

## *B* physics in Run II

Valentin E. Kuznetsov  
(for the DØ Collaboration)

*Department of Physics  
University of California  
Riverside, CA 92521-0413, USA*

### Abstract

Run II at the Tevatron started on March 1, 2001 with a design instantaneous luminosity of  $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ . The upgraded DØ detector is expected to collect  $2 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 2.0 \text{ TeV}$  in approximately 2 years. The DØ collaboration is planning to make measurements in a number of important areas of B physics, including  $\sin(2\beta)$ ,  $B_s$  mixing, the  $\Lambda_b$  lifetime and rare B decays. In this note we describe the upgraded DØ detector and highlights of the B physics program in DØ.

## 1 Introduction

In March 1, 2001 a new run at the Tevatron started. With the increase in luminosity due to the new Main Injector, the Tevatron is expected to deliver an integrated luminosity of  $2 \text{ fb}^{-1}$  in the first two years. The DØ detector was significantly upgraded for this run in order to take full advantage of this high luminosity. The physics program of DØ covers many topics of high energy physics from the Higgs search to B physics. It is expected that the upgraded DØ detector with its silicon vertex detector, inner tracking system, improved muon system, forward and central preshower detectors as well as the robust calorimeter can perform exciting B physics measurements. Among them we expect to study the spectroscopy and lifetimes of various *B* mesons as well as look for rare decays of the *B*'s, to perform QCD tests and search for CP violation and  $B_s$  oscillations. In this paper we discuss the *B* physics program at DØ in Run II.

## 2 Experimental Layouts

Details of the DØ detector can be found elsewhere [1]. Here, we briefly summarize the main features of the upgraded detector. In the center, closest to the beampipe, DØ has a silicon microstrip tracking system (SMT), which consists of six barrel segments with disks in between and three more disks located at each end of the tracker. The barrel and disks are based on  $50 \mu\text{m}$  pitch silicon microstrip detectors, providing spatial resolution  $\sim 10 \mu\text{m}$ . At each end of this system two large disks are placed in order to increase the  $\eta_{det}$  coverage. The SMT system is enclosed within the central fiber tracker (CFT). Together the SMT and CFT represent a complete, robust tracking system of the detector. The DØ detector has momentum resolution at the level of  $\sigma(p_T)/p_T = 0.02 - 0.05$  for low  $p_T$  tracks with quite high tracking efficiency for charged particles at  $|\eta_{det}| < 2.5$ . Vertex reconstruction resolution is expected to be  $15 - 30 \mu\text{m}$  in the  $(r - \phi)$  plane for primary vertices and for secondary vertices it is expected to be of the order of  $40 \mu\text{m}$  in the  $(r - \phi)$  and  $80 \mu\text{m}$  in the  $(r - z)$  planes, respectively. A major upgrade of the muon system together with central and forward scintillators will allow us to trigger and reconstruct muon tracks. Electron and muon identification will be possible in the central and forward regions.

The current trigger system of DØ only allows us to trigger on muons and electrons for B physics studies. Although di-lepton triggers provide a source of triggered B events, they significantly reduce the event yield, and a new Level 1 tracking trigger and Level 2 silicon track trigger are under construction and are expected to be installed during 2002.

Commissioning of the DØ detector is under way. The beamspot r.m.s. width in the beam direction has been measured to be  $30 \pm 3 \mu\text{m}$ . The impact parameter resolution is  $\sim 60 \mu\text{m}$  for tracks above 0.5 GeV and  $\sim 40 \mu\text{m}$  for tracks above 5 GeV. The alignment of the detector is under development.

### 3 $B$ physics at DØ

The weak decays of  $B_d$  and  $B_s$  mesons play a crucial role in the study of CP violation effects both within and beyond the Standard Model. The CKM [2] matrix elements can be represented in the Wolfenstein parameterization [3] as a set of four parameters  $A, \lambda, \rho, \eta$ . The parameters  $A$  and  $\lambda$  are known with good accuracy [4]:

$$\lambda = 0.2196 \pm 0.0023, \quad |V_{cb}| = (39.5 \pm 1.7) \times 10^{-3} \quad A = \frac{|V_{cb}|^2}{\lambda^2} = 0.819 \pm 0.035.$$

The  $\rho$  and  $\eta$  parameters can be extracted mostly from four processes: CP violation in the neutral kaon system, oscillations of  $B_d^0$  and  $B_s^0$  mesons, and charmless semileptonic  $b$  decays. The last three of these are the subject of great interest in the Run II  $B$  physics program.

