LHCb Status and Plans

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1 Introduction

LHCb is the dedicated flavour physics experiment at the LHC. While ATLAS and CMS search for the direct production of new states, LHCb is designed to see their indirect effect on charm and beauty decays, via virtual production in loop diagrams. Such an indirect approach can be very powerful: e.g. the discovery of B^0–$\overline{B}^0$ mixing [1] demonstrated that the top quark was unexpectedly heavy: $m(t) > 50\,\mathrm{GeV}/c^2$, before it had been directly observed. Key topics for LHCb include the study of CP violation—is it due to a single phase in the quark mixing (CKM) matrix, as in the Standard Model?—and the study of rare decays: flavour-changing neutral current decays (e.g. $B^0_s \to \mu^+\mu^-$) are strongly suppressed in the Standard Model, but may be enhanced by Supersymmetry or other new physics.

Since b-hadron production is strongly forward-peaked at the LHC, LHCb is a forward spectrometer covering the angular region from 10–300 mrad from the beam axis (but operating in collider mode), as shown in Fig. 1. The $b\overline{b}$ cross-section is large: it has been measured to be $284 \pm 53\,\mu$b at the LHC (at $\sqrt{s} = 7\,\mathrm{TeV}$) [2] which results in about 100,000 $b\overline{b}$ pairs being produced per second at LHCb ($\sim 10^4\times$ the B factories). Charm production is a factor ~ 20 higher [3], so the LHC is an excellent environment for the precision study of flavour physics.

There are other advantages of flavour physics at the LHC. All b-hadron species are produced at high energy, and B^0_s physics is rich and little explored until now. The enormous production rate has allowed LHCb to overtake the B factories even for B^0 and B^+ decays. For example, the recent measurement $\mathrm{BR}(B^+ \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6 \pm 0.2) \times 10^{-8}$ [4] is the rarest B decay ever observed. The previous best limit (from Belle) was $< 6.9 \times 10^{-8}$ [5]. With the large boost at LHCb B decay lengths are of order 1 cm, allowing excellent decay-time determination. Finally, the forward pseudorapidity coverage $2 < \eta < 5$ is complementary to the central detectors for other physics, including electroweak, QCD, and the search for exotics.

The LHCb detector is described in Ref. [6]. It features a precise silicon vertex detector (VELO) that approaches to within 8 mm of the beams, and a high-performance

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[1] On behalf of the LHCb collaboration.

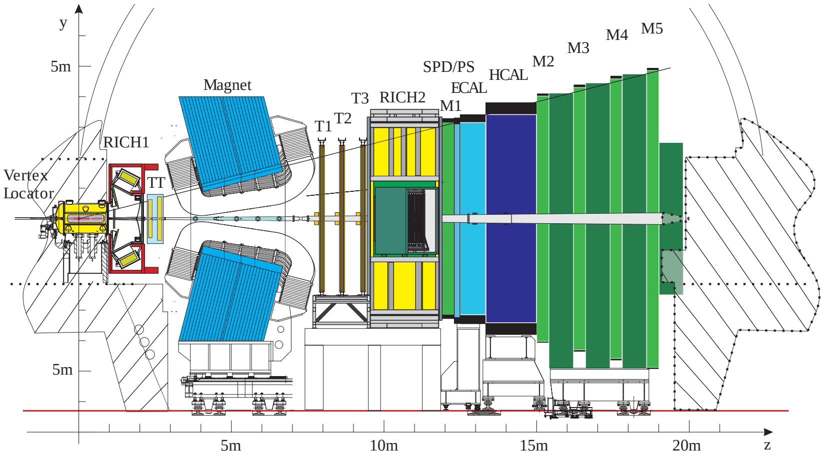

Figure 1: Layout of the LHCb detector.

particle identification system based on RICH detectors. The trigger of the experiment is designed to be efficient for fully hadronic final states, as well as those containing leptons or photons, and the output data rate to storage is a few kHz.

2 LHCb status

LHCb has run successfully over the last three years, taking data with high efficiency (greater than 90%), and with all subdetectors working as designed. In 2011 an integrated luminosity of $1\,\mathrm{fb}^{-1}$ was recorded, which has been used for a wide variety of physics analyses, with 58 published papers to date and an even larger number of preliminary results sent to conferences. In 2012 the detector continues to run well, at a luminosity that is levelled at $4 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The physics results are reviewed in many contributions to this conference, and just a few highlights are mentioned here. B_s^0–$\overline{B}{}_s^0$ oscillations have been measured with the world's best precision, see Fig. 2 (a). Radiative B decays have been studied, Fig. 2 (b), and the ratio of $B_s^0 \to \phi\gamma$ and $B^0 \to K^*\gamma$ branching fractions determined, as well as the CP asymmetry for $K^*\gamma$. For the rare decay $B_s^0 \to \mu^+\mu^-$ LHCb has set the most stringent limit on the branching ratio, $< 4.5 \times 10^{-9}$ at 95% CL. A few candidates are seen, as shown in Fig. 2 (c), compatible with the Standard Model expectation, but not enough to yield a significant observation. The limit on the branching ratio gives strong constraints on new physics models. The $B^0 \to K^{*0}\mu^+\mu^-$ decay is another mode that is very sensitive to new physics, and different angular distributions have been studied, including the forward-backward asymmetry shown in Fig. 2 (d), for which the zero-crossing point has been measured for the first time and found to be

