Proton beam irradiation facility plan at J-PARC and activity on displacement damage study

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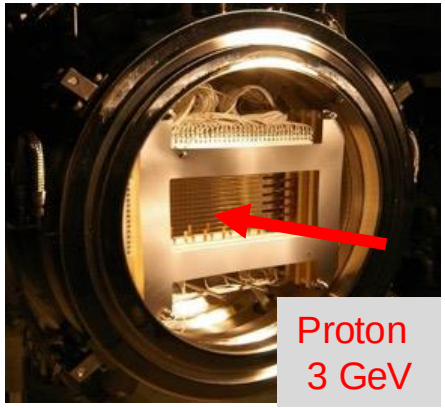
Outlook

- Displacement cross section
- Measurement of displacement cross section
  - J-PARC for 0.4 – 30 GeV
  - FNAL for 120 GeV
  - Plan at CERN for 430 GeV
- Proton beam irradiation facility plan in J-PARC
- Summary

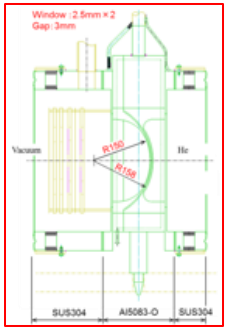
J-PARC = Japan Proton Accelerator Research Complex

Target for high-intensity hadron accelerator and superconductor in high radiation area

Proton beam window in J-PARC spallation neutron source: Aluminum alloy (ϕ 0.6 m)



Proton 3 GeV

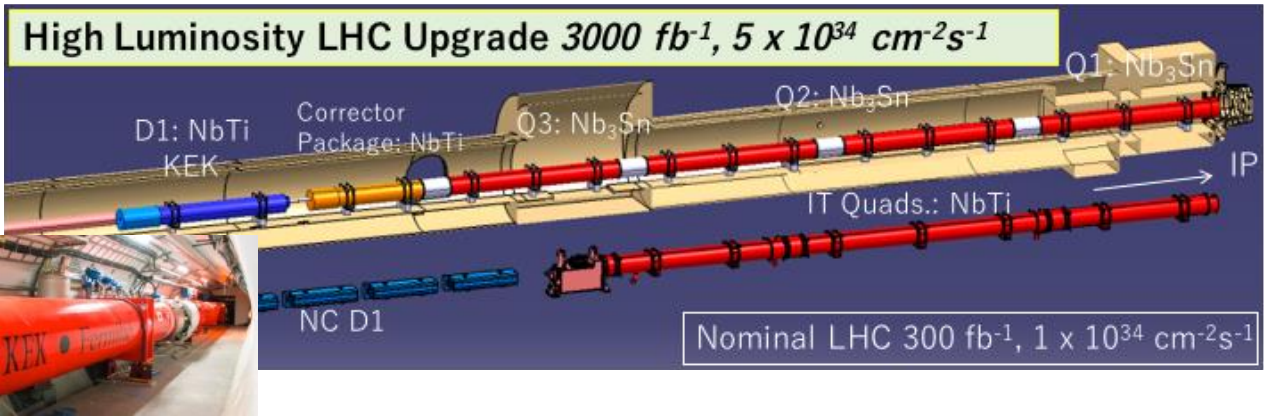


T2K beam window Titanium alloy (Ti-6Al-4V)

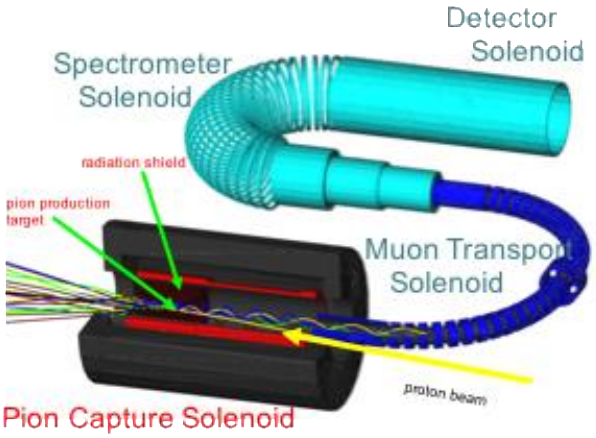
Proton 30 GeV

- For damage estimation of beam intercepting material, dpa is utilized based on displacement cross section.
- High accuracy of the displacement cross-section is required.

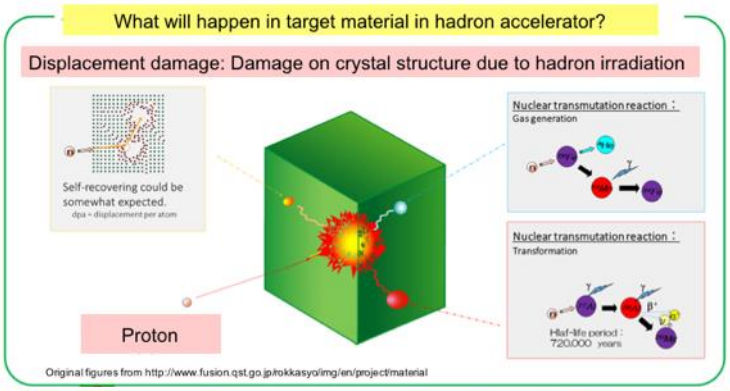
- Resistivity change due to radiation is crucial for Superconductor(SC) magnet sustaining damage.

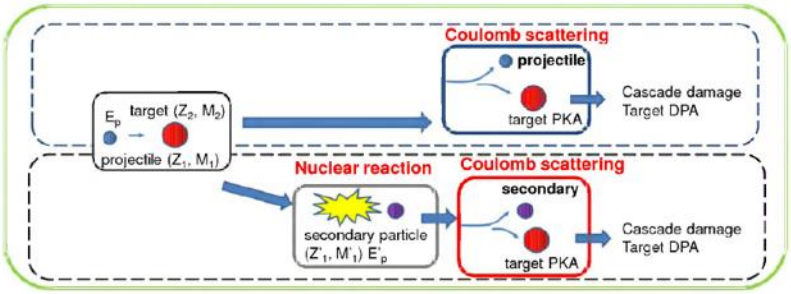


SC magnet system in beam line of COMET (J-PARC)



Displacement cross section (X-sec)



