The T2K Optical Transition Radiation Monitor

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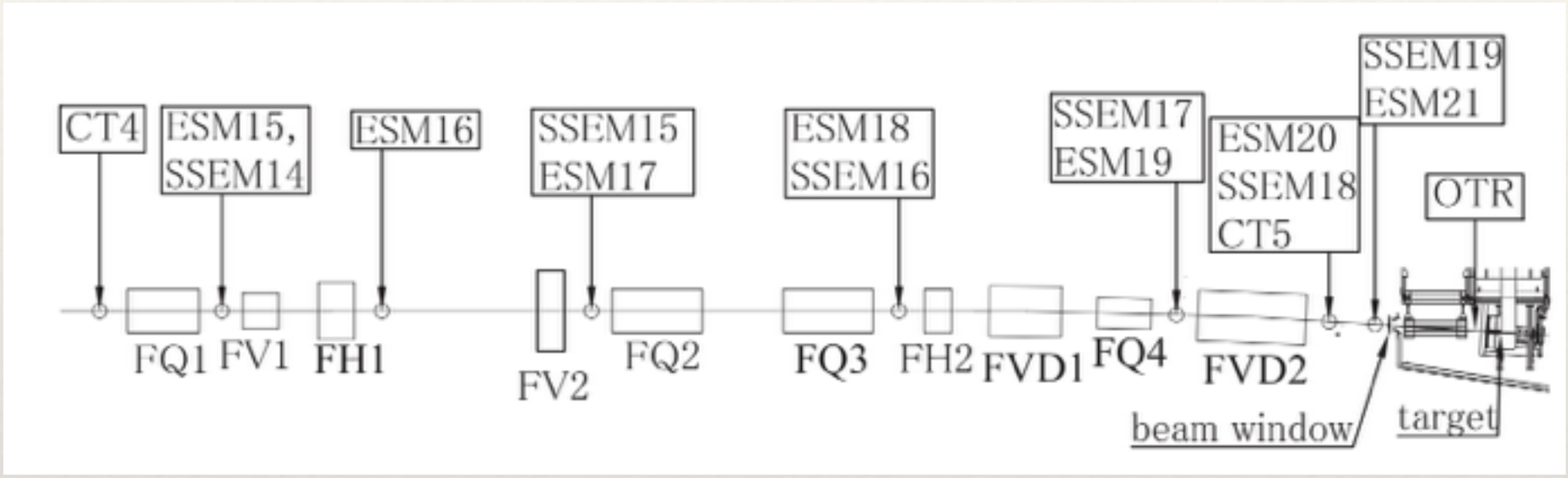
Outline

- Introduction and motivation for the OTR monitor
- Description of the T2K OTR monitor
- History of the T2K OTR monitor systems
- Operational experience with the first OTR monitor
- Construction and installation of the new OTR monitor
- Operation of the new OTR monitor
- Ongoing studies and plans to improve the monitor

Motivation for the OTR Monitor (1)

- Proton beam profile monitors are critical for the operation of neutrino beam lines
  - Beam position and emittance measurements are physics inputs and ensure safe operation of the beam on target



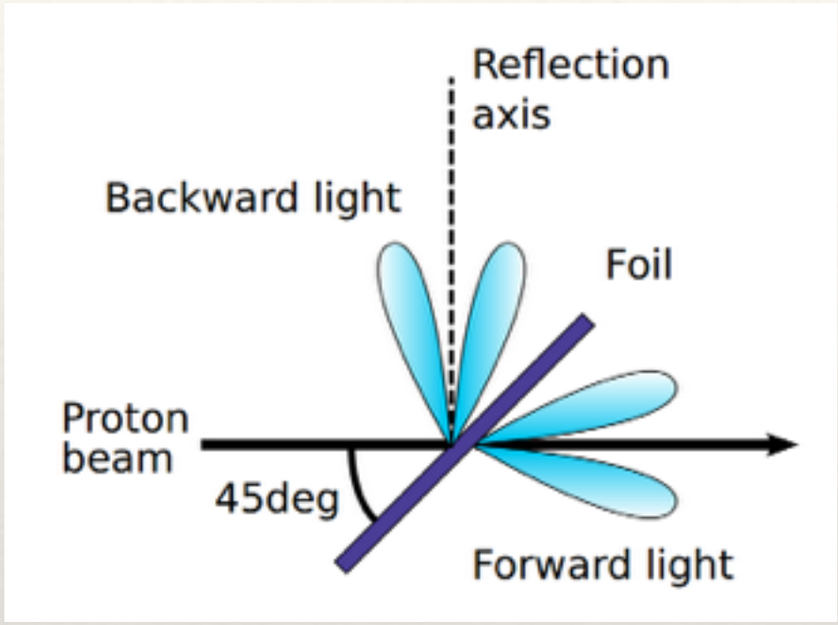
- In the T2K beam line, there are two pairs of secondary emission (SSEM) and electrostatic (ESM) monitors after the last vertical dipole magnet
  - The lever arm to the target is long, so we want a beam position measurement near the target to reduce the uncertainty on the beam position at the target

Motivation for the OTR Monitor (2)

- The SSEM monitors make beam profile measurements that can be used to extrapolate the beam width to the target
  - Important to know the targeting efficiency
  - Ensure the target safety from a too narrow beam
- During continuous beam operation, we have to remove all but the most downstream SSEM to minimize irradiation of surrounding beam line equipment
  - If we can have a beam monitor in the secondary beam line (inside the target hall), then there is no concern about irradiation of primary beam line elements
  - There is space between the collimator and target for a monitor, but the radiation environment is very high - 5.4e8 Sv/hr
  - An optical transition radiation monitor was developed for operation here

Optical Transition Radiation Monitor

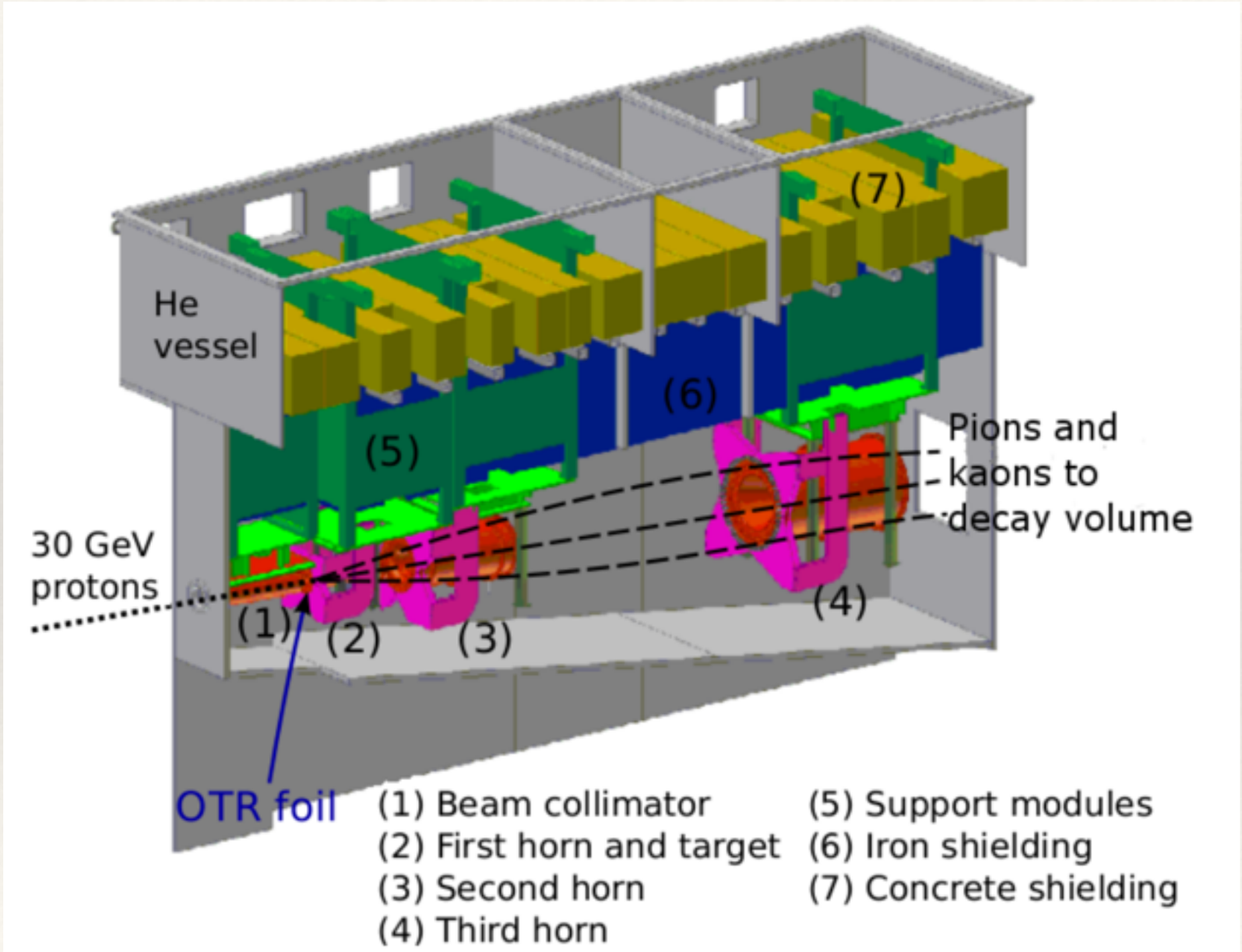
- Optical transition radiation (OTR) monitors have been used in a number of beam lines
- A foil is place in the beam and forward and backward transition radiation is produced



