C-band RF photoinjector cavity for testing photocathodes under extreme fields

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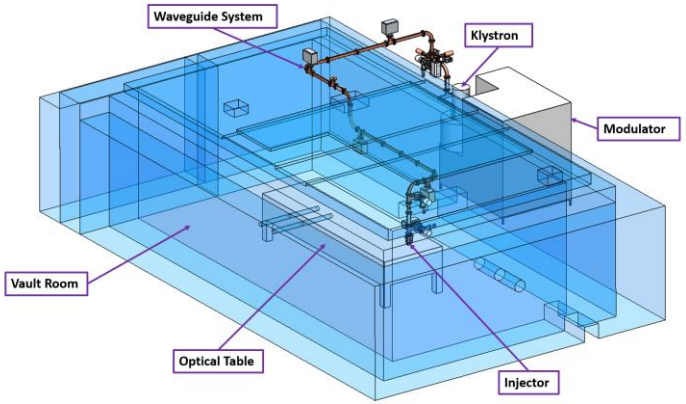
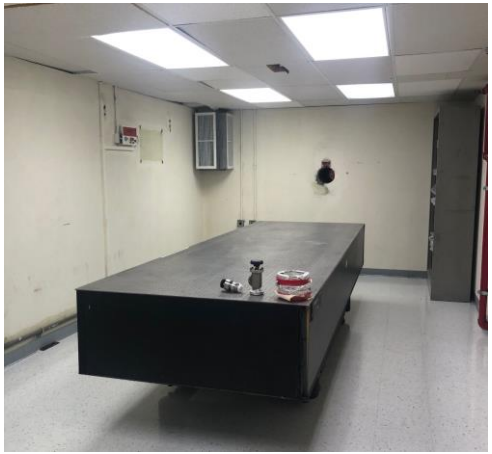
CARIE: CAthodes and Rf Interactions In Extremes

- Project funded by the U.S. DOE through the Laboratory Directed Research and Development (LDRD) program at Los Alamos National Laboratory (LANL).
- Motivation
  - To meet National Security mission needs of compact accelerator facilities, e.g., X-ray sources, for material science studies.
- Goal
  - To build a C-band cryo-cooled photoinjector study facility
  - To study photocathodes that operate at an electric field in excess of 100 MV/m

CARIE facility development

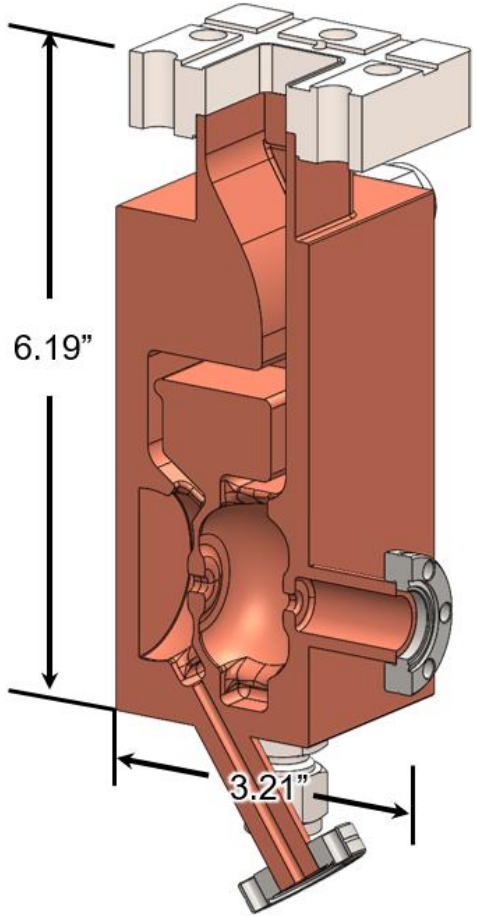
- 50-MW C-band klystron to be installed this year.
- Accelerator vault accommodating average electron beam power up to 20 kW.
- Co-located with the Applied Cathode Enhancement and Robustness Technologies (ACERT) facility.





