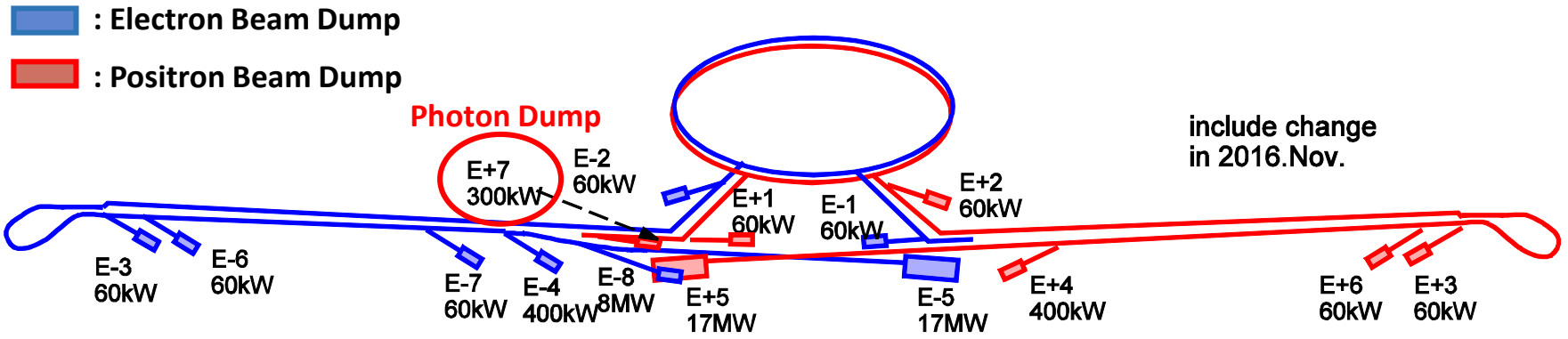
A Photon Dump Study for ILC Undulator Positron Source

Yu Morikawa

ILC Beam Dumps



Total 15 Beam dumps in ILC . Beam dumps are classified into 5 types.

Type	Power	Purpose	Absorber	Place
A	60kW	Tune-up	Solid material	9[E-1,E-2,E-3,E-6,E-7,E+1,E+2,E+3,E+6]
B	400kW	Tune-up & Emergency	Solid material	2[E-4,E+4]
C	300kW	Photon Dump	Water ? Graphite ?	1[E+7]
D	8MW	5 + 5 Hz Operation	Liquid-water	1[E-8]
E	17MW	Main Beam-Dump	Liquid-water	2[E-5,E+5]

Outline

【Purpose】

- Studying about feasibility of Graphite Photon Dump for ILC Undulator Positron Source

【Contents】

1.Design of Graphite photon dump
2.Energy deposition & DPA calculation
3.Temperature simulation
4.Thermal stress simulation

⇒focus on 250GeV High luminosity stage in this talk

Graphite Dump Design

For 250GeV High luminosity stage

Design of Graphite Photon Dump

【Base Idea】

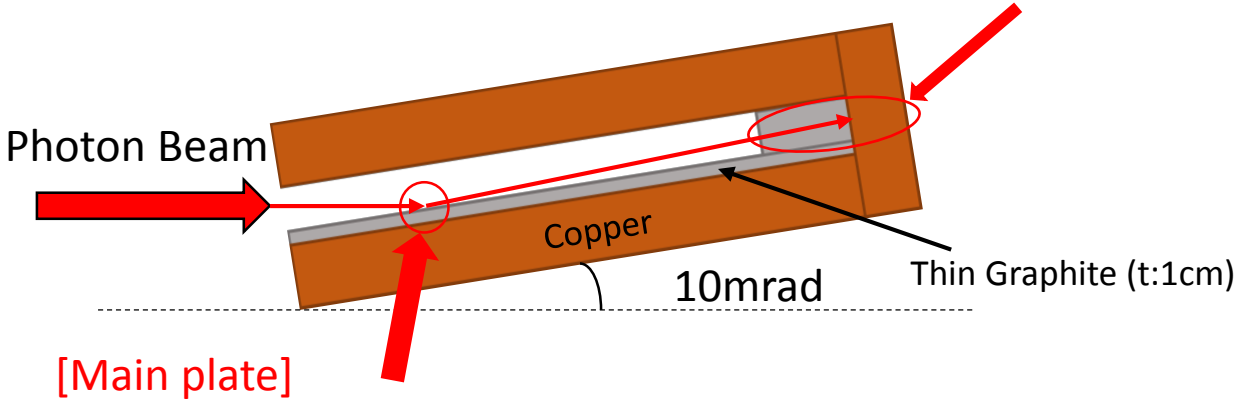
①To enlarge the photon beam spot on beam dump

・**putting long distance** between positron target and beam dump(**2km**).

②To absorb beam heat only by thin Graphite

・**tilting beam dump** (almost horizontally:**10mrad**)

【Base Design】



Absorbing⇒72kW(62%) of beam power@250GeV stage

Scattering⇒84kW(38%) of beam power@250GeV stage

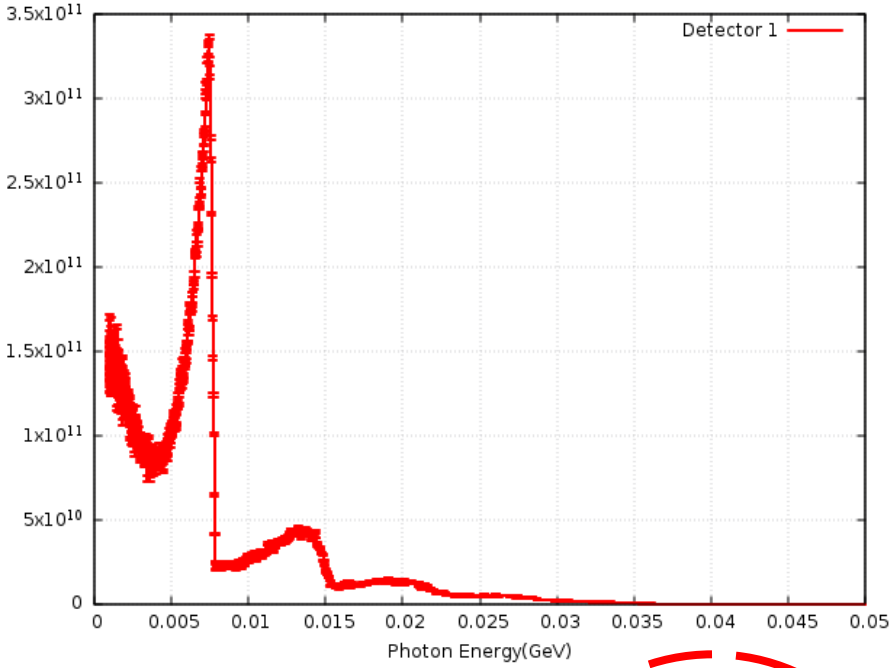
Cooling mechanism : Only cooling water in copper

No cooling, protection gas : No need to introduce to beam window

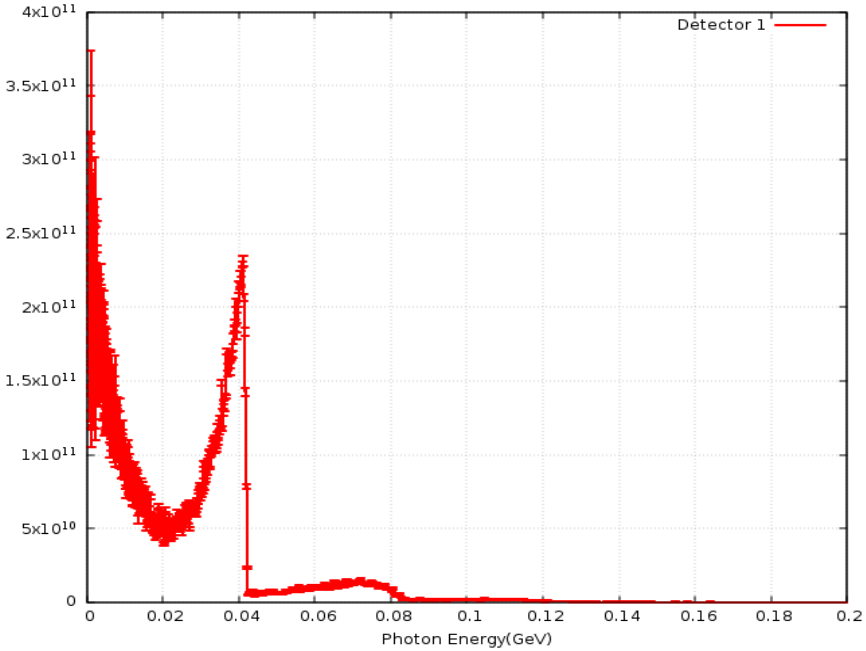
Energy deposition & DPA

Photon beam property

Energy spectrum of 250GeV stage undulator photon



Energy spectrum of 500GeV stage undulator photon

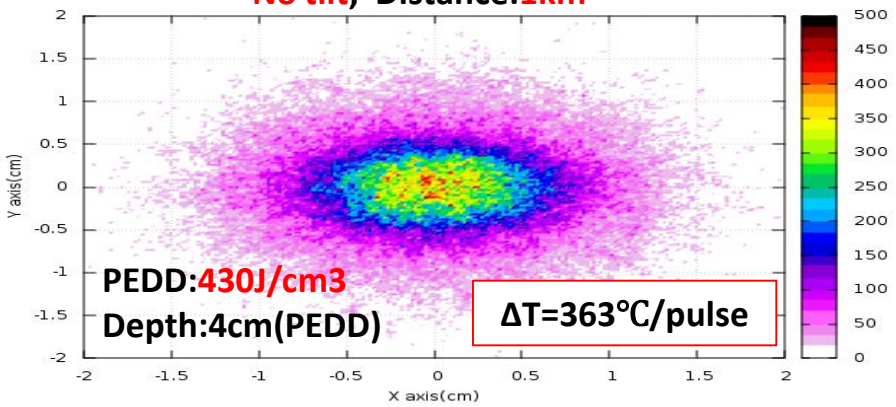


Photon Beam	250GeV stage	500GeV stage
Num of photons/bunch	8E12	2E12
Num of bunches/pulse	1312, 2625	
Pulse repetition	5Hz	
Peak Photon Energy	7MeV, 14MeV…	41MeV, 73MeV…
Beam power	60kW, 120kW	52kW, 104kW

