High Power Target Instrumentation at J-PARC for Neutron and Muon Sources

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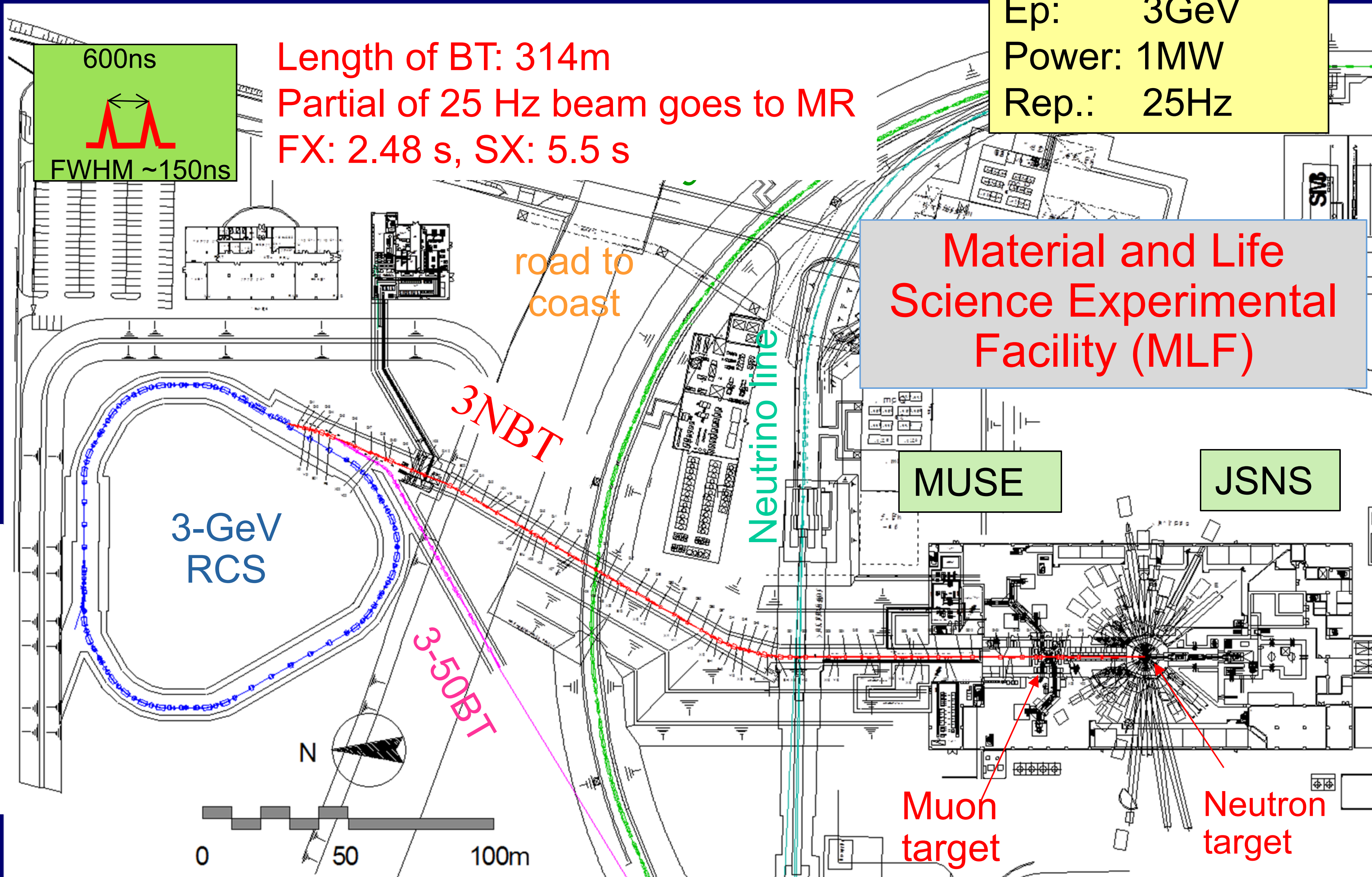
1) JAEA/J-PARC, 2) KEK/J-PARC

Outline

- Introduction
- Present mercury target status
- R&D of beam instruments for MLF
  - Beam monitor
  - Beam flattening system
  - 2D profile monitor
- Future plans at J-PARC
  - Facility for R&D of ADS (TEF)
  - 2nd target station for MLF

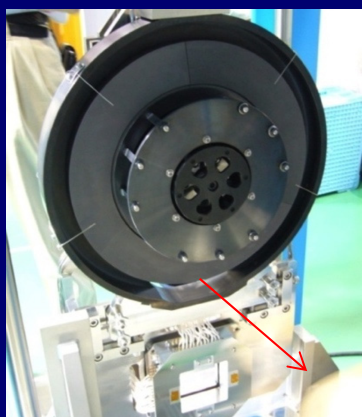
J-PARC = Japan Proton Accelerator Research Complex

Beam transport to MLF



Targets placed at MLF

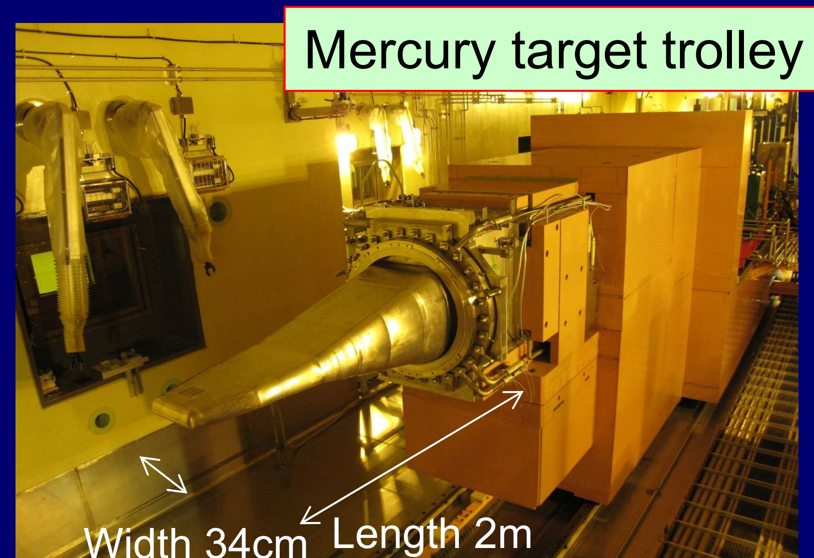
- Muon target
  - Carbon graphite (IG430)
  - 8% beam lost(80 kW loss)
  - Highest intensity in the world

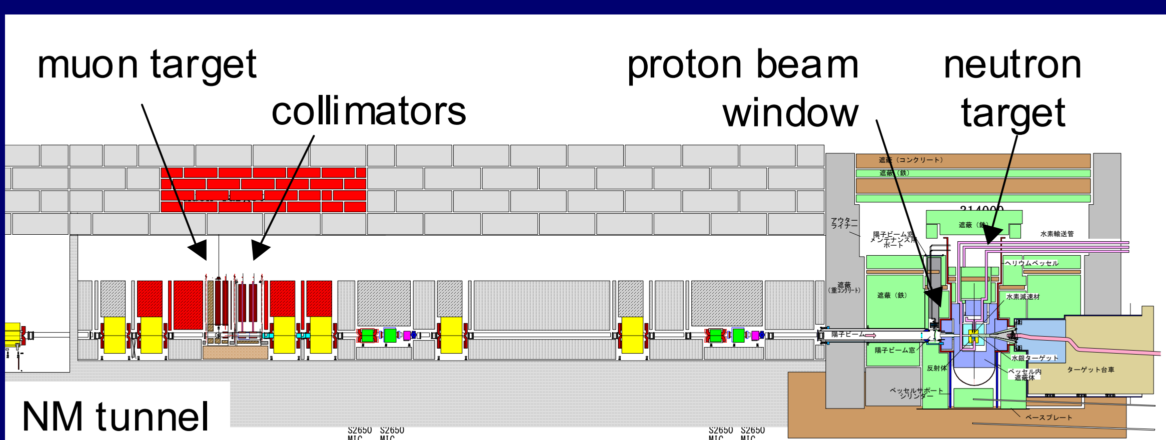


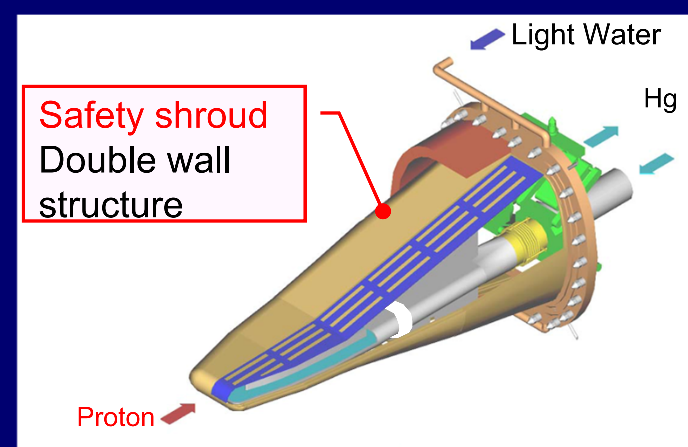
Rotating target

Thick. 2cm
Diam. 30 cm

- Neutron target
  - Mercury
  - Highest pulse intensity in the world



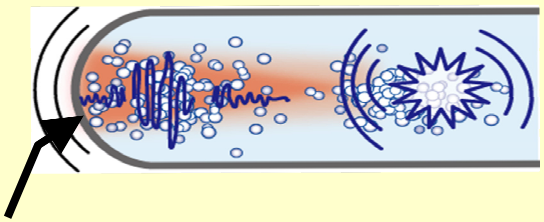




Present status of the mercury target

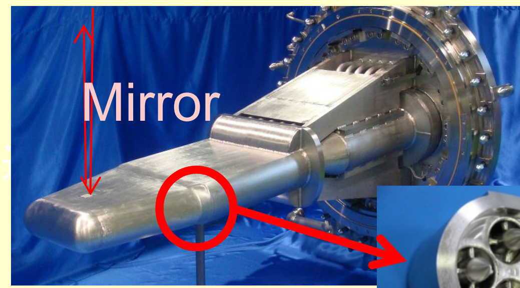
Efforts to mitigate cavitation damage with gas micro-bubbles

