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Engineering for Particle Accelerators

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U.S. Particle Accelerator School (USPAS)

SRF cavity design, RF measurements and tuning, part 2

16 January 2020

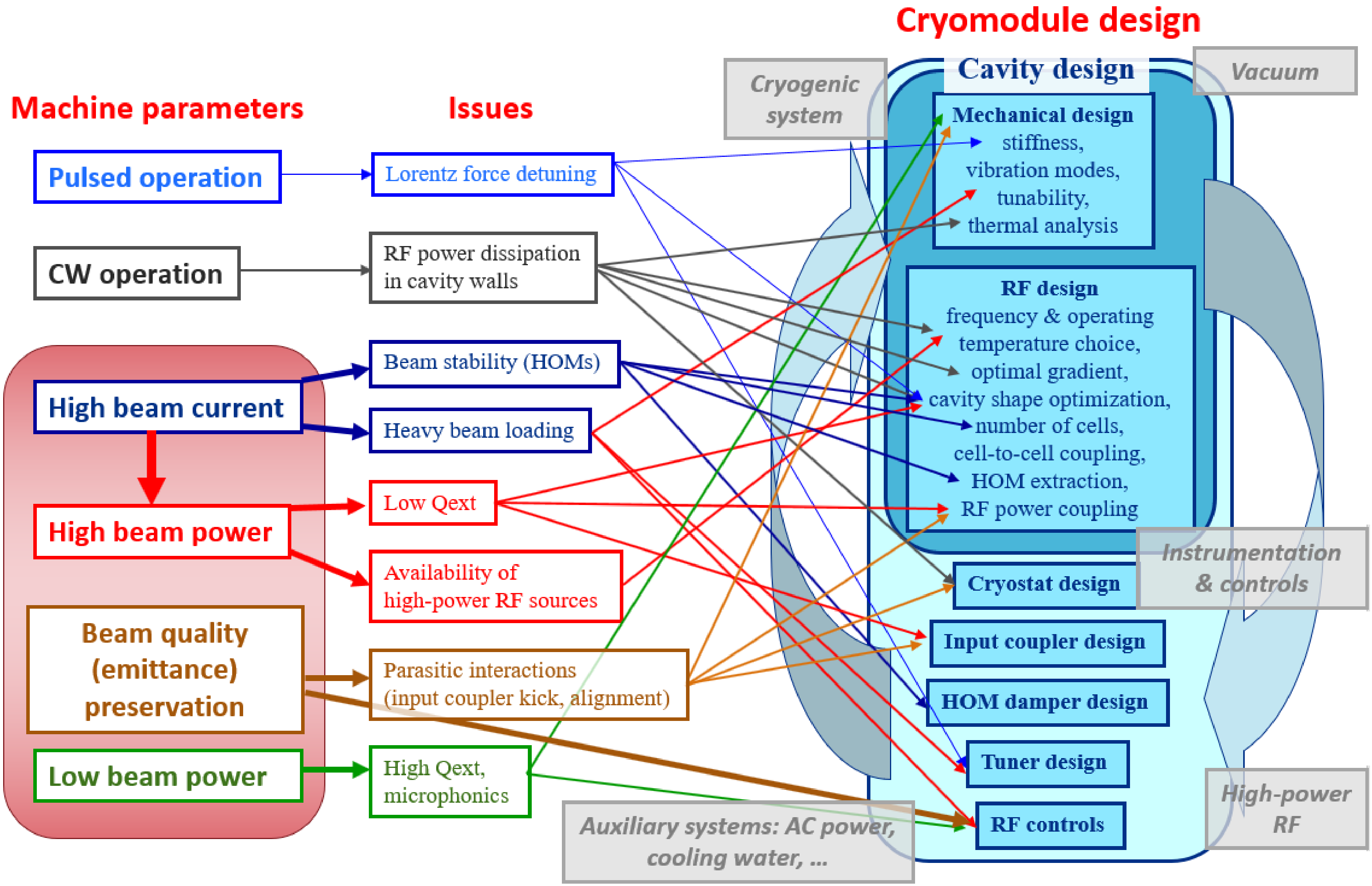
Development of SC accelerating structures

Daily Schedule

	Wednesday	Thusday
9:00-11:30	Th. Nicol, Mechanical Engineering in Superconducting Magnet and RF Cryomodule Design	V. Yakovlev, The fundamentals of large scale linear accelerator engineering
11:30-12:00		**T. Khabiboulline, SRF cavity EM and mechanical design, RF measurements and tuning**
14:00-15:30		Th. Nicol, Mechanical Engineering in Superconducting Magnet and RF Cryomodule Design
15:30-17:00	V. Kashikhin, Conventional, Permanent, and Superconducting Magnets Design	V. Kashikhin, Conventional, Permanent, and Superconducting Magnets Design
19:00-21:00	Study	Study

Fermilab

Development of SC accelerating structures

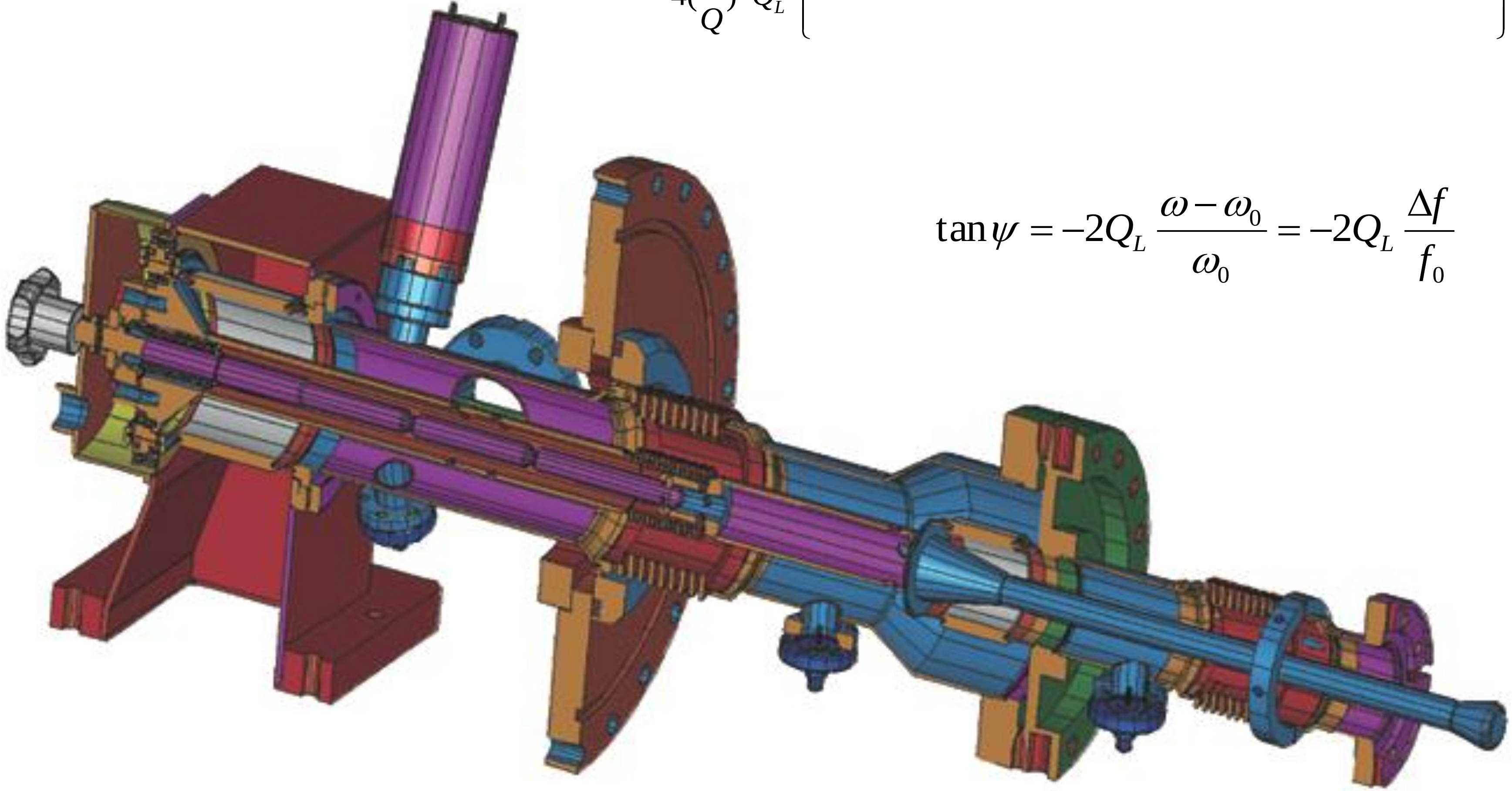


Power coupler design

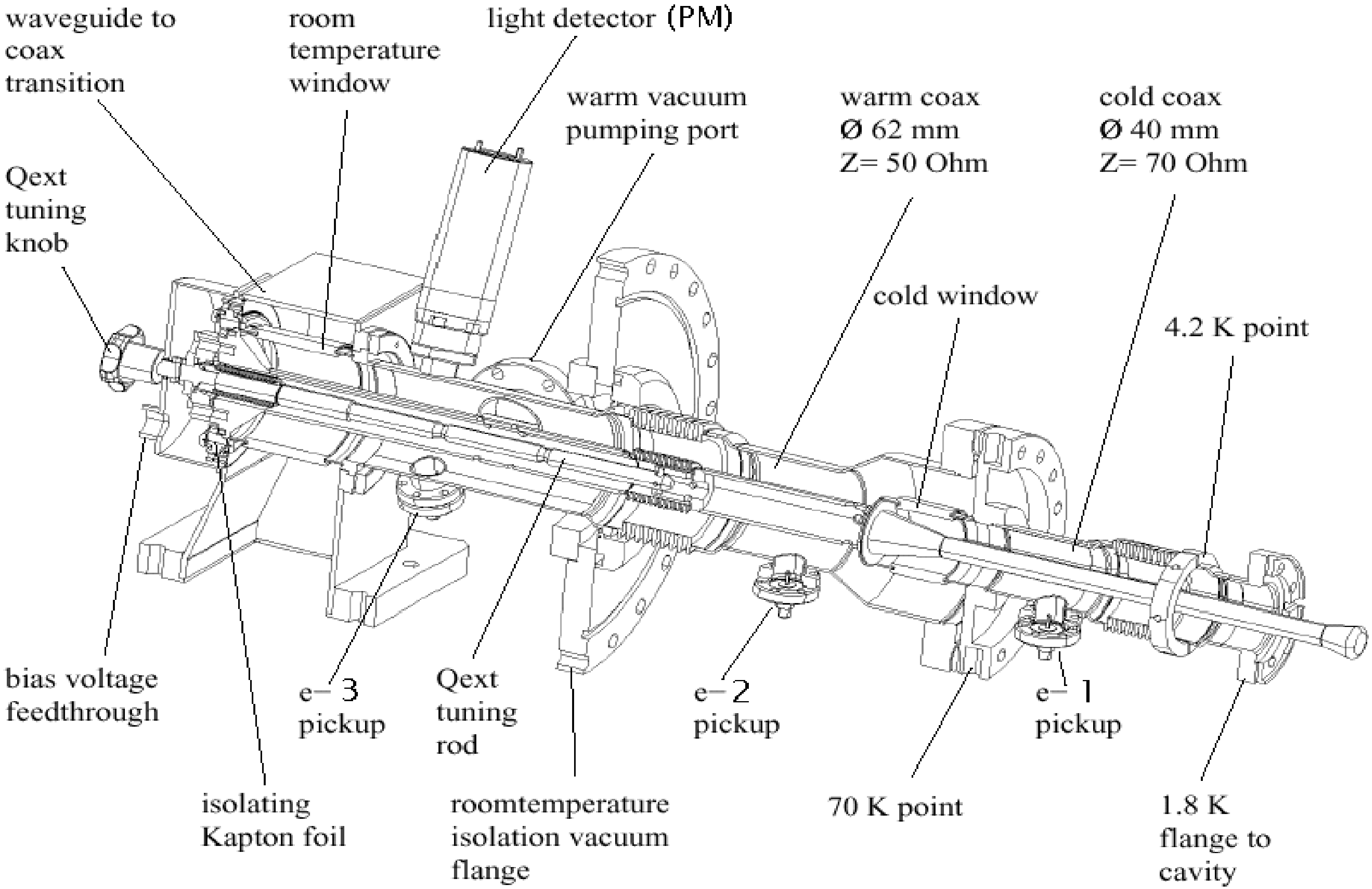
TTF-3 Coupler,
adjustable coupling

$$P_g = \frac{V_{cav}^2}{4(\frac{R}{Q})\cdot Q_L}\left\{(1+\frac{(\frac{R}{Q})\cdot Q_L I_{b0}}{V_{cav}}\cos\phi_b)^2 + (\tan\psi + \frac{(\frac{R}{Q})\cdot Q_L\cdot I_{b0}}{V_{cav}}\sin\phi_b)^2\right\}$$

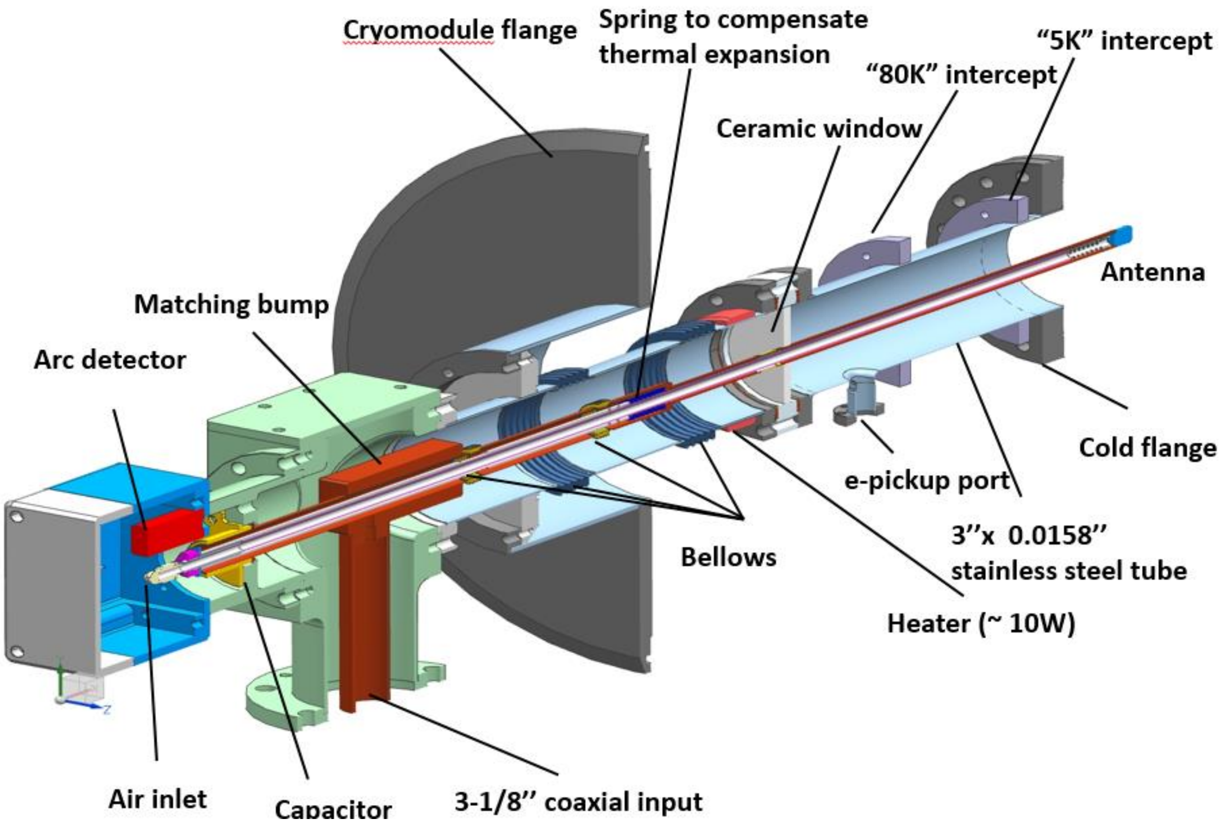
$$\tan\psi = -2Q_L\frac{\omega-\omega_0}{\omega_0} = -2Q_L\frac{\Delta f}{f_0}$$



Power coupler design



325 MHz coupler



Parameter	Value
Frequency	325 MHz
Pass band (S_{11}<0.1)	> 1 MHz
Operating power (CW)	25 kW
HV bias	~ 2 kV

PIP-II SSR cavity, fixed coupling

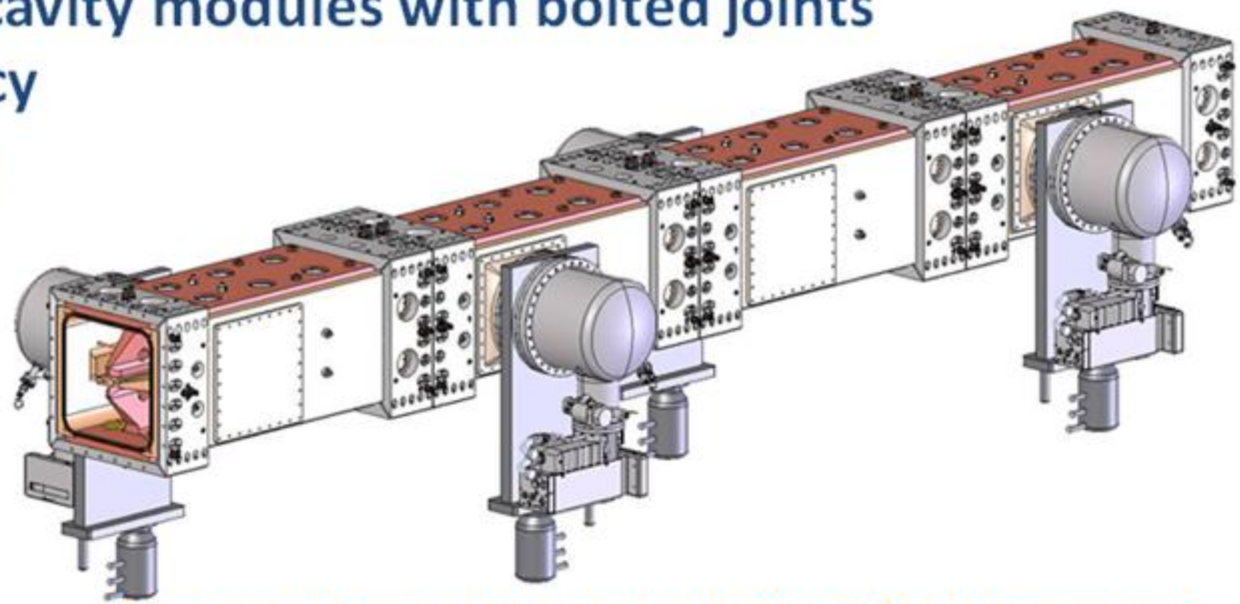
P, kW	2K / Pl, W	15K / Pl, W	125K / Pl, W
0	0.06 / 52	0.58 / 151	2.02 / 40
3	0.10 / 86	0.81 / 211	2.35 / 47
6	0.15 / 129	1.03 / 268	2.68 / 54
20	0.35 / 301	2.07 / 538	4.25 / 85
30	0.50 / 430	2.82 / 733	5.36 / 107

Extra

Bead pull measurements of RFQ

PXIE RFQ Design Features

- All OFHC copper body machined from solid billets
- 4-vane cavity structure with fly cut modulated vane tips
- Four ~ 1.12 m long cavity modules with bolted joints
- 162.5 MHz frequency
- Total length: 4.46 m
- Pi-mode rods for mode stabilization
- Distributed fixed slug tuners

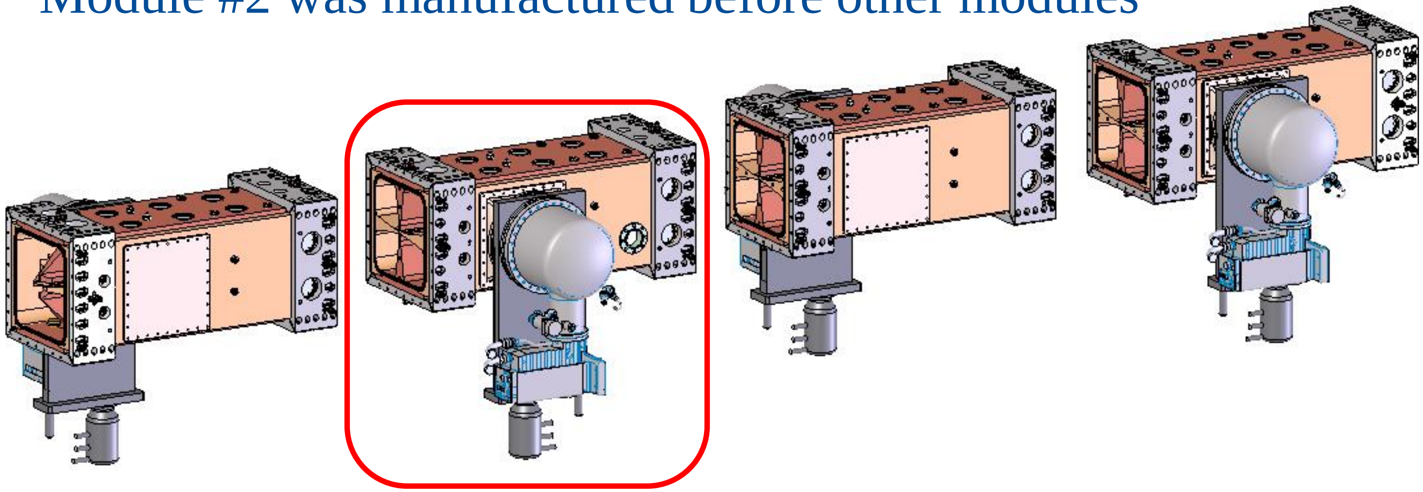


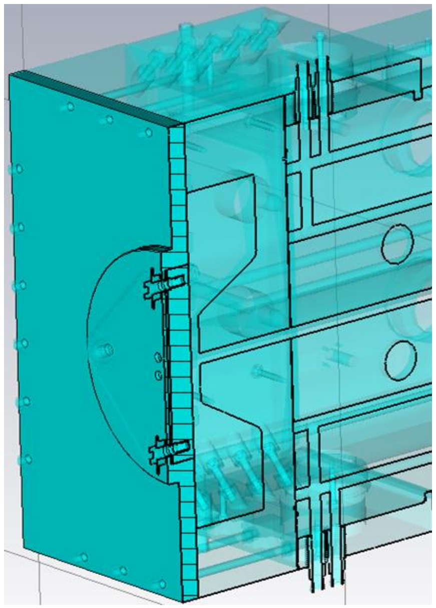
CAD model of assembled 4-module PXIE RFQ design concept

Accelerating H- from 300 keV to 2.1 MeV

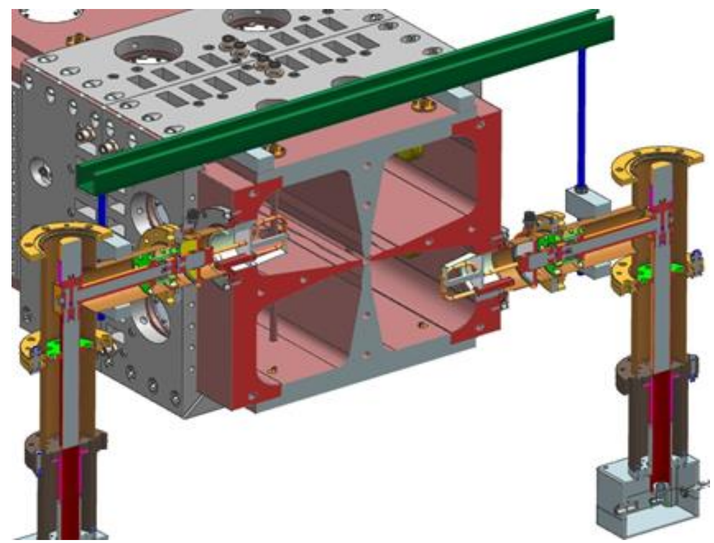
Bead pull measurements of RFQ

Module #2 was manufactured before other modules

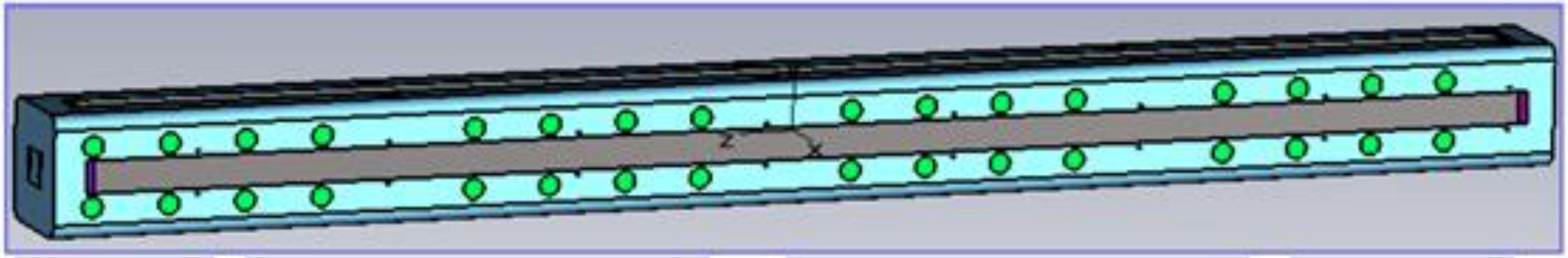


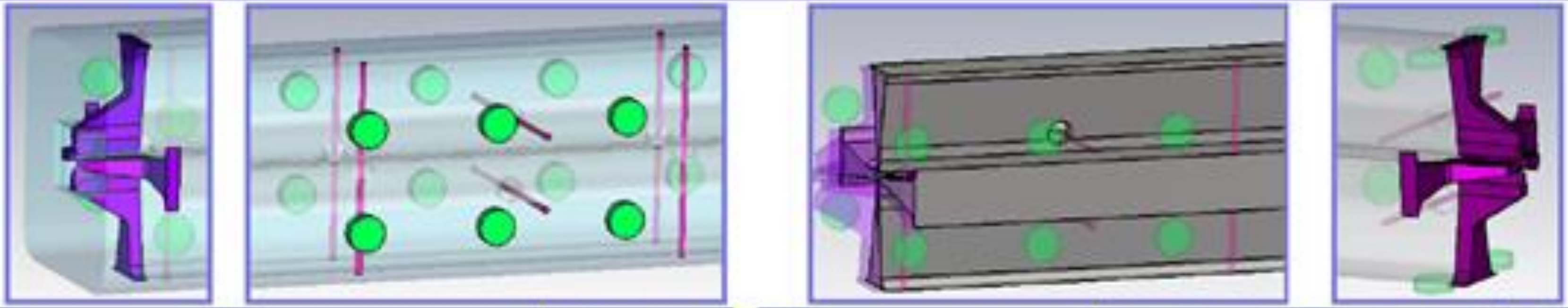


Tuner at one end of the RFQ. 50 mm protrusion, frequency shift is 45 kHz.



Bead pull measurements of RFQ



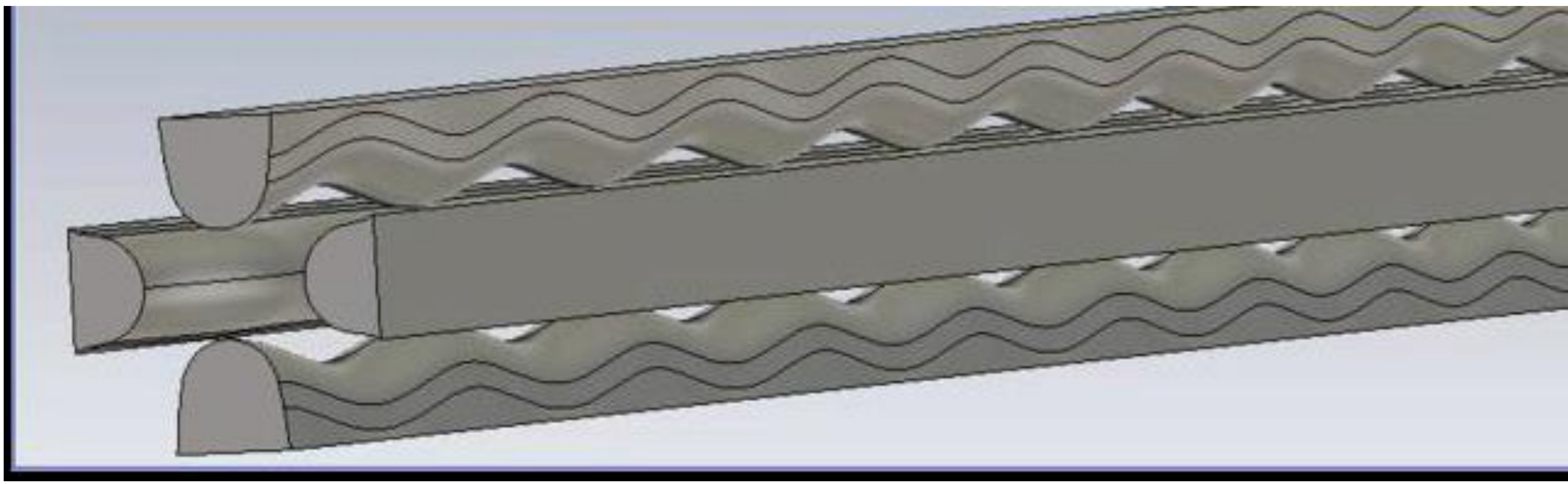


Parameters	PXIE
Frequency, MHz	162.499
Frequency of dipole mode, MHz	181.99
Q factor	14985
Q factor drop due to everything, %	-14.7
Power loss per cut-back, W (In/Out)	336/389
Total power loss, kW	73.8
L_max, mm	172.73

Part	Total, kW	Per unit, W	%
Walls	29.5	-	40
Vanes	31	7764	42
Input cut-backs	1.34	336	1.8
Output cut-backs	1.56	389	2.1
Pi-mode rods	5.53	173	7.5
Tuners	4.79	59.9	6.5

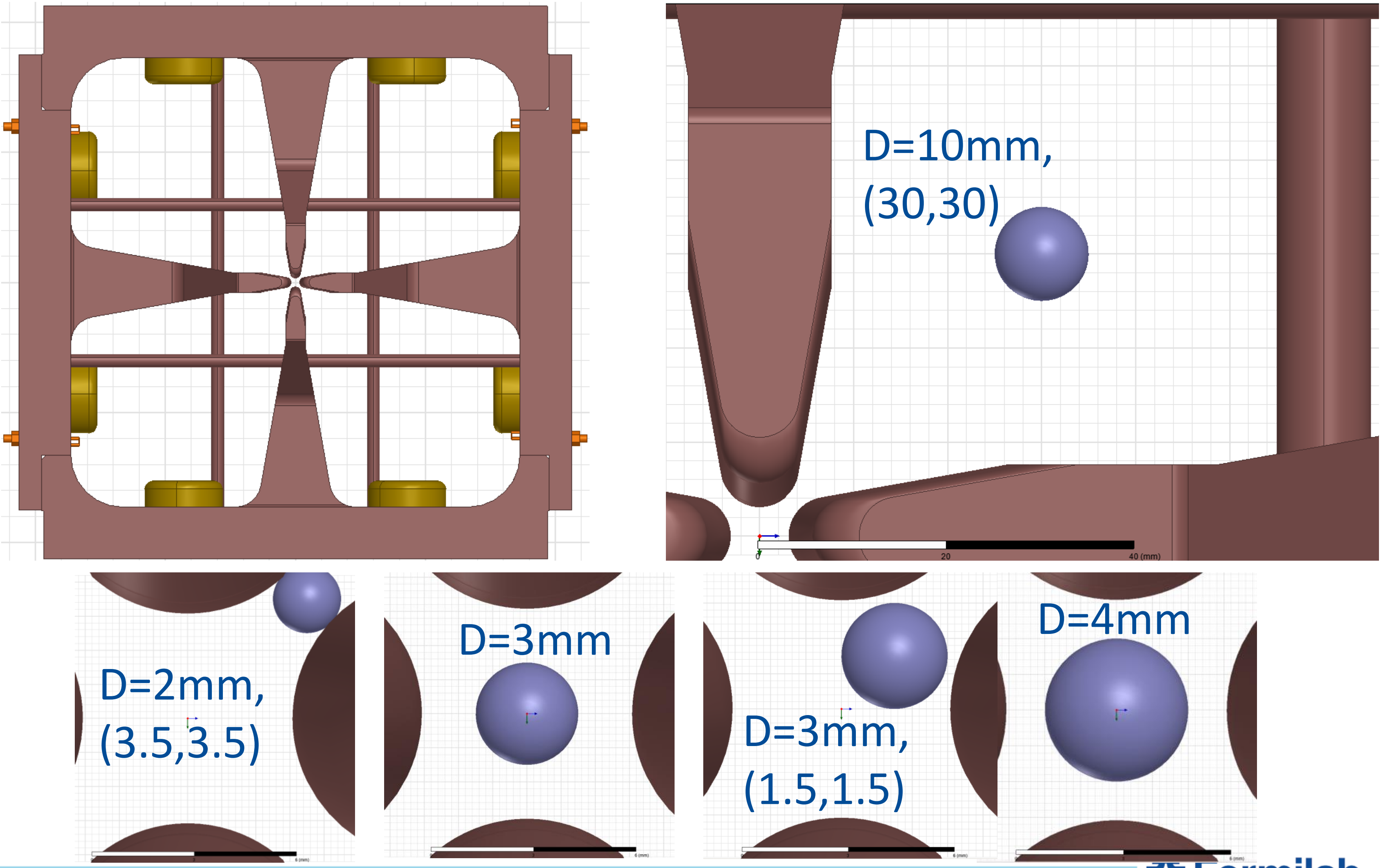
Bead pull measurements of RFQ

Sweeping vane tip profile along modulation curve.

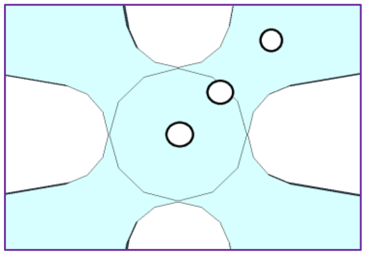


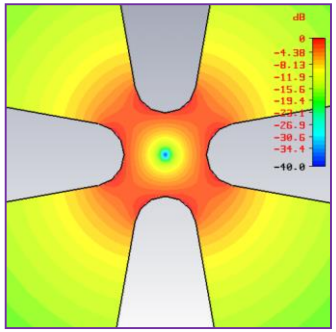
Complete vane tip solid models.

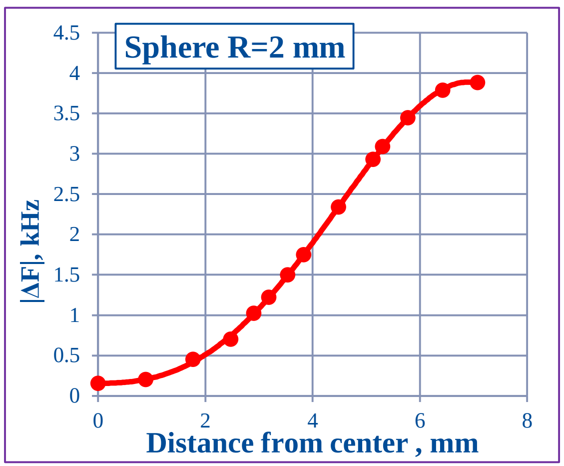
Bead pull measurements of RFQ



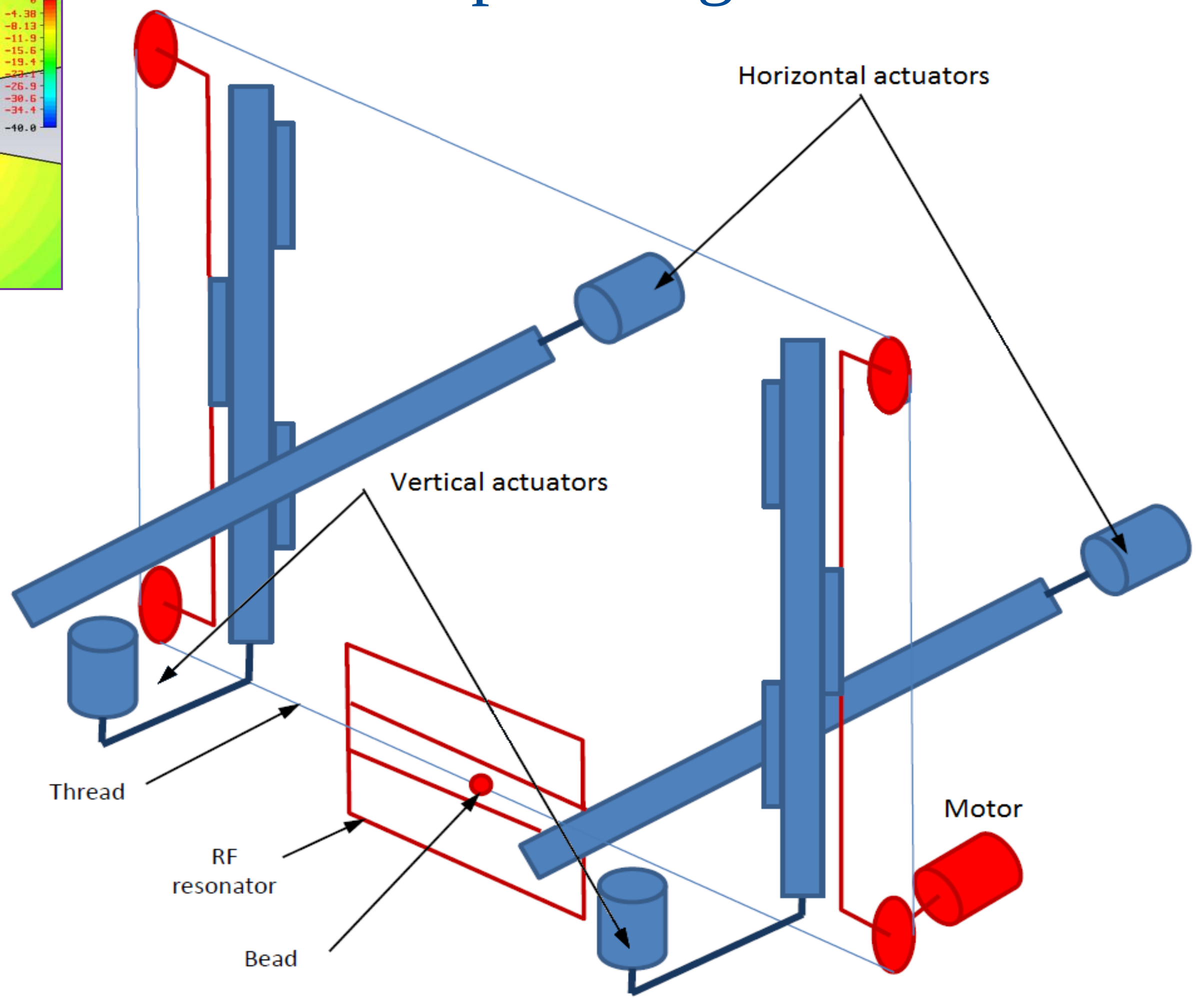
Bead pull measurements of RFQ







Bead pull diagram



Bead pull measurements of RFQ

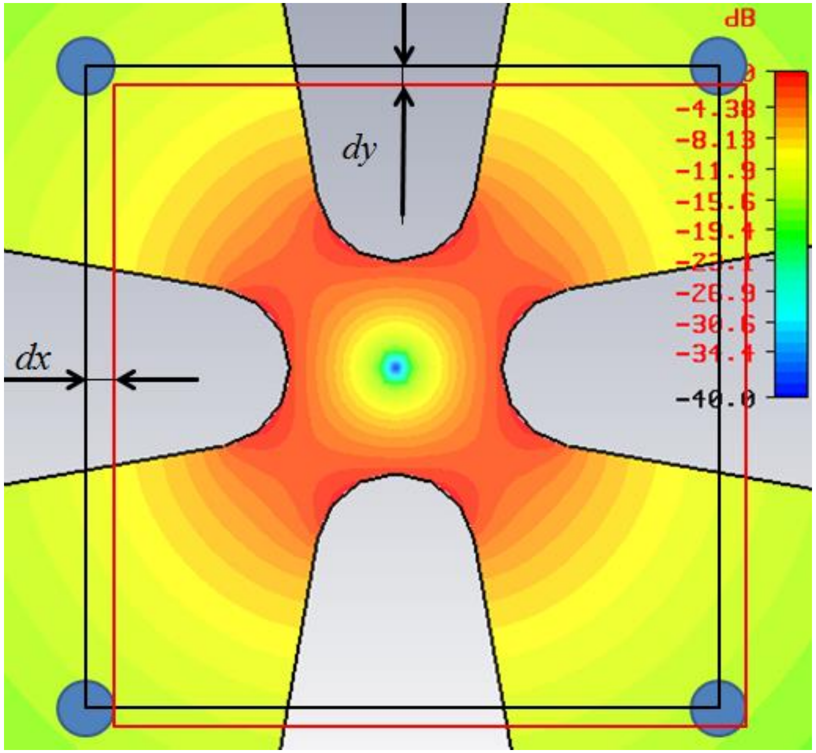
Positioning error can be compensated by averaging of measurements in all 4 quadrants

$$df\,(x+dx,y+dy)\approx c\cdot f(x,y)+\alpha(x,y)\cdot dx+\beta(x,y)\cdot dy$$

$$x=y\Rightarrow\alpha(x,y)=\beta(x,y)$$

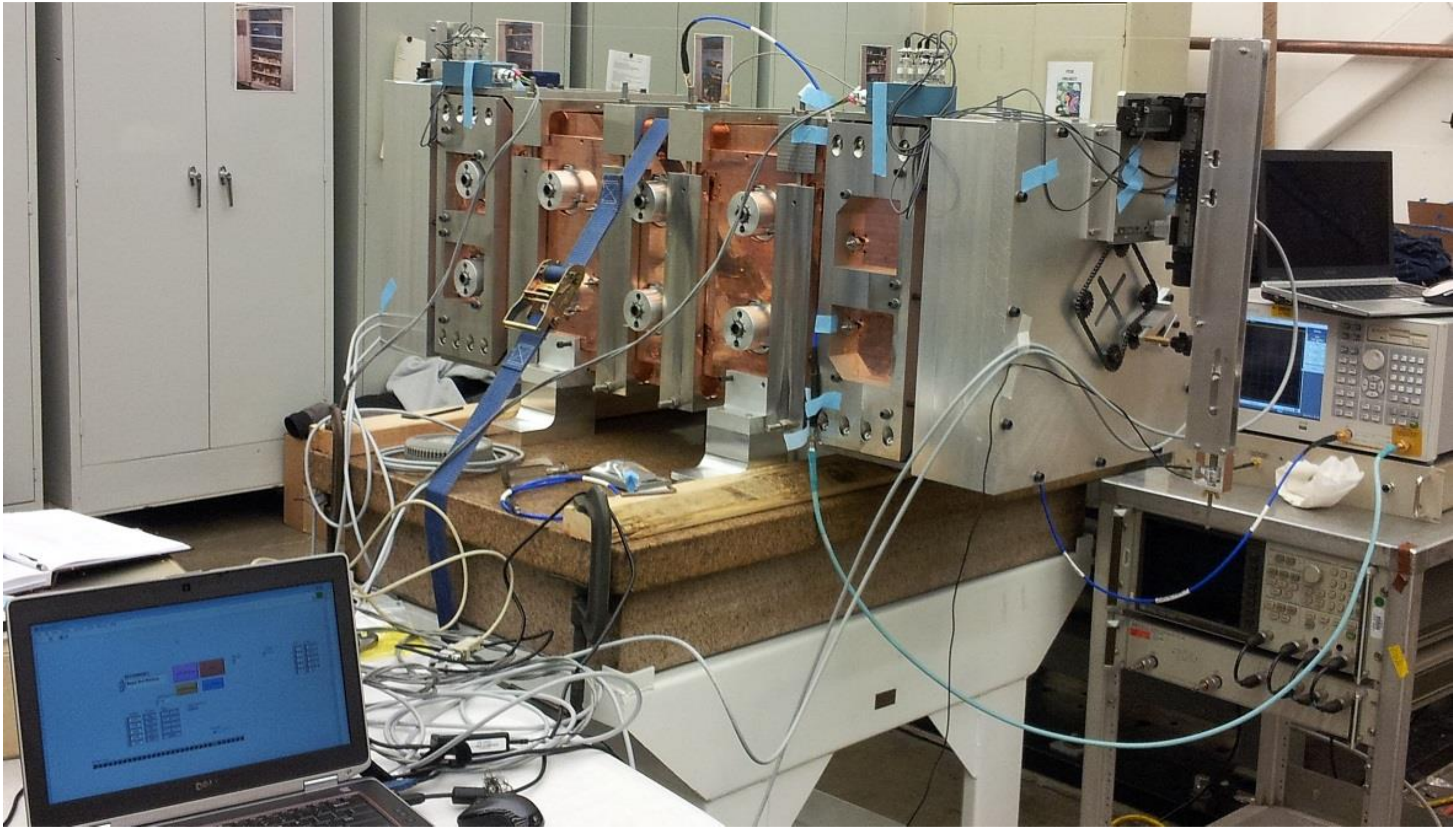
$$\alpha(-x,y)=-\alpha(x,y);\alpha(x,-y)=-\alpha(x,y)$$

$$\beta(-x,y)=-\beta(x,y);\beta(x,-y)=-\beta(x,y)$$



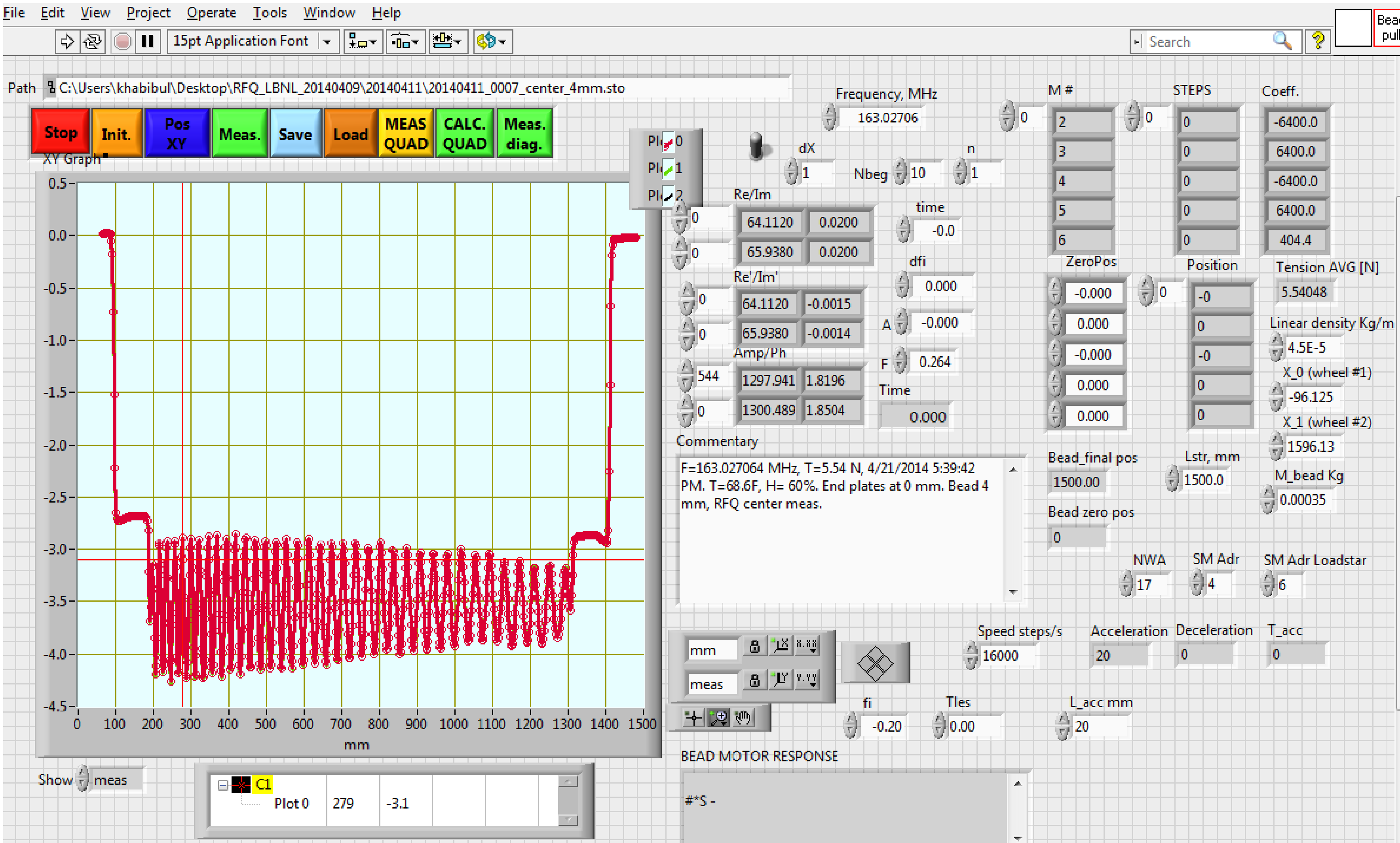
$$df\,(x+dx,y+dy)+df\,(-x+dx,y+dy)+$$
$$df\,(x+dx,-y+dy)+df\,(-x+dx,-y+dy)\approx 4c\cdot f(x,y)$$

Bead pull measurements of RFQ



Bead-pull setup on RFQ Module #2

Bead pull measurements of RFQ

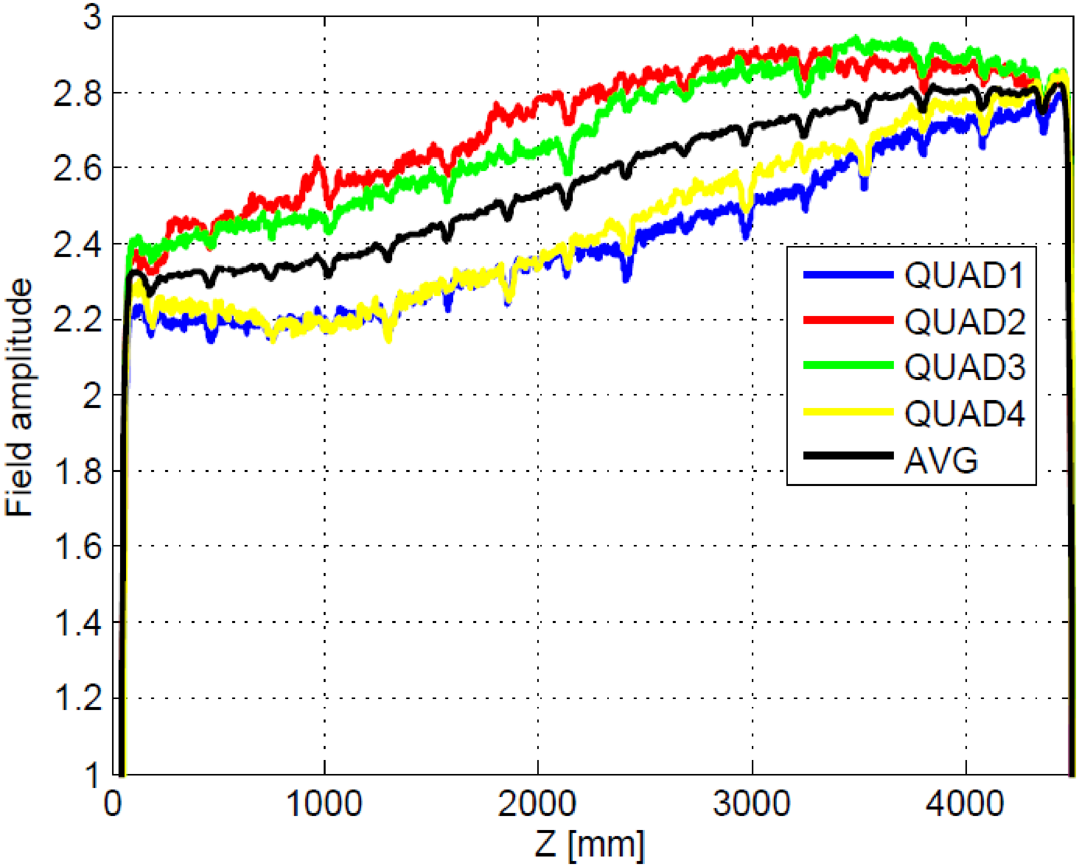


Program allow to position bead in any location near cavity center and measure field flatness. Multiple passes and post processing is included.

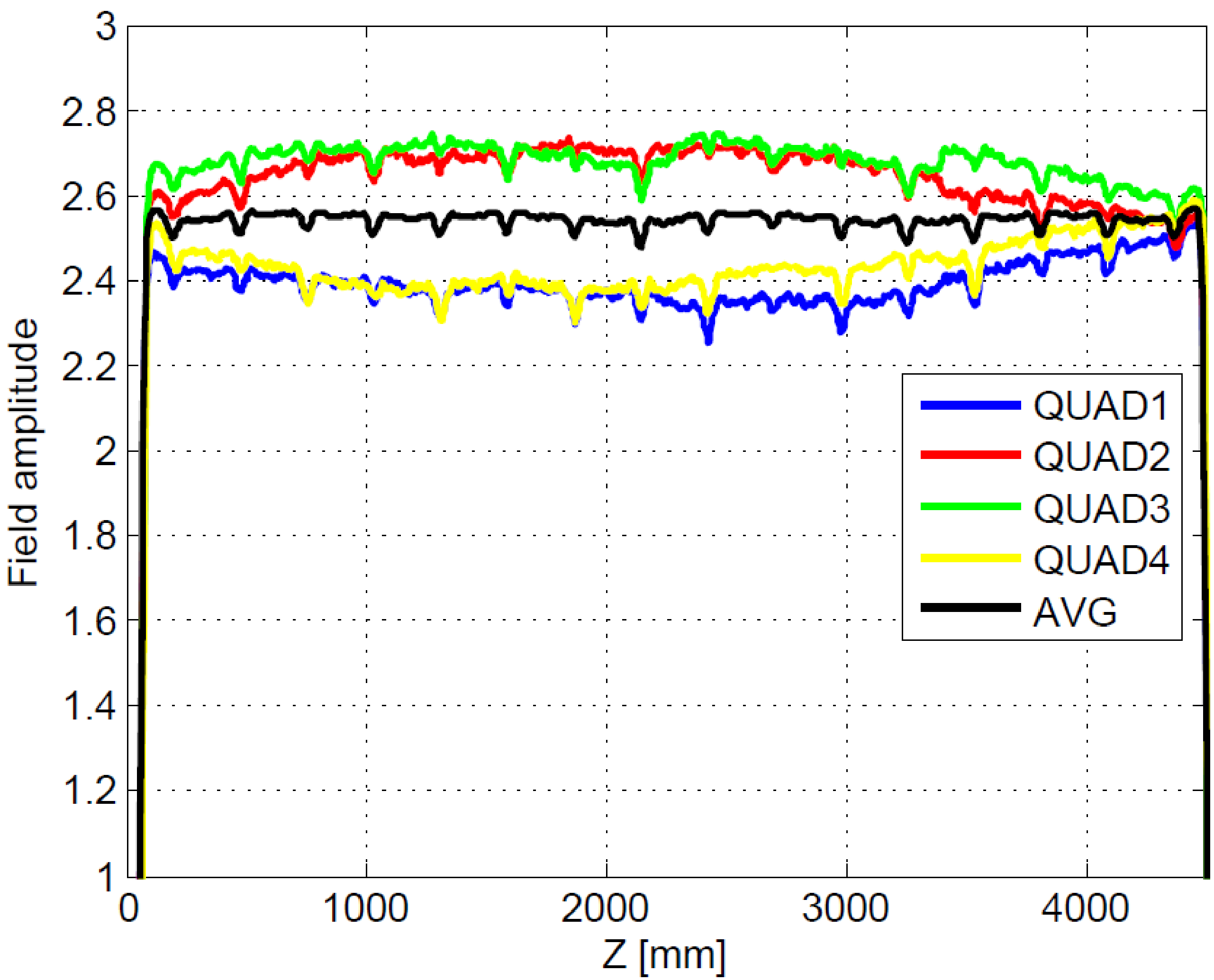
Bead pull measurements of RFQ

- Quadrant measurements: single quadrants 1 to 4 and average filed amplitude along RFQ length @ 30 mm radial offset.

- First bead pull measurement before tuning, FF approximately 80% for avg.



Bead pull measurements of RFQ



- After final FF tuning: Freq= 162.443 MHz FF=98%

Bead pull measurements of RFQ