Fundamental Power Couplers of PIP-II project

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World Wide Fundamental Power Coupler meeting #6

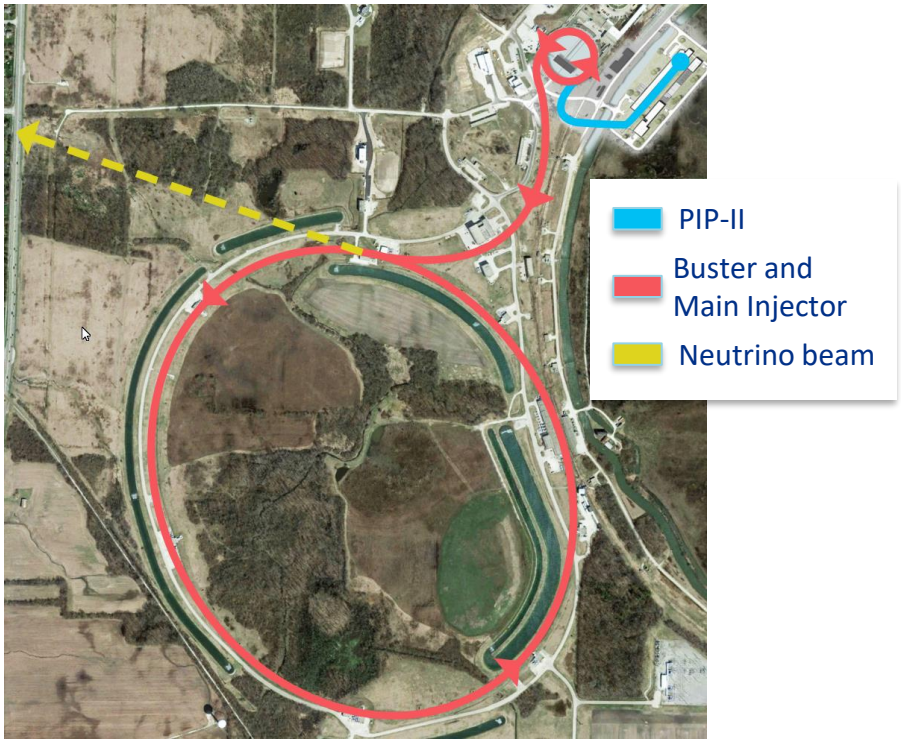
2-3 July 2024

Outline:

- PIP-II project
- Couplers requirements
- RFQ coupler
- 325 MHz, Single Spoke Resonator (SSR) coupler
- DC block
- 650 MHz coupler
- 650 MHz, Low cryogenic loading coupler.
- 1.3 GHz, Lowe cryogenic loading coupler.
- Testing new conductive ceramics.
- 325 MHz coupler test stand
- 650 MHz coupler test stand
- Measurements of loss tangent of ceramics

PIP-II project:

PIP-II (Proton Improvement Plan) – superconducting 800 MV linac, which will serve as proton injector for Fermilab Accelerator complex.



Main PIP-II parameters

Parameter	Value	Units
Beam energy	800	MeV
Beam particles	H-	
Beam power	1.2	MW
Average current	2	mA
Frequency	162.5 harmonics	MHz

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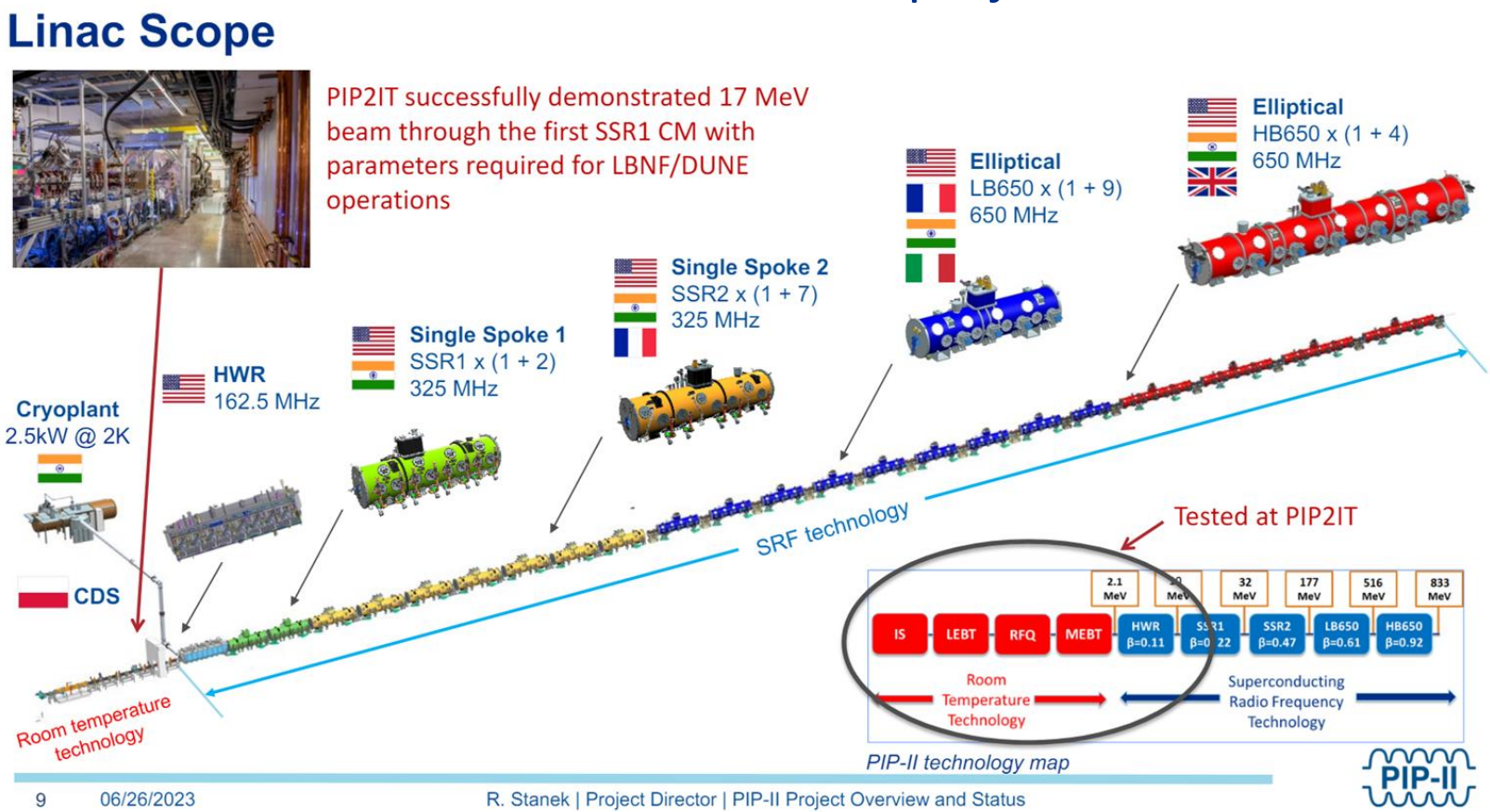
PIP-II is international project:



Couplers of PIP-II project, types and number.

Cavity Type	Coupler type	Number of couplers	Max. power to beam, kW	Max. Power in coupler, kW
RFQ	RFQ	2	=<20	70
HWR	HWR	8	4.5	5.5
SSR1	SSR	16	4.4	4.9
SSR2	SSR	35	12.4	15
LB650	“650MHz”	36	29.3	35.8
HB650	“650MHz”	24	44.4	56

Total number of types of couplers

4

Total number couplers

121

RFQ coupler

Parameters:

Frequency: 162.5 MHz

Operating power: 75 kW

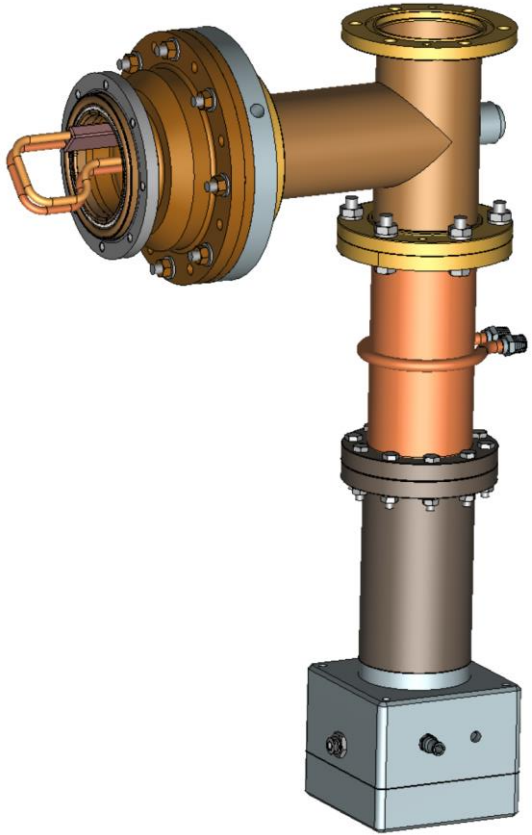
Ceramic sizes: OD 152 mm x ID 33 mm x 4mm

