LHCb commissioning and operation

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The LHCb detector was commissioned with beam in November and December 2009. The time alignment was performed and data for space alignment taken both with and without magnetic field. When data taking was restarted in 2010, a second iteration on time and space alignment was performed. The resulting detector performance lead amongst others to good invariant mass resolution, as could be demonstrated in the Λ measurement yielding m= 1115±2.5 MeV/c^2. This article will report on procedures used and progress in commissioning the detector for the first LHC physics run.

1 Introduction

The Large Hadron Collider beauty (LHCb) experiment [1] (Fig. 1) is a dedicated experiment for the precision measurements of rare and CP-violating decays of B-mesons. The experimental techniques applied allow for a highly efficient sampling of beauty events. Since the $b\bar{b}$ production in pp collisions at 7-14 TeV is strongly favored in the forward/backward region, LHCb has been constructed as a single arm forward spectrometer.

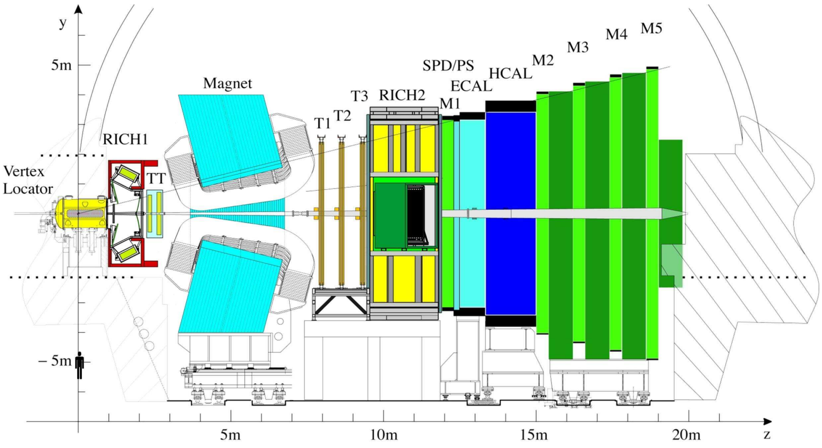

Figure 1: The Large Hadron Collider beauty experiment (LHCb)

The detector surrounding the pp collision point is a silicon strip detector known as the Vertex Locator, VELO. The VELO is positioned, during data taking, with active silicon only 8 mm from the LHC beam. The VELO location, extremely close to the interaction point, and its high resolution leads to excellent impact parameter performance, critical for B decay identification. Inclusion of the impact parameter measurement in the trigger system leads to early and efficient selection of B decays. The momentum and invariant mass measurement is performed with a dipole magnet and the VELO, together with the Tracker Turicensis (TT) (before the magnet), the silicon Inner Tracker (IT), and the drift tube Outer Tracker (after the magnet).

The particle ID is performed by the RICH, calorimeters and muon systems. The K-π and K-p separation is achieved by two Ring Imaging Cerenkov detectors: RICH1, located after the VELO, has two different radiators, aerogel and gaseous C_4F_{10}, to cover the lower (up to $\approx$10 GeV/c) and middle momentum range (10$\leq$p$\leq$60 GeV/c); RICH2, behind the tracking stations, covers the highest momentum range (16$\leq$p$\leq$100 GeV/c) using CF_4.

After the RICH2 come the LHCb calorimeters identifying photons, electrons and hadrons by converting them into showers. They supply the hardware (Level 0) trigger for high E_T electrons, photons and hadrons. The rejection of a high background of charged pions requires longitudinal segmentation of the electromagnetic shower detection, a preshower detector (PS), followed by the main section of the ECAL. The electron trigger must also reject a background of π^0s with high E_T, provided by a scintillator pad detector (SPD) plane in front of the PS. The thickness of the ECAL is 25 radiation lengths for optimal energy resolution, while the hadronic colorimeter has 5.6 interaction lengths.

The muon system, furthest away from the interaction point, is used for the muon identification and is included in the Level 0 trigger to select high-p_T muons. It is composed of five stations of wire chambers (M1-M5). In M1 GEMs are used in the inner region.

