HiRadMat
High-Radiation to Materials

Expression of Interests on the Future HiRadMat Experiments

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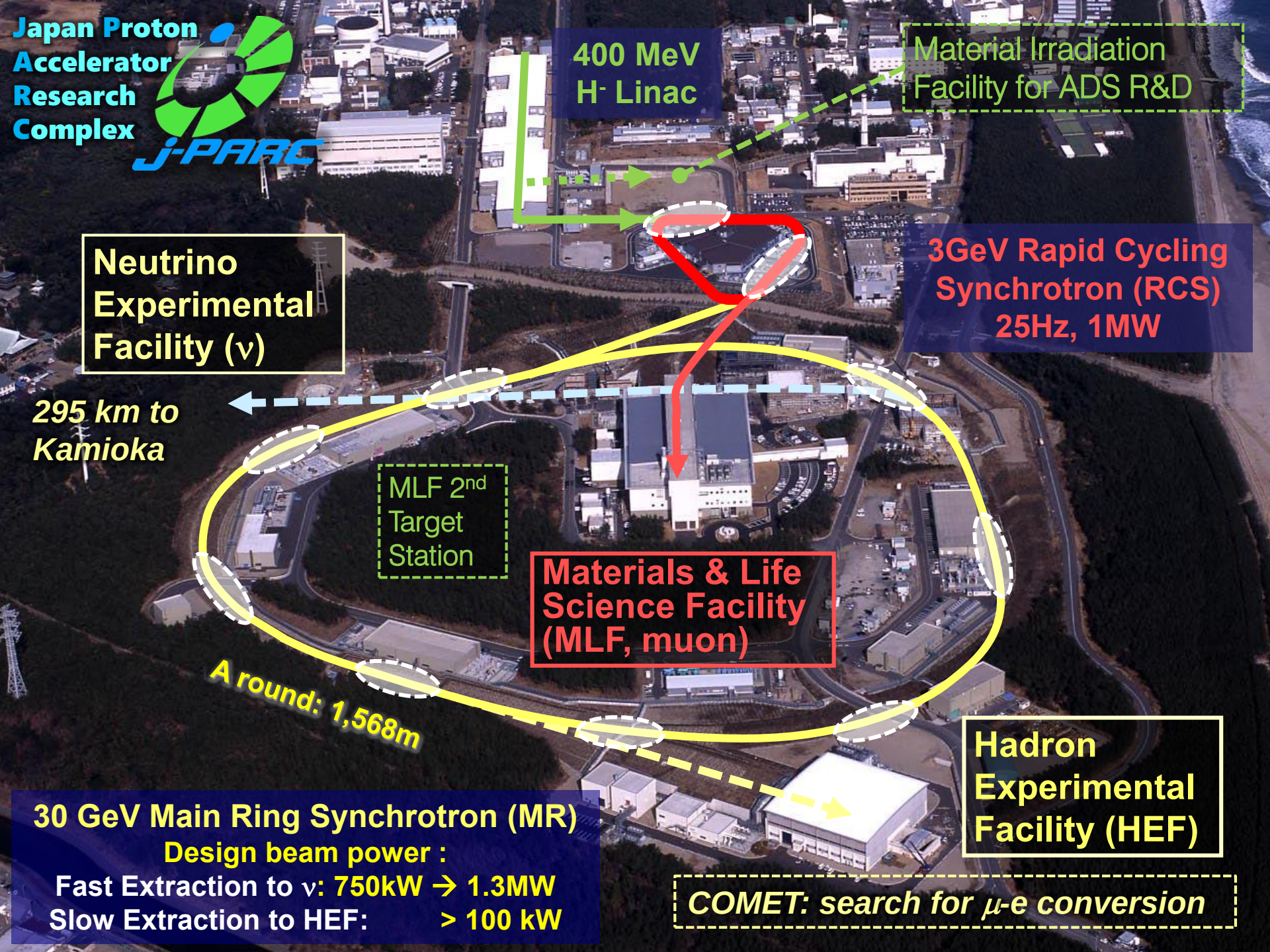
from J-PARC

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments


Japan Proton Accelerator Research Complex
J-PARC
400 MeV H⁻ Linac
Material Irradiation Facility for ADS R&D
Neutrino Experimental Facility (ν)
3GeV Rapid Cycling Synchrotron (RCS) 25Hz, 1MW
295 km to Kamioka
MLF 2nd Target Station
Materials & Life Science Facility (MLF, muon)
A round: 1,568m
Hadron Experimental Facility (HEF)
30 GeV Main Ring Synchrotron (MR)
Design beam power :
Fast Extraction to ν: 750kW → 1.3MW
Slow Extraction to HEF: > 100 kW
COMET: search for μ-e conversion

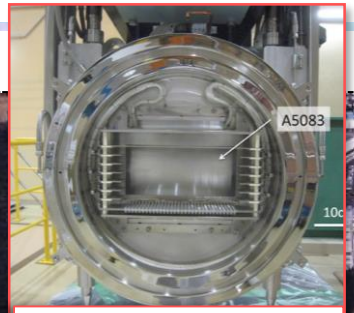
Overview

- J-PARC consists of a series of the world's most intense accelerators and experimental facilities producing and utilizing high-intensity proton beams
- Future experiments at HiRadMat facility will provide great opportunities to J-PARC for its undergoing researches and developments on accelerator, beamline & detector components

3 Letter-Of-Interests being submitted

1. **Thermal shock experiments of advanced target / window / dump materials with high energy proton beam at HiRadMat Facility** [S.Makimura/T.Nakadaira/TI/M.Futakawa et al]
2. **Displacement cross section of target and beam window materials for 440 GeV/c protons** [S.Meigo et al]
3. **Development of the Next Generation High Radiation Tolerant Detector with the High Intensity Proton Beam at HiRadMat Facility** [H.Nishiguchi, Y.Hashimoto et al]