- The amount of light is proportional to the number of protons crossing the boundary
- By focusing and imaging the light, we can get a 2-D image of the beam profile in the transverse plane
- No electrical components need to be placed near the beam if the optical system can transport the light to a lower radiation environment

The T2K OTR Monitor (1)

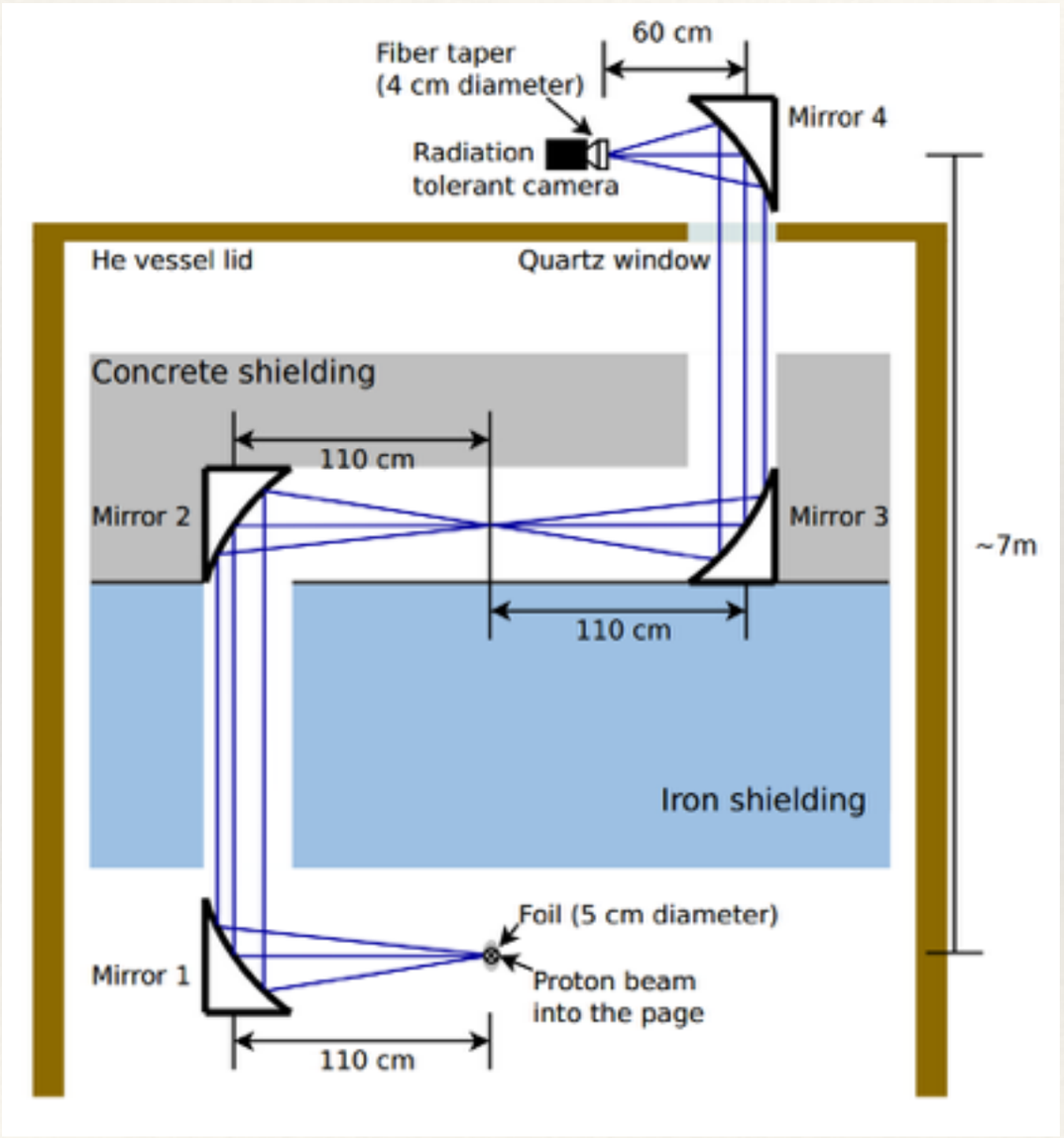
- The T2K OTR monitor (developed by York U., U. of Toronto and TRIUMF) places a foil 30 cm upstream of the T2K target and 60 cm downstream of the collimator



Monitor details described in **NIM A703, (2013), 45–58**

The T2K OTR Monitor (2)

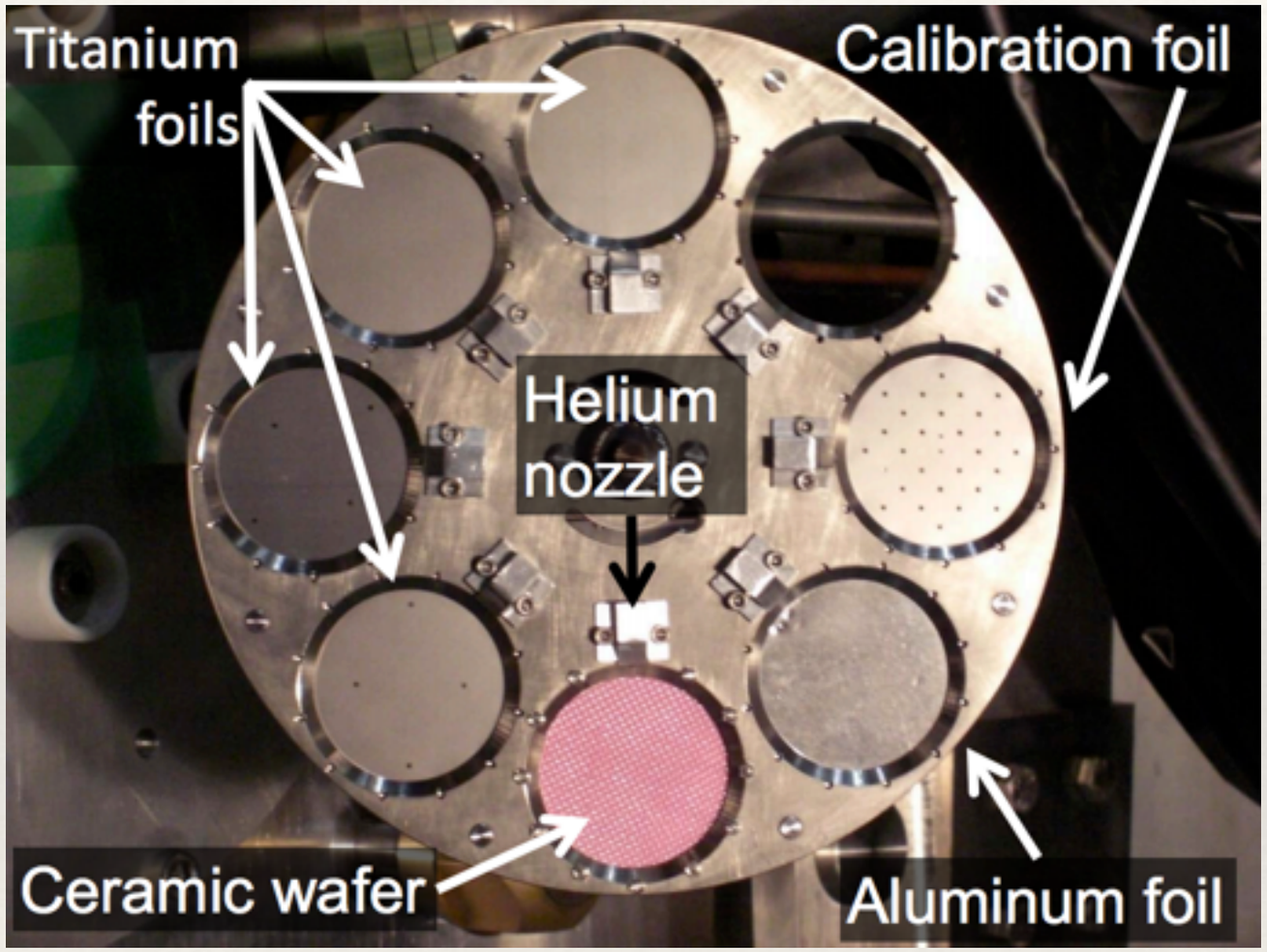
- The foil is 45° to the beam, so the backward light is produce perpendicular to the beam



- The first parabolic mirror is 110 cm from the foil, where the radiation level is 0.8e4 Sv/hr
- Two more parabolic mirrors transport the light through the shielding
- There is a quartz window in the helium vessel lid for transport of the light
- A fourth mirror focusses the image on a radiation hard camera+fiber taper

