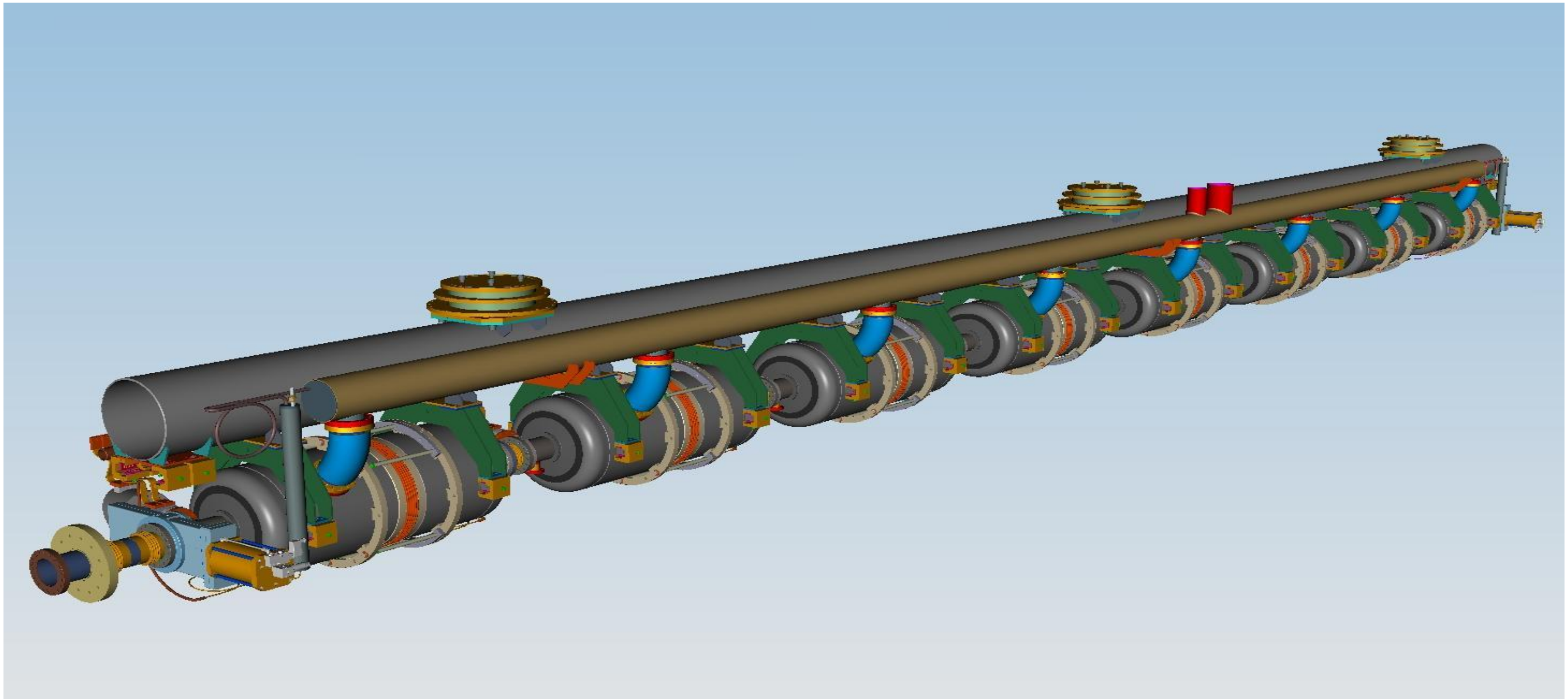


- Heat load in Cavity beam pipe due to Thermal Radiation coming through cryomodule warm end .

Arun Saini, N. Solyak

Tuesday 650 MHz cavity Meeting, 13 Aug. 2013

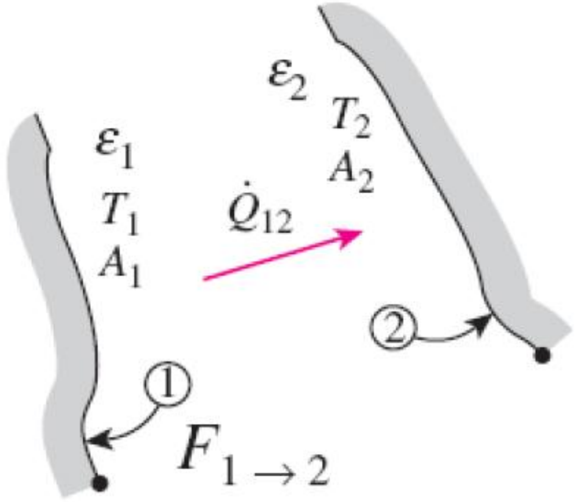
Thermal Radiation

- Radiation emitted by a surface: $\dot{Q} = A\epsilon\sigma T^4$
  - ϵ =1; for a black body.
- Net radiation exchange between two surfaces:

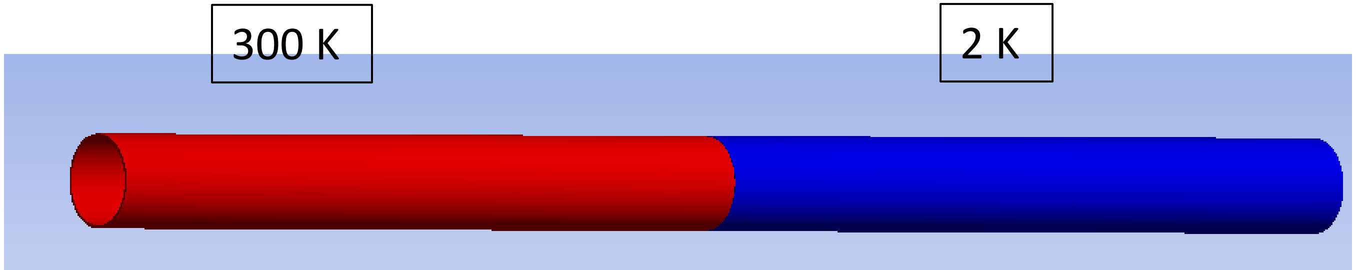
$$\dot{Q}_{12} = \frac{\sigma.({T_1}^4 - {T_2}^4)}{\frac{(1-\varepsilon_1)}{A_1.\varepsilon_1} + \frac{(1-\varepsilon_2)}{A_2.\varepsilon_2} + \frac{1}{A_1 F_{12}}}$$

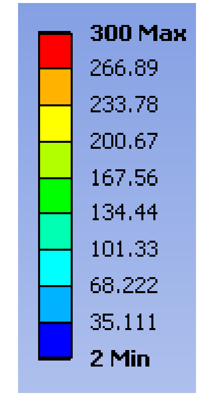
For Black bodies

$$\dot{Q}_{12} = \sigma.({T_1}^4 - {T_2}^4).A_1 F_{12}$$



Case 1 : Maximum heat transfer from 300K to 2 K





- ***Assumptions:***
  - Both boundaries are next to each other.
    - No interception from 80 K and 5 K
  - Both are black bodies.
- Net Radiation transfer

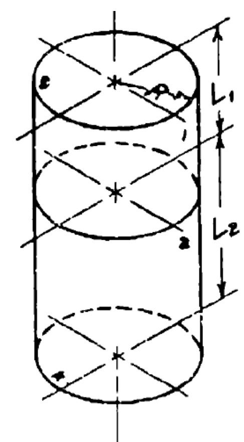
$$F_{1-2} = \frac{L_2}{2R} + \frac{1}{4}\left[\sqrt{4+\frac{L_1^2}{R^2}} + \frac{L_2}{L_1}\sqrt{4+\frac{L_2^2}{R^2}} - \left(\frac{L_1+L_2}{L_1}\right)\sqrt{4+\left(\frac{L_1+L_2}{R}\right)^2}\right]$$