Targets & Windows at J-PARC



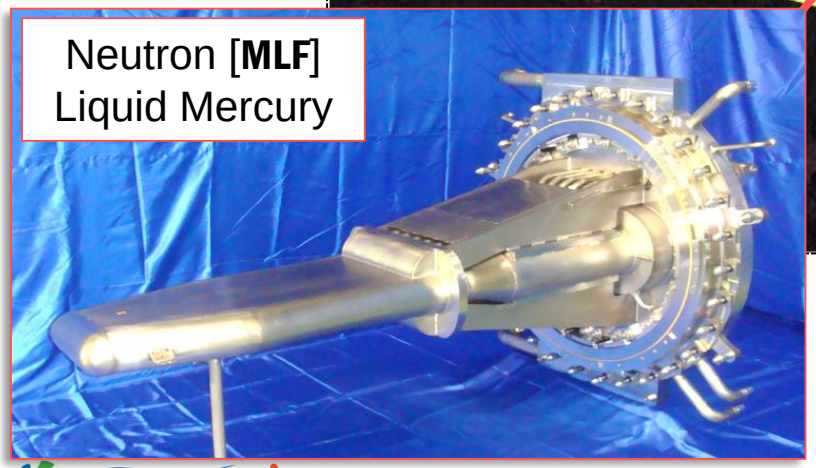
Al A5083 BW

Neutrino [ν]
He-cooled graphite

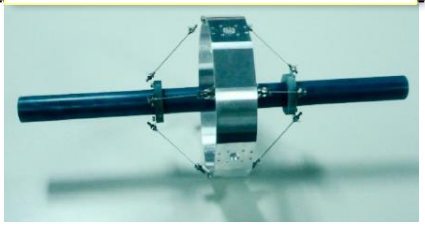
Muon [**MLF-MUSE**]
Rotating Graphite

Ti-6Al-4V BW

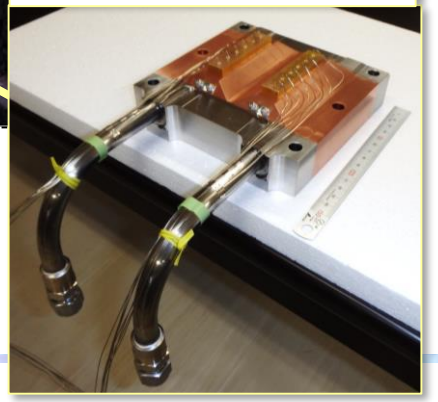
Neutron [**MLF**]
Liquid Mercury



Graphite [COMET]



Hadron [**HEF**]
Water cooled gold



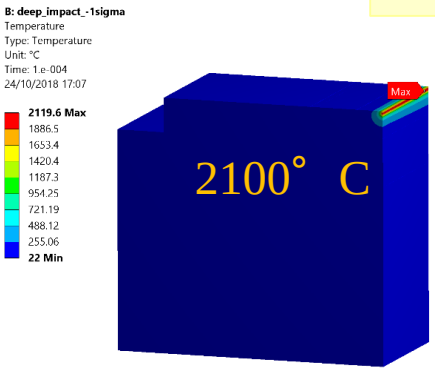
1. Advanced Targetry Material Studies

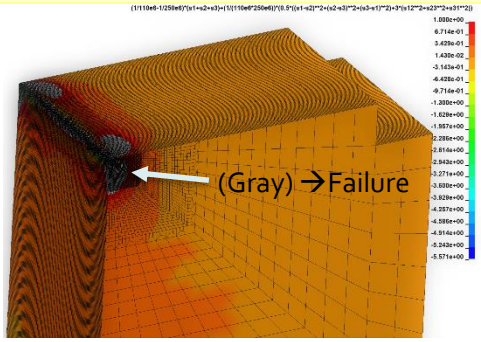
- For power upgrade aiming several hundred kW to MW, upgrade of each target and beam window system should be completed in a timely manner:
  1. Nickel (or Platinum) rotating target at HEF
  2. Light material (SiC composite, SiC-coated graphite) in place of (or combined with) the graphite target for ν, MLF muon, COMET at HEF
  3. Highly-ductile Tungsten target for COMET second phase, MLF second target station
  4. Syst. studies on Ti-alloy grades as beam window material
  5. Graphite, copper alloy, stainless steel for MR abort beam dump, with reference to CERN's beam dump design
  6. Lead Bismuth Eutectic (LBE) target at proposed Material Irradiation Facility for ADS

Study of Solid Materials with Thermal Shock(1)

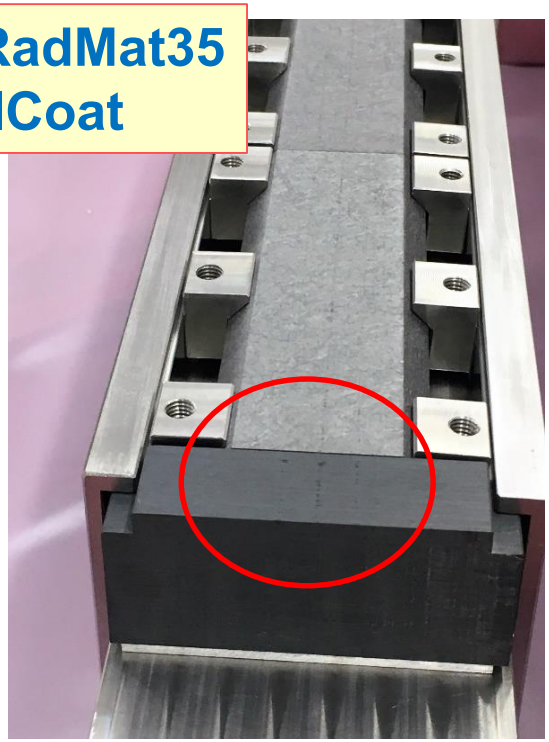
- NITE-SiC/SiC
  - Density 3.2 g/cc (SiC) → more secondary emission than graphite
  - SiC fibers + matrix, control mechanical properties / to replicate ductility

