MATERIAL PHYSICS STUDIES FOR HIGH GRADIENT CAVITIES AT UCLA CYBORG BEAMLINE

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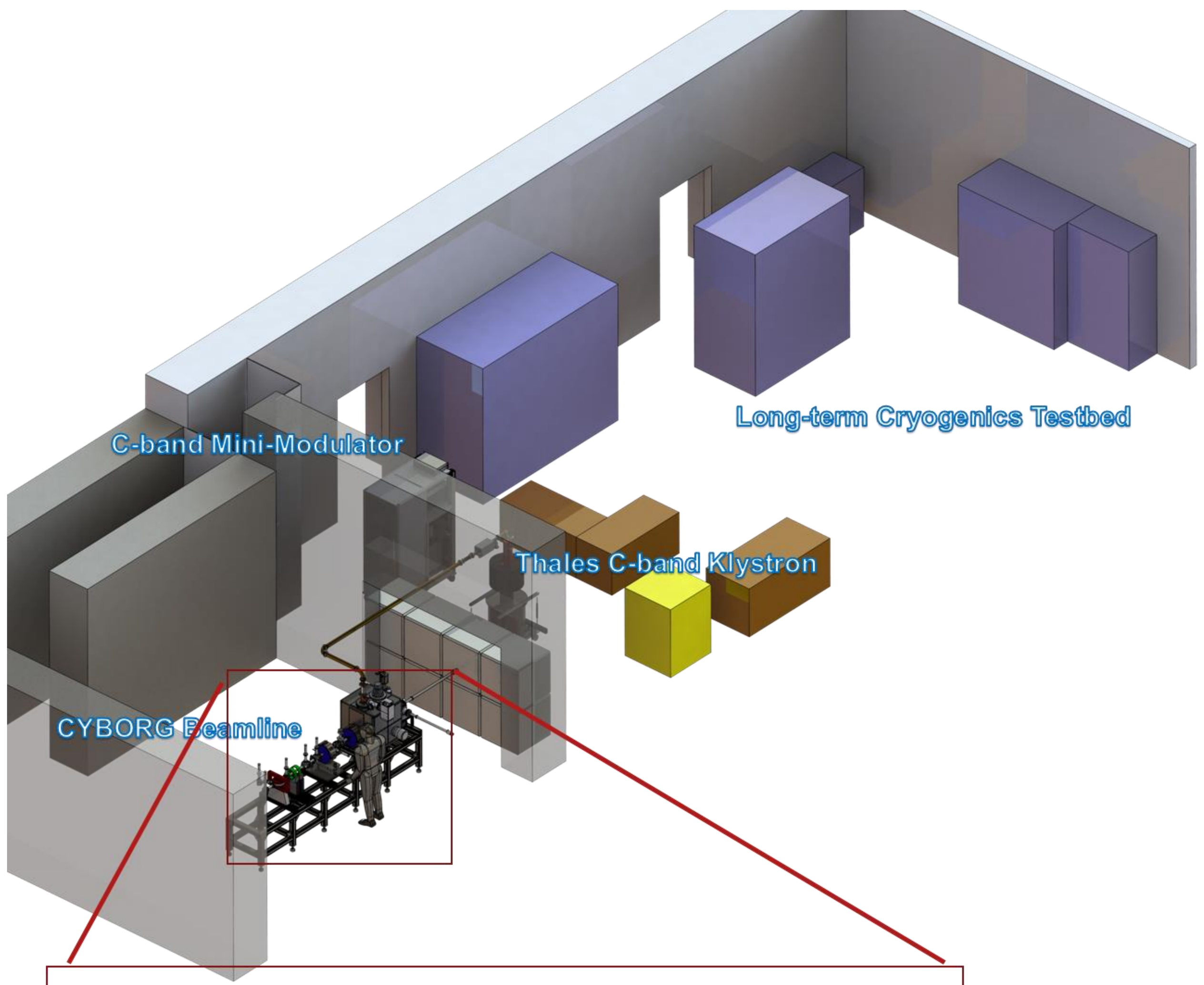
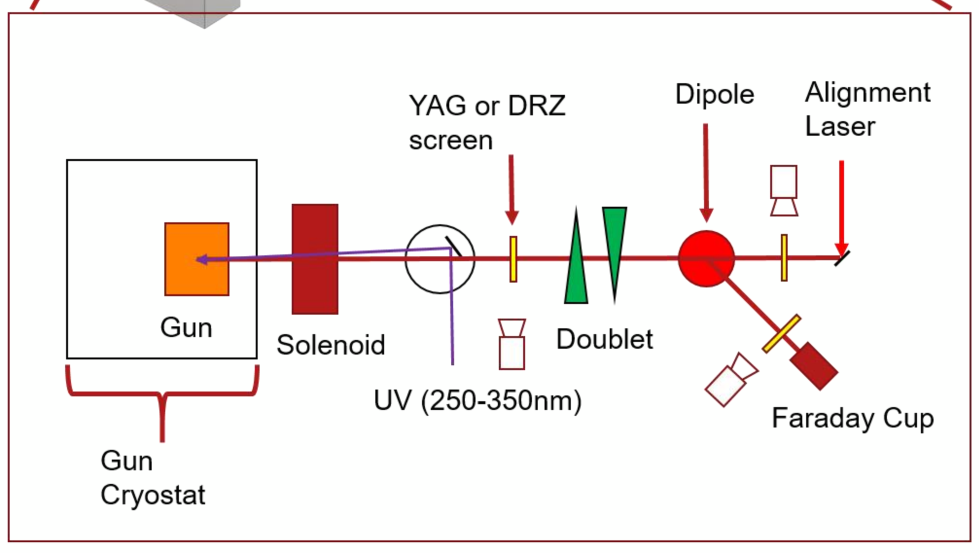
Abstract

High gradient RF cavities, especially those at frequencies above S-band, are critical in several concepts for future electron linacs such as the ultra-compact X-ray free electron laser (UCXFEL) and the Cool Copper Collider (C^3). These two designs in particular rely on the cryogenic operation of RF cavities, taking advantage of several complementary physical effects. It is then advantageous to develop in greater detail an understanding of the complex surface and material physics associated with high gradient RF fields in normal conducting cavities. We present here measurements made at the CYBORG (CrYogenic Brightness-Optimized Radiofrequency Gun) beamline at UCLA. In this first phase of study we will relate our temperature dependence measurements of dark current and other RF cavity figures of merit to the general material science research goals via a modified theory of anomalous skin effect regime. The theory will also be presented with additional results from low level RF cavity testing. Future directions will be presented including the status of the second phase of the beamline in which photoemission of novel cathodes in extreme conditions will be studied.

CYBORG Beamline





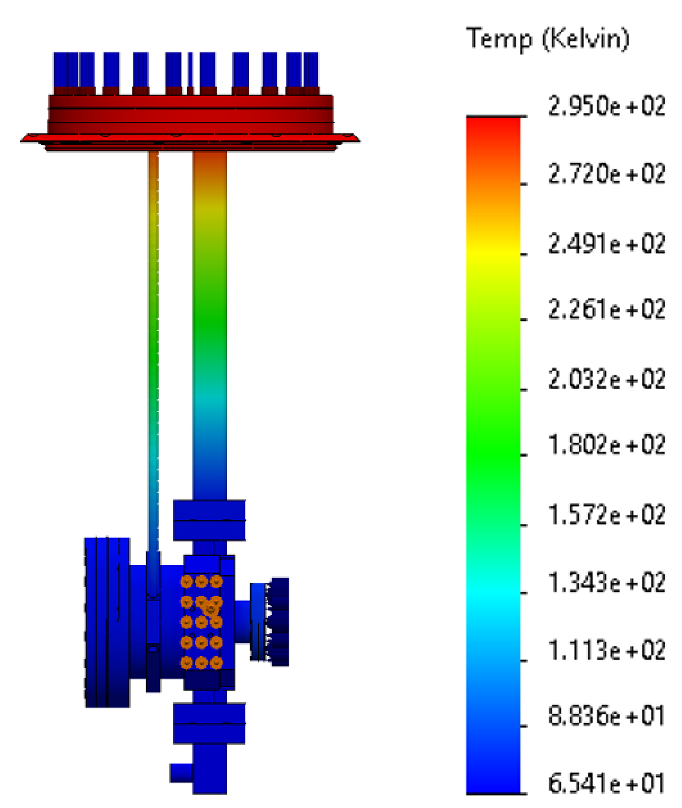
Multi-Objective Testing of High Gradient RF Accelerators (MOTHRA) laboratory and CYBORG beamline (above)

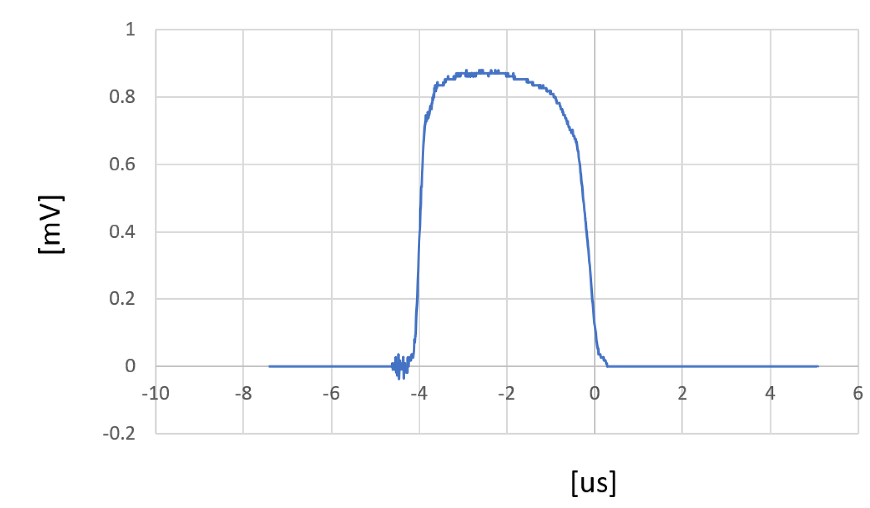
3 main functions: (1) an infrastructure development platform for future normal conducting cryogenic accelerators like [1]; steppingstone to ultra high gradient ultra-compact xfel photoinjector UCXFEL [2,3]; and test bed for low temperature cathode studies for the Center for Bright Beams (CBB) [4].

Brightness improvements at threshold photocathode emission with scaling law below

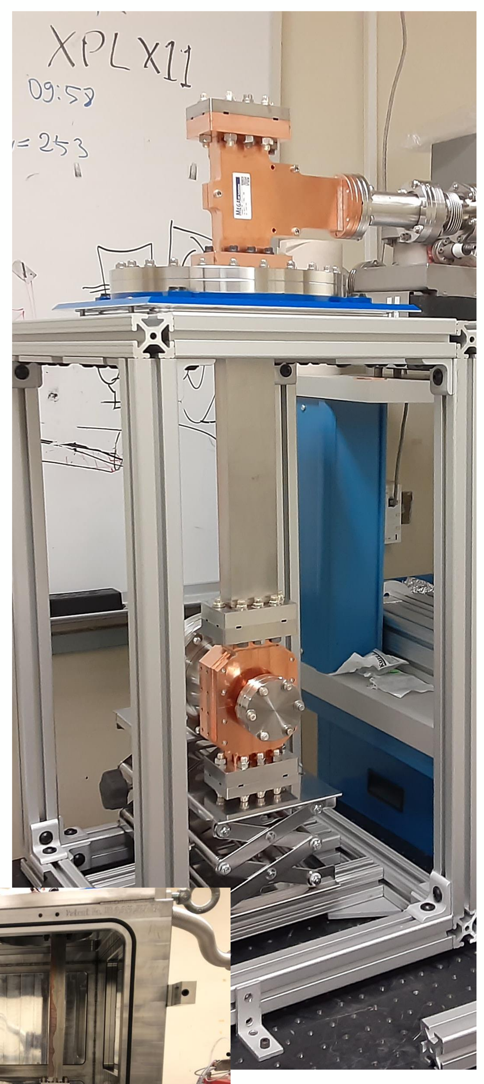
$$B_{1d} \approx \frac{2ec\varepsilon_0}{k_B T_c}\left(E_0 \sin\varphi_0\right)^2$$

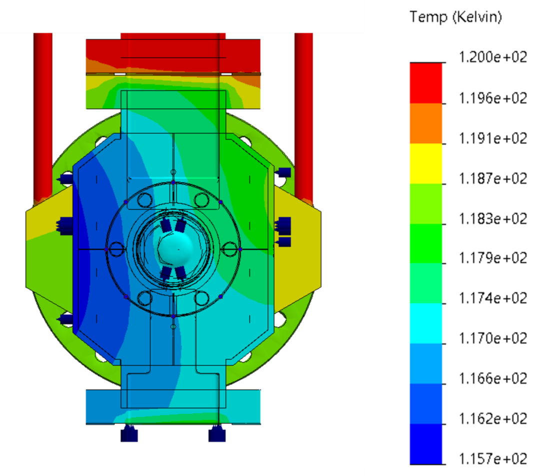
Photogun Thermal Balance



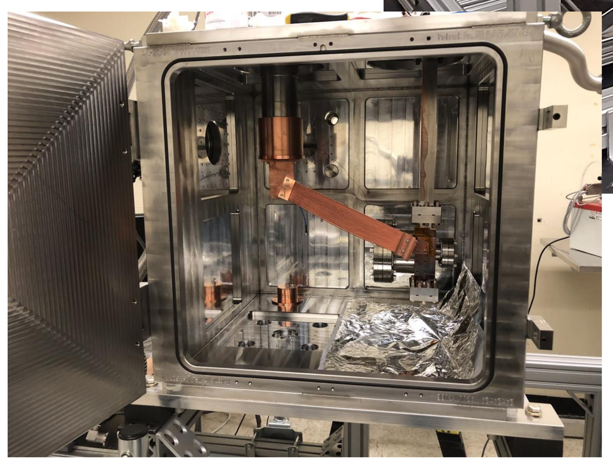


C-band klystron forward output from Thales tube with XK5 pulse tank and custom PFN. 5710 MHz central frequency (corresponding here to 500 kW)

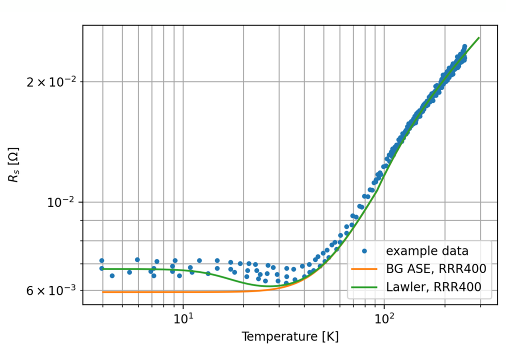




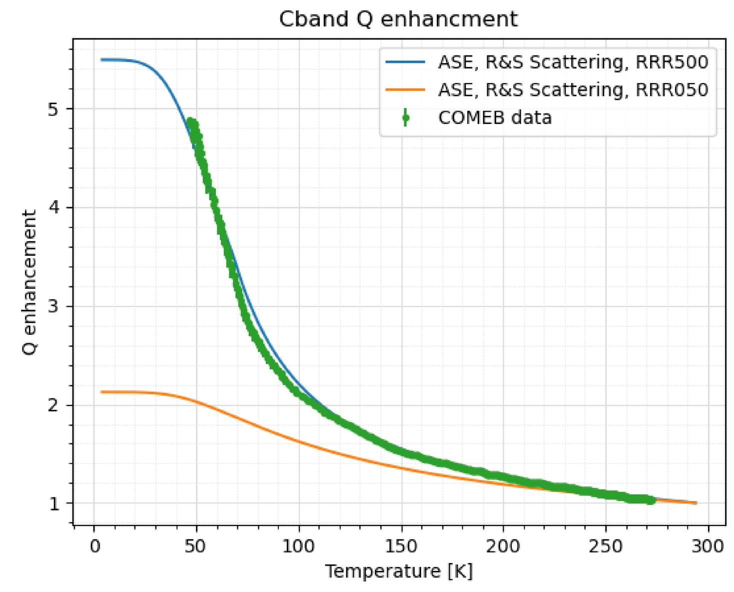
Thermal simulations of heat leaks and conduction cooling through gun. Note the support struts were found to be necessary during initial commissioning thus significantly reducing the heat leaks expected



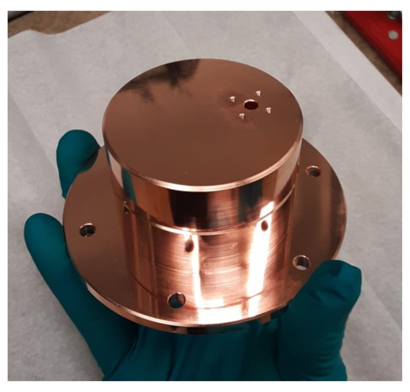
Basic Cavity Physics



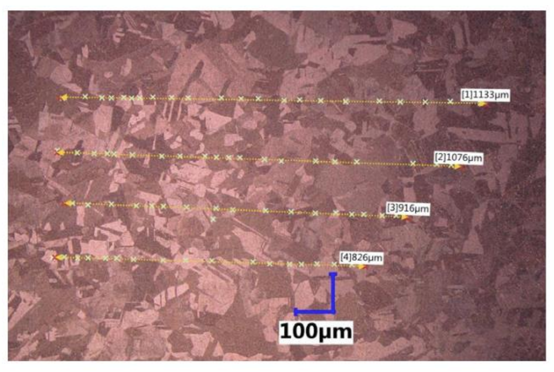
Comparison of Reuter and Sondheimer predictions to example data from Tantawi et al. and our thin film approximation model for an RRR of 400 (above)



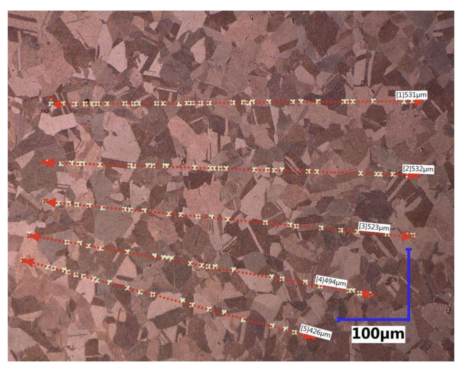
LLRF pillbox measurements of Q enhancement at cryogenic temperatures



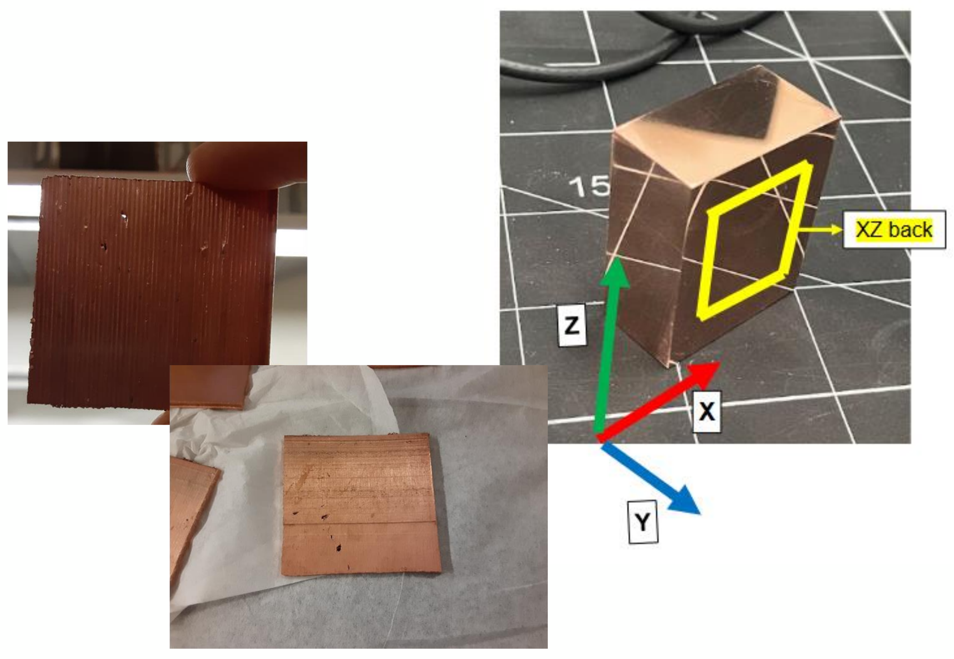
Coupon cut from 2% Silver CuAg brick showing pock marks extending at least 1/16" into bulk (below left) no porosity observed in 0.8% Silver coupon (below right)



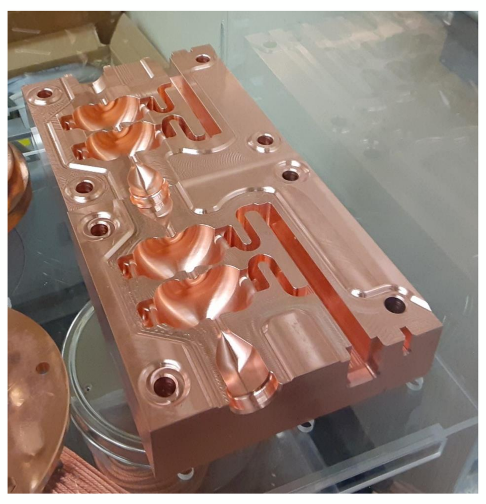
For 0.8% Ag grain size diameter of 121 ± 20um



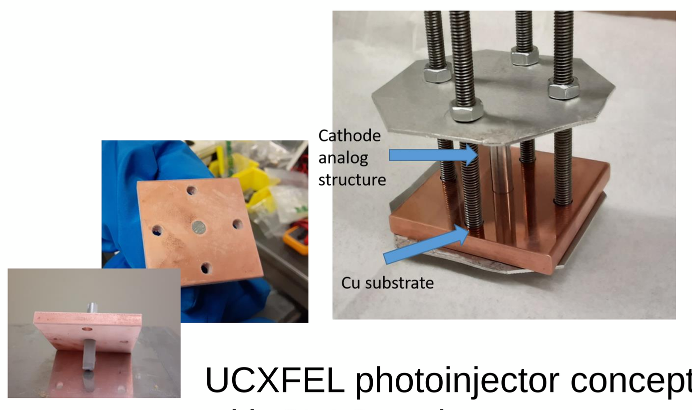
For 2% Ag grain size diameter of 106 ± 20um



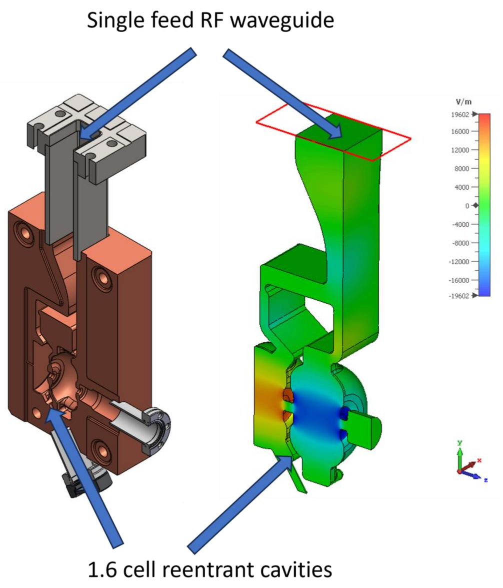
Phase2 and beyond

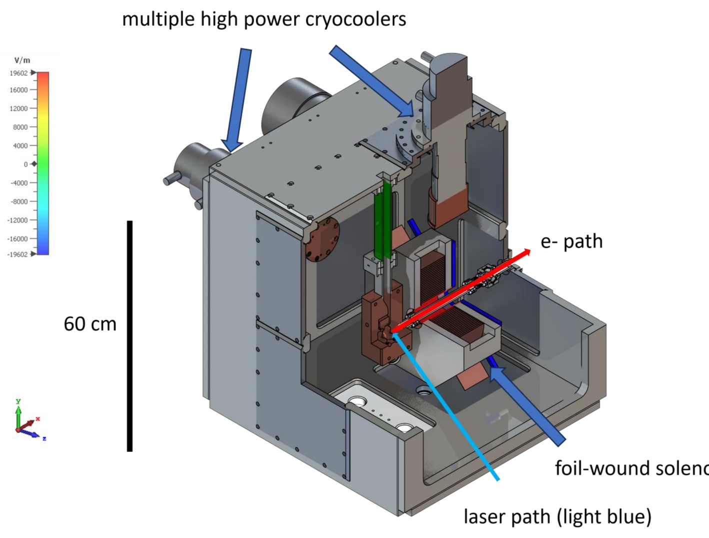


High power BDR test cavities (left); cathode coupling test (below)



UCXFEL photoinjector concept with SLAC cavity geom + LANL coupling + UCLA cryo





Future Directions

The RF and cryogenic subsystems of the CYBORG beamline are nearing full completion. CYBORG is fully housed in its long-term cryostat and static load cooling with the gun can begin soon. Dark current measurements as a function of the full range of operational temperature from 295K to below 77K will be made in the coming months as soon as additional radiation shielding is added to the lab bunker space. Cathode integration tests will continue with the addition of RF seal testing in cryogenic pillboxes. Preparations for high power BDR tests will continue.

References

[1] M. Bai et al., C3: A "cool" route to the higgs boson and beyond, 2021.
[2] J. B. Rosenzweig et al., "An ultra-compact x-ray free-electron laser," New J. Phys., vol. 22, p. 093 067, 2020, doi:10.1088/1367-2630/abb16
[3] R. R. Robles, O. Camacho, A. Fukasawa, N. Majernik, and J. B. Rosenzweig, "Versatile, high brightness, cryogenic photoinjector electron source," Phys. Rev. Accel. Beams, vol. 24, p. 063 401, 6 2021, doi:10.1103/PhysRevAccelBeams.24.063401
[4] G. Lawler et al., "RF Testbed for Cryogenic Photoemission Studies," in Proc. IPAC'21, 2021, paper WEPAB096, pp. 2810–2813, doi:10.18429/JACoW-IPAC2021-WEPAB096

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