Update on the C-band High Gradient Research Activities at LANL

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Outline of this talk

- Introduction and LANL C-band project overview
- Status of high gradient cavity testing at CERF-NM
- Status of CARIE: the high gradient RF injector test facility
- Summary and near-term plans

LANL High Gradient C-band research

The goals for LANL's high gradient project are

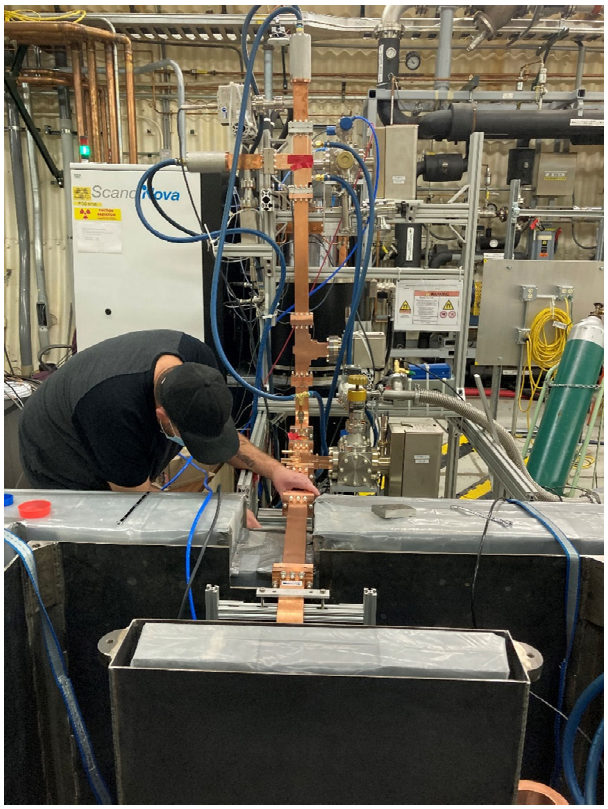
- To build a C-band (5.712 GHz) high gradient rf breakdown study facility (2019-2022).
- To build a C-band cryo-cooled photoinjector study facility (2022-2025).
- To conduct material studies.

This work was funded by Los Alamos National Laboratory (LANL) Laboratory Directed Research and Development (LDRD) program and Technology Evaluation and Development (TED) funds.

LANL C-band Engineering Research Facility (CERF-NM)

CERF-NM was built with $3M of LANL's internal infrastructure investment.

- Powered with a C-band Canon klystron
- Conditioned to 50 MW
- Frequency 5.712 GHz
- 300 ns – 1 μs pulse length
- Rep rate up to 200 Hz (typical 100 Hz)
- Nominal bandwidth 5.707-5.717 GHz



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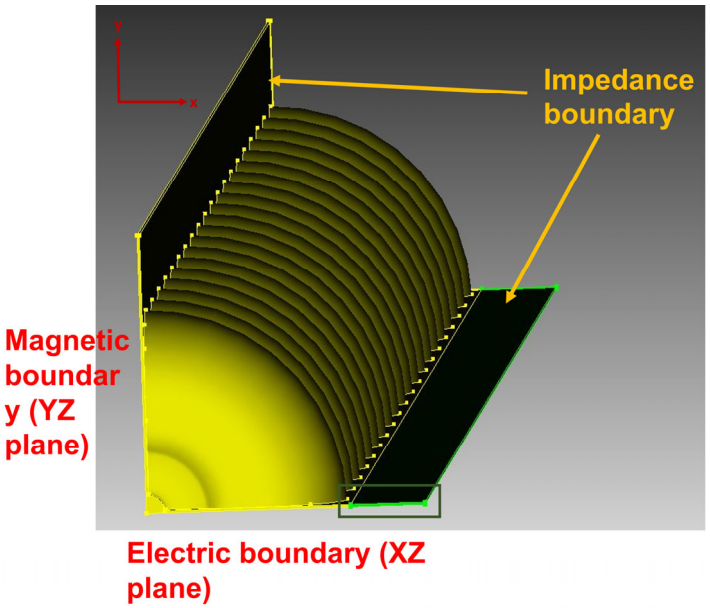
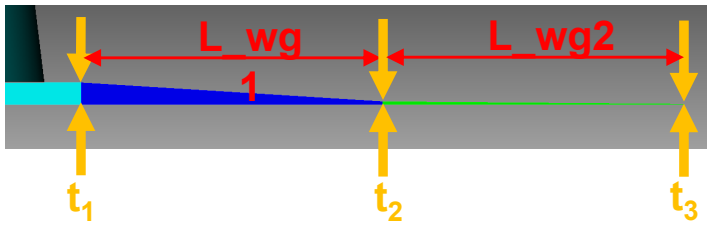
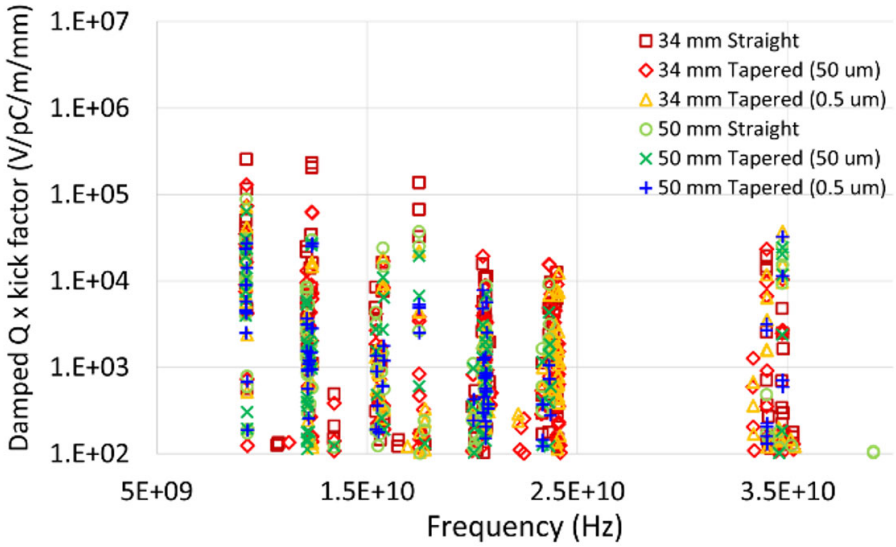
NiCr absorbers for HOM suppression

We conducted extensive optimizations of HOM suppression in a 20-cell C-band accelerating structure with NiCr absorbers.

