



# High Power Main Couplers for CW/RF operations ( PIP-II experience)

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# PIP-II 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

## SSR1 & SSR2 coupler:

Frequency	325 MHz
Power	30 kW, CW

## Buncher coupler:

Frequency	162.5 MHz
Power	3 kW, CW

## LB & HB 650 coupler:

Frequency	650 MHz
Power	110 kW, CW

## HWR coupler:

Frequency	162.5 MHz
Power	10 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 expensive.
- **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.**

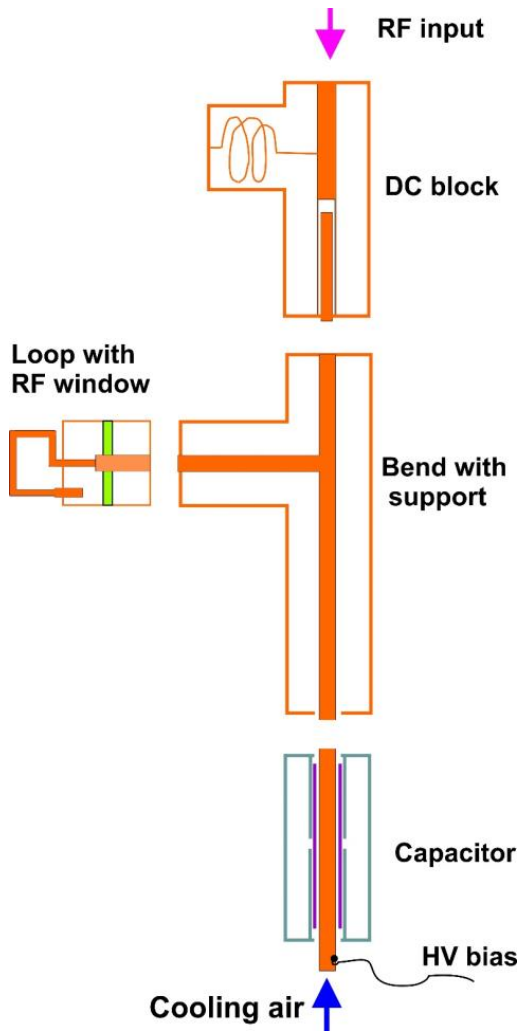
Based on this principles the couplers were designed:

- for RFQ, 162.5 MHz;
- for spoke cavities SSR1 & SSR2, 325 MHz;
- for elliptical cavities LB & HB 650 MHz.

RFQ and SSR1 & SSR2 couplers were built and tested.

