The JPARC Neutrino Target

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for

J-PARC ν Beam-line Construction Group

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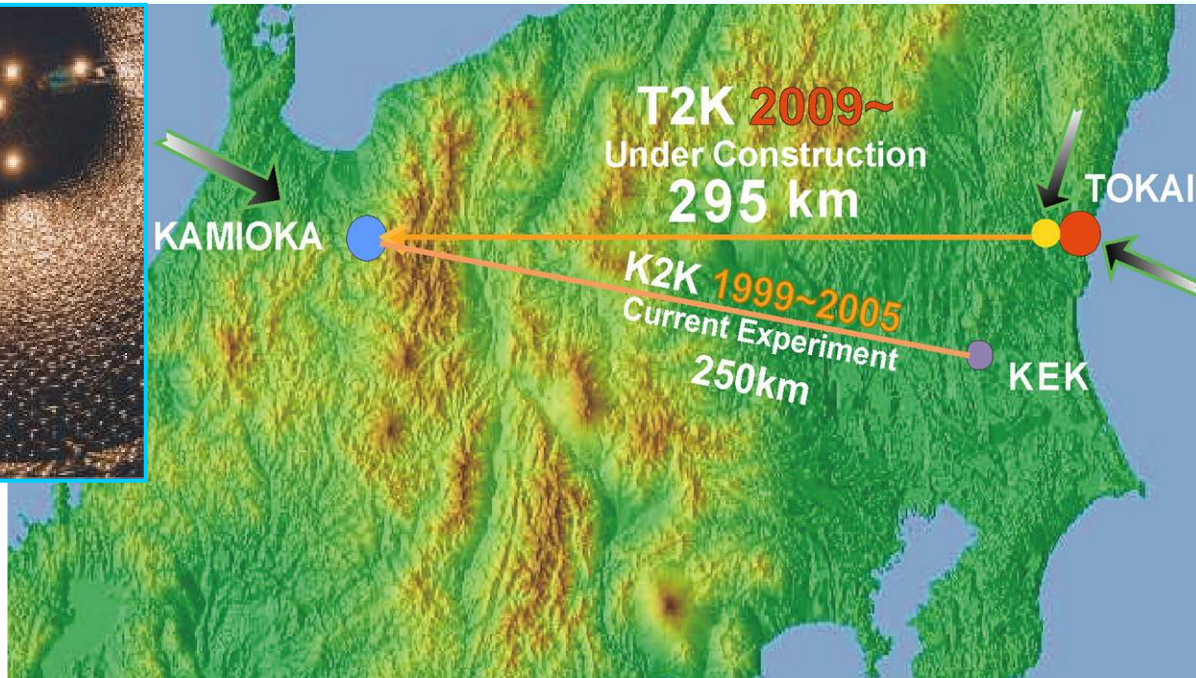
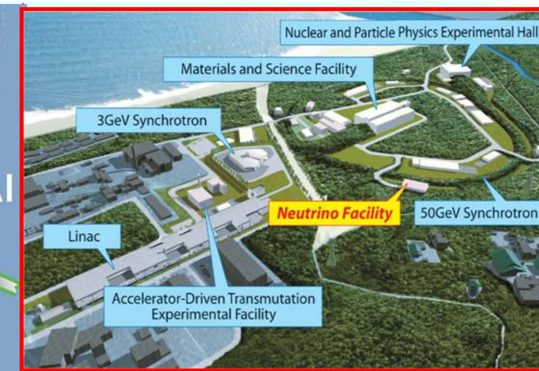
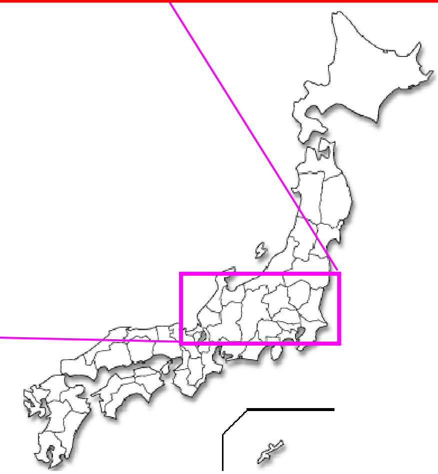
T2K (Tokai to Kamioka) ν experiment



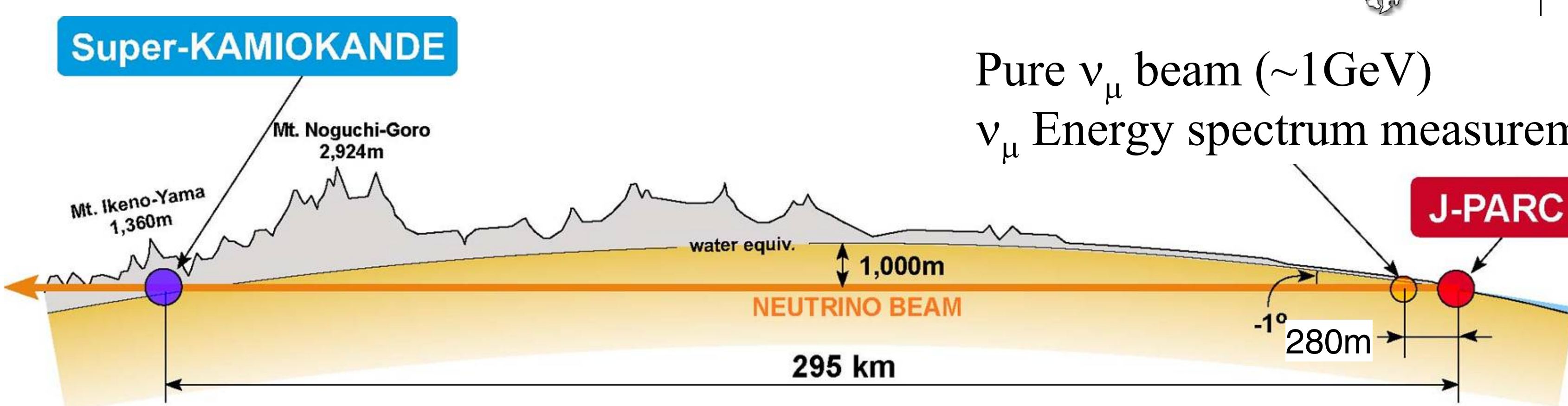




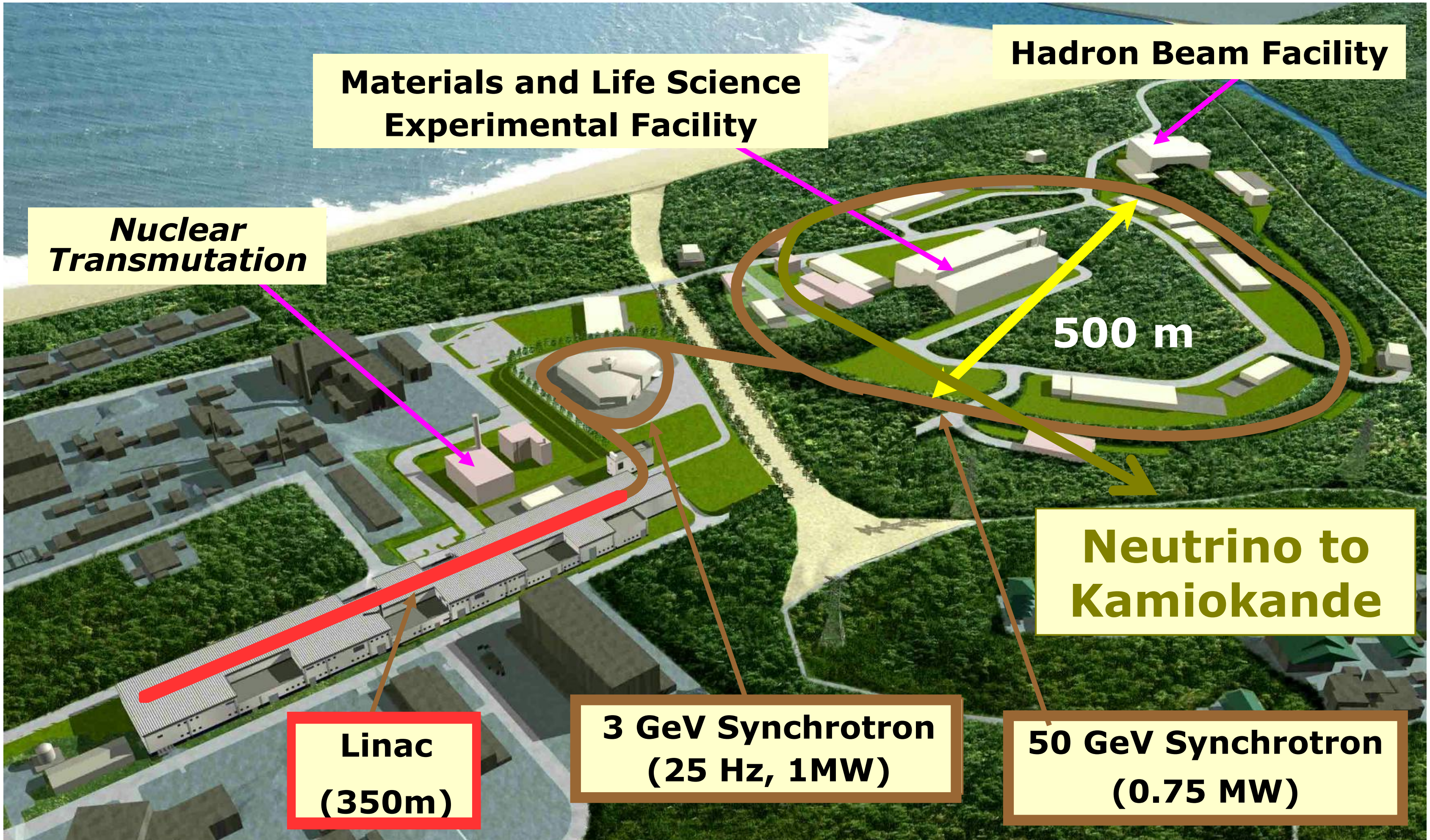
Main Physics goals: **Discovery of $\nu_\mu \rightarrow \nu_e$ Oscillation**

Pure ν_μ beam (~1GeV)

