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

(J-PARC/JAEA) Shin-ichiro Meigo

Outlook

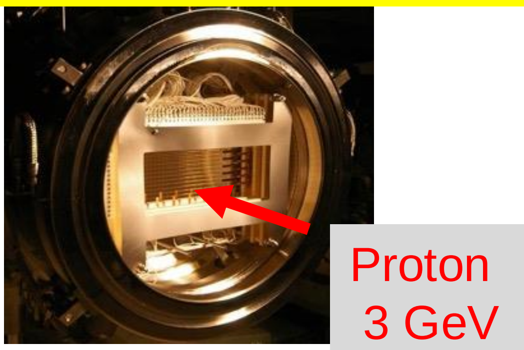
- Introduction
  - J-PARC future plan
  - Proton beam irradiation facility
  - PIE facility
- Measurement of displacement cross section
- Summary


Tokai 36º28"
Granada 37 º 19"
Hadron Experiment Facility
30GeV Synchrotron MR (0.75MW)
Materials & Life Science Facility (MLF)
Bird's eye photo
Neutrino Exp. Facility (294km to Super KAMIOKANDE)
3GeV Synchrotron RCS (25Hz,1MW)
Transmutation Facility (TEF) (Phase II)
Linac 400MeV(50mA)
JRR-3M 800m to MLF
JFY2007 Beam
JFY2008 Beam
JFY2009 Beam
J-PARC = Japan Proton Accelerator Research Complex

Introduction

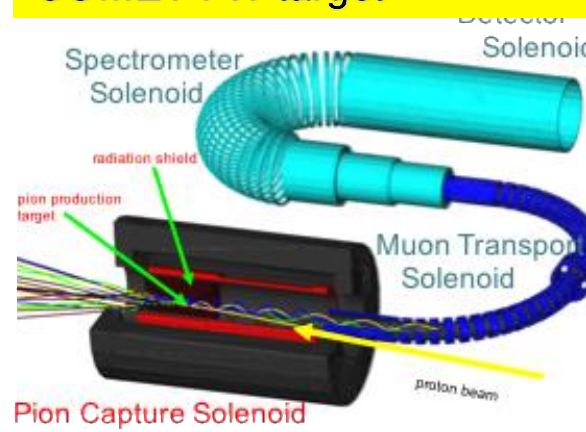
- The allowable beam power can be said to be determined by the targetry materials in the high-power accelerator.
- Study of material damage is crucial.

Proton beam window: Al alloy
(J-PARC neutron source at MLF)

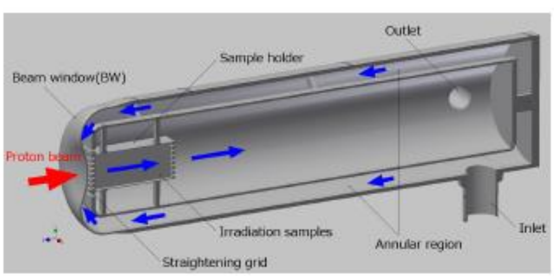


Beam window: Ti alloy
(J-PARC Neutrino facility)

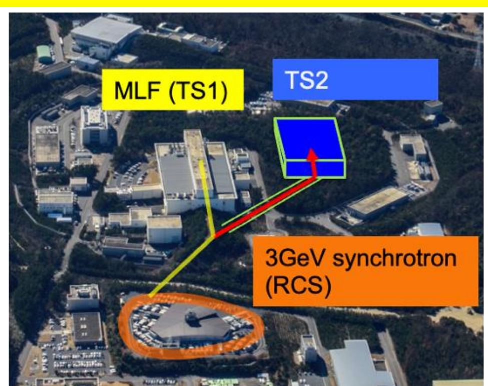
COMET : W target

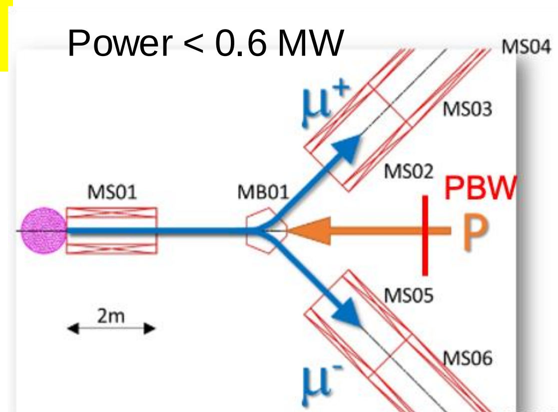


Lead-Bismuth eutectic (LBE) target at new facility (plan)



W target: J-PARC TS2 for neutron and muon (plan)





Recent status regrating MLF

- MLF – TS1
  - Achieved design value of 1 MW long term (> 2 weeks) operation on April
  - Since high-dew point was observed in the helium vessel, the beam operation was stopped ahead of a week of schedule. The cause might be the air leak from seal for vessel (i.e, pillow seal on the mercury target vessel) or slow leek at modelator.
  - Due to the insufficiency of tentative waste storage for the target, the target vessel will be exchanged by 2 years instead of every year.
- MLF – TS2
  - Maximum power given accelerator group: 2.5 MW (ultimate plan)
  - Power < 0.6 MW (Possible fixed tungsten target?)
- (Personal opinion) MLF needs targetry advisory committee
  - Their committee coupling science fruit. In the past the targetry aspect was deeply discussed.

Previous facility plan for ADS at J-PARC

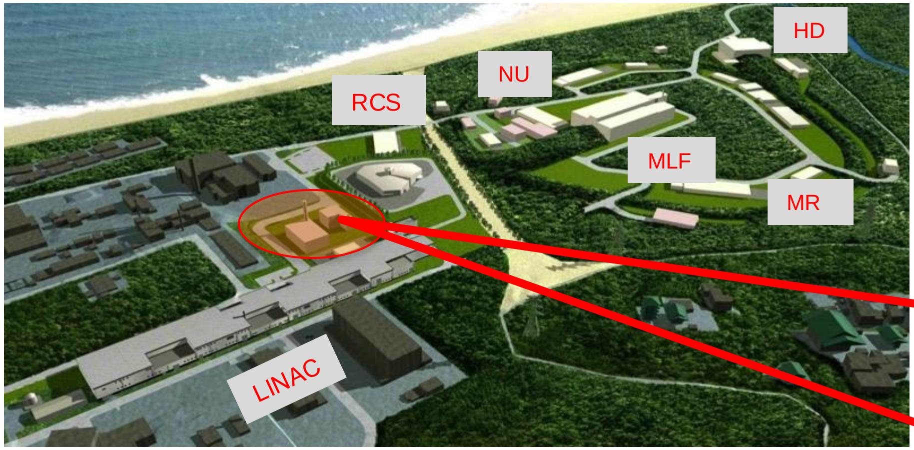
Accelerator Driven System (ADS) developed by JAEA

30 MW proton CW LINAC (SC)

1.5 GeV 20 mA

Sub-critical core (k_{eff} ~ 0.95, i.e., neutrons x 200 times)

Target : Lead Bismuth Eutectic (LBE)



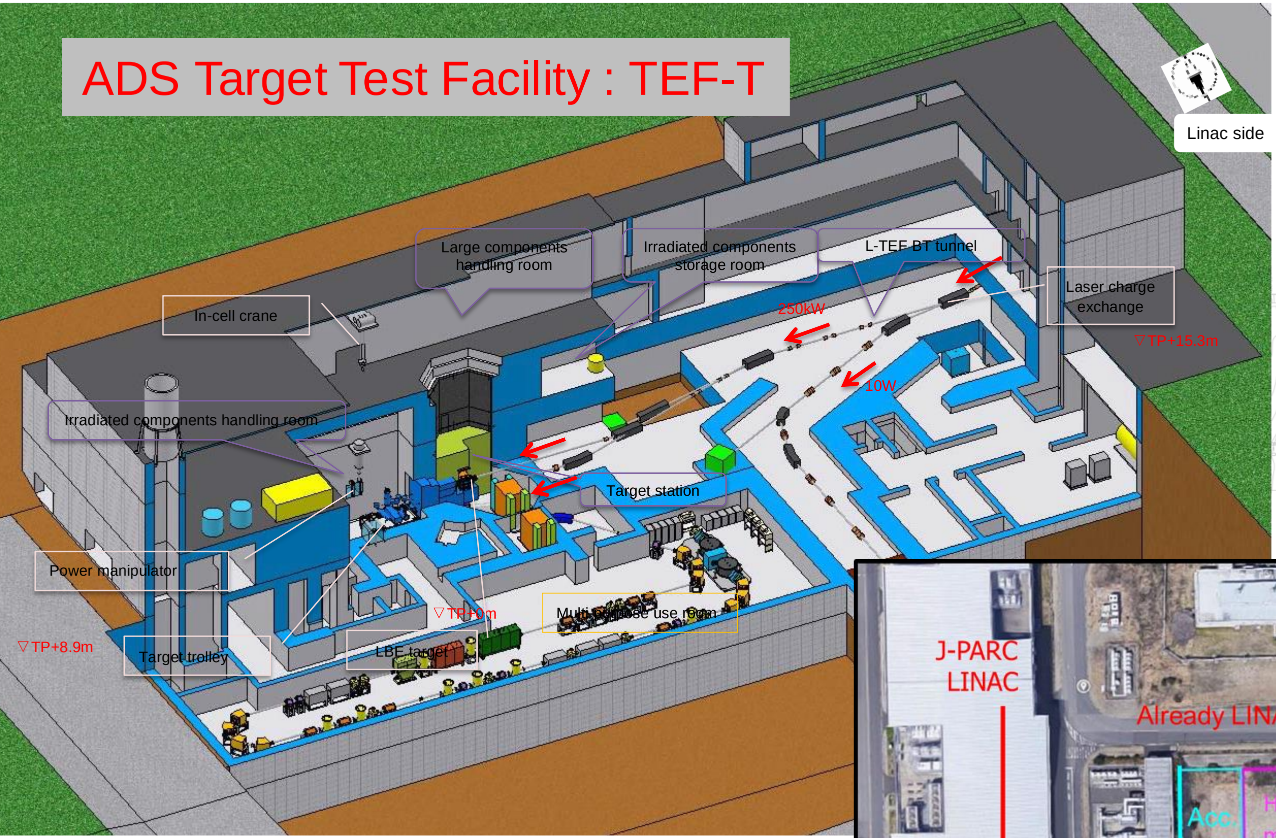
ADS Target Test Facility (TEF-T)

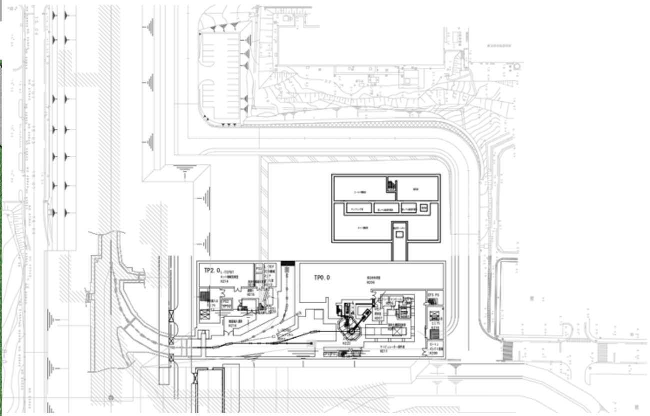
Investigate engineering characteristics of LBE target

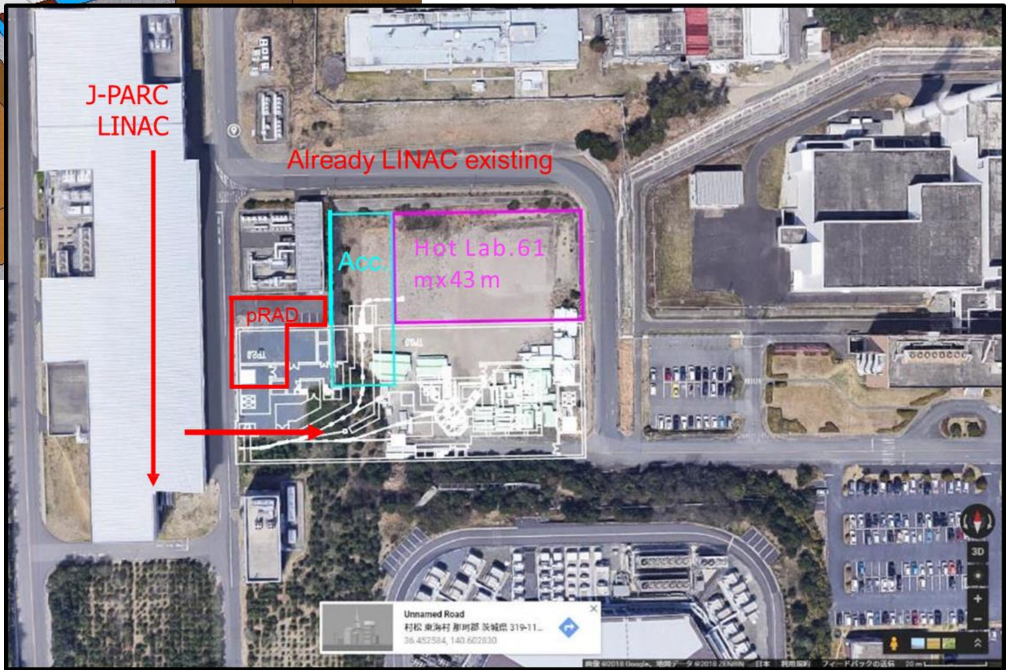
- *400MeV-250kW proton Beam*
- *LBE Temperature < 500℃*
- *Oxygen potential controlled*
- *Hot cell for PIE samples preparation*

- LINAC: Linear accelerator
- RCS: Rapid Cycling Synchrotron
  3-GeV synchrotron
- MR: Main Ring (30-GeV synchrotron)
- MLF: Material Life Science Experimental Facility
- HD: Hadron experimental facility
- NU: Neutrino experimental facility

