RF couplers for PIP-II

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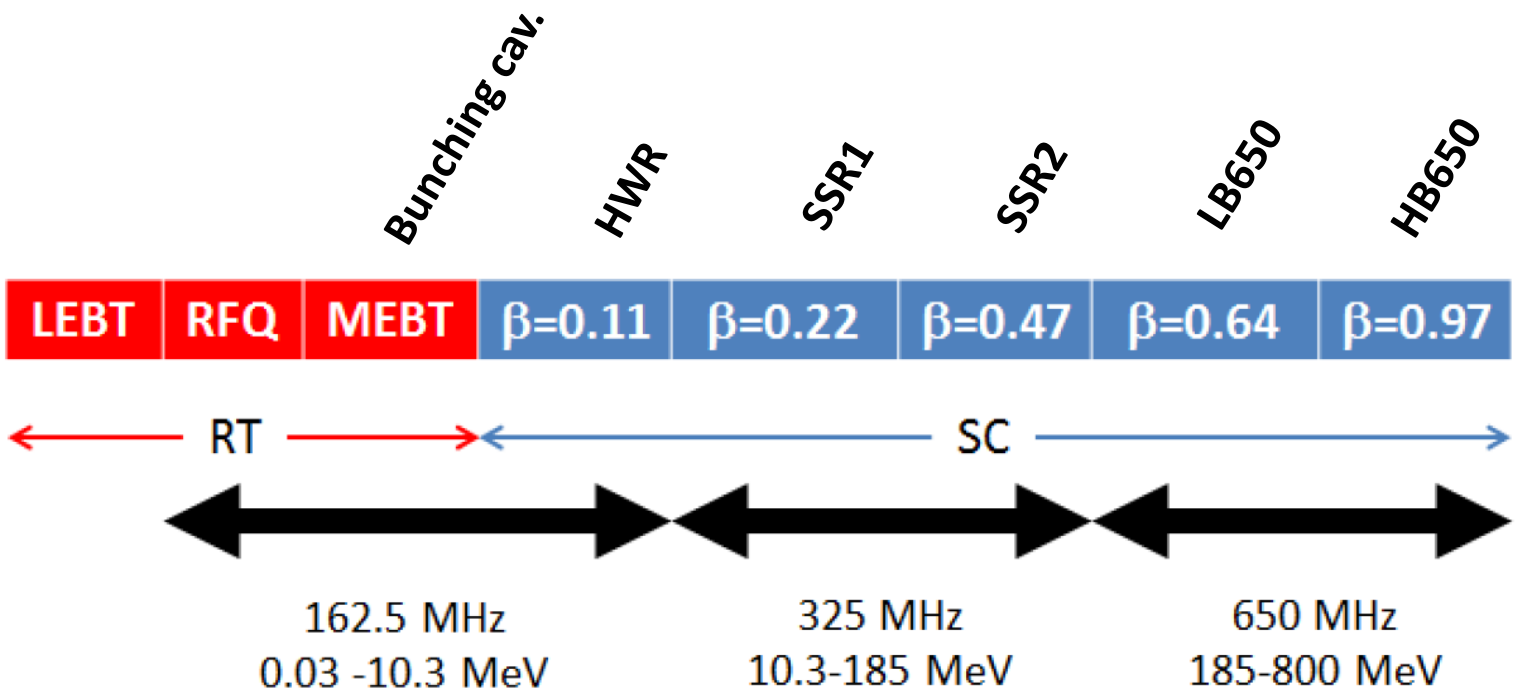
PIP-II linac technology map



Performance parameter	
Linac beam Energy	800 MeV
Linac Beam Current	2 mA
Linac Pulse Length	0.55 ms
Linac Pulse Repetition Rate	20 Hz
Linac Upgrade Potectial	CW

PIP-II linac includes:

Room temperature cavities:

- RFQ room temperature cavity.
- Bunching cavity x 4.

5 types of SC cavities:

- HWR x 8,
- SSR1 x 16,
- SSR2 x 35,
- LB 650 x 33,
- HB 650 x 24 elliptical cavities.

Each cavity requires a coupler.

Total number of couplers: 122 (RFQ uses 2 couplers).

Operating parameters of cavities determine the requirements to couplers:

(Requirements meets parameters of upgrade version of PIP-II with 5 mA current.)

RFQ coupler:

Frequency	162.5 MHz
Power	75 kW, CW

Buncher coupler:

Frequency	162.5 MHz
Power	3 kW, CW

HWR coupler:

Frequency	162.5 MHz
Power	10 kW, CW

SSR1 & SSR2 coupler:

Frequency	325 MHz
Power	30 kW, CW

LB & HB 650 coupler:

Frequency	650 MHz
Power	110 kW, CW

All couplers were designed and some prototypes were built and tested.

Principles of design:

- **Simplicity of vacuum part of coupler:**
  no moving parts, no bellows.
  simple configuration – more reliable, easy to clean, less expansive.
- **Air cooling of antennas (no water) – Not so severe consequences in case of leak.**
- **Ability to apply high voltage bias to suppress a multipactor.**
- **Avoid a copper coating of stainless steel.**

Based on this principles the RFQ, SSR1 & SSR2, LB & HB 650 couplers were design.

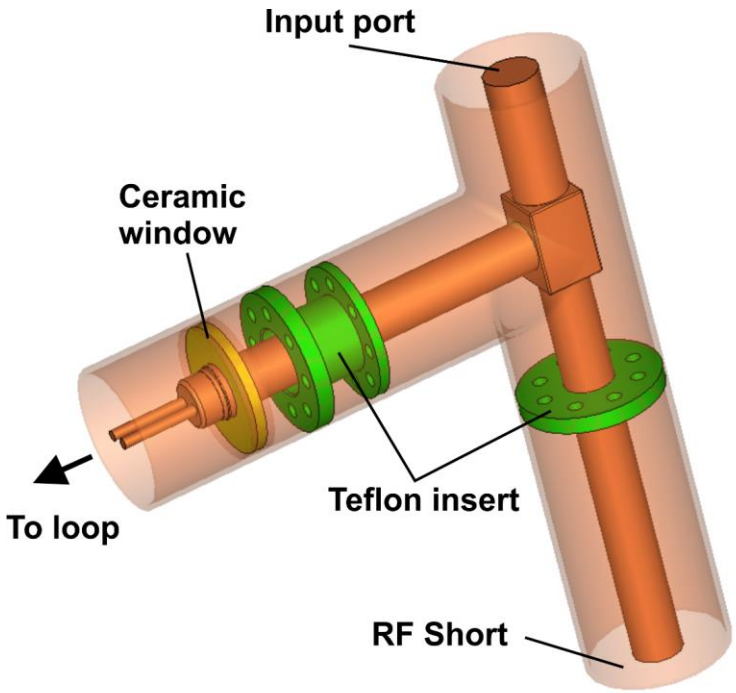
RFQ and SSR1 & SSR2 couplers were built and tested.

RFQ coupler:

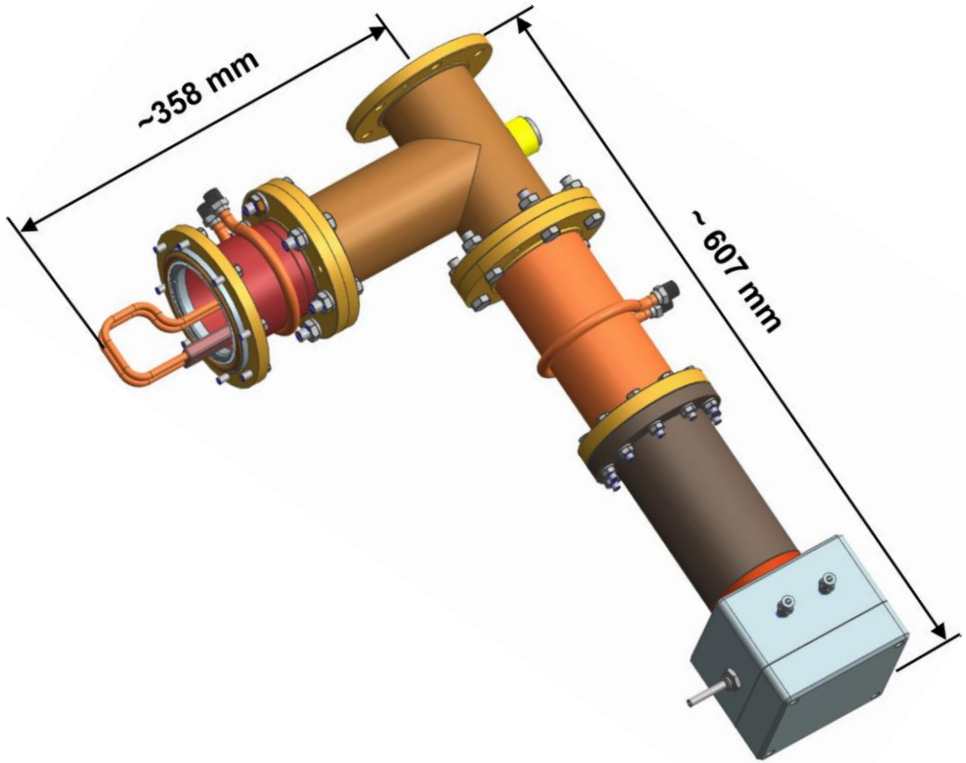
Frequency 162.5 MHz

Power 75 kW, CW

Electrical configuration

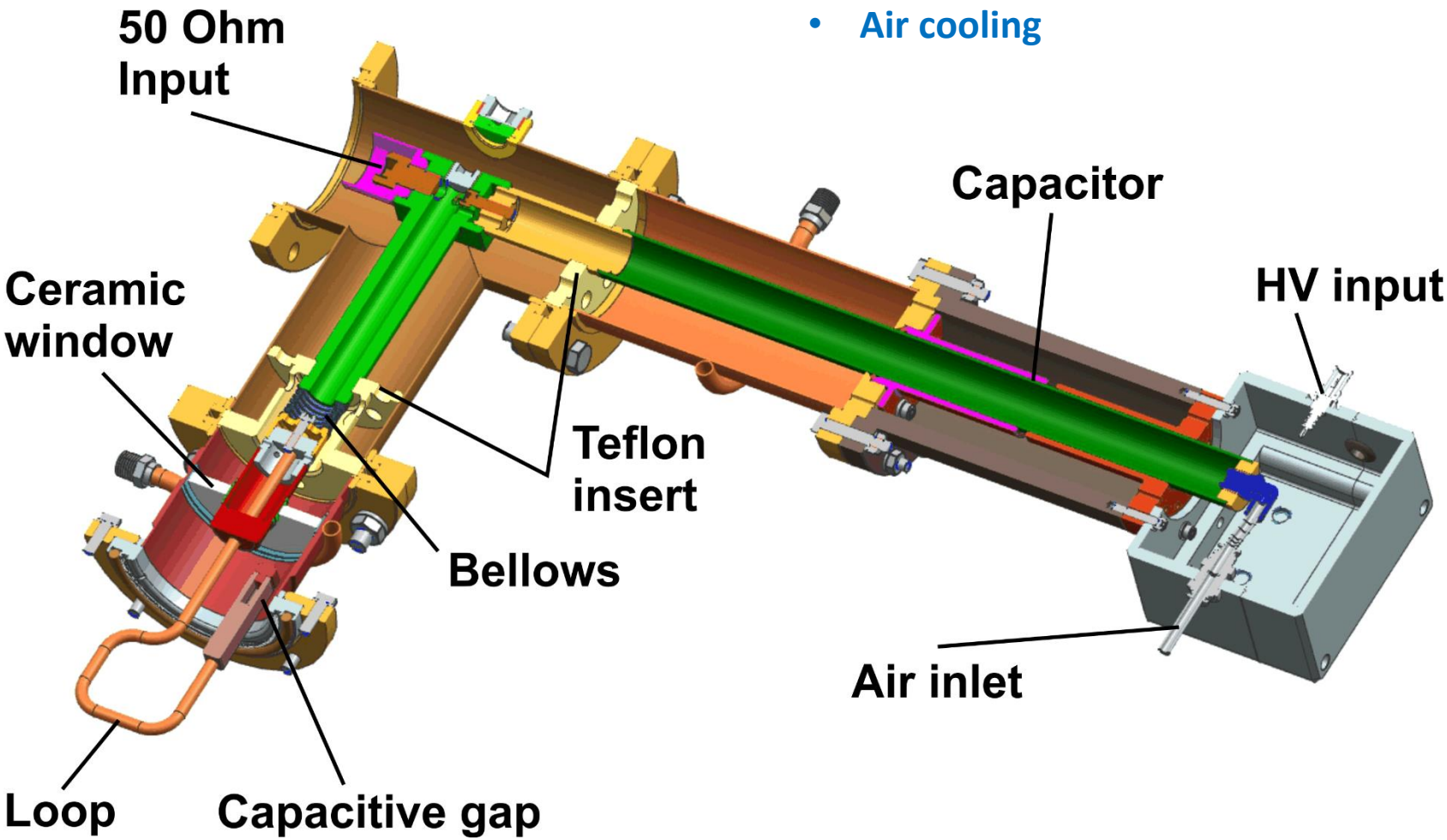


Overall sizes

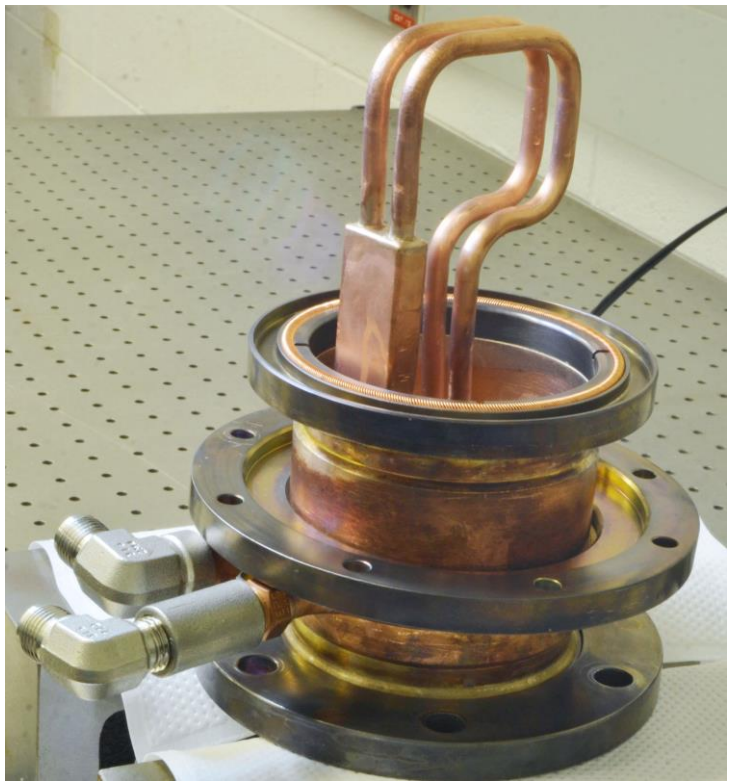


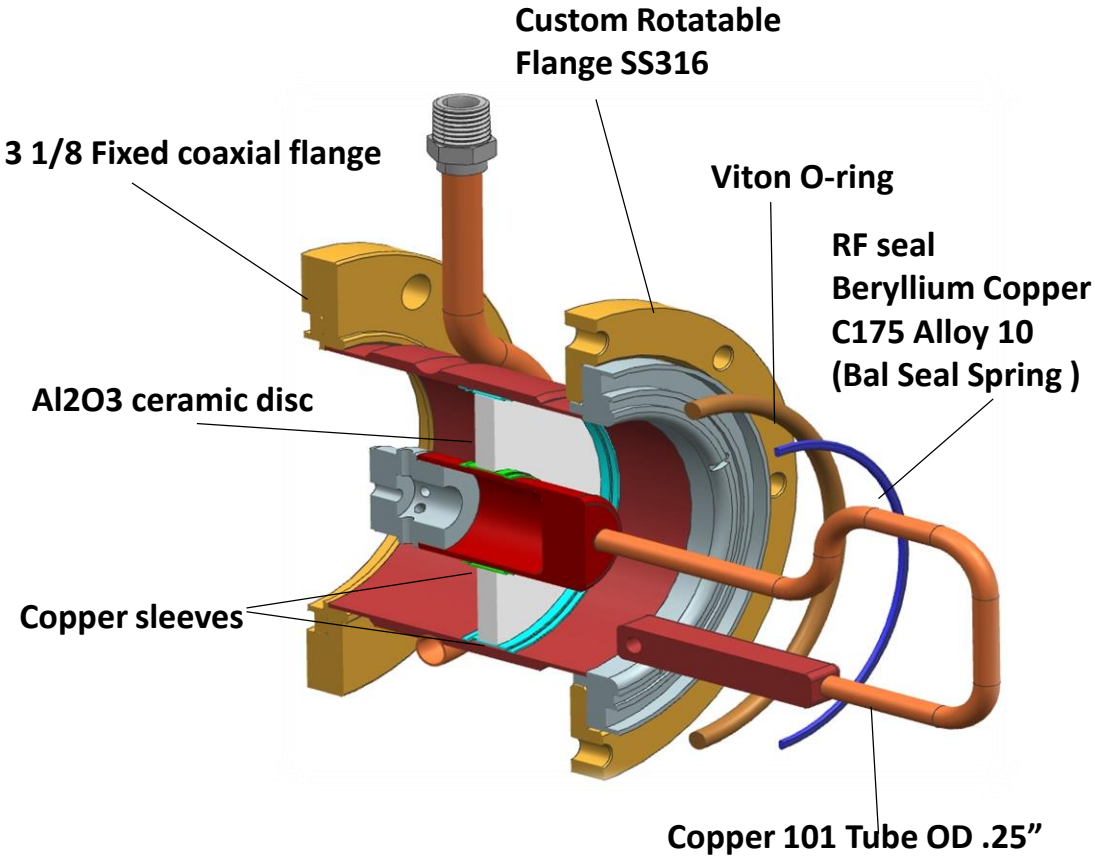
Some features of RFP coupler:

- Not grounded loop (HV bias applicable)
- Air cooling

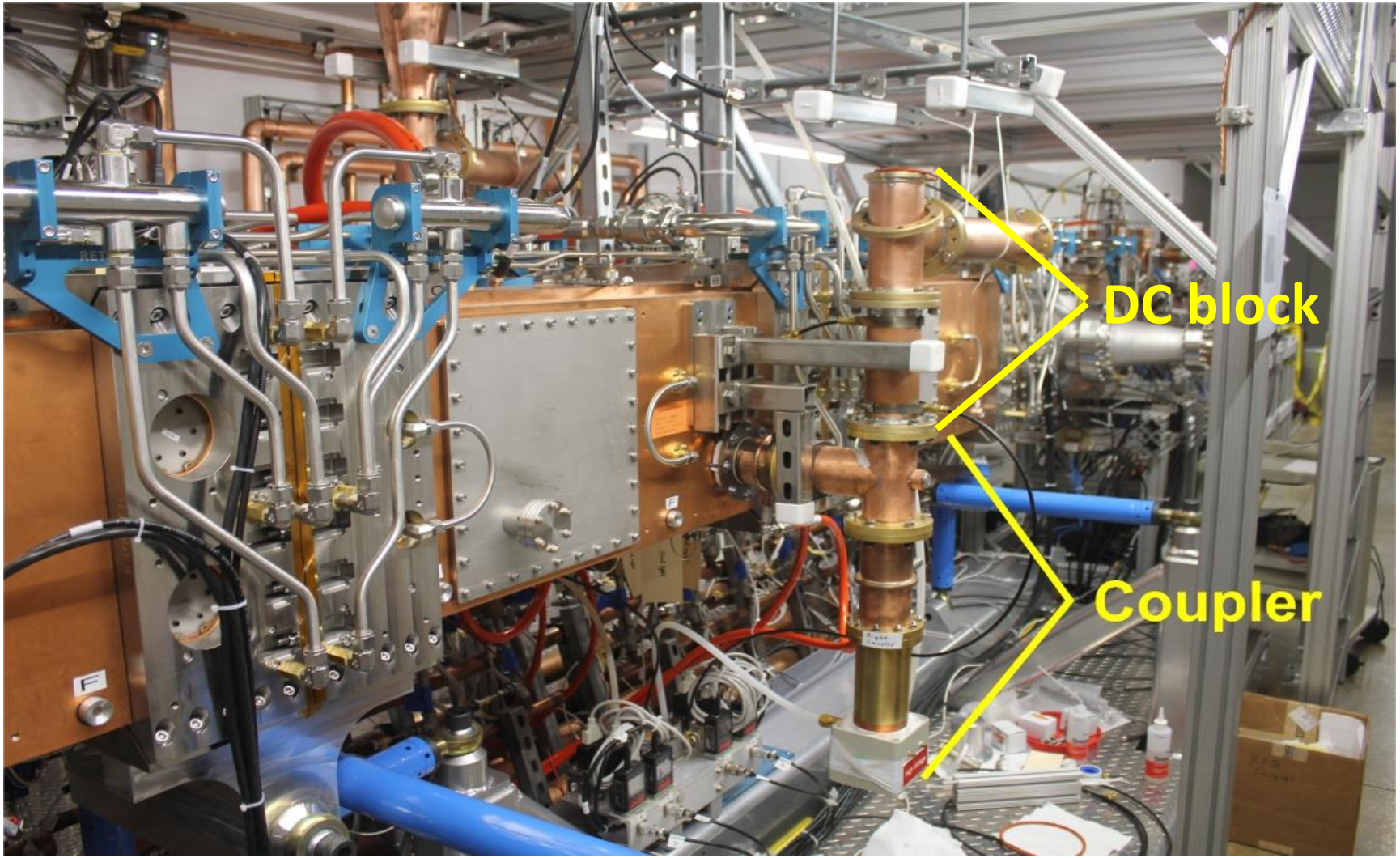


Ceramic window assembly:





RFQ coupler connected to RFQ cavity:

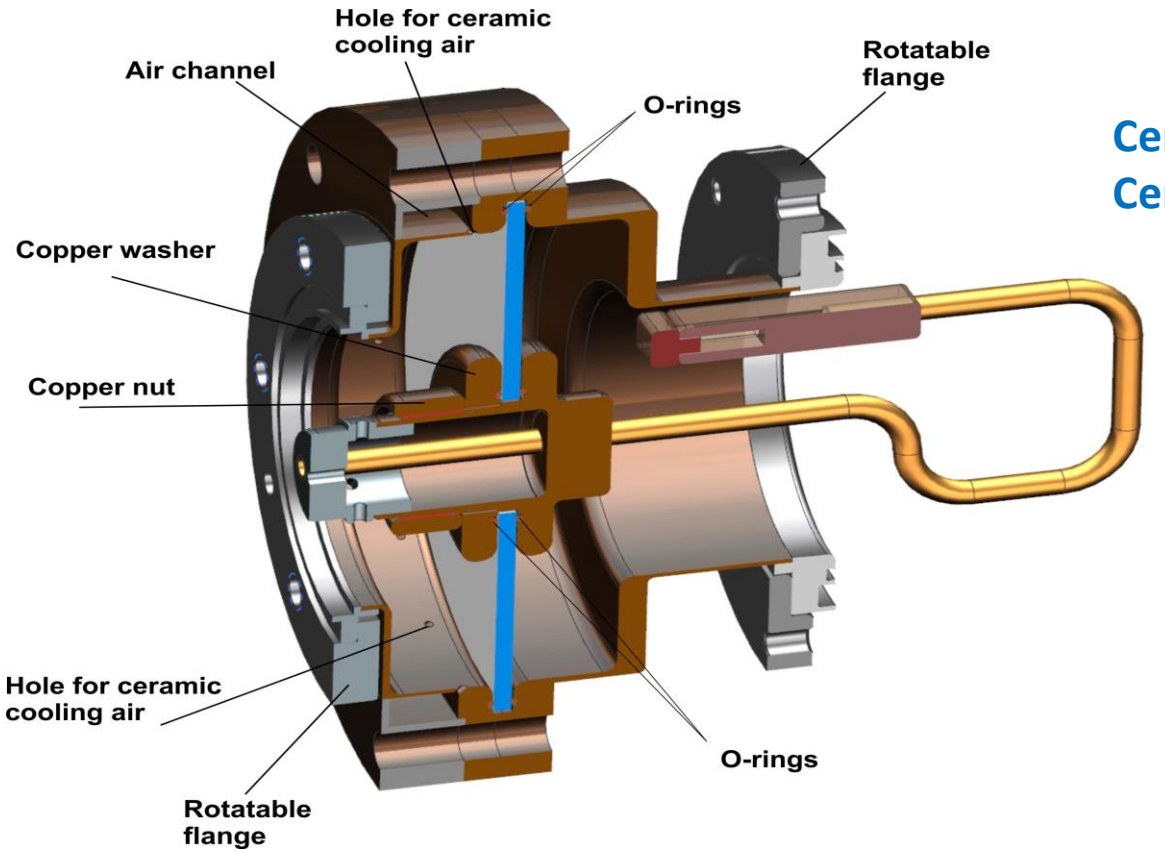


Results of testing:

- Two couplers with four ceramic window units were produced.
- Couplers were tested at RFQ cavity up to 65 kW in pulse and CW modes.
  CW mode integrated time was ~ 500 hours.
- Two windows were broken. The reason is not clear enough.
  The most probable reasons are not enough air cooling or/and low quality of window brazing.
- Remaining two windows are installed to RFQ cavity and operating in pulse mode now.

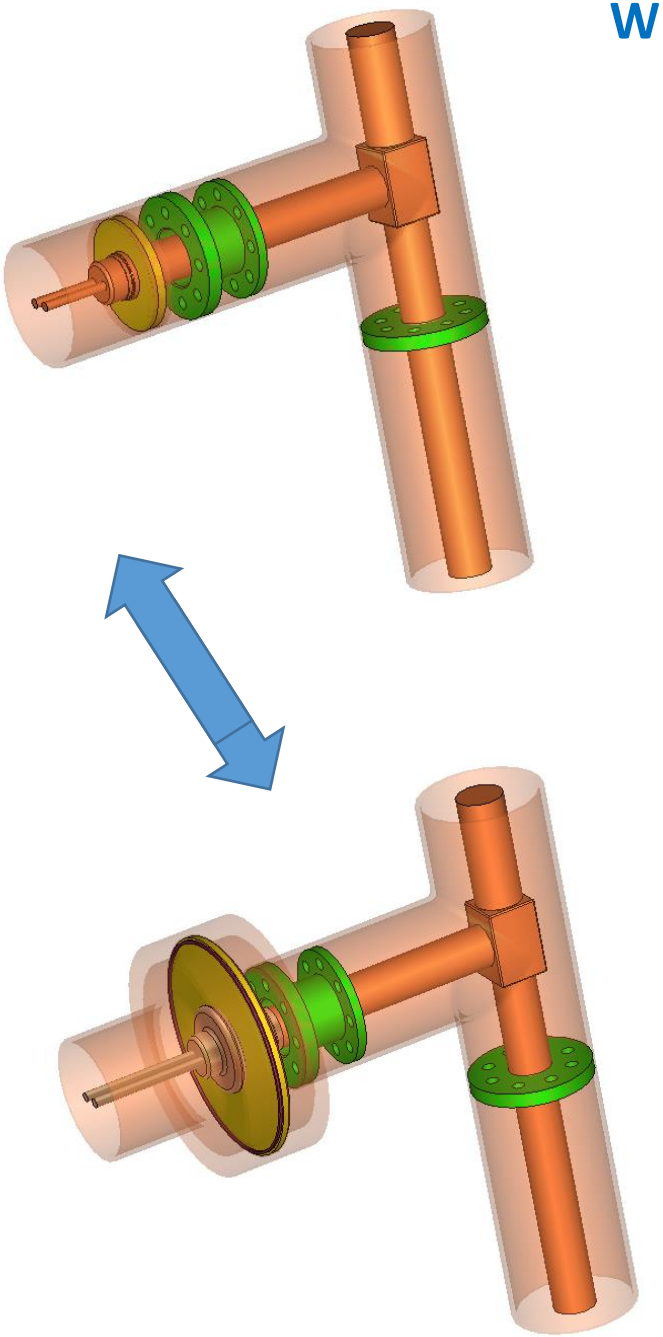
Backup RF windows:

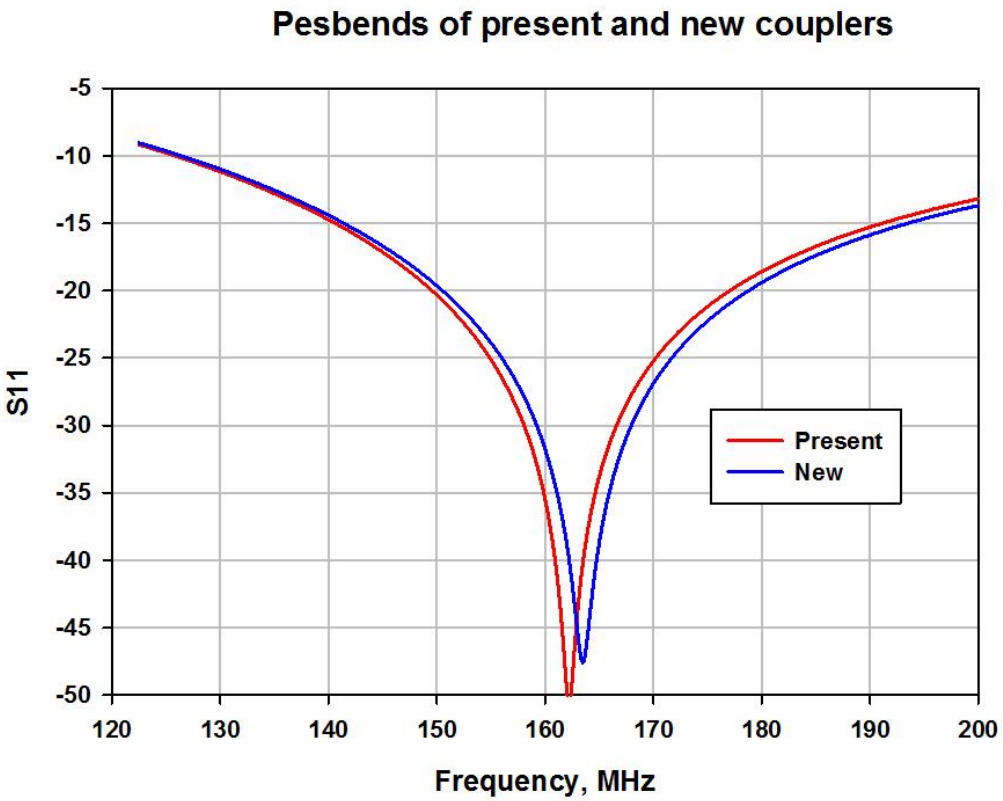
We decided to design and build “backup” ceramic windows units with bigger and replaceable ceramics. Ceramic disk will be vacuum sealed by Viton rings or aluminum diamond seals. We expect that new window will be powerful enough. In case of broken window the ceramic disk can be change easily for new one.



Ceramic diameter 6’’ (was 3’’)
Ceramic thickness 4 mm (0.16’’)

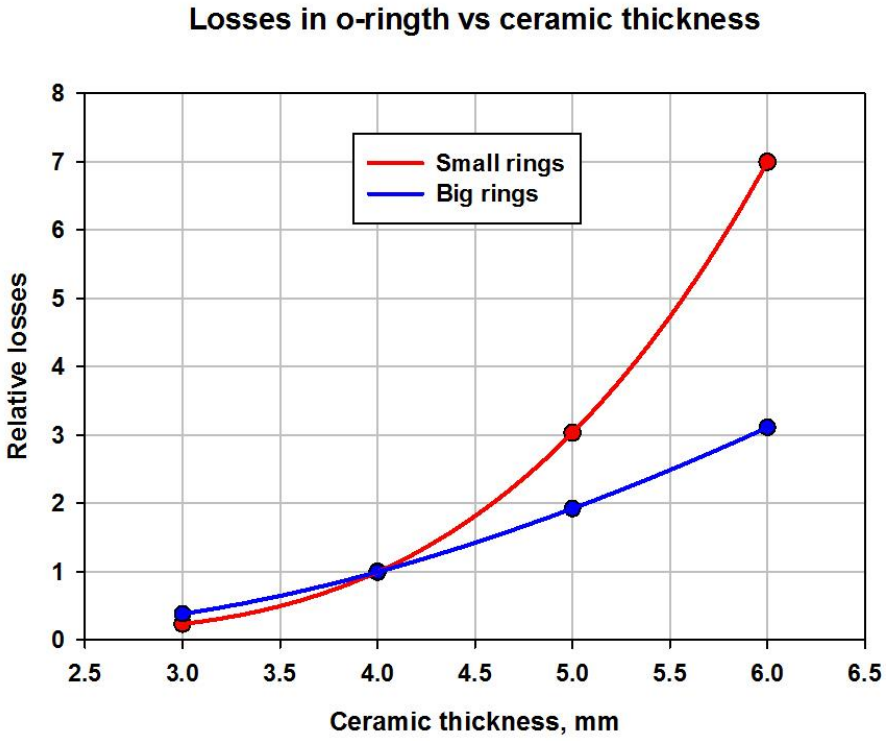
Window units are interchangeable.

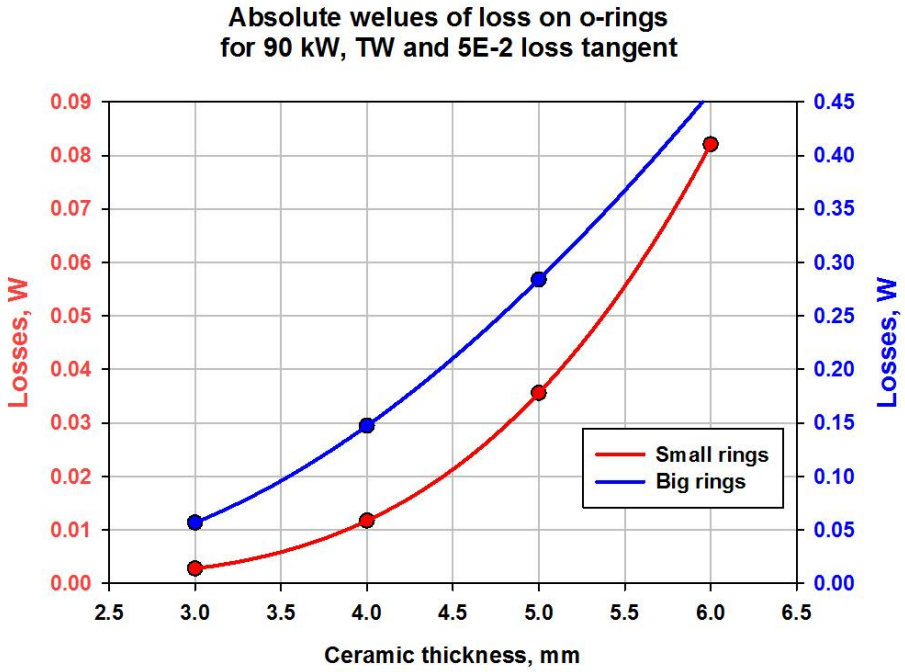




Relatively and absolute losses in Viton (rubber) rings.

Ceramic thickness was chosen 4 mm





SSR1 & SSR2, 325 MHz coupler:

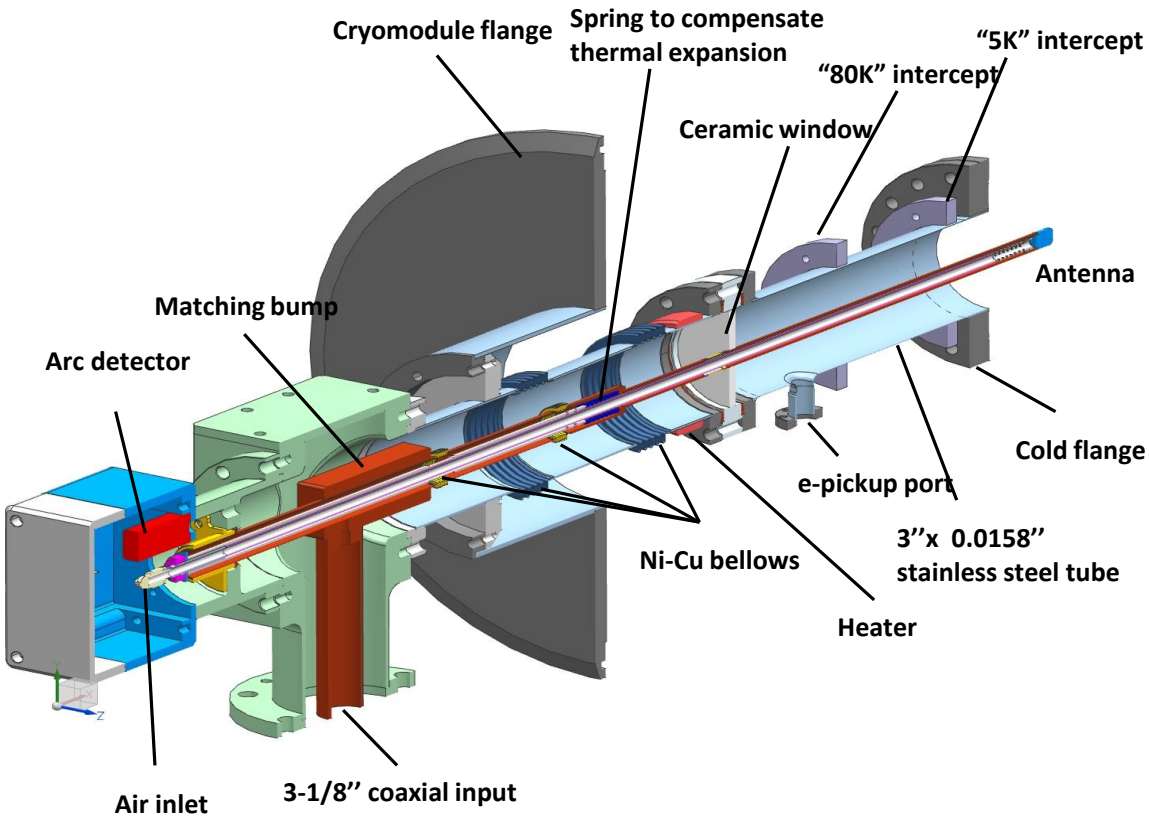
Design power:
30 kW, CW, full reflection

RF Window:
Single, room temperature, alumina, OD 73mm (2.87''), ID 12.7mm (0.5''), thick. 6mm (.236'')

Antenna:
Copper 0.5'', air cooled, HV bias.

Outer conductor:
SS, ID 73mm (2.78''), 0.4mm wall thickness, no Cu coating.

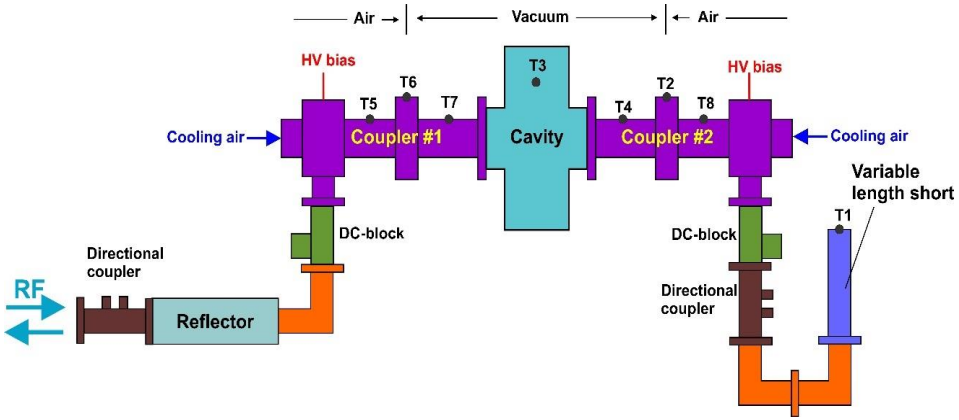
Impedance 105 Ohm



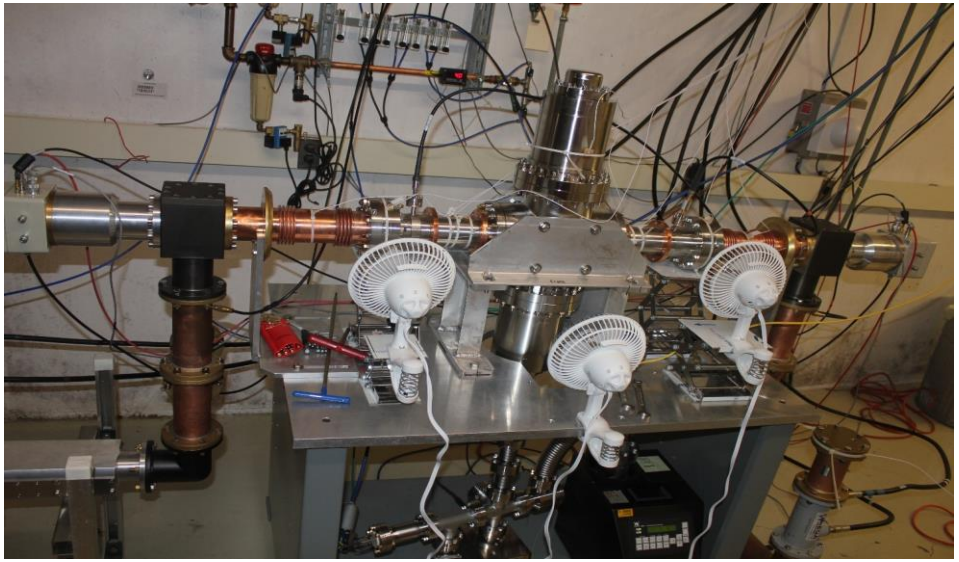
Thermal properties of coupler:

P, kW	"2K ", W	"5K", W	"70K", W
0	0.06	0.58	2.02
3	0.10	0.81	2.35
6	0.15	1.03	2.68
20	0.35	2.07	4.25
30	0.50	2.82	5.36

Results of testing, 325 MHz couplers:



Test stand of 325 MHz couplers



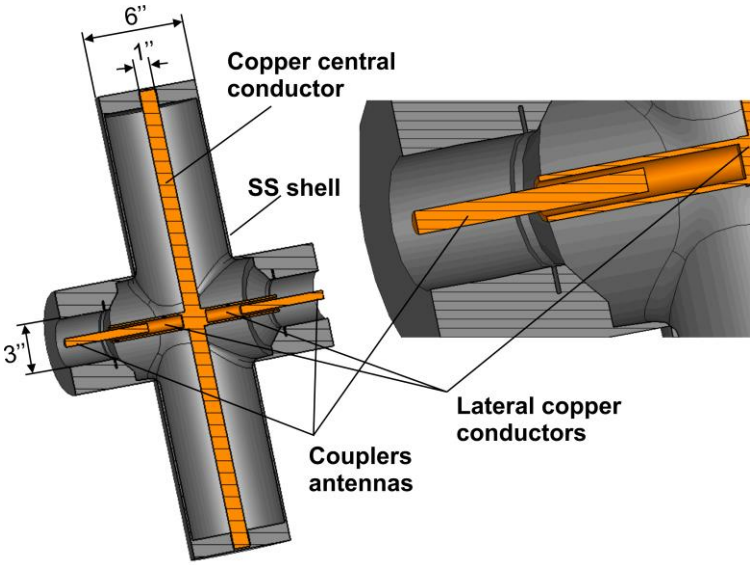
- Three prototypes were produced and tested in test stand at room temperature.
- Pair of couplers were successfully tested up to 30 kW, CW, full reflection, 90 dgr. step reflection phase.
- Then couplers were tested up to failure. Window was destroyed at 47 KW, CW, full reflection.
- One prototype was successfully tested with SSR1 SC cavity in cryomodule up to 10 kW, CW. Coupler demonstrated designed thermal parameters.
- 10 couplers are under production.

