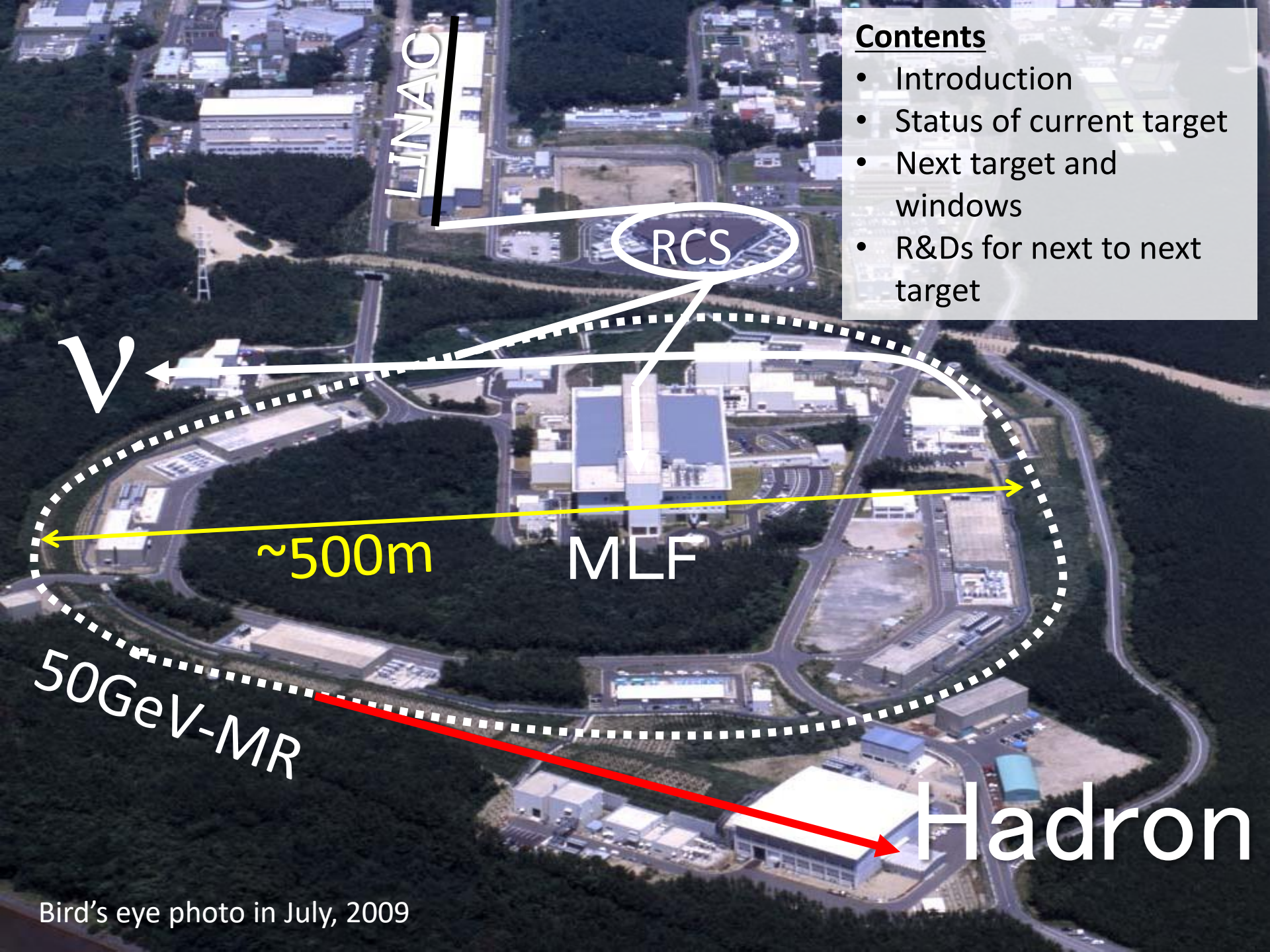
Target and Window Upgrades at J-PARC Hadron Experimental Facility

Hitoshi Takahashi

KEK / J-PARC Center

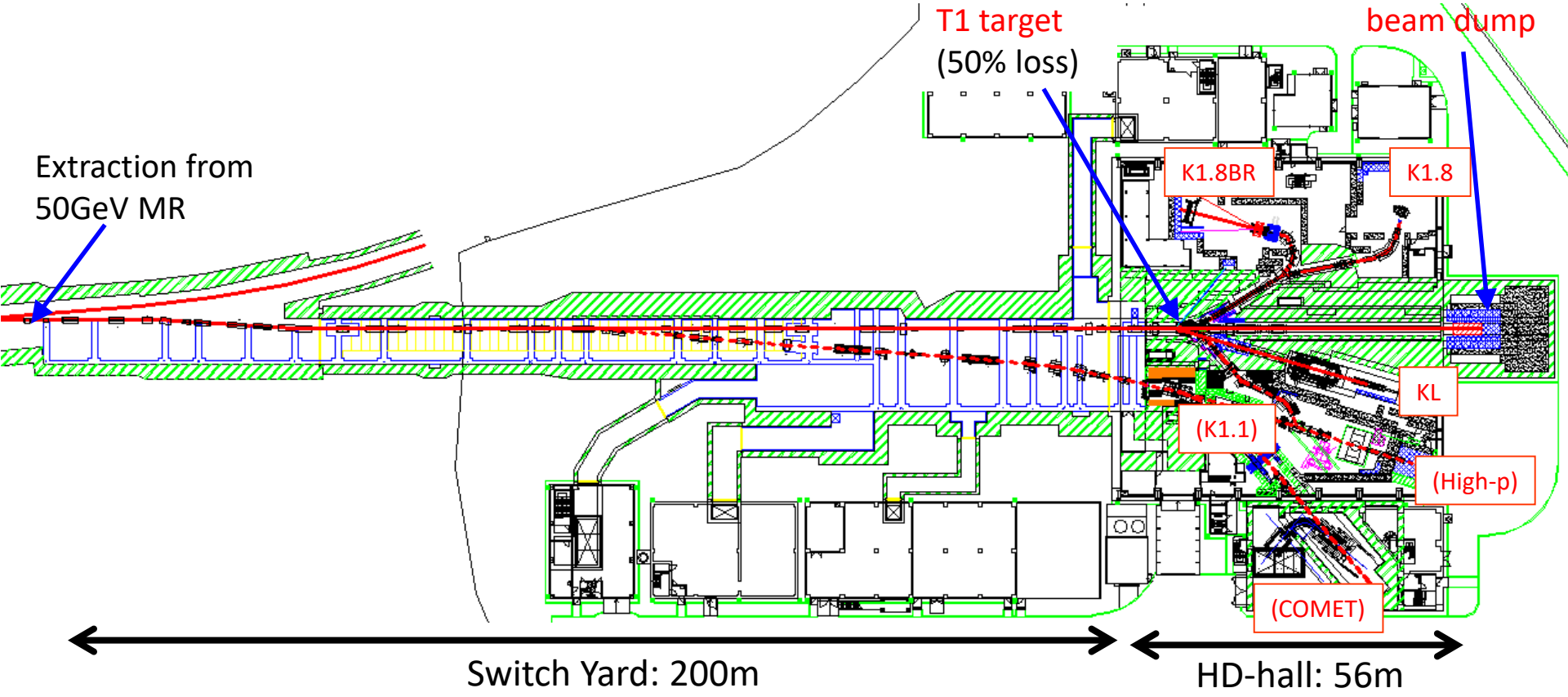


Contents

- Introduction
- Status of current target
- Next target and windows
- R&Ds for next to next target

Bird's eye photo in July, 2009

Hadron Experimental Facility (HD-hall)



- ✓ Various secondary beams: π, K, p-bar, ….
- ✓ Currently only one production target: T1
- ✓ KL: kaon rare decay
- ✓ K1.8, K1.8BR, (K1.1): strangeness nuclear physics, etc.
- ✓ New primary beam lines are now under construction (high-p, COMET)

Requirements for Production Target

- Target to produce secondary beams (Kaons, pions, antiprotons, ...) for particle and nuclear physics experiments
  - Charged secondary beam lines: K1.8, K1.8BR, (K1.1)

