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B Physics Expectations for Tevatron Experiments

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The B physics expectations for the Tevatron includes two time scales. The near future expectations are based on the rich B physics program of the both running experiments CDF and D0. The longer term expectations include the huge potential of the future BTeV experiment. Most of the potential interesting B physics analysis of CDF and D0 have already been studied but are statistically limited. We will focus in this article mainly on those and point out their potential with more data. We will as well briefly present some of the highlights of the BTeV physics program.

1 Introduction

The Tevatron experiment has a huge b production rate which is 3 orders of magnitudes higher than the production rate at e^+e^- colliders running on the $\Upsilon(4S)$ resonance. Among the produced states there are as well heavy and excited states which are currently uniquely accessible at the Tevatron, such as for example B_s, B_c, λ_b, θ_b, B^{**} and B_s^{**}. Dedicated triggers are able to pick 1 B event out of 1000 light flavor QCD events by selecting leptons and or events with displaced vertices already on hardware level.
The aim of the Tevatron experiments is to provide constraints to the CKM matrix which exploit the features of a hadron collider and are thus complimentary to the B physics program of the B factories (fig. 1). This mainly involves constraining the side of the CKM triangle opposite to the angel γ via various measurements in the B_s system but as well measurements on α and γ can be performed, especially once it its possible to detect decays into neutral particles with the BTeV detector.

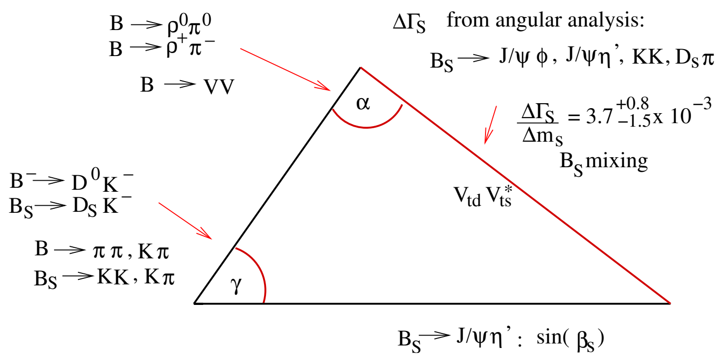

Figure 1: Potential constraints of the CKM matrix by the Tevatron experiments.

2 The Detectors

Both the CDF and the D0 detector are symmetric multi-purpose detectors having both silicon vertex detectors, high resolution tracking in a magnetic field and lepton identification. CDF is for the first time in an hadronic environment able to trigger already on hardware level on displace vertices. Thus it is very power full in fully hadronic B modes. A Time-of-Flight system and the energy-loss measurements in the drift chamber provide particle identification (ID). The CDF detector has a large extension of the tracking system in radial direction and thus provides a good mass resolution. D0 has an excellent muon coverage and better forward tracking. Thus it is very strong in J/Ψ and semileptonic modes.
BTeV which will start in 2009 is instrumented at small angles with respect to the beam. Using the forward region has many advantages:
- The useful cross-section is higher, due to the large acceptance at small transverse momentum.
- Often both B's are in the detector acceptance, giving a high efficiency for flavor-tagging.
- The boost in beam direction allows to accurately measure the decay time in that direction
- The forward detector geometry allows to install a RICH detector for superb particle ID.

BTeV will be equipped with a high resolution pixel detector with a resolution of 5-10 μm used for vertex triggering already on level 1. It will have an excellent electro-magnetic calorimeter for detecting neutral particles with a high spatial and energy resolution.

3 CP Violation in $B \to h^+h^-$

CDF uses the large two track trigger sample (requiring two displaced tracks) to search for $B \to h^+h^-$ decays. Additional cuts on the transverse momentum of both legs, their impact parameter, the sum of their transverse momenta, the decay width of the reconstructed B in x/y plane and the impact parameter of the B are applied. Additionally an isolation cut has be proved to be very useful for background rejection. In about 180 pb^{-1} of data 893 $\pm$ 47 candidates have been reconstructed (fig 2). Four major modes overlap to from a single bump.

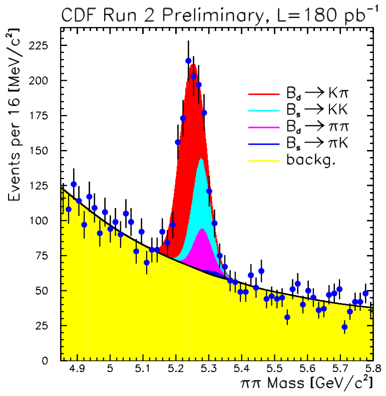

Figure 2: $M_\pi\pi$ distribution of the $B \to h^+h^-$ candidates after all selection cuts. The result of the fit is overlaid..

