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Tevatron and LHCb

A. Sarti
INFN, Laboratori Nazionali di Frascati - Frascati, Italy

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Summary. — I review some recent flavour physics results of CDF and D0 experiments at the Tevatron and discuss the expected performance of the LHCb experiment at LHC. While the Tevatron experiments have proven the potential for flavour physics studies at hadron machines, producing outstanding results in the B_s sector, the LHCb experiment, that has just started to take data at the LHC, is expected to significantly improve the precision reached in some key measurements already with the data collected in the first LHC run (expected to end in 2011).

PACS 13.20.He – Leptonic, semileptonic, and radiative decays of bottom mesons.
PACS 13.20.Fc – Leptonic, semileptonic, and radiative decays of charmed mesons.
PACS 13.25.Hw – Hadronic decays of bottom mesons.
PACS 13.25.Ft – Hadronic decays of charmed mesons.

1. – Introduction

The CDF and D0 experiments have pioneered the flavour physics studies at the hadron colliders. By exploiting the large production cross section of $b\bar{b}$ and $c\bar{c}$ pairs, and carefully optimizing the trigger strategies to efficiently select B and D meson decays, they were able to improve the experimental knowledge of many decays and observables not, or poorly, accessible to the experiments at e^+e^- colliders like CLEO, BaBar or Belle.

The LHCb goal is to perform B physics studies at the LHC. Learning from the CDF and D0 experience proved to be fundamental in designing the experiment trigger and layout. LHCb has started to take data and soon will analyze the largest B-meson sample ever collected, largely improving the Tevatron results. The LHCb expected performance, evaluated using MC simulations and being cross checked on first data, is compared to the CDF and D0 results in the following: the study of rare B_s decays is presented in sects. **2** and **3** while the sensitivities of CP studies in $B_{d,s}$ and D sectors are reviewed in **4** and **5**.

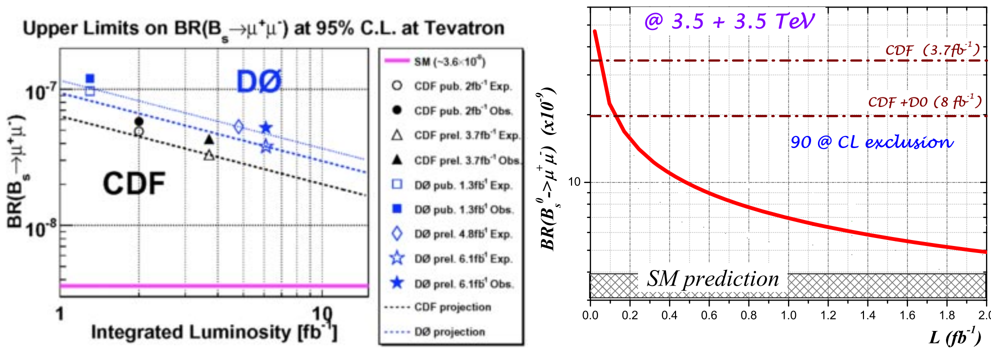

Fig. 1. – Left: upper limits on BR($B_s \to \mu\mu$) at 95% CL at Tevatron. The CDF and D0 projected sensitivities as a function of L is shown (dotted lines). Right: exclusion limit for BR($B_s \to \mu\mu$) at 90% CL from the LHCb experiment. Current ($3.7\,\mathrm{fb}^{-1}$) and final ($8\,\mathrm{fb}^{-1}$) CDF results are shown.

2. – $B_s \to \mu\mu$ decay

The $B_s \to \mu\mu$ is predicted to be very rare in the Standard Model (SM), $\mathrm{BR}(\mathrm{B_s} \to \mu\mu) = (3.6 \pm 0.3) \cdot 10^{-9}$, due to the effective Flavour Changing Neutral Current (FCNC) mechanism and the helicity suppressions and is thus sensitive to the enhancement foreseen in several New Physics (NP) models (*e.g.* models that foresee a large $\tan\beta$ or R-parity violation). Observing or placing an upper limit on the BR($B_s \to \mu\mu$) is a crucial step in constraining or observing NP processes and models.

