# BEAM LOSS MONITORING AND MACHINE PROTECTION SYSTEM DESIGN AND APPLICATION FOR THE ALICE TEST ACCELERATOR AT DARESBURY LABORATORY

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*Abstract*

ALICE is a demonstrator accelerator system which has been designed and built at Daresbury Laboratory. The heart of this facility is an ERL accelerator and a powerful multi-terrawatt laser. It serves as an advanced test facility for novel accelerator and photon science applications. Beam loss monitoring and machine protection systems are vital areas for the successful operation of ALICE. These systems are required, both for efficient machine set up and for hardware protection during operation. This paper gives an overview of the system design, commissioning details and a summary of the systems' effectiveness as a diagnostic tool.

## INTRODUCTION

ALICE is an energy recovery linac accelerator with a design acceleration of 35 MeV. With a possible average beam power of 455 W, it is essential that a successful beam loss monitoring (BLM) and machine protection system (MPS) is installed. The scheme developed is a dual system devised from that used at ELBE at Rossendorf [1, 2]. One system uses the beam position monitoring (BPM) system to measure the beam current at various points and compare it with upstream measurements, whilst the other uses ionization chambers to measure the radiation induced by a beam loss [3].

## ALICE BLM SYSTEM

The beam loss induced radiation is detected by a series of long ionization chambers (LIC) distributed around the machine as shown in Figure 1. These chambers consist of an air-filled coaxial cable (Andrew HJ4-50, 50 Ω) with a 1 kV potential to attract the ionised gas particles forming a current flow. This current, although very small, can be measured to give an indication of localised beam loss. In order to determine the resolution, sensitivity and linearity of the system, each chamber had to be fully characterised using various beam and magnet settings.

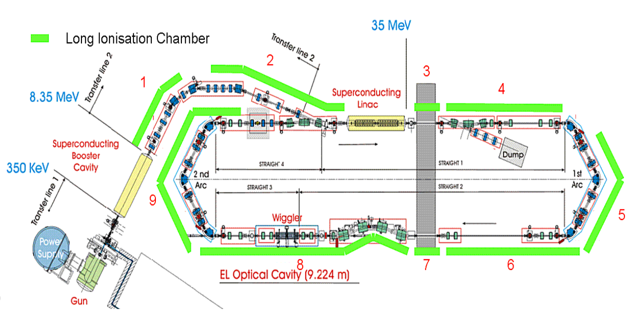


Figure 1: Long ionisation cable distribution.

## EXPERIMENTAL RESULTS

The experiments were performed using different train lengths and by changing the current in various dipole magnets whilst monitoring the signal in the adjacent LIC sensors. The experiments were performed using dipole 3 of straight 1 (ST1 DIP-03), and dipoles 1, 2 and 3 from arc 1 (ARC1 DIP-01, ARC1 DIP-02, ARC1 DIP-03). The ionisation chambers tested were BLM4 (ST1), BLM5 (ARC1) and BLM 6 (ST2). Figure 2 shows the position of DIP-03 in ST1 and DIP-01, DIP-02 and DIP-03 in ARC1 in detail.

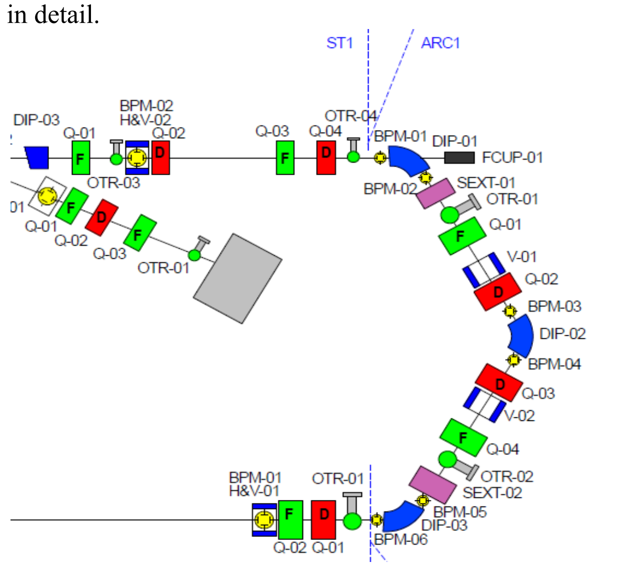


Figure 2: Detail of ST1 and ARC1 of ALICE.

