LANL Perspective and Interest in C3

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LANL Perspective and Institutional Support

- The purpose of this talk is to express LANL’s institutional support of C3 as an opportunity to realize an e+e− collider as a future precision machine.
- LANL has a long history in normal-conducting electron accelerators and views C3 as a mechanism to elevate this baseline technology to new frontiers.

- Topics in the following slides:
  - Introduction to LANL’s current high-gradient NCRF technology development activities
  - Motivation for LANL’s institutional interest in high-gradient NCRF technologies

LANL recognized the value of cyro-cooled NCRF a long time ago

1992 – Ground Test Accelerator

- 35-keV, 50-mA CW H- injector
- 2.5-MeV RFQ (operated at 20K with beam)
- 3.2-MeV after first DTL section (tested at 20K)

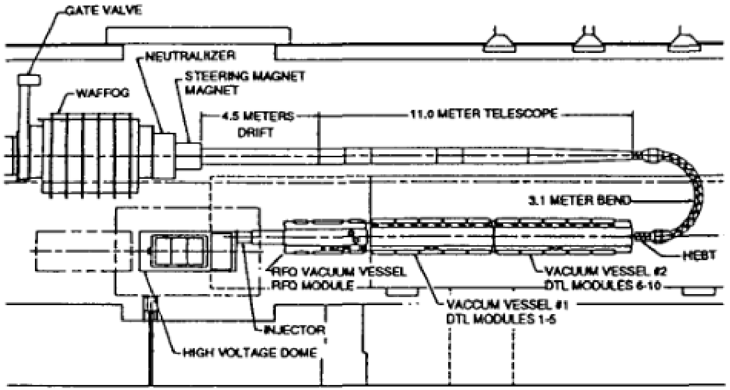


Fig. 1. Schematic of the GTA.

“Commissioning the GTA accelerator”, O. R. Sander, et al, 1992 LINAC Conference

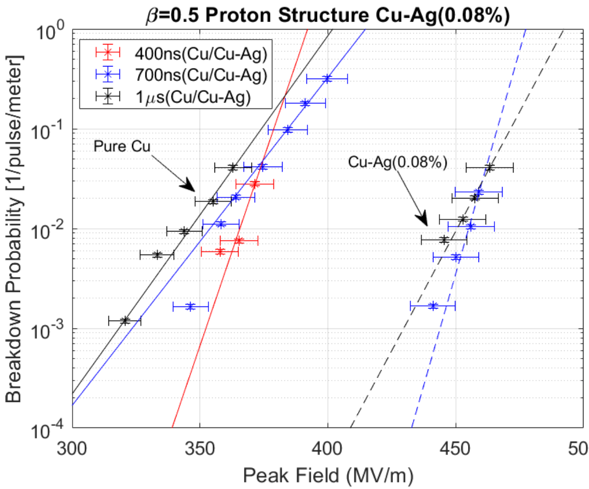
The GTA was designed to operate at 20k because:

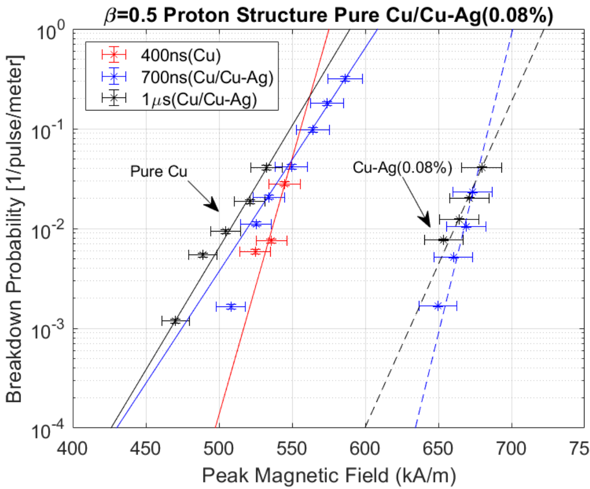
- Lower Ohmic heating
- Lower thermal expansion coefficient
- Combination leads to better operating stability

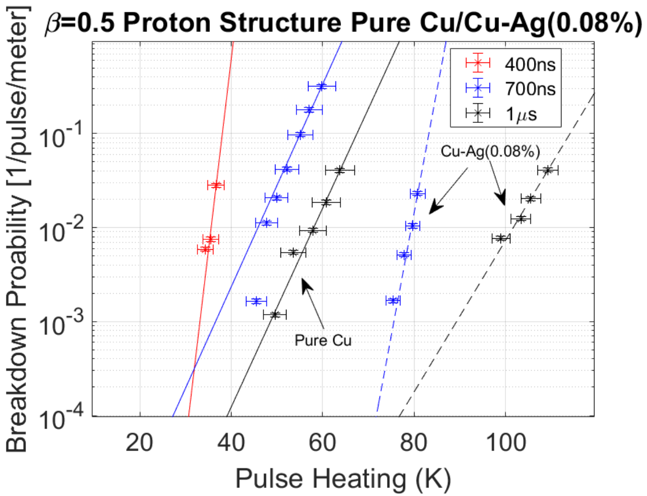
Sheffield’s AFEL was designed to operate at 77K

LANL’s C3 contributions illustrate sustained support

- Pioneer in developing a US C-band high gradient testing program.
- LANL commissioned the high gradient test stand called C-band Engineering Research Facility – New Mexico (CERF-NM).
- Existing C-band testing of structures in excess of 200 MeV/m