The LHCb [1], CDF [2] and D0 [3] experiments have implemented similar analysis strategies for the $\mathrm{B}_s \to \mu\mu$ study. After the event preselection, the geometrical information is combined through algorithms, like NNEt (CDF) or Boosted Decision Trees (D0) or into a Geometrical Likelihood (LHCb), in order to maximize the background rejection power and signal efficiency. The muon ID information is then used to refine the event selection and the IM distribution to evaluate the confidence levels.

Control samples are used to assess the performance and calibrate the likelihood and the invariant mass PDFs. Their selection uses the same cuts as the signal samples, in order to minimize the systematic effects and biases. The decay channels used are $B \to J/\psi K^+$, $B \to J/\psi K^*$ and $B \to h^+h^-$: while the first ones are sharing the same trigger with the signal sample, the last ones have the same kinematics. In LHCb 1M of $B \to J/\psi K^+$ and 200k $B \to h^+h^-$ are expected with an integrated luminosity (L) equal to $1\,\mathrm{fb}^{-1}$, while D0 and CDF, respectively, have reconstructed 1.7k and 20k $B \to J/\psi K^+$ events with $L = 1.6\,\mathrm{fb}^{-1}$ and $3.7\,\mathrm{fb}^{-1}$.

While LHCb expects, with $L = 1\,\mathrm{fb}^{-1}$ and assuming the SM BR, 5 signal (S) events, and 45 background (B) events in the most sensitive region ($GL > 0.5$ and $\Delta m < 60\,\mathrm{MeV}/c^2$), CDF and D0 already expect 2 SM events in their sample. The backgrond reduction plays thus a central role in the future developments of those data analysis. The current limits from CDF on the $B_s(B_d) \to \mu\mu$ BR are < 43 $(7.6) \cdot 10^{-9}$ at 95% Confidence Level (CL) while the expected limit from D0 with $5\,\mathrm{fb}^{-1}$ is $53 \cdot 10^{-9}$ at 95% CL. New results are expected soon since the analysis of large datasets ($8\,\mathrm{fb}^{-1}$) for both experiments is ongoing, with D0 analysis including now the single muon trigger line and the improved particle ID that uses the $\mathrm{d}E/\mathrm{d}X$ info from the silicon detector. The expected Tevatron limit for $L = 10\,\mathrm{fb}^{-1}$ is around 6 times the SM BR prediction(see fig. 1,

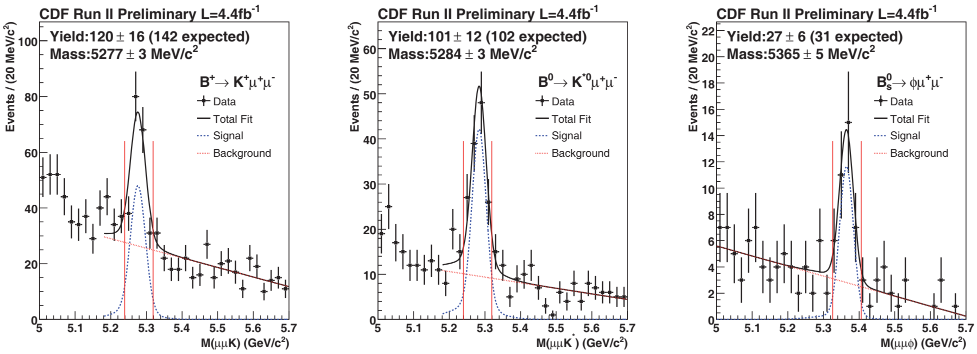

Fig. 2. – The CDF B invariant mass of $B^+ \to K^+\mu\mu$ (left), $B^0 \to K^*\mu\mu$ (middle), and $B_s \to \phi\mu\mu$ (right) decays, for $L = 4.4\,\mathrm{fb}^{-1}$.

left). Channels in ee and $e\mu$ are nearly ten times worse, nevertheless CDF has currently the world best result [4]. The LHCb potential, evaluated on the basis of full MC simulation and 2010 data results, is competitive with Tevatron already with $L = 0.1$–$0.2\,\mathrm{fb}^{-1}$, while for a 5σ evidence of a NP BR ($1.2 \cdot 10^{-8}$) an integrated luminosity of $5\,\mathrm{fb}^{-1}$ will be needed (see fig. 1, right).

