CrYogenic Brightness-Optimized Radiofrequency Gun (CYBORG)

HG2022

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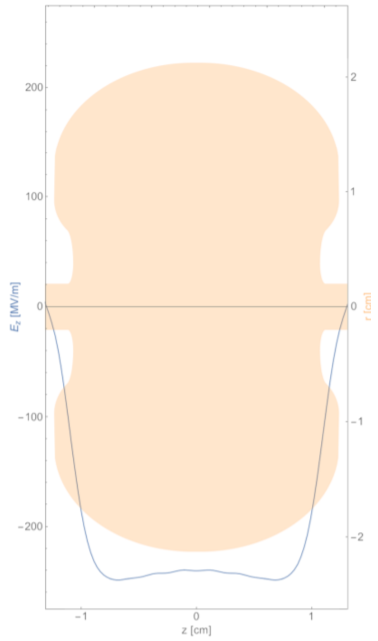
Outline of presentation

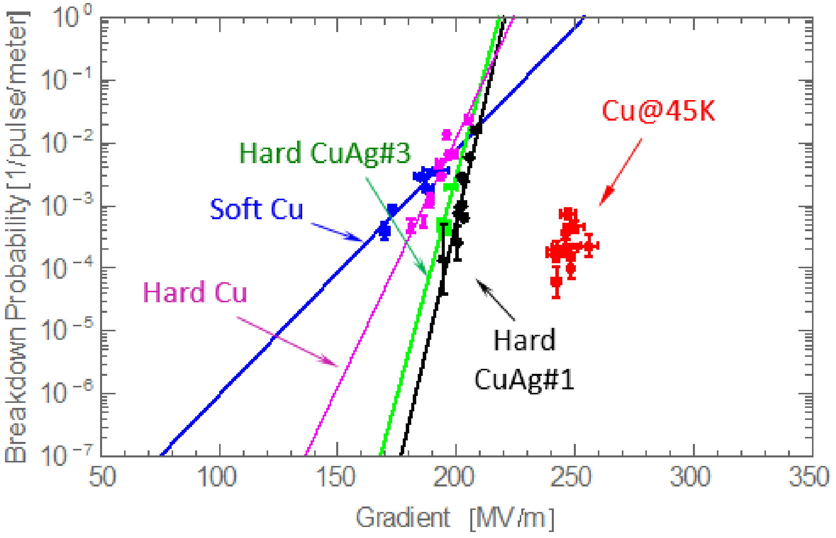
1. Background & motivations
2. CYBORG Design
3. Fabrication status & LLRF
4. Future Steps
5. Conclusions

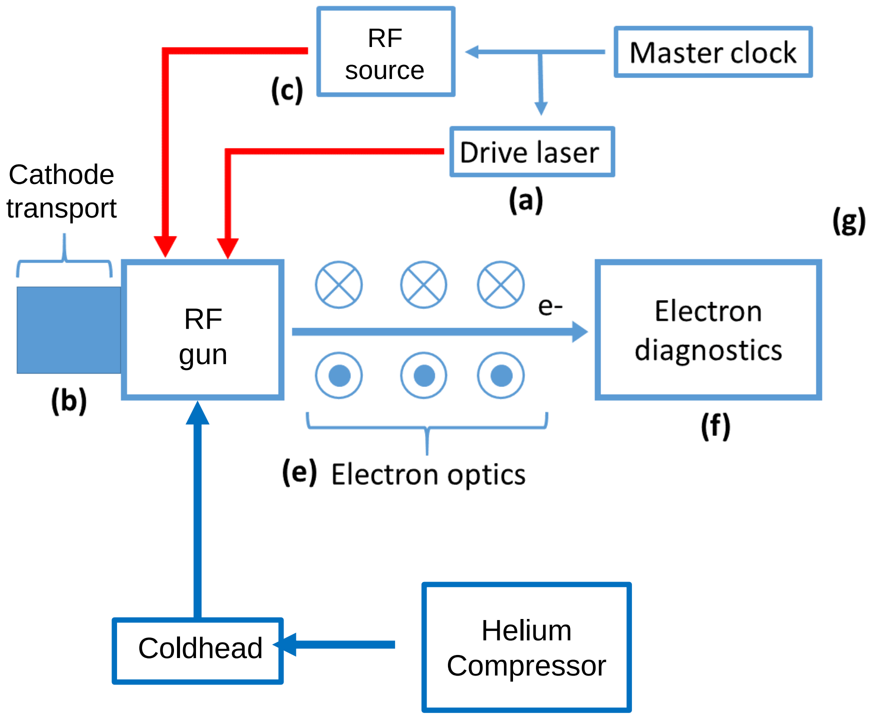
1) CYBORG Functions

1. Cavity fabrication & structure test
2. Infrastructure development
3. Low temperature emission/photocathode test bed



RR Robles et al. *Physical Review Accelerators and Beams* 24 (6), 063401

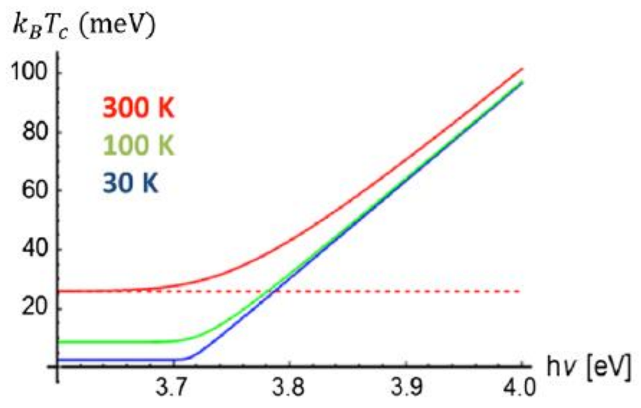


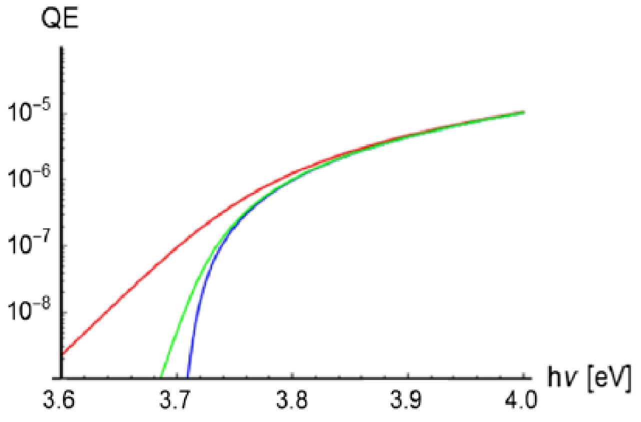


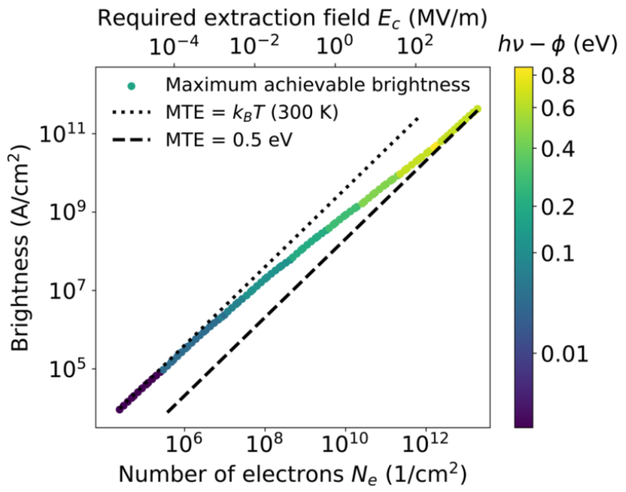
1) CYBORG Functions (2)

- Collaboration within NSF Center for Bright Beams
- Low temperature at increases launch field and decreases cathode mean transverse energy but also QE
- Test bed for cathodes cold & high field environment

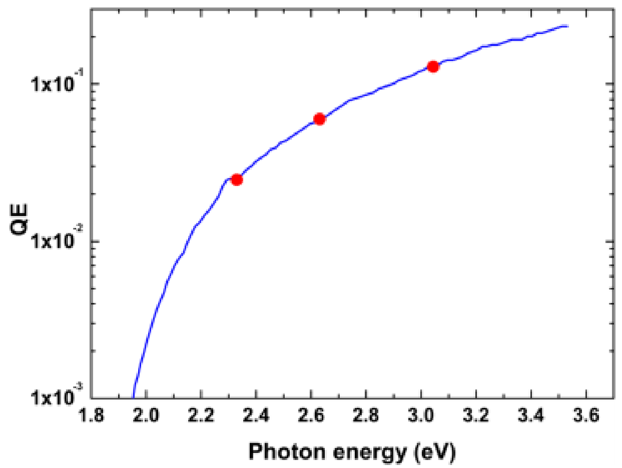
$$B_{e,b} \approx \frac{2ec\varepsilon_0}{k_B T_c}\left(E_0 \sin\varphi_0\right)^2$$