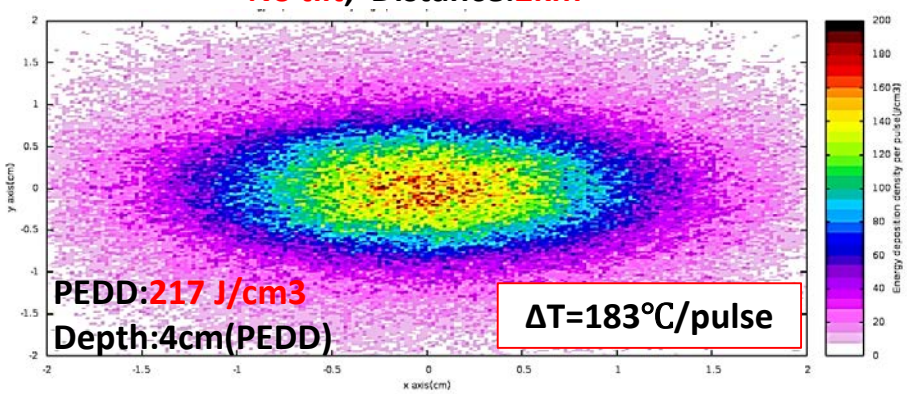
Calculation by Yokoya-san

Energy deposition

▪ No tilt, Distance:1km



▪ No tilt, Distance:2km

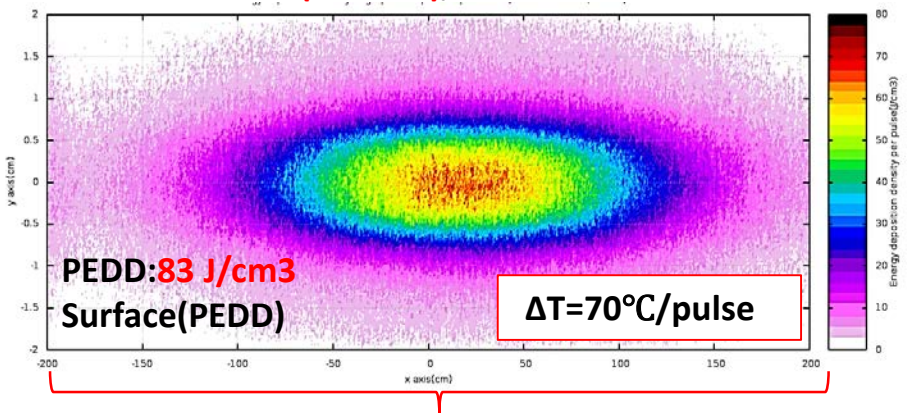


Calculated energy deposition of Graphite

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

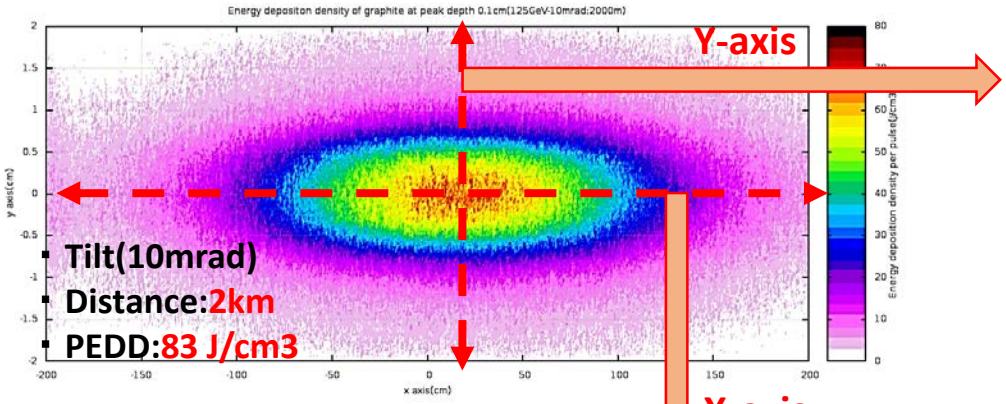
* Distance : from Positron Target to Dump
* PEDD : Peak Energy Deposition Density