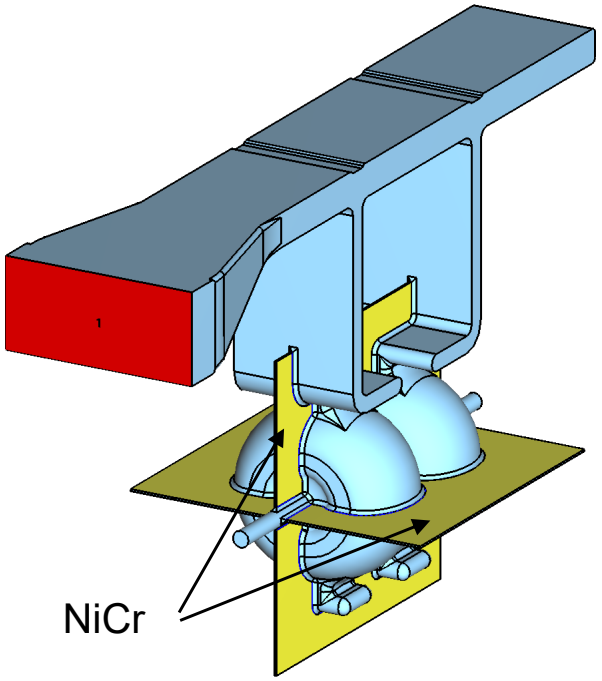


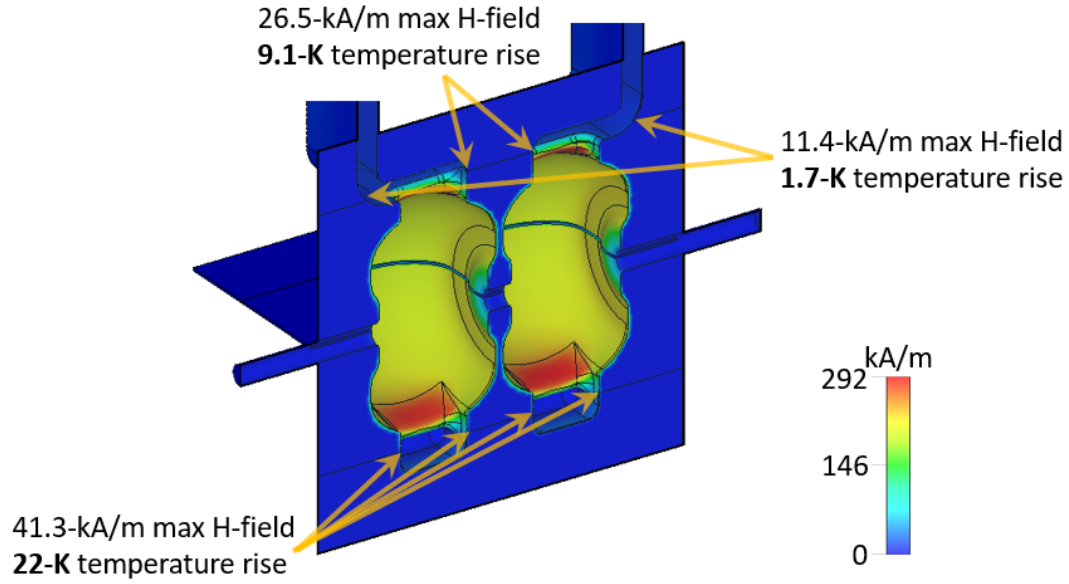




Two-cell test cavity with NiCr absorbers

- A two-cell cavity was designed to test if a structure with NiCr aborbers can be conditioned to high gradients.
- Issues to be studied: pulse heating, HOM generation during breakdown.





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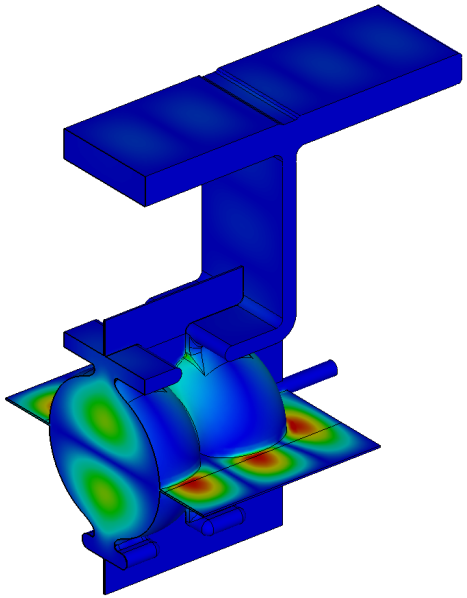
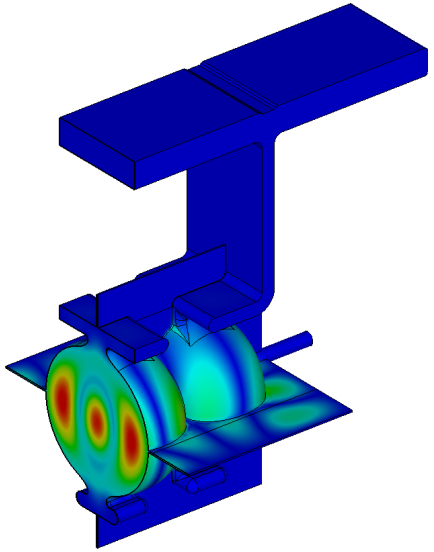
Various HOMs