- 4 coupler produced by “Mega Ind.” were successfully tested at test stand up to 20 kW, CW, full reflection, 90 dgr step. 1.5 hour at each step.

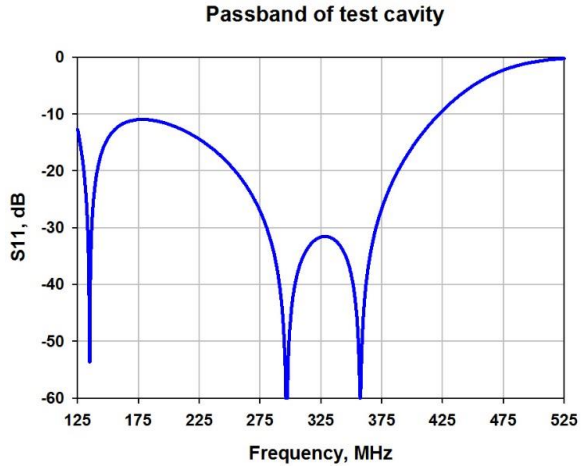
- Two coupler made of “Mega Ind.” were tested with cavity up to 10 kW, CW. One of them was tested twice. Last coupler (tested twice) got ‘mysteries’ leak. Leak happen after test in midnight without RF power during cavity warming up. But window is always warm, temperature of window T ~ room temperature. Small leak appeared In the middle of ceramic, no visible damages. We do not understand what happened.

325 MHz coupler test stand

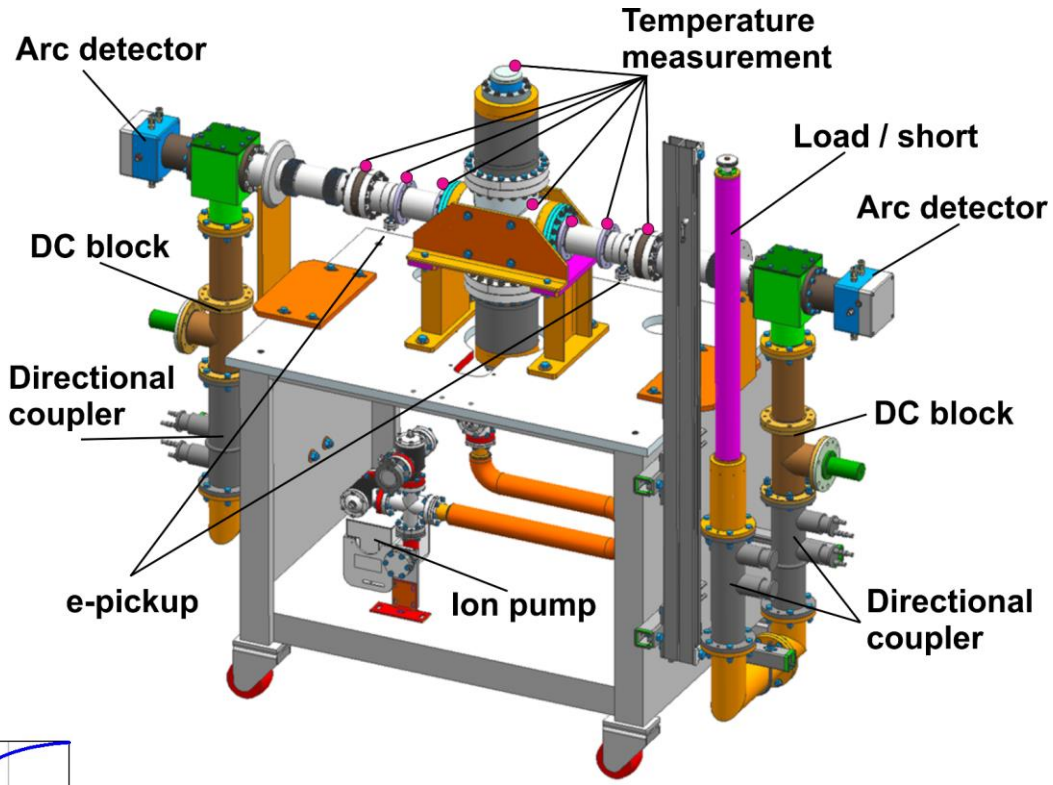
SS cavity under vacuum:

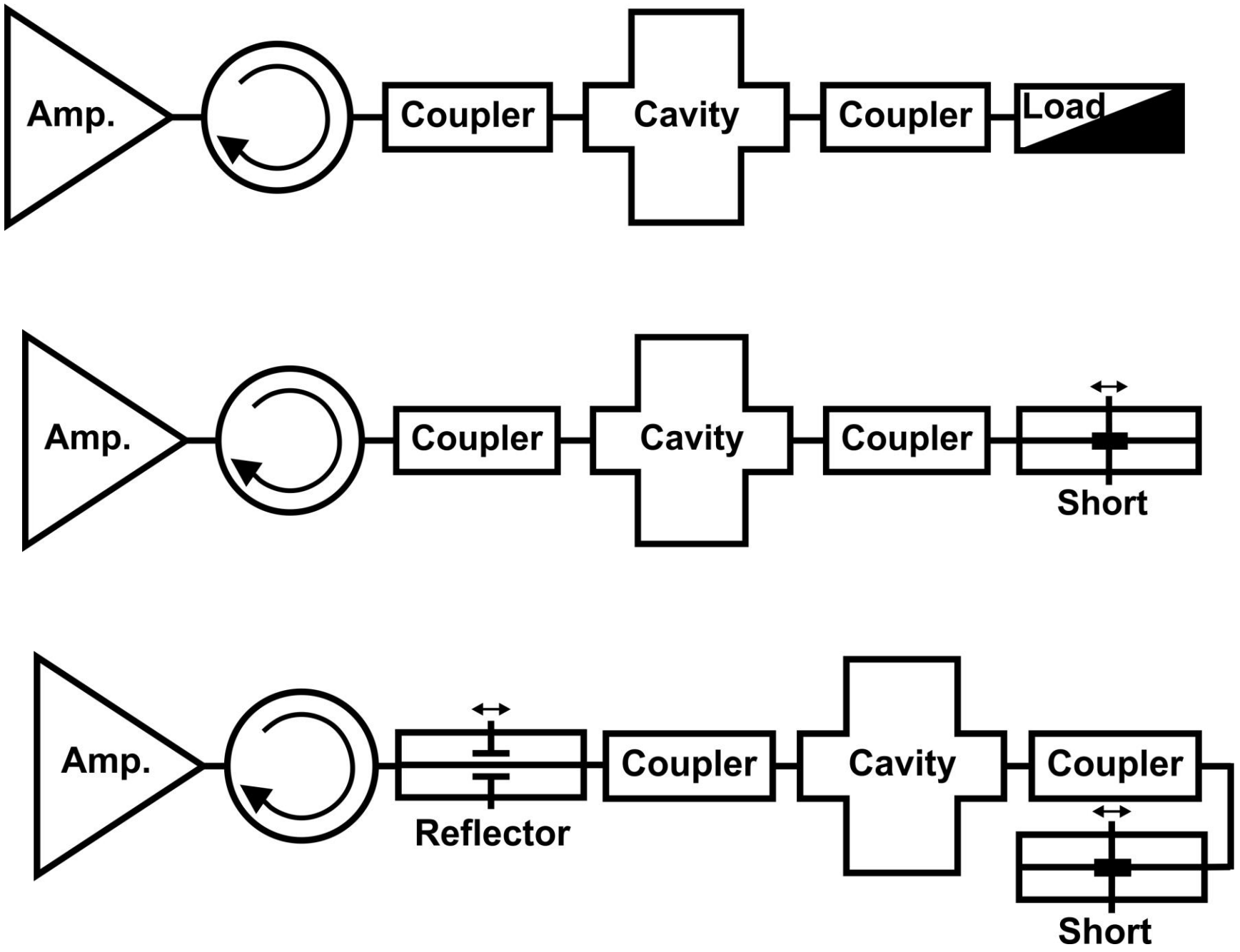


Size of the cavity was chosen big enough to avoid multipactor .



325 MHz coupler test stand configuration:

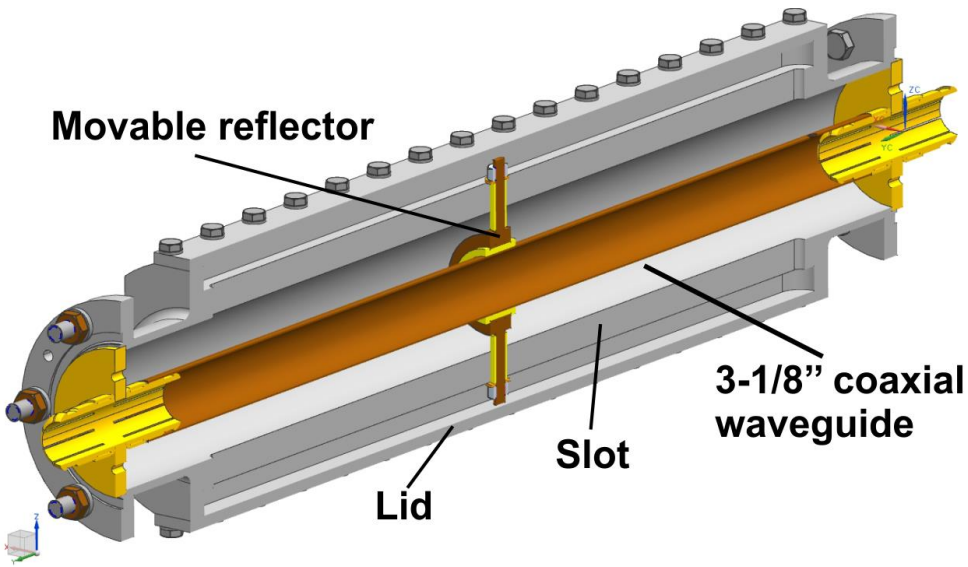


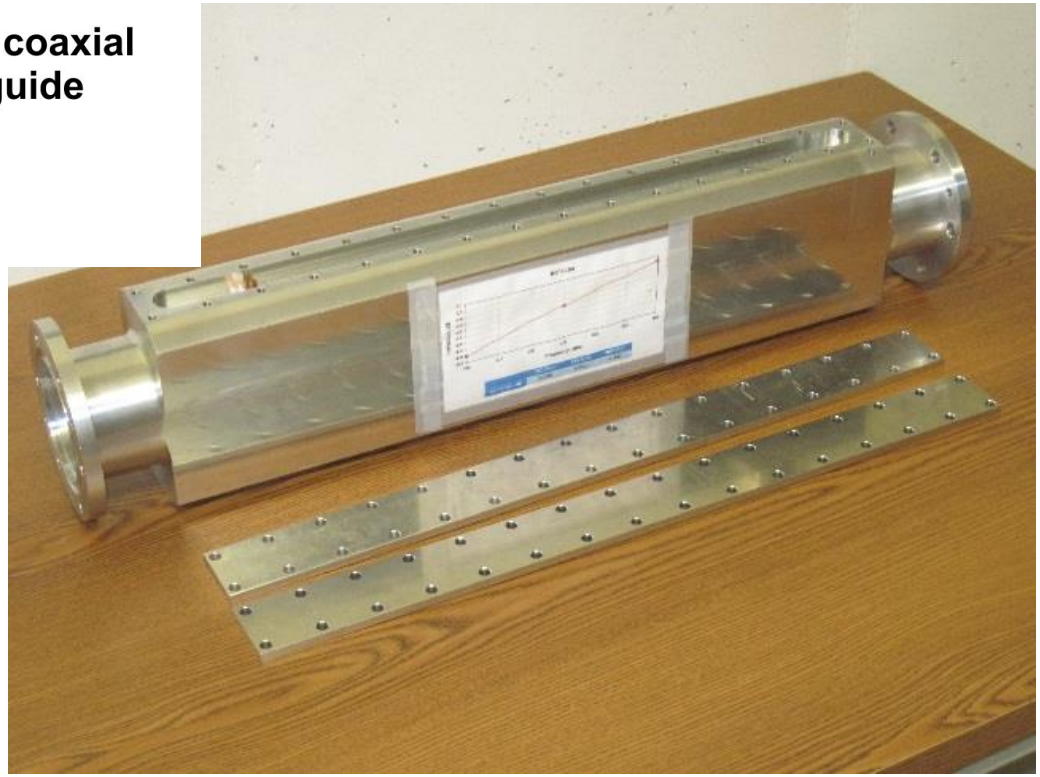

Amp.
Coupler
Cavity
Coupler
Load
Amp.
Coupler
Cavity
Coupler
Short
Amp.
Reflector
Coupler
Cavity
Coupler
Short

We test couplers in standing wave mode (full reflection). To increase testing power we use resonance. Resonance tined by movable reflector. Testing power can be 5 times higher then power of RF source.

RF source: SS, 10 kW, CW, 325 MHz.

