Commissioning and Performance of the LHCb Outer Tracker

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Abstract

The LHCb experiment is a single arm spectrometer, designed to study CP violation in B-decays at the Large Hadron Collider (LHC). It is crucial to accurately and efficiently detect the charged decay particles, in the high-density particle environment of the LHC. For this, the Outer Tracker was constructed, consisting of ~55,000 straw tubes, covering in total an area of 360 m^2 of double layers. The detector is foreseen to operate under large particle rates, up to 100 kHz/cm in the region closest to the beam. The front-end electronics is expected to provide the precise (0.5 ns) drift-time measurement, at an average occupancy of 5% and at 1 MHz trigger rate. At the time of the conference, the detector has been commissioned with cosmic-ray events and with the first LHC beam collision data. After dedicated studies to establish timing and spatial alignment, the first results on the detector performance (efficiency, resolutions, etc.) have been obtained.

Key words: Outer-Tracker, Straw-tubes, Drift-chambers

The LHCb detector is a single arm spectrometer [1]. Its tracking system is divided in a silicon detector close to the interaction region, a dipole magnet, and a tracking system behind the magnet. By measuring the deflection of the charged particles by the magnetic field, the momentum of the particles is determined. The tracking system behind the magnet is divided in two parts: a small silicon detector (IT) at high rapidity in the highest particle flux region, and a gaseous straw tube detector, the Outer Tracker (OT), covering most of the LHCb acceptance. The OT has a modular design: 168 long F-modules (500×34 cm^2), and 96 short S-modules above and below the beam-pipe. One F-module consists of two staggered layers of 64 straws, electrically floating at the center and read out at the two ends (256 channels). The anode is a 25 μm thick gold-plated tungsten wire; the cathode is made of a carbon-doped (XC) kapton straw with a diameter of 4.9 mm on the inside, and aluminum at the outside for electrical grounding and shielding.

1. Detector Production and Installation

The straw-tube modules (185 F-modules and 110 S-modules) were made in three production sites from 2004 to 2006. All materials and production tools were centrally distributed to all sites, and the production procedures and quality checks were standardized. During mass-production, stringent quality criteria were applied on the wire tension (70 grams) and HV behavior of each single wire. After production, the dark current after HV training (typically ~1 nA per wire), and the gas-tightness of the entire module (of the order of 10^{-4} l/s at an overpressure of 7 mbar) were checked for acceptance [2]. Finally the response of each wire of each module was checked with a radioactive ^{90}Sr source (a β-source, emitting electrons of energies up to 2.3 MeV). An automatized test-setup was built to irradiate the full width of each module with a ^{90}Sr line source in steps of 1 cm along the entire module length. The corresponding current response of each wire was recorded (see Fig. 1), thus allowing the detailed qualification of each module through the observation of various possible defects (bad wire-locator positioning, straws deformations, abnormally high wire currents, etc.).

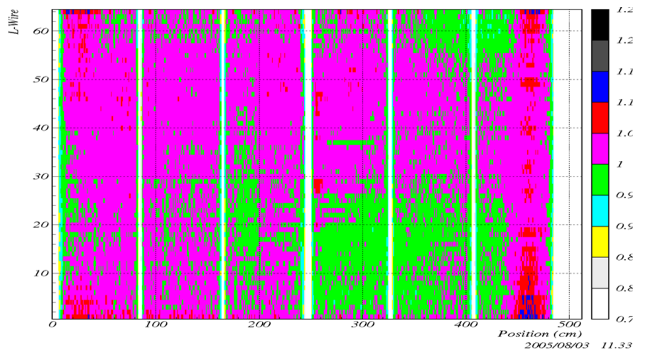

Figure 1: Typical module response to a ^{90}Sr source (in arbitrary units represented by the z-axis grayscale code): all 64 wires (vertical axis) are scanned in steps of 1 cm along the entire (5 m) module length (horizontal axis).

