The JPARC neutrino target

KEK
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(For J-PARC target/monitor Group)

High-power targetry for future accelerators

Ronkonkoma, NY.

Next generation LBL experiments in Japan

"J-PARC - Kamioka neutrino project"

Baseline ~295km

Conventional ν_μ beam

Beam Energy ~1GeV

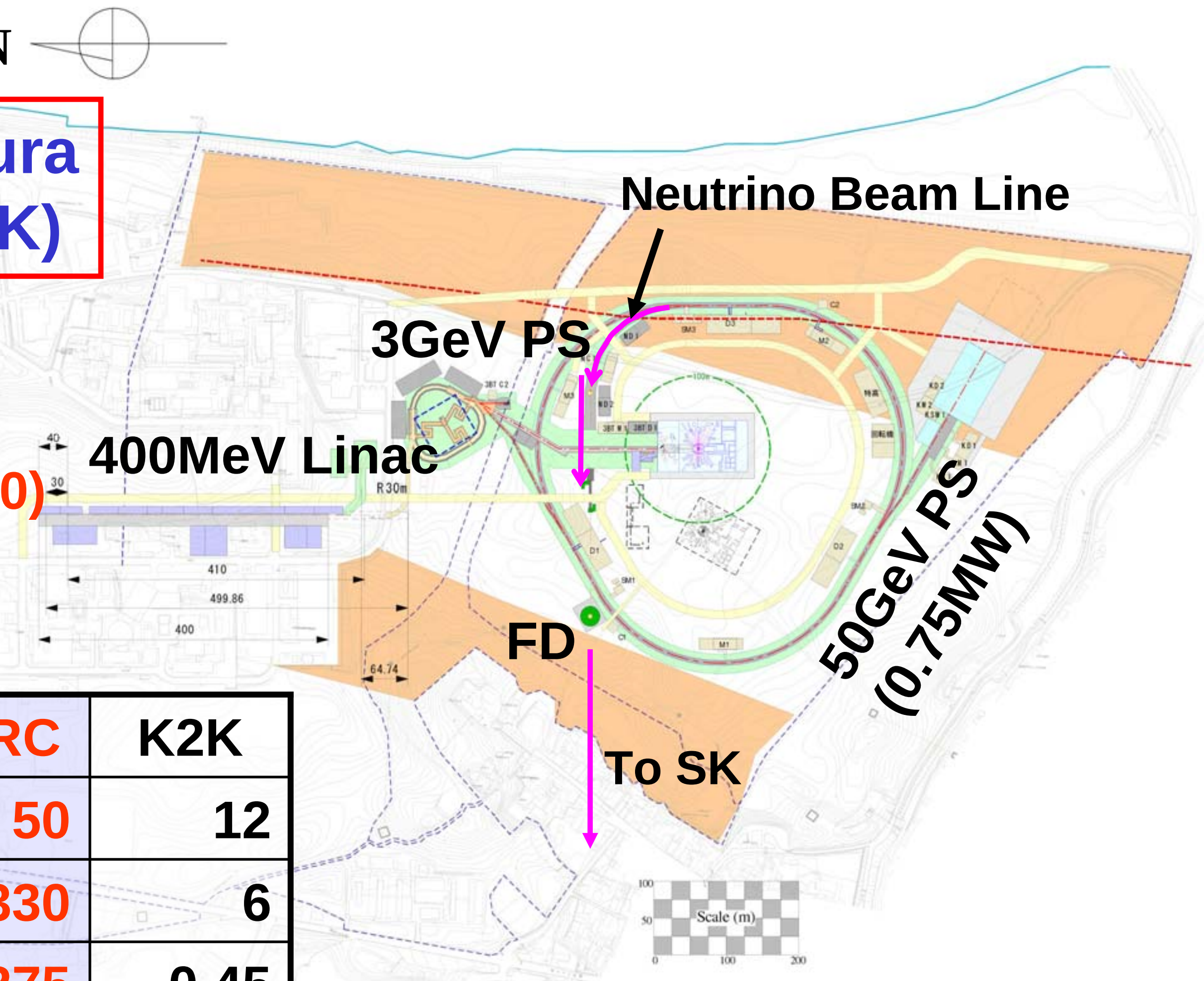
→ Will be adjusted to the oscillation maximum

Beam power	Far detector	Physics
0.75MW	Super Kamiokande(50kt)	disappearance $\nu_\mu \rightarrow \nu_X$ appearance $\nu_\mu \rightarrow \nu_e$ NC measurements

J-PARC facility

JAERI@Tokai-mura
(60km N.E. of KEK)

Construction
2001～2006 JFY
(Approved in Dec.2000)



	J-PARC	K2K
E (GeV)	50	12
Int. (10^{12}ppp)	330	6
Rate (Hz)	0.275	0.45
Power (kW)	750	5.2

JPARC neutrino beamline

Proton beam kinetic energy

50GeV (40GeV@T=0)

# of protons / pulse

3.3×10^{14}

Beam power

750kW

Bunch structure

8 bunches

Bunch length (full width)

