FIRST EVIDENCE FOR \( B_s \to \phi\phi \) AND PENGUIN B DECAYS AT CDF

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We present the first evidence of the decay mode \( B_s \to \phi\phi \) and a measurement of partial width and direct CP asymmetry for the \( B^+ \to \phi K^+ \) decay using 180 pb\(^{-1}\) of data collected by the CDF II experiment at the Fermilab Tevatron collider. We measure: BR(\( B_s \to \phi\phi \)) = (1.4 \pm 0.6\,(\text{stat.}) \pm 0.2\,(\text{syst.}) \pm 0.5\,(\text{BR})) \cdot 10^{-5}\), where the last error is due to the uncertainty on the \( B_s \to J/\psi \phi \) branching ratio used as normalization, BR(\( B^+ \to \phi K^+ \)) = (7.2 \pm 1.3\,(\text{stat.}) \pm 0.7\,(\text{syst.})) \cdot 10^{-6}\) and \( A_{CP}(B^+ \to \phi K^+) = -0.07 \pm 0.17\,(\text{stat.}) \pm 0.06\,(\text{syst.}) \). We also briefly discuss prospects for studying other charmless \( B \to VV \) decays at CDF.

Several precision measurements on \( B_{u,d} \) meson decays are available, yet many crucial theory predictions on \( B_s \) mesons, including mixing, CP violation and the decay width difference, \( \Delta \Gamma_s \), are still to be tested. \( B_s \to VV \) decays offer insights to both CP violation and \( \Delta \Gamma_s \) thanks to the presence of CP-odd and CP-even components in the decay amplitude. \( B_s \to \phi\phi \) decays are the first charmless \( B_s \to VV \) to be observed. This channel has been considered extensively in the literature\(^1\), even as a probe for New Physics along with other \( B_s \) modes. A recent calculation\(^2\) predicts a branching ratio of \( 3.7 \cdot 10^{-5}\). In the Standard Model (SM) the decay is mediated by \( b \to s\bar{s}s \) penguin amplitudes which have shown discrepancies with the SM predictions, confirmed by recent data, for certain CP asymmetry measurements\(^3\). \( B^{\pm} \to \phi K^{\pm} \) decays are mediated by the same quark-level transition and have been already studied at B-factories\(^4\). Measuring precisely rates and CP violation parameters in as many such decays as possible may help in determining the source of the above discrepancies.

We report the first evidence of the \( B_s \to \phi\phi \) decay and the first measurement, at hadron colliders, of CP-averaged BR and direct CP asymmetry (\( A_{CP} \)) for \( B^+ \to \phi K^+ \) (charge conjugate modes are implied here unless otherwise stated). In order to cancel the production cross section uncertainty as well as to reduce the systematic uncertainty on detector efficiencies, the branching ratios are extracted from ratios of decay rates of signals and well known \( B \) decay modes. In particular \( B_s \to J/\psi \phi \) and \( B^+ \to J/\psi K^+ \) decays, characterized by the same number of secondary vertices and charged tracks in the final state as our signals, were used respectively in the \( B_s \to \phi\phi \) and \( B^+ \to \phi K^+ \) analysis.

For this measurement we rely on the precision measurement of charged particle trajectories reconstructed in the central drift chamber (COT) and the silicon detector (SVX II). A complete description of the CDF II detector can be found elsewhere\(^5\). The dataset used here was collected by the displaced track trigger, which is based, at Level 1, on the eXtremely Fast Tracker\(^6\) and, at Level 2, on the Silicon Vertex Tracker\(^7\) devices. The trigger selection is described in detail elsewhere\(^8\). In addition a trigger with relaxed requirements was part of the trigger menu with a prescale factor automatically adjusted to fill the DAQ bandwidth available at low instantaneous luminosity. We use 180 pb\(^{-1}\) of integrated luminosity, and effectively only 100 pb\(^{-1}\) for the prescaled trigger.

