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STATUS OF GAS SHEET MONITOR FOR PROFILE MEASUREMENTS AT FRIB*

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Abstract

We report on the status of work on a non-invasive profile monitor under development for use at the Facility for Rare Isotope Beams (FRIB), a heavy-ion LINAC which produces high-intensity, multi-charge state beams. The measurement will be made by collecting photons generated at the interaction point of the beam and a collimated molecular gas curtain. These photons will be collected with an intensified camera system, generating a two-dimensional image and allowing for measurements of profile, beam halo, and other properties more prevalent at specific locations of interest, such as charge state spread after folding segment bends. Included will be ongoing design specifications, simulation results, and discussion of measurement techniques for acquiring signal from the device.

INTRODUCTION

A non-invasive profile measurement device using nitrogen gas fluorescence is in development for use in the Facility for Rare Isotope Beams (FRIB), a high-intensity heavy ion facility which can provide beams of a variety of different ion species and charge states.

By using a non-interceptive method, it is possible to sample the state of the beam during operation, providing information about the spread of the charge states at points of interest, such as after bending magnets in the folding LINAC sections of FRIB. This method also allows the state of the beam to be measured in both transverse directions at once [1].

One way to accomplish this is by creating an ultra-thin, rarefied gas curtain and collecting the photons released in the interaction between the beam and the working gas. This is known as beam-induced fluorescence (BIF) and has the advantage of being a simpler system design than similar ionization-based monitors, which require an electrode to sweep the electrons or ions into the detector and a magnet to steer them to the correct location to be collected. Additionally, BIF monitors have greater time resolution, since the time for the interaction particles to travel to the detector is negligible [2]. By introducing only a small amount of gas to the system, both pumping requirements and interaction effects like scattering and charge stripping are reduced [3].

Assuming the gas sheet is uniform and thin, photons collected can then be correlated to the profile of the beam with some degree of accuracy. This technique has been used successfully with protons and lighter ions at other facilities [1,3-5].

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SYSTEM OVERVIEW AND REQUIREMENTS

The beamline device is divided into three sections:(i) the gas generating chamber; (ii) the main interaction chamber; and (iii) the optics system. Within the gas generating section, nitrogen gas is pumped into a reservoir which feeds into a thin rectangular cavity. Molecules of nitrogen are emitted from a slit at the front of the cavity and are further collimated into sheet by a slit placed between the generating and main chambers as shown in Figure 1.

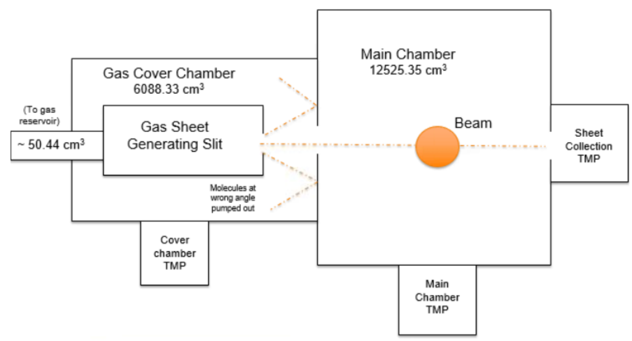

Figure 1: Overview of device layout.

Considerations

Although rarefied, gas generated from the monitor will require significant pumping to prevent contamination and protect the rest of the high vacuum system and this must be accounted for in appropriately sizing of the pumps.

For the measurement to correlate with the beam profile, the sheet must be thin and uniform, positioned at a 45-degree angle to the incident beam with the detector perpendicular to the point of interaction. Careful alignment must be performed to ensure that the angle of interaction is correct [6].

Signals generated by the interaction will be of relatively low intensity. The fluorescence interaction generates a small signal compared to ionization monitors due to fluorescence cross sections being lower than ionization cross sections. To assist with collection and reduce scattering from reflection, the interior of the main chamber will be blackened and an intensified camera array will be used to amplify the incoming signal. Light is gathered by the camera system at a small solid angle, and relatively few photons, are released in the interaction. For example, using a residual-type BIF, Tsang et al. noted a production of 7 photons per 3×10^8 ion Uranium bunch with hydrogen as the working gas [7]. Photon production is expected to be higher with use of a collimated sheet, as well as nitrogen as the working gas since it has a greater fluorescence cross

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section. However, additional amplification and noise reduction techniques will still be needed the optics system [1,2].

