PROCEEDINGS OF SCIENCE

The LHCb Detector - Global Status

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The LHCb experiment has been designed to perform precision measurements of CP asymmetries and rare decay searches of B mesons. The construction and installation of the LHCb detector has been completed. This paper reports about the expected detector performance and the commissioning of the experiment with cosmic rays and particle beams, with special emphasis on the time alignment of the various subsystems. It will be shown that LHCb is fully ready to exploit data from CERN's Large Hadron Collider for first physics measurements.

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1. Introduction

In the last decade impressive progress has been made in B-physics. The BABAR and Belle experiments produced many results testing the CKM mechanism of the Standard Model stringently, and the two Tevatron experiments, CDF and D0, have produced several interesting measurements in the B_s^0 sector. At this moment, the data show a striking agreement with the Standard Model.

On the other hand, the level of CP violation in the Standard Model cannot explain the absence of antimatter in our universe. A new source of CP violation beyond the Standard Model is needed to understand this matter-antimatter asymmetry, implying new physics. Particles associated to new physics could manifest themselves indirectly in beauty- or charm-meson decays via their virtual effects in loop diagrams and produce contributions that change the expectations of CP violation phases. They may also generate decay modes forbidden in the Standard Model.

Therefore, the emphasis of the LHCb experiment has shifted more to the search for physics beyond the Standard Model. Thanks to the large b-quark cross section expected in p-p collisions at LHC energies, the high event reconstruction efficiency of the detector, and the flexible high-level trigger based on software, the LHCb experiment is ready to significantly extend the sensitivity to new physics as the next generation heavy flavour experiment. Already in the first year of physics data taking LHCb will contribute to an improvement of several interesting measurements [1].

2. Detector description and performance

The LHCb experiment will exploit the high $b\bar{b}$ cross-section of $\sim 500\mu$b expected at $\sqrt{s}$ = 14 TeV energy of the colliding protons at the LHC[1]. Given that the $b\bar{b}$ pairs are mostly produced in the forward or backward direction, the LHCb detector was designed as a forward spectrometer, covering a pseudo-rapidity range of $1.9 < \eta < 4.9$. Selecting B-mesons with transverse momentum $p_T > 2$ GeV/c, the b-hadron production cross-section is $\sim 230\mu$b. In order to maximize the probability of a single interaction per beam crossing, it was decided to limit the luminosity in the LHCb interaction region to $2-5\times 10^{32}$ cm^{-2} s^{-1}. This choice facilitates the study of B-physics and has the additional advantage of reducing the radiation damage due to high particle flux at small angles. In these conditions one year of "normal" LHCb running ($\sim 10^7$s) corresponds to 2 fb^{-1} of integrated luminosity and about 10^{12} $b\bar{b}$ pairs produced in the region covered by the spectrometer.

The detector and the trigger of the experiment are especially designed to reach excellent performance in the specific B-meson decays that usually have small Branching Ratios (BR), while rejecting the background, which is mostly due to inclusive $b\bar{b}$ and inelastic p-p interactions.

A schematic view of the LHCb spectrometer is shown in Figure 1. The detector is described in great detail in [2]. The following sections provide a brief outline of the experimental setup and summarize the expected performance.

2.1 Tracking system

The tracking system consists of the VErtex LOcator system (VELO) and four planar tracking stations: the Tracker Turicensis (TT) upstream of the 4 Tm dipole magnet, and stations T1-T3

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[1] The $b\bar{b}$ cross-section scales roughly linearly with the energy, so one can easily scale the given cross-sections for lower $\sqrt{s}$ values.