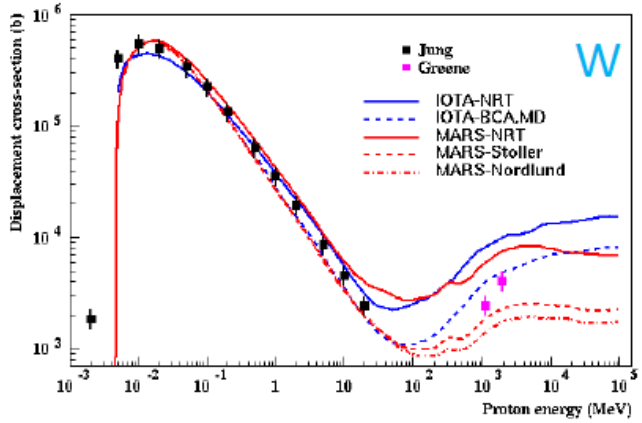


- dpa (displacement per atom):
  Widely used as damage index for fission and fusion reactors, and accelerator fac.
  dpa = Fluence x displacement X-sec
- Lack of data above 20 MeV: Difficult validation of calculation models

⇒ Experiments started at J-PARC

Displacement cross section:
- Following Matthiessen's low obtained by observation of electrical resistivity [Ω/m].
- To sustain the damage in sample, cryocooling is required for T < 20 K.

N. Mokhov, HPTW2016



$$\sigma(E) = \Delta\rho/(\phi \cdot \rho_f)$$

σ(E): Displacement cross section [b]
Δρ: Change of resistivity [Ω/m]
Φ: Fluence of incident protons [/cm^2]
ρ_f: Resistivity change by Frenkel pair [Ω/m]

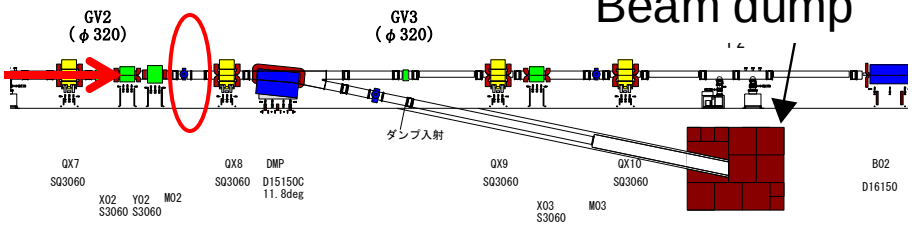
Displacement cross section at J-PARC

- Instruments equipped upstream of beam dump for 3GeV synchrotron (RCS Rapid Cycling Synchrotron) : available various kinetic energy of proton 0.4~3 GeV
  - Precious beam turning and monitor (beam scanning made for alignment)
  - Achieved ~4 K (but used ~8 K to maintain normal conducting at sample)

