

Updated Search for $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ at CDF

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The decay $B_s^0 \rightarrow \mu^+ \mu^-$ is very sensitive to contributions from new physics processes. Thus the Tevatron and LHC experiments are hunting for an observation of a $B_s^0 \rightarrow \mu^+ \mu^-$ signal. In this article the updated search for $B_s^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$ by the CDF experiment is presented. The CDF result was received with great interest because an excess over the background expectation is seen, although of modest statistical significance and still consistent with the prediction of a standard model signal and other experimental results.

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The flavor-changing neutral current decays $B_s^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$ are strongly suppressed in the standard model (SM) because they require higher order diagrams. Their branching ratios are predicted to be $(3.2 \pm 0.2) \times 10^{-9}$ and $(1.0 \pm 0.1) \times 10^{-10}$, respectively [1]. Physics beyond the SM could significantly alter these values, making the decays a sensitive probe for new physics. So far the $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decay was not observed in any experiment and the upper limits on the branching ratios provide stringent constraints on the parameter space of several new physics models.

Using a data sample of 7 fb^{-1} collected at the Tevatron $p\bar{p}$ collider, the CDF experiment presented an updated search for $B_s^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$ decays [2]. Compared to the previous CDF result [3] based on a data sample of 2 fb^{-1} , the sensitivity is improved by the increased integrated luminosity, an extended muon trigger acceptance, and a more powerful signal-to-background discrimination.

Muons are detected by two types of chambers in the central (C) rapidity region of $|\eta| < 0.6$ and in the forward (F) region of $0.6 < |\eta| < 1$. Dimuon events are triggered by a pair of muons with either both muons in the central region (CC) or one in the central and one in the forward region (CF). An improved understanding of the trigger performance allowed to increase the acceptance by 20% compared to the previous analysis which excluded regions of rapidly changing efficiency.

The two muon tracks are fitted to a common vertex and baseline requirements [3] are applied. In the remaining sample, the dimuon invariant mass signal region from 5.169 to 5.469 GeV is blinded and the final selection is optimized using simulated signal events and background events from mass sidebands. With a neural network [4] of 14 input variables the background could be suppressed about twice as efficiently as in the previous analysis for the same signal acceptance. Overtraining was avoided by using statistically independent training and validation samples. It was checked that the neural network selection does not bias the mass distribution and, using $B^+ \rightarrow J/\psi K^+$ decays, that the distribution of the network output, v_N , is well described by the simulation.

To exploit the varying signal-to-background ratio as a function of v_N and dimuon invariant mass, $M_{\mu^+\mu^-}$, the data is split into bins in both variables. An optimization on the expected upper limit yields eight bins in v_N and five bins in $M_{\mu^+\mu^-}$. Expected background rates and signal efficiencies are calculated for each of the 40 bins for the CC and CF sample.

Since the combinatorial background has a smooth dependency on $M_{\mu^+\mu^-}$, it is estimated by an extrapolation from the mass sidebands to the signal region using a linear function. The sideband region is restricted to $M_{\mu^+\mu^-} > 5 \text{ GeV}$ to avoid contributions from $B \rightarrow \mu^+ \mu^- X$ events. Background from B meson decays to two hadrons that are misidentified as muons could peak in the signal region. Its contribution is estimated by taking the kinematic distribution from simulation, the normalization from known branching ratios, and momentum dependent misidentification probabilities measured in $D^0 \rightarrow K^- \pi^+$ decays. The $B_{(s)}^0 \rightarrow h^+ h'^-$ background yield is highest in the most sensitive neural network bin. In the B^0 search window of the CC sample it is comparable to the combinatorial background in this bin. The $B_{(s)}^0 \rightarrow h^+ h'^-$ contribution in the B_s^0 search window is about an order of magnitude lower. The background estimation procedure was verified on control samples consisting of muon pairs with like-sign charge, with negative proper decay time, or with relaxed muon identification requirements.

With the background estimate at hand, one can determine whether the data is consistent with

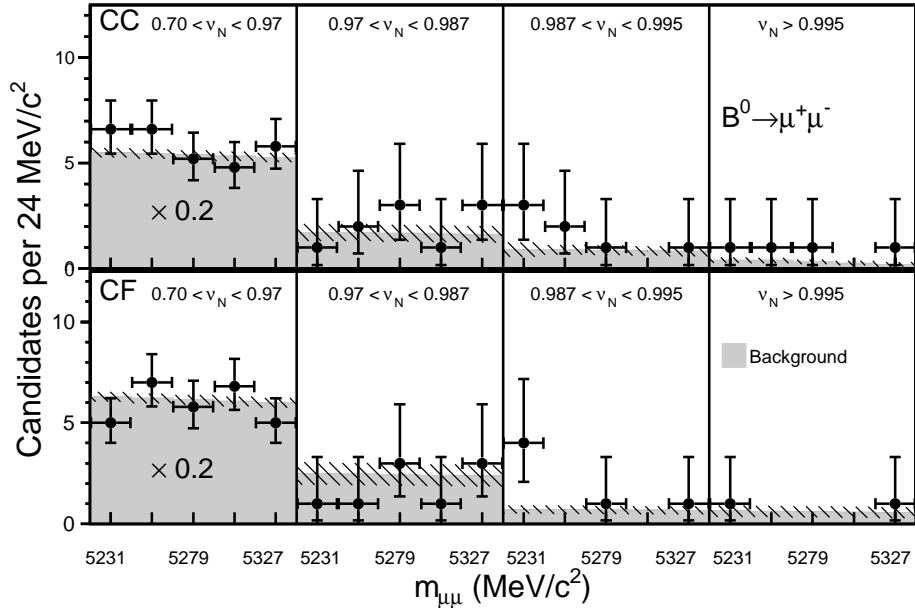


Figure 1: Number of observed events in the B^0 search region versus $M_{\mu^+\mu^-}$ and v_N for the CC (top) and CF (bottom) sample compared to the background estimation. The systematic uncertainty on the background is indicated by the hatched area.

