# Heating of a DCCT and a FCT due to wake losses in PETRAIII, simulations and solutions

D. Lipka, MDI, DESY Hamburg

# Outlook

- PETRA III overview
- DCCT problem, calculation, simulation, solution
- FCT problem, simulation, solution
- Summary

# PETRA III overview

new Experimental Hall


**Parameters:**

- circumference: 2304 m
- energy: 6 GeV

- emittance: 1 nmrad
- emittance coupling : 1% (10 pmrad!)

- current: 100 (200) mA
- # bunches: 40 / 960

- straight sections: 9
- undulators: 14
- undulator length: 2, 5, 10 (20) m

- supplement to X-FEL
  ➔ cost effective!

Courtesy Gero Kube

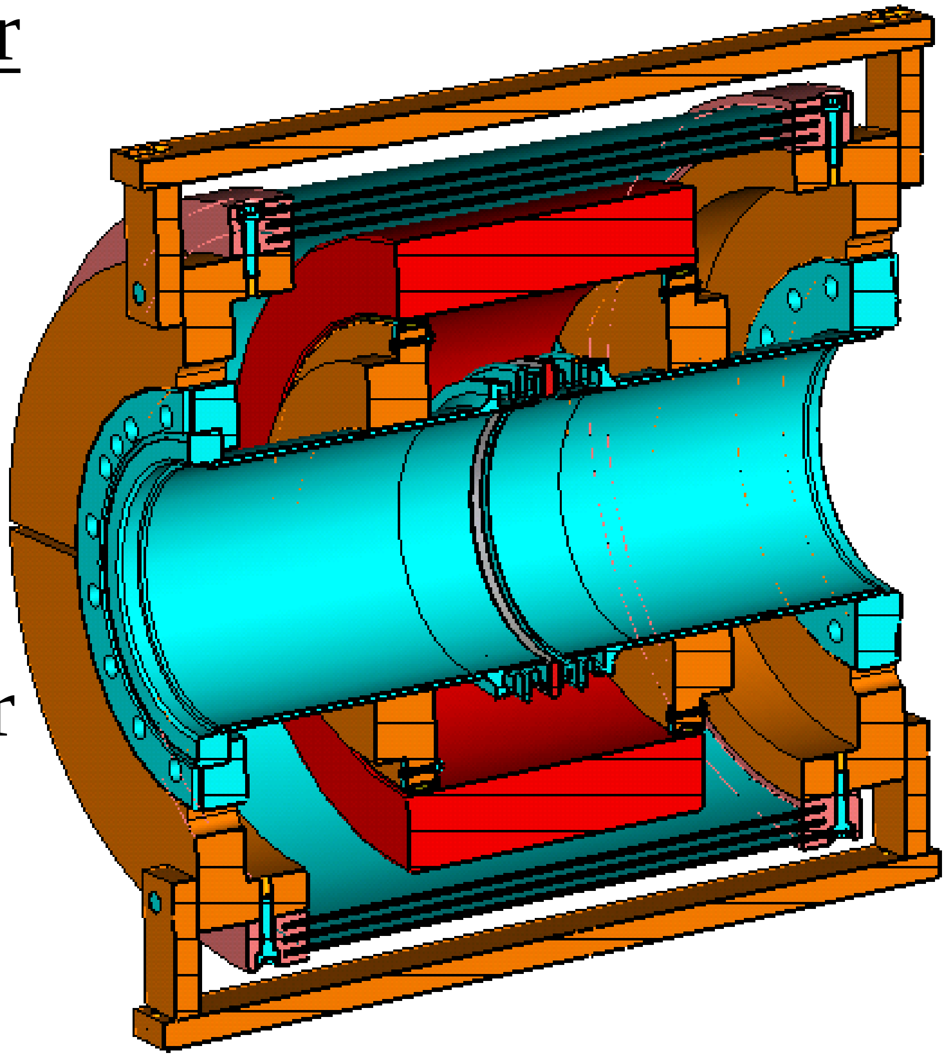
# DCCT

DC Current Transformer

Measurement of beam current

Setup consists of pipe, ceramic, core, bellow, shielding

Temperature sensor near bellow



# DCCT Problem at 2010

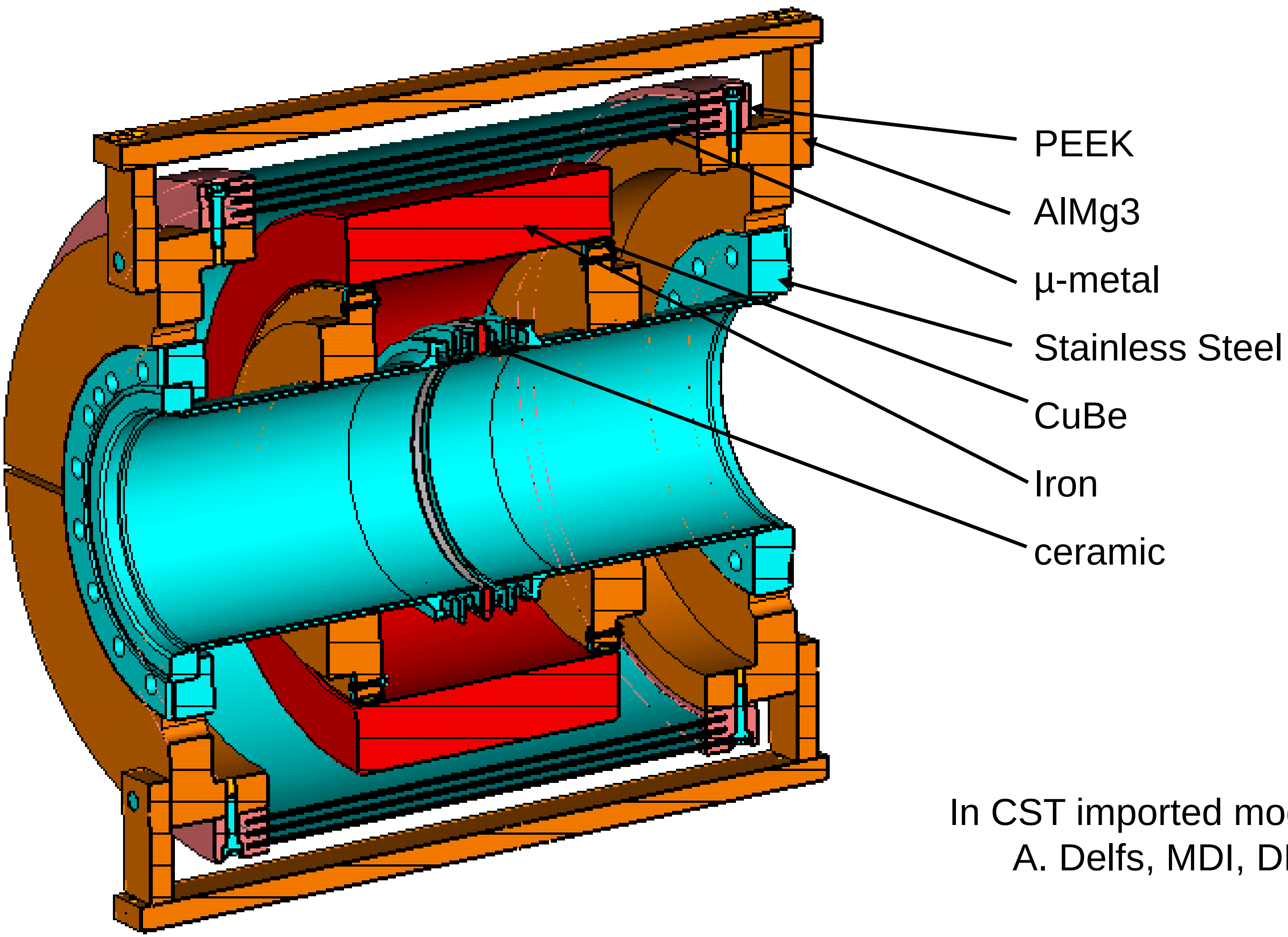
- Two cases of operation with different temperatures at the current monitor observed
- Case 1: $I_1$=85 mA, N=160 Bunches gives about 70°C
- Case 2: $I_2$=65 mA, N=40 Bunches gives about 130°C
- Questions:

1. Why case 2 higher temperature?
2. Why temperature high?

# DCCT: Answer 1

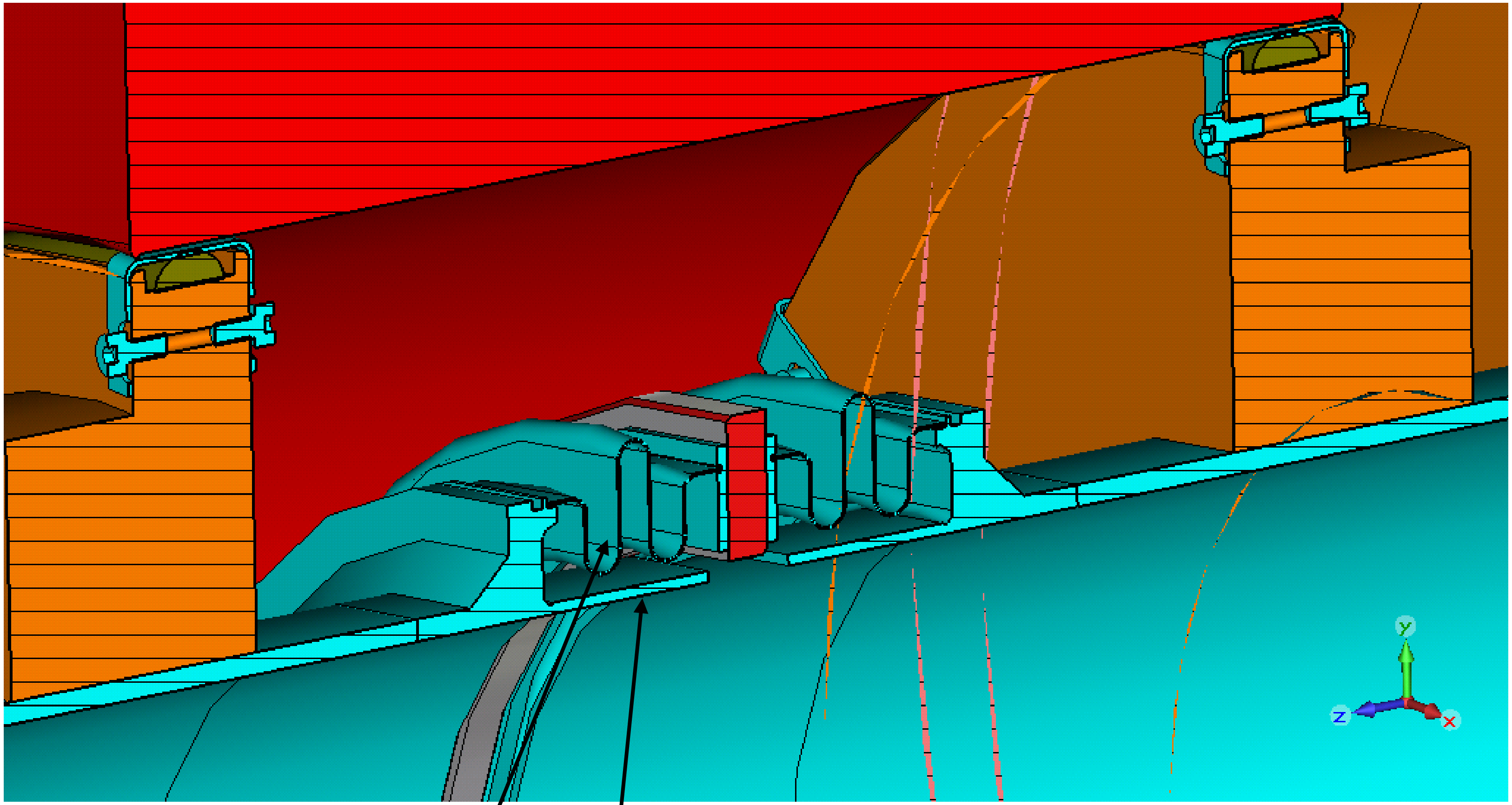
- Power $P = I\,Q\,k_{loss}$
- I is mean beam current
- Q is charge = $I\,\Delta t$
- $\Delta t$ is bunch distance = t / N
- t is PETRA III revolution time = 7.685 µs
- $k_{loss}$ is voltage loss per charge for a structure
- Result in $P = I^2\,t\,k_{loss} / N$
- $P_1/P_2 = 0.43$
- Because $P_2$ is higher the temperature is higher!
- Compare: $P_{E\text{-}XFEL,max}/P_2 = 0.0001$

# Setup DCCT




In CST imported model from
A. Delfs, MDI, DESY

# DCCT: inner setup




Bellow shielded, but results in a resonator

Ceramic coated with Molybdenum.

When a charged particle moves through DCCT, it looses energy due to gap=8.2 mm!

