

## Application of CYBORG Beamline for Future Collider Studies

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UCLA<sup>1</sup>, Los Angeles, CA, USA





# Outline of presentation

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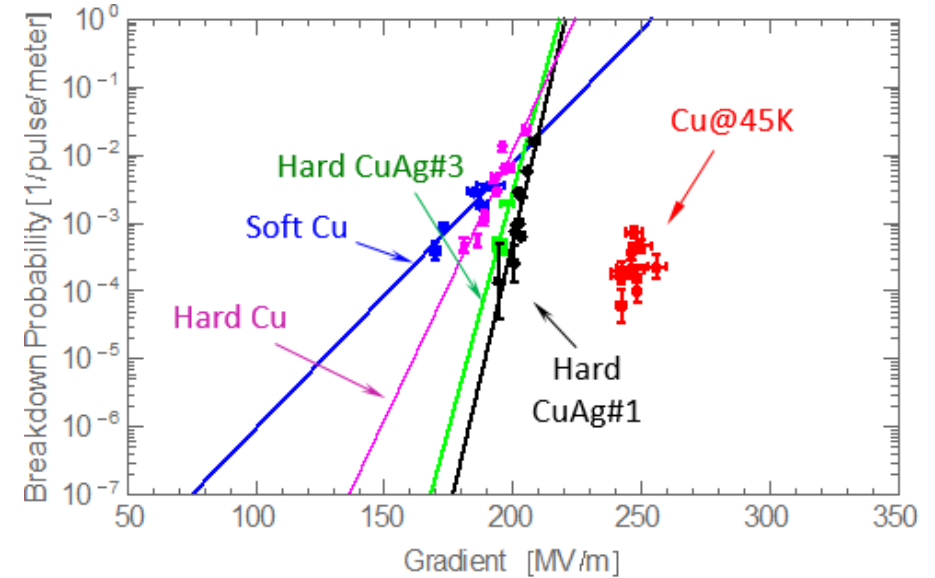
1. Background
2. General program overview
3. CYBORG Beamline overview
4. Future testing
5. Conclusions



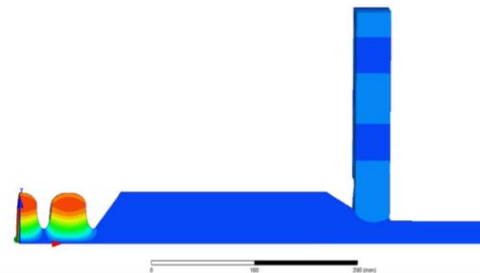
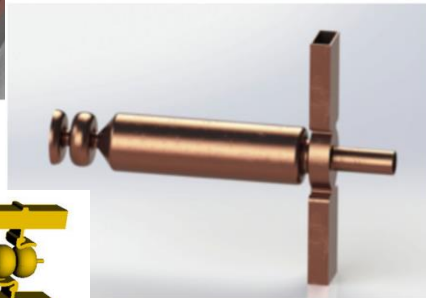
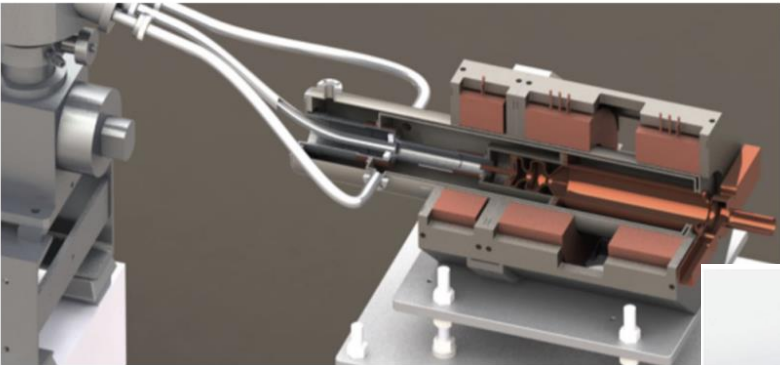
# 1) Background



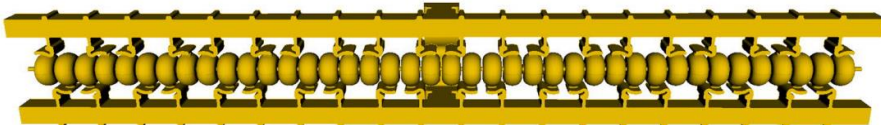
- Significant interest in photoinjector; wakefield; fundamental high field physics
- Broad interest in high gradient cavity development with focus on brightness
- Cryogenic breakdown reduction  $\Rightarrow$  higher accelerating gradients possible
- TopGun previous development in S-band
- More cryo manageable C-band + interest in broader applications  $\Rightarrow$  Cool Copper Collider relevance



$$B_{e,b} \approx \frac{2ec\epsilon_0}{k_B T_c} (E_0 \sin \varphi_0)^2$$



Next generation high brightness electron beams from ultrahigh field cryogenic rf photocathode sources  
 JB Rosenzweig, et al. - Physical Review Accelerators and Beams, 2019





# 1) CYBORG Functions



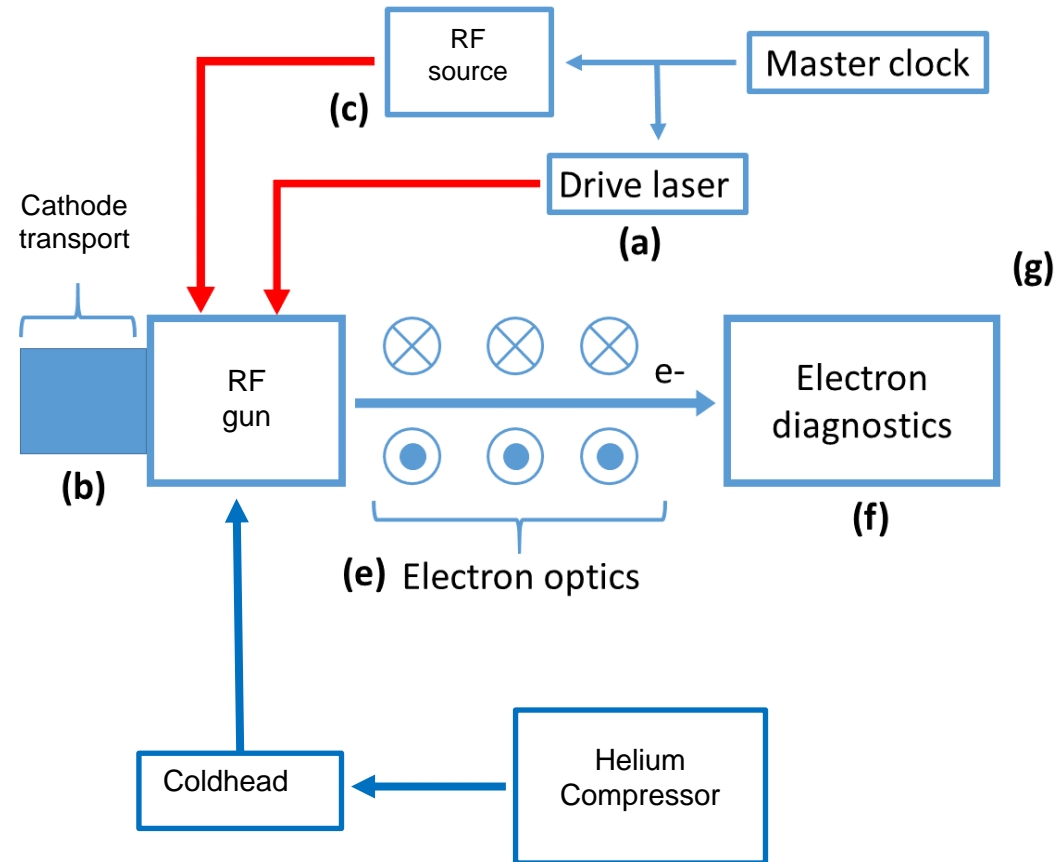
- Simplest NC RF beamline integration using CrYogenic Brightness Optimized Radiofrequency Gun (CYBORG)

## 1. Ultra-high gradient photoinjector prototype

1. Integrated infrastructure template
2. Cathode load-lock development
3. RF prototype, black plane etc.

## 2. Cryogenic emission testing:

1. Dedicated high gradient RF test stand for cathodes incl. novel semiconductors
2. Cryogenic dark current and breakdown





# 1) CYBORG Function 1



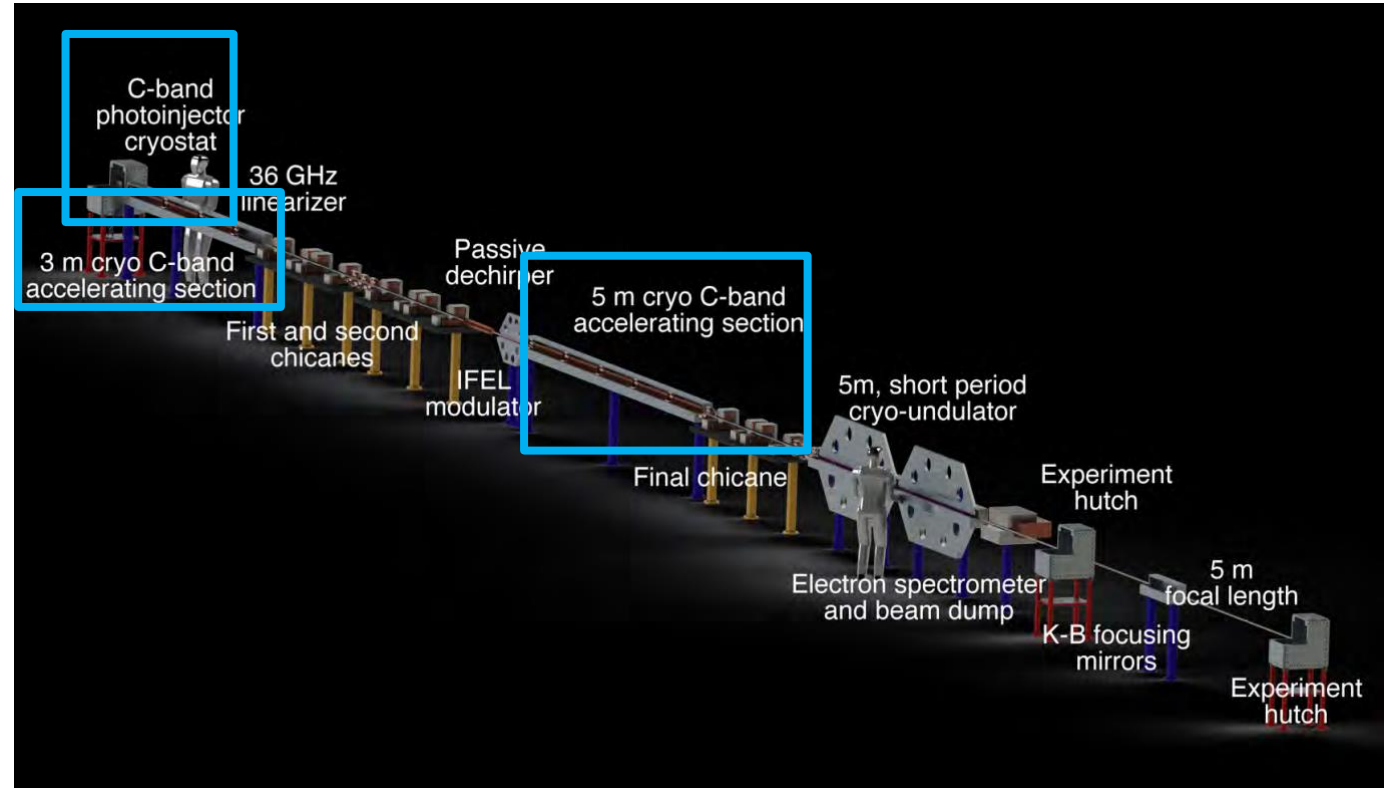
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J. Rosenzweig et al., New Journal of Physics, vol. 22, no. 9, p. 093067, 2020. doi:10.1088/1367-2630/abb16c



