

# RF-Mechanical design of the 650 MHz buncher

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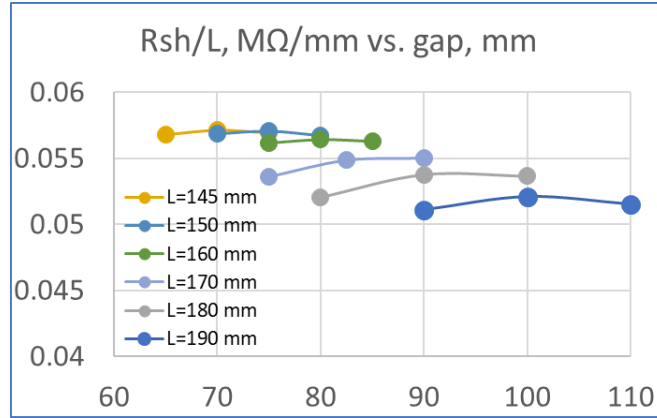
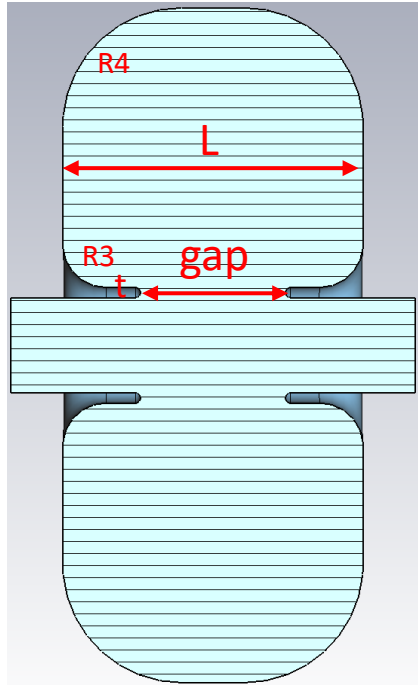
Why separate feeding of the cavity cells is better than use of a coupled-cell resonator:

1. No coupling cells and coupling slots, which also improves  $R_{sh}$  by  $\sim 20\%$  compared to pi-structure
2. The separate cells are shorter, that allows further improvement transit time factor and shunt impedance;
3. No power combiner in the amplifier, which provides 1.5-2 dB loss and additional cost.
4. One needs not a big coaxial line, but a number of thinner coaxial cables. The cables may have higher loss than a coaxial line, but because of (1-3) the total input power from the grid may be even smaller than for a coupled cell cavity.
5. No high-power coupler, which is expensive, may be unreliable (big ceramic window) and needs long time for design and tests;
6. The separate cell cavity needs individual phase control, which is not a problem.

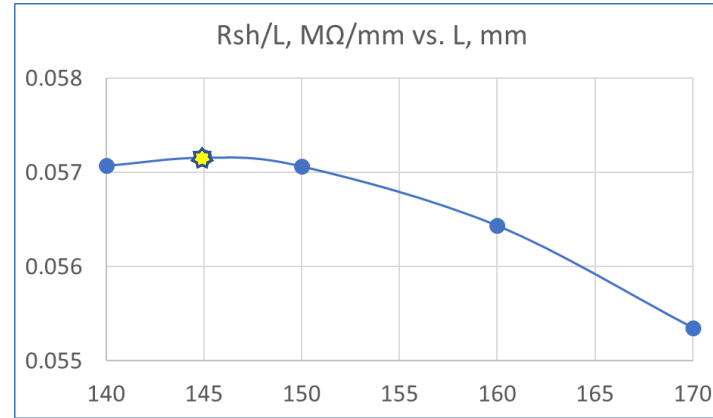
Separate feeding cavity design was completed on 09/13/2021

# RF design

All parameters in mm

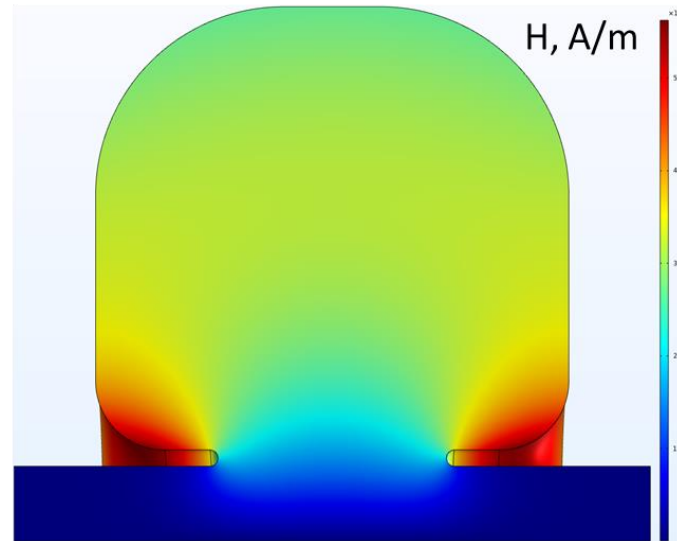
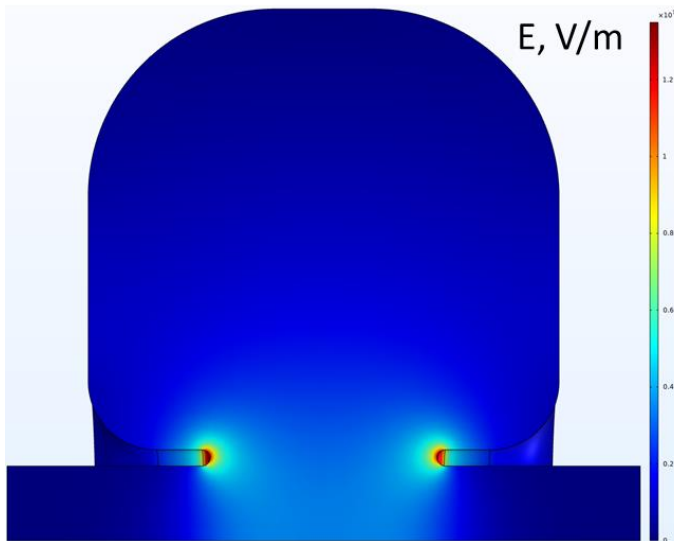


$R_{sh} / L$  vs. gap length



Maximum of  $R_{sh} / L$  vs. cavity length

Parameter	Value
$\phi_{aperture}$	46
$\phi_{cavity}$	323.4/326.74/329.82
L	140/145/150
gap	65/70/75
t	5
R1	2.5
R2	2.5
R3	21
R4	55/57.5/60

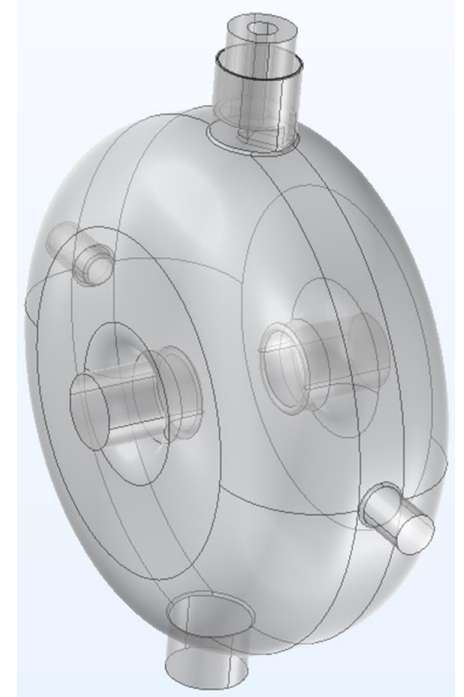
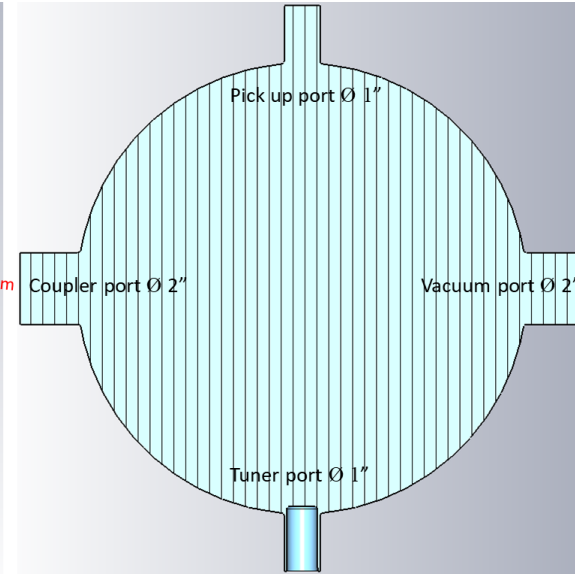
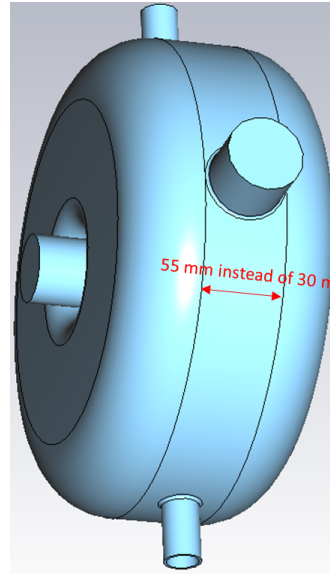


V = 300 kV  
 $\beta = 0.841$  (800 MeV)

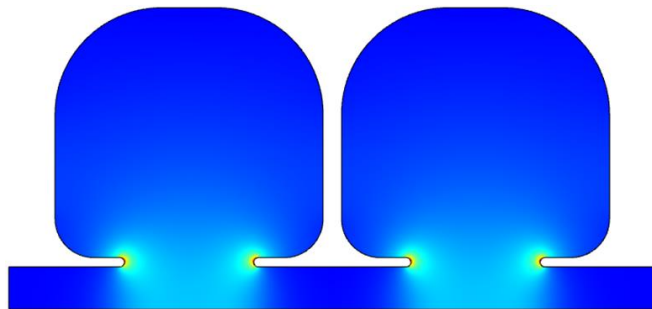
Parameter	L = 140 mm	L = 145 mm	L = 150 mm
$V_{eff}$ , kV	272.5	269.8	267.0
R/Q, $\Omega$	277.5	280.8	283.2
Q	28790	29520	30220
$R_{sh}/L$ , MΩ/m	57.07	57.16	57.05
Losses, kW	9.29	8.78	8.33
$E_{max}$ , MV/m	13.9	13.25	12.7

# RF design

U, V	R, Ohm	Lcell, m	E <sub>max</sub> , V/m	V <sub>eff</sub> , V	DF	Oberhead	E <sub>kil</sub> , V/m
2.50E+06	5.72E+07	0.145	1.33E+07	2.70E+05	2.00E-02	4.00E-01	2.40E+07
N cells	P/cell, W	P <sub>tot</sub> , W	L, m	E <sub>max</sub> , V/m	P <sub>av</sub> /cell, W	P <sub>av</sub> /tot, W	E <sub>max</sub> /E <sub>kil</sub>
5	4.22E+04	2.11E+05	0.725	2.46E+07	8.45E+02	4.22E+03	1.02E+00
6	2.93E+04	1.76E+05	0.87	2.05E+07	5.87E+02	3.52E+03	8.53E-01
<b>7</b>	<b>2.15E+04</b>	<b>1.51E+05</b>	<b>1.015</b>	<b>1.75E+07</b>	<b>4.31E+02</b>	<b>3.02E+03</b>	<b>7.31E-01</b>
8	1.65E+04	1.32E+05	1.16	1.53E+07	3.30E+02	2.64E+03	6.39E-01
9	1.30E+04	1.17E+05	1.305	1.36E+07	2.61E+02	2.35E+03	5.68E-01
10	1.06E+04	1.06E+05	1.45	1.23E+07	2.11E+02	2.11E+03	5.12E-01
11	8.73E+03	9.60E+04	1.595	1.12E+07	1.75E+02	1.92E+03	4.65E-01
12	7.33E+03	8.80E+04	1.74	1.02E+07	1.47E+02	1.76E+03	4.26E-01
13	6.25E+03	8.12E+04	1.885	9.44E+06	1.25E+02	1.62E+03	3.94E-01
14	5.39E+03	7.54E+04	2.03	8.77E+06	1.08E+02	1.51E+03	3.65E-01
15	4.69E+03	7.04E+04	2.175	8.19E+06	9.39E+01	1.41E+03	3.41E-01
16	4.12E+03	6.60E+04	2.32	7.67E+06	8.25E+01	1.32E+03	3.20E-01
17	3.65E+03	6.21E+04	2.465	7.22E+06	7.31E+01	1.24E+03	3.01E-01
18	3.26E+03	5.87E+04	2.61	6.82E+06	6.52E+01	1.17E+03	2.84E-01
19	2.92E+03	5.56E+04	2.755	6.46E+06	5.85E+01	1.11E+03	2.69E-01
20	2.64E+03	5.28E+04	2.9	6.14E+06	5.28E+01	1.06E+03	2.56E-01



Cell to cell coupling



F1 650.6671021  
F2 650.6683445

$\Delta f \sim 1.2$  kHz

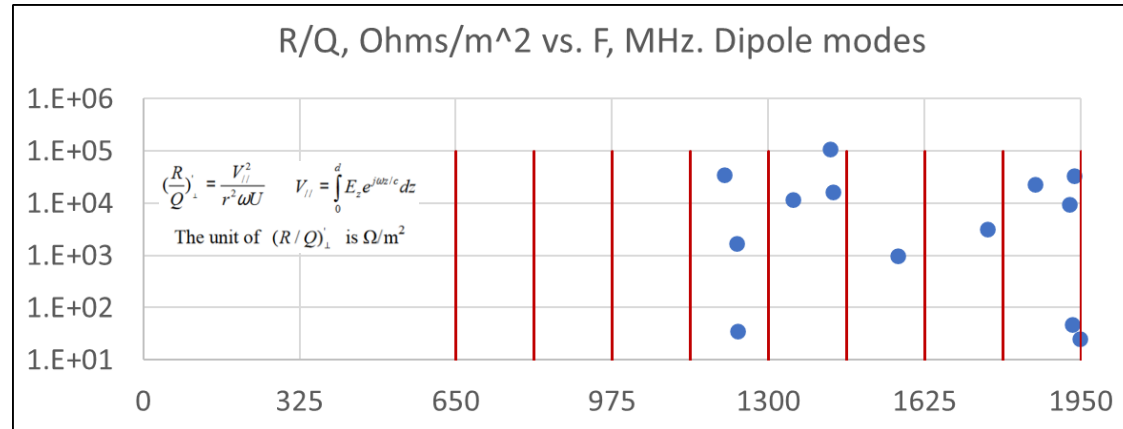
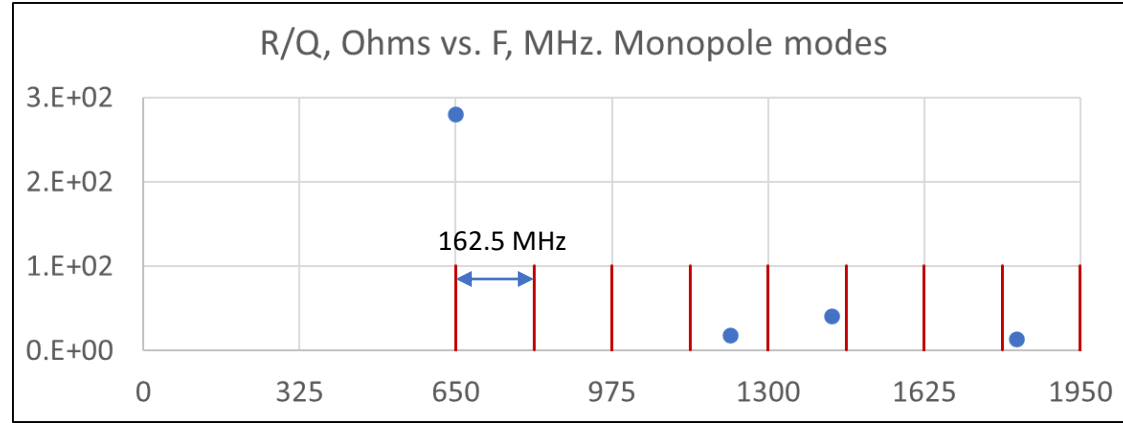
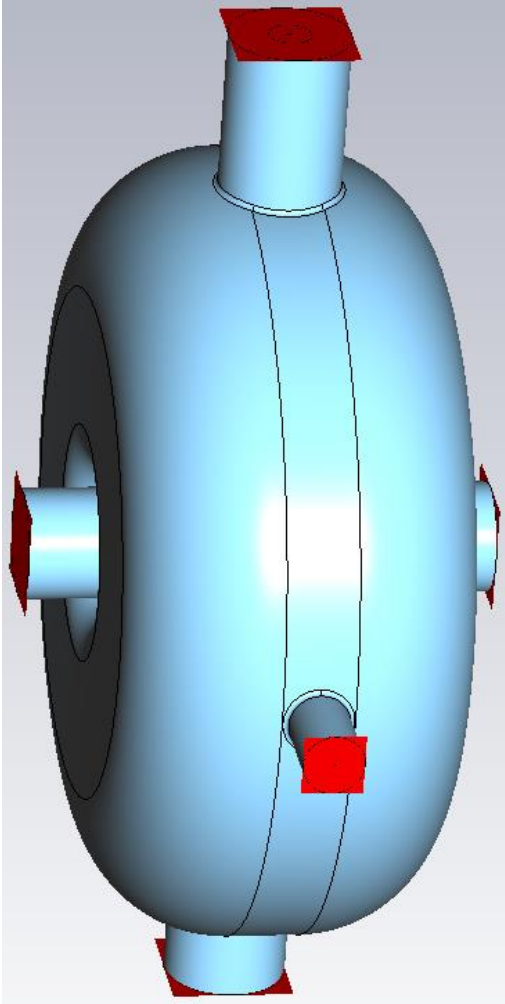
Parameter	Value
$\varnothing_{aperture}$	46
$\varnothing_{cavity}$	326.74/319.1
L	145
gap	70
t	5
R1	2.5
R2	2.5
R3	21
R4	57.5/45

V = 300 kV  
 $\beta = 0.841$  (800 MeV)

Parameter	No ports	4 ports
V <sub>eff</sub> , kV	269.8	269.8
R/Q, $\Omega$	280.8	281.7
Q	29520	28917
R <sub>sh</sub> /L, M $\Omega$ /m	57.16	56.2
Losses, kW	8.78	8.94
E <sub>max</sub> , MV/m	13.25	13.25

# RF design, HOM's up to 2 GHz

Port's BC applied



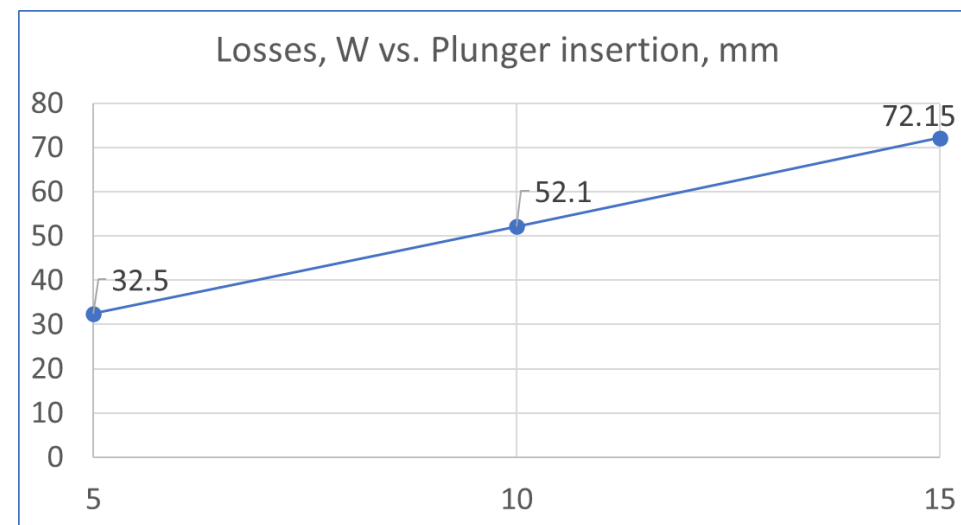
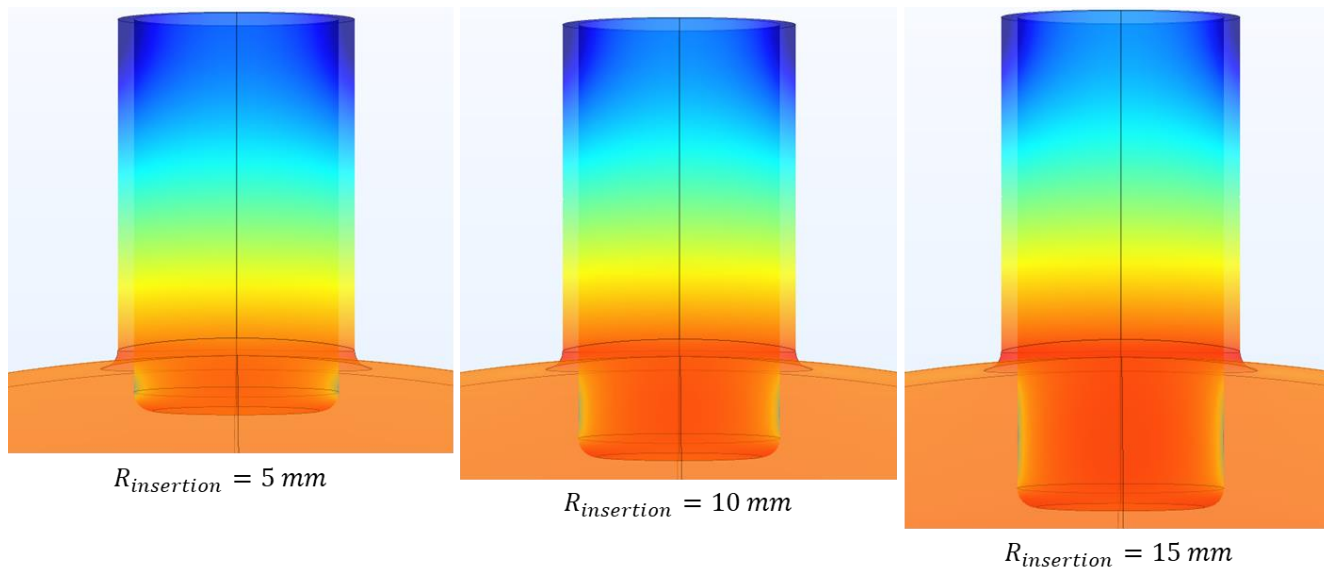
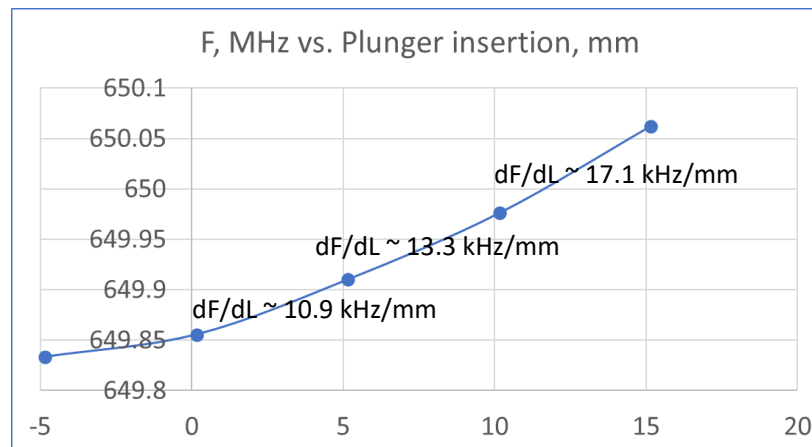
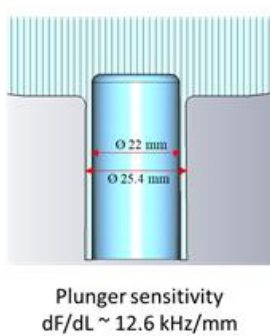
Monopole, m = 0

F, MHz	R/Q, Ω	Q <sub>ext</sub>	Q <sub>cavity</sub>
650.000	2.81E+02	2.5E+04	2.92E+04
1221.607	1.88E+01	1.89E+06	3.73E+04
1431.673	4.12E+01	1.02E+04	2.72E+04
1817.310	1.32E+01	2.33E+04	1.13E+04

m ≥ 1

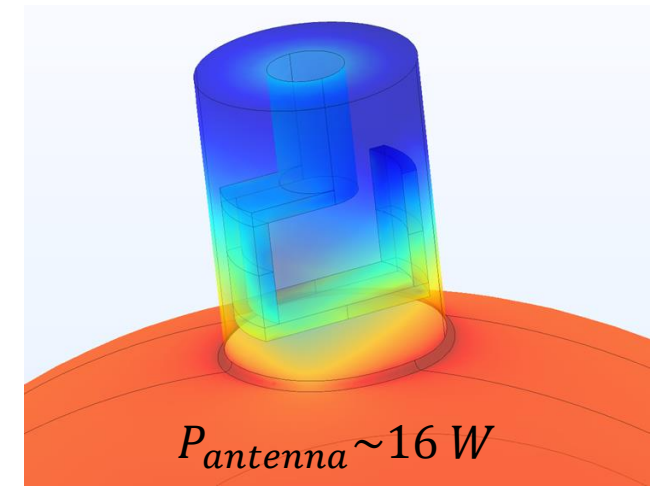
F, MHz	$(R/Q)_{\perp}, \Omega/m^2$	Q <sub>ext</sub>	Q <sub>cavity</sub>
1203.069	7.93E+00	6313	4.61E+03
1207.507	3.51E+04	1.89E+06	3.70E+04
1233.400	1.71E+03	1.12E+05	2.56E+04
1236.031	3.55E+01	1.14E+04	3.21E+04
1350.614	1.19E+04	6.04E+04	3.24E+04
1429.210	1.11E+05	5714	4.02E+04
1434.044	1.67E+04	2.49E+04	4.05E+04
1569.860	2.01E+03	7175	4.57E+04
1576.470	8.41E-05	3.53E+07	4.82E+04
1578.802	2.88E-02	1.29E+04	5.28E+04
1677.496	6.17E+01	3937	3.38E+04
1689.249	1.02E+00	1.37E+04	4.43E+04
1755.785	3.22E+03	5.64E+04	2.94E+04
1758.544	5.10E+03	2.97E+04	3.67E+04
1854.736	3.00E+04	9.86E+04	1.24E+03
1916.479	1.05E+04	4876	3.83E+04
1926.444	9.52E+03	1.07E+04	2.35E+04
1931.249	4.86E+01	4.40E+06	4.22E+04
1931.531	8.99E+03	2.13E+04	5.19E+04
1934.704	2.37E+04	1.18E+06	3.85E+04
1936.059	3.41E+04	7.20E+05	3.38E+04
1947.611	2.59E+01	3449	3.22E+04
1966.735	3.78E+02	9300	2.02E+04

# RF design, plunger tuner



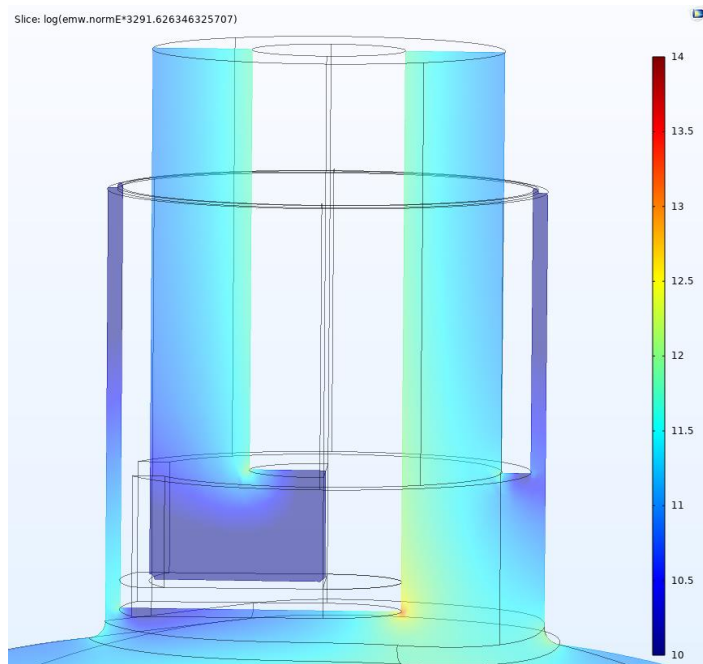
# RF design, power coupler

Voltage = 300 keV  $Q_{external} = 2.5 \cdot 10^4$

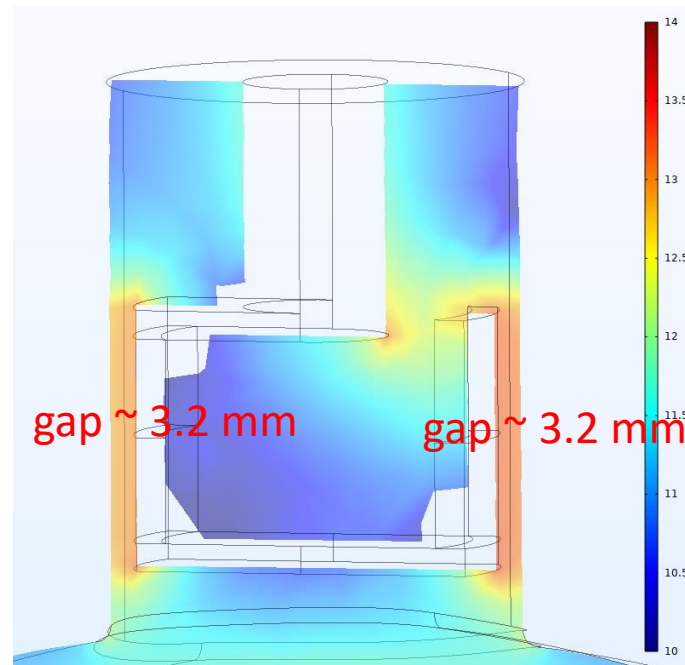


Log scale of E-fields in the same range

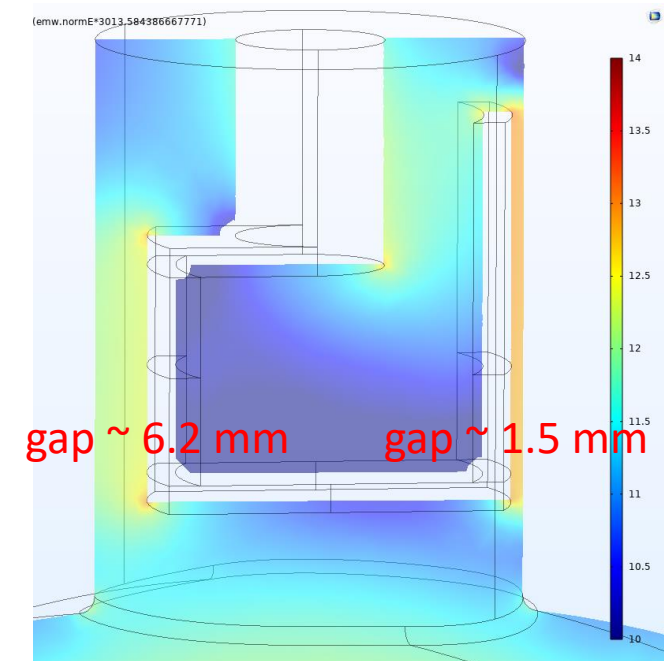
CH structure coupler



Loop coupler 1

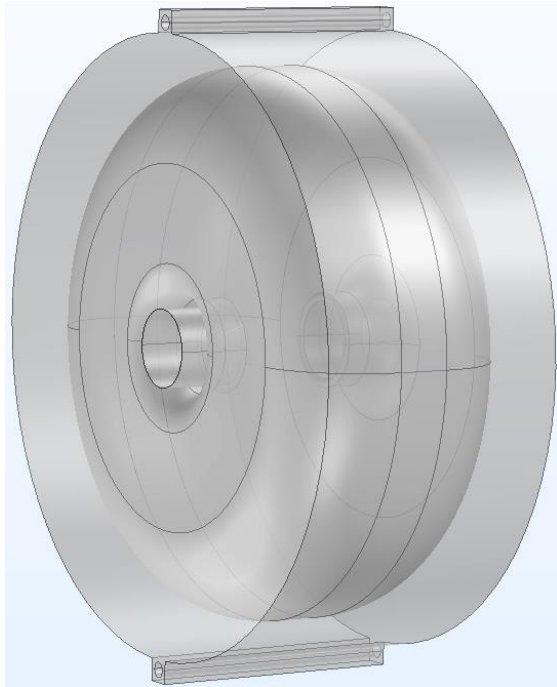


Loop coupler 2



# RF design, water cooling, vacuum

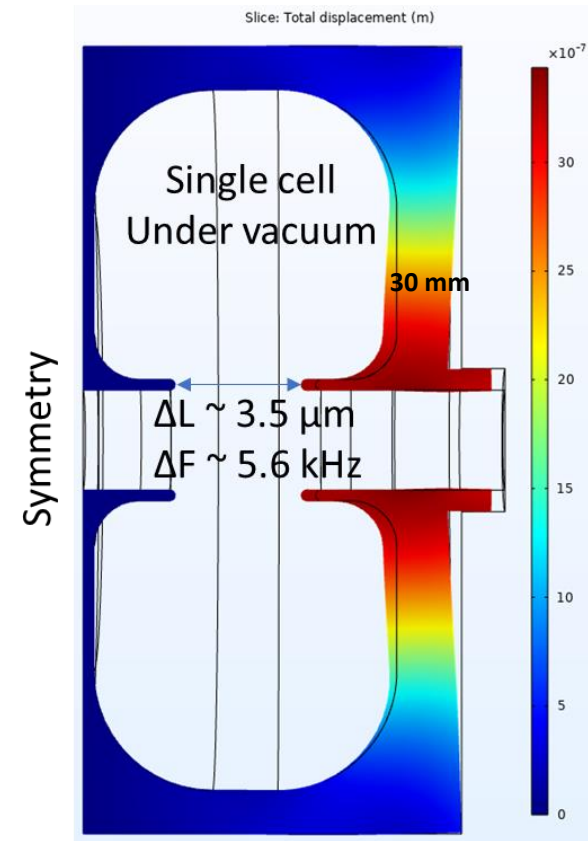
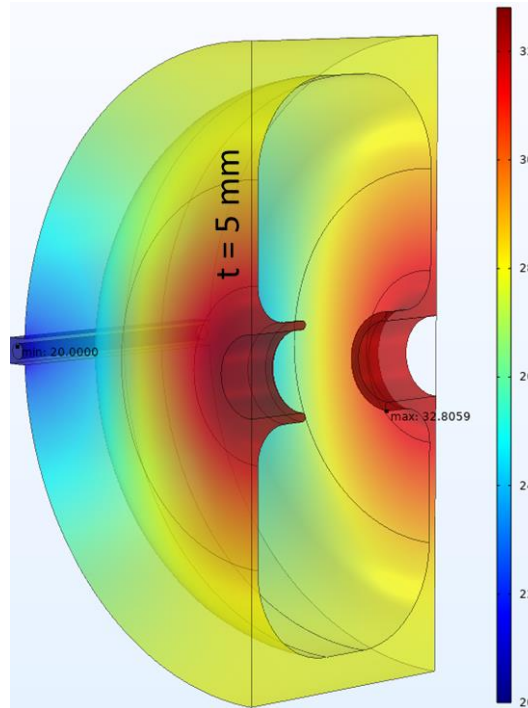
2 water channels,  $\varnothing$  9 mm



Voltage = 300 kV, duty cycle 5%

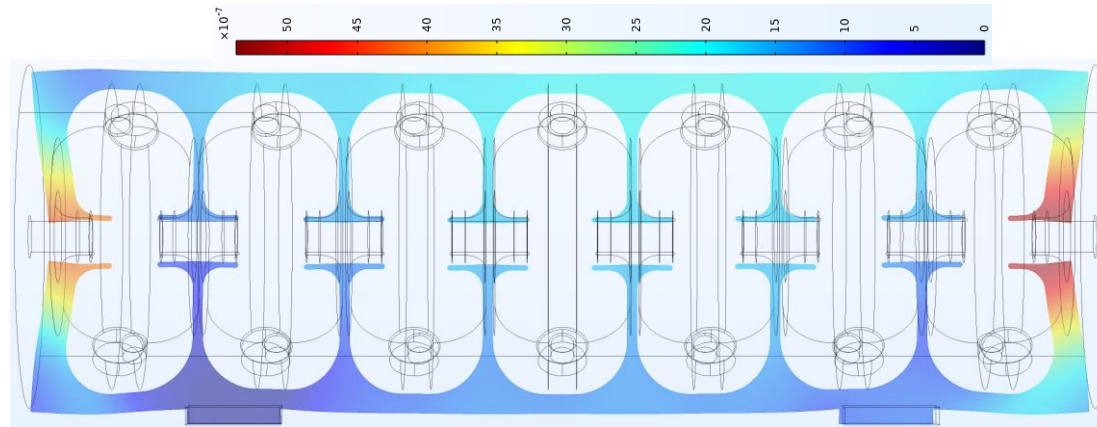
Outer wall 20 mm

$\Delta T \sim 12.8^\circ\text{C}$

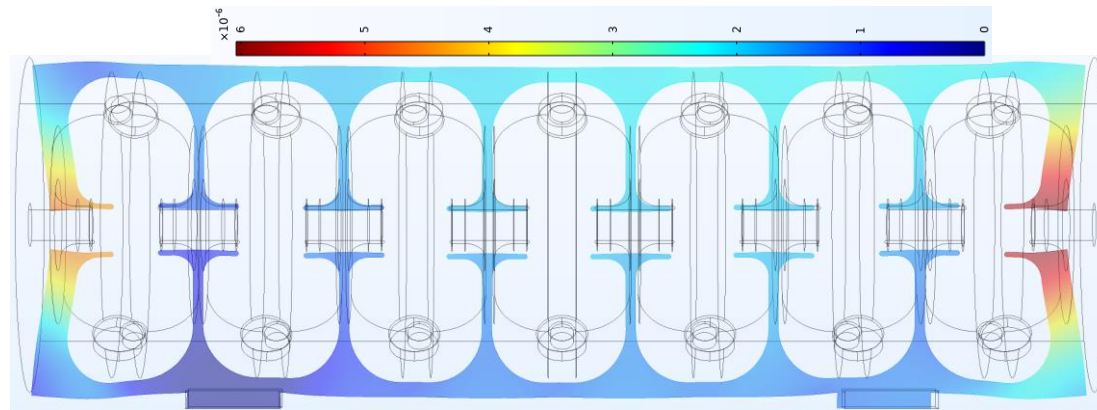




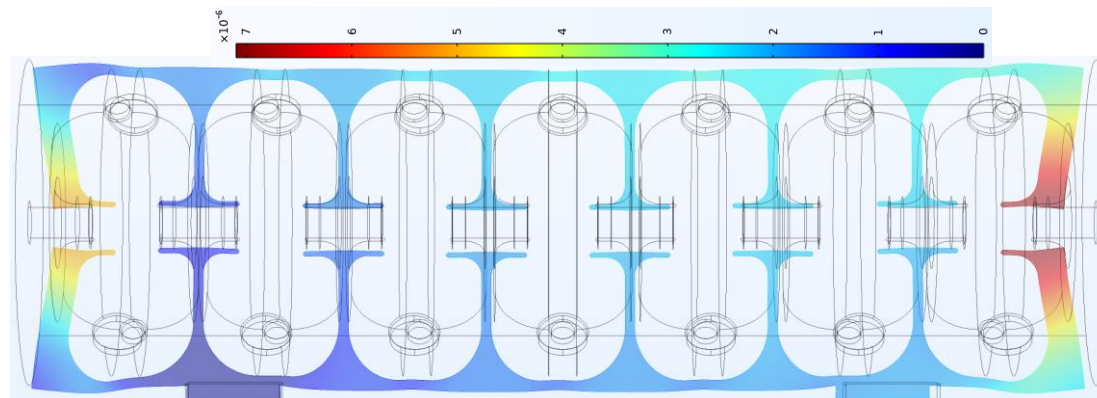
# Mechanical design, deformation due to gravity + vacuum



Outer wall thickness 20 mm  
Weight ~ 394 kg



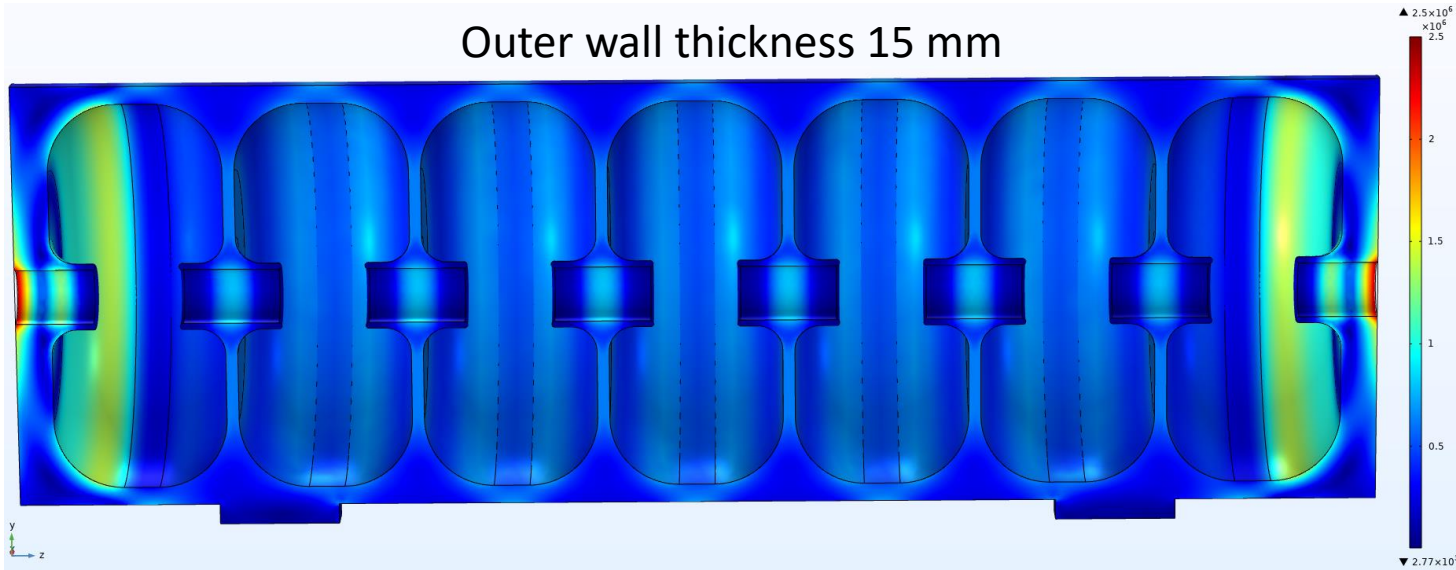
Outer wall thickness 15 mm  
Weight ~ 337 kg



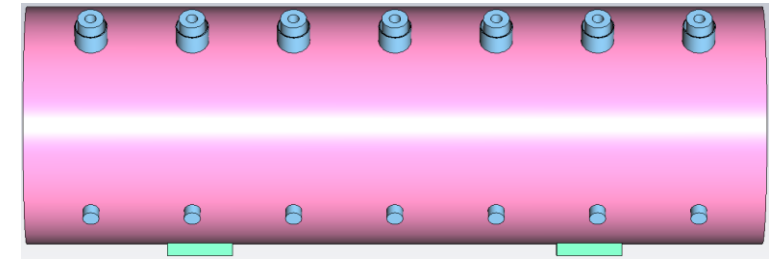
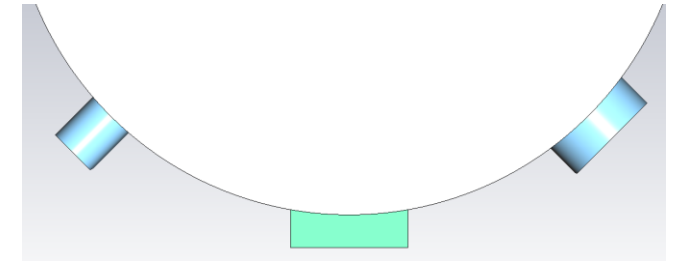
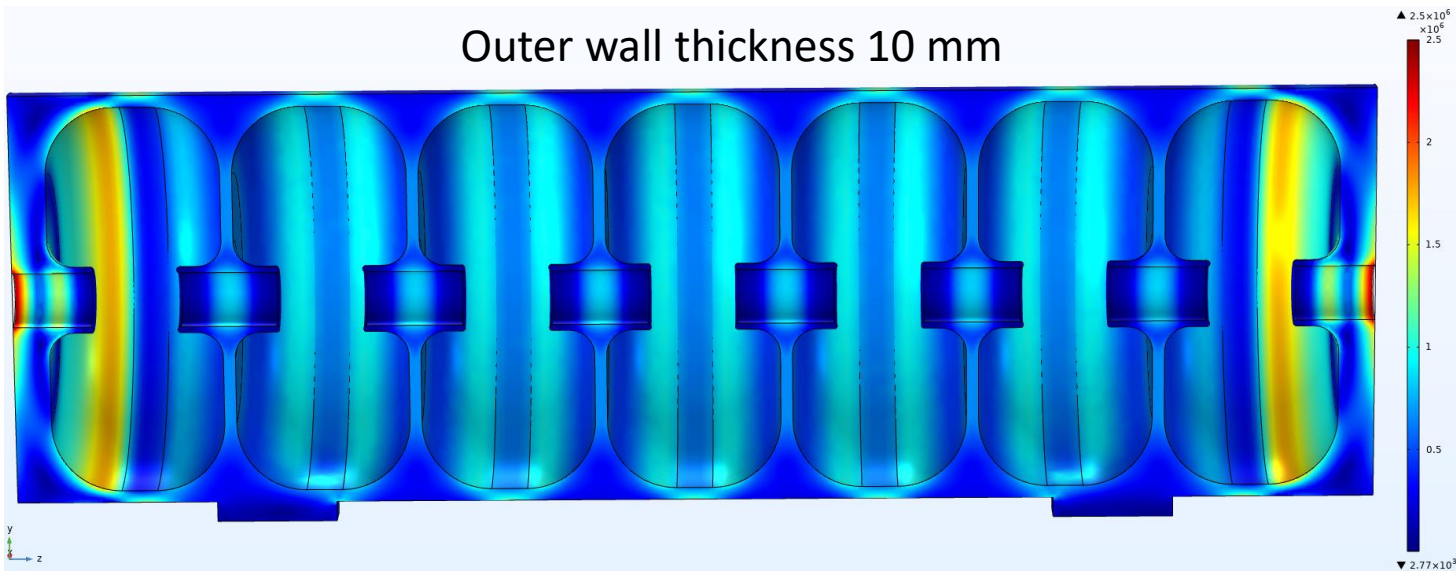
Outer wall thickness 10 mm  
Weight ~ 283 kg

# Mechanical design, deformation due to gravity + vacuum

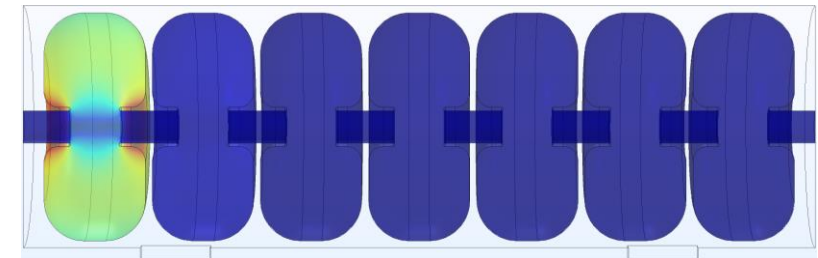
Outer wall thickness 15 mm



Outer wall thickness 10 mm



2 supports lags



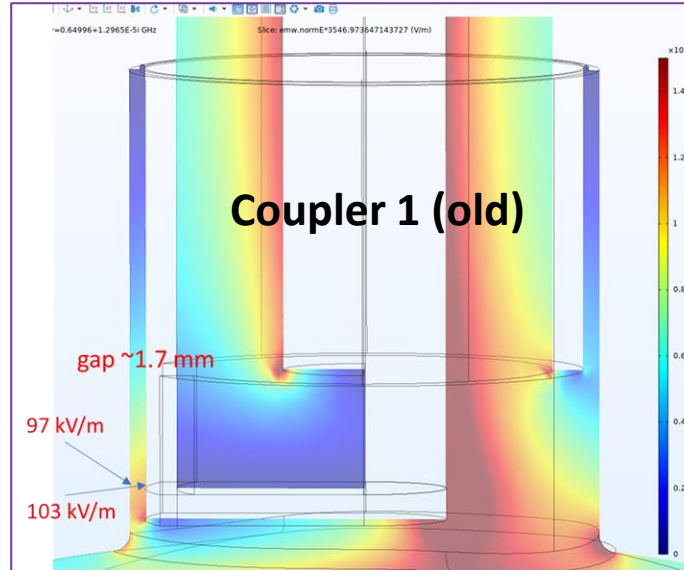
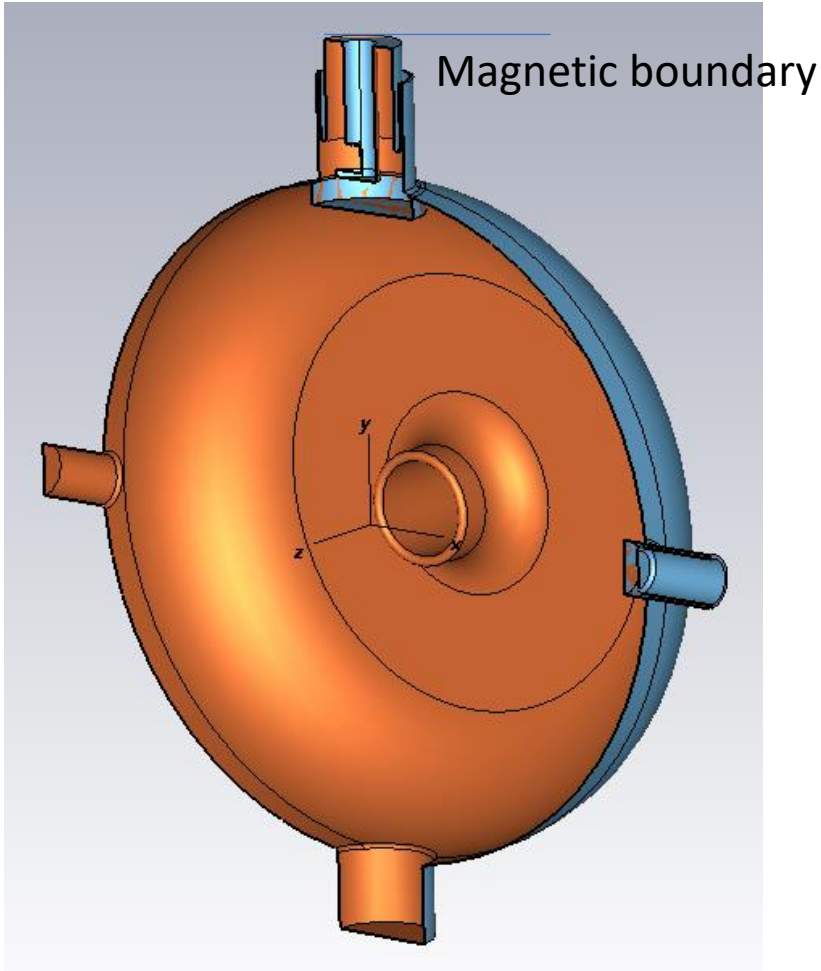
Thickness, mm	$\Delta F$ , kHz
10	-5.9
15	-5.45

Frequency change due to vacuum

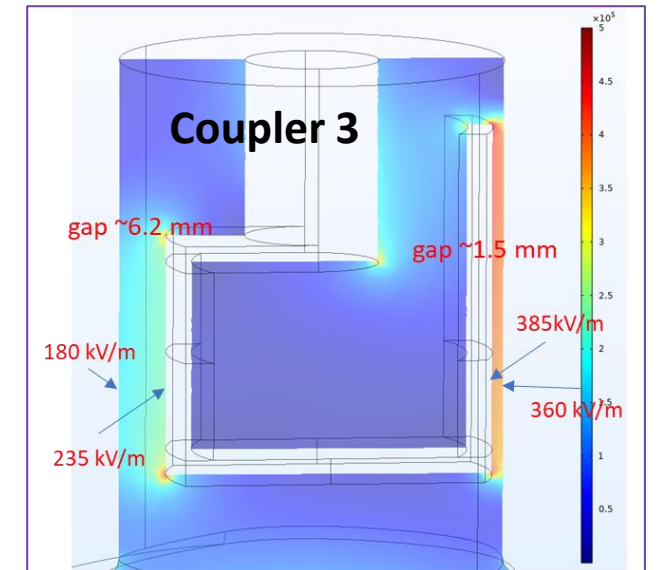
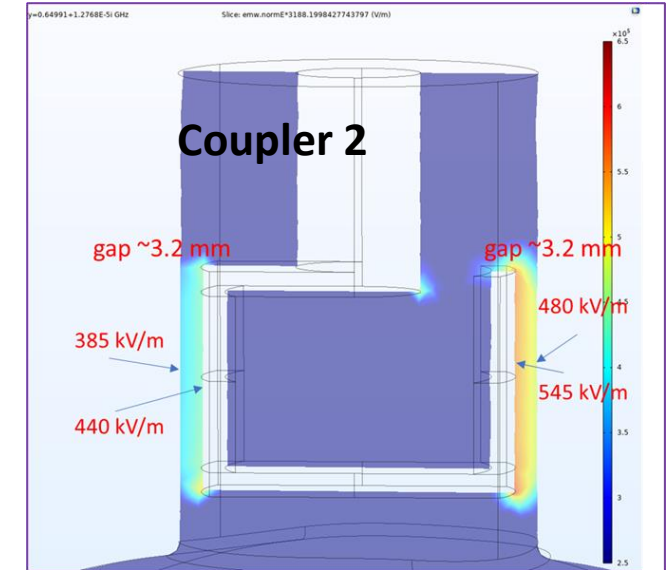
Von Mises stresses in 7-cells cavity under vacuum are  $< 2\text{MPa}$

# Multipacting simulations

Total design voltage of the multicavity PIP-II 650 MHz re-buncher is  $U_{\text{nom}} = 2.5 \text{ MV}$  (without transit time factor).  
Chosen number of cavities  $N = 14$ , so design voltage per cavity  $U_{14 \text{ nom}} = 2500/14 \approx 179 \text{ kV}$ .

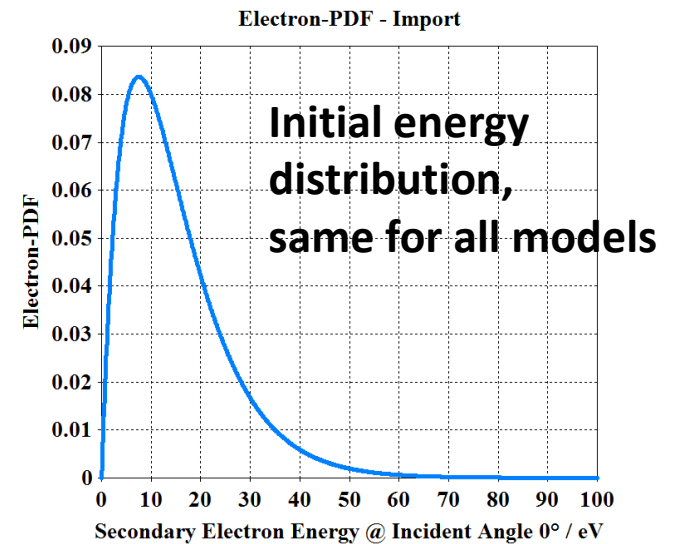
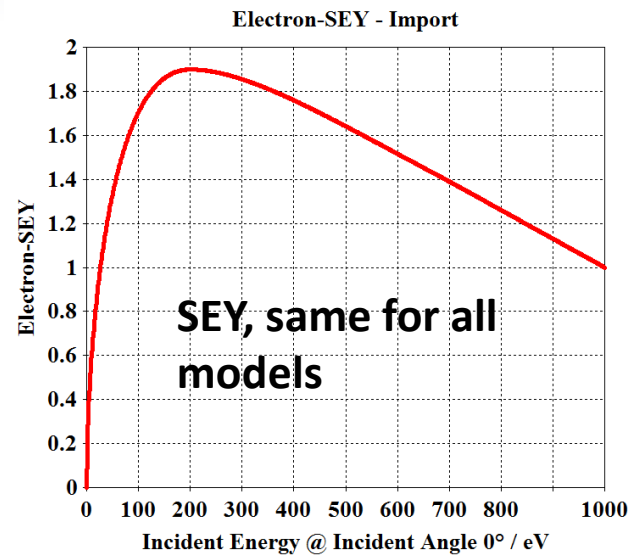
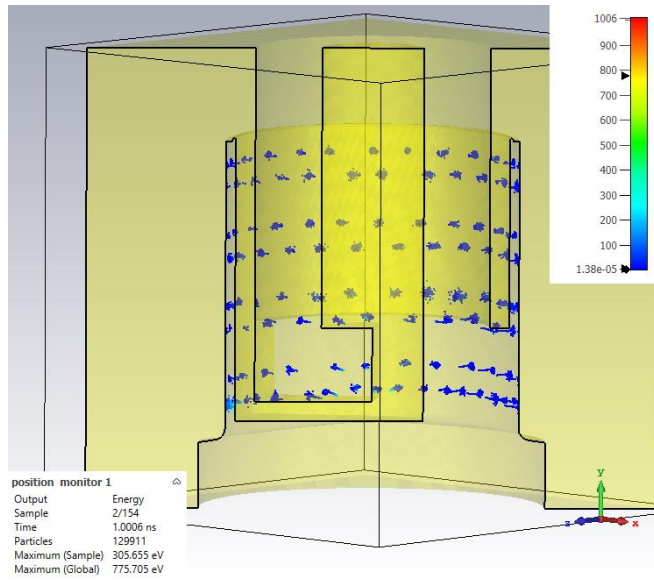
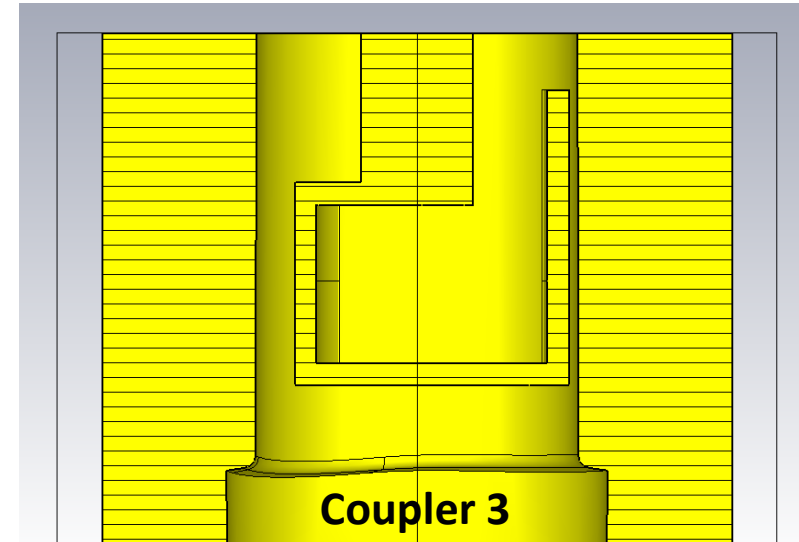
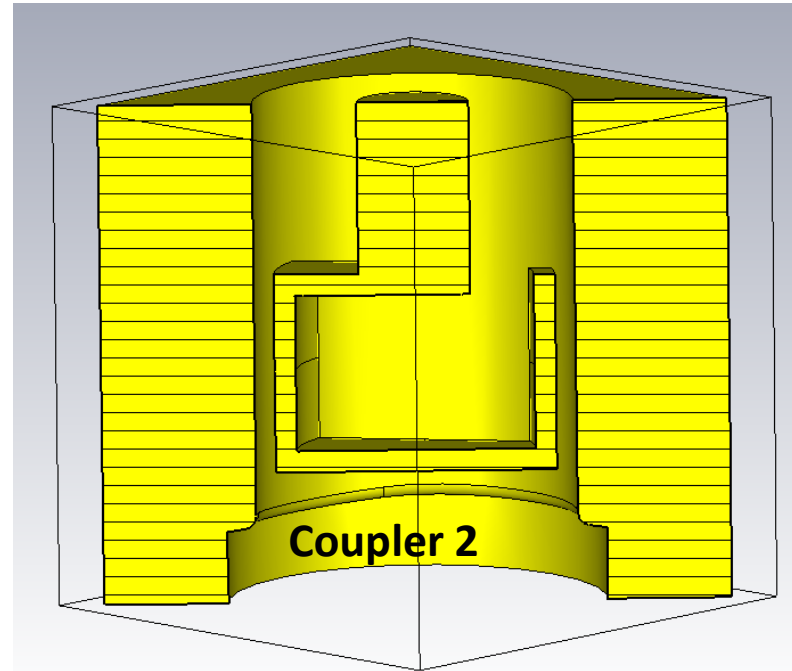
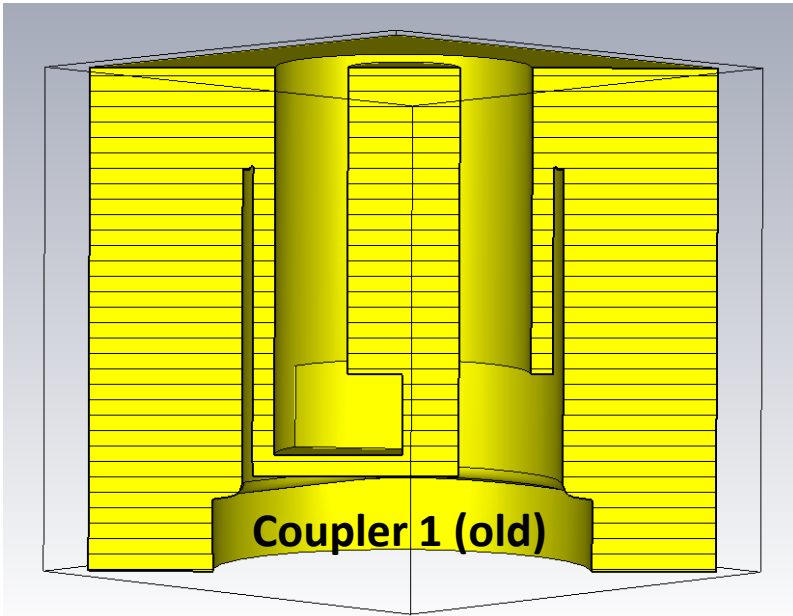


Electric field in the gaps of the coupler designs at  $U_{14} = 300 \text{ kV}$ .

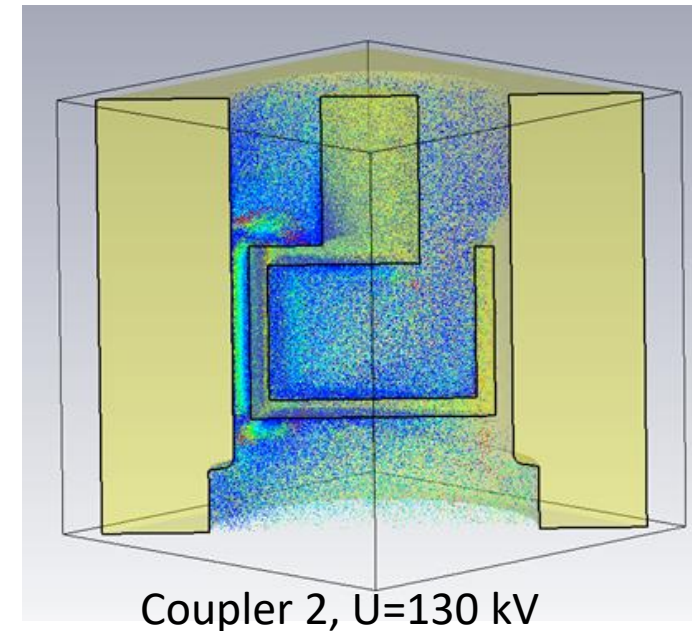
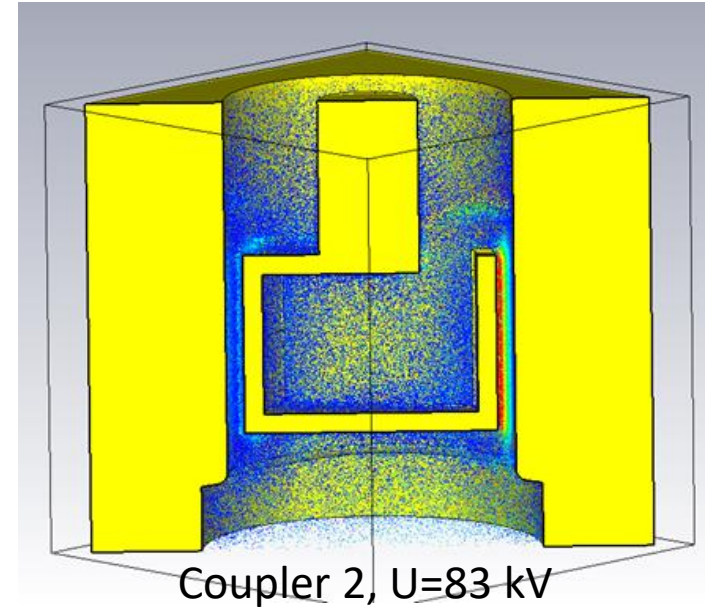
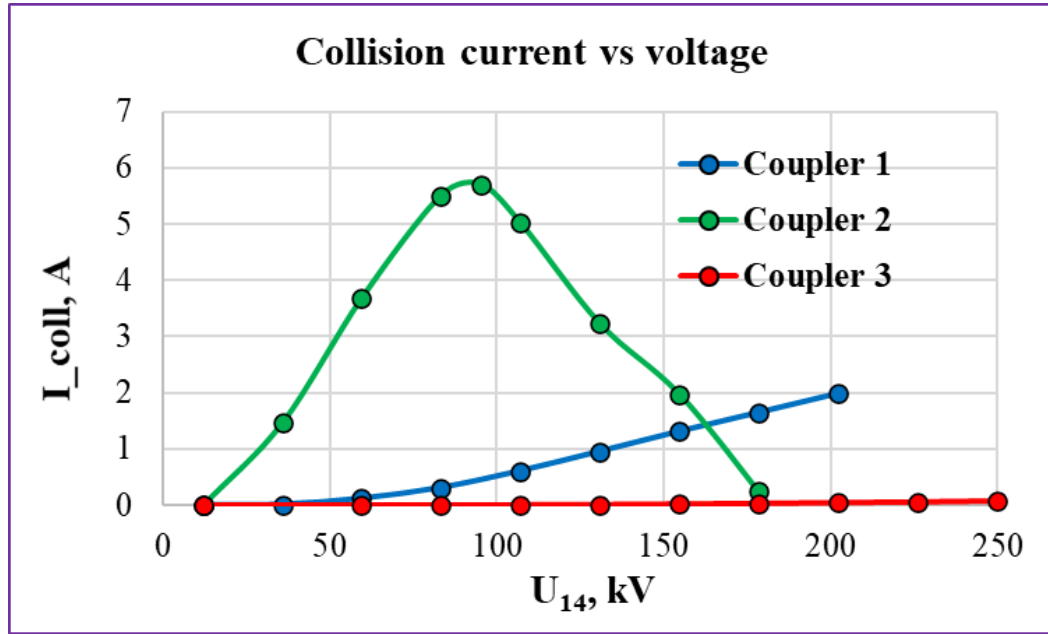


Model for eigen mode field simulation, i.e., there is SW in the coupler.  
Planes of symmetry are not used.

# Multipacting simulations, PIC models

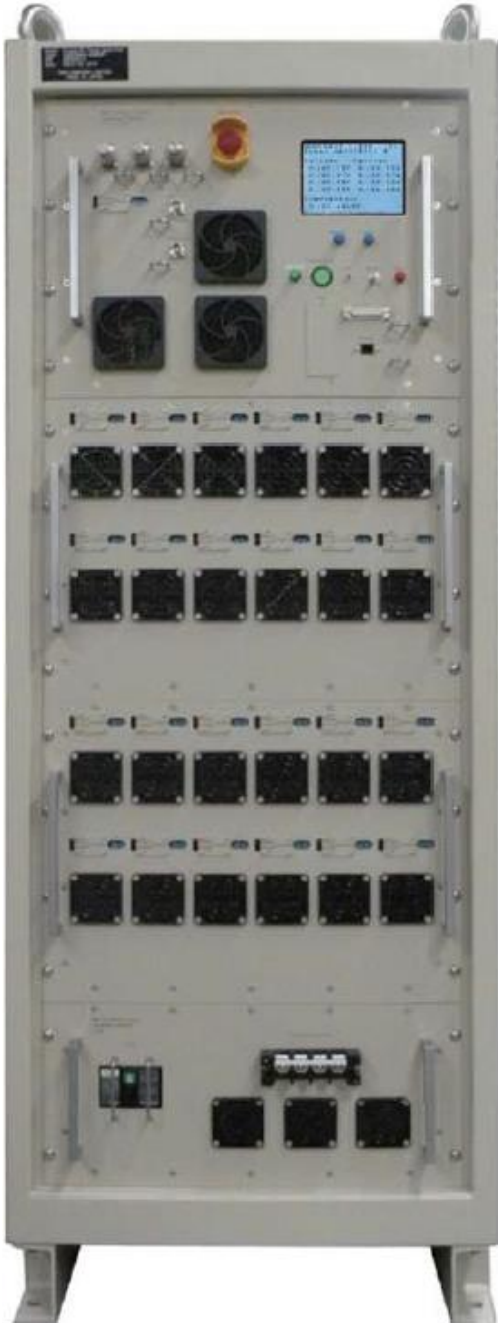


# Multipacting simulations, PIC models



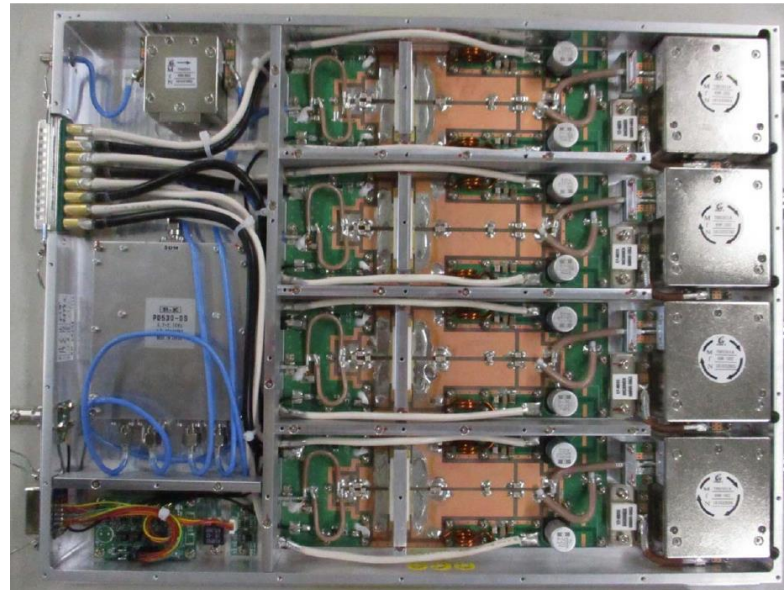
The coupler #3 is free of MP in the voltage range that corresponds to 14 cavities variant.

# RF amplifiers, R&K

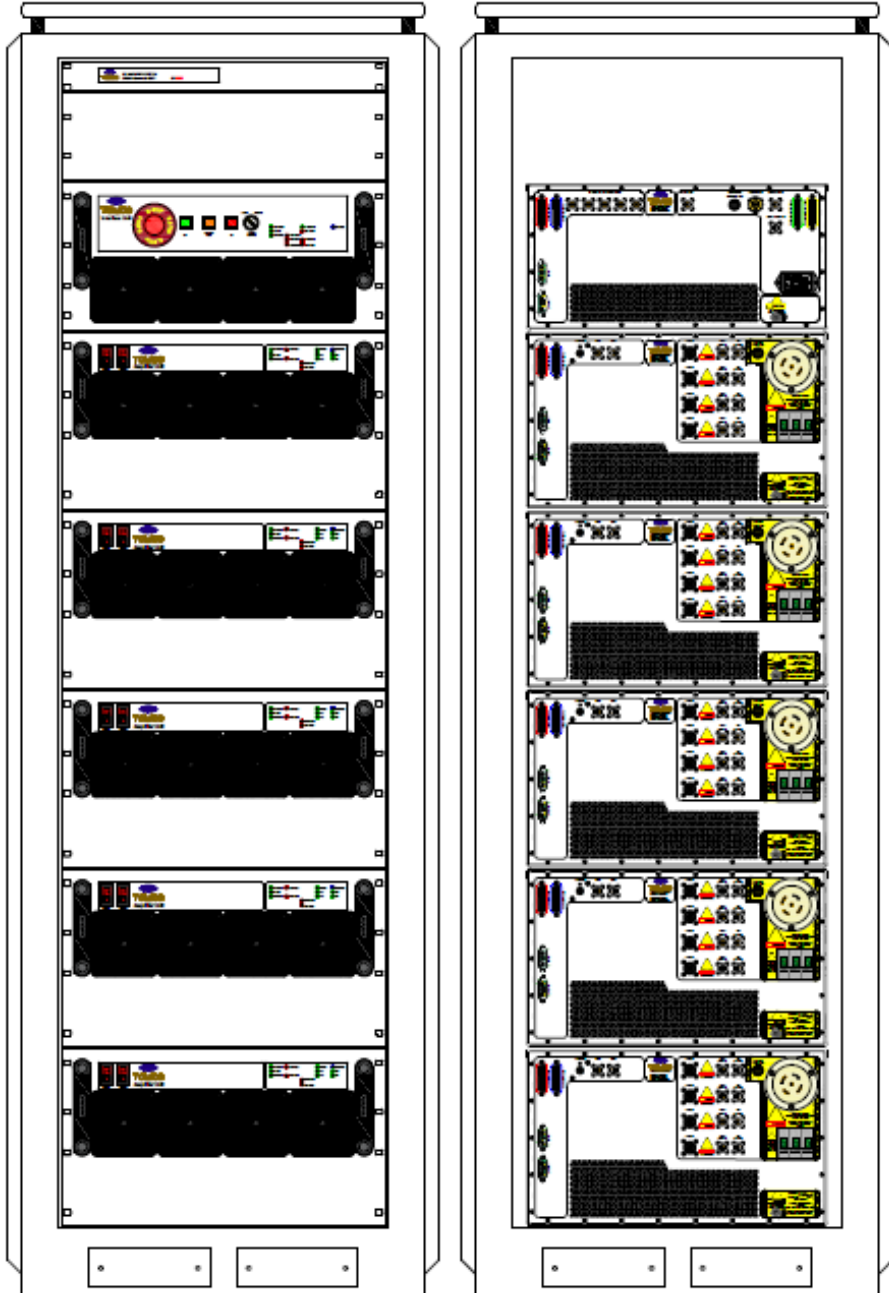


Item	Description	Qty	Unit Price	Lead Time
01	SSA 650MHz, 5.5kWL Pulse, 14CH CA650BW2-5767RP-14CH Spec: EH-CT-2645-X-00	1 pc	\$365,000.00	10 months ARO
02	SSA 650MHz, 3kW L Pulse, 20CH CA650BW2-5565RP-20CH Spec: EH-CT-2643-X-00	1 pc	\$281,000.00	10 months ARO

- Quote validity: June 17, 2021
- Manufacturer: R&K Company Limited
- Country of Origin: Japan
- Trade Terms: Ex-works, Fuji-city, Japan (Incoterms 2020)
- Payment Terms: TBD



# RF amplifiers, TOMPCO



Line no	Description	Qty.	Price per unit USD	Extended price USD
001	<p>RF Amplifier System</p> <p>Model no.: BT60K-GammaS-6857                      Operating Frequency: 650MHz                      Output Power: 20 x 3kW PEP                      Max. duty cycle: 2.5%                      Max. pulse width: 1ms</p> <p>System consists of,</p> <ul style="list-style-type: none"> <li>• 5 x BT12K-SSPA-6857</li> <li>• 1 x BT60K-INT-6857</li> </ul> <p><i>This system contain 20 x 3kW independent RF channels</i></p> <p><i>Interconnecting cables included</i></p>		\$313,000.00	\$313,000.00

# Summary

- RF design completed
  - Accelerating cell optimized for maximum  $R_{sh} / L$
  - 14 independent accelerating cells combined in 2 cavities
    - 7 cell in each cavity, length <1.2m each
  - 200 kHz range tuning plunger proposed
  - Cavity MP free up to 300 kV
- Power coupler design optimized for minimizing MP
  - FPC MP free up to 300 kV
- Power amplifier bids received
  - 300-400 k\$ for 14 channel, 5.5 kW each
- Next steps:
  - Production drawings for cavities
  - Cavity procurement
  - Purchase FPC and Pickup parts
  - LLRF development