Los Alamos NATIONAL LABORATORY

Materials for Bright Beams 2025

C-band high-gradient activities at LANL

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Emilio Nanni, *SLAC*

James Rosenzweig, *UCLA*

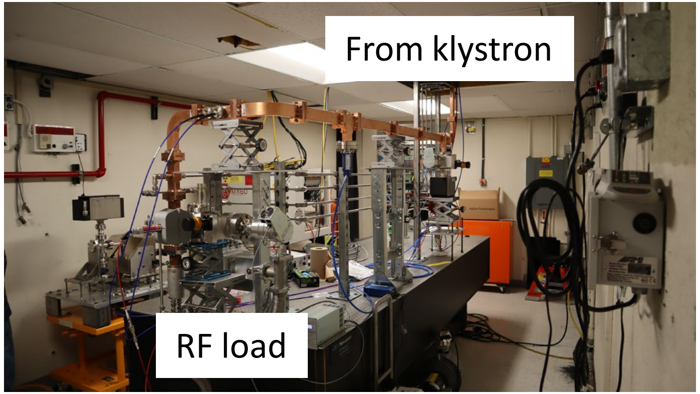
Materials for Bright Beams Workshop 2025, Cornell University
July 18th, 2025

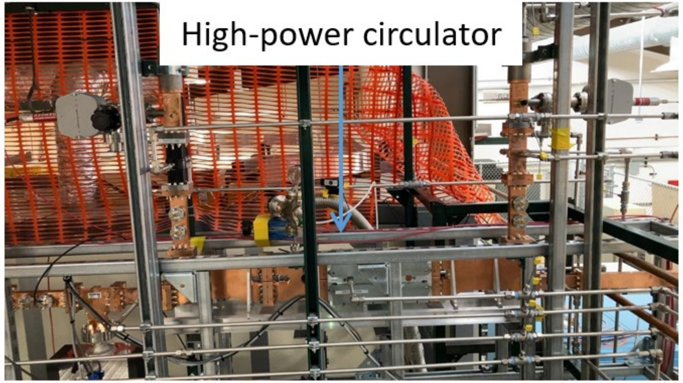
LA-UR-25-27289

Outline

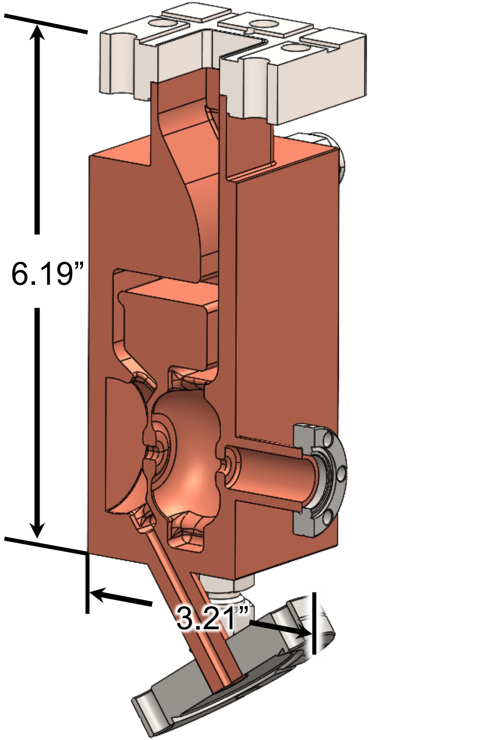
- CARIE updates
- HOM-damping accelerator structure
- Ceramic-enhanced accelerator structures
- Copper-coated cavity

