An Optical Transition Radiation Monitor for the T2K Proton Beam Line

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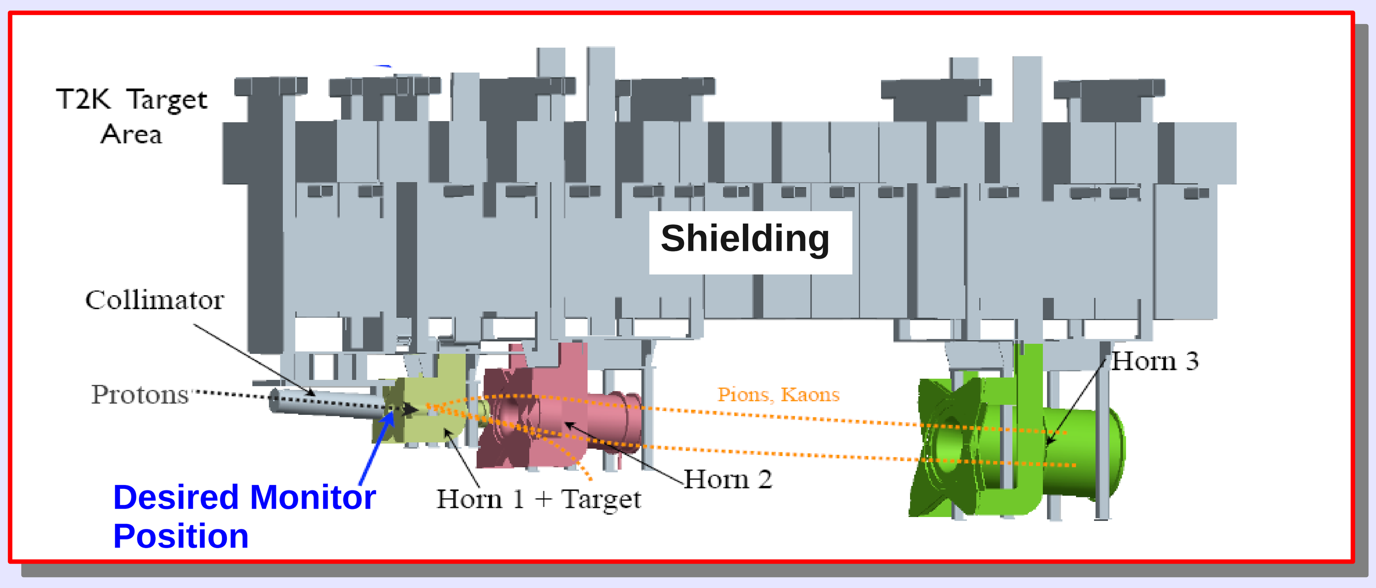
Motivation

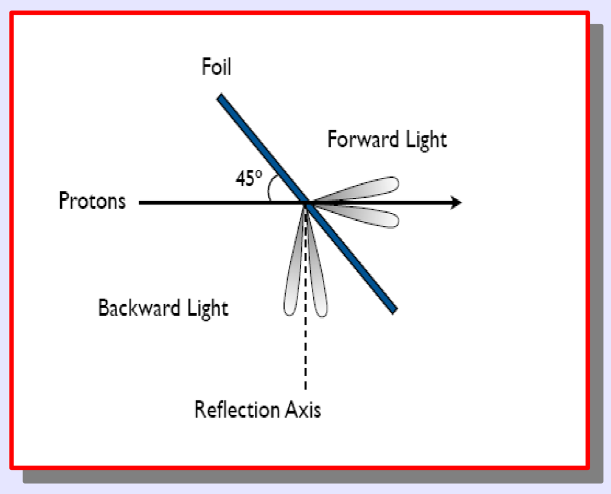
- T2K neutrino beam is created when 30 GeV/c protons collide with a graphite target producing pions and kaons that decay to neutrinos
- It is necessary to measure the proton beam profile with a beam monitor immediately before the beam hits the target
- This region is a high radiation environment, so we should avoid electrical and electronic components near the target

