B-PHYSICS AT TEVATRON*

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During the run period (1992–1995) CDF experiment has collected 110 pb^{-1} of $p\overline{p}$ collisions at 1.8 TeV center of mass energy. The highlights of the CDF B physics results are described, among them the most important are the measurement of B hadron masses, lifetimes and mixing as well as the observation of the B_c meson and the measurement of the CP violation parameter $\sin 2\beta$. Run IIa will give a unique opportunity of extended B physics studies due to the high luminosity of 2 fb^{-1} of $p\overline{p}$ collisions and the major upgrades of both Tevatron experiments, CDF and D0. The perspectives for the B measurements, specially the studies of heavier B hadrons are described, together with the Run I highlights.

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1. Introduction

During the running period 1992-1995 (Run I) CDF experiment has collected 110 pb^{-1} of $p\overline{p}$ collisions at 1.8 TeV center of mass energy. Due to the large ($\sim$ 100 μb) cross-section for $b\overline{b}$ production in $p\overline{p}$ collisions Tevatron provides a good opportunity for high statistics B physics studies. A large number of measurements have been performed. The highlights include the measurements of B hadron masses, lifetimes and mixing. Also for the first time the B_c meson was observed. CDF obtained also a competitive measurement of the CP violation parameter $\sin 2\beta$.

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During the first part of Run II, which started at the end of 2002, Tevatron plans to deliver 2 fb^{-1} of $p\overline{p}$ to each of CDF and D0 experiments at the center of mass energy of 1.96 TeV. Apart from the increased statistics, both CDF and D0 detectors enhanced their potential by the series of major upgrades of the tracking, particle identification and triggering systems. CDF and D0 are capable, beside improving the Run I results, to study the heavier B hadrons, search for B_s mixing, measure the CKM angle γ and study the Λ_B and B_c. This program complements the measurements at B-factories working at the $\Upsilon(4S)$ resonance.

2. Run I results

This report restricts itself mostly to the measurement of B hadron masses, lifetimes, mixing and CP violation from the CDF experiment. The precise silicon vertex detector is essential for selecting events with B hadrons. After installing the new silicon tracking system, as a part of Run II upgrade, D0 experiment is also capable of performing precise B physics studies.

B hadron data samples are selected by triggering on the semileptonic B decays. This approach ensures a cleaner signal with limited statistics.

CDF has measured the lifetimes and masses of all B hadrons. The heavy B mesons and Λ_B baryon are not produced at the $\Upsilon(4S)$ resonance, at which e^+e^- machines are operating. CDF is the only experiment observing B_c meson [1] (Fig. 1) and provides the world average for B_s and Λ_C masses and lifetimes. The measured values are [1–4]:

$$\begin{array}{ll} m(B_s) = 5.3699 \pm 0.0023 \pm 0.0013\,\mathrm{GeV} & \tau(B_s) = 1.36 \pm 0.10\,\mathrm{ps} \\ m(\Lambda_B) = 5.621 \pm 0.004 \pm 0.003\,\mathrm{GeV} & \tau(\Lambda_B) = 1.32 \pm 0.17\,\mathrm{ps} \\ m(B_c) = 5.40 \pm 0.39 \pm 0.13\,\mathrm{GeV} & \tau(B_c) = 1.36 \pm 0.10\,\mathrm{ps}\,. \end{array}$$

In the framework of the Standard Model, the source of the CP violation and B mixing are the transitions between quarks described by the Cabibbo–Kobayashi–Maskawa matrix. In this model CP violation arises due to the irreducible phases in the CKM matrix.

The CDF Run I the measurement of $\sin 2\beta$, one of the angles of the unitarity triangle, is obtained by extracting the amplitude of the CP asymmetry in the decay $B^0/\overline{B^0} \to J/\psi K^0_{\mathrm{S}}$:

$$A(t) = \frac{N_{B_d \to J/\psi K_{\mathrm{S}}} - N_{\overline{B_d} \to J/\psi K_{\mathrm{S}}}}{N_{B_d \to J/\psi K_{\mathrm{S}}} + N_{\overline{B_d} \to J/\psi K_{\mathrm{S}}}} \sim \sin 2\beta \sin \Delta m_d t\,.$$

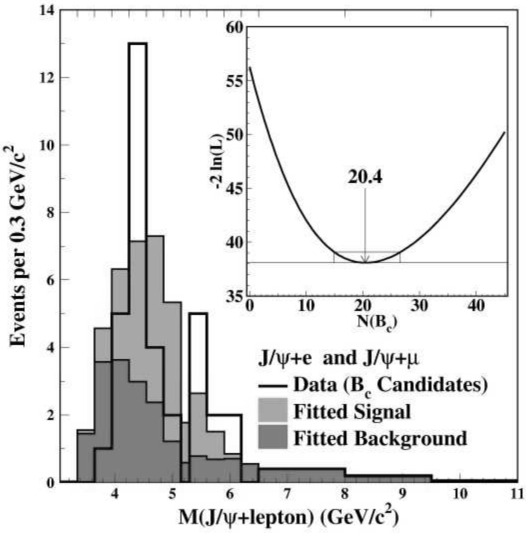

Fig. 1. Observation of B_c-invariant mass distribution plot (J/ψ + lepton).

Additionally, the decay channel $B^0/\overline{B^0} \to \psi(2S)K^0_{\rm S}$ is used to improve precision of the measurement. Both channels require identification of the B meson flavor at production, mostly based on the opposite side lepton, on jet charge tag and on the same side pion tags.

