AIDA-2020-CONF-2016-004

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Conference/Workshop Paper

The Beam Profile Monitoring System for the IRRAD Proton Facility at the

Blerina Gkotse (CERN) *et al*

10 November 2015

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **15: Upgrade of beam and irradiation test infrastructure**.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site <http://aida2020.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=AIDA-2020-CONF-2016-004>

The Beam Profile Monitoring System for the IRRAD Proton Facility at the CERN PS East Area

Blerina Gkotse, Maurice Glaser[*], Emanuele Matli, Federico Ravotti
Experimental Physics and Beams Department
European Organization for Nuclear Research (CERN)
CH-1211, Geneva 23, Switzerland
blerina.gkotse@cern.ch; maurice.glaser@cern.ch; emanuele.matli@cern.ch; federico.ravotti@cern.ch

Kock Kiam Gan, Harris Kagan, Shane Smith, Joseph Warner
Department of Physics
The Ohio State University
Columbus, OH 43210, USA
gan.1@osu.edu; harris.kagan@cern.ch; ssmith@physics.osu.edu; warner.512@osu.edu

ABSTRACT

In High Energy Physics (HEP) experiments, devices are frequently required to withstand a certain radiation level. As a result, detectors and electronics must be irradiated to determine their level of radiation tolerance. To perform these irradiations, CERN built a new irradiation facility in the East Area at the Proton Synchrotron (PS) accelerator. At this facility, named IRRAD, a high-intensity 24 GeV/c proton beam is used. During irradiation, it is necessary to monitor the intensity and the transverse profile of the proton beam. The Beam Profile Monitor (BPM) for IRRAD uses 39-channel pixel detectors to monitor the beam position. These pixel detectors are constructed using thin foil copper pads positioned on a flex circuit. When protons pass through the copper pads, they induce a measurable current. To measure this current and determine the total flux of protons passing through the thin foil copper detectors, a new data acquisition system was designed as well as a new database and on-line display system. In its final configuration, the IRRAD facility exploits four BPM devices located along the path of the irradiation beam. In this work, we present the design and the architecture of the BPM system, some results on its performance during the commissioning of the IRRAD proton beam, as well as the planned upgrades for this system.

KEYWORDS
BPM, High Energy Physics, IRRAD, Radiation Hardness

1. INTRODUCTION

In HEP experiments such the one at the CERN Large Hadron Collider (LHC), devices are frequently required to withstand a certain radiation level. As a result, detector materials, equipment and electronic systems must be irradiated to assess their level of radiation tolerance. To perform these irradiations, CERN built a new irradiation facility in the East experimental area at the Proton Synchrotron (PS) accelerator. At this facility, named IRRAD, a Gaussian 24 GeV/c proton beam of variable size ranging from ~5×5mm^2 to

[*] Corresponding author. Tel.: +41 22 767 2058

$20{\times}20mm^2$ (FWHM) is used to irradiate experimental devices [1]. The IRRAD beam is delivered in "spills" with a maximum intensity of $5{\times}10^{11}$proton per spill and about 400ms duration. Several spills per PS accelerator super cycle (CPS) are delivered to IRRAD resulting in a variable beam intensity depending on the number of users simultaneously served by the whole CERN accelerator complex. During irradiations, it is thus necessary to monitor in real-time the intensity and the transverse profile of the proton beam.

The IRRAD Beam Profile Monitor (BPM) uses 39-channels pixel detectors to monitor the beam position. These pixel detectors, that must withstand high-cumulated radiation levels, are constructed using thin foil copper pads positioned on a flex circuit. When protons pass through the copper pads, they induce a measurable current. To measure this current and thus determine the proton beam intensity, a new data acquisition system was designed as well as a new database and on-line display system. In its final configuration, the IRRAD facility exploits four BPM detectors located along the path of the irradiation beam as shown in Fig. 1.

