J-PARC Neutrino Beamline Monitor Overview

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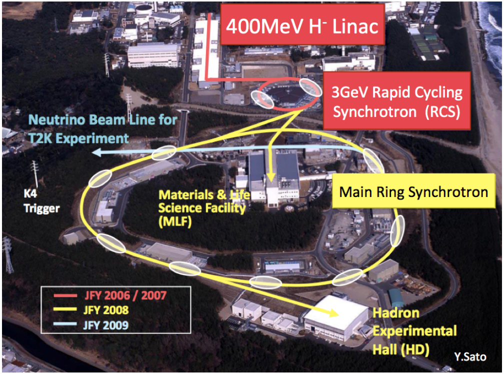
Outline

- J-PARC NU Beamline and Beam Monitor Overview
- Upgrade Plans and Status
  - US/Japan joint project in 2015 and 2016 : Beam Profile Monitor R&D

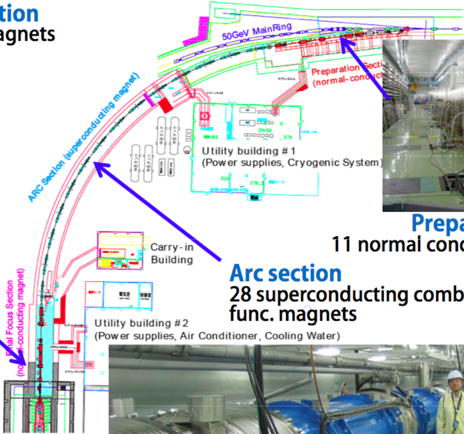
J-PARC Overview



- Composed of 400 MeV Linac, 3 GeV RCS, 30 GeV MR
- Design beam power: 750kW (Currently ∼320kW)
- Beam from J-PARC MR undergoes fast extraction into the J-PARC NU primary beamline
  - KEK Neutrino group is responsible for this part of the beamline

T2K Primary Beamline

Final focusing (FF) section
10 normal conducting magnets



Preparation section
11 normal conducting magnets

Arc section
28 superconducting combined func. magnets

- Beam orbit (and beam loss) should be firmly controlled anytime.

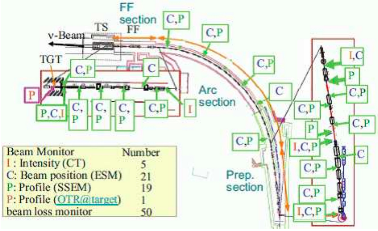
Why Are the T2K Proton Beam Monitors Important?

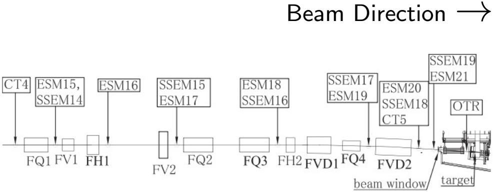
- Required to correctly steer the proton beam/protect beamline equipment
- Information from proton beam monitors is used as input into the T2K neutrino flux prediction simulation

T2K Primary Beam Monitors

Primary Beamline Monitors

Final Focusing Section (these are used for flux simulation inputs)



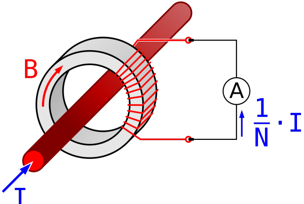


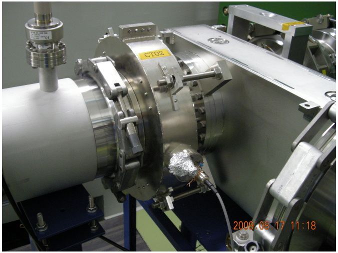
- 5 CTs (Current Transformers) – monitor beam current
- 50 BLMs (Beam Loss Monitors) – monitor beam loss
- 21 ESMs (Electrostatic Monitors) – monitor beam position
- 19 SSEMs (Segmented Secondary Emission Monitors) – monitor beam profile during beam tuning
- 1 OTR (Optical Transition Radiation) Monitor – monitors beam position and profile at target
- MUMON (Muon Monitor) – monitors muon flux and profile after target (see later talk by K. Nakamura)