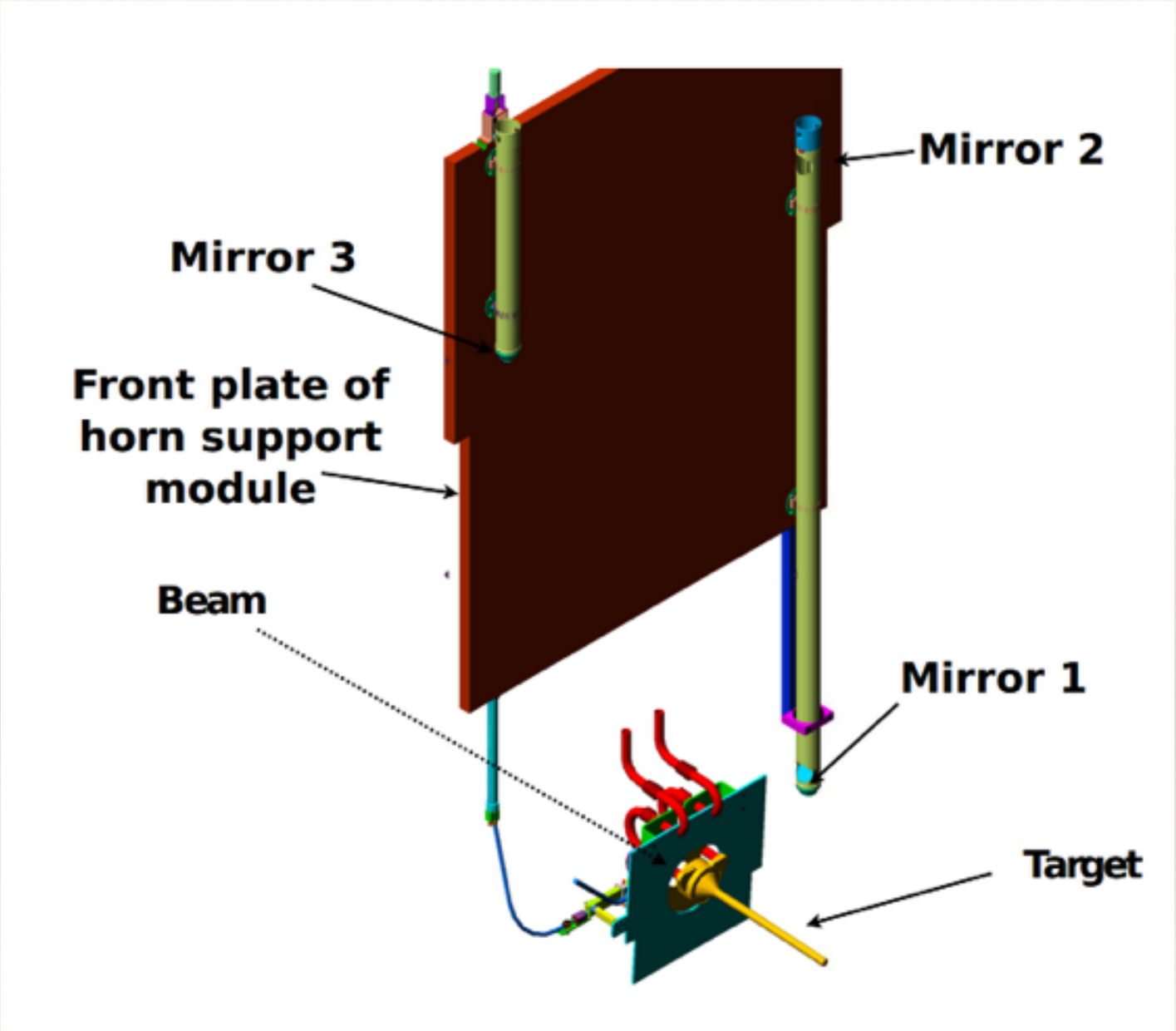
Target Foils

- There is a need to have multiple foils that can be place in the beam or used for calibration



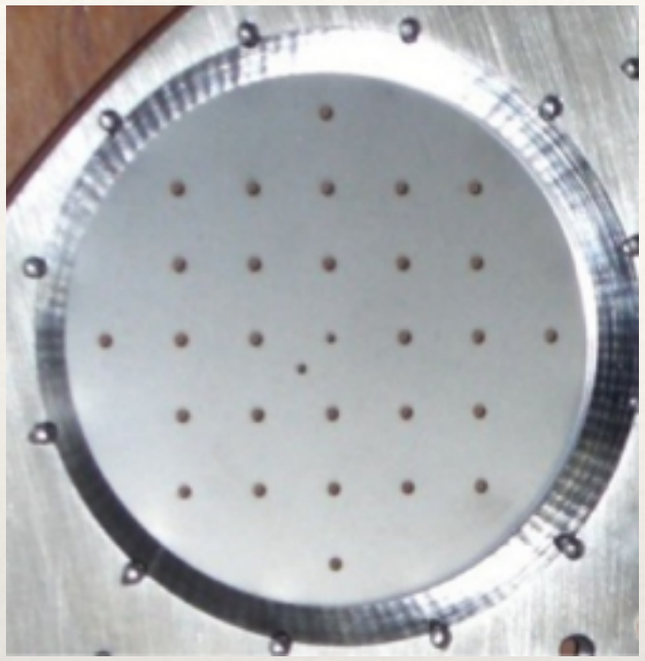
- 4 Titanium alloy (15V-3Cr-3Sn-3Al) foils used for regular beam operation
- One Al foil with higher reflectivity produces ~2.5 times the OTR light
- A ceramic wafer produces fluorescent light - used alt low beam intensity
- A calibration foil has a surveyed precision machined hole pattern used to set the absolute position and distance scales

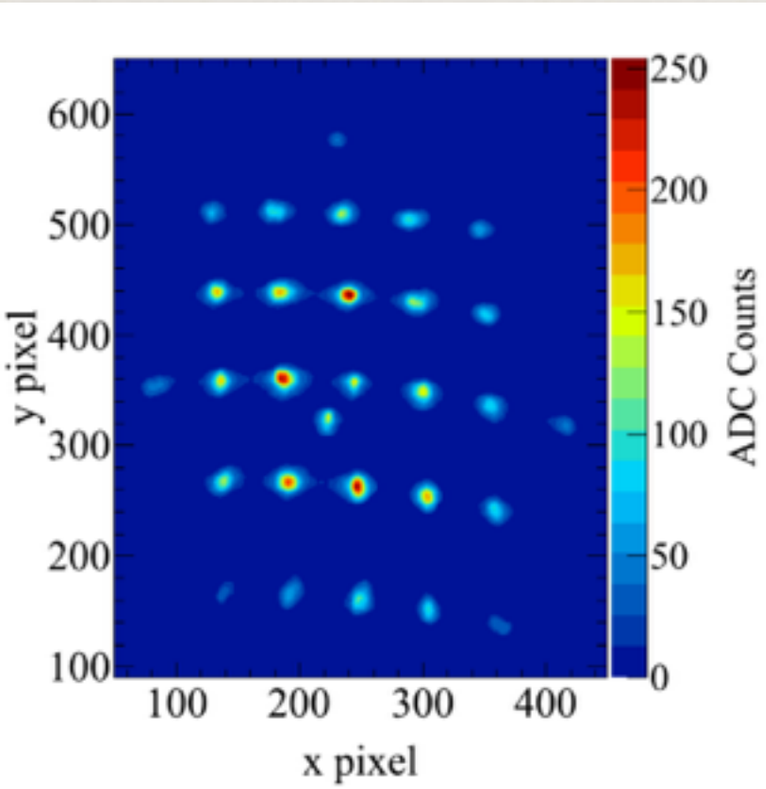
Rotating the Target Foil



- A stepping motor is located above the shielding in the helium vessel
- There is a long rigid shaft through the front plate of the horn support module
- A flexible shaft couples the rigid shaft to the foil disk
- A plunger engages when the foils are in position and a microswitch is activated