ν_μ Energy spectrum measurement



J-PARC Facility

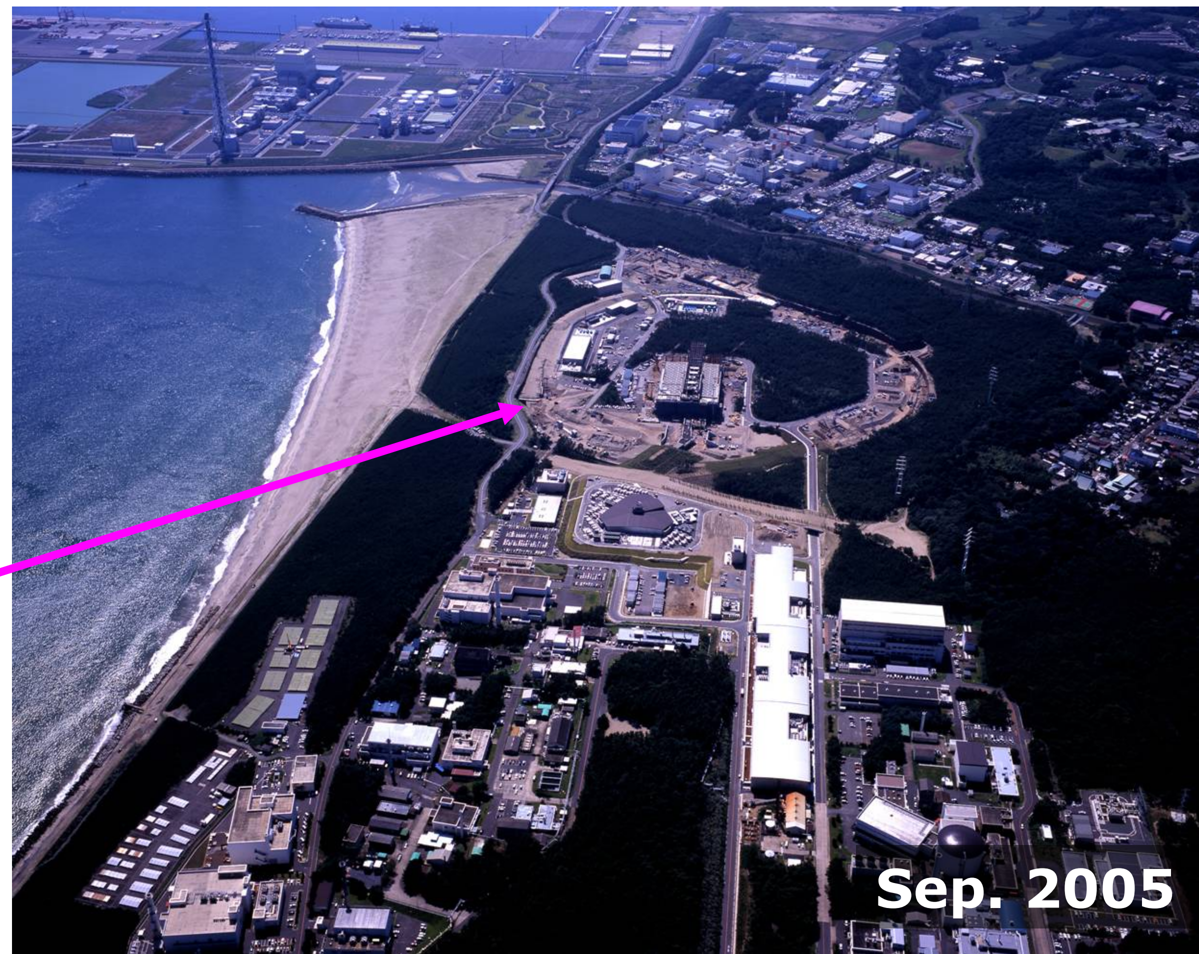


J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA (aka JAERI)

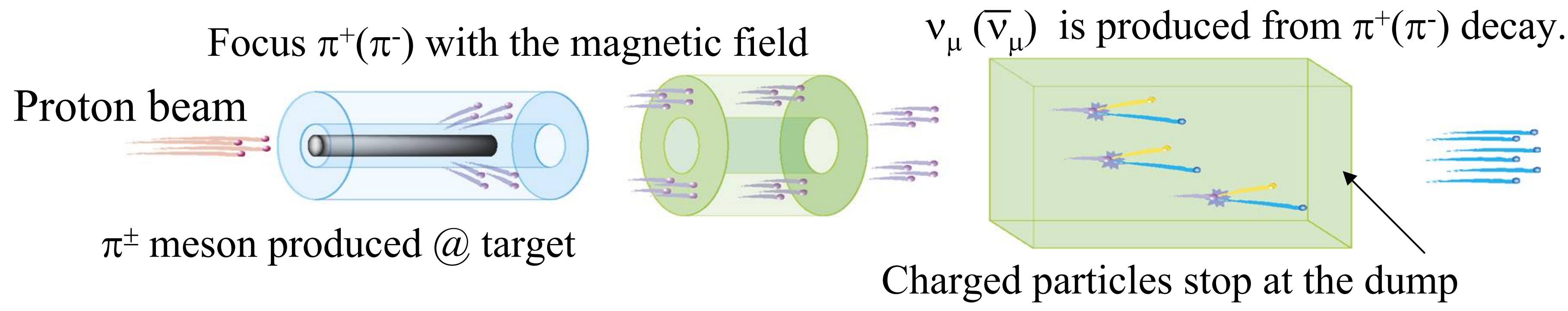
J-PARC status

- **Buildings for LINAC and 3GeVPS finished.**
- **North-east part of tunnel for 50GeV PS finished.**
- **South-west part of tunnel will finish in FY2006.**
- **First beam on 50GeV PS <u>in FY2008</u>**



J-PARK ν beam

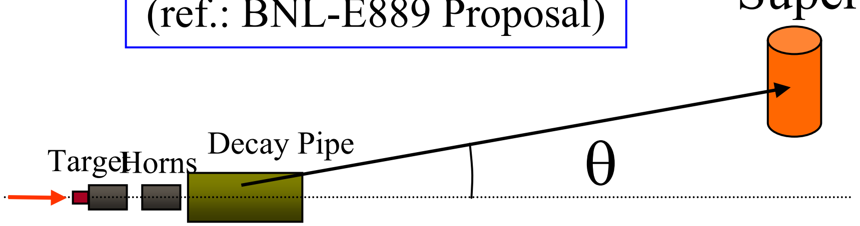
- Conventional ν_μ beam

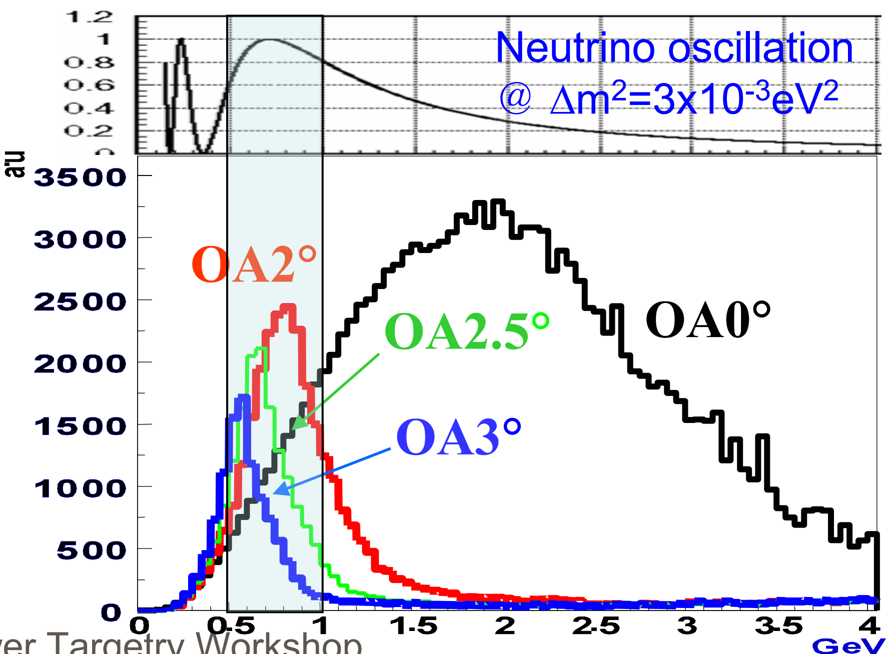


- Narrow band beam:

  Off-axis beam

First Application
(ref.: BNL-E889 Proposal)



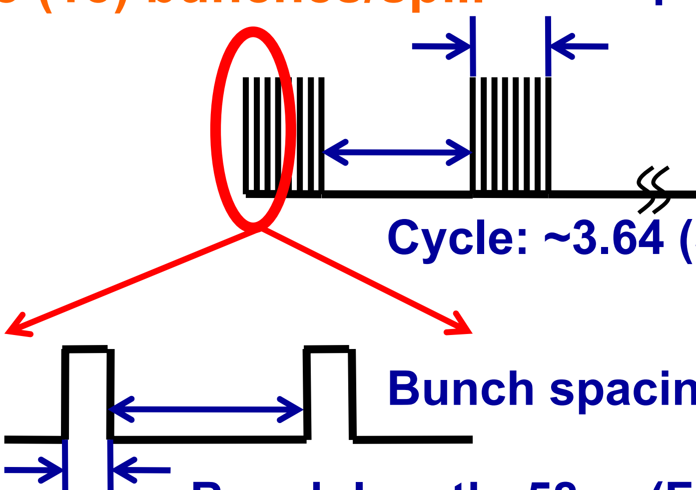


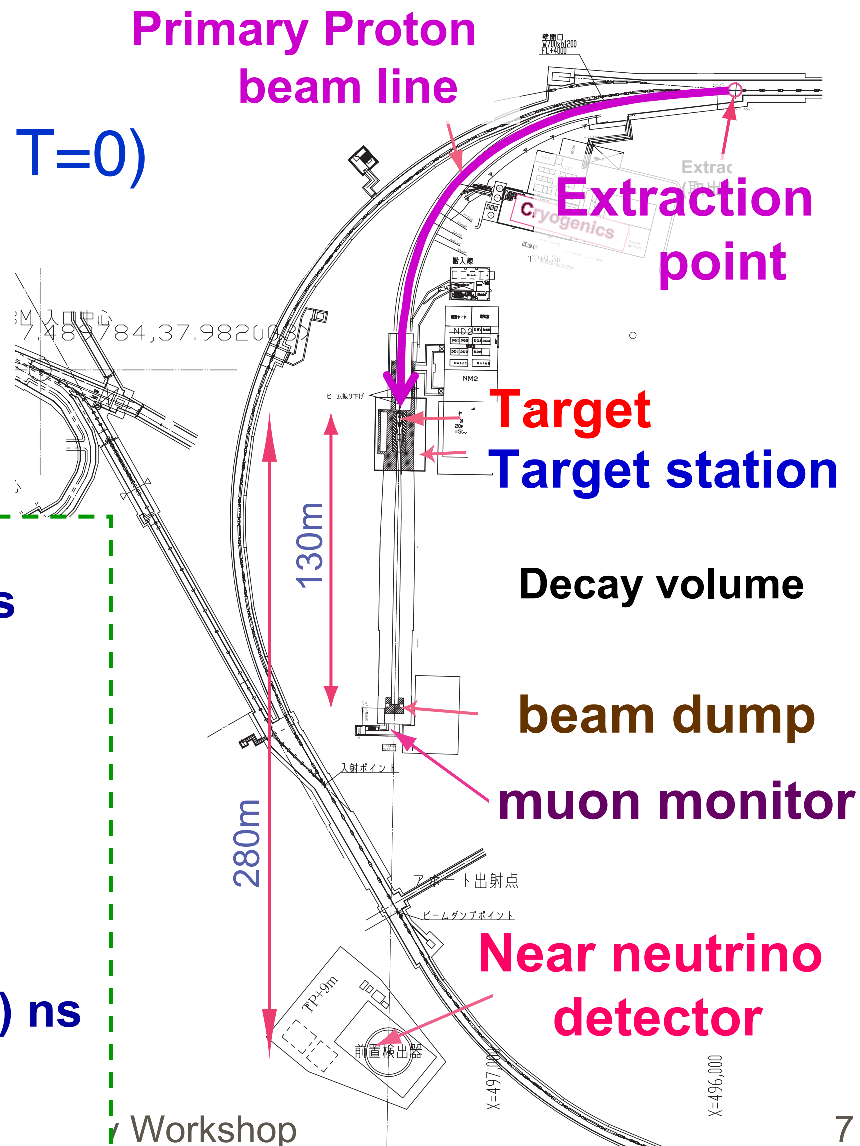
J-PARC neutrino beam line

Proton Energy	50GeV
	(40/30GeV @ T=0)
# of Protons / pulse	3.3×10^{14}
Beam Power	750kW

