The First Experience with LHC Beam Gas Ionization Monitor

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Abstract

The Beam Gas Ionization Monitors (BGI) are used to measure beam emittance on LHC. This paper describes the detectors and their operation and discusses the issues met during the commissioning. It also discusses the various calibration procedures used to correct for non-uniformity of Multi-Channel plates and to correct the beam size for effects affecting the electron trajectory after ionization.

INTRODUCTION

The Beam Gas Ionization monitors (BGI), often called Ionization Profile Monitors (IPM) on LHC are configured to measure electrons produced in ionization of Neon gas, injected into LHC vacuum chamber. The pressure of injected gas reaches 10^{-8} mbar. The beam passes between two ceramic electrodes with difference of potentials of 4 kV, over a distance of 85 mm. This potential brings the electrons to Multi-Channel Plate (MCP, from Photonis), where the signal is amplified. A phosphor screen is located 2 mm behind the MCP. It is deposited on a right-angle prism, which is the only optical element inside the vacuum. In order to minimize the transverse spread of the electrons, external magnetic field of 0.2 T, directed along electric field lines, is applied. Light produced by the phosphor screen is directed through a vacuum window to an optical system and a CID intensified camera (Thermo-Scientific CID8712D1M-XD4). A schematics of the LHC BGI and a picture of the outside flange are shown in Fig. 1.

The image is amplified in tunnel electronics, which also allows to control the gate of the camera and gain of the internal camera intensifier. A cable of about 150 meter length connects the tunnel electronics with a framegrabber, which is a BTV card installed in a VME crate in the underground gallery. There is no access to the gallery during machine run.

Server programs are running on the crate CPU, controlling the HV and processing the image. The beam profiles are fitted with gaussian assuming linear contribution from the background.

MCP USAGE

During the 2011 run the HV on the MCPs was kept on for most of the time. As a result a local decrease of gain, mainly in the typical beam position, were visible. This nonhomogenity of the MCP response affects the beam profile reconstruction.

Therefore, it was decided to exchange the MCPs during the winter technical stop. Due to technical difficulties the operation has been performed on beam one BGIs only (two out of four installed on LHC). The exchange has not been

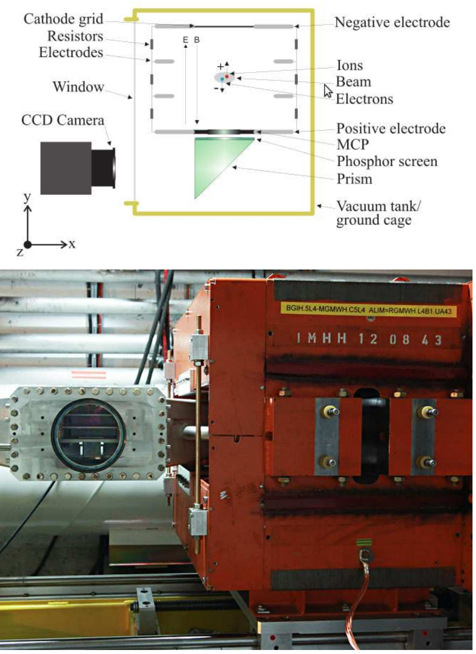


Figure 1: Up: a schematics of LHC BGI (from [1]). Bottom: a photo of the LHC BGI (flange with optical port) in the tunnel, with magnet displaced.

done in a clean room, what could affect the durability of the new equipment. A picture of an MCP in its holder is shown in Figure 2.

Figure 2: Multi-channel plate in its holder.

The newly installed MCPs had a much higher gain but, at the same time, were more sensitive to the signals produced by high-intensity beams. One of them got broken during a scrubbing run in March 2012, when a large electron cloud signal probably lead to high current through the MCP. The second one started to show very unstable HV readings after a crash of HV server which has shut down the voltage sharply. Therefore the remaining two detectors with old MCPs are used along the 2012 run.

A calibration mechanism, which allows to compensate for non-uniformity of the MCP response, has been foreseen [1]. It is based on Electron Generation Plate (EGP), which emits a uniform distribution of electrons. Observation of the image of this emission on the MCP allows to measure gain distribution over surface.