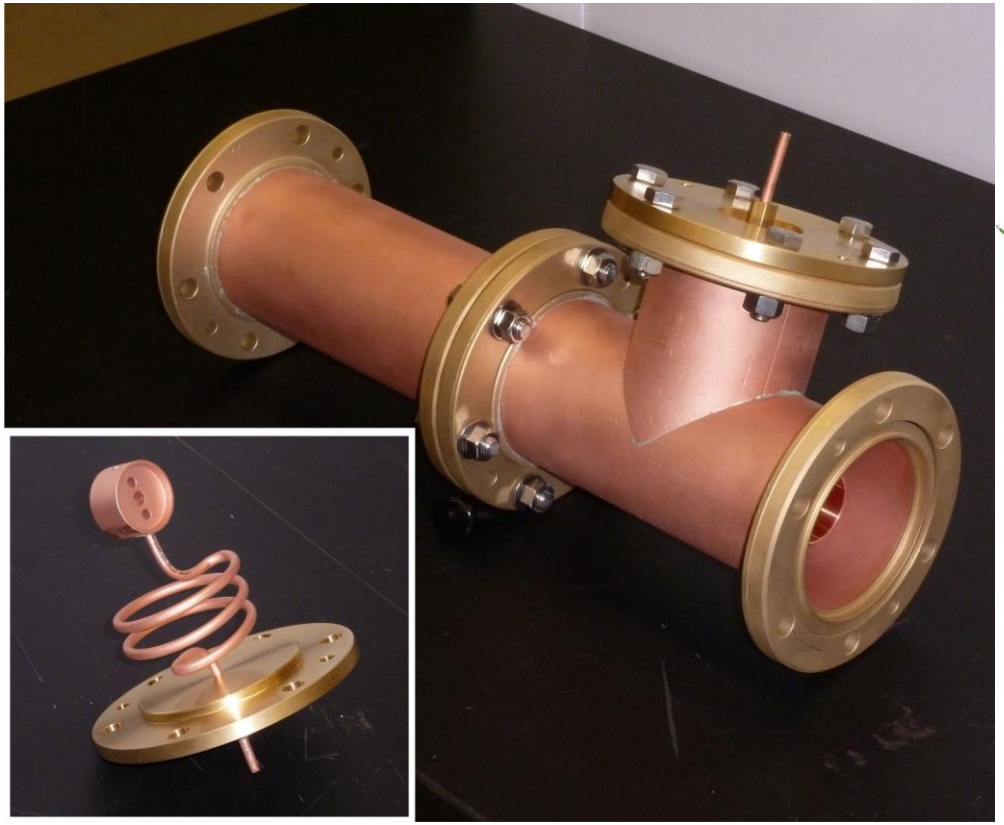
Testing power: up to 50 kW, CW

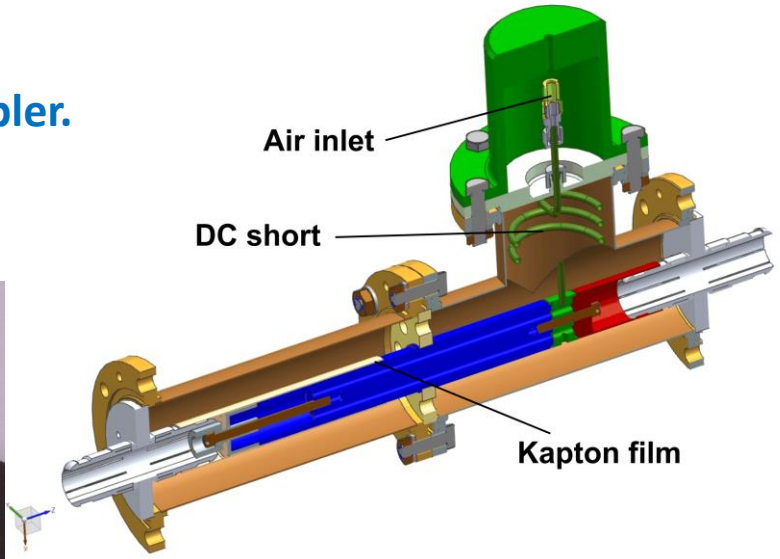


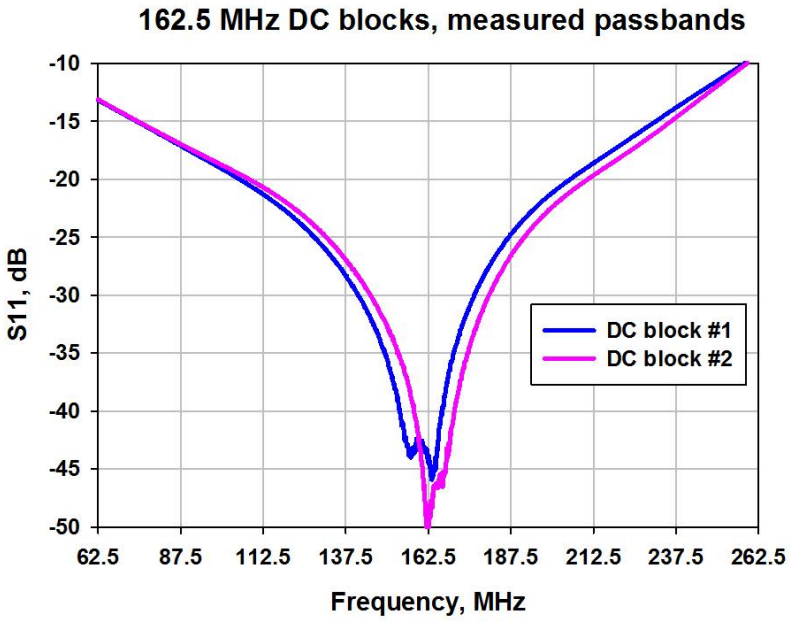


Multipcator in all couplers (different frequencies) is suppressed by HV bias.

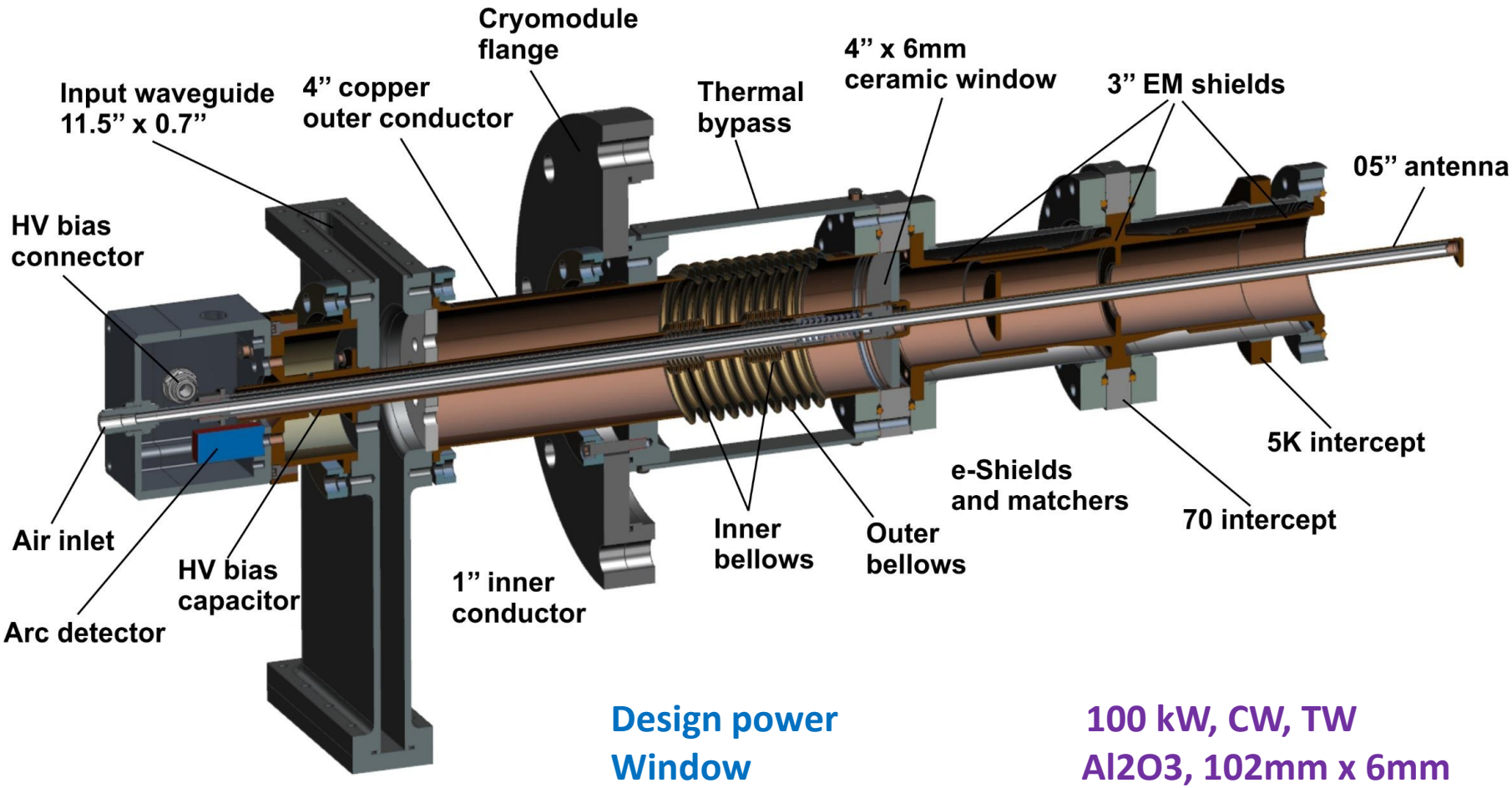
To decouple and protect RF source against HV,
'DC blocks' installed between RF source and coupler.





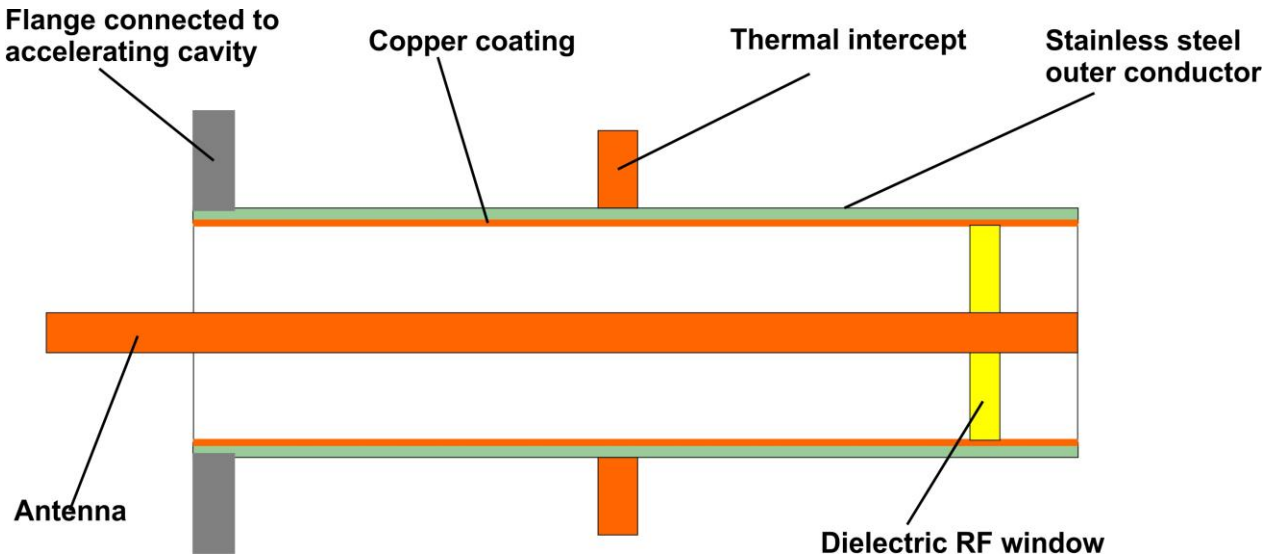


Structure of 650 MHz coupler, new design

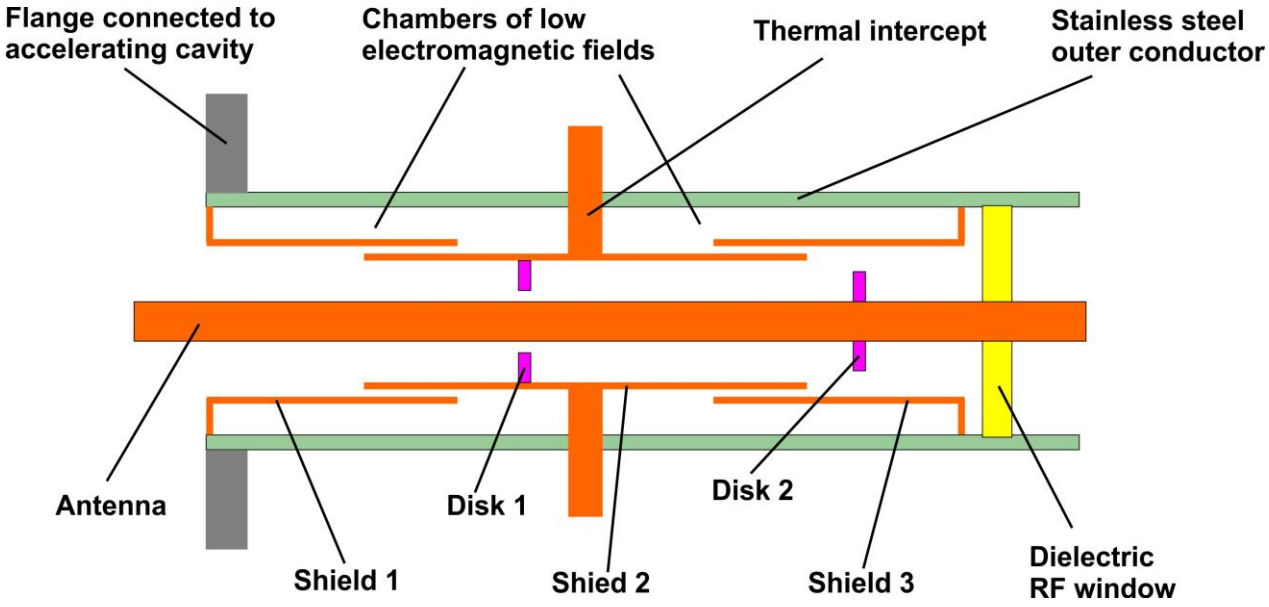


Design power	100 kW, CW, TW
Window	Al2O3, 102mm x 6mm
Outer conductor (vacuum)	72mm
Antenna	D 12.7mm
Cooling	Air
Multipactor	HV bias