From 3GeV RCS

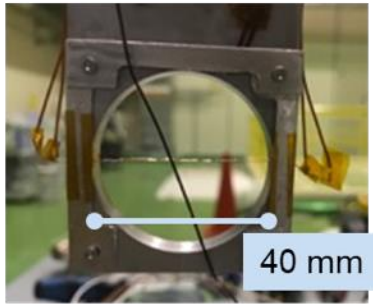
To MLF

Beam dump

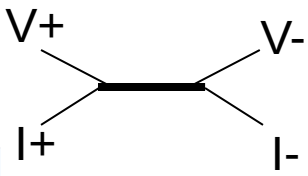


Cryocooler and sample

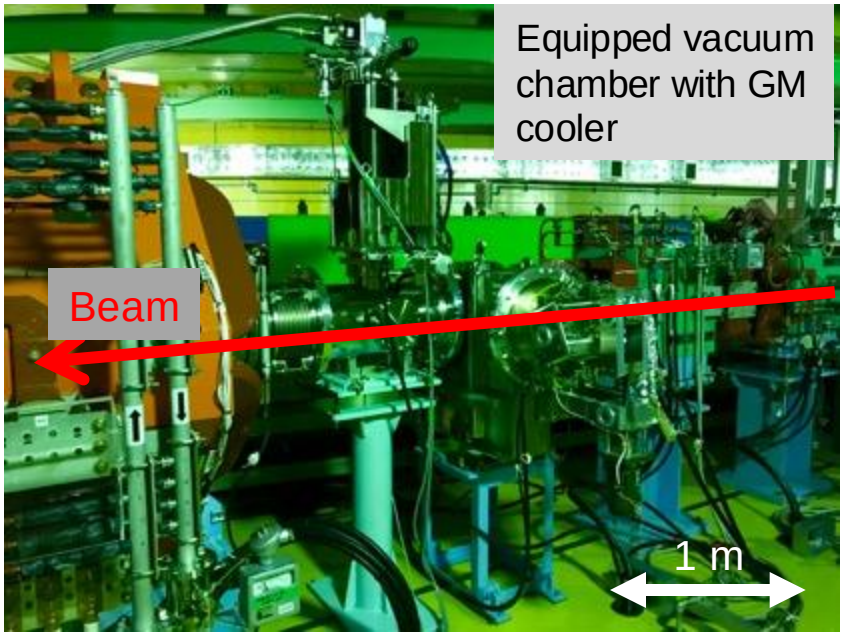
Nb wire (Φ 0.25 mm) 99.9%



To obtain precious resistance
4 electrodes applied



Sample wire



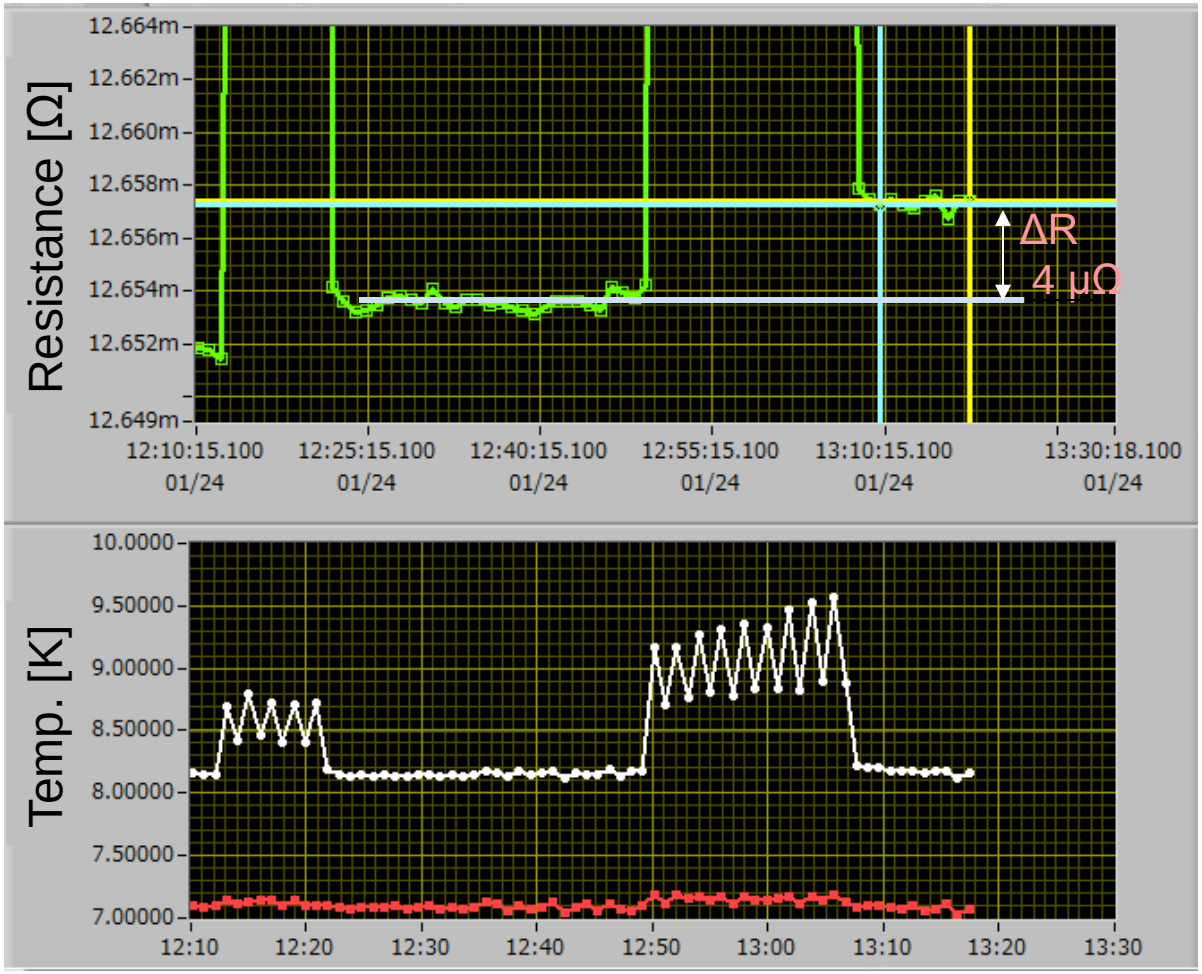
Equipped vacuum chamber with GM cooler

H. Matasuda, J. Nucl Sci, 57:10 1141 – 1151 (2020).

Experimental results of displacement X-sec

Cross section for 0.4, 0.8, 1.3, 2.2 and 3.0 GeV protons were observed.
- Proton beam repetition rate ~ 1 Hz

Resistivity and temperature during irradiation



$$\sigma(E) = \Delta\rho/(\phi \cdot \rho_f)$$

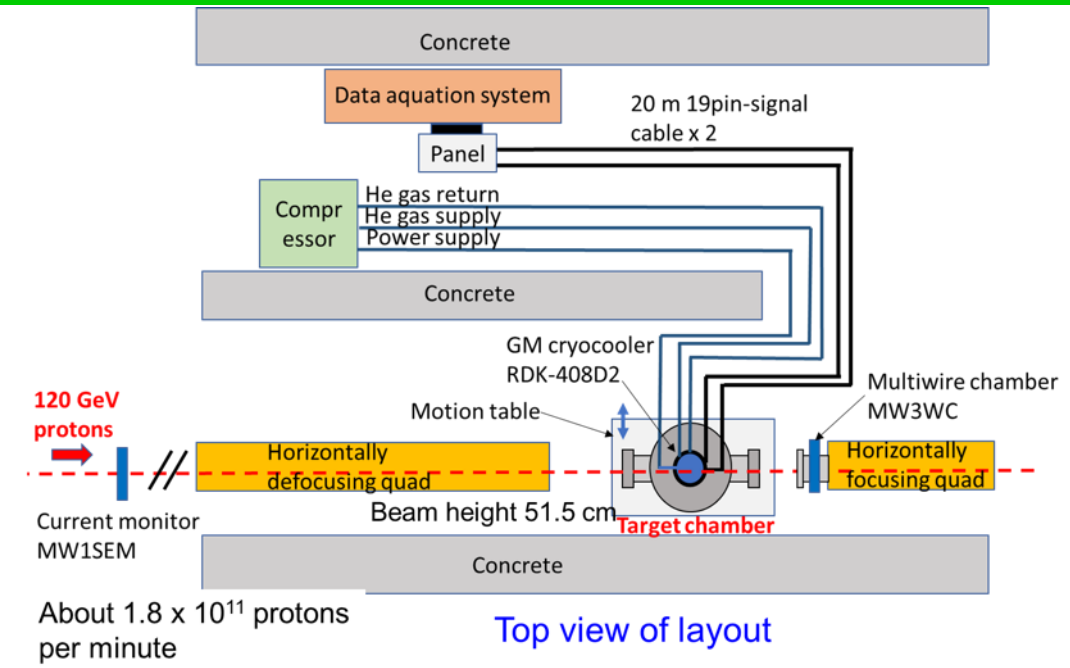
Δρ (resistivity): ΔR x L/A
L, A: sample geometry
Φ (proton fluence):
observed by beam monitor
ρ_f: resistivity change by a Frankel pair

Tk [GeV]	Experimental result [b]
0.4	1920±455
0.8	2140±508
1.3	2390±568
2.2	2250±534
3.0	2550±606

