Charmless B decays at CDF

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In this paper I review the most recent CDF II results in the field of charmless B decays: the measurement of the relative branching fractions of B^0 and $B_s^0 \to h^+h^{'-}$ decays, the direct CP asymmetry in the $B^0 \to K^+\pi^-$ decay, the limits on the $\Lambda_b^0 \to h^+h^{'-}$ branching fractions, the first evidence of $B_s^0 \to \phi\phi$ decay and the measurement of direct CP asymmetry in the $B^+ \to \phi K^+$ decay.

1. INTRODUCTION

The charmless decays of the b hadrons provide one of the most stringent tests of the CKM matrix and potential windows to New Physics effects. While several decays of the B^0 and B^+ mesons have already beenmeasured at the $\Upsilon(4S)$, the Tevatron offers unique access to the B_s^0 and Λ_b^0 decays.

2. TRIGGER AND DATASET

The analyses reviewed in this paper have been performed by using a $\approx$180 pb^{-1} data sample recorded by the CDF II experiment at the Tevatron $p\overline{p}$ collider.

A detailed description of the CDF II detector can be found in [1]. The data have been selected with a three-level trigger system. At Level 1, charged tracks in the central drift chamber transverse plane are reconstructed by a hardware processor (XFT) [2] and the trigger requires two oppositely charged tracks with transverse momenta $p_T > 2$ GeV/c, $p_{T1} + p_{T2} > 5.5$ GeV/c and an opening angle $\Delta\phi < 135^o$. At Level 2 the online Silicon Vertex Tracker (SVT) [3] associates the silicon hits positions to the XFT tracks. The impact parameter of the track (d_0) is measured with respect to the beamline with a 50 μm resolution, which includes a $\approx$30 μm contribution from the transverse beam size as measured by the SVT. At Level 2 separate trigger selections are applied for two-body and multibody decays:

- Two-body decays: the two tracks have 100 μm $<\mid d_0 \mid<$ 1.0 mm and an opening angle between 20^o and 135^o. The track pair is also required to be consistent with originating from a particle having transverse decay length $L_{xy}(B) > 200$ μm and an impact parameter $\mid d_0(B) \mid< 140$ μm.
- Multibody decays: the two tracks have 120 μm $<\mid d_0 \mid<$ 1.0 mm and an opening angle between 2^o and 90^o. Also in this case it is required a transverse decay length $L_{xy}(B) > 200$ μm, but no request is applied on the impact parameter $d_0(B)$.

A complete event reconstruction is available at Level 3 using the offline software and this is used to confirm the Level 1 and Level 2 trigger requirements on offline quantities.

3. Measurement of branching fractions and CP asymmetries in $B^0 \to h^+h^{'-}$

This analysis uses the data collected by the trigger optimised for two-body decays. In the offline selection, to enhance the purity of the sample, further cuts are imposed on transverse momenta and impact parameters of the two tracks, and on transverse decay length, impact parameter and isolation of the B candidate. Isolation is defined as $\frac{p_T(B)}{p_T(B)+\sum p_T}$, where the sum runs on every other track within a cone of radius 1 in η-ϕ space around the B candidate flight direction. This cut is particularly effective in rejecting combinatoric background. The set of cuts is chosen to maximise the quantity $S/(S+B)^{1/2}$,where S is the number of expected signal events estimated from a detailed detector and trigger simulation using GEANT [8], and B is the background estimated by extrapolating the sidebands. The resulting invariant mass distribution computed by assigning the pion mass to both tracks is reported in Figure 1, which shows a clean peak with 893±47 signal events, with width 38±2 MeV/c^2 and a peak S/B better than 2.

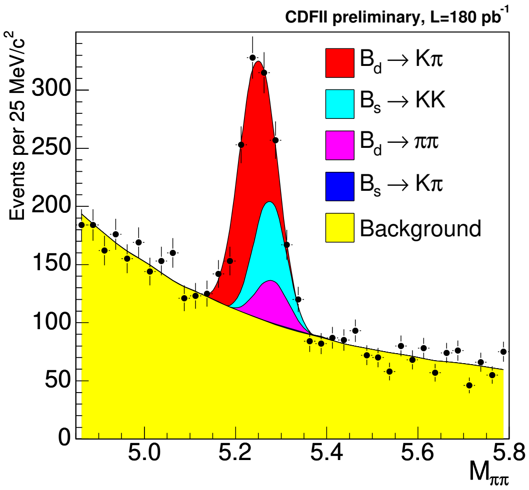

Figure 1. $B^0 \to h^+h^{'-}$ mass distribution computed with the pion mass assignment to both tracks. The contributions of the signals and of the background, as determined from the fit, are reported in different colors.

