Proton beam monitors at JSNS of J-PARC

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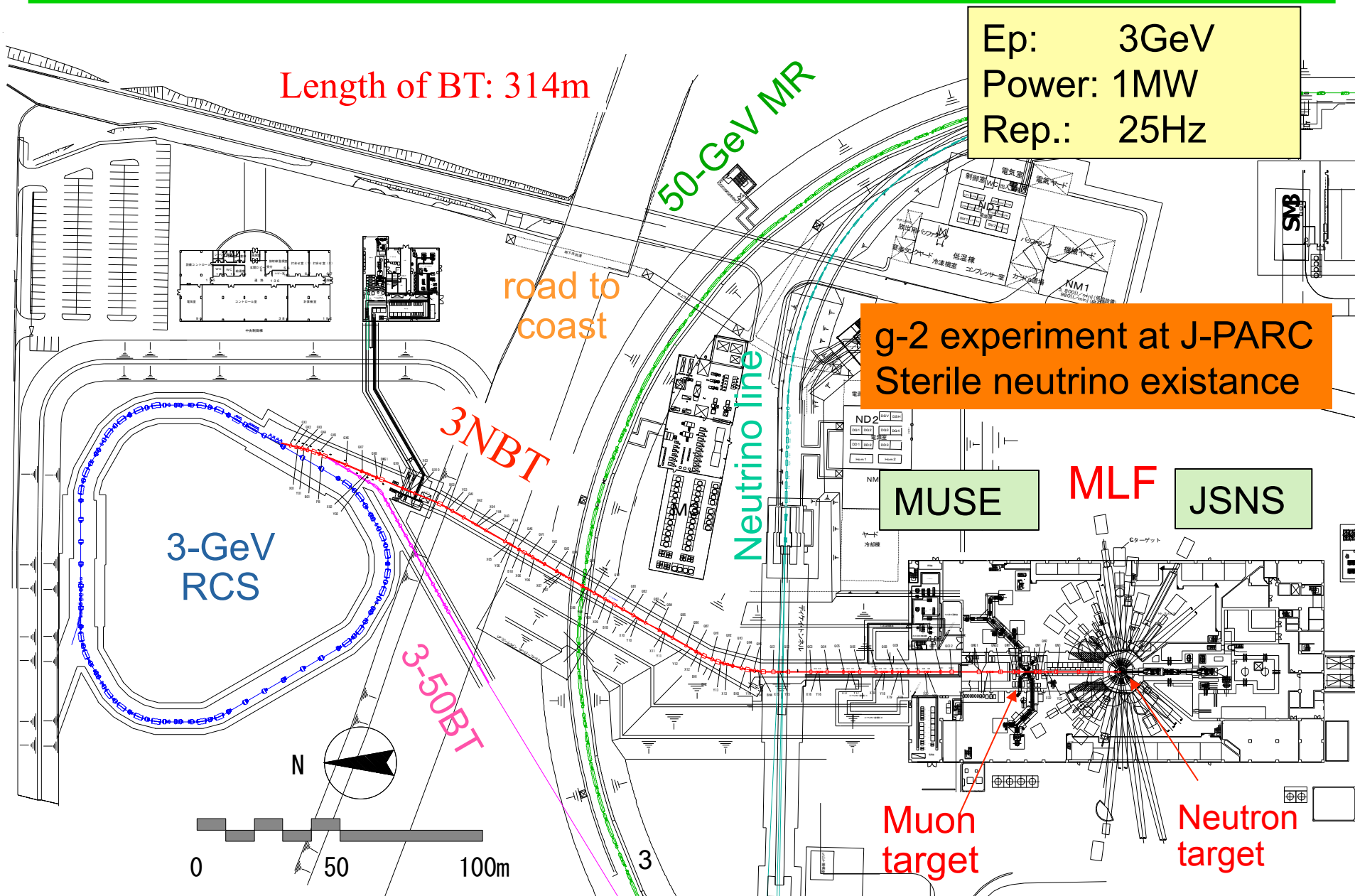
- Introduction
- Beam monitor system at JSNS
  - Multi Wire Profile Monitor
  - Beam Halo Monitor
- Beam flattering system
- Proton Beam window
- ADS program at J-PARC (TEF-T, TEF-P)