### *ST1 DIP-03*

Figure 3 shows the signal from BLM4 in straight section 1 and BLM5 in ARC 1. Here the current from ST1 DIP-03 was changed from 0 A to 40 A in steps of 5 A, nominal value was 26 A.

We can see how the signal in BLM4 increases as soon as we leave the nominal current value. BLM5 does not seem to be affected. Towards the lower current values, we measured a high increment in sensor signal, when we expected the opposite. This is probably due either to the vacuum vessel of an OTR screen, which has a long metallic arm in the starboard side of the accelerator (that is on the left looking downstream) or the EMMA extraction line.

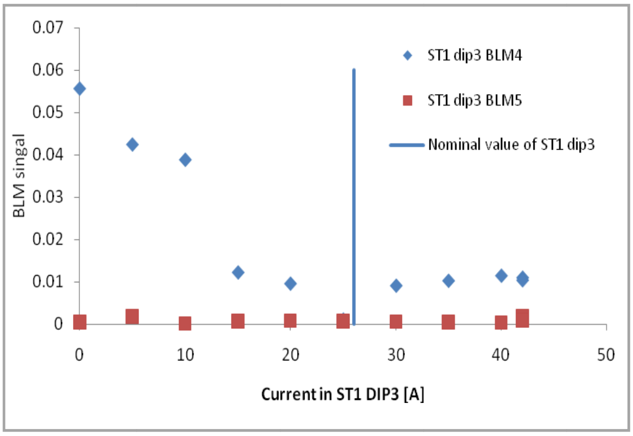


Figure 3: BLM4 & 5 with varying current in ST1 DIP-03.

### *ARC1 DIP-01*

Figure 4 shows the signal from ionisation chamber BLM5, located next to ARC1, the first bending section of ALICE. When we vary the current in DIP-01, the first dipole (out of 3) in this section, as expected, we have a high increase of signal which decreases as we move away from nominal. This is due to the beam hitting less beam pipe and less accelerator components such as quadrupoles, sextupoles, screen vacuum vessels, etc. In the lower end of dipole current settings we start to see an increment of BLM signal, which is probably due to backscattering off the lead shielding surrounding the external face of this bending section.

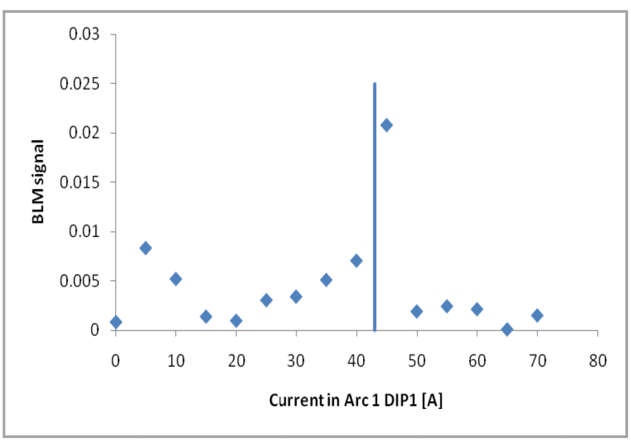


Figure 4: BLM5 with varying current in ARC1 DIP-01.

### *ARC1 DIP-02*

Figure 5 shows the behaviour of BLM5 along with that of BLM6 (the ionisation chamber in the next straight section) whilst varying the current in ARC1 DIP-02. We observe similar behaviour as when we varied dipole 1, measuring an increment towards the lower current settings due to the lead shielding.