Antenna type: Loop, air cooled, rotatable

HV bias: ~ up to 5 kV

Input: Standard 3-inch 50 Ohm coaxial

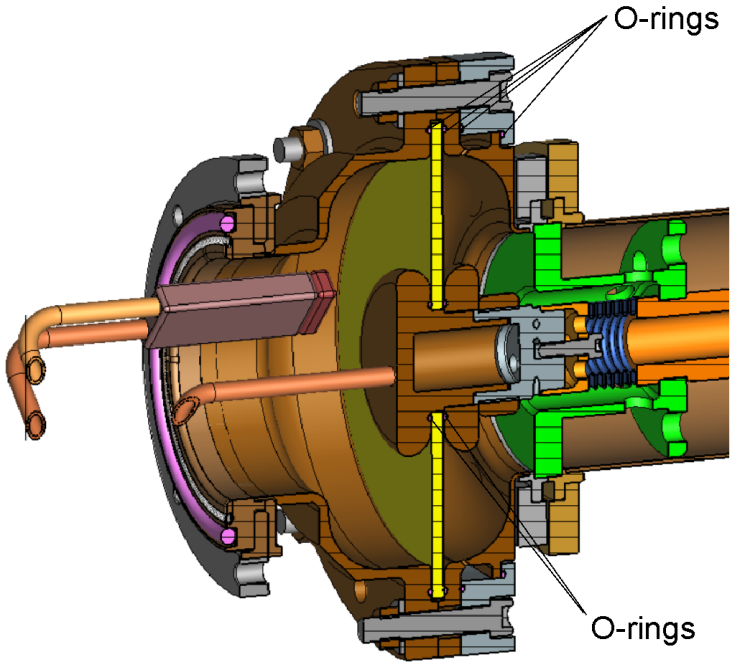
Number of couplers: 2



Dismountable window of RFQ coupler

Vacuum requirements of RFQ allow to use Viton O-rings.

Couplers are made dismountable. Ceramics disks can be replaced if necessary.



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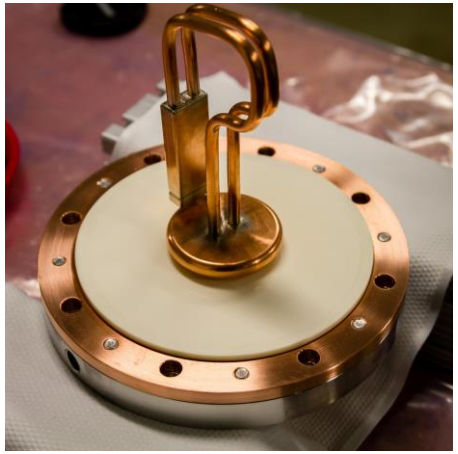
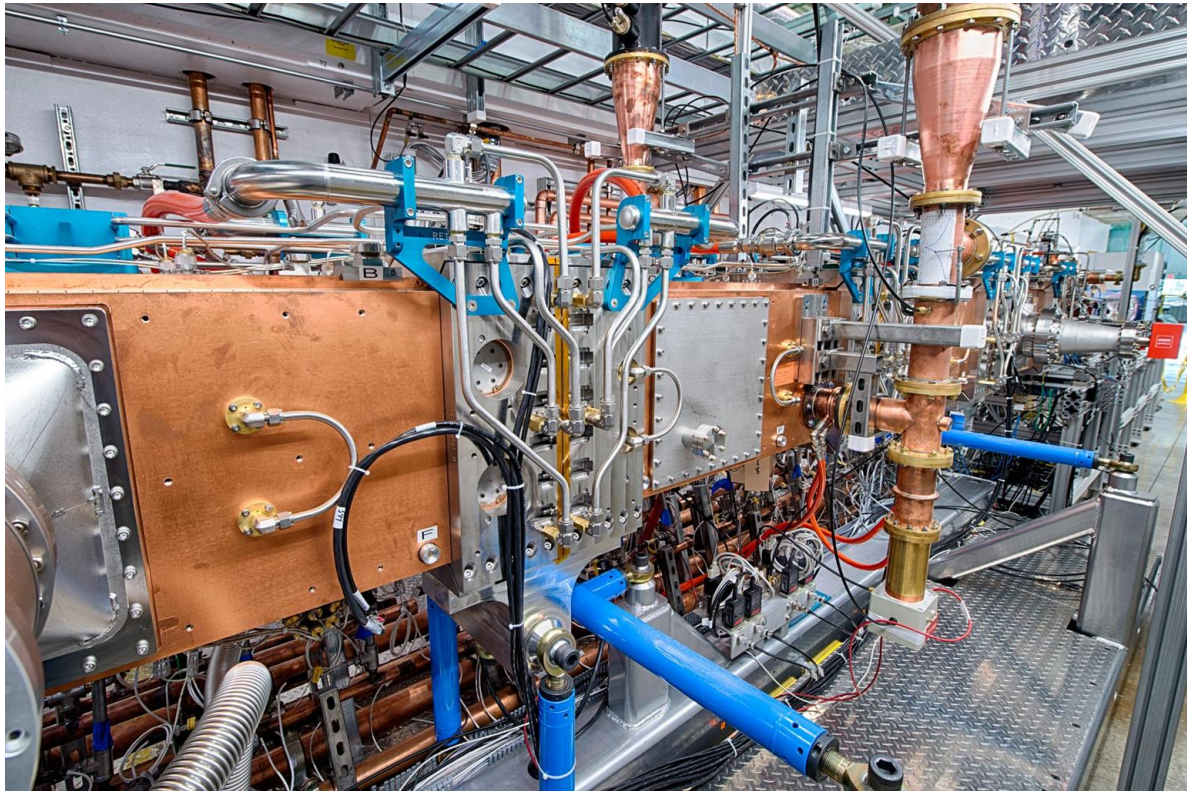
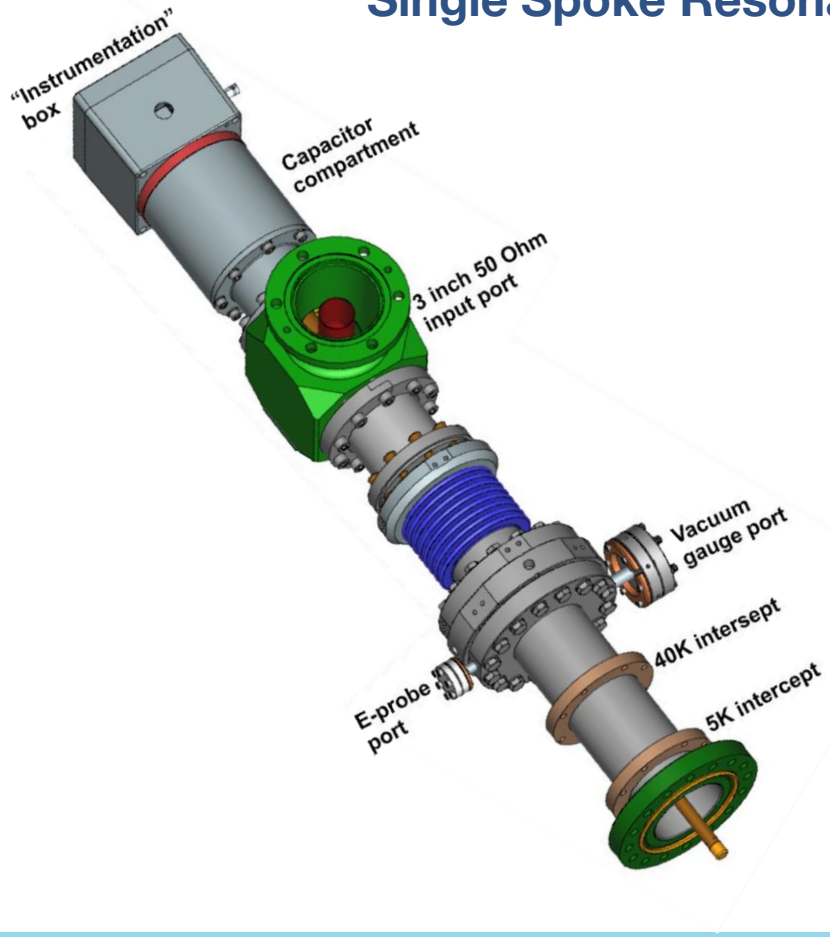




Single Spoke Resonator(SSR) coupler



Parameters:

Frequency: 325 MHz

Operating power: 12 kW

Ceramic sizes: OD 101 mm x ID 25.4 mm x 7mm

Antenna type: copper OD 12.7mm, air cooled

HV bias: ~ up to 5 kV

Input: Standard 3-inch 50 Ohm coaxial

Number of couplers: XX

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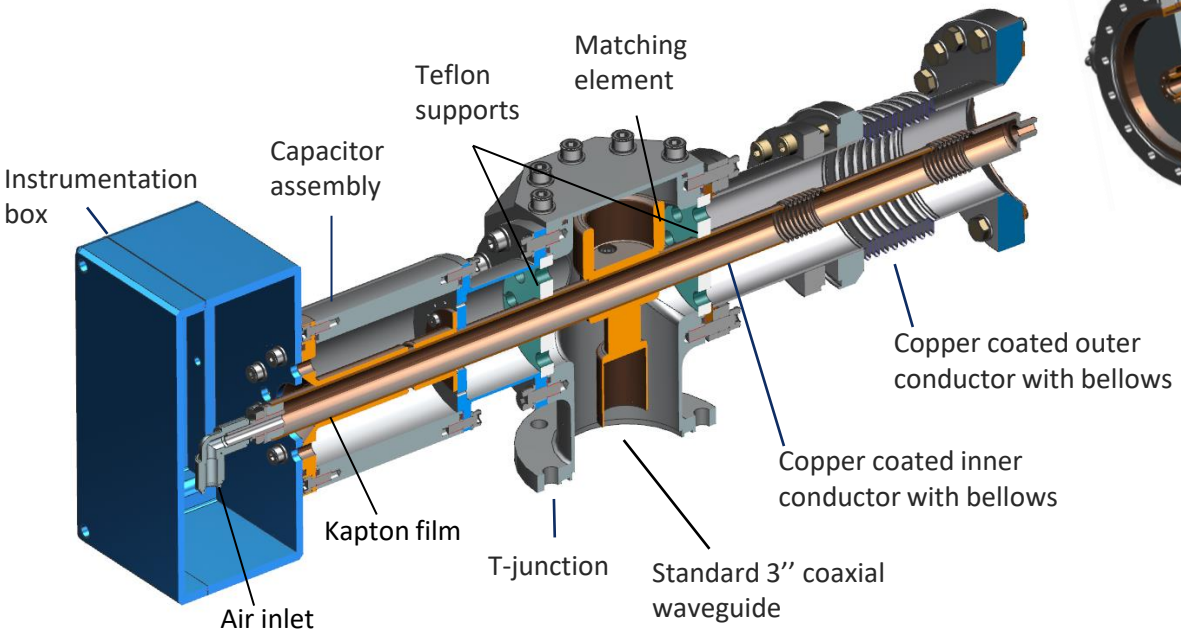
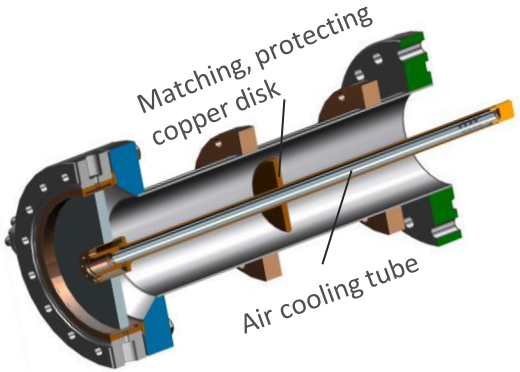
Air part of 325 MHz coupler





Vacuum part of 325 MHz coupler

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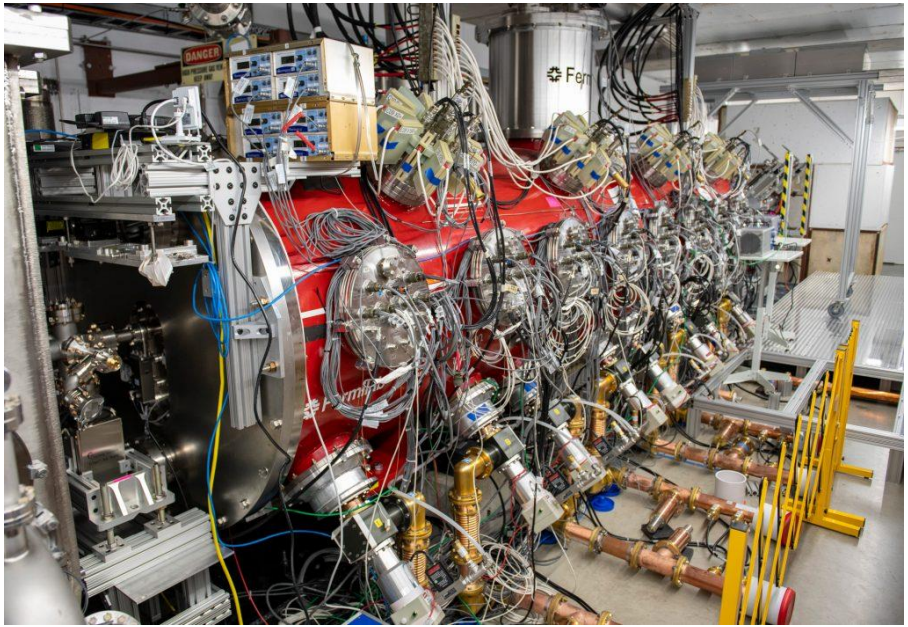
Installing vacuum parts of SSR couplers

Couplers at SSR-I cryomodule



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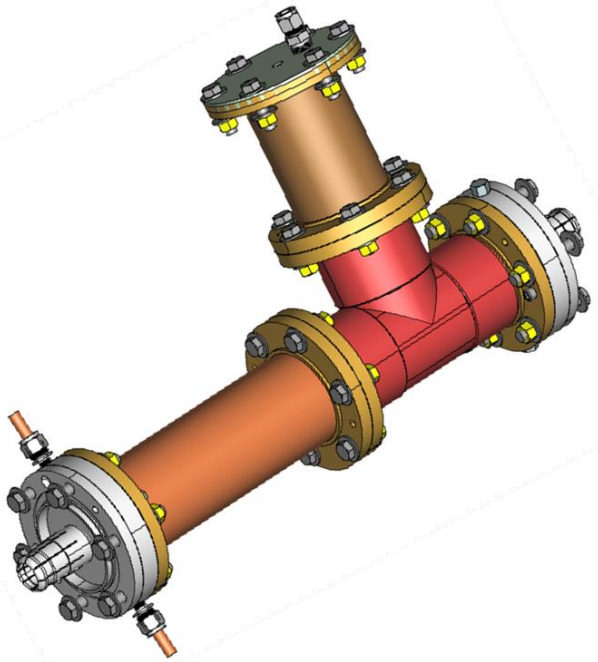
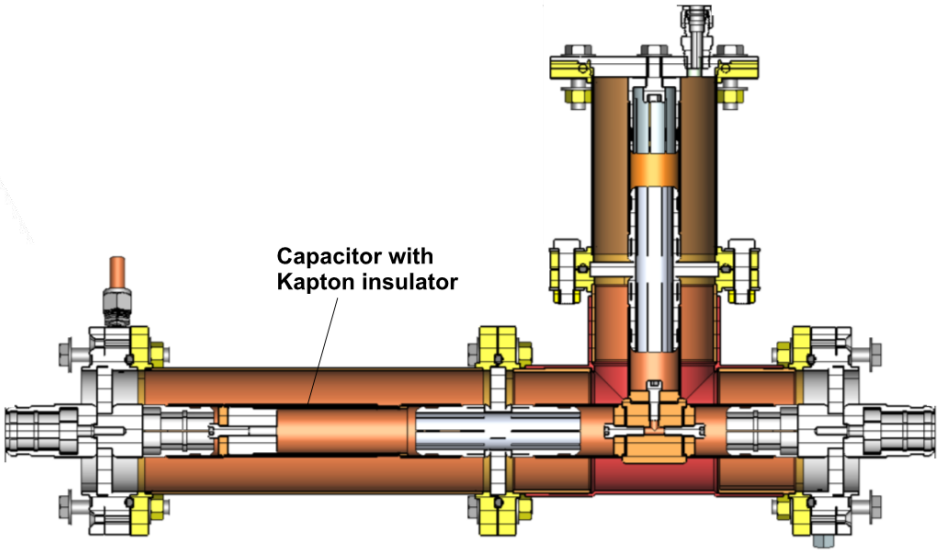
DC block

