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PRE-COMMISSIONING OF THE WIDE-DYNAMIC RANGE HALO MONITOR TO BE INSTALLED IN THE FERMILAB MI-8 LINE*

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Abstract

The beam halo can contribute to beam losses in accelerators and is very difficult to measure. With an increase in beam intensity following the PIP-II upgrade at Fermilab, the beam losses are expected to be higher with some coming from the beam halo. Therefore, it is important to measure the sources of beam halo to minimize the beam losses. A modified Halo Monitor developed by J-PARC will be installed in Fermilab MI-8 transfer line to measure the beam halo. In this paper, an update on the beam profile monitor fabrication is covered. The updates include the location selection for the Halo Monitor in the MI-8 transfer line, shielding options for instrumentation, and the next steps in commissioning.

INTRODUCTION

The MI-8 line transfers 8 GeV proton beam with intensity of 5×10^{12} from the Booster Ring to the Recycler Ring, the Main Injector, and the Booster Neutrino Beamline at Fermi National Accelerator Laboratory (Fermilab).

Following the PIP-II upgrade at Fermilab, the beam intensity will increase along with beam losses [1]. Therefore, measuring the beam halo will help us determine the sources of halo to minimize the beam losses. The beam halo is defined as the outer layer of the 95 % beam emittance, where these particles will get lost and irradiate the machine.

A Halo Monitor was first installed at J-PARC Main Ring in 2012 to measure the beam halo of a 3 GeV proton beam after collimation to study the effects of collimators [2]. As a part of the US-Japan Science and Technology Cooperation Program in High Energy Physics, a modified design of the Halo Monitor is built by J-PARC to be installed in the Fermilab MI-8 transfer line where it will have the capability to measure the beam halo of an 8 GeV proton beam with intensity of 5×10^{12} up to magnitude of 10^{-6} [3].

In this paper, the overall design of the wide-range beam profile monitor, location selection using lattice and shielding options are discussed, along with a timeline of completion and further ongoing analysis.

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HALO MONITOR DESIGN

Target System

The Halo Monitor utilizes a three-target system. The first target is a titanium foil to measure the profile of the beam core through optical transition radiation (OTR). The second target is an aluminum foil with a hole at the center to measure the profile of the outer section of the beam core and inner section of the beam tails. The third target is chromium doped alumina screen to measure the beam halo through fluorescence (FL). There are four alumina screens that move in horizontal and vertical directions and this is a separate system than the rest of the targets. This will allow to measure the beam core and the halo at the same time. The similar target system of the Halo Monitor Unit-1 at J-PARC is discussed in more depth in Ref. [4].

Optical System

The Offner optics are installed inside the Halo Monitor and this configuration is shown in Fig. 1 where Zemax was used for ray tracing. There is a 100mm diameter hole in the upper right concave mirror for the path of the proton beam from the right, where the beam interacts with the desired target. The reflected OTR/FL light from the target travels through the Offner optics system, and arrives at the diffuser screen and the rest of the secondary optics system.

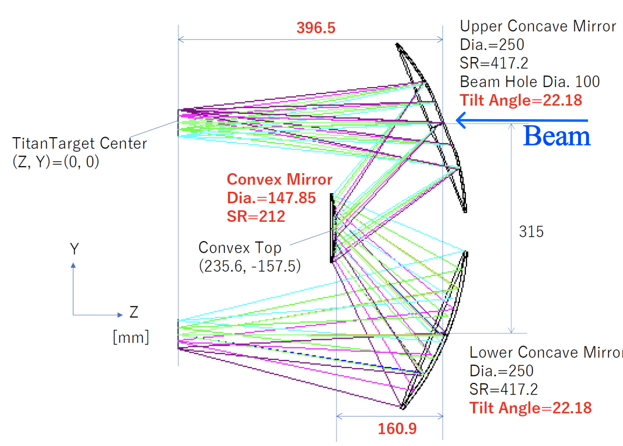

Figure 1: Ray tracing through the Offner optics where the length measurements are given in mm.

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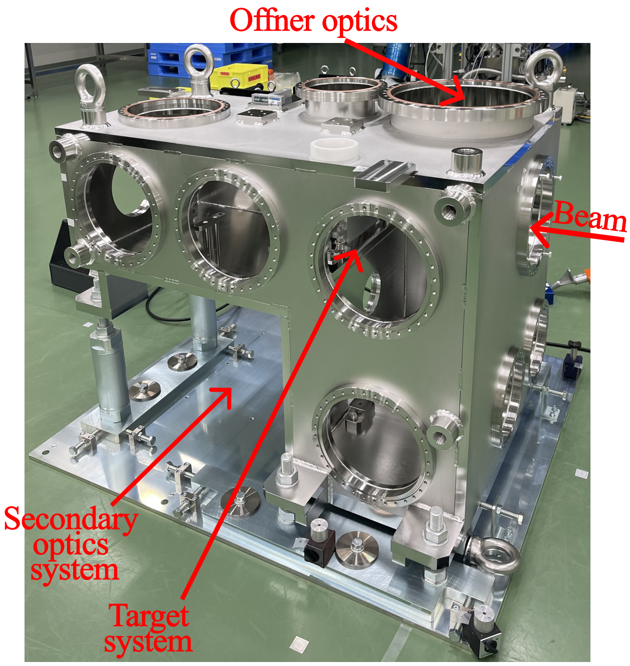

Figure 2: The completed Halo Monitor chamber.

