3 The DØ experiment at the Tevatron $p\bar{p}$ collider: Search for rare decays of the B_s^0-mesons

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The full DØ collaboration consists of 86 institutes from 19 countries:
Argentina (1), Brazil (3), Canada (4), China (1), Czech Republic (3), Colombia (1), Ecuador (1), France (8), Germany (6), India (3), Ireland (1), Korea (1), Mexico (1), Netherlands (3), Russia (5), Sweden (4), United Kingdom (3), United States of America (36) and Vietnam (1)

(DØ Collaboration)

Until LHC at CERN starts its operation in 2007, the Tevatron at the Fermi National Accelerator Laboratory, Batavia, USA, is the world's highest-energy accelerator with an available center of mass energy of $\sqrt{s} = 2$ TeV. The so-called Run II of the $p\bar{p}$ collider has started in 2001 and addresses some of the most important questions in particle physics. The most recent physics results involve direct searches for as yet unknown particles and forces, including both those that are predicted in the Standard Model (SM) like the Higgs boson and those that would come as a surprise. Other important aspects of this programme will be the precise measurements of the top quark properties, new accurate determinations of the mass of the W boson and the couplings of the electroweak bosons. Moreover, numerous measurements of various B meson decay modes have already allowed the investigation of B meson properties that are not accessible at other colliders as well as CP-violating effects.

The DØ detector at Tevatron is now fully operational and collision data are taken with a high global efficiency. In 2004 Ralf Bernhard spent a ten-months research period at Fermilab where he participated in detector optimization studies and operation shifts helping a smooth running of the experiment. Presently, about 600 pb^{-1} of $p\bar{p}$ collision data are recorded on tape and we have started with a physics analysis programme of searches for rare B_s^0 meson decays, which will be the main content of Ralf Bernhard's PhD thesis. The study of the B_s^0 meson is presently unique to the Tevatron collider since B_s^0 is not produced at the $\Upsilon(4S)$ resonance at which e^+e^- B-Factories like BaBar and Belle are running. This work represents an important ingredient for the preparation of physics analysis at the upcoming LHCb. Our search programme is dedicated to flavor-changing neutral current (FCNC) B_s^0 decays, that are forbidden in the SM at tree level. However, they proceed through higher order diagrams and have therefore very small SM branching fractions. The FCNC decays of the B mesons are particularly important for probing the quark flavor sector of the SM and for providing severe constraints on several models beyond the SM. For instance, the decay amplitude of $B_s^0 \rightarrow \mu^+\mu^-$ can be significantly enhanced in most extensions of the SM: in type-II two-Higgs-doublet models (2HDM) the branching fraction depends only on the charged Higgs mass M_{H^+} and $\tan\beta$, the ratio of the two neutral Higgs field vacuum expectation values, with the branching fraction growing like $(\tan\beta)^4$ (1). In the minimal supersymmetric standard model (MSSM), however, $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) \propto (\tan\beta)^6$, leading to an enhancement by up to three orders of magnitude (2) compared to the SM value of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = 3.5 \times 10^{-9}$, even if the MSSM with minimal flavor violation (MFV) is considered, in which case the CKM matrix is the only source of flavor violation. In minimal supergravity models, an enhancement of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$ is correlated (3) with a sizeable increase of $(g-2)_\mu$, the anomalous magnetic moment of the muon. A large value of $\tan\beta$ is theoretically well-motivated by grand unified theories

(GUT) based on minimal SO(10) (3; 4). Finally, $B_s^0 \to \mu^+\mu^-$ is also sensitive to supersymmetric models with non-minimal flavor violation structures such as the generic MSSM (5) or R-parity violating supersymmetry (6). Since this decay shows such a strong sensitivity to many new models and its amplitude is theoretically very clean, it allows clearly one of the most sensitive searches for new physics with the statistics presently available at the Tevatron. Moreover, in a long-term perspective, the discovery of this process is definitely one of the most important prospects in the B-physics program of hadron colliders.

