Fermilab FERMILAB-Conf-00/272-E CDF/D0 October 2000

Tevatron Measurements Related to CP violation

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The Tevatron collider experiments collected data from 1992 to 1995. CP violation related measurements have been produced with this sample achieving results which clearly state CDF and $D\emptyset$ ability in extracting significant CKM information from $p-\bar{p}$ collisions.
The most up to date results and future plans for both experiments are discussed in this paper.

1. Introduction

The Tevatron experiments CDF [1] and $D\emptyset$ [2,3] each integrated in $1992-1998$ more than $110\,pb^{-1}$ of data at $\sqrt{s}=1.8\,TeV$ (Run I). This data sample gave us the possibility of performing various measurements of b hadron properties, even beyond expectations: masses, lifetimes, cross sections, branching ratios, oscillation parameters and the discovery of the B_c meson.

So far at the Tevatron, only the CDF experiment has had the capability to measure CP violation in B decays. This will change in the next run (Run II), when major upgrades of both experiments will make CDF and $D\emptyset$ capable of similar performances in the B physics sector.

After a brief review of the most up-to-date results in these fields, I will focus on CP violation related parameters, including the measurement of $\sin 2\beta$ and the observation of channels interesting for CP violation in Run II.

2. A Short Overview of Tevatron Results

The Tevatron contribution to B physics goes well beyond CP violation. Crucial contributions came and will come out from our experiments in fields unique to its environment until the advent of LHC: the Tevatron will be the only competitor to b factories until the LHC era, and the only experimental environment able to explore the B_s and Λ_b states until then.

2.1. Cross Section

Our confidence in QCD mainly relies in its predictivity, continuously tested in new challenging environments. Both CDF and $D\emptyset$ [4–9] have independently measured the integrated and differential B_d production cross section, yielding in both cases results in disagreement over NLO theory. Figure 1 shows the comparison between the in-

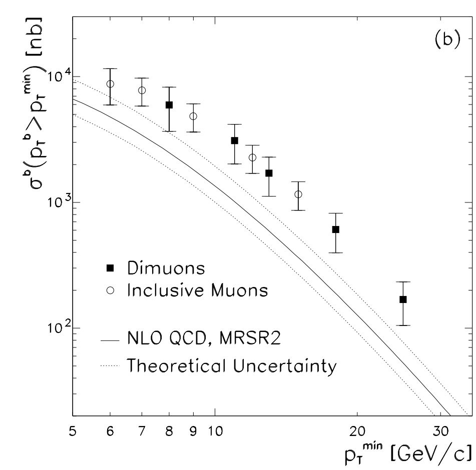

Figure 1. Tevatron ($D\emptyset$) measured B production cross section compared to NLO QCD predictions (smooth lines). The measurements have been carried on various samples (different markers) with consistent results.

*On behalf of the CDF and $D\emptyset$ collaborations.

tegral $(\sigma(p_t^b > p_t^{min}))$ cross section measured at $D\emptyset$, and the NLO prediction. The observed disagreement roughly corresponds to a factor 2-3, common also to the CDF result. A similar excess was also observed by both experiments running at $\sqrt{s} = 630\,GeV/c$. The b production cross section in the forward region has been investigated by $D\emptyset$ exploiting muon tagged b-jet samples [8], with a similar $\times 2 - \times 3$ excess with respect to NLO predictions. CDF also measures the exclusive B meson cross section based on fully reconstructed $B^- \rightarrow J/\psi K^-$ and $B^\circ \rightarrow J/\psi K^*$ decays: $\sigma(p\bar{p} \rightarrow B^\circ X, p_t(B^\circ) > 6\,GeV, |y(B^\circ)| < 1) = 3.51 \pm 0.42^{stat\,\&}_{uncorr.syst.} \pm 0.53^{correlated}_{systematics}$.

2.2. Lifetime

B meson lifetime and fragmentation, together with many branching fraction ratios have been measured in Run I. Many of these results are competitive and complementary with their analogous measurements performed in e^+e- environments. Figure 2 reports the measured b mesons lifetimes [10–12].
The latest addition is the B_s lifetime, measured from ≈ 600 $B_s \rightarrow D_s \ell X$ reconstructed events.

