BEAM HALO MEASUREMENT USING A COMBINATION OF A WIRE SCANNER TYPE BEAM SCRAPER AND SOME BEAM LOSS MONITORS IN J-PARC 3-GEV RCS.

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Abstract

Transverse beam halo is one of the most important beam parameters because it should limit the performance of the high intensity beam accelerator. Therefore the transverse beam halo measurement is one of the important issues to achieve the design beam power of 1MW in the J-PARC 3-GeV RCS. Thus the new beam halo monitor, which is combined a wire scanner and some beam loss monitors, was developed and installed in the extraction beam transport line. By using several beam loss monitors with different sensitivities, an ultra-wide dynamic range can be achieved and beam profile including both of the beam core and halo can be obtained.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) has been beam commissioned for initial beam tuning tests since October 2007 [1] and afterwards we started user operation for the Material and Life science experimental Facility (MLF) and the 50-GeV Main Ring synchrotron (MR). Since December 2009, we have started a beam tuning for high-intensity beams and 420kW beam operation could be demonstrated successfully [2]. In order to achieve the design performance of the 1MW of the RCS, the LINAC is required both of the beam energy upgrade from 181MeV to 400MeV and the beam current upgrade from 25mA to 50mA. For the beam energy upgrade, a new accelerating structure "Annular-ring Coupled Structure (ACS)" had been installed in 2013. And then, during the summer shutdown in 2014, new front-end consisted both of the ion source and the Radio Frequency Quadrupole (RFQ) are replaced for the beam current upgrade in the LINAC [3]. Then the beam energy upgrade and the beam current upgrade in the LINAC were completed. After completing these LINAC upgrades, the RCS is to start the final beam tuning toward the design output beam power of 1 MW.

To provide such a high power proton beam for the MR with small injection beam loss or for the MLF with broad range and uniformity irradiation to the target using the octupole magnet [4], it is required to improve the extraction beam quality, namely to achieve the Low-Halo and High-Intensity beam by finer beam tuning in the RCS. Therefore the measurement of the transverse beam profile including both of the beam core and the beam halo is one of the key issues for the high power beam operation in the RCS. Thus a new beam halo monitor was developed and installed at the 3GeV-RCS to Neutron source Beam Transport (3NBT) line as shown in Fig. 1. And examination of the new halo monitor with the extraction beam was started. In this paper, we report the first trial test of the new beam halo monitor after the LINAC energy upgrade.

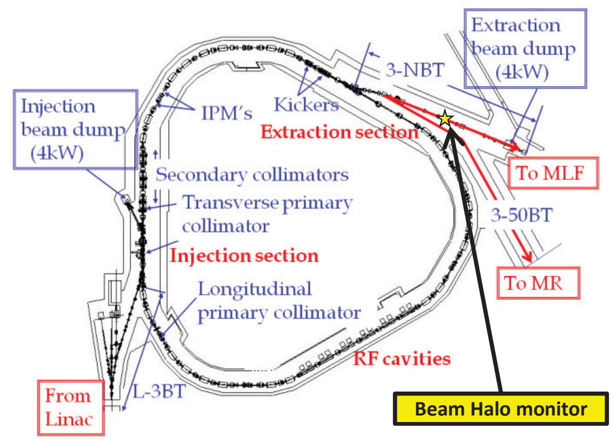

Figure 1: Top view of the RCS and location of the beam halo monitor installation.

NEW BEAM HALO MONITOR

Concept Design

For the halo measurement of the extraction beam from the RCS, the original beam halo monitor, which was a scraper plate type detecting the emissive secondary electron and the plate temperature during the beam irradiation into the scraper plate, had been installed at the 3NBT line [5]. The scraper plate was limited to scanning within the beam halo area, thus the beam core cannot be observed. Moreover, it is difficult to obtain the pure signal due to the secondary electron emission because there are much floating electrons in the vacuum chamber and they disturb the raw signal of the halo monitor. On the other hand, the temperature did not increase during the beam irradiation because the sensitivity is too low to detect the beam halo component.

