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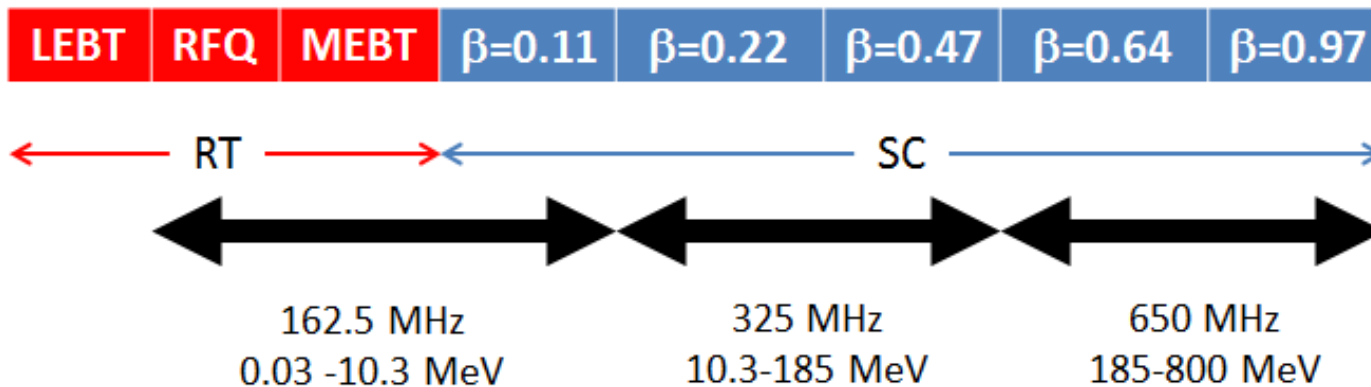
Fundamental Couplers for PIP-II, design and operation experience.

Sergey Kazakov,
Cryomodule Workshop
September 7, 2018, BARC, Mumbai, India

PIP-II couplers

PIP-II project:

Performance Parameter	Value	Unit
Particle species	H ⁻	
Linac Beam Energy	800	MeV
Linac Beam Current	2	mA
Linac Pulse Length	0.55 - CW	ms
Linac Pulse Repetition Rate	20 - CW	Hz



PIP-II couplers

- **Room temperature cavities:**
 - RFQ.
 - Bunching cavities (4 pc).
- **5 types of superconductive cavities:**
 - Half Wave Resonators, HWR (8 pc).
 - Superconductive Spoke Resonator 1, SSR1 (16 pc).
 - Superconductive Spoke Resonator 2, SSR2 (35 pc).
 - Low Beta 650 MHz Cavity, LB 650 (33 pc).
 - High Beta 650 MHz Cavity, HB 650 (24 pc).

Total number of couplers: 122.

PIP-II couplers

Requirements to couplers:

(Requirements meets CW version of PIP-II with 5 mA current.
Requirements are revised now for 2 mA version.)

RFQ coupler:

Frequency 162.5 MHz
Power 75 kW, CW

SSR1 & SSR2 coupler:

Frequency 325 MHz
Power 30 kW, CW

Bunching coupler:

Frequency 162.5 MHz
Power 3 kW, CW

LB & HB 650 coupler:

Frequency 650 MHz
Power 110 kW, CW

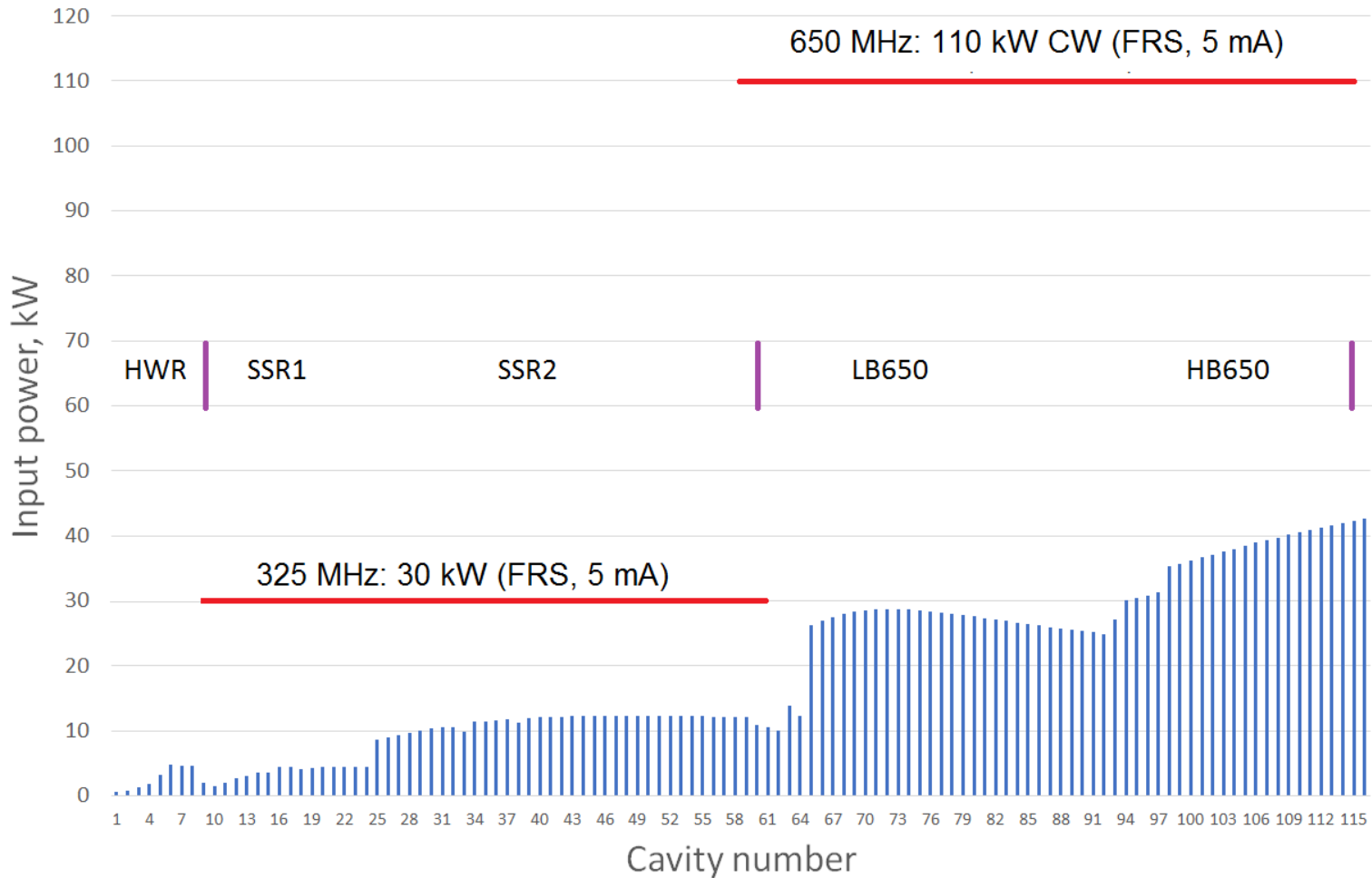
HWR coupler:

Frequency 162.5 MHz
Power 10 kW, CW

All couplers were designed and all, except 650 MHz couplers, were built and tested.

PIP-II couplers

Power consumption of the cavities at 2 mA in the nominal regime.