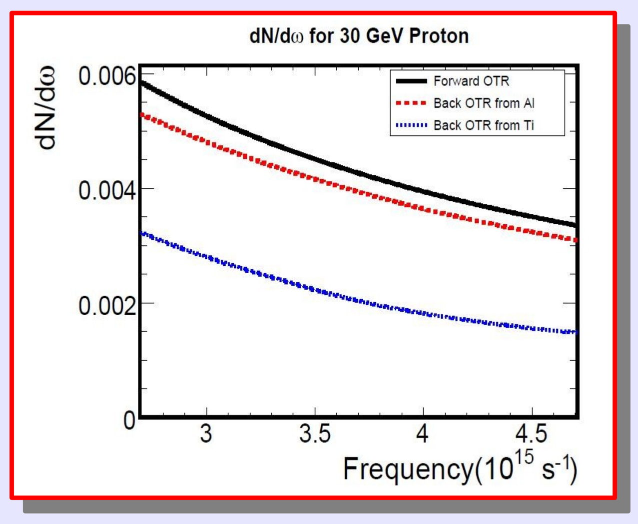
- The monitor should measure the beam position with 1 mm accuracy to meet physics goals
- Real time monitoring to make beam abort decisions based on beam profile at target (target safety)



Optical Transition Radiation

- Transition radiation is produced when charged particles move between materials with different dielectric constants
- Electric field changes and difference is released as radiation
- Radiation is produced in the forward and backward (reflected) directions
  - Amount of backwards light depends on the reflectivity of the material
  - Backwards light is used for this monitor
- Spectrum is broad with more light at longer wavelength
- Angular distribution of light peaks at 1/γ
- Can monitor a beam by placing a thin metal foil in the beam and imaging the OTR light