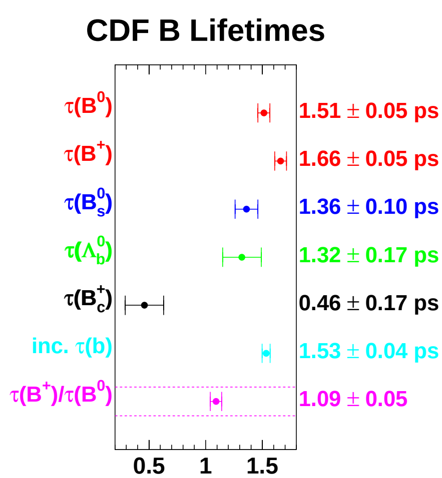

Figure 2. Tevatron collection of measurements on b-mesons lifetimes (CDF).

2.3. Brave New Meson: the B_c Discovery

B hadron masses have been accurately measured at the Tevatron. Results are summarized in table 1 Among these is reported also the mass

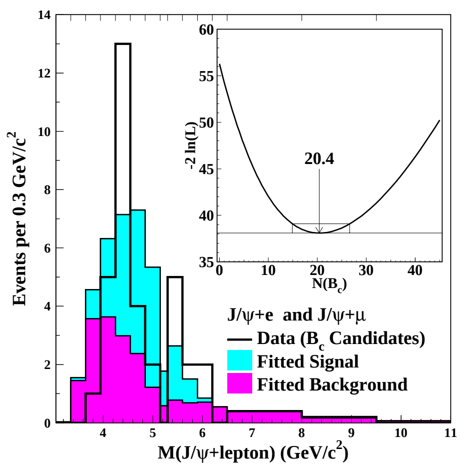

Figure 3. Invariant mass spectrum for 3 lepton candidates showing the excess due to the presence of the B_c meson. The inset shows the maximum likelihood fit to determine the number of B_c mesons in the sample.

Hadron	Observed Mass
B^-	$5279.1 \pm 1.7 \pm 1.4$
B°	$5281.3 \pm 2.2 \pm 1.4$
B_s°	$5369.9 \pm 2.3 \pm 1.3$
B_c^-	$6400 \pm 390 \pm 130$
Λ_b	$5621 \pm 4 \pm 14$

Table 1
B hadron spectroscopy at the Tevatron (CDF)

of a newcomer in the realm of b-flavoured mesons: the B_c meson. The B_c mesons were discovered by CDF [13,14] through their semileptonic decays, $B_c^\pm \rightarrow J/\Psi \ell^\pm X$. A fit to the $J/\Psi \ell$ mass distribution yielded about 20 events from the B_c meson (see figure 3). The same sample allowed to measure also the B_c lifetime (see table 2) [14].

2.4. Oscillation and Tagging

The $B_d^\circ - \bar{B}_d^\circ$ oscillation frequency has been measured at the Tevatron exploiting different techniques. Whichever technique is applied, the underlying principle is always the same: identify a B rich sample, build an algorithm to decide the flavour of each B meson in the sample. The time evolution of the $B/\bar{B}$ asymmetry:

$$\mathcal{A}(t) = \frac{N(t)_{unmixed} - N(t)_{mixed}}{N(t)_{unmixed} + N(t)_{mixed}} = \mathcal{D}\cos(\Delta m\, t)$$

or the time-integrated asymmetry are then measured. The *dilution* $\mathcal{D}$ takes into account the fact that the tagging algorithm lies N_W times out of $N_R + N_W$ total events $\left(\mathcal{D} = \frac{N_R - N_W}{N_R + N_W}\right)$. The dilution is thus a quantity which characterizes the tagging algorithm together with its *efficiency* ϵ, which quantifies the fraction of the sample to which the algorithm is applicable ($\epsilon = N_{tagged}/N_{tot}$).

From the point of view of the resolution on $\mathcal{A}$, the effect of the tagging algorithm is roughly that of reducing the effective size of the sample by ϵD^2. Several flavour tagging algorithms have thus been investigated and tuned to the CDF environment. Three of them have subsequently been employed in CP violation and mixing measurements:

- **Same Side Tagging** exploits the charge correlation between the reconstructed B meson and soft tracks coming from the b fragmentation jet. This correlation is similar to that existing between the charge of the pion and the flavour of the B meson produced in the decay of B^{**} exited states. Details on the tagger selection (proximity and transverse momentum with respect to the reconstructed B) depend on the specific analysis performed.