Calibration Method





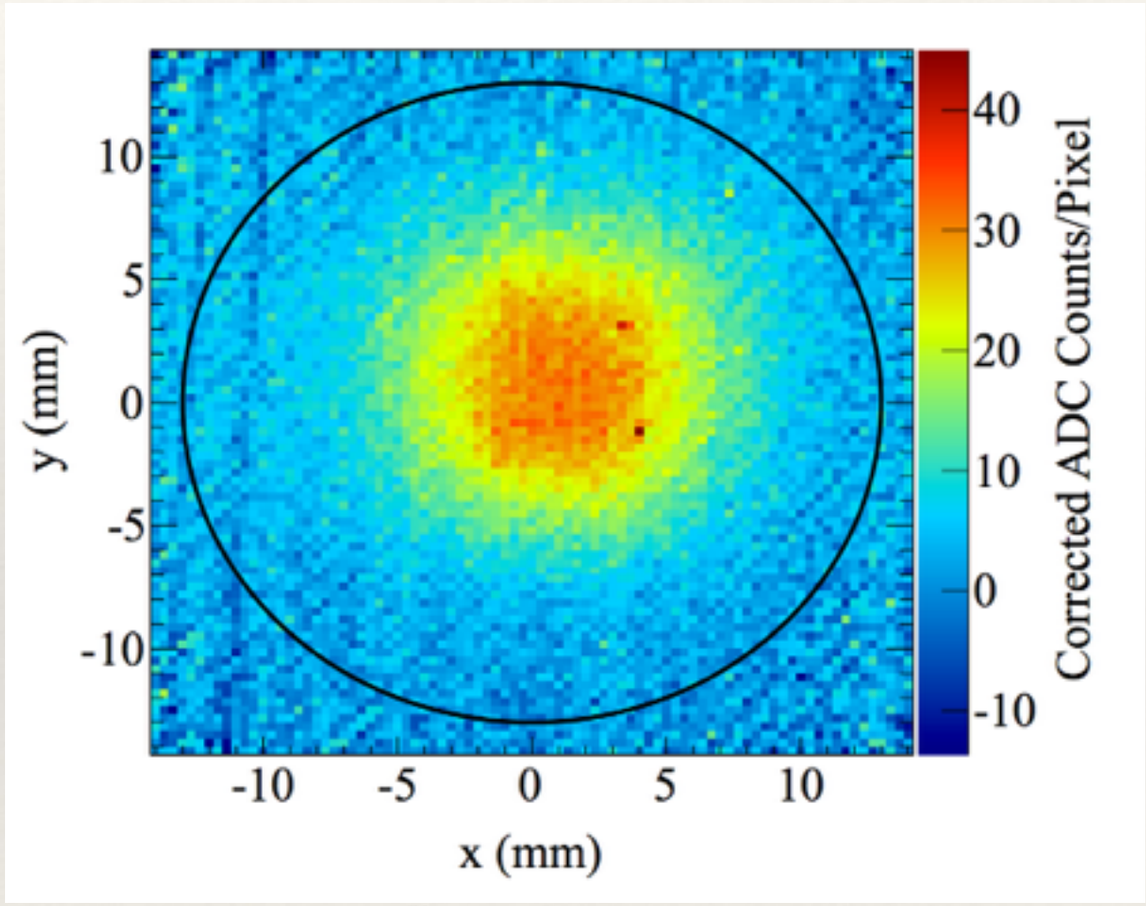
- Before installation of horn 1, the calibration foil hole position is surveyed relative to the horn axis
- Filament and laser light back-light the calibration foil and images are taken of the light propagated through the optical system
- The imaged hole positions are used to correct the image to the absolute position and distance scale at the foil while correcting for the distortion induced by the optical system

History of T2K OTR Monitors

- 2008-2009: The OTR I system was built and installed in the T2K secondary beam line. At the same time, a spare OTR II system was made.
- 2009-2013: The OTR I system operated in the T2K beam.
- 2013-2014: T2K horns are replaced. The OTR II system was installed on the new horn 1. A new spare OTR III system was built.
- 2014: First operation of the OTR II system in the beam without problems.

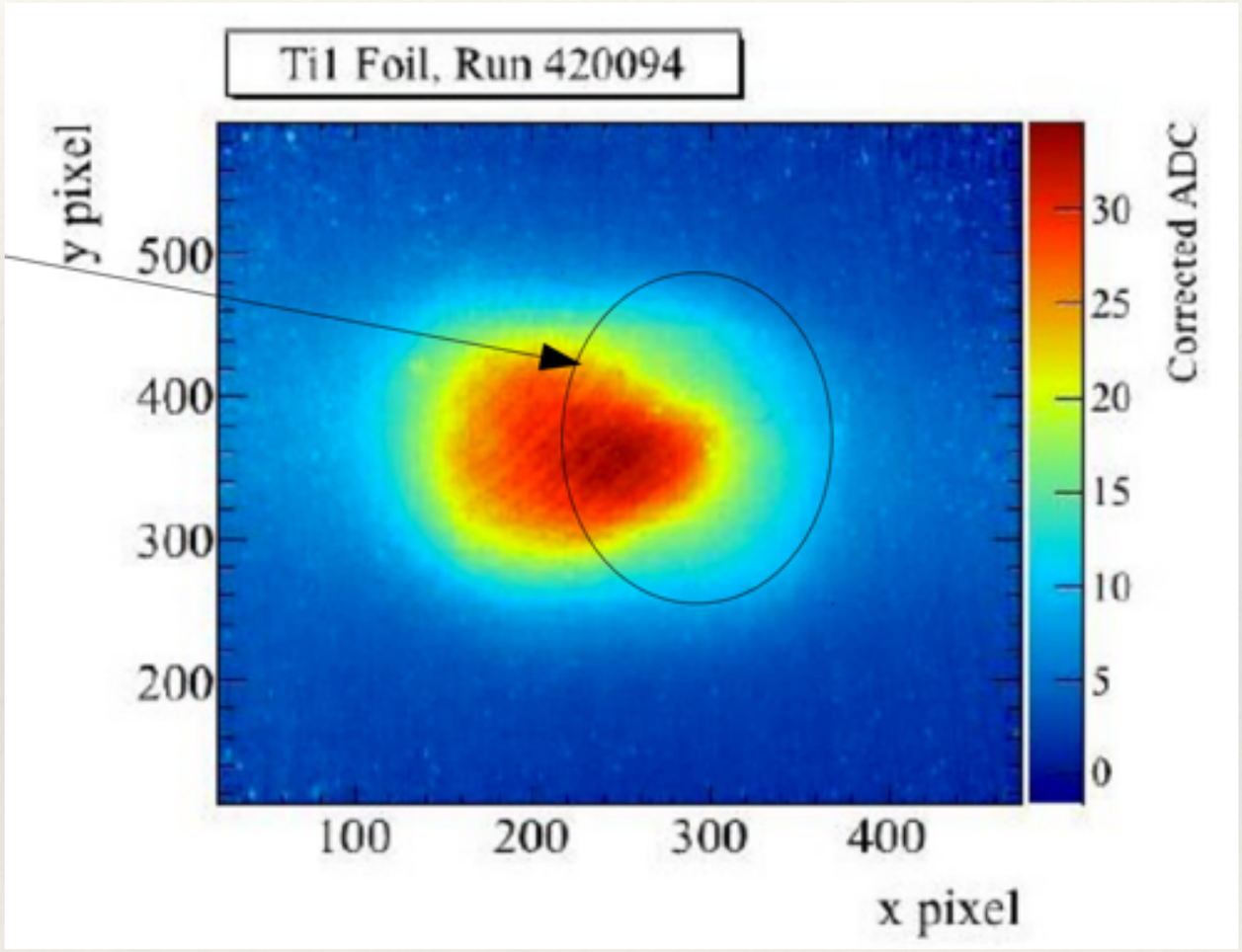
OTR I Operation

- The OTR I system operated stably for 6.6e20 protons on target using two of the Ti foils for most of the data
- Provided a stable measurement of the beam position at the target with ~0.5 mm accuracy for each spill
- Some discrepancies with the upstream SSEM monitors for the beam width measurement (4 mm RMS vs. 5 mm RMS) still to be resolved