The quality of the straw-tube modules from the mass production was very high: typically the uniformity of the module responses were measured to be better than ±10%, while less than 1% of the total channels were not functional (mostly wires deliberately disconnected due to shortcuts, and mostly located in the first few modules produced).

The detector and the front-end electronics have been installed from 2006 to 2007 (see Fig. 2). During installation, additional quality tests were performed in situ to check the gas-tightness and the response of individual wires to a ^{55}Fe source: the excellent signal response uniformity already observed with the ^{90}Sr scan setup during production was confirmed by the tests in situ and only a handful of additional non-functional channels was found.

Figure 2: View of IT and OT through the LHCb dipole magnet.

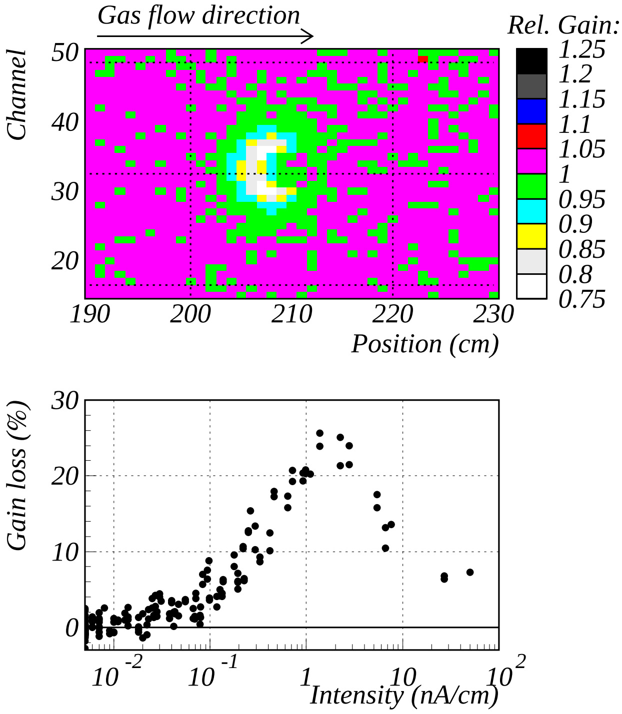

Figure 3: Upper panel: the ratio of two scans before and after irradiation shows the relative gain loss after an irradiation of 20 hours. The source was centered on channel 32 on position 208 cm. Lower panel: the gain loss is shown for each measurement (pixel of $0.5 \times 1\ cm^2$) as a function of the source intensity in that pixel. The gain loss is highest at moderate intensity, around 2 nA/cm.

2. Aging Studies

The LHCb Outer Tracker (OT) detector has shown to suffer from gain loss after irradiation in the laboratory at moderate intensities. Under the influence of irradiation, a small insulating layer of a substance containing hydrocarbons is deposited on the anode wire, thereby reducing the signal response of the detector. The gain loss is quantified by comparing the 2-dimensional current profile before and after irradiation. A typical example is given in Fig. 3, which shows that the gain loss occurs mainly upstream the source position (this was found to be due to the creation of ozone in the avalanche) and is not proportional to the source intensity, but is largest for moderate intensities of the order of 2 nA/cm (this remains true if the module is irradiated at different HV values or with different source strengths).

The detector modules were constructed with the two-component epoxy Araldite AY103-1, and the plastifier di-isopropyl-naphthalene was shown to be the culprit of the gain loss. Given the complexity of the subject, a detailed treatment of the aging phenomenon, its characteristics, its causes, its prevention and cure, are beyond the scope of the present article. An in-depth discussion can be found in Ref. [3] and references therein. At the time of the conference, besides a number of preventive actions to reduce the deterioration of the detector response (heating the modules for 2 weeks at 40^oC to increase the outgassing rate, adding a few percent of oxygen to the counting gas to decrease the aging rate through the enhancement of ozone formation in the avalanche, and lowering the gas flow rate in order to limit efficient removal of the ozone formed in the avalanche), a treatment (“HV training”) has been devised that removes the insulating deposits on the anode wire, consisting in the application of large HV values that take the OT drift-tubes in the discharge regime and produce high dark currents [4].