Beam transport to MLF



Ep: 3GeV
Power: 1MW
Rep.: 25Hz

g-2 experiment at J-PARC
Sterile neutrino existance

Whole length 320m

B: 9
Q: 54
STR: 45

Pulse

600ns

FWHM ~150ns

← 3GeV RCS

pulse magnet to
50-GeV MR

beam dump

horizontal bend

muon target

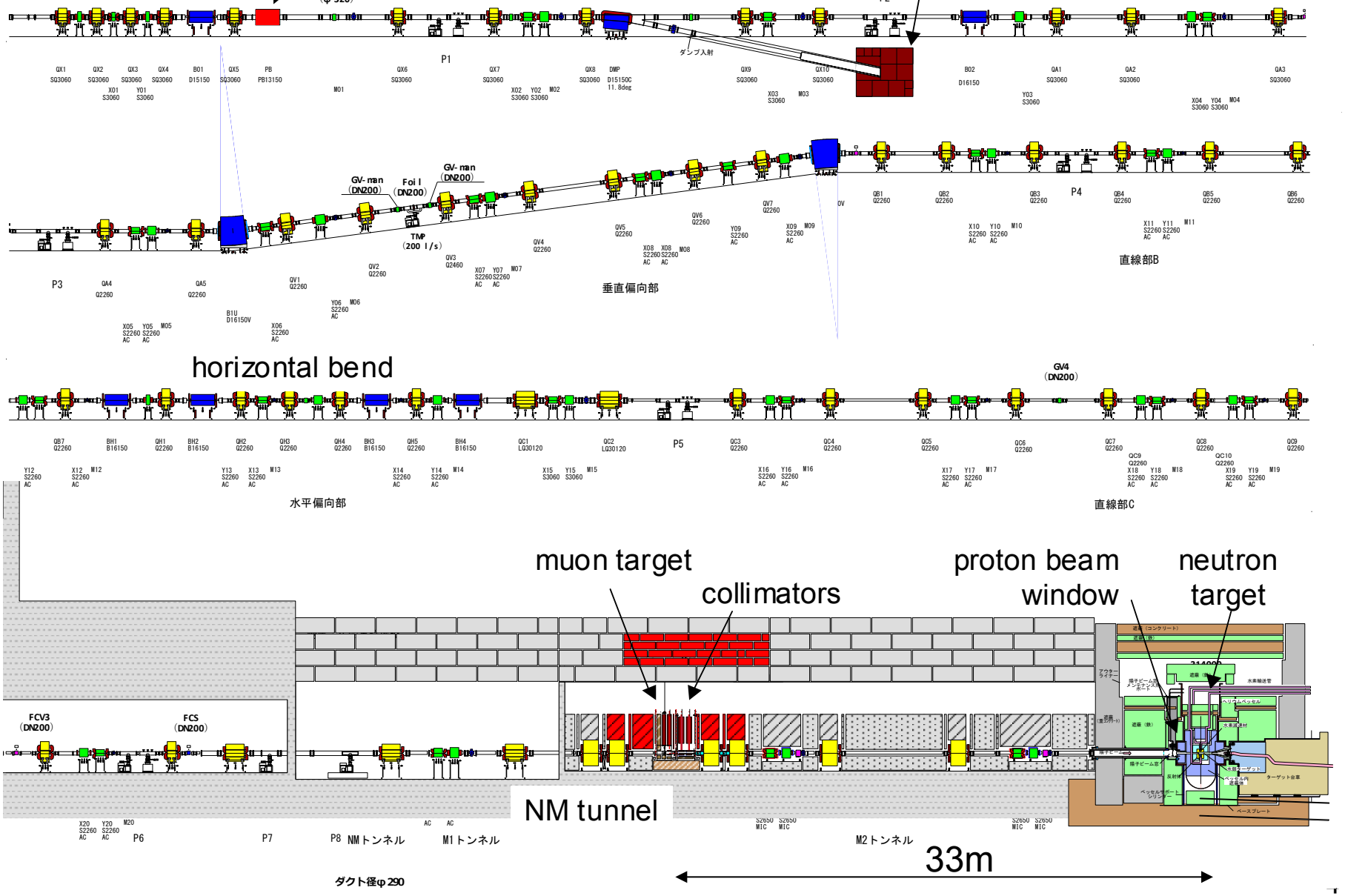
collimators

proton beam
window

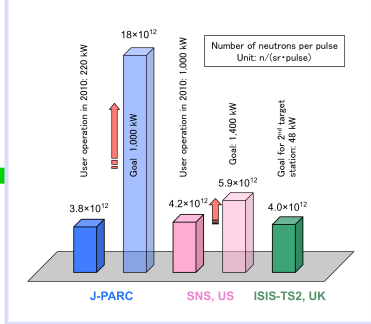
neutron
target

NM tunnel

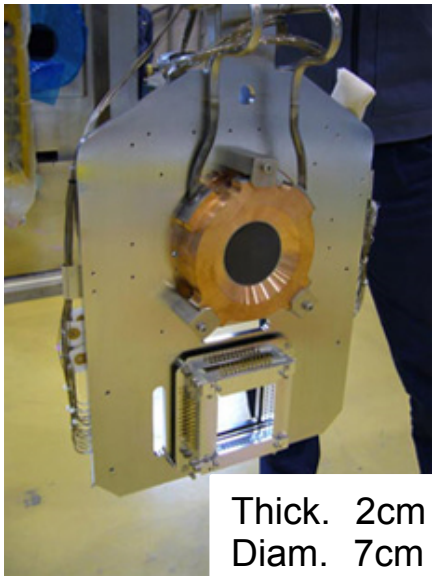
33m



Targets located at MLF

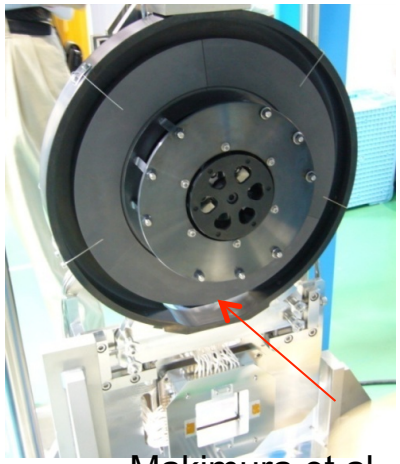


- Muon target(Stationery type)
  - Carbon graphite (IG430)
  - Highest intensity in the world
- Neutron target
  - Mercury
  - Highest pulse intensity in the world

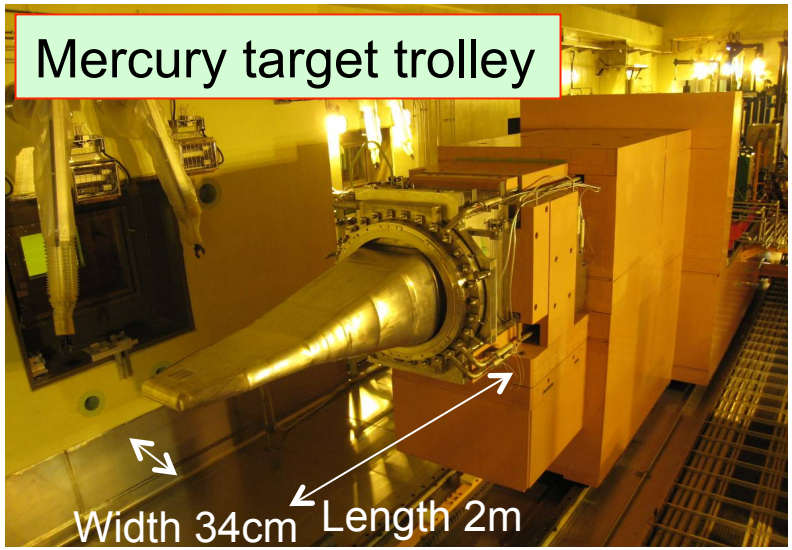


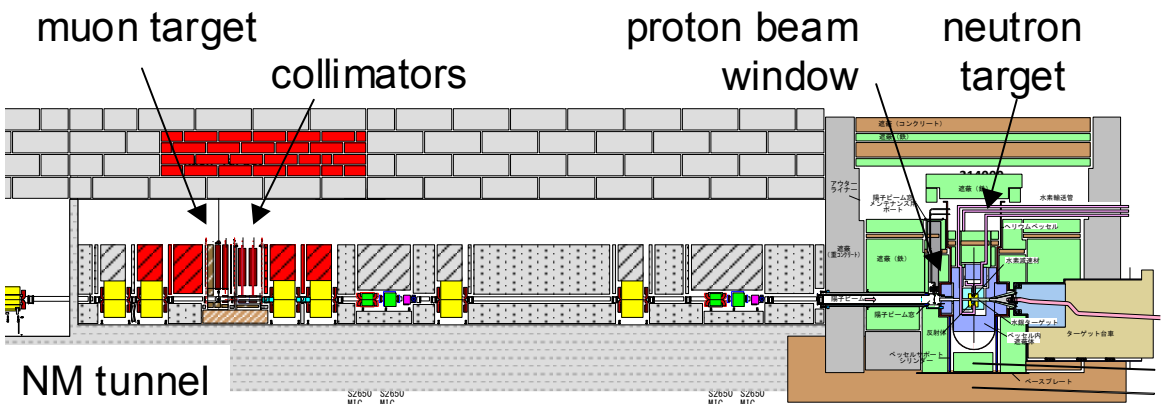
Thick. 2cm
Diam. 7cm

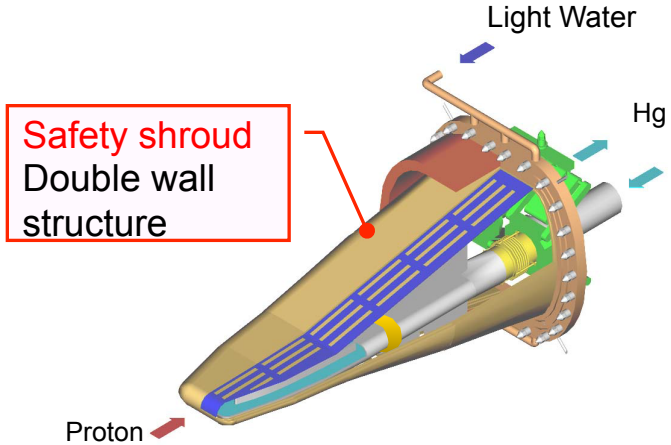
Rotating type (6rpm)



Makimura et al.



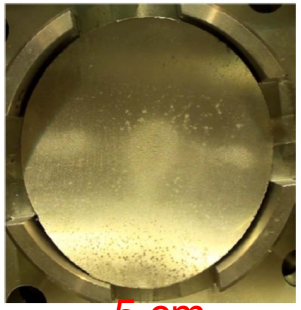




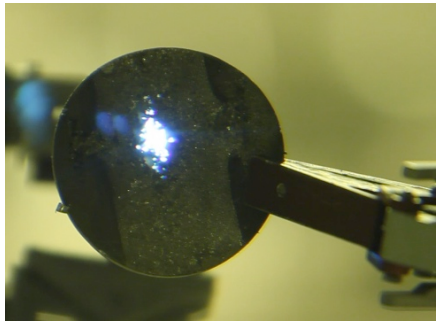
Proton beam at the target

- 3NBT・MLF beam operational status
  - Beam study with 0.6 MW beam
  - User operation with 0.3MW beam
  - 1 MW study planned Oct 2014
- Handling of high intensity proton beam
  - Importance of beam profile
  - Pitting damage proportional to 4th power of the peak current density at target (P4 Law)
    - Rastering does not help mitigation.
- JSNS harder condition than SNS
  - SNS: 60Hz, Storage ring without muon target
  - JSNS: 25Hz, RCS with muon target
- Although helium bubbling mitigates the pitting damage, peak reduction is essential. Beam flattening by the non linear beam optics was developed.

王(king) sign appearing

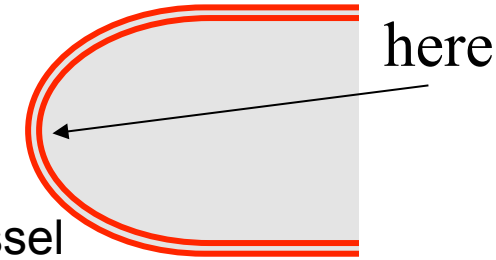


Damage at JSNS target



Pin holes at target of SNS

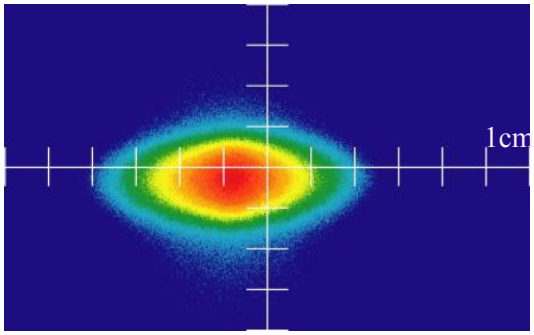
Pin holes are permitted at the inside wall of SNS but not allowed at JSNS due to wall structure.



