READINESS OF THE LHCB EXPERIMENT FOR FIRST DATA

Adriano Lai
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari,
Dipartimento di Fisica, Cittadella Universitaria
Monserrato (Cagliari), Italy

This paper deals with the present status of the LHCb detector, with special emphasis on the commissioning tests and analysis. The detector response has been widely tested by means of cosmic particle events and with the very first beam before the LHC rupture in September 2008. Some of the results of these studies are reported. Finally, plans on the use of the first beam data, expected in 2009, are shortly presented.

1 Introduction

The LHCb experiment at the Large Hadron Collider is designed for the search of New Physics in CP violation and rare decays of the B quark. A scheme of the LHCb apparatus is given in fig. 1. A wide description of the LHCb experiment can be found in ref. [1]. The installation of the full LHCb apparatus has been concluded during 2007, with the only exception of the first muon station, called M1, whose installation is to be completed by July 2009.

At the nominal LHC luminosity, LHCb foresees an integrated luminosity of 2 fb^{-1} per year, corresponding to the production of $270 \times 10^9 B_d$ and $70 \times 10^9 B_s$ per year, besides the access to all the possible b-hadron species.

The main experimental challenges are the high average track multiplicity (about 30 tracks per rapidity unit) and the huge background (80 mb from inelastic cross section to be compared with a σ_{bb} effective cross section of 230 μb). Also, the branching ratios of B-meson decays relevant for the LHCb physics are of the order of 10^{-8} to 10^{-9}.

Table 1 summarizes the design performance of the LHCb sub-detectors.

Besides the performance of the single sub-detectors, the key LHCb point to cope with the challenges above is the trigger architecture. This is conceived in two levels. A hardware level,

