ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG64

INTEGRATION OF LHC-TYPE BEAM LOSS MONITORS INTO THE MACHINE PROTECTION SYSTEM (MPS) FOR THE SIS100 SYNCHROTRON AT FAIR*

K. Laihem[†1], F. Ameil[1], R. Baer[1], M. Dziewiecki[1], K. Fuchsberger[2], T. Habermann[1], V. Kleipa[1]
[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[2]Beampilots, Koppl, Austria

Abstract

The SIS100 heavy ion synchrotron is the central machine of the FAIR (Facility for Antiprotons and Ions Research) project at GSI. It presents complex challenges due to its features handling high-intensity ion beams from protons up to uranium. It demands sensitive **B**eam **D**iagnostics (**BD**) with a robust **M**achine **P**rotection **S**ystem (**MPS**). Due to anticipated extreme conditions, one safety subsystem includes LHC-type **B**eam-**L**oss **M**onitors (**BLM-IC**). These **BLM-IC** detectors play a critical role in **BD** and **MPS**, strengthening protection measures by enhancing monitoring capabilities for severe beam losses and triggering emergency beam dump requests. These **BLM-IC** are gas based **I**onization **C**hambers which aim to prevent beam-induced quenching of superconducting magnets and protect other machine components from damages. This document outlines a conceptual study of **MPS**, integrating 168 LHC-type **BLM-IC** to safeguard the SIS100 synchrotron. The integration involves upgrading the readout electronic chain and adopting FPGA-based logic firmware to handle intricate rate counting requirements over specified time windows. Additionally, hardware sanity checks are proposed to prevent non-conformities and ensure reliability alongside beam loss rate counting. Overall, the focus on beam loss monitoring for the SIS100 within the FAIR project underscores the necessity for sophisticated diagnostic tools and protective measures to ensure the safe and efficient operation of this state-of-the-art synchrotron.

INTRODUCTION

Loss of even small fractions at a circulating beam can induce quenching of superconducting magnets or inflict physical damages. Detecting and monitoring lost particles is vital for safeguarding equipment integrity, triggering a request for an emergency beam dump upon surpassing predefined **BLM-IC**s thresholds. Thresholds can be calculated or estimated through simulations or derived from dedicated experiments adopting the LHC approach discussed in [3]. The beam dump is executed via the **F**ast **B**eam **A**bort **S**ystem (**FBAS**) introduced in [2]. Beyond preventing quenching and damages, particle loss detection aids in assessing aperture constraints, orbit perturbations, and beam oscillations. Mitigation strategies against damages are crucial due to extensive downtime for repairs.

Table 1: Protons and Uranium ions, energies and intensities at FAIR

Prticles / Ions	Energy	Intensity particles/(8 bunches)
Proton p	30 GeV	$2.5\ 10^{13}$
Uranium U(28+)	200 MeV/u	$5.0\ 10^{11}$
Uranium U(73+)	850 MeV/u	10^{10}

The FAIR facility allows for the simultaneous run of up to four experiments [1], offering a diverse range of ion species from protons to uranium ions. The relevant subsystem safeguarding the SIS100 integrates **I**onization **C**hamber (**IC**) detectors detectors (**BLM-IC**) (see Fig. 1). Proton and uranium ion energies and intensities are summarized in Table 1. At high-intensity beams, safeguarding the synchrotron with a **M**achine **P**rotection **S**ystem is crucial. The beam is transported from the synchrotron SIS18 to SIS100. Its path contains critical areas for potential beam losses. One can enumerate, injection point, acceleration, and extraction. The planned machine protection system for SIS100 shares 168 **BLM-IC**s with the beam diagnostics system and can be efficiently adapted to optimize the circulating beams at the SIS100 synchrotron and safeguard its equipment.

BLM-IC INTEGRATION IN SIS100 MPS

BLM-IC are detectors suited for both (**BD**) and (**MPS**) as depicted in Fig. 2A, due to their capability for absolute dose measurement. The **BLM-IC** provides information on beam presence through beam loss at the position where they are mounted. They can prevent quenching if installed close enough to a superconductive magnet. **BLM-IC**s are usually mounted in areas where potential beam losses are expected, like injection, extraction, slits, targets, and degraders. Additionally, these detectors accommodate a diverse range of particle and ion species with their corresponding energies at FAIR which reinforces their effectiveness in machine protection applications.