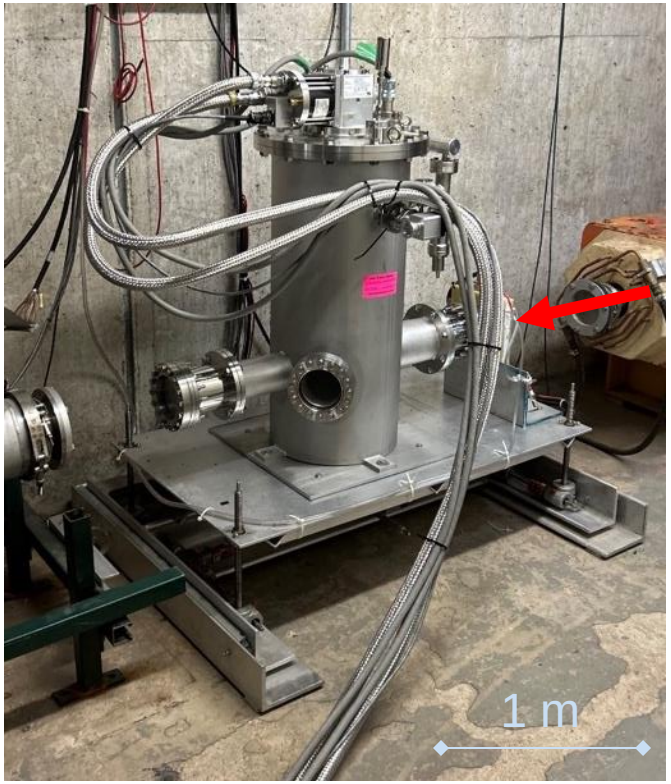
Error is dominated by resistivity change for a Frankel pair creation.
ρ_f = 14 ± 3 Ωm

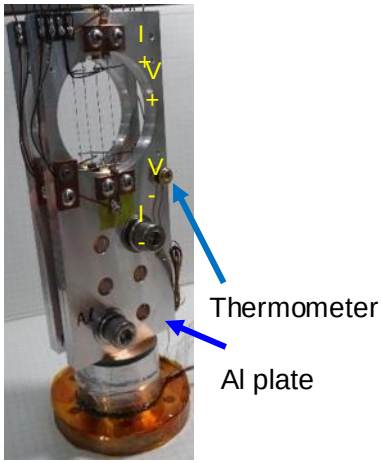
Experiment at FNAL

Similar manner of J-PARC experiment was applied at Fermilab Beam Test Facility (FTBF) M03.

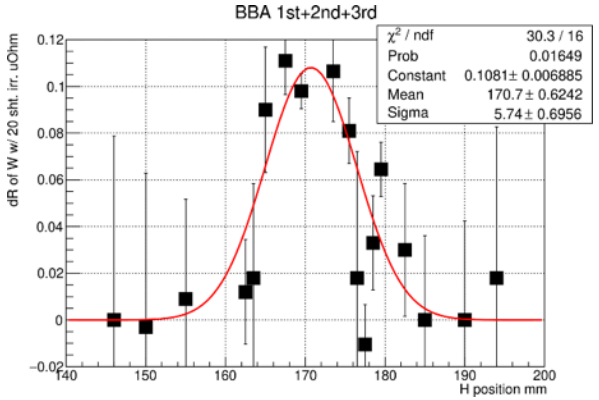


GM cooler RDK-408D2

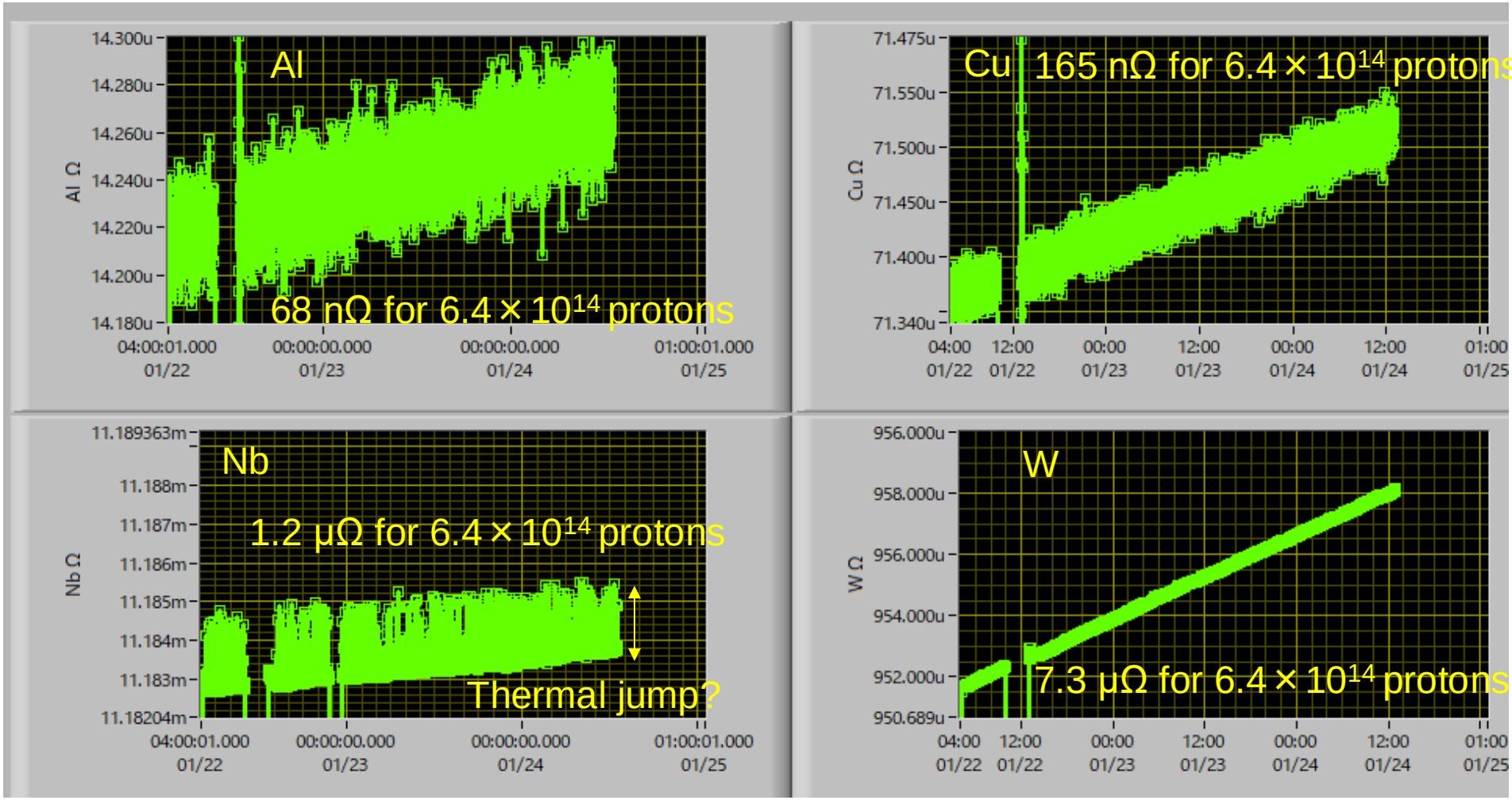




Horizontal beam position and width were scanned by using motion table.