# RFQ coupler:

## RFQ coupler structure:

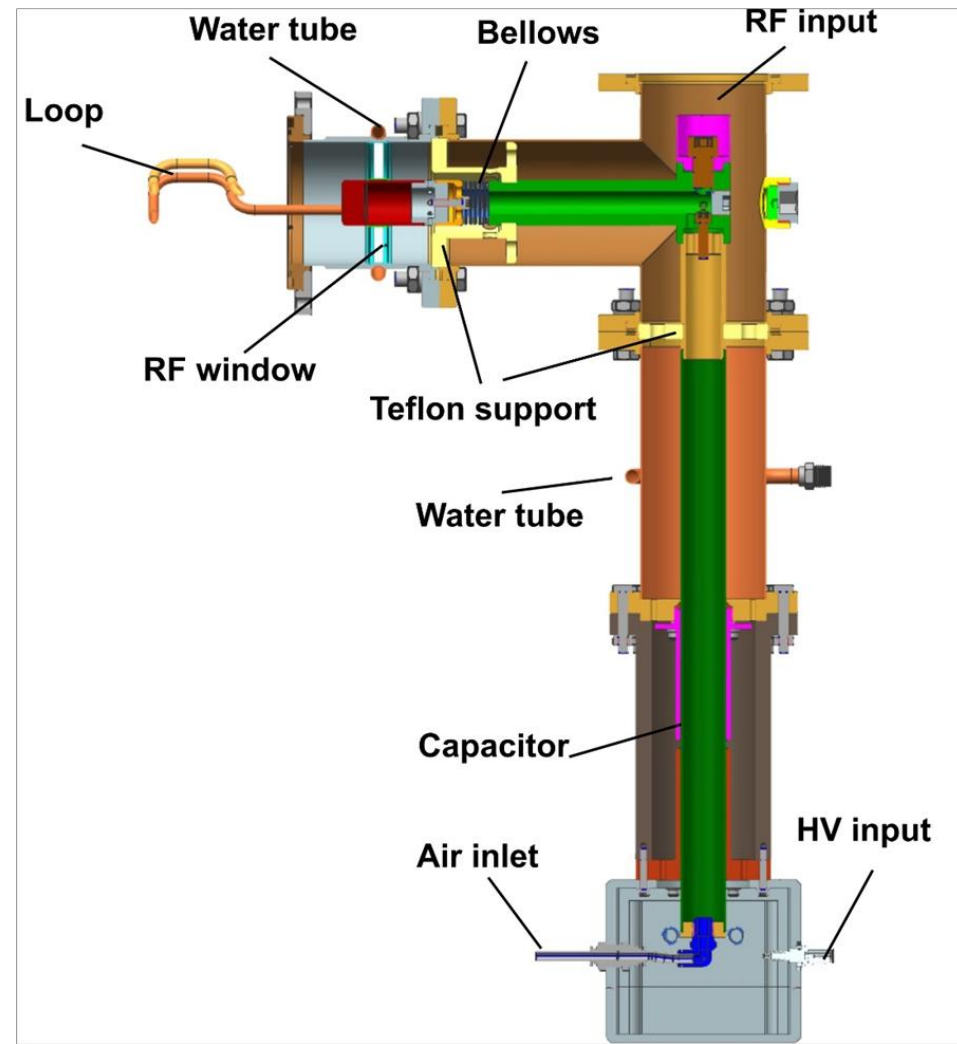


### Main features:

- Not grounded loop
- Rotatable loop
- Air cooling of loop
- HV bias

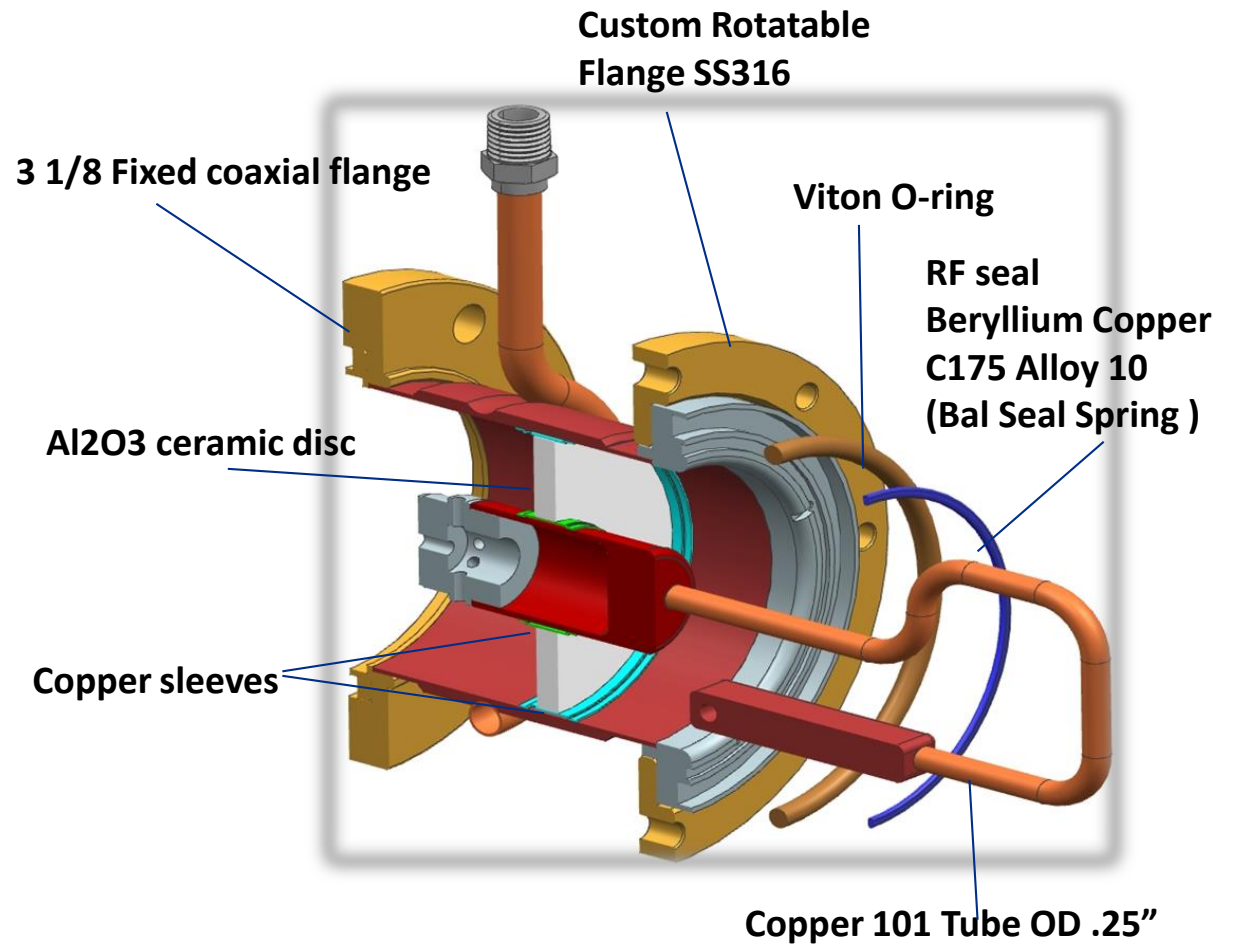
**DC block protects RF source against HV of bias.**