{1}

$$\dot{Q}_{12} = \sigma.(T_1^{\ 4} - T_2^{\ 4}).A_1F_{12}$$

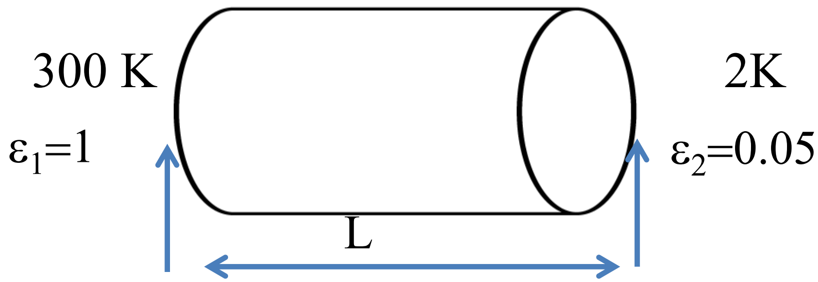
$$for\ \frac{R}{L} >> 1 \quad A_1F_{12} = \pi.R^2; \quad R = 0.059m$$

$$\dot{Q}_{12} = 5W$$

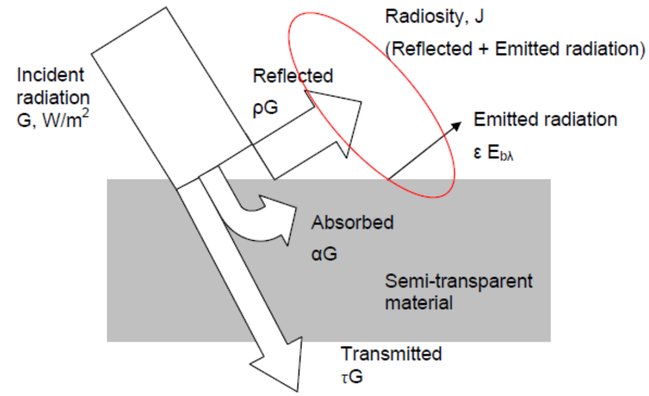


Case 2 : Minimum heat transfer from 300K to 2 K

- *Assumptions:*
  - 2K boundary is grey and opaque surface.
    - No transmission for opaque surface.

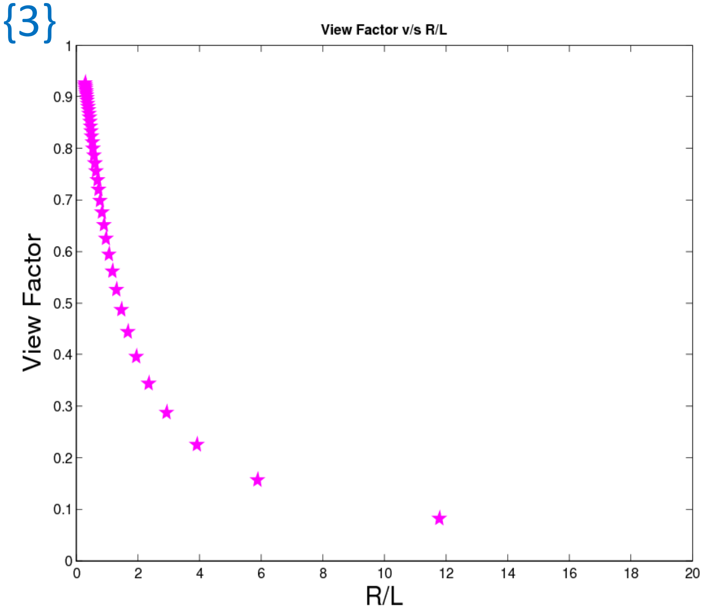


{3}



- For L =0.2 m; Radiation reaching to cavity beam pipe ~ 0.16 W.

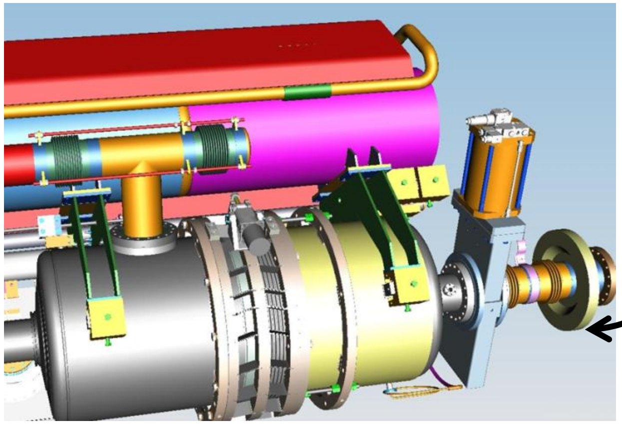
- ***Conclusion*** : Radiation heat load lays in interval of [0.16 5]