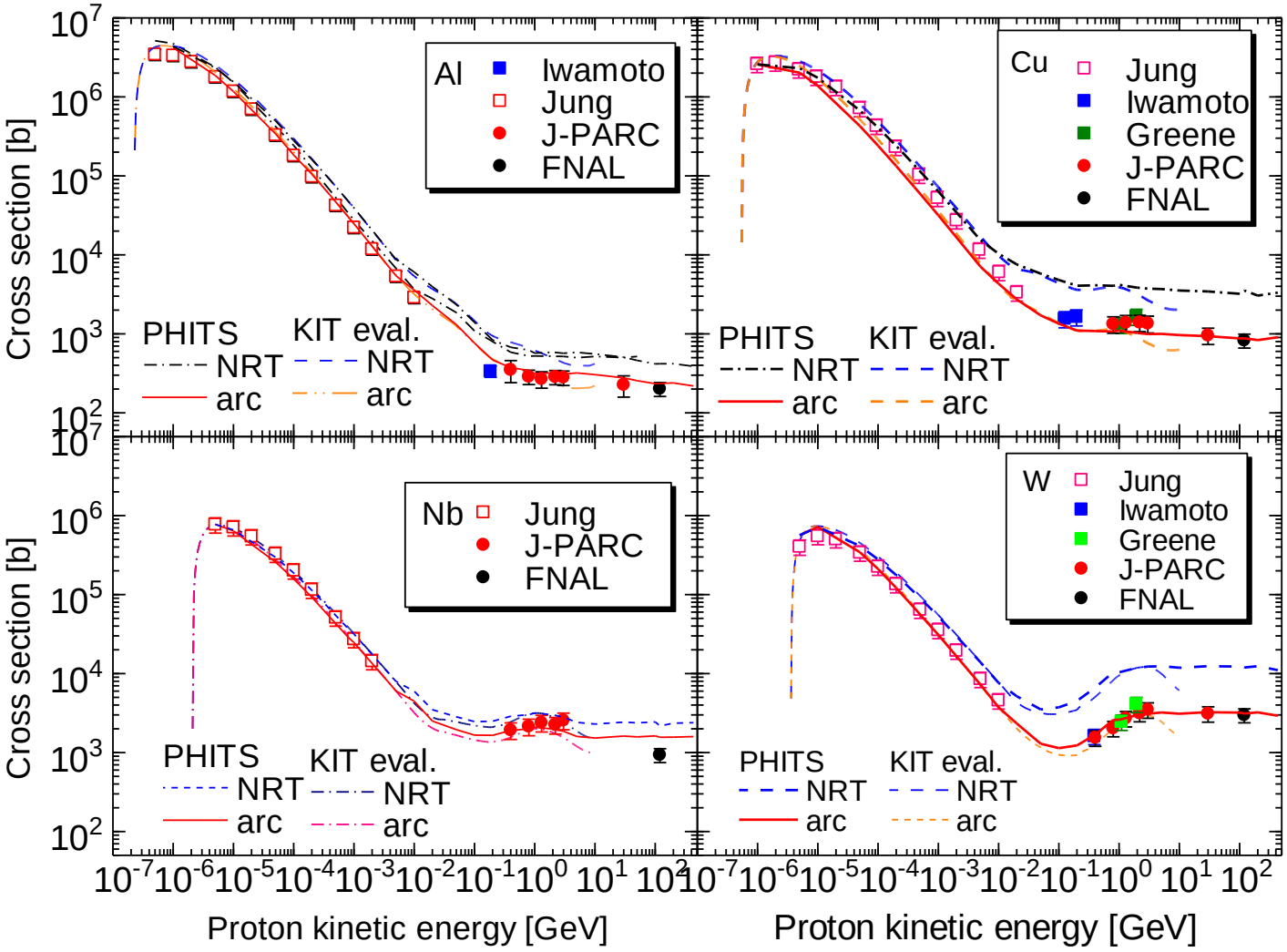


Electrical resistance change



Electrical resistance changes of metals at 8 K under 120 GeV proton irradiation

Comparison with calculation



NRT/Exp ~2

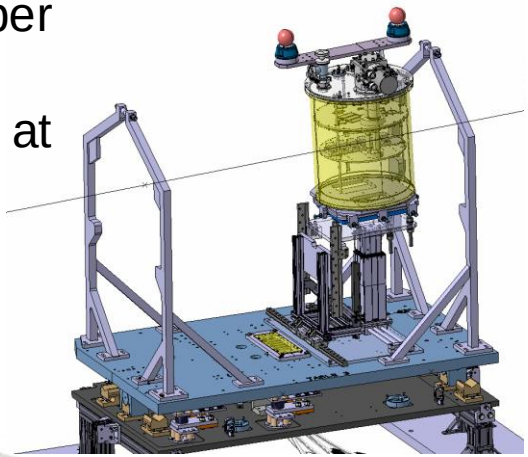
NRT/Exp ~4

H. Matsuda, JNST 57 1141 (2020), S. Meigo, EPJ Web of conf 239 06006 (2020)
Y. Iwamoto

Ep 440 GeV at HiRadMat CERN (plan)