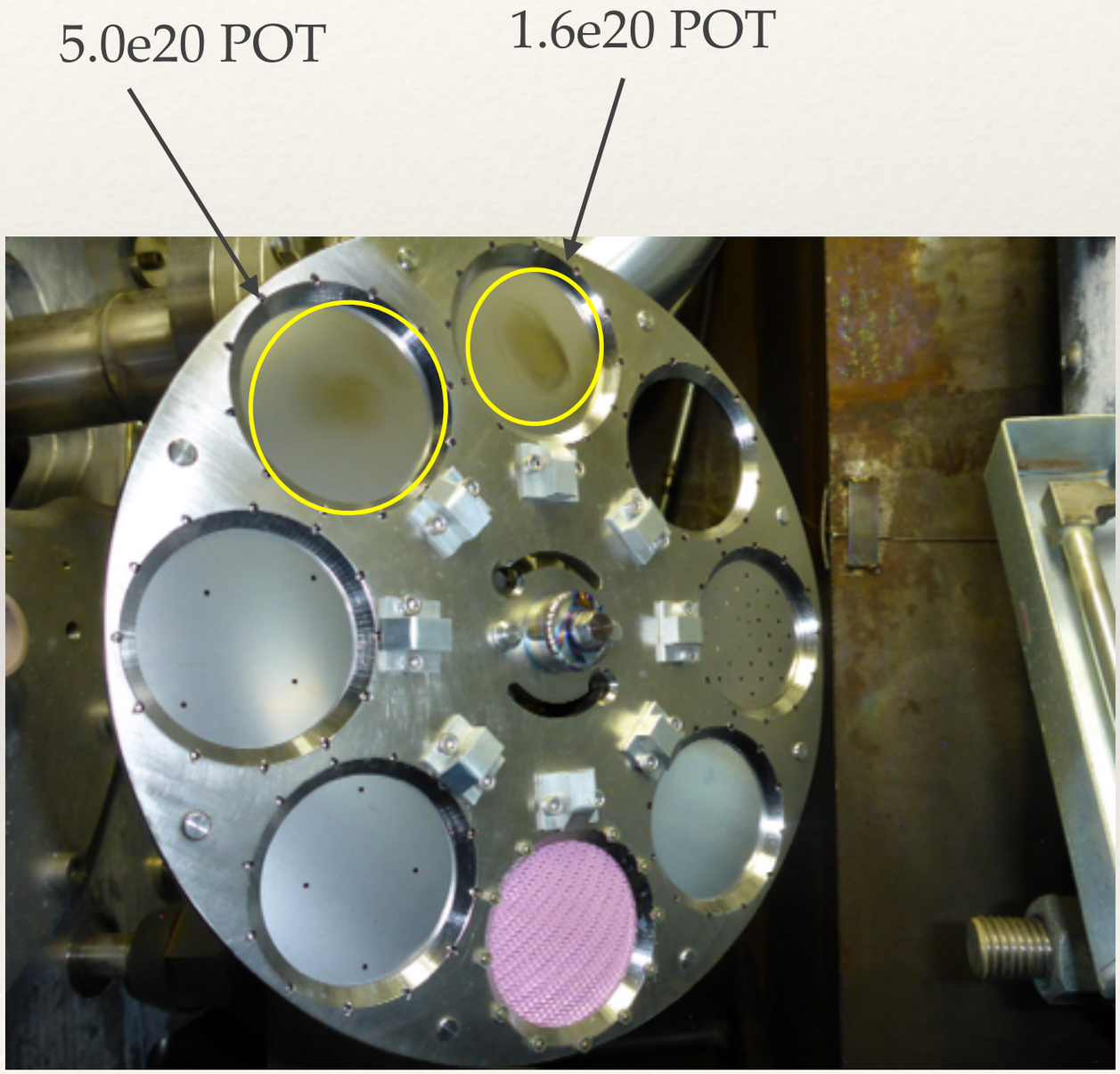
Stability of Operation

- Eventually in 2012, we saw some degradation of the light and distortion of the imaged OTR profiles
- We hypothesized that this could be due to radiation damage of the foil
  - It was not observed on the foils that are regularly in the beam
  - With the removal of the first horn we could look at these foils



OTR Foils After Beam Exposure

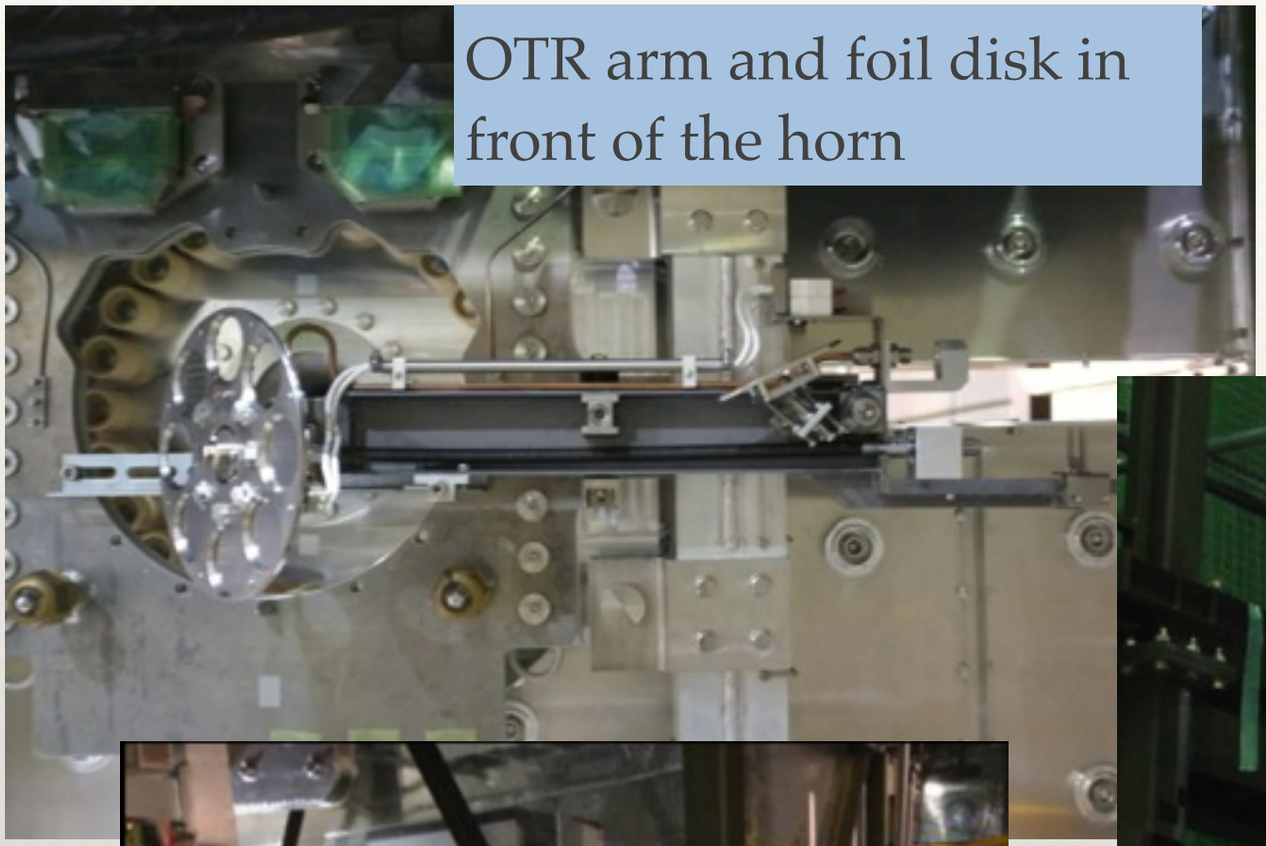
- Darkening of the foil is where the beam is impinging is observed
- Appears to be worse for the foil that was in the beam for less POT
  - This foil was being used when there was a small air leak in the helium vessel
- Thanks to Tada-san, the OTR disk was removed and stored, so the foils can be tested
  - https://www.youtube.com/watch?v=8tbY-WcBkAw



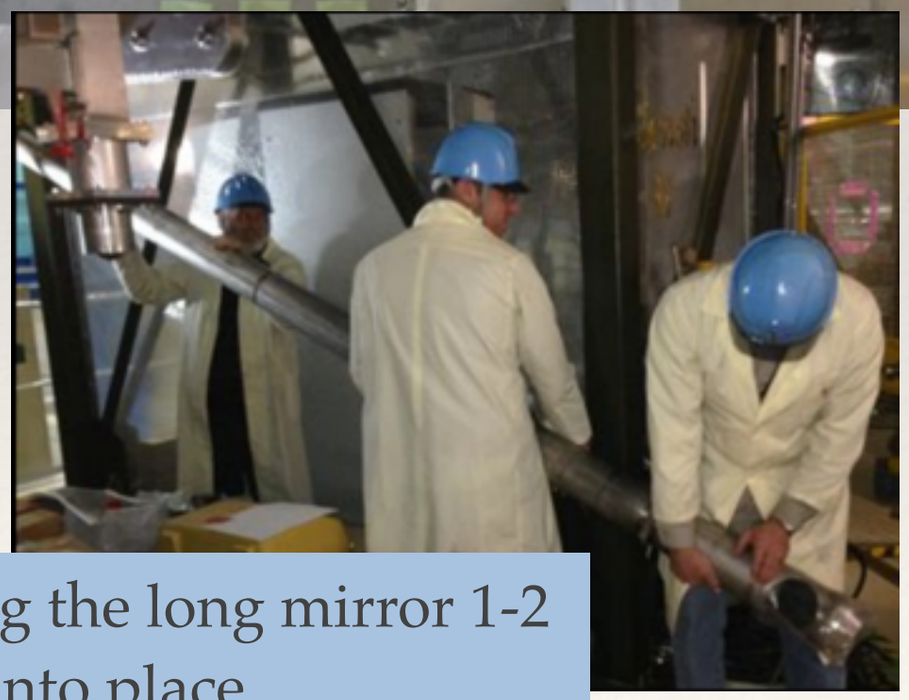
OTR II(III) Construction & Installation

- The OTR II(III) system is almost unchanged from the OTR I system
  - Change to the installed foils:
  - No Al foil installed this time
  - Installed a foil with a cross hole configuration for an in-beam calibration
- Most time-consuming part of the construction was the alignment alignment of the mirrors over the ~10 m long optical system