## RFQ coupler cut-view:





# Ceramic window assembly:



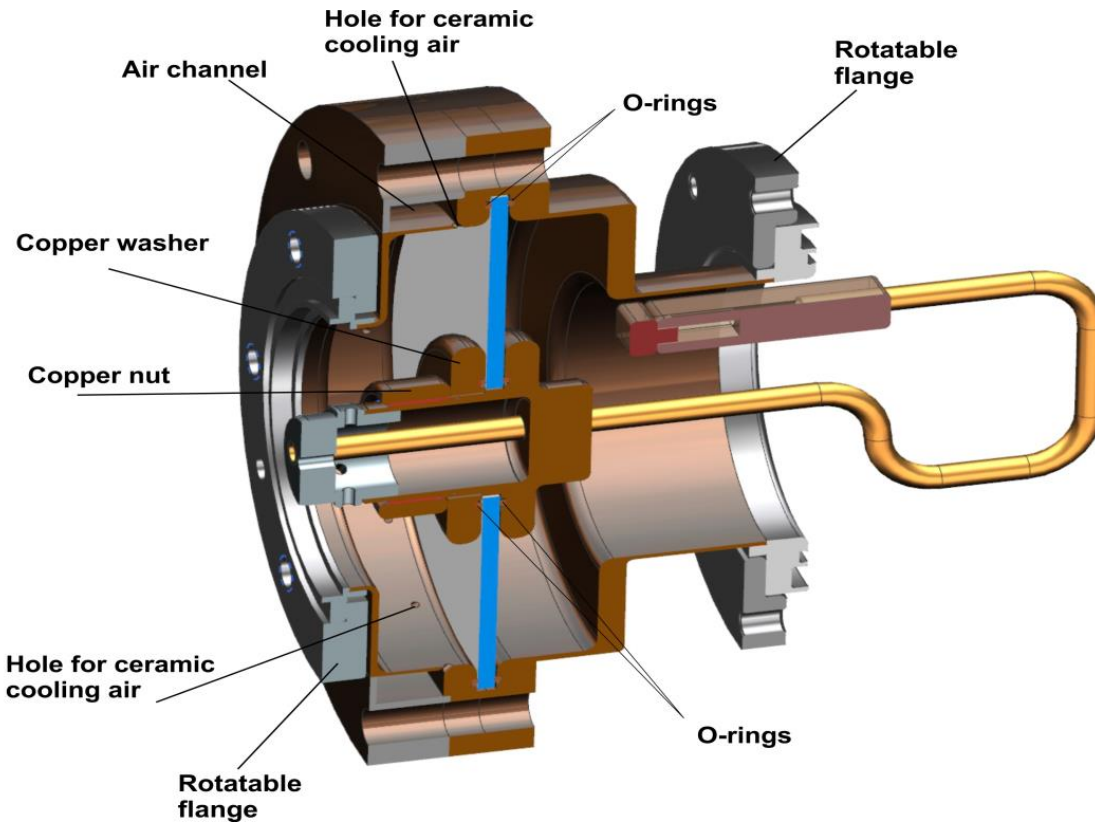
# Results of testing:

- **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  $\sim 500$  hours.**
- **Two windows were broken. The most probable reasons are not enough air cooling (by mistake).**

# New RF windows with replaceable ceramics.

We designed and built ceramic windows units with bigger and replaceable ceramics. Ceramic disk is vacuum sealed by Viton rings. We expect that new window will be powerful. In case of broken window the ceramic disk can be change easily for new one

( cost of ceramic disk < 1 k\$, cost of brazing unit ~10 ~20k\$)



Ceramic diameter 6'  
Ceramic thickness 4 mm





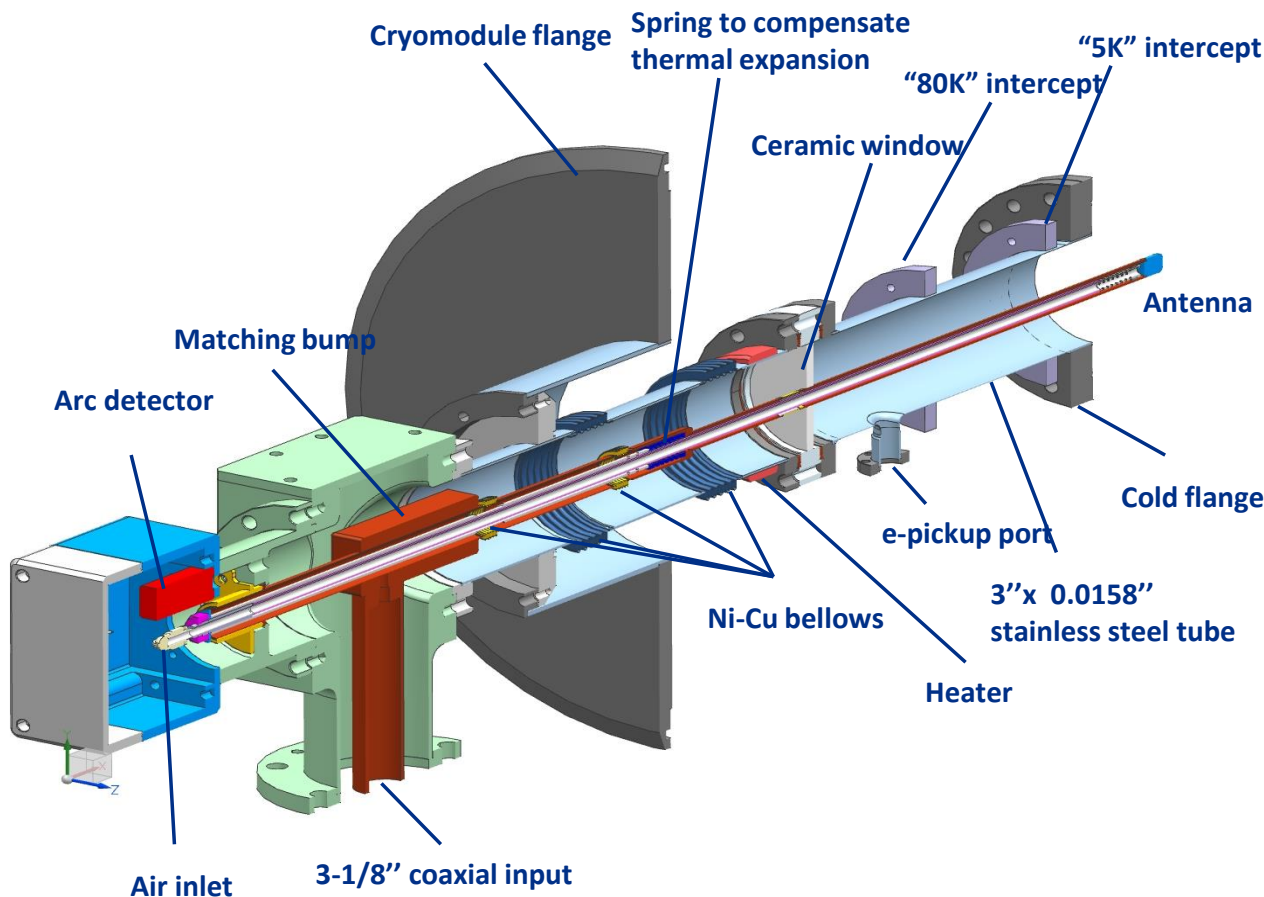
# SSR1 & SSR2, 325 MHz coupler:

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, not Cu coated.

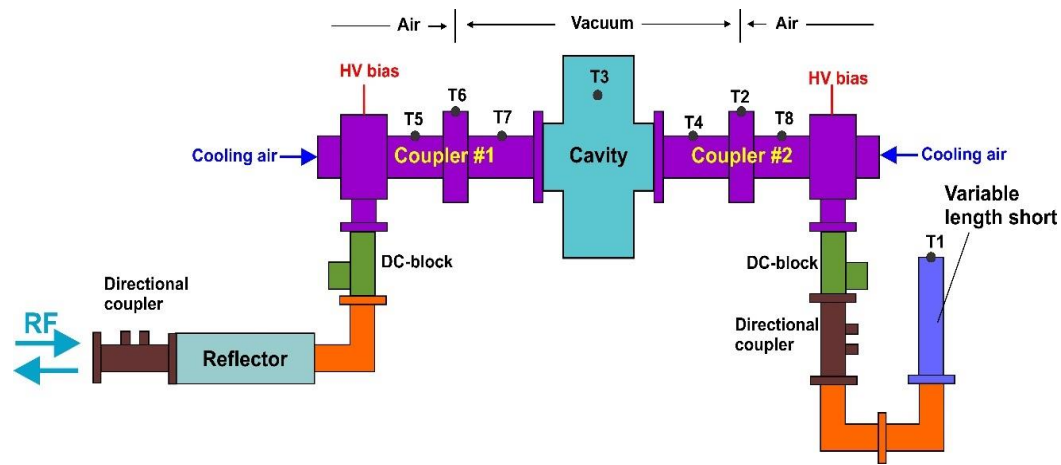


Impedance of  
vacuum part 105 Ohm

Thermal properties of coupler:

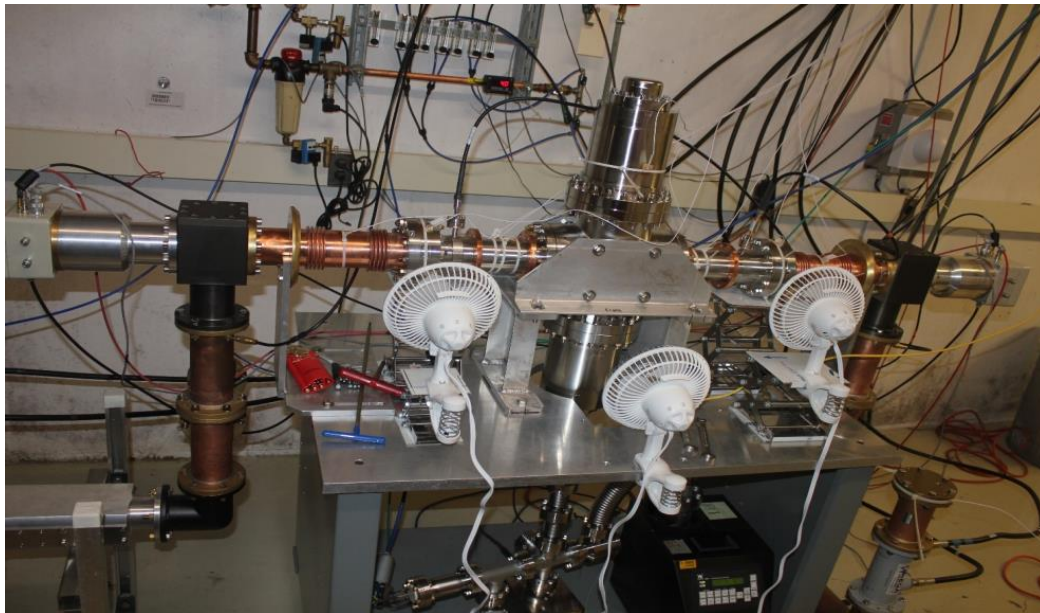
P, kW	"2K ", W	"5K", W	"70K", W
0	0.06	0.58	2.02
3	0.10	0.81	2.35
6	0.15	1.03	2.68
20	0.35	2.07	4.25
30	0.50	2.82	5.36

# Results of testing, 325 MHz couplers:



- Pair of couplers were successfully tested up to 30 kW, CW, full reflection, 90 dgr. step reflection phase.

