RFQ coupler review

S. Kazakov, O. Pronitchev, V. Poloubotko

05/21/2013

Content:

1st talk, S. Kazakov

- Requirements
- Configuration
- RF parameters
- Multipactor and its suppression
- Thermal analyses
- Possible test cavity configuration

2nd talk, V. Poloubotko

Stress analyses

3rd talk, O. Pronitchev

Mechanical design

Requirements

RFQ parameters (from RFQ FRS)

Parameter	Value
Ion type	H-
Beam current	1-10 mA
Beam energy	0.03-2.1 MeV
Frequency	162.5 MHz
Duty factor (CW)	100%
Total RF power	≤ 130 kW
Number of couplers	2

Coupler requirements

Parameter	Value
Frequency	162.5 MHz
Operating power (SWR: $1 \div \infty$)	75 kW
Coupling type	Loop
Output port diameter	~3"
Input impedance	50 Ohm

All simulations was done for 80 kW

Expected problems:

• Multipactor exists for this combination of frequency, RF power and dimensions. Measures to suppress a multipactor are necessary.

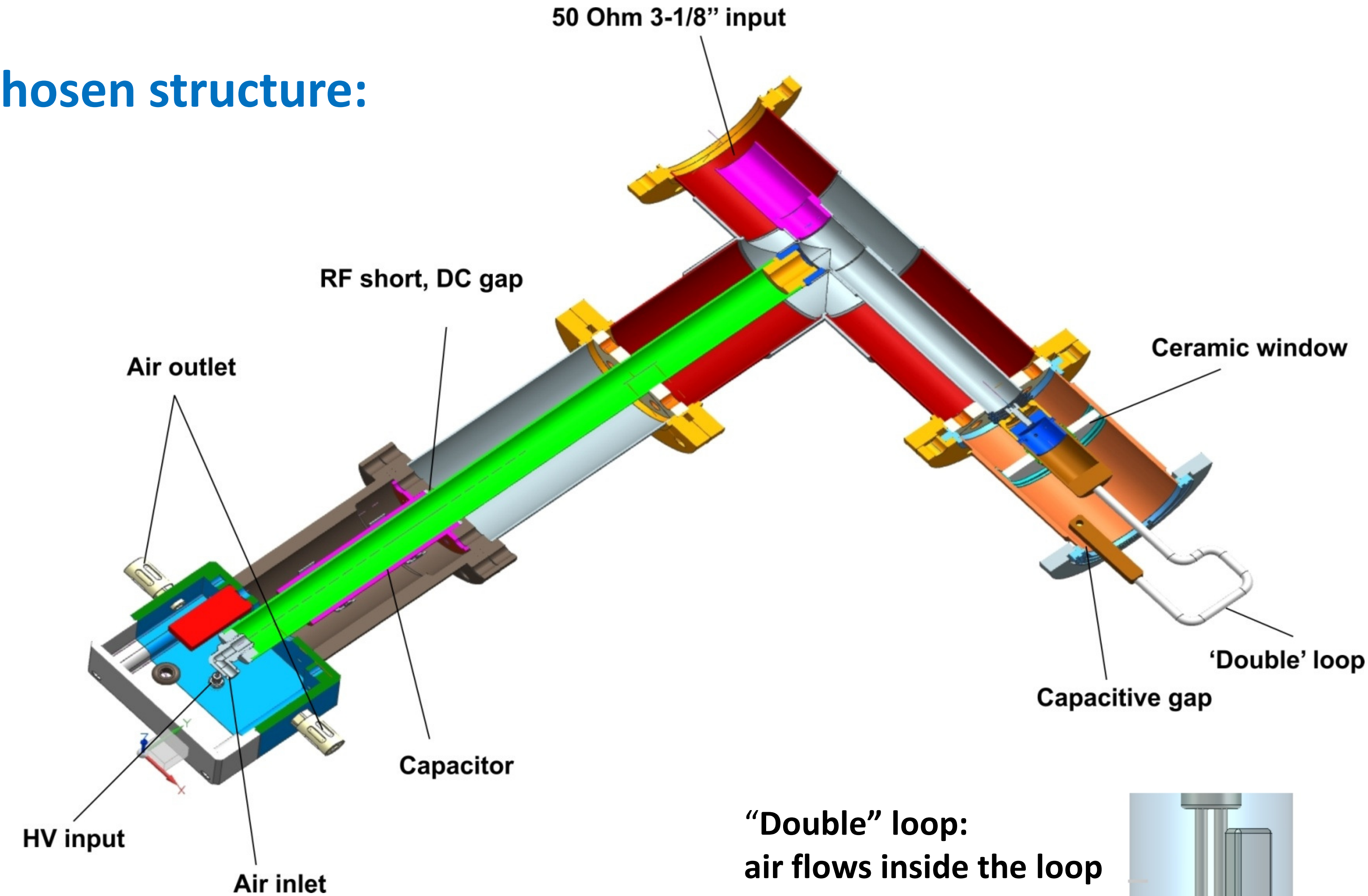
• Loop will be heated by magnetic field of cavity. Loop must be cooled.

We have chosen a simple structure which allows to solve these problems:

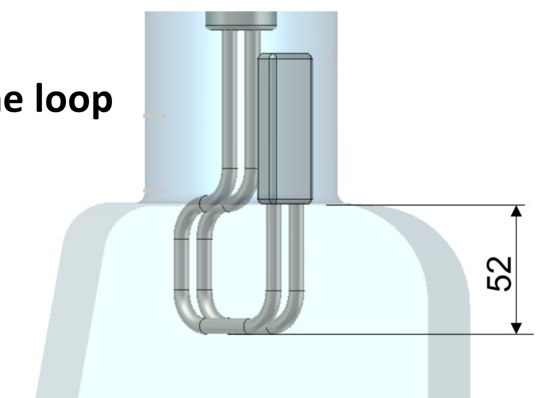
• Not grounded loop enables to apply HV bias to suppress a multipactor in a coaxial and inside of cavity around loop. Backup – external magnetic multipactor suppression.

• Cooling media is air: simple, allows to apply HV bias, less severe consequences in the case of a leak

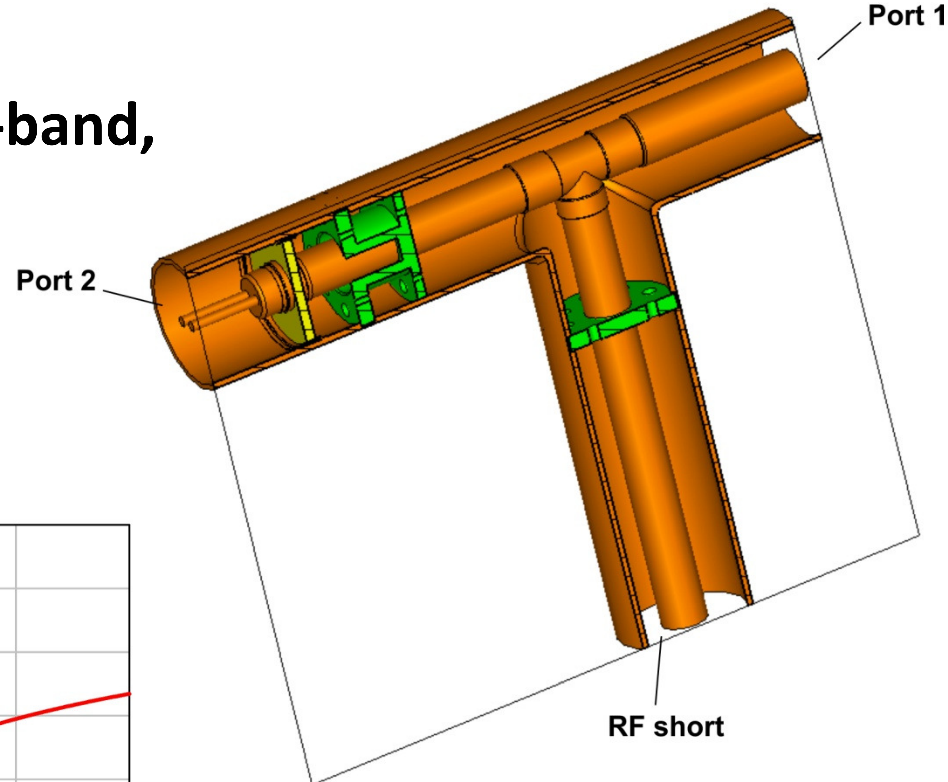
Chosen structure:

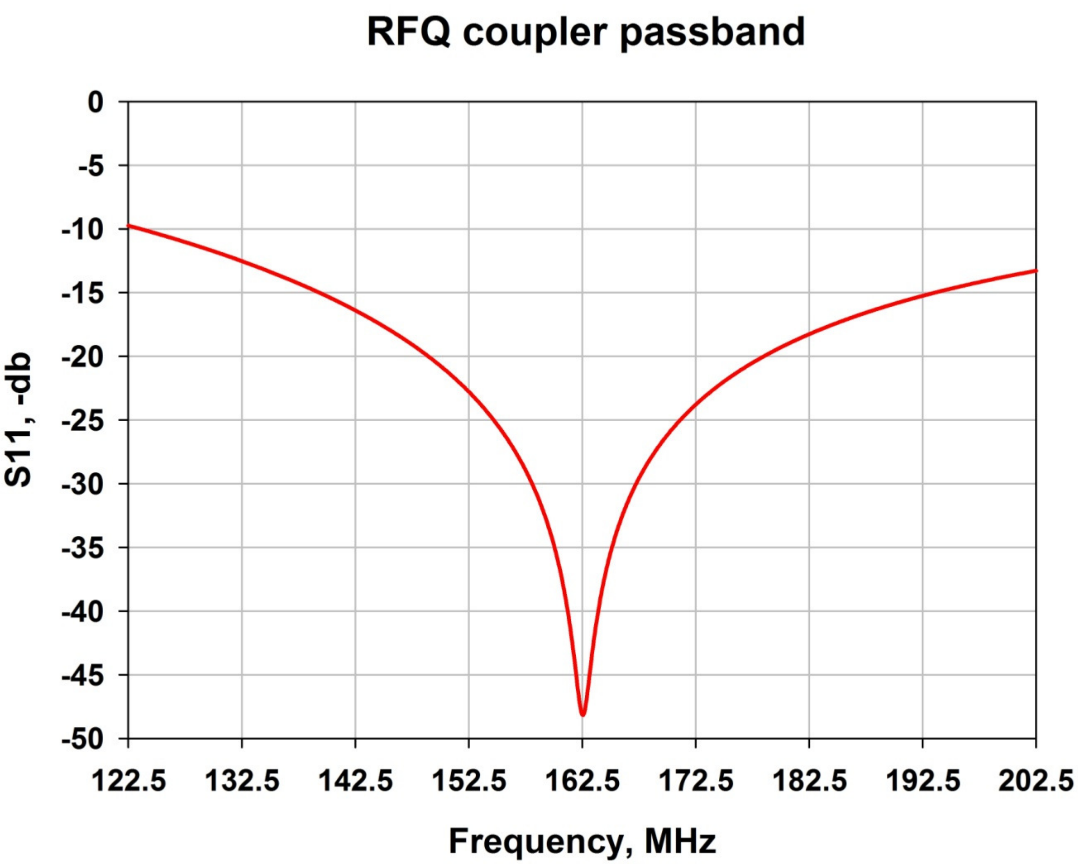


"Double" loop:
air flows inside the loop



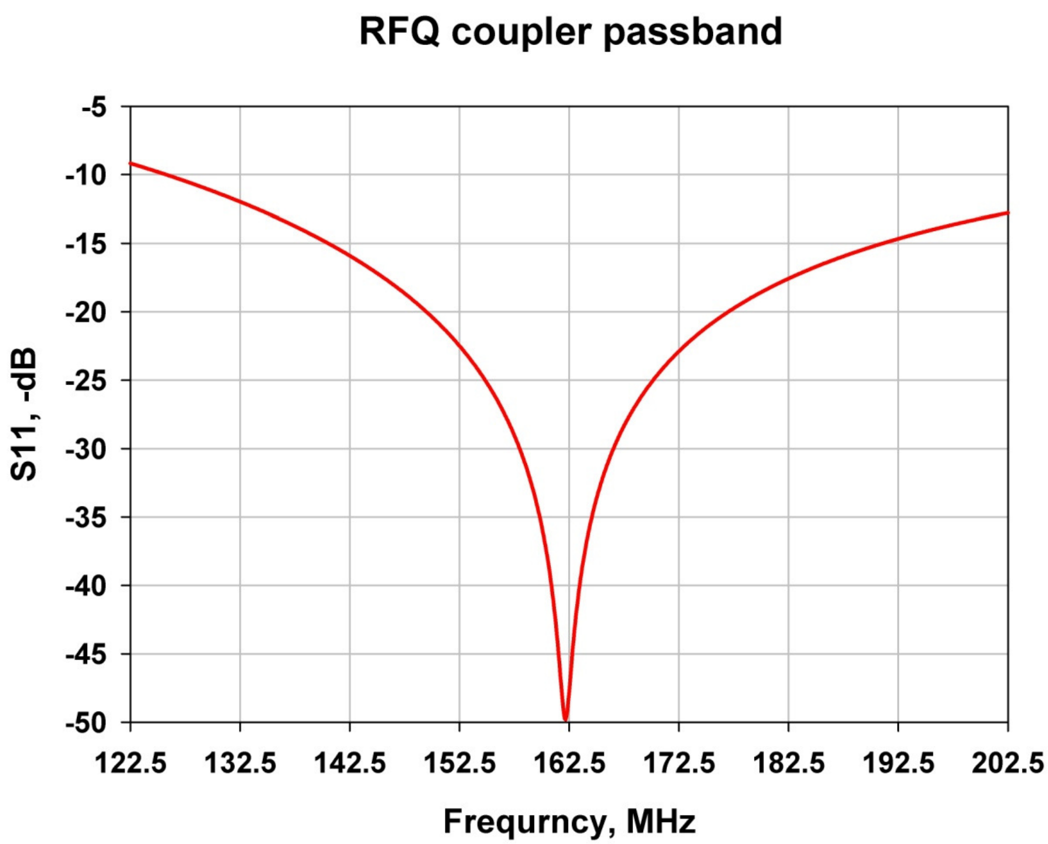
RF structure, frequency pass-band, horizontal port orientation

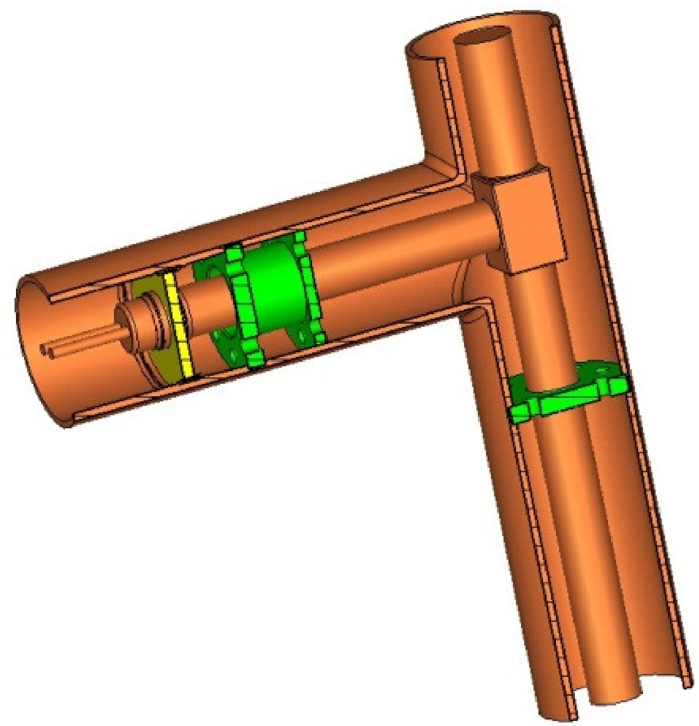




Coupler has a wide passband of ~30MHz, ~18.5%, (S11 < 0.1). This indicates that high precision is not required during manufacture of the coupler components.

