ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF025

FAST INTENSITY MONITOR BASED ON CHANNELTRON ELECTRON MULTIPLIER

G.M.A. Calvi[†], G. Magro, V. Lante, L. Lanzavecchia, A. Parravicini, E. Rojatti, C.Viviani,
Fondazione CNAO, Pavia, Italy

Abstract

The paper concerns the Fast Intensity Monitor (FIM) designed for CNAO (Centro Nazionale di Adroterapia Oncologica), the Italian facility of Oncological Hadrontherapy.

The FIM detector has been designed with the purpose of having a continuous and non-destructive measurement of the beam intensity in the High Energy Beam Transfer (HEBT) line. The passage of the beam through a thin aluminum foil produces secondary electrons whose yield depends on beam species (protons or carbon ions), intensity and energy. Secondary electrons are focused on the Channeltron Electron Multiplier (CEM) input, multiplied and sensed over a precision resistor.

In order to minimize the perturbation to the beam, the foil is grounded and the read out electronics is floating. This complicates the electronics design, but it is a key point to make FIM use possible continuously even during patients treatment.

Measurements performed with the FIM are discussed and checked against reference detectors.

INTRODUCTION

CNAO is one of the few accelerators worldwide capable to perform hadrontherapy with both protons and carbon ions; nowadays more than 1000 patients completed the treatment, two thirds of them with carbon ions [1]. The dose delivery treatment by pencil beam scanning technique, presently used at CNAO, is the most advanced method in hadrontherapy machines for achieving accurate treatments of target volumes. The beam is directed to each tumor voxel by controlling fast magnets deflectors and beam energy for transversal position and longitudinal penetration, respectively. A non-destructive measurement of the beam intensity in the HEBT line is favourable because, nowadays, this parameter is no longer measured before dose delivery system and because it can be used to sense fast intensity ripples of extracted beam.

DETECTOR OVERVIEW

CEM

In order not to perturb the beam, an ultra-thin aluminum foil (0.8 µm thickness) is traversed by the extracted particles [2]; the signal originated from secondary emission effect is amplified along a single channel electron multiplier (CEM) (Fig.1) [3]. The FIM monitor, made up by the thin aluminum foil, CEM itself and electronics read-out will be installed at the beginning of CNAO extraction line. Results presented in this paper were collected during preliminary measurements performed with the FIM installed at beam isocenter in a treatment room.

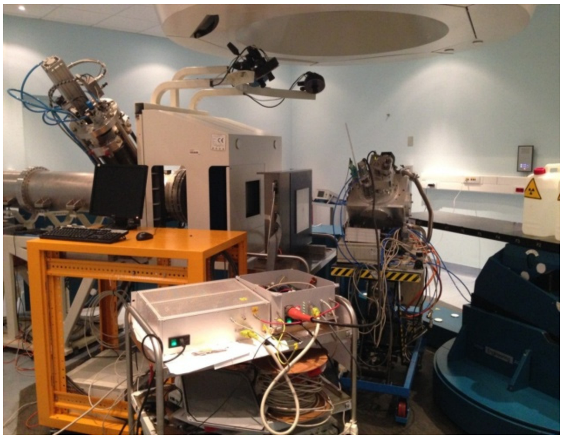

Figure 1: CEM Channeltron Electron Multiplier detector in its vacuum chamber, placed just after the nozzle and the ionization chamber.

Electronics and Processing

The FIM electronics architecture is depicted in Fig. 2.

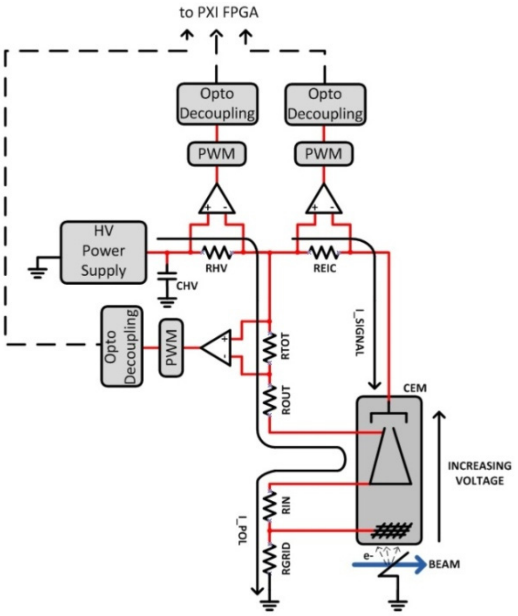

Figure 2: FIM Electronics Architecture.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF025