TEF-T and Proton beam irradiation facility



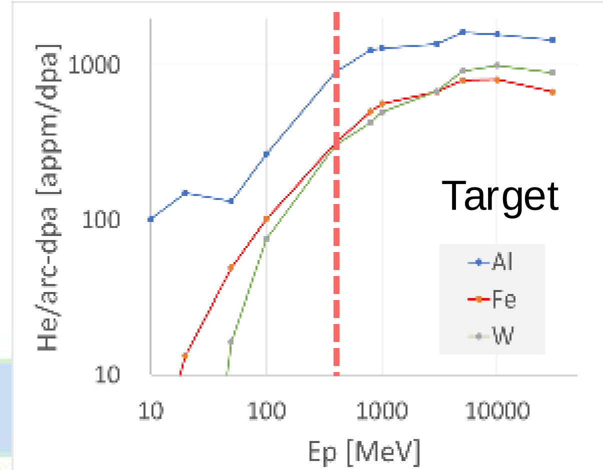


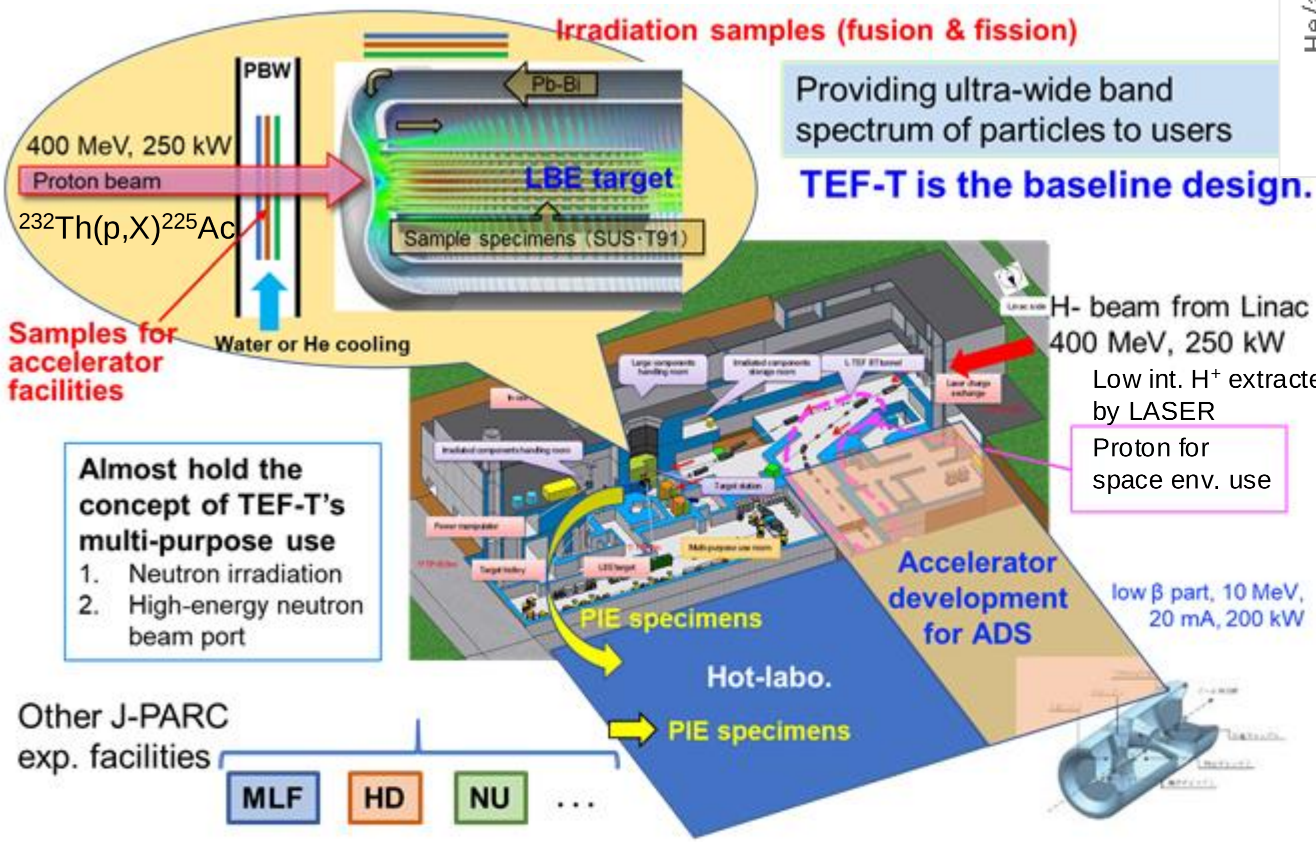


J-PARC proton beam irradiation facility

- Proton beam irradiation facility planned at J-PARC
  - H^- beam 0.4 GeV, Power >250 kW with 25 Hz
  - Peak 50 mA, Width 0.5 ms, Rep. 25 Hz
  - Dose >20 dpa/year at the Pb-Bi (LBE) target
  - LINAC upgrade 25 → 50 Hz

Simular He/dpa for high energy region with 0.4 GeV protons.





- 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)

Target at new facility

- Technical Design Report has been published to JAEA report.
- Tungsten target or modular LBE target (MEGAPIE) : new candidate

Table 2.4-1 Main parameters of the proton beam for TEF-T

Injection direction	Horizontal injection
Energy / Current	400 MeV / 0.625 mA
Power	250 kW
Repetition rate	25 Hz
Pulse width	About 500 μs
Beam shape	Gaussian (4 cm in FWHM)
Peak beam current density	30 μA/cm² at maximum

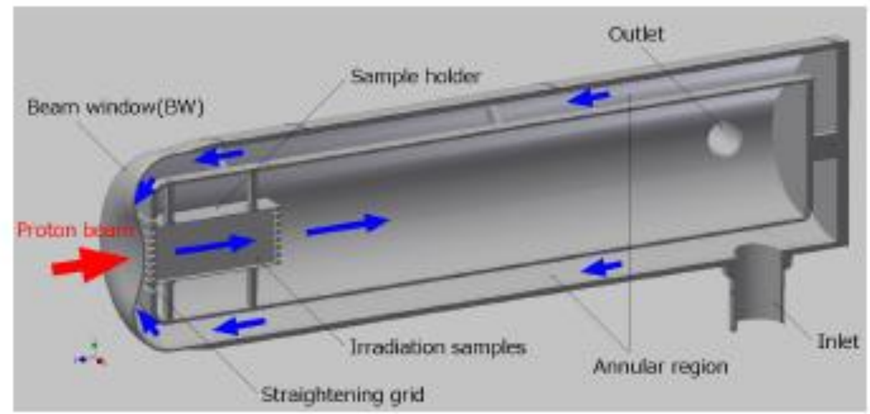
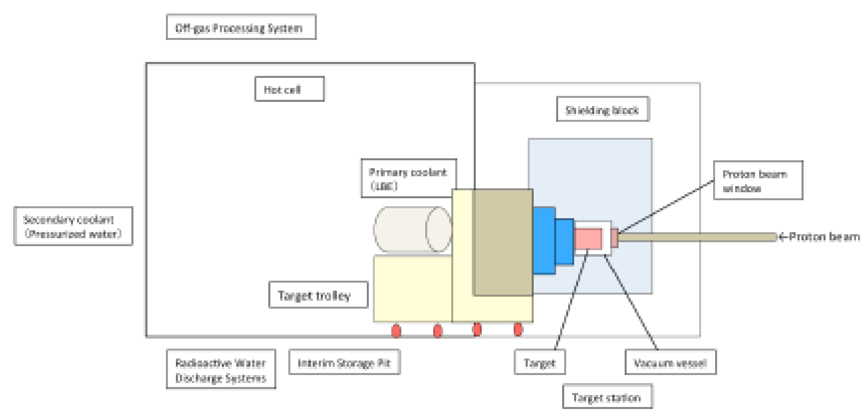


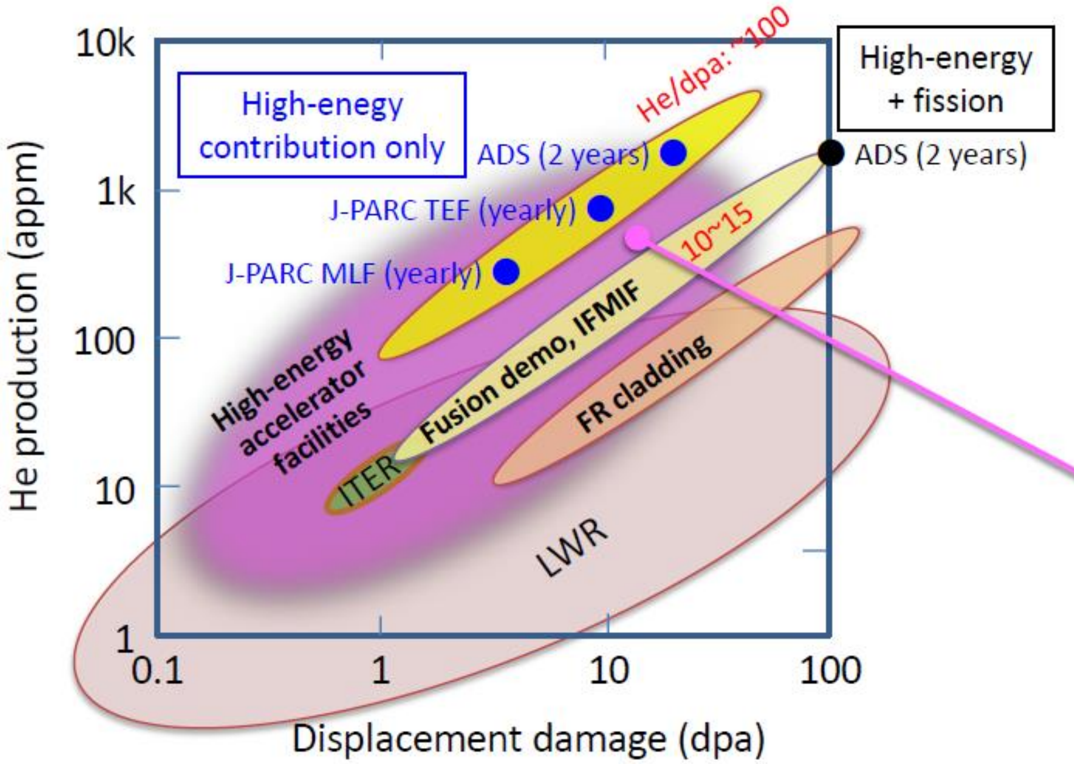
Table 2.4-2 Main parameters of the TEF-T spallation target

Target material	LBE (Lead-bismuth eutectic)
Structure	Double tube type
Dimensions	Diameter of the inner tube: 105 mm Diameter of the outer tube: 150 mm Total length: 800 mm Thickness: 2 mm (beam window) ~ 5 mm (body)
Maximum temperature	500°C (window), ~500°C (Irradiation plate)
Operating temperature	400/500°C (LBE)
Estimated life	5,000 hours/year or 10 dpa
Structural material (<450°C)	SUS316L
Structural material (>450°C)	T91 (Modified 9Cr-1Mo steel)
Cover gas	Ar gas
Secondary coolant	Pressurized water



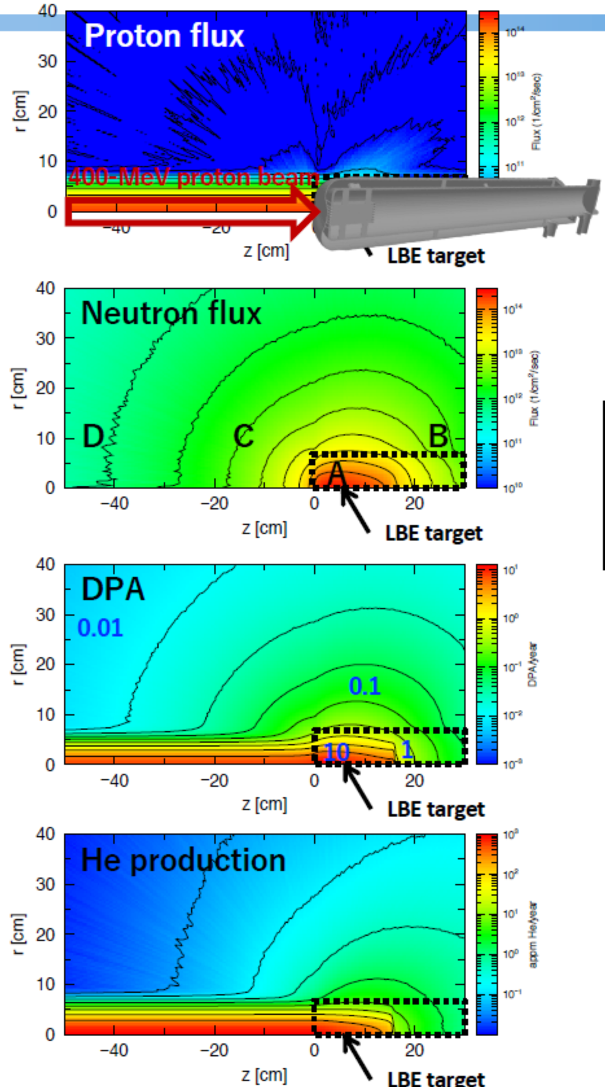
Simulation of fission and fusion environment

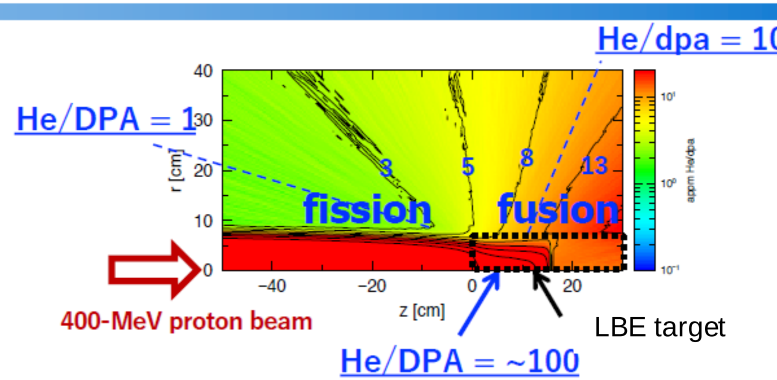
- Displacement damage (dpa) and He production are the most important parameters to dominate radiation damage of materials.
- The He/dpa ratio is the parameter to characterize irradiation environments depending on particle energies.



Region of interest where the new irradiation facility will cover

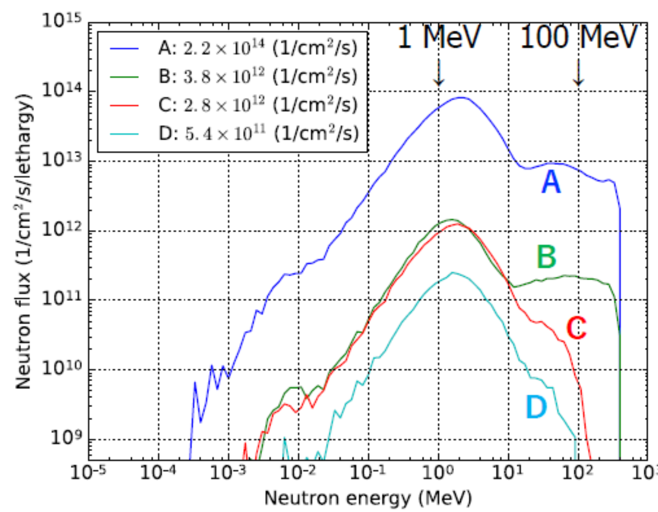
Variate of irradiation circumstance





He/dpa = 1 ~ 100

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



Covering circumstance of nuclear reactor, fusion reactor, and high-energy accelerator

Difficulties of PIE at J-PARC

- Due to the Japanese specified law for radioactive material, the beam-irradiated material is difficult to ship to other hot cells in JAEA to perform post-irradiation examination (PIE).
  - J-PARC facility:

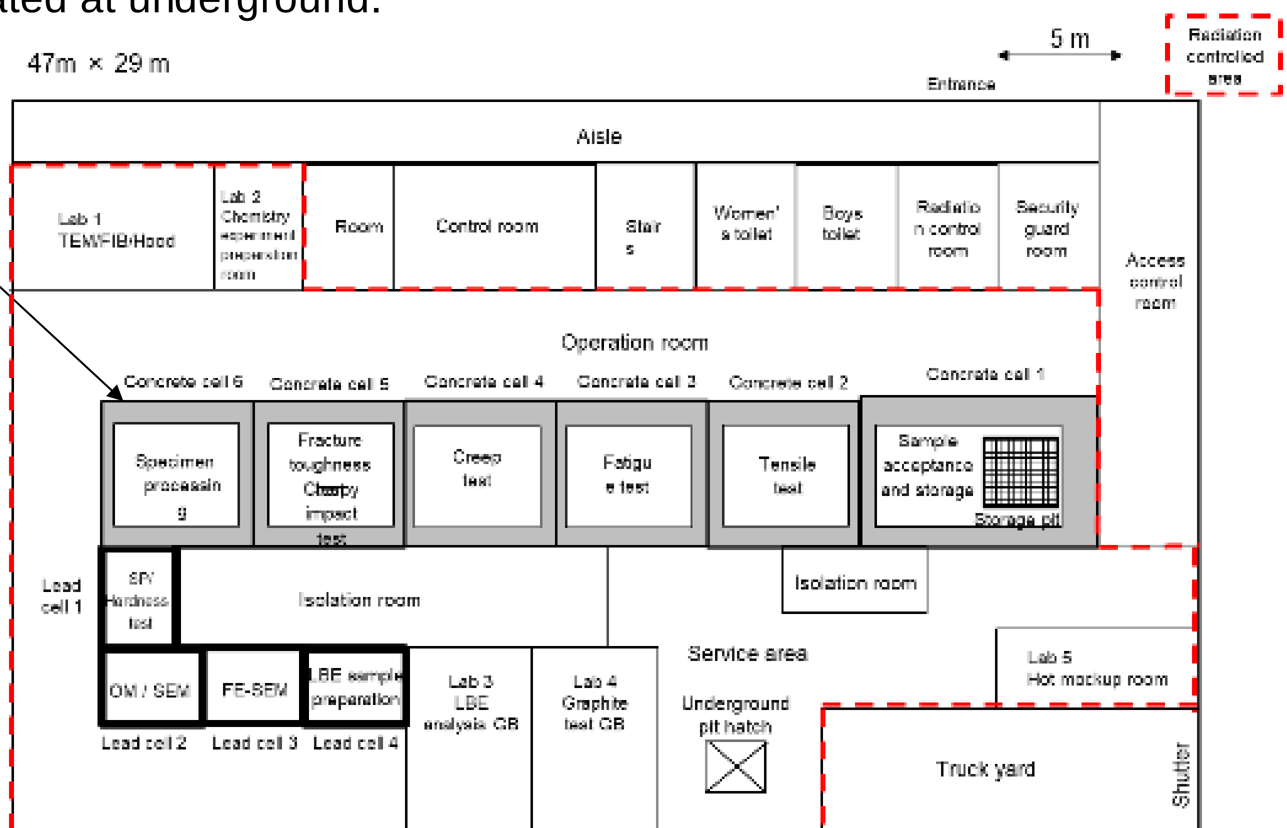
    Radioactive material (coupled with the accelerator)
  - JAEA facility:

    RI and fuel but radioactive material (because not coupled with the accelerator)
- To ship another cells in JAEA, we have been struggling to change the radioactive material to RI legally, but many difficulties remain.
- Simultaneously, we are developing alternative way based on small-punch and nano-indenter to overcome the difficulty.

