First Beam Profile Measurements by Beam Induced Fluorescence at the J-PARC Neutrino Extraction Beamline

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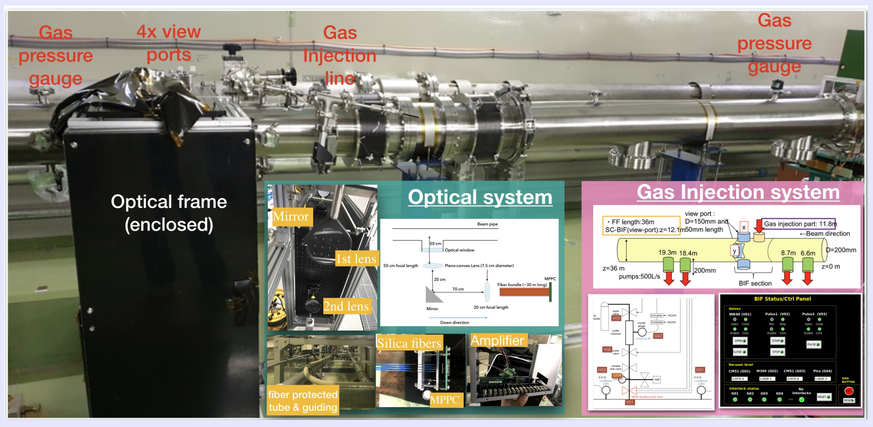
Abstract

A Beam Induced Fluorescence (BIF) profile monitor is under development at the J-PARC neutrino extraction beamline, where neutrinos are produced using 30 GeV protons from the J-PARC MR accelerator. Towards the goal of continuously and non-destructively measuring the 1.3MW proton beam profile spill-by-spill using fluorescence from proton interactions with injected gas, a full working prototype monitor was installed in the beamline in 2019. The prototype includes a scheme for pulsed injection of N_2 gas into the ultra-high vacuum beampipe and two optical readout arms, a conventional one using an Image Intensifier coupled to a CID camera, along with an array of optical fibers coupled to a Multi-Pixel Photon Counter array. Initial beam tests of the system were carried out in early 2020, and BIF light was successfully observed in both optical systems. Details of the prototype monitor, along with first proton beam profile measurement results, will be shown. Improvement plans towards continuous operation of the new profile monitor will also be discussed.

BIF at J-PARC Neutrino Beamline

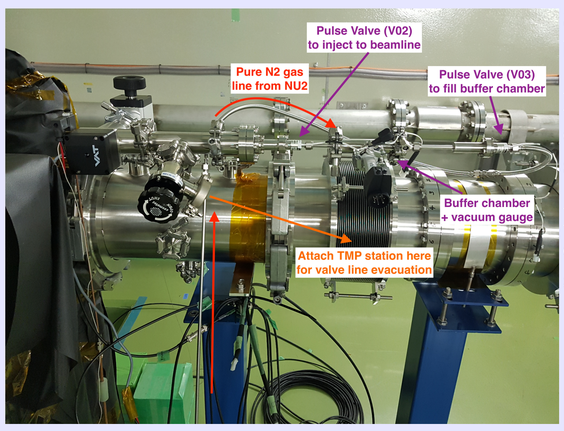


Installed prototype BIF Monitor

Working prototype Beam Induced Fluorescence monitor was installed in the J-PARC neutrino extraction beamline in 2019. Consists of :

- Pulsed gas injection valve system to inject N_2 gas
- Two fused quartz beam windows to allow light to escape the beampipe
- Beampipe walls near the BIF interaction region darkened by Diamond-Like Carbon coating
- Two independent optical focusing and light detection systems

Gas Injection System



Gas injection valve line

Peak pressure reached depends on conductance of valve line. Minimizing conductance is essential for maximizing pressure bump

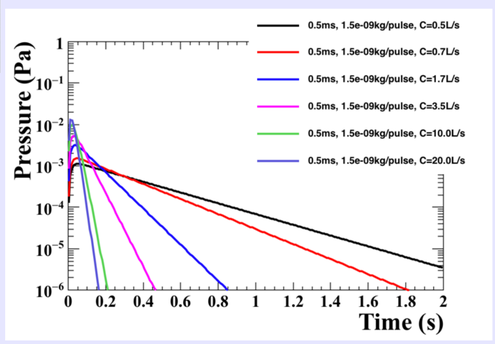
Current conductance is only ∼0.7 L/s

Aim to reach a maximum pressure of around 10^{-2} Pa by improving conductance to 10 L/s

Sub-ms-long gas pulse injected at the timing of each beam spill using pulse valve

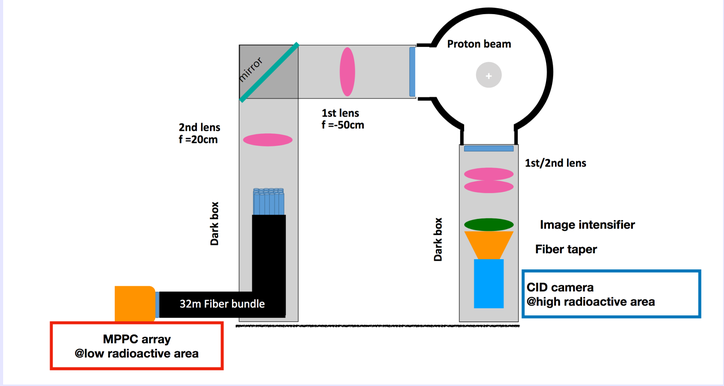
Buffer chamber upstream of the pulse valve is periodically filled by another pulse valve and acts as a safety chamber