# 1) CYBORG Function 2



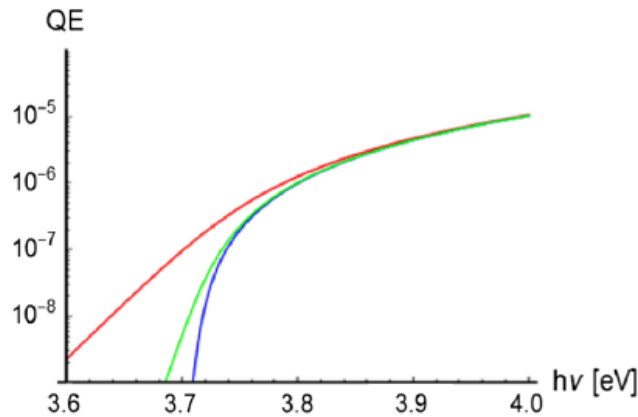
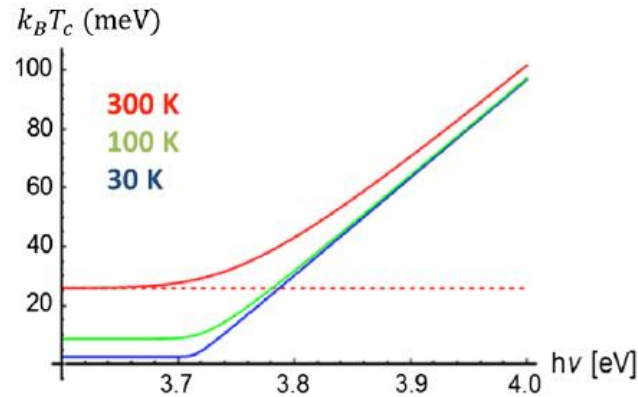
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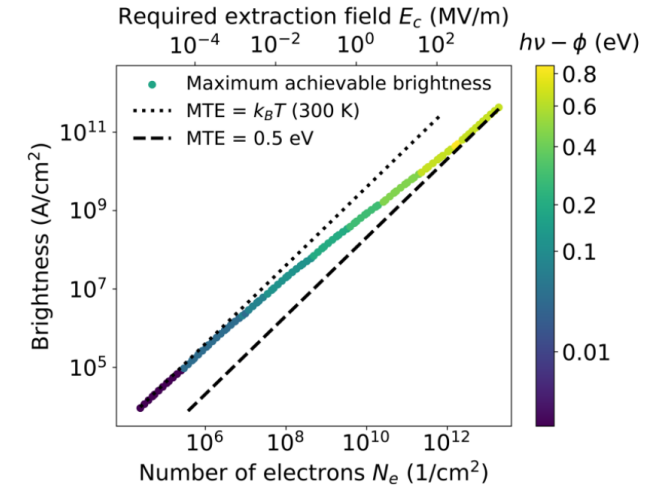
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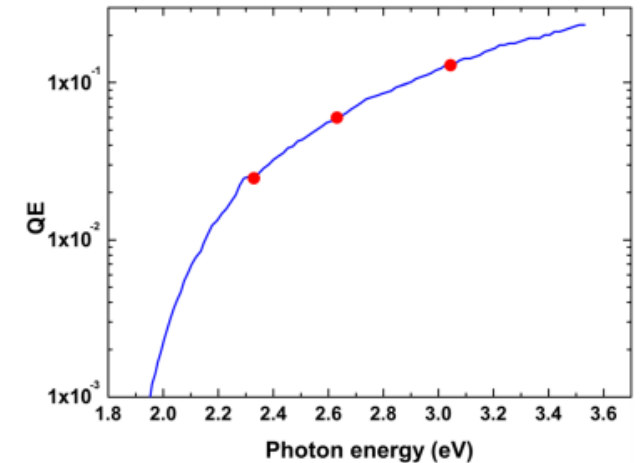
1. Dedicated high gradient RF test stand for cathodes incl. novel semiconductors
2. Cryogenic dark current and breakdown



J.B. Rosenzweig et al., Nucl. Instrum. Methods Phys. Res. A, vol. 909, p. 224-228, 2018. doi:10.1016/j.nima.2018.01.061



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



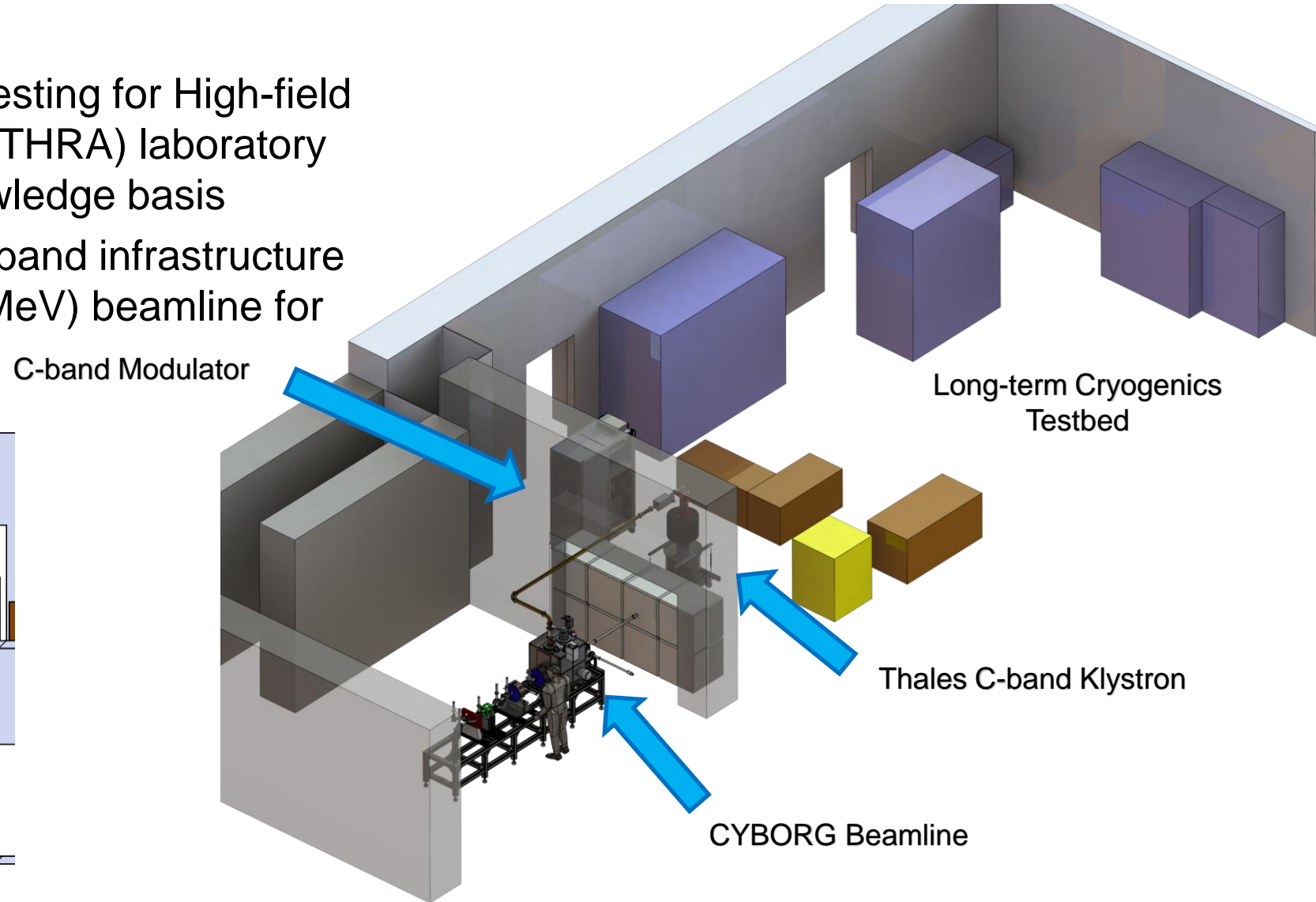
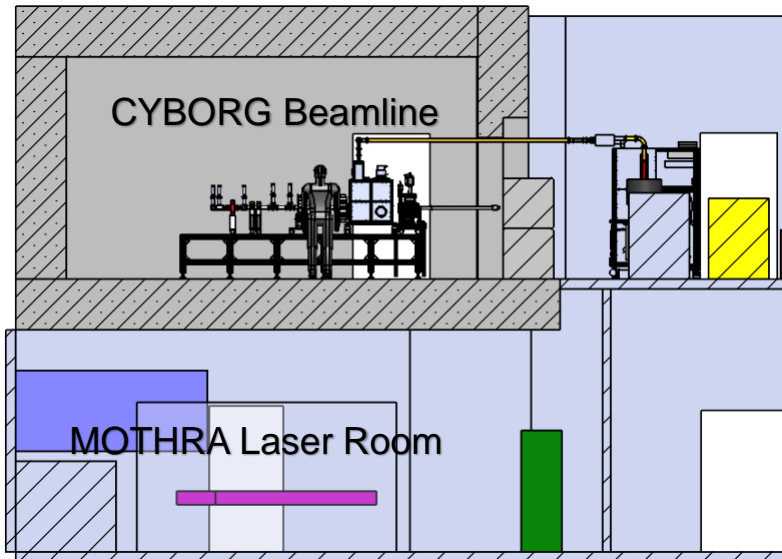
L. Cultrera et al., Appl. Phys. Lett. 103, 103504 (2013).



