Imperial College London

T2K

Science and Technology Facilities Council

T2K Optical Transition Radiation Monitor

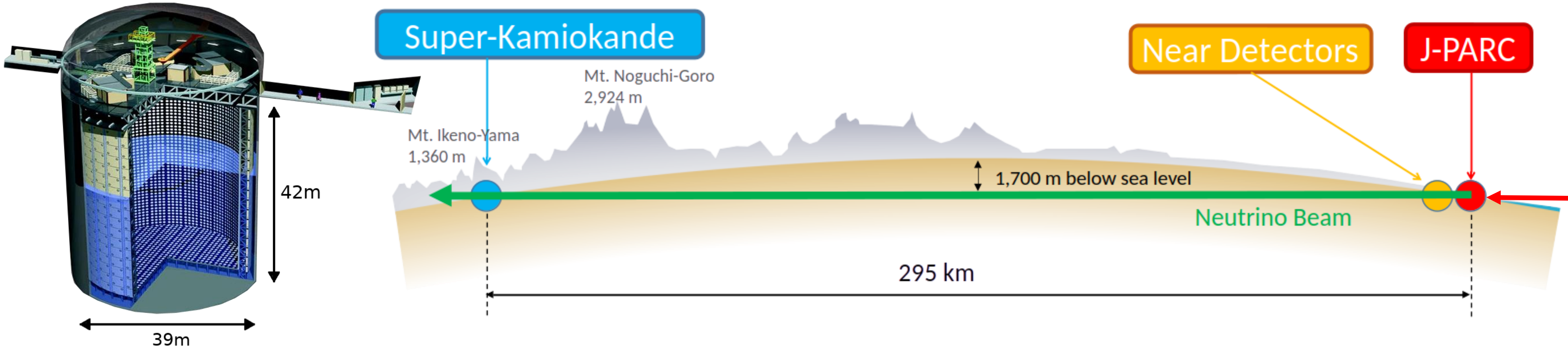
NuFACT 2023 Seoul

22 August 2023

Charlie Naseby

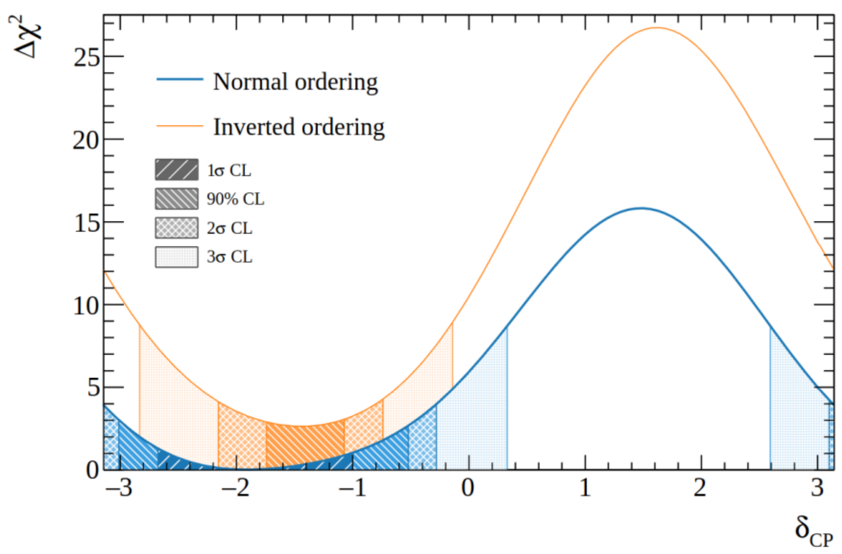
On behalf of the T2K experiment

T2K



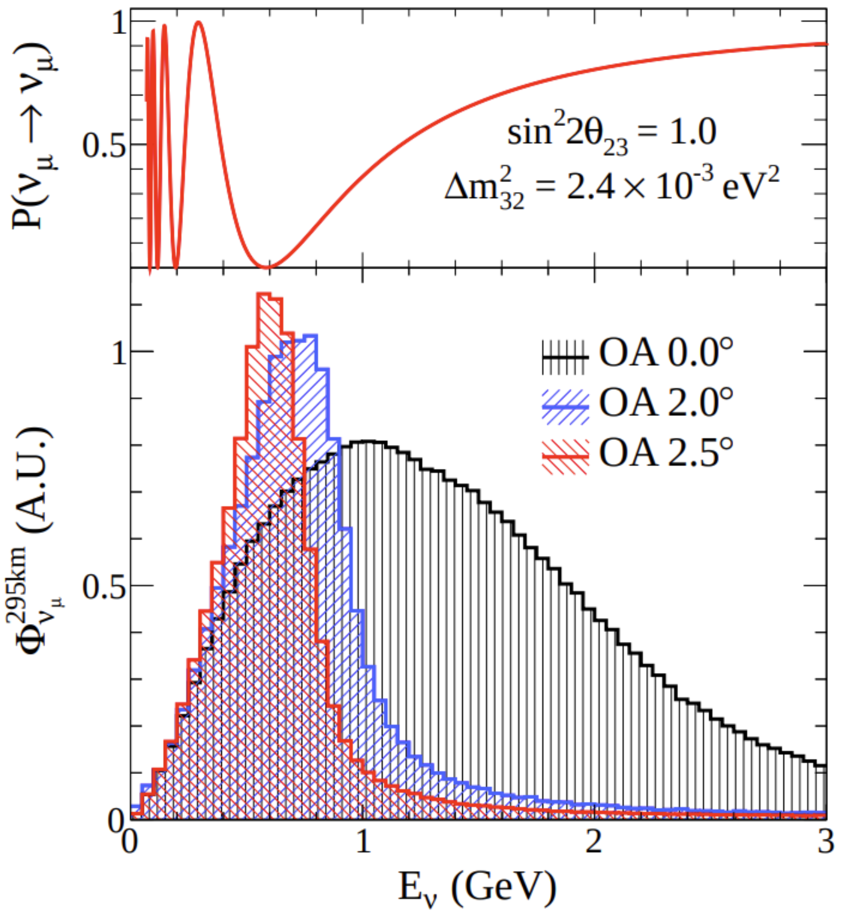
- Generate a ν_μ dominated neutrino beam on Japan's east coast.
- Neutrino beam is measured by a suite of near detectors.
- Neutrinos are subsequently detected by Super-Kamiokande after oscillation.
- Extract world-leading results on oscillation parameters. (See talks by A. Blanchett, D. Cherdack)

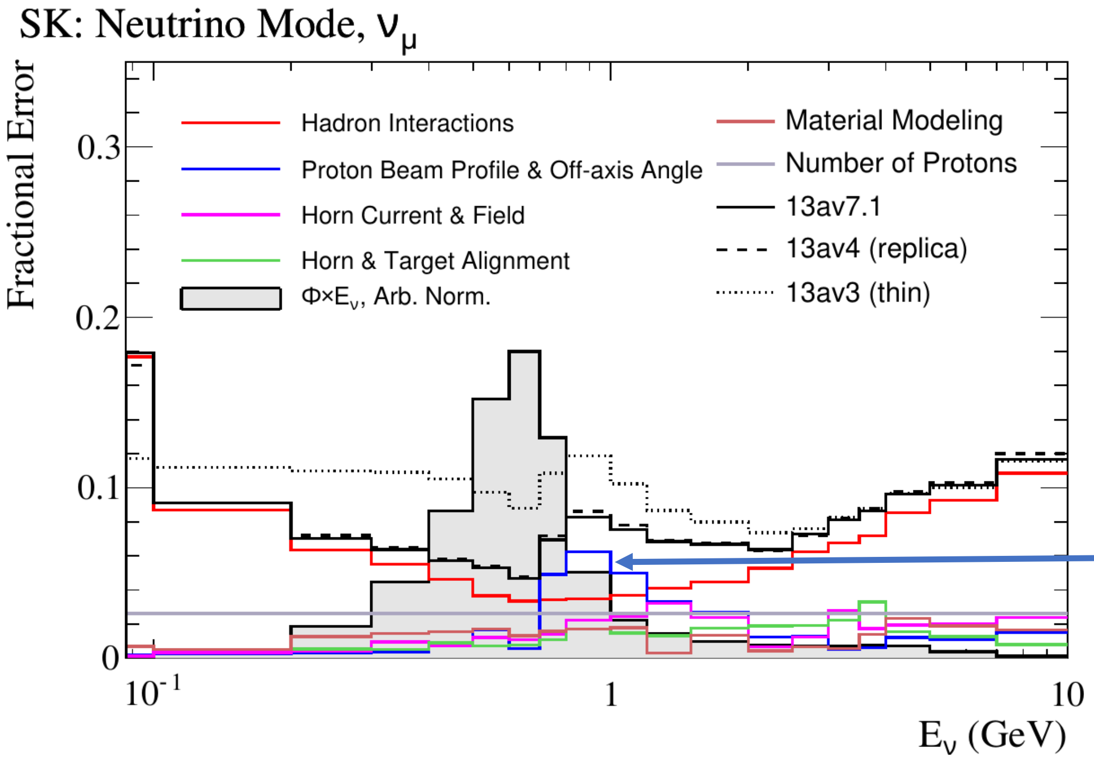
T2K δ_{CP} result



T2K Flux

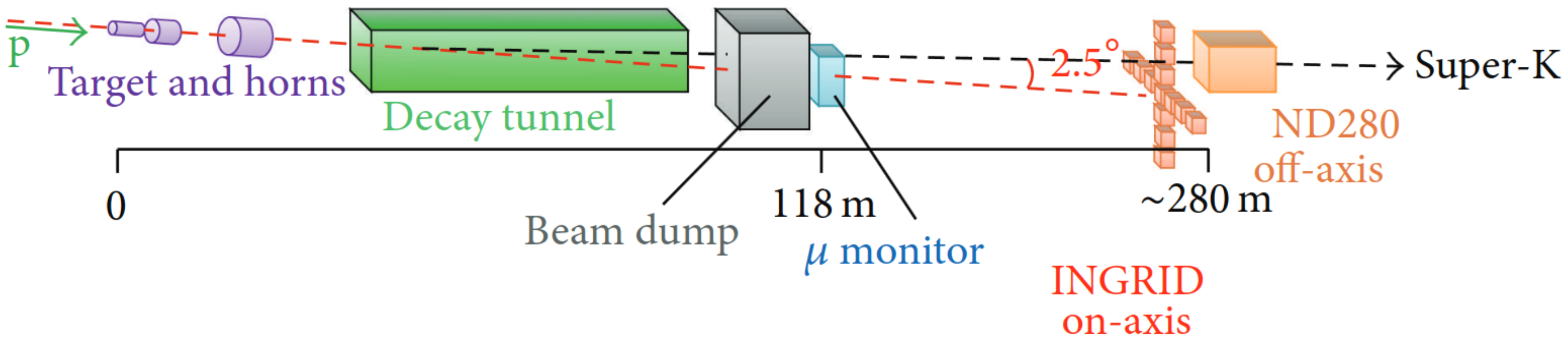
- T2K uses an off-axis neutrino beam, create a boosted group of pions and allow them to decay to $\nu_\mu + \mu^+$.
- Due to the decay kinematics of the pions, the precise value of this off-axis angle significantly affects neutrino flux.



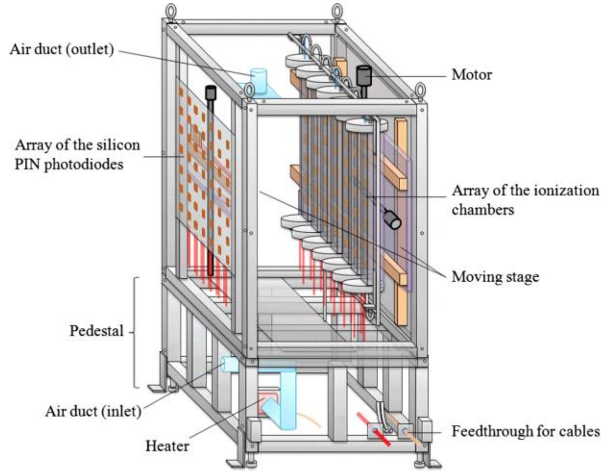


- Uncertainty related to proton beam and off-axis angle now leading uncertainty on ν_μ flux around 1 GeV. (See talk by M. Friend)

Controlling Off-axis Angle



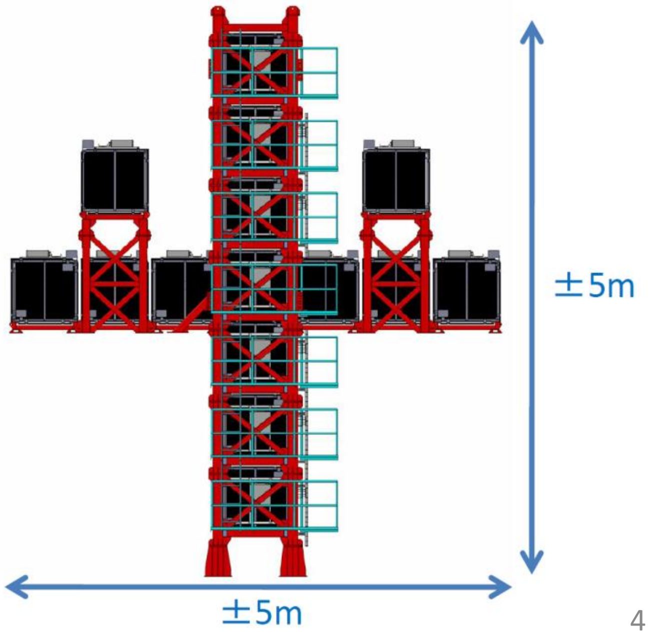
MUMON



- Pions produced by striking a graphite target with a proton beam.
- Produced pions are focused by magnetic horns and allowed to decay.
- Decay of pions yields a broad-angle neutrino beam and muons.
- T2K monitors position of beam center with three methods:
    1. **Primary proton beam monitoring**
    2. Decay muon monitoring with MUMON
    3. Neutrino beam monitoring with INGRID

