J-PARC OTR Monitor

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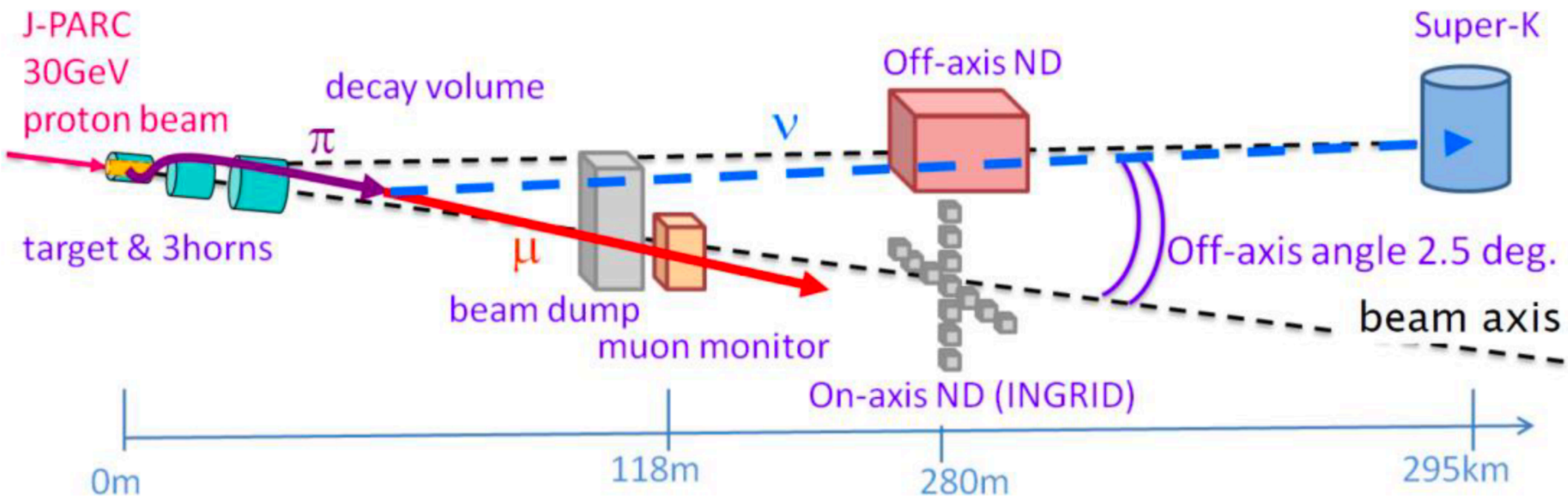
2019/Oct/23

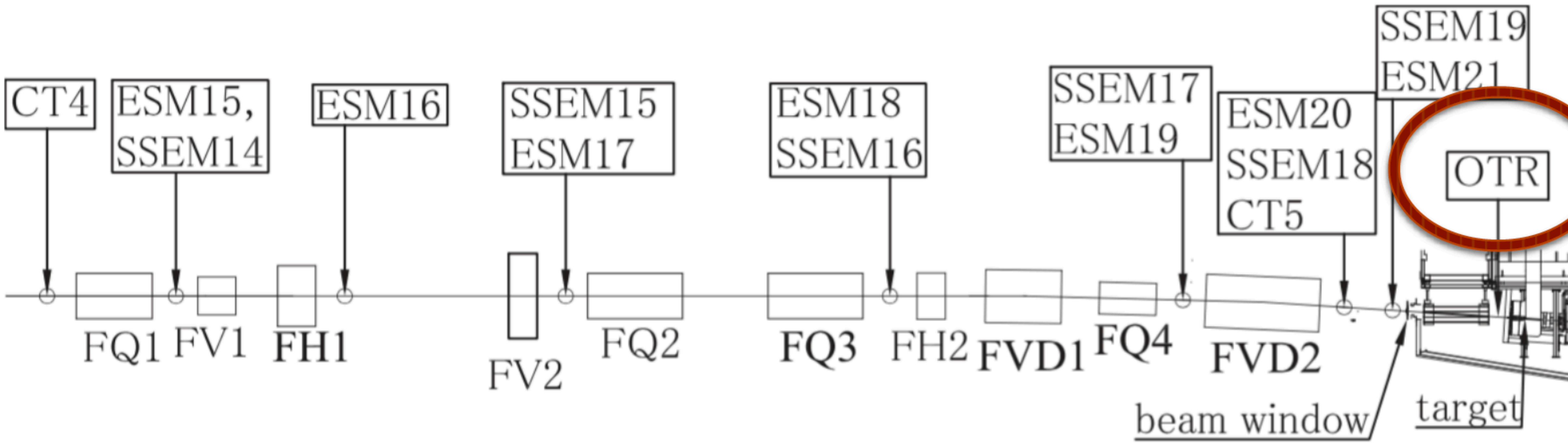
NBI - 2019 @Fermilab

The T2K Experiment

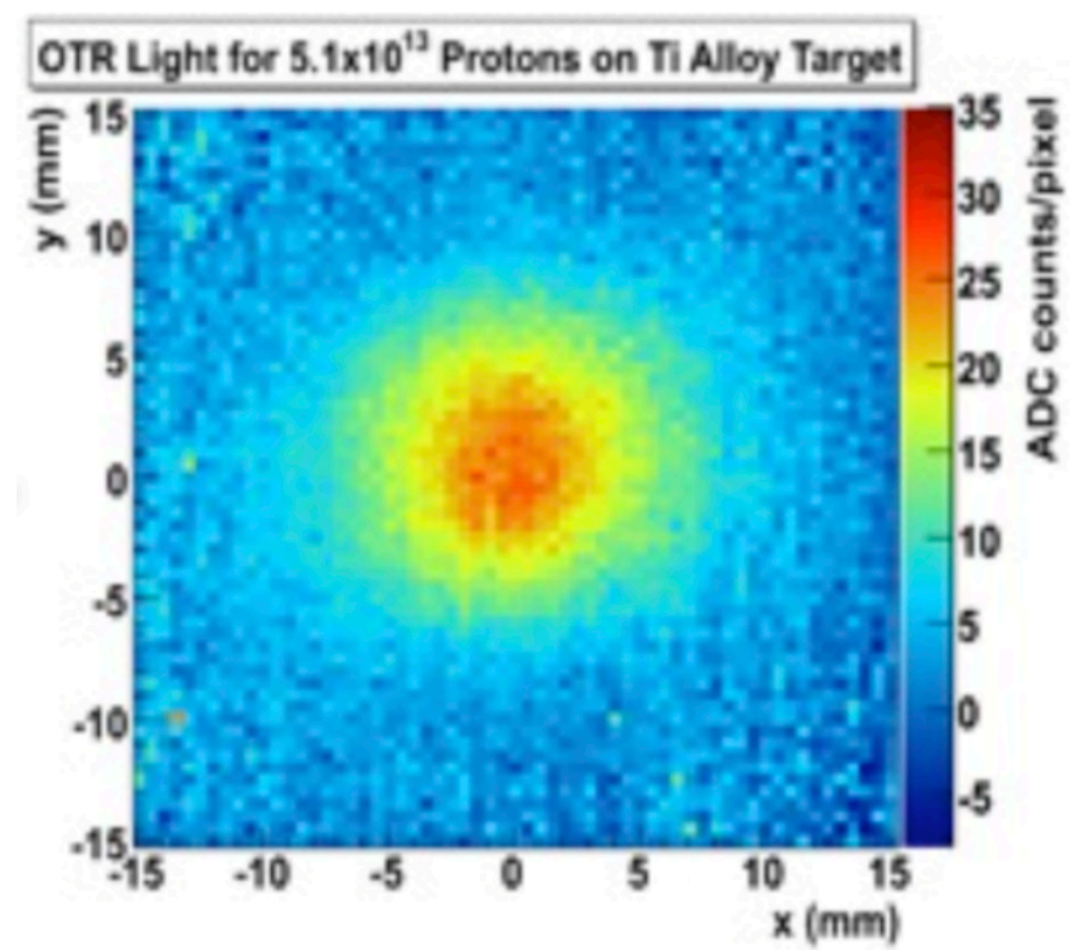


- 30 GeV proton beam hits a graphite target and produces π's and K's.
- 3 magnetic horns focus the π's and K's to select the beam mode (ν or $\bar{\nu}$).
- Off-axis near detectors measure the un-oscillated flux (~0.6 GeV narrow beam).
- Off-axis far detector, Super-Kamiokande, measures the oscillated spectrum, 295 km from neutrino source.

The T2K Beam Monitors

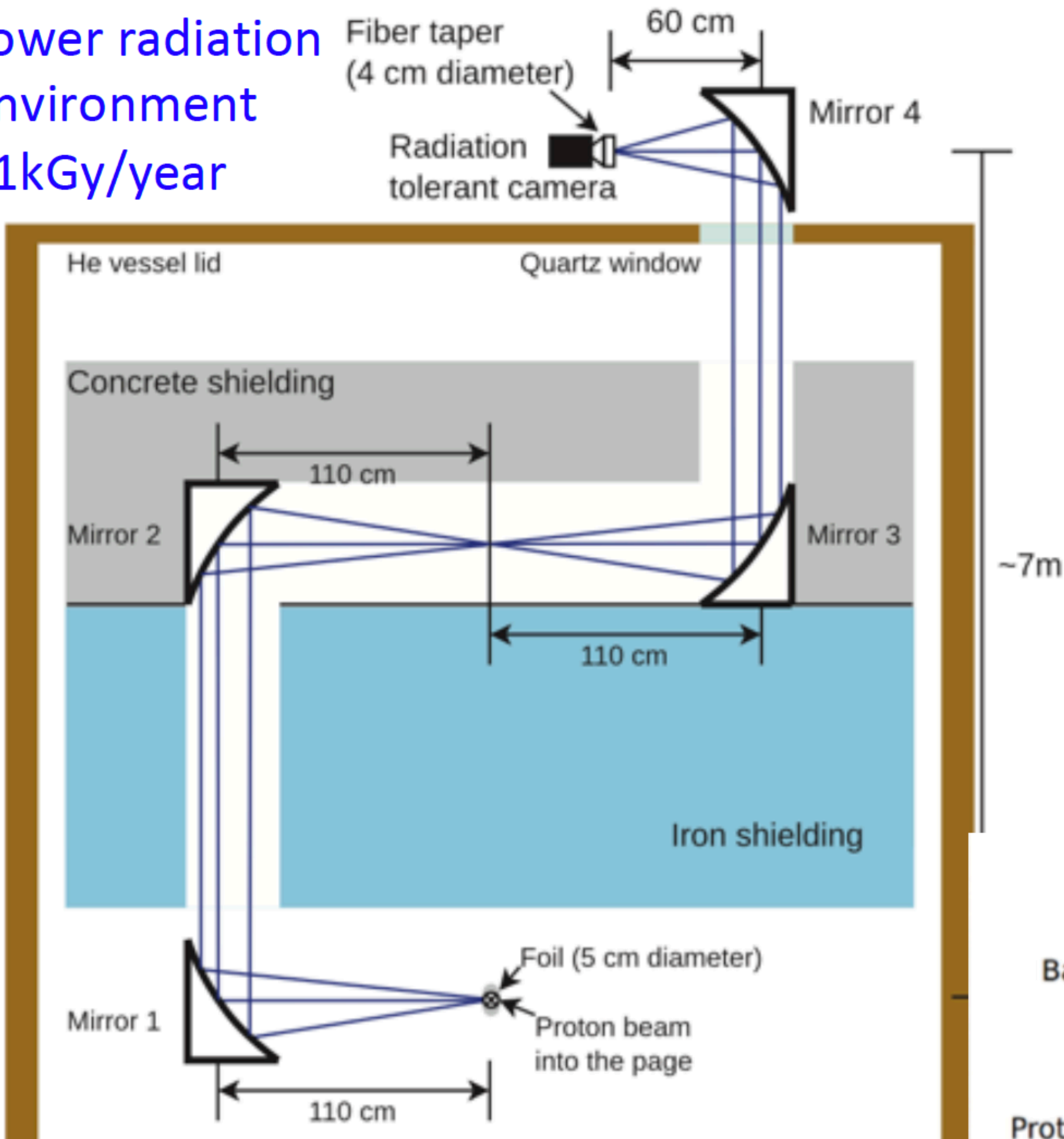


- Beam position is reconstructed using ESMs, SSEMs and the OTR monitors.
- The Optical Transition System (OTR) monitor is the last proton beam monitor (30 cm) before the target.
- Beam profile measurements are used for beam commissioning, online monitoring and neutrino flux prediction.