## Test stand of 325 MHz couplers

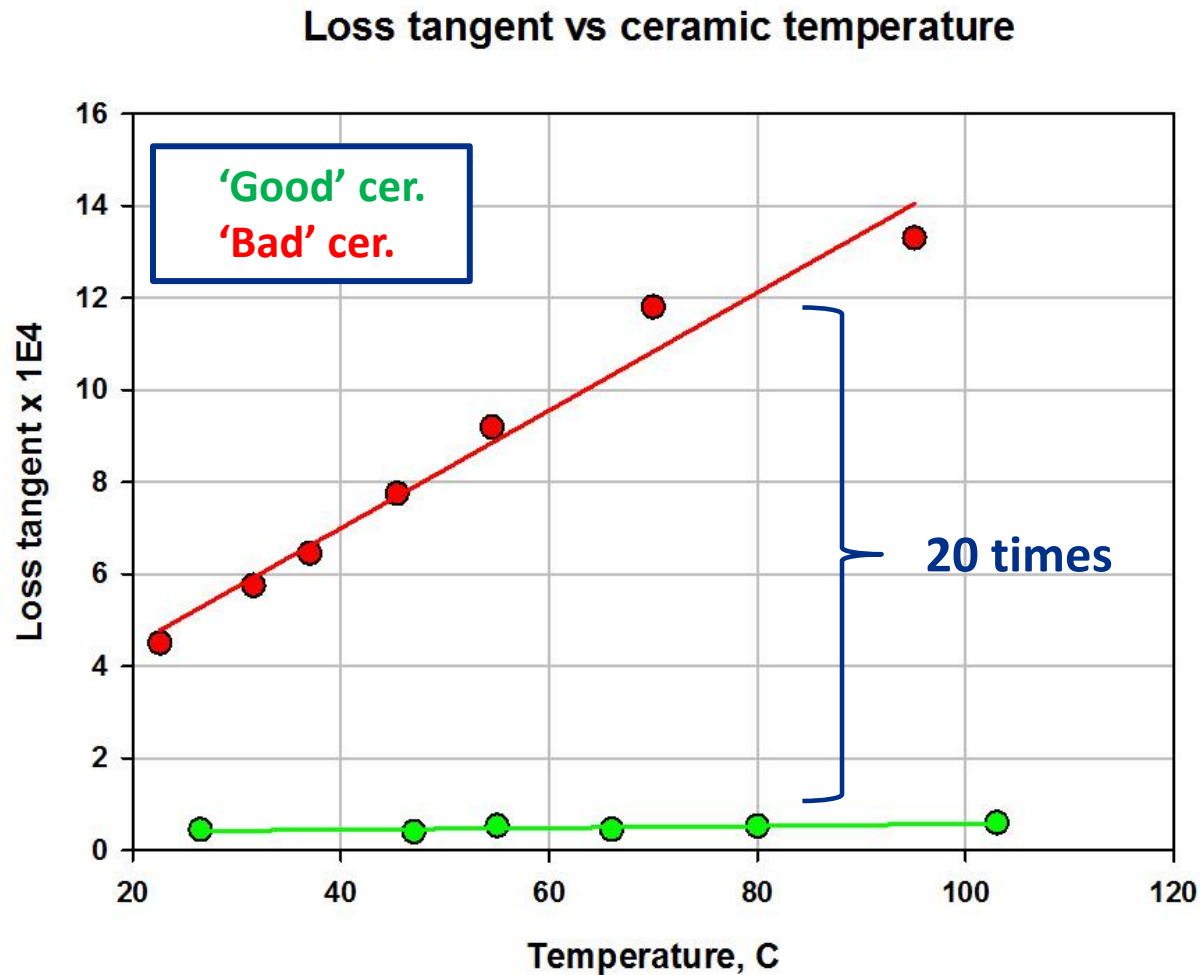


### Problems:

- Difficult to find experienced vendor. Four (in USA) companies were tried. Only one works properly – CPI.
- The quality of ceramics is not always good enough.

One window was broken during the high power test at 20 kW level( CW, full reflection).  
The reason is lossy ceramic.