Pictures from the OTR II/III Work



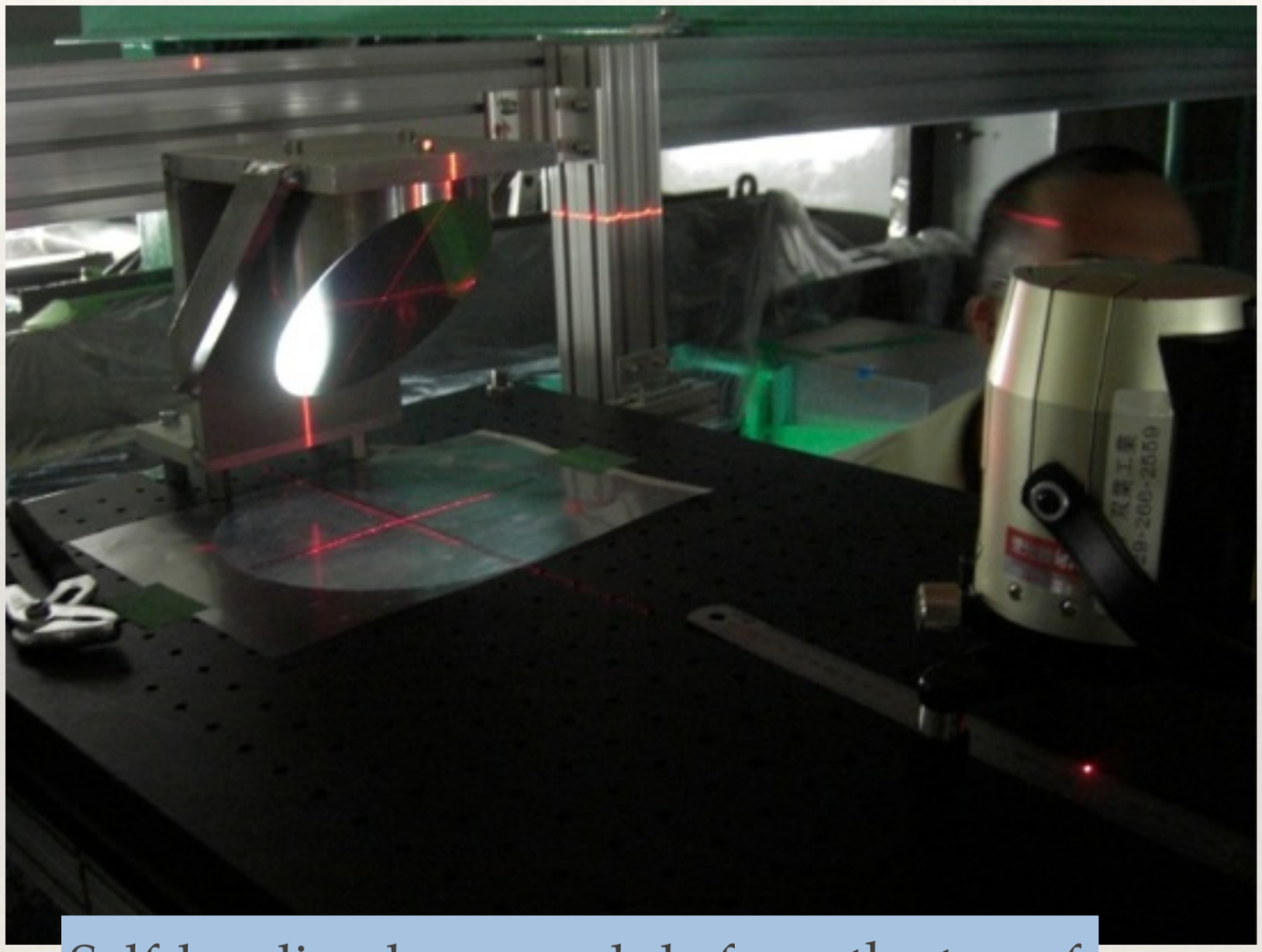
OTR arm and foil disk in front of the horn



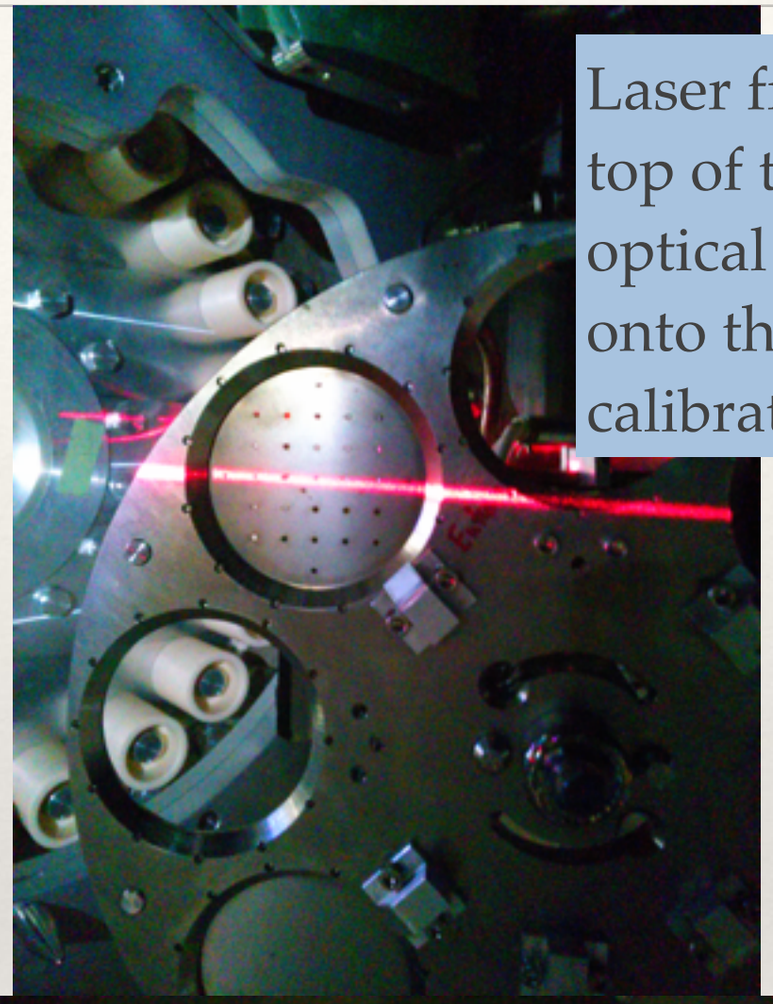
Lifting the long mirror 1-2 tube into place

Theodolite used to survey the calibration foil position

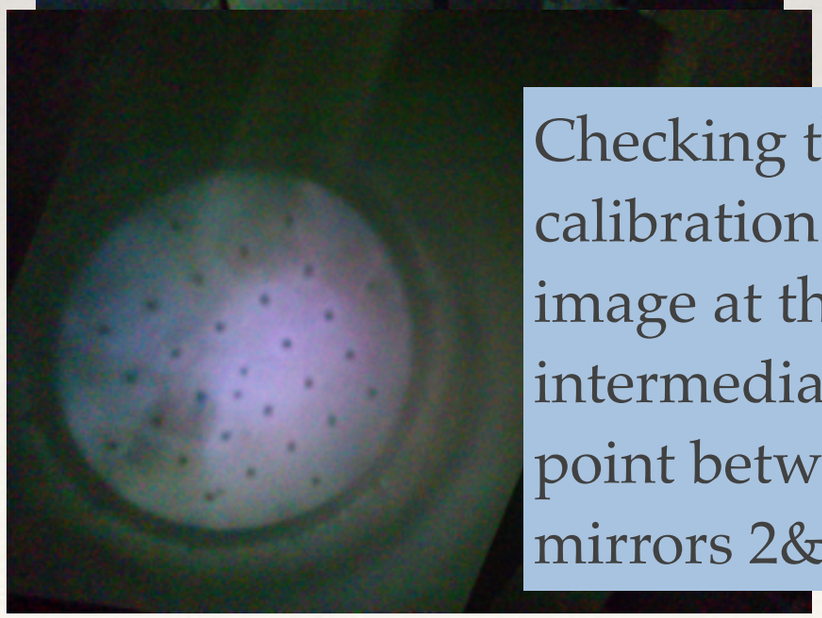
Pictures from the OTR II/III Work



Self-leveling laser module from the top of the optical system



Laser from the top of the optical system onto the calibration foil

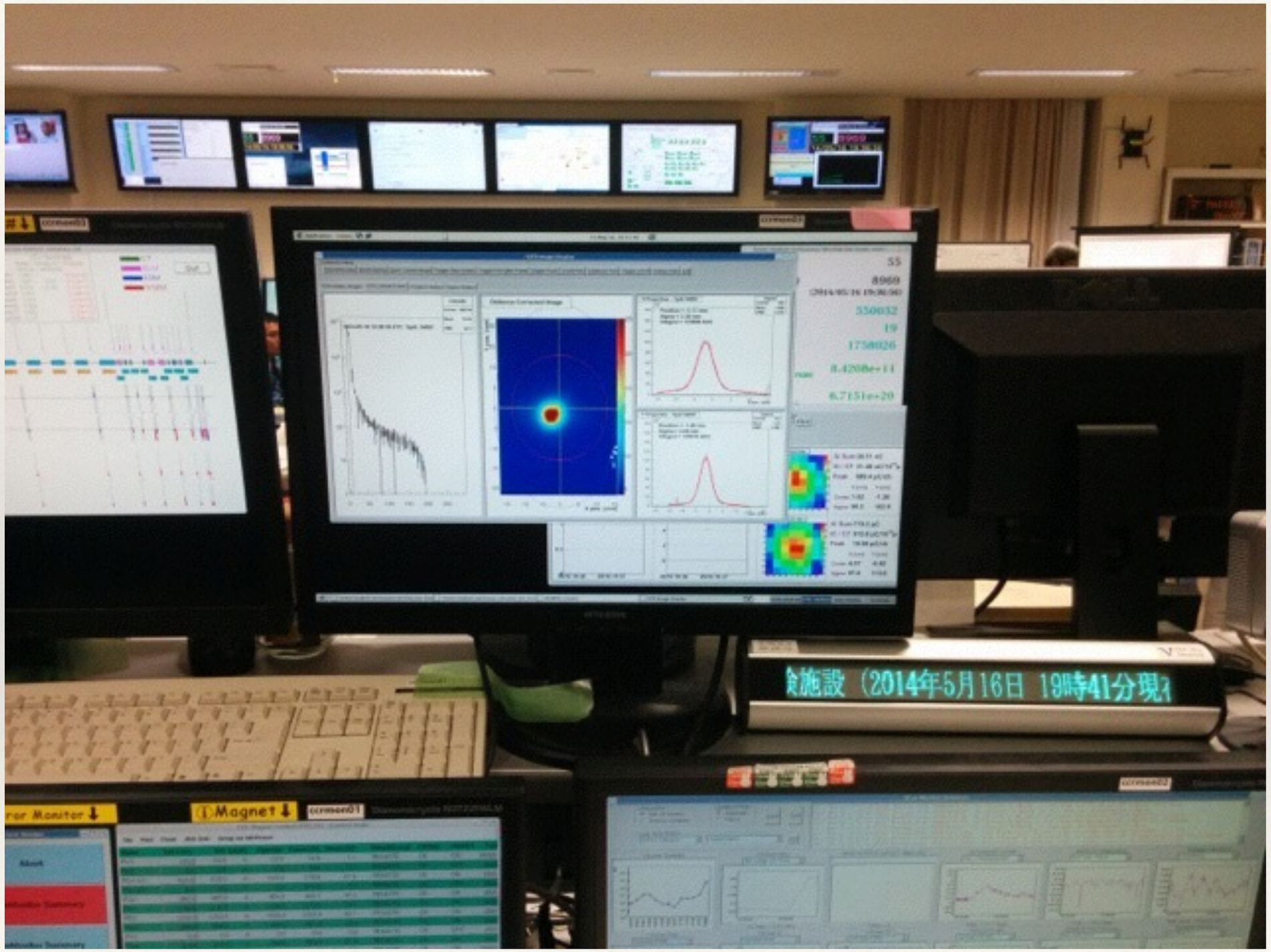


Checking the calibration foil image at the intermediate focal point between mirrors 2&3

First Beam after Restart This May

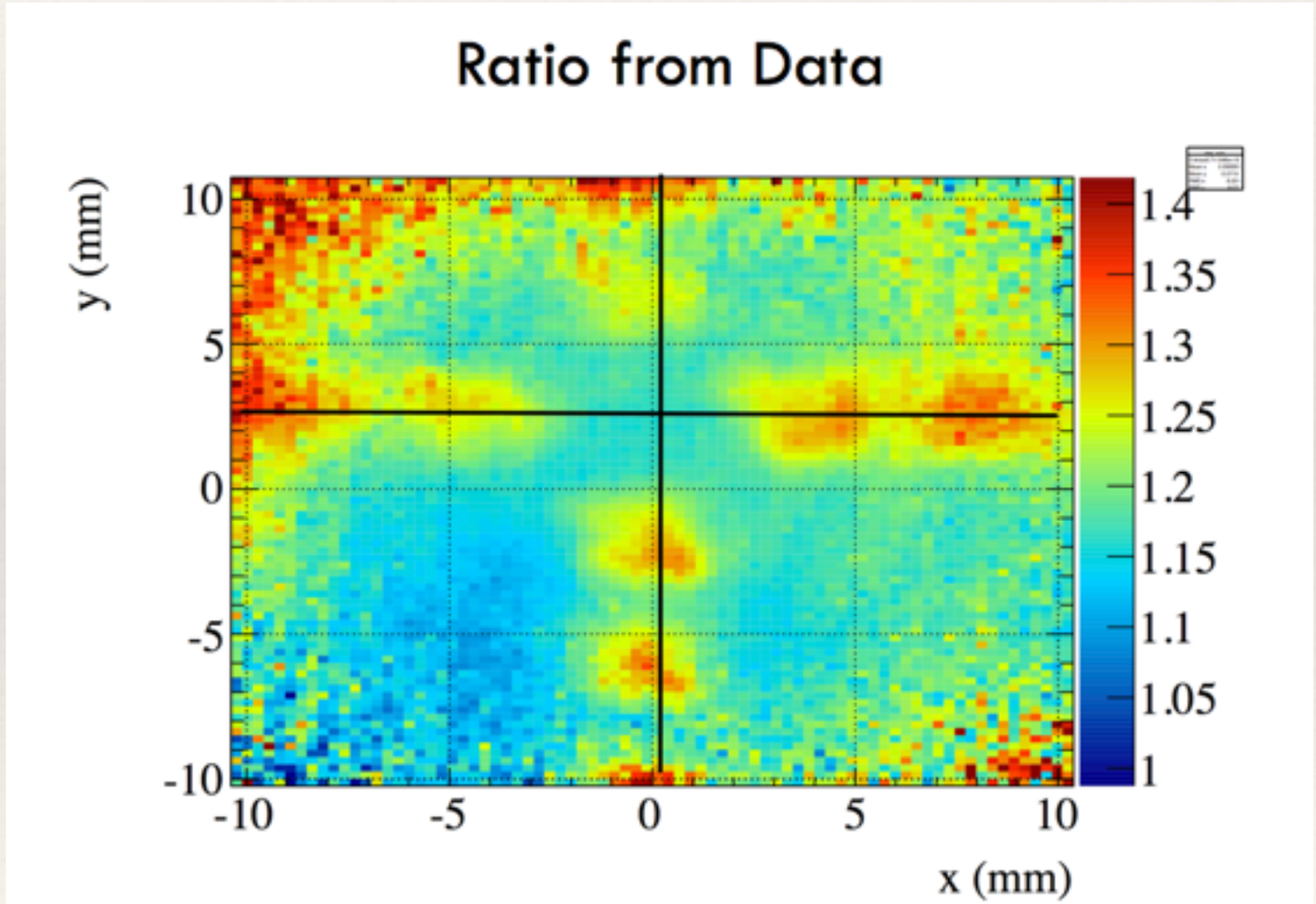
With the ceramic foil (fluorescent light), we observed the first beam on target after the restart this May

The OTR monitor played a critical role in the beam tuning and study of the beamline operation with the new horns.



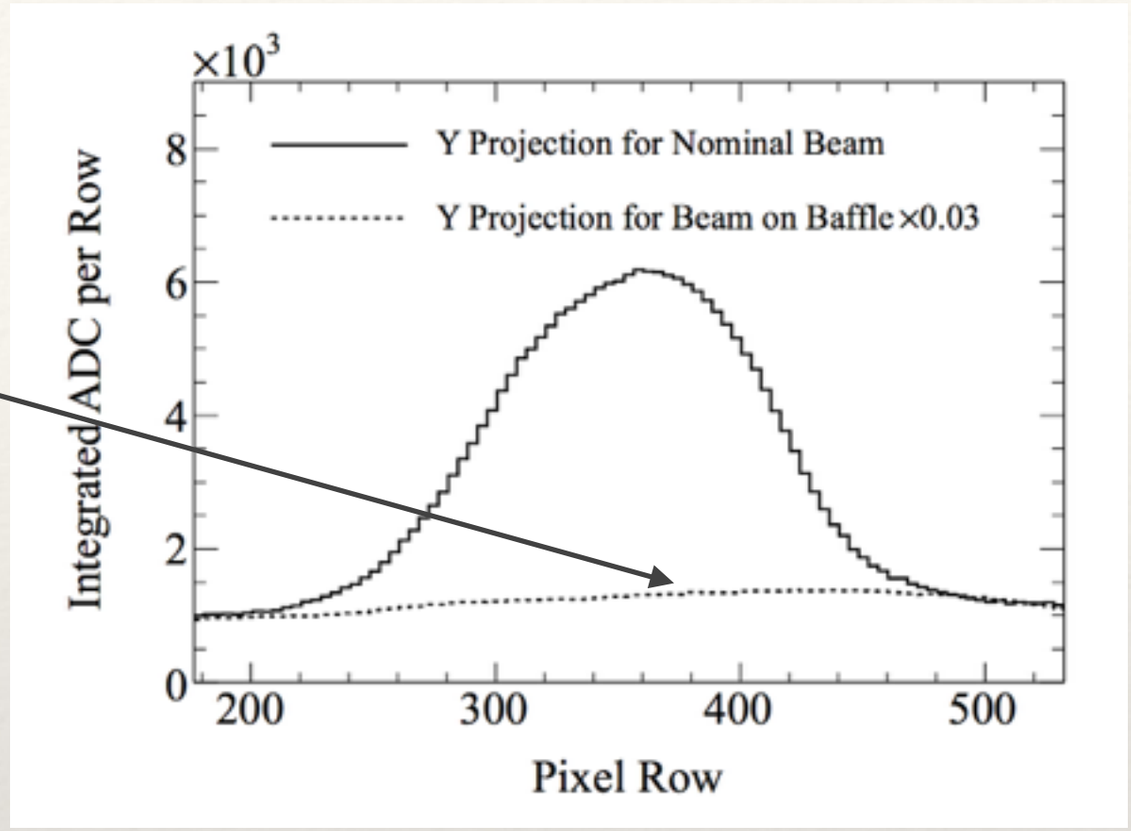
Operation of the OTR II System

- So far, the OTR II system is operating with similar performance to the OTR I system
- We have taken data with the beam on the foil that has the cross configuration
- In a preliminary analysis, we can observe the hole positions
- We are working to use this information to reduce systematic uncertainties in the beam position and width measurements