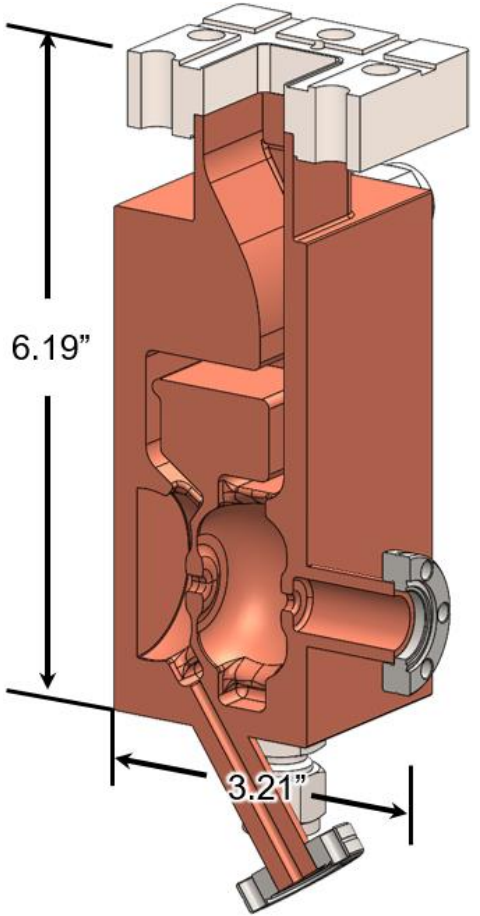
CARIE photoinjector RF cavity

- Accelerator cell profile provided by SLAC and UCLA.
- First high power test: at room temperature, without the cathode plug.
  - Goal: to verify the high-gradient performance of the RF design.
  - Fabrication in progress.



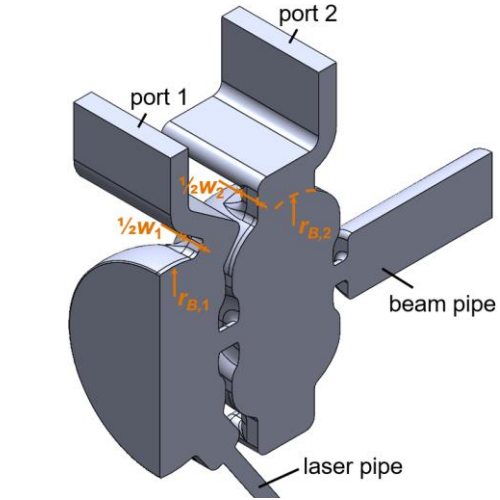
CARIE photoinjector RF cavity

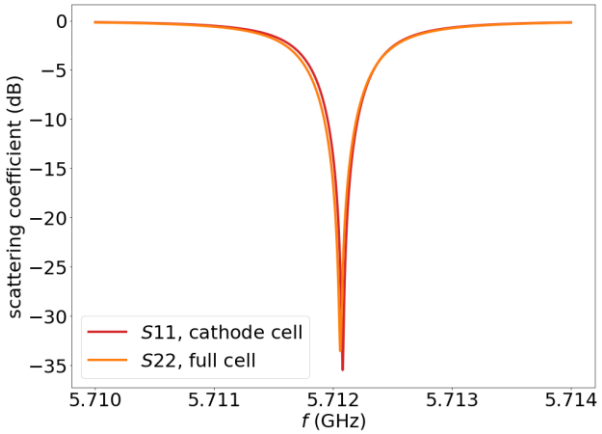
Design parameters	
Operating frequency f_0	5.712 GHz
Cathode cell length l_{cath} / ½λ_0	0.6
Full cell length l_{full} / ½λ_0	1.0
Full cell shunt impedance R_{sh} (r_{sh})	3.09 MΩ (118 MΩ/m)
Cathode cell unloaded quality factor $Q_{0,cath}$	14695
Full cell unloaded quality factor $Q_{0,full}$	13603
Entire-cavity unloaded quality factor $Q_{0,cav}$	14170
Cavity coupling factor β	1.00
RF power for 100-MV/m cathode field	1.4 MW
RF power for 240-MV/m cathode field	8.0 MW