Conventional coupler

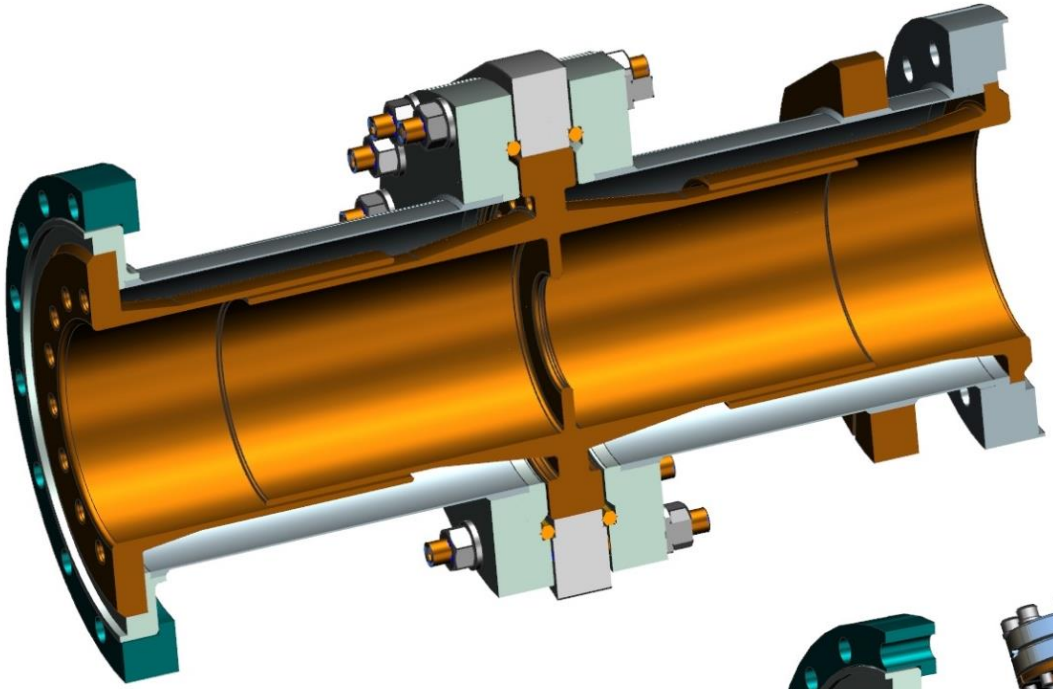


New approach

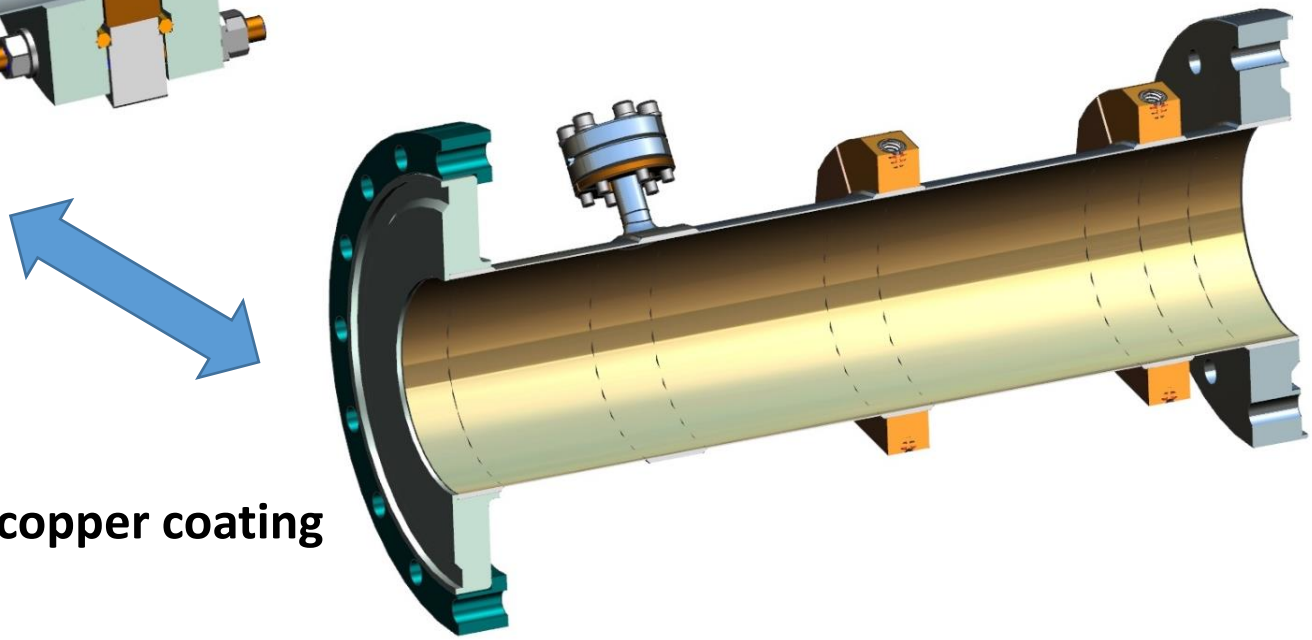


Two version of vacuum outer conductor were design:

- **New with electromagnetic copper shields**
- **Conventional with copper coating**
- **Outer conductors are interchangeable.**

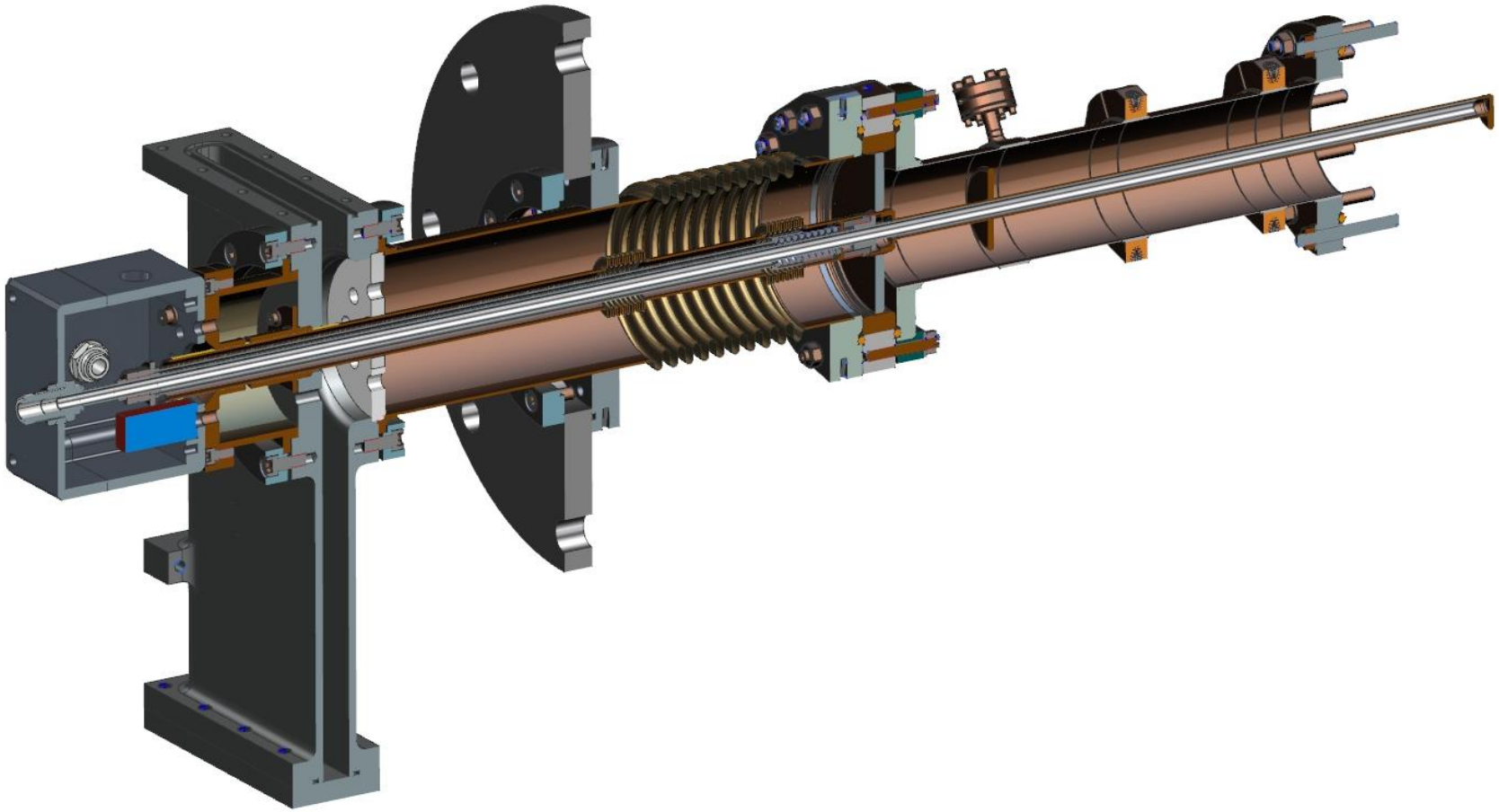


No copper coating



With copper coating

Configuration with ‘conventional’ outer conductor



Thermal properties of 650 MHz coupler

	2K, W	5K, W	70K, W	293K, W	T window, K, min/max
New, 0 kW	0.15	0.6	3.3	-2.7	288/288
New, 100 kW	0.55	0.93	6.2	21	334/347
Conv., 0 kW	0.41	1.46	3.0	-3.1	288/288
Conv., 100 kW	0.97	4.1	11.4	20	331/344

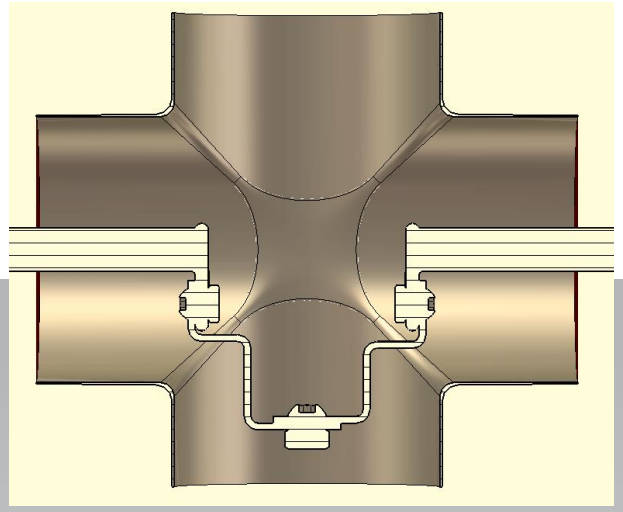
Cryo-plant power consumption:

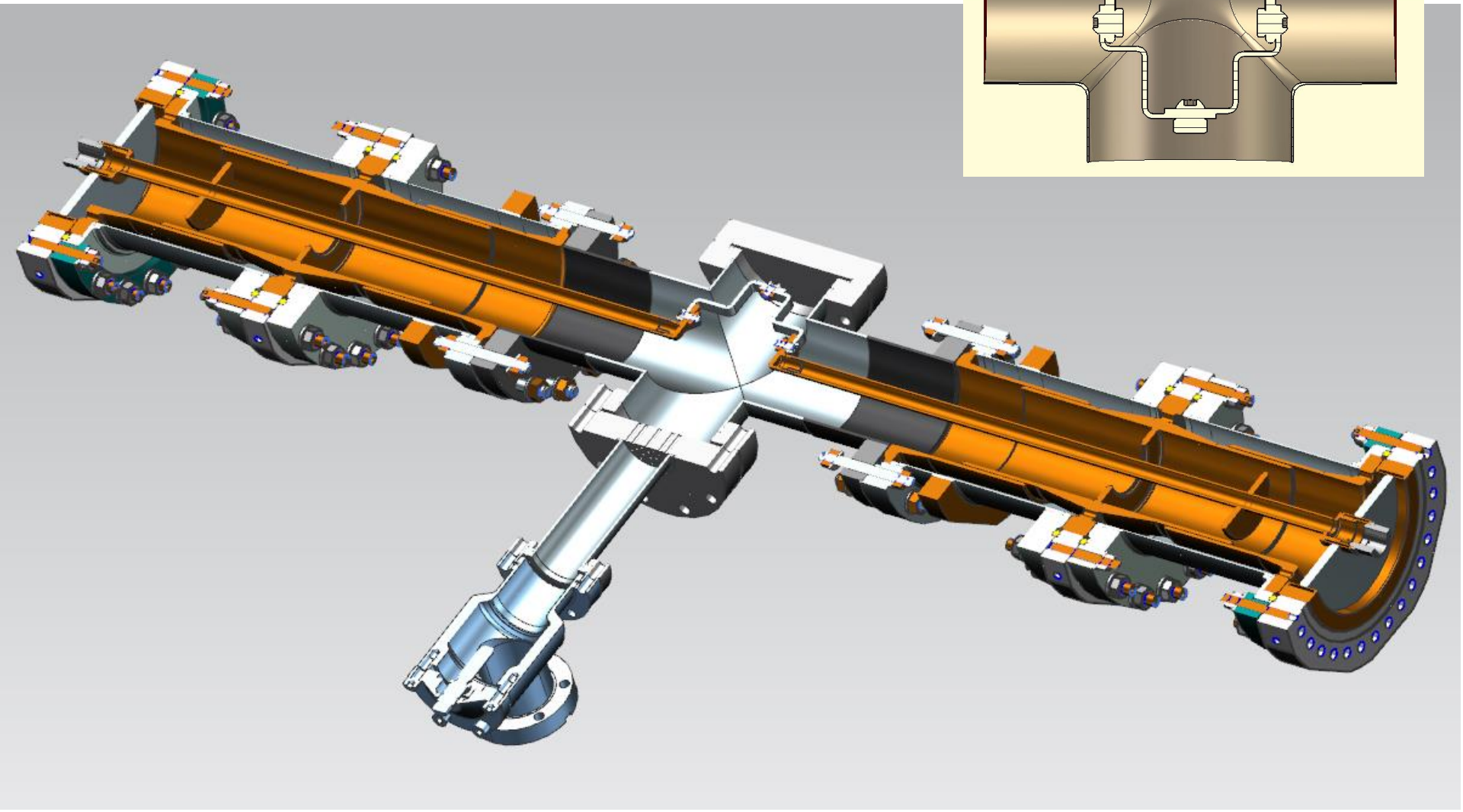
New = 0.55*960 + 0.93*220 + 6.2*20 ~ 857 W
Conv. = 0.97*960 + 4.1*220 + 11.4*20 ~ 2061 W

New configuration requires 2.4 times less power of cryo-plant to compensate cryo-loading.