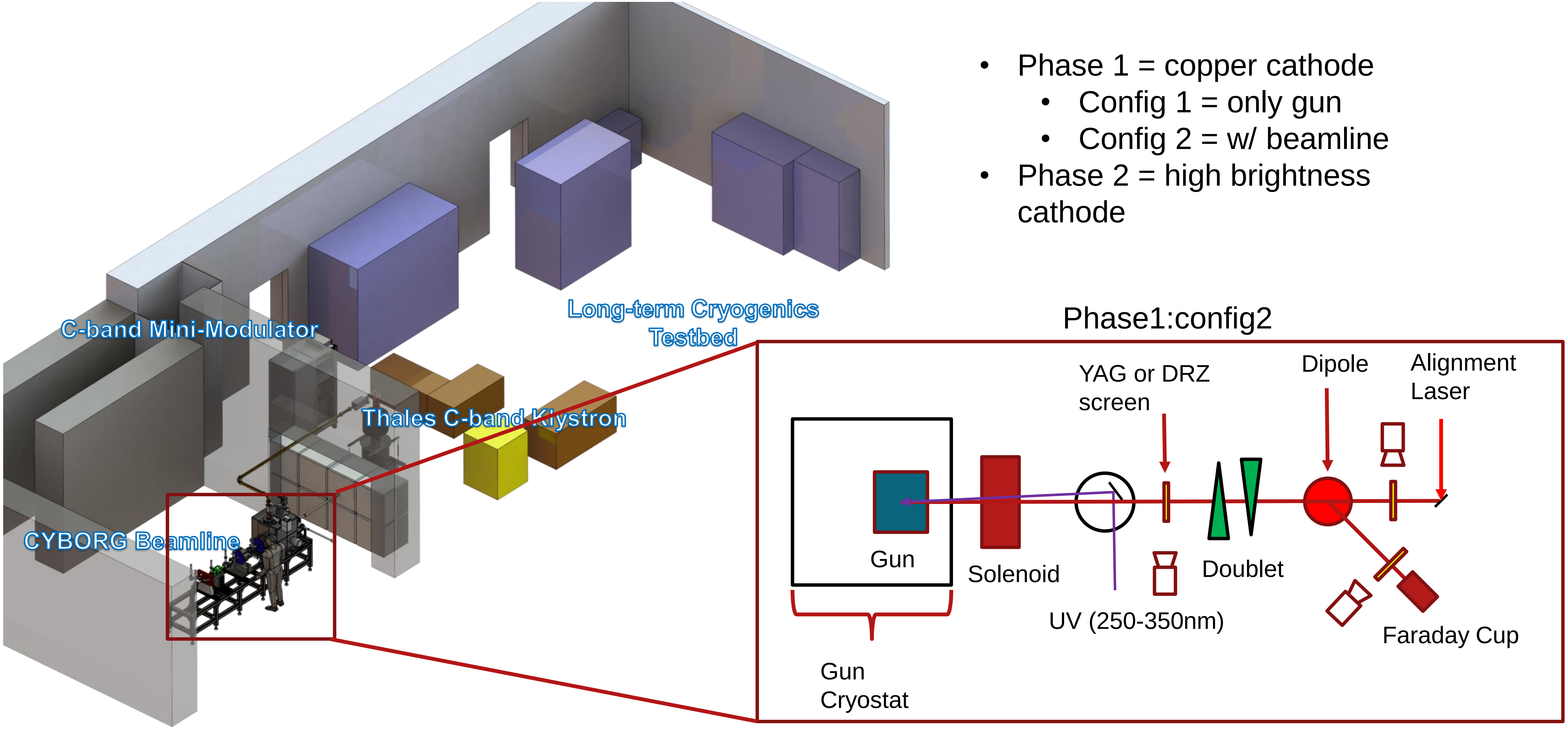
J. K. Bae, I. Bazarov, P. Musumeci, S. Karkare, H. Padmore, and J. Maxson, J. Appl. Phys. 124, 244903 (2018).



L. Cultrera et al., Appl. Phys. Lett. 103, 103504 (2013).

1) Beamline development phases

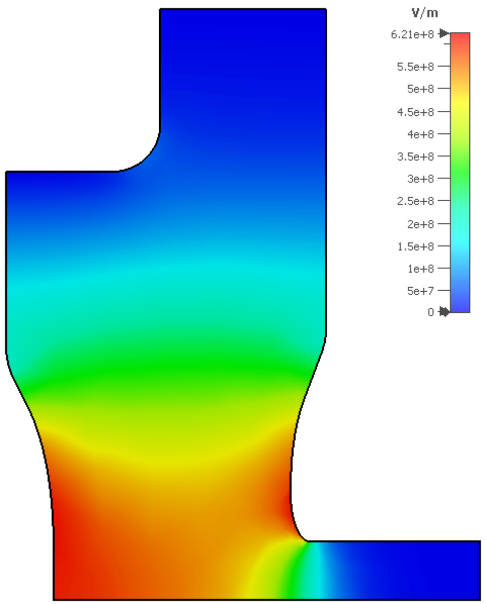
- Phase 1 = copper cathode
  - Config 1 = only gun
  - Config 2 = w/ beamline
- Phase 2 = high brightness cathode



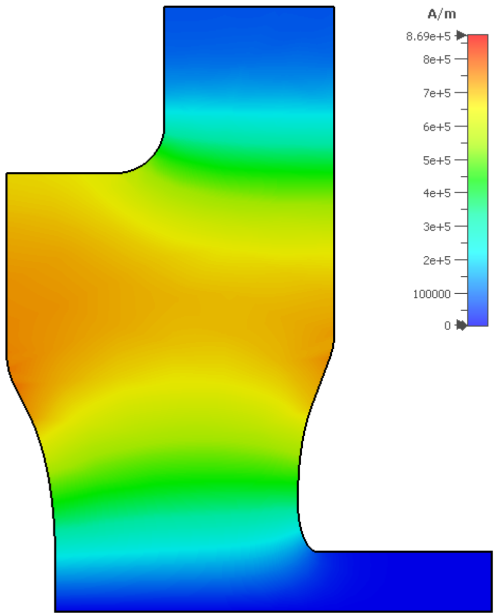
2) RF Design Parameters

- Reentrant cavity with high shunt impedance
- Peak electric field around cathode surface

E field magnitude



H field magnitude



Parameter	295K	77K	45K
Launch field	-	120 MV/m	120 MV/m
Frequency	5.695 GHz	5.712 GHz	5.713 GHz
β	0.7	4	5.3
Q0	8579	23000	38000
Filling time	-	0.26 us	0.3 us
RF Power requirement	-	0.52 MW	0.48 MW
Energy deposition	-	0.17 J/pulse	0.1 J/pulse

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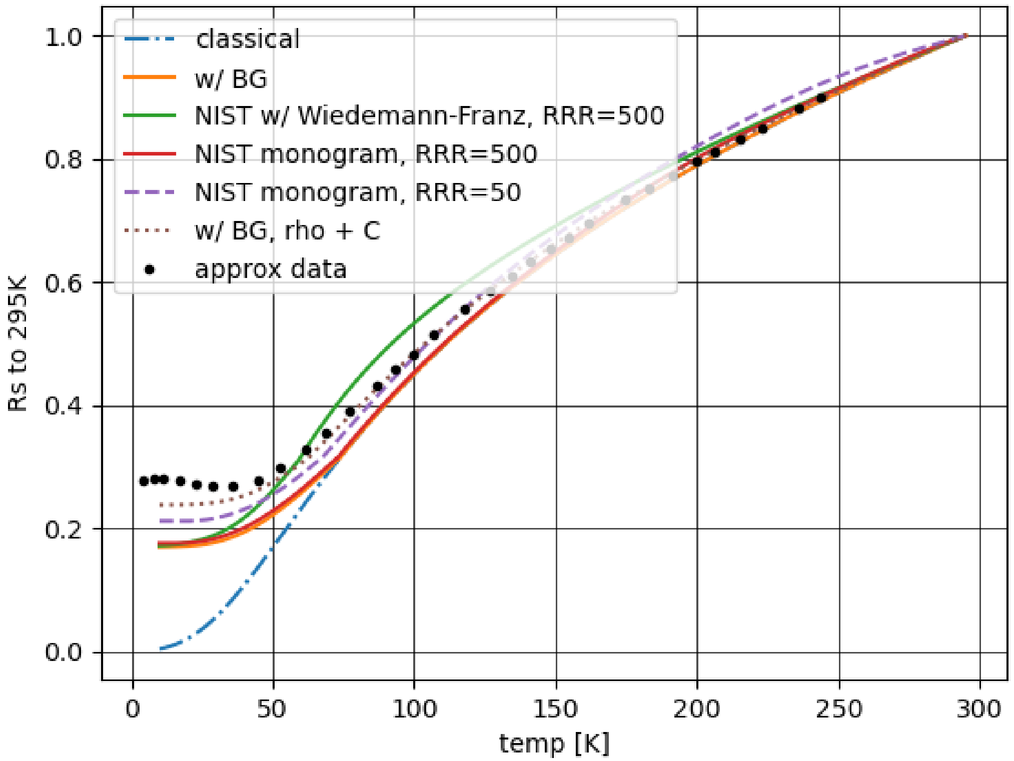