} See talk by Y. Sato

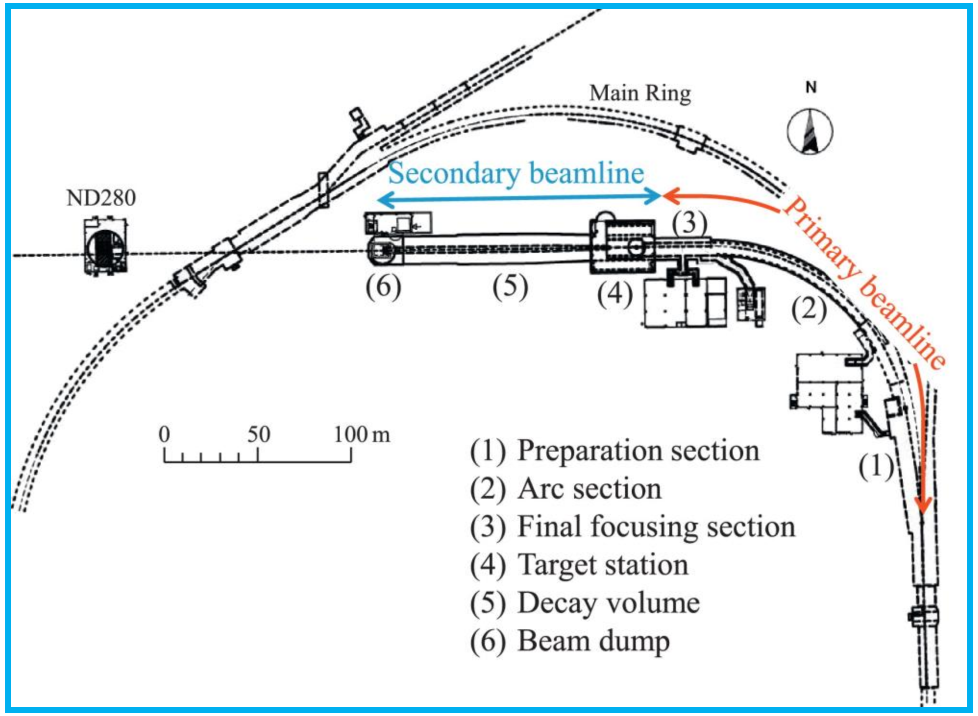
INGRID

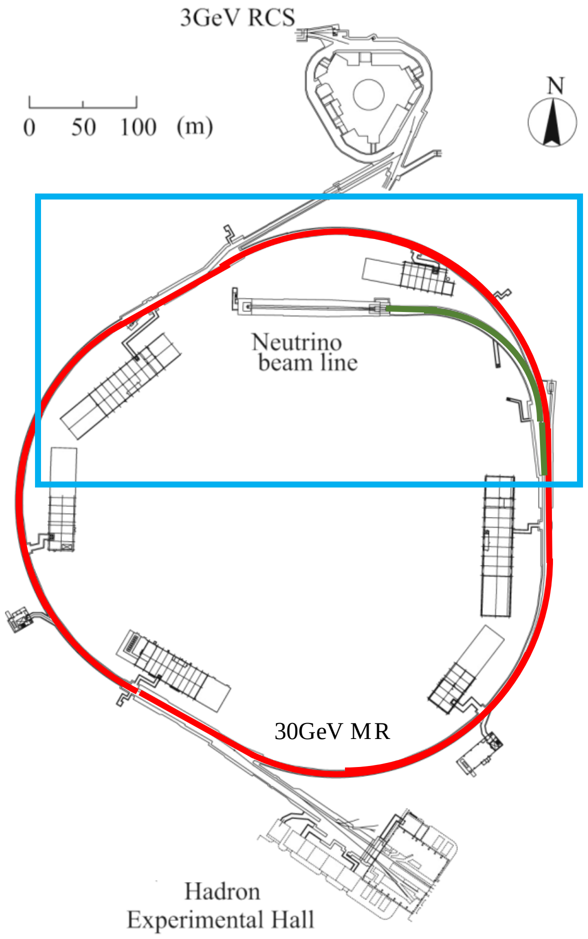


T2K Primary Beamline

- Makes use of the 30GeV J-PARC proton Main Ring.
- Newly upgraded, 1.36s repetition rate 540kW (1.53×10^{14} PPP) continuous achieved.
- All 8 bunches from this ring are fast extracted by a kicker magnet into the neutrino beamline.
- Normal-conducting preparation section after beam extraction.
- Superconducting arc section bends beam west towards Super-Kamiokande.

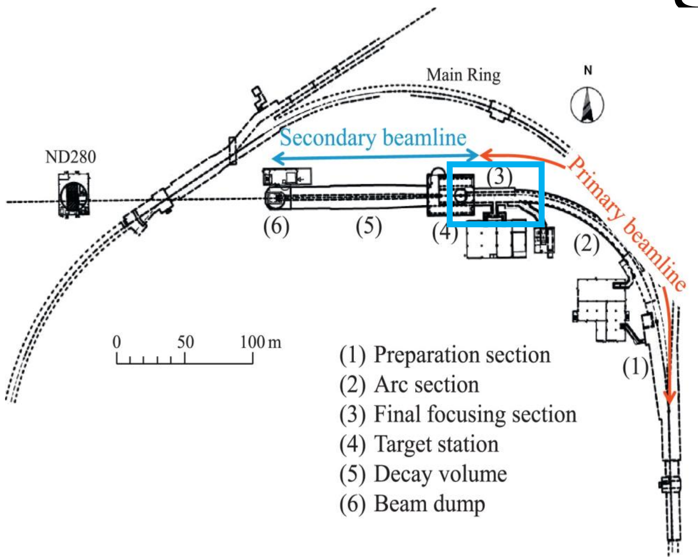
(See talk by T. Nakadira)

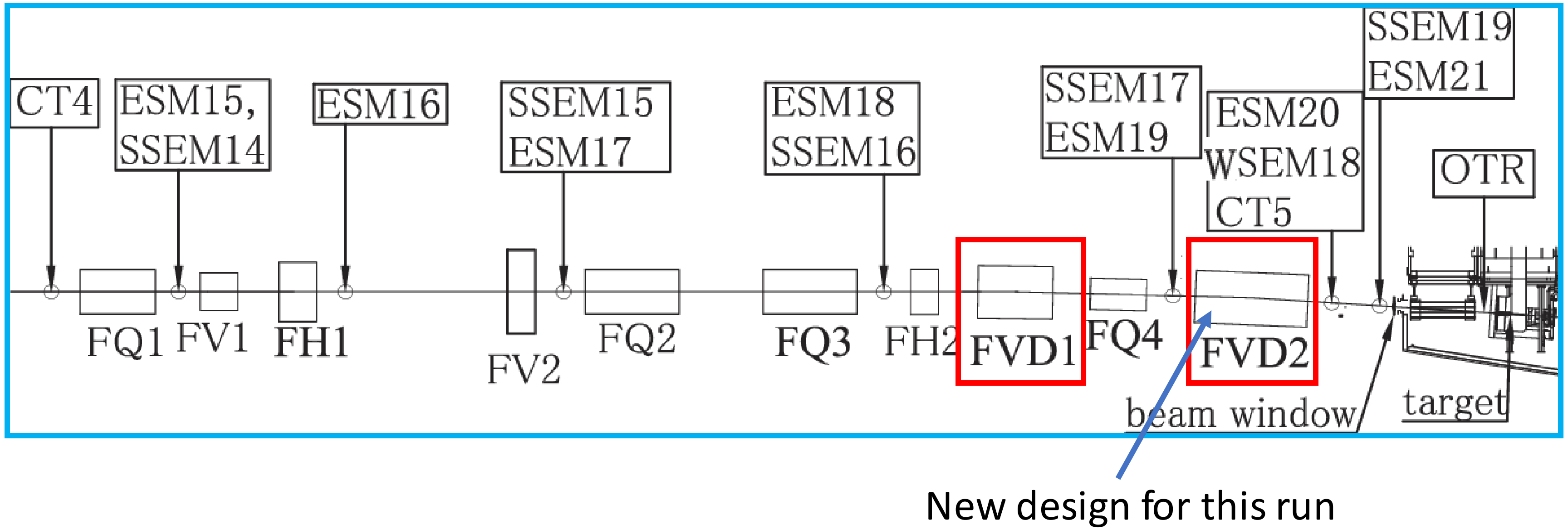




doi.org/10.1016/j.nima.2013.06.105

Final Focusing Section

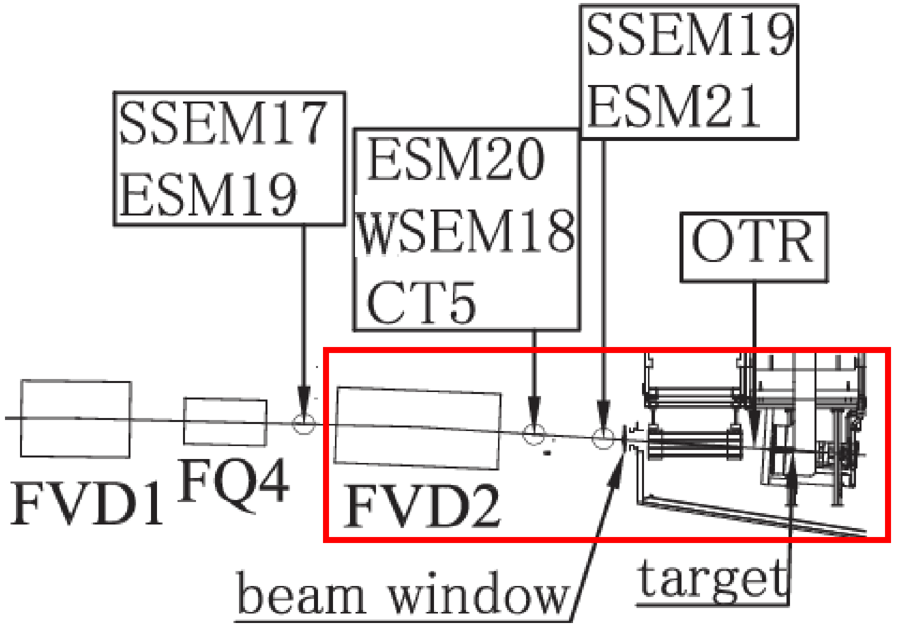


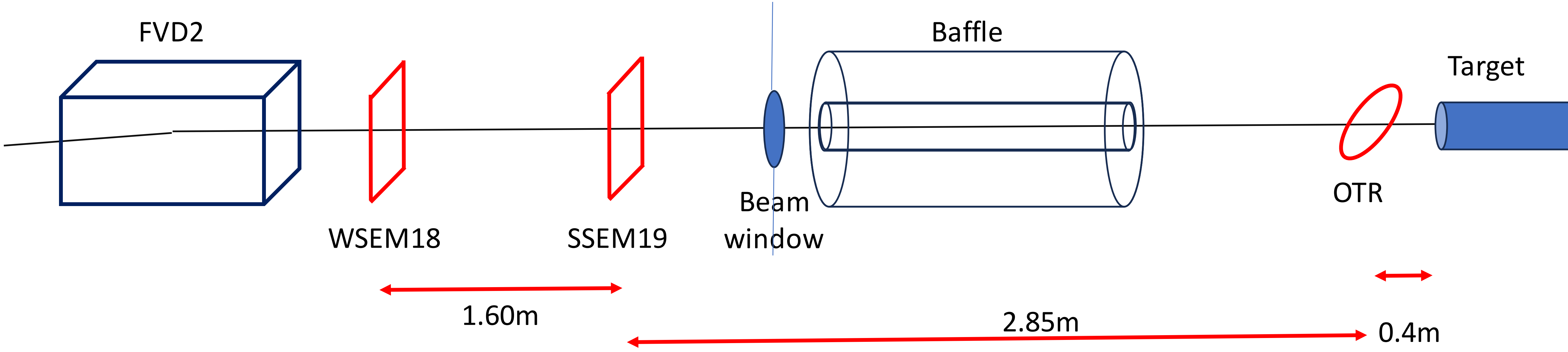


- Beam then enters normal-conducting final focus section.
- Monitor beam position at several positions using ElectroStatic Monitors (ESMs) or position and profile with Segmented Secondary Emission Monitors (SSEMs) or Wire SEMs (WSEMs).
- Two bending magnets, including a new, shorter magnet, deflect the beam downwards to provide the 2.5 degree off-axis angle to Super-K.
- Beam then passes through a beam window into a helium vessel, through a collimater and impinges on a graphite target.

Terminal Beam Monitoring

- For neutrino off-axis angle, we need proton beam angle and position at the target.
- Beam missing the target could cause significant damage
  - Needs continuous monitoring.
- After final bending magnet there are two beam monitors WSEM & SSEM - provide beam position and width.

