Couplers for Project X

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TTC meeting on CW-SRF, 2013

Requirements to Project X couplers

Cavity SSR1 (325MHz):

Max. energy gain - 2.1 MV,
Max. power , 1 mA case - 4.2 kW,
Max. power , 5 mA case ~ 11 kW

Cavity SSR2 (325MHz):

Max. energy gain - 4.4 MV
Max. power ,1 mA case - 4.4 kW,
Max. power , 5 mA case ~ 22 kW

325 MHz couplers has to provide reliable operation at power level of ~ 30 kW, CW

Cavity LE650 (650MHz):

Max. energy gain - 11.2 MV,
Max. power , 1 mA case - 25.2 kW,
Max. power , 5 mA case ~ 56 kW

Cavity LE650 (650MHz):

Max. energy gain - 17.3 MV,
Max. power , 1 mA case - 24.5 kW,
Max. power , 5 mA case ~ 87 kW

650 MHz couplers has to provide reliable operation at power level of ~ 100 kW, CW

Common technology and parts when possible for both couplers

Single window or double windows?

Two windows Pros:

- **cold window can be placed closer to structure**
- **It simplifies cryomodule-cavities assembling**
- **Higher reliability (?)**

Cons: Complicity and price.

What previous experience says?

Facilities except ILC-like (FLASH, TTF, STF, improved TTF-III couplers supposed to be used in Cornell ERL) use single window couplers .

Most powerful examples: of CW couplers/windows:

APT coupler (700MHz):
Single planar window with inter-cooling (cooling air two ceramic windows)
Tested power 1 MW (TW), 850 KW (SW)
Average power density through ceramic ≈ 2.3 kW/cm^2.

Super-KEKB ARES(Accelerator Resonantly coupled with Energy Storage**) (509 MHz): Single planar window**
Tested 950 kW CW (supposed operating power 800 kW)
Average power density through ceramic ≈ 4.4 (3.7) kW/cm^2.

Toshiba 1MW CW 508 MHz klystron:
Single coaxial planar window. Tested power 1.2 MW CW
Average power density through ceramic ≈ 5.6 kW/cm^2.

Single-window couplers for SC cavities (S. Belomestnykh)

Facility	Frequency	Coupler type	RF window	Q_{ext}	Max. power	Comments
LEP2 [4,5,6]	352 MHz	Coax fixed	Cylindrical	2×10^6	Test: 565 kW 380 kW Oper: 100 kW	Traveling wave Stand. wave@ Γ=0.6
LHC [5,7]	400 MHz	Coax variable (60 mm stroke)	Cylindrical	2×10^4 to 3.5×10^5	Test: 500 kW 300 kW	Traveling wave Standing wave
HERA [8,9]	500 MHz	Coax fixed	Cylindrical	1.3×10^5	Test: 300 kW Oper: 65 kW	Traveling wave
CESR [10,11] (Beam test)	500 MHz	WG fixed	WG, 3 berillia disks	2×10^5	Test: 250 kW 125 kW Oper: 155 kW	Traveling wave Standing wave Beam test
CESR [12,13]	500 MHz	WG fixed	Disk WG	2×10^5	Test: 450 kW Oper: 300 kW 360 kW	Traveling wave Beam power Forward power
TRISTAN [14]	509 MHz	Coax fixed	Disk coax	1×10^6	Test: 200 kW Oper: 70 kW	
KEK-B [15,16]	509 MHz	Coax fixed	Disk coax	7×10^4	Test: 800 kW 300 kW Oper: 380 kW	Traveling wave Standing wave
APT [17]	700 MHz	Coax variable (±5 mm stroke)	Disk coax	2×10^5 to 6×10^5	Test: 1 MW 850 kW (fixed coupler)	Traveling wave Standing wave
JLAB FEL [18]	1500 MHz	WG fixed	Planar WG	2×10^6	Test: 50 kW Oper: 35 kW	Very low ΔT

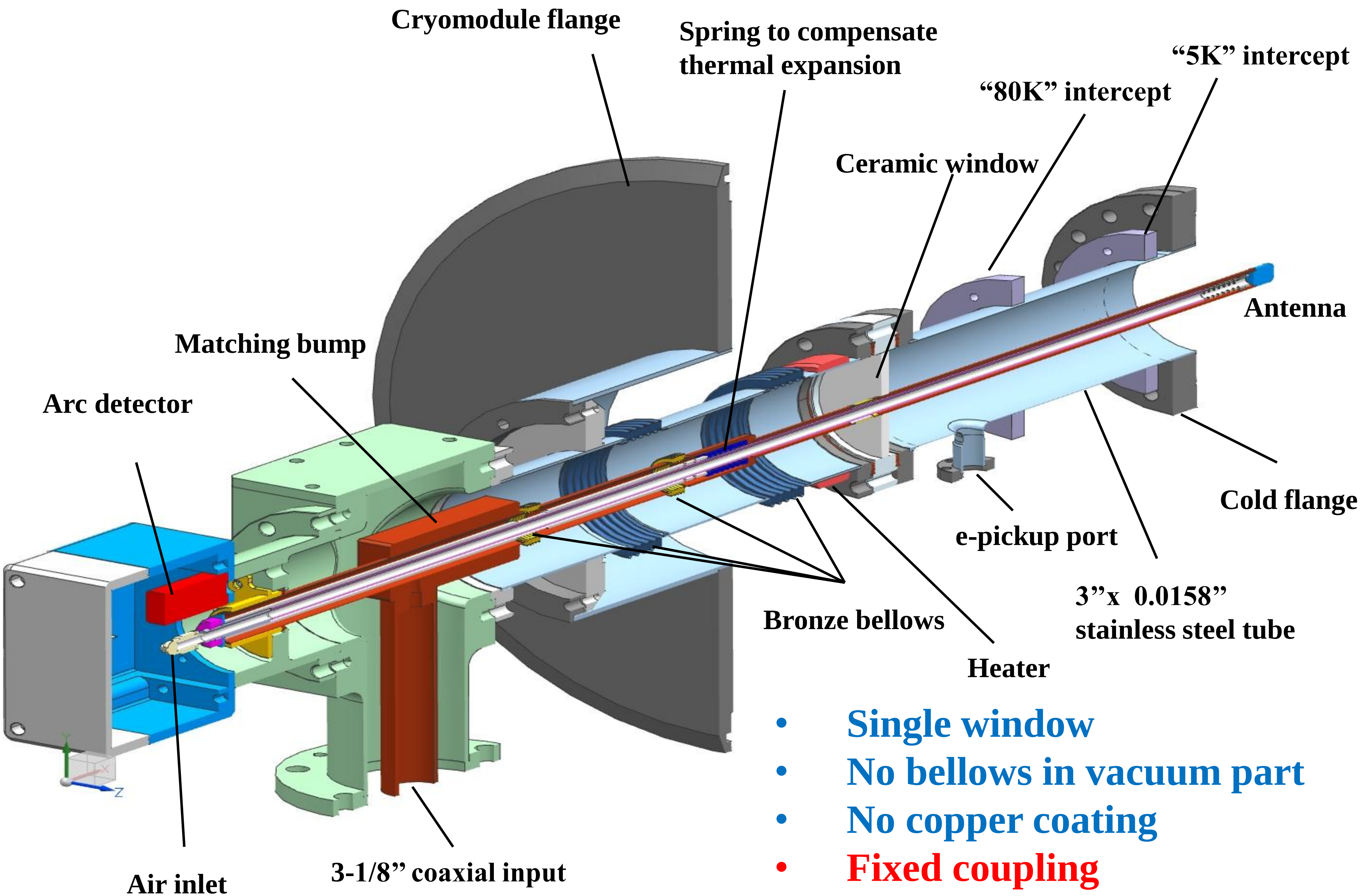
Single window or double windows?

