CERF-NM:
The C-band Engineering Research Facility in New Mexico

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International Workshop on Breakdown Science and High Gradient Technology (HG2021)

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LDRD

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Outline of This Talk

- Acknowledgements
- Project Overview
- CERF-NM: the C-band Engineering Research Facility in New Mexico
  - Capabilities
  - Components
  - Layout
  - Status
- Summary and near term plans

Acknowledgements and Thanks

- Frank Krawczyk – initial vision, project inception, strong leadership
- Leadership team (co-PIs and advisors): Dmitry Gorelov, Samantha Lawrence, Danny Perez, Evgenya Simakov, Tsuyoshi Tajima
- Project team members: Jon Acosta, Soumendu Bagchi, Amber Black, Ryan Fleming, Andrew Garmon, Tim Germann, Todd Jankowski, Mohammad Karim, Harbhajan Khalsa, Mark Middendorf, Paolo Pizzol, Adrian Romero, Bill Romero, Mitchell Schneider, Tsuyoshi Tajima, Gaoxue Wang,
- Facility support – klystron installation, lead work, etc.
- Nathan Moody, John Smedley, Stephen Milton, Toni Taylor – supportive and helpful line management
- Emeritus: Frank Krawczyk, Mark Kirshner
- Slides from: Dmitry Gorelov, Mark Middendorf, Danny Perez, Evgenya Simakov, Gaoxue Wang
- Colleagues at SLAC & UCLA

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Project Overview

CERF-NM is being built up and operated under a number of internal Lab programs, including LDRD funding.

Why is Los Alamos interested in high gradients?

Why is Los Alamos interested in C-band?

Why do this work at Los Alamos?

Overview: Why high gradients?

National-Scale Facilities: cost scales as size (length) of the accelerator.

$L \sim V_{beam}$ / Gradient

→ double the gradient, halve the cost

Capability Transition: improve accessibility

Higher gradients → same beam voltage in smaller space

Same voltage → similar output (e.g. X-ray energy)

Smaller space → enters range of accessibility for small institutions

More installations → more science enabled

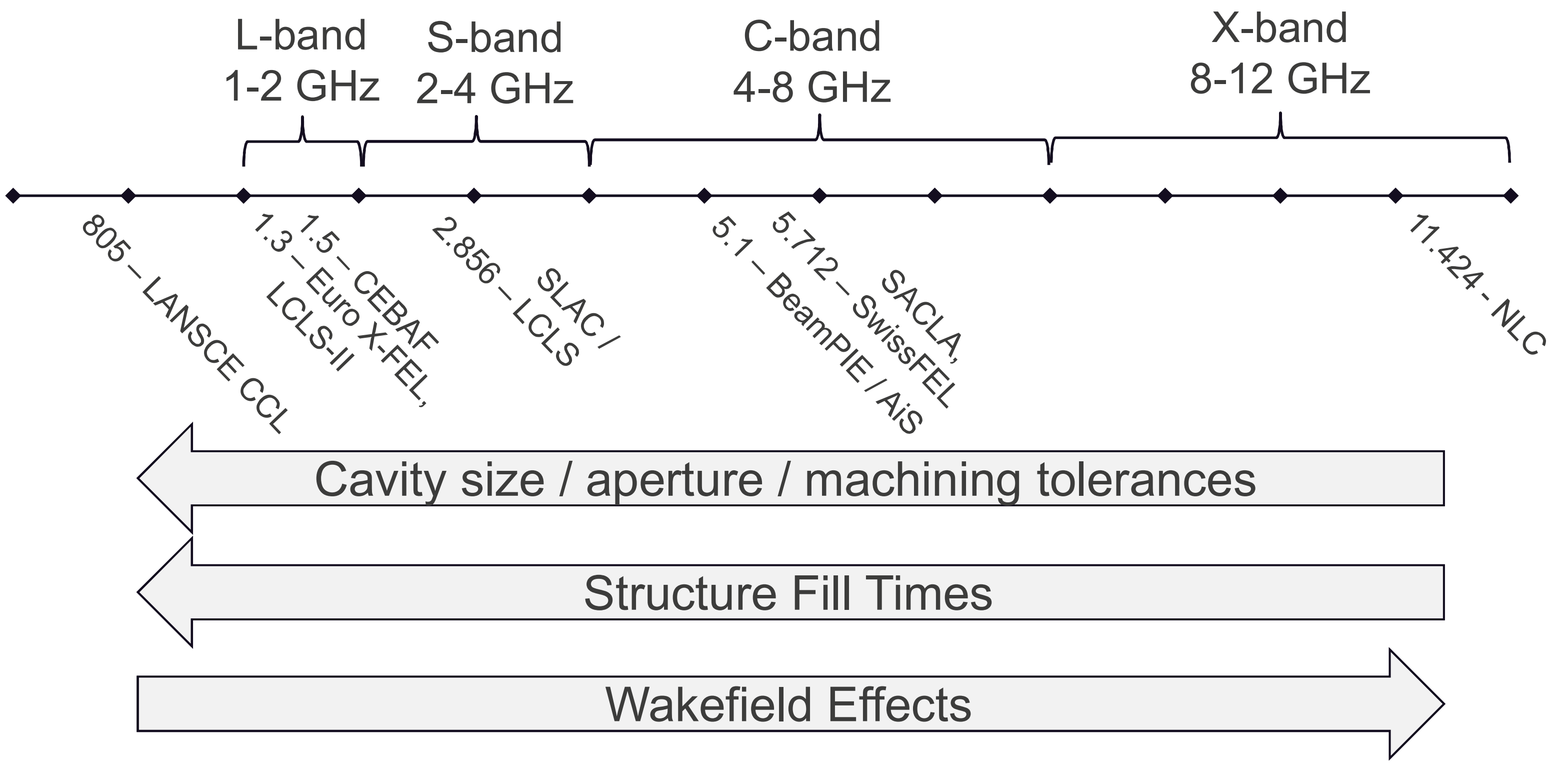
Compact Accelerators: enabling feasibility

