Update on the High Gradient C-band project at LANL

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Outline of this talk

- Introduction and LANL C-band project overview
- Experimental activities
  - ✓ CERF-NM: High gradient C-band test stand
  - ✓ CARIE: new high gradient RF injector test facility
- Summary and near-term plans

Introduction: why Los Alamos

Achieving high-gradient performance (low breakdown rates, low field emission, new materials for HOM absorption, cathodes at high gradient etc.) is a *materials science* problem.

Los Alamos is, at core, a materials science laboratory with particular expertise and interest in metallurgy.

Los Alamos also considers itself the steward of accelerator science for the NNSA part of the DOE complex.

Thus, Los Alamos has both an institutional interest in, and capability to address, this problem space.

High gradient C-band work directly aligns with future NNSA and LANL missions.

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LANL High Gradient C-band research

The goals for LANL's high gradient project are

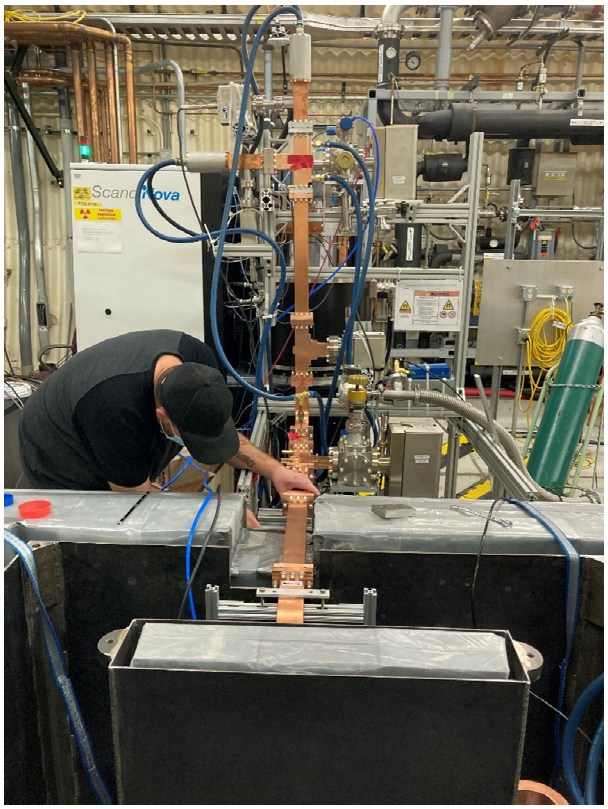
- To build a C-band (5.712 GHz) high gradient rf breakdown study facility (2019-2022).
- To build a C-band cryo-cooled photoinjector study facility (2022-2025).
- To conduct material studies.
- To develop C-band compact accelerator facility for X-ray production or UED (future).

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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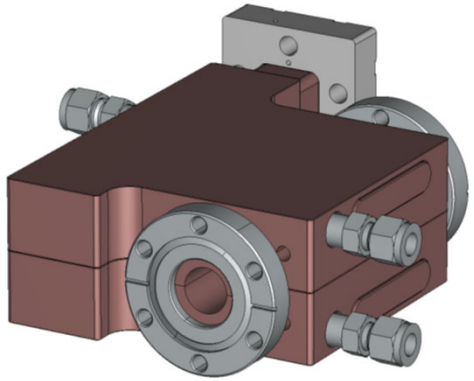
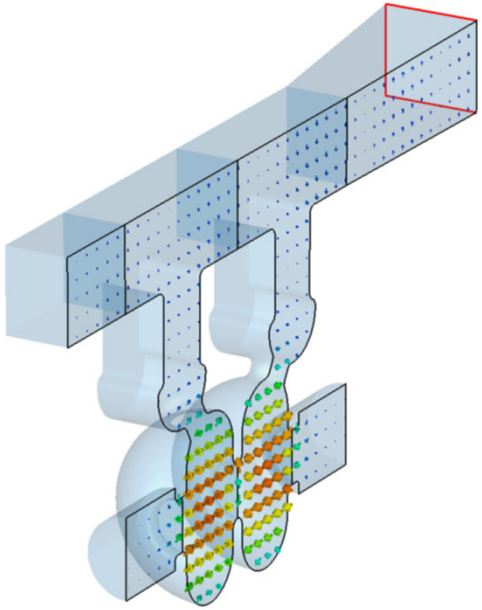
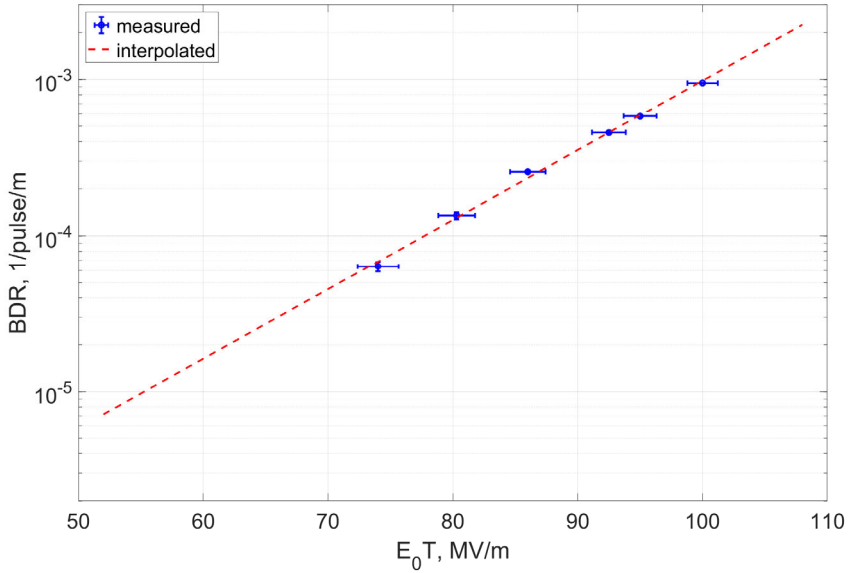
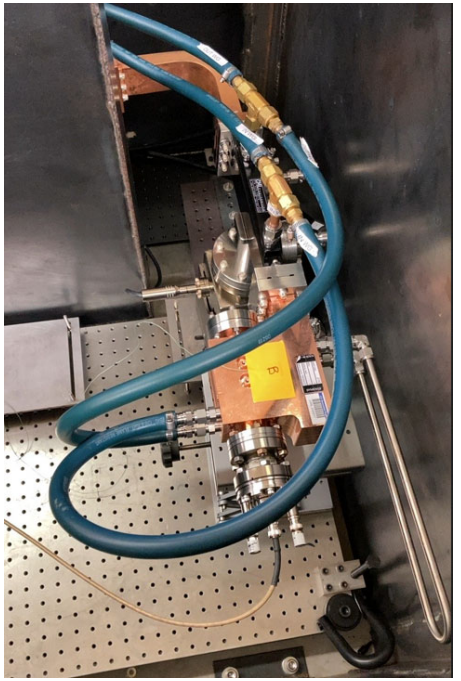
Prototype booster cell for LANSCE upgrade tested in FY23