Target vessel
SNS: 4 walls
JSNS: 3 walls -> 4 walls in next

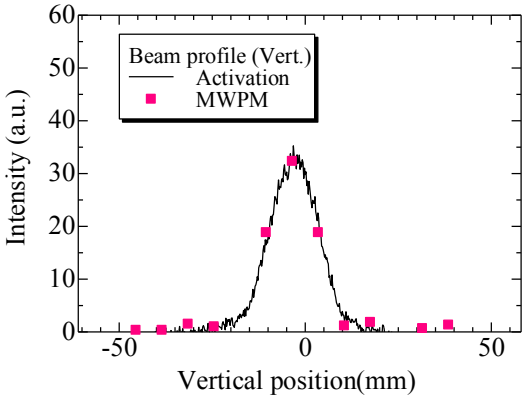
First beam measurement with foil activation

- 2D profile required for confirmation of tilting beam
- Placing aluminum foil (Al: 1mm-t) placed at the target vessel, residual does was observed by imaging plate (IP).
- No tilting of beam found

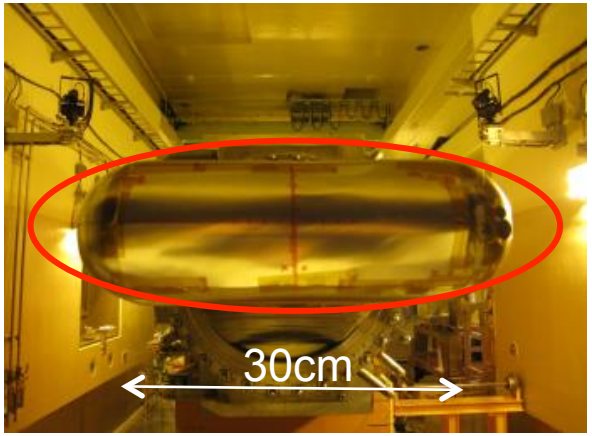


2D profile obtained by foil with IP

Good agreement with MWPM



Placed Al foil 1st beam



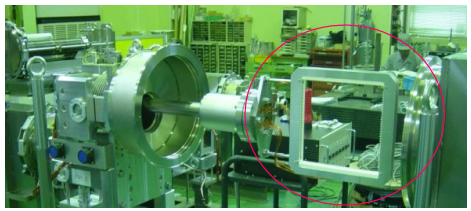
Removed after irad.

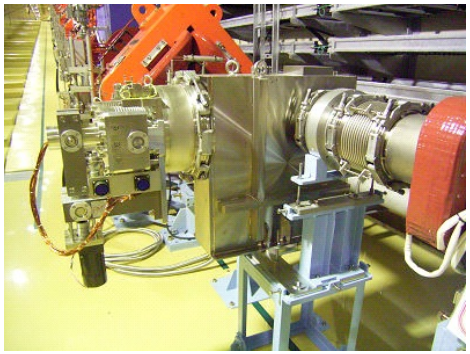
Only perform 1st beam

Beam diagnostics for profile and halo

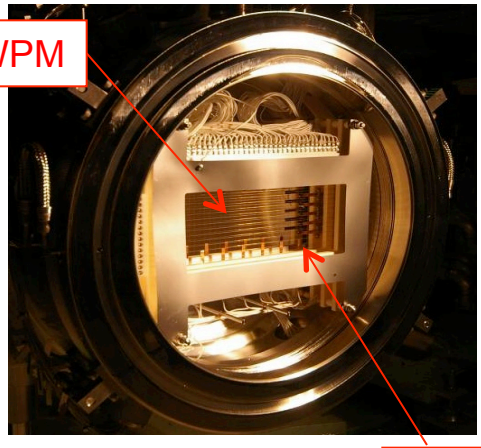
- Profile monitor and halo monitor (Online type)
  - Multi Wire Profile Monitors (MWPMs) (15 sets located) : SiC wires
  - Stationary MWPM at proton beam window (PBW) placed at 1.8 m upstream of the mercury target
- 2D profile： Residual radiation read by the IP (Offline type)

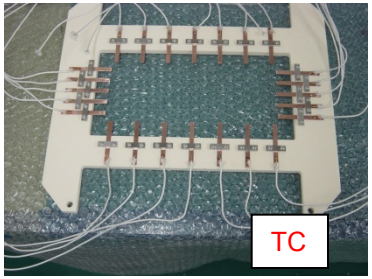
  After beam operation: IP was attached at the target by the remote handling





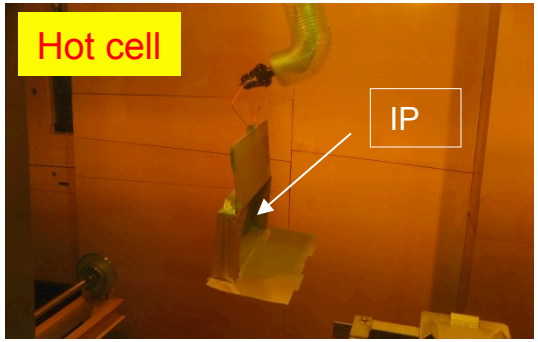
MWPM

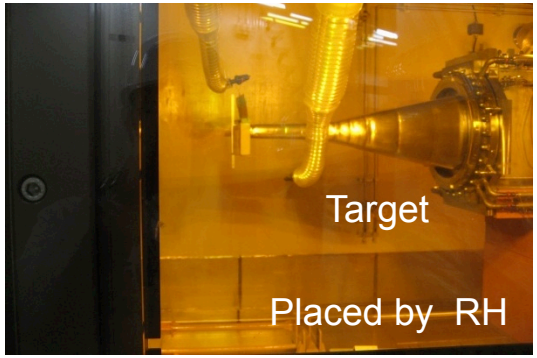




Halo monitor
- SEC
- TC

Monitors at PBW



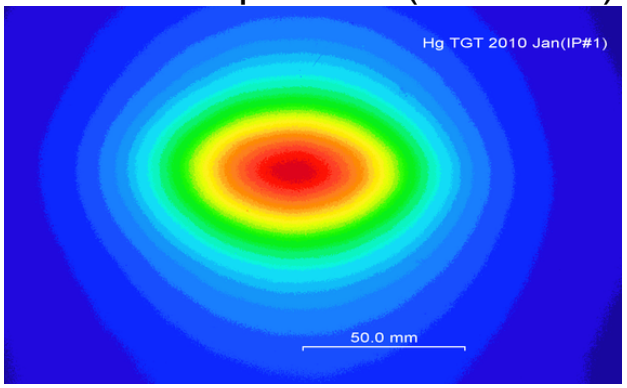


Imaging Plate(IP)

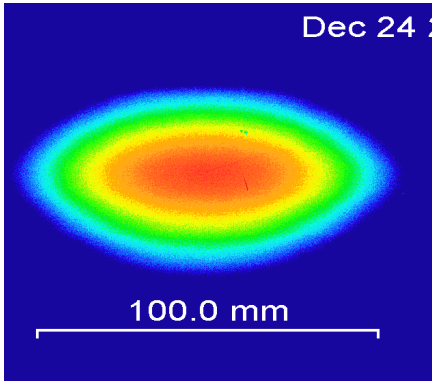
Beam profile at the mercury target

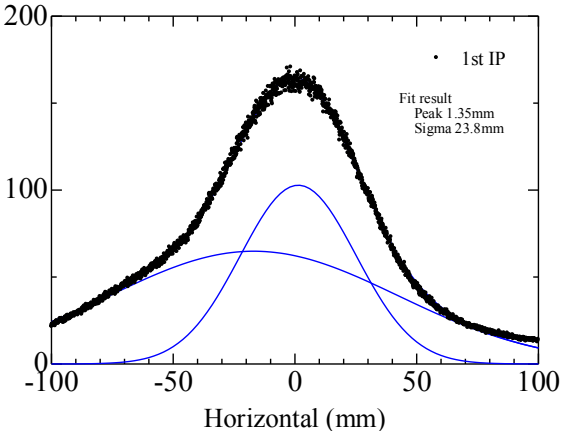
2-D measurement by IP

0.1 MW operation (2009 Dec)



0.2 MW operation (2010 Dec)

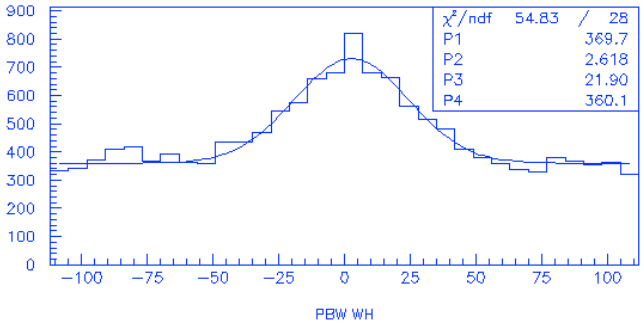


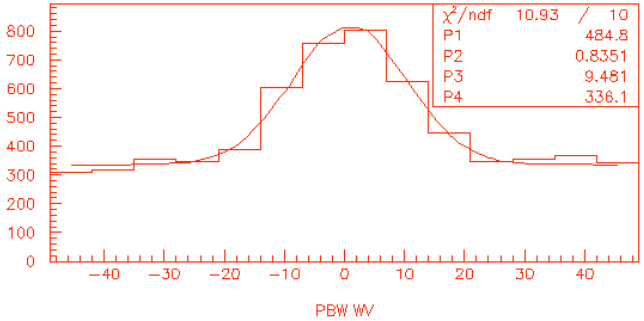


Obtained only 6 days of cooling duration after irradiation of 0.2 MW beam
⇒ Possible for 1MW with certain cooling time