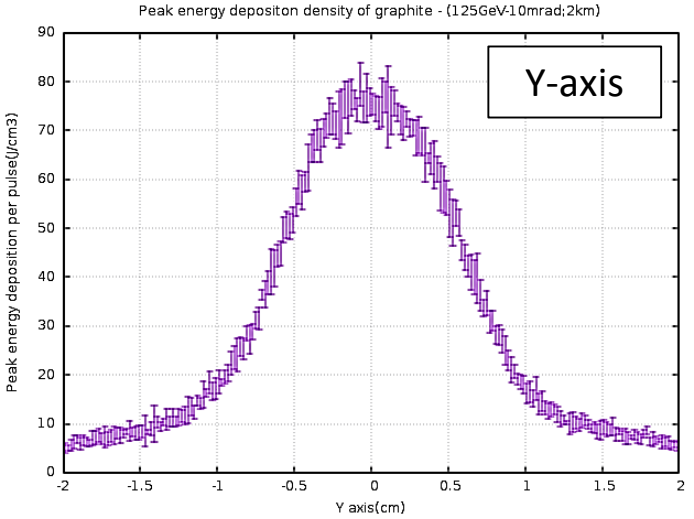
▪ Tilt(10mrad), Distance:2km

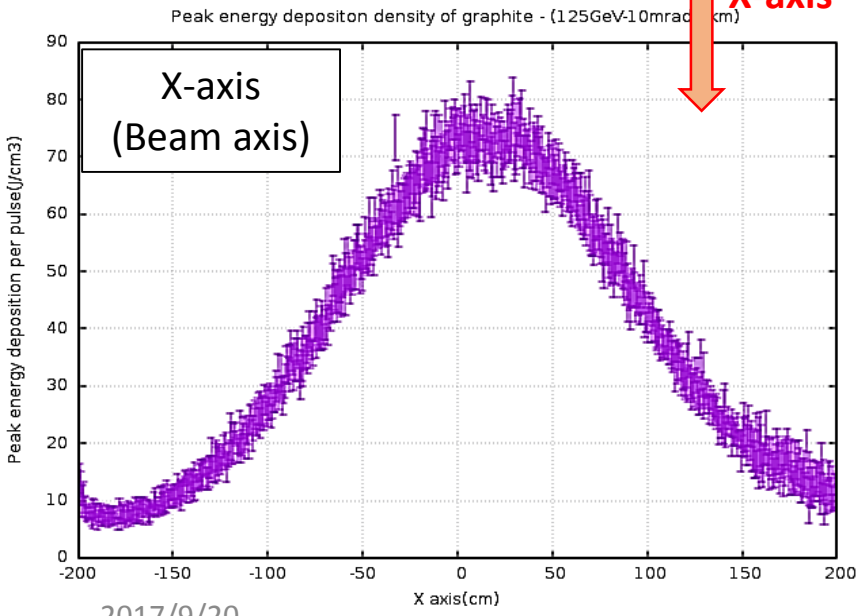


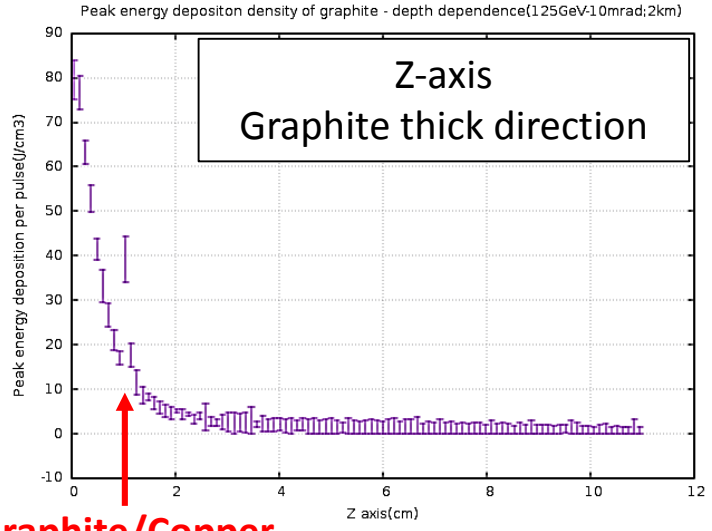
X scale is 100 time larger

Energy deposition-2km,10mrad



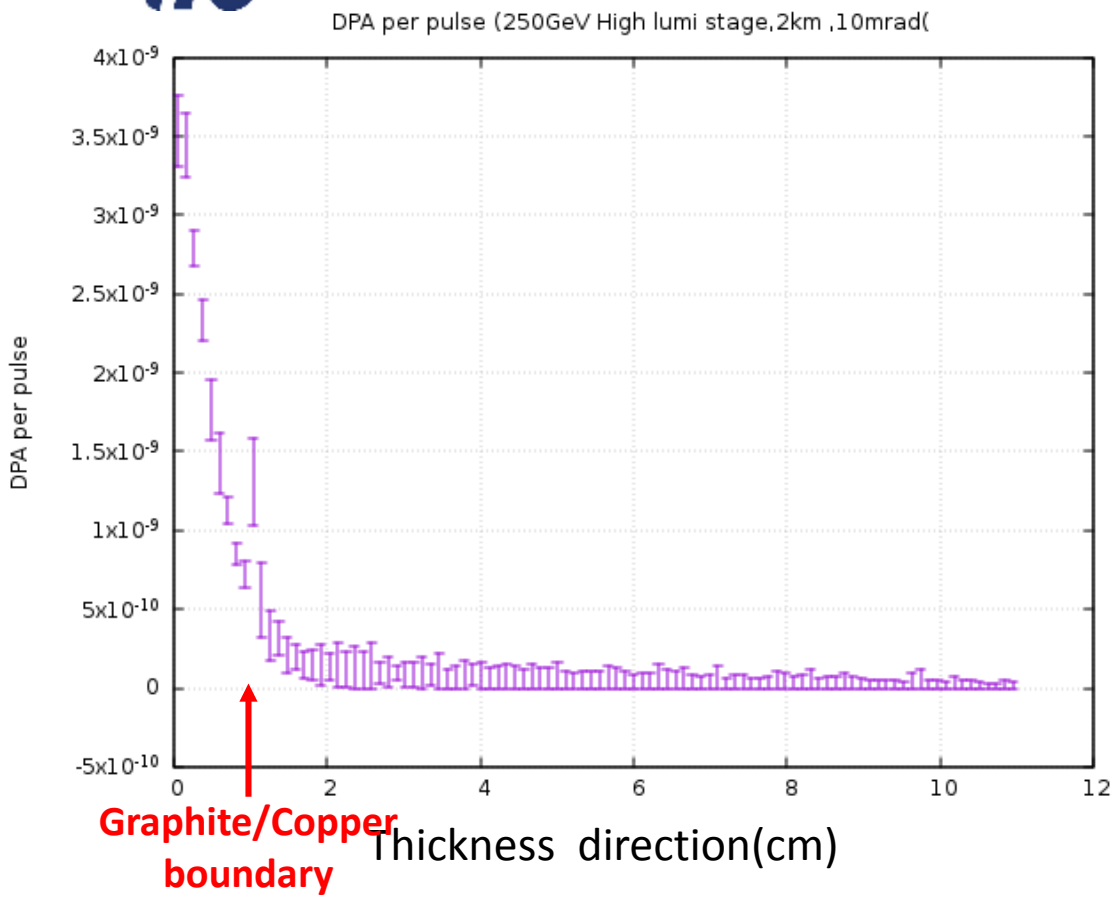






Graphite/Copper boundary

DPA



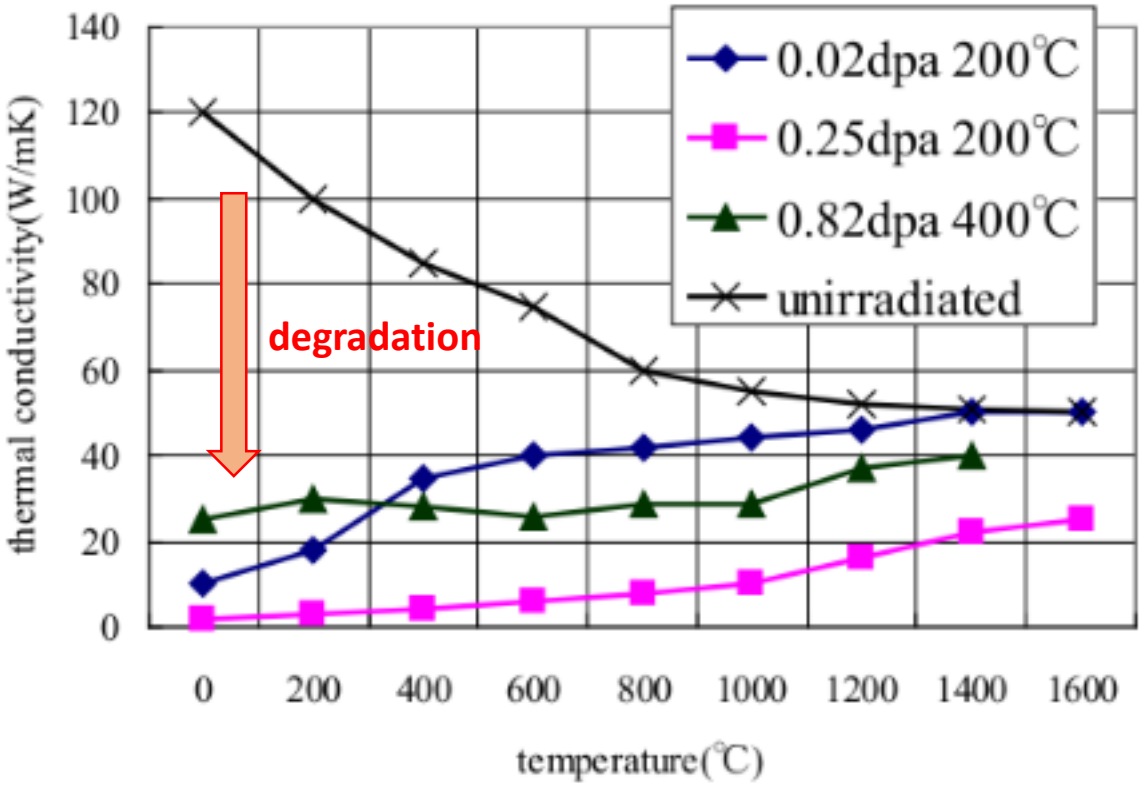
Carbon Density : 1.82g/cm3,
Carbon Energy threshold of DPA =30eV

250GeV High Lumi stage : 3.5×10^{-9}/pulse

⇒DPA 0.315 / 5000hour operation

Temperature & Thermal Stress

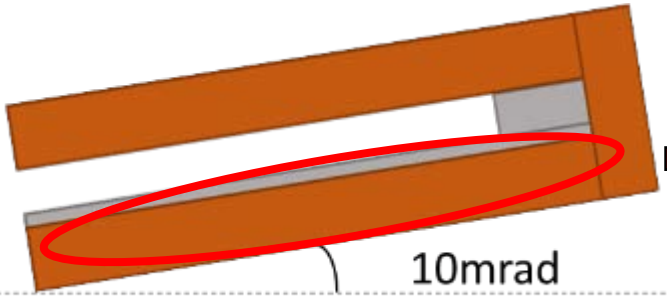
Degradation of Graphite thermal conductivity

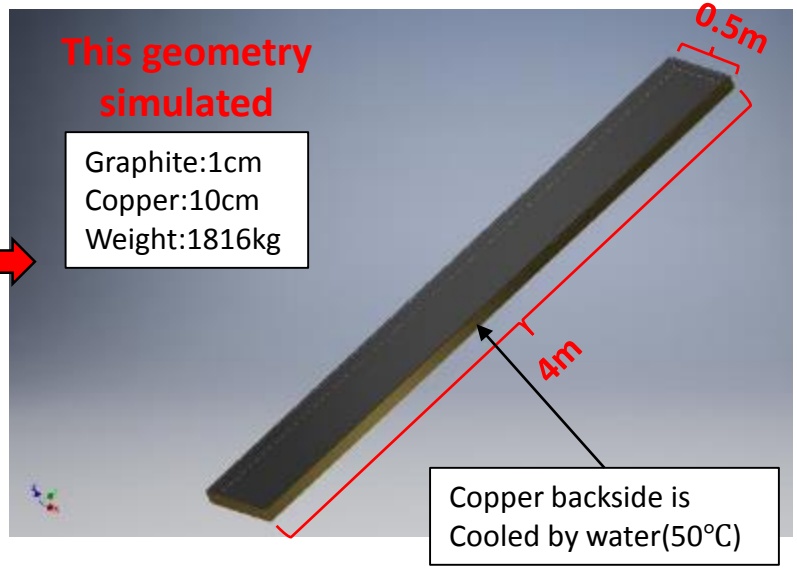


- Thermal conductivity is degraded by radiation.
- Higher operation temperature reduces degradation of thermal conductivity.(annealing effect)

Neutron irradiation effect to thermal conductivity
(T. Maruyama et al., Journal of Nuclear Materials 195(1992) 44-50.)

Simulation Geometry





[Settings]

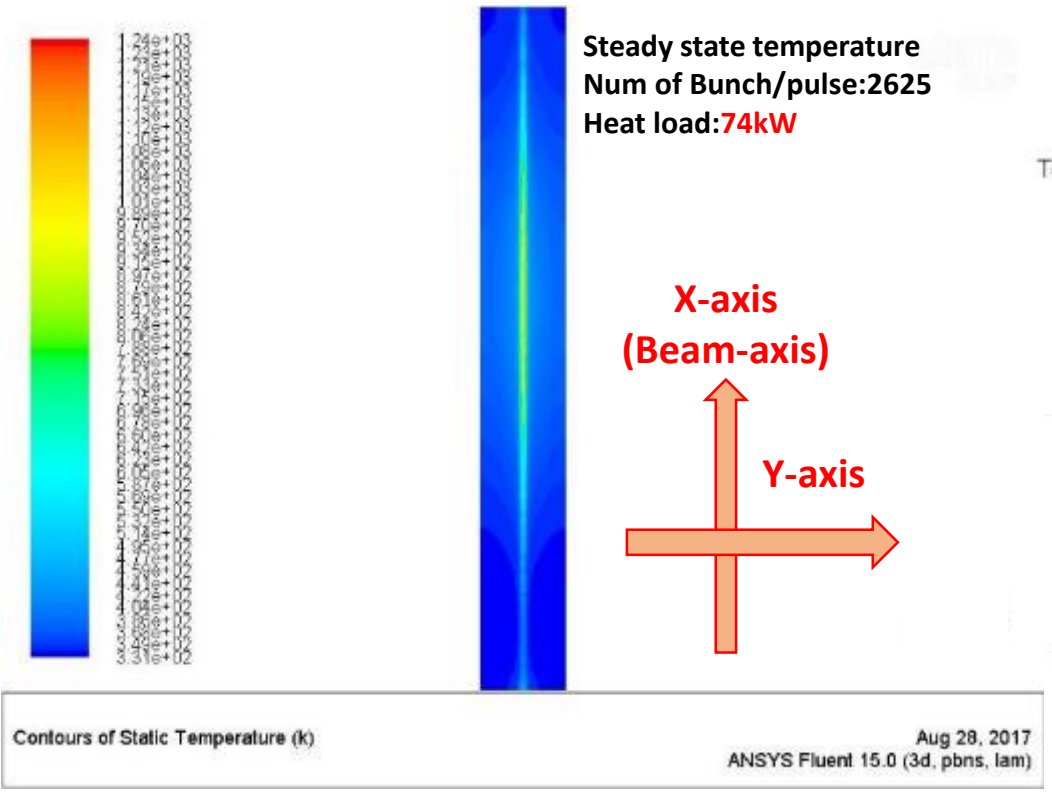
- **Steady state calculation**
- **Equations: Energy transfer**
- **Heat transfer rate of water is set to 1kW/m2-k**
- **Cooling path is only backside cooling water(50℃)**

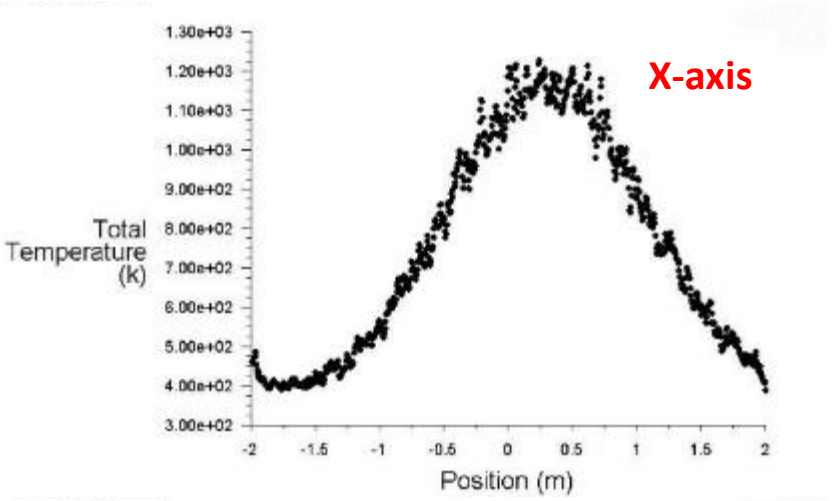
Material Property	Copper	Graphite
Density(kg/m3)	8978	1820
Specific heat(j/kg-k)	381	650
Thermal conductivity(w/m-k)	387.6	10 (degradation by radiation)

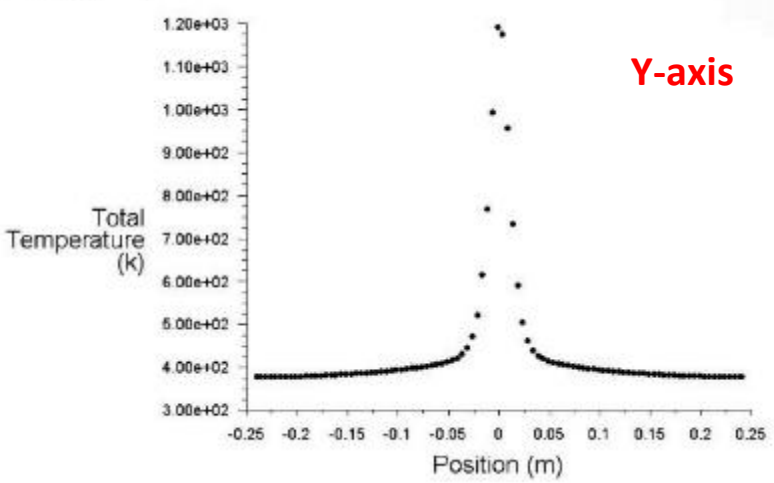
*Degradation of the thermal conductivity occurs in the beam irradiation portion, but degradation value is set throughout the graphite plate in this simulation.