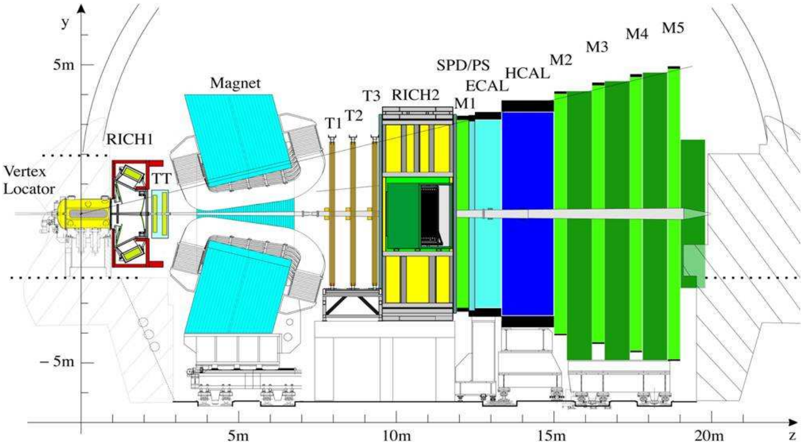

Figure 1: Schematic view of the LHCb detector

downstream of the magnet. VELO and TT use silicon microstrip detectors. In T1-T3, silicon microstrips are also used in the region close to the beam pipe (Inner Tracker, IT) whereas straw-tubes are employed in the outer region of the stations (Outer Tracker, OT).

The VErtex LOcator (VELO) provides precise measurements of track coordinates close to the interaction region in order to identify the displaced secondary vertices which are a distinctive feature of b- and c-hadron decays. It consists of 21 stations arranged along the beam axis, each providing a measurement of the radial and azimuthal track-coordinates. This detector allows to reconstruct primary vertices with an excellent precision: 10 (60) μm in the transverse (parallel) direction to the beam axis. The measurement of the impact parameter of tracks relative to the primary vertex, a crucial parameter for identifying particles originating from a B-decay, has a precision of σ_{IP} = (14 + 35/$\mathrm{p_T}$) μm (with $\mathrm{p_T}$ in GeV/c units). More details can be found in [3].

The tracking stations TT and T1-T3 allow to measure the momentum of the charged particles with a precision of σ_p/p = (0.4 + 0.0015$\times$ p) % (with p in GeV/c units) with > 95% efficiency. The overall performance of the tracking system allows to reconstruct the invariant mass and proper time of B-mesons with a resolution of $\sigma_m \sim$ 15 - 20 MeV/c^2 and $\sigma_t \sim$ 30 - 40 fs respectively, depending on the channel.

2.2 Particle identification

Particle identification (PID) is a fundamental requirement for LHCb. It is essential for the goals of the experiment to separate pions from kaons in selected B-hadron decays, and to determine the B-flavour at production (B-tagging). Since the momentum spectrum is rather soft at large polar angles, while at small polar angles the momentum spectrum is harder, the particle identification system consistes of two RICH detectors to cover the full momentum range. The upstream detector, RICH 1, covers the full LHCb acceptance and detects the low momentum charged particles in a range of $\sim$ 1-60 GeV/c using aerogel and C_4F_{10} radiators, while the downstream detector, RICH 2, has a limited angular acceptance and covers the high momentum range from $\sim$ 15 - 100 GeV/c , using a CF_4 radiator. The kaon PID efficiency is expected to be at the level of 88% (averaged over the full momentum range) while pion contamination stays at the level of 3%.

The calorimeter system of the experiment comprises a scintillator-pad-detector (SPD), a preshower detector (PS), an electromagnetic calorimeter (ECAL) and a hadron calorimeter (HCAL). It provides the identification of electrons, hadrons and neutrals (photons and π^0) as well as the measurement of their energies and positions. Its information is used at the first trigger level (L0) to select particles from B-decays with a transverse energy deposit $E_T > 2\text{-}3$ GeV/c .

The muon system is designed to identify and select high p_T muons at trigger level L0, and to provide offline muon indentification for the reconstruction of muonic final states and B-flavour tagging. It consists of five stations (M1-M5) equipped mainly with multi wire proportional chambers. For the innermost region of station M1, which has a high particle occupancy, triple-GEM detectors are used. For a muon PID efficiency of 90% the misidentification rate is $\sim$ 1.5%.

2.3 Trigger system

The LHCb trigger is organized in two layers: Level-0 (L0) and the High-Level-Trigger (HLT). The L0 trigger is a hardware trigger, implemented on custom-made electronics. It selects events with relatively high p_T (typically $>$ 1-4 GeV/c) electrons, muons, photons and hadrons in the final state that most likely come from a B-decay. The decision is taken within a latency of 4 μs at the input frequency of 40 MHz with an output rate of 1 MHz.