SSR couplers are connected to RF power amplifier through " DC-block" (it blocks DC current and transmits RF). **The purpose of the DC-block is to protect the amplifier from high voltage of coupler bias.**





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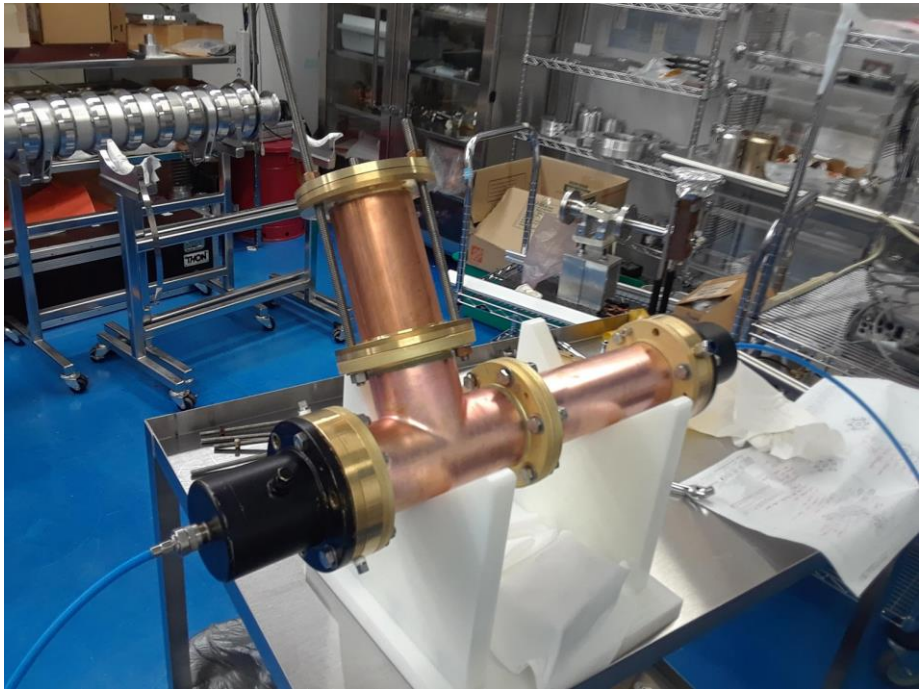
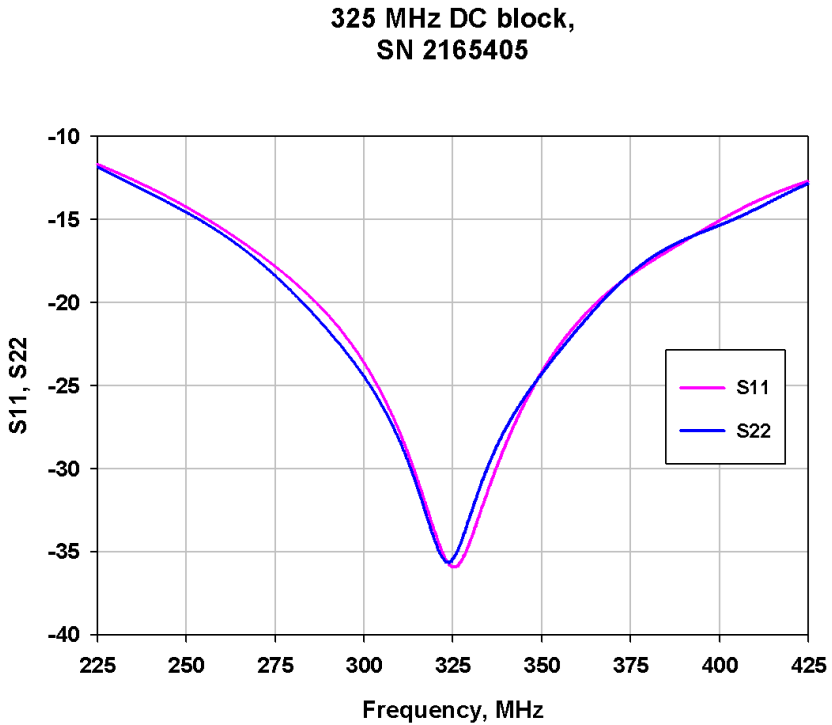
Adjusting the length of short of DC block





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650 MHz coupler

Parameters:

Frequency: 650 MHz

Operating power: 47 kW

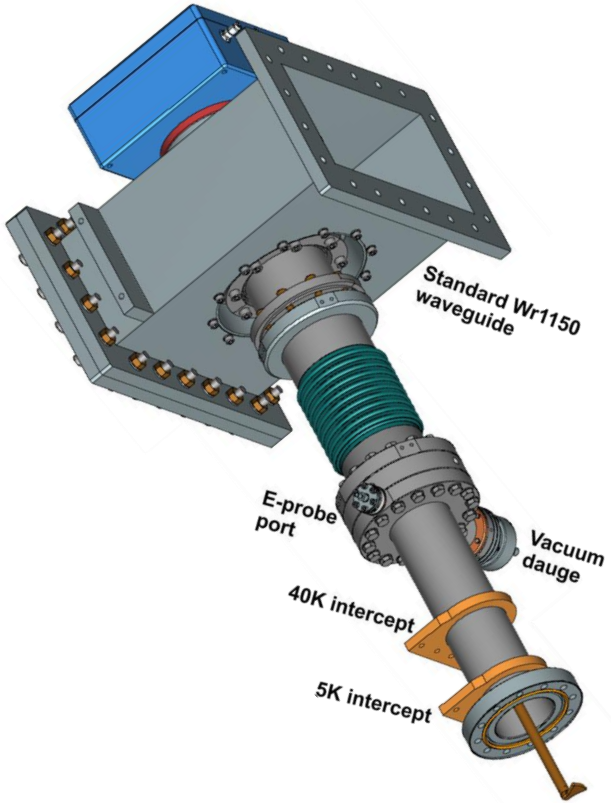
Ceramic sizes: OD 101 mm x ID 25.4 mm x 7mm

Antenna type: copper OD 12.7mm, air cooled

HV bias: ~ up to 5 kV

Input: Standard WR1150 waveguide

Number of couplers: XX



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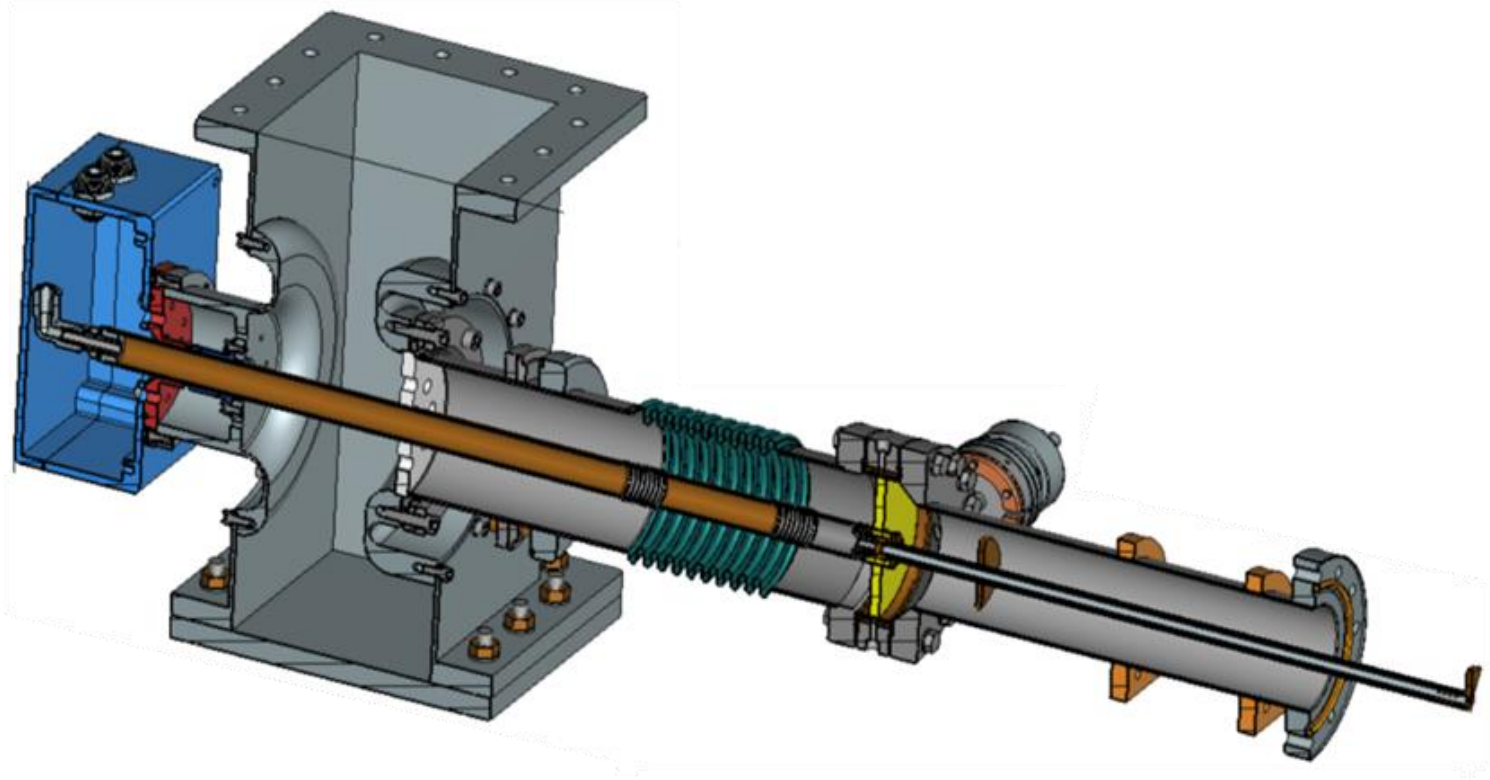
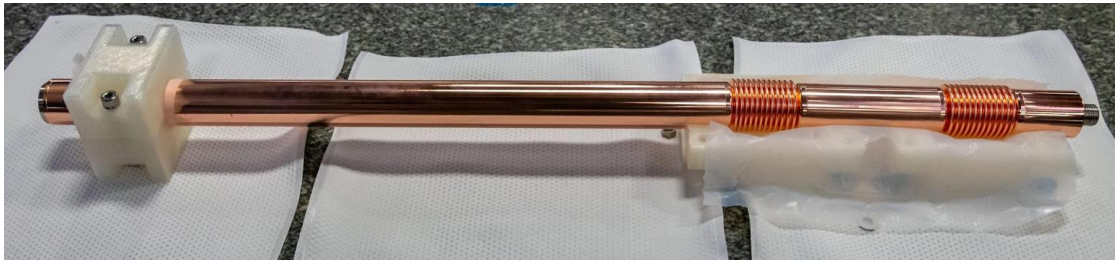
Cut view of 650 MHz coupler