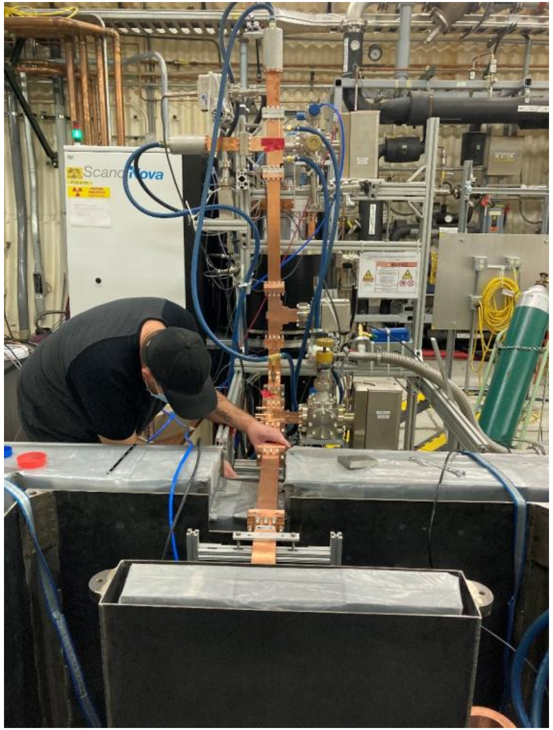


M. E. Schneider, S. V. Baryshev, et al., *Compact High gradient C-band Accelerators for Medical Accelerators*, AccApp ’21 (2021). https://www.ans.org/meetings/wm2021/session/view-920/#paper_2398.

LANL C-band Engineering Research Facility (CERF-NM)

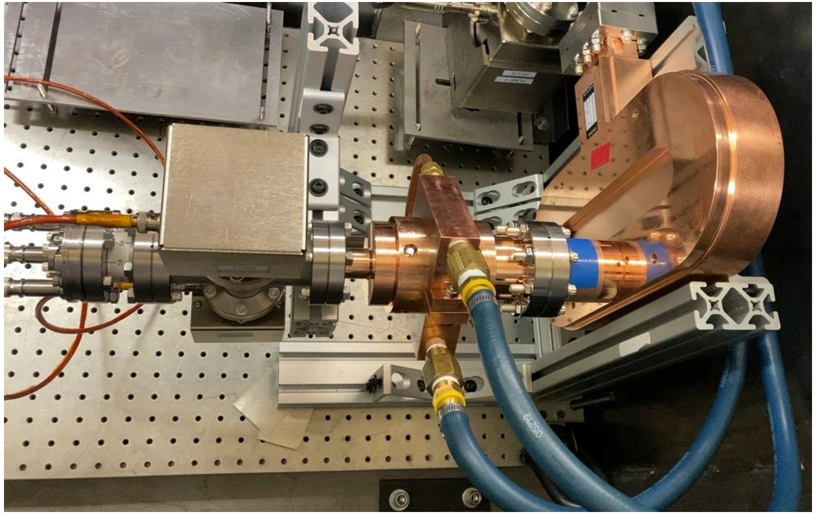
CERF-NM was built with $3M of LANL's internal infrastructure investment.

- 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 (100 Hz typical)
- Nominal bandwidth: 5.707 – 5.717 GHz

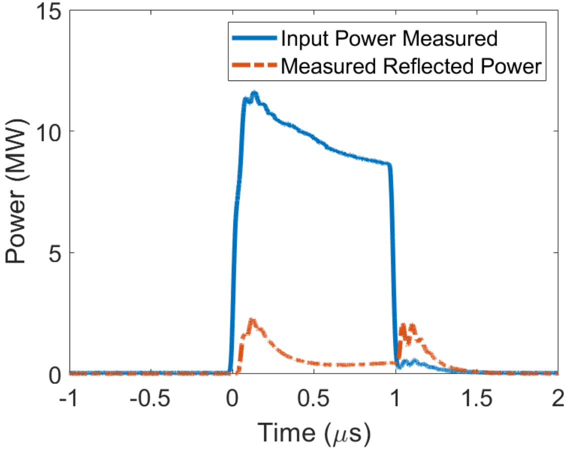


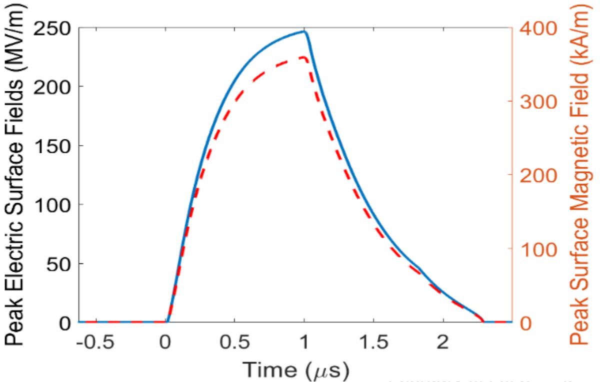
The first a/λ = 0.105 cavity was fabricated and tested up to the maximum available power

The cavity was conditioned at 1 μs pulse length.



