Update on the Cathodes and Radiofrequency Interactions in Extremes (CARIE) high gradient photocathode test stand at LANL

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06/26/2024

Outline of this talk

- Introduction and LANL C-band project overview
- Status of CARIE construction: the high gradient RF injector test facility
- New photoinjector with the cathode plug
- Summary and near-term plans

LANL High Gradient C-band research

The goals for LANL's high gradient project are

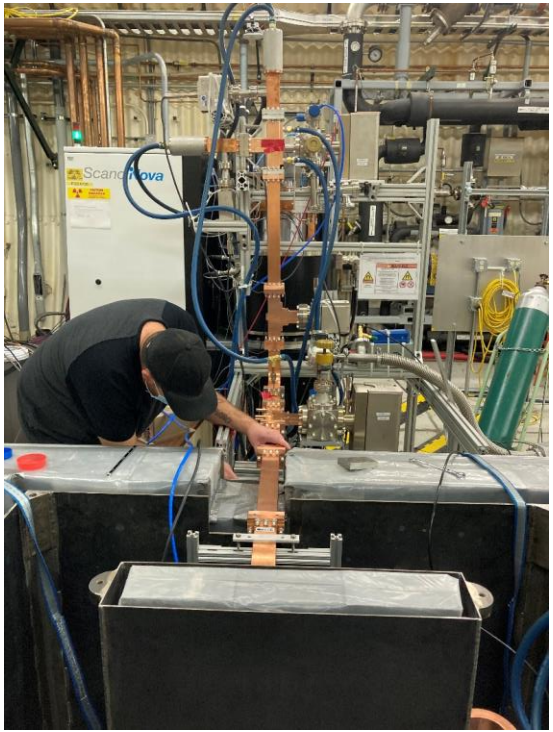
- To build a C-band (5.712 GHz) high gradient rf breakdown study facility (2019-2022).
- To build a C-band cryo-cooled photoinjector study facility (2022-2025).
- To conduct material studies.

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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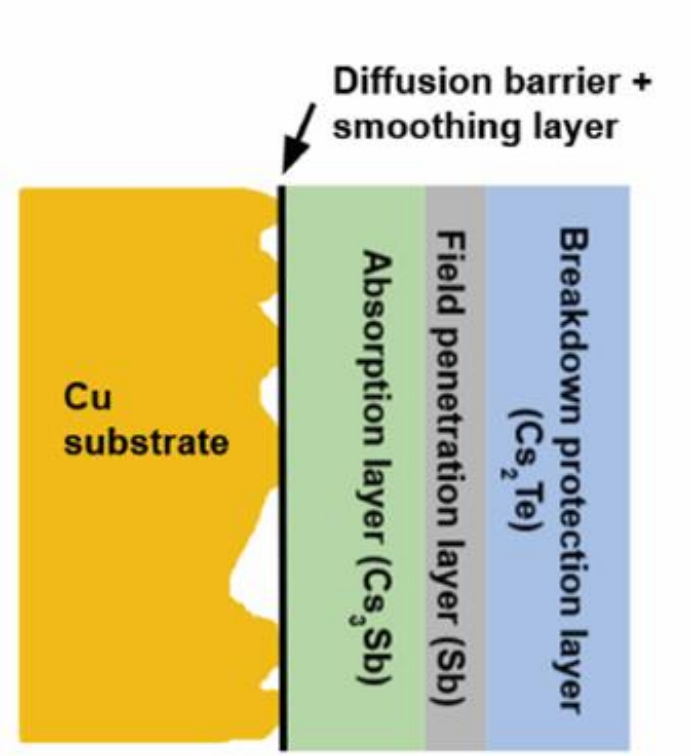
CARIE: Cathodes And Rf Interactions in Extremes

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 klystron is fully conditioned

- Maximum power and repetition rates are determined by the limitations of the chiller.

