Muon Collider Relevant R&D at LANL

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November 1, 2024

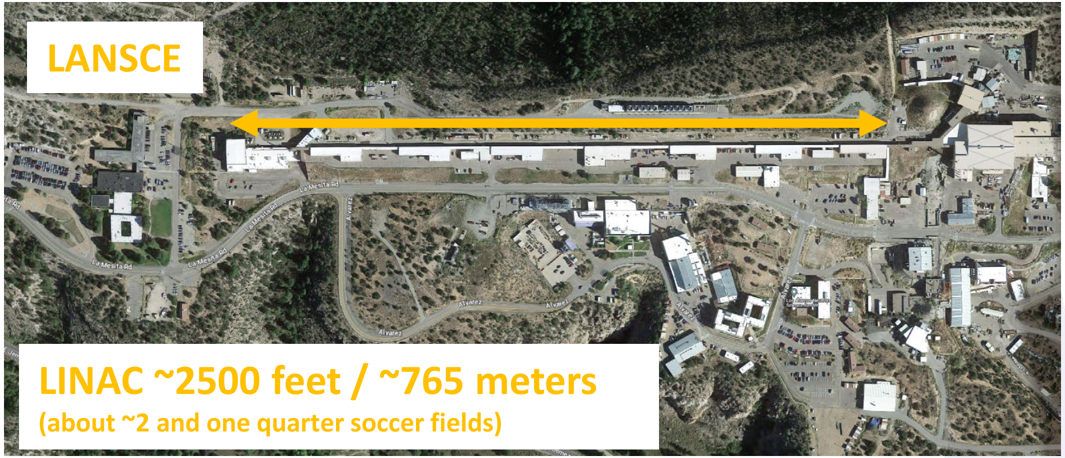
LA-UR-24-31713

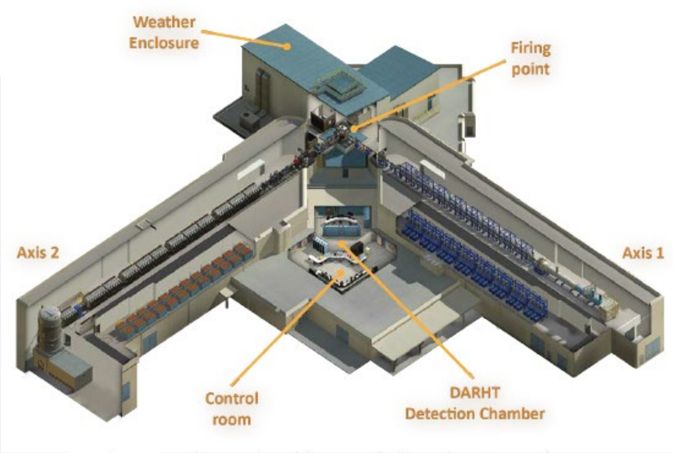
Outline

- **Background on LANL accelerator capability (4 slides)**
- **Big projects in progress, or imminent (6 slides)**
  - Los Alamos Neutron Science Center (LANSCE) Modernization Project
  - LANSCE 805 MHz high-power RF modernization
- **Other projects and capabilities of interest (7 slides)**

Background and history

LANL has a “no-kidding” world-class accelerator capability





Dual-Axis Radiographic Hydrodynamic Test facility (DARHT)

Approximately 300 employees working at LANSCE, DARHT or on accelerator related technology.

LANL has the only real accelerator capability within the Nation’s national security enterprise

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LANSCE is a repurposed 800 MeV linear accelerator sending two beams (H^+ and H^-) to six areas

Louis Rosen, "Father of LANSCE".

Operations began in 1972 as the Los Alamos Meson Physics Facility (LAMPF) for a twenty-year basic nuclear physics program

- Most powerful proton beam in the world (until the early 2000s)
- Beam delivery was flexible
- Defense applications began within a decade

In the 1990s, the facility was renamed the Los Alamos Neutron Science Center and repurposed as a user facility for stockpile stewardship

View of the LANSCE accelerator complex from the west

Entering its sixth decade of service, LANSCE is a unique LANL capability

Isotope Production Facility (IPF)

- Medical and other isotopes for the isotope program
- Short-lived isotopes for defense programs, non-/counterproliferation, and criticality safety

Proton Radiography (pRad Facility)

- Dynamic radiography for defense programs and counterproliferation

Ultra-Cold Neutron Facility (UCN)

- Unique probe for nuclear physics, possible future defense program uses

Lujan Neutron Scattering Center (Lujan Center)

- Neutron scattering and imaging for defense programs and nuclear energy
- Nuclear physics for defense programs

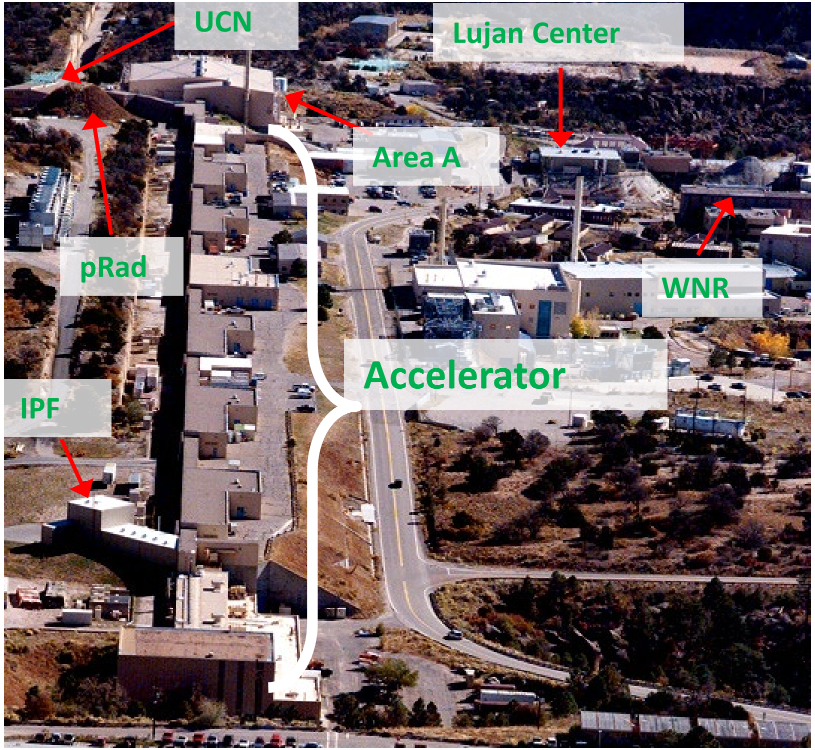
Weapons Neutron Research Facility (WNR)

