BEAM LOSS STUDIES FOR THE CERN PS BOOSTER USING FLUKA

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Abstract

In view of future upgrade plans, the beam loss monitor (BLM) coverage of the four PS Booster (PSB) rings was reviewed. FLUKA studies at Linac4 injection and PSB extraction energies were performed to simulate the loss patterns. The results of these studies, presented in this paper, have led to the proposal to double the number of beam loss monitors in the PSB.

INTRODUCTION

The PSB consists of four superposed rings, each of which can be filled or not with particle beams from its injector. Currently, proton beams of 50 MeV are provided by Linac2. In the future this will be replaced by a new injection system ('charge-exchange') with Linac4, which will allow increasing the injection energy from 50 to 160 MeV and reducing injection losses. In addition, the extraction energy of the PSB will be increased from its present limit of 1.4 to 2 GeV within the framework of the LIU PSB project [1].

Currently, the BLM system consists of two 'ACEM' type BLM monitors, for each of the 16 Booster sections, vertically oriented, and placed downstream of the 1st bending magnet in-between rings 1 and 2 and rings 3 and 4. These monitors will have to be consolidated in any case, as they are not fabricated anymore. The consolidation plan foresees a replacement by LHC-type monitors, which are based on parallel plate ionization chambers (IC) [2] with an active volume of 1.5 l and by the recently developed smaller and flat monitors (FLAT-IC) [3] in case they would appear to be sensitive enough to detect the losses arising from the main aperture restrictions of the PSB.

The FLUKA simulations reported here were performed with the goal to optimize the type, position and number of the new BLMs for the current and future beam energies and to verify if the present coverage would still be sufficient for the future running conditions.

FLUKA RESULTS

The central task of the FLUKA studies was to simulate in detail the sensitivity and the response of the newly developed LHC-IC and FLAT-IC type BLM monitors in terms of energy deposition and particle spectra they are exposed to, due to beam losses at the vertical and horizontal aperture limitations of the PSB [4]. In order to obtain a realistic radiation field from the beam losses and to evaluate the sensitivity of the new monitors with a high reliability, the rather complex PSB geometry had to be modelled in sufficient detail. This also includes the specific material of each element. Fig.1 shows the geometry of one extended Booster period as modelled for the FLUKA simulation. A magnetic field map is implemented in each of the bending magnets [5].

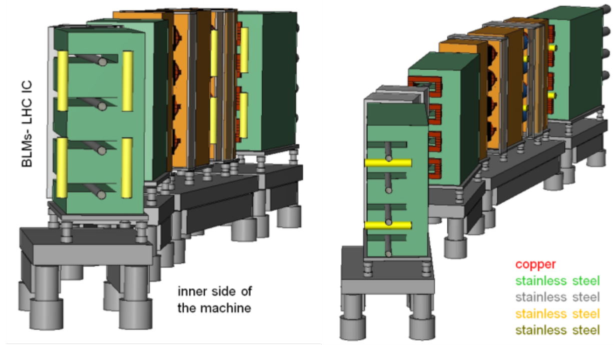

Figure 1: Geometry of an extended Booster Period as implemented in FLUKA with vertically (left) and horizontally oriented BLMs (right). The basic lattice is 0.5D-F-B-B-F-0.5D (D-defocussing, F-focussing, B-bending magnet).

The next step is to simulate the beam losses. Based on beam optics studies, the highest beam loss probabilities within one Booster period are expected at the vertical aperture limitation, located at the exit face of the 1st bending magnet (BM) and named 'source I' in this study, and at the horizontal aperture limitations, located at the centers of the focussing quadrupoles (QFs) and named 'source II' (only the center of the 1st QF is considered in this study). For both sources the protons are assumed to interact with the surface of the steel beam pipe of the 3rd ring [4]. A high-intensity ISOLDE-type beam of 10^{13} p/1.2s/ring is considered, with a beam loss rate of 1%, i.e. 8.3×10^{10}p/s both at the vertical and at the horizontal aperture limitations.