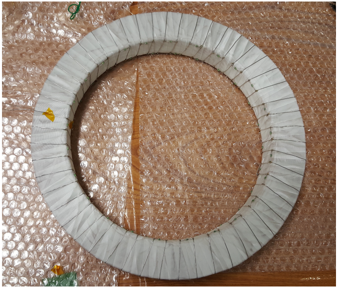
CTs

5 CTs (Current Transformers) + 2 R&D PPS-CTs

- Monitor proton beam intensity – CT05 (most downstream CT) generally used for T2K POT calculation
- 50-turn toroidal coil around a cylindrical ferromagnetic core
    - Current induced on wire proportional to beam intensity
- Had some trouble with instability of calibration over time
- Recently finished re-calibration campaign – reduced absolute systematic error from 2.7% $\rightarrow$<1.5%



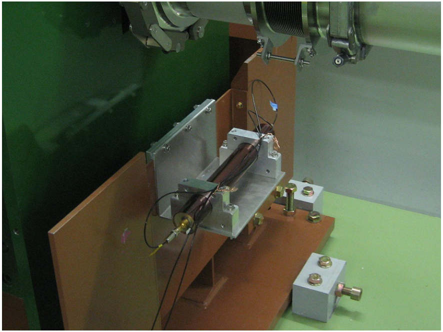




BLMs

50 BLMs (Beam Loss Monitors)

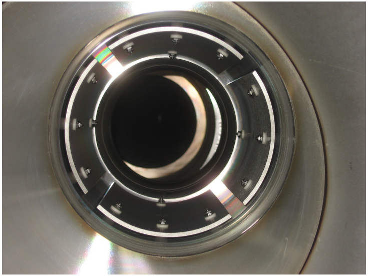
- Continuously monitor beam loss
- Wire proportional counter filled with an Ar-CO_2 mixture
- Ionizing particles produced by beam loss ionize gas in chamber $\sim$proportional to amount of beam loss
    - Actually, some BLM response function needed..
    - Have sensitivity down to a 20 mW beam loss
- The BLM signal is integrated during each beam spill, and if it exceeds a set threshold a beam abort interlock signal is fired



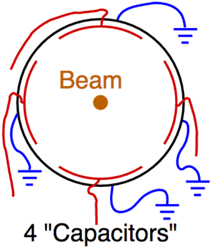
ESMs

21 ESMs (Electrostatic Monitor)

- Non-destructively, continuously monitor the proton beam position
- Four segmented cylindrical electrodes surrounding the proton beam orbit
  - Beam passage induces charge on electrodes proportional to distance from that electrode
- Precision on the beam position is better than 450 μm
- However, ESMs are used for monitoring stability of beam position, rather than for calculating absolute beam position
- Now starting re-calibration campaign



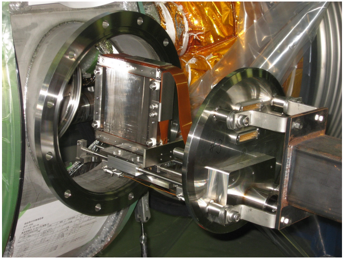
Electrostatic Monitor (ESM)



SSEMs

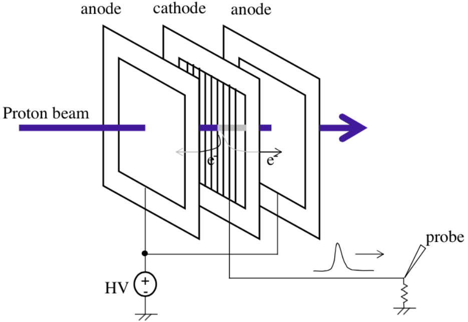
19 SSEMs (Segmented Secondary Emission Monitor)

- Measure beam profile during beam tuning
- Most downstream SSEM (SSEM19) is used continuously
  - All other SSEMs are extracted during standard beam running since SSEMs cause ($\sim$0.005%) beam loss
- Two 5-μm-thick titanium foils stripped horizontally and vertically, with a 5-μm-thick anode HV foil between them
  - Strip width ranges from 2 to 5 mm, optimized according to the expected beam size
  - Precision on the beam width measurement is 200 μm
- Move remotely into and out of the beamline laterally on a traveling nut moving along a screw which is turned by a remotely controlled motor; motion monitored by microswitches