- Nuclear physics for defense programs, counterproliferation, and criticality safety
- Electronics testing for industry and global security

Area A

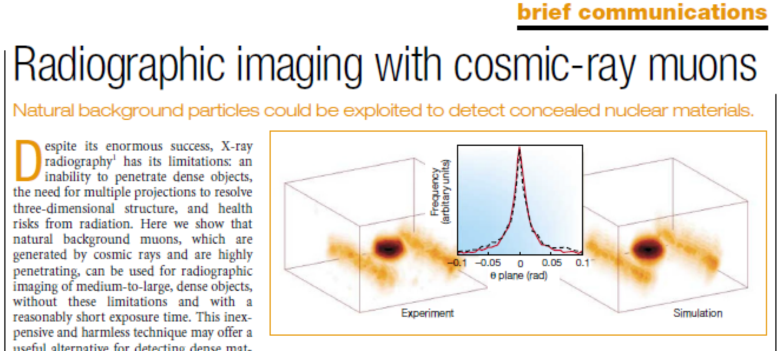
- *Future experimental possibilities*

NNSA work
Other work



100-800 MeV proton energies
six target stations (three neutron spallation targets)

LANL does have some history with muon imaging and acceleration


brief communications

Radiographic imaging with cosmic-ray muons

Natural background particles could be exploited to detect concealed nuclear materials.

Despite its enormous success, X-ray radiography[1] has its limitations: an inability to penetrate dense objects, the need for multiple projections to resolve three-dimensional structure, and health risks from radiation. Here we show that natural background muons, which are generated by cosmic rays and are highly penetrating, can be used for radiographic imaging of medium-to-large, dense objects, without these limitations and with a reasonably short exposure time. This inexpensive and harmless technique may offer a useful alternative for detecting dense mat-

K. Borozdin, et. al., *Nature* 422, 277 (2003)

Cosmic-ray muon imaging still very active at LANL.


RESEARCH ARTICLE | OCTOBER 01 2003

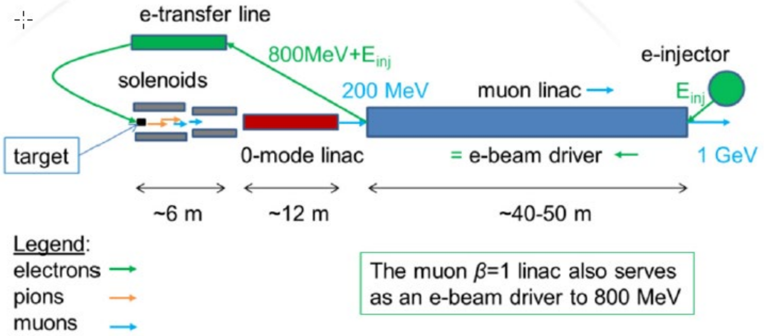
Detection of high-Z objects using multiple scattering of cosmic ray muons

William C. Priedhorsky; Konstantin N. Borozdin; Gary E. Hogan; Christopher Morris; Alexander Saunders; Larry J. Schultz; Margaret E. Teasdale

Check for updates

Rev. Sci. Instrum. 74, 4294–4297 (2003)