The trigger system has two stages. The Level 0 (L0) trigger is implemented in hardware and selects events with high p_T (μ, e, γ, h) at a rate of 1 MHz (input rate 40 MHz). The higher level trigger is implemented in software; after L0 confirmation, it associates L0 objects with large impact parameter tracks and performs inclusive and exclusive selections. The rate to storage is 2 kHz at an event size of 35 kB.

2 Commissioning steps

2.1 Commissioning without beam

After installation, the commissioning started for all sub-systems in parallel. The first round of commissioning made use of electrical test pulses for the tracking systems and optical LED and laser pulsing systems for the calorimeters and RICH detectors. This allowed to verify the correct channel connectivity, the testing of the data acquisition and the building of the control software. With the help of test pulses an internal time alignment of sub-detectors with a precision of $\approx$1 ns was achieved.

In 2008 the data taking with cosmic events started. Despite the forward geometry of LHCb it was possible to acquire 4 million cosmic particle shower events and perform a global time alignment between calorimeters [2], muon stations [3][4], Outer Tracker [5], Inner Tracker [6] and RICH detectors.

2.2 Commissioning with non colliding proton beam

Located very close to the injection line of LHC beam 2, LHCb was able to use particles produced during LHC injection tests. The proton beam coming from the SPS at an energy of 450 GeV was dumped on the injection line beam stopper 350 m downstream of LHCb. This created a particle shower hitting the LHCb detector from the back. These dense particle showers allowed for an initial time and space alignment of LHCb. This was especially useful for the VELO [7] and the Silicon Trackers which, due to their small sizes, could not profit from cosmic particle shower events. Interactions between single proton beams circulating in the LHC and the residual gas in the beam pipe provided particle tracks with less density, suitable for the Outer Tracker time alignment and vertex studies.

2.3 Commissioning with proton-proton collisions

The final step in the commissioning of LHCb began with the first proton-proton collisions at 450 GeV energy per beam in 2009. All sub-detectors and the L0 trigger were used to record about 300 000 collision events at 450 GeV before the winter stop. This data was used to achieve better spatial [8] and time alignment but also to start particle reconstruction, leading amongst others to the measurement of K_s, Λ and ϕ decays.

3 Operation

In March 2010 routine detector operation with proton-proton collisions at 3.5 TeV per beam started. For the VELO this further step in energy was of vital importance as only now the beam crossing angle allowed the closing of the VELO. During proton beam injection and energy ramping the VELO stays at a distance of 28 mm from its nominal position, when the LHC beam is stable, it can be moved in close to the beam. The VELO closure during stable beam operation was first achieved on the 1^{st} of April 2010 and currently takes less than 15 minutes. The reproducibility of the closed position relative to the beam is a few μm in the x-direction. The IT and TT have shown the expected signal to noise ratio and unbiased tracking residuals of 65 μm. The corresponding figure for the Outer Tracker is about 270 μm. Both Silicon Trackers and the Outer Tracker have less than 1 % of dead channels. The good performance of all tracking detectors has lead to a high tracking efficiency and in turn good invariant mass resolution. The reconstructed mass of the Λ with the first 65 μb^{-1} is $1115 \pm 2.5\,\mathrm{MeV/c^2}$ (PDG: $1115.683 \pm 0.006\,\mathrm{MeV/c^2}$), see Figure 2.

The particle identification (PID), which is crucial for the analysis of hadronic B-decays, strongly relies on the performance of the RICH detectors. As Figures 3 and 4 show, the $\phi \rightarrow K^+K^-$ selection power with RICH particle identification is excellent in comparison to the same data set without RICH PID.

The calorimeter works very effectively, providing the first level trigger at LHCb. The energy calibration provides a π^0 mass of 135.16 ± 0.02 MeV/c^2 with $\sigma = 6.06\,\mathrm{Mev/c^2}$, in agreement with the PDG value (134.9766 ± 0.0006) MeV/c^2. The good performance of the muon system has lead to the reconstruction of more than 2000 J/Ψs from di-muon events in the first 12.8 nb^{-1}.

