BEAM LOSS MONITORING STUDY FOR SIS100 AT FAIR

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Abstract

FAIR, the facility for antiproton and ion research, planned as a multi-disciplinary accelerator facility, will extend the existing GSI complex in Darmstadt, Germany. In the FAIR start version, the new synchrotron SIS100 will provide proton or heavy ion beams for a variety of experiments. The GSI synchrotron SIS18 will operate as injector for SIS100. The current study focuses on beam loss measurements for SIS18 and SIS100. The aim of this study is to find quantitative methods to measure beam losses around the machine, mainly SIS100, on an absolute scale. The contribution will present results of two pilot experiments carried out in the high-energy beam lines and at the SIS18 with Uranium ions in the energy range up to 900 MeV/u. In the first experiment the Uranium beam was totally stopped in a Copper target and the particle shower measured with LHC-type ionization chambers. In the second experiment, the beam was slowly excited in the SIS18 synchrotron to create controlled losses on a scraper. The loss rate was calculated by the ROOT code based on data from DC current transformer and plastic scintillation beam loss monitor. Experimental data are compared against the predictions of FLUKA simulations.

MOTIVATION

The FAIR facility is based on operation modes, which allow performing up to four experiments at the same time. It will provide vary species of ions and particles. The most important species for beam loss monitoring investigation purposes are protons and uranium ions. Designed energies and intensities for protons and uranium ions are: p - 30 GeV $2.5 \cdot 10^{13}$ particles, U(28+) - 200 MeV/u, $5 \cdot 10^{11}$ particles and U(73+) - 850 MeV/u, 10^{10} particles. The beam should be delivered from the synchrotron SIS 18 to SIS 100 and along the high-energy beam transfer line HEBT, to experiments. The most critical points where one can expect beam losses are: injection, acceleration and extraction of the beam.

The FAIR beam loss monitoring (BLM) system planned to be based on the different types of particle detectors. It will be helpful in observing the beam losses around the SIS 100 synchrotron and useful in protecting the machine components and unnecessary activation.

In order to investigate and determine possible loss scenarios and prove a new and existing BLMs the beam loss monitoring study in frame of Ph.D. work was started. In this paper two experiments with two different particle detectors are described. The first part concentrates on the experimental test of BLMI (Beam Loss Monitor Ionization chamber) LHC-type of ionization chamber[1] which is a new BLM for existing GSI BLM system ABLASS (A Beam Loss Acquisition and Scaling System)[2] and the second part describes the beam loss experiment with scintillation detector which is already used in the BLM system of SIS 18 at GSI.

BLMI EXPERIMENT

The experiment took place on the high-energy beam line at GSI and had two aims.

At the first, the test of the beam loss monitor was performed and the signal response of such BLM was measured in mixed radiation field at various energies and intensities.

At the second, the simulation of the response function in known radiation field using FLUKA code[3] was done and compared with experimental data and at the third, our simulation concept was proven, based on the comparison between experimental and simulation data.

Experimental Part

The experimental setup consists of a uranium ions beam, beam loss target and a set of three BLMIs.

Uranium ions were delivered from SIS18 via high-energy transfer line to the experimental cave. The energies and intensities of uranium ions were varied in range of 300-900 MeV/u and $10^7 - 5 \cdot 10^8$ particles respectively.

The beam loss target is made of copper cylinder 4 cm in radius and 2 cm thick. The target was 45 degrees inclined with respect to the beam line. The effective thickness of copper target is about 2.8 cm, which is more than the range of uranium ions in copper for the highest of chosen experimental energies[4].

The BLMs are the LHC-type of ionization chambers. The uncovered BLM is shown in Fig 1.

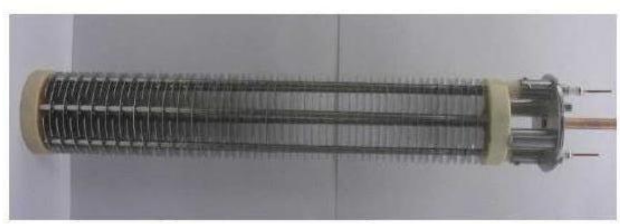

Figure 1: The BLM LHC-type ionization chamber without steel cover [1].