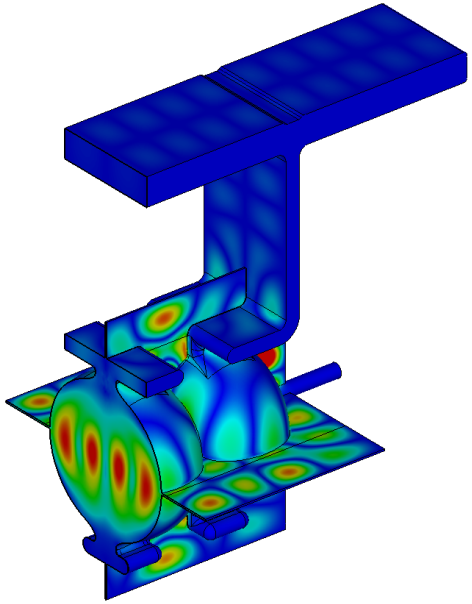
TM110 mode
9.21 GHz



TM021 mode
12.31 GHz



TM121 mode
17.62 GHz



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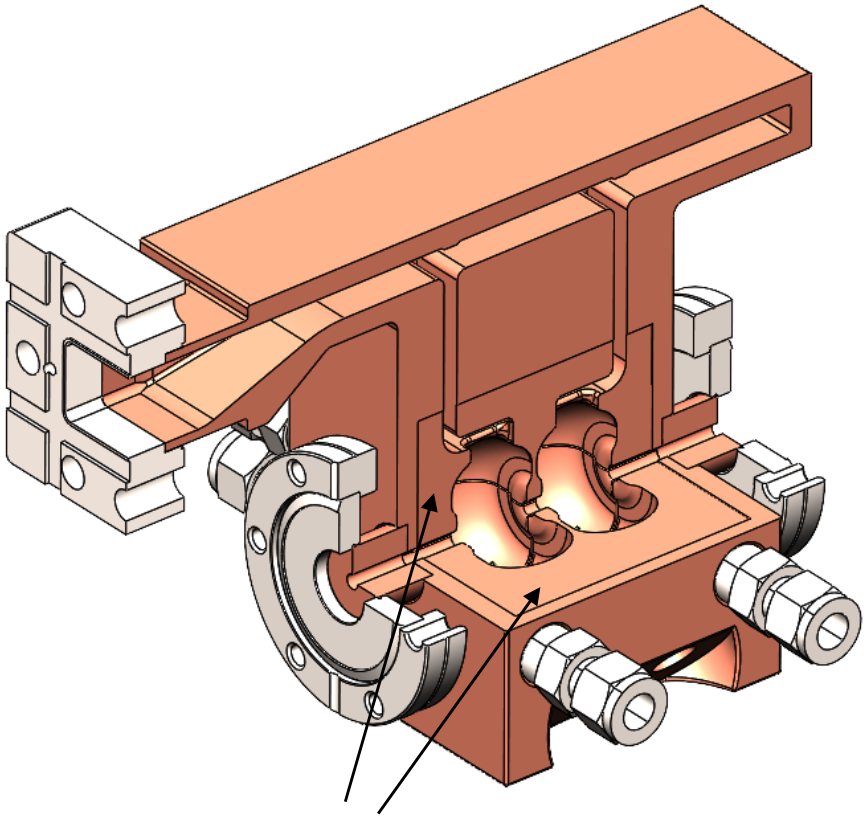
Fabrication of the cavity with absorbers

The cavity will be fabricated in four quadrants and several steps:

- Pre-fabrication of quadrants with HOM damping manifolds.
- Deposition of Ni and Cr layers.
- Fabrication of all cavity features that will remove unwanted NiCr layer.
- Final brazing and heat treatment of NiCr.



Absorber slots will be covered with NiCr

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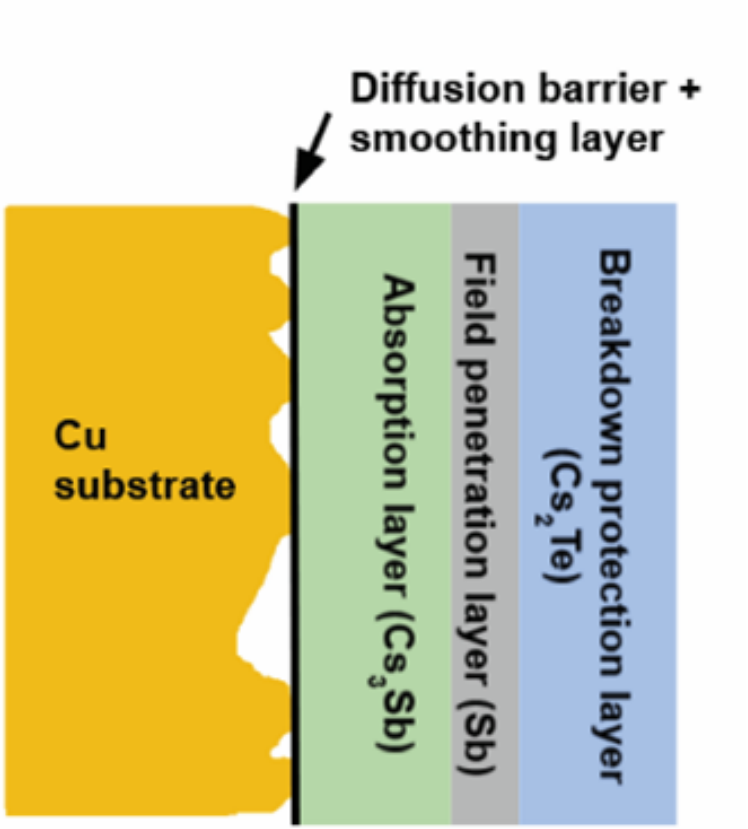
Summary and test plans for the cavity with NiCr absorbers

- Design of the cavity with NiCr absorbers is complete.
- Procurement is complete. Fabrication started in Dymenso.
- Delivery is expected in August of 2024 followed by testing at CERF-NM.