Pneumatic valve downstream of the pulse valve closes in the case of an interlock, which is fired if any pressure along the beamline exceeds a set value



Expected pressure vs. time for different gas injection valve conductances

Light Focusing and Detection

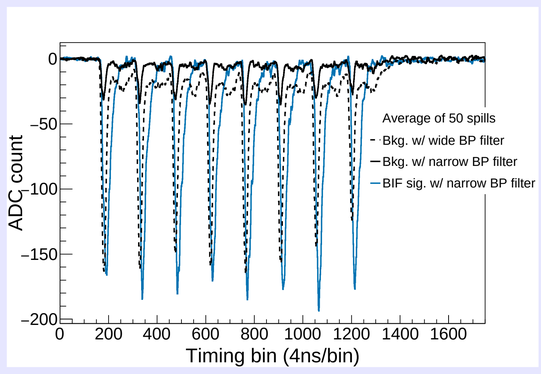


Schematic diagram of the BIF monitor optical systems.

Two light detection systems are installed :

1. Vertical measurement arm
   - Lenses and mirror focus the light downwards onto an array of silica core optical fibers
   - Optical fibers transport fluorescence light away from the high-radiation area near the beamline and into a lower-radiation environment inside a subtunnel ∼30 meters away
   - Light detected by array of Multi-Pixel Photon Counters (MPPCs)
   - Sub-ns timing resolution + single photon counting capability
2. Horizontal measurement arm
   - Two lenses focus light onto MCP-based gated Image Intensifier coupled to radiation-hard CID camera by a fiber taper
   - High-resolution and relatively radiation hard

Mitigating Backgrounds



Observed beam-induced background on an optical fiber before and after background mitigation (with optical filtering of 400±200 nm and 400±40 nm respectively) and observed BIF signal after mitigation

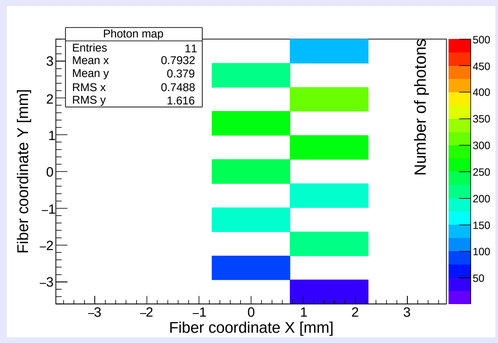
Beam-induced backgrounds are observed on both optical systems

Background is reduced on optical fibers by aggressive optical filtering around 390 nm and selecting light outgoing from the fibers at $<12^{\circ}$

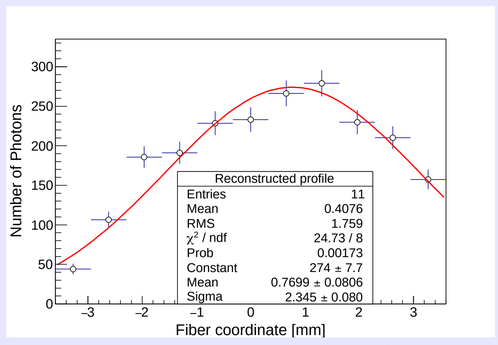
Background is reduced on Image Intensifier by shielding blocks

First Profile Measurements

Various beam tests of the prototype monitor were carried out in early 2020



2D vertical beam measurement by optical fiber + MPPC readout



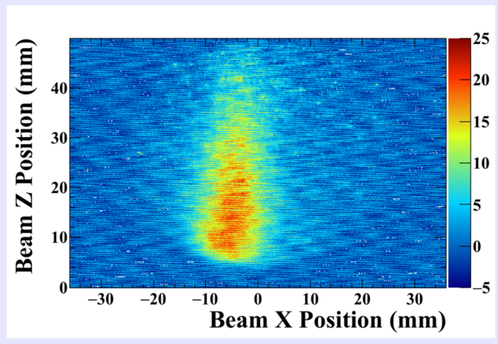
1D vertical beam measurement by optical fiber + MPPC readout

A clear beam profile was observed in both optical systems

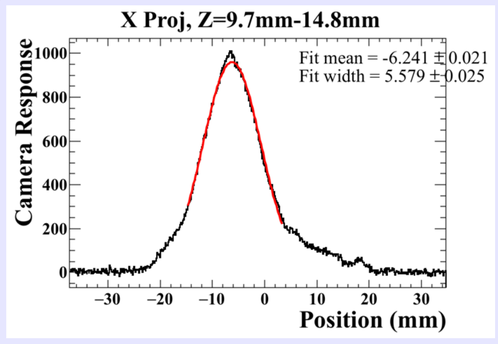
Intensity of the detected light is correlated with the amount of injected gas and correlated between the two optical systems

Measured beam position and width are relatively consistent with expectation from fit to neighboring monitors

Further data analysis + alignment calibration underway



2D horizontal beam measurement by Image Intensifier + CID camera



1D horizontal beam measurement by Image Intensifier + CID camera

Ongoing Work + Improvements Towards a Working Monitor

Currently finalizing measurements of :

- Optical system alignment
- Absolute signal calibration
- Extraction of BIF light and background light wavelength
- Measurement of time-dependence to understand beam-induced space-charge effects

Planned improvements :

- Gas system :
  - Reduce injection valve conductance to improve pressure bump
  - Upgrades to gas injection control system
- Optical systems :
  - Improve optical fiber + MPPC measurement arm by increasing number of optical fibers (?)
  - Improve optical fiber + MPPC measurement arm by using a fiber type with better transmission at the BIF wavelength
  - Test shorter optical fibers leading to radiation-hard photosensors
  - Improve Image Intensifier + CID camera arm by higher gain intensifier (?)

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