Secondary Optical System

Once the OTR/FL light arrives at the diffuser screen outside of the chamber, the light is collected by the CMOS camera with an attached image intensifier.

The fabrication of the Halo Monitor is completed in Japan. Figure 2 shows the chamber during the alignment process. The mirrors will be placed inside the chamber from the top opening during installation in the tunnel and the target system will be placed before shipment to the US, followed by minor adjustments upon arrival.

LOCATION SELECTION IN THE MI-8 LINE

There are five possible locations available to install the Halo Monitor downstream of the collimators in the MI-8 transfer line to observe the effects of collimation. There are two operational collimators in the MI-8 line, with two additional units installed during summer shutdown 2025 as shown in Fig. 3, along with possible locations downstream.

The collimation regions are high-radiation areas where this can harm sensitive equipment and the first two locations are considered to be too close to the collimators.

The beam losses also tend to be higher in the vertical direction due to the horizontal ellipse-shaped beam pipe where the beam halo and unstable particles will hit the aperture. Therefore, it is important to choose a location with a higher beta function in the vertical direction. The location should ideally be placed in a straight section i.e. minimal dispersion to remove the effects of the momentum spread on the beam size. Hence, looking for a low dispersion area is ideal.

Once these characteristics are taken into consideration, Loc. 5 has a higher beta function on the *x*-axis. Loc. 3 and Loc. 4 were the ideal possible locations for the Halo Monitor installation. In conclusion, Loc. 4 was chosen since it is further downstream from the collimators for protection.

The lattice for Loc. 4 are shown in Fig. 4. The green shaded area is approximately 5 m long and the Halo Monitor is approximately 1.2 m in length, excluding the space for the flanges. The average beta and dispersion values at the beginning and at the end of this available area are given, along with the values for the two operational collimators upstream.

SHIELDING

To protect the Halo Monitor from radiation, a wall is planned to be installed in the tunnel after the collimators to minimize the secondary particles from damaging the equipment.

The secondary optical system will be located underneath the upper part of the chamber as shown in Fig. 2. The equipment is planned to be protected by building a shield cover around it. Currently, tungsten sheet is considered to protect sensitive equipment from radiation.

Aluminum tags were placed at the possible location during last beam run, and then the tags were collected during shutdown to analyze the radiation exposure levels on the tags to evaluate each location. To support the aluminum tag readings, Fluka simulation package will be used to assess how much radiation and secondary particles to expect at the secondary optical systems as a result of collimation upstream. The simulations will take into account a box made of tungsten sheets as a shielding cover and the overall halo monitor chamber.

TIMELINE AND DISCUSSIONS

A group from Fermilab has traveled to Japan to participate in the alignment test of the Halo Monitor using a 3D Faro arm, and Mitotoyo laser tracking system. The results of both methods were in agreement and indicated that the Halo Monitor had passed the alignment tests.

Linear motion actuators will be installed on the Halo Monitor in Fermilab to control the movements of the target system. While the OTR target system will be controlled horizontally, the FL halo target system horizontally and vertically. The design and controls of the linear actuators are currently in progress at Fermilab.

The Halo Monitor is prepared for shipment from Japan to arrive at Fermilab. A spool piece has been built and installed in Loc. 4 during shutdown 2025. The installation of the Halo Monitor is planned for summer shutdown of 2026 along with cable pulling in the tunnel. The commissioning to take place during 2026 Run in September.

While Zemax has been used for simple ray tracing before, simulations regarding the OTR light using are ongoing using the Offner optics system. The objective is to achieve this by using the electric field of a single electron at the incidence and applying this in the Zemax physical optics propagation analysis tool. The OTR has been used in Zemax before