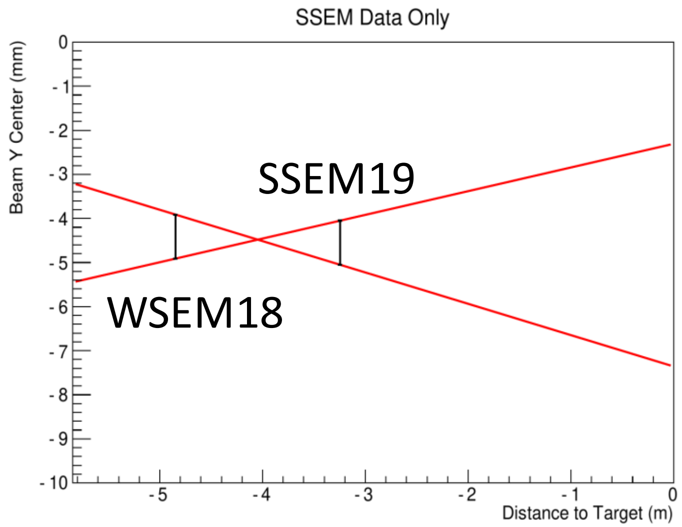


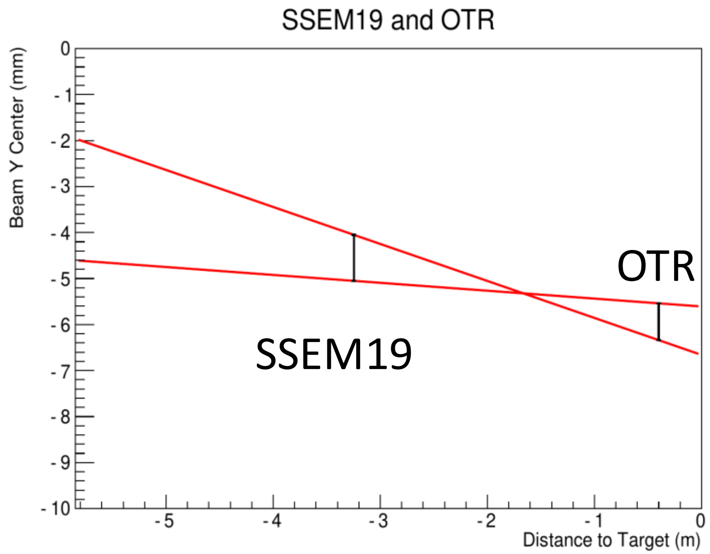


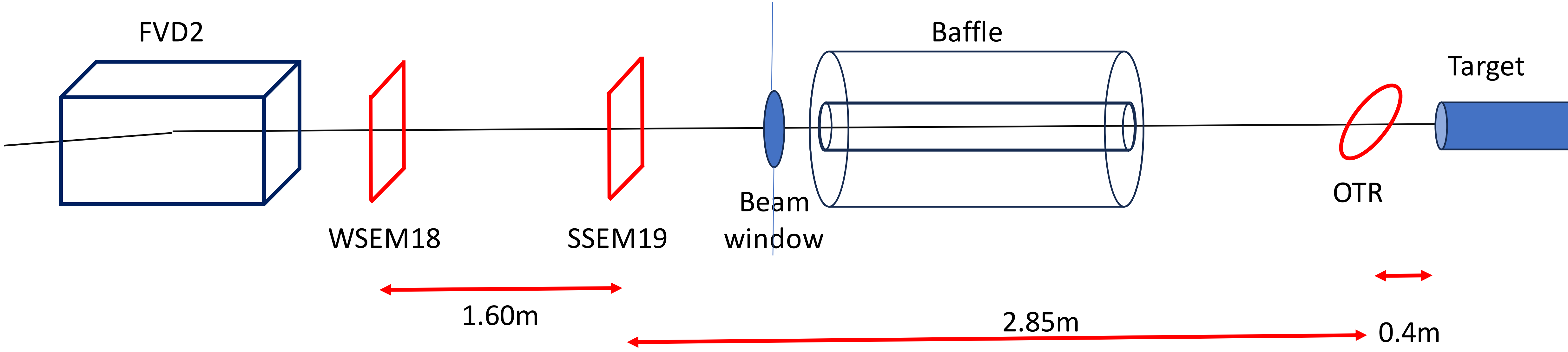
The Need for OTR

During continuous running, only use SSEM19 and OTR

- Using WSEM & SSEM alone requires significant extrapolation to the target.
- The OTR monitor close to the target significantly reduces the positional uncertainty.

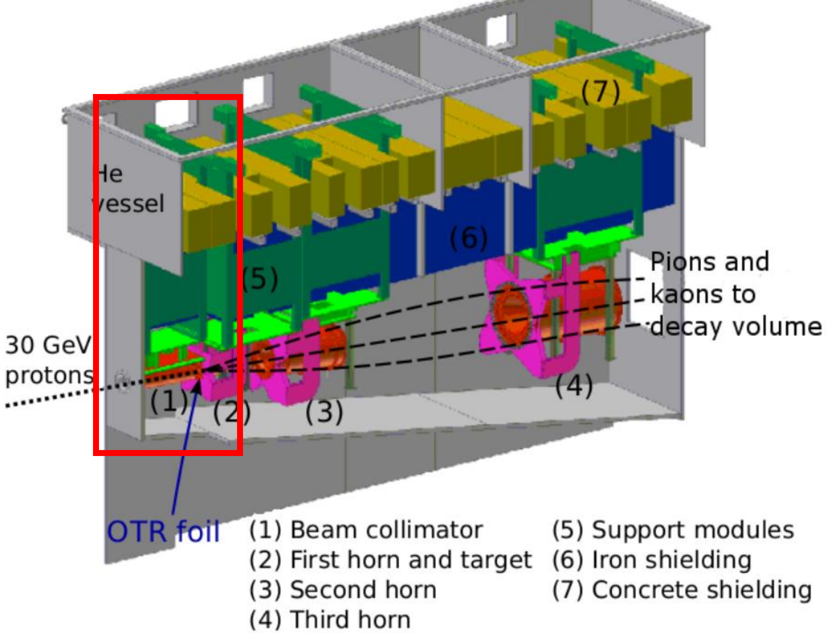


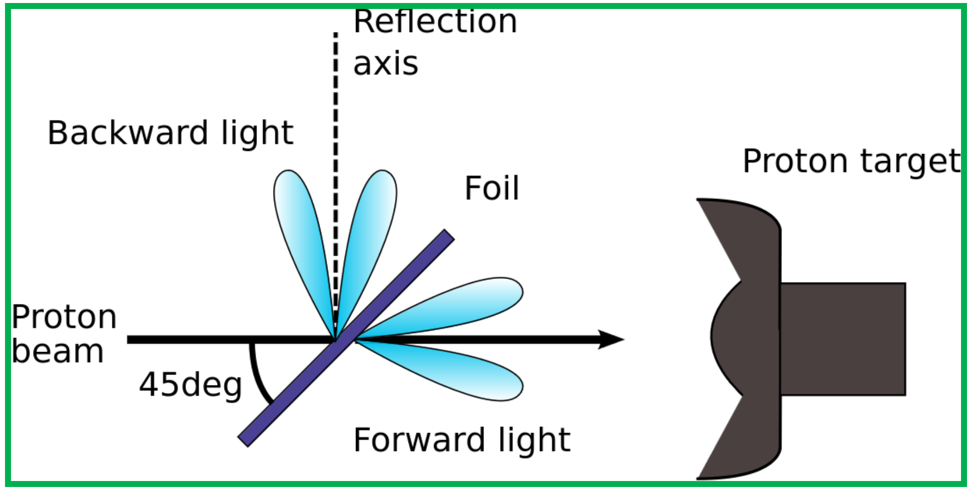


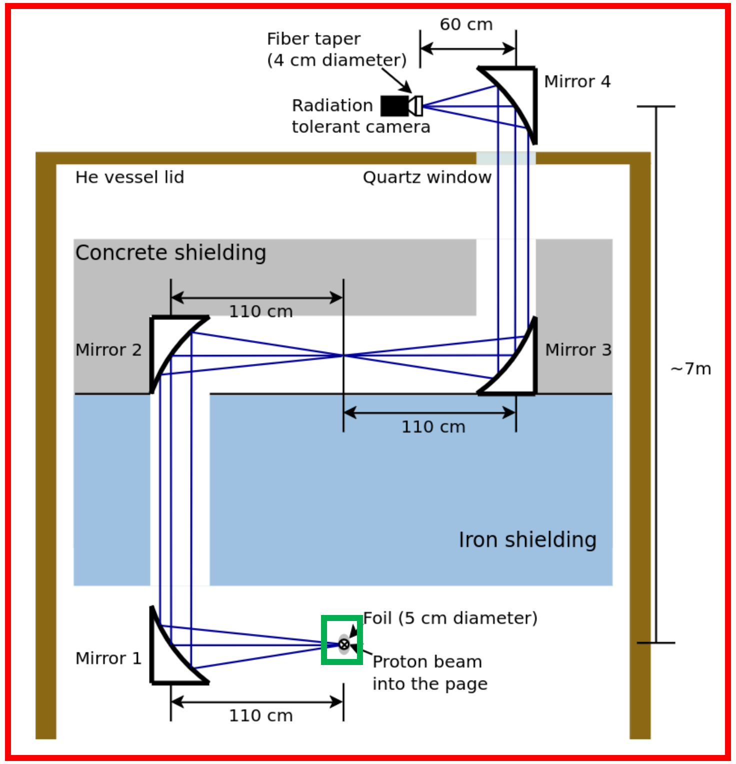


The OTR

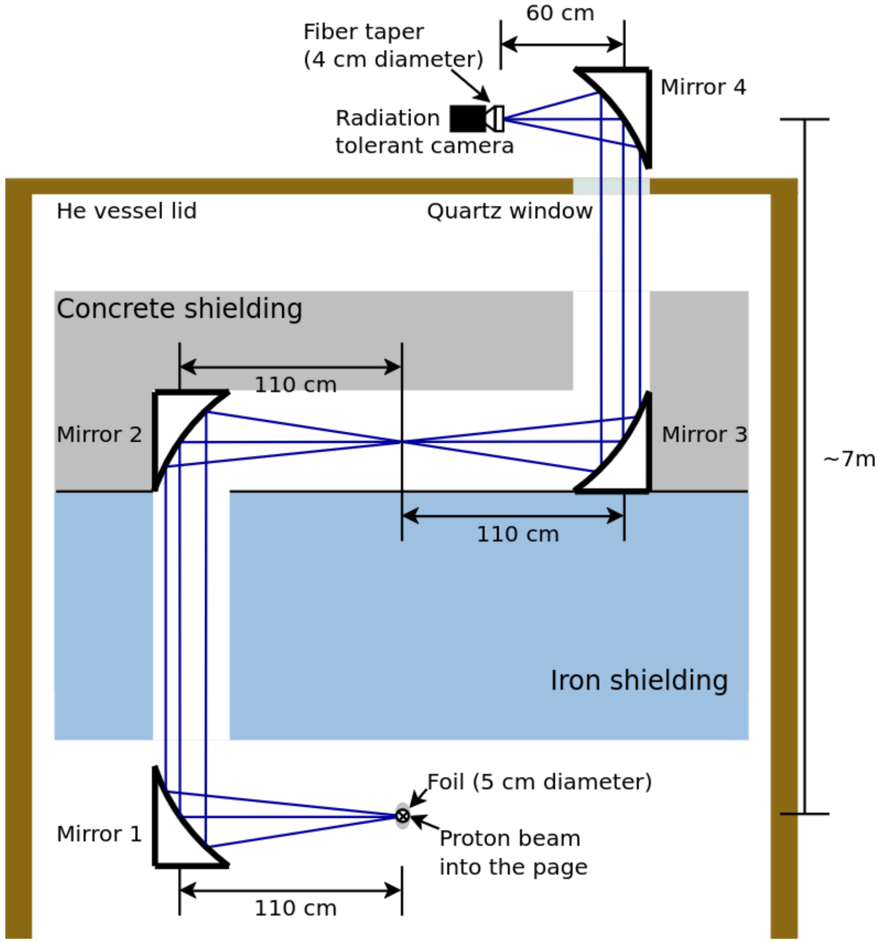
- Close to the target, in an extremely radioactive environment, unable to place sensitive electronics nearby.
- Once irradiated, maintenance is extremely challenging.
- Needs to be as simple and reliable as possible.
- Use optical transition radiation, protons incident on a thin conductive foil generate light at the surface.
- Collect and transport OTR light to a lower radiation area before measurement.



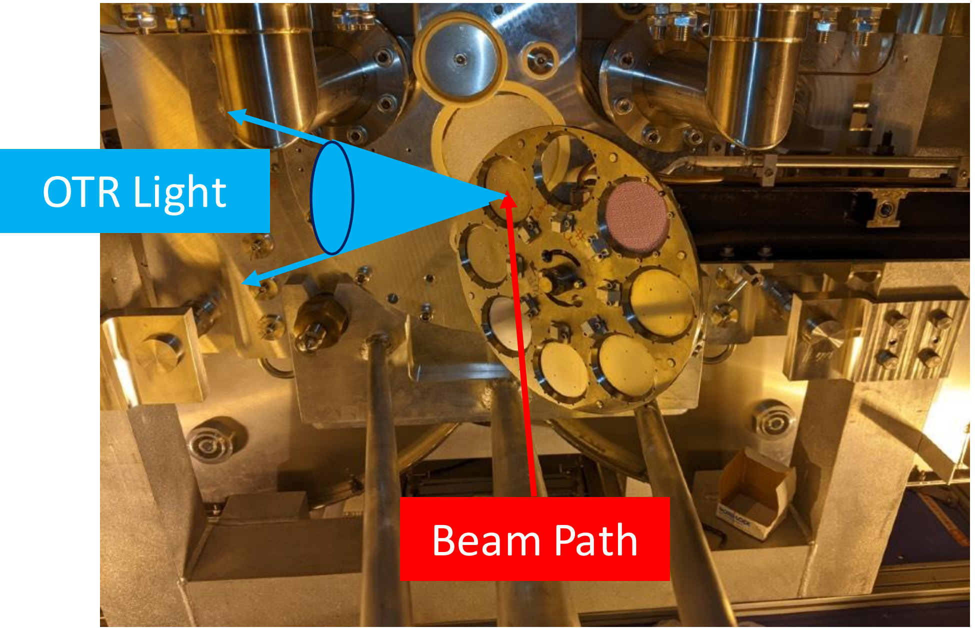




Hardware Overview



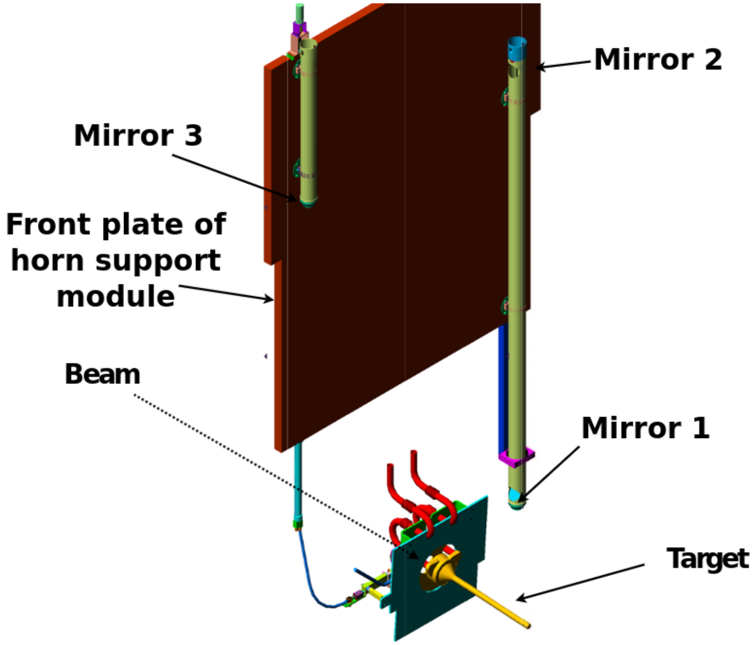
- Previous system used 50um thick Titanium foils, thin to reduce heat deposition.
- The Titanium OTR foils are held on a rotatable disk at 45° to the beam.
- Disk rotates, allowing different foil types to be inserted into the proton beam path.

