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DESIGN STUDY FOR NON-INTERCEPTING GAS-SHEET PROFILE MONITOR AT FRIB*

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Abstract

Non-invasive profile monitors offer a significant advantage for continuous, online monitoring of transverse beam profile and tuning of beam parameters during operation. This is due to both the non-destructive nature of the measurement and the unique feature that some monitors have of being able to determine both transverse profiles in one measurement. One method of interest for making this measurement is the use of a thin gas curtain, which intercepts the beam and generates both ions and photons, which can be collected at a detector situated perpendicular to the gas sheet. This study will investigate the requirements for developing such a measurement device for use at the Facility for Rare Isotope Beams (FRIB), which produces high-intensity, multi charge state, heavy ion beams. Included will be initial design specifications and an analysis of alternatives between ionization and beam-induced fluorescence measurement techniques for acquiring signal from the gas sheet.

INTRODUCTION

The Facility for Rare Isotope Beams will produce high intensity heavy ion beams of many species and charge states. To characterize the transverse profile of the beam, measurements [1] can be made by either intercepting the beam directly, using techniques such a wire scanner, SEM grid, or impinging the beam directly on a detector [2]. This has the disadvantage of being susceptible to damage from thermal cycling and sputtering, especially at high intensities.

Therefore, there is an interest in developing a non-invasive method for measuring the transverse profile which can provide information of the state of the beam in both transverse profile directions. For example, it may be advantageous to monitor the spread of the charge states in multi-charge state beams at locations such as bends in the folding LINAC sections of FRIB, as demonstrated in Fig. 1.

One way to accomplish this is by creating a thin gas sheet that the beam interacts with in a minimally invasive way and measuring the distribution of ions, electrons or photons formed [3].

Preliminary work is being done to develop a gas-sheet style monitor based on this success with residual and introduced gas monitors that can be used with high-intensity heavy ions. Similar devices have been successfully developed for lighter ion and proton machines at facilities such as Fermilab and J-PARC [1, 4-6].

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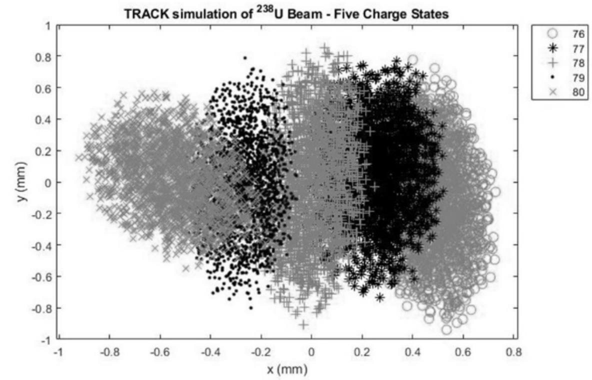

Figure 1: Example of charge state spread generated from TRACK simulation data at a 60 degree bend.

BEAM INDUCED FLUORESCENCE

Beam-induced fluorescence, or BIF monitors measure photons emitted from a working gas when excited by the beam. Imaging is accomplished using photomultiplier tubes or very sensitive intensified camera arrays. The wavelength of the photon is dependent on the energy loss in the beam-gas interaction [7].

The advantage of this technique is that the system is simpler compared to gas ionization monitors, which require electrodes to sweep the ions or electrons to the detector, as well as possibly a parallel dipole to guide them along a spiral path to the desired location and prevent image broadening. There is also better time resolution from photons than ions, due to the difference in time it takes them to travel to the detector. However, the main drawback of this technique is low signal intensity compared to measurement of ionization, since the fluorescence cross section of a gas is generally much lower than its ionization cross section and the light collected will only a small fraction of the total light emitted. Optical systems can gather photons at a small solid angle, therefore amplification and noise reduction for the signal is required [7].

Fluorescence Cross Section

Fluorescence cross section has a q^2 dependence, where q is the charge of the ion and the differential particle energy loss of the beam-gas interaction. Total photon yield is proportional to the gas pressure, the number of particles in a bunch, and the square of the ion charge. For ions at a high charge state, the fluorescence cross section should be high enough to yield enough light for measurement to be made [8].