58ns

Bunch spacing

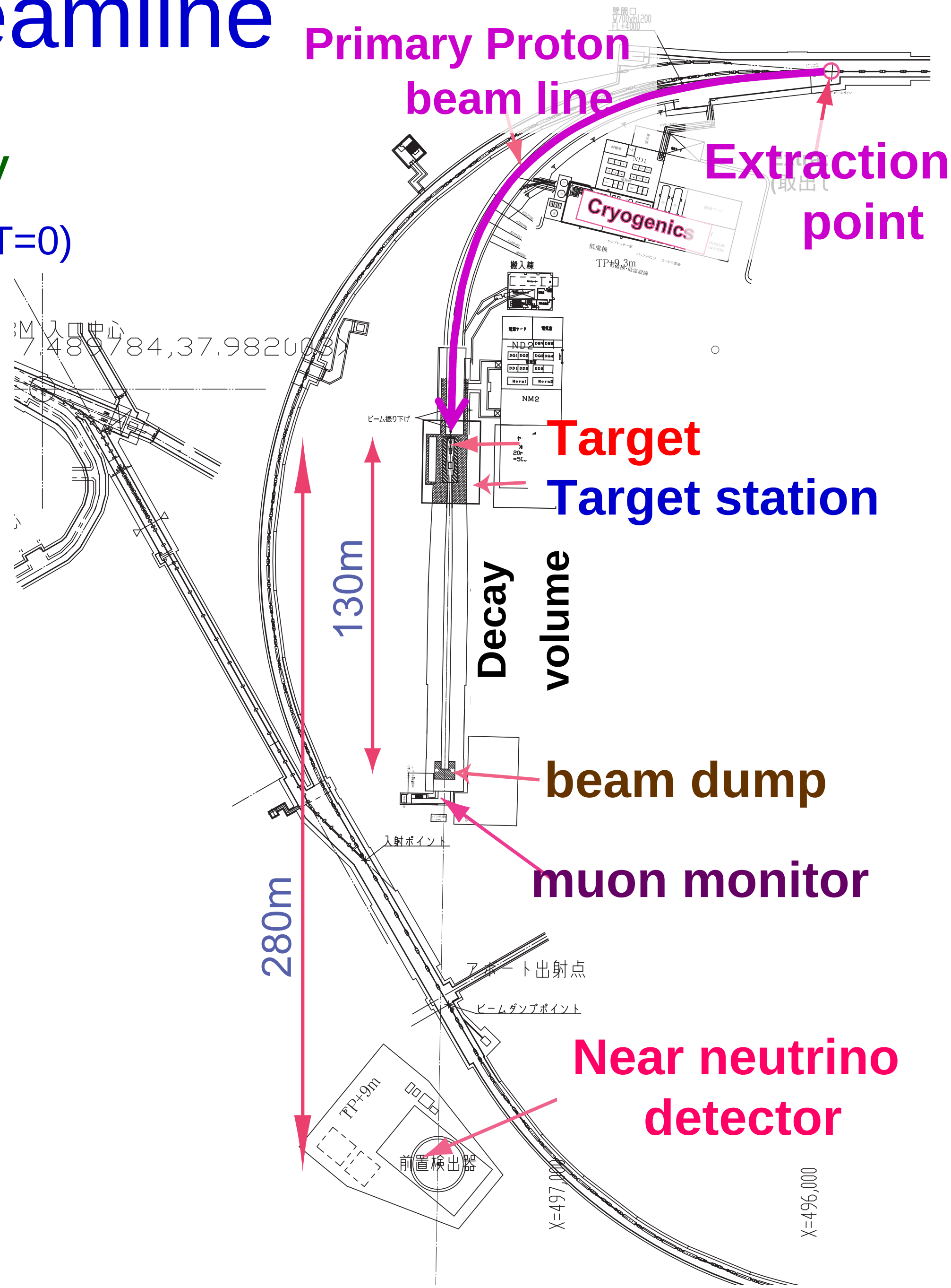
598ns

Spill width

~5μs

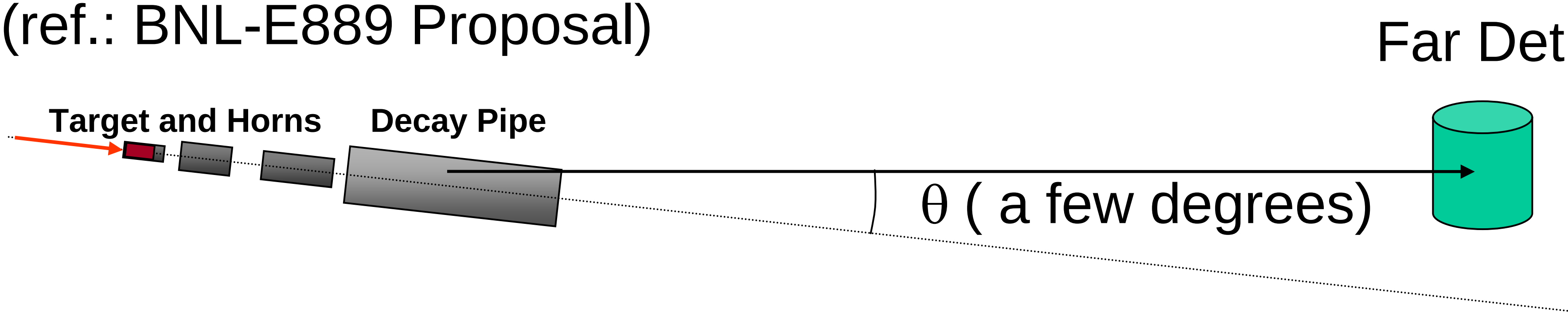
Cycle

3.53sec



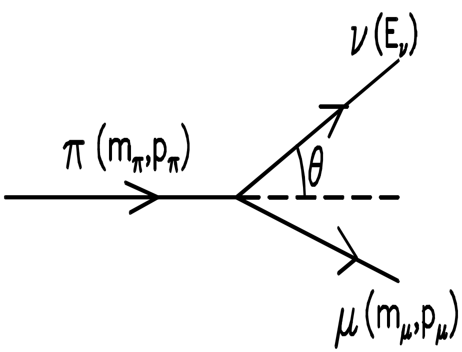
Off Axis Beam (another NBB option)

(ref.: BNL-E889 Proposal)

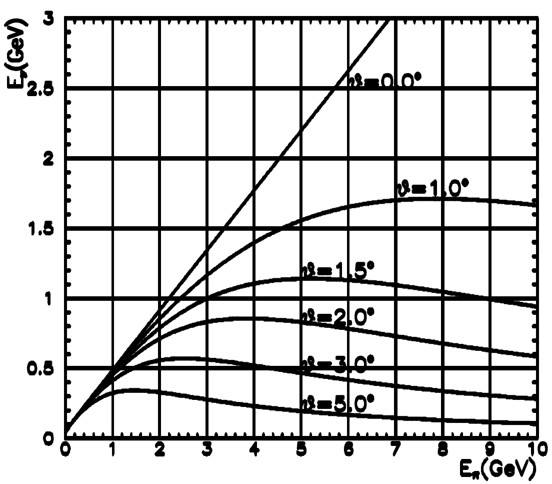


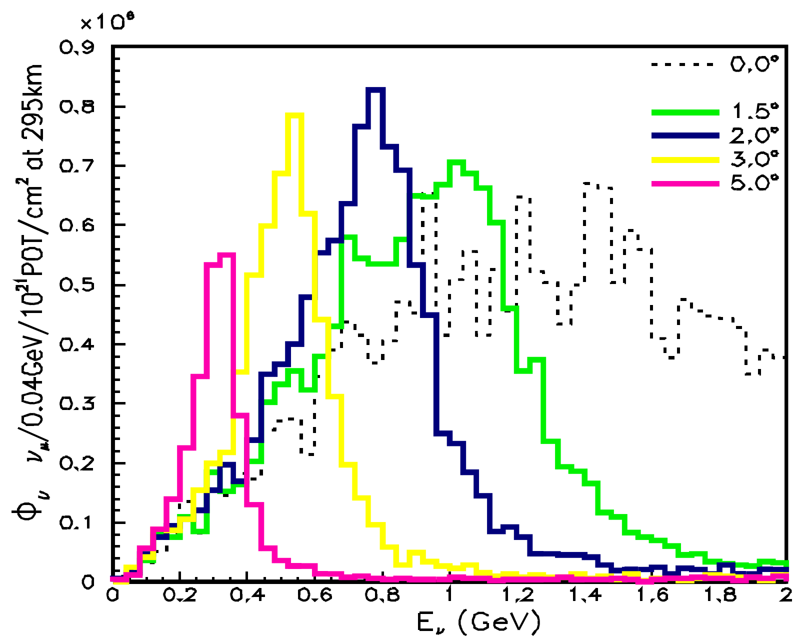
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



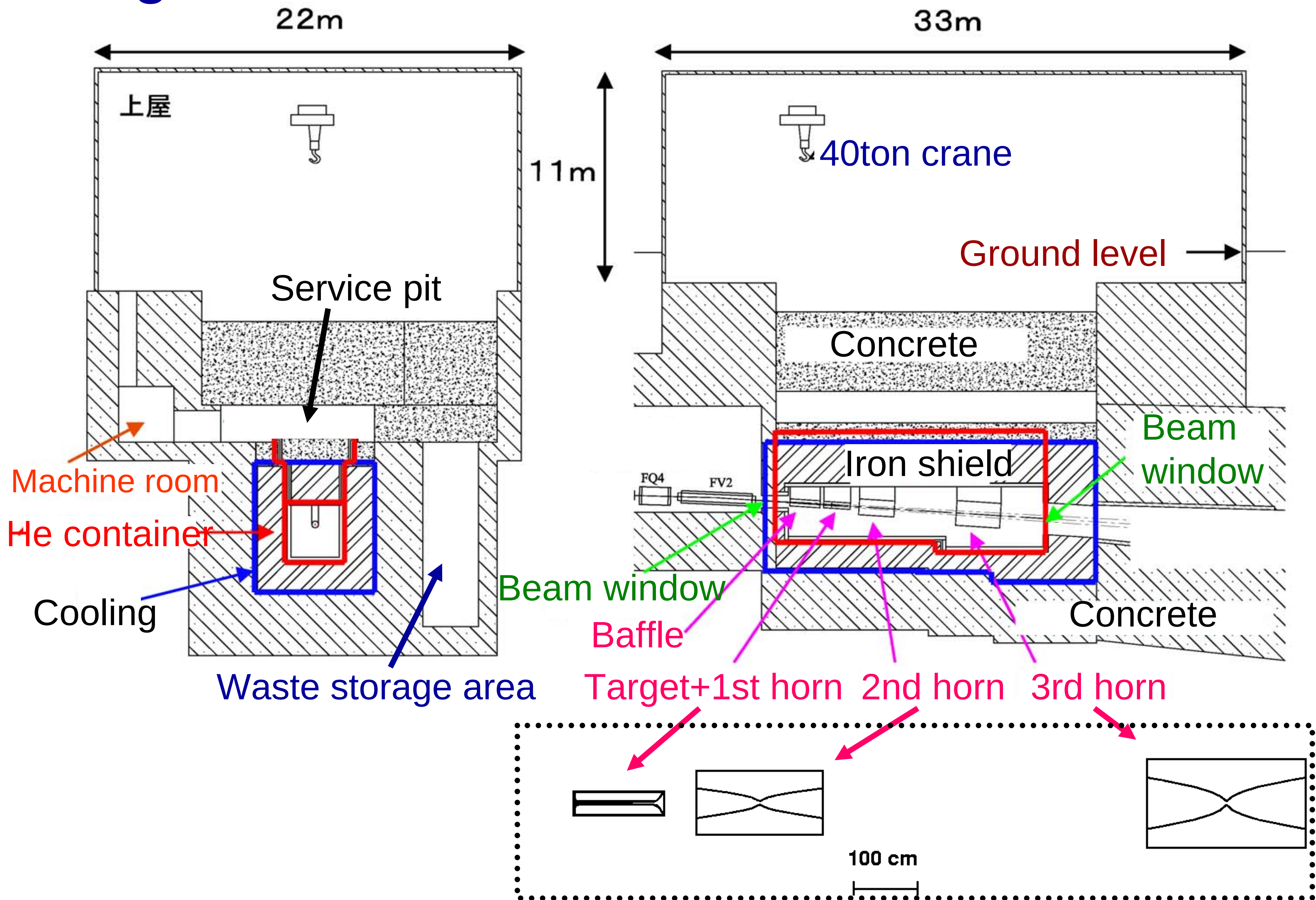
$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$





Quasi Monochromatic Beam

Target station



Target for JHF neutrino

Requirements

Solid target   Easy to handle

melting point should be high enough.