The BLM has a cylindrical shape and consists of a set of 61 aluminum plates, which are held by 6 stainless steel connection rods. The inner diameter of the cylinder is 8.8 cm. It is covered by 2 mm thick stainless steel. The top and the bottom of a BLM are closed by 5 and 4 mm stainless steel plates respectively. The inner volume of the BLM is isolated from the atmosphere and filled with nitrogen at 1.1 bar.

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BLMIs were situated in three different positions downstream from the beam loss target. The BLMI1 was located on the distance of 40 cm in front of the target and 30 cm underneath the beam. The BLMI2 was situated on the distance 120 cm at the left hand side from the target, 60-degree shifted with respect to the beam line and had the same height level as the BLMI1. The BLMI2 was shielded by support construction. The BLMI3 was stand on the left hand side from the target on a distance of 150 cm and was shifted on 24-degree with respect to beam line. BLMI3 had the same height position as a beam line.

The signal from the detectors is converted to frequency via charge to frequency converter[5] and collected by ABLASS. The example of output signals from BLMIs in ABLASS system produced by uranium ions at energy 600 MeV/u is shown in Fig. 2.

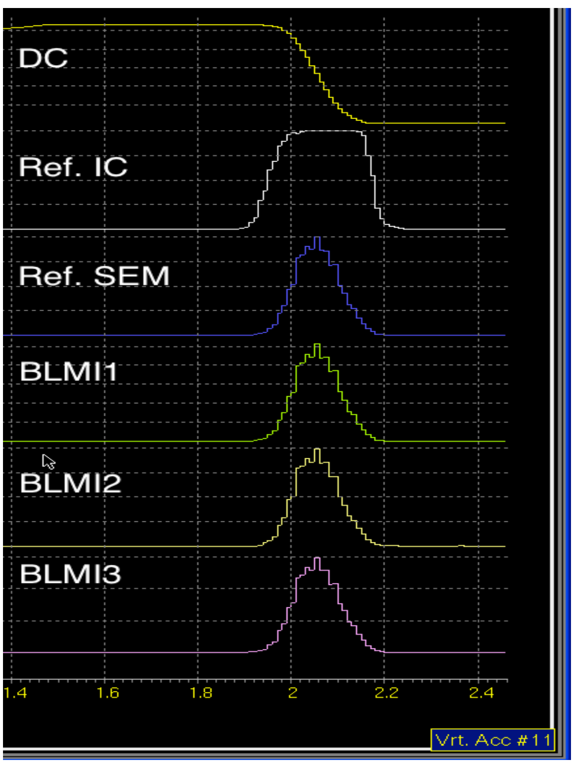

Figure 2: The signal from Reference detectors and BLMIs in arbitrary units.

The first curve from the top is the signal from a DC-transformer in the SIS 18. After the acceleration the uranium beam reached a flattop and then was slowly extracted to the high-energy beam line. The 2nd and the 3rd signals are from reference detectors, which allow us to calculate the intensity of the beam. The 4th-6th curves are signals from BLMIs. Experimental data were taken for 300, 600 and 900 MeV/u and normalized by intensity of the beam.

Simulation Part

FLUKA code was used for performing simulations of BLMI response function. A full-scale model of the experimental cave and BLMIs was created in the FLUKA code. The BLMI response function was obtained as follows.

The energy deposition (ED in units of GeV/primary) in effective volumes between the electrodes of BLMI was calculated. Knowing the ED we can divide ED by the average energy needed to produce an electron-ion pair in nitrogen and obtain the total amount of created electron-ion pairs. Assuming that the electrodes collect all created electrons we can calculate response as a charge per primary in units of C/p according the formula:

$$Q = \frac{ED}{W} \cdot e \tag{1}$$

Q – charge in Coulombs per primary particle [C/p],
ED – energy deposition in GeV per primary particle [GeV/p],
W – average energy needed to produce an electron-ion pair for nitrogen is 35 eV/e-ion pair[6]
e – elementary charge in Coulombs [C].