The goal of this experiment was to measure the breakdown rates at accelerating gradients up to 100 MV/m.









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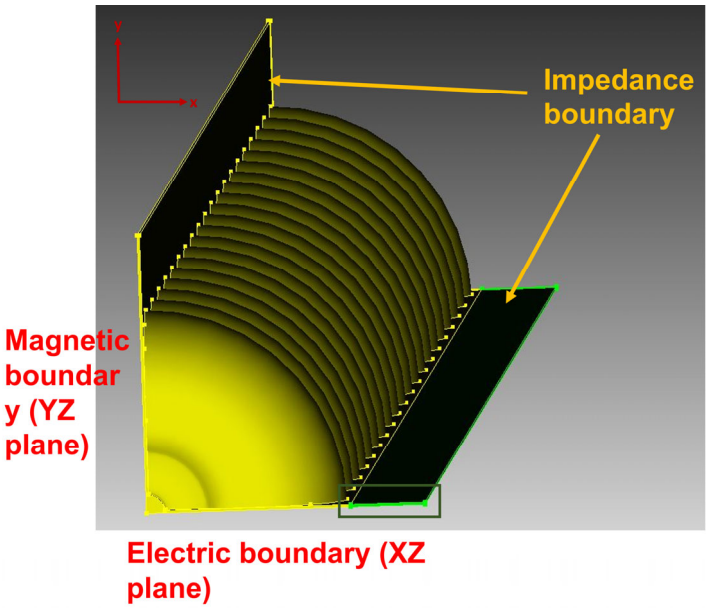
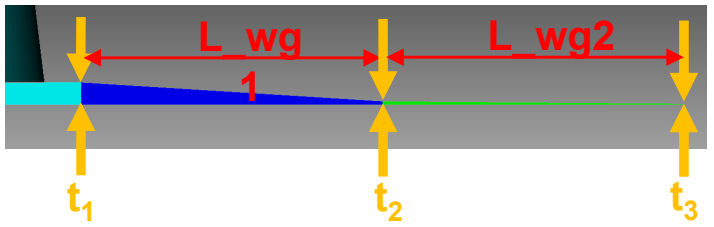
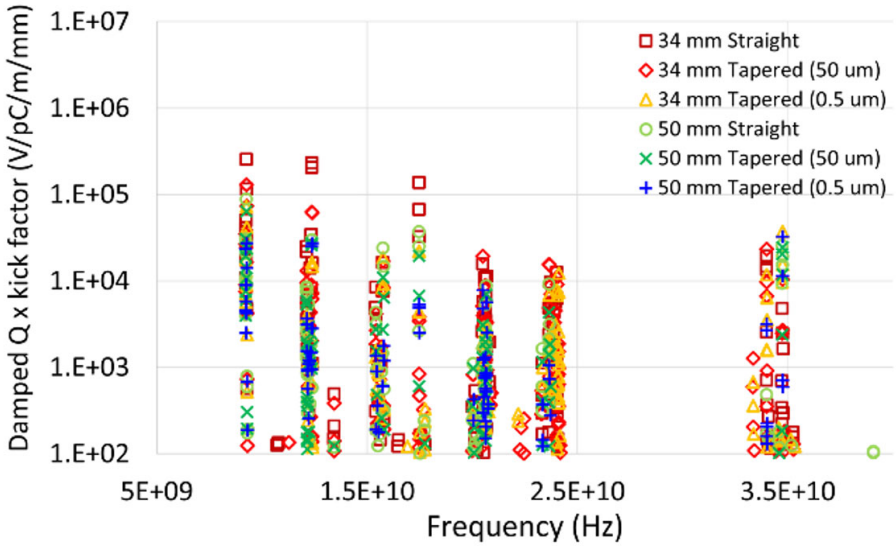
NiCr absorbers for HOM suppression