BLM-IC Deployment at the SIS100 Synchrotron

The **BLM-IC** detectors shown in Fig. 1C are long tubes (chambers) containing parallel aluminum electrodes. Each chamber holds about 1.5 liters of nitrogen gas (N_2) at 100 mbar overpressure. These detectors operate at 1.5 kilovolts and are sensitive to different types of radiation [6].

* This work is supported by GSI Helmholtz Centre for Heavy Ion Research
† k.laihem@gsi.de

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG64

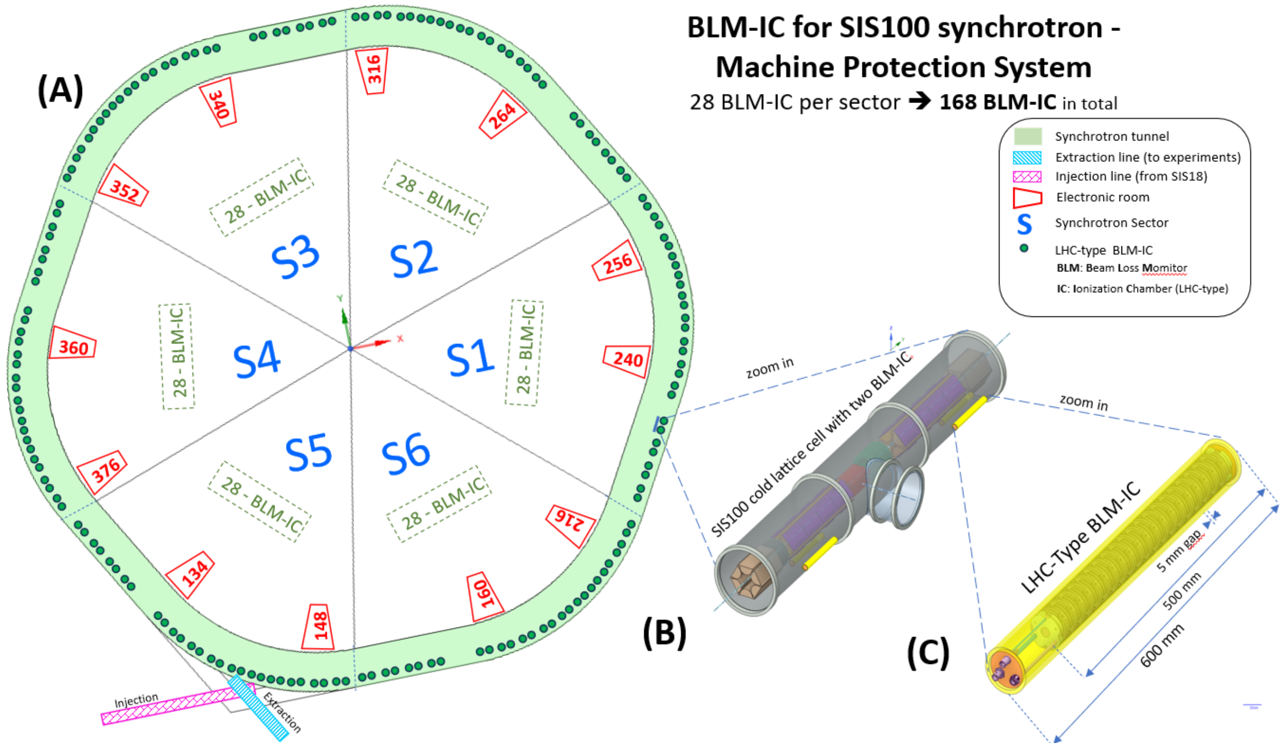

Figure 1: **(A) BLM-IC** deployement layout over the SIS100 synchrotron for beam diagnostics and **M**achine **P**rotections **S**ystem (**MPS**). In total, 168 LHC-Type **BLM-IC** over the synchrotron ring. **(B)** Cold magnets lattice cell including two dipoles, two quadrupoles and correctors. **(C)** LHC-type **BLM-IC** detector. In average two **BLM-IC** per cold lattice cell with 86 lattice cells over the SIS100.