Parts of 650 MHz coupler



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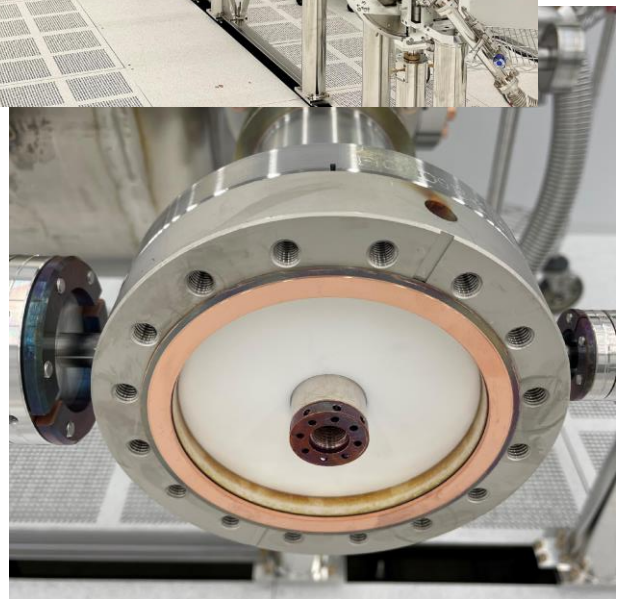

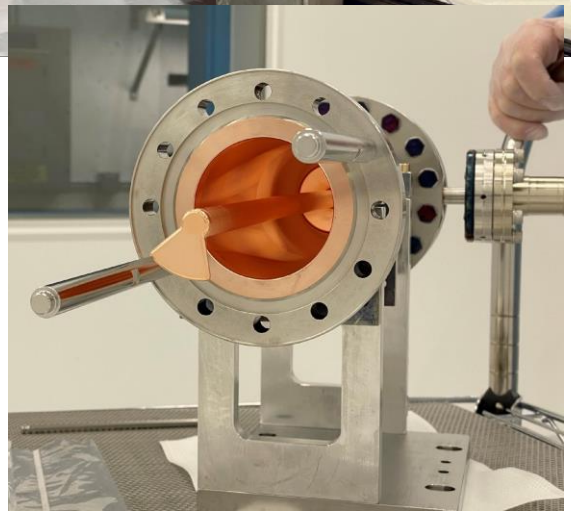

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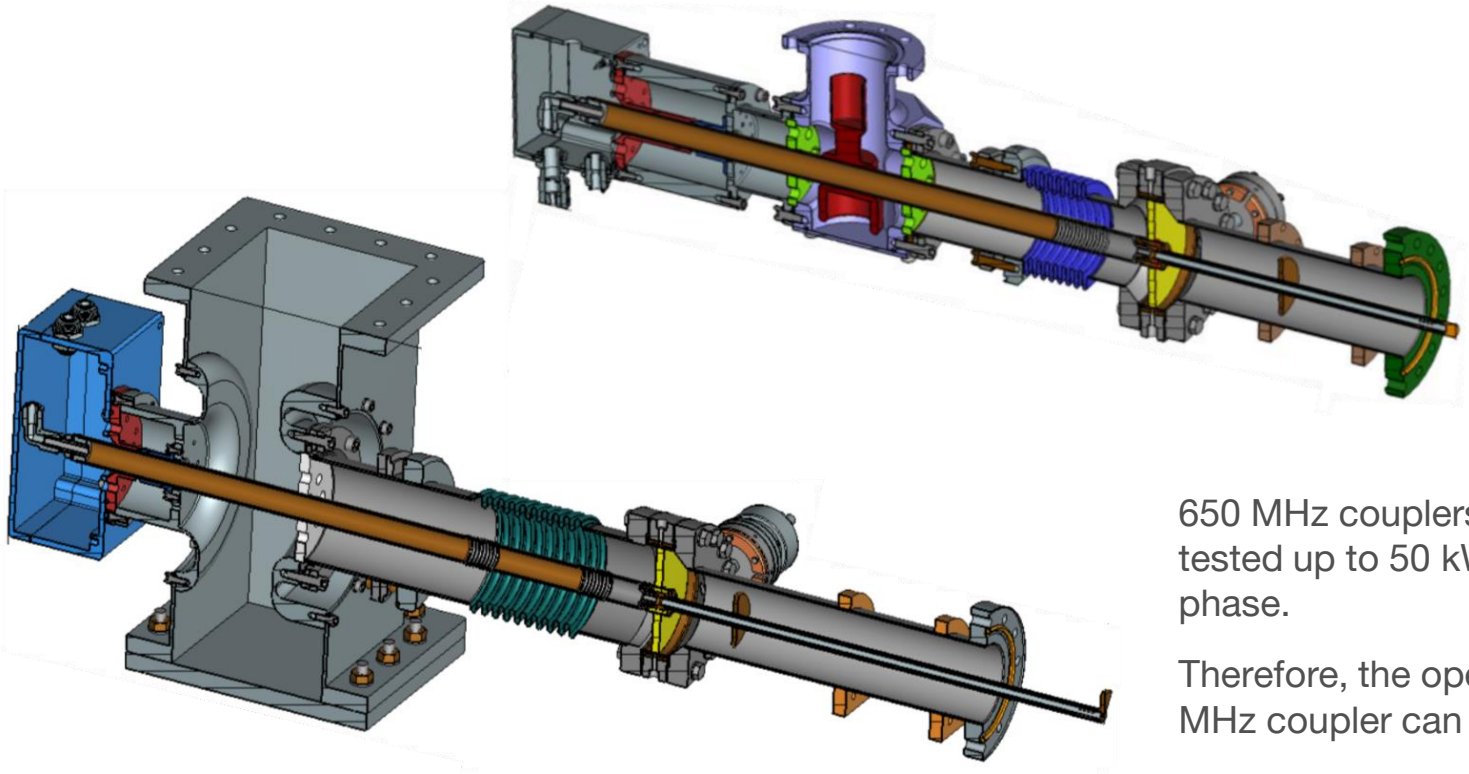
Configurations of 325 MHz and 650 MHz couplers are very similar



650 MHz couplers were successfully tested up to 50 kW, full reflection, any phase.

Therefore, the operating power of 325 MHz coupler can be > 50 kW.