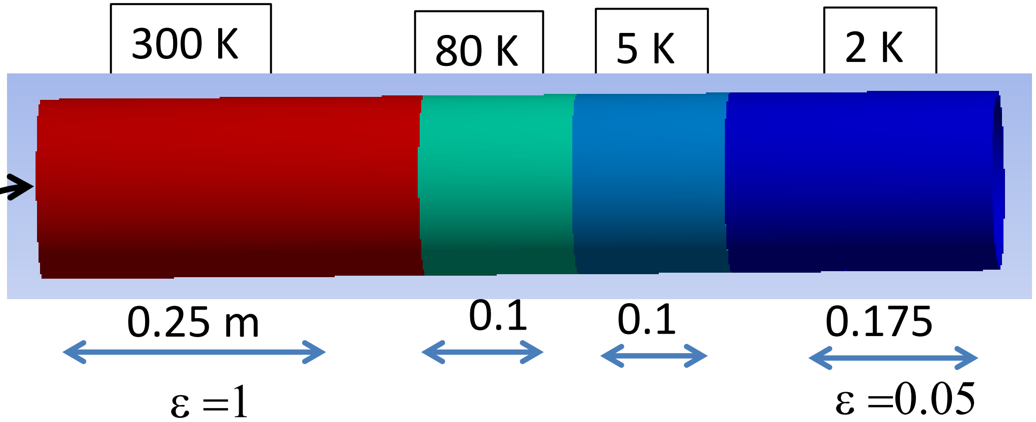


View Factor from bottom to curved surface

{2}

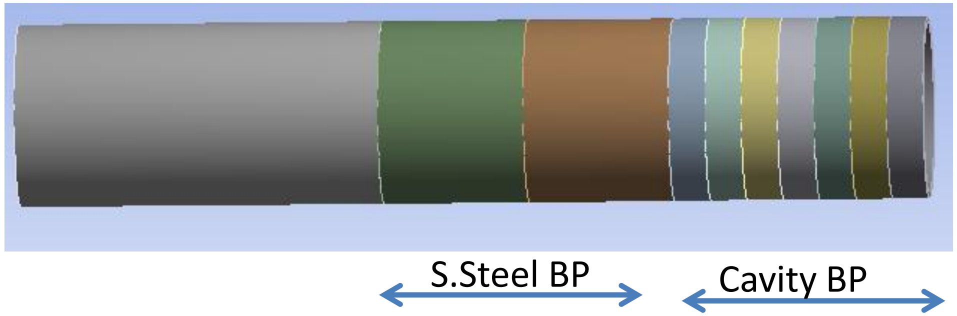
Case 3 : Simplified Realistic model

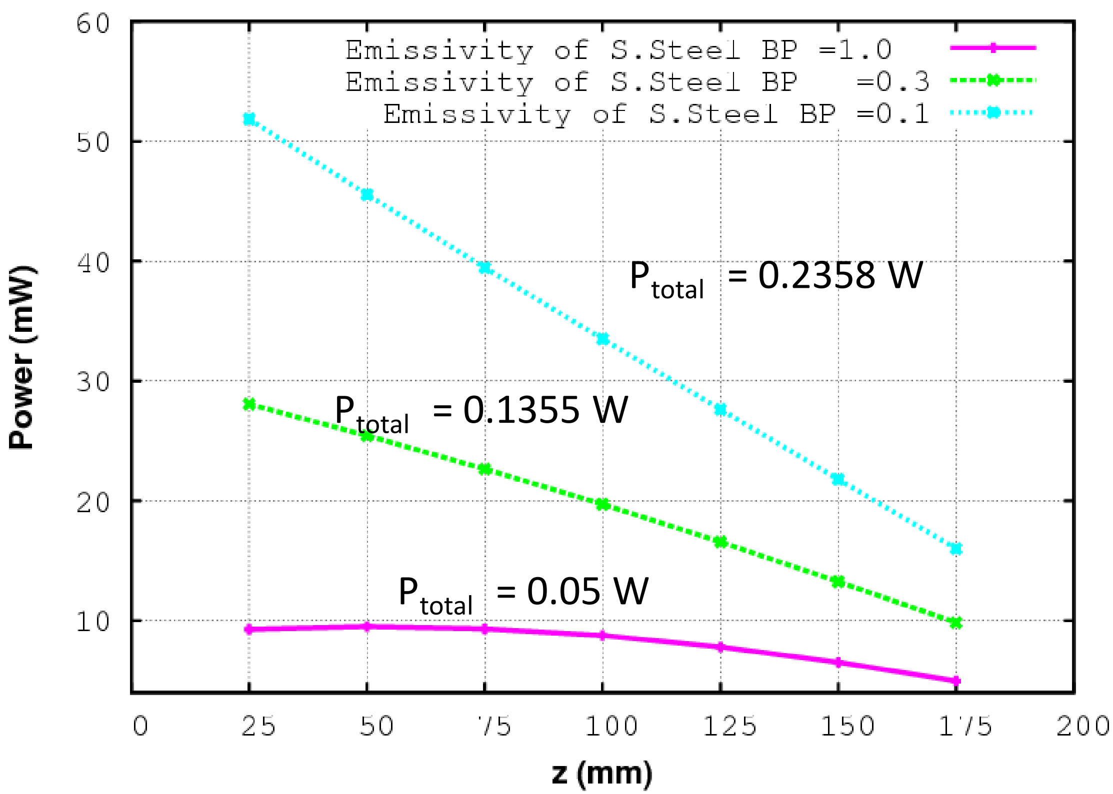




- ANSYS simulation is performed for simplified model.
  - Steady state surface to surface radiation boundary condition is applied.
  - $$\dot{Q}_{net} = \dot{Q}_{emit} - \dot{Q}_{inci} + (1-\varepsilon)\dot{Q}_{inci}$$
  - No Convection effect.
  - Emissivity of 80 K and 5 K Stainless steel pipe is varied.

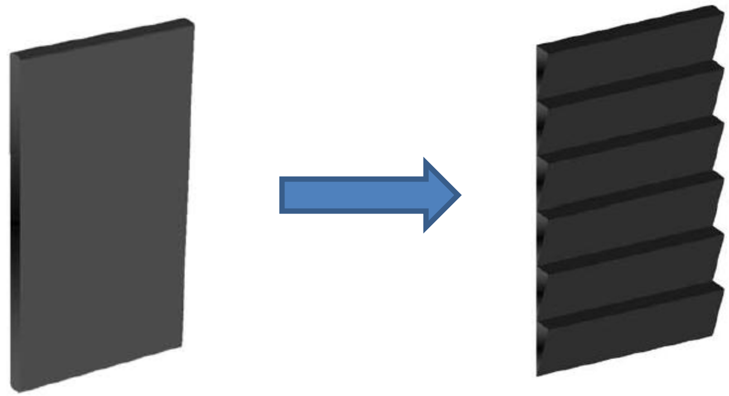
Power deposited in Cavity Beam Pipe (BP)





- Conclusion:
- High emissivity of 80 K and 5K pipes can reduce energy deposition in Cavity BP.
- Reducing the radius of Steel BP might also help.

How to increase emissivity

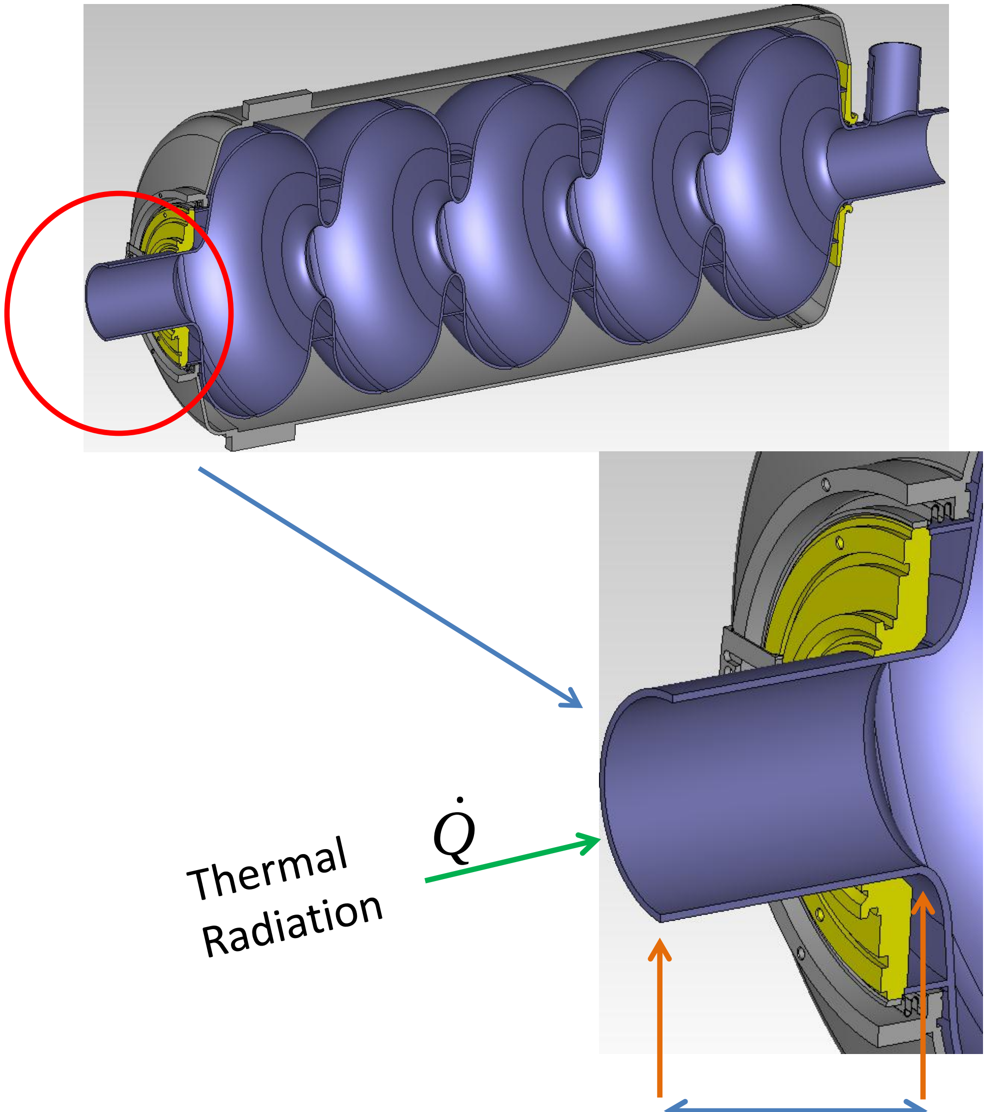


Black Surface Rough *Black Surface*

- Rough surface is better attenuator than smooth surface.
  - Sandblasting and chemical etching
- High emissivity also leads to high conduction heating load which can be easily intercepted by 80 K and 5 K cold sheild.