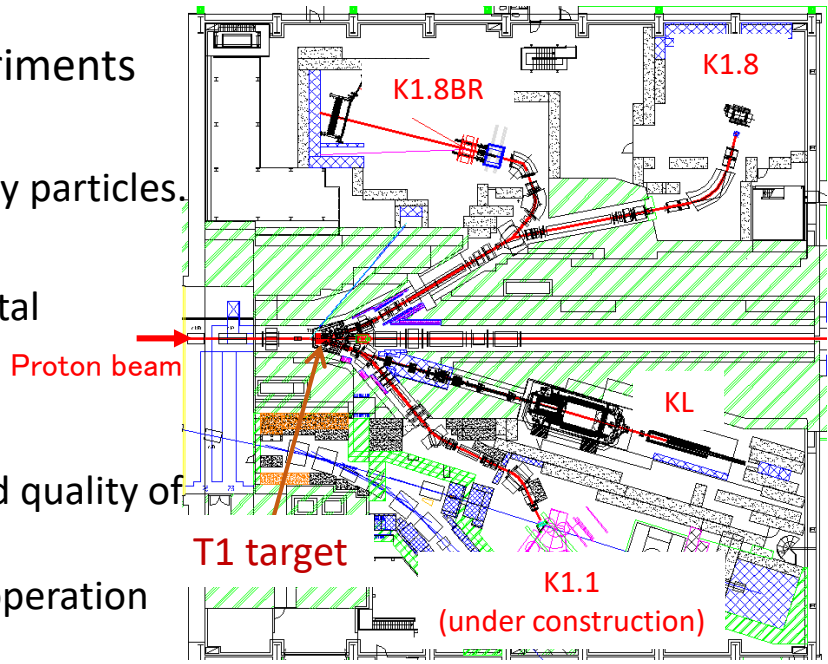
  → Point source is desirable in order to separate secondary particles.
  - Neutral secondary beam line: KL

  → Point source is desirable in order to reduce experimental background.
- Requirements

  ① Large mass number and high density for intensity and quality of secondary beams

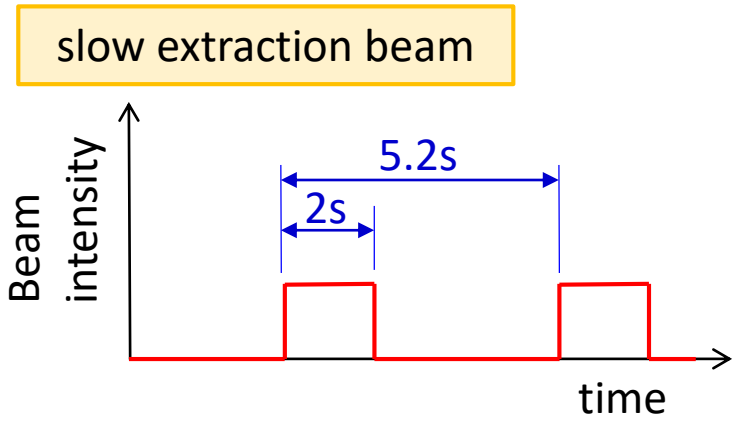
  ② Radiation hardness and chemical stability for stable operation

  ③ Sufficient cooling efficiency for high-intensity beam

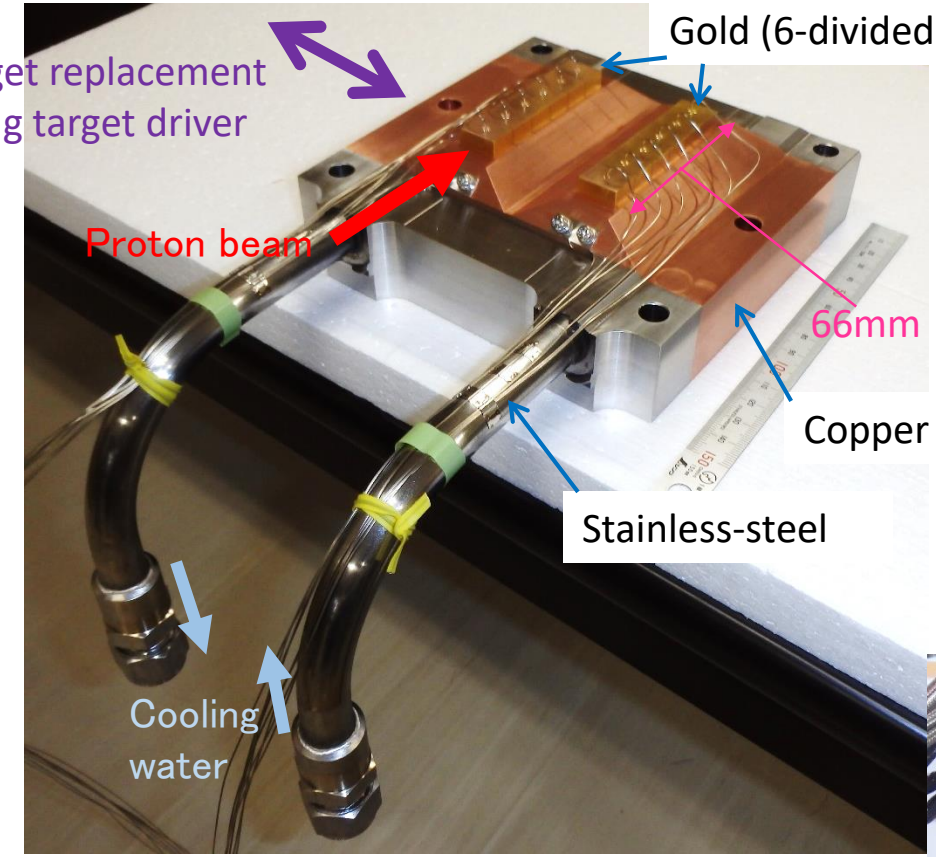


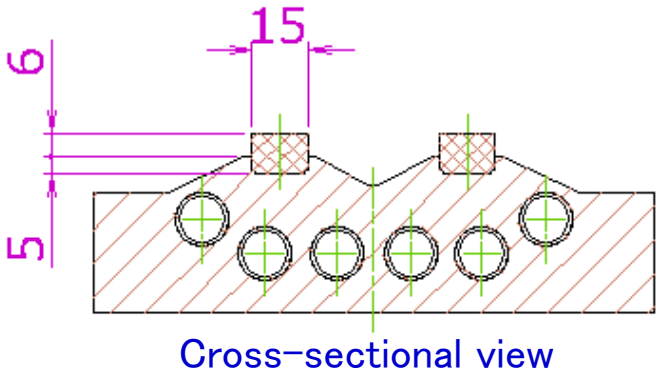
Beam conditions

- Primary proton beam energy: 30 GeV
- Spill structure: 2-sec extraction and 5.2-sec repetition
- Beam loss at target: 50%
- Beam size at T1 target: (σ_x, σ_y) = (2.5mm, 1.0mm)

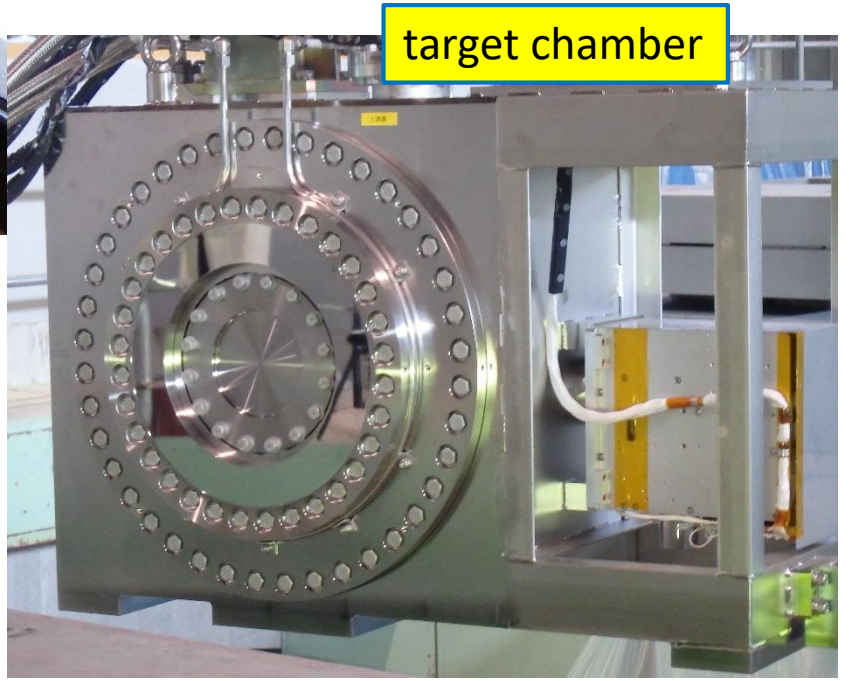


Current Hadron Target





*Gold, copper, and stainless-steel are bonded by HIP (Hot Isostatic Pressing)