New hot-lab for PIE

- For the PIE of the samples irradiated at the new facility, a new hot lab is planned to be constructed adjacent to the new facility.
- J-PARC needs a hot lab for PIE not only for MLF but also for other facilities of T2K and Hadron.
- Allowing us to dismount MLF’s target vessel for mercury
  - Specimens placed at LBE target will be transferred to cells by the channel located at underground.

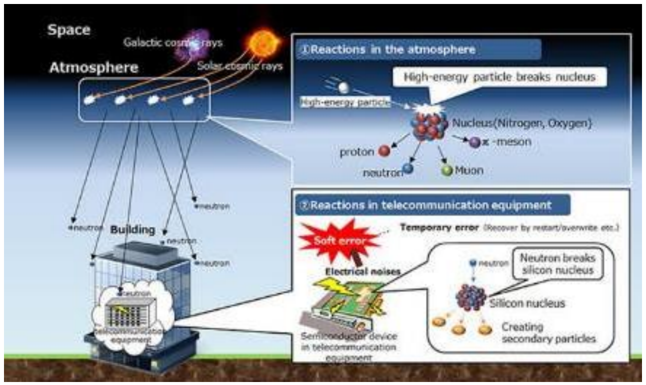
Cells for PIE with manipulators



Proton beam facility for other purpose use

Single Event Effect (SEE)

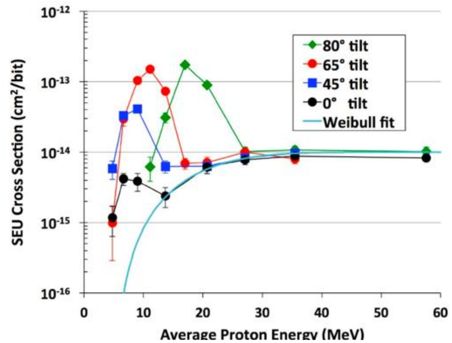
On the earth by neutron

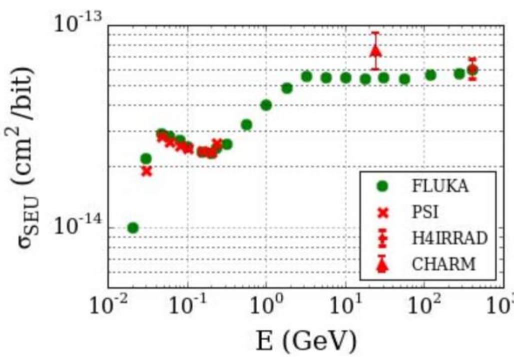


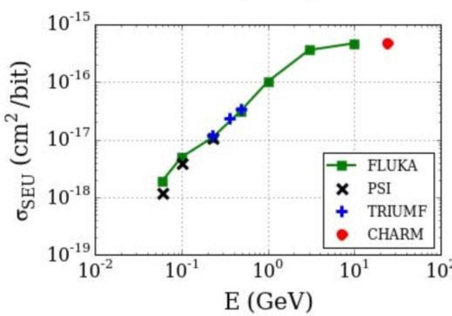
In space by charged particles (mainly protons)

Space Strategy Fund (starting):
1 T¥ (~7 B USD) for 10 years

SEU X-sec for protons
Fit by Weibull function



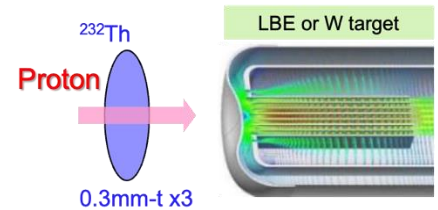


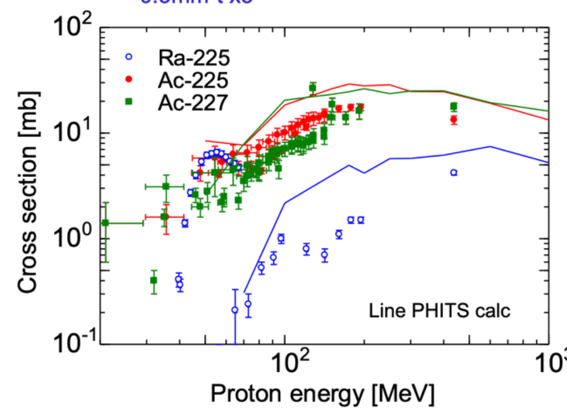


R. G. Alia+, IEEE 65, 8, 1750-1758 2018

RI medicine production

(aka transmutation)
Ac-225, Mo- 99





α decay, β^- decay

Th-226 30.6 min	Th-227 18.7 d	Th-228 18.7 d	Th-229 7880 y
Ac-225 10.0 d	Ac-226 1.22 d	Ac-227 21.7 y	Ac-228 6.15 h
Ra-224 3.6 d	Ra-225 14.9 d	Ra-226 1600 y	Ra-227 42.2 m

Ra-225->Ac-225 (Free Ac-227)
Ac-225 without Ac-227 100 GBq/year

Science Council of Japan
Future Science Promotion Initiative (2023 edition)

J-PARC

提　言

未来の学術振興構想（２０２３年版）

令和５年（２０２３年）９月２５日

日　本　学　術　会　議

https://www.scj.go.jp/ja/info/kohyo/kohyo-25-t353-3.html

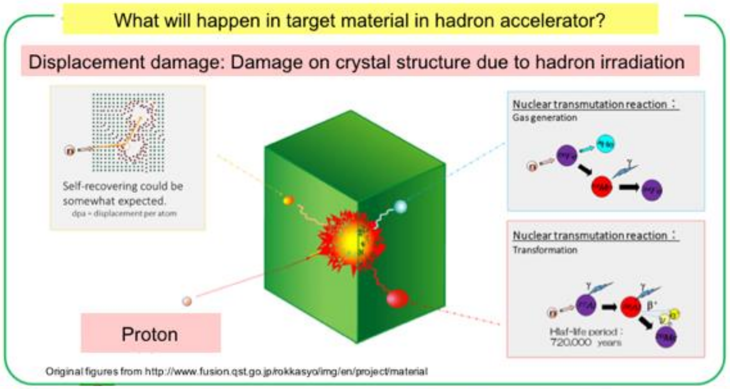
⑯ 量子ビームを用いた極限世界の解明と人類社会への貢献

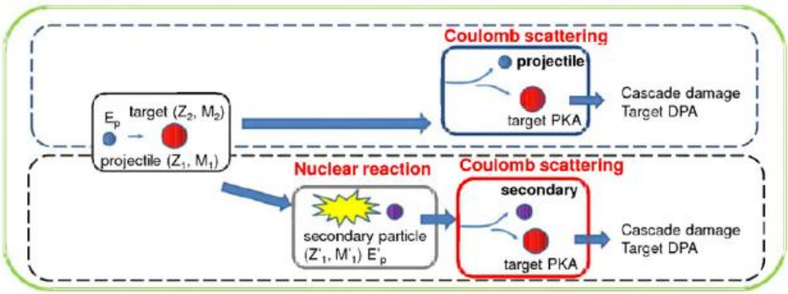
No.	学術の中長期研究戦略の名称	提案者
133	持続可能な社会基盤構築に繋がる重元素研究の推進（再掲）	櫻井　博儀（理化学研究所・仁科加速器科学研究センターセンター長、日本学術会議連携会員）
135	複雑・不均一系の分子ダイナミクスに挑む量子光科学拠点の構築	渡辺　芳人（自然科学研究機構・分子科学研究所所長、日本学術会議連携会員）
136	J-PARC での高強度重イオンビームによる超高密度物質の研究	服部　利明（筑波大学数理物質系数理物質系長）
137	MLF 第２ターゲットステーション：中性子・ミュオン科学の新たな展開	小林　隆（J-PARC センターセンター長）
138	量子ビーム施設統合マルチプローブ学術研究基盤	山内　正則（大学共同利用機関法人高エネルギー加速器研究機構機構長、日本学術会議連携会員）
139	超伝導加速器研究拠点	小関　忠（大学共同利用機関法人高エネルギー加速器研究機構加速器研究施設加速器研究施設長）
140	新学術分野の創成と社会課題の解決を実現する先端放射光科学	横山　利彦（日本放射光学会会長）
141	大強度低速陽電子ビームによる物性科学・基礎科学の革新的展開	藤浪　眞紀（日本陽電子科学会会長）
142	世界を先導できる大型パワーレーザー施設による国際中核拠点の構築	兒玉　了祐（大阪大学・レーザー科学研究所所長、日本学術会議連携会員）
143	高エネルギー大強度陽子ビームが拓く核子エンジニアリング社会	小林　隆（（国研）日本原子力研究開発機構／大学共同利用機関法人高エネルギー加速器研究機構Ｊ－ＰＡＲＣセンターセンター長）
144	２１世紀の量子プローブ「ミュオン」を用いた学際科学の新展開	久保　謙哉（日本中間子科学会会長）
145	紫外線域の高輝度小型放射光源を基盤とする国際研究・人材育成拠点の形成と動的局所構造解析による量子物質科学・量子生命科学の推進	島田　賢也（広島大学・放射光科学研究センターセンター長）
146	中性子ビーム利用の中長期研究戦略	加倉井　和久（日本中性子科学会会長）
147	アト秒レーザー科学研究施設（ALFA）	山内　薫（東京大学・大学院理学系研究科教授、日本学術会議連携会員）
148	大強度高品質ミュー粒子ビームによる宇宙の起源の解明と新しい科学分野の開拓	上野　一樹（大阪大学大学院理学研究科准教授）

The council adpted :
“Nucleon engineering society pioneered by high-energy high-intensity proton beams”

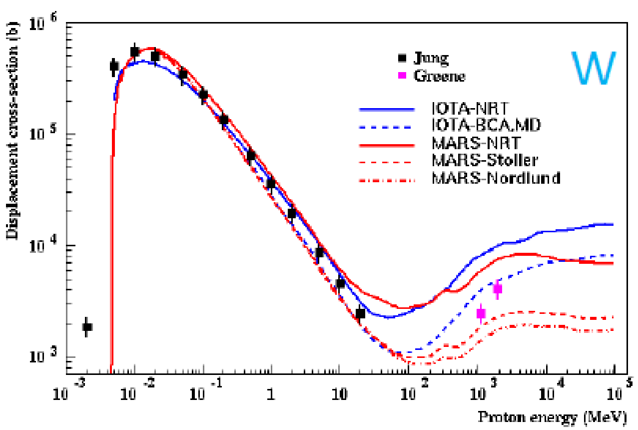
- Elucidation of the extreme world using quantum beams and contribution to humanity

Displacement cross section





N. Mokhov, HPTW2016



- dpa (displacement per atom) : Widely used as damage index of material
  dpa = Fluence x displacement X-sec
- Lack of data above 20 MeV: Difficult validation of calculation models

⇒ Experiments conducted 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.

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

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]

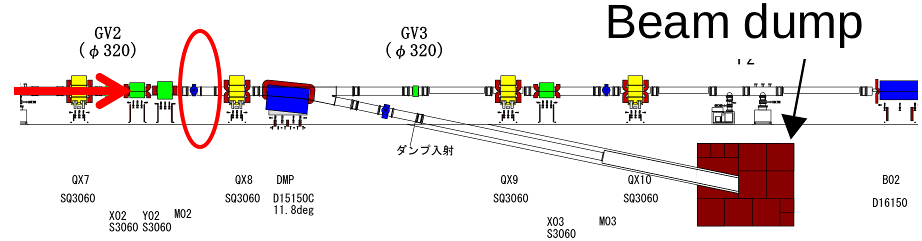
Displacement cross section experiment

- RCS (0.4 – 3 GeV) and MR (8 GeV)
- FTBF at FNAL (120 GeV)
  - Precious beam turning with beam scanning and monitor are required.
  - Achieved ~4 K (but used ~8 K to maintain normal conducting at sample)