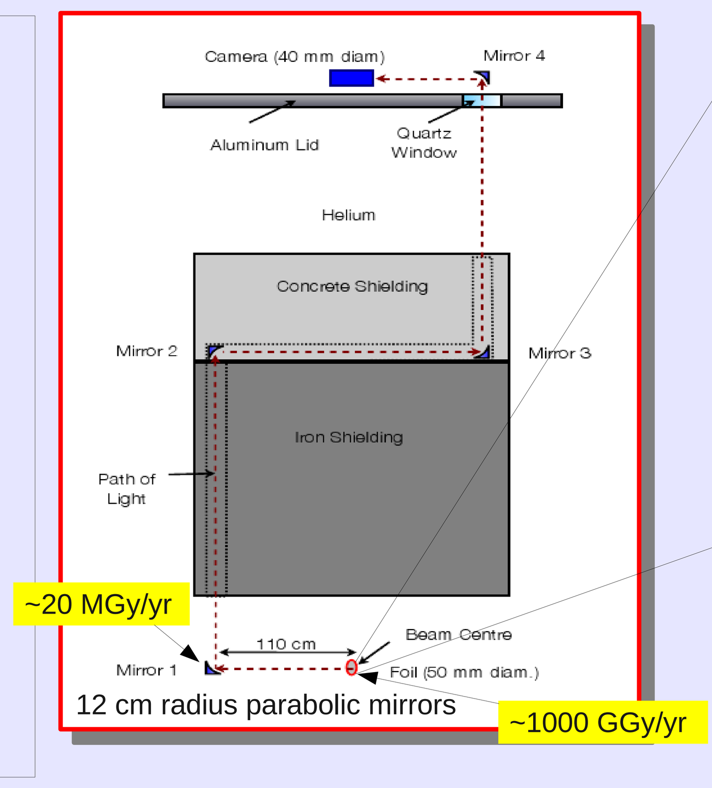




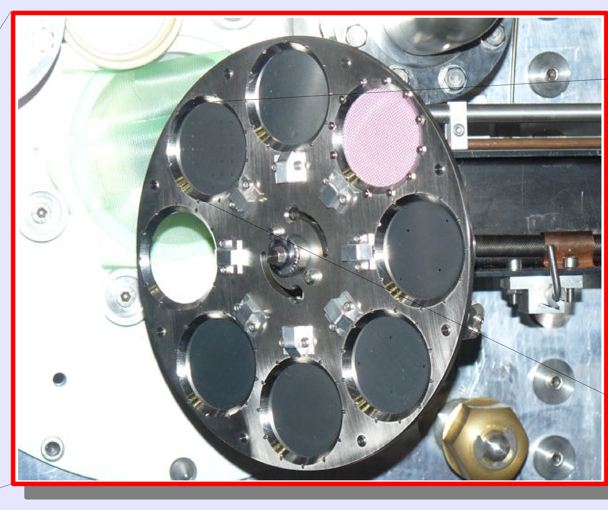
Design and Installation

Top Level System Design

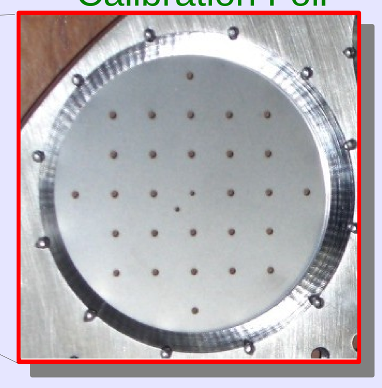
- The OTR target foil is installed 30 cm upstream of the T2K target, at a 45° angle to the beam direction
- To minimize radiation damage, a rad. hard CID camera is installed above the shielding
  - DAQ system synchronizes camera to beam arrival and reads out images
- A system of 4 parabolic mirrors and optical tubes transports the light through the shielding with ~10% efficiency



Target Wheel Design



Calibration Foil

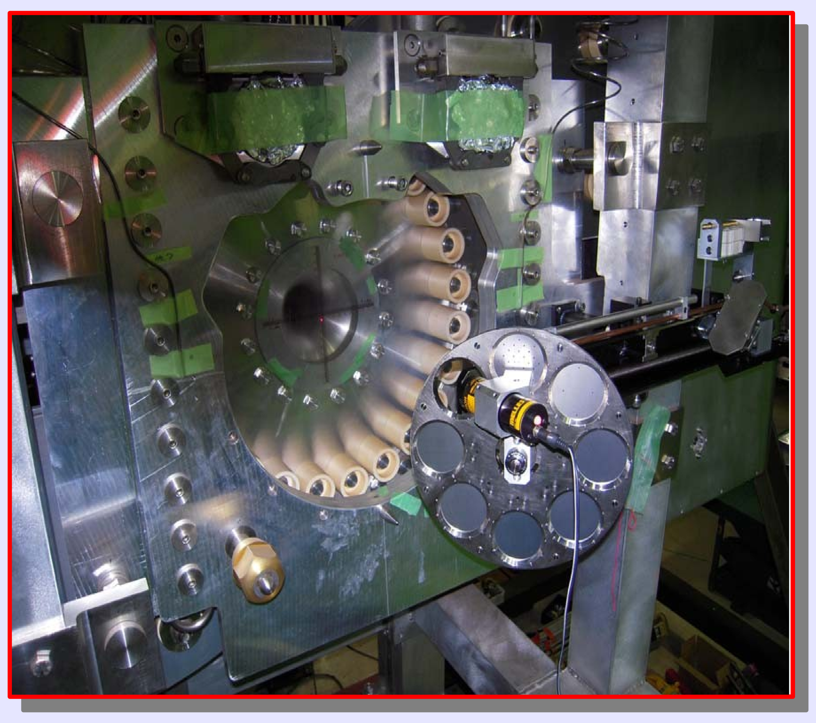


- 8 OTR target configurations are selectable using the target wheel
- Wheel can be rotated by a motor installed above the shielding and connected by a flexible shaft
- Targets include Ti alloy, Al alloy, a calibration foil, a ceramic plate for fluorescent light, and no target