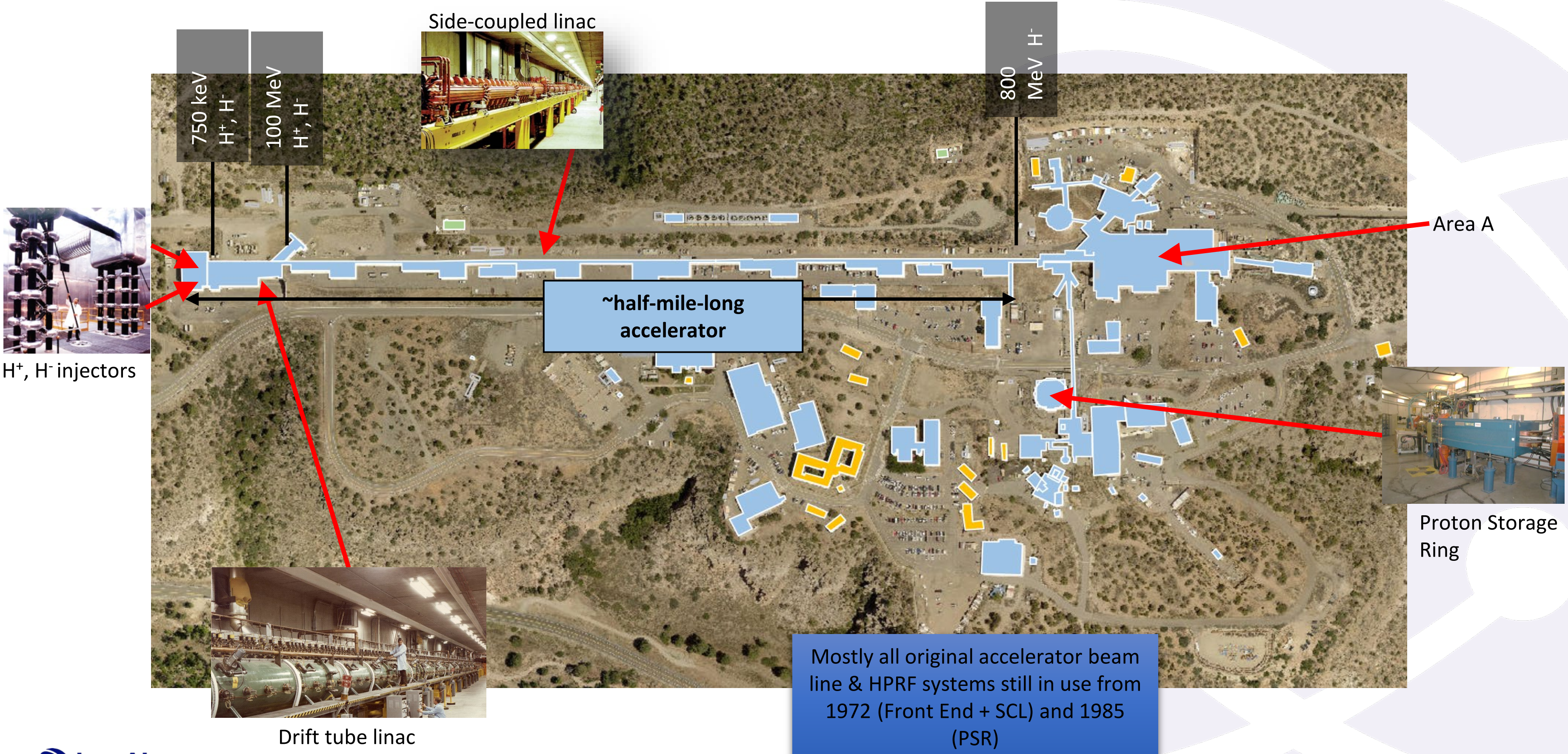
https://doi.org/10.1063/1.1606536



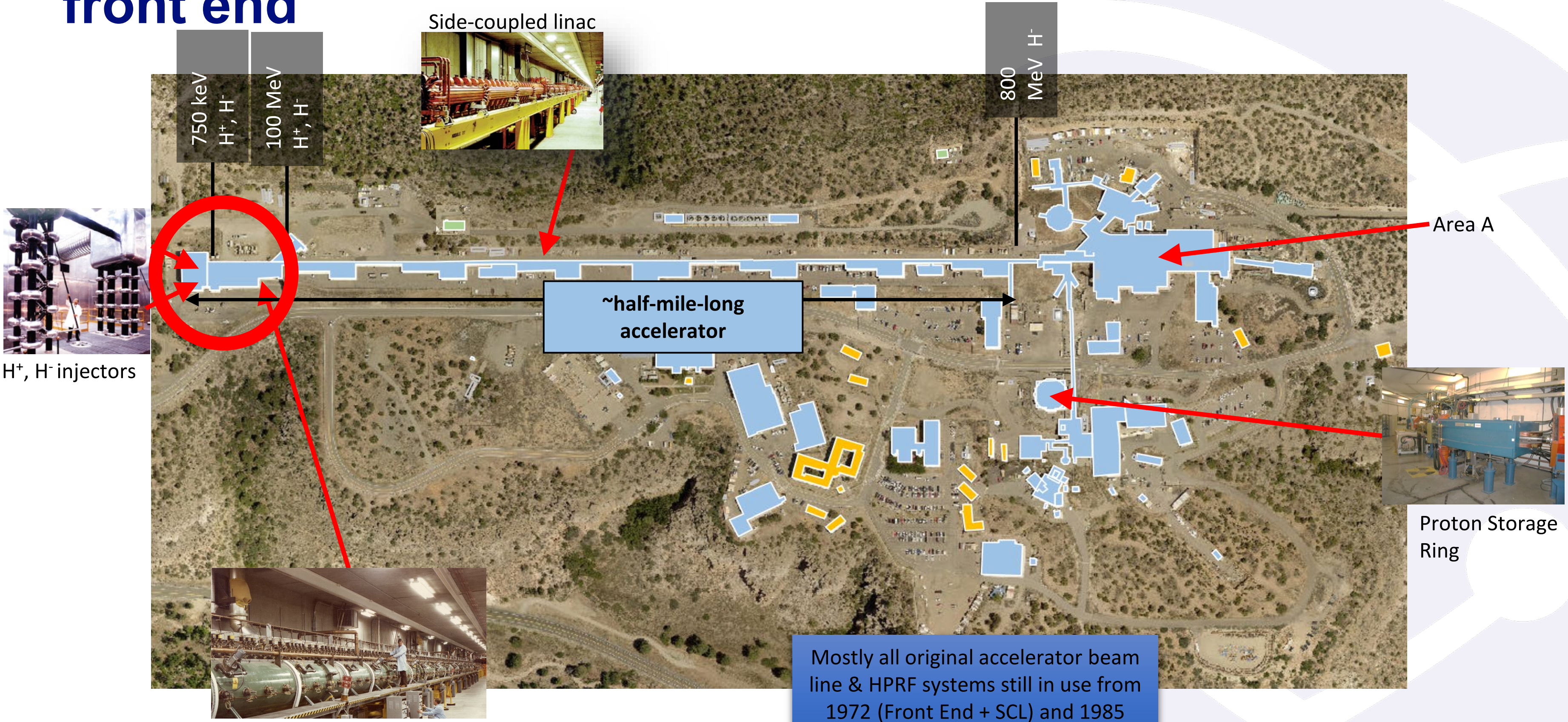
R. W. Garnett, et. al.,"A Compact Muon Accelerator for Tomograph and Active Interrogation", LINAC 2016

LAMP

LANSCE systems are almost all original from 1972



We recently received CD-0 approval to revitalize the front end

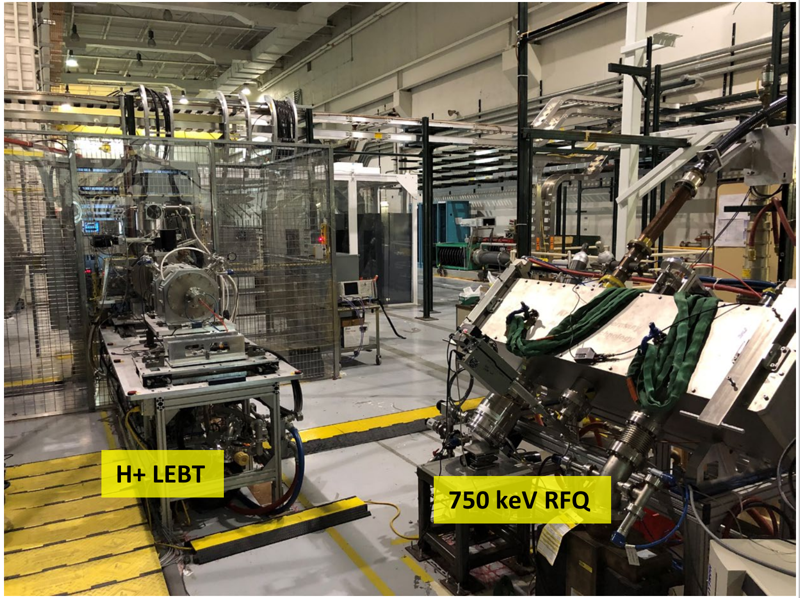


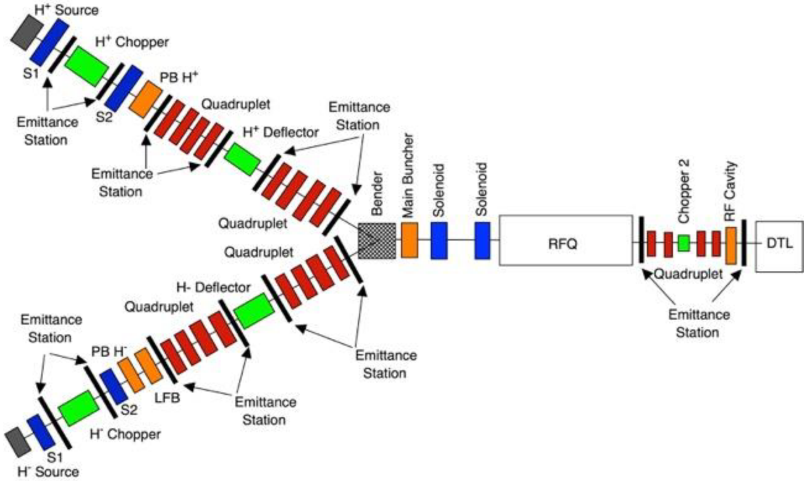
Mostly all original accelerator beam line & HPRF systems still in use from 1972 (Front End + SCL) and 1985 (PSR)

