

OTR IMAGING OF INTENSE 120 GEV PROTONS IN THE NUMI BEAMLINE AT FNAL *

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Abstract

An Optical Transition Radiation (OTR) detector has been installed in the Fermilab NuMI proton beamline, which operates at beam powers of up to ~350 kW, to obtain real-time, spill-by-spill beam profiles for neutrino production. As part of the Run II collider plan and the NuMI neutrino program, a series of OTR detectors were designed, constructed and installed in various beamlines at Fermilab. NuMI OTR images of 120 GeV protons for beam intensities up to 4.1×10^{13} at a spill rate of 0.5 Hz and small transverse beam size of ~1 mm (σ) are presented here. Beam profiles are extracted from the OTR images and compared with an adjacent secondary-electron emission (SEM) monitor. The OTR detector provides two-dimensional beam shape, such as ellipticity and tilt, as well as beam centroid and beam intensity information. In addition, the response of the OTR detector over time is examined to look for signs of foil aging.

INTRODUCTION

Optical Transition Radiation (OTR) occurs when a charged particle transverses a material boundary where there is a change in the index of refraction. OTR is emitted in both the forward and the backward directions relative to the particle motion. The radiation pattern is a radially polarized cone of light with its peak intensity at a radius of $1/\gamma$, where γ is the particle Lorentz factor. The first observation of OTR was by Goldsmith and Jelley [1].

OTR detectors have been used extensively to measure transverse beam shape in electron accelerators. Recently, CERN incorporated OTR detectors in various transfer lines to measure proton bunches used for operation of the LHC [2]. As part of the Run II collider plan and the NuMI neutrino program, a series of OTR detectors were designed, constructed and installed in various beamlines at Fermilab. Previous near-field OTR images, from other Fermilab beamlines, of lower-intensity 120 GeV and 150 GeV protons with larger transverse beam size have been presented [3] [4] [5].

EXPERIMENTAL SETUP

OTR Detector for NuMI

A collaboration of Fermilab and Argonne National Laboratory developed an OTR detector design optimized to measure both proton and antiprotons in the energy range of 120 to 150 GeV and for bunch intensities from

~ 5×10^{10} to ~ 1×10^{14} particles. Figure 1 shows a block diagram of these detectors. The NuMI OTR detector uses two independently inserted 6 micron Kapton foils with 0.12 micron of aluminum. These foils reduce the proton beam scatter by 70% compared with an adjacent SEM monitor (SEM). The foils are tilted 45 degree to the beam axis in order to reflect the backward OTR perpendicular to the beamline. One foil is used as a primary OTR screen while the second foil is periodically inserted into the beam to track changes to the primary foil.

In addition, the detector utilizes a radiation-hardened CID camera [6] that can be rotated to the Scheimpflug angle [7] to maintain focus across the foil. The detector also has two filter wheels consisting of neutral density filters and two orthogonal polarizing filters. The focus lens can switch between near-field and far-field imaging.

The detector acquires OTR images for every beam pulse. A front-end PC uses a Labview acquisition and analysis program to process these images. The analysis produces the beam X and Y centroids and sigmas as well as the beam tilt and ellipticity. A more detailed description of the OTR detector can be found in reference [8].

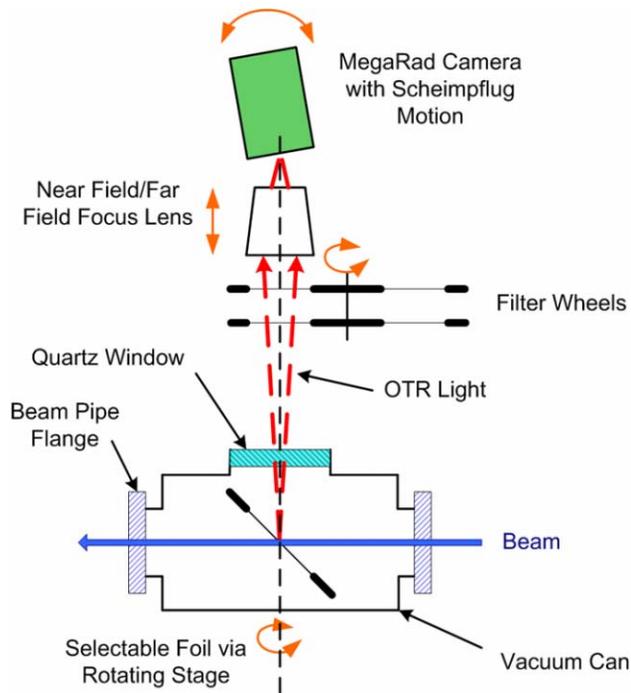


Figure 1: Block diagram of FNAL OTR detector.