## 2) Program Overview



- CYBORG beamline not trivial task
- Robust program at Multi-Option Testing for High-field Radiofrequency Accelerators (MOTHRA) laboratory (right and below) to establish knowledge basis
- Suitable for cryogenics testing; C-band infrastructure development; low energy (single MeV) beamline for cathode studies

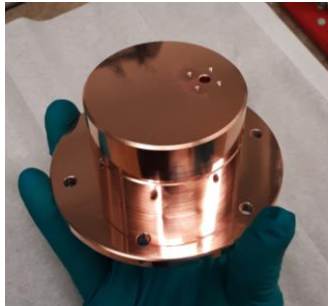
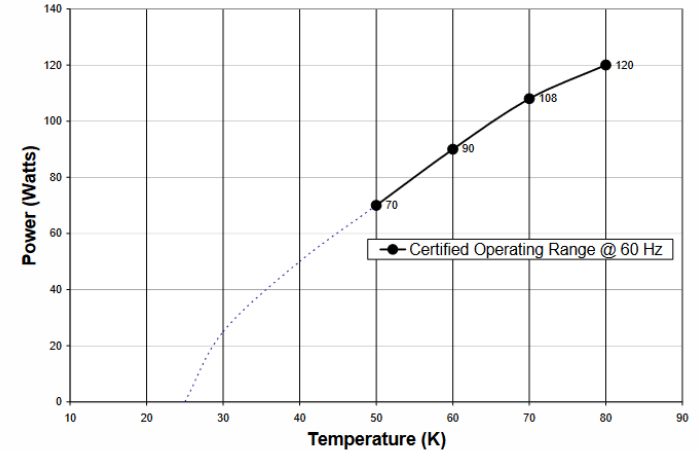




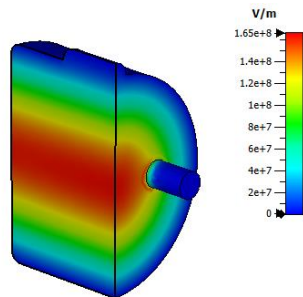
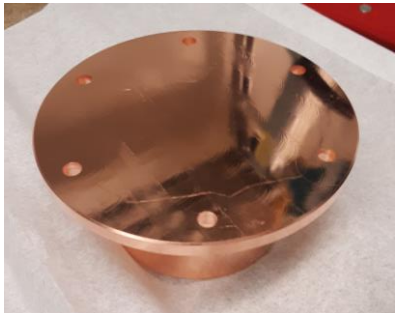
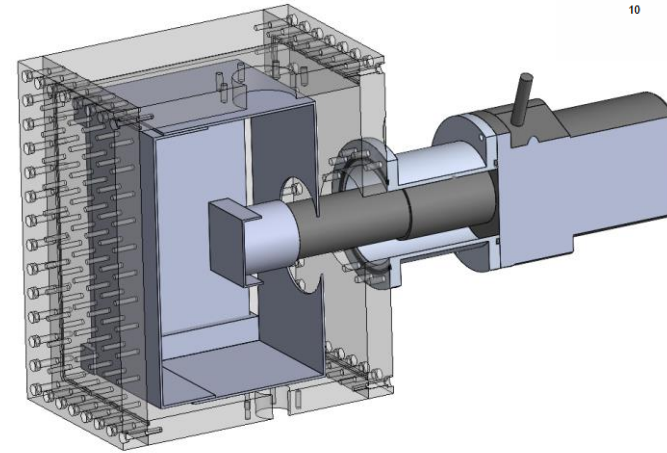
# 2) Cryostat v1



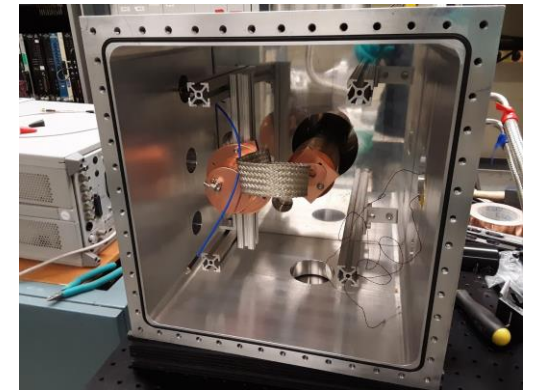
- Small test cryostat for initial cryocooler commissioning; material property studies; and LLRF tests
- C-band pillbox surface resistivity measurements as function of temperature, alloy (CuAg), surface finish etc.
- Helps inform CYBORG simulations (e.g. RF power deposition) which informs operational parameters



$$Q_0 = \frac{\Gamma}{R_s}$$



G.E. Lawler, N. Majernik, and J.B. Rosenzweig,  
Proc. IPAC'21, no. 12, p. 2818–2821, 2021.  
doi:10.18429/JACoW-IPAC2021-WEPAB098



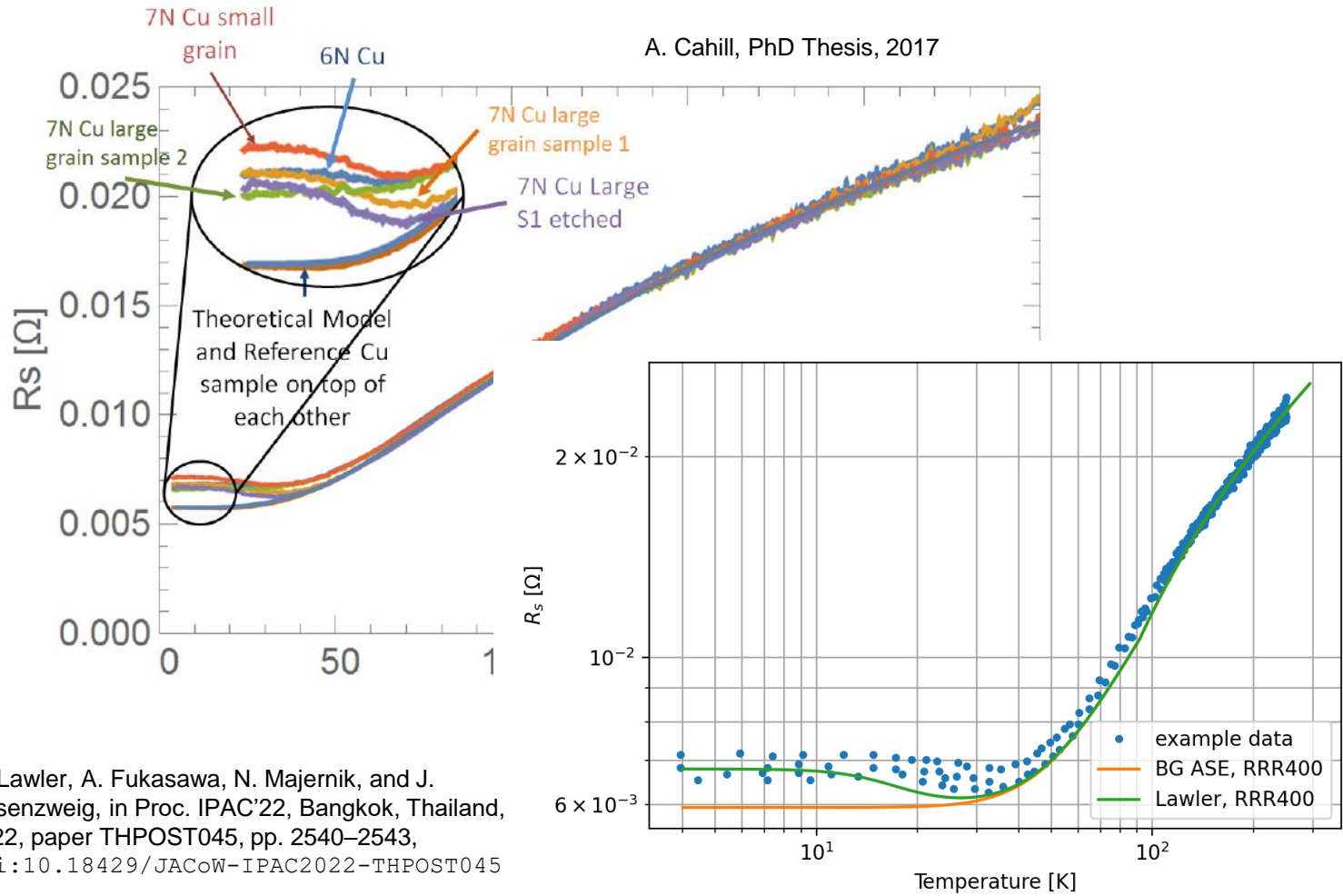




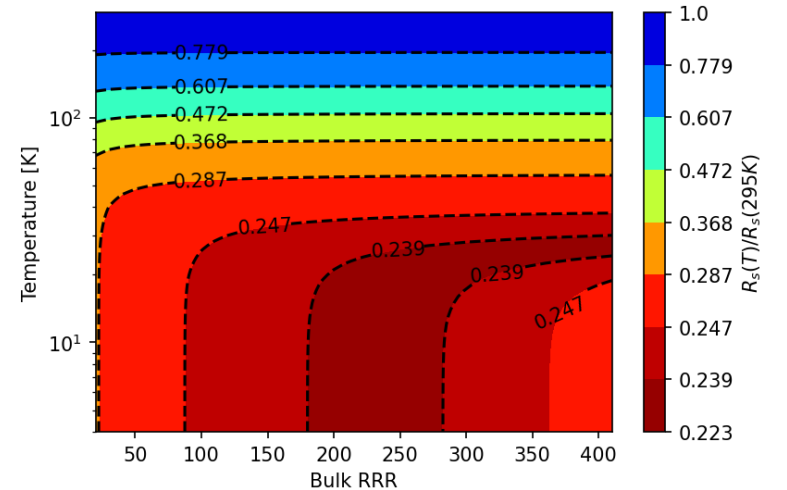
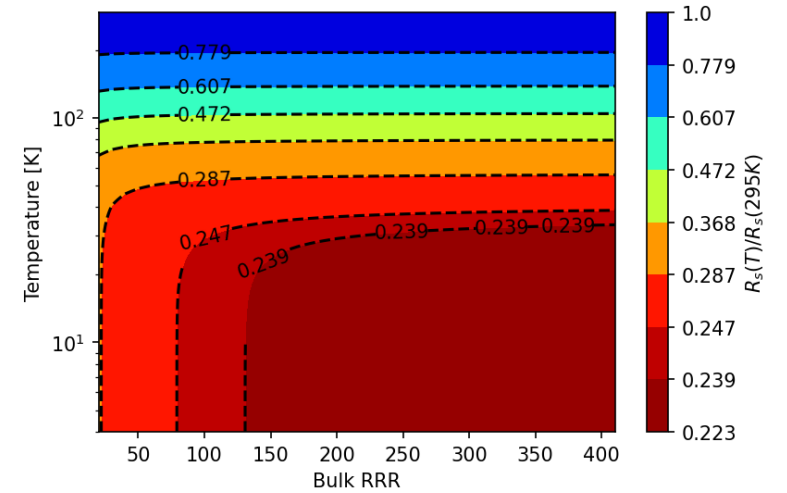
# 2) LLRF Measurements



- Copper pillbox cavities used for Cband low level LLRF



G. Lawler, A. Fukasawa, N. Majernik, and J. Rosenzweig, in Proc. IPAC'22, Bangkok, Thailand, 2022, paper THPOST045, pp. 2540–2543, doi:10.18429/JACoW-IPAC2022-THPOST045

