CDF results on $b \to s\mu\mu$ decays

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1 Introduction

Rare decays of bottom hadrons mediated by the flavor-changing neutral current (FCNC) process $b \to s\mu^+\mu^-$ occur in the standard model (SM) through higher order (loop) amplitudes. A variety of beyond-the-standard-model (BSM) theories, on the other hand, favor enhanced rates for these FCNC decays, where heavy exotic particle may participate in the loops. These processes are thus very interesting tools to search for BSM physics. In particular, these three-body decays provide observables sensitive to NP, *e.g.* the branching ratios, their dependence on the di-muon mass distribution and the angular distributions of the decay products.

We summarize recent $b \to s\mu^+\mu^-$ results from the CDF experiment based on the full 9.6 fb^{-1} dataset collected in $p\overline{p}$ collisions at $\sqrt{(s)}$ = 1.96 TeV. The decays analyzed are; $B^+ \to K^+\mu^+\mu^-$, $B^0 \to K^{*0}(892)\mu^+\mu^-$, $B^0 \to K^0_s\mu^+\mu^-$, $B^+ \to K^{*+}(892)\mu^+\mu^-$, $B^0_s \to \phi\mu^+\mu^-$, and $\Lambda^0_b \to \Lambda\mu^+\mu^-$. The latter two decays were first observed by CDF [1] in 2011. From an angular analysis of the $B \to K^*\mu^+\mu^-$ decays we also present updated results on the transverse polarization and T-odd CP asymmetries reported earlier [2].

2 Branching Ratios

The signal yields of the analyzed rare decays are obtained by unbinned maximum log-likelihood fits to the invariant mass distributions, shown in Figure 1.

The measured relative branching ratios with resepect the corresponding reference chan-

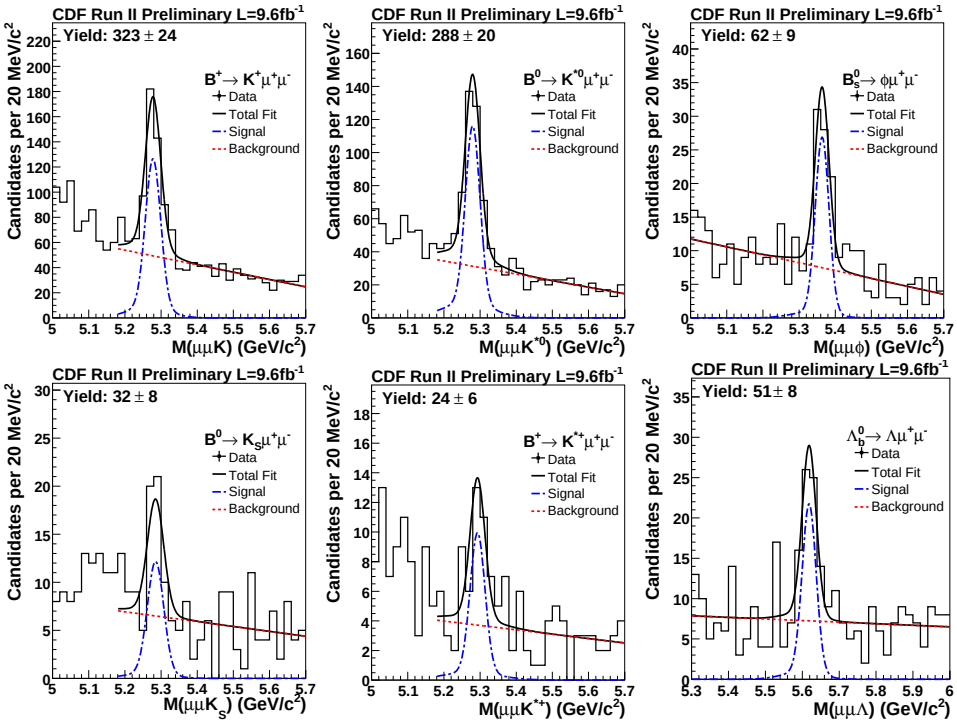

Figure 1: Signal yields in $B^+ \to K^+\mu^+\mu^-$, $B^0 \to K^{*0}(892)\mu^+\mu^-$, $B^0 \to K_s^0\mu^+\mu^-$, $B^+ \to K^{*+}(892)\mu^+\mu^-$, $B_s^0 \to \phi\mu^+\mu^-$, and $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ modes.

