Photon Dump Design
for ILC Undulator Positron Source

KEK : Yu Morikawa

Purpose of today's meeting

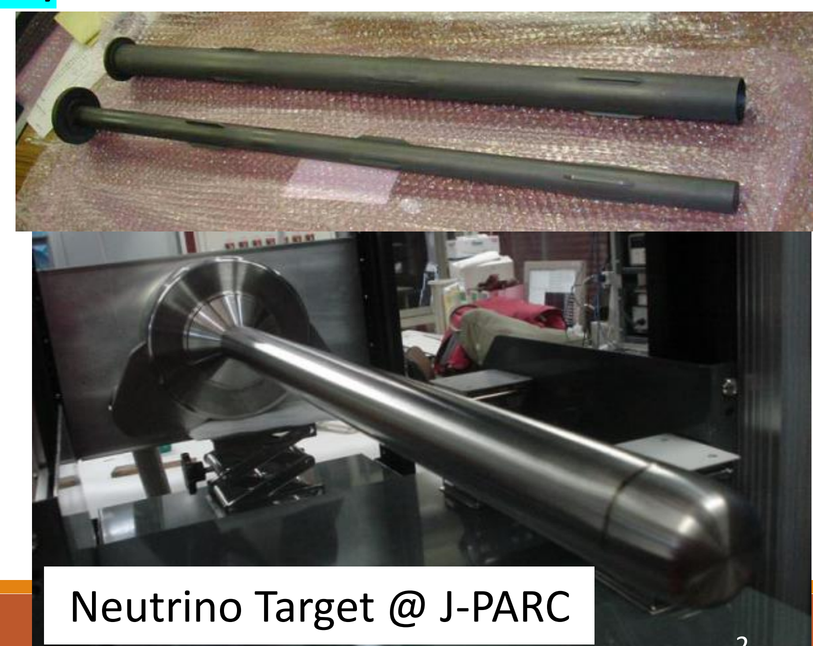
- Introducing the issues on the ILC photon dump.
  (very localized heat load, impossible to control the beam size)

- We are considering the graphite as a candidate of absorber of photon dump. Now we are getting to start the discussion with Japanese company.

  We would like to hear your comments and suggestions.
  (Radiation damage, material fatigue, operation experiences)

Toyo Tanso Co (Tanso means carbon in Japanese)

Muon Target @ J-PARC

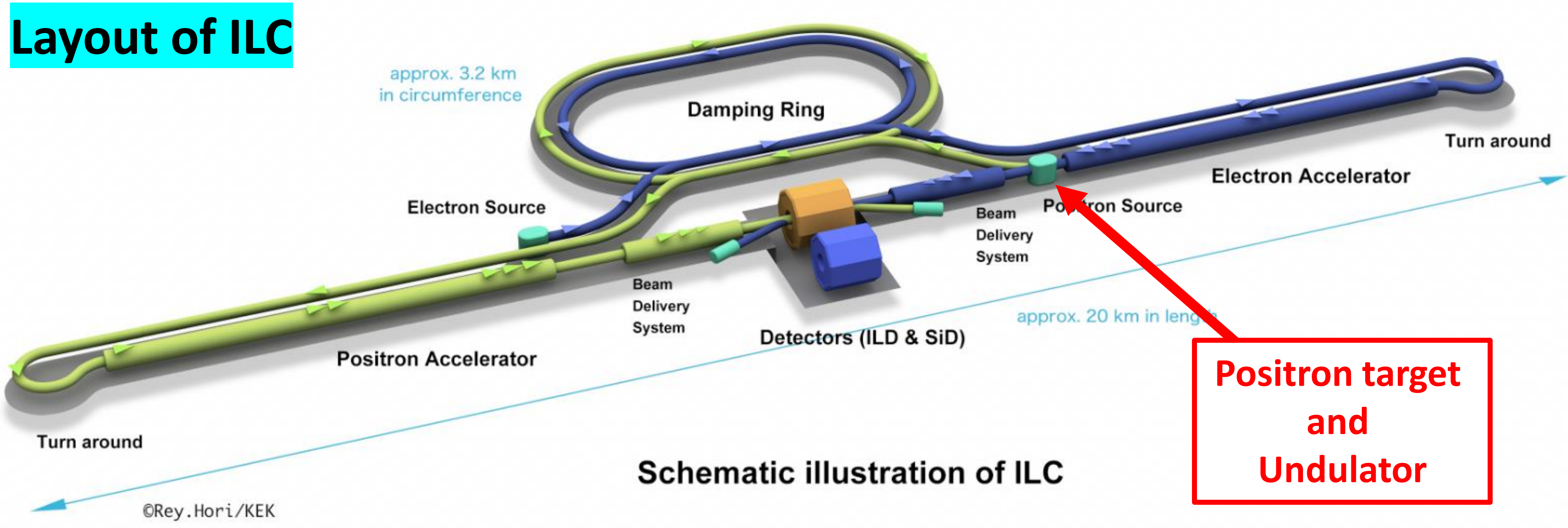


Neutrino Target @ J-PARC

International Linear Collider

- ILC positrons are generated by using undulator.
- Undulator is located at the end of main electron linac.

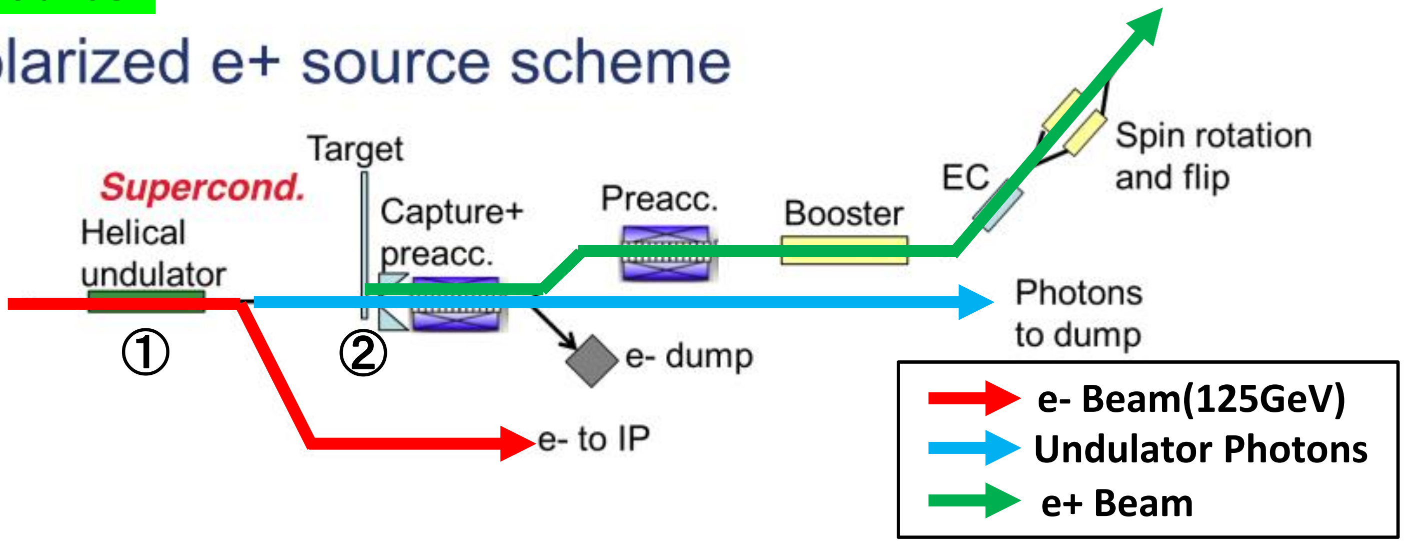
Layout of ILC



The Generation of e+ for the ILC

Undulator e+ source*

- The polarized e+ source scheme



1. The helical undulator generates photons with energy of several MeV.
2. The target is irradiated with undulator photons to generate e+.

Heat Load

- **Up to 120kW of photons are generated by Undulator.**
- **Only 4 kW of energy is deposited on the target.**
- **Remaining 116kW must be absorbed at the photon dump.**

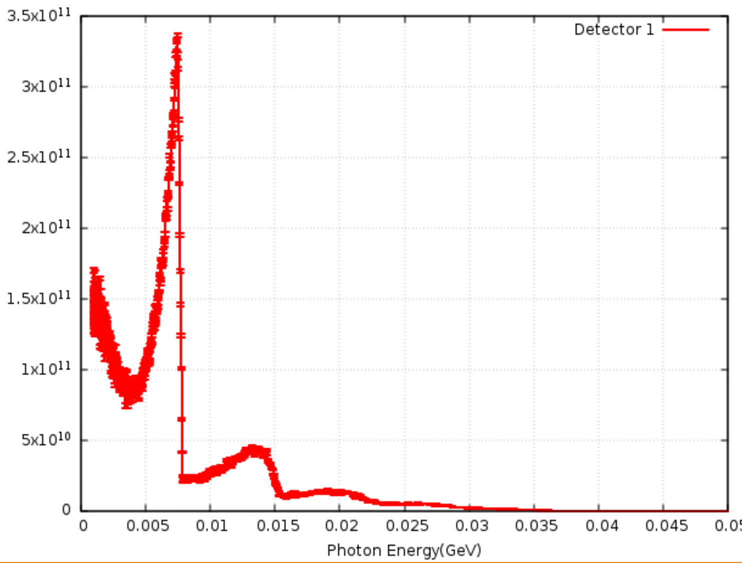
* G. Moortgat-Pick et al., "Undulator e+ source summary", AWLC2020.

Undulator Photon Property

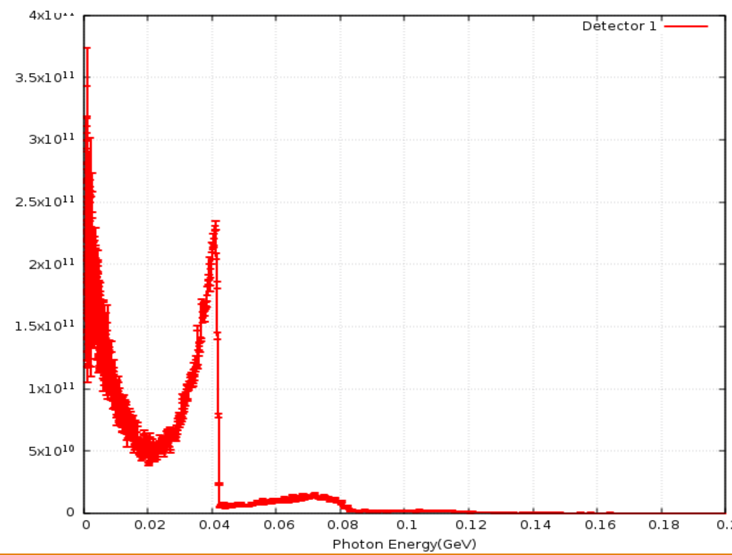
Photon Beam	250GeV stage		500GeV stage	
Num of photons/bunch	8E12		2E12	
Pulse repetition	5Hz			
Num of bunches/pulse	1312	2625	1312	2625
Beam power	**60kW**	**120kW**	**52kW**	**104kW**
Average Photon Energy	**Around 10MeV**		**Around 20MeV**	

$\sim 1 \times 10^{17}$ (photons/sec) **of 10MeV average energy** with a **3μrad** angular spread

Energy spectrum of 250GeV stage



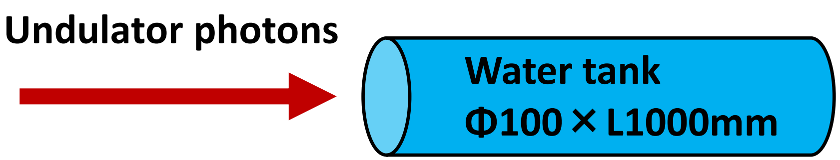
Energy spectrum of 500GeV stage



Calculation by Yokoya-san

TDR Photon Dump

TDR photon dump design
(Water Dump)



[Structure]

- Beam window : 1mm-thick 64Ti
- Cylindrical water tank : ϕ100 × L1000mm
  12bar pressurized(boil temp ~187℃)

[Thermal issues]

- Power density in beam window
  ⇒0.5kW/cm2 ~**dT 425℃/pulse**
- Peak temperature rise in **water** = **dT 190℃/pulse**
- High pressure wave will attack the window/tank.

・TDR design will not be realized(heat load on window and water).

Thermal issues in photon dump

- Large number of particle/sec ⇒ **High and localized heat load.**
- **Photons beam are not able to control(such as rastering).**
- Photon beam size is very small; ~3mm at target, angular spread~3μrad
  ⇒ Photon beam size only spreads 3mm even 1km away.

We need overcome these difficulties.

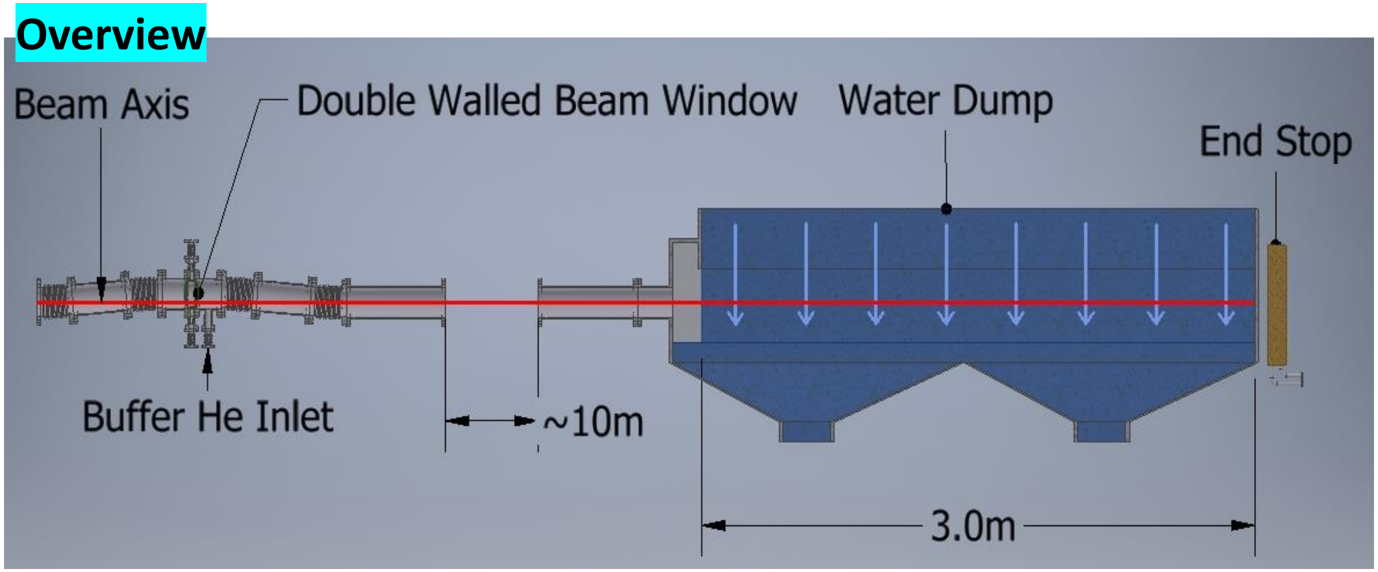
New photon dump ideas

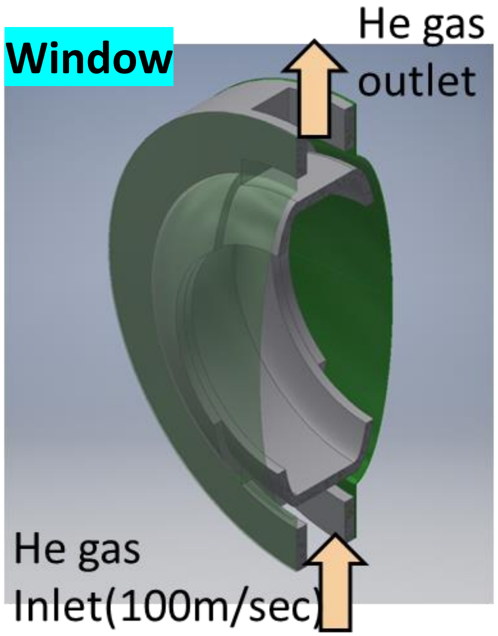
[Idea-1] Water Curtain dump
[Idea-2] Graphite dump

[Idea-1] Water Curtain by Peter Sievers

①Beam incidents to falling water(**Water Curtain**)
This system can accept water boiling.
Pressure wave don't attack the window.

②**Double Walled Beam Window** cooled by Helium gas.
This window is tumbled to reduce the radiation damage.





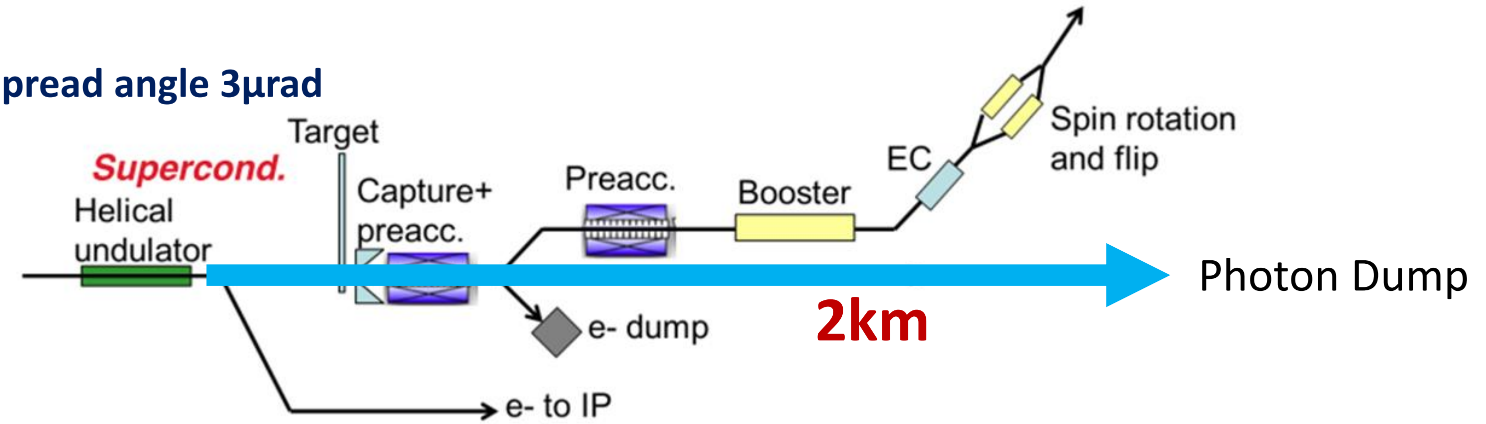
・We are concerned that **complicated system** and **difficulty to deal with failures**.
(Gas leak, Window tumbling, Water falling)

[Idea-2] Graphite Photon Dump by KEK

Enlarge the photon beam size at photon dump.