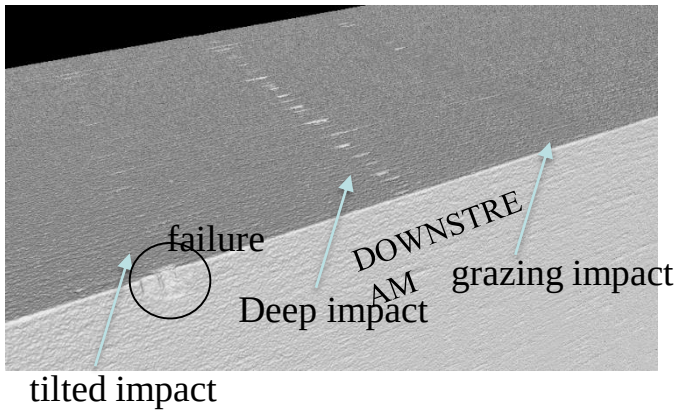
J. Maestre et al RaDIATE2018

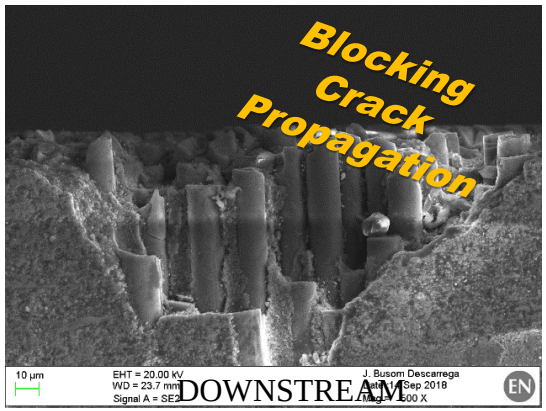




HiRadMat35 TDICoat





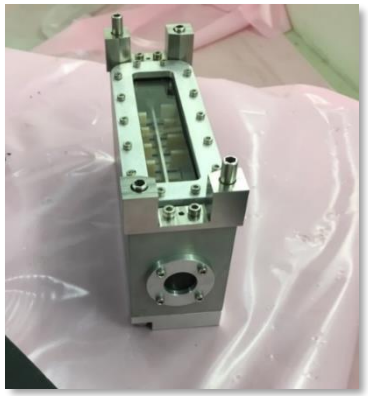


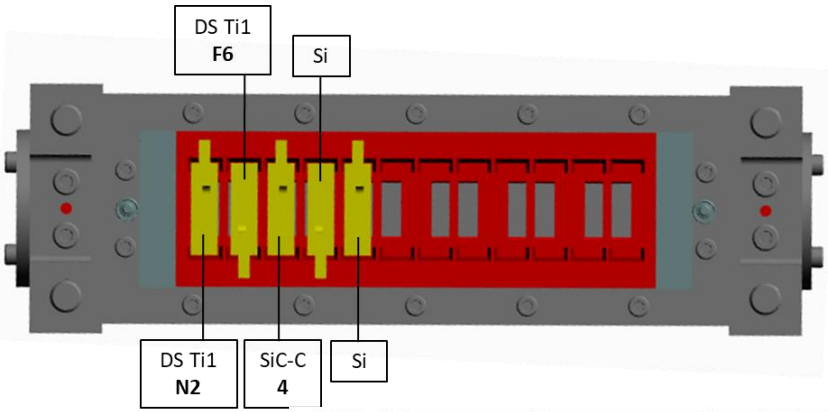
To continue the studies with various impact parameters, especially to compare behavior between cold and irradiated specimen at next BLIP run

Study of Solid Materials with Thermal Shock(2)

- SiC-coated graphite / Titanium Alloy (cold & irradiated at BLIP) exposed to thermal shock at HiRadMat in autumn JFY2018

