

# DEVELOPMENT OF A BEAM LOSS MONITOR AND TRANSVERSE BEAM DYNAMICS STUDIES AT ARRONAX C70XP CYCLOTRON.

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## Abstract

The ARRONAX Interest Public Group uses a multi-particle, high energy and high intensity industrial accelerator which has several beam lines used for various purposes. For improvement of operations, ARRONAX has fostered and installed robust air-based Beam Loss Monitors (BLMs) outside the beam pipes. BLMs consist of four active detecting plates and are integrated within the experimental physics and industrial control system (EPICS [1]) monitoring and data acquisition system. Each BLM has been tested for the pre-commissioning phase with beams at low intensity (600 pA to 6 nA on target). Comparative studies and selection of the BLMs has led to their installation at high intensity beam lines. BLMs are now used in beam dynamics studies to investigate transverse characteristics while in regular operation. They support present and future operations extension foreseen at ARRONAX.

The results from experimental studies on BLMs at low beam intensity and status of beam dynamics studies at high intensity ( $\mu\text{A}$ ) are presented here.

Keywords: BLM, beam dynamics, EPICS, Gas ionization detector, Cyclotron, Proton.

## INTRODUCTION

The ARRONAX cyclotron operation described in [2] relies on a few limited number of standard diagnostics for high intensity (100s  $\mu\text{A}$ ) irradiation of targets which are dedicated mostly to medical radio-isotopes production. It has been proposed to extend the diagnostics for machine protection with robust air-based Beam Loss Monitors (BLM [3]) based on a design by iThemba labs [4]. BLM of such kind never used before by any accelerator. These monitors have been tested at a low intensity beam line before being installed on the beam lines where high intensity irradiation occur and they are now part of a global study to help mitigate losses. This latter study also include quadrupole scan technique to verify adequate operation configurations.

## BLM INTEGRATION

A 12-channel SY5527LC CAEN power supply provide the required voltage to the BLM differential plates when located in the beam lines. The readout electronics, provided by iThemba Labs is based on beaglebone (BB) board [5] running Ubuntu- 8 and 48 channel board (BB8 and BB48) are available and integrated within the EPICS (see Fig. 1). Operators can control both voltage supply to BLMs and

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BB device settings with CS-Studio [6]'s Operator Interface (OPI).

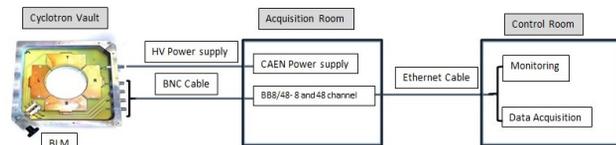


Figure 1: BLM connection flow chart.

## BLM TEST (PRE-COMMISSIONING PHASE)

Six BLM have been built. In order to perform geometrical, stability, repeatability and comparative studies, various experimental tests were performed at low intensity beam line with beam intensities ranging from 600 pA to 6 nA. This is done such that a selection of BLM with similar response can be applied before installation to high intensity beam lines. For these tests, the BLMs were installed a few cm downstream the exit of the beam line on a moveable table. This table has 2 degrees of freedom (vertical-axis translation and rotation). The experimental setup (see Fig. 2) includes a "Harmattan R928" photomultiplier detector (light detector), used as a proton beam intensity monitoring reference (light emission by proton interactions with matter [7]) and a large instrumented beam dump 0.5% uncertainty verified aluminum Faraday cup at used beam intensity as shown in Fig. 2.

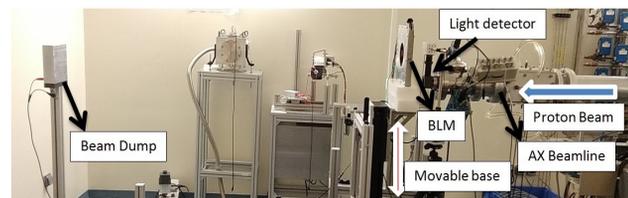


Figure 2: BLM test experimental setup.

Four BLMs were tested under irradiation. The fifth and sixth BLM were not selected due to improper wiring connection at the time of tests. Some experiments were performed twice or thrice to check the repeatability of our results. BLMs were tested with BB8 being connected with 20 m BNC cables. Types of experiment performed on BLM are listed below:

- Beam irradiating the BLM (direct) for geometrical and repeatability studies. Fixed intensity beam irradiation

with varying BLM supply voltage to find suitable power supply prior to its use in high intensity beam lines.

- Materials were added in front of BLM to check their impact and simulate beam pipe (indirect).