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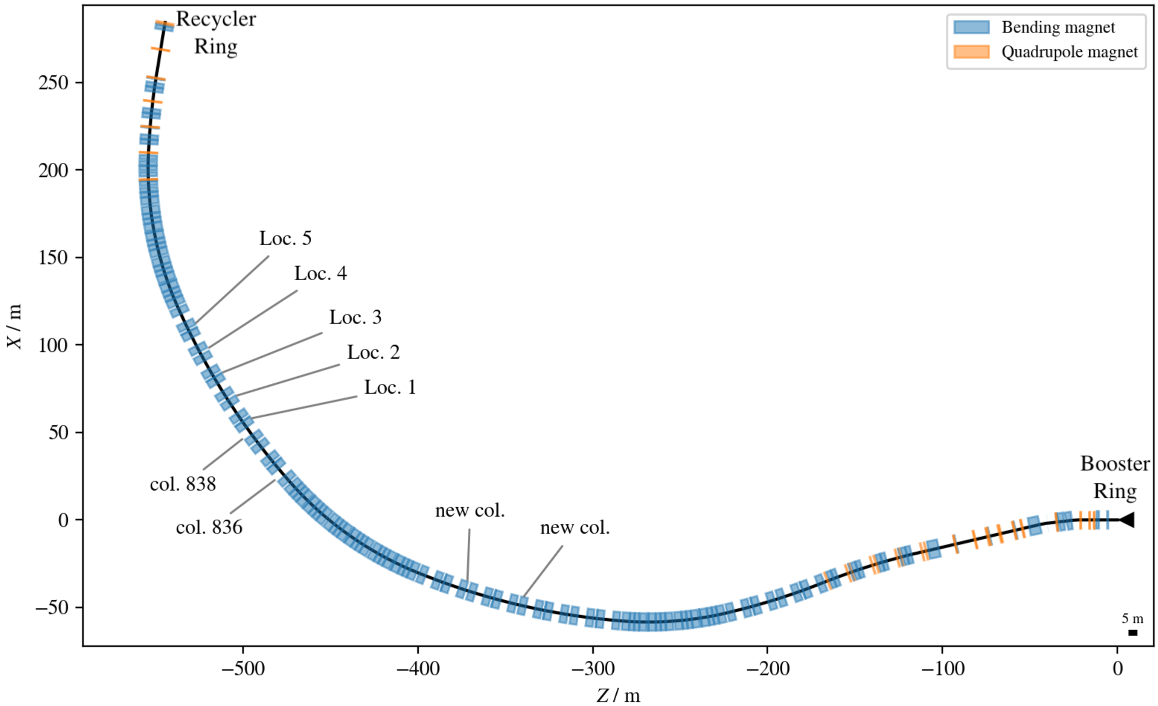

Figure 3: Possible locations in the MI-8 line where the beam travels from the Booster Ring to the Recycler Ring.

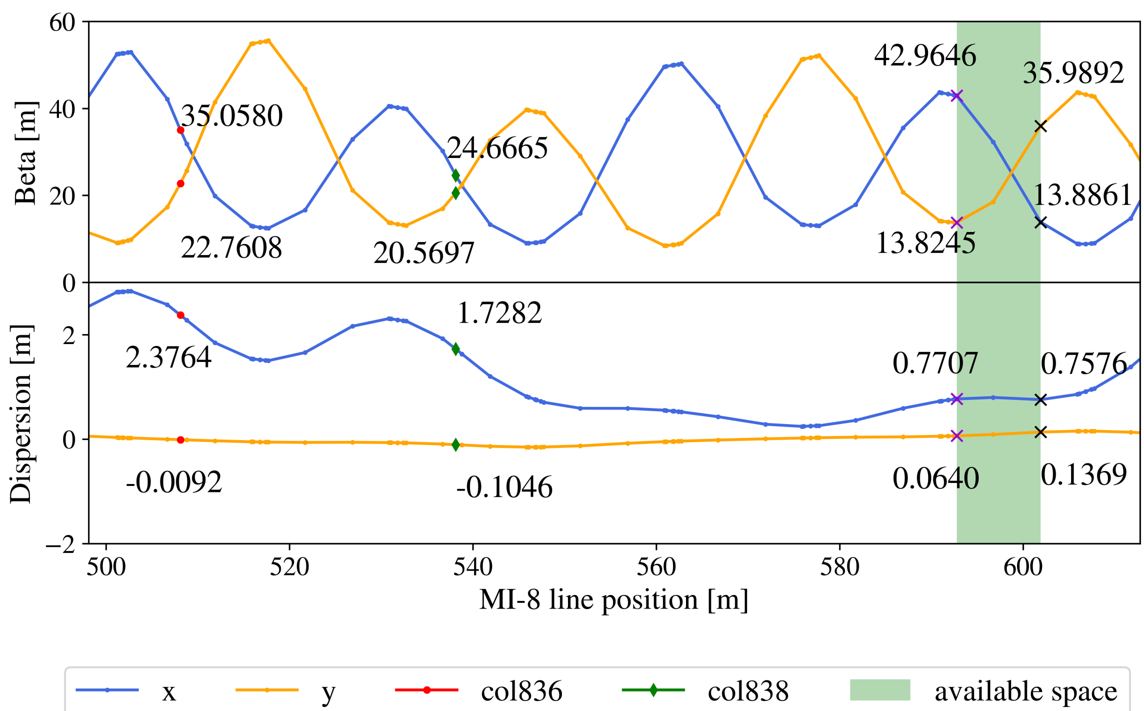

Figure 4: The lattice of the chosen location.

and Refs. [5, 6] go in depth in explanation. These simulations will be compared to the data after the Halo Monitor is commissioned.

The halo measurements will be conducted using a single bunch proton beam due to the lifetime effects of FL light [4]. FL has a longer afterglow than OTR while OTR is considered to be a spontaneous interaction. The afterglow time for an 8 GeV beam will be calculated to analyze the beam halo of multi-bunches in the MI-8 transfer line.

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