CARIE test stand status

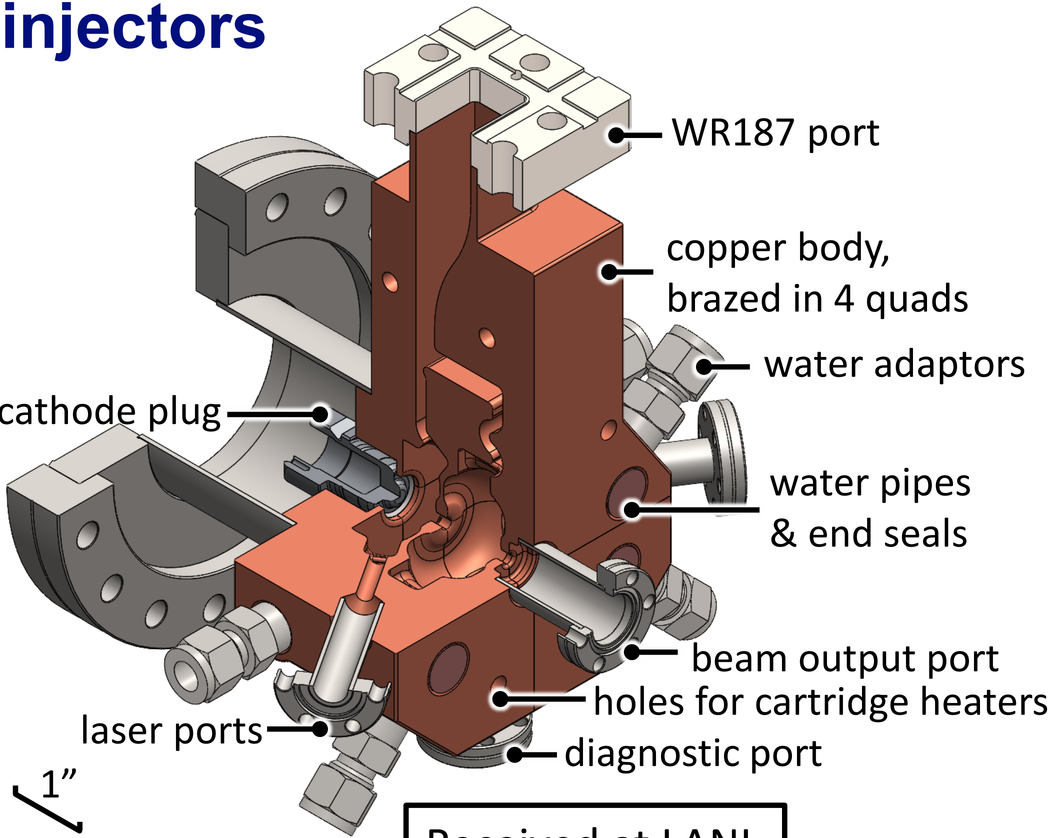




CARIE C-band RF Photoinjectors



Ready for high-power test

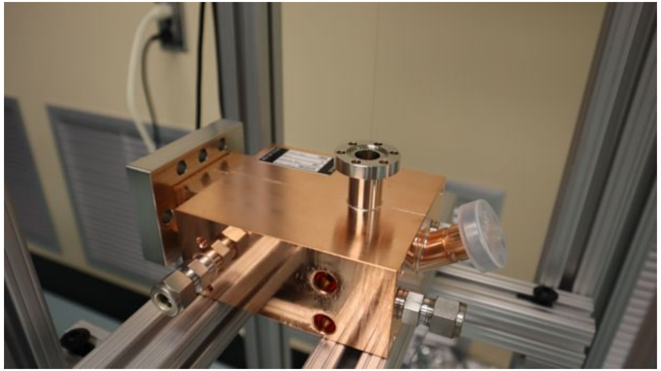


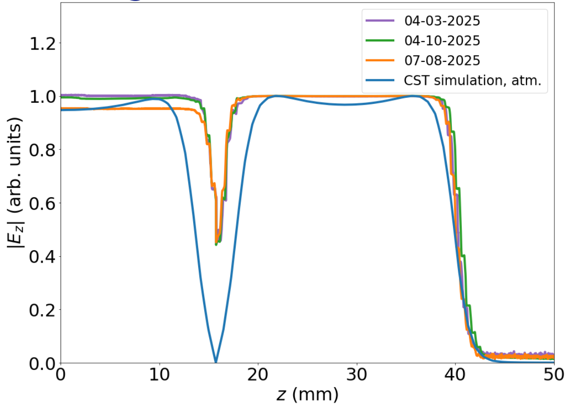
Received at LANL

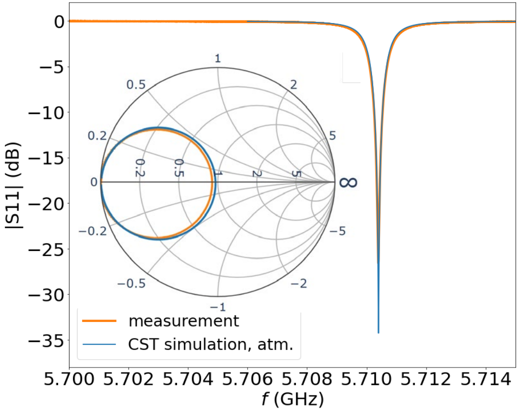
H. Xu, *et al.*, “C-band photoinjector radiofrequency cavity design for enhanced beam generation,” in *Proc. IPAC 2023*.
H. Xu, *et al.*, “RF and multipactor analysis for the CARIE RF photoinjector with a photocathode insert,” in *Proc. IPAC 2024*.

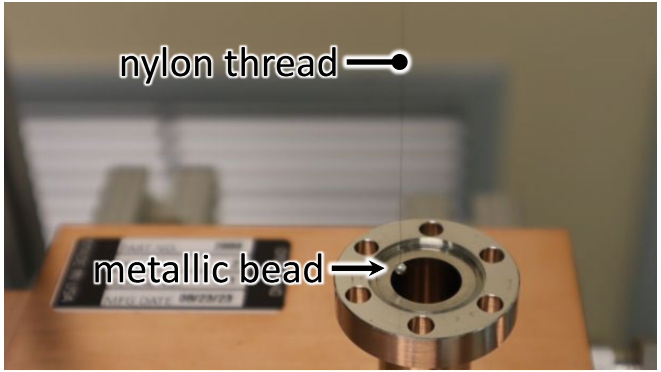
CARIE C-band RF Photoinjectors

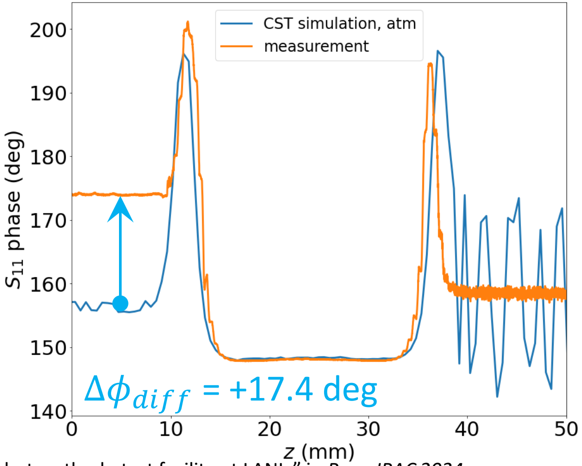
Low-power test: frequency, field balance, and phase advance.