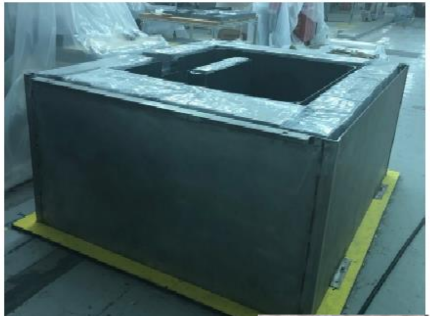
- Maximum coupled power: 14 MW
- Peak surface electric field: 255 MV/m
- Peak surface magnetic field: 373 kA/m

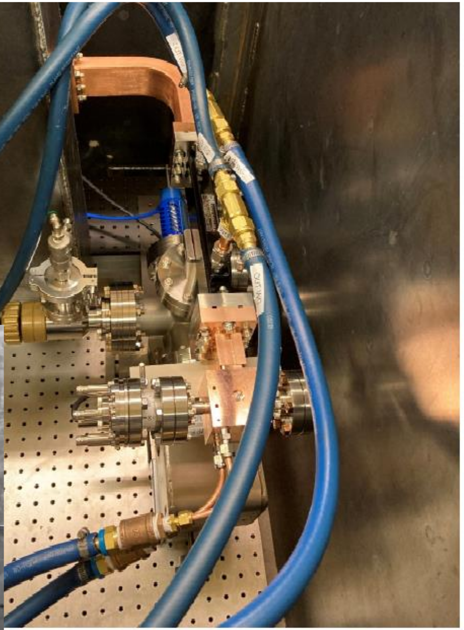


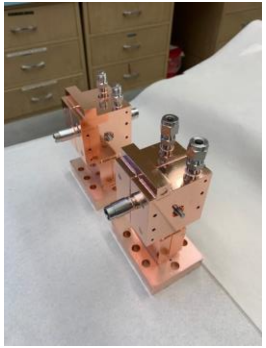


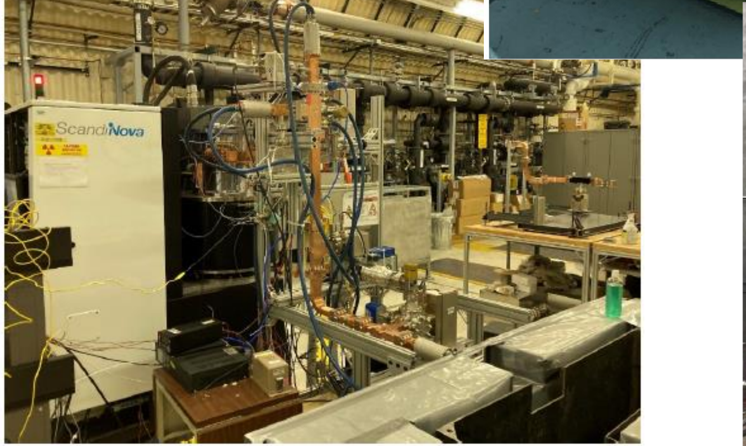
LANL leverages technology development to offer compelling options for a demonstration facility

- Growing test capability (x2)
- Large accelerator tunnel
- Support buildings, shielding
- Cryogen infrastructure
- *Funded by HEP and internal LDRD funds*









Status and plans for LANL's C-band facilities

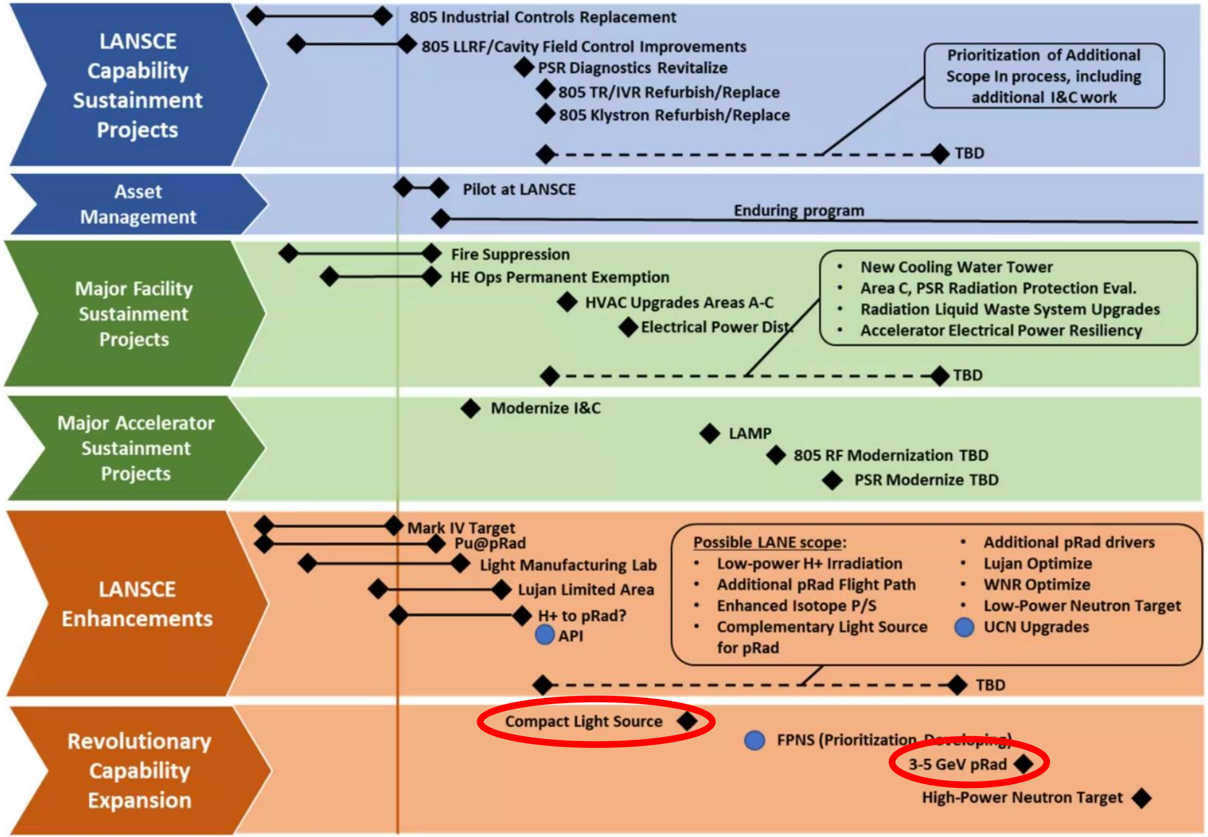
CERF-NM

- We plan to test multiple a/λ = 0.105 cavities fabricated with different methods.
- We will test an optimized proton booster cavity and ceramic-enhanced accelerator structures (LDRD ER project)
- Possible addition of cyro-cooling to test cavities