CARIE: Cathodes And Rf Interactions in Extremes

A new three-year project was funded at LANL to demonstrate operation of high-quantum-efficiency cathodes in a high-gradient RF injector.

- Project builds upon LANL's expertise in high-gradient C-band and high-QE photocathodes.
- The proposed heterostructured cathode will include multiple layers to ensure atomic flatness of the surface, high QE, and the ability to withstand high electric fields with no breakdown.
- Target beam parameters: 250 pC, 0.1 μm*rad, $B_{5D} = 10^{16}$ A/m^2.
- The project started in October of 2022.



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CARIE vault

- A location was identified on LANSCE mesa that can accommodate a 20 kW electron beam.
- The vault was cleaned for the new experiment.
- A modulator for the 50 MW C-band klystron has finally arrived.
- The klystron is installed. Conditioned to 35 MW of the output power, 1.5 μs pulse width, 50 Hz rep rate.

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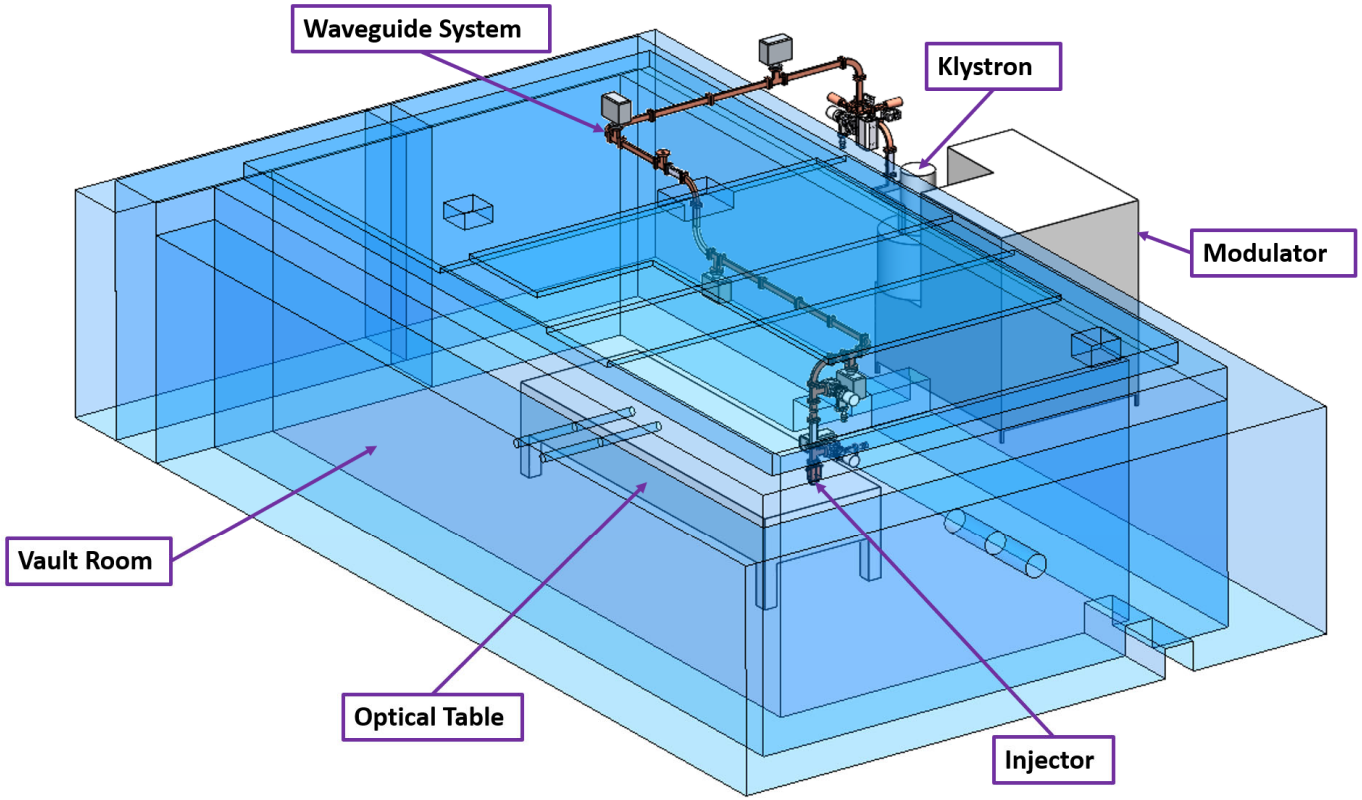
CARIE vault facility lineout – design with a magic T



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50 MW power circulator for CARIE

- Fabricated by Microwave Techniques LLC.
- Received at LANL in January, 2024.
- Designed to operate at 50 MW of power, 1 μs pulse, 100 Hz repetition rate.
- Must be filled with SF6 at 55 psi.
- Problem: CML WR187 windows are designed for 40 psi, Microwave Techniques WR187 windows are designed for 35 psi.
- Microwave Techniques states that if filled to 30 psi, should operate up to 10 MW of power.

