IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10442-4

Colloquia: IFAE 2009

LHCb perspectives with early data

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(ricevuto il 19 Settembre 2009; pubblicato online il 28 Ottobre 2009)

Summary. — The LHCb experiment will play soon an important role in the sector of B-Physics by performing new key measurements looking for New Physics. In this paper we will discuss some relevant measurements feasible with early data.

PACS 13.20.He – Decays of bottom mesons.

1. – Introduction

The full physics programme of LHCb will be certainly realized by collecting several fb^{-1} of integrated luminosity. However, LHCb can achieve important results already with a few hundreds of pb^{-1}. Due to the complexity of the LHC machine and to the many unknowns connected to its start-up, it is very difficult to foresee how much time will be needed to collect a given amount of integrated luminosity. However, considering the nominal operation of LHC (*i.e.* an instantaneous luminosity of $2 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ at the LHCb interaction point and $10^7\,\mathrm{s}$ of data taking per year), LHCb should be able to collect about $0.5\,\mathrm{fb}^{-1}$ of data in a couple of months of running.

One of the unresolved questions of particle physics nowadays is the presence of physics beyond the Standard Model (SM) expected at the scale of the TeV and not yet observed. Recently, some new measurements seem to indicate an evidence of New Physics (NP) in the flavour sector. Such an evidence was first claimed by the $\mathrm{UT_{fit}}$ Collaboration, which employed in their analysis (in particular) the measurements of the B_s mixing phase performed by the CDF and DØ experiments at the Tevatron. They found that the B_s mixing phase deviates about 3 standard deviations from the SM expectation [1]. Another crucial measurement for the quest of NP in the flavour sector is that of the branching ratio of the very rare decay $B_s \to \mu^+\mu^-$. This FCNC mode is expected to have within SM a branching ratio of $(3.35 \pm 0.32) \times 10^{-9}$, but it can be significantly enhanced by the presence of NP. The current upper limit measured by CDF and DØ and averaged by HFAG is 4.7×10^{-8} [2, 3].

Another relevant puzzle which still survives from the beginning of the B-factory lives and can be solved by LHCb in its early data taking phase, involves the direct *CP* asymmetry term measured by Belle [4] and BaBar [5] with the $B_d \to \pi^+\pi^-$ decay, where a discrepancy between the two experiments at the level of 2 standard deviations exists.

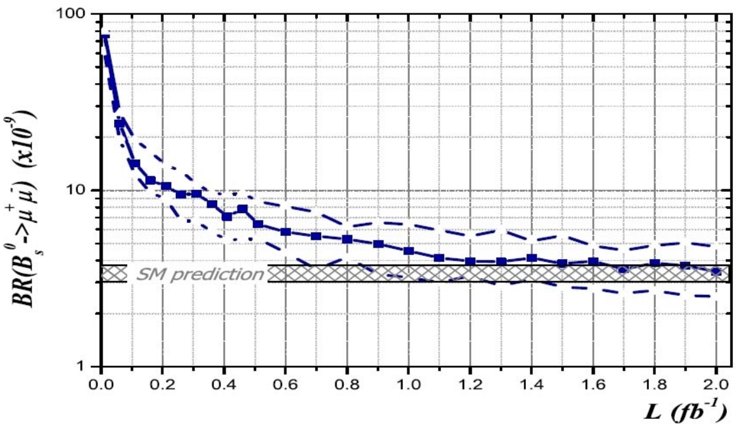

Fig. 1. – $B_s \to \mu^+\mu^-$ branching ratio exclusion limit (assuming no signal is present) at 90% CL. The band between the dashed lines corresponds to a statistical uncertainty at 90% CL due to the limited Monte Carlo statistics used to evaluate the expected background.

In the following, the LHCb perspectives with the very first data will be briefly discussed.

2. – Exploiting $0.2\,\text{fb}^{-1}$ of integrated luminosity

In this section we will discuss the LHCb potential for some key measurements that will be performed by collecting an integrated luminosity of about $0.2\,\text{fb}^{-1}$.

2˙1. *The search for decay $B_s \to \mu^+\mu^-$ decay.* – According to the most recent analysis, LHCb will reach the same sensitivity as CDF at the end of its data taking (assuming that CDF will take data until the end of 2010 collecting $8\,\text{fb}^{-1}$ of integrated luminosity). This corresponds to excluding a region up to a value of the branching ratio of about 2×10^{-8} as shown in fig. 1.

2˙2. *Measurements of the B_s mixing phase through the $B_s \to J/\psi\phi$ decay.* – LHCb will trigger and reconstruct $12k$ $B_s \to J/\psi\phi$ decays [6]. The expected sensitivity on the B_s mixing phase is 0.1 rad. The HFAG avarage [3] on the B_s mixing phase is $2\beta_s = 0.77^{+0.29}_{-0.37}$. This means that LHCb will confirm or disprove the forementioned evidence of NP very early, if the current central value is real.

2˙3. *$B \to h^+h^{-'}$ decays.* – LHCb will trigger and reconstruct 40k $B \to h^+h^{-'}$ decays [7]. The family of the B hadron decays into pairs of charmless charged mesons or baryons comprise a rich set of channels, each one characterized by charged and time-dependent *CP* asymmetries. The LHCb Collaboration realized a quite advanced analysis which allows to fit several decay modes simultaneously. Figure 2 shows, as an example, the distribution of the $\pi\pi$ invariant mass([1]) of 12 different final states, with the fit result superimposed.