From 3GeV RCS

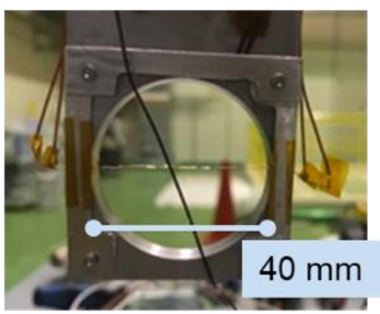
To MLF

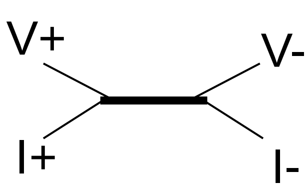
Beam dump



Cryocooler and sample

Al, Cu, Nb, Fe W wire
(Φ 0.25 mm) 99.9%

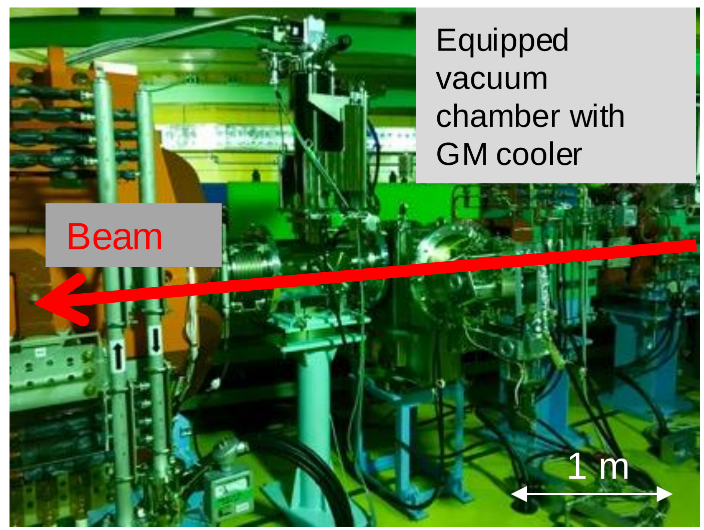




Sample wire

To obtain precious resistance reading with 4 terminals applied

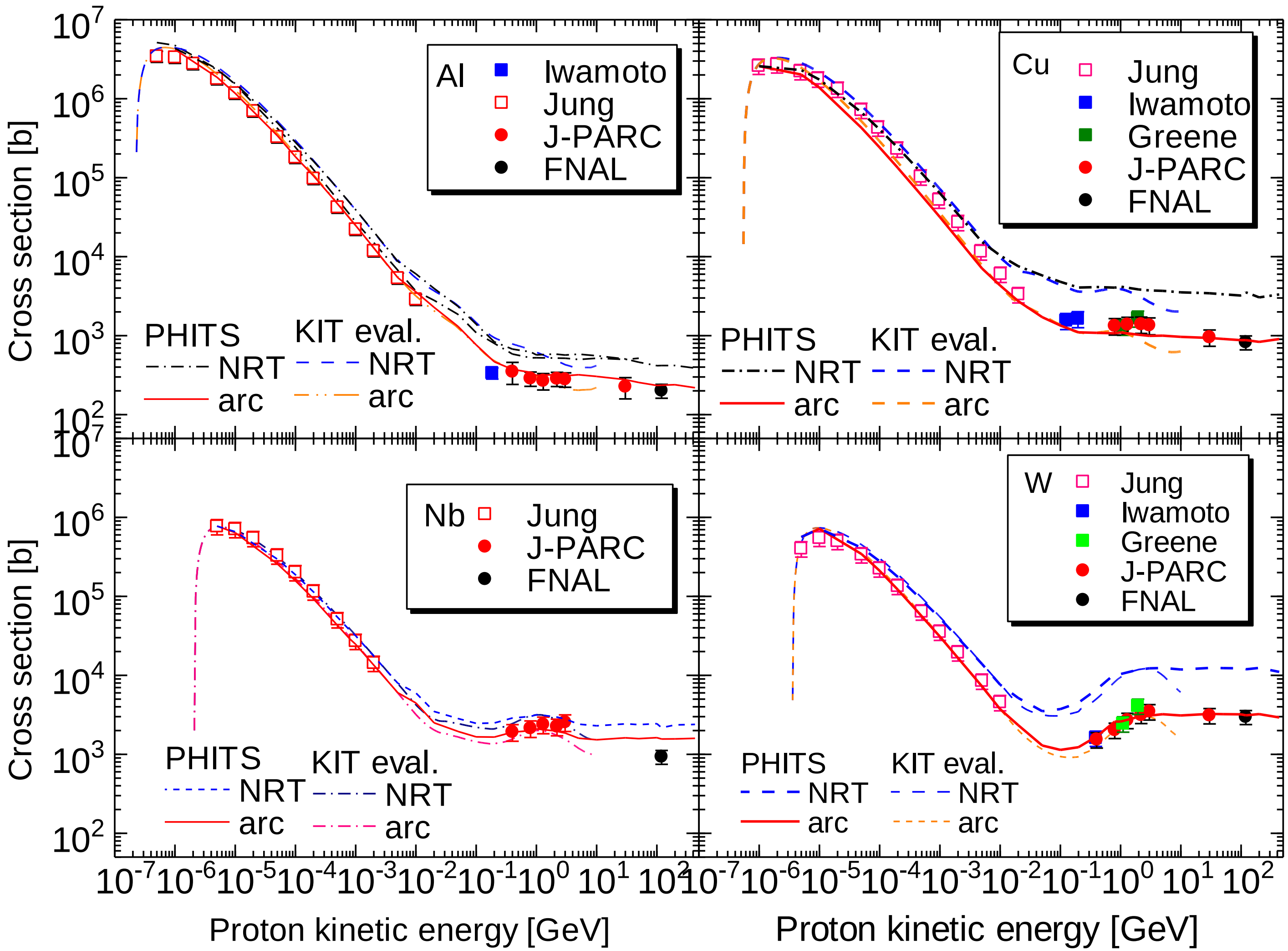
J-PARC RCS



FNAL FTBF

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

Comparison with calculation



NRT

$$N_d(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d} & , & \frac{2E_d}{0.8} < T_d < \infty \end{bmatrix},$$

arc-dpa

$$N_{d,\mathrm{arcdpa}}(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d}\xi_{\mathrm{arcdpa}}(T_d) & , & \frac{2E_d}{0.8} < T_d < \infty \end{bmatrix}$$

$$\xi_{\mathrm{arcdpa}}(T_d) = \frac{1 - c_{\mathrm{arcdpa}}}{(2E_d/0.8)^{b_{\mathrm{arcdpa}}}} T_d^{b_{\mathrm{arcdpa}}} + c_{\mathrm{arcdpa}}.$$

X-sec: similar tendency of NRT and arc-dpa calculation up to Ep<120 GeV

But we have to check for 440 GeV.
→ HiRadMat exp

FLUKA recently available arc-dpa

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

Ep 440 GeV at HiRadMat CERN

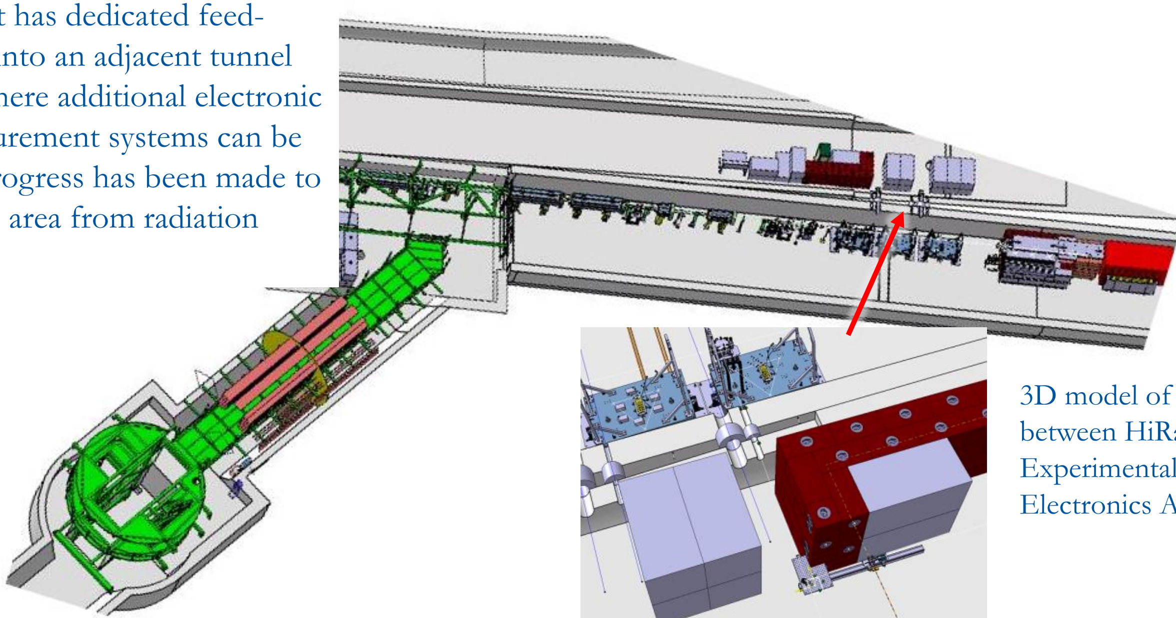
HiRadMat

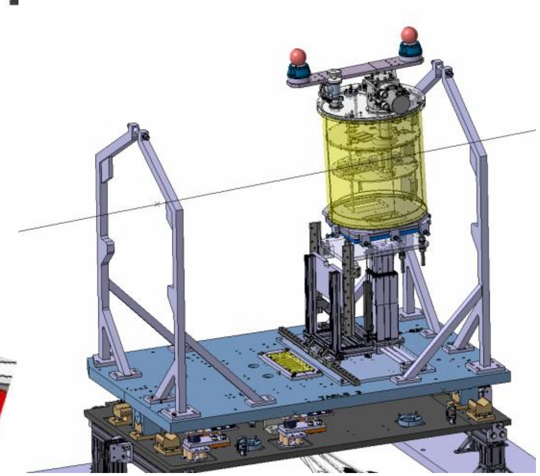
Irradiation Area

Vacuum cryostat will borrow from SC-COIL

TT61

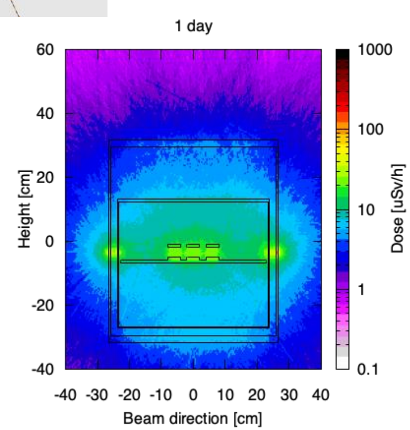
HiRadMat has dedicated feed-throughs into an adjacent tunnel (TT61) where additional electronic and measurement systems can be added. Progress has been made to shield this area from radiation effects.





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

12 ARIES 20-Dec-18 5th RaDIATE Collaboration Meeting



FLUKA
Dose for 1 day cooling

- Maybe RaDIATE somewhat supporting this

Experiment planned in 2025

Summary

- J-PARC will build a new facility for the study of material damage and other essential uses.
- User community established (domestic member ~250 persons)
  - Technical Advisory Committee of the new facility requires an international user community.
  - Please join this community
  - Letter of Intent
- High energy region displacement cross section:
  - Successfully obtained the data up to 120 GeV. At HiRadMat, we will obtain the data of 440-GeV protons in the next year.

Collaborators of displacement cross sections:

(J-PARC/JAEA)	Y. Iwamoto, H. Matsuda, H. Iwamoto, S. Hashimoto, F. Maekawa
(J-PARC/KEK)	M. Yoshida, T. Nakamoto, S. Makimura, T. Ishida
(Kyoto Univ)	A. Yabuuchi, T. Yoshiie
(FNAL)	K. Yonehara, Z. Liu, K. Lynch
(CERN)	N. Charitonidis, A. Goillot, P. Simon, V. Stergjou, E. Andersen

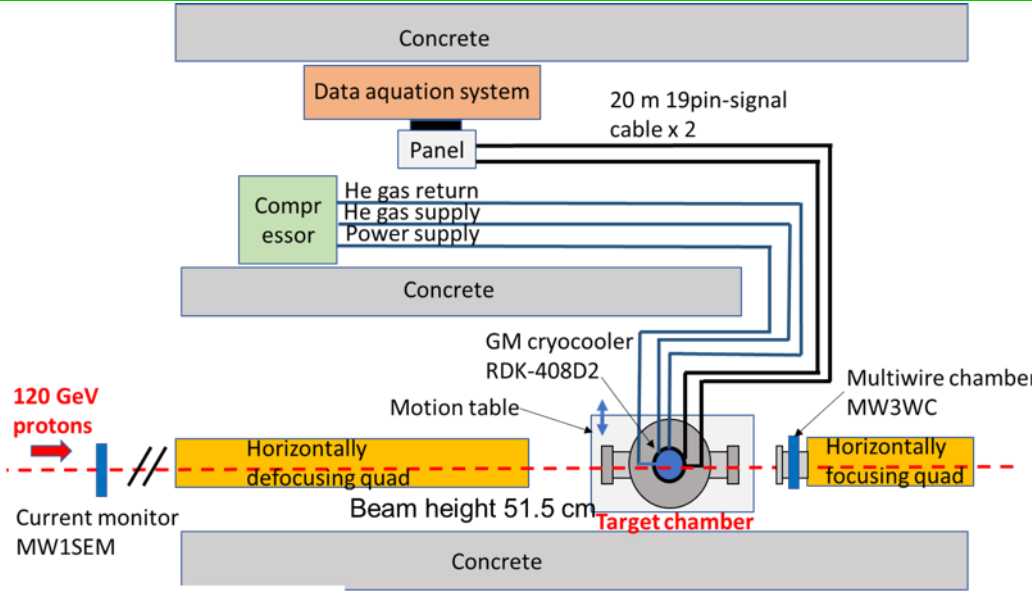
Accoutrements:

- 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.

Supplement

Experiment at FNAL

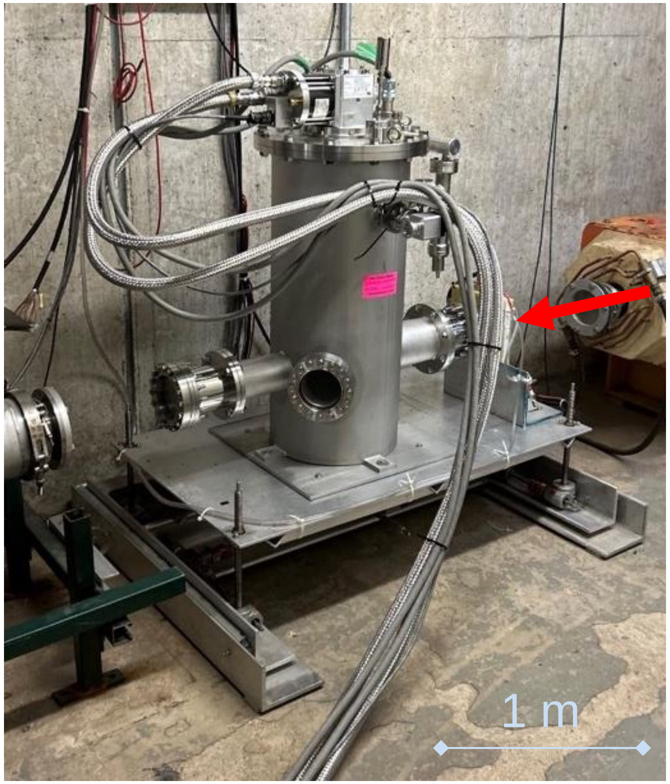
Similar manner of J-PARC experiment was applied at Fermilab Beam Test Facility (FTBF) M03.