nels are:

$$\begin{aligned}
\mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to J/\psi K^+) &= [0.44 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)/\mathcal{B}(B^0 \to J/\psi K^{*0}) &= [0.85 \pm 0.07(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)/\mathcal{B}(B_s^0 \to J/\psi\phi) &= [0.90 \pm 0.14(\text{stat}) \pm 0.07(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^0 \to K_s^0\mu^+\mu^-)/\mathcal{B}(B^0 \to J/\psi K_s^0) &= [0.38 \pm 0.10(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-)/\mathcal{B}(B^+ \to J/\psi K^{*+}) &= [0.62 \pm 0.18(\text{stat}) \pm 0.06(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-)/\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda) &= [2.75 \pm 0.48(\text{stat}) \pm 0.27(\text{syst})] \times 10^{-3}.
\end{aligned}$$

The absolute branching ratios, obtained by substituting the reference branching ratios

with their PDG [3] values, are

$$\begin{aligned}
\mathcal{B}(B^+ \to K^+\mu^+\mu^-) &= [0.45 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-) &= [1.14 \pm 0.09(\text{stat}) \pm 0.06(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) &= [1.17 \pm 0.18(\text{stat}) \pm 0.37(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^0 \to K_s^0\mu^+\mu^-) &= [0.33 \pm 0.08(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-) &= [0.89 \pm 0.25(\text{stat}) \pm 0.09(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-) &= [1.95 \pm 0.34(\text{stat}) \pm 0.61(\text{syst})] \times 10^{-6}.
\end{aligned}$$

All the numbers are consistent with the B factory measurements [4] and enable us to extract NP sensitive quantities from angular observables.

3 Differential Branching Ratios

We measure the differential branching ratios with respect to the (squared) dimuon mass, $q^2 = M_{\mu\mu}^2 c^2$. Same fit procedure as the global fits are performed in six exclusive q^2 bins to extract the signal yields. In the fits only the signal fractions are varied, keeping the mean B hadron masses and the background slopes fixed. Figure 2 shows the differential branching ratio distributions for $B \to K\mu^+\mu^-$ (K_s^0 and K^+ modes combined), $B \to K^*\mu^+\mu^-$ (K^{*0} and K^{*+} modes combined), $B_s^0 \to \phi\mu^+\mu^-$, and $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ modes. The SM (red curve) predictions are taken from [5]. In the Λ_b^0 plot our data is also compared to the SM prediction based on our measured BR value of 1.95×10^{-6} (blue dashed curve). Also shown, as green vertical bands, are the charmonium veto regions which are excluded throughout our analysis. No significant deviations from SM prediction are observed.

The isospin asymmetry between the B^+ and B^0 differential branching ratios is defined as, $A_I = [dB(B^0) - r\ dB(B^+)]/[dB(B^0) + r\ dB(B^+)]$, where, $1/r = \tau(B^+)/\tau(B^0) = 1.071 \pm 0.009$ [3], and equal production of B^+ and B^0 is assumed. Figure 3 shows A_I for the $B \to K\mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ modes. No significant deviation from zero is observed. We measure the integrated asymmetries as

$$\begin{aligned}
A_I(B \to K\mu^+\mu^-) &= -0.11 \pm 0.13(\text{stat}) \pm 0.05(\text{syst}), \\
A_I(B \to K^*\mu^+\mu^-) &= 0.16 \pm 0.14(\text{stat}) \pm 0.06(\text{syst}).
\end{aligned}$$

They are consistent with the B factories and LHCb results [6].