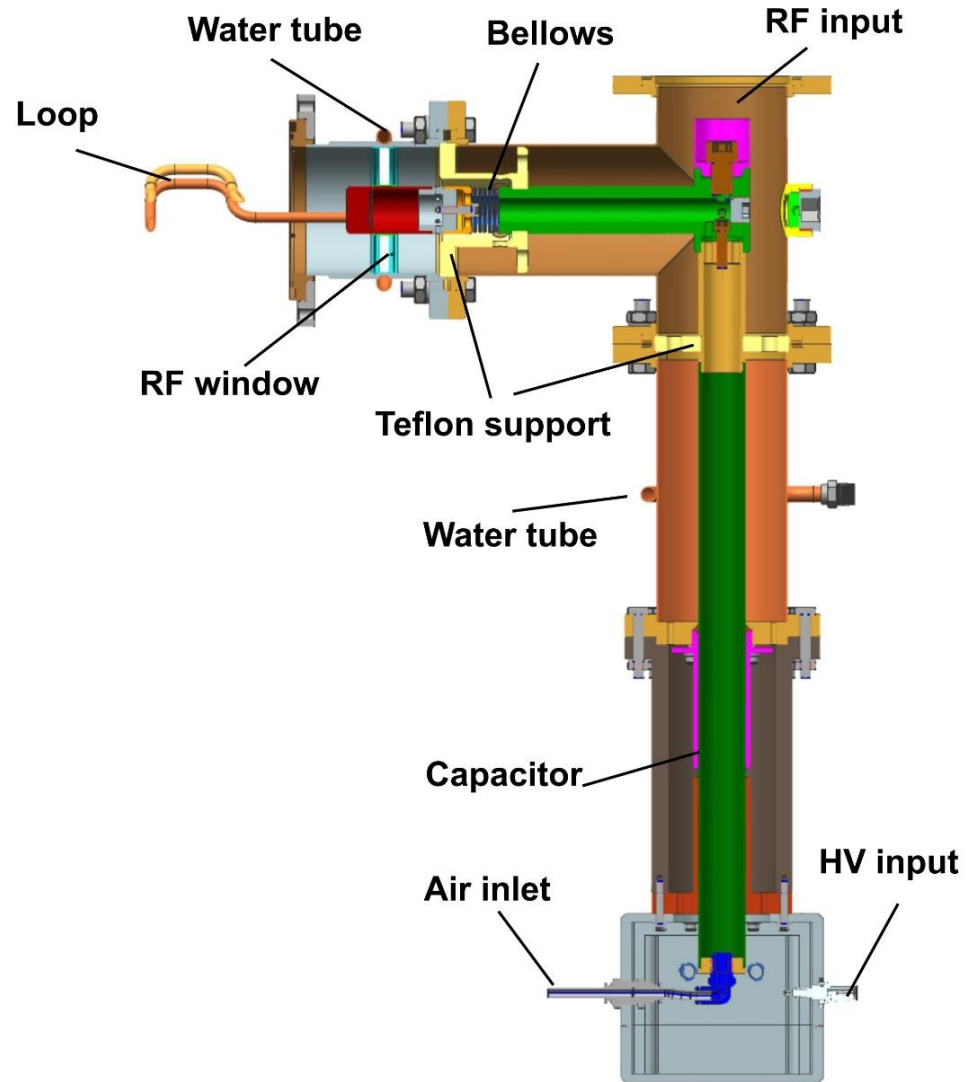
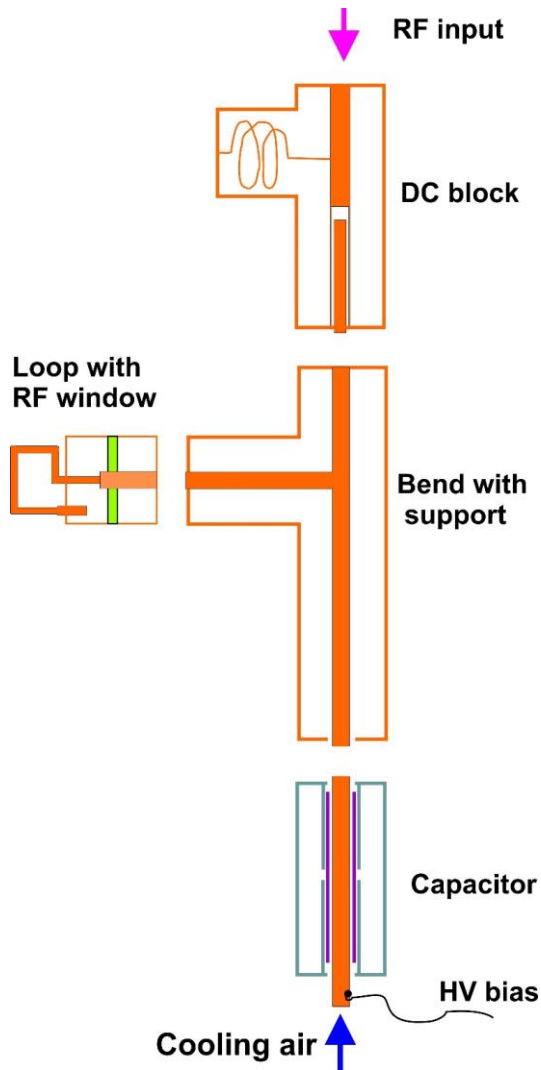


PIP-II couplers

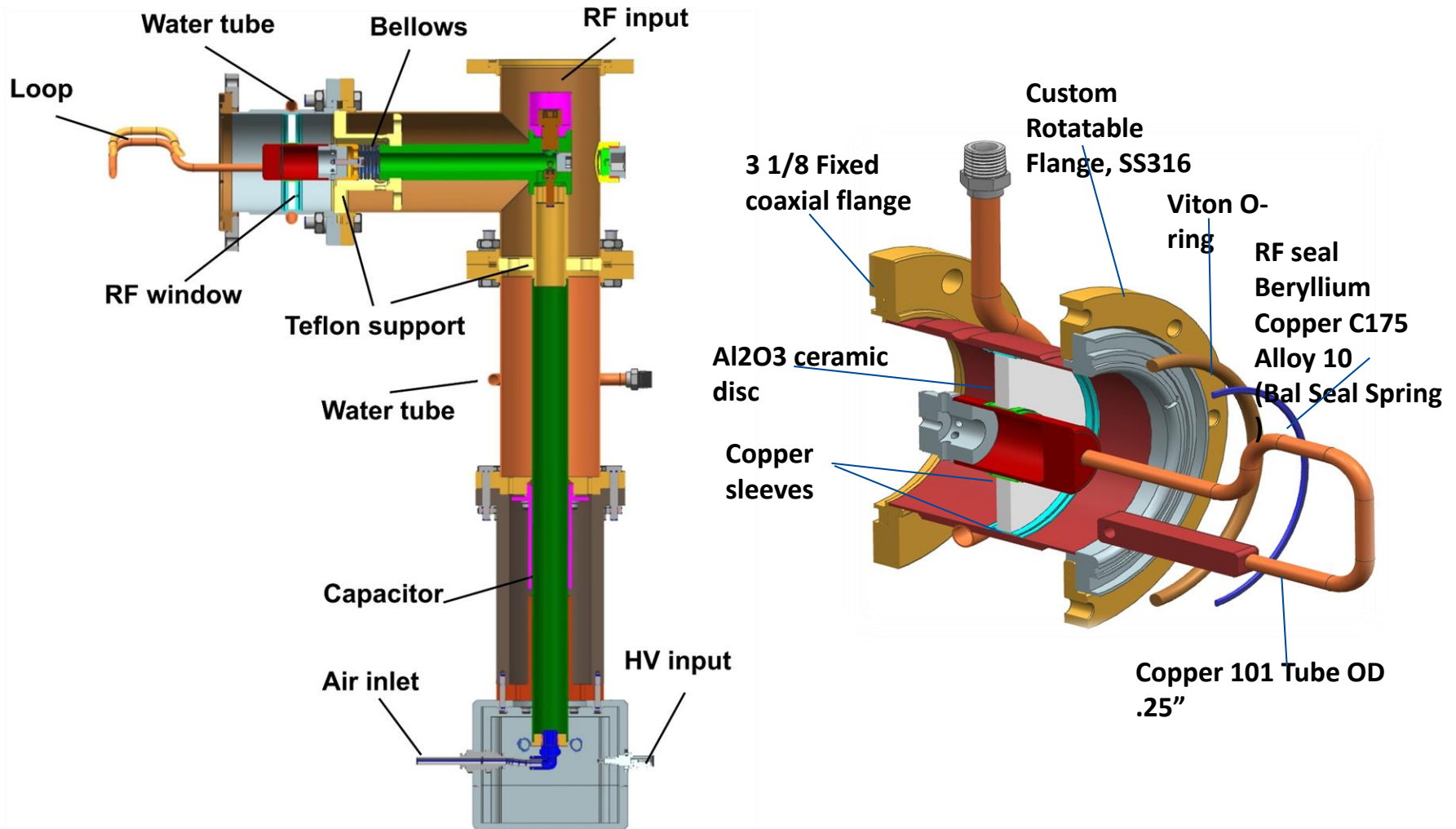
Principles of design:

- **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.**

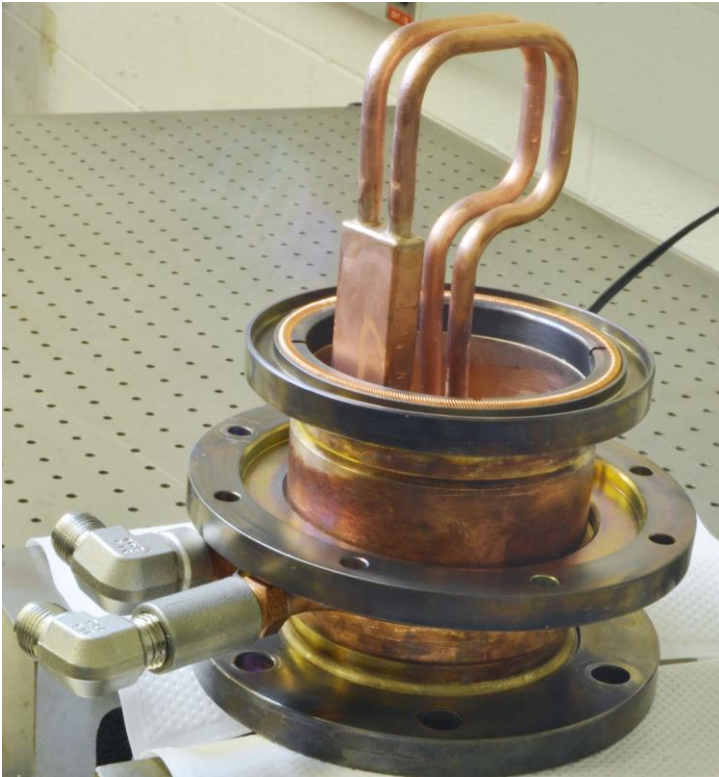
162.5 MHz RFQ coupler, logic of configuration



