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CHARACTERIZATION OF THE IRRAD BEAM PROFILE MONITOR AND POSSIBLE IMPROVEMENTS VIA CROSS-ANALYSIS WITH MULTIWIRE PROPORTIONAL CHAMBER

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Abstract

The IRRAD Proton Facility at CERN relies on locally designed beam-profile monitors (BPM) to supervise the high-intensity 24 GeV/c proton beam extracted, for irradiation-experiment purposes, from the CERN Proton Synchrotron. Based on metal-nano-layer sensors and readout electronics leveraging a Charge-Sensitive Amplifier with integrated 20-bit ADC and ARM controller, such a BPM features minimal particle interaction, good radiation hardness, and high sensitivity. Yet, the growing users' demand for precise irradiation of modern electronics requires ever more detailed beam information, thus driving the introduction of future IRRAD upgrades.

In this paper, we investigate whether improved irradiation precision can be obtained by leveraging the presence of an additional IRRAD-based detector, a MultiWire Proportional Chamber (MWPC). Using beam-profiling data collected both at the BPM and MWPC levels over a period of multiple days, we performed a comparison analysis of data-driven analytical models of both sensors. Given that MWPC provides wider spatial coverage, with a bit lower precision, than BPM but is not as radiation-hard, we suggest that data fusion guided by both models and advanced data-processing software can be used to enhance the apparent characteristics provided by the IRRAD BPM-based beam-profiling system. These results are crucial for the future improvements needed to handle the profile monitoring of new types of beams in IRRAD, e.g., heavy-ion and low-intensity proton beams.

INTRODUCTION

The IRRAD facility, located on the T8 beamline of the experimental East Area at CERN, exploits a 24 GeV/c proton beam extracted from the Proton Synchrotron (PS). Dedicated Beam Profile Monitor (BPM) sensors are used there to constantly perform quality monitoring of the transverse proton- or ion-beam profile, which is, nominally, Gaussian with a size of $12 \times 12 \text{ mm}^2$ FWHM (Full Width at Half Maximum) [1].

Each Beam Profile Monitor (BPM) sensor developed at IRRAD, based on the Secondary Electron Emission ef-

fect [2], features a matrix of 39 pixelated metal pads of about $4 \times 4 \text{ mm}^2$ area (see Fig. 1). Its spatial resolution (distance between two pad centers, either horizontally or vertically) is 4.5 mm. Each BPM is connected to a 40-channel dedicated electronic Data Acquisition (DAQ) system that samples the data stream of each pad to eventually 32-bit stored floating point numbers, yielding an average bandwidth of almost 10 Mb/day per BPM.

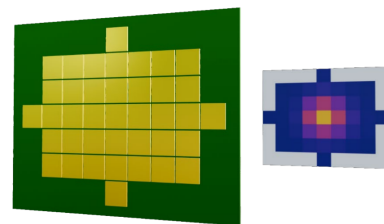


Figure 1: Graphical model of a BPM-sensor printed circuit board (PCB) (left-hand side), confronted with an example of measurement data seen as an image (right-hand side).

Such BPMs feature minimal particle interaction, good radiation hardness and high sensitivity. Yet, the growing users' demand for precise irradiation tests, in particular for modern electronics, calls for ever more detailed beam information, thus driving the introduction of future IRRAD upgrades. Since designing, manufacturing, and testing improved beam profiling sensors is both time-consuming and expensive, one way to, at least temporarily, address these new requirements may be to synthetically improve the current characteristics of BPMs via data fusion using supplementary sensor information.

In this paper, we suggest that the data extracted from simultaneous beam-profiling measurements from both BPMs and a wide MultiWire Proportional Chamber (MWPC) can be used to improve the overall performance of BPMs, even after removal of the MWPC. This type of data-fusion approach using multiple sensors has been shown to be quite effective in fault detection and system diagnosis [3].

In the sequel, we describe the experimental protocol we followed, present the collected data, illustrate how data fusion can be applied to the current BPM system to improve its characteristics, and conclude before discussing future work.

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EXPERIMENTAL PROTOCOL

We used two measuring devices during this experiment. A MWPC device was positioned in the IRRAD experimental area upstream from the tables where the Devices Under Test (DUT) are installed (see Fig. 2). This sensor is equipped with 32 wires horizontally (and 32, vertically), spaced 6 mm each; the total area is $10 \times 10 \text{ cm}^2$ [4]. The second device is the existing BPM 2 (out of 4) from the IRRAD infrastructure [1]; it is located about 3.5 m downstream from the MWPC.