→ 4MW @ Phase II

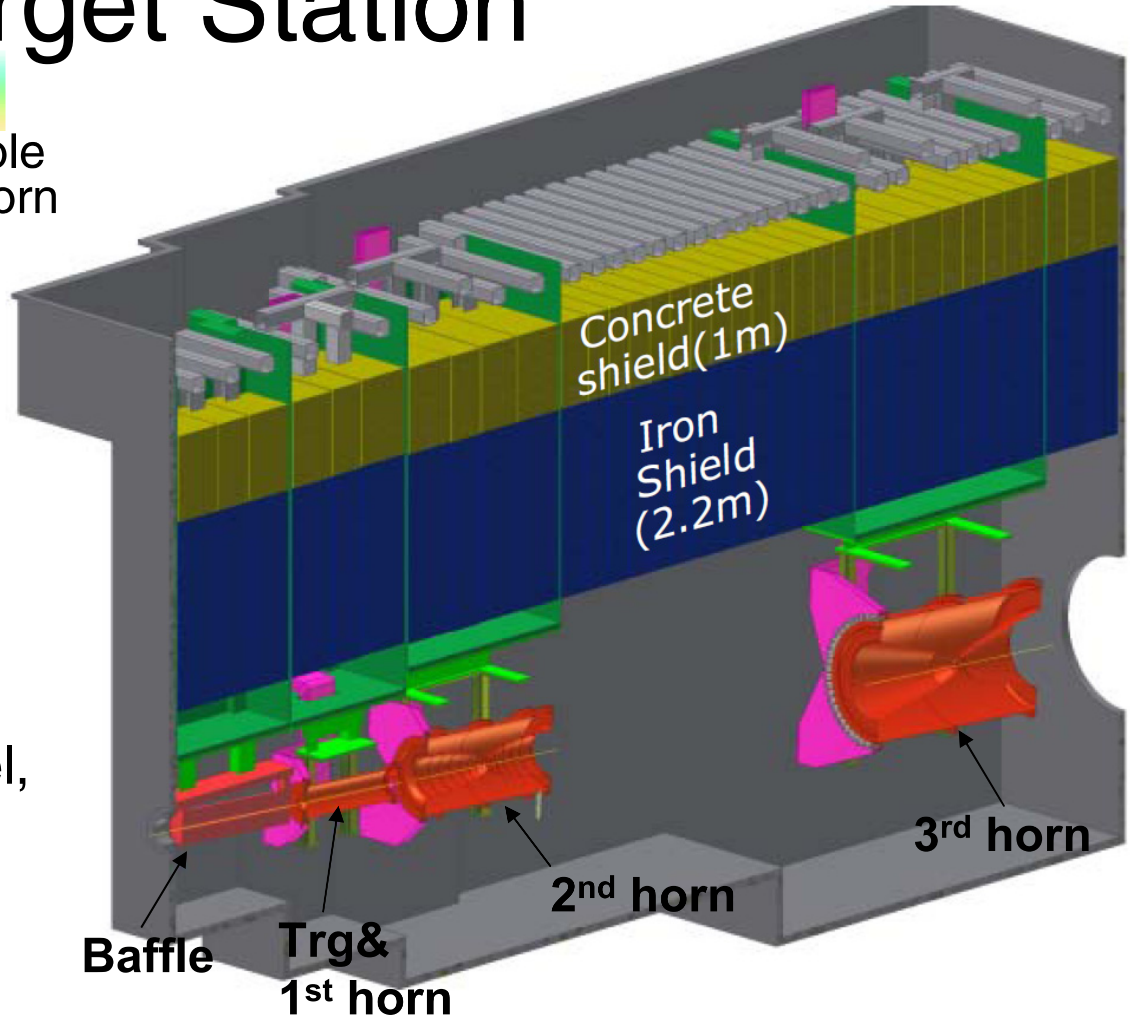
Bunch structure

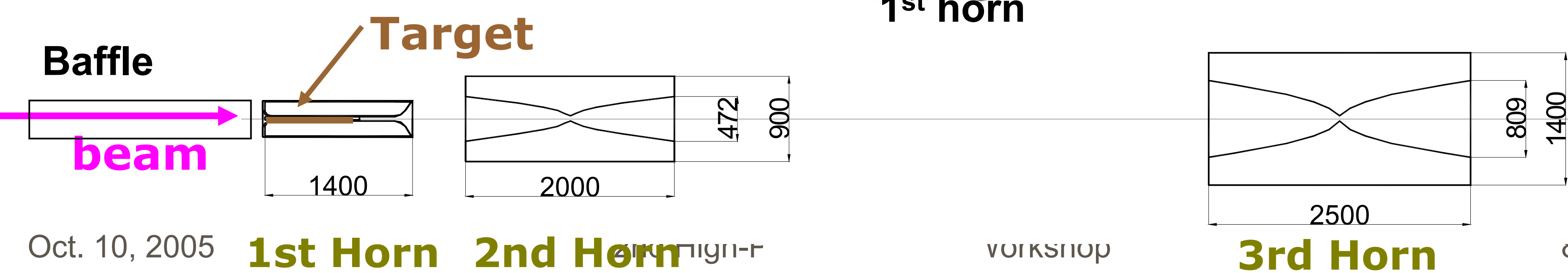




Target Station

- Accommodate
  - Baffle: Graphite, 32mmϕ hole x 1.7m long to protect 1st horn
  - Target
  - 3 Horns
- Area filled with Helium gas
  - reduce Tritium, NOx production
- Highly radio-activated
  - ~1Sv/h,
  - Need remote-controlled maintenance system
- Need cooling (Helium vessel, radiation shield,..)

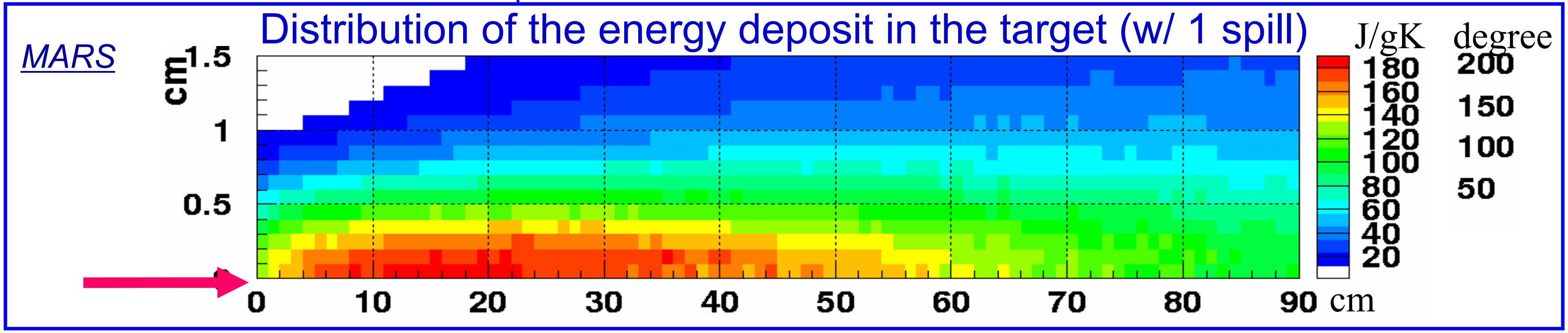




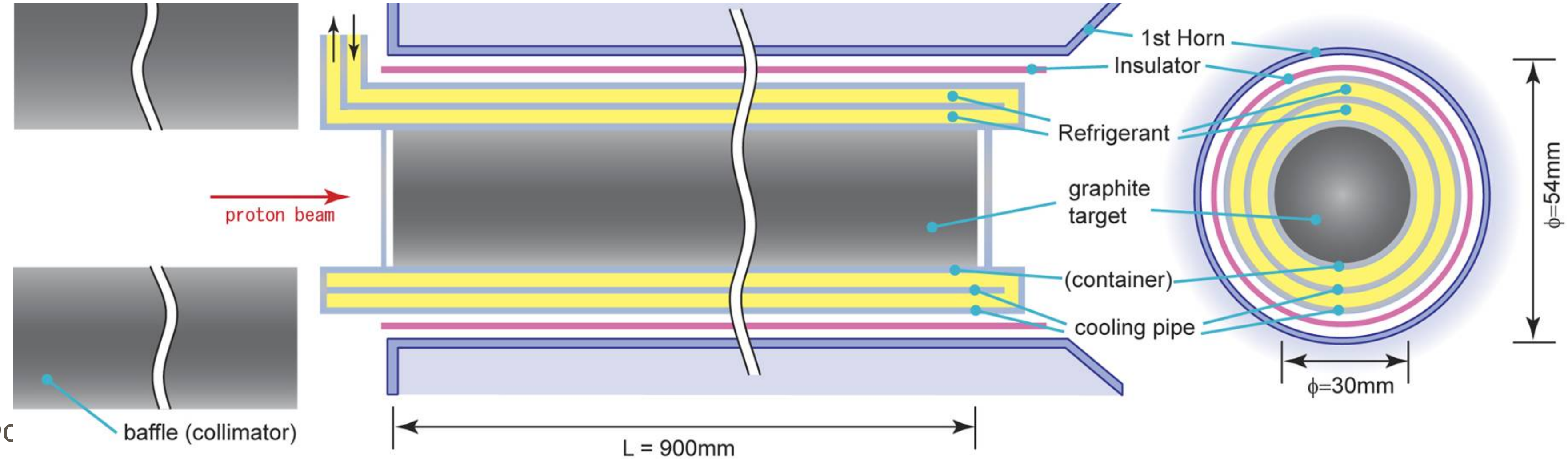
Target : Conceptual design

- Core: Isotropic-Graphite : IG-43 (Toyo Tanso Co. Ltd)
  - Energy deposit… Total: 58kJ/spill, Max:186J/g