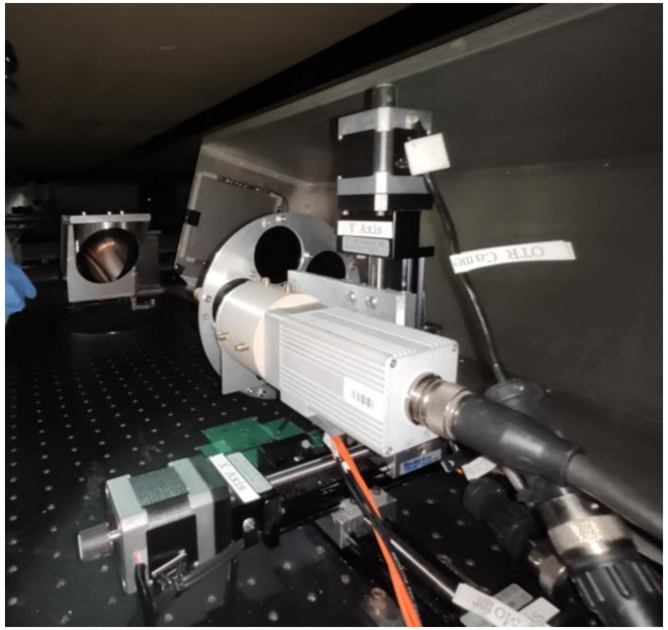


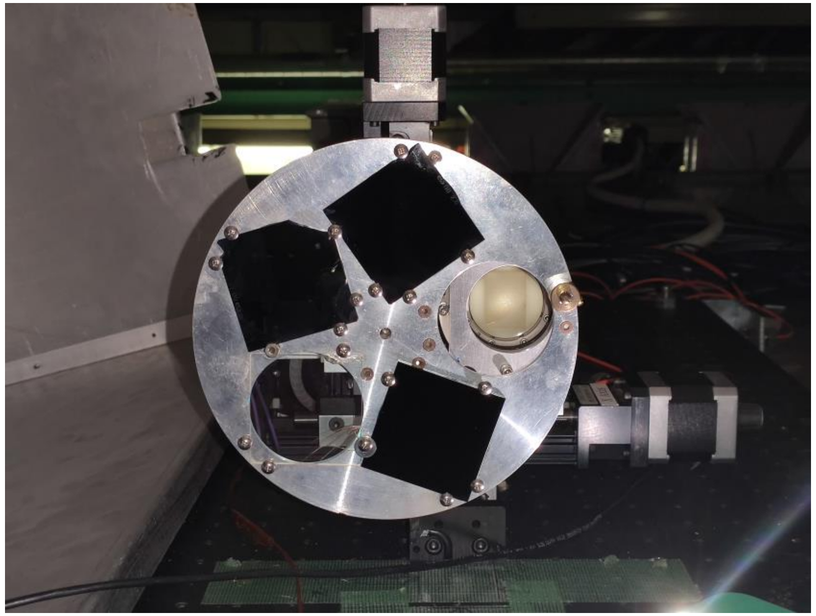
- Rotation is achieved by a motor outside of the shielding.
- Microswitch and spring-loaded plunger used to ensure alignment of the disk with the beam.
- Foil disk is attached via an arm to the first magnetic focusing horn.

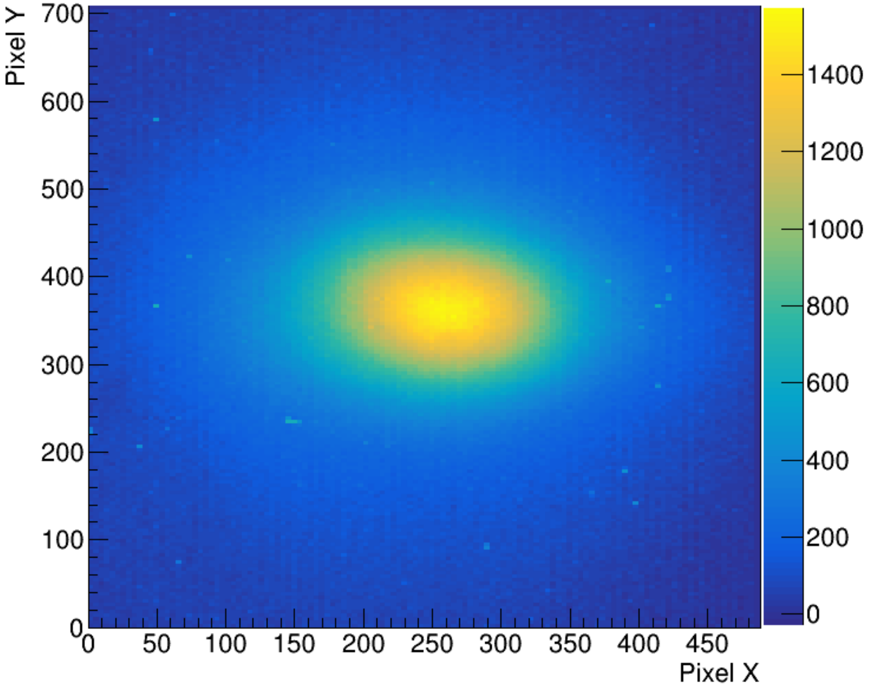
Hardware Overview

- Four parabolic mirrors transfer the light to a radiation hardened Charge Injection Device (CID) camera.
- Camera is placed on a XYZ stage to obtain optimal image position and focus.
- An optical fiber taper converges the image onto the image sensor.
- Selectable optical density filters can be used to reduce light intensity at high power running.



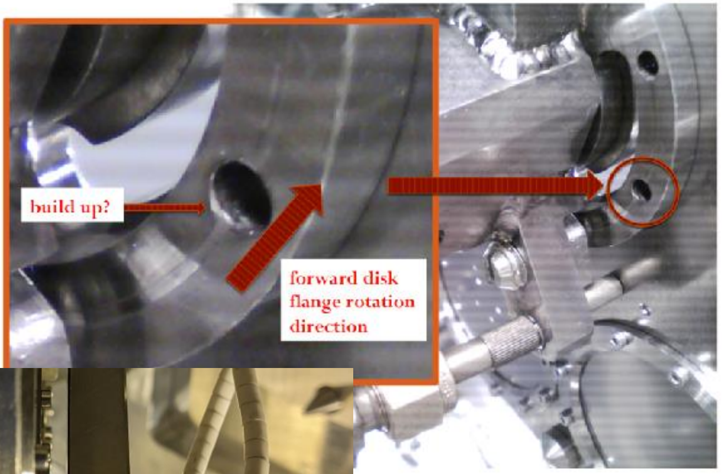


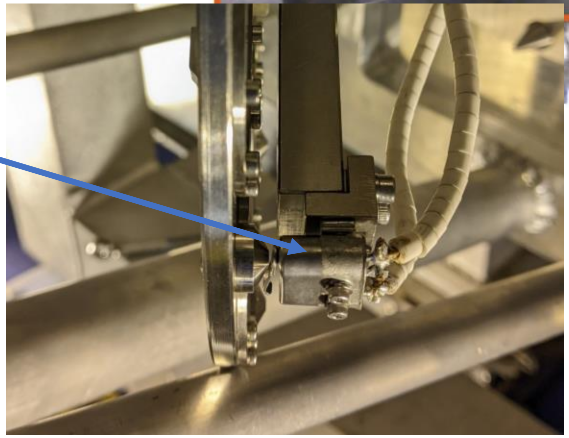


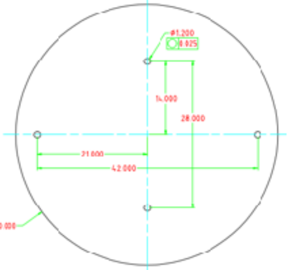


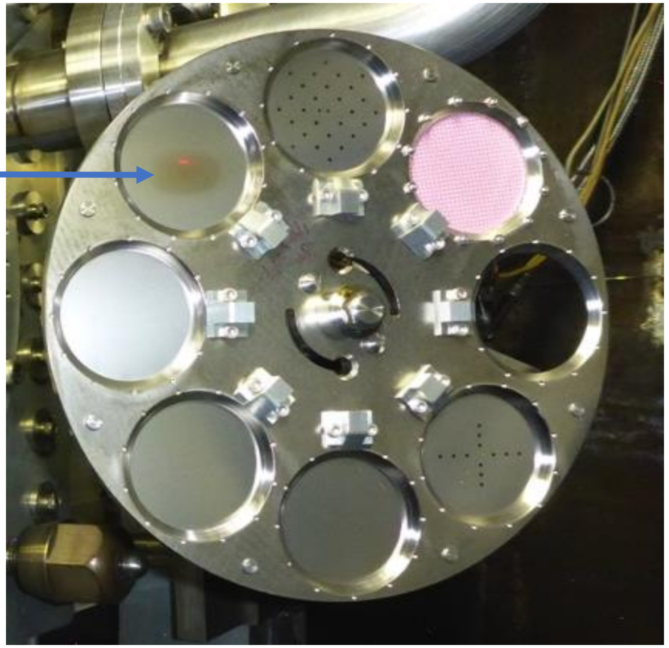
OTR Disk Replacement

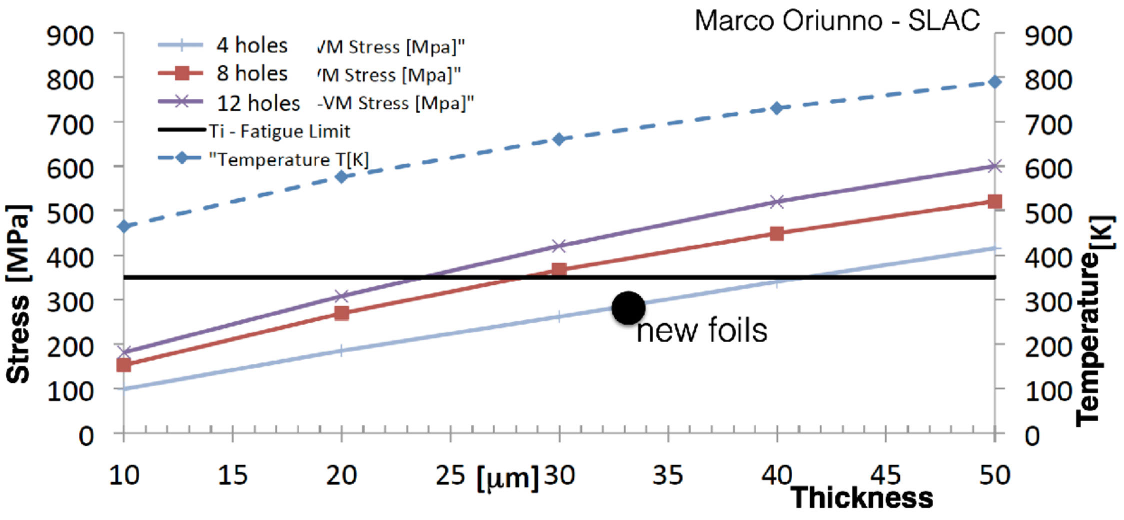
- Previous OTR was installed in 2013, started observing issues with disk rotation in 2015.
- Microswitch used to verify disk position later became misaligned.
- J-PARC upgrade towards 1.3MW operation: previous 50um foils would fail over time due to fatigue stress.
- Foils were seen to darken due to radiation damage, reducing light yield.
- Replacement was required.