During a 4-week data-acquisition campaign (from 19 March 2025 to 16 April 2025), we collected data under different experimental settings, both¹ for the MWPC voltage (from 60 to 150 V) and the PS proton beam intensity (from 4×10^{10} to 8×10^{11} protons per spill). This volume of data allowed us to carefully select the test samples for this case study. To perform the analysis in the operational sensitivity range of both detectors, we used the test data corresponding to a beam intensity equal to 4×10^{11} protons per spill.



Figure 2: The protons from the PS T8 beamline exit the beam pipe on the left of the picture, transit rightward through the MWPC (in yellow) before reaching the IRRAD motorized shuttle for DUT management, near the back wall.

RESULTS

We compared the measurements performed, at the same time, by the MWPC and BPM. Figure 3 provides processed excerpts of such data (taken in the period 21–23 March 2025), together with their Gaussian fits along the X and Y axes. These plots represent the averaging over 300 simultaneous measurements (one per spill), giving us the average one-hour characteristic of a spill.

One can notice that the beam appears non-centered when looking at the MWPC plots, while the BPM ones indicate perfect alignment. This is probably due to the fact that the BPM were carefully positioned using sensitive geolocation equipment, which was not available when introducing the MWPC for this experiment. Its setup is very similar to the irradiation of a DUT. The MWPC sits on a remote-controlled stage (also described as a “table”) and is positioned in-beam only when the test begins.

¹ The IRRAD BPM is a passive device.

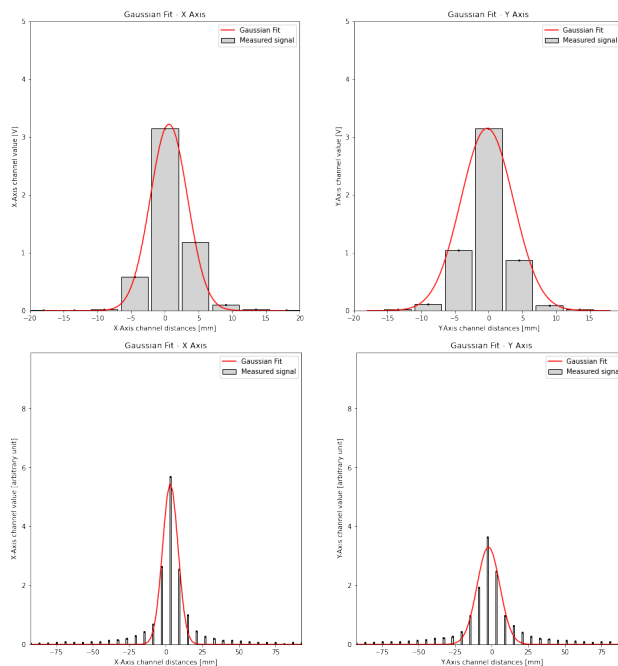


Figure 3: Average data and their Gaussian fits, in red, along the X- and Y-axes of BPM (top) and MWPC (bottom) sensors.

Even though one could expect, on physical grounds, that these measurements would fit a Gaussian distribution, one can visually notice that, at least in the case of MWPC, the data suggests that the beam is not gaussian, neither along the X nor the Y axis (see also Fig. 4). Indeed, the signal measured at the tails is not converging to zero as fast as a Gaussian distribution would require, and the maxima exceed their fits. It is more difficult to visually assess whether such a non-Gaussian behavior is also present for the BPM. Yet a Shapiro-Wilk test yields a p-value of 0.0 (also in words: zero), thus supporting this claim: the transverse beam profile measured with multiwire chamber *is not* Gaussian. We surmise that such a result could be explained by (1) the measurements taking place outside of the transfer line and/or (2) interactions of protons with air along the way.

BPM POSSIBLE IMPROVEMENTS

The non-Gaussian nature of the IRRAD T8-line proton beam suggests that a better profile could be provided to monitor the beam characteristics, either for the irradiation experiments performed at IRRAD, but also upstream, for beam management at the PS control level. Even though the MWPC data distribution is not Gaussian, it should be possible to fit it with a better-suited parametric model, e.g., a Voigt distribution, often used when dealing with atmospheric artifacts (see, e.g., [6]), or Student’s t-distribution, used to fit particle scattering data (see, e.g., [7]). The impact of such a correction on future experiments should also be assessed.