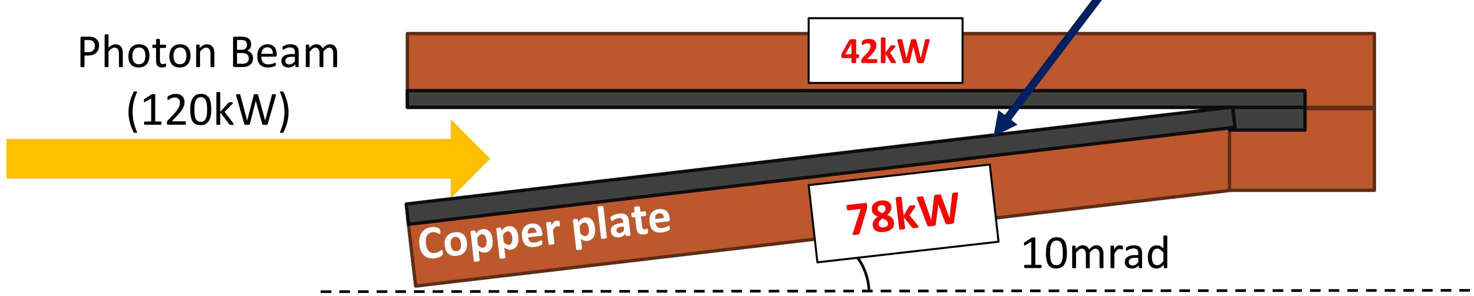
①Distance

Photon beam spread angle 3μrad



②Angle

Absorber 10mrad

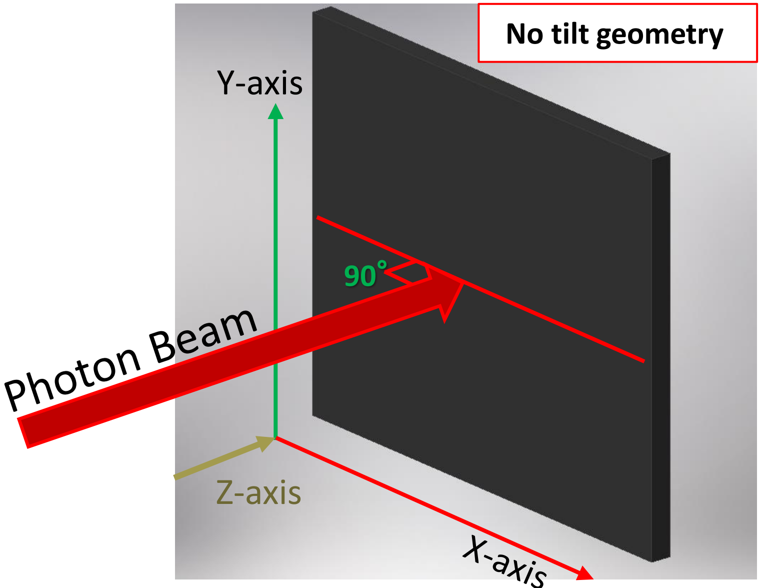


Energy deposition – no tilt case

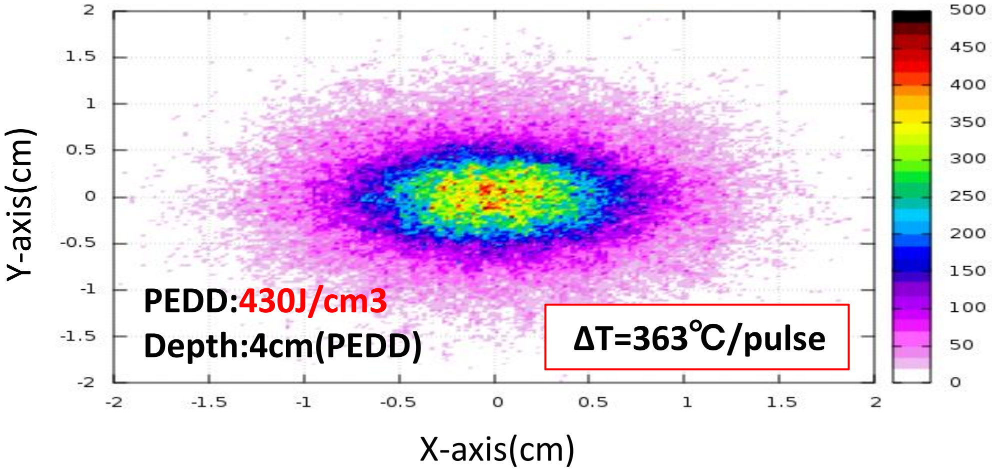
Calculation energy deposition of Graphite

- **Simulation by FLUKA**
- **250GeV Stage Photon**
- **Bunches per pulse:2625**
- **Graphite density:1.82g/cm3**

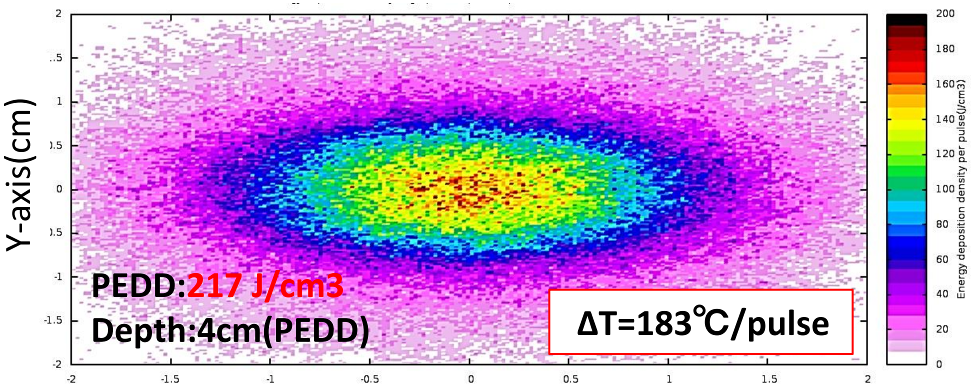
*** Distance : from Positron Target to Dump**
*** PEDD : Peak Energy Deposition Density**



・No tilt, Distance:1km

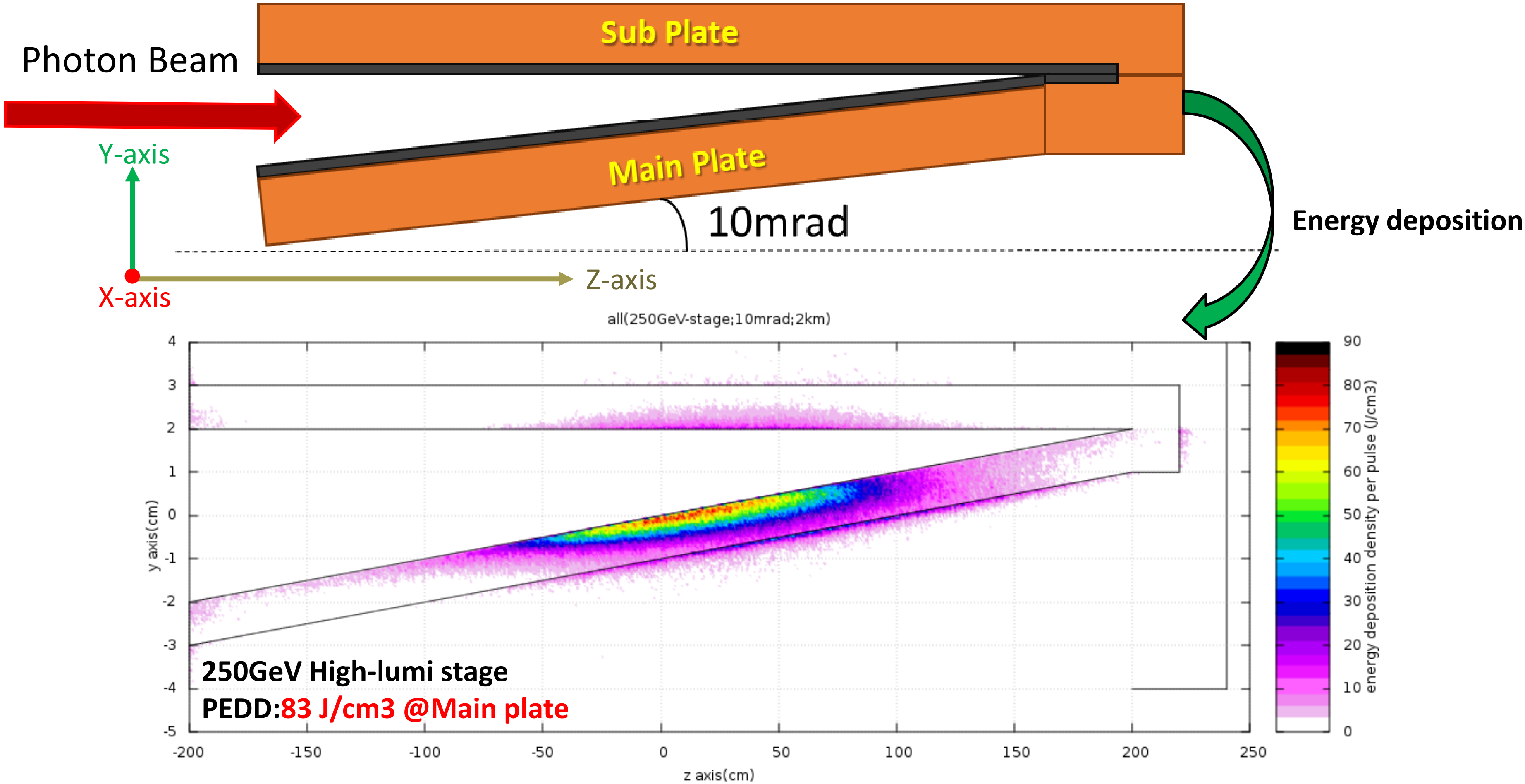


・No tilt, Distance:2km

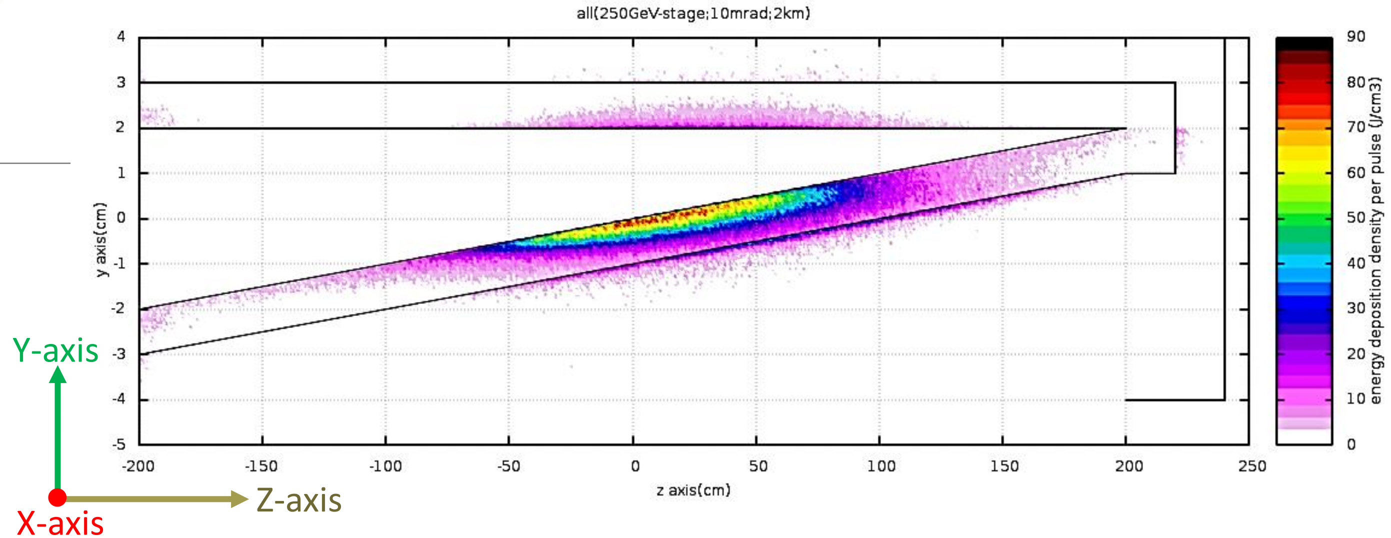


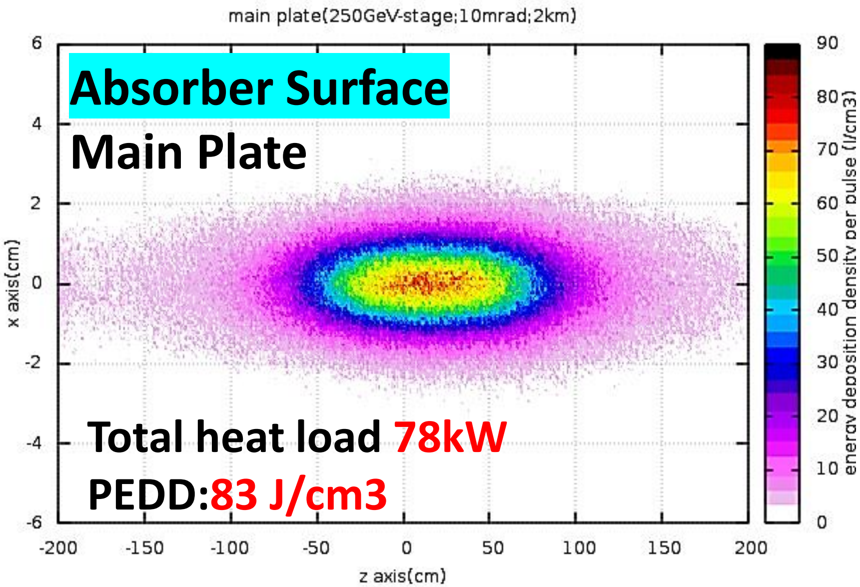
Scale is different from other.