# DCCT simulation

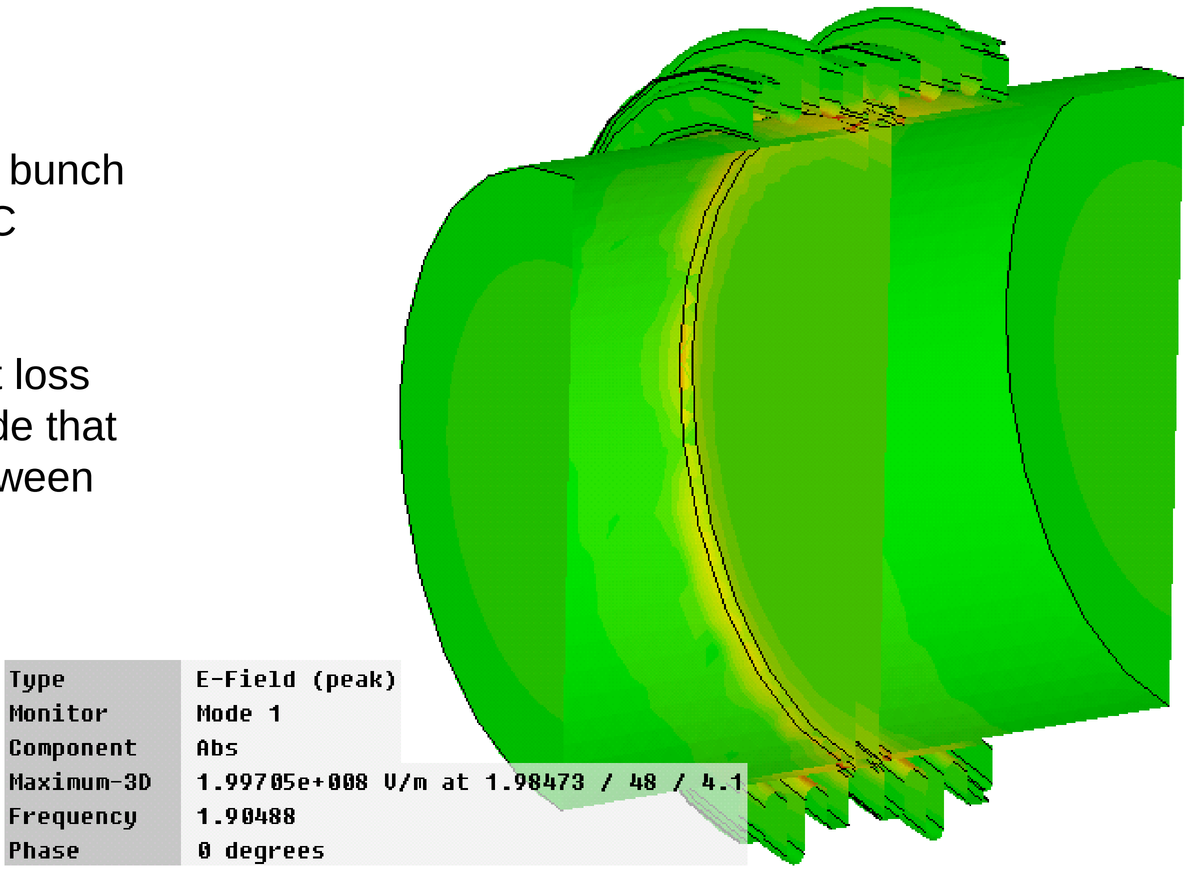
1. Wakefield simulation with beam: get loss factor
2. Eigenmode of setup: get field distribution of losses
3. Thermal: input power and field distribution (all power will be used for heating), get temperature distribution

# DCCT: Wakefield and Eigenmode Simulation

Setup: only vacuum part because of coated ceramic

Wake loss factor with 13.2 mm bunch length results to $k_{loss}$=39.1 V/nC ->$P_1$=13.6 W, $P_2$=31.7 W

Eigenmodes observed: highest loss factor of several V/nC with mode that has highest field amplitude between shielding and bellow



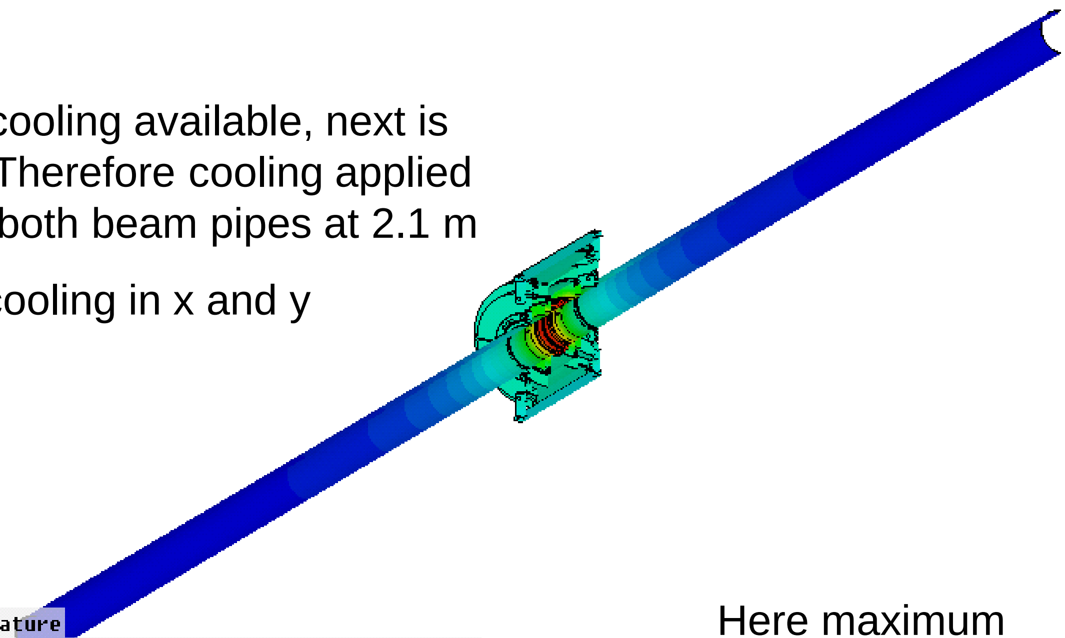

Field distribution of mode with highest loss factor

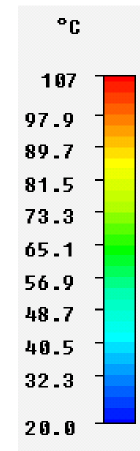
# DCCT Temperature Distribution $P_2$

Included: heat conductivity of all materials and heat radiation

No special cooling available, next is 4.2 m away. Therefore cooling applied at the end of both beam pipes at 2.1 m

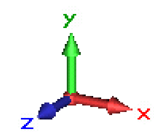
No cooling in x and y



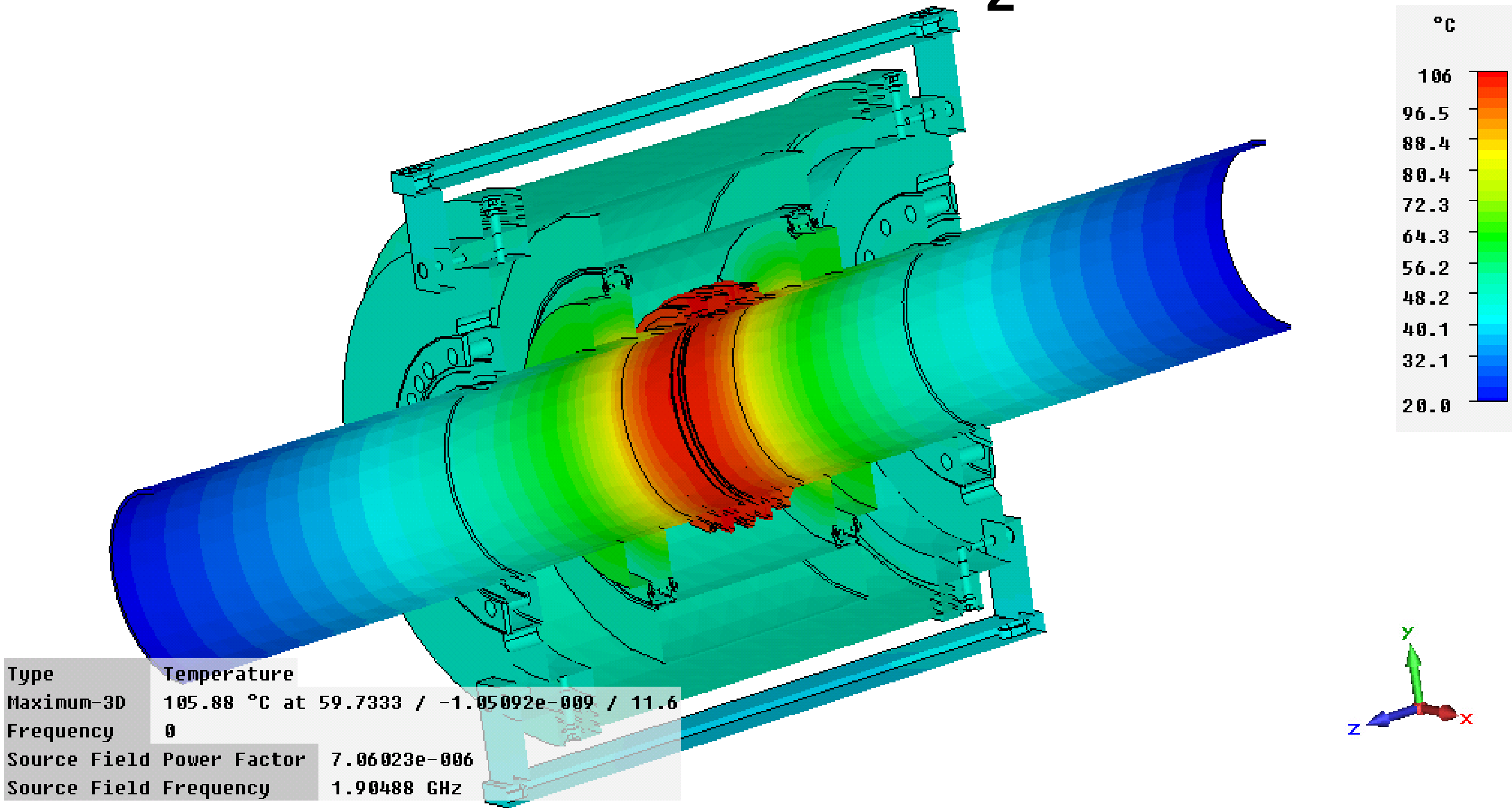



| | |
|---|---|
| Type | Temperature |
| Maximum-3D | 107.445 °C at 59.7333 / -1.05092e-009 / 11.6 |
| Frequency | 0 |
| Source Field Power Factor | 7.06023e-006 |
| Source Field Frequency | 1.90488 GHz |

Here maximum temperature of 107 °C



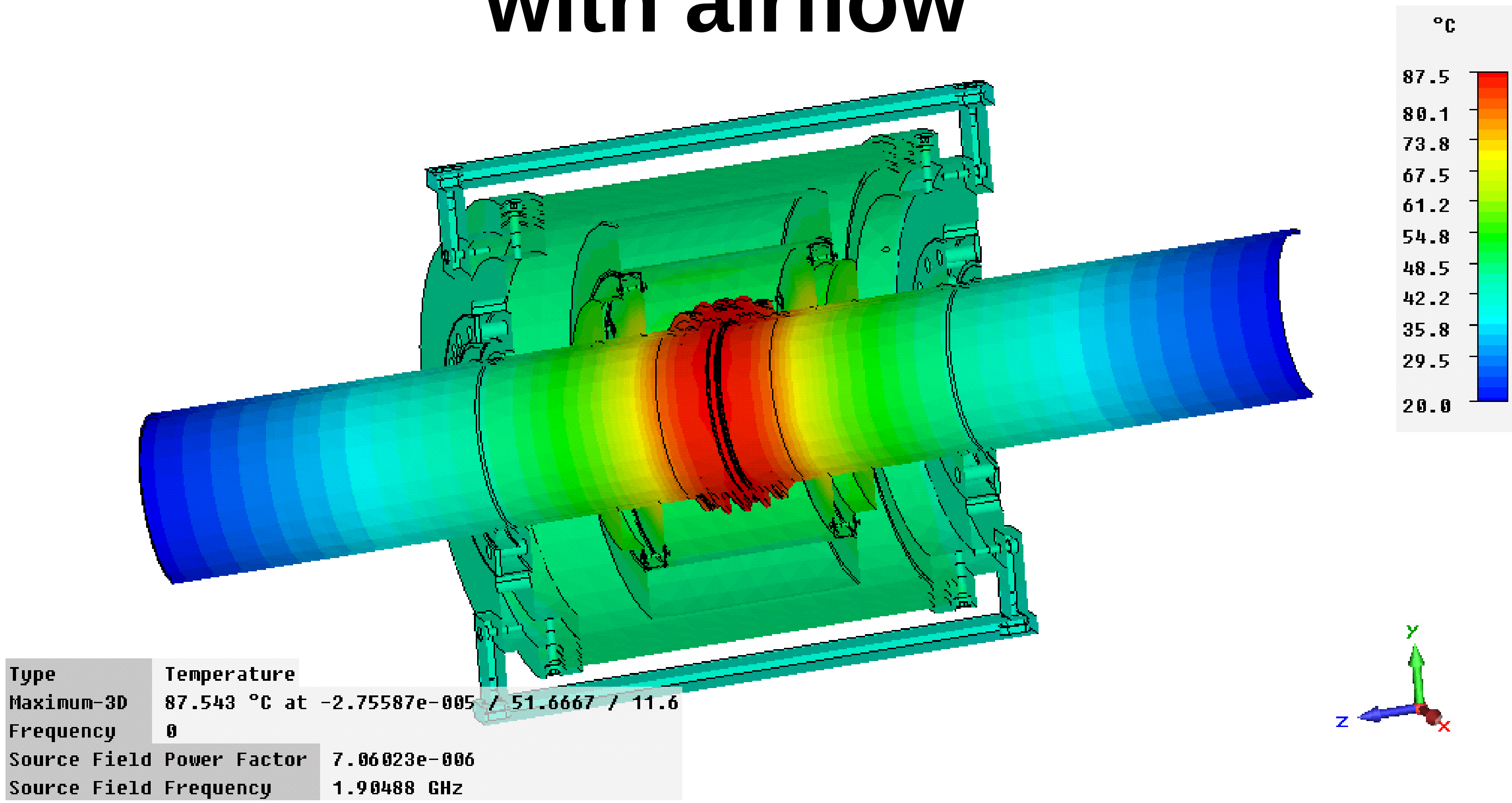
# DCCT: Temperature distribution shortened $P_2$




Here the distance to cooling is only 200 mm, $T_{max}$=106°C, because heat radiation along pipe acts like a cooling, therefore this shortened model can be used

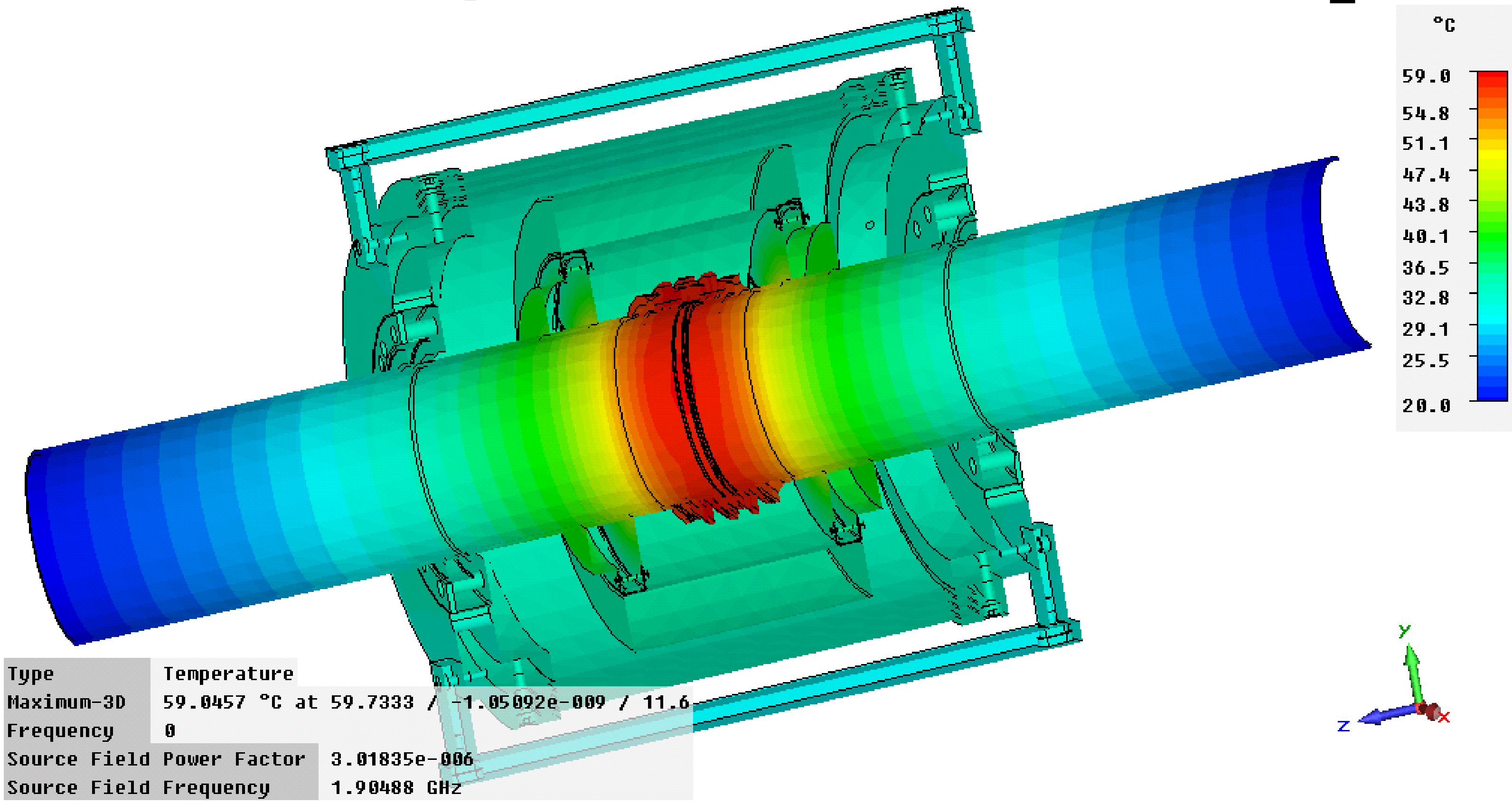
Measured 130°C; Simulation underestimates temperature by 18%, reason: mesh, perhaps higher loss factor in reality