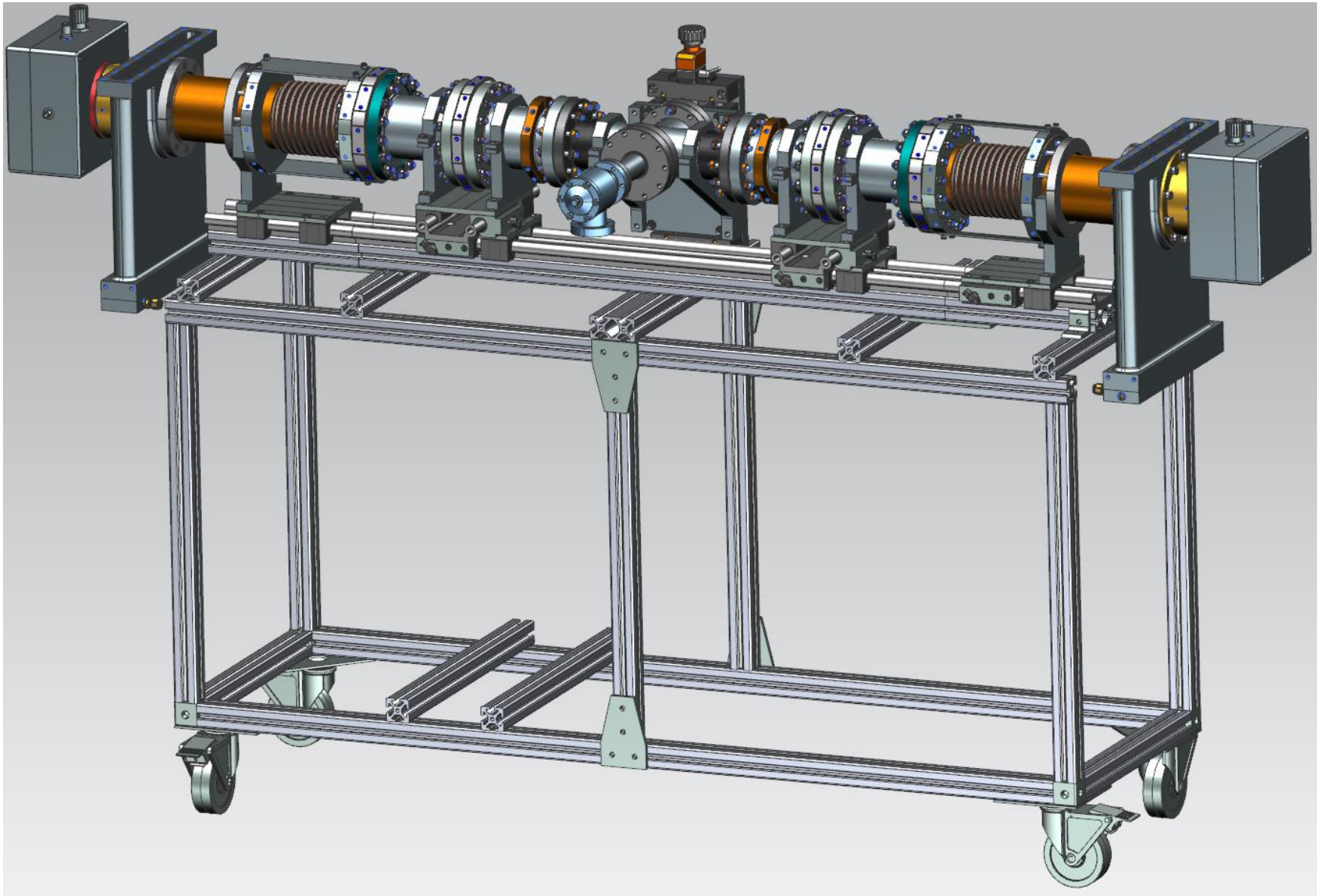
Two couplers are under production.

650 MHz coupler test stand is under design

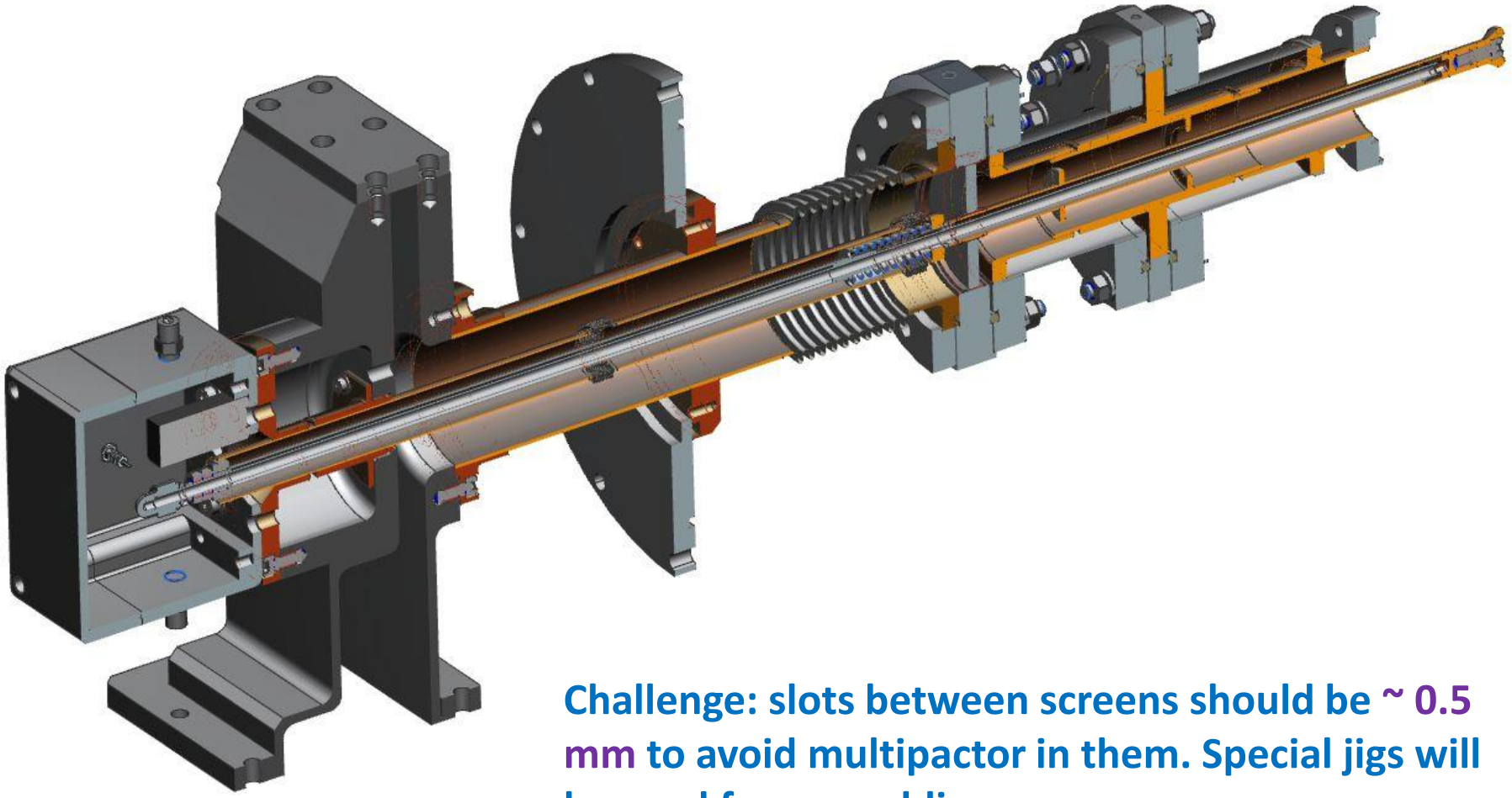




650 MHz coupler test stand

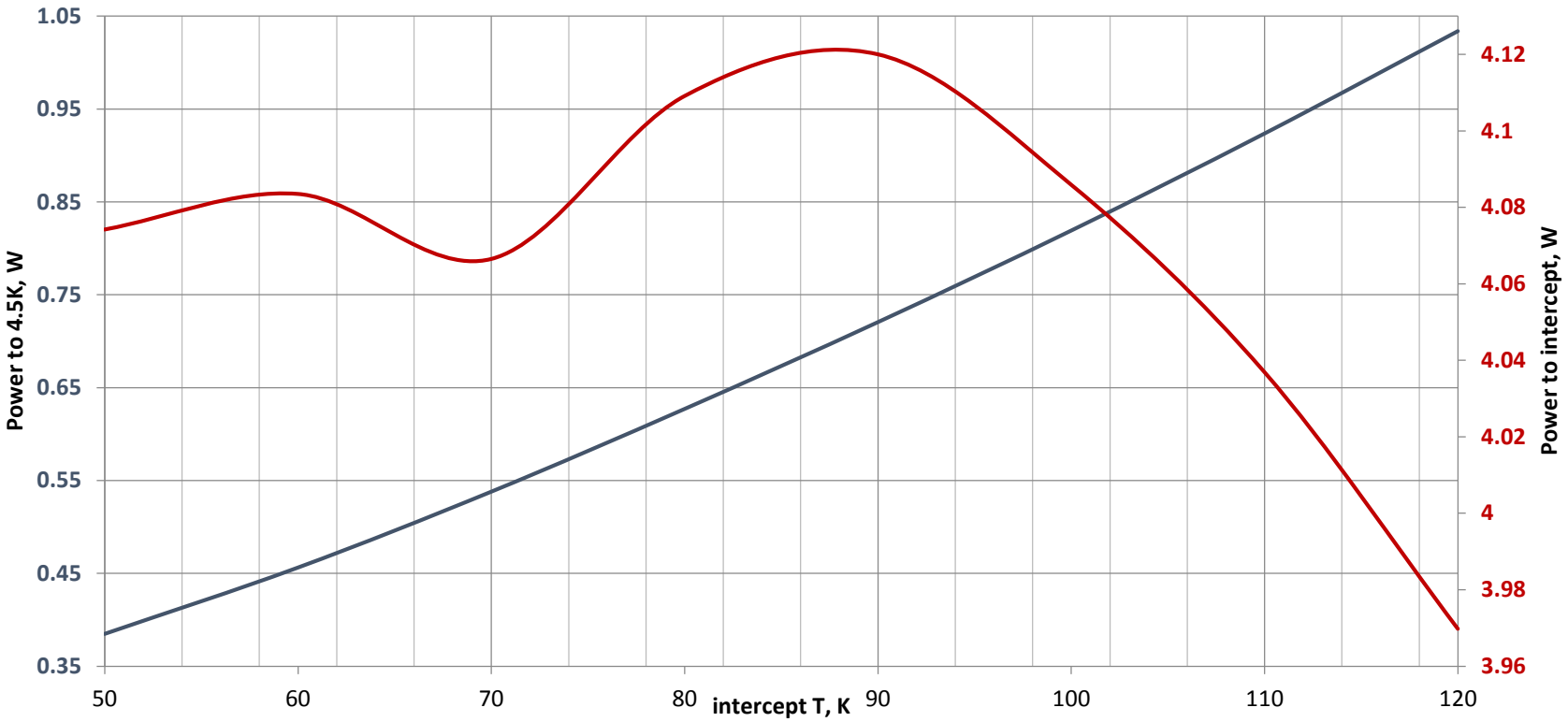


1.3 GHz coupler was designed for potential industrial SC accelerator.
Supposed cavity temperature is 4K (no 5K thermal intercept).
Coupler has TTF-III output flange.



Challenge: slots between screens should be ~ 0.5 mm to avoid multipactor in them. Special jigs will be used for assembling.

Total cryogenic loads, 20 kW transmitted power



Two couplers were produced.
We suppose to test them before October.

Other projects.

Team of Illinois Accelerator Research Center (IARC) works for 650 MHz superconducting industrial accelerator. Each SC cavity will consume 250 kW, CW RF power. It will be accelerator with conducting cooling of accelerating structure (without liquid Helium). Available 4K commercial cryocoolers exist with a refrigeration power of 2 W at 4K temperature and several vendors are developing higher capacity units. It means that cryo-loading from coupler should extremely low, ~ 1W at 4K for ~ 250 kW transmitted power. We are working for design of this coupler.