To resolve these problems, the new halo monitor installed at the 3NBT adjoining the original halo monitor. The conception of this new halo monitor is that the beam signal disturbance by the floating electrons should be suppressed and the quick signal response should be achieved. Thus the new halo monitor is combined a wire scanner and the several kinds of beam loss monitors (BLM), and it detects the radiation due to the beam scraping by the wire scanner. Figure 2 shows the schematic diagram of the

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new halo monitor. It has two wire scanners for horizontal and vertical scanning respectively, and a head of the wire scanner is composed a stainless steel wire put on the aluminium frame. The diameter of the wire was change from 1mm to 0.1mm after the LINAC energy upgrade. The wire scanner can be scanning during the full range of the extraction beam distribution. By using the several kinds of BLM with the different sensitivities, an ultra-wide dynamic range can be achieved and the transverse beam profile including the beam core and beam halo elements can be reconstructed.

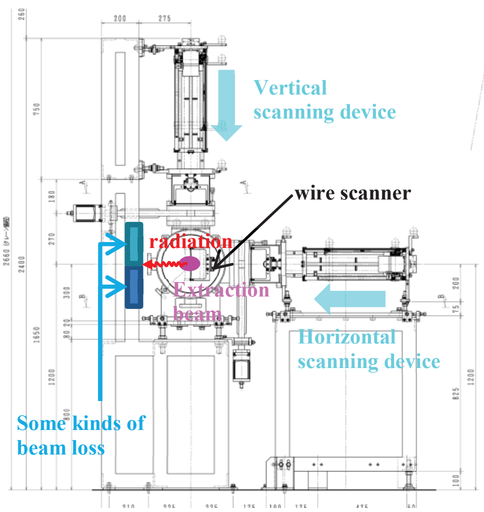

Figure 2: Schematic diagram of the new beam halo monitor.

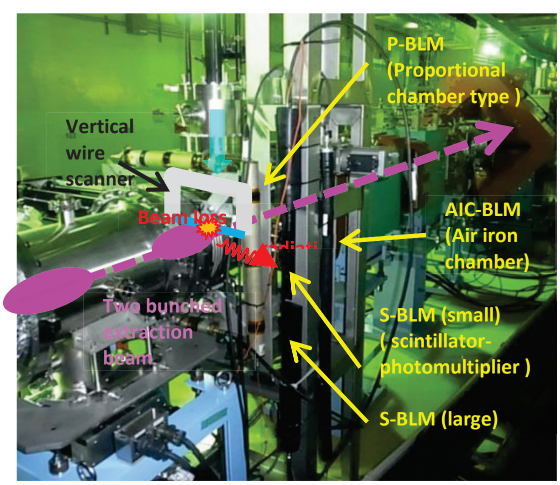

Figure 3: Photograph of the new beam halo monitor. Several kinds of beam loss monitor were attached.

Newly-devised Radiation Detect Systems

In the RCS, several kinds of BLM were installed as following; proportional counter type (P-BLM), plastic scintillator and photomultiplier pair type (S-BLM), and air ionization chamber type (AIC-BLM) [6]. At first all type of the BLMs were used for the beam halo measurement as shown in Fig. 3. However the AIC-BLM cannot detect the radiation signal due to the downsizing of the wire diameter. Moreover not only the sensitivities but also the time responsibilities are different among these BLMs; especially it is difficult to obtain the time structure of the bunched beam by using the P-BLM. From these results of the demonstrational beam test, S-BLMs are adopted for the beam halo monitor because they have good time responsiveness. We chose a common photomultiplier tube (PMT). And we controlled the sensitivities of the S-BLM by changing the size of the plastic scintillator or the distance from the wire scanner to S-BLM. For the first trial test, two kinds of S-BLM were assembled. One is the small plastic scintillator type as shown in Fig. 4, and the other is the large plastic scintillator type in Fig. 5. The small type S-BLM has a light guide for a support of the thin plastic scintillator. Two large type S-BLMs were assembled. One wsa installed close to the wire scanner together with the small type S-BLM as shown in Fig. 3. The other was installed upstream of about 5m away from the wire scanner. The aim of the near large type S-BLM is a high sensitivity detector to measure beam halo elements. And the aim of both the near small type and the far large type S-BLMs are a low sensitivity detectors to measure beam core elements.