162.5 MHz RFQ coupler



162.5 MHz RFQ coupler

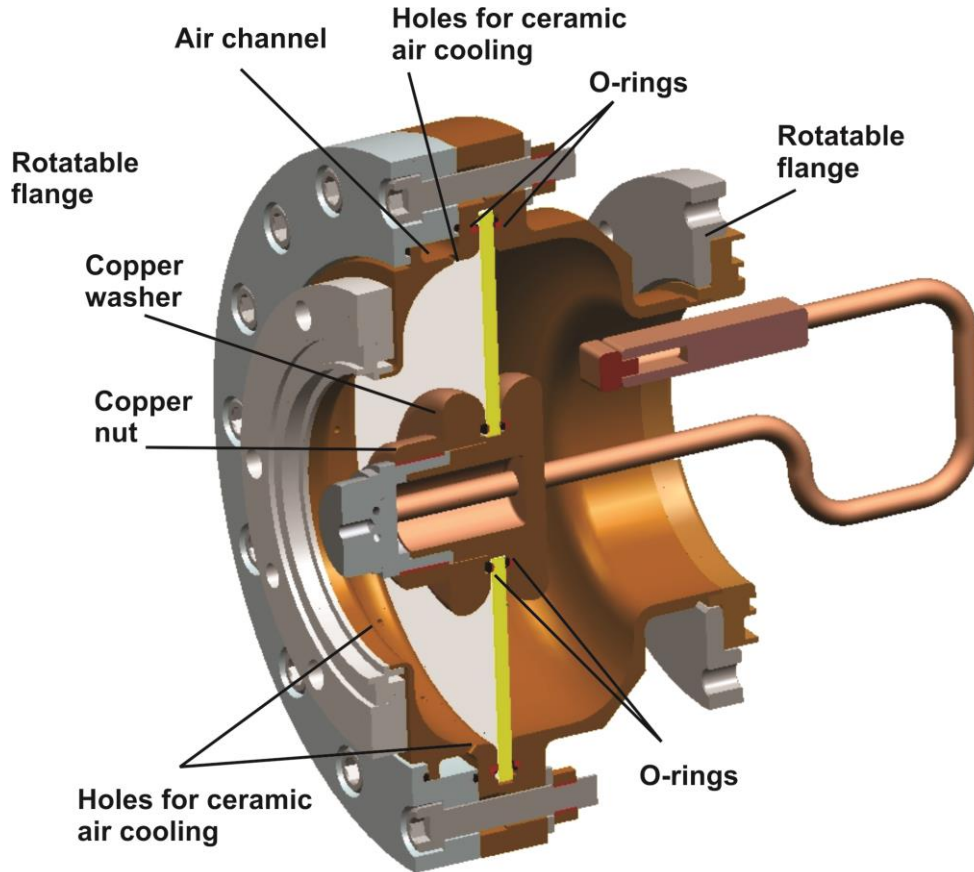


Two coupler and four windows unit were produced.

Two windows failed after ~ 500 h work in CW mode.

162.5 MHz RFQ coupler

Windows with replaceable ceramic and Viton O-rings were designed.

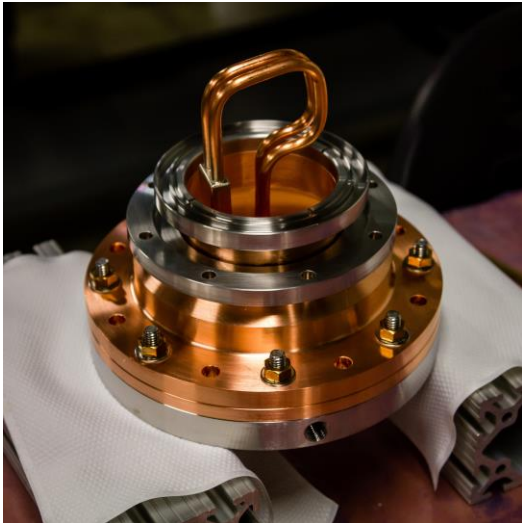
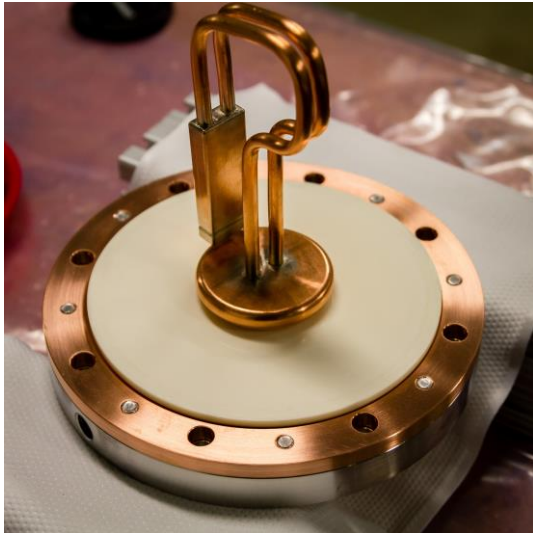


Diameter of ceramics was increased up to 6”.

In case of broken window (broken ceramics), the ceramics can be replaced easily (and one order less expensive).

We have 8 spare ceramic disk on the shelf.

162.5 MHz RFQ coupler



162.5 MHz RFQ coupler

We hope we solved the problem with RFQ couplers.
Ceramics is large, stresses are small. Multipactor is suppressed by HV bias.

Couplers works already more then 8 months in CW mode.

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:

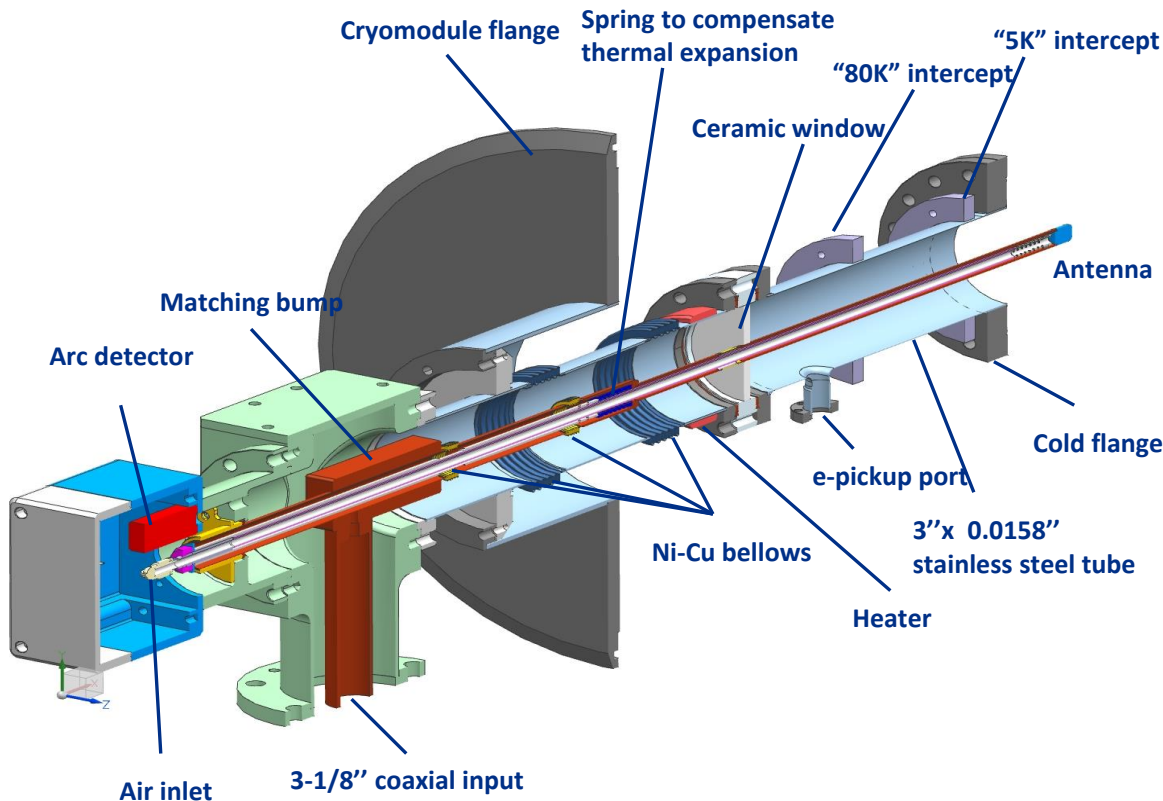
Copper 0.5", air cooled, HV bias.

