conditions for Run II compared to Run I

4 Detector Upgrade

The upgrade builts on existing strength to identify and measure leptons, photons and jets, with a nearly complete solid angle coverage for calorimetry and muons detection.

The high luminosity and bunch spacing as well as the increase in detector occupancy require extensive changes in the detector of Run I. Higher level of radiation requires extensive shielding too. Computing and data storage systems must be able to handle a $\simeq 40$ fold increase in event collection with respect to Run I.

An overall view of the DØ detector is shown on figure 3, with primary detector systems still remaining: the liquid argon calorimeter and the central part of the muon detector system. The major element of the upgrade is the replacement of the non-magnetic inner tracking system with a high precision integrated tracker including a solenoid [4].

4.1 Central Tracking System

The new high precision compact tracker enhances the identification of electrons and muons, allows the in situ calibration of the calorimetric energy scale and makes the whole area of B physics studies accessible to DØ .

The central tracking detector consists of:

- A Silicon Microstrip Tracker (**SMT**): 6 barrels of silicon detectors with 3D readout interspersed with 14 z-disks that extend out to $|\eta|$=3 (figure 4). Staggered planes in the SVX barrels overlap such as to yield an average of 5.5 layers on track. The single point resolution has been shown to be $\leq 10\ \mu$m.

  Electronic readout will be done using the 128 channel SVX II readout chip developed by Fermilab and Lawrence Berkeley Laboratory. Each channel contains a charge sensitive preamp, 32 stages of analog pipeline delay, an 8 bit analog to digital converter, and sparse data readout.

  The **SMT** is equipped with 840,000 channels.

- A Central Fiber Tracker (**CFT**): eight superlayers of scintillating fibers, each arranged as two layers axial and stereo of staggered fiber doublets. The fibers are mated to 8-11 m multiclad clear fiber waveguides which conduct the light to photodetectors.

  The photodectectors are capable of detecting single photons with high efficiency at high rates and with large gain. For the first time in a high energy physics experiment, a large number (77,000) of visible light photon counters (VLPC's) are used. VLPC's are impurity band conduction devices derived from solid state photomultipliers. Test results indicate they can detect single photons with quantum efficiencies up to 80% and gains $\geq 10^4$. A cosmic ray test has confirmed that single point resolution for doublet layers are $\simeq 100\ \mu$m with hit efficiencies of 99.5 %.

- A superconducting solenoid, 2.8 meter long, 50 cm in diameter, installed inside the central calorimeter cavity.

- Preshower detectors made of scintillating strips equipped with wavelength shifter readout. The central preshower is mounted between the magnet coil and the outer wall of the central cryostat while the forward preshowers are mounted on the front face of the forward cryostats.

4.2 Calorimeter

The Uranium-Liquid argon calorimeter is intrinsically radiation hard, and no upgrade or modifications are needed, except for the front end electronics which has to be completely changed due to shortened bunch crossing intervalls.

4.3 Muon System

One of the strong feature of the DØ detector is its almost complete muon coverage. In the central region ($|\eta|\leq 1$), three superlayers of proportionnal drift tubes (**PDT**), one inside and two outside of a 1.5 m shield of a toroidally magnetized iron, allow to measure the muon momentum. Two layers of scintillators are used in the trigger. In the forward direction, **PDT** are replaced with mini-drift tubes (**MDT**). Three layers of highly segmented scintillator counters provide the trigger.

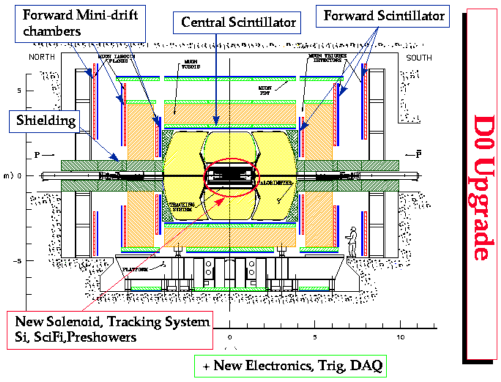

Figure 3. The DØ detector

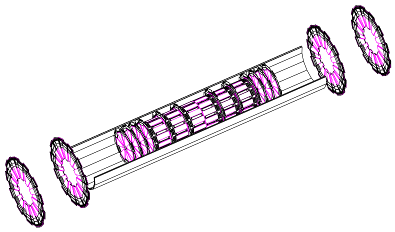

Figure 4. The Silicon Microvertex Tracker

Of particular B physics relevance is the lowered muon p_T threshold from 4 GeV/c in Run I to 1.5 GeV/c in Run II. Due to the presence of a central magnetic spectrometer, the momentum resolution is significantly enhanced to Run I capabilities.

5 Trigger System

The trigger system has to cope with a 10 fold higher luminosity and a $\sim$ 40 fold decrease in the time between beam crossing (from 4 μs to 132 ns). These two parameters require significant upgrade of the entire trigger system.

The first trigger stage (L1) includes scintillating, tracking and calorimeter detectors. It provides a trigger decision in less than 4.2 μs with a rate of 10 kHz.

The second stage (L2) comprised preprocessors to reorganize the detector and L1 trigger information and a global processor to test for correlation between L1 triggers. The L2 trigger has a rate of 1 kHz at a maximum deadtime of 5 %.

The third level (L3) is a conventionnal multiprocessor farm, where each node receives one event at a time and performs full reconstruction. A 20 Hz output is written into a massive storage system.

6 Beyond Run II: TeV33

Run II promises a rich and varied physics program at the Tevatron. However there remains much interesting high p_T physics which require integrated luminosities with an order of magnitude larger, $\simeq$ 30 fb^{-1}. As an example, it may be possible to observe light and intermediate Higgs bosons in a mass range $80 \leq M_H \leq 130$ GeV/c^2. Of particular interest would be the measurement of the W mass to 20 MeV/c^2 and of the top mass to 1 GeV/c^2.

The challenge is to trigger and record data with an instantaneous luminosity of 1×10^{33} cm^{-2} s^{-1}. Preliminary studies have shown that this is feasible providing upgrade detectors beyond the Run II upgrades. The best strategy for running during the TeV33 era is under discussion.

7 Conclusion

The DØ detector upgrade consisting of a new tracking system, an improved muon detection system, new triggers, and upgraded electronics, is on schedule to be completed for data taking in spring 2000.

The energy frontier will remain at the Tevatron until the middle of the next decade. The higher integrated luminosity and the increase in sensitivity of the upgraded DØ detector will allow the full exploitation of a rich program of physics. Many precision measurements will provide stringent tests of the Standard Model and possibly give some hints of deviation from its predictions. There exist good chance to either discover new physics or, in its absence, to severly constrain the extension to the Standard Model.

Acknowledgments

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