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

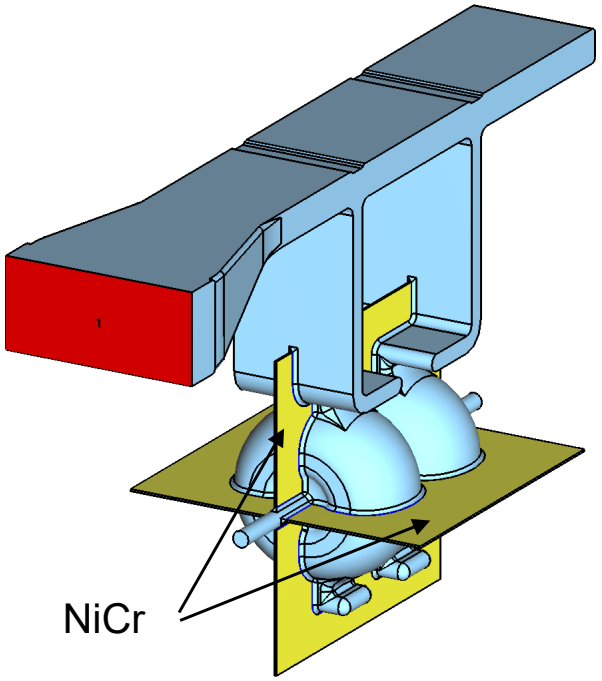


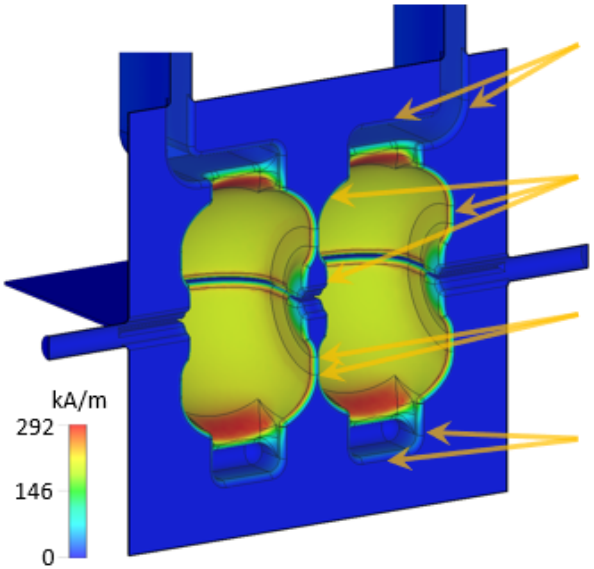




Two-cell test cavity with NiCr absorbers

- 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.





RF couplers
1.2-kA/m max H-field
0.02-K NiCr temperature rise

Cell profile curves
15.0 kA/m to 38.7 kA/m H-field
2.9-K to **19.4-K** NiCr temperature rise

Coated corners at boundary of cells
38.7 kA/m H-field
19.4-K NiCr temperature rise

Symmetry stubs
1.5 kA/m to 15.0 kA/m H-field
0.03-K to **2.9-K** NiCr temperature rise

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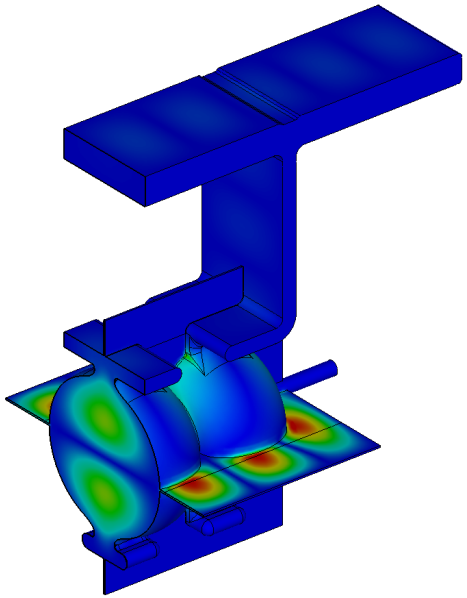
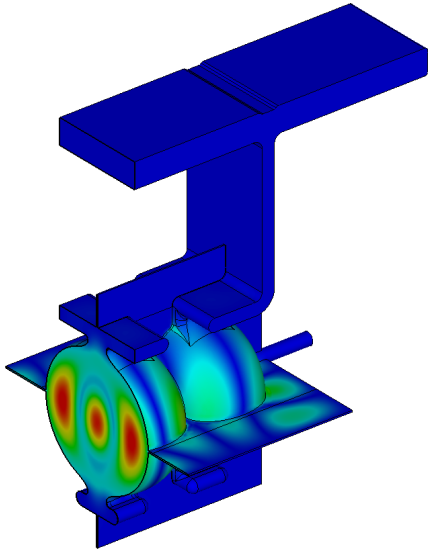
Various HOMs