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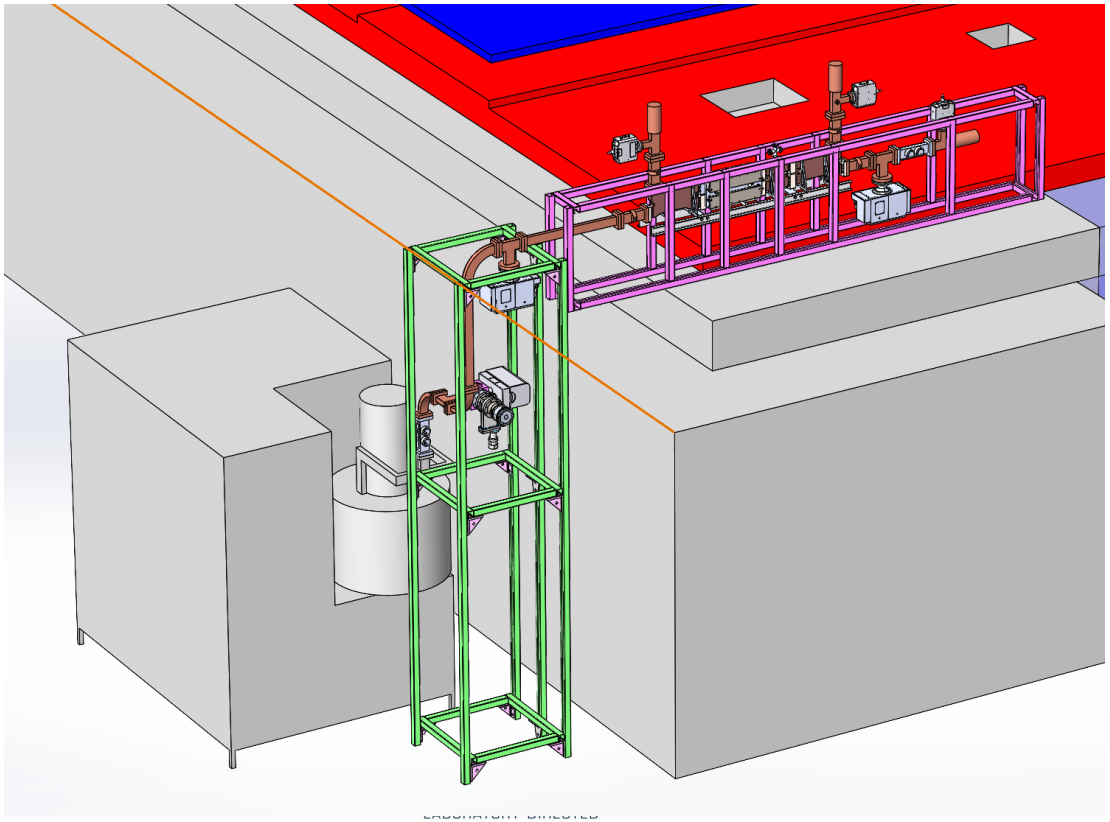
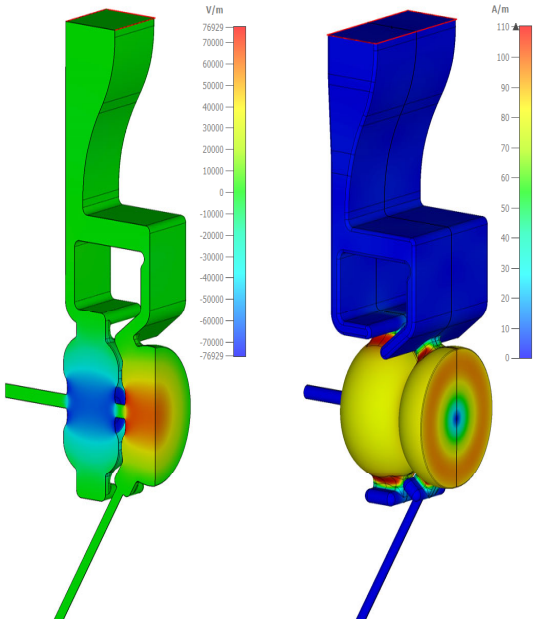
CARIE vault facility lineout – design a circulator

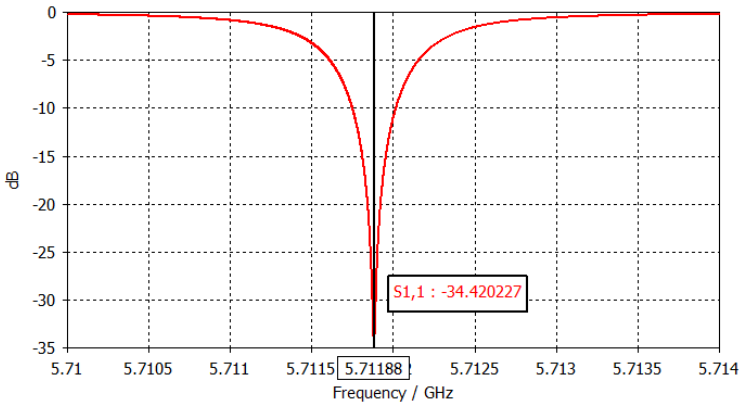
- Installation is currently in progress.

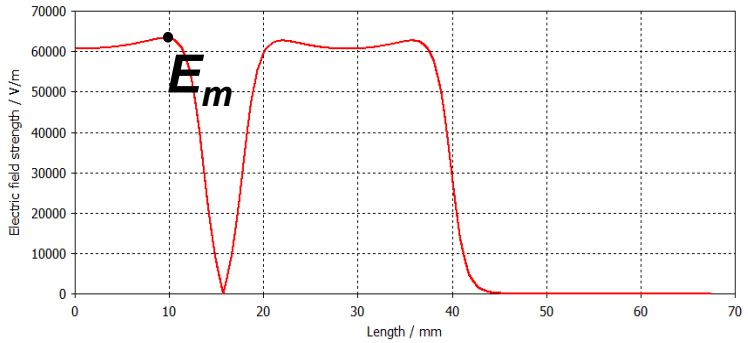


RF photoinjector electromagnetic design

- RF design for the all-copper photoinjector is complete.
- 1.6 cell injector
- Two waveguides couple the half-cell and the full cell with 180^0 phase advance.
- E_{surf}/E_{cath}=1.28, $H_{surf}Z_0/E_{cath}$=0.64.
- Power for E_{cath}= 240 MV/m is about 8 MW.