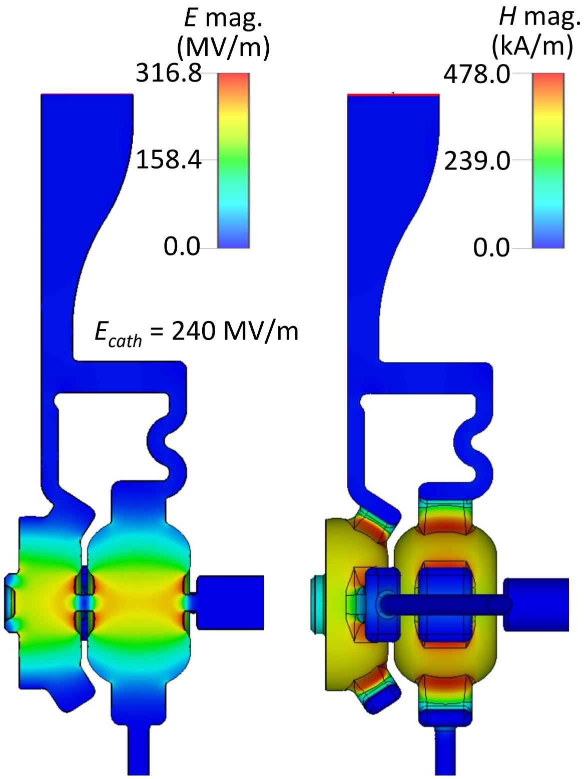


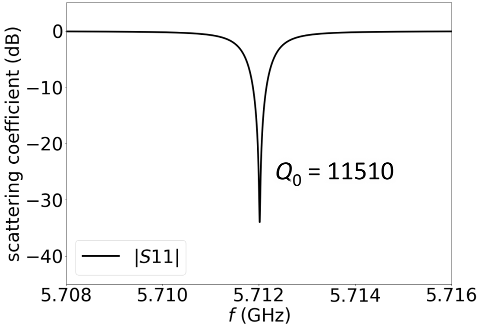
In atm.	CST	Measured
f_0 (MHz)	5710.40	5710.39
Q_0	11936	12657
Q_l	6081	6722
coupl. fac β	0.963	0.883
norm. E_{cath}	0.989	0.957
$\Delta\phi$ (deg)	180.0	171.3

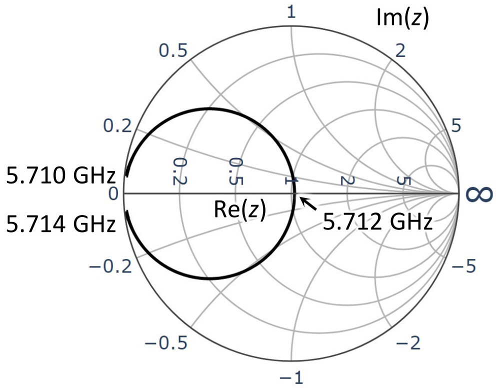
Los Alamos NATIONAL LABORATORY E. Simakov, *et al.*, “tatus of the CARIE high gradient photocathode test facility at LANL,” in *Proc. IPAC 2024*.

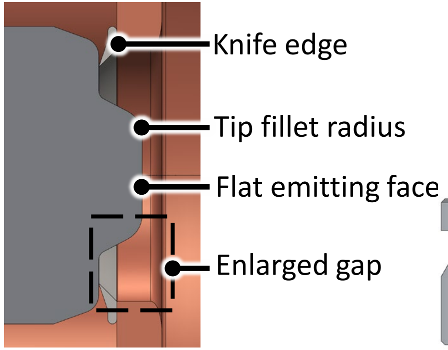
CARIE C-band RF Photoinjectors

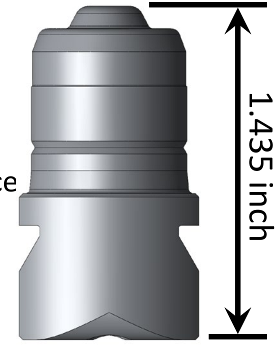
Testing photocathode plug inserts.
Multipactor suppression.



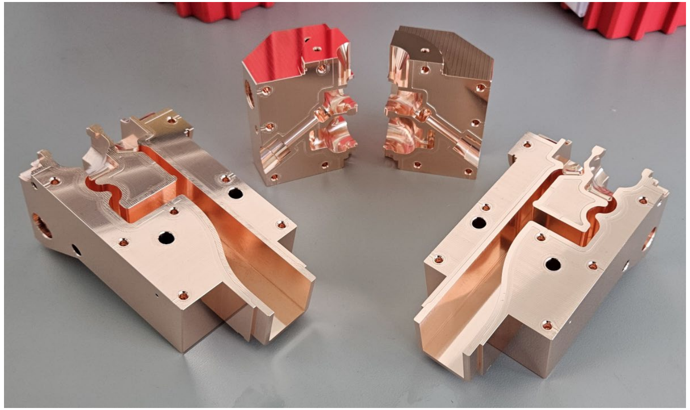






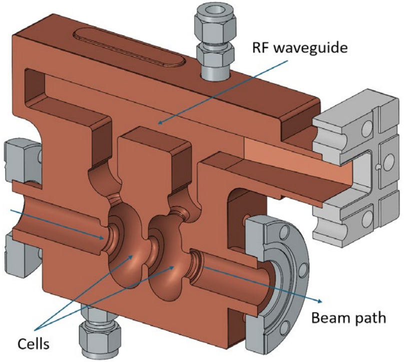


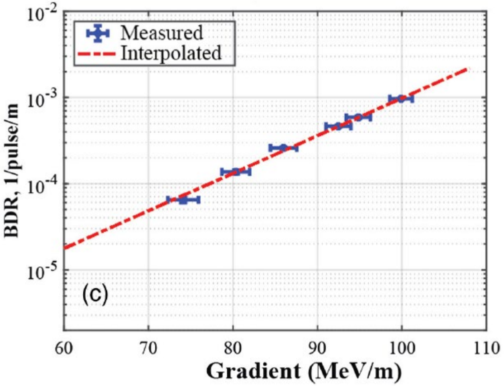
INFN-SLAC-LANL plug



A. Alexander, *et al.*, "High gradient RF photoinjector at LANL," in *Proc. IPAC 2024*.

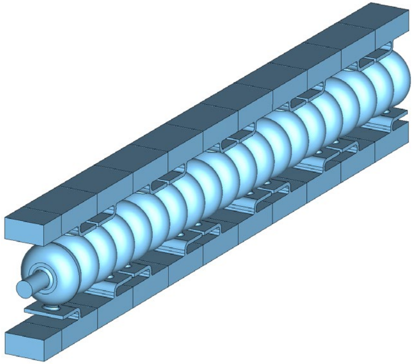
CARIE test stand for cryo-HG structure for 3 GeV H- beams