# DCCT: Temperature distribution $P_2$ with airflow




Here the simulation box increased with cooling at $x_{min,max}$ and $y_{min,max}$, $T_{max}$ reduces from 106°C to 87.5 °C

# DCCT: Temperature distribution $P_1$

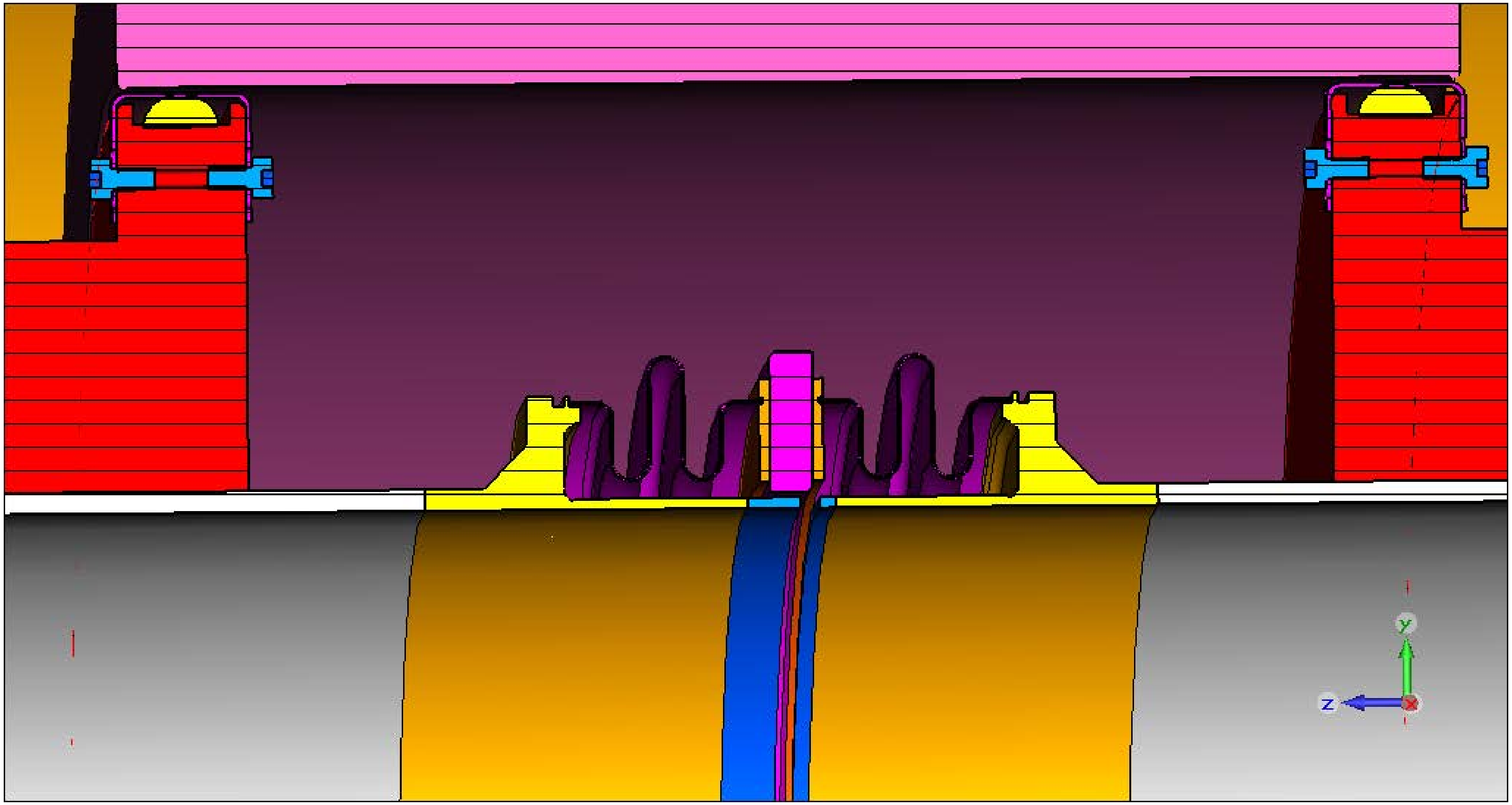



Airflow switched off.

