DØ Prospects for Run II Physics

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Run II at the Tevatron will begin in the spring of 2001. With $p\overline{p}$ collisions at $\sqrt{s} = 2.0$ TeV and an expected instantaneous luminosity of 2×10^{32} cm^{-2} s^{-1}, DØ is expecting to collect an integrated luminosity of 2 fb^{-1} in the first two years of running. The ongoing upgrade of the detector will allow the experiment not only to take full advantage of the high luminosity but will also allow for a rich B physics program at DØ. In this paper the prospects for some important B physics measurements will be reviewed. These measurements include CP violation, B_s mixing, rare B decays, and lifetimes and mass measurements of bottom particles such as the Λ_b and B_c.

1. Introduction

The next run of the Tevatron in $p\overline{p}$ collider mode is scheduled to begin in the spring of 2001. With the increase in luminosity due to the new Main Injector, the Tevatron is expected to deliver in the first two years of running an integrated luminosity of 2 fb^{-1} at an increased energy of $\sqrt{s} = 2.0$ TeV. With subsequent running and luminosity upgrades Fermilab's DØ and CDF experiments plan to collect an integrated luminosity of 15-30 fb^{-1} by the year 2007. With a b cross section much larger than at e^+e^- machines (150 μb versus 1 nb) and the production of all B hadron species, the Tevatron will play a major role in B physics exploration.

The DØ detector is undergoing a major upgrade [1] in order to take full advantage of this high luminosity. The upgraded detector with its silicon vertex detector, inner tracking system, muon trigger arrays and forward and central preshower detectors will allow for a rich B physics program. For the first year of running DØ will mainly trigger on muons and electrons for the B physics studies. After that, the installation of a trigger processor will allow the experiment to extend the trigger to secondary vertices.

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2. Measurement of $\sin(2\beta)$ in $B \to J/\psi K_s$

DØ expects to make an accurate measurement of the decay $B \to J/\psi K_s$ with $J/\psi \to \mu^+\mu^-(e^+e^-)$ and $K_s \to \pi^+\pi^-$. The interference of direct decays into $J/\psi K_s$ with those that proceed via $B^0 - \bar{B}^0$ mixing (followed by a decay into the same final state) produces CP violation in this decay mode. The time dependent asymmetry, defined as:

$$A_{CP} = \frac{\Gamma(\overline{B}^0 \to J/\psi K_s) - \Gamma(B^0 \to J/\psi K_s)}{\Gamma(\overline{B}^0 \to J/\psi K_s) + \Gamma(B^0 \to J/\psi K_s)} \quad (1)$$

is directly related to the CKM parameter β:

$$A_{CP}(t) = \sin(2\beta)\sin(\Delta m_d t) \quad (2)$$

The full reconstruction of the $J/\psi K_s$ final state is needed in this measurement, including the reconstruction of the primary and secondary vertices, the J/ψ and K_s masses, and a determination of the B's flavor at production. With the upgraded muon scintillation counter arrays and the new preshower detectors DØ will be able to trigger on muons as well as electrons. The expected trigger efficiencies for $B \to J/\psi K_s$ are $\sim 30\%$ for dimuons and $\sim 20\%$ for dielectrons.

Monte Carlo studies using the full detector simulation and event reconstruction have been performed. Fig. 1 shows the B invariant mass after a constrained fit forcing the $\pi^+\pi^-$ $(\mu^+\mu^-)$

mass to the K_s (J/ψ) mass, and the K_s vertex to point to the B vertex which in turn was forced to point back to the primary vertex. The reconstruction efficiency for $B \to J/\psi K_s$ is about 10%, giving in 2 fb^{-1} 40,000 fully reconstructed events in $J/\psi \to \mu^+\mu^-$ and 30,000 in $J/\psi \to e^+e^-$.