Backup

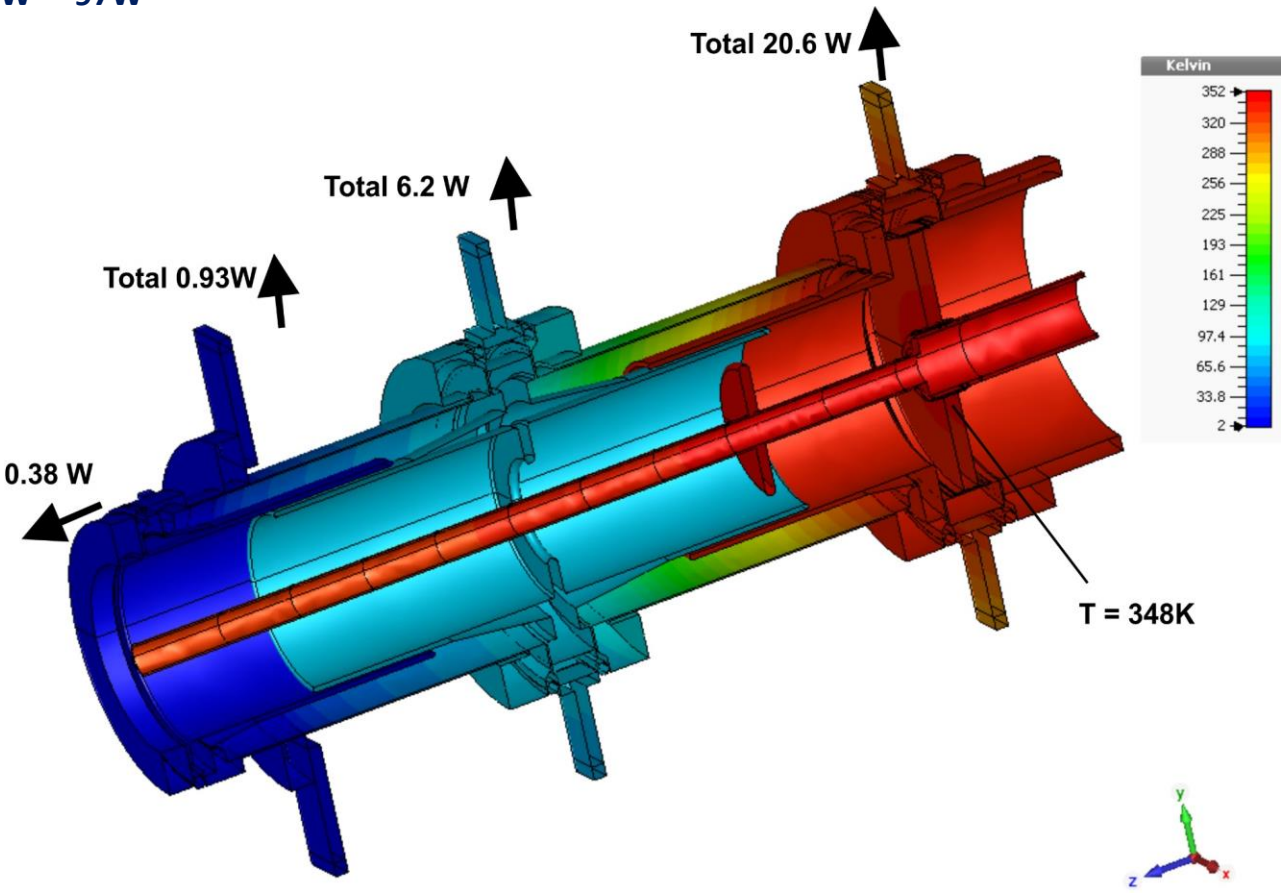
P = 100 kW, TW, Air = 3.0g/s

Loss in antenna = 77W +20W = 97W

ΔT_air ≈ 38C

T_tip ≈ 34C

P_rad = 0.17W



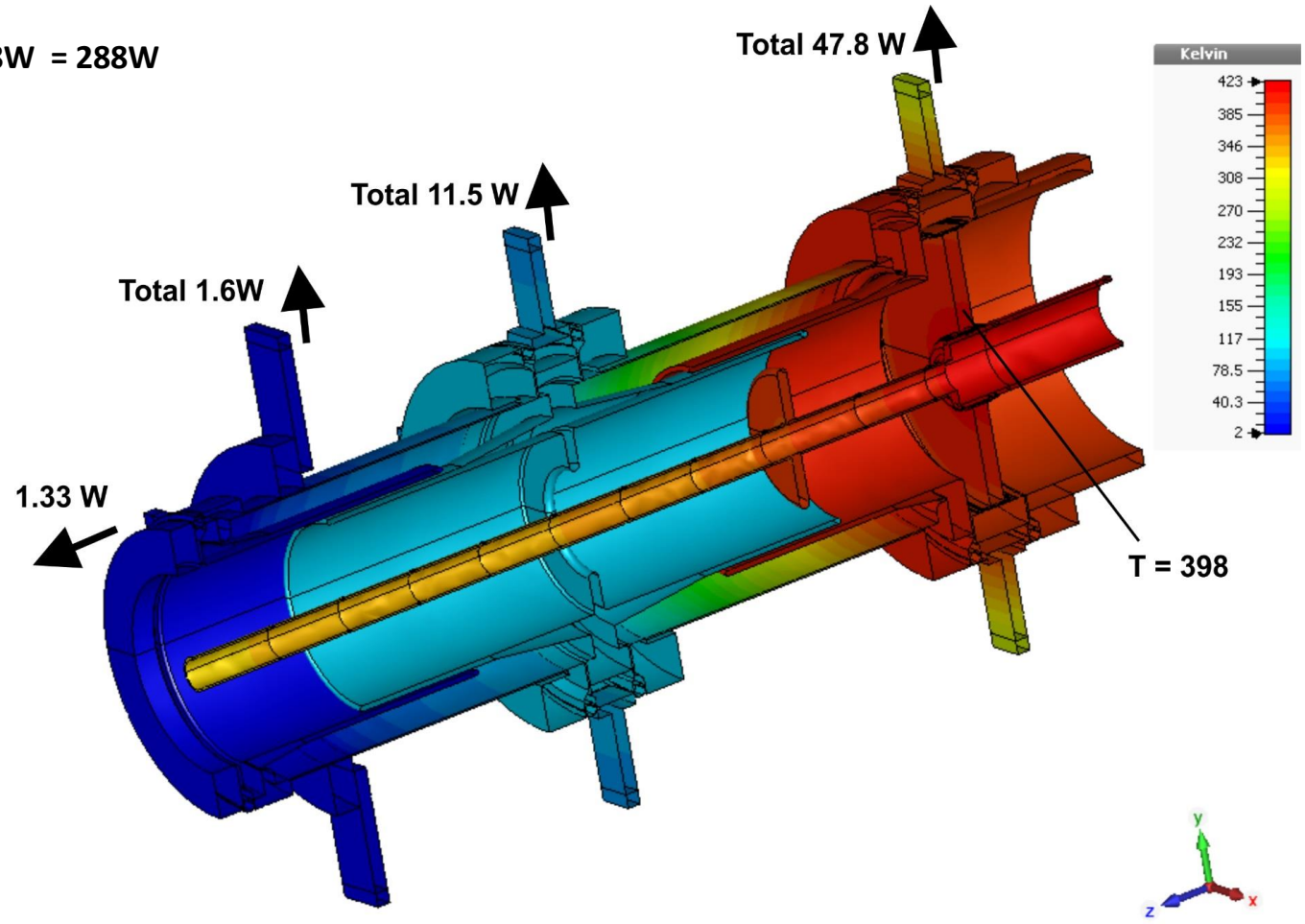
P = 300 kW, TW, Air = 5 g/s

Loss in antenna = 230W+58W = 288W

Δ_Tair ≈ 72C

T_tip ≈ 44C

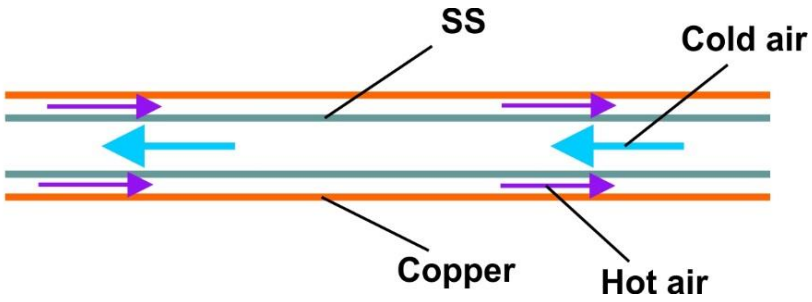
P_rad = 0.19W



Air cooling of antenna

Pressure drops:

Inner pipe: OD 9.5 mm, ID 7.7 mm, Length ~ 1m
Antenna ID 10.9 mm, Length ~ 0.41 m



Pressure drop at inner pipe:

3 g/s: ΔP = 0.06 bar, V = 64 m/s
5 g/s: ΔP = 0.16 bar, V = 107 m/s

Pressure drop at antenna:

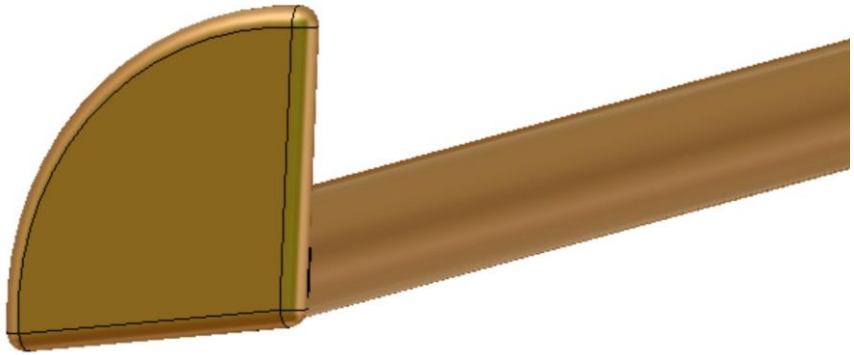
3 g/s: ΔP = 1.3 bar, V = 113 m/s, Convection ~ 550 W/(K*m2)
5 g/s: ΔP = 3.2 bar, V = 189 m/s, Convection ~ 830 W/(K*m2)

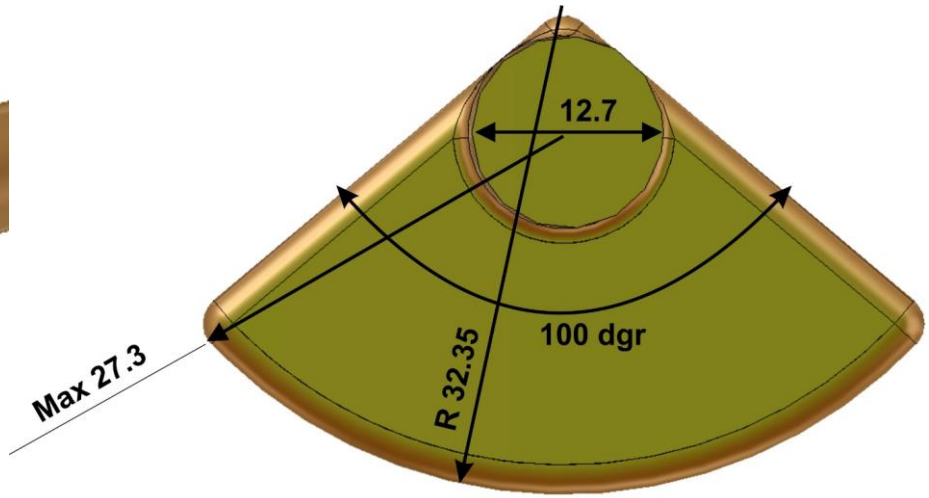
Inlet pressure

~ 2 bar for 3 g/s
~ 4 bar for 5 g/s

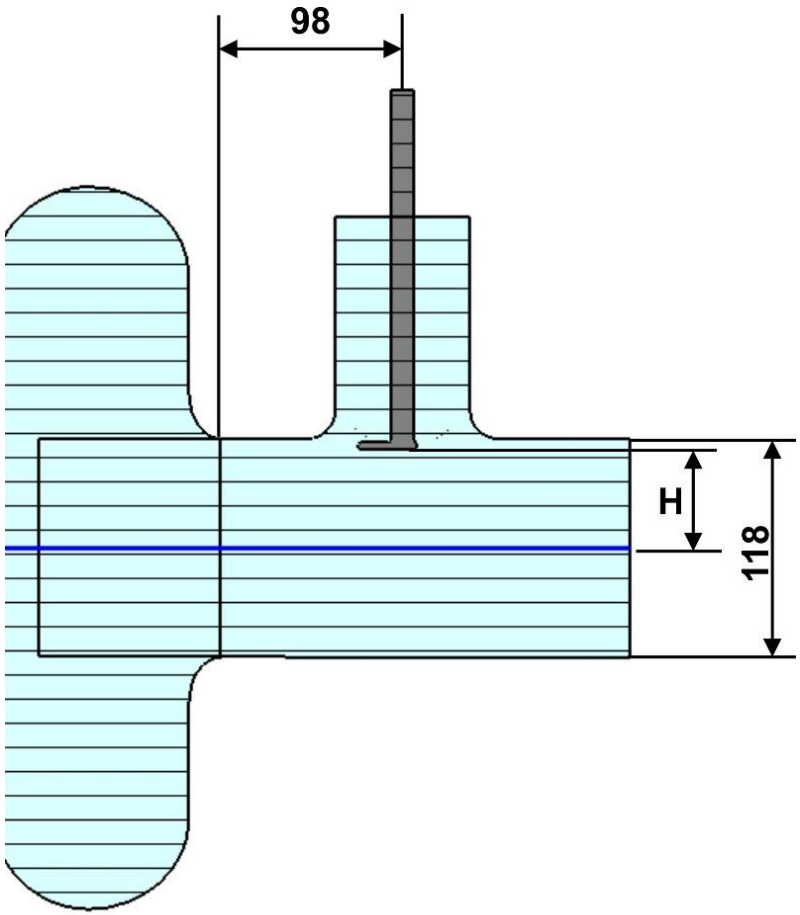
Antenna tip and coupling.

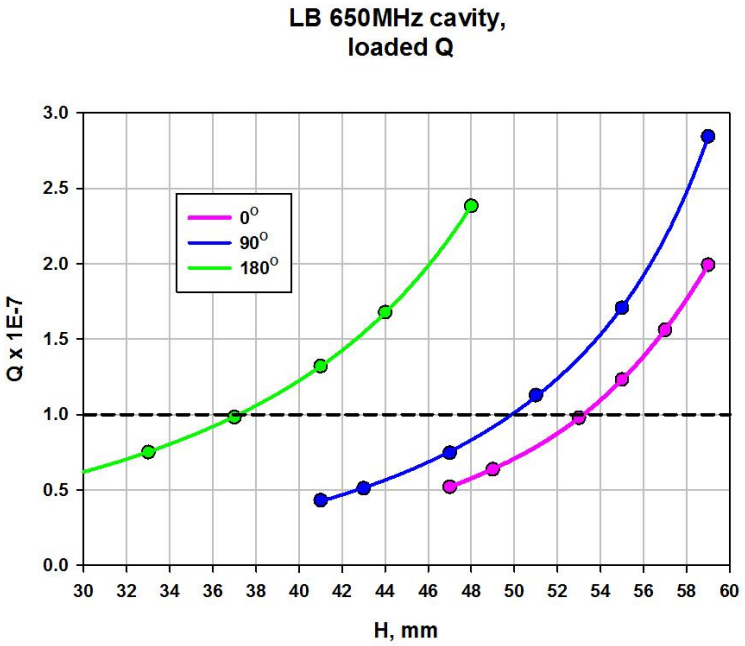
“Goose foot” shape improves a coupling and allows to change coupling by rotation of antenna





LB 650 MHz cavity coupling:





HB 650 MHz cavity coupling: