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DETECTOR RESPONSE STUDIES OF THE ESS IONIZATION CHAMBER

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Abstract

The European Spallation Source (ESS), currently under construction in Lund, Sweden, will be a pulsed neutron source based on a proton linac. The ESS linac is designed to deliver a 2 GeV beam with a peak current of 62.5 mA at 14 Hz to a rotating tungsten target for neutron production. One of the most critical elements for protection of an accelerator is a Beam Loss Monitoring (BLM) system. The system is designed to protect the accelerator from beam-induced damage and unnecessary activation of the components.

The main ESS BLM system is based on ionization chamber (IC) detectors. The detector was originally designed for the LHC at CERN resulting in production of 4250 monitors in 2004-2008 (IC-2004). In 2014-2017 a new production of 830 detectors (IC-2016) with a modified design was carried out to replenish spares for LHC and make a new series for ESS and GSI. This contribution focuses on the results from a measurement campaigns performed at the HiRadMat (High-Radiation to Materials) facility at CERN, where response of IC-2016 detectors has been studied. The results may be of interest to other facilities that are using existing or plan to use new generation of IC monitors as BLM detectors.

INTRODUCTION

The European Spallation Source (ESS) is a science facility [1, 2], which is currently being built in Lund, Sweden and will provide neutron beams for neutron-based research. The neutron production will be based on bombardment of a tungsten target with a proton beam of 5 MW average power. A linear accelerator (linac) will accelerate protons up to 2 GeV and transport them towards the target, through a sequence of a normal conducting (NC) and superconducting (SC) accelerating structures (Fig. 1). In 2023 the beam commissioning of Normal Conducting Linac (NCL) has successfully advanced up to including fourth DTL tank.

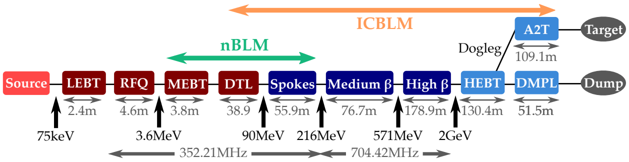

Figure 1: Layout of the ESS linac and BLM system coverage. Red colour represents the NC and blue the SC parts of the linac.

Beam Loss Monitoring (BLM) systems play an important role in machine commissioning, tuning, and operation. By measuring secondary particle rates close to the beam line, these systems provide information about beam loss levels along the machine. The BLM systems are designed to protect the machine from beam-induced damage by detecting unacceptably high beam losses and promptly triggering a request to the Beam Interlock System to stop the beam production. Two types of BLM systems differing in detector technology have been conceived at ESS. The neutron sensitive BLM (nBLM) system [3] is based on 82 neutron detectors primarily covering the lower energy part of the ESS linac. Conversely, the Ionisation Chamber-based BLM (ICBLM) system [4] consists of 266 ionisation chambers (ICs) located almost exclusively along the SC part of the linac.

The ESS ICBLM system is based on parallel plate gas Ionisation Chambers (ICs) originally developed by CERN for LHC (IC-2004) [5] and manufactured and tested in 2004-2008 at the Institute for High Energy Physics (IHEP) in Protvino. IC-2004 type detectors were selected as the ICBLM detectors due to their fast response, no gain variation (with possible exception around the target region) and large dynamic range of 10^8 (pA–mA). In addition to this, they require little maintenance. New production line (IC-2016) [6] was set up in 2014-2017 for ESS, CERN and GSI needs.

When introducing a new detector, it is important to validate its response versus corresponding simulations. In order to validate and fully characterise the new chambers their response in terms of drift time, calibration and saturation was studied at the HiRadMat (High-Radiation to Materials) facility at CERN. The facility offfers the opportunity to perform these unique tests due to several reasons, namely, possibility of beam parameters in wide desired range, available beam diagnostics, availability of cables with required grounding, last but not least, having HiRadMat experts around for fast feedback during the test. BLM experiments have been performed at HiRadMat since 2012, starting with experiments BLM19 and BLM2. Currently, the BLM55 experiment is dedicated to focus on three studies:

- Comparison of the IC production lines IC-2004 and IC-2016.
- Comparison of two types of Little Ionization Chambers (LICs), namely, LHC type (LIC-sem) and new LIC with IC ceramics (LIC-ic).
- Testing of the new Proportional Chambers (PCs).

DETECTOR DESIGNS UNDER TESTS

The IC detector active zone consists of 61 parallel electrodes with a 5.75 mm distance between the electrodes in

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IC-2004 detectors. The gap between electrodes in IC-2016 detectors, was reduced to 5.71 mm for every second electrode while keeping the same spacer length. The electrodes are made of a 0.5 mm and 0.54 mm thick aluminium in case of IC-2004 and IC-2016 detectors, respectively. The gap between electrodes is built to reduce the drift path and recombination probability of the ions and electrons, in order to achieve the desired linearity.