Profile result by the IP
- Fitted by two Gaussian curves
  Contribution of primary protons and secondary particles (almost neutrons)

MWPM at PBW





Result by MWPM
Fitting by Gaussian
- Width and position for each pulse obtained
- Beam width transformed to the width at the target

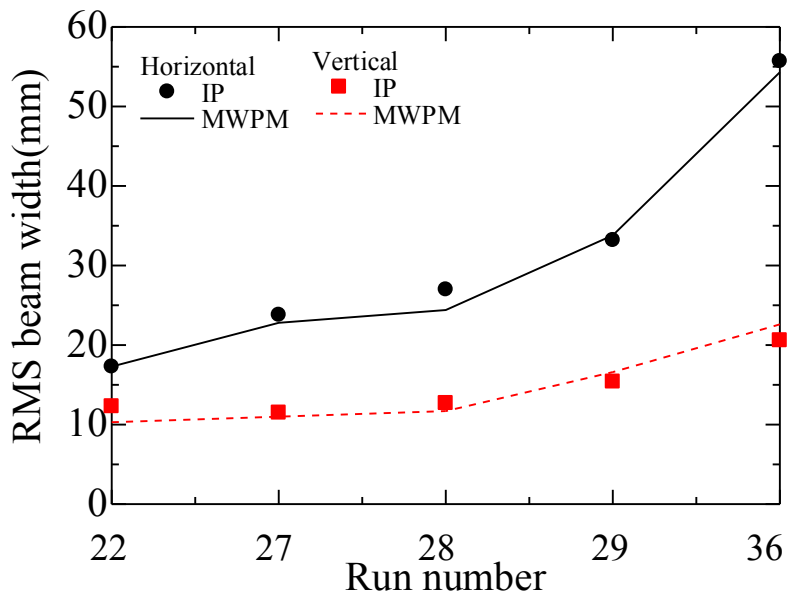
Trend of beam width at the mercury target

- Comparison of experimental results

To obtain low peak density, beam width gradually expanded

Unit: mm

	2009 Apr (Run#22)		2009 Nov (Run#27)		2009 Dec (Run#28)		2010 Jan (Run#29)		2010 Dec (Run#36 200kW)	
	σh	σv	σh	σv	σh	σv	σh	σv	σh	σv
MWPM	17.3	10.3	22.8	11.0	24.4	11.7	33.8	16.6	54.3	22.6
IP	17.3	12.3	23.8	11.5	27.0	12.7	33.2	15.4	55.7	20.6



- Both results by MWPM and IP show good agreement
  - Demonstration of reliable method
  - Reliable peak density on real time can be obtained by MWPM.

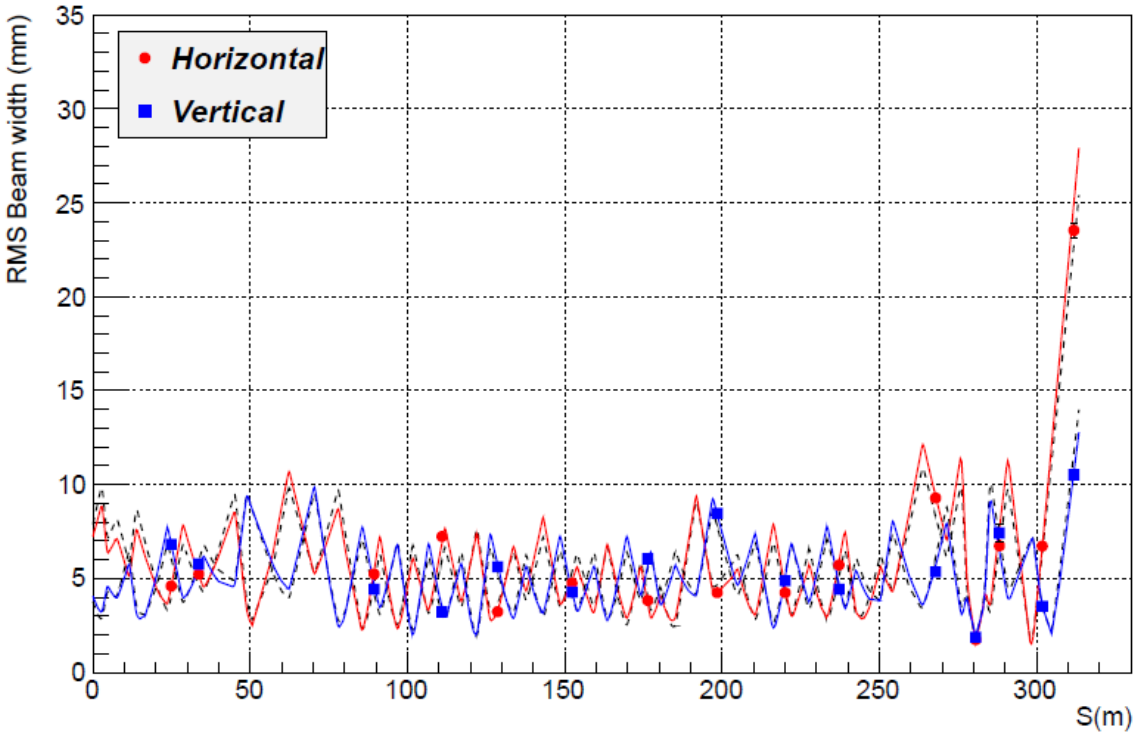
Anomaly beam status observed by MWPM, beam stopped by MPS

Beam width obtained by MWPM

Transverse emittance (RMS) and twiss parameters fitted with the beam width

⇒ Good agreement in whole beam line

Being analyzer of beam at RCS extraction



Result of RMS emittance

unit: mm mrad

300kW:

$\varepsilon_{h,v}$ 5.7, 4.9 π

Twiss parameter

300kW twiss parameter

αx -1.84, βx 20.4m

αy 0.57, βy 5.26m

Calculation of 300 kW case (by RCS group)

ε 5.4 π

αx -2.35, βx 24.8m

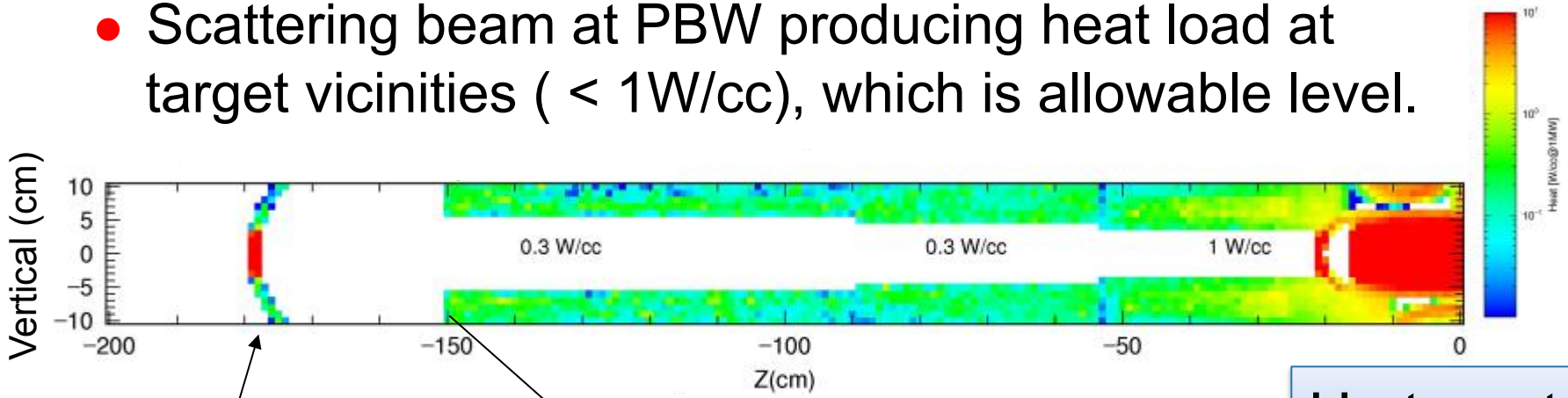
αy 0.89, βy 5.88m

Residual dose at beam transport:
Back ground except several points

Good agreement with the design calculation

Beam halo measurements

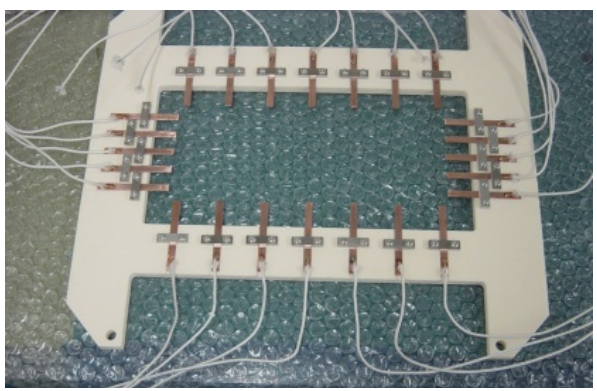
- Heat distribution at entrance of target station
  - Scattering beam at PBW producing heat load at target vicinities (< 1W/cc), which is allowable level.