NuMI Beamline

The Neutrinos at the Main Injector (NuMI) beamline is used to generate intense ν_μ beams via the decay of pion and kaon secondaries produced from 120 GeV protons

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impacting the NuMI target [9]. The beamline was initially designed to accept up to 4×10^{13} 120 GeV protons per pulse at a repetition rate of 0.53 hertz. Recent Main Injector studies have supplied 4.1×10^{13} protons per pulse at 0.45 hertz to the NuMI target. Normal operation of the NuMI beamline switches between two modes. During most operating periods NuMI receives $\sim 2.4 \times 10^{13}$ protons per pulse at the target. During short periods where there is no antiproton production, NuMI receives $\sim 3.2 \times 10^{13}$ protons per pulse from the Main Injector.

Presently, NuMI uses a segmented titanium foil SEM just upstream of the NuMI target and shield wall as a target beam profile monitor [10]. This target SEM measures the beam profile for every pulse. The NuMI OTR detector is installed just downstream of the target SEM but still in front of the shield wall.

NUMI OTR MEASUREMENTS

The NuMI OTR detector has taken measurements at various times over the past year. In March of 2007, the primary OTR foil was inserted into the NuMI beamline for continuous operation. Both near-field and far-field OTR images have been taken for beam intensities from $\sim 2.2 \times 10^{13}$ to 4.1×10^{13} . Far-field imaging will not be presented in this paper but is discussed in another paper presented at this conference [11]. Figure 2 shows a histogram of the beam pulse intensities during ~ 80 days of continuous operation. This corresponds to $\sim 6.5 \times 10^{19}$ protons through the primary OTR foil.

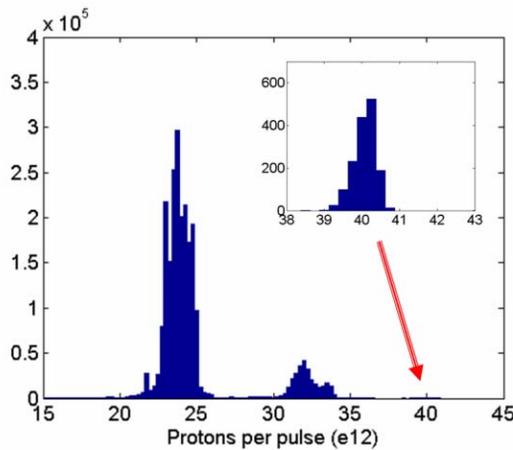


Figure 2: NuMI beam pulse intensities for ~ 80 days of operation while OTR foil is in beam path.

Figure 3 shows OTR images for bunch intensities of $\sim 2.4 \times 10^{13}$ and $\sim 4.1 \times 10^{13}$. This figure also shows the beam projections with Gaussian fits. The images show the increase in beam size with increase in beam intensity. The images also show an increase in the beam ellipticity with higher intensities. This shows the advantage of a two-dimensional beam shape monitor, such as an OTR detector, over other standard one-dimensional profile monitors.

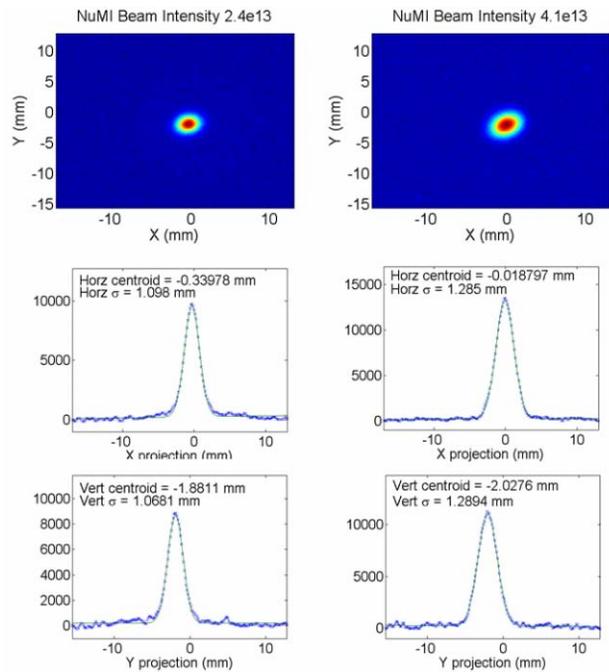


Figure 3: NuMI OTR beam images and horizontal and vertical projections with Gaussian fits for 2.4×10^{13} and 4.1×10^{13} protons per bunch.