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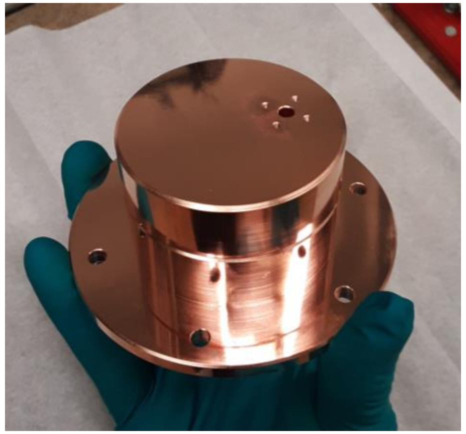
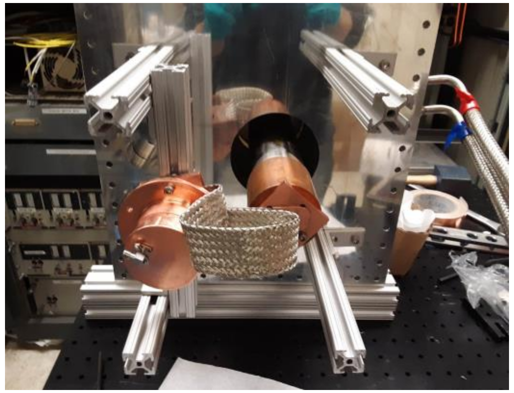
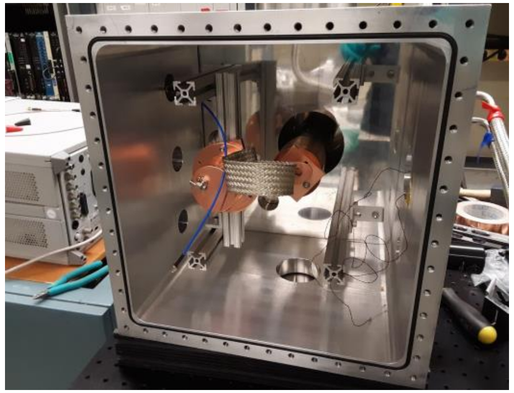
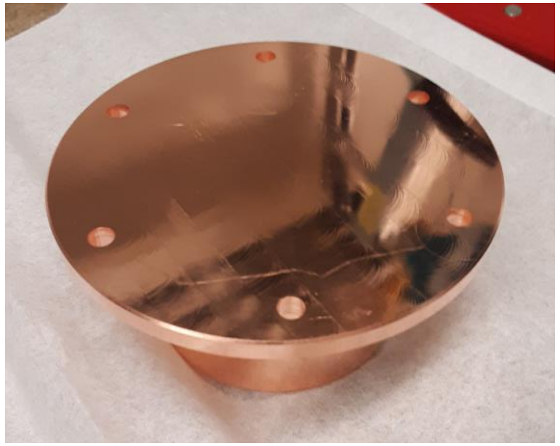
3a) LLRF Measurements

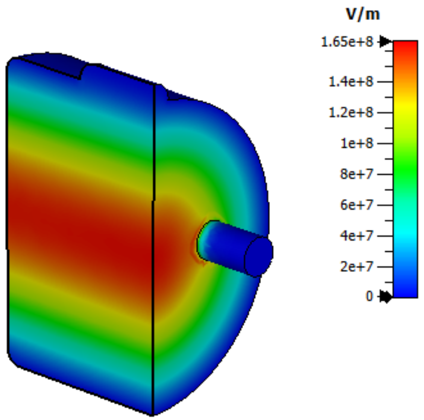
- Copper pillbox cavities used for Cband low level LLRF

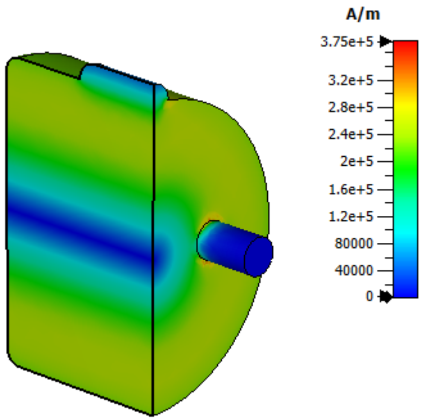






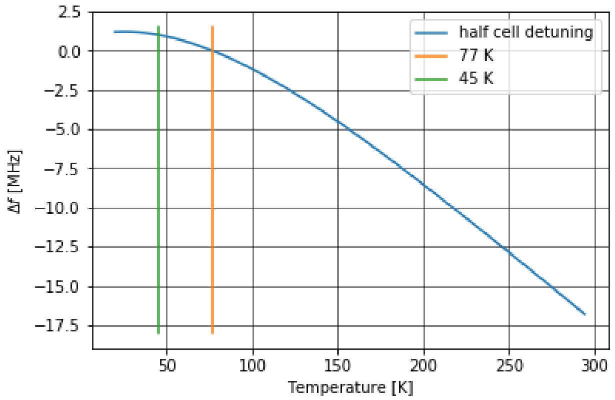




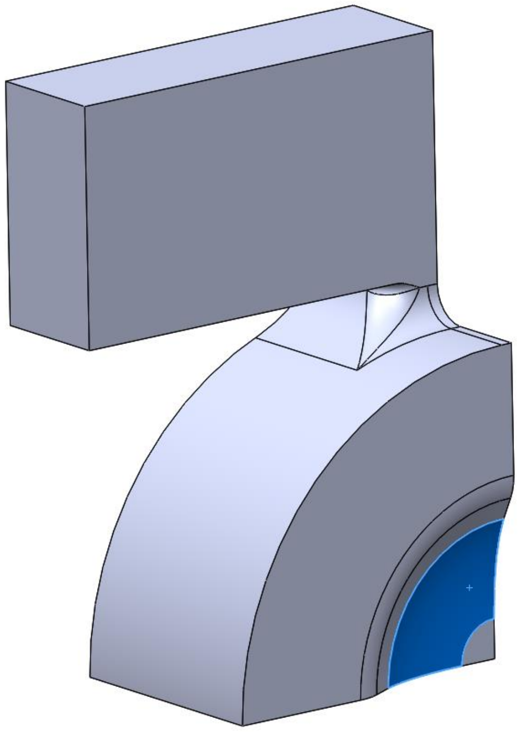


2) Surface Sensitivity

- Cryogenic temperature provides additional RF stability
- Slater perturbation theory gives frequency change from small displacement of one surface
- Default 10 um
- For surfaces of high field tolerance reduced to 5 um (detuning > ≈ |0.2| MHz w/ 10 um perturbation, most |10s| kHz)
- Adding in quadrature leads to 1.6 MHz from following

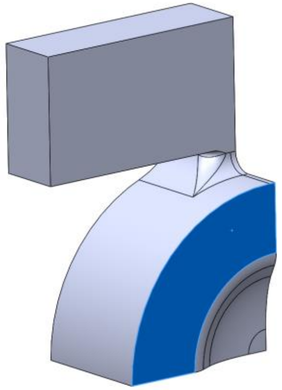


$$\Delta f_i = \Delta s_i \frac{f_0}{4U} \int_{S_i} \left(\mu \left|H_0\right|^2 - \epsilon \left|E_0\right|^2\right) dS$$