Lower Temperature because of lower power

Measured 70°C, simulation lower by 16%

# DCCT: 1. proposal of smaller gap

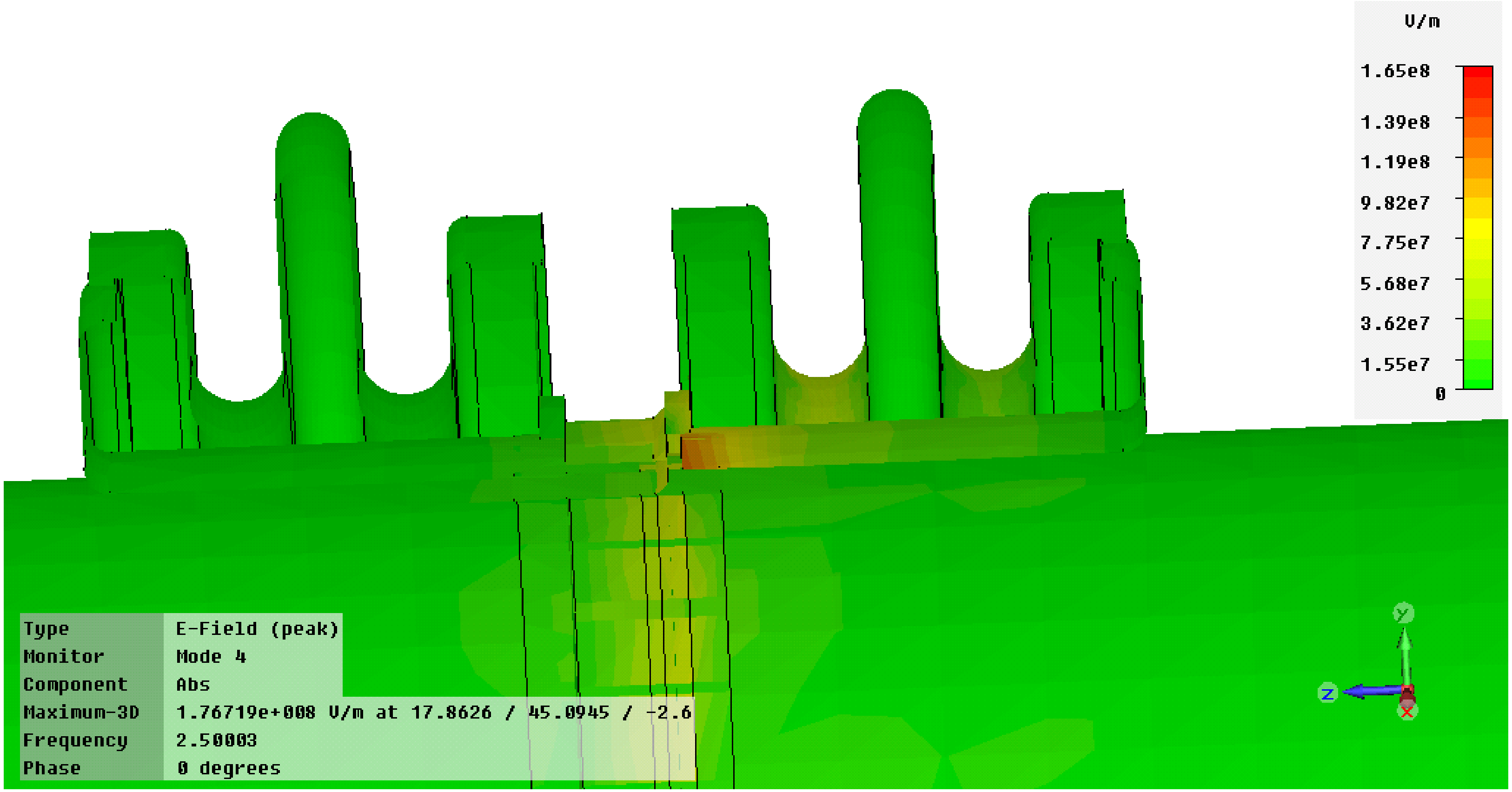



Smaller gap = 1.7 mm should reduce energy loss

Gap near chamfer to result in good energy transmission

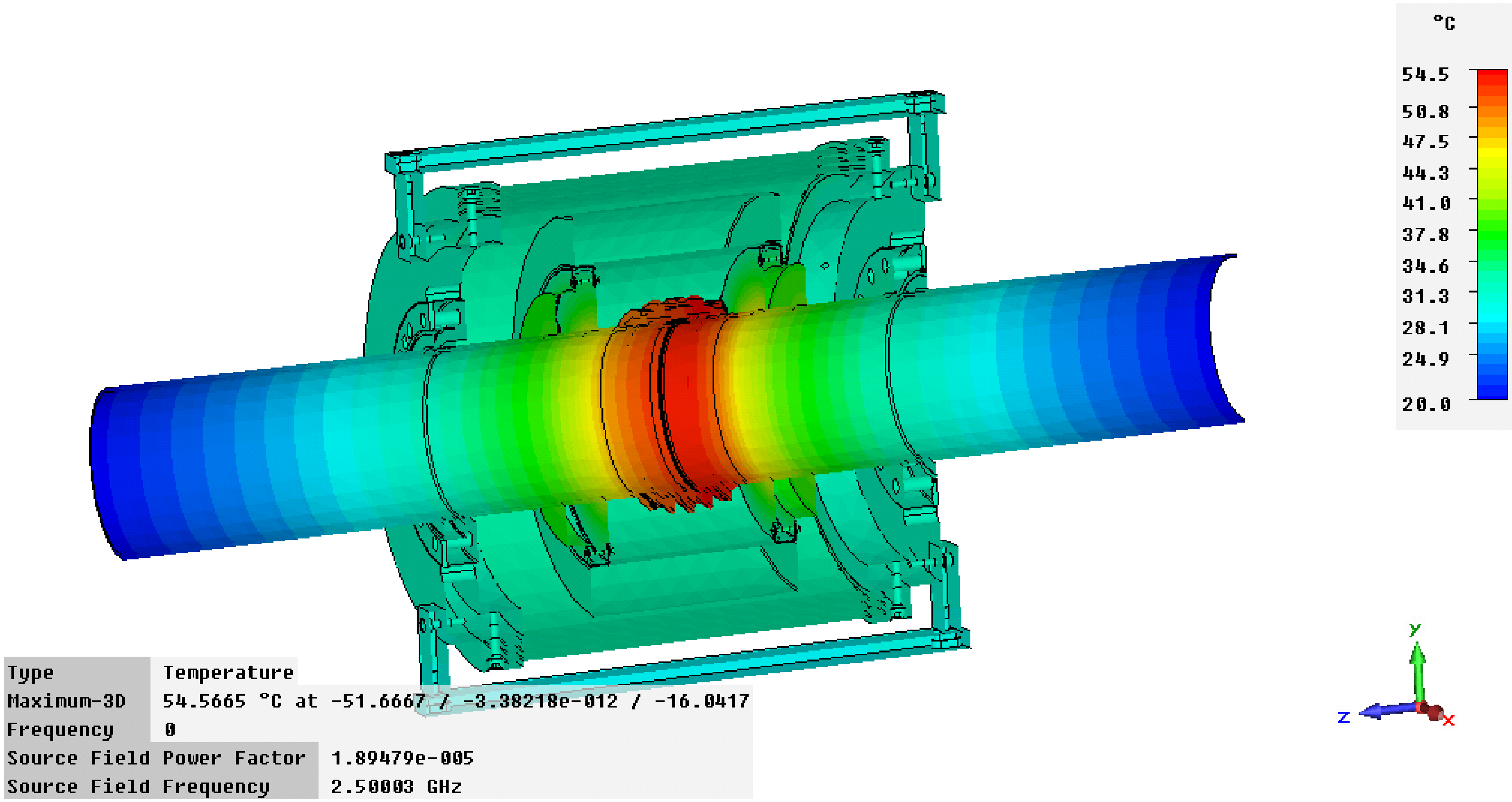
$K_{loss}$ = 15.1 V/nC

# DCCT: 1. proposal Eigenmode distribution



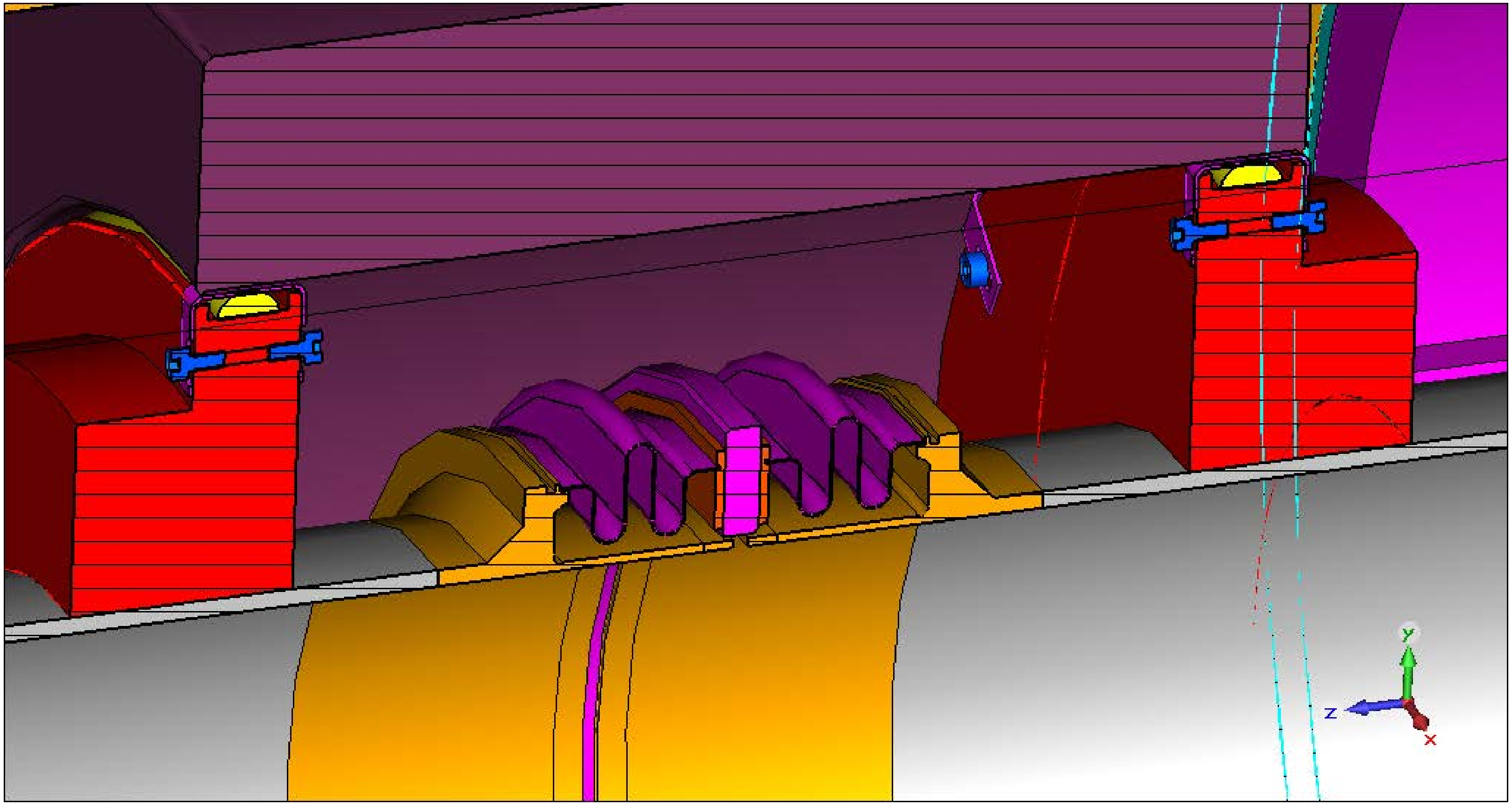

Field amplitude near gap

# DCCT: 1. proposal temperature distribution $P_2$




Maximum temperature reduced from 106 °C to 55°C (remember: simulation underestimates temperature)

# DCCT: 2. proposal without coating

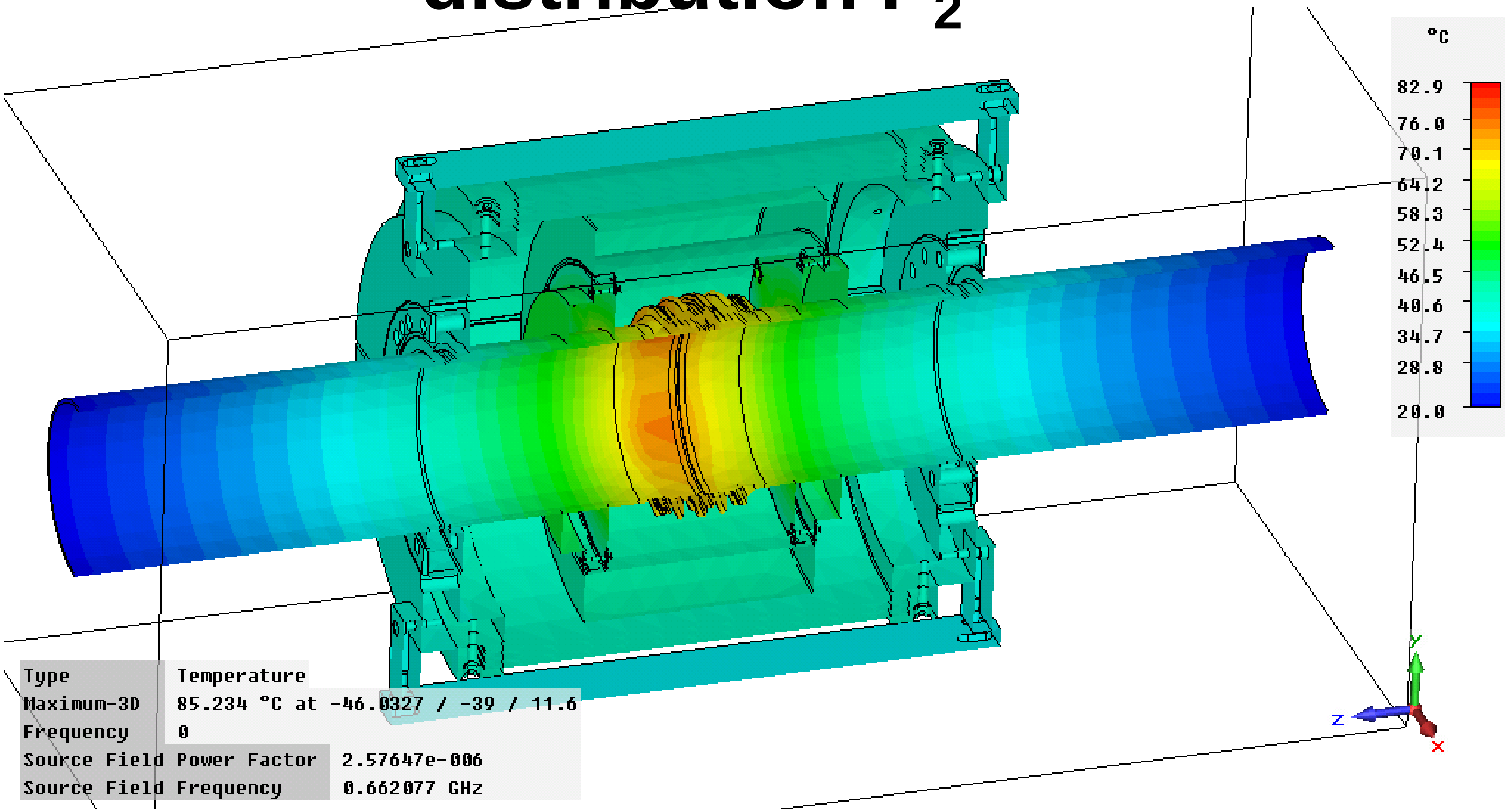



gap = 1.7 mm symmetrically below ceramic

Ceramic without coating to result in higher energy transmission

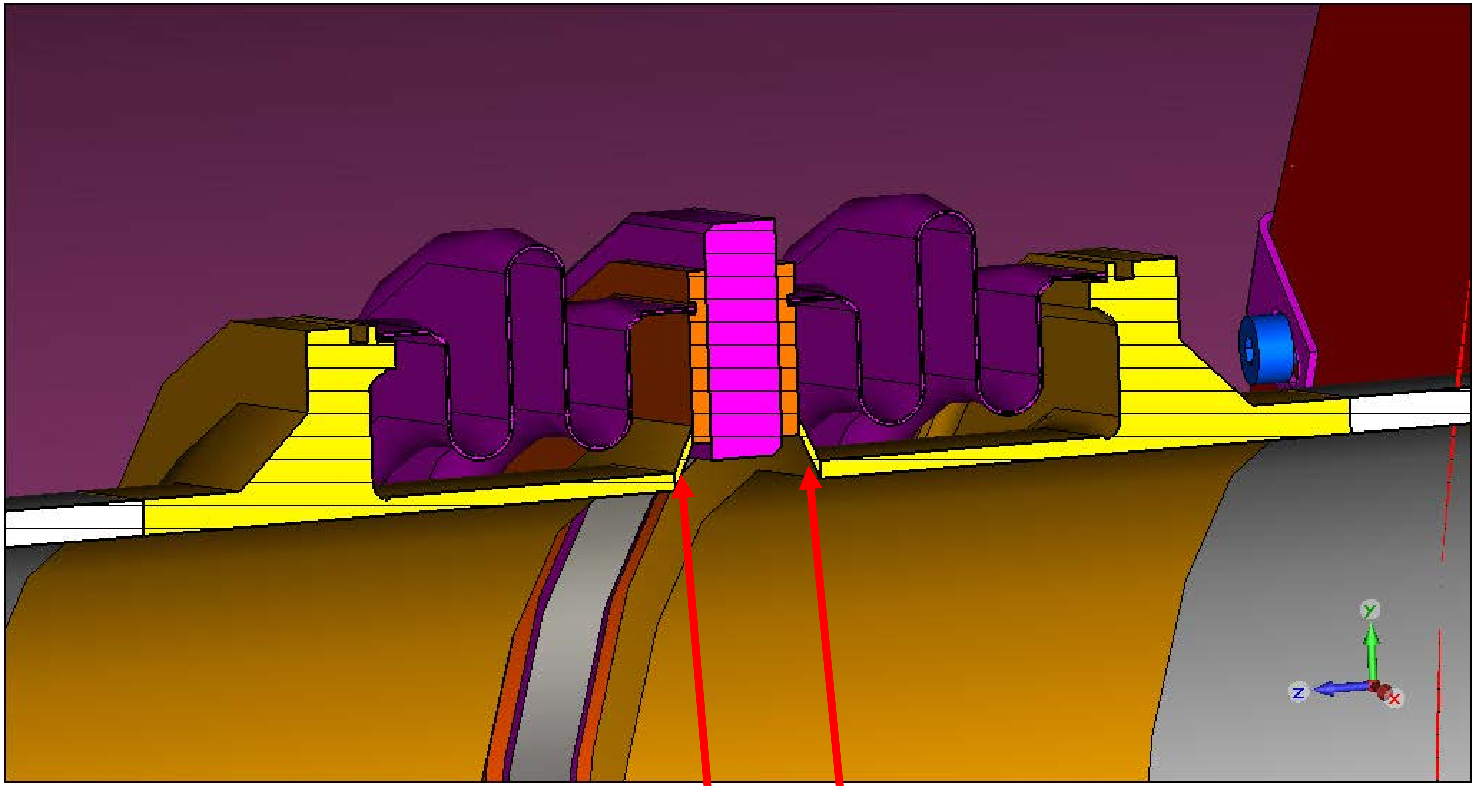
$K_{loss}$ = 26.6 V/nC, because gap is deeper without coating

# DCCT: 2. proposal temperature distribution $P_2$




Maximum temperature reduced from 106 °C to 85°C (remember: simulation underestimates temperature)

# DCCT: 3. proposal with coating and additional shielding



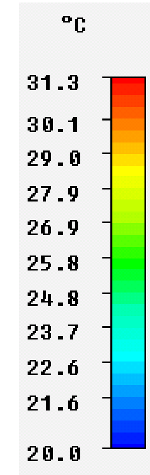

gap = 8.2 mm like origin, coating actives

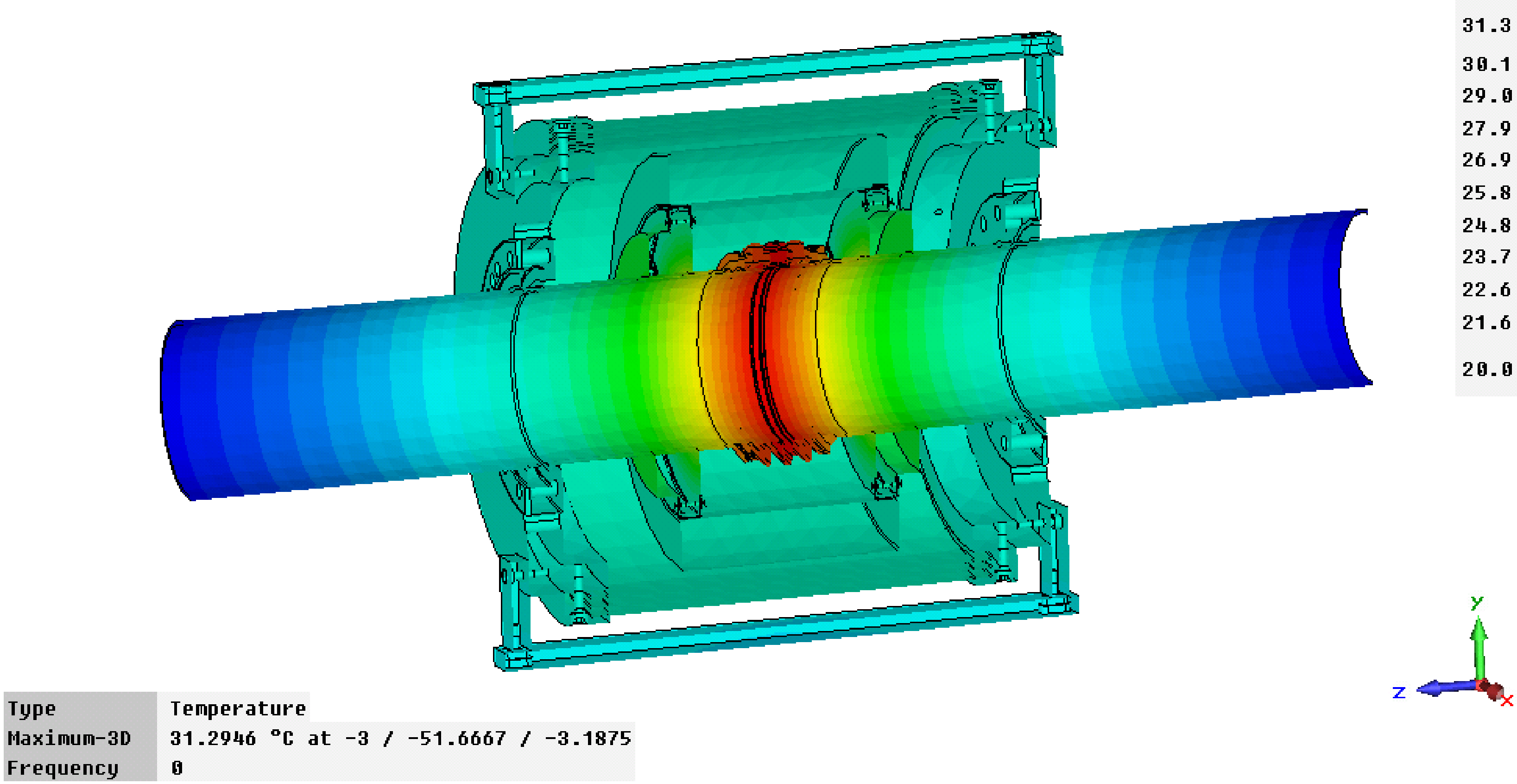
Shielding of resonator

$k_{loss}$ reduced to 4.4 V/nC, because influence of resonator avoided ($P_2$=3.6 W)