The expected luminosity of the Tevatron,  $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ , in Run II will lead to a huge rate of  $b\bar{b}$  production,  $\sim 10^{11}$  events/year. This enormous rate will allow us to study various  $B$  decays modes, search for CP violation and  $B_s$  mixing. Primary interest will focus on the study of CP-violation, and related constraints on  $|V_{td}/V_{ts}|$  from  $B_s$  mixing.

#### 3.1 CP violation

CP violation search in  $B$  decays is one of the highest priorities in DØ. It is well known that an asymmetry in the  $B$  system is generated if the weak decay phase,  $\phi_{decay}$ , is different from the mixing one,  $\phi_{mixing}$ . Defining mass eigenstates as  $|B_1\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$  and  $|B_2\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$  we have the following definition of  $\phi_{mixing}$  and  $\phi_{decay}$ :

$$\frac{q}{p} = \sqrt{\frac{m_{12}^* - i\Gamma_{12}^*/2}{m_{12} + i\Gamma_{12}/2}} \simeq \frac{V_{tb}^*V_{td}}{V_{tb}V_{td}^*} = e^{-2i\phi_{mixing}}, \quad \bar{\rho}(f) = \frac{\langle f|H|\bar{B}^0\rangle}{\langle f|H|B^0\rangle} = \eta_f e^{-2i\phi_{decay}}$$

Experimentally, we need to look for the asymmetry of the final state,  $f = J/\Psi + K_s$ :

$$A_{CP}(t) = \frac{\Gamma(\bar{B}_d^0 \rightarrow f) - \Gamma(B_d^0 \rightarrow f)}{\Gamma(\bar{B}_d^0 \rightarrow f) + \Gamma(B_d^0 \rightarrow f)} = \sin(2\beta) \sin(\Delta m_d t),$$

and try to measure the quantity  $A_{obs} = D_{mix} D_{tag} D_{bgd} A_{CP}$ . Here the dilution factor  $D_{tag} = 1 - 2p_{misstag}$  is defined via the correct tag probability  $p_{misstag}$  and together with efficiency  $\varepsilon$  defines the tag's effectiveness,  $\varepsilon D_{tag}^2$ ; where the mixing factor  $D_{mix} = \sin(\Delta m_q t) = x_q/(1+x_q)$  and  $D_{bgd} = \sqrt{S/(S+B)}$ . The uncertainties on  $\sin 2\beta$ :

$$\sin 2\beta = \text{Im} \left[ - \left( \frac{V_{tb}^*V_{td}}{V_{tb}V_{td}^*} \right) \left( \frac{V_{cs}^*V_{cb}}{V_{cs}V_{cb}^*} \right) \left( \frac{V_{cd}^*V_{cs}}{V_{cd}V_{cs}^*} \right) \right],$$

are defined as

$$\sigma(\sin 2\beta) \simeq e^{x_d^2 \Gamma^2 \sigma_t^2} \sqrt{\frac{1+4x_d^2}{2x_d^2}} \frac{1}{\sqrt{\varepsilon D^2 N}} \sqrt{1 + \frac{B}{S}},$$

where  $N$  is the number of reconstructed events. The three blocks in  $\sin 2\beta$  comes from  $B^0 - \bar{B}^0$  mixing,  $\left( \frac{V_{tb}^*V_{td}}{V_{tb}V_{td}^*} \right)$ , final decay fraction  $\bar{\rho}(f)$ ,  $\left( \frac{V_{cs}^*V_{cb}}{V_{cs}V_{cb}^*} \right)$  and  $K^0 - \bar{K}^0$  mixing,  $\left( \frac{V_{cd}^*V_{cs}}{V_{cd}V_{cs}^*} \right)$ . Flavor tagging efficiency will play a crucial role in final purity of the samples. We have summarized it in Table 1. All numbers are based on our knowledge from Run I and MC studies. As can be seen from the table our tag effectiveness will be  $\sim 10\%$ . The golden mode is expected to be the decay of  $B \rightarrow J/\Psi + K_s$  which is quite easy to trigger when  $J/\Psi \rightarrow \ell^+\ell^-$ . The following cuts can be applied in this case:  $p_T > 1.5$  GeV for muon tracks,  $p_T(K) > 0.5$  GeV and  $|\eta_{det}| < 2$ . We expect to have approximately 40000  $B^0 \rightarrow J/\Psi + K_s$  and 20000  $B^0 \rightarrow J/\Psi + K^{0*}$  events. For the time-independent analysis, assuming  $2 \text{ fb}^{-1}$  integrated luminosity,  $S/B \simeq 0.75$ , and a tag effectiveness  $(\varepsilon D^2)_{tag} \simeq 9.8\%$ , our expectation leads to  $\delta(\sin 2\beta) \simeq 0.04$  for the case of  $J/\Psi \rightarrow \mu^+\mu^-$  and  $\delta(\sin 2\beta) \simeq 0.05$  for the  $J/\Psi \rightarrow e^+e^-$  channel. Such precision, together with other measurements, will tune the position of the unitary triangle in the  $\rho - \eta$  plane and help us better understand the SM parameters.