IMAGE PROCESSING

The camera produces artifacts because of the way it transforms the signal (CCIR format) and because of detector elements. It also picks-up electronic noise. The typical image after digitization is shown in Fig. 3.

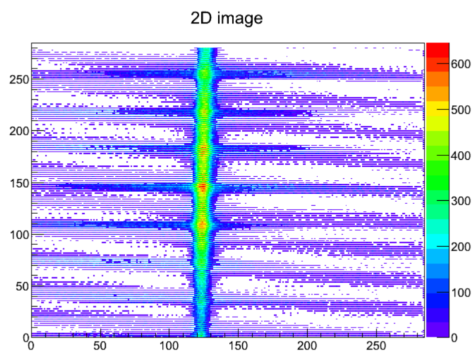


Figure 3: 2D beam image after digitization. Transverse strips are artefacts.

Various filters are tested in order to clean the images. Simple Fourier filter on unfolded, 1D image, seems to provide basic removal of some of the artefacts, but the investigation continues.

CAMERA GAIN CONTROL

The width and amplitude of an ideal gaussian are independent parameters but in a presence of background and non-uniform gain of the MCP the control of the amplitude is necessary to obtain correct measurement of σ. In case of LHC BGI the intensifiers build-in into the cameras provides the best way to control the signal amplitude with large precision and without regulating the sensitive HV. The choice of the optimal amplitude range is a compromise between a possible gas injection pressure, HV settings and camera dynamic range.

An example of the BGI measirement evolution during a ramp of beam energy is shown in Fig. 4.

CALIBRATION WITH ORBITAL BUMP

The scale calibration of the BGI can be performed using orbital bump method. The orbital bump amplitude is regulated with large precision using Beam Position Monitors

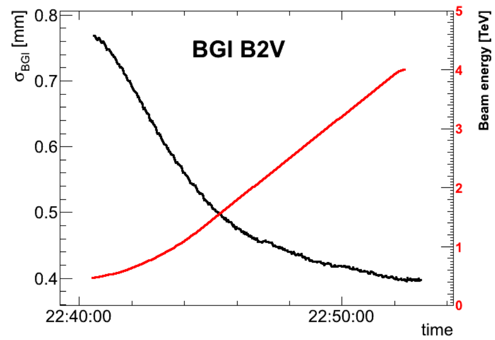


Figure 4: Beam size behaviour during ramp of Pb beam. Beam energy is given in ZTeV.

(BPM). A relation between BGI position and BPM position allows to obtain pixel scaling factor.

The advantage of this method is that it takes into account all possible scaling effects (optical system magnification, camera pixel size, etc.). The disadvantage can be the accuracy of the orbit determination: BGI is located in space in which the BPMs are about 60 meters away. This space contains magnetic elements, therefore the beam position interpolation has limited accuracy. During Long Shutdown 1 (LS1) additional BPMs will be installed in vicinity of BGI.

In Fig.5 determination of the scaling factor is shown. The pixel size is found to be 0.095 ± 0.003 mm. The measurement have been performed during Machine Development (MD) period in June 2012, using high intensity and low emittance proton beam at 4 TeV.

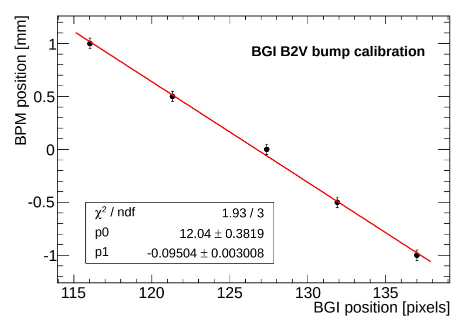
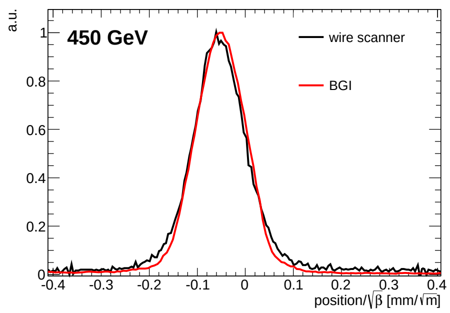


Figure 5: Calibration of the BGI scale using orbital bump.