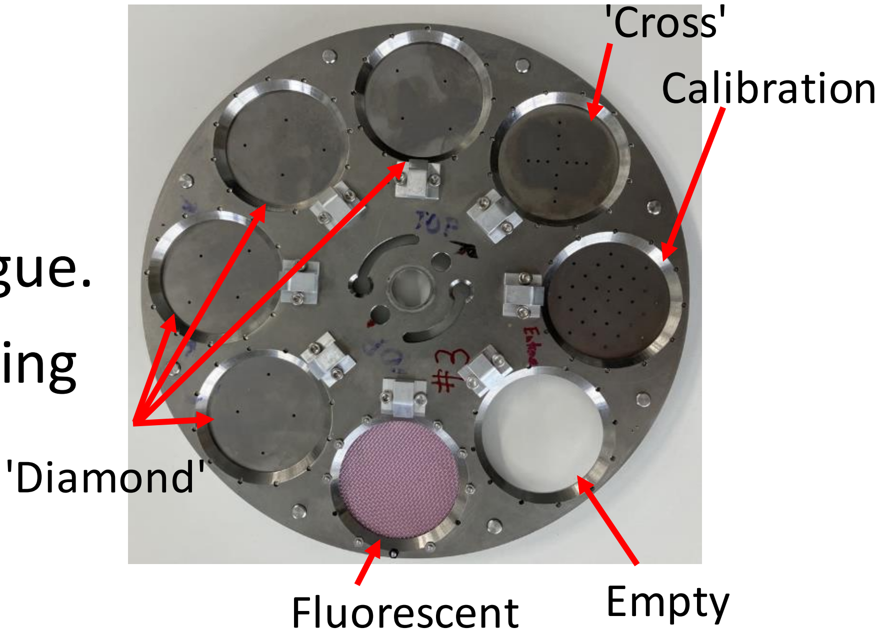


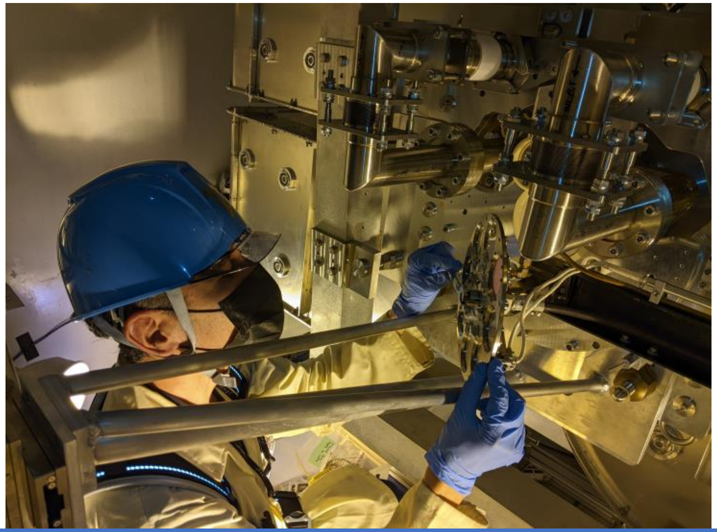


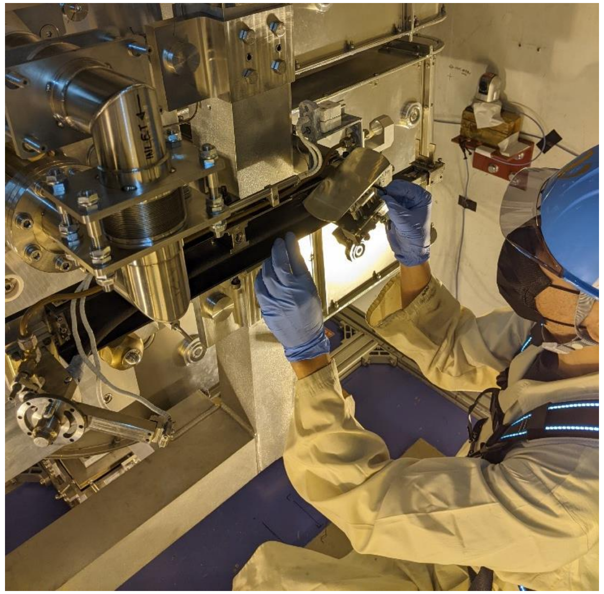


OTR Replacement II

- New foil disk with thinner 33um Ti foils, more resilient to fatigue.
- All Ti foils now have holes for backup alignment procedure using a backlight.
- Harder, stainless steel flange to prevent wear that caused rotation difficulties.
- Better characterisation and alignment of microswitch.
- Installation work performed late 2022.



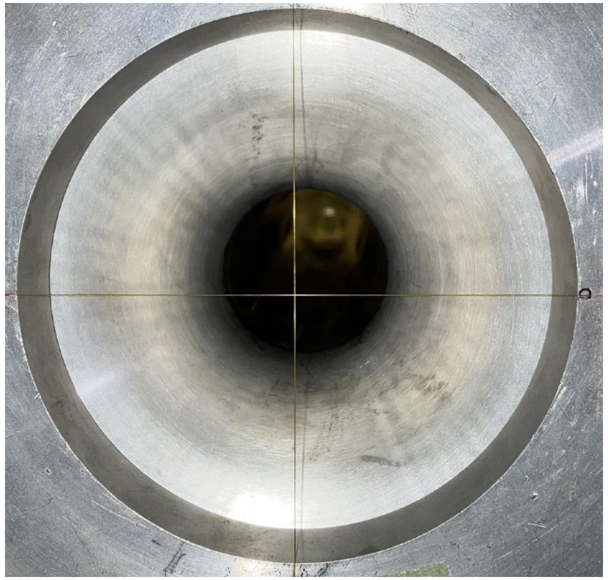


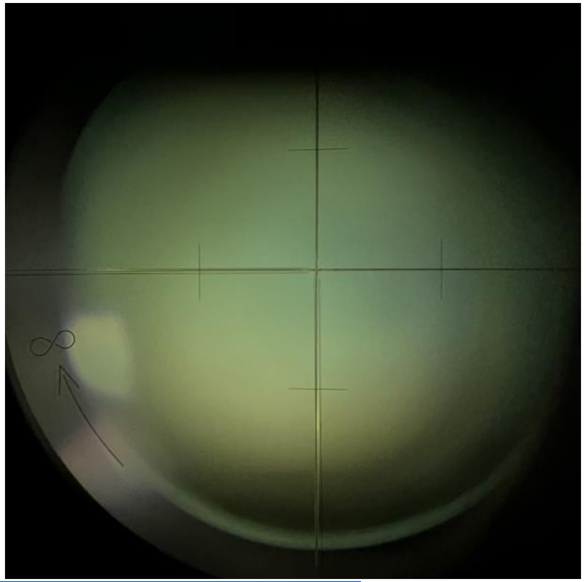


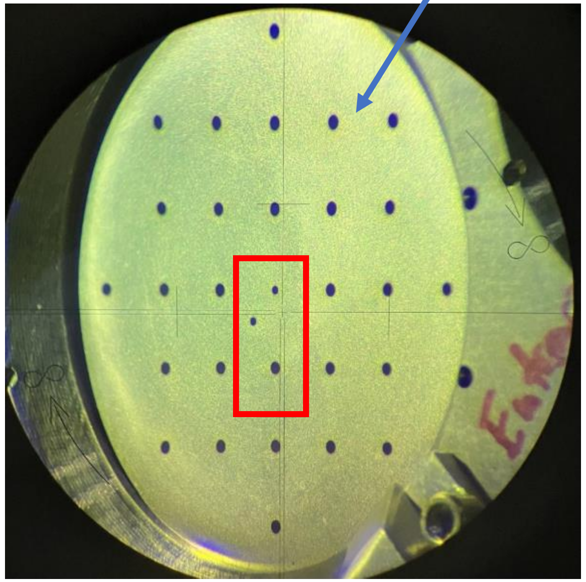
OTR Replacement III

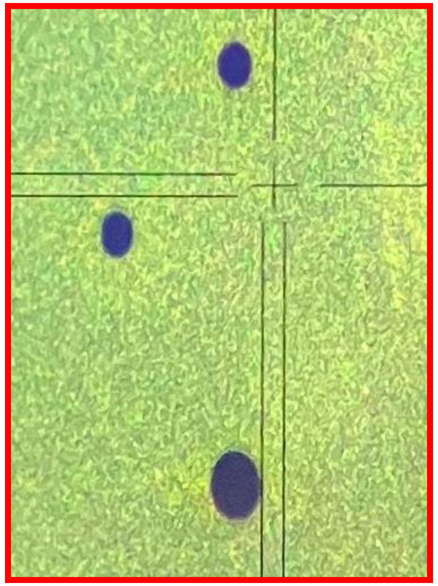
- Leading uncertainty on OTR beam position measurement is alignment of OTR foils with the target.
- Measured with theodolite along the beam-axis:
  - Use centered fishing lines on magnetic horn, where target will be placed
  - Align the theodolite crosshairs with fishing lines
  - Install OTR disk
  - Record crosshair position on foil

Calibration foil – holes used as reference points



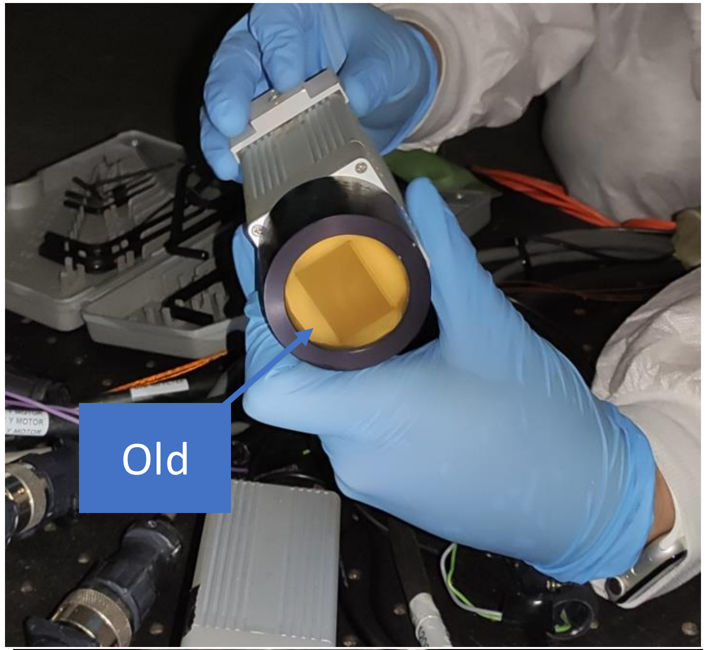


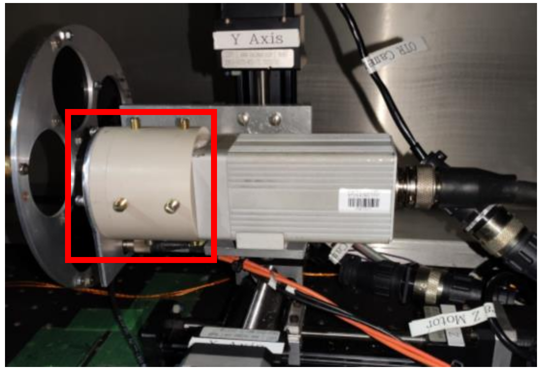


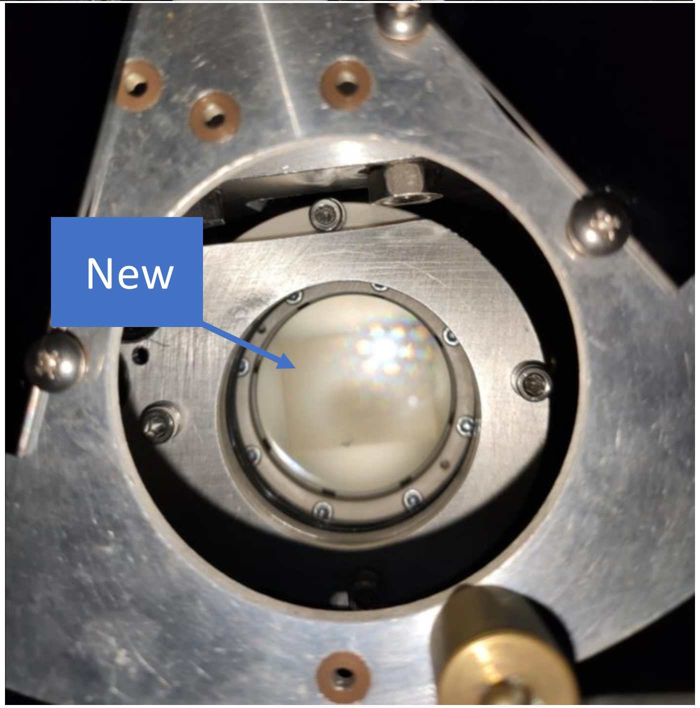


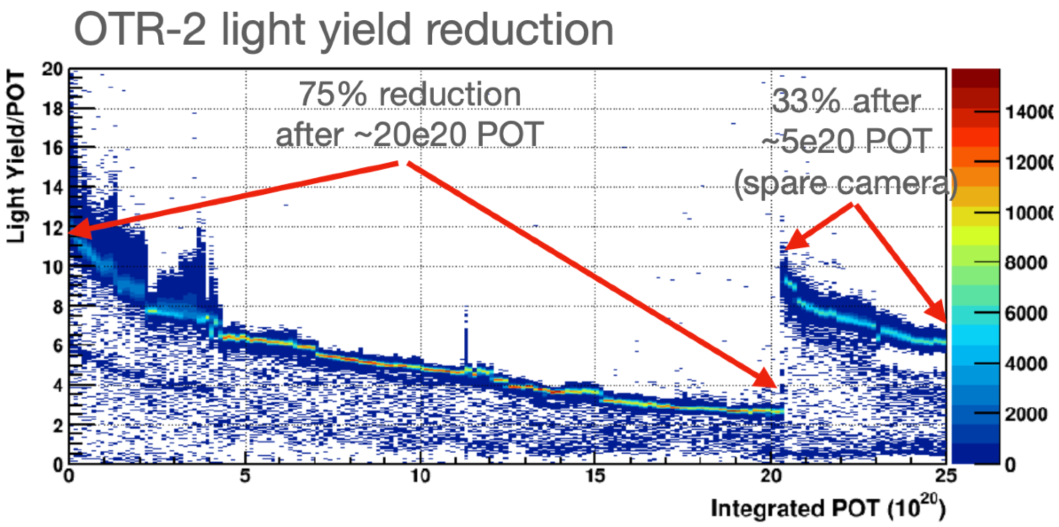
Camera Taper

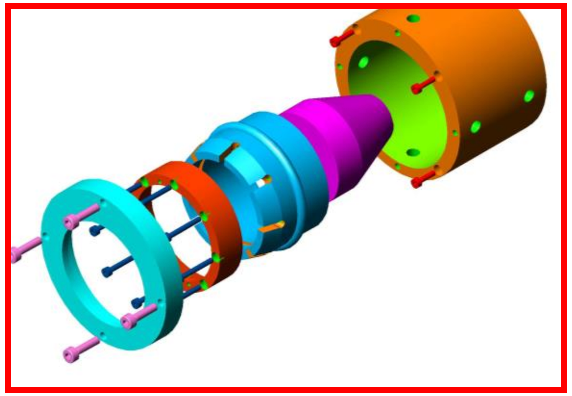
- Previously observed radiation damage causing darkening in the fiber taper attached to the camera sensor.
- Caused a continuous reduction in OTR light reaching the camera.
- Old taper was glued to camera sensor, now have swappable fiber taper for easier replacements.