The High-Level-Trigger selects exclusive B-decay modes as well as auxiliary signals for systematic studies, such as inclusive B-decays. The HLT is a software trigger, implemented as selection algorithms on a computing farm of $\sim$ 1800 CPUs and runs asynchronously. It starts with confirming the high p_T L0-candidates, after which it selects events with fully or partially reconstructed B-decay modes. The data acquisition rate after the HLT is 2 kHz and the event size 35 kB. Therefore minimum bias (MB) data can be recorded at a maximum rate of 2 kHz and MB physics can be performed on early data with large data samples.

3. Commissioning

The LHCb commissioning strategy can be summarized in three steps. First, test- and calibration pulses were used for the commissioning of the individual detector parts; in a second step cosmic rays were employed by some subsystems, and finally the commissioning was done with particle beams for the full detector.

3.1 Commissioning with test pulses

In the initial phase, each sub-detector was commissioned independently. Safety issues were checked and hardware operations and controls tested. Calibration pulses were used to test the response of the hardware, including a check of the control- and data-cables and testing of the trigger signals. Calibration pulses were also used to check the channel mapping and to spot any anomalous electronic channels (dead or noisy). Initial settings for the time alignment were set to reasonable values leading to coherence of the data produced for each sub-detector. After some debugging more than 99% of the electronic channels of each subsystem were fully operational.

Once all the subsystems were basically ready, the system was exercised as a whole. The LHCb experiment has been read out at a maximum hardware trigger rate of 1 MHz in 2009 and the data storage at 2 kHz output rate has been tested.

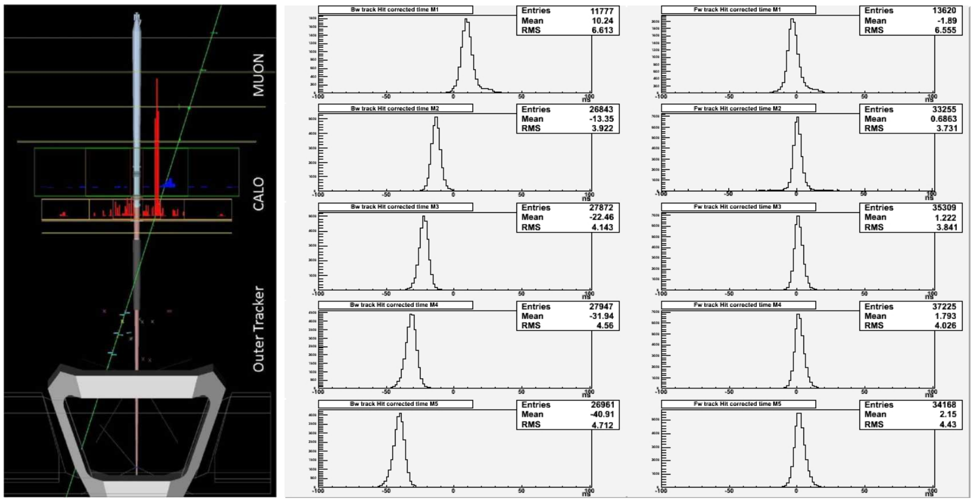

Figure 2: (Left) Event display of a cosmic event reconstructed by the OT, Calo and Muon systems. (Right) Time distribution of muon hits in stations M1-M5 with backward (left) and forward (right) tracks.

3.2 Commissioning with cosmic rays

Several cosmic runs have been performed to commission parts of the experimental setup. Although the configuration of the LHCb experiment is not well suited for cosmic runs (the rate of tracks within ±250 mrad from horizontal is well below 1 Hz), several million useful cosmic events have been recorded. In order to acquire cosmic events, the ECAL/HCAL and MUON trigger has been slightly relaxed: the thresholds on p_T and E_T have been lowered in order to be sensitive to minimum ionizing particles and the coincidence of only two muon stations has been required. Cosmic events have also been extremely useful to commission the trigger, since the same logic as for real data has been used.

Cosmic runs allowed us to achieve a good spatial alignment and a coarse time alignment for the big subsystems (Calorimeter, Muon and Outer Tracker). In Figure 2 an event display of a reconstructed cosmic event is shown together with the time distributions (residuals with respect to the trigger time) of hits in muon stations M1-M5 for reconstructed muon tracks. The trigger was given by the SPD and HCAL detectors and the timing has been adjusted for forward tracks. The obtained time resolution of 4 ns is according to expectations.

