325 MHz coupler designs

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Parameters of SSRx cavities:

cavity type	β_G	Freq MHz	$U_{acc,\ max}$ MeV	E_{max} MV/m	B_{max} mT	R/Q, Ω	G, Ω	$*Q_{0,2K}$ $\times 10^9$	$P_{max,2K}$ W
SSR0	β=0.114	325	0.6	32	39	108	50	6.5	0.5
SSR1	β=0.215	325	1.47	28	43	242	84	11.0	0.8
SSR2	β=0.42	325	3.34	32	60	292	109	13.0	2.9

Max. power into the beam 3.34 kW (1mA) / 13.36 kW (4mA)

Main requirements to coupler:

With over coupling and over head, coupler has to operate reliably at CW power level ~ 6kW (1mA) / 20kW (4mA)

We have two designs of 325 MHz couplers:

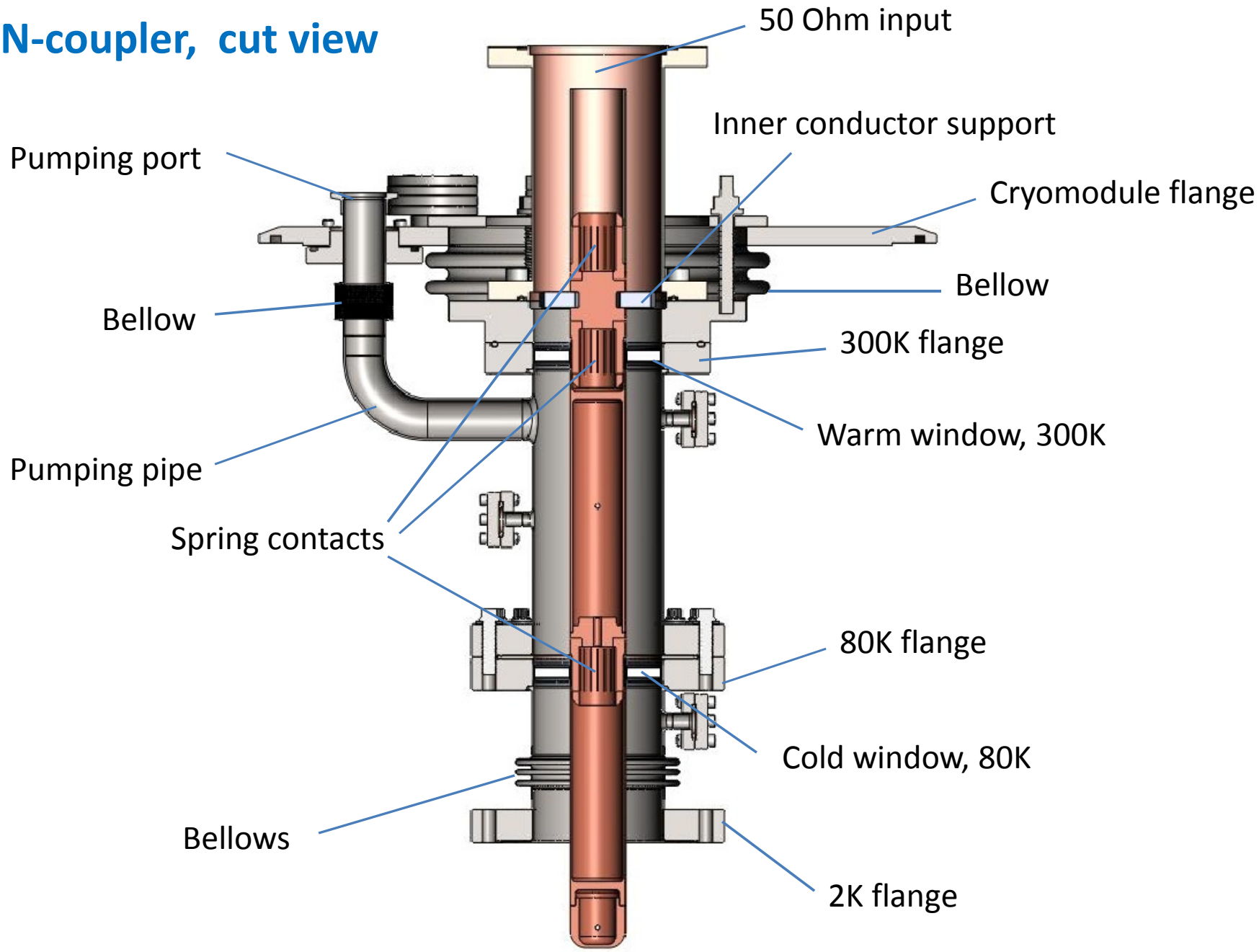
Khabiboullinne –Nicol coupler (KN-coupler).
Coupler was designed for pulse operation with SSR1 cavity.

Kazakov coupler (Ka-coupler)
New design for CW operation for Poject X.

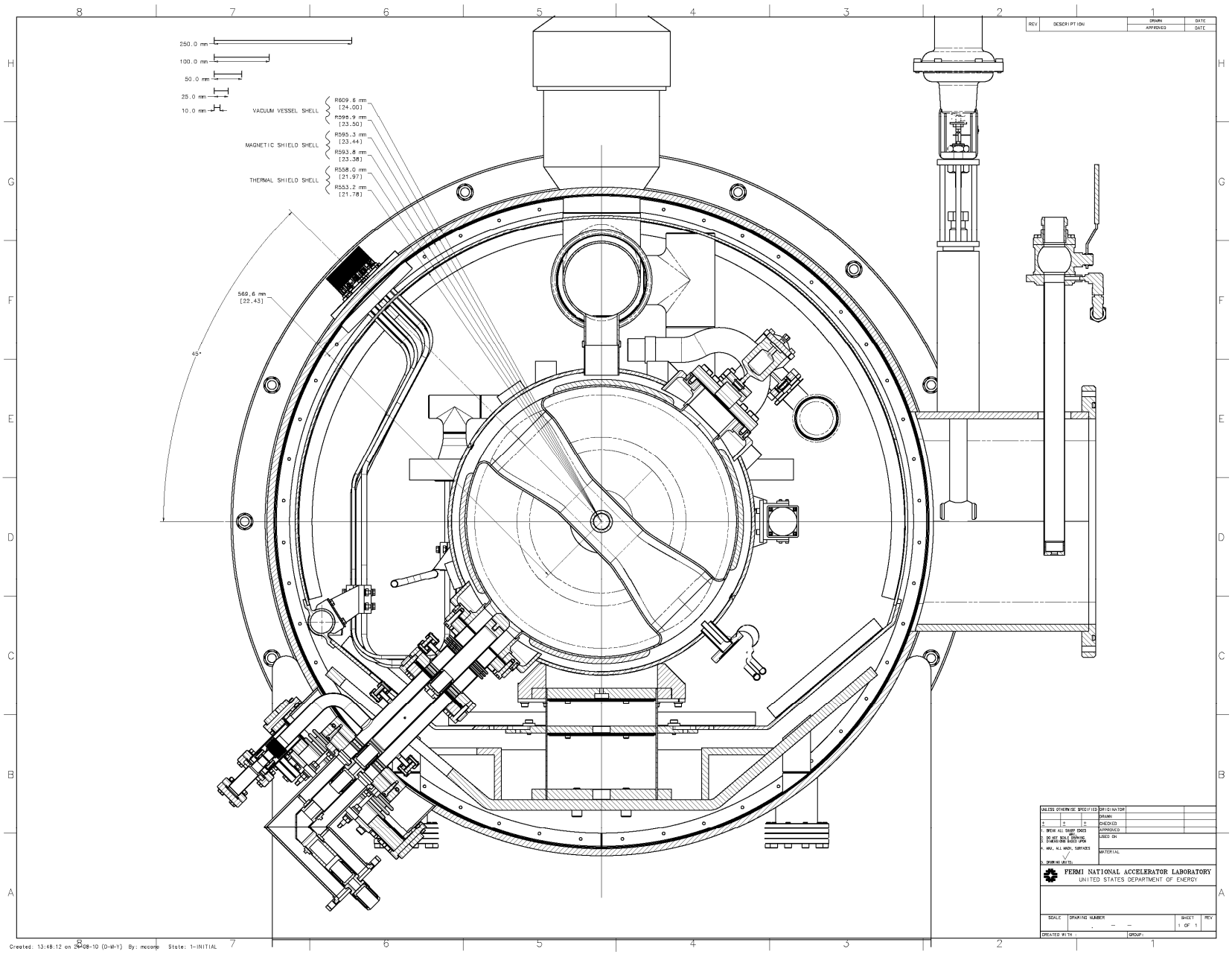
Q: What design is preferable for Project X?