CARIE: Cathodes And RF Interactions in Extremes

- A new three-year LDRD DR is funded at LANL to demonstrate operation of high-quantum-efficiency (high-QE) cathodes in a high-gradient RF injector
- Target beam parameters: 250 pC, 0.1mm-mrad.
- Five-year goal: build an operational C-band cryo-cooled copper accelerator which could be used to drive an ICS source to provide up to 130 keV photon bursts for material studies

Notional LANSCE/DMMSC experimental capability roadmap motivates our high-gradient NCRF studies



LANSCE Capability Sustainment Projects

805 Industrial Controls Replacement

805 LLRF/Cavity Field Control Improvements

PSR Diagnostics Revitalize

805 TR/IVR Refurbish/Replace

805 Klystron Refurbish/Replace

Prioritization of Additional Scope In process, including additional I&C work

TBD

Asset Management

Pilot at LANSCE

Enduring program

Major Facility Sustainment Projects

Fire Suppression

HE Ops Permanent Exemption

HVAC Upgrades Areas A-C

Electrical Power Dist.

- New Cooling Water Tower
- Area C, PSR Radiation Protection Eval.
- Radiation Liquid Waste System Upgrades
- Accelerator Electrical Power Resiliency

TBD

Major Accelerator Sustainment Projects

Modernize I&C

LAMP

805 RF Modernization TBD

PSR Modernize TBD

LANSCE Enhancements

Mark IV Target

Pu@pRad

Light Manufacturing Lab

Lujan Limited Area

H+ to pRad?

API

Possible LANE scope:

- Low-power H+ Irradiation
- Additional pRad Flight Path
- Enhanced Isotope P/S
- Complementary Light Source for pRad
- Additional pRad drivers
- Lujan Optimize
- WNR Optimize
- Low-Power Neutron Target
- UCN Upgrades

TBD

Revolutionary Capability Expansion

Compact Light Source

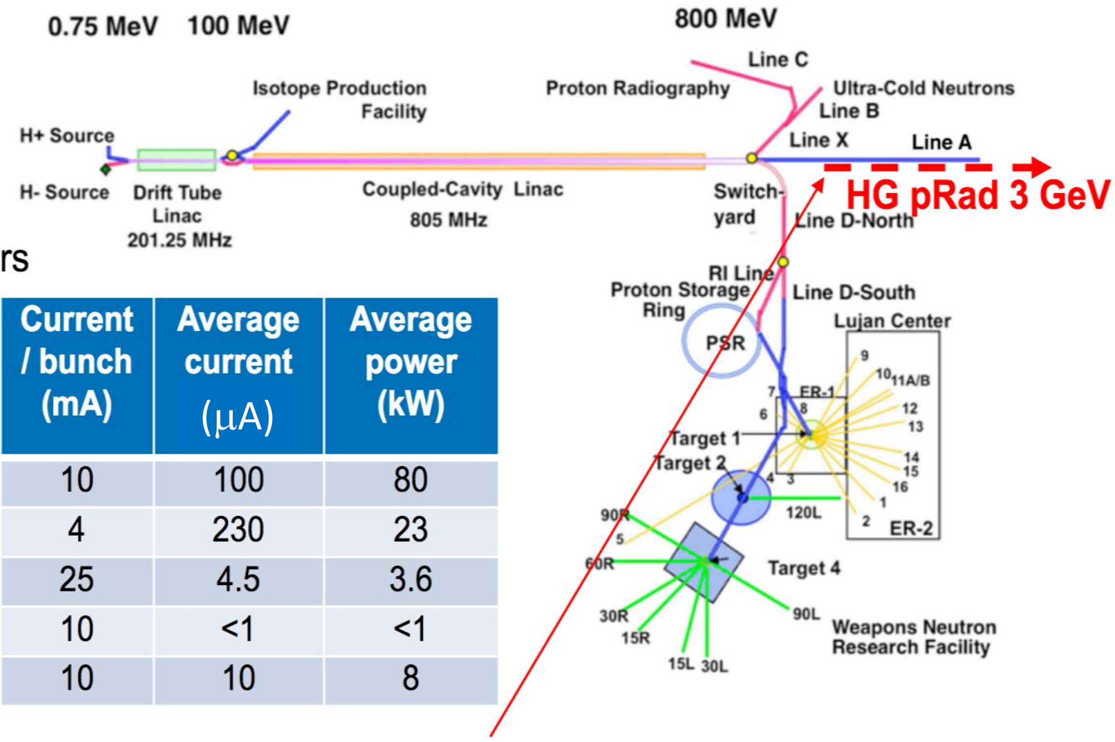
FPNS (Prioritization Developing)

