LHCb Preshower (PS) and Scintillating Pad Detector (SPD): commissioning, calibration, and monitoring

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Abstract. The calorimeter system of the LHCb experiment comprises in front to the electromagnetic and hadronic calorimeters a double detector, aimed at tagging the electric charge and the electromagnetic nature of the calorimeter clusters for the first level of trigger. It consists of two planes of scintillating pads separated by a 2.5 radiation lengths lead sheet. The first scintillating plane is the SPD. The second plane and the lead form the Preshower. Their design and construction are recalled. Their performance and calibration strategies are discussed and illustrated by recent results.

1. Introduction
The LHCb experiment, one of the four particle physics detector experiments on the Large Hadron Collider accelerator at CERN, will perform a through study of CP-symmetry violation and rare decays of b-hadrons which should complete the understanding of quark flavor physics in the framework of the Standard Model, and may reveal assign of the physics beyond. Interest in CP violation comes not only from elementary particle physics but also from cosmology, in order to explain the dominance of matter over antimatter observed in our universe, which could be regarded as the largest CP violation effect ever seen.

The LHCb is a single arm spectrometer with a forward angular coverage from approximately 10 mrad to 300 mrad in the horizontal projection and 250 mrad in the vertical projection. The choice of the detector geometry is motivated by the fact that at high energies both the quarks from bb-pairs are predominantly produced at small angles to the beams, a feature exploited in the flavor tag (as described in the LHCb technical proposal [1]). The LHCb consists of a beam pipe, a magnet, the Vertex Locator (VELO), four stages of tracking system, two Ring Imaging Cherenkov, the calorimeters, the Muon System, and the Trigger [2] (Figure 1).

The LHCb trigger has two decision levels. Using custom made electronics, the first decision is made based on high transverse momentum hadrons or electrons found in the calorimeter system, or muons found in the muon system, at the bunch crossing rate of 40 MHz. All data from the detector are then read out at a rate of 1 MHz and sent to a CPU farm for further event reduction. For this purpose, all the detector information is available.

2. LHCb Calorimeter and SPD/PS detector role
The main purpose of the calorimeter system is the identification of hadrons, electrons and photons, and the measurement of their energies and positions. This information is the basis of the Level 0
trigger, and therefore has to be provided with sufficient selectivity in a very short time. The set of
constraints resulting from this functionality defines the general structure and the main characteristics
of the calorimeter system and its associated electronics [1]. The ultimate performance for hadron and
electron identification will be obtained at the offline analysis level. This stage, however, has little
influence on the detector design.

The Calorimeter is composed of an electromagnetic calorimeter (ECAL), followed by a hadron
calorimeter (HCAL), and before both of them there is a double detector made by three layers, the
Scintillator Pad Detector (SPD), a 2.5 radiation lengths lead wall, and the Preshower (PS) [3]. The
SPD/PS system helps the calorimeter on the requirement of good background rejection and reasonable
efficiency on the detection of photons with enough precision to enable the reconstruction of B-decay
channels containing a prompt photon or $\pi^0$ and on the electron identification. The SPD (Scintillator
Pad Detector) identifies charged particles, and allows electrons to be separated from photons. The
PreShower detector identifies electromagnetic particles. The electromagnetic calorimeter ECAL, of
the shashlik type, measures the energy of electromagnetic showers. The hadronic calorimeter HCAL,
made of iron with scintillator tiles, measures the energy of the hadrons.