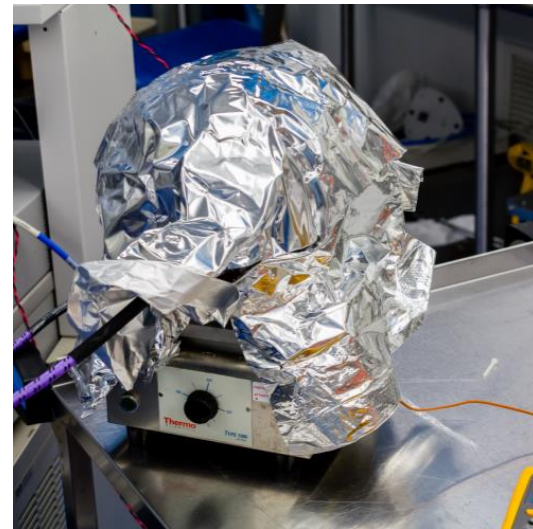
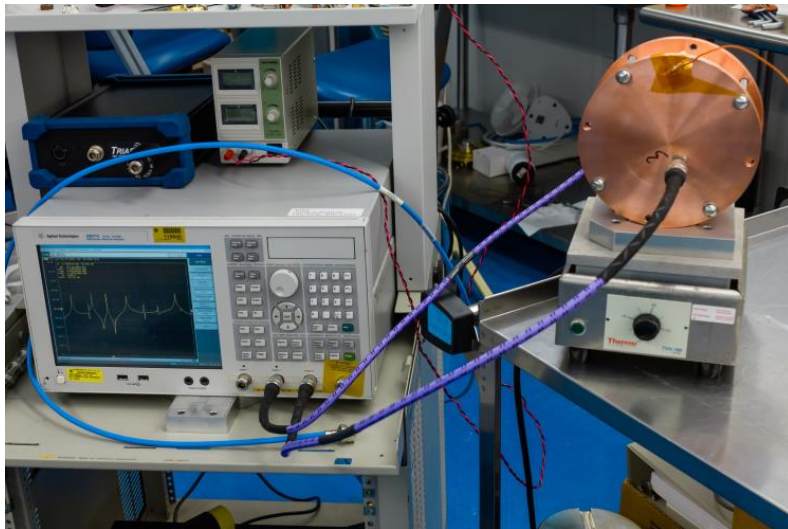
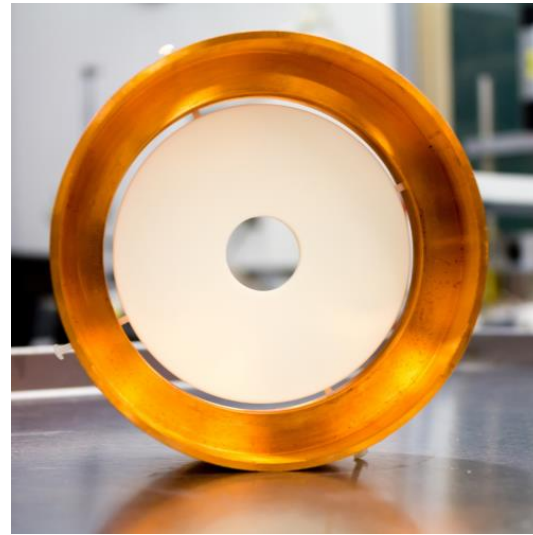
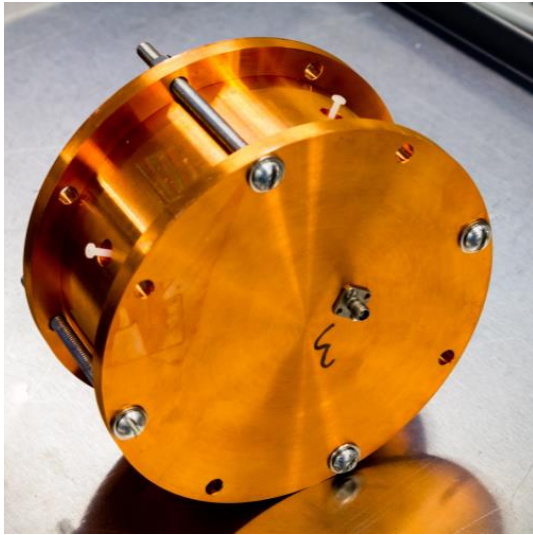
The same vendor, same composition, but losses is 20 times higher and there is a strong dependence of losses on temperature:





# Setup for ceramics measurements

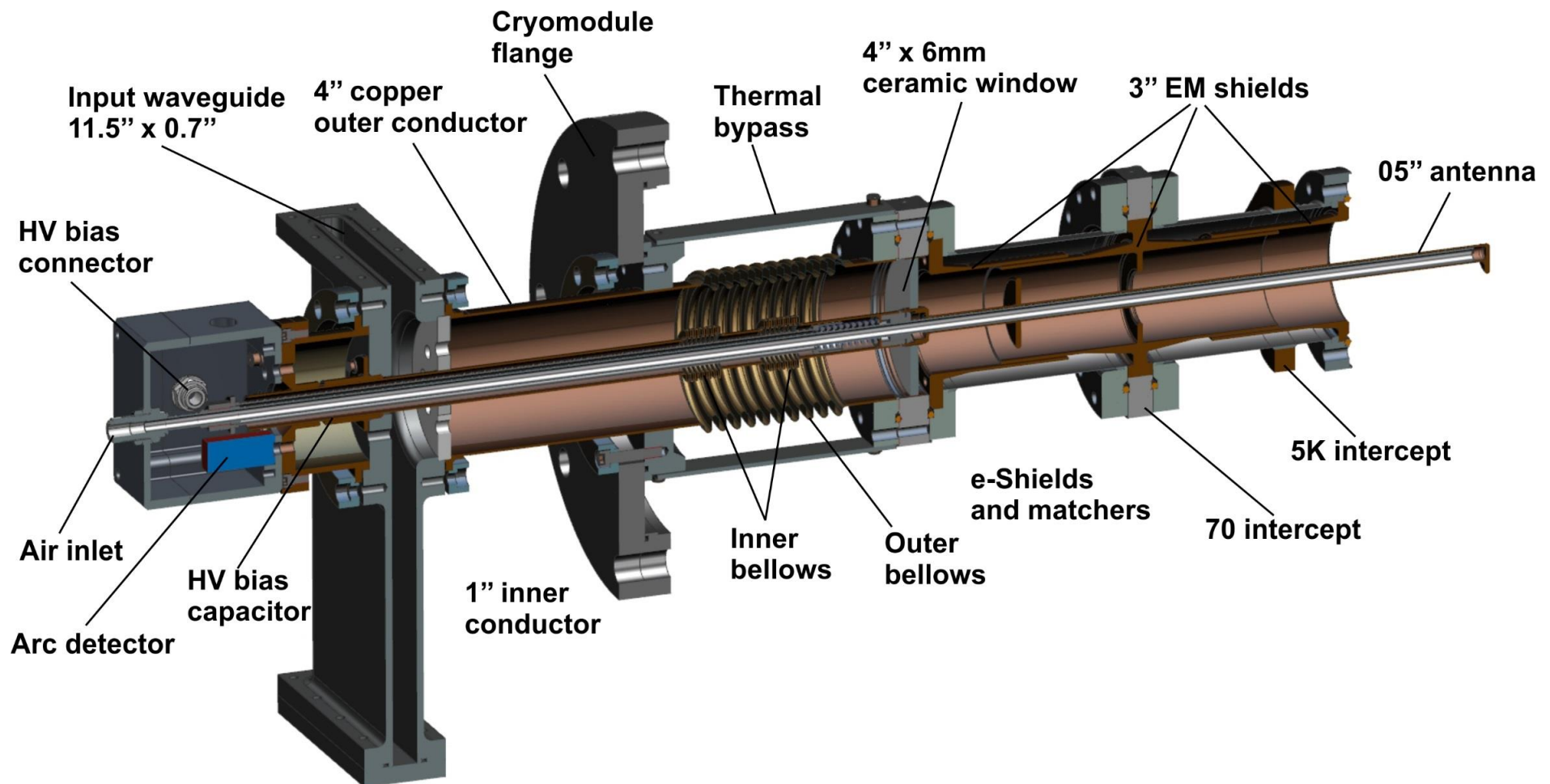
Now we control each disks at room temperature. If all disks are similar in bunch, one disk is measured for temperature dependence.