No resonance found below cutoff (2.44 GHz)

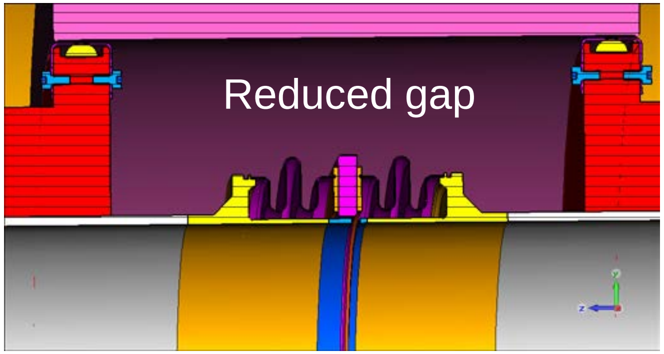
# DCCT: 3. proposal temperature distribution $P_2$

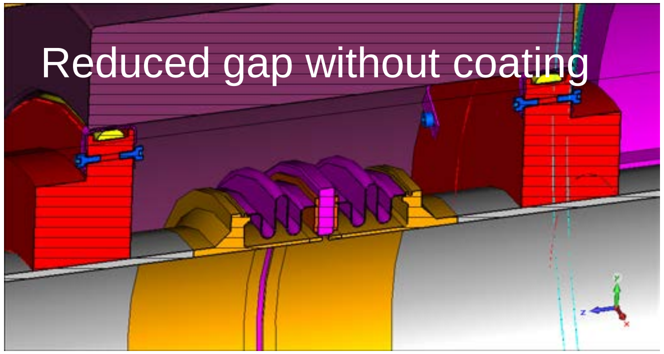


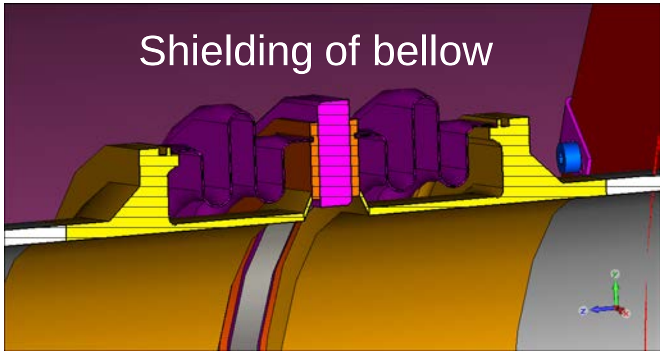




Maximum temperature reduced from 106 °C to 31°C (remember: simulation underestimates temperature)

# DCCT: solution



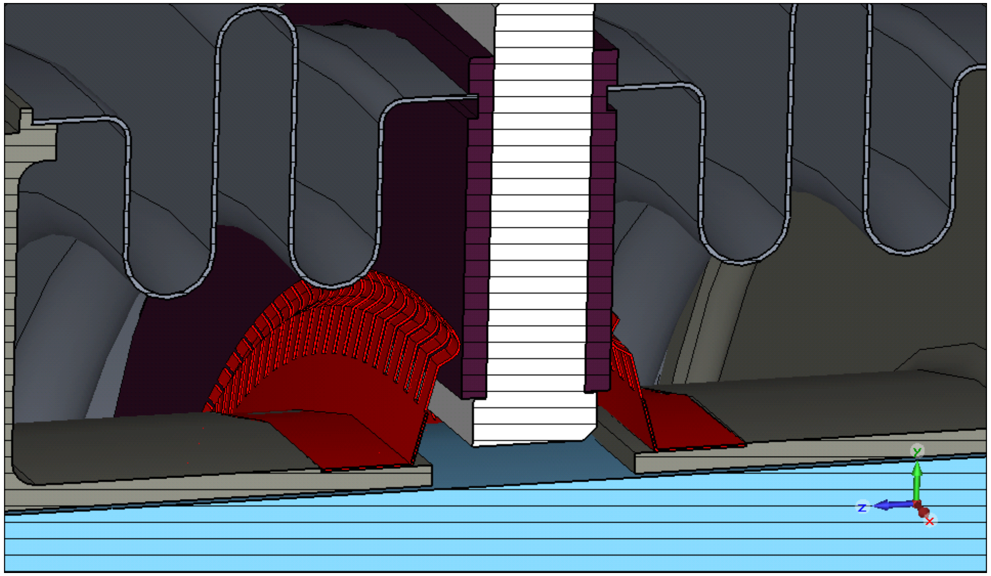




One of the proposals is realized:

Shielding of the bellow is realized.

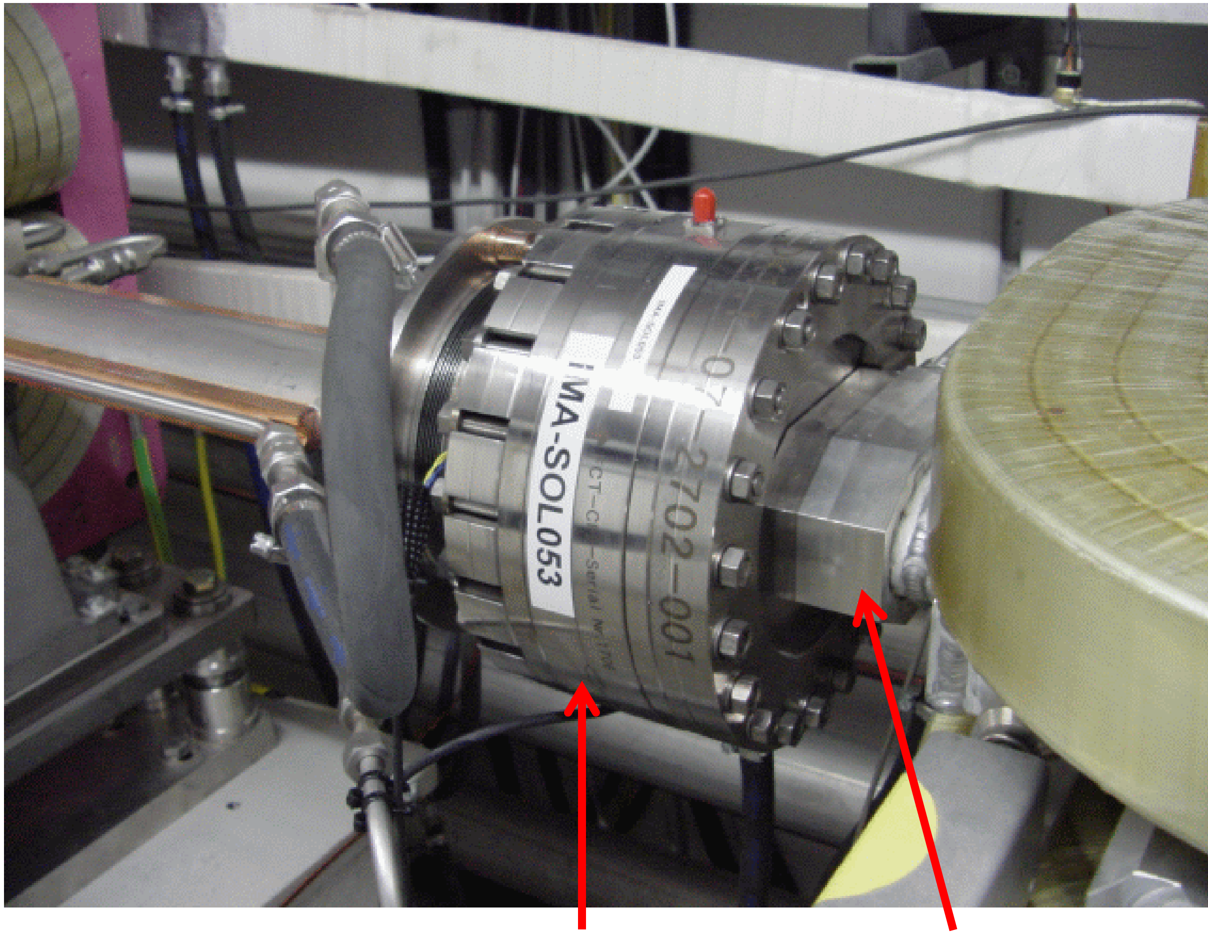
Temperature decreased from 130°C with I=65mA to e.g. 80°C with I=80mA and N=40 bunches.



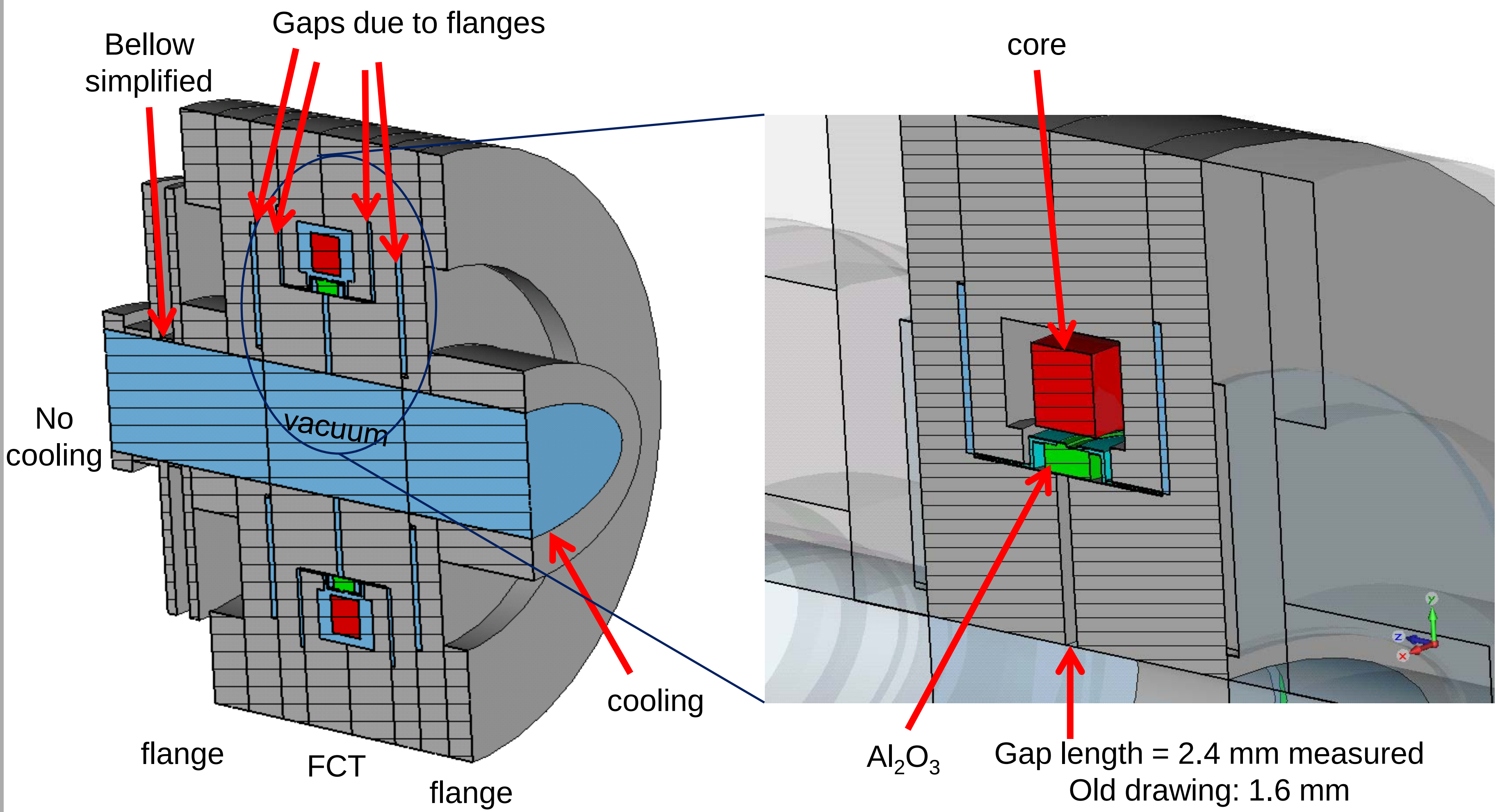
# Fast Current Transformer: FCT

- In 2011 FCT was broken
- Question: find reason
- Probably too high temperature

- FCT: fast responds therefore higher signal for shorter time necessary
- Core and ceramics delivered by company