Outer conductor:

SS, ID 73mm (2.78"),
0.4mm wall thickness,
no Cu coating.

**Thermal properties of coupler
(without thermal radiation of antenna):**

P, kW	"2K", W	"5K", W	"70K", W
0	0.07	0.35	1.9
10	0.20	0.62	4.6
20	0.33	0.89	5.7



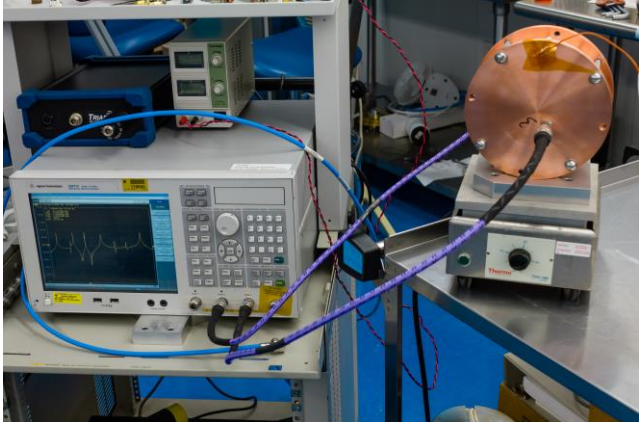
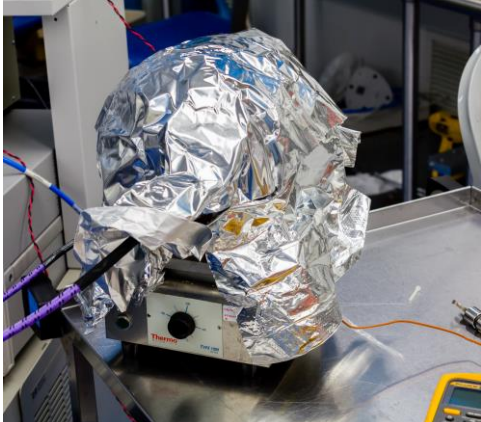
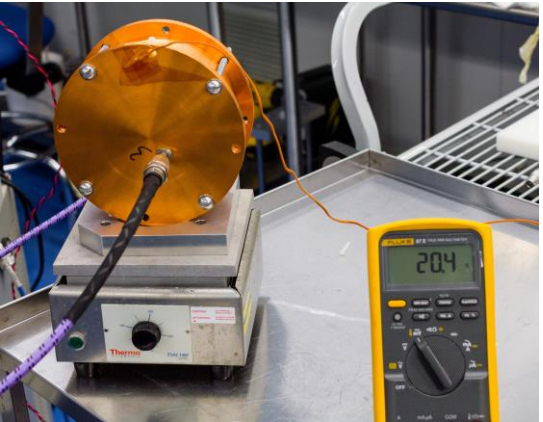
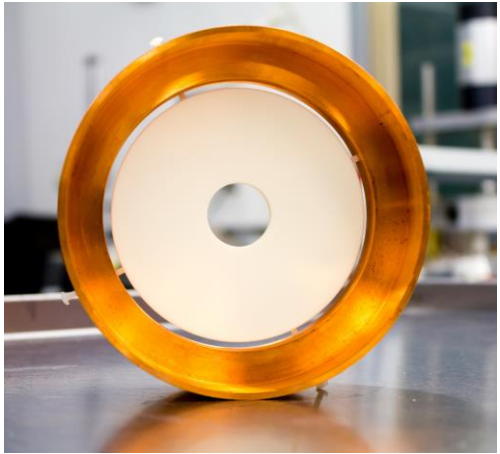
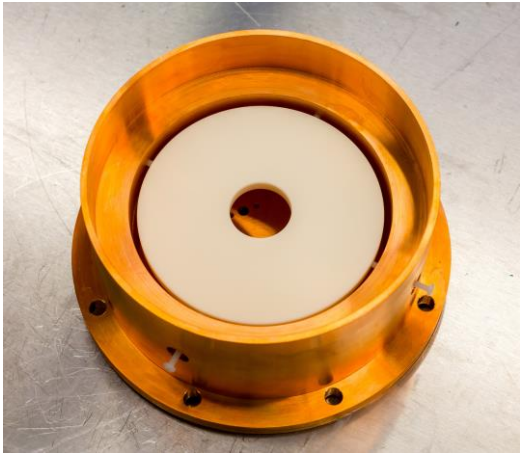
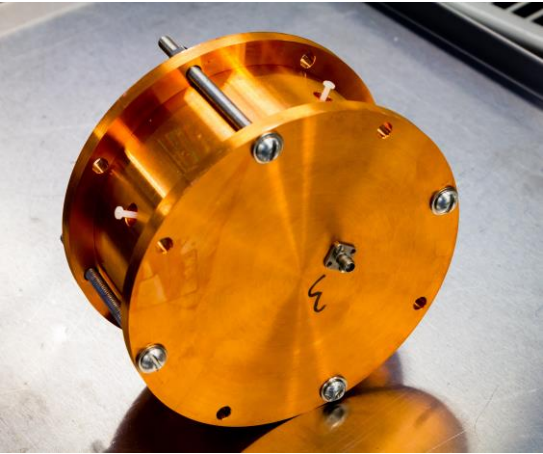
325 MHz coupler

Current status

- Couplers were successfully tested up to 30 kW, CW, full reflection, 90 dgr. step reflection phase.
- Couplers were tested up to failure. Window was destroyed at 47 KW, CW, full reflection.
- 11 antenna with windows were produced by CPI.
- 1 antenna with windows was produced by CoorsTek, 4 are under production
- 6 cavity were qualified with couplers (ready to be installed to cryomodule). Additional 2 cavity will be qualified soon.

325 MHz coupler

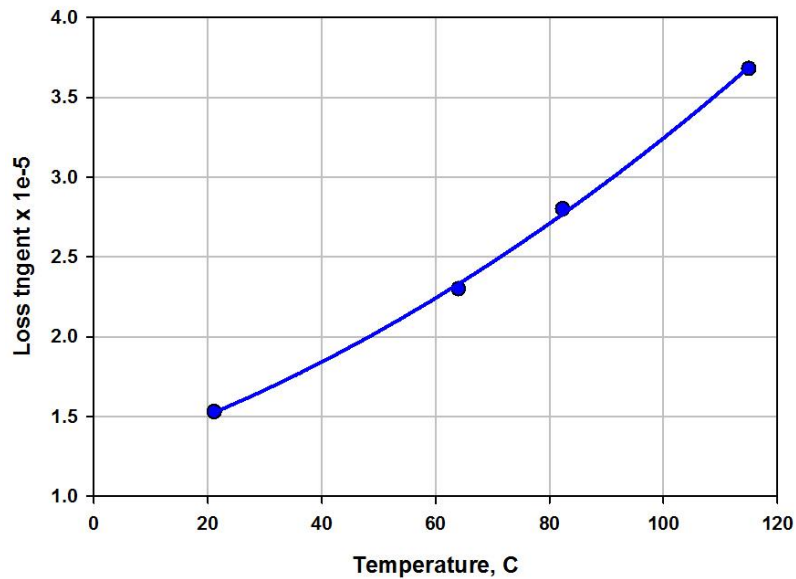
Each ceramic disk is measured before to be brazed.