- **We do not expect RF breakdown – power is low**
- **Geometry choice is minimizing cryo-loading and providing reliable operation at appropriate RF power level.**
- **Only thermal stress is possible reason of window destruction**
- **Multipactor is reduced by high impedance and will be suppressed using HV bias if necessary.**

Conclusion:
“Entities must not be multiplied beyond necessity”
Single-window is a right choice for Project X.

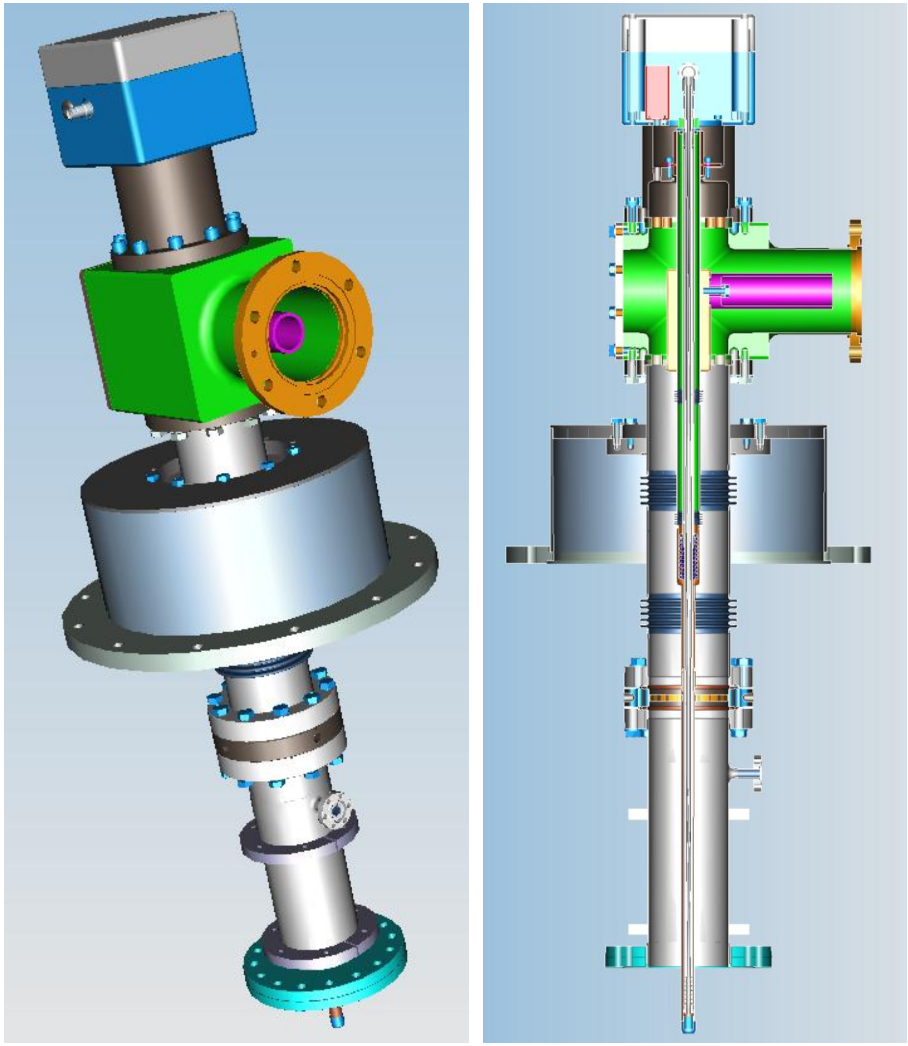
Experiments with prototypes (1st set of full size couplers) give us most answers

325 MHz coupler



- Single window
- No bellows in vacuum part
- No copper coating
- Fixed coupling

325 MHz coupler parameters

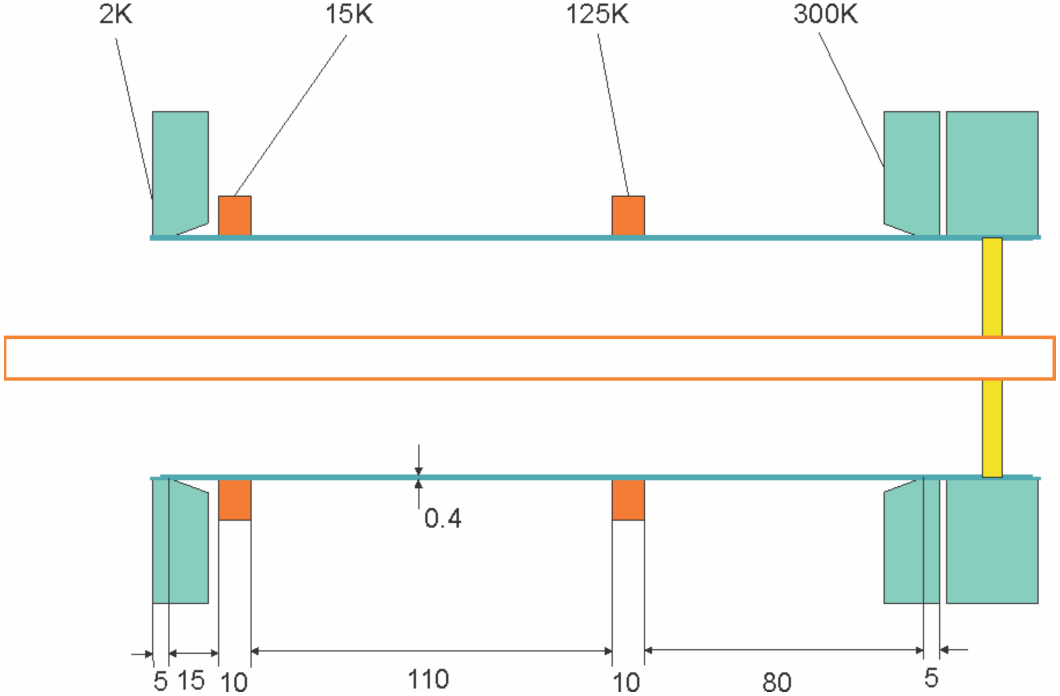


Design power 30 kW, CW
Air cooling of central conductor
HV bias on central conductor
No copper coating in vacuum part
Pulse power (breakdown in air) ~ 400 kW
Multipactor threshold > 6 kW SW (>25kW TW)
Pass band (S11 < -20dB) ~ 50MHz, (15%)

