Measurement of Displacement Cross Section of Window and Target Materials at J-PARC

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Contents

- Introduction
  - Experimental facility for ADS in J-PARC
  - Proton beam window at MLF
  - Activation cross section measurement at beam transport
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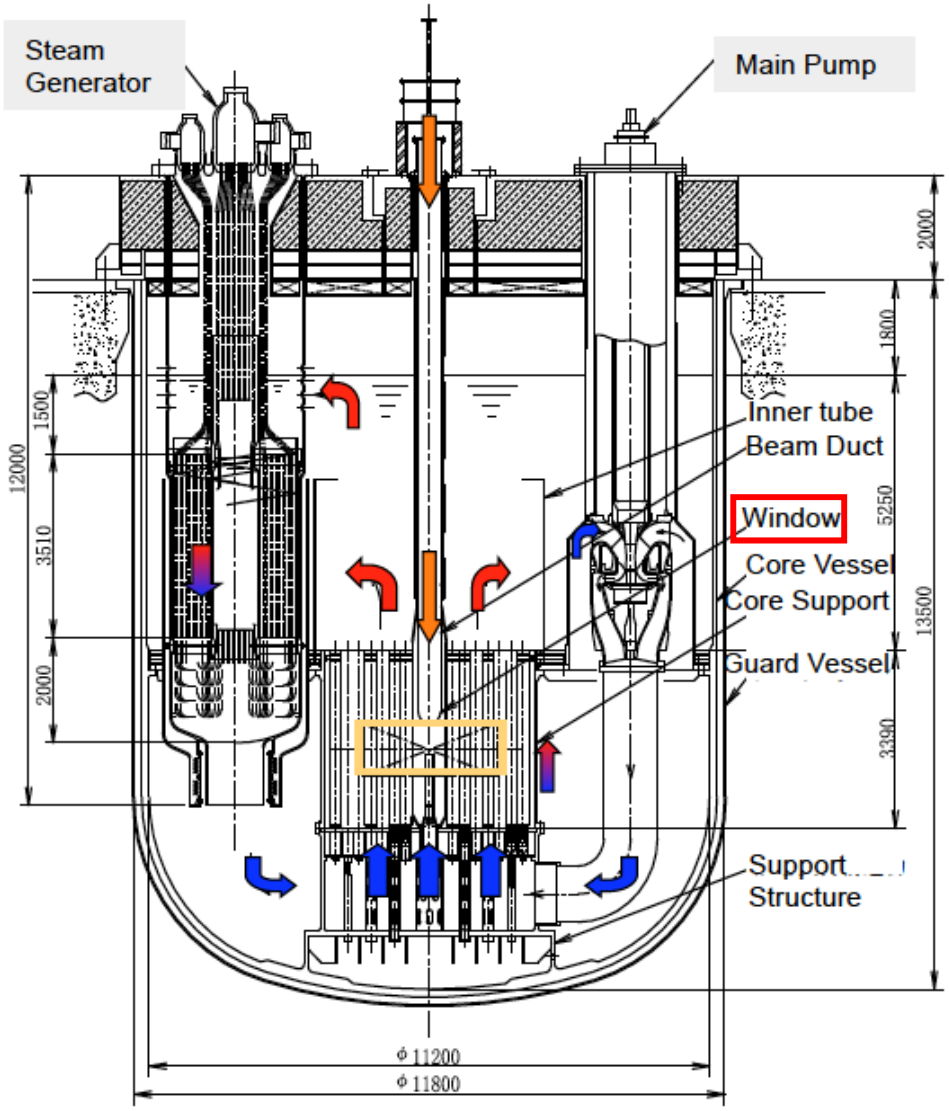
  - Protons for Ep 0.4 to 3 GeV at 3NBT
  - Protons for Ep 3 to 30 GeV at MR
- Summary

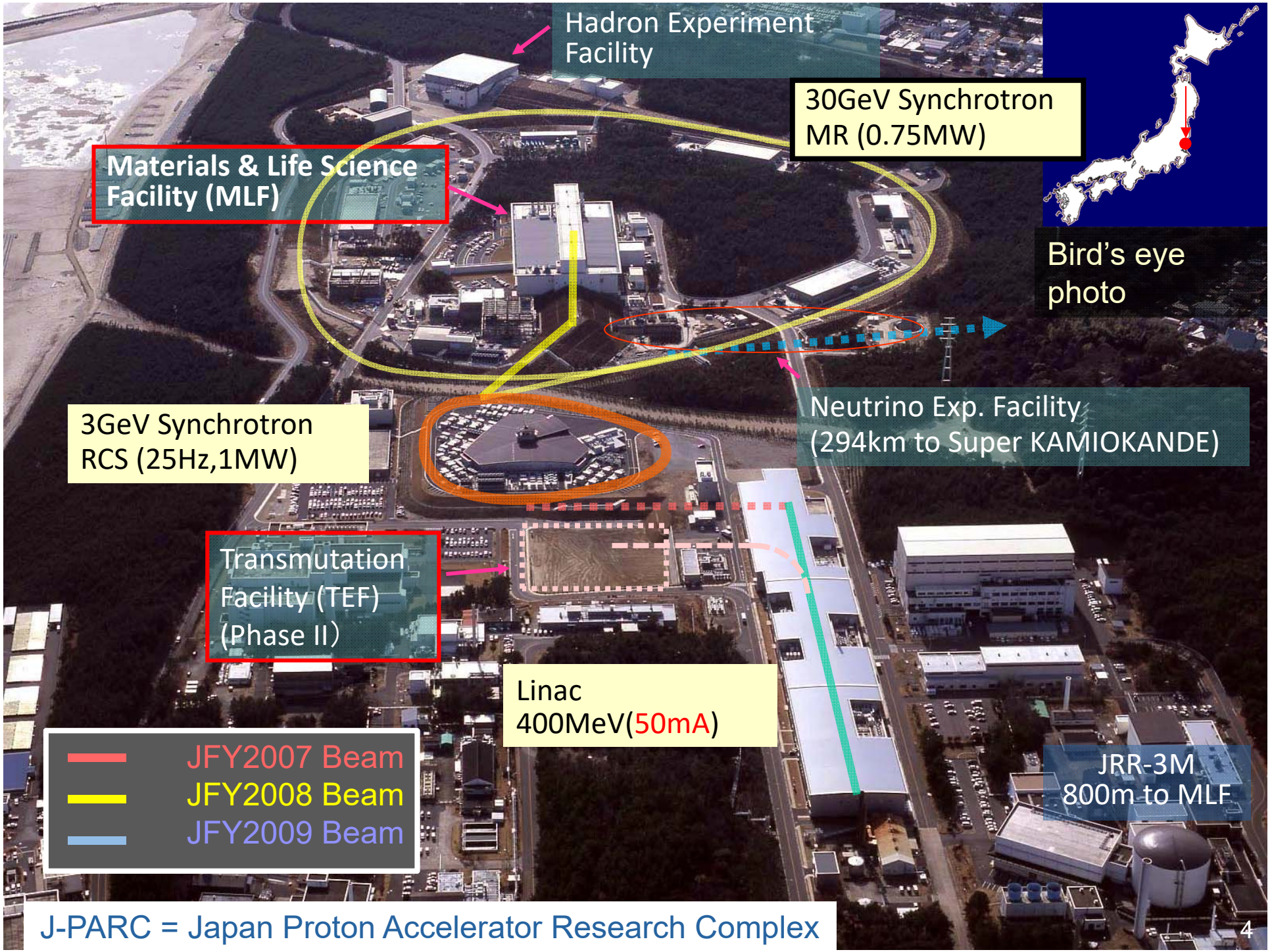
ADS Proposed by JAEA - LBE Target/Cooled Concept -

- Proton beam : 1.5GeV ~20MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : k_{eff} = 0.97
- Thermal output : 800MWt
- Core height : 1,000mm
- MA initial inventory : 2.5t
- Fuel composition :

  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate :

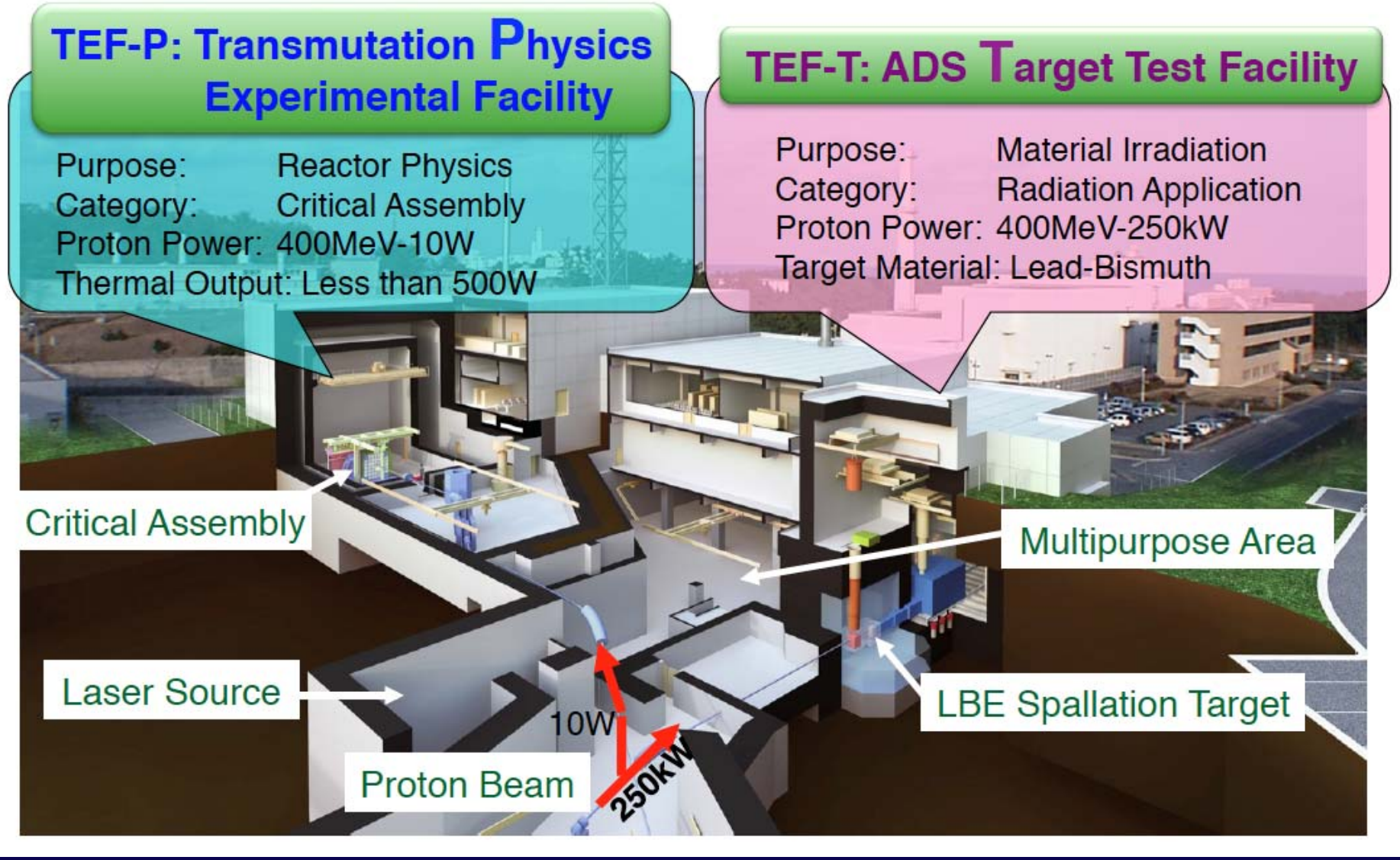
  10%MA / Year (**10 units of LWR**)
- Burn-up reactivity swing : 1.8%Δk/k





J-PARC = Japan Proton Accelerator Research Complex

Transmutation Experimental Facility (TEF) in J-PARC

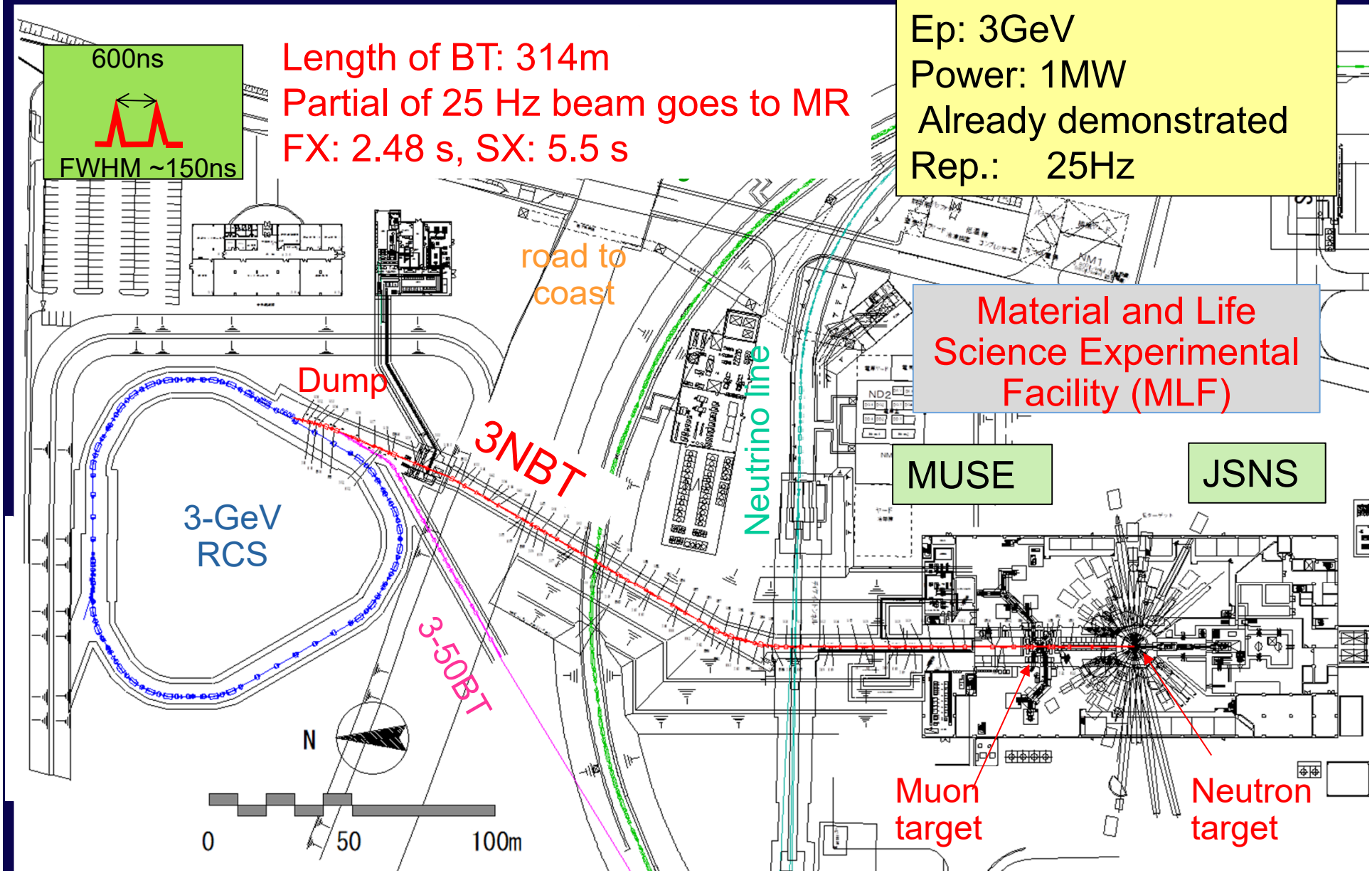


For R&D of ADS, 0.4 GeV beam by LINAC will be delivered to TEF.

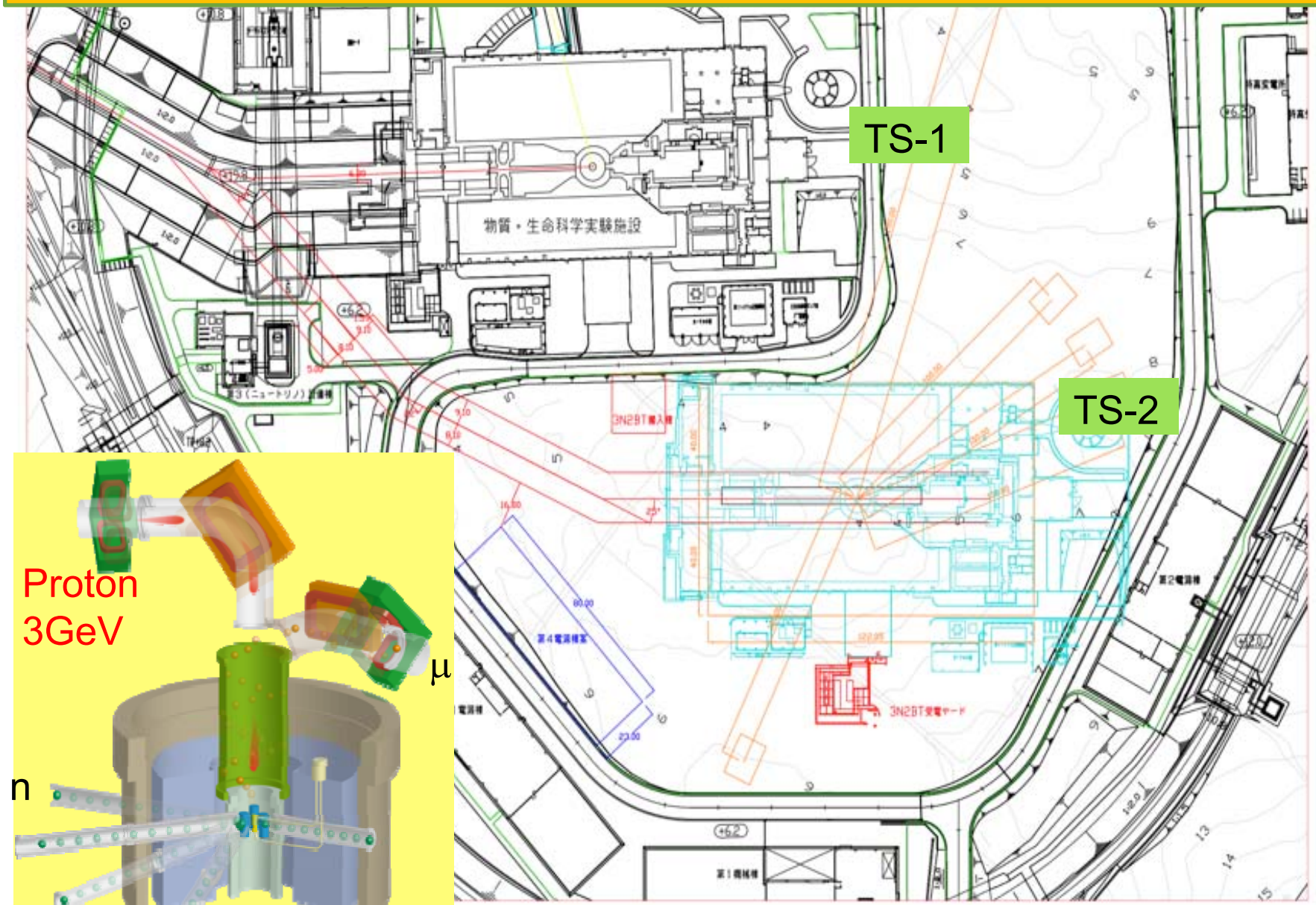
Beam transport from RCS to MLF

600ns

J-PARC

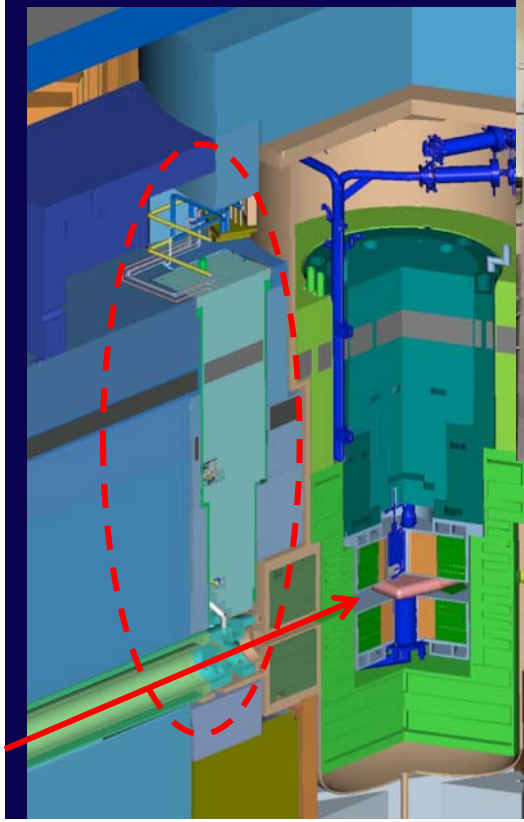


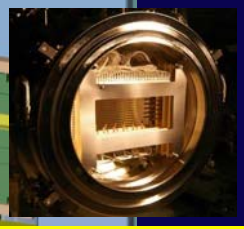
1st target ST (TS-1): 24 Hz: 1MW
2nd target ST (TS-2) 1Hz : 42kW (Designed to accept 1 MW)



Lifetime of Proton Beam Window

- Lifetime estimation based on Post Irradiation Examination (PIE) for safety shroud (AlMg3) at SINQ in PSI
- Considering difference of proton energy, to predict lifetime of the PBW with high accuracy for validation of calculation

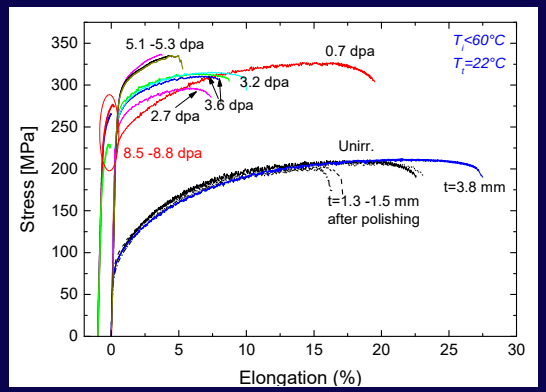


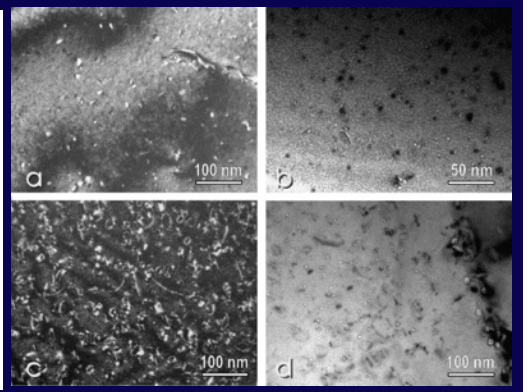


Height: 3.8m
Weight : 10t

Result at SINQ/PSI for 0.6GeV

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





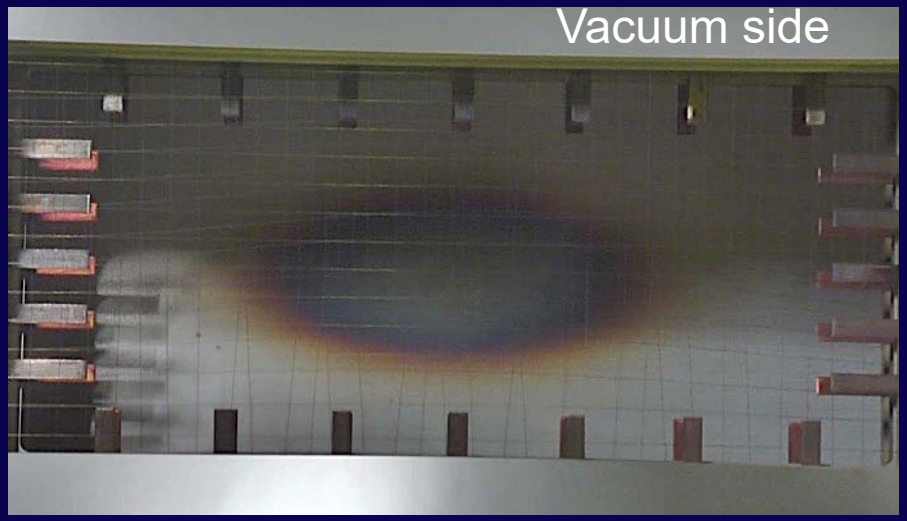
Lifetime of PBW: Determined by He gas production (2000 appm) 2 years

S. Meigo, et al, J. Nucl Mat. 450 141 (2012)

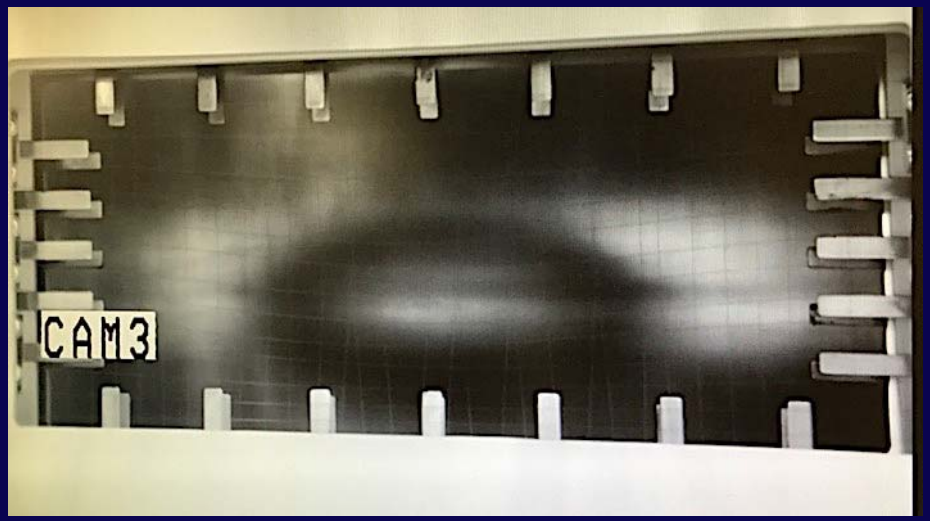
By recent PIE result of the SINQ (3300 apmm), the lifetime may be applicable to 3 years.

Inspection replaced PBW

PBW#1 (obs. 2013 Oct) 1916 MWh (1.4×10^{22} POT)

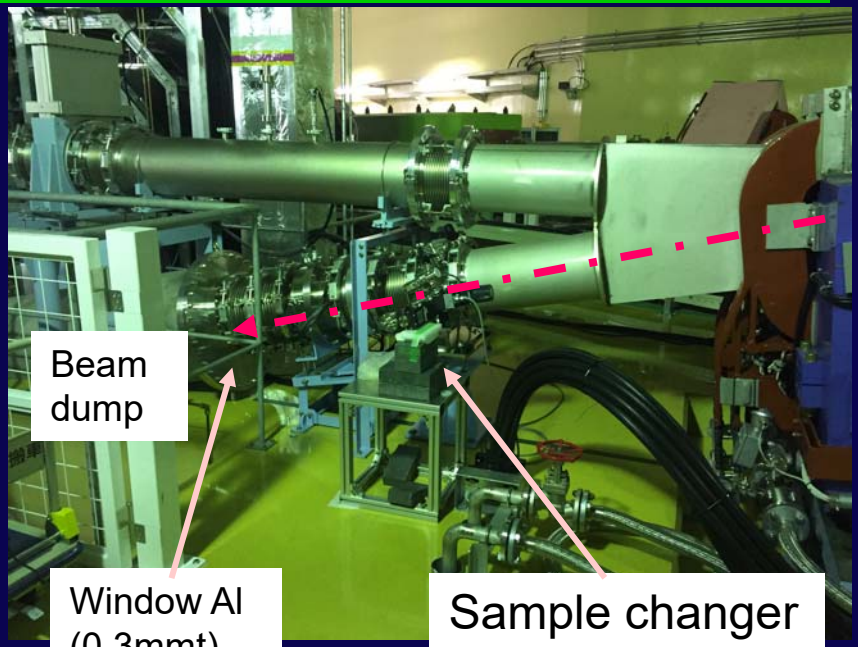


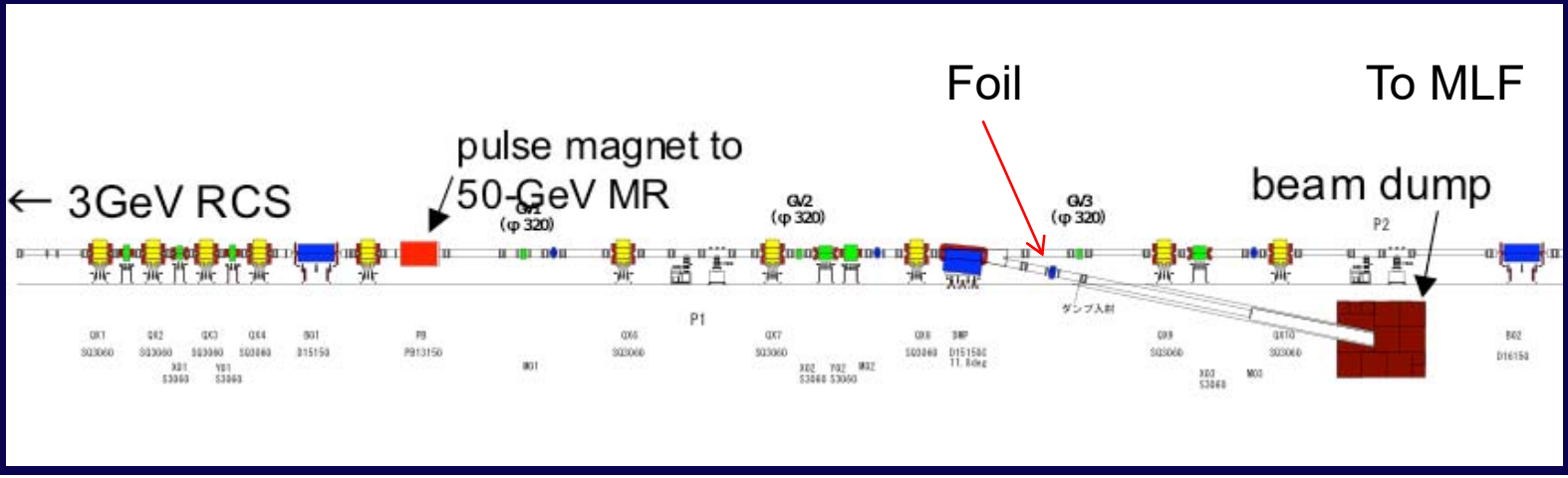
PBW#2 (obs. 2017 Aug) 2510 MWh (1.9×10^{22} POT)



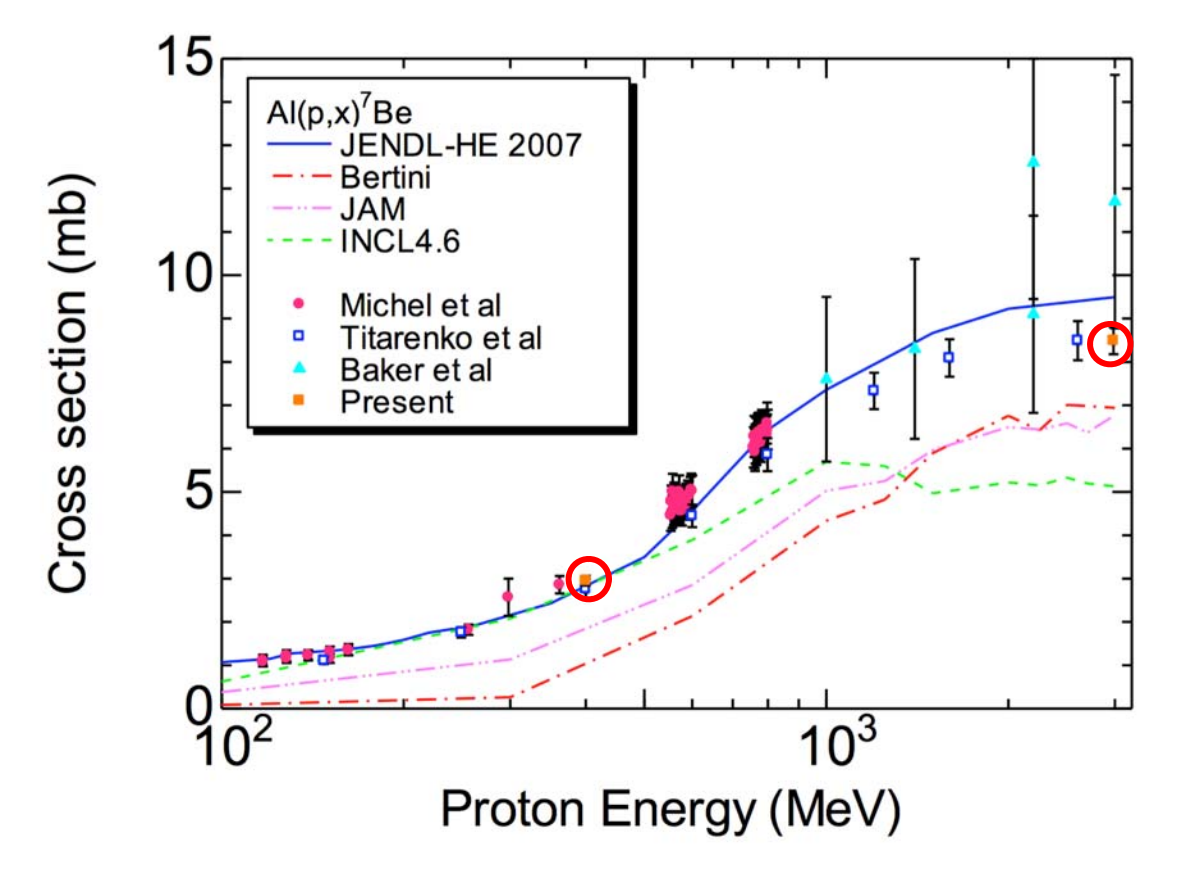
Measurement of activation of aluminum

- Foil (45x25mm, 0.5mmt) placed at beam dump line with linear guide for control beam irradiation
- Projectile : 3-GeV and 400 MeV proton
  - RCS injection energy: 400 MeV
  - RCS extraction energy with acceleration : 3 GeV
  - Changing extraction timing, the energy can be varied 0.4～3 GeV.



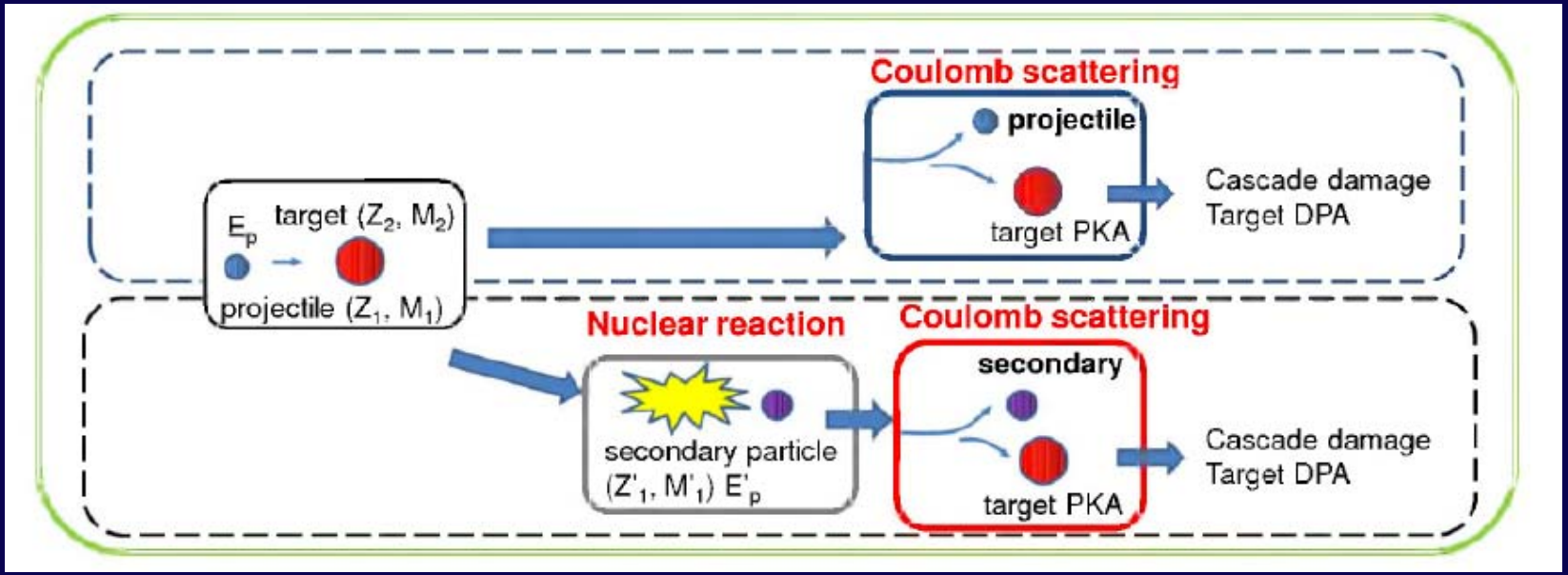


Obtained activation cross section



- Due to well calibrate monitor and beam control, good accuracy of incident protons number
- Frequently 0.4 and 3 GeV protons used for accelerator tuning
- DPA cross section of 3 GeV will be measured at first.

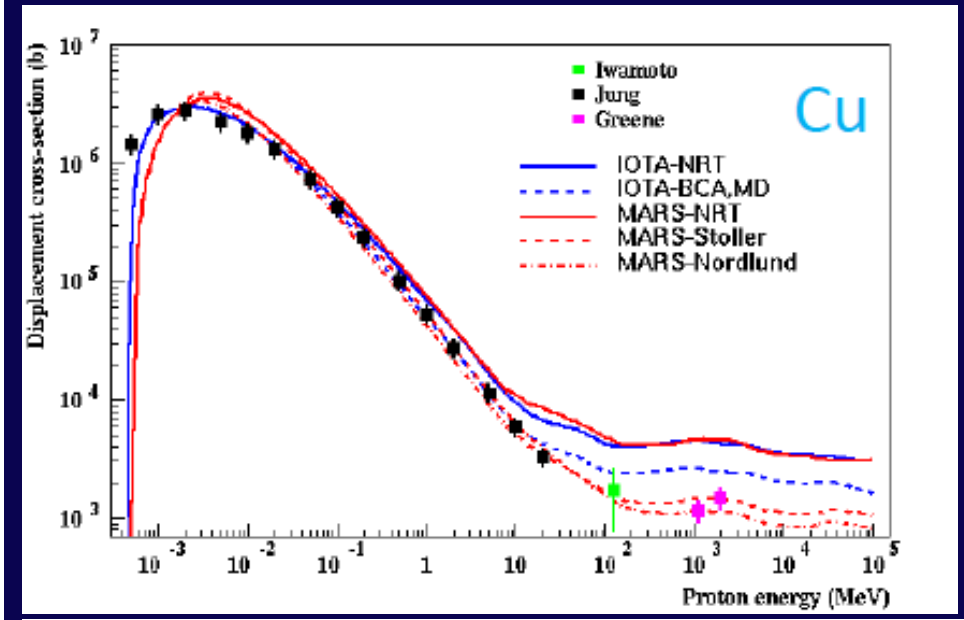
PKA and DPA

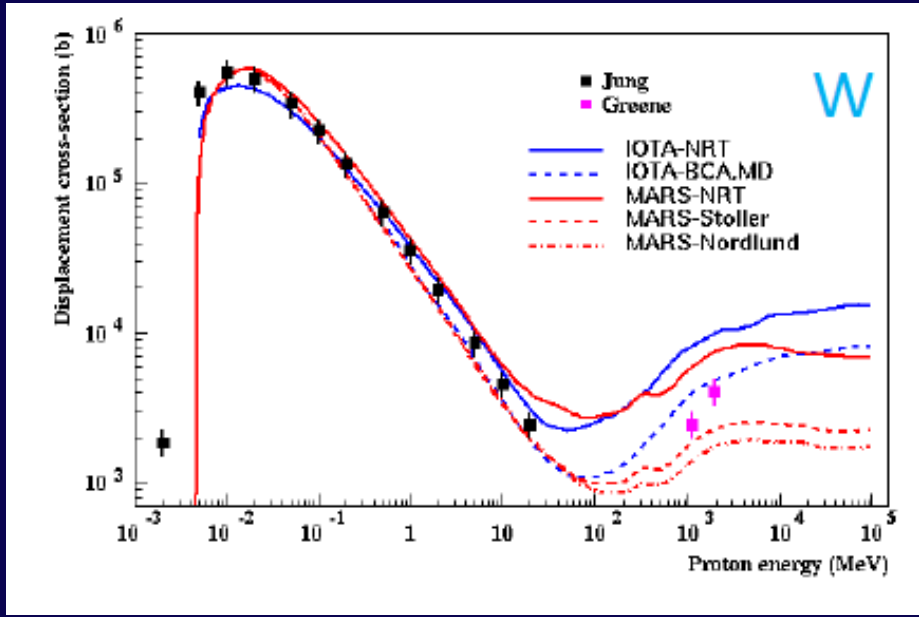


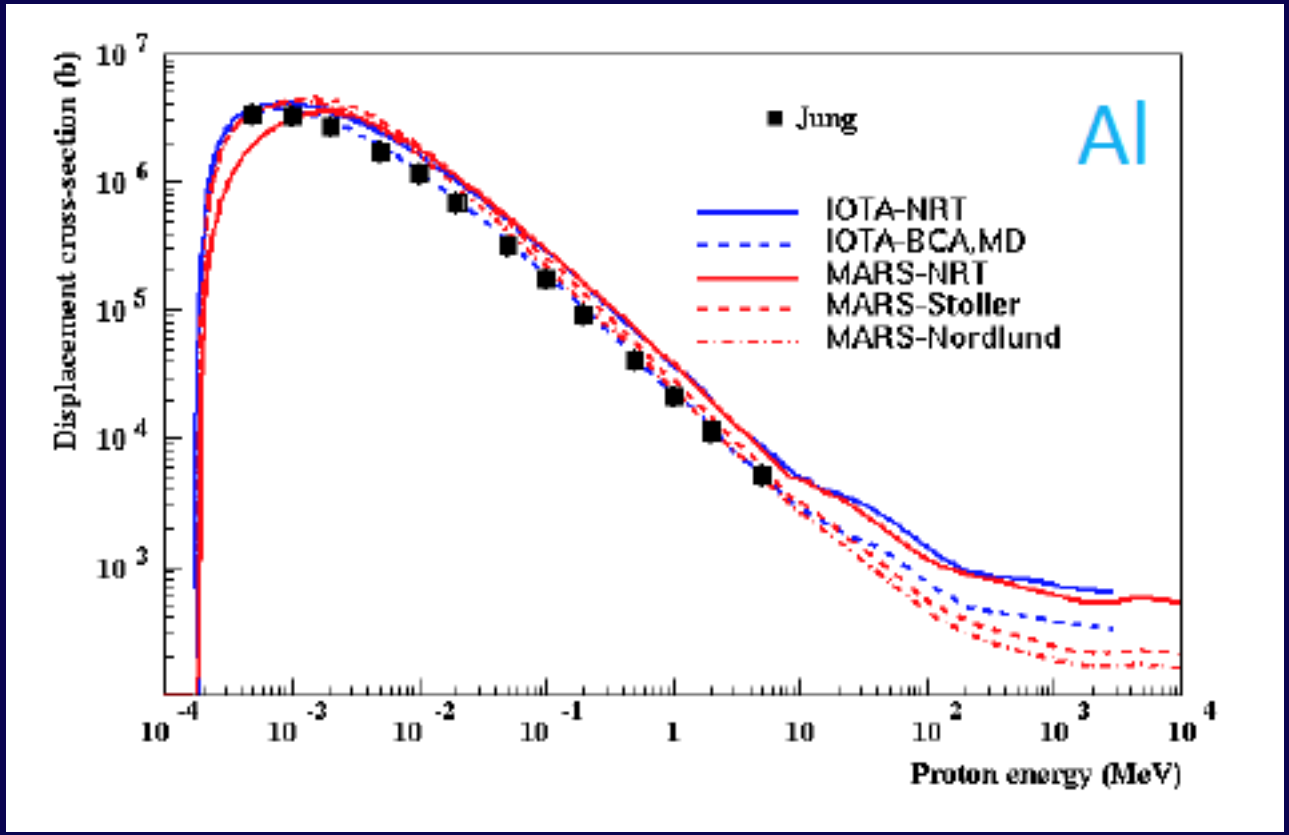
- DPA (Displacement per Atom) is estimated by calculation based on PKA.
- Please see last night presentation

DPA cross sections

- Although DPA is widely utilized for estimation of target material damage, DPA cross section has not been enough validated.
  - DPA = flux x DPA cross section
  - DPA cross section has been measured only Cu and W for a few energies of protons (5 experimental data above 20 MeV!)
  - DPA cross section with calculation showing large discrepancies among models.
- For validation and improve of calculation model, DPA cross section will be measured in J-PARC. Fund is approved by the MEXT.






Displacement cross-section (b)
Proton energy (MeV)
Jung
Al
IOTA-NRT
IOTA-BCA,MD
MARS-NRT
MARS-Stoller
MARS-Nordlund

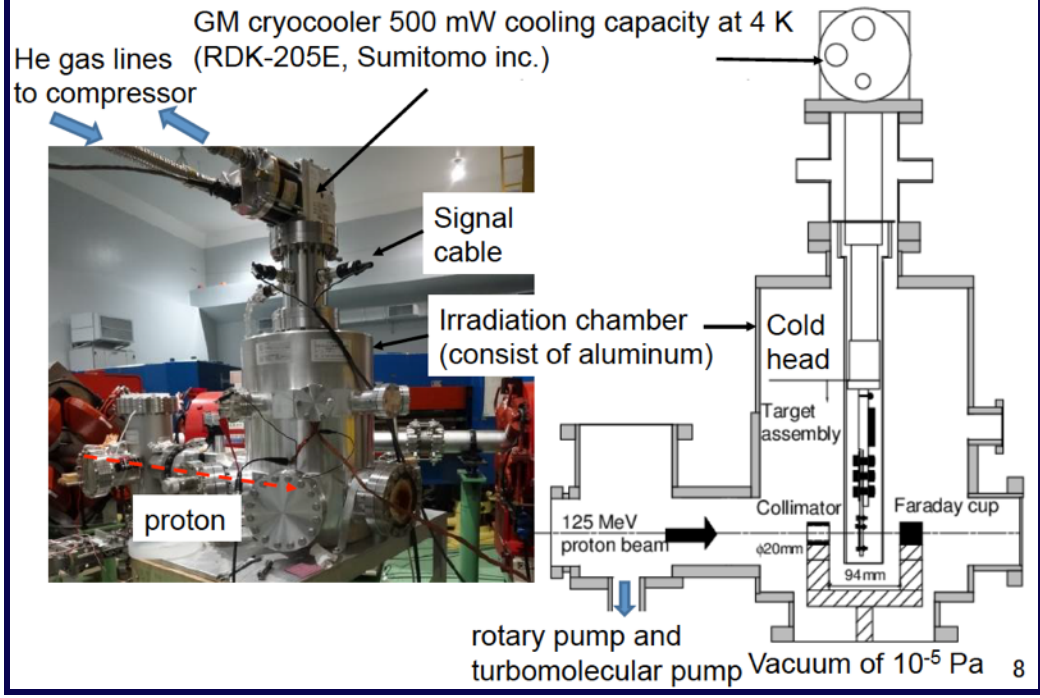
Measurement of DPA cross section

- Irradiation on metal at cryogenic temperature with GM cryocooler
- By observing increase of electrical resistance, the cross section can be observed.

Measurement for Cu already performed at Kyoto Univ. for 125 MeV proton

Experiment at J-PARC
- Samples and GM placed at exit of 3-GeV synchrotron for various energy of proton 0.4 to 3 GeV
- Other experiment performed at other sites for energy < 400 MeV

Irradiation chamber with GM cryocooler



Damage rate

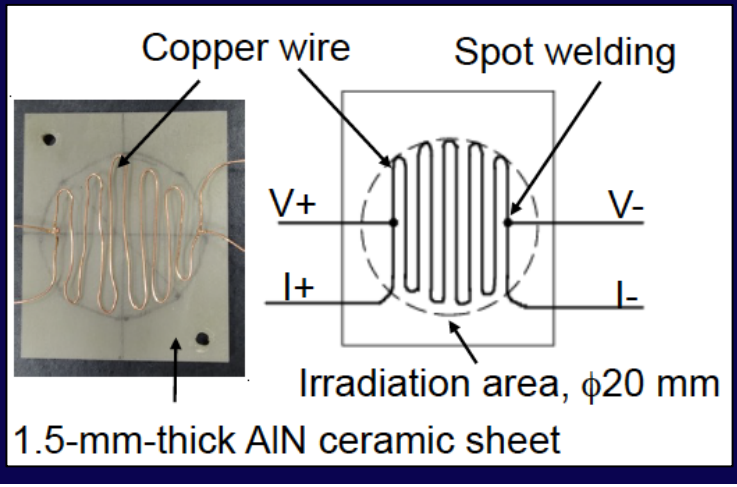
$$\sigma_{exp} = \frac{1}{\rho_{FP}} \frac{\Delta\rho_{metal}}{\phi}$$

$\Delta\rho_{metal}$: Electrical resistivity change(Ωm)

Φ: Beam fluence(1/m^2)

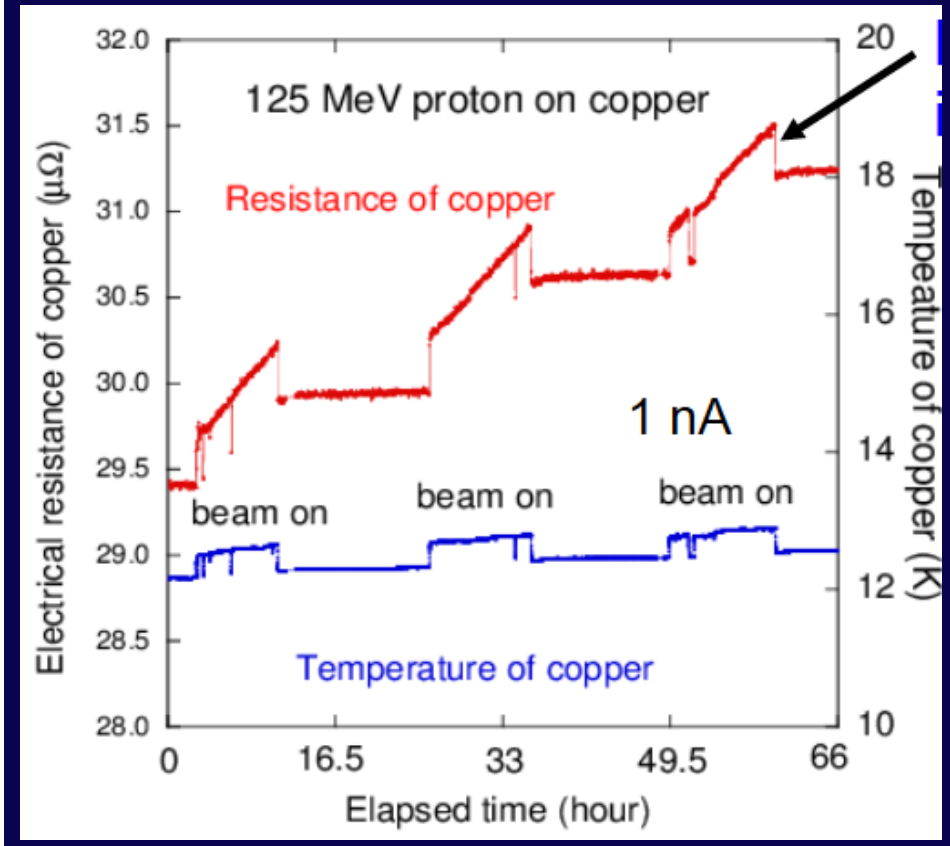
ρ_{FP}: Frenkel-pair resistivity (Ωm)

J. Nucl. Mater. 49 (1973/74) 161.

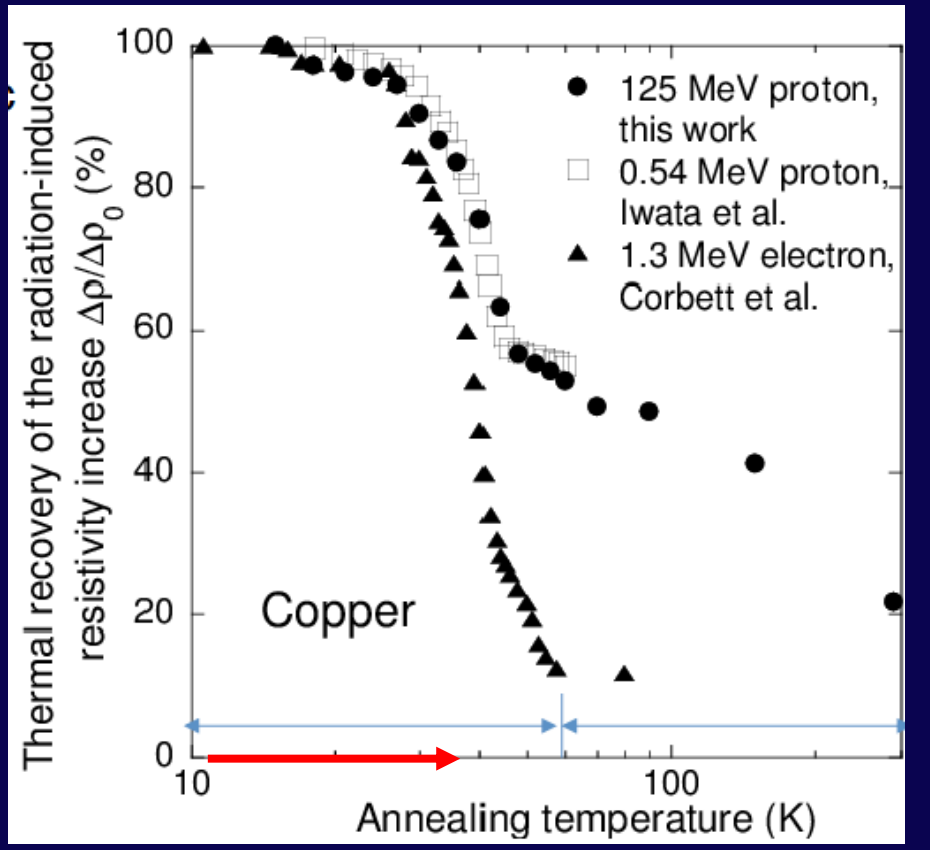


Experimental condition

How much of protons is necessary?



How much of temp rising is allowed?



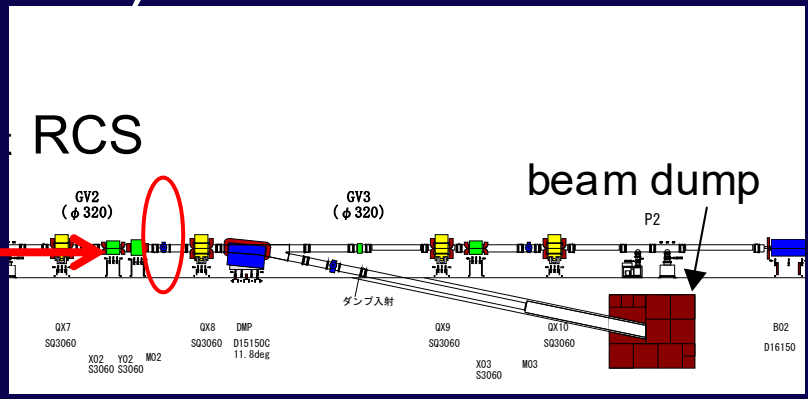
1 nA x 12h = 3×10^{14} protons
Several shots of beam at MLF

Y. Iwamoto et al.

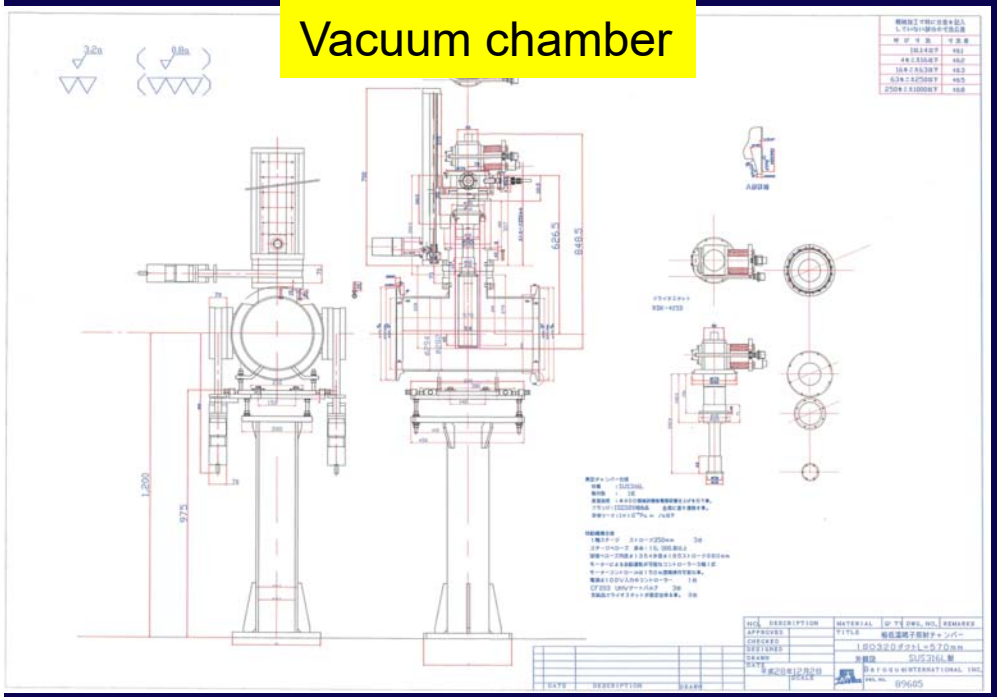
Temp rising ~20 K will be acceptable.
If time permits, lowest beam is preferable.
However, it makes worse accuracy of beam charge. (Vary 1×10^{10} – 2×10^{13} protons/shot)

Plan for Ep 0.4~3 GeV

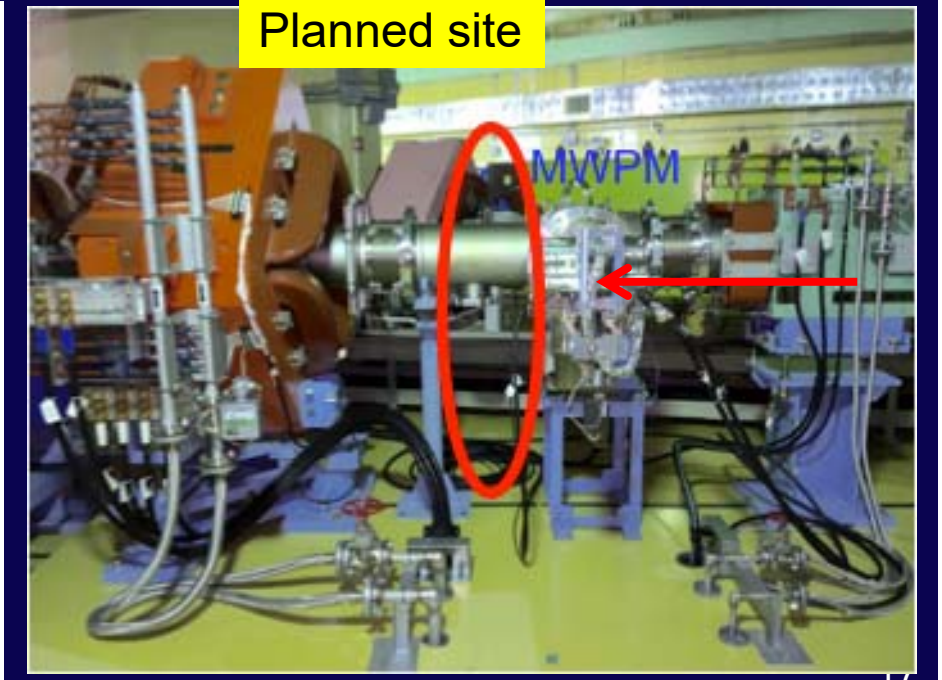
- Experiment at 3NBT (0.4～3 GeV) in JFY2017
  - Fabrication chamber(～Sep)
  - Installation (Sept.）
  - Exp.：Cooling ～Nov.
    Beam test (Dec.)



Vacuum chamber

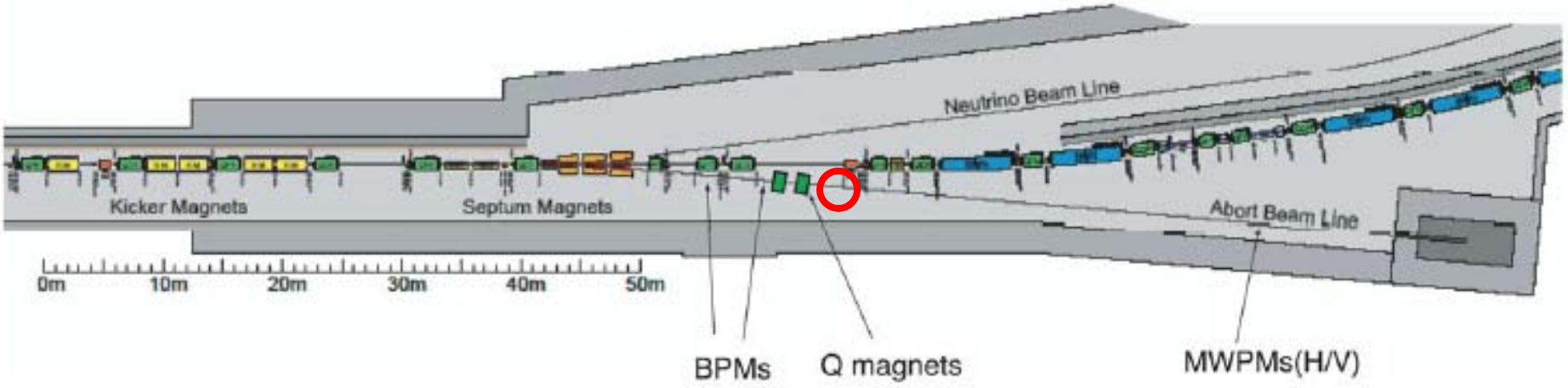


Planned site



Plan for 3～30 GeV

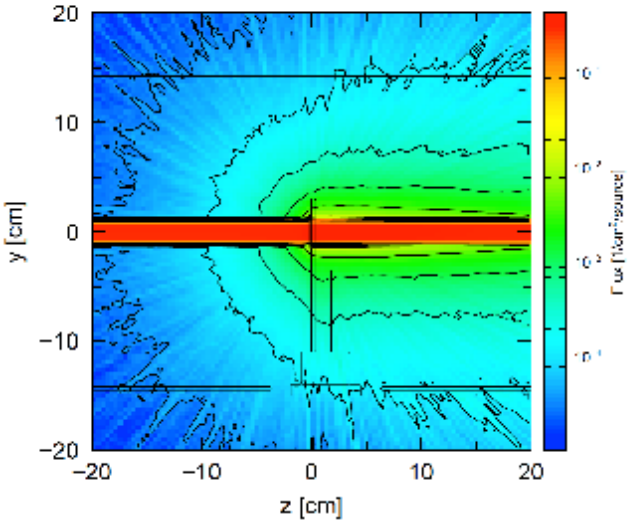
- Using MR beam
  - Difficult to carry out experiment at hadron hall due to expand plan of building.
  - Decided to perform experiment at MR abort dump
  - Approval by PAC will be required, which will be held June 2017.



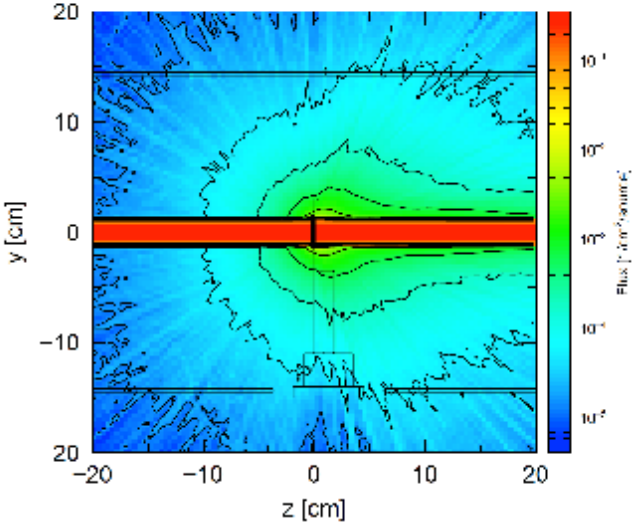
Estimation radio activity

Particles flux during irradiation

30 GeV



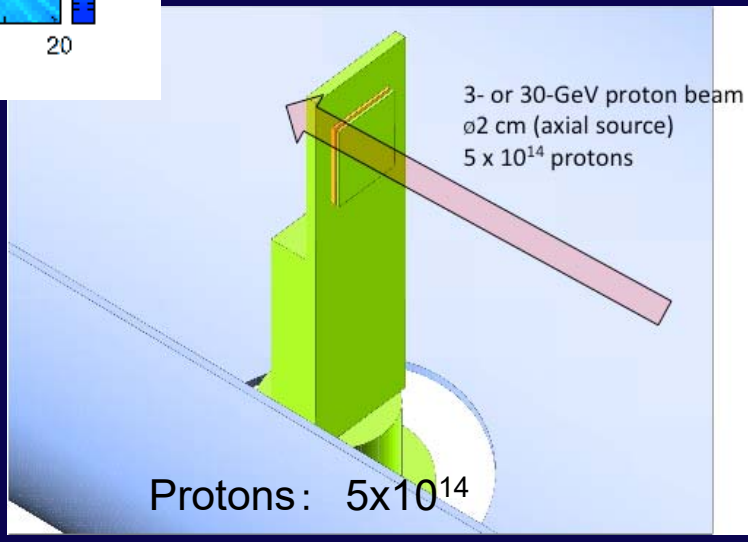
3 GeV



Incident energy	4h (μSv/h)	7days (μSv/h)
3 GeV	19	0.01
30 GeV	29	0.02

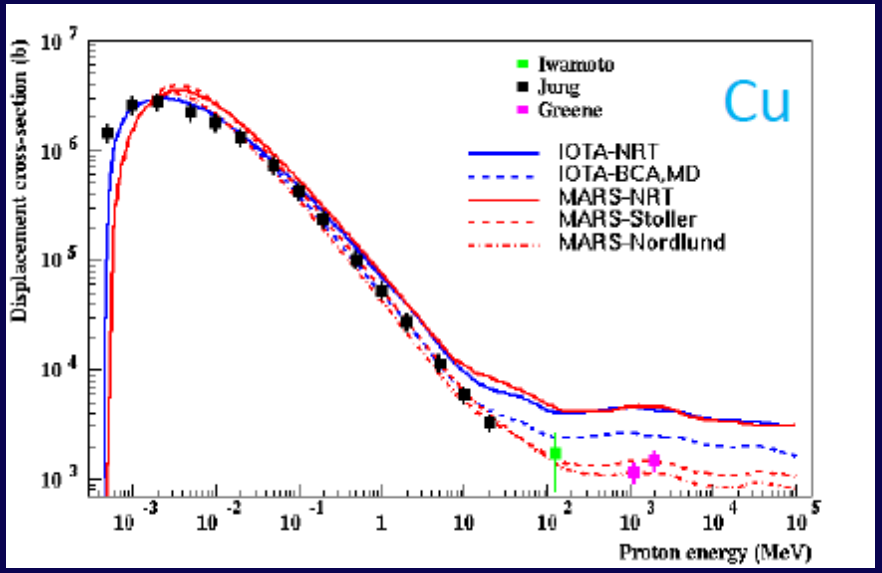
※ Distance from samples 0.3m

Calc. model



- Residual dose: Confirmed enough small for handling

Detail design to obtain good accuracy



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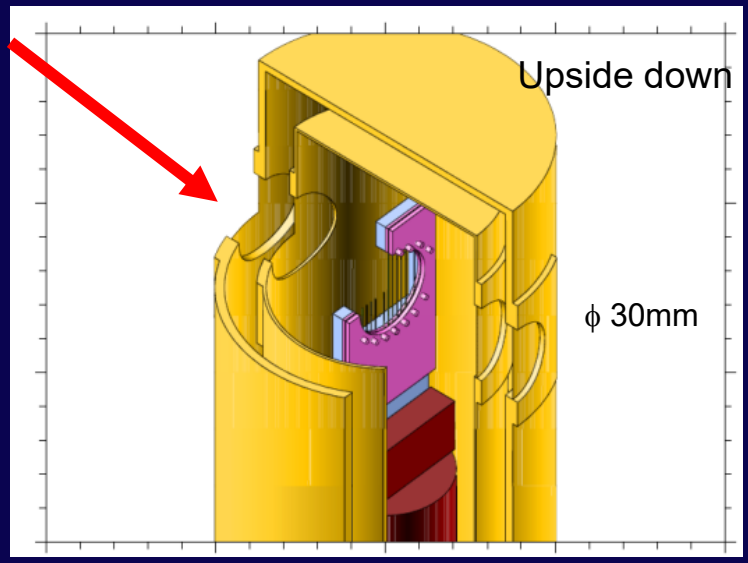
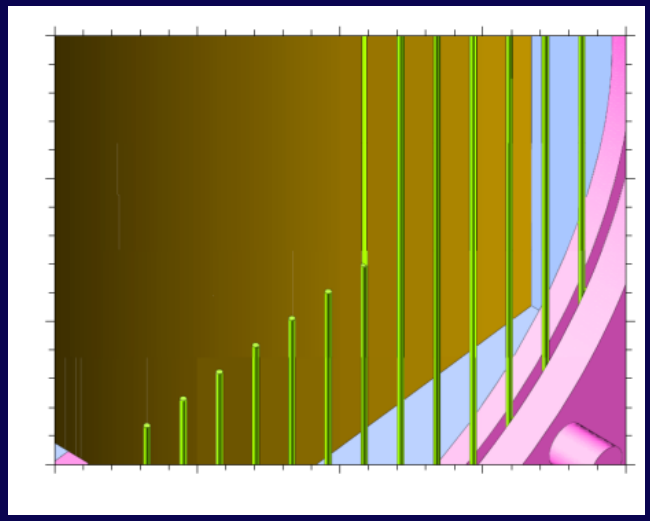
Φ: Beam fluence(1/m^2)

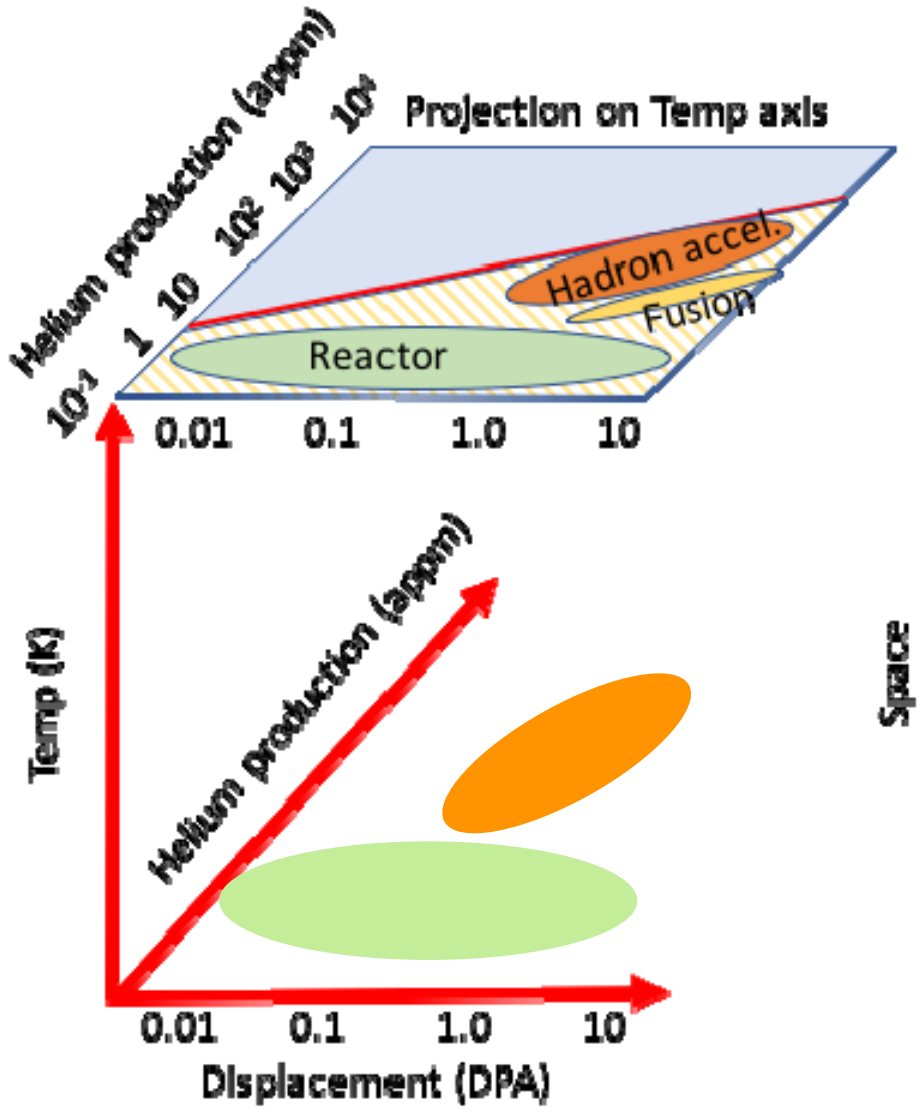
ρ_{FP}: Frenkel-pair resistivity (Ωm)

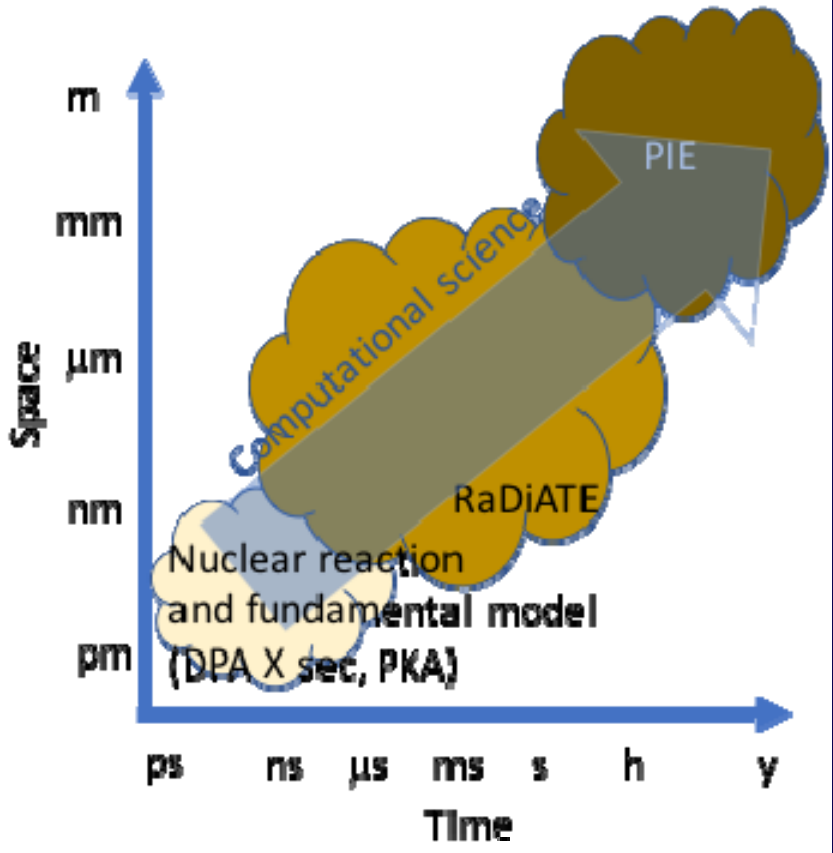


Close up of wire sample



- Beam width and intensity can be observed precisely. With the help of calculation, simple fluence can be determined.
- Frenkel-pair resistivity can be obtained by using thin window configuration with additional experiment with low energy proton (Ep<10 MeV).


Helium production (appm)
10⁻¹
1
10
10²
10³
10⁴
Projection on Temp axis
Hadron accel.
Fusion
Reactor
0.01
0.1
1.0
10
Temp (K)
Helium production (appm)
0.01
0.1
1.0
10
Displacement (DPA)


Space
m
mm
μm
nm
pm
PIE
Computational science
RaDiATE
Nuclear reaction
and fundamental model
(DPA X sec, PKA)
ps
ns
μs
ms
s
h
y
Time

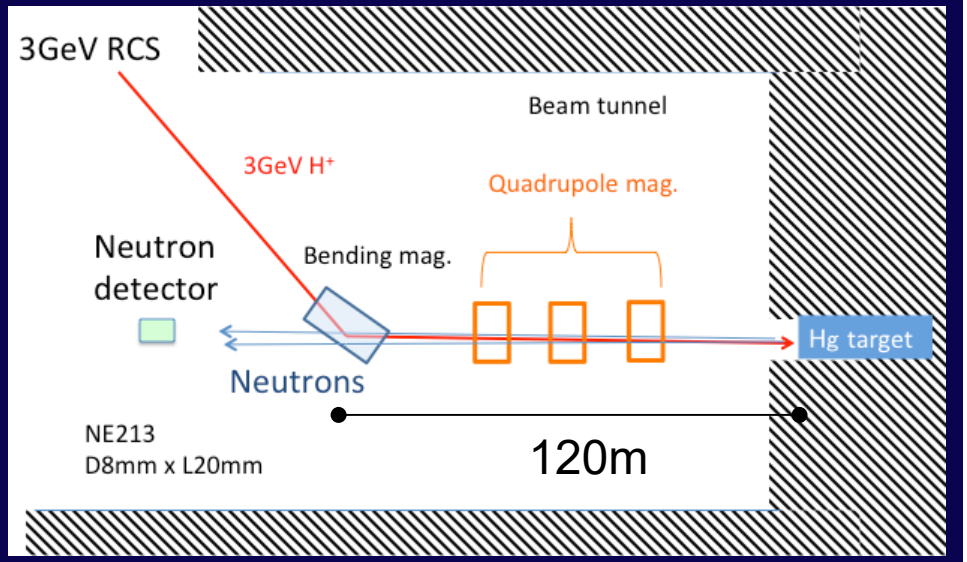
Schedule

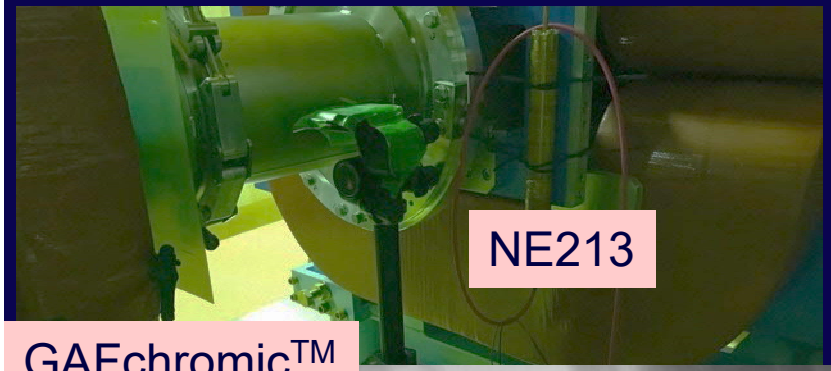
	JPY16	JPY17	JPY18	JPY19
Exp. DPA x-sect of 0.4～3 GeV(JAEA)	Procurement	Experiment		
Exp. DPA x-sec of 4 ～30 GeV (KEK)	Procurement	Preparations	Experiment	
Revise calculation (JAEA)				Analysis

Target: Cu, Al, Fe, Nb, W

Future plan for DPA by spallation neutron

- Neutron spectrum at backward angle of mercury will be also available for DPA x-sec measurement.
  - $1x10^{11}$ n/m^2/s at 1MW
  - Long duration ~1year available





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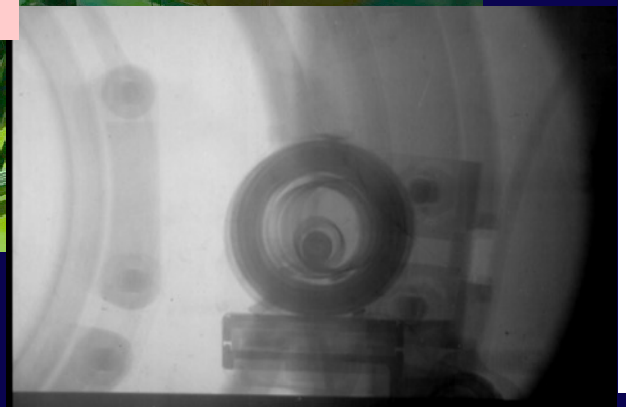

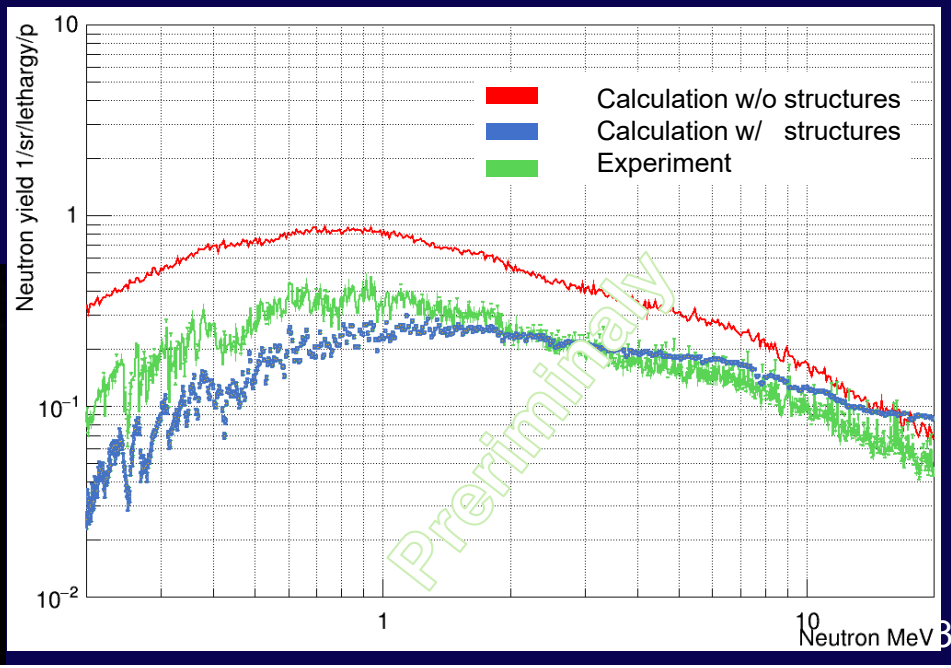

Summary

- To obtain DPA cross section, measurement for 0.4～30 GeV protons will start in J-PARC.
  - Procurement finished for GM cryocooler, instruments for resistance, and vacuum chamber
  - Experiment for 0.4～3 GeV protons will start in this JPY after changing license granted by Nuclear Regulatory Agency (NRA).

Collaborators of experiment

- JAEA (Shin-ichiro Meigo)
  - Yosuke Iwamoto
  - Fujio Maekawa
  - Hiroki Iwamoto
  - Hiroki Matsuda
  - Shioichi Hasegawa
- KEK (Makoto Yoshida)
  - Tatsuya Nakamoto
  - Taku Ishida
  - Shunsuke Makimura
  - Tsutomu Mibe

Attending this workshop

Thank you