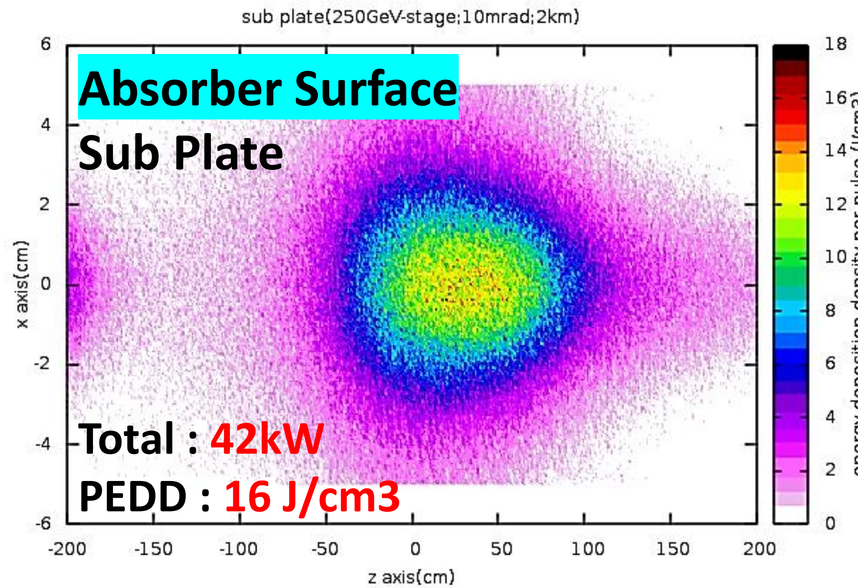
Energy deposition – Graphite dump



Energy deposition – Graphite dump

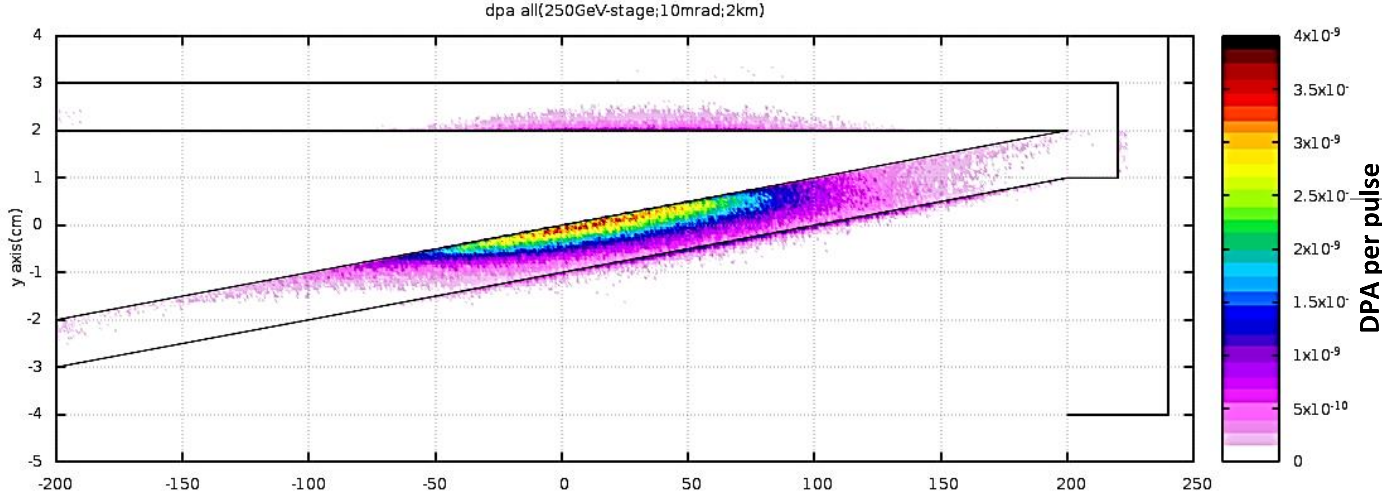




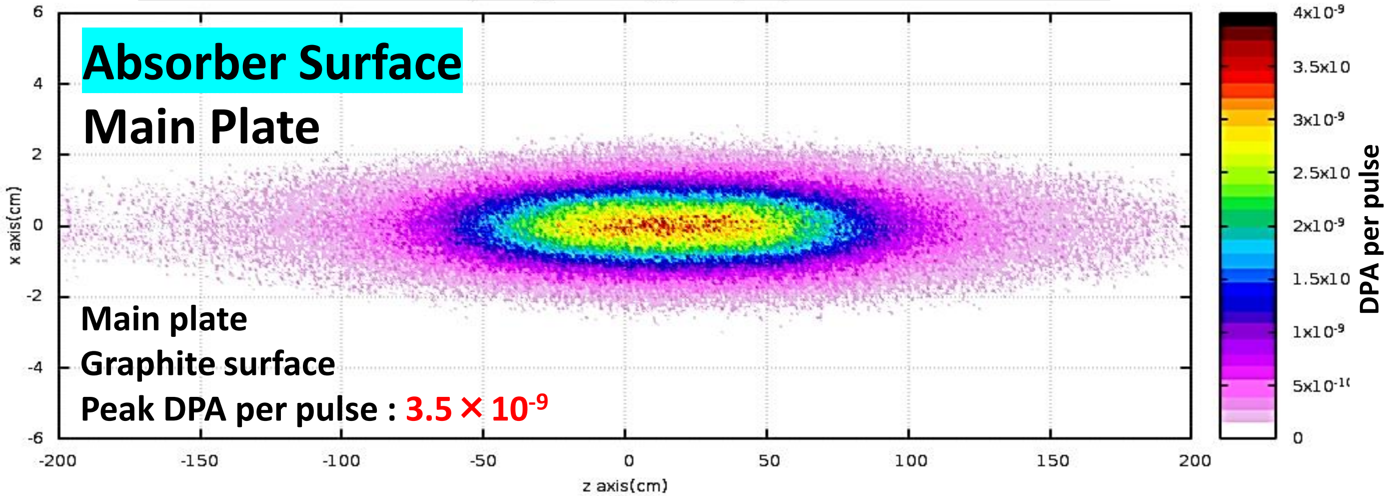


Scale is different from others

DPA



DPA 0.315 after 5000 hour operation

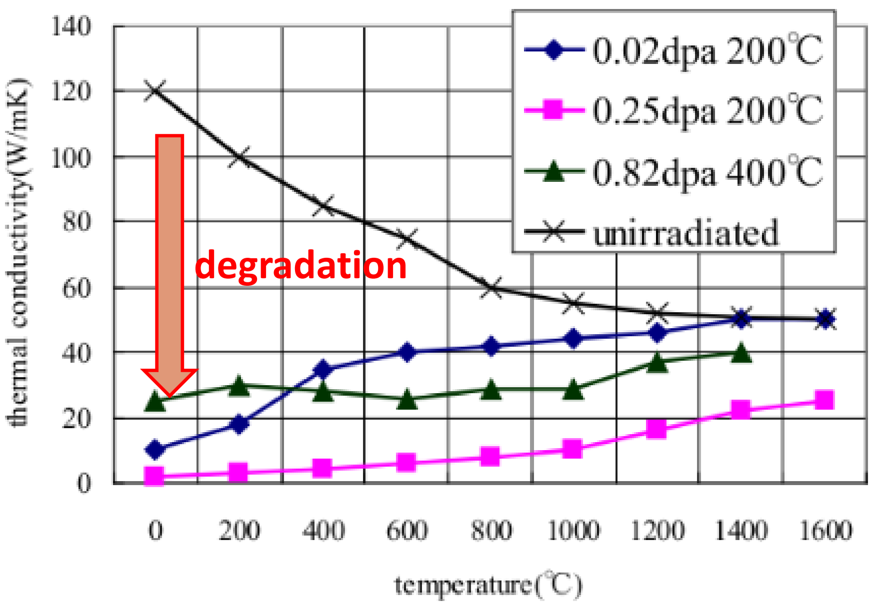


*Carbon Density : 1.82g/cm3,
*Carbon energy threshold of DPA =30eV

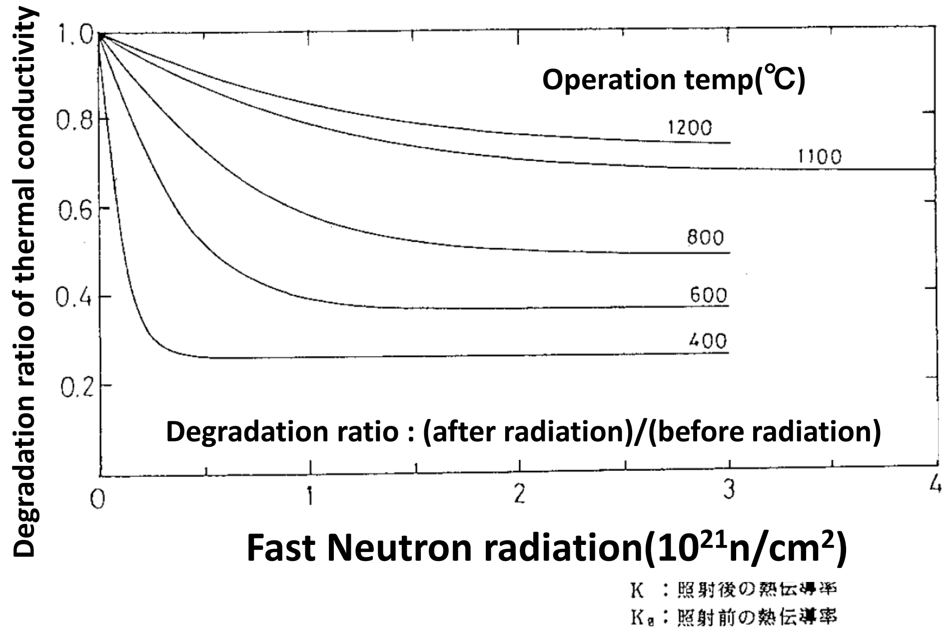
Temperature simulation

Graphite Conductivity 20W/Km

Degradation of Graphite thermal conductivity



Degradation by radiation*1

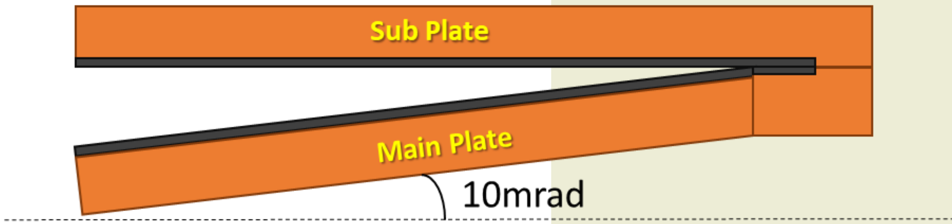


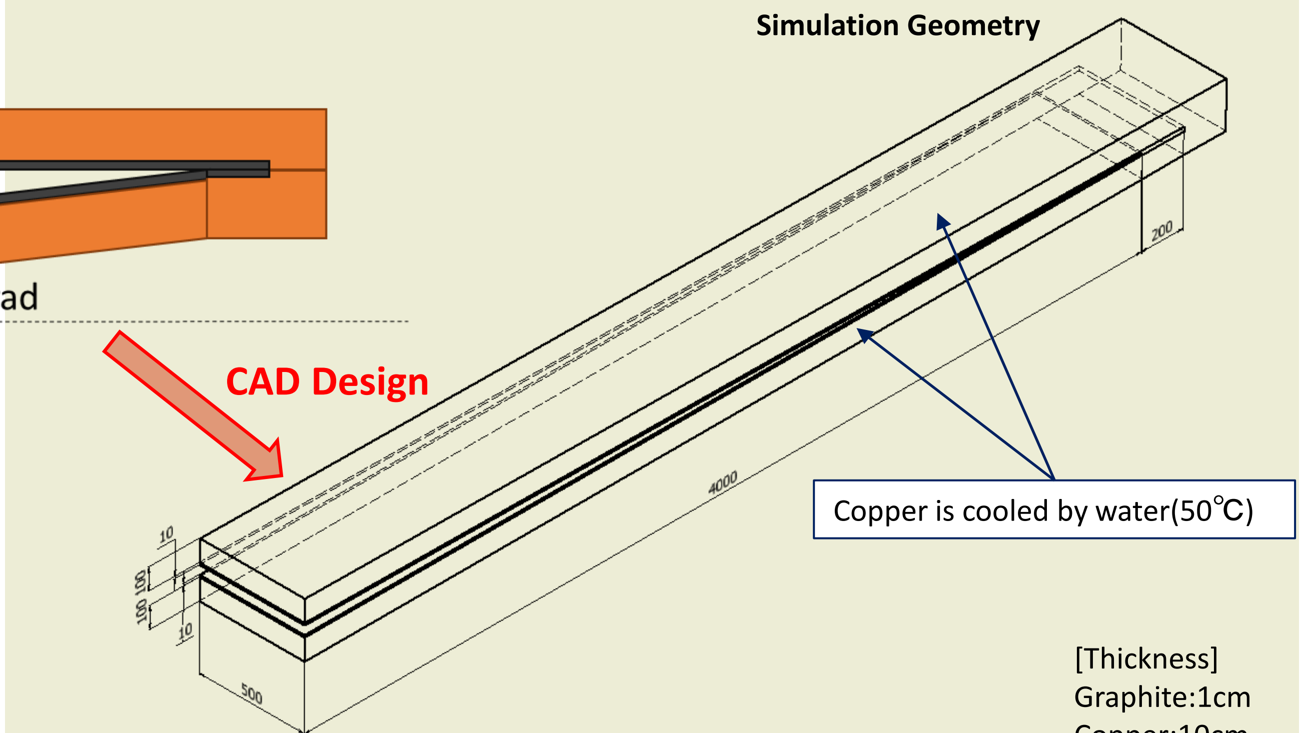
Anneal effect*2

- Thermal conductivity is degraded by radiation.
- High temperature operation reduces degradation of thermal conductivity.(anneal effect)

*1 Neutron irradiation effect to thermal conductivity (T. Maruyama et al., Journal of Nuclear Materials 195(1992) 44-50.)
*2 An explication of design data of the graphite structural design code for core components of high temperature engineering test reactor (Ishihara M, Iyoku T, Toyota J, Sato S, Shiozawa S (1991) ,JAERI-M report 91–153)

Simulation settings





[Thickness]
Graphite:1cm
Copper:10cm

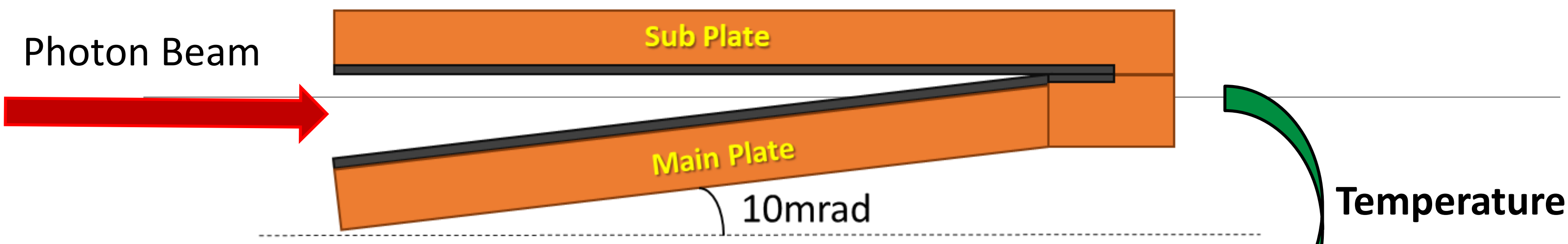
- Steady state calculation
- Equation: Energy transfer
- Heat transfer rate of copper/water is set to **1kW/m2k**
- Copper plate is cooled by water(**50℃**)

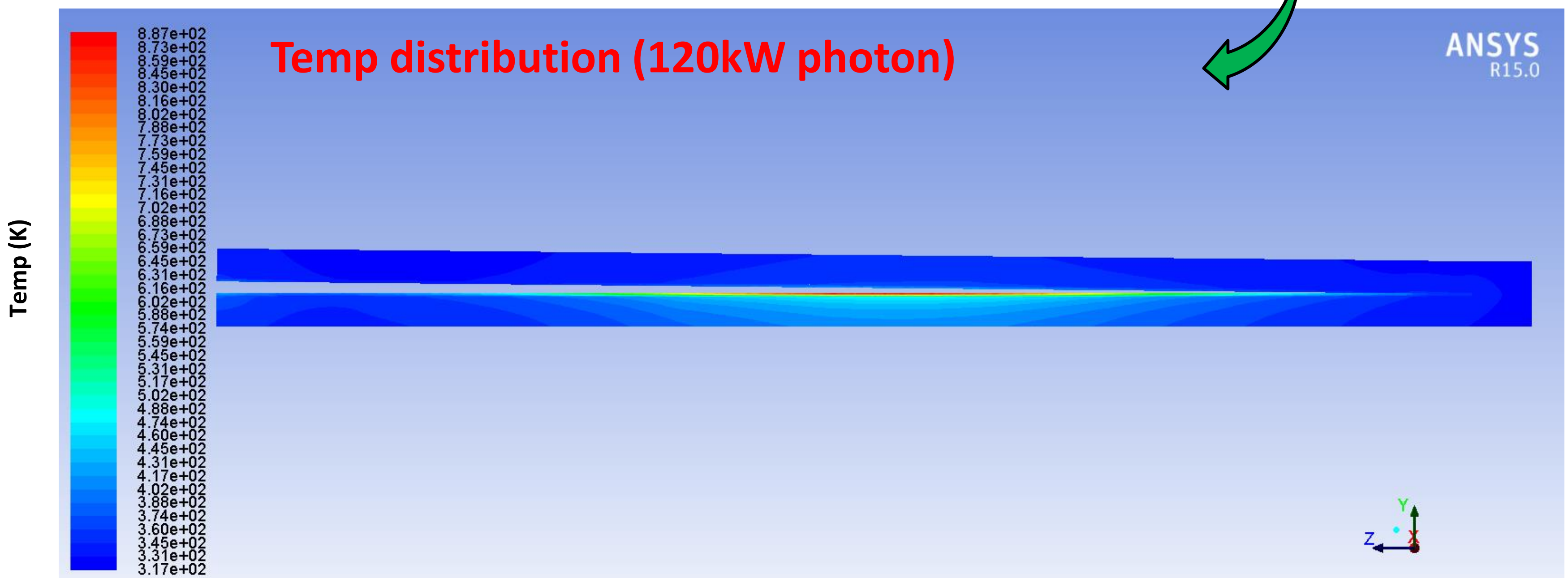
Material Property	Copper(IG430)	Graphite
Density(kg/m3)	8978	1820
Specific heat(J/kg-k)	381	650
Thermal conductivity(w/m-k)	387.6	**20** (degradation by radiation)

*Degradation of the thermal conductivity occurs in the beam irradiation portion, but degradation value is set throughout the graphite plate in this simulation.