Temperature distribution

Graphite conductivity：10W/(Km)



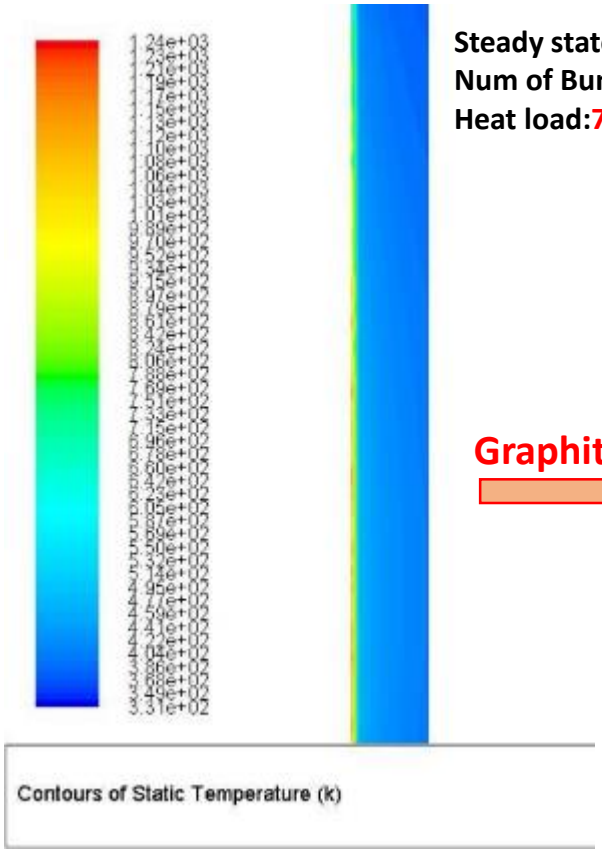




- **Max temperature is 967℃(1240K) for 250GeV-High lumi stage**

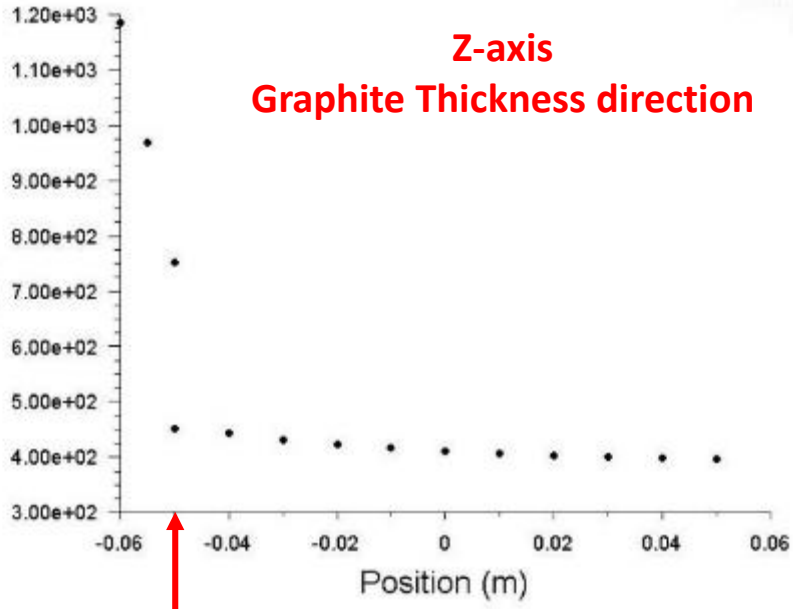
Temperature distribution

Graphite conductivity：10W/(Km)



Steady state temperature
Num of Bunch/pulse:2625
Heat load:74kW

Z-axis
Graphite Thickness direction



Z-axis
Graphite Thickness direction

Graphite/Copper boundary

- Max temperature is 967℃(1240K) for 250GeV-High lumi stage

Deformation and thermal stress

【Analysis】

Temperature distribution data export to Ansys mechanical.

Evaluating the total deformation and Von Mises stress

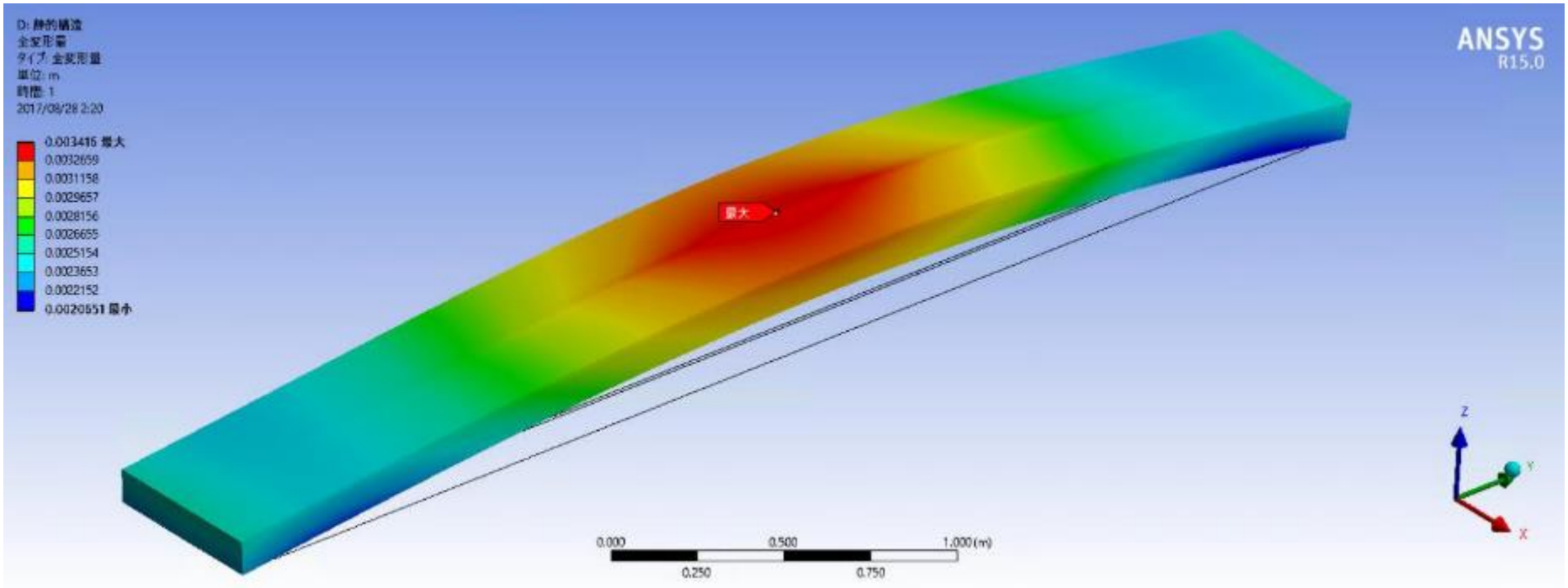
【Material Property】

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

Deformation

【Total Deformation】

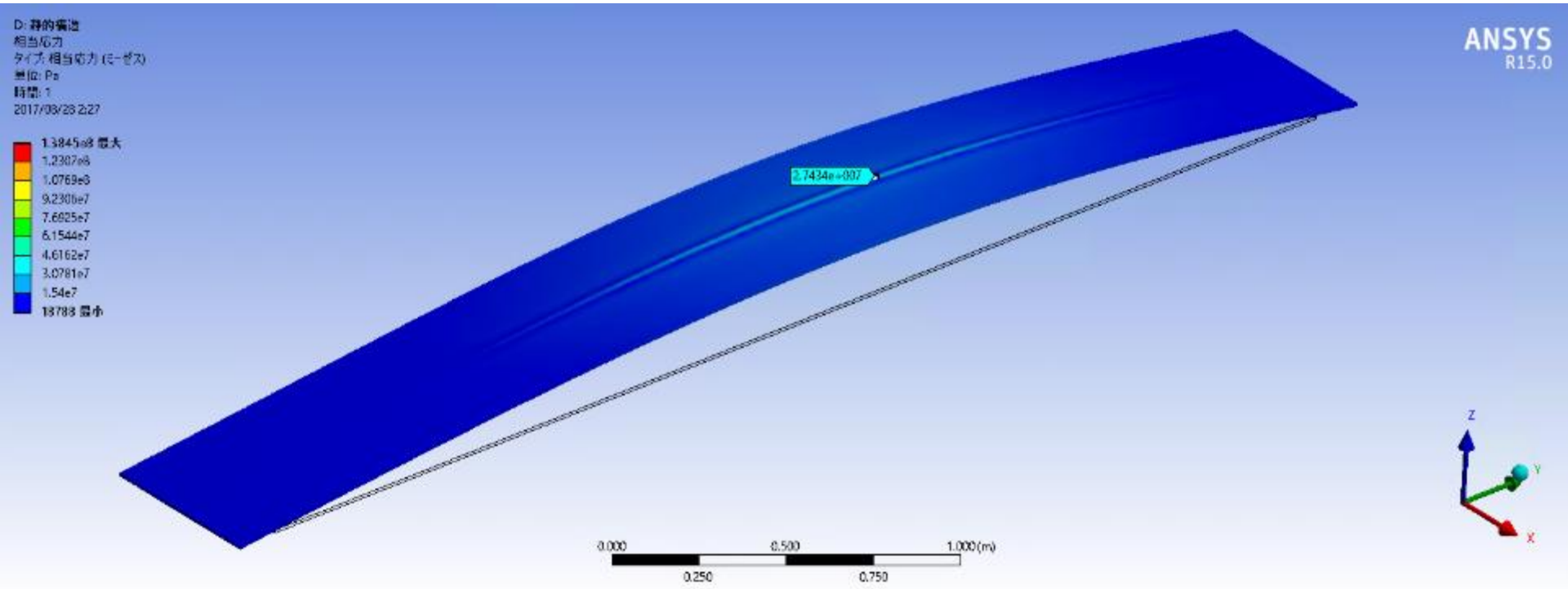
Deformation by thermal expansion. (not including the self-weight)