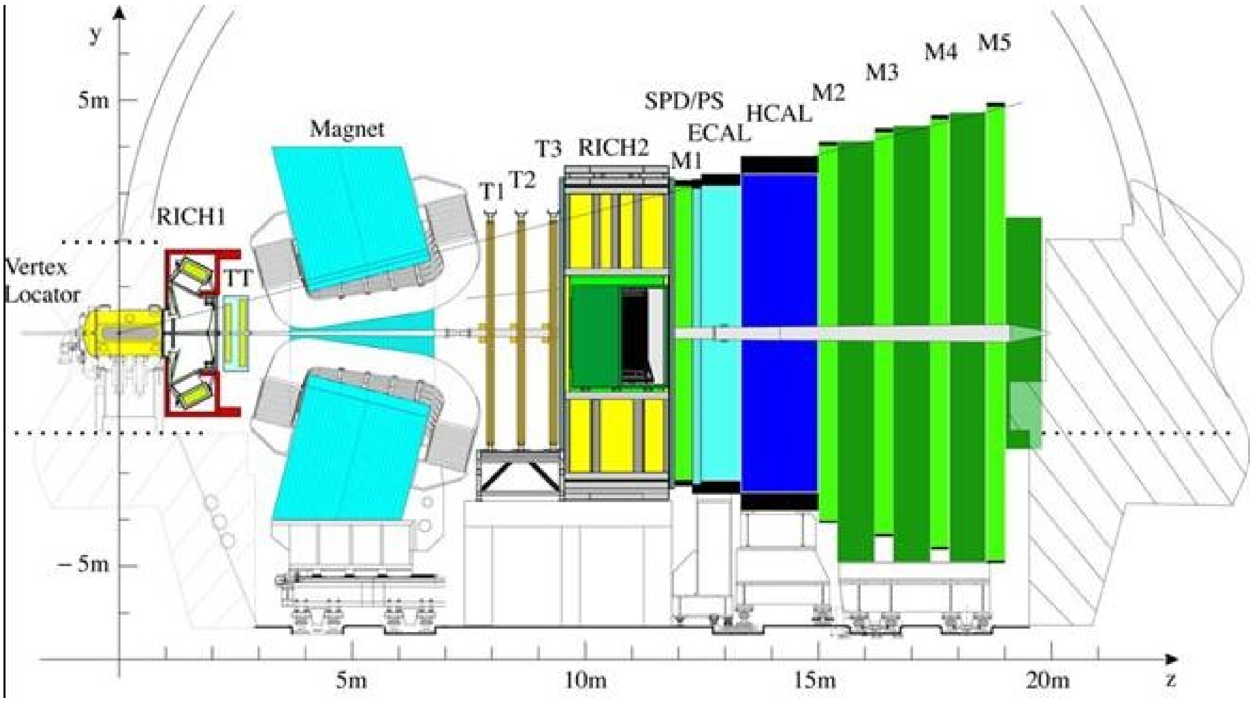

Figure 1: Schematic view of the LHCb apparatus.

or Level0 (L0), reduces the effective input rate of 12 MHz to 1 MHz and is based on the identification of muon, electromagnetic and hadron high p_T candidates. The software level, also called High Level Trigger (HLT), is a C^{++} application, running on a scalable PC farm of up to 4000 quad-core computing nodes (Event Filter Farm, EFF). The HLT algorithm is organized in two stages, the first one (HLT1) checks the L0 candidate using information coming from the tracking sub-detectors and adds impact parameters and lifetime cuts. The second one (HLT2) is able to perform global event reconstructions and decay channel selections. The output of the HLT corresponds to a rate of 2 kHz and an event size of about 40 kbytes. The software approach provides basically two important advantages:

- Possibility to intimately tune the trigger algorithms following the study evolution;
- Natural increase of processing power due to the technological scaling in computing.

Since the last two years and in particular during the whole 2008, LHCb has been widely and deeply commissioned using different techniques. Some of them are illustrated in the following, along with the results obtained.

2 LHCb commissioning

2.1 Commissioning with cosmic particles

LHCb is a single-arm spectrometer, conceived according to a strictly projective geometry with respect to the interaction point (IP). Cosmic particles (cosmics) have not the right orientation to test the LHCb sub-detectors, nevertheless they are still well visible in the large area sub-detectors: the Muon Detector, the Colorimeters and the Outer Tracker. As the Muon Detector and the Calorimeters are the basic building blocks of the L0 trigger, cosmics are also a useful tool to test the operation of the trigger logics.

Table 1: Key nominal performance parameters of the LHCb sub- detectors.

VELO (Vertex Locator)	$\sigma(IP) \approx (14 + 35/p_T(GeV))\ \mu m$ $\sigma(t) \approx (40 - 100)$ fs
TRACKING	$\epsilon = 95\%$ when $p > 5\ GeV$ and $1.9 < \eta < 4.9$; $\sigma(p)/p \approx 0.4\%$ $\sigma(m[B_s \to \mu\mu]) \approx 20\ MeV$ $\sigma(m[K^*\mu\mu]) \approx 15\ MeV$
MUON, RICH	$\epsilon(K) \approx 88\%$ for 3% π misidentification; $\epsilon(\mu) \approx 95\%$ for 5% π/K misidentification
ECAL	$\sigma(E)/E \approx [9.4/\sqrt{E(GeV)} + 0.83] \times 10^{-2}$ $\sigma(m[B_s \to \phi\gamma]) \approx 90\ MeV$
LEVEL-0 Trigger	$\epsilon(B_{d,s} \to J/\psi X) \approx 90\%$ $\epsilon(B_{d,s} \to hh) \approx 50\%$

In the nominal configuration, the L0 Muon trigger foresees the coincidence of at least one hit for each one of the five stations, aligned according to a projective geometry from the IP. This configuration is not usable with cosmics, giving a trigger rate practically equal to zero. Instead, the Muon L0 has been operated according to two configurations:

- At least one hit in station M3. This trigger condition corresponds to an average trigger rate of about 60 Hz;

- Coincidence of at least one hit in stations M4 and M5, corresponding to an average trigger rate of 4 Hz.

On the other side, the Calorimeter trigger has been operated by setting both the Electromagnetic and Hadronic part at very high gain, in such a way to trigger on MIPs.