CEM has to be polarized with increasing voltage values over four terminals, named Grid, Input, Output and EIC i.e. Electrical Insulated Collector. The ultra-thin aluminum foil is grounded. Three different high voltage resistors, RGRID, RIN and ROUT are foreseen to control the high voltage partitions along CEM structure; its intrinsic channel resistance plays a key role, indeed the electrons multiplication value depends on (OUT - IN) voltage difference. After some preliminary tests on beam a suitable set of values results RGRID = 10 MOhm, RIN = 5 MOhm and ROUT = 10 MOhm, while the intrinsic channel resistance is measured indirectly to be around 110 MOhm. Being the beam-generated signal quasi-dc, the readout electronics cannot be AC decoupled from the EIC collector, thus it needs to work at floating high potential with respect to ground. Electronics local supply has been referred to the CEM high voltage supply. Due to that, the front-end electronics resulted to be floating few kV over ground potential and then the signals have been properly decoupled. The electronics input signals are two currents, I_POL and I_SIGNAL. I_POL is the polarization current of CEM sensed over RHV and RTOT resistances, I_SIGNAL is the current obtained by multiplied electrons on EIC, proportional to beam intensity, sensed over REIC. These obtained voltage drops are then differentially amplified with a low-input bias, high bandwidth instrumentation amplifier and then low-pass filtered at 50 kHz. The obtained analog signals are finally converted into a Pulse Width Modulation PWM signals. In order to keep the system fast reacting the PWM output frequency has been set to 1 MHz, with an output dynamic ranging from 10% to 90%. As shown in Figure 3, the system demonstrated an outstanding linearity in a range of CEM output currents from 0 to 6.5 µA, leading to a sensitivity of 12.26 %/µA for the amplifier high gain (obtained resolution 20 nA). Three identical electronics paths are foreseen, in order to give a complete description of the hot EIC node. The signal acquisition and processing have been implemented in a PXI FPGA card, capable to acquire the PWM signal coming from Front End Electronics FEE with a fixed 100 MHz sampling rate. The signal is processed by counting at 100 MHz the high level duration of the PWM and then down sampled by averaging at 10 kHz.

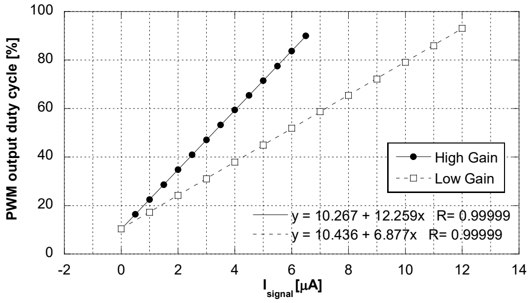

Figure 3: Dynamic and linearity of one read-out path for the two available gains. Tests performed by injecting an I_SIGNAL generated by a Keithley 6221 current source.

RESULTS AND DISCUSSION

Firstly the FIM instrument has been tested on beam with fixed energy, fixed number of particles and fixed CEM gain (HV 3000 V corresponds to a CEM gain of ~10^7) to validate its performances on single synchrotron extraction cycle, hereinafter spill. Number of particles is fixed by dose delivery system with a resolution of about 2 ‰ and beam energy by the RF cavity with a resolution of about 1 keV. In Figure 4 single spills I_SIGNAL are depicted, both for protons and carbon ions. The designed electronics architecture shows expected performances [4].