([1]) The invariant mass spectrum is built assuming that all the decay products are pions. The particle identification is used as an observable in the final fit in order to disentangle the various components.

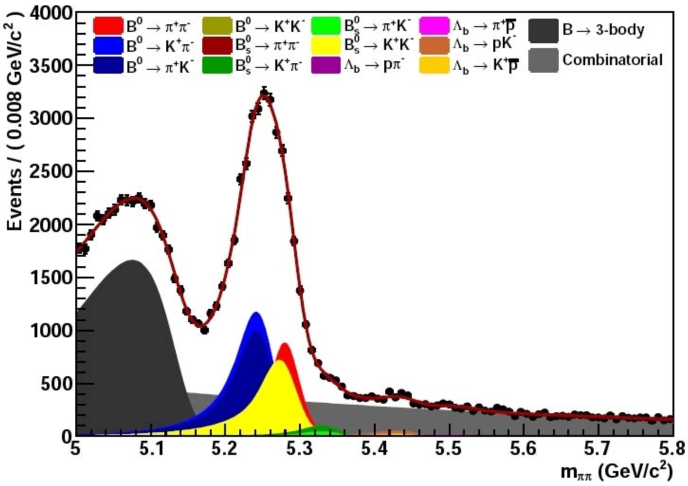

Fig. 2. – Distribution of the $B \to h^+h^{-\prime}$ invariant mass from a Monte Carlo sample corresponding to an integrated luminosity of $0.2\,\text{fb}^{-1}$, with the result of the maximum likelihood fit superimposed. The various signal and background components contributing to the whole line shape are also shown.

The LHCb sensitivity for the CP asymmetry terms will reach the precision of the B-factories for what concerns the B_d sector (direct and mixing-induced CP asymmetry terms $C_{CP}^{\pi^+\pi^-}$, $S_{CP}^{\pi^+\pi^-}$ and the charge asymmetry $A_{CP}^{K^+\pi^-}$), while in the B_s sector LHCb will improve the already measured charge asymmetry $A_{CP}^{\pi^+K^-}$ by CDF [8] and will give, most probably, the first measurement for the time-dependent asymmetry terms $C_{CP}^{K^+K^-}$ and $S_{CP}^{K^+K^-}$. Table I reports the sensitivities expected for the CP asymmetry terms with an integrated luminosity of $0.2\,\text{fb}^{-1}$.

3. – Exploiting $0.5\,\text{fb}^{-1}$ of integrated luminosity

By collecting some more statistics LHCb will explore other measurements, amongst which one of the most interesting involves the $B_d \to K^{*0}\mu^+\mu^-$ decay. The number of expected reconstructed events is about 2k. Considering that the B-factories have collected few hundreds of events and CDF less than one hundred, LHCb will surpass the present statistics already within a few weeks of data taking. This FCNC decay proceeds via a $b \to s$ transition through a loop diagram. NP processes can therefore enter at the same level as the SM processes, making the decay a sensitive probe of NP contributions. The branching ratio as a function of the di-muon invariant mass squared q^2 and the forward-backward asymmetry (AFB)(^{2}) can both be affected in many NP scenarios [9]. The zero crossing-point of this asymmetry as a function of q^2 has received particular theoretical attention. The SM predicts a value $q^2 = 4.36^{0.33}_{-0.31}\,\text{GeV}^2/c^4$ [10]. The sensitivity of LHCb corresponding to $L = 0.5\,\text{fb}^{-1}$ is about $1\,\text{GeV}^2/c^4$.

(^{2}) This asymmetry is constructed from the number of forward- and backward-emitted positive muons in the di-muon rest frame.

TABLE I. – *LHCb sensitivities for the* $B \to h^+h^{-'}$ CP *asymmetry terms, expected with* $0.2\,\text{fb}^{-1}$ *of integrated luminosity.*

Quantity	Current experimental knowledge	LHCb $0.2\,\text{fb}^{-1}$	Quantity	Current experimental knowledge	LHCb $0.2\,\text{fb}^{-1}$
$S_{CP}^{\pi^+\pi^-}$	-0.65 ± 0.07	0.13	$S_{CP}^{K^+K^-}$	$0.77 \pm 0.18(^*)$	0.11
$C_{CP}^{\pi^+\pi^-}$	-0.38 ± 0.06	0.13	$C_{CP}^{K^+K^-}$	$0.09 \pm 0.04(^*)$	0.15
$A_{CP}^{K^+\pi^-}$	$-0.098^{+0.012}_{-0.011}$	0.008	$A_{CP}^{\pi^+K^-}$	$0.39 \pm 0.08 \pm 0.05$	0.05

(*) These quantities are still unmeasured, we show a prediction of their values obtained using U-spin symmetry arguments. For more details see [11].

4. – Conclusions

Although LHCb will realize its full programme with several fb^{-1} of integrated luminosity, it will be extremely competitive with some measurements already exploiting very early data. By collecting about $0.2\,\text{fb}^{-1}$ of data, LHCb will confirm or disprove the evidence of NP in the B_s mixing phase claimed by the Tevatron experiments. In addition, it will look for NP through other outstanding measurements, like the branching fraction of the rare $B_s \to \mu^+\mu^-$ decay. Other important measurements achievable with $0.2\,\text{fb}^{-1}$ of integrated luminosities will involve the CP asymmetry terms of the $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays. Increasing the collected data up to $0.5\,\text{fb}^{-1}$, it will possible to explore NP effects also employing the $B_d \to K^{*0}\mu^+\mu^-$ decay, by measuring its forward-backward asymmetry.

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