Little Ionization Chambers (LICs) were designed by Protvino and CERN to reduce the sensitivity with respect to the IC-2004 detectors. The reduction of active volume decreases the drift charge production resulting in lower sensitivity. It is interesting to compare the two types of LICs, namely the LHC type (LIC-sem), where Secondary Emission Monitors (SEM) insulators were used and the new LICs with IC ceramic disk (LIC-ic). The original LIC design was found to exhibit additional signal not related to the incoming particle showers. Thus, the ceramic insulator was replaced with the IC ceramic disk under the assumption that this would cure the non-uniformities close to the ceramic resulting in additional signal. Moreover, LIC was designed to reduce the sensitivity by a factor of 20-30 compared to the IC-2004 detectors, however, a factor of ~12 was reached for LIC-sem. The difference can be attributed to the difference in ceramic plates between LIC-ic and LIC-sem.

The new detector prototype, Proportional Chamber (PC), has the same outside geometry as IC-2004 detectors and was designed to achieve higher gain compared to the IC-2004 detectors, namely ~10–100 higher, depending on the applied bias voltage. Six new PC prototypes filled with different gas mixture and different central wire diameter have been manufactured. One of these PCs has been tested at HRM together with the ICs. This PC is filled with Ar+CO_2 gas mixture and has a central wire with 25 µm diameter.

BLM55 HIRADMAT SETUP

HiRadMat is a user facility at CERN, designed to provide high-intensity short-pulse 440 GeV/c proton or 173.5 GeV/n ^{208}Pb beams to a dedicated target area [7]. The unique capability of HiRadMat is to test the dynamic effects of short beam pulses on material samples or full scale accelerator components like beam loss monitors, collimators or beam dumps as well as particle detectors.

The BLM detectors are placed on a mechanical support at 3.2 m downstream from the start of the dump (Fig. 2). A FLUKA based simulation of expected particle fields around the dump has been performed (Fig. 3)[1]. The simulation indicates that at 3.2 m–3.3 m downstream from the start of the dump and at height ~80 cm the absorbed dose is approximately uniform and homogeneous in beam direction. Moreover, the doses are expected within the statistical error to be approximately independent of the vertical position at the detector locations.

The BLM detectors are connected from the area of HiRadMat dump to the Control Room in BA7 (Fig. 4). Due to low signal current the detector cables are connected through one patch panel and not grounded (Fig. 5). Data acquisition was performed with an oscilloscope (Tektronix, MSO 5) with a sampling rate of 6.25 GHz, where 1-6 waveforms per beam intensity (protons per bunch) were recorded for offline analysis.

RESULTS FROM 2022 SETUP

IC Results

Four IC detectors, two from IC-2004 production and two from IC-2016 production, were placed in a mixed row-column positions with respect to the dump (Fig. 6). The data was collected at several beam intensities ranging from 1 to 288 bunches per pulse.

Figure 7 shows the extracted charge as a function of beam intensity where charge was calculated over 80 µs time window from the signal start. The figure demonstrates a linear response and no saturation at high fluxes for all four IC detectors under test. According to the aforementioned simulation, the dose is expected to be uniform at all four detector locations. The measured signal response is consistent with simulation predictions for 3 detectors (two from IC-2004 and one from IC-2016) with variations ~15%, indicating that the differences in this case are dominated by the detectors location. However, there is a larger discrepancy for one of the IC-2016 detector, namely ~35%, which is assumed to be due to detector location and/or potentially larger variations in detector sensitivity.

Nitrogen filed ICs, are expected to have charge drift times of ~300 ns [8] and 84 µs [9] for electrons and ions, respectively. However, the measured signal was observed to exhibit longer ion drift times with the signal shape closer to what is expected for a coaxial instead of planer geometry in the region where ion drift is expected to dominate (Figs. 8 and 9). The observations could be explained by electronic attachment (electron reaction with neutral molecules) and/or more than one gas component contributing to the positive charge drift.

Figure 2: BLM detector setup at HiRadMat test.

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[1] Courtesy of J. Hunt and L. Esposito, CERN

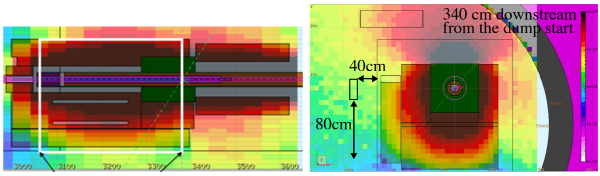

Figure 3: Simulated dose map (288 bunches) around the BLM detector locations (black square) at HiRadMat dump.