Main plate is expanded and main plate is arched 3.4mm in the surface direction

Thermal Stress

【Von Mises Stress of Graphite】

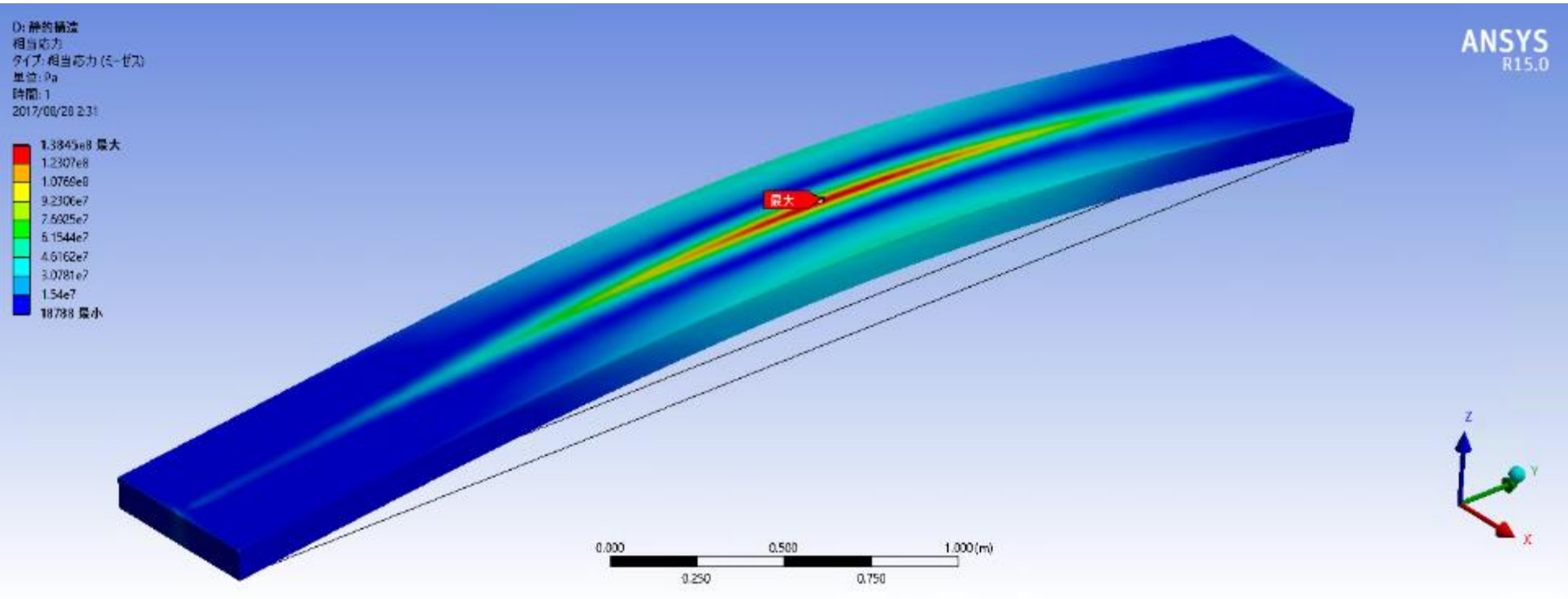


Max Von Mises stress of Graphite-plate : 27MPa

Tensile strength of Graphite-plate:37MPa

Thermal Stress

【Von Mises Stress of Copper】



Max Von Mises stress of Copper-plate : 138MPa

Tensile strength of Graphite-plate : 200MPa

Summary

【Photon dump for 250GeV High lumi stage】

- The maximum temp of graphite would be suppressed below 1000℃.
- The DPA will reach 0.3 in 1 year operation.
  ⇒ possible to use several years without replacement
- If the oxygen concentration in the vacuum is sufficiently reduced,
  there is no need to introduce a beam window in this graphite dump design.
- Main plate is arched on the surface side and there is problem of thermal stress.
  ⇒ Next issue is to consider a structure that suppress the thermal stress.

Simulation results

（PEDD）83J/(cm3/pulse) ⇒ ΔT=70℃/pulse
（DPA） 3.5E-9/pulse⇒ 0.315@5000h radiation
（MAX Temp）970℃ @ Graphite thermal conductivity : 10W/(Km)
580℃ @ Graphite thermal conductivity : 20W/(Km)⇒ back up slide
（Max Stress） Graphite : 27MPa , Copper : 138MPa

【Next plan】

- Evaluation of back plate which absorb scattered beam.
- Evaluation of radioactive products and Dose rate
- Make detailed design that can suppress the thermal stress

Back up

Calculation check

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

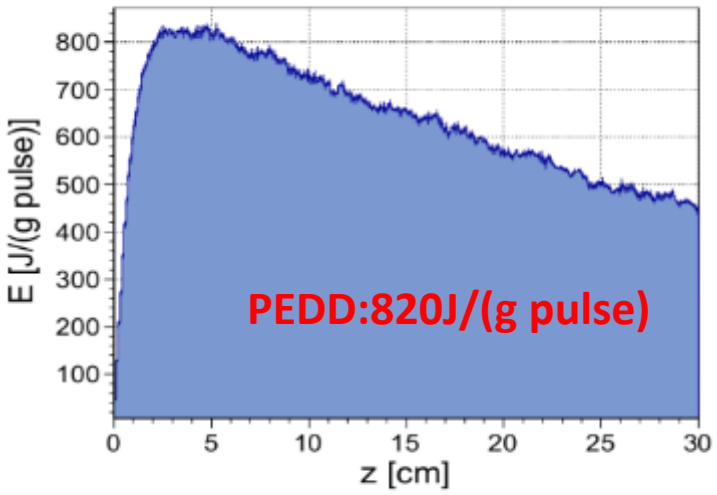
500GeV stage High luminosity
Graphite Energy deposition

Distribution of Energy Deposition in Graphite

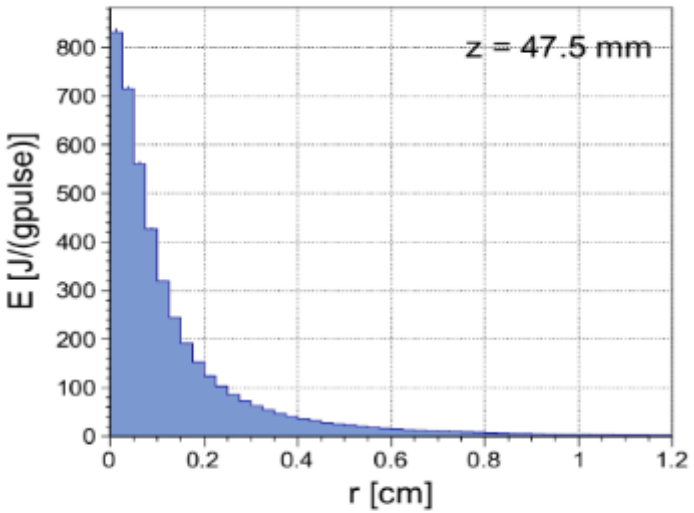
First 30 cm of graphite at ≈48 m from e^+ target

A.Ushakov-san

Energy along Beam Axis



"Hottest" Radial Energy Profile



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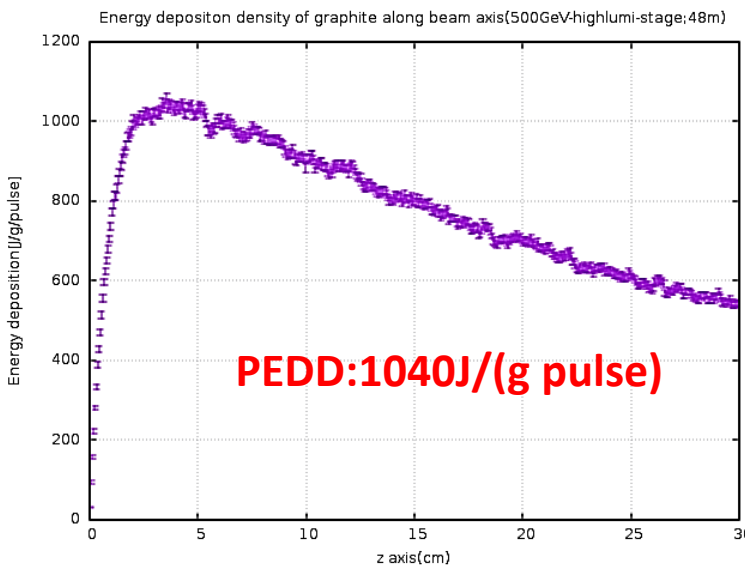
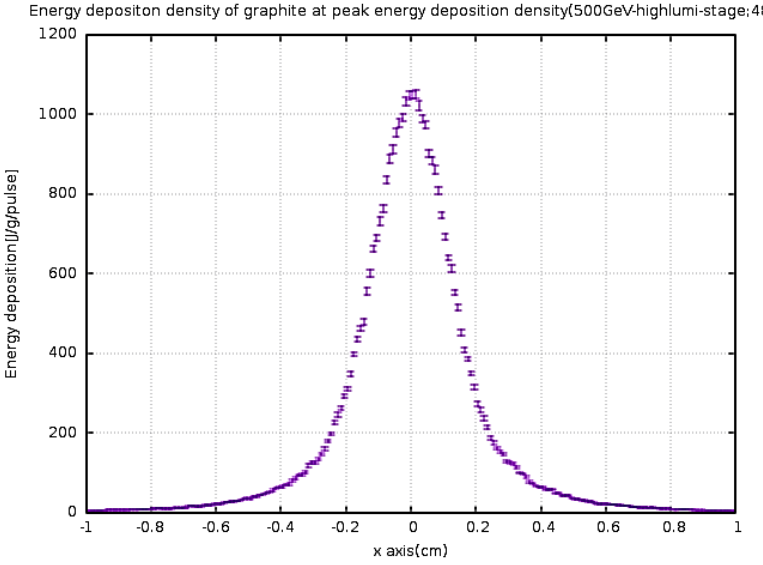
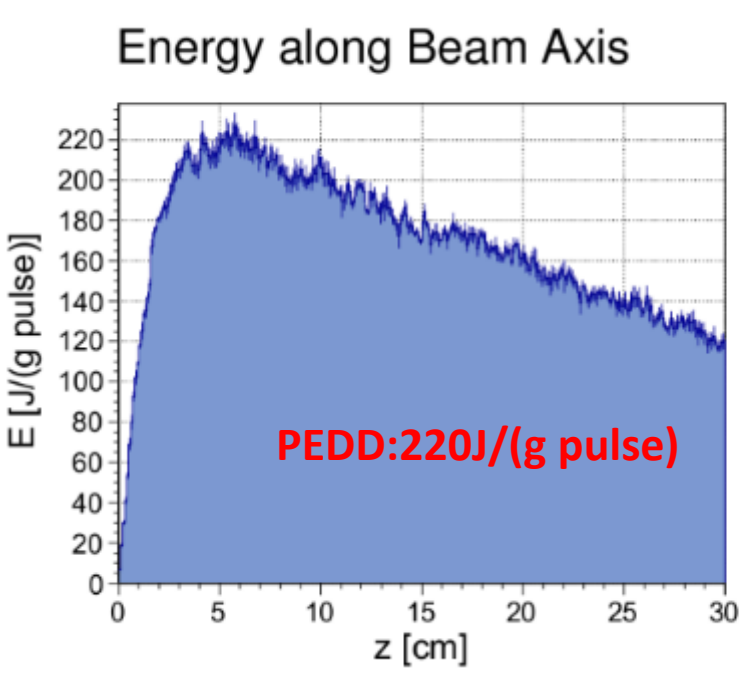