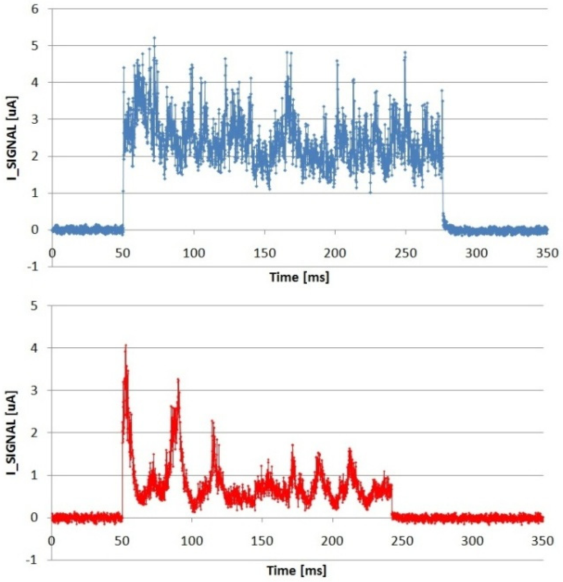

Figure 4: Single spill I_SIGNAL for 500x10^6 protons at 110.96 MeV energy (top plot) and 10x10^6 carbon ions at 208.57 MeV/u energy (bottom plot).

With the same number of particles further tests were carried out to re-construct a Bethe-Bloch trend of extracted charge (obtained as integral of the FIM current over one spill) in function of beam energy increased spill after spill. A linear relationship between the secondary electron emission and the energy loss in the foil is expected. Presently, the CEM is installed in a stand-alone tank, placed at beam isocenter, and the beam shall cross the end-of-line thin window and a 1-cm thick silica tank input window, before reaching the aluminium foil. Figure 5 shows the expected trends, thus validating the principle of production/collection of electrons, both for protons and carbon ions. The discrepancy from the expected curve at lower energies, can be explained by the scattering effects of the silica window, becoming negligible at higher energies. Finally the FIM instrument has been tested with beam, by varying HV polarization and, for each HV voltage value, by varying particle type at a fixed number of particles, 500x10^6 protons/spill and 10x10^6 carbon ions/spill, respectively. After some preliminary tests the HV range was chosen in between 2600 and 3500 V. The CEM Gain is expected to be constant at fixed HV polarization value and not to depend

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF025

on the number of input electrons/seconds under the maximum linearity value of 10% of I_POL [3]. In fact a "fast" time dependency affects CEM gain, in particular the collected I_SIGNAL integrated over a 400 ms period (after noise subtraction) decreases spill after spill both for protons and carbon ions.

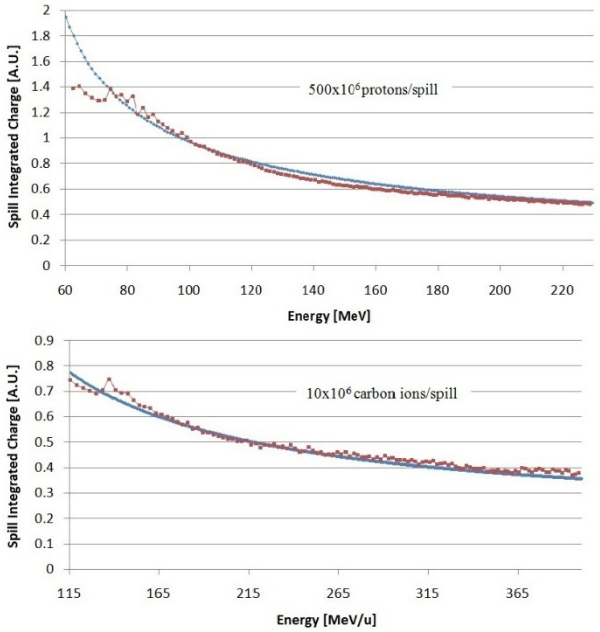

Figure 5: Extracted charge normalised to Bethe-Bloch trend at 62 MeV/u for protons (top plot) and 115 MeV/u for carbon ions (bottom plot).

In Figure 6 this effect is depicted over 100 spills at a fixed HV value of 3000 V, a fixed energy of 110.96 MeV/u for protons and 208.57 MeV/u for carbon ions and a fixed number of particles.