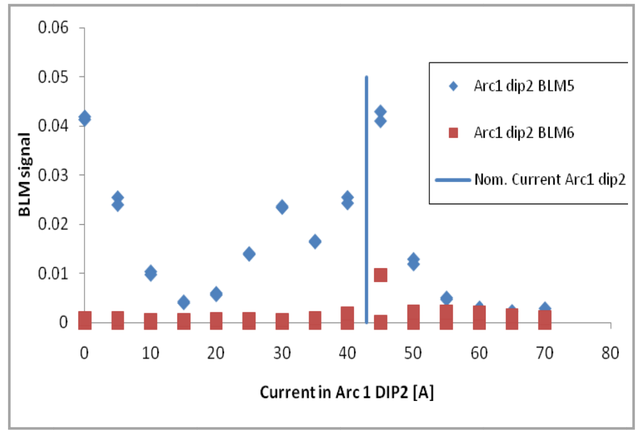


Figure 5: BLM5 & 6 with varying current in ARC1 DIP-02.

### *ARC1 DIP-03*

ARC1 DIP-03 is the last dipole of this sector with straight section 2 immediately downstream; therefore, varying the current in this dipole will greatly affect BLM6. This is what we see in Figure 6, where BLM5 does not respond as much as BLM6 to current changes from nominal value. However, both chambers respond to the radiation backscattering from the lead shielding when the beam hits it during low current settings of DIP-03. Note the low signal at the higher end of the plot; this could be due to the lack of material (machine components) on the internal side of this section of ALICE.

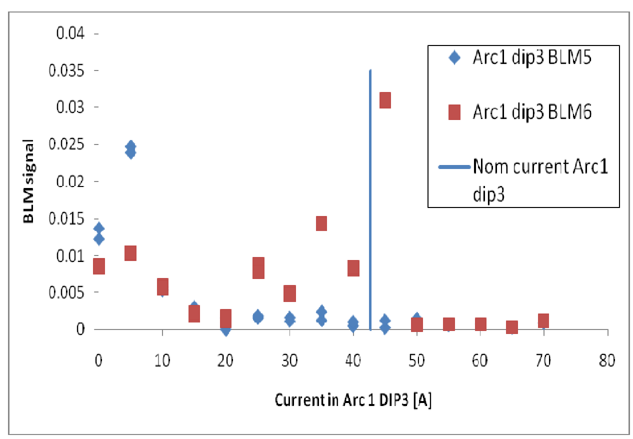


Figure 6: BLM5 & 6 with varying current in ARC1 DIP-03.

### *Linearity Check*

Several measurements were taken for BLM4 whilst maintaining the current setting for ST1 DIP-03 at 20 A. The train length was then incremented from 1 µs to 10 µs to vary the charge the BLM sensor would see. Figure 7 shows the linearity of the chambers response to this train length variation.

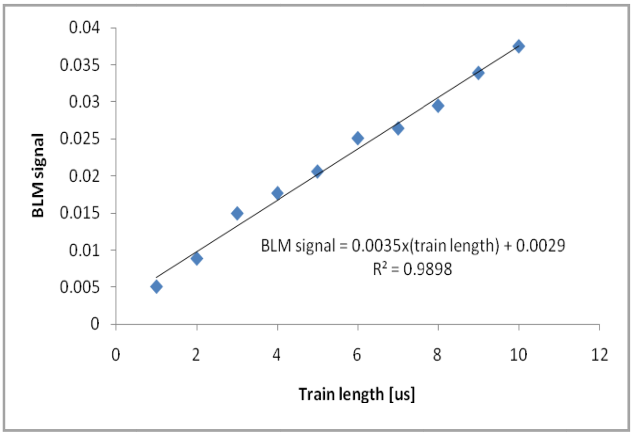


Figure 7: BLM4 with ST1 DIP-03 at 20 A with varying train lengths.

### *Comparison with MonteCarlo Simulation*

A simple geometry of ST1 was implemented into FLUKA [4] and run with settings for different beam angles, each angle corresponding to a different current value of ST1 DIP-03.