KN coupler

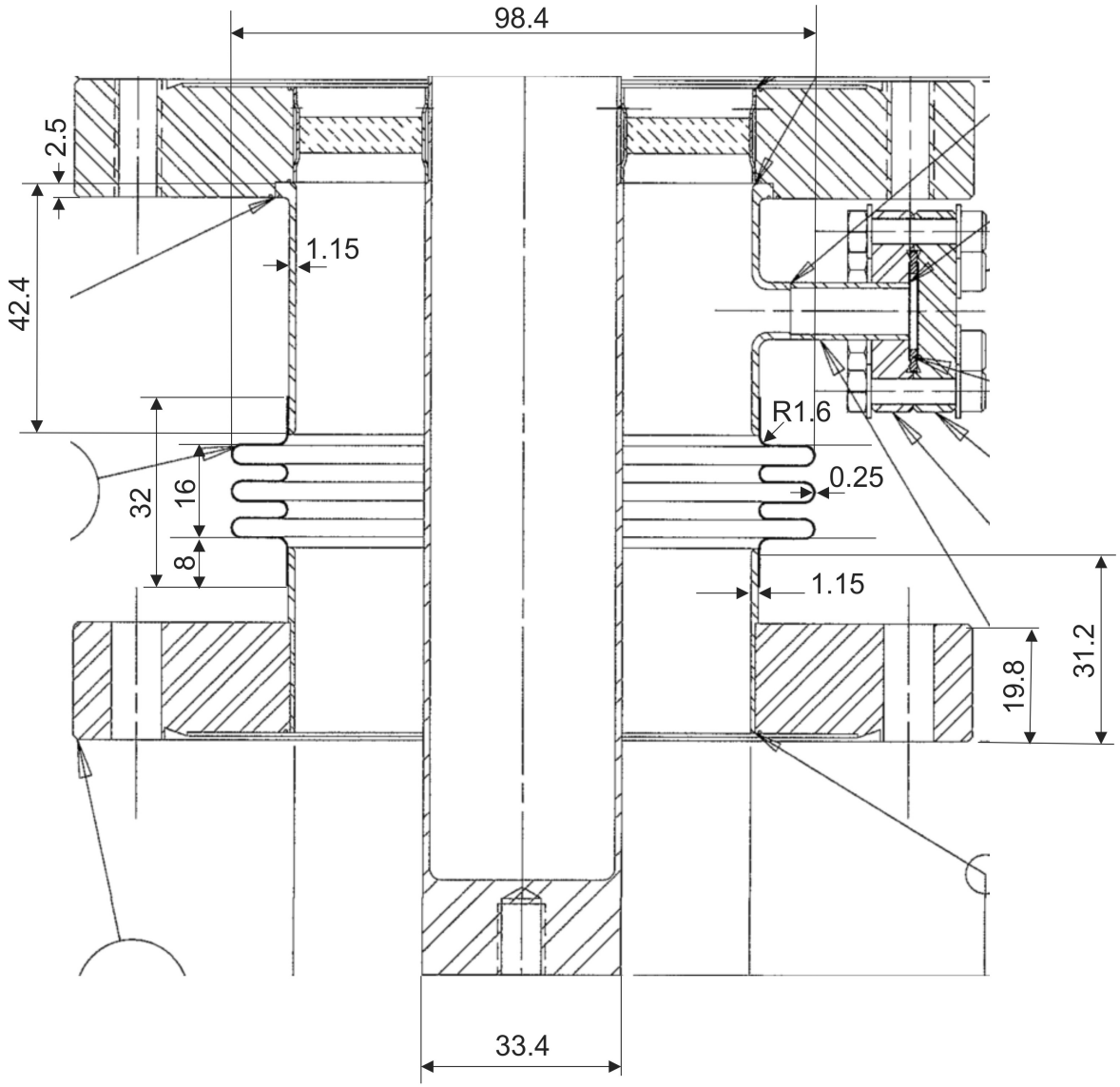
KN-coupler, cut view



KN coupler integrated with cryomodule

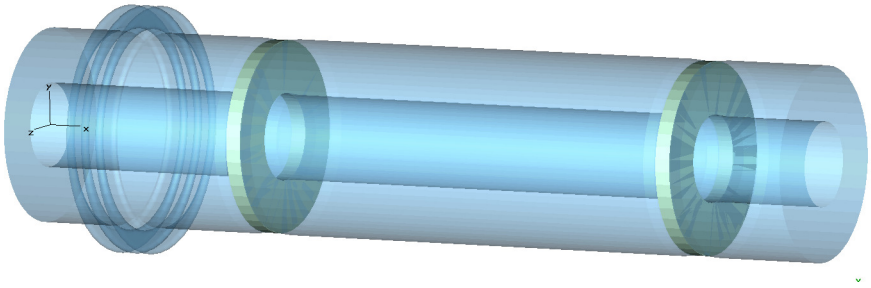


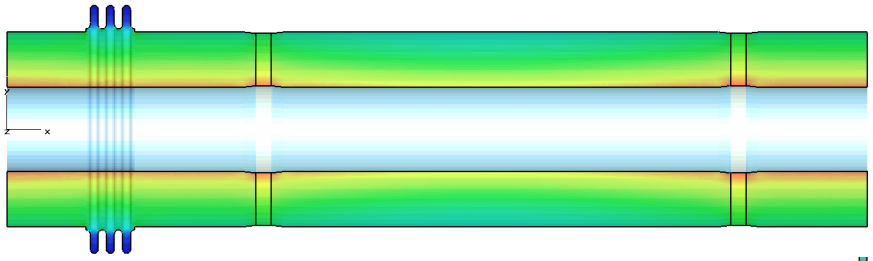
Sizes for thermal calculations:



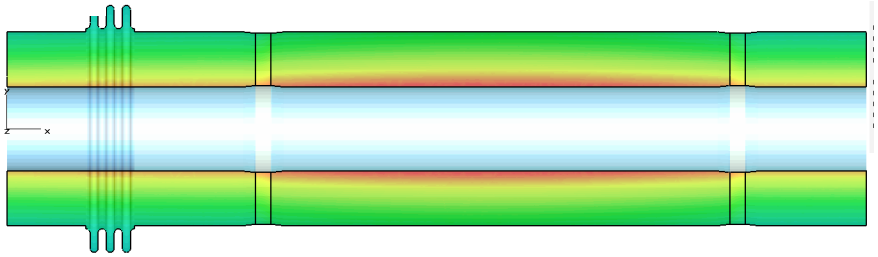
Length of bellow is 68mm

RF simulation:

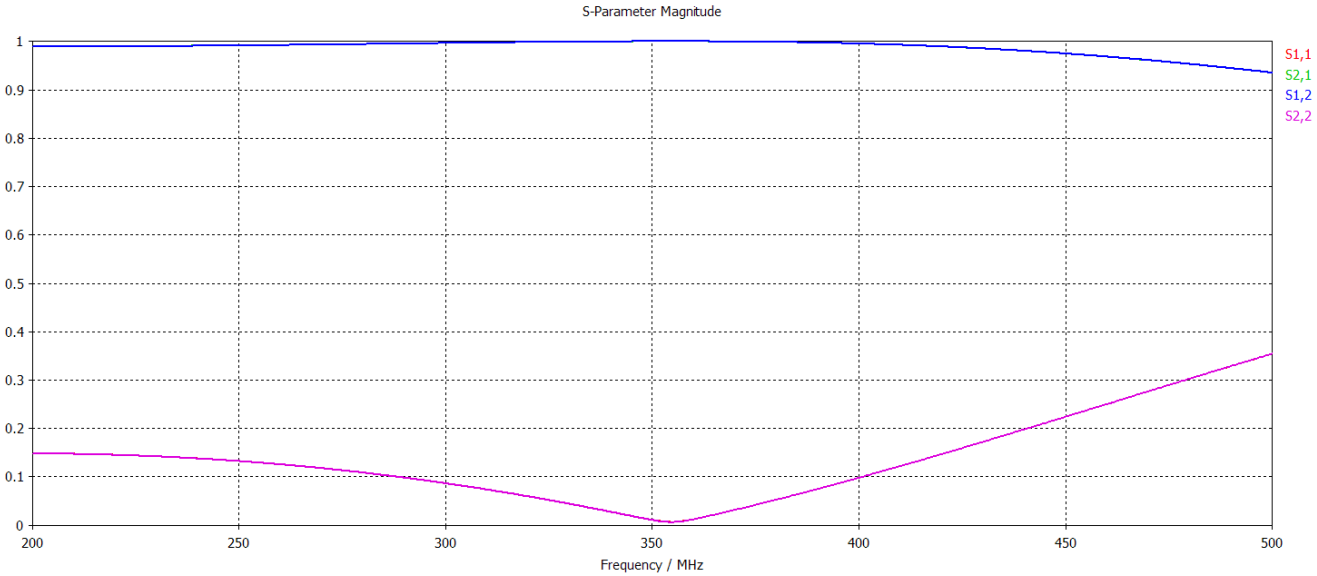




E-field

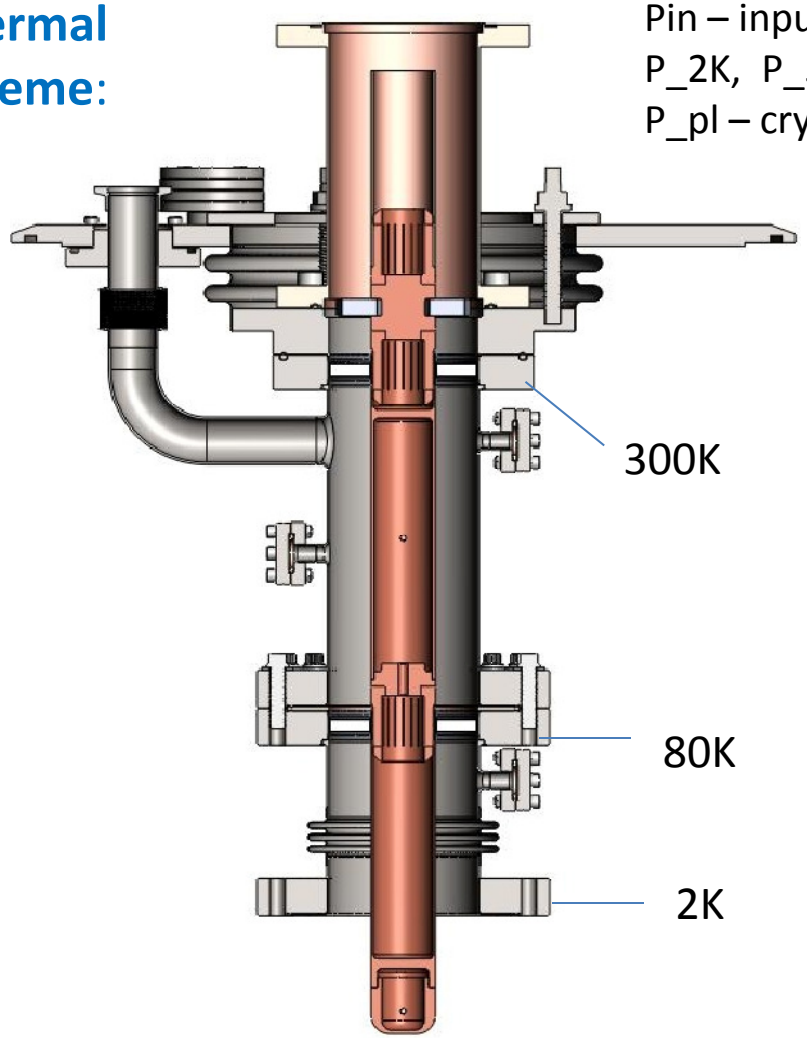


H-feld



	P_2K / P_pl, W	P_5K / P_pl, W	P_80K / P_pl, W	P_pl total, W
Pin = 0kW	0.27 / 254	-/ -	2.95/ 59	313
Pin = 6kW	1.19/ 1063	- / -	3.67/ 73	1136