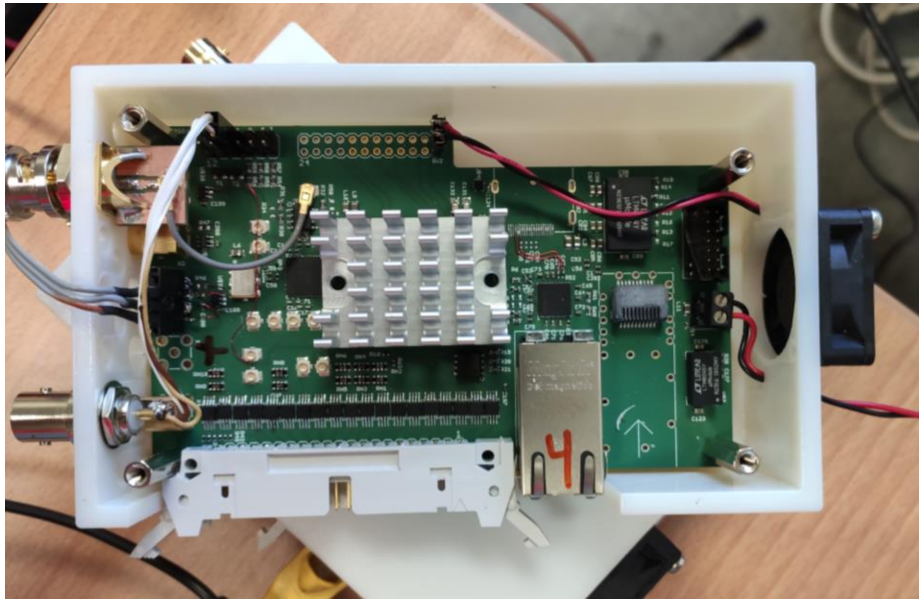


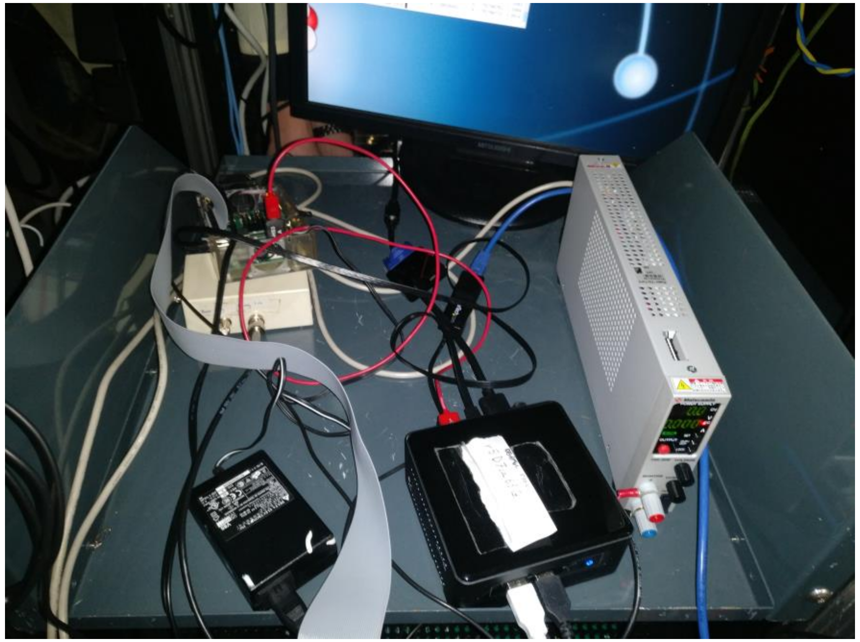




OTR DAQ

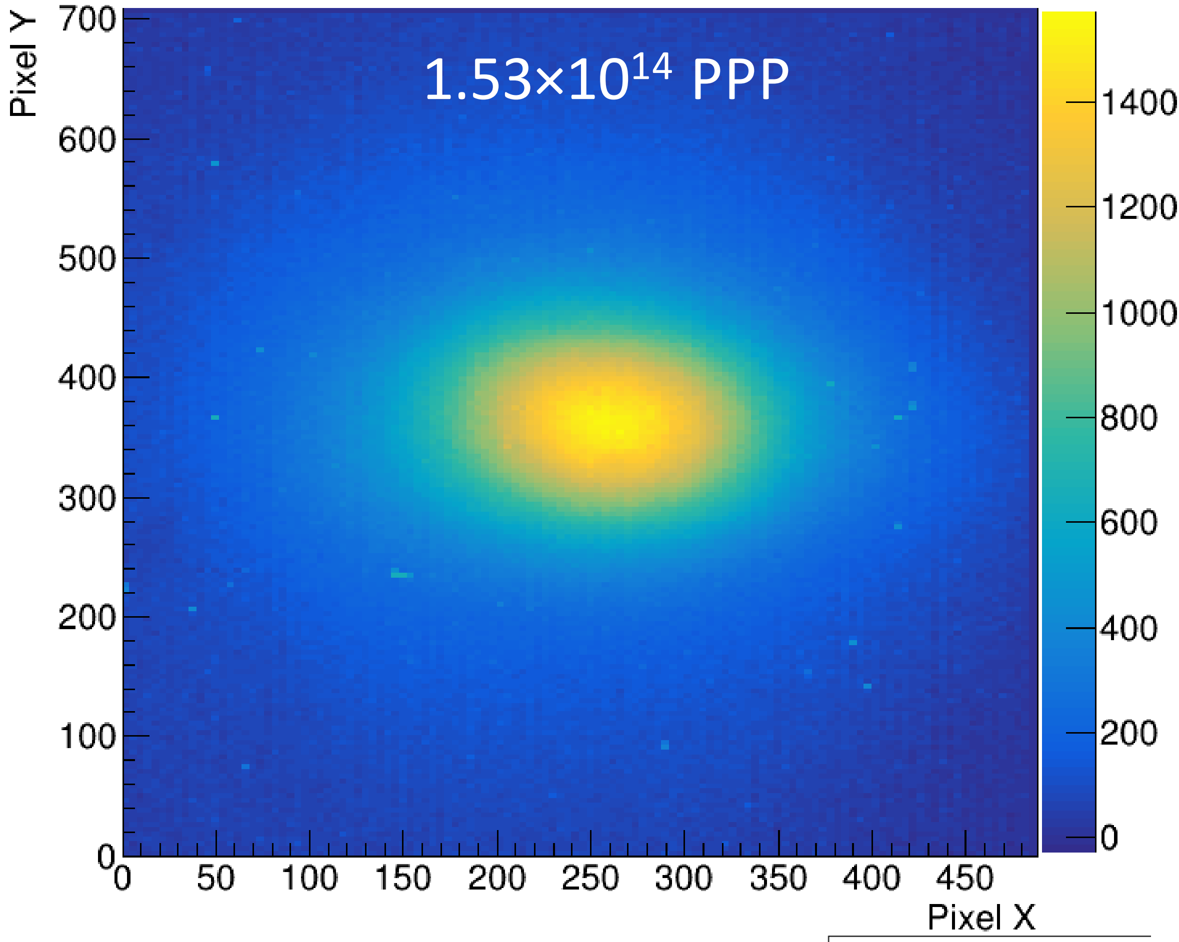
- To support 1.16s repetition of the J-PARC Main Ring, the OTR DAQ required an upgrade.
- RS-170 signal from OTR camera (analogue B&W) is digitised with a new 27MHz ADC board.
- Ethernet interface to a PC running Linux, compresses images and transfers to beam DAQ.
- This PC is also used for slow-control.
- More portable software, easier upgradability in future, spare boards available.

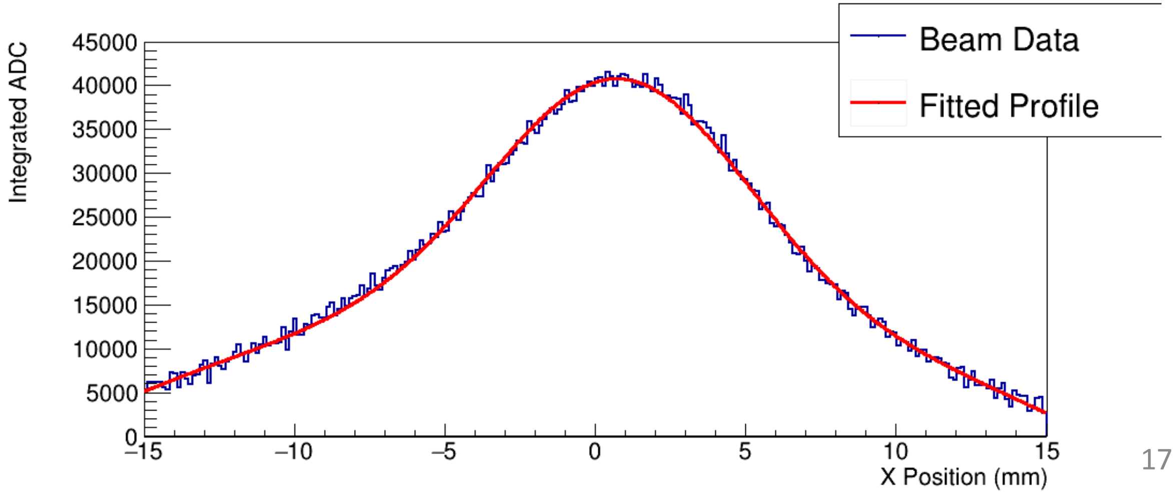




Beam Data

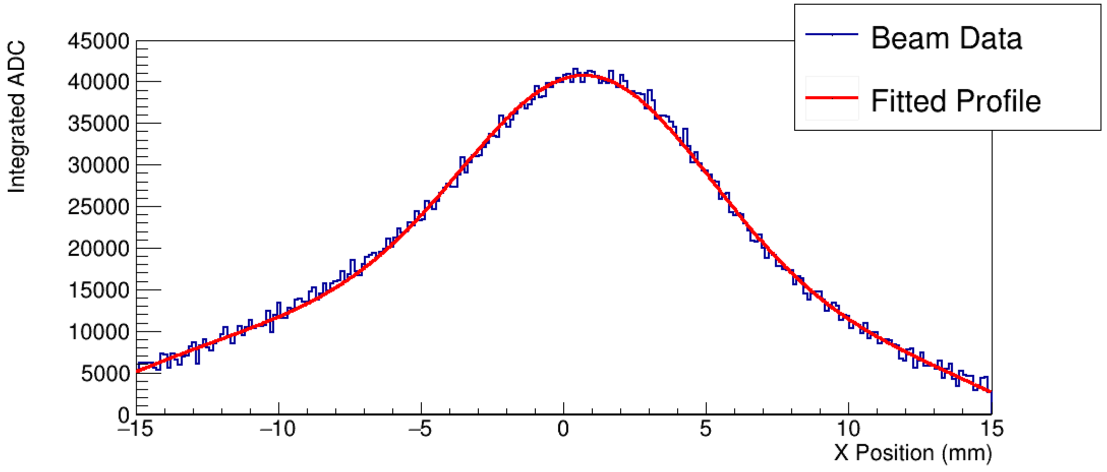
- Took data during April running period, T2K run 12.
- Up to 540kW continuous with 1.36s repetition.
- Take image of OTR light coincident with the beam.
- Correct for distortion of mirror system and convert to position on the foil.
- Fit a 2D Gaussian combined with a linear + quadratic background to beam images.