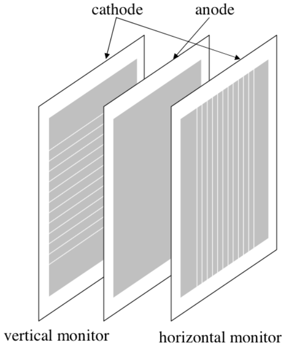
J-PARC NU SSEM Principle and Design

SSEM Principle



- Protons interact with foils
- Secondary electrons are emitted from segmented cathode plane and collected on anode planes
- Compensating charge in each cathode strip is read out as positive polarity signal

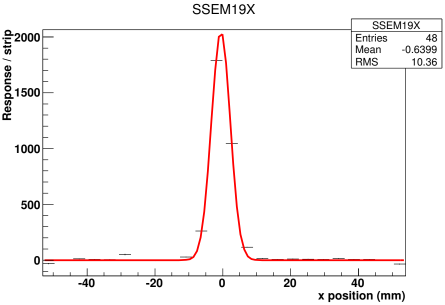
J-PARC NU SSEM

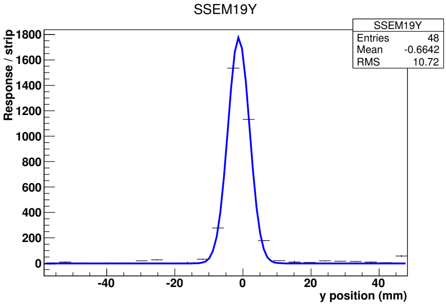


- Single anode plane between two stripped cathode planes
- 5 μm thick Ti foils

SSEM Data

Signal in SSEM19 from a single beam bunch:



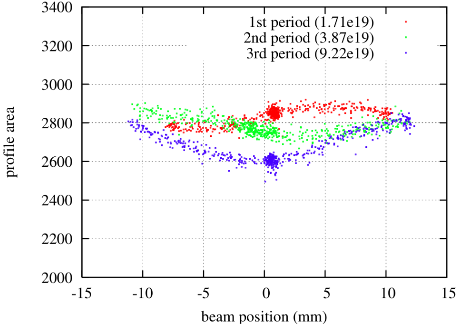


- Each strip produces a measured signal
- Signal from all strips can be fit to a Gaussian to extract beam position and profile at each SSEM

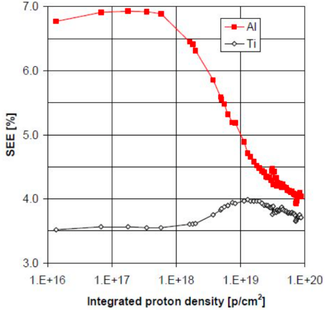
Ti SSEM Degradation

Plots from J-PARC SSEM TDR (2007)

J-PARC NU SSEM

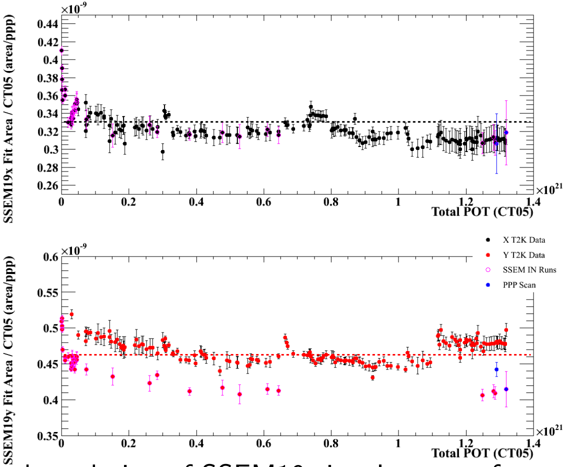


CERN SSEM



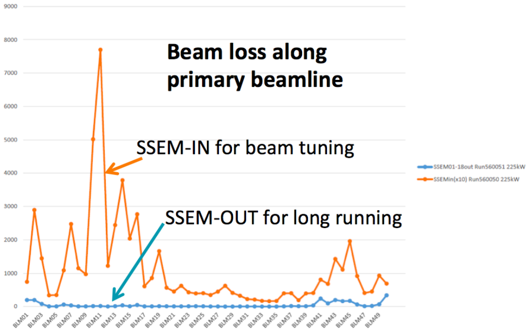
- Previously found degradation of Ti after irradiation:
  - Efficiency of Ti is stable up to 10^{18} protons/cm^2 and slowly rises by 15% before dropping back towards its original value between 10^{18} and 10^{20} protons/cm^2
- Current SSEM19 has seen $\sim 1.5 \times 10^{21}$ POT
  - No major degradation of the SSEM19 signal has been seen yet, but have reached an untested # of POT
  - SSEM19 may not be usable long-term at 750 kW

