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A New Expected Upper Limit on the Rare Decay $B_s \to \mu^+\mu^-$ with the DØ Experiment

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We present a new expected upper limit of the rare decay branching ratio $B_s \to \mu^+\mu^-$ using about 5 fb^{-1} of Run II data collected with the DØ detector at the Tevatron. When setting limits on the branching ratio, selected events are normalized to reconstructed $B^\pm \to J/\Psi K^\pm$ events in order to decrease the systematic uncertainty. The resulting expected upper limit is $\mathscr{B}(B_s \to \mu^+\mu^-) = 4.3(5.3) \times 10^{-8}$ at the 90% (95%) C.L.

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1. Introduction

The $B_s \to \mu^+\mu^-$ decay involves a Flavor Changing Neutral Current. It is forbidden at the tree level within the Standard Model and can only occur through higher order electroweak penguin and box diagrams with a predicted branching ratio of $(3.6 \pm 0.3) \times 10^{-9}$ [1]. Since enhancements by several orders of magnitude are expeceted in many extensions of the Standard Model, such processes provide sensitive signature to search for new physics. Current most stringent published experimental constrain for this branching ratio is an upper limit of 5.8×10^{-8} obtained at the 95% C.L. by CDF with 2 fb^{-1} of data [2]. DØ has also published limits [3] and this report presents an update of the preliminary upper bound of 9.3×10^{-8} obtained at the 95% C.L. with 2 fb^{-1} of DØ data [4].

The Tevatron hadron collider produces large amounts of all kind of bottom hadrons, even those like the B_s which are too heavy to be accessible at the $\Upsilon(4S)$ resonance. However the benefit of the high $b\bar{b}$ production rate and of the high luminosity delivered by the Tevatron is reduced by the more challenging hadron collider environment. Interesting processes have to be extracted out of high track multiplicity events. In this experimental environment, the DØ detector takes benefit of its good muon identification and its wide acceptance, allowing highly selective triggers based on single- and dimuon triggers as far as B physics is concerned.

2. Measurement of the $B_s \to \mu^+\mu^-$ branching ratio

The data used in this analysis are the complete dimuon triggered data collected by DØ up to December 2008, corresponding to an integrated luminosity of 5 fb^{-1}. These data are split and handled as 3 independent subsamples corresponding to 3 different trigger lists with luminosities of 1.3, 1.9 and 1.6 fb^{-1}, called respectively Run IIa, Run IIb-1 and Run IIb-2 data. This separate treatment allows to take into account the dependence of the B reconstruction efficiency with the period of data taking. Between the first and the second sample, the DØ vertex detector has been upgraded by inserting an additional layer of silicon strip detectors close to the beam pipe. And between the second and the third sample the trigger table has undergone major changes to cope with the higher instantaneous luminosity. In the end the 3 results are combined in one upper limit.

The $\mathscr{B}(B_s \to \mu^+\mu^-)$ branching ratio is measured through its normalization to the number of reconstructed $B^+ \to J/\Psi K^+$, with $J/\Psi \to \mu^+\mu^-$ following this formula:

$$\mathscr{B}(B_s \to \mu\mu) = \frac{N(B_s \to \mu\mu)}{N(B^+ \to J/\psi K^+)} \times \frac{\varepsilon(B^+)}{\varepsilon(B_s^0)} \times f\left(\frac{b \to B^+}{b \to B_s^0}\right) \times \mathscr{B}(B^+ \to J/\psi K^+, J/\psi \to \mu\mu)$$

where $N(B_s)$ and $N(B^+)$ are the number of observed B_s and B^+ in the search mass window, and f is the fragmentation ratio between $b \to B^+$ and $b \to B_s$. The reconstruction efficiencies ε are estimated from the simulation. This B^+ decay channel offers the advantage of a high rate and is reconstructed using the same procedure than the searched B_s. This allows some systematics cancellation, namely we get rid of the dimuon efficiency uncertainty. To simplify the calculation, the $B^0 \to \mu^+\mu^-$ contribution is conservatively assumed to be negligible in the search mass window. The last point to be mentioned is that 2006 PDG values are used as inputs in this formula in order to remain consistent with CDF's result.