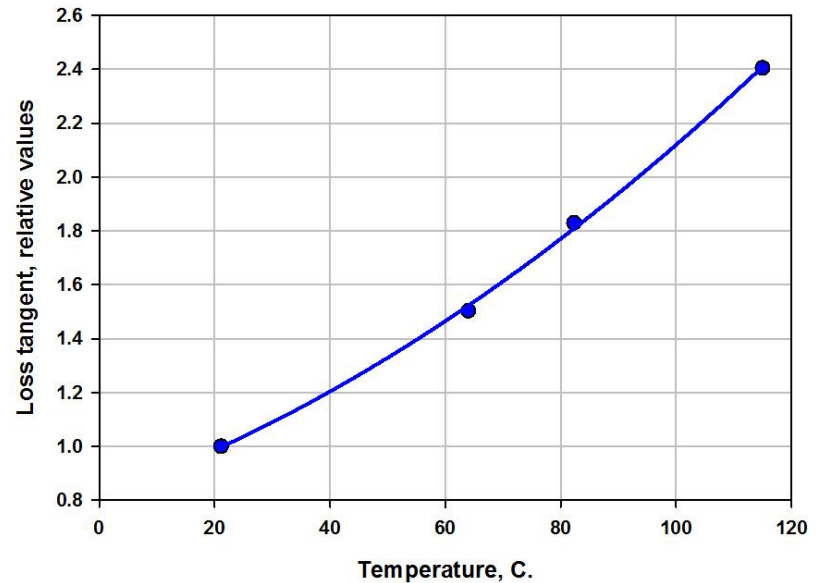
325 MHz coupler

CoorsTek ceramic measurements, $F \sim 2.7$ GHz

CoorsTek ceramics, 13 disks, 03/28/2018,
loss tangent, absolute values



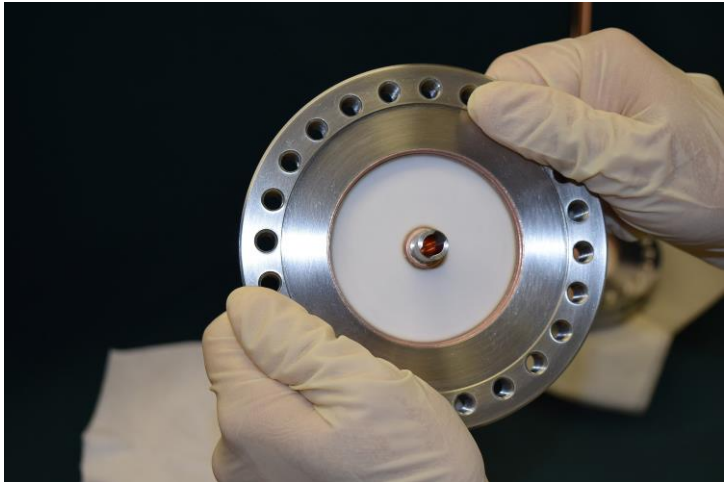
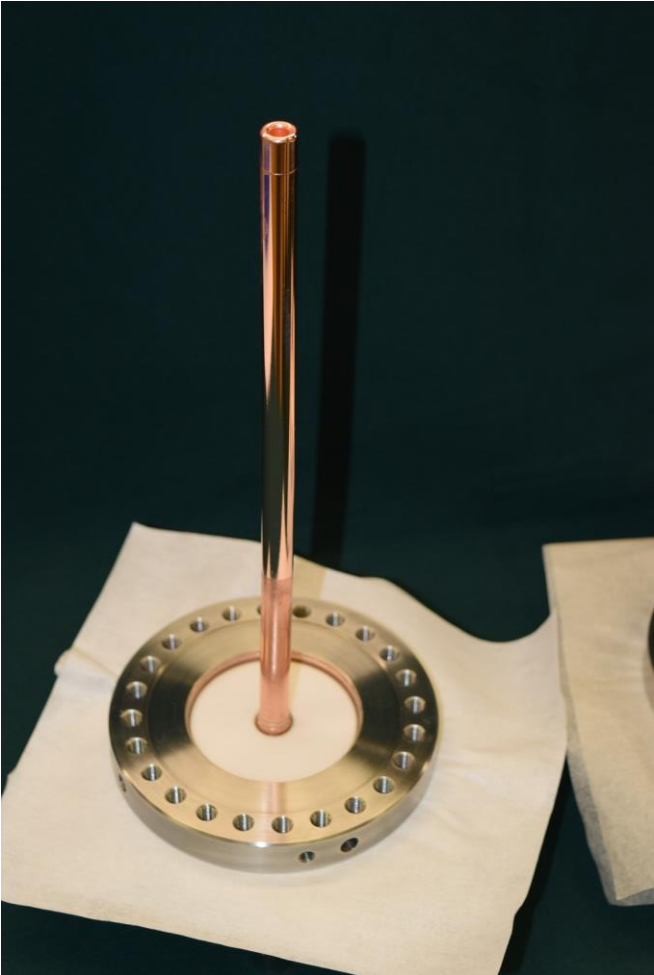
CoorsTek ceramics, 13 disks, 03/28/2018,
loss tangent, relative value.



Some times ceramics is extremely good: loss tangent $\sim 1.5E-5$ at 2.7 GHz

325 MHz coupler

Antenna made by CPI

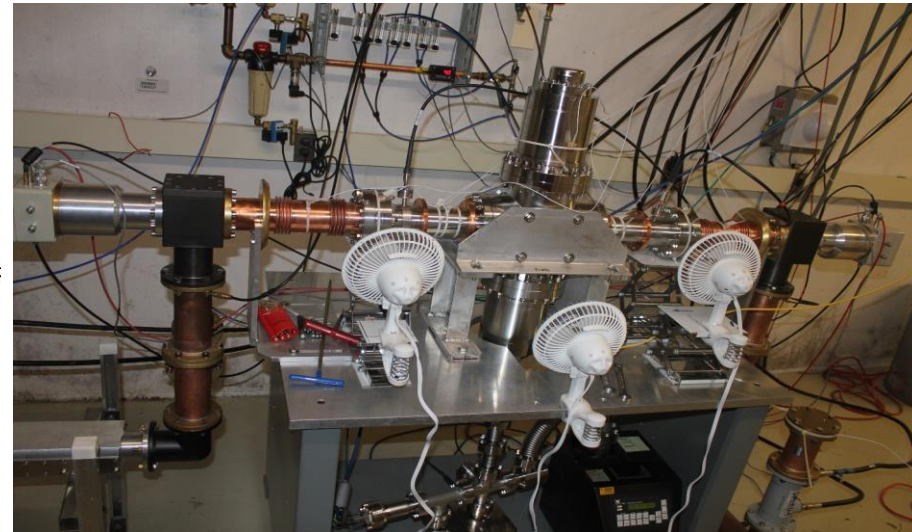
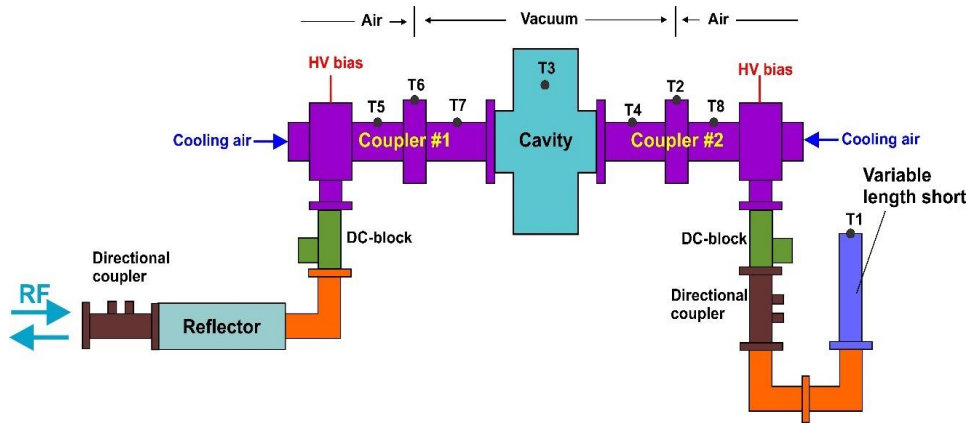


325 MHz coupler

Coupler qualification:

Each couplers (each pair of couplers) is qualified at test stand.

Qualification: running coupler at full reflection mode, CW, at qualification power level for ~ 2 hours at each reflecting phase point. It is 4 phase point with 90 dgr. steps. Total time ~ 8 hours. Qualification power depends on operating power. It is still debated how much it shall be. Qualification is not conditioning. After qualification the couplers are re-cleaned and installed to cavity without conditioning. **Really, the couplers do not require a conditioning. HV bias suppresses any activity.**