Temperature distribution

Graphite conductivity : 20W/(Km)

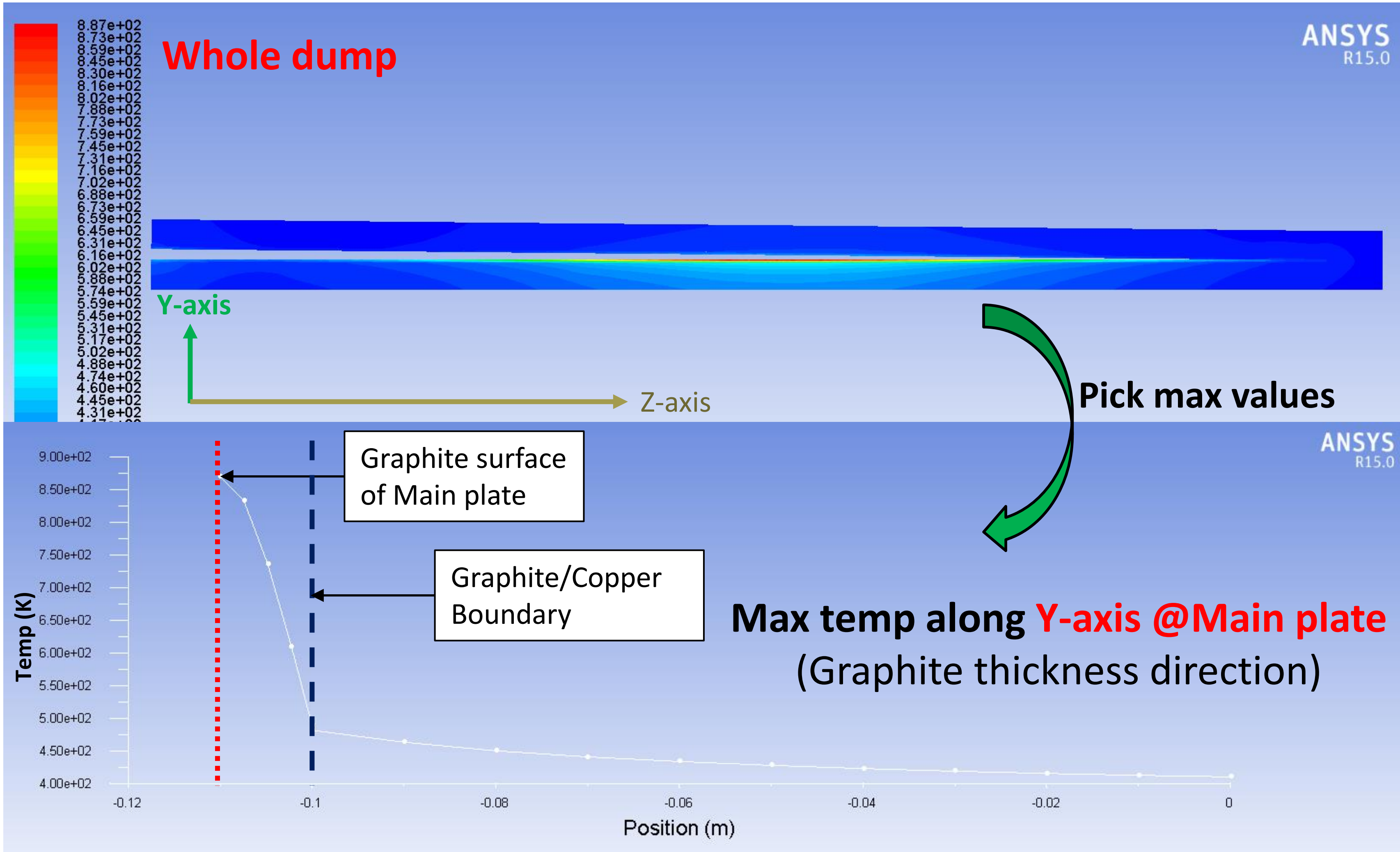




- **Max temp of graphite(120kW photon beam) : 614℃(887K) @ Main plate**
  143℃(416K) @ Sub plate

Temperature distribution Graphite conductivity：20W/(Km)

Beam



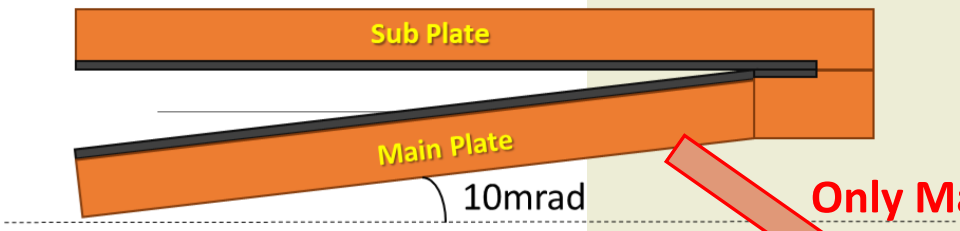
- **The temp gradient in graphite is very high,**

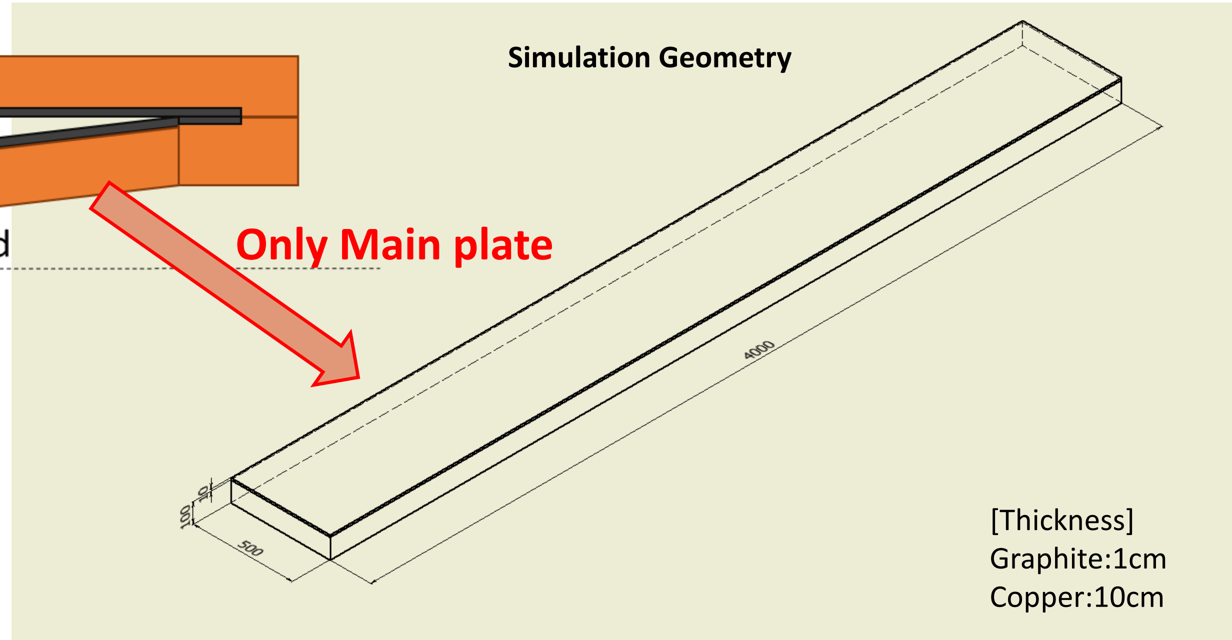
⇒Max temp strongly depends on graphite thermal conductivity.

Thermal stress simulation

Graphite Conductivity 20W/Km

Simulation settings

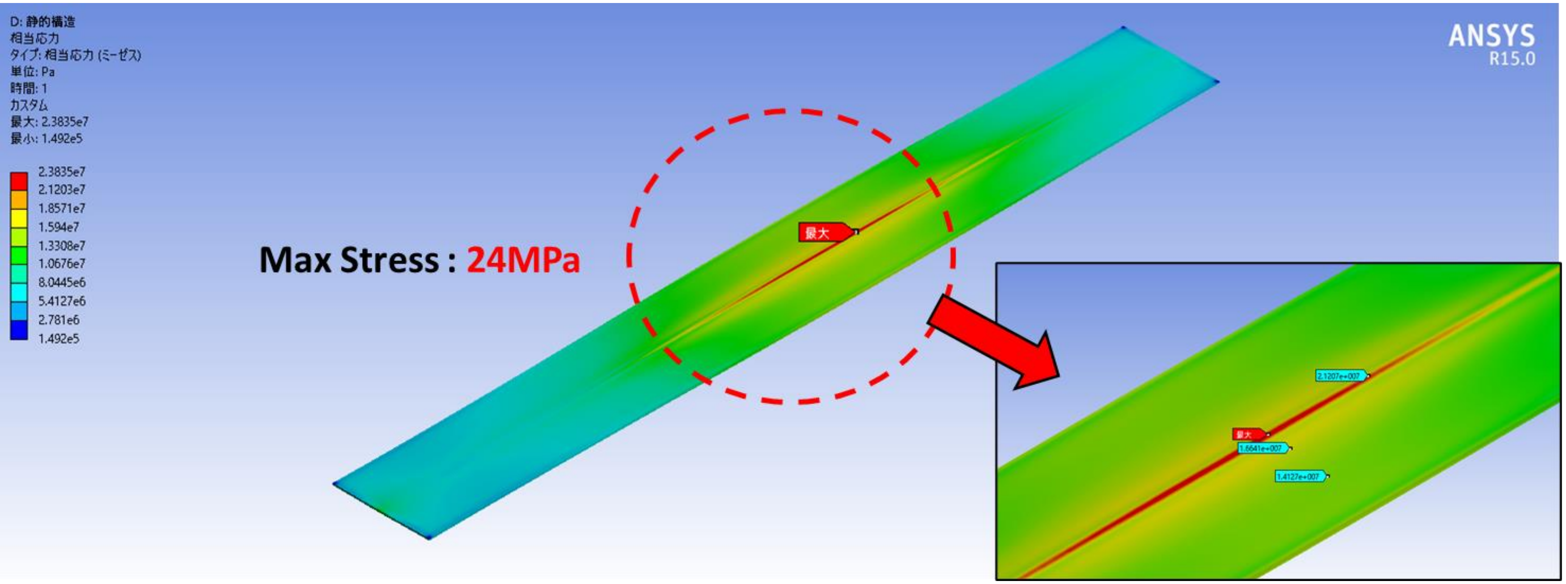


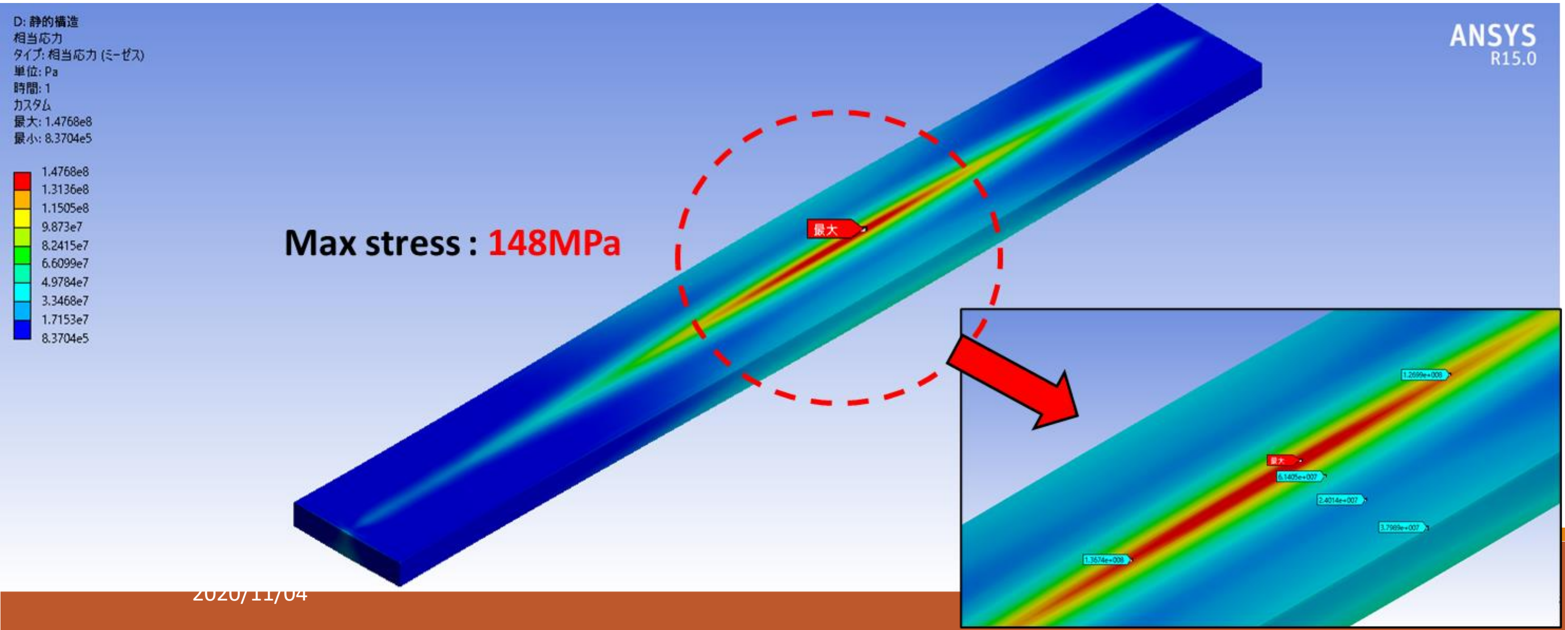


【Material Property】

	Graphite(IG430)	Copper
Density(g/cm3)	1.82	8.9
Expansion rate(1/℃)	4.5e-6	1.77e-5
Young‘s modulus(GPa)	9.8	118
Poisson ratio	0.12	0.34
Tensile strength(MPa)	**37**	**200**

Von Mises Stress





Summary of photon dump issues

- ✓ **TDR Photon dump design will not be realized.**
- ✓ **Graphite type of photon dump seems to be possible with some optimization.**

  [Simulation results]

  （PEDD）83J/(cm3/pulse) ⇒ ΔT=70℃/pulse

  （DPA） 3.5E-9/pulse ⇒ 0.315@5000h operation

  （Max Temp）614℃ @ Graphite thermal conductivity : 20W/(Km)

  （Max Stress） Base design : Graphite : 25MPa , Copper : 148MPa

  Some optimization needs to suppress the thermal stress.

- ✓ **Now we are getting to start the detail designing.**
  We would like to hear your comments and suggestions.

(Radiation damage, material fatigue, operation experiences)

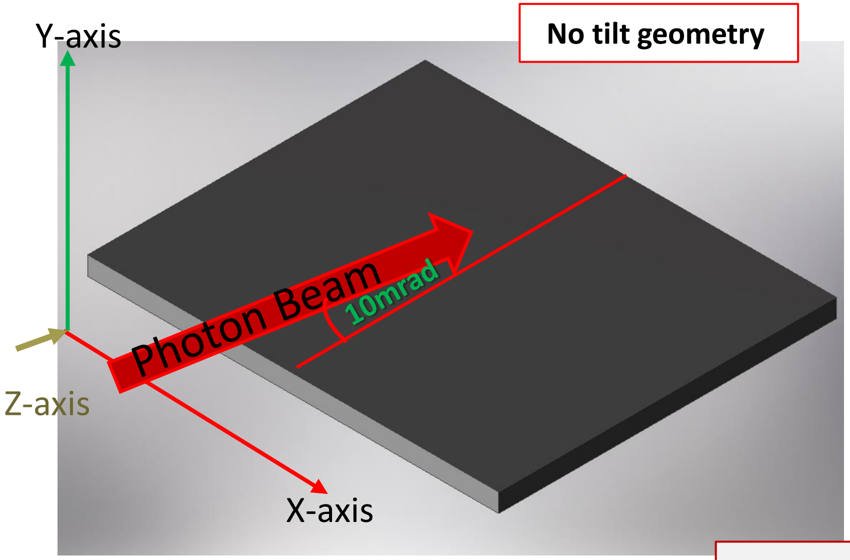
Back up

Energy deposition – tilt effect

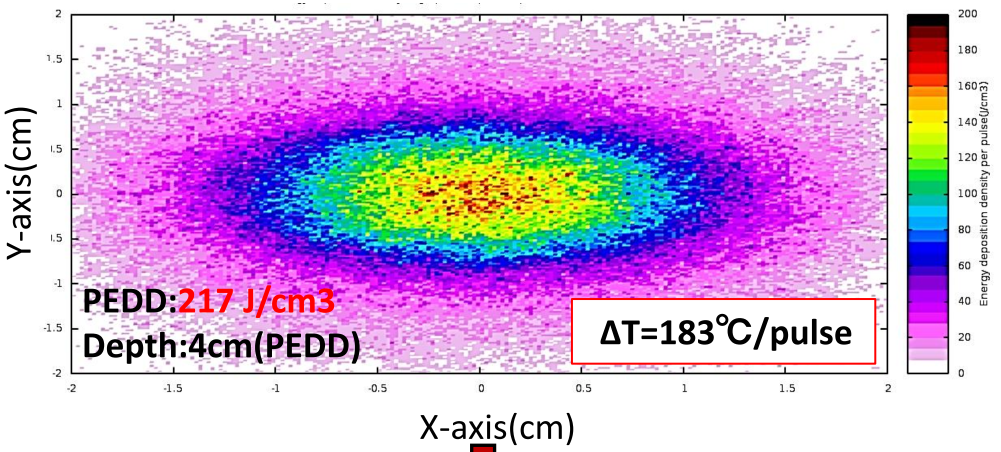
Calculated energy deposition of Graphite

- **Simulation by FLUKA**
- **250GeV Stage Photon**
- **Bunches per pulse:2625**
- **Graphite density:1.82g/cm3**

*** Distance : from Positron Target to Dump**
*** PEDD : Peak Energy Deposition Density**

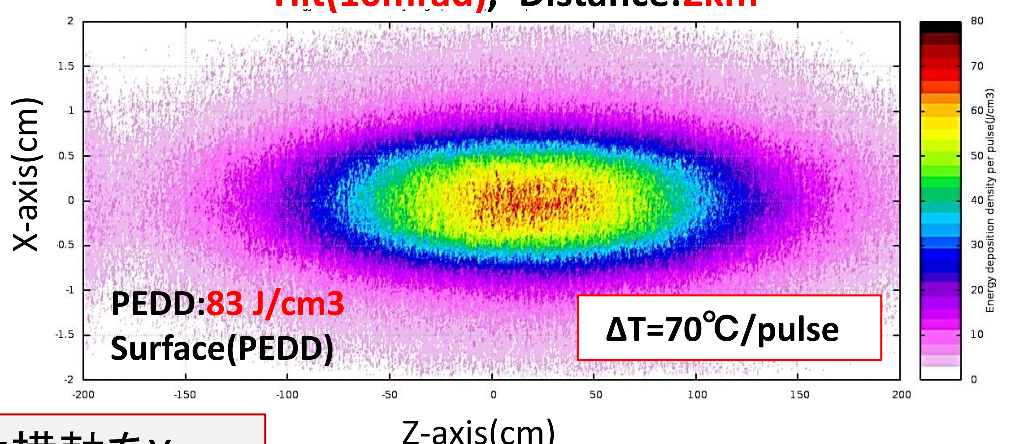


▪ ~~No tilt~~(normal injection,垂直入射), Distance:2km



10mrad tilt

▪ Tilt(10mrad), Distance:2km



▪下図は横軸をX, 縦軸をZ

Z scale is 100 time larger

Calculation check

LCWS2016[Is the Solid/Ar-Gas Photon Dump Possible?]
Comparison with Ushakov-san

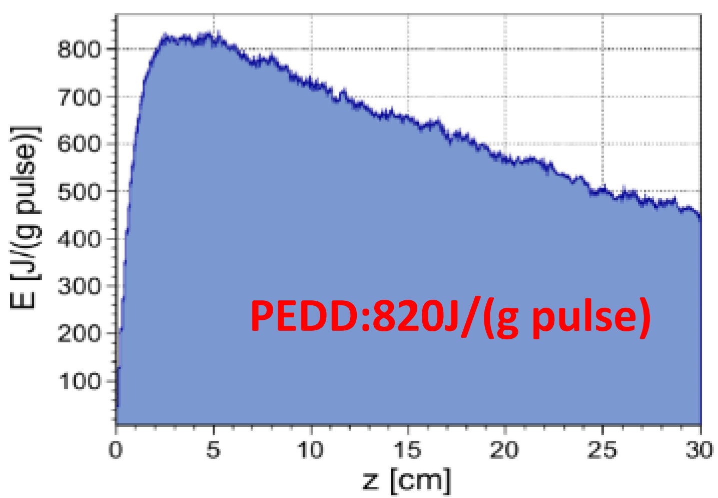
500GeV stage High luminosity
Graphite Energy deposition