The simulation predicts sizeable signals in this mass region from B^0 and B^0_s two-body decays: $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$, $B^0_s \to K^-\pi^+$, overlapping into a single unresolved bump. The relative fractions of each $B_{d,s} \to h^+h^{'-}$ mode, along with the direct CP asymmetry in the self tagging mode $B^0 \to K^+\pi^-$, are determined with an unbinned likelihood fit which combines kinematic and particle identification information. The likelihood for event i is written as

$$L_i = (1-b)\sum_j f_j L_j^{kin} L_j^{PID} + bL_{bck}^{kin} L_{bck}^{PID} \quad (1)$$

where the index j runs on the signal modes and the parameters f_j are their relative fractions determined by the fit and b is the background fraction.

The kinematic term is $L_j^{kin} = P_j(M_{\pi\pi}|\alpha)P_j(\alpha, p_{tot}) = G(M_{\pi\pi} - M_j(\alpha), \sigma_M)P_j(\alpha, p_{tot})$. $M_j(\alpha)$ is obtained by solving for $M_{\pi\pi}$ the following approximate expression for the invariant mass of a particle pair:

$$M^2_{h_1h_2} \approx M^2_{\pi\pi} + (1+\frac{p_1}{p_2})(m_2^2 - m_\pi^2) + (1+\frac{p_1}{p_2})(m_1^2 - m_\pi^2) \quad (2)$$

The variable $\alpha = (1 - p_1/p_2)q_1$ is the signed momentun imbalance of the decay. p_1 (p_2) is the smaller (larger) track momentum and q_1 is the charge of the smaller momentum track, and $p_{tot} = p_1 + p_2$ is the scalar sum of the momenta of the two tracks. G is a gaussian distribution and $P_j(\alpha, p_{tot})$ is the joint probability distribution of α and p_{tot} for each signal mode after the effect of all reconstruction cuts. The $P_j(\alpha, p_{tot})$ are parameterised by product of polynomial and exponential functions using Monte Carlo samples.

The particle identification information is based on the dE/dx measurement in the drift chamber and it is summarised in the single observable $\mathtt{i} = (\frac{dE}{dx_{meas}} - \frac{dE}{dx_\pi})/(\frac{dE}{dx_K} - \frac{dE}{dx_\pi})$ for each track. dE/dx_K (dE/dx_π) is the expected dE/dx value of the track in the kaon (pion) mass hypothesis. The probability distribution of $\mathtt{i}$ is almost independent on momentum for kaons and pions. In the likelihood $L_j^{PID} = pdf_j^{PID}(\mathtt{i}_1, p_1(\alpha, p_{tot}), \mathtt{i}_2, p_2(\alpha, p_{tot}))$ the probability distribution functions pdf_j^{PID} are determined by making use of a huge calibration sample of $D^0 \to K\pi$ decays, tagged by the presence of a $D^{*\pm}$, collected by the multybody trigger. The fit takes into account the residual correlation in the dE/dx response of tracks in the same event, due to residual time-dependent baseline fluctuations in the drift chamber response. In the momentun range of interest the measured K/π separation is close to 1.4σ. The background is described by $L_{bck} = L_{bck}^{kin} \cdot L_{bck}^{PID}$, with the kinematic term $L_{bck}^{kin} = P_{bck}(\alpha, p_{tot}) \cdot (e^{c_0 + c_1 \cdot M_{\pi\pi}} +$

c_2), where $P_{bck}(\alpha, p_{tot})$ is parameterised from the sidebands of real data and the c_i are free parameters determined by the fit. The likelihood term related to particle identification for background is similar to the signal one and assumes that the background is composed of pions, kaons, protons and electrons, while muons are indistinguishable from pions with the available resolution.