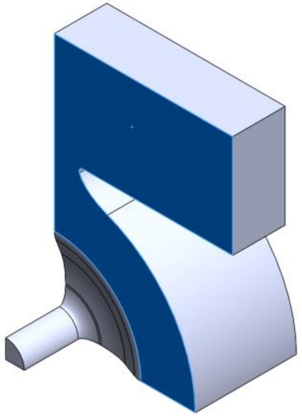
area [mm^2]	tolerance [μm]	detuning [MHz]
195	5	−0.779

2) Surface Sensitivity



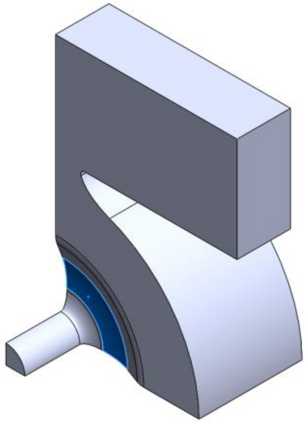
area [mm^2]
720

tolerance [μm]	detuning [MHz]
5	0.648



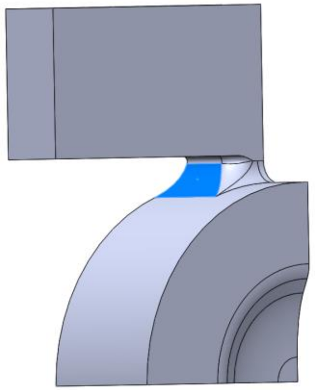
area [mm^2]
2006

tolerance [μm]	detuning [MHz]
5	0.643



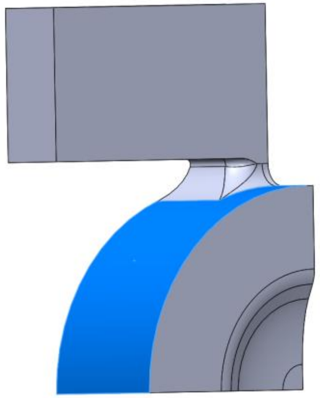
area [mm^2]
158

tolerance [μm]	detuning [MHz]
5	-0.533



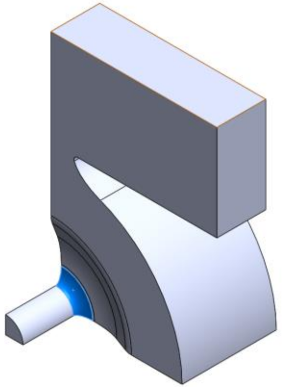
area [mm^2]
136

tolerance [μm]	detuning [MHz]
5	0.196



area [mm^2]
1301

tolerance [μm]	detuning [MHz]
5	1.21

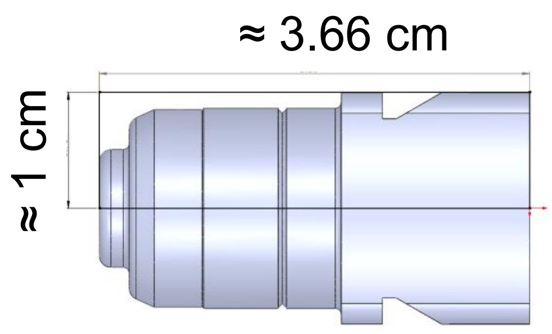


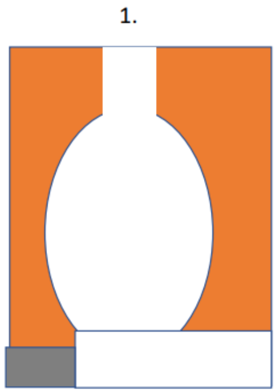
area [mm^2]
49.1

tolerance [μm]	detuning [MHz]
5	-0.261

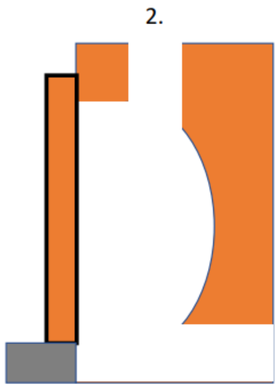
2) Cathode Interface

- Forward compatibility needed for INFN style mini puck, etc.
- For phase 1 of test bed, CF flange sealed off w/ blank from back of cavity and test copper cathode

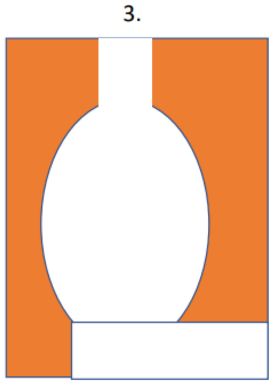




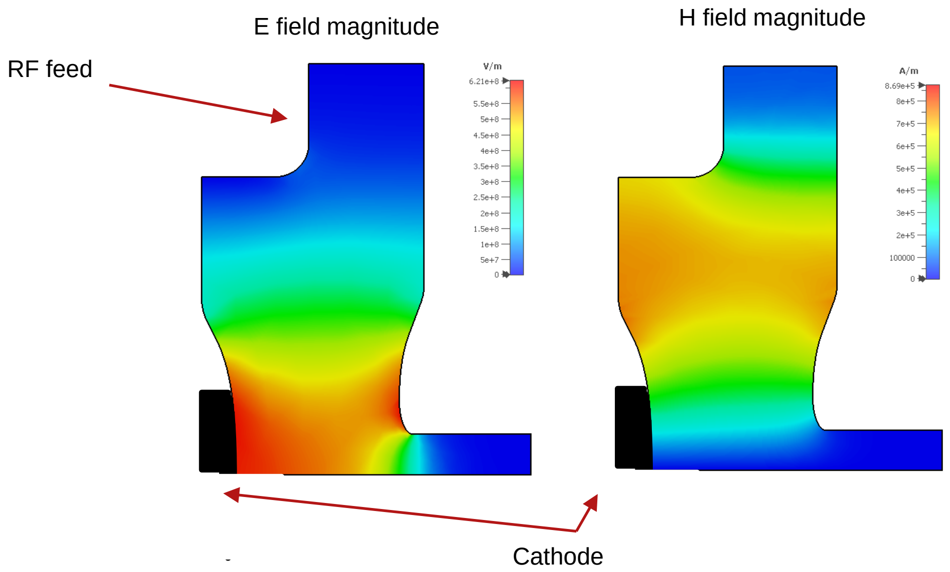
- Plug directly into cavity
- Useful for 1.6 cell to max gradient