The simulation of BLMI experiment was divided into two parts: the 1st part is done for BLMIs where the inner structure of the detector was not taken into account. The energy deposition in this case is calculated in the effective volume; the 2nd part of simulations takes into account the inner structure of the BLMI and calculations of energy deposition were done in volumes between electrodes.

Results

The result for the first part of simulations is shown in Fig. 3.

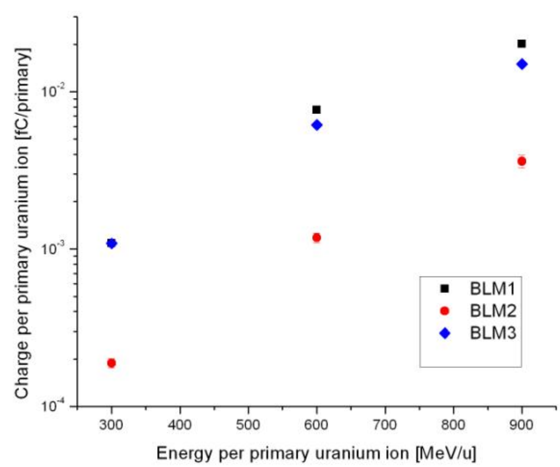

Figure 3: The simulated response function of LHC-type ionization chamber.

Analysis of the result shows that the response function of BLMI depends linearly on energy of primary ion in half-logarithmic scale and also on the position of BLMI in respect to the beam loss point.

The response function for the BLMI2 is about one order of magnitude lower than for BLMI 1 and 2 due the shielding effect of support construction of the beam line.

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The contribution of different particles to the total response function of BLMI1 is shown in Table 1.

Table 1: Contribution to the Total Response Function from Different Particles

	All	p	π^+	π^-	n	e^+	e^-	μ^+	μ^-	γ
Percentage	100	78.1	0.39	1.4	4.4	1.3	4.1	0.2	0.12	0.7

Protons make 80% contribution to the total response function. The second largest contributors are electrons and neutrons, which together yield about 8%.

The result of simulation for the 2nd part, where the inner structure of the 1st beam loss monitor was taken into account, is shown in Fig. 4.

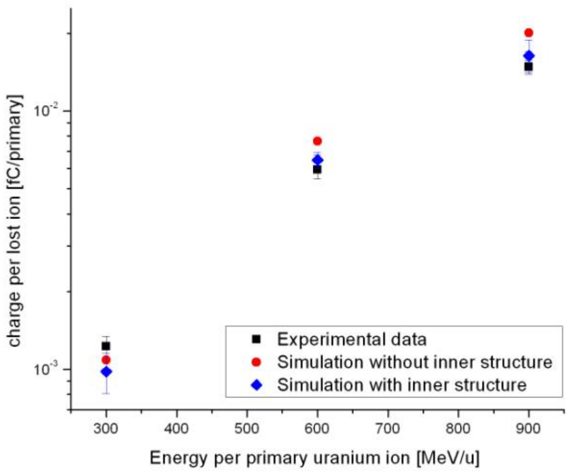

Figure 4: BLMI1 response function of LHC-type ionization chamber. Comparison between experimental data and simulations.

The analysis of the figure shows that the simulations where the inner structure was taken into account give better agreement to experimental data.

The ratio between experimental data and simulations with inner structure for all beam loss monitors are shown in Table 2.

Table 2: Comparison Simulation vs. Experimental Data

	BLMI1	BLMI2	BLMI3
300 MeV/u	0.8	1.02	1.8
600 MeV/u	0.8	0.7	2.0
900 MeV/u	0.6	0.7	0.9

The discrepancy between simulation and experimental data for the BLMI3 should be checked additionally.

Nevertheless, taking into account experimental uncertainty which is about 20% one can see that the ratio between simulation data and experiment allow using the FLUKA approach in future investigation of BLMI in different radiation fields.