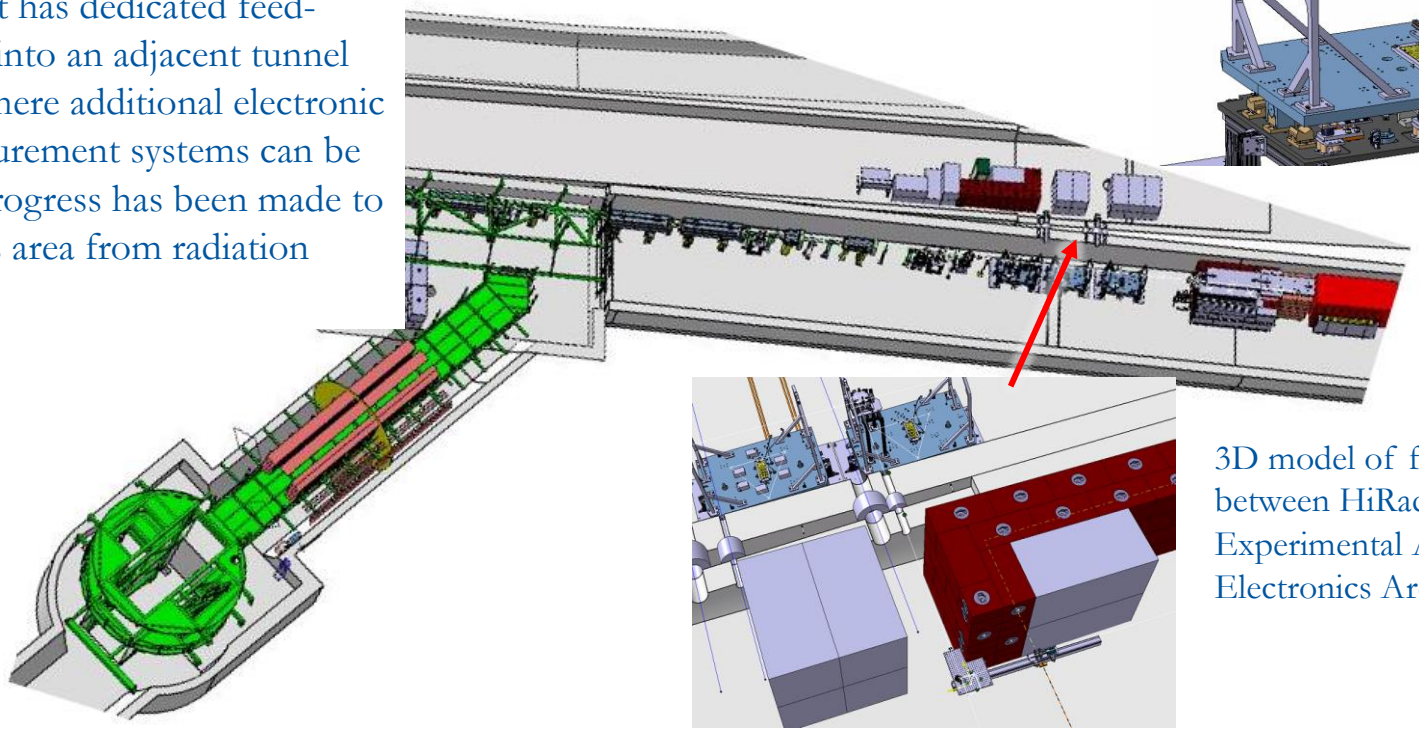
Irradiation Area

Borrowing vac. chamber and cryocooler from MPE-CB group, using at HiRadMat



TT61

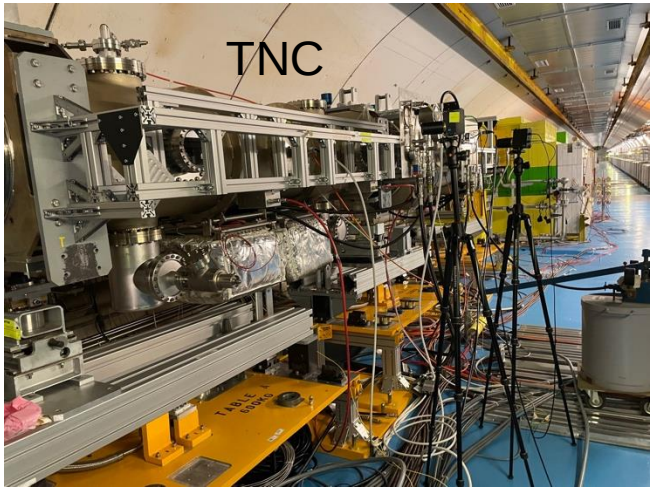
HiRadMat has dedicated feed-throughs into an adjacent tunnel (TT61) where additional electronic and measurement systems can be added. Progress has been made to shield this area from radiation effects.

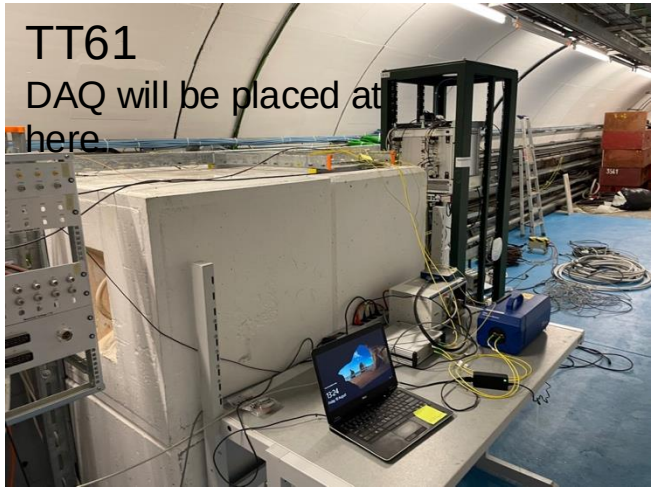


3D model of feed-through between HiRadMat Experimental Area and Electronics Area.

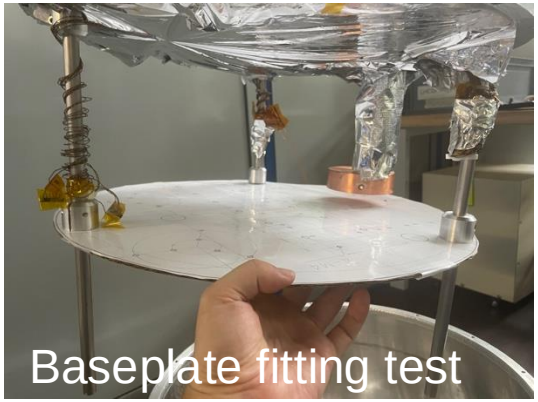
The proposal was approved and it will be conducted in May 2025

Status at HiRadMat





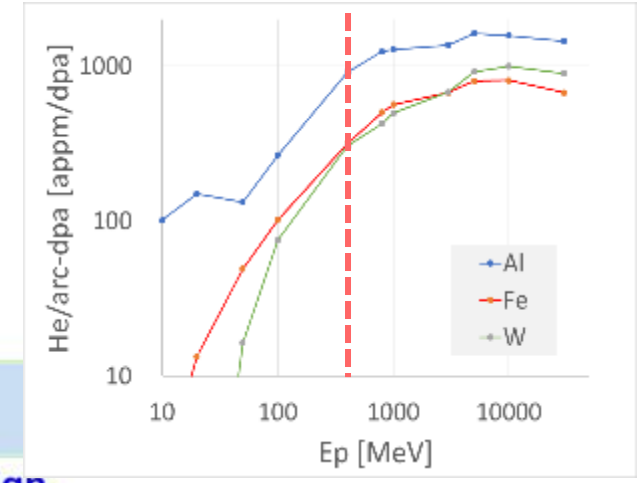
Vessel with new
base plate on
movable table