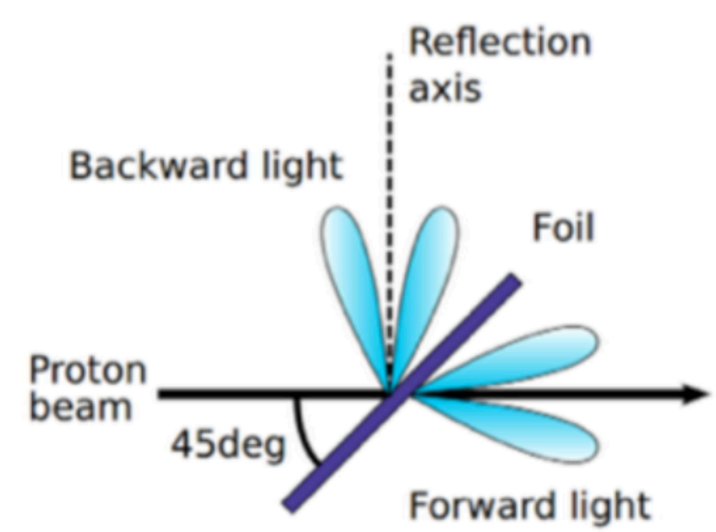
The Optical Transition Radiation System

Lower radiation environment ~1kGy/year

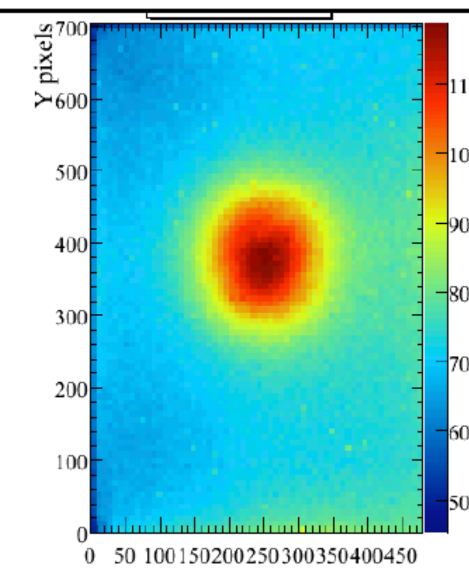


High radiation environment (~5e8 Sv/h)

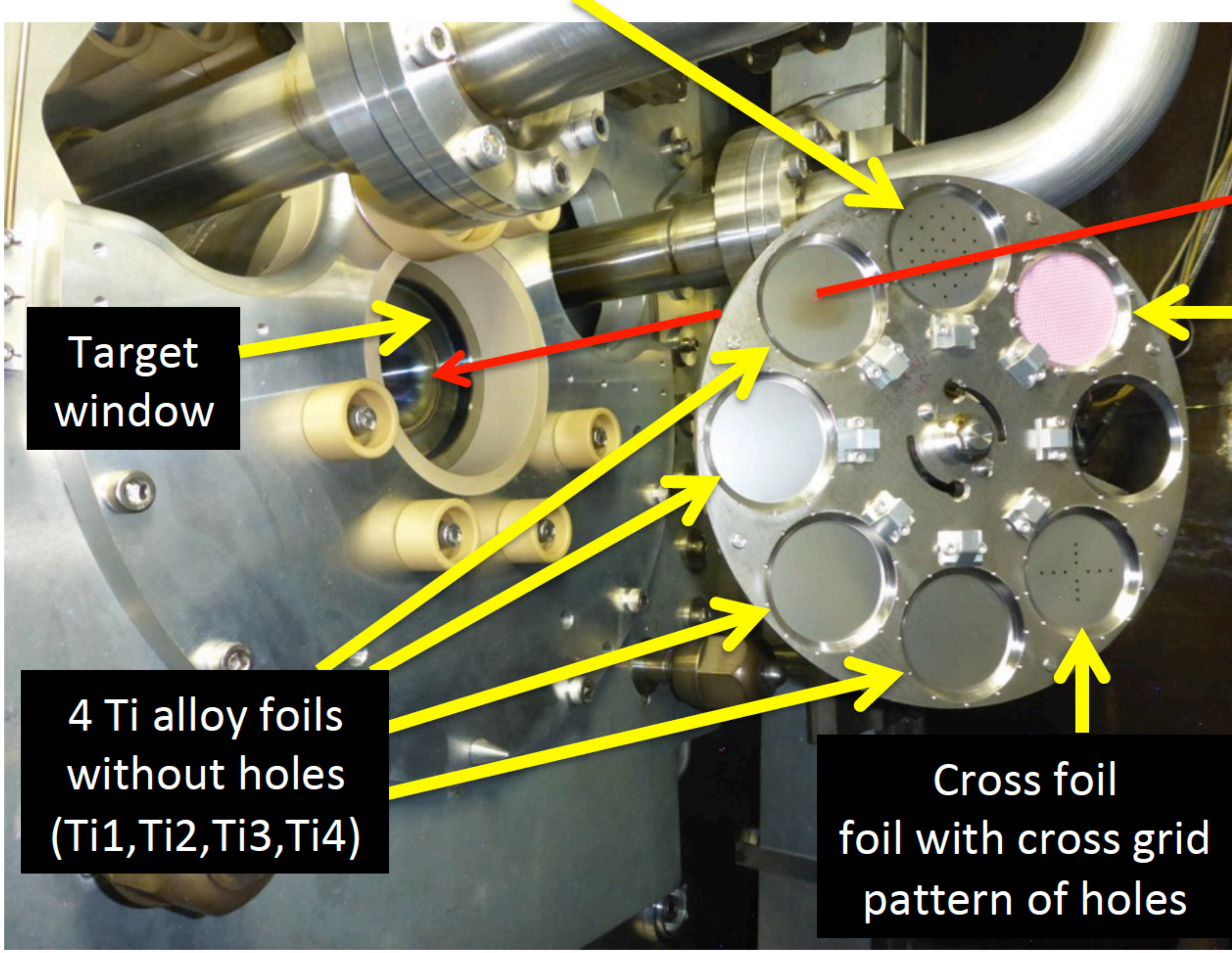
- Proton Beam hits a 50 μm-thick Ti foil at 45° and produces optical transition light 90° relative to proton beam direction.
- Light is then transported to a camera in the He vessel shielding by 4 parabolic mirrors.



2D proton beam profile by camera



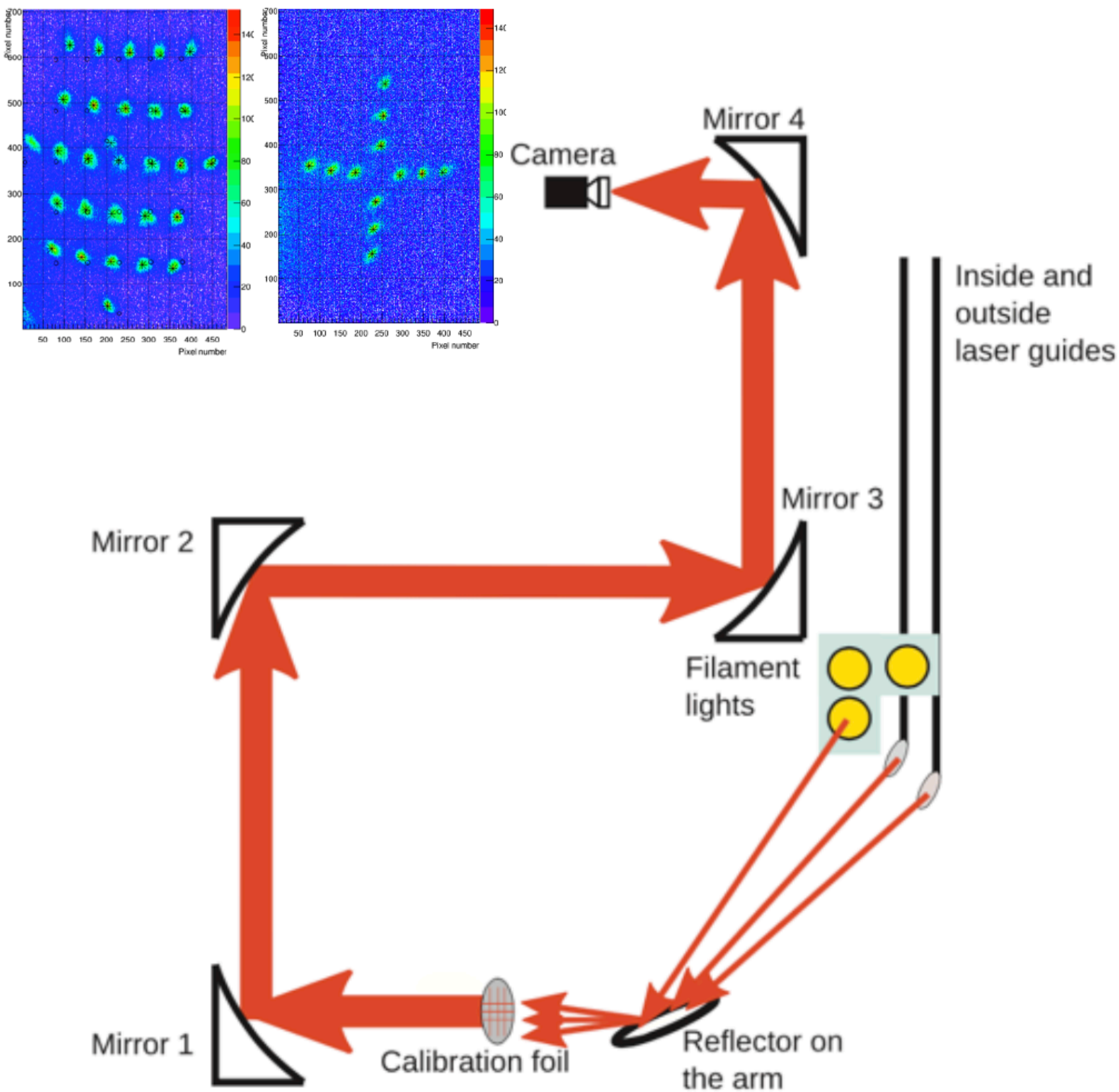
The OTR Foil Disk



- OTR Foil Disk is rotated remotely.
- 8 different foils allow for different running modes.

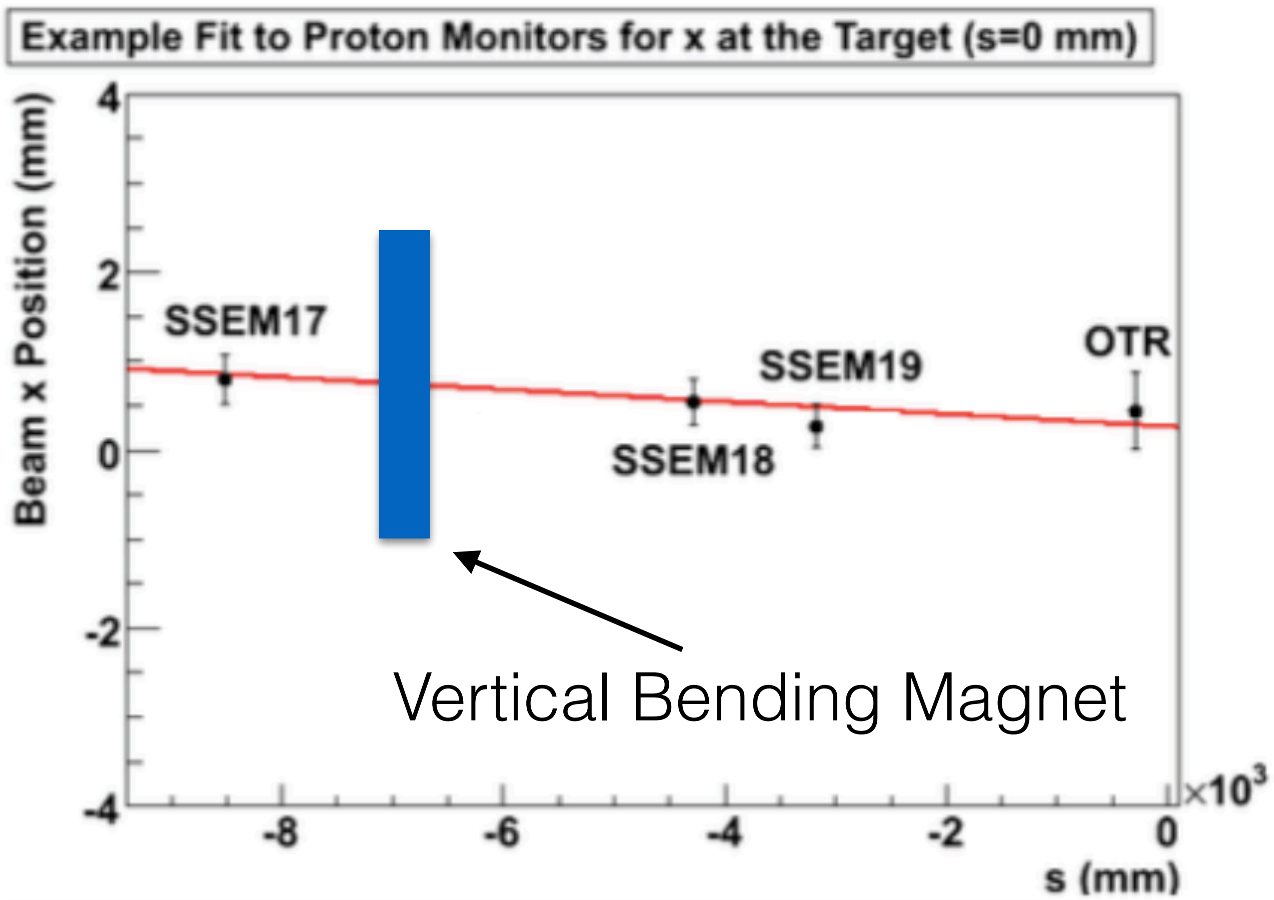
OTR Calibration

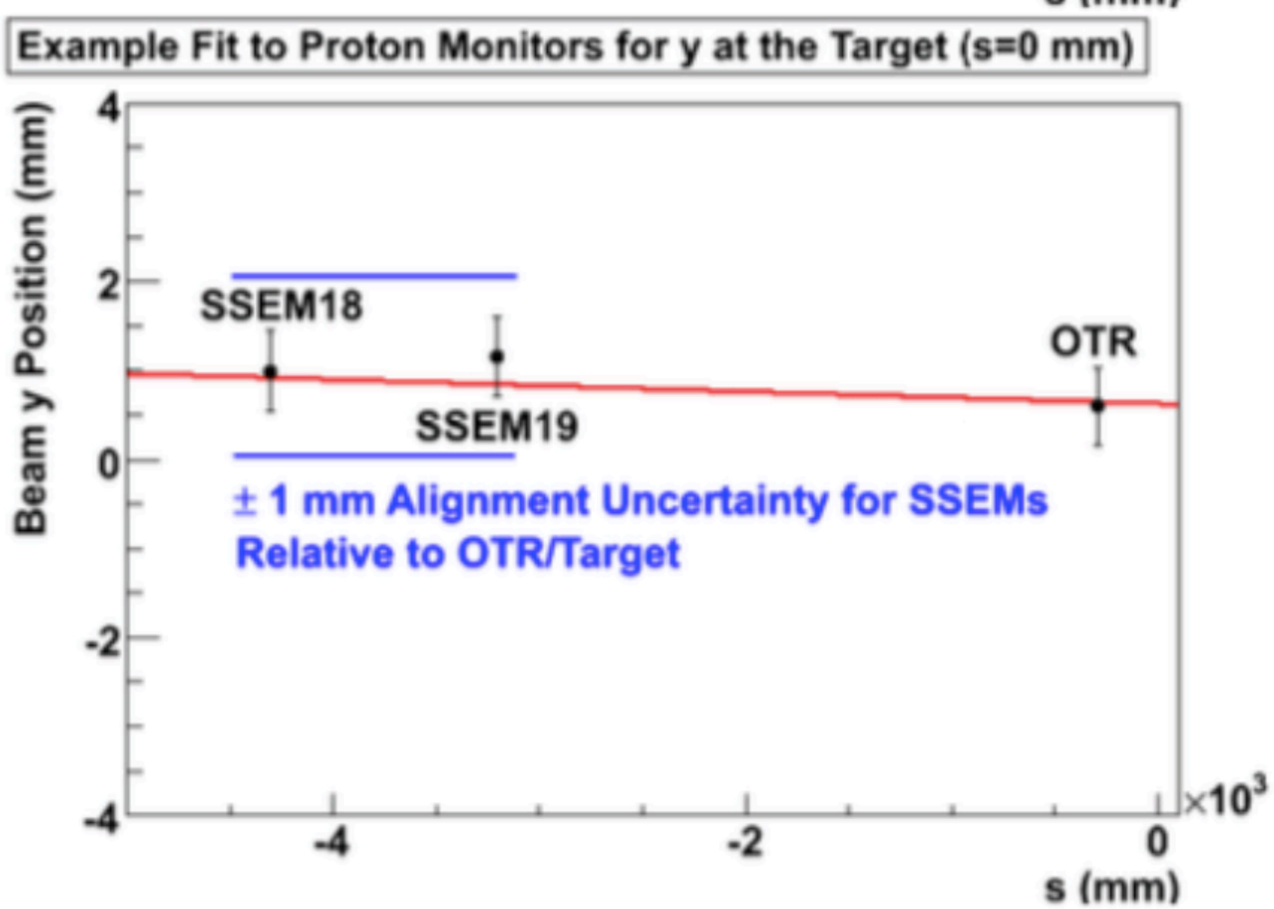
Calibration and cross foils images



- Holes in Calibration and Cross foils were surveyed relative to Horn 1 axis position and are used for calibration/monitoring.
- **Calibration Foil:** Used with filament or laser light for absolute position and correction of optical distortion caused by parabolic mirrors.
- **Cross Foil:** Used for calibration with OTR light.