The signal selection procedure is optimized in an unbiased manner by keeping the search window blind. After a set of sequential cuts, the background is further reduced by cutting on the output of a Boosted Decision Tree, which is trained with simulated signal events whereas the background is modeled by the data invariant mass sideband. The cut on this discriminating variable is chosen by maximizing the criteria proposed by G. Punzi [5] with the signal yield estimated within the Standard Model. The observed dimuon invariant mass distributions after selection are shown in figures 1 and 2. The background number of events is estimated after an exponential interpolation of the sideband population into the signal region. In addition possible non negligible contributions of misidentified $B_s \to K^+K^-$ and $B^0 \to K^+\pi^-$ are included. Their contributions are about 20 times smaller than the combinatorial background. The Standard Model expected $B_s \to \mu^+\mu^-$ yields in the search mass region are respectively 0.192 ± 0.034, 0.193 ± 0.034 and 0.139 ± 0.025 in the 3 data samples. The corresponding background estimations are respectively 2.16 ± 0.62, 3.73 ± 1.07 and 2.15 ± 0.63.

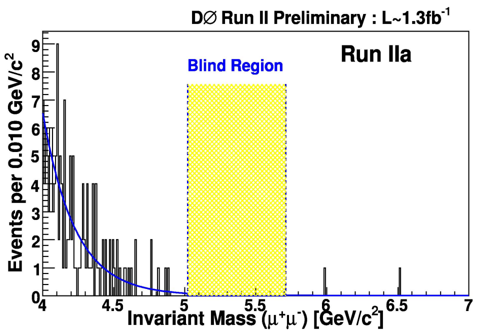
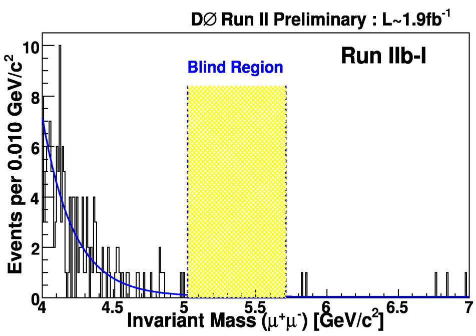


Figure 1: Dimuon invariant mass distribution of the Run IIa data, with the search window blinded.



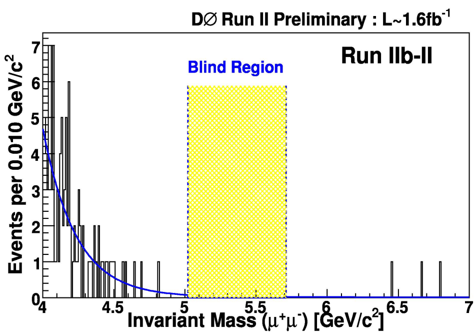


Figure 2: Dimuon invariant mass distributions of the Run IIb-I and Run IIb-2 data, with the search window blinded.

The box is kept closed and only expected limits are quoted, under the background only assumption in the signal region. The expected bayesian upper limits for the branching ratio are found to be $7.6\ (9.4) \times 10^{-8}$ for Run IIa data, $9.9\ (11.0) \times 10^{-8}$ for Run IIb-1 data and $10.0\ (13.0) \times 10^{-8}$ for Run IIb-2 data at the 90% (95%) C.L. A combined upper limit of $4.3\ (5.3) \times 10^{-8}$ is derived for the complete set of available Run IIb DØ data. The highest contribution to systematics uncertainties comes from the fragmentation ratio between B^+ and B_s which enters the $B_s \to \mu^+\mu^-$

branching ratio formula normalized to the B^+ decay. Before unveiling the signal region, several improvements are ongoing. The most significant would be the inclusion of single-muons triggers and also further reducing the background.

3. Conclusion

The sensitivity reached by this analysis is the best current one and it is similar to the CDF result, of the order of 5×10^{-8} at the 95 % C.L. It improves the previous DØ bound by a factor of 2.

Current experimental sensitivity is one order of magnitude above the Standard Model expectation, still leaving an opportunity to search for new physics effects. Even without any observation, this mode provides the best constrain on number of extensions of the Standard Model. New models parameter space will be further reduced significantly in the next 2 years, as the Tevatron performances are extremely good and twice as much data as already collected are expected until the end of the Run II.

References

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