B-Physics and Triggers at DØ: Operational Experience *

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During RunII the DØ experiment successfully pursued a large and varied b-physics programme. This article reports on the operational experience, i.e. detector and triggers from a b-physics perspective.

1. Introduction

After undergoing considerable upgrades, the Tevatron $p\bar{p}$ collider at Fermilab has been running at $\sqrt{s} = 1.96$ TeV since April 2001. It delivered approximately 1.3 fb^{-1} of integrated luminosity in its first major running period up to March 2006. Located at the Tevatron storage ring is the multi-purpose DØ detector, which had been upgraded in parallel with the accelerator. The upgrade included a new tracking system consisting of a Silicon Microstrip Tracker (SMT) and a Scintillating Fibre Tracker (CFT), a solenoid magnet proving a 2 Tesla field and new drift tubes and shielding for the forward muon system. A full description of the upgraded DØ detector can be found in [1]. The detector components particularly relevant to b-physics are discussed in further detail below.

DØ distinguishes two distinct data taking periods: RunI from 1992 to 1996 at $\sqrt{s} = 1.8$ TeV with a total dataset of 110 pb^{-1} and the ongoing RunII at $\sqrt{s} = 1.96$ TeV from April 2001 onwards. Between March and June 2006, further upgrades to the DØ detector were implemented, of which the introduction of a new layer of silicon detectors (L0) close to the beam pipe was the most relevant for b-physics. Data taking prior to June 2006 is known as RunIIa and since then as RunIIb. Except where indicated otherwise, these proceedings refer to RunIIa.

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2. Detector

The strength of the DØ detector from a b-physics perspective has always been its wide muon coverage, up to a pseudorapidity η of 2.2. The muon system consists of three layers of drift tubes, 10 cm wide in the central region ($|\eta| < 1$) and 1 cm in the forward region ($1 < |\eta| < 2.2$). Interspersed between the drift tubes are scintillating counters, used for triggering and rejection of cosmics. Located between the innermost and middle layer of drift tubes are 1.8 T iron toroid magnets. These allow a rough momentum measurement at the highest trigger level without having to rely on the tracking detectors, providing a fast, clean and simple trigger. The polarity of both the muon and the tracking magnetic field are reversed on a regular basis to account for systematic effects. The completely redesigned (after RunI) tracking system inside the 2 Tesla field allows the measurements of impact parameter and particle lifetimes at DØ, something which had not been possible before the upgrade. In the tracking system closest to the interaction region is the SMT with a typical strip pitch of 50–80 μm. It has a barrel-disk hybrid structure and was designed to provide tracking and vertexing coverage in the pseudorapidity range $|\eta| < 3.0$. For RunIIb, the outermost disks have been removed to make space for the readout of L0. First measurements using cosmic rays indicate that adding L0 results in a 30% improvent in the impact parameter resolution wrt to RunIIa. The CFT consists of eight concentric cylinders of pairs of scintillating-fibre doublets. On each cylinder, the inner doublet runs parallel to the beam axis and the outer doublet is mounted at a stereo angle of $\pm 3°$, alternating with each cylinder. The tracking volume extends to a radius of approximately 52 cm. Located outside the superconducting coil is the uranium-liquid-argon calorimeter. The calorimeter has been optimised for high p_T physics, but low p_T electrons can be used to tag semileptonic b-decays. With the tagging efficiency ε defined as the number of tagged decays divided by the total number of events, the tagging purity η defined as the number of correctly tagged decays divided by the number of all tagged decays and the dilution $D = 2\eta - 1$, the tagging power [2] for electrons $\varepsilon D^2(e) = (0.21 \pm 0.07)$ % when used in opposite side tagging. For comparison, $\varepsilon D^2(\mu)$ is (1.48 $\pm$0.17) %. It should be noted that the backgrounds for electrons and muons and hence the criteria used to select tagging muons and electrons are very different and the absolute numbers for the tagging power reflect this.