- ***SNS data suggests that 70 % of total static heat load comes from thermal radiation.***

Temperature Distribution in Cavity Beam Pipe



For 1D steady state equation.

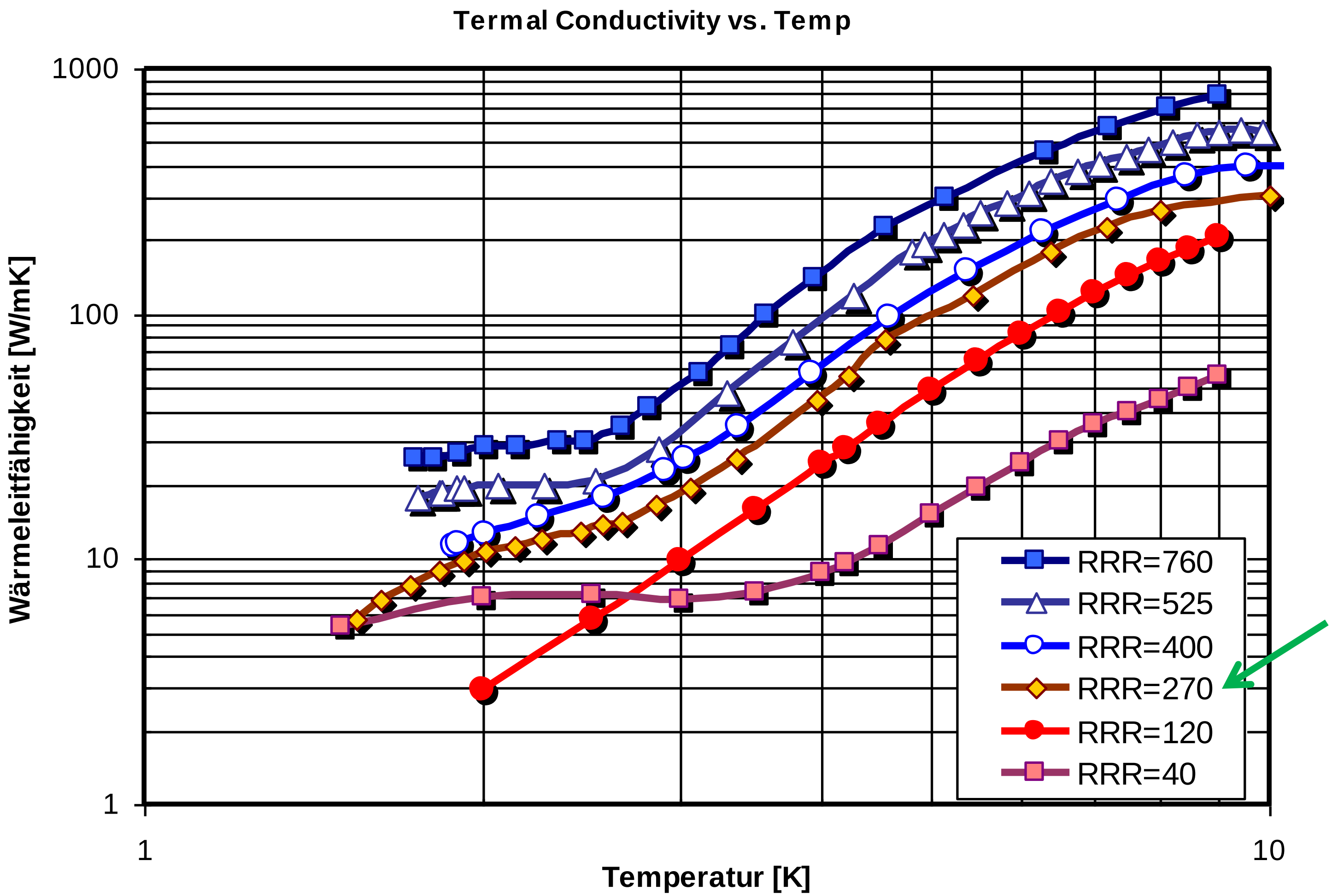
$$\frac{\partial^2 T}{\partial z^2} = -\frac{q}{K}$$

$q =$ Rate of heat generated per unit volume of beam pipe

K = Thermal conductivity.

$$K_{avg}(i) = \frac{\int_{T_1}^{T_2} K(T_{i-1}).dT}{T_2 - T_1}$$

Thermal conductivity data :D. Reschke/DESY, Dec. 2003



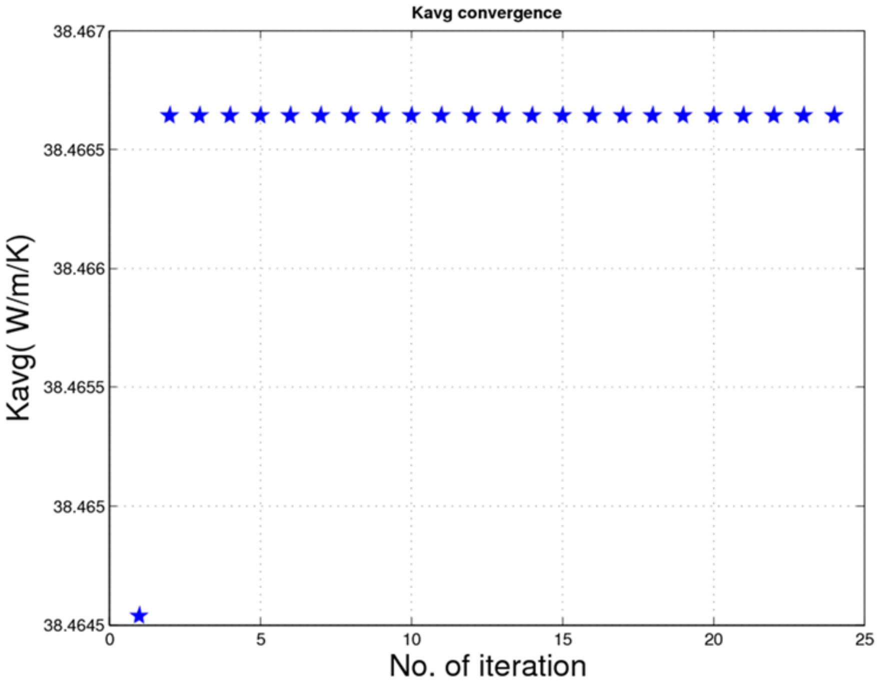
Fit:

$$L270(T) := \exp\left(-4.57848 + 31.01\cdot\ln(T) - 54.77795\cdot\ln(T)^2 + 46.41167\cdot\ln(T)^3 - 17.89282\cdot\ln(T)^4 + 2.56625\cdot\ln(T)^5\right)$$