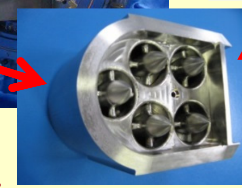
Mercury target vessel

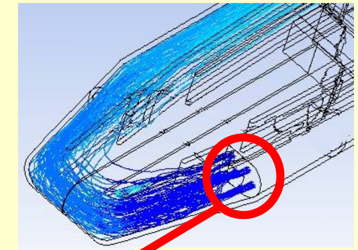


Beam window (2.5 mm-t)
Most vulnerable to cavitation damage

Vibration measurement with a Laser Doppler Vibrometer(LDV)





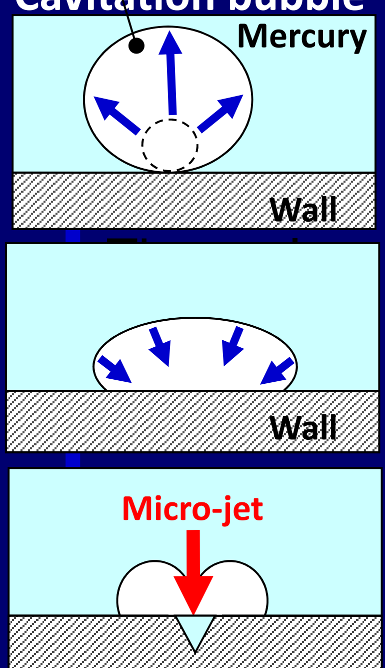


Bubbling distribution

He-gas micro-bubbles injecting into Hg target

Swirl type bubbler

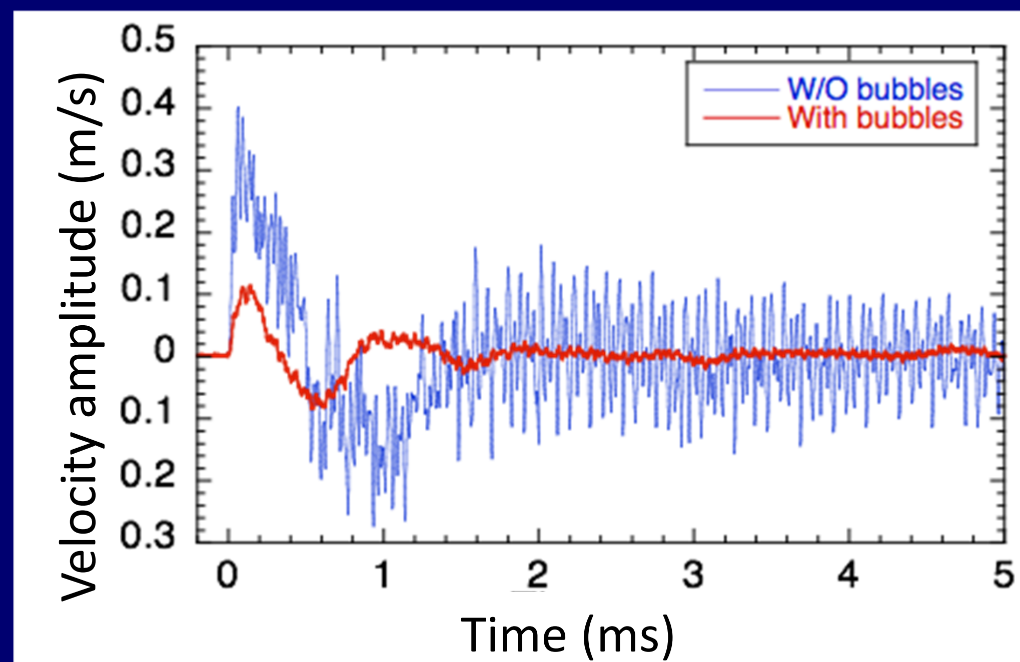
Cavitation bubble



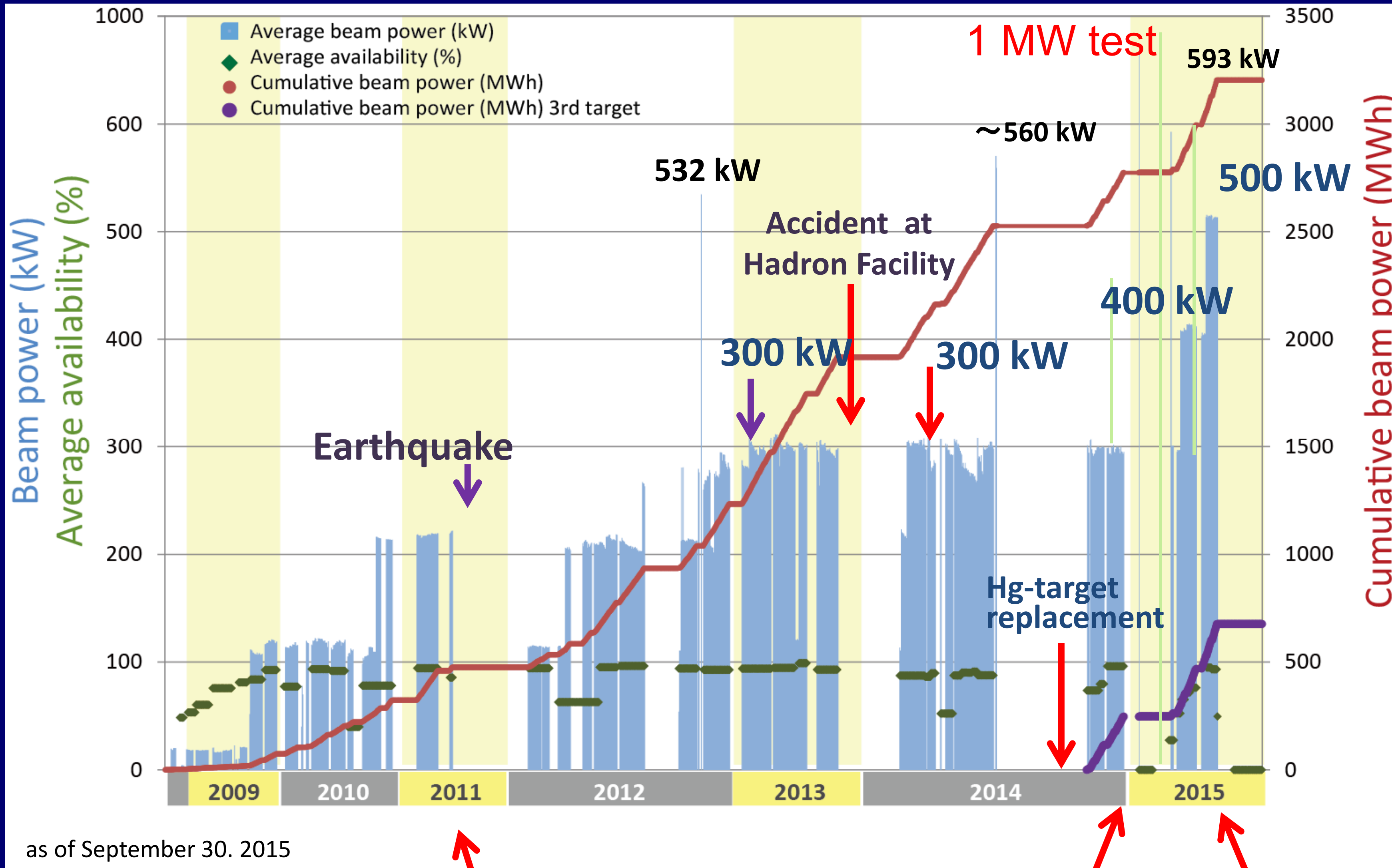
Bubble inflates by the mercury negative pressure.

Cavitation bubble shrinks rapidly.