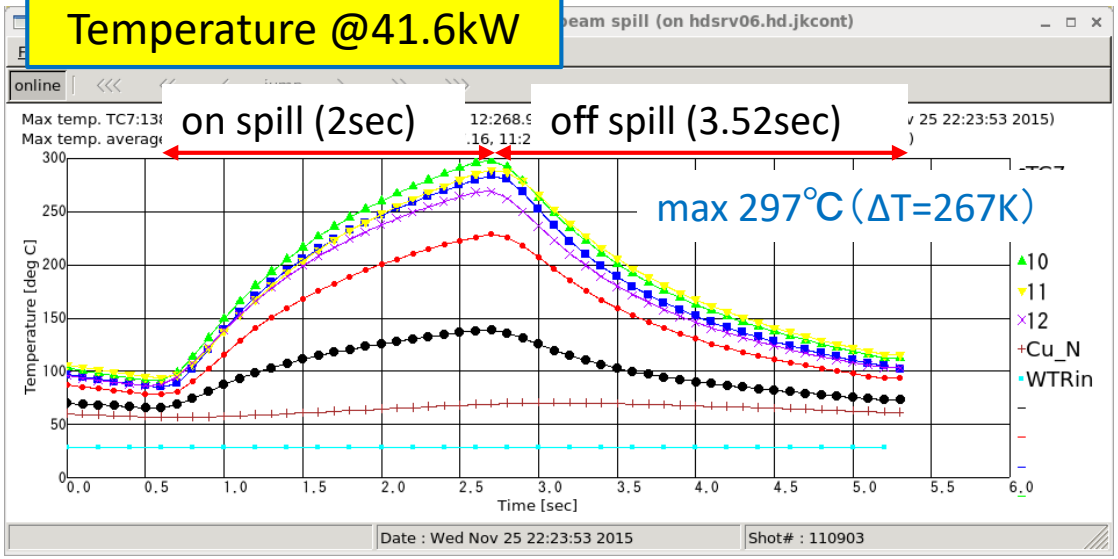


- Up to 57 kW beam (5.2s spill cycle)
- Indirectly water-cooled
- Gold was chosen due to the good thermal conductivity and thermal expansion coefficient close to that of copper
- Involved in airtight chamber and He gas is circulated to monitor the target soundness

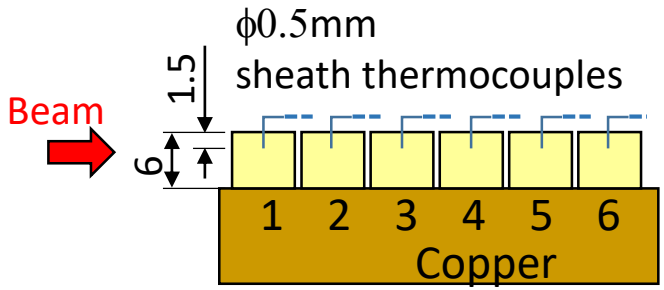
Beam Operation

- Installation: Sep. 2014
- Beam ope.: Apr. 2015 -

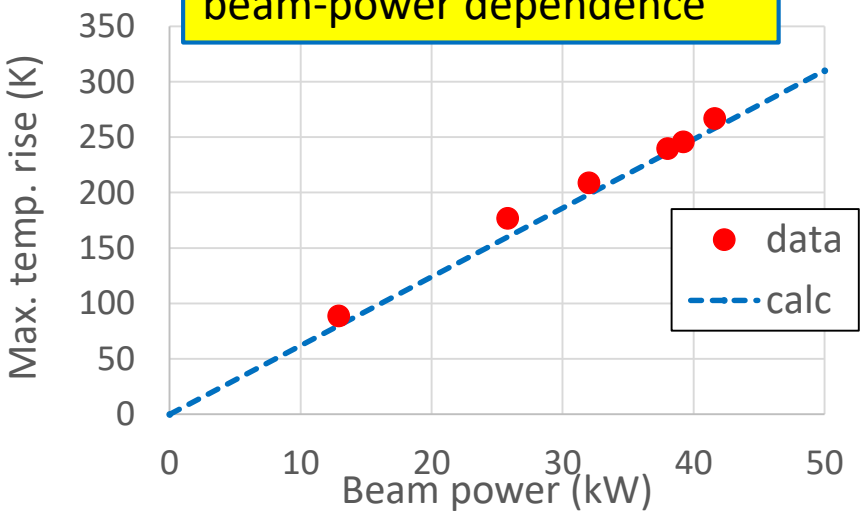
Temperature @41.6kW



Temperature of each gold piece is measured with thermocouples every 100ms



beam-power dependence



Measured temperature was in good agreement with calculation

Status of Current Target

- Specification
  - Max beam power: 57 kW (5.2s cycle)
  - Estimated life of Ti-alloy windows: 50 kW x 7.5k hours
    - Accumulated strain due to creep deformation will reach the endurance limit (1 %).
    - Accumulated radiation damage will reach 2 DPA. (T2K replaced their window after 1.8 DPA irradiation.)
- Current status
  - Stable operation without any serous problems since the installation
  - Achieved beam power: Max 51 kW in continuous operation
  - Beam exposure time: 4909 hours

Target upgrade is necessary for higher beam power

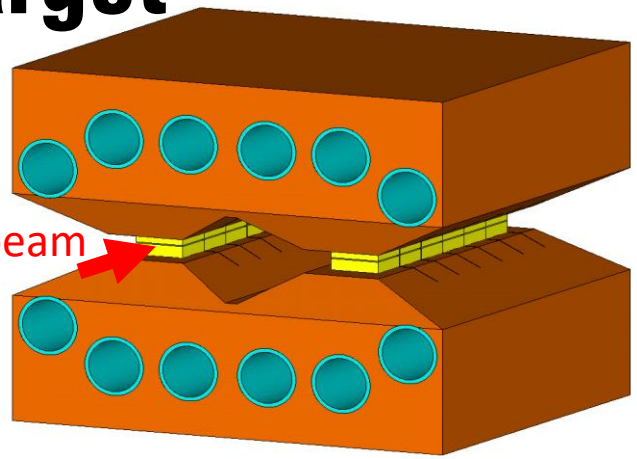
Upgrade Plan of Production Target

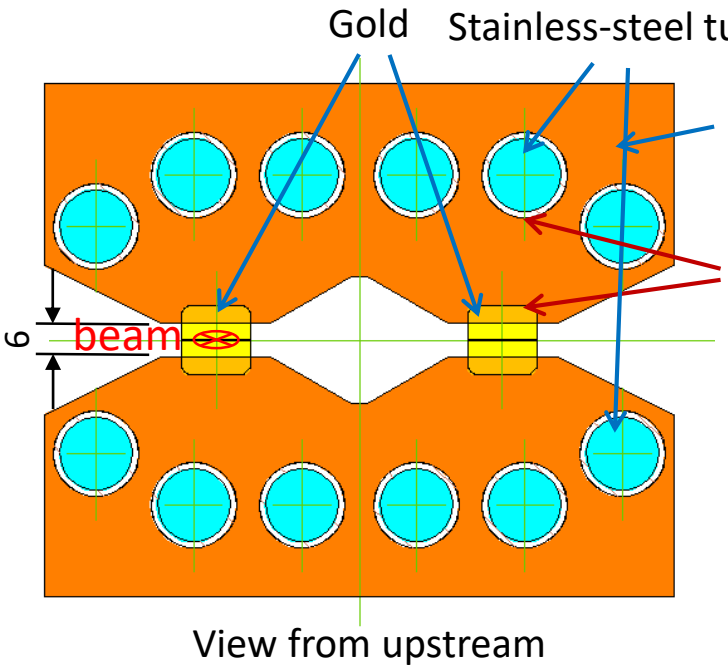
- Current
  - indirectly water-cooled gold target
  - Ti-alloy windows
  - up to 57 kW
- Next
  - indirectly water-cooled gold target with improved structure
  - Be windows
  - up to 95 kW
  - fabrication process is established
  - will be installed this November
- Next to next
  - directly cooled rotating euro-coin target
  - water or He-gas cooled
  - up to 150 – 200 kW
  - several R&Ds are in progress
  - will be installed in 2023?

