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## **Fundamental Couplers Activities in FNAL**

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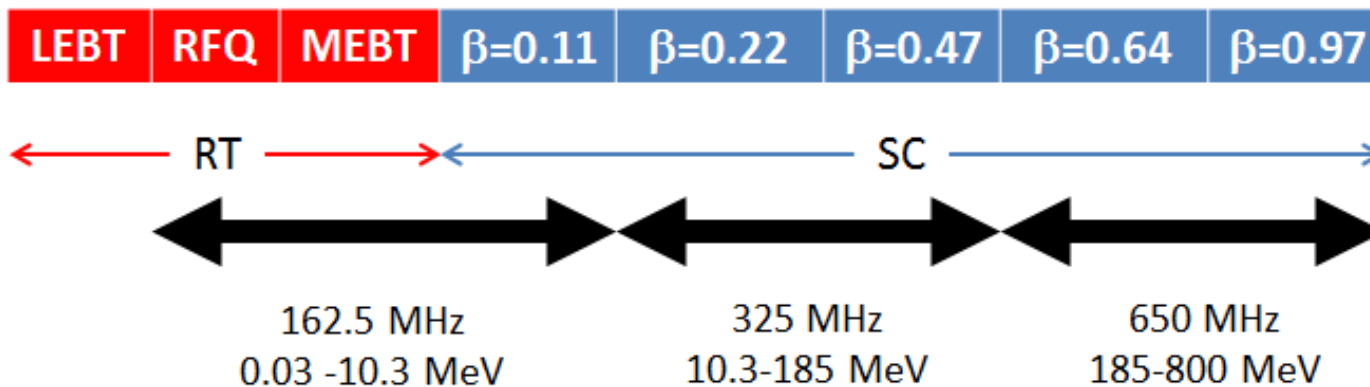
June 5-6, 2018, CERN

Worldwide Workshop on Fundamental Power Couplers

# PIP-II couplers

PIP-II project:

Performance Parameter	Value	Unit
Particle species	H <sup>-</sup>	
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

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- **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

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## 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:

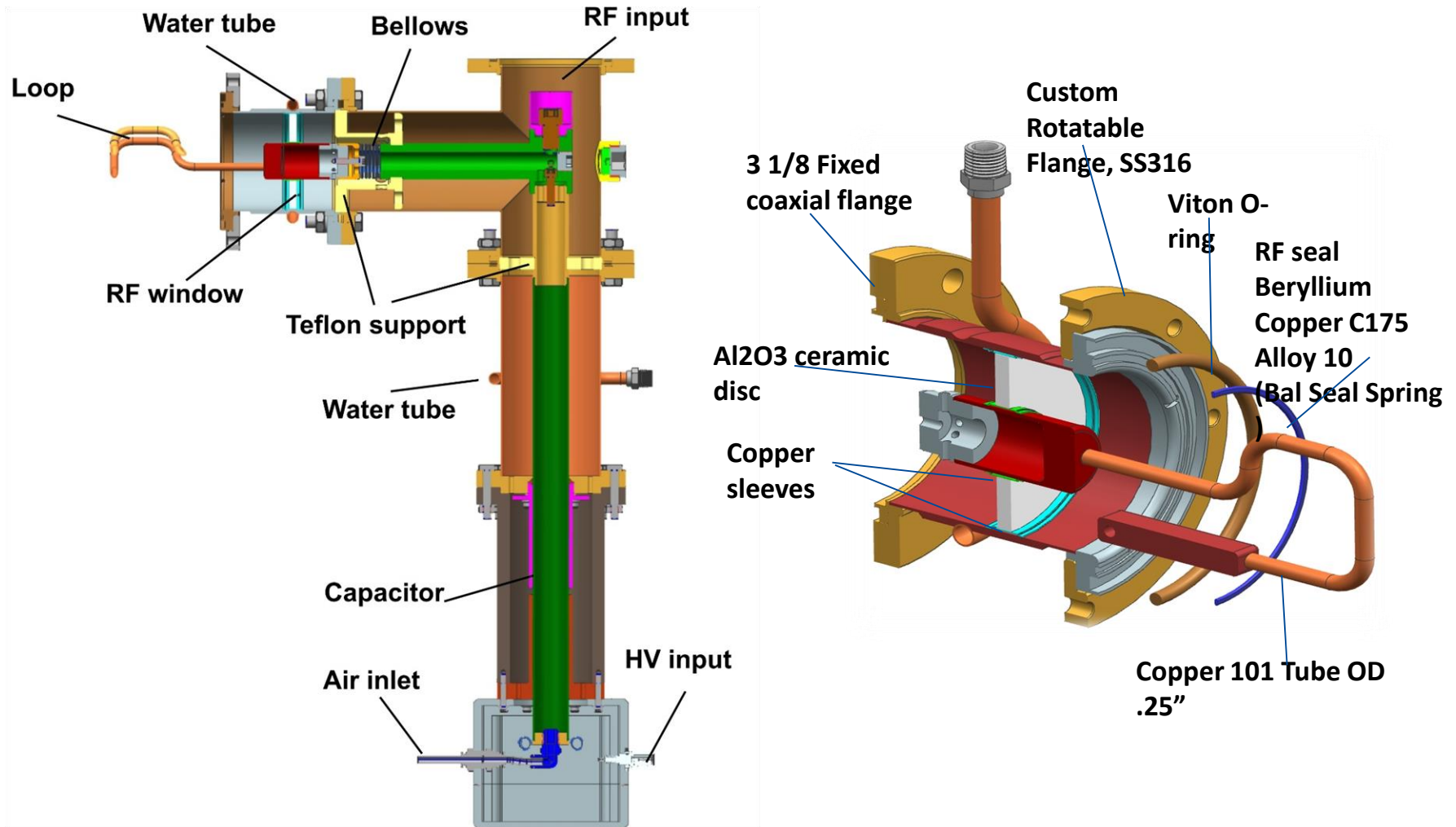
Frequency 650 MHz  
Power 110 kW, CW

### HWR coupler:

Frequency 162.5 MHz  
Power 10 kW, CW

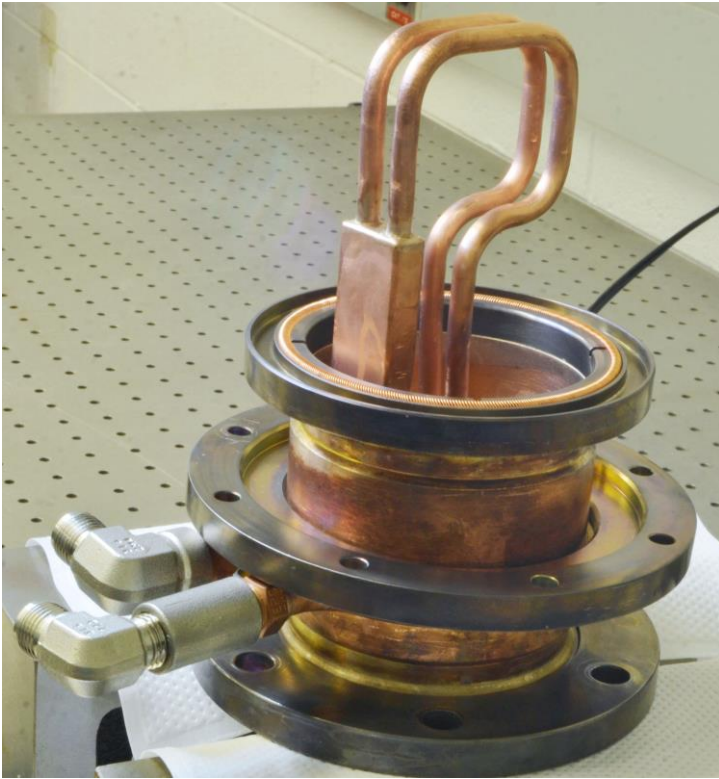
**All couplers were designed and all, except 650 MHz couplers, were built and tested.**

# 162.5 MHz RFQ coupler



# 162.5 MHz RFQ coupler

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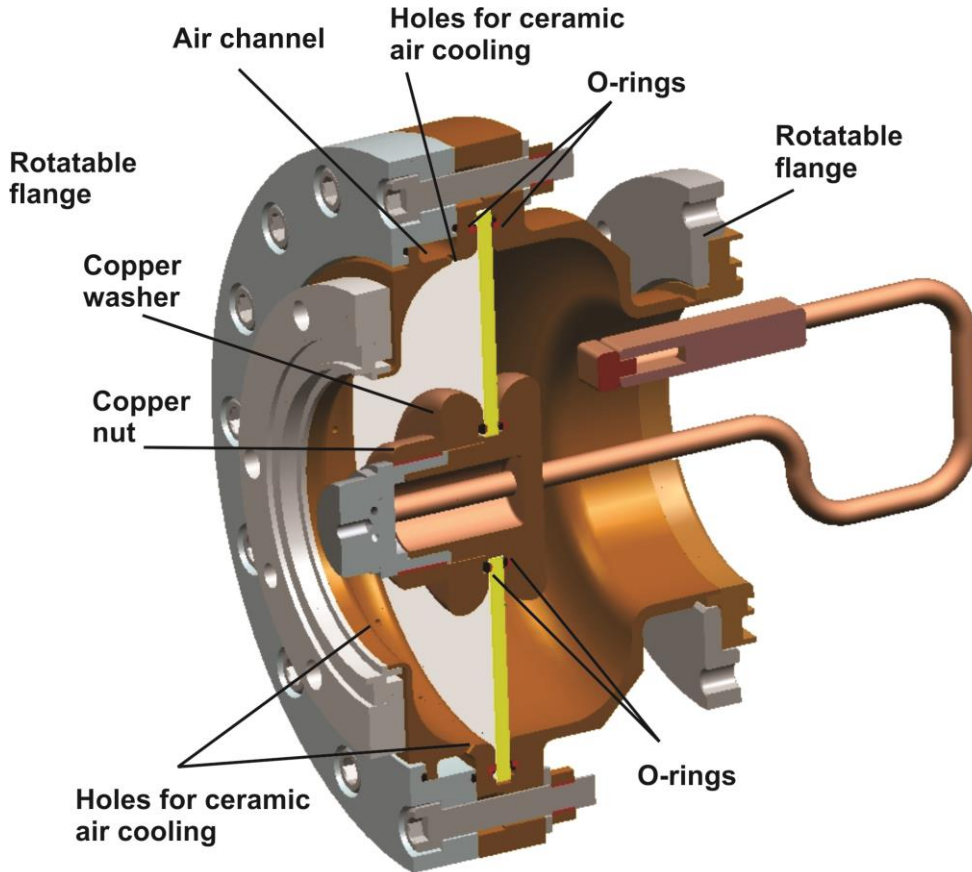


Two coupler and four windows unit were produced.

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.



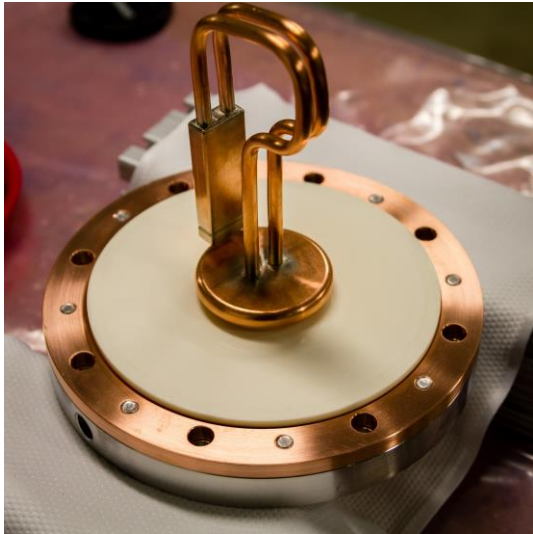
Diameter of ceramics was increased up to 6”.

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

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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 3 months. Total time > 350 hours 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:**

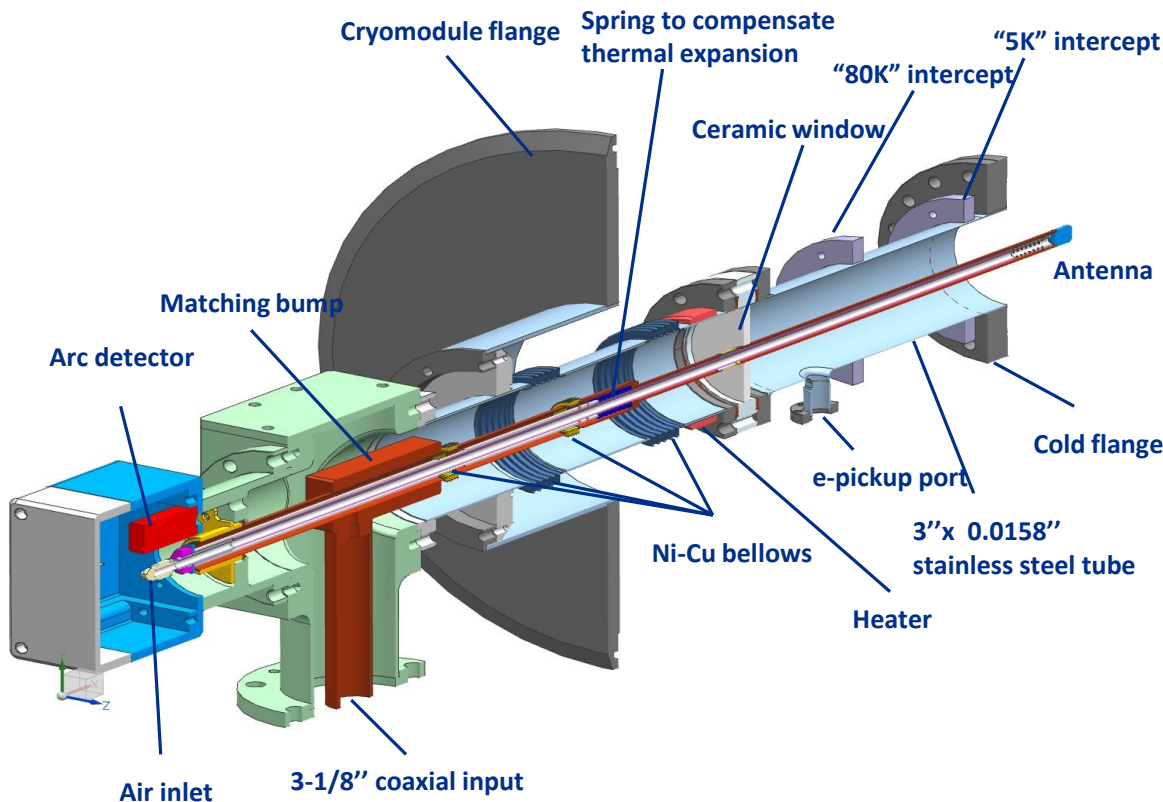
Copper 0.5", air cooled, HV bias.

**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

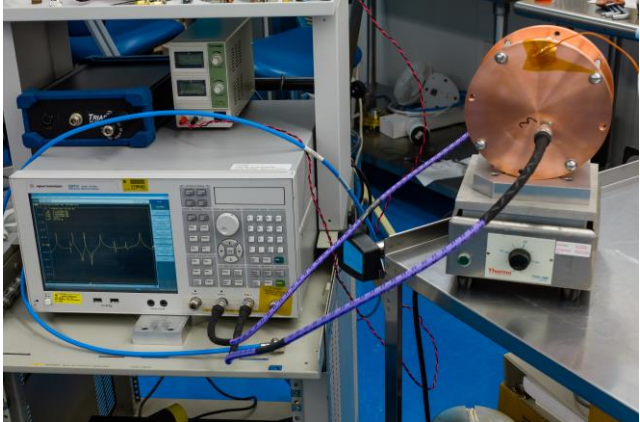
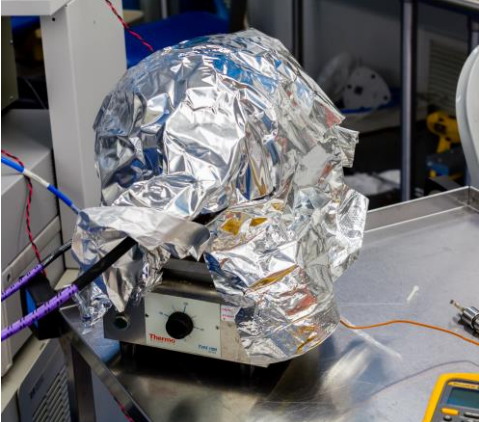
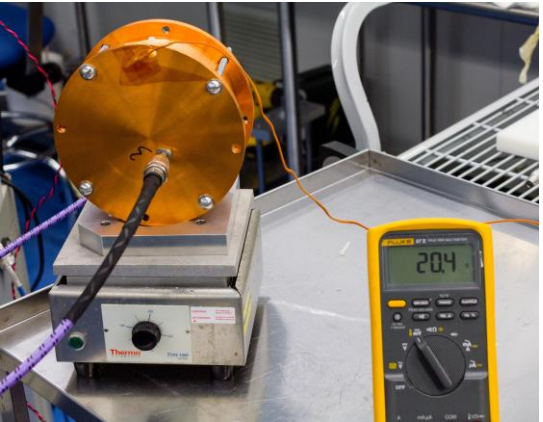
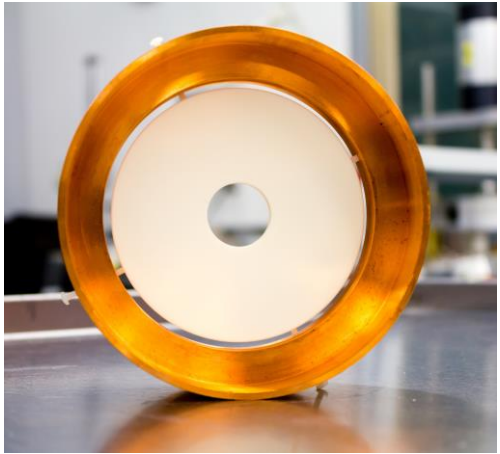
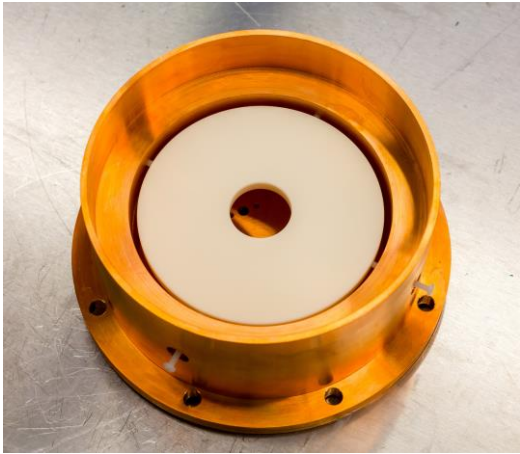
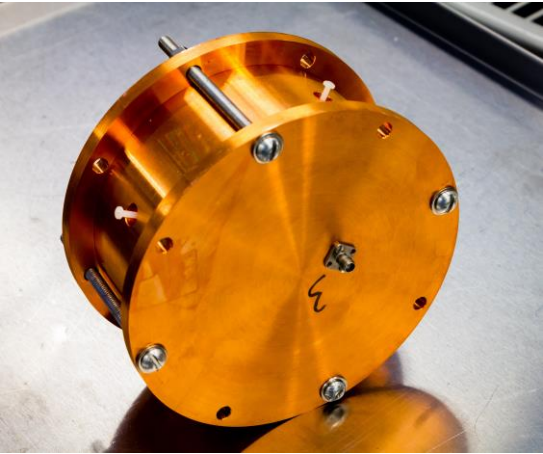
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## Current status

- 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.
- 5 couplers produced by CPI.
- 6 couplers are under production in CPI
- Three cavity were qualified with couplers (ready to be installed to cryomodule). Additional five cavity should be qualified before fall.

# 325 MHz coupler

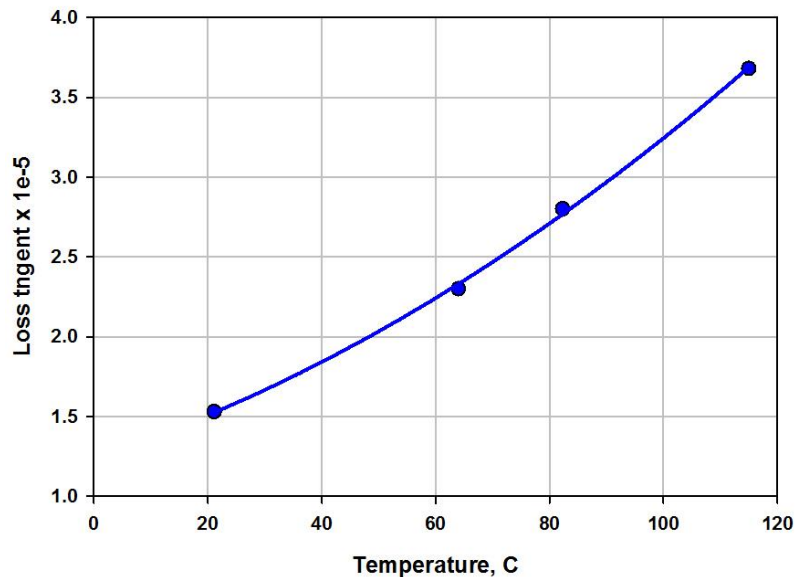
Each ceramic disk is measured before to be brazed.



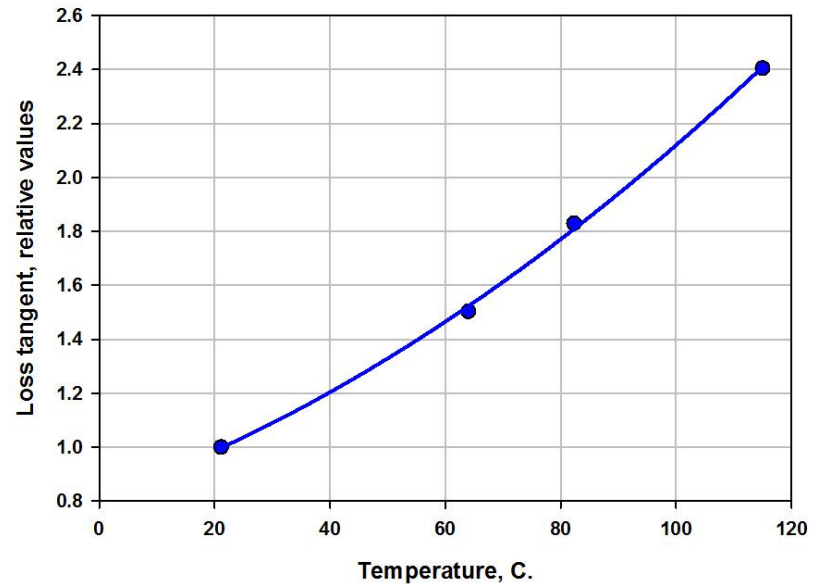
# 325 MHz coupler

## 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.

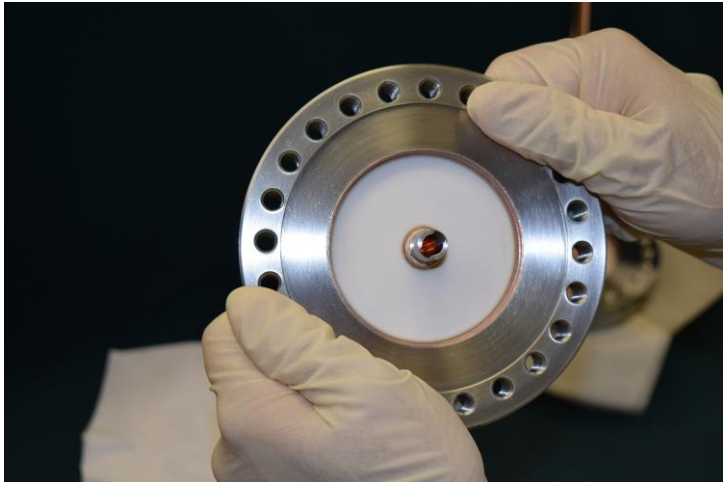
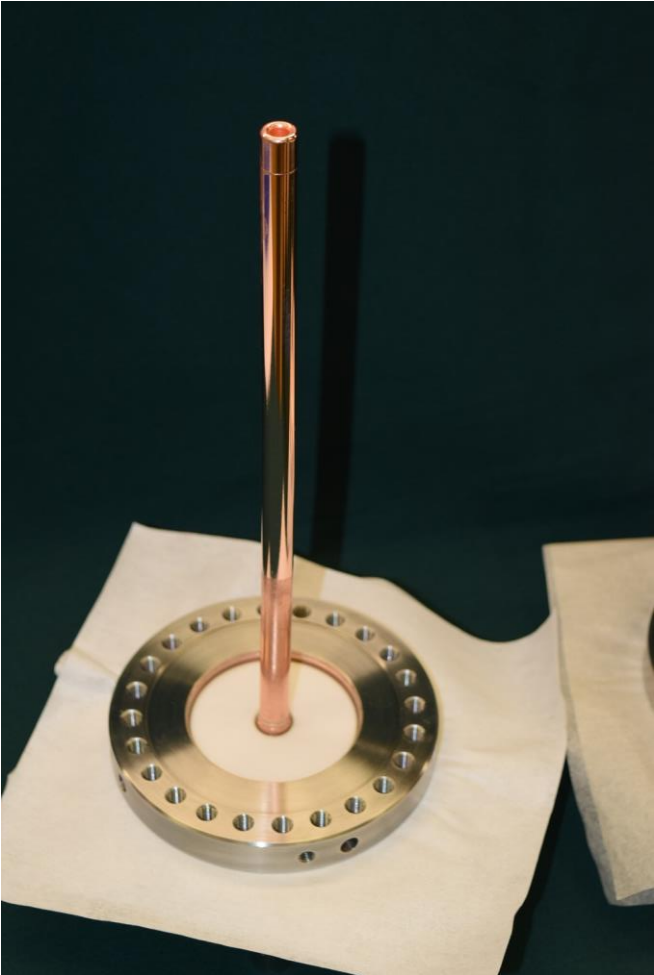


Some times ceramics is extremely good: loss tangent  $\sim 1.5E-5$  at 2.7 GHz



# 325 MHz coupler

## Antenna made by CPI

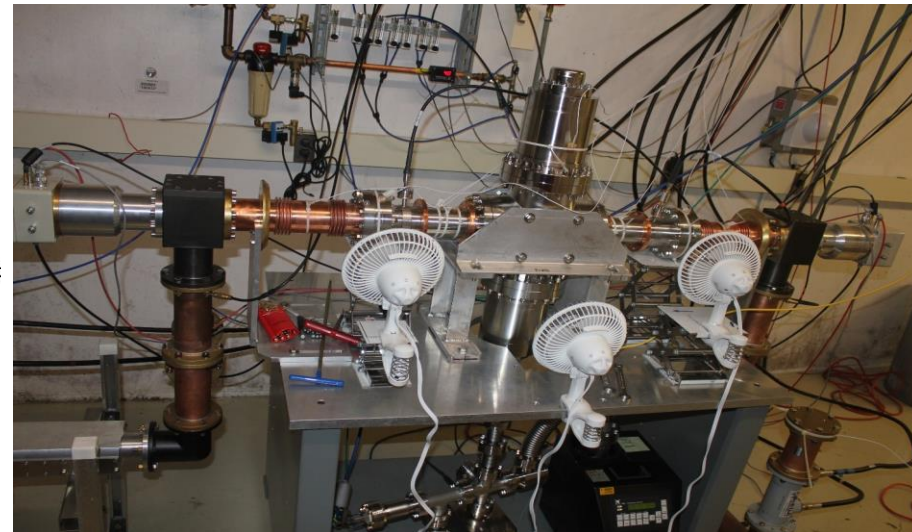
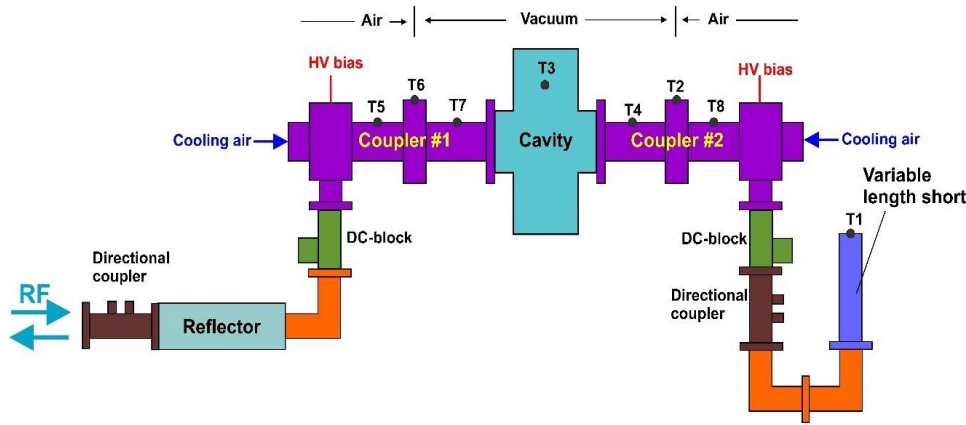


# 325 MHz coupler

## 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

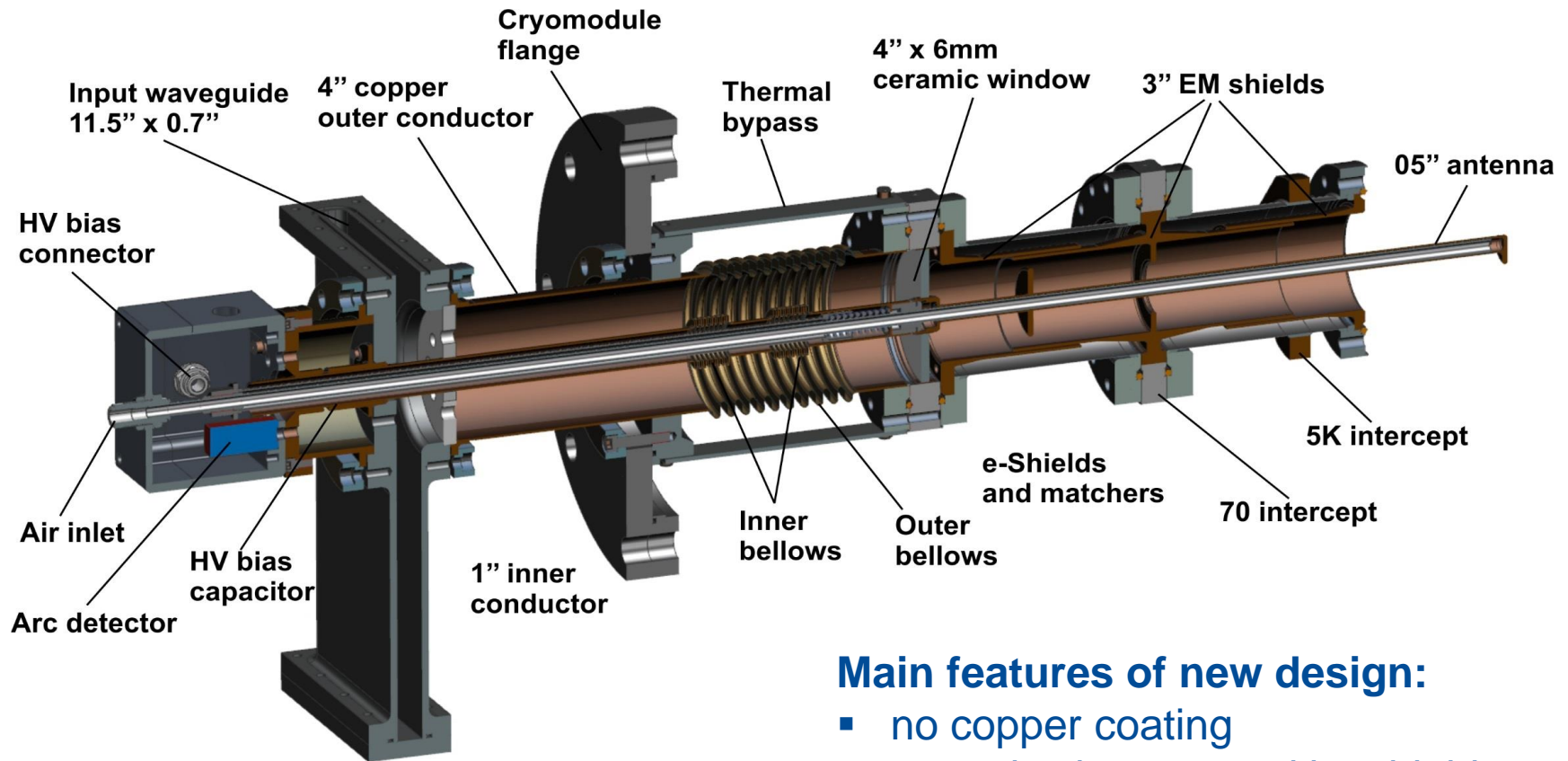
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## Problem and issues with current design:

- Wall thickness of vacuum outer conductor is rather small, 0.4 mm. It causes difficulties for handling. The wall thickness will be increased in next bunch of couplers.

# 650 MHz coupler

## LB & HB coupler, new design

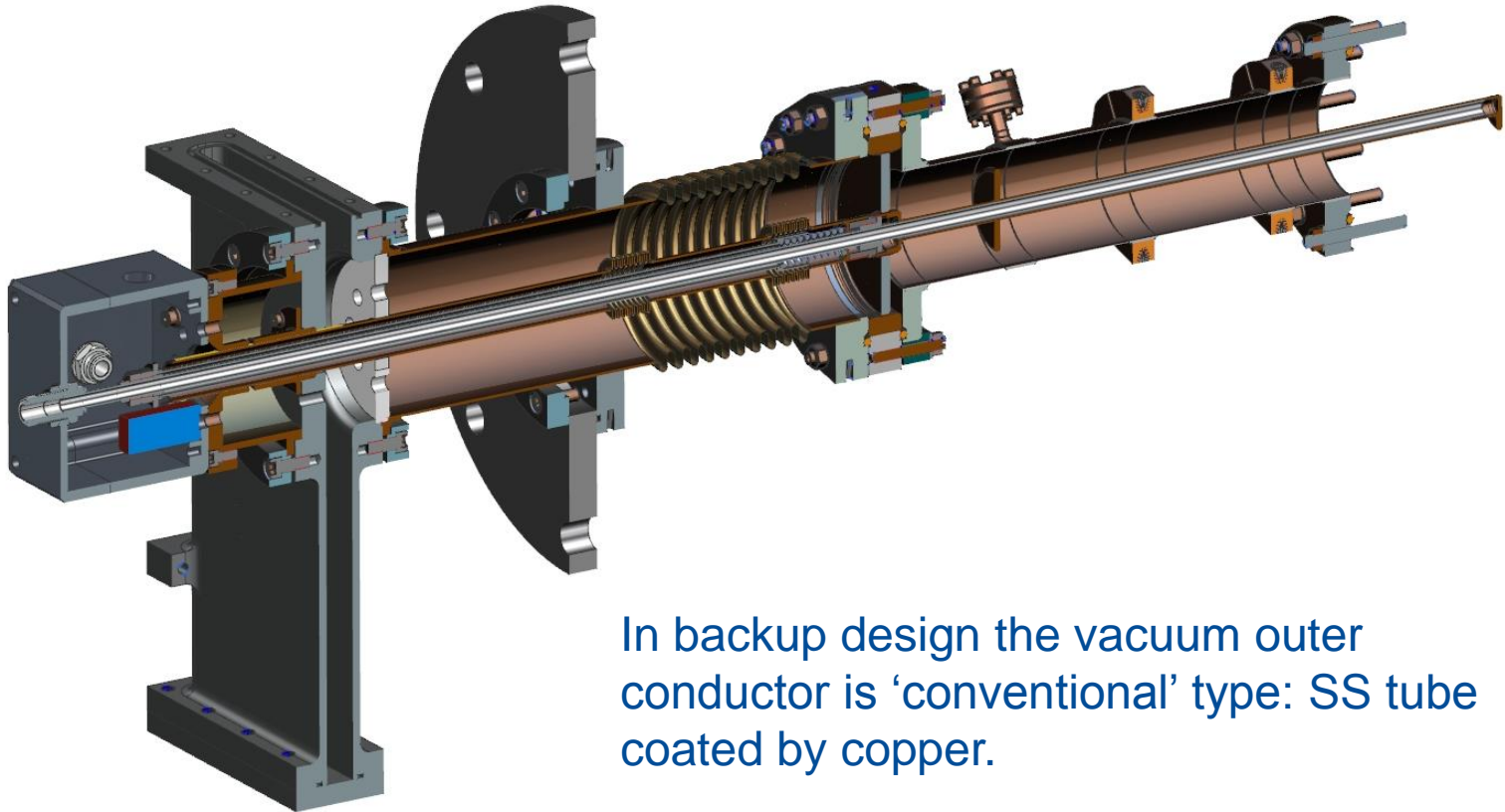


### Main features of new design:

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

# 650 MHz coupler

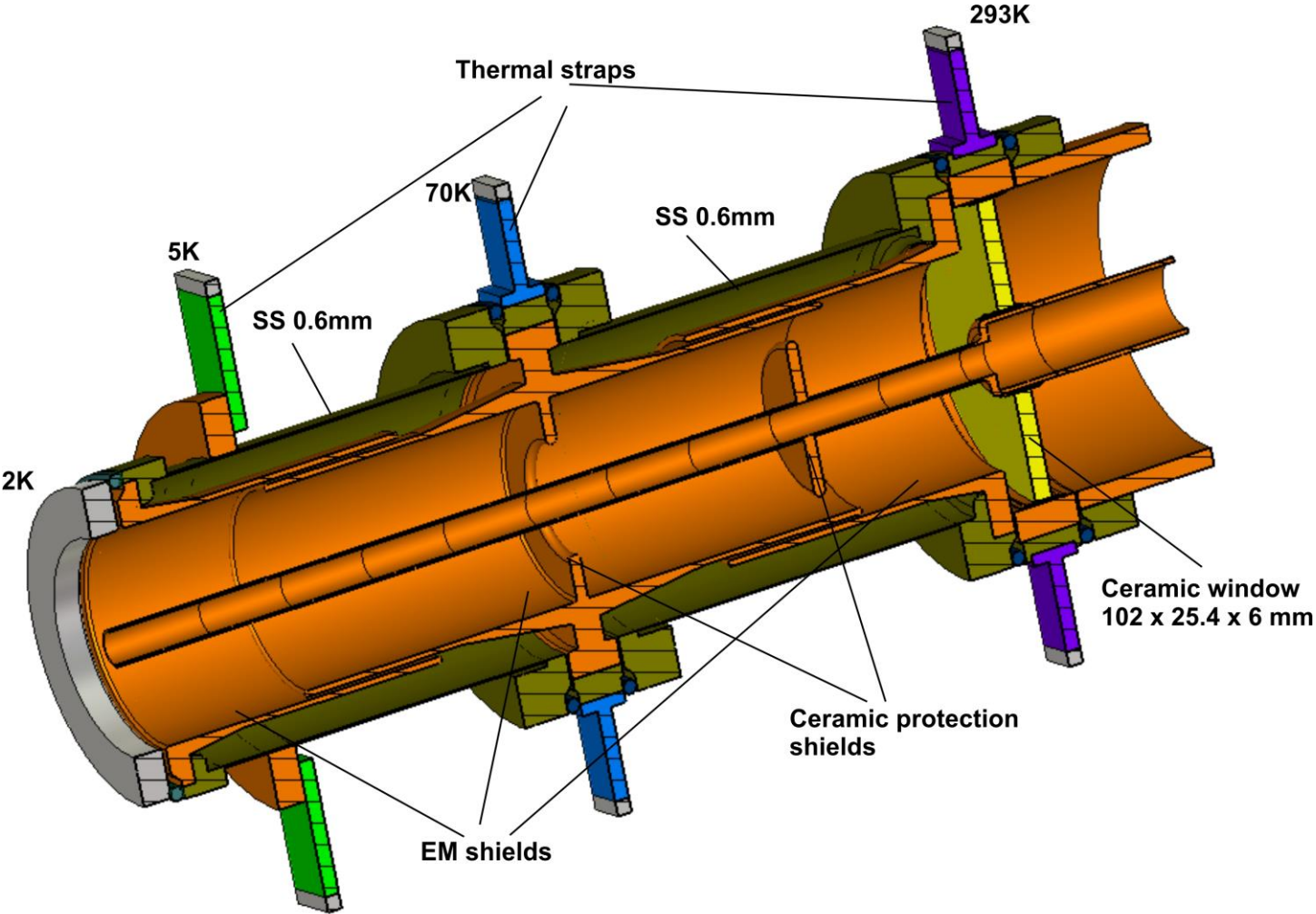
## LB & HB coupler, backup design



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

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## 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

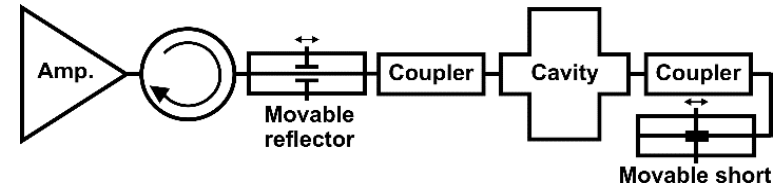
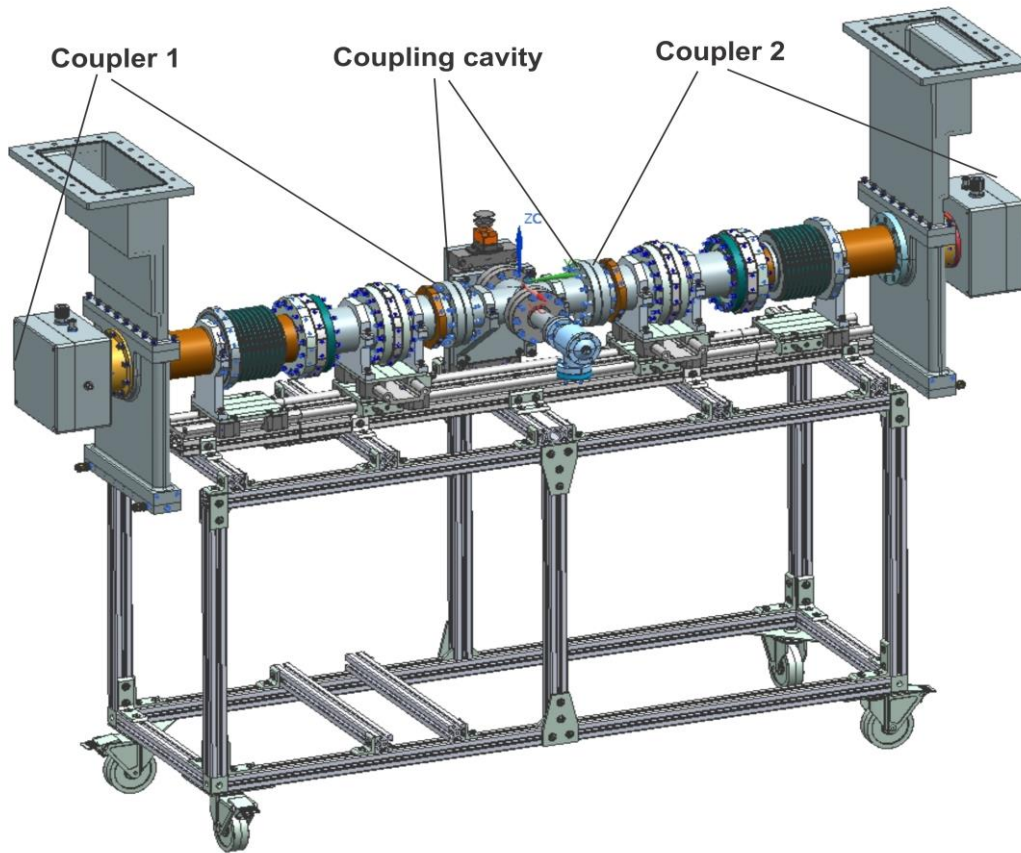
- Two coupler prototypes with four vacuum parts are under production.
- Four vacuum parts are already made by CPI.
- Test infrastructure is under construction.





# 650 MHz coupler

## Couplers test bench.

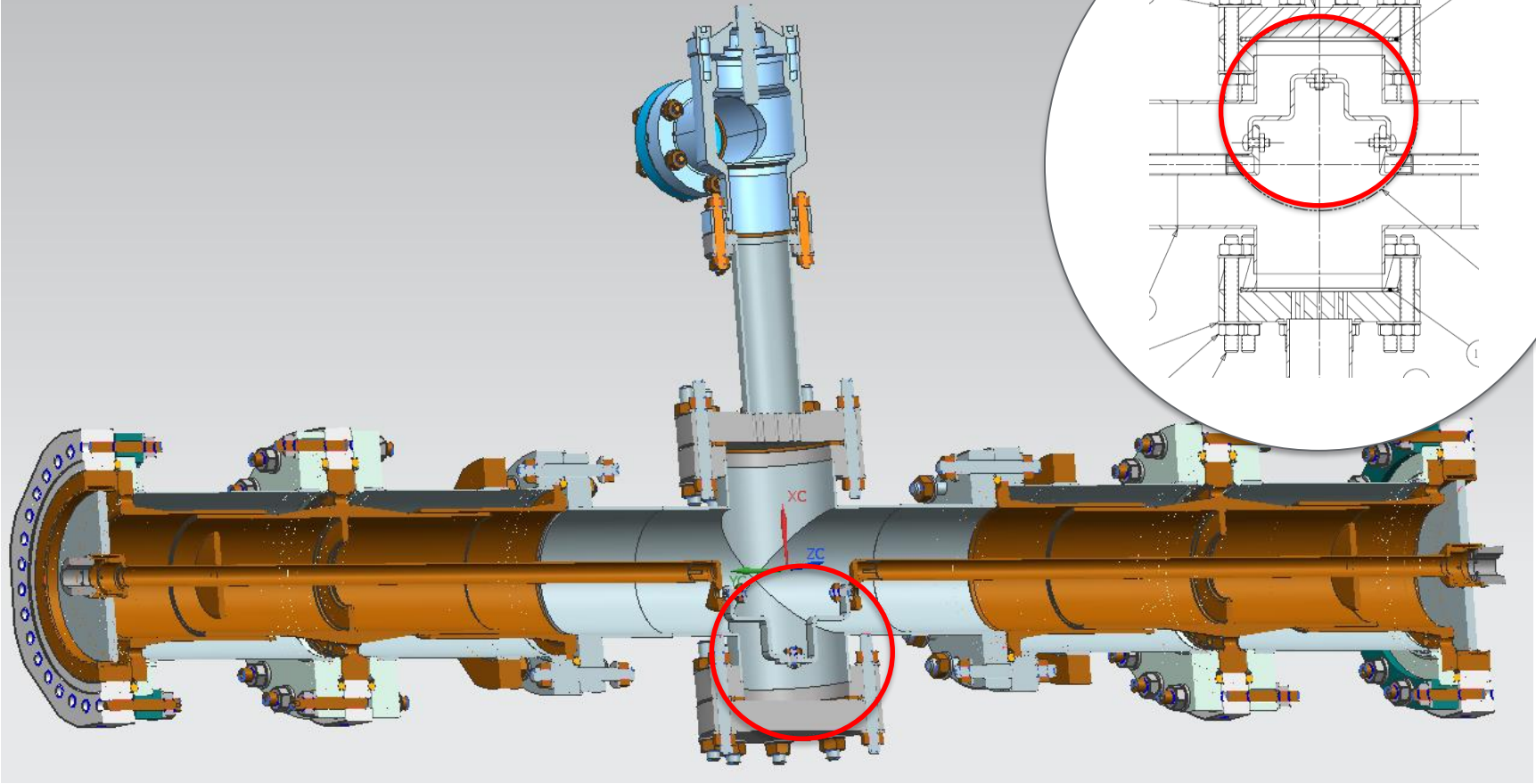


Couplers will be tested in resonance mode with full reflected power. It will allow to increase the level of testing power more than 100 kW using 30 kW RF source.



# 650 MHz coupler

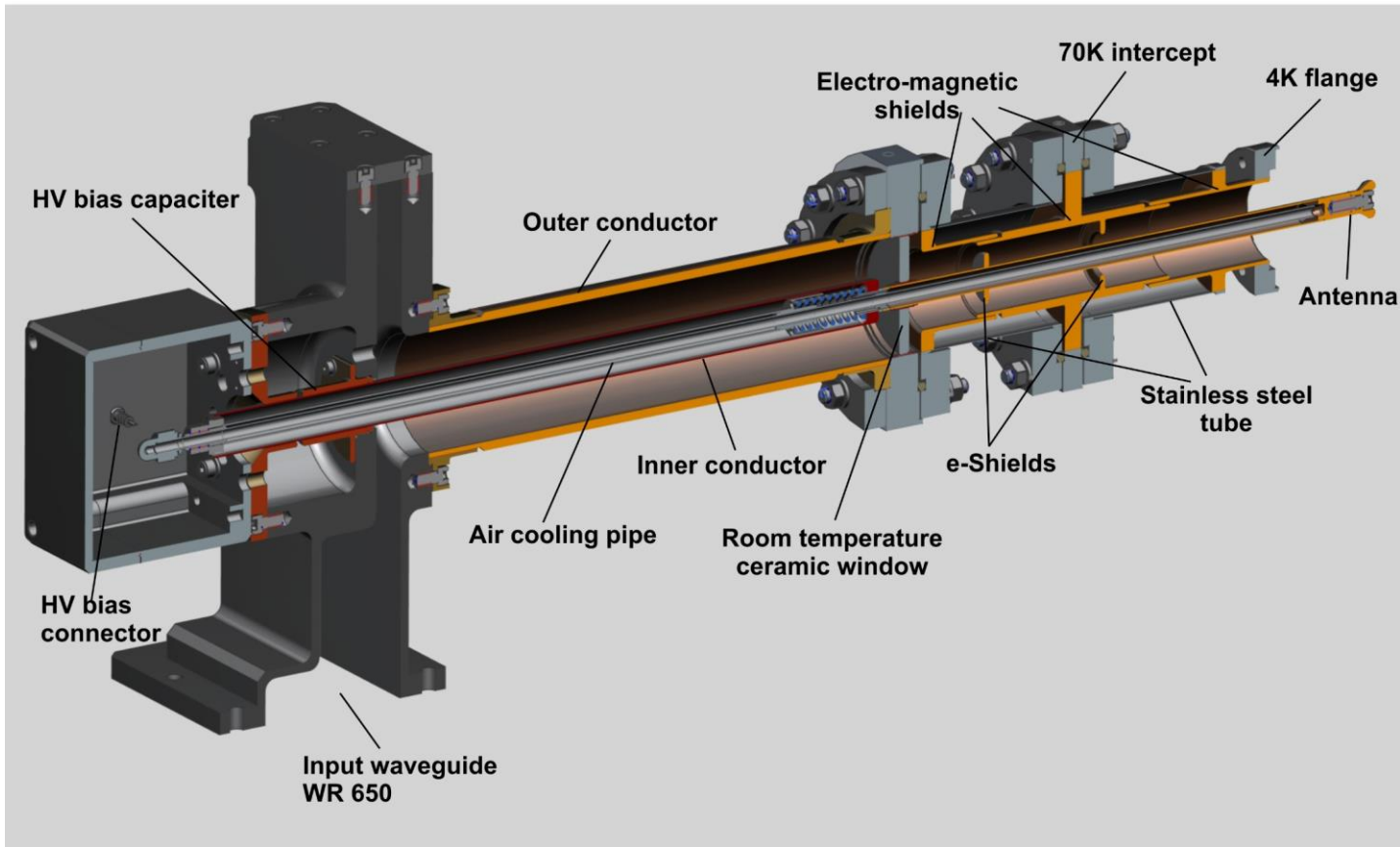
During the test (qualification the antennas will be connected electrically and mechanically).



After the test couplers will be re-cleaned.

# 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

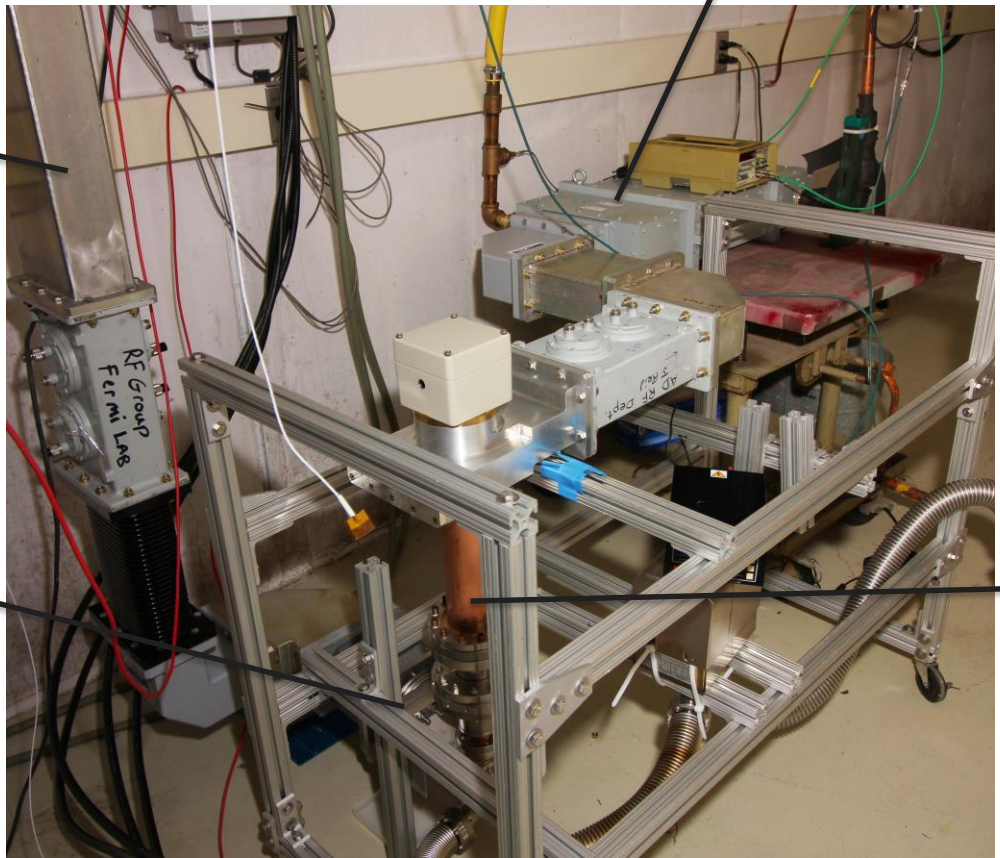
## Coupler at test stand

Waveguide to  
30 kW, CW source.

Matched load

RF vacuum window

Coupler



## 1.3 GHz coupler

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### 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

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Power	Time
27 kW	~ 14min
20 kW	~ 1 hour
15 kW	~ $\infty$

### Conclusion:

New configuration works:

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

# 1.3 GHz coupler