- Good for cathode tests
- High gradient (120 MV/m) but lower than plug alone

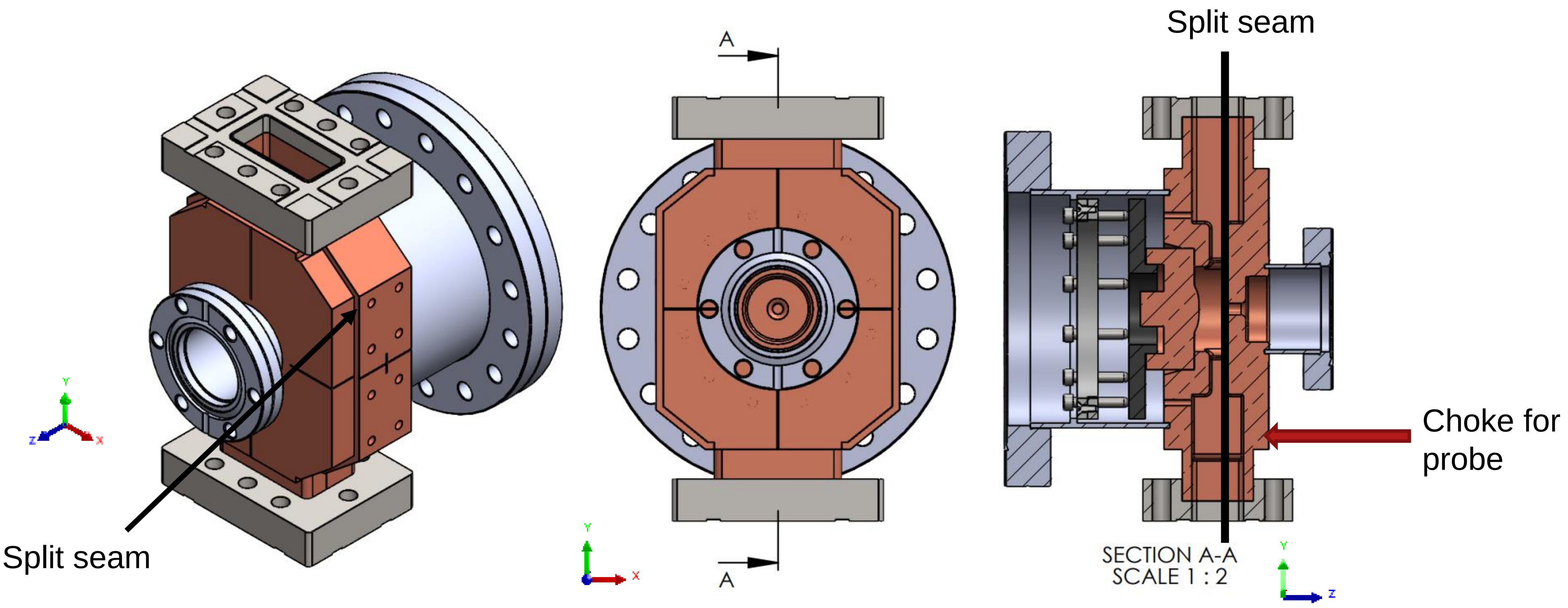


- No cathode exchange
- Highest achievable gradients



2) Drawings

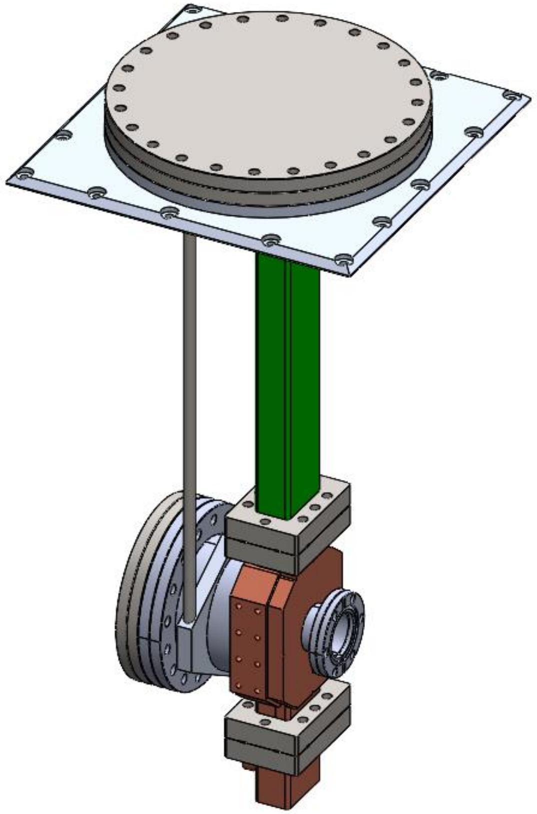
- Split seam for brazing necessitated by tolerance location
- Drawings with fully removable backplane based on FERMI gun design

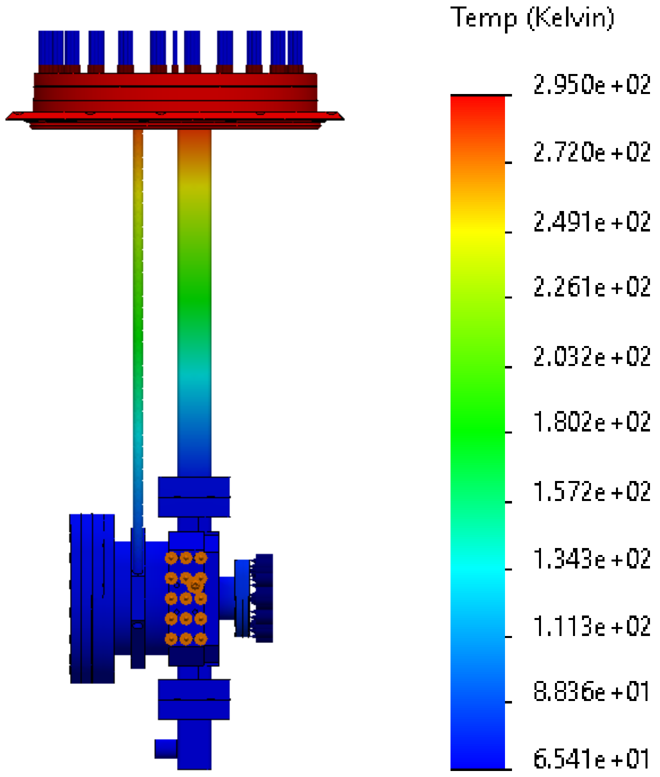


2) Steady State Thermal Sim

- Steady state thermal simulation results w/ 15W cooling from press fit with 3W heat leak budget

Description	Materials	Equivalent Area	Equivalent Power @ 65K	Equivalent Power @ 45K
Downstream CF flange	stainless, edge welded bellows	85 mm^2	4.8 W	5.2 W
Waveguide	Stainless	588 mm^2	6.6 W	7.1 W
Supports	Stainless + 2” G10	TBD	0.6 W	0.8 W
Diagnostic probes	Copper wiring	1.6 mm^2	≈ 0.1 W	≈ 0.1 W
Radiation	-	25000 mm^2	< 0.1 W	< 0.1 W
Pumping on dummy side	TBD	TBD	TBD	TBD
Upstream load lock	TBD	TBD	TBD	TBD
1Hz pulse heating	-	TBD	≈ 0.1 W	≈ 0.1 W





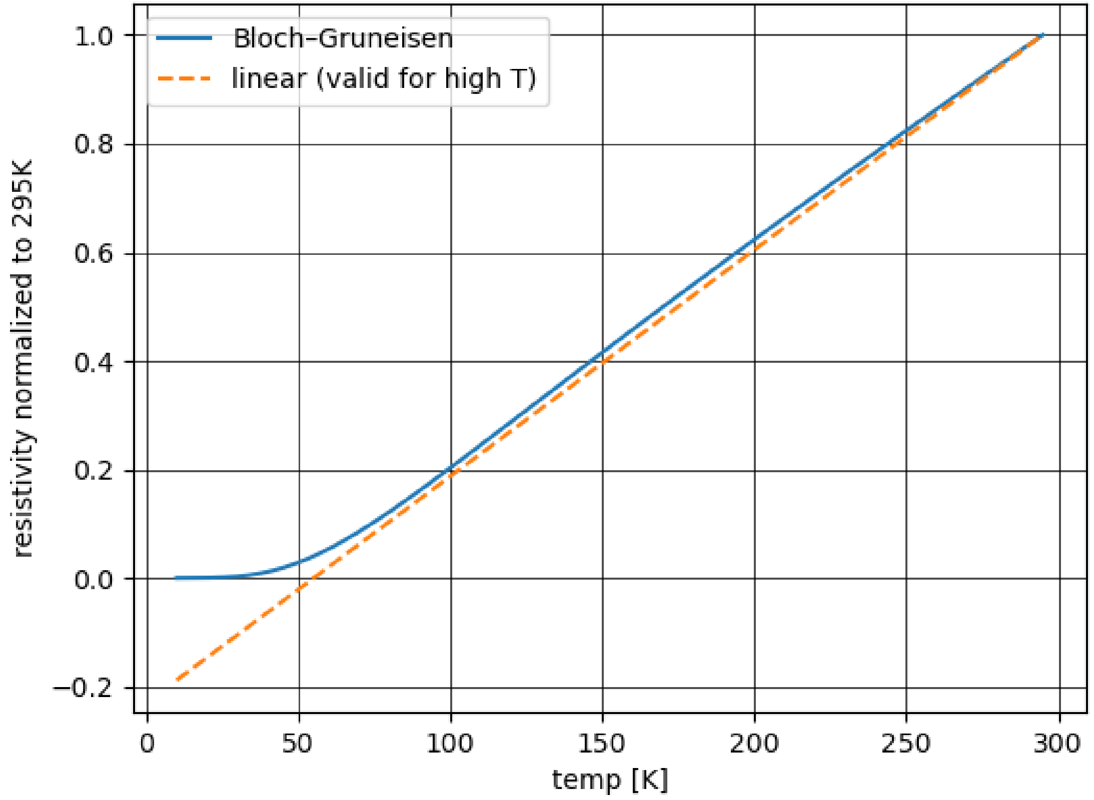
3) Pulse Heating

- Application to cryogenics worth working through similar RF pulsed heating calculation from Pritzkau (below)
- valid for linear bulk resistivity (also below)
  - Pritzkau linear model used for dashed curve previously (right)

$$\rho_{res}(T) = 7.012 \times 10^{-11} T - 3.865 \times 10^{-9}\ (\Omega \cdot \mathrm{m}), \qquad 273\mathrm{K} \leq T \leq 800\mathrm{K}$$