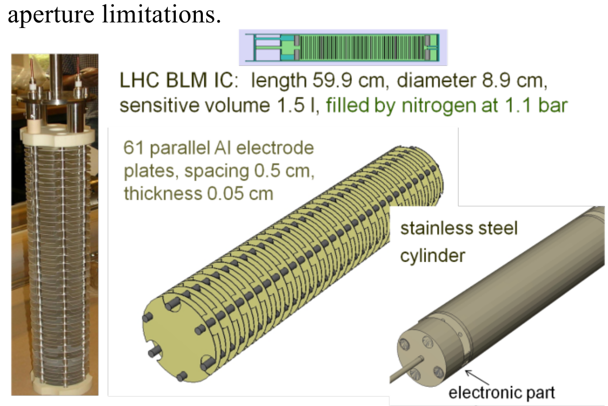

Figure 2: Geometry of the LHC-IC type BLM, comparing the geometry modelled in FLUKA (right) with a real photo (left).

In order to study the response of the BLMs to a radiation field, 16 positions for the vertical BLM orientation and 8 positions for the horizontal BLM orientation were defined around the machine. These positions are illustrated in Fig.1 (yellow cylinders).

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Response of the LHC-IC Type BLMs to the Beam Losses at the Two Aperture Limitations

The response of the LHC-IC type BLMs in terms of current was extracted in two different ways. The first method is based on the following analysis procedure. In the first step the fluence spectra of all particles within the active volume of the BLMs are extracted. In the next step the spectra are folded with a detector-specific response function expressed in $fC \times cm^2$/primary [6]. The folded spectra are then integrated over energy to obtain the result in terms of charge/primary. In the final step the results are multiplied with the beam loss intensity in order to obtain the expected current to be measured by BLMs (for more details see [4]). The second method is to directly calculate the energy deposited in the active volume of the BLMs expressed in GeV/primary. The charge is then extracted by using the conversion factor W, i.e. the average energy required to produce an electron-ion pair (34.8±0.2 eV for the case of nitrogen). While the two methods gave the same results, the folding method has advantages: much less CPU time is required to achieve good statistics, and the detailed geometry of the BLMs shown in Fig.2 is not required, since all details including the effects due to the additional material like electrodes are taken into account by the detector-specific folding function.

The results for the response of the LHC IC type BLMs expressed in pA, due to 1% beam losses at the vertical aperture limitation inside the 3rd ring (source I) for the

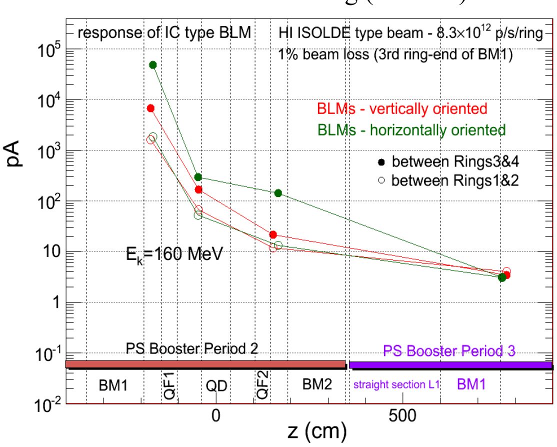

Figure 3: Expected currents to be measured by differently oriented LHC-IC type BLMs for the source I.

case of a future injection energy of E_k=160 MeV are shown in Fig.3. Four points associated with each of the curves indicate the currents expected to be measured at the 4 BLM locations along the beam direction: 1) downstream of the 1st BM, 2) between the multipole and the QD, 3) downstream of the 2nd QF and 4) downstream of the 1st BM in the next section. The color code of the curves identifies the different BLM orientations, vertical (red) and horizontal (green).

