COMMISSIONING OF THE BEAM LOSS MONITORING SYSTEM FOR THE HADES BEAM-LINE AT GSI

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Abstract

The High Acceptance Di-Electron Spectrometer experiments at GSI (HADES) require high-intensity heavy ion beams. Monitoring and minimization of the beam losses are critical for the operation at the desired beam intensities. FAIR-type Beam Loss Monitor (BLM) system based on sixteen plastic scintillator detectors is installed along the beam line from the SIS-18 synchrotron to the experiment location. The detectors are used in counting mode, with maximum counting rate of order of 20 MHz. The system has been commissioned during the 2018 beam time. Details on the detector setup, its calibration procedure and how it can be used for quantitative beam loss determination are presented.

BLM DETECTOR

A photograph of the detector components is shown in Fig. 1. The light from 20x20x75 mm^3 BC408 plastic scintillator is converted in an electrical signal by a Hamamatsu R6427-20 photomultiplier (PMT). The PMT active area is 25 mm. The selected photomultiplier has a large dynamic range, low leakage current and gain variation of less than 50% between different PMTs. An active voltage divider (AVD) was developed at GSI to power the PMT. The main features of the divider are:

- limited (maximum) average anode current, hence the longevity of the PMT is ensured
- improved gain stability
- operating at 10^7 counts per second (cps) counting rates, at current of 0.7 mA provided from the power supply.
- total current required of only 0.7 mA for the operation of the voltage divider

For operational considerations and possible radiation damage of the electronics the PMT signal is send over a long cable, on average 150 m, to data acquisition system based on level discriminators and a counters [1]. The typical signal width after shaping from the cable is of order of 20 ns. Hence, due to pile-up, for normally distributed 10^7 signals per second, the data acquisition system will count on average 8x10^7 pulses.

BLM PLACEMENT AND CALIBRATION

The BLM detector are placed around the aperture limitations of the HADES beam line. Details about the beam line layout and beam optics are presented in Ref. [2]. There are always at least two detectors near an expected beam loss location. A photograph of one of the BLM at the beam line is shown in Fig. 2. The active volume of each detector is placed symmetricly relative to the aperture limitation, reducing the signal dependence on possible asymmetric beam

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Figure 1: An assembled BLM detector is shown to the right of the photograph. In the middle the scintillator, photomultiplier and voltage divider are shown. A disassembled active voltage divider is placed to the left of the photograph.

losses. For example at the location shown in Fig. 2 the beam loss is expected to occur due to the small vertical aperture of the upstream magnet vacuum chamber, therefore the BLM is placed in the horizontal plane. This layout reduces the total number of BLM detectors needed for the beam line optimization.

The distance of the detector to the beam axis was chosen based on FLUKA [3, 4] simulations of the particle shower created during a beam loss. The detectors are attached to the beam tube at a distance of 0.3 m from the beam axis. Depending on the nearest upstream magnet they are instilled at about half a meter from the nearest upstream quadrupole or a meter from the nearest upstream dipole magnet. The exact positions are determined based on mechanical constrains. This placement leads to suppression of the signals from heavy ions of 3 orders of magnitude versus the signal from protons and neutrons. Moving the detector away from the heavy ion shower allows to operate the PMT at the same voltage independent of the accelerated ion species. The detector were not mounted further away as it is advantageous to keep them in the proton shower created by the lost particles. This point will be discussed in next section on quantitative determination of the beam loss.

The detector system was calibrated with a ^{137}Cs γ-source. The discriminator thresholds of all detectors where set to the same value. Their high voltages were adjusted until the same predetermined counting rate was reached with the γ-source mounted on the top of each detector. Fig. 3 shows the fit

Figure 2: BLM (the black cylinder) behind a switching magnet (in red). The beam aperture is limited due to the dipole vacuum chamber in vertical direction.

of the detector response to the 661.7 keV γ-rays from the calibration source. The fit was performed as follows:

- The simulated deposited energy was scaled to fit the position of the Compton edge.
- The detector resolution was determined from the shape of the Compton edge.
- The number of counts in the data was scaled to match the height of the Compton edge. This is a correction for the acquisition time.

Applying the above transformation the measured counting rate with ^{137}Cs was reproduced within 10%.