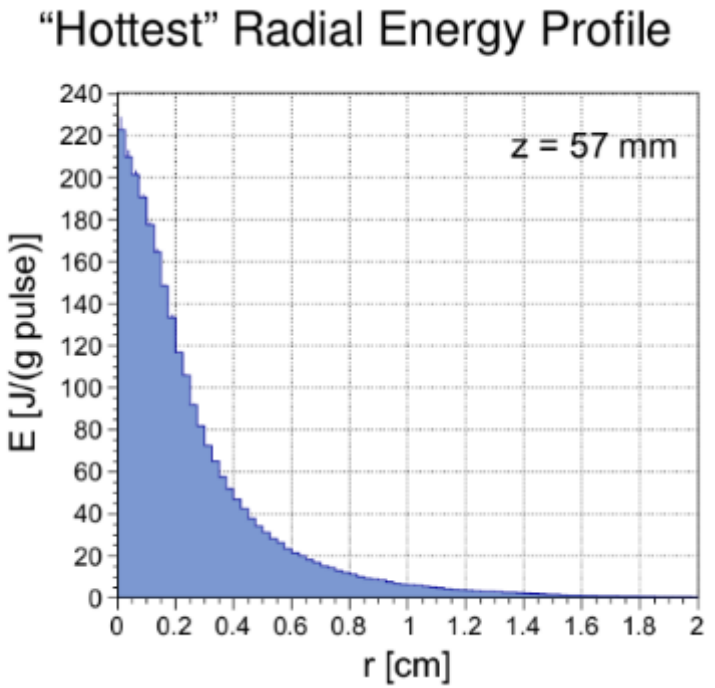


Mesh size :(X-Y,Z)=(20um,60um),Carbon density : 1.82g/cm3

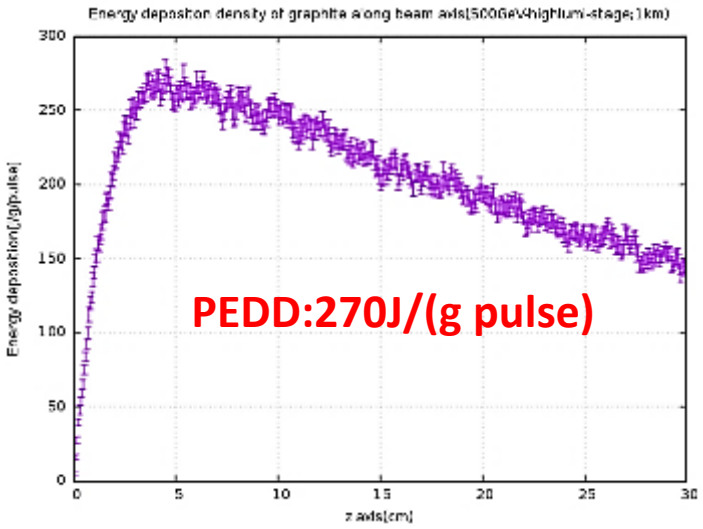
Energy in Far Graphite Dump (1 km from Target)

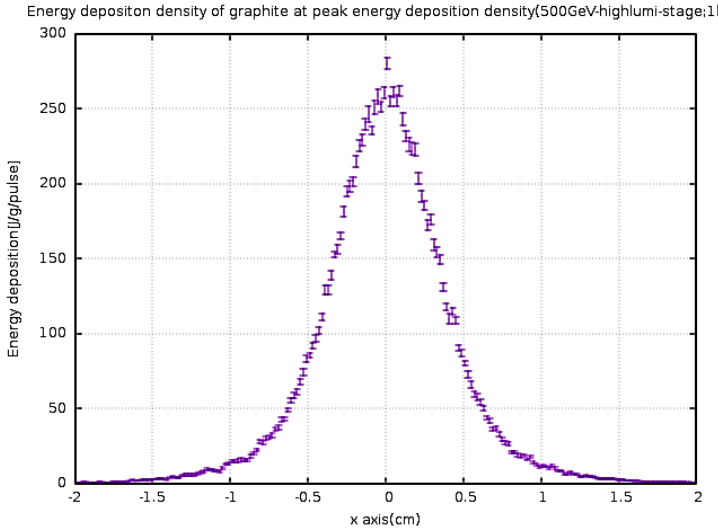
A.Ushakov-san





Morikawa



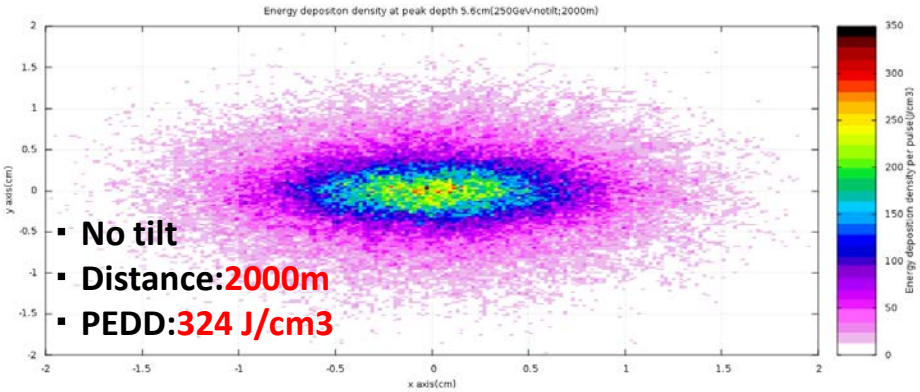


Mesh size :(X-Y,Z)=(20um,60um),Carbon density : 1.82g/cm3

Tilting effect

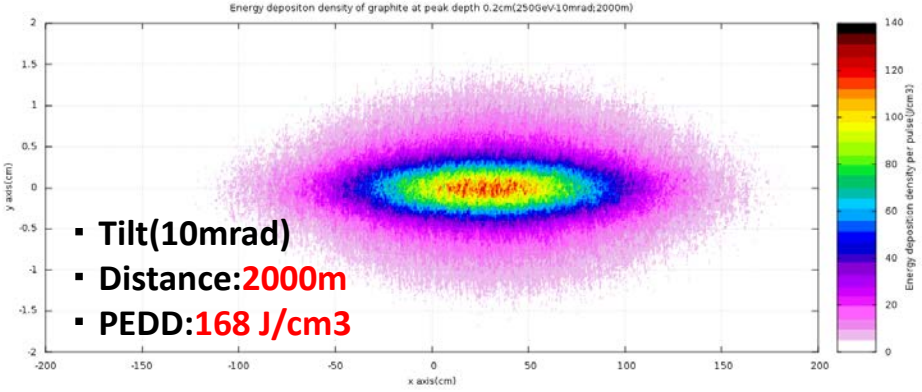
Depth dependence of Energy deposition

No tilt



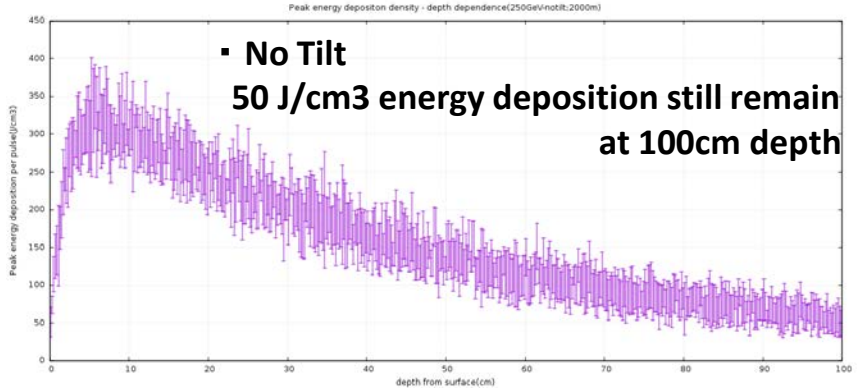
- No tilt
- Distance:2000m
- PEDD:324 J/cm3

Tilt(10mrad)

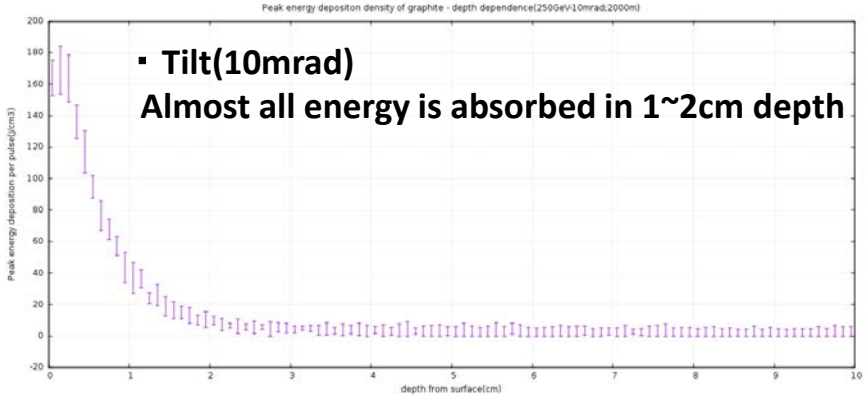


- Tilt(10mrad)
- Distance:2000m
- PEDD:168 J/cm3

Energy deposition density vs graphite depth



- No Tilt
  50 J/cm3 energy deposition still remain at 100cm depth

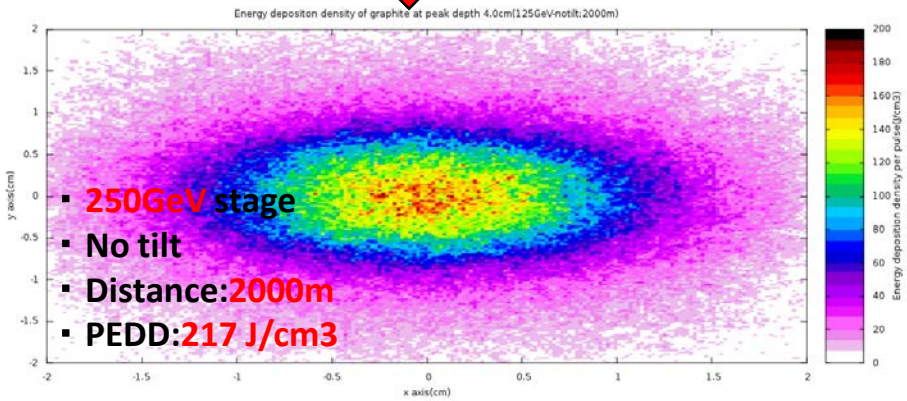


- Tilt(10mrad)
  Almost all energy is absorbed in 1~2cm depth

***500GeV stage Photon Beam**

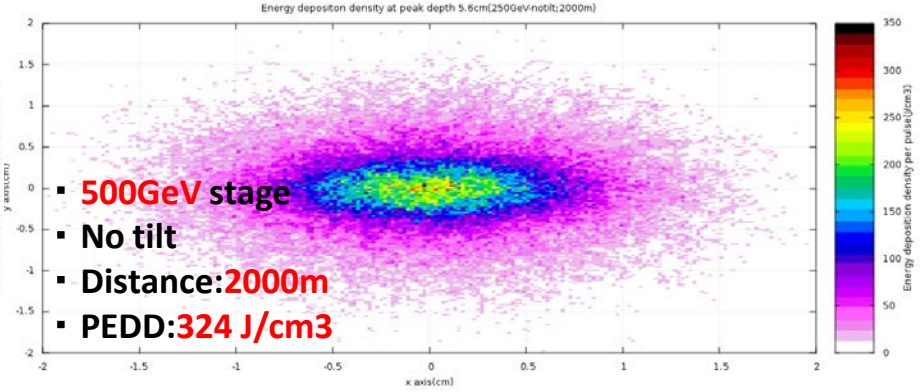
Energy deposition(250GeV & 500GeV stage)