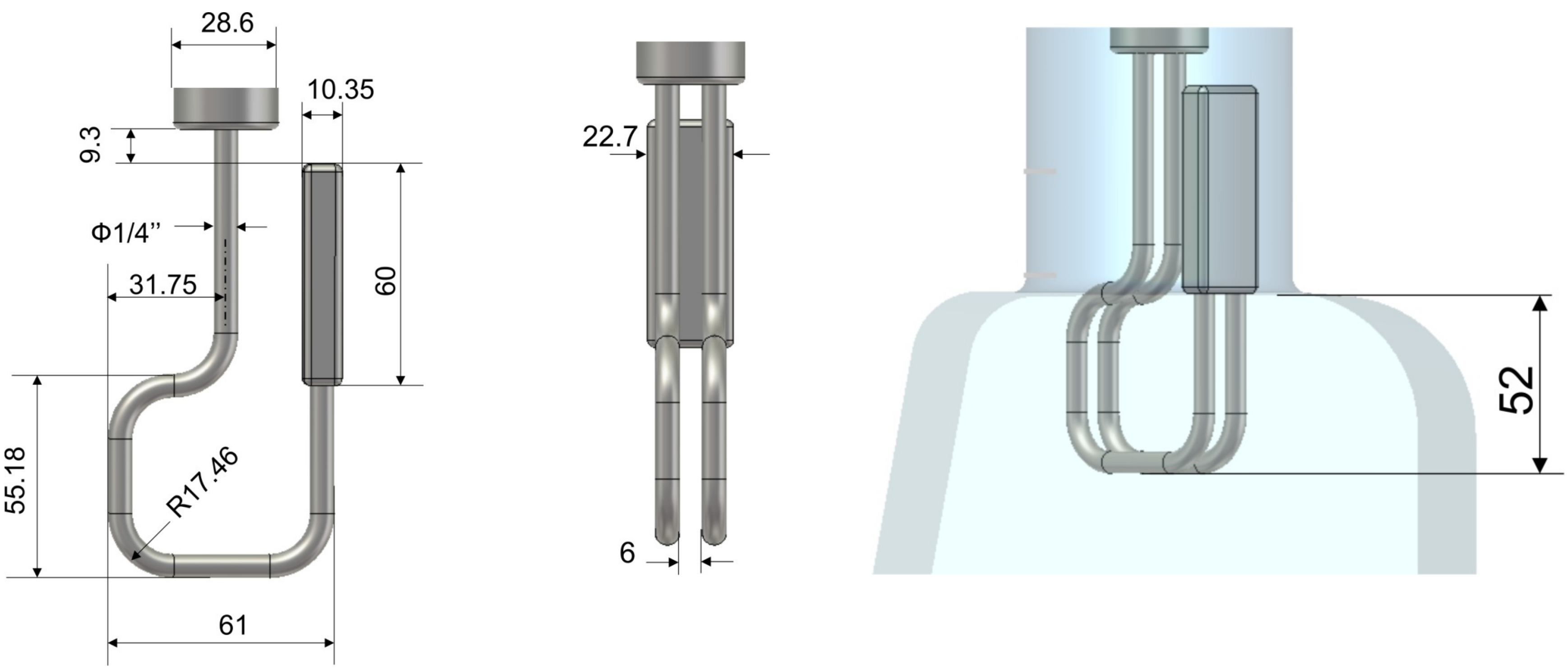
RF structure, frequency pass-band, vertical port orientation



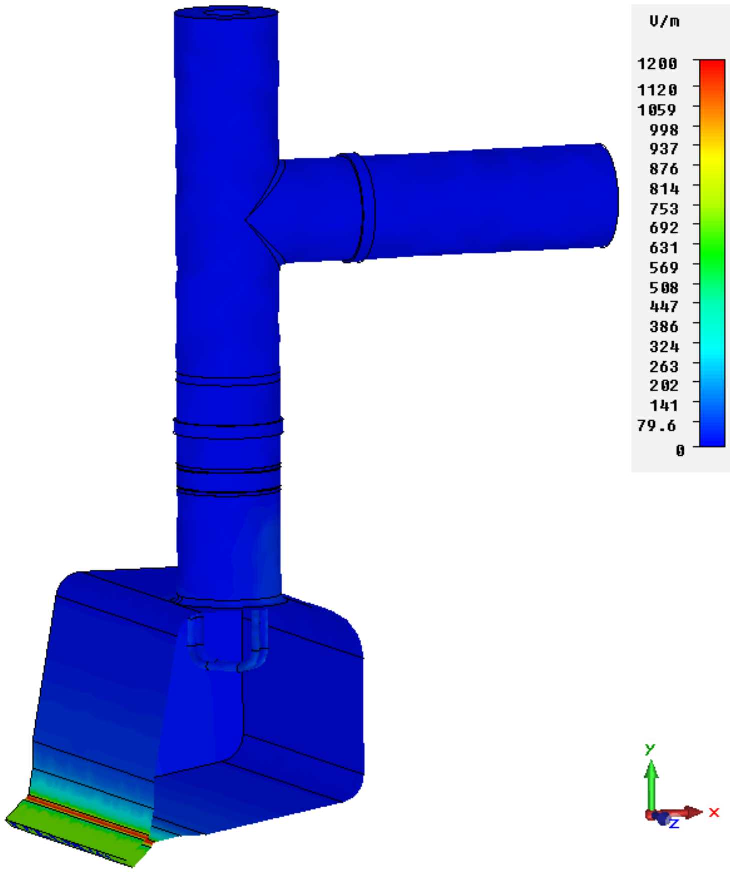


Loop dimensions and penetration.

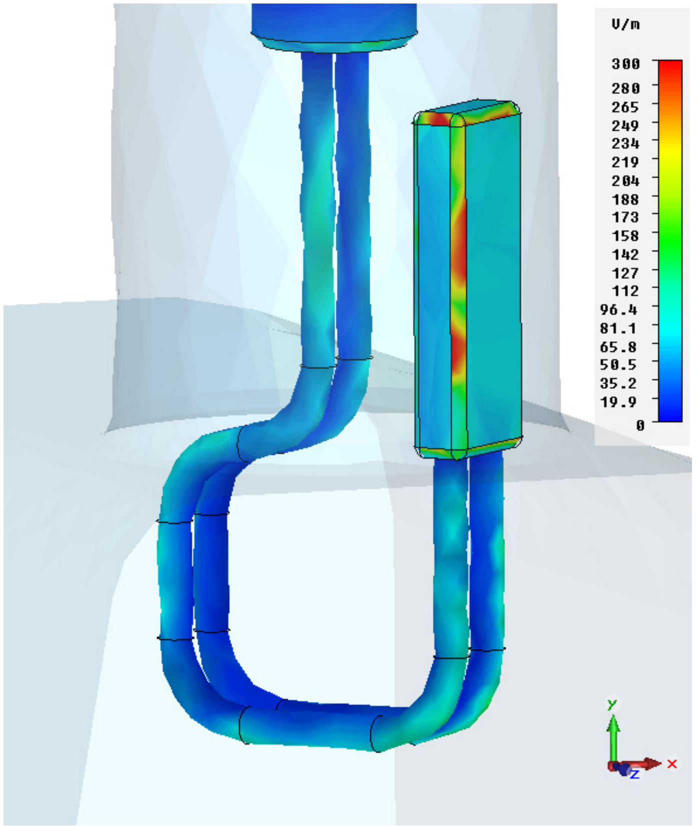
Coupling can be adjusted by loop rotation. Dimensions of the loop and it penetrations were chosen to provide optimal coupling with 45° loop orientation relative to the position of max/min coupling. This allows the coupler to be tuned to compensate for both simulation and manufacturing inaccuracies.



Maximum electric field at coupler surfaces



Max. E-field at vane surface
(60 kV at vane): 12.6 MV/m



Max. E-field at loop surface
(60 kV at vane): 3.2 MV/m

TKx16

Filed at loop 4 times less then field at vane,
Should be no breakdown in the coupler.

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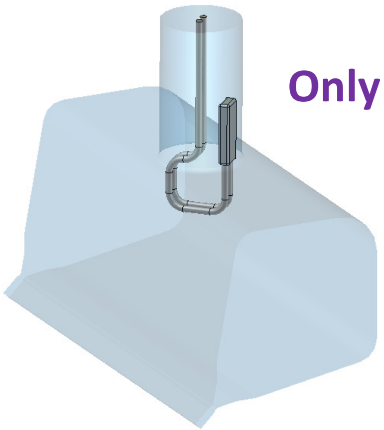
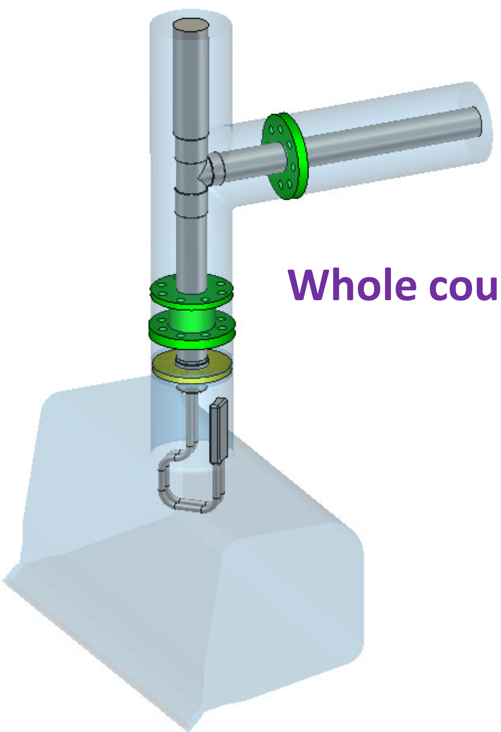
TKx16 Electric field

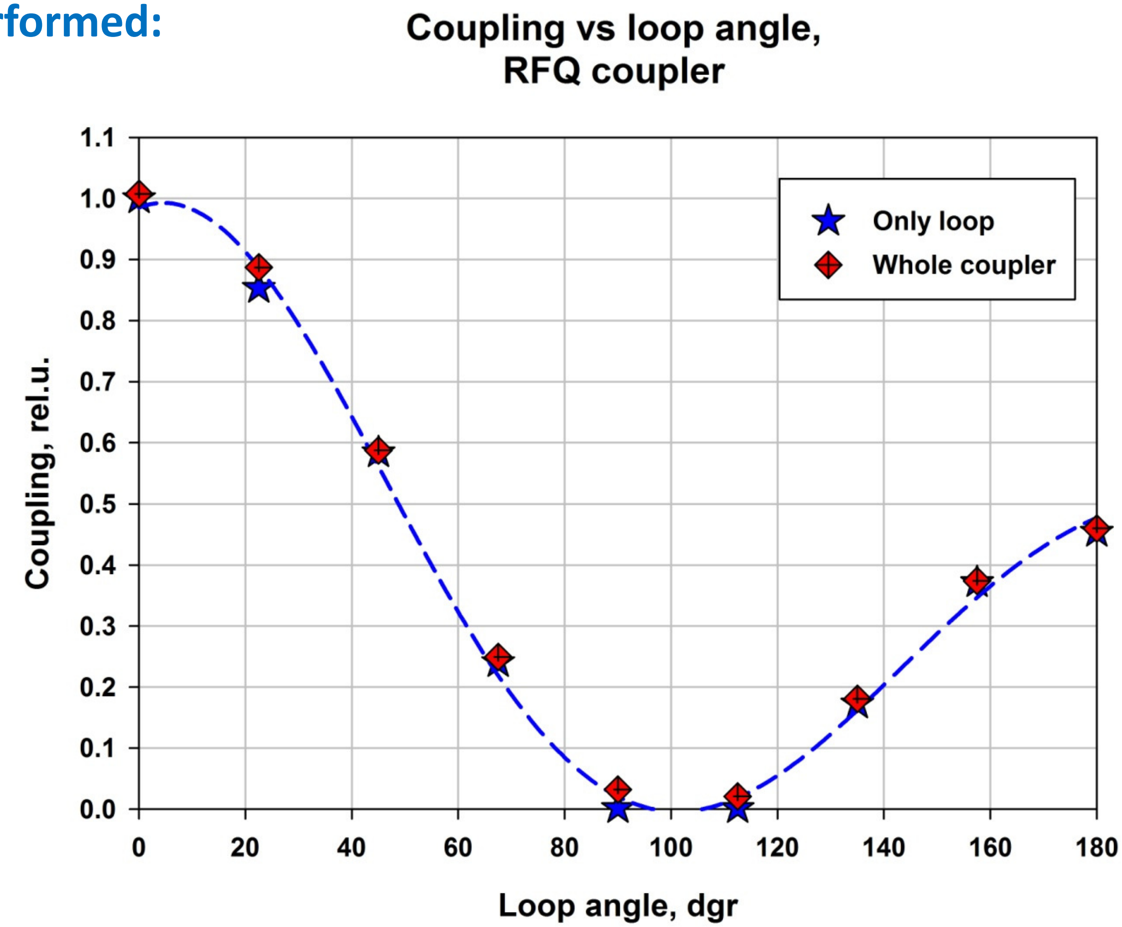
Timergali Khabiboulline x4693 13342N, 5/20/2013

Coupling vs. orientations

Two type of simulation were performed:

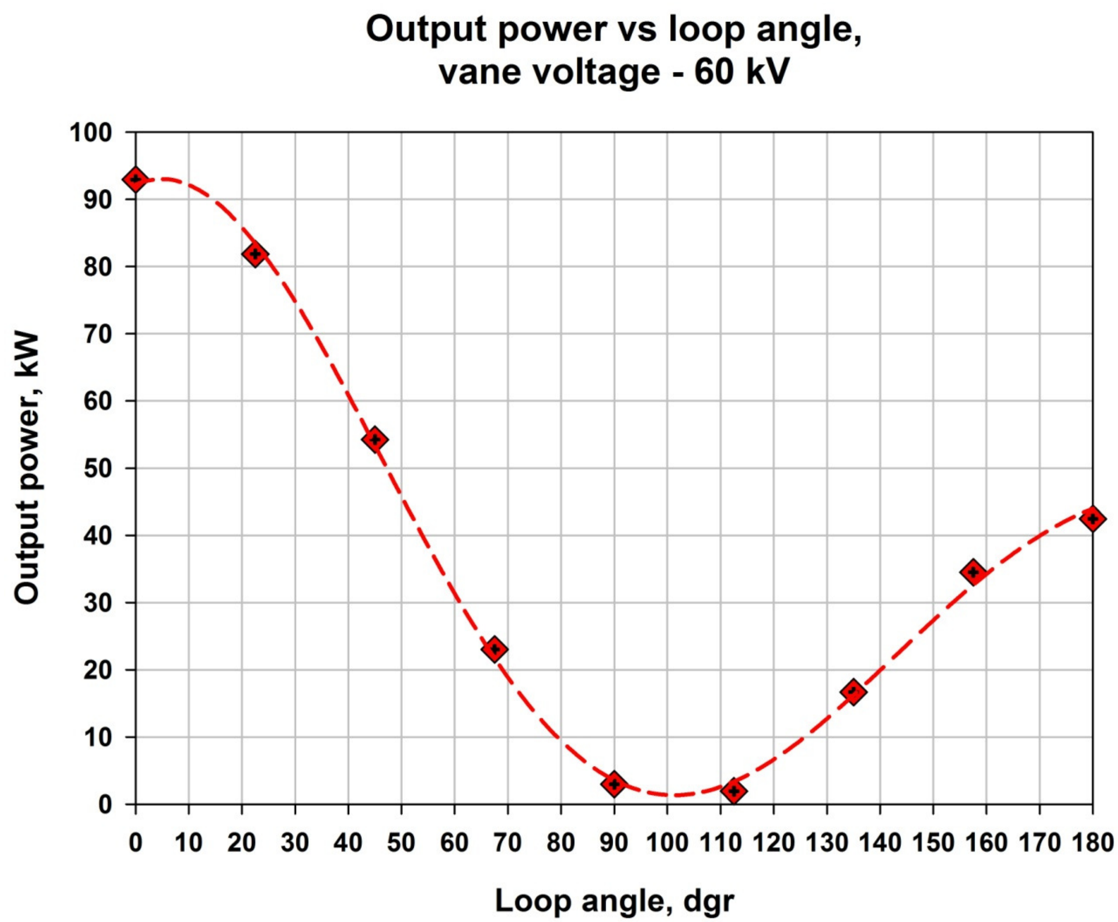






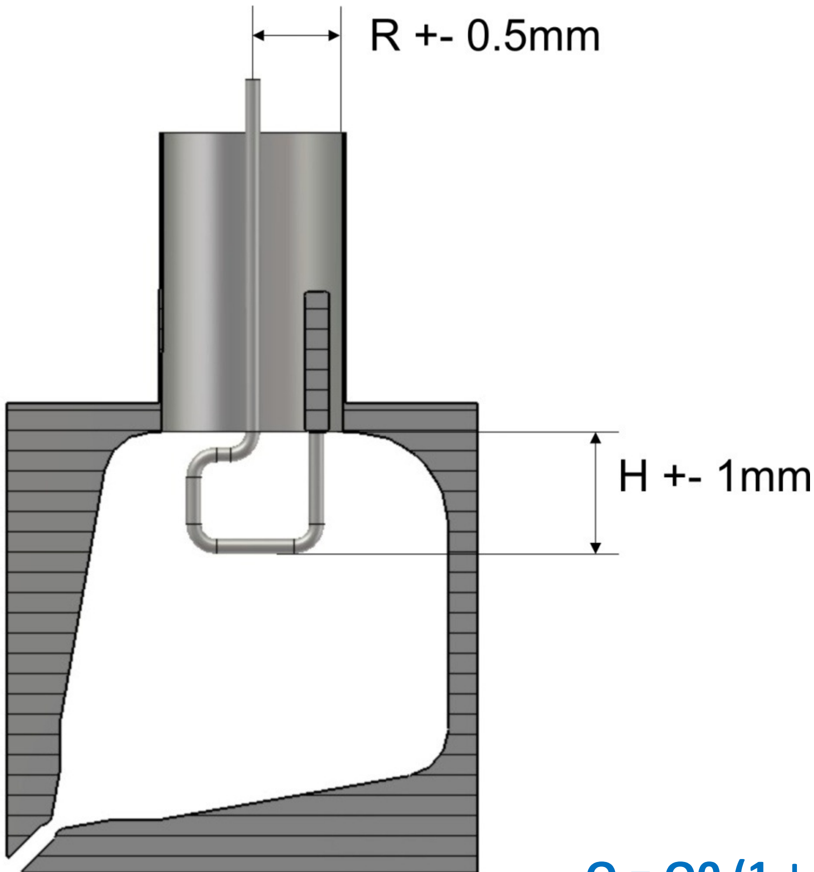
- **Both type of simulations give the same results. It means that coupler is good matched.**
- **Orientation matters. 180° loop rotation gives different coupling. The reason is asymmetrical location of the coupler relative to the cavity.**

Absolute value of power vs. loop angle



Operating angle ~ 45°

Sensitivity to loop sizes



R	RF out (rel. un)
R - 0.5mm	1.0274
R	1.0000
R + 0.5mm	0.9348

TKx19

H	RF out (rel. un)
H + 1mm	1.0870
H	1.0000
H- 1mm	0.9605

TKx110

$Q = Q0\ (1 \pm \Delta)$ $\Delta < 0.1$

Cavity field deviation ~ $0.25*\Delta^2$ (for optimal coupling) < 2.5E-3

In reality a vibration should be order or several order less.
We suppose to check vibration (and cooling) at the simple model.

