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Search for non-standard model physics in rare decays at CDF

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We present two recent results obtained by the CDF collaboration at the Tevatron collider. We first describe the first polarization measurement in a charmless B_s^0 decay in two light vector mesons, $B_s^0 \to \phi\phi$, using 2.9 fb^{-1}of data. An angular analysis of the final state decay products allows CDF to determine a longitudinal polarization fraction $f_L = 0.348 \pm 0.041(stat.) \pm 0.021(syst.)$, which is inconsistent with naïve expectations based on the V-A nature of weak currents and confirms the pattern of lower than expected longitudinal polarization fraction in $b \to s$ penguin dominated $B \to VV$ decays. We then report on the first observation of the electroweak penguin decay $B_s^0 \to \phi\mu^+\mu^-$ and on the measurement of the differential decay rate, longitudinal polarization fraction and forward-backward asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ decays using 4.4 fb^{-1} of data.

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The Tevatron collider has provided in the last decade an impressive amount of $p\bar{p}$ collision data that the two collaborations, CDF and D0, have very fruitfully exploited. In particular, large samples of fully reconstructed B-meson decays have been collected. In this talk we will review two recent results from the CDF collaboration: the first angular analysis of charmless $B_s^0 \to \phi\phi$ decay for the determination of polarization amplitudes [1], and the measurement of forward-backward asymmetry and differential decay rate in $B^0 \to K^{*0}\mu^+\mu^-$ [2]. Both decays proceed through a $b \to s$ quark level process, and, in the Standard Model (SM), the dominant diagram are the $b \to s$ gluonic and electroweak penguin respectively. The same penguin amplitudes are involved in several processes which have shown some discrepancies with the SM predictions and are sensitive to the presence of non-standard model effects. In particular, both SM and new physics interpretations have been considered to explain the lack of a dominant longitudinal polarization for several penguin dominated $B \to VV$ decay modes [4]. Measurements of polarization amplitudes in new modes, including $B_s^0 \to \phi\phi$ decays, have been proposed [5] to resolve this issue. Three independent amplitudes govern these type of decays, corresponding to the possible polarizations of the final state mesons. It is attractive to test the existing theoretical predictions for these polarization amplitudes [6].

Evidence for the $B_s^0 \to \phi\phi$ process has been reported for the first time by CDF with low statistics [7]. Here, we use data corresponding to 2.9 fb^{-1} of integrated luminosity. Event selection is the same as was used for the branching ratio measurement [8], which was based on 295 ± 23 $B_s^0 \to \phi\phi$ signal candidates. CDF measured the branching ratio, $\mathrm{BR}(B_s^0 \to \phi\phi) = [2.40 \pm 0.21(\mathrm{stat.}) \pm 0.27(\mathrm{syst.}) \pm 0.82(\mathrm{BR})] \cdot 10^{-5}$, using for normalization the $\mathrm{BR}(B_s^0 \to J/\psi\phi)$ from ref. [9], corrected for the current measurements [3] of f_s/f_d[1]. The dominant systematic uncertainty, labeled (BR), originate from the $\mathrm{BR}(B_s^0 \to J/\psi\phi)$ alone. This result is in agreement and supersedes our previous measurement[7], and is as well compatible with recent theoretical predictions [6].

The angular distribution of the $B_s^0 \to \phi\phi$ decay products can be described using the helicity variables, $\vec{\omega} = (\cos\vartheta_1, \cos\vartheta_2, \Phi)$, where ϑ_i is the angle between the direction of the K^+ from each $\phi \to K^+K^-$ and the direction opposite the B_s^0 in the vector meson rest frame, while Φ is the angle between the two resonance decay planes. We use the transversity amplitude decomposition of the total decay amplitude[2], related to the helicity one by $A_0 = H_0$, $A_\parallel = (H_+ + H_-)/\sqrt{2}$ and $A_\perp = (H_+ - H_-)/\sqrt{2}$. The differential decay rate can be expressed as $\frac{d^4\Gamma}{dt d\vec{\omega}} \propto \sum_{i=1}^{6} K_i(t) f_i(\vec{\omega})$ where the $K_i(t)$ terms account for the exponential decay and the time evolution of the B_s^0 state due to mixing and decay width differences $\Delta\Gamma_s$ while the $f_i(\vec{\omega})$ are functions of the helicity angles only. We measure the untagged decay rate integrated in time, neglecting the tiny B_s^0 mixing phase (in SM) and assuming no direct CP violation. The differential decay rate then depends on the polarization amplitudes at $t = 0$ and on the light and heavy B_s^0 mass-eigenstate lifetimes, τ_{L} and τ_{H}, as follows:

