THE RADIATION MONITORING SYSTEM FOR THE LHCb INNER TRACKER

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Abstract

The performance of the LHCb Radiation Monitoring System (RMS) designed to monitor radiation load on the Inner Trackersilicon micro-strip detectors is presented. The RMS comprises Metal Foil Detectors read-out by sensitive Charge Integrators. MFD is a radiation hard detector operating at high charged particle fluxes. RMS is used to monitor radiation load as well as relative luminosity of the LHCb experiment. The results obtained by the RMS during LHC operation in 2010–2011 are compared to the Monte-Carlo simulation.

THE LHCB DETECTOR AND THE SILICON TRACKER

The LHCb experiment is the forward spectrometer and one of the four experiments located at the LHC. The main aim of the LHCb is precise measurement of the CP-violation and research of the B-meson rare decays [1].

The LHCb, as high energy physics detector, consists of following parts: Vertex Locator (VELO), Inner and Trigger Trackers (IT, TT) and Outer Tracker to reconstruct tracks of charge particles and they decay vertexes and to separate Primary (proton-proton collisions) and Secondary (B-mesons decay) Vertexes (PV, SV); Magnet to measure charge particle momentum; Cherenkov Detectors (RICH1, RICH2) to separate kaons and pions; Hadronic and Electromagnet Calorimeters (HCAL, ECAL) to measure the particles energy; Muon detector to detect the muons.

The LHCb Silicon Tracker (ST) is a large-surface silicon microstrip detector that constitutes an important part of the LHCb tracking system. It uses single-sided silicon strip detectors with a strip pitch of approximately 200 µm, produced from 6” wafers and arranged into up to 38 cm long readout strips. he Silicon Tracker consists of two parts: the “Tracker Turicensis” is located in between RICH1 and the LHCb dipole magnet and the “Inner Tracker” [2] covers a cross-shaped area around the LHC beam pipe in tracking stations T1–T3, in between the LHCb dipole magnet and RICH2.

The level of charged hadron fluxes at the location of the silicon sensors of the IT-2 station varies from about 10^4 to $10^5\,cm^{-2}s^{-1}$ at nominal LHCb luminosity ($2 \times 10^{32}\,cm^{-2}s^{-1}$) [3]. These fluxes are high enough to make a significant damaging impact onto the performance of the IT sensors and their frond-end electronics (Beetle). So, IT requires the system to monitor radiation loads on Si-sensors. This is task for the Radiation Monitoring System.

THE RADIATION MONITORING SYSTEM FOR THE LHCB INNER TRACKER

The main goal of the Radiation Monitoring System (RMS) is a measurement of the radiation dose load onto silicon micro-strip sensors of the IT LHCb as well as front-end electronics in order to exclude their damage as a result of an unexpected radiation incident, i.e. change of the beam trajectory, partial beam loss in the region of the detector etc [4, 5].

The RMS is based on the Metal Foil Detector (MFD) technology. The principle of the MFD operation explores Secondary Electron Emission (SEE) phenomena from the metal foil surface (emission layer $\sim$10-50 nm) caused by impinging charge particles. SEE causes extra positive charge on an isolated metal foil read out by sensitive Charge Integrator (ChI).

Several MFD advantages have determined our choice for the IT RMS:

- The possibility to provide extremely low mass of the detecting material (from practical point of viewfew tens µm);
- Simple readout electronics (charge integrators and scalers);
- Low operating voltage ($\sim$20 V);
- High radiation tolerance;
- Long term performance with minimal maintenance;
- Low cost.

From the technical point of view MFD is a 5-layer structure manufactured out of 50 µm thick Al foils supported by insulating epoxy frames. The central sensitive layer is connected to the readout electronics, while two neighboring (from both sides) accelerating layers are biased by positive voltage (HV, 24 V) to reduce recombination after SEE. The two outer shielding layers are grounded. RMS Sensor and accelerating layers are divided into 7 parts (110 × 75 mm, with a layout which is similar to IT silicon sensors size). The RMS consists of 4 modules (Top, Cryo, Bottom, Access) containing 7 sensors each (in total 28 sensors), which are located at IT-2 station ($\sim$8.4 m from interaction point) around the Beam Pipe. Due to IT-boxes overlapping the Top-module is shifted up on $\sim$5 cm from the Beam Pipe.