Shrink energy concentrates to one point



Operational history of JSNS



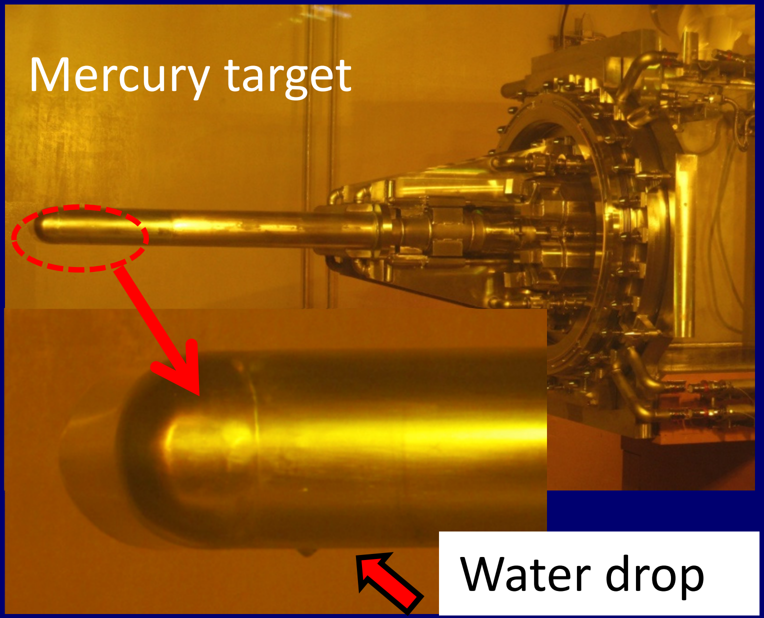
Hg-target replacement

～1 month interruption due to the fire in MLF

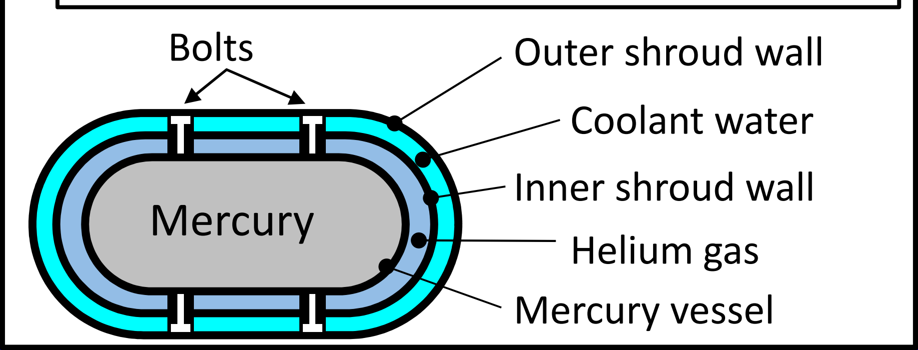
Interruption due to a trouble of Hg-target

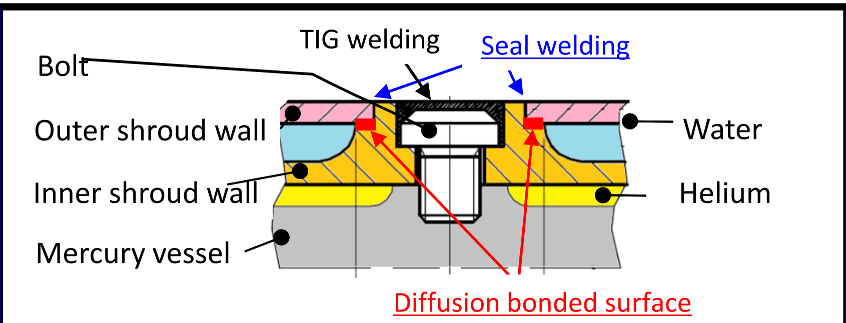
Water leak events at mercury target

- In April 2015, water leak of mercury target was found during 500 kW beam operation. Coolant water in target shroud soaked out through the defect of the welding.
- On Nov 2015, similar event happened. Water leaked into inner shroud so that we can not find the leaked point (possibly mirror).
- Welding of water channel might be cause of the issue. Since no robust target and no enough space for storage remains, operational beam power is decided as 200-kW.



Vertical cross section of the target vessel



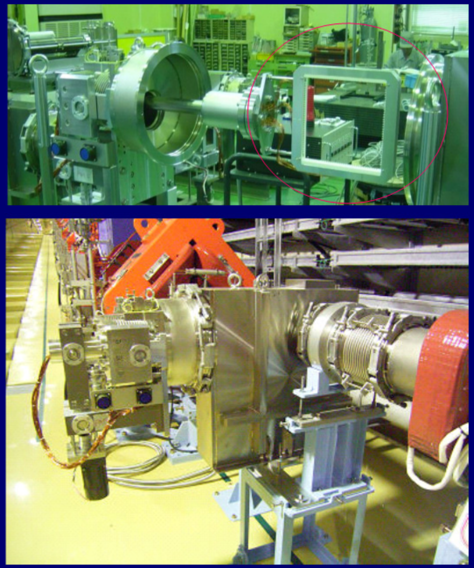


R&D for high power beam instruments

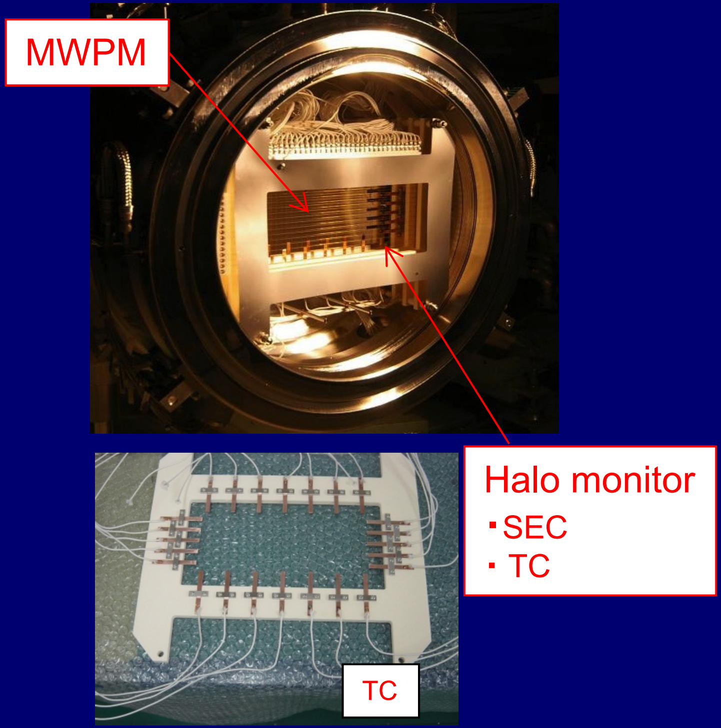
Beam diagnostics for profile and halo

- Profile monitor and halo monitor (online monitor)
  - Multi Wire Profile Monitors (MWPMs) : SiC wires (15 sets)
  - Stationary MWPM at proton beam window (PBW), separation between vacuum and helium, placed at 1.8 m upstream of the mercury target
- 2D profile：Image of residual dose read out by imaging plate (IP)

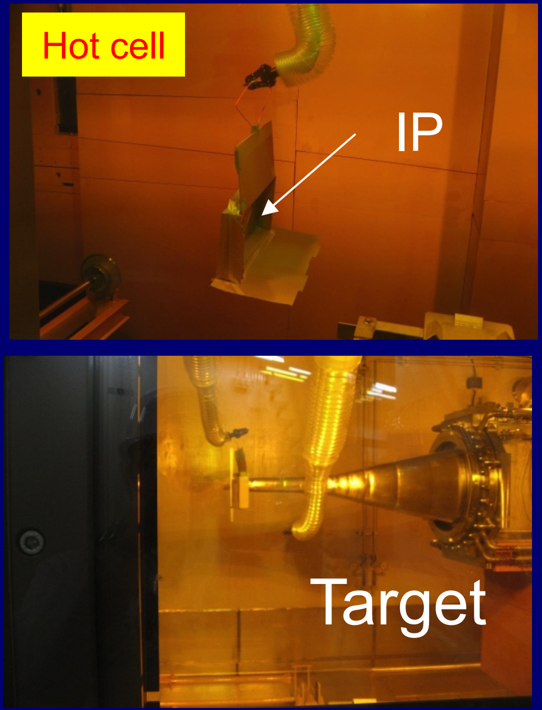
  IP attached to target by remote handling after beam irradiation



MWPM



Monitors at PBW



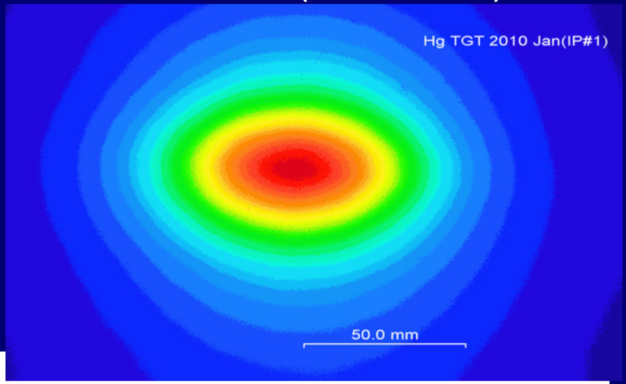
Imaging Plate(IP)

Beam profile at mercury target

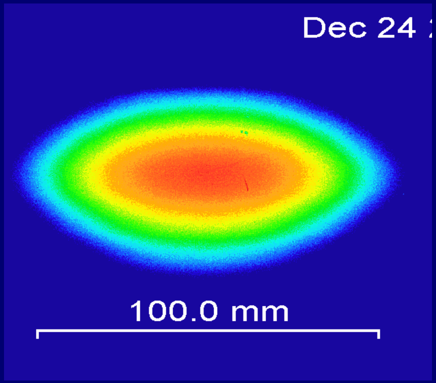
2-D measurement by IP

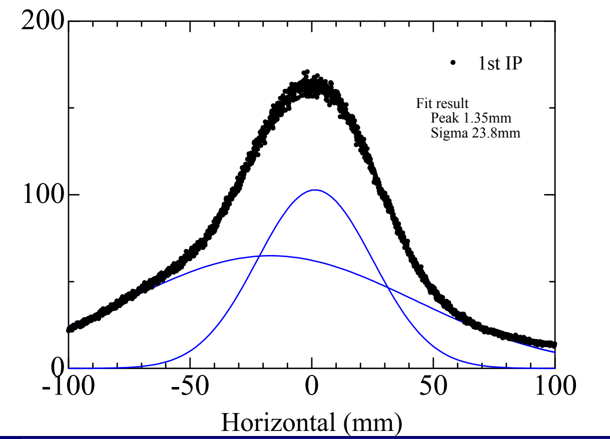
MWPM at PBW

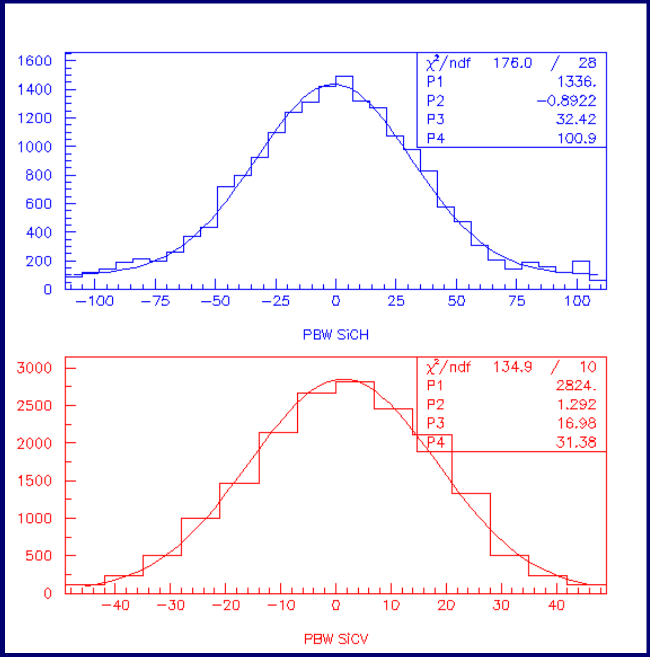
0.1 MW (2009 Dec)



