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CKM physics at CDF

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A precise knowledge of the CKM matrix elements is one of the primary goals of the CDF experiment. The Tevatron collider at Fermilab, operating at $\sqrt{s} = 1.96$, collected 1 fb^{-1} of data corresponding to a huge $b\bar{b}$ sample. In this paper the recent measurements performed in the CKM sector will be presented.

1. Introduction

At Tevatron the properties of B mesons can be studied with high precision, thanks to the high b production cross section. CDF II [1] is a multi-purpose 4π coverage detector with an high resolution tracking and subdetectors to make particle identification. Moreover, the use of specialized triggers based on leptons and displaced tracks from primary vertex allow the selection of pure B meson samples. In this paper we are describing the determination of $\frac{|V_{td}|}{|V_{ts}|}$ obtained measuring the mass differences Δm_s and Δm_d (section 2) and the first step towards the γ angle measurement using the $B \to DK$ modes (section 3).

2. B_s^0 mixing

Neutral B mesons ($b\bar{q}$, with q=d,s for $\overline{B_d^0}$,$\overline{B_s^0}$) oscillate from particle to antiparticle due to flavor changing weak interactions. The probability density P_+ (P_-) for a $\overline{B_q^0}$ meson produced at proper time $t = 0$ to decay as a $\overline{B_q^0}$ (B_q^0) at time t is given by:

$$P_\pm(t) = \frac{\Gamma_q}{2} e^{-\Gamma_q t}[1 \pm \cos(\Delta m_q t)] \quad (1)$$

where Δm_q is the mass difference between the two mass eigenstates B_q^H and B_q^L [2] and Γ_q is the decay width, which is assumed to be equal for the two mass eigenstates.

Particle-antiparticle oscillation have been observed and well established in the B_d system. The mass difference Δm_d is measured to be $\Delta m_d = (0.505 \pm 0.005) ps^{-1}$[3].

A measurement of Δm_s combined with Δm_d would determine the ratio $|V_{td}/V_{ts}|$ with a significantly smaller theoretical uncertainty contributing to a stringent test of the unitarity of the CKM matrix.

To measure time-dependent oscillation in the B_s^0 sector three ingredients are needed: a large B_s^0 sample with good signal to background ratio, a good resolution on the proper decay time and the b flavor at production time.

We reconstructed B_s^0 decays in hadronic ($\overline{B_s^0} \to D_s^+\pi^-, D_s^+\pi^-\pi^+\pi^-$) and semileptonic ($\overline{B_s^0} \to D_s^{+(*)} l^- \overline{\nu_l}, l = e$ or μ) decay mode obtaining 3600 fully recostructed B_s^0 and 37000 partially reconstructed B_s^0.

The proper decay time for each B_s^0 is calculated from the measured distance between the production and decay points, the measured momentum and the B_s^0 mass [3].

The B_s^0 flavor (b or $\bar{b}$) at decay is determined unambiguously by the charges of the decay products. At the Tevatron, the dominant b quark production mechanism produce $b\bar{b}$ pairs. We can define two regions, the first is the same side region, where the $\bar{b}$ becomes a B_s^0 and we identify the production flavor looking at the charge of the fragmentation kaon (same-side-tag). The other region is the opposite region where the second b hadron decays and we identify the production flavor using the charge of the lepton from semileptonic decays or the sum of charges of the b-jet tracks (opposite-side-tag).

The effectiveness $Q \equiv \epsilon D^2$ of these techniques is quantified with an efficiency ϵ, the fraction of signal candidates with a flavor tag, and a dilution

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$D \equiv 1 - 2w$, where w is the probability that the tag is incorrect. For the opposite side tagging $Q = 1.5 \pm 0.1\%$ and for the same side tagging $Q = 3.5\%(4.0\%)$ in the hadronic (semileptonic) decay sample. The fractional uncertainty on Q is approximately 25%.

An unbinned maximum likelihood fit is used to determine the B_s^0 oscillations frequency in the data corresponding to a total integrated luminosity of about 1 fb^{-1}. Instead of fitting directly for Δm_s we use the "amplitude scan" method [4]; the signal oscillation term in the likelihood of the Δm_s becomes $L \propto \frac{1 \pm AD\cos(\Delta m_s t)}{2}$.