3-5 GeV pRad

High-Power Neutron Target

Los Alamos NATIONAL LABORATORY

A 3-GeV booster for pRad can be built with high gradient NCRF



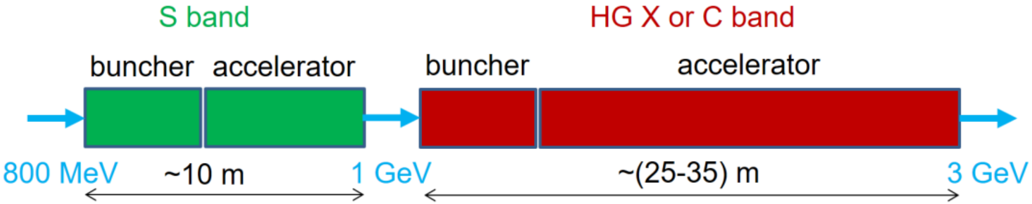
LANSCE Beam Parameters

Area	Rep. Rate (Hz)	Pulse Length (μs)	Current / bunch (mA)	Average current (μA)	Average power (kW)
Lujan	20	625	10	100	80
IPF	100	625	4	230	23
WNR	100	625	25	4.5	3.6
pRad	1	625	10	<1	<1
UCN	20	625	10	10	8

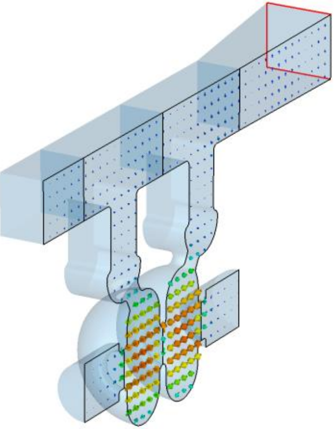
Potential Location of High-Gradient pRad booster to 3 GeV at LANSCE

A 3-GeV booster for enhanced proton radiography can be based on our high-gradient, cryo-cooled, NCRF technology

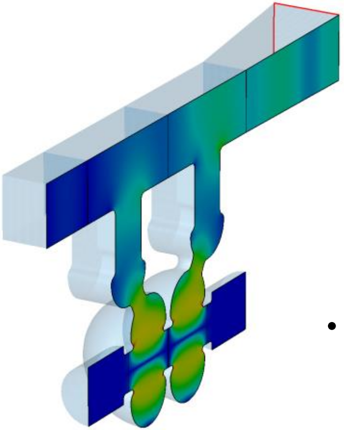
- Add a high-gradient (HG) linac section after the existing LANSCE linac to increase the proton beam energy from 800 MeV to 3 GeV.
- Why: This increases proton radiography (pRad) resolution 10 times.
- How: Compact 3-GeV high-gradient pRad booster:
  - Will be based on S- & C-band HG structures adapted for protons (v/c = 0.84 – 0.97). Prototype high-gradient proton C-band cavities will be tested at LANL.
  - Will have an optimal beam-physics design based on front-to-end modeling.
  - Fits the site and can be used in parallel with the existing 800-MeV pRad.
  - Can be the first-ever high-gradient normal-conducting proton linear accelerator.



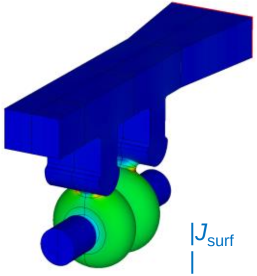
High-gradient test cavity with distributed coupling is designed and being fabricated

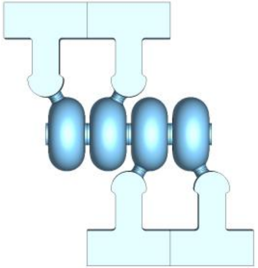


E-field in cut plane



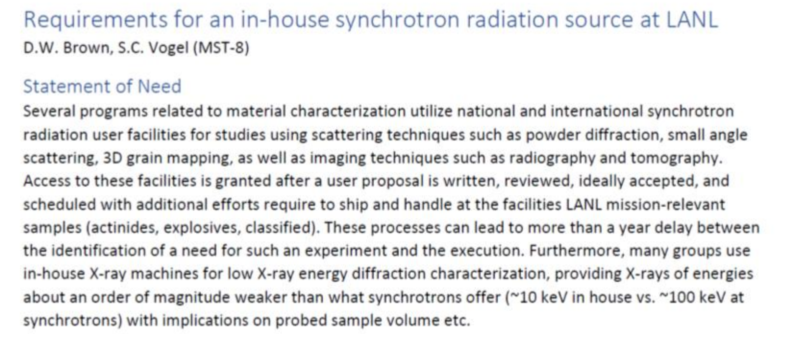
Power flow snapshot





- The test cavity was designed for 5.712 GHz (not 5.635 GHz), to be tested at the existing LANL C-band RF test stand: 50-MW klystron with <1 µs pulse at 100 Hz.
- Simplified cell shape – no noses (not efficient for large beam apertures: a = 6.5 mm, r = 21.9 mm; a/r = 0.3); reduces E_{max} by 45%.
- Large RF couplers: each delivers one-half of the RF power fed into waveguide.

ICS has been identified as an important NNSA tool

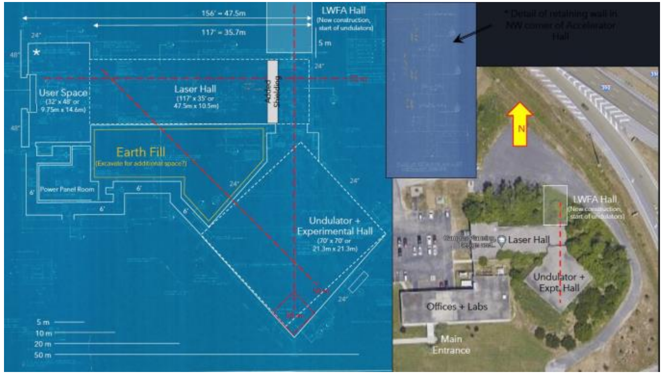


Requirements for an in-house synchrotron radiation source at LANL

D.W. Brown, S.C. Vogel (MST-8)

Statement of Need

Several programs related to material characterization utilize national and international synchrotron radiation user facilities for studies using scattering techniques such as powder diffraction, small angle scattering, 3D grain mapping, as well as imaging techniques such as radiography and tomography. Access to these facilities is granted after a user proposal is written, reviewed, ideally accepted, and scheduled with additional efforts require to ship and handle at the facilities LANL mission-relevant samples (actinides, explosives, classified). These processes can lead to more than a year delay between the identification of a need for such an experiment and the execution. Furthermore, many groups use in-house X-ray machines for low X-ray energy diffraction characterization, providing X-rays of energies about an order of magnitude weaker than what synchrotrons offer (~10 keV in house vs. ~100 keV at synchrotrons) with implications on probed sample volume etc.