The RMS readout electronics consists out of the six 5-channel sensitive ChIs [6] and 32-channels LVDS VME-scaler (C.A.E.N. V830 LC). The ChIs were developed at INR (Kyiv, Ukraine) and have been modified at MPIfK (Heidelberg, Germany). The ChI’s principle of operation includes a current-to-frequency converter allowing to achieve high dynamic range (up to 10^6). A current from the stable external source (250 pA) is injected to the ChI's inputs to make base lines (25 kHz). The tipical features of the RMS is presented in Table 1. The RMS is designed for the monitoring of charge particle fluxes exceeding $\sim$2500 MIP/s per sensor.

Table 1: Typical Features of the RMS

Name	Value
ChI conversion factor	10 fA—1 Hz
SEE factor	$\sim$25 SE/MIP
RMS response	30 MIP/cm^{2}s—1 Hz

RESULTS

During the year 2010 LHC has provided colliding proton beams at 7 TeV (c.m. energy) delivering 42 pb^{-1} at LHCb, in total. The charged particle fluxes high enough to evoke a signal in the RMS were during high intensity beams (starting from the 20$^{\text{th}}$ of September'10) which contributed 29 pb^{-1} into the total delivered luminosity. As it is shown in Fig. 1 RMS response is linear correlated with the LHCb measured luminosity. This has been used to calibrate the RMS for measuring luminosity in future as well as to extrapolate RMS measured data on low intensity beams colliding which usually occur at the beginning of the LHC operation after shutdowns.

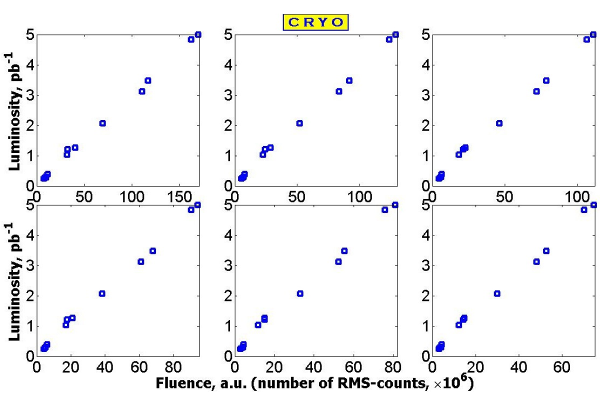

Figure 1: Correlation between the RMS response and the LHCb measured Integrated Luminosity in 2010. The response from 6 sensors of the RMS's Cryo module is presented for illustration.

LHCb Integrated Luminosity Measured by the RMS

In 2011, the first protons collisions at LHCb occurred on the 14$^{\text{th}}$ of March. Till 18$^{\text{th}}$ of March low intensity beams collided producing charged particle fluxes insufficient to evoke a response in the RMS. Total integrated luminosity of these first collisions has not exceeded 3% of the annual one.

Due to power cut the RMS had not been operating 10 days in July missing 41 pb^{-1} of data which correspond to $\sim$6% of annual integrated luminosity.

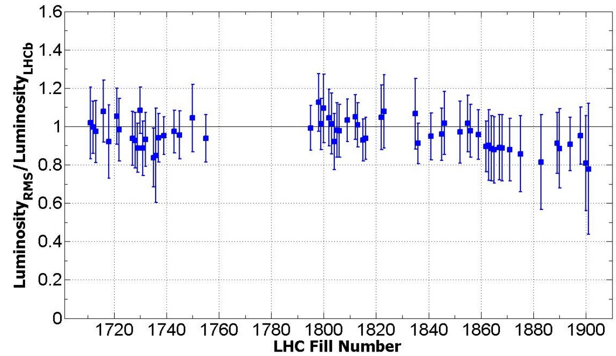

Figure 2: A Ratio of the luminosity measured by RMS to the LHCb one.

So, the RMS measured about 90% of the total integrated luminosity. The uncertainty of those measurements is about 10%. This accuracy is sufficient for the on-line monitoring of the integrated luminosity during pp-collisions at the LHCb.