4 Angular Analysis of $B \to K^*\mu^+\mu^-$ Decays

The differential distributions of the $B \to K^*\mu^+\mu^-$ decays [7] are described by four independent kinematic variables; the di-muon invariant mass squared (q^2), the angle θ_μ between

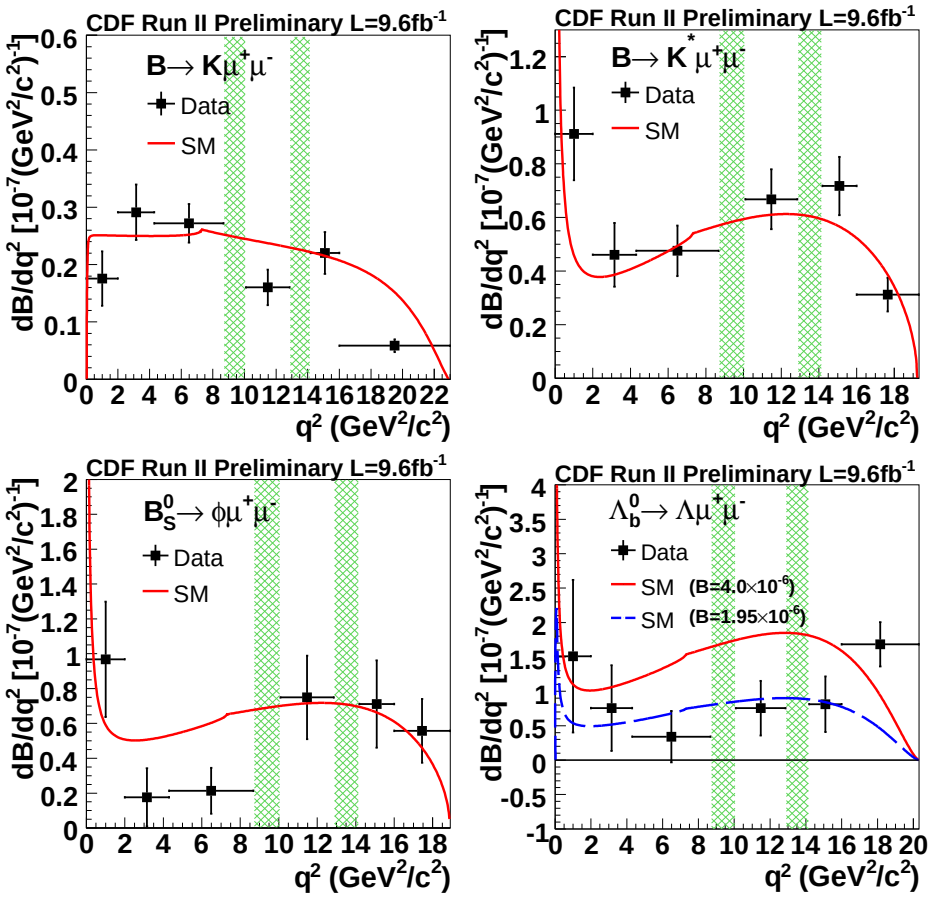

Figure 2: Differential branching fractions with respect to squared dimuon mass, q^2, in $B \to K\mu^+\mu^-$ (K_s^0 and K^+ modes combined), $B \to K^*\mu^+\mu^-$ (K^{*0} and K^{*+} modes combined), $B_s^0 \to \phi\mu^+\mu^-$, and $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ modes.

the μ^+ (μ^-) direction and the direction opposite to the B ($\overline{B}$) meson in the di-muon rest frame, the angle θ_K between the kaon direction and the direction opposite to the B meson in the K^* rest frame, and the angle ϕ between the two planes formed by the di-muon and the K-π systems. The distributions of θ_μ, θ_K, and ϕ are projected from the full differential decay distribution and can be parametrized with four angular observables, A_{FB}, F_L, $A_T^{(2)}$

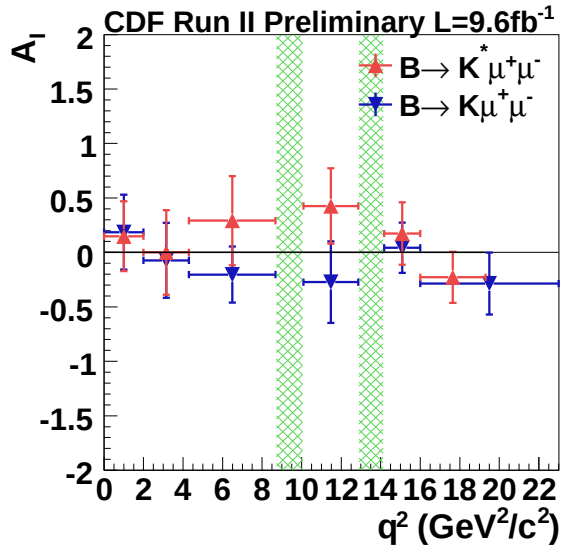

Figure 3: Isospin asymmetry between neutral and charged B mesons in $B \to K^* \mu^+ \mu^-$ and $B \to K \mu^+ \mu^-$ modes.