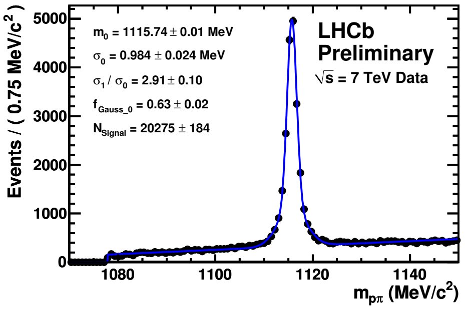

Figure 2: Mass of the Λ

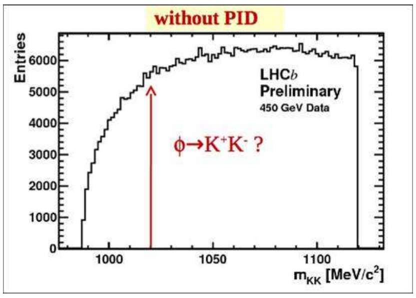

Figure 3: $\phi \rightarrow K^+K^-$ selection without RICH detectors

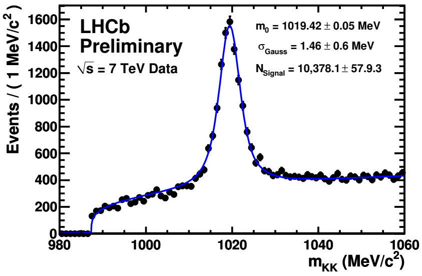

Figure 4: $\phi \rightarrow K^+K^-$ selection using RICH detectors

The central run control allows the shift leader to steer the detector from only two panels. The first panel controls the high voltage settings of all detectors in accordance with the LHC machine state. The second is the central data acquisition control panel. In addition to the shift leader, a data manager is the only other person needed to run LHCb; he/she checks the online data quality through histograms for each sub-system.

4 Conclusions and outlook

With $14\,\mathrm{nb}^{-1}$ of acquired integrated luminosity the LHCb detector has proven to be fully ready for data taking. This was achieved by careful preparation, utilizing test pulses and cosmic showers. First collisions were used to conclude commissioning and high statistics data are currently used to fine tune calibrations. Ahead lies an intense and exciting physics programme based on an expected integrated luminosity of $1\,\mathrm{fb}^{-1}$ by the end of 2011 with many channels to look at [10]: the tree-level determination of γ, charmless charged two-body B-decays, measurement of mixing-induced CP violation in $\mathrm{B}_s^0 \rightarrow J/\Psi\phi$, analysis of the decay $\mathrm{B}_s \rightarrow \mu^+\mu^-$, analysis of the decay $\mathrm{B}^0 \rightarrow K^{*0}\mu^+\mu^-$, analysis of $\mathrm{B}_s^0 \rightarrow \phi\gamma$ and other radiative B-decays.

References

[1] A. A. Alves *et al.* [LHCb Collaboration], JINST **3** (2008) S08005.

[2] M. Calvi *et al.*, CERN-LHCb-PUB-2010-015.

[3] M. Frosini *et al.*, CERN-LHCb-PUB-2009-028.

[4] S. Furcas *et al.*, CERN-LHCb-CONF-2009-025.

[5] A. Pellegrino *et al.*, LHCb-TALK-2010-013.

[6] J. van Tilburg *et al.*, CERN-LHCb-CONF-2010-004.

[7] S. Borghi *et al.*, Nucl. Instrum. Meth. A **618** (2010) 108.

[8] M. Deissenroth [LHCb Collaboration], J. Phys. Conf. Ser. **219** (2010) 032035.

[9] M. Adinolfi *et al.*, Nucl. Instrum. Meth. A **603** (2009) 287.

[10] B. Adeva *et al.* [The LHCb Collaboration], arXiv:0912.4179 [hep-ex].