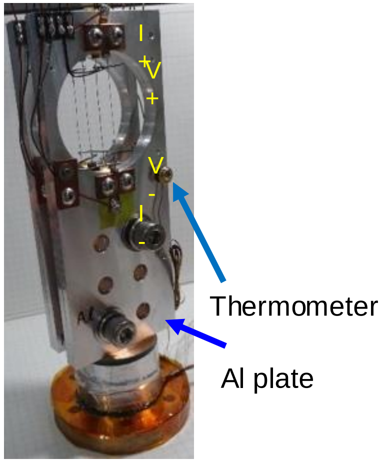


About 1.8 x 10^{11} protons per minute

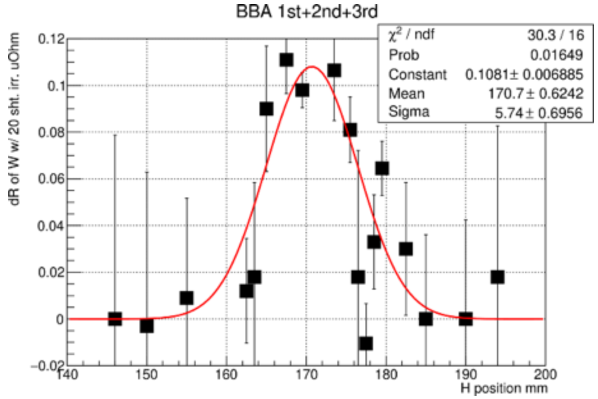
Top view of layout

GM cooler RDK-408D2





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



Disp. X-sec calculation in PHITS

J-PARC

- Cross section given by $\sigma_{disp-calc}(E) = \sum_i \int_{E_d}^{T_i^{max}} N_d(T_i) \frac{d\sigma}{dT_i} dT_i,$

Displace number
i : particle species

  - Widely utilized Norgett-Robinson-Torrens (NRT) model
  - arc-dpa model
    - Nordlund and Konobeyev's parameter applied

arc: Athermal Recombination Correction

Displace number by NRT model (N_d)

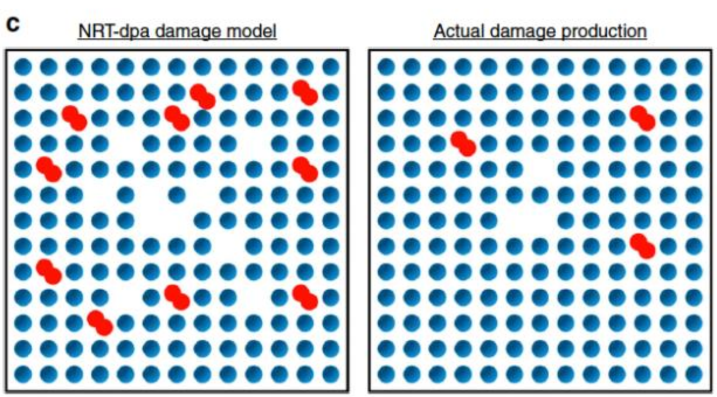
$$N_d(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d} & , & \frac{2E_d}{0.8} < T_d < \infty \end{bmatrix},$$

T_d: Displacement energy

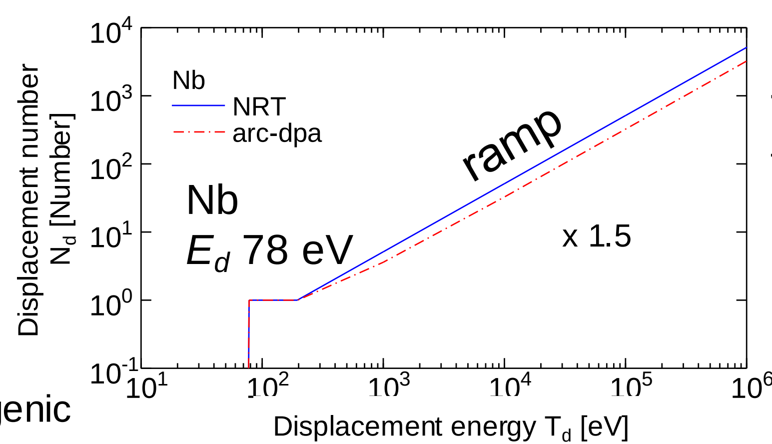
Displace number by arc-dpa model ($N_{d\ arcdpa}$)

$$N_{d,arcdpa}(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d} \xi_{arcdpa}(T_d) & , & \frac{2E_d}{0.8} < T_d < \infty \end{bmatrix}$$

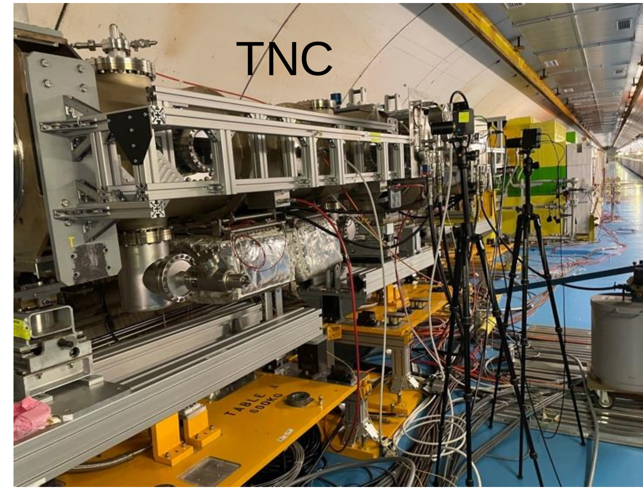
$$\xi_{arcdpa}(T_d) = \frac{1 - c_{arcdpa}}{(2E_d/0.8)^{b_{arcdpa}}} T_d^{b_{arcdpa}} + c_{arcdpa}.$$

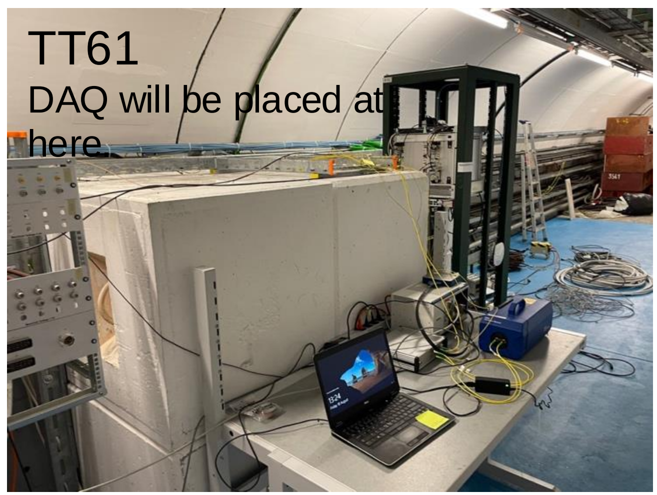


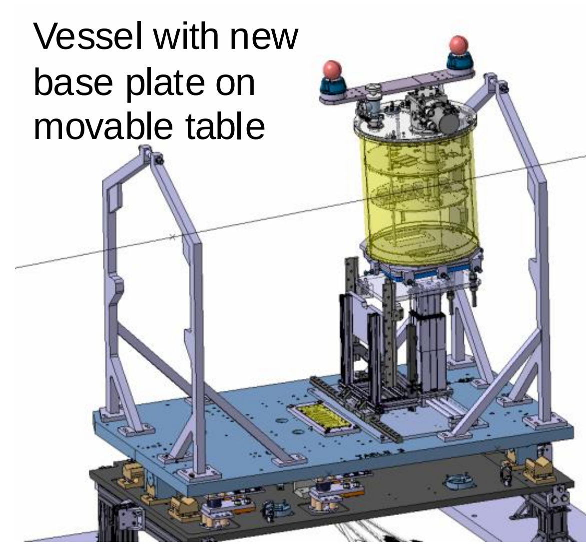
arc-dpa: instantaneous recombination at cryogenic

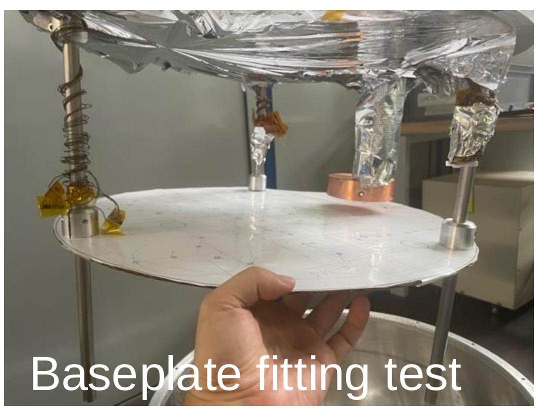


For ramp region $T_d > 2E_d/0.8$, the difference between the two models is a factor of 1.5.





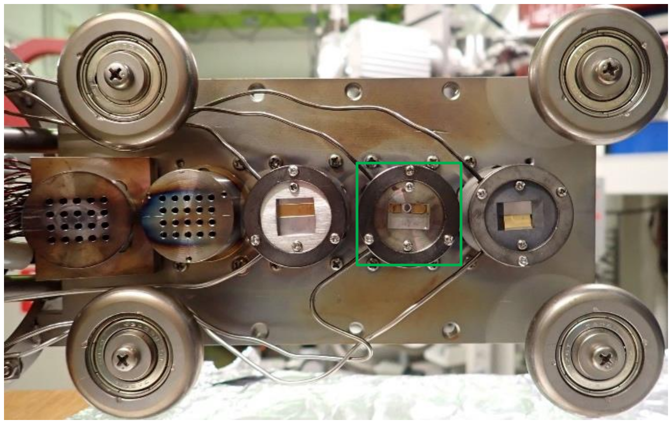


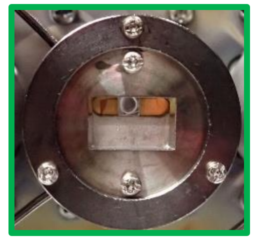


- Ready to do the test in April 2025.

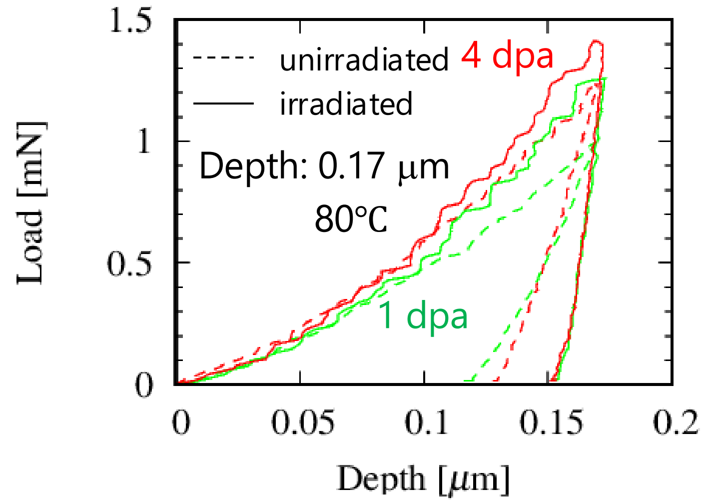
Al alloy test with nano indenter

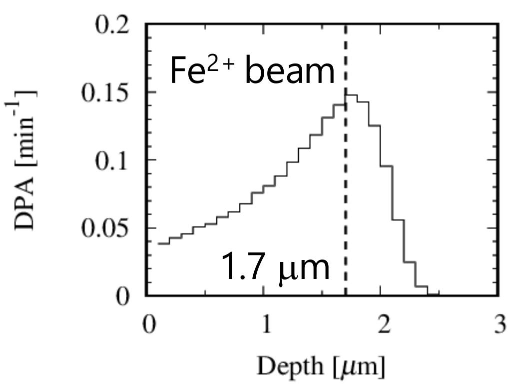
Irradiation on aluminum alloy (A5083) at HIT

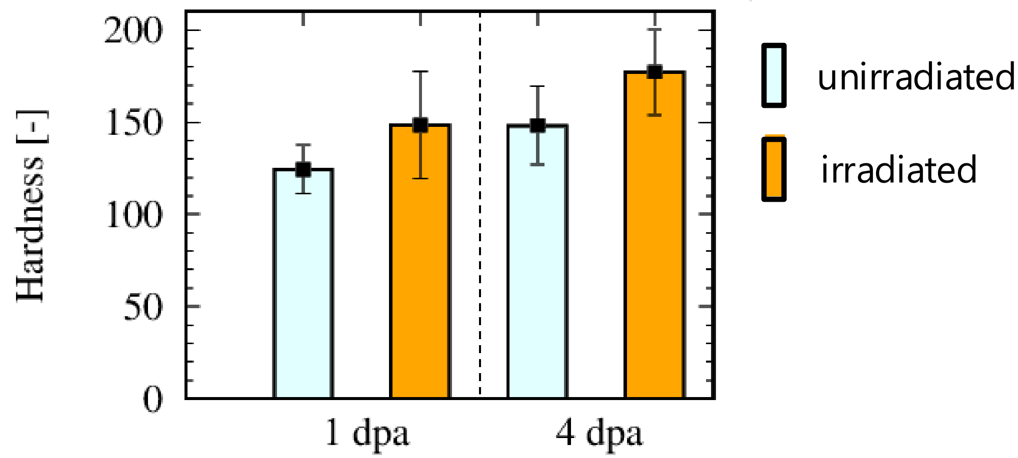




Specimen holder



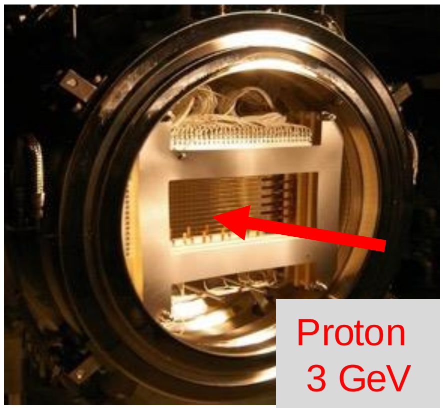


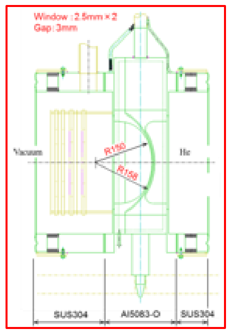


- Hardness investigated using Berkovich indenter for specimens irradiated to 1- and 4-dpa
- Dual beam irradiation test planed

Beam intercept materials and damage

Proton beam window in J-PARC spallation neutron source: Aluminum alloy (ϕ0.6 m)

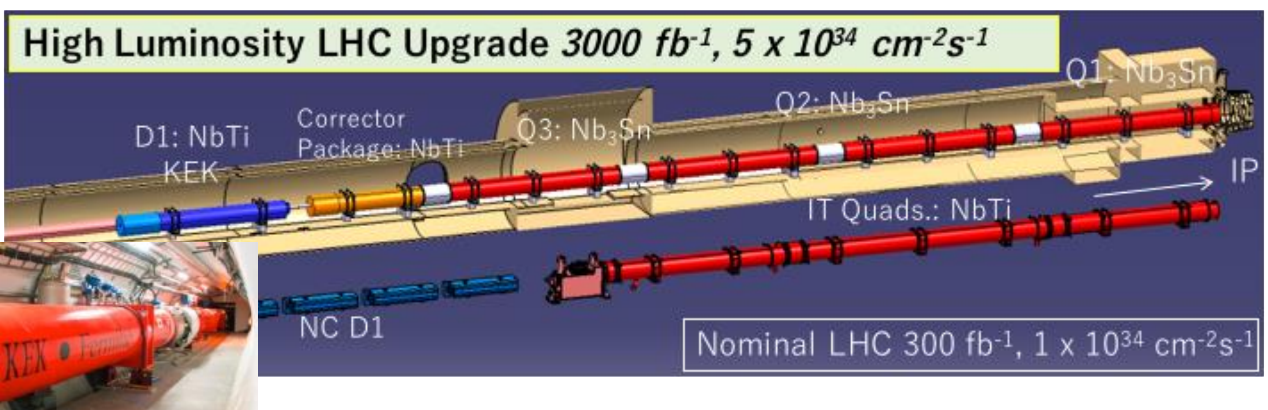




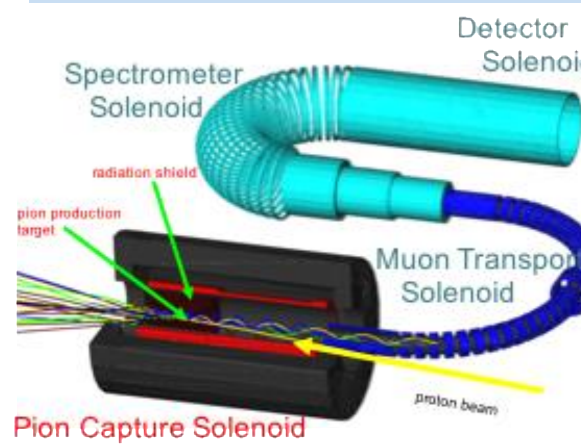
T2K beam window
Titanium alloy (Ti-6Al-4V)

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

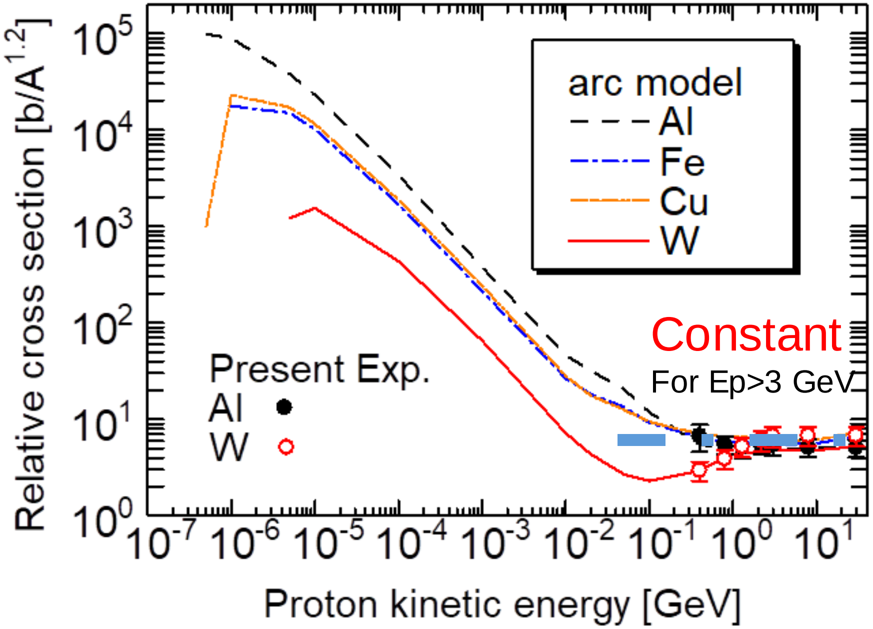
- Resistivity change due to radiation is crucial for Superconductor(SC) magnet sustaining damage.