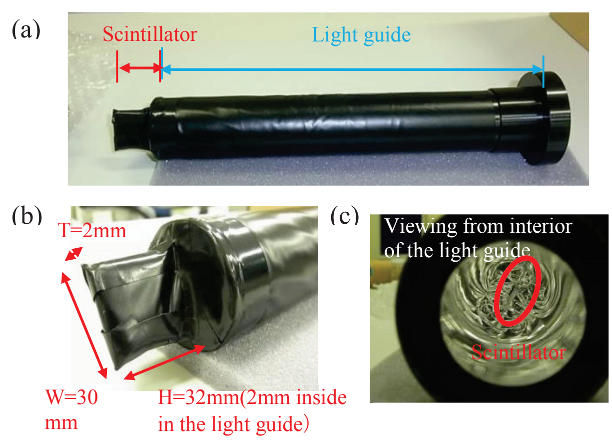

Figure 4: Photographs of the Small Scintillator type BLM. It has a light guide for a support of the thin plastic scintillator.

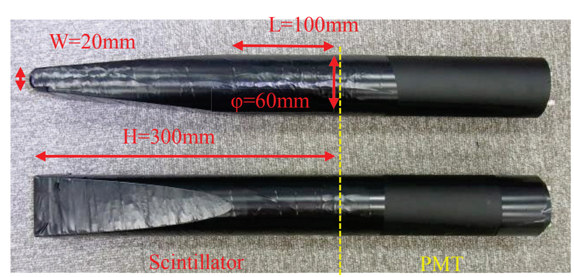

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Figure 5: Photograph of the Large Scintillator type BLMs

BEAM HALO MEASUREMENT

Background Suppression

Beam loss monitor detects the whole radiations which are generated at the all over the place around the new halo monitor. In order to reconstruct the beam profile from the S-BLM signals, we need to search for the pure signal of the radiation generated at the wire scanner among the whole radiation signal detected by the S-BLMs. Background signal, which is defined as a signal of the radiation generated at everywhere without the wire scanner, can be measured from the S-BLM during the wire scanner retracting. And then, pure S-BLM signals from the wire scanner can be obtained by subtracting the background signal from the whole signal as shown in Fig. 6.

(a)

(b)

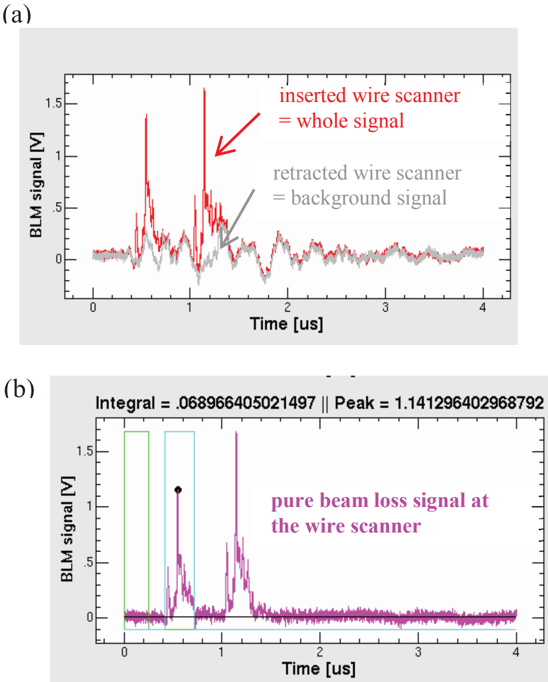

Figure 6: Typical result of the noise reduction of the S-BLM signal. (a): Comparison of the raw S-BLM signals between inserted and retracted the wire scanner. (b): pure beam loss signal at the wire scanner after the background noise reduction.