OTR Impact on Beam Profile





- Proton Beam Monitor measurements are used to extrapolate the beam position and angle on the target.
- OTR measurements help to reduce uncertainties
(monitor closest to target).
- Biggest impact on beam Y-position uncertainty:

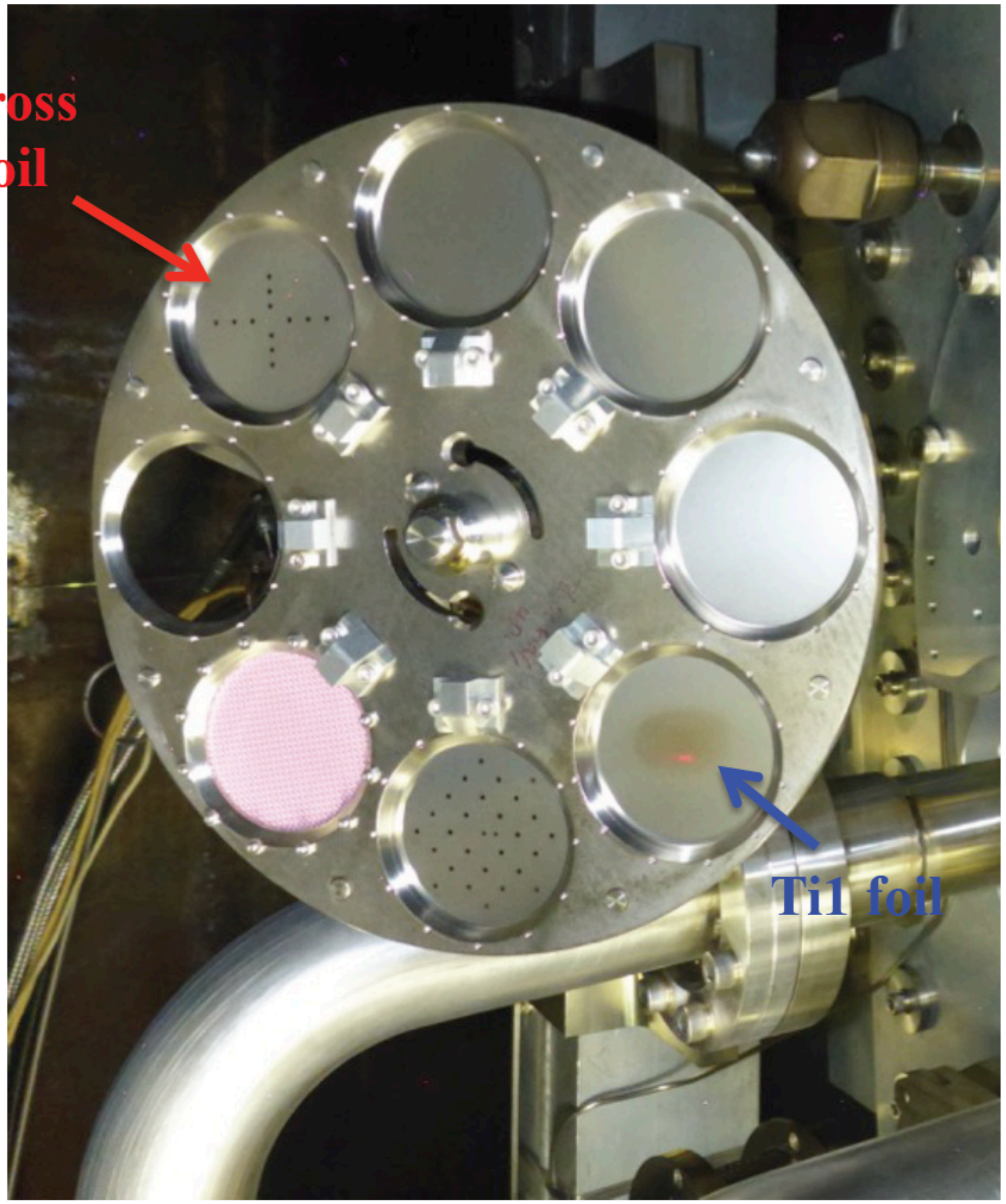
	Extrapolation uncertainty	
	Without OTR	With OTR
Pos. X (mm)	0.5	0.5
Pos. Y (mm)	2.3	0.5
Angle X (mrad)	0.08	0.08
Angle Y (mrad)	0.5	0.3

OTR History

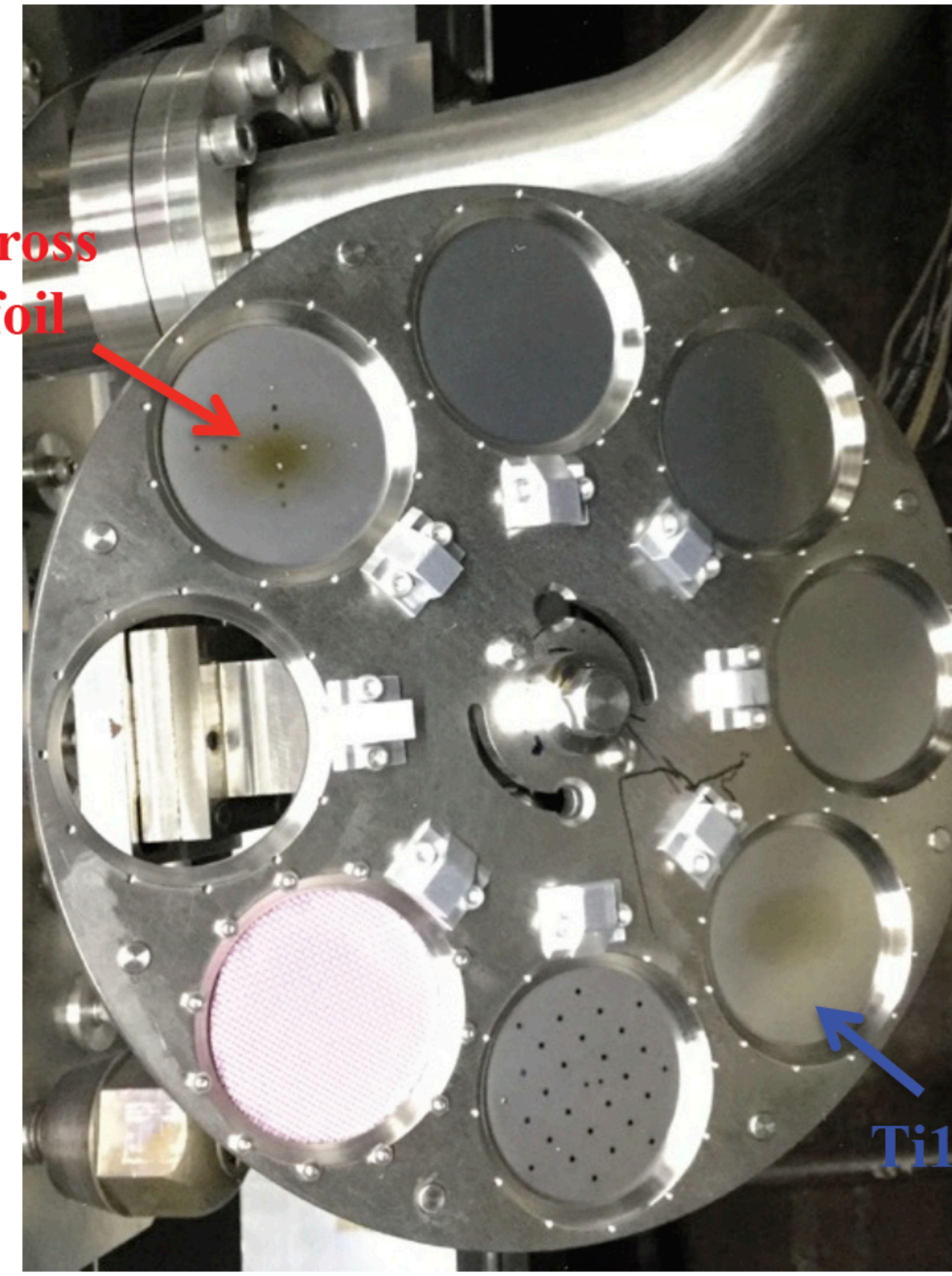
- **OTR-I:**
  - Stable operations during 2009-2013.
- **OTR-II:**
  - Built in 2009 as spare system for OTR-I.
  - Assembled and aligned in Jan. 2011.
  - Operating since 2014.
  - Cross-foil is used during data taking since Jan. 2016 (disk flange issue).
  - Changed to spare camera on Mar. 2019 due to darkening of fiber taper.
  - New Linux DAQ system tested on Mar. 2019. Parallel operation with Windows system expected for Nov. 2019 run.
- **OTR-III:**
  - Built in 2013, stored as a spare of OTR-II.
  - Assembled and calibrated in 2014.
  - Replaced disk flange.
- **OTR-IV:**
  - Ready, same as OTR-III.

OTR-II Foil Darkening

August 2015 inspection
Ti1 foil: ~5x10^{20} POT
Cross foil: ~0x10^{20} POT

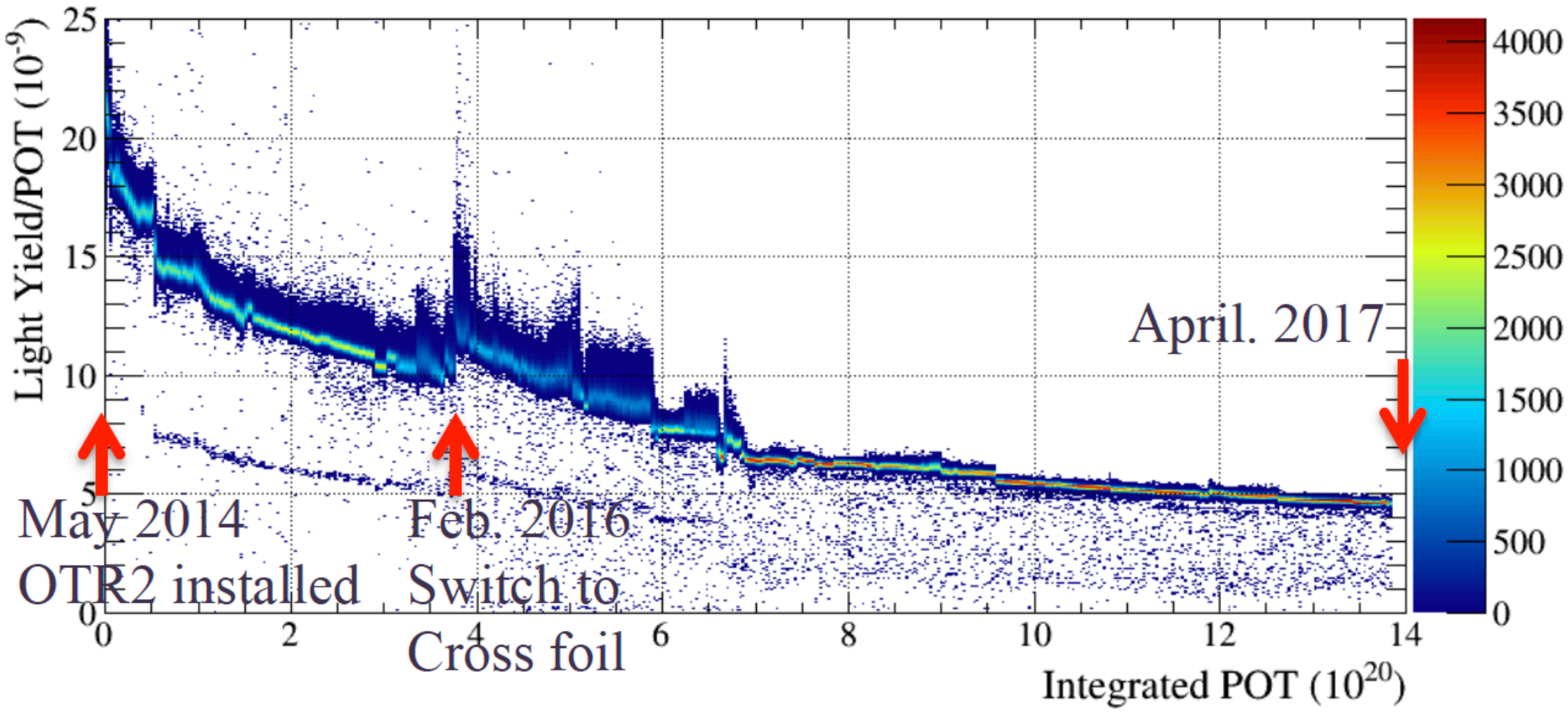


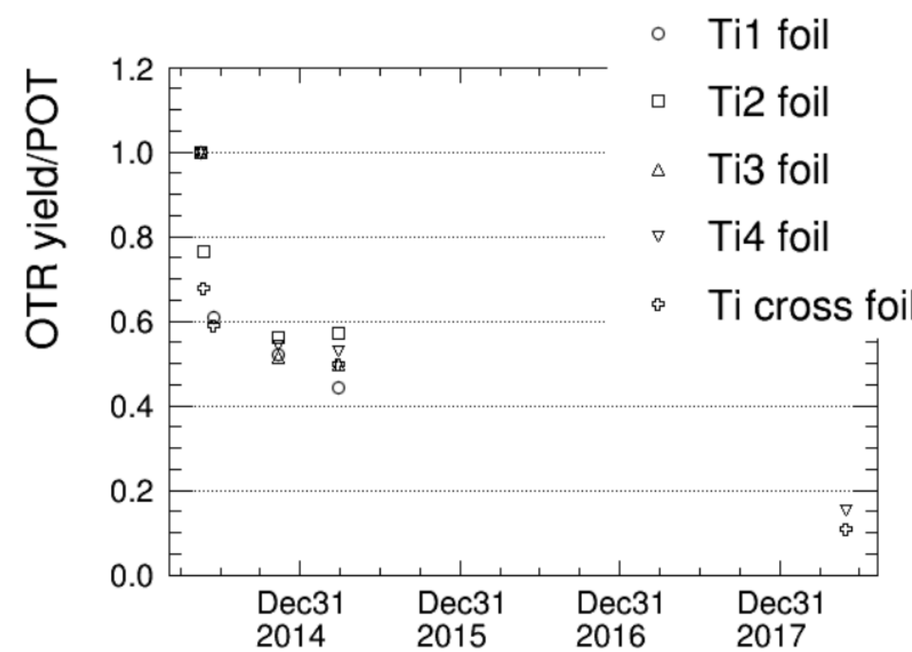
July 2017 inspection
Ti1 foil: ~5x10^{20} POT
Cross foil: ~11x10^{20} POT