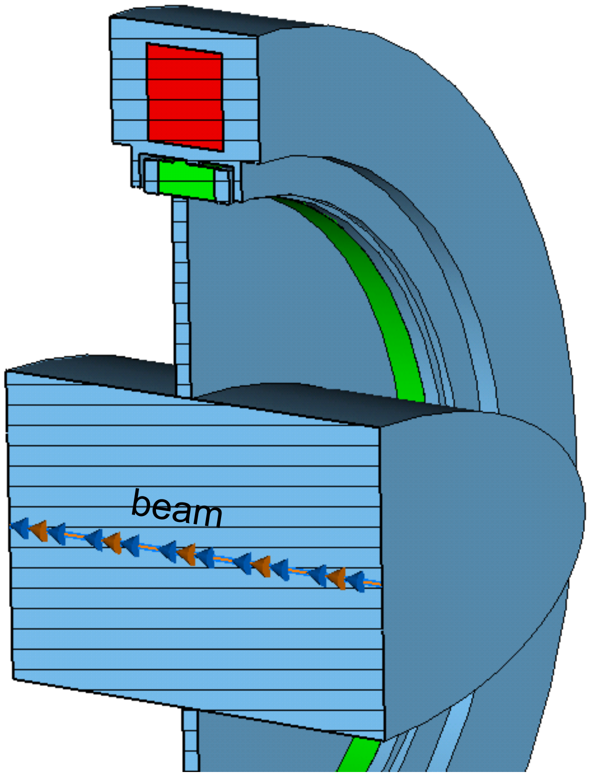


# FCT: simulation setup

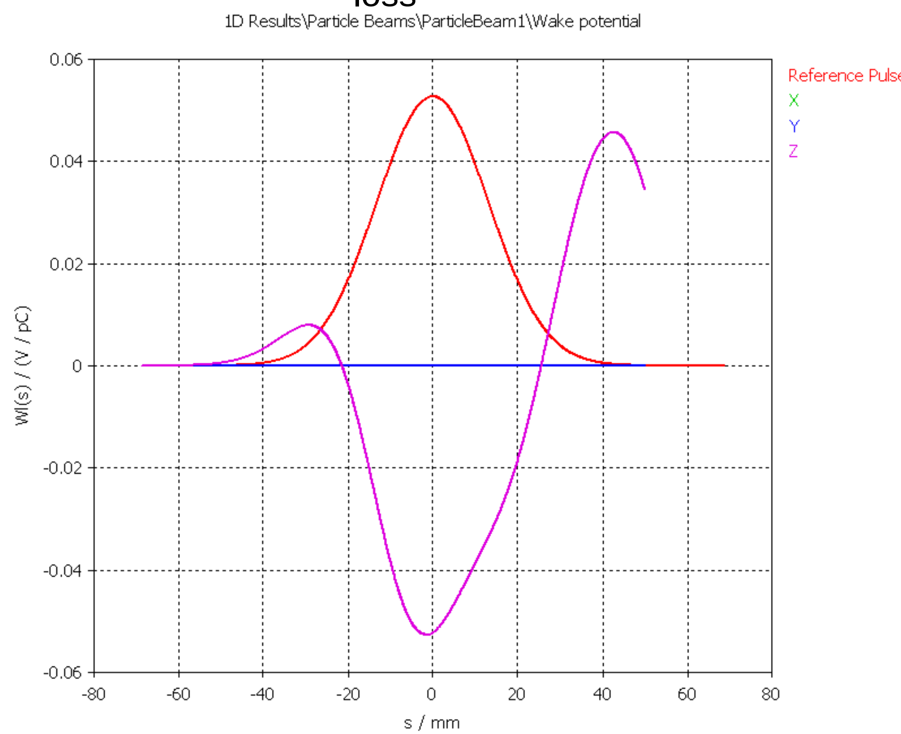


# FCT: wakefield simulation result

Setup simplified to simulate only interesting region



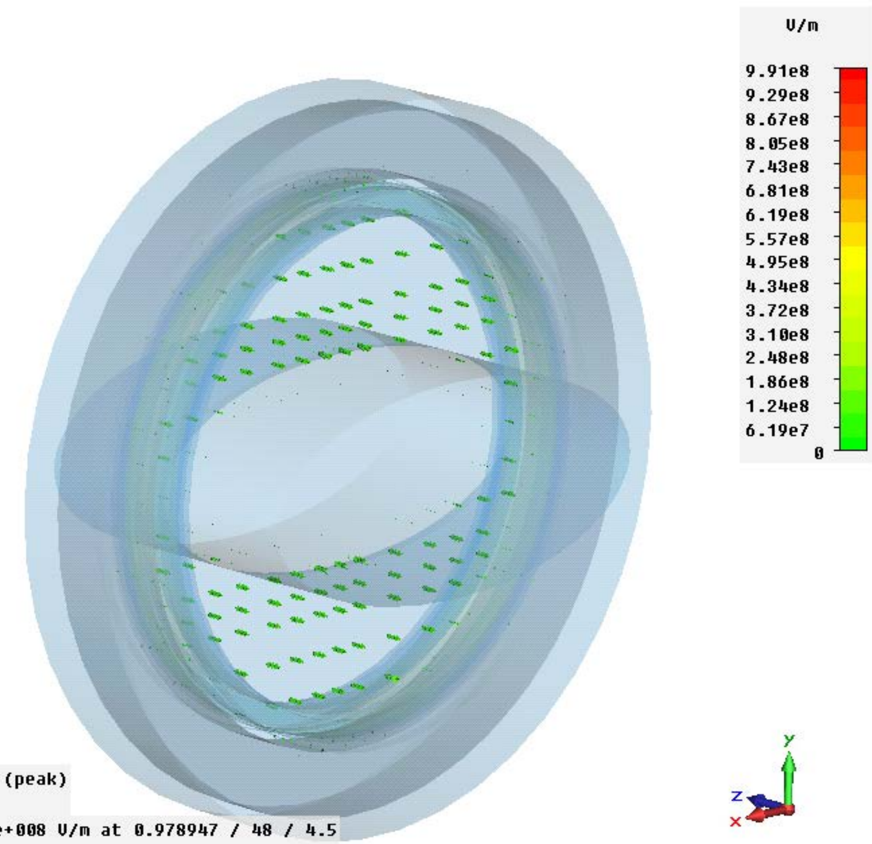

Wake potential, convolution integral results in loss factor $k_{loss}$ = 34.5 V/nC




$P = I\,Q\,k_{loss} = I^2\,t\,k_{loss} / N$ = 47.9 W with I = 85 mA and N = 40

# FCT: Eigenmode simulation result

- Dominant field distribution shows strong electric field in gap
- $k_{loss}$ of this mode results in 25.2 V/nC
- Difference to wakefield results carried by higher order fields
- This mode will be used for thermal simulation and scaled to the wakefield power

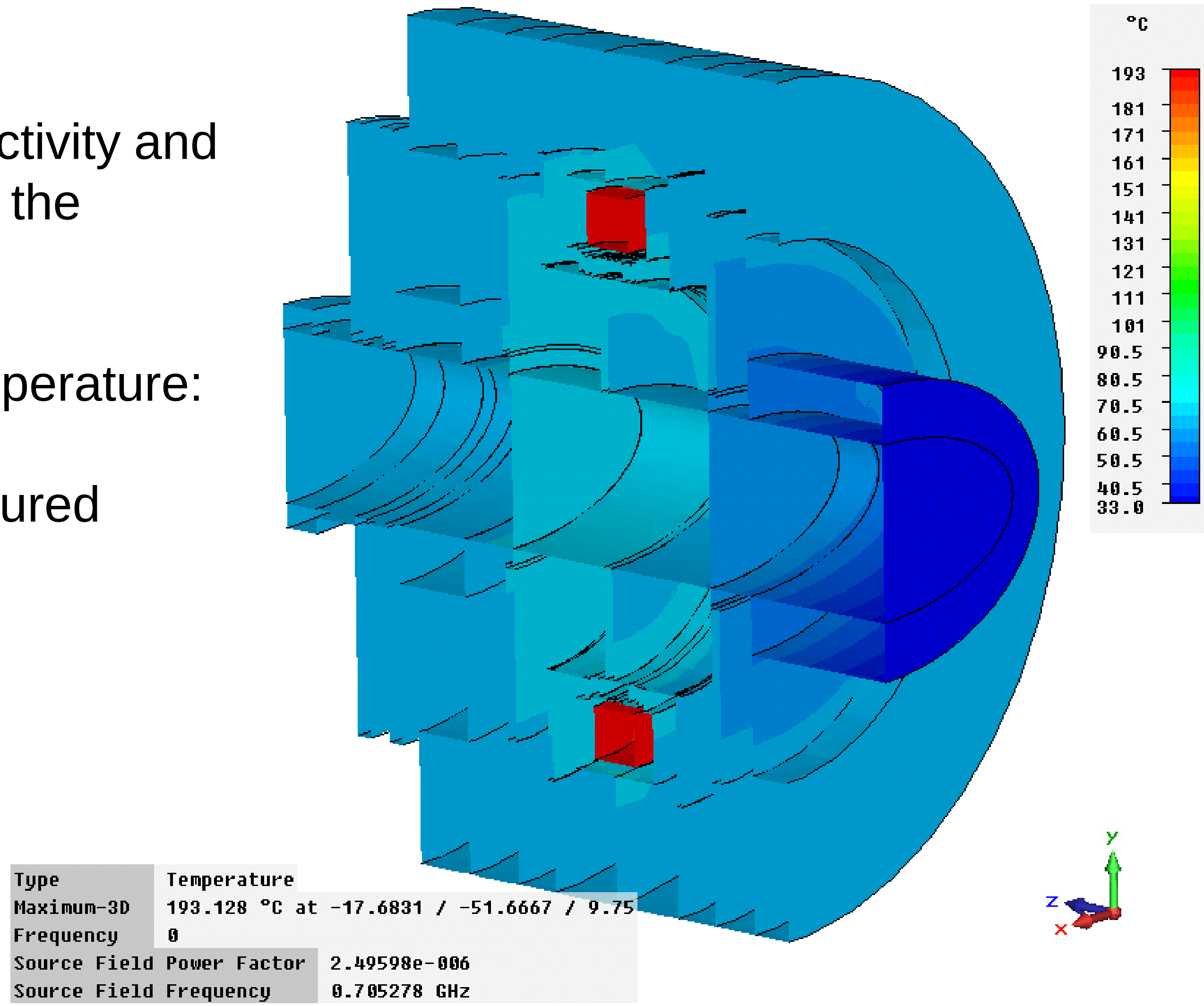



| | |
|---|---|
| Type | E-Field (peak) |
| Monitor | Mode 2 |
| Maximum-3D | 9.90859e+008 V/m at 0.978947 / 48 / 4.5 |
| Frequency | 0.705278 |
| Phase | 0 degrees |

# FCT: thermal simulation result

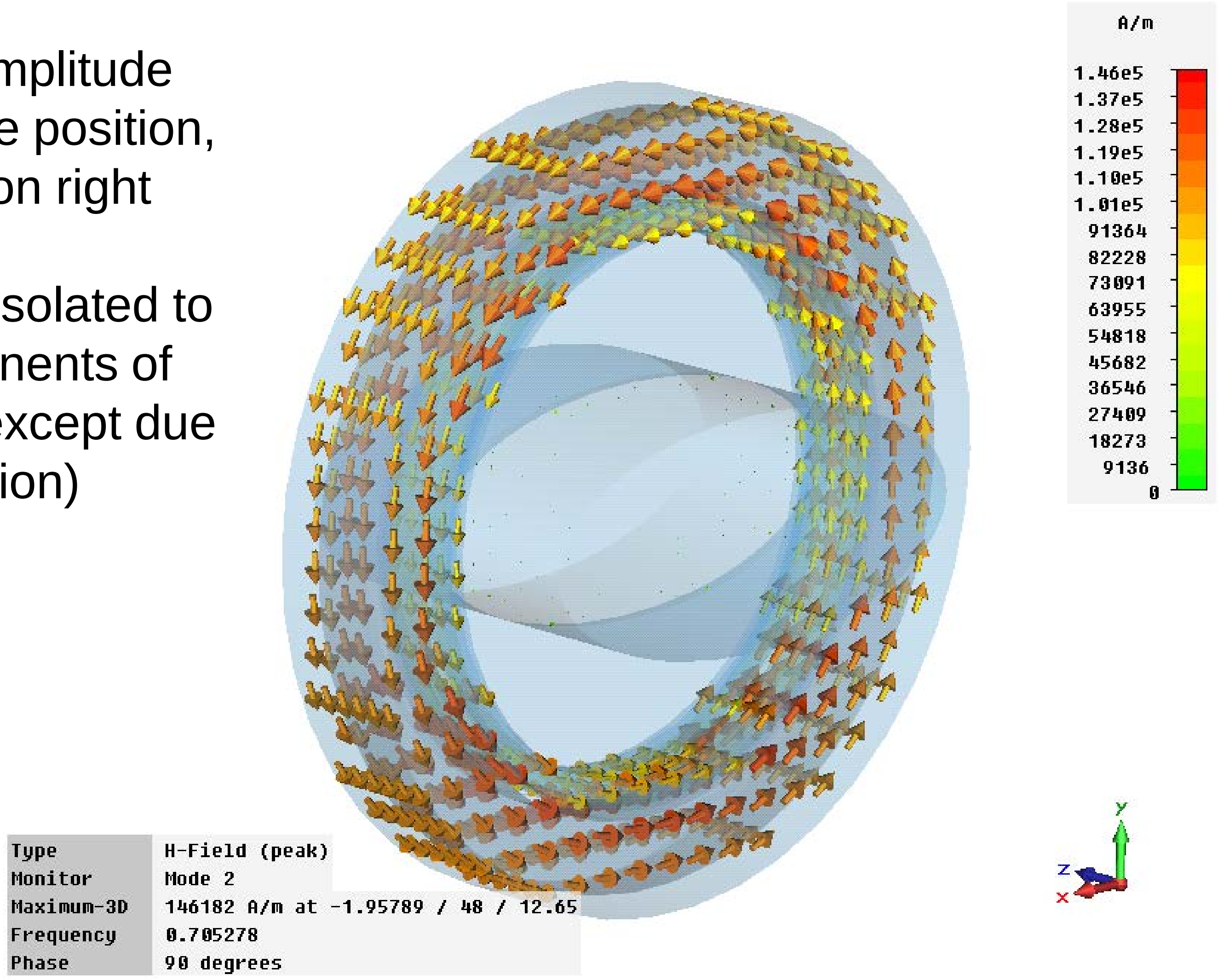
Settings: thermal conductivity and radiation with respect to the material properties

- Core get highest temperature: 193.1 °C
- Body: 64.9 °C (measured 74°C)



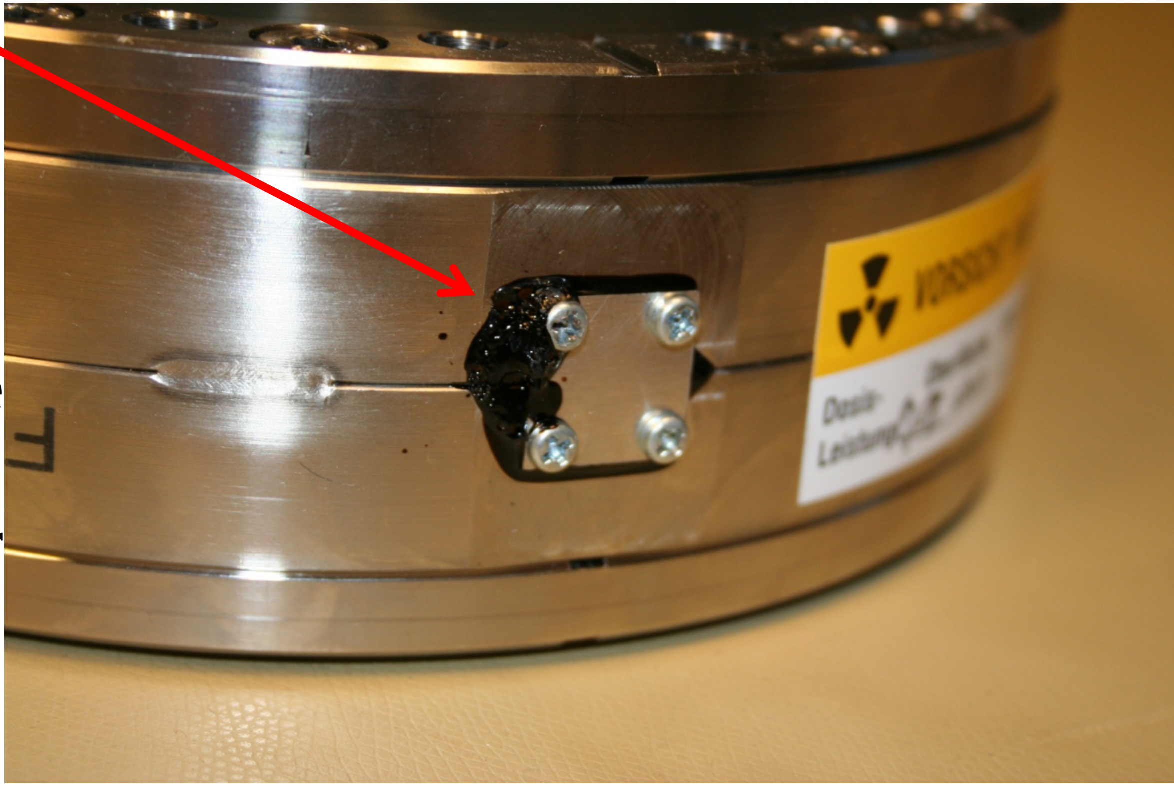
# FCT: reason for core temperature

- Magnetic field amplitude maximum at core position, see distribution on right plot
- Core is thermal isolated to the other components of the simulation (except due to thermal radiation)