0.2 MW (2010 Dec)







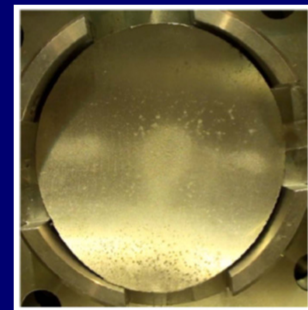
Only 6 days cooling after irradiation of 0.2 MW beam, the image was obtained.
⇒ Possible for 1MW with certain cooling time

Profile result by the IP
- Fitted by two Gaussian
  Convolution primary protons and secondary particles

Result by MWPM
- Fit by Gaussian
- Width and position for each pulse obtained
- Good agreement width result by IP

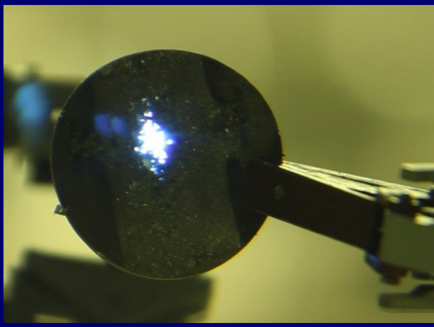
Proton beam at the target

- Beam operational status
  - Study with 1 MW beam
  - User operation with 0.5MW
- Cavitation damage is critical for high power beam with short pulse
  - Proportional to 4th power of the peak current density at target
  - Useless beam scanning to mitigate damage
  - More serious than SNS due to high energy per pulse (JSNS 40 kJ/shot)
- Although helium bubble injection mitigates the damage, peak reduction is essential.
- Required development of beam flattening system

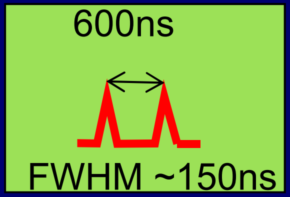


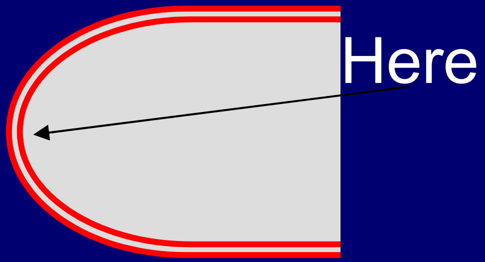
5 cm

Damage at JSNS target



Pin holes at target of SNS by R. Bernie





Target vessel

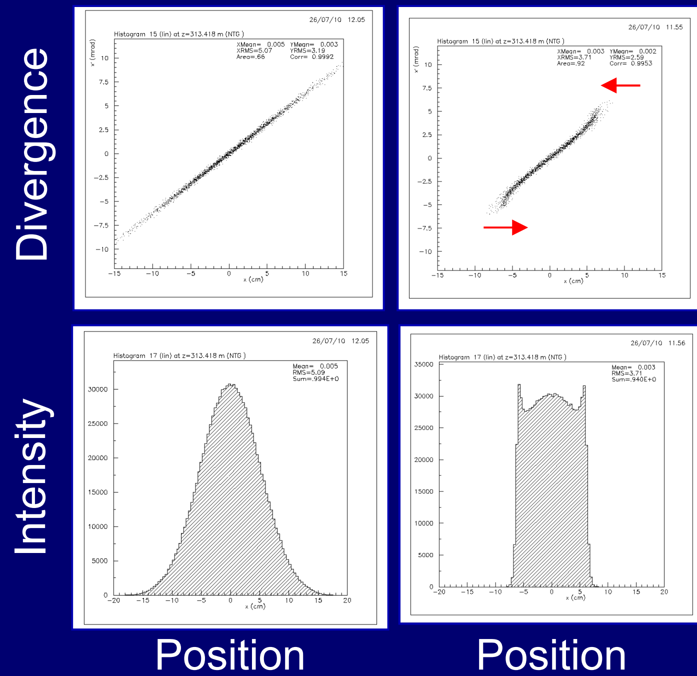
Beam flattening system

- Principle: Beam edge folded by non-linear optics

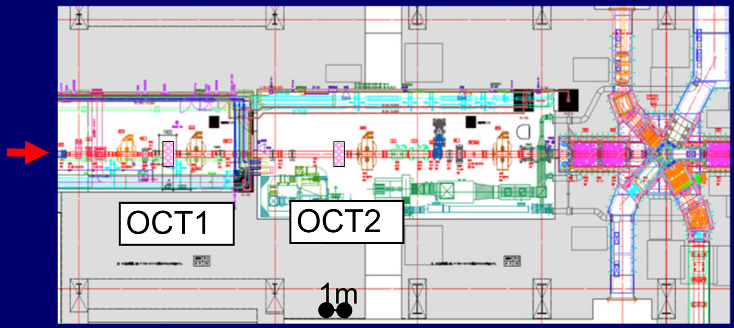
Linear | Non-linear

Phase space

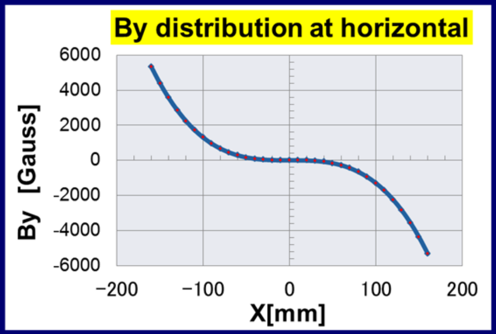
Real space (Horizontal)