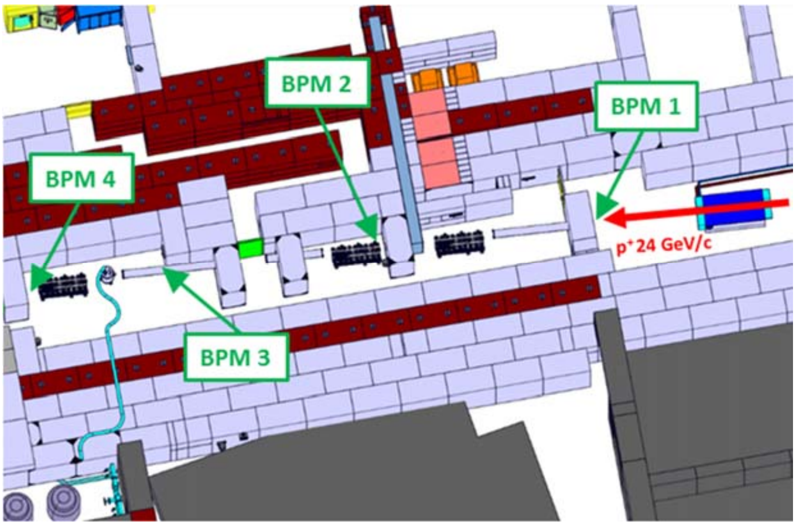

Figure 1. Position of the four BPM devices along the IRRAD facility at CERN.

The new BPM data acquisition system uses low noise integrators. The voltages from each integrator are scaled and limited before connection to a 16-bit ADC. Furthermore, an Arduino Yún collects the data from the ADC and controls its transmission over the Ethernet port to a server for further processing and storage. Finally, the live beam position and intensity data are available to the IRRAD users, as well as to the operators at the CERN Control Centre (CCC), via a dedicated web-based display.

Two BPM data acquisition systems were assembled in 2014 and were used to read out two BPM detectors during the commissioning of the new facility. Four additional BPM data acquisition systems were assembled, and later installed at the beginning of the irradiation run 2015. In this work, we detail the design and the architecture of the IRRAD BPM system, as well as its performance and foreseen upgrades.

2. OPERATION PRINCIPLE AND CHOICE OF THE DETECTOR MATERIAL

The need for an on-line method to determine the position and the profile of the high-intensity proton beam of IRRAD motivated the feasibility study of an instrument based on the proton-induced Secondary Electron Emission (SEE) from thin metal foils [2]. Secondary emission of electrons from the surface of a plate occurs when a charged particle beam crosses this. The liberated charge comes mainly from delta rays escaping from the plate, with a small contribution due to the secondaries produced in the interactions of the beam particles with the plate. The total collected charge is proportional to the intensity of the impinging beam.

For IRRAD, the foils are required to withstand high-radiation levels (10^{17}-10^{18} p/year are cumulated on a few square cm area) and be made of a low cost and relatively short radioactivity lifetime material. Moreover, they have to be on the one hand thin to avoid the proton scattering but on the other hand, thick enough to allow easy handling. Finally, the material has to show an SEE yield strong enough to avoid the usage of an external bias and thus maintain the simplest operation principle as possible. Aluminum (Al) and Copper (Cu) foils have been chosen as a good compromise to satisfy these requirements. Details about the preliminary measurements leading to this choice are described in Ref. [3].

3. BPM HARDWARE AND SYSTEM ARCHITECURE

3.1. Detectors

The BPM detector element for the measurement of the proton beam profile consists in 39 separate pixels (Cu pads of 4×4mm^2 spaced by 0.5mm one to the other) covering a total area of 36mm×27mm on the beam transversal plane. These pixels are built on a six layers Kapton/Cu flex circuit as shown in Fig. 2 (left-hand side). The Cu pads in the various internal layers are connected through vias while a top and a bottom Cu layer act as shields. The Cu thickness is of 1.75µm/layer while the Kapton thickness is of 120µm/layer for a total overall thickness of ~700µm. The right-hand side of Fig. 2 shows a BPM detector installed in its final position inside the IRRAD facility. Single-pad BPM detectors, one Cu pixel with active areas of 5×5mm^2, 7×7mm^2 and 10×10mm^2 were also built for the alignment of the remote controlled tables used in IRRAD [4]. One of these BPM single-pad detectors is shown on the top of Fig. 2 (left-hand side).

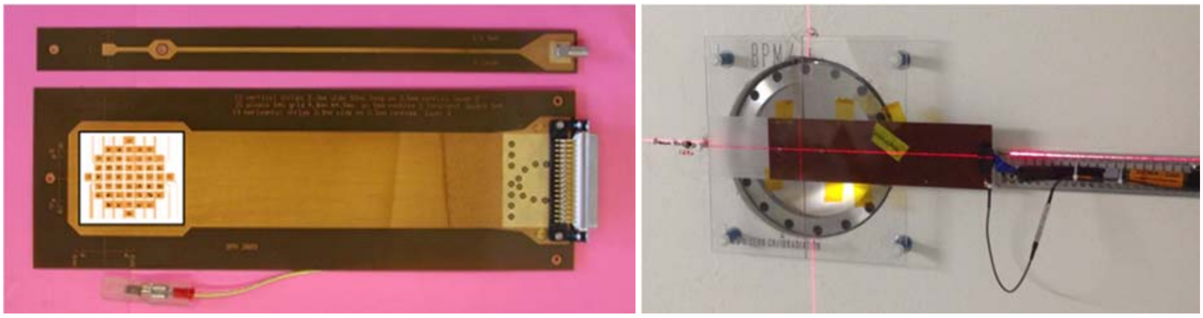

Figure 2. BPM pixel detector for beam profile with 39-pads and single-pad (left-hand side). BPM pixel detector installed in the IRRAD (right-hand side).

The detector pixels are directly connected to the data acquisition (DAQ) system by a shielded, high-speed 40-channel, 50Ω, 40AVG micro-coaxial cable from Samtec [5]. The cables linking the four IRRAD BPM detectors to the DAQ systems located outside the irradiation area are 20m to 35m long.

3.2 Data Acquisition System

The BPM DAQ unit shown in Fig. 3 has been designed to measure detector signals in the 10pA-to-500pA range with an adjustable dynamic range. This uses commercial off the shelf, low-noise switched integrators (Burr Brown ACF2101) to amplify the BPM detector signals. A TI ADS1115 analog-to-digital converter (16 bit, 2-3 bits noise) subsequently measures the charge integrated over the 400ms proton spills. A commercially available Arduino Yún microcontroller board based on the *ATmega32u4* handles the whole DAQ process, including the timing synchronization and the background noise measurement. A total of 50 channels can be read out in parallel (analog inputs). 40 channels from the BPM pixel detector (through the Samtec cable) and other 10 auxiliary channels (LEMO connectors on the front panel visible in Fig. 3) to readout the single pad detectors. The DAQ unit has three outputs. An *Analog Output* port provides the inverted output of the integrators and it is used to show the output of a selected integrator channel during operation. The *Reset Output* and the *Gate Output* are instead used to check in real time (with an oscilloscope) the synchronization of the timing parameters of the BPM with the signals provided by the PS accelerator [6].

Moreover, the DAQ unit is equipped with the following digital (input) ports:

- *Trigger* (configurable NIM/TTL). This signal, directly connected to the Arduino, it is used to inform that a proton spill will occur upon its reception (beam trigger);
- *CPS* (configurable NIM/TTL). This signal can be used to inform the Arduino that, after this input signal is received, a new super cycle of the PS accelerator (CPS) begins;

as well as with two communication ports:

- *USB 2.0* (located on the rear panel). This port is used to provide external storage media to the Arduino as well as to update the DAQ software;
- *Ethernet* (located on the rear panel). This port is used by the Arduino to access the CERN network over a wired connection.

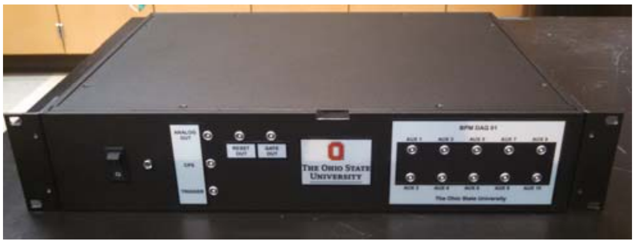

Figure 3. IRRAD BPM Data Acquisition System.

The rest of the system architecture comprises a rack-mounted local HP Server running a dedicated software used to collect through Ethernet the data from the four DAQ units and to send them to a centralized ORACLE database where the spill-by-spill beam positions are stored for later analysis.

4. BPM DATA DISPLAY

The proton beam profile information from the IRRAD facility is also displayed in real-time on a dedicated CERN web-page[1]. This is used by the IRRAD facility operation team and users to check beam quality and the alignment of the irradiation systems, as well as by the PS accelerator operation team at CERN Control Center (CCC) to tune and steer the irradiation beam over the T8 beam-line.

Figure 4. IRRAD BPM real-time display. The "main" BPM page is shown on the left-hand side. The "BPM all" display page is shown on the right-hand side of the picture.

[1] www.cern.ch/opwt/irrad

Fig. 4 shows some of the user interface pages of the web-application developed to retrieve the data from the BPM database. This application perform a first level data correction (e.g. background compensation) and analysis of the displayed data. On the left-hand side of Fig. 4 the "main" BPM page shows, for every BPM device, the intensity over each of the 39-channels and computes the basic information on the horizontal (x) and vertical (y) beam profiles such as the center (x_0,y_0) of the Gaussian shape, the sigma (σ) and the full width at half maximum (FWHM). Moreover, this page also provides information about the longitudinal beam profile, by displaying a plot of the beam-induced charge integrated by the DAQ over time.

The "BPM all" page shown on the right-hand side of Fig. 4 provides instead in a combined view the footprint of the proton beam recorder simultaneously in the four locations along the IRRAD beamline. This allows, on one hand to full control the beam trajectory over the ~30m long IRRAD facility, as well as to optimize the irradiation of materials and samples by choosing the appropriate beam size and thus exploit the natural proton beam divergence. Finally, by integrating the current measured by the 39-channels, or by a subset of them, it is possible to monitor during operation the total proton intensify delivered to IRRAD or the proton flux impinging on small-size samples during irradiation.

5. BPM PERFORMANCE AND OUTLOOK

In order to use the BPM data as an operational tool to monitor the beam conditions, it is essential that the response of the BPM detectors follow linearly the variation of the beam intensity. Although the material being irradiated and crossed by the beam may affect the amplitude of the BPM signal, the BPM1 device, installed upstream the irradiation systems in IRRAD (see Fig. 1), can be used and calibrated for this purpose.

The plot in Fig. 5 shows the variation of the total current integrated by BPM-1 as function of the proton spill intensity. The reference beam intensity of each spill was measured using a Secondary Emission Chamber (SEC) provided by the CERN Beam Instrumentation Group [7]. The agreement of the two data series is better than +/-7%.

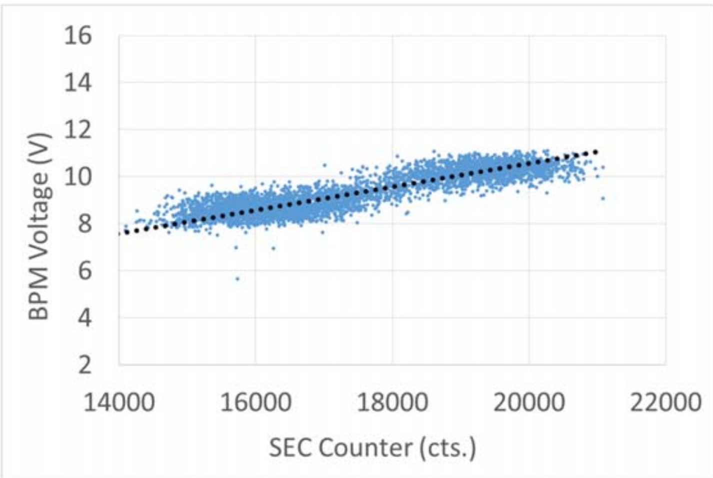

Figure 5. Response of the IRRAD BPM-1 device as a function of the proton beam intensity measured by the Secondary Emission Chamber on the T8 beam line.