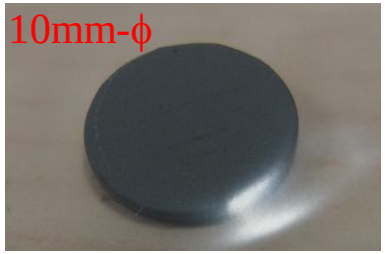
HRMT43 BeGrid2

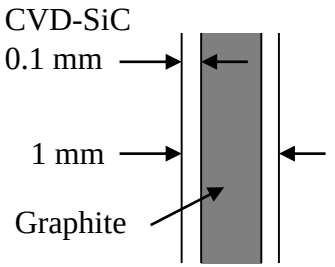


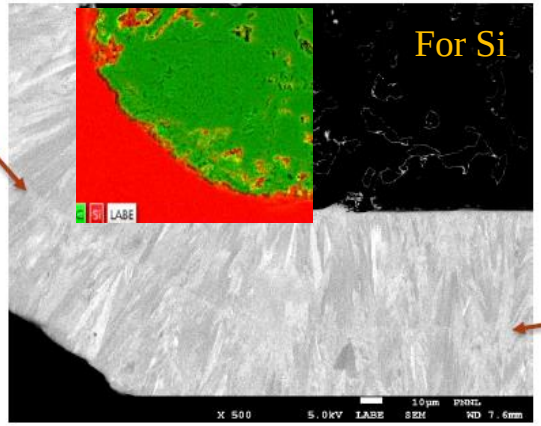


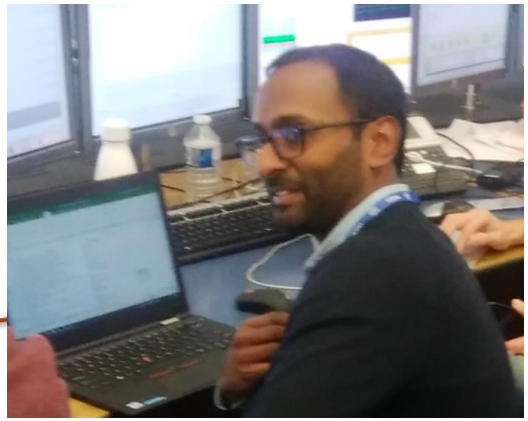
BOX-3

- Ti-6Al-4V Gr5
- Ti-3Al-2.5V Gr9
- SiC-coated Graphite IG-630U









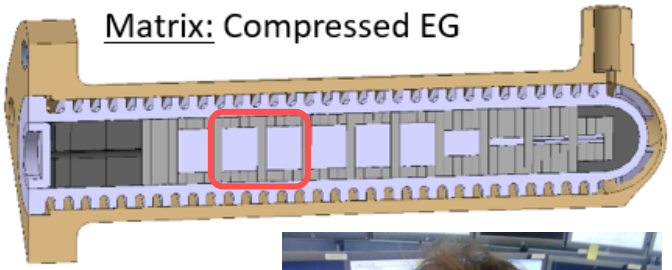
- How did the SiC-coating on graphite behave with beam impact?
- How different between Ti-6Al-4V(α+β) and Ti-3Al-2.5V(nearly α) ?
- ***How different between irradiated at BLIP / un-irradiated ?***

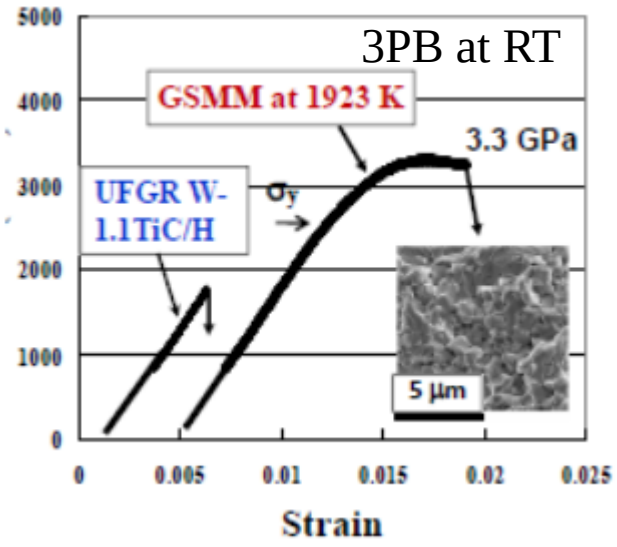
Study of Solid Materials with Thermal Shock(3)

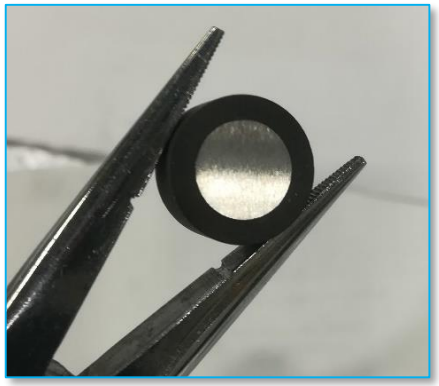
- Highly-Ductile W (TFGR W-1.1TiC)
  - Tungsten: high density/melting point, but become brittle by recrystalization at 1200'C
  - 3D MA (FineGrain) → HIP → recrystallization under grain boundary sliding (GSMM): segregation / precipitation of TiC at grain boundary 13 :

HRMT48
PROTAD

Target 5:
Core: Ø 10 mm Ta +
Ø 10 mm W + W-1.1TiC + Ø 10 mm Ir
+Ø 2 mm Ta tube
Matrix: Compressed EG





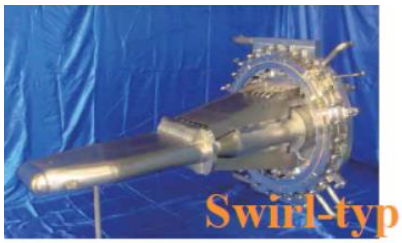


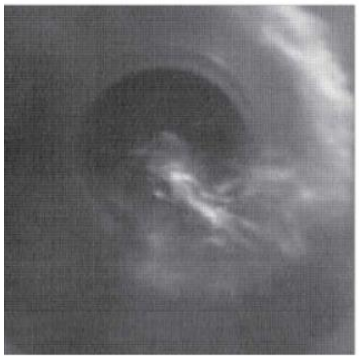
Colour Legend		
W-(1.2%) TiC	S1	HQ-GSMM
	S2	LQ-GSMM
	S3	HQ-w/o GSMM
	S4	HQ-w/o GSMM
	S5	Hot rolled
W	S6	Hot rolled and recrystallized
	S7	Hot rolled

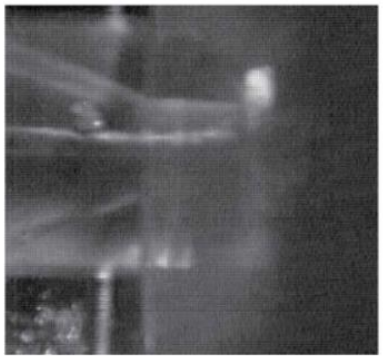
The fabrication process is improving. Need to continue studies, especially irradiation run at BLIP, and thermal shock studies (w-w/o irrad?)