Using different logic combinations of the above Muon and Calorimeter trigger conditions, about two millions events have been acquired during Summer 2008. Remarkable results coming from the use of these events from cosmics are the time alignment of the Muon system and the study of its efficiency. The muon system has a special importance in the first data taking runs, because, besides being part of the hardware trigger, it plays a crucial role in the study of interesting rare decays, e.g. $B_s \to \mu^+\mu^-$, which are channels promising relevant results even with the relatively low statistics of the first year of data taking.

The Muon system was firstly aligned using a hardware procedure, based on a dedicated pulsing system and internal adjustable delays. This first alignment allowed using trigger and acquiring events displaced within the triggered time +/- one bunch crossing cycle. This first coarse hardware alignment gave an average time resolution $\sigma \sim 11\ ns$. On the data acquired a refinement of the alignment was possible, correcting for the particle time of flights between the stations and reducing the time residuals with respect to the average track time. This analysis procedure took the system to be aligned with an average time resolution ranging between 5 and 6 ns. These values correspond with what expected from measurements in laboratory tests for the operating voltage of 2.5 kV at which the muon chambers were intentionally operated during the commissioning phase. The nominal operating voltage is 2.7 kV, chosen as the optimal point with respect to detector efficiency, safe operation and detector lifetime.

Another study realized on data from cosmics regards the muon detector efficiency. Owing to the projective structure of the LHCb apparatus, cosmic tracks are not suitable for a direct study of the detector efficiency. However, a significant result can be obtained grouping the reconstructed tracks in bins of tanθ, where θ is the angle between the track and the corresponding

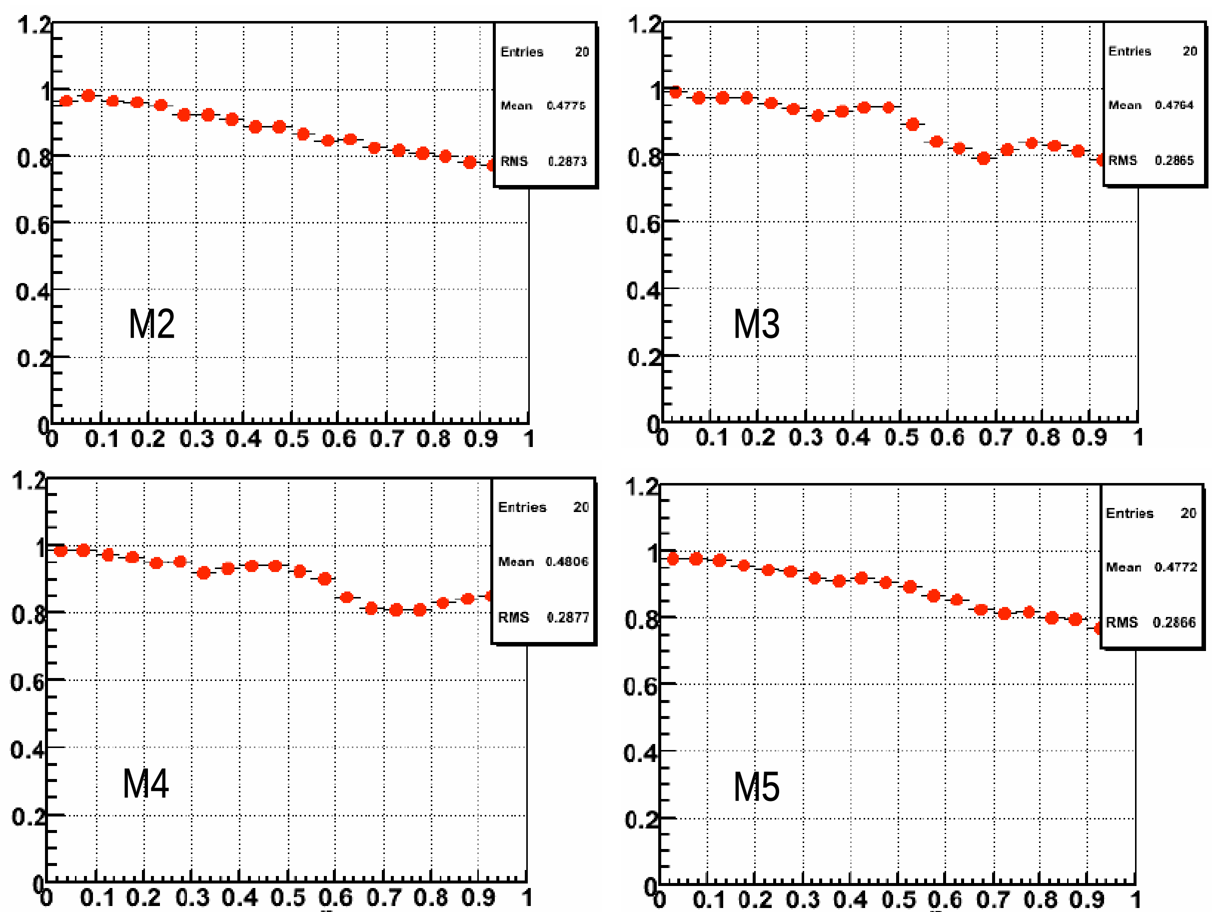

Figure 2: Geometrical efficiency of the four muon stations M2-M4 as a function of the tanθ, chosen as a projectivity parameter. Perfect projectivity corresponds to tan$\theta = 0$, where the efficiency is extrapolated to a value compatible with 1.

projective direction, taken as the line connecting a specific hit point on the chamber and the Interaction Point. These plots show the strong dependence of the efficiency from the track angle and allow extrapolating to the value of tan$\theta = 0$, corresponding to the projective geometry (see fig.2).

2.2 Beam tests

What done during months with cosmic particles could be better done in a few hours or days with beam. During 2008 there has been only a few such opportunities: injection tests (August-September) and the first (a few hours) LHC circulation on 10^{th} September.

Injection tests consist in the injection of a proton beam (called Beam2) from the SPS ring into the LHC, where it is completely stopped on a full beam graphite dump (named TED [2]). The TED is placed about 340 m behind the LHCb detector. Impinging on the TED, the beam generates a high flux of particles, not collinear to the LHC beam axis, but inclined 8 $mrad$ horizontally and 12 $mrad$ vertically. In the centre of the blast the flux is about 10 $particles/cm^2$, corresponding to about a factor 20 more than nominal. In proximity to the LHCb interaction point this corresponds to about 0.1 $particles/cm^2$ per blast.

LHCb profited of two usable LHC injection test, The first consisting of about 5×10^9 protons per shot (one shot every 48 s during about one day of data taking), the second 2×10^9 protons per shot for two days of data taking. Both runs provided about 700 reconstructed tracks in

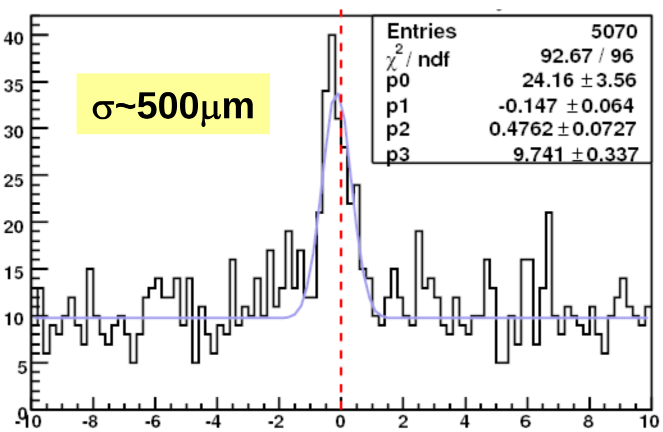

Figure 3: Hit residuals in the VeLo to TT extrapolation

the VELO detector. Events were triggered by hit multiplicity in the Scintillator Pad Detector (SPD) and consecutive triggers centred on the triggered event were acquired (so called Time Alignment Events or TAE). Injection, or TED, runs were extremely useful tests to verify space and time alignment within single sub-detectors and among sub-detectors. In particular, they were the first opportunity to gather significant statistics in small area detectors (VELO, TT), where cosmic particle rates are too small to perform significant studies in a reasonable time.