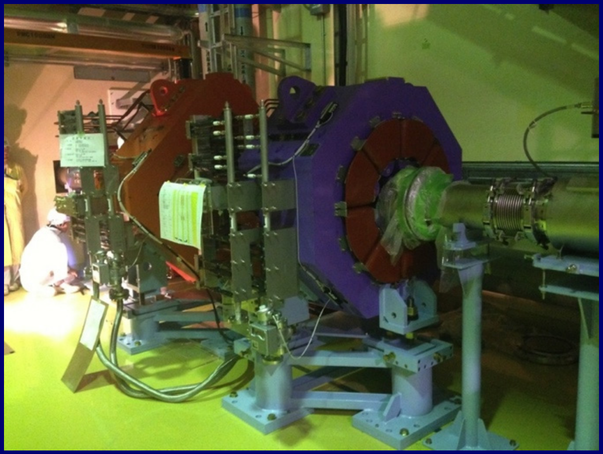


Octupole magnet: 800 T/m^3



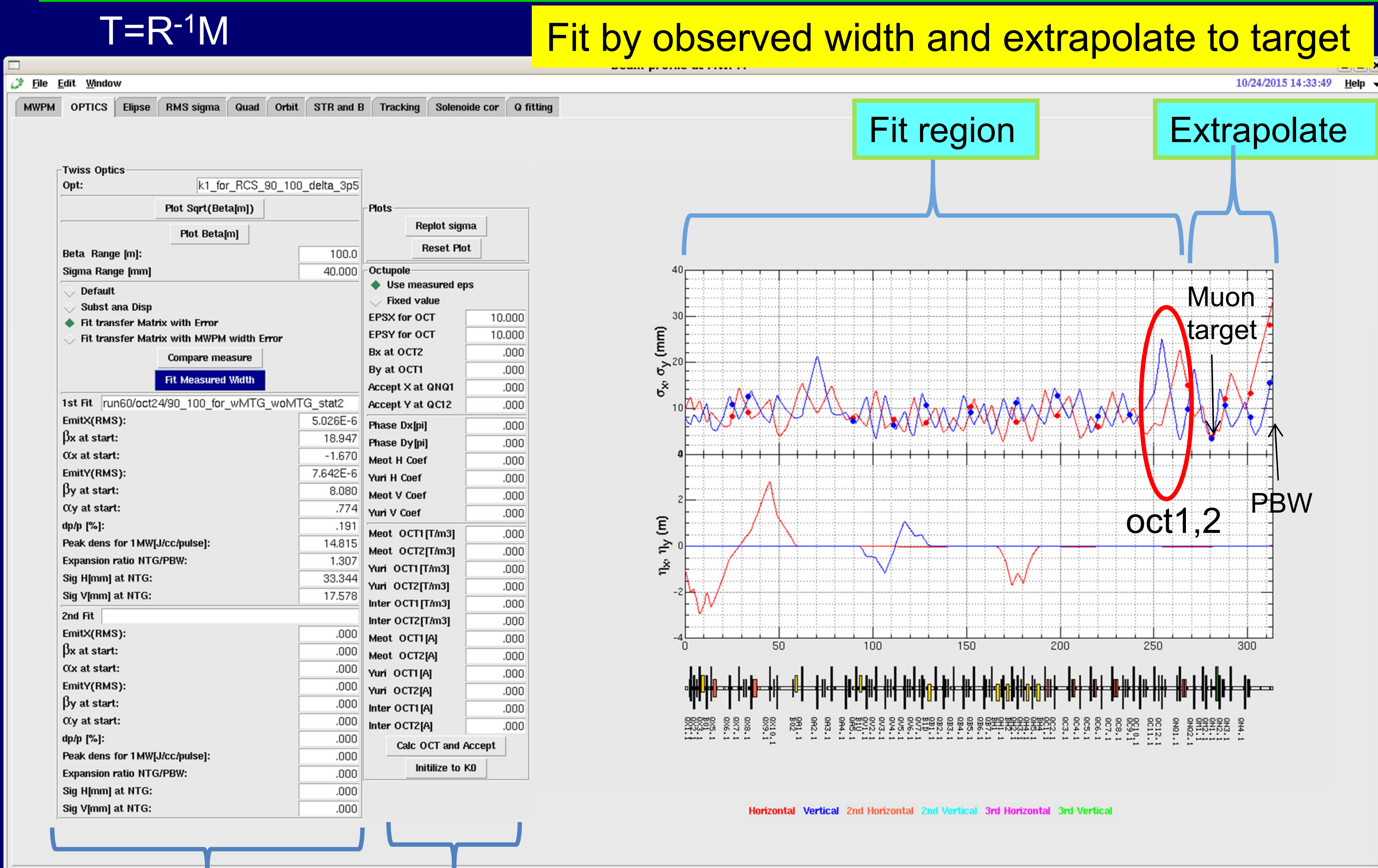
Horizontal plan





Beam tuning tool with SAD code

$T = R^{-1}M$



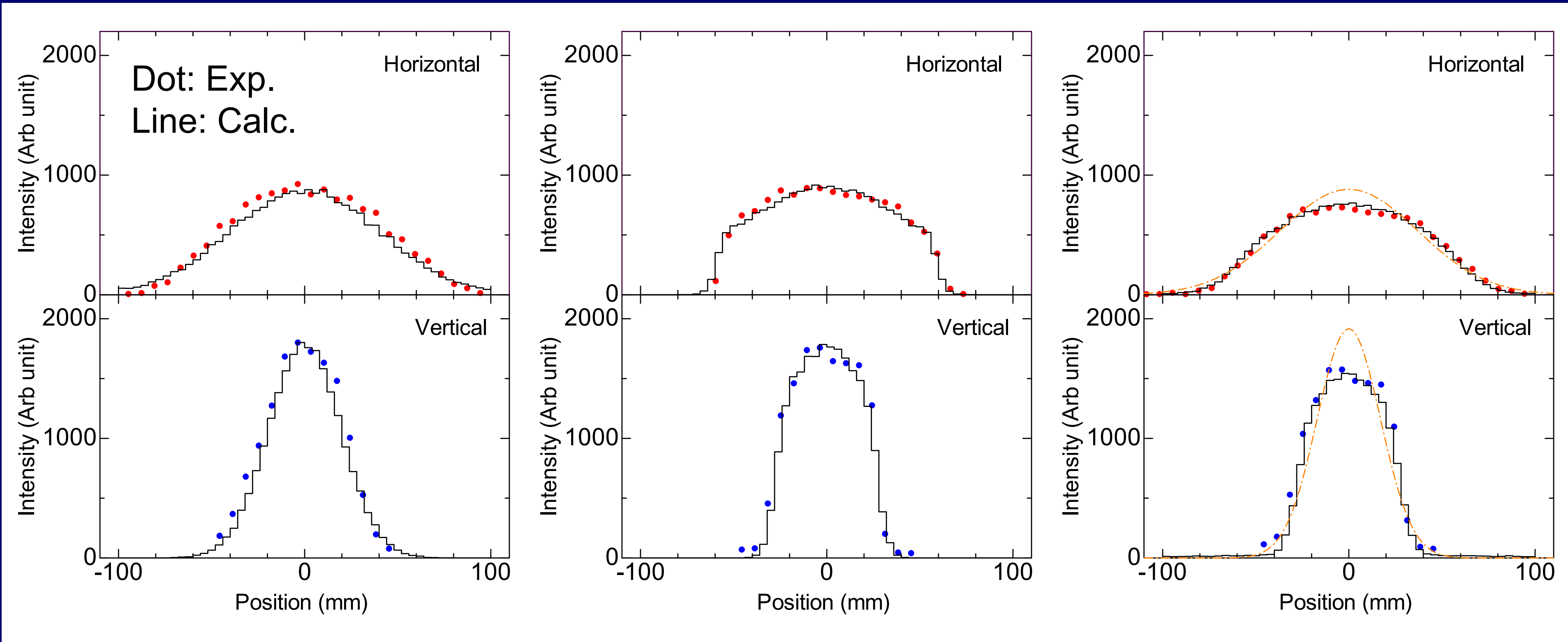
Fitted parameter OCT tuning Beam profile can be estimated by tracking

Obtained beam profile

OCT 0A

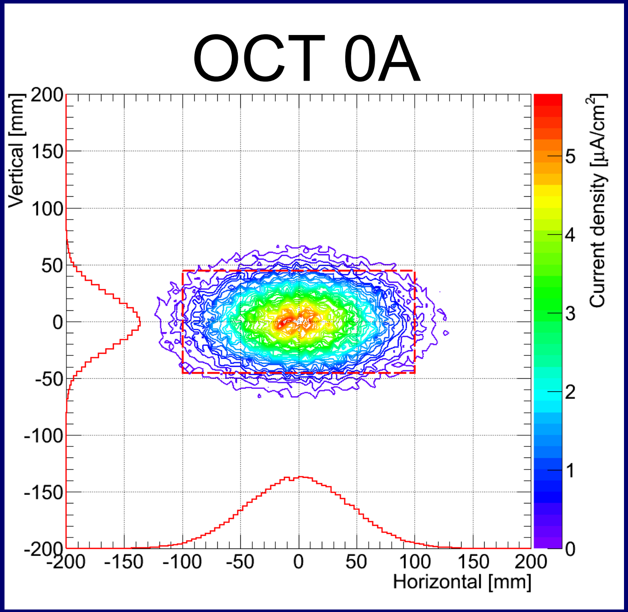
OCT 698A

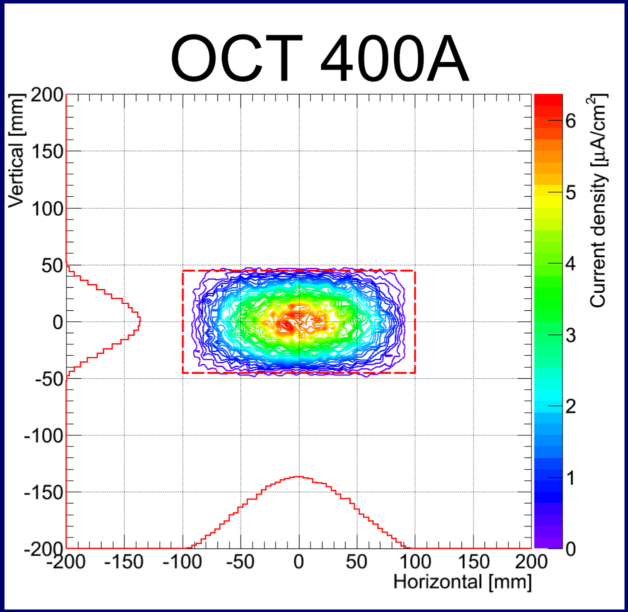
OCT 698A
with muon target

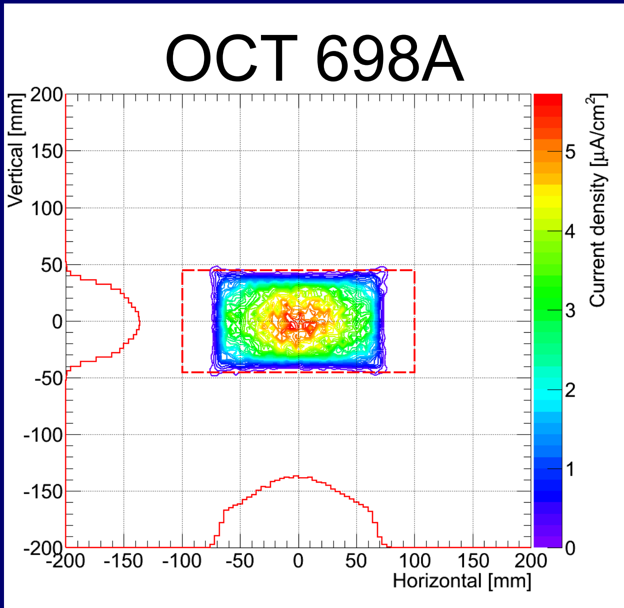


- Flat beam was obtained and lower intensity of halo was observed
- Good agreement of calculation even for with muon target
- Peak smaller by 14 % and 20 % at horizontal and vertical. Overall 30~40 % reduced.