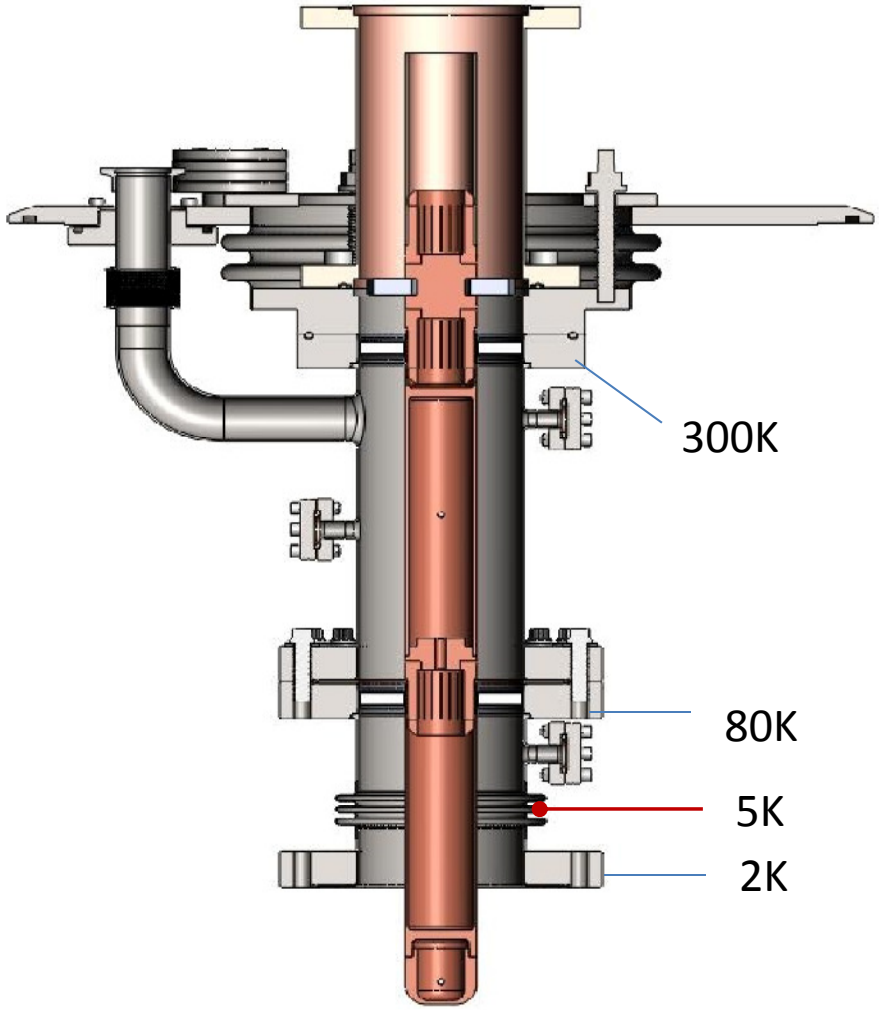
Thermal scheme:



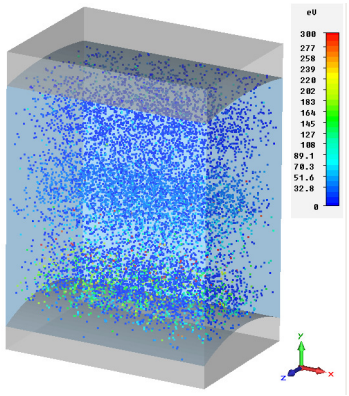
Pin – input power
P_2K, P_5K, P_80K – dissipated powers at 2K, 5K, 80K
P_pl – cryo-plant power

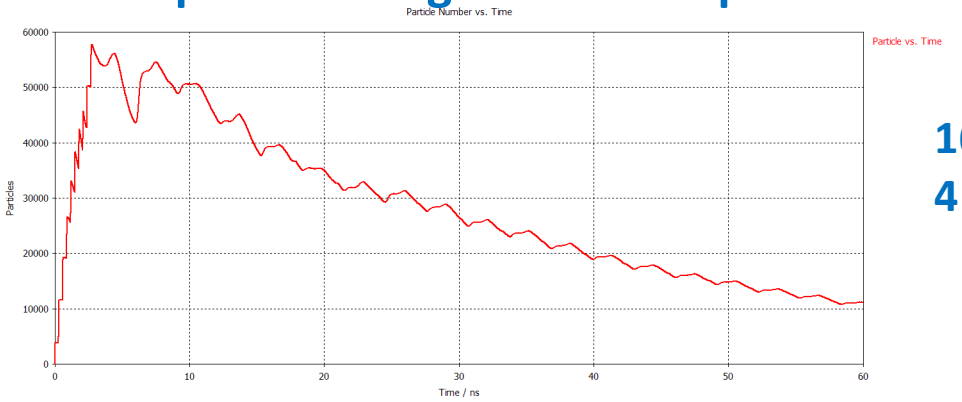
	P_2K / P_pl, W	P_5K / P_pl, W	P_80K / P_pl, W	P_pl total, W
Pin = 0kW	0.0012 / 1	0.53 / 138	2.70 / 54	193
Pin = 6kW	0.63/ 558	1.06 /275	4.41 / 88	921

Thermal scheme:

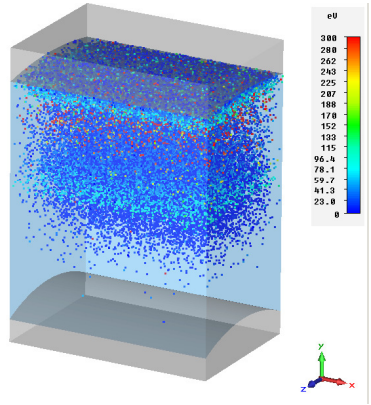


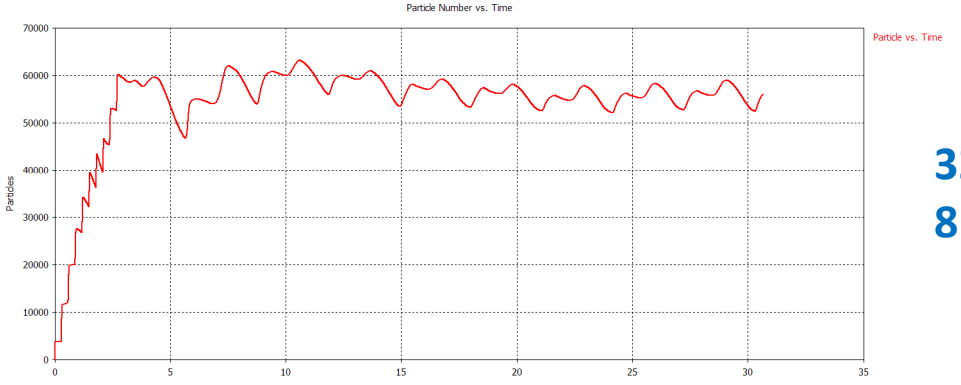
Multipactor in regular coaxial part



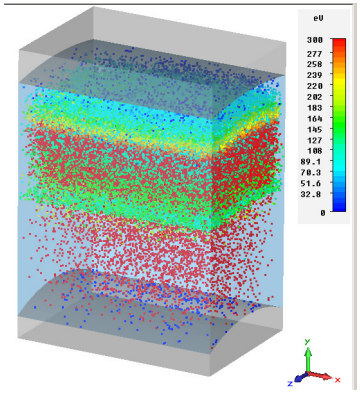


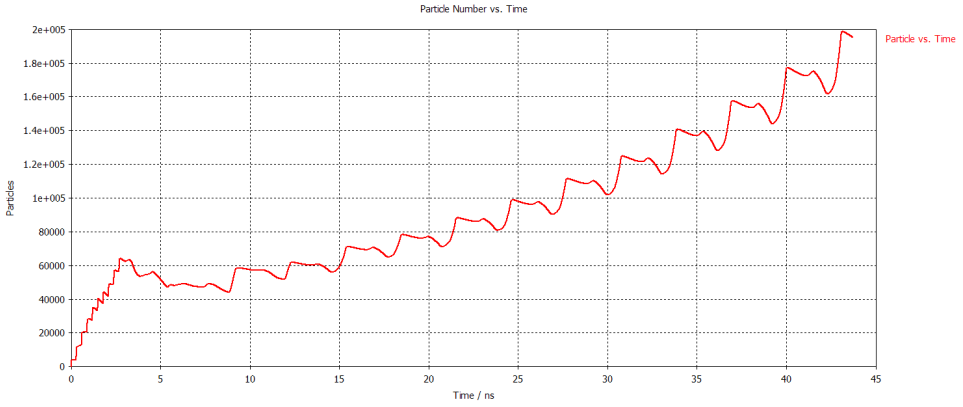
16 kW TW,
4 kW SW





32 kW TW,
8 kW SW





64 kW TW,
16 kW SW

No multipactor in bellows region

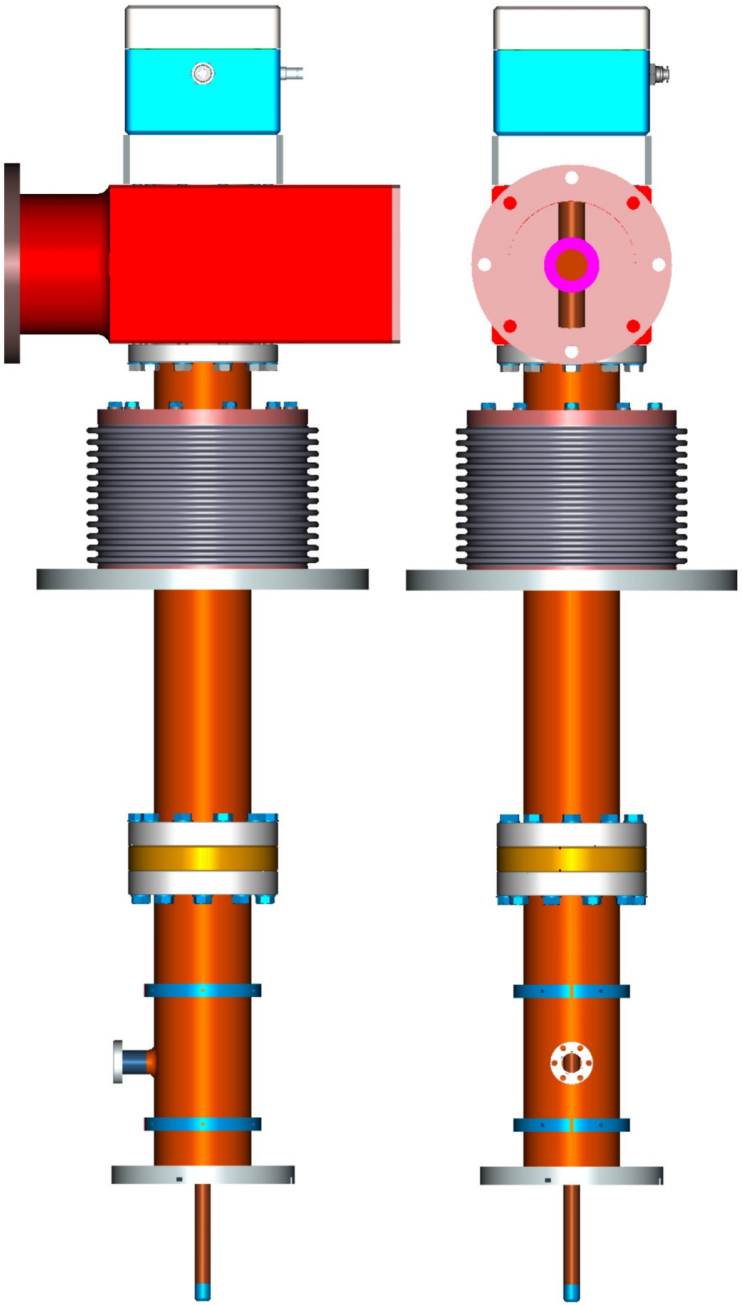
Experimental results:

Couplers was tested up to 750 kW pulse power / 4 kW av. power

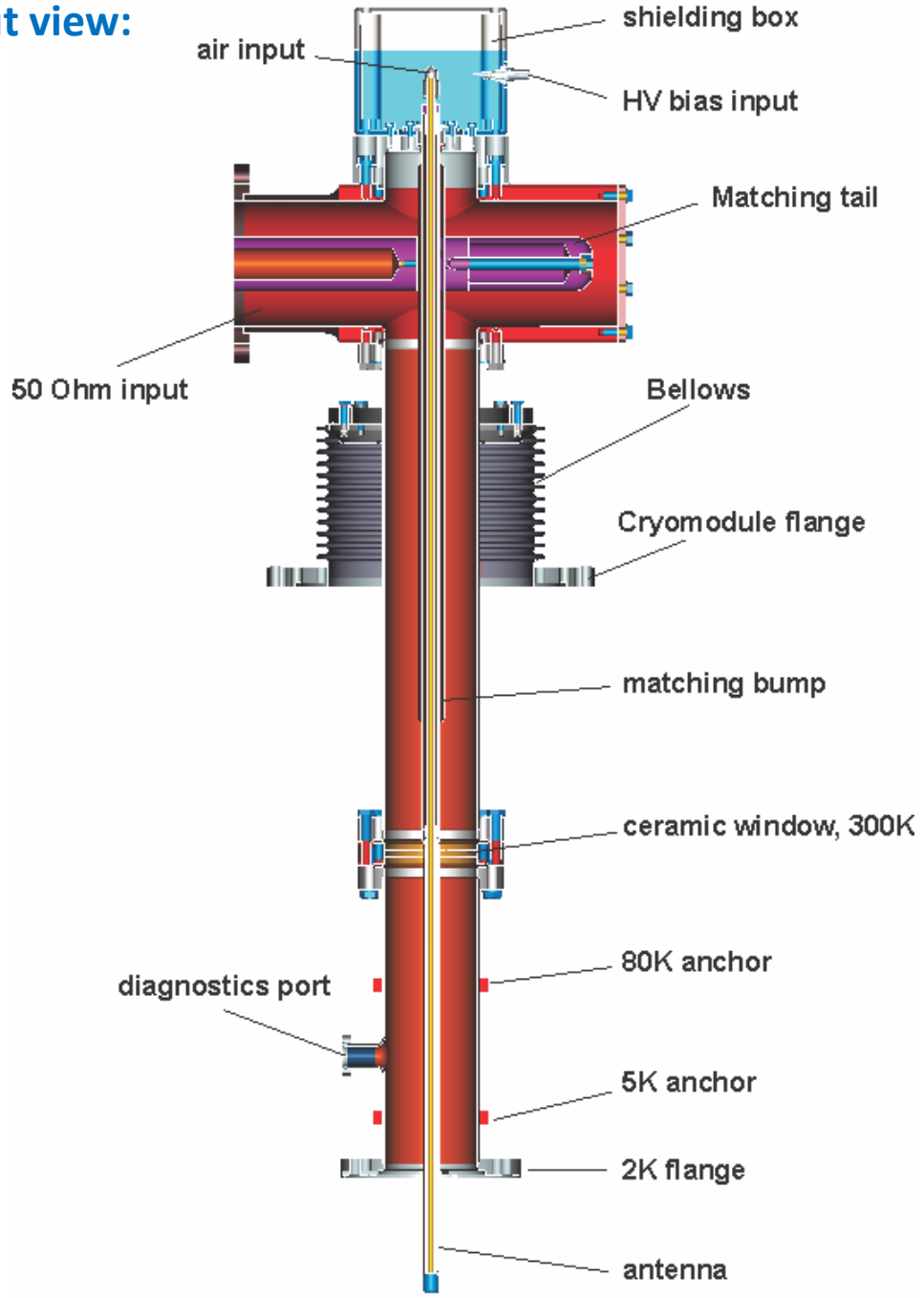
Weak MP was observed in power range 20 -70 kW

Ka coupler

General view:

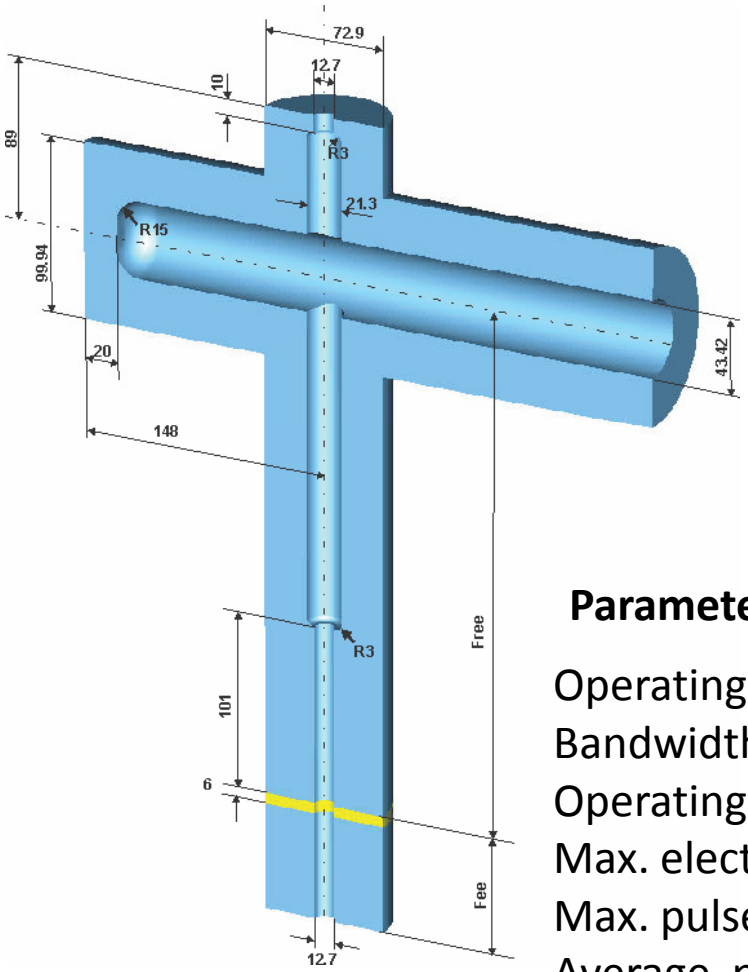


Cut view:

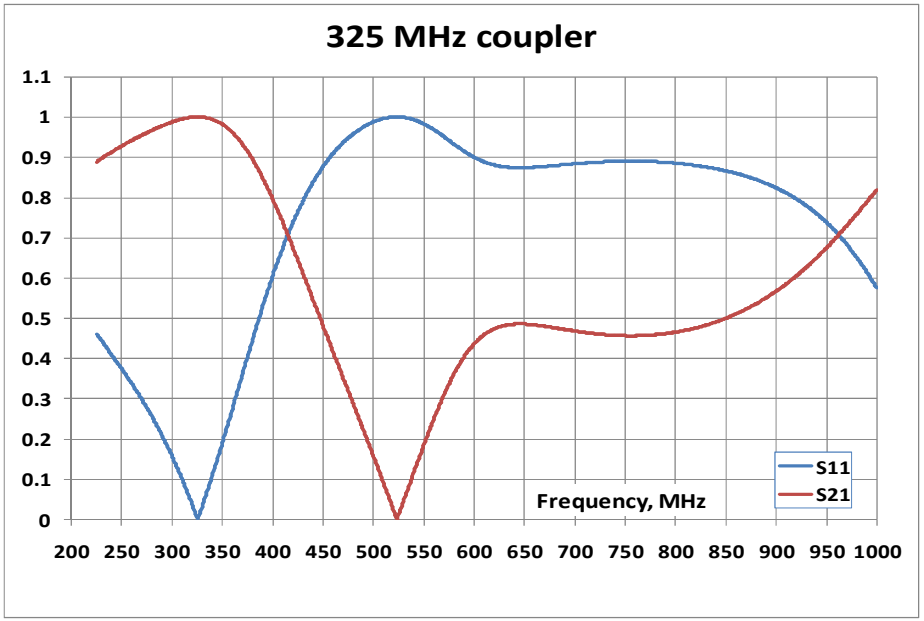


Electrical design

Dimensions:



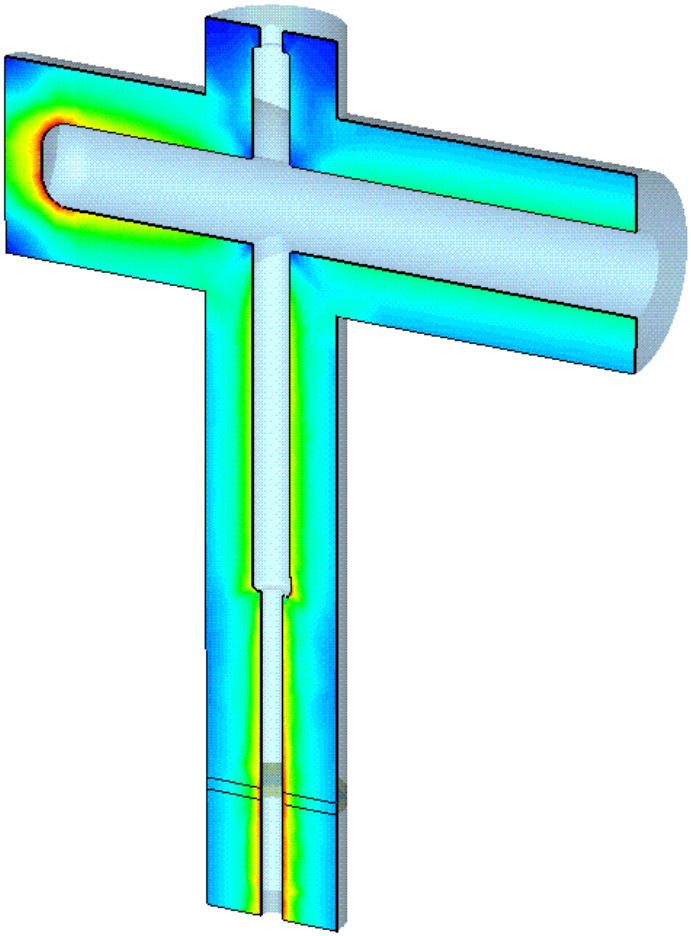
Passband:



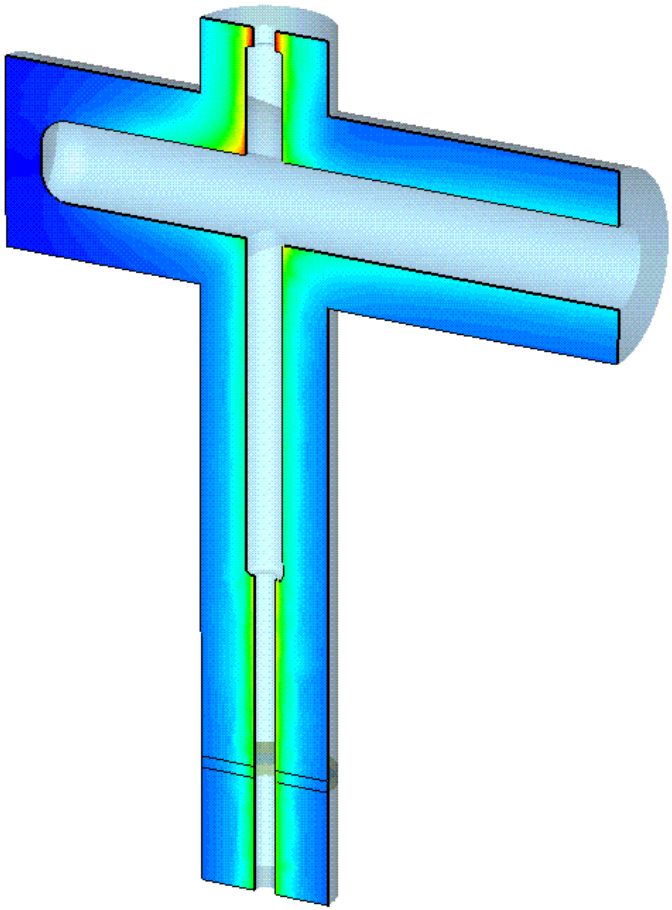
Parameters:

Operating frequency	325MHz
Bandwidth (s11 <0.1)	28 MHz
Operating CW power	6 kW
Max. electric field in air (TW)	1.32 kV/cm
Max. pulsed power (TW, 20kV/cm)	1.4 MW
Average power flow through ceramic (6kW, TW)	0.15 kW/cm2
Maximum power flow through ceramic (6kW, TW)	1.4 kW/cm2

E-field:



H-filed:

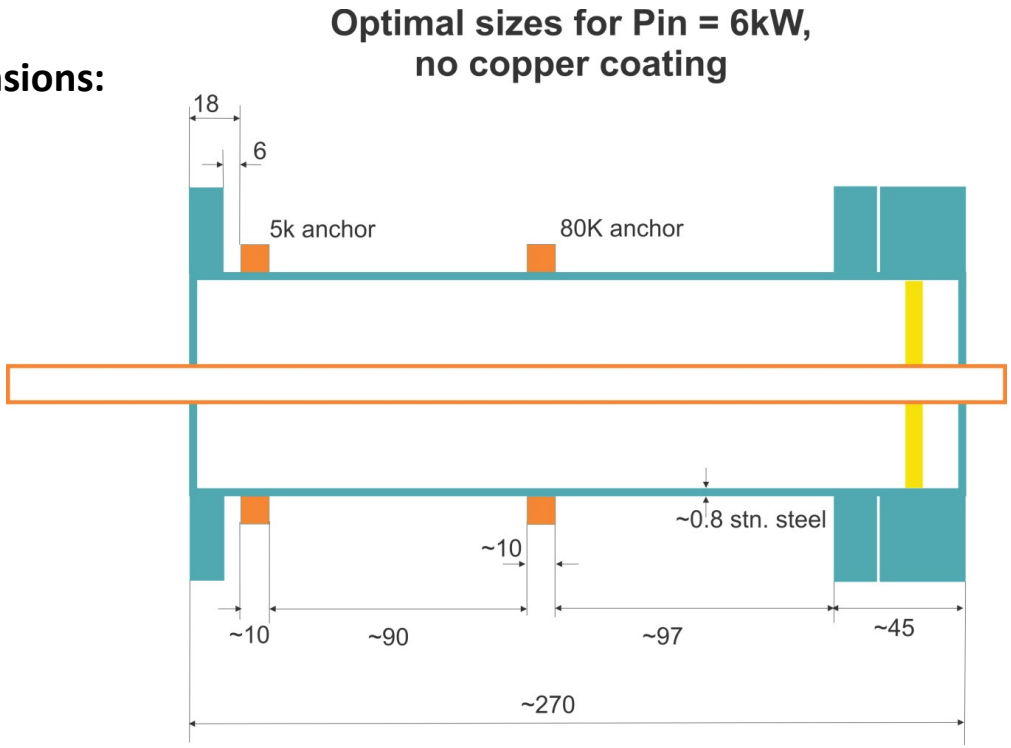


Max. electric field in air (6kW, TW) **1.32 kV/cm**

Max. pulsed power (TW, 20kV/cm) **1.4 MW**

Thermal properties

Dimensions:



	P_2K / P_pl, W	P_5K / P_pl, W	P_80K / P_pl, W	P_pl total, W
Pin = 0kW	0.02 / 17	0.69 / 179	4.29 / 86	282
Pin = 6kW	0.12/ 108	1.10 / 286	5.05 / 101	495

Pin – input power
P_2K, P_5K, P_80K – dissipated powers at 2K, 5K, 80K
P_pl – cryo-plant power

Loss in antenna:

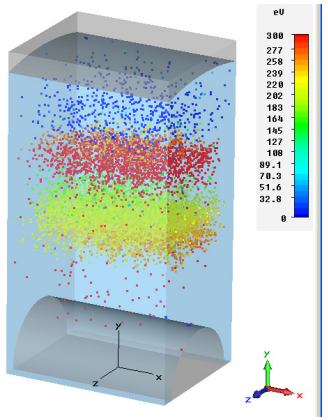
Antenna length	≈ 320mm
Antenna diameter	12.7 mm
Material	Copper
Loss (inp. 6kW, TW)	2.1W

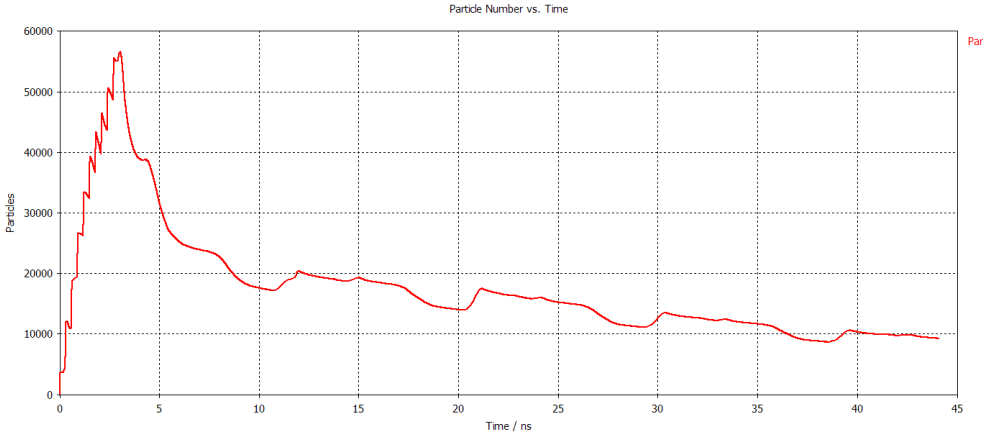
Loss in ceramic:

Ceramic outer diameter	72.9mm
Ceramic inner diameter	12.7
Ceramic thickness	6mm
Loss (TW)	0.39*δ*Pinp (δ – cer. loss tang.)

