THE FIRST LHC BEAM IMPACT MEASURED
BY THE LHCB INNER TRACKER RADIATION MONITORING SYSTEM

O. Y. Okhrimenko[1], **V. M. Iakovenko**[1,2], **V. M. Pugatch**[1]

[1] *Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv, Ukraine*
[2] *Laboratoire de l'Accélérateur Linéaire, Université Paris-Sud, Orsay, France*

In present paper, the performance of the LHCb Inner Tracker (IT) Radiation Monitoring System (RMS) is described. The first Beam impacts detected by the RMS are presented. The charge particle fluxes are evaluated. The RMS measured data agree well with Monte-Carlo simulation.

1. Introduction

1.1. The LHCb Detector and the Silicon Tracker

The LHCb experiment is the forward spectrometer and one of the four huge experiments located at the LHC. The main aim of the LHCb is precise measurement of the CP-violation and researching 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 (Fig. 1).

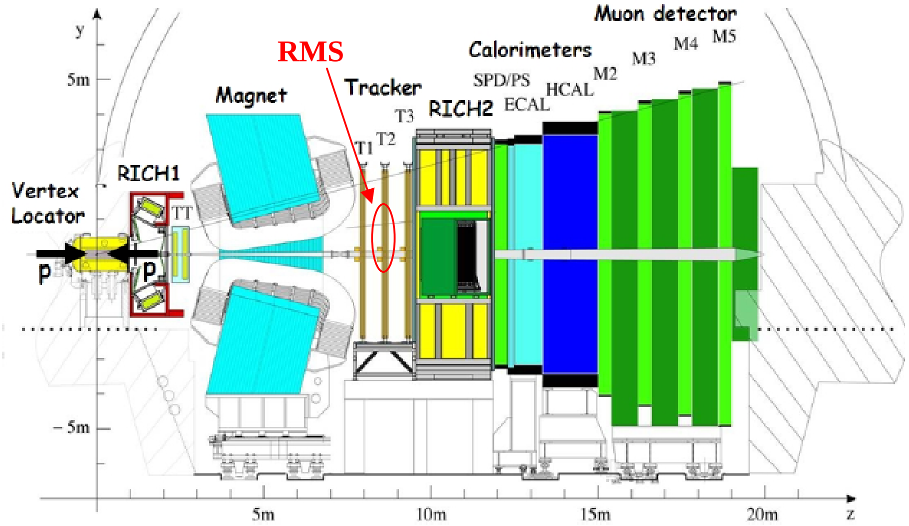

Fig. 1. The LHCb detector.

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. The 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 $10^4\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to $10^5\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at nominal LHCb luminosity ($2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) [3]. These fluxes level are high enough to make a significant 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.

1.2. The Radiation Monitoring System of 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].

The RMS is based on the Metal Foil Detector (MFD) technology. The principle of the MFD operation is Secondary Electron Emission (SEE) from the metal foil surface (emission layer ~10 - 50 nm) caused by impinging charge particles. SEE causes extra positive charge on a 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 view - few tens µm);
- Simple readout electronics (charge integrators and scalers);
- Low operating voltage (~20 V);
- High radiation tolerance;
- Long term performance with minimal maintenance;
- Low cost.

The 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 neighbouring (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 (~8.4 m from interaction point) around the beam-pipe (Fig. 2). Due to IT-boxes overlapping the Top-module is shifted up on ~5 cm from the beam pipe.

The RMS readout electronics consists out of the six 5-channel sensitive ChIs [5] 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).

Typical features of the RMS

Name	Value
ChI conversion factor	1 fA - 1 Hz
SEE factor	~25 SE/MIP
RMS response	30 MIP/cm^{2}s - 1 Hz