Positioned around the SIS100 synchrotron ring, approximately 168 **BLM-IC** serve both the Machine Protection System and Beam Diagnostics. They are strategically placed at critical areas where potential beam losses are expected (injection, extraction, scrapers, collimators). Employing pairwise deployment, each cold lattice cell is equipped with two **BLM-IC**s as depicted in Fig. 1B. Analog data from these detectors are digitized at the Current to Frequency Converter (IFC) in a niche tunnel and processed in dedicated electronic rooms, each hosting an **MPS** rack with processing capabilities for up to 30 **BLM-IC**s per **DIOB** crate illustrated in Fig. 2B, allowing simultaneous real-time processing, onlone monitoring and archiving for postmortem analysis.

BLM-IC SIGNAL ACQUISITION AND PROCESSING

BLM-ICs quantify beam losses generating integrated analog current signal over the ionization chamber. This analog signal is then converted and digitized into a frequency signal using a current-to-frequency converter IFC, tailored specifically for Ionization chamber based BLMs. The IFC boasts a response time of up to the microsecond range and extends the frequency limit beyond 1 MHz. This extension enhances the linear range by a factor of 100, with a conversion factor reaching 10^{13} C/pulse [4]. The frequency signal is split to both (**BD**) and (**MPS**) through an active Fan-Out. The split frequency signal is fed into the **MPS** Digital Input Output Card for processing. Data processing involves analyzing loss patterns over time, particle types, beam energies, and intensities. Real-time processing requires specialized hardware, with modern **F**ield-**P**rogrammable **G**ate **A**rrays (**FPGA**s) offering resources for intricate processing and can be reprogrammed, making them well-suited for future upgrades. The used **FPGA** is ARRIA II GX - EP2AGX125DF25, explored for real-time monitoring. Tunnel niches house relevant readout cards and digitizers like the current to frequency converters (IFC) to optimize electronic lifespan. DIOB cards process received signals, counting pulses within predefined time windows. Following pulse count processing, the algorithm compares counts to predefined thresholds using a threshold compactor, triggering an emergency beam dump if thresholds are exceeded. The received frequency signals are processed by a **DIOB** (**D**igital **I**nput **O**utput **B**oard), which a main task in counting digital pulses and comparing counts to defined thresholds. The pulses count are carried out within five predefined short time windows ranging from 100 µs, 1 ms, 10 ms, 100 ms to 1 s plus a cycle time-windows defined by start and stop cycle signals.

SIS100 BLM-IC SANITY CHECKS

To prevent non-conformities and ensure reliability alongside beam loss counting, sanity checks are proposed to be regularly or continuously used. They shall minimize the likelihood of failure events leading to incidents resulting from