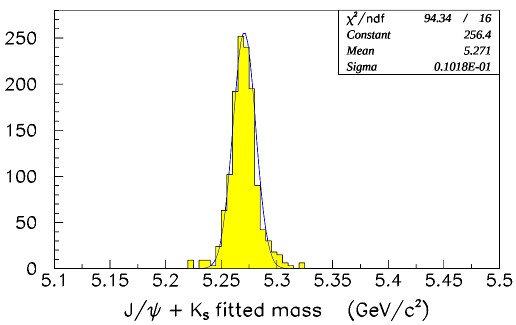

Figure 1. Reconstructed B mass after performing a constraint fit to $B \to J/\psi K_s$

For B tagging of the initial flavor two methods are employed. Same side tagging (SST) which makes use of the correlation between the charge of the nearby pion and the B flavor due to fragmentation or B^{**} production, and opposite side tagging (OST) which requires the identification of the other B in the event. SST requires the reconstruction of soft pions from the primary vertex. In OST if the B decays semileptonically, its flavor is determined by the charge of the lepton; if not, its flavor can be determined by the p_T weighted net charge of its jet. The effectiveness of a tagging method is quantified by ϵD^2, where ϵ is the tagging efficiency and D is the dilution factor. D is equal to $2P-1$, where P is the probability that the method tags the flavor correctly. Extrapolating from the effective tagging efficiencies measured by CDF in Run I [2], DØ expects to achieve an effective tagging efficiency of $\epsilon D^2 \sim 10\%$.

The accuracy of a time dependent $\sin(2\beta)$ measurement is given by:

$$\sigma(\sin 2\beta) \approx e^{x_d^2 \Gamma^2 \sigma_t^2} \sqrt{\frac{1+4x_d^2}{2x_d}} \frac{1}{\epsilon D^2 N} \sqrt{1+\frac{B}{S}} \quad (3)$$

where x_d and Γ are the mixing parameter and decay width of the B_d, σ_t is the proper time measurement resolution (which is about 90 fs), N is the number of events, and S/B is the signal to background ratio (extracted from CDF Run I data to be about 0.75). With these considerations, in the first two years of running DØ will be able to measure $\sin(2\beta)$ with an uncertainty of 0.04 (0.05) in the dimuon (dielectron) mode. With both channels combined DØ expects a final error of 0.03.

DØ will also look for CP violation in $B_s \to J/\psi\phi$ decays, which has the same trigger requirements and similar reconstruction efficiencies to $B \to J/\psi K_s$. The expected SM asymmetry in this channel is not within DØ's experimental reach, therefore an observation of such asymmetry would be a clear signal of new physics.

3. α and γ in two body B decays

A measurement of the CP asymmetry in the decays $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ would yield information on the unitary triangle angles α and γ. Unfortunately, at hadron machines without significant π/K separation, only fits to the masses and decay times can be used to separate the previous two decays from each other and from $B_d \to K^+\pi^-$ and $B_s \to K^-\pi^+$, making this a very difficult measurement.

In order to measure the CP asymmetry, the initial flavor must be tagged. This could be done using the opposite side lepton. Requiring a lepton plus two tracks trigger, and with a total detection efficiency between 0.25-0.5%, DØ is expecting to record about 1000 events in the channel $B_s \to K^+K^-$. The other channels, $\pi^+\pi^-$:K^+K^-:$K^+\pi^-$:$K^-\pi^+$, will be approximately in the ratio 1:2:4:0.5.

Since DØ lacks π/K ID the use of the B mass is the way to separate the previous four decays. Fig. 2 shows the reconstructed B mass for four different channels when the pion mass is assigned to the two tracks coming from the B vertex. A global likelihood fit to the B decay time for the four previous decays plus the probabilities given by the plot in Fig. 2 will yield information on the CP asymmetries. It should be noted that the two decays that have similar masses ($\pi^+\pi^-$ and K^+K^-) have very different oscillation frecuencies. From the CP asymmetries, a determination

