Rare $B_s$ and $D$ Decays with the DØ Detector

Arthur Maciel, for the DØ Collaboration
Centro Brasileiro de Pesquisas Físicas — CBPF, 22290-180 Rio de Janeiro, Brazil
E-mail: maciel@fnal.gov

Abstract. Searches for the $B_s^0 \rightarrow \mu^+\mu^-$ and $D^\pm \rightarrow \pi^\pm \mu^+\mu^-$ rare decays yield no observed signal, and upper limits are set for these branching ratios. At 90% CL these are respectively $\mathcal{B} < 7.5 \times 10^{-8}$ and $\mathcal{B} < 3.9 \times 10^{-6}$, and constitute the most stringent limits at the time of this conference.

1. Introduction

Two rare decays involving flavor-changing neutral-currents (FCNC) are investigated: $B_s^0 \rightarrow \mu^+\mu^-$ and $D^\pm \rightarrow \pi^\pm \mu^+\mu^-$. These are complementary in nature since they deal with FCNCs in the down and up quark sectors respectively. FCNC transitions are naturally suppressed in the Standard Model (SM) by the GIM mechanism (forbidden at tree level, they can only proceed through higher order diagrams), with different effectiveness in either sectors due to the different levels of flavor symmetry breaking in each case. Besides, the $B_s^0 \rightarrow \mu^+\mu^-$ decay is further suppressed (by a factor $\sim (m_\mu/M_{B_s})^2$) due to helicity conservation. The motivation behind searches for such rare decays is the possibility that phenomena that escape SM description may become competitive with the SM transition amplitudes and therefore become detectable. No indication of a signal is found in either search reported here, and the branching fraction limits obtained are the most stringent to date. Both results are preliminary. Searches for rare $B$ and $D$ hadron decays by the CDF collaboration are reported by J. Heuser in these proceedings.

Data comes from $\overline{p}p$ collisions (1.96 TeV/c$^2$ C.M.) generated at the Tevatron ($RunII$, now with over 3.2 fb$^{-1}$ of integrated luminosity delivered) and collected by the DØ detector [1]. In particular, the $B_s$ decay analysis benefits from an extra - innermost - layer of silicon sensors installed in the DØ tracking volume during the Tevatron shutdown in July 2006 which divides $RunII$ into two segments; $RunIIa$ (with 1.3 fb$^{-1}$ collected by DØ) and $RunIIb$ (ongoing). In both decays studied here, dimuon triggers constitute the primary source of data selection.

2. $B_s \rightarrow \mu^+\mu^-$

The expected SM branching ratio for this channel was calculated [2] to be $(3.42 \pm 0.54)^{-9}$. This result includes QCD corrections, and the quoted errors are dominated by non-perturbative hadronic uncertainties. An upper limit for this branching ratio (of $\mathcal{B} < 5.0 \times 10^{-7}$ at 95% CL) was obtained [3] by the DØ collaboration, from 0.24 fb$^{-1}$ of data, in the fall of 2004. Since then, integrated luminosity has more than doubled every 12 months, and the limit reported here is extracted from about 2 fb$^{-1}$ of Tevatron $RunII$ data, and includes data used in previous DØ results [4].
Figure 1. Event yields after selection for the RunIIa (left) and RunIIb (right) data sets.

This analysis uses the full (1.3 fb$^{-1}$) data set from RunIIa and also another 0.6 fb$^{-1}$ from RunIIb. The latter portion comes from a DØ with new components and electronics still in the process of tuning and optimization. For this reason, the data sets are treated separately as two independent analysis whose results are then combined. The process of discriminating signal candidates from other sources of muon pairs occurs in two stages; (i) a pre-selection based on track quality and impact parameter, kinematics and isolation, and dimuon vertex formation $\chi^2$, pointing angle, and decay length significance. (ii) a final background reduction by means of a likelihood ratio built from standard DØ discriminators as explained in [3]. The signal region is kept blinded throughout the selection process.