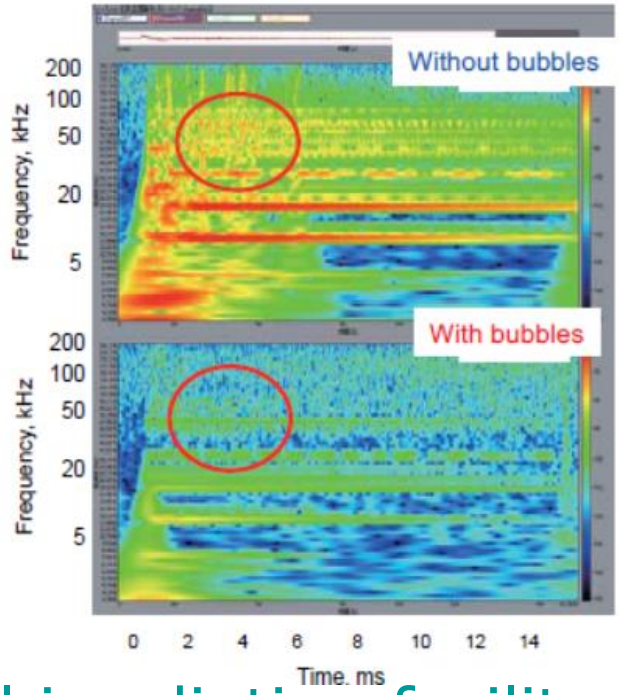
Study of Shock Wave on Liquid Metal Target

- Liq-Mercury target







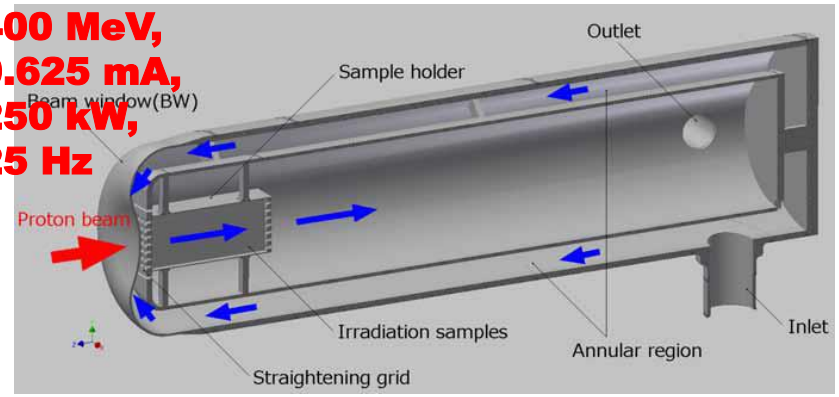


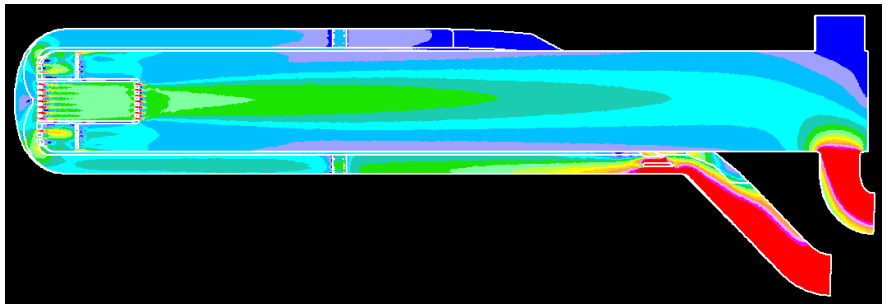
Liquid metal, or substituting liquid, are contained in a confined vessel w-w/o flow and gas bubbling.

Effects of various flow paths and flow rates are to be investigated.

- LBE target for material irradiation facility

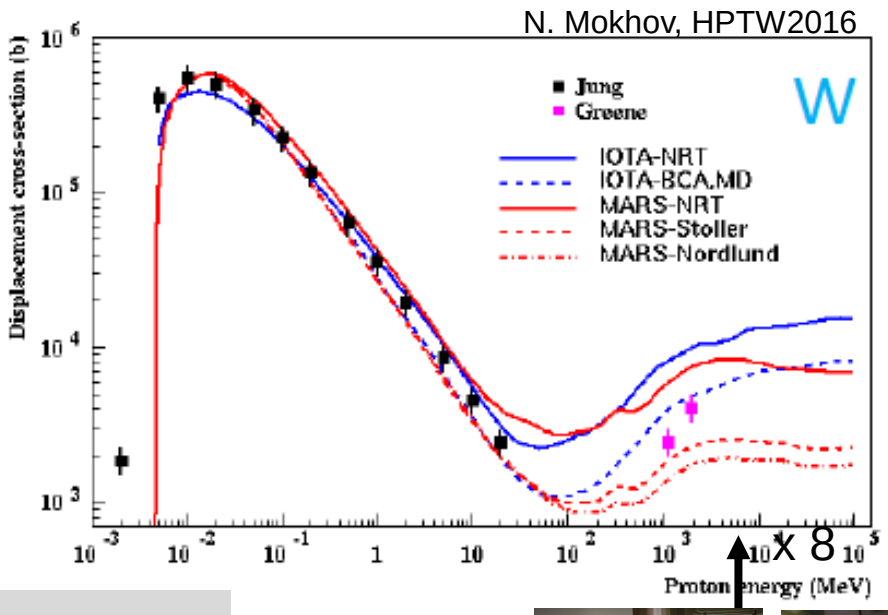
400 MeV,
0.625 mA,
250 kW,
25 Hz





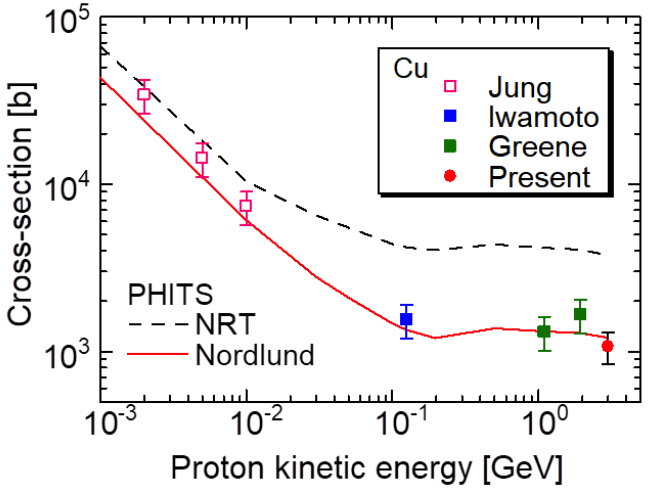
Stainless Steel-T91
LBE inlet : 400 ℃ outlet 500 ℃