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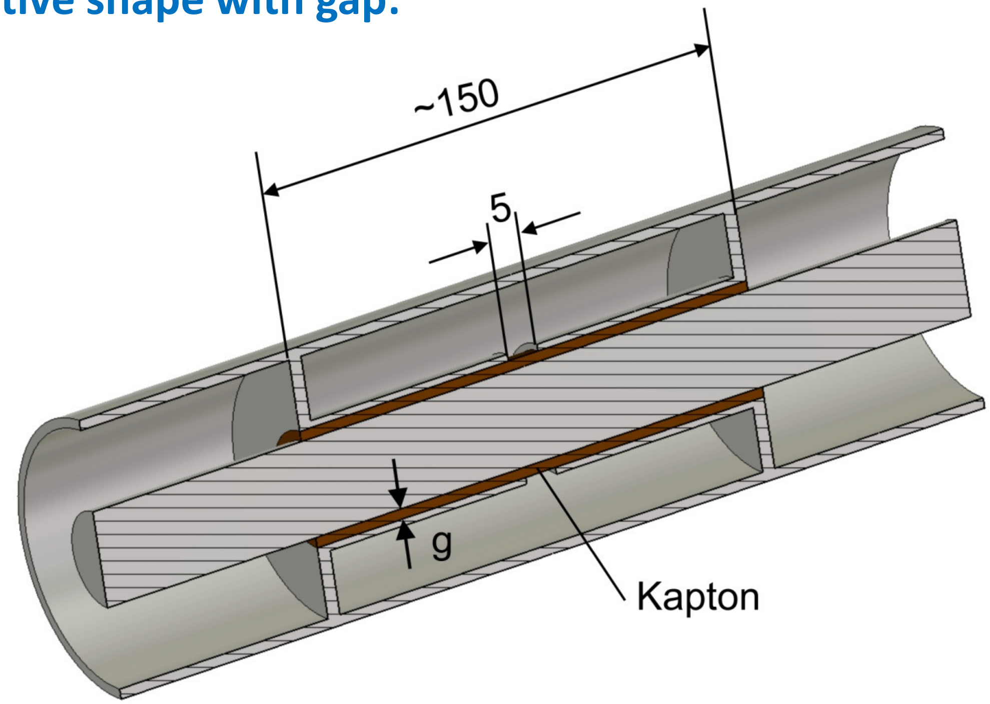
TKx19 Large nonlinearity. Better to add more points.
Timergali Khabiboulline x4693 13342N, 5/20/2013

TKx110 Here alson large nonlinearity. Better to check the reason
Timergali Khabiboulline x4693 13342N, 5/20/2013

Geometry of capacitor

Effective shape with gap:



0.025mm kapton tape provides strength 7.5 kV
To suppress multipactor we need ~4kV

Isolation

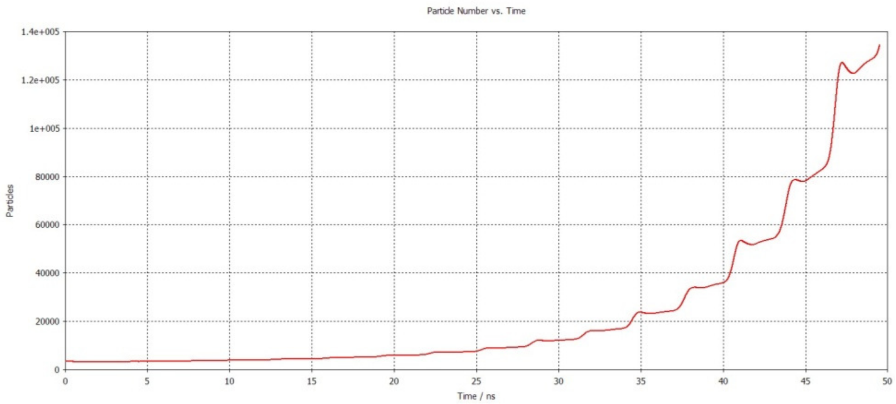
g, mm	Isolation, dB
0.05	-67 dB
0.1	-59 dB
0.2	-50 dB

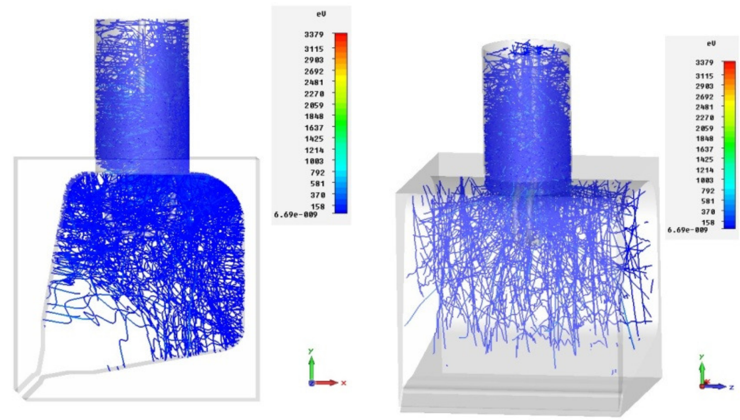
Dielectric strength of kapton

Thickness µm	Strength kV/mm
25	303
50	240
75	205
125	154

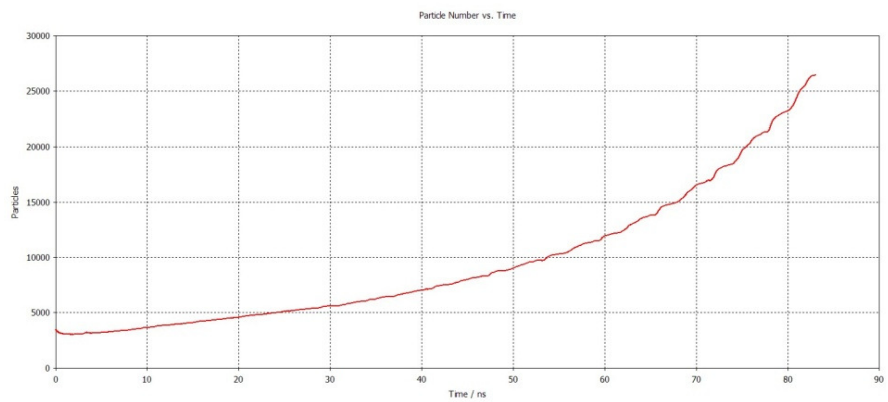
Multipactor and its suppression

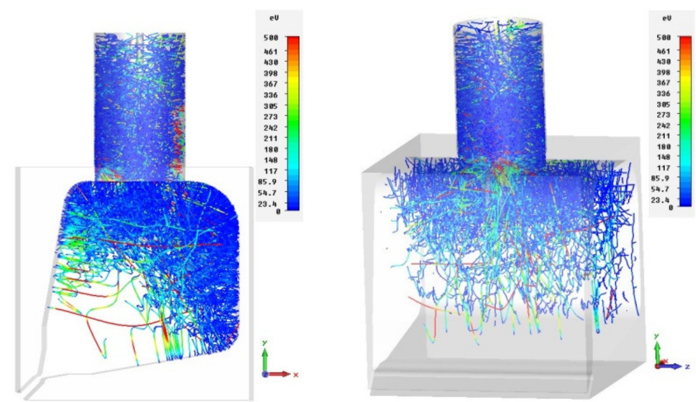
Vane V



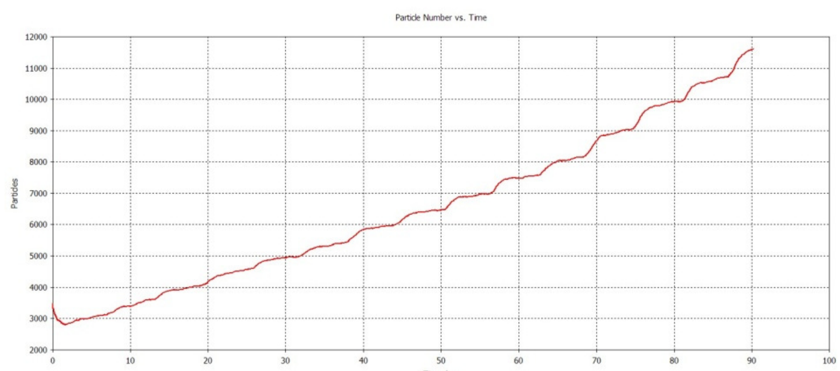


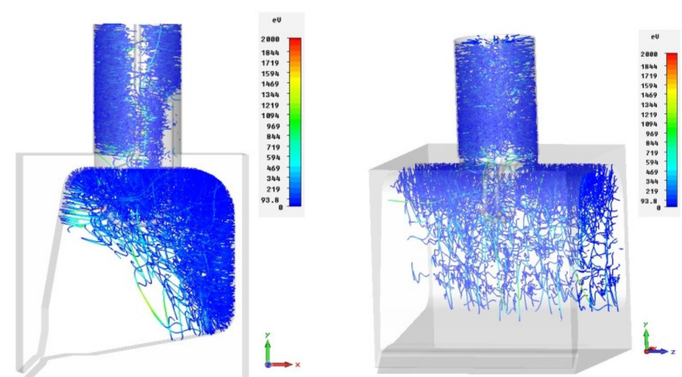
3.8 kV





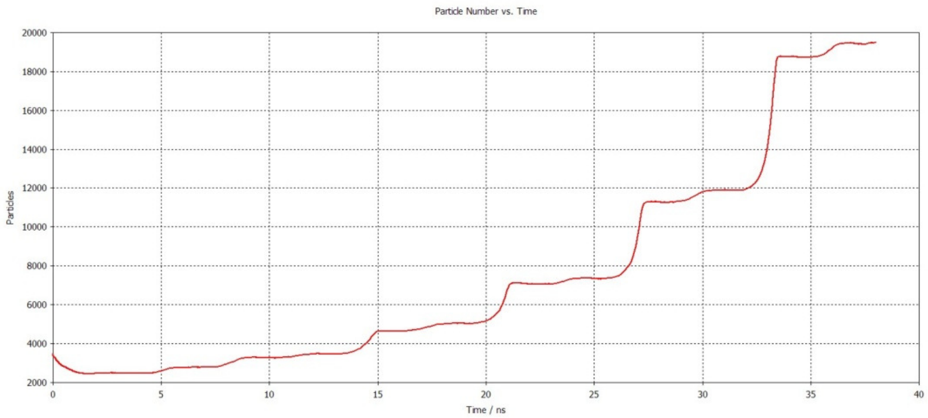
7.5 kV

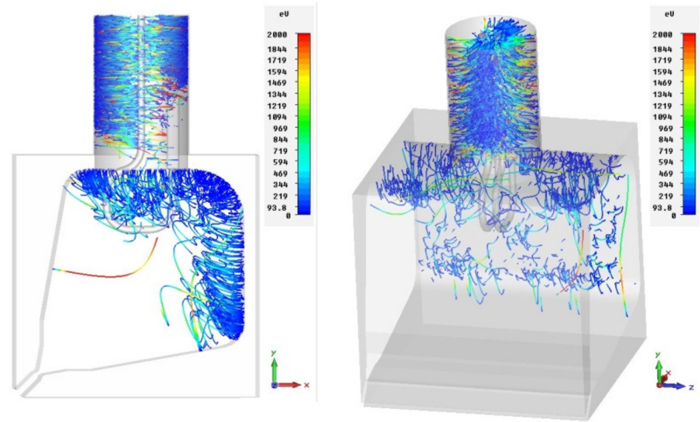




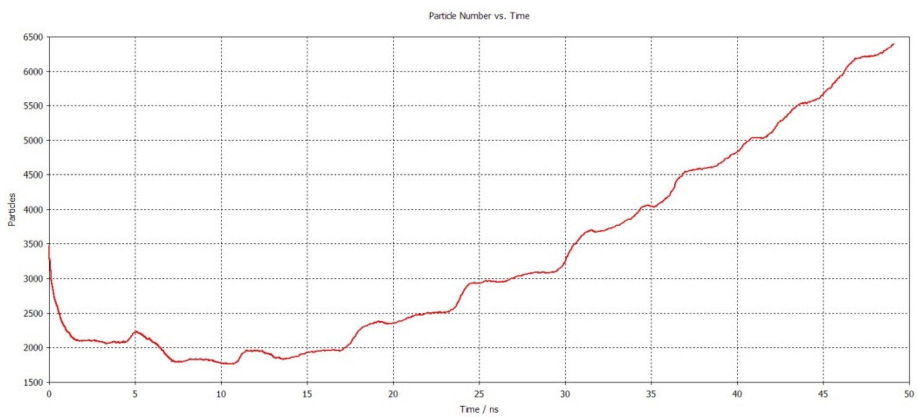
15 kV

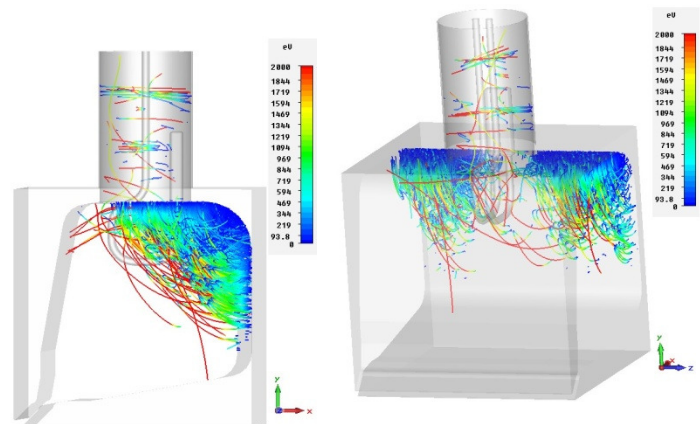
Vane V





30 kV





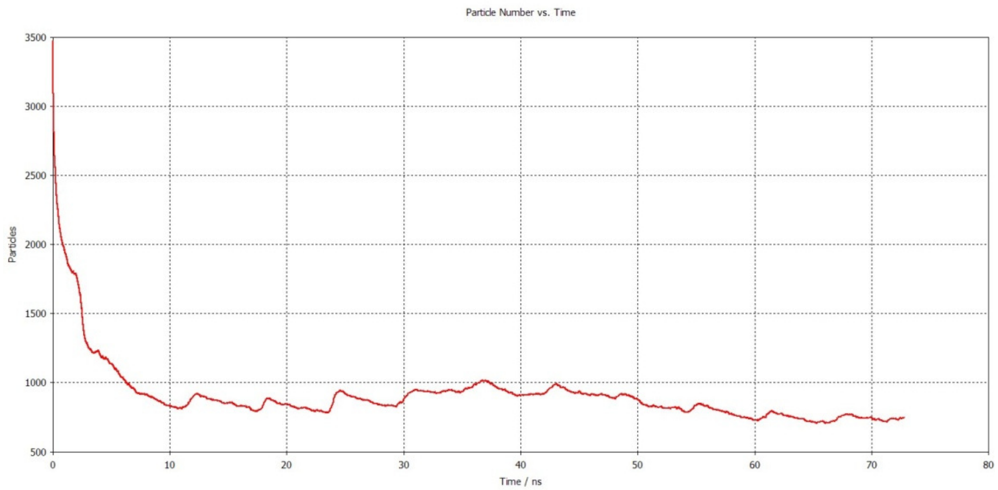
60 kV

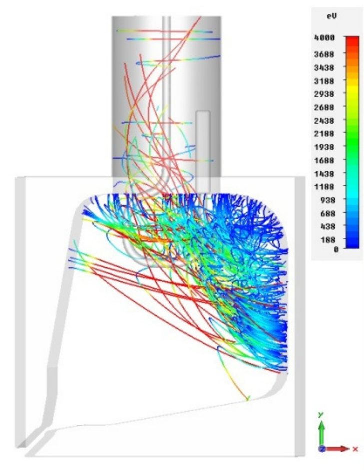
Simulations show that

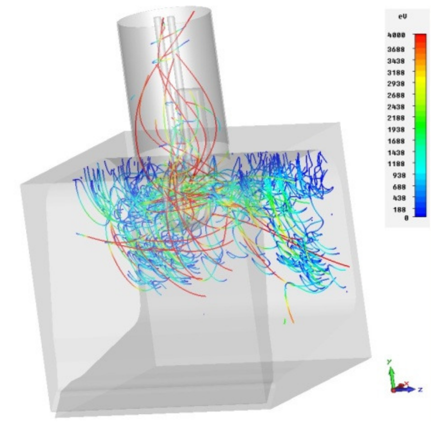
multipacor exists at 4 KV – 60 kV range of vanes voltage

(in input coaxial and cavity volume)

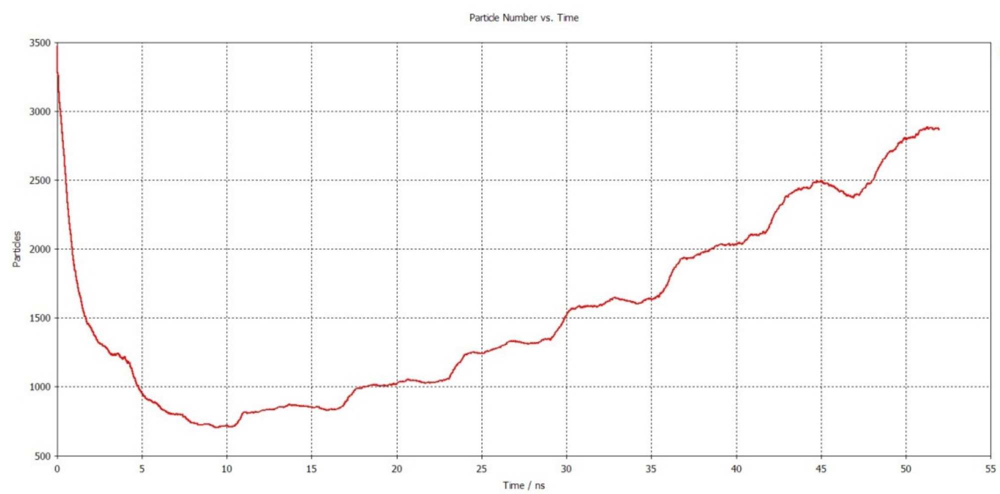
60 kV, +4 kV

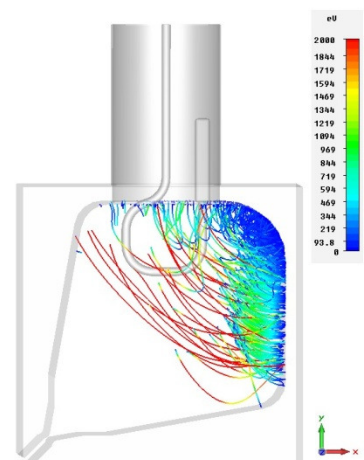


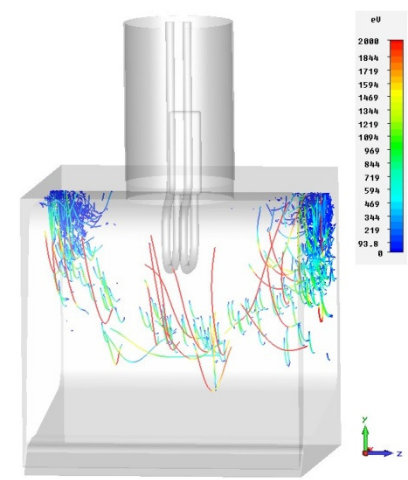




60 kV, -4kV







- **Multipactor exists near operating region of fields strengths.**

- **Multipactor can be suppressed by 4 kV HV bias.**

- **For multipactor suppression we can use external magnetic field as well (back up).**

Thermal analyses

Thermal analyses was made for input power level 80 kW, CW.

Total loss in coupler ~ 185 W (ceramic loss tang. 1e-4)
Total loss in coupler ~ 212 W (ceramic loss tang. 1e-3)

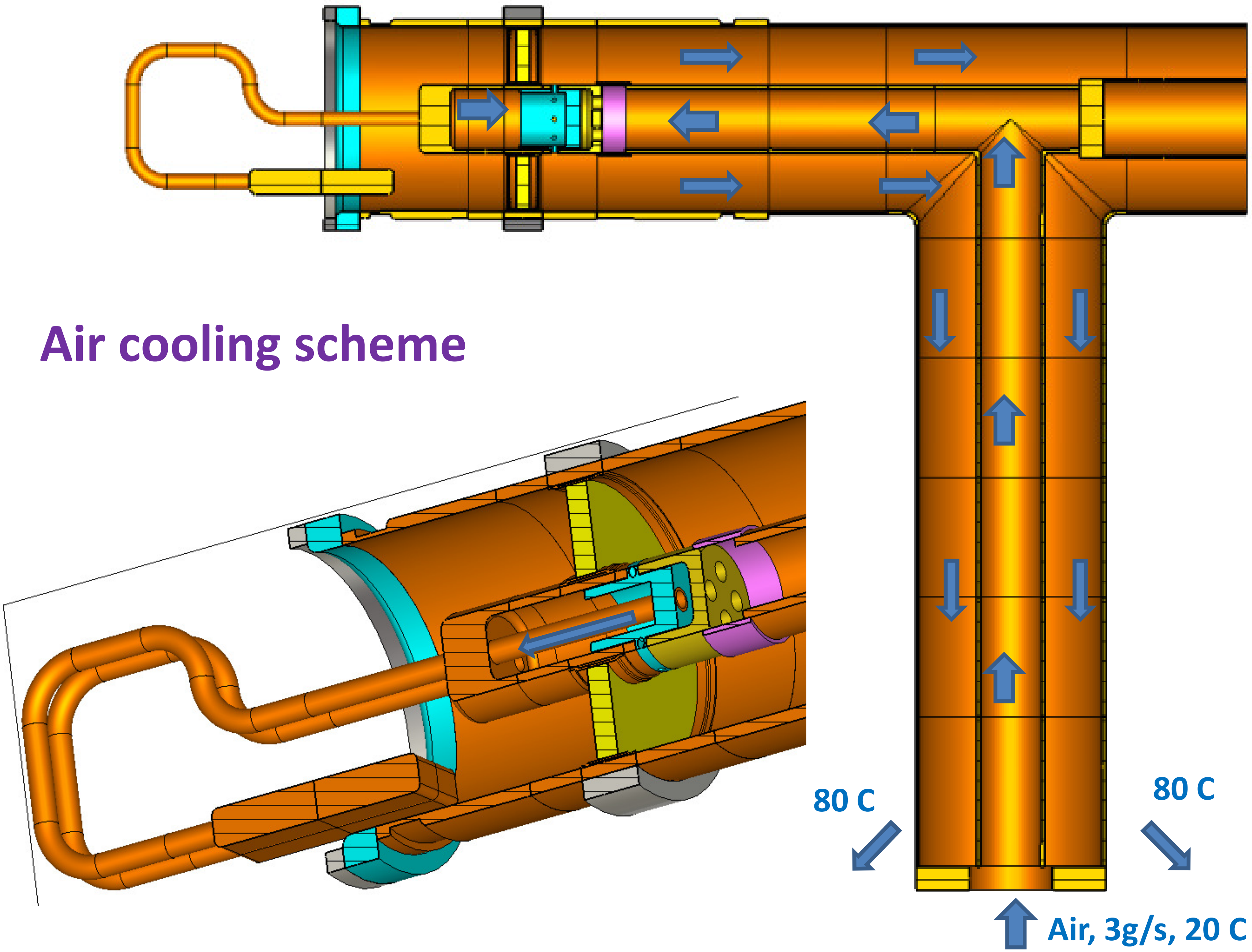
Loss in ceramic ~ 3.3 W (loss tang. 1e-4)
Loss in ceramic ~ 33 W (loss tang. 1e-3)

Loss in loop ~ 132 W

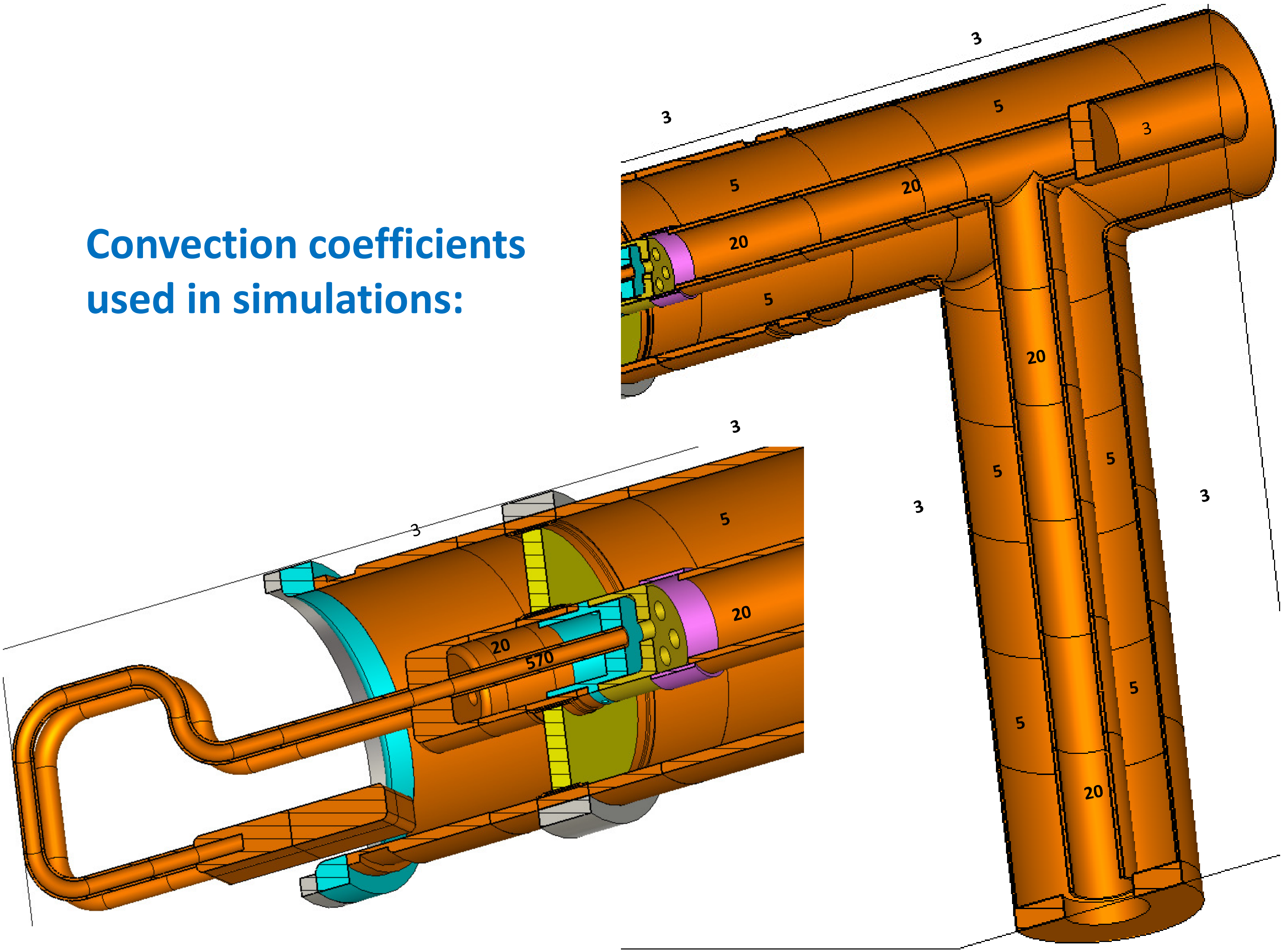
Air cooling:

Flow rate: ~3g/s
Pressure drop ~0.6 bar
Max. air velocity ~140 m/s
Input air temperature ~20 C
Output are temperature ~80 C

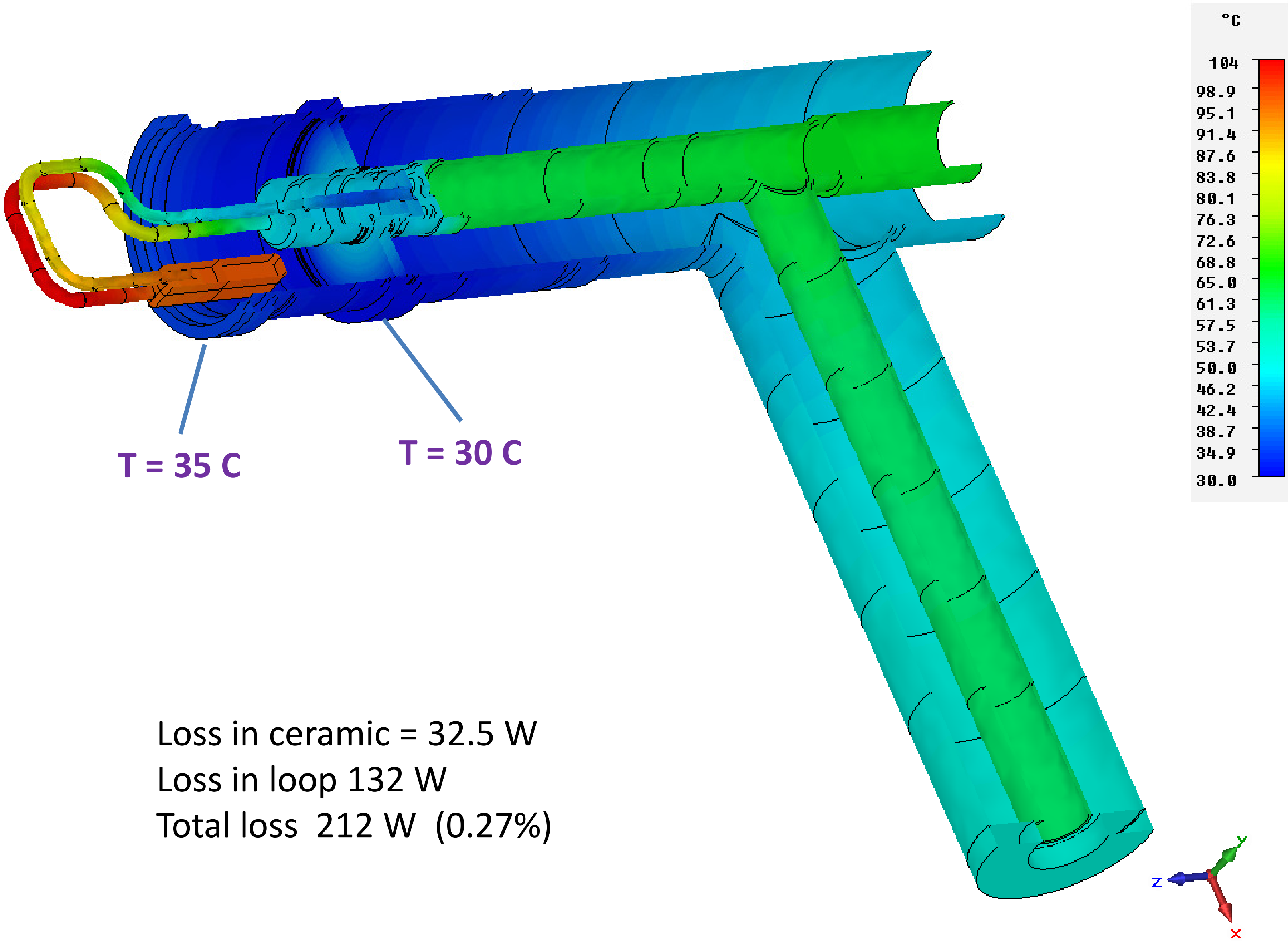
Air cooling scheme



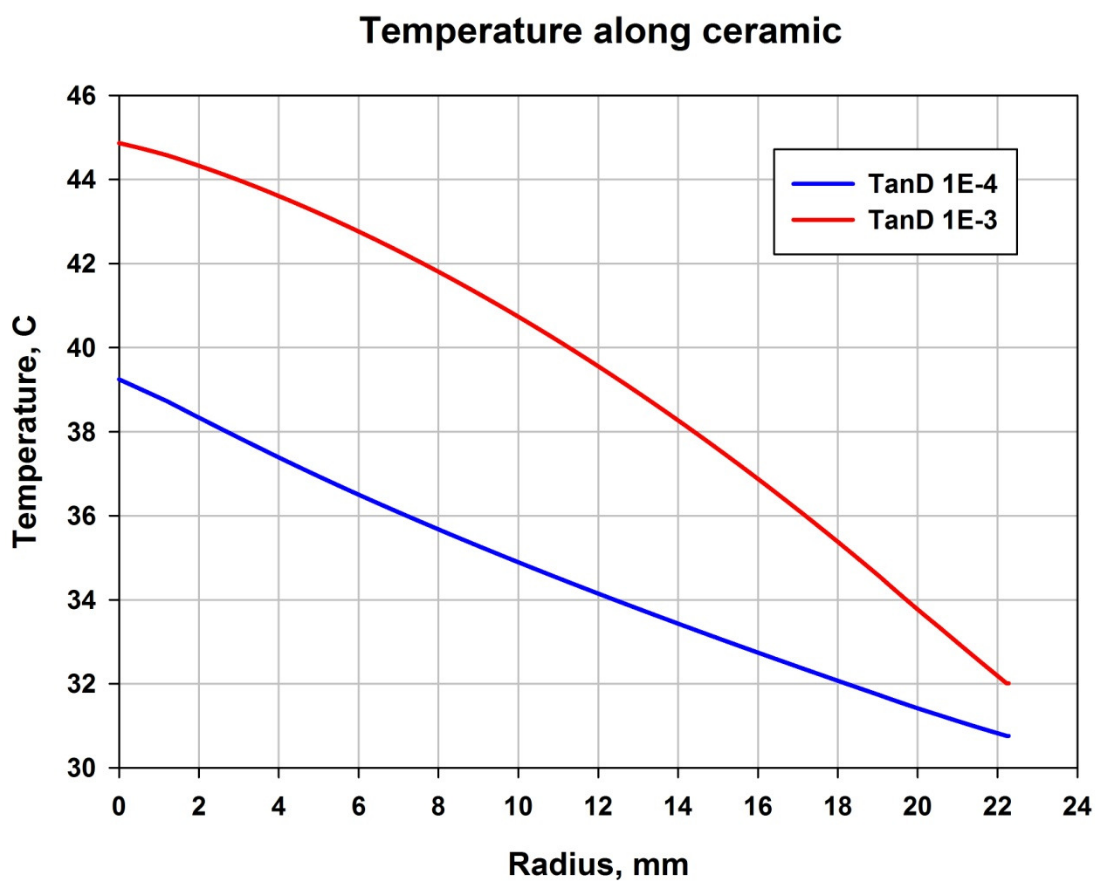
Convection coefficients used in simulations:



Case of P = 80 kW, TW, Tng δ = 1E-3



Loss in ceramic = 32.5 W
Loss in loop 132 W
Total loss 212 W (0.27%)



Max grad = 0.5 C/mm

Max grad = 0.8 C/mm

TKx114

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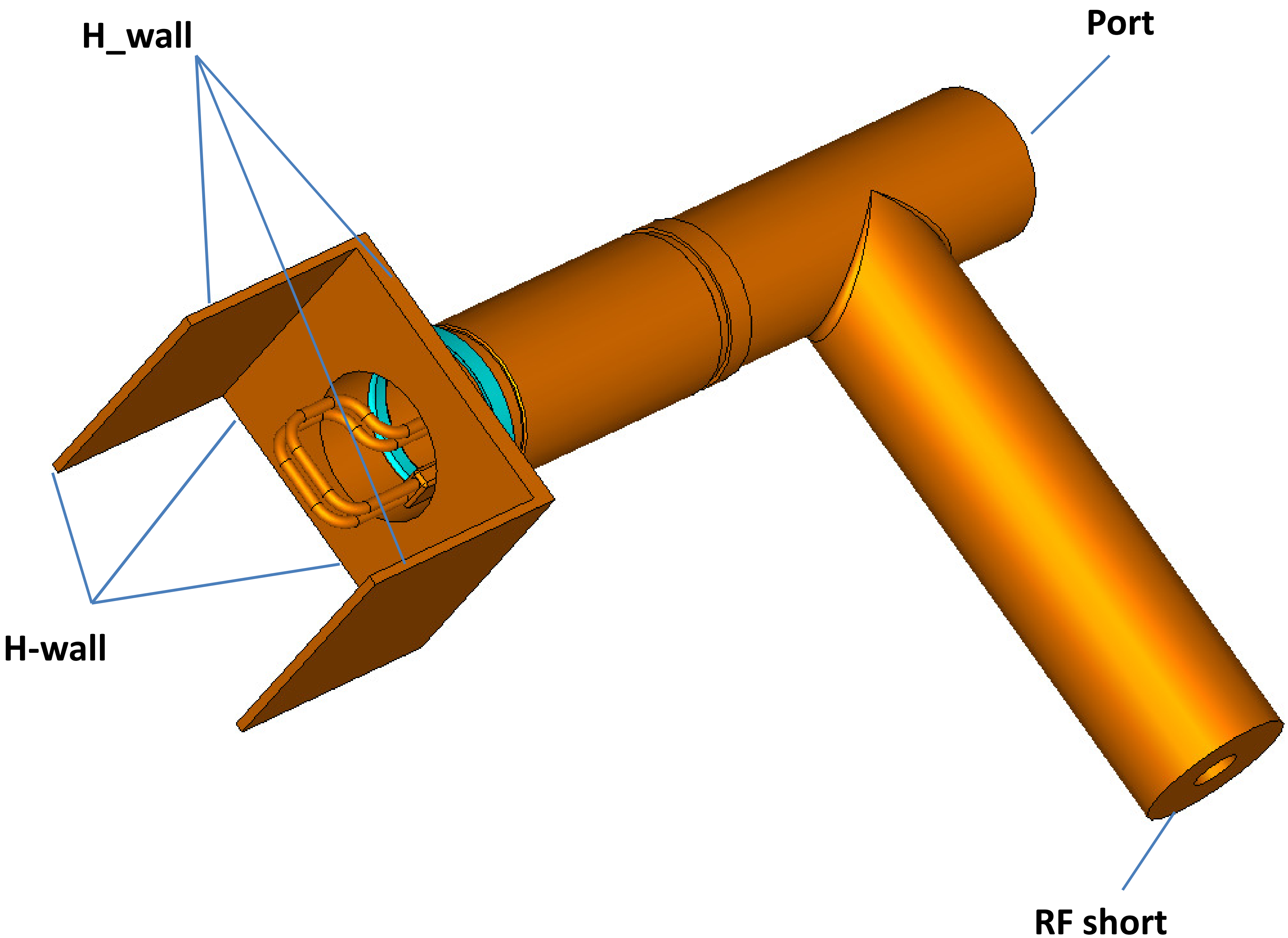
TKx114 Show exaples of safe operation with higher gradients from existing couplers

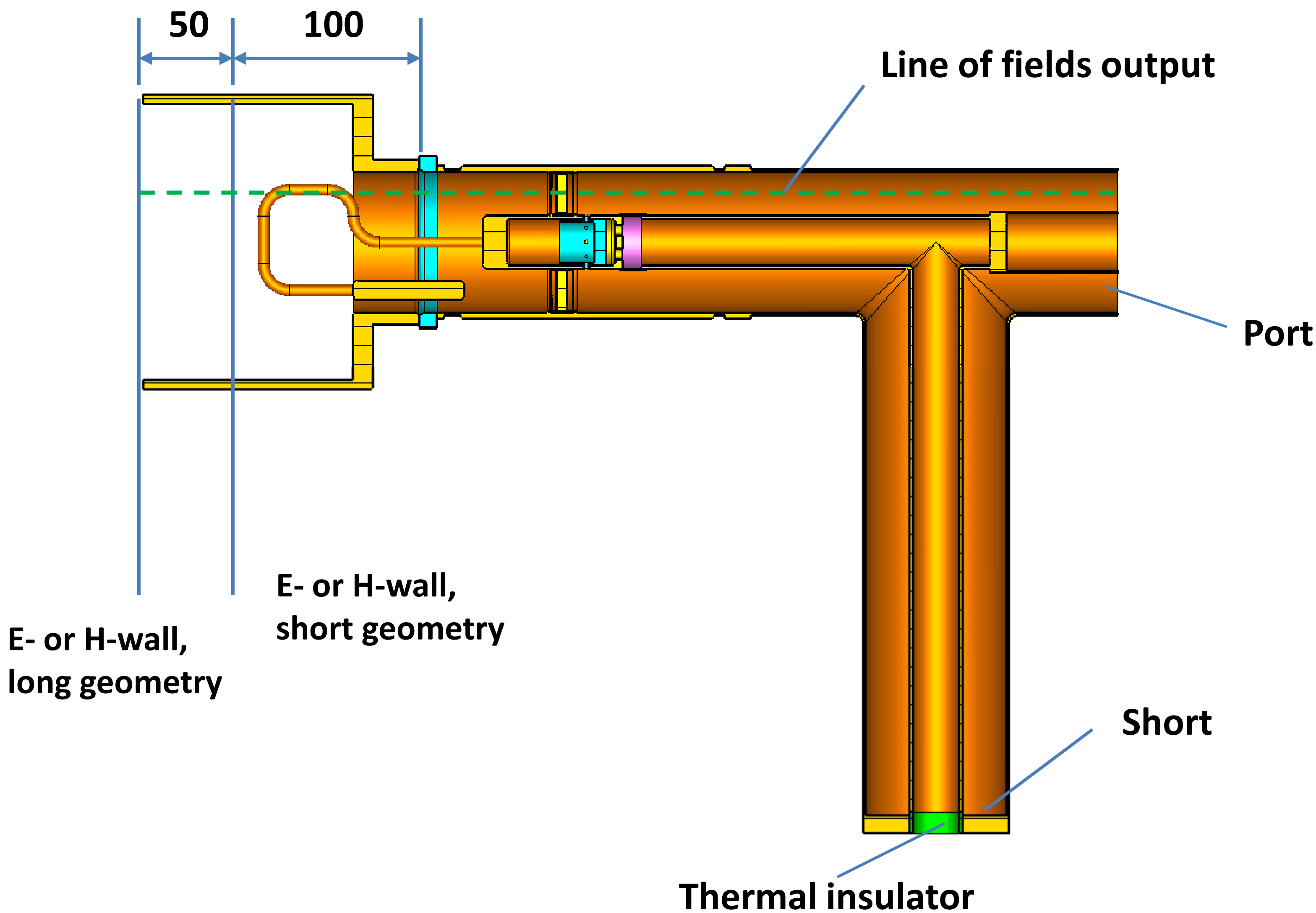
Timergali Khabiboulline x4693 13342N, 5/20/2013

Heating of RFQ coupler in case of full reflection (case of strongly detuned RFQ cavity)

Geometry. Coupler excites line with two H-walls

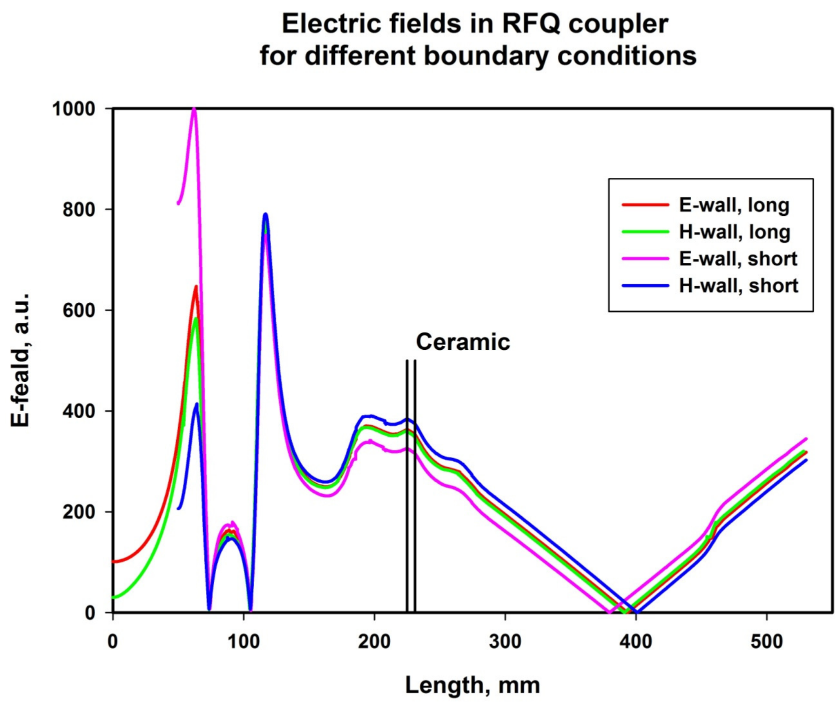


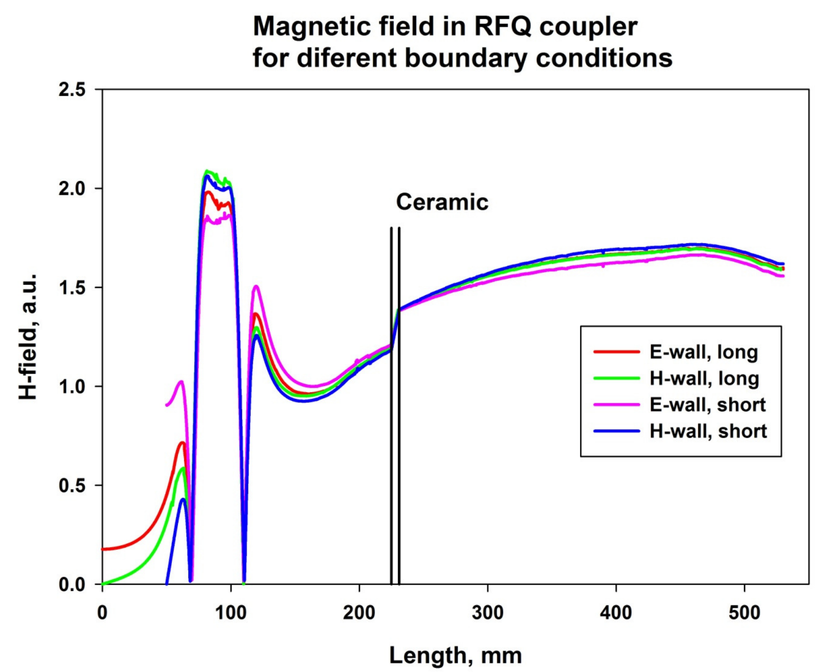
Four different boundary conditions were simulated:



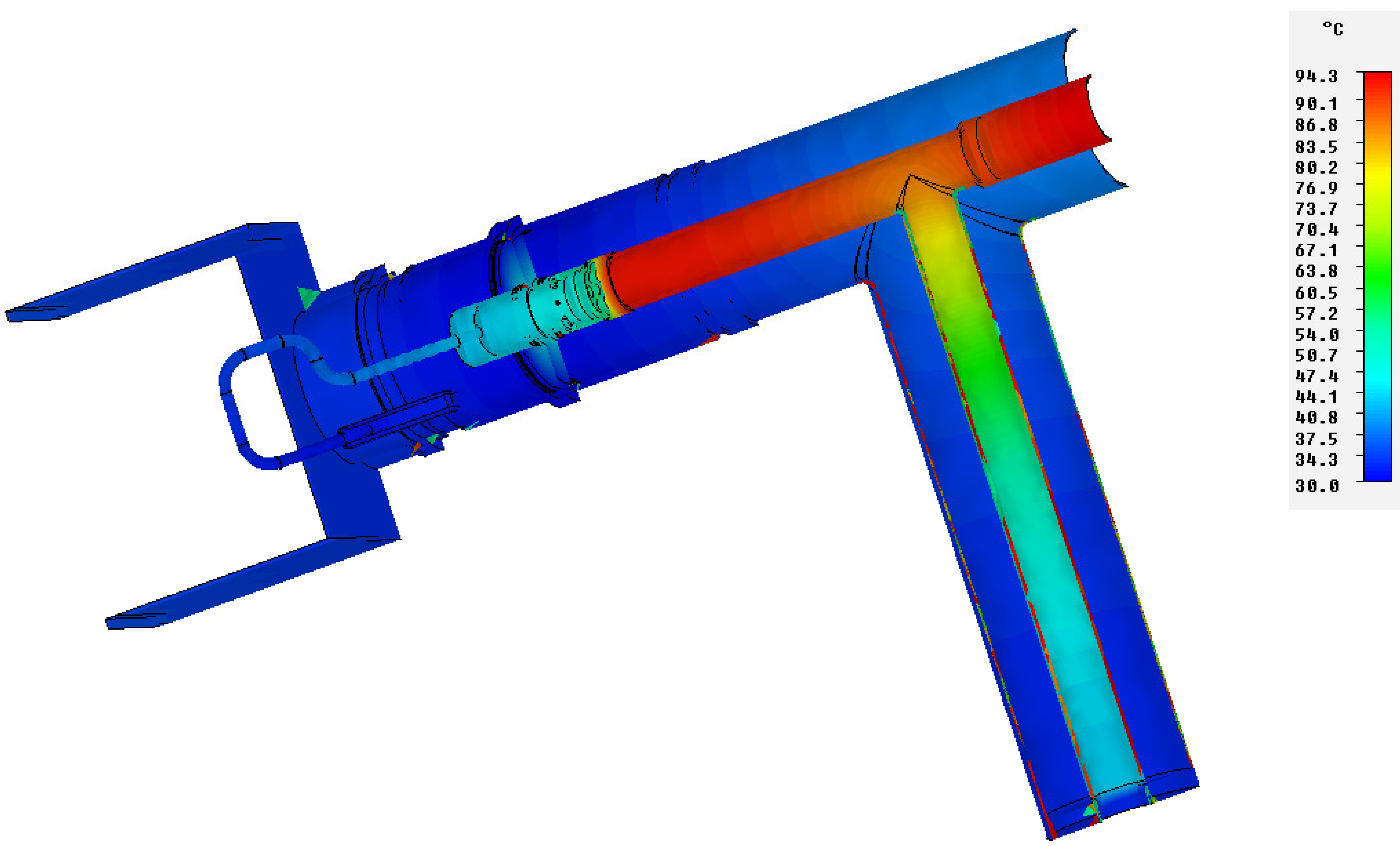
Field distribution inside coupler practically does not depend on boundary condition in case of non-resonant full reflection.

Fields along line:

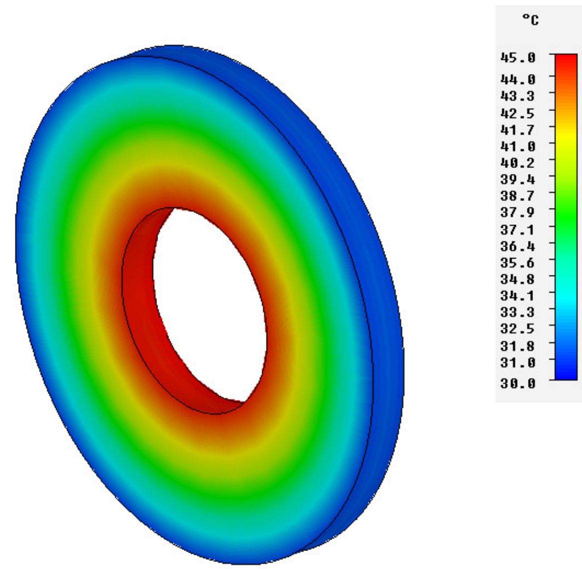




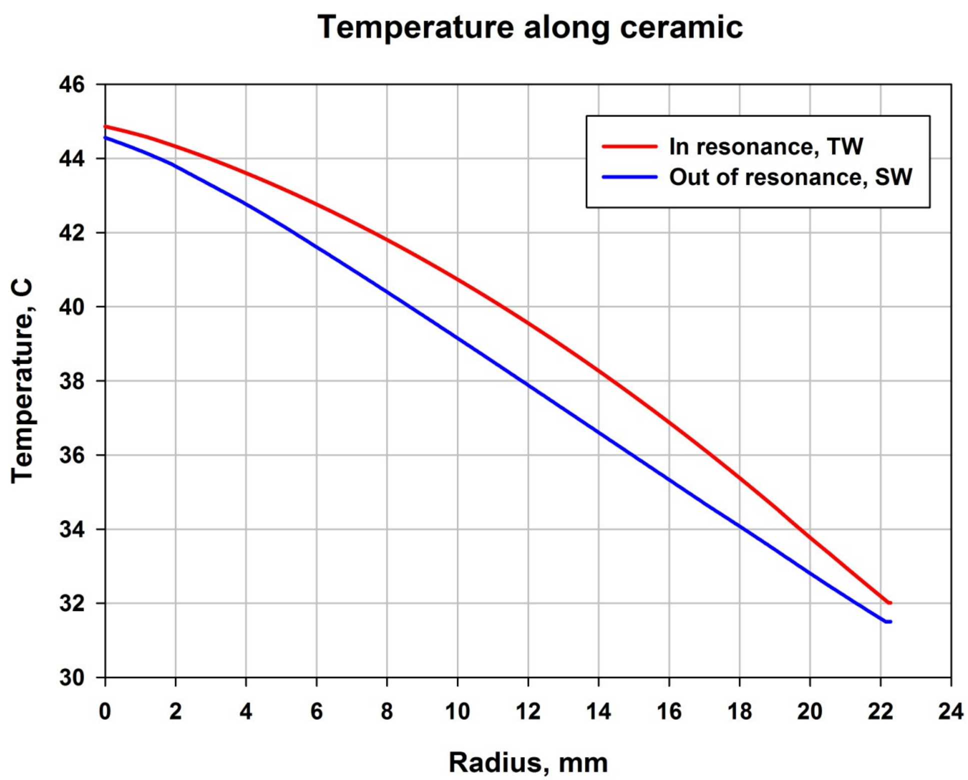
Temperature distribution in case of full non-resonance reflection, P = 80 kW, Tng δ = 1e-3. Air flow rate ~ 3g/s.



Temperature of ceramic in case of non-resonance

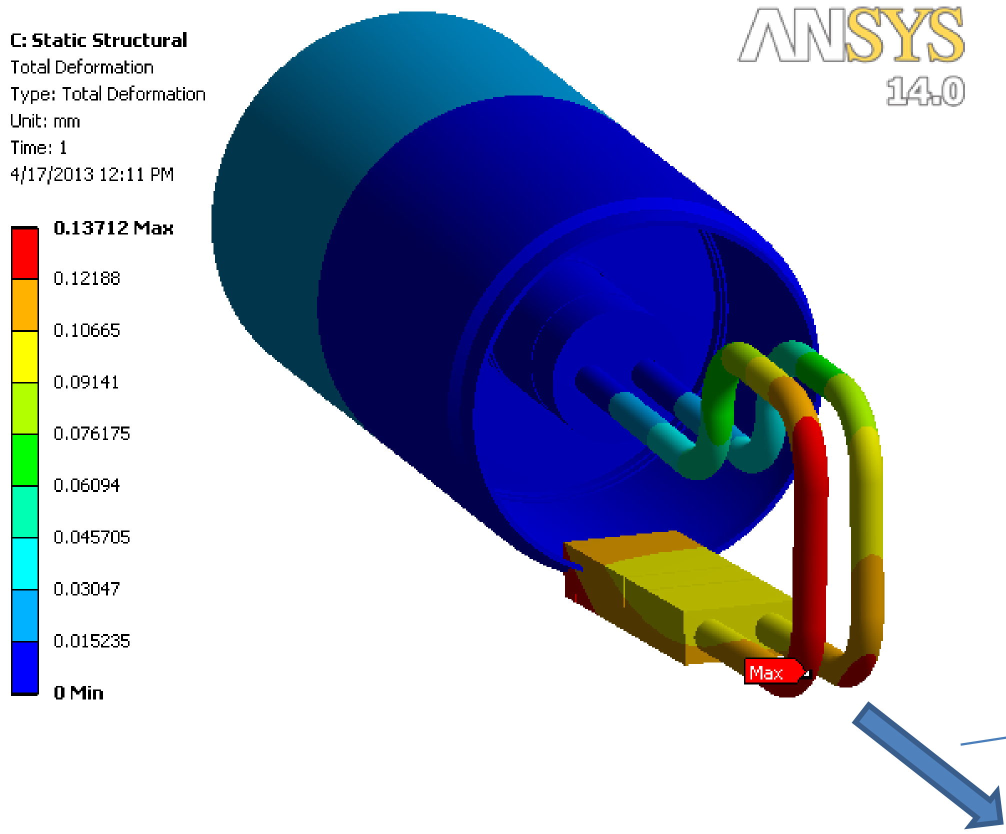


There is no big difference between resonance (TW) and non-resonance (SW) cases:
(Tng δ = 1e-3)



Stress analyses (Valery Poloubotko)

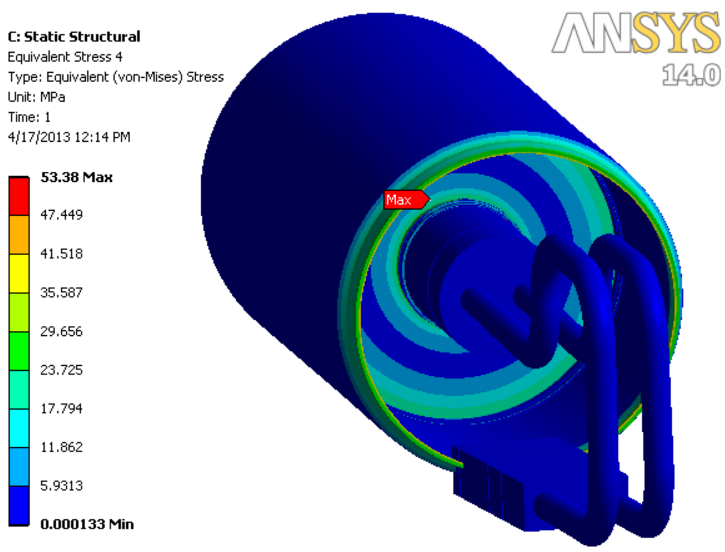
Loop displacement caused by non-uniform hating.

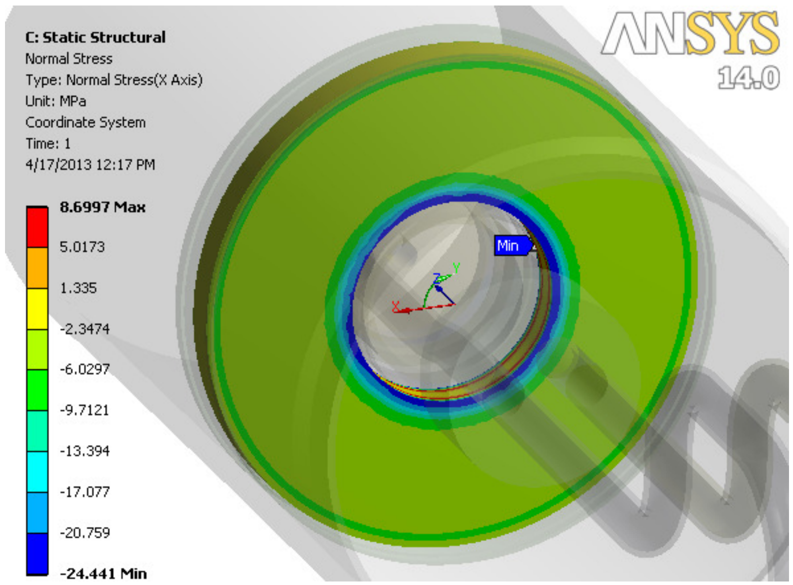


Direction of maximum displacement

Displacement of loop caused by heat is negligibly small. Maximum displacement ~ 0.14 mm

Thermal stress in ceramic

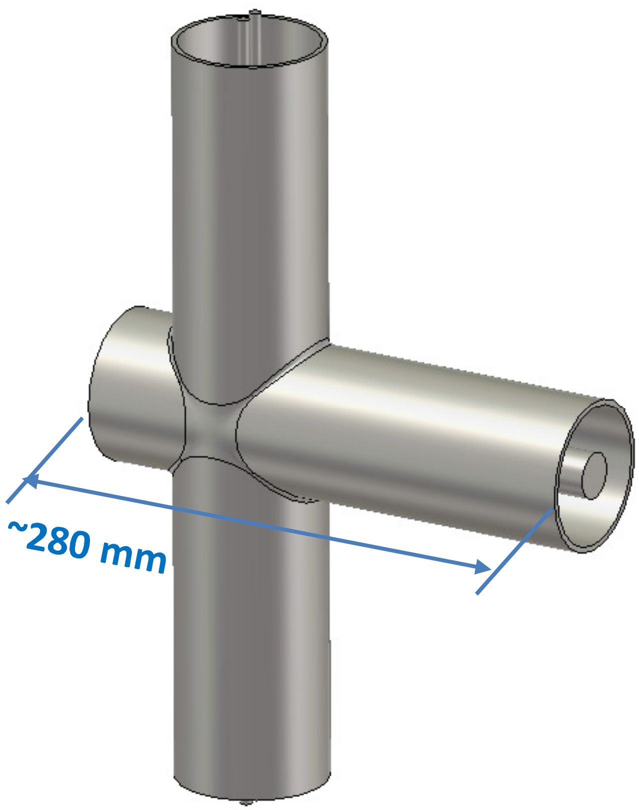


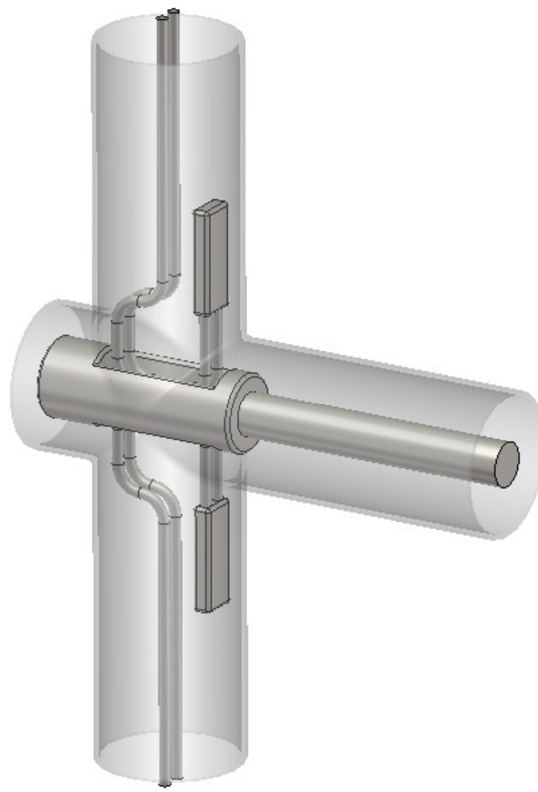


The maximum stress is compression stress and it is dozens of times less than the critical compression stress

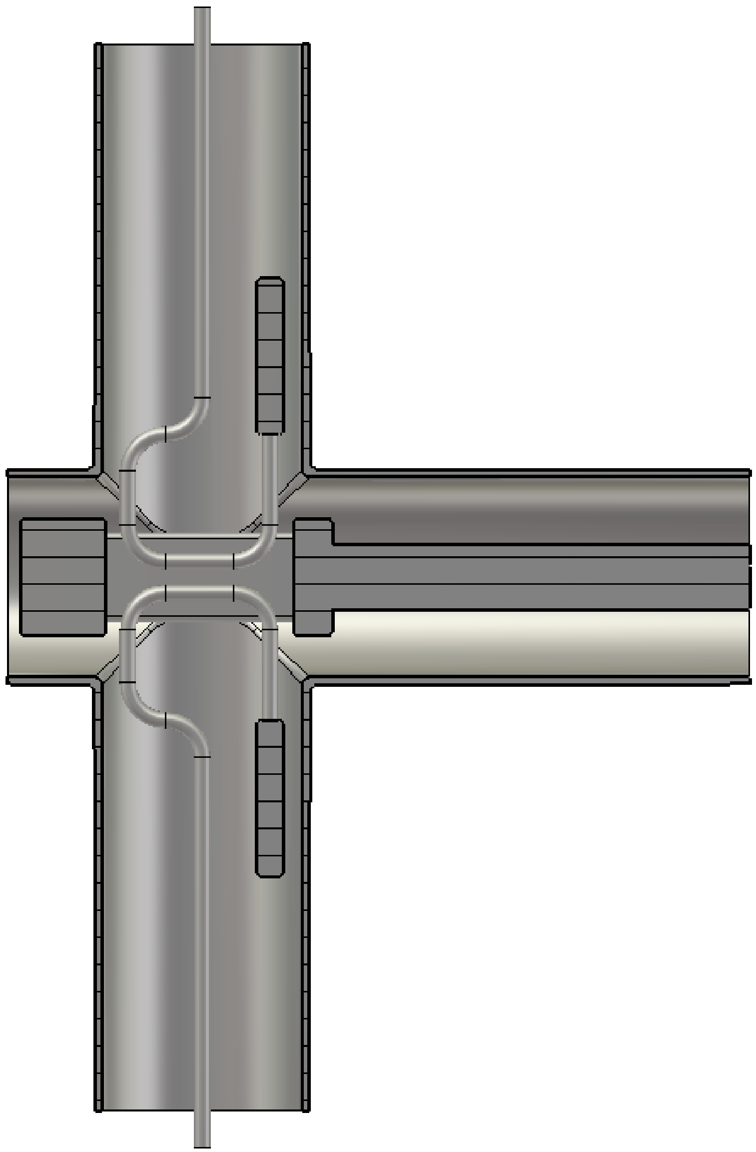
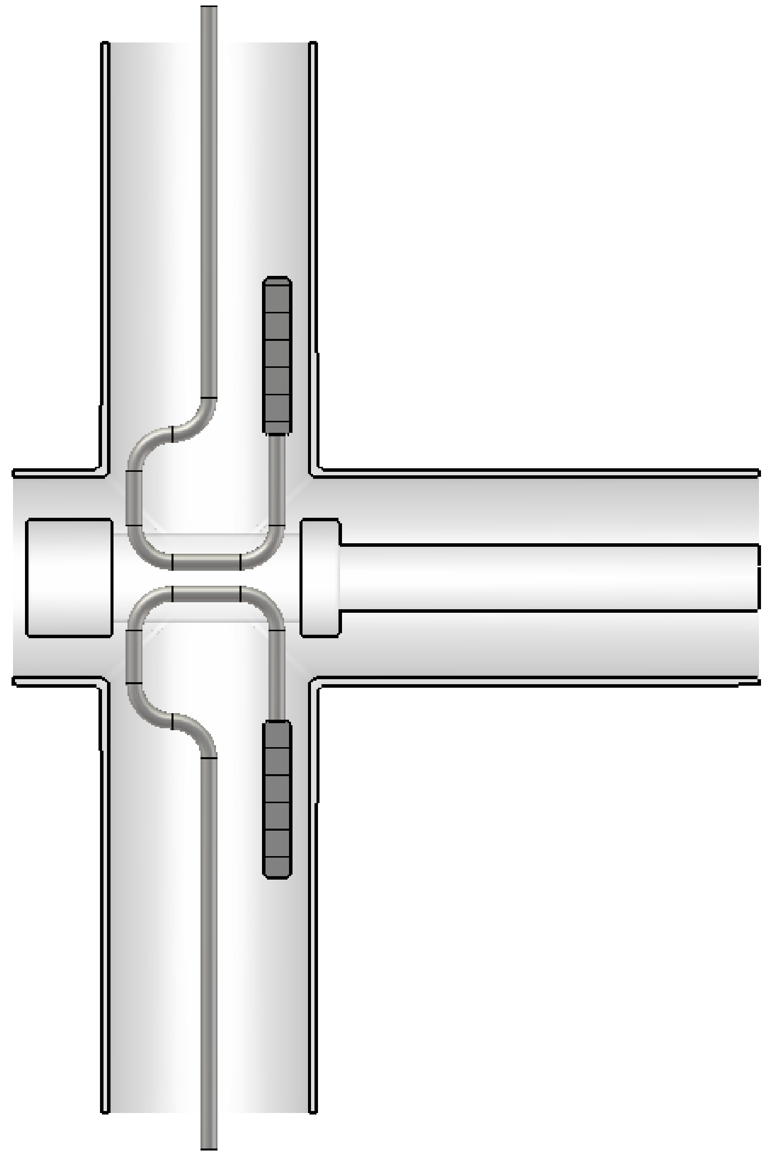
Test cavity for RFQ coupler test

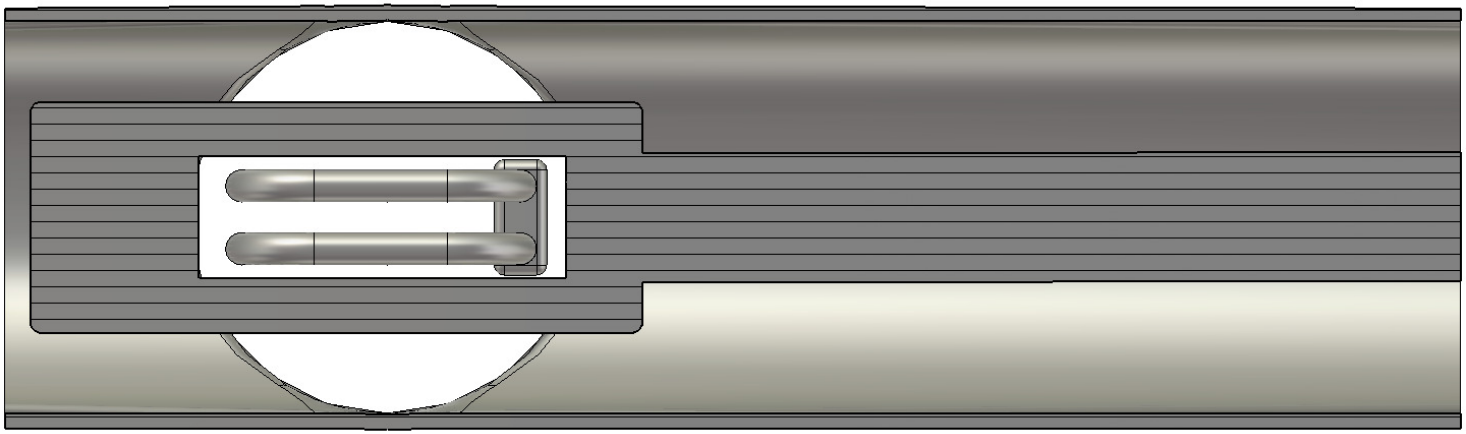
Wave length is 1.85 m. Cavity is big and expansive. We need something else.

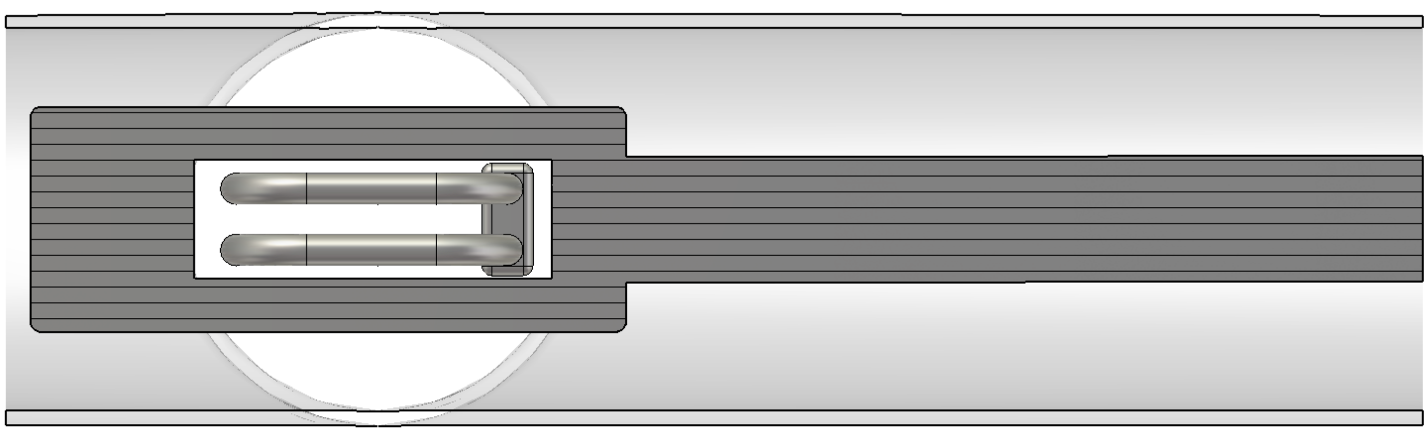




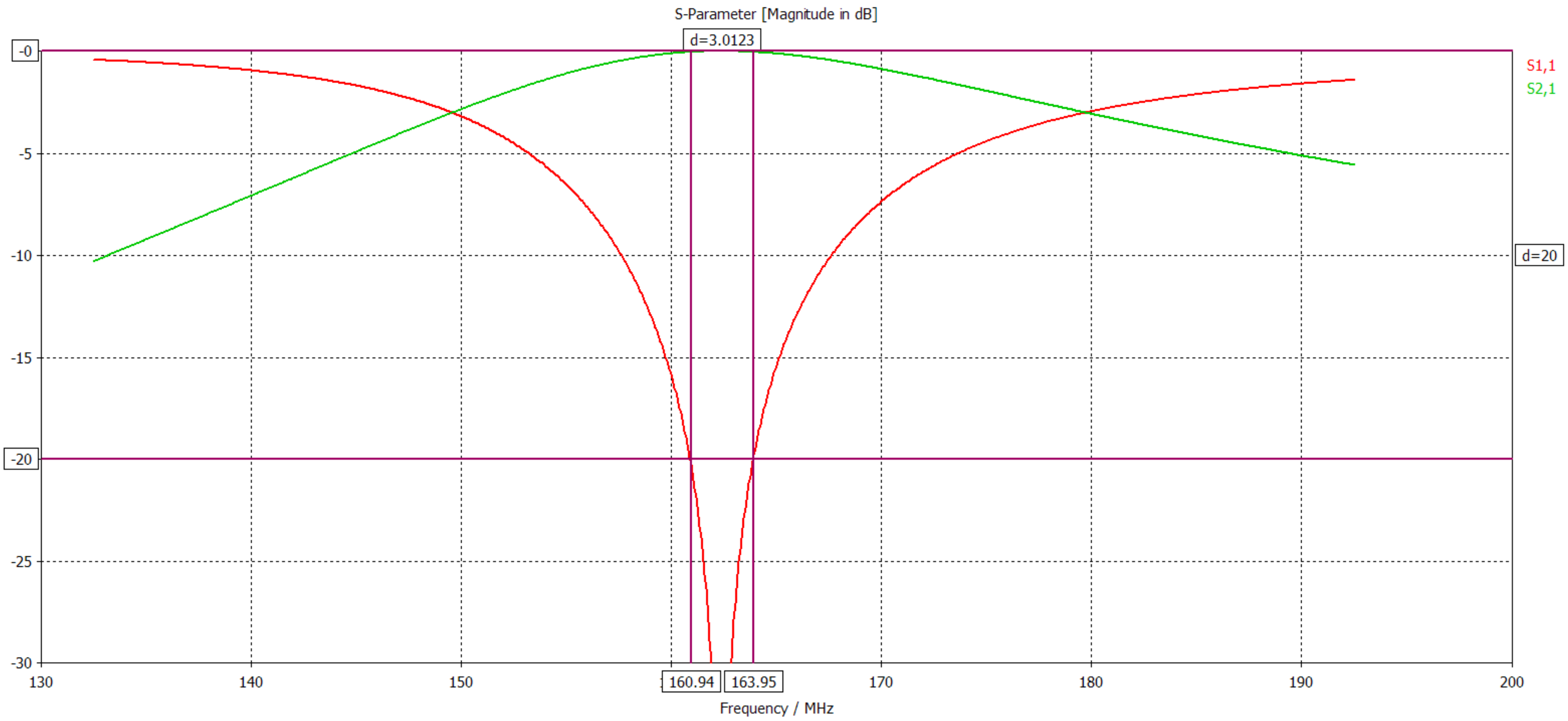
It seems we found compact and not expensive geometry.
In this configuration we can check power ability of ceramic window, but cannot check loop heating/cooling – fields are different around loop.



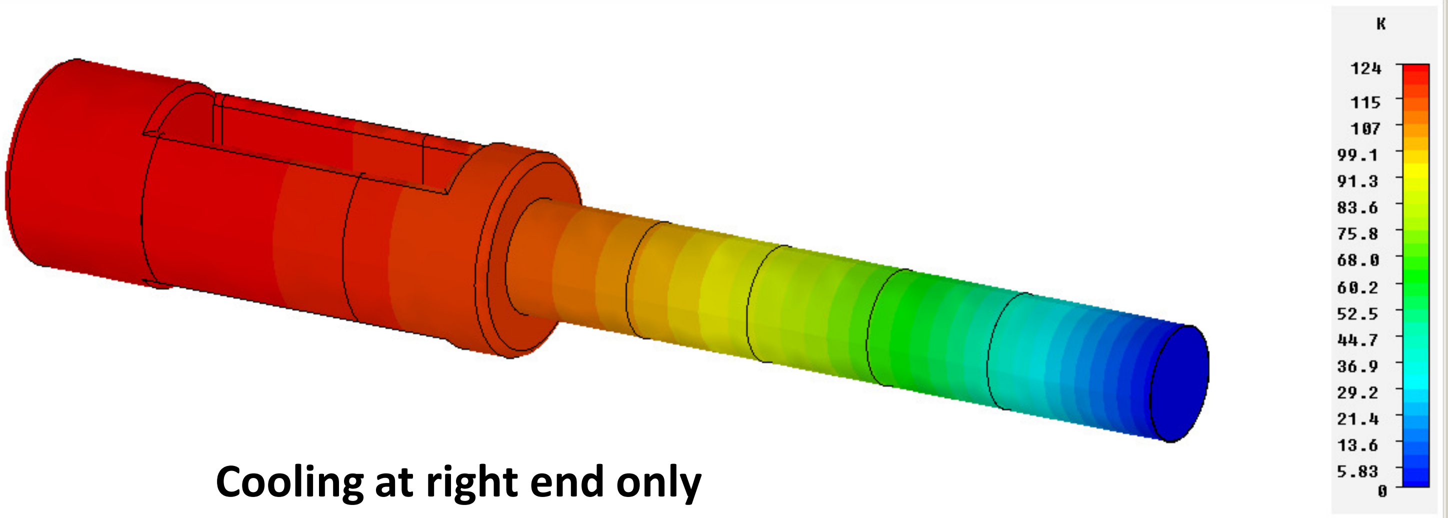


Pass band of test configuration is ~ 3 MHz, Q ~ 5.4.
Resonant frequency will be adjusted by changing capacitive gap. TKx117

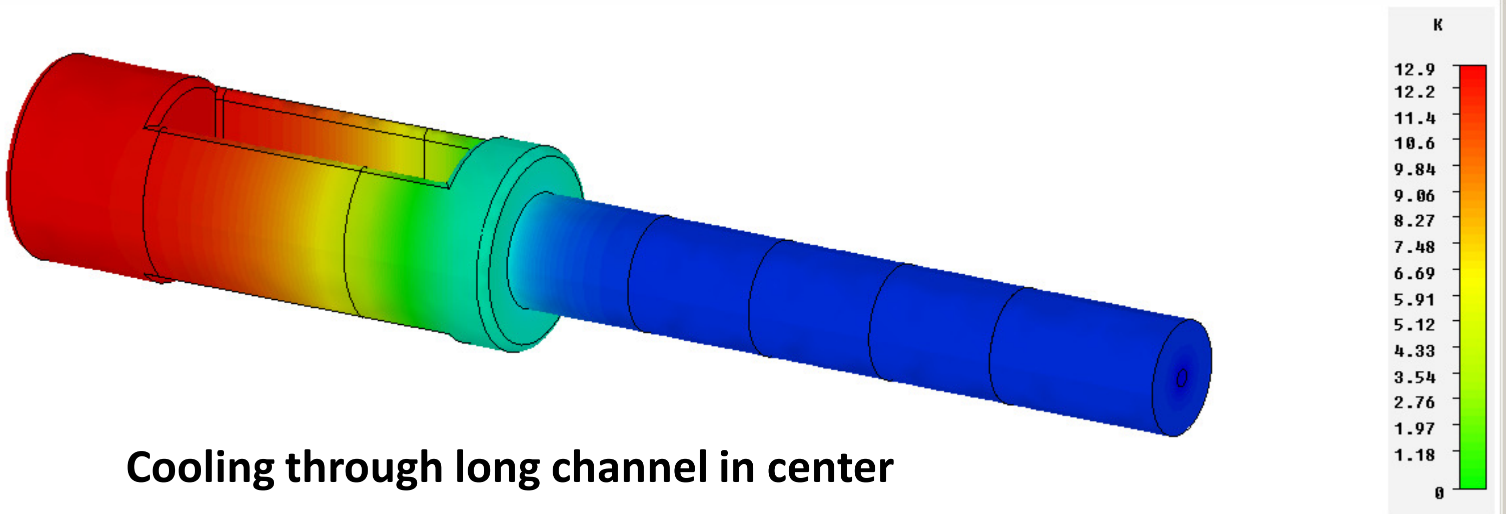


TKx117 Which gap? Between loops?
Timergali Khabiboulline x4693 13342N, 5/20/2013

Temperature rise estimation. P ~ 232W. TKx118



Cooling at right end only



Cooling through long channel in center

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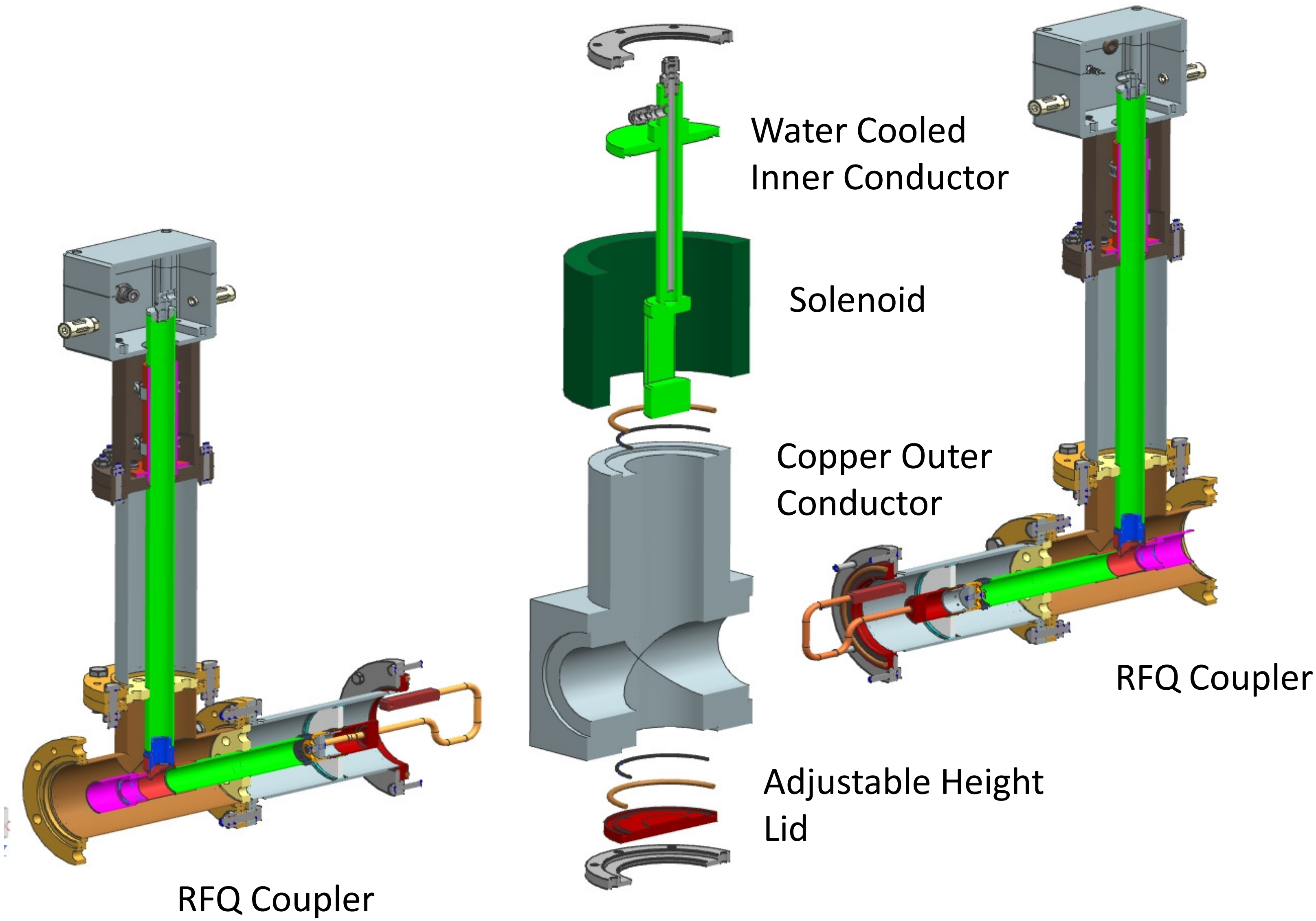
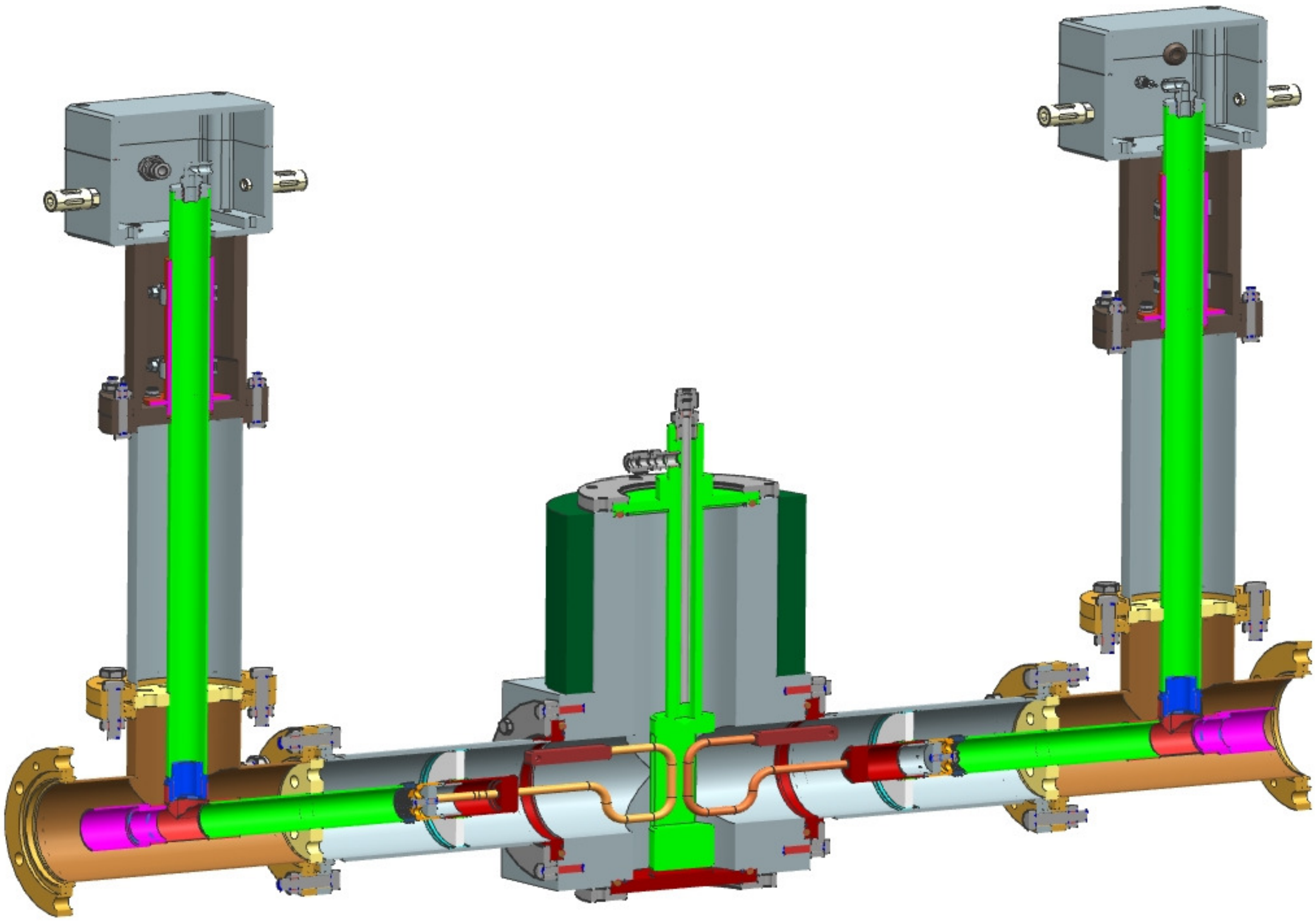
TKx118 What is transmitted power? 80 kW?
Timergali Khabiboulline x4693 13342N, 5/20/2013

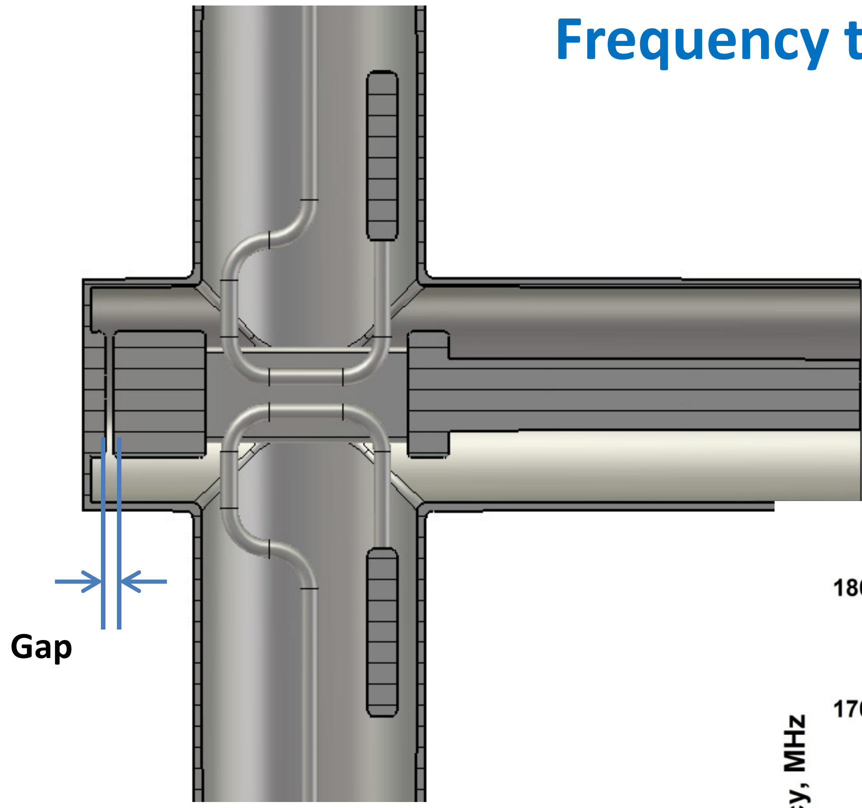
Test Stand for RFQ Couplers

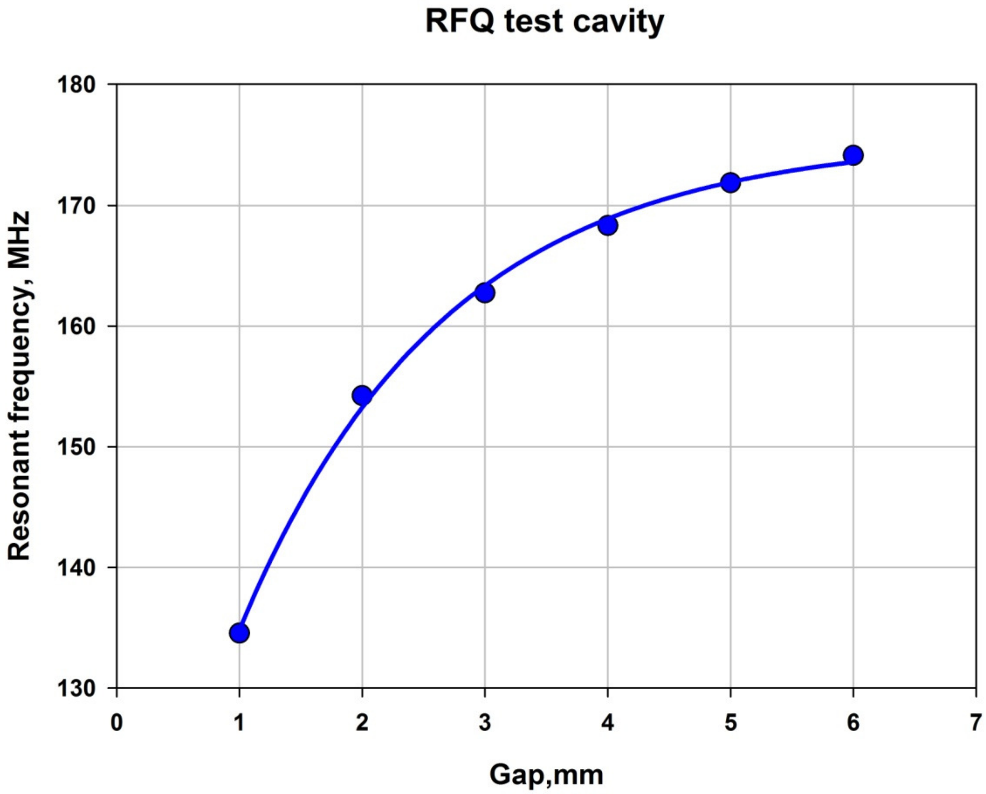


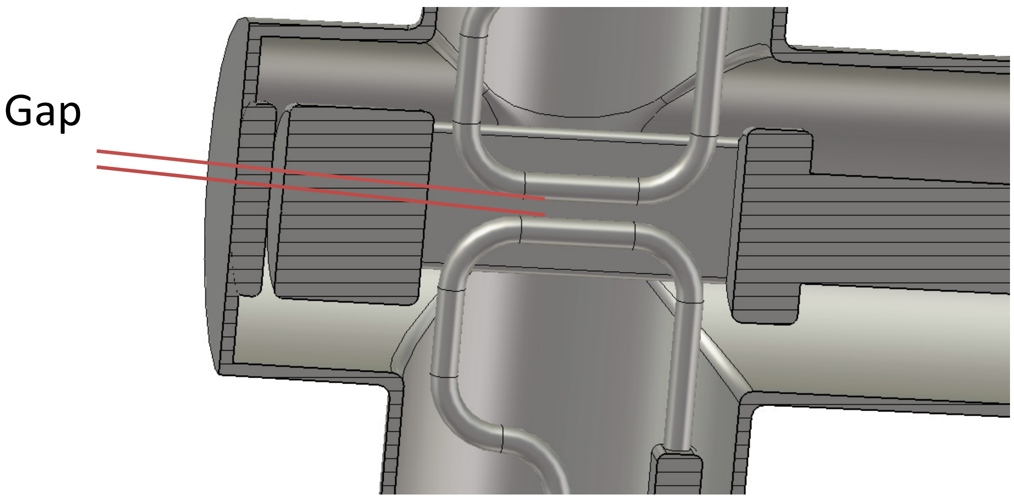
Test Stand for RFQ Couplers

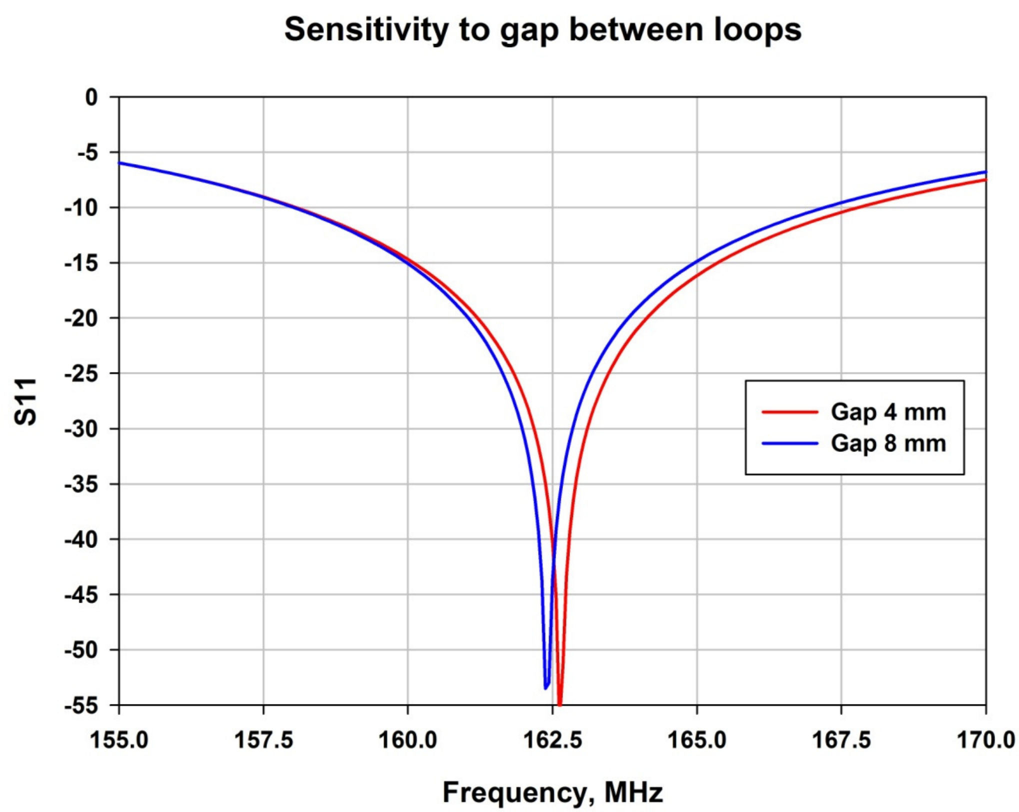


Frequency tuning by changing capacitive gap.









Resonant frequency is not sensitive to gap size between loops