3. Detector Commissioning

For the detector commissioning, various types of events have been used. Thanks to the built-in test-pulse facility (injecting pulses with adjustable heights and time phases into the front-end electronics preamplifiers), dedicated stand-alone runs can be taken, scanning the amplifier thresholds and the test-pulse timing. A number of monitoring and data-quality analysis tasks have been developed, e.g. to determine dead and noisy channels. All dead channels and most noisy channels have been repaired: as of now, less than 0.1% of the channels have a noise occupancy larger than 10^{-4} (inferior to 1% of the highest occupancy expected from collision events).

The capability of the LHCb Calorimeter and MUON Systems to trigger on cosmic-ray events has provided a large sample of clean tracks through OT. In the early days, this has permitted the training of the online monitoring and offline data-analysis chains. Moreover, studies based on the minimization of the tracking residuals allowed the determination of the differences in the time phases of the various detector channels, as well as of space misalignments between the three detector stations. In the electronics design, as well as in the cabling,

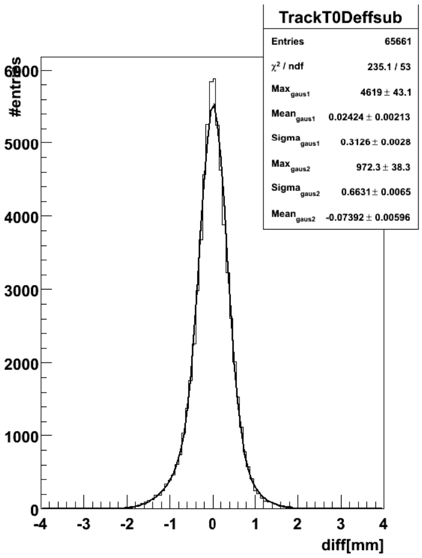

Figure 4: Residuals from track minimization (cosmic events). The curve denotes the double-gaussian model fitted to the data.

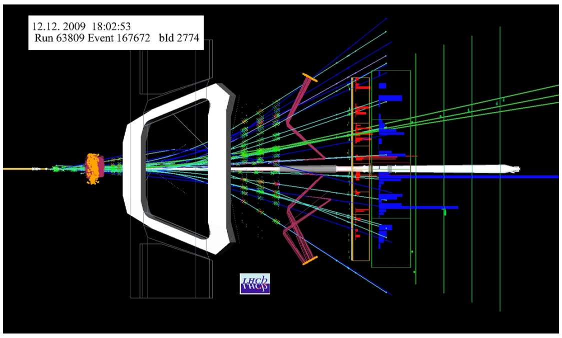

Figure 5: Beam-beam collision event recorded by the LHCb detector. The OT hits are denoted by crosses and form the three vertical lines just downstream of the dipole magnet.

great care was taken to minimize time differences in the signal distribution to all detector channels. The timing differences determined from the cosmic data (and later confirmed in the beam data) were found to be quite small (of the order of 2-3 nanoseconds) and of no consequence for the detector efficiency during data taking (the front-end electronics can operate with readout windows of up to 75 ns while typical drift-time spectra are of the order of 45 ns); they will therefore only be corrected offline to achieve optimal tracking resolution. Concerning the spatial alignment, great care was taken during installation in the positioning of the OT stations, in order to provide a carefully aligned detector (±0.5 mm) from the very beginning of the experiment. Although detailed studies of space misalignments based on various types of tracks (cosmic-ray events, magnet-off and magnet-on collision data) are still on-going (final results need larger data samples to constrain the degrees of freedom for the straw-tubes modules), preliminary results indicate the accuracy of the present detector alignment to be in line with expectations. Fig. 4 shows an example of the residuals obtained