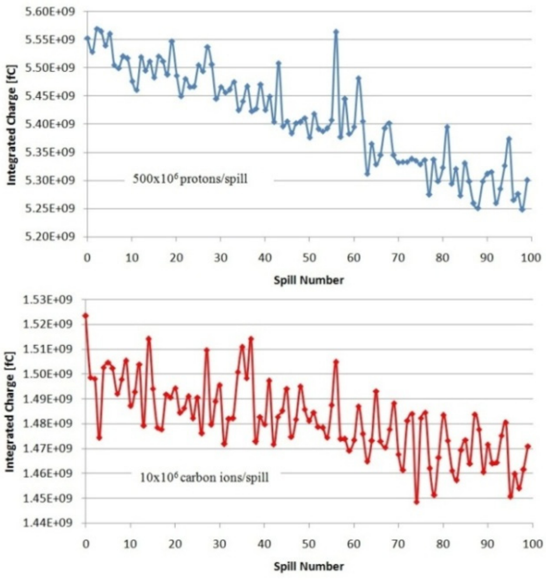

Figure 6: Integrated charge over 100 consecutive spills at same energy, gain and number of particles. 5 seconds last between consecutive spills.

Furthermore, also a "slow" time dependency has been observed. HV values were scanned during 5 consecutive 8 hours shifts. For the same number of particles and energy, a constant number of secondary electrons is expected at CEM input (calculated by dividing integrated output charge for CEM Gain [3]), consequently the higher the gain the higher the integrated charge at CEM output is expected. On the contrary an unexpected behaviour results, as depicted in Figure 7 for 500x10^6 protons/spill at fixed 110.96 MeV/u energy. From Figure 7 a drop of FIM Gain although HV value increases is measured along consecutive run numbers. Comparable results are obtained for carbon ions. The switching OFF/ON of high voltage between consecutive runs is the main addressed reason for "fast" and "slow" instabilities.

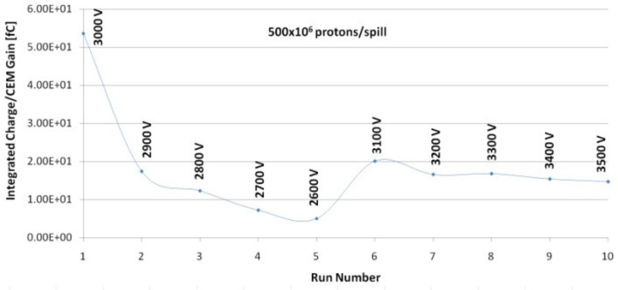

Figure 7: Calculated input charge in function of high voltage and run progressive number.

CONCLUSION

This work focuses on the not-interceptive spill intensity monitoring. An ultra-thin metallic foil based detector with 50kHz overall bandwidth and 1% resolution (test bench results) has been developed and its output has been measured with different gains and beam energies. An excellent performance results for detection of beam intensity ripples [4]. Otherwise a slow and fast time dependence behaviour on overall gain makes FIM not suitable to be used, presently, as a stand-alone beam intensity monitor. A stable installation on CNAO HEBT line with constant environment conditions and fixed HV value is foreseen soon to investigate these phenomena over a long period.

REFERENCES

[1] S. Rossi, “The National Centre for Oncological Hadrontherapy (CNAO): Status and perspectives, PhysicaMedica”, Available online 31 March 2015, ISSN1120-1797, http://dx.doi.org/10.1016/j.ejmp.2015.03.001

[2] J. Bosser, G. Ferioli, P. Lefevre, J. Mann, G. Molinari, “Profile Measurement in the LEAR Transfer Line”, SPS/ABM/Note/87-06, LEAR Note 87-04.

[3] ChanneltronCEM 4820 COA G datasheet, EC No. 10-6360, Photonis USA Inc. Specification.

[4] M. Caldara, J. Bosser, G.M.A. Calvi, L. Lanzavecchia, A. Parravicini, E. Rojatti, and C. Viviani, "Online Spill Intensity Monitoring for Improving Extraction Quality at CNAO", in *Proc. 6th International Particle Accelerator Conference*, Richmond, VA, USA, paper MOPHA050, pp. 907-909, ISBN: 978-3-95450-168-7 `http://jacow.org/IPAC2015/papers/mopha050.pdf`, 2015.