The RMS data agrees well with the LHCb ones [7]. Figure 2 presents a ratio of the integrated luminosity measured by RMS to LHCb's one calculated for the 61 LHC Fills ($\sim$400 pb^{-1}, April-May'11).The uncertainty of the on-line LHCb's luminosity data is about 10%.

Radiation Load over IT Si-sensors Measured by the RMS

As it was mentioned above, RMS's main goal is monitoring of the radiation load on LHCb Inner Tracker sensors. During the 2011 year RMS performance allowed to measure 90% of the radiation load. Perfect linearity of the RMS response with respect to the integrated luminosity (see Fig. 1) makes it possible to extrapolate data into the 'unmeasured zone.

In total, over 1 fb^{-1} integrated luminosity has been delivered to the LHCb in 2011 year. Dose Distribution over IT Si-sensors measured by the RMS corresponding to this integrated luminosity is shown in Fig. 3.

An absorbed dose varies from 100 to 400 Gy depending upon the sensor. Sensors closest to Beam Pipe get higher doses then peripheral ones. These doses correspond to (0.4–1.5) $\times$ 10^{12} MIP/cm^2 which results in 50–200 μA leakage currents increase over Si-sensors, respectively. This requires Si-sensors cooling down and bias voltage tuning to keep reliable operation of the IT. The uncertainty of the measurements does not exceed 10%.

The leakage currents data evaluated by the RMS are in good agreement with a direct leakage current measurements as well as with the Monte-Carlo predictions for the charged particle fluxes (see below).

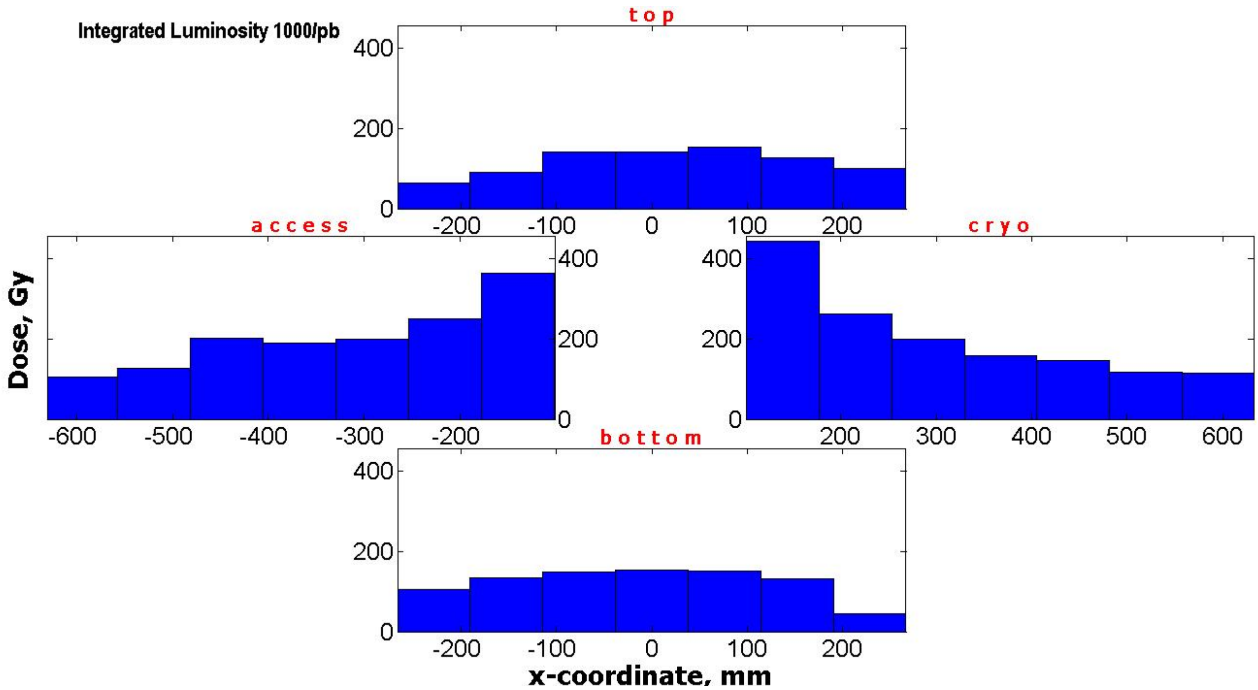

Figure 3: Dose Distribution over the IT Si-sensors measured by the RMS in 2011.