Tag	$\varepsilon D^2(\%)$	$\varepsilon D^2(\%)$
	measured CDF Run I	DØ capabilities
same side	$1.8 \pm 0.4 \pm 0.3$	2
soft lepton	$0.9 \pm 0.1 \pm 0.1$	3.1
jet charge	$0.8 \pm 0.1 \pm 0.1$	4.7
opp. side		none (no $K$ id)
combined		9.8

Table 1: Flavor tagging efficiencies for both CDF and DØ detectors based on knowledge from Run I and MC studies [7].

### 3.2 $B_s$ mixing

Oscillations in the  $B$  system occurs because of high-order corrections, as shown in Fig. 1. The mass

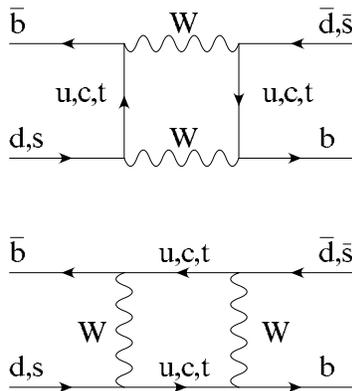


Figure 1: Feynman diagrams responsible for mixing in the  $B$  systems.

eigenstates,  $B_L$  and  $B_H$ , are different from the CP eigenstates  $B_q^0$  and  $\overline{B}_q^0$ :

$$|B_L\rangle = p|B_q^0\rangle + q|\overline{B}_q^0\rangle \quad |B_H\rangle = p|B_q^0\rangle - q|\overline{B}_q^0\rangle, \quad q = d, s \text{ quarks.}$$

where  $\Delta m_q = m_{B_H} - m_{B_L}$ . Many analysis of  $B_d^0 - \overline{B}_d^0$  oscillations have been performed by several collaborations and their results have been combined to give [5]:  $\Delta m_d = 0.489 \pm 0.008 \text{ ps}^{-1}$ . For the case of  $B_s^0$  mesons, due to their large mass difference  $\Delta m_s$ , the  $B_s^0$  oscillation frequency is thought to be much higher than for  $B_d^0$ . Existing data exclude small values of the mixing parameter  $x_s$ ,  $x_s = \Delta m_{B_s^0} / \Gamma_{B_s^0} > 19.0$  at the 95% CL [5].

Various decay modes of  $B_s^0$  mesons are under investigation by the DØ collaboration. Among them  $B_s^0 \rightarrow D_s^-(K^-K^+\pi^-)\pi^+$ ,  $B_s^0 \rightarrow D_s^-(K^-K^+\pi^-)3\pi^+$ ,  $B_s^0 \rightarrow D_s^-(K^-K^+\pi^-)\ell^+\nu$ ,  $B_s^0 \rightarrow D_s^*X$ . The final data sample will be determined by the quality of the track and secondary vertex reconstruction algorithms. Final states of  $B$ 's are expected to be fully reconstructed in hadronic mode(s) and they can be tagged by the charge of the lepton and reconstructed charm meson and/or kaon. The initial state required for a  $B_s$  mixing search can be tagged by applying opposite-side tagging techniques.

We expect to collect of the order of 40,000 events in semi-leptonic channel  $B_s^0 \rightarrow D_s^-\ell^+\nu$ . But due to the escaping neutrino, the momentum resolution is reduced, significantly reducing the  $\Delta m_s$  reach. The hadronic mode(s) of the  $B$ 's, e.g.  $B_s^0 \rightarrow D_s^-\pi^+$  do not have this limitation, but require a lepton from the other  $B$  in order to trigger on these events. In this case the event yield is highly suppressed, leaving us a few thousand events by the end of the run unless a new trigger can be established. The MC studies indicate that DØ will be able to measure a mixing parameter  $x_s \simeq 30$ .