LANL is current working on a joint NNSA proposal with LLE for an ICS capability at Omega

Will lead into a higher performance ICS system at LANSCE based on high-gradient NCRF

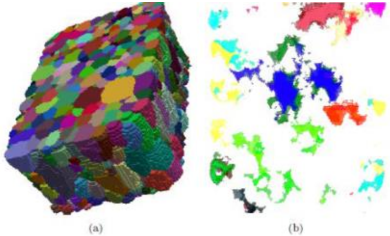


Figure 37: (a) A 3D reconstruction of the orientation field of the UN phase. (b)U_3Si_5 orientation field, where 10 layers are projected onto a 2D plane.

High-energy diffraction microscopy of nuclear fuel

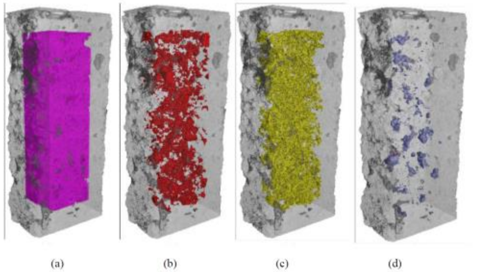


Figure 41: Four phases segmented from a rectangular region of interest selected from a 3D tomographic reconstruction of the measured UN-U_3Si_5 sample. (a) UN, (b) U_3Si_5, (c) U(Si,N), and (d) pores).

CT of nuclear fuel

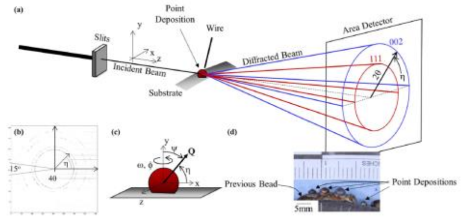
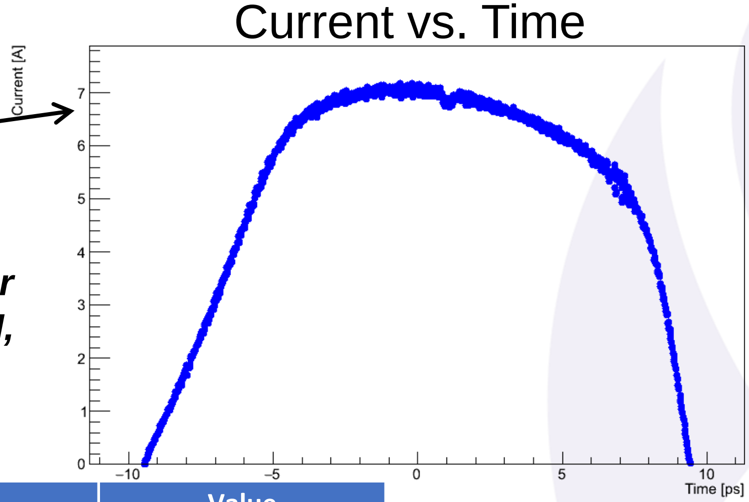


Fig. 1—(*a*) Schematic of the beamline during the point deposition experiments. (*b*) Representative detector image. (*c*) Schematic of point deposition on substrate with relevant coordinate systems. (*d*) Image of point depositions on the substrate and on top of a previous line deposition.

In situ AM studied by synchrotron diffraction & radiography

CARIE: a higher gradient and a lower cathode emittances will make a huge difference for a DMMSC-type XFEL

(3) Implies 500:1 compression to achieve 3.5 kA at MaRIE undulator, which leads to other problems (CSR, uBI, etc)



In Steve Russell’s baseline injector design, we suppress the thermal emittance by keeping the RMS beam sizes very small, which makes a very long, low current bunch

We might be able to have twice the current (and need only half the compression) at the same total emittance if (1) the thermal emittance contribution vanished and (2) we can operate at a higher accelerating gradient

Property	Value
Energy	195 MeV
Charge	100 pC
Thermal ε_n (copper$^{*)}$	41 nm
Residual ε_n	60 nm
Total RMS ε_n	73 nm
RMS Length	5.5 ps
RMS Energy Spread	0.08%

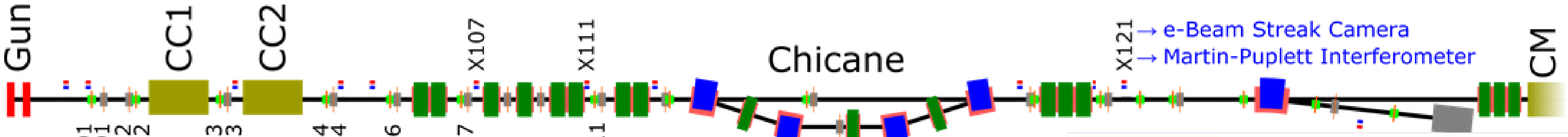
$$\varepsilon_{therm} \sim \sigma\sqrt{\frac{W}{mc^2}}$$