Status:

- **3 couplers are in production.**
- **Will be ready ~ July 2013**

325 MHz coupler cryo-loading



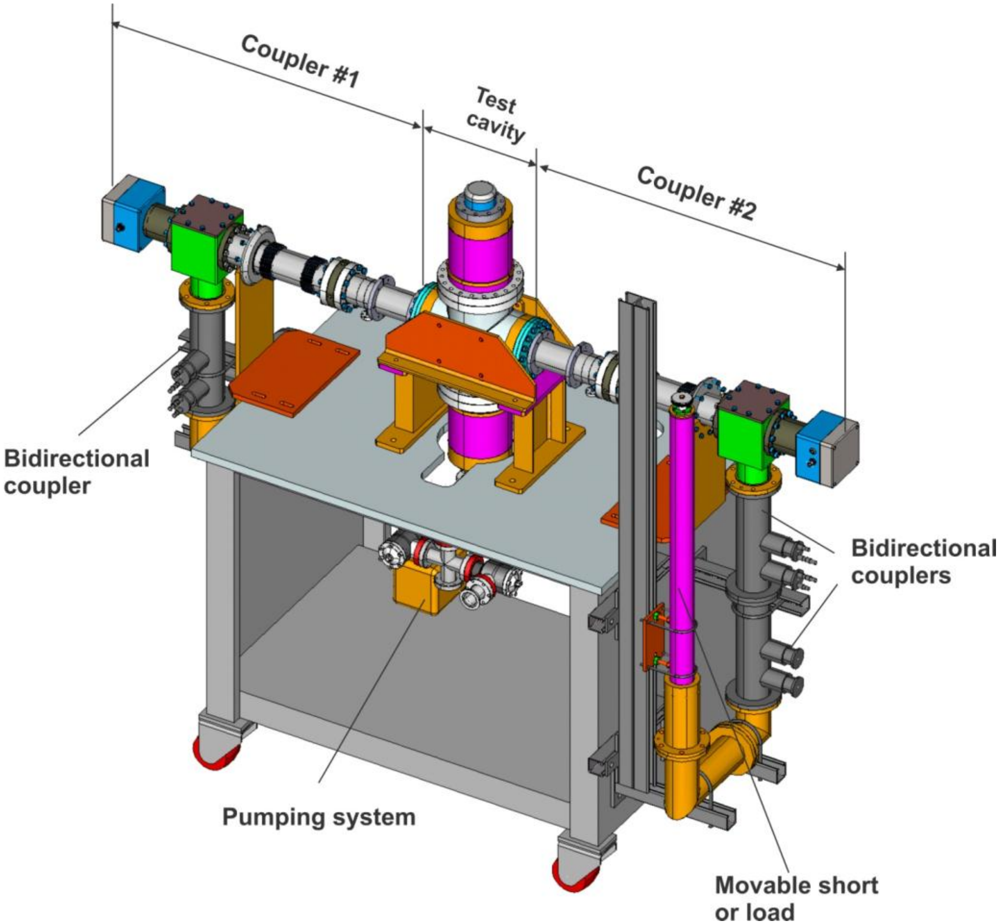
Inner conductor:
Solid copper

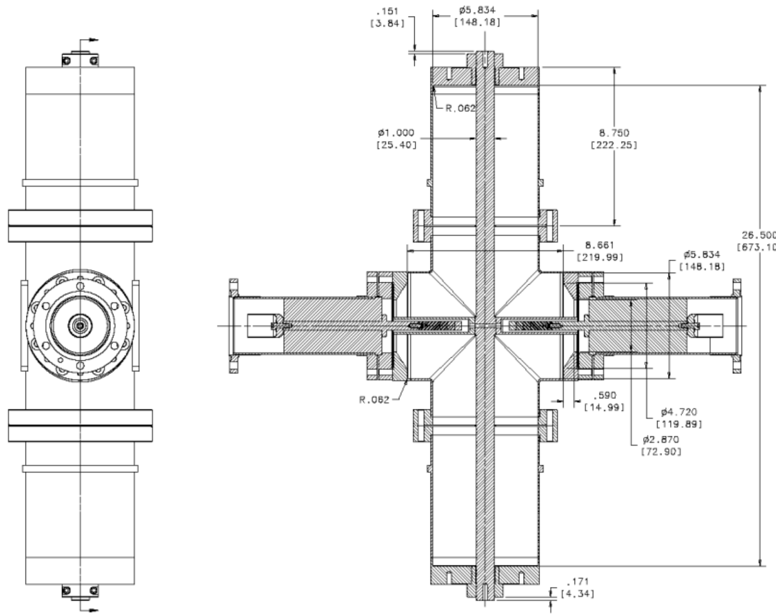
Outer conductor:
- **0.4 mm thick SS**
- **No copper coating**
- **Interceptors 15K, 125K**

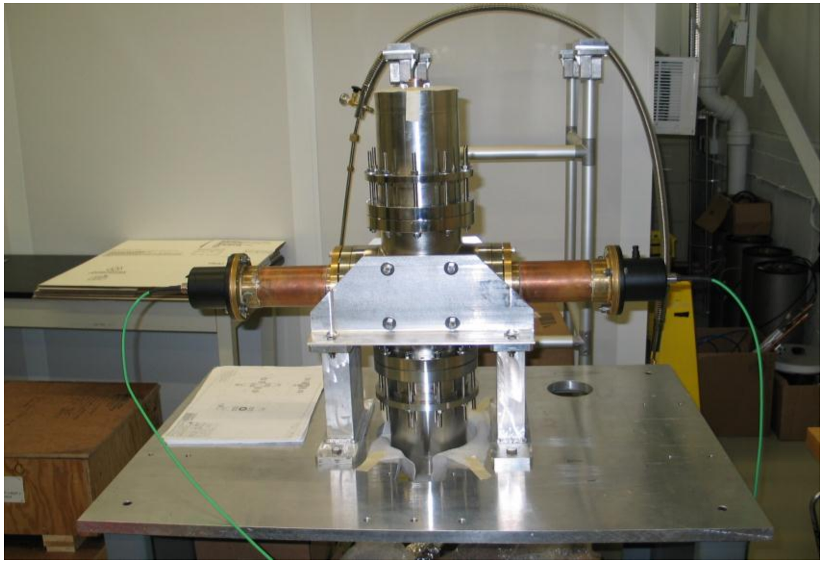
	P_2K / P_pl, W	P_15K / P_pl, W	P_125K / P_pl, W	P_pl total, W	
Pin = 0kW	0.06 / 52	0.58 / 151	2.02 / 40	243	Static loss
Pin = 3kW	0.10 / 86	0.81 / 211	2.35 / 47	344	PXIE
Pin = 6kW	0.15 / 129	1.03 / 268	2.68 / 54	451	PX , 1mA
Pin = 20 kW	0.35 / 301	2.07 / 538	4.25 / 85	924	PX, 5mA, no overhead
Pin = 30 kW	0.50 / 430	2.82 / 733	5.36 / 107	1270	PX, 5mA, with overhead
Cryo coeff.	860	260	20		