The parameter A is left free in the fit while D is supposed to be known and fixed in the scan. We fit for the oscillation amplitude A fixing Δm_s to a probe value. The oscillation amplitude is expected to be consistent with A=1 when the probe value is the true oscillation frequancy, and consistent with A=0 when the probe value is far from the true oscillation frequency. Fig.1 (upper) shows the fitted value of the amplitude as a function of the oscillation frequency.

The significance of the potential signal is evaluated from $\Lambda \equiv log[L^{A=0}/L^{A=1}(\Delta m_s)]$, the logarithm of the ratio of likelihoods for the hypothesis of oscillation (A=1) at the probe value and the hypothesis that A=0, which is equivalent to random production flavor tags. Fig.1 (lower) shows Λ as a function of Δm_s. A minimal value of $\Lambda = -6.75$ is observed at $\Delta m_s = 17.3\ ps^{-1}$. The significance of the signal is quantified by the probability that randomly tagged data would produce a value of Λ lower than -6.75 at any value of Δm_s. We obtained a significance of 0.2%.

We find $\Delta m_s = 17.31^{+0.33}_{-0.18}$ (stat.) $\pm$ 0.07 (syst.) ps^{-1}. The systematic on Δm_s is dominated by the uncertainty on the absolute scale of the decay time measurement.

The measured $B_s^0 - \overline{B_s^0}$ oscillation frequency is then used to derive the ratio $|V_{td}/V_{ts}| = \xi\sqrt{\frac{\Delta m_d}{\Delta m_s}\frac{m_{B_s^0}}{m_{B_d^0}}}$. Using $m_{B_s^0}/m_{B_d^0} = 0.9830$ [3] with negligible uncertainty, $\Delta m_d = (0.505 \pm 0.005)ps^{-1}$ and $\xi = 1.21^{+0.047}_{-0.035}$ [5] we find $|V_{td}/V_{ts}| = 0.208^{+0.001}_{-0.002}$ (exp.) ${}^{+0.008}_{-0.006}$ (theo.) . The uncertainty on the latter is dominated by

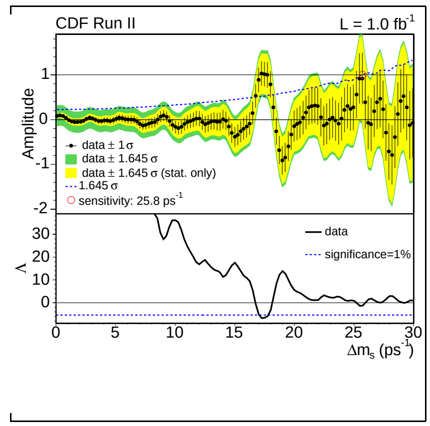

Figure 1. Upper: Amplitude vs Δm_s. Lower: $\Lambda \equiv log[L^{A=0}/L^{A=1}(\Delta m_s)]$ vs Δm_s.

lattice calculation than Δm_s. Fig. 2 shows the allowed region in the $\overline{\rho}\ \overline{\eta}$ plane after all the constraints have been applied including Δm_s measurement by CDF.

3. γ angle measurement

The partial widths of $B^- \to D^0_{(CP)}K^-$ decays provide a theoretically clean way of measuring the CKM angle γ. There are several method to extract γ depending on D^0 modes used:

- The GLW (Gronau-London-Wyler) method [6], that use $D^0_{flav} \to K^-\pi^+$, $D^0_{CP+} \to K^+K^-, \pi^+\pi^-$ and $D^0_{CP-} \to K_s^0\pi^0, K_s^0\Phi, K_s^0\omega$.
- The ADS (Atwood-Dunietz,-Soni) method [7], that use $D^0_{flav} \to K^-\pi^+$ and the doubly cabibbo suppressed $D^0_{dcs} \to K^+\pi^-$.
- The Dalitz method [8], that use the $D^0_{flav} \to K_s^0\pi^+\pi^-$.

All these methods require no tagging or time-dependent measurements.