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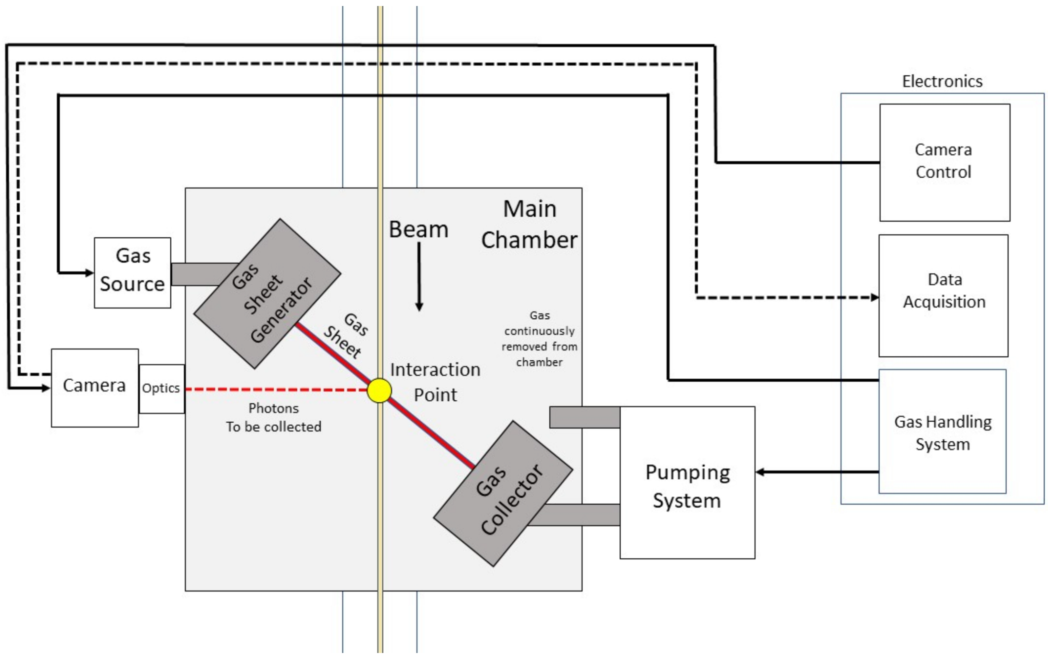

Figure 2: High-level overview of proposed system.

The working gas for the system is chosen to be nitrogen, due to its relatively high fluorescence cross section and suitability for the vacuum system [9]. Due to the charge state dependence, such a measurement scheme is appropriate to use with heavy-ion beams, although this will need to be validated with simulation and testing [10].

SYSTEM OVERVIEW AND REQUIREMENTS

Geometry and Collection

To measure both transverse profiles, a thin gas sheet is placed at angle to the beam. A planar collection scheme is used to correlate the profile to the collected light and transforms exist for generating the beam profile from the observed photons.

The measured photon distribution represents the 2D beam profile to good accuracy when the gas density is uniform and thin. The use of an ultra-thin gas sheet therefore has the advantage of reducing the interaction of the beam, which mitigates concerns with charge stripping and scattering effects, as well as reducing the amount of gas introduced into the system that must be subsequently removed and simplifying the overall measurement [5].

Figure 2 shows a high-level overview of the proposed system. The main interaction chamber will consist of a gas sheet generator, a collector to catch and remove the sheet after interaction and an outer chamber used to contain any extraneous gas molecules from the sheet. A pumping system will maintain vacuum in the chamber and remove the sheet past the interaction point. Signal will be collected by an intensified camera array positioned perpendicular to the interaction point and sent to processing electronics away from the beamline.