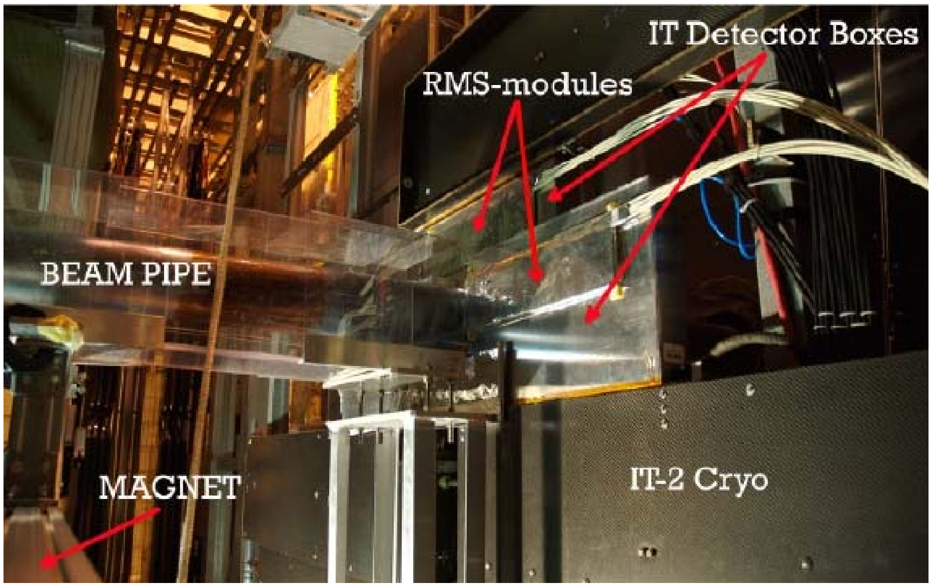

Fig. 2. Photo of the RMS modules installed at IT-2 station.

2. The First LHC Beam Impact Measured by the LHCb IT RMS

The RMS is designed for the monitoring of charge particle fluxes exceeding ~300 MIP/cm^{2}s. During the first collisions at the LHC in November-December'09 proton beams intensities were not high enough to produce charge particle fluxes that could be detected by the RMS. Yet, there were two incidents when charge particle fluxes have evoked the RMS response. It has happened during aperture scan (midnight 02-03/12/2009) and high-intensity beam collisions (14/12/2009) with the beams energy of $\sqrt{s}$ = 900 GeV.

According to the LHC logbook at about midnight on the 02-03/12/09, in the IP-8 aperture scans (vertical (V) and horizontal (H)) were made. Beam was moved in vertical and horizontal plane up to ~±1 cm from the center position. During each of V-scans proton beam has touched the beam pipe and resulted in significant particle fluxes, which were detected by the RMS (Fig. 3). In the Fig. 3 all RMS-modules response (baselines subtracted) are shown during only 2nd V-scan.

The RMS data compared with other Beam and Background Monitoring Tools, such as Beam Loss Scintillators (BLS), Beam Loss Monitors (BLM) and Beam Condition Monitors (BCM) [6, 7] have demonstrated good agreement with other monitoring systems. During each of V-scan 7 spikes of charge particle fluxes were detected by the RMS. The magnitude of the spikes reached ~500 Hz at the sensors closest to the beam pipe (Figs. 3 and 4).

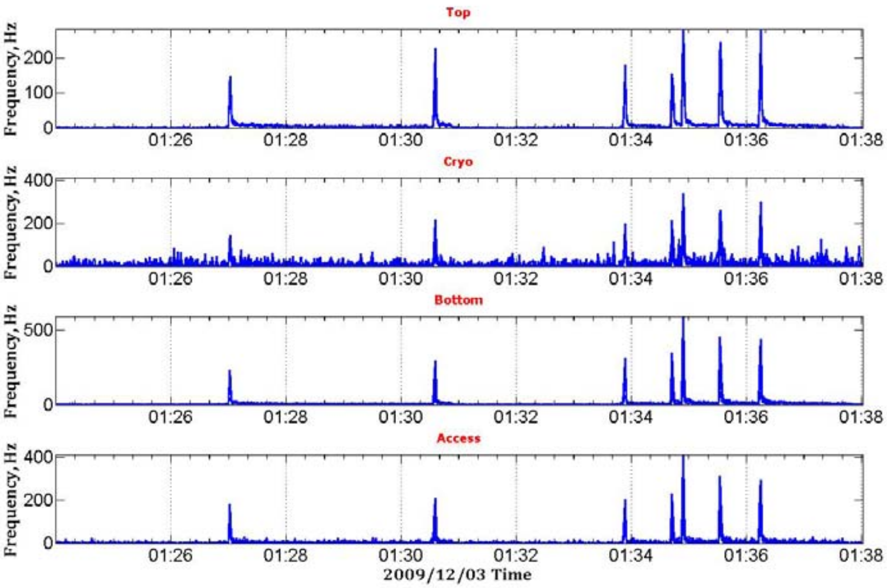

Fig. 3. The RMS responses on beam interaction during aperture scan (03/12/09).