Using the GLW method the parameters needed for the γ measurement are:

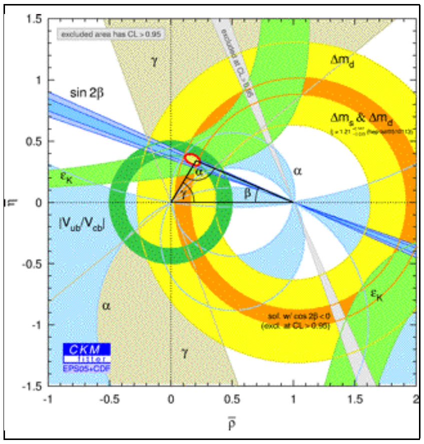

Figure 2. Allowed region in the $\overline{\rho}\,\overline{\eta}$ plane once all the constraints have been applied including Δm_s measurement by CDF with $\xi = 1.21^{+0.047}_{-0.035}$.

- $R = \frac{BR(B\to D^0_{flav}K)}{BR(B\to D^0_{flav}\pi)}$
- $R_+ = \frac{BR(B^-\to D^0_{CP+}K^-)+BR(B^+\to D^0_{CP+}K^+)}{BR(B^-\to D^0_{CP+}\pi^-)+BR(B^+\to D^0_{CP+}\pi^+)}$
- $A_{CP+} = \frac{BR(B^-\to D^0_{CP+}K^-)-BR(B^+\to D^0_{CP+}K^+)}{BR(B^-\to D^0_{CP+}K^-)+BR(B^+\to D^0_{CP+}K^+)}$

A_{CP+} and $R_{CP+} = R_+/R$ are related to the angle γ, the magnitude r of the ratio of the amplitudes for the processes $B^- \to \overline{D^0}K^-$ and $B^- \to D^0K^-$, and the relative strong phase δ between these two amplitudes, through the relations $R_{CP+} = 1 + r^2 + 2r\cos\delta\cos\gamma$ and $A_{CP+} = 2r\sin\delta\sin\gamma/R_{CP+}$.

The first step is the measurement of the ratio $R = \frac{BR(B\to D^0_{flav}K)}{BR(B\to D^0_{flav}\pi)}$. We used the small kinematics differences between distinct modes and the particle identification information provided by the specific ionization (dE/dx) in the drift chamber. The K/π separation using dE/dx is $\sim 1.5\sigma$.

The analysis is performed on a sample corresponding to an integrated luminosity of ~ 360 pb^{-1}.

Our goal is to measure the relative yield of $B^- \to D^0K^-$ to $B^- \to D^0\pi^-$. We used an unbinned maximum likelihood fit which combines kinematics and dE/dx information.

Using simulated B^+ events we can observe from Fig. 3, where the invariant mass distribution is reported, that other channels contribute to the background. Moreover, the principal background contribute to the mass region of the DK signal is the $B^+ \to \overline{D^{0*}}\pi^+$. We choose as fit window the range of mass between 5.17 and 5.60 GeV/c; in this region the only significant physics backgrounds are $B^+ \to \overline{D^0}\pi^+$ and $B^+ \to \overline{D^{0*}}\pi^+$.

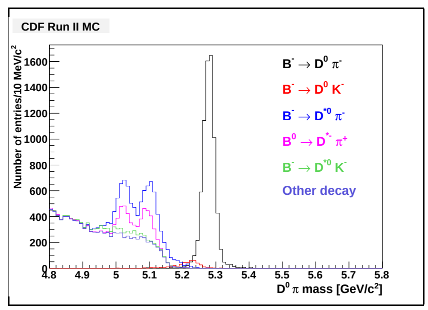

Figure 3. Invariant mass of $B^+ \to \overline{D^0}\pi^+$ plus c.c (simulation).

The variables used in the fit are:

- $M_{D^0\pi}$ which is the invariant mass assigning the pion mass at the track from B.
- The momentum imbalance α defined as:
  - if $p_{tr} < p_{D^0}$ $\quad \alpha = 1 - p_{tr}/p_{D^0} > 0$
  - if $p_{tr} \geq p_{D^0}$ $\quad \alpha = -(1 - p_{D^0}/p_{tr}) \leq 0$

  where p_{tr} is the momentum of the track from B and p_{D^0} is the momentum of D^0. These two variables ($M_{D^0\pi}$ and α) provide some separation between $B^+ \to \overline{D^0}\pi^+$ and $B^+ \to \overline{D^0}K^+$ as we can see from Fig. 4 where the mass vs α is shown for the two channels.