    → $\Delta T \approx 200K$. $\sigma_{eq} = 7.42$ [MPa] ↔ Tensile strength = 37.2 [MPa]

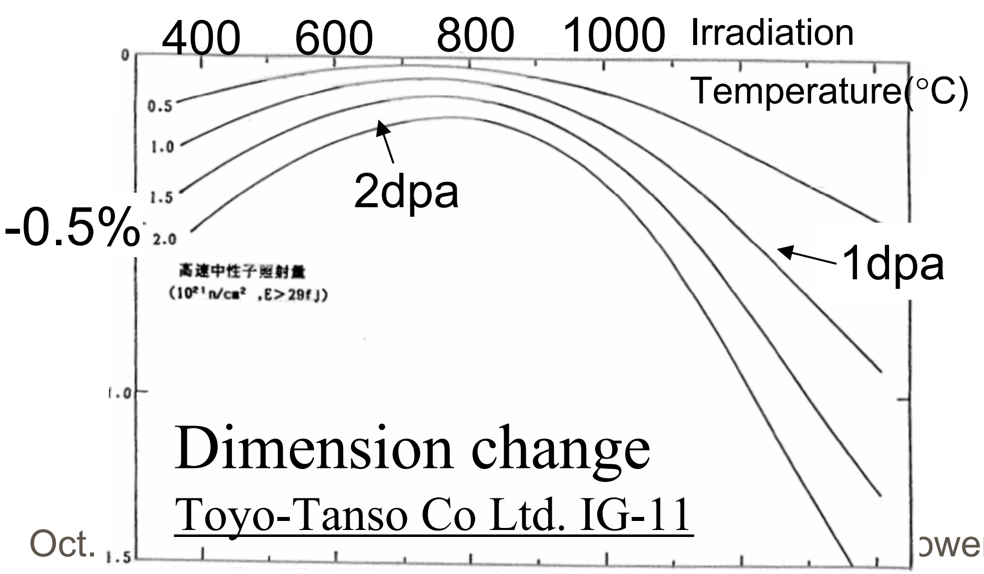


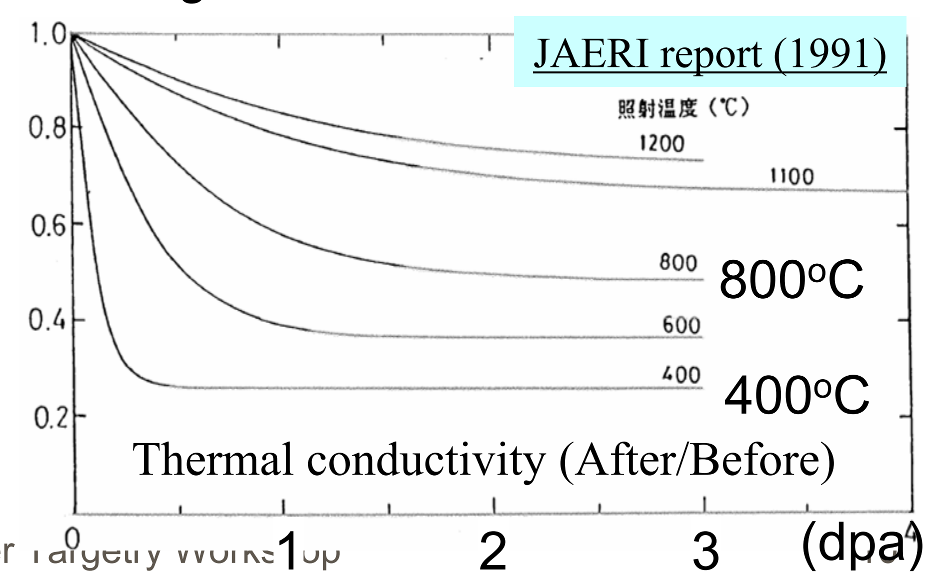
- Co-axial 2 layer cooling pipe: Graphite / Ti-6Al-4V, Helium cooling



Irradiation Effect of Graphite

- Expected radiation damage of the target
  - The approximation formula used by NuMI target group : 0.25dpa/year
  - MARS simulation : 0.15~0.20 dpa/year
- Dimension change … shrinkage by ~5mm in length in 5 years at maximum.
  ~75μm in radius
- Degradation of thermal conductivity … decreased by 97% @ 200 °C
  70~80% @ 400 °C
- Magnitude of the damage strongly depends on the irradiation temperature.
  - It is better to keep the temperature of target around 400 ~ 800 °C



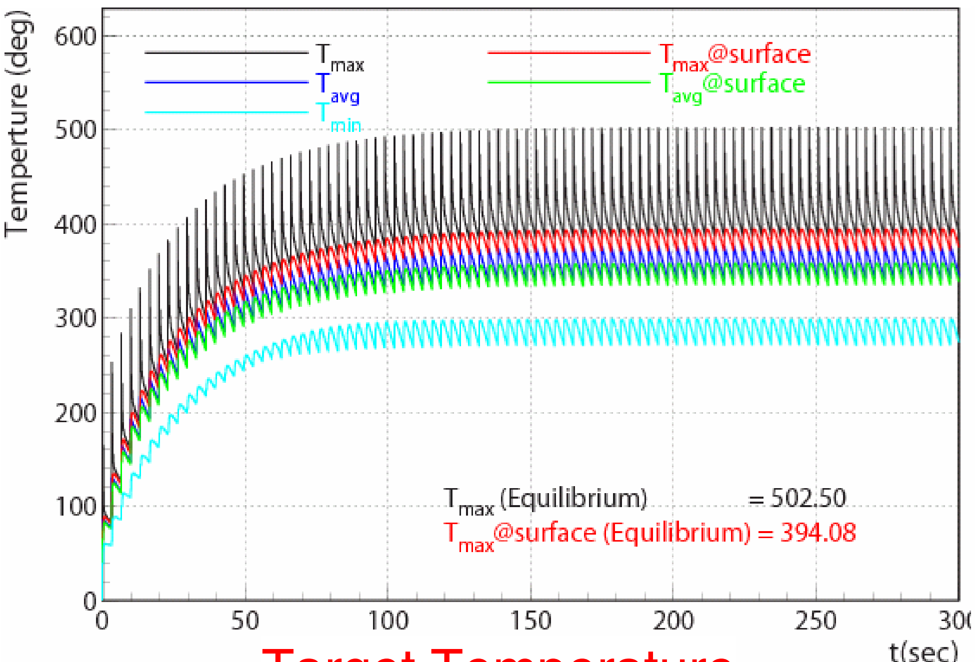


Target cooling : Water or Helium?

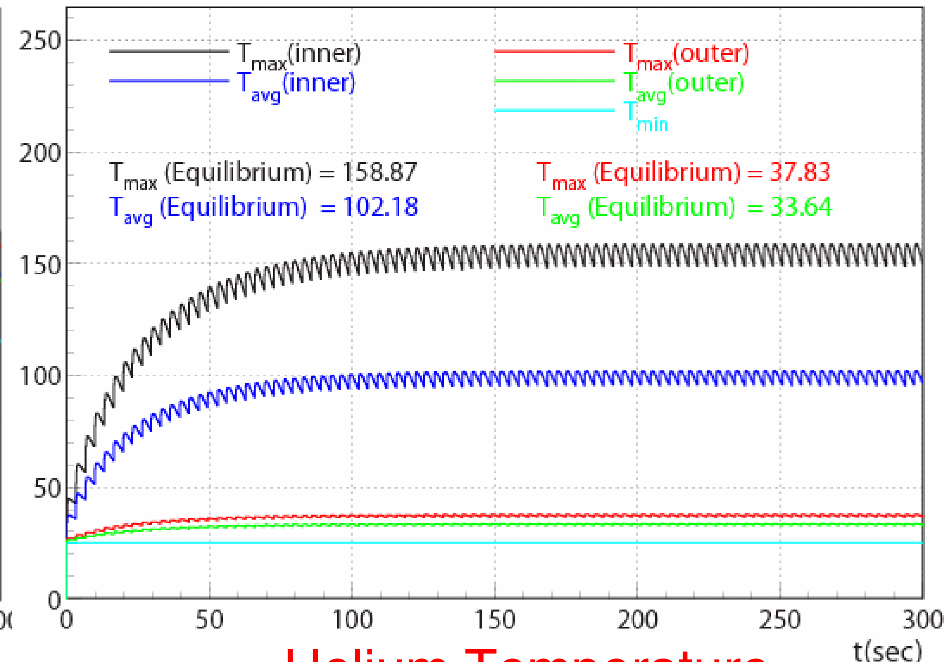
	Water Cooling	Helium Gas cooling
Advantage	☺Very Efficient ← High Heat transfer ratio ☺ Already tested. ☺ Simple circulation system	☺We can control T_{target} to minimize the irradiation effect. (T_{target} = 400 ~ 800 °C) ☺ Reduce radioactive waste water ☺ No target container is needed
Disadvantage	☠large Irradiation effect ← $T_{target} \leq 300°C$ to avoid the water boiling: T_{target} @ surface < 100°C ☠Target container is needed. ☠ΔP_{water}= ~2MPa due to the temperature rise by a beam hit. ☠Huge radioactive waste water	☠ Very High flow rate ~ 2000 l/min [0.5MPa] ~ 12000 l/min [0.1MPa] ☠ Circulation system is complicated. ☠ Special treatment for the high temperature gas (200°C) is necessary.