The fit returns raw relative fractions which need to be corrected for the different efficiencies of the selection cuts for each decay mode in order to provide measurements of branching fractions. Part of the effects determining the different efficiencies are estimated using the detector simulation, part using real data, this has been done in particular for the efficiencies of the B isolation cut, for the relative efficiency of the trigger track processor for kaons and pions and for the detector charge asymmetry.

3.1. Results

In the B^0 sector the measurements of the relative branching fraction $\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.21 \pm 0.05(stat.) \pm 0.03(syst.)$ and of the direct CP asymmetry $A_{CP}(B^0 \to K^+\pi^-) = -0.022 \pm 0.078(stat.) \pm 0.012(syst.)$ are compatible with the measurements performed by BaBar and Belle [4]. In the B^0_s sector the measurement of $\frac{f_s \cdot BR(B^0_s \to K^+K^-)}{f_s \cdot BR(B^0 \to K^+\pi^-)} = 0.46 \pm 0.08(stat.) \pm 0.07(syst.)$ allows to extract the absolute branching fraction $BR(B^0_s \to K^+K^-) = 31.1 \pm 5.4(stat.) \pm 5.2(syst.)$ by using the world average of the branching fraction of the $B^0 \to K^+\pi^-$. No evidence is found for the $B^0_s \to K^-\pi^+$ decay and the resulting limit is $BR(B^0_s \to K^-\pi^+) < 5.4 \cdot 10^{-6}$ @90% C.L..

Limits on rare modes dominated by penguin annihilation and exchange diagrams have been searched for by adding their expected contributions to the likelihood. No evidence is found for these modes. The limits are $BR(B^0 \to K^+K^-) < 1.82 \cdot 10^{-6}$ @90 % C.L. and $BR(B^0_s \to \pi^+\pi^-) < 1.6 \cdot 10^{-6}$ @90 % C.L and improve a previous CDF II result [5].

4. Search for $\Lambda^0_b \to h^+h^{'-}$ decays

Theoretical predictions for the $\Lambda^0_b \to pK$ and $\Lambda^0_b \to p\pi$ branching fractions lie in the range (1.4-1.9)$\times 10^{-6}$ for pK decays and (0.9-1.2)$\times 10^{-6}$ for $p\pi$ decays [6]. The $\Lambda^0_b \to ph^-$ branching ratio has been normalised to the branching ratio BR($B^0_d \to K\pi$)= (1.85 $\pm$ 0.11)$\times 10^{-5}$ [7], which is a topologically similar decay. The relationship between the number of events (N) and branching fractions of the signal and normalising mode are given by: $\mathrm{BR}(\Lambda^0_b \to ph^-) = N(\Lambda^0_b \to ph^-)/A$ and $A = \frac{\epsilon_\Lambda}{\epsilon_B} \cdot \frac{f_\Lambda}{f_d} \cdot \frac{R \cdot N(B \to h^+h^{'-})}{BR(B^0_d \to K\pi)}$ where ϵ_Λ (ϵ_B) is the total efficiency of observing a Λ^0_b (B^0_d) and f_Λ (f_d) is the b-quark hadronization fraction of the Λ^0_b (B^0_d). We use $f_\Lambda = 0.099 \pm 0.017$ and $f_d = 0.397 \pm 0.010$ [7], for a resulting value of $f_\Lambda/f_d = 0.25 \pm 0.04$. The efficiencies are estimated with the simulation of the detector and of the trigger. R is the relative fraction $N(B^0_d \to K\pi)/N(B \to h^+h^{'-})$ measured in the $B^0 \to h^+h^{'-}$ analisys.

The search has been performed with a blind analysis, by hiding the data in the signal mass region. The signal region is unblinded only after fixing all the selection criteria and estimating the systematic unsertainties. The background level is estimated by fitting the invariant mass spectrum and interpolating in the blinded signal region. Possible biases in the background estimate due to the cut optimisation procedure are avoided by splitting the full sample in two statistically independent subsamples and using one subsample for the cut optimisation and the other subsample for the measurement of the background level. Figure 1 shows the invariant mass distribution after all the selection criteria are applied, with the dotted line indicating the blinded region where a signal is expected. The solid line indicates the fit region used to determine the expected background level. In the search region also the Monte Carlo distributions of the $\Lambda^0_b \to p\pi$ and $\Lambda^0_b \to pK$ signals are reported. From the plot it is clear that the main source of background in the search window is combinatoric, while the contribution from the $B \to h^+h^{'-}$ is negligible.