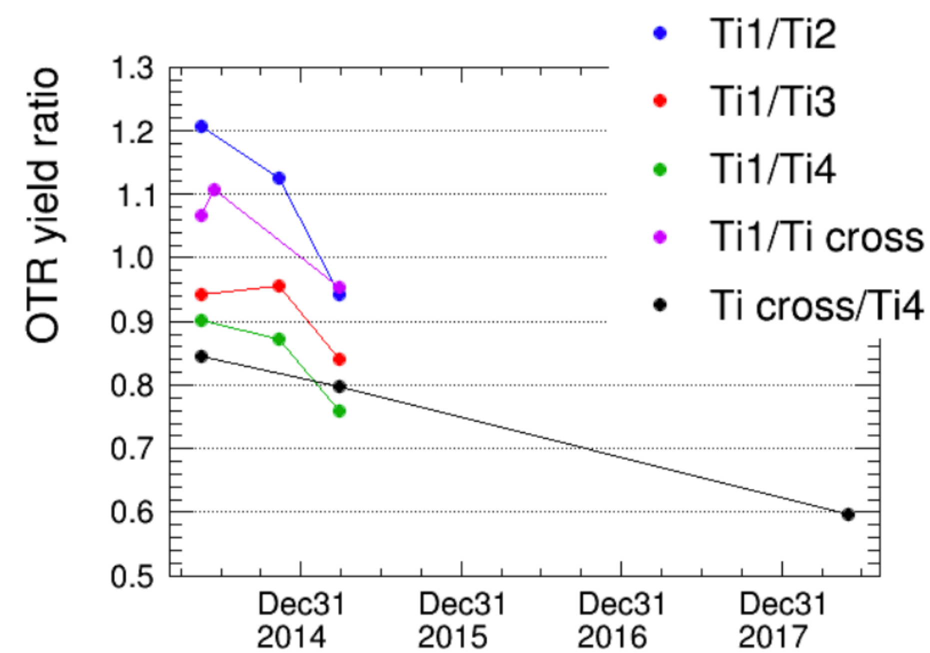
More details on radiation study during Ishida-san's talk this Thursday

OTR-II Light Yield

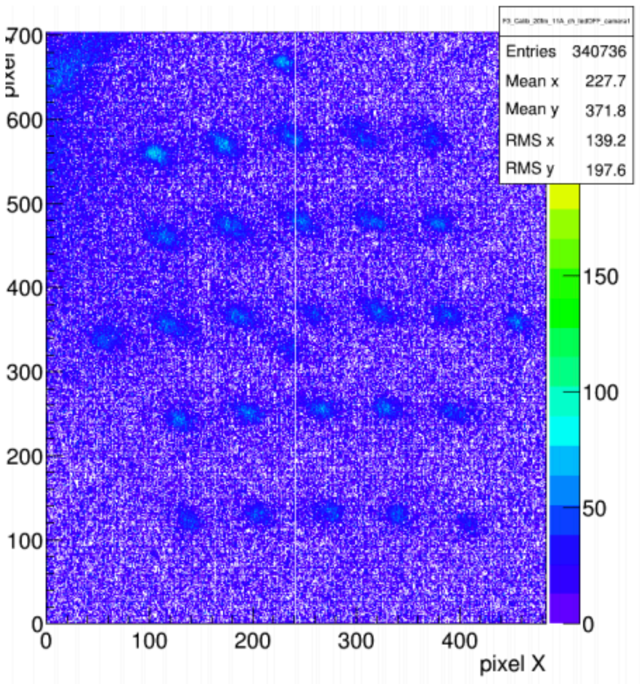


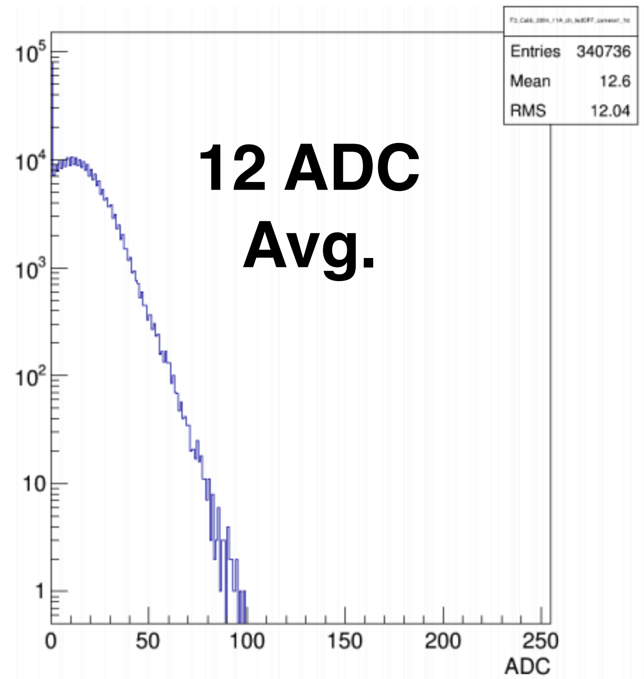


- OTR light yield reduction is seen in all foils.
- Partly due to foil darkening, but main reason is darkening of the fiber taper in front of the camera due to radiation.
- A new camera+taper system was installed this Spring 2019 and it will be used for the coming data taking period
Nov. 2019 - Feb 2020.