Higher gradients → higher voltage in a given size

Higher gradients → target voltage with a smaller system

Impacts viability of concepts for cargo scanning, sterilization, etc.

Overview: Why C-band?



C-band is *convenient*, for a number of metrics, for high-performance accelerators. In particular, a naturally "good fit" to hard X-ray FELs.

Overview: Why Los Alamos?

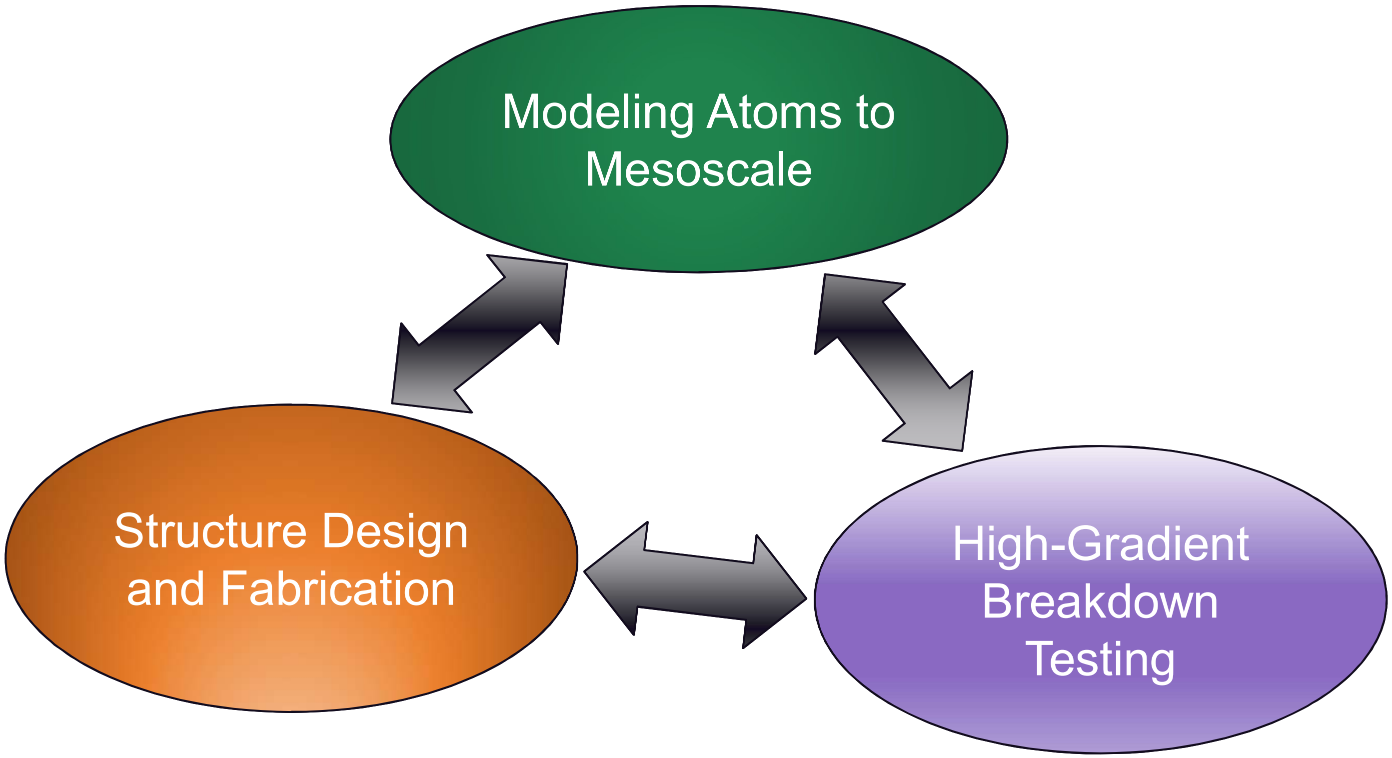
Posited: Achieving high-gradient performance (low breakdown rates, low field emission, etc.) is a *materials science* problem.