- **325 MHz coupler can operate without copper coating**

325 MHz coupler test stand







Test stand cavity with dummy couplers

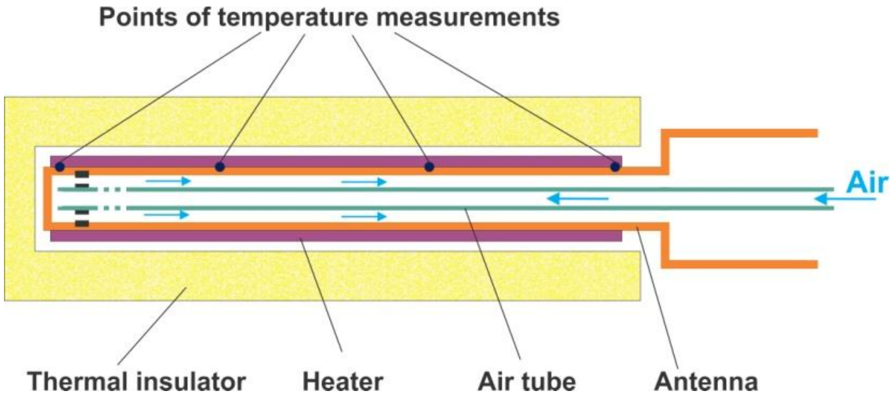
Dimensions of test stand cavity were chosen to prevent multipactor

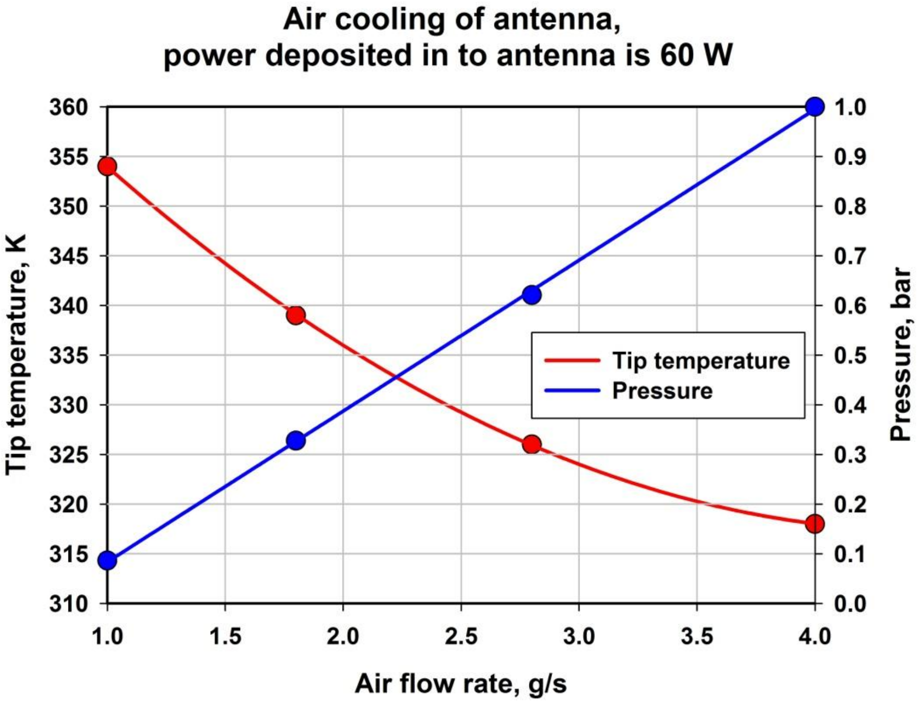
Antennae do not touch the walls of cavity

Central conductor mockup testing

Measurements of antenna cooling.

- **Air cooling performance were checked.**
- **Air cooling provides good antenna cooling at RF power level ~ 100 kW.**
- **Pressure drops and air flow rate are moderate**
- **No acoustics resonance, whistle effect.**