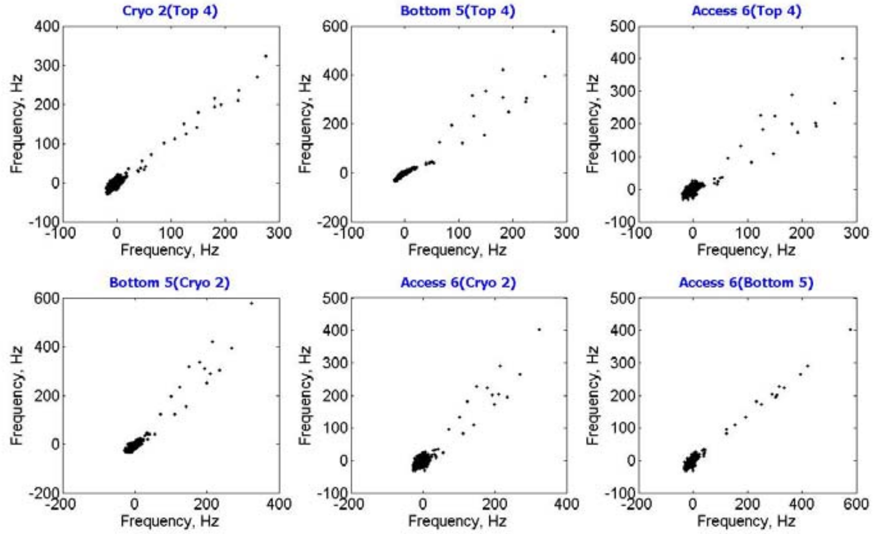

Fig. 4. Time correlation plots between four closest to beam pipe working RMS sensors
(Top 4, Cryo 2, Bottom 5 and Access 6) to be sure that all modules reacted on radiation at same time.

2.1. Estimation of the charge particle fluxes measured by the RMS

As it was mentioned above, the RMS has 1 Hz response to the 30 MIP/cm^{2}s flux of charged MIPs. This is an average value from the previous measurements with Metal Foil Detectors (INR, Kyiv; DESY, HERA-B, Hamburg; CERN, Geneva). Multiplying the RMS rates by factor 30 one obtains the charged particle fluxes in [MIP/cm^{2}s]. The RMS channel's rates and the corresponding charged particle fluxes are shown in Figs. 5 and 6, respectively. Accordingly to the RMS data, charged particle fluxes have reached up to ~1.7×10^4 cm^{-2}s^{-1} and ~10^3 cm^{-2}s^{-1} over the time of aperture scan and high-intensity beams collisions, respectively.

As it was expected, the maximum rates/fluxes were detected by the sensors, which are closest to the Beam Pipe, notably Top-4, Cryo-1, Bottom-3&5, Access-6 (unfortunately, Bottom-4 and Access-7 didn't work), whereas the Top-module rates/fluxes were lower in comparison to Bottoms ones, because Top-module was shifted up by 5 cm.

2.2. Comparison between real and Monte-Carlo simulation of the RMS response.

Using standard software Gauss v38r0 1000 events were generated with 450 GeV proton energy (data sample: $APPCONFIGOPTS/Gauss/MC09-b450GeV-md100-fix1.py") [8].

Charged particles, only, were included in simulation. The number of hits in each sensor was calculated. After that, the normalized simulated data were presented in comparison to the RMS real data, as shown in Fig. 7.

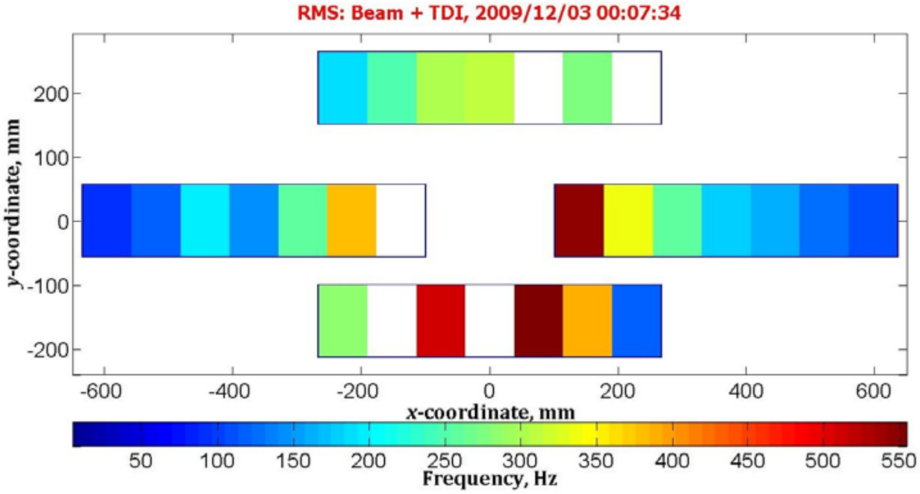

Fig. 5. The RMS sensor’s response distribution on radiation (white – non-operational sensors).