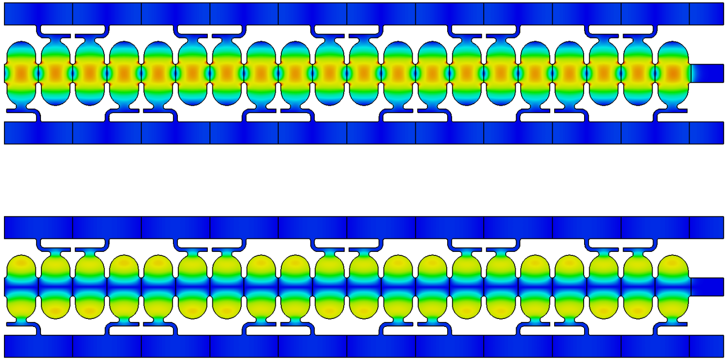




Two-cell, room-temperature prototype has been conditioned to high gradients.

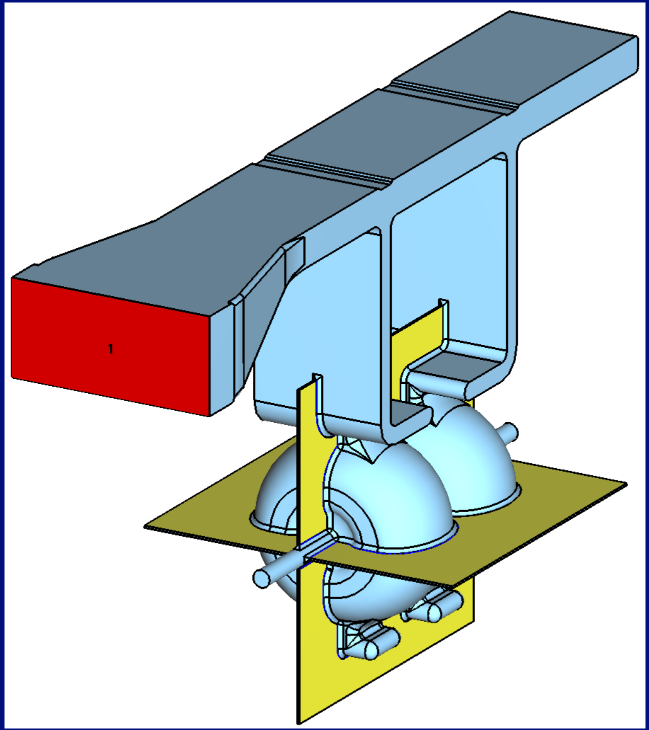
New project: 5.634 GHz (14×201.25 MHz), to be prototyped at 5.712 GHz at CARIE at liquid-nitrogen temperature.

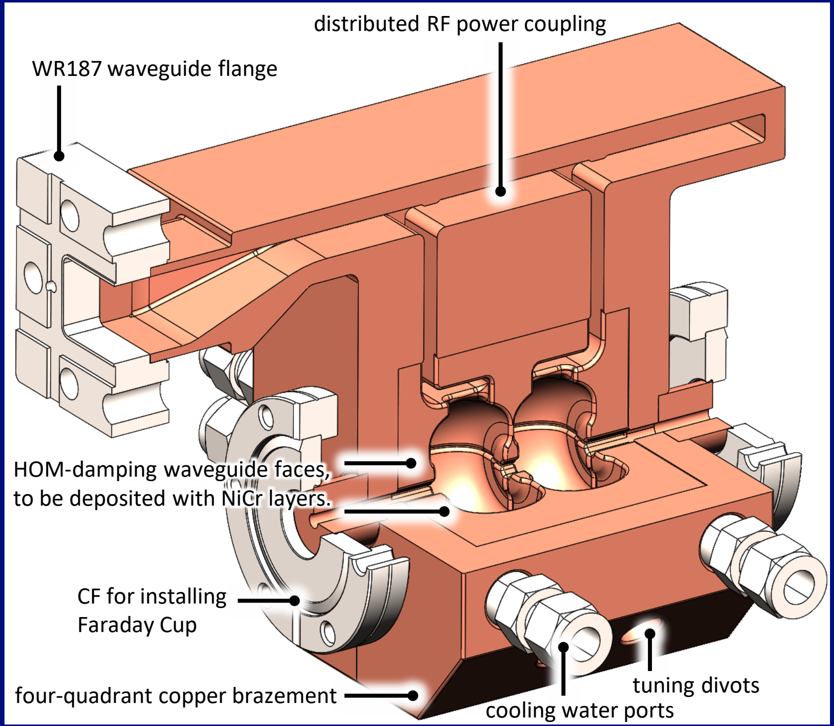




M. Zuboraj, *et al.*, "High-gradient performance of a prototype accelerator cavity for a 3 GeV booster," *PRAB*, 021001 (2024).
S. Kurennoy, *et al.*, "Accelerating structures for high-gradient booster at LANSCE," in *Proc. NAPAC 2022*.