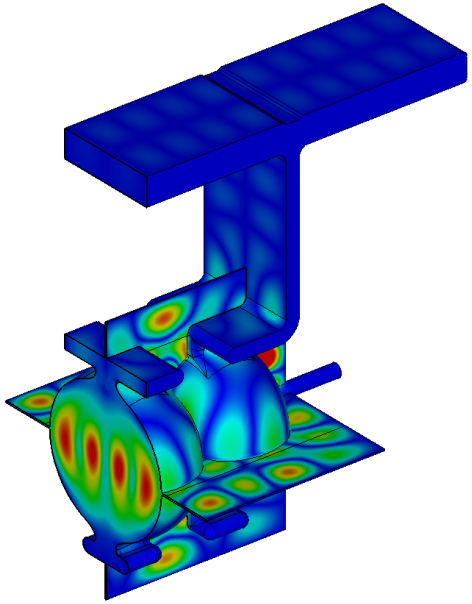
TM110 mode
9.21 GHz



TM021 mode
12.31 GHz



TM121 mode
17.62 GHz



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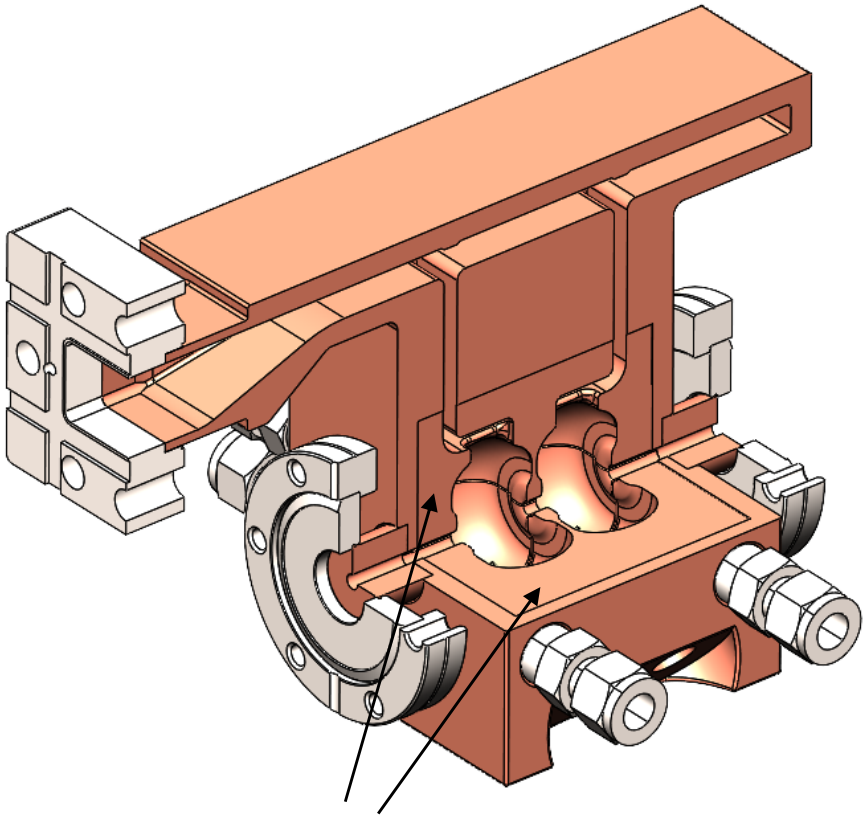
Fabrication of the cavity with absorbers

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 CERF-NM

LANL C-band high gradient test stand is currently operational

- Testing of the SLAC copper beta=0.5 cavities, two a/λ = 0.105 cavities, and a LANSCE proton booster cavity is finished.
- In FY24 we will be testing a two-cell distributed-coupling structure with NiCr HOM absorbers. We also consider other tests.

<u>The test stand is open to collaborators.</u>

We consider adding capability to cool cavities under test to cryogenic temperatures.