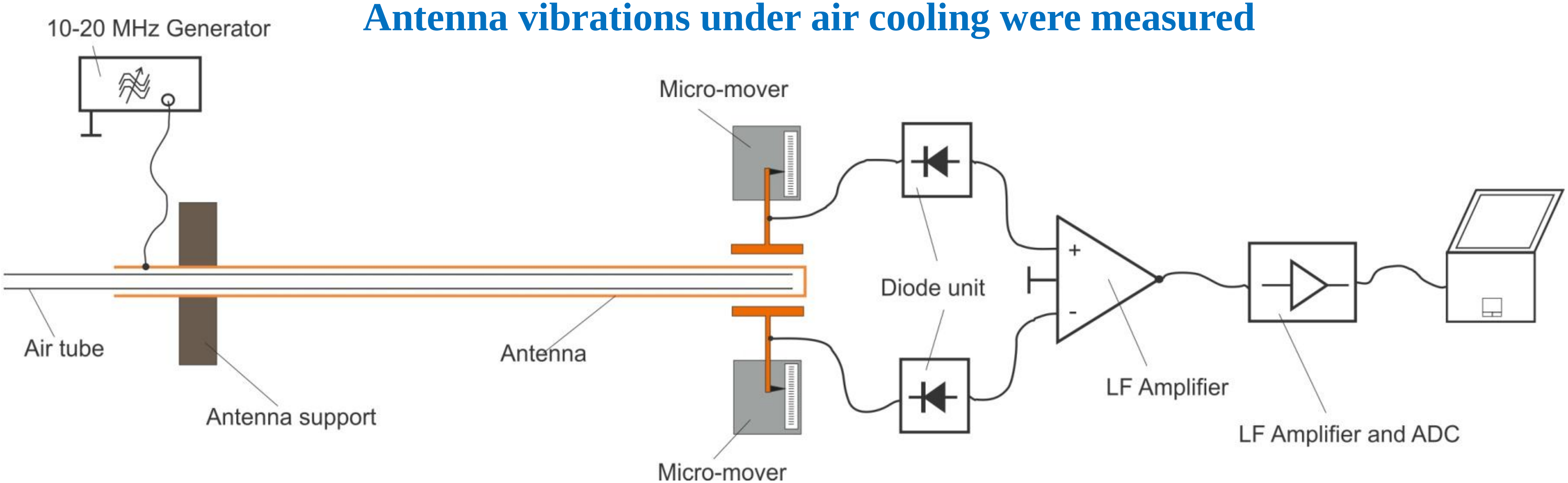




- **Air cooling can be used up to 100 kW of RF power**

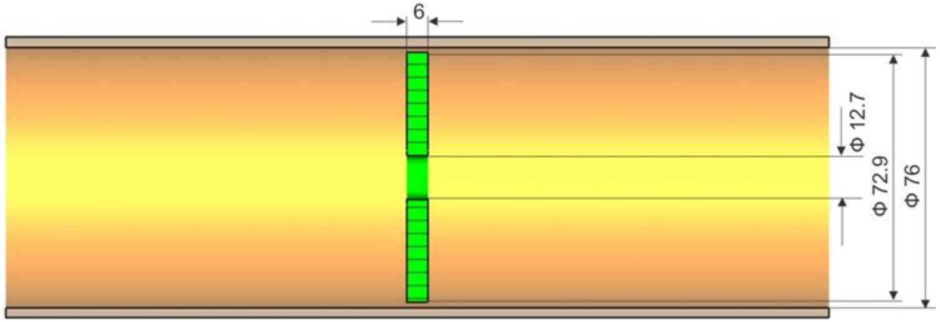
Central conductor mockup testing

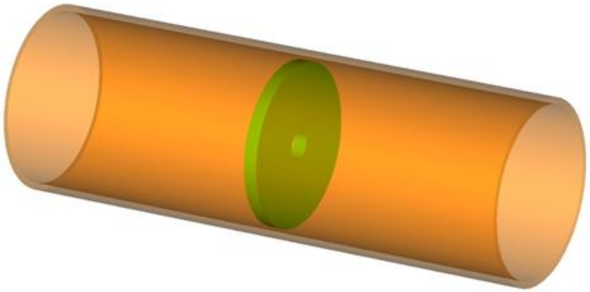
Antenna vibrations under air cooling were measured



Test results: Motion caused by cooling air flow is ≤ $3 \cdot 10^{-3}$ mm.
(allowable transverse deviations ~ 1 mm)