3. – $b \to ll$ decays

While the analysis of inclusive semileptonic decays represents a tough challenge for the hadron colliders experiments, exclusive decays have already proven to be affordable. Dimuon decays can be triggered with high efficiency and accurate predictions of SM observables [5] can be obtained in few remarkable cases like the forward-backward asymmetry (A_{FB}), the A_{FB} spectrum and zero (s_0) as a function of $\mu\mu$ invariant mass (q^2) and the BR as a function of q^2 distributions. New Physics processes can contribute with terms of the SM size and modify BR and angular distributions. Those observables have thus a high sensitivity to several NP models. The current experimental knowledge comes from the B-factory experiments (BaBar, Belle) that, with ~ 400 events in total, measured a BR($B^0 \to K^*\mu\mu$) $= (1.22^{+0.38}_{-0.32}) \cdot 10^{-6}$ that agrees to within $\sim 30\%$ with the SM prediction and attempted also to measure A_{FB} as a function of q^2 and to determine s_0. The CDF [6] experiment has pioneered the study of $b \to sll$ decays performing the first observation of the ϕ mode. The obtained yields in $4.4\,\mathrm{fb}^{-1}$ are, respectively, 120, 100 and 30 events for the K, K^* and ϕ modes (see fig. 2) with resolutions comparable to the B-factories. LHCb [1] expects ~ 700 events with $L = 0.5\,\mathrm{fb}^{-1}$ (7 TeV center-of-mass energy), achieving a possible exclusion of the SM preditcion of s_0 at 3.1σ.

4. – $B_s \to J/\psi\phi$

The study of b $\to$ s transitions in CP violation processes is another situation where NP contributions could be detected. A good candidate is, for example, the ϕ_s CKM angle, counterpart of the well-known ϕ_d ($\sin 2\beta$) angle that is predicted to be small by the SM: $\phi_s = 0.0368 \pm 0.0018$ (CKMfitter, sum. 07). A decay channel suited for the ϕ_s measurement is the $B_s \to$ J/$\psi\phi$ that is accessible due to the relatively large BR($\sim 3 \cdot 10^{-5}$) and to the presence of two muons in the final state that can be used

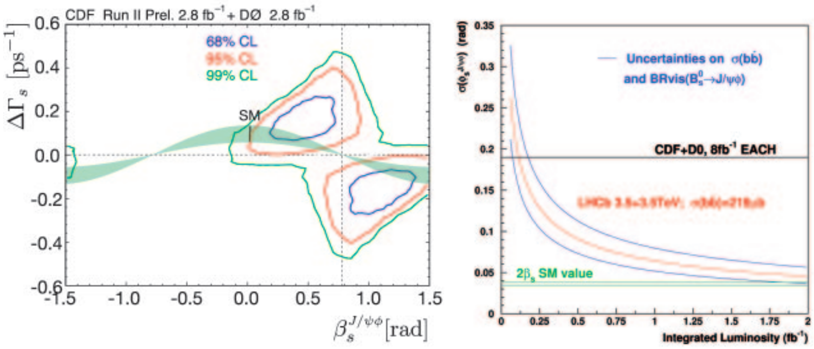

Fig. 3. – Left: CDF and D0 combined 2D confidence level contours in the $\beta_s^{J/\psi\phi}$-$\Delta\Gamma_s$ plane. Right: LHCb sensitivity to ϕ_s (rad) as a function of the integrated luminosity.

as an efficient trigger. Since the $J/\psi\phi$ state is not a pure CP eigenstate, an angular analysis of the decay products is needed in order to disentangle the even ($\eta_f = -1$) and odd ($\eta_f = 1$) CP states. The ϕ_s angle can be extracted by measuring the time dependent CP asymmetry $A_{CP}(t)$, whose key ingredients are the time resolution (σ_t) that is ~ 90 fs and 38 fs respectively in CDF and LHCb, and the tagging performance (ϵD^2)(1), measuread on control channels like $J/\psi K^+$, $J/\psi K^*$ and $D_s\pi$. Measured yields of $B \to J/\psi K^+$ decays are 3.2k and 2k, respectively for CDF and D0 with $L = 2.8\,\mathrm{fb}^{-1}$, while 13k events are expected in LHCb with $L = 0.5\,\mathrm{fb}^{-1}$.