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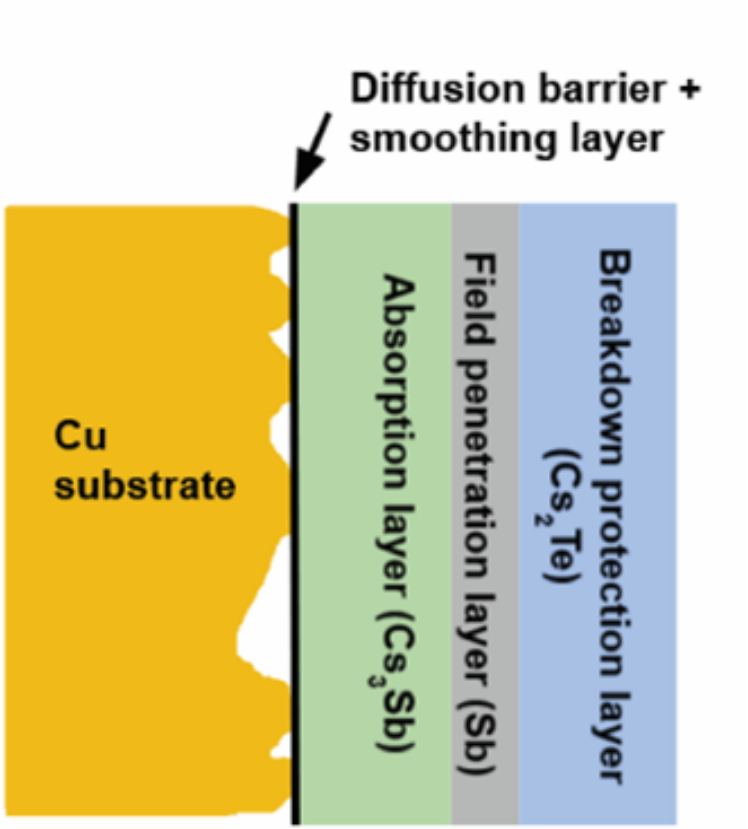
CARIE: Cathodes And Rf Interactions in Extremes

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 being installed. To be tested in October, 2023.

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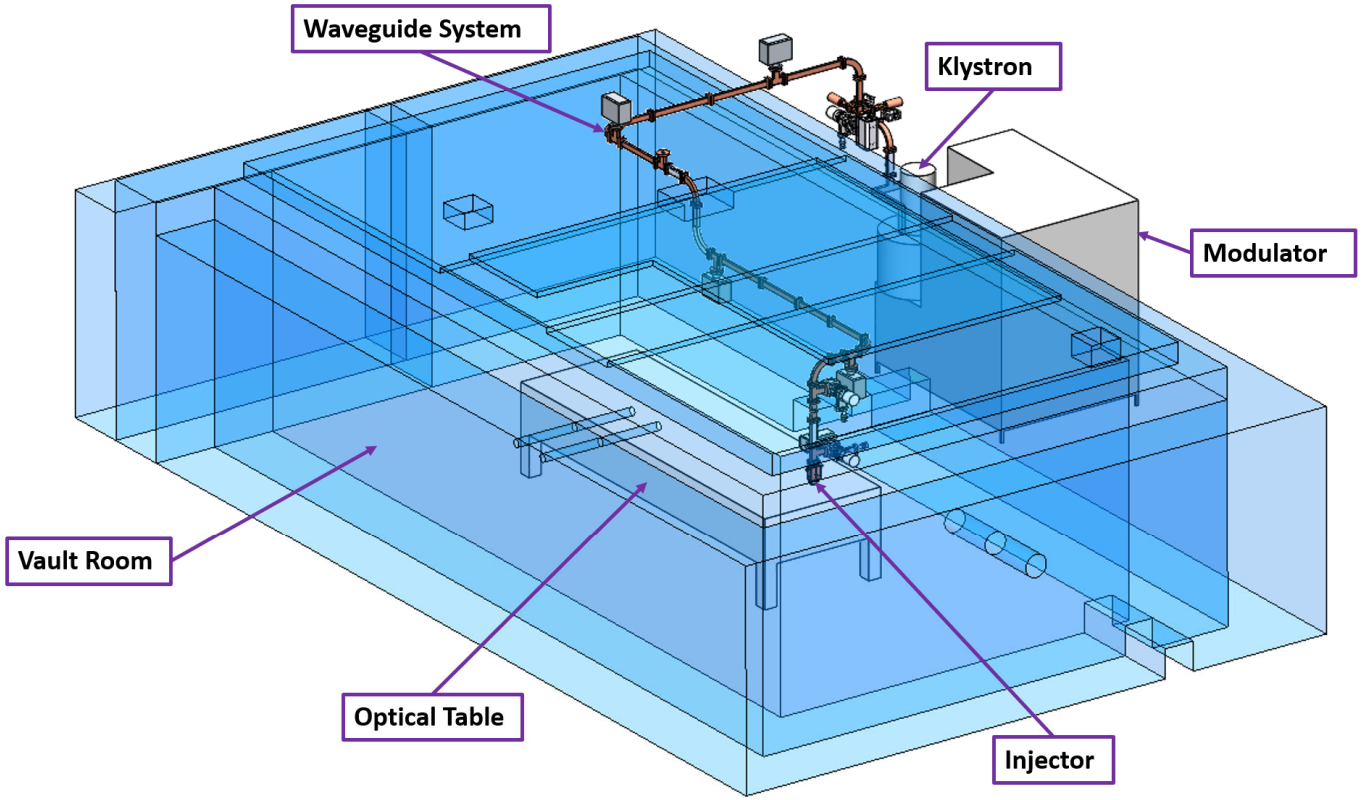
CARIE vault facility lineout