HOM-damping structure: NiCr plating as HOM absorber

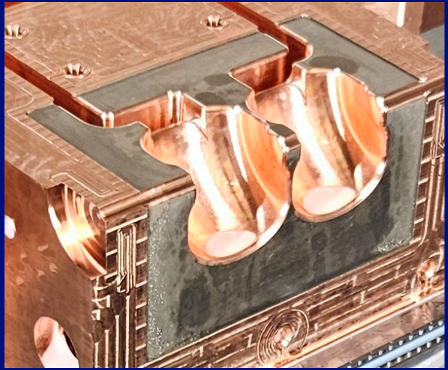




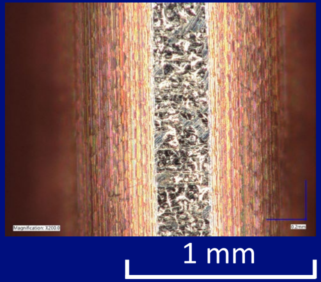
Damping HOMs, preserving fundamental mode, testing high-gradient performance.

D. Kim, *et al.*, “Design study of HOM couplers f or the C-band accelerating structure,” in *Proc. IPAC 2022*.
H. Xu, *et al.*, “Design of a two-cell C-band accelerator cavity with high-order mode damping,” in *Proc. IPAC 2024*.
M.B. Andorf, *et al.*, “ESPPU INPUT: C^3 within the ‘Linear Collider Vision’,” *arXiv preprint arXiv:2503.20829*, (2025).
W.H. Tan, *et al.*, “Emittance preservation in the C3 main linear accelerator,” in *NIM-A*, 170660 (2025).

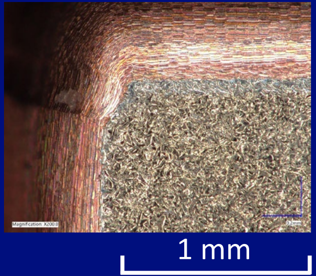
HOM-damping structure: NiCr plating as HOM absorber

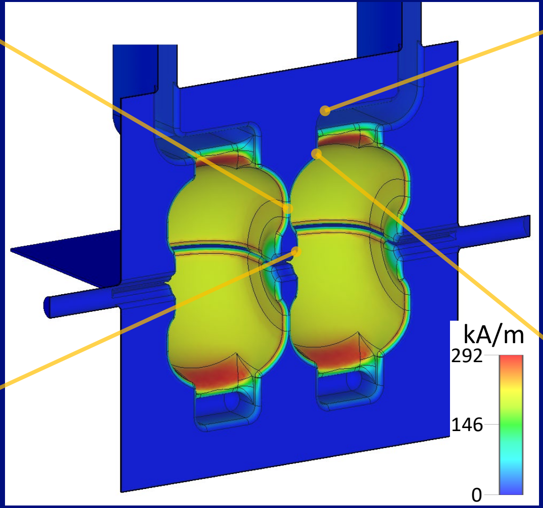


38.7 kA/m H-field
19.4-K NiCr temperature rise



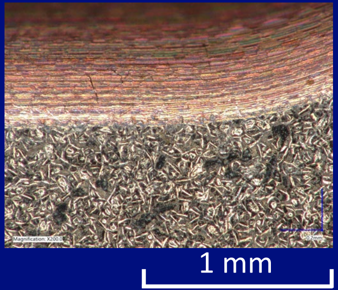
15.0 kA/m to 38.7 kA/m H-field
2.9-K to **19.4-K** NiCr T-rise



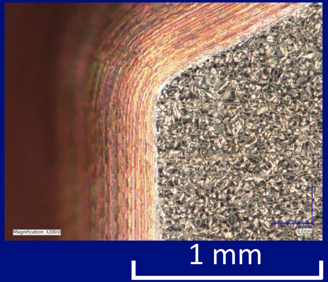


Figures show NiCr plating before annealing.
Plating recipe provided by SLAC.

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

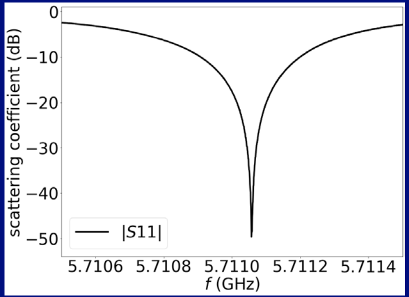


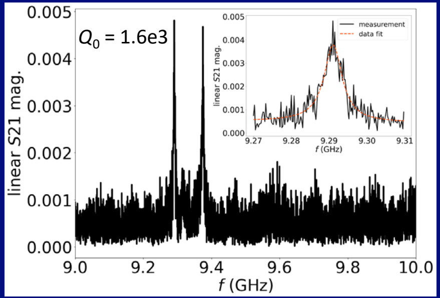
15.0 kA/m to 38.7 kA/m H-field
2.9-K to **19.4-K** NiCr T-rise

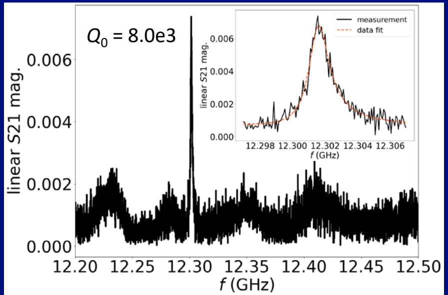


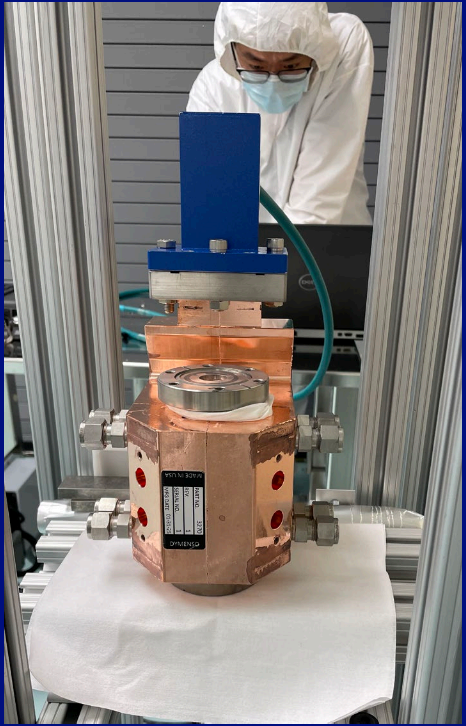
Four-quad machining, NiCr plating, precision machining, brazing/annealing.