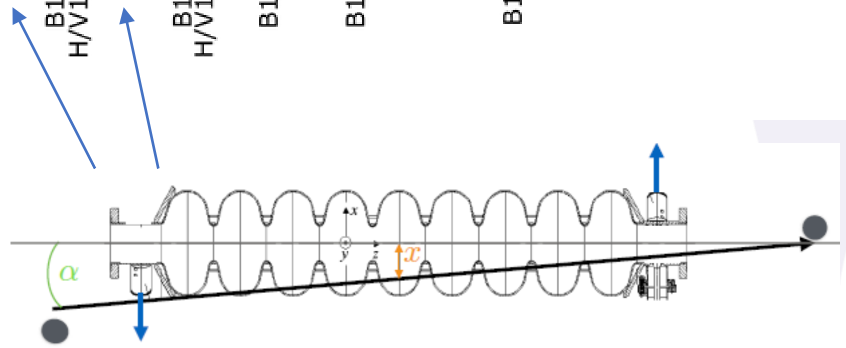
Excess energy from emission process

$$\varepsilon_{total}^2 = \varepsilon_{thermal}^2 + \varepsilon_{residual}^2$$

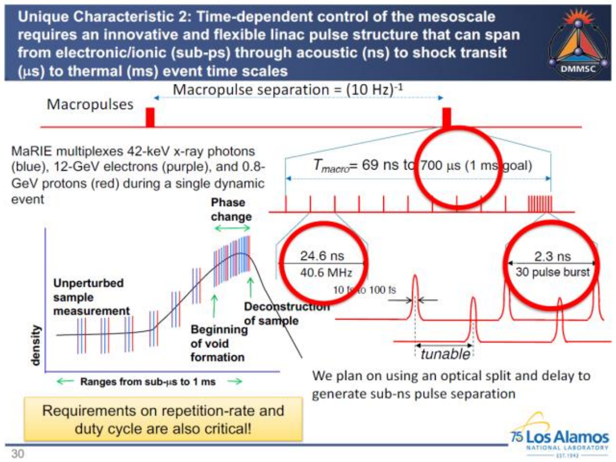
Original SRF MaRIE baseline design is not compatible with required DMMSC pulse structure (but high-gradient NCRF would be)

- FAST (Fermilab Accelerator Science and Technology) upstream beamline: Photocathode rf Gun, two capture cavities, BPMs (B1xx), correctors (H/V1xx), and imaging station beamline crosses (X1yy) are indicated.





MaRIE (Matter-Radiation Interactions in Extreme) XFEL facility is one possible solution for the DMMSC.



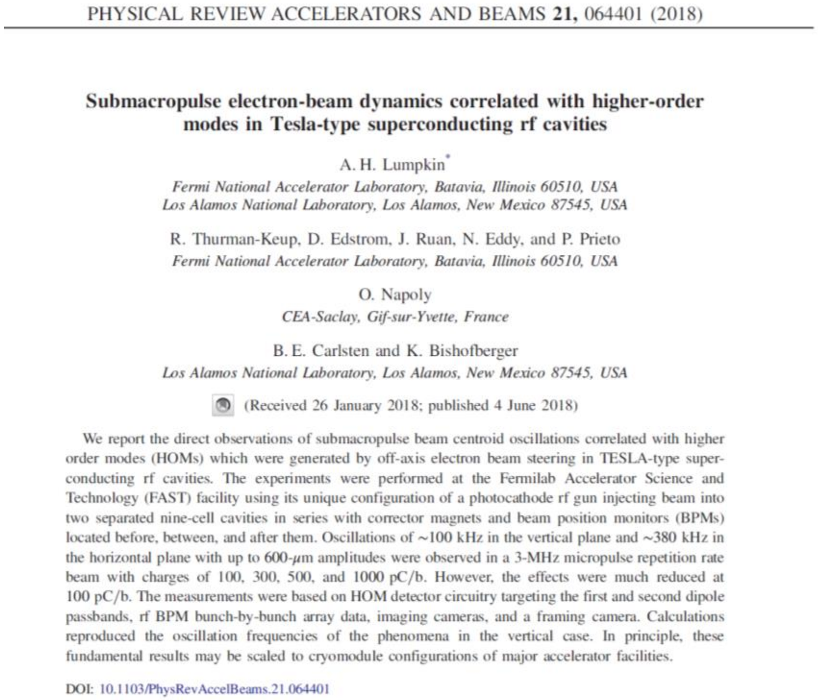
Unique Characteristic 2: Time-dependent control of the mesoscale requires an innovative and flexible linac pulse structure that can span from electronic/ionic (sub-ps) through acoustic (ns) to shock transit (μs) to thermal (ms) event time scales

MaRIE multiplexes 42-keV x-ray photons (blue), 12-GeV electrons (purple), and 0.8-GeV protons (red) during a single dynamic event

We plan on using an optical split and delay to generate sub-ns pulse separation

Requirements on repetition-rate and duty cycle are also critical!