### Direct and Indirect Beam Irradiation with BLM Vertical Movement

During the irradiation of the BLM with 6 nA, 70.3 MeV proton beam, the supporting table was translated vertically at a very slow speed (approx. 0.32 mm/sec). The result shows as a scan of the geometrical response of the BLM active plates (see Fig. 3). All BLMs showed similar geometry and amplitude of signals, after renormalization to the intensity reference measurements done with the light detector and beam dump.

A 150 mm thick polystyrene high density block, sufficient for stopping proton (verified by G4 simulations [8]) was placed between beam exit window and BLM. BLM showed no signals during experiment which means BLM is very less sensitive towards uncharged particle (neutron, gamma).

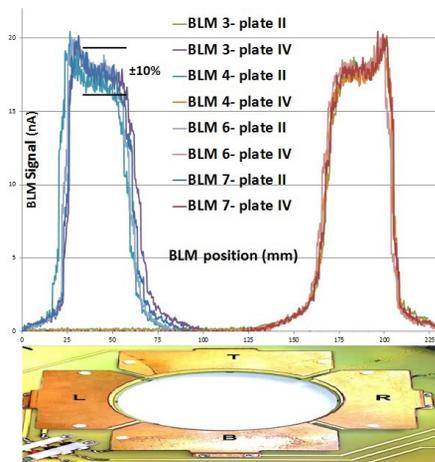


Figure 3: Different BLM signals with two of its active plate.

### Indirect Beam Irradiation with rotating BLM on Vertical Axis

To simulate experimental conditions similar to operations, a 5 mm thick beam pipe was placed in the BLM's hollow circular part. While irradiating, the BLM with the pipe were rotated in steps of 5 degree and rotation have shown, when pipe is inter-spaced signals multiplied up to 3 times with respect to direct irradiation. In G4beamline, Virtual detector showed multiplied signals due to shower particle (charged) generation with indirect (beam pipe) irradiation.

### Fixed Intensity Beam Irradiation with Varying BLM Supply Voltage

Each BLM was irradiated with fixed beam intensity on target and with varying supply voltage. It was repeatedly experimented with different beam intensities (600 pA to 6 nA). Studies indicated a linearity response of the detector at 220 Volts.

### BLM Test Result

Geometrical response from detector did not show unexpected behavior. The BLM do measure increase of charges behind a pipe. These BLM were then installed in our high intensity beam lines and regularly monitored.

## BLM INSTALLATION ON HIGH INTENSITY BEAM LINES

At the time of writing two BLMs have been clamped around the beam pipes. As shown in Fig. 4, a first BLM is located upstream a doublet and a second one 1.65 m away. Both locations have gaskets which are sensitive points if losses occur.

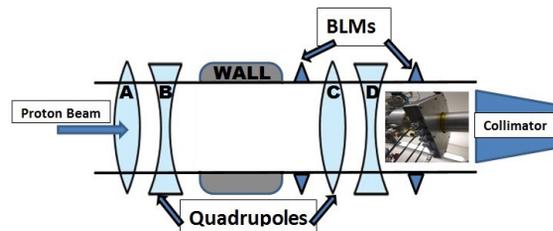


Figure 4: Beam line layout with 2 BLM installed.

Several independent runs (Total counts is 13 see Fig. 5) spanning over more than 100 hrs and of the order of 130  $\mu$ A on target have been performed. The configuration of each magnetic element of the accelerator and beam lines (including dipoles, steerers, quadrupoles) during runs were set according to in-house standard operational relevance (eg. Beam transmission rate). This allowed to accumulate data from the BLM as given in Fig. 5. Losses were all

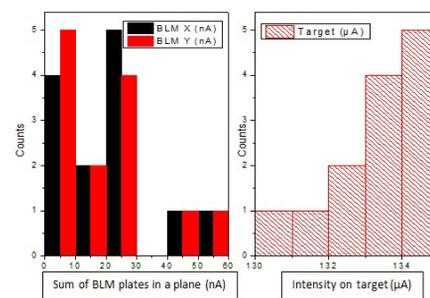


Figure 5: On the right, target average intensity ( $\mu$ A) and on the left, average signals from BLM (nA) for each plane.

the time measured, and with some configurations went up to 60 nA. For runs with BLM measurements above 40 nA, post-operation tests on vacuum and gasket showed leakages and damages. This advocated the need to set a minimum threshold for the losses measured on the BLM. This limit was proposed to be 30 nA.

After the first two quadrupoles, BLM helps to indicate losses at that location while the downstream BLM shows indication of the second pair of quadrupole. Thus, transverse beam dynamics studies based on quadrupole scan have

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been performed. These studies include BLM signals and the collimator 4-finger upstream the target which measure integrated current deposited by particles.