2. Displacement Cross-section Measurement

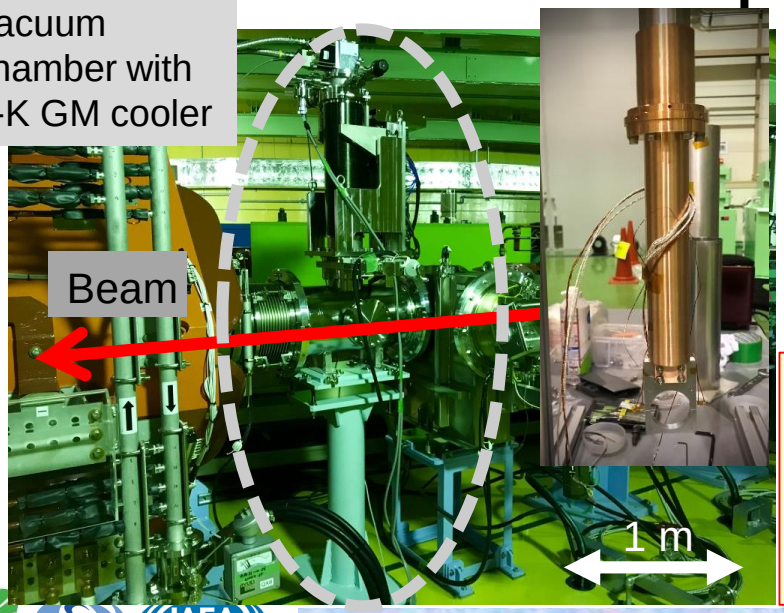


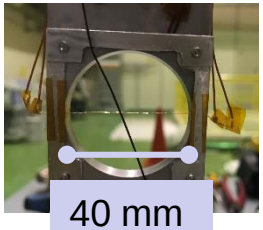
- Experiment at 3-GeV Rapid Cycling Synchrotron (RCS)
- Under cryotemperature (~ 20 K), displacement cross section(σ) was obtained by increase of resistivity ($\Delta\rho_{cu}$) due to proton irradiation with average flux ($\overline{\phi(E)}$)

$$\sigma_{exp}(E) = \Delta\rho_{Cu}/(\overline{\phi(E)}\rho_{FP}),$$



Vacuum chamber with 4-K GM cooler





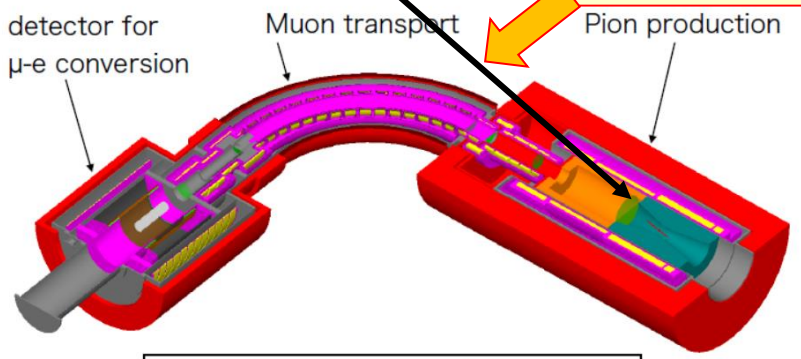
Dpa is vitary important parameter to represent target/window lifetime evaluation. To improve errors for high energy proton, measurements at J-PARC, FNAL and CERN are to be envisaged.

3. High Radiation Tolerant Detector

- COMET: Coherent Muon-to-Electron Transition

8GeV, 3kW
(56kW for phase-II)

In-beam Extinction Monitor



COMET Phase-I Layout

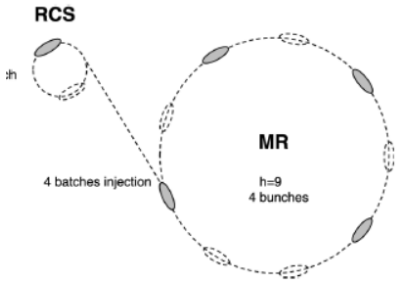
$B(\mu \rightarrow e+\gamma) = 10^{-11} \sim 10^{-14}$ (SUSY-GUT)
$< 4.2 \times 10^{-13}$ (MEG 2016)

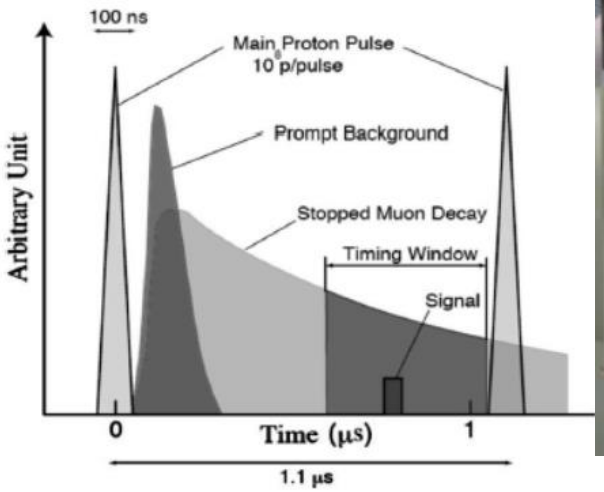
$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$