The selection cuts and the position of the search window have been determined from an op-

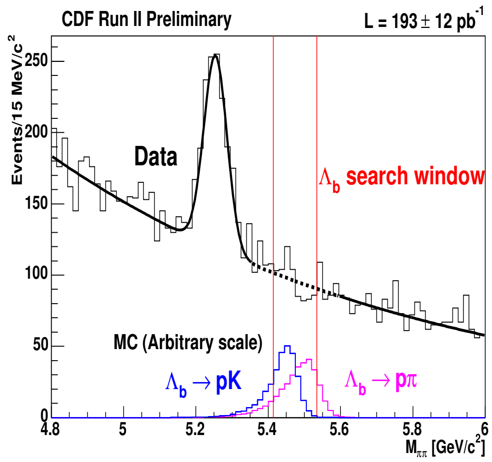

Figure 2. Di pion invariant mass distribution. The fitting function is used to extract the number of $B \to h^+h^{'-}$ and background events. The dashed curve is the extrapolation of the fitting function in the region not used to perform the fit. The scales of the Monte Carlo signal distributions are arbitrary.

timisation procedure applied using the first subsample. The figure of merit $S/(1.5+\sqrt{B})$ [9], where S and B are respectively the signal and background events, is maximised. B is determined by extrapolating the fit performed in the sidebands (4.8 - 5.335 GeV/c^2 and 5.595 - 6.0 GeV/c^2) to the search window. In the formula the constant has been chosen in order to favor selections maximising the sensitivity reach at 3σ significance. When the background is large, as in our case, this expression reduces to the usual $S/\sqrt{B}$, while it reduces to $s/1.5$ when the background is low. In both cases it reduces to $\epsilon_\Lambda/(1.5+\sqrt{B})$, where ϵ_Λ is the signal efficiency determined with Monte Carlo. The optimised cuts require $\mid d_\Lambda \mid < 50$ μm, $L_{xy}(\Lambda) > 400$ μm and $min(\mid d_{01} \mid, \mid d_{02} \mid) > 180$ μm, and the optimised search window is determined to be between 5.415 and 5.535 GeV/c^2.

The expected background is determined using the second subsample and fitting the shape of the mass distribution with a combination of a gaussian for the $B \to h^+h^{'-}$ signal and some combinations of exponential and polynomial functions for the combinatoric background. The estimate is 772±31 expected background events in the Λ_b^0 search window and 726±82 $B \to h^+h^{'-}$ events, where the quoted error includes both the statistical error and the systematic error estimated as the fluctuation of the yields for different choices of the background model. The relative efficiency $\epsilon_\Lambda/\epsilon_B$ is estimated with Monte Carlo samples of $\Lambda_b^0 \to ph^-$ and $B_d^0 \to K\pi$. The total number of events in the signal region is 767, consistent within the error with the predicted background, 772±31. Upper limits on the branching fractions can be calculated using a Bayesan method with uniform prior distribution, taking into account both statistical and systematic uncertainties. The most relevant sources of systematic error are the uncertainty on the $B \to h^+h^{'-}$ yield, on the background estimate, on the relative efficiency $(\epsilon_\Lambda/\epsilon_B)$ correction factor and on f_Λ/f_d. The resulting upper limits are 2.3×10^{-5} at 90% C.L. for $\Lambda_b^0 \to pK^-$ and 2.9×10^{-5} at 90% C.L. for $\Lambda_b^0 \to p\pi^-$ [10]

5. Measurement of A_{CP} in the $B^+ \to \phi K^+$ decay and first evidence of the $B_s^0 \to \phi\phi$ decay

This analysis has been performed using the data collected by the multybody trigger. To cancel the uncertainty on the B production cross section and to reduce systematic uncertainties on detector efficiencies, the branching fractions are extracted from ratios of the decay rates of interest normalized to the well established and topologically similar $B_s^0 \to J/\psi\phi$ and $B^+ \to J/\psi K^+$ decay modes.