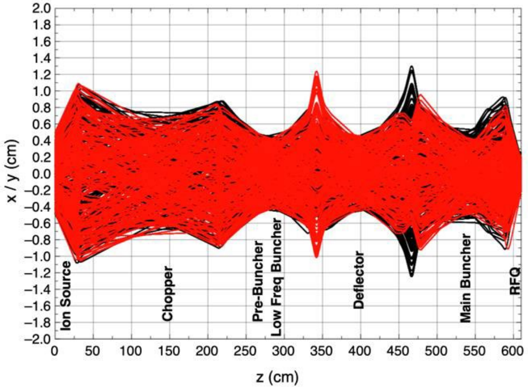
The LANSCE Modernization Project

The NNSA intends to continue LANSCE operations for several more decades, which requires significant efforts to revitalize the aging facility.

RFQ Test Stand



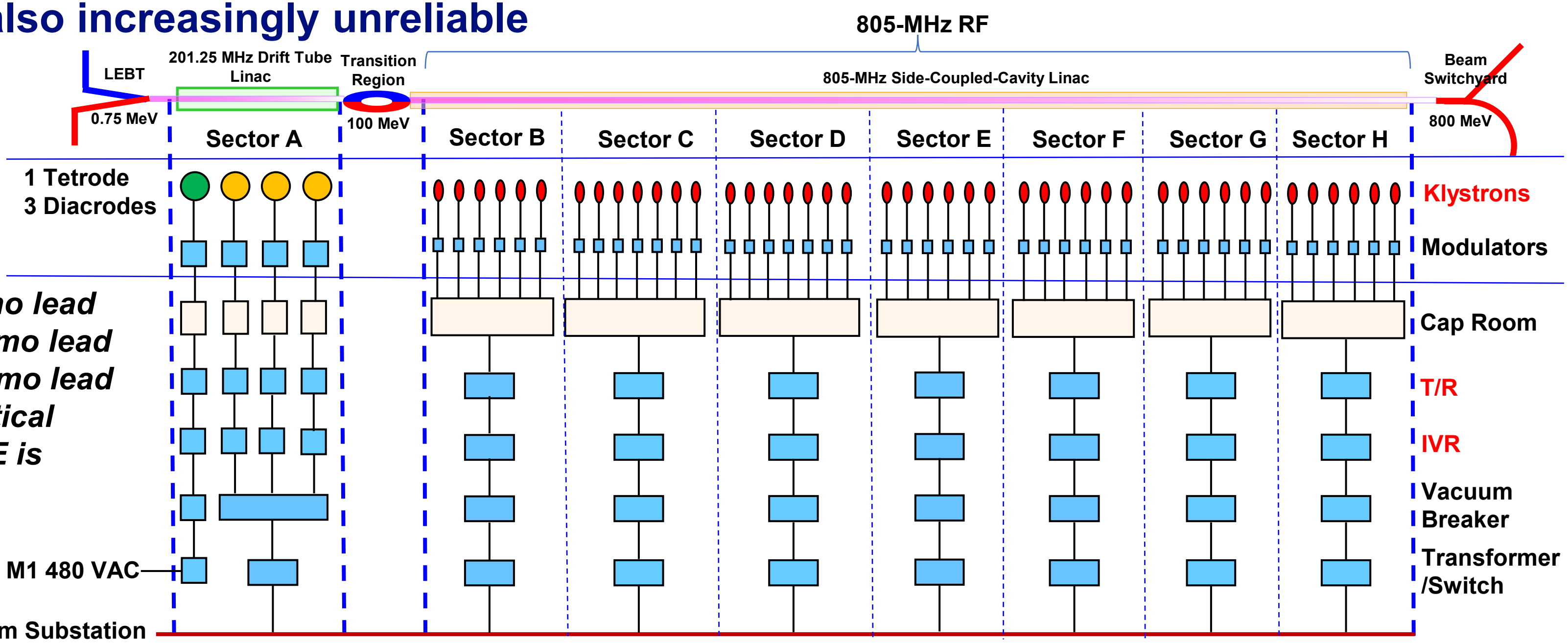




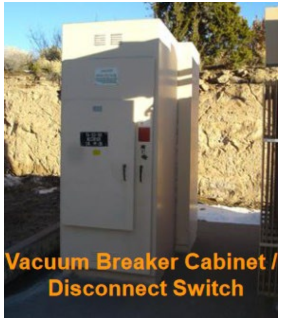
- Injector and DTL will be replaced:
- Dual species H+/H- will be preserved

805 MHz HPRF Replacement

LAMP addresses single-point-of-failure vulnerabilities up to 100 MeV, but 805-MHz HPRF system is also increasingly unreliable



Klystrons (18 mo lead time), T/Rs (36 mo lead time), IVRs (24 mo lead time) are all critical spares LANSCE is running out of



We can fix the problem with a more modern vacuum tube-based system…

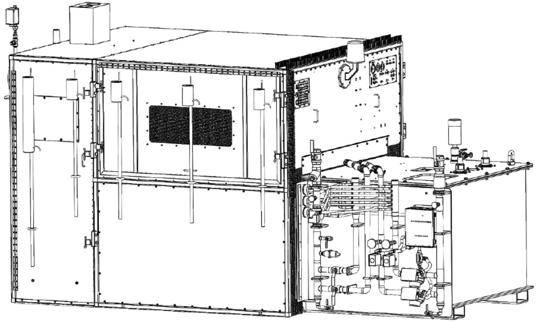
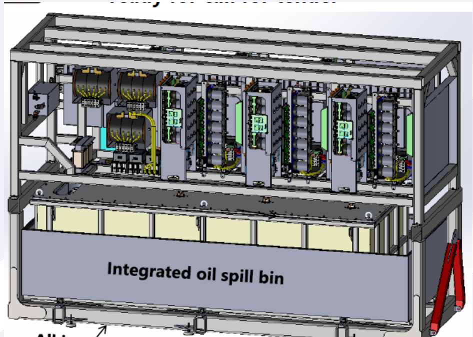