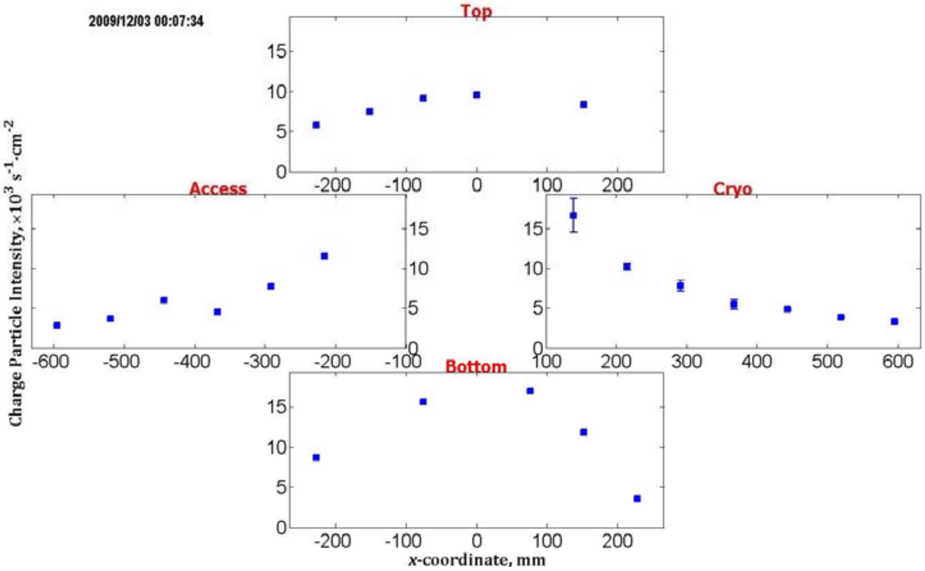

Fig. 6. Flux distribution over the RMS sensors.

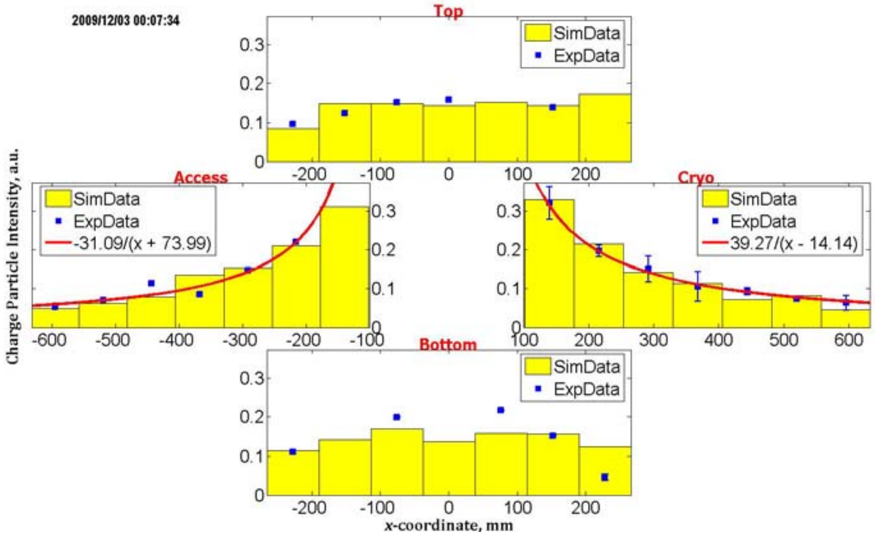

Fig. 7. Comparison between real and MC simulated RMS data.

As one can see, simulated hits distribution is in a good agreement with real data for the Access and Cryo modules. The difference between simulated and real data for the Top and Bottom modules can be explained by the fact that during vertical aperture scans Beam interactions occurred at the border of the Beam Pipe.

Two fits ($\sim e^{-x}$ and ~1/x) for the shape of the charged particle fluxes distribution made for the Cryo-module data reveal the fact that the intensity of charged particle flux slows down as $\frac1 r$ in case of the Magnet switched on.

3. Conclusions

Over the time of the LHC operation in November-December'09, the LHCb IT RMS was being operated permanently. During the first collisions, charged particle fluxes were not sufficient (~300 MIP/cm^2s) to evoke noticible response of the RMS. While during the vertical aperture scan (midnight 02-03/12/09) and high-intensity Beams collisions (14/12/09), some unexpected increases of the radiation background were detected by the RMS. The RMS data are in a good agreement with the measurements by other Beam and Background Monitoring Tools (BCM, BLS, BLM).

The maximum charged particle fluxes were estimated during the November-December operation as well as their distribution over the RMS-sensors was compared with the Monte-Carlo simulation. Fluxes as high as $\sim 1.7 \times 10^4$ $cm^{-2}s^{-1}$ and $\sim 10^3$ $cm^{-2}s^{-1}$ was detected in case of V-scan and high-intensity Beams collisions, respectively.

The RMS has demonstrated expected performance with respect to the ability to detect spikes of the radiation background as well as long term reliable operation.

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