BEAM LOSS MONITORING AT THE EUROPEAN SPALLATION SOURCE

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At the European Spallation Source linear accelerator will generate 5 MW beam of protons at 2 GeV to be delivered to a target to produce neutrons for science experiments. This high power accelerator will require significant amount of beam instrumentation, among which the beam loss monitoring system is one of the most important for operation. An LHC type ionization chamber [1] is planned to be used with ~54 μC/Gy sensitivity. At most 1.5 mGy/sec radiation levels are expected close to the beam pipe during normal operation, resulting in up to 80 nA current signal in detectors. Loss monitor electronics is designed to be able to measure currents as little as 1% of the expected current up to as much as 1% of the total beam loss, thus ~800 pA – few mA. In order to study beam loss pattern along the accelerator a coherent model of the whole machine is created for the purposes of Monte Carlo particle transport simulations. Data obtained using the model will be stored in a database together with the initial beam loss conditions. The contents of the database will then be processed using custom neural network algorithms to optimize number and position of the loss monitors and to provide reference on the beam loss localization during operation of the machine.

Predicted power density levels

The ESS linac consists of an ion source, low energy beam transport, medium energy beam transport, drift-tube linac – all at room temperature, spoke section, medium-beta and high-beta sections – all superconducting, followed by a high energy beam transport and accelerator-to-target sections. Quadrupole magnets in between the cold sections of the accelerator will also be kept at room temperature. A MARS model of spoke and medium/high beta accelerating sections was composed. A quadrupole doublet was inserted in the middle of every adjacent cryomodule. MARS [2, 3, 4] Monte Carlo particle transport code was used to simulate beam losses and generate power density maps. Power density was calculated for normal operations, when a maximum allowed beam loss equals to 1 W/m. Beam was lost uniformely on a beam pipe with the shallow loss angle of 3 mrad in the simulations. Power density, in Gy/sec is shown in Figures 1 and 2 for beam energy 200 MeV and 2 GeV respectively.

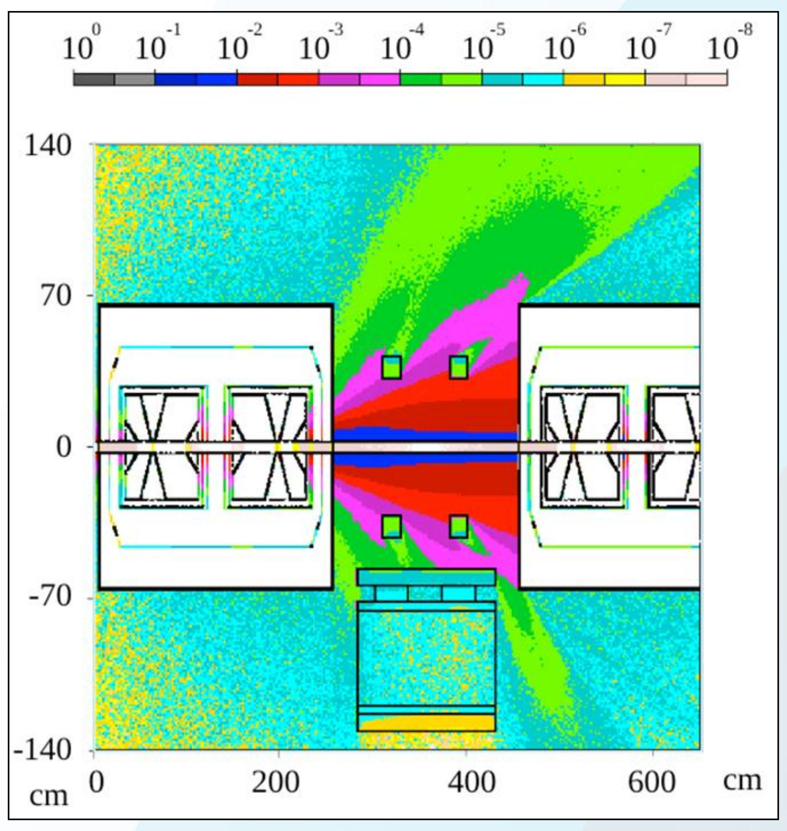

Figure 1: Power density, in Gy/sec, for 1 W/m distributed beam loss on a beam pipe, at 200 MeV.