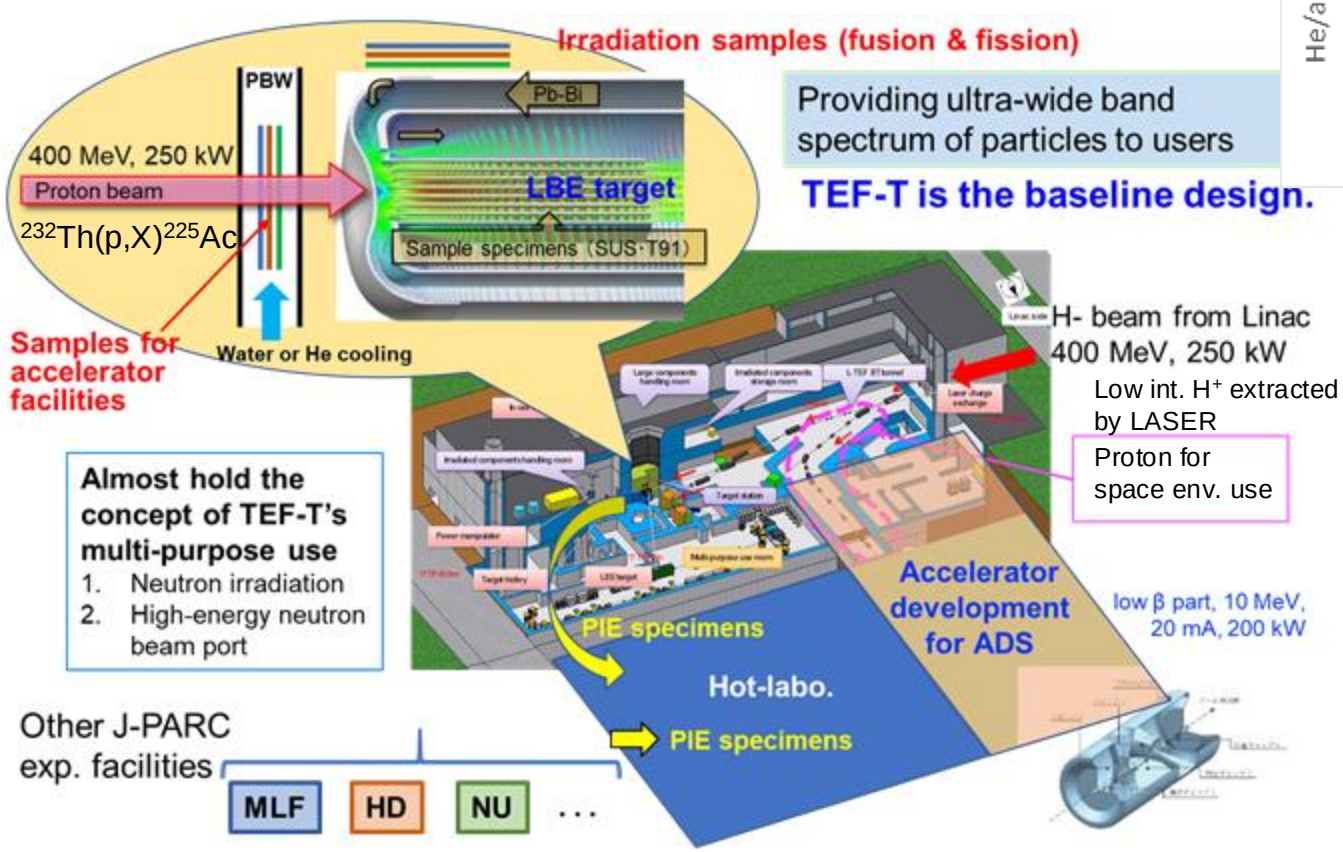


J-PARC proton beam irradiation facility

- Proton beam irradiation facility
  - H^- beam 0.4 GeV, Power >250 kW with 25 Hz
  - Dose >20 dpa/year at the Pb-Bi (LBE) target
- User communities established for multi-purpose
  - Head of mat. irradiation: Makimura-san

With 0.4 GeV proton, sample receives equivalent He/dpa for high energy region.