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.

Project Components



Related talks at this workshop

Theory, Modeling and Simulation

- Danny Perez, “Atomistic modeling of the coupling between electric fields and bulk plastic deformation in RF structures,” Wednesday
- Gaoxue Wang, “Ab initio alloy design for C-band accelerators,” Wednesday

Structure Design and Fabrication

- Evgenya Simakov, “Development and high power testing of C-band accelerator components,” Tuesday

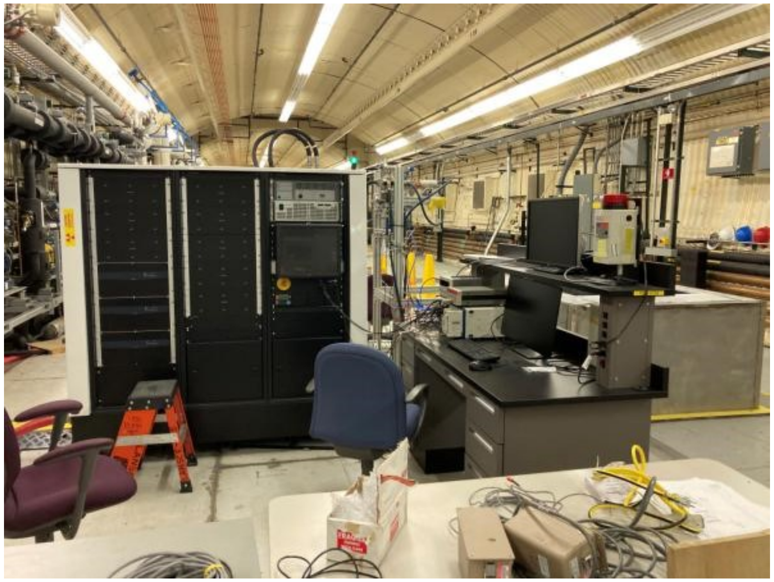
High-Power RF Systems

- Mark Middendorf, “The LANL C-band Engineering Research Facility (CERF-NM) Test Stand Installation, Operation and Initial Conditioning,” Wednesday

CERF-NM: Capabilities Overview

- RF power: klystron, 5.712 GHz (± 5 MHz)
  - 50 MW, 0.3 - 1 μs pulse duration, up to 200 Hz (100 Hz nominal)
  - Magic T splits power into 2 x 25 MW ports
- RF power delivery
  - WR187 waveguide
  - Rect.-to-circular mode converters
- Shielded enclosure
  - up to 5 MeV (kinetic), 10 μA average current (100 nC / RF pulse @ 100 Hz)
  - Usable volume: 1.2m x 0.6m x 0.9m (48” x 24” x 36”) ~ 0.68 m^3
  - Removable experiment support platform with standardized hole pattern
- Cryocooler
  - Now being used for low-power testing

Installation Overview



- Presently located in the LEDA accelerator tunnel
- Eventually… hope to build a bunker rated for higher beam energies and average currents
  - Full structure testing
  - Beam generation, capture and characterization