background only or whether there is an excess. To obtain a quantitative result on the $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ branching ratio in the form of a limit or measurement, the signal yield is normalized to the number of $B^+ \rightarrow J/\psi K^+$ decays which are kinematically similar. The relative efficiency is determined using simulation and muon reconstruction efficiencies measured in data. Based on these numbers 1.9 B_s^0 signal events are expected in the CC+CF sample in the SM. This is the first time a non-negligible contribution from the SM signal is expected in a $B_s^0 \rightarrow \mu^+ \mu^-$ search at the Tevatron.

The unblinded data for the B^0 search window is shown in Fig. 1. It is well consistent with the background estimation and a 95% C.L. limit of $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 6.0 \times 10^{-9}$ is obtained.

In the highest v_N bin of the B_s^0 search window the data shows an excess over the background estimate as can be seen in Fig. 2. The level of agreement is evaluated using a likelihood ratio whose expected distribution is determined with pseudoexperiments. For the background only hypothesis a p-value of 0.27% is calculated. Taking into account the SM contribution, it increases to 1.9%.

Since the third highest v_N bin in the CC sample also shows an excess, the analysis was carefully checked for effects which could produce such a peak. Peaking $B_{(s)}^0 \rightarrow h^+ h^-$ background is unlikely because it is not seen in the B^0 search window. A $B_s^0 \rightarrow \mu^+ \mu^-$ signal at this bin is also unlikely because the v_N distribution is well modeled by the simulation for $B^+ \rightarrow J/\psi K^+$ decays. Peaking combinatorial background would have been discovered in the selection cross-checks or shown up in the $B^0 \rightarrow \mu^+ \mu^-$ search. Thus a statistical fluctuation in the third highest v_N bin is the most likely explanation. Given the large number of 80 bins considered in this analysis such a deviation can be expected. If only the two highest v_N bins are used to evaluate the agreement with the background expectation, p-values of 0.66% and 4.1% are obtained for the background-only and background+SM hypotheses, respectively.

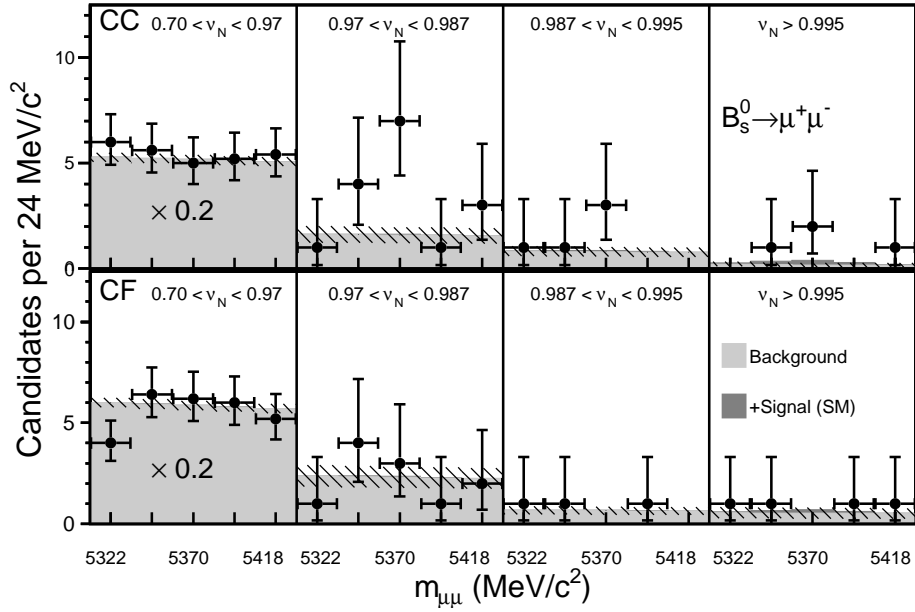


Figure 2: Number of observed events in the B_s^0 search region versus $M_{\mu^+\mu^-}$ and v_N for the CC (top) and CF (bottom) sample compared to the background+SM signal estimation. The systematic uncertainty on the background is indicated by the hatched area.

Given the marginal agreement with the background-only hypothesis, CDF performs a measurement of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = 1.8_{-0.9}^{+1.1} \times 10^{-8}$ and sets a 90% C.L. interval of $4.6 \times 10^{-9} < \mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 3.9 \times 10^{-8}$. This result is consistent with the 90% C.L. limits quoted by CMS [5] and LHCb [6]. Although the excess is of modest statistical significance, it is likely that $B_s^0 \rightarrow \mu^+\mu^-$ signal events contribute to the observed data. In this sense it can be regarded a first indication of a $B_s^0 \rightarrow \mu^+\mu^-$ signal which should not be confused with a claim for new physics.

References

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