A first conclusion can be drawn immediately. As visible from Fig.3, the first 3 monitors in-between rings 3 and 4 measure higher currents by factors of 8, 2.5, 7 for horizontal BLM orientation, offering a higher sensitivity to the position of the source than the vertical orientation while the current of the last monitors located in the next Booster period appears to be independent of the BLM orientation. A further advantage of horizontally oriented detectors is a more efficient way to distinguish beam losses of the lower (1,2) and the upper (3,4) rings. Although the conclusions drawn are based on the results associated with the proton beam energy E_k=160 MeV, the same conclusions are also valid for the higher energies.

A direct comparison of the currents to be measured by horizontally oriented LHC-IC type BLMs at different beam energies, E_k=160 MeV and 2 GeV is shown in Fig.4. The energy dependence is extracted for two different beam loss scenarios, i.e. at the vertical aperture limitation, source I (left panel of Fig.4), and at the horizontal aperture limitation in QF1, source II (right panel of Fig.4). As is clearly visible in Fig.4, the values read by the BLMs in the next Booster period are smaller by 2-3 orders of magnitude compared to values close to the source for both energies. The values at E_k=160 MeV are smaller by 2 orders of magnitude compared to E_k=2 GeV (the values expected for the present extraction energy E_k=1.4 GeV are only smaller by a factor of 1.5 compared to E_k=2 GeV). In absolute terms, the currents of ~4 pA for source I and ~5 pA for source II at E_k=160 MeV expected for the BLMs in the next Booster period are actually factors of 2-3.5 below the sensitivity threshold of 10 pA and thus immeasurable.

Given the lower sensitivity threshold of the LHC-IC type monitors of about 10 pA, the present number of BLMs per section would thus not be sufficient for the new injection energy of E_k=160 MeV, since beam losses at both aperture limitations of one period could not be detected by the BLM in the next period. For the present and future extraction beam energies, on the other hand, two BLMs per section (downstream of the 1st BM, between rings (1,2) and (3,4)) would be completely sufficient. Based on this study, the proposal is therefore to double the number of BLMs in the PSB section by adding two more BLMs, e.g. between the multipole corrector and the defocusing magnet. This would allow distinguishing whether the losses per section were due to the horizontal or the vertical aperture limitations, even at injection energy.

Response of the FLAT-IC Type BLMs to the Beam Losses at the Aperture Limitations

Since the PS Booster is very compact with 4 superposed rings and hardly any free space in-between different machine elements, a proposal was made to use instead of the LHC-IC type the FLAT-IC BLMs. These detectors were recently developed specifically for the PSB [3]. The length and the height of the FLAT-IC are about 2 times smaller, so that the space between the different machine elements is now sufficient for the new detectors to fit in. However, the active volume of the FLAT-IC type detector is only 0.125 l, i.e. 12 times smaller than for the IC type BLMs, thus resulting in lower sensitivity.

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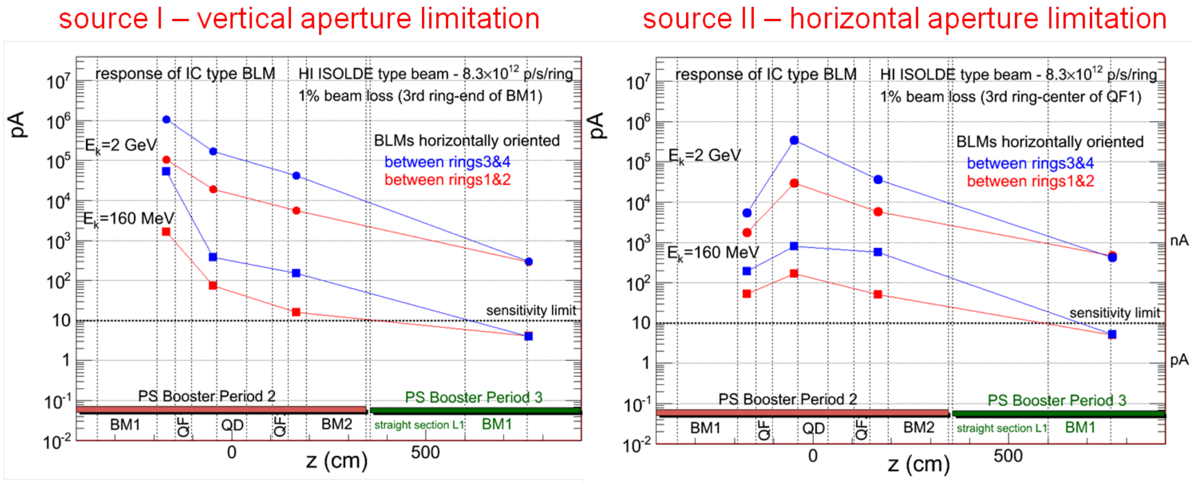