INTERCALIBRATION WITH WIRE SCANNER

Wire Scanners (WS) provide a reference emittance measurements to other instruments on LHC. Because of fragility of the carbon fibers from one side and low sensitivity of BGI from the other side the typical proton beam does not allow to intercalibrate BGI with the WS. A unique opportunity is presented by lead ion beam. On September 12, 2012 a beam of low intensity (15 bunches, about 10^{10} charges in total) has been in the machine. This beam have low intensity and a maximum gas injection can be performed. At the same time the use of the Wire Scanners was still allowed (no danger to the wire neither to magnet quench). All together the ion beams allowed to measure the emittance with WS to compare it with BGI.

The BGI and WS are located in different locations around the ring. In order to compare profiles obtained by both instruments a scaling of the profiles with optical β function must be done. In Fig. 6 a comparison of beam profiles is presented at injection and at flat top. The β functions used are shown in Table 1.



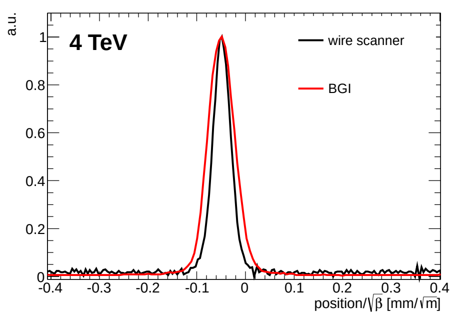


Figure 6: Comparison of beam profiles in wire scanner and in BGI at injection and at 4 TeV.

At injection the BGI profile corresponds quite well to the Wire Scanner one. On the other hand at 4 TeV, when beam becomes quite small, the BGI profile is significantly larger.

Table 1: Optical β functions for WS and BGI [2].

B2V [m]	WS	BGI
injection	418.95	217.19
flat top	451.04	225.35

CORRECTION IN QUADRATURE

The broadening of the profile at flat top with respect to the wire scanner one can have many reasons. The following ones are investigated:

- distortion of electron trajectories due to beam space charge;
- contribution from electron-emitting elements;
- smearing of electron position due to gyroradius;
- smearing due to dispersion of the electrons produced in MCP (about $32\ \mu\mathrm{m}$);
- optical point spread function PSF ($22\ \mu\mathrm{m}$ [3]);
- cross-talk between pixels in the camera.

Two of the effects have been already estimated and they are too small to explain the observed effect. Both of them have the nature of PSF, and can be corrected in quadrature in order to obtain real beam width:

$$\sigma_{beam} = \sqrt{\sigma_{BGI}^2 - \sigma_{PSF}^2} \quad (1)$$

In the following it is assumed that the other effects can be corrected in the same way. In Fig. 7 the preliminary results of cross-calibration between wire scanner and BGI are presented. The WS emittance during the ramp (calculated using relativistic gamma for protons) are represented with green dots. Red curve shows beam energy evolution and black line is BGI emittance obtained assumed $\sigma_{\mathrm{PSF}} = 0.3\ \mathrm{mm}$. Relatively low quality of the BGI signal can be observed, as beam intensity was small.

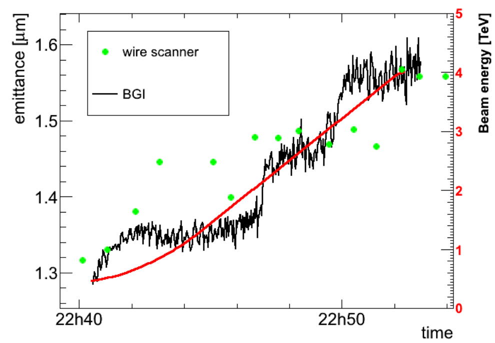


Figure 7: Emittance behaviour during ramp.

CONCLUSIONS

Initial results of the BGI commissioning on LHC beams are presented. Main aspects concerning the signal processing, scale calibration and correction of the MCP ageing are discussed. A necessary quadratic correction to the beam size measured by the BGI is shown. Preliminary results for ion beam are promising.

ACKNOWLEDGMENT

Authors want to thank to Michaela Schaumann for help with analysis of ion-beam data and to Vincent Baglin, Francois Bellorini and Didier Calegari who build and serviced the gas injection system.

REFERENCES

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[2] http://beta-beating.web.cern.ch

[3] D. Kramer et al., CERN-AB-2005-072