The successful exploitation of the four main 39-pad pixelated BPM devices installed along the IRRAD beam-line motivated the upgrade (within the EU-funded project AIDA-2020 [8]) of the initial BPM system. The upgrade will consist of new, pixelated detectors with increased spatial resolution and smaller total area coverage (22mm×22mm). These new BPM devices, called "mini-BPMs", together with the single-pad devices already in use, will allow improving the alignment precision and speeding up the alignment procedure of the IRRAD remote-controlled tables and shuttle system.

For this upgrade, new DAQ units have been produced while the new mini-BPM devices are being manufactured. Since the new mini-BPM uses less channels per device, a channels-concentrator PCB has been developed in order to merge the signals from several detectors in a lower number of 40-channel cables such as the existent DAQ system architecture, based on 50 readout channels, can be efficiently exploited. An example of the connectivity for the new mini-BPM devices is shown in Fig 6.

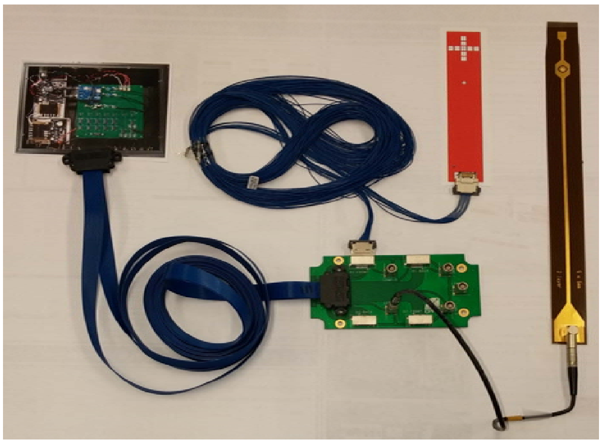

Figure 6. Connectivity of the new "mini-BPM" devices. The channel-concentrator PCB merges the signals from several mini- and singe-pad BPM devices onto a 40-channel cable.

ACKNOWLEDGMENTS

The authors would like to thank Tony Smith (Liverpool University), Nicola Pacifico (University of Bergen) and Christophe Sigaud (CERN EP-ESE) for their assistance in the development of the BPM system for the PS proton irradiation facility as well as for their contribution in the construction of the initial prototypes. This project has received funding from the European Commission project AIDA, as well as from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

REFERENCES

1. F. Ravotti, "IRRAD: The New 24 GeV/c Proton Irradiation Facility at CERN," *Proceedings of Twelfth International Topical Meeting on Nuclear Applications of Accelerators (AccApp'15)*, Washington, DC, Nov. 10-13, 2015.
2. K. Bernier, et al., "Calibration of secondary emission monitors of absolute proton beam intensity in the CERN SPS north area," *CERN Yellow Report 97-07* (1997).
3. F. Ravotti, M. Glaser, M. Moll, "Dosimetry Assessments in the Irradiation Facilities at the CERN-PS Accelerator," *IEEE Trans. Nucl. Sci.*, **53**(4), pp. 2016-2022 (2006).
4. M. Glaser, M. Moll and F. Ravotti, "AIDA Milestone Report MS31 - Movable Irradiation Tables Operational," https://cds.cern.ch/record/1594787/files/AIDA-MS31.pdf (2013).
5. "Samtec web-page," https://www.samtec.com/.
6. J. Warner, "New Beam Profile Monitoring System for the Proton Irradiation Facility at the CERN PS East Area," *Proceedings of DPF2015*, Ann Arbor, MI, Aug. 4-8, 2015.
7. F. Ravotti, M. Glaser, M. Moll, "Upgrade scenarios for irradiation lines: Upgrade of the Proton Irradiation Facility in the CERN PS East Area," AIDA Deliverable Report D8.4, http://cds.cern.ch/record/1951308/files/AIDA-D8_4.4.pdf (2014).
8. "AIDA-2020 Project," http://www.cern.ch/aida2020.