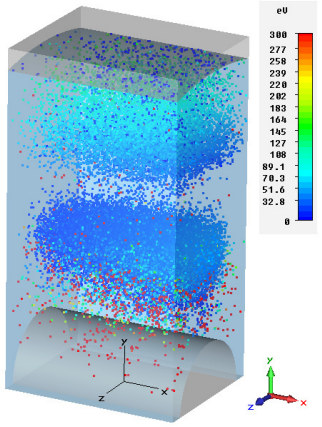
Loss (Pinp = 6kW, δ = 1E-4) 0.23W

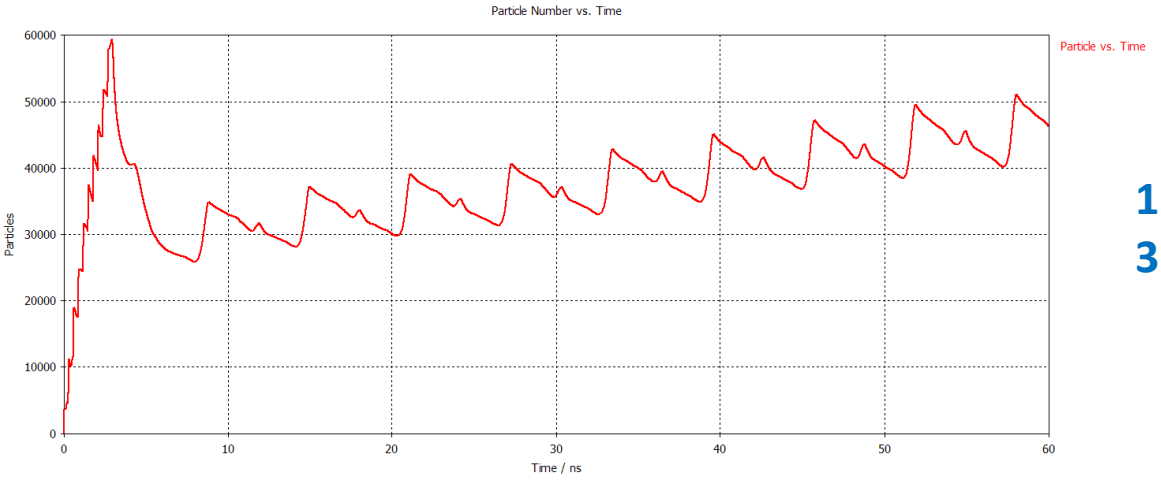
Multipactor in coaxial part of Ka-couplar





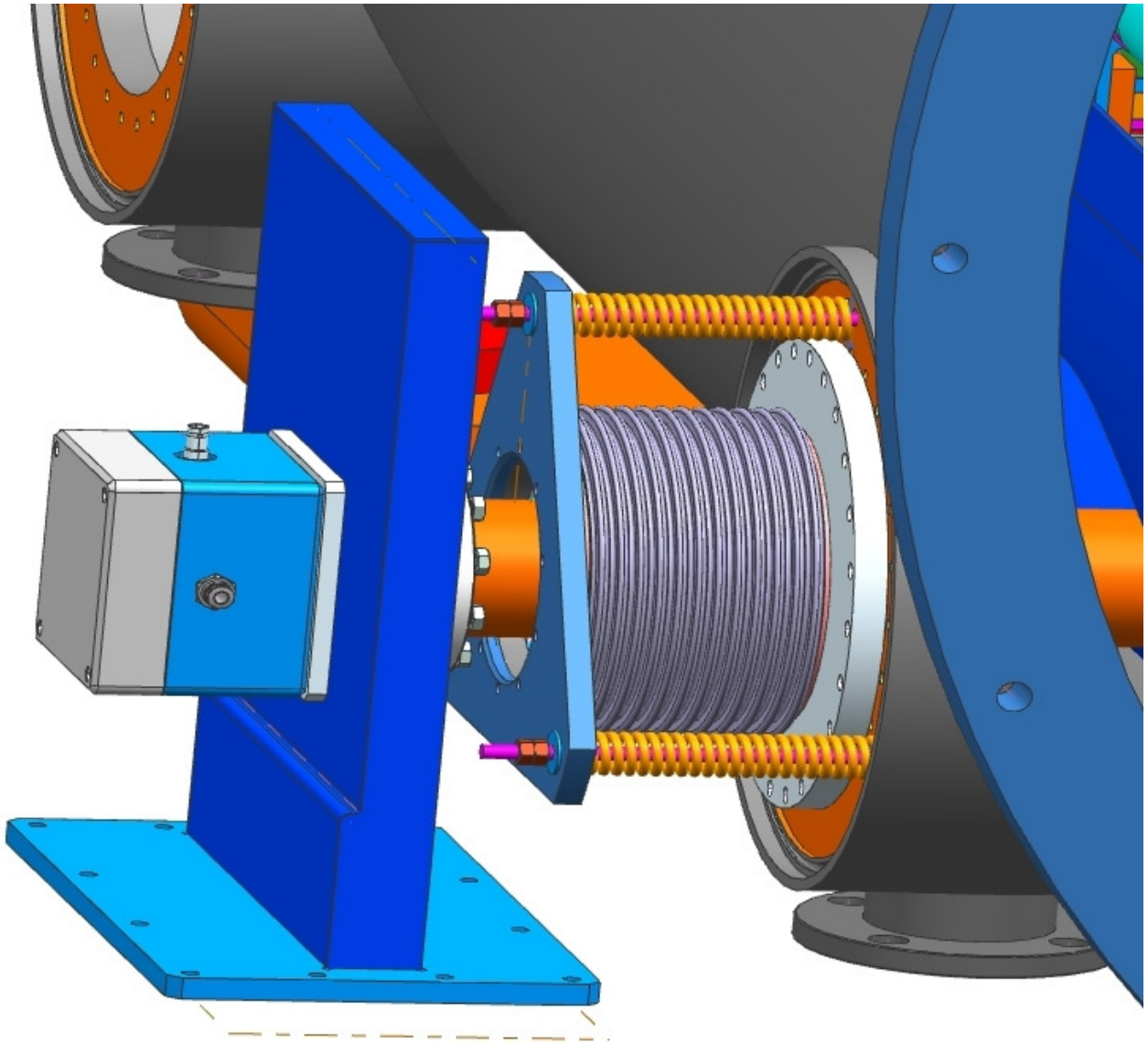
64 kW TW,
16 kW SW





128 kW TW,
32 kW SW

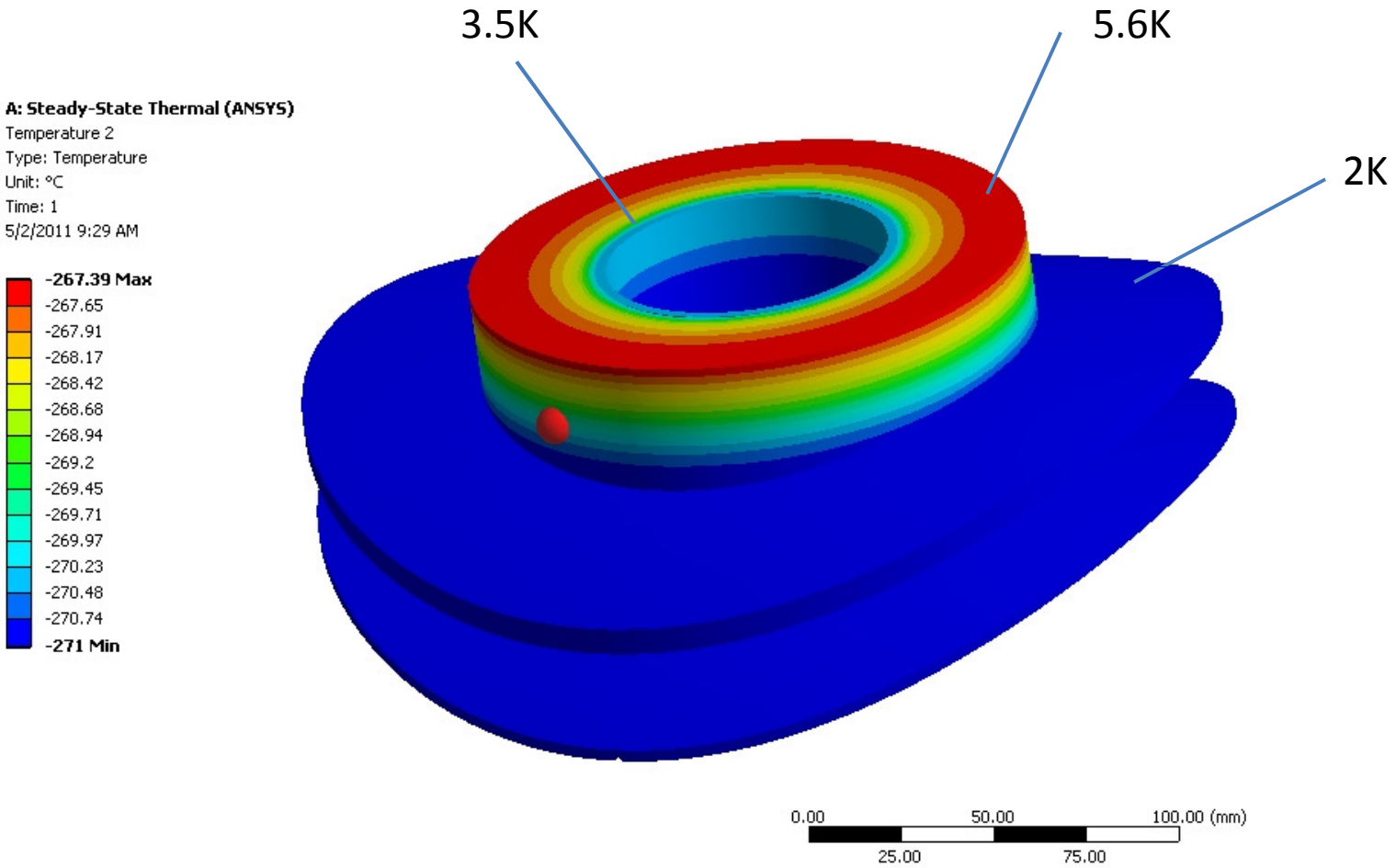
The way to compensate atmospheric pressure (example of 650 MHz coupler)