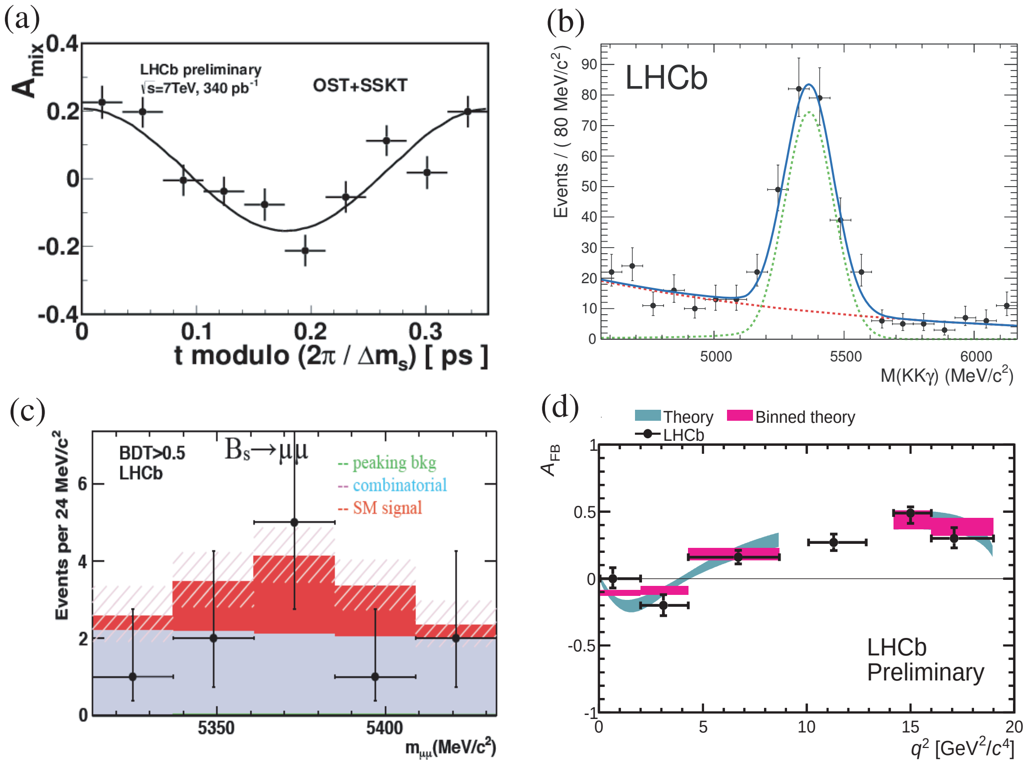

Figure 2: (a) B_s^0 oscillations seen in the asymmetry as a function of decay time for the $D_s^- \pi^+$ channel. (b) Invariant mass distribution of $B_s^0 \to \phi\gamma$. (c) Invariant mass distribution of $B_s^0 \to \mu^+\mu^-$ candidates. (d) Forward-backward asymmetry of $B^0 \to K^{*0}\mu^+\mu^-$ decays, as a function of q^2.

in agreement with the Standard Model expectation.

CP asymmetries have been studied in the two-body decays of B hadrons to charmless final states, as illustrated in Figs. 3 (a) and (b). The $\sim 10\%$ asymmetry between the CP-conjugated $B^0 \to K\pi$ decays is clear from the raw distributions, and remains after the small corrections for production and detector effects. In a related analysis the first $> 3\,\sigma$ evidence has been seen for CP violation in B_s^0 decays. A precise measurement has also been made of the CP phase of B_s^0 mixing (ϕ_s), which is expected to be small in the Standard Model. In Fig. 3 (c) the very clean signal for $B_s^0 \to J/\psi\,\phi$ decay that is used for this study is shown, which has a mass resolution of about 8 MeV/c^2. In Fig. 3 (d) it can be seen that the result for ϕ_s is compatible with the Standard Model, and also gives the world's best measurement of the decay width difference in the B_s^0 system, $\Delta\Gamma_s$. Important steps have been made towards the measurement of the most poorly known angle of the Unitarity Triangle, γ, through the observation of the suppressed modes in $B \to DK$ decays.