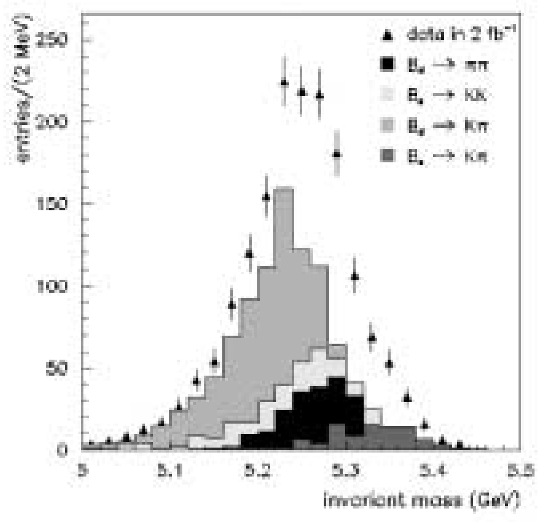

Figure 2. Reconstructed B mass for four different decay channels. The pion mass has been assigned to the two tracks coming from the B vertex.

of α and γ is possible [3]. The level of uncertainty in this extraction remains to be determined.

4. B_s Mixing

B_s mesons are not produced in B factories at e^+e^- machines, therefore this measurement is exclusive to hadron colliders. A measurement of Δm_s from B_s mixing is high on the priority list of DØ's B physics topics.

Due to the high oscillation frequency Δm_s, experiments need very good decay length and momentum resolution in order to be able to observe the oscillations as a function of proper time. Semileptonic decays like $B_s \to \phi l^+ X \nu$ have the advantage that they are easy to trigger on and can provide a large statistical sample. On the other hand, due to the presence of the neutrino, the B_s momentum can not be accurately measured, which limits the Δm_s reach. For oscillation frequencies below ~ 18 ps^{-1} DØ is planning to use semileptonic decays to make a measurement of Δm_s.

For faster oscillation frequencies exclusive decays such as $B_s \to D_s \pi$ and $B_s \to D_s \pi\pi\pi$, where the D_s is reconstructed as $\phi\pi$ and $K^* K$, will be used. In these modes the final flavor is tagged by the D_s charge, and the initial flavor by an opposite side lepton. Triggering on this single lepton, DØ expects to collect about a thousand of these events in 2 fb^{-1}. This fully reconstructed decay modes will enable DØ to reach values of Δm_s up to ~ 22 ps^{-1}.

DØ is investigating better trigger scenarios, such as lowering the p_T threshold of the lepton and requiring another moderately high p_T track (or tracks), which would increase the Δm_s reach.

5. Rare B decays

Rare B decays like $b \to s l^+ l^-$ and $b \to d l^+ l^-$ represent Flavor Changing Neutral Currents processes (FCNC). In the SM these FCNC processes are not allowed at tree-level, and therefore require loop diagrams which are sensitive to higher mass scales and new physics, such as Supersymmetry [4]. The possibility of measuring three such FCNC B decays in Run II with the DØ detector has been studied in Ref. [5], and a summary of the results is presented here.

5.1. $B_d^o \to K^{*o} \mu^+ \mu^-$, with $K^{*o} \to \pi^\pm K^\mp$

In this decay the dimuon mass spectrum and the muon FB asymmetry are sensitive to new physics. During Run II DØ will be in a position to make a competitive measurement of this reaction. To test this ISAJET events, weighted to match the dimuon mass distribution and asymmetry given in Ref. [6], were generated and run through the DØ trigger simulation. The selection procedure required 1) two muons with $p_T^\mu > 1.5$ GeV and $|\eta^\mu| < 1.6$, 2) a dimuon transverse momentum $p_T^{\mu\mu} > 5.0$ GeV, 3) an isolation cut of $I > 0.6$, 4) $p_T^{\pi(K)} > 0.5$ GeV and $p_T(K^*) > 2.0$ GeV, 5) a secondary vertex transverse separation of $100 \mu m$ and 6) a dimuon mass outside the J/ψ and $\psi(2S)$ mass windows. For 2 fb^{-1} and a branching fraction of 2×10^{-6} DØ expects about 700 signal events and a similar amount of background events. The background rates were estimated using extrapolations based on CDF run I experience. Fig. 3a shows the dimuon mass distribution for the 700 signal events. The two low bins around 3 GeV are due to the removal of the J/ψ and $\psi(2S)$. The asymmetry as a function of the dimuon mass is shown in Fig. 3b. Figures 3c and 3d show the equivalent distributions but with a 1:1 signal to background ratio, with the background distributed according to phase space. The observed asymmetries, corrected for the background contributions, are 0.11±0.11 and -0.33±0.06 for $M_{\mu\mu} < 2$ GeV and $M_{\mu\mu} > 2$ GeV respectively.