Distribution of Energy Deposition in Graphite

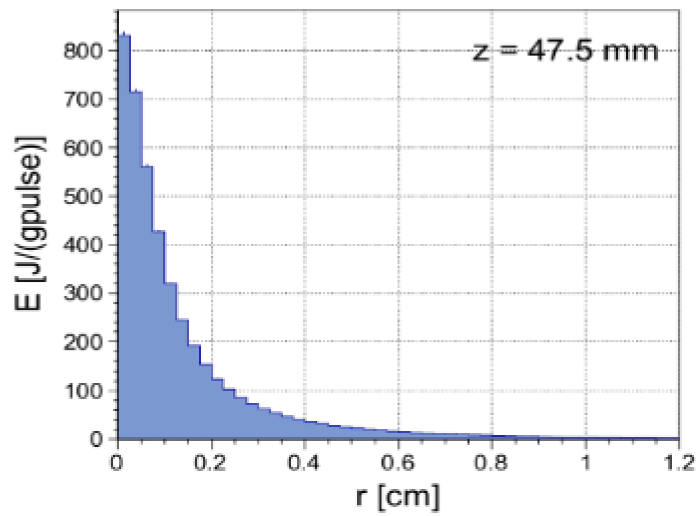
First 30 cm of graphite at ≈ 48 m from e^+ target

A.Ushakov-san

Energy along Beam Axis

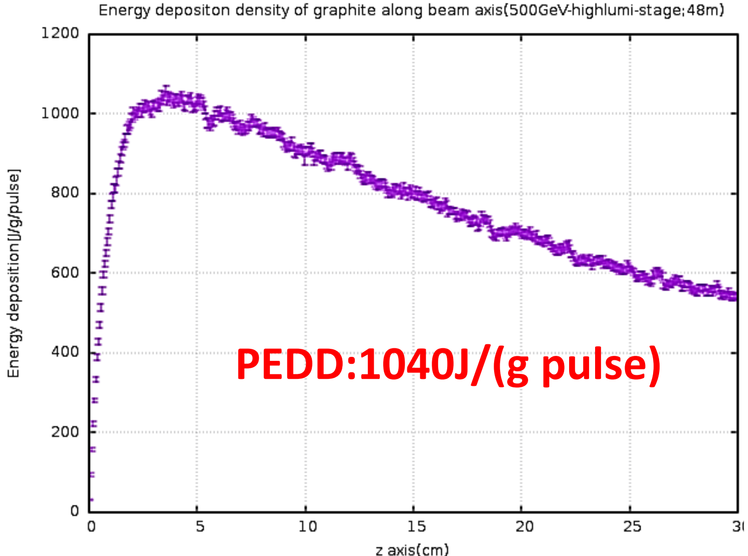


“Hottest” Radial Energy Profile

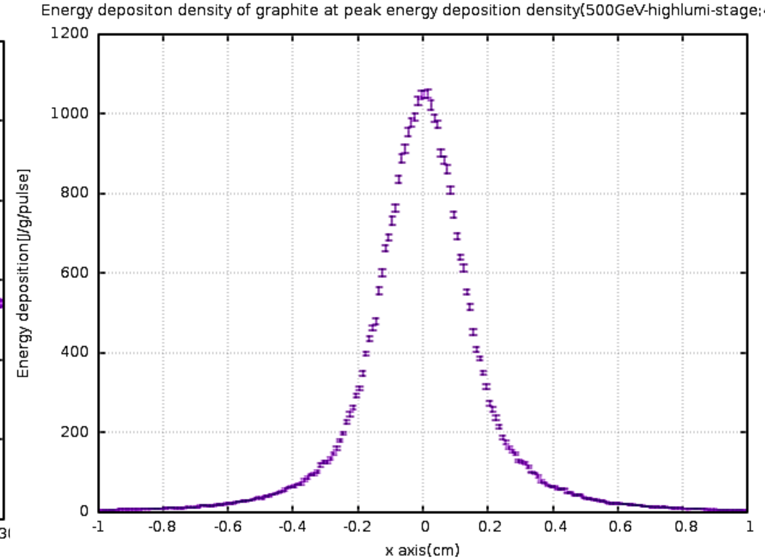


Morikawa

Energy depositon density of graphite along beam axis(500GeV-highlumi-stage;48m)



Energy depositon density of graphite at peak energy deposition density(500GeV-highlumi-stage;4

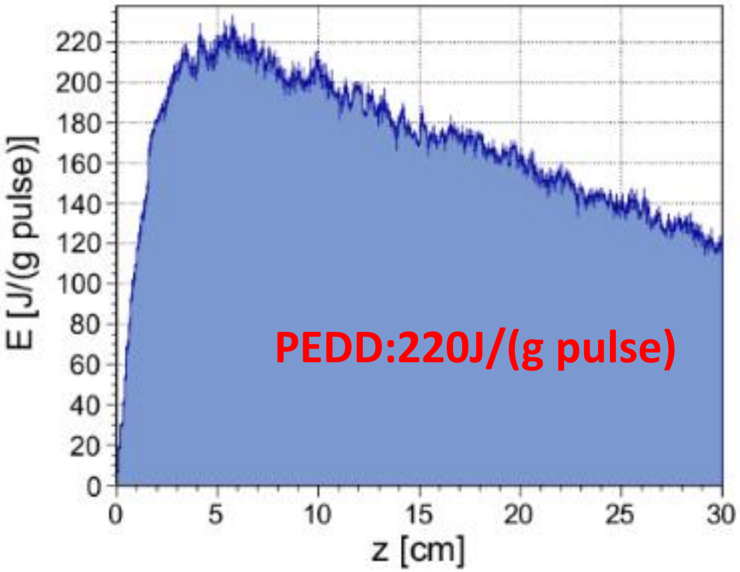


Mesh size :(X-Y,Z)=(20um,60um),Carbon density : 1.82g/cm3

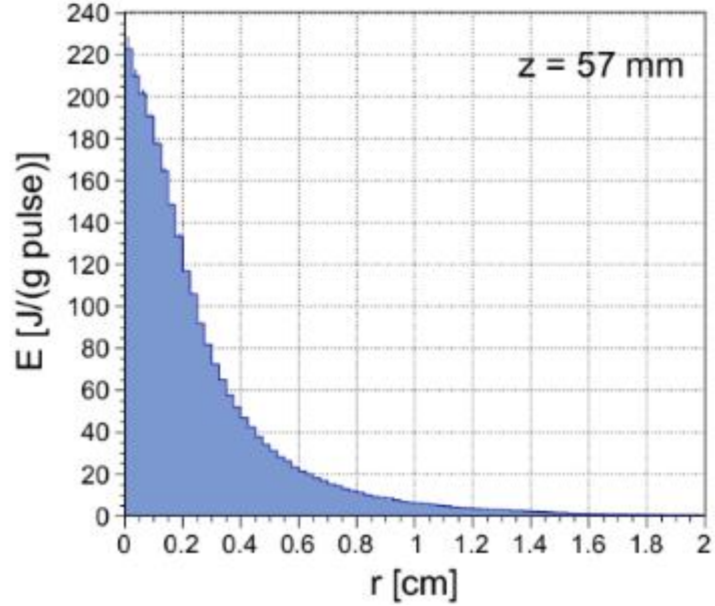
Energy in Far Graphite Dump (1 km from Target)

A.Ushakov-san

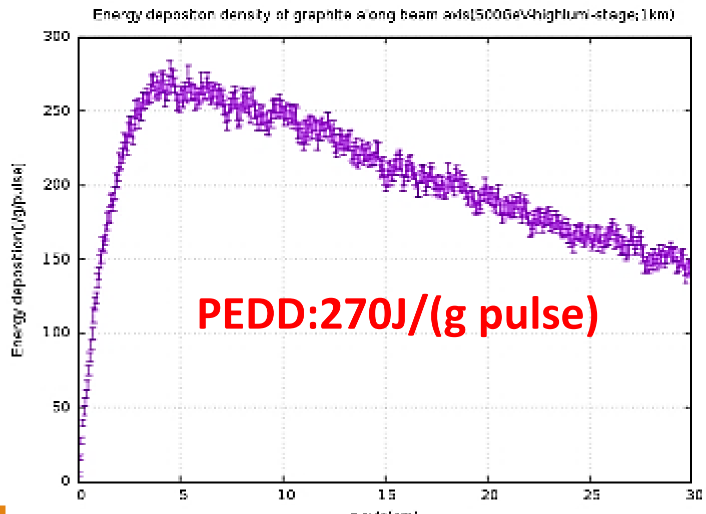
Energy along Beam Axis

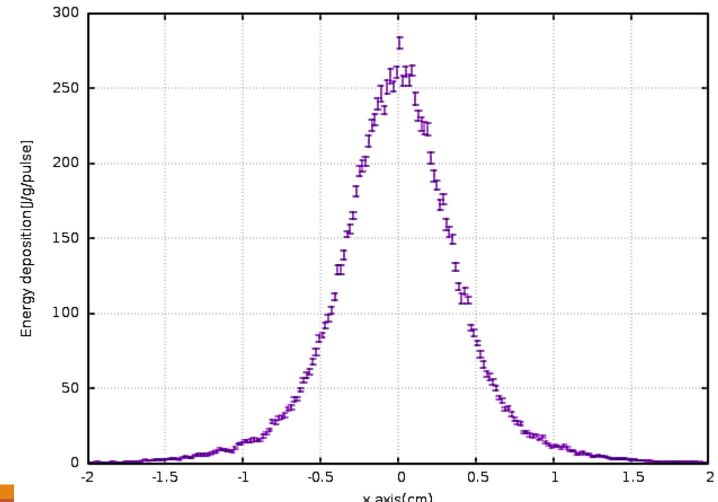


“Hottest” Radial Energy Profile



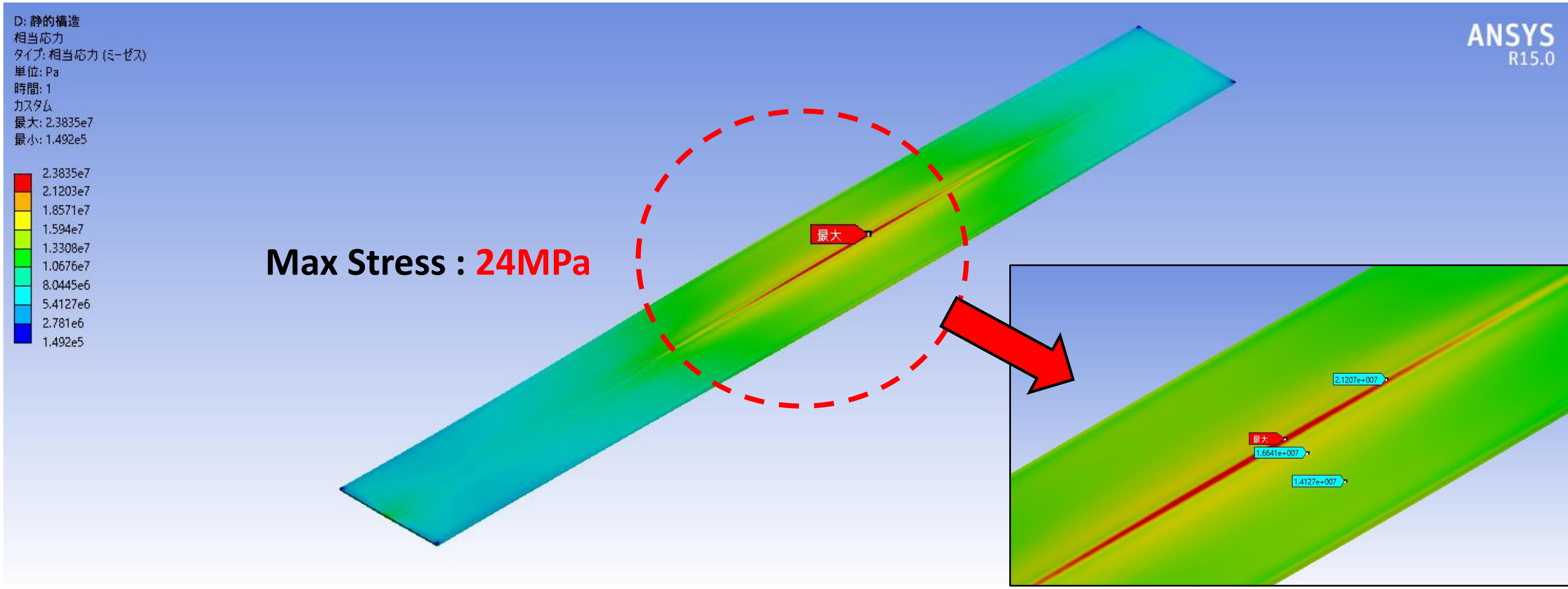
Morikawa





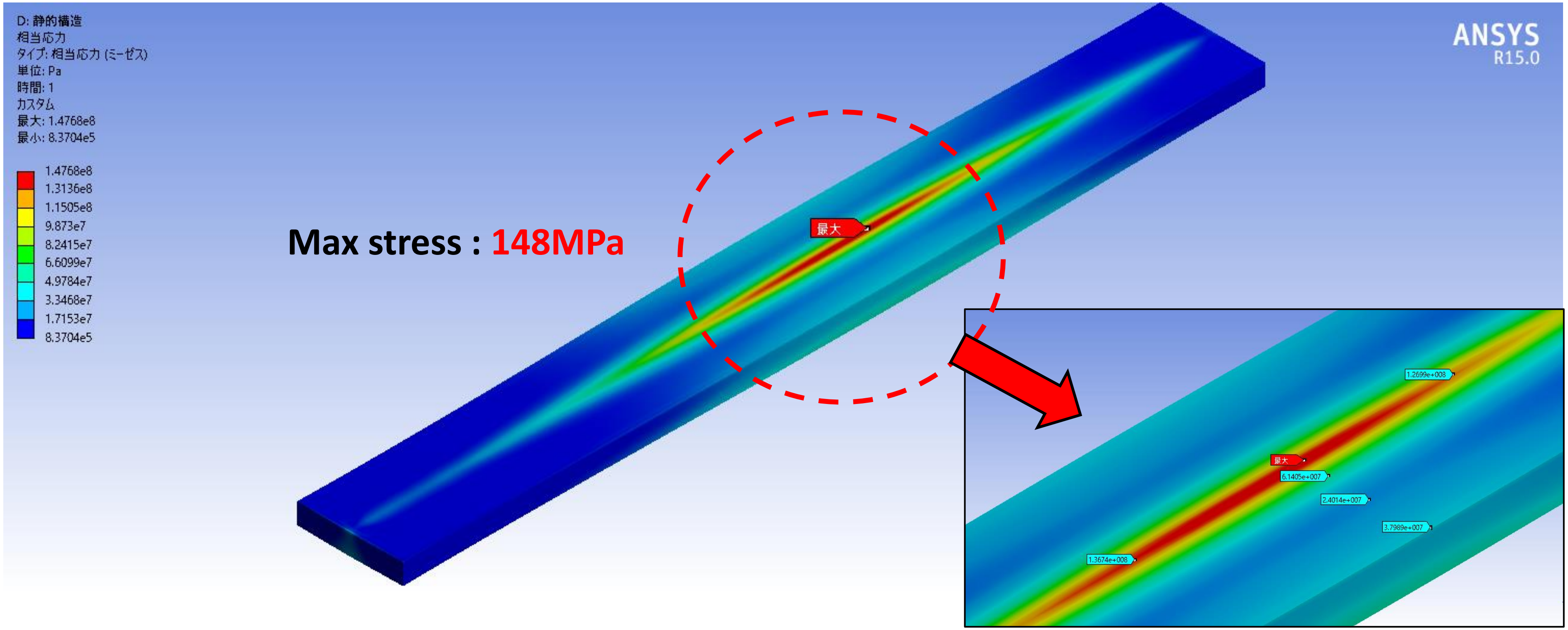
Mesh size :(X-Y,Z)=(20um,60um),Carbon density : 1.82g/cm3

Thermal Stress - Graphite



Thermal Stress - Copper

【Von Mises Stress of Copper】



Graphite oxidation

Oxidation speed

- In J-PARC Neutrino experience*,The speed of the oxidization of IG-430 at 800 ℃ measured in the helium atmosphere with 1,000 ppm oxygen is 4.0×10^{-5} mass%/hour/ppm.