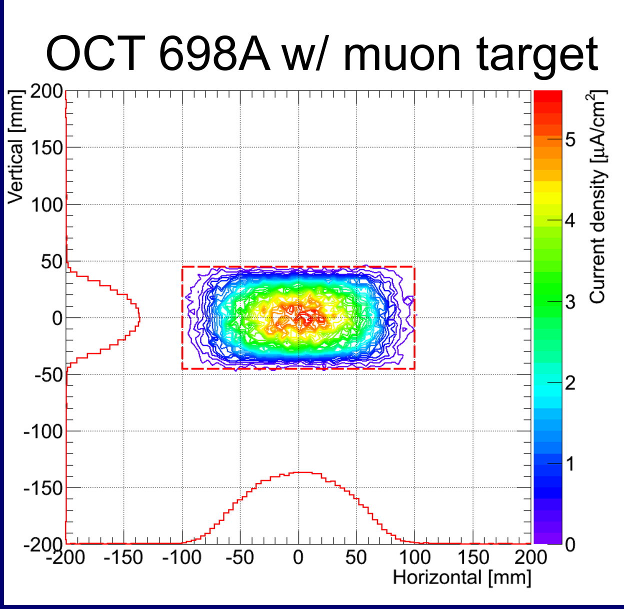
Beam profile at neutron target (calculation)





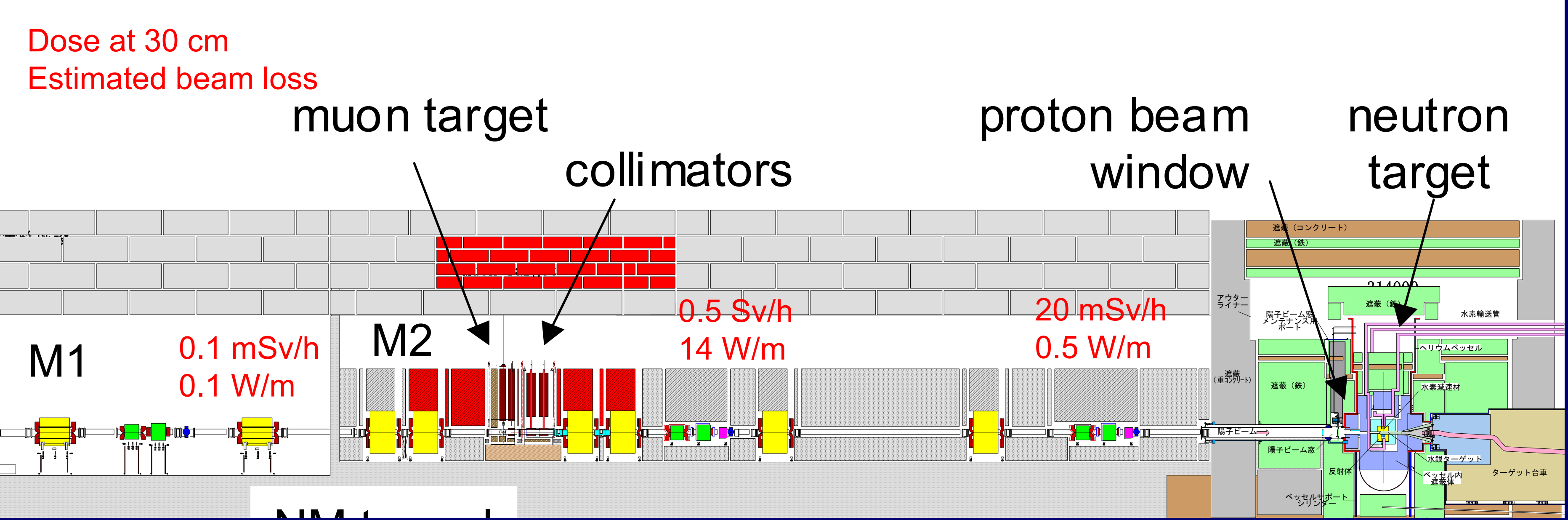


- Ideal shape obtained



Beam loss status

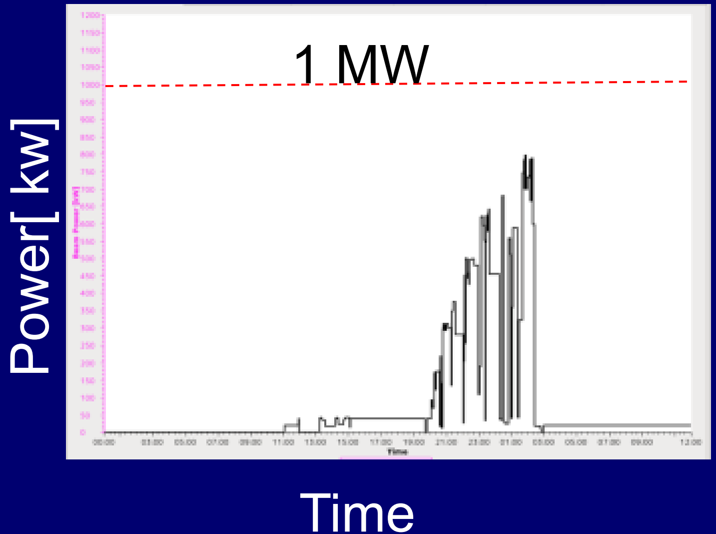
- Beam loss was quantitatively observed by mean of activation obtained by dosimeter for 500 kW.



- No significant beam loss aroused due to non-linear optics.
- To decrease the beam loss at hands on maintenance area (M1) with obtaining more flat shape, star shaped duct following Q mag with large aperture is installing at the present.

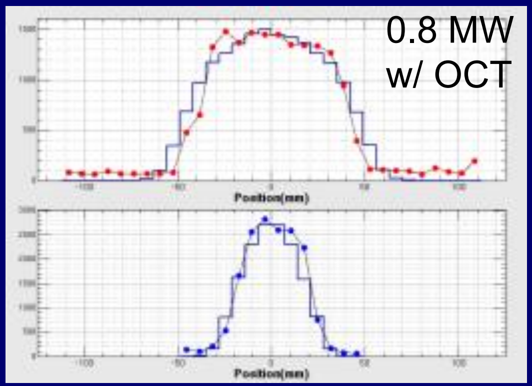
Demonstration ~1 MW beam operation

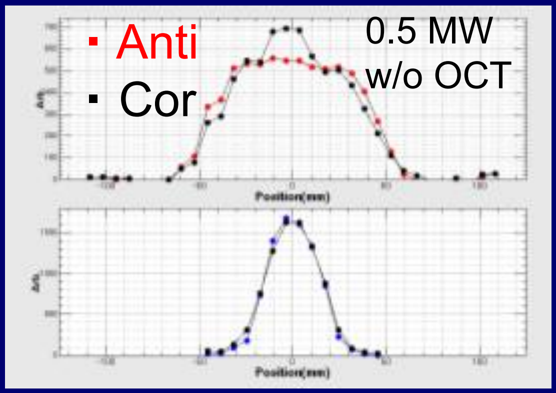
- Demonstrated 0.8 MW (0.9 MWeq) for short duration (70 s x 7times) due to outgas release from foil at RCS for charge exchange
- Radiation dose at target station showed as same as 0.5 MW beam



- Beam profile
  - Anti-correlated painting makes flat shape
  - 30 % of peak reduction (11 J/cc/pulse) achievable for 1MW beam operation

Beam power (MW)	25Hz equiv. power (MWeq)	Allowable RF rep. (Hz)	RCS inject. paint	Area of paint (π mm mrad)
0.5	0.52 (SX)	25	Anti	150
0.8	0.86 (FX)	25	Cor	100
0.94	1.0 (FX)	0.16	Cor	100

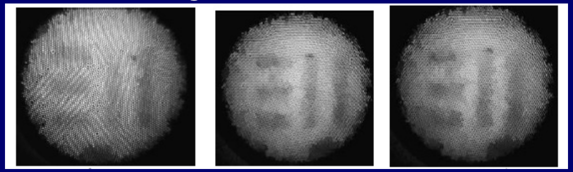




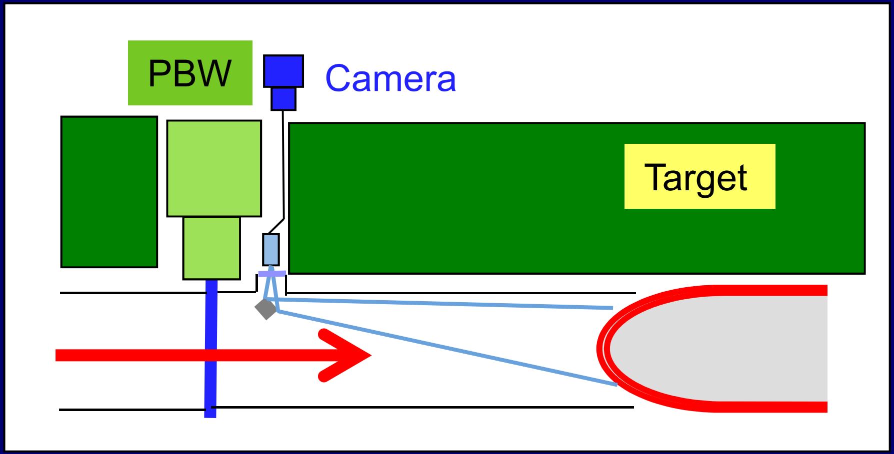
Development new profile monitor

A new profile monitor required to continuously observe 2D profile withstanding high power beam

Fujikura Fiber

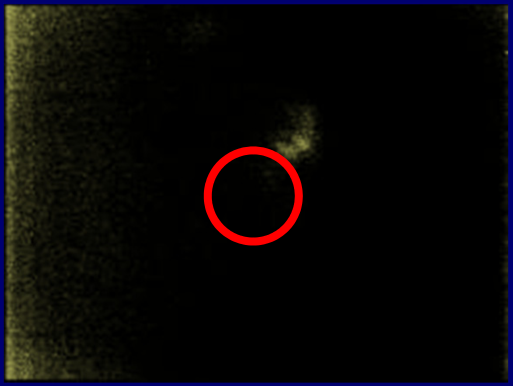


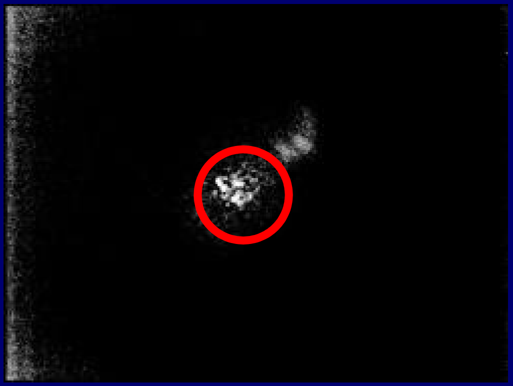
0 Gy 1 MGy 2 MGy



- Rad hard fiber scope (Fujikura FIGR-20, 20000 pixels) coupled with near-IR filter
- Applicable for high temperature target (for ADS target)
- Developing luminescent type