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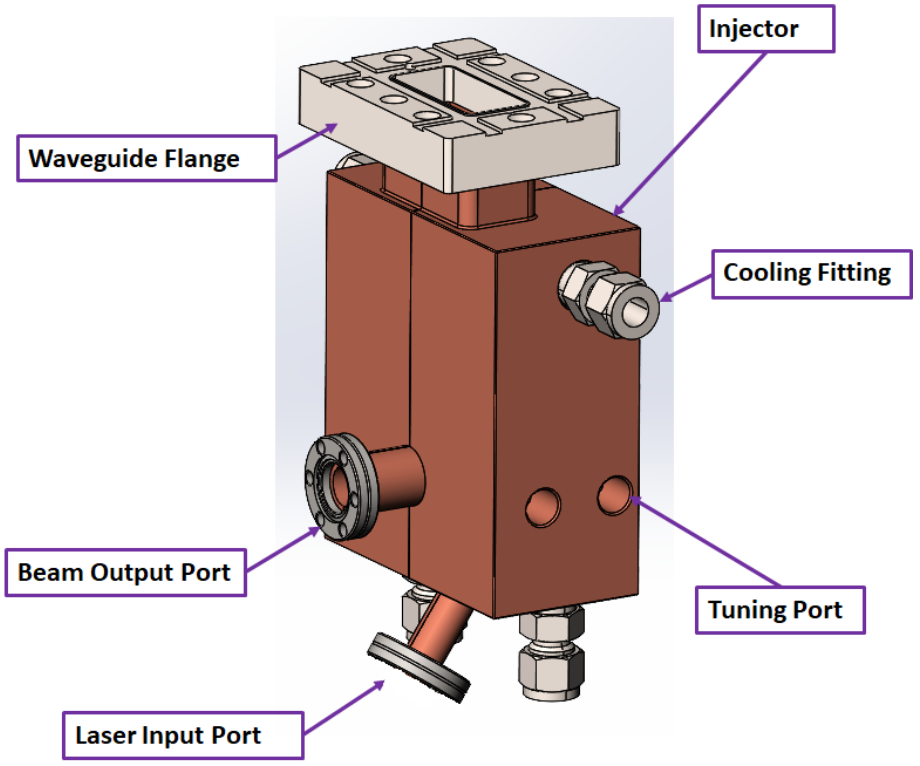
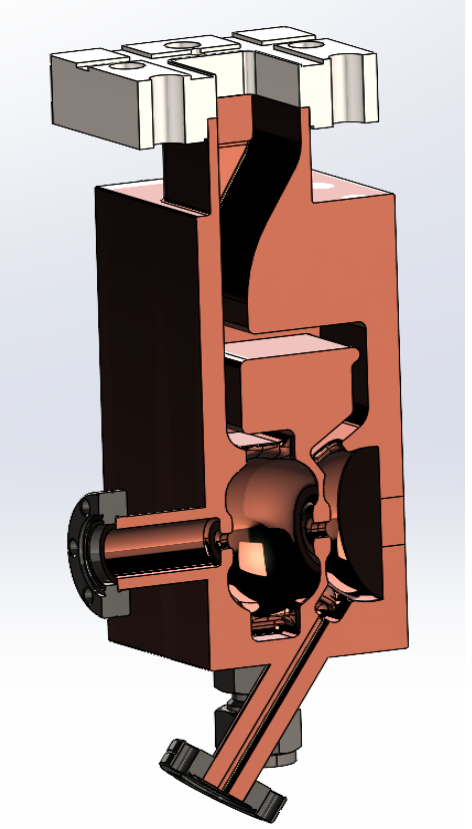
RF photoinjector fabrication

- We will first fabricate and test an all-copper injector with no cathode plug.
- CAD design for the all-copper photoinjector is complete.
- The cavity was received at LANL in October, 2023.





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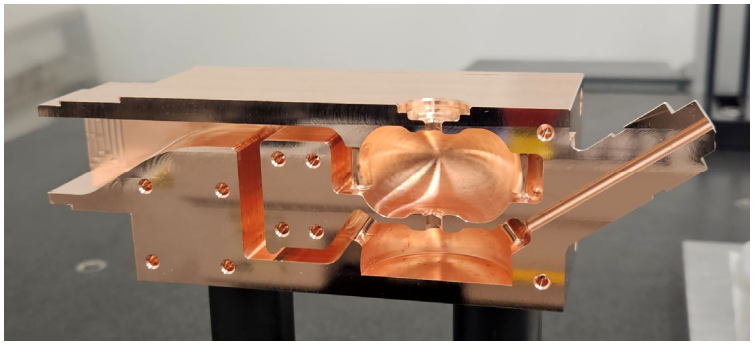
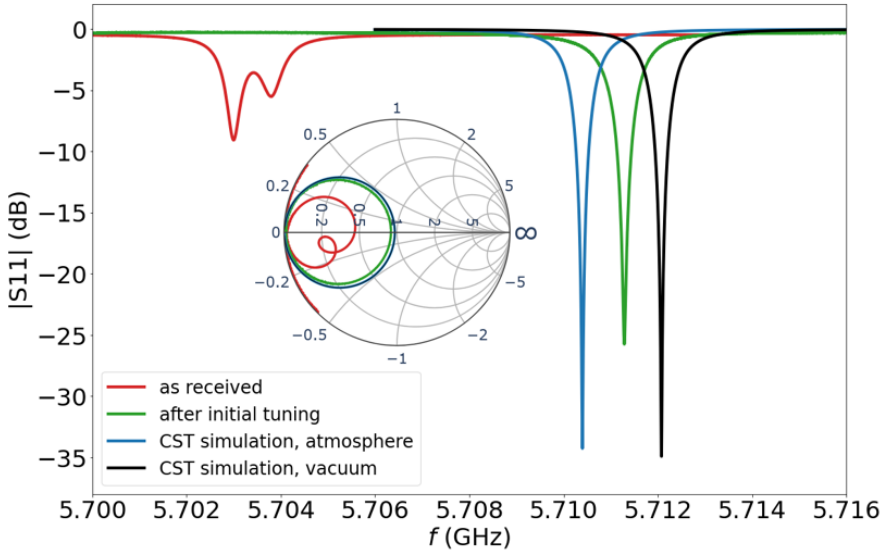
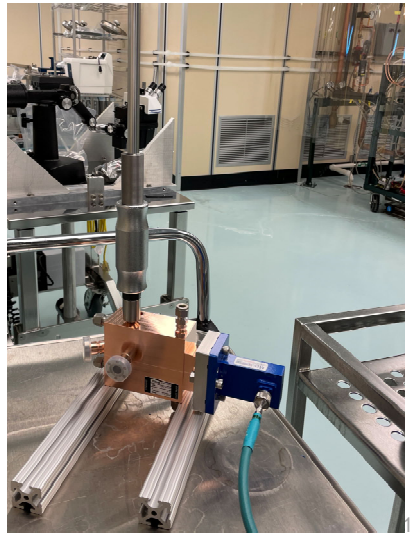
RF photoinjector cold testing