⇒With 1000ppm oxygen and 800℃ operation temp, Graphite plate is 1mm oxidized after 250 hours operation in our dump design.
Of course, This oxidation time is 1,000 times longer if oxygen concentration is 1ppm.

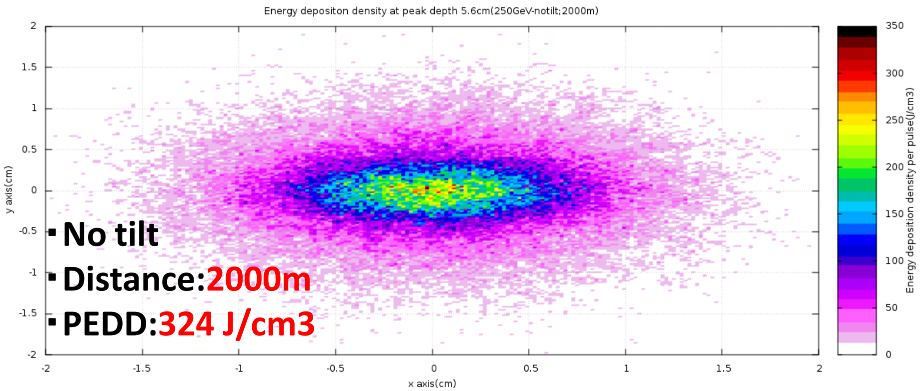
How much residual oxygen concentration can be lowered in our vacuum system?

*The oxidization speed of IG-430 and the tensile strength of the oxidized IG-430 are measured by Toyo sanso Co. Ltd. commissioned by KEK

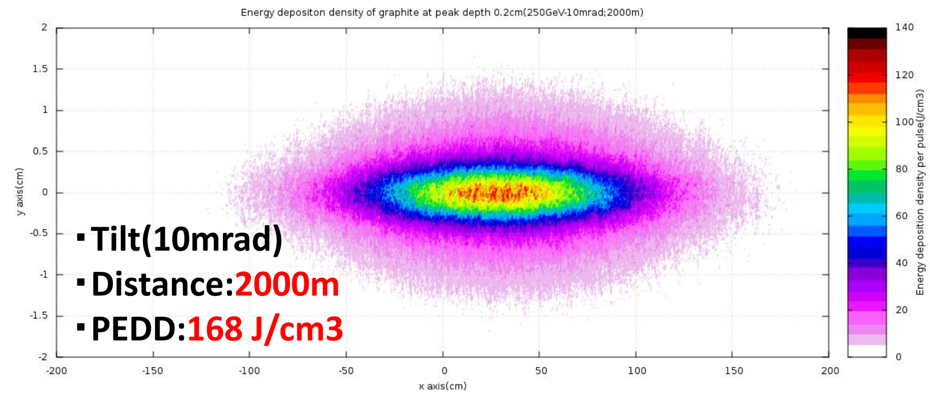
Tilting effect

Depth dependence of Energy deposition

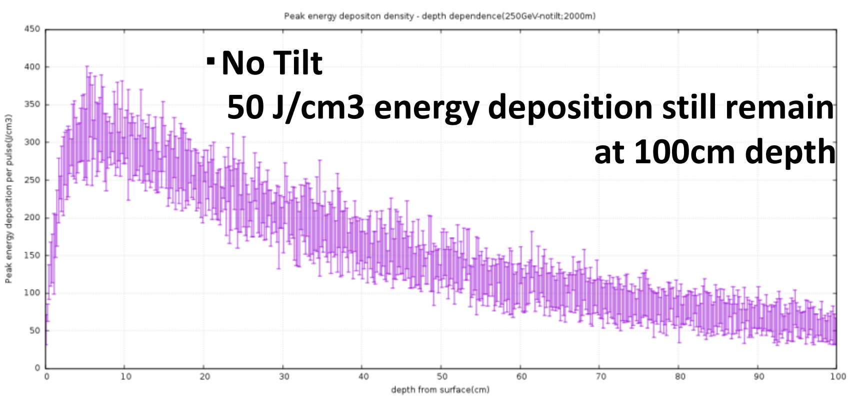
No tilt

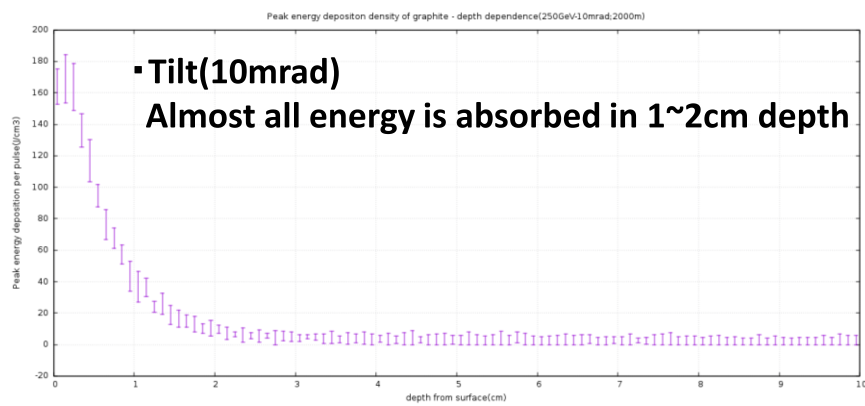


Tilt(10mrad)



Energy deposition density vs graphite depth

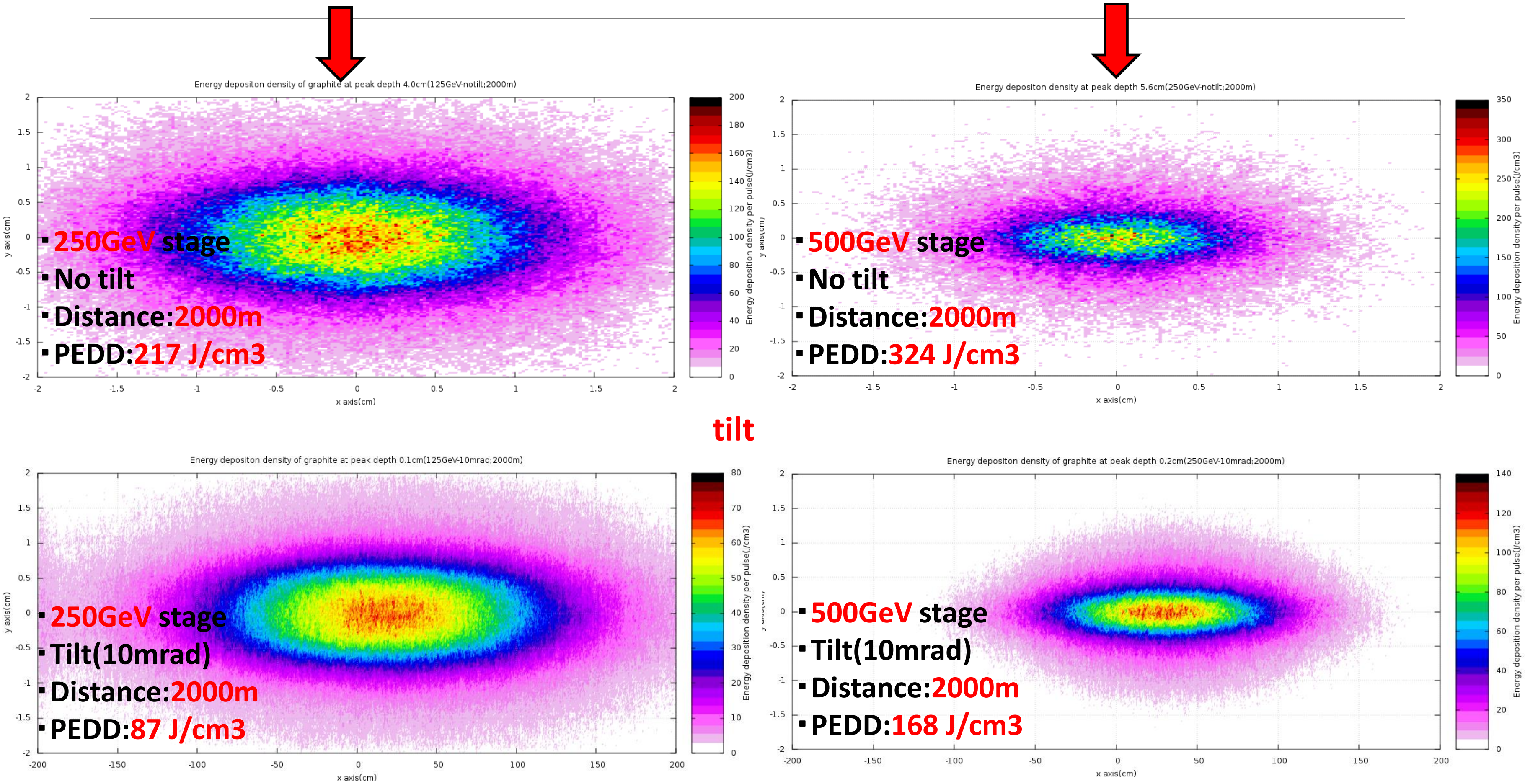




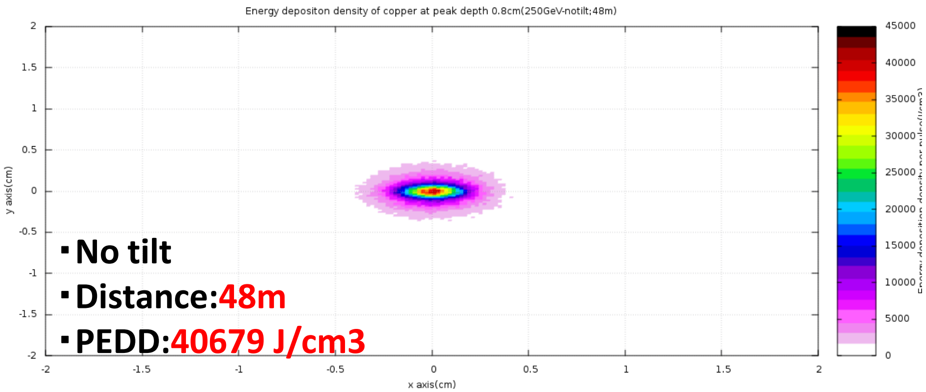
***500GeV stage Photon Beam**

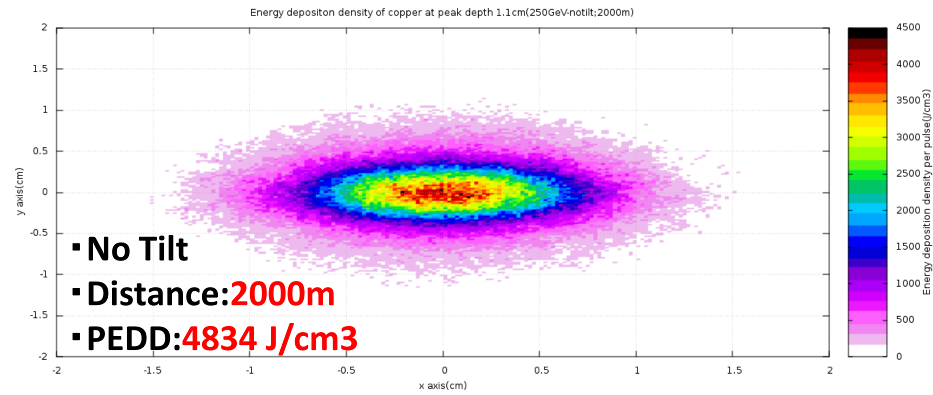
Energy deposition(250GeV & 500GeV stage)

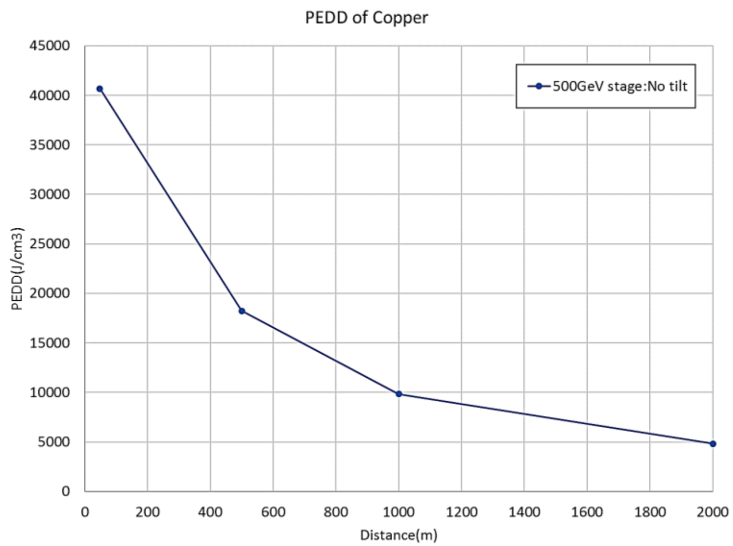
250GeV stage Photon Beam | **500GeV stage Photon Beam**