- **Opposite Side Tagging** b quarks in $p\bar{p}$ collisions are mostly produced in $b\bar{b}$ pairs. Neglecting mixing effects, the initial flavour of the reconstructed B is known once the flavour of the *opposite* b quark is determined.
  Two types of opposite side tagging algorithms have been exploited so far:

  - **Soft Lepton Tagging**: given the large semileptonic branching fraction of b mesons, the charge of the produced lepton can be exploited to tag the charge of the W boson emitted by the decaying b quark, and thus the beauty content of the meson.

  - **Jet Charge Correlation** the *jet charge* is a quantity statistically correlated to the charge of the b quark originating a jet. It is defined as:

    $$Q_{jet} = \frac{\Sigma_i\, q_i\, \vec{p}_i \cdot \vec{a}}{\Sigma_i\, \vec{p}_i \cdot \vec{a}}$$

    Where $\vec{a}$ is the jet axis and the sum is carried over all the tracks contained in the jet. Since the b quark charge uniquely identifies its flavour, Q_{jet} is another useful beauty tagger.

The efficiency and dilution of each algorithm have been measured in our environment. The typical ϵD^2 achieved by using the 3 algorithms together is approximately 6% for Run I data.

Six different measurements [15–20] of Δm_d have been produced at the Tevatron exploiting different tagging methods, reconstruction strategies and samples. These have been summarized in table 2 and figure 4.

$\Delta m_d\,(ps^{-1})$	Sample	Tagging
	$B^\circ \to \ell^+ D^{(*)-} X$	
$0.471^{+0.078}_{-0.068} \pm 0.034$	$B^+ \to \ell^+ \bar{D}^\circ X$	SST
	single lepton ev.	
$0.500 \pm 0.052 \pm 0.043$	$B^\circ \to J/\psi K^{*\circ}$	SLT &
	$B^+ \to J/\psi K^+$	JETQ
$0.450 \pm 0.045 \pm 0.051$	$e + \mu$	SLT
$0.516 \pm 0.099^{+0.029}_{-0.035}$	$B \to D^{*+} \ell^- X$	SLT
	dilepton ev.	
$0.503 \pm 0.064 \pm 0.071$	$\mu + \mu$	SLT
$0.562 \pm 0.068^{+0.041}_{-0.050}$	$B_d^\circ \to D^{(*)+} X$	SLT
	single lepton ev.	

Table 2
Δm_d measurements at the Tevatron (CDF)

The $B_s^\circ - \bar{B}_s^\circ$ oscillation frequency Δm_s has been probed at CDF [19] in the partial reconstruction of the decay $B_s^\circ \to D_s^- \ell^+ X \nu \to \phi \ell^+ X \nu$.

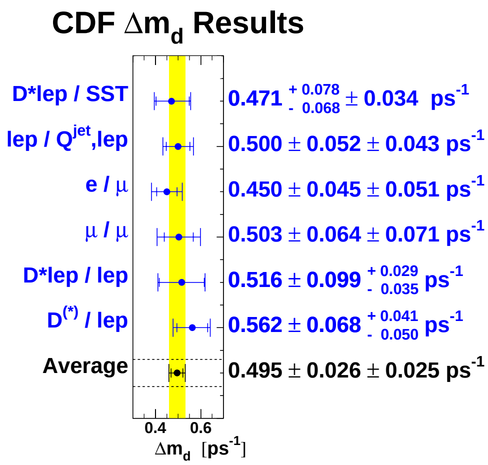

Figure 4. Tevatron collection of measurements on Δm_d (CDF).

The signal is reconstructed in the two lepton ($\mu\mu$ and μe) trigger sample, with the remaining lepton used as flavour tag for the production flavour of the B_s meson partly reconstructed. The analysis results in a signal of 1068 partly reconstructed B_s's with a purity of 61%, giving a lower bound on Δm_s: $\Delta m_s > 5.8\,ps^{-1}$ at 95% confidence level [19].