The ratio of the mean free path of the nitrogen molecules is significantly larger than the length scale of the generator, which puts the gas in the desired free molecular flow regime. This is represented by the Knudsen number, characterized by the mean free path of the molecule, λ, over the characteristic length of the system, l, see Eq. (1). The system is in molecular flow at a Knudsen ratio greater than 10.

$$K_n = \frac{\lambda}{l} \tag{1}$$

The mean free path of the molecules in the generator slit is approximately 704 mm, making the Knudsen number 7040. To achieve this, the generating slit will need to be machined to a depth of 0.1 mm, which could pose challenging due to tolerances at that scale.

DESIGN OF MECHANICAL SYSTEM

To facilitate manufacturing, the gas sheet generating slit will be formed from a half-cylindrical slug machined on one side to the required depth and capped with a flat top connected to the reservoir and gas injection. The generating slit will be secured to the gas cover and attached to a rotatable CF flange to allow for alignment of the cover slit with the collimator and interaction point. A SOLIDWORKS model is shown in Figure 2.

The gas sheet generator has dimensions of length 100 mm by width 100 mm with a depth of 0.1 mm. The slit widens to 110 mm at its exit to widen the area of the gas curtain, shown in Figure 2.

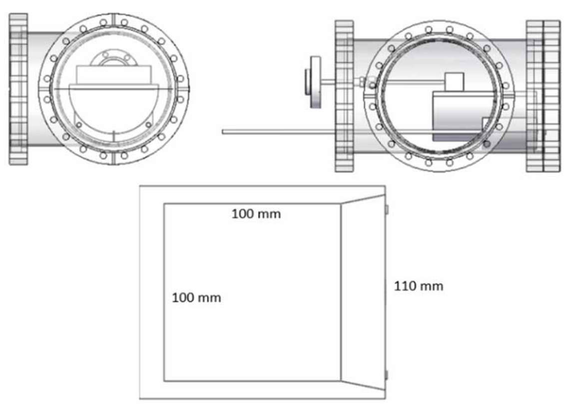

Figure 2: SOLIDWORKS model of sheet generator prepared for MolFlow+ simulation.

The collimator is to be located 10 mm from the exit of the gas sheet generator and sized slightly larger at 0.3 mm and 160 mm. The width of the collimating slit is determined such that approximately 10% of the gas molecules exiting the gas sheet generator enter the main chamber, or molecules that deviate from a path about 0.4 radians from the x-z plane.

For both the main chamber and gas cover sheet, off-the-shelf components will be used. The cover chamber will be manufactured using a vacuum nipple modified to hold the gas sheet generating slit in place, for alignment with the collimator and interaction point.

Three turbomolecular pumps will be used to prevent the buildup of gas in the system, one placed in the gas cover before the collimating slit to remove excess nitrogen emitted from the generator at undesirable angles, one in the main chamber of the device to maintain high vacuum, and one at the exit of the main chamber to collect the gas sheet.

SIMULATION

The device was initially modeled using simplified geometry as reported in [8], using MolFlow+, a Monte Carlo gas dynamics simulation software [9].

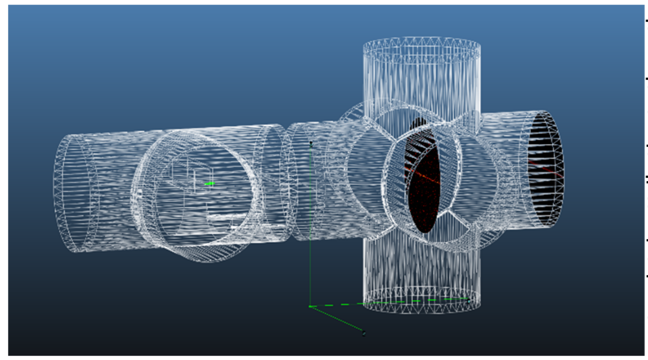

Figure 3: Molflow+ simulation set up.

Simulations were updated to include more complex geometry, as well as consideration for distance of the gas sheet generator opening to the collimating slit. Figure 3 shows the prepared volume of the model in MolFlow+, while Figure 4 shows a close-up of the pressure distribution at the gas sheet exit point of the model.

The gas is introduced on one of the reservoir chamber faces with a cosine desorption and outgassing rate of 0.001 mbar-liter/s.