SSEM Degradation – Not Seen in T2K



- No clear degradation of SSEM19 signal seen so far
- Beam position isn't constant for full run
- PPP isn't constant for full run
  - As POT increased, so did PPP
  - Signal integral isn't linear with PPP – this IS corrected for

Measured Beam Loss Due to SSEMs

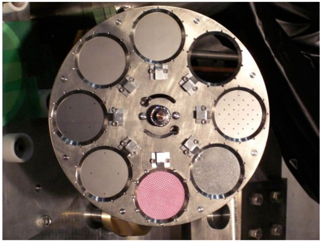


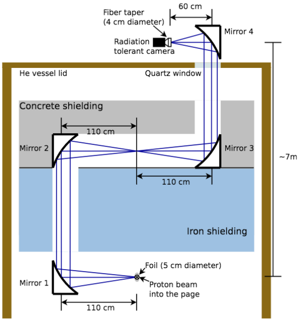
- Beam loss When SSEMs are in is quite high
  - ~0.005% beam loss at each SSEM
- Can cause radiation damage, activation of beamline equipment
  - SSEMs upstream of the target station cannot be used continuously

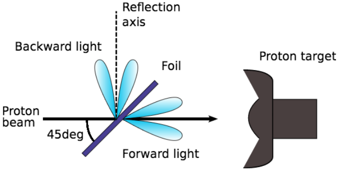
OTR

1 OTR (Optical Transition Radiation Monitor)

- Continuously monitors beam profile at the target
- OTR light is produced when charged particle travels between 2 materials with different dielectric constants
  - Proportional to beam profile
- T2K OTR monitors backwards-going light from 50-μm-thick Ti foil directly upstream of the target
  - 8 foils mounted on rotatable disk
  - Light is directed to TS ground floor by a series of 4 mirrors and then monitored by a camera

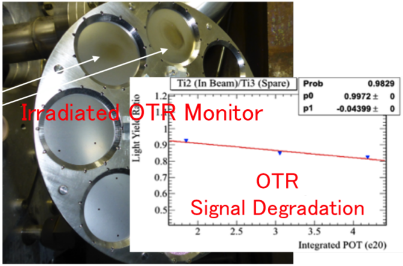






Some OTR Issues

- OTR generally working well, but ...
- Gradual decrease in OTR signal size with integrated incident POT has been observed



- OTR disk rotation became unreliable
  - Now taking all data on Ti foil with cross-hole pattern
    - No problem for beam-on
    - Can take calibration data without rotating OTR disk during beam-off
  - Cause found: OTR disk is held into place by a plunger with a spring inside that engages with a hole – the spring constant of that spring seems to become large after many rotations (even on a test bench)
    - Now working on alternate plunger/spring for next OTR version
- OTR measured beam position drifted in early 2015
  - Worked in TS during summer 2015 to try and determine the cause, but didn't find any cause yet
  - Now beam position measurement is stable

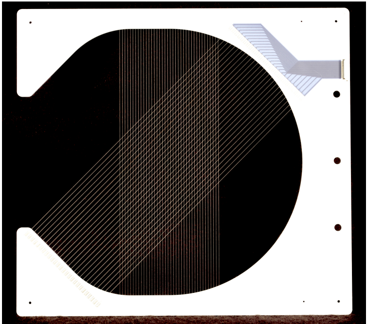
Beam Profile Monitoring R&D

- SSEMs monitor the beam profile but are *destructive* and cause *beam loss*
- Only the most downstream SSEM (SSEM19) can be used continuously
    - Although we haven't seen SSEM19 signal degradation yet, it won't necessarily be usable for a long period of time at high beam power
- OTR monitors the beam position directly upstream of the target
    - Degradation of the OTR foils has been observed
- The beam profile must be monitored continuously, so we are working on R&D for profile monitors that work well at high beam power
    - Wire Secondary Emission Monitor (WSEM) as a US/Japan joint project
    - Beam Induced Fluorescence Monitor (BIF) – see later talk by C. Bronner