3. CP Violation Measurements at the Tevatron

The success of the B physics program at the Tevatron went well beyond expectations with the measurement of $\sin 2\beta$ performed by CDF. In fact, CDF collected and successfully exploited the biggest sample of $B \to J/\psi K_s$ decays ever gathered by a single experiment of the pre b-factory era.
At the same time CDF was able to identify and study in its run I data sample various physics channels which will be exploited in Run II for CP violation related measurements (like $B \to D\pi$, $B \to J/\psi\phi$ etc.). They show the ability of Tevatron experiments to perform measurements in fields traditionally considered inaccessible to our detectors: the fully hadronic decay modes of the B meson.

3.1. $\sin 2\beta$

CDF exploited the large B cross section at the Tevatron to obtain a large sample of $J/\psi K_s^\circ$ decays to measure $\sin 2\beta$. The analysis reported here uses the entire Run I data sample of $110\,pb^{-1}$ and is described in detail in [21].

3.1.1. Sample composition

The J/ψ sample is identified by selecting two oppositely charged muon candidates each with $p_t > 1.4\,GeV$. The K_s° candidates are found by matching oppositely charged tracks, assumed to be pions. The K_s° candidates are required to have $p_t\,(K_s^\circ) > 700\,MeV$ and to travel a significant distance from the primary vertex. The $\mu^+\mu^-\pi^+\pi^-$ parent candidate is constrained to point back to the primary vertex. To further improve the signal-to-background ratio, B candidates are required to have $p_t\,(B) > 4.5\,GeV$.

The data are divided into two samples which are called SVX and non-SVX samples. The SVX sample requires both muon candidates to be well measured by the silicon vertex detectors. The B candidates in this sample have a proper decay time resolution of $\sigma_{ct} \approx 60\,\mu m$. The non-SVX sample contains events in which one or both of the muon candidates are not measured in the silicon vertex detector. B candidates in this sample have a low proper decay time resolution of $\sigma_{ct} \approx 300 - 900\,\mu m$. The SVX sample and the non-SVX sample contain 202 ± 18 and 193 ± 26 events respectively. The SVX subsample was used for a previous measurement of $\sin 2\beta$ (see [22]).

3.1.2. Flavour Tagging

Since flavour tagging plays a key role in this measurement, the dilution and efficiency for each tagging algorithm exploited were carefully measured on control samples as close as possible to the one selected for the measurement.
At the Tevatron the strong interaction creates $b\bar{b}$ pairs at sufficiently high energy that the B mesons are largely uncorrelated. CDF measured the tagging dilutions for the opposite side algorithms using a sample of 998 ± 51 $B^\pm \to J/\psi K^\pm$

decays. The evaluation of the performance of the same side tagging is somewhat harder: CDF employed both the $B \to \nu\ell D^{(*)}$ ($\approx$ 6000 events) which has large statistic but is kinematically different from $B \to J/\psi K_s$, and $B \to J/\psi K^{*\circ}$ ($\approx$ 450 events) which has small statistic but looks kinematically closer to the measurement sample.

The dilution in the same side tagging is measured in the $B \to \nu\ell D^{(*)}$ decay and then downscaled with a montecarlo simulation from the $p_t\,(B)$ region of the semileptonic decay (at an average p_t of about $21\,GeV$) to the lower B momentum of the $B \to J/\psi K_s$ (at an average p_t of about $12\,GeV$). The dilution in the non-SVX sample is found to be $\mathcal{D} = (17.4 \pm 3.6)\,\%$.

The Soft Lepton tag dilution is directly measured on $B^\pm \to J/\psi K^\pm$ to be $\mathcal{D} = (62.5 \pm 14.6)\,\%$.

The JETQ algorithm is applied rejecting all events below the threshold $|Q_{jet}| = 0.2$. The dilution evaluated applying the JETQ algorithm to $B^\pm \to J/\psi K^\pm$ is $\mathcal{D} = (23.5 \pm 6.9)\,\%$.

The performances of the three tagging algorithms are summarized in table 3. The combined tagging performance is $\epsilon\mathcal{D}^2 = (6.3 \pm 1.7)\,\%$ with an efficiency of about $\epsilon \approx 80\%$.

Tagging	ϵ (%)	$\mathcal{D}$ (%)
SST SVX	35.5 ± 3.7	16.6 ± 2.2
SST non-SVX	38.1 ± 3.9	17.4 ± 3.6
SLT all	5.6 ± 1.8	62.5 ± 14.6
JETQ all	40.2 ± 3.9	23.5 ± 6.9
Combined	≈ 80	

Table 3
Summary of the tagging algorithms performance. All numbers are in percent. The efficiencies are obtained from the $B \to J/\psi K^\circ_s$ sample. The dilution parameters are derived from the $B^\pm \to J/\psi K^\pm$ sample.

3.1.3. The Measurement

An unbinned likelihood fit is used to determine $\sin 2\beta$. The parameters in the fit can be described as a vector with 65 components. The value of $\sin 2\beta$ is a free parameter of the fit, while the remaining 64 parameters describe other features of the data. The likelihood function is described in detail in [21].

The fit yields $\sin 2\beta = 0.79^{+0.41}_{-0.44}\,(stat + syst)$. The asymmetry is shown in figure 5 together with the fit results. Using the Feldman-Cousins approach, CDF finds a positive non-zero value for $\sin 2\beta$ at 93% confidence level.

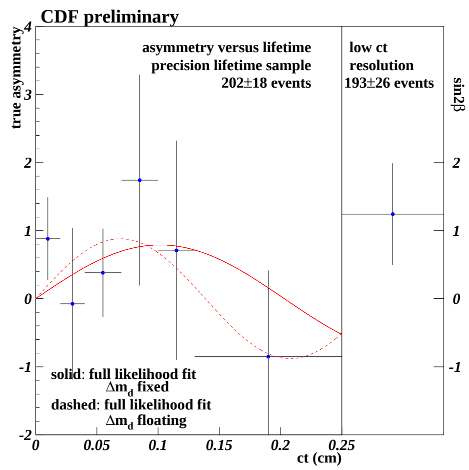

Figure 5. The true asymmetry as a function of time for $J/\psi K^\circ_s$ events. The data points are sideband subtracted and have been combined according to the effective dilutions for the single and double tags. The time integrated asymmetry for non-SVX events is shown on the right.

3.2. Hadronic Signals

CDF extracted significant evidence of its ability to reconstruct fully hadronic decays of the B meson already on Run I data, with much lower statistics and less favorable trigger scenarios than the Run II environment.

In fact, CDF Run I had no specific trigger for hadronic B decays and most of these events are identified using J/ψ or leptons. Given the small branching ratios involved, the measurements in these channels are currently statistically limited. In Run II the Tevatron experiments will have an hadronic trigger which will allow the selection of hadronic B decays without relying on the pres-

ence of leptons in the final state.
A typical example is the reconstruction of the $B \rightarrow D\pi$ decay, successfully carried out on the Run I sample collected with a single lepton trigger.

4. CP violation in Run II

CDF and $D\emptyset$ plan to collect $2fb^{-1}$ of integrated luminosity in the first two years of data taking, starting from March 2001 (*Run II*). The goal will be that of collecting more than $15fb^{-1}$ before the start of LHC at CERN. Both experiments have been upgraded to cope with the new physics program. A considerable effort has been dedicated to the tracking system of both experiments, which has proven to be essential for event selection and reconstruction in the heavy background of $p-\bar{p}$ collisions [23].
Leading goals for Run II are the accurate measurements of $\sin 2\beta$ and γ, but with the realization of detector performances many more promising possibilities are coming at the Tevatron hand. Future projections are based on Run I data from CDF as much as possible.

4.1. $\sin 2\beta$

CDF expects [1] to increase its $J/\psi K_s^\circ$ sample by improving the silicon detector acceptance by a factor ≈ 1.5, the integrated luminosity by a factor $\times 20$ and the muon coverage and acceptance $\times 2$. The projected $\sin 2\beta$ precision is based on a sample of 10^4 $J/\psi K_s^\circ$ candidates. This estimate neglects further improvements like the one due to the increase in B production cross section ($\approx \times 1.1$) when $\sqrt{s}$ goes from $1.8\,GeV/c$ to $2.0\,GeV/c$. The control samples used to measure dilution will grow by similar factors. Neglecting the expected improvements in tagging capability CDF anticipates a precision of $\sigma^2(\sin 2\beta) \approx 0.078^2\,(stat) + 0.031^2\,(syst)$.

$D\emptyset$ expectations [24] for this mode are summarized in table 4. The reconstruction strategy is similar to the one identified in CDF: starting from a sample of dimuon events at trigger level, the analysis looks for a $J/\psi \rightarrow \mu\mu$ and $K_s \rightarrow \pi^+\pi^-$ with various kinematical and geometrical cuts in order to improve the S/B ratio.

$B \rightarrow J/\psi K_s$	Central	Central + full tag	Full η
Events Produced	430000	430000	430000
Trigger Type	multi-ℓ	multi-ℓ	multi-ℓ
Tagged Events	236	492	1443
$\mathcal{D}$ (%)	28	28	22
$\delta \sin 2\beta$	0.24	0.16	0.12

Table 4
$\sin 2\beta$ goals at $D\emptyset$. Three different reconstruction strategies are investigated (see text).

Broader rapidity acceptance has been one of $D\emptyset$ distinctive features since its initial design: $D\emptyset$ will be the first experiment to seriously explore heavy quark physics in the forward region. This is reflected also in its $\sin 2\beta$ goals. Table 4 presents three different scenarios:

- *Central*: both triggering and $J/\psi K_s$ reconstruction are performed in the central detector region
- *Central with full tag*: triggering is extended to the full muon detector η coverage ($|\eta| < 3$), while the $J/\psi K_s$ reconstruction is still restricted to the central region
- *full* η: both triggering and event reconstruction are extended to the full muon detector η coverage.

The resolution goal at $D\emptyset$ and CDF for the measurement of $\sin 2\beta$ look, in conclusion, very similar and will significatively contribute to the results coming from b factories.

4.2. γ

Currently two different methods are being considered for the extraction of γ from the Tevatron data. The first is based on the decay $B_s^\circ \rightarrow D_s^- K^+$. The second is a pure event counting experiment, based on the reconstruction of $B^\pm \rightarrow D^\circ K^\pm$.

4.2.1. $B_s^\circ \rightarrow D_s^- K^+$

The four time dependent branching fractions $B_s/\bar{B}_s \rightarrow D_s^\mp K^\pm$ contain terms proportional to

$\sin\gamma \pm \delta$ and thus allow, in principle, the extraction of γ with discrete ambiguities. Preliminary studies, parameterizing detector resolution and background pollution, suggest that the resolution on $\sin\delta \pm \gamma$ will lay between 0.43 and 0.79 depending on S/B assumptions.

4.2.2. $B^{\pm} \to D^{\circ} K^{\pm}$

Another way to extract γ had been originally suggested by Gronau, London and Wyler [25]. It is based on measuring $B^{\pm}$ decay rates involving $D^{\circ}/\bar{D}^{\circ}$ mesons and requires the interference between two amplitudes that are significantly different in magnitude, causing the resulting asymmetries to be small. A refinement of this method has been suggested by Atwood, Dunietz and Soni [26] using decays to final states that are common to both D° and $\bar{D}^{\circ}$ and that are not CP eigenstates. In particular, large CP asymmetries can result from the interference of the decays $B^{-} \to K^{-}D^{\circ}$ and $B^{-} \to K^{-}\bar{D}^{\circ}$ with $D^{\circ} \to f$ being a doubly cabibbo-suppressed decay, while $\bar{D}^{\circ} \to f$ is Cabibbo-allowed. The measurement of interference effects in these modes allows the extraction of γ without the knowledge of $BR\left(B^{-} \to K^{-}\bar{D}^{\circ}\right)$.

In a preliminary study [27], CDF has investigated the two D° final states $K^{-}\pi^{+}$ and $K^{-}\pi^{+}\pi^{-}\pi^{+}$.
CDF expects to collect about 10^{2} events in $2\,fb^{-1}$. The sensitivity on γ is investigated in a toy montecarlo study: a resolution on γ of about 20° seems achievable with realistic assumptions on branching ratios knowledge and the expected S/N ratio.