Figure 4: Data acquisition in Control Room BA7.

Figure 5: Cable connections in the tunnel.

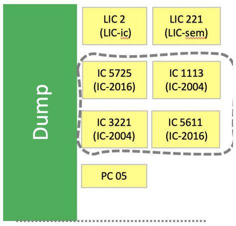

Figure 6: IC locations (marked with gray dashed line).

LIC Results

The two LIC detectors, LIC-sem (LHC type with SEM insulators) and the new LIC-ic (with ceramic disk as in IC), were tested in parallel with IC detectors. The IC to LIC ratio of measured integrated charge in 80 µs was observed to be as expected around 20 for LIC-ic and 12 for LIC-sem (Fig. 11) at higher intensities. Larger discrepancies at lower intensities are due to lower LIC sensitivity. The ratio values were extracted by comparing the charge measured with each LIC to the average value of the charge measured by the two IC detectors placed just below the LICs (Fig. 10, left).

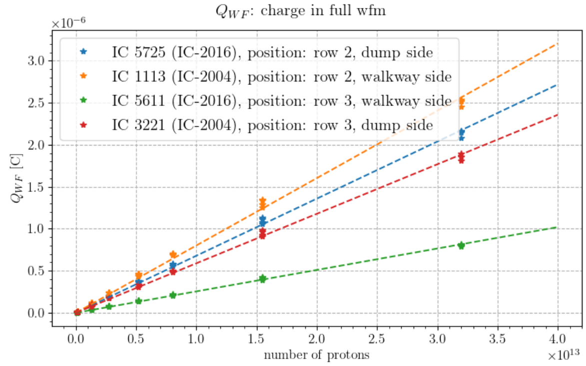

Figure 7: Charge collected with IC detectors versus beam intensity.

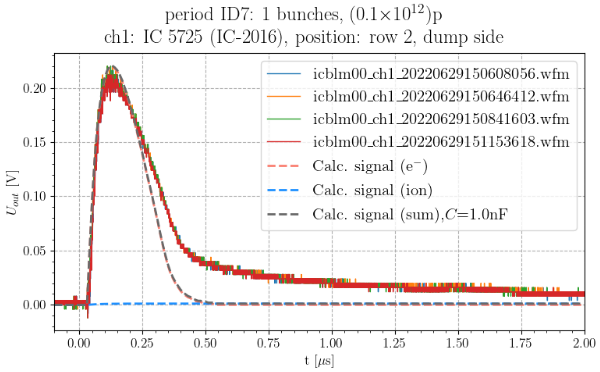

Figure 8: Measured and calculated IC signal for beam intensity of 1 bunch per pulse.

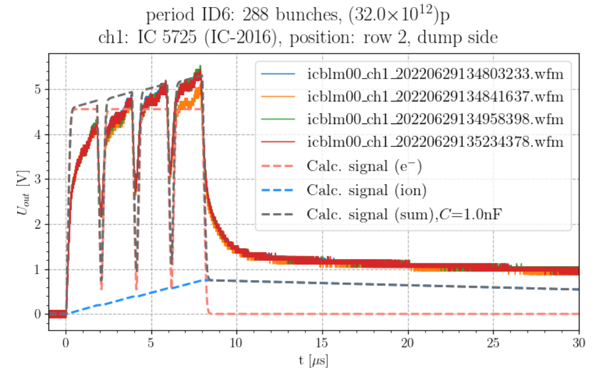

Figure 9: Measured and calculated IC signal for beam intensity of 288 bunches (4 trains of 72 bunches) per pulse.

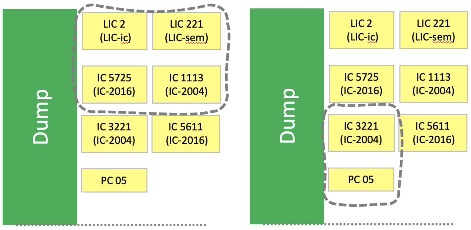

Figure 10: IC and LIC (left) and IC and PC (right) detectors used to for calculation of charge rations in Figs. 11 and 12, respectively.

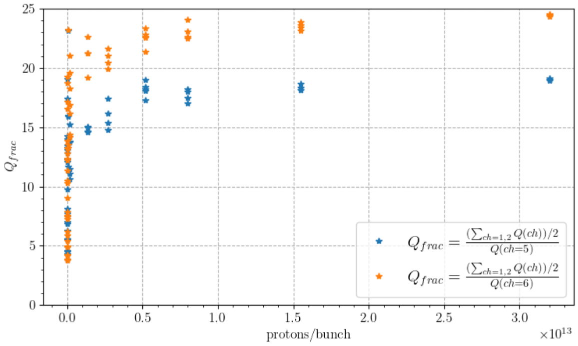

Figure 11: Measured IC/LIC charge ration versus beam intensity. Blue points corresponds to LIC-sem and orange points to LIC-ic.