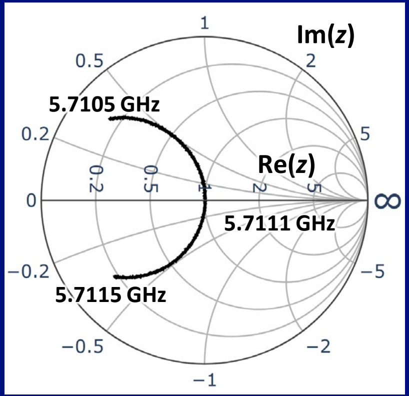
HOM-damping structure: Fundamental mode & HOMs

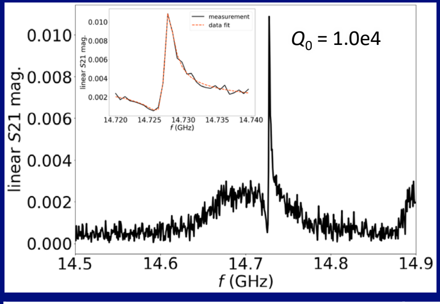


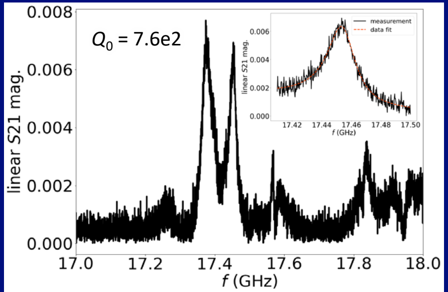






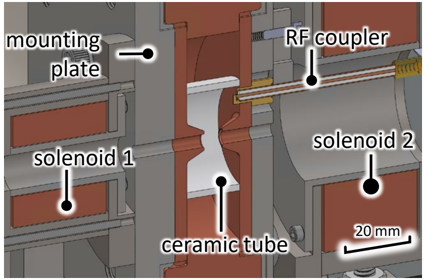


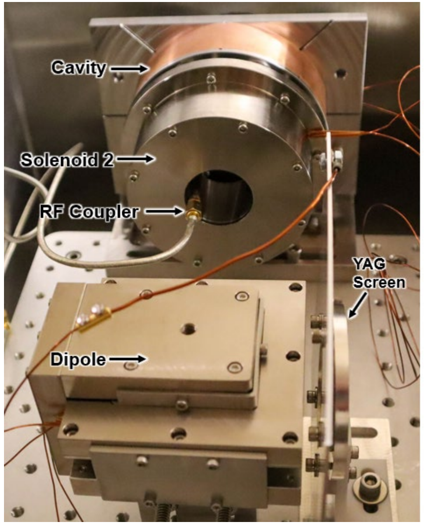


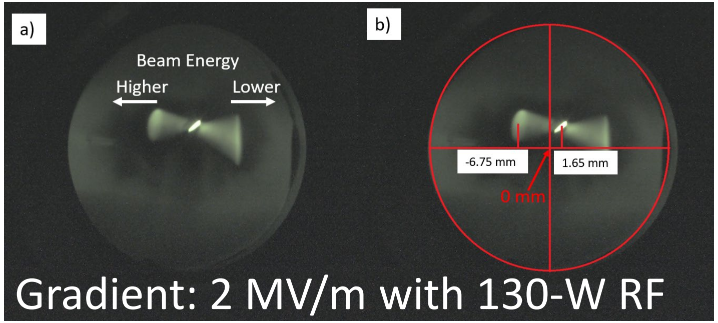


Fundamental mode	CST simulation	Measurement
Resonant frequency	5710.4 MHz	5711.1 MHz
Unloaded quality factor Q_0	13573	13329
Coupling factor β	1.00	0.98