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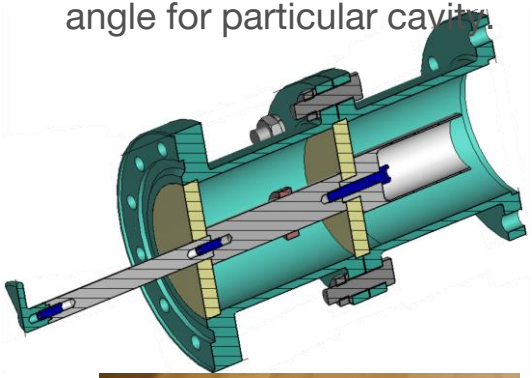
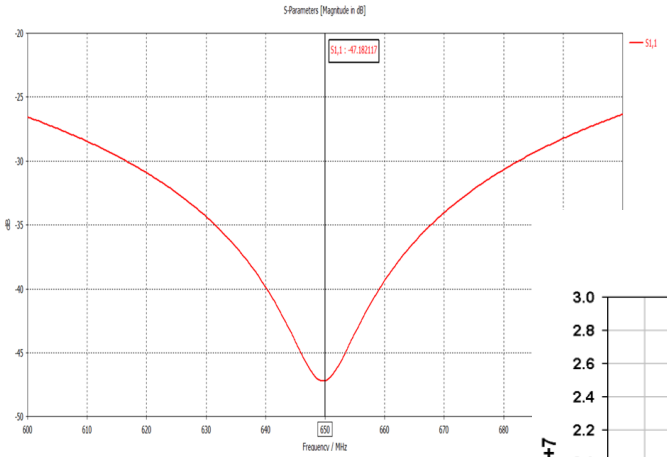
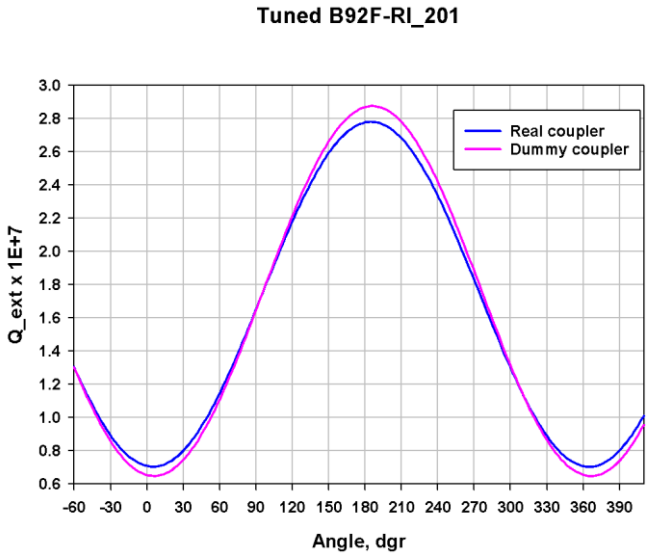
650 MHz dummy coupler

Tip of antenna of 650 MHz coupler is not axial symmetrical and has a “goose foot” shape. It allows to change coupling by rotating antenna. We use dummy coupler to find a right antenna angle for particular cavity.







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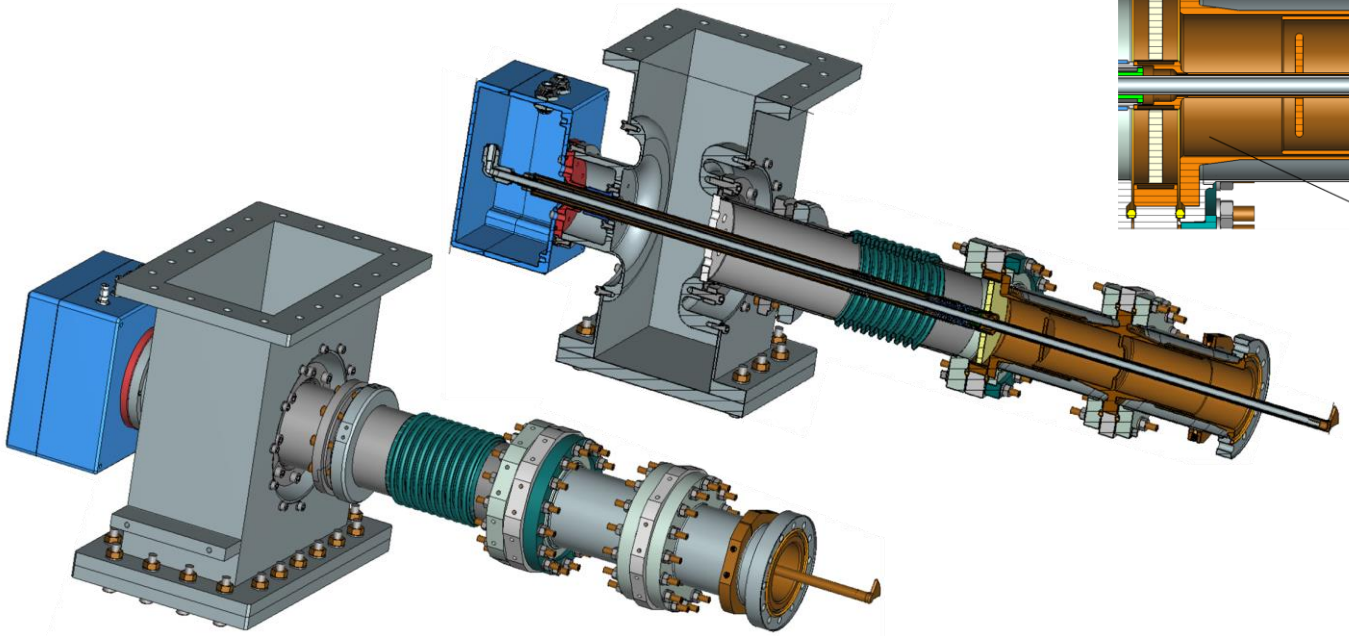
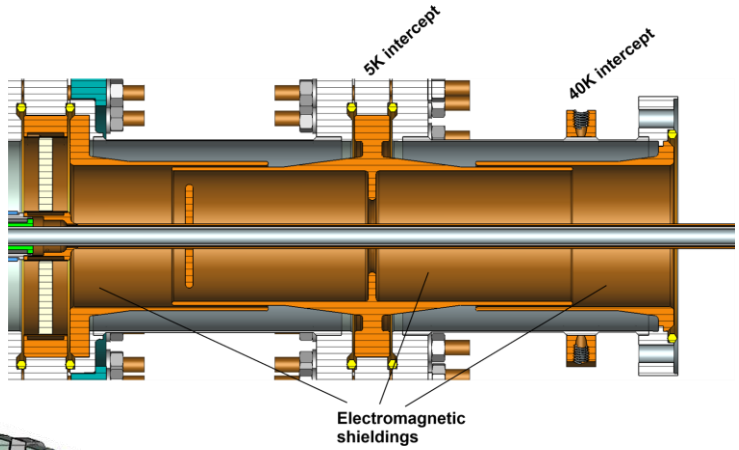
650 MHz coupler with electromagnetic shields (low cryogenic loading)

No copper coatings, reduced cryogenic loading.
Will be used for accelerators with conducting cooling.
Tested up to 50 kW, CW, full reflection.