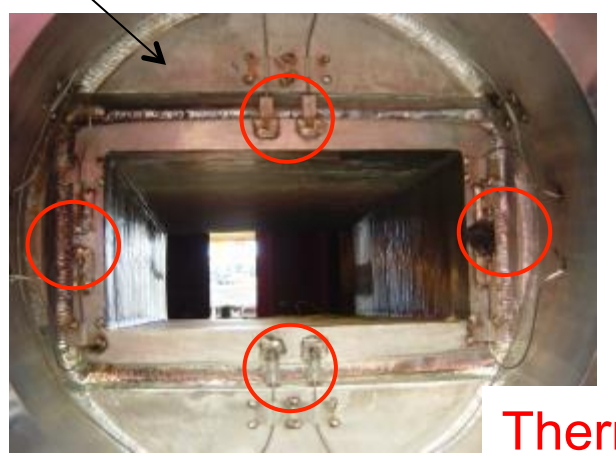
Hg target

PBW (Al 5mm-t)

Proton beam entrance at target station



PBW Halo monitor TC-type



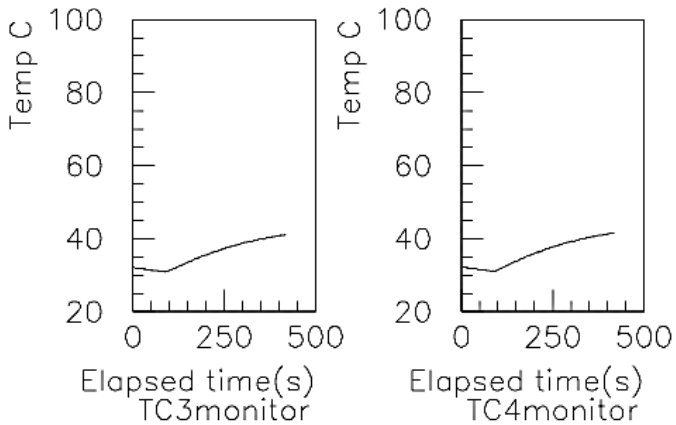
Thermocouples

Beam halo measurement

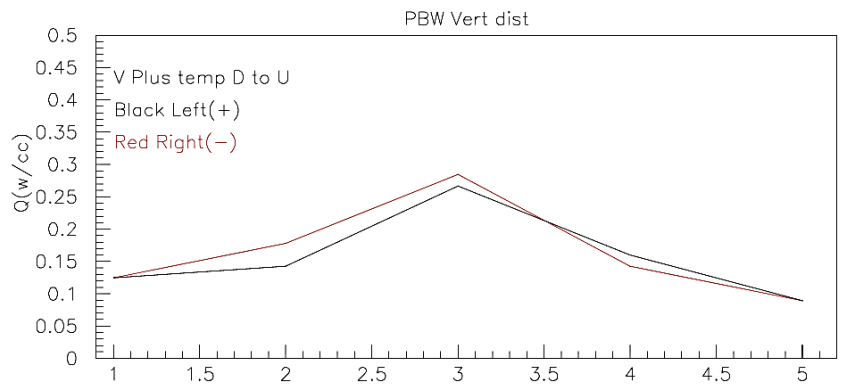
- Heat deposition obtained by the thermo couples
  - After 6 hours operation, temperature will saturate.
- Heat deposition density deduced by temp rising due to beam

$$Q(w/cc)=\rho C \quad dT/dt$$

ρ: Density(g/cc), C: Thermal capacity (J/g/K), T:Temp (K),t: Time(s)



Temperature trend at halo monitor



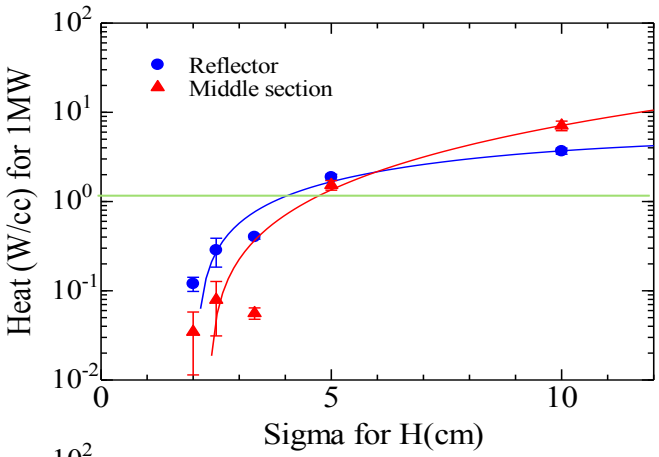
Horizontal position

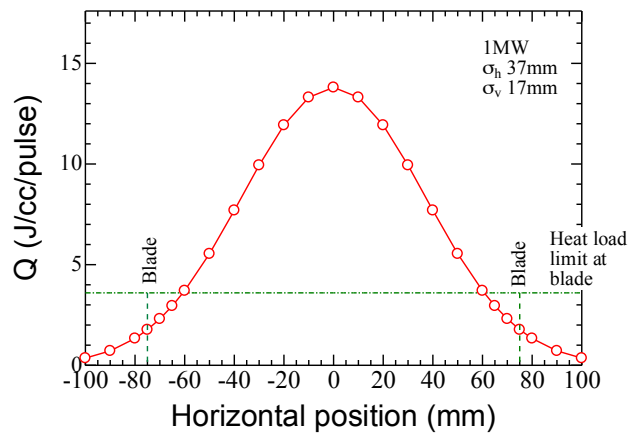
For beam of 0.3 MW: Heat at target vicinity ～0.3W/cc

- Peak density and beam halo ⇒ Giving optimum operation parameter
- Developed expert system for beam control (Beam orbit and profile)
  - Even a rookie can control the beam with confident as an expert.

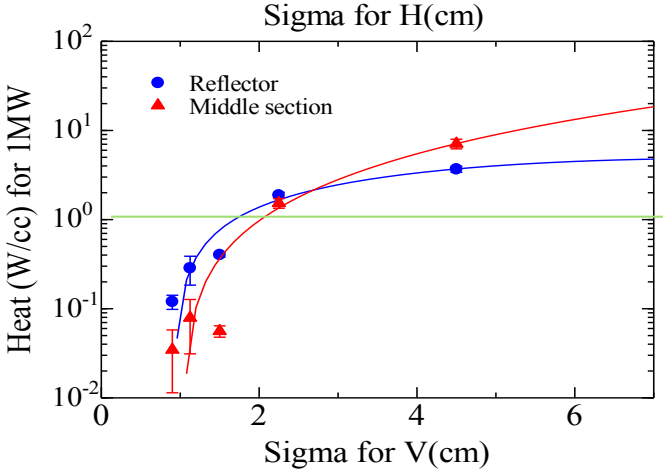
Limit of beam expansion by linear optics

- MWPM shows that the distribution is monotonous Gaussian.
- Expanding Gaussian beam to decrease the peak density
  - Vicinity of the target < 1W/cc(0.04J/cc/pulse)
  - Target blade < 90W/cc(3.5J/cc/pulse)
- Beam distribution can be approximated by monotonous Gaussian.