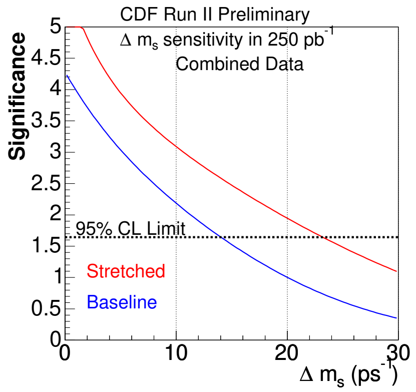

Figure 3: Potential reach for Δm_s limit based on 250 pb^{-1} of data.

Statistical methods using mass, kinematic variables and particle identification (dE/dx only) are used to extract the fraction of each component. Several results can be obtained by this study. The ration of the B_d modes

$$\frac{BR(B_d \to \pi^\pm \pi^\mp)}{BR(B_d \to K^\pm \pi^\mp)} = 0.24 \pm 0.06 \pm 0.05$$

is in good agreement with the current world average: 0.025 ± 0.025 [1].
The direct CP asymmetry is :

$$A_{CP}(B_d \to K^+\pi^-) = -0.04 \pm 0.08 \pm 0.006,$$

which is compatible both with zero, and with the measurements performed by BaBar and Belle collaborations [2]. On the B_s sector we measure:

$$BR(B_s \to K^+K^-) = 0.50 \pm 0.08 \pm 0.07 * BR(B_d \to K\pi) * (f_s/f_d)$$

No evidence is found for the other B_s decay for which a sizable BR is expected. The following limit is set:

$$BR(B_s \to K^\pm\pi^\mp) \leq 0.11 * BR(B_d \to K^\pm\pi^\mp) * (f_s/f_d) \text{ @ } 90\% \; CL$$

We have as well measured limits on rare decays although the search was optimized on the higher static modes, thus those limits might be improved with a specific analysis.

$$BR(B_d \to K^\pm K^\mp) \leq 0.17 * BR(B_d \to K^\pm\pi^\mp) \text{ @ } 90\% \; CL$$
$$BR(B_d \to \pi^\pm\pi^\mp) \leq 0.10 * BR(B_d \to K^\pm K^\mp) \text{ @ } 90\% \; CL$$

All those results are dominated by statistical uncertainties (or at least there is potential to reduce the systematic uncertainties ones they are dominating). We expect considerable improvements by moving on to the full data set and adding TOF for particle identification. On the longer term (once B_s mixing is measured) the $B \to h^+h^-$ decay modes will be used to measure the CKM angle γ exploiting U-spin symmetry as it has been proposed by R. Fleischer [3].

4 B_s Mixing sensitivity

The B_s mixing potential of both CDF and D0 have been already extensively discussed in other contributions to this proceedings [4], thus it is just briefly summarized here. While CDF mainly focus on hadronic modes exploiting the two track trigger and the good momentum resolution of the reconstructed decays, D0 is concentrated on high static semileptonic modes ($B_s \to \mu DX$) due to their very good muon system (fig 4). The overall opposite side tagging performance for CDF is $\epsilon D^2 \approx 1.8\%$ while the one from D0 is about 1% higher due to the better soft muon tagger. Both experiments have successfully applied a combination of all their opposite side tagger for measuring Δm_d on semileptonic B decays and obtain the following values which are consistent to the world average:

$$\Delta m_d = 0.536 \;\pm\; 0.037 \text{ (stat)} \pm 0.009 \text{ (sc)} \pm 0.015 \text{ (sys) ps}^{-1} \text{ (CDF)}$$
$$\Delta m_d = 0.456 \;\pm\; 0.034 \text{ (stat)} \pm 0.025 \text{ (sys) ps}^{-1} \text{ (D0)}$$

sc refers to uncertainties due to sample composition. Using the current performance and amount of data CDF is expect to be able to set a limit on Δm_s of 14-23 ps^{-1} (fig 3).