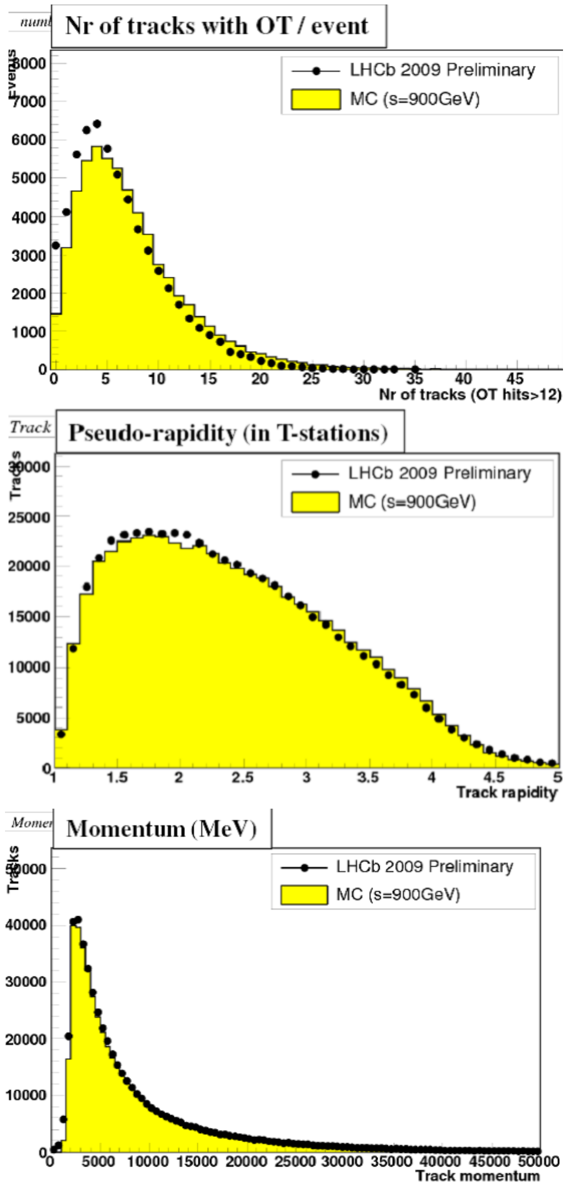

Figure 6: Comparison between the 2009 collision data and the corresponding Monte Carlo predictions: number of OT tracks per event (upper panel); track pseudo-rapidity (central panel); track momentum (lower panel). No beam-gas correction was applied to the data.

from track minimization in cosmic events: a double-gaussian model was fitted to the data, from which an intrinsic spatial resolution of about 220 μm was estimated (spatial misalignments still partially to be corrected for).

At the end of 2009, the LHC machine produced the first beam-beam collisions (see Fig. 5). Few bunches per beam circulated in the LHC ring at the injection energy of 450 GeV (later raised to 1.2 TeV). Several beam-gas and beam-beam collision events were recorded by LHCb. During the whole data-taking period, the entire OT detector was operational at nominal HV (1550 V).

Hit occupancies and number of tracks per event, as well as their angular and momentum distributions, were found to be in agreement with what is expected from Monte Carlo simulations (once corrected for the beam-gas contamination), as shown in Fig. 6.

The study of the 2009 beam-beam collision data, still ongoing, allowed the first check of the OT performance with the LHC beam. All studies are based on the tracking procedure, which proved to work successfully from the very beginning, after the initial tuning of timing and spatial alignment based on cosmic events. The key quantity is the drift-time of the straw tubes, extracted from the recorded TDC time after corrections for time-of-flight and propagation time along the wire (see Fig. 7).