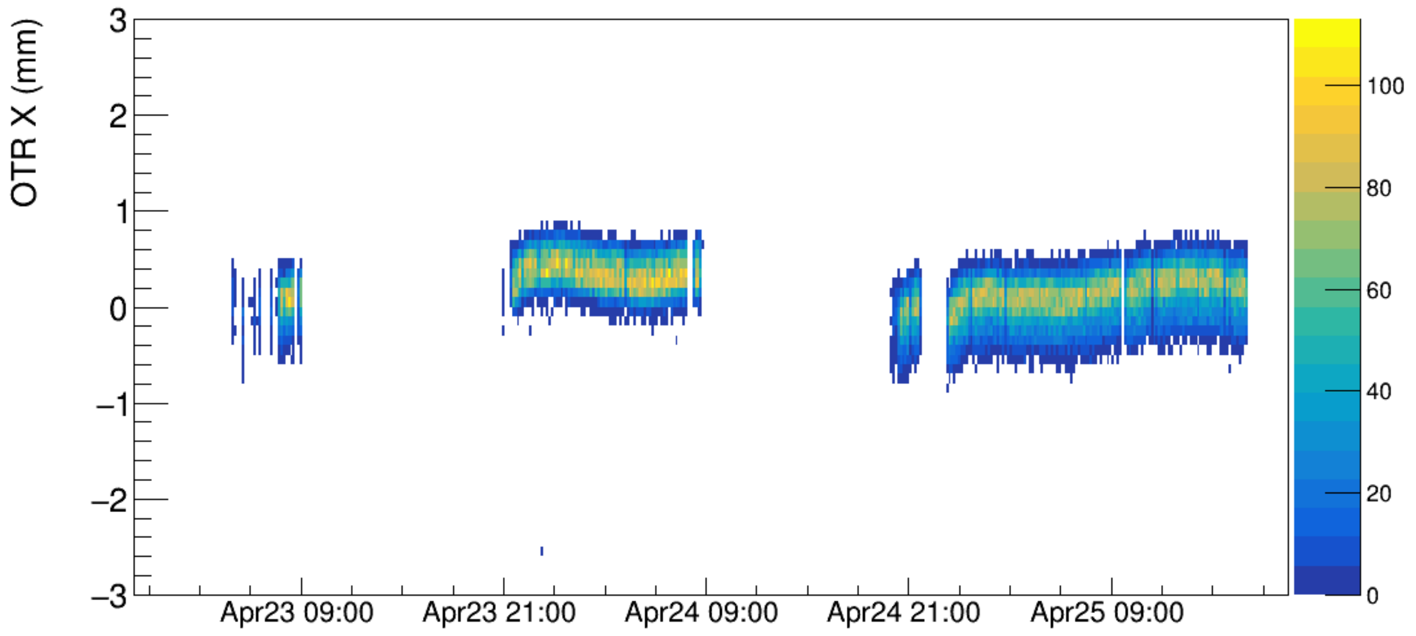


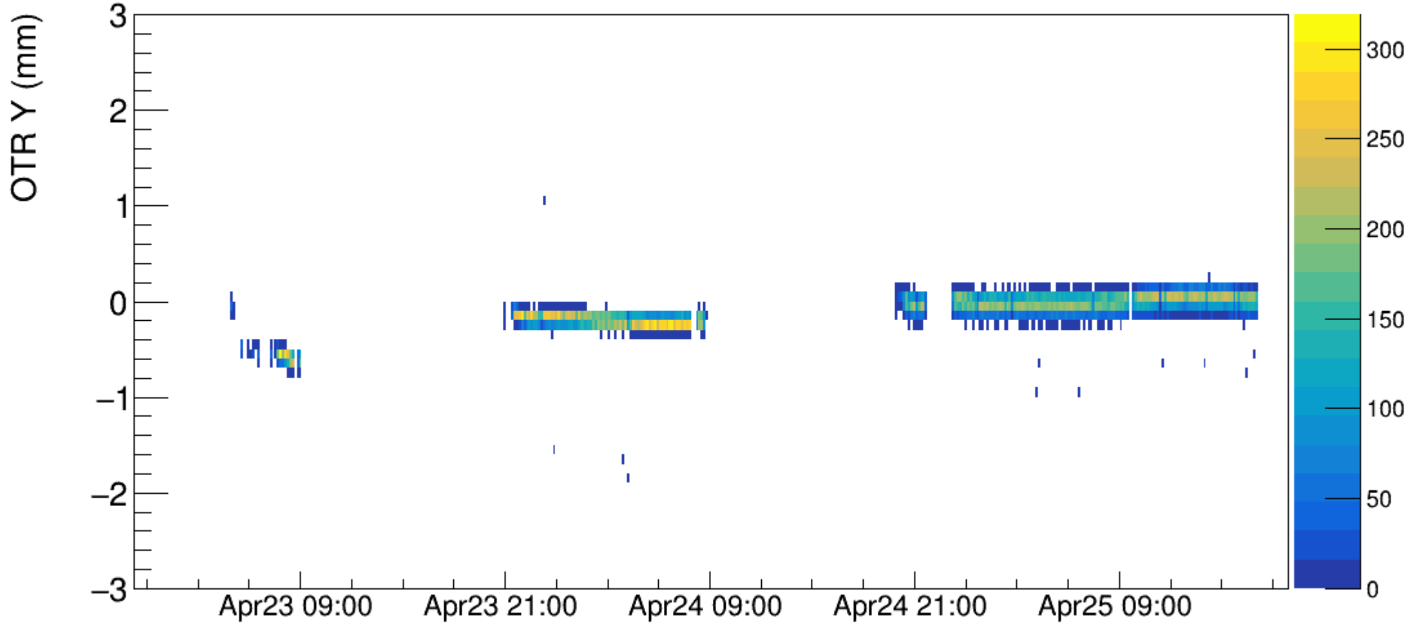


Beam Data

- Plot center of the Gaussian over time.
- Good stability seen throughout run.
- Beam is known to be more stable in X than Y.

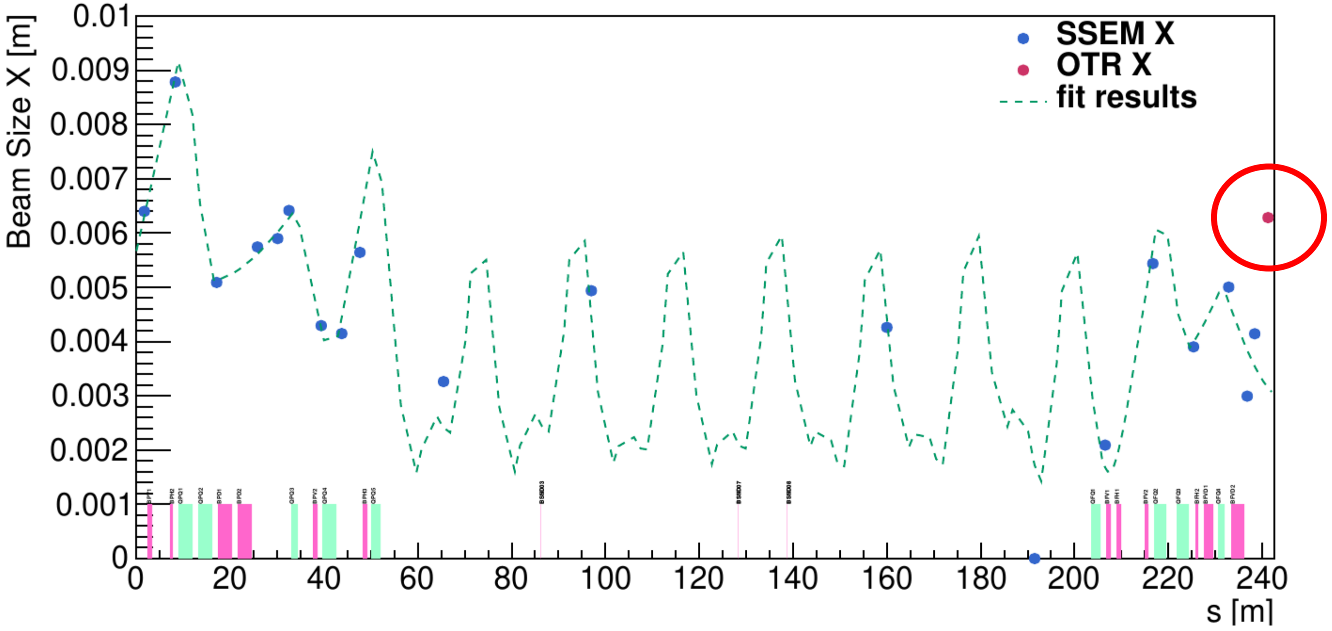


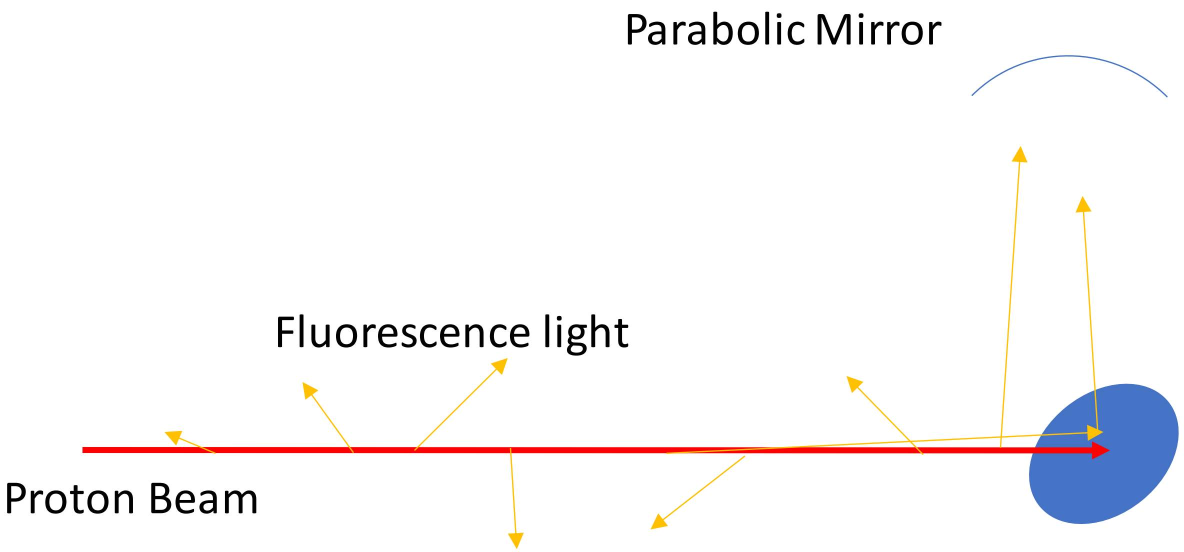




Background light

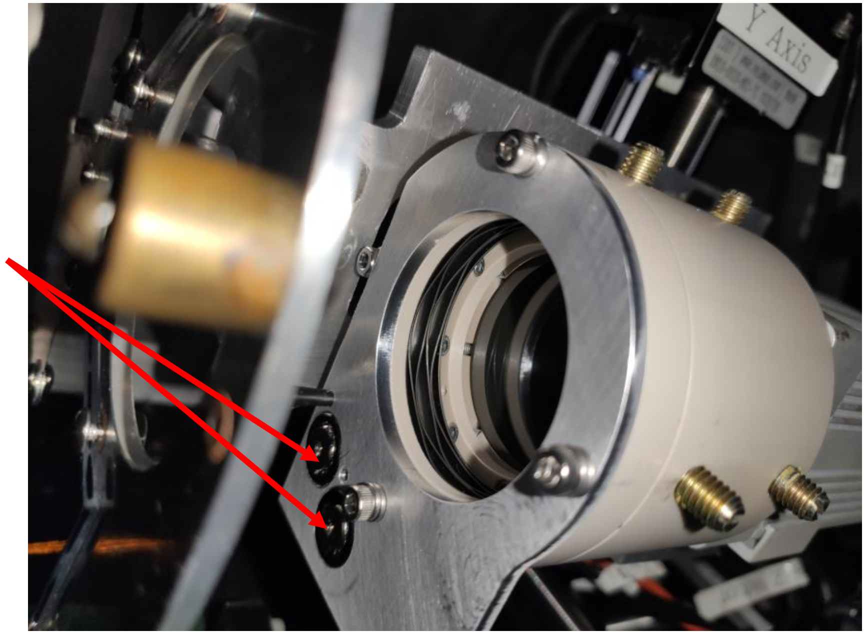
- OTR has consistently observed higher beam width than other monitors.
- Leading hypothesis is beam-induced Helium fluorescence.
- Light reflecting from OTR foil and entering mirrors causing a diffuse background.
- Plan on investigating the timing structure of this background, excited He has very short lifetimes 67-153ns, this can't be done with the camera.

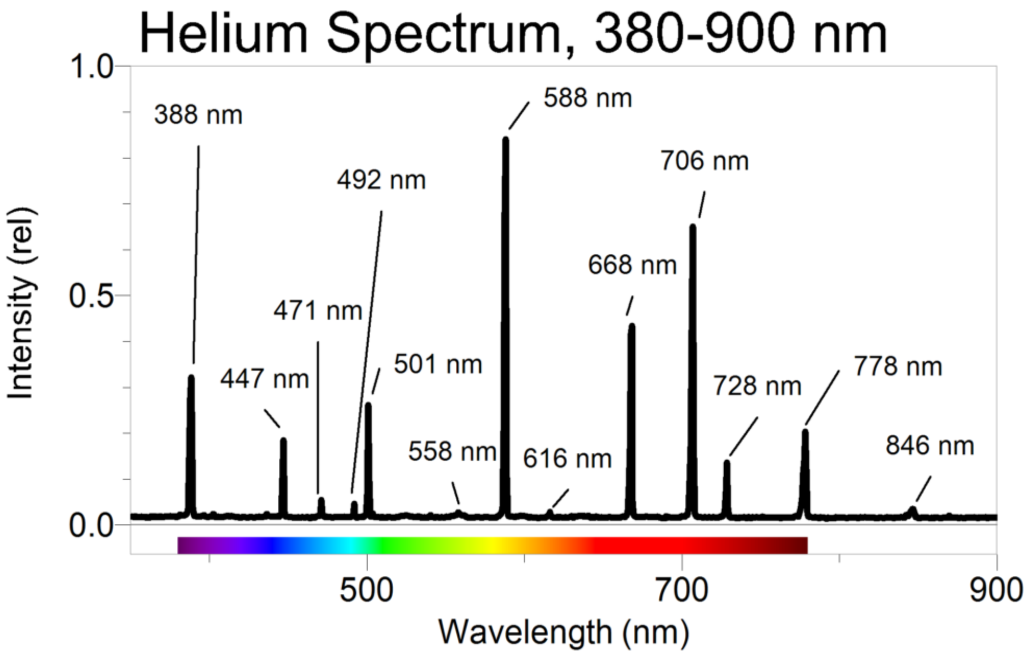




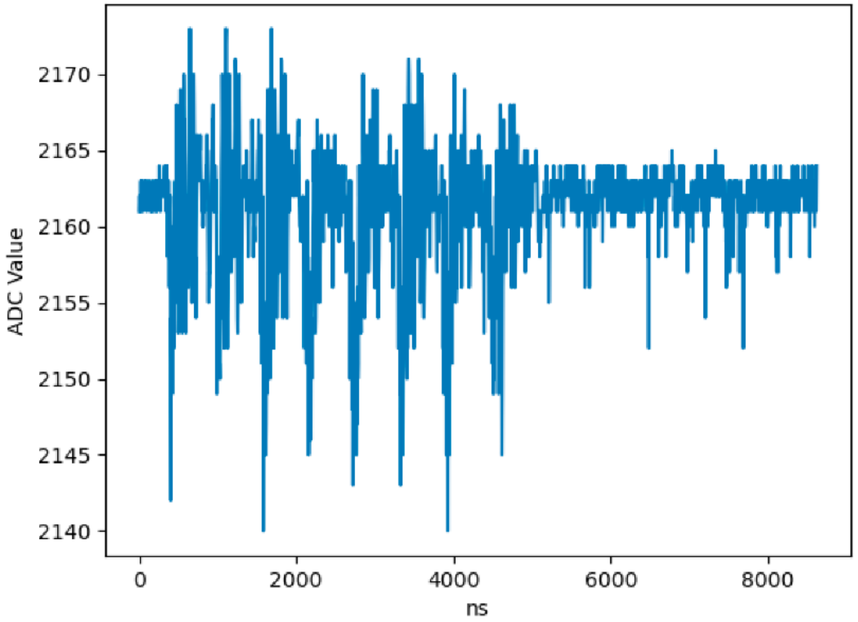
Background Light II

- Have mounted optical fibers to camera, plan to place these in the background light region at the focal plane.
- Record light arrival with a PMT and probe timing structure.
- Can use optical filters to investigate the wavelength dependence.





- Demonstrated principle and DAQ during recent run.
- Observed noise in fibers coincident with beam bunches.