OTR-II Light Yield

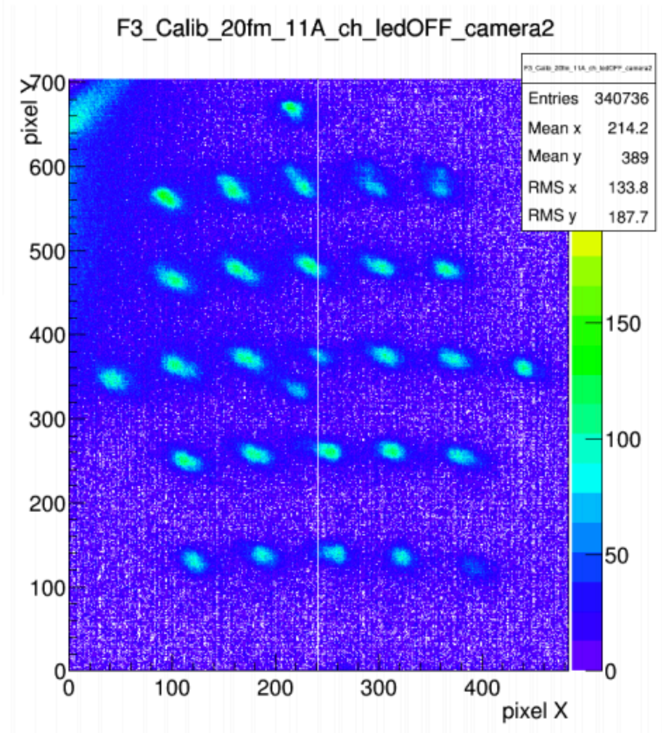


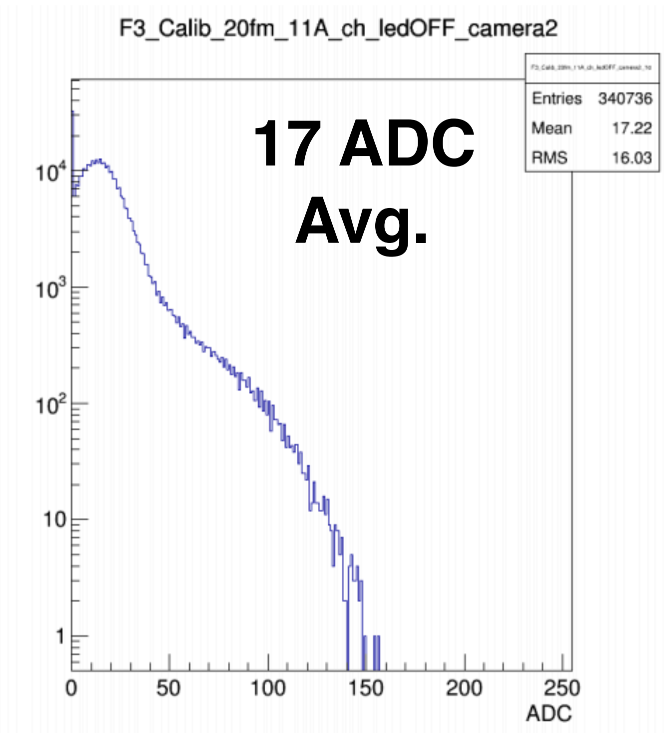


12 ADC Avg.

Old camera

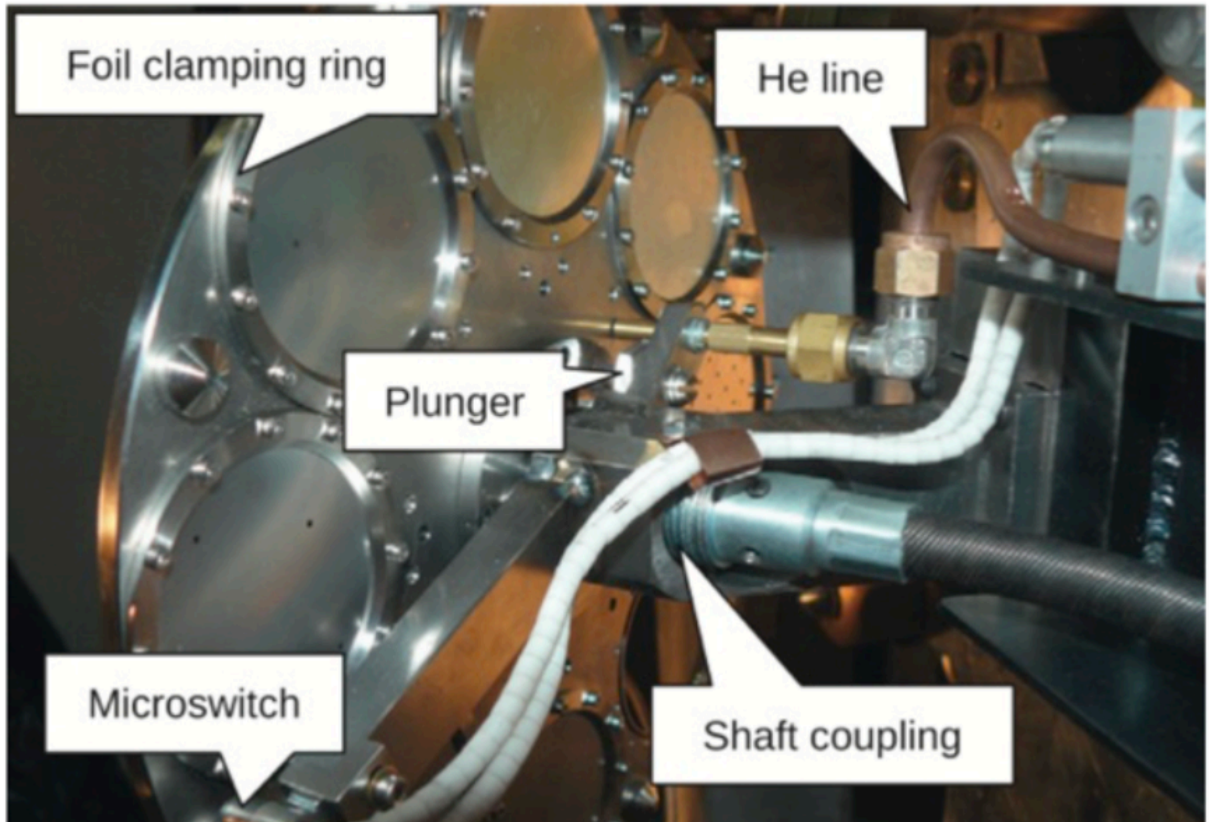
Spare camera

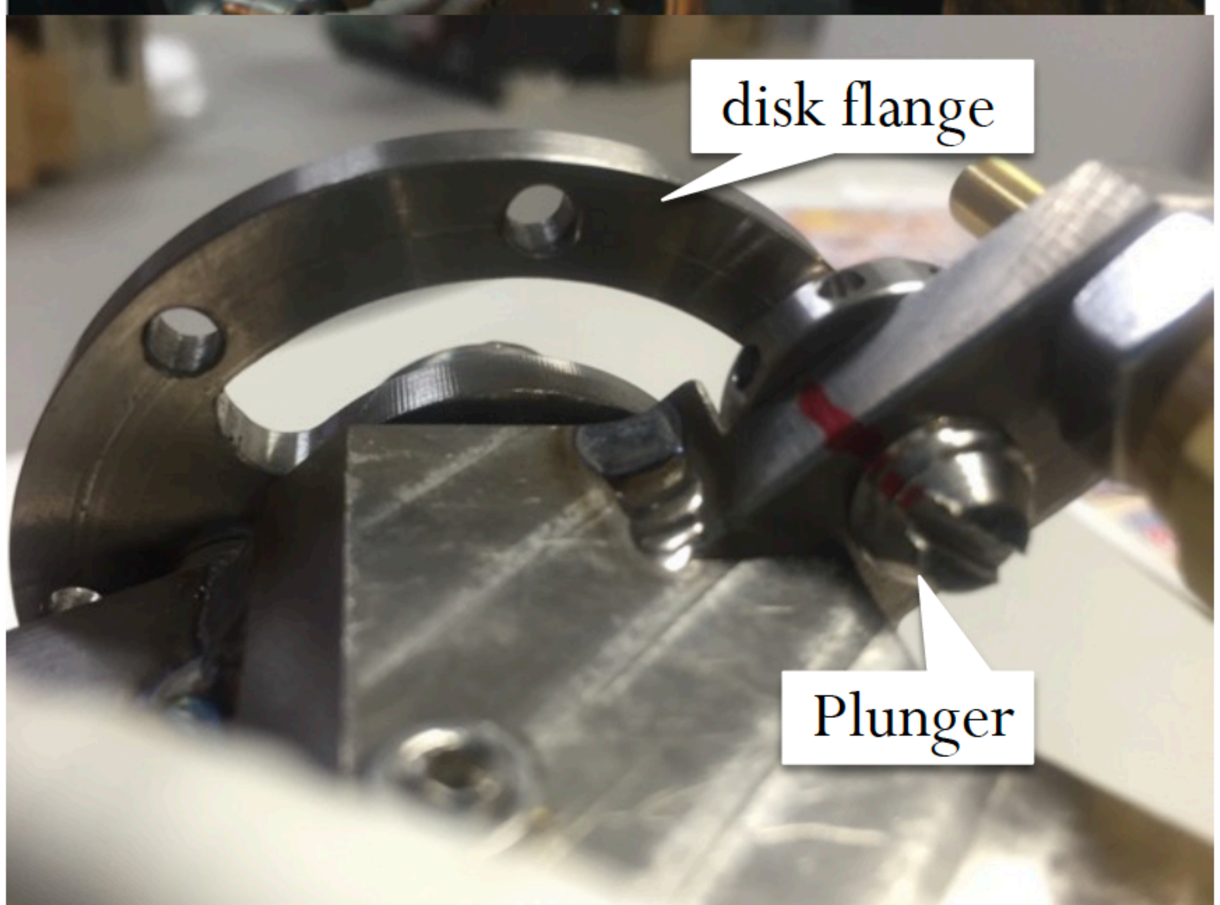




17 ADC Avg.

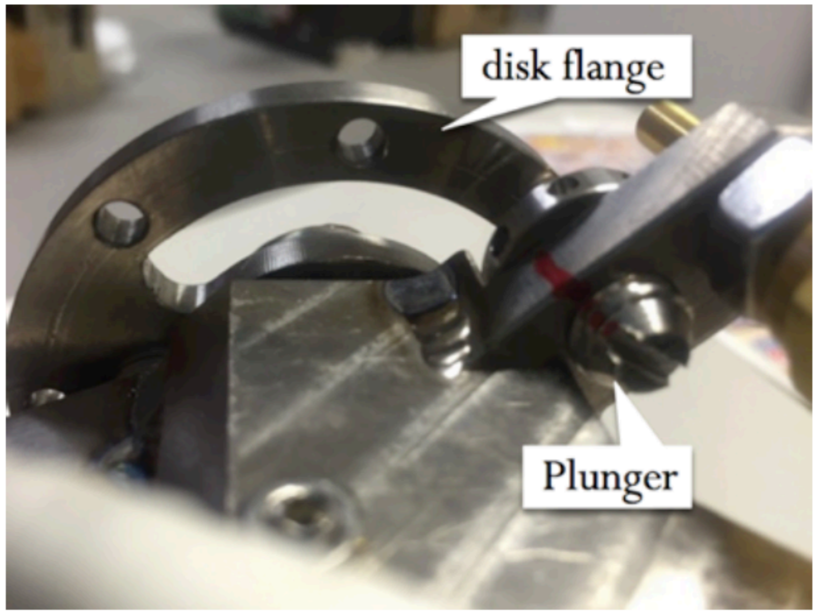
OTR-II Rotation Mechanism Problem





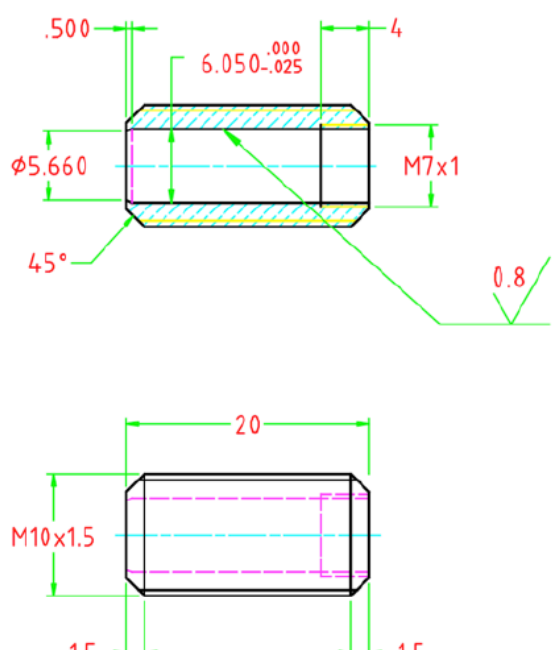
- Rotations became stiff due to flange/plunger damage:
  - Motor needs more torque for rotating.
  - Observed damage to Ti flange caused by stainless steel plunger ball.
- Reverse rotations are still possible.
- Issue with Microswitch that checks disk position.
- OTR disk is fixed in the cross-foil position during data taking.

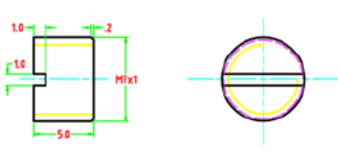
OTR-III & IV Improved Flange/Plunger



Stainless steel commercial plunger:

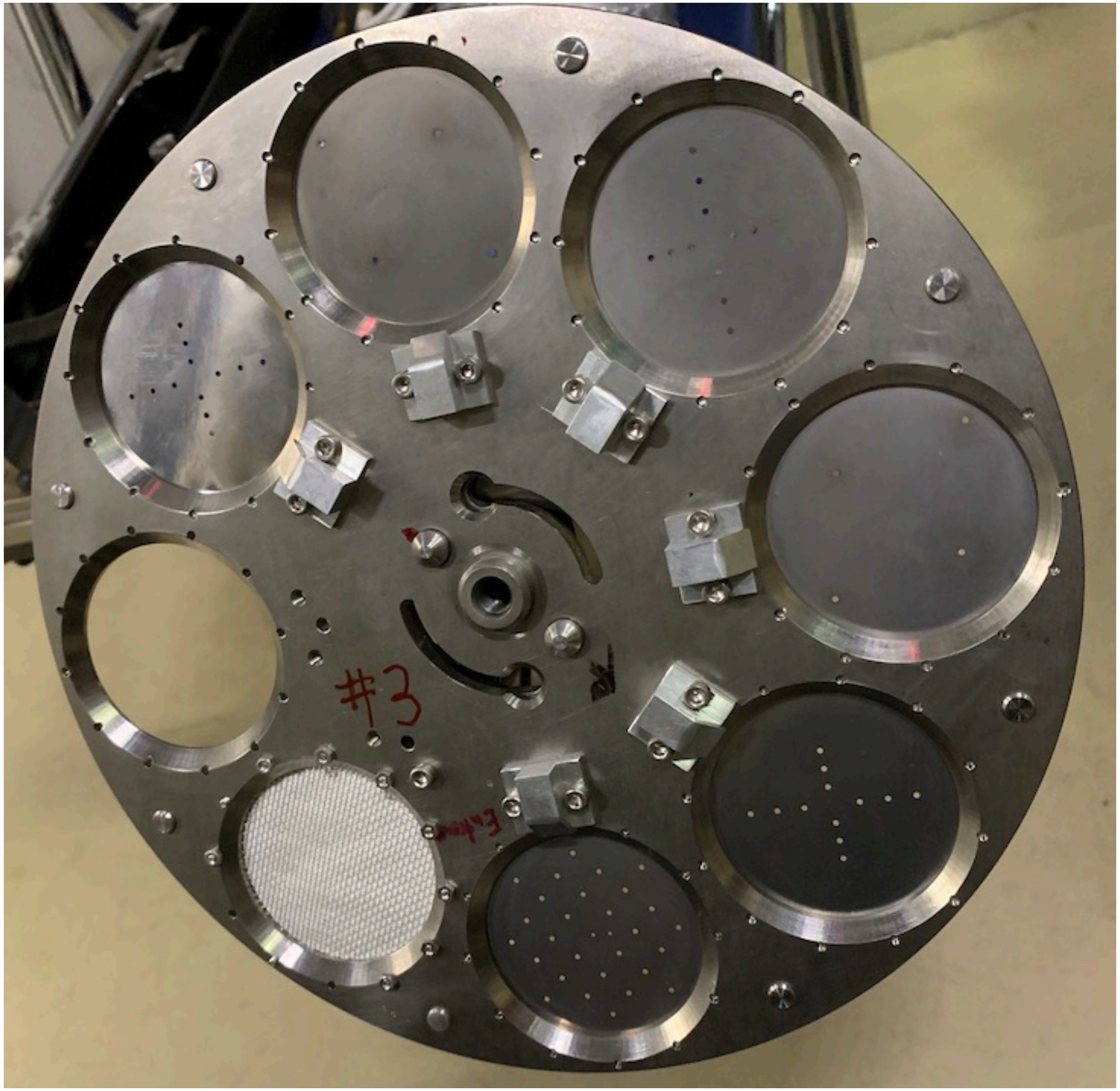
New plunger:





- New custom plunger and disk flanger made of 440C Stainless Steel.
  - Better than commercial plunger and Ti flange of OTR-II.
- Tested for 100 rotations with no evidence of damage.
- No damage is expected in the operation time period.

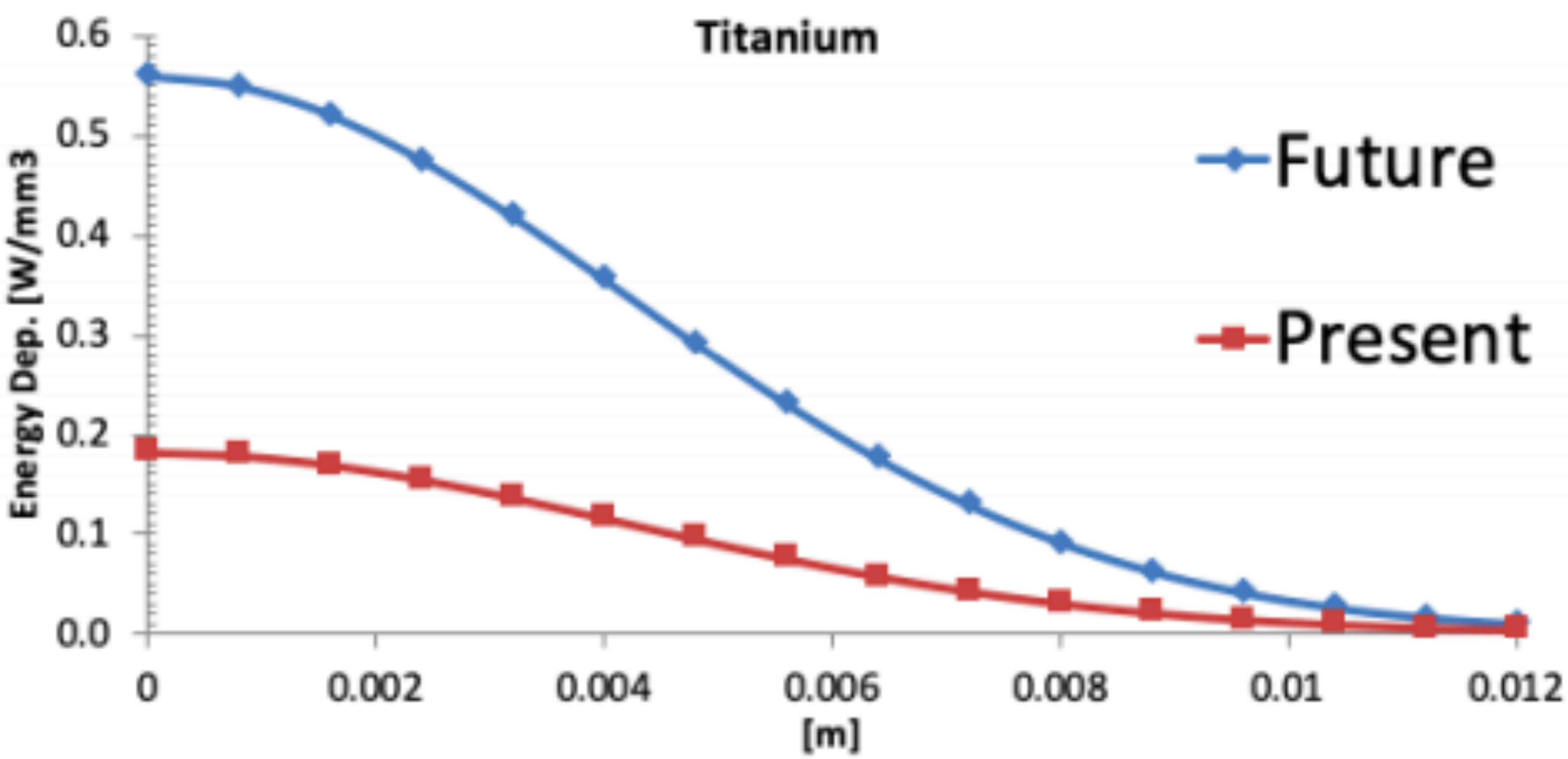
OTR-III and IV Disks



- Both disks are identical.
- All foils have holes, which allows for position monitoring using filament/laser light.
- Currently, same foil material is installed (Ti-15V-3Cr-3Sn-3Al).
- Ti grade 5 (Ti-6A-4V) is also being studied and might replace some of the Ti foils.