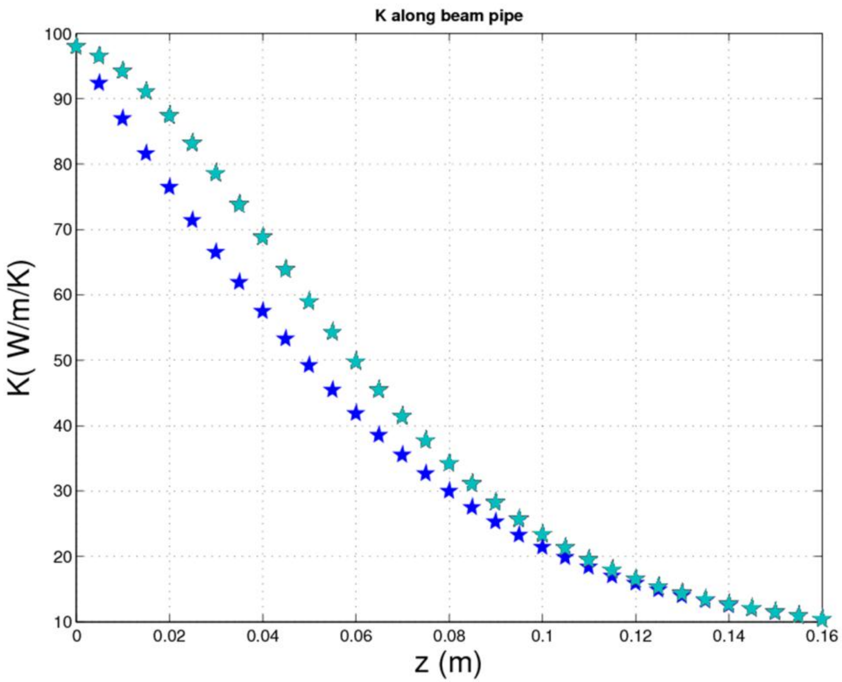
$$L400(T) := \exp\left[-4.38 + 31.0\cdot\ln(T) - 54.69\cdot\ln(T)^2 + 46.40\cdot\ln(T)^3 - 17.917\cdot(\ln(T))^4 + 2.5741\cdot\ln(T)^5\right]$$