Thermal shock resistance

Candidate

→ Graphite Target

Melting point	$\sim 3550^\circ C$
Thermal conductivity	$\sim 100 W/m \cdot K$
Thermal expansion	$\sim 4 \times 10^{-6} /^\circ C$
Young's modulus	$\sim 10 GPa$

Determination of the size (radius) of the target

External conditions

- Inner radius of the horn

  minimum r_{target}~10mm

  (heat load from radiation)

  maximum r_{target}~15mm

  (pions are not well focused)

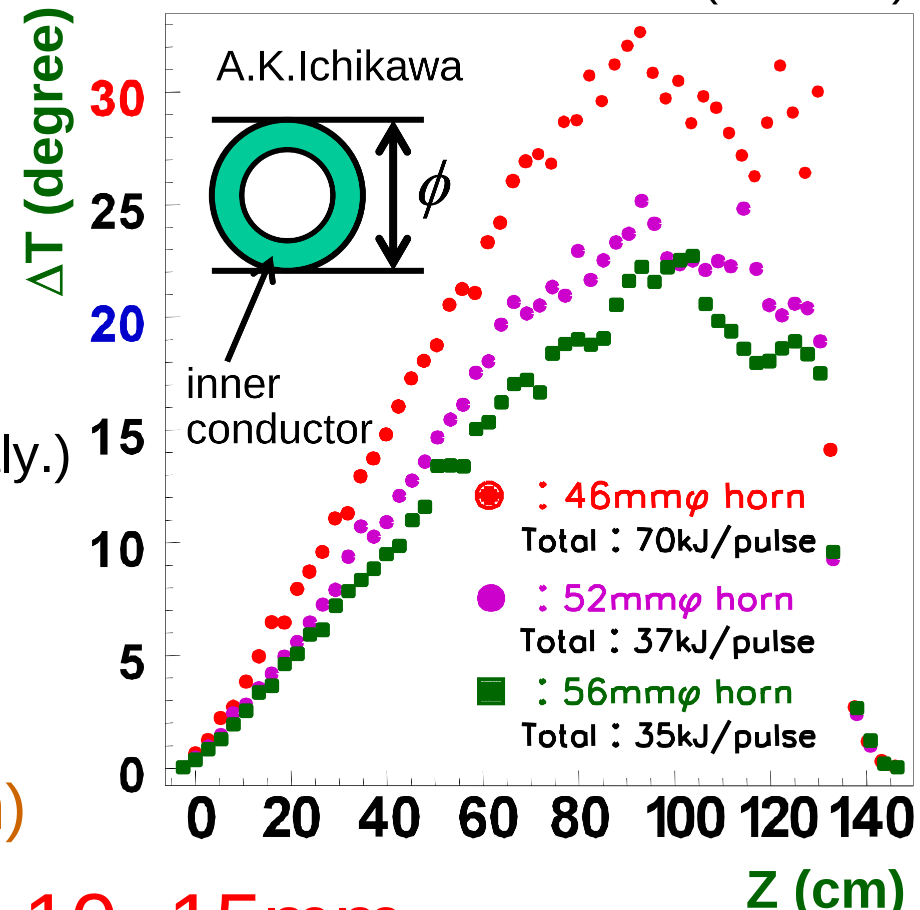
  (Target needs to be embed in the 1st horn to focus pions efficiently.)

- Size of the beam at the target

  Larger than σ_r~0.4cm

  (for 24π mm mrad beam)

Temperature rise / pulse of the inner conductor (1st horn)

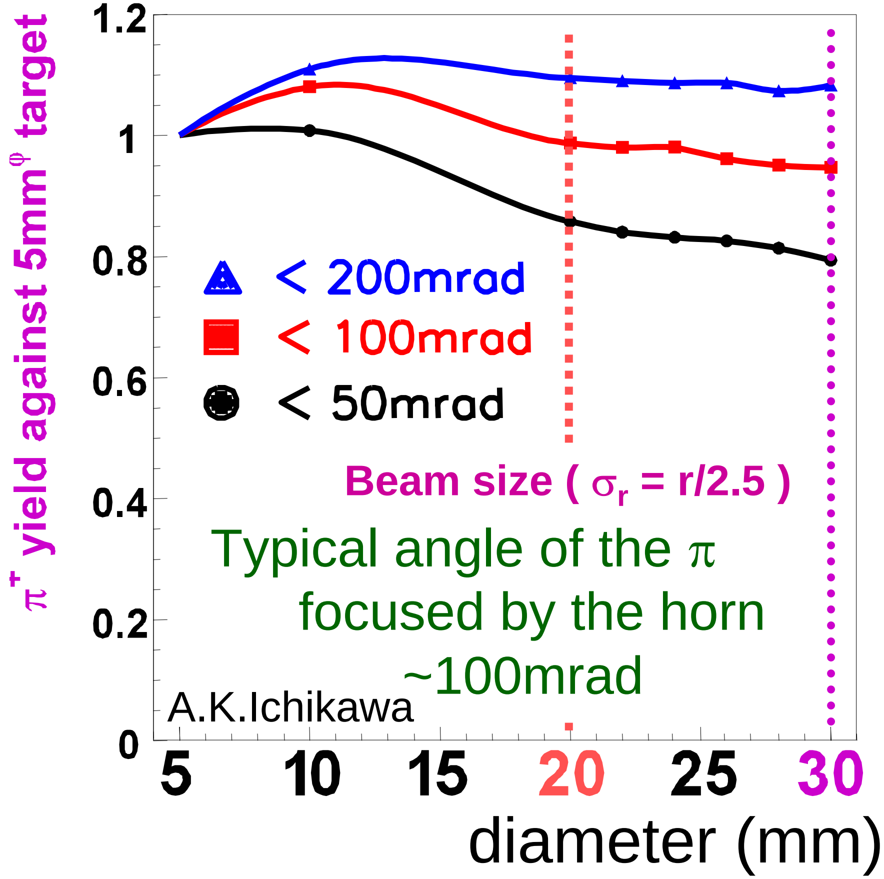


Radius of the target : 10~15mm

Determination of the size (radius) of the target

Yield of pions (=neutrinos)

Smaller is better (reduce the absorption of pions)



But even if we change diameter from 20mm to 30mm, the difference of # of π is ~5%

↓

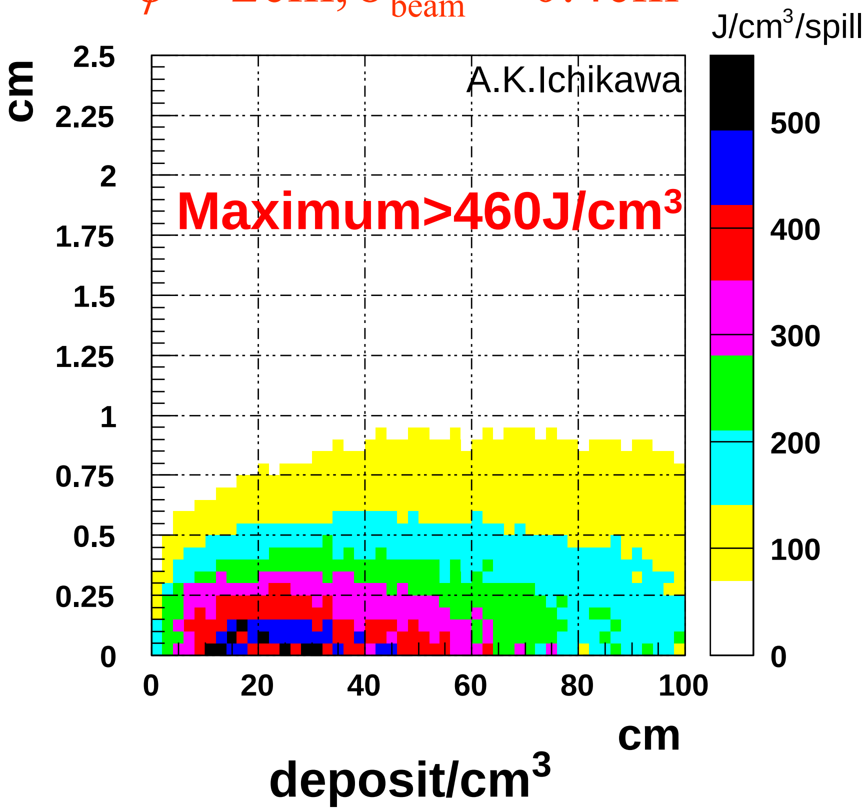
effect of the π absorption in this region is fairly small