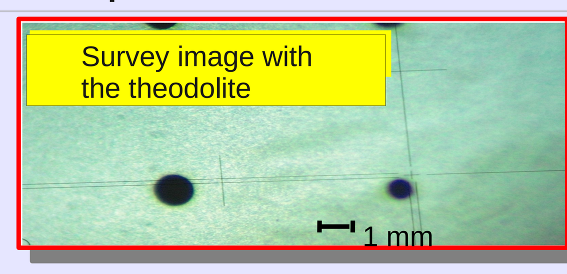
Target Foil Material Selection

- The target foils should withstand the stress of up to 5×10^{13} 30 GeV/c protons/mm^2 for a single beam spill
- Have a large enough reflectivity to produce sufficient OTR light
- 50 μm thick titanium (Va, Cr, Sn, Al) alloy foils are chosen after ANSYS simulation confirming the material can withstand the stress
  - Only ~3 KeV energy loss for average proton crossing foil
- An aluminium alloy foil is also installed, which has higher reflectivity to produce more light at lower intensities

Alignment



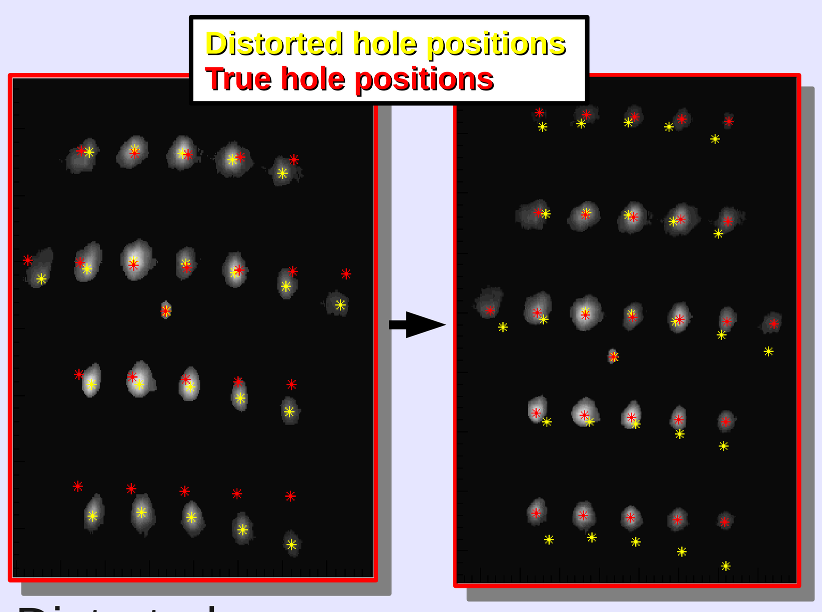
- The OTR target wheel was aligned to the center axis of first magnetic horn
- The positions of the calibration foil holes relative to the horn axis were measured using a theodolite with 0.3 mm accuracy
- Regular imaging of the calibration foil shows that the position is stable



Calibration and Performance

Image Distortion

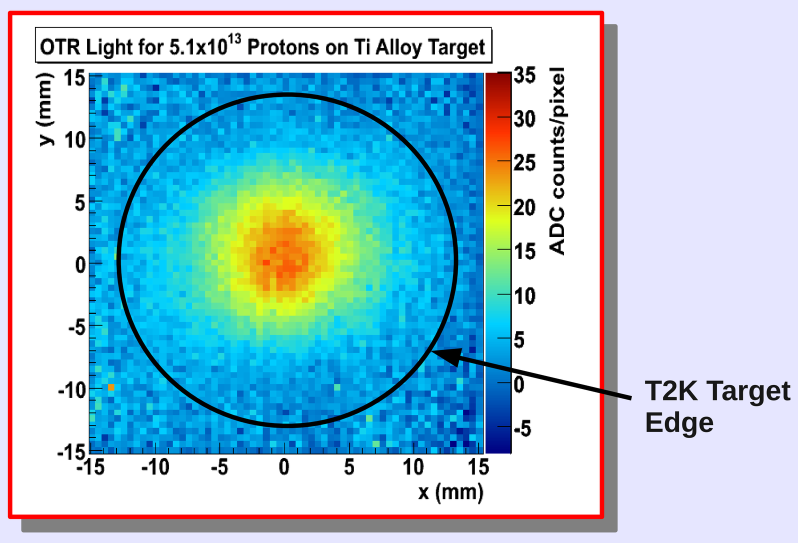
- Optical system introduces distortions to images
- Backlit images of the calibration foil show the distortion of 30 hole positions
- Distorted hole positions are found
- Map to pre-distortion positions is created
- Mapping is used to correct images
- Distortion is measured bi-monthly and is stable