So far, we have analyzed 300 pb^{-1} of DØ data that were taken with a special two-muon trigger. For the search of the rare candidate events we have used discriminating variables to best exploit the properties of the signal decay and the multi-variate technique of a random-grid search to optimize the analysis. The signal region itself was kept hidden during the optimization in order to avoid any bias. The events next to the region around the B_s^0 invariant mass were used to determine the background. As a normalization mode we reconstructed $B^\pm \to J/\psi(\to \mu^+\mu^-)K^\pm$ events, as shown in the left part of Fig. 3.1. Since the efficiencies to detect the $\mu^+\mu^-$ system in signal and normalization events are similar systematic effects tend to cancel.

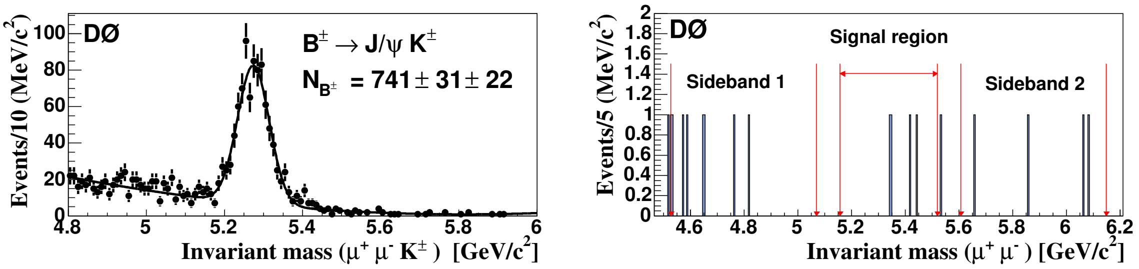

Figure 3.1:
Left: invariant mass distribution for candidates in the normalization channel $B^\pm \to J/\psi K^\pm$.
Right: the remaining sample with our standard discriminating variables.

After unblinding the signal box for 240 pb^{-1} integrated luminosity the mass spectrum shown in the right panel of Fig. 3.1 resulted. We observe four events while 3.7 ± 1.1 are expected from the sidebands. We have published just recently the resulting upper limit for the branching fraction of $B_s^0 \to \mu^+\mu^-$ of 4.1×10^{-7} at a 90% C.L.(7). Our result presently represents the world-best upper limit on this decay and can be used to constrain models beyond the SM. For the Moriond conference 2005 we updated the analysis with more available data and obtained as preliminary result an improved upper limit of 3.0×10^{-7} at a 90% C.L.

The anticipated luminosity at Tevatron will accumulate to 2 fb^{-1}, when LHC starts its operation in 2007. In case of no signal, this amount of DØ data may lead to an expected upper limit on the branching fraction of $B_s^0 \to \mu^+\mu^-$ to 1.2×10^{-7}, if the analysis is re-optimized. Although such a limit will be sufficient to exclude regions of very large $\tan\beta$ in the framework of supersymmetric models, it will still be a factor 30 above the SM branching fraction. Thus, an experimental sensitivity to this rare decay at the level of the SM is clearly out of reach at Tevatron. The LHCb experiment, at the other hand, expects an annual yield of 17 reconstructed $B_s^0 \to \mu^+\mu^-$ decays.

Our second search at DØ concerns the exclusive non-resonant FCNC decay $B_s^0 \to \mu^+\mu^-\phi$, which belongs to the class of the $b \to s\,l^+l^-$ quark transitions caused by electroweak penguin diagrams. The analysis for $B_s^0 \to \mu^+\mu^-\phi$ is still ongoing and the signal region has not yet been examined. The branching fraction of the non-resonant decay is normalized to the known resonant decay $B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi$ which has the same final state. For the Moriond conference 2005 we have presented the experimental reach with our current 300 pb^{-1} of DØ data (9). Our present exclusion potential is 1.0×10^{-5} (95% C.L.) including systematic uncertainties which is almost seven times better than the published limit (10). We are planning to open the signal box for the summer conferences 2005.

In fall 2005, a new layer of silicon detectors will be inserted into the existing DØ silicon detector. This new layer is very close to the beam pipe and its installation becomes necessary to compensate for the radiation induced damage of the existing silicon device (11). We have contributed to the R&D phase of this new layer and developed together with the Swiss based company Dyconex long flexible fine-pitch cables, which transmit the analog signals from the silicon sensors to the front-end electronics situated at the module's end. After several prototype runs, the production-type cables were successfully procured and tested in summer 2004.

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