50 MW C-band RF: Canon E37212 klystron & ScandiNova Model K2-2 Modulator

- 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

50 MW C-band klystron

- Conditioned to 50 MW
- Frequency 5.712 GHz
- 300 ns – 1 μs pulse length
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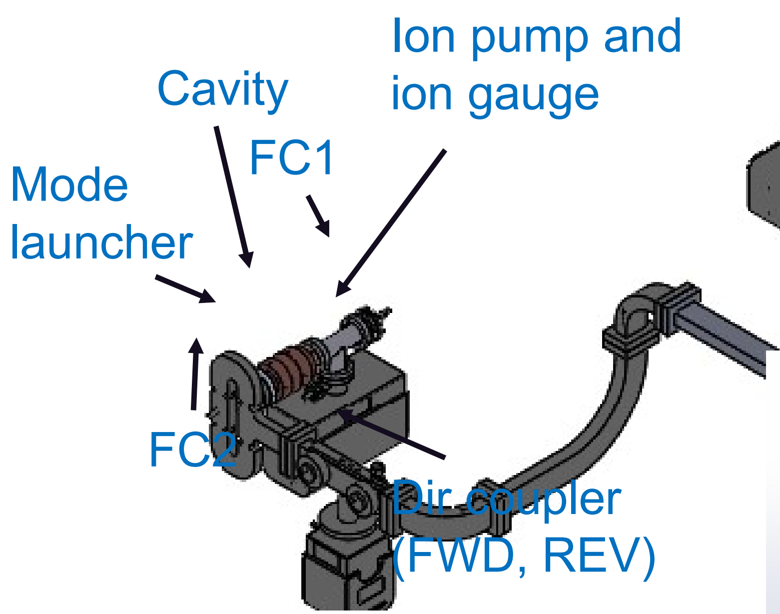
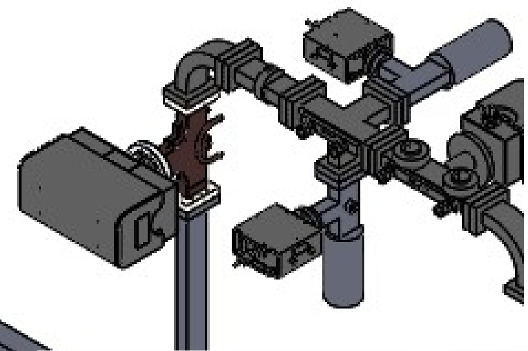
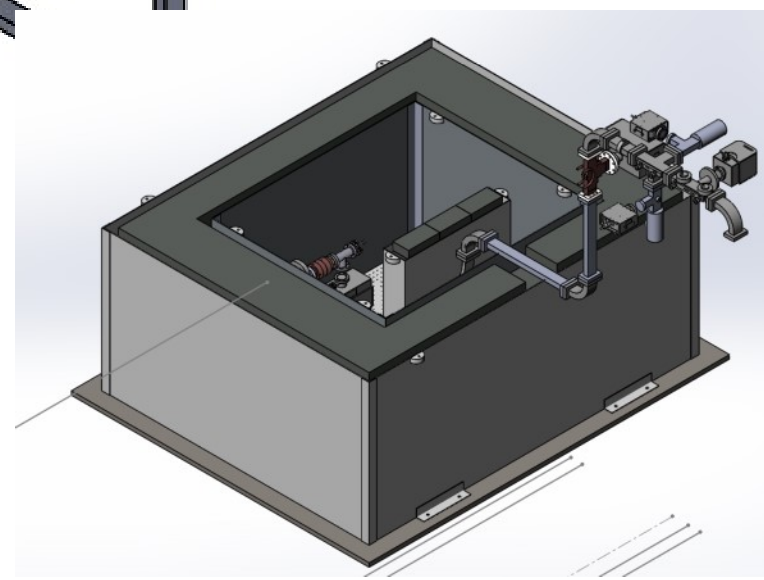
More Details:
Mark Middendorf's
Wednesday Talk