However more experiments with different species and energies are planned for future benchmarking of the simulations.

CONTROLLED BEAM LOSS EXPERIMENT AT SIS18

The experiment with controlled beam losses on ion scraper was performed at SIS 18 section.

The aim of the experiment is detecting the losses in known position and obtaining information concerning the relative losses along the SIS 18 ring.

Uranium ions were utilized in order to produce losses on ion scraper at SIS 18 section. In normal operation the uranium beam is injected from the UNILAC to SIS 18 for further acceleration and extraction. In this experiment uranium beam is injected to SIS 18 ring, accelerated and stored for several seconds. During that time the beam was excited by beam exciter and increased in transversal direction. Excited beam hit the scraper producing beam losses.

The information on the experiment is shown in Fig. 5.

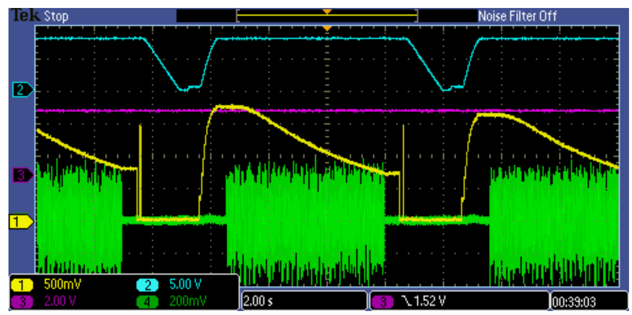

Figure 5: Beam profile and signal from the BLM based on scintillation detector.

Yellow curve is a beam current, which was measured by the beam current transformer. One can see that after injection the energy of the beam increases then the beam reached a flattop where accelerator works as a storage ring and then the beam spot was blown up by exciter (green curve).

As beam loss monitors two scintillation detectors were utilized. Beam loss monitors were situated downstream with respect to the beam losses position on a distance 2 and 5 meters respectively. The data are collected through the ABLASS data acquisition system and used in further analysis with a ROOT code[7]. The beam loss experiment was performed with uranium beam of different energies and intensities in range of 100-900 MeV/u and $10^8 - 10^9$ particles respectively. Figure 5 shows the signal from beam loss monitor (red curve) and DC transformer black curve.

The loss rate is calculated by the ROOT code. The calculation is based on the following concept: during the storage time (when the accelerator works as a storage ring) the beam experiences small losses due to intra beam scattering, gas scattering, etc. Within the period, when the exciter is off, the total amount of beam particles is fitted by an exponential function, in order to determine the life time of the beam. If the beam would not be excited, the intensity would follow this exponential function (see the Fig. 6, red curve). Throughout the machine cycle, in case

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when the beam is excited, one can calculate the number of lost particles on the collimator for each time bin by taking the difference between the extrapolated life time function and the actual number of particles measured by DC transformer.

The Fig. 6 shows the measured beam intensity (black curve) and BLM signal (blue curve) in arbitrary units. At the beginning of flattop one can see BLM signal mostly from background. At the 2nd second of machine cycle beam was excited and we can observe the BLM signal.

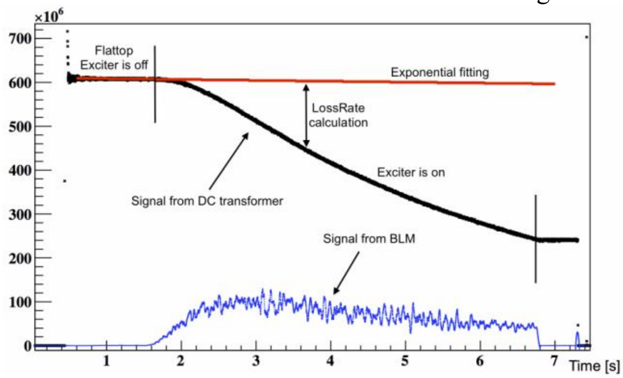

Figure 6: The signals measured by DC transformer and scintillation beam loss monitor.