Conserve beam aspect ratio
H:V=2.2:1



Heat deposition at vicinity＜1W/cc
σ_h <37mm, σ_v <17mm
Target blade: no issues

- Limit for 1MW operation with linear optics
  Peak heat at the target: 14J/cc/pulse

Beam flattening system

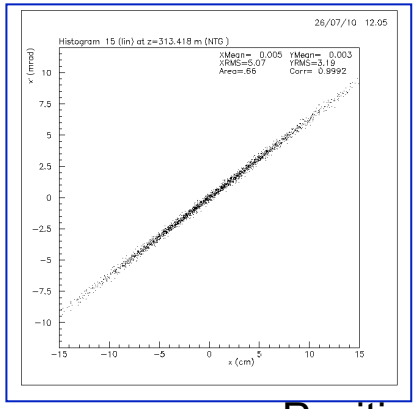
- Beam edge folding by non-linear optics (octupole magnet)

Linear

Non-linear

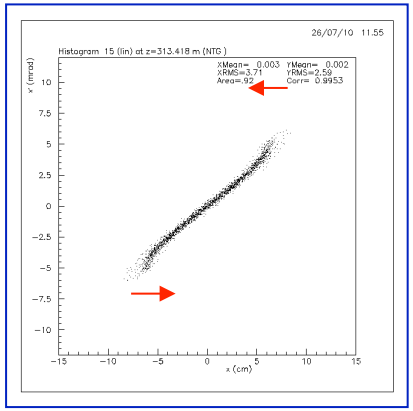
Phase space distribution

Divergence



Position

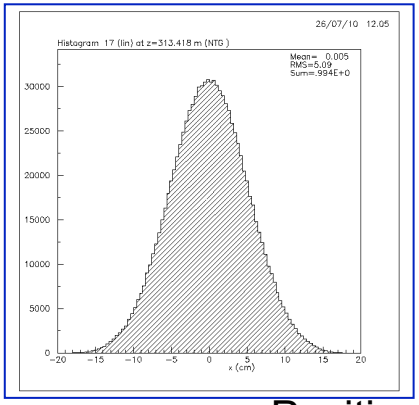
Divergence



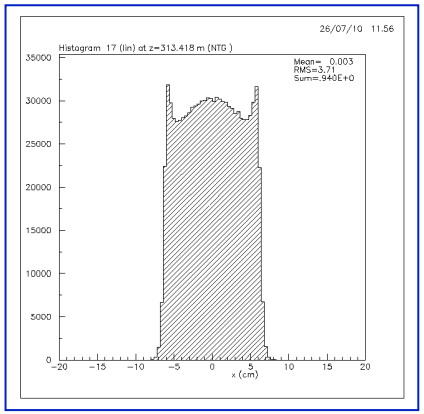
Position

Octupole magnet

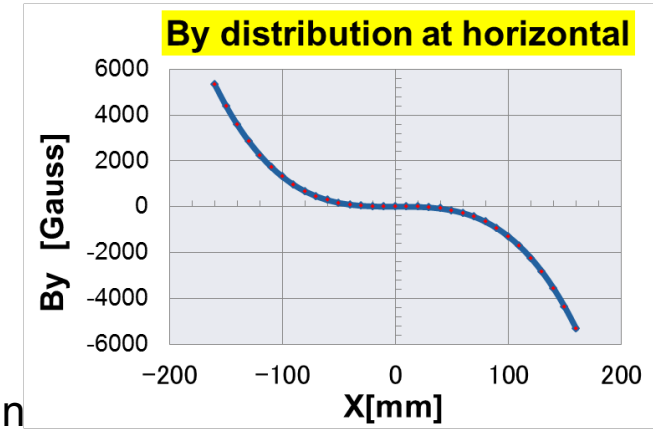
Horizontal distribution



Position

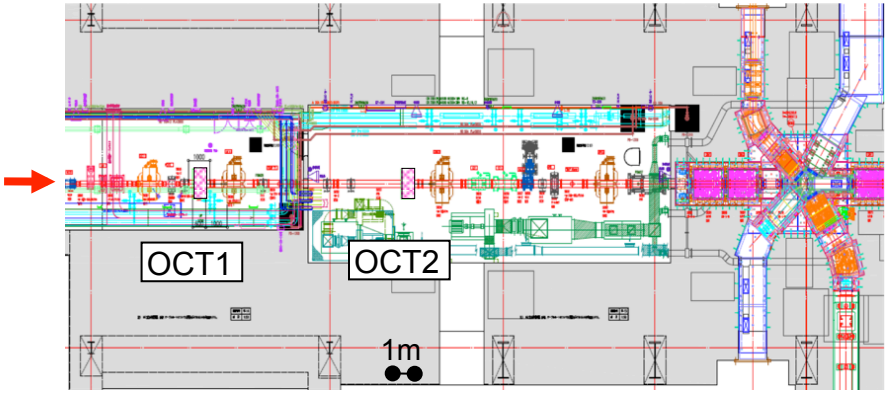


Position



Installation of OCT magnets

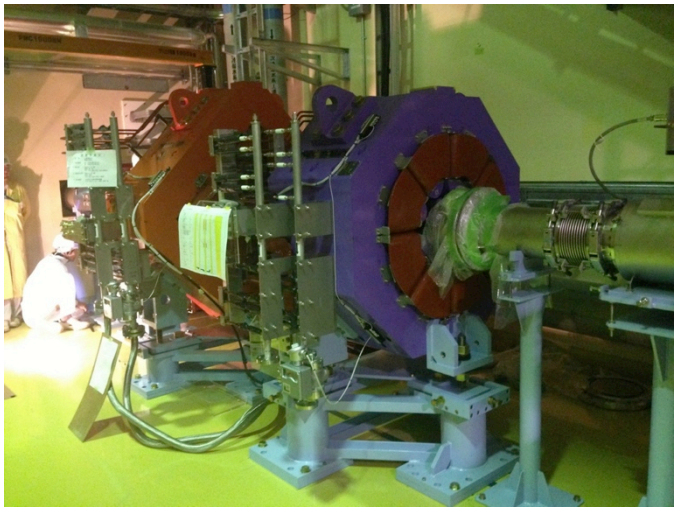
- For peak reduction, octupole magnets were installed on July 2013.
  - OCT1 and OCT2 installed at downstream 3NBTand M1 tunnels
  - Beam Position Monitor (BPM) placed at OCT1,2 for beam centering



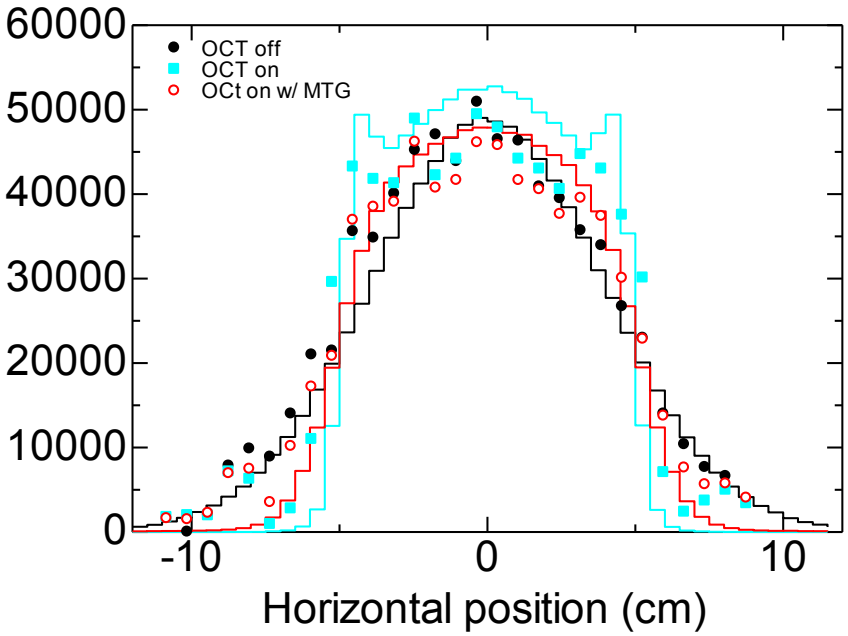
Horizontal view

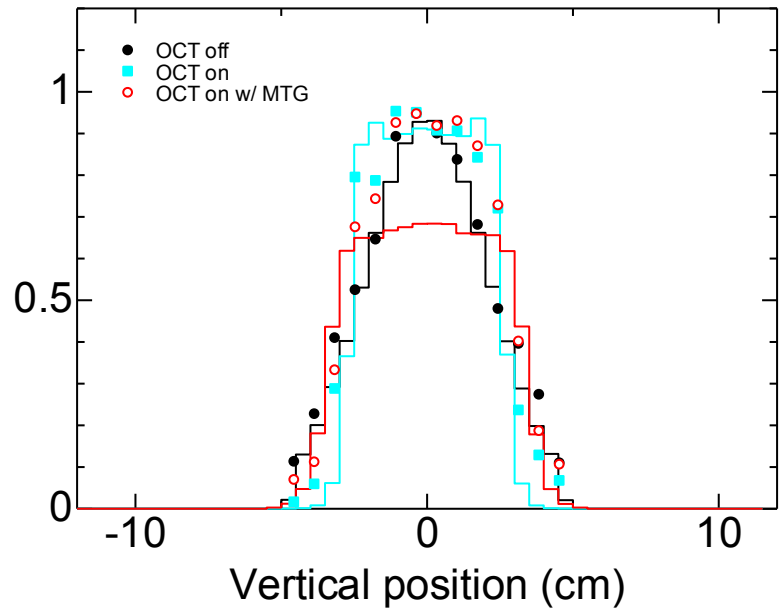
Completed installation of OCT1 at downstream of 3NBT tunnel

