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An Optical Transition Radiation Monitor for the T2K Proton Beam

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The neutrinos studied in the T2K long baseline neutrino experiment are generated by the decay of hadrons produced when a 31 GeV proton beam is incident on a graphite target. Shifts in the proton beam position and direction at the target will cause changes in the neutrino energy spectra seen by the T2K off-axis neutrino detectors, while a small shift in the beam position or width when operating at high beam power can cause damage to the target, hence the need for accurate measurements of the proton beam profile near the target. The Optical Transition Radiation (OTR) monitor measures the profile of the proton beam perpendicular to the beam direction by imaging transition radiation produced by the beam as it traverses a metallic foil located 30 cm upstream of the target. The OTR monitor provides fine grained 2D images of the beam, giving better than 1 mm accuracy for beam position and width measurements, while placing only optical and mechanical components in the high radiation environment near the T2K target. This talk will include an introduction to the theory of transition radiation, a discussion of the OTR monitor design and implementation, and results from the first year of operation.

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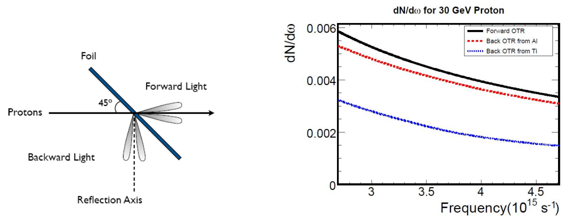

Figure 1: Left: Illustration of the transition radiation production at foil oriented 45° relative to the particle beam. Right: Spectrum of transition radiation production in the optical region.

1. The T2K Experiment

The T2K long baseline neutrino measurement has been described in detail elsewhere [1]. T2K uses an off-axis detector configuration in which it is important to precisely measure the properties of the proton beam before it collides with the target, in order to constrain the spectrum of produced neutrinos. When operating at full power (750 kW), the radiation dose 30 cm upstream of the target and 110 cm from the beam axis is $\sim$20 MGy/10^7 sec. An optical transistion radiation (OTR) monitor has been designed to monitor the proton beam in this high radiation environment.

2. Theory of OTR Detectors

Transition radiation is produced when charged particles pass between media with different dielectric constants. Fig. 1 illustrates the production of transition radiation the forward and backward directions, when a foil is placed at 45° relative to the incident particles. The differential production cross-section can be derived [2] and is found to peak at an angle of $\theta = 1/\gamma$ relative to the beam or reflection axis, corresponding to 1.7° for 31 GeV/c protons. Fig. 1 shows the spectrum of transition radiation in the optical region (OTR).

An image of a particle beam profile can be obtained by placing a thin metal foil in the particle beam and focusing and imaging the backwards produced OTR light. OTR detectors have been successfully employed previously for various applications, including proton beam monitoring in the NUMI beamline at Fermilab [3].

3. Design and Operation of the T2K OTR Monitor

Central to the T2K OTR montitor design, is a system of parabolic mirrors that transport OTR light through shielding to the camera to minimize the radiation dose seen by the camera, as shown in Fig 2(a). Target foils are installed 30 cm upstream of the target on an 8 position target wheel that is connected by a flexible shaft to a motor installed above the shielding. The installed targets include: 1 aluminum, 4 50 μm thick titanium alloy, 1 cermamic, a calibration foil, and a blank position. The ceramic and aluminum targets are used at intensities of $< 1\%$ and $1-5\%$ of the design intensity respectively, while the titanium foils are used at higher intensities. The response of the titanium foils to thermal stresses was simulated using ANSYS and found to be acceptable for beam powers up to 750 kW.

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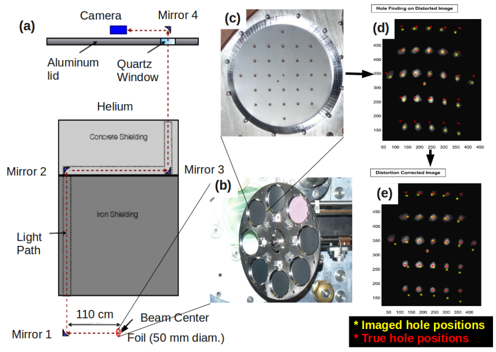

Figure 2: (a) Diagram of the OTR monitor optical system, where the beam direction is into the page. (b) Image of the OTR target wheel, including the installed targets. (c) Image of the calibration foil. (d) Backlit image of the calibration foil take by camera at the far end of the optical system. (e) Backlit image of the calibration foil after correction for the optical system distortions.

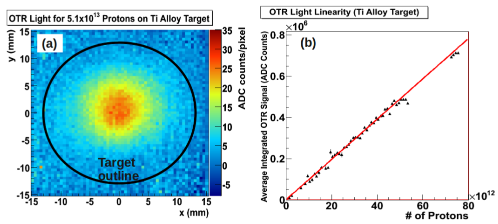

Figure 3: (a) Representative image of OTR light from a single beam pulse. (b) Linearity of OTR light production on the titanium foil as a function of protons per beam pulse.

The calibration foil contains an array of 30 machined holes and is aligned to the beam axis. Laser or filament light sources are used to backlight the foil, and the light seen through the calibration holes is imaged by the camera. A distortion map constructed using the imaged and true hole positions is used to correct the image, as illustrated in Fig 2(c-e).

The T2K OTR monitor has operated at beam intensities of up to 8×10^{13} protons per pulse. Fig. 3(a) shows an example OTR image for a single spill incident on a titanium foil. The OTR monitor is found to measure the beam position and width with $\sim 100\ \mu$m resolution. Fig. 3(b) shows the linearity of the the OTR light production on the titanium foil with protons per pulse. The number of photons seen agrees within 10% with expectation. OTR light production from the aluminum foils is ~ 2.5 times that seen from titanium, as is expected due to the higher reflectivity of the aluminum.

References

[1] R. Terri [T2K Collaboration], Nucl. Phys. Proc. Suppl. **189**, 277 (2009).

[2] Ter-Mikaelian, M. L., "High-energy Electromagnetic Processes in Condensed Media", John Wiley and Sons (1972)

[3] V. E. Scarpine, G. R. Tassotto and A. H. Lumpkin, FERMILAB-CONF-07-301-AD

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