Calibration Curve Acquiring

In order to reconstruct the beam profile from the S-BLM signals, every calibration curve formula between the number of particles and each S-BLM signals must be determined. To control the number of particles in the RCS, we can adjust some parameters of the injected LINAC beam as follows; a macro pulse width, a chopped intermediate pulse width, and number of the intermediate pulses.

For the high sensitivity detector; the near large type S-BLM, we can control the ultra-low beam intensity by adjusting the number of the chopped intermediate pulses in which the pulse width of 56ns was fixed. The measurement result of the ultra-low particle numbers was summarized in Fig. 7. At the same time, we obtained the scanning data of the near large type S-BLM signal. Assuming that all signals of the S-BLM were not saturated, total radiation signal due to each ultra-low intensity beam can be estimated by integrating the distribution of the scanning data. Figure 8 shows the result of the estimated total radiation signal. By combining these two results, we can acquire the calibration curve formula as shown in Fig. 9.

(a)

(b)

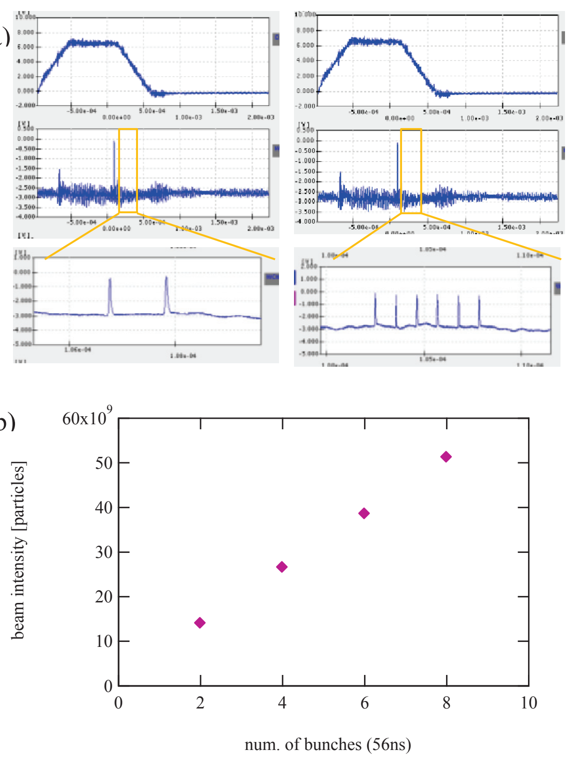

Figure 7: Particle numbers measurement in the ultra-low intensity beam. (a): Typical wave forms of the shift bump magnet and the injected intermediate pulses. (b): Beam intensity plot dependent on the number of bunches.

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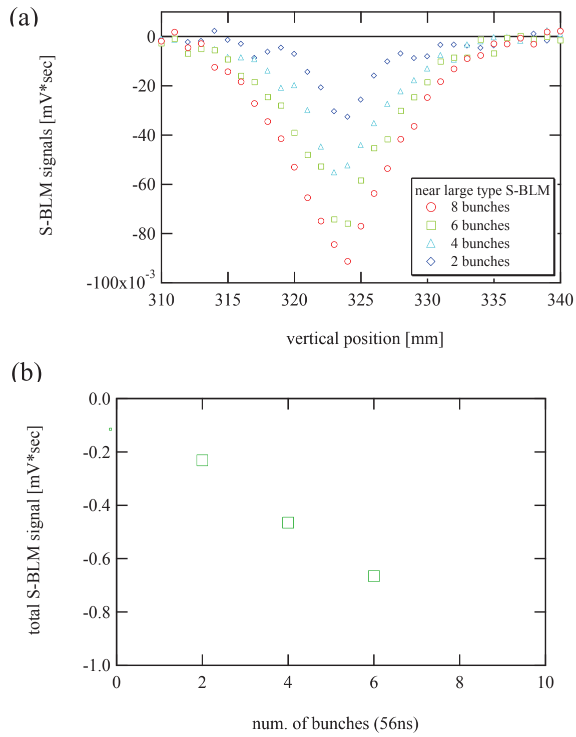