Energy deposition in copper





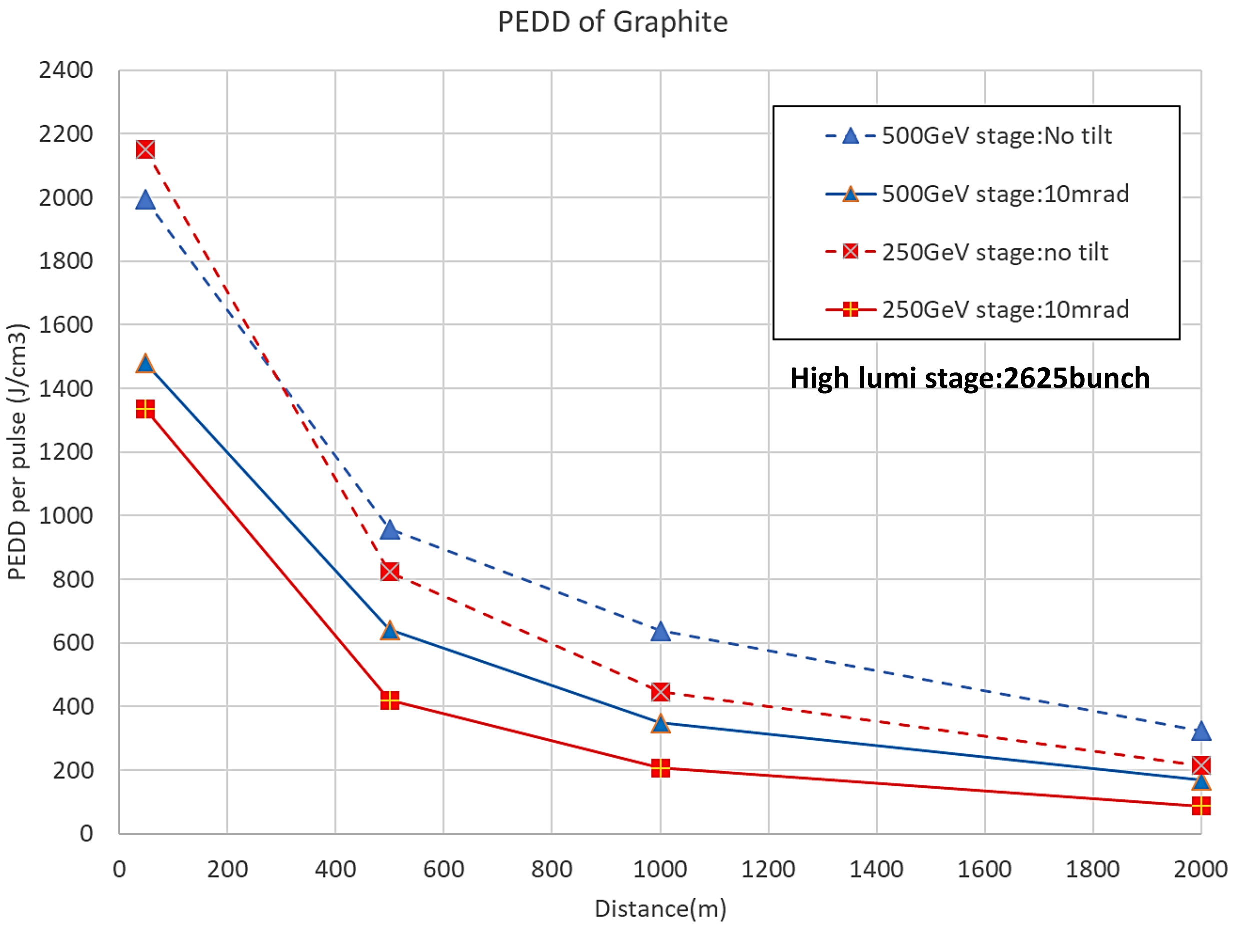


*500GeV stage Photon Beam

* Distance : from Positron Target to Dump

* PEDD : Peak Energy Deposition Density

Alternative Design – Photon Dump Energy deposition



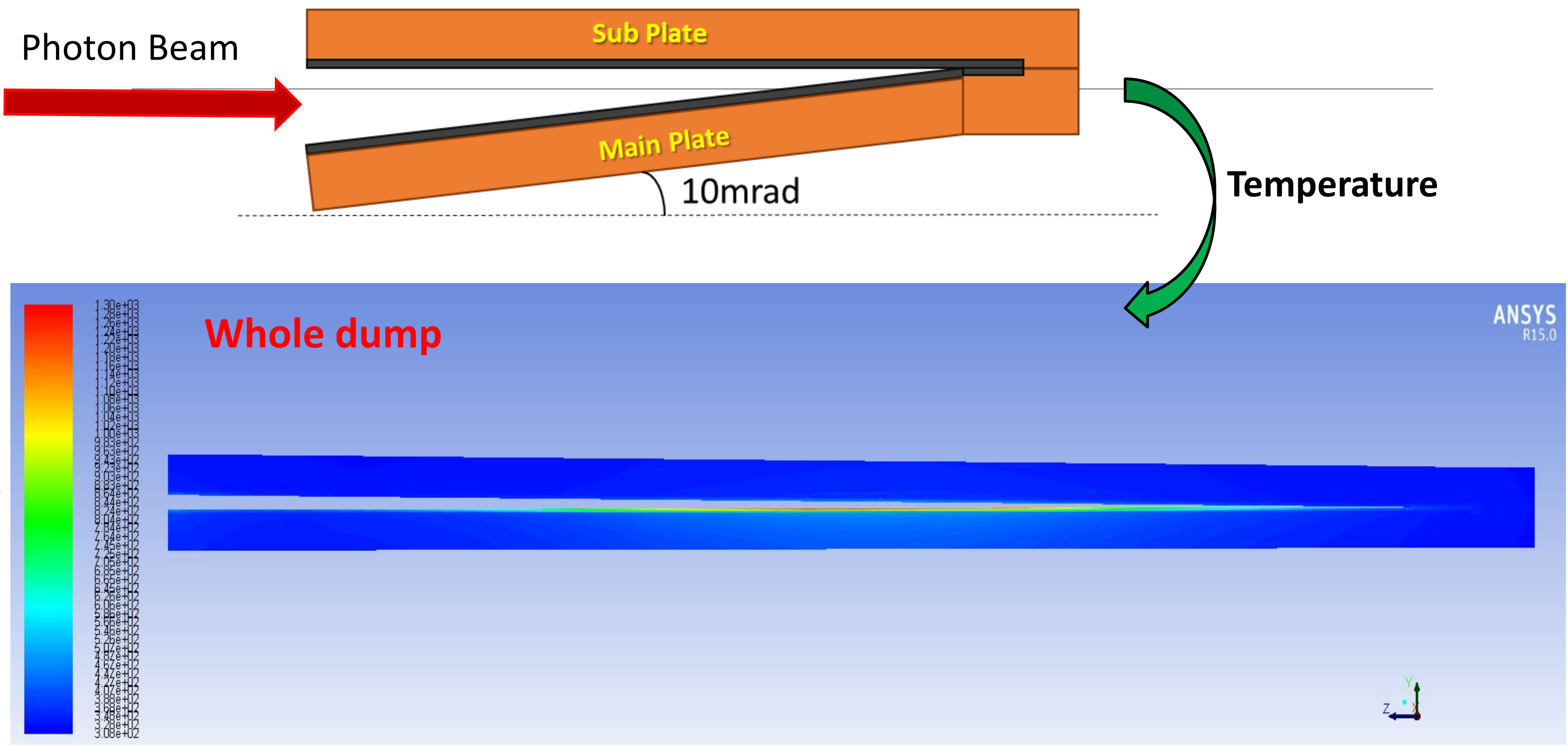
*** Distance : from Positron Target to Dump**
*** PEDD : Peak Energy Deposition Density**

Temperature simulation

Graphite Conductivity 10W/Km

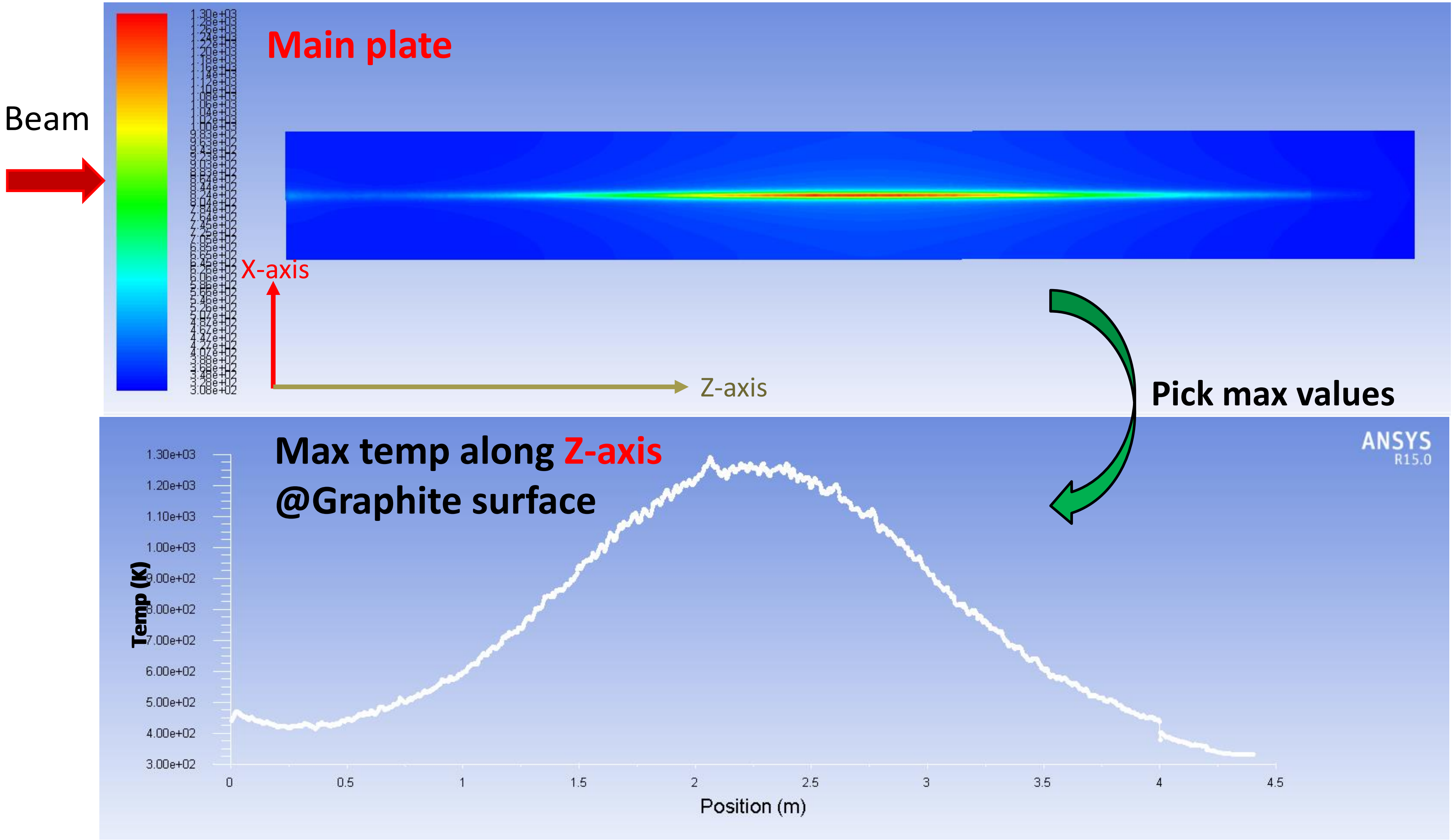
Temperature distribution

Graphite conductivity : 10W/(Km)



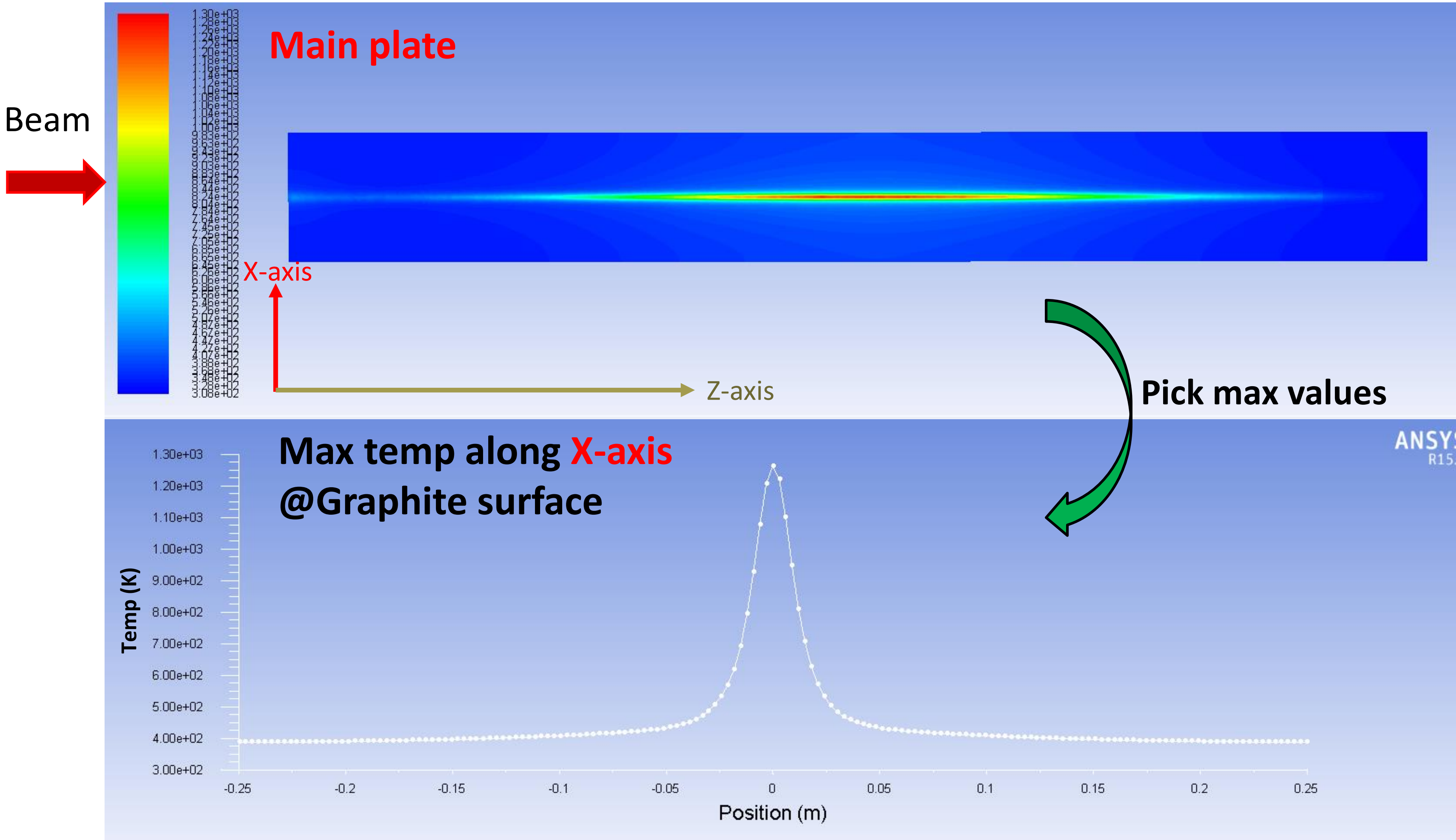
- Max temp for 250GeV-High lumi stage : 1027℃(1300K) @ Main plate
  193℃(466K) @ Sub plate

Temperature distribution Graphite conductivity : 10W/(Km)



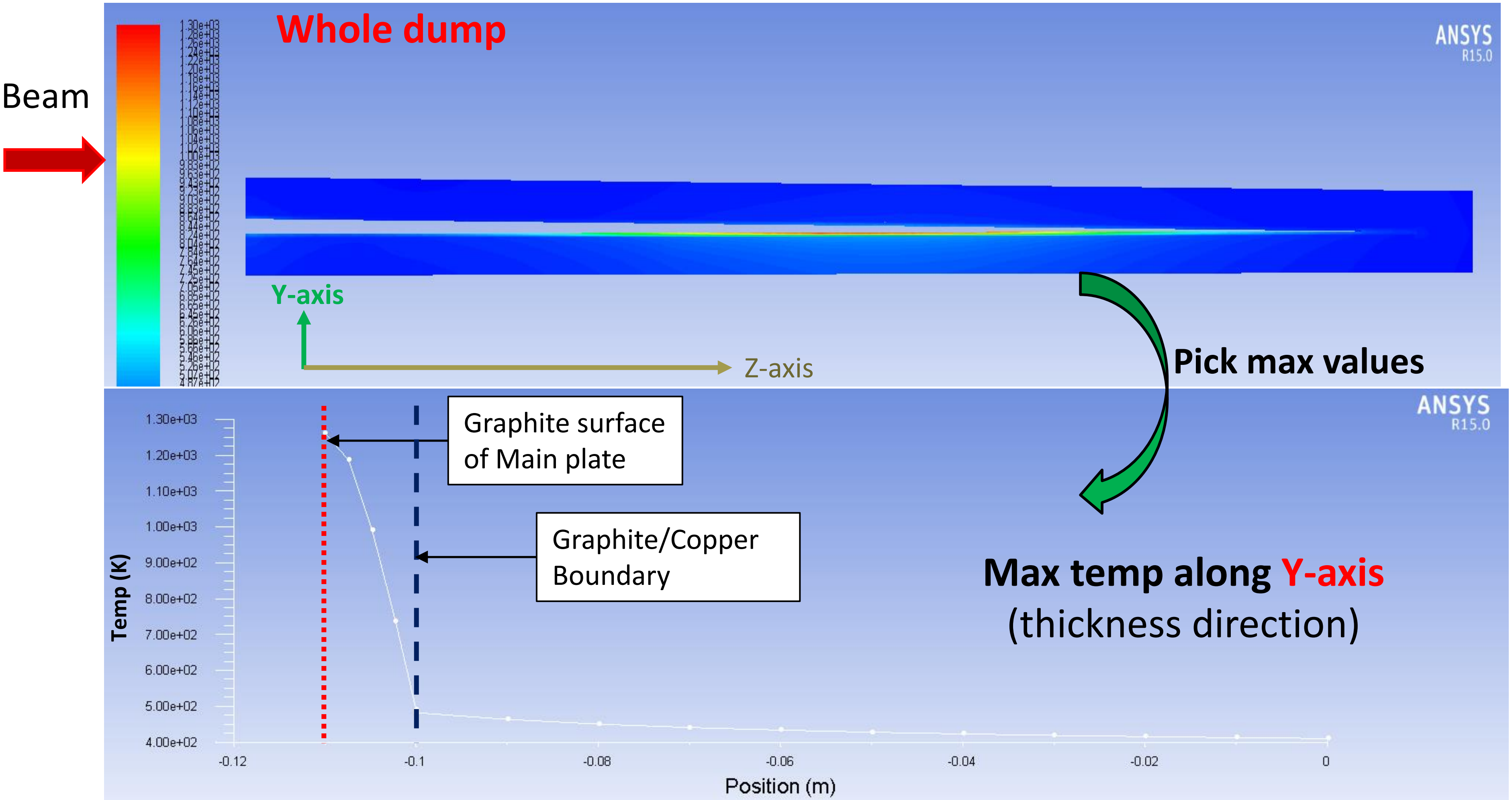
- Max temperature is 1027℃(1300K) for 250GeV-High lumi stage

Temperature distribution Graphite conductivity：10W/(Km)



- **Max temperature is 1027℃(1300K) for 250GeV-High lumi stage**

Temperature distribution Graphite conductivity：10W/(Km)



