Commissioning of the Scintillator Pad Detector of LHCb with cosmic rays and first LHC collisions

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Abstract. The Scintillator Pad Detector is part of the LHCb calorimeter system which includes a pre-shower with 2.5 radiation length, an electromagnetic and an hadronic calorimeter. The goal of the Scintillator Pad Detector situated upstream of the calorimeters is to tag charged particles entering the calorimeter system. This contribution discusses the requirements for the synchronization and calibration of the SPD detector. The requirements, methods and precisions obtained at the several stages are presented.

1. Introduction
The Large Hadron Collider (LHC) placed at CERN started to provide collisions in autumn 2009. In 2010 it has reached center of mass energies of 7 TeV and will start to test several extensions of the Standard Model (SM) of interactions and elementary particles. The LHCb detector [1, 2, 3] is one of the four experiments of LHC and it has been specially conceived to study B mesons physics: the study of CP violation and B rare decays [4].

The structure of this document is as follows. In Section 2, a description of the LHCb calorimeter is given. The commissioning of the SPD and its results are discussed in Section 3 and 4 focusing on the time alignment and its calibration. Finally, some conclusions will be drawn in Section 5.

2. The LHCb calorimeter
The LHCb calorimeter [5] is made of four subdetectors: Scintillator Pad Detector (SPD), Pre-Shower detector (PS), Electromagnetic Calorimeter (ECAL) and Hadronic Calorimeter (HCAL). In front of the electromagnetic and hadronic calorimeters incoming particles cross two planes of scintillating cells separated by a lead layer of 2.5 radiation lengths. The first layer of cells is the SPD.

The calorimeter system is used at several stages. It provides high transverse energy hadron, electron and photon candidates for the first trigger level (L0) [6] and for the reconstruction. In particular, the SPD is used as part of the L0 which works at a frequency of 40 MHz by tagging the electromagnetic candidates as electrons or photons and by providing a fast estimation of the charged track multiplicity per event. Its multiplicity has already been efficiently used as the standalone trigger for the LHC injection test events and as part of the minimum bias trigger on any proton-proton interaction in first 2009 & 2010 collisions. It also has been used to monitor the luminosity and it can be used to veto high occupancy events when the luminosity provided by the LHC will be high.
The SPD is composed by a layer of 6016 square scintillating plastic cells. The cells have a depth of 1.5 cm, and a side length ranging from 4 to 12 cm to accommodate the fact that the occupancy decreases as the distance to the beam pipe increases. The lateral segmentation is the same as in the PS and ECAL, which is mainly used for photon identification. The cells are readout by wave-length shifting fibres, which take the light to 64-channel multi-anode phototubes. The SPD very front-end (VFE) electronics integrates the PMT signal in the 25 ns window defined by the LHC bunch crossing rate [7]. Then, it performs a binary discrimination with a threshold placed at half the peak of the deposition of minimum ionizing particles (MIP). The resulting bit is used to tag the trigger candidates as electrons or photons, and the sum of bits determines the event charged multiplicity. In order to cope with the required working frequency, the SPD VFE design includes two independent integrators and comparators for each channel, which are used alternatively.

3. Time alignment
A first requirement of the commissioning of the detector was the synchronization of its integration time to the passage of particles from LHC collisions. This needed to be done with a precision of 1 ns, in order to both maximize the signal efficiency and reduce the spill-over. The delay in the integration time is applied at the VFE level, which implies that groups of 64 channels have the same starting integration time. At the right integration time there should not be signal in the previous bunch crossing and a small signal in the following one. To do that it has been used the capability of the LHCb trigger to readout several consecutive bunch crossing around the bunch crossing where the collision takes place [8].

A first synchronization with respect to the electromagnetic and hadronic calorimeter integration time was obtained by using cosmic rays. Vertical flux in the cavern has been measured to be 0.9 Hz/m² (under HCAL). In order to mimic as much as possible the particles coming from p-p collisions, a selection of horizontal cosmics (< 30°) was performed with an estimated rate of 0.0046 Hz/m². The events were triggered using the coincidence of signal at the ECAL and HCAL at a rate of 10 Hz. Although LHCb geometry is not well suited for cosmics, more than 4 million were triggered. The reconstruction of cosmic tracks is done by using only the calorimetric information. This provides information of the slope of the track and the arrival time of the cosmic muons with respect to the integration of the calorimeters. The later was obtained by comparing the energy collected by the calorimeters in consecutive integration windows [9]. As can be seen in Figure 1 the statistical precision provided by the method, using 1 million cosmic events, is around 0.5 ns with a synchronization relative to the ECAL of 2 ns. The delays obtained using this method were implemented in October 2009.

