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# Future CDF and D0 B Physics

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ABSTRACT

A new period of data taking started on March 2001 for both collaborations CDF and D0. In 2 years around 2 $fb^{-1}$ of data should be collected by both experiments with a huge number of events containing $B$ mesons available to perform many kinds of measurements. In this paper we discuss our expectations for a few of these measurements. These expectations rely on the experience gained by analyzing the Run I data whenever it is possible and on Monte Carlo otherwise.

## 1 Introduction

$B$ mesons result to be a very good laboratory to study several fundamental characteristics of the Standard Model so that two $B$-factories have been build. These dedicated machines will measure some of the parameters which govern physics in the $B$ sector, leaving uncovered other important items that instead can be investigated at hadron colliders.

The main reasons to do $B$ physics at the Tevatron are:

1) large production cross section, $\sigma(p\bar{p}) \approx 100\mu$b at $\sqrt{s} = 1.8$ TeV while $\sigma(e^+e^-) \approx 1$ nb at $\Upsilon(4s)$. The drawback is the higher inelastic cross section which is $\sim 10^3$ times larger. To overcome this difficulty specialized triggers have been studied. In Run I both experiments relied on leptons by exploiting semileptonic $B$ decays but loosing a lot of statistics due to the low branching ratio. A new trigger strategy have been set up in Run II based on displaced tracks which allows to keep also hadronic decays.

2) all $B$ species are produced. This is an important difference respect to the $B$-factories where only "light" $B$ can be studied.

3) precise $B$ physics measurements have already been done. This is another good reason to invest in $B$ research at hadron colliders. CDF with Run I data has done many precise analysis like $B_d - \bar{B}_d$ mixing frequency determination [1], [2], [3]. Moreover, CDF has been the first experiment which measured $\sin(2\beta)$, [4],, whose error was dominated by statistics.

As it can be seen from this introduction, CDF and D0 collaborations have the chance of perform many $B$ physics measurements in Run II. This paper describes only few of them, those which are considered more relevant by the author: $B_s$ mixing and lifetime difference, $CP$ violation in the Standard Model and beyond.

## 2 Analysis Requirements

The measurement of mixing frequency, $\Delta m$, the two mass matrix eigenstates $B_h$ and $B_l$ mass difference, requires the identification of the $B$ flavor at both production and decay time. Moreover, since a time dependent analysis is performed, it is necessary to reconstruct precisely the decay time. The latter request can be satisfied with a high precision vertex detector as CDF had in Run I and both CDF and D0 will have in Run II.

$CP$ violation may occurs in several ways, but at the moment the most studied at the Tevatron is the violation in the interference between decays with and without mixing, which happens in decays with final states common

Table 1: *Summary of tagging capabilities $\epsilon D^2$ (%)for CDF and D0.*

| Tag | $\epsilon D^2$ CDF Run I | $\epsilon D^2$ CDF Run II | $\epsilon D^2$ D0 Run II |
|---|---|---|---|
| Same side | $1.8 \pm 0.4 \pm 0.3$ | 2.0 | 2.0 |
| Soft lepton | $0.9 \pm 0.1 \pm 0.1$ | 1.7 | 3.1 |
| Jet charge | $0.8 \pm 0.1 \pm 0.1$ | 3.0 | 4.7 |
| Opp. side $K$ | none | 2.4 | none |

to $B$ and $\bar{B}$. By fitting the experimental time dependent asymmetry, $A(t) = (N^{\bar{B}}(t) - N^B(t))/(N^{\bar{B}}(t) + N^B(t))$ angles of Unitary Triangle can be extracted. These measurements need the reconstruction of the specific decay channel (for example $B_d \to J/\psi K^0_s$), the measurement of the decay time (see mixing) and the identification of the $B$ flavor at production time.

Tagging the $B$ flavor is one of the most crucial steps of all the analysis mentioned. CDF in Run I developed several methods summarized in table 1. These methods will be used by both experiments in Run II. The figure of merit for a tagging algorithm is $\epsilon D^2$ where $\epsilon$ is the tagging efficiency (number of tagged events divided by the total number of events) and $D$ is the dilution defined as the difference between the rightly and wrongly tagged events divided by their sum.

## 3 $B_s - \bar{B}_s$ mixing

The mixing frequency has been precisely measured for $B_d$ meson and only a lower limit exists for $B_s$. In this case $x_s = \Delta m_s \Gamma_s$ ($\Gamma_s = (\Gamma_l + \Gamma_h)/2$) is expected to be around 20. In order to resolve so fast oscillations besides a good detector resolution full reconstructed $B_s$ decays are necessary. This requirement can be achieved only with hadronic decays where no neutrino is missing. The $B_s$ mixing measurement is an important test inside the Standard Model and the determination in the same experiment of $B_s$ and $B_d$ oscillation frequency is even more important because of the relation $|V_{td}|^2 / |V_{ts}|^2 \propto \Delta m_d / \Delta m_s$ ($V_{td}$ and $V_{ts}$ are 2 elements of the CKM matrix) from which it is possible to extract $|V_{td}|^2 / |V_{ts}|^2$ with high precision. At the time being, this is possible only at the Tevatron.

CDF and D0 are planning to measure the oscillation frequency in $B_s \to D^-_s \pi^+$ and $B_s \to D^-_s \pi^+ \pi^- \pi^+$ decays. D0 in 2 fb$^{-1}$ of data will have between

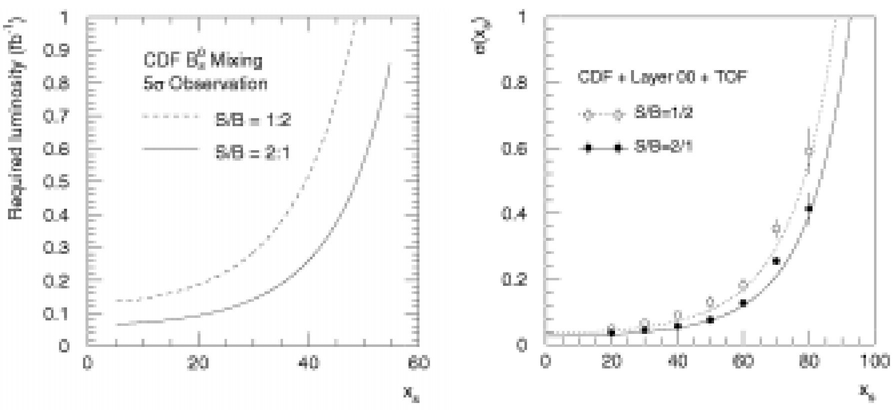


Figure 1: *Left: Required luminosity to measure at* $5\sigma$ $x_s$ *as function of* $x_s$*. Right: Error on* $x_s$ *as function of* $x_s$*.*

100 and 300 events from the first decay and between 300 and 900 from the second one by triggering on the lepton on the other side of the $B_s$. In this case the lepton tags the initial flavor while the $D_s$ charge the final one. In this measurement D0 will also use a sample of ~1000 $B_s \to J/\psi K^*$ with $K^* \to K^+\pi^-$ events. Combined D0 $x_s$ reach is between 20 and 30. CDF is expecting to collect about 20,000 events of $B_s \to D_s^-\pi^+$ and $B_s \to D_s^-\pi^+\pi^-\pi^+$ by means of the displaced tracks trigger (SVT). Under the assumption of $\epsilon D^2 \sim 11.3\%$ CDF will be able to measure $x_s$ up to a value of 63 or 56 depending on what will be the signal to noise ratio. In figure 1 is shown on the left the required luminosity to perform a $5\sigma$ measurement and on the right the error on $x_s$ both as function of $x_s$. If $x_s$ is below 30 it will be measured with low statistics and once the oscillations are observed $x_s$ will be measured precisely.

## 4 $CP$ violation: $\sin(2\beta)$

The old CDF measurement gave $\sin(2\beta) = 0.79^{+0.41}_{-0.44}$ stat.⊕sys. This error can be projected to Run II as sum two contributions: $\sigma(\sin(2\beta)) = \sigma(A)/D \oplus \sin(2\beta) \cdot \sigma(D)/D$. The former scales with statistics and in 2 fb$^{-1}$ of data $\sigma(A)/D = 0.067$, the latter depends on how well the dilution is known. D is measured in a control sample of $B^\pm \to J/\psi K^\pm$ and its error is statistically dominated. $\sigma(D)/D$ is expected to be 0.027. By inserting these numbers in previous formula $\sigma(\sin(2\beta)) = 0.072$, under the pessimistic assumption $\sin(2\beta) = 1$. This projection is conservative because CDF already increased the di-lepton trigger bandwidth and the number of expected $J/\psi$ per $\mathrm{nb}^{-1}$ is almost 2.8 times the previous one. The final error on $\sin(2\beta)$ will be 0.043.

D0 assumes the same signal to noise ratio of CDF and almost the same tagging power to tune its Monte Carlo simulation in order to have a reliable evaluation of $\sigma(\sin(2\beta))$. With respect to CDF, D0 has a better muons and electrons coverage resulting in a bigger data sample. The output of the analysis performed on simulated data is $\sigma(\sin(2\beta)) = 0.04$ for $J/\psi \to \mu^+\mu^-$ and $\sigma(\sin(2\beta)) = 0.05$ for $J/\psi \to e^+e^-$ with a combined error of 0.03.

## 5 $CP$ violation: $B \to h^+h^-$

The study of hadronic charmless $B$ decays and the optimization of an hadronic trigger at CDF has been motivated at the beginning by the possibility of extracting $\sin(2(\beta+\gamma))$ (which is $\sin(2\alpha)$ if $\alpha+\beta+\gamma=\pi$) from the $B_d \to \pi^+\pi^-$ decay asymmetry. But, since the penguin pollution could be large, this decay doesn't seem a viable method to obtain $\sin(2\alpha)$. R.Fleisher in his work [5] suggested to exploit $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decay asymmetries to measure $\gamma$. The four asymmetries, $A_{dir}(\pi^+\pi^-)$, $A_{dir}(K^+K^-)$, $A_{mix}(\pi^+\pi^-)$ and $A_{mix}(K^+K^-)$ are function of several parameters including the angle $\gamma$. With SVT trigger CDF expect around 5,000 $B_d \to \pi^+\pi^-$ events per $\mathrm{fb}^{-1}$ 20,000 $B_d \to K^+\pi^-$, 10,000 $B_s \to K^+K^-$ and 2,500 $B_s \to K^+\pi^-$. The separation of these contributions will be done by combining two different particle identification methods: time of flight and $dE/dx$ from the drift chamber. The expected error on the experimental asymmetries is $\sigma A_{tot}(K^+K^-) \sim 0.08$ and $\sigma A_{tot}(\pi^+\pi^-) \sim 0.14$. To connect these errors to the $\gamma$ precision some theoretical and experimental assumptions are necessary: flavor SU(3) symmetry, signal to noise 1:2 and $x_s = 30$. The final error $\sigma(\gamma) \sim 10^o$ includes either the statistical and the systematic contributions due mainly to the assumptions done.

D0 just started the exercise of evaluating the $\gamma$ precision measurement. By triggering on the other $B$ in the event D0 estimates to have between 300 and 600 tagged $B_d \to \pi^+\pi^-$, from 650 and 1300 $B_s \to K^+K^-$, from 1300 and 2600 $B_d \to K^+\pi^-$ and between 150 and 300 $B_s \to K^+\pi^-$. The full exercise is still in progress.

## 6 $CP$ violation: $\gamma$ from $B_s$ decays

The four decay rates of $B_s(\bar{B}_s) \to D_s^- K^+$ and $B_s(\bar{B}_s) \to D_s^+ K^-$ depend on $\sin(\delta \pm \gamma)$ and $\cos(\delta \pm \gamma)$ as discussed in [6]. This method, not based on asymmetry analysis, is theoretically clean and the decays have a reasonable branching ratio. But background separation, especially $B_s \to D_s\pi$, it is difficult. Thanks to SVT CDF expects about 850 events of both decays per 2 $\mathrm{fb}^{-1}$. The most probable value of the error on $\sin(\delta \pm \gamma)$ is 0.43 and 0.79 for signal to background of 1:1 and 1:6, respectively.

## 7 $\Delta\Gamma/\Gamma$ measurement and $CP$ Violation beyond Standard Model

The lifetime difference between the heavy and light $B_s$ could be large, and $\Delta\Gamma/\Gamma = 1/2(\Gamma_h - \Gamma_l)/(\Gamma_h + \Gamma_l)$ in the Standard Model is expected between 0.05 and 0.20. $\Delta\Gamma/\Gamma$ measurement, besides a direct test of the model, is an indirect way of measuring $B_s$ mixing because $\Delta\Gamma \propto \Delta m_s$. $B_s \to J/\psi\varphi$ is the "golden" decay channel for this measurement . CDF in Run I reconstructed $19 \pm 5$ events in which the longitudinal polarization has been measured [7]. In Run II more than 4,000 events are expected in 2 $\mathrm{fb}^{-1}$ and the achievable error $\sigma(\Delta\Gamma/\Gamma) \sim 0.05$.

This decay can be used also to search for new physics beyond the Standard Model. $CP$ violation here should be $\sim 3\%$. If it is larger it will due to new physics contributions. With 4,000 events and by assuming $\epsilon D^2 = 9.7\%$ CDF can obtain an error on the asymmetry of the order of 0.1 or less depending on $x_s$.

## 8 Conclusions

CDF and D0 reaches on few $B$ physics items have been discussed. Both experiments with 2 $\mathrm{fb}^{-1}$ of data will be able to constrain one side and 2 angles of the Unitary Triangle by measuring $\sin(2\beta)$, $\gamma$ and $x_s$. Two more measurements have been briefly illustrated: $\Delta\Gamma/\Gamma$ and search for $CP$ violation beyond Standard Model in the $B_s \to J/\psi\varphi$ decay. The major part of discussed analysis involve $B_s$ decays and therefore will be unique to the Tevatron in the near future.

## References


1. F. Abe *et al*, Phys. Rev. D**60**, 112004 (1999).
2. F. Abe *et al*, Phys. Rev. D**60**, 072003 (1999).
3. F. Abe *et al*, Phys. Rev. D**59**, 032001 (1999).
4. F. Abe *et al*, Phys. Rev. D**61**, 072005 (2000).
5. R. Fleisher Phys. Lett. B **459**, 306 (1999).
6. R. Aleksan *et al*, Z. Phys. C**54**, 653 (1992).
7. F. Abe *et al*, Phys. Rev. Lett**75**, 3068 (1999).