FEM simulation of He cooling

- Assumptions: 0.19MPa
  He Initial temperature: 25 °C
  He flow rate: 6000 [l/min] → 194 [m/sec]
  Heat convection rate: 820 [W/m²/K]



Target Temperature

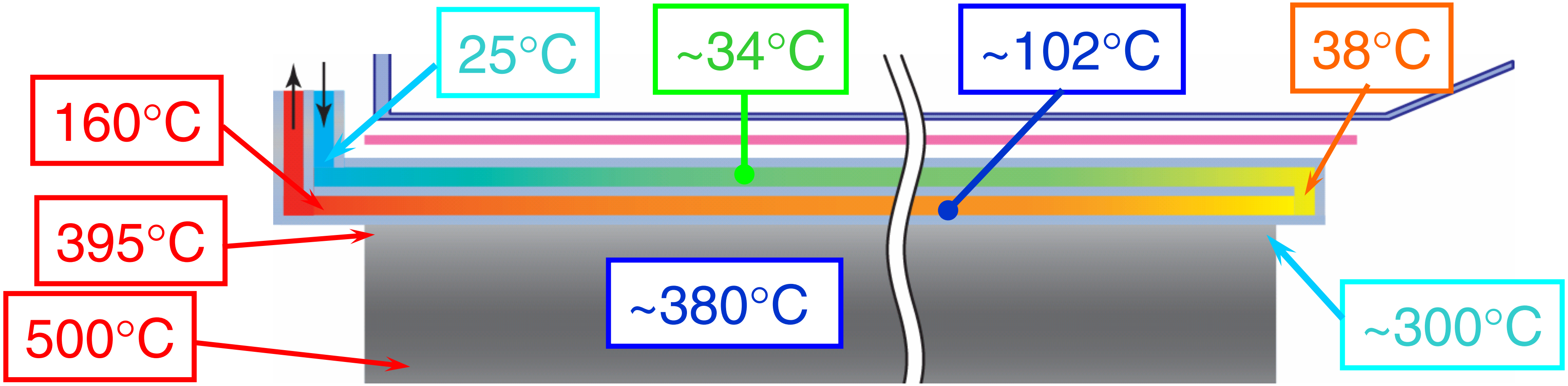


Helium Temperature

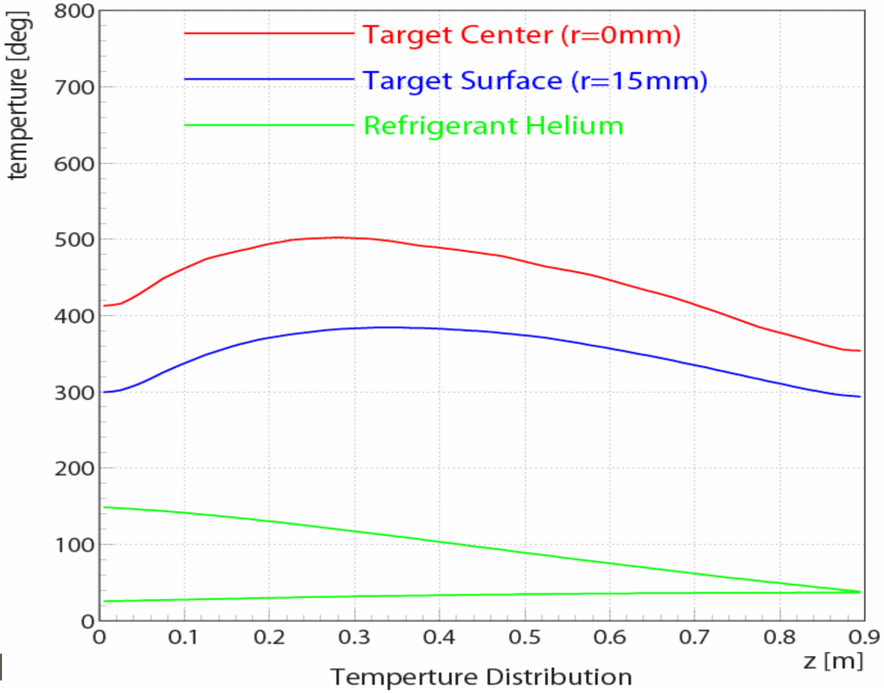
Max: ~ 500 °C
Min: ~ 300 °C
Avg. : ~380 °C

Max: ~160 °C
(ΔT = 135 °C)
Avg. : ~40 °C

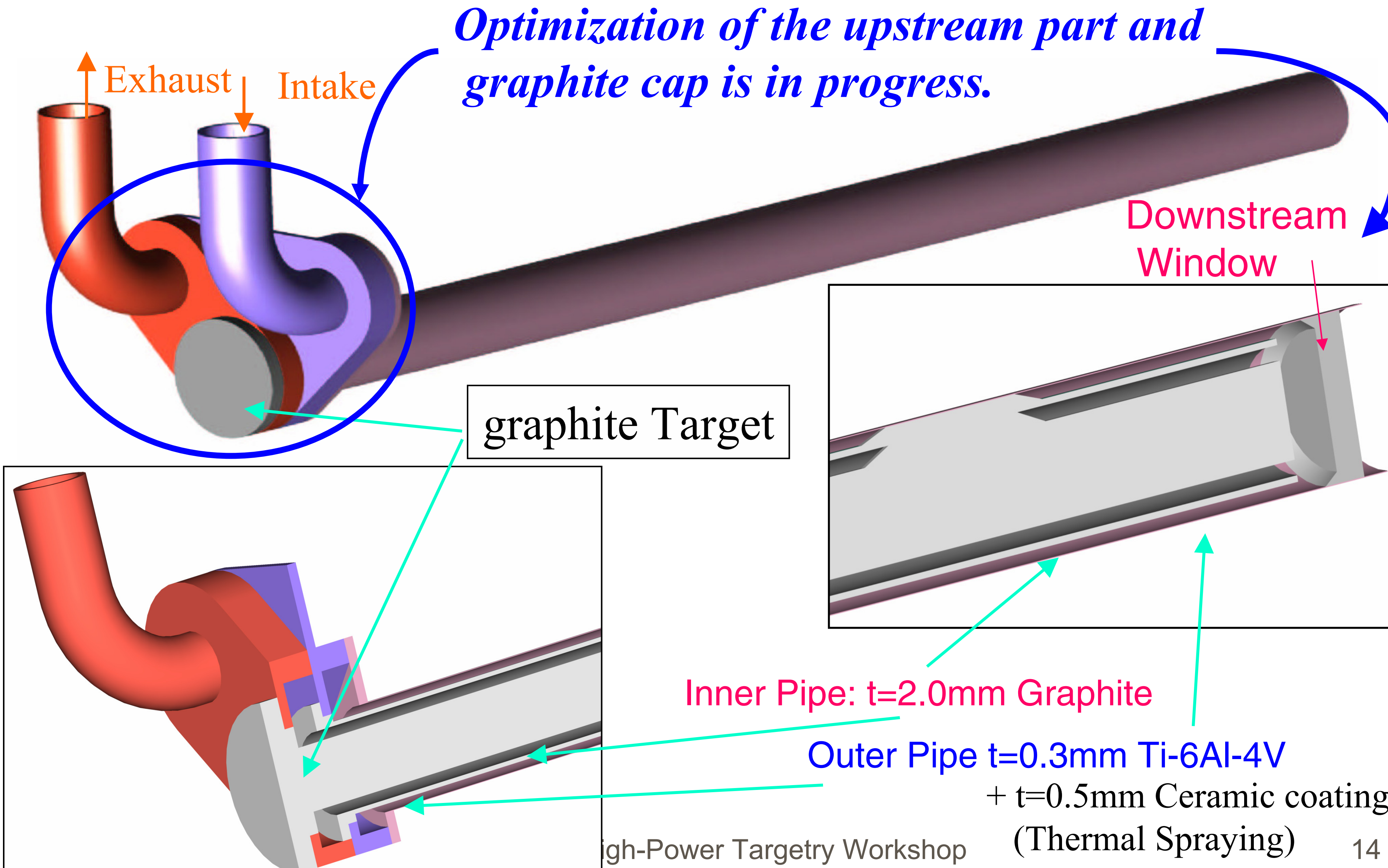
FEM simulation of He cooling



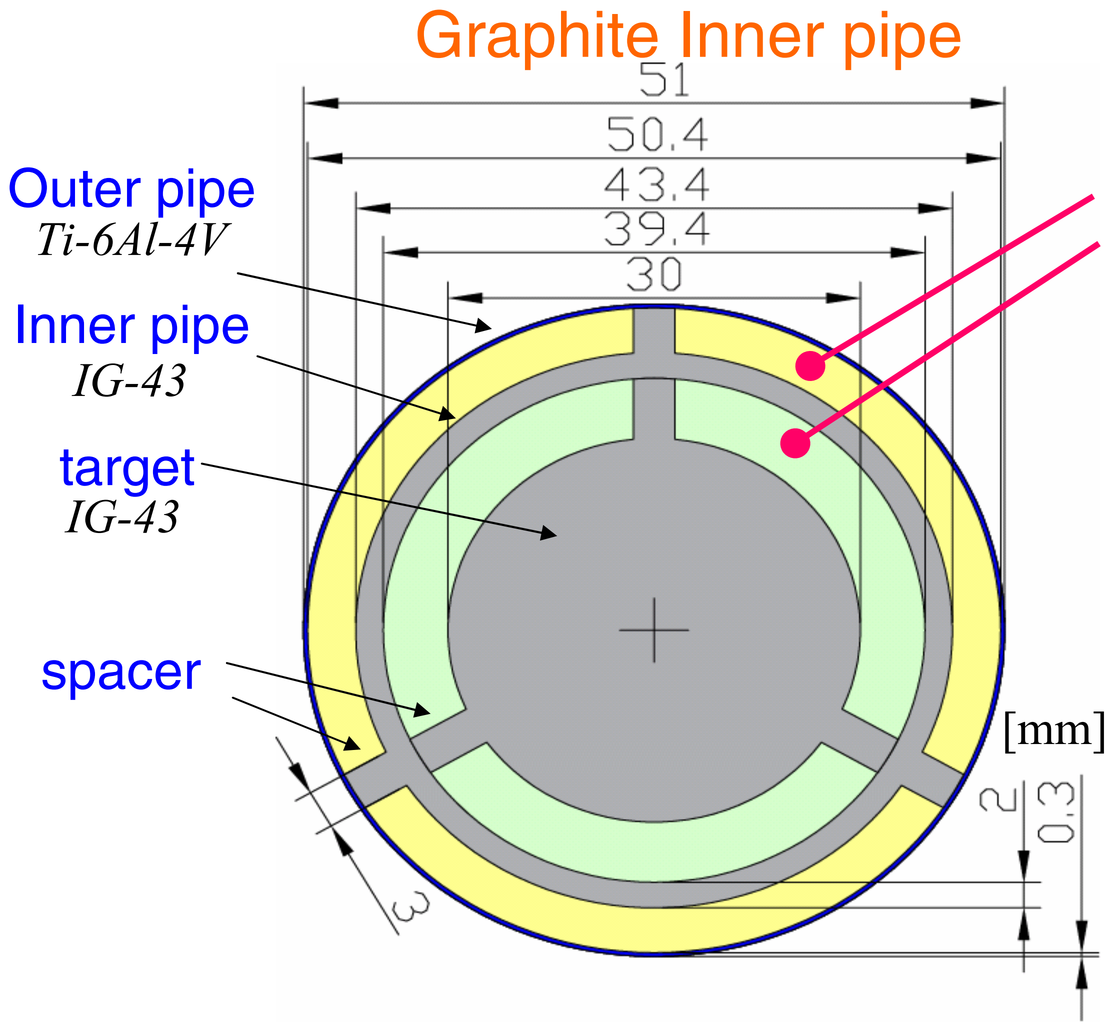
- Assumptions: 0.19MPa (←Possible pressure drop at the downstream of target is taken into account.)
- He Initial temperature: 25 °C
  He flow rate:
  6000 [l/min] → 194 [m/sec]
  Heat convection rate:
  820 [W/m²/K]