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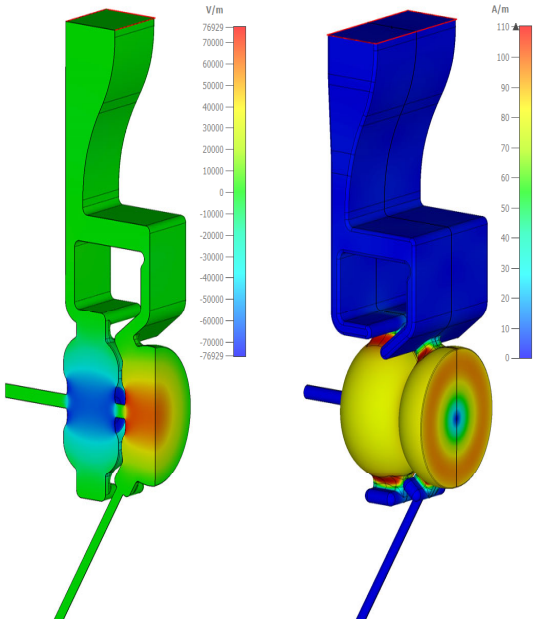
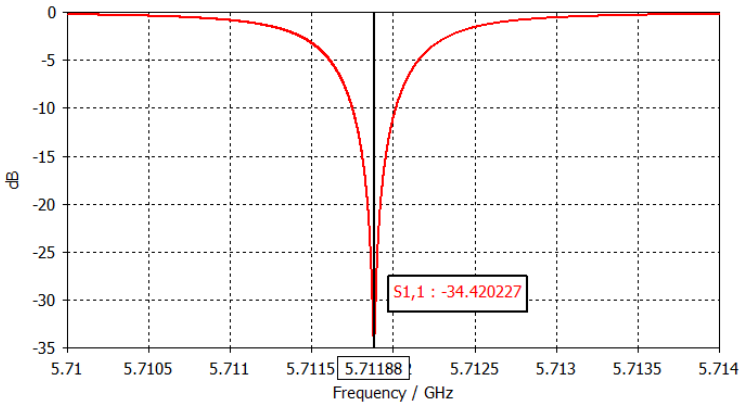
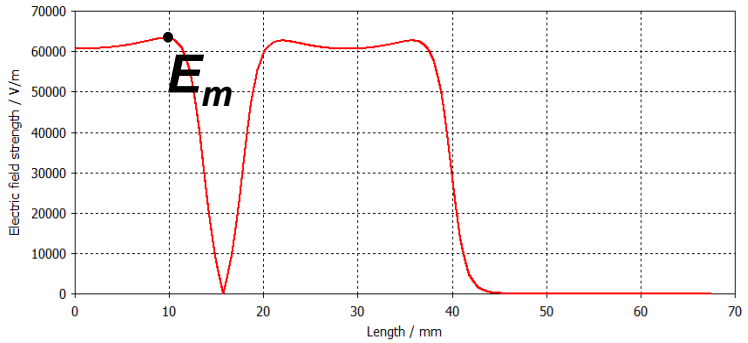
RF photoinjector electromagnetic design

- 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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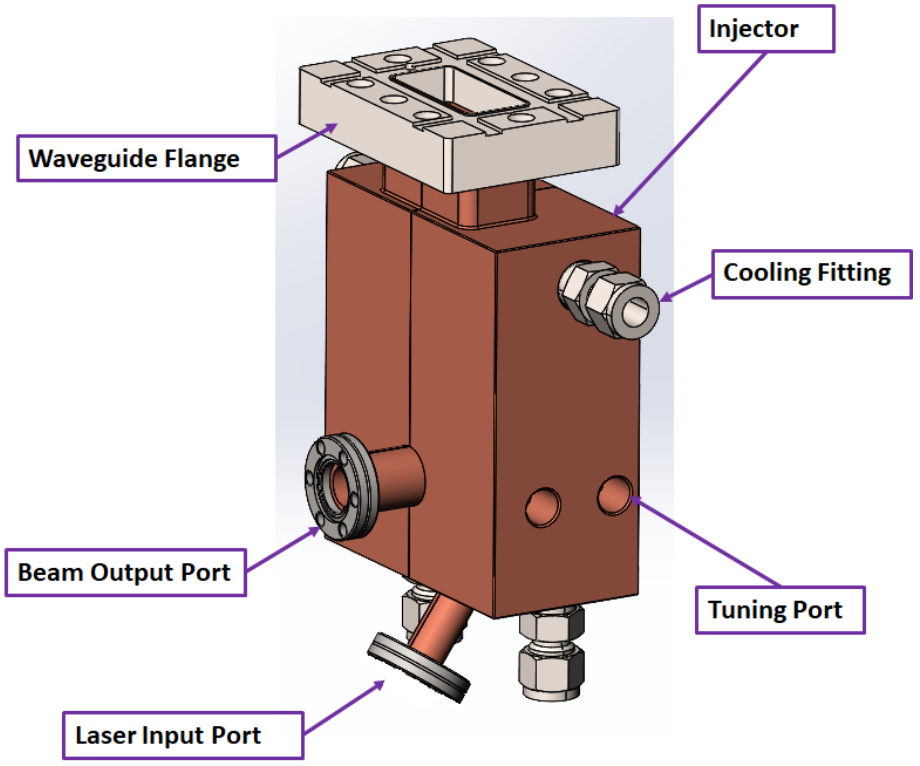
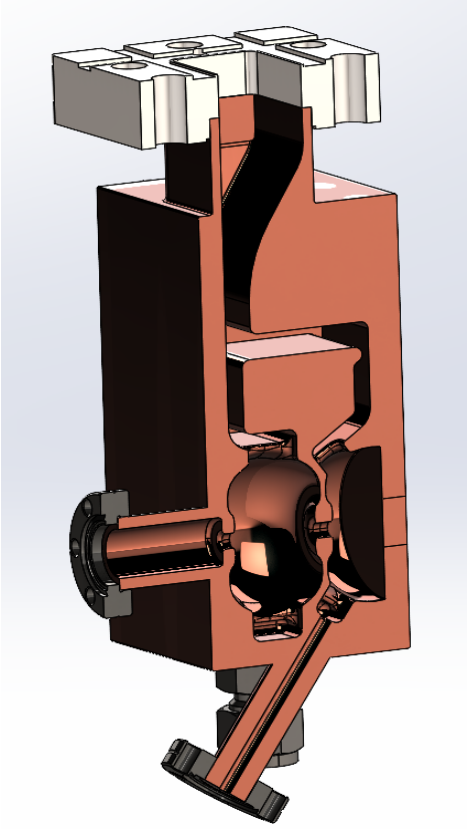
RF photoinjector fabrication