Results from the TED runs mainly concern the check of the space alignment of the VELO in itself and the relative alignment between the VELO and the TT, placed about 1.5 m one with respect to the other, which is obtained comparing the difference between the hit coordinate in the TT and the extrapolated hit position from the VELO corresponding to the same track. The alignment precision of the VELO has been measured to be about 3.4 μm for x and y translation and 200 μrad for z rotation. Also the relative TT-VELO alignment is within the specifications: the track residuals correspond to about 500 μm, with offsets between 150 and 300 μm, to be compared with the expected uncertainty in VELO-TT extrapolation of 300 μm (see fig. 3).

The first circulating beams during September 10^{th} 2008 (LHC inauguration) could not be exploited as wished for commissioning purposes, owing to the very short duration. All the experimental teams, however, were exited for the good response of the Control and DAQ systems and for the first possibility to operate the Muon trigger with a projective 4-fold coincidence.

2.3 Full Experiment System Tests

Neither run on cosmics nor on injected beams allow a complete test of the trigger and DAQ system at full rate. In order to have an exhaustive test of the back-end part of the LHCb machine, dedicated procedures have been developed. These are realized in the so called Full Experiment System Test (FEST) runs, having the aim to get the system already prepared to receive, process and analyze the huge amount of events expected in the first hours and days of collisions.

Raw Monte Carlo events are generated and injected into the HLT chain as if coming from the back-end read-out boards (the Tell1 boards). In practice, these stream of events emulate the output of the front-end part of LHCb. The generated data contain a sample of 2 kHz of pre-selected events that are expected to pass the HLT algorithm, in such a way to test its proper operation and speed. The FEST allows testing several crucial parts of the system software: the run control system (the data injector is treated as a sub-detector), the data stream, the dynamic node balancing in the EFF, data monitoring, data storage and the interaction with the GRID for the offline analysis. The FEST framework has been tested successfully in January 2008.

FEST runs at incresed speed and performance are planned until the first beam arrives.

3 Activities during the 2009 shutdown

A number of hardware intervention are still foreseen during the 2008-2009 shutdown, before the LHC closure, scheduled for the end of July 2009.

At the detector level, the M1 installation and commissioning is to be completed, The ECAL requires small modifications of the HV and readout boards, a small percentage of Muon channels in station M2-M5 has to be fixed. The installation of the Event Filter Farm is to be completed to have a full size read-out network to allow full rate readout (1 MHz) from the front-end. Optimization work is still necessary and will proceed on the Experiment Control System, and regular FEST runs are scheduled about one week per month until the first collisions to optimize the HLT performance.

4 Conclusions and outlook

As a result of the tough commissioning work during 2007 and 2008, the experiment is well advanced in preparing the reception of the first collisions at moderate luminosity, as soon as LHC will be able to deliver significant physics, hopefully by the end of 2009.

The first collisions at low energy (450 GeV), during the LHC setup runs, will be precious to refine and optimize the system alignments with high statistics in all the detector channels. For this task the tools have been already developed and tested successfully but the operation of the apparatus in nominal conditions was not always possible without collisions.

The remaining installation work and the minor repairs are foreseen to be completed by Summer 2009.

The LHCb target for the first year of run, which today appears to be a fairly reachable target, at least from the experiment point of view, is to collect and quickly exploit $0.2 - 0.3\ fb^{-1}$ of physics. This is expected to be sufficient to produce significant measurements, in particular in the following noteworthy channels:

- $2\beta_s$ measurement from the $B_s \rightarrow J/\psi(\mu^+\mu^-)\ \phi$ decay,
- the branching ratio of the $B_s \rightarrow \mu^+\mu^-$ rare decay,
- the forward-backward asimmetry A_{FB} in the decay $B_d \rightarrow K^*\mu^+\mu^-$,

where accuracy comparable or better than the present B-factories is possible already in the first year of LHCb data taking.

Acknowledgments

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