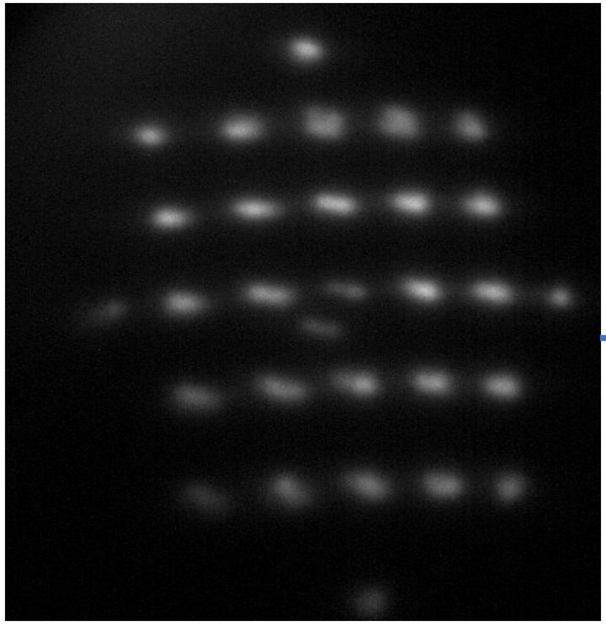
Conclusions

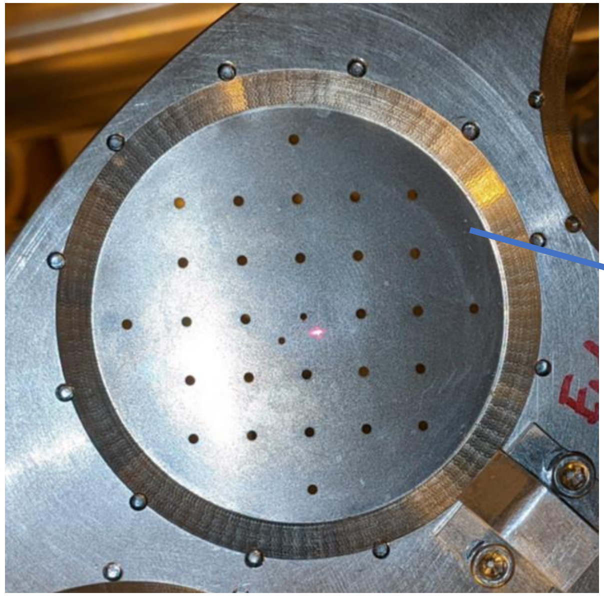
- T2K physics results rely on a well understood neutrino beam.
- The OTR is critical for this and for safe beam operation.
- Significant upgrades have been performed in preparation for >1MW beam operation.
  - New foil design
  - Replacement OTR disk
  - New DAQ

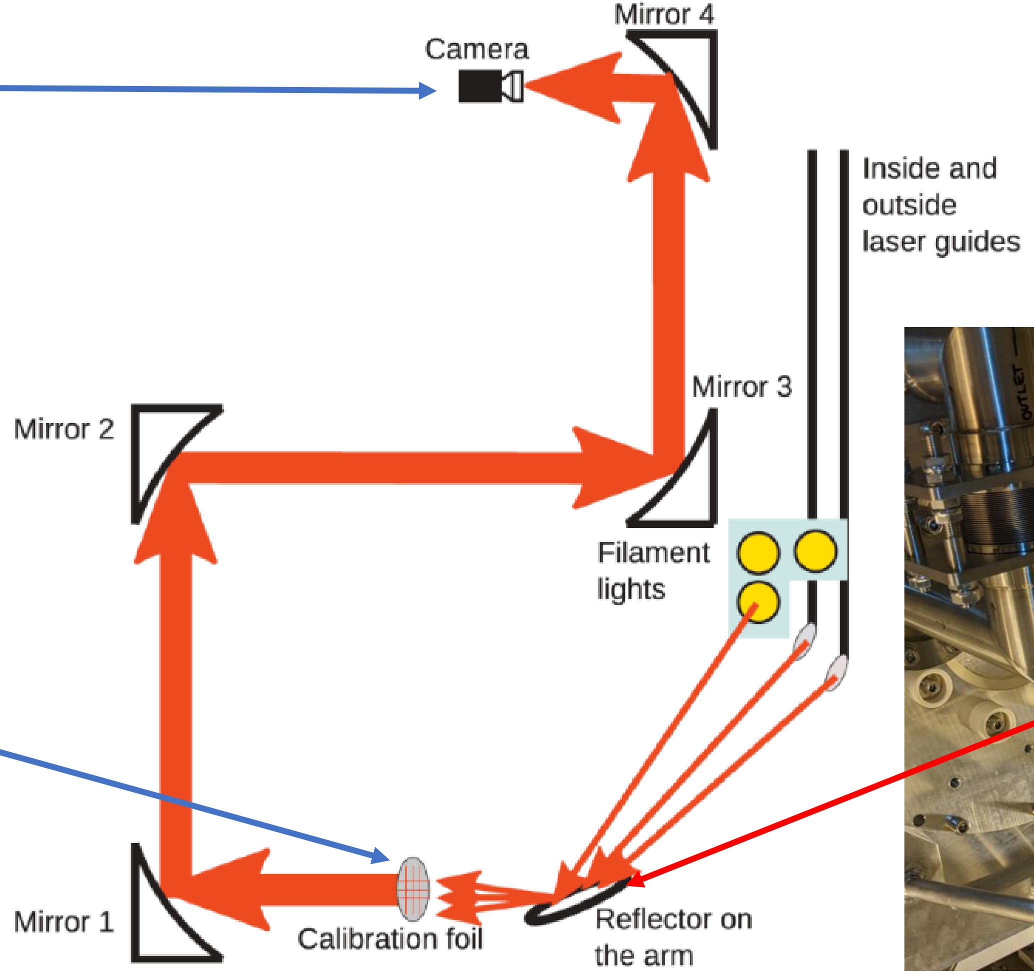
- Successful operation of these upgrades with new repetition rate and beam power.
- Lots of great work from many people to make this possible.

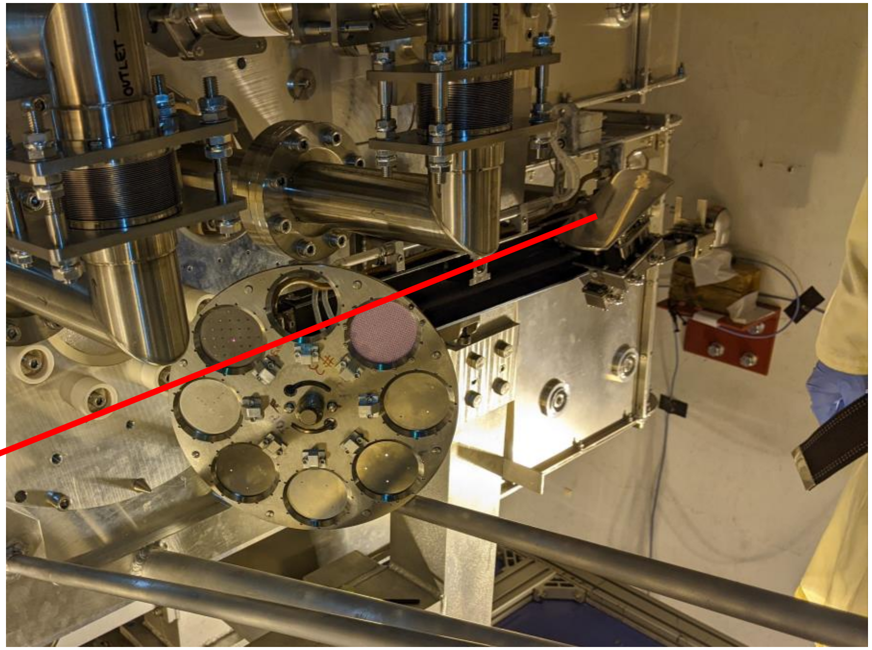
Backups

Calibration



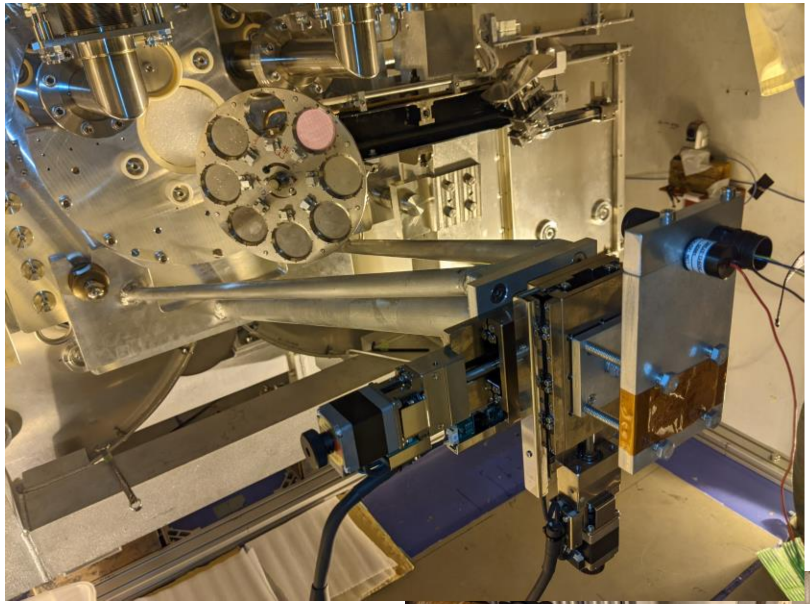


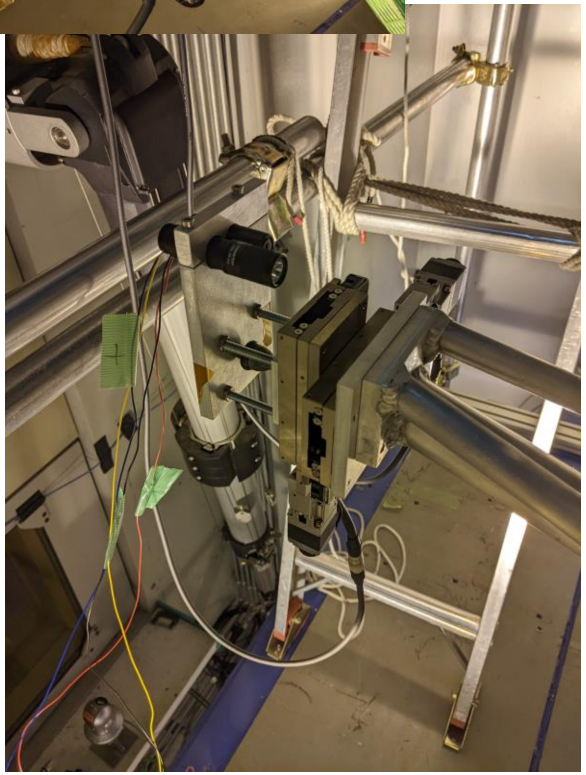


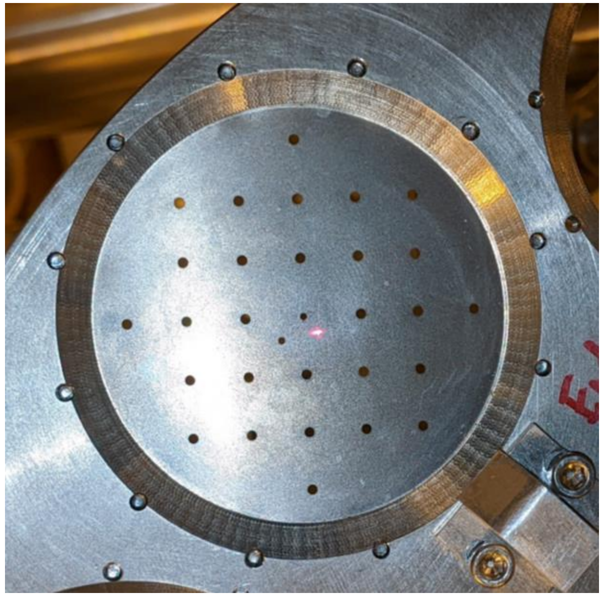


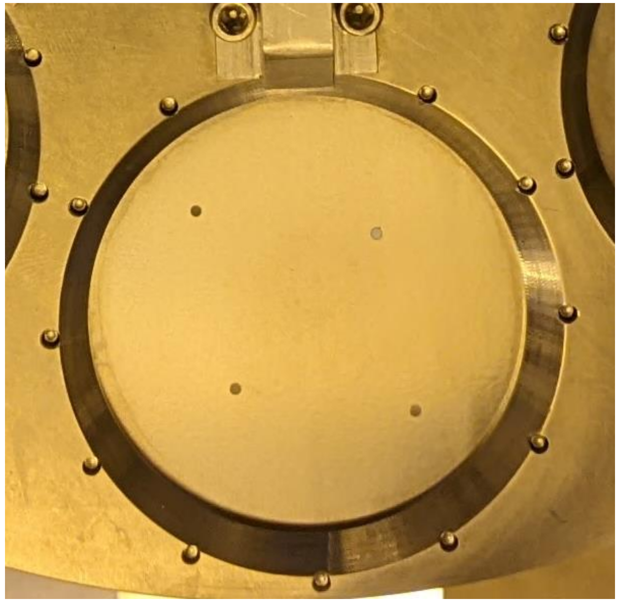
Calibration

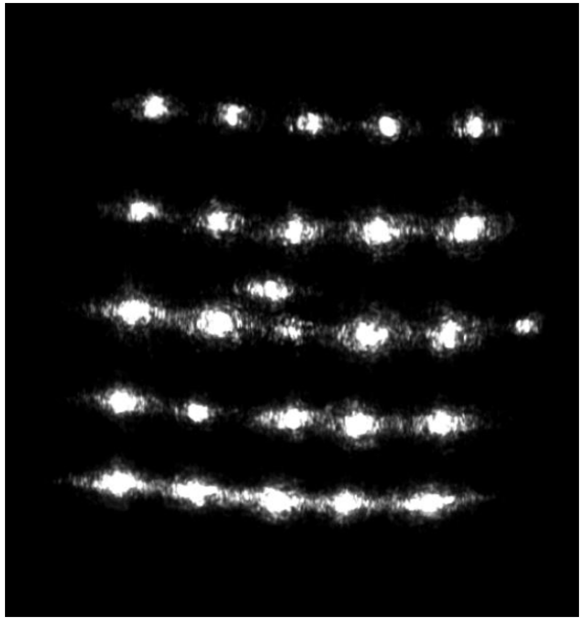
- Shine a laser at the foil from the front.
- Record laser position when laser shines through each calibration foil hole.
- Move to diamond foil and record image at camera when laser is at each position.
- Obtain map true position on foil -> position at camera.











SSEM & WSEM