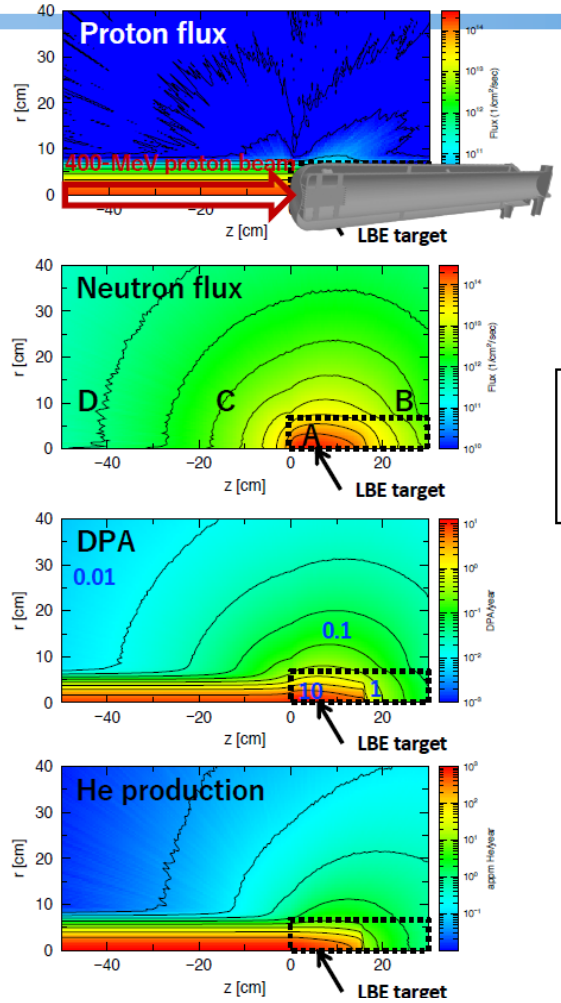


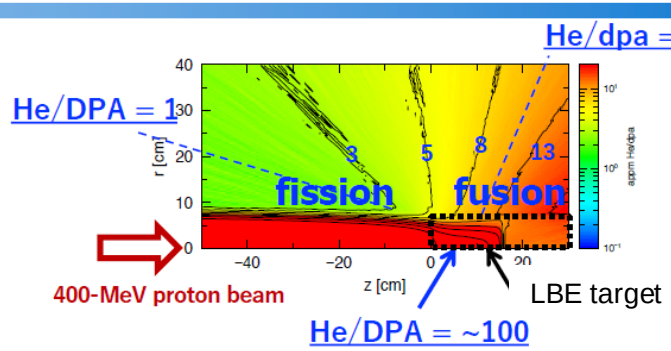
- Building Hot-lab is also planned for PIE
- Multi-purpose use
  1. Irradiation fac.
  2. Neutron for soft error
  3. RI medicine ^{225}Ac
  4. Space env. use

ADS: accelerator driven system
TEF-T: ADS Target Test facility (JAEA Tech 2017-3)

Variate of irradiation circumstance

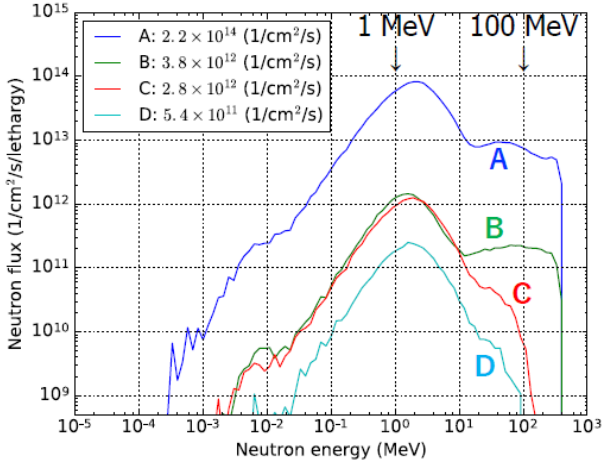
Simulation of fission and fusion environment





He/dpa = 1 ~ 100

➡ Irradiation under the fission and fusion environments is possible although the flux is not very intense.

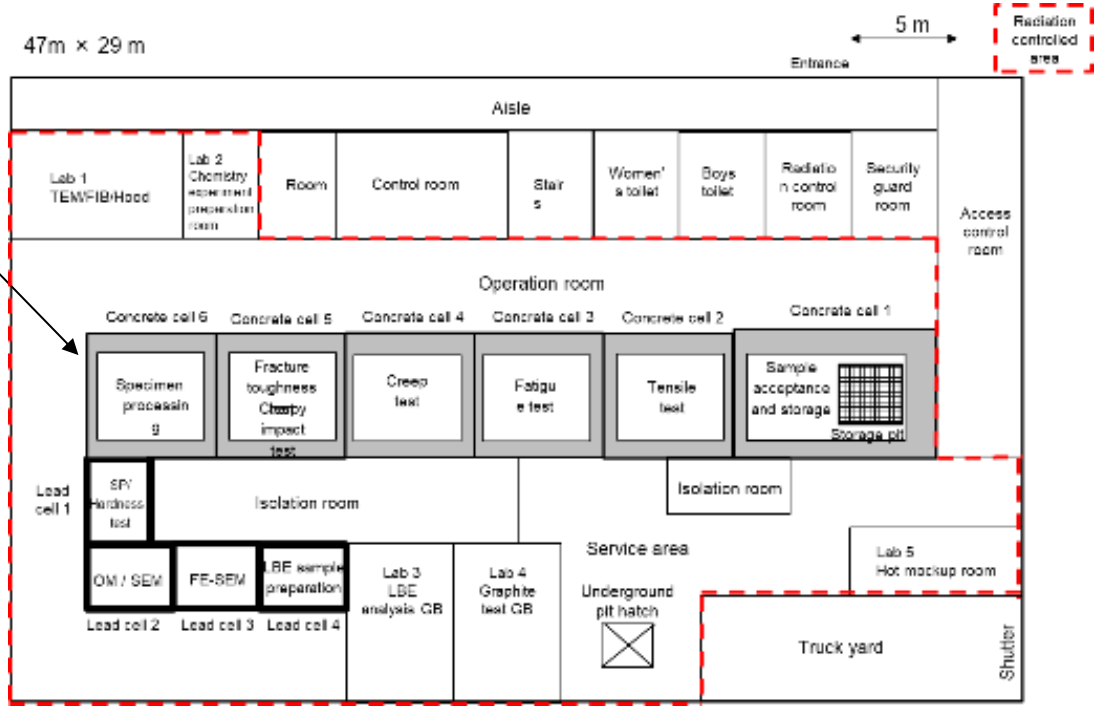


High-energy accelerator and fusion users were excavated by attending their conference

Hot lab for PIE

- For the PIE of the samples irradiated at new facility, a new hot lab is planned to be constructed adjacent to the new facility.
- Due to the difference in the law regarding the irradiation sample environment, PIE has not been performed at J-PARC.
  - JAEA: Radio Isotope
  - J-PARC: Activated materials
- J-PARC needs hot lab for PIE not only for MLF, but also other facilities of T2K and hadron.
- Allowing to dismount MLF's target vessel for mercury

Cells for PIE
- With manipulators



- Specimens placed at LBE target will be transferred to cells by the channel located at underground.
- We will minimize the space of the hot lab to reduce the cost.

Summary

- Displacement cross-section:
  - Successfully obtained the experimental data from 400 MeV to 120 GeV
  - 440 GeV data will be obtained at HiRadMat.
  - arc-dpa : good agreement, NRT: Overestimate by factor 2 to 8
- Proton beam irradiation facility plan
  - Please join in the users' community, if you are interest in this facility.
  - Ready to be build
  - Hopefully, budget will be assigned.

Accoutrements:
- This project includes the results of "Measurement of displacement cross-section at J-PARC for structural material utilized at ADS" entrusted to JAEA by the Ministry of Education, Culture, Sports, Science, and Technology of Japan (MEXT).
- This work was supported by JSPS KAKENHI Grant Number JP19H02652 and the U.S.Japan Science and Technology Cooperation Program in High Energy Physics.
- This project has received funding from the European Unions Horizon Europe research and innovation program under grant agreement No 101057511.