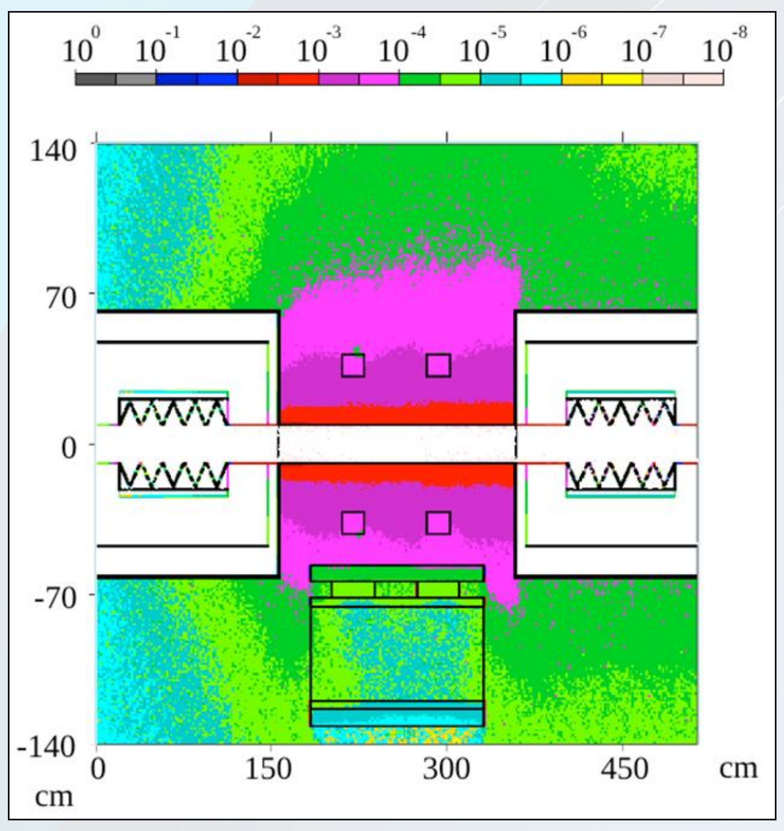

Figure 2: Power density, in Gy/sec, for 1 W/m distributed beam loss on a beam pipe, at 2 GeV.

Time response

One of the main purposes of the BLM system is to protect accelerator from damage in case of accident beam loss. The ESS machine protection system will be linked to the BLM system and receive beam abort signals if necessary. The system will be designed to be fast enough to prevent accelerator damage. To understand better how quickly one would have to react, a time period in which a full beam would start melting stainless steel or copper accelerator components was calculated. Figure 3 summarizes the outcome and shows that the response time strongly depends on a beam size and gets relatively relaxed at energies above ~10-20 MeV. Note that the response time in Figure 3 is a detector reaction time (time in which a detector gives measurable current signal) plus time for electronics to issue a beam abort signal.