The Fig. 7 shows the diagram BLM signal vs. loss rate for several beam energies. The analysis of this diagram shows, that BLM signal and loss rate depend linearly on each other for given position of beam loss monitor. For each energy, the data were approximated by a linear fit and the ratio between BLM signal and loss rate was retrieved.

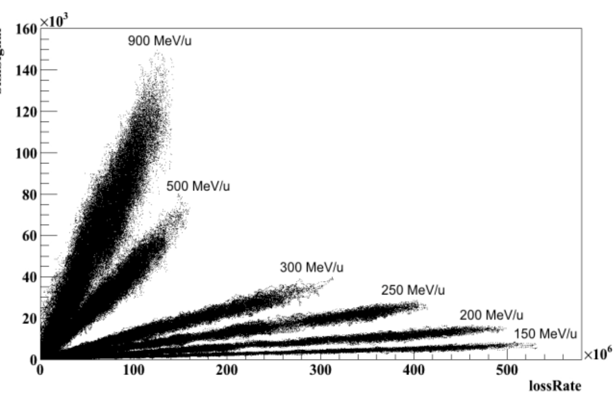

Figure 7: Diagram shows the BLM signal vs. loss rate.

The dependence between ratio and the beam energy is shown in Fig. 8 and seems to follow linear dependence on energy.

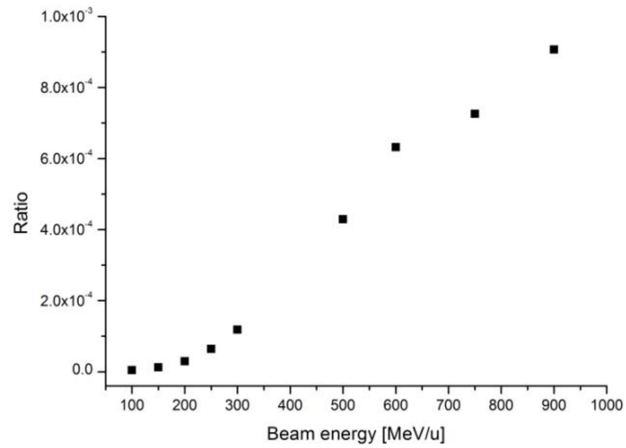

Figure 8: Blm signal to loss rate ratio in dependence on beam energy.

OUTLOOK

Two experiments on beam losses were performed.

During the first experiment, the new beam loss monitor LHC-type ionization chamber was tested. Experimental data were crosschecked with FLUKA simulations. Based on the result we can say that our simulation approach gives reliable result. However, further testing of BLMI with different ions is needed.

Also a beam loss experiment at SIS 18 synchrotron was performed. The loss rate depends linearly on beam energy. For the future investigation it was concluded to use the BLMI jointly with scintillation beam loss monitor in order to crosscheck the performance of each type of BLM.

REFERENCES

[1] M. Stockner, "Beam loss calibration studies for high energy proton accelerators", Ph.D. Thesis, Geneva, (2007).

[2] T. Hoffmann *et al.*, "Experiences on Counter Applications and Beam Loss Measurement at the GSI Synchrotron", 11th Beam Instrumentation Workshop 2004 (BIW 04), Knoxville, Tennessee, USA, p.294.

[3] A. Ferrari, P.R. Sala, A. Fasso, and J. Ranft, "FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

[4] I. Strasik *et al.*, "Depth-profiling of the residual activity induced by 950 MeV/u uranium ions in copper", Slovak University of Technology, Bratislava, Slovak Repuplic; GSI, ITEP, GSI-Acc-Note-2006-11-002 November 19, (2006).

[5] H.Reeg "A current digitizer for ionization chembers/sems with high resolution and fast response", GSI, Darmstadt.

[6] International Commission on Radiation Units and Measurements. Average energy required to produce an ion pair. Technical report, ICRU Report 31, Washington D.C., (1979).

[7] R. Brun, F. Rademakers, "ROOT: An Object-Oriented Data Analysis Framework", http://root.cern.ch.

ISBN 978-3-95450-127-4