Ceramic-Enhanced Accelerator Structures



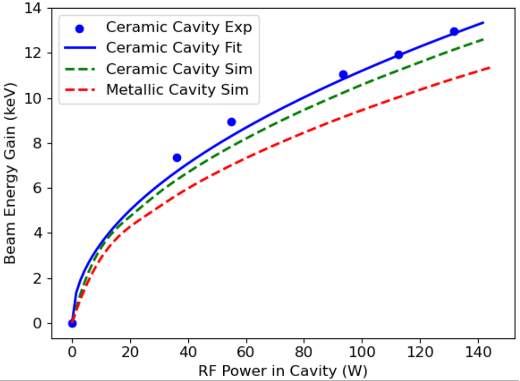




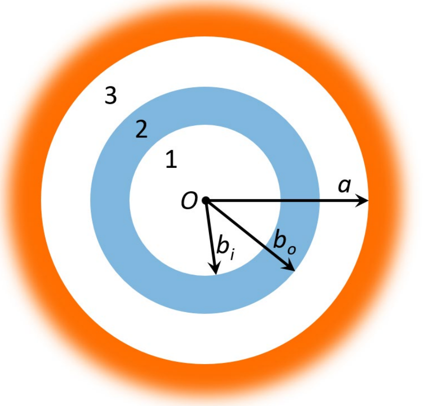
5.712 GHz

Trans-Tech D-3500:
$\epsilon_r = 34.5$
$\tan(\delta) = 1.1 \times 10^{-4}$

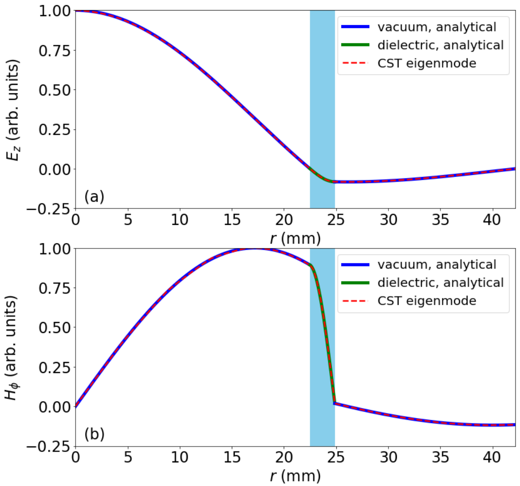
Euclid Techlabs BT37:
$\epsilon_r = 37.6$
$\tan(\delta) = 2.8 \times 10^{-4}$



20%-40% higher shunt impedance;
Robust operation (tested for space environment);
Simplified manufacturing.



TM02 mode



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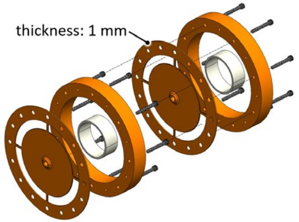
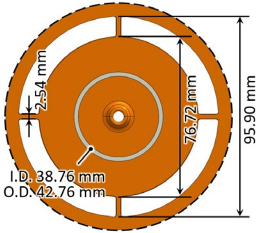
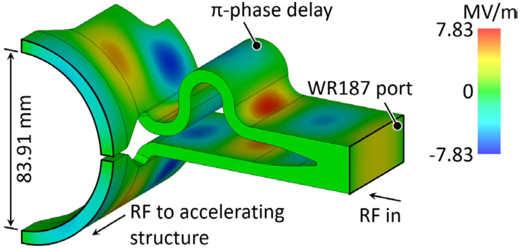
J. Upadhyay, *et al.*, "Design of a ceramic enhanced normal conducting standing wave accelerator structure for higher shunt impedance," *NIM-A*, 166669 (2022).
K. Shipman, *et al.*, "Experimental testing of a ceramic enhanced accelerator cavity," in *Proc. IPAC 2024*.

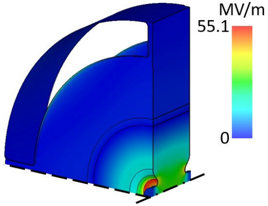
Ceramic-Enhanced TW Accel. Structures

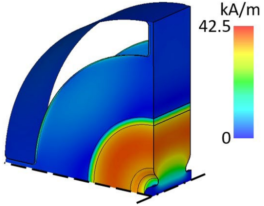
Trans-Tech D-3500 Ceramic	CST simulation
Resonant frequency	5712.0 MHz
Phase advance	120 deg per cell
Shunt impedance	**162** MΩ/m
Group velocity	**3.1%** c_0