The MWPC and BPM detectors provide quite complementary features:

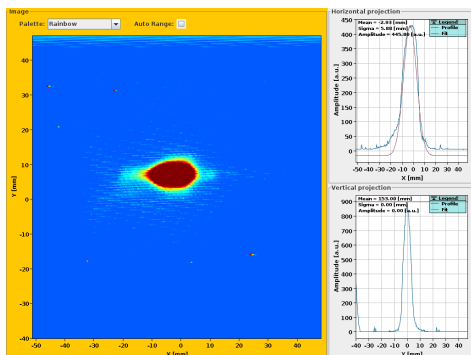


Figure 4: Beam profile captured via a “beam TV” (BTV) [5] radiating screen (PS control center). This kind of beam imaging is performed “on-demand”. The BTV screen, inserted within the beam trajectory for measurement purposes, cannot stay in-beam all the time, since the observation is destructive to the beam properties (due to caused absorption and scattering), and, conversely, a high-intensity beam causes damage to the screen itself.

- the BPM supports better spatial resolution, but less coverage of the beam field than the MWPC;
- the BPM provides centered horizontal and vertical lines, which the MWPC lacks (no centered wires);
- the MWPC cannot stay long in beam, since it is not as radiation hard as the BPM, which can sustain the high PS beam intensities.

We thus intend to use, in the future, data fusion to enable enhanced measurements at the BPM level. We envision that, building on the MWPC-informed model mentioned above, the BPM acquisition system could be digitally enhanced accordingly. For instance, using MWPC-informed synthesized data could be useful when BPM measurements exhibit saturation, as they sometimes currently do. Another venue for development could be the creation of a “virtual BPM” that builds upon the use of machine-learning techniques to artificially introduce additional, “synthetic” BPM pads.

CONCLUSION AND FUTURE WORK

We perform a comparison experiment between a MWPC and a BPM to better characterize the IRRAD beam-monitoring capabilities. Preliminary results suggest that the Gaussian hypotheses used to model the PS T8 line beam are not warranted.

We intend to use the collected data to provide a better modeling of the IRRAD BPM system, while possibly improving the sensitivity of the current beam-profiling detectors via data fusion with MWPC-informed information.

REFERENCES

- [1] B. Gkotse, M. Moll, F. Ravotti, and M. Glaser, “IRRAD: the new 24 GeV/c proton irradiation facility at CERN”, CERN, Geneva, Switzerland, Rep. AIDA-2020-CONF-2016-006, 2015.
- [2] I. Mateu *et al.*, “A Beam Profile Monitor for High Energy Proton Beams Using Microfabrication Techniques”, in *Proc. IBIC'20*, Santos, Brazil, Sep. 2020, pp. 86–89. doi: 10.18429/JACoW-IBIC2020-TUPP37
- [3] A. Abid, M. T. Khan, and J. Iqbal, “A review on fault detection and diagnosis techniques: basics and beyond”, *Artif. Intell. Rev.*, vol. 54, pp. 3639–3664, 2021. doi: 10.1007/s10462-020-09934-2
- [4] K. Bilko *et al.*, “CHARM High-energy Ions for Micro Electronics Reliability Assurance (CHIMERA)”, *IEEE Trans. Nucl. Sci.*, pp. 1549–1556, Jan. 2024. doi: 10.1109/TNS.2024.3358376
- [5] S. Burger and E. Bravin, “A new control system for the CERN TV beams observation”, CERN, Geneva, Switzerland, Rep. CERN-AB-2008-041, 2008.
- [6] S. Reuter, J. S. Sousa, G. D. Stancu, and J.-P. Hubertus van Helden, “Review on VUV to MIR absorption spectroscopy of atmospheric pressure plasma jets”, *Plasma Sources Sci. Technol.*, vol. 24, no. 5, p. 054001, Aug. 2015. doi: 10.1088/0963-0252/24/5/054001
- [7] R. J. Beckman and M. E. Johnson, “Fitting the student-t distribution to grouped data, with application to a particle scattering experiment”, *Technometrics*, vol. 29, no. 1, pp. 17–22, 1987. doi: 10.2307/1269879