Shields above M1 tunnel opened for transport OCT2 to tunnel



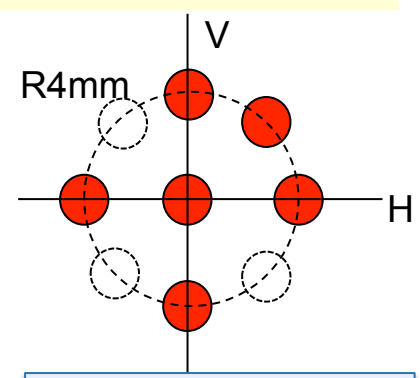
Beam profile with OCTs





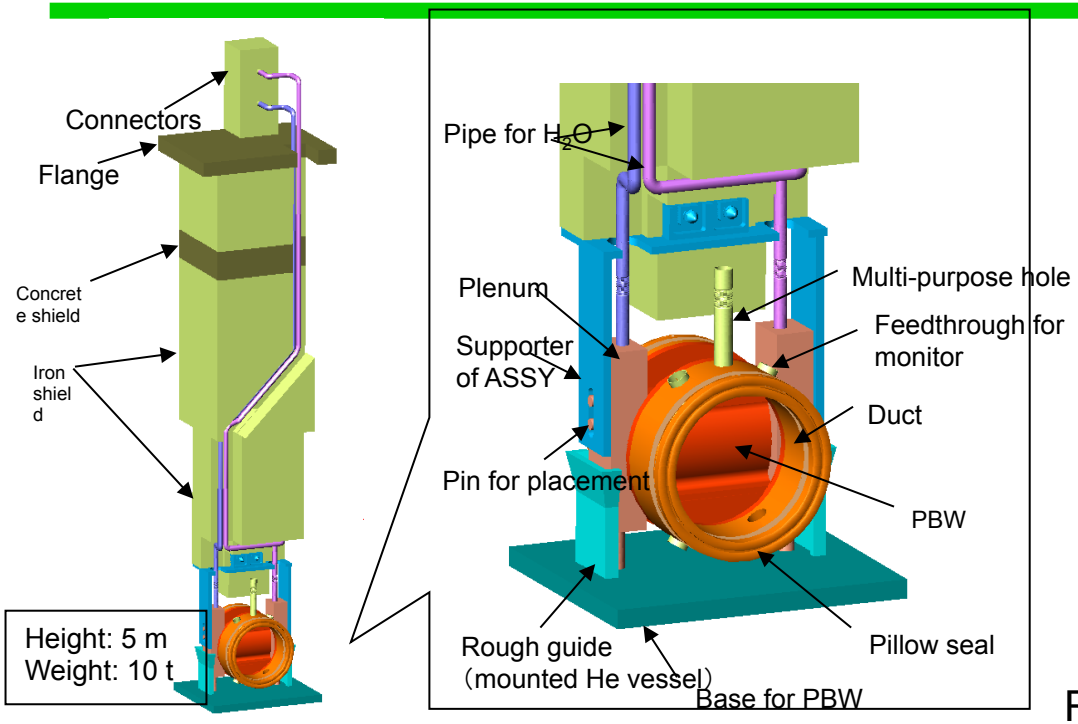
- Simulation (DECAY-TURTLE PSI ver.) shows good agreement. Muon target does not give worse influence on vertical distribution.
- Heat load at target vicinities and radiation dose at entrance of target station became 1/3.
- Not found significant radiation loss due to OCT magnets. This system will use Oct 2014.

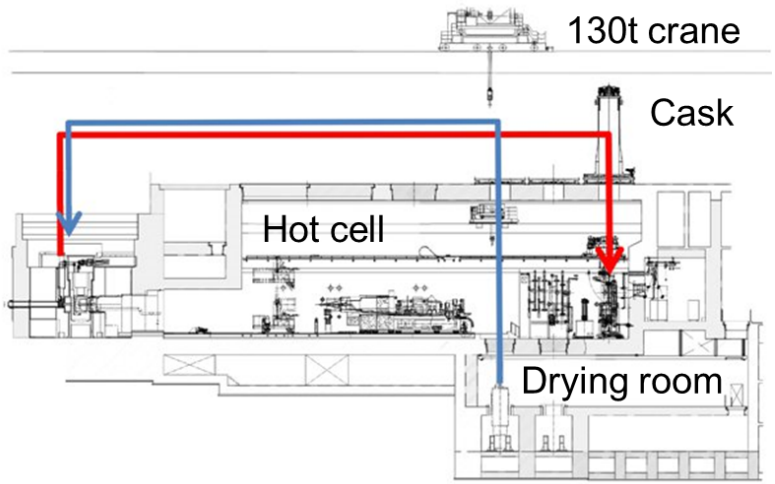
Beam position trend at muon target



Beam position rotates instead of rotating target

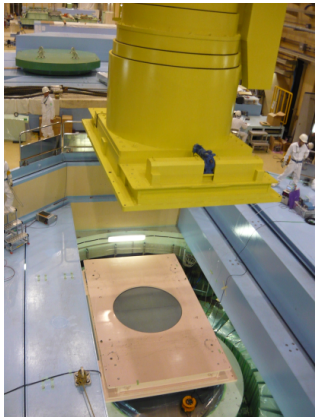
Proton beam window (PBW)





Remote Handling (RH) devices at JSNS

- PBW: a boundary between vacuum and helium region
- Remote handling replacement

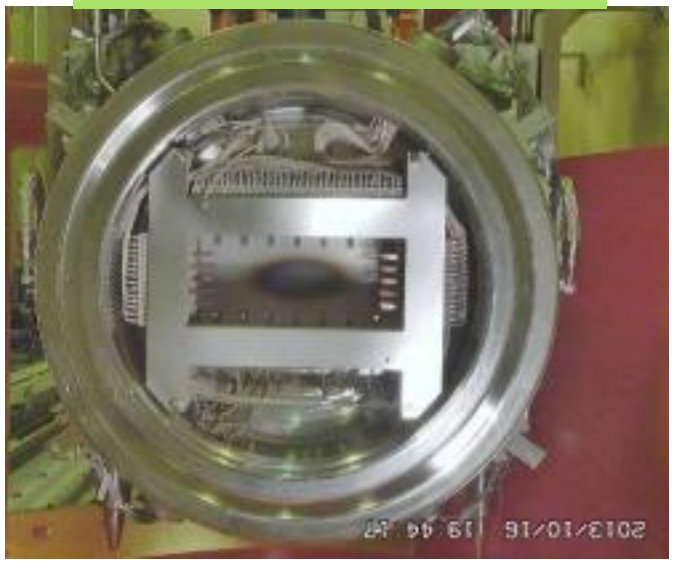


Floor valve

Replacement of Monitor/PBW

- Accumulated power: 2GWh, which was 1/5 of design (Lifetime of PBW 2years H: 2000 appm, He 1000appm determined based on the PIE result at PSI)
- In 2012 Oct., strange spots were found at helium side and replacement was decided.
- Strange spots may be caused erosion by the radiolytic acid in vessel. Leakage of helium vessel found.
- Status of PBW#2 will be observed this summer.

PBW at vacuum side

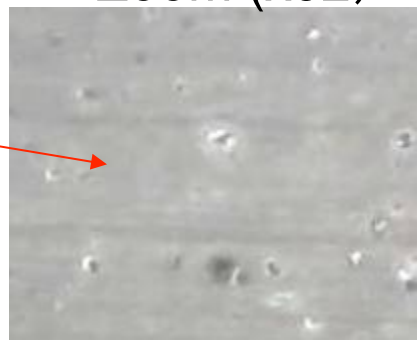


Received 2GWh
$2x10^{21}$ pot
$4x10^{20}$ p/cm^2

Inspection 2012
by high-zoomed camera

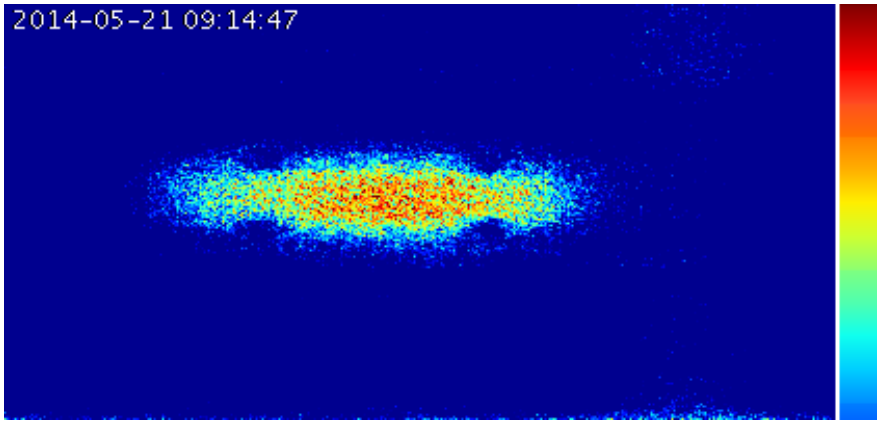
PBW at helium vessel side

Zoom (x32)