Outstanding Background Light Problem

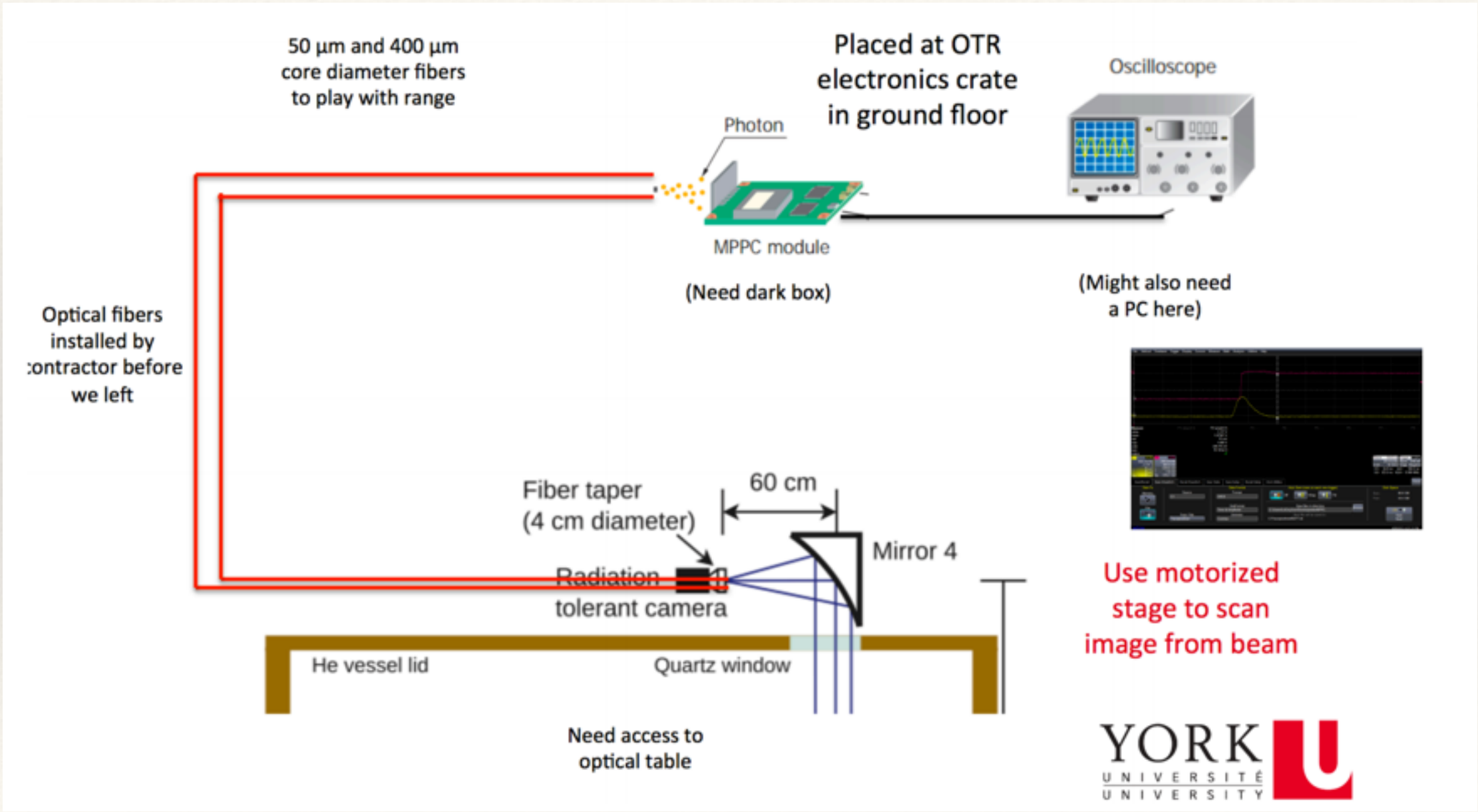
- We have long had the problem of an unknown source of background light in the OTR images
  - Limits the accuracy of the beam position and width measurements
- Hypothesize that it is fluorescent light produced by the He or ceramic materials on the horns and reflecting off of the foil



- Two approaches to understand it:
- Improved analysis based on a ray-tracing simulation with tuned alignment of the mirrors may allow us to better test background model hypotheses
- Plan to measure the time dependence of the background light to see if it is prompt or has some lifetime

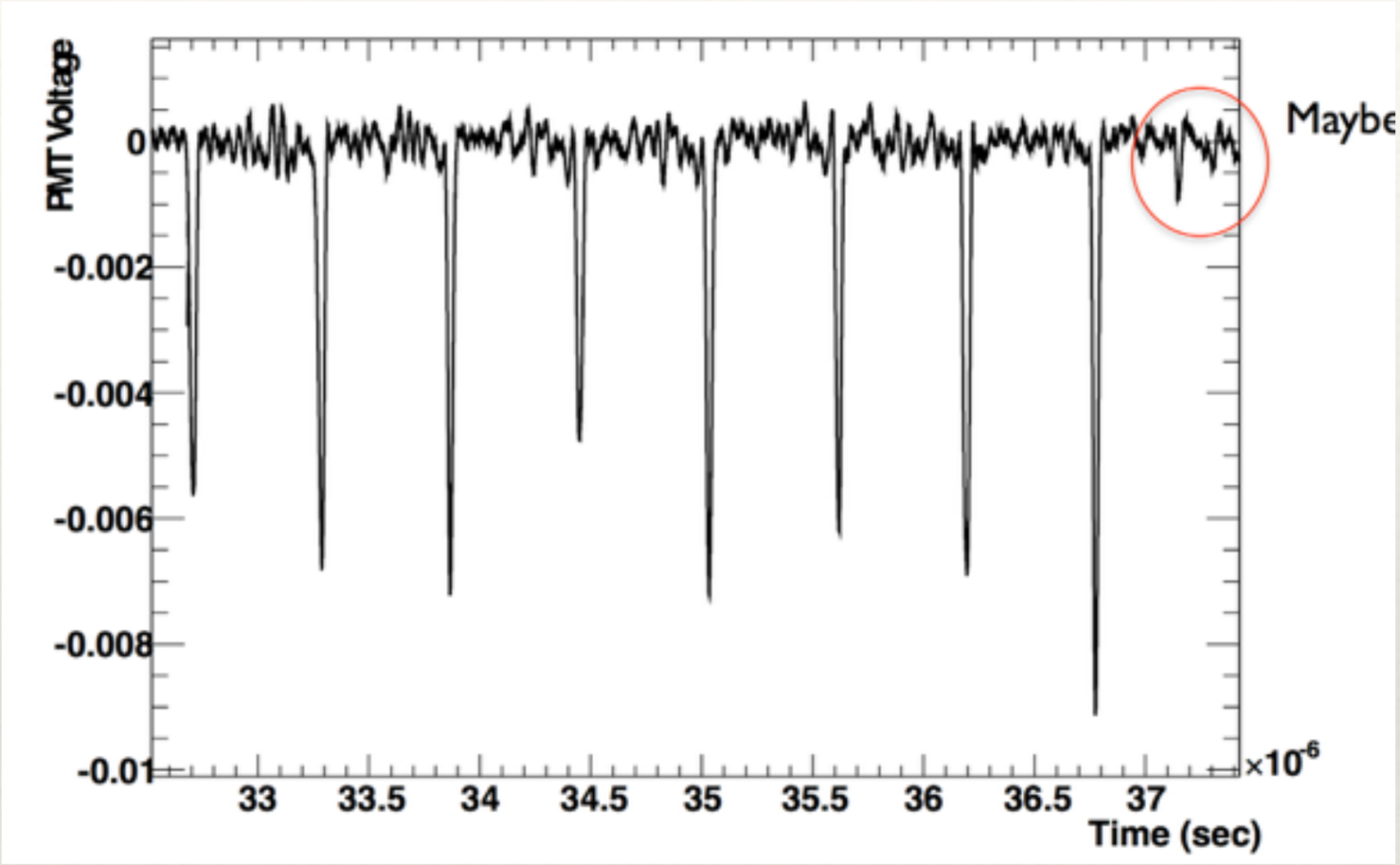
Background Light Measurement

- We installed optical fibers to transport light from the camera location to the TS ground floor where we can detect the photons with a PMT or MPPC



Preliminary Background Light Measurement

- During the May/June 2014 operation we were able to take some data with a PMT



- We observed the bunch structure of the beam but did not see any clear signal of photons between bunches
- Plan to take more statistics this fall

Conclusion

- The OTR beam monitor has been operating successfully in the T2K beam line since the beginning of operation, providing profile information at the target for every spill
- The OTR I system was removed in during last year's shutdown
  - We had a chance to see the OTR foils and confirmed darkening of the foil corresponding to observed changes in the OTR images
  - Effect appears to be less for the foil that has only been operated in pure He
- The OTR II system was assembled and a new spare OTR III system was built in 2013-2014
- The OTR II system is now installed and operated in May/June of 2014
- We are still making some studies of the observed background light and improving the image analysis to improve the monitor accuracy

Extra Slides

Measurements of Optical System

E. Pinzon, York U.