Measuring of ceramic window properties

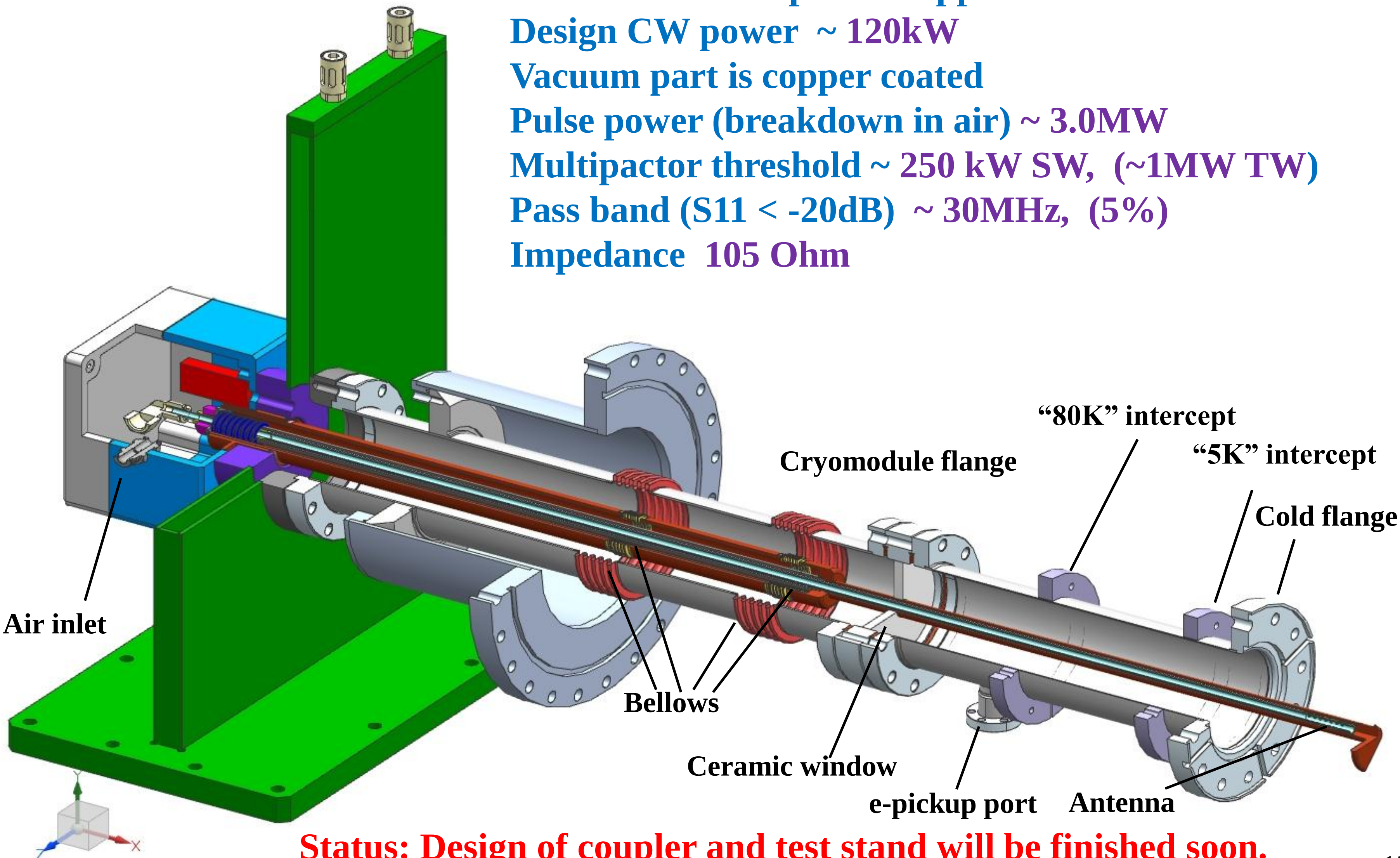




- **Measured dielectric loss tangent ~ 10^{-4} at 2.7 GHz**

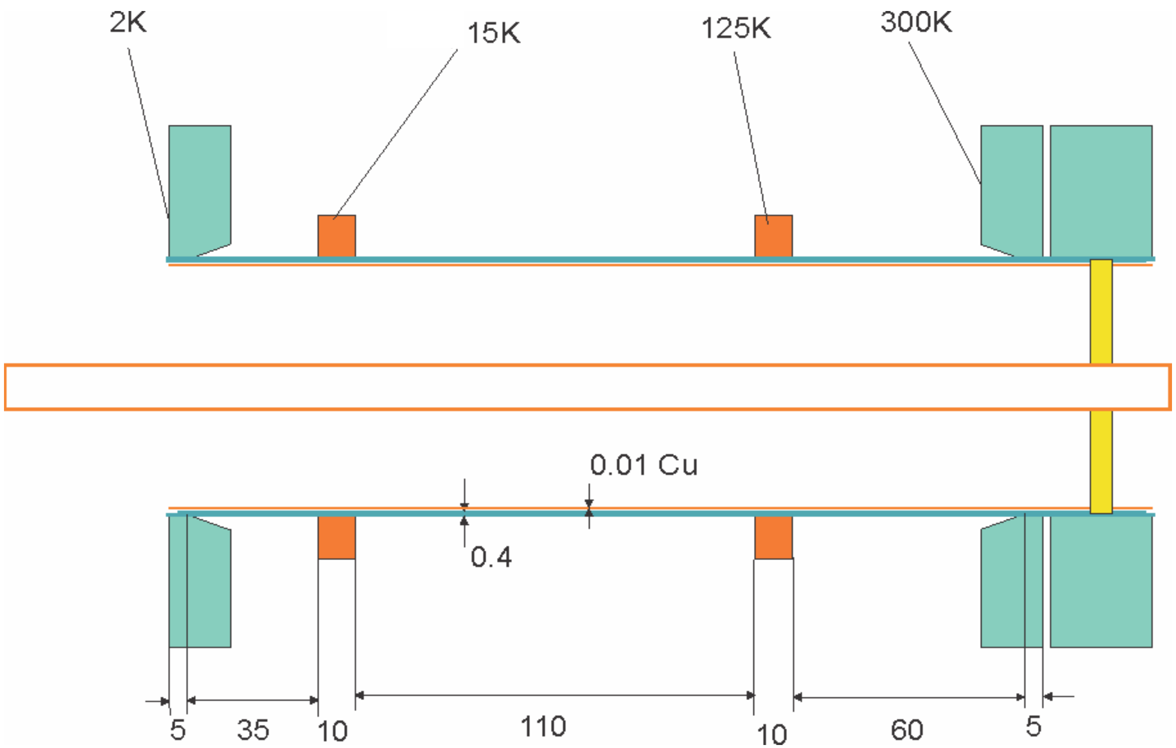
650 MHz coupler

Design power 120 kW, CW
Air cooling of central conductor
HV bias for multipactor suppression
Design CW power ~ 120kW
Vacuum part is copper coated
Pulse power (breakdown in air) ~ 3.0MW
Multipactor threshold ~ 250 kW SW, (~1MW TW)
Pass band (S11 < -20dB) ~ 30MHz, (5%)
Impedance 105 Ohm



Status: Design of coupler and test stand will be finished soon.

650 MHz coupler cryo-loading



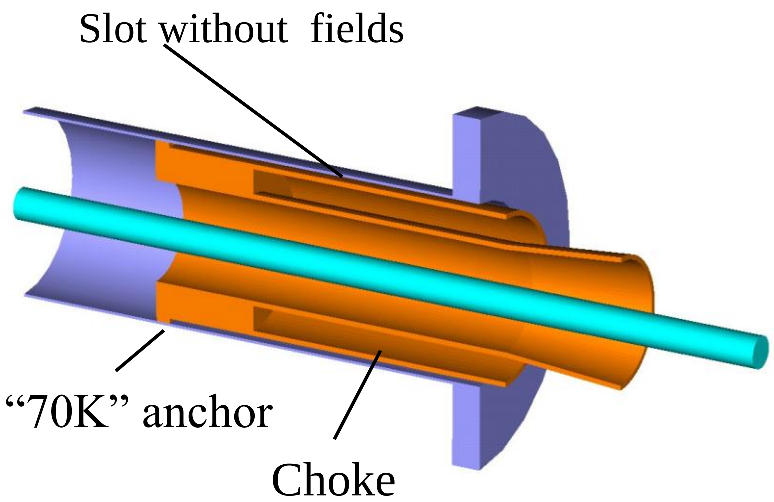
Inner conductor:
Copper tube

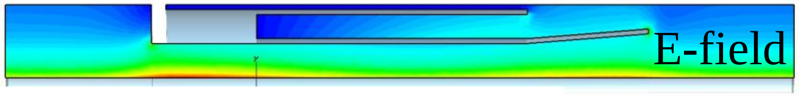
Outer conductor:
SS tube Copper coated

	P_2K / P_pl, W	P_15K / P_pl, W	P_125K / P_pl, W	P_pl total, W
Pin = 0kW	0.24 / 207	1.76 / 458	4.46 / 89	754
Pin = 30kW	0.30 / 258	1.97 / 512	4.74 / 95	865
Pin = 70kW	0.36 / 310	2.26 / 588	5.31 / 106	1004
Pin = 120kW	0.45 / 387	2.65 / 689	6.03 / 121	1197

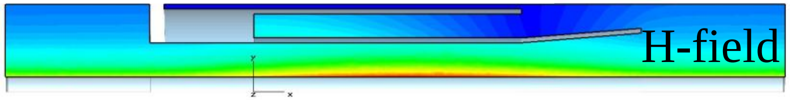
- **650 MHz coupler copper coated**

Configuration without copper coating and dynamic losses

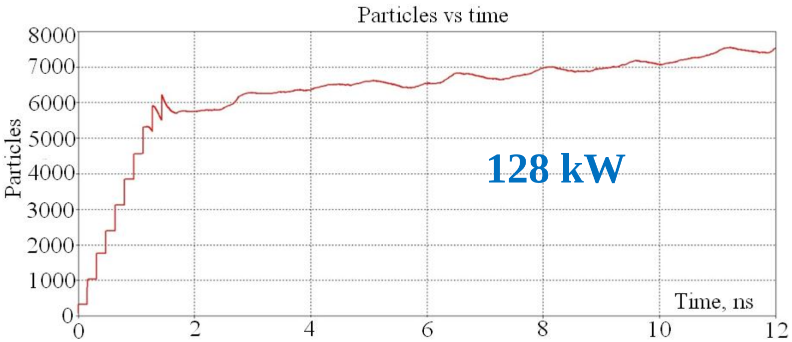




Pass band ~ 100 MHz (15%)