- 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 on Monday.





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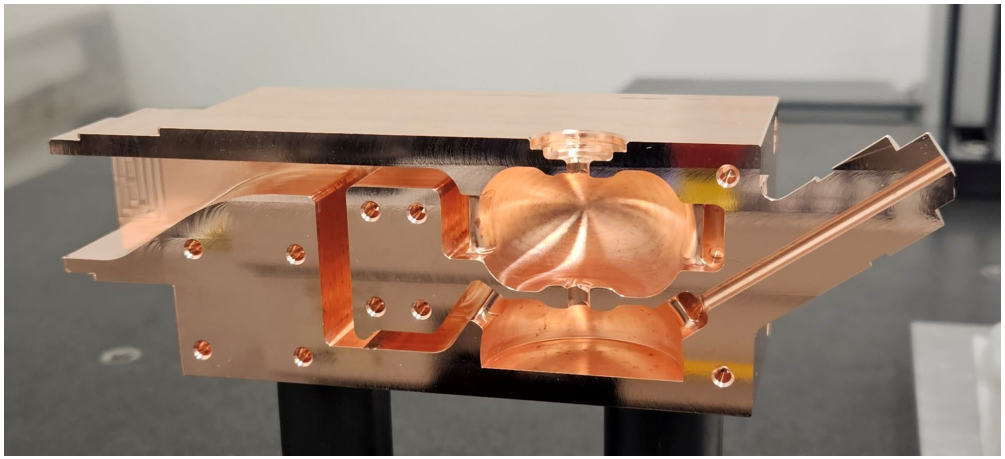
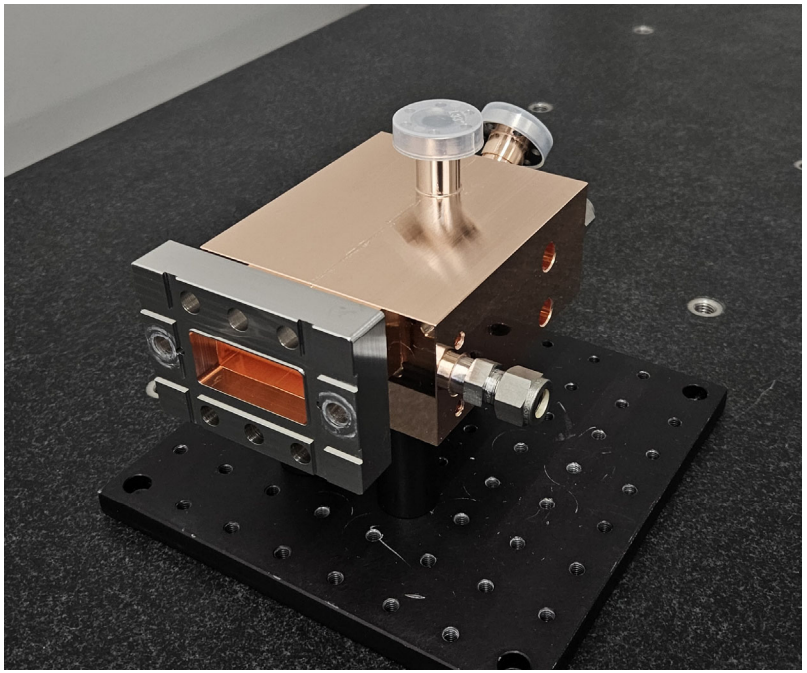
Photographs of the photoinjector

- The photoinjector is received at LANL.
- Cold test and tuning is planned for October, 2023.
- High power tests are planned for early 2024.





Photos courtesy to P. Borchard at Dymenso.

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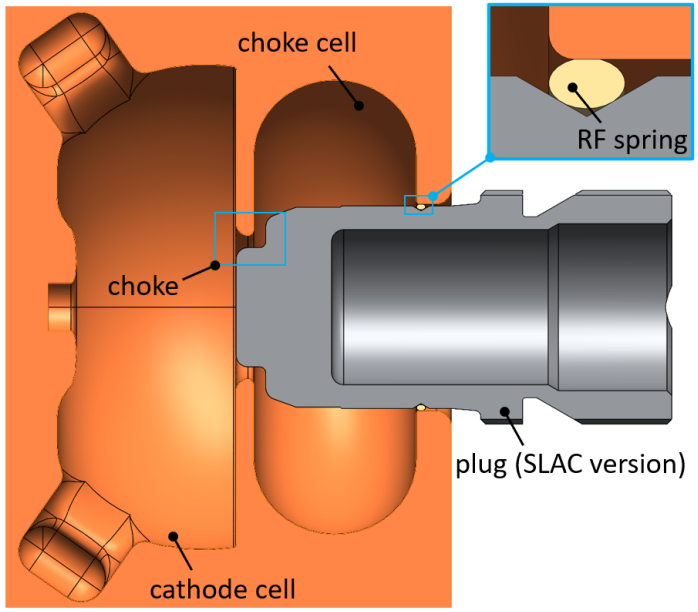
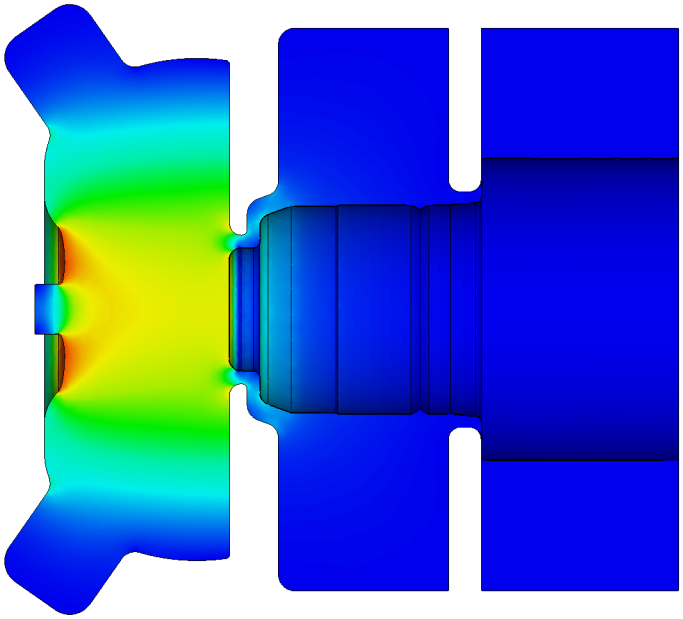
Photoinjector with a cathode plug

- CARIE facility will be used to study behavior of cathodes at high gradient.
- RF and mechanical designs for a cavity with INFN-type plug are in progress.
- The choke cavity will reject the fundamental mode coupling into the plug insertion hole.





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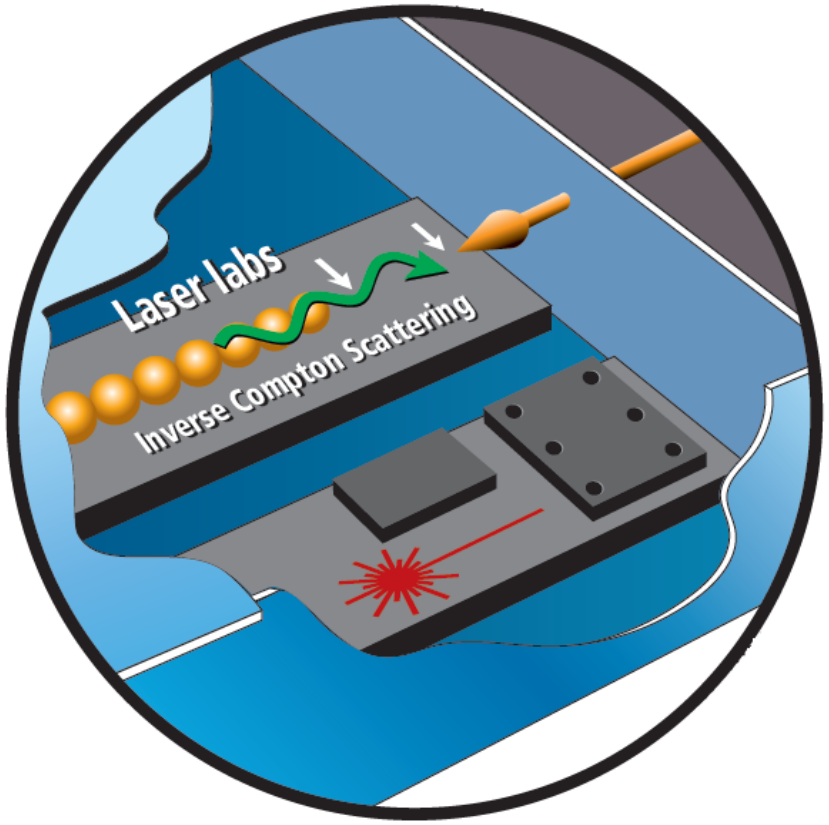
LANL has plans for further developing its C-band accelerator capabilities

- 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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