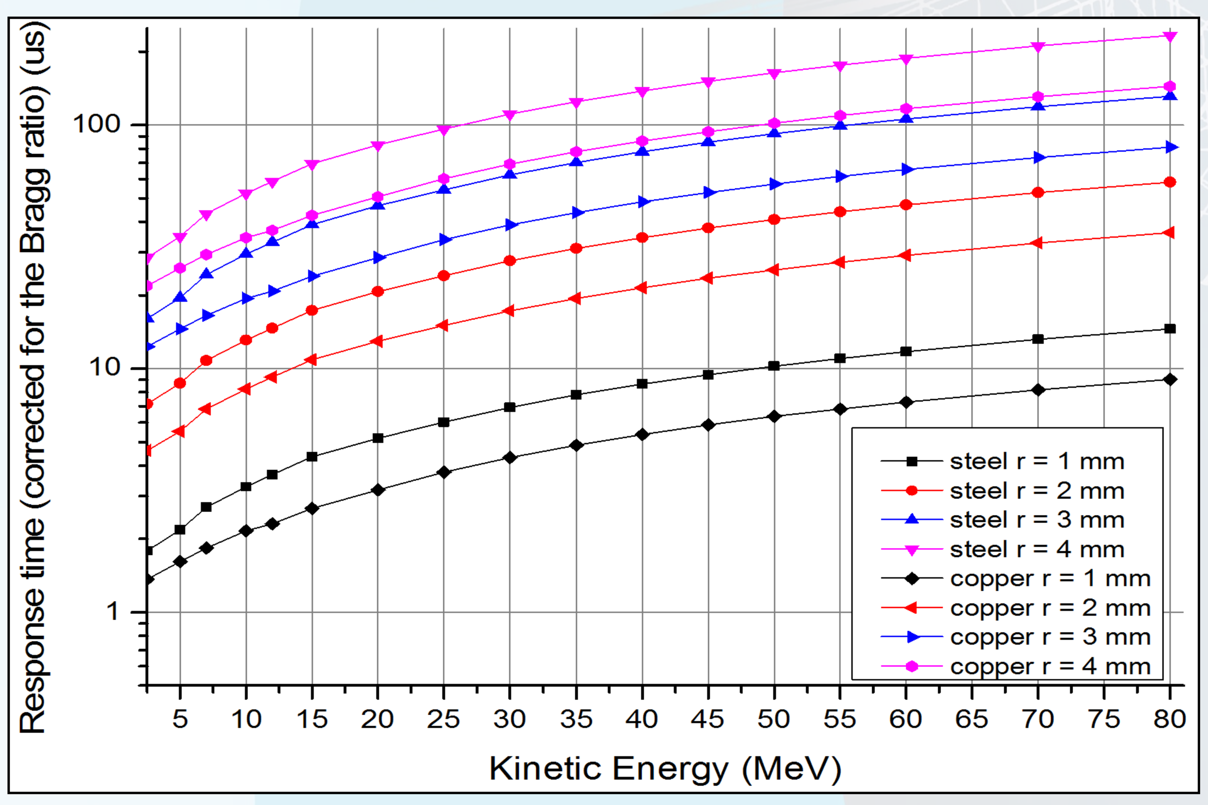

Figure 3: Desired time response (in μsec) for ionization chambers at different proton beam energies in the range of 5 MeV – 80 MeV

Expected currents

BLM system is required to be able to measure at least 1 % of the maximum allowed beam losses during normal operations up to 1 % of the total beam loss. Ionization chamber, similar to those used at LHC, is planned as a main beam loss monitor at ESS. This detector has ~ 54 μC/Gy of sensitivity [1]. Based on the expected power density levels at ~ 20-25 cm from the beam pipe, as seen in Figures 1 and 2, we require the loss monitors to be able to measure a current in the range of ~800 pA – few mA.

BLM electronics

	Required at ESS	SNS	DESY-XFEL	LHC
Detector Type	IC	IC	Scint. + PMT	IC
Beam abort time (μs)	10	10	4	89
Elect. B.W. (kHz)	350	35 & 1		
Elect. dyn. range (dB)	128	126		136
Min. inp. cur. (pA)	800	324		50
Max. inp. cur. (μA)	2000	644		200
Elect. Platform	MTCA.4	VME	MTCA.4	VME
Digitizer	16 bit, >100 MSa/s	16 bit, 100 kSa/s	14 bit, 1 MSa/s	12 bit,40 MSa/s
Det. cable length (m)	60	23-91	50-100	400

Table 1: ESS BLM requirements in comparison with the SNS, DESY-XFEL and LHC systems.

Table 1 makes a comparison between some of the ESS BLM requirements and specifications of SNS [5], DESY-XFEL [6] and LHC [7]. It shows that none of these systems is fully compatible with the ESS. The beam abort time of the SNS and LHC BLM system does not meet the ESS machine protection requirements. Also, the electronics platform of these systems does not comply with the platform planned for ESS. The DESY-XFEL system meets these two requirements, but its front-end electronics is designed for a different type of detector, invalid at ESS due to dynamic range considerations. Also the timing requirements of the DESY-XFEL system are different from those at ESS.
Currently, an in-house development of the BLM electronics is under study. The front-end electronics can be in the form of a rear transition module (RTM) measuring signals from several BLMs. The RTM can be compatible with the micro telecommunications computing architecture (MTCA.4) standard so that it can be connected to a commercial digitizer card where the signals are converted to digital and FPGA processed for loss calculation and threshold comparison.

BLM layout optimization

Creating a complete, coherent model of the whole accelerator is crucial for many aspects of the design phase of the machine and also for later when the facility is operational. Monte Carlo particle transport simulations performed with this kind of model brings answers to the questions raised by the machine and radiation protection issues and complement beam physics particle tracking works. Although the machine model is used for simulations of various kinds, beam instrumentation focuses on using it to predict consequences of beam losses in order to optimize the number and positioning of the BLMs. Based on first assessments it was requested that a BLM is placed in front and back of each quadrupole magnet. However, a more sophisticated optimization studies are planned, namely using of neural network for the necessary data processing. Successful usage of similar techniques (i.e. genetic algorithms) in accelerator physics is shown in [8].

References: [1] M. Stockner et al, "Classification of the LHC BLM Ionization Chamber", Proceedings of DIPAC 2007; [2] N.V. Mokhov, "The Mars Code System User's Guide", Fermilab-FN-628 (1995); [3] N.V. Mokhov, S.I. Striganov, AIP Conf. Proc. 896, pp. 50-60 (2007); [4] http://www-ap.fnal.gov/MARS/; [5] D. Gassner, R. Witkover, "SNS Beam Loss Monitor Electronics Final Design Review", a power point presentation, 23 July 2002; [6] L. Fröhlich, "Machine Protection for FLASH and the European XFEL", Dissertation, Universität Hamburg, Hamburg 2009; [7] C. Zamantzas, "The Real-Time Data Analysis and Decision System for Particle Flux Detection in the LHC Accelerator at CERN", Ph.D. thesis, 2006.; [8] A. Hofler, et. al. "Innovative Applications of Genetic Algorithms to Problems in Accelerator Physics", Physical Review Special Topics, Accelerators and Beams 16