250GeV stage Photon Beam



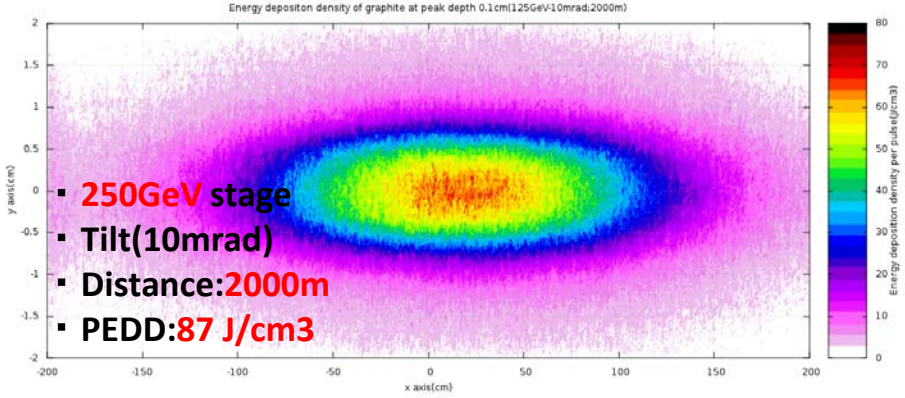
- 250GeV stage
- No tilt
- Distance:2000m
- PEDD:217 J/cm3

500GeV stage Photon Beam

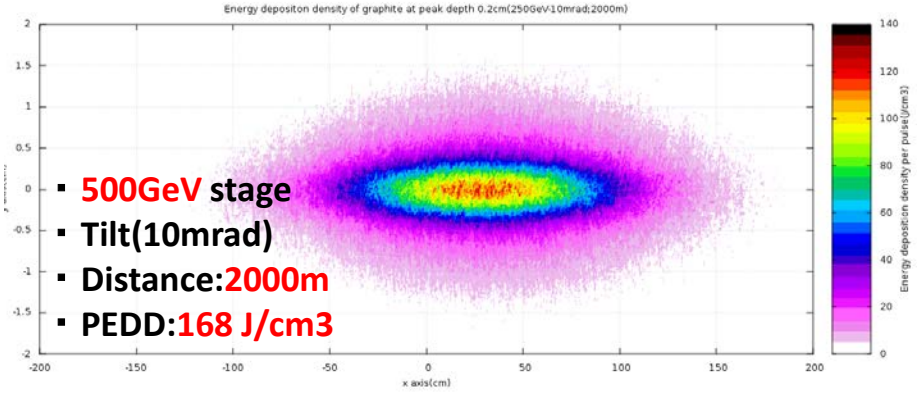


- 500GeV stage
- No tilt
- Distance:2000m
- PEDD:324 J/cm3

tilt

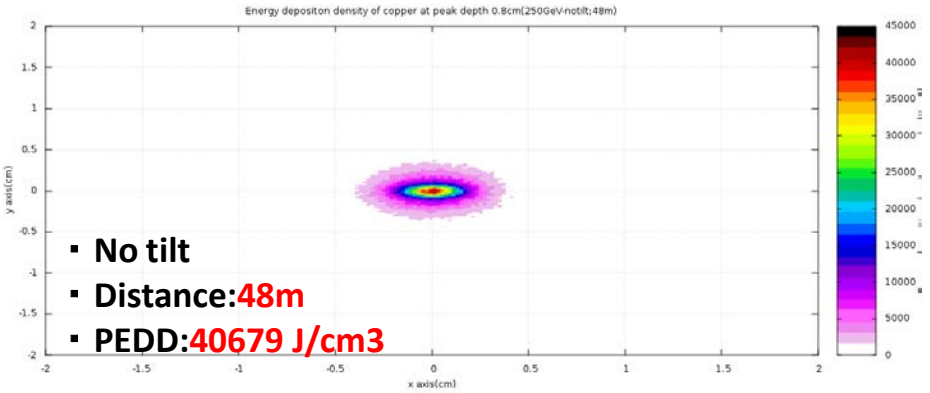


- 250GeV stage
- Tilt(10mrad)
- Distance:2000m
- PEDD:87 J/cm3

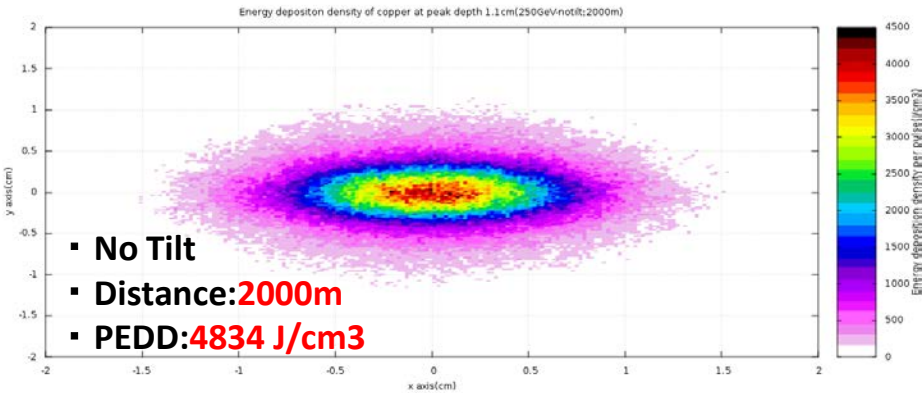


- 500GeV stage
- Tilt(10mrad)
- Distance:2000m
- PEDD:168 J/cm3

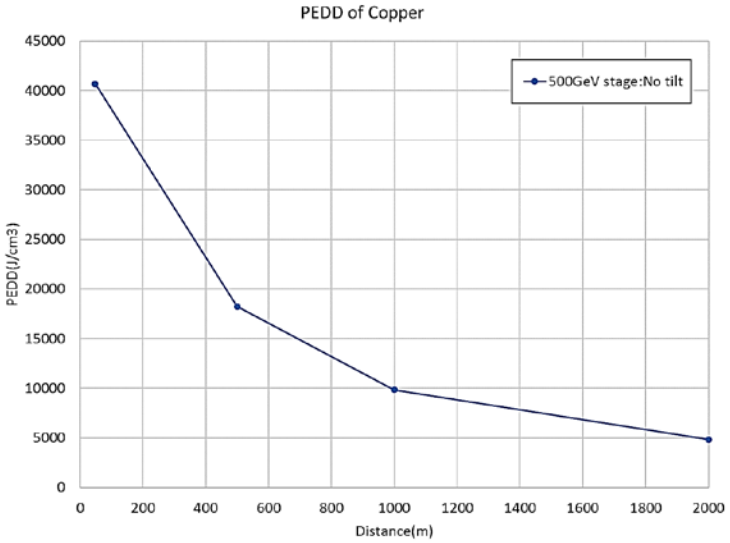
Energy deposition in copper



- No tilt
- Distance:48m
- PEDD:40679 J/cm3

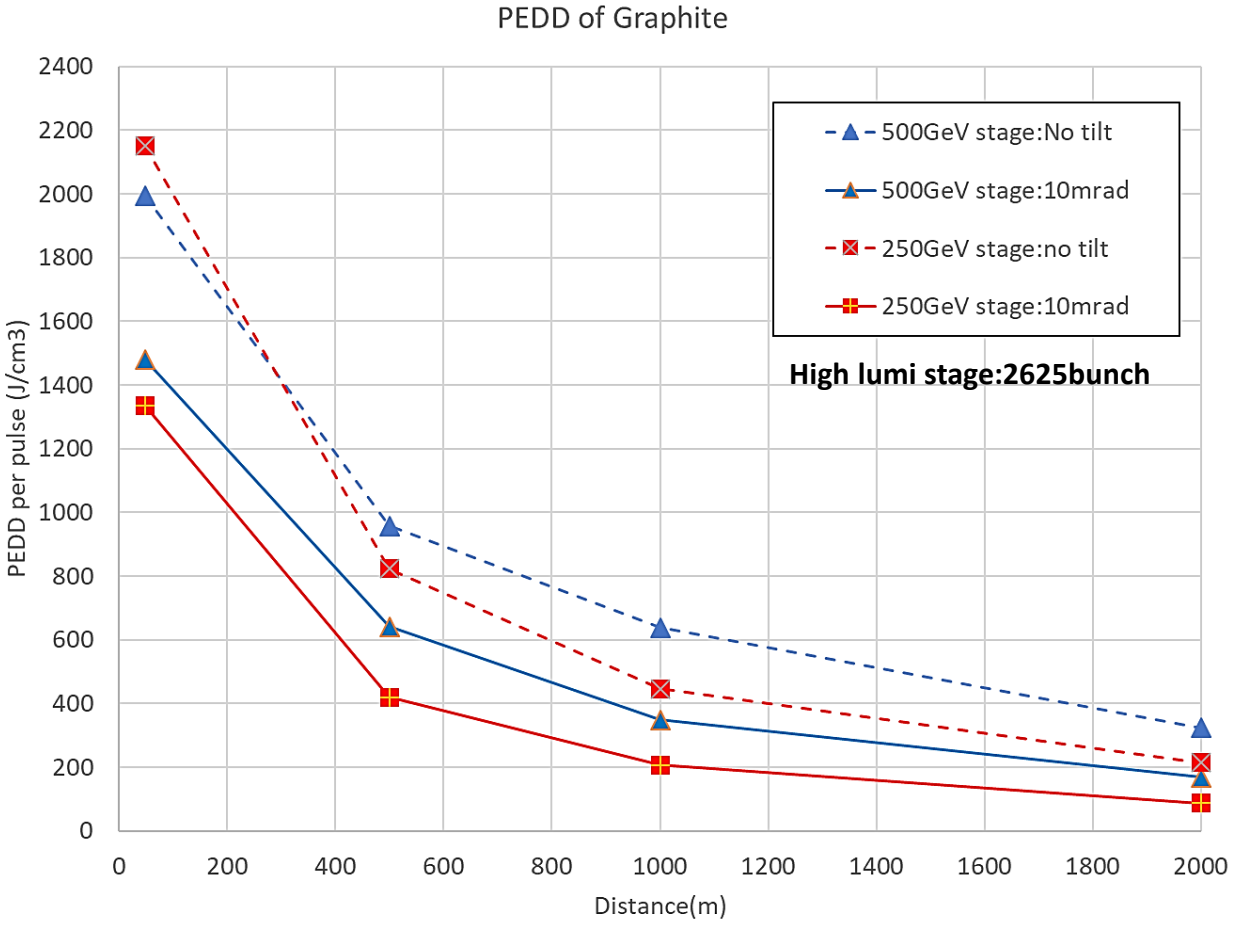


- No Tilt
- Distance:2000m
- PEDD:4834 J/cm3



*500GeV stage Photon Beam
* Distance : from Positron Target to Dump
* PEDD : Peak Energy Deposition Density

Alternative Design – Photon Dump Energy deposition



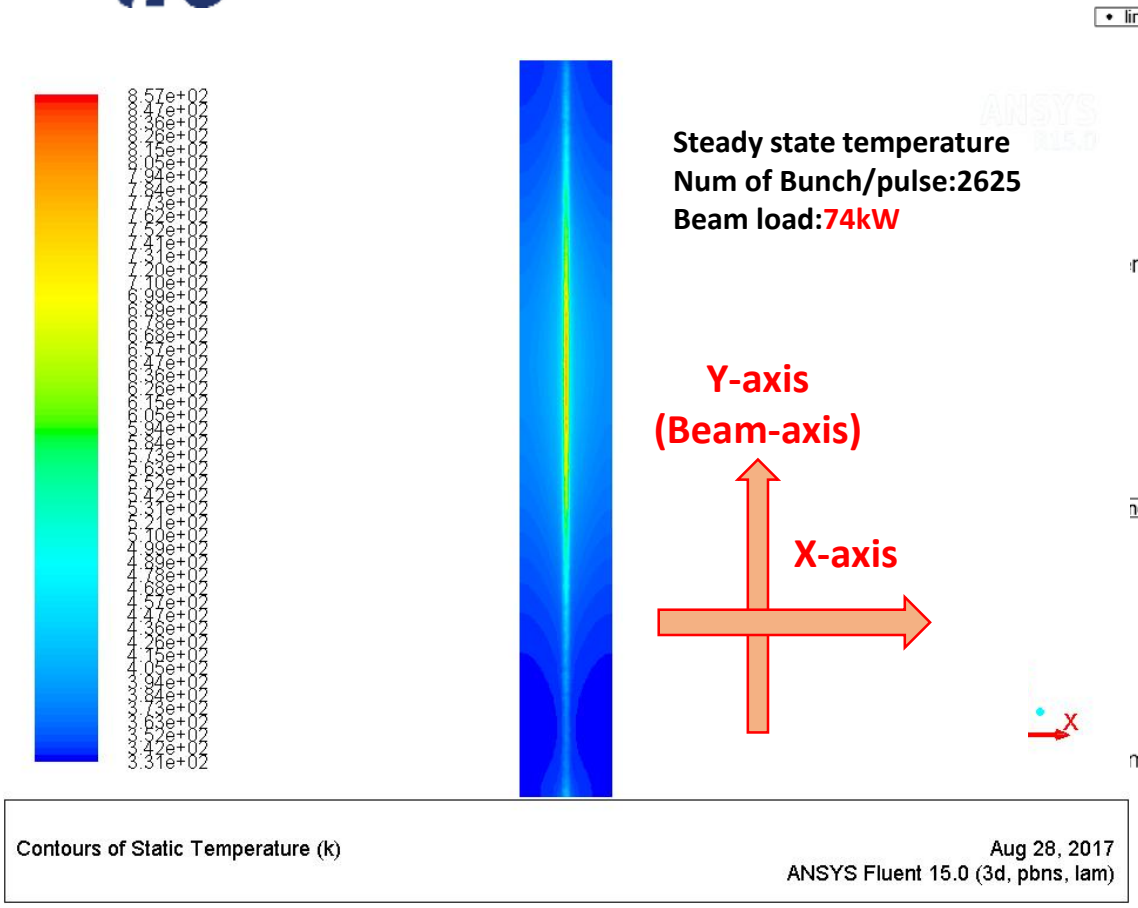
*** Distance : from Positron Target to Dump**
*** PEDD : Peak Energy Deposition Density**

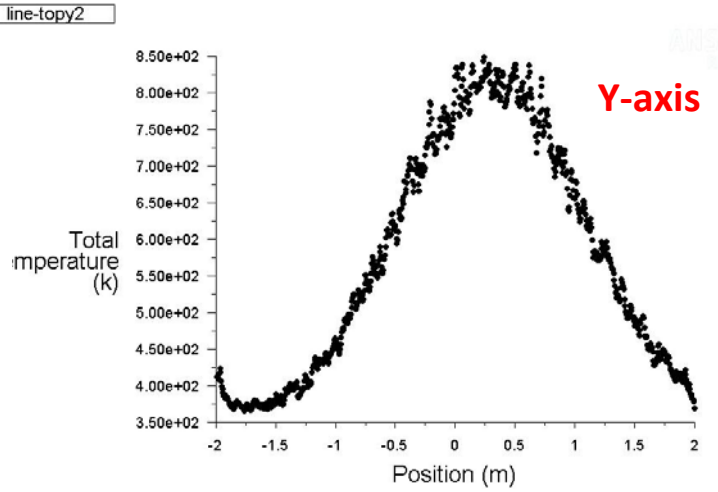
Temperature simulation

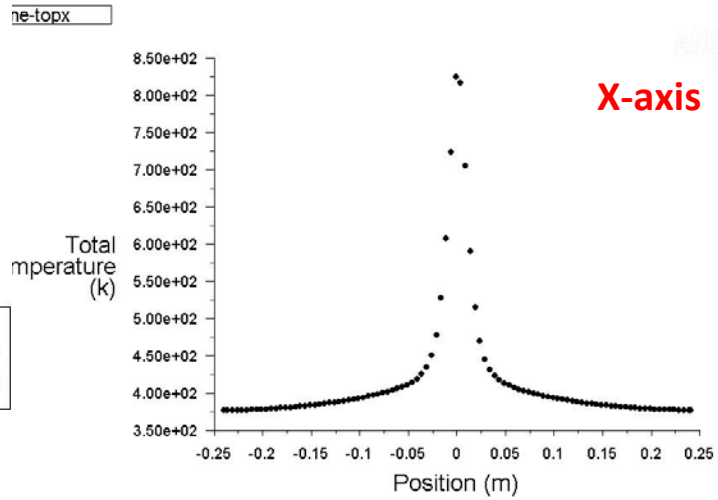
Graphite Conductivity 20W/Km

Temperature distribution

Graphite conductivity：20W/(Km)



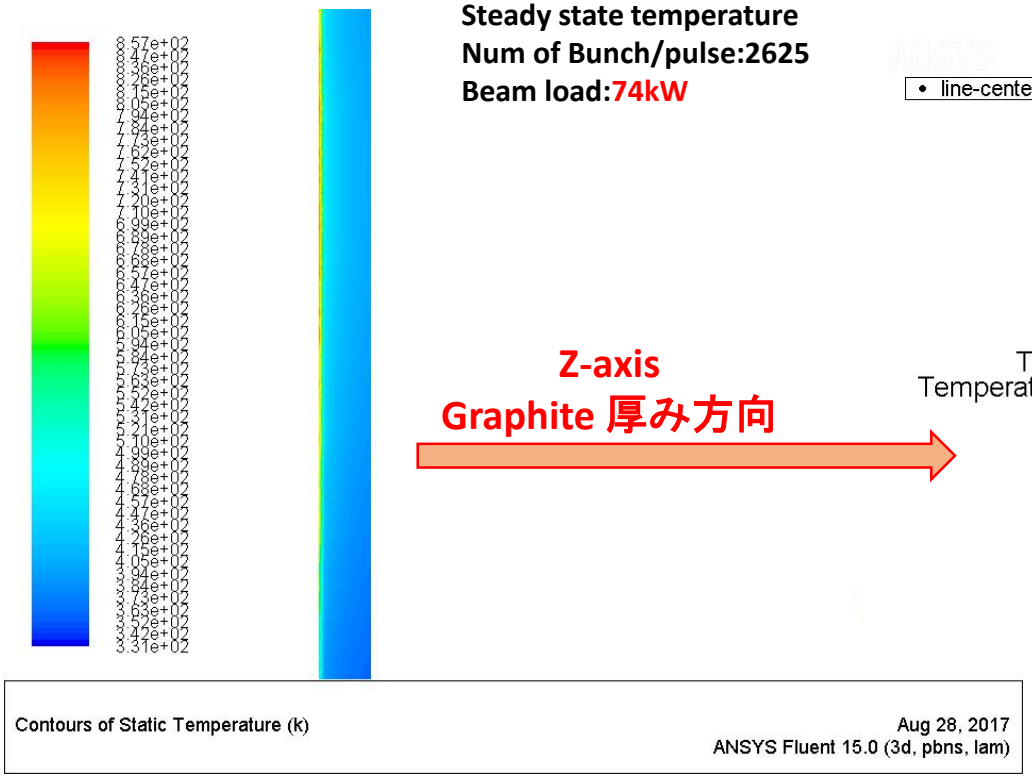




- **Max temperature is 584℃(857K) for 250GeV-High lumi stage**

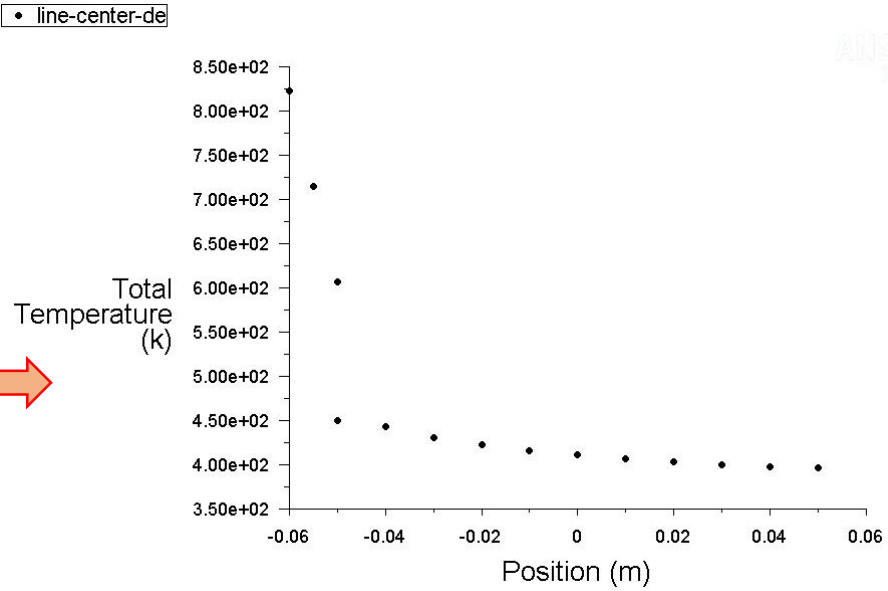
Temperature distribution

Graphite conductivity：20W/(Km)



Steady state temperature
Num of Bunch/pulse:2625
Beam load:74kW

Z-axis
Graphite 厚み方向



- **Max temperature is 584℃(857K) for 250GeV-High lumi stage**