Test Enclosure and Nominal Waveguide Run



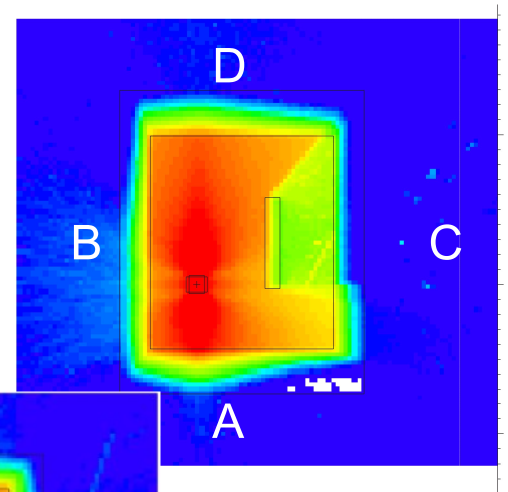


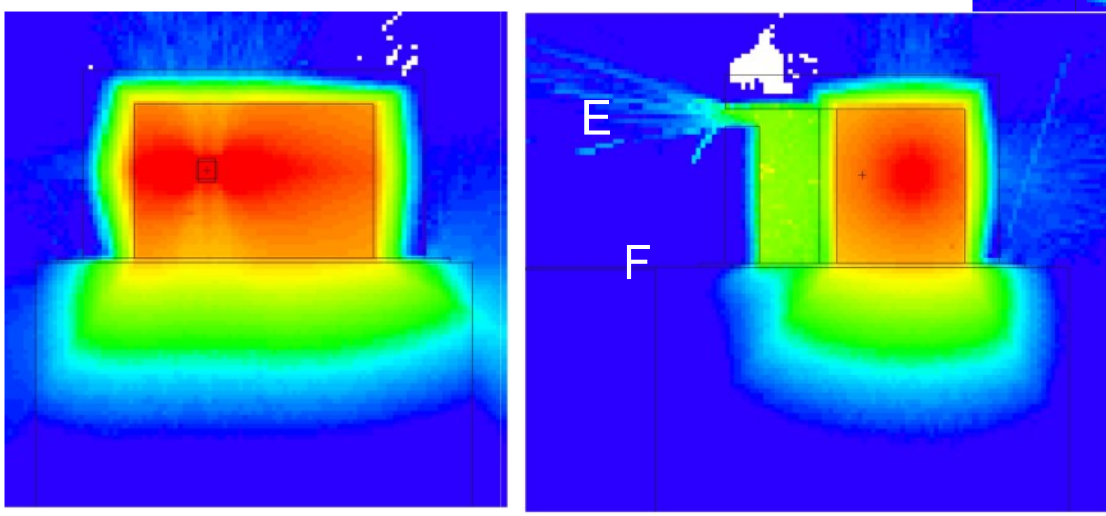


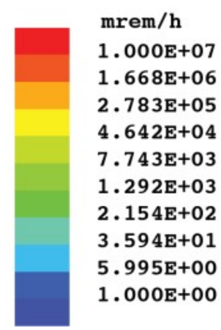
Radiologically certified for dark currents up to 5 MeV and 10 μA.

Radiation Shielding Calculations

- A=8,
- B=3,
- C=0.5,
- D=1.6,
- E=40,
- F=0.4 (all in mrem/h)
- All spill scenarios are for 5 MeV, 10 μA (CW-average)







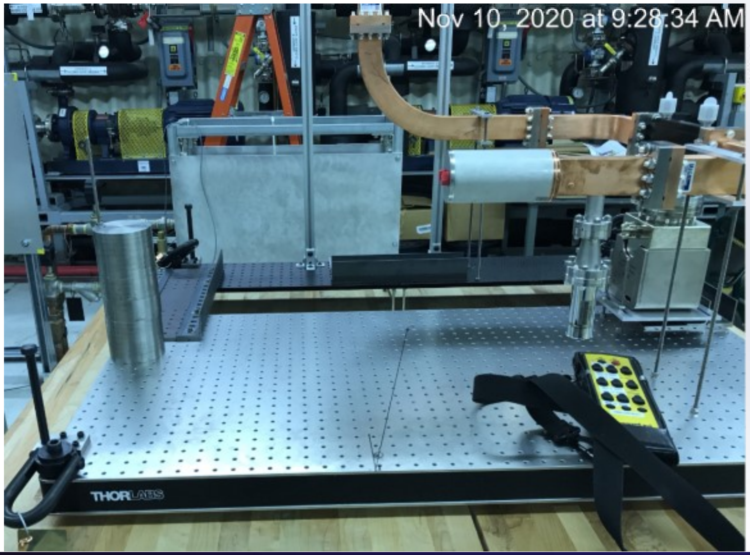
“As-Built” enclosure (without lids)