B candidates are reconstructed first by detecting $\phi \to K^+K^-$ and $J/\psi \to \mu^+\mu^-$ decays. Background from mismeasured tracks is reduced by requiring a good vertex χ^2, while combinatoric background is reduced by exploiting several variables sensitive to the long lifetime, relatively hard p_T spectrum of B mesons and the isolation of the B hadrons inside the b-quark jets. The cut values are optimized by maximizing the usual

$S/\sqrt{S+B}$ for the already observed $B^+ \to \phi K^+$ signal and $S/(1.5+\sqrt{B})$ for $B^0_s \to \phi\phi$ whose branching ratio is unknown. While the signal S is derived from Monte Carlo, the background B is estimated from the ϕ sideband ($1.04 < m_{KK} < 1.06$ GeV/c^2) appropriately normalized.

The $B^\pm \to \phi K^\pm$ yield and A_{CP} are extracted simultaneously from an extended unbinned maximum likelihood fit on four variables to the combined B^+ and B^- sample: the three-kaon invariant mass, the invariant mass of the ϕ candidate, the cosine of the ϕ meson helicity angle and the measured dE/dx deviation from the expected value for pions for the lowest momentum trigger track. The likelihood function has seven components: signal, partially reconstructed $b \to \phi X$ decays, combinatoric background, $B^+ \to K^{*0}(892)\pi^+$, $B^+ \to f_0(980)\pi^+$, non-resonant $B^+ \to K^+K^-K^+$ and non-resonant $B^+ \to K^+\pi^-\pi^+$. For each component the likelihood function is the product of four one-dimensional probability distribution functions of the fit variables, assumed to be uncorrelated, which are parameterised from a combination of Monte Carlo simulation and sideband data. The measured value is $A_{CP} = -0.07 \pm 0.17^{+0.03}_{-0.02}$ [11]. The branching fraction is measured relatively to the $B^+ \to J/\psi K^+$ mode, which is reconstructed with the same requirements as the $B^+ \to \phi K^+$ candidates except for the invariant mass of the two muons being within 100 MeV/c^2 of the J/ψ mass. From the $B^+ \to \phi K^+$ yield (47.0±8.4 events) and the $B^+ \to J/\psi K^+$ yield (439±22 events) and the correction for the relative trigger and reconstruction efficiciency between the two modes, it is measured $BR(B^+ \to \phi K^+) = (7.6 \pm 1.3(stat.) \pm 0.6(syst.)) \times 10^{-6}$ [11].

The $B^0_s \to \phi\phi$ signal is selected requiring two pairs of kaons with an invariant mass within 15 MeV/c^2 of the world average ϕ mass. The search is performed in a blind way fixing the selection requirements and evaluating the combinatoric background from independent samples before examining the signal region in the data. In a region of ±72 MeV/c^2 around the world average B^0_s mass, corresponding to a window three times the expected mass resolution, 8 events are observed. The combinatoric background and the reflection from $B^0 \to \phi K^{*0}$, where the pion from the K^{*0} is assigned the kaon mass, are the two main sources of background expected in the B^0_s signal region. After subtracting these two contributions, the signal yield is $7.3^{+3.2}_{-2.5}$ events, and the resulting one-sided Gaussian significance of the signal is 4.7σ. The $BR(B^0_s \to \phi\phi)$ is measured relative to the $B^0_s \to J/\psi\phi$ decay, reconstructed requiring one pair of kaons and one pair of muons within 15 and 50 MeV/c^2 of the world average ϕ and J/ψ mass respectively, and applying the other kinematic selection criteria similar to the $B^0_s \to \phi\phi$ mode. As in the $B^+ \to \phi K^+$ case, the $B^0_s \to \phi\phi$ decay rate is derived from the $B^0_s \to \phi\phi$ yield, from the $B^0_s \to J/\psi\phi$ yield and the relative efficiency between the two modes. It is measured $BR(B^0_s \to \phi\phi) = (14^{+6}_{-5}(stat.) \pm 6(syst.)) \times 10^{-6}$ [11], where the systematic error is dominated by a 36 % contribution due to the uncertainty on $BR(B^0_s \to J/\psi\phi)$.

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