Thermal conductivity

$K_{average}$ with no. of iteration

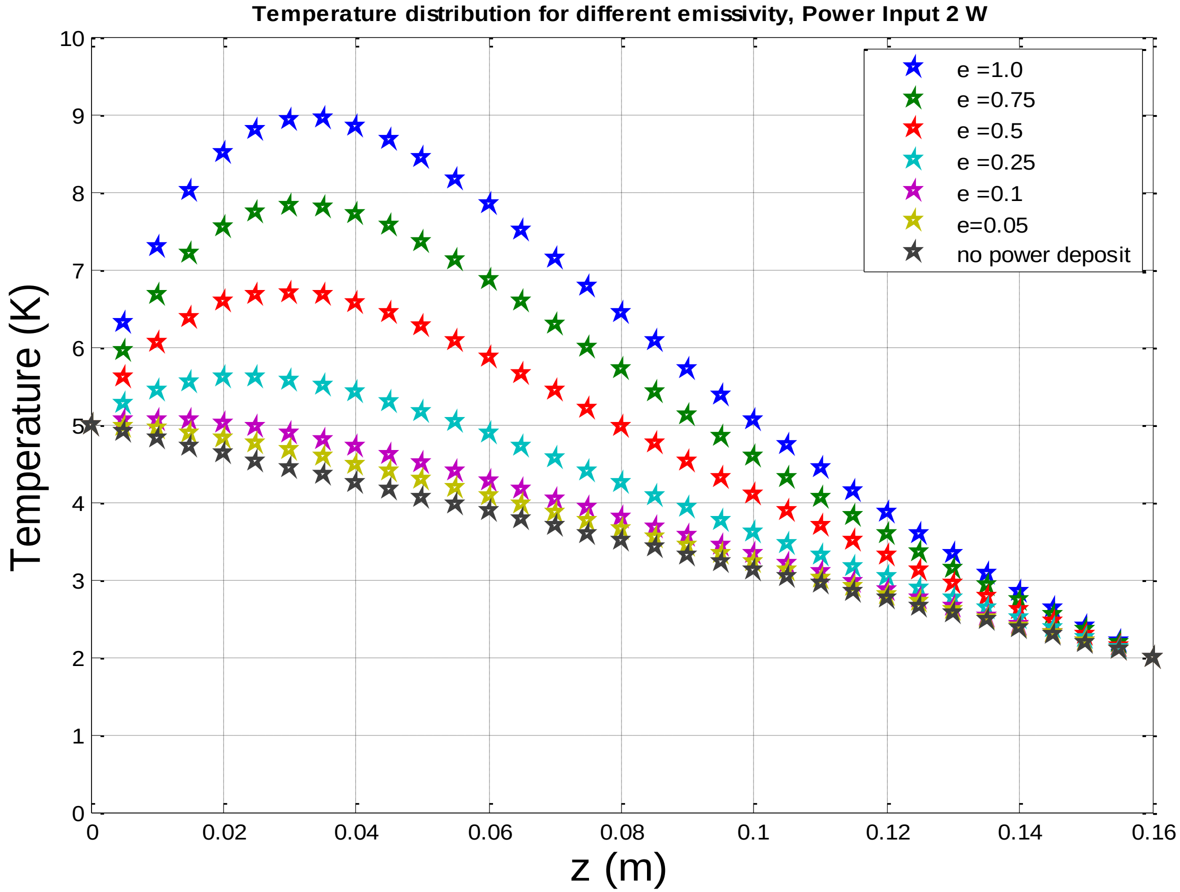


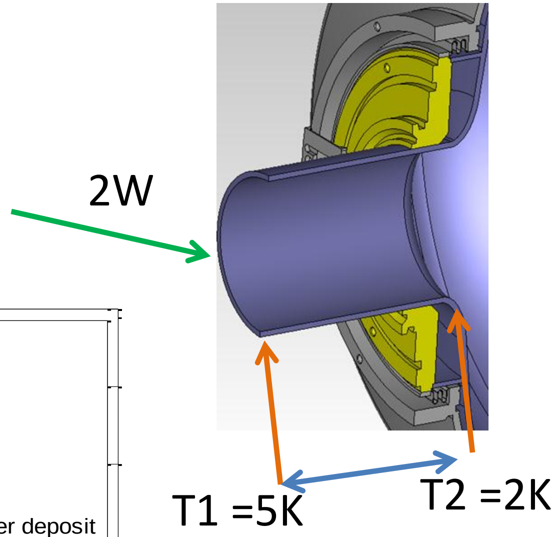
Thermal conductivity along beam pipe



Temperature Distribution in beam pipe for different emittances

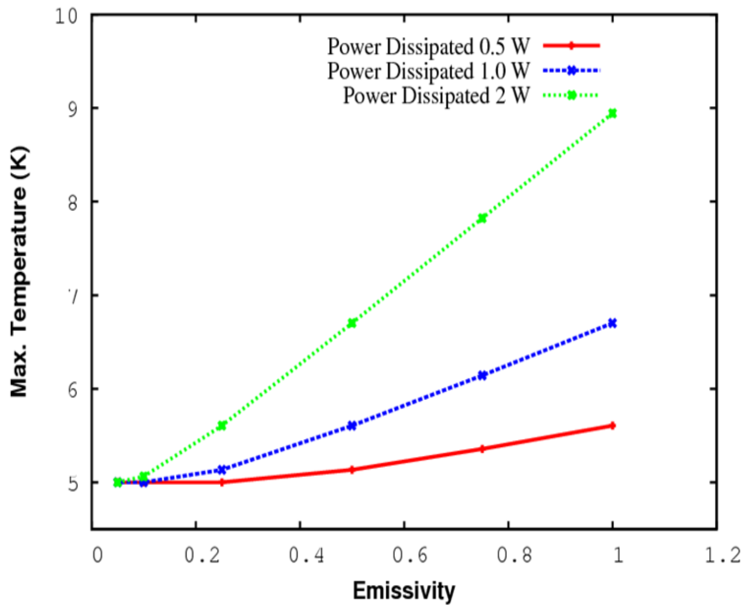
- *Input power is 2 W*



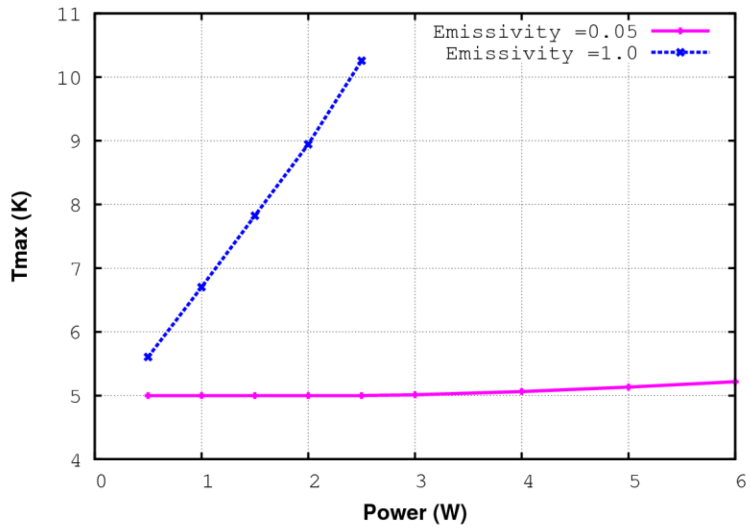


Maximum Temperature in Cavity Beam Pipe

Variation in Max. Temperature with emissivity



Variation in Max. Temperature with input thermal radiation



Calculation of additional RF losses in cavity beam pipe.

- Rise of temperature in beam pipe results increase in BCS surface resistance.
- Surface resistance is calculated for given temperature distribution in beam pipe.
  - Assumption
    - Rs = 10 n Ω @ 2 K.

$$Rs(T) = Rs(2K) * \frac{T_2}{T} * \exp\left(\frac{\Delta}{k_B.T_c}.\left[\frac{T_c}{T_2} - \frac{T_c}{T}\right]\right) \forall \quad T < T_c$$

$$Rs = \sqrt{\frac{\mu.\pi.f}{\sigma}} \forall \quad T > T_c$$

$$P_d = \frac{1}{2}.Rs.\int H^2.ds$$

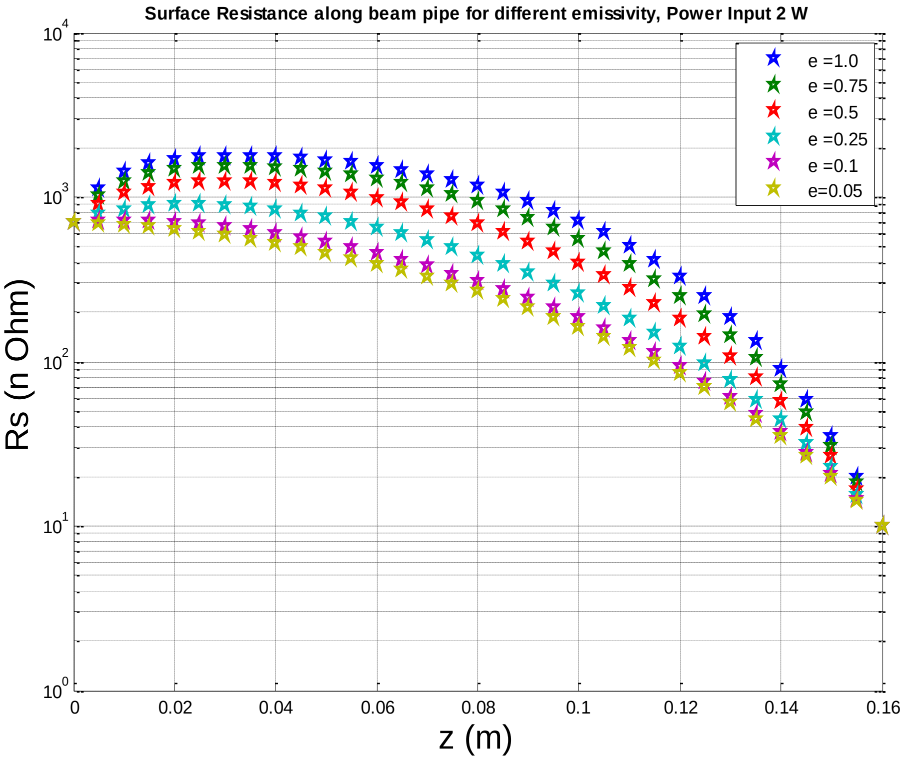
$$Q = \frac{\omega.U}{P_d}$$

- Surface magnetic fields in beam pipe is calculated using SLANS for 1 J stored energy.
- For Max. Voltage gain of 17.5 MeV in 650 MHz cavity, stored energy is ~ 122.5 J.

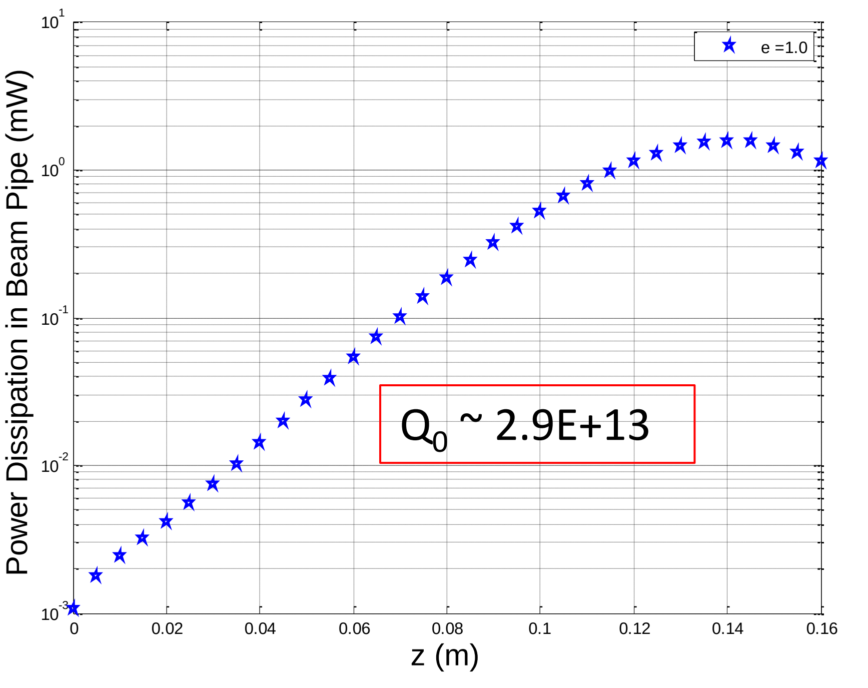
Surface resistance & RF power dissipation in beam pipe.