3. Trigger

DØ uses three levels of triggers to reduce the initial event rate of 1.7 MHz to an average output rate of approximately 50 Hz. The first trigger level is hardware based and relies on three detector components: The calorimeter using 0.2×0.2 η-ϕ trigger towers, the central track trigger using the axial layers of the CFT to find tracks and the muon system. Triggers in the muon system look for scintillator and wire hits consistent with muons, but no p_T measurement is performed. Tracks found in the CFT can be confirmed by muon hits, therefore enabling p_T cuts on muons at the first trigger level. The output rate of this trigger level is 2 kHz. At the second trigger level the previous results are refined and additional event information, e.g. wire and scintillator times for muons, is added. Also at this level is the Silicon Track Trigger (STT). It uses tracks from the first level track trigger to define roads in the SMT. Within these roads, SMT clusters are found and the track is refitted. This leads to an improved p_T measurement and provides the first opportunity to make an impact parameter measurement. It should be noted that a pure displaced vertex trigger similar to CDF is not feasible due to the bandwidth restrictions at the first trigger level. The third level trigger is software based and performs a partial reconstruction of the event. All standard physics objects (tracks, muons, electrons, jets, taus) are available and can be used directly or in combination to accept or reject events. Derived quantities like primary and secondary vertices, missing E_T, impact parameter significance and invariant masses are also available.

3.1. Trigger strategy

The goal of the b-physics trigger strategy is to maximise the number of b-physics events being written to tape, as opposed to aiming for the maximum exposed luminosity. This is achieved by absorbing any bandwidth which becomes available at lower luminosities as high p_T triggers, which have to be able to run unprescaled at all luminosities use less and less bandwidth.

All b-physics triggers at DØ triggers rely on muons. The triggers can be divided into three major groups: Di-muon triggers, unbiased single muon triggers and single muon triggers with an impact parameter requirement. The di-muon triggers aim to detect any b-decays involving a J/ψ (Υ), rare decays (e.g $B_s^0 \rightarrow \mu\mu$) or single muon decays where the second muon is used to tag the flavour of the decay. These triggers are generally very clean and can run up to high luminosities. In RunIIa the main di-muon trigger was based on triggers in the muon system only, making use of the full eta coverage of the muon system, unlike the track based triggers which rely on the CFT and are therefore confined to the central part of the detector. This trigger ran unprescaled at all luminosities up to 150×10^{30} cm^{-2}s^{-1}. The second group are unbiased single muon triggers: A large number of b-physics analyses rely on a lifetime unbiased trigger. These triggers used track matched muons at the first and third trigger level, with p_T cuts of 3, 4 or 5 GeV. They were typically turned off around 50×10^{30} cm^{-2}s^{-1} in RunIIa and are now running up to 100×10^{30} cm^{-2}s^{-1}, with an additional track match required at the second trigger level. Finally there are impact parameter biased single muon triggers: The goal of these triggers is to identify the long lived B-mesons. By requiring a sizable impact parameter on a muon, this muon can be used to tag a b-decay without biasing the signal. During RunIIa, the b-physics triggers did not rely on the STT trigger terms. After the STT's planned late commissioning, the established b-triggers proved sufficient to cope with RunIIa luminosities. This has changed for RunIIb and the b-physics group now relies heavily on the improved p_T measurement that the STT provides.

4. High luminosity challenges

Over the course of RunIIa the instantaneous luminosity at the start of a store has steadily increased, regularly reaching 160×10^{30} cm^{-2}s^{-1} at the end of RunIIa. This is expected to increase further in RunIIb, with some scenarios projecting up to 300×10^{30} cm^{-2}s^{-1}. Measurements in RunIIa have shown that the occupancy in the innermost layer of the CFT rose from 10 % at a luminosity of 40×10^{30} cm^{-2}s^{-1} to up to 25% at 150×10^{30} cm^{-2}s^{-1}. As a consequence, the average amount of CPU required to reconstruct an event rose from $\sim$18 GHz$\times$s to $\sim$65 GHz$\times$s in the same luminosity range. The increase in the amount of CPU required becomes increasingly non-linear with rising luminosity. The situation is worse for the third level trigger, which operates under much tighter time constraints than the offline reconstruction. As b-physics triggers often rely on the intrinsically slow reconstruction of low p_T tracks, it may not be possible to run b-physics triggers at all luminosities. To tackle these problems, DØ pursued a tri-fold approach: The replacement of the CFT readout front end boards reduces the noise and therefore the occupancy in the CFT. The tracking algorithm for the third level trigger has been re-written to be three times faster than the RunIIa algorithm. And finally the trigger computing farm has been upgraded to increase the amount of CPU available.

5. Conclusions

By playing to its strengths, i.e. the extended muon coverage and the new tracking system, the b-physics programme at DØ so far has been a great success as documented by the DØ results presented at this conference. Up-to-date the DØ Collaboration has published ten b-physics related papers [3] in RunIIa, including the world's most precise measurement of the B_s^0 lifetime [4] and an early direct limit on the B_s^0 oscillation frequency [5]. While the increasing instantaneous luminosities pose a challenge, the increasing amount of data and the additional silicon layer provide good opportunities for b-physics precision measurements at DØ in the future.

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