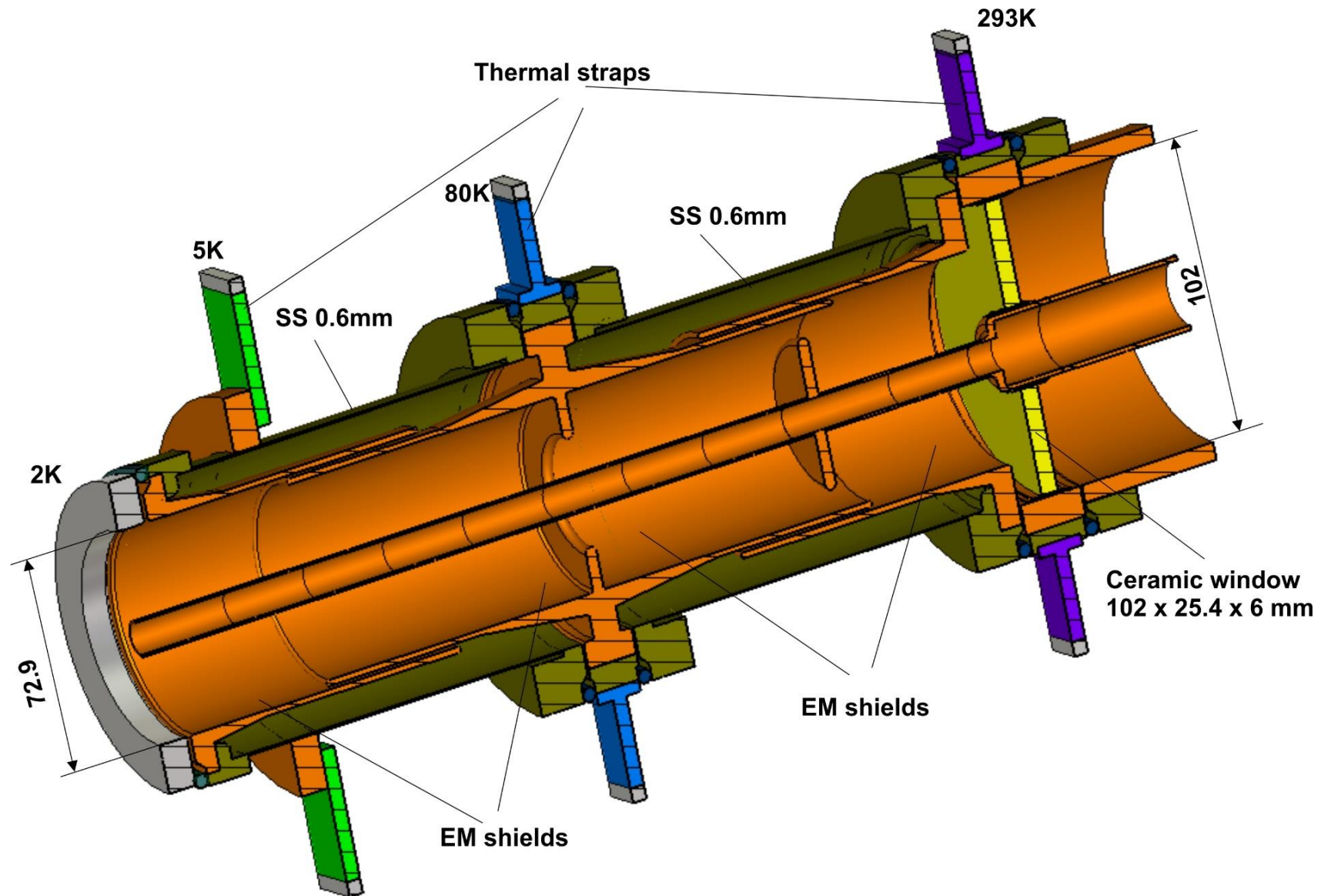


# LB & HB, 650 MHz coupler, new design.

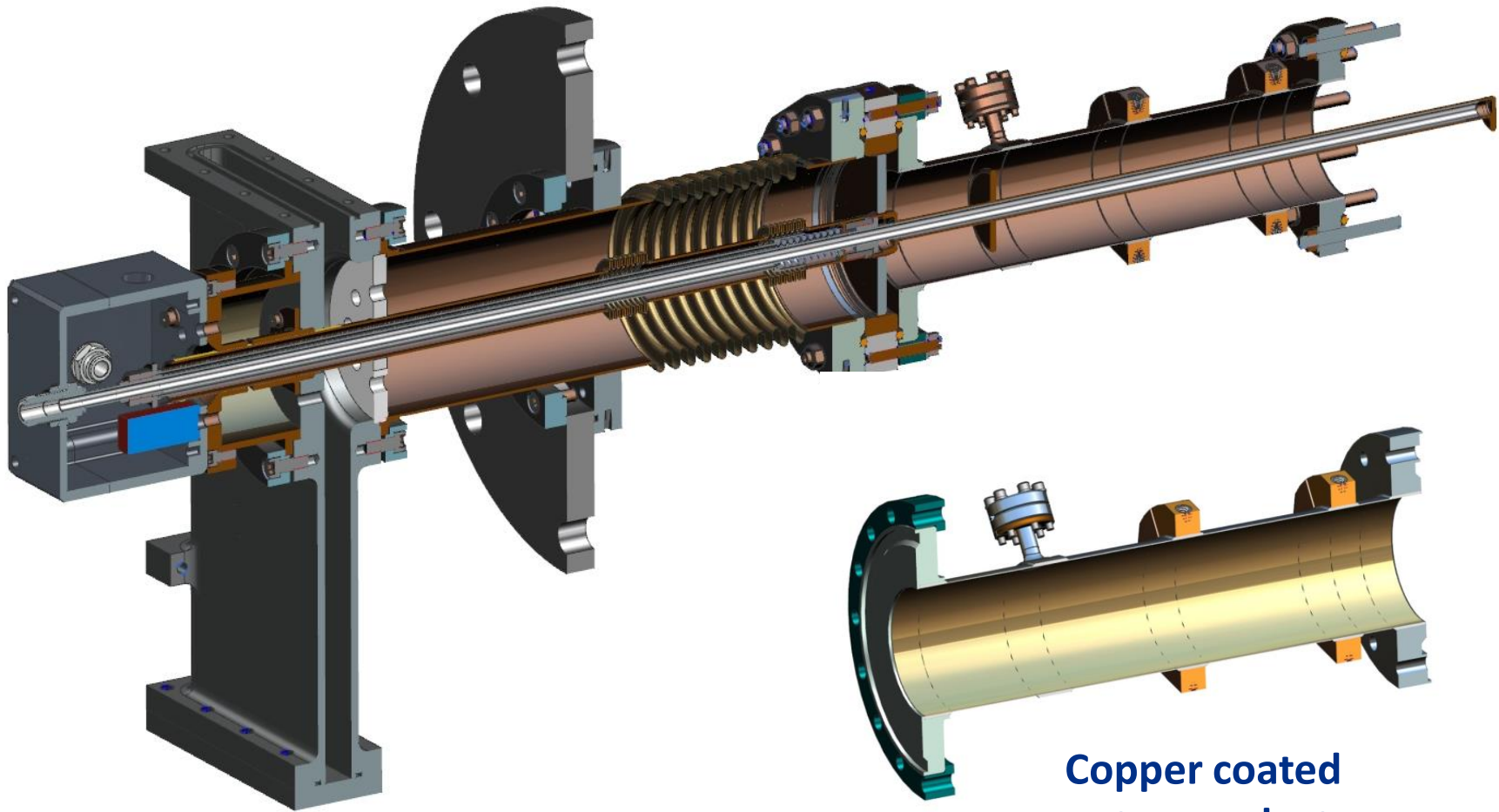
Designed power – 100 kW, CW



# Vacuum part of 650 MHz coupler, new design



# LB & HB, 650 MHz coupler, conventional design



Copper coated  
outer conductor

# Thermal properties of 650 MHz couplers

	2K, W	5K, W	70K, W	293K, W
New, 0 kW	0.15	0.6	3.3	-2.7
New, 100 kW	0.55	0.93	6.2	21
Conv., 0 kW	0.41	1.46	3.0	-3.1
Conv., 100 kW	0.97	4.1	11.4	20

## Cryo-plant power:

**New** =  $0.55 \cdot 960 + 0.93 \cdot 220 + 6.2 \cdot 20 = 857$  W of cryo-plant.

**Conv.** =  $0.97 \cdot 960 + 4.1 \cdot 220 + 11.4 \cdot 20 = 2061$  W of cryo-plant.

**New design requires ~ 2.4 times more efficient.**

**Two prototypes of new design and two prototypes of conventional design are under production.**

# Our experience:

## RFQ, 162.5 MHz coupler

- Two 3'' RF windows broken after 500 h of CW – lack of cooling.
- New 6'' RF windows with replaceable ceramics are designed and built. Windows are installed to RFQ for test.

## SSR, 325MHz coupler

- Couplers were tested and satisfy the requirements.
- There are issues with production - not experienced vendors.
- Ceramic quality is important, each disc must be controlled .

## 650 MHz coupler.

- New design without copper coating is completed.
- Coupler prototypes are under production.