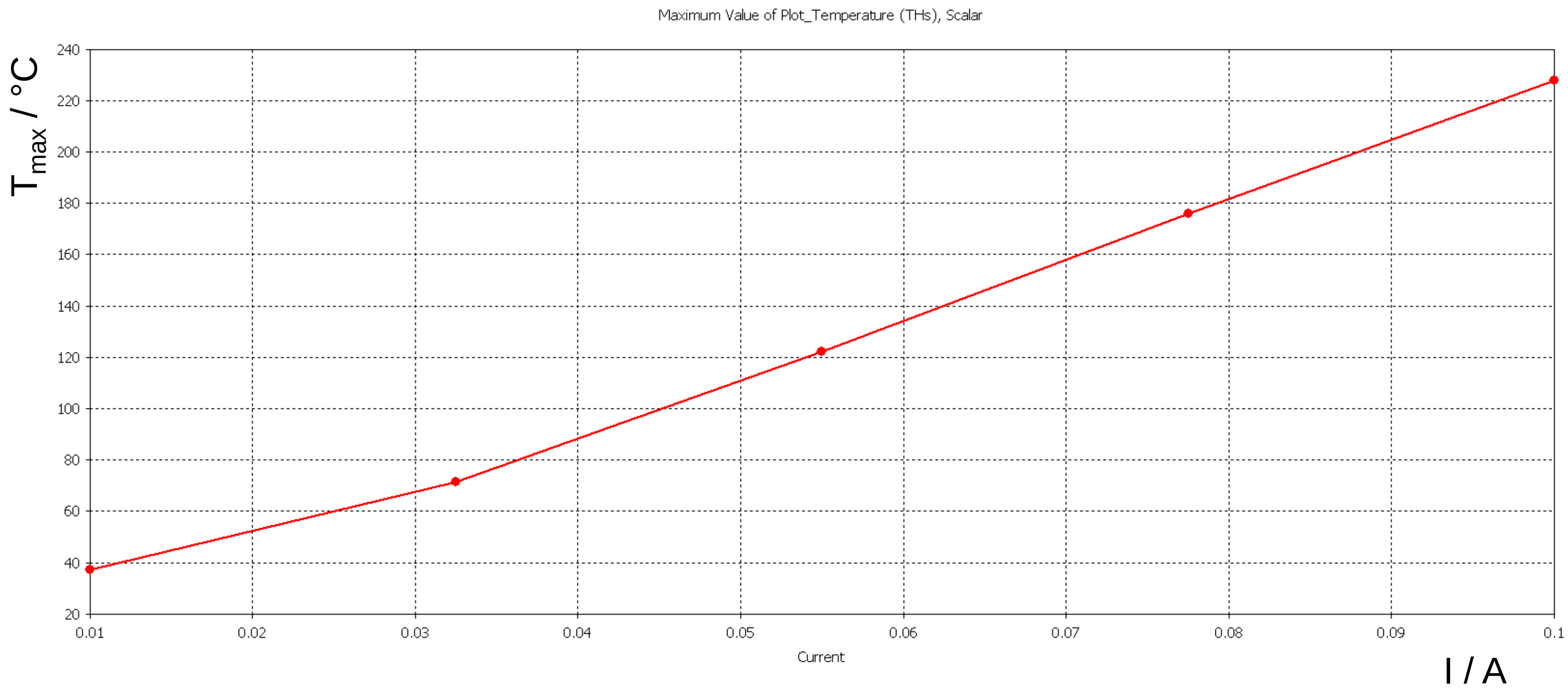
# FCT: after dismounting

- Melting of inner materials observed
- Assumption: inner temperature was above 300 °C
- Simulation does not verify such temperature with used boundary conditions: more power or lower cooling



# FCT: variation of beam current

- Maximum temperature at core as a function of beam current, 40 bunches in storage ring



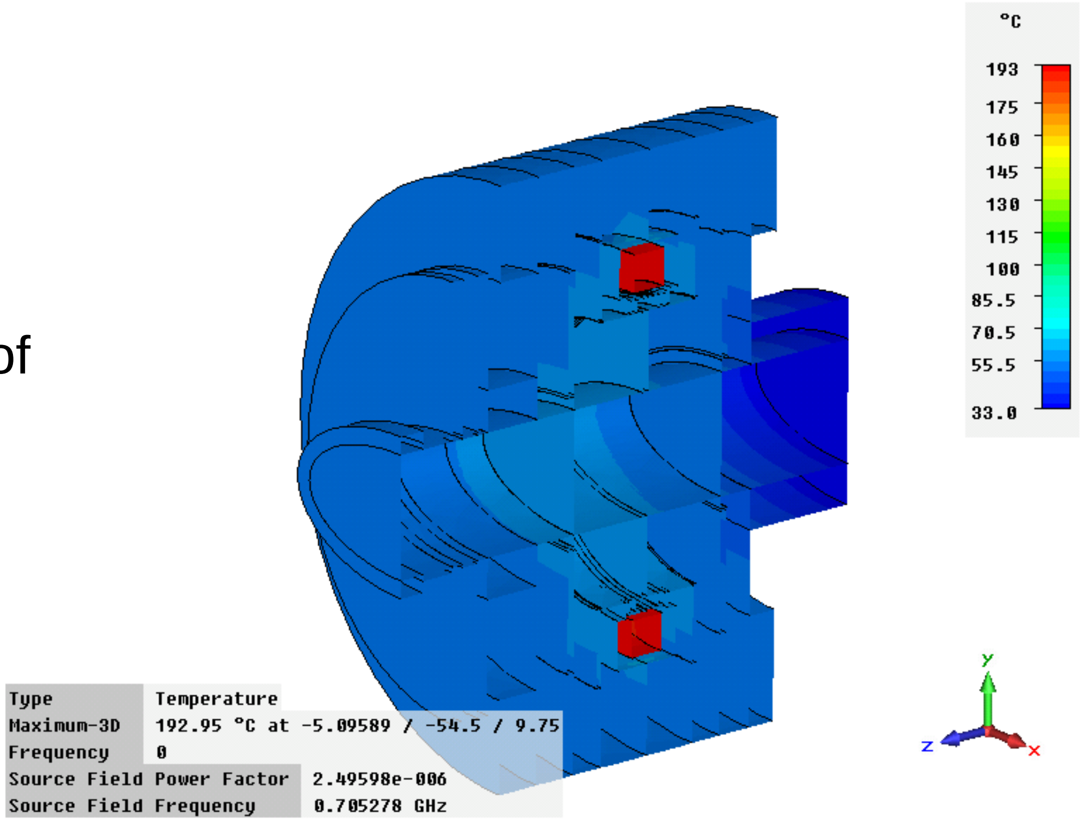

Maximum beam current temperature about 230°C

# FCT: influence of air cooling outside

Simulated air cooling around body by introduction of T=const. after 1 mm transversally with air surround

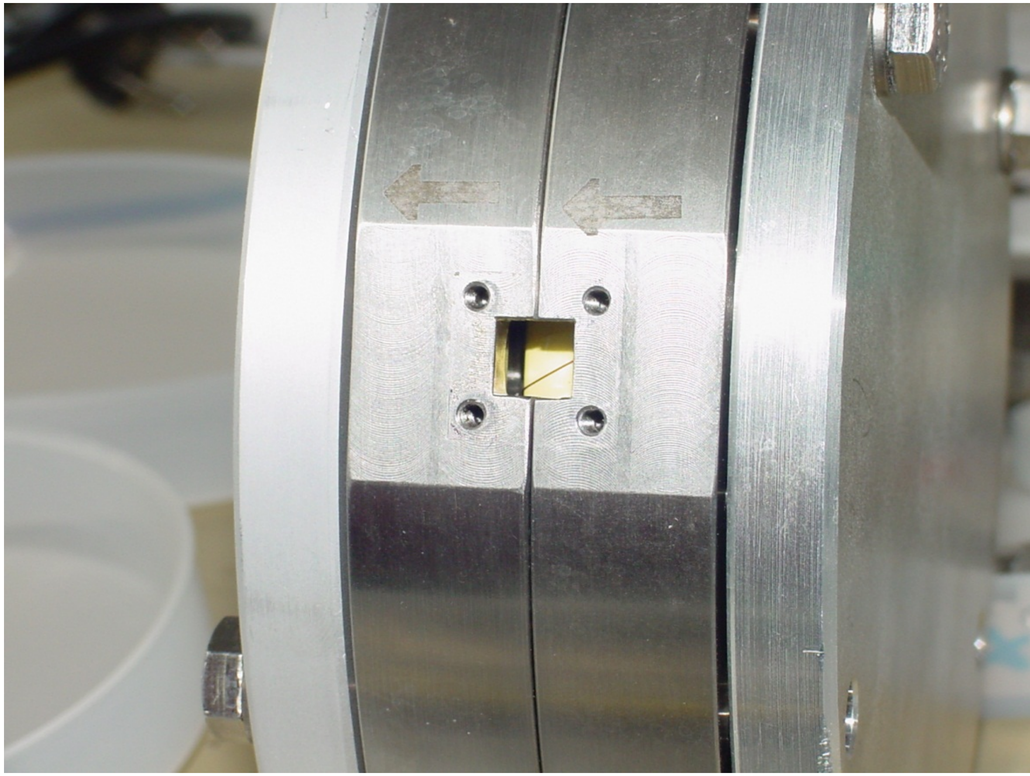
Result: core lower temperature of 0.2°K and body lower temperature by 10.9°K

Therefore: higher influence to body temperature but negligible influence to core temperature



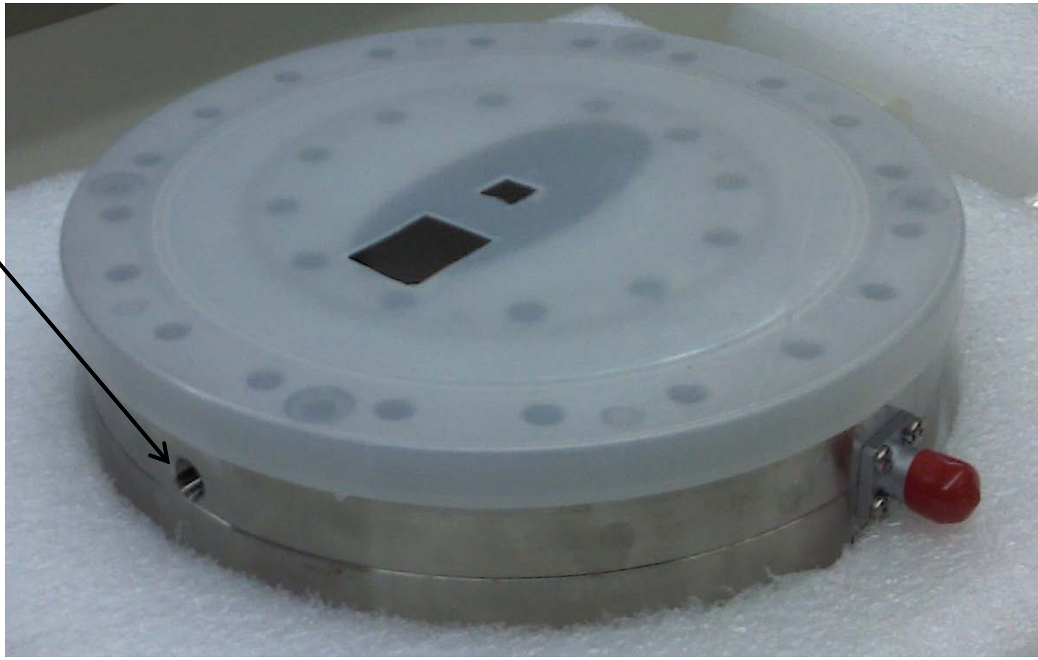
# FCT: interim solution

- Keep additional hole open and added air cooling to this hole by small tube
- Temperature on body decreased from 74°C to 50°C with 40 bunches and no damage



# FCT: final solution

- Company changed isolation of core material
- 2 additional holes with connectors for air cooling
- Temperature sensor on core



# Summary

- Simulation of wake losses to get loss factor
- Calculation of induced power with loss factor and machine settings
- Simulation of Eigenmodes to get loss distribution
- Optional: thermal simulation to get temperature (thermal boundary condition)
- When power >~10 W (my private suggestion):
  - Change geometry or
  - Add cooling: P between 10 and 100 W air cooling, above water cooling