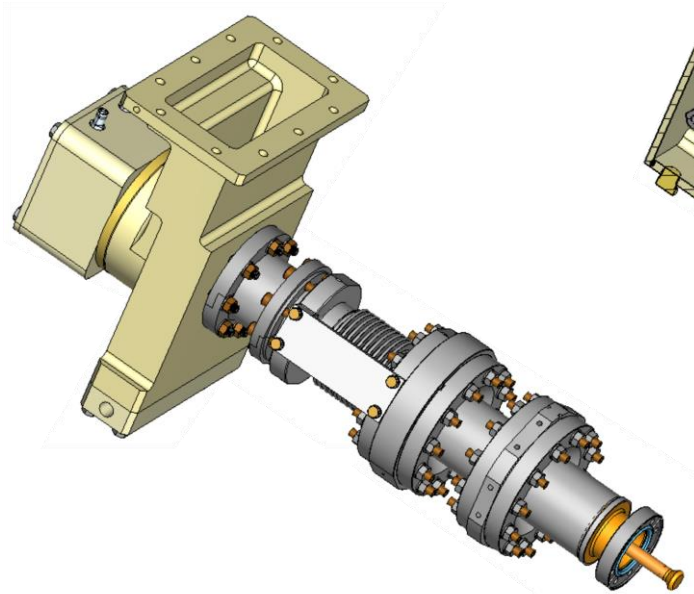


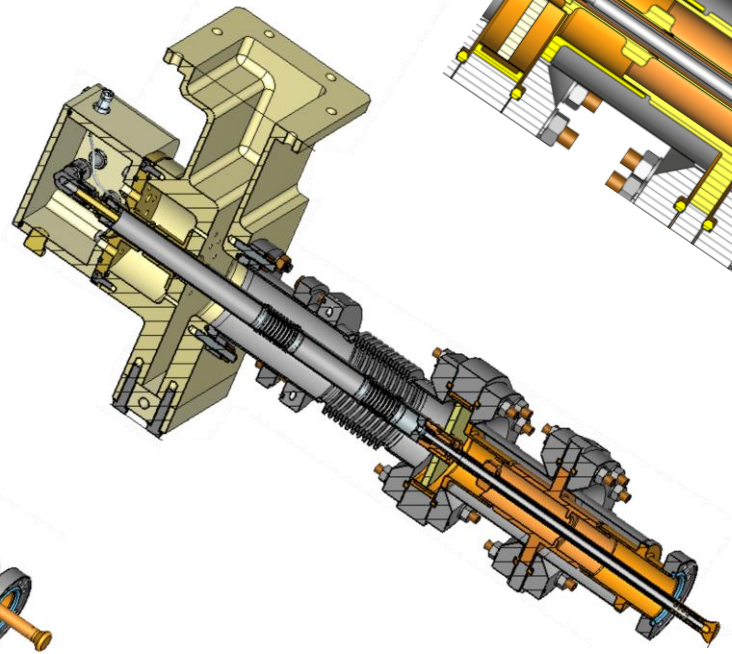


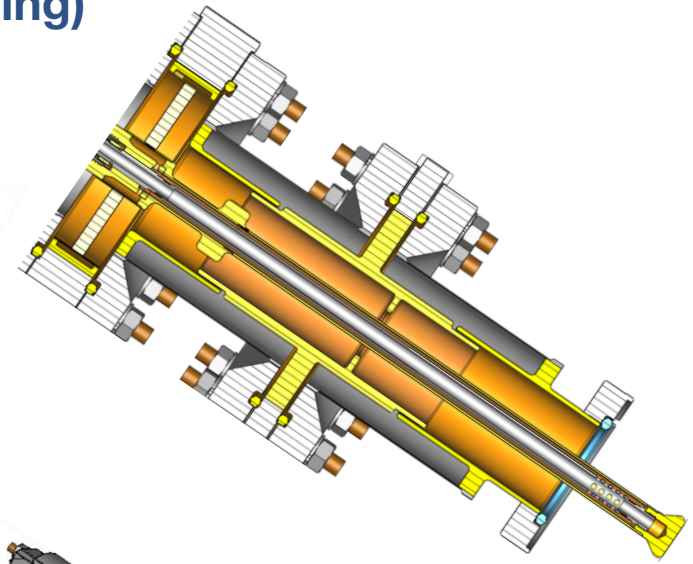
Fermilab

1.3 GHz coupler with electromagnetic shields (low cryogenic loading)

No copper coatings, reduced cryogenic loading.
Will be used for accelerators with conducting cooling.
Prototype was tested up to 27 kW, CW, TW.







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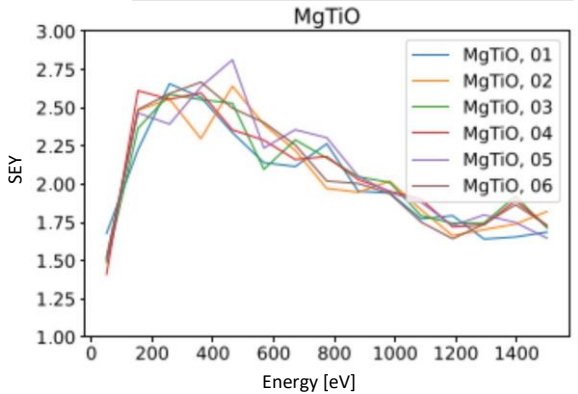
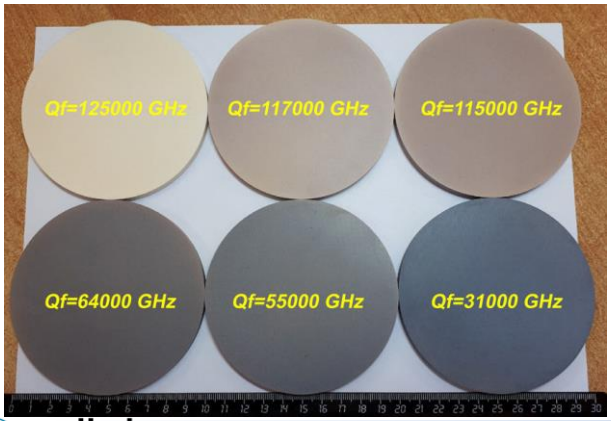
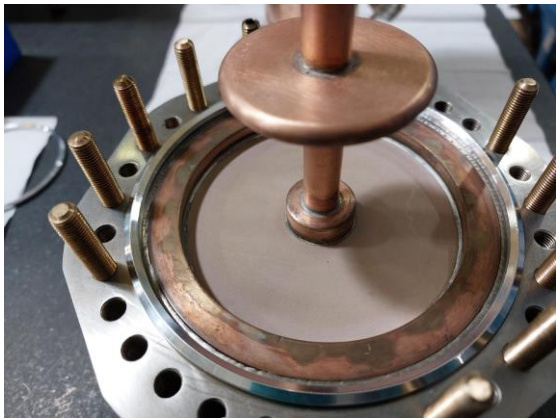
Magnesium Titanate Conductive Ceramic

- Low loss, mildly conductive ceramic prevents charge buildup
  - Controllable conductivity from 10^{-12} to 10^{-8} S/m
  - Relative dielectric constant ε_r=15
  - Figures of merit, Q×f, in the range 30,000–125,000 GHz, providing tan δ ~ 10^{-5} @ 650 MHz
- SEY measured, peak < 2.75
- Waveguide and coaxial window designs fabricated & tested

A. Grudiev, et al, CLIC Note 1175, CERN-ACC-2022-006





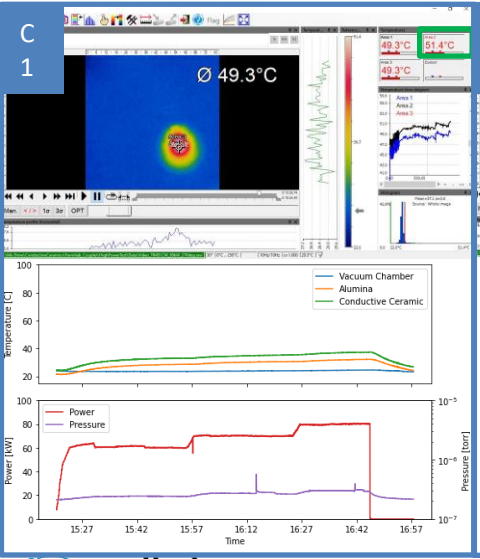


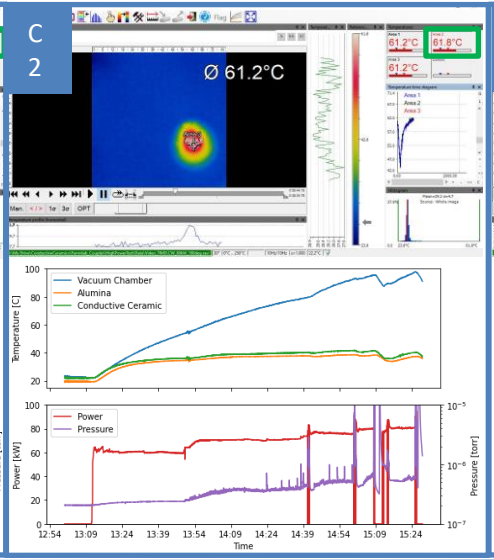
Supported by DOE Office of Nuclear Physics SBIR DE-SC0017150

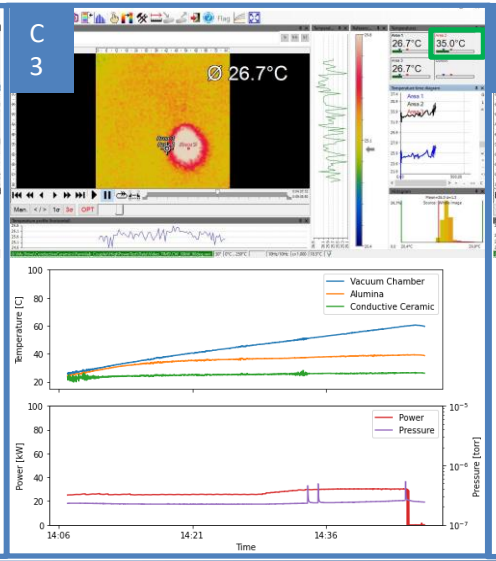
High-Power Test Results

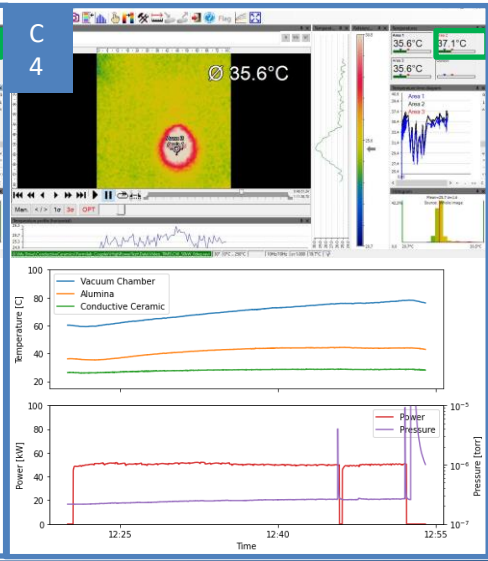
- Field configuration 1:
  - 80 kW
  - 51.4°C CC window
  - 41.8°C CC flange
  - 38.7°C Al_2O_3 flange
  - No vacuum activity
- Field configuration 2:
  - 80 kW
  - 61.8°C CC window
  - 37.5°C CC flange
  - 32.3°C Al_2O_3 flange
  - Some vacuum activity
- Field configuration 3:
  - 30 kW
  - 35.0°C CC window
  - 28.3°C CC flange
  - 39.3°C Al_2O_3 flange
  - Limited by vacuum interlock (data not shown)
- Field configuration 4:
  - 50 kW
  - 37.1°C CC window
  - 28.8°C CC flange
  - 44.4°C Al_2O_3 flange
  - Limited by vacuum interlock (data not shown)

B. Freemire, et al, IPAC'24, WEPS17









Inspection & Conclusion

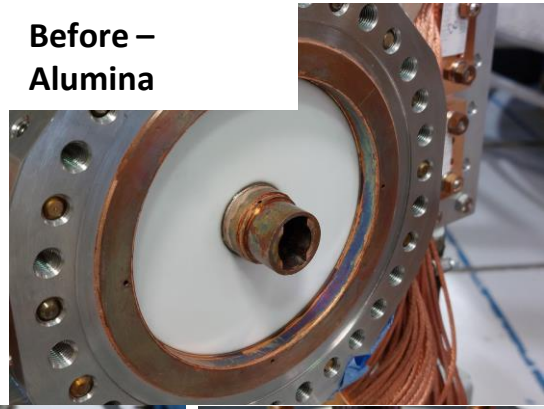
- Pickups showed significant electron activity near alumina window, minimal activity near conductive ceramic window
- After high power test:
  - No change in conductive ceramic window appearance
  - Significant discoloration of alumina window

➢ Multipacting on alumina window limited achievable power in two field configurations

✔ Power in other two configurations administratively limited to 80 kW
  - No indication conductive ceramic window could not achieve higher power

Before – Conductive Ceramic

Before – Alumina

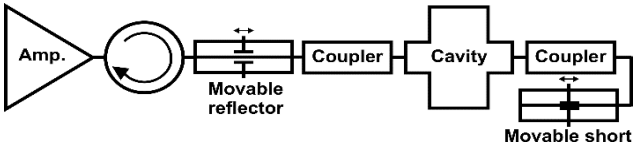


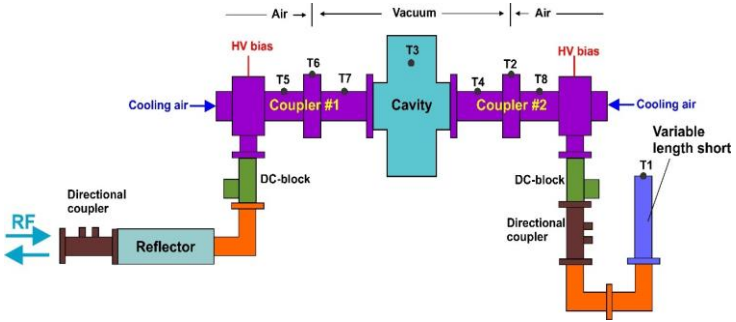
After – Conductive Ceramic

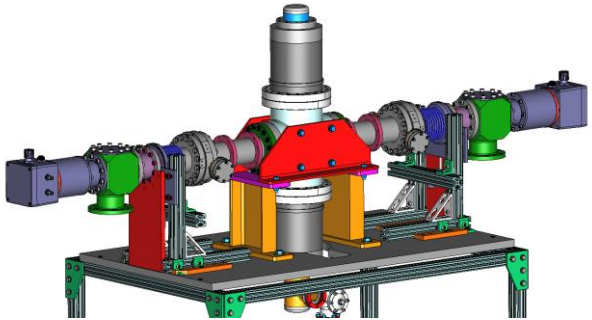
After – Alumina

Coupler test stand, 325 MHz

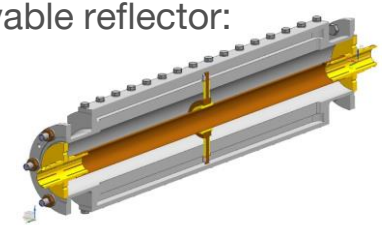
Power amplification ~ 5:







Movable reflector:



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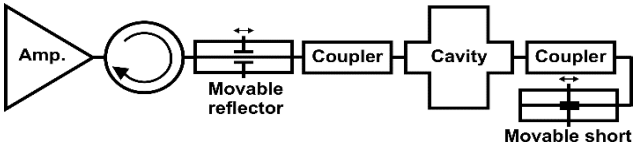
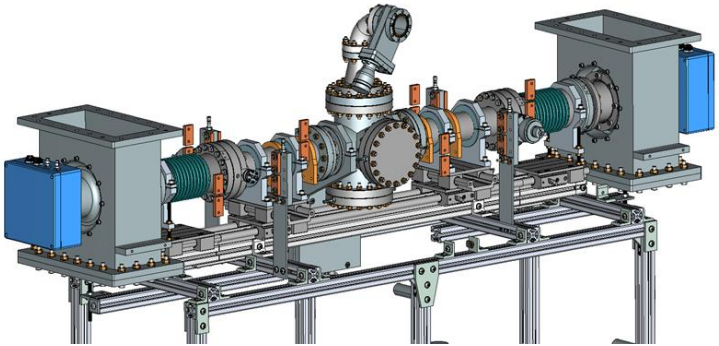
Coupler test stand, 650 MHz

Power amplification ~ 5:





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Procedure of testing

Test preparation:
Couplers and coupling cavity are assembled/disassembled in clean room, class 10.
Couplers with coupling cavity is baked at temperature 120C x 48 hours.

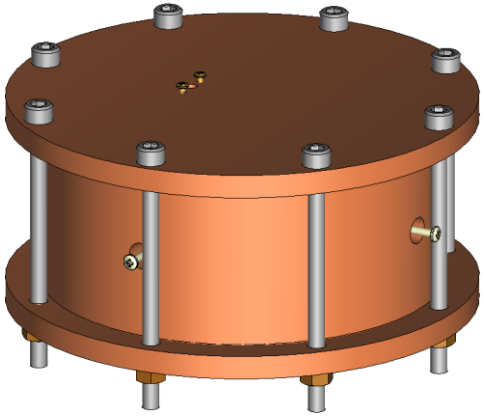
Stage 1: Testing with bias.
Goals:
325 MHz couplers – 12 kW, CW, full reflection, 4 phase pints.
650 MHz couplers – 47 kW, CW, full reflection, 8 phase points.

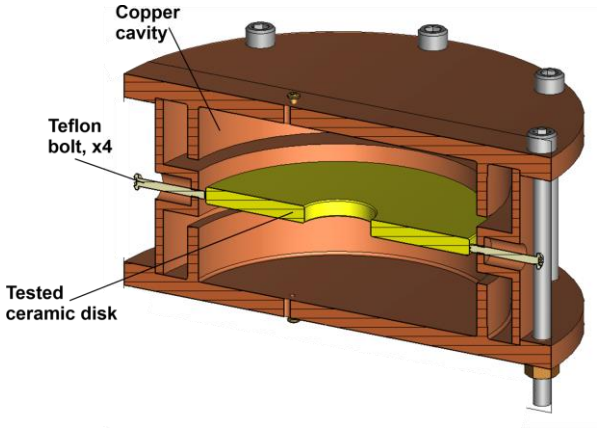
Testing protocol for each phase points

Pls. length, ms	10	100	300	600	CW
Max. power, 325 MHz, kW	25	25	25	20	12
Max. power, 650 MHz, kW	100	100	100	70	47

Stage 2: Cleaning without bias

Measuring the loss tangent of ceramics





Frequency of measurements ~ 2.4 GHz

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