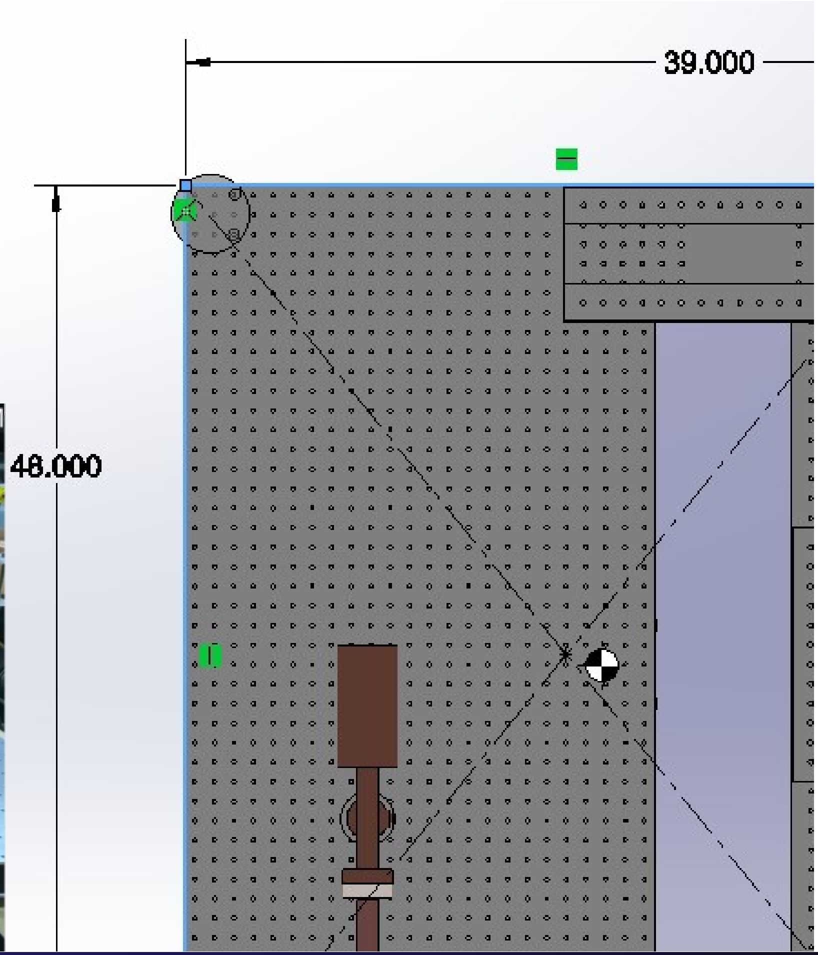
Initial lead stacked walls…

…and with wrapped lead and steel shells in place

Removable Experimental Support Platform

- Experimental support based on optical breadboard.
- Removable via crane
- Slots over internal rad. Shield
- One currently assembled, could build more if cadence warrants

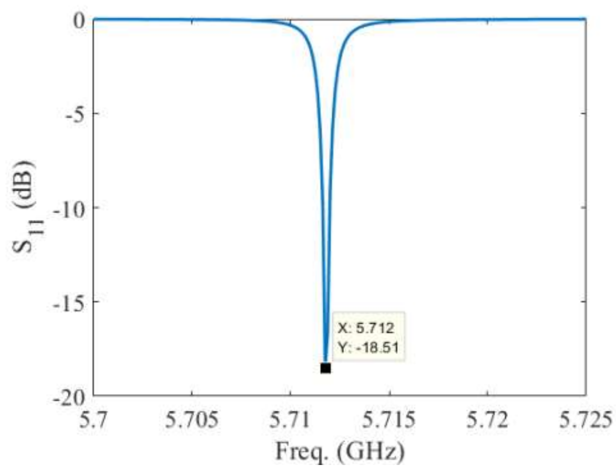


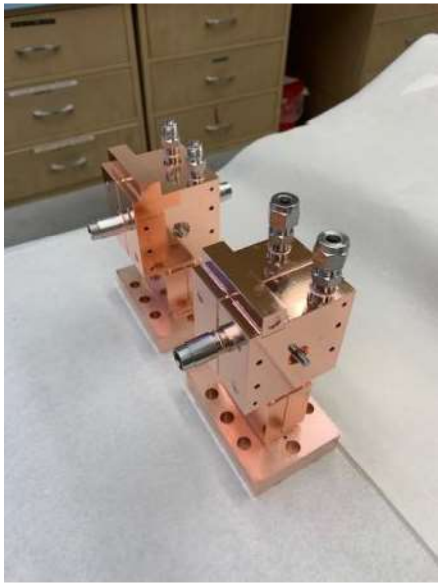


First test-fit of experimental platform in test chamber

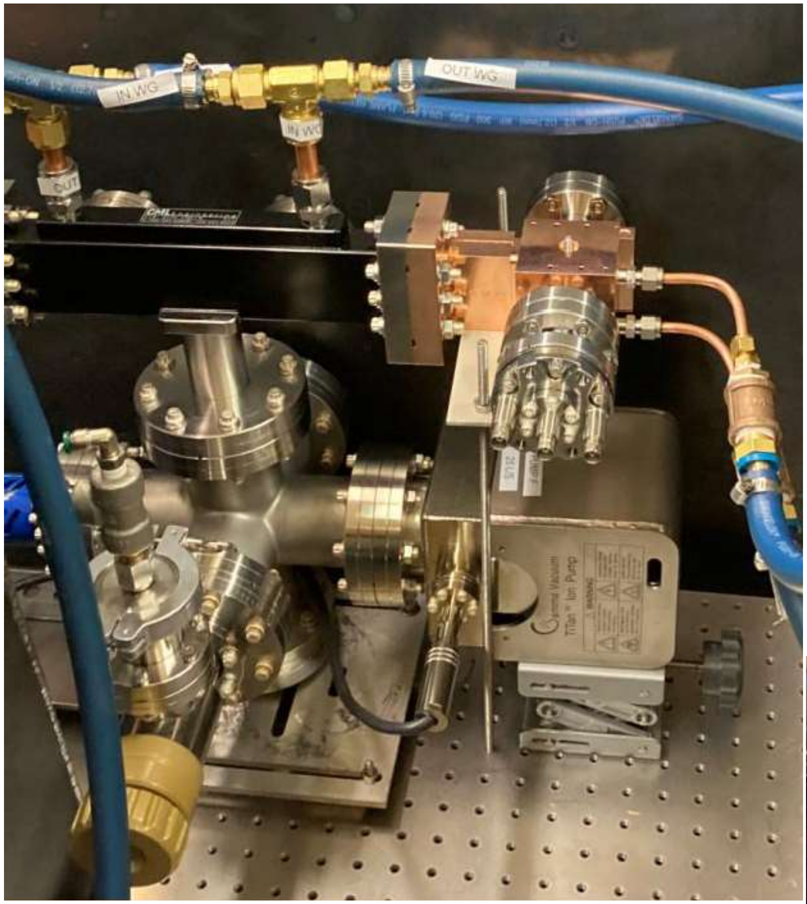
First test article: SLAC C-band beta=0.5 cavity