- Tuning of the photoinjector was successful.
- Tuned frequency 5710.53 MHz in air (5712.15 MHz in vacuum).
- Measured Q-factor 11869 (computed Q-factor 11934).

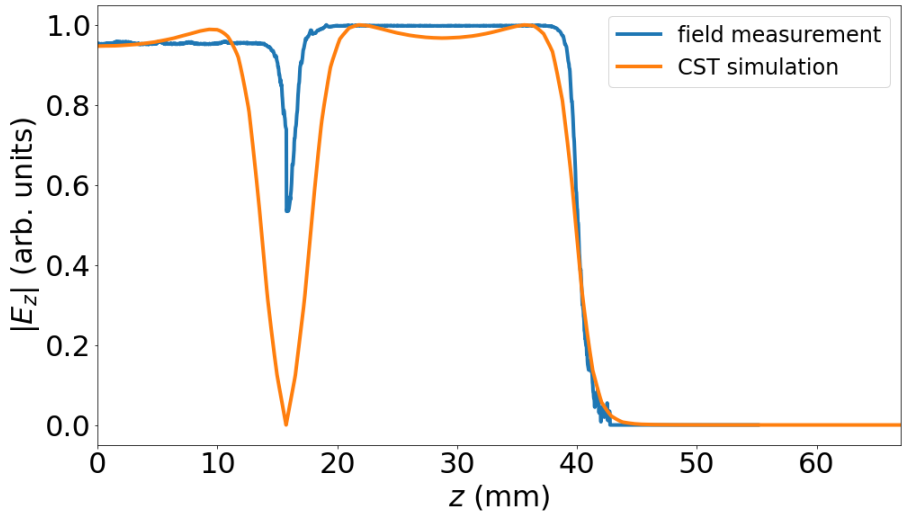






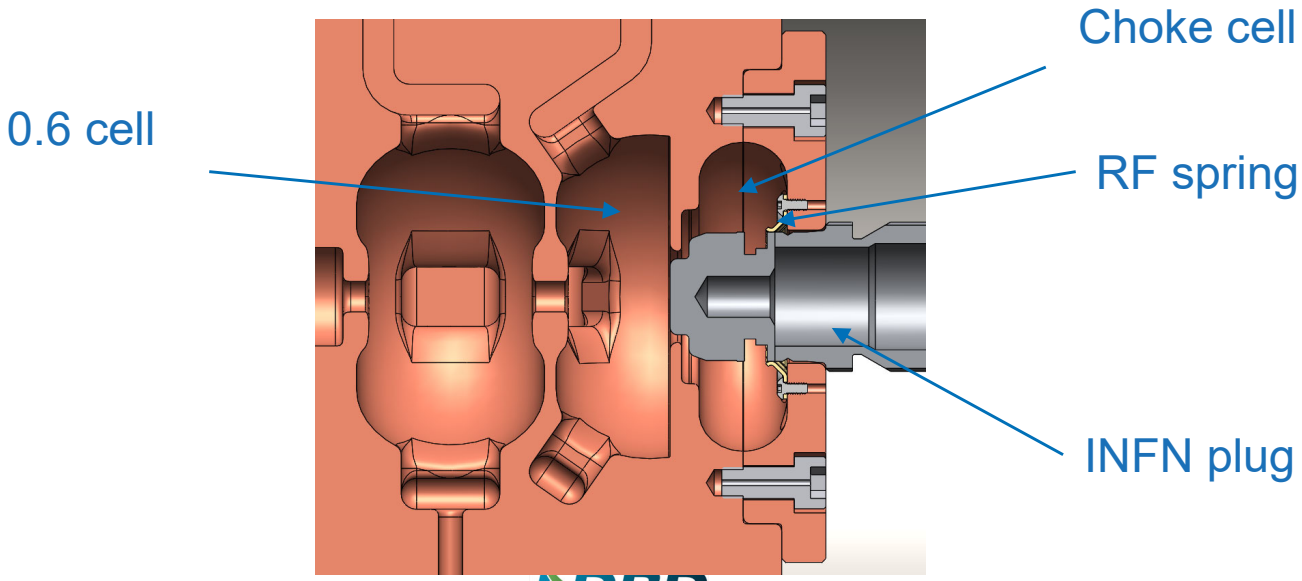
Field profile measurement

- Good agreement with CST after tuning on 11/14/2023.
- Cathode field is 95% of the field in full cell.



Photoinjector with a cathode plug

- CARIE facility will be used to study behavior of cathodes at high gradient.
- INFN-style cathode plug will be used for inserting cathodes.
- The choke cavity will reject the fundamental mode coupling into the plug insertion hole.