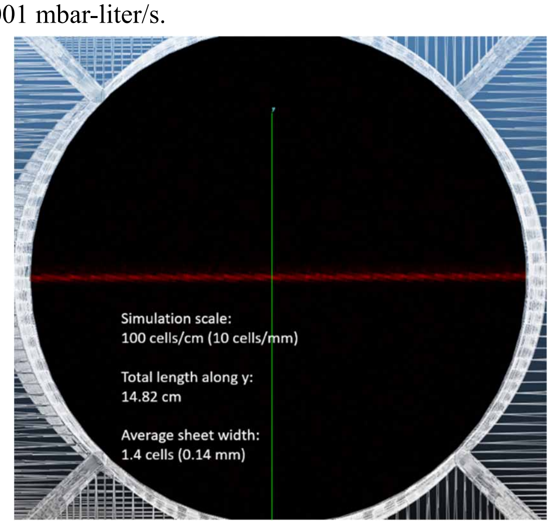

Figure 4: Width of the sheet at removal as seen along the x-y plane.

The interaction point is placed at the center point of the main chamber, and the gas sheet generator is positioned without the angle to facilitate measurement of the sheet width.

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The width of the sheet at the center point of the main chamber was found to be 0.14 mm (see Figure 4).

MEASUREMENT

The proposed design for signal acquisition involves positioning an intensified camera perpendicular to the interaction point. For bench testing to determine uniformity of sheet thickness and density, a hot-cathode gauge on a movable platform will be positioned in place of the camera system.

Photons will be produced in the range of 390 to 470 nm [1]. After validation of the gas sheet, the hot-cathode gauge will be replaced with an intensified camera with sensitivity in this range. Future work will include design of the optics platform and system specifications.

Use in Beam Halo Measurements

Additional functionality can be added to this device to allow for monitoring beam halo. Since profile image generated is two-dimensional, a coronagraph modification to the optics could be made to block the core of the beam when halo measurements are desired. This technique is adapted from optical coronograph devices used to view the halo of the sun and would be done by adding a movable occulting disk, an additional field lens and Lyot stop to mitigate diffraction effects caused by masking the core. This technique has been previous deployed in beam halo monitors with good results [10].

CONCLUSION

Work continues on the design of a molecular dynamics-based gas-sheet monitor to be used with high-intensity heavy ions beams generated at FRIB. This paper presented an update on the design work performed. Future work will include further specifications on the optics system and bench testing of the initial mechanical design.

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REFERENCES

[1] I. Yamada *et al*., “High-intensity beam profile measurement using a gas sheet monitor by beam induced fluorescence detection”, *Phys. Rev. Accel. Beams*, vol. 24, no. 4, p. 042801, Apr. 2021.
doi:10.1103/PhysRevAccel-Beams.24.042801

[2] F. Becker, “Beam Induced Fluorescence Monitors”, in *Proc. DIPAC'11*, Hamburg, Germany, May 2011, paper WEOD01, pp. 575-579.

[3] J. Kamiya *et al.,* “Evaluation of 2-D Transverse Beam Profile Monitor Using Gas Sheet at J-PARC LINAC”, *J. Phys: Conf. S.*, vol. 1350, p. 012149, 2019.
doi:10.1088/1742-6596/1350/1/012149

[4] S. Szustkowski, B. T. Freemire, S. Chattopadhyay, and D.J. Crawford, “Development of a Gas Sheet Beam Profile Monitor for IOTA”, in *Proc. IPAC'18,* Vancouver, Canada, Apr.-May 2018, pp. 2326-2329.
doi:10.18429/JACoW-IPAC2018-WEPAL065

[5] N. Ogiwara *et al.*, “A Non-destructive Profile Monitor Using a Gas Sheet”, in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2102-2104.
doi:10.18429/JACoW-IPAC2016-WEOBB03

[6] C.P. Welsch, “Non-destructive Beam Profile Monitors”, in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 1234-1239.
doi:10.18429/JACoW-IPAC2017-TUXB1

[7] T. Tsang, D. Gassner, and M. Minty, “Residual gas fluorescence monitor for relativistic heavy ions at RHIC,” *Phys. Rev. ST Accel. Beams*, vol. 16, p. 102802, 2013.

[8] A. Lokey and S. M. Lidia, “Design Study for Non-Intercepting Gas-Sheet Profile Monitor at FRIB”, in *Proc. NA-PAC'22,* Albuquerque, NM, USA, Aug. 2022, pp. 229-231.
doi:10.18429/JACoW-NAPAC2022-MOPA80

[9] Molflow+, https://molflow.web.cern.ch/

[10] A. Goldblatt, E. Bravin, T.M. Mitsuhashi, F. Roncarolo, and G. Trad, “Design and Performance of Coronagraph for Beam Halo Measurements in the LHC”, in *Proc. IBIC'16,* Barcelona, Spain, Sep. 2016, pp. 254-257.
doi:10.18429/JACoW-IBIC2016-MOPG74