Energy deposit in the target

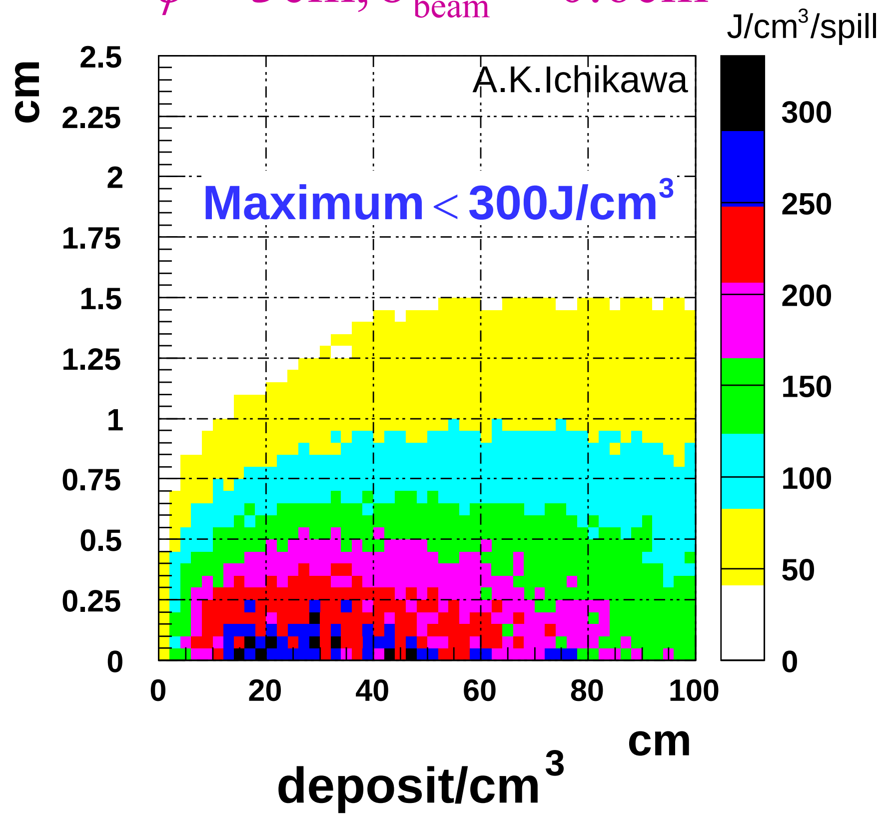
Target and beam size dependence

Carbon (density 1.81g/cm^3)

$\phi = 2\text{cm}, \sigma_{beam} = 0.4\text{cm}$



$\phi = 3\text{cm}, \sigma_{beam} = 0.6\text{cm}$



This time, we used the target with **ϕ=30mm**

in the calculations and the simulations.

Estimation the temperature rise

Material properties used in the simulation

Temperature dependences

have to be taken into account.

Specific heat

→ increased at higher temp.

→ Temperature rise is overestimated

Maximum temperature rise (ΔT_{max})

Constant ~240K

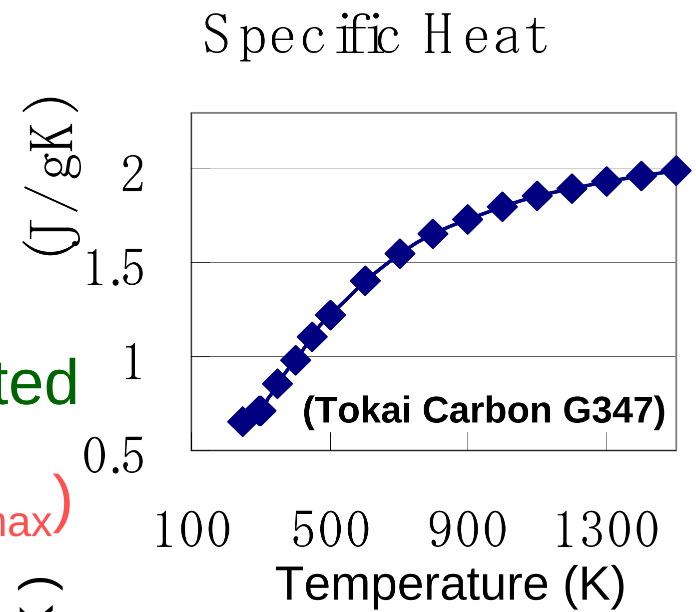
Temp. dependent ~170K

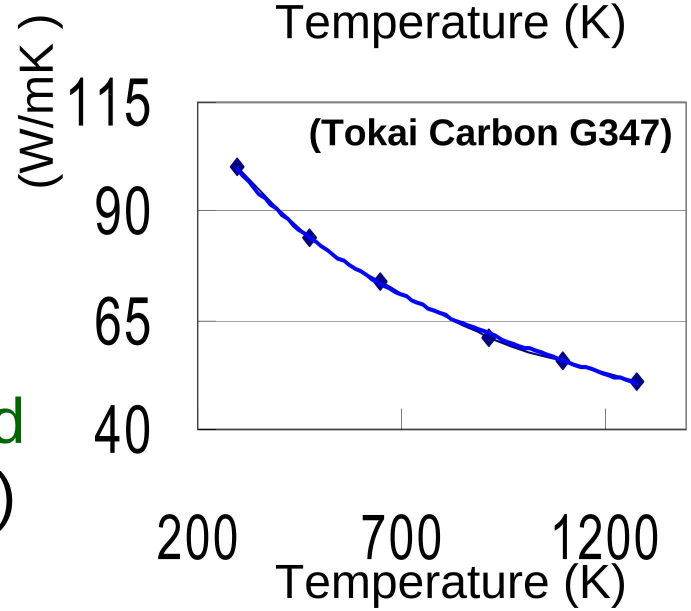
Thermal conductivity

→ decreased at higher temp.

→ Temperature at the center of the target is underestimated

(Still, far below the melting point)