Future of OTR in T2K's High Intensity Beam

Beam Conditions	Present	Upgrade
Nb. Protons 30 GeV	2.5e14	3.2e14
Repetition Time [s]	2.2	1.16
Beam Energy [MW]	0.545	1.32

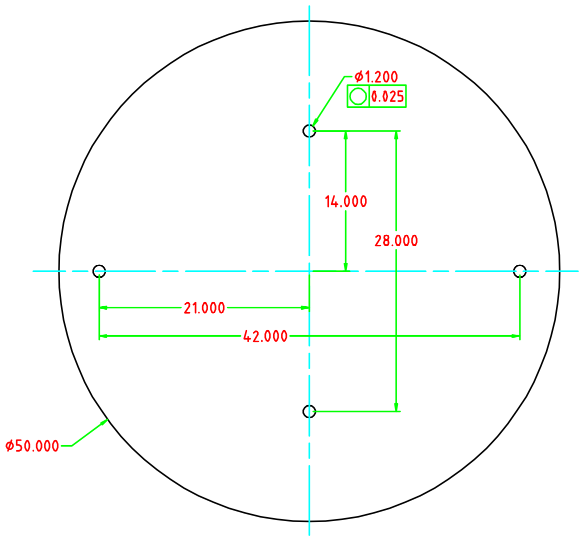


- Evaluation of current OTR foils during high intensity beam.
- Significant stress and foil heating are predicted after the upgrade.
- Initial OTR design only had solid foils. Holes were not included in the stress simulations.

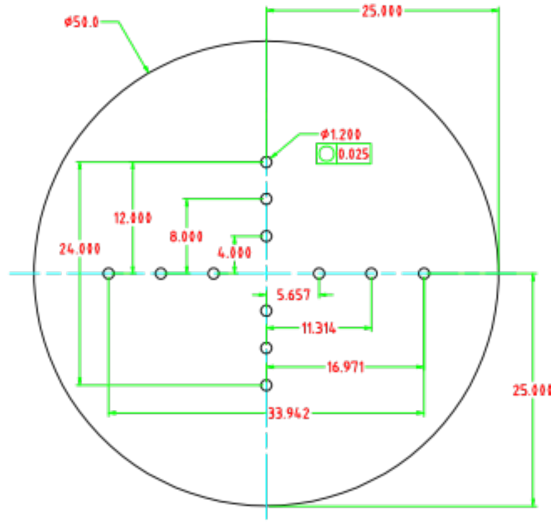
Marco Oriunno - SLAC

Future of OTR in T2K's High Intensity Beam

"1 Hole"



"3 Holes"



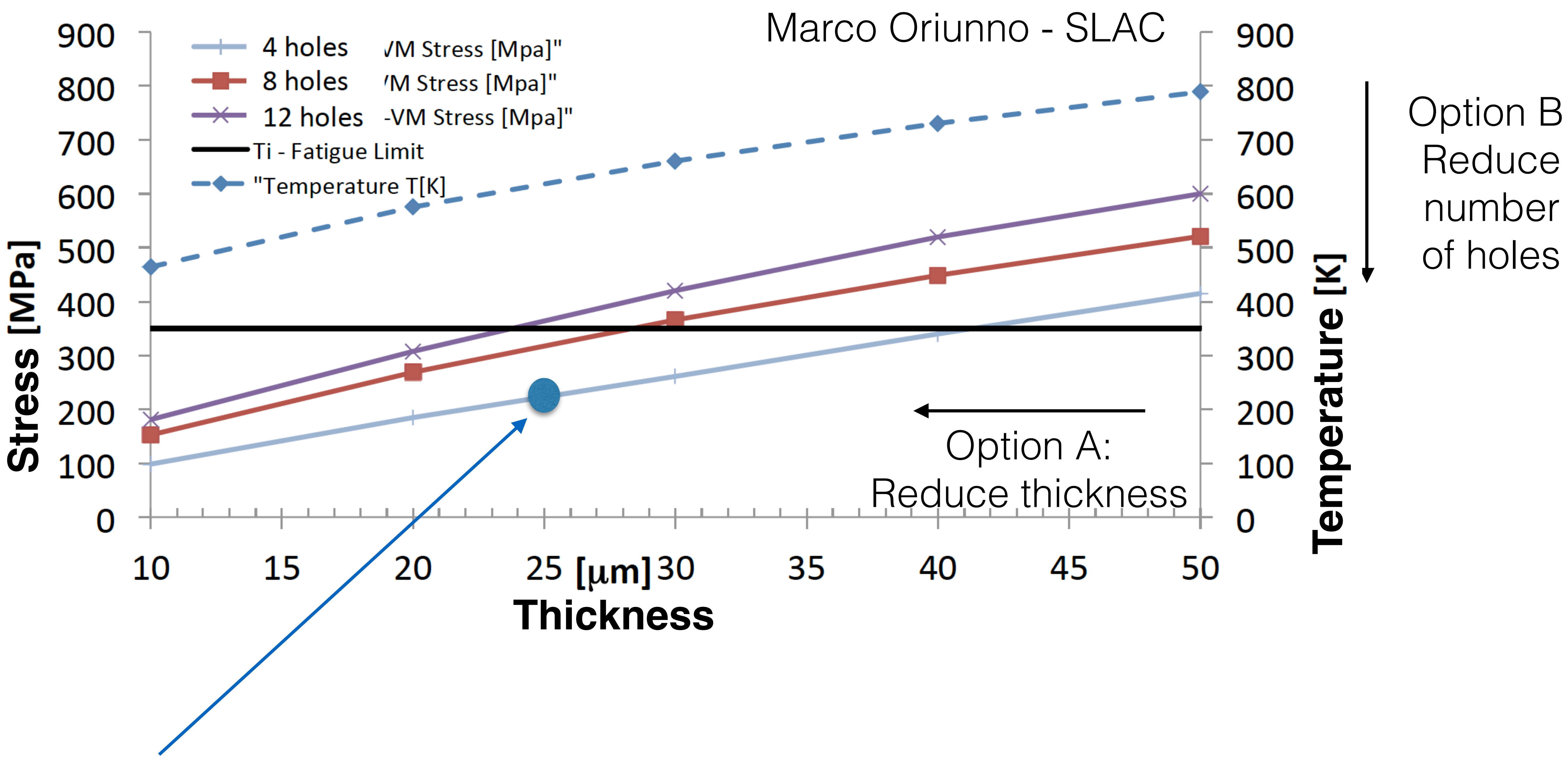
- Foil stress is much higher for upgraded beam (more than x2).
- Calibration holes also concentrate stress and increase the maximum stress by another factor of 2.

Present – 50 um foil	No Holes	Holes
Temp [K]	526	529
Stress [Mpa]	133	235
Dep.Power [W]	0.80	0.78

Upgrade– 50 um foil	No Holes	Holes
Temp [K]	784	789
Stress [Mpa]	295	568
Dep.Power [W]	1.99	1.95

Marco Oriunno - SLAC

Options for OTR Foils in MW Beam



- Simply reducing the number of holes or the thickness of the foil is probably not enough. Likely need to do both.

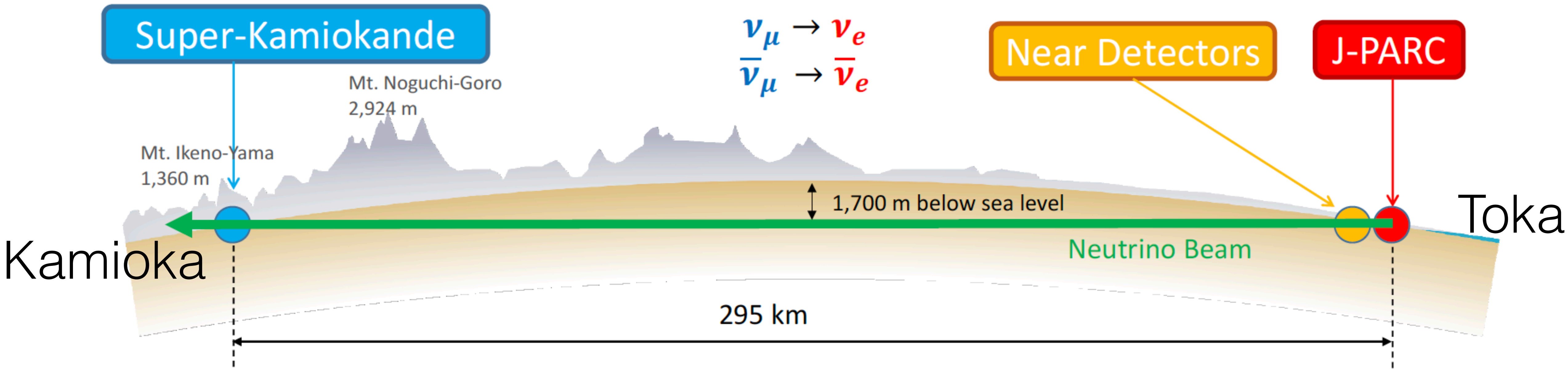
- Vendors are being sought.

Summary

- The Optical Transition Radiation (OTR) monitor measures the proton beam profile in T2K.
- OTR-I operated stably during 2009-2013.
- OTR-II presented issues, but operation is stable since 2014.
- New Fiber Taper and Camera are being used since Mar. 2019 and light yield has increased.
- Upgrade on the DAQ system: tested on Mar. 2019 and next T2K run will use current Windows DAQ system in parallel with the new Linux system.
- Upgrades were made for OTR-III & IV and installation is expected for 2020.
- Studies of Ti foil thickness and topology are ongoing for future beam intensity upgrade.