- bulk electric resistivity as function of temperature based on phonon model

$$\rho(T) = A\left(\frac{T}{\Theta_R}\right)^n \int_0^{\Theta_R/T} \frac{t^n}{(e^t - 1)(1 - e^{-t})} dt$$



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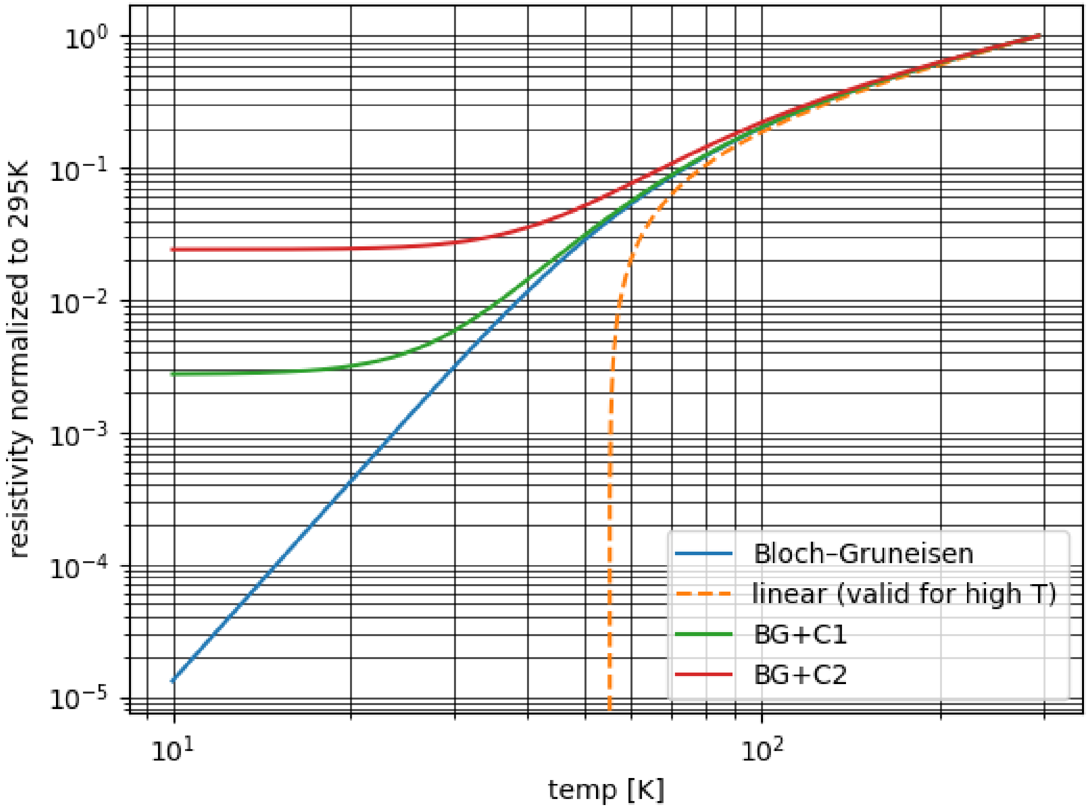
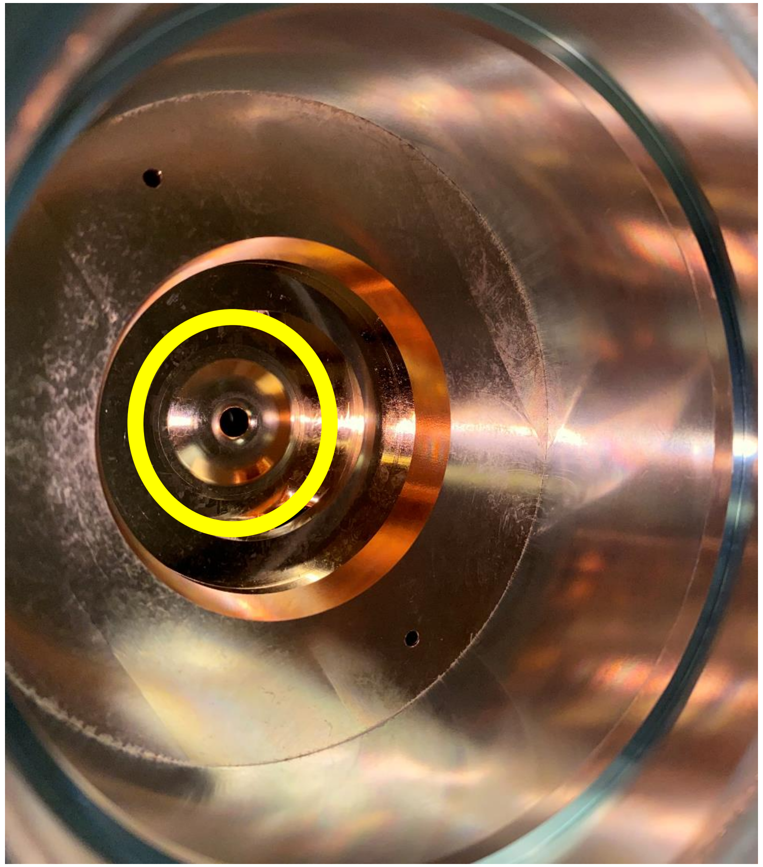
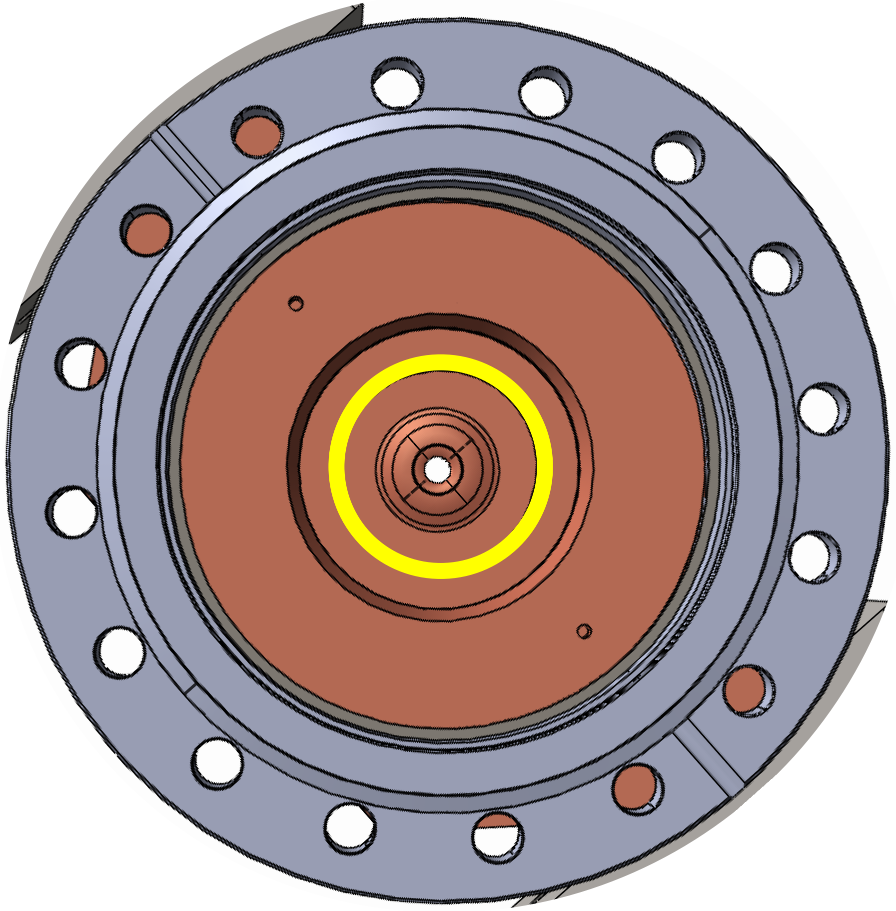
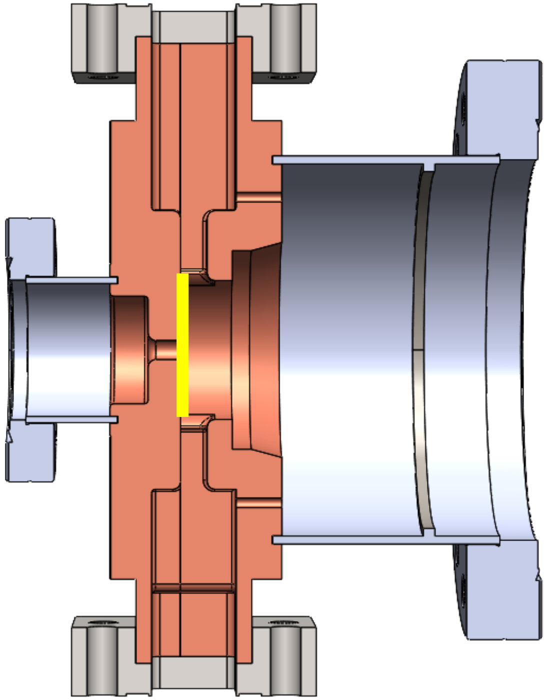