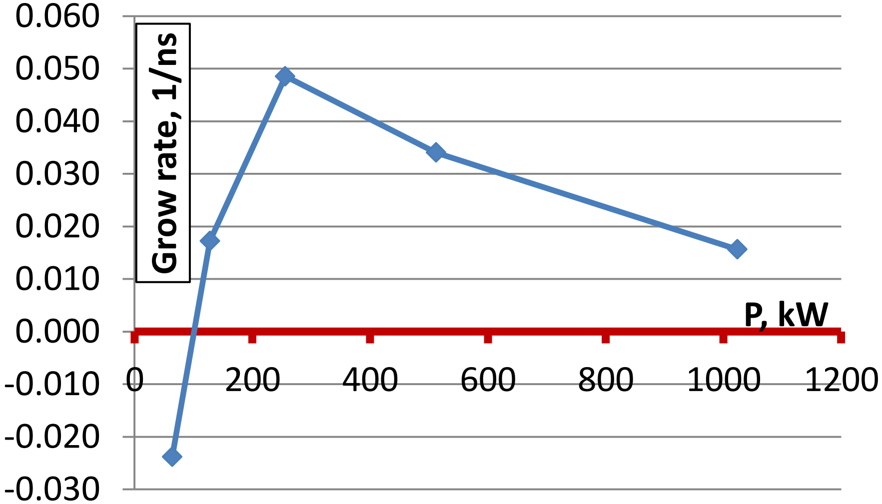


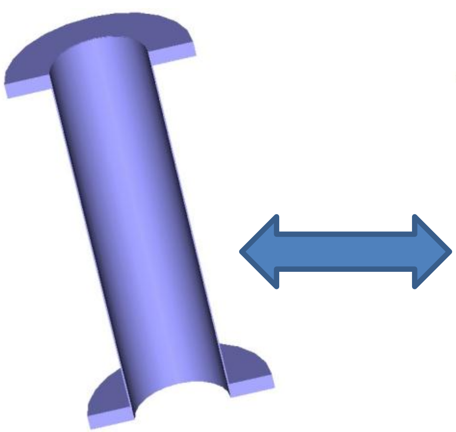
Multipactor in copper insert

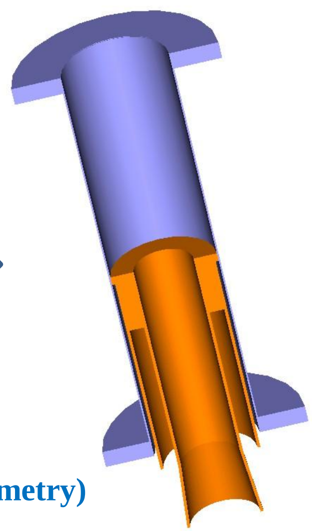


Experiment should not take much resources.
Only vacuum pipe of coupler has to be changed.