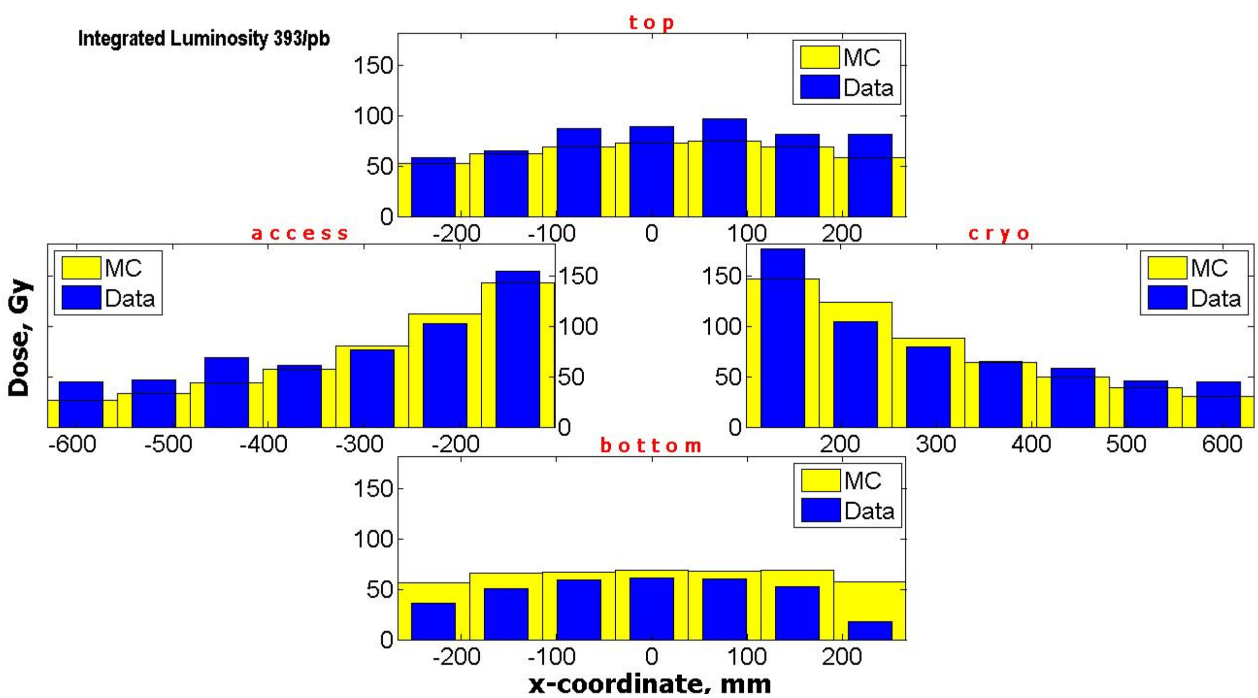

Figure 4: Comparison between real and MC simulated RMS data.

Comparison Between Real and Monte-Carlo Simulated RMS Response

Using standard LHCb software (Gauss v38r9) [8], 10k events under following condition were generated:

- a center of mass energy of the colliding proton beams—7 TeV,
- the average number of pp-interaction (including elastic which is not visible in the detector) per bunch crossing (ν) is 2.5,
- different LHCb Dipole Magnet polarity—up and down,
- charge particle, only, were included.

These conditions are very similar to the real one during 2011 LHC operational year.

The resulting particle fluxes distribution over sensors in comparison with the data measured by the RMS is shown in Fig. 4.

Good agreement is observed for all modules but the 'Bottom' one. This disagreement is under study and might be caused by the Beam Pipe supporting tools located just in front of the RMS not included in the MC simulations.

CONCLUSION

During the LHC operational year 2011 the Radiation Monitoring System has provided monitoring of the radiation load on Si-sensors of the LHCb Inner Tracker. RMS data have allowed also to determine the integrated luminosity as well. The RMS data are in good agreement with data obtained by other detectors as well as with Monte-Carlo simulations. These data are planned to be included into the on-line monitoring of the radiation load and integrated luminosity.

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