Proper decay time measurements were performed using the muon tracks measured in the silicon vertex detector. Events with the low lifetime resolution were used to build the asymmetry integrated over lifetime, which is still a measure of $\sin 2\beta$. CDF experiment has measured $\sin 2\beta$ to be [5]:

$$\sin 2\beta = 0.91 \pm 0.32(\text{stat}) \pm 0.18(\text{syst}).$$

The CDF $\sin 2\beta$ measurement was the best direct indication, that the CP symmetry is violated in the b quark system. Recently, the dedicated B factories BaBar and Belle delivered results with both statistical and systematic errors three times smaller than those of CDF.

Mixing was also measured for B_d using several channels. The results are summarized in Fig. 2. A limit on heavy B_s mixing has been determined to be $\Delta m_{\rm S} > 5.8{\rm ps}^{-1}$ at 95% confidence level [6].

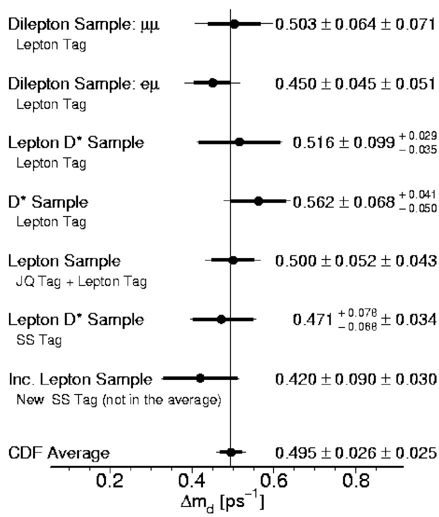

Fig. 2. Summary of B_d mixing measurements.

3. Run IIa physics prospects

Run IIa, which started at the end of 2001, is going to provide 2 fb^{-1} to each of the Tevatron experiments. To improve the overall performance, CDF and D0 have undergone major upgrades in recent years. CDF modifications [7], most important for B physics, include the new silicon tracker, new COT tracking chamber, new DAQ with less dead time and the TOF system improving the strangeness tagging performance. The muon detector coverage has been doubled to cover a range of $|\eta| < 2$.

The D0 Silicon Microstrip Tracker is greatly improving the tracking performance. New electronics, DAQ and trigger speed up the data collection, and Silicon Track Trigger (coming only summer 2002) will allow triggering on tracks with impact parameter resolution of $\sim 30\mu$m. One of the highlights of the D0 experiment is the excellent lepton and tracking coverage ($|\eta| < 2$ for muons, $|\eta| < 2.5$ for electrons and $|\eta| < 3$ for tracks).

With 2 fb^{-1} of data each of the Tevatron experiments should significantly improve the precision of $\sin 2\beta$ measurement up to about ± 0.05 (CDF) (Fig. 3) [8] and ± 0.04 (D0). CDF has excellent proper time resolution and very good signal-to-noise, whereas the D0 detector has excellent tracking coverage in the the central and forward region. The mixing of B_s meson will be measured from the process $B_s \to D_{\mathrm{S}}^- \pi^+$. CDF expects significant yields in hadronic B_s decay modes. These signal sample will allow CDF to probe B_s mixing well above the region expected by Standard Model fits to other measureables, which is $x_{\mathrm{S}} \approx 20$.

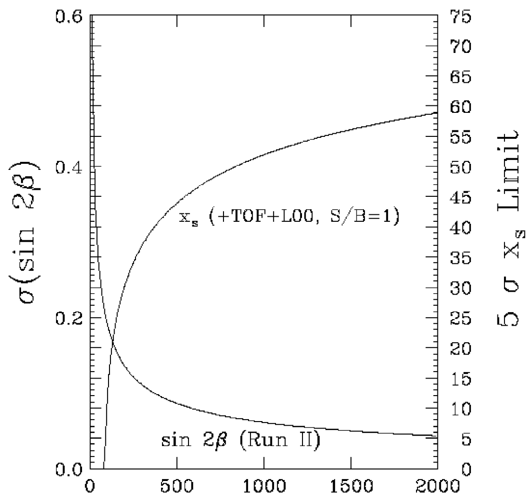

Fig. 3. Precision of the $\sin 2\beta$ measurement and B_s mixing sensitivity as a function of the integrated luminosity at CDF.

Both experiments will measure the CP violation angle γ in a combination of $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays. The estimated error should be around 7^{circ}, assuming the signal to background ratio of about 1/2.

CDF and D0 attempt will also to study $\Delta\Gamma_{\rm S}/\Gamma_{\rm S}$ (lifetime difference between heavy $B_s^{\rm H}$ and light $B_s^{\rm L}$) in $B_s \to J/\psi\phi$ and in $B_s \to D_{\rm S}^+ D_{\rm S}^-$ decays. In case of CDF the expected precision of the combined result from both processes is ± 0.04.

Tevatron experiments intend also to improve the measurements of B hadrons masses and lifetimes, and to search for rare decays.

4. Conclusions

Tevatron experiments have a rich physics program to exploit 2 fb^{-1} of data to be collected in Run II. The main goals of the B physics program are: the measurement of the B_s oscillations, the measurement of the angle γ of the unitarity triangle, improved measurement of $\sin 2\beta$ and the study of $\Delta\Gamma_{\rm S}/\Gamma_{\rm S}$. In large part, especially for the heavier B hadrons, this program is complementary to the studies performed by the B factories working at $\Upsilon(4S)$ resonance, where only the light B_d mesons are produced.

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