Event yields for both data sets after the selection process are displayed in figure 1. In both cases the observed counts in the signal region are compatible with the expected backgrounds. The latter are determined by means of linear and exponential interpolations from the sideband populations, and are found to be $0.8 \pm 0.2$ and $1.5 \pm 0.5$ events respectively. Branching ratio limits are extracted relative to a well measured normalization channel, $B^\pm \rightarrow J/\psi K^\pm$. The same dimuon selection is applied to the $J/\psi \rightarrow \mu^+\mu^-$ thereby largely cancelling uncertainties, and the additional $K$ selection efficiency is determined from Monte Carlo (MC) simulation with extensive cross checks from real data. Beyond relative efficiencies, the normalization process uses relative production and branching ratios extracted from PDG(2006). Assuming Poisson probabilities for data counts, limits are obtained in a (flat prior) bayesian approach [5]. All uncertainties from PDG inputs and observed counts are propagated into an overall detection efficiency assumed gaussian. These are dominated by background expectation estimates and the $(b \rightarrow u=s)$ fragmentation ratio ($\sim 15\%$). The branching ratio limits for each data set are respectively $7 \times 10^{-8}$ and $3.1 \times 10^{-7}$, and when combined yield $B < 7.5 \times 10^{-8}$, all at 90% CL, approximately 20 times above the expected SM rate. This analysis is now being repeated with reprocessed RunIIb data where tuning problems associated with the newly installed hardware have been resolved.

3. $D^\pm \rightarrow \pi^\pm \mu^+\mu^-$
This decay addresses similar FCNC physics, this time with transitions in the up quark sector ($c \rightarrow u\mu^+\mu^-$) and with a stronger GIM suppression, where non-resonant SM branching fractions are again expected to be as low as $10^{-9}$ [6]. In the SM, the decay under study can proceed either in resonant mode (dominated by a $\phi \rightarrow \mu^+\mu^-$ intermediate state) or through non-resonant penguin and box diagrams. In order to investigate the non-resonant transitions, the resonant regions of the $\pi\mu\mu$ spectrum must be analyzed and benchmarked first. To this end, dimuon candidates (RunIIa data, 1.3 fb$^{-1}$) undergo a track quality and kinematics selection, and the resulting mass spectrum is restricted to the region of the $\phi \rightarrow \mu^+\mu^-$ peak. A third ($\pi$ candidate) track is searched that satisfies standard track quality and vertex formation criteria with the dimuon. The invariant mass of the three body system is shown in figure 2 in the range 1.4
Figure 2. Event yields after selections for (L) resonant modes, and (R) non-resonant search.

to 2.4 GeV/c², where a double structure is evident. The solid line reflects a binned likelihood fit assuming contributions from the $D^+_s$ and $D^±$ mesons (modeled by gaussian functions), and combinatoric background. The distance between the two gaussian means is constrained to the known (PDG) mass difference of the two mesons, and so is their width ratio to the mass ratio. The combined fit yields 254 ± 36 $D_s$ and 115 ± 31 $D$ candidates, with a statistical significance of 8$σ$ above background. The significance of the $D^±$ yield, treating both combinatorial and $D^+_s$ candidates as background, is 4.1$σ$. The meson yield ratio $D/D_s$ is related to the ratio of branching fractions, following similar methods as used in the previous section for determining relative efficiencies and production rates. From the known (PDG) branching fractions for the normalization mode ($D^+_s \rightarrow \pi^±\phi \rightarrow \pi^±\mu^±\mu^-$), a result $\mathcal{B}(D^± \rightarrow \pi^±\phi \rightarrow \pi^±\mu^±\mu^-)$ is extracted as $\mathcal{B} = (1.8 \pm 0.5 \pm 0.6) \times 10^{-6}$, which is consistent with two recent measurements [7], and with the expected value of $(1.86 \pm 0.26) \times 10^{-6}$ given by the product of the two decay fractions separately. There follows a search for the same $D^±$ signal, now in the continuum of the dimuon invariant mass by excluding the $\phi$ region, and with re-optimized selection cuts. No evidence of signal above background is detected (right figure 2), and a 90% CL limit is set at $\mathcal{B}(D^± \rightarrow \pi^±\mu^±\mu^-) < 3.9 \times 10^{-6}$, the lowest limit to date, still approximately 500 times above the expected SM rate.

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