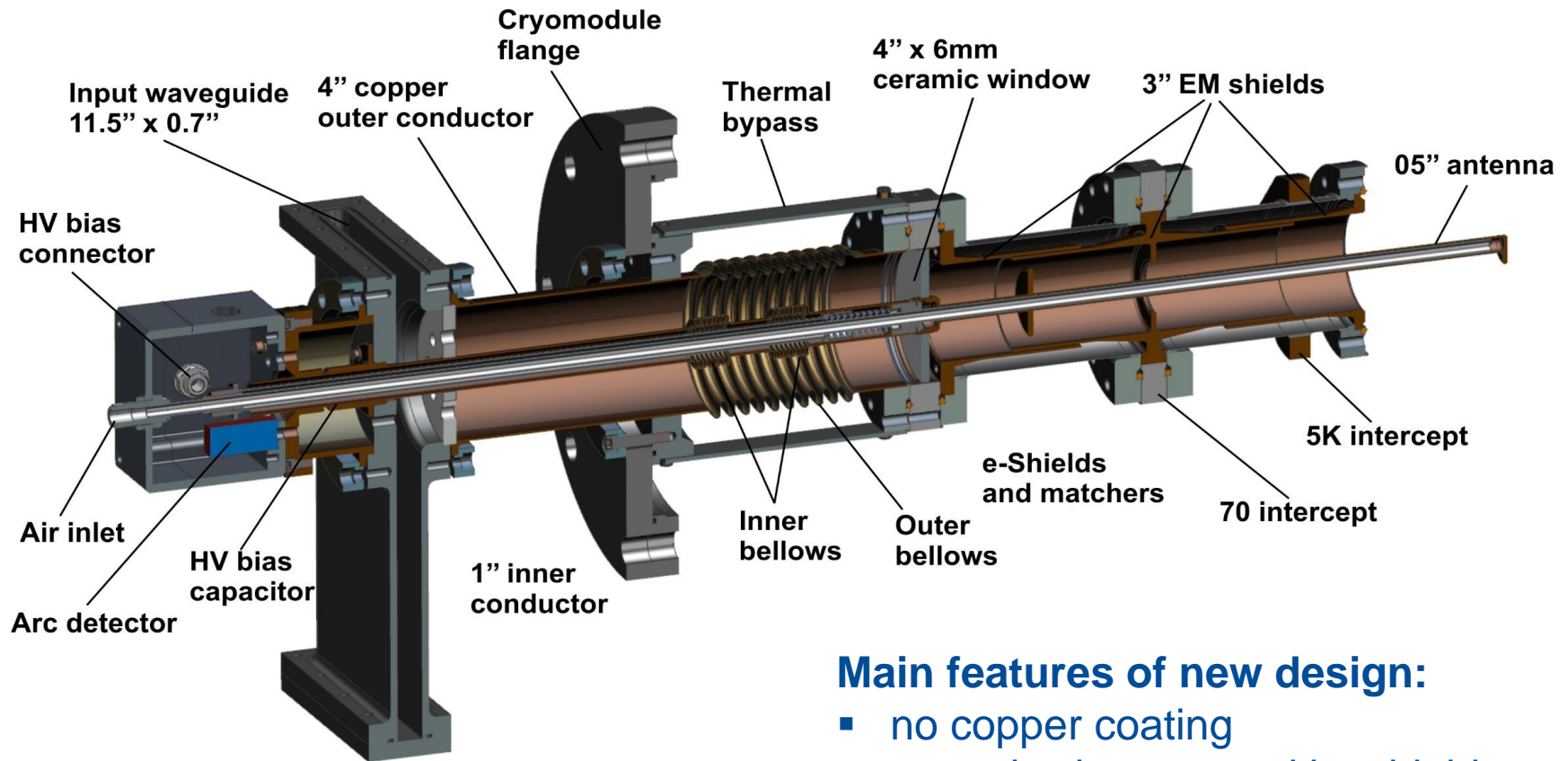
325 MHz coupler

Problem and issues with current design:

- Wall thickness of vacuum outer conductor is rather small, 0.4 mm. It causes difficulties for handling. The wall thickness is increased up to 0.8 mm.

650 MHz coupler

LB & HB coupler, new design

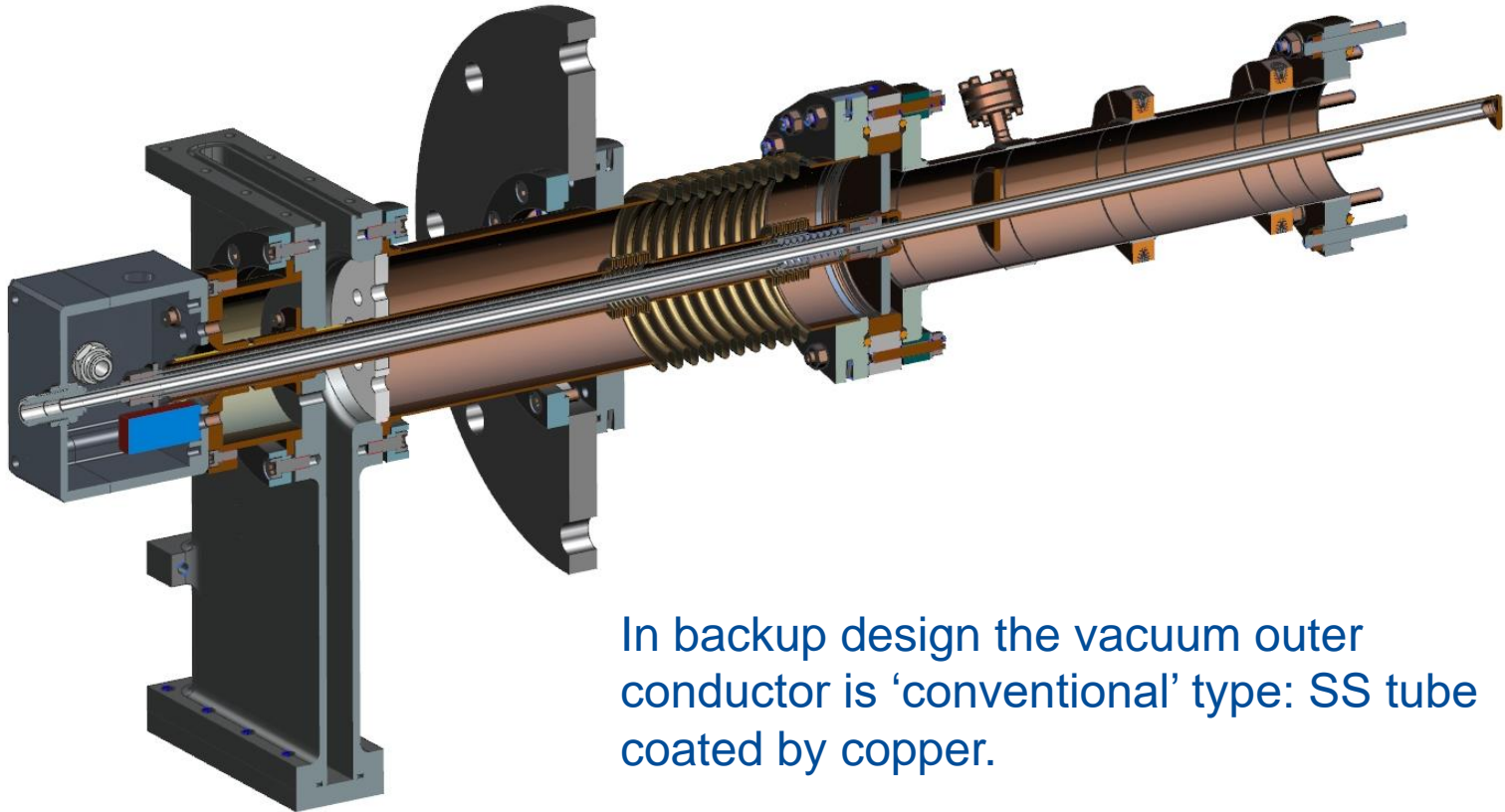


Main features of new design:

- no copper coating
- ceramics is protected by shields
- better cryogenics properties