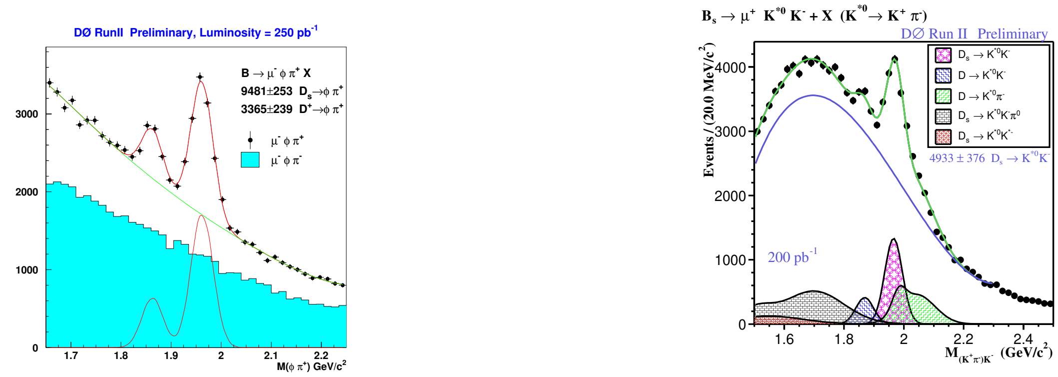

Figure 4: $B_s \to \mu D X$ candidates from D0, where $D \to \phi\pi$ (left) and $D \to K^{*0}K^-$(right).

5 Rare Decays: $B_s \to \mu^+\mu^-$

While the decay $B_s \to \mu^+\mu^-$ is not allowed on tree level and heavily suppressed on loop level $(BR(B_{d(s)} \to \mu^+\mu^-) \approx 3.5 \times 10^{-9}(1.0 \times 10^{-10}))$ [5], there are some SUSY models which predict an up to three orders of magnitudes higher branching ratio than the Standard Model. The key issue of this analysis is to find discriminating variables to reject huge background. CDF performed a blind analysis based on 171 pb^{-1} of data. 1.05 $\pm$ 0.30 (1.07 $\pm$ 0.31) background events were expected in a 3σ mass window around the $B_d(B_s)$ mass. One common event was found. Which results in the following limits:

$$BR(B_s \to \mu^+\mu^-) \leq 5.8^{-7} \text{ @ } 90\%\ CL$$
$$BR(B_d \to \mu^+\mu^-) \leq 1.5^{-7} \text{ @ } 90\%\ CL$$

Figure 5 shows the expected limits as function of integrated luminosity. Although we are probably not sensitive to the Standard Model predictions we are able to reject many New Physics models. D0 expects to observe 3.7 $\pm$ 1.1 background events and find $B_s \to \mu^+\mu^-$ candidates (fig 6). This results in the current world best limit of :

$$BR(B_s \to \mu^+\mu^-) \leq 3.8^{-7} \text{ @ } 90\%\ CL$$

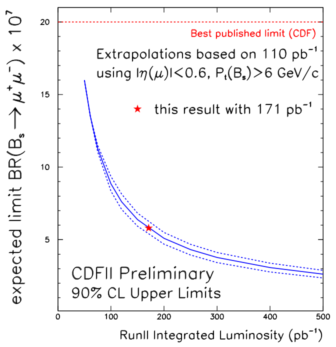

Figure 5: $B_s \to \mu^+\mu^-$: expected limit (CDF).

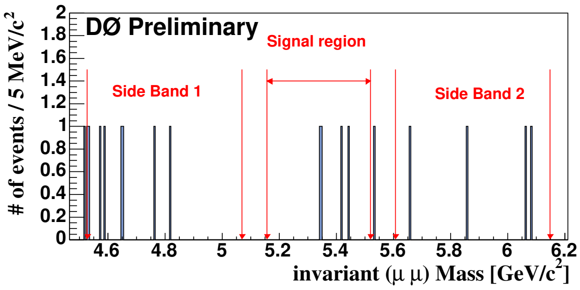

Figure 6: $B_s \to \mu^+\mu^-$ candidates (D0).

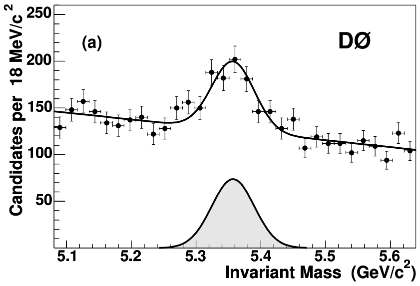

Figure 7: Mass of $B_s \rightarrow J/\Psi\Phi$ candidates from D0.

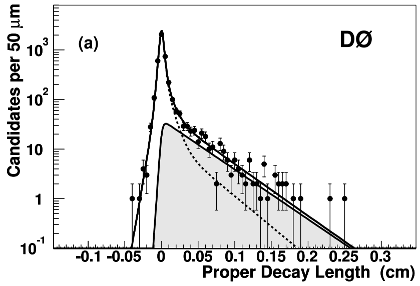

Figure 8: Lifetime of $B_s \rightarrow J/\Psi\Phi$ candidates from D0.

6 $B_s \rightarrow J/\Psi\Phi$

Both CDF and D0 have performed several B mass and lifetime measurements. For B^+, B^0, B_s and Λ_b the Tevatron measurements are the world best ones. Both experiments have measured the B_s mass and lifetime in the following decay mode, $B_s \rightarrow J/\Psi\Phi$ (fig 7/8) and obtain the following results, where the lifetime τ_s is measured with respect to τ_d from the topological similar decay $B_d \rightarrow J/\Psi K^{*0}$: $M(B_s) = 5360 \pm 5 MeV/c^2$, $\tau_s/\tau_d = 0.980^{+0.075}_{-0.070}$(stat)$\pm$0.0003(syst) from D0 and $M(B_s) = 5366.01 \pm 0.73$(stat)$\pm$0.033(syst)$MeV/c^2$ and $\tau_s/\tau_d = 0.980 \pm 0.072$(tot) from CDF. Additional to the mass and lifetime measurement CDF has (and D0 will soon) performed a measurement of the polarization amplitudes. If small CP violation effects are neglected the heavy and light B_s mass eigenstates correspond to the CP even and odd eigenstates. This means by fitting the different angular distributions of S+D waves (CP even) and P waves (CP odd) we are able to separate the mass eigenstates.Combined with the lifetime fit (fig 9) it is thus possible to determine $\Delta\Gamma_s$ the decay width difference of the heavy and light B_s mass eigenstate.

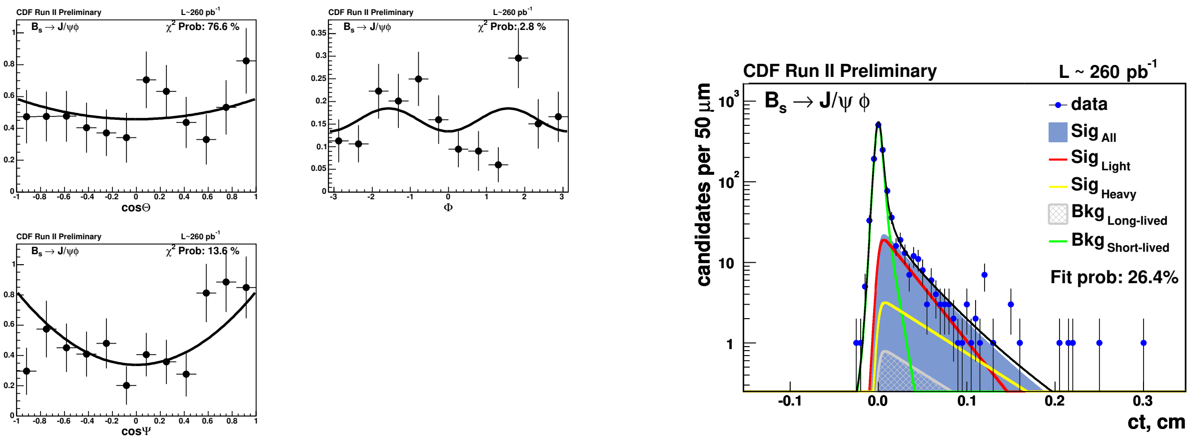

Figure 9: Fit of angular distribution of the decay particles in the J/Ψ rest-frame (left), combined fit of the lifetime of the heavy and light mass eigenstates (right).

This then provides a not mixing related cross check of Δm_s. The following results are obtained (fig 10):

$$
\begin{gathered}
|A_\perp| = 0.354 \pm 0.098 \pm 0.003 \\
A_0 = 0.784 \pm 0.039 \pm 0.007 \\
\tau_L = 1.05^{+0.16}_{-0.13} \pm 0.02 \text{ ps} \\
\tau_H = 2.07^{+0.58}_{-0.40} \pm 0.03 \text{ ps} \\
\Delta\Gamma/\Gamma = 0.65^{+0.25}_{-0.33} \pm 0.01 \\
\Delta\Gamma = 0.47^{+0.19}_{-0.24} \pm 0.01 \text{ ps}^{-1}
\end{gathered}
$$

As cross check the same analysis was done with the $B_d \to J/\Psi K^{*0}$ mode and the measured polarization amplitudes compare well to previous Babar and Belle measurements. With about 200 signal events CDF finds a large value for the lifetime difference which is about 2.5 σ way from being zero.