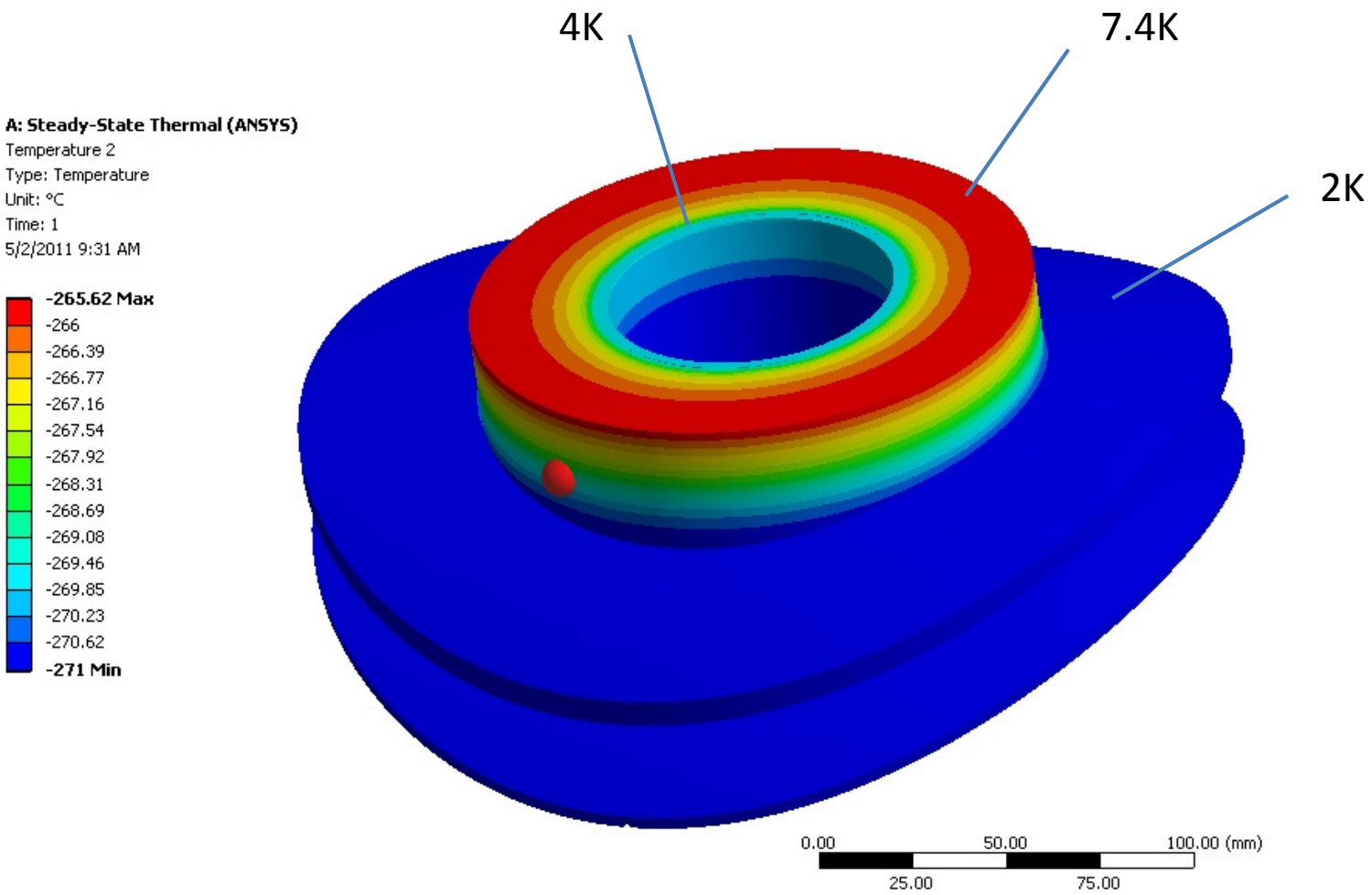
What heat flow through coupler flange SSRx cavity can sustain?

Simulated by Serena Barbanotti.

0.5W heat flow:



1W heat flow:


4K
7.4K
2K
A: Steady-State Thermal (ANSYS)
Temperature 2
Type: Temperature
Unit: °C
Time: 1
5/2/2011 9:31 AM
-265.62 Max
-266
-266.39
-266.77
-267.16
-267.54
-267.92
-268.31
-268.69
-269.08
-269.46
-269.85
-270.23
-270.62
-271 Min
0.00
50.00
100.00 (mm)
25.00
75.00

Pro and con

KN, pro:

1) Most significant advantages: it was built and tested already up to 750kW input power.
2) Coupler has two windows. It makes operation more reliable.

KN, con

1) Complicated structure. It is more expensive in production
2) Two windows requires additional pumping.
3) To apply HV bias an additional equipment has to be designed
4) Multipactor level is 32kW for TW or 8kW for SW. It is higher than operation level, but close enough. It can be problem for 4mA upgrade version of accelerator.
5)Spring type of contacts between inner conductors cause concern. Inperfect contact may cause additional heating.

6) Main concern is high power dissipation around 2K. Coupler 'as is it' (without 5K thermo-anchor) dissipates about 1.2 W for 6kW input power. SSRx flange allows this level of power flow, but it is 40% of cavity losses at 2K. Problem could be more serious in case of 4 mA upgrading.
Timergaly suggested to put 5K thermo-anchor at the middle of bellows. It improves situation, but power dissipation is still not too small - 0.63W. It requires modification: brazing thermo-anchor ring to bellows.

Ka, pro

1) Simple structure, chipper in production
2) Designed for HV bias
3) Multipactor threshold is higher ~ 120kW, TW
4) Dissipated power around 2K is smaller, 0.12W for 6kW input power. Can be used for upgraded version.

Ka, con

1) Single window, less reliable.

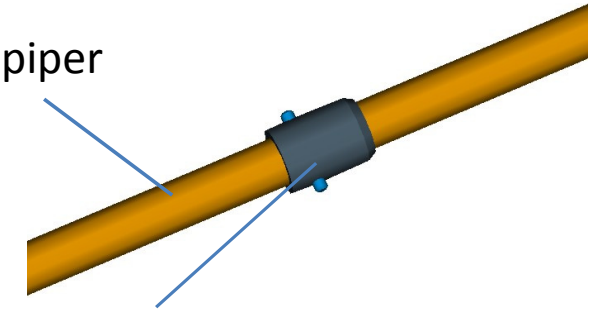
My opinion:

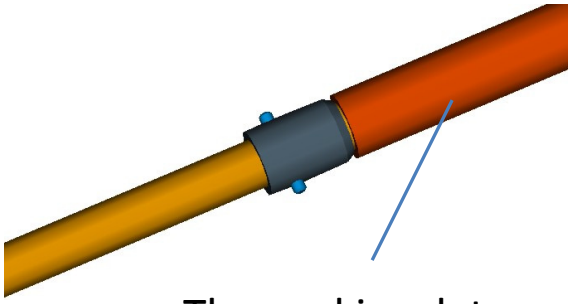
Let's make and test prototypes of Ka-coupler.
In case of success we will have coupler with better thermal parameters, which can be used for upgrade version of accelerator.
In the case of failure we have a fallback – KN coupler.