OTR Detector Response over Time

The choice of an aluminized Kapton foil for the NuMI OTR was made to minimize the scatter of the NuMI beam. Issues of foil lifetime at this high beam intensity are not well understood but it was assumed that the foil would change over time. Figure 4 shows a comparison of the measured horizontal σ from the SEM monitor and the OTR detector over a period of 80 days. One can see from the figure that value of σ for the OTR detector is slowly diverging from the value from the SEM monitor. Although there is a difference in these two measurements, it is not clear that this could be attributed to a change in the OTR foil.

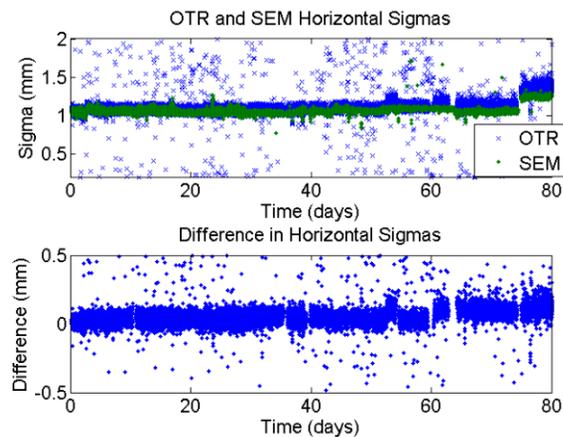


Figure 4: Comparison of the horizontal σ between the SEM monitor and the OTR detector over time.

After ~ 70 days with the primary foil in the NuMI beamline, the secondary foil was temporarily inserted into

the beamline. The OTR images from this foil were compared to OTR images taken with the primary foil to look for signs of change in the primary foil. Figure 5 shows OTR images and projections for the primary and secondary foils under similar beam conditions. These images give similar centroid and σ values for both foils but the OTR intensity from the primary foil is clearly reduced.

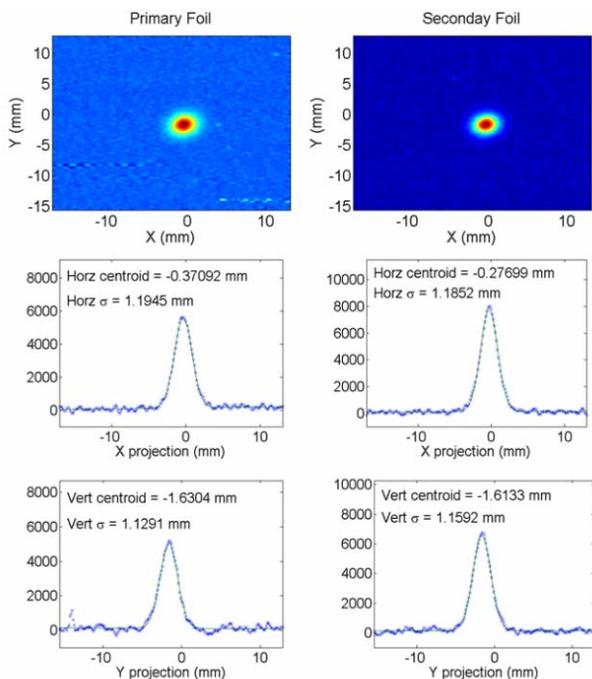


Figure 5: Comparison of OTR images taken with the primary and the secondary foils under similar beam conditions after ~70 days of primary foil operation.

CONCLUSION

We have successfully operated an OTR detector upstream of the NuMI target with over 6.5×10^{19} 120 GeV protons. The generated OTR images give a good measure of the NuMI beam shape and these values compare well to the present SEM monitor. Early indications are that the OTR Kapton foil has aged but still produces acceptable images for beam shape measurements.

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