However, not all the detectors could be aligned with this method: in particular, the VELO, TT and IT detectors are too small or too far away from the detectors providing the trigger to participate in the cosmic runs.

3.3 Commissioning with beam induced events

As part of the LHC machine commissioning, beam synchronization tests have been done during which a single bunch of protons was directed along a transfer line between the SPS accelerator and the LHC, and dumped onto a beam absorber before entering the LHC tunnel. As beam dump served the TED (Transfer line External beam Dump) which is located about 340 m downstream of the LHCb detector. Secondary (and tertiary, etc.) tracks travelling at small angles were detected and reconstructed by the VELO, TT and IT subystems. The fluence was about 100 particles/cm^2.

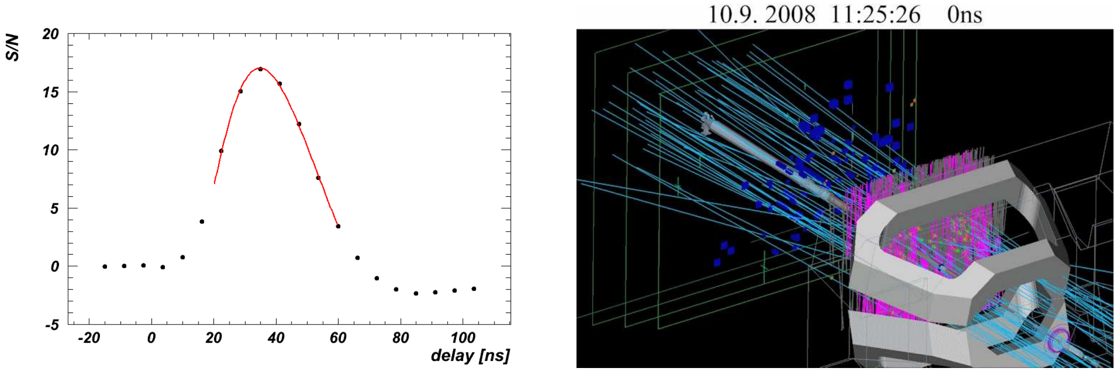

Figure 3: (Left) Single/noise ratio for an IT-module as function of the trigger delay.
(Right) Reconstructed tracks of a high-multiplicity event seen by LHCb on September 10, 2008

These events have been used to perform a more precise time- and spatial-alignment. For the time alignment of the silicon microstrip detectors, runs were taken where the delay between the sampling time and the trigger time was varied in steps of a few ns and the most probable value of the the signal/noise ratio was determined for each detector part. The delay time for the subsequent data taking was then chosen as the one with the highest signal/noise ratio, as illustrated in Figure 3. After this procedure the detectors were time aligned with a precision better than 2 ns. Details on the spatial alignment of these subdectors can be found in [3].

Finally on September 10, 2008, proton bunches circualted for the first time in the accelerator. Besides some beam-gas events, several so called splash events have been recorded with the detector, where the beam hit a collimator (TDI) about 50 m upstream of LHCb. First collison events have been recorded in the LHC pilot run, which took place in the weeks subsequent to the HCP 2009 conference and which demonstrated the readiness of the LHCb detector for physics.

4. Conclusion and outlook

The installation of the LHCb detector is completed, and all subsystems are commissioned and ready for physics data taking. Cosmic rays and beam induced events were very useful to commission the various subsystems. The full detector has also been read out at a maximum hardware trigger rate of 1 MHz and LHCb is fully operational for the first physics run in 2010.

Large Minimum Bias data samples will be collected at a rate of 2 kHz, as soon as the LHC delivers p-p collisions. The first data will be used for calibration of the detector, followed by a first exploration of low $\mathrm{p_T}$ physics at LHC energies and the commissioning of the full trigger. A few observables sensitive to NP, such as the BR for $\mathrm{B_s^0} \to \mu^+\mu^-$ and the CP asymmetry of $\mathrm{B_s^0} \to \mathrm{J}/\psi\,\phi$, should be already accessible at the end of the first year of physics data taking.

References

[1] The LHCb Collaboration, *Roadmap for selected key measurements of LHCb*, arXiv:0912.4179 [hep-ex] 2009.

[2] The LHCb Collaboration, *The LHCb Detector at the LHC*, JINST 3 S08005.

[3] St. Hansmann-Menzemer, *LHCb tracking commissioning*, these proceedings.