Distorted calibration foil image

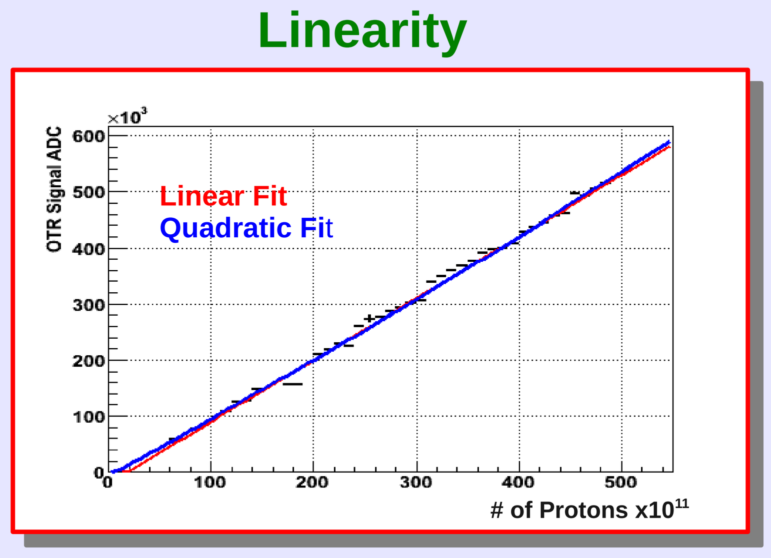
Calibration image after correction

Reconstructed 2D Beam Profile



We reconstruct the 2D beam profile from the image of OTR light created by 5×10^{13} protons on the Ti alloy foil