Back-Up

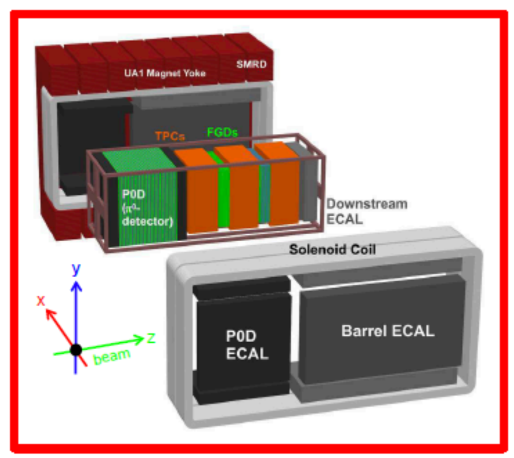
The T2K Experiment



Far Detector

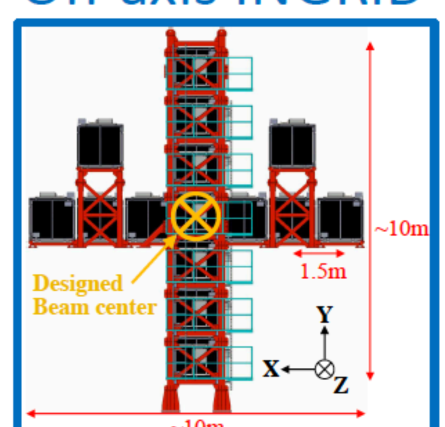
Near Detectors

Off-axis ND280

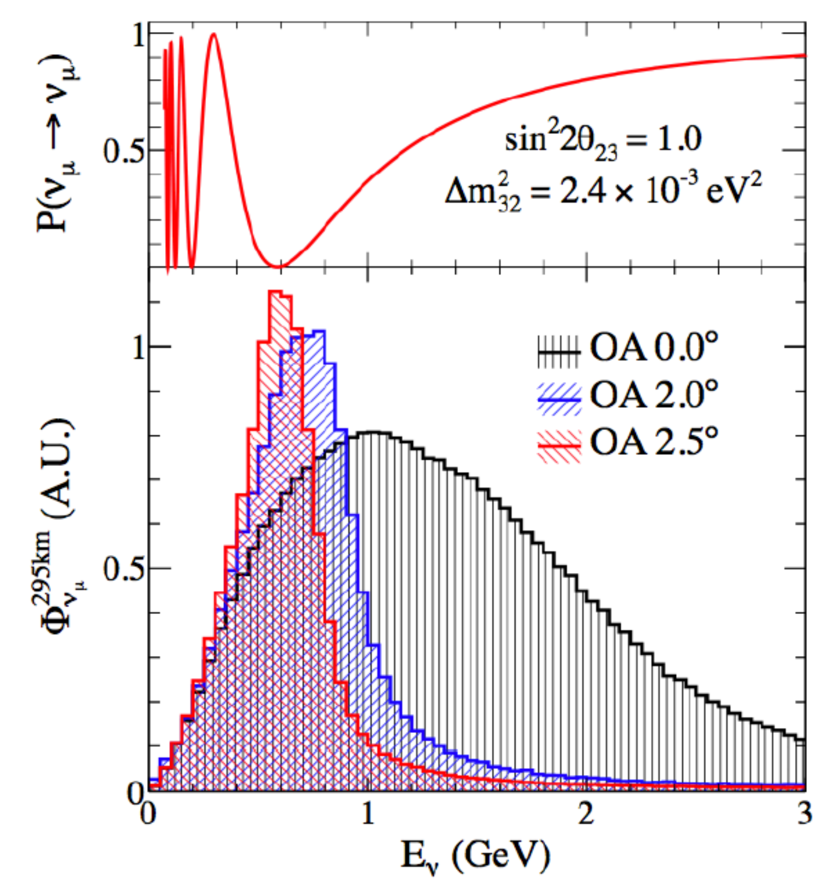


WAGASCI

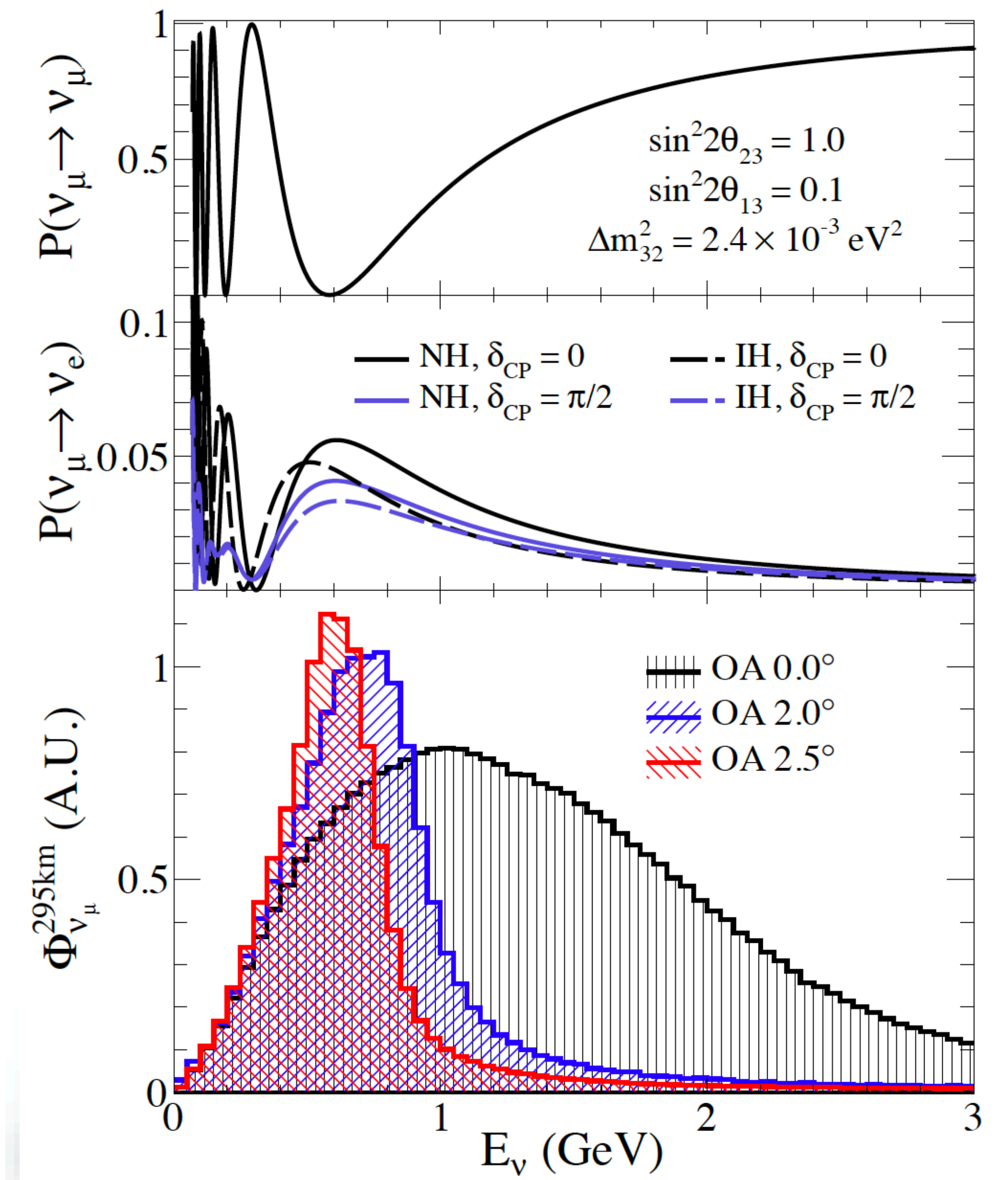
On-axis INGRID

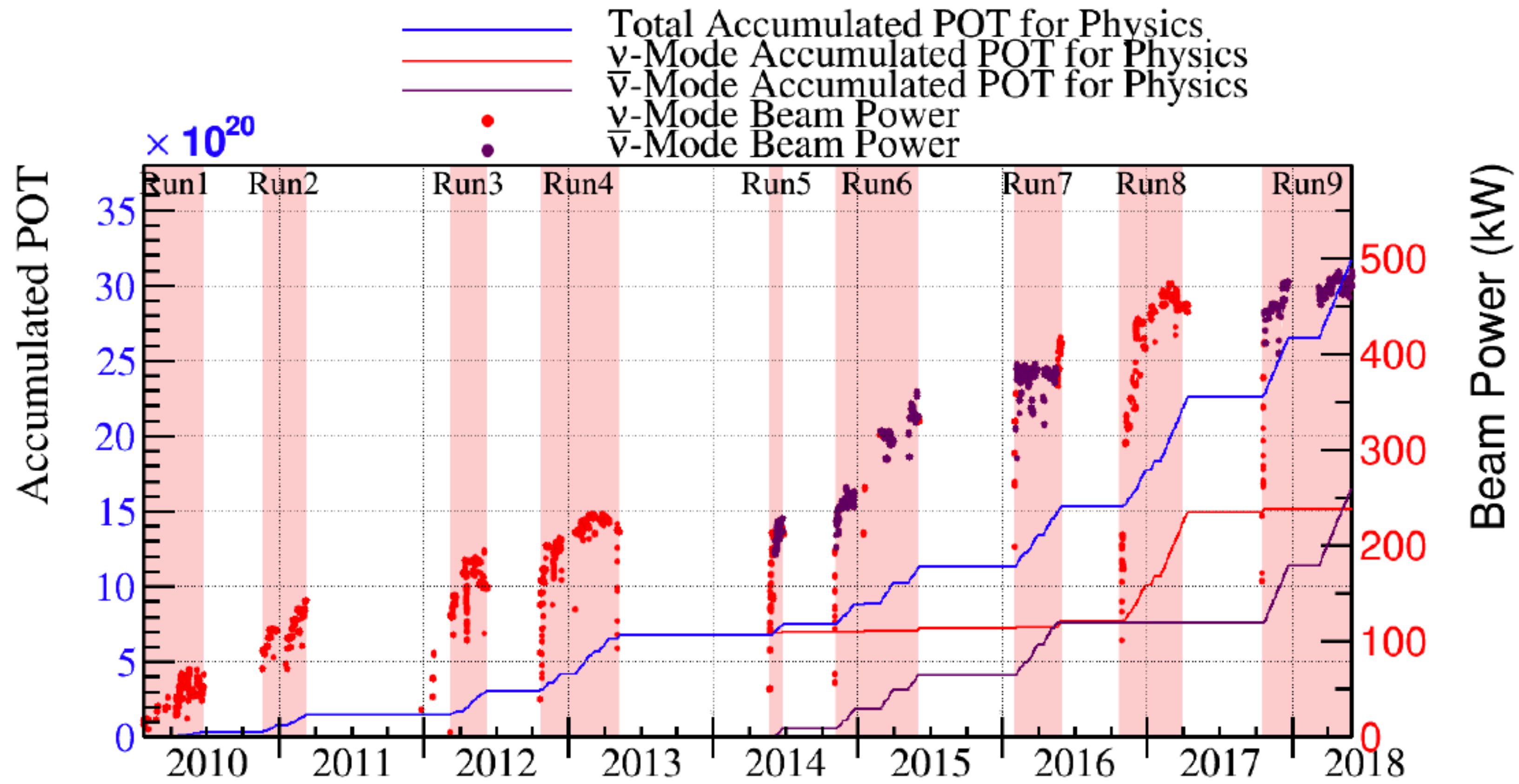


2.5° “off-axis”



The T2K Neutrino Beam





- Off-axis angle tuned for maximal ν_μ disappearance

- Latest result includes combined data from runs 1-9:
  - ν_μ: 1.51 x 10^{21} POT
  - $\bar{\nu}_\mu$: 1.65 x 10^{21} POT

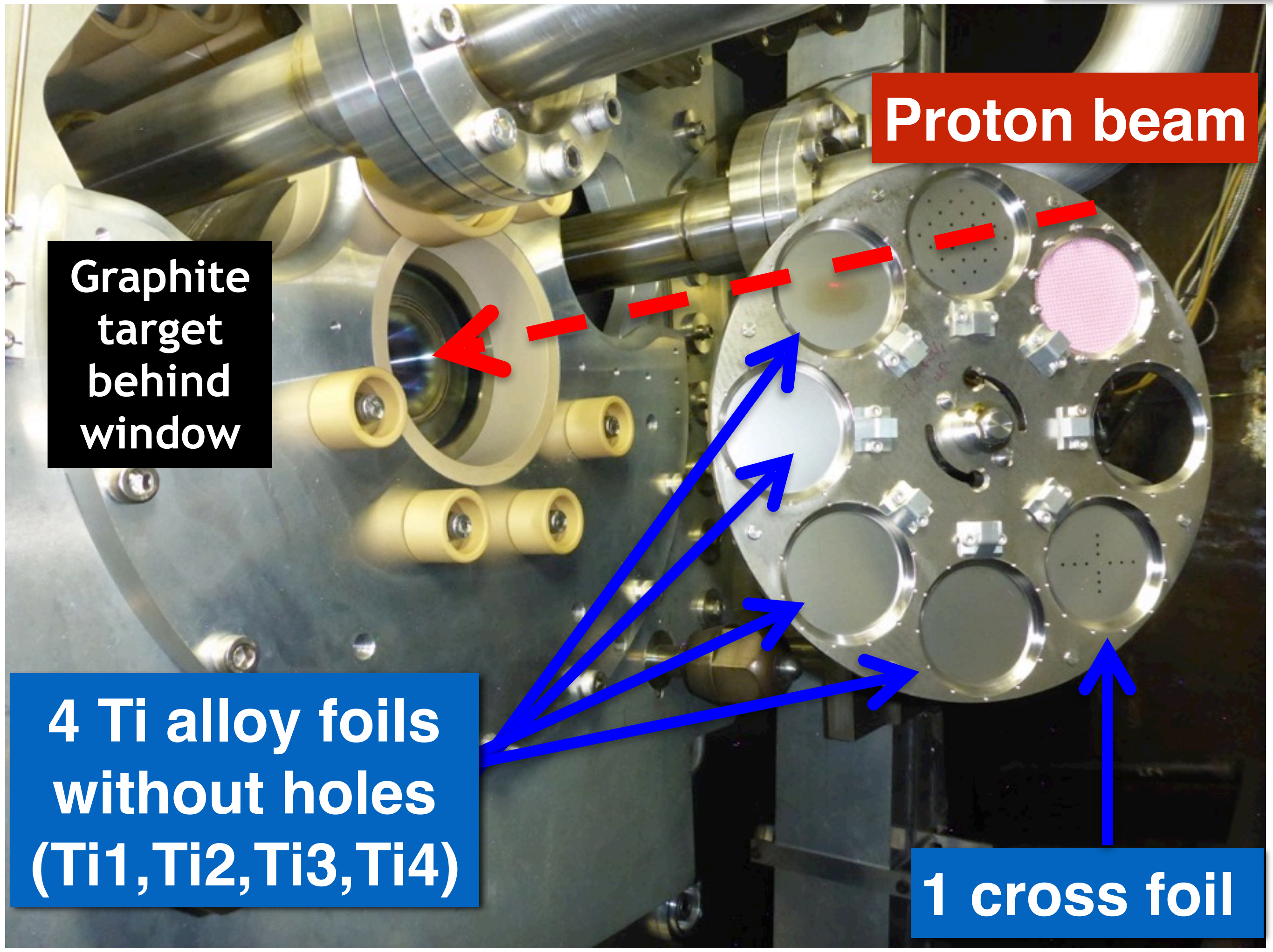
    (POT: protons on target)

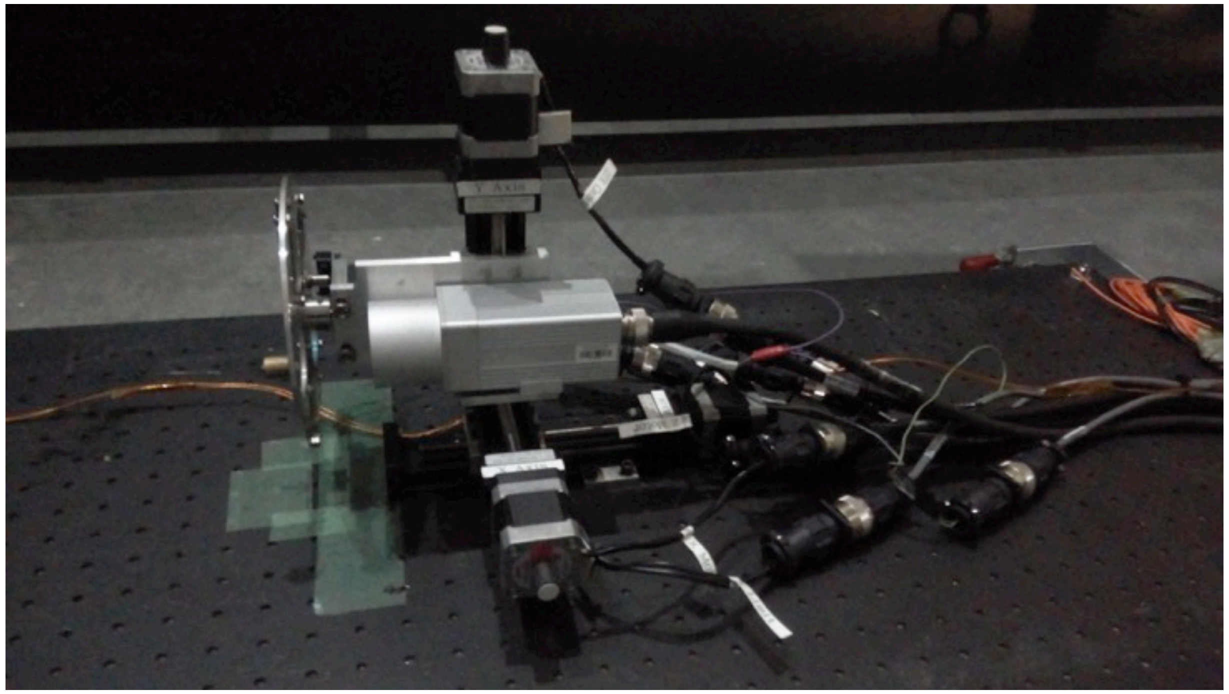
Beam operating at ~480 kW

The T2K OTR Set-Up

Top of He vessel

OTR II





OTR-I Operation Result

- OTR1 operated stably for **6.6e20** protons on target

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Optical transition radiation monitor for the T2K experiment