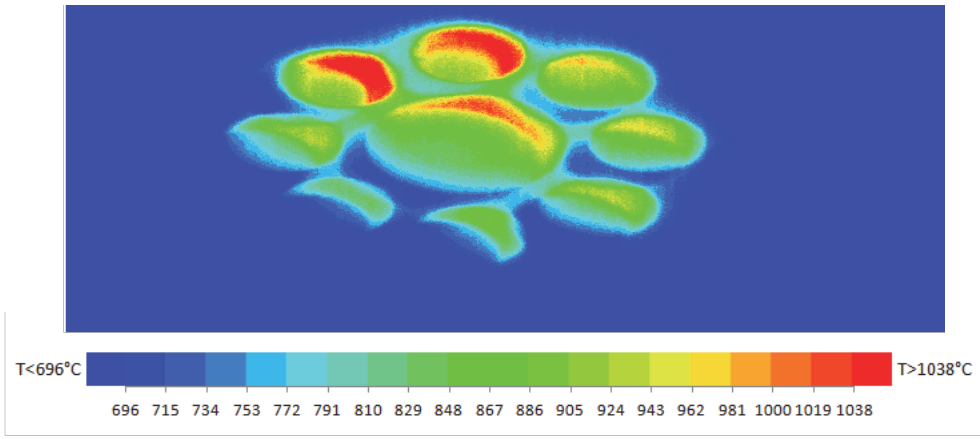
Profile Monitor

SNS monitor



SNS web page

SINQ VIMOS

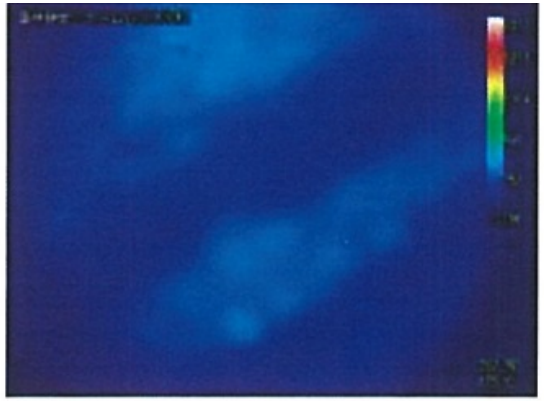


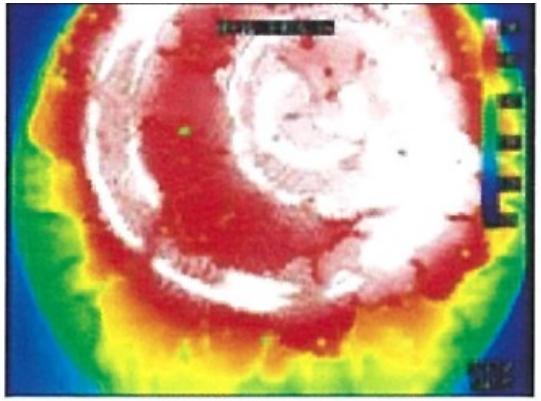
K. Tomsen, IBIC2012

Rad hard Fujikura fiber utilized for transfer imaging

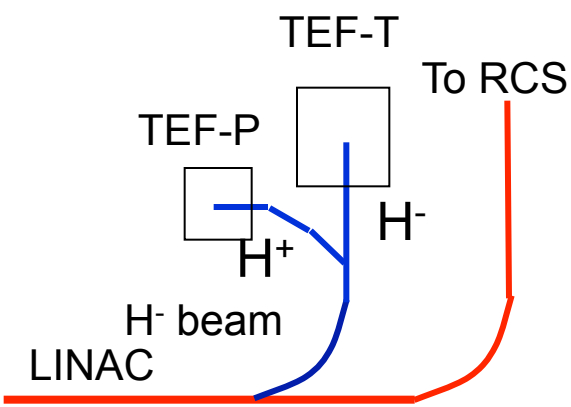
- IR system developing

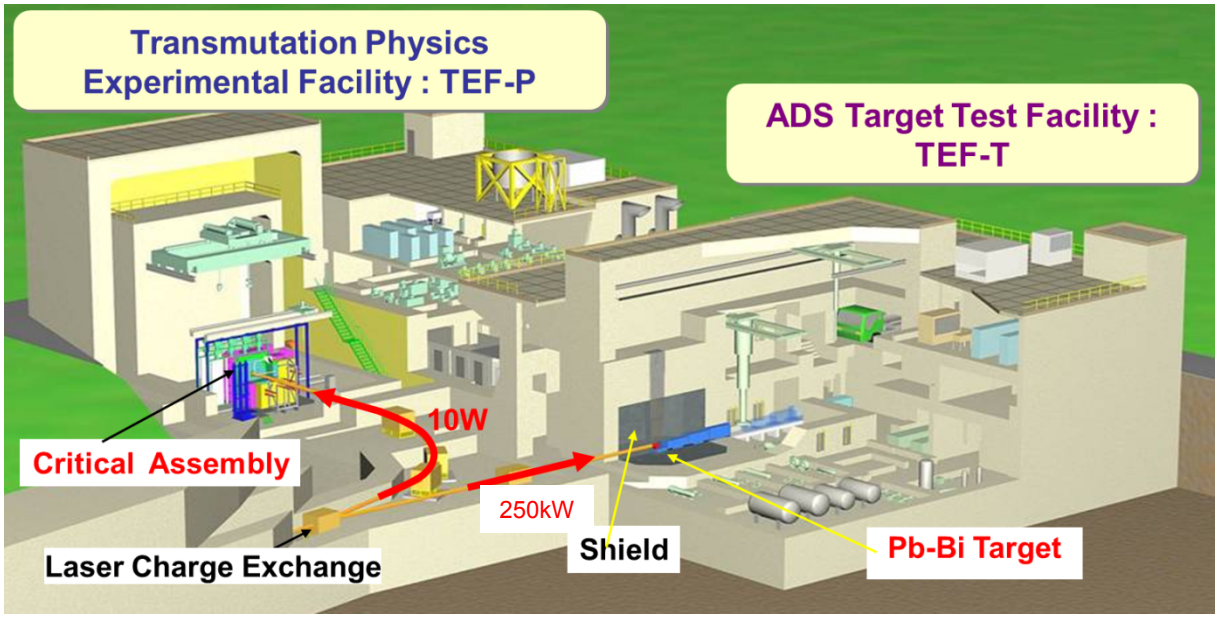
  High temp:
  Watch status of rotating carbon target
  Low temp(<100C)
  Watch JSNS and TEF-T target
  (new technique req.)



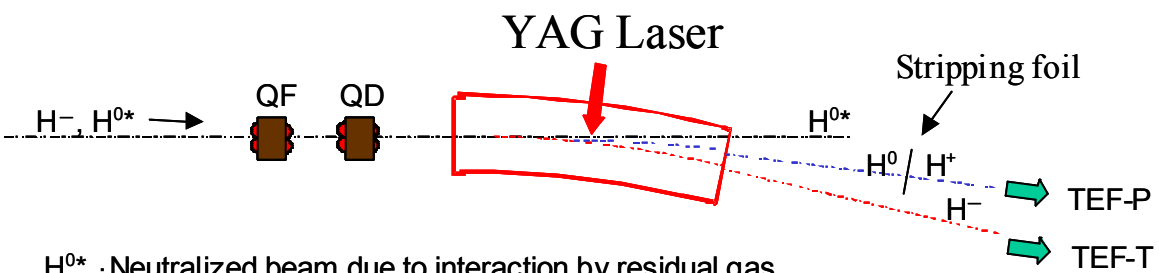


TEF-P and TEF-T





Lower beam extraction based on Laser charge exchange



H^{0*} : Neutralized beam due to interaction by residual gas
H^{0} : Neutralized beam due to interaction by laser

- Some budget including beam diagnostic TEF-T approved by government.
- At TEF-T beam line, non-linear optics or rastering system will be installed
- First beam ~2019

Conclusion

- Using present beam monitor system based on MWPMs and halo monitors, high power beam operation can be performed with highly confident.
- Beam flattening system based on octupole magnets was installed, which can reduce peak heat density from design condition by 30-40 %.
- PBW was replaced. (corrosion spot?)
- New monitor system developing
- ADS program beginning at J-PARC

Thank you for your attention