The current D0/CDF [7,8] combined result in $\Delta\Gamma_s$, ϕ_s plane shows a deviation from SM with a probability of 3.4% (2.12σ, see fig. 3, left). This result is being reviewed in order to include the latest CDF result [9] based on $L = 5.2\,\mathrm{fb}^{-1}$ that implements several analysis improvements, like the use of the full power of the Same Side Kaon Tagger algorithms ($\epsilon D^2 = 3.2\%$), the use of PID information for all the dataset and the inclusion of the $J/\psi KK$ model in the ϕ_s extraction, and shows a better agreement with the SM prediction. D0 is also improving its analysis implementing the Boosted Decision Trees algorithms to improve the S/B ratio. LHCb [1] will be able to perform a 5σ measurement for a ϕ_s central value that is Tevatron (NP)-like with $\sim 400\,\mathrm{pb}^{-1}$ (see fig. 3, right). The expected statistical uncertainty on ϕ_s is ~ 0.07 rad for $L = 1\,\mathrm{fb}^{-1}$: more than $2\,\mathrm{fb}^{-1}$ are needed to reach the sensitivity for a SM value measurement.

5. – Charmless hadronic two body decays and charm studies

The analysis of rare non-leptonic decays ($B \to h'h$) at an hadron collider is particularly interesting due to the abundance of two body decays that can be simultaneously reconstructed and studied: twelve different B_d, B_s and Λ_b decays into p, π and K pairs can be used to measure direct CP violation parameters and to perform time dependent CP studies. While some of the $B \to h'h$ decays are reasonably well known, there are a few that are still unobserved, with expected branching ratios below 10^{-6}. The same argument holds for the study of charm meson decays: hadron colliders can benefit from

(1) Total (same sign + opposite sign tagging) ϵD^2 values for CDF, D0 and LHCb experiments are: 4.8%, 4.7% and 6.2%.

the large production cross section for $c\bar{c}$ pairs ($\sim 6 \times \sigma(b\bar{b}, \sim O(\text{mb}))$ but particular care must be taken in designing the trigger([2]). In CDF the large sample of D mesons is triggered by the hadronic trigger line while in LHCb there will be dedicated leptonic and hadronic trigger lines (with bandwidth sharing with B samples dependent on the trigger rate/luminosity).

The current experimental knowledge of $B \to h'h$ is mainly driven by the B-factories and CDF [10]. LHCb expects to give a significant contribution already with $L = 0.2\,\text{fb}^{-1}$, given the high trigger efficiency and the excellent particle ID performance of the two RICH systems, where the kaons and pions from the B-mesons can be discriminated in a wide momentum range (1–100 GeV/c). The total LHCb selection efficiency for $B \to h'h$ decays is $\sim 1.3\%$ with an expected yield, assuming $L = 2\,\text{fb}^{-1}$, of nearly 380k events in total implying that LHCb will match a $L \sim 3\,\text{fb}^{-1}$ CDF statistics with $L \sim 100\,\text{pb}^{-1}$. On the charm side, the B-factories were able to reach a precision of ~ 0.5 and 0.3 respectively on $\sigma(A_{CP})$ using ~ 50k $D^0 \to \pi\pi$ and 120k $D^0 \to KK$ tagged events. CDF was able to reconstruct 270k and 780k tagged events, respectively, achieving a $\sigma(A_{CP})$ of 0.19 (0.11) with $L = 4.8\,\text{fb}^{-1}$ [11]. LHCb expects to reconstruct $\sim 40 \times 10^6$ $D^0 \to K\pi$ right sign and $\sim 4 \times 10^6$ $D^0 \to KK$ tagged events in $100\,\text{pb}^{-1}$ with sensitivity to CP violation observables under evaluation.

6. – Conclusions

Tevatron beautifully demonstrated the power of hadronic collider experiments in the flavour physics field performing B and D meson CP studies, and placing the world best limits on several rare decays. The largest b, c hadron sample ever collected will be soon available for data analysis in CDF, D0 (with an expected final L of $\sim$ 8–10 fb^{-1}) and LHCb, that just started its data taking at 7 TeV Center-of-Mass (CoM) energy. A lot of new and improved results are expected in the near future: LHCb expects to collect and analyze $\sim$ 0.1–0.3 fb^{-1} by the end of 2010, while CDF and D0 will double the statistics used in their analyses with several improvements in the strategies and detector performance. A great time is ahead for flavour-addicted physicists: the hadron colliders experiments are ready to make one more step towards the precision era.

* * *

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