The final synchronization with respect to particles from the interaction point was obtained by scanning the starting time of integration during part of the collision data-taking of 2009 [10]. After a second scan in 2010, the analysis of the results allowed to find the optimal delay parameters with a statistical precision of about 0.3 ns with 600k events and a VFE intercalibration of about 1 ns. Figure 2 shows the last delays applied in the electronics in April 2010.

4. Calibration
The second important aspect of the SPD commissioning is its calibration. The initial position of the discriminating thresholds were determined from a calculation based on the different gain factors that enter in the detection chain: the number of photoelectrons at the PMT, the gain of the PMT (calibrated as a function of the high voltage), and the gain of the electronics [11], this will be referred as precalibrated units. The fine calibration has to be done with charged particles from cosmic rays and LHC collisions.
Due to the binary output of the SPD electronics it is necessary to use dedicated methods based on the scan of the threshold position. The procedure measures the SPD efficiency to detect charged particles as a function of the discriminating threshold. The efficiency is defined as the ratio between the number of hits with a track in a given cell and the number of tracks pointing to a given cell. The result of the efficiency as a function of the threshold can be compared with the theoretical expectation given by the integral of the convolution of a Landau and a Poisson distribution. The Landau distribution describes energy lost by charged particle traversing a thin layer of material while the Poisson distribution describes fluctuations in the number of photoelectrons generated at the photocathode. The shape of the theoretical function as a function of the SPD threshold in precalibrated MIP units can be seen in Figure 3. The resolution in the electronics to set the threshold is 5% of $E_{MIP}$ which directly sets our objective resolution at the 5% level.

The first threshold calibration was performed using cosmic rays using a discriminant threshold of 1 precalibrated MIP. The track selection criteria was based on two main requirements. Firstly, the direction of the cosmic had to have low angle to avoid excessive ionization in the detector and secondly the arrival time of the cosmic had to be centered in the integration window to avoid any loss in the signal. As the statistics were limited, only a correction factor per VFE was
Figure 3. Theoretical efficiency as a function of the discriminant threshold in precalibrated units.

Table 1. Statistics used for calibration.

| Threshold ($E_{MIP}$) | # collisions |
|-----------------------|--------------|
| 0.3                   | 2.5 M        |
| 0.5                   | 2.7 M        |
| 0.8                   | 3.9 M        |
| 1.0                   | 3.8 M        |

extracted. As cells in the same VFE have the same high voltage applied we were sensitive to possible problems in the HV settings. Figure 4 shows the correction factor per VFE obtained from cosmic data and one can see that the pre-calibration was correct up to a 20% level.

Figure 4. Threshold correction per VFE obtained from cosmic analysis. The horizontal line sets the perfect calibration where the correction is not needed.

The channel by channel calibration has been performed using the first data collected in the 2010 run. Data at four different threshold in precalibrated units has been taken with the statistics shown in Table 1.

The corrections have been obtained by fitting the theoretical function to the experimental points, using as free parameters: the calibration constant, the number of photoelectrons and...
the maximum efficiency. The result of one of this fits can be seen in Figure 5. The distribution of the cell calibration constants is shown in Figure 6 where one can see that the dispersion is of the order of 20% which confirms the results obtained with cosmic rays. This corrections were applied to 97% of the cells in June 2010. The missing 3% have not abandoned the high efficiency plateau and a dedicated study to calibrate them will be soon performed with new collision data by taking data at higher threshold values.

5. Conclusions
The SPD is a fully operational detector which is approaching its final design requirements. The commissioning with cosmic rays provided an excellent starting point for the time alignment and for the threshold calibration. The statistical precision in the relative time alignment measurement using cosmics rays was 2 ns while the threshold calibration showed that the precalibration was correct up to the 20% level. The final time alignment with collisions has provided a precision of 1 ns. The final calibration constants have confirmed the results obtained with cosmics rays and have already been applied to the 97% of the cells.

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