3. SPD/PS design
The SPD and PS are two planes of scintillator pads separated by a lead 12 mm thick sheet. A groove in
each pad holds the helicoidal wave lift shifting (WLS) optical fiber which collects the scintillating
light (Figure 5). The transmission of this light is done by long clear fibers to multi-anode
photomultipliers tubes (MAPMT) that are located, along with the Very Front End (VFE) electronics in
boxes above and below the detector in order to optimize the light yield at the MAPMTs. To handle the
data for the first trigger level as quickly as possible, the signals are shaped directly at the VFEs.
on the PS the VFE just shapes and integrates the signal, the SPD VFE includes a discriminator telling whether a cell has been hit. The PS signal is digitised in the Front End (FE) electronics placed in crates on top of the calorimeter detectors after 20-30 m of cable (see Figure 3). The FE boards hold the data of each channel, sampled at 40 MHz, in digital pipelines waiting for the first level trigger decision. Next to the FEs, the SPD Control Boards (CB) includes the functionality necessary to configure the SPD VFEs and deliver the SPD multiplicity trigger.

3.1. Cell geometry

The cell granularity of SPD/PS is projective as respect to ECAL. As displayed in Figure 4, the cells are about 4x4 cm$^2$, 6x6 cm$^2$, and 12x12 cm$^2$ for inner, middle, and outer parts, respectively. The exact size of the cells is proportional to their distance from the vertex in order to obtain a pointing geometry.

Each square represents a group of 64 cells (a few are only 32) which corresponds to a readout electronics group of channels. Both SPD and PS planes are divided in 8 vertical parts called Super Modules (SM) which contain from 7 to 22 VFE units with its corresponding electronics positioned on the boxes over and below de detector cells.

3.2. Detector pads calibration

The detector structure provides an average of about 25 photoelectrons in response to a minimum ionizing particle (MIP) which is enough to allow to distinguish between electron and photon showers.
All the cells were calibrated before the installation using the final Super Modules and some calibrated MAPMTs. The SMs were placed horizontally and data was taken to obtain the number of photoelectrons per MIP on each cell. Figure 6 shows an example of the measured number of photoelectrons of all the cells in a SM.

![Figure 5. A SPD/PS detector cell. It can be observed the helicoidal WLS fiber and the LED.](image1)

![Figure 6. Number of photoelectrons per MIP on all the cells in one of the Super Modules of the SPD/PS.](image2)

4. Commissioning

4.1. Pedestals/offset and noise

Prior to any measurement with any of the SPD/PS detectors, it is necessary to perform an analysis of the noise and the pedestals (or threshold offset for the SPD) for all channels. The SPD/PS pedestals and noise have been extensively studied and the results are plotted in Figure 7 and Figure 8. All the PS channel pedestals are below 300 ADC counts with a mean of about 140 ADC counts. And, whereas 1 MIP is approximately 10 ADC counts, the noise is essentially less than 1.2 ADC counts.

![Figure 7. PS pedestals and noise (all 6016 channels).](image3)

![Figure 8. SPD offset values (all 6016 channels).](image4)

On the SPD side, the channel offset values are distributed around –70 mV with a standard deviation of about 70mV (as exposed in Figure 8). Although the noise on SPD channels is not represented here, it is confined to values lower than 3 mV, which is much less than the signal corresponding to 1 MIP (100 mV).
4.2. Time alignment

Since all signals between the VFE and the FE boards communicate through long cables (20-30 m) and the time requirements for the data capture are sharp (the detector clock is of 40 MHz), all the FE boards are equipped with time delay units to ensure a correct communication on each line.

For the PS electronics there are three phases (Figure 9) to be set so the data transmission has no errors. Additionally, these phases are correlated.

- The signal integration starting time ($\Phi_{VFE}$). It depends essentially on the data cable length and integration clock.
- The sampling of the VFE signal by the ADC in the FE ($\Phi_{VFE-ADC}$).
- The sampling of the ADC signal by the FEPGA ($\Phi_{ADC-FE}$).