The above gives a taste of the results so far from LHCb, focussing on those key

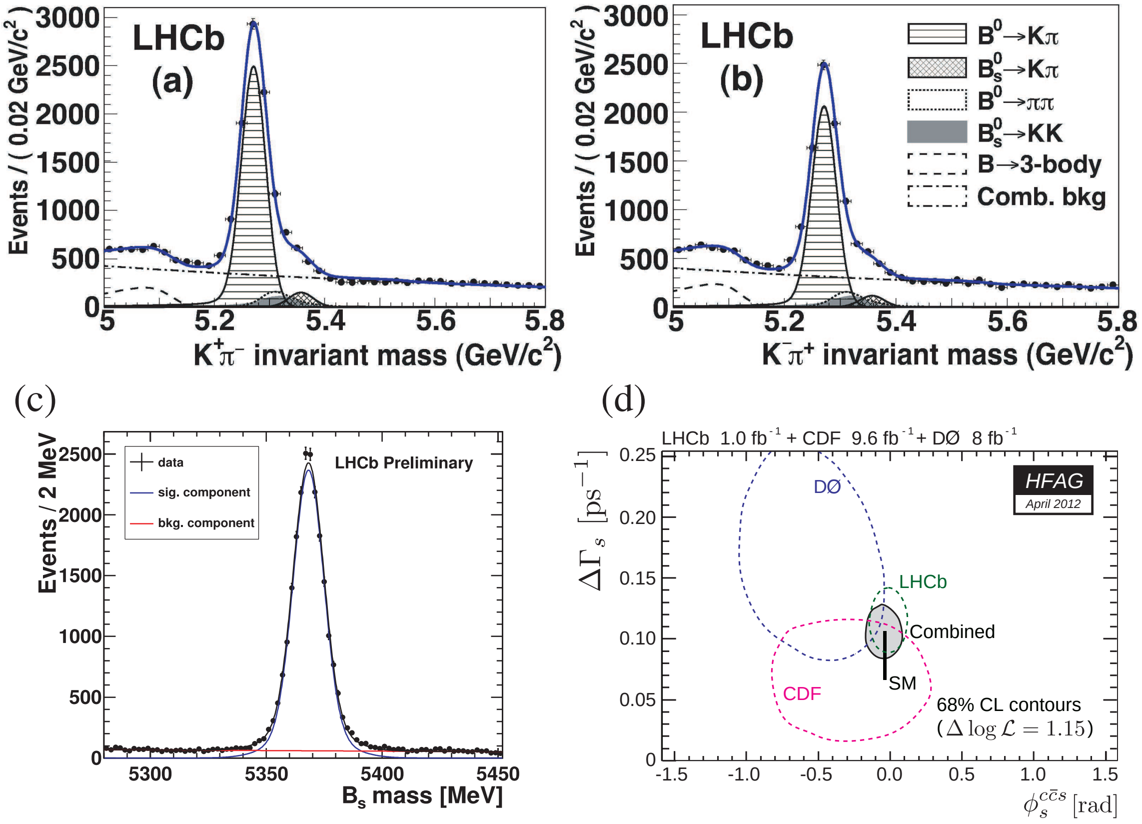

Figure 3: (a) $K^+\pi^-$ invariant mass distribution showing signals from two-body B decays, with the largest contribution from $B^0 \to K^+\pi^-$. (b) $K^-\pi^+$ invariant mass distribution, with the largest contribution from $\overline{B}^0 \to K^-\pi^+$ decays. (c) Invariant mass distribution of $J/\psi(\mu^+\mu^-)\,\phi(K^+K^-)$ candidates. (d) Experimental constraints on the decay width difference $\Delta\Gamma_s$ and CP phase ϕ_s in $b \to c\bar{c}s$ decays [7].

measurements that had been identified before the experiment started taking data [8]. The results have already had a strong impact on models of physics beyond the Standard Model, as illustrated in Fig. 4 (a). In addition there have been many interesting results in spectroscopy, observing new excited states of B mesons and Λ_b baryons, new decay modes such as $B_c^+ \to J/\psi\,\pi^+\pi^+\pi^-$, and studying exotic states such as the $X(3872)$. Numerous electroweak and QCD measurements have also been performed. While the majority of the results have been in good agreement with Standard Model expectations, there have been a few surprises: evidence has been seen for CP violation in charm decays, and for an isospin asymmetry in $B \to K\mu^+\mu^-$ decays, which require further study with more data. Details of all these analyses can be found in the dedicated talks from LHCb at this conference, along with their references.