Prototype design of Target system



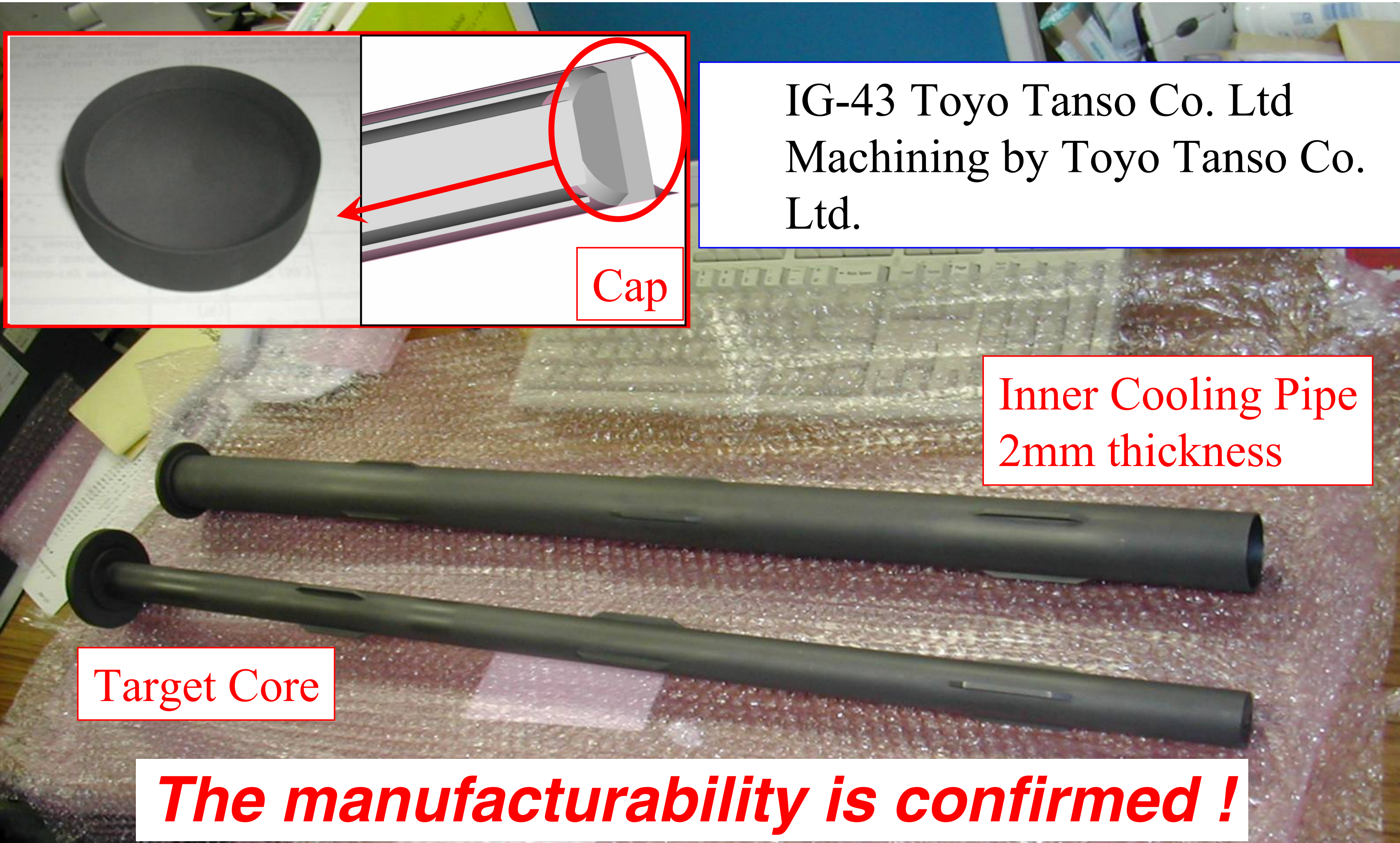
Target / Cooling pipe design

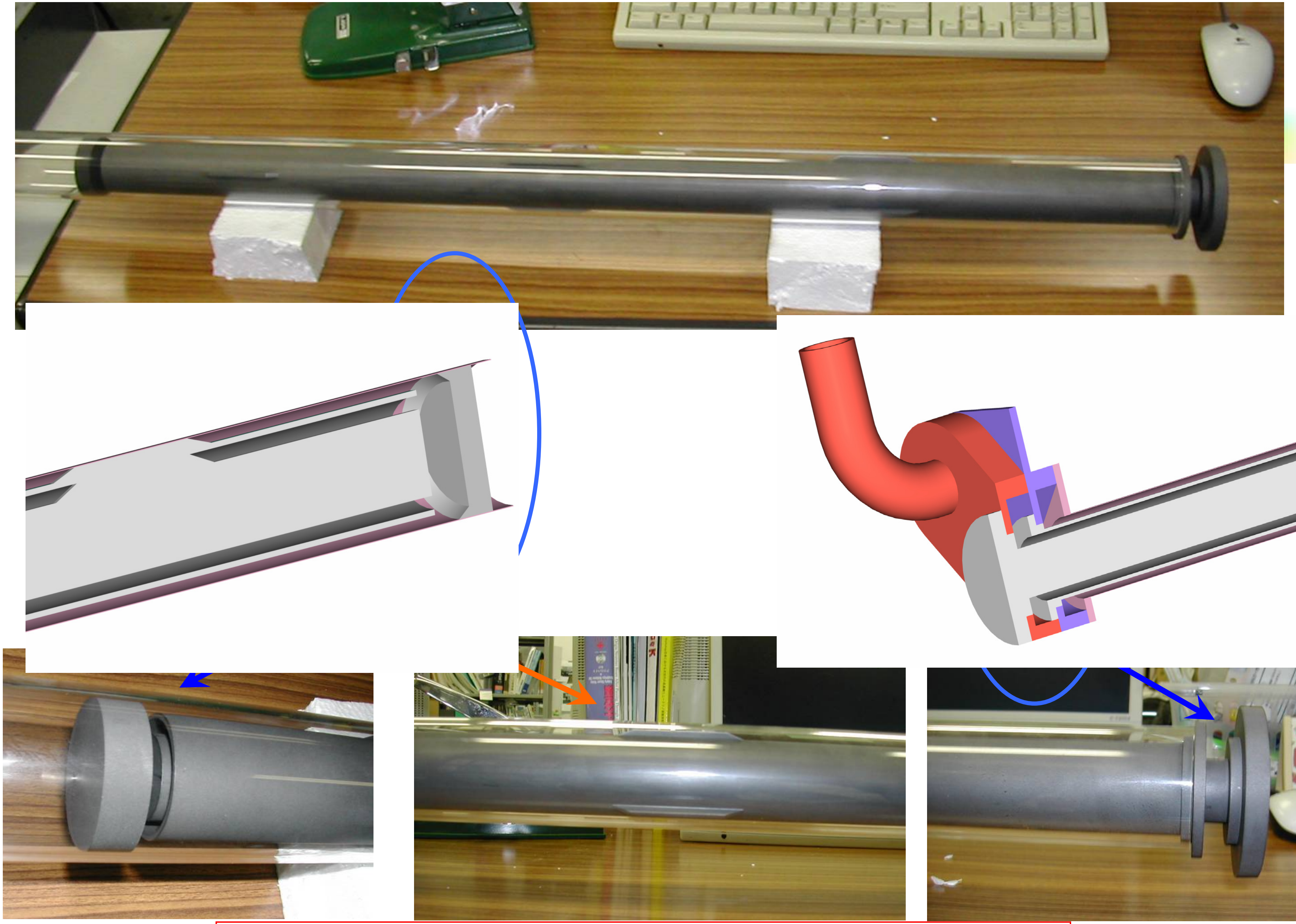


- Sectional area $= 5.1\times10^{-4}$ [m^2]
- Pressure drop = ~0.8MPa

cf. Inner radius of 1st horn = 54mmϕ

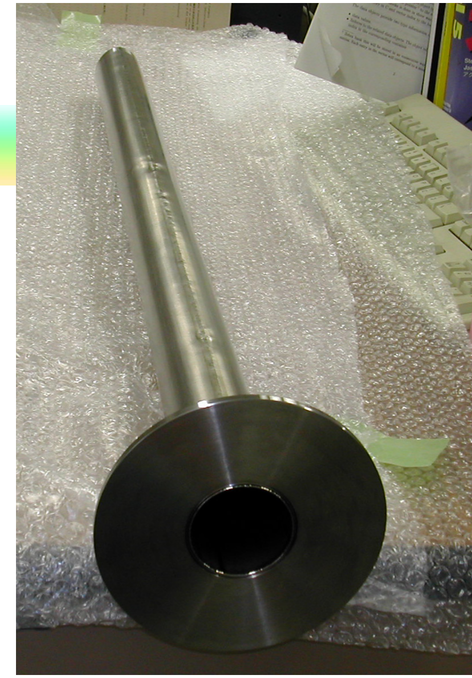
Mechanical Prototype of Graphite Parts





Assembled with the acrylic-plastic outer-pipe

Prototypes of Ti-Alloy parts

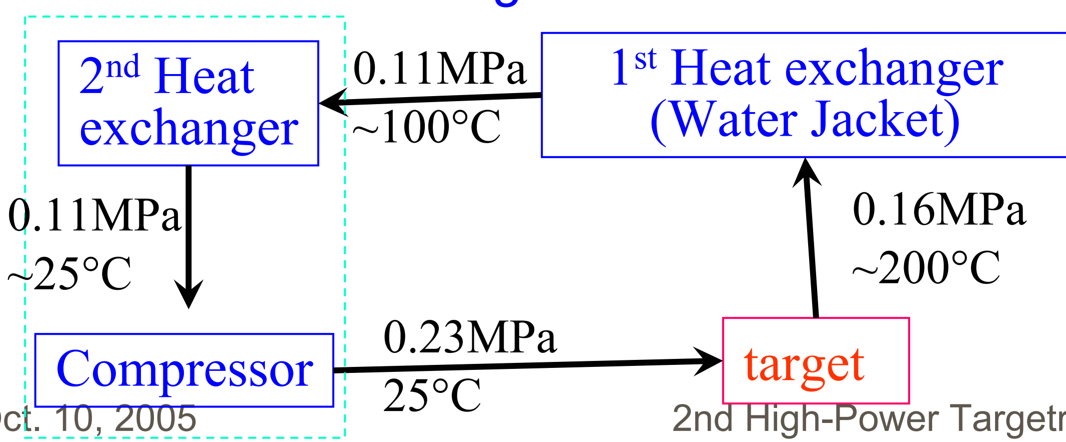


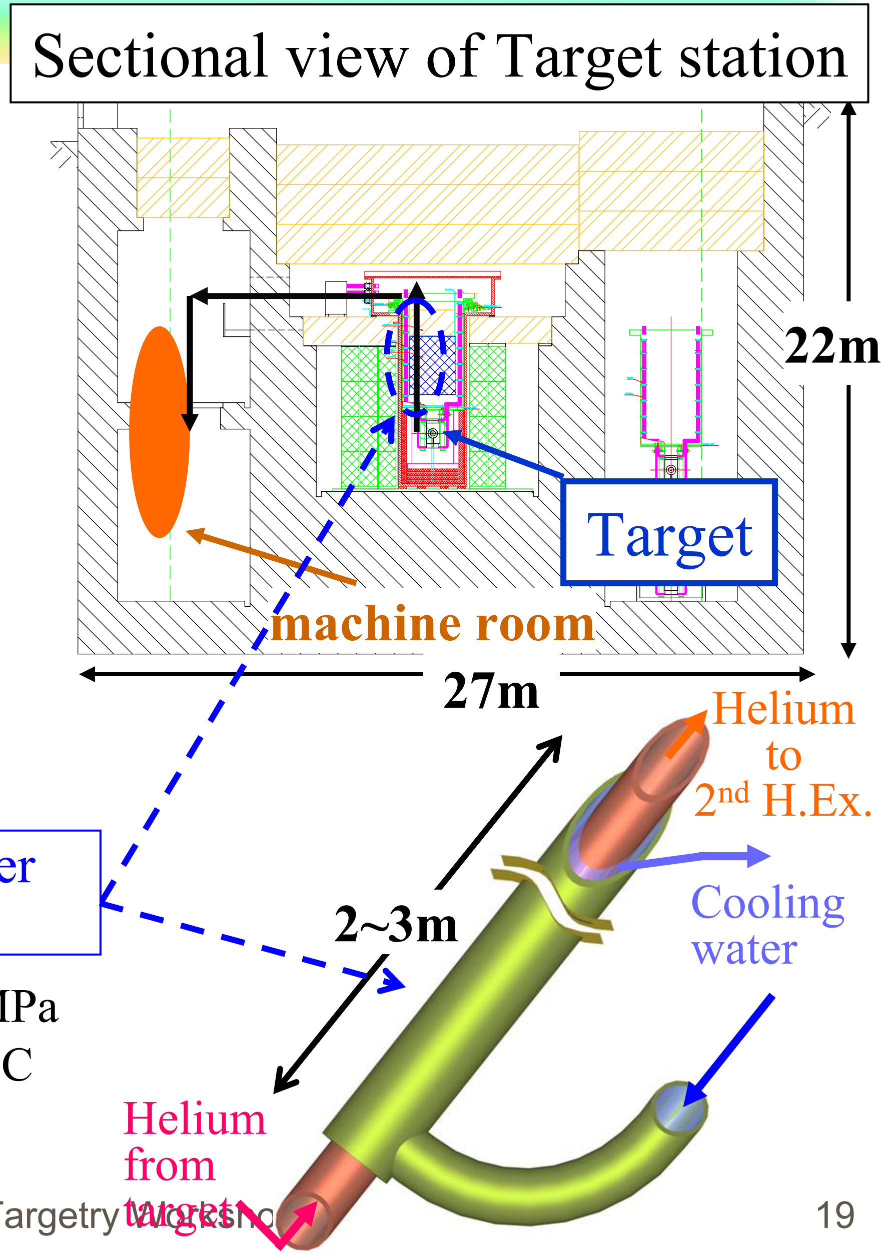
- Check the manufacturability
  - Made Ti-6Al-4V pipe with 0.3mm thickness by TIG welding
    - Pass the Helium leak test and pressure proof test
  - Test of the brazing between Ti-6Al-4V and Graphite
    - Pretreatment for Ti-alloy (Ni-plating) is effective.
    - We have narrowed down the blazing material

Brazing material	Strength [MPa]		note
	Tensile	Shearing	
BAg-8 + Ti (2%)	8.6	13.3	BAg8(JIS Z3261) …Ag72%+Cu
BPd-4	11.3	15.6	Pd 15% + Ag 65% + Cu

Helium circulation system

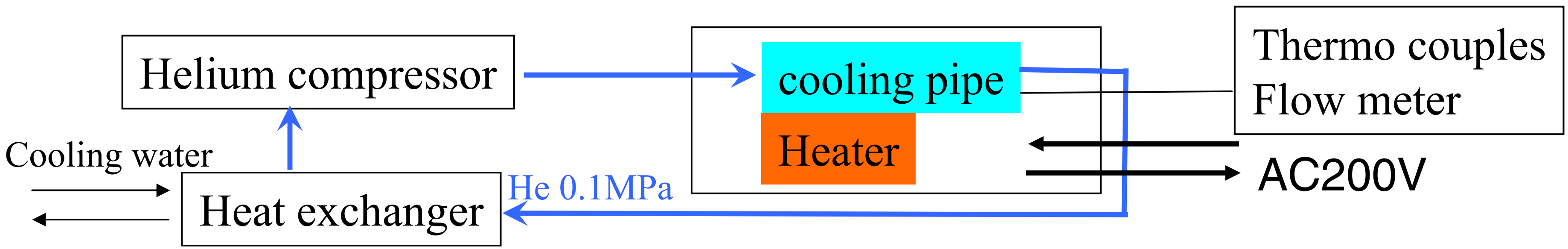
- Helium system is placed at the machine room of the TS.
  - Helium compressor
  - 1st Heat exchanger (Water Jacket)