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



Discussion of cross section in high-energy region

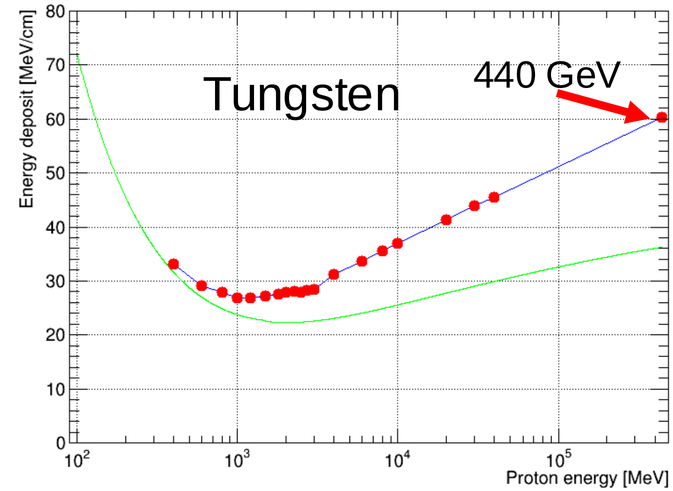


Speculation of $A^{1.2}$ law

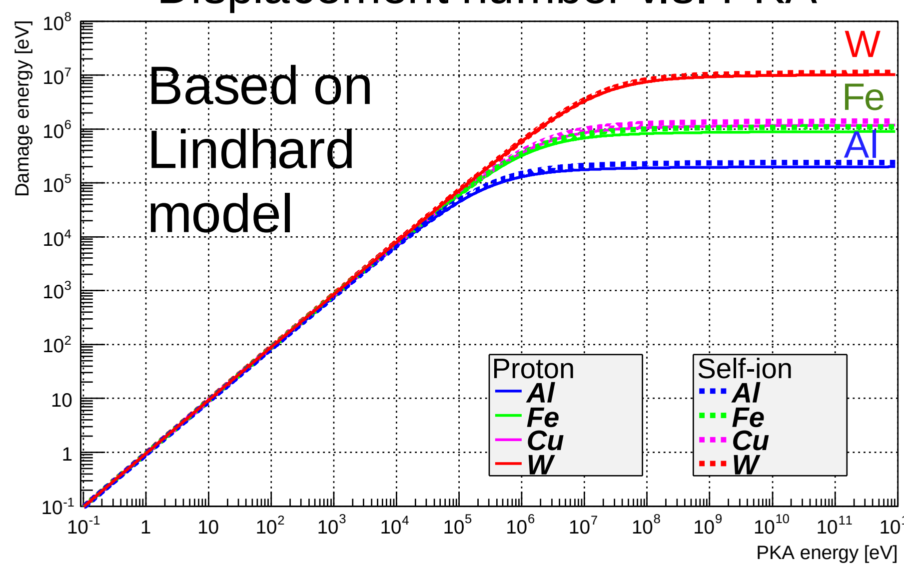
- Reaction X-sec $A^{2/3}$
- Disp. Number (Sat.) $A^{1.6}$
- Outgoing energy (PKA) A^{-1}
- Overall $\sim A^{1.2}$

Applicability should be confirmed for further higher energy (*i.e.*, Ep 440 GeV).

Energy deposition density on materials

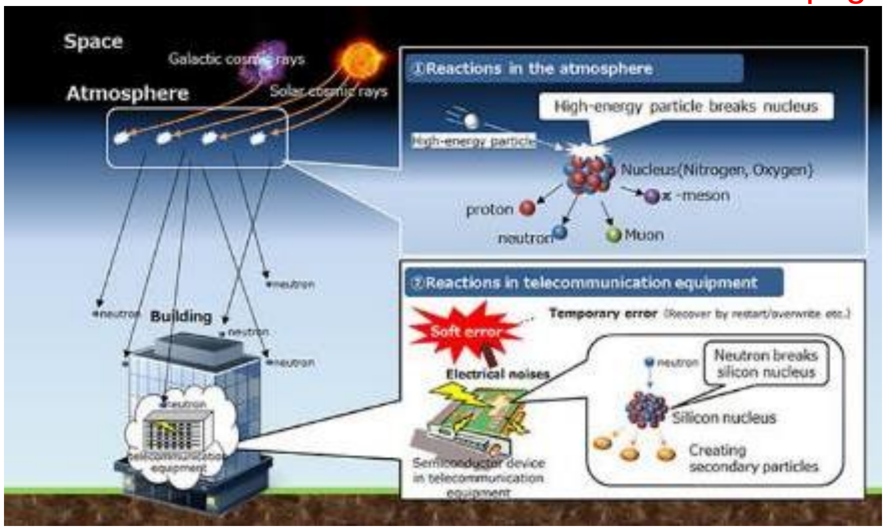


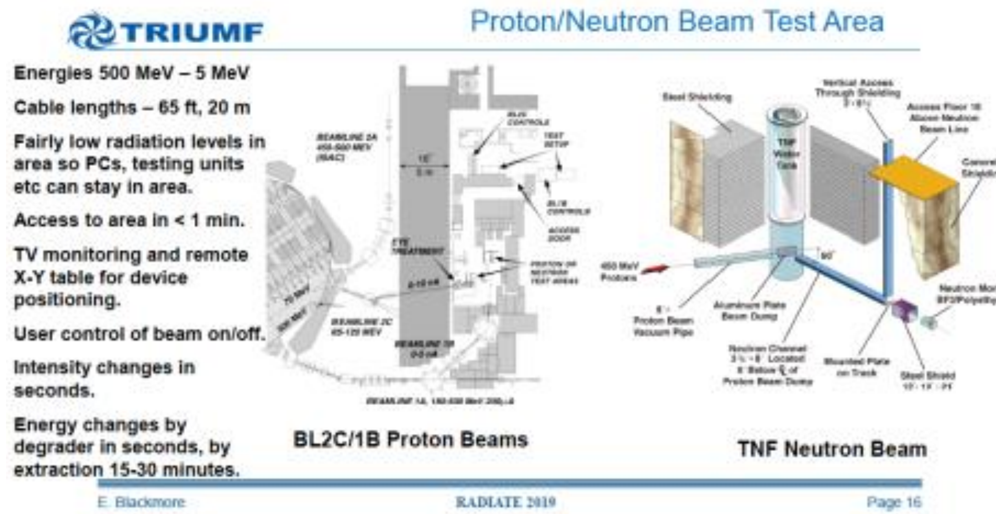
Displacement number v.s. PKA



Soft errors and semiconductor

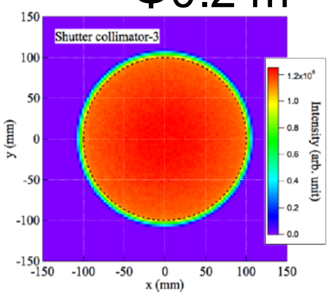
Hitachi web page



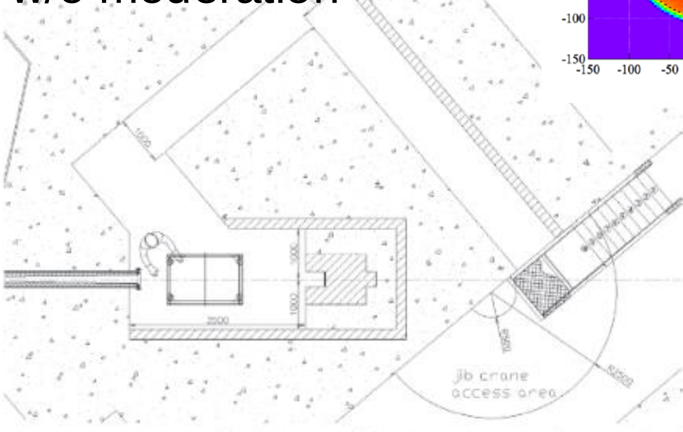


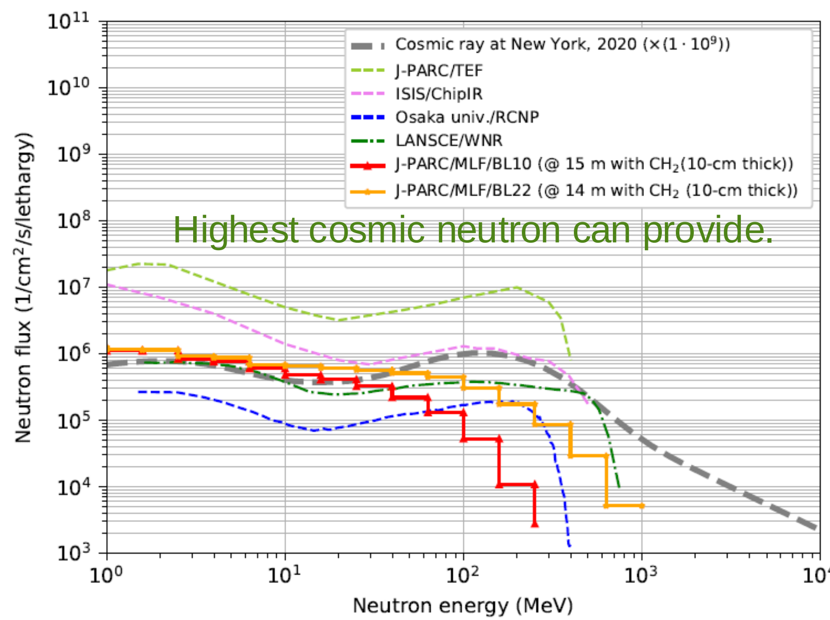
Neutron beam profile

Φ0.2 m



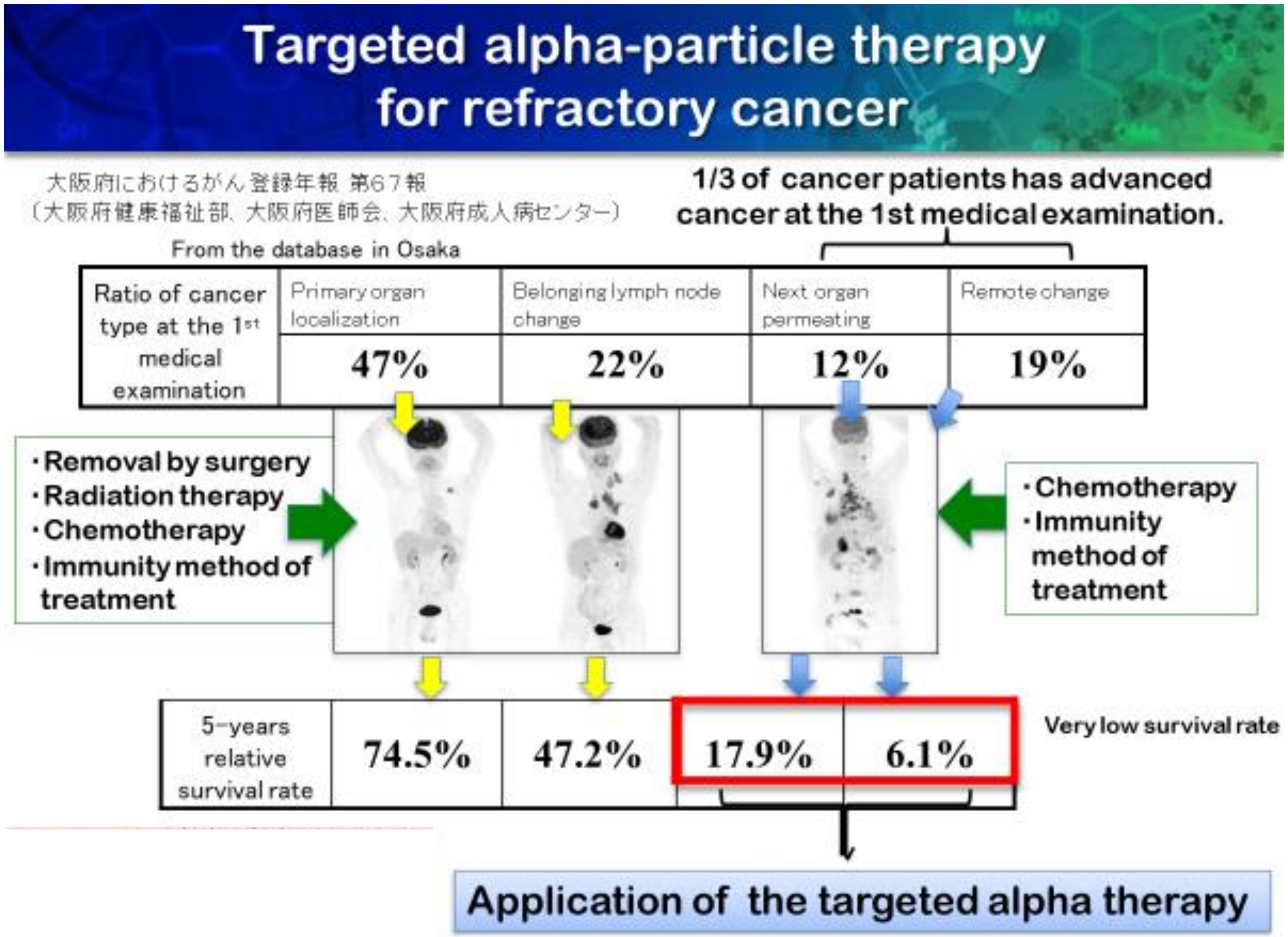
Neutron beam line w/o moderation



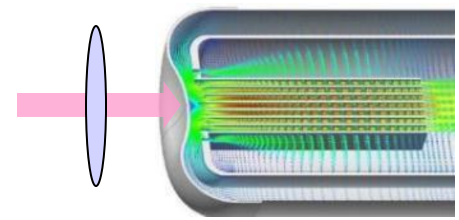


RI medicine production

- Production of RI for medicine for Targeted Alpha Therapy (TAT)
- α-emitting nuclides such as ^{225}Ac ($T_{1/2}$ 10 d) play important roles.
- ^{211}As production was promoted at RCNP and RIKEN using ^{209}Bi(α,2n)^{211}At reaction.



^{232}Th target
(Φ60 mm x 1mm-t)



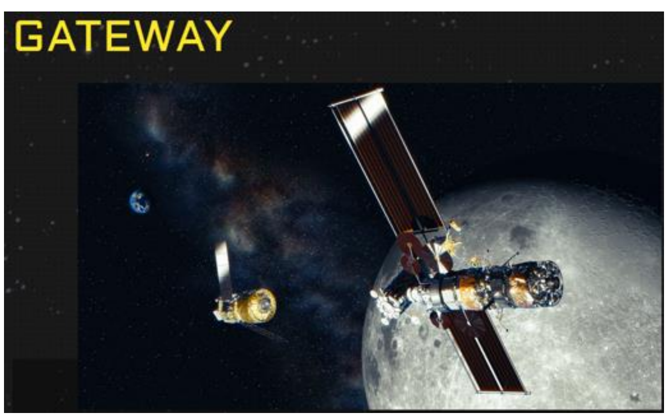
LBE target
(D 150 x L 800 mm)

^{225}Ac production rate from ^{226}Ra w/o ^{277}Ac($T_{1/2}$ 22y)
~ 30 GBq/year

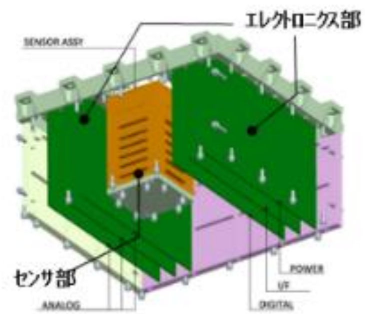
Proton for space use

To enhance the construction of the new facility, we explore the multi-purpose use for use of proton with low intensity, as well.

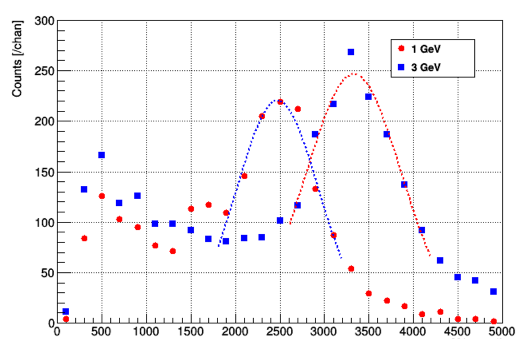
Japan Aerospace Exploration Agency (JAXA): MMX (MMX: Martian Moons Exploration) Launch 2024 and return to earth 2029



Interplanetary Radiation Environment Monitor (IREM)



Experiments made at RCS beam dump

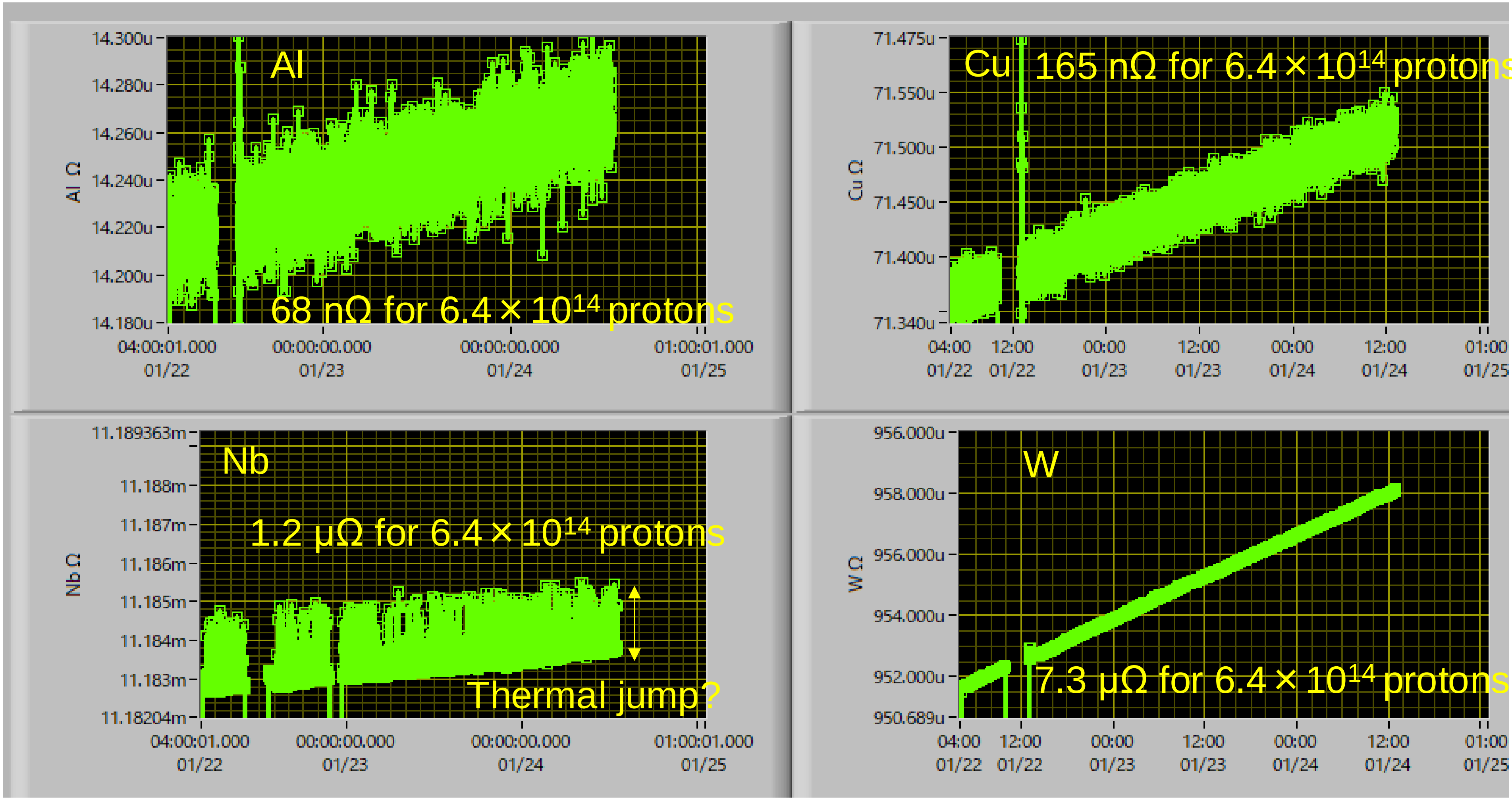


CHARMS (Charging and Radiation Monitors for Space weather) by NICT

NICT: National Institute of Information and Communications Technology

- J-PARC with JAXA and NICT conducted the experiment at 3NBT.
- Laser charge exchanger in new facility makes it possible more frequently

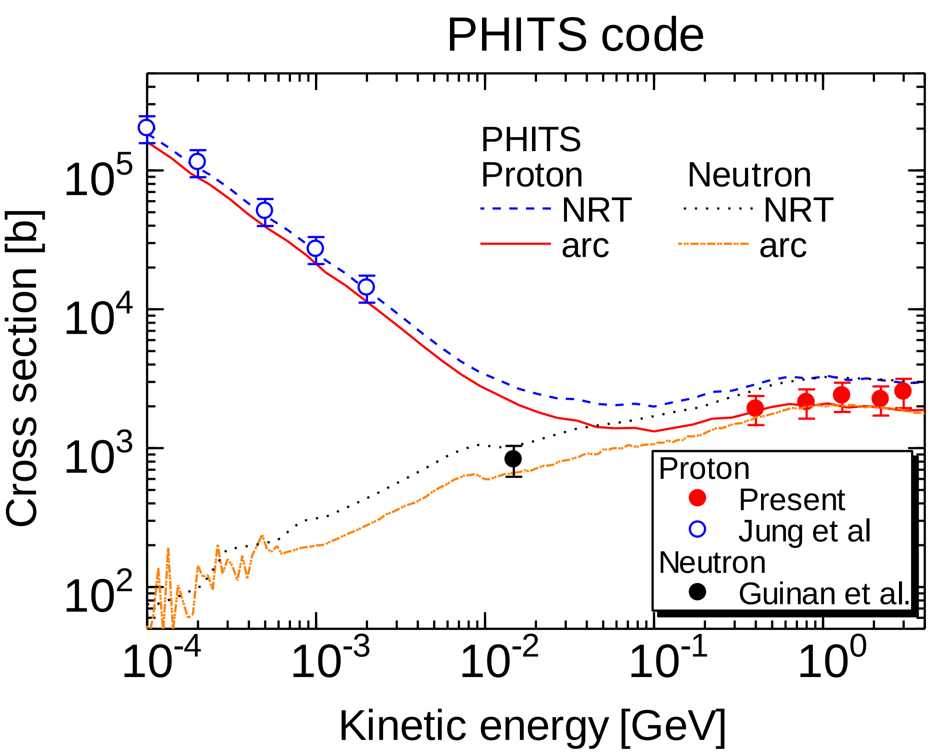
Electrical resistance change

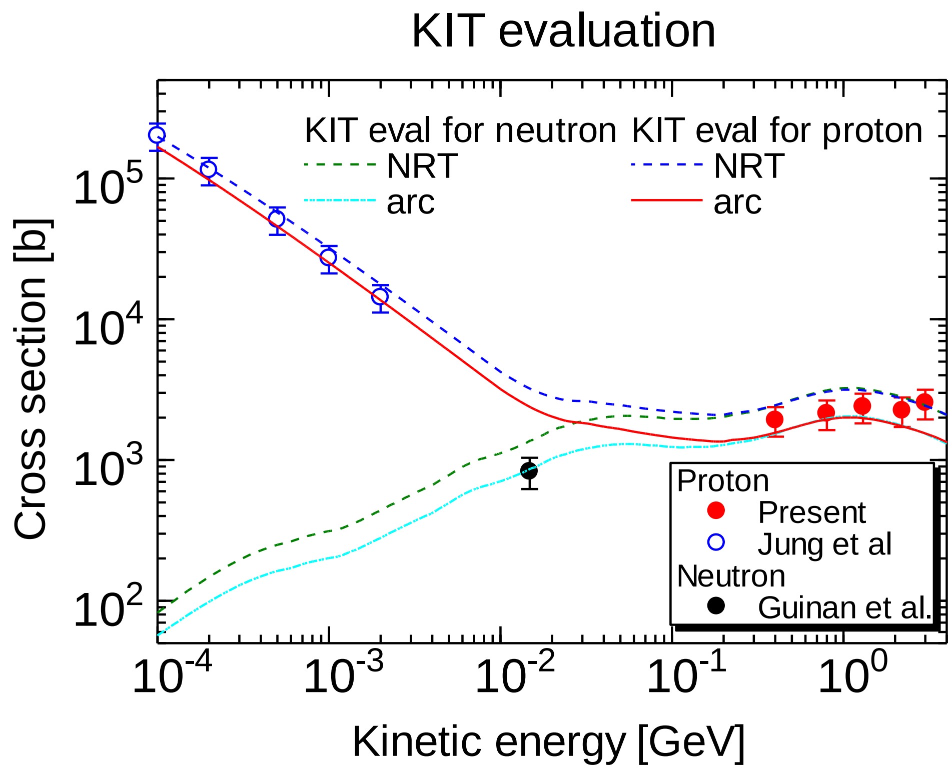


Electrical resistance changes of metals at 8 K under 120 GeV proton irradiation

Comparison of Nb X-sec for neutron incident

With similar manner, data for 14-MeV neutron was deduced from the LLNL experiment.
M.W. Guinan et al., JNM 108&109 95 (1982)

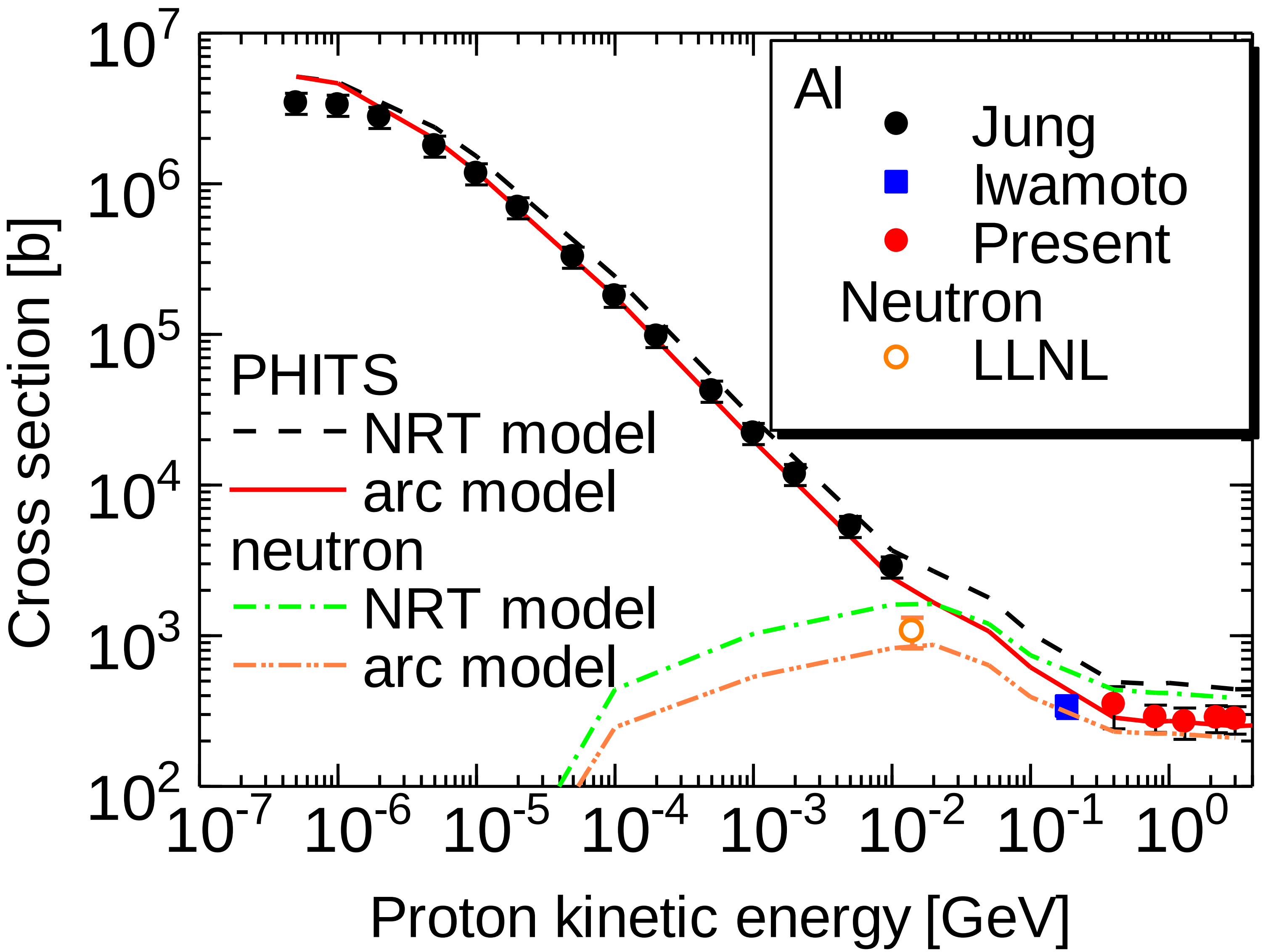




NRT and arc-dpa showing agreement with experiment within error

NRT: Overestimation 50%
arc-dpa: good agreement

Neutron results similar to proton E>100 MeV:
proton incident (nuclear force + Coulomb force)
⇒ Showing applicability for high energy region neutrons



Cross section [b]
Proton kinetic energy [GeV]
Al
Jung
Iwamoto
Present
Neutron
LLNL
PHITS
NRT model
arc model
neutron
NRT model
arc model

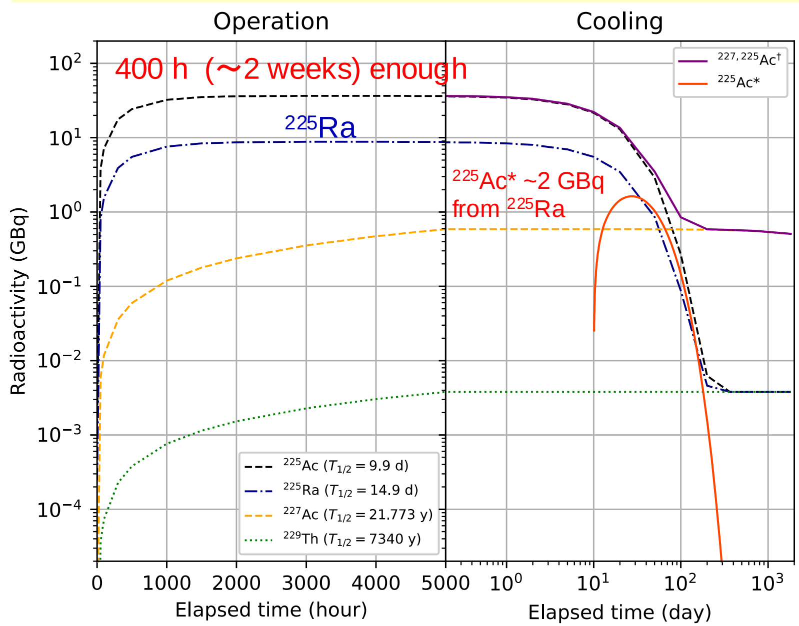
Estimation of Ac-225 production at new facility

- ^{225}Ac : TRIUMF produced already

^{232}Th (p,x)^{225}Ra cross section [mb] for Ep 438 MeV

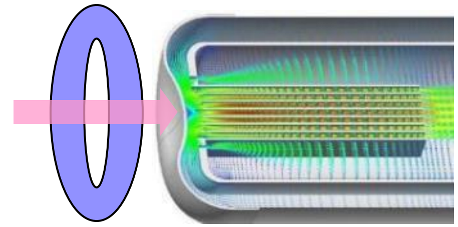
Exp.	PHITS calc.
4.2	5.1

Production estimation with ^{232}Th 1-mmt target

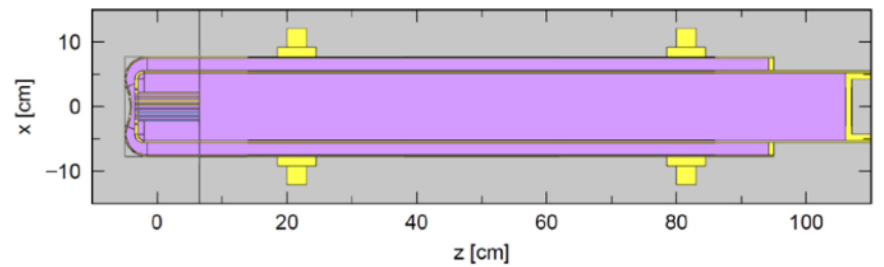


※J-PARC operation : 5000 h/year

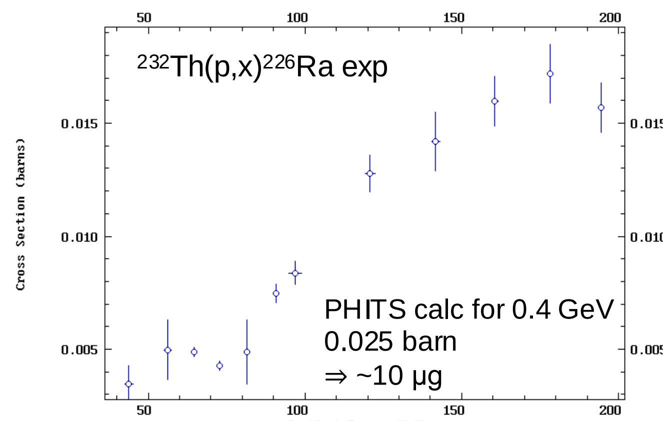
^{232}Th target (1 mmt, Φ110 - 60 mm, 78 g)
Irradiation 25 kW beam(10% of overall)



※ Law of small amount of nuclear fuel Th < 0.9 kg
※ Detail target design under consideration



Available ^{226}Ra production?



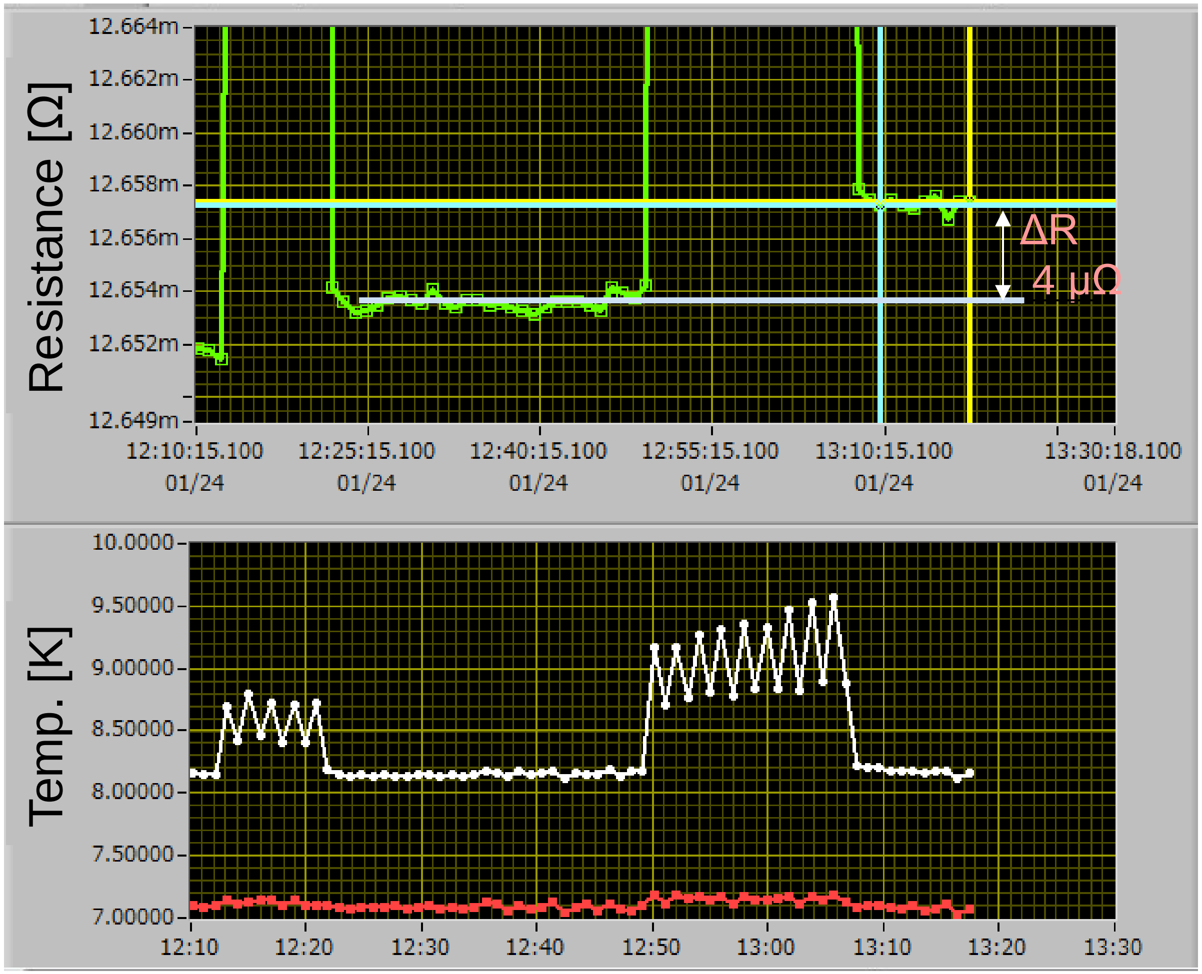
- 5 mmt Th ~10 GBq/mon. ⇒ ~100 GBq/year
- Note : Reactor (JOYO) ^{226}Ra 2 g ⇔ 24 GBq/60d

- Insufficient production of ^{226}Ra
- Availability Tb production like CERN?

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



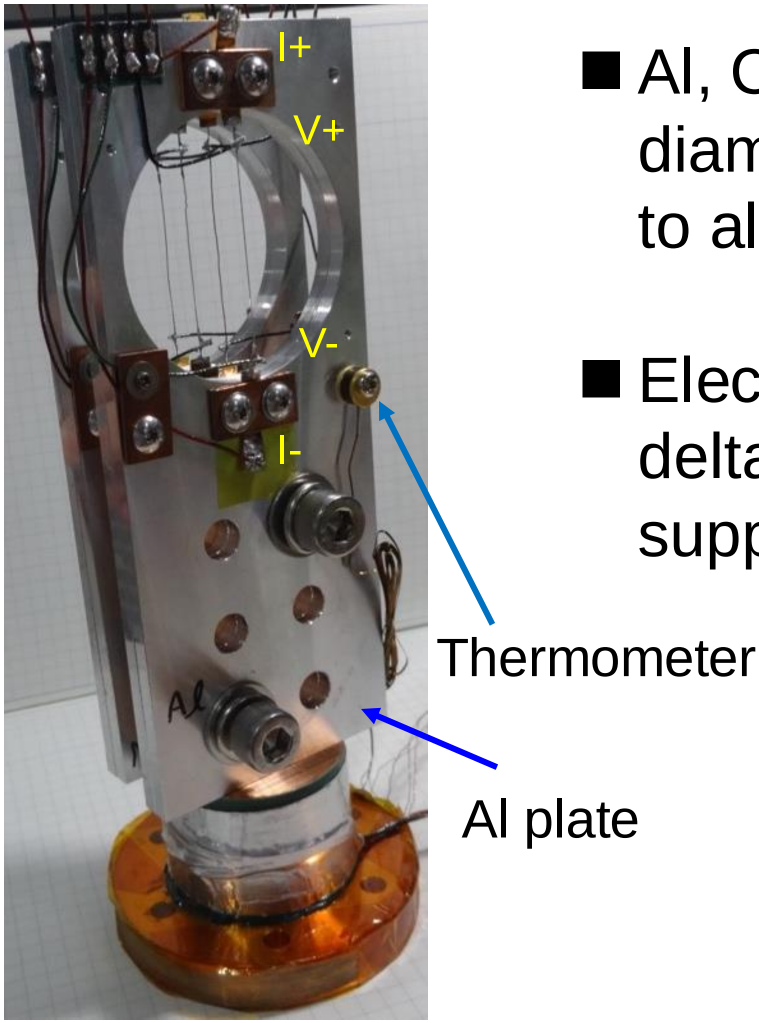
$$\sigma(E) = \Delta\rho / (\phi \cdot \rho_f)$$

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

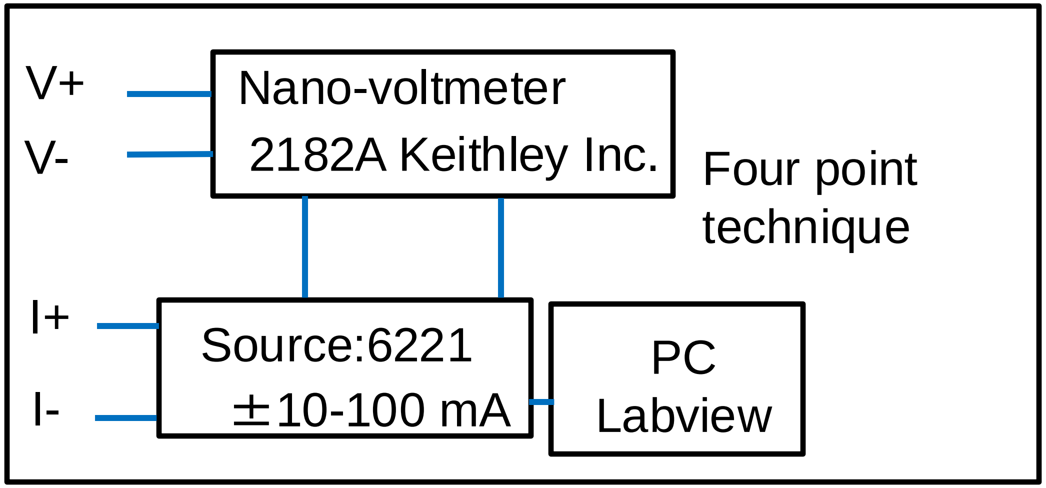
Tk [GeV]	Experimental result [b]
0.4	1920±455
0.8	2140±508
1.3	2390±568
2.2	2250±534
3.0	2550±606

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

- Al, Cu, Nb, and W wires with 0.25 mm diameter and 40 mm length were fixed to aluminum plate.
- Electrical resistance measurement using delta-mode 4-terminal method with suppressed thermoelectromotive force.



Sample assembly



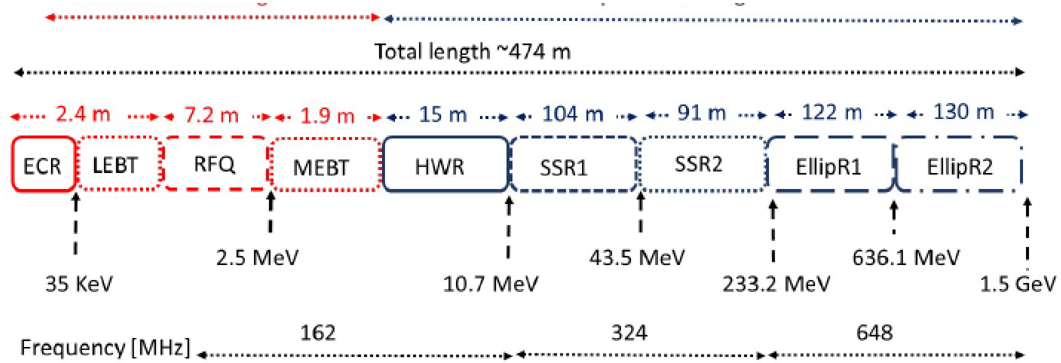
Data taking system

Role of niobium (Nb) material in accelerator

- Superconducting accelerator: Mainly used Nb

JAEA-ADS accelerator (1.5 GeV, 20 mA)

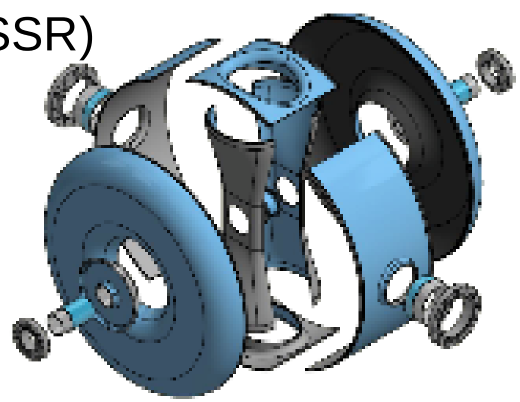
Normal conducting   Super conducting (SC)



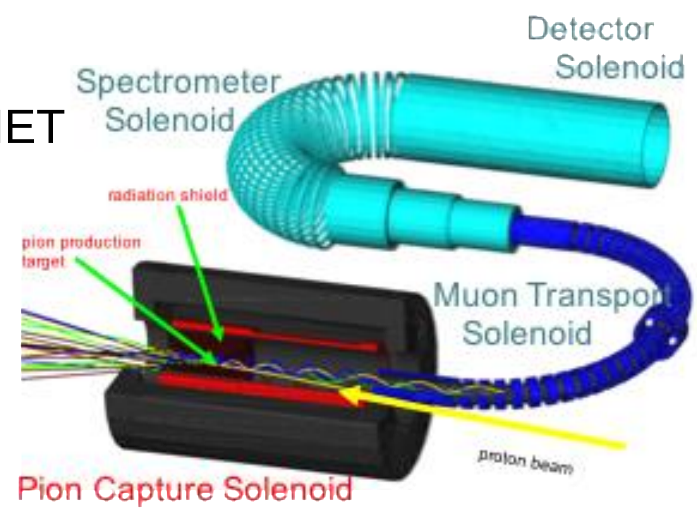
B. Yee-Rendon et al., Phys. Rev. Accel. Beams **24**, 12010 (2021)

SC magnets:
Neutrino facility at J-PARC

Prototype for ADS: Nb
(Spoke: SSR)



J-PARC COMET
SC solenoid



- Data of Nb for proton projectile are required.