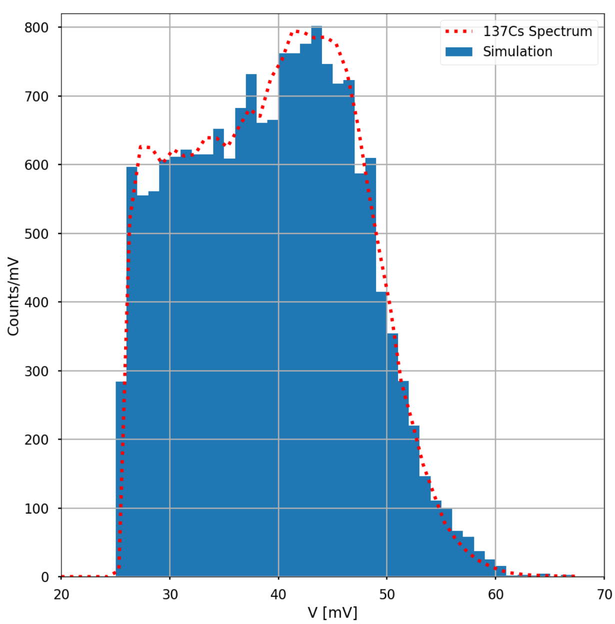

Figure 3: A fit of the BLM response to 661.7 keV γ-rays from ^{137}Cs source.

QUALITATIVE LOSS DETERMINATION

The described system was placed in operation during the 2018 beam time. Fig. 4 shows a graphical user interface with the counting rates of the BLM along the beam line. The data from the system is used qualitatively for optimization of the beam transmission. In the future the system will provide quantitative beam loss information. This can be achieved as follows.

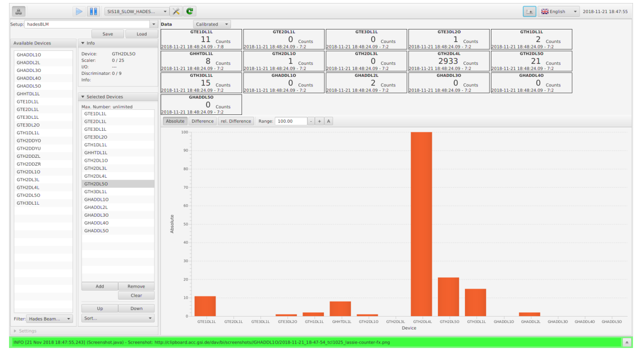

Figure 4: GUI interface showing the counting rates of the BLM along the HADES beam line.

Lets consider the beam line segment shown in Fig. 5. The beam comes from the left, passes a quadruple doublet and a dipole magnet. Three BLM are positioned in this segment, one behind each magnet. They are labeled BLM1,2,3, with index increasing along the beam direction.

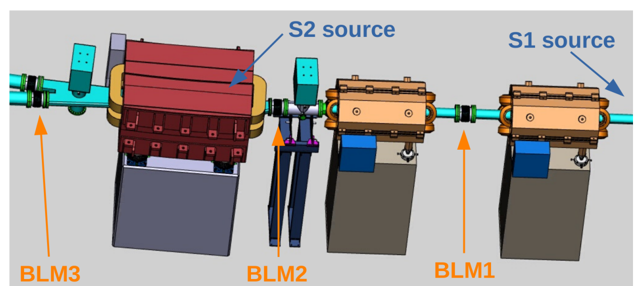

Figure 5: A section of the HADES beam line consisting of a quadrupole doublet and a switching magnet. The beam comes from the right.

Fig. 6 shows the simulated signal from the three beam loss monitors due to impact of ^{107}Ag ions with energy of 1580 MeV/u, 20 cm downstream from the front face of the switching magnet. The observed counting rate will be equal to the integral of the corresponding cure above the discriminator threshold. The standard threshold is 25 mV. In this case BLM2 which is closed to the loss location will have the highest counting rate. This is illustrated in the lower graph of Fig. 7 labeled *S2 25 mV threshold*. The circles connected by the continuous blue curve show the expected counting rates in the above beam loss scenario. Same distribution can be obtained if the loss source was located between BLM1 and BLM2. The ambiguity in the beam loss location leads to ambiguity on the number of lost particles too.

In the simulated signal of the BLM3, there is a bump at about 500 mV, see Fig. 6. It corresponds to the proton shower created by the fragmentation of the ^{107}Ag on the iron yoke of the magnet. The protons are forward focused due to the