- **Max temperature is 1027℃(1300K) for 250GeV-High lumi stage**

Design of Water Curtain

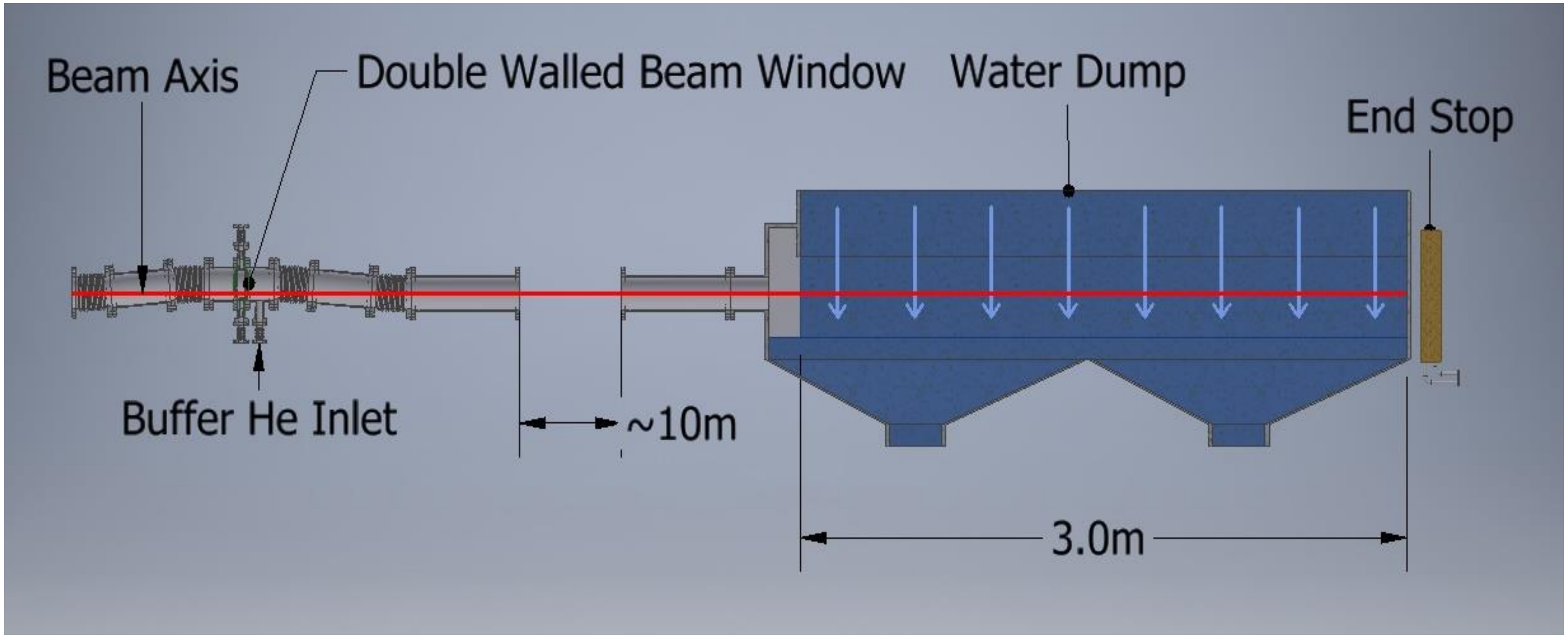
・故障の検知、故障の対応が難しいように見える。

【Base Idea】

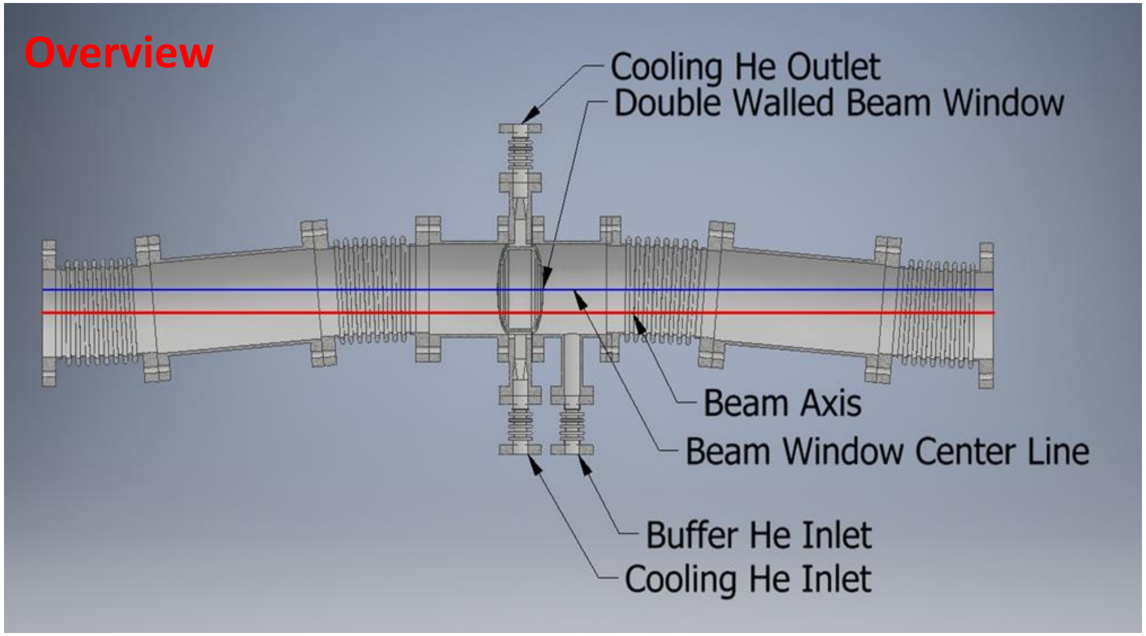
①Beam incidents to falling water(**Water Curtain**)
This system can accept water boiling.

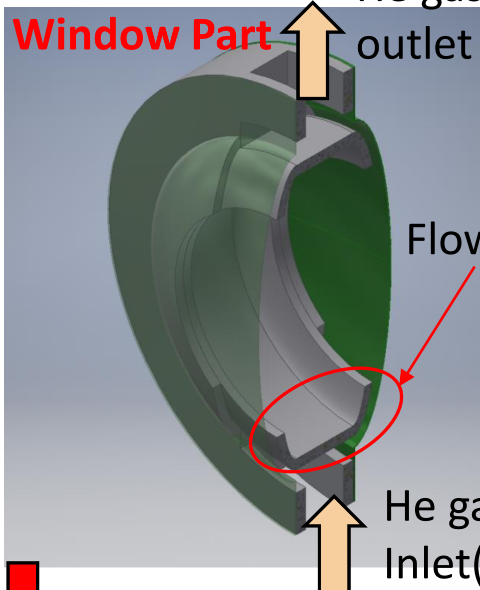
②**Double Walled Beam Window** Cooled by Helium gas.
This window is tumbled to reduce the radiation damage.

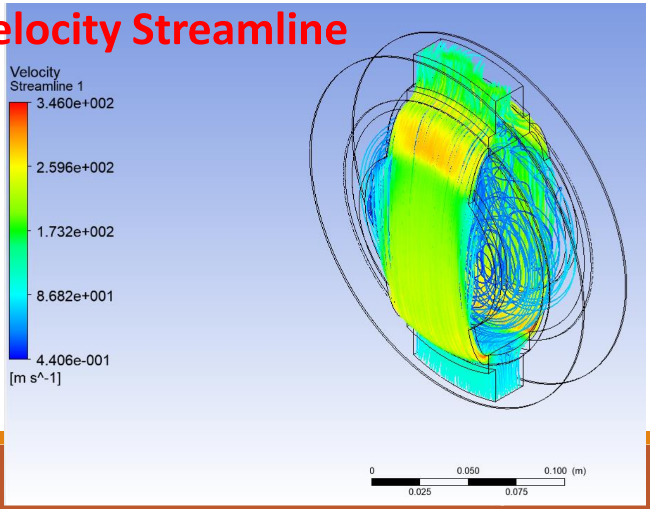
【Base Design】



Base Design of Double Walled Window

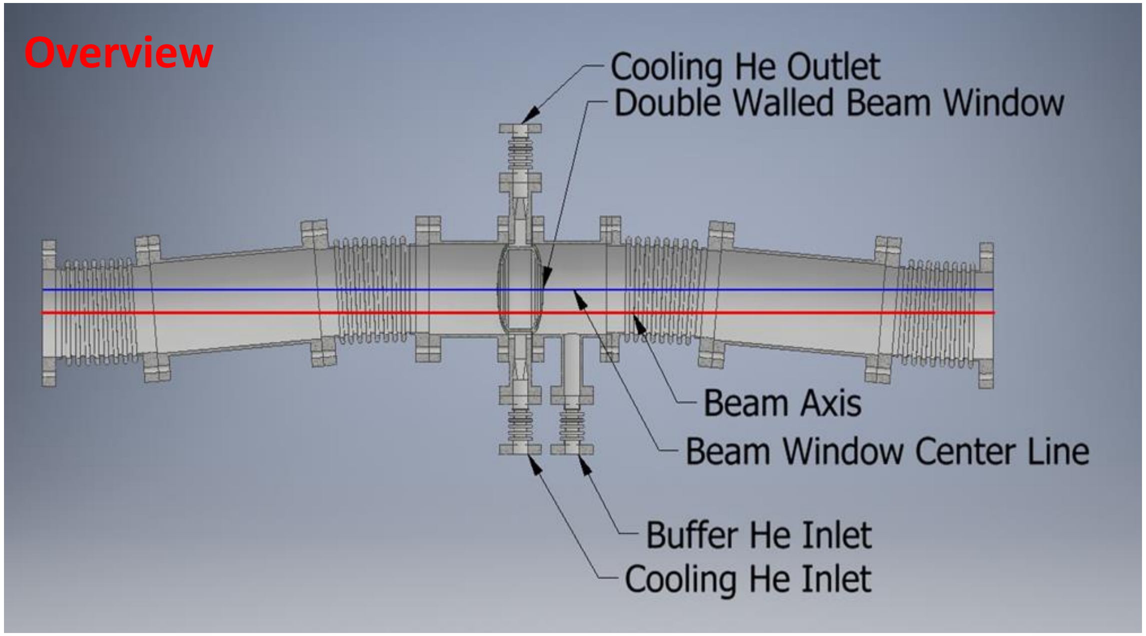


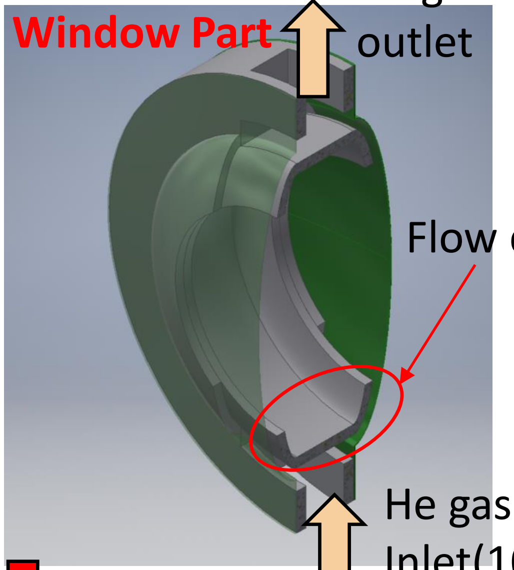


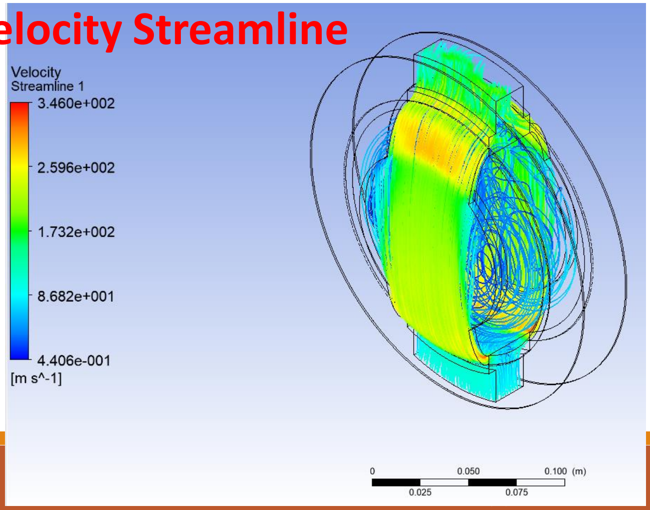


- Elliptical shape ϕ15cm(long axis), ϕ4cm(Short axis)
- Tumbling Window by bellows system.
  Tumbling radius=3cm, 1.9sec/turn(0.53Hz)
- Helium gas cooling
  Gas velocity of introductory part:100m/sec,
  Heat transfer coefficient : ~0.1W/cm2K

Base Design of Double Walled Window







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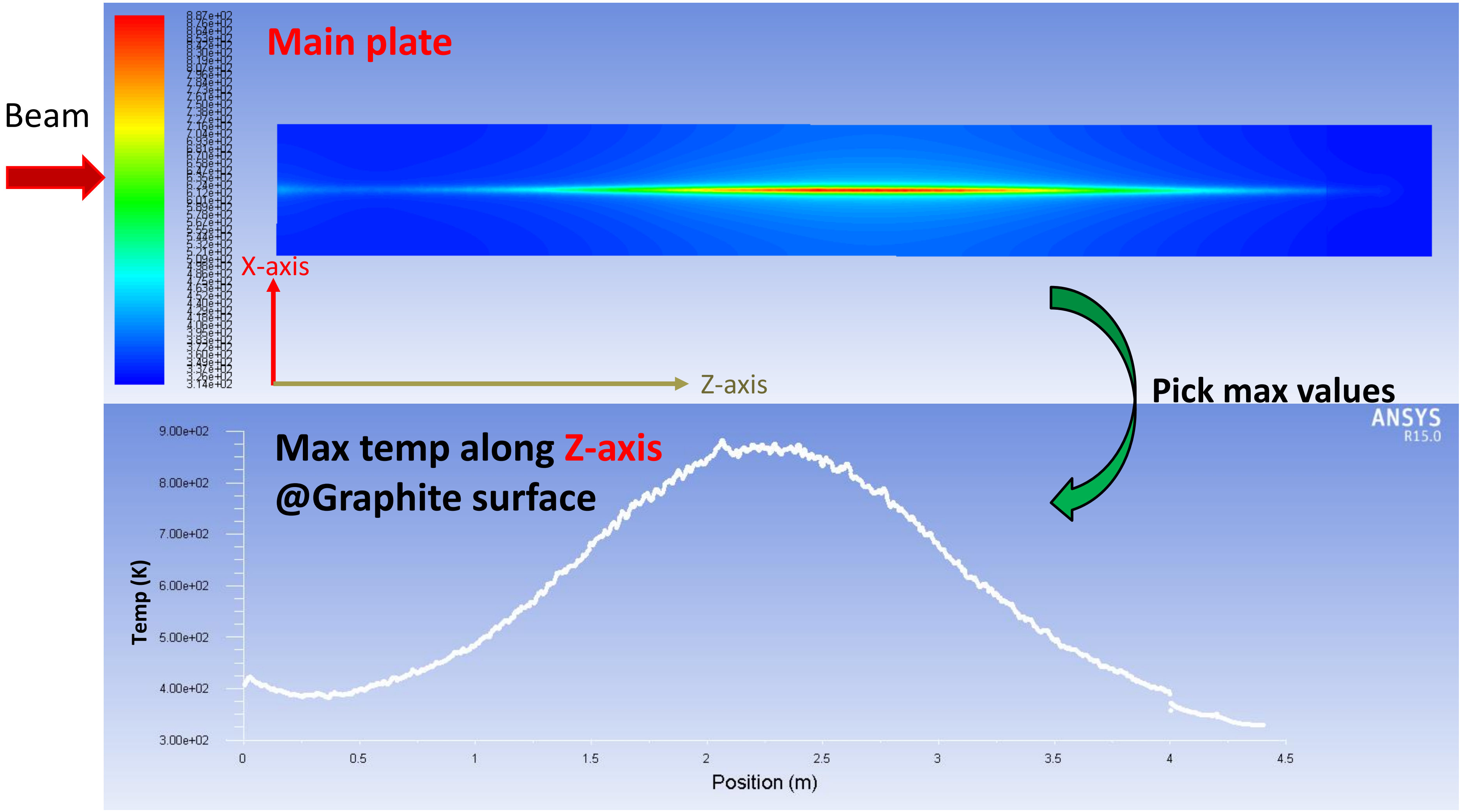
- Helium gas cooling
  Gas velocity of introductory part:100m/sec,
  Heat transfer coefficient : ~0.1W/cm2K

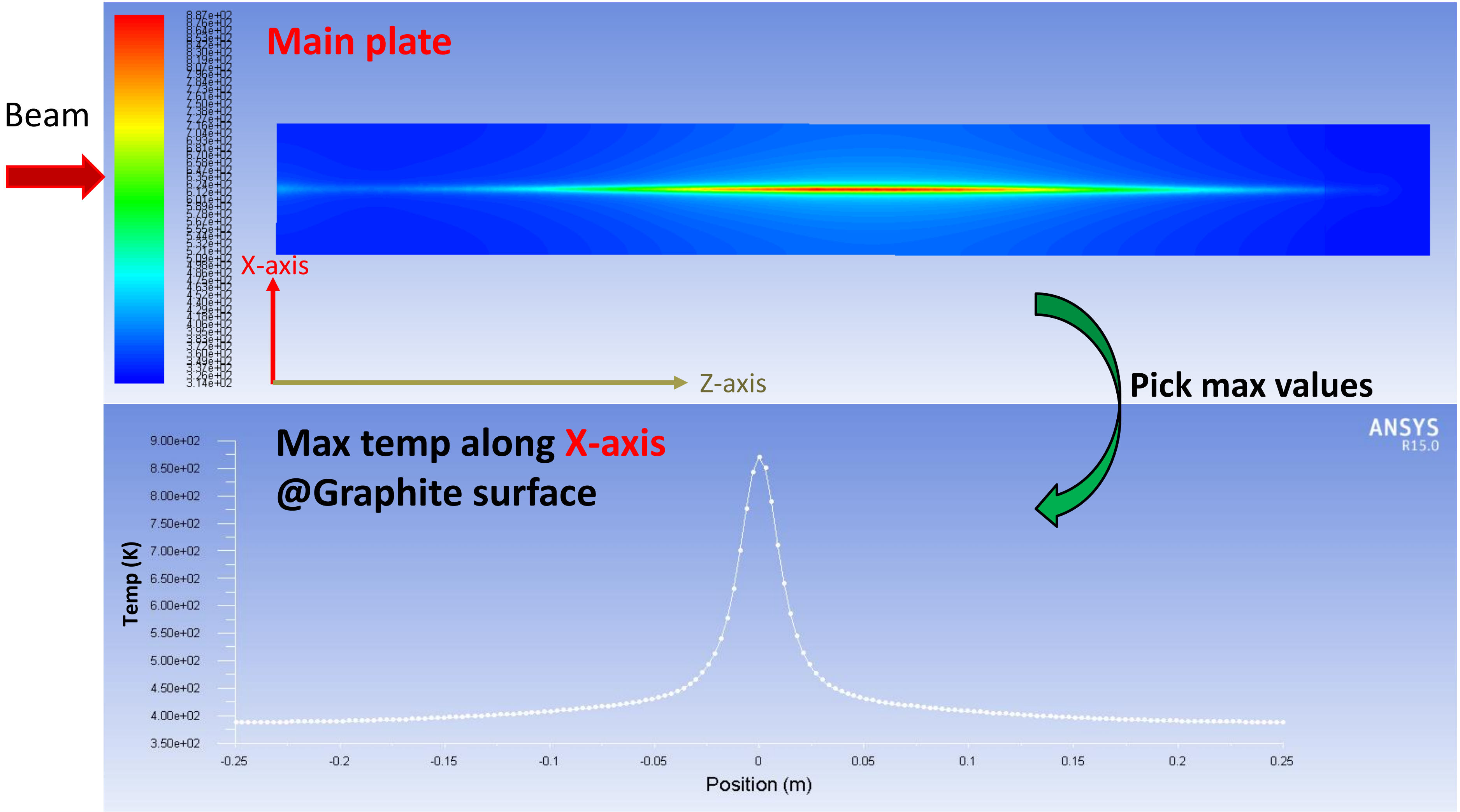
- 課題を簡単に述べる。
  ガス導入系の複雑さ/難易度。
  ガス漏洩(放射化物)の管理

Temperature distribution Graphite conductivity : 20W/(Km)



- **Max temperature is 614℃(887K) for 120kW photon beam**

Temperature distribution Graphite conductivity：20W/(Km)



- Max temperature is 614℃(887K) for 250GeV-High lumi stage