4.2.3. $B \to \pi\pi, KK, K\pi$

The measurement of the CP asymmetry in this decay mode is sometimes thought as a measurement of α. In fact it is more correct to see it as a measurement of $\beta + \gamma$ whenever $\alpha + \beta + \gamma = \pi$ is not assumed.
The key to measure the CP asymmetry in this channel is to trigger on the decay mode in hadronic collisions. CDF will do this with a dedicated trigger system, capable of triggering on secondary vertices. Trigger yield and background rates have been extensively studied with simulation tools, exploiting real Run I data whenever possible. The $B^{\circ} \to \pi\pi$ signal yield is obtained from Monte Carlo simulation [28]. Assuming $BR\,(B^{\circ} \to \pi\pi) = 1{\cdot}10^{-5}$, CDF expects to collect a sample of the order of 10^{4} events in $2\,fb^{-1}$.
A study based on specialized test trigger data, described in [28], addresses the issue of combinatorial background and finds a signal-to-background ratio (S/B) not worse than $1:18$ (resulting after trigger and the first offline cuts).
Contributions from $B \to K\pi$ and $B \to KK$ can be separated from the full untagged sample exploiting the particle ID tools available in the detector (mainly with the measurement of dE/dx and a Time of Flight device).
In Run II CDF expects to reach $\epsilon\mathcal{D}^{2} \approx 9.1\%$ thanks to the detector improvements (increased muon detector coverage, a novel particle identification system). Assuming this flavour tagging CDF expects to measure the CP asymmetry in $B \to \pi\pi$ with an uncertainty of 0.09 [28].

A preliminary study [29] has been performed in order to explore the achievable resolution on γ if β is assumed known with good resolution, extracting the information from the asymmetry on $B \to \pi\pi, KK, \pi K$ [30].

The study is based on the idea that as long as $U-spin\,SU(3)$ holds, the $B_{d} \to \pi\pi$ and $B_{s} \to KK$ asymmetries differ from each other only because of the different effects of CKM phases. A simultaneous fit of the time-dependent asymmetry in these channels would measure the weak phases involved, determining γ once β is known with sufficient precision.
The dependence on various physics parameters and on the violation of the $U-spin\,SU(3)$ assumption is investigated in a toy montecarlo. The resulting resolution is $\delta\gamma \approx 10^{\circ}$ when a S/N ratio of $1:2$ is assumed after all analysis cuts.

4.3. Δm_{s}

The other crucial measurement, which is attainable only at hadron colliders, is the measurement of Δm_{s}. A large sample of $\approx 20,000$ fully reconstructable B_{s}° decays in the modes $D_{s}^{-}\pi^{+}$, $D_{s}^{-}\pi^{+}\pi^{-}\pi^{+}$ is expected. The particle identification upgrades are expected to raise the b flavour tagging efficiency up to $\epsilon\mathcal{D}^{2} = 11.3\%$ by exploit-

ing kaon identification in the same-side tag of B_s° mesons. The CDF silicon system will have good impact parameter resolution: the proper lifetime resolution is expected to be about $45\,fs$. With all these improvements combined, a better than five-sigma measurement of Δm_s is possible for $\Delta m_s < 40\,ps^{-1}$ [28].
$D\emptyset$ [24] expects to collect $\approx$ 2000 fully reconstructable B_s° decays, with a lifetime resolution of better than 5%. This should reflect in the possibility of measuring values of $x_s < 25$.

4.4. $B_s^\circ \to J/\psi\phi$

Among CDF goals for Run II there are also tests for new physics signals beyond the standard model: the CP asymmetry in $B_s^\circ \to J/\psi\phi$ measures the weak phase of V_{ts} which is expected to be very small in the standard model. The $J/\Psi\phi$ signal yield at CDF has been observed to be $\approx$ 60% that of $B_d \to J/\psi K_s$. Extrapolating results from the $J/\psi K_s$ study [1] CDF expects the asymmetry resolution on $B_s^\circ \to J/\psi\phi$ to range from ≈ 0.1 to ≈ 0.2 as x_s varies from 10 up to 45.

4.5. What Else?

Many other hadronic channels will be at reach for the Tevatron experiments in Run II. Many of these have been suggested as candidates for alternative measurements of the CKM sector.

CDF is currently exploring this wide range of possibilities and its reach will certainly go beyond the *golden* channels of CP violation studies.

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