    - The outflow of heat from the exhaust helium (~200°C) to the TS should be minimized to keep the alignment precision.
    - The helium pipe will be surrounded by the water jacket. → It work as a heat exchanger.
  - 2nd Heat exchanger





He cooling test (1/20 scale)

- Measure the cooling power using the heater which simulates the heating at the target.



- The flow rate of Available Helium-compressor is 1/20 of actual system
  - Small size heater and cooling pipe is used so that the helium flow is turbulence as well as actual target cooling.
  - Heating power is also 1/20.
- Heat exchanger for this test is not commercially available → We made the double-tube for the heat exchange using Swagelok® joints.

Test of 1st Heat Ex.

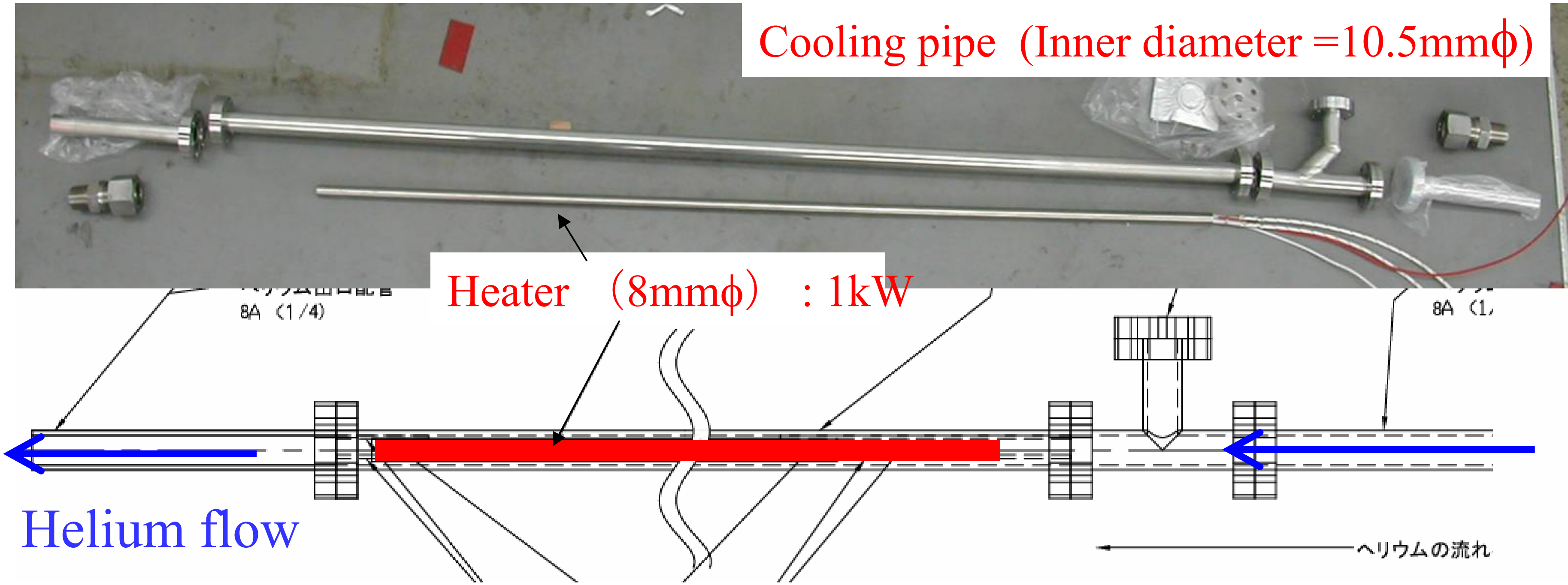
He cooling test parameter

	1/20 test	Actual equipment
Inner/Outer radius of flow path	8mmϕ / 10.5mmϕ	30mmϕ / 39.4mmϕ
Heating power	~1KW / 600mm	~20kW / 900mm
Helium flow rate	1[g/s] / 370[l/min]	24[g/s] / 9000[l/min]
Helium flow speed	170[m/s]	290[m/s]
Reynolds number	~3500	~22000
Heat transfer coeff.	670 W/m²/K	~790 W/m²/K
Helium ΔT	200K	200K
Heater Temp.	~300°C	~570°C