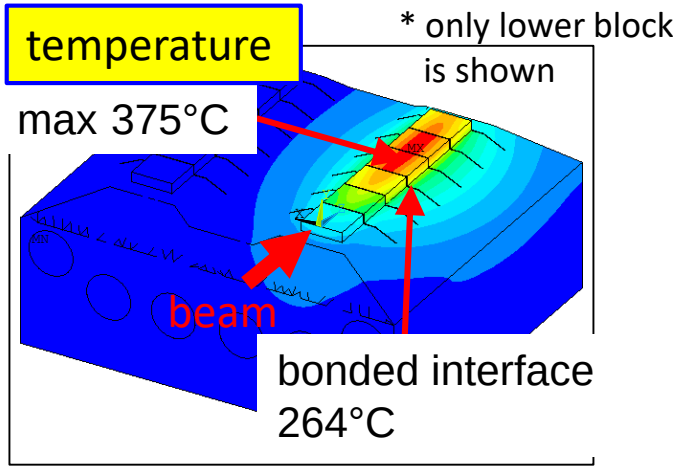
Indirectly water-cooled fixed target

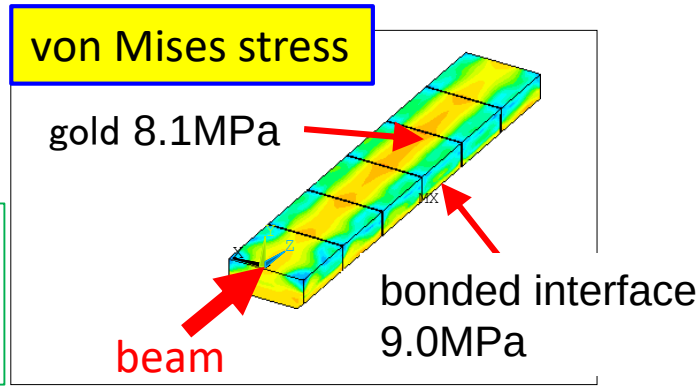
- Gold target with copper cooling block is turned over and stacked on another gold target.
- Each of the gold targets has almost same structure as current target.
- Size of gold is optimized for secondary-beam yield and cooling efficiency.
- **95 kW** proton beam can be accepted. (5.2s cycle)
- Fabrication process is already established.

➡ will be installed this year









Allowable stress:
13.2 MPa (@264°C)
13.0 MPa (@375°C)

Beam Windows of Target Chamber

Current: **Titanium alloy (Ti-6Al-4V)**

- Thermal stress:

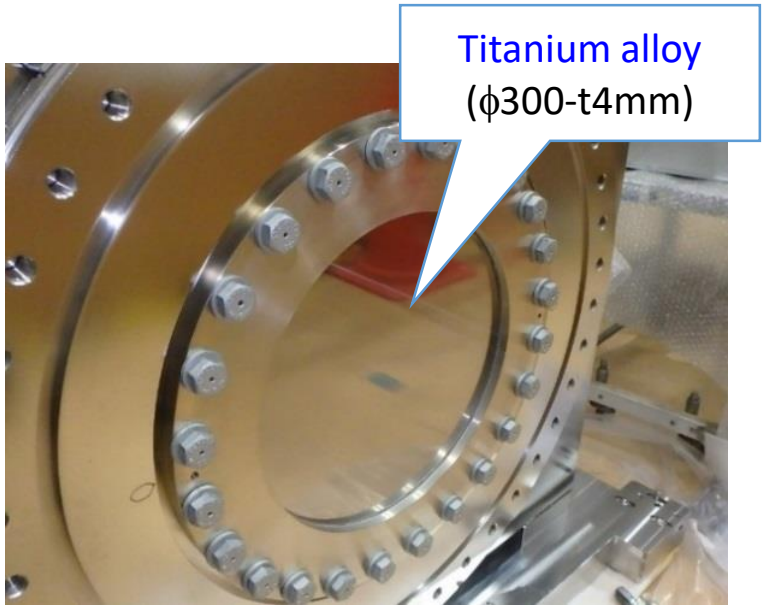
  OK up to 10^7 cycles (~ 15k hours)

- Accumulated strain due to creep deformation:

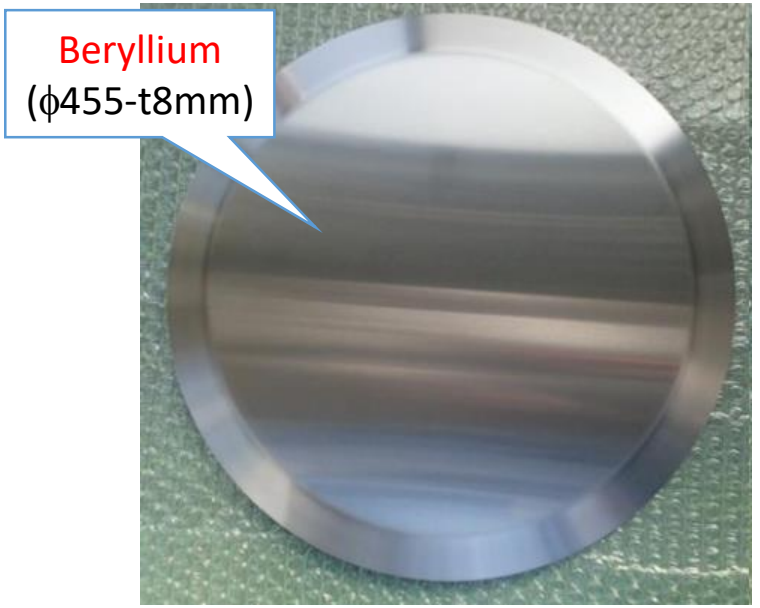
  will reach the endurance limit (1 %)

  in ~50 kW x 7.5k hours

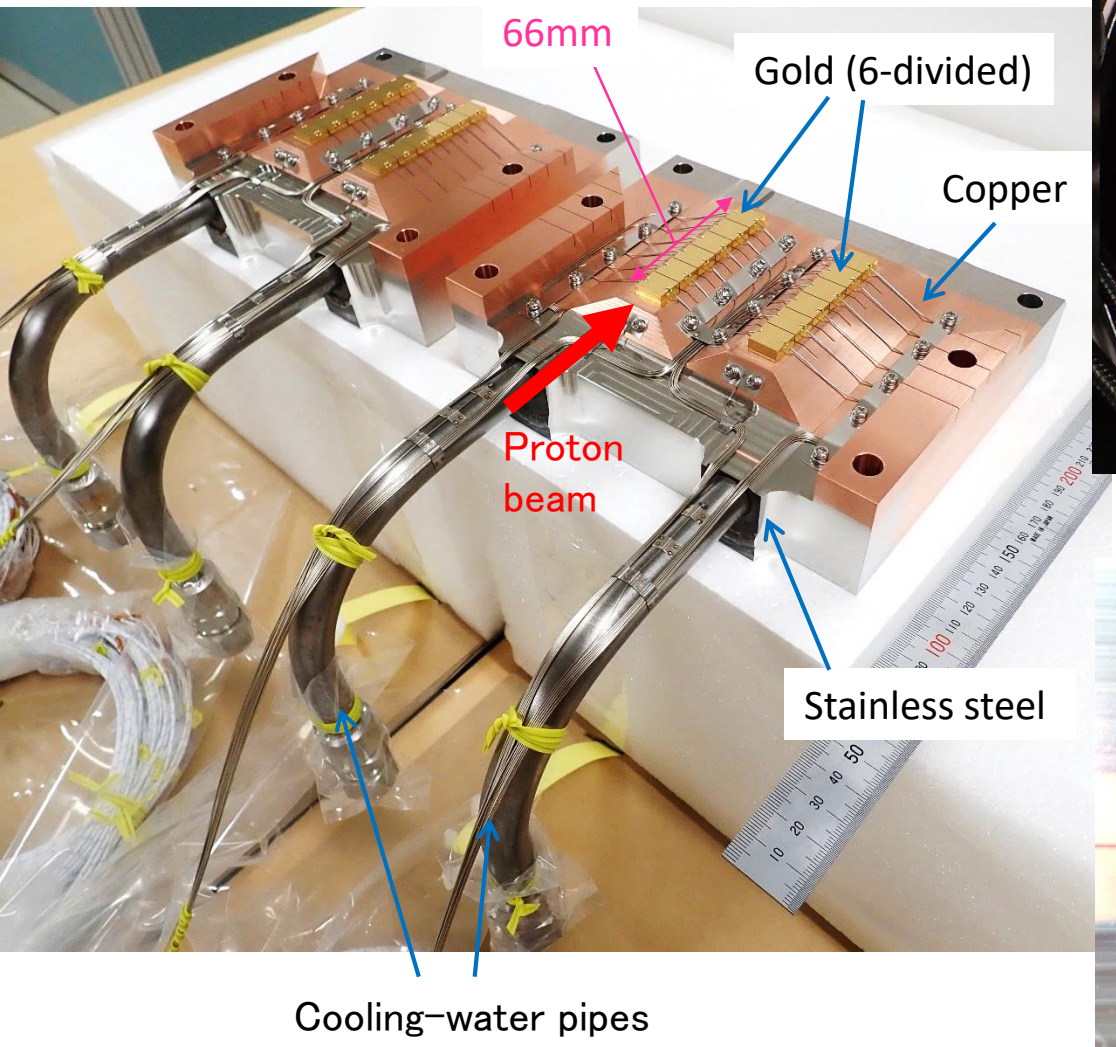
=> This limited the life of current target