PC Results

The experimental prototypes of the PCs with different gases and central wires have been designed by Protvino to achieve ~10–100 higher gain compared to IC-2004 detectors. A voltage scan has been performed for one of the PCs at two different beam intensities. Figure 12 shows the extracted ratio of charge collected by PC and charge collected by IC placed directly above the PC (Fig. 10, right). The charge was calculated as an integral over a 80 µs time window from the signal start. The observed ratio is around 6–10 at 1.8 kV. The differences are potentially due to the detector positions with PC positioned rather low where higher variations in doses can be expected.

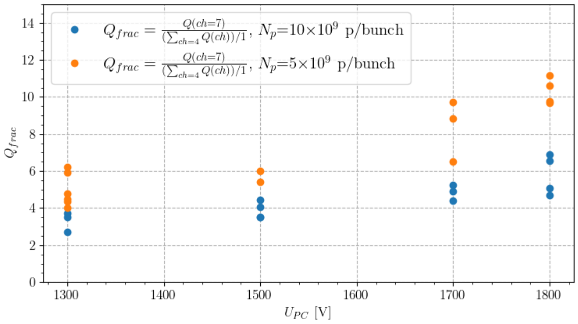

Figure 12: Measured PC/IC charge ratio as a function of bias voltage for two intensities.

CONCLUSION

2022 IC results indicate similar performance of IC-2004 and IC-2016 detectors. However, detector-to-detector performance variations are potentially larger for IC-2016 monitors compared to the IC-2004 monitors. In order to resolve this question, further study has been performed in 2023 with IC data taking during two beam time runs in July and August 2023 at HiRadMat. The analysis of this data is currently on-going.

For LICs the results show the ration IC/LIC to be as expected around 20 for LIC-ic and 12 for LIC-sem at higher beam intensities while larger discrepancies were observed at lower intensities. The ration PC/IC was found to be around 6–10 at 1.8 kV. Nevertheless, LIC-ic and PCs require more time and further efforts to test, design, simulate and issue a new prototype production line.

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REFERENCES

[1] R. Garoby *et al.*, "The European Spallation Source design," *Phys. Scr.*, vol. 93, no. 1, p. 014 001, 2018. `doi:10.1088/1402-4896/aa9bff`

[2] S. Peggs *et al.*, "ESS technical design report," ESS ERIC, Tech. Rep. ESS-DOC-274, 2013. `http://eval.esss.lu.se/cgi-bin/public/DocDB/ShowDocument?docid=274`

[3] I. Dolenc Kittelmann *et al.*, "Neutron sensitive beam loss monitoring system for the european spallation source linac," *Phys. Rev. Accel. Beams*, vol. 25, no. 2, p. 022 802, 2022. `doi:10.1103/PhysRevAccelBeams.25.022802`

[4] I. D. Kittelmann *et al.*, "Ionisation Chamber Based Beam Loss Monitoring System for the ESS Linac," in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 136–140. `doi:10.18429/JACoW-IBIC2019-MOPP023`

[5] E. B. Holzer *et al.*, "Development, Production and Testing of 4500 Beam Loss Monitors," in *Proc. EPAC'08*, Genoa, Italy, Jun. 2008, pp. 1134–1136. `https://jacow.org/e08/papers/TUPC037.pdf`

[6] V. Grishin, B. Dehning, A. V. Koshelev, A. Larionov, V. S. Seleznev, and M. Sleptsov, "Ionization Chambers as Beam Loss Monitors for ESS Linear Accelerator," in *Proc. IBIC'17*, Grand Rapids, MI, USA, Aug. 2017, pp. 454–457. `doi:10.18429/JACoW-IBIC2017-WEPWC03`

[7] F. J. Harden *et al.*, "Hiradmat: A facility beyond the realms of materials testing," *J. Phys. Conf. Ser.*, vol. 1350, no. 1, p. 012 162, 2019. `doi:10.1088/1742-6596/1350/1/012162`

[8] A. Peisert and F. Sauli, *Drift and diffusion of electrons in gases: a compilation (with an introduction to the use of computing programs)*. CERN, 1984. `doi:10.5170/CERN-1984-008`

[9] H. Ellis, R. Pai, E. McDaniel, E. Mason, and L. Viehland, "Transport properties of gaseous ions over a wide energy range," *At. Data Nucl. Data Tables*, vol. 17, no. 3, pp. 177–210, 1976. `doi:10.1016/0092-640X(76)90001-2`