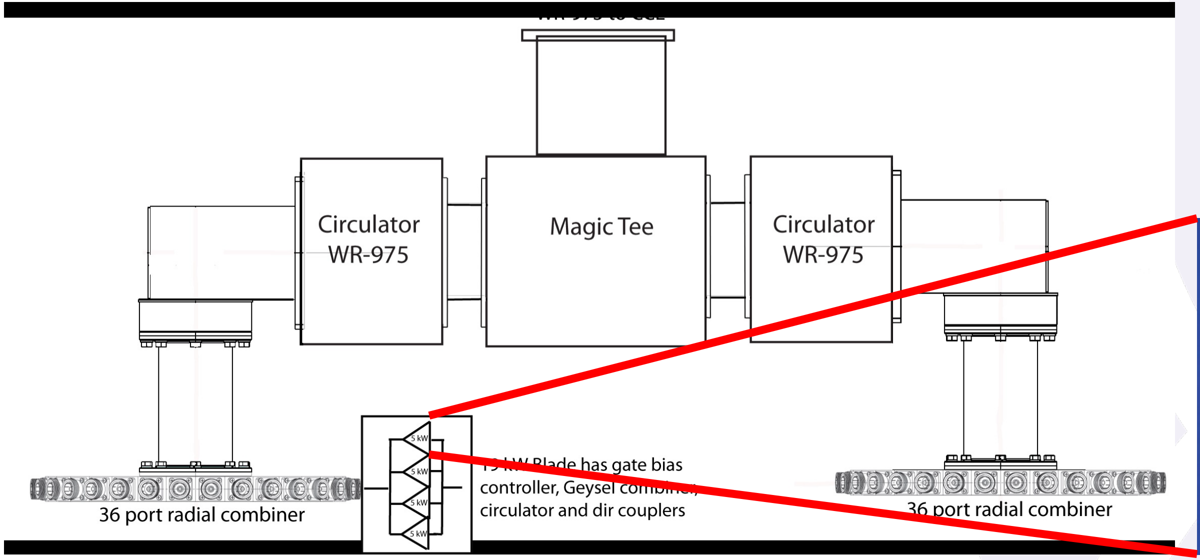
Figure 1. Complete System for LANL.

Spallation Neutron Source (SNS) system adapted for LANSCE

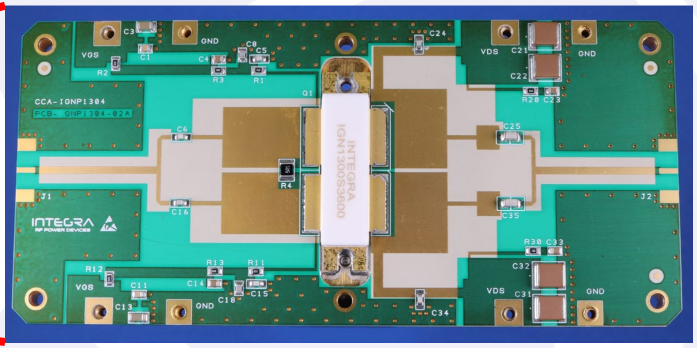
European Spallation Source (ESS) system adapted for LANSCE



…or leapfrog conventional approaches with high-power, solid-state amplifiers (SSAs)



805 MHz GaN, 3.6 kW SSA
(Integra Technologies)



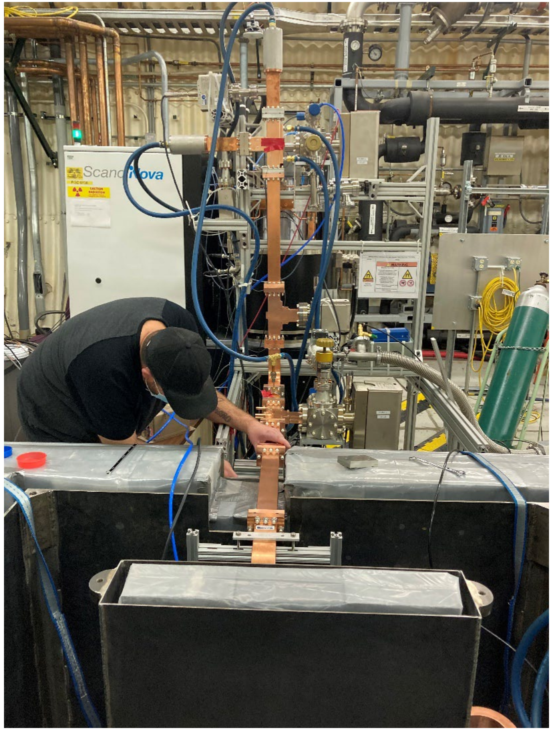
We can combine the outputs of 100s of SSAs to achieve the required power levels for LANSCE. We are actively pursuing this option right now.

Other projects of interest

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

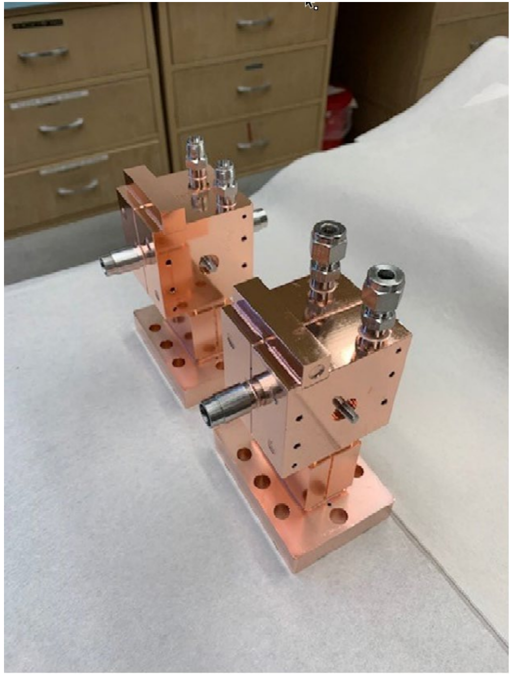
CERF-NM is available for use as a test stand for high gradient investigations of novel structures and materials.