The angle ($\theta$) that a dipole applies to the beam can be calculated using (1), where $l$ is the magnetic length, in this case 0.211 m, and $B$ the magnetic field. $B$ and $B\rho$ can be calculated from expressions (2) and (3):

$$\theta = \frac{Bl}{B\rho} \tag{1}$$

$$B\rho = \frac{p}{e}[Tm] = 0.0884312Tm \tag{2}$$

$$B = m \cdot I + c = 0.0013794 \cdot I + 0.0001744 \tag{3}$$

With $p$ being the momentum and $e$ the electron charge, the result is given for the beam energy used in our experiments of 26 MeV. In (3) $m$ and $c$ are parameters unique to ST1 DIP-03 and $I$ is the current in amperes.

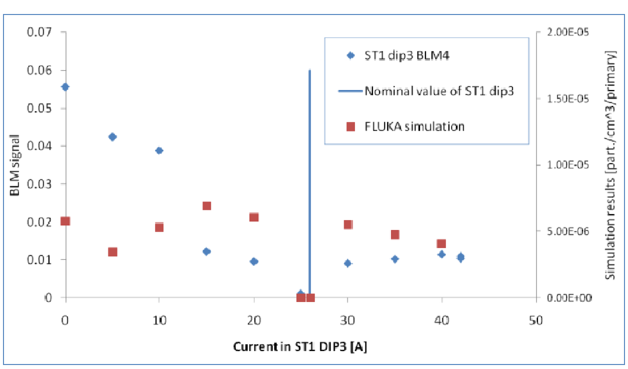


Figure 8: BLM4 with varying current in ST1 DIP-03 compared to FLUKA simulation results.

Figure 8 shows that the simulation seems to follow the BLM signal when the current of the dipole is around the nominal value, as expected, but fails to give the same result at the lower current settings. This is probably due to the simulation geometry missing a piece of equipment or accelerator component that may cause that increment of signal as commented previously (vacuum vessel or EMMA extraction line).

## CONCLUSIONS

Three different BLM sensors where tested during an experiment in ALICE. The BLM sensor signals responded as expected when varying dipole currents. More detail in the simulation is required in order for it to be a more realistic approximation. Simulations will give us a better understanding of the BLM signal and what it means to the beam.

It can be seen from this system analysis that, although these long ionization chambers are reliable tools for the detection of ionizing radiation, it is debatable whether they should be used as a machine protection system on ALICE. The problem is clear that a given loss of beam will not give a consistent detected signal level in all positions along the chamber length. This is due to the fact that the signal level is greater when the chamber sees a larger radiation shower; which could be generated by a small loss at a shallow angle or a larger loss hitting a larger object. This results in difficulties in setting a maximum beam loss threshold within the MPS to guarantee protection to beam pipes and machine components. The only way to guarantee this protection is to switch the machine off at the lowest detected radiation level for a dangerous beam; however, this would give a system that was intolerant to any beam loss. It could become a good tool for beam loss analysis and machine protection if we would add extra BLM sensors located symmetrically from the current ones or use the BPM signals to measure the charge in conjunction with the BLM signal. That would allow us to deduce the real beam loss level.

Since ALICE is currently limited to a reduced average beam power which is considered to be safe, this system is being modified for use as a diagnostic tool. The analogue values produced by the BLM system are to be graphically displayed via the EPICS accelerator control system which can allow the machine to be set up for zero loss.

## REFERENCES

[1] P. Michel, R. Schurig, J. Teichert, "Beam loss monitoring with long ionization chambers at ELBE". Radiation Source ELBE Annual Report 2002, p9.

[2] A. Buchner, J. Voigtlander, F. Gabriel, H. Langenhagen, "Machine interlock system improvements by new beam loss monitors". Radiation Source ELBE Annual Report 2002, p11.

[3] S. R. Buckley and R. J. Smith, "Beam loss monitoring and machine protection designs for the Daresbury Laboratory energy recovery linac prototype" EPAC 06, June 2006, Edinburgh, TUPCH038.

[4] FLUKA, www.fluka.org