650 ° C 980 ° C 1300 ° C



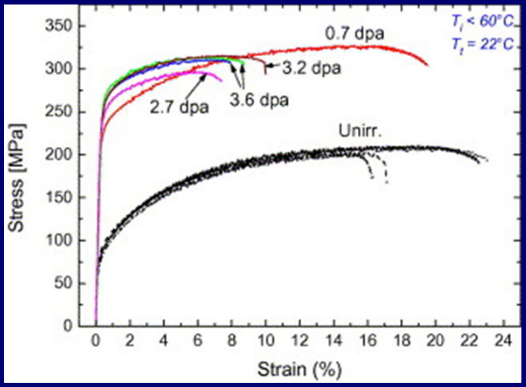


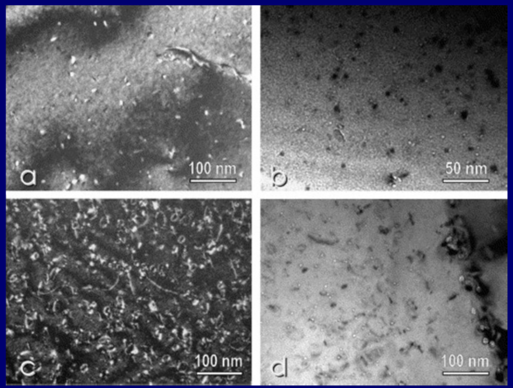
Proton beam window lifetime

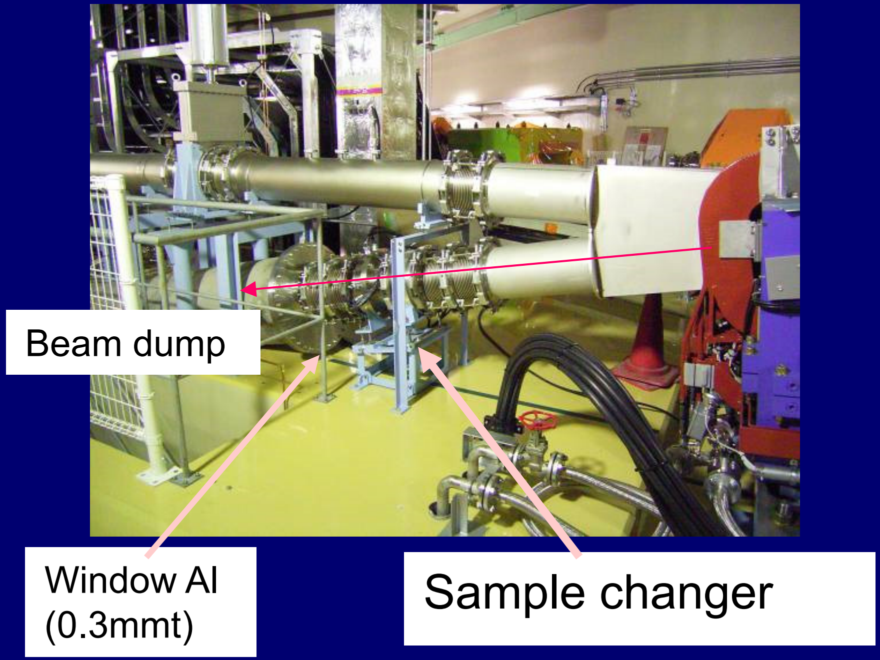
- To predict lifetime of the PBW with high accuracy, precious validation of calculation code for nuclear reaction is necessary.
- Production cross section measurement was carried out.