$$\frac{d^3\Gamma}{d\vec{\omega}} \propto \tau_{\mathrm{L}}\left(|A_0|^2 f_1(\vec{\omega}) + |A_\parallel|^2 f_2(\vec{\omega}) + +|A_0||A_\parallel| \cos\delta_\parallel f_5(\vec{\omega})\right) + \tau_{\mathrm{H}}|A_\perp|^2 f_3(\vec{\omega}), \qquad (1)$$

where $\delta_\parallel = \arg(A_0^\star A_\parallel)$. We perform an unbinned maximum likelihood fit to the reconstructed mass of the B_s^0 candidates and the helicity variables in order to measure the polarization amplitudes. The analysis is cross-checked by measuring polarization in $B_s^0 \to J/\psi\phi$ events collected with the same displaced vertex trigger; we find agreement within 1-2% with CDF and D0 measurements [10].

[1] We actually use: $\mathrm{BR}(B_s^0 \to J/\psi\phi) = (1.35 \pm 0.46) \cdot 10^{-3}$

[2] The polarization amplitudes are normalized so that the following condition holds: $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$.

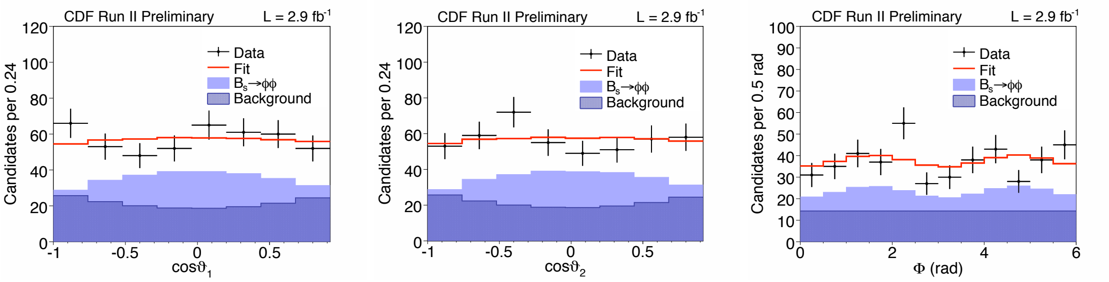

Figure 1: $B_s^0\to\phi\phi$ angular distribution with overlayed fit result for signal and background.

Fit projections on the angular variables and the results for the polarization observables compared to recent theory calculations are shown in Fig. 1 and Fig. 2. Several sources of systematic uncertainty are considered: using simulated samples, we estimate a 1.5% uncertainty from unaccounted for backgrounds; possible biases induced by the dependence of the angular acceptance on $\Delta\Gamma_s$ and by the non-uniform acceptance with the B_s^0 proper decay time introduce an uncertainty of 1% on polarization fractions; uncertainties in $\tau_{\mathrm{L(H)}}$ affect the polarization observables by 1%.

In conclusion for $B_s^0\to\phi\phi$ we find a significantly suppressed longitudinal fraction, which is found to be smaller than in other $b\to s$ penguin $B\to VV$ decays [3]. This result agrees, within uncertainties, with predictions based on QCD factorization [6], and implies the hyerarchy $H_0 \simeq H_+ >> H_-$, possibly induced by a large penguin annihilation contribution [4, 5].

Using 4.4 fb^{-1} integrated luminosity CDF made the first observation of the $B_s^0\to\phi\mu^+\mu^-$ decay with 26 ± 7 signal events and a statistical significance of 6.3σ. The branching ratio is measured relative to the $B_s^0\to J/\psi\phi$ mode and corresponds to $\mathrm{BR}(B_s^0\to\phi\phi) = [1.44\pm0.33(stat)\pm0.46(syst)]\cdot 10^{-6}$. With the same data ~ 100 candidates for $B^\pm\to K^\pm\mu^+\mu^-$ and $B^0\to K^{*0}\mu^+\mu^-$ decays are used for the first measurement, at hadron colliders, of their differential decay rate with respect to the $\mu^+\mu^-$ invariant mass squared (q^2). In addition, measurements of the longitudinal polarization fraction, F_L, in $B^0\to K^{*0}\mu^+\mu^-$ and of the muon forward-backward asymmetry, A_{FB}, are performed as a function of q^2 by studying respectively the emission angle of the kaon in the K^{*0} rest frame ($\cos(\theta_k)$) and the emission angle ($\cos(\theta_\mu)$) of the $\mu^+(\mu^-)$ with respect to the opposite of the $B(\bar{B})$-meson direction in the dimuon rest frame. Unbinned likelihood fits are performed to the B candidate reconstructed mass and decay angles to extract $F_L(q^2)$ and $A_{\mathrm{FB}}(q^2)$, using high mass sideband data