3) Cavity faces



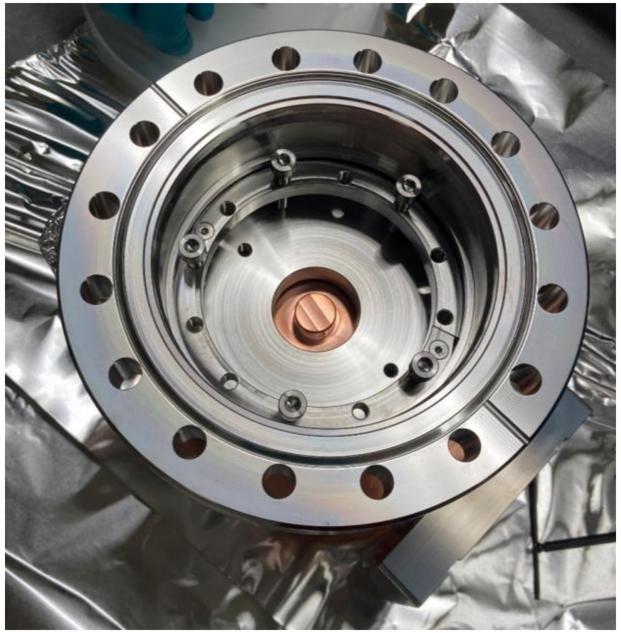


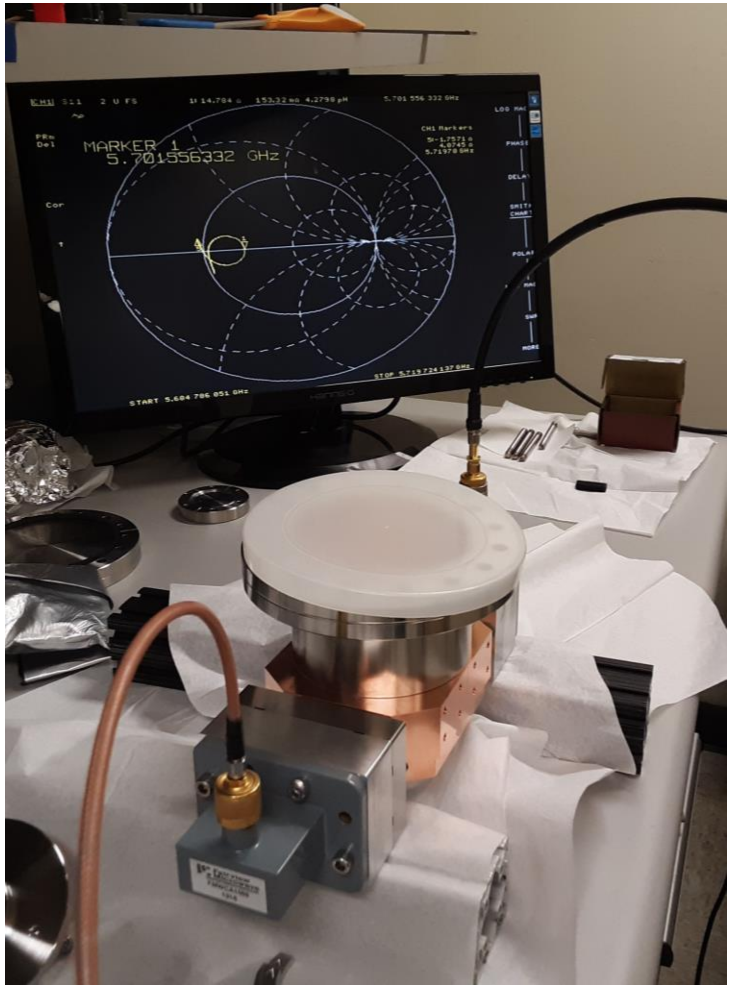


3) LLRF Measurements

- 295K resonance 6 MHz higher than intended and coupling lower
- Attributed to presence of braze material
- Q0 = 4200 with no clamp, up to 7649 so far

	Measurement	Design/Simulation
f0	5.701 GHz	5.695 GHz
β	0.52	0.7
QL	≈ 5000	5167
Q0 (partial clamp)	≈ 4600	-
Q0 (clamped)	7649	8579



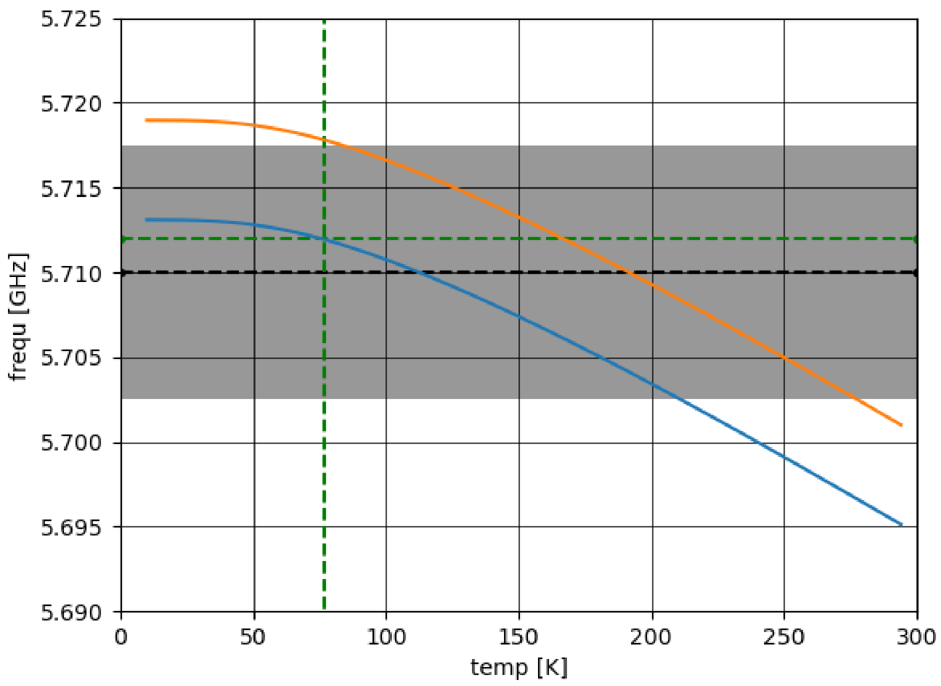


3) Cband RF Power

- 15 MHz bandwidth of klystron cryo outside range
- Verify bandwidth using new C-band mini-modulator

Parameter	100K
Launch field	120 MV/m
Frequency	5.711 GHz
β	3.1
Q0	18000
Filling time	0.25 us
RF Power requirement	0.56 MW
Energy deposition	0.22 J/pulse