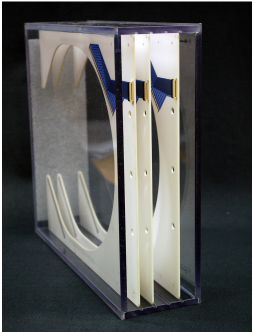
New "WSEM" Prototype

- New FNAL-Style WSEM (Wire Secondary Emission Monitor) designed for J-PARC NU beamline
- Monitor beam profile using twinned 25 μm Ti wire $\rightarrow$ like SSEMs but with beam loss reduced to 3% of SSEM loss
  - Signal size also reduced to $\sim$1% – may not work at very low beam intensities
  - Prototype R&D monitor fabricated by FNAL monitor experts using 2015 US/Japan fund – Huge thanks to Gianni, Dan, Wanda, ...

Finished Plane



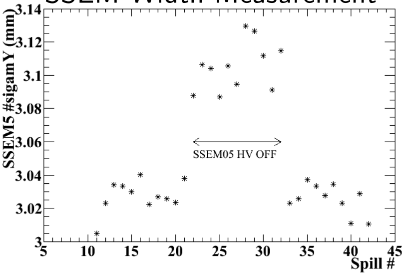
In Shipping Container



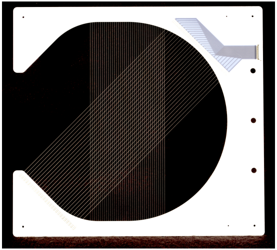
WSEM Prototype Design

- FNAL-Style (C-shape) WSEM prototype final design + fabrication done at FNAL in JFY2015
- 2 full monitors + 1 spare plane fabricated (5 planes)
  - X-planes have 2 wire sets mounted: x wires (at 45°) + anode wires
    - Planes w/ 2 different anode-wire spacings (2 mm, 6 mm) fabricated; 2 mm pitch plane installed
  - Y-planes have 1 wire set mounted: y wires (at 45°)
- Twinned 25 μm Ti grade 1 wire w/ 3 mm pitch
- 200 mm aperture (monitor can't be limiting aperture)
- Kapton cables for WSEM signal readout

SSEM Width Measurement



WSEM Plane

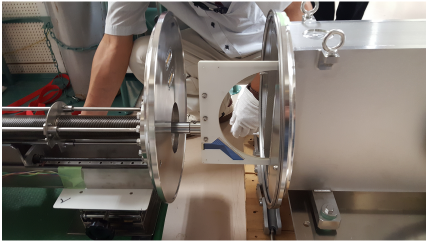


WSEM Mounting

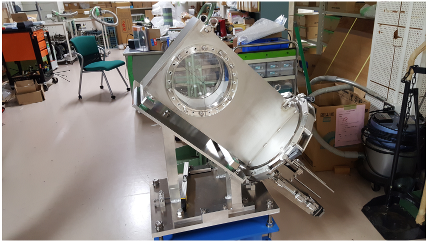
WSEM installation at J-PARC in 2016 supported by US/Japan fund

- Mounted 2 WSEM planes (X+Y+anode) together
  - 3-cm-thick Al plate between them
- Mounted WSEM on J-PARC-style lateral mover
  - Mounted by 2 vacuum vented screws to holding piece (also new for WSEM) connected to mover shaft
    - Need to modify connector scheme for next WSEM version..
- Mount mover system on 45° stage for survey

WSEM 2 Planes Mounted



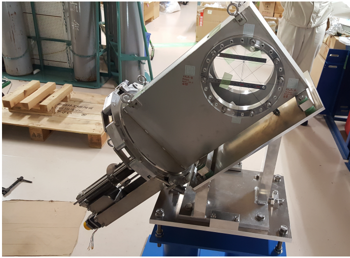
Mover at 45°



WSEM Optical Survey

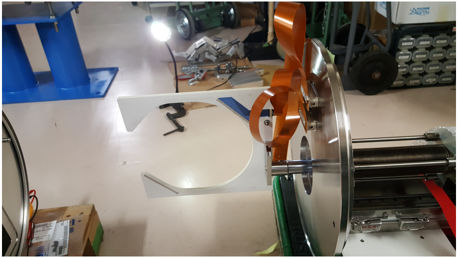
- Optical survey of chamber using clear window
  - Survey used precisely etched lines on clear windows on each side of WSEM chamber
  - Horizontal and vertical survey done
  - Stickers on chamber mark surveyed points – can use these for alignment in the tunnel
- Alignment of wires also checked – SSEM IN microswitches adjusted (moved back) so that middle of two center Y wires is centered on the beam
  - Wire alignment was slightly off-center – need better connector to hold monitor for next version