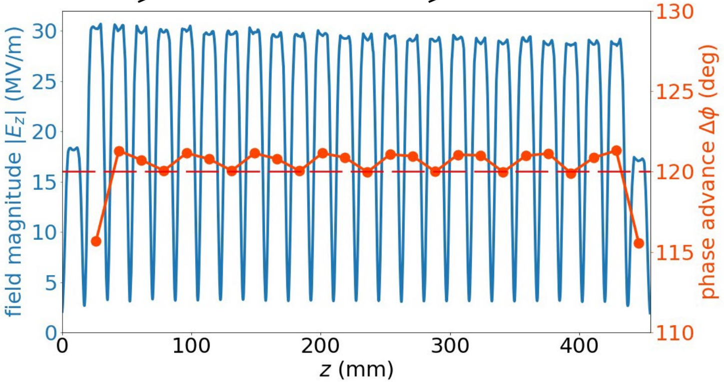


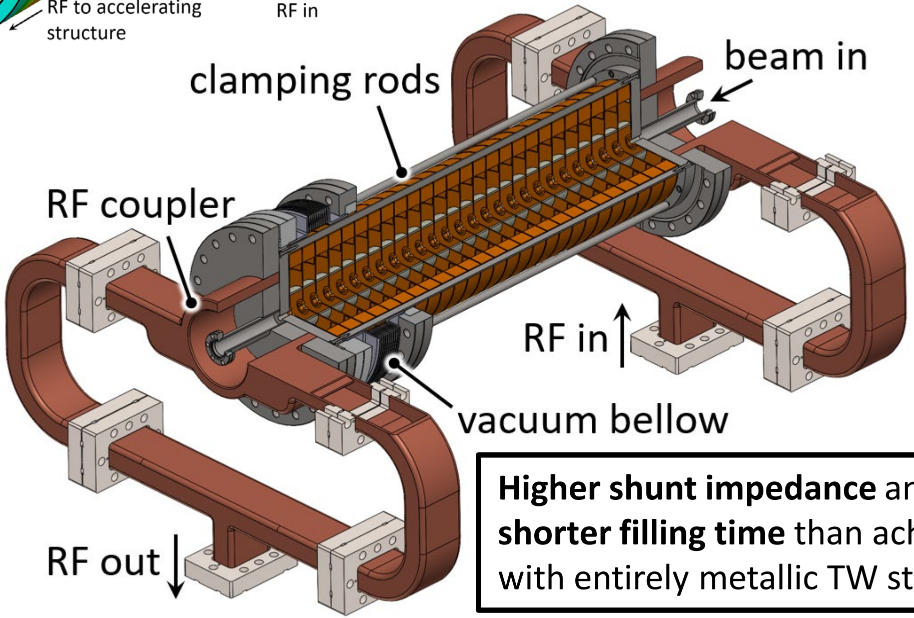








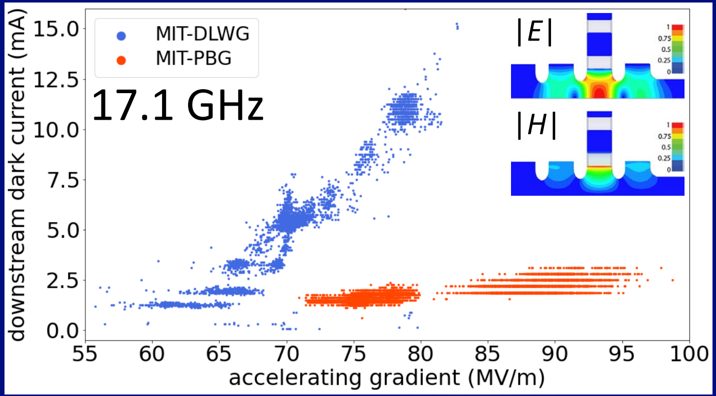


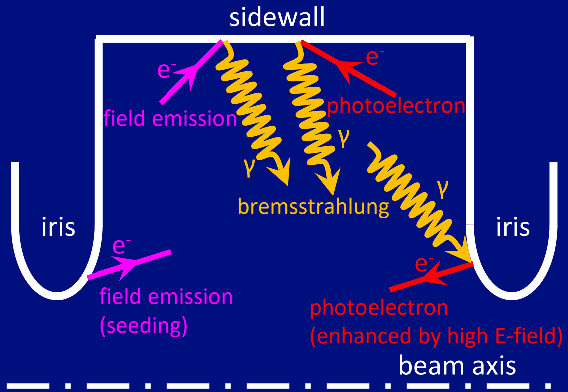


Higher shunt impedance and **shorter filling time** than achievable with entirely metallic TW structure.

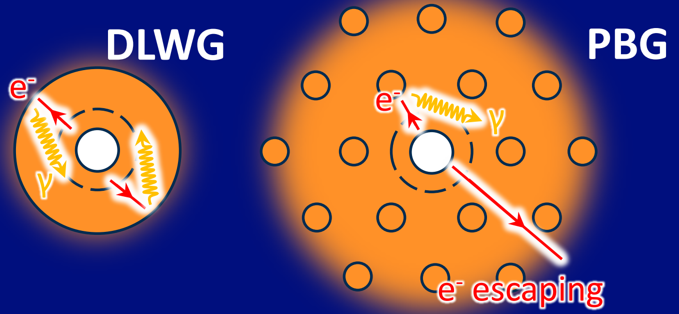
H. Xu, *et al.*, "Ceramic enhanced travelling wave accelerator structure," US Patent App. 18/779,986 (2025).
H. Xu, *et al.*, "High-efficiency traveling-wave accelerating structure with ceramic insertion," in *Proc. IPAC 2024*.

Copper-Coated Cavity: Breakdowns vs. Bremsstrahlung

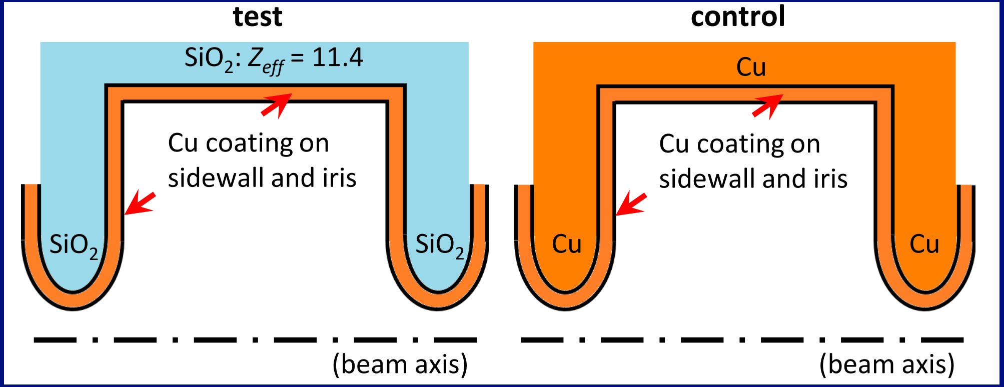




Hypothesis: iterative enhancement of internal dark currents by bremsstrahlung photoelectron cycles.



Same iris, distinct dark currents.



B.J. Munroe, *et al.*, "Experimental high gradient testing of a 17.1 GHz photonic band-gap accelerator structure," in *PRAB*, 031301 (2016).
H. Xu, "Measurement of internal dark current in a 17 GHz, high gradient accelerator structure," in *PRAB*, 021002 (2019).

Copper-Coated Cavity: Minimizing Accelerator SWaP

- Size, Weight, and Power (SWaP) minimization for compact accelerators.
- Copper coatings of polymer matrix composites, e.g., PEEK.
- Fast fabrication and low cost.

Copper-coated PEEK accelerator cavity tests can meanwhile verify impact by Bremsstrahlung/internal dark currents on breakdowns.

Acknowledgments

U.S. DEPARTMENT OF ENERGY

Office of Science

NNSA

National Nuclear Security Administration

LDRD

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

SLAC

UCLA

MIT

Summary

- C-band high-gradient research activities at LANL depend on development of advanced materials.
- CARIE photoinjector cavities have been fabricated. High-power test of the first photoinjector with planar copper cathode is starting soon.
- New project was funded to continue high-gradient activities at CARIE.
- Novel accelerator structure for damping higher-order modes is under fine-tuning and the high-power test is starting soon.
- Ceramic-Enhanced Accelerator Structures were developed and tested up to hundred-watt RF power. Novel traveling-wave linac was invented.
- Copper-coated cavity minimizes SWaP for compact accelerators and can be used for studying emerging theories of high-gradient RF breakdowns.