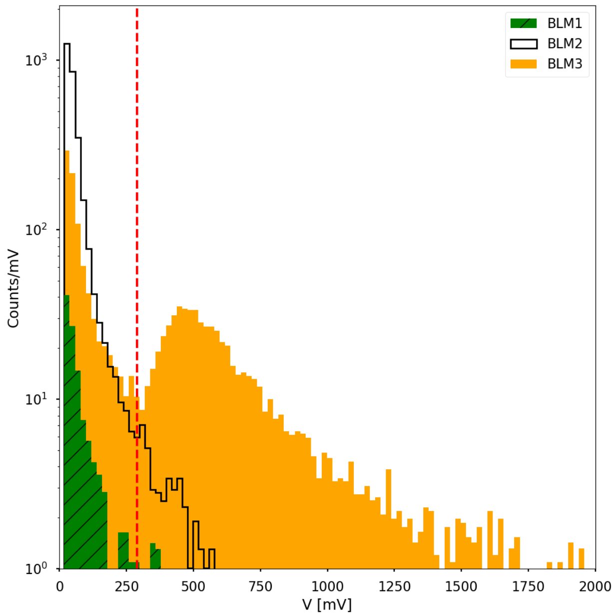

Figure 6: Simulated signal distribution from a loss between detectors BLM2 and BLM3 (S2 loss scenario).

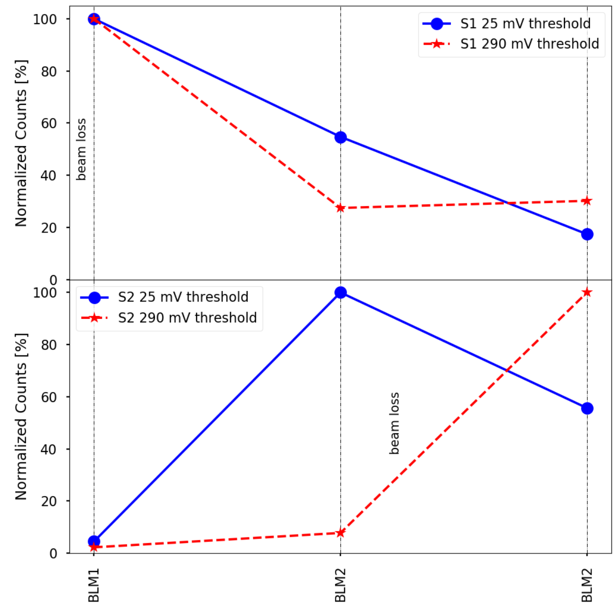

Figure 7: Ratios of the BLM counts above 25 mV and 960 mV, normalized to 100%, from two different locations of the beam loss.

center of mass motion. The peak tail to the right corresponds to protons from the shower which have smaller energy and hence leave larger signal when they punch through the BLM active volume. This peak is not present in the simulated signals for BLM1 and BLM2 as they are upstream relative to the loss location (upstream form the source of the proton shower). Therefor the presence or absence of the proton peak uniquely determines weather the BLM is downstream or upstream relative to the beam loss location. The presence of this peak can be detected by setting the discriminator threshold to 290 mV, as indicated with the vertical dashed line in Fig. 6.

This is illustrated in Fig. 7, where the results of two beam loss scenarios, S1 and S2, are shown. In the S1 case the beam is lost upstream relative to BLM1,2 and 3, while in the S2 case the beam is lost between BLM2 and BLM3 (the scenario which was ben already discussed). The dashed red line corresponds to threshold set just bellow the proton peak, while the blue continuous line corresponds to a low threshold, where the counting rate is dominated by neutrons scattering in the active volume of the detector. The points from each curve are re-normalized so that the maximum counting rate corresponds to 100%. The maximum in the high threshold counting rate points to the detector, upstream from the beam loss location. Therefore the following sequence of steps can be used to determine the location of the beam loss and the number of the lost particles in a given section of the beam line:

- In the group of detectors installed in the section of interest, select the one with the highest counting rate at the high threshold setting. The beam loss is upstream relative to this detector and downstream from next upstream detector.
- Fit the ratio of the counting rates at low threshold to simulations and determine the beam loss position.
- After fixing the position fit the expected absolute counting rates based on simulation to the observed rates, determine the number of lost particles.

Technically it may be impossible to optimize the higher threshold setting for each beam species and energy. As the proton energy is dominated by the center of mass momentum, the threshold can be set for a heavy ion accelerated to the highest SIS-18 energy. For any other beam the protons will have lower momentum, hence higher energy deposition in the BLM.

In the presented simulation the effect of the magnetic fields on the secondary shower was not considered. The fields will influence the proton peak in BLM3 but it will not change the suggested approach for quantitative beam loss determination.

CONCLUSIONS AND PLANS

A beam loss monitoring system based on scintillator detectors was build and placed in operation at the GSI-HADES beam line. The system can be used for quantitative determination of the beam loss location and amount of lost particles. It will be calibrated in the upcoming beam blocks using controlled beam loss along the beam line. This data will determine the accuracy of the described system.

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