Estimation of the temperature rise

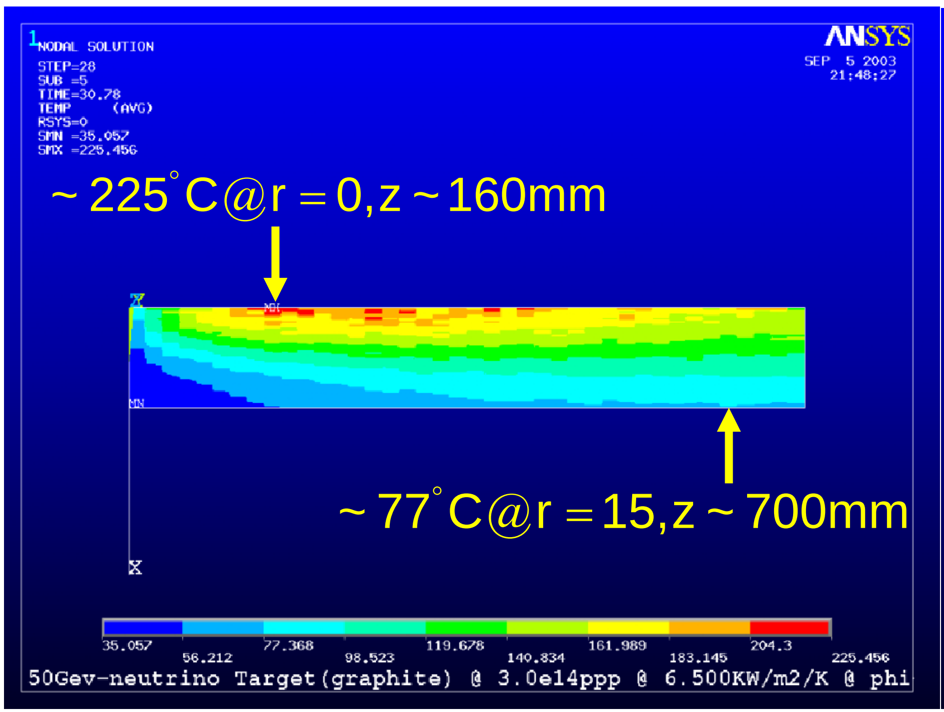
Parameters

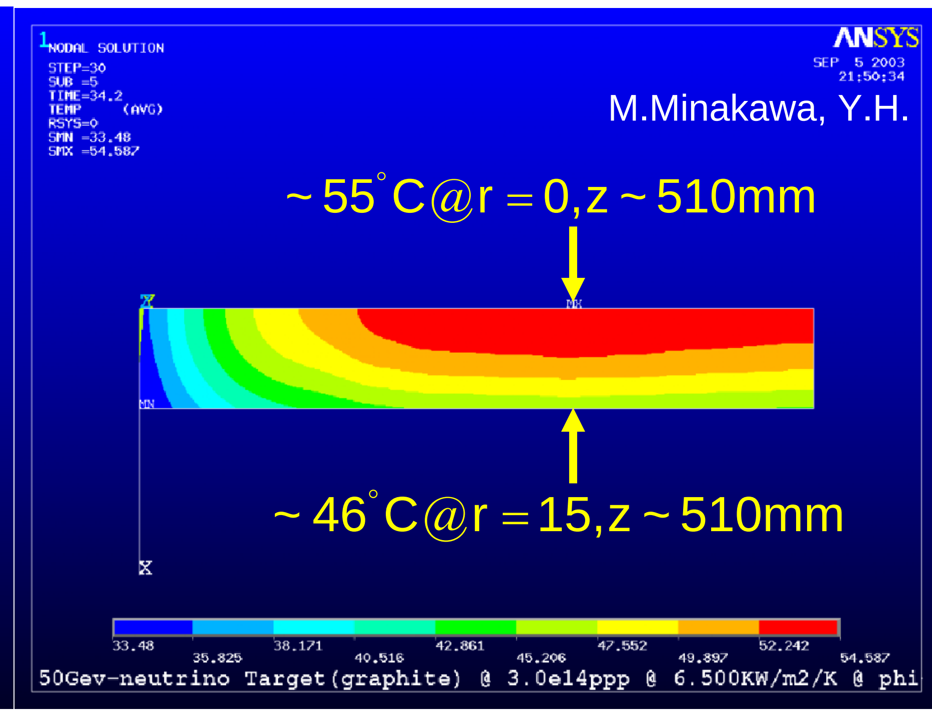
Thermal convection coefficient = 6.5W/m^2/K

Temperature of the surrounding area = 30^{o}C (fixed)

just after the spill (after 5μs)

just before the next spill (after 3.53s)





Time dependence of temperature

Maximum temperature

Center (r=0mm)

~ 225˚C

far below the melting point

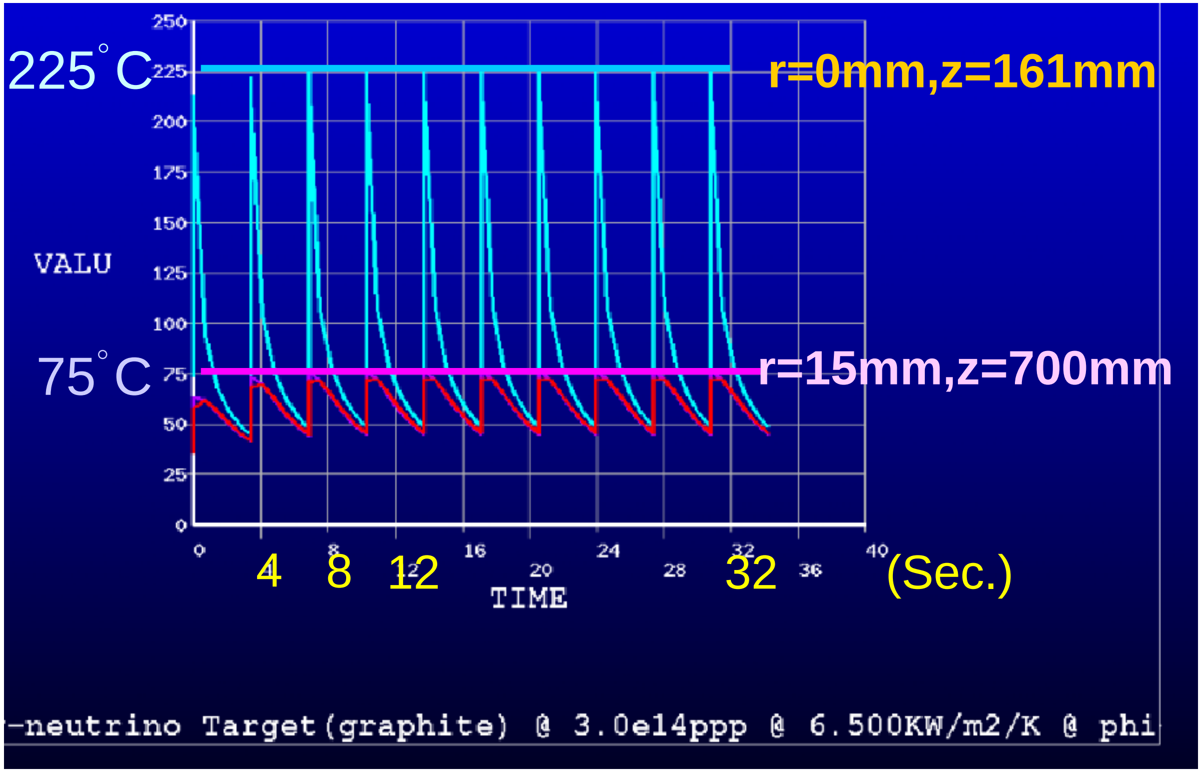
Surface (r=15mm)

~ 75˚C

(temperature of

the surrounding area

was fixed at 30 ºC)



M.Minakawa, Y.H.

→ Consider direct water cooling

To keep the surface temperature below 100ºC,

water temperature should not exceed ~50ºC.

Thermal convection coeff. needs to be larger than ~6kW/m^2/K.

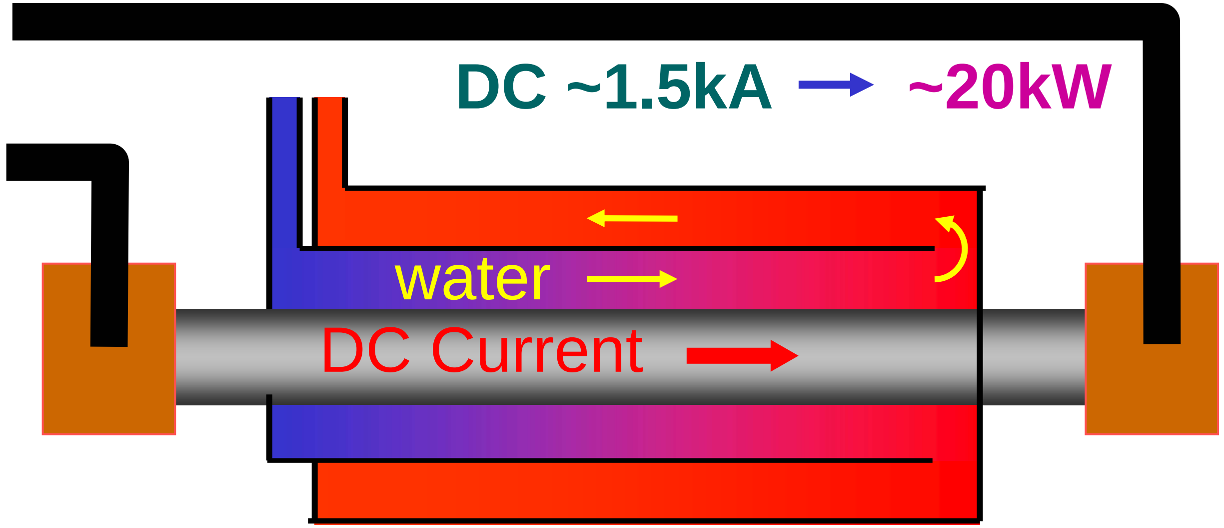
→ Is it possible?

Cooling test

According to the results from the calculations,

heat transfer rate → larger than ~6kW/m^2/k.

→ Heat up the target with DC current and try to cool by the flowing water.