- *Input power is 2 W*

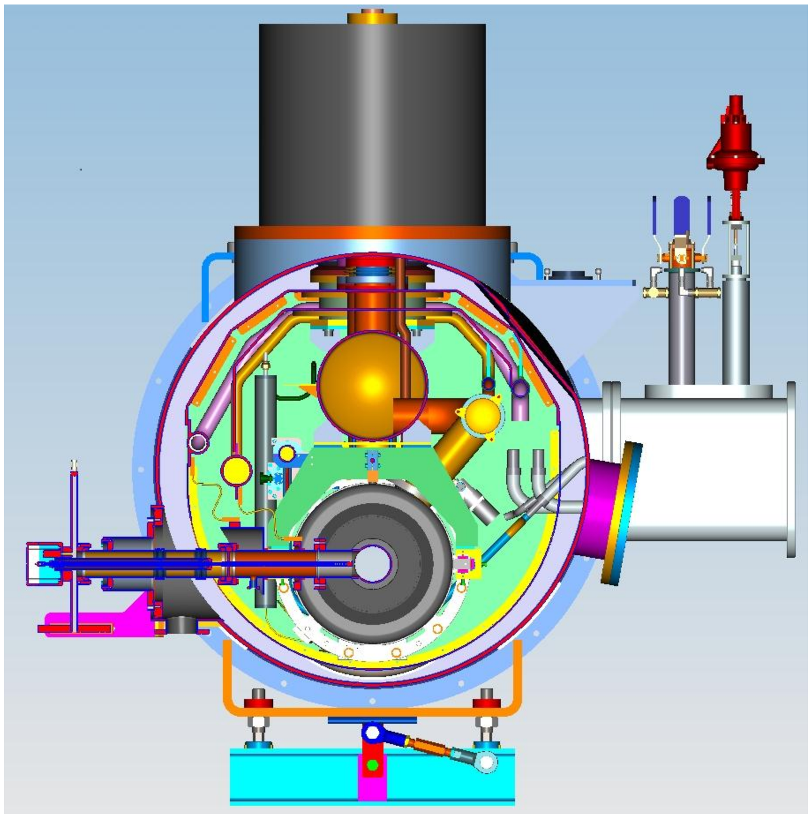
Surface Resistance along beam pipe

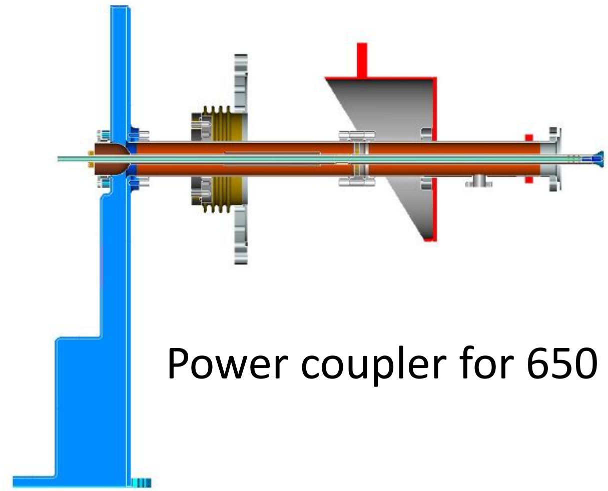


RF Power dissipation in beam pipe for operating gradient

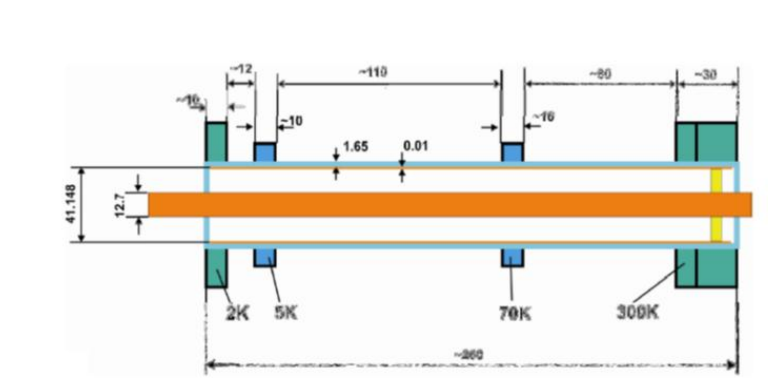


Heat load in Cavity beam pipe due to Thermal Radiation coming through Power coupler





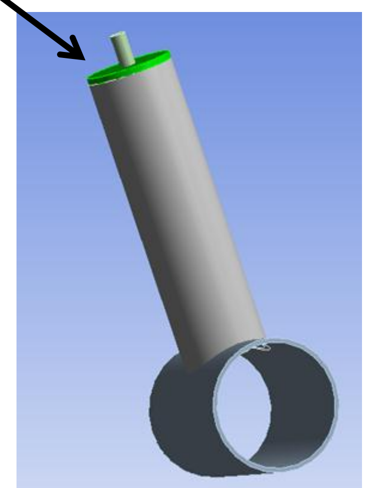
Power coupler for 650 MHz cavity



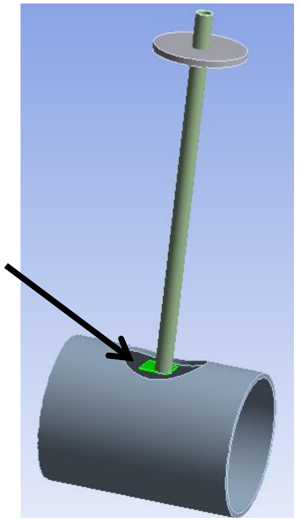
Dimensions of cold part of power coupler

Radiation Surfaces.

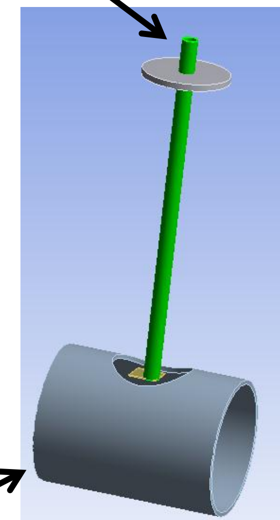
Ceramic Window @ 300 K



Antenna tip
@ 300 K



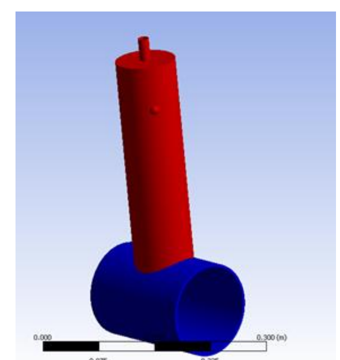
Antenna @ 300 K



Cavity Beam pipe @ 2K

- Emissivity of Ceramic Window =1.
- Emissivity of Antenna tip and Antenna = 0.1
- Emissivity of Niobium pipe = 0.05