We measured the CC1 and CC2 generated dipole HOM kicks at 1-MHz and 3-MHz repetition rates



PHYSICAL REVIEW ACCELERATORS AND BEAMS **21,** 064401 (2018)

Submacropulse electron-beam dynamics correlated with higher-order modes in Tesla-type superconducting rf cavities

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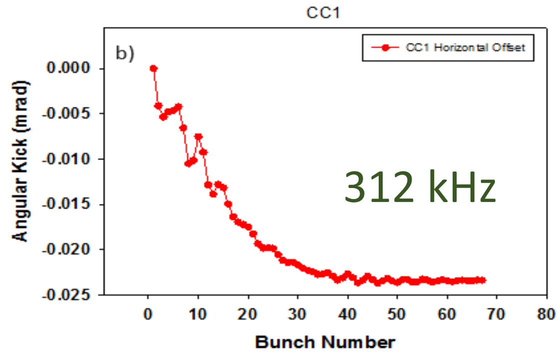
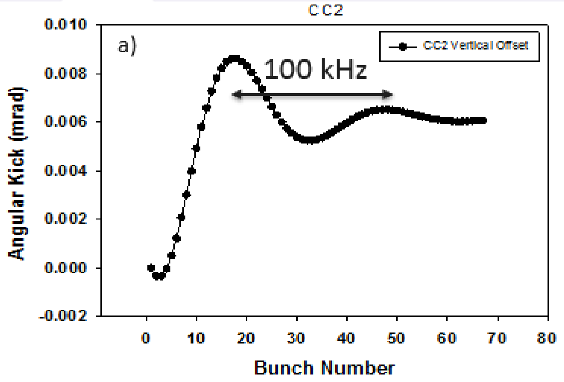
(Received 26 January 2018; published 4 June 2018)

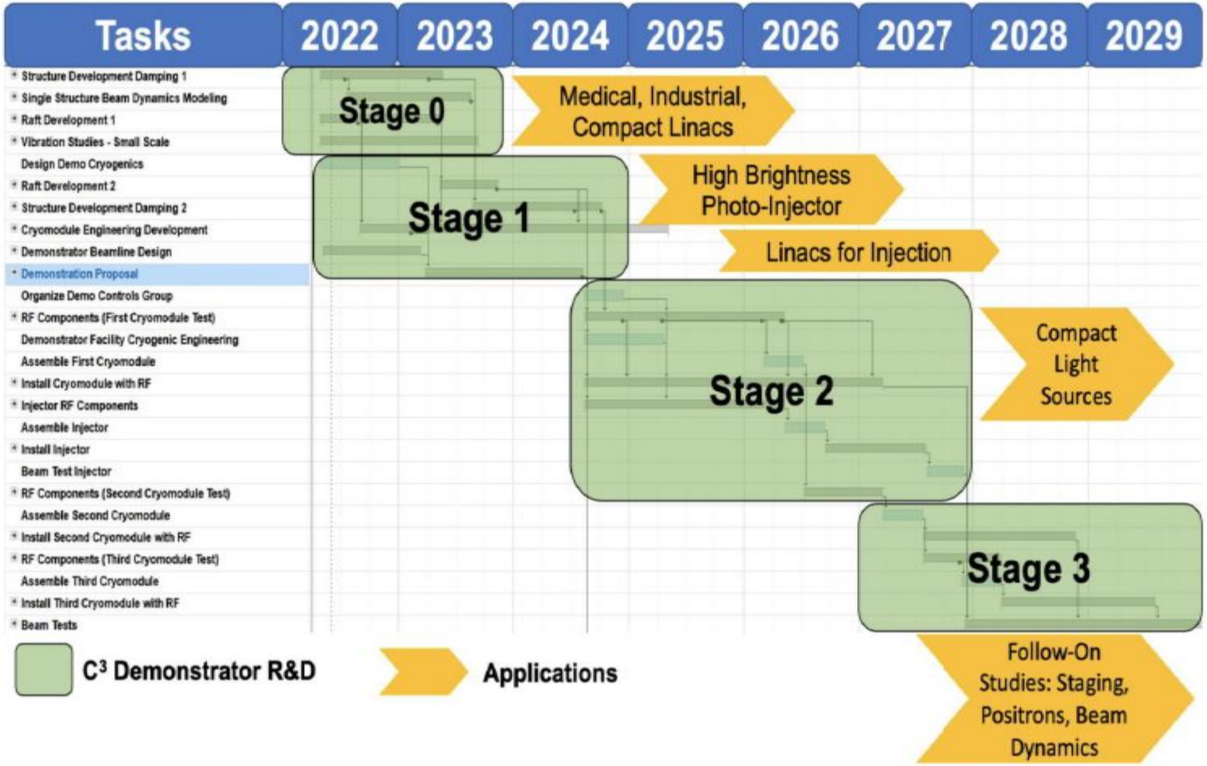
We report the direct observations of submacropulse beam centroid oscillations correlated with higher order modes (HOMs) which were generated by off-axis electron beam steering in TESLA-type superconducting rf cavities. The experiments were performed at the Fermilab Accelerator Science and Technology (FAST) facility using its unique configuration of a photocathode rf gun injecting beam into two separated nine-cell cavities in series with corrector magnets and beam position monitors (BPMs) located before, between, and after them. Oscillations of ~100 kHz in the vertical plane and ~380 kHz in the horizontal plane with up to 600-μm amplitudes were observed in a 3-MHz micropulse repetition rate beam with charges of 100, 300, 500, and 1000 pC/b. However, the effects were much reduced at 100 pC/b. The measurements were based on HOM detector circuitry targeting the first and second dipole passbands, rf BPM bunch-by-bunch array data, imaging cameras, and a framing camera. Calculations reproduced the oscillation frequencies of the phenomena in the vertical case. In principle, these fundamental results may be scaled to cryomodule configurations of major accelerator facilities.

DOI: 10.1103/PhysRevAccelBeams.21.064401





LANL high-gradient NCRF development and applications needs align with C3 prototype and application schedule



Concluding Remarks

- LANL views C3 as a technology gateway for basic and applied applications
- C3 technologies (novel RF coupling and cryo operation) align directly with LANL priorities and capabilities
  - We are already providing a crucial role and have strong community engagement
- Unique within the DOE complex, LANL enables leveraged use of NNSA funds in this broader mission (we truly collaborate rather than compete for funding)
- LANL is proud to be part of the international high-gradient NCRF collaboration