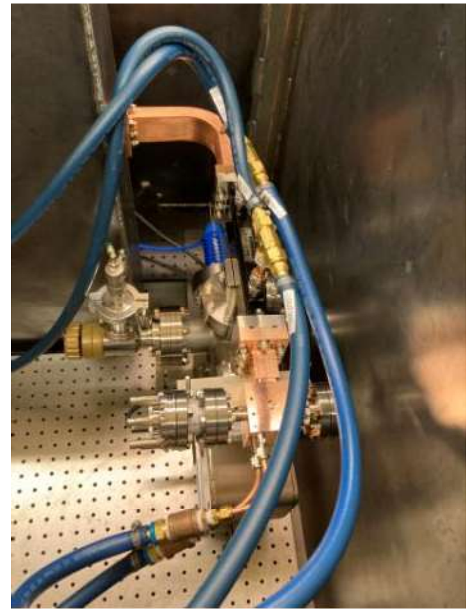
- LANL’s high gradient C-band test facility is the only high gradient C-band test facilities in the US and is open to collaborators.
- LANL provided us with Technology Evaluation and Development (TED) funding to test SLAC’s C-band beta=0.5 cavities at high gradient.
- First cavity to go for testing next week.





SLAC cavity installed in CERF-NM

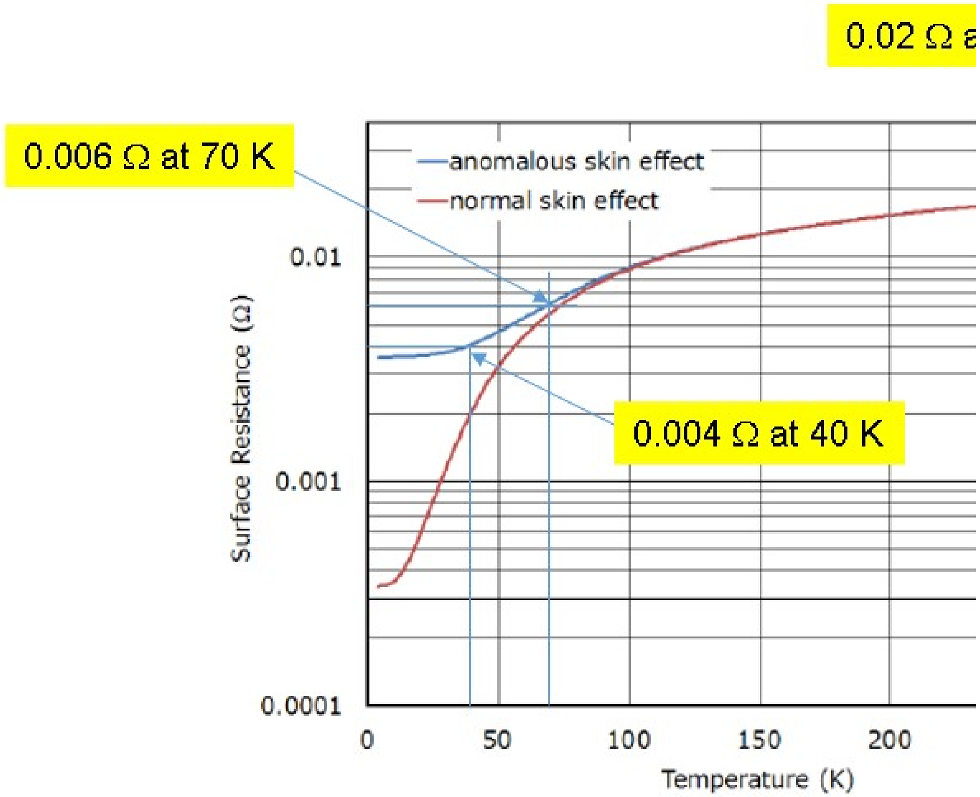




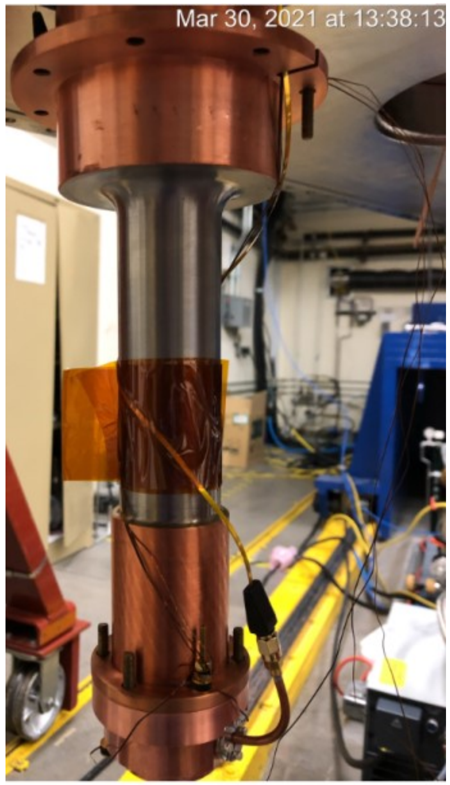
Cryo-cooling copper cavity

- 4-5 times higher Q-factor, 4-5 times lower rf power needs for high gradient.

- Higher achievable gradients.



Sumitomo 4K cryocooler

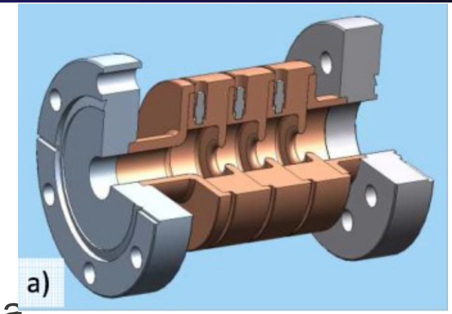


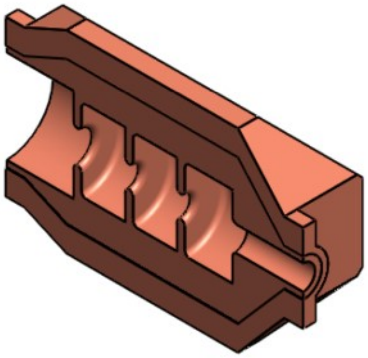
Cold Head Model		RDK-415D
1st Stage Capacity	5	35 W @ 50 K
	6	45 W @ 50 K
2nd Stage Capacity	5	1.5 W @ 4.2 K
	6	1.5 W @ 4.2 K
Minimum Temperature[2]		<3.5 K
Cooldown Time[2]	5	<60
	6	<60

A related project led by Tsuyoshi Tajima is developing our expertise for cryocooler operation and measurements.

Plan for testing C-band cavities

- Benchmark cavity
  - Fabricated by conventional machining.
  - Brazed in a hydrogen furnace – soft copper.
- Welded cavity
  - Fabricated by conventional machining in two halves.
  - Welded at LANL. LANL unique capability. Will result in a hard copper structure.





- Same geometry with new materials
  - We plan to fabricate the same geometry of copper-silver with different contents of silver.
  - The structures will be welded.
  - The best content of silver will be evaluated in simulations.

- Cryo-cooled cavity
  - The same geometries and materials will be tested at cryogenic temperatures.

Near-term test plans

- The high gradient test stand is finally coming online.

- FY21 outlook
  - Waveguide line is fully conditioned to 30 MW, 1 microsecond long pulses, 100 Hz repetition rate.
  - March - May, 2021: testing of SLAC's beta = 0.5 cavities.
  - June-July, 2021: conditioning of the mode launchers.
  - August – September, 2021: testing room-temperature cavities.

- FY22 outlook
  - Cryogenic temperature testing.
  - Materials coupons testing.

Conclusions

- The Los Alamos C-band Test stand (CERF-NM) is operational.
- We are about to start testing and fabricating cavities
  - Various materials
  - Various fabrication methods
  - Ours and collaborators' cavities
- Theory and modeling of the breakdown process
  - Multiscale physics required
  - Thermal stress driving Frank-Read sources for slip / dislocation – results in surface perturbations
- Materials search
  - Broad-scale modeling of dilute copper alloys for property optimization
  - Will prepare & characterize promising candidates, also characterize the materials we use to make cavities.