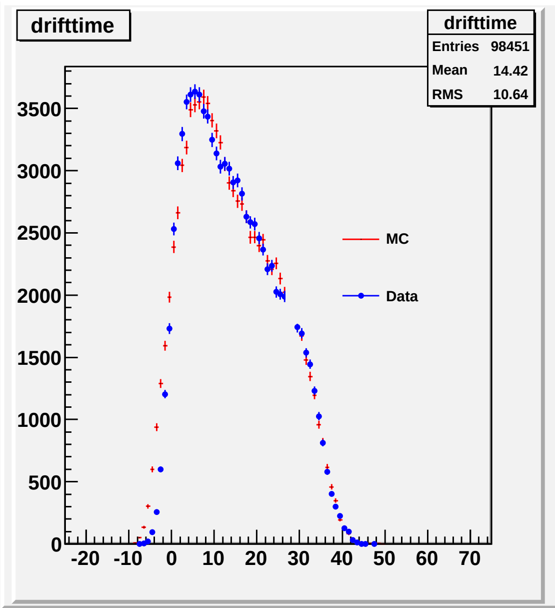

Figure 7: Distribution of the average drift-time (in nanoseconds) for all OT straw tubes from beam-beam collision events, compared to what is expected from Monte Carlo simulations.

The comparison between the hit predictions from the tracking and the actual drift-times demonstrated the validity of the $T(r)$ relation extracted from the test-beam data [5] (see Fig. 8).

The tracking prediction for the distance of a hit from the anode wire was also used to study the hit efficiency along the cell profile. As shown in Fig. 9, a flat efficiency distribution with a

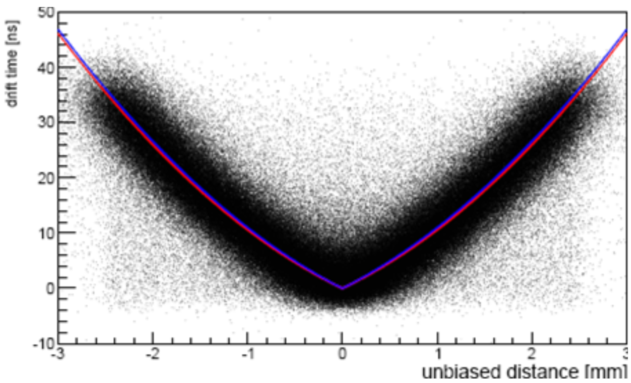

Figure 8: $T(r)$ relation linking the drift-time to the distance of the particle impact point from the anode wire. Two (practically overlapping) curves denote two fits to the 2005 test-beam [5] and to the 2009 beam data, respectively.

plateau of 99% was found, as expected from the test-beam data [5].

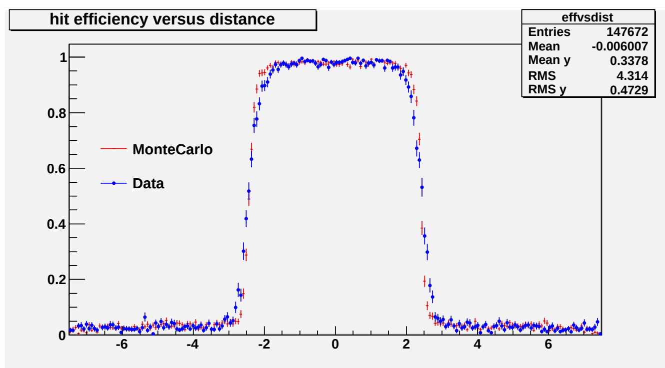

Figure 9: Hit efficiency as a function of the distance (in mm) of the hit from the anode wire. Both data and Monte Carlo simulations are shown.

4. Summary and Conclusions

The LHCb experiment is a single arm spectrometer, designed to study CP violation in B-decays at the Large Hadron Collider. The Outer Tracker detector was constructed to accurately and efficiently detect the charged decay particles and measure their momenta. It consists of ~55,000 straw tubes, covering in total an area of 360 m^2 of double layers. At the time of the conference, the detector has been installed and commissioned with cosmic-ray events and with the first LHC colliding beams. Dedicated studies to establish timing and spatial alignment, as well as the first results on the detector performance (efficiency, resolutions, etc.) have been presented. Although aging remains a concern, these studies confirmed that the Outer Tracker detector is fully operational and will perform as expected since the very beginning of the LHCb Experiment.

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