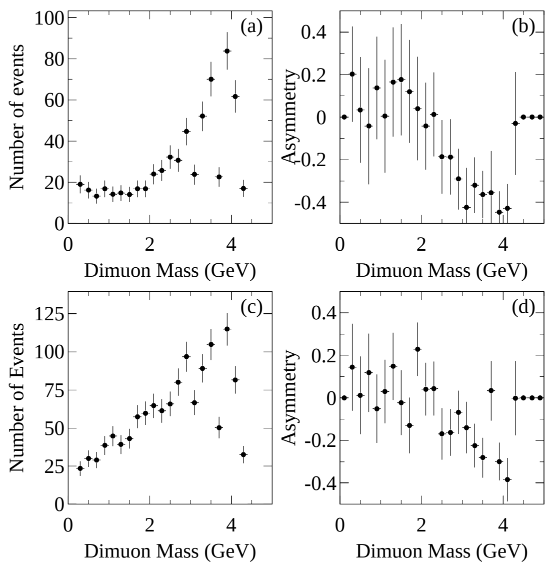

Figure 3. Dimuon mass distribution (a,c) and asymmetry (b,d) in the decay $B_d^\circ \rightarrow K^{*\circ}\mu^+\mu^-$. (c) and (d) have a 1:1 signal to background ratio. The experimental resolution is not included.

Since DØ will also trigger on electrons the decay channel $B_d^\circ \rightarrow K^{*\circ}e^+e^-$ will also be accessible, giving an increase in statistics of about 50%. The channel $B^+ \rightarrow K^+\mu^+\mu^-$, which has similar trigger and reconstruction characteristics, will also be studied.

5.2. $b \rightarrow s\mu^+\mu^-$

This process is very difficult to separate from the regular dimuon background. The main sources of dimuons for $M_{\mu^+\mu^-} < 7$ GeV are 1) sequential b decays ($<$ 4 GeV) or $b\overline{b}$ and $c\overline{c}$ events in which both quarks decay semileptonically, 2) b or c decays combined with π and K decays, and 3) Drell-Yang process. Fig. 4a-c show the expected $\mu^+\mu^-$ spectrum due to heavy quark production for $|\eta^\mu| < 1.6$ and (p_T^μ,$p_T^{\mu\mu}$) ($> 1.5,> 2.0$), ($> 1.5,> 5.0$) and ($> 3.0,> 5.0$) Gev respectively.

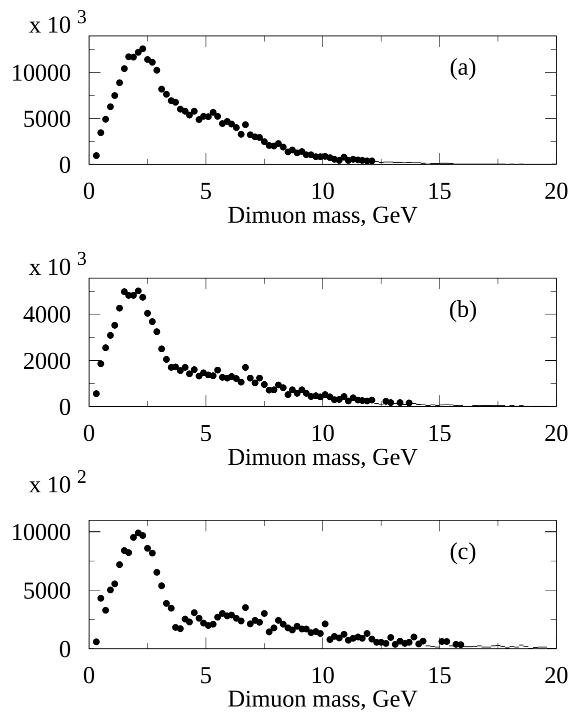

Figure 4. $M_{\mu^+\mu^-}$ spectrum due to non-resonant $Q\overline{Q}$ production. See explanations on Sec. 5.2