and A_{im} [8]

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L \cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K),$$
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu,$$
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\phi} = \frac{1}{2\pi}[1+\frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi].$$

where $\Gamma \equiv \Gamma(B \to K^* \mu^+ \mu^-)$, A_{FB} is the muon forward-backward asymmetry, F_L is the K^* longitudinal polarization fraction, $A_T^{(2)}$ is the transverse polarization asymmetry, and A_{im} is the triple-product asymmetry of the transverse polarizations.

We perform an unbinned maximum log-likelihood fit, simultaneously fitting K^{*0} and K^{*+} in the three angles, θ_μ, θ_K, and ϕ, to extract the four angular observables. Figure 4 shows the fitted results with the SM expectations. All the results are consistent with previous measurements and no significant deviation from SM is observed within current precision.

5 Summary

We have reported the total and differential branching ratios in various $b \to s\mu\mu$ rare decays with the full CDF data sample. The NP sensitive observables of interest, measured in

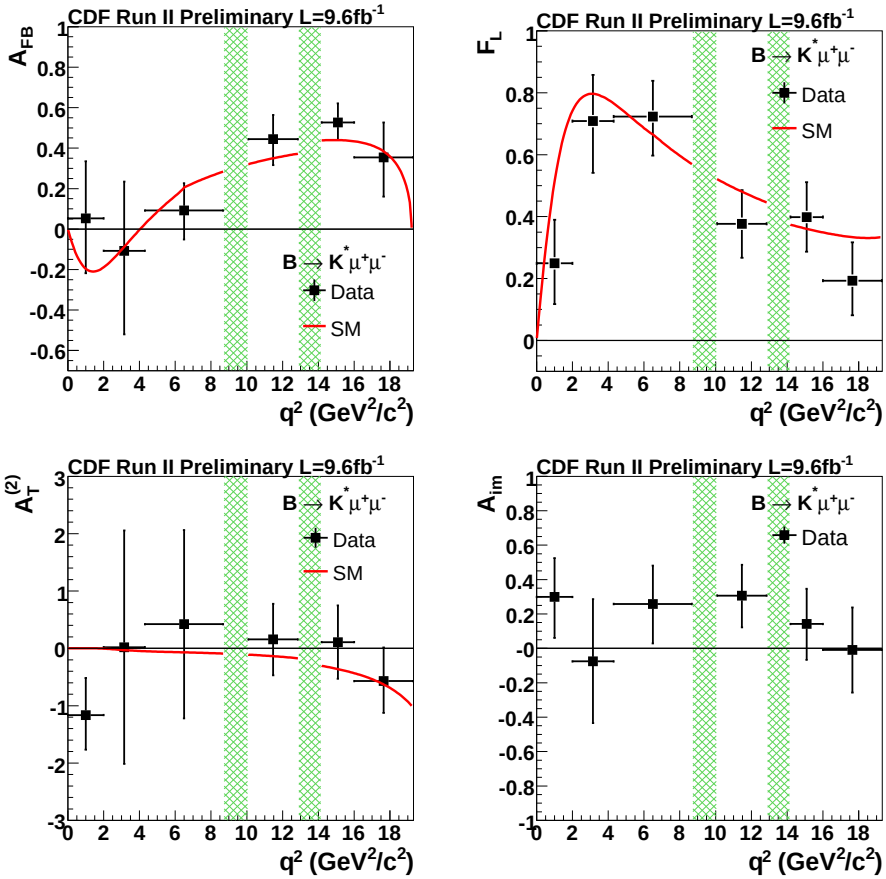

Figure 4: Angular analysis results of A_{FB}, F_L, $A_T^{(2)}$ and A_{im} with respect to squared dimuon mass, q^2, for $B \to K^* \mu^+ \mu^-$ decays.

$B \to K^* \mu^+ \mu^-$ angular analysis, are consistent with standard model expectations and other experiments.

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