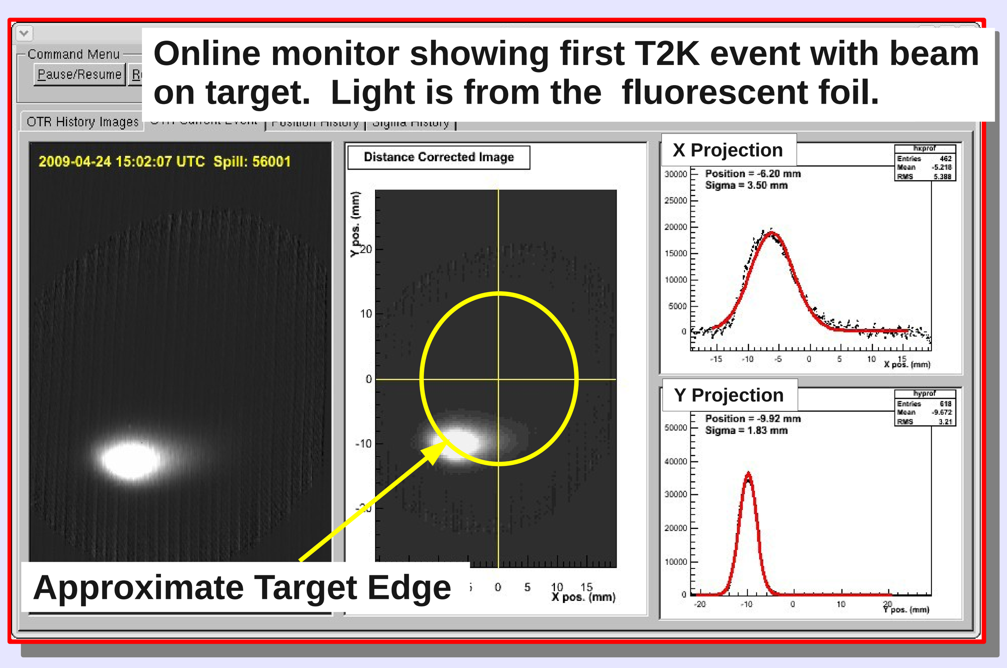
Linearity



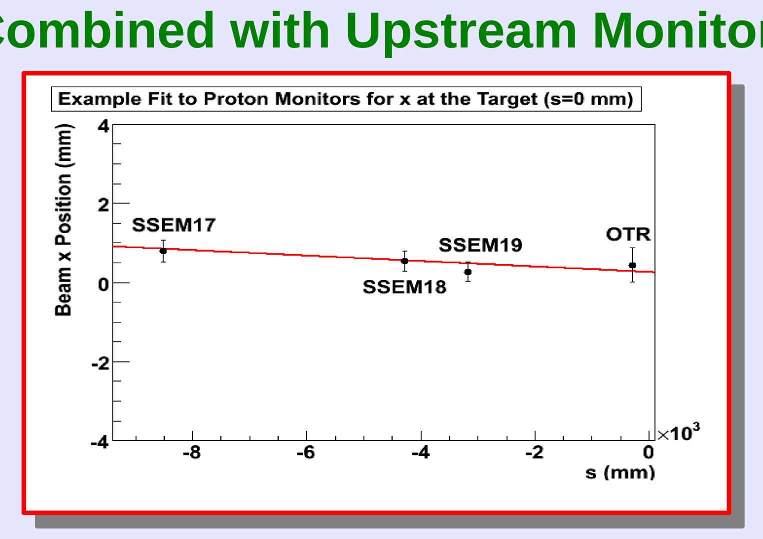
The total OTR light (integrated ADC counts) is linear with the number of protons traversing the foil, as expected.

Online Monitoring

- OTR images are monitored in real time
- OTR monitor measurements are used while tuning beam orbit to the target center
- Beam position and width monitoring can be used to make beam abort decisions

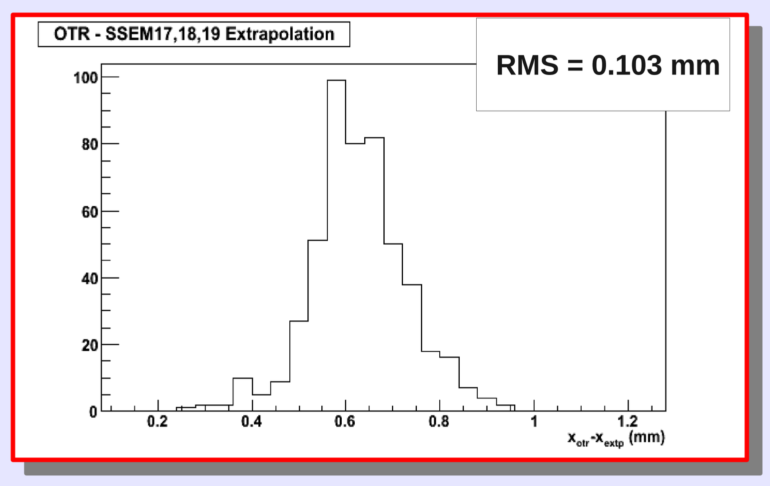


Combined with Upstream Monitors



Fits to the OTR measurements as well as upstream secondary emission monitors give the beam position and angle at the target.

Position Resolution



The difference between the OTR measurement and a fit to upstream monitors gives a measurement of the combined resolution: 100 μm or bettter for the position measured by OTR.

Conclusion: The OTR monitor for the T2K beam line was designed with the goal of measuring the proton beam position near the T2K target with better than 1 mm resolution. It has achieved this goal using a novel optical system design that should allow the monitor to survive in the high radiation environment near the T2K target.