![Figure 9. Phases to be set within PS boards.](image)

![Figure 10. Phases to be set within SPD boards.](image)

![Figure 11. PS time alignment: sample VFE integration ($\Phi_{ADC-FE}$ fixed).](image)

The alignment method followed for the PS phases comprises three steps:

- $\Phi_{VFE}$ is obtained scanning and searching for the maximum value from the VFE output.
- Fix a correct value of $\Phi_{ADC-FE}$, then, using LED signal, it can be scanned the allowed $\Phi_{VFE} - \Phi_{VFE-ADC}$ difference (Figure 11).
- Taking a fixed $\Phi_{VFE}$, it is possible to scan the allowed $\Phi_{ADC-FE}$ and $\Phi_{VFE-ADC}$ region from pedestal measurements (Figure 12).
In the case of the SPD electronics (Figure 10), the phases to be set within SPD boards are just the ones corresponding to the signal integration starting time ($\Phi_{\text{VFE}}$) and the VFE data read at the FE ($\Phi_{\text{VFE-FE}}$), which are correlated as well. Unlike PS signal, the data sent by the SPD VFEs is only 1 or 0 for each channel. Fortunately, the VFE includes a special mode which allows different patterns to be sent and perform bit error rate tests. These can be done for all possible $\Phi_{\text{VFE}}$ and $\Phi_{\text{VFE-FE}}$. As for the PS, a 2D plot can be obtained but is not included in the present document for space saving.

4.3. LED measurements
All SPD/PS channels have taken measurements using the LED system. In Figure 13 it is illustrated a 2D display of the PS detector showing measured LED peak signal in ADC counts above the pedestal value. Due to the fact that LED signals vary on a large scale, the LED system will be essentially dedicated to detect dead channels, check the detector stability, and help for the coarse time alignment.

![Figure 13](image)

**Figure 13.** PS measures of LED light peak value in ADC counts above pedestal value.

![Figure 14](image)

**Figure 14.** A cosmic event measured by all the calorimeter detectors (SPD, PS, ECAL, and HCAL).

![Figure 15](image)

**Figure 15.** SPD coarse time adjustment example: accumulated signal during a cosmic run in consecutive time slots.

![Figure 16](image)

**Figure 16.** Example of a SPD/PS mapping problem. On top, ECAL signal and the scattered signal on PS are shown. On bottom, the mapping has been fixed.

4.4. Cosmics measurements
Data from cosmic events has been taken using all the calorimeter at an approximated rate of 10 Hz using the HCAL and ECAL coincidence as a trigger. These cosmic runs are the nearest approach to
the normal data taking previous to the beam and include the full data and first level trigger paths. Even sometimes the runs are done together with other parts of the LHCb detector, such as the muon chambers and the trackers.

Cosmic runs are useful not only for checking the detector functionality, their data can also be analysed providing an initial time alignment between sub-detectors and to identify problems such as mapping issues like miscabling, mislabelling (Figure 16) and non-working channels.

The calorimeter presents a very useful feature which offers the possibility of storing +/-7 previous and next time slots (or experiment clock cycles). This way, the data taking strategy is simple; the events are triggered with ECAL and HCAL coincidence and include the data corresponding to the same time slot plus the 7 previous and 7 next time slots for time alignment.

After some runs, the pipelines in the FE electronics have been adjusted so most of the cosmic events are triggered in the same time slot as ECAL and HCAL for both SPD and PS. In Figure 15 it is shown, as an example, that the accumulated signal on SPD in consecutive time slots is a peak centered in the same time slot as the trigger. At the present moment, further analyses are ongoing for fine time alignment (within one clock cycle) which would lead to a good starting point for the exact integration time when the first LHC beam will be available.

5. Calibration methods

Although SPD and PS are very similar in construction and electronics, their data output is not. While the PS digitizes the signal with 10 a bit ADC, the SPD provides a discriminator (i.e. 1 bit for each channel). This difference leads to dedicated calibration methods for each one. Along with the MAPMT gain values (set by their bias voltage), the SPD needs to adjust the threshold and measure the offset values whereas the PS, the gain corrective values and pedestals, which will be performed periodically with a frequency depending on the corresponding stability.