650 MHz coupler

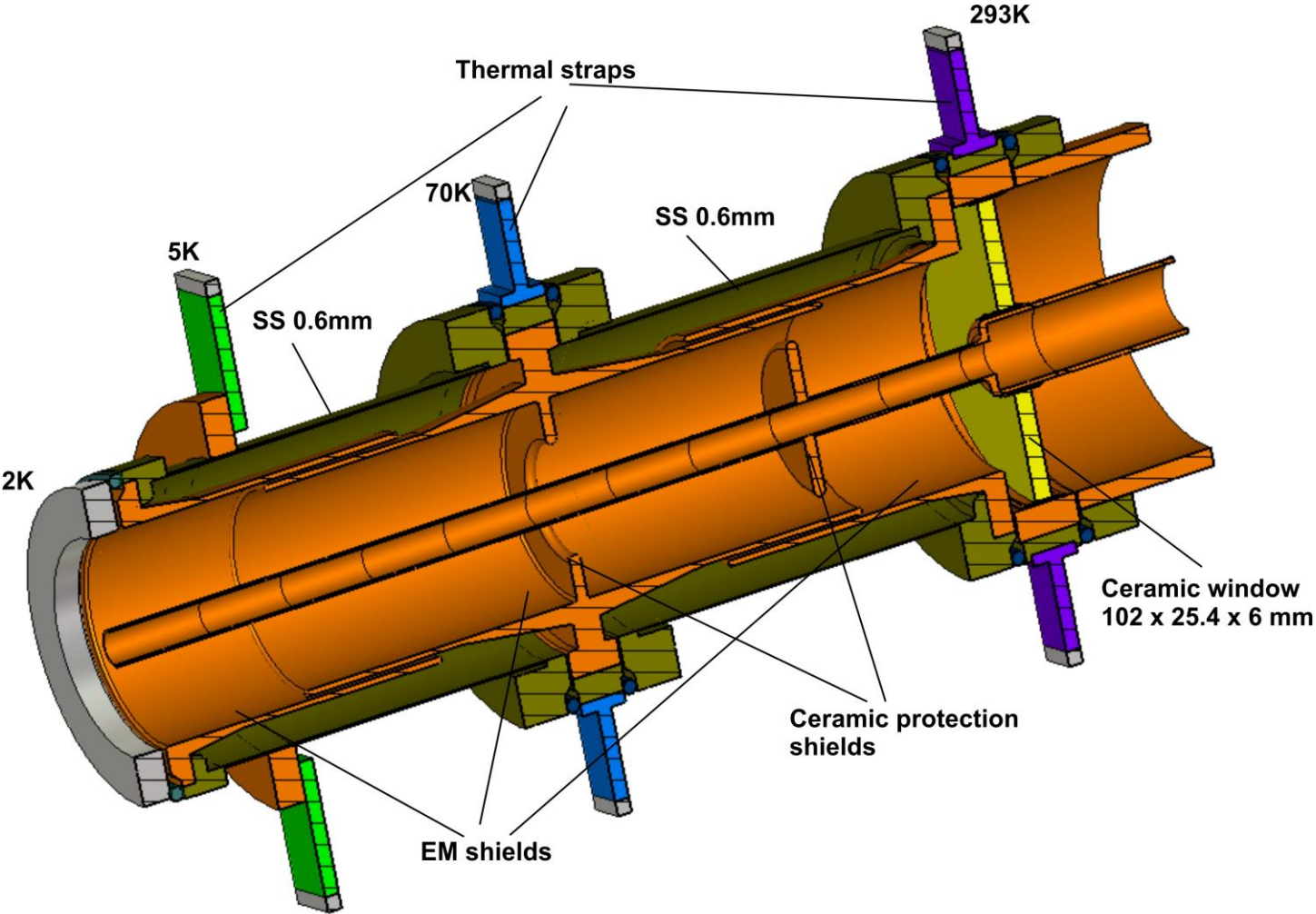
LB & HB coupler, backup design



In backup design the vacuum outer conductor is 'conventional' type: SS tube coated by copper.

650 MHz coupler

Vacuum part of coupler, new design



650 MHz coupler

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
Bckp, 0 kW	0.41	1.46	3.0	-3.1
Bckp, 100 kW	0.97	4.1	11.4	20

100 kW:

New = $0.55 \cdot 960 + 0.93 \cdot 220 + 6.2 \cdot 20 = \mathbf{857 \text{ W}}$ of cryo-plant

Bckp = $0.97 \cdot 960 + 4.1 \cdot 220 + 11.4 \cdot 20 = \mathbf{2061 \text{ W}}$ of cryo-plant

New design requires ~ 2.4 times less power of cryo-plant.

650 MHz coupler

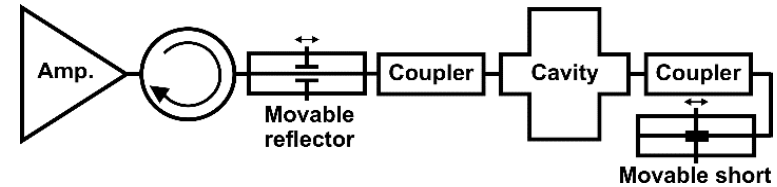
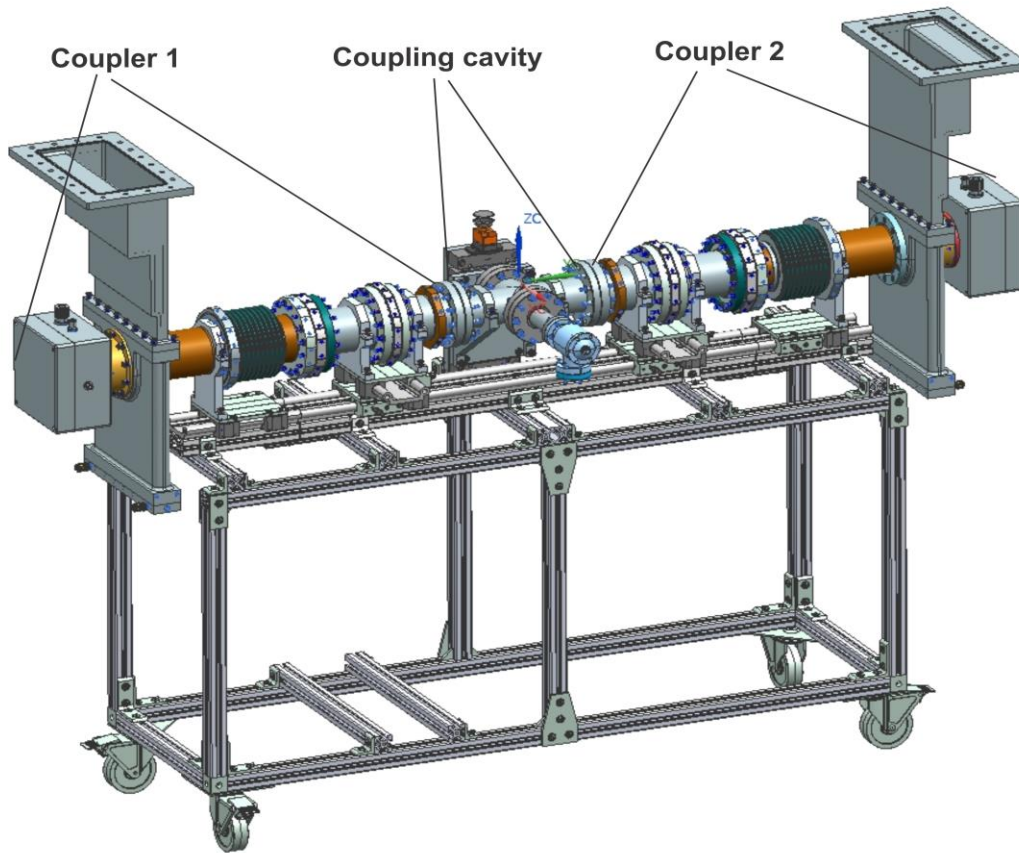
Current status

- Two coupler prototypes with four vacuum parts are under production.
- Four vacuum parts are already made by CPI.
- Test infrastructure is under construction.



650 MHz coupler

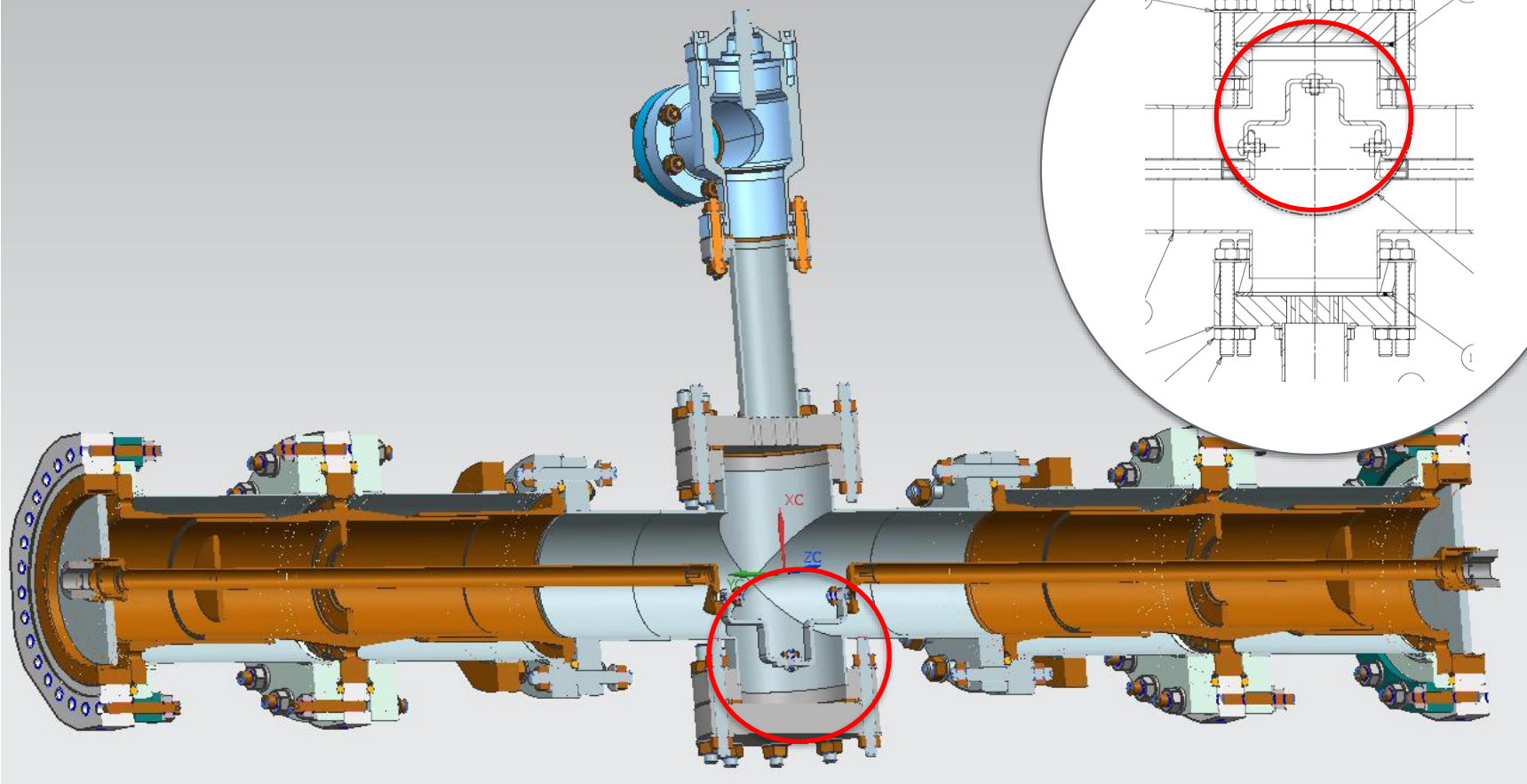
Couplers test bench.