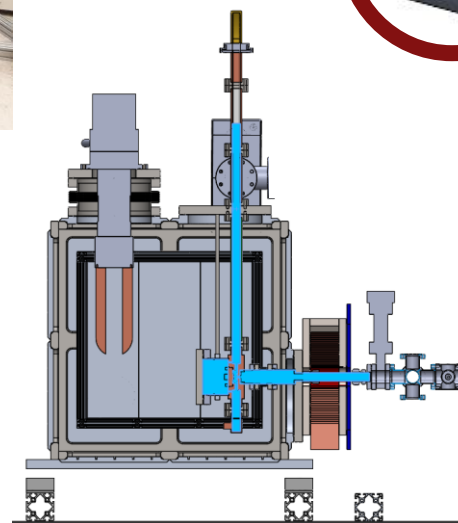
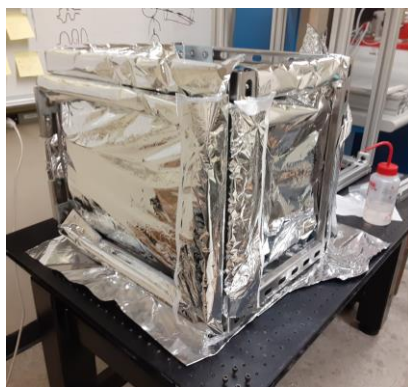
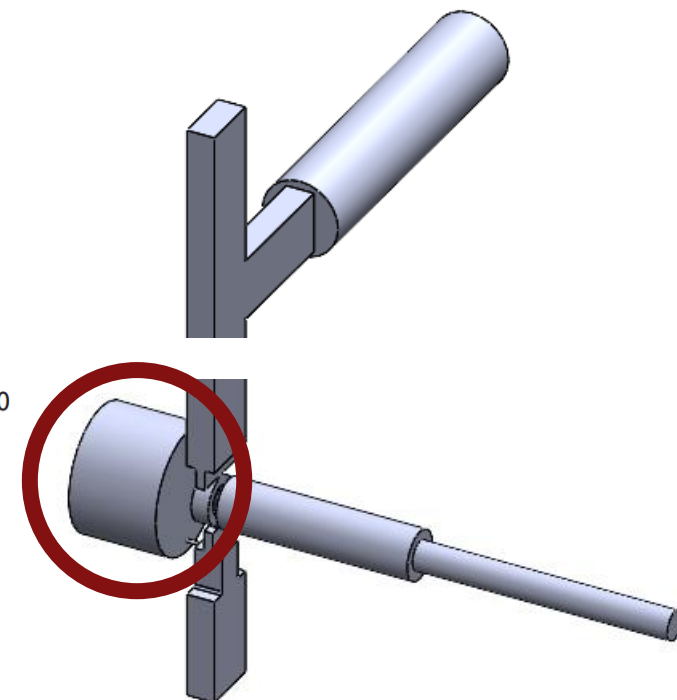
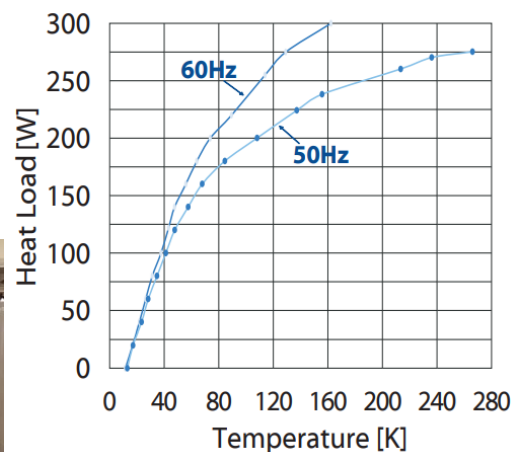
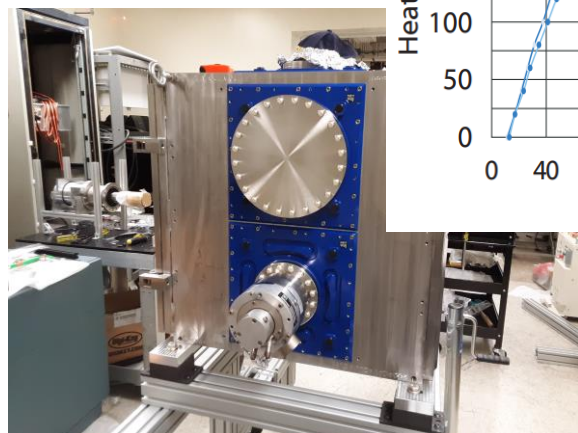




## 2) Cryostat v2



- Much larger cryostat needed for CYBORG with waveguide, beam pipe etc.
- Many considerations to consider
- Size of chamber, multiple layer insulation needed for radiation shielding, nested UHV vacuum chamber far from easy pumping locations, cryocooler power limitations, etc.



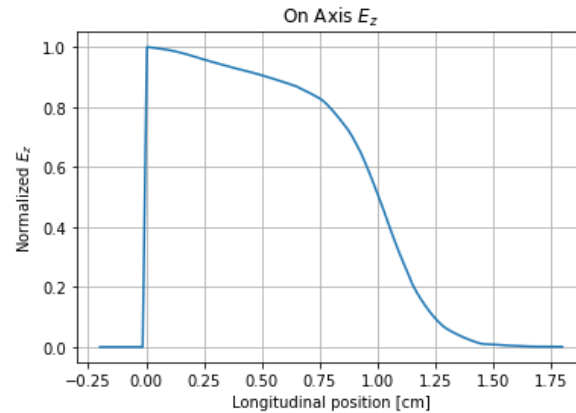


# 3) Photogun specifications

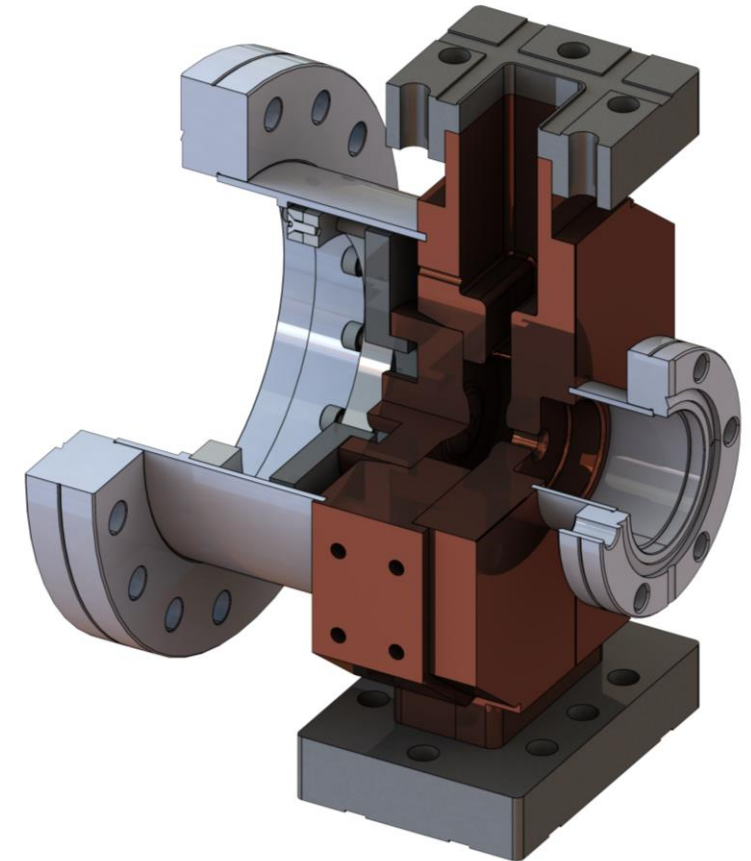
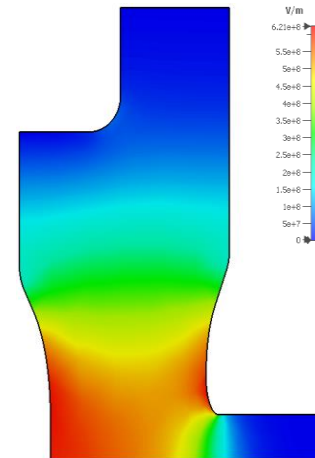


- Reentrant cavity with high shunt impedance
- Cryogenic temperature provided RF stability and cathode studies
- 2.9 factor improvement of  $Q_0$  from 300K to 77K
- Cancel quadrupole moment

Parameters	Value
Launch field	>120 MV/m
Operating temp	295K down to < 65K
Cavity frequency @	5.710 GHz
Beta	4 @ 77K
$Q_{ext}$	6056
$Q_0$	24750



E field magnitude



G. E. Lawler et al., Proc. IPAC'22, no. 13, p. 2544–2547, 2022.  
doi:10.18429/JACoW-IPAC2022-THPOST046

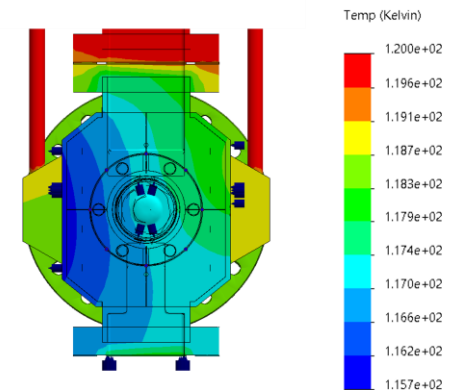
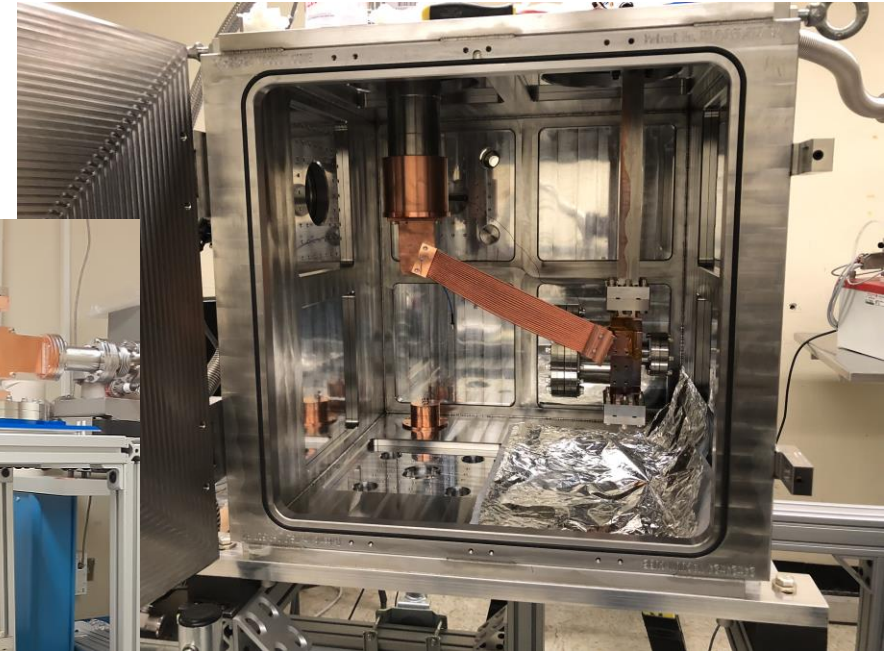
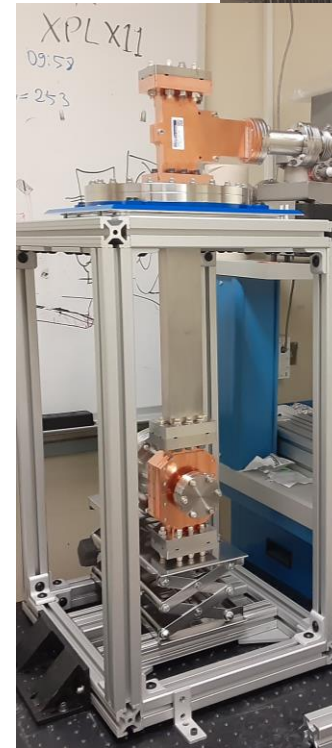
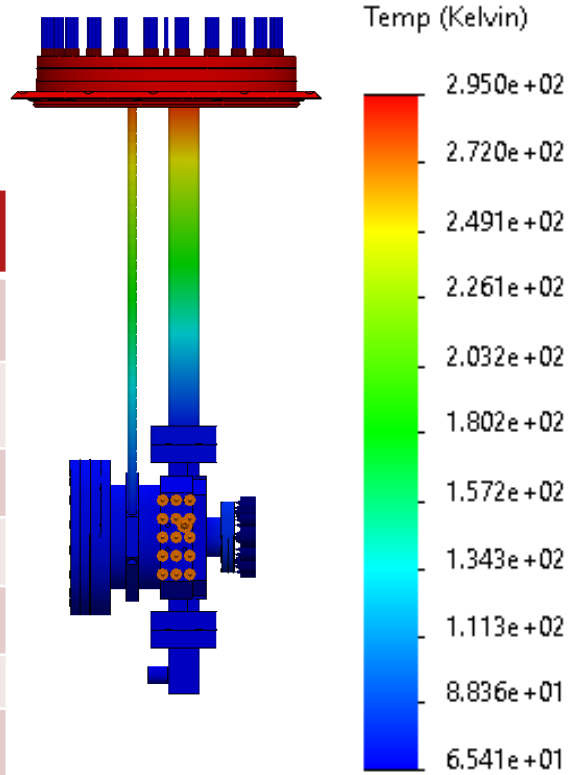


# 3) Thermal Balancing



- Primary initial and ongoing testing of CYBORG examining thermal balancing
- Full power RF power into gun requires additional radiation shielding underway now
- Accounting of major heat leaks below with simulation of temperature gradients

ID	Description	Materials	Equivalent Area	Equivalent Power
001	6" plug flange	Stainless steel (CF flange), edge welded bellows	436 mm <sup>2</sup>	< 1 W
002	2.75" downstream flange	Stainless steel (CF flange), edge welded bellows	85 mm <sup>2</sup>	< 1 W
003	Waveguide	Satinless steel	588 mm <sup>2</sup>	Approx 10 W
004	Supports	Stainless steel, aluminum, G10	TBD	TBD
005	Diagnostic probes	Copper wiring of various gauges	50 mm <sup>2</sup>	5 W
006	Alignment rails	TBD	TBD	TBD
007	Radiation	N/A	25000 mm <sup>2</sup>	< 1 W
008	Pumping on dummy side			

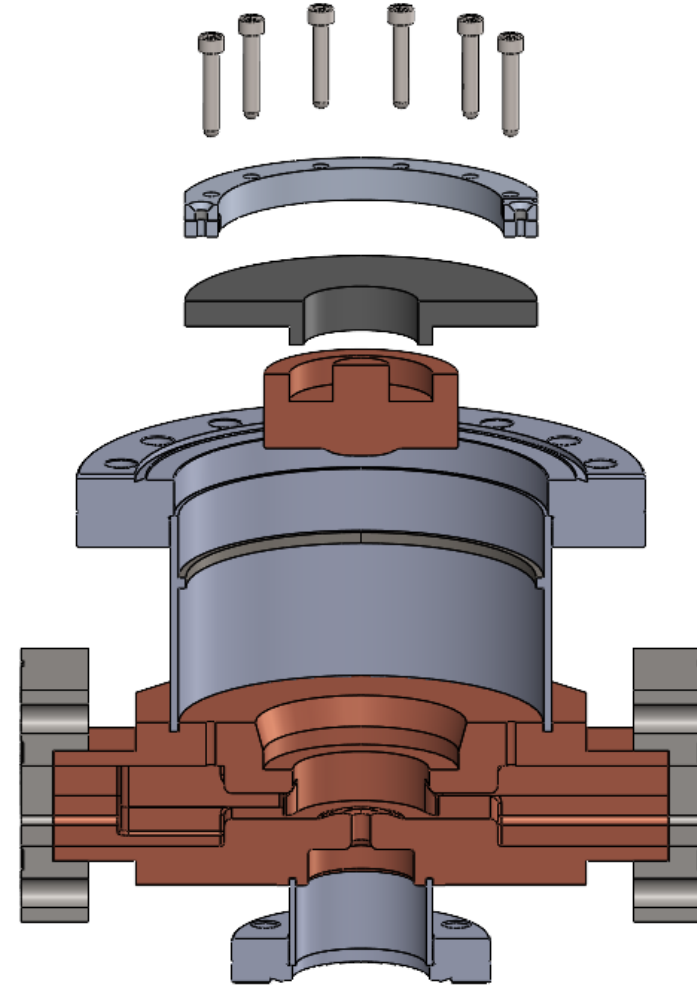
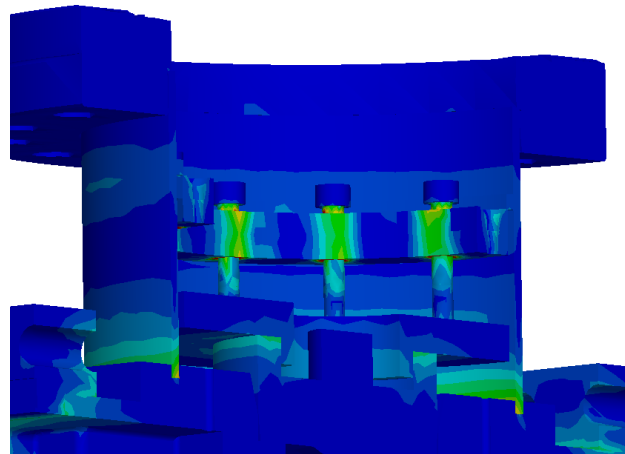
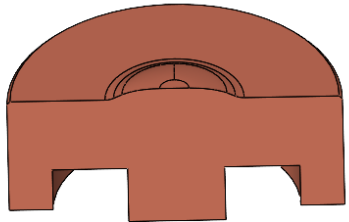




# 3) Phase1 Cathode



- Phase1 of CYBORG Cu cathode tests
- Cathode backplane press fit to begin
- Functional at Elettra lab in Trieste, Italy for FERMI seeded FEL
  - Uses high gradient BNL/SLAC/UCLA 1.6 cell electron gun
- Slow exchange not intended for final cathode testing but allows versatility with respect to cathode load lock integration

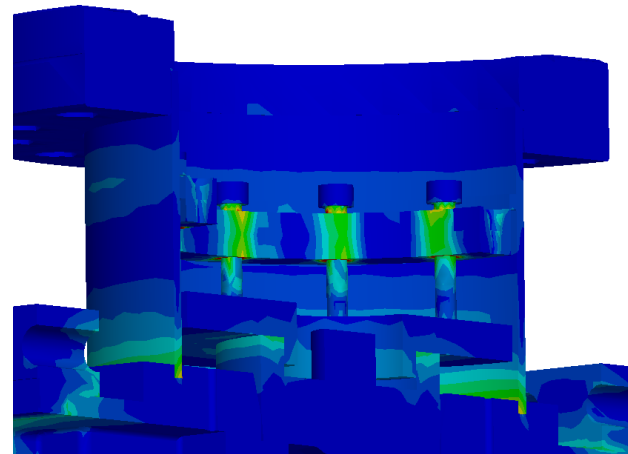
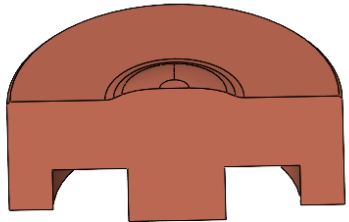
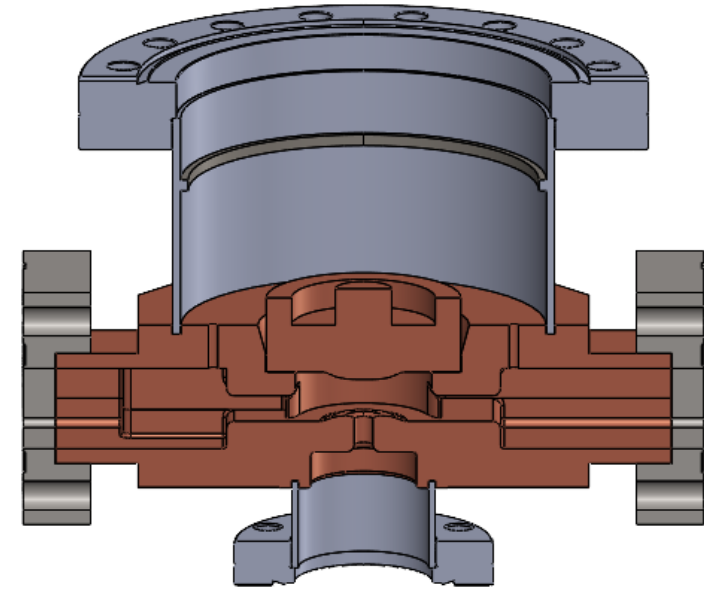
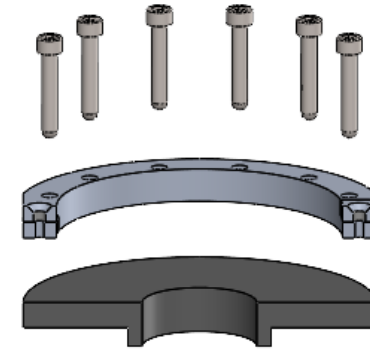




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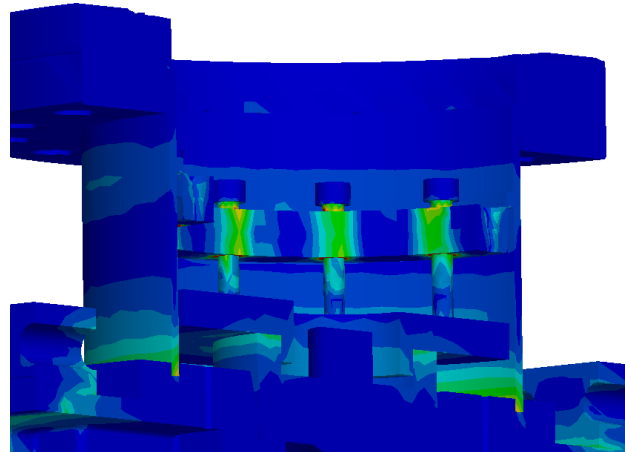
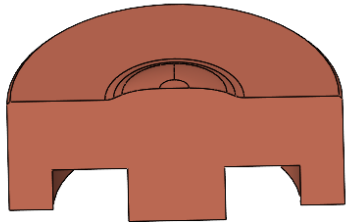




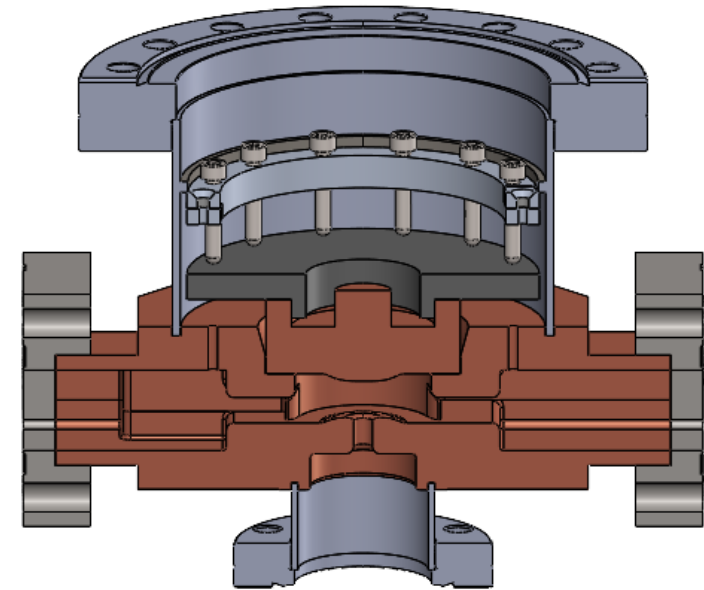
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For use in Phase1

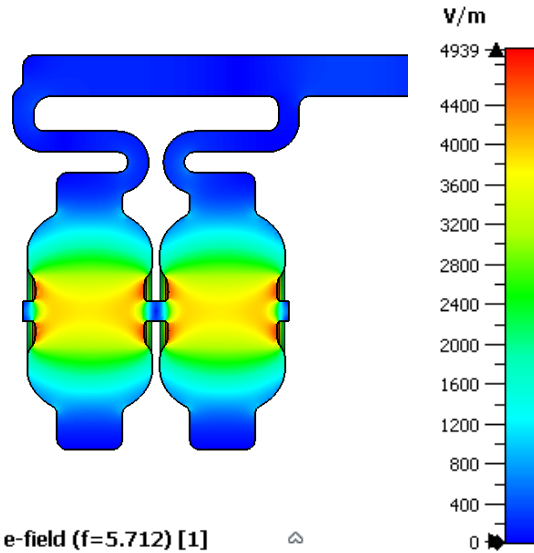




# 3) High power structure

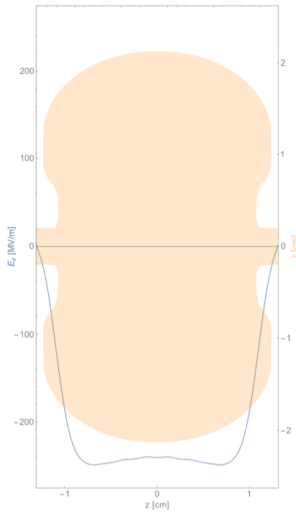
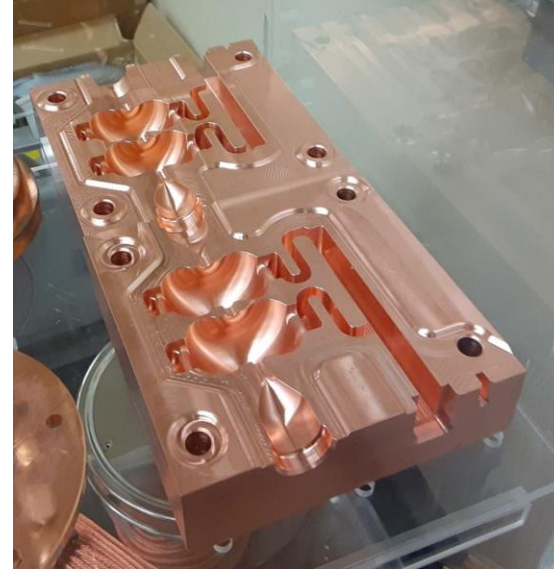
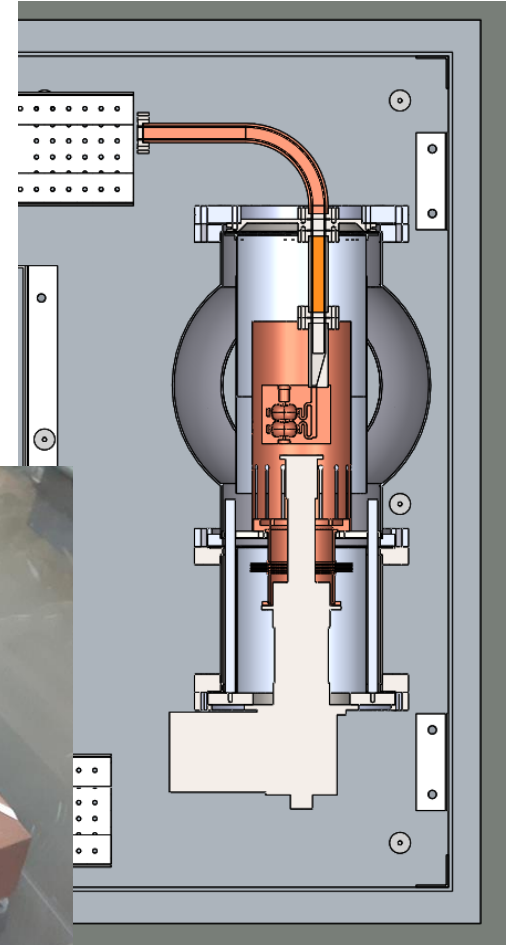
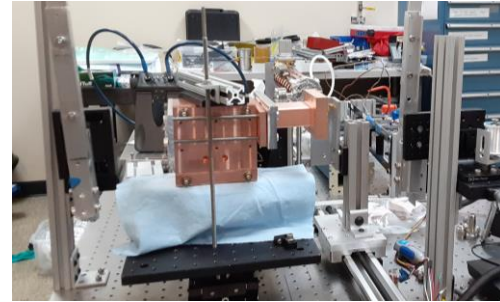
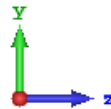


- Create test bed for hosting multiple different experiments into various structures and material alloys
  - Brazeless joint testing, copper-silver and more exotic alloys perhaps w/ Mo etc.
- Logic of cryogenics, assembly, and general diagnostics for actual experiments
- Example here using 2 cell distributed-coupling in Cband (to right)
- Full cell cavity geometry chosen for future UCXFEL photoinjector



**e-field (f=5.712) [1]**

Component	Abs
Frequency	5.712 GHz
Phase	90 °
Cross section	A
Cutplane at X	0.000 mm
Maximum (Plane)	13414.7 V/m
Maximum	13414.7 V/m



R. Robles et al., Phys. Rev. Accel. Beams, vol. 24, no. 6, p. 063401, 2021.  
doi:10.1103/PhysRevAccelBeams.24.063401



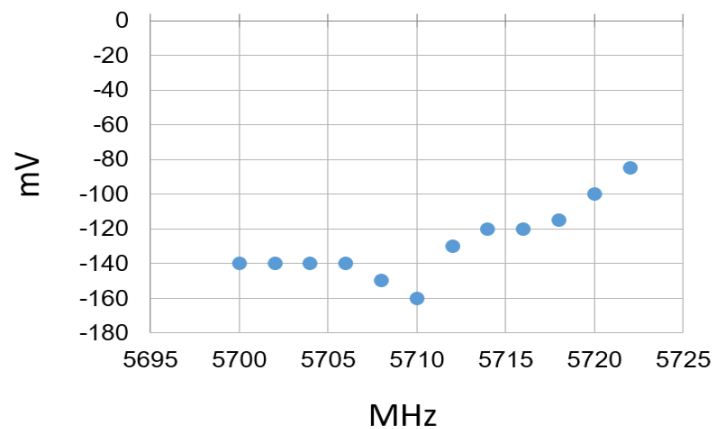
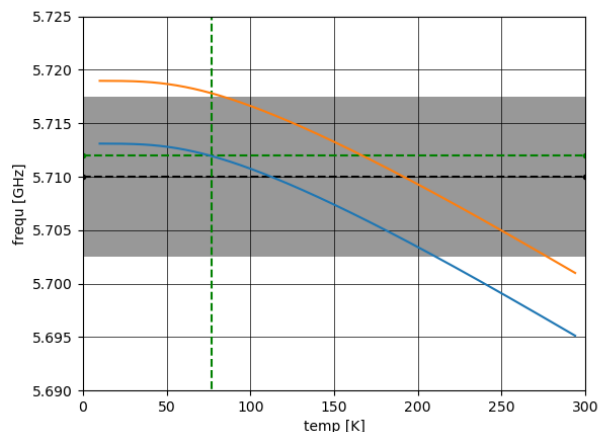


# 3) Cband RF Power

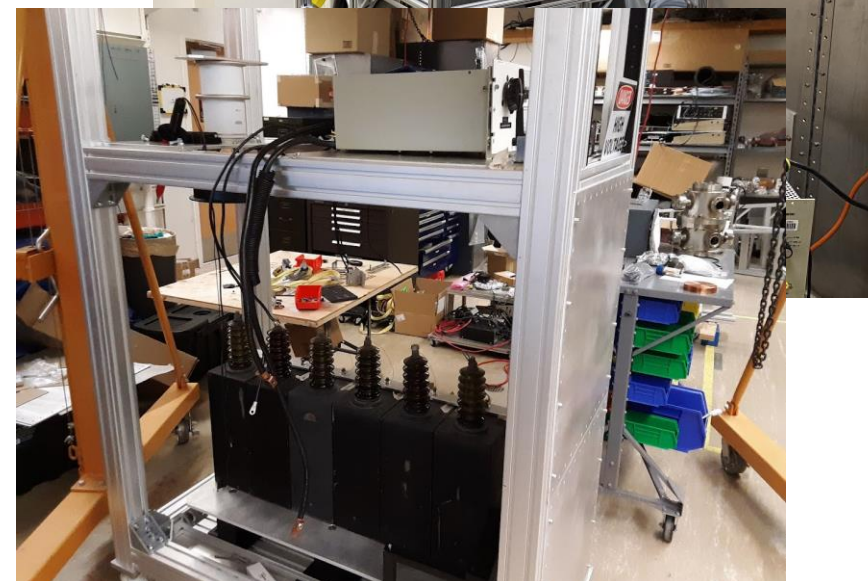
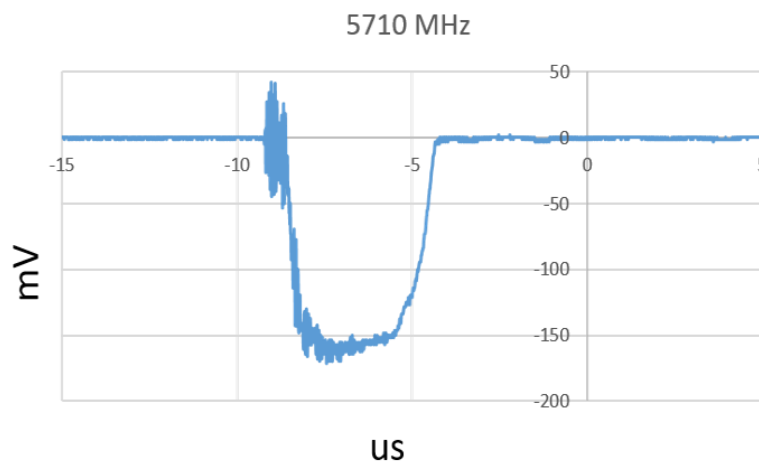


- Resurrected Thales C-band klystron to single MW power sufficient for 1<sup>st</sup> cryogenic beamline (right)
- In-house built modulator for C-band under completed and functioning nominally
- C-band SLED development in collaboration with Tantawi group at SLAC

Thales Klystron Bandwidth



Measurement w/ simulated cool down (orange line)  
Design w/ simulated cool down (blue line)

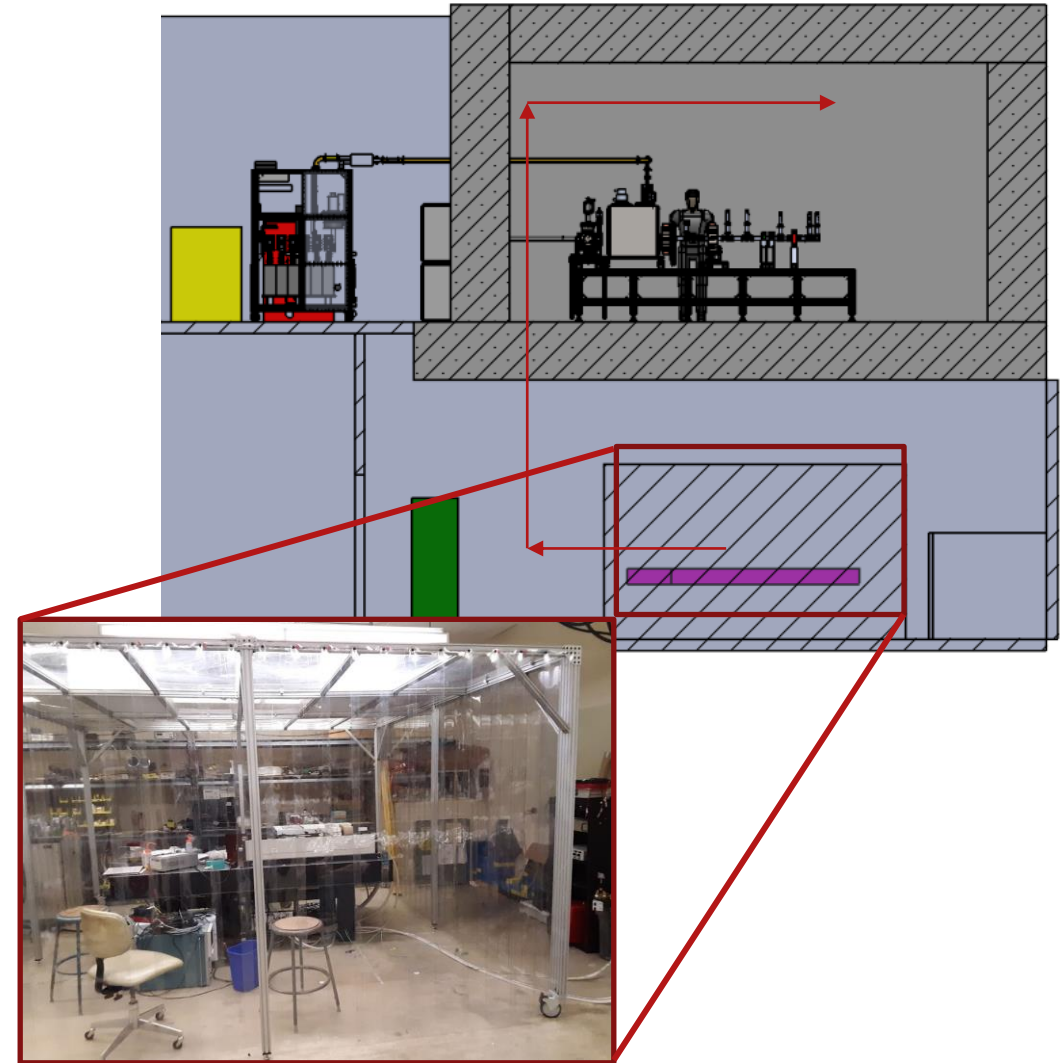
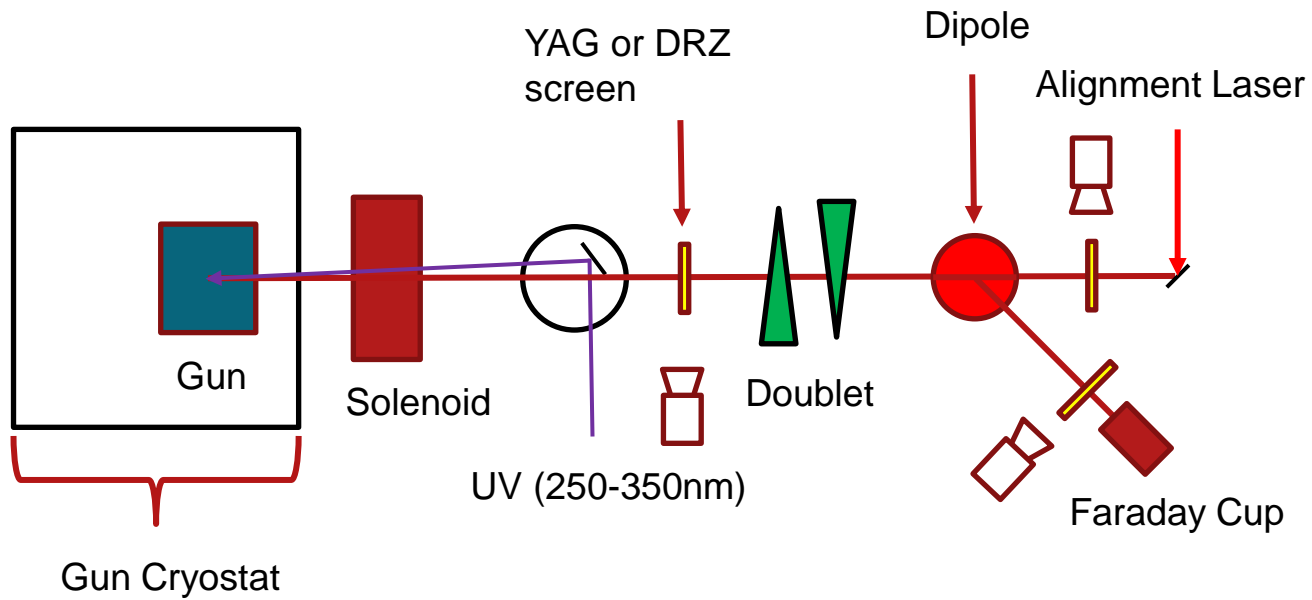




# 3) Phase1



- Config2 goals:
  - Cryogenic copper photoemission
  - Cryogenic QE
  - Preliminary lower prevision MTE measurement

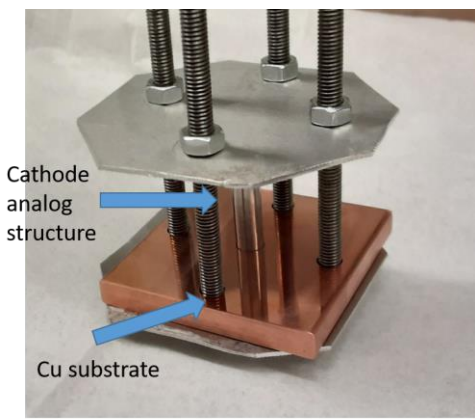
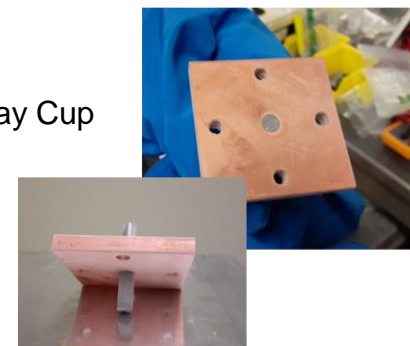
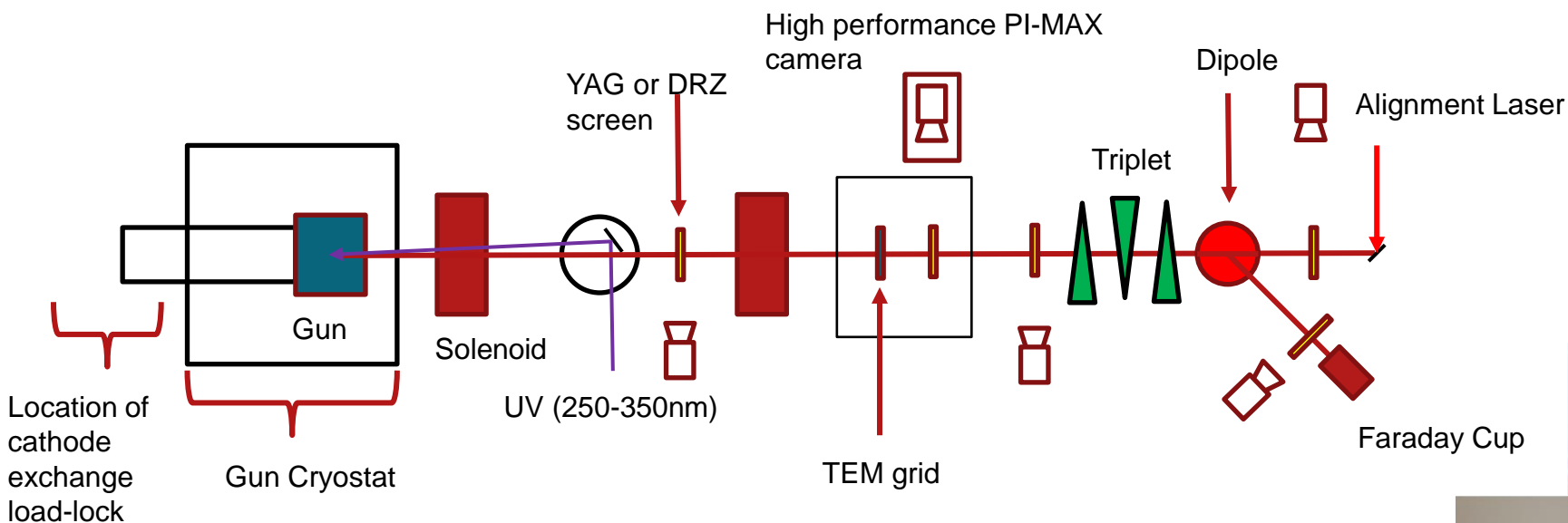
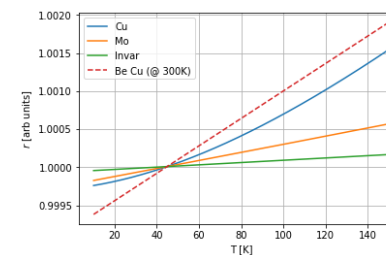
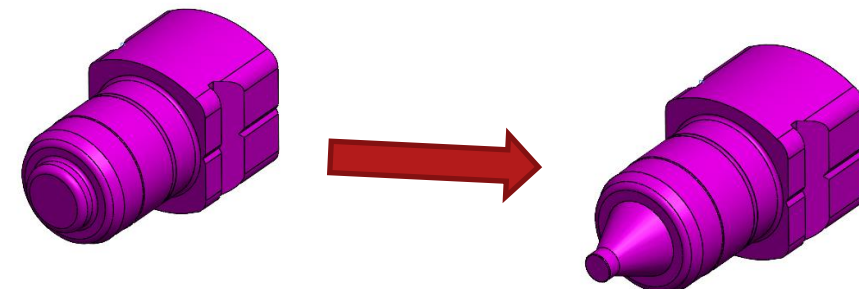




# 4) Phase2



- load lock and phase 2 diagnostics (schematic below)
- High precision MTE measurement setup needed
- Cathode coupling work in parallel underway using interference fit idea (right)
  - RF spring and knife edge seals difficult for cryo
- Slight INFN minipuck mod needed

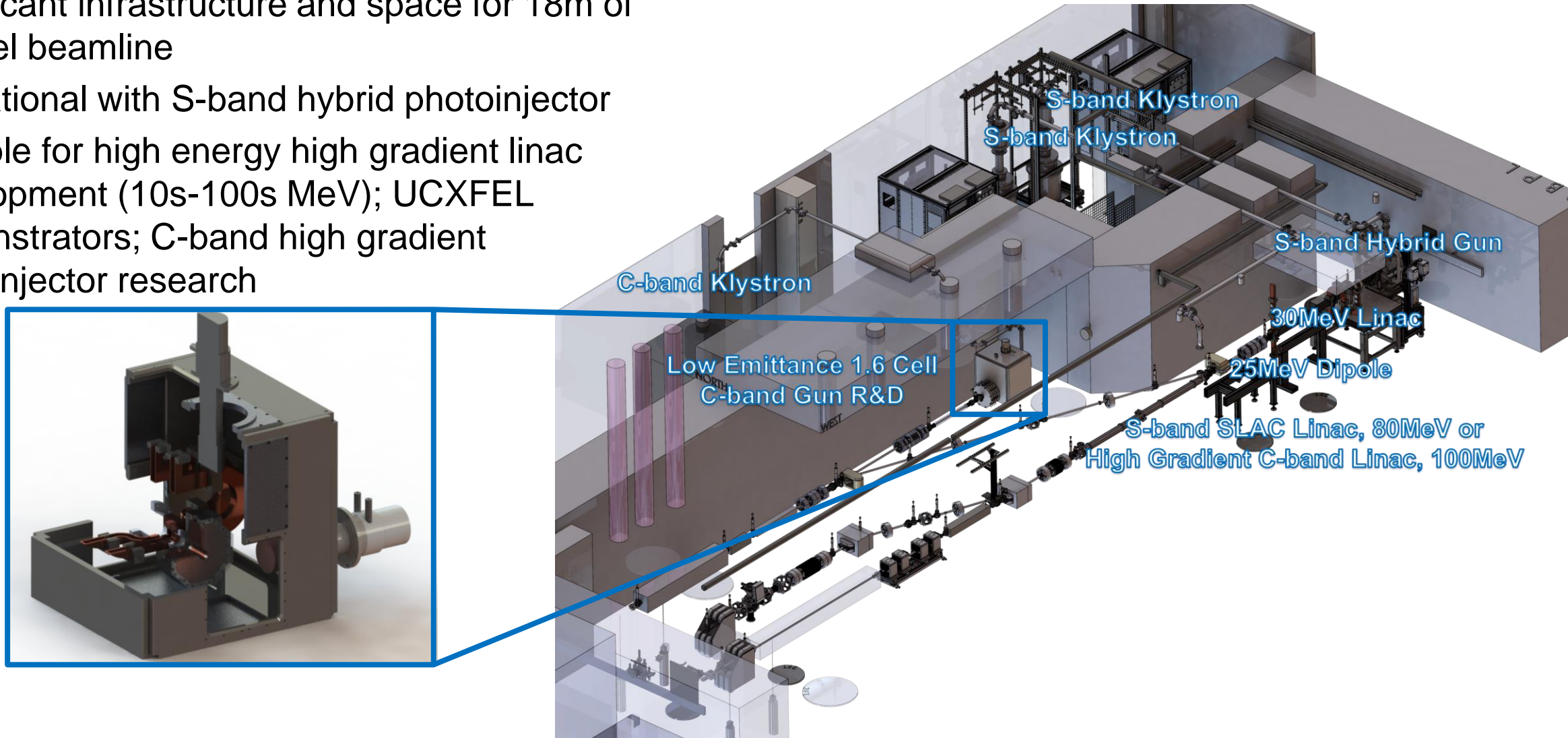




# 4) MITHRA Lab



- Significant infrastructure and space for 18m of parallel beamline
- Operational with S-band hybrid photoinjector
- Suitable for high energy high gradient linac development (10s-100s MeV); UCXFEL demonstrators; C-band high gradient photoinjector research

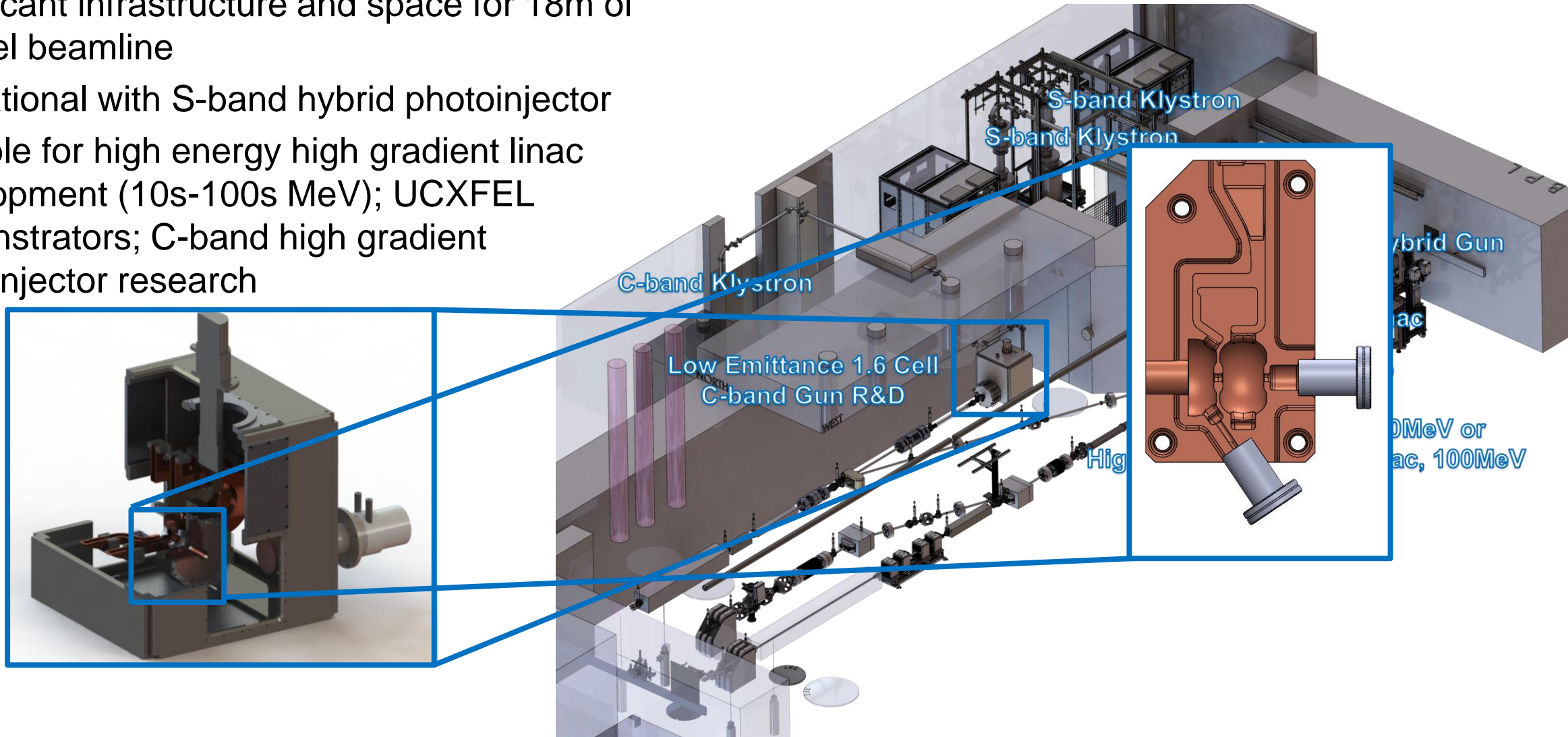




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# 5) Conclusions



1. CYBORG next step in long line of bright photogun work at UCLA
2. MOTHRA lab developed as robust testing ground for building pragmatic knowledge base necessary for normal conducting cryogenic C-band cavity-based beamline commissioning
3. Lessons learned and future research trajectory synergistic with C<sup>3</sup> on many fronts



# Collaborators



- Obed Camacho, *Jacob Cunningham*, Atsushi Fukasawa, *Richard Li*, Nathan Montanez, Brian Naranjo, *Jake Parsons*, *April Smith*, *Sean O'Tool*, *Arathi Suraj*, *Zhaoyan Sun*, Yusuke Sakai, Oliver Williams



- Paul Carriere, Nanda Matavalam



- Evgenya Simakov, Anna Alexander, Petr Anisimov, Haoran Xu



- Fabio Bosco, Martina Carillo



- Zenghai Li, Sami Tantawi, Nathan Majernik



- Andrea Mostacci, Bruno Spataro