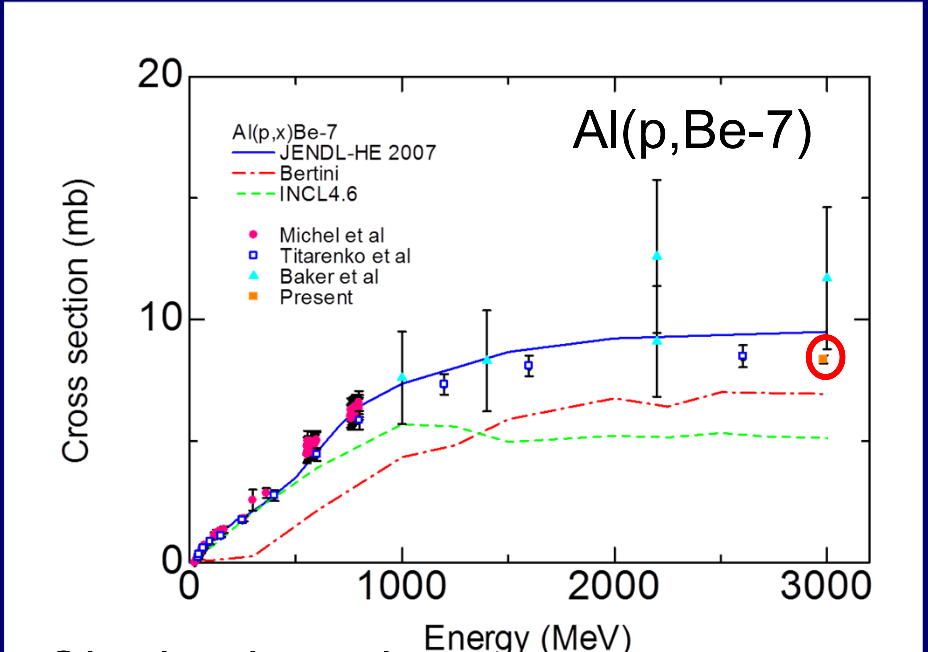
Result at SINQ/PSI for 0.6GeV

Y. Dai, et al, J. Nucl Mat. 343 184 (2005)







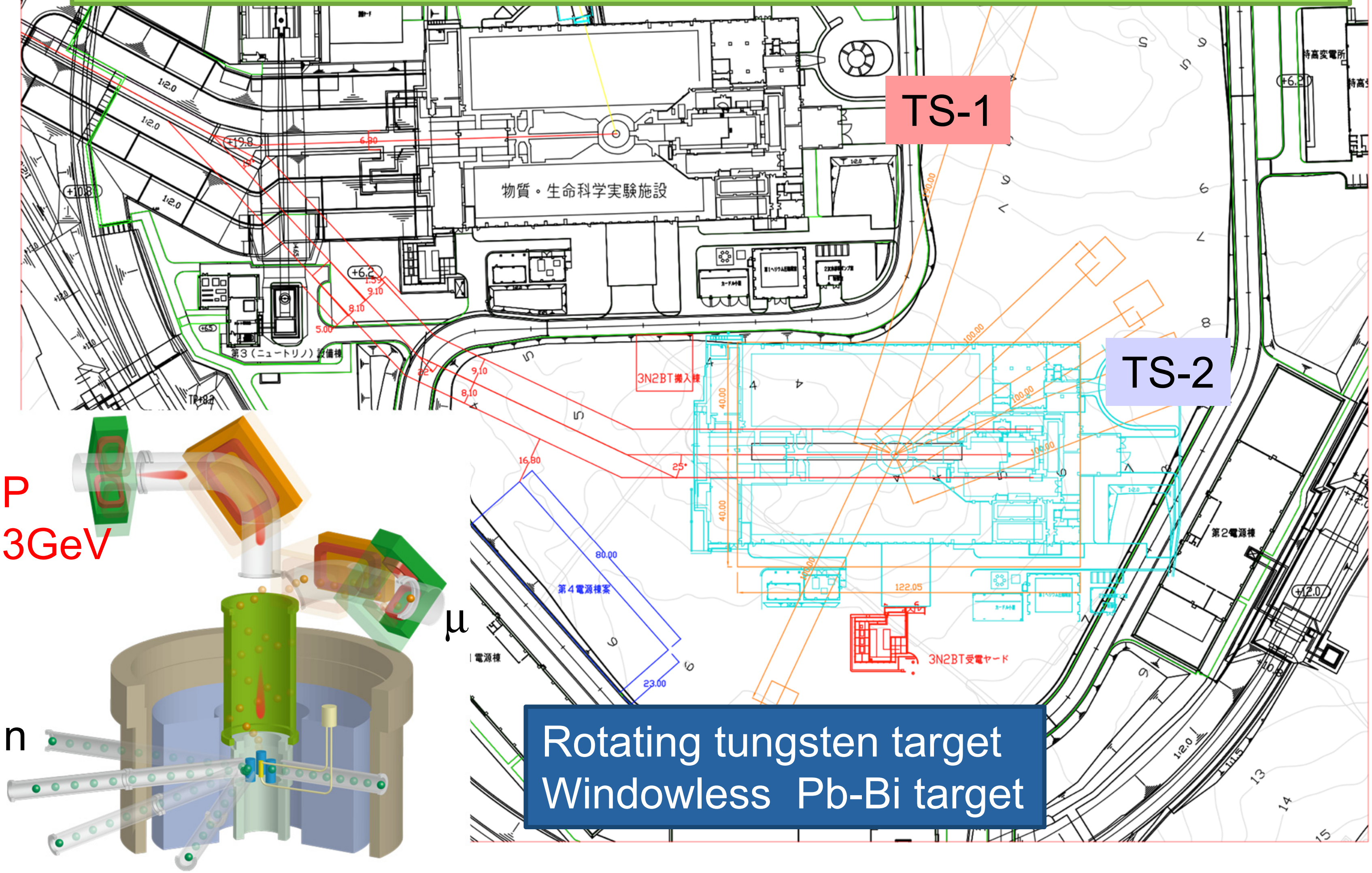


Obtained good accuracy

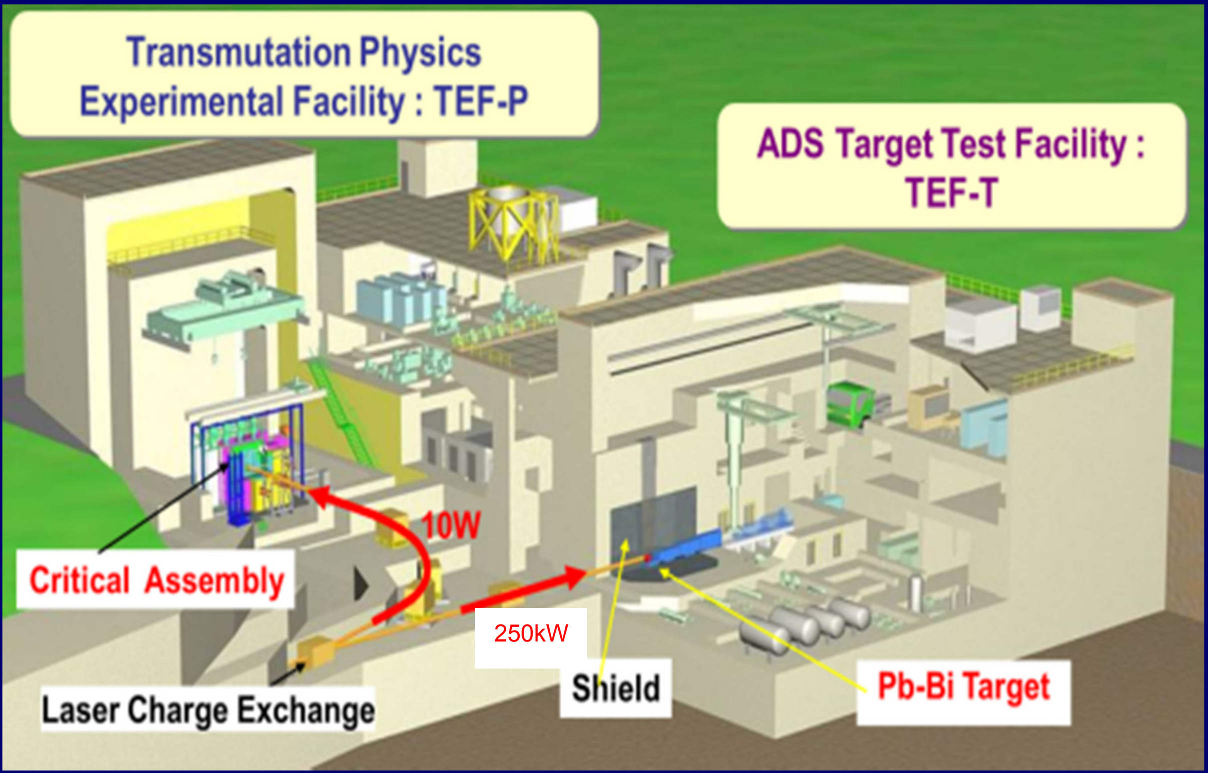
Future plans at J-PARC

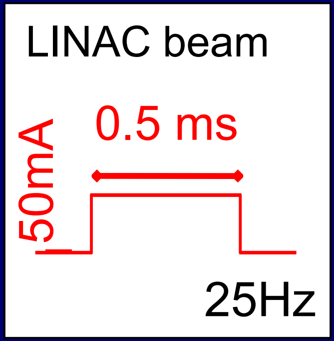
2nd target station for MLF

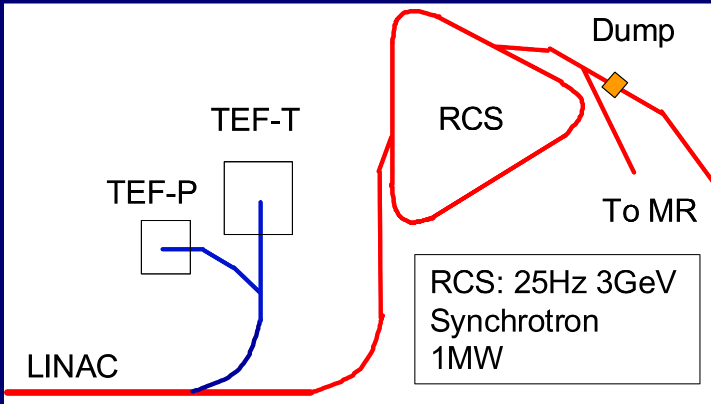
1st target ST (TS-1): 24 Hz: 1MW
2nd target ST (TS-2) 1Hz : 42kW (Designed to accept 1 MW)



New facility at J-PARC for R&D of ADS



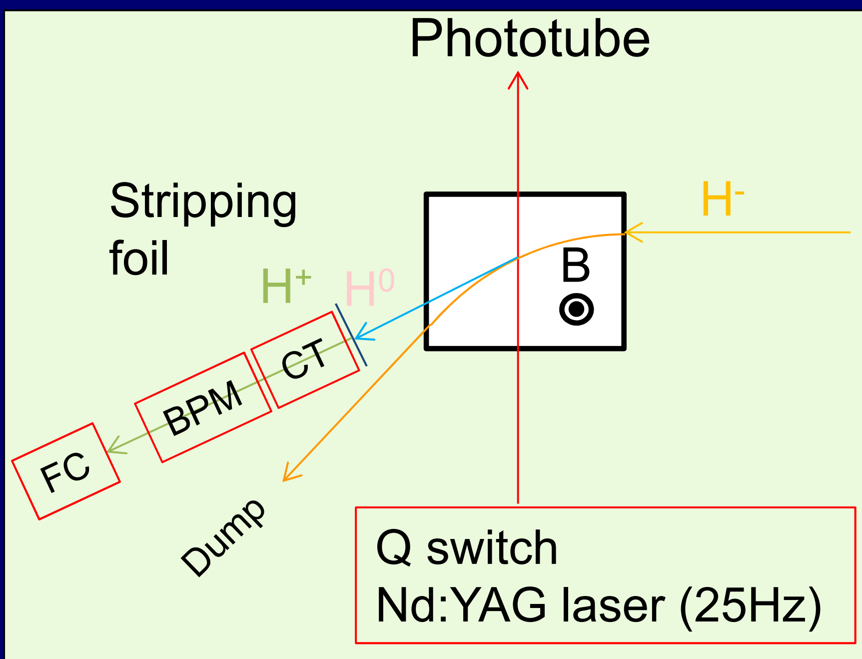


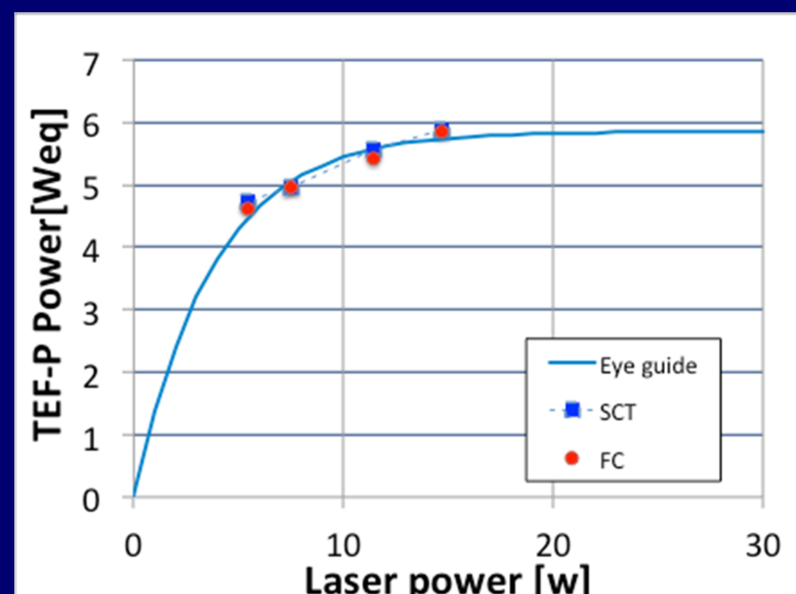


- TEF-T: Lead Bismuth (Pb-Bi) target test facility
  - H^- beam, 25Hz, 400 MeV, 250 kW
  - Multi purpose use: High energy neutron beam line and ISOL
- TEF-P: Subcritical assembly (Minor actinide, Am, Np)
  - H^+ beam, 25Hz, 400 MeV, 10 W
    - Laser charge exchange(LCE) developing

R&D of Laser Charge Exchanger(LCE)

- LCE was examined at RFQ test-stand using 3MeV H^- beam was conducted last week.
- Demonstrated 5 W equivalent power of beam for TEF-P (0.4 GeV, 25 Hz, peak I=50mA) extraction.





Summary

- To mitigate cavitation damage on the mercury target vessel, beam flattening system has been developed. Peak intensity will be reduced by ~30 % of linear optics.
- Present beam operation had started with power of 0.5 MW. After installation of revised mercury target at the welding, the power will be ramped up the beam power to 1 MW.
- For R&D of ADS, TEF facility hopefully will start in a few years.

Thank you for your attention

Be patient for development of the target and instruments