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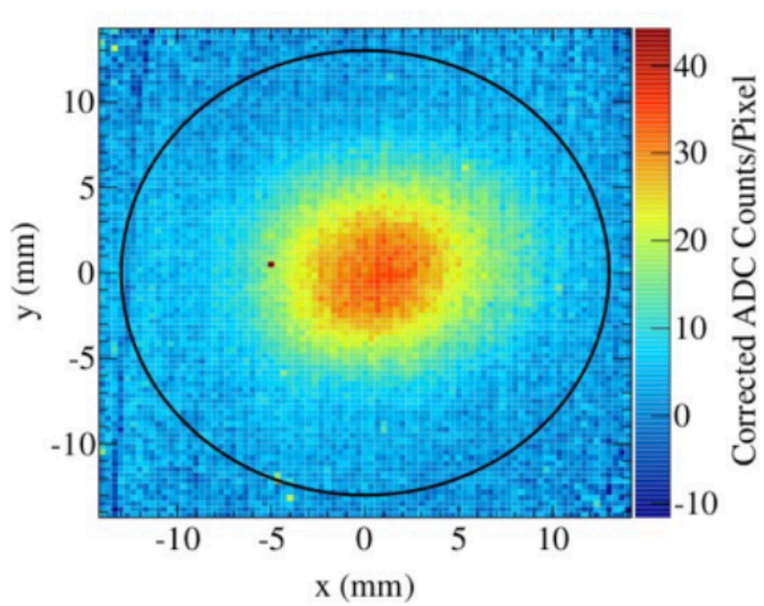
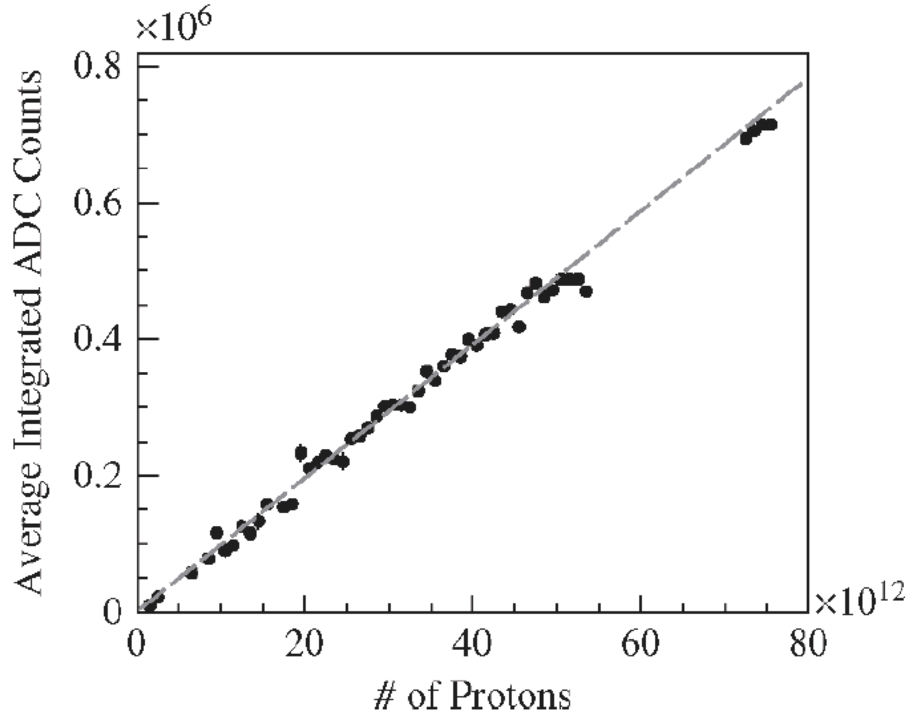
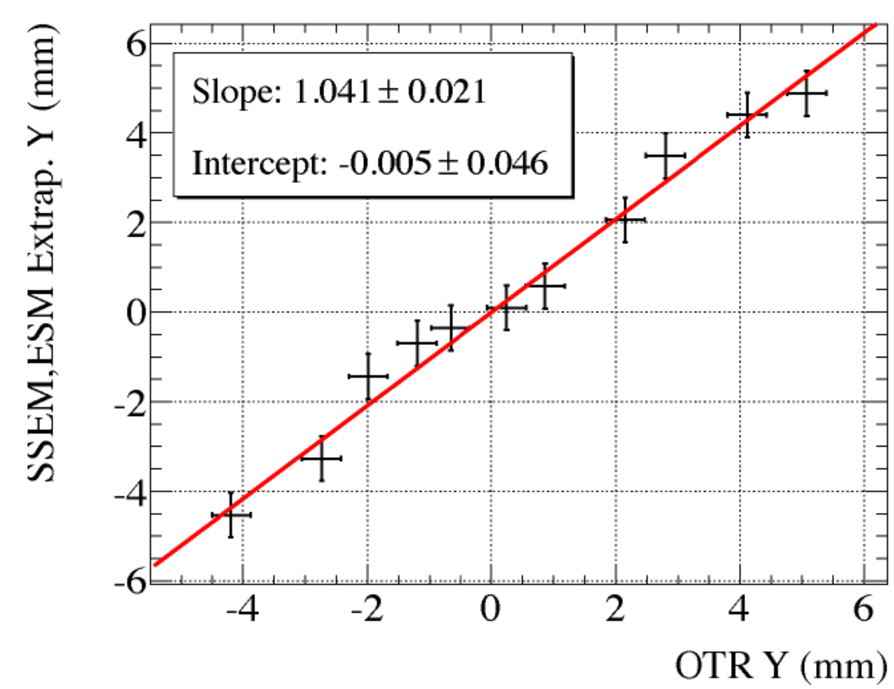
OTR profile on Ti foil 9e13 protons



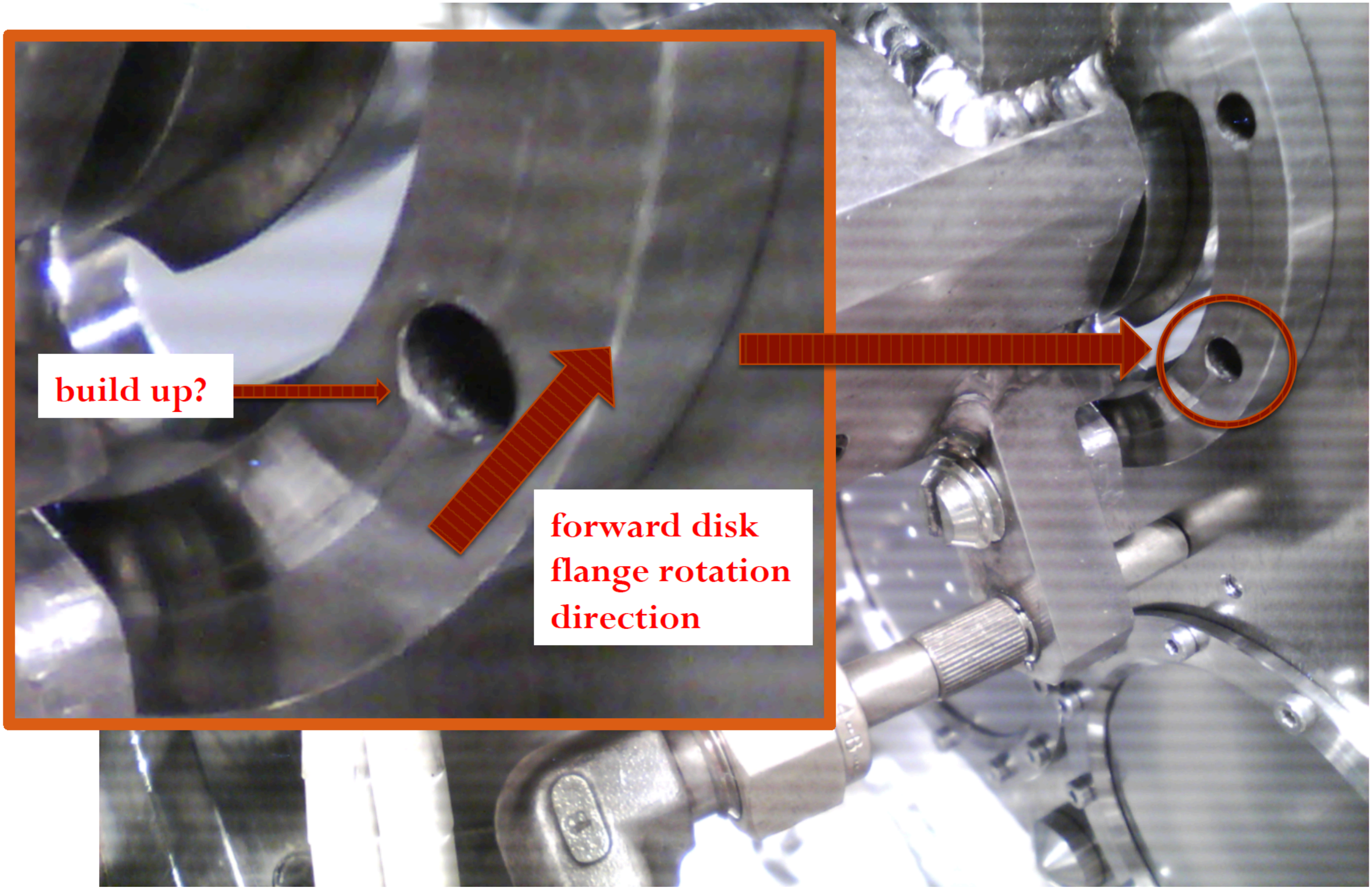
OTR light linearity with beam intensity



Consistent with beam line SSEM monitors



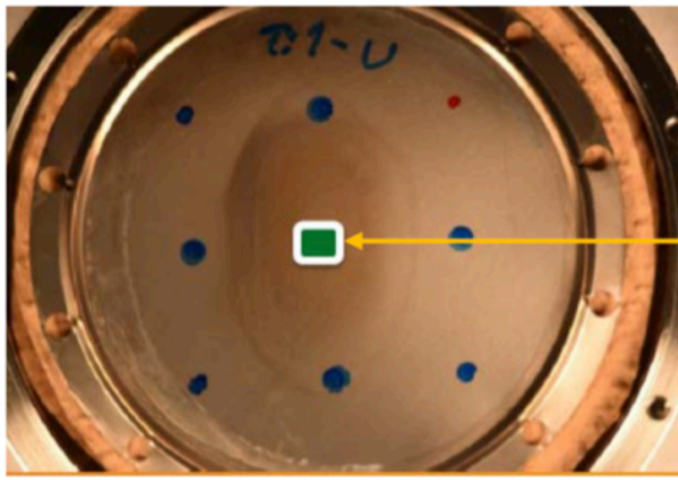
OTR-II Rotation Mechanism Problem

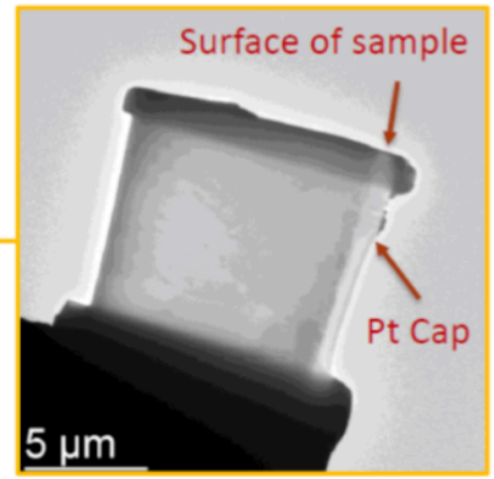


OTR-I Radiation Studies - NBI 2017

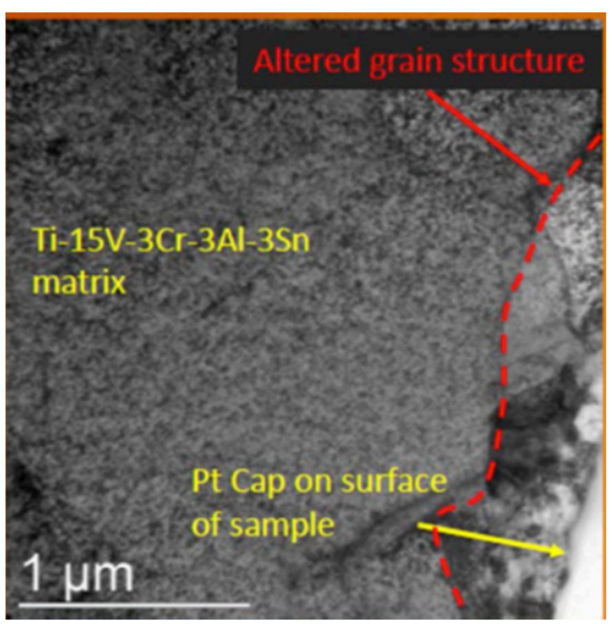
OTR1 foil radiation damage studies

Ti1 foil

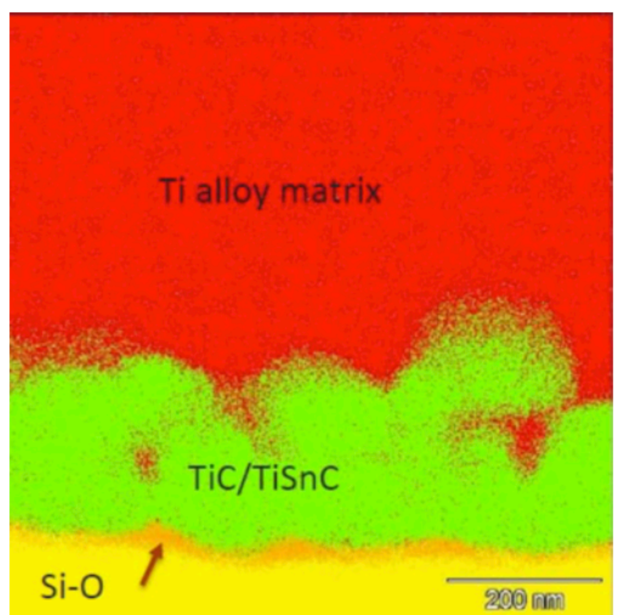




TEM image



Elemental mapping



- OTR1 foils (Ti-15V-3Cr-3Sn-3Al) are **world's most irradiated Ti specimens**
  - **Ti1: 1.6e20 POT**
  - **Ti2: 5.0e20 POT**
- Ti1 foil was transported to PNNL on Jan. 2016 for post-irradiation examination
- Different grain structure at surface where discoloration is visible
- Discolored region at surface made of Si-0/Ti-C layers
- Si may come from vessel-evacuating booster-pump oil
- Andy Cassela's talk: PNNL (Graphite/ Ti) in the RaDIATE session

Mitchell Yu