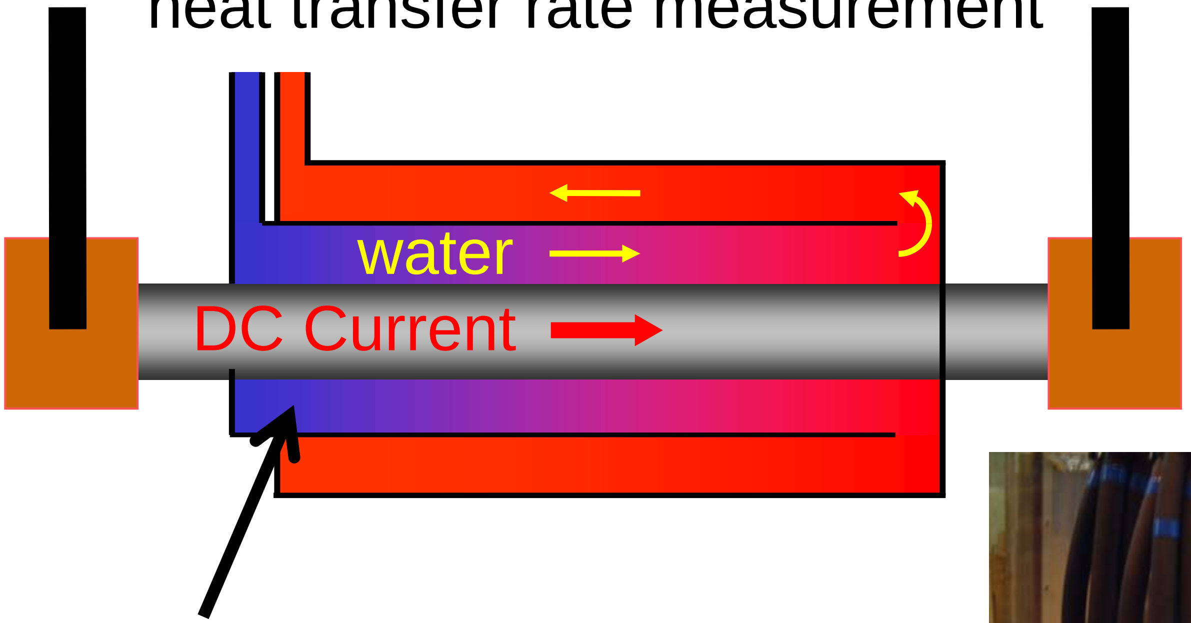


measure water flow rate and temperature at various points

→ estimate the heat transfer rate.

Cooling test set up

heat transfer rate measurement



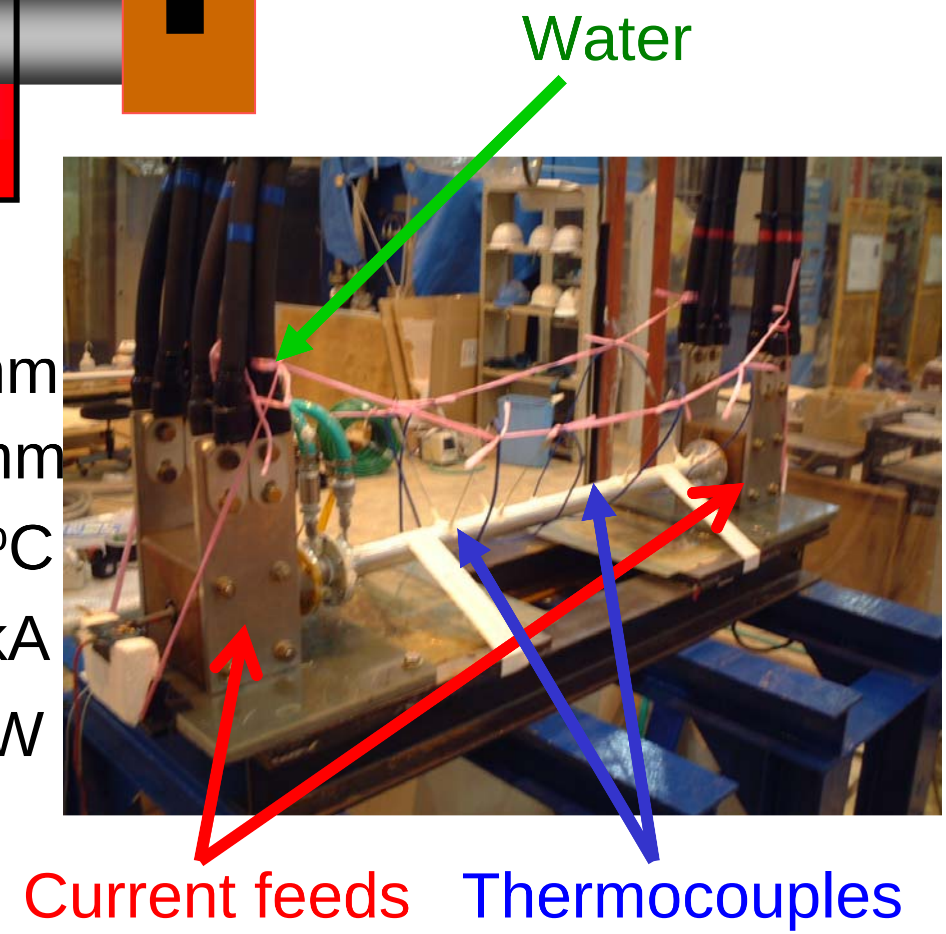
Thickness of the water path : 2mm

Radius of the target: 15mm

Water temp. (in) ~25ºC

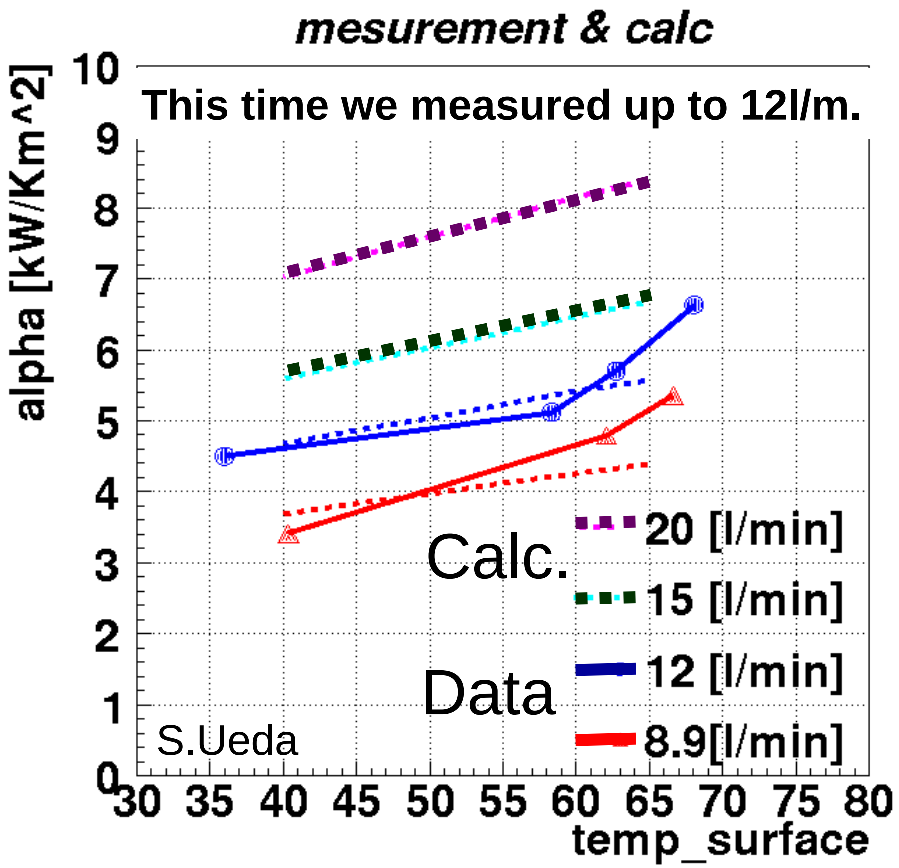
DC Current: up to 1.3kA

corresponds to ~ 20kW



Cooling test results

Results & calculations



Theoretical formula

$\alpha = 0.023 \times Re^{0.8} \times Pr^{0.4} \times \lambda \times d^{-1}$

Re Reynolds number

Pr Prandtl number

λ Thermal conductivity

d equivalent diameter

(Re and Pr also depend

on the surface temp.)

Measurements and theoretical calculations seem to agree

$\alpha > 6kW/m^2/k$ → cab be achieved when

the flow rate is more than 18l/m

Change of the material properties by neutron irradiation

The thermal conductivity is largely reduced

by the neutron irradiation effect (about by factor 10.)

T.Maruyama et al., J. of nucl. materials, 195(1992), 44-50

↓

Reduce the thermal conductivity by factor 10 in the simulation.

Temperature at the center was increased

but it was saturated after 10 spills

and the maximum temperature was less than 400 ^{o}C.

(Temperature of the surface did not change or slightly reduced.)

Effect of the neutron irradiation on thermal conductivity will not be the problem.

Actual design of the target

Direct cooling or put in the container?

This time, we tested the "direct cooling".