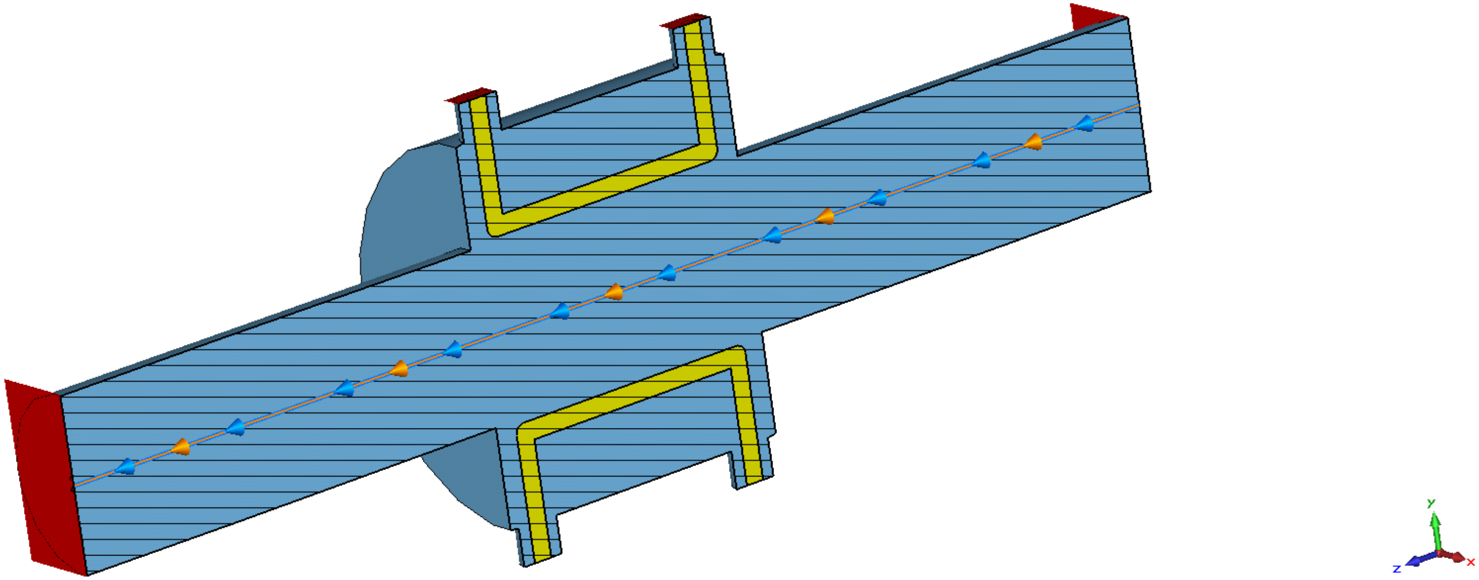
Thanks to

Maike Pelzer, Klaus Knaack, Reinhard Neumann

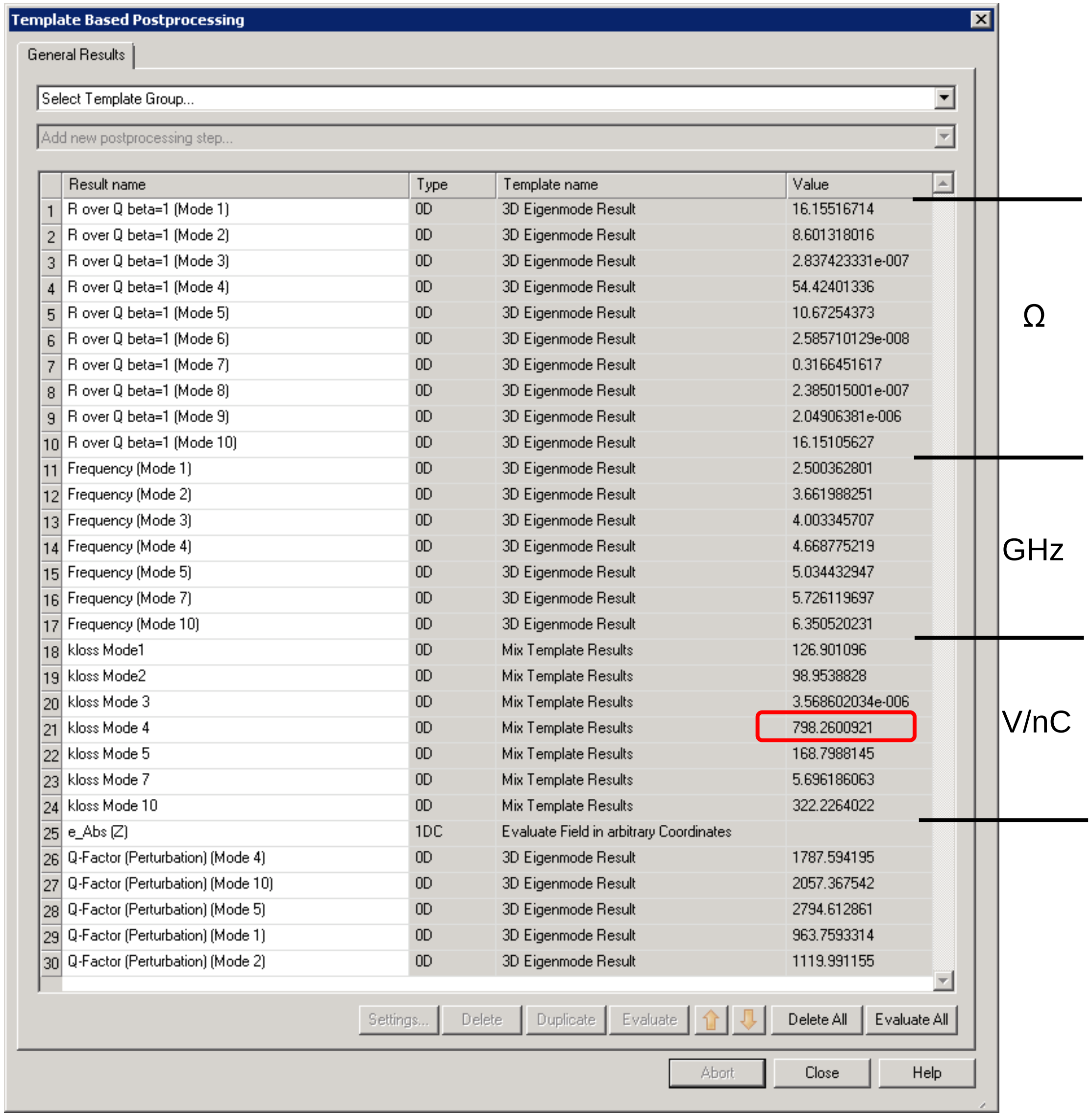
Thank you for your attention!

# Homework

- CST 2012, windows 64 bit server, 2 core from 8 used
- WAK solver: 4.2e-4 ns steps, time duration 3 min 24 s
- Eigenmode: time duration 42 min, 23 s



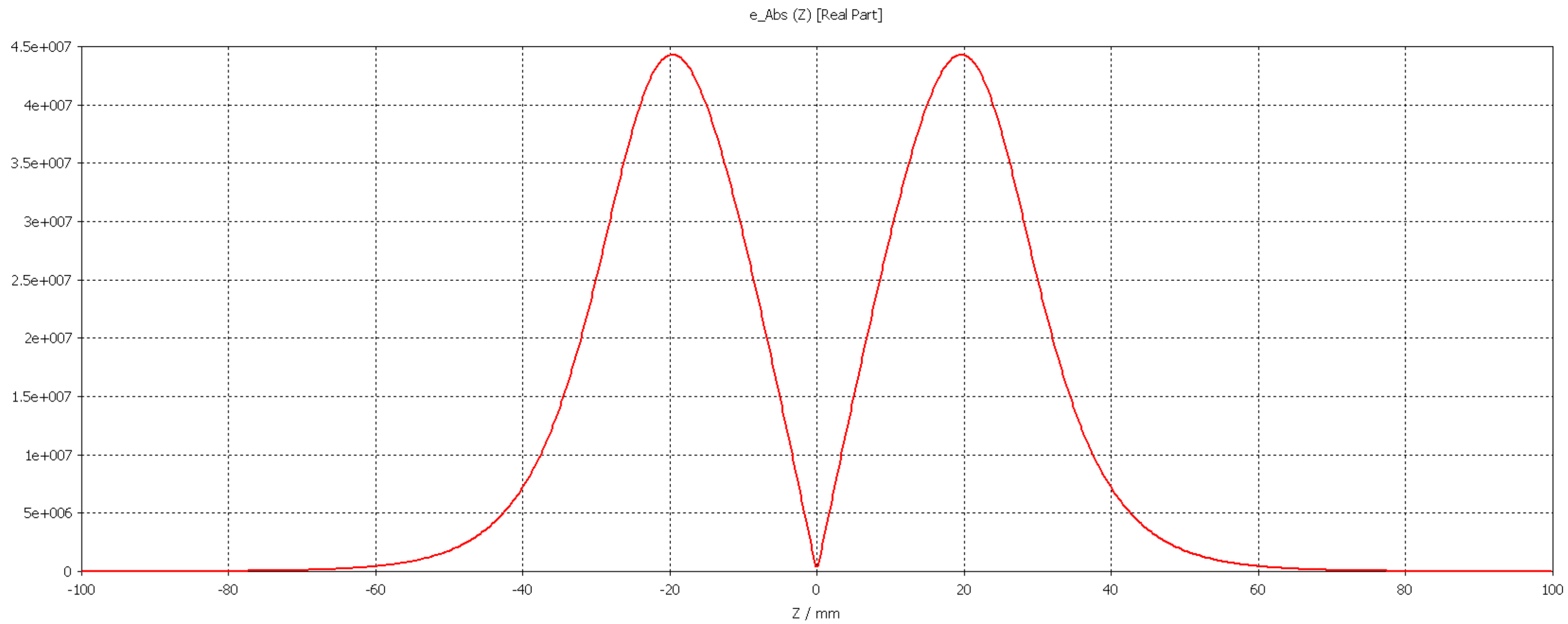
# Homework: Eigenmodes



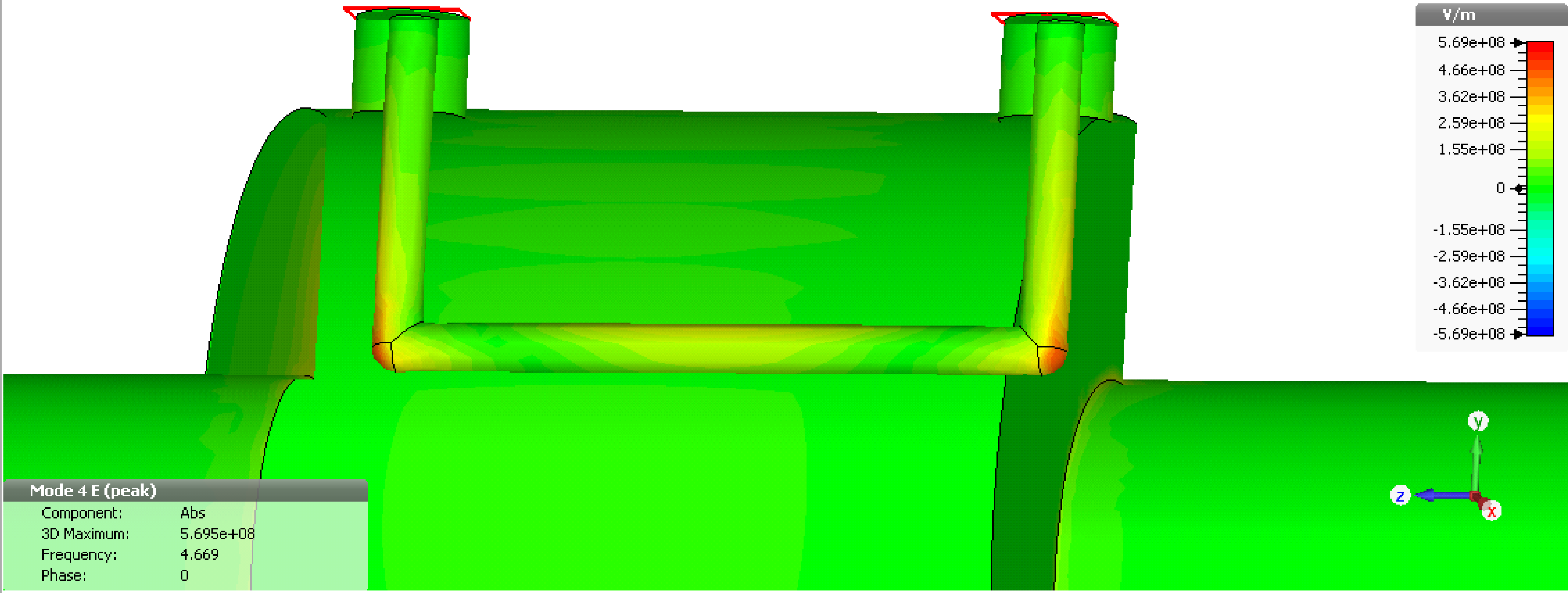

| | Result name | Type | Template name | Value |
|---|---|---|---|---|
| 1 | R over Q beta=1 (Mode 1) | 0D | 3D Eigenmode Result | 16.15516714 |
| 2 | R over Q beta=1 (Mode 2) | 0D | 3D Eigenmode Result | 8.601318016 |
| 3 | R over Q beta=1 (Mode 3) | 0D | 3D Eigenmode Result | 2.837423331e-007 |
| 4 | R over Q beta=1 (Mode 4) | 0D | 3D Eigenmode Result | 54.42401336 |
| 5 | R over Q beta=1 (Mode 5) | 0D | 3D Eigenmode Result | 10.67254373 |
| 6 | R over Q beta=1 (Mode 6) | 0D | 3D Eigenmode Result | 2.585710129e-008 |
| 7 | R over Q beta=1 (Mode 7) | 0D | 3D Eigenmode Result | 0.3166451617 |
| 8 | R over Q beta=1 (Mode 8) | 0D | 3D Eigenmode Result | 2.385015001e-007 |
| 9 | R over Q beta=1 (Mode 9) | 0D | 3D Eigenmode Result | 2.04906381e-006 |
| 10 | R over Q beta=1 (Mode 10) | 0D | 3D Eigenmode Result | 16.15105627 |
| 11 | Frequency (Mode 1) | 0D | 3D Eigenmode Result | 2.500362801 |
| 12 | Frequency (Mode 2) | 0D | 3D Eigenmode Result | 3.661988251 |
| 13 | Frequency (Mode 3) | 0D | 3D Eigenmode Result | 4.003345707 |
| 14 | Frequency (Mode 4) | 0D | 3D Eigenmode Result | 4.668775219 |
| 15 | Frequency (Mode 5) | 0D | 3D Eigenmode Result | 5.034432947 |
| 16 | Frequency (Mode 7) | 0D | 3D Eigenmode Result | 5.726119697 |
| 17 | Frequency (Mode 10) | 0D | 3D Eigenmode Result | 6.350520231 |
| 18 | kloss Mode1 | 0D | Mix Template Results | 126.901096 |
| 19 | kloss Mode2 | 0D | Mix Template Results | 98.9538828 |
| 20 | kloss Mode 3 | 0D | Mix Template Results | 3.568602034e-006 |
| 21 | kloss Mode 4 | 0D | Mix Template Results | 798.2600921 |
| 22 | kloss Mode 5 | 0D | Mix Template Results | 168.7988145 |
| 23 | kloss Mode 7 | 0D | Mix Template Results | 5.696186063 |
| 24 | kloss Mode 10 | 0D | Mix Template Results | 322.2264022 |
| 25 | e_Abs (Z) | 1DC | Evaluate Field in arbitrary Coordinates | |
| 26 | Q-Factor (Perturbation) (Mode 4) | 0D | 3D Eigenmode Result | 1787.594195 |
| 27 | Q-Factor (Perturbation) (Mode 10) | 0D | 3D Eigenmode Result | 2057.367542 |
| 28 | Q-Factor (Perturbation) (Mode 5) | 0D | 3D Eigenmode Result | 2794.612861 |
| 29 | Q-Factor (Perturbation) (Mode 1) | 0D | 3D Eigenmode Result | 963.7593314 |
| 30 | Q-Factor (Perturbation) (Mode 2) | 0D | 3D Eigenmode Result | 1119.991155 |

# Homework: Eigenmodes

Mode 4: field strength along particle trajectory
I made tube longer such that field is not cutted by tube



# Homework: Eigenmode




Field amplitude highest at strip corners

# Homework: WAK solver

$k_{loss}$ = 857 V/nC