Thales Klystron Bandwidth

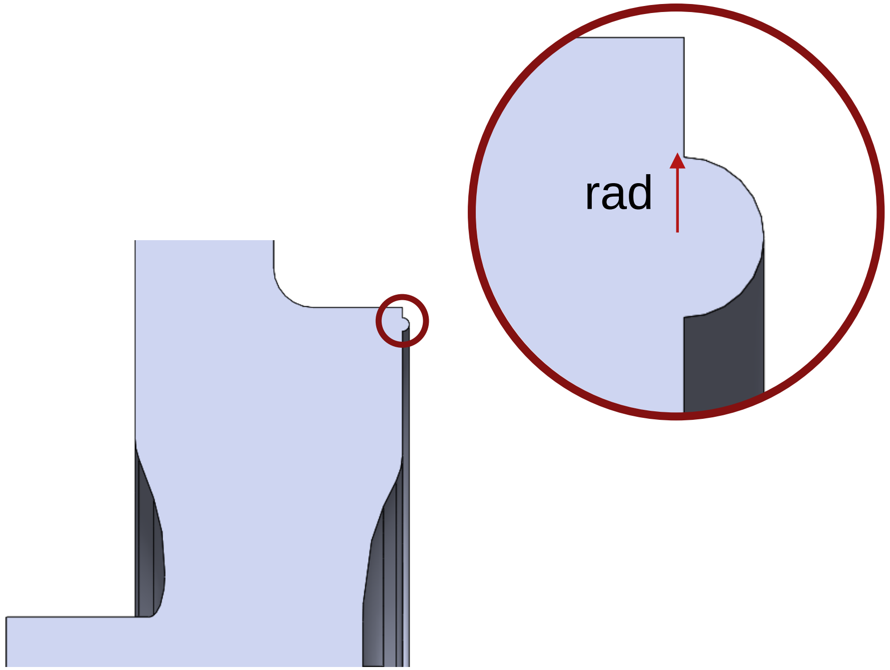


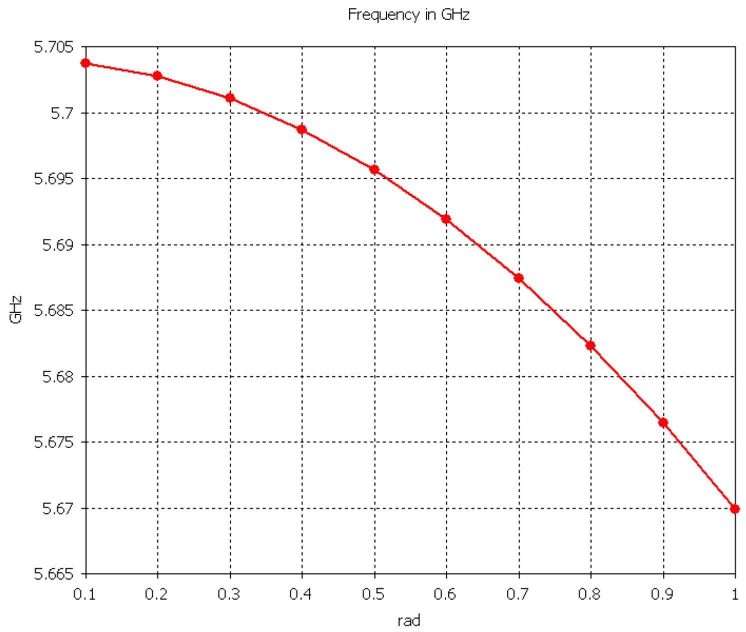
Measurement w/ simulated cool down

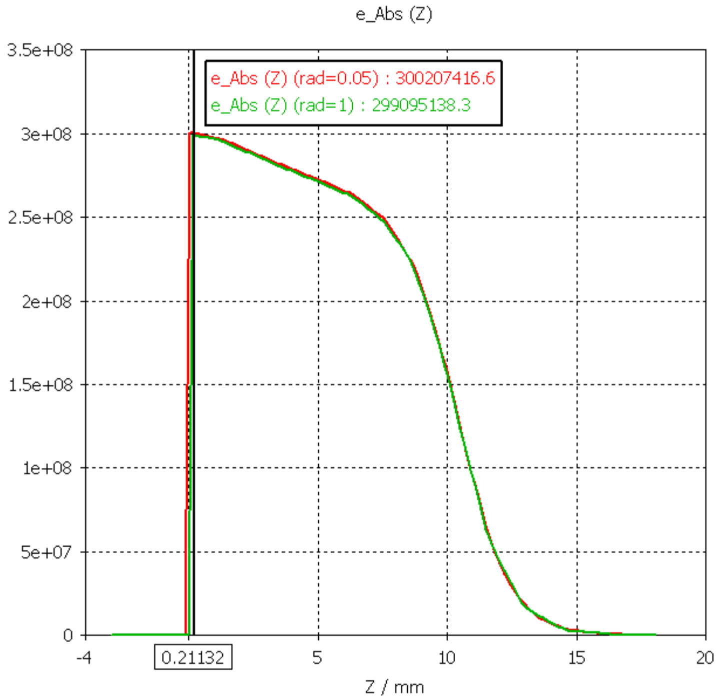
Design w/ simulated cool down

4) Backplane Modifications

1. Removal of material on backplane in high H, low E area on next backplane
2. Small hole for possible bead pull measurement
3. Optimization for acceptable cathode plug

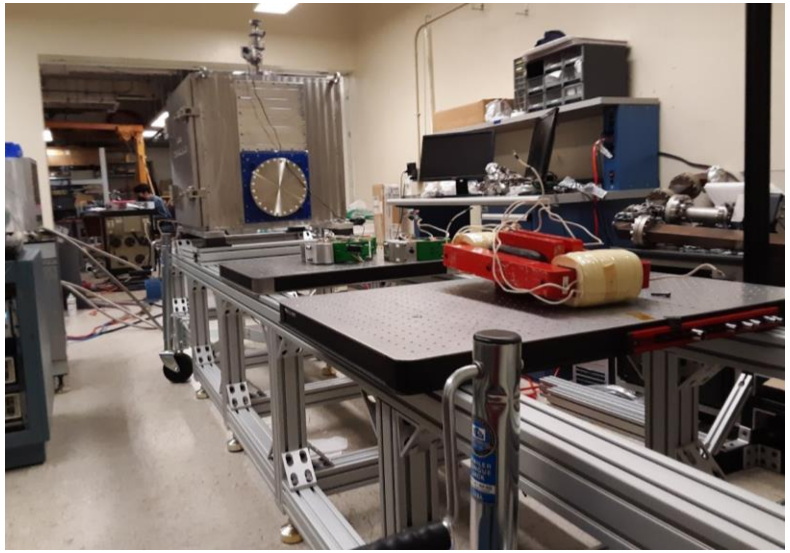


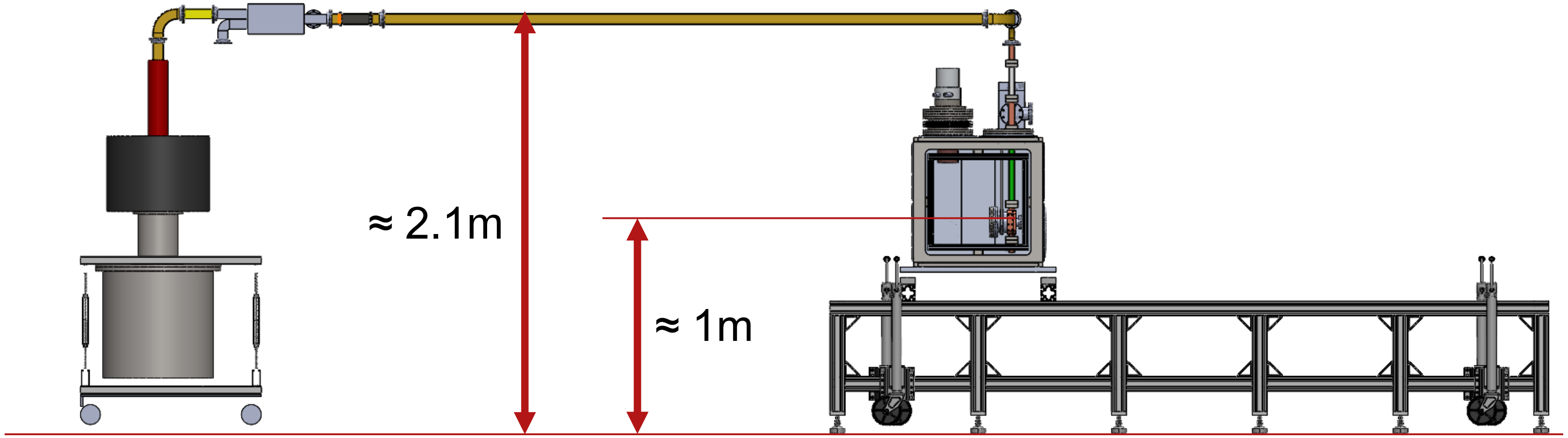




4) Phase1:config1

- Config 1 Goals:
  - LLRF (bead drop)
  - UHV test
  - cooldown & temperature stability
  - high power RF tests
  - Optimize RF pulse heating + cooling
  - SHI vibration isolation





5): Conclusions

1. CYBORG is part of planned high gradient cryogenic cathode test bed and stepping stone to high gradient cryogenic photoinjector
2. Preliminary LLRF tests begun & ongoing
3. Next steps are finishing infrastructure for high powered tests and beamline

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