A new limit for  $|V_{ts}/V_{td}|$  can be obtained using the well-known relation:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s^0}}{m_{B_d^0}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2 = \frac{m_{B_s^0}}{m_{B_d^0}} \frac{\xi^2}{\lambda^2} \frac{1}{(1-\rho)^2 + \eta^2},$$

where theoretical uncertainties are included in the quantity  $\xi$  [6]:

$$\xi = \frac{f_{B_d} \sqrt{B_{B_d}}}{f_{B_s} \sqrt{B_{B_s}}} = 1.16 \pm 0.05.$$

### 3.3 Rare $B$ decays

Rare  $B$  decays like  $b \rightarrow s\ell^-\ell^+$  and  $b \rightarrow d\ell^-\ell^+$  represent Flavor Changing Neutral Currents (FCNC) and are not allowed in SM at tree-level. Any evidence of these processes will indicate new physics, such as Supersymmetry [8]. The possibility of such measurements in DØ detector has been studied in [9]. What was not mentioned so far is a possibility to study the following decay mode  $B_s \rightarrow D_s^{*-} D_s^{*+}$  with the following decay  $D_s^{*\pm} \rightarrow D_s^{\pm} \gamma$ . The production cross section of  $D_s$  plays an important role in  $\nu_\mu \rightarrow \nu_\tau$  neutrino oscillations experiments where contamination of  $\nu_\tau$  neutrinos coming from  $D_s \rightarrow \tau \nu_\tau$  needs to be controlled.

### 3.4 Other measurements

DØ will continue with the measurements of the  $b\bar{b}$  cross section and  $b\bar{b}$  correlations. Such measurements will help to resolve the outstanding disagreements between theory and experiment. One of the typical examples is  $\Lambda_b \rightarrow J/\Psi \Lambda^0$  decay. There is an existing discrepancy between the spectator model prediction ( $\tau(\Lambda_b^0)/\tau(B^0) = 1$ ) and current data measurements ( $\tau(\Lambda_b^0)/\tau(B^0) = 0.79 \pm 0.05$ ). In Run II DØ will have 20 times more statistics and collect  $\sim 15000$  fully reconstructed events of  $\Lambda_b \rightarrow J/\Psi \Lambda^0$  with  $J/\Psi \rightarrow \ell^-\ell^+$  and  $\Lambda^0 \rightarrow p\pi^-$ . This large sample plus a constrained fit to the masses and vertices will allow DØ to achieve a  $\Lambda_b$  mass and lifetime resolution of 16 MeV and 0.11 ps, respectively. Another possibility is to look for the  $B_c^\pm \rightarrow J/\Psi \ell^\pm \nu$  mode. By the end of the run we expect to collect of the order of 600 events which will make significant improvements in the  $B_c$  mass and lifetime measurements.

## 4 Conclusion

The DØ detector has been collecting Run II data from the Tevatron collider since March 1, 2001. The prospects for B physics in the DØ program are excellent. With  $2 \text{ fb}^{-1}$  of integrated luminosity DØ expects to perform various QCD tests, measure  $\sin 2\beta$  with an accuracy of 0.03, search for  $B_s$  mixing in a range up to  $x_s \simeq 30$ , study rare decays of the B mesons and perform various spectroscopy and lifetime measurements.

## 5 Acknowledgments

This talk would not have been possible without the help of a large number of people. I am especially thankful for the wise comments of my colleagues Brad Abbott, Vivek Jain, Rick Jesik, Su Yong Choi, John Ellison, Ann Heinson. Finally, I would like to thank all members of organizer committee, especially Jose Angel Hernando, for choosing a nice place for the meeting and for their help during the conference.

## References

- [1] J. Ellison, talk given at *QFTHEP'2000 the XVth International Workshop in High Energy Physics and Quantum Field Theory, Tver, September 14-20, 2000*
- [2] N. Cabibbo, Phys. Rev. Lett. **10** (1963) 531; M. Kobayashi and K. Maskawa, Prog. Theor. Phys. **49** (1973) 652.

- [3] L. Wolfenstein, Phys. Rev. Lett. **51** (1983) 1945.
- [4] S. Mele, Phys. Rev. D **59** (1999) 113011.
- [5] Particle Data Group, Phys. Rev. **D66** (2002) 010001-1.
- [6] C. Bernard, Nucl. Phys. (Proc. Supp.) **B94** (2001) 159.
- [7] B Physics at the Tevatron, Run II and beyond, FERMILAB-Pub-01/197.
- [8] H. E. Haber and G.L. Kane (Michigan U.), Phys. Rept., (1985), 117
- [9] A. Zieminski, Studies of Rare B Decays with the DØ Detector for Run II, DØ note, April 2000.