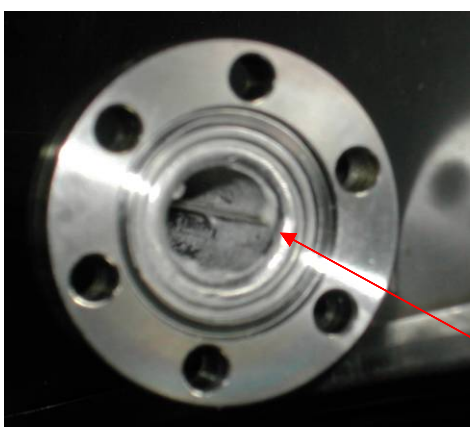
1/20

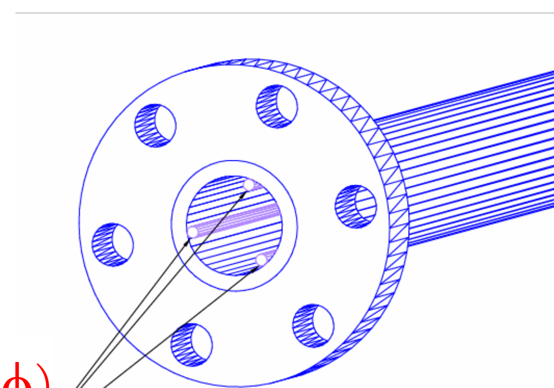
← Turbulence →

Test setup



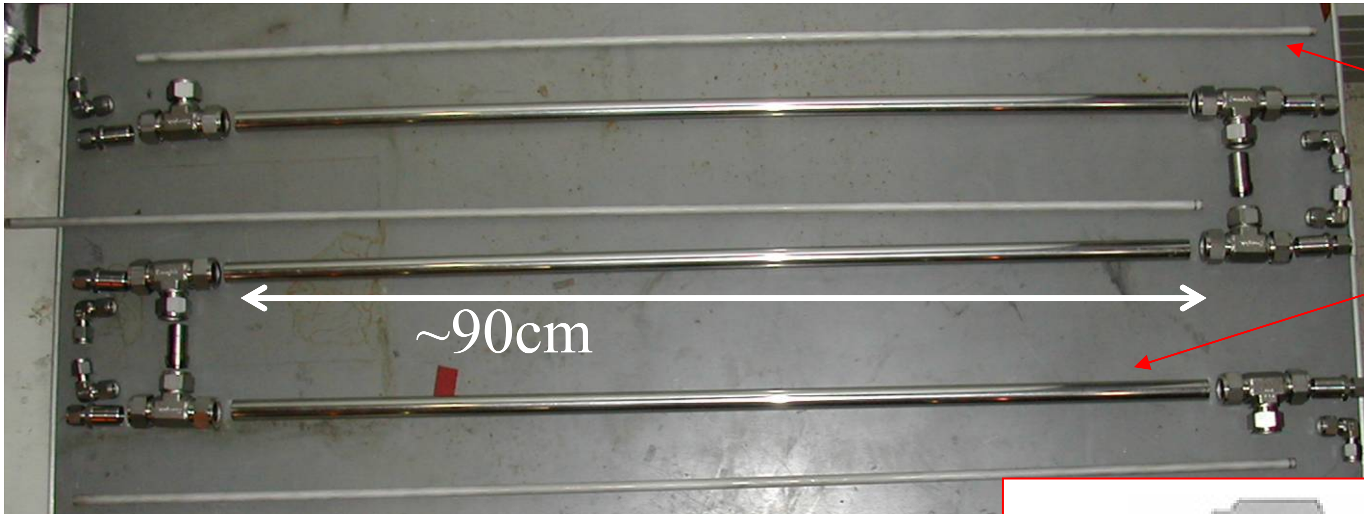
Cooling pipe (Inner diameter =10.5mmϕ)
Heater (8mmϕ) : 1kW
8A (1/4)
Helium flow
ヘリウムの流れ





Ceramic spacer (1mmϕ)

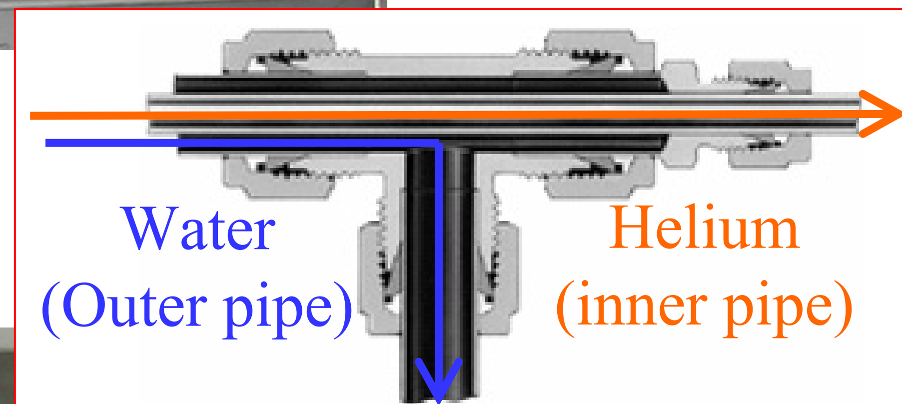
Heat Exchanger



Expectation:

Helium: 200°C → 25°C @ 1g/s

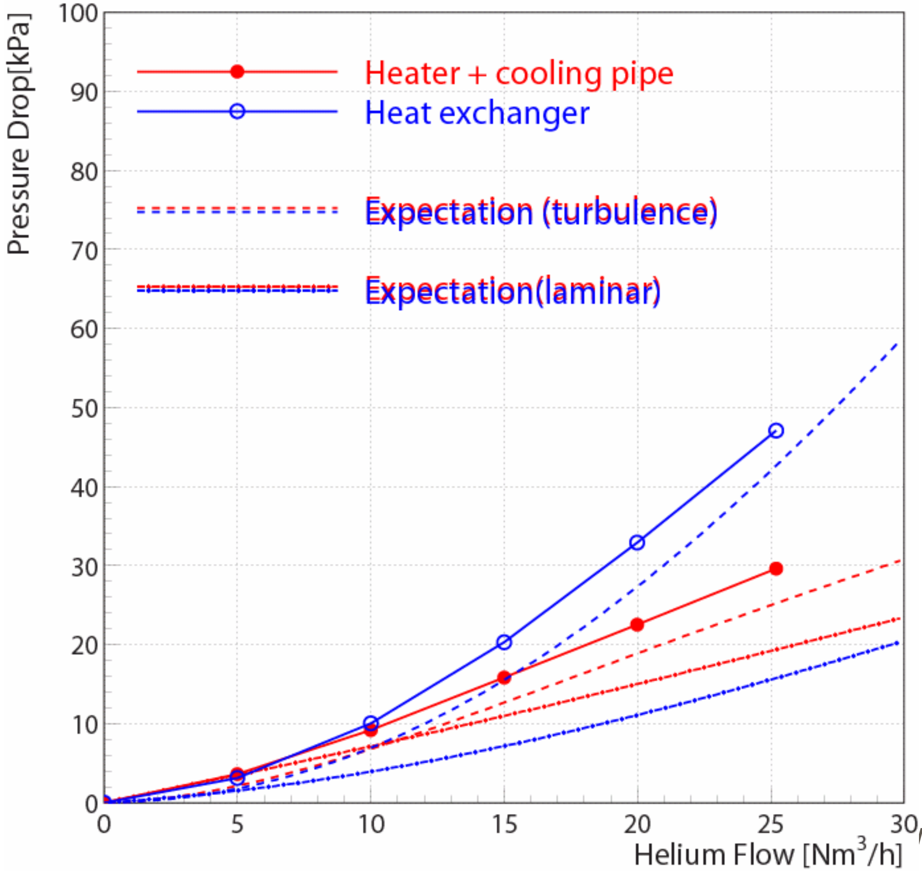
Water: 15°C → 17°C @ 10 l/min

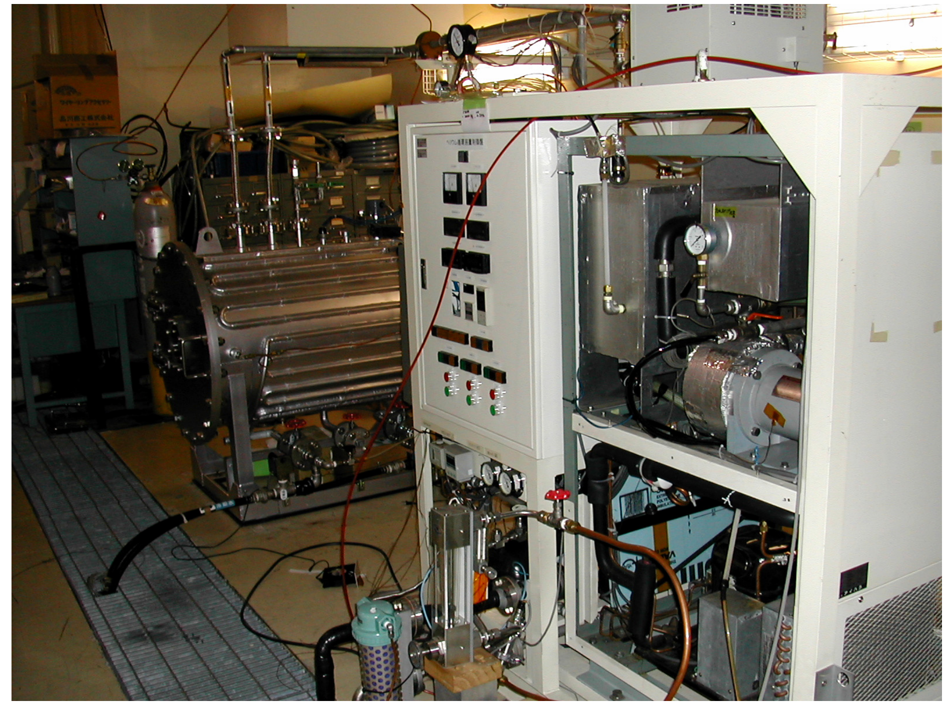


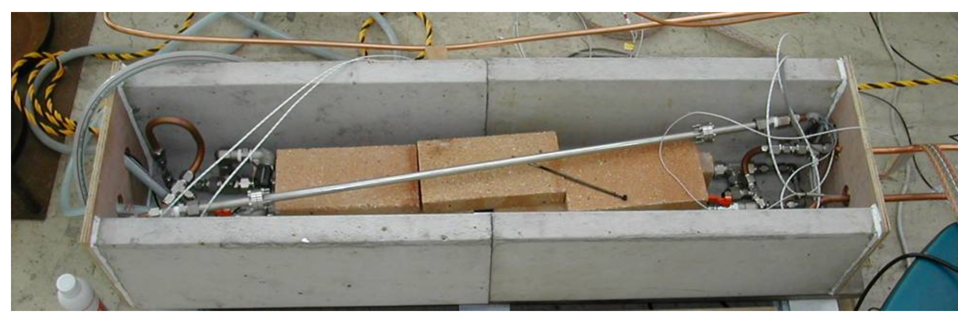
This heat exchanger has the purpose of the test of the water-jacket for the helium cooling pipe (1st heat exchanger) in the actual system.

He flow @ test setup

- Helium mass flow rate of ~1.2[g/s] is achieved. (←1g/s is expected)
- Measured pressure drop indicates the flow is turbulence.







He cooling test result

	measured	expected
Heating power	~1.1KW	
Helium flow rate	1.2[g/s] / 220[l/min] @ 0.19MPa	
Helium flow speed	100[m/s] @ intake (0.19MPa) 200[m/s] @ exhaust (~0.16MPa)	
Heat transfer coefficient	640 $W/m^2/K$ @ middle of target	795 $W/m^2/K$ (average)
Helium ΔT	182K	178K
Heater surface Temp. @ center	180°C	~167°C

- The heat exchanger works well.
  - Helium: 185°C→14°C @ 1.2g/s
  - Water: 13.7°C →16.3°C @ 8.6 l/min

Summary

- T2K ν experiment … Neutrino Oscillation search. 2009~
- J-PARC … Japan Proton Accelerator Research Complex
  - Linac + 3GeV PS + 50 GeV PS → MLF, Hadron beam, ν beam
  - Construction is in progress.
  - Neutrino beam line ... 1St application of Off-axis Narrow band beam.
- Neutrino Target
  - Graphite Bar + Co-axial 2-layer cooling pipe (graphite, Ti-Alloy)
  - Helium Gas Cooling
    - Several difficulties are found in the water cooling.
    - The cooling capability is checked by the FEM and the 1/20-scale test.
  - 1st Prototype of the target and cooling pipe is designed.
    - Mechanical prototypes of the graphite parts are made.
    - Welding of Ti-Alloy and the brazing between graphite and Ti-Alloy are tested.d