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG64

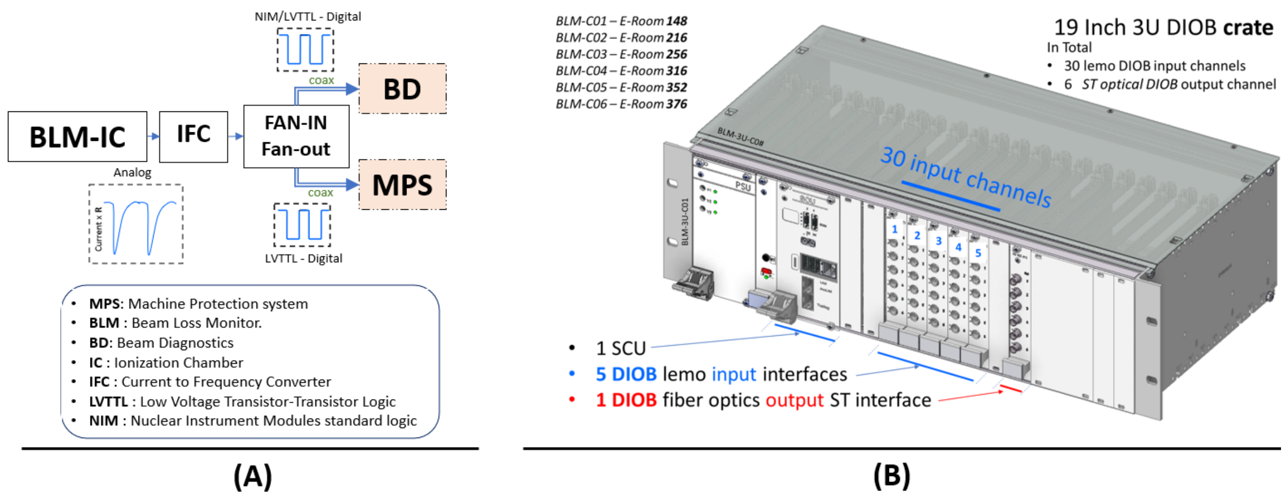

Figure 2: **(A)** Synoptic scheme of **BLM-IC** integration for both Beam Diagnostics (**BD**) and Machine Protections System (**MPS**) - **(B)** 19 Inch 3U DIOB crate, including one **SCU** (**S**tandard **C**ontrol **U**nit), 5 lemo input channels interfaces and one fibe optics output ST interface. Each DIOB interfaces can handle 6 input/output channels

non-conformities in the system (such as high voltage power supplies and cable connectivity) [7]. The connectivity test, or modulation test, introduces a small harmonic signal at the high voltage applied to the **BLM-IC**, altering the detector's output signal by generating a small but detectable current change. Regular checks ensure that hardware remains in optimal condition, aiming to maintain it "*as good as new*". These proposed continuous checks verify both the high voltage power supply and cable integrity for each of the 168 detectors. If issues are detected, such as malfunctions or disconnections, no harmonic variation is detected in current measurements. This prompts withholding the beam permit and enabling safety procedures by either stopping injection to SIS100 or triggering an emergency beam dump.

CONCLUSION

This document presents a conceptual study of a Machine Protection System (MPS) designed to safeguard the SIS100 synchrotron within the FAIR project. The MPS can incorporates up to 168 LHC-type Beam Loss Monitors (**BLM-IC**) to monitor beam loss events. This integration requires upgrading the readout electronic chain and implementing FPGA-based logic firmware to handle real-time rate counting over specified time windows. Counts are compared to predefined thresholds and decision are made to keep the beam circulating, to stop injection or trigger an emergency beam dump request. Additionally, hardware sanity checks can be conducted to prevent non-conformities and ensure the reliability of the system. This emphasis on beam loss monitoring underscores the importance of diagnostic tools and protective measures in ensuring the safe and efficient operation of the SIS100 synchrotron within the FAIR project.

REFERENCES

[1] O. Kester, P. Spiller, and H. Stoecker, "FAIR project at GSI", *World Scientific Publishing*, pp. 611–622, 2016, doi:10.1142/9789814436403_0032

[2] C. Omet *et al.*, "SIS100 Availability and Machine Protection", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 4171–4174. doi:10.18429/JACoW-IPAC2016-THPOY033

[3] M. Sapinski *et al.*, "Estimation of Thresholds for the Signals of the BLMs around the LHC Final Focus Triplet Magnets", in *Proc. IPAC'12*, New Orleans, LA, USA, May 2012, paper THPPR037, pp. 4053–4055.

[4] H. Reeg,"A current digitizer for ionisation chambers/SEMS with high resolution and fast resoponse", in *Proc. DIPAC'99*, Chester, UK, May 1999, paper PS20, pp. XX–XX.

[5] M. Saccani, E. Effinger, W. Viganò, C. Zamantzas, "The Beam Loss Monitoring System after the LHC Long Shutdown 2 at CERN", in *Proc. IBIC'22*, Kraków, Poland, Sep. 2022, pp. 220–224. doi:10.18429/JACoW-IBIC2022-TUP03

[6] M. Stockner, B. Dehning, C. Fabjan, E. B. Holzer, D. K. Kramer, "Classification of the LHC BLM Ionization Chamber", in *Proc. DIPAC'07*, Venice, Italy, May 2007, paper WEPC09, pp. 328–330.

[7] J. Emery *et al.*, "First experiences with the LHC BLM sanity checks", *J. Instrum.*, vol. 5, p. C12044, Dec. 2010. doi:10.1088/1748-0221/5/12/C12044