- $p_{tot} = p_{tr} + p_{D^0}$.
- ID, which contains the dE/dx information for the track from B, defined as:

$$ID = \frac{\frac{dE}{dx}_{meas} - \frac{dE}{dx}_{exp}(\pi)}{\frac{dE}{dx}_{exp}(K) - \frac{dE}{dx}_{exp}(\pi)}. \quad (2)$$

In particular ID = 0 if the track is a pion and ID = 1 if the track is a kaon. To distinguish between BDK and BDπ mode, we applied the particle identification to the track from B.

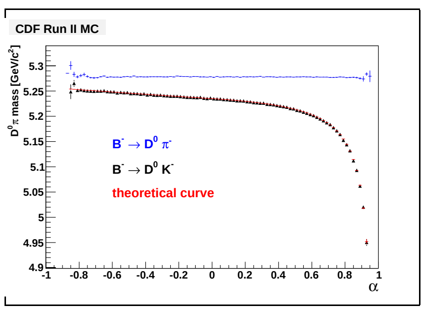

Figure 4. Mass vs α using MC. Blue: $M_{D^0\pi}$. Black: M_{D^0K}. Red: theoretical curve obtained using the analytical formula.

We measured the ratio

$$R = \frac{BR(B \to D^0_{flav} K)}{BR(B \to D^0_{flav} \pi)} = (0.065 \pm 0.007(stat) \pm 0.004(sys)). \quad (3)$$

In Fig. 5 the B invariant mass is reported (points) with superiposed the fit projections (solid lines).

The world average for this ratio is 0.0830 ± 0.0035 [3].

We also have signals for the DCP modes, ~ 380 $B^- \to D_{CP}\pi^- \to [K^+K^-]\pi^-$ and ~ 100 $B^- \to D_{CP}\pi^- \to [\pi^+\pi^-]\pi^-$,but we decided to move to the 1 fb^{-1} for the complete analysis, where we have about 26000 $D^0\pi$ events and we estimated a resolution for R_{CP} and A_{CP} of 0.1 comparable to the current resolution at B factories.

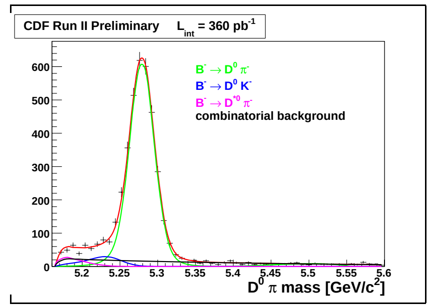

Figure 5. B invariant mass (points) with superiposed the fit projections (solid lines)

Another interesting channel that permit a very clean measurement of the γ angle is the $B_s \to D_s K$. Final state of both sign are accessible by both B_s mesons with similar-sized amplitudes (λ^3):

$$B^0_s \to D^{\pm}_s K^{\mp} \qquad \overline{B^0_s} \to D^{\mp}_s K^{\pm}$$

The B_s oscillation cause the amplitudes to interfer. In this case we need a time dependent CP asymmetry measurement. We expected about 200 D_sK events in 1 fb^{-1} and also the measurement of the branching ratio $\frac{BR(B^0_s \to D^-_s K^+) + BR(\overline{B^0_s} \to D^+_s K^-)}{BR(B^0_s \to D^-_s \pi^+) + BR(\overline{B^0_s} \to D^+_s \pi^-)}$ alone will be an important new result.

REFERENCES

1. D.Acosta et al.,CDF Collaboration,Phys.Rev.D71,032001(2005).
2. C.Gay,Annu.Rev.Nucl.Part.Sci.50,577(2000).
3. Particle Data Group, http://pdg.lbl.gov/
4. H.G.Moser,A.Roussarie,NIM A384,491-505
5. M.Okamoto, hep-lat/0510113
6. M.Gronau, D.Wyler, PLB 265,172.
7. D.Atwood,I.Dunietz,A.Soni, PRL 78,3257.
8. A.Giri, Y.Grossman, A.Soffer, J.Zupan, PRD 68, 054018.