Individual cells

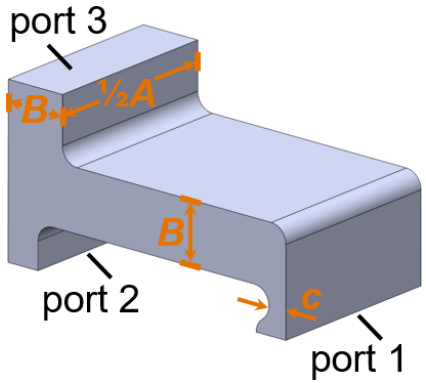
- Goal: both cells on critical coupling, at 5.712 GHz.
- Resonant frequency tuning by the elliptical cell profile minor radii ($r_{B,1}$ and $r_{B,2}$).
- On-resonance coupling tuning by the slot widths (w_1 and w_2).
- Oversized beam pipe: accommodating the beam transverse dimension variation.

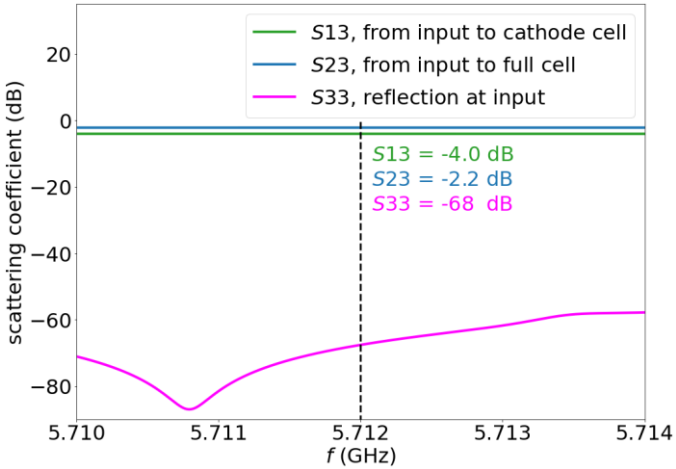




Waveguide splitter

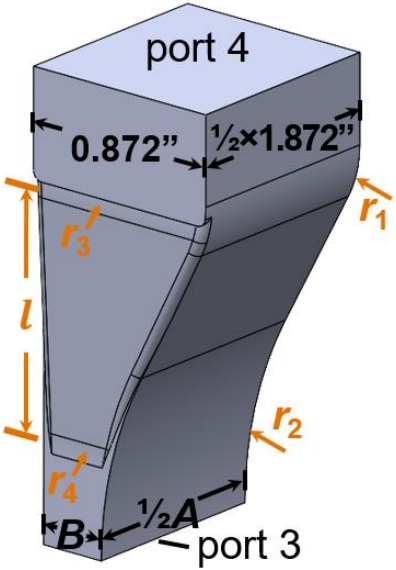
- Goals
  - To ensure that the peak electric fields in the individual cells are identical.
  - To minimize the power reflection at the input.
- Power split tuning by the choke size (*c*).
- Phase delay tuning by dimension *A*.
- Reflection tuning by dimension *A* and *B*.