In this analysis we have used \( \phi \to K^+K^- \) and \( J/\psi \to \mu^+\mu^- \) decays. Combinations of three or four tracks with \( p_T > 0.4 \text{ GeV}/c \) are fit to a common vertex. At least one pair of tracks must satisfy the trigger requirements (trigger tracks). To isolate \( J/\psi \to \mu^+\mu^- \) decays at least one muon must be identified in...
The signal, χ → φK⁺. For 

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formed. The signal region was hidden until 

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simulation and sideband data 

measured in the COT. Data are fit to seven cat-

calories: signal, partially reconstructed b → 

φX decays, combinatorial background, 

B → K⁺0(892)π⁺ and three B decay modes which 

peak in the signal region, including 

B → f₀(980)K⁺ and non-resonant decays. The 

latter contributions are fixed by their rela-

tive decay rates and detection efficiencies 

to the B⁺ → K⁺0(892)π⁺ one, which is de-

termined from the fit. A combination of 

Monte Carlo simulation and sideband data 

was used to model the signal and background 

shapes. The fit returns N_φK = 47.0 ± 8.4, 

A_{CP} = -0.07 ± 0.17 and N_{K⁺0π⁺} = 7.8 ± 6.0 

from which we estimate a B⁺ → f₀K⁺ con-

tamination of 11%.

A similar fit uses m_µK and m_µµ on 

B⁺ → J/ψK⁺ candidates selected in the 

same way as in the B⁺ → φK⁺ analysis
above but requiring the invariant mass of two muons within 100 MeV/c^2 of the J/ψ mass. The result is N_{ψK} = 439 ± 22 and A_{CP} = 0.046 ± 0.050, where the error is statistical only.

The B^+ → φK^+ BR ratio is calculated as:

$$\frac{\text{BR}(φK^+)}{\text{BR}(ψK^+)} = \frac{N_{φK}}{N_{ψK}} \frac{\text{BR}(ψ → μμ)}{\text{BR}(φ → KK)} \frac{ε_{ψφ}}{ε_{φφ}},$$

where $ε_{ψφ}/ε_{φφ} = 0.685 ± 0.015$, derived from MC, represents the total detector efficiency ratio of the two channels. World average $^4$ φ, J/ψ and B^+ → J/ψK^+ partial widths are used. The muon efficiency, $ε_μ = 0.810 ± 0.021$, is determined in a sample of inclusive J/ψ. Systematic uncertainties on signal yield and asymmetry are evaluated by varying the parameterizations used in the likelihood fit, including the shape of the f_0 resonance. For the branching ratio determination we consider also the uncertainty on the relative detection efficiency, which is the dominant one, and add it in quadrature to the yield uncertainty. For A_{CP} we conservatively assign a 5% systematic uncertainty from charge dependent detector asymmetries using the statistical uncertainty on the B^+ → J/ψK^+ asymmetry. The results are reported in Table 1.

| Yield     | 47.0 ± 8.4 ± 1.4 | 7.3 ± 2.8 ± 0.4 |
| BR · 10^3 | 0.72 ± 0.13 ± 0.07 | 1.4 ± 0.6 ± 0.6 |
| A_{CP}    | −0.07 ± 0.17^{+0.06}_{−0.05} | − |

The B_s → φφ signal is selected requiring two kaon pairs with invariant mass within 15 MeV/c^2 of the φ mass. We then apply the following selection: vertex goodness-of-fit $χ^2 < 10$, decay length $L_{xy} > 350$ μm, $B_s$ reconstructed impact parameter $d_0^p < 80$ μm, the minimum momentum of the φ mesons $p_T^φ > 2.5$ GeV/c and minimum impact parameter of the two kaons in each of the φ mesons ($d_0^1 > 40$ μm, $d_0^2 > 110$ μm). The $B_s → φφ$ candidate invariant mass distribution is shown in Fig. 2. In a region of ±72 MeV/c^2 around the $B_s$ mass, a window three times the expected mass resolution, we count 8 signal candidates.