	Pulse Width (μs)	Pulse Width (μs)	Pulse Width (μs)
Rep rate (Hz)	**1**	**1.25**	**1.5**
1	**36 MW**	**36 MW**	**36 MW**
20	**N/A**	**36 MW**	**36 MW**
40	**N/A**	**25 MW**	**20 MW**

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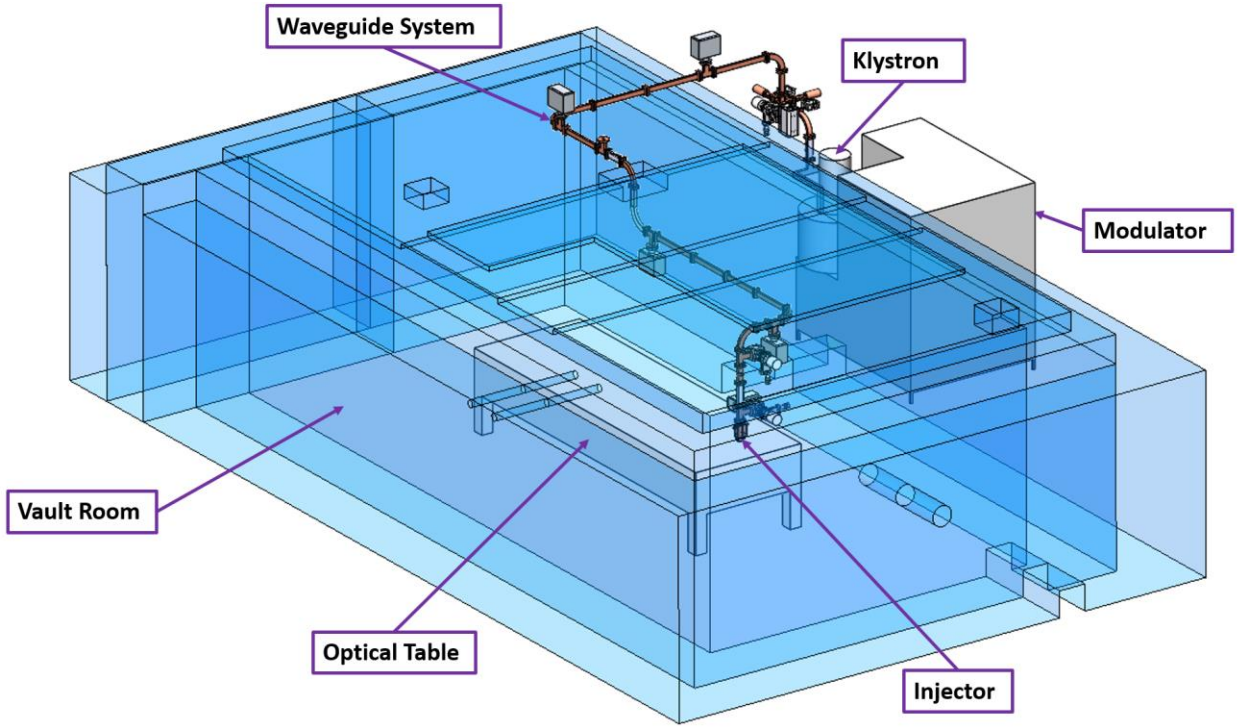
CARIE vault facility lineout – design with a magic T



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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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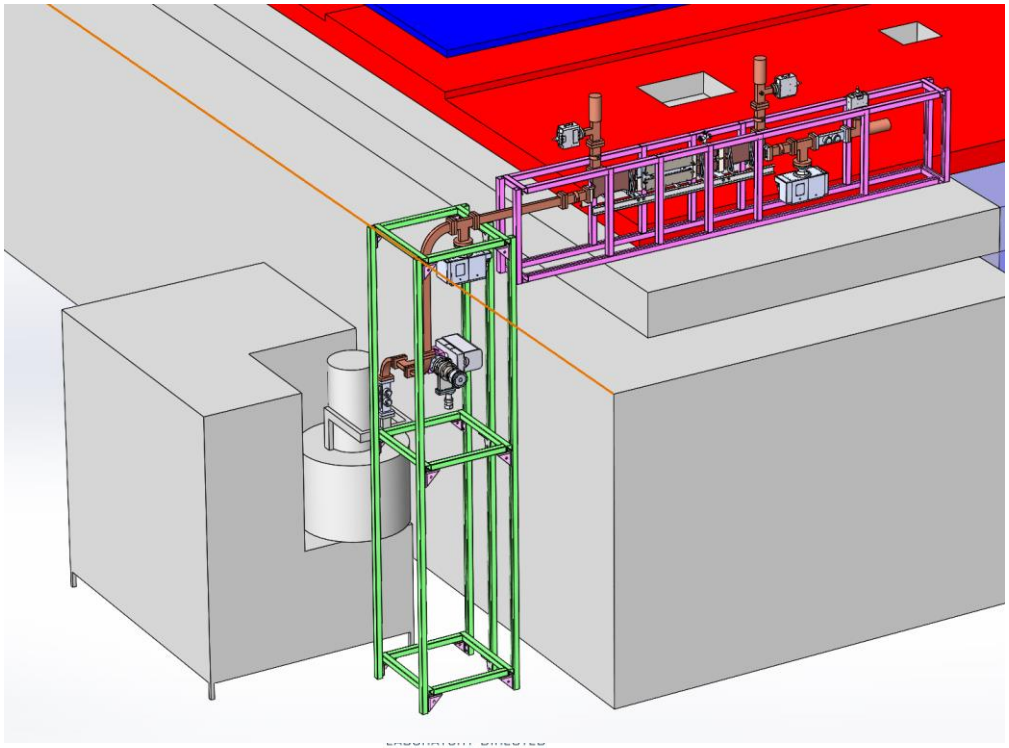
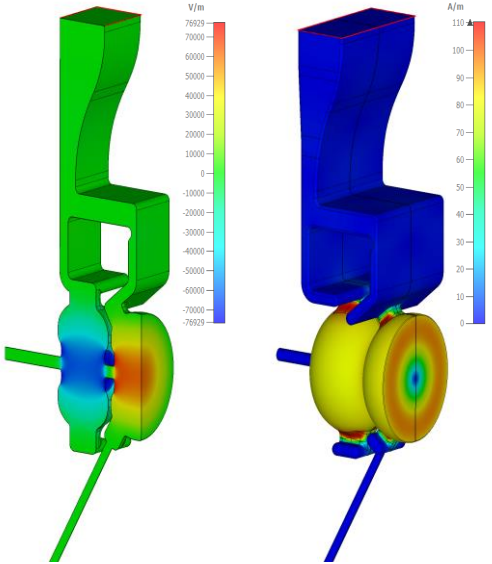
CARIE vault facility lineout – design a circulator

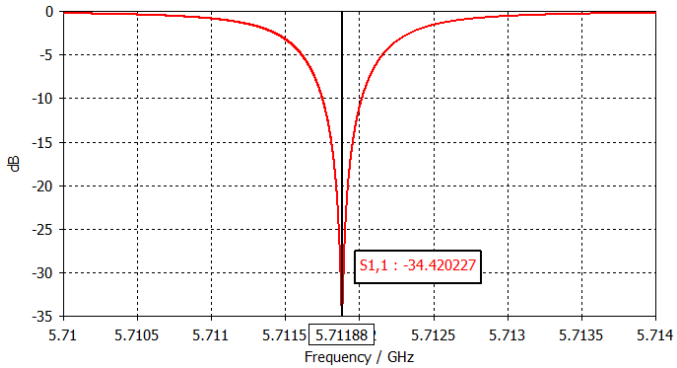
- Installation is currently in progress.

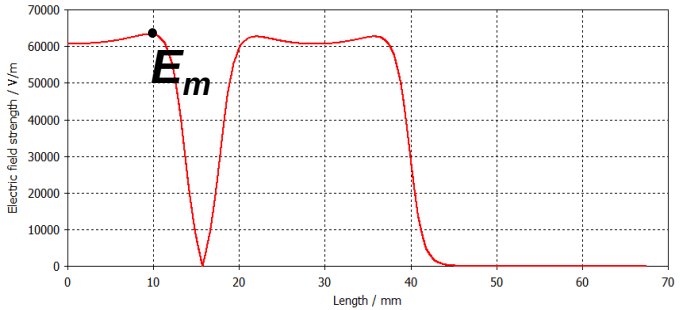


RF photoinjector electromagnetic design

- 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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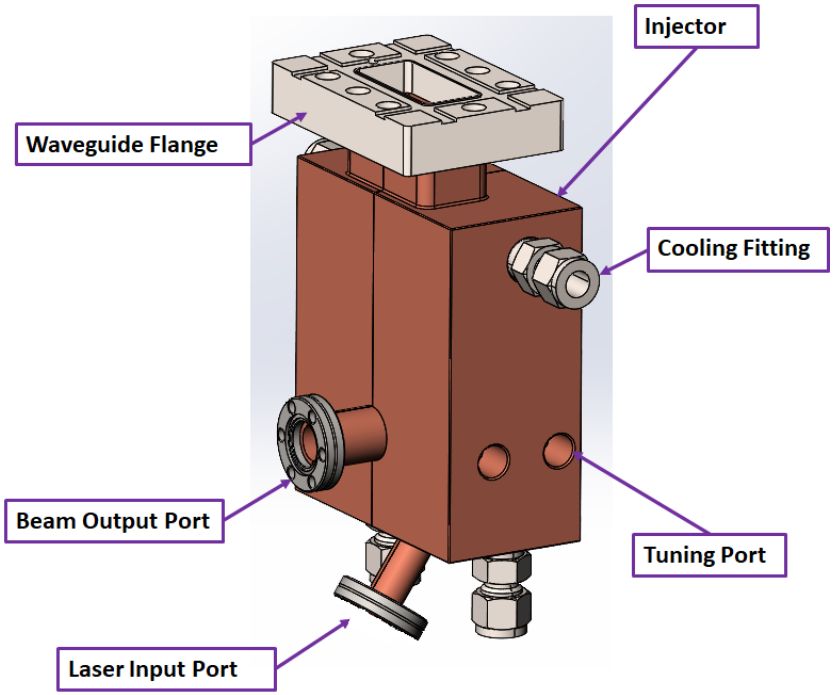
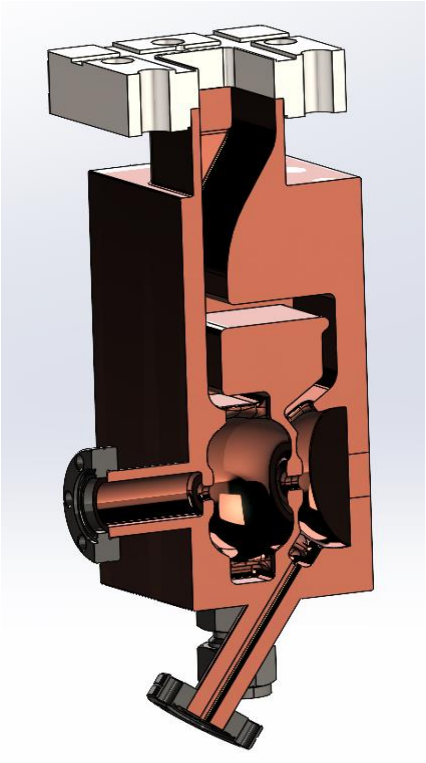
RF photoinjector fabrication

- 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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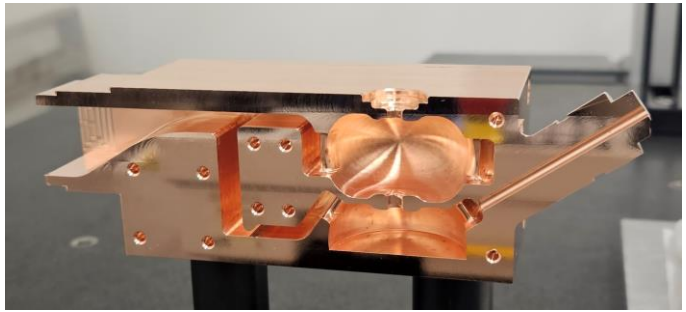
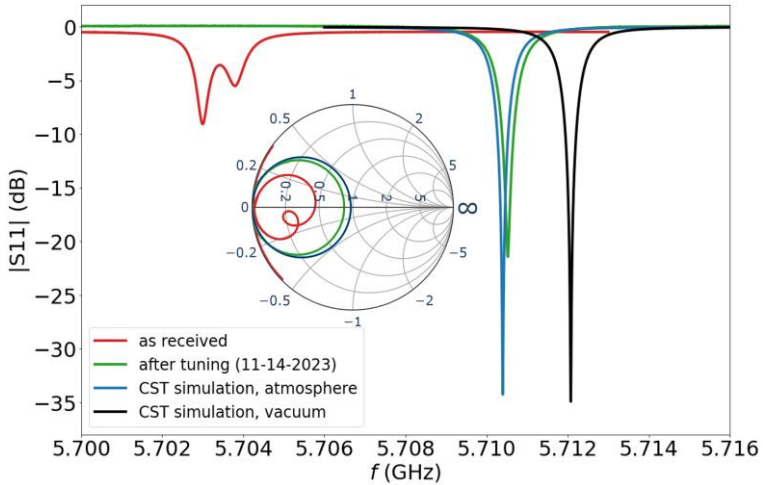
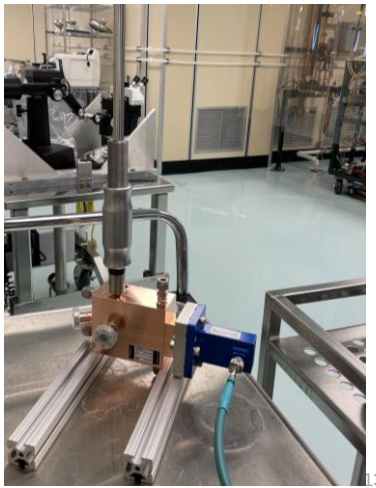
RF photoinjector cold testing

- 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).

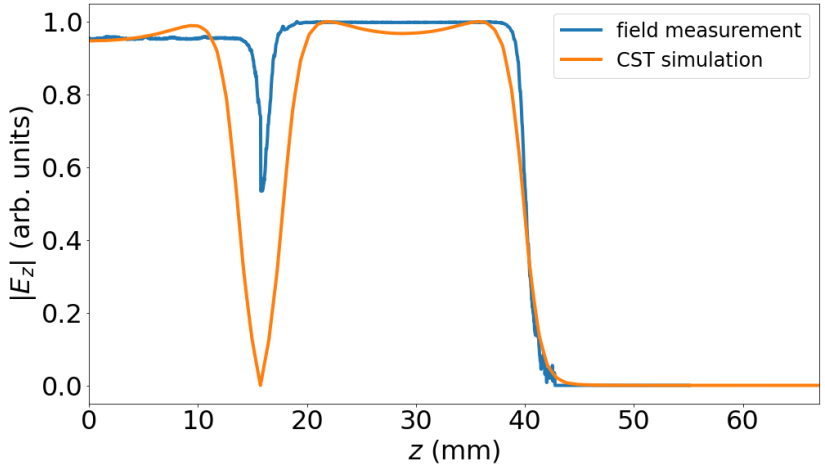






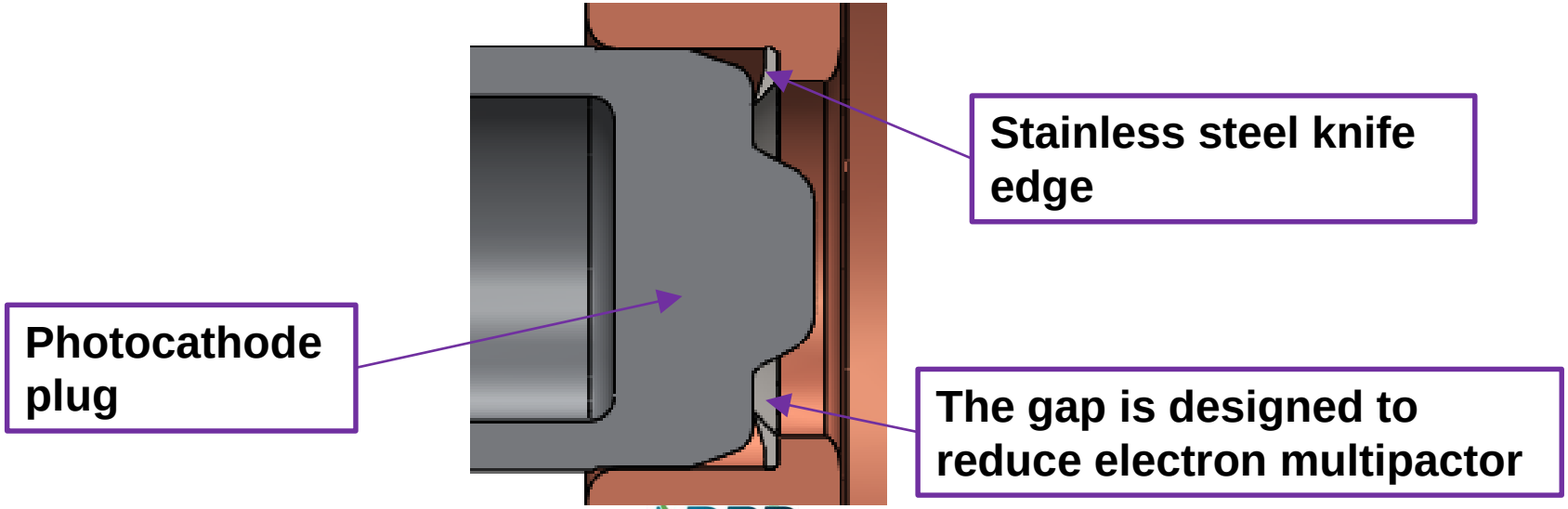
Field profile measurement

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

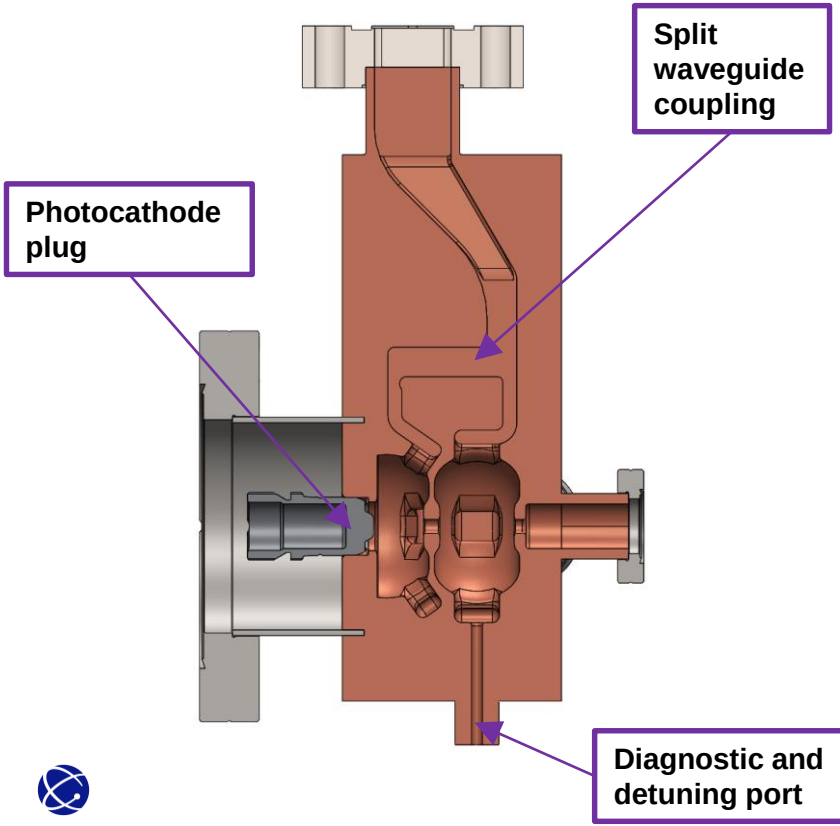


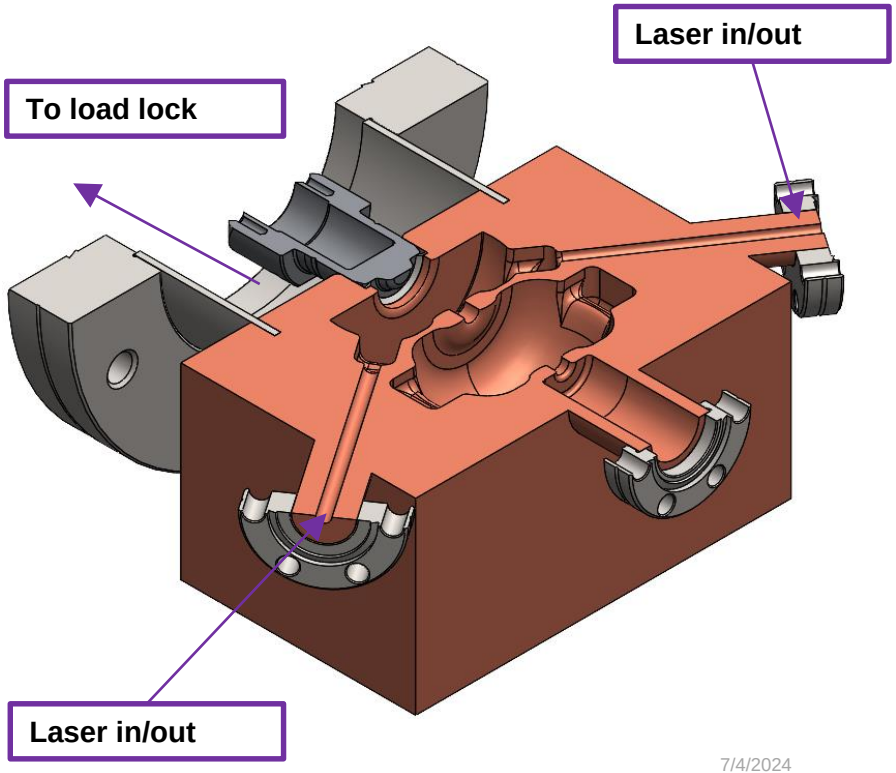
Photoinjector with a cathode plug

- 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.



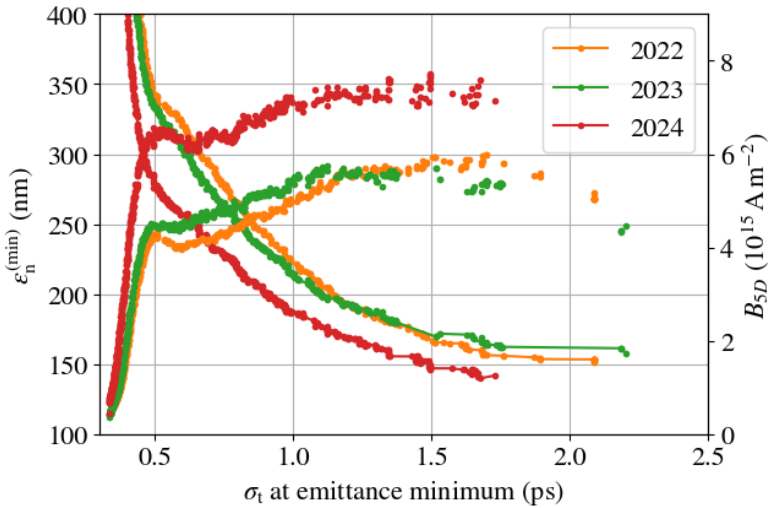
CAD design of the injector with a plug





Multi-objective optimizations of beam propagation

- A solenoid is used for emittance compensation.
- Multi-objective optimizations of beam propagation were conducted in collaboration with Cornell U.
- RF fields in injector were symmetrized
- Multiple parameters were optimized:
  - Solenoid's position and field
  - Initial beam size and spatial intensity distribution
  - Beam launch phase and bunch shape – very important!



Optimized beam parameters

Variables	Best Emittance	Best Brightness
$\varepsilon_n^{\min}$	140 nm	146 nm
B_{5D}	7.58 kA μm^{-2}	7.72 kA μm^{-2}
p	78	77
$\sigma_t(0)$	1.84 ps	1.62 ps
$r_{\max}/\sigma^0_{\{x,y\}}$	0.0534	0.1991
$\sigma_{\{x,y\}}$	199 μm	205 μm
$B_{\text{sol}}/B^{\max}_{\text{UCLA}}$	0.9784	0.9886
Δz_{sol}	−8.39 mm	−9.21 mm
ϕ_{RF}	−1.6°	−2.3°

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

- Director Initiative money were allocated in FY22 to jump start this facility.
- Current LANL LDRD project ends in October, 2025.
- We are actively doing program development to get continuing operation and development funding for the CARIE facility.
- Several ideas under consideration – MeV Ultrafast Electron Diffraction facility, ICS experiment (requires linac energy booster), ARDAP accelerator development proposals.