✓ *ANSYS simulation shows power deposition in cavity beam pipe is ~ 0.15 W*



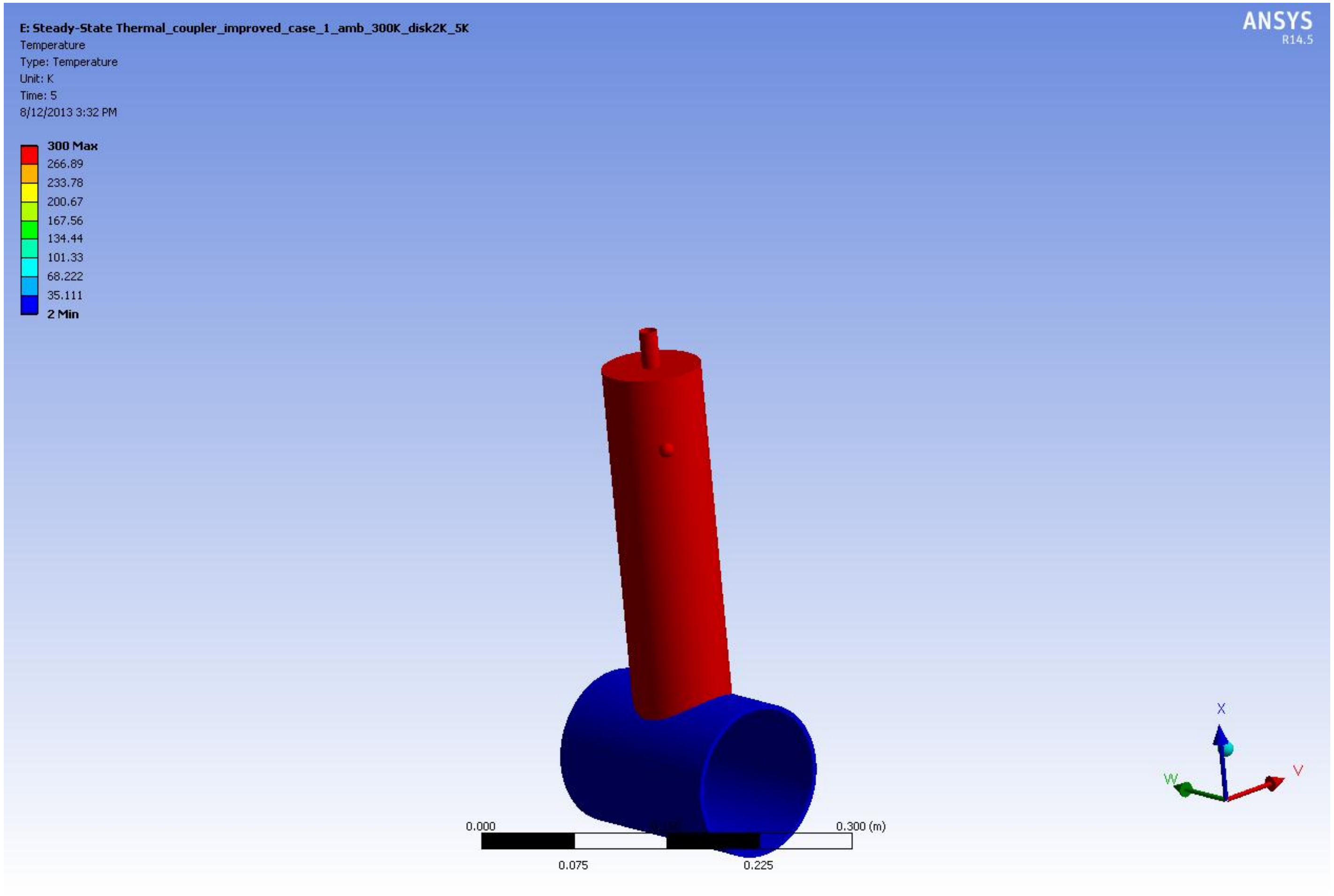
Summary

- Analysis is performed to analyze heat load in beam pipe due to cryomodule warm end and power coupler.
  - Estimation for simplified configuration shows no problem in beam pipe.
- Next Steps
  - Improving the model and perform the more precise studies.

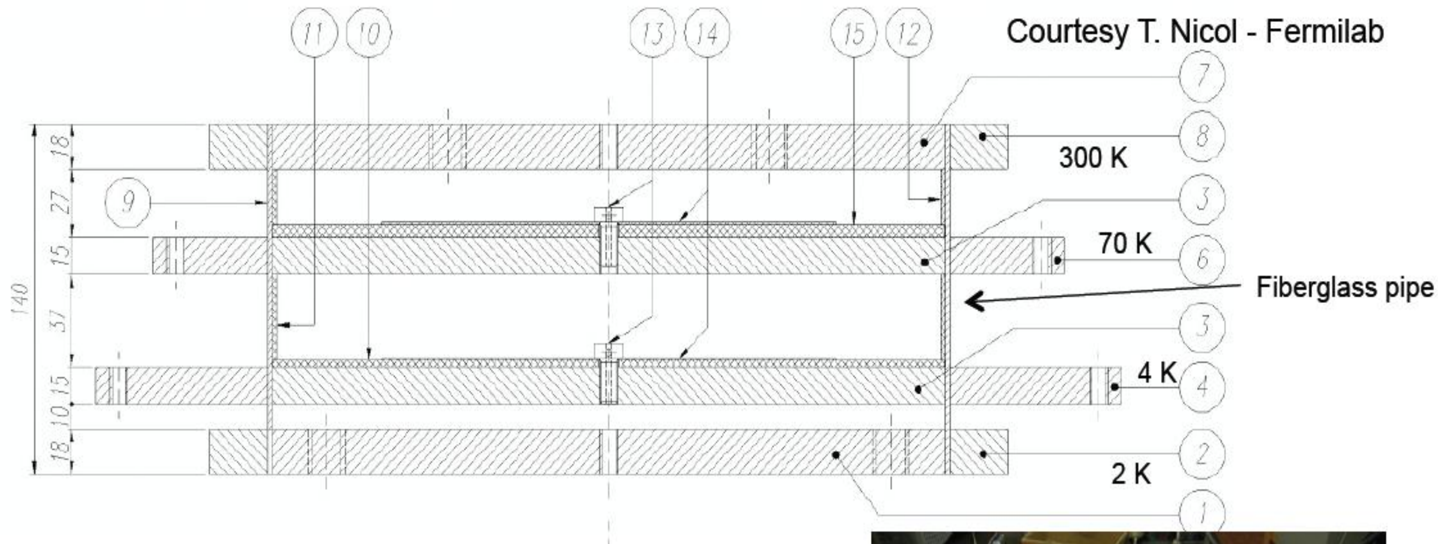
References

1. http://webserver.dmt.upm.es/~isidoro/tc3/Radiation%20View%20factors.pdf
2. http://www.dtic.mil/dtic/tr/fulltext/u2/a284447.pdf
3. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05643103

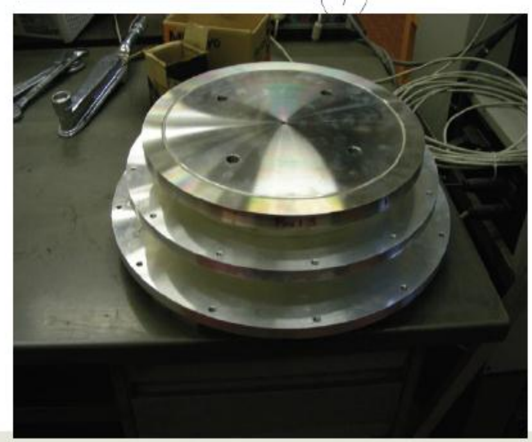
Back-up slides


E: Steady-State Thermal_coupler_improved_case_1_amb_300K_disk2K_5K
Temperature
Type: Temperature
Unit: K
Time: 5
8/12/2013 3:32 PM
300 Max
266.89
233.78
200.67
167.56
134.44
101.33
68.222
35.111
2 Min
ANSYS
R14.5
0.000
0.300 (m)
0.075
0.225
X
W
V

Design Example
ILC Cryomodule Support Post



- Total Heat Leak (conduction & radiation)
  - 70 K - 10.5 W
  - 5 K - 0.9 W
  - 2 K - 0.03 W
- Can support up to 50 kN



Thermal design: Heat load assessment

	2 K circuit	
	Static	Dynamic
RF load @ 8.5 MV/m & 5 10⁹		22.58
Tie rods connections from shield	0.12	
Phase separator support frame	0.44	
Thermal radiation[1]	0.40	
Cabling	0.10	
Coupler[2]	1.00	6.77
Total [W]	**2.07**	**29.35**

[1] Based on 0.1 W/m² from 77 K surfaces and 2 W/m² from 300 K.

[2] Static from SNS estimates (30% conduction, 70% radiation)

Dynamic based on SNS estimate, 30% of RF load

	70 K circuit	
	Static	Dynamic
Tie rods connections to shield	8.14	
G10 shield supports	52.10	
Phase separator support frame	18.33	
Thermal radiation[1]	15.08	
Coupler		
Cabling	1.00	
Total [W]	**94.65**	**0.00**

$$P_{RF} = \frac{(E_{acc} L_{act})^2}{R/Q \; Q_0}$$