## TRANSVERSE BEAM DYNAMICS STUDIES

Transverse beam dynamics studies, here used "Quadrupole gradient modulation [9] (quad scan)" technique. As there are no beam position monitor (BPM) installed in our beam lines, measurements are done at the collimator and BLM level which are used to study beam focal point, local beam size and beam centering. By adding and subtracting (proton deposition- $\mu\text{A}$ ) two opposite facing plates, it is possible to estimate local beam size and positioning respectively.

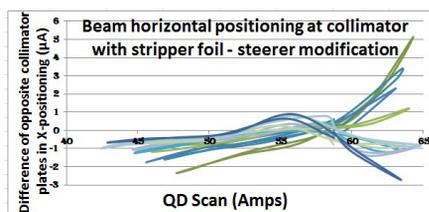


Figure 6: Beam positioning as function of quadrupole current with stripper foil (azimuthal) – Steerer modification.

An off centred beam gets dipole kick with quad scan. From experimental data analysis, it has been found that stripper foil [10] azimuthal location helps to mitigate the measured beam displacement by centering the beam during a quad scan (see Fig. 6). It has been observed that with the beam at center, BLM signals significantly lower down and vacuum pressure also gets better operationally. Range of Stripper foil settings (-15.89 mm to -22.99 mm with step size of 1mm) were used each represented with different color (see Fig. 6) and -19.40 mm was found the best setting which is then used to do quad scans for focal point studies (see Fig. 7).

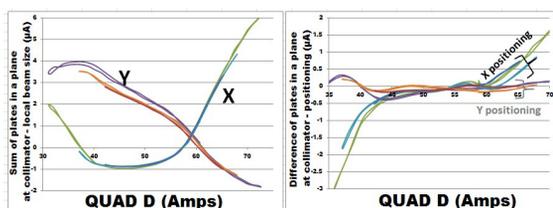


Figure 7: Comparison of Beam size changes and positioning as function of quadrupole current with different beam intensity on same day.

In Fig. 7, Beam intensity used for scan is 10, 30, and 50  $\mu\text{A}$  represented with different colors. Plots are normalized at 10  $\mu\text{A}$  level. quad scan performed in such a way, One can observe loops in curves which shows effect of hysteresis. Quad scans showed similar shape, focal point and positioning. With increase in beam intensity, focal point is not getting affected much which means focal point on the same day (i.e.

same library, machine temperature, beam line settings) at 10  $\mu\text{A}$  beam will be same for beam at much higher intensity. At 10 $\mu\text{A}$ , the quad scans are more secure (weak location [2]) from the point of view of vacuum and we can go up to higher range of quad scan.

## CONCLUSION AND DISCUSSION

The external and simple BLM have lead to a proposition for upper limits on the measured losses, towards beam line protection. The BLM are also giving significant and useful information of the beam with the setting modification (Stripper foil, Quad scan). Quadrupole scans studies with measurements at the end-of-line collimator, is giving understanding of upstream beam condition. At present, only collimator is being used for valid positioning at the end of our beam lines and are trying to find a correlation between collimator and BLM positioning. Future experiments based on this results and ongoing simulations are foreseen to be performed towards development of a strategy for operators to tune the machine and potential emittance measurements.

## ACKNOWLEDGMENTS

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## REFERENCES

- [1] EPICS, <https://epics.anl.gov>
- [2] F.Poirier, S. Girault et al, "Studies and upgrades on the C70 cyclotron ARRONAX", in Proc. 21th Int. Conf. on Cyclotrons and their Applications (Cyclotrons' 16), Zurich, Switzerland, Sep. 2016, pp. 235-237.
- [3] F. Poirier et al., "On-Going Operations with the Cyclotron C70 ARRONAX", in Proc. 20th Int. Conf. on Cyclotrons and their Applications (Cyclotrons' 13), Vancouver, Canada, Sep. 2013, paper MOPPT010, pp. 49-51.
- [4] iThemba labs, <https://tllabs.ac.za/>
- [5] BeagleBone, <https://beagleboard.org>
- [6] CS-Studio, <https://www.controlsystemstudio.org>
- [7] J.-O. Lill, "Charge integration in external-beam PIXE", Nuclear Instruments and Methods in Physics Research B 150 (1999) 114-117.
- [8] G4Beamline simulations, <http://www.muonsinternal.com>
- [9] M.G. Minty and F. Zimmermann, "Measurement and control of charged particle beams", Springer-Verlag Berlin Heidelberg, New York, 2003.
- [10] D. Vandeplassche et al, "Extraction simulation for the IBA C70 cyclotron", in Proc. 18th Int. Conf. on Cyclotrons and Their Applications (Cyclotrons'07), Giardini-Naxos, Italy, Oct. 2007, pp. 63-65.