It seems to be working.

But

- The target will not be dissolved?
- If water get into the deep inside of the target ...

→ Boiled when the beam hits the target (?)

- 90cm long target can not be made by using the best material.

If we put the target in a metal container,

water does not contact with the target,

it is possible to cut the target in small pieces,

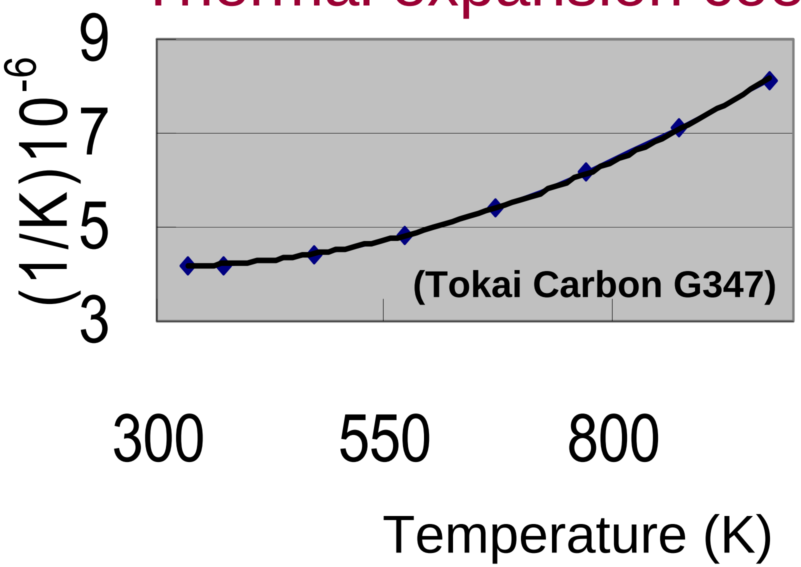
even if the target brakes up, the target material does not flow away.

→ We are planning to put the target in a container and measure the heat transfer rate.

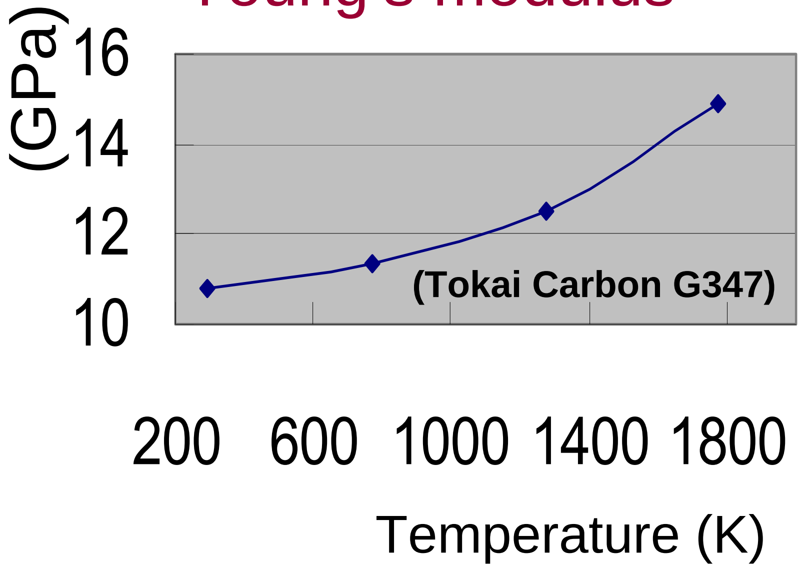
Estimation of the thermal stress

Material properties used in the simulation

Thermal expansion coeff.



Young's modulus



If these temperature dependences
are taken into account,
the estimated thermal stress will be increased.

Estimation of the thermal stress (Analytical)

Analytical calculations

$$
\begin{cases}
\sigma_z^{stat} \approx -\dfrac{2}{3}\dfrac{E\alpha T_0}{1-\nu} \\
\sigma_\phi^{stat} \approx -\dfrac{E\alpha T_0}{3(1-\nu)} \\
\sigma_r^{stat} \approx -\dfrac{E\alpha T_0}{3(1-\nu)} \\
\sigma_z^{dyn} \approx \pm\dfrac{1}{3}E\alpha T_0
\end{cases}
$$

E Young's modulus

ν Poisson ratio

α linear expansion coeff. (thermal)

T_0 Temperature

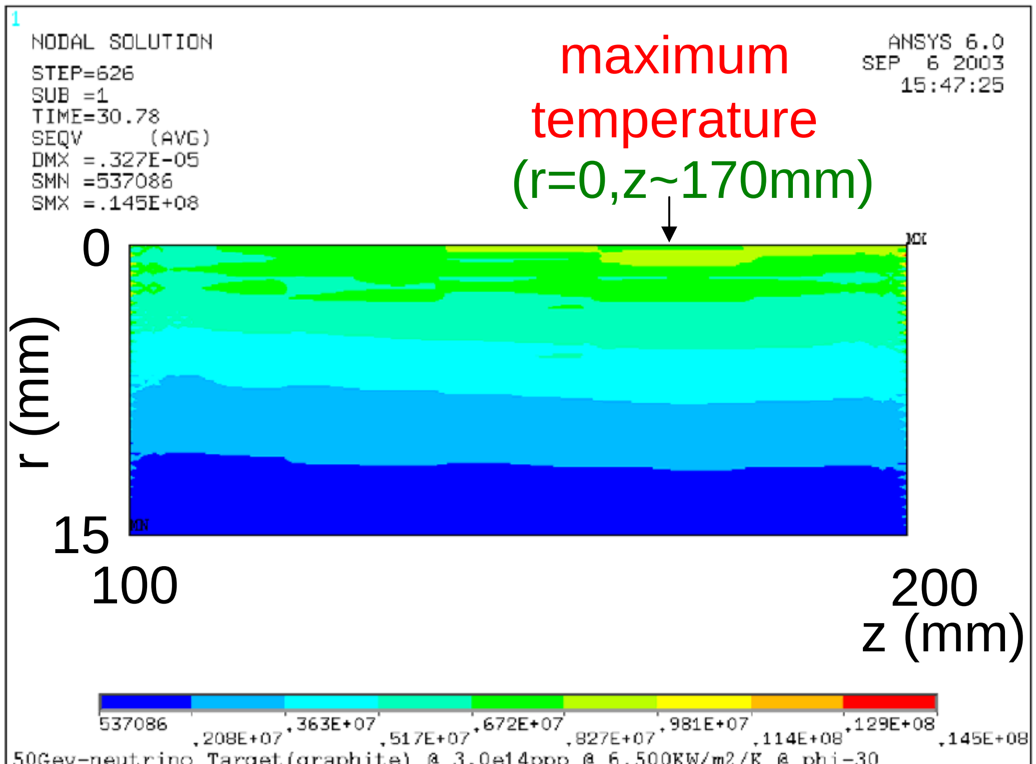
Manufacturer	Type	Equivalent stress (MPa)	Tensile strength (MPa)
Toyo Tanso	IG-43 ISO-88	~7 ~11	37.2 68.6
Poco Graphite	ZXF-5Q	~15	95.0
Tokai Carbon	G347	~6	31.4

Here, we do not have the data of temperature dependences of the material properties other than G347, we assume that the shape of the temperature dependences are the same.

Thermal stress estimation (ANSYS)

Condition: Simulate the hottest part (z=100mm ~ 200mm)
Both of the edges (z=100 & 200mm) are fixed (z direction).

just after the spill (after 5μs)



Equivalent stress

@ maximum temperature (r=0,z~170mm)

~8.8MPa.

(analytical calc: 6.0MPa)

[Tensile strength (Tokai Carbon G347) : 31.4MPa]

@ r=0, z=200mm ~14.5MPa.