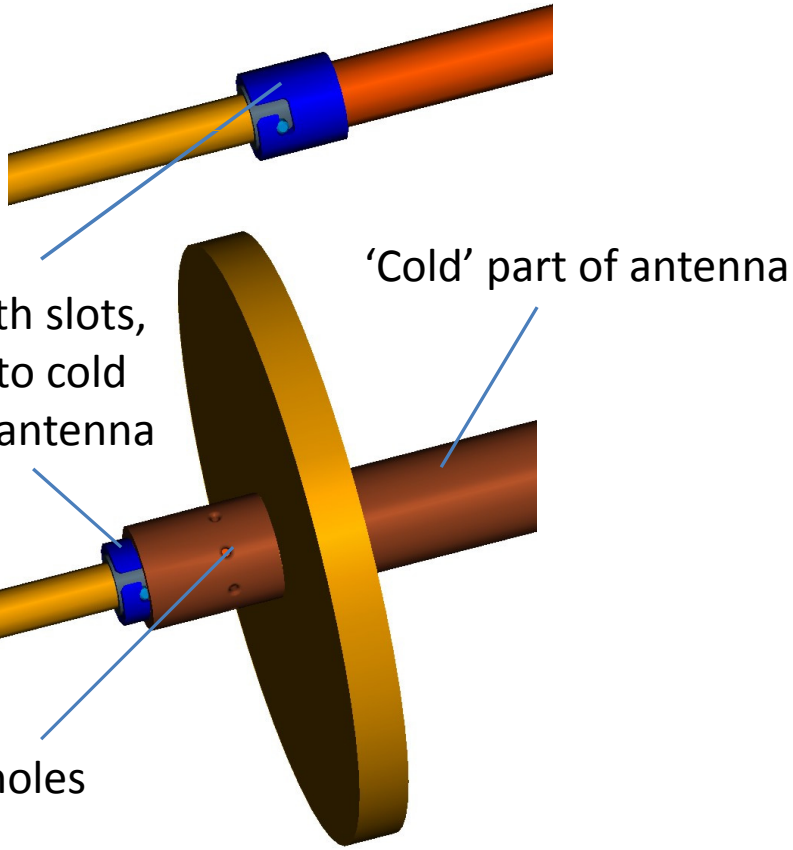
Ka-coupler has similar parts and technology with 650MHz coupler.
Making 650MHz coupler, we make a half of 325MHz coupler.
It should reduce price of Ka-coupler.
(We have to make 650 MHz coupler , we have no alternative)

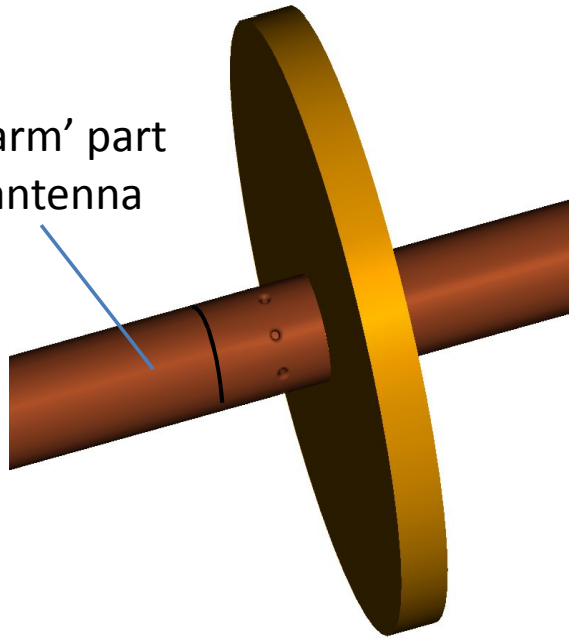
Backup

‘Cold’ part – ‘warm’ part antenna contact

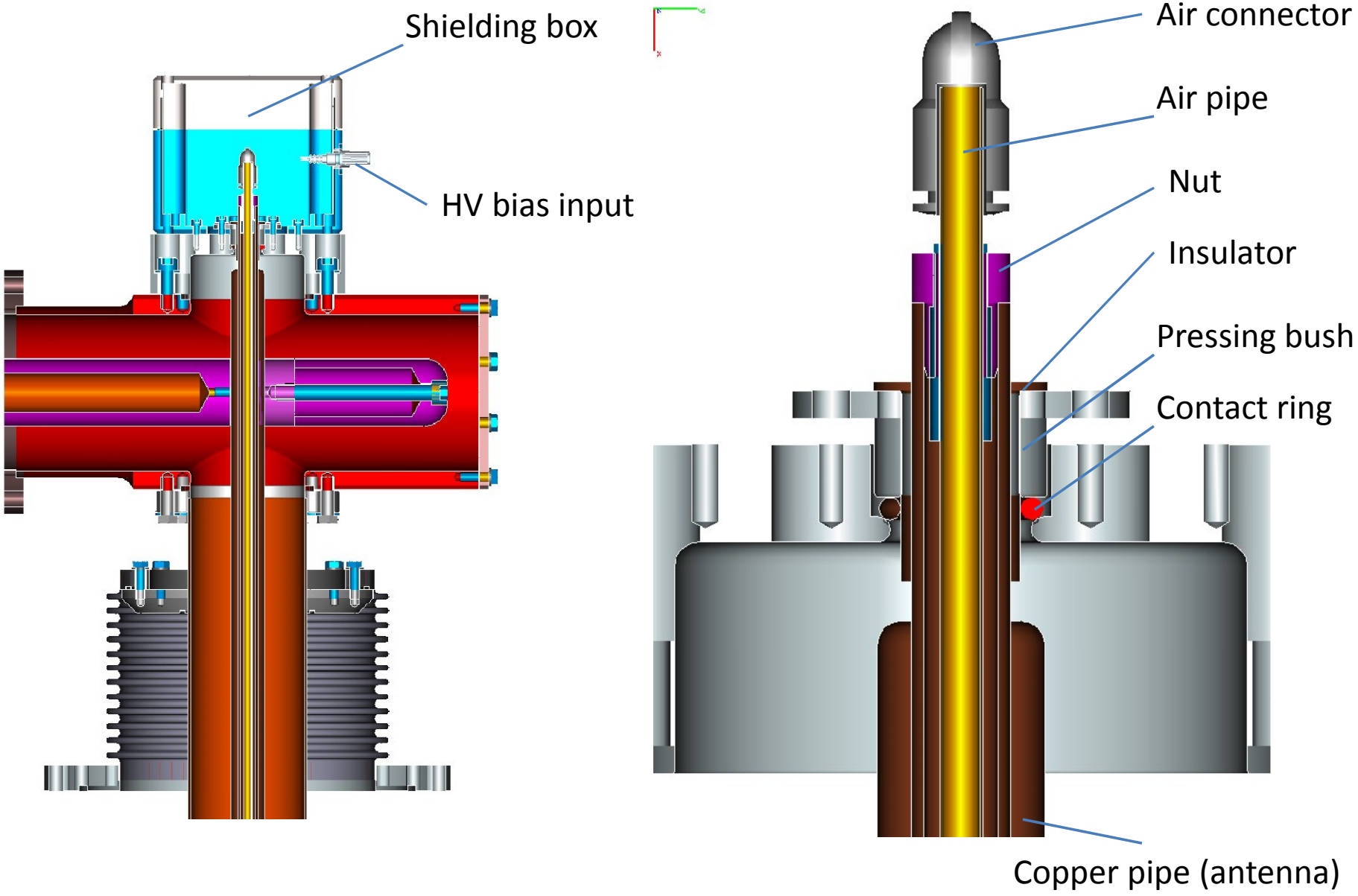




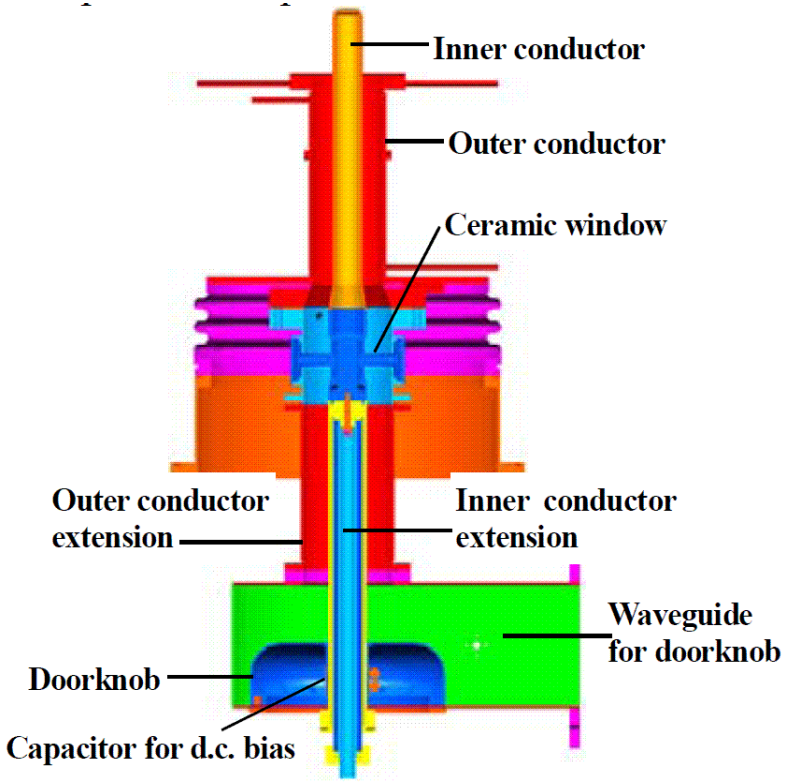




Connection of inner conductor with outer box



SNS - example of successful usage of single window couplers in superconductive linac:



SNS coupler (805MHz):

Single planar window

Tested (TW) 750kW x 1.3ms x 60pps (58.5kW average)

2MW x 0.65ms x 60pps (78kW average)

Tested (SW) 600kW x 1.3ms x 60pps (46.8kW average)

Average power density through ceramic ≈ 0.9 kW/cm2

Most powerful examples: of CW couplers/windows:

APT coupler (700MHz):
Single planar window with intercooling (cooling air two ceramic windows)
Tested power 1 MW (TW), 850 KW (SW)
Average power density through ceramic ≈ 2.3 kW/cm2

Super-KEKB ARES:
Single planar window
Tested 950 kW CW (supposed operating power 800 kW)
Average power density through ceramic ≈ 4.4 (3.7) kW/cm2

Toshiba 1MW CW 508 MHz klystron:
Single coaxial planar window
Tested power 1.2 MW CW
Average power density through ceramic ≈ 5.6 kW/cm2