Chamber after survey



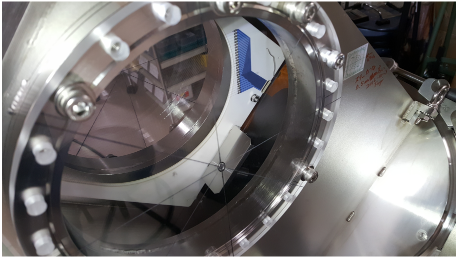
WSEM Kapton Cables

- Kapton cables designed to bring WSEM signal to vacuum feedthrough
- Vacuum feedthrough Dsub connectors attached to Kapton cables
- Kapton cables installed in chamber and attached to WSEM
    - Cables don't fit so well – should maybe be re-designed for next version
- Checked electrical connection for each wire to outside of flange connector – no short, each wire is connected
- SSEM OUT microswitches moved in to give a little extra space for cables



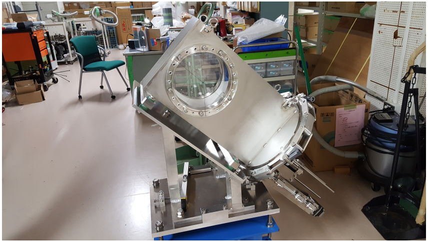
WSEM Motion Check

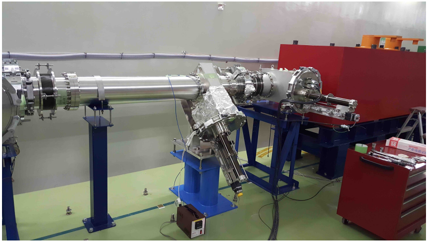
- Closed chamber
- Checked motion of WSEM by motor IN+OUT 10x
  - No problem, although cables do noticeably move on (resting on) and off of WSEM plane during motion
- Checked wire connectivity again after motion test by opening clear flanges – no problem



WSEM Prototype Beamline Installation

- Installed WSEM in beamline
  - Originally had some vacuum issue so tried baking WSEM, but seems vacuum issue was unrelated to WSEM out-gassing
- Optical survey done based on chamber position
- Beam test to be performed as soon as possible
  - Not done yet due to beam schedule, mover controller instabilities

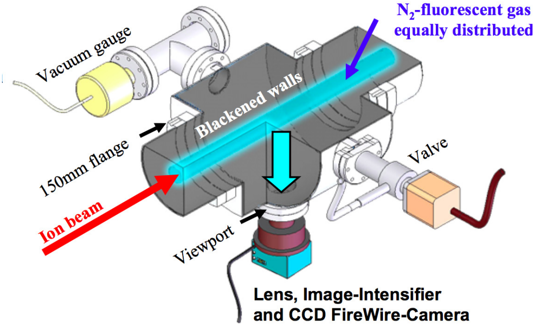




Beam Induced Fluorescence Monitor

See Talk by C. Bronner

- Beam Induced Fluorescence (BIF) monitor
  - Uses fluorescence induced by proton beam interactions with gas injected into the beamline
  - Continuously and non-destructively monitor proton beam profile
- Now doing R&D for various components for detection, gas systems



Conclusion

- Proton beam monitoring in neutrino beamline essential for ensuring stable, well-understood neutrino beam
- Proton beam loss, intensity, position, profile monitors generally working well
  - Periodic calibration updates, general maintenance required
  - DAQ for CTs, ESMs, OTR should be upgraded to have shorter readout latancy for future 1 Hz beam spill repetition rate
- R&D underway for new reduced-loss and non-destructive beam profile monitors for high proton beam power
  - New R&D FNAL-style WSEM installed for testing in NU beamline during 2016 summer – signal test will be done very soon