(Because both of the edges were fixed)

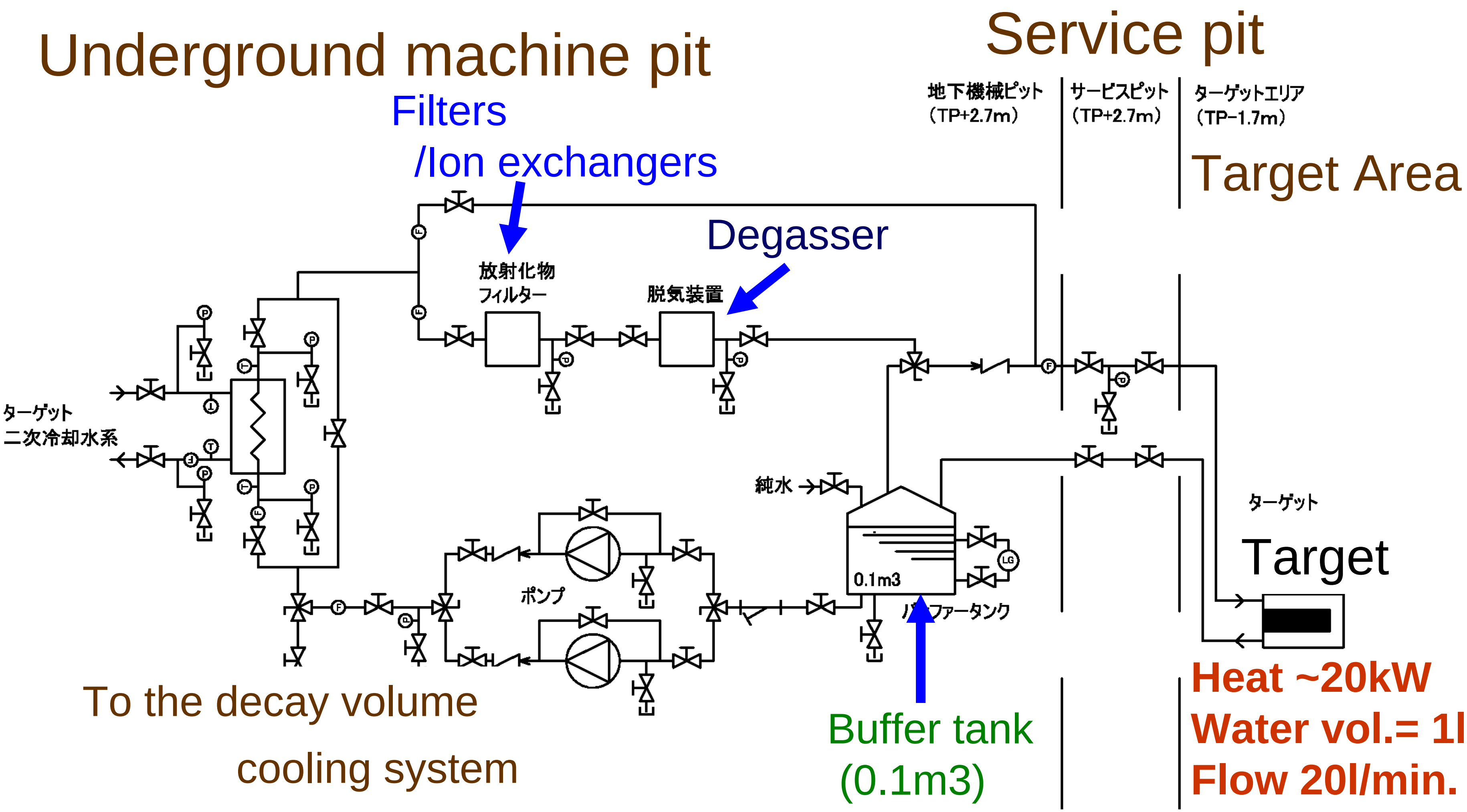
→ slightly larger but consistent with the analytical calculations

(due to the approximation of the temperature distribution)

Water system for the target cooling

We have to remove H_2,N ions and heavy metal ions.

Also, the water have to be cooled.(Δ_T(water)~15^{o}C@20l/min.)



Radioactive residues

(target and cooling water)

1) Target (By Nakano)

size ϕ=30mm, L=900mm

density 1.8g/cm3

# of generated Be^7 ~9×10^{12}(Bq)

after 1yr of running, cooled for 1day ~14Sv/h

2) Cooling water (By K.Suzuki)

after 20 days of running Tritium ~30(MBq)

Summary (I)

For the JPARC ν experiment,

solid target R&D is now ongoing.

material	Graphite (or C/C composite ?)
dimensions	diameter ~30mm
	length 900mm (2 interaction length)
cooling	Water (direct or put in the case?)
	Heat transfer rate > ~ 6kW/m^2/K
cooling method	Direct cooling → seems to work
	Water flow rate ~20l/min.
temperature rise	~ 175 ^{o}C (center)
	~ 25^{o}C (surface)
thermal stress	~ 9MPa (for G347)
	[Tensile strength (G347) ~ 31MPa]

Summary (II)

R&D Items (We want to test/check the following items.)

- Cooling test

  Set the water flow rate at 20l/min. and confirm the method.

  Measure the heat transfer rates with a target container.

- Stress test

  Beam test (with same energy concentration) Where?

- Irradiation effects other than the thermal conductivity

- Search for the best material

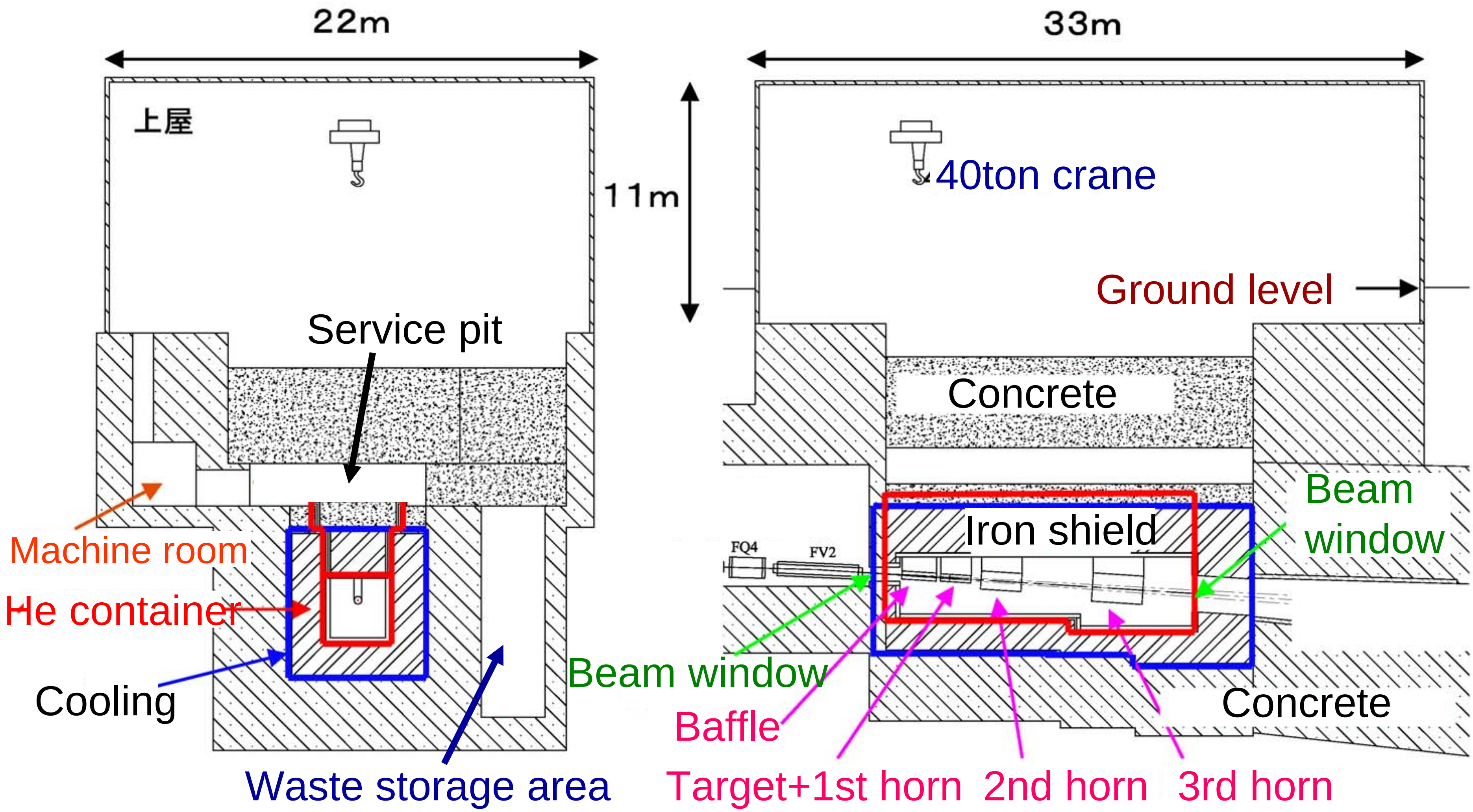
  (Usually, graphite, whose tensile strength is large,
  has large Young’s modulus.
  → the thermal stress is also getting larger.)

  Temperature dependences of the material properties.

Summary (III)

- Design of the entire system has to be fixed.

  How to fix (support) the target, alignments etc...



Summary (IV)

- Target handling

How to remove the target from the horn remotely?

(It may be necessary to remove the target from the horn when the target part is broken.)