Observable	Result
BR	$[2.40\pm0.21\pm0.85]\cdot10^{-5}$
$\lvert A_0\rvert^2$	$0.348\pm0.041\pm0.021$
$\lvert A_\parallel\rvert^2$	$0.287\pm0.043\pm0.011$
$\lvert A_\perp\rvert^2$	$0.365\pm0.044\pm0.027$
$\cos\delta_\parallel$	$-0.91^{+0.15}_{-0.13}\pm0.09$

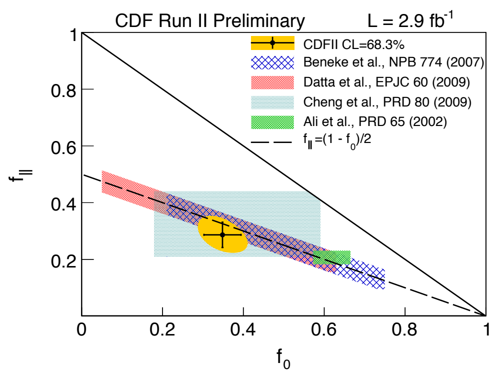

Figure 2: $B_s^0\to\phi\phi$ experimental results with stat. and syst. uncertainties (left panel), comparison to recent theory predictions (right panel).

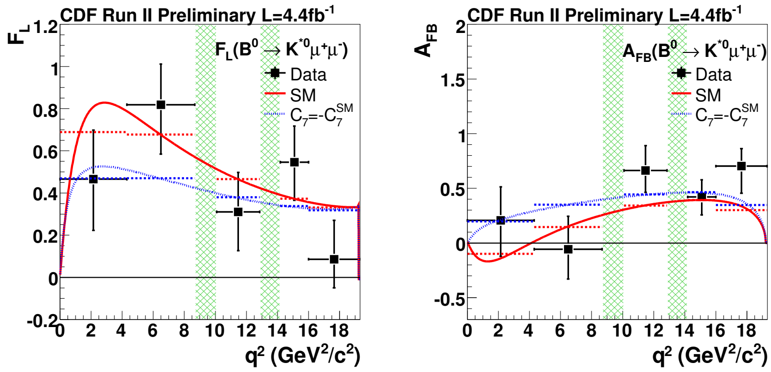

Figure 3: $F_L(q^2)$ and $A_{\rm FB}(q^2)$ for $B^0 \to K^{*0}\mu^+\mu^-$.

to model combinatorial background and acceptance in angular variables derived from phase space Monte Carlo simulations. The contribution ($\sim 8\%$) of signal with wrong assignment of the kaon and pion mass to the K^{*0} decay products is also taken in to account in the fit. Regions in q^2 corresponding to charmonium resonances are excluded. Results are displayed in Fig. 3 and compared with SM expectation and with an hypothetical new physics scenario where the sign of the photon penguin amplitude with respect to the weak vector or axial vector one is reversed, thus illustrating the sensitivity to new physics contributions. Theoretical predictions are quite precise for $A_{\rm FB}$, especially in the low q^2 range $1 < q^2 < 6\,{\rm GeV}/c^2$. CDF result in this range is: $A_{\rm FB} = 0.43\,^{+0.36}_{-0.37} \pm 0.06$. This compares well with the analogous measurement from Belle: $A_{\rm FB} = 0.26\,^{+0.27}_{-0.30} \pm 0.06$ [11]. Both show a slight enhancement with respect to the prediction $A^{th}_{\rm FB} = -0.05\,^{+0.03}_{-0.04}$ [12], that will be interesting to check with more data from Tevatron, B-factories and LHC.

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