It was found in Ref. [7] that in the inclusive search $b \rightarrow s\mu^+\mu^-$it is necessary to restrict the dimuon mass to the high tail window 3.9$<$ $M_{\mu\mu}$ $<$4.4 GeV, which only includes about 7% of the events. This is necessary in order to avoid the resonance production and sequential decay backgrounds. With cuts very similar to the ones described in Sec. 5.1, DØ expects to record about 2000 events in the previous mass window, which is three orders of magnitude smaller that the backgrounds shown, for example, in Fig. 4.c. Additional cuts on the event topology and common vertex may reduce the backgrounds by an order of magnitude, leaving a signal to background ratio of 1:100. This small S/B ratio plus the theoretical uncertainties in predicting the high mass dimuon tail may prevent DØ from establishing the $b \rightarrow s\mu^+\mu^-$signal.

5.3. $B_s^\circ \to \mu^+\mu^-$

Assuming a B_s to B_d fraction of 40%, and a $B_s^\circ \to \mu^+\mu^-$branching ratio of 4×10^{-9} DØ expects only about 10 recorded events in 2 fb^{-1} of data. Unless the branching ratio is significantly boosted by new physics, the measurement of this decay is rather hopeless.

6. Other Measurements

DØ will continue with the measurements of the $b\bar{b}$ cross section and their correlations, which will help to resolve the outstanding disagrements between theory and experiment. Beauty mesons and baryons that decay into at least one lepton will be studied by DØ . The next two subsections provide a short summary of two such cases.

6.1. $\Lambda_b \to J/\psi\Lambda^0$

With 2 fb^{-1} of data it will be possible to measure the Λ_b mass and lifetime in the exclusive channel $\Lambda_b \to J/\psi\Lambda^0$ with $J/\psi \to \mu^+\mu^-(e^+e^-)$ and $\Lambda^0 \to p\pi^-$. DØ expects 15,000 fully reconstructed events in this reaction. This large sample plus a constraint fit to the masses and vertices will allow DØ to achieve a Λ_b mass and lifetime resolution of 16 MeV and 0.11 ps respectively.

6.2. $B_c^\pm \to J/\psi l^\pm \nu$

With the J/ψ decaying into dileptons, this channel is easy to trigger. DØ expects about 600 events in this channel, which is a sample large enough to make significant improvements in the B_c mass and lifetime measurements.

7. Conclusions

The prospects for successful B physics studies in Run II by DØ are excellent. With 2 fb^{-1} of integrated luminosity DØ expects to 1) continue QCD studies, 2) measure $\sin(2\beta)$ to an accuracy of 0.03, 3) measure B_s mixing with a Δm_s reach of about 22 ps^{-1}, 4) put limits on the CKM angles α and γ, 5) study rare B decays, and 6) measure the lifetime and mass of several B mesons and baryons.

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REFERENCES

1. See "DØ Status of Run II Detector", Hal Evans, this proceedings.
2. T. Affolder *et al.*, Phys. Rev. D**61**, 072005 (2000).
3. R. Fleischer, Phys. Lett. B**459**, 306(1999).
4. See "Photonic and Leptonic Rare B decays", Ahmed Ali, this proceedings.
5. "Studies of Rare B Decays with the DØ Detector for Run II". A. Zieminski, DØ note, April 2000.
6. C. Creub, A. Ioannissian and D. Wyler, Phys. Lett. B**346**, 149(1995).
7. B. Abbott *et al*, DØ Collaboration, Phys. Lett. B**423**,419(1998).