5.1. PS Calibration procedure

Taking advantage of the fact that the occupancy is relatively low (about the 10%), there is the possibility of running offline pedestal measurements on data.

On the FE boards, there are gain corrective factors for all channels to compensate for the non-uniformities of the detector and MAPMTs. A good way to find out the gain corrective factors with MIP particles involves the following steps: first select the expected gain (by setting the corresponding PMT bias voltage), then, identify the channel with the highest MIP value and tune the PMT bias voltage so 1 MIP corresponds to 10 ADC counts. Once this is done, adjust the other channels of the same MAPMT corrective factors so all of them present 10 ADC counts per MIP.

**Figure 17.** SPD threshold scan for one channel without signal. The 1 to 0 transition shows the offset value of the channel. Offset measurements require about 1000 triggers and 128 steps.

**Figure 18.** Energy deposited in a SPD cell derived from a threshold scan (from MC simulations). The expected optimum value to separate electrons for photons is 0.7 the energy of the MIP peak.
5.2. SPD calibration: threshold scan

SPD is a binary detector intended to distinguish between charged particles and photons. Each channel output is 0 or 1 depending whether the input signal is below or over a programmed threshold. Although a direct and accurate measurement of the signal is not feasible, there is the possibility to perform a threshold scan.

A threshold scan suitable for the offset measurements (or even LED periodic signals) is performed by, first, fixing a low threshold value, taking N events. Afterwards, it is repeated for increasing values of threshold. In the end, it can be represented the number of ones obtained divided by N for each threshold value. The transition from 1 to 0 is a measure of the VFE signal (Figure 17).

When a threshold scan is done using particles signal the output of the SPD on each step represents the number of events with an energy (proportional to the threshold) or lower. Therefore, the resulting accumulated histogram is differentiated in order to obtain the number of events with a deposited energy (Figure 18). The total estimated time is about 30 seconds per step by 20 threshold steps to be able to fit a curve of the MIP peak. Once the peak is fitted, the expected optimal threshold position to distinguish between photons and charged particles is 0.7 times the energy value of the peak.

6. Monitoring

A dedicated Monitoring farm will reconstruct events online at 5 Hz. Dedicated tools are being developed and will be useful to monitor:

- The PS trigger rate stability done by checking that the ADC MIP value is constant.
- The PS coefficient of energy for ECAL correction. It can be calibrated with electrons and refine the MIP calibration.
- The SPD efficiency on charged particles identification.
- The occupancy for checking the pedestal stability, the detector ageing, and noisy channels.
- The crosstalk between channels.
- Dead channels.

In addition there will be 10 Hz of LED triggers during normal data taking synchronized with empty bunches. LEDs will be flashed by regions and their data is aimed for the fast detection of dead and noisy channels.

7. Conclusions

The SPD/PS system, two planes of scintillator pads separated by a lead sheet, is designed for the tagging of the electric charge and the electromagnetic nature of the LHCb calorimeter clusters for the first trigger level. Both SPD and PS detectors are fully equipped and working at the present.

Runs have been made using cosmic data to test the detector functionality, electronics, data acquisition and trigger paths, and efficiencies. In addition, cosmic data has been used for time alignment between calorimeter sub-detectors.

SPD and PS calibration methods have been studied and require different approaches. PS needs MIP particles to adjust the gain corrective factors, while a threshold scan is essential in order to distinguish charged particles from photons at the SPD.

The tools for the monitoring the efficiency and correct operation of the SPD/PS have been defined and are under development.

References

[1] S. Amato et al. (LHCb collab.) 1998 LHCh Technical Proposal (CERN LHCC 1998-4)
[2] S. Amato et al. (LHCb collab.) 2003 LHCh reoptimized Detector Design and Performance Technical Design Report (CERN LHCC 2003-030)
[3] S. Amato et al. (LHCb collab.) 2003 LHCh Calorimeters Technical Design Report (CERN LHCC 2000-0036)