7 Charmless $B \to VV$

Although charmless decays have much smaller branching ration as $b \to c\bar{c}s$ transitions they are interesting to study in order to test predictions from QCD factorization. Additionally it is possible to measure the CKM angles α and γ by comparing angular distributions of various $B \to VV$ decays. The first $B \to VV$ decay studied at CDF is $B_s \to \phi\phi$. A blind analysis has been performed and 12 events have been found in the search window while about 2 background events had been expected (fig 11). The following branching ratio has been measured based on 179 pb^{-1}, which is in good agreement with the predictions from QCD factorization:

$$
\begin{gathered}
BR(B_s \to \phi\phi) = (1.4 \pm 0.6(\text{stat})\pm 0.2(\text{syst})\pm 0.5(BR)) \times 10^{-5} \\
\text{QCD factorization: } BR(B_s \to \phi\phi) = 3.68 \times 10^{-5} \text{ [6]}
\end{gathered}
$$

This signal is very clean thus soon an angular analysis as described above will be performed.

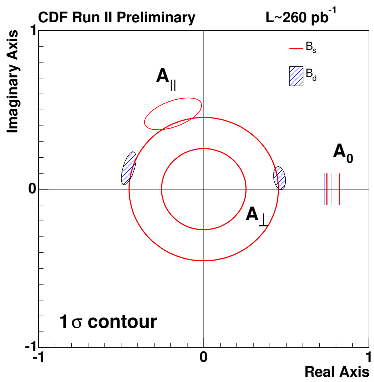

Figure 10: Measured polarization amplitudes for $B_s \to J/\Psi\Phi$ (CDF).

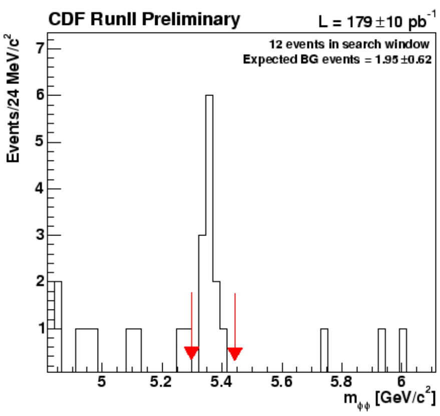

Figure 11: $B_s \to \phi\phi$ candidates (CDF).

8 BTeV

BTeV is planing to start the construction of the detector 2005 and to start data taking 2009. As already described above the BTeV detector is specialized on B physics needs. Table 1 summarizes its potential for constraining the CKM matrix ones 2 fb^{-1} of data are taken. But the BTeV program is not only focused on Standard Model physics but it has a high sensitivity to New Physics as well. Using b and c decays mediated by loop diagrams BTeV is sensitive to mass scales of up to several TeV. This will at one point eventually be the only way to distinguish between different New Physics models.

Decay	BR ($\times 10^{-6}$)	# of Events	S/B	Parameter	Error or Value
$B \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7,500	7	$\gamma - 2\chi$	8°
$B \to J/\psi(l^+l^-)K_S$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s\pi^-$	3000	59,000	3	x_s	75
$B^- \to D^0(K^+\pi^-)K^-$	0.17	170	1		
$B^- \to D^0(K^+K^-)K^-$	1.1	1,000	>10	γ	13°
$B^- \to K_s\pi^-$	12.1	4,600	1		<4° +
$B^0 \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^0 \to \rho^+\pi^-$	28	5,400	4.1		
$B^0 \to \rho^0\pi^0$	5	780	0.3	α	≈4°
$B_s \to J/\psi(l^+l^-)\eta$	330	2,800	15		
$B_s \to J/\psi(l^+l^-)\eta'$	670	9,800	30	$\sin(2\chi)$	0.024

Table 1: Potential CKM physics reach of the BTeV experiment with 2 fb^{-}1 of data

References

[1] Calculations based on HFAG 2004

[2] ICHEP 2004, Proceedings World Scientific submitted by M. Giorgi, Y. Sakai

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