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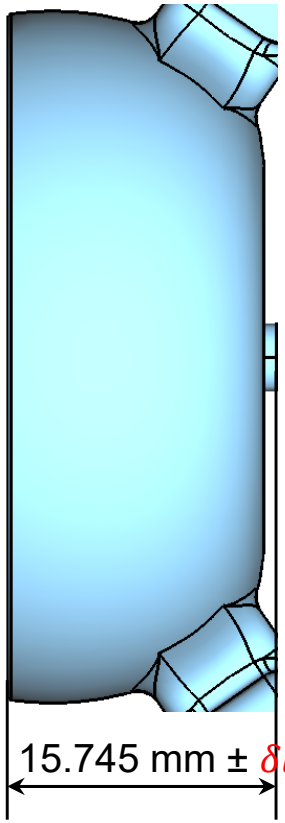
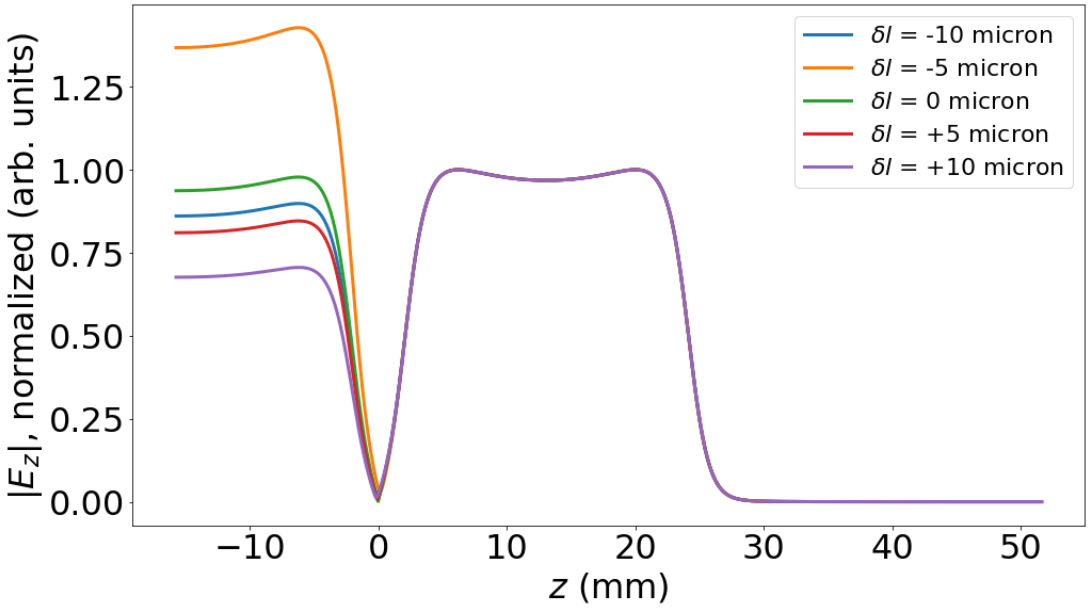
Thoughts on the cathode plug positioning accuracy…



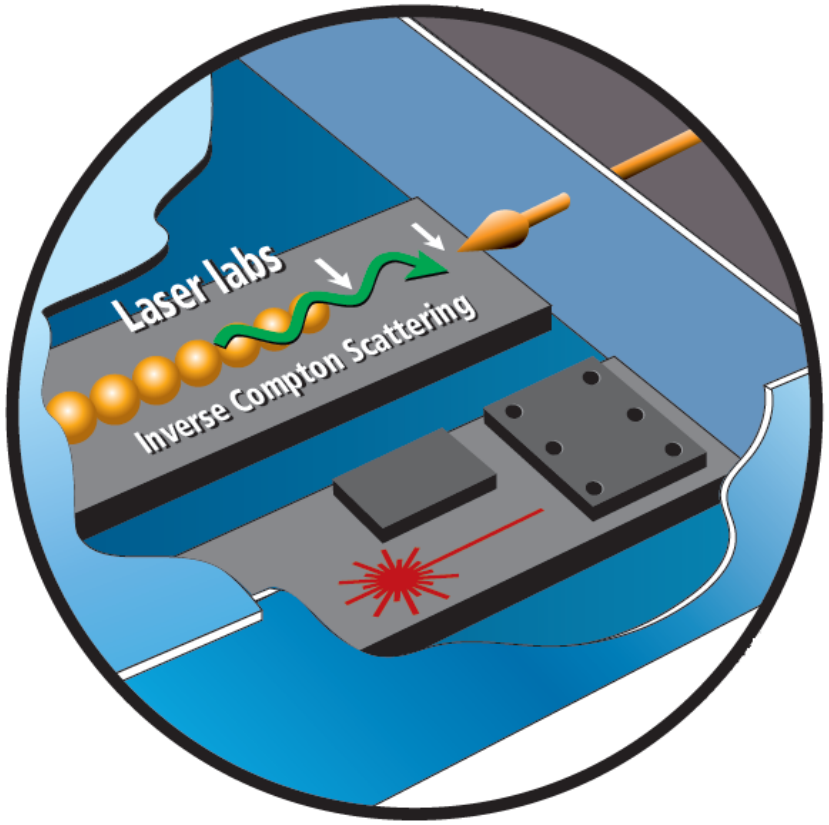
CST simulation of the field profile for different cathode plug positions:



Micron-scale alignment tolerance is required, between the photocathode surface and the cathode-cell plane.

LANL has plans for further developing its C-band accelerator capabilities

- Director Initiative money were allocated in FY22 to jump start this facility.
- 5-year goal: build operational C-band cryo-cooled copper accelerator.
- Ultimate goal: provide 43 keV and 100 keV photon bursts for material studies with Inverse Compton Scattering
- Another project idea under development – MeV Ultrafast Electron Diffraction facility.



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