Couplers will be tested in resonance mode with full reflected power. It will allow to increase the level of testing power more than 100 kW using 30 kW RF source.

650 MHz coupler

During the test (qualification the antennas will be connected electrically and mechanically).



After the test couplers will be re-cleaned.

650 MHz coupler

Current status.

Two vacuum parts of new design and two vacuum parts of backup design are produced by CPI.

Air parts of couplers are under production.

Test facility is under development.

First high power run is planned to be performed on December 2018.

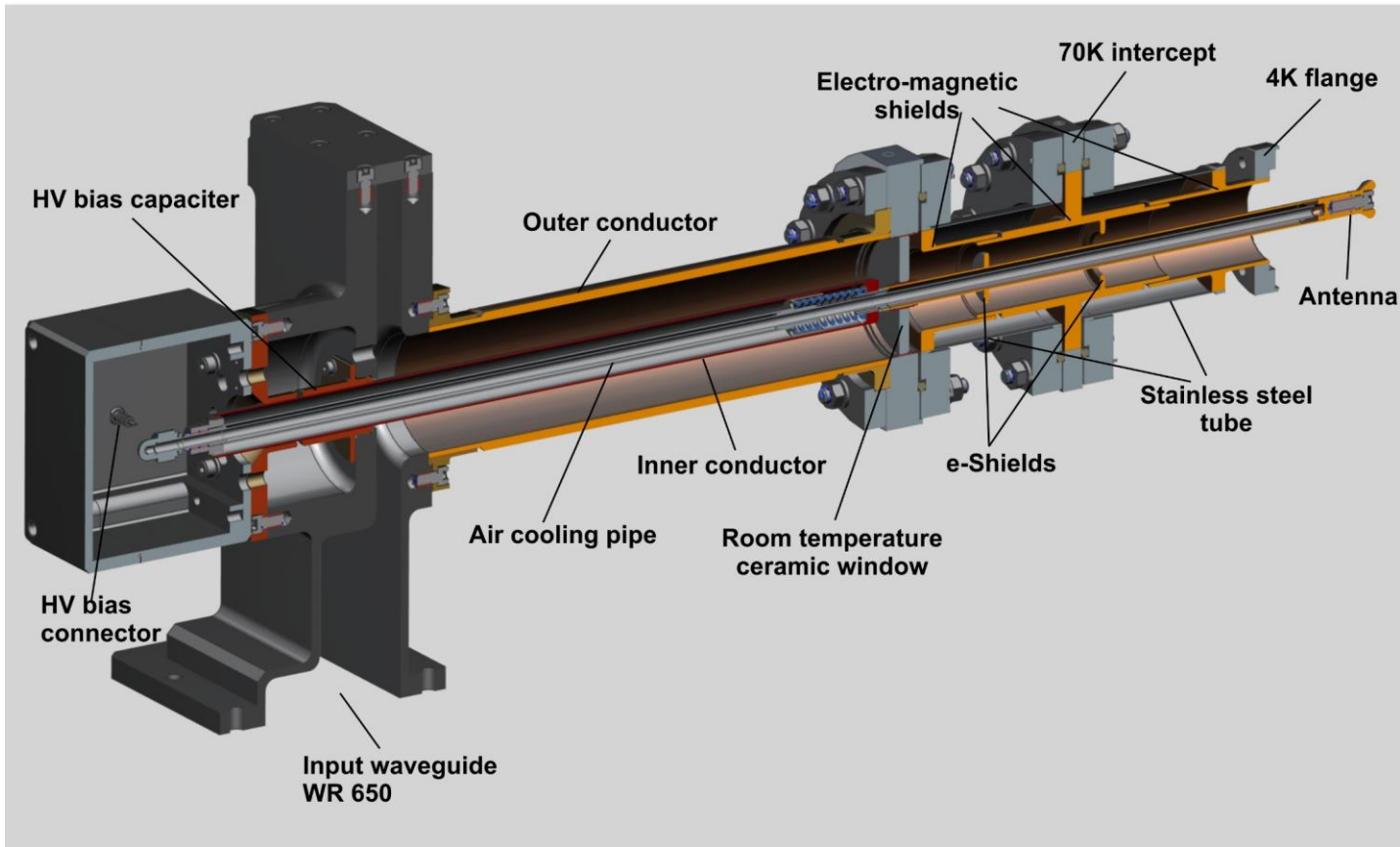
1.3 GHz coupler

Good news:

We verified the approach (with electromagnetic shields) at 1.3 GHz coupler prototype. 1.3 GHz coupler with configuration similar to 650 MHz coupler (scaled) was successfully tested,

1.3 GHz coupler

1.3 GHz prototype coupler was successfully tested in last week.



Design is similar to 650 MHz coupler design.

1.3 GHz coupler

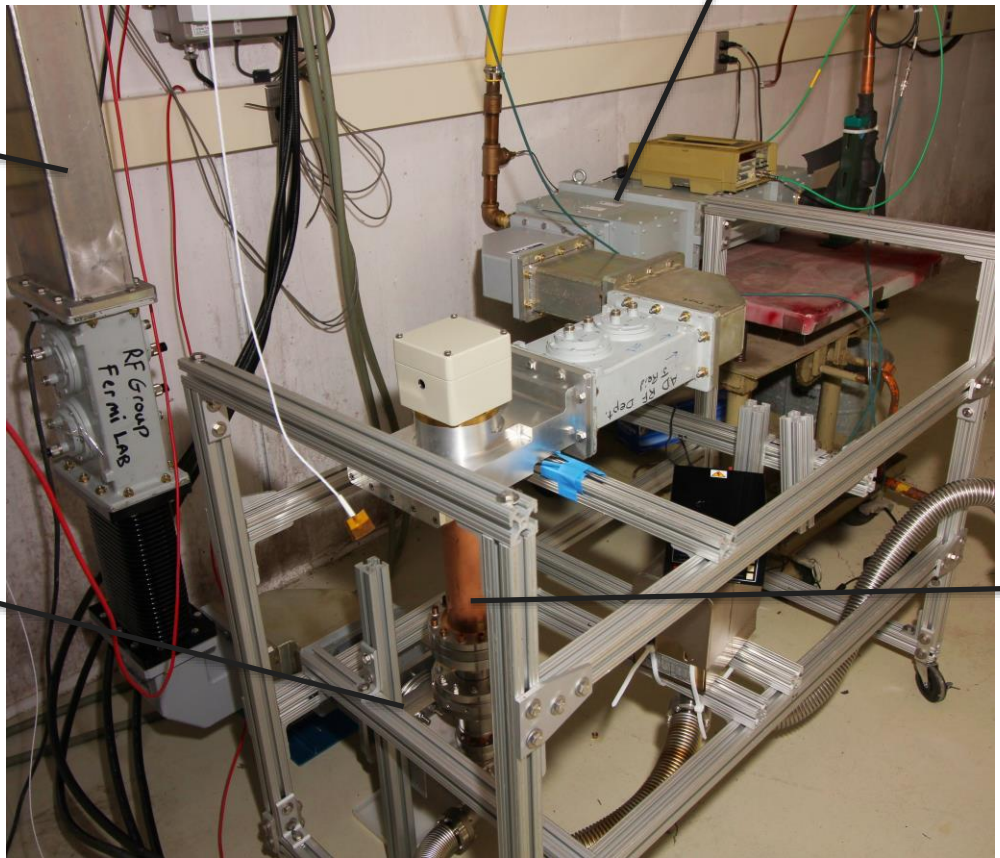
Coupler at test stand

Waveguide to
30 kW, CW source.

Matched load

RF vacuum window

Coupler



1.3 GHz coupler

Test results:

Coupler was tested in pulse and CW modes. + 3kV bias was applied in all tests.

- In pulse mode the coupler was tested up to 15 kW/ 10ms only. RF source (IOT) was not stable in pulse mode.
- There was no sign of any vacuum activity (no evidences of multipactor) during the pulse mode test. Vacuum level was $\sim 2E-8$ Torr.

Other test were in CW mode.

- Maximum power 27 kW, CW, TW was reached.
- Power level was limited by RF source (IOT) .
- Time was limited by temperature (vacuum level) of waveguide RF window. Window became hot and vacuum level reached upper limit $1E-6$ Torr.

1.3 GHz coupler

Power	Time
27 kW	~ 14min
20 kW	~ 1 hour
15 kW	~ ∞

Conclusion:

New configuration works:

- No multipactor in slots, no multipactor in SS chambers.
- No other vacuum activities.

1.3 GHz coupler