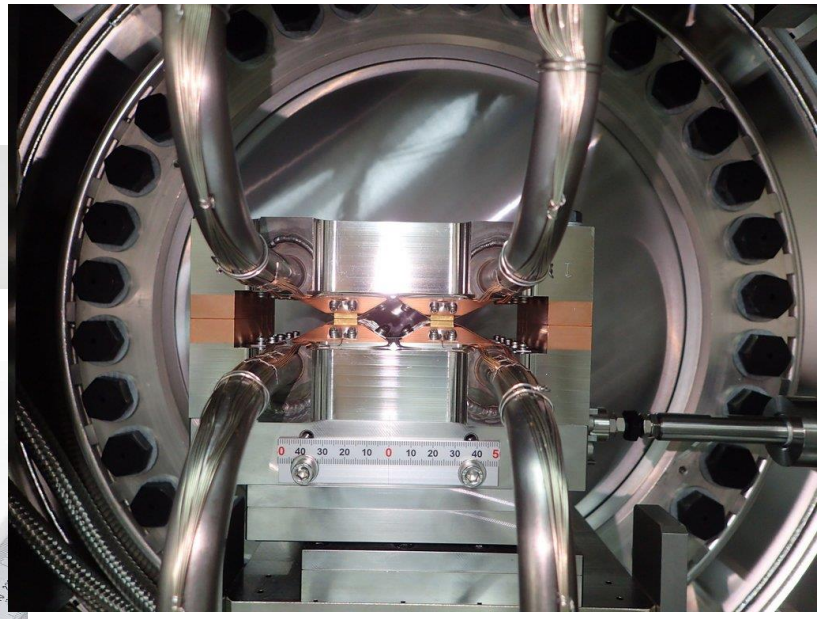


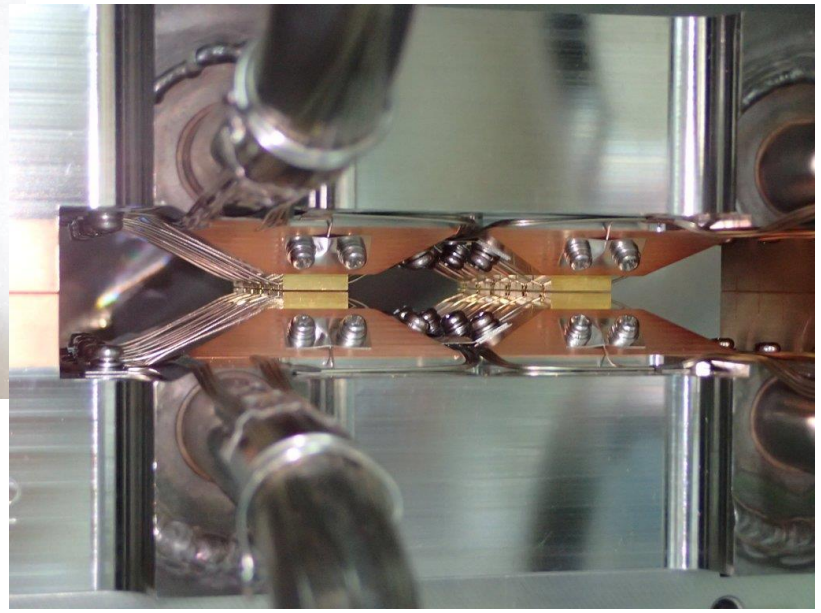
Next: **Beryllium**



New Gold Target

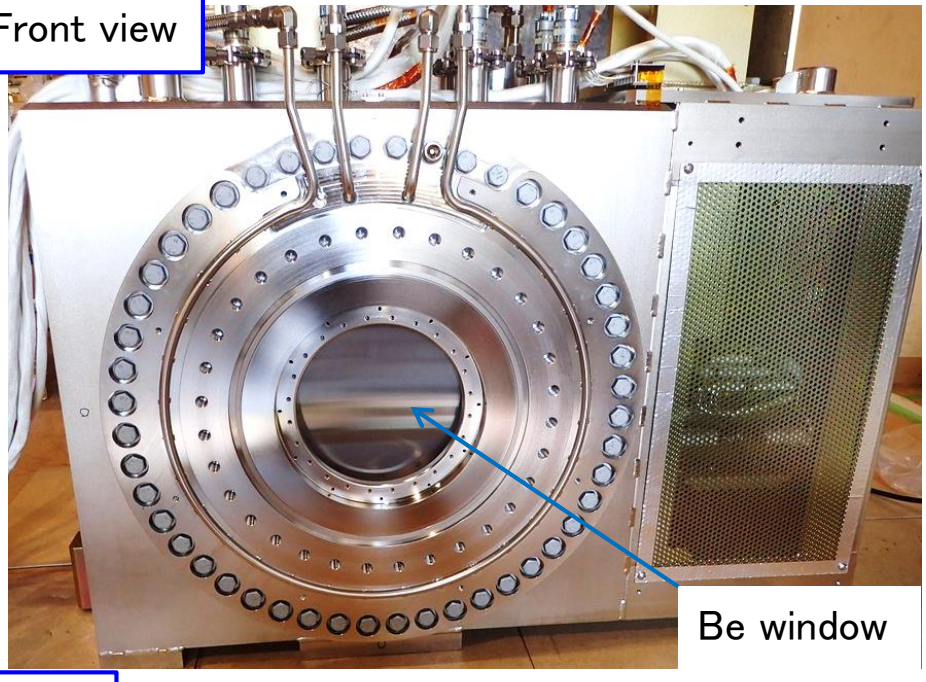




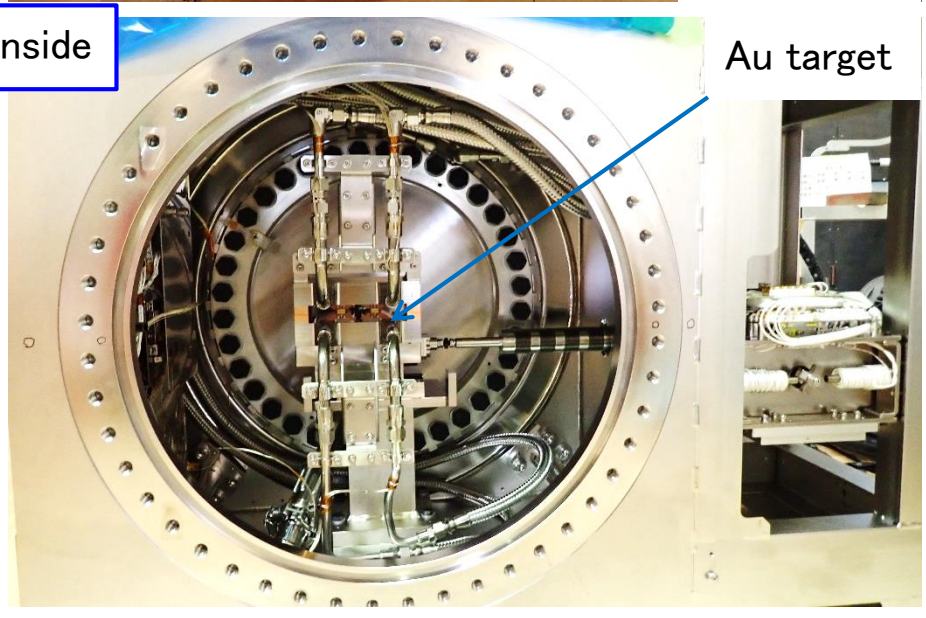


New Target Chamber and Windows

Front view

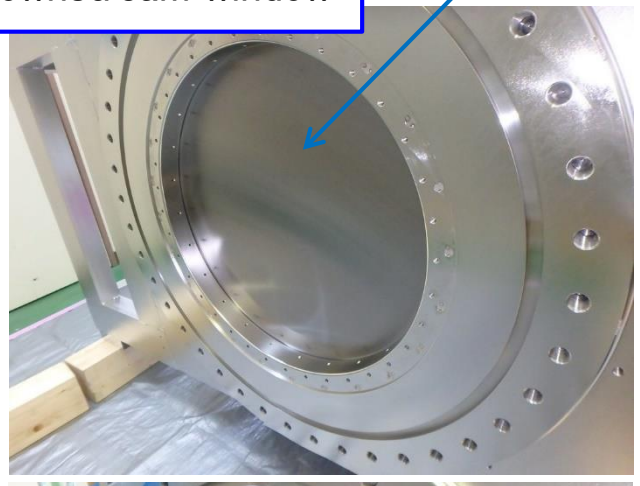


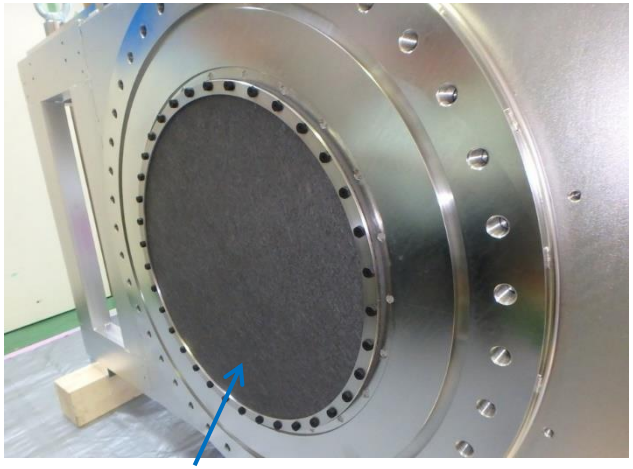
Inside



Downstream window

Be window





C/C composite partition wall
to prevent Be fragments from scattering

Upgrade Plan of Production Target

- Current
  - indirectly water-cooled gold target
  - Ti-alloy windows
  - up to 57 kW
- Next
  - indirectly water-cooled gold target with improved structure
  - Be windows
  - up to 95 kW
  - fabrication process is established
  - will be installed this November
- Next to next
  - directly cooled rotating euro-coin
  - water or He-gas cooled
  - up to 150 – 200 kW
  - several R&Ds are in progress
  - will be installed in 2023?

- Fabrication and assembly were completed.
- Examinations before installation were successfully passed.

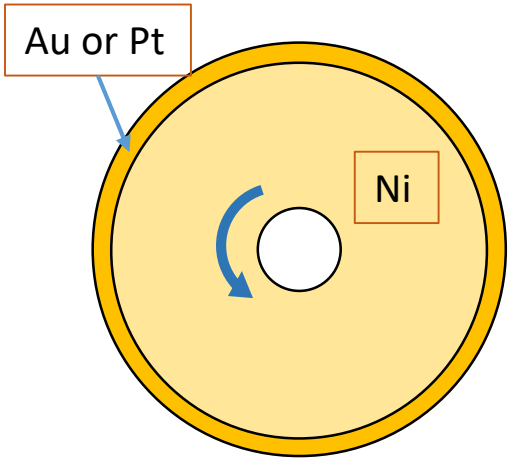
➡ ***Ready to install !***

Upgrade Plan of Production Target

- Current
  - indirectly water-cooled gold target
  - Ti-alloy windows
  - up to 57 kW
- Next
  - indirectly water-cooled gold target with improved structure
  - Be windows
  - up to 95 kW
  - fabrication process is established
  - will be installed this November
- Next to next
  - directly cooled rotating euro-coin target
  - water or He-gas cooled
  - up to 150 – 200 kW
  - several R&Ds are in progress
  - will be installed in 2023?

Next to Next Hadron Target

- Rotating “Euro Coin” target
  - nickel disks with gold or platinum edge
- Water cooled or He-gas cooled
- Several R&Ds are in progress

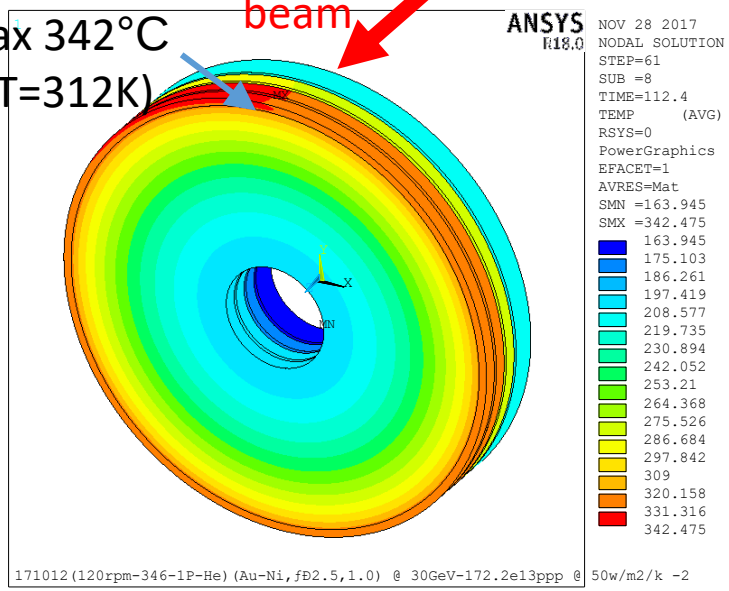


Results of thermal analysis (Au, 150kW, 5.52s cycle)

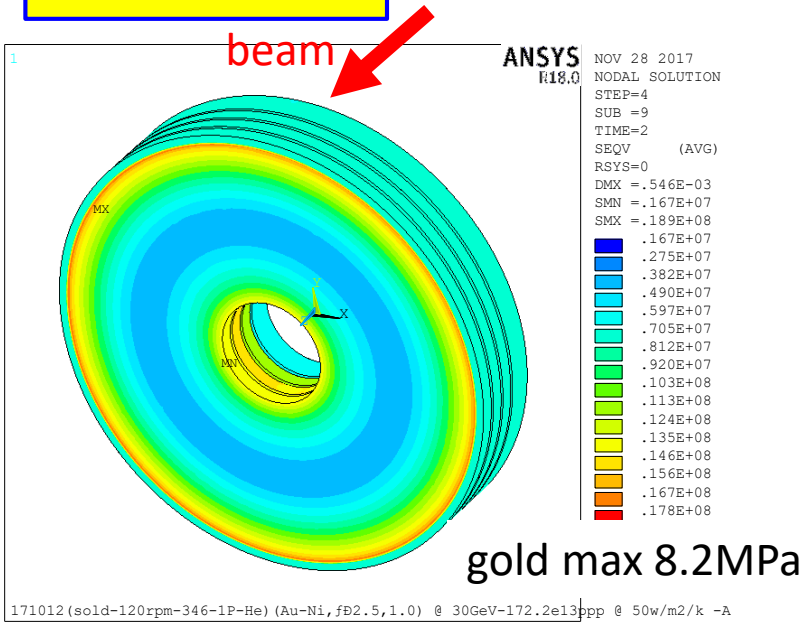
He gas cooled (assuming 50 W/m^2/K)

temperature

max 342°C
(ΔT=312K)



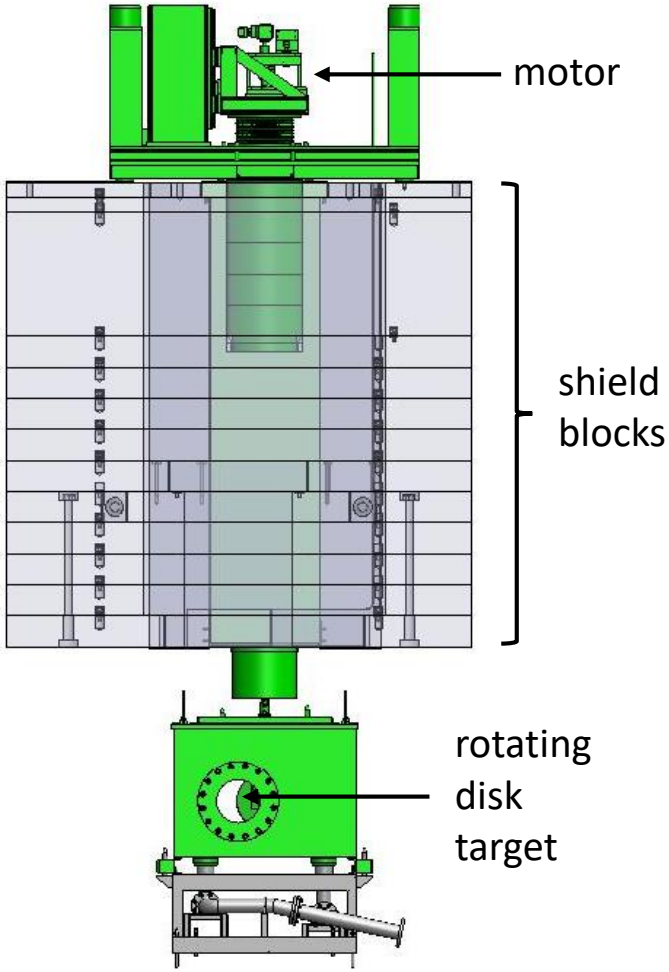
von Mises stress



gold max 8.2MPa

Rotating method

Previous design



issues:

- airtightness of chamber
- large system in high-radiation area

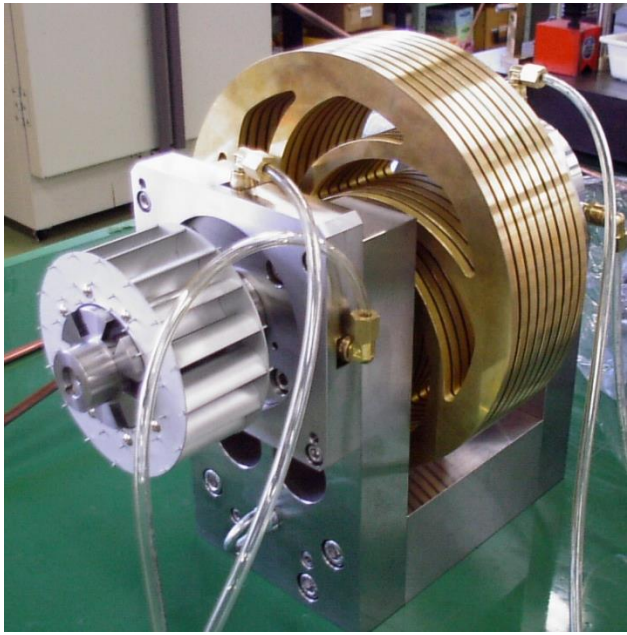
New idea

water turbine

He gas turbine

No need for motor and long shaft

- airtightness of chamber can be achieved easily
- simple and small components in high-radiation area



Comparison of cooling/rotating methods

water

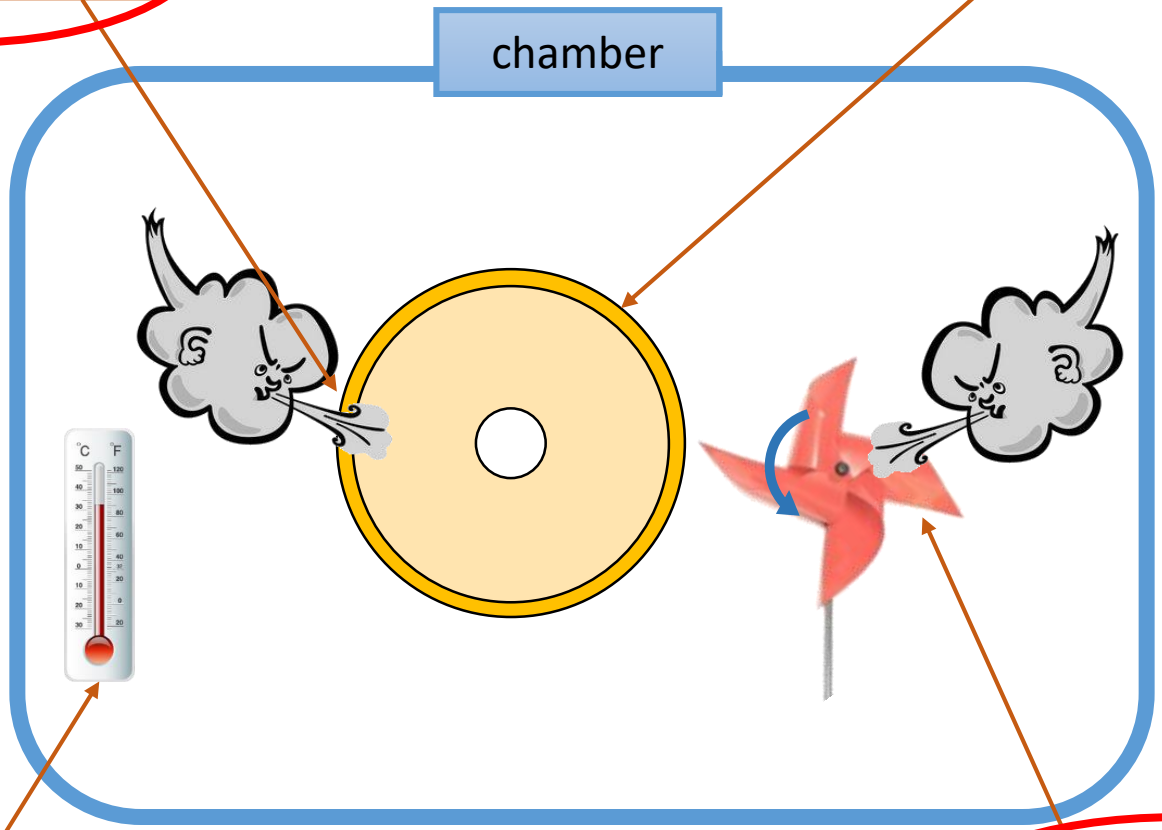
- good cooling efficiency
  - capable of higher beam power
- large rotating torque
- need corrosion resistance
- large amount of tritium generation
- need R&Ds of water circulation system
  - pumping up from bottom tank
  - ion exchanger
  - recombinator
- also need He-gas circulation system
  - moisture is contaminated to He gas

He gas

- clean (small amount of NOx, H gas, and tritium generation)
- no need for water circulation system
- cooling efficiency is unknown
- rotating torque is unknown
- need large-flow He-gas circulation system

R&Ds for “Euro Coin” Target

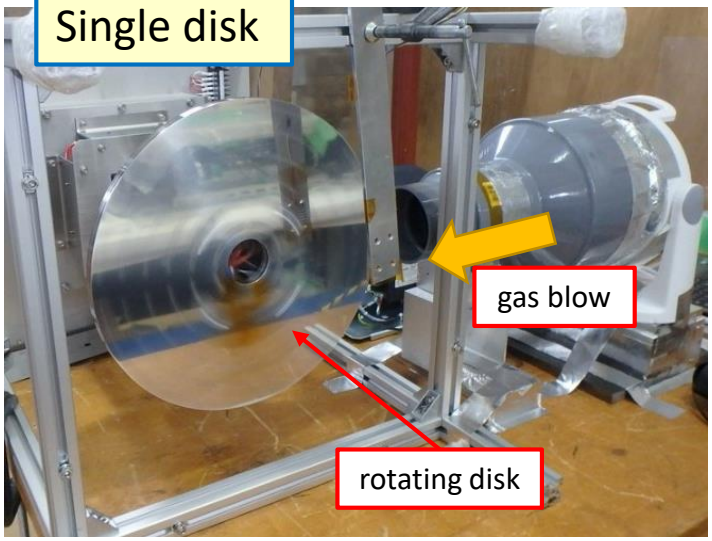
- He-gas cooling efficiency
- fabrication of “Euro Coin”

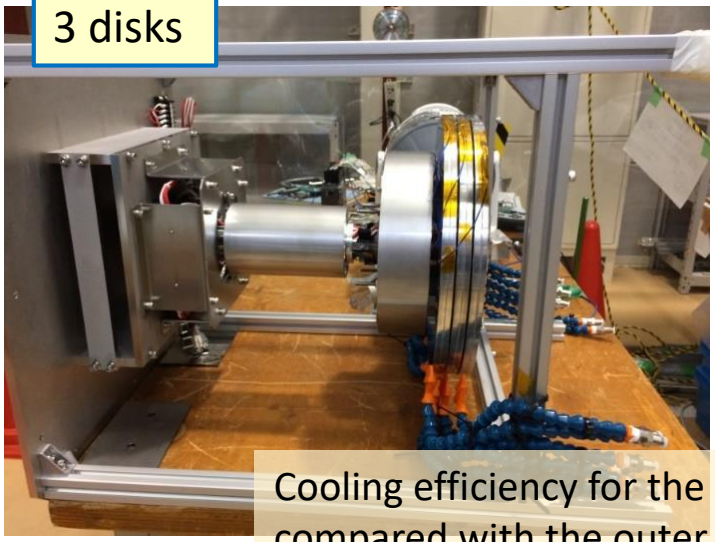


- temperature monitor
- gas turbine
- rotation monitor
- bearing

Efficiency of He-Gas Cooling

Simple flat disk(s)

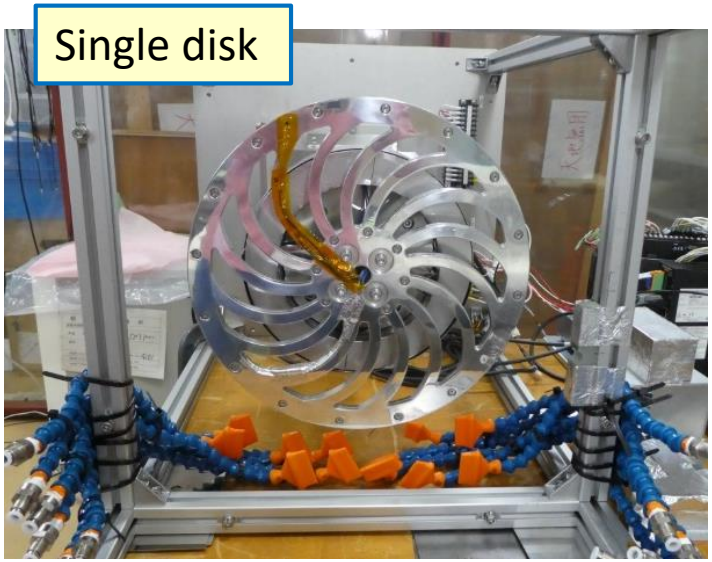


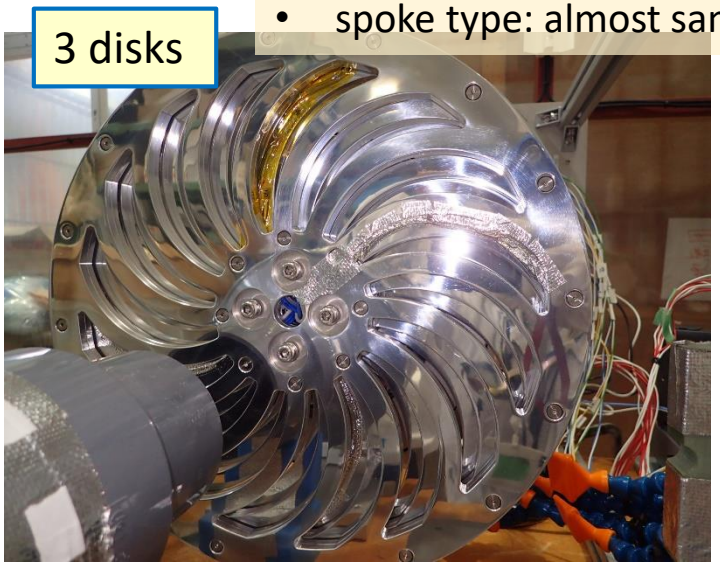


Cooling efficiency for the inner disk compared with the outer disks

- flat type: less than half
- spoke type: almost same

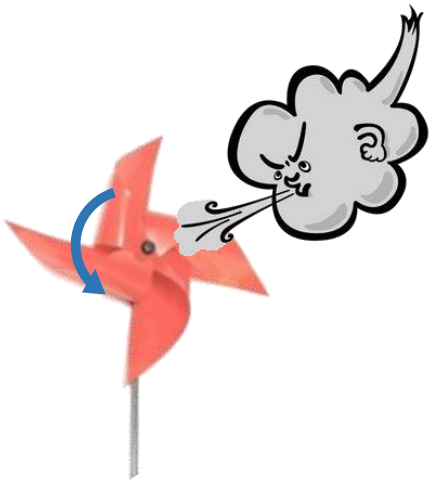
Spoke-type disk(s)

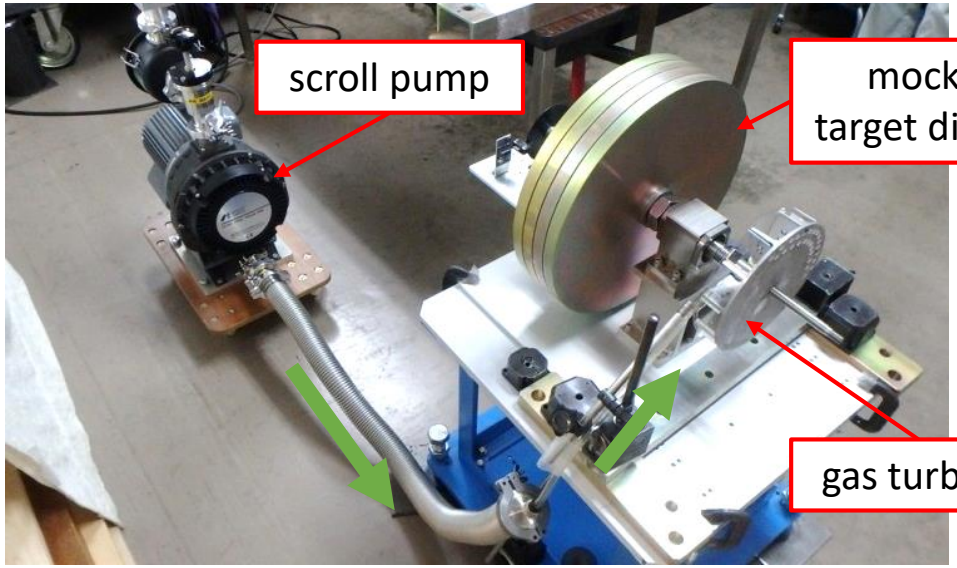




R&Ds for “Euro Coin” Target

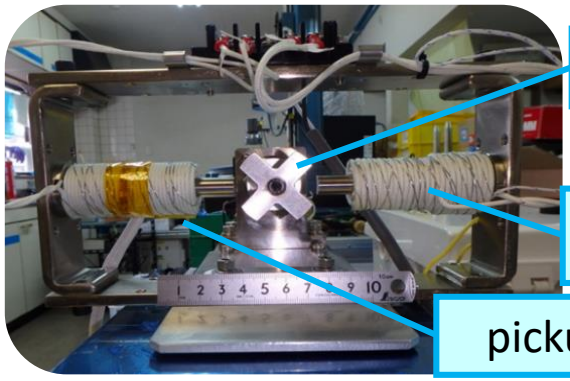
Simple rotation test using exhaust of scroll pump

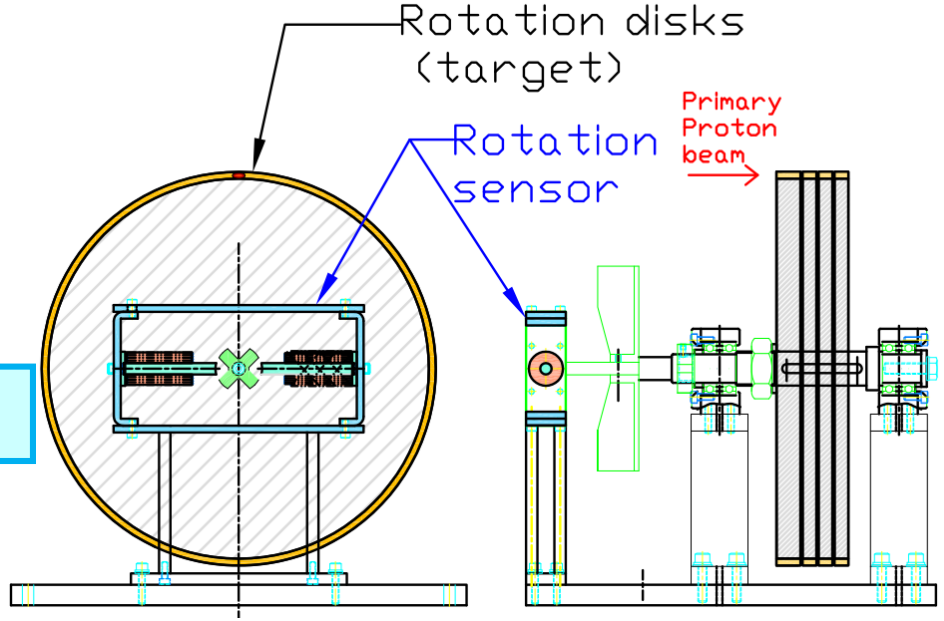




Test of radiation-hard rotation sensor

made of iron and ceramic cables





Summary

- Current target
  - indirectly water-cooled type made of gold.
  - worked very stably for ~5000 hours since installation.
  - max beam power of 51 kW was achieved. (design: max 57 kW)
- Next target
  - almost same structure as current target.
  - cooling efficiency is improved by adding another cooling block.

  => max beam power is 95 kW (5.2-s cycle)
  - beam windows are also upgraded: Ti-alloy => Be
  - fabrication and assembly were completed. => Ready to install
  - will be installed this November.
- Next to next target
  - rotating “Euro-Coin” target directly cooled by water or He-gas.
  - max beam power is 150 – 200 kW.
  - several R&Ds are in progress.