Two sources of background are expected: combinatorial background and $B_d → φK^{*0}$ cross-feed with the pion from $K^{*0}$ decay mis-identified as a kaon. The first type of background is studied using a background enriched sample where both φ meson candidates have invariant masses lying in the φ mass sideband region. Its contribution in the signal region was estimated as 0.35 ± 0.37 events. From Monte Carlo the expected $B_d → φK^{*0}$ background is estimated as 0.40 ± 0.18 events. In both cases statistical and systematic uncertainties are included.

The probability of Poisson fluctuation of background to the observed or higher number of events is $1.3 · 10^{-6}$, corresponding to a 4.7 σ significance. Adding the events selected uniquely by the prescaled trigger we find 12 signal candidates with $1.95 ± 0.63$ background, corresponding to a 4.8 σ significance.

A sample of $B_s → J/ψφ$ is selected requiring one pair of kaons and one pair of muons within respectively 15 and 50 MeV/c^2 of the φ or J/ψ mass and criteria similar to the
$B_s \to \phi\phi$ case on decay length and kinematics. A clean signal of $69 \pm 10$(stat.)$\pm 5$(syst.) $B_s \to J/\psi K^*\phi$ events is extracted from a fit to the $B_s$ invariant mass distribution. The systematic error is evaluated using alternative background models. From MC simulation we expect a background in the signal peak of $3.9 \pm 1.7$ events from $B_d \to J/\psi K^{*0}$ decays with a mis-identified kaon.

The $B_s \to \phi\phi$ decay rate is derived from:

$$\frac{BR(\phi\phi)}{BR(J/\psi \phi)} = \frac{N_{\phi\phi}}{N_{J/\psi \phi}} \frac{BR(J/\psi \to \mu\mu)}{BR(\phi K^0 \to K\mu\mu)} \frac{\epsilon_{\phi\phi}}{\epsilon_{J/\psi \phi}},$$

where $\epsilon_{\phi\phi}/\epsilon_{J/\psi \phi} = 0.816 \pm 0.015$ and $\epsilon_{\mu} \approx 0.92$. We use the world average $\phi$ and $J/\psi$ branching ratios and $BR(B_s \to J/\psi \phi) = (1.42 \pm 0.51) \cdot 10^{-3}$, obtained correcting the CDF measurement for the current world average $f_s/f_d$ ratio, to finally derive the result reported in Table 1.

The uncertainty on the $B_s \to J/\psi \phi$ yield and background evaluation contribute 6.9% to the relative BR systematic error. The efficiency ratio is affected by uncertainties in the polarization of the decay vector particles and by theory uncertainty on $\Delta \Gamma_s$. We conservatively vary the longitudinal polarization of the $B_s \to \phi\phi$ decay from 0 to 100% and $\Delta \Gamma_s$ in the range $0 < \Delta \Gamma_s/\Gamma_s < 0.3$. Summing in quadrature all contributions we estimate a total relative systematic uncertainty error on the $BR(B_s \to \phi\phi)$ of 14%. The uncertainty from $BR(B_s \to J/\psi \phi)$, 36%, is then the dominant one.

Thanks to the new displaced track trigger, CDF is accumulating high quality data on several other charmless decays. As an example, Fig. 3 shows the invariant mass of $B_d \to \phi K^{*0}$ candidates, reconstructed in a similar way as the $B_s \to \phi\phi$ above, with a signal of $\sim 60$ events and $S/B > 3$. It will allow precision measurement of polarization and nicely illustrates the CDF potential to exploit light vector resonances in $B_s$ decays. With two to three times the data used here CDF should detect a signal of $B_s \to K^{*0}K^{*0}$ with an expected $2$ BR of $\approx 3.7 \cdot 10^{-5}$.

In summary, we have shown the first evidence of $B_s \to \phi\phi$ and measure: $BR(B_s \to \phi\phi) = (1.4 \pm 0.6$(stat.)$\pm 0.2$(syst.)$\pm 0.5(BR)) \cdot 10^{-5}$. For the $B^+ \to \phi K^+$ channel we measure the partial width and $A_{CP}$ which agree with available measurements within uncertainties.

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