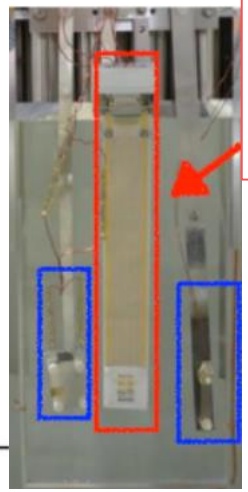
$$E_{\mu e} \approx m_\mu - B_\mu \sim 105.1 \text{ MeV}$$ for Al

Extinction Factor =

$$\frac{\text{\#of residual protons btw. 2 bunches}}{\text{\#of protons in a bunch}} < 10^{-10}$$

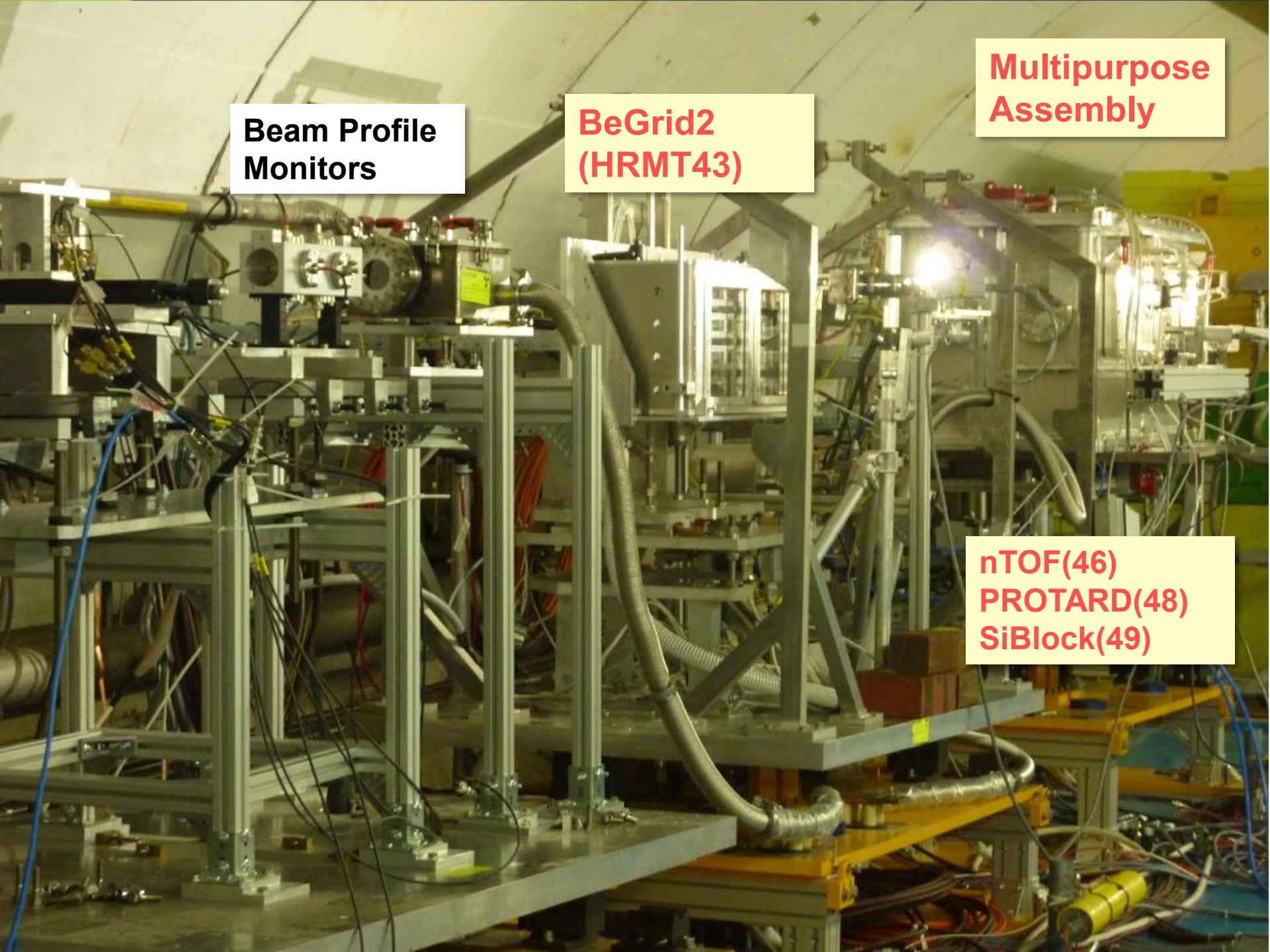




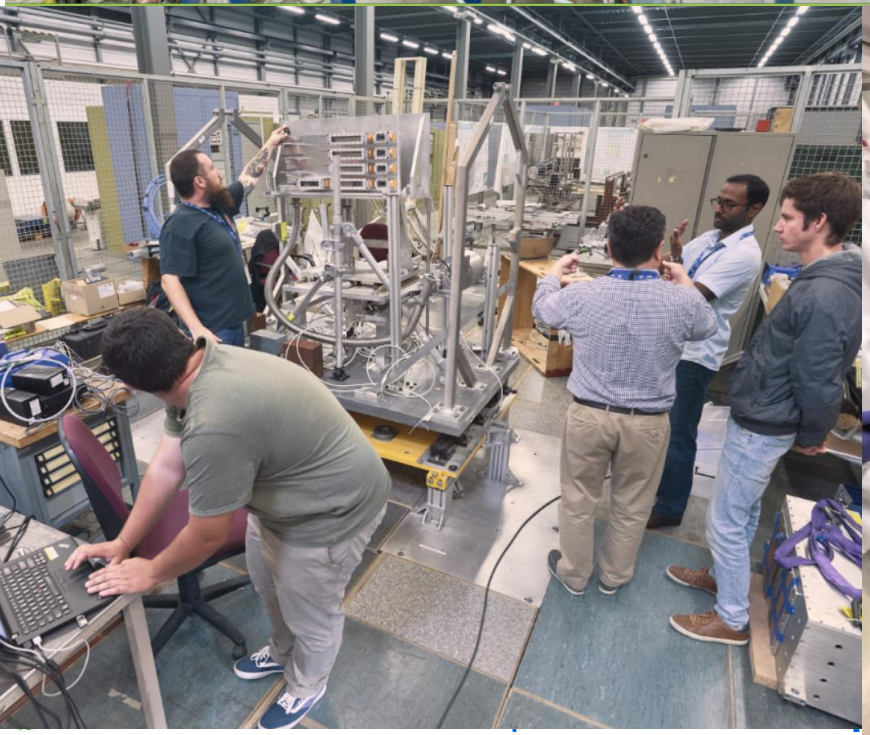


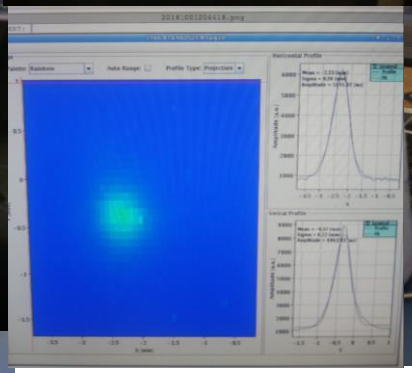
Single crystal CVD Diamond
(4mmx4mm,0.5mmt)

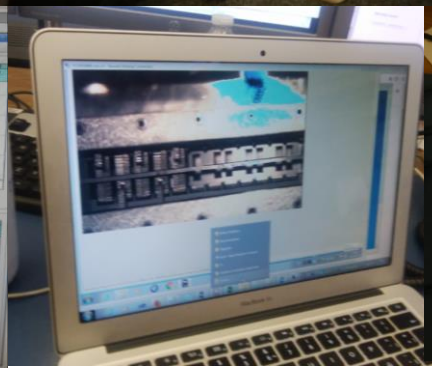
- Charge collection ~10ns
- down to single MIP level
- Vias Voltage to be off during main bunches

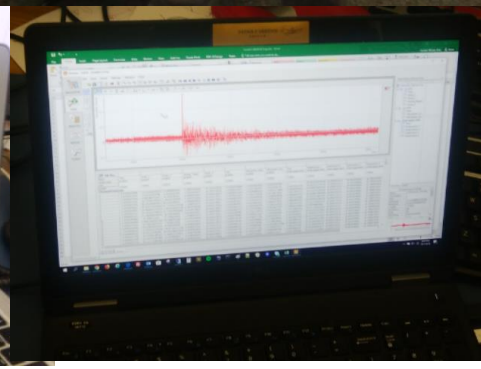

Beam Profile Monitors
BeGrid2 (HRMT43)
Multipurpose Assembly
nTOF(46)
PROTARD(48)
SiBlock(49)

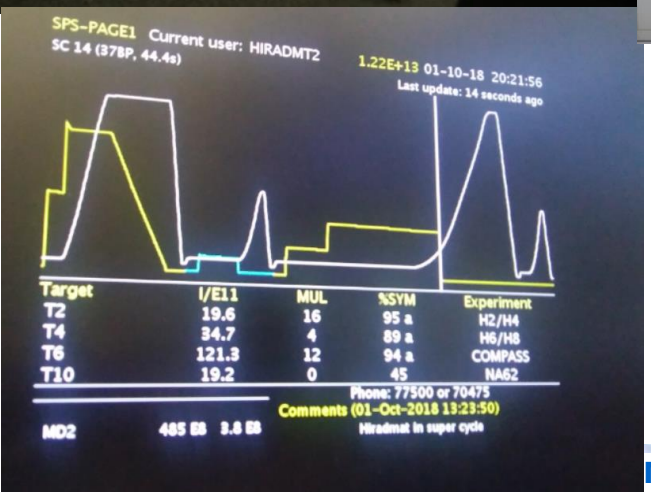












- Sep.28: PROTARD, SiBlock Completed ☺
- Sep.29: PROTARD Completed ☺
- Oct.1~2: BeGrid2 Completed on 4am ☺

Sturm und Drang !

Summary

- HiRadMat is the only facility dedicated to thermal shock studies
  - Remarkable achievements to research and developments on high power targets, beam windows, collimators, beam dumps and other accelerator assemblies.
  - The facility has no equivalent and is indispensable for the world-wide high power accelerator communities.
  - The facility provides indispensable opportunities for young enthusiastic and talented engineers to design forefront accelerator materials and hardware
- J-PARC express strong interest on the future experiments to be managed at HiRadMat facility
  1. Advanced target/window/dump material developments
  2. Displacement Cross-Section Measurement
  3. In-beam rad.-tolerant detector to count intra-bunch MIPs

J-PARC-CERN Cooperation AMENDMENT No.2

- COOPERATION IN THE DEVELOPMENT OF PROTON LINEAR ACCELERATORS (2011~)
- Amendment No.1: COOPERATION IN THE DEVELOPMENT OF PROTON ACCELERATORS (2016~)
- No.2: Expand the co-operation to the fields of high-intensity accelerator target facilities and relevant technologies, to fully realize and accomplish the benefits of the high intensity proton accelerators:
- The Parties intend to co-operate in the following areas of activities:
  4. Research and development of beam intercepting devices, such as targets, beam windows, collimators and beam dumps, including mechanical engineering and material expertise utilized in such devices;
  5. Research and development of technologies and engineering techniques applied to the design, operation, and maintenance of high intensity accelerator target facilities, including target containment vessels and supporting infrastructure systems

To be in effect soon, + 5years (until 8 April, 2026)

HiRadMat