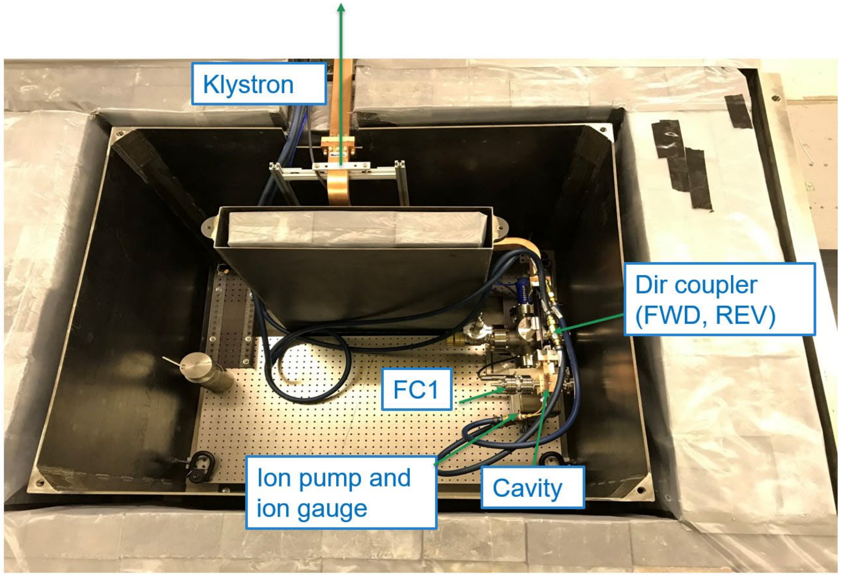
- Powered with a C-band Canon klystron
- Conditioned to 50 MW
- Frequency 5.712 GHz
- 300 ns – 1 μs pulse length
- Rep rate up to 200 Hz (typical 100 Hz)
- Nominal bandwidth 5.707-5.717 GHz

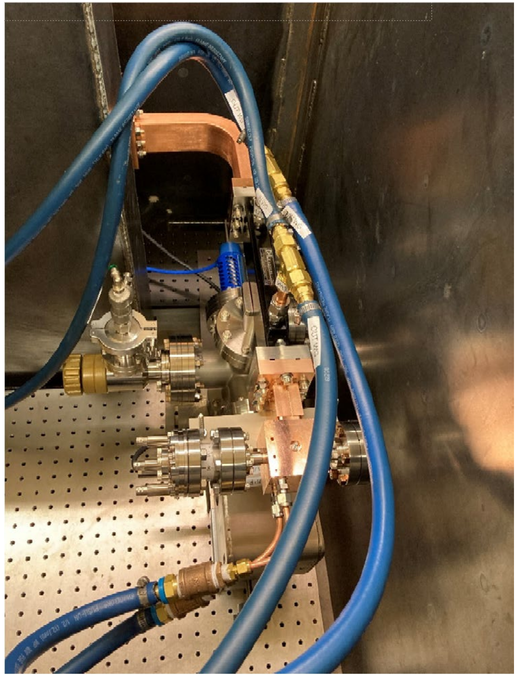


The first two high gradient cavities were tested at CERF-NM in 2021

The first cavities tested were manufactured by SLAC.

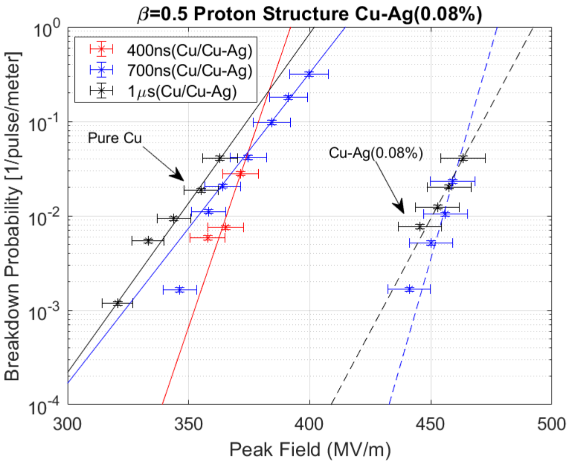


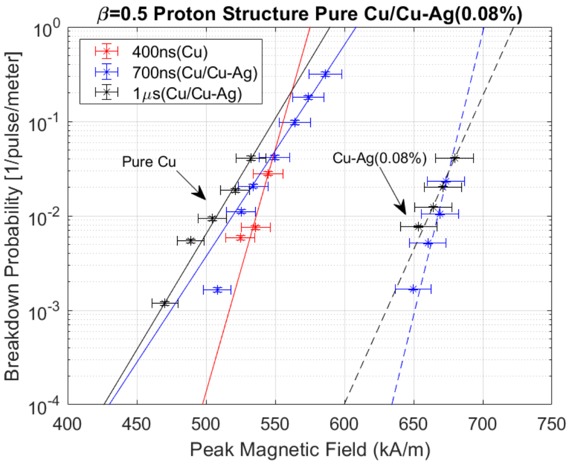


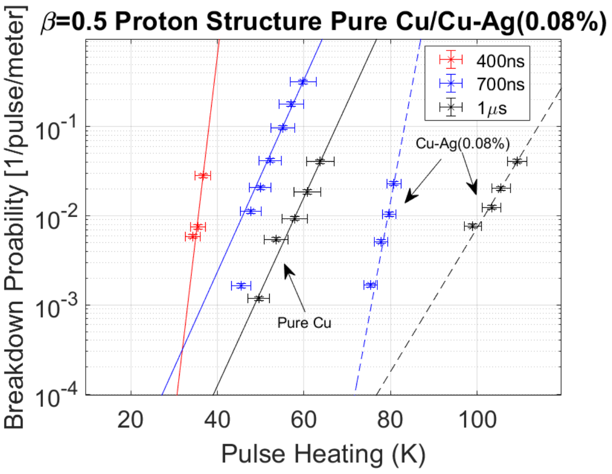


Peak surface electric fields in excess of 300 MV/m demonstrated

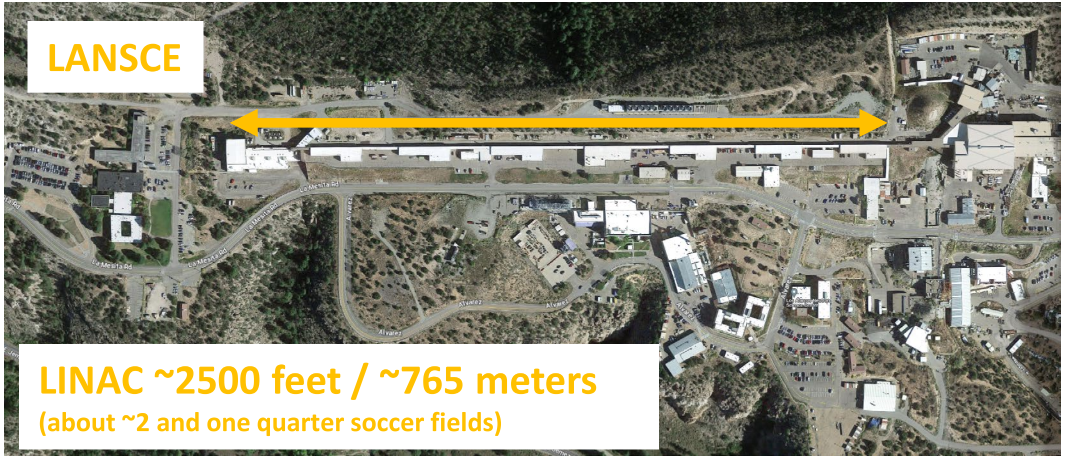
Breakdown probabilities were recorded for three different pulse lengths for copper and copper-silver cavities.







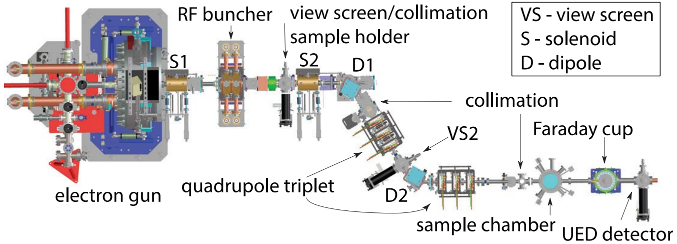
Conventional accelerator instrumentation and controls are done in house



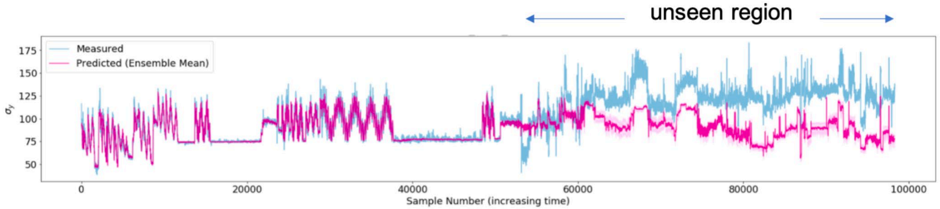
- We are an EPICS - 3.15 Facility with over ~171,000 Process Variables
  - 233 NI cRIO IOCs
  - 184 Altera FPGA IOCs
  - 79 cPCI Timing IOCs
  - 19 VME IOCs – some interface to CAMAC
  - 23 Allen Bradley PLCs
- Our controls network consists of redundant core switches with 110 leaf switches running 4 virtual networks

- We have about 1,500 network addressable devices (equipment with its own IP Address)
- ~110 Workstations provide easy access to the LANSCE Control System.
- 20 Servers and 44 **Virtual** Servers
- ~930 Graphical User Interfaces
- ~880 Scripts

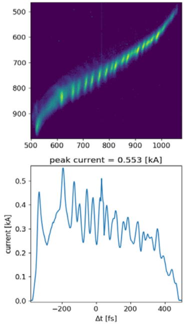
LANL is also a leader in applying AI/ML to accelerator control

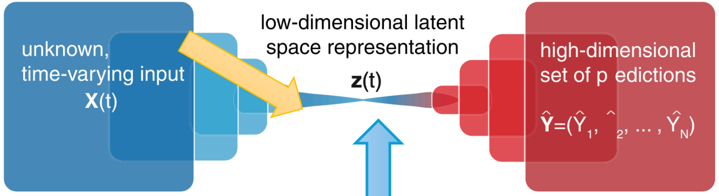


Machine Learning for Complex Systems



Robust ML with Adaptive Feedback for Time-Varying Systems





Robust ML with Hard Physics Constraints

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}, \quad \nabla \cdot \mathbf{B} = 0,$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}, \quad \nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$

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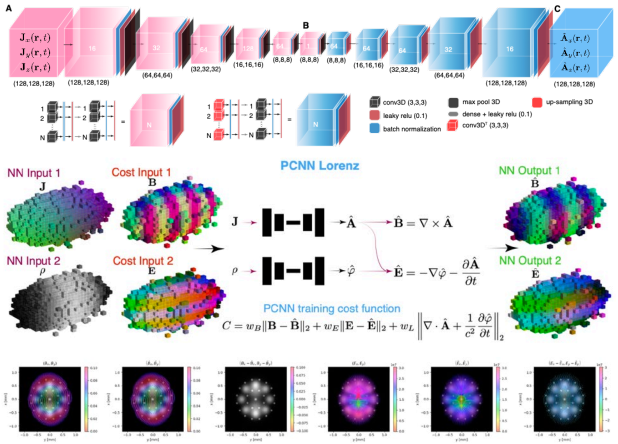
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

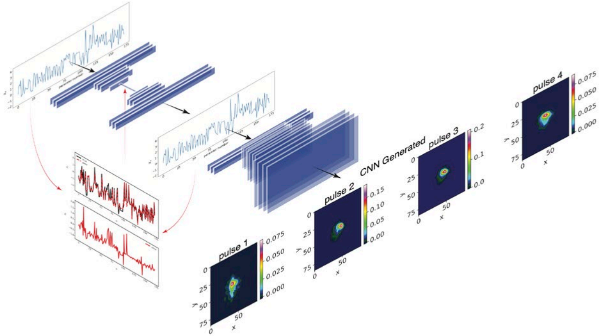
This includes using ML techniques for virtual diagnostics…

3D Convolutional Neural Network with Maxwell's Equations built in as hard physics constraints to generate electromagnetic fields of intense charged particle beams.

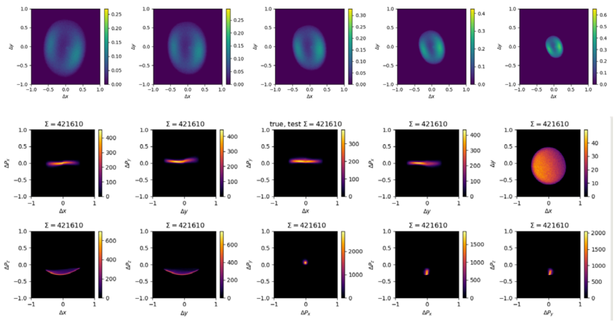


A. Scheinker and R. Pokharel. "**Physics-constrained 3D convolutional neural networks for electrodynamics.**" APL Machine Learning **1**, 026109 (2023);

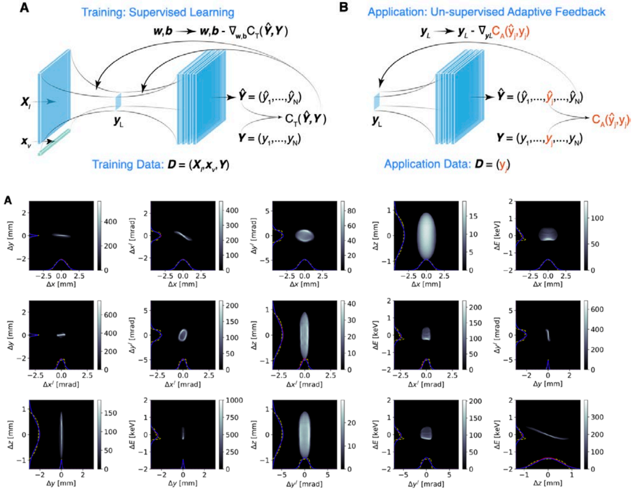
DARHT Diagnostic 1: Generative Encoder-Decoder Convolutional Neural Network Generating Deconvolved Pinhole Images



DARHT Diagnostic 2: Mapping downstream measurements to input beam phase space.



Generative ML for 6D Phase Space Projections

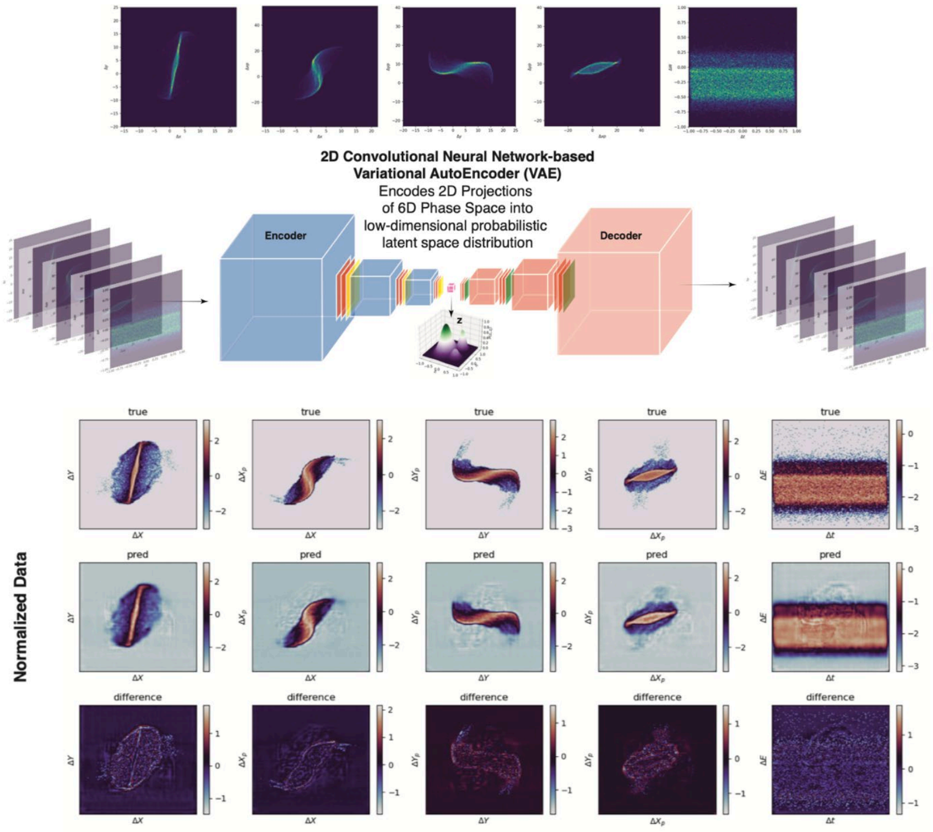


A. Scheinker, et al. "**Adaptive autoencoder latent space tuning for more robust ML beyond the training set for 6D phase space diagnostics of a time-varying UED compact accelerator.**" *Physical Review E* 107, 045302, 2023.

…and autonomous tuning

Online Autonomous Tuning of the FRIB Accelerator using Machine Learning
PI: Peter Ostroumov, FRIB

LANL PI: Alexander Scheinker



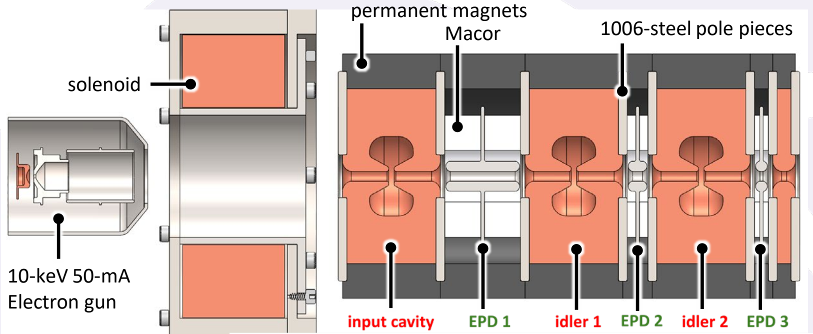
Summary

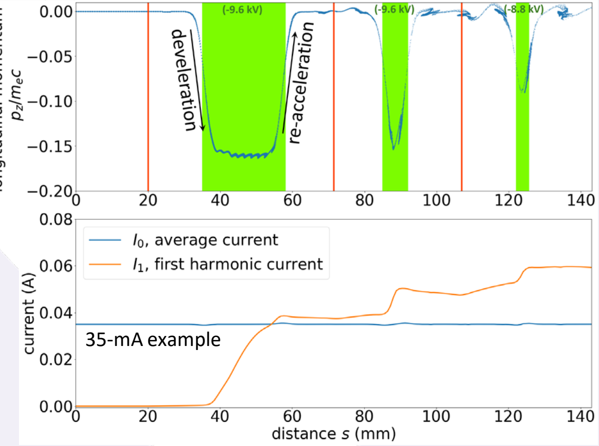
- LANL has a significant accelerator capability.
- We are open to collaboration where it makes sense.
- Our facilities, such as CERN-NM, are available for use by the wider community.
- Questions?

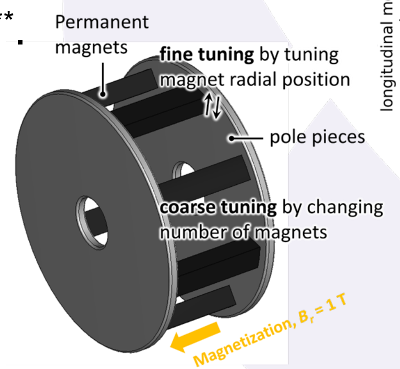
Backup slides

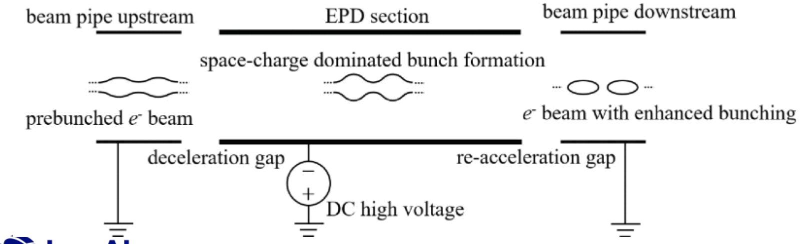
Electrostatic Potential Depression (EPD*) for highly efficient and compact RF sources

- Bunching DC electron beam