CURRENT STATUS OF WORK

Gas Sheet Modelling

Modelling is done using MolFlow+ [11]. Starting from the geometry detailed in [1] the gas sheet generator is formed from two planes set 0.1 mm apart, with dimensions 100 mm long by 50 mm wide. The generator is contained in a gas slit cover which removes gas molecules emitted at an angle greater than about 0.4 radians from the x-z plane. The distance from the gas sheet generator to the collimating slit is 10 mm. After collimation, the gas sheet travels 110 mm before being removed from the system. The distribution of the gas sheet can be approximated from measuring the flux of particles exiting the system at the back face of the model, as shown in Fig. 3.

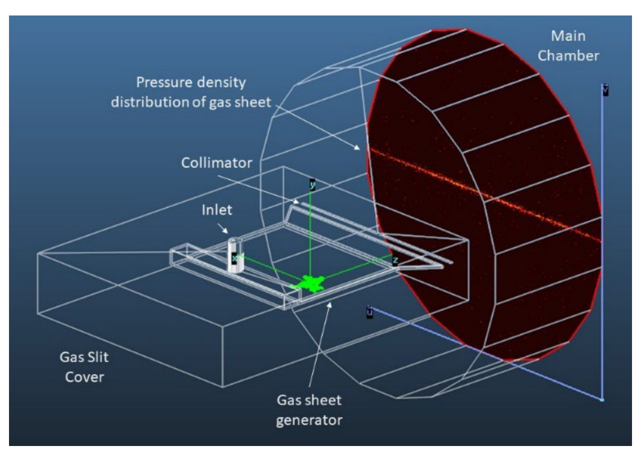

Figure 3: Molflow+ model showing the configuration of the simulation and distribution of the gas sheet at exit point.

Gas is introduced from a circular plane meant to simulate an inlet pipe, with a cosine desorption and outgassing rate

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of 0.001 mbar*l/s. Gas molecules that escape into the generator enter a molecular flow regime, with a mean free path of approximately 704 mm. The width of the gas sheet is found by looking at the pressure distribution on a plane opposite of the generator that removes gas molecules from the system upon impact, as seen in Fig. 4. The distance to this wall can be varied depending on the anticipated spread of the gas sheet thickness.

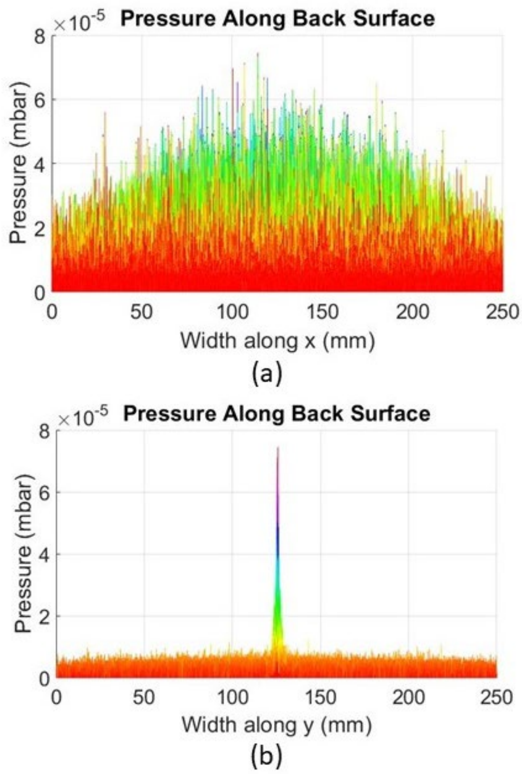

Figure 4: Width of gas sheet as seen from (a) x-z plane, and (b) y-z plane.

Further Modelling

The interaction of the beam with the gas sheet will be modelled using Geant4, which can provide estimates for photon yield and interaction effects. The geometry and flow rate parameters can be adjusted to fit the needs of the heavy-ion interaction, and this will be determined by future modelling of the interaction in Geant4 [12].

CONCLUSION

The goal of this project will be to develop a molecular dynamics-based gas-sheet monitor that can be used with high-intensity heavy ions. A high level overview of the system was presented, as well as some preliminary work on modelling of the gas sheet based on prior work on similar devices.

ACKOWLEDGEMENTS

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