Figure 4: Response of horizontally oriented BLMs in pA to beam losses at the vertical (left panel) and horizontal aperture limitations (right panel) of the 3rd ring for different beam energies (E_k=160 MeV and 2 GeV).

A direct comparison of the response of the two types of detectors, LHC-IC and FLAT-IC for the two sources at injection energy E_k=160 MeV is shown in Fig.5.

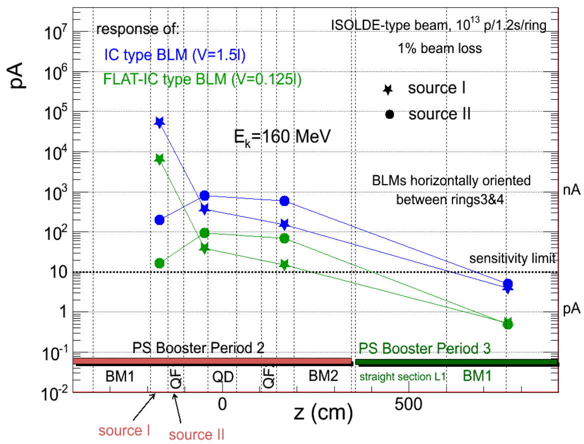

Figure 5: A direct comparison of the currents expected to be measured by the two types of BLMs, LHC-IC (blue) and FLAT-IC (green). The results are shown for the future injection energy E_k=160 MeV, and separately for source I (stars) and source II (circles).

As visible from Fig.5, the simulation shows the currents to be about a factor of 10 on average smaller for the FLAT-IC compared to the LHC-IC, roughly scaling with the active volume. For the future injection energy E_k=160 MeV, currents of 95 pA for source II (dominant at E_k=160 MeV) and 40 pA for source I are expected to be measured by the FLAT-IC BLMs at the second location (between the multipole corrector and the QD), i.e. factors of 10 and 4 above the threshold. However, the combination of LHC-IC (downstream of the 1st BM) and FLAT-IC type of BLMs (between the multipole corrector and the QD) will provide a sensitivity to beam loss rates of $>10^{10}$ p/s at the injection energy E_k=160 MeV, i.e. to >0.1% losses of ISOLDE (10^{13}p/1.2s/ring)-type and to >1% losses of LHC 25 ns (1.6×10^{12}p/1.2s/ring)-type beams. This combination will clearly distinguish whether the losses per section are due to horizontal or vertical aperture limitations.

CONCLUSIONS

A new beam loss monitor system is planned to be installed in the PS Booster. The response of two types of monitors, LHC-IC and FLAT-IC, has been studied with FLUKA simulations. The LHC-IC type is the most suitable detector due to the higher sensitivity. However, given the lower sensitivity threshold of 10 pA, the present number of BLMs per section would be sensitive to beam losses at both aperture limitations only for PSB extraction energies, but not for losses at the horizontal aperture limitation for the future injection beam energy of E_k=160 MeV. Based on this study, the proposal is to double the number of BLMs in the PSB section by adding two more BLMs. A combination of LHC-IC (downstream of the 1st BM) and FLAT-IC type BLMs (between the multipole corrector stack and the QD) will overcome the problems associated with the limited available space, providing the sensitivity to beam loss rates of $>10^{10}$ p/s at E_k=160 MeV and distinguishing between the two sources. Presently, the BLMs are vertically oriented. This study shows a clear preference for horizontal orientation.

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