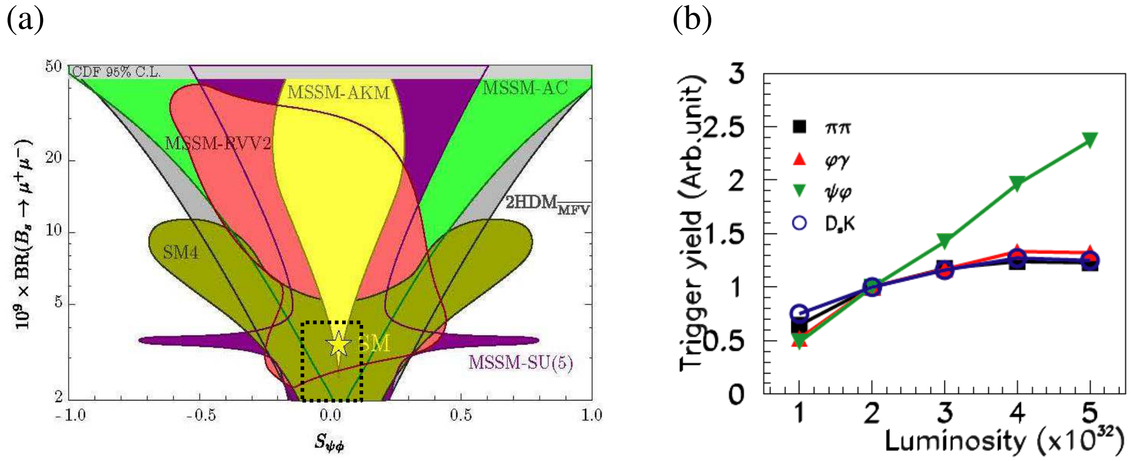

Figure 4: (a) Parameter space of various models for physics beyond the Standard Model, in the plane of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$ *vs.* the B_s^0 mixing phase $S_{\psi\phi} = \phi_s$, taken from [9]; the Standard Model point is shown with a star, and the constraints from LHCb are shown by the dashed box. (b) Trigger yield for different B decays normalized to the trigger yield expected in nominal conditions at a luminosity of 2×10^{32} cm^{-2}s^{-1}; the hadronic yields saturate, while the muon triggers continue to gain with increased luminosity.

3 Plans

By the end of the extended 2012 run, LHCb expects to have tripled its data sample, ready for detailed analysis during the first long shutdown of the LHC over 2013–14. In 2015 we expect to run at 13 TeV which will give significantly higher production cross-sections for heavy flavours (increasing roughly linearly with centre-of-mass energy). In the period 2015–17 we expect to further double the integrated luminosity, to a total of around 5–7 fb^{-1}. At this point the data-doubling time would become excessive, so it is planned to upgrade the experiment to run at higher luminosity.

The present detector could run at luminosities $\sim 10^{33}$ cm^{-2}s^{-1} once the machine reaches its nominal number of bunches, corresponding to 25 ns spacing. However, it is currently limited to a read-out rate of 1 MHz. To trigger at an increased event rate requires a substantial change in the LHCb read-out architecture. The present first level trigger is implemented in hardware [6]. Trigger selections are made at the 40 MHz beam crossing rate using either the calorimeters or the Muon system. Criteria are based on the deposit of several GeV of transverse energy, E_{T}, by charged hadrons, muons, electrons or photons. While this provides high efficiencies on dimuon events, it typically removes half of the fully hadronic signal decays. In these hadronic decays the E_{T} threshold required to reduce the rate of triggered events to an acceptable level is already a significant fraction of the B meson mass. Any further increase in the rate requires an increase of this threshold, which then removes a substantial fraction of signal decays. The trigger yield therefore saturates for hadronic channels with increasing luminosity, as shown in Fig. 4 (b).

The most effective way of upgrading the trigger is to supply the full event information, including whether tracks originate from the displaced vertex that is characteristic of heavy flavour decays, at each level of the trigger. This requires reading out the whole detector at 40 MHz and then analysing each event in a trigger system implemented in software. A bigger CPU farm, more disk storage and more computing power will be needed to swallow a factor 5–10 more events at the output of the software trigger. The upgraded detector will be able to collect at least $5\,\mathrm{fb}^{-1}$ per year, for a total of $50\,\mathrm{fb}^{-1}$ over lifetime of the upgrade. The annual signal yields will be higher by a factor of around ten for muonic B decays and twenty or more for heavy-flavour decays to hadronic final states, compared to those obtained by LHCb in 2011.

The detailed physics case for the LHCb upgrade was presented in Ref. [10]. Following endorsement of the physics case by the LHCC, the experiment was encouraged to prepare Technical Design Reports (TDRs), and a Framework TDR has been submitted in May 2012 [11] giving an overview of the schedule, cost and participating institutes. After the current period of R&D it is planned to submit TDRs for the subsystems next year, to be ready for installation of the upgraded detector during the second long shutdown of the LHC in 2018. An exciting future lies ahead for the experiment, searching for signs of physics beyond the Standard Model in the flavour sector and beyond.

References

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