Figure 8: S-BLM signal measurement in case of low sensitivity detector. (a) :Beam profiles obtained from the scanning signals of the near large type S-BLM. (b): Total S-BLM signal plot dependent on the number of bunches.

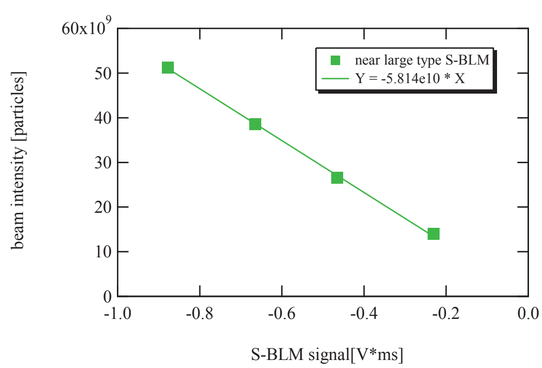

Figure 9: High sensitivity calibration curve for the near large type S-BLM.

For two low sensitivity detectors; the near small type S-BLM and the far large type S-BLM, we acquired the calibration curve with the same method. In this high beam intensity case, we controlled the beam intensity by adjusting the macro pulse width in which the chopped intermediate pulse width was 432ns and full intermediate pulses were used. Figure 10 shows the calibration curve formulas for each S-BLM.

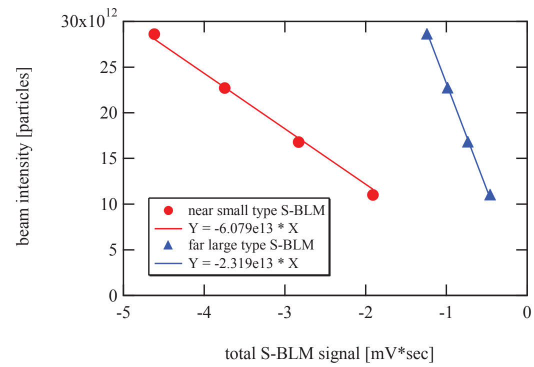

Figure 10: low intensity calibration curves for the near small type S-BLM and far large type S-BLM.

Reconstruction of the Transverse Profile

After completing each calibration curve acquiring, we demonstrated the transverse beam profile reconstruction with the new halo monitor. In this first trial beam test, the output beam power was 340kW equivalent. All PMTs were excited by a common power supply and the high voltage was fixed on -1kV.

Three plots in the Fig. 11(a) show the all scanning S-BLM data. The red circle and blue triangle plots were obtained by the near small type S-BLM and the far large type S-BLM respectively. The green square plots were obtained by the near large type S-BLM. By using the low sensitivity detectors, the beam core profile can be measured. However beam halo elements cannot be measured and then beam edge is underestimated. On the other hand, by using the high sensitivity detector, the beam core cannot be measured because the S-BLM signals are saturated. But the beam halo element can be measured. These results indicate that the beam core and halo elements can be measured separately by using the different sensitivity detectors.

Next step was reconstruction of the transverse beam profile from these scanning data. Only by using each sensitivity calibration curve formula, transverse beam profile with wide dynamic range can be reconstructed directly as shown in Fig. 11(b). These plotted the conversion data and any other correction was not necessary to join together all measured plots. Two beam core profiles overlapped thoroughly, and beam core and halo profiles adjoined smoothly. Thus we approve that the new halo monitor can measure the transverse beam profile with wide dynamic rage and the absolute value of the beam halo components can be evaluated.

In this first trial beam test, we verified to achieve the wide dynamic range of 10^8 - 10^{13} particles. Now, in order to expand the dynamic range more widely, additional S-BLMs with different sensitivity were installed and the HV power supplies to excite all PMT independently were set up. Then we will examine the new halo monitor in more detail in the next beam test.

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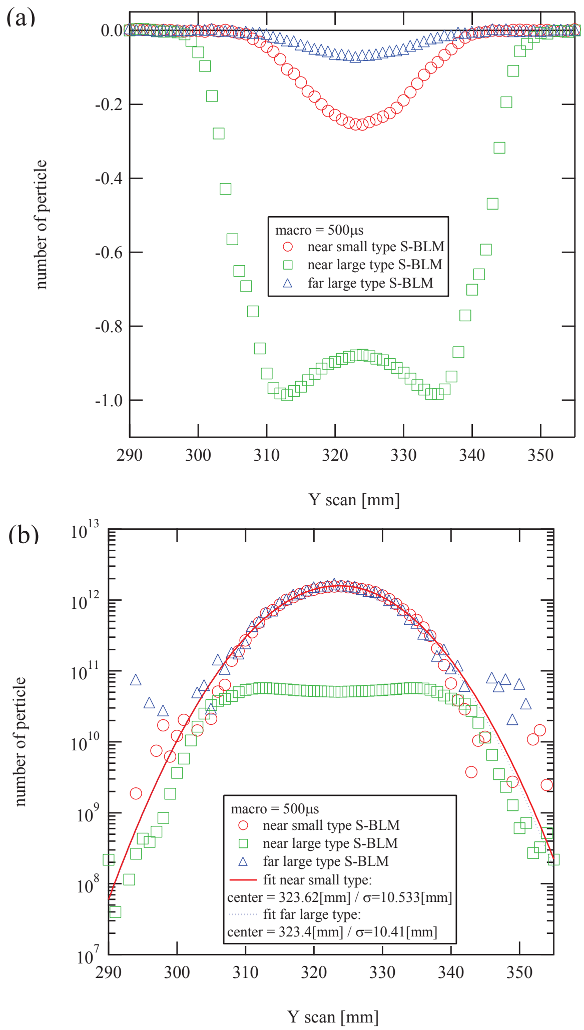

Figure 11: Demonstration of the transverse beam profile reconstruction with the output beam power of 320kW equivalent. (a) : Each S-BLM signal plots. (b) : Conversion data plots by using each sensitivity calibration curve formula.

SUMMARY

In the J-PARC RCS, new beam halo monitor, which is combined a wire scanner and some beam loss monitors, was developed to measure the transverse profile of the extraction beam. This new halo monitor aims to achieve the ultra-wide dynamic range. By using several beam loss monitors of plastic scintillator type with different sensitivities, the transverse beam profile including the beam core and halo elements can be reconstructed.

In the first trial beam test, we set up one high sensitivity S-BLM and two low sensitivity S-BLMs. The sensitivity of the S-BLM is controlled by changing the size of the plastic scintillator or by changing the distance from the wire scanner. At first, each calibration curve formulas for three S-BLMs were acquired. And next, we demonstrated the reconstruction of the transverse beam profile. Only by using sensitivity calibration curve formulas for the each S-BLM, transverse beam profile with wide dynamic range can be reconstructed directly. Any other correction was not necessary to join together all measured plots. It is great advantage of the new halo monitor, and we can approve that the absolute value of the beam core and halo components can be evaluated.

In this first trial beam test, we verified to achieve the wide dynamic range of 10^8 - 10^{13} particles. Now, in order to expand the dynamic range more widely, additional S-BLMs with different sensitivity was installed and the HV power supplies to excite all PMT independently were set up. Then we will examine the new halo monitor in more detail in the next beam test.

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