It seems multipactor threshold ~ 100 kW, TW

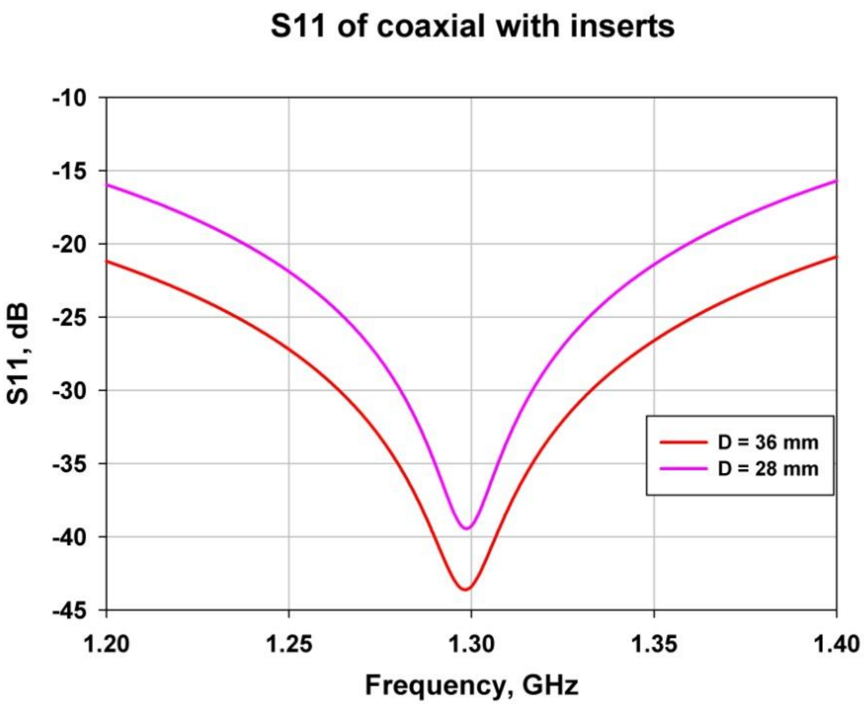


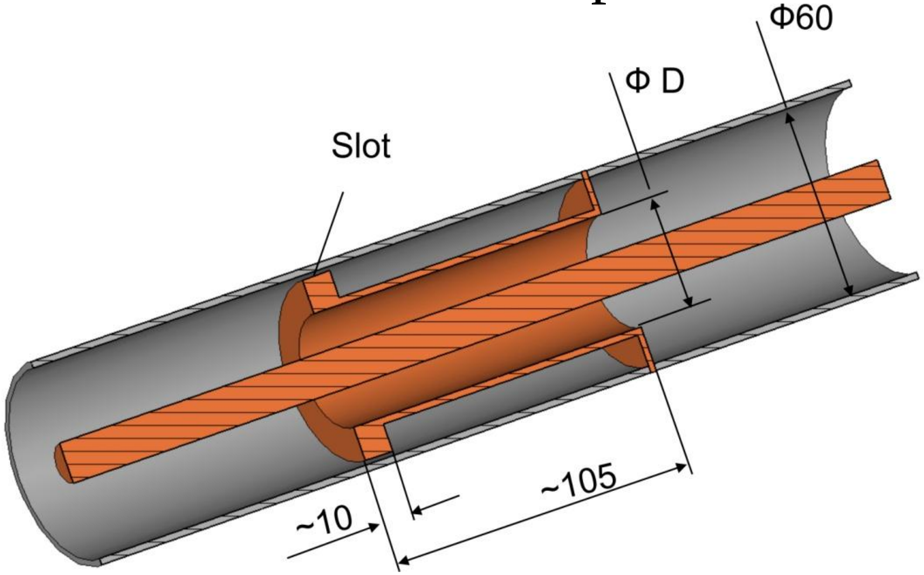


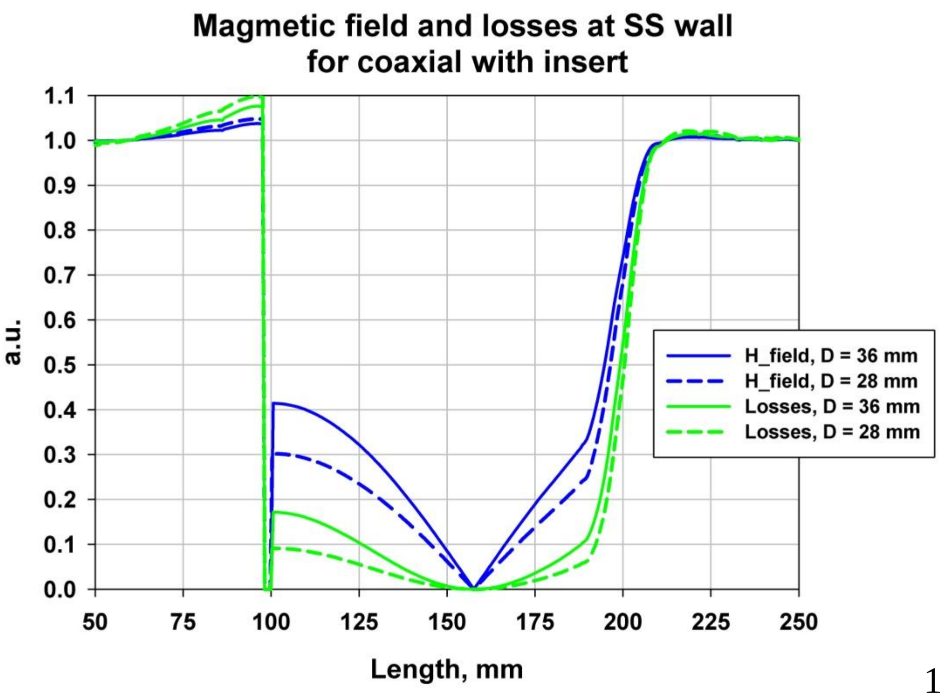


(Antenna tip has to fit new geometry)

The same approach can be used for 1.3 GHz coupler



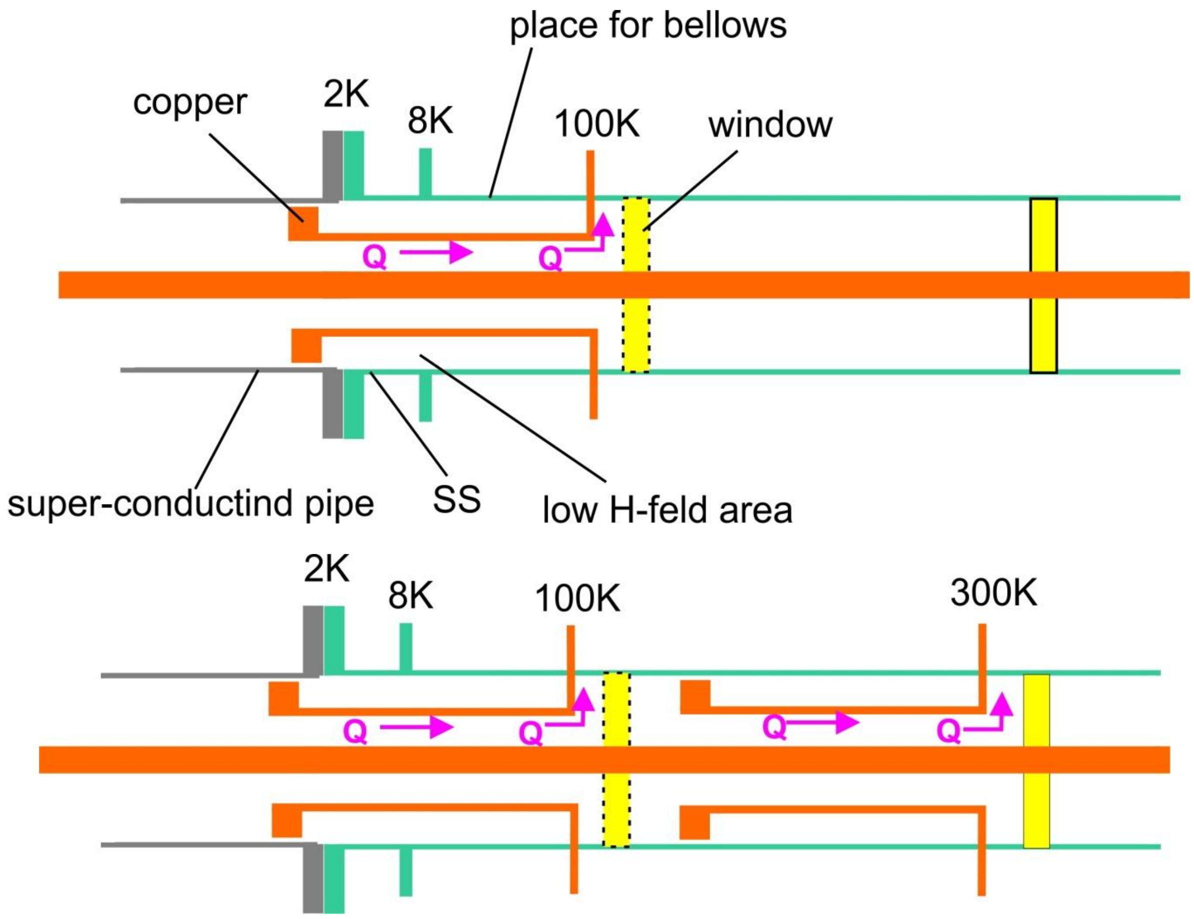




The insert of this shape decreases losses in SS wall 10 – 20 times

Multipactor has to be checked

Possible configurations of 1.3 GHz coupler



- Multipactor simulations needed
- Cleaning and assembly is more complicated

Summary

Project X couplers under development at FNAL will have:

- Similar RF and mechanical designs
- Single, warm vacuum window
- High Voltage for multipactor suppression
- Air cooling of central conductor
- “15K” and “125” thermal intercepts in outer conductor
- No bellows in the cold, vacuum part
- Separate window assembly
- No copper coating for 325 MHz coupler
- Tests not done yet

- What are the benefits and risks of single windows or double windows?
  - Single window: simple, cost effective, higher RF power, vacuum reliability
  - Double window: vacuum reliability, lower cryo-load, additional vacuum
- What vacuum monitoring is required?
  - Vacuum monitoring help to reduce risk of damage. Vacuum gages with operating range ~ 10^{-9} – 10^{-4} Tor wired to interlock.
- What are the best cooling schemes?
  - Depends on RF power level, coupler design. Could be conduction, cooling media flow, radiation and convection cooling.
- How can we minimize fabrication risk, e.g., with respect to copper plating?
  - Provide appropriate risk analysis and reduce all risk factors. Copper plating could generate particles and increase risk of contamination.
- How can we reduce conditioning time and cost?
  - Bake when possible, pre-conditioning and in-situ warm conditioning
- How does clean-ability (e.g. HPR) impact coupler designs?
  - Surfaces should be smooth and accessible for cleaning, avoid semi-trapped volume. Particle free vacuum parts.
- Is High Voltage (HV) bias necessary?
  - Yes, when multipactor can not be processed away in reasonable time