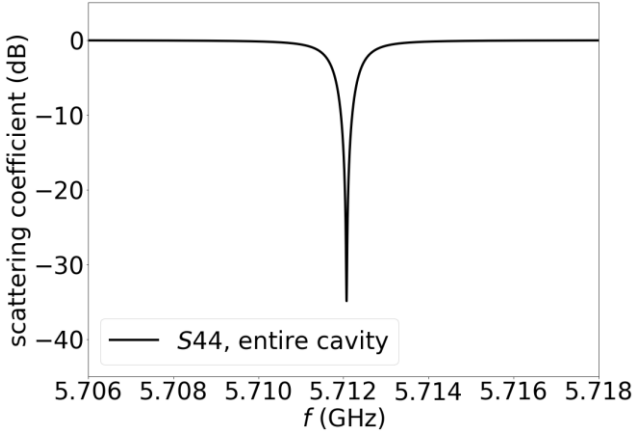
Waveguide horn taper

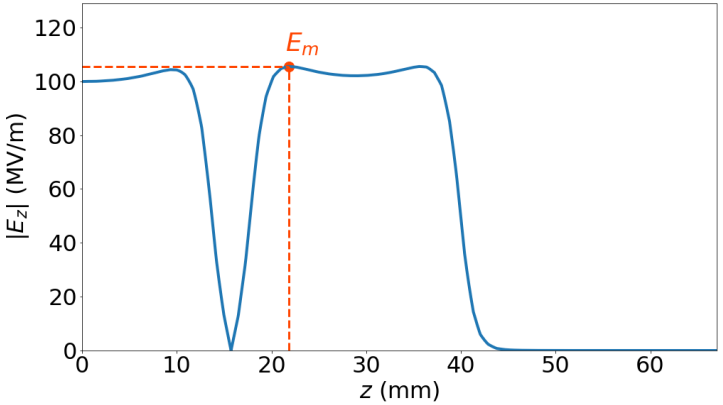
- Goals
  - To adapt the waveguide with dimensions A and B to the standard WR187 port.
  - To minimize reflection of input power, at 5.712 GHz.
- CST Frequency Domain Solver optimizer
  - 4X fillet radius.
  - Taper section length.
  - < -60 dB reflection attained.



Entire-cavity RF analysis

- Critical coupling at 5.712 GHz.
- Identical peak electric field magnitude in the individual cells.
- Peak accelerating field magnitude E_m.



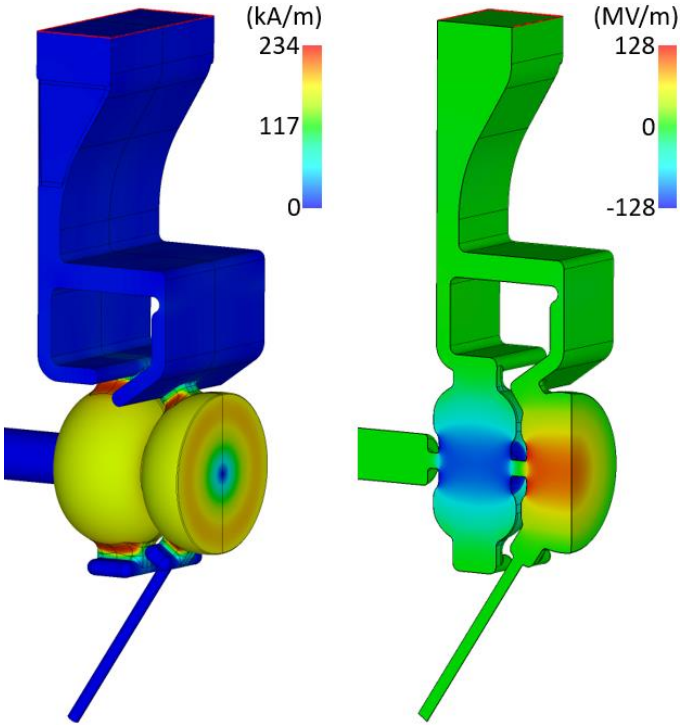


Entire-cavity RF analysis

- Local peak E-field normalized to E_m.
- Local peak H-field normalized to (E_m/Z_0).
  - Z_0 = 377 Ω.

Electric field local peak values	
Cathode cell overall	1.20
Cathode plane	0.94
Cathode cell coupling slot	0.48
Full cell overall	1.20
Full cell coupling slot	0.30
Choke	0.059

Magnetic field local peak values	
Cathode plane	0.55
Cathode cell coupling slot	0.69
Full cell coupling slot	0.66
Choke	0.035



100-MV/m cathode peak field

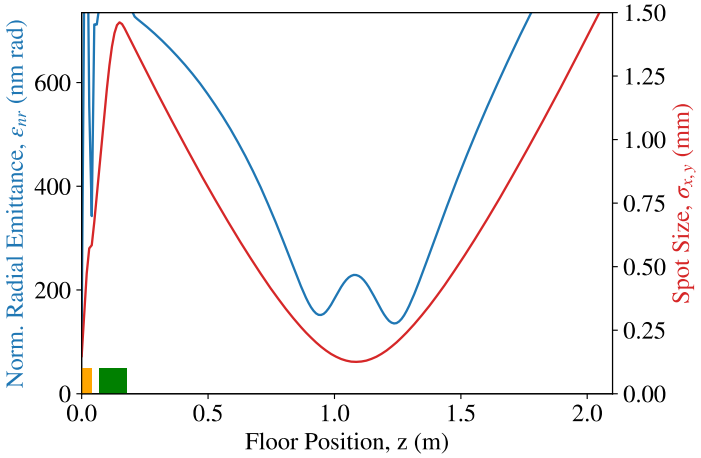
Fabrication and challenges

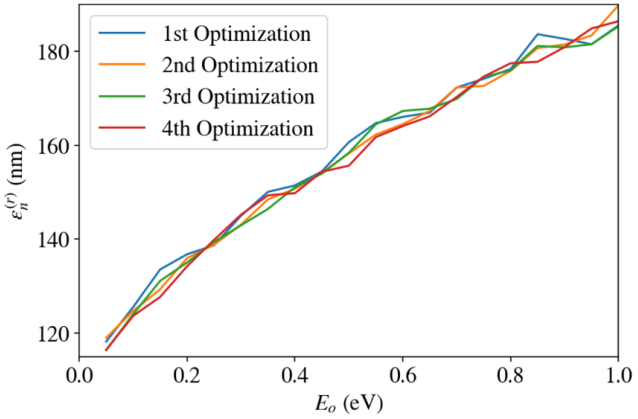
- OFHC copper cavity fabricated in halves, and then brazed together.
- One pair of tuners for each cell.
- Machining tolerance sensitivity.
  - 0.001-inch increase of the elliptical cell profile minor radius results in 5-MHz reduction in the cell resonant frequency.
  - 0.001-inch increase of the waveguide splitter choke size results in 1% increase in the peak electric field ratio in the cathode cell to that in the full cell.

Emittance compensation

- Based on the UCLA TOPGUN analysis.
- Minimized normalized emittance is a function of the excess energy.

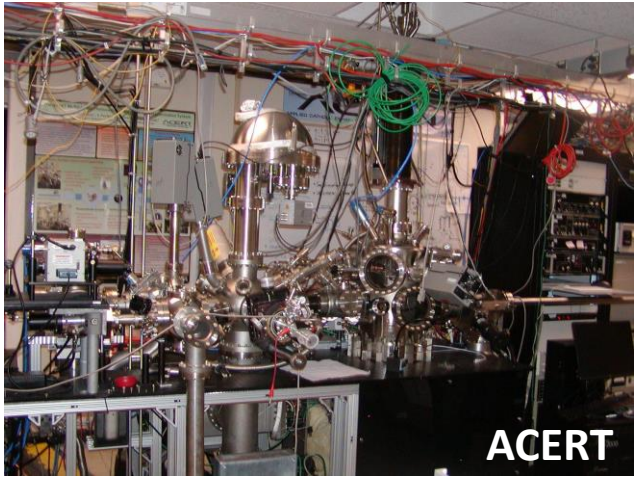
Optimization parameters	
Cathode peak electric field	240 MV/m
Bunch charge	250 pC
Laser rms sopt size	220 μm
Launching phase	125.4 deg
Laser uniform pulse length	7.34 ps
Solenoid center position (cathode plane at z = 0)	125 mm
Solenoid field FWHM	74 mm
Solenoid peak field	0.5854 T





Next steps

- High power test of the first photoinjector RF cavity.
- Photocathode development (ACERT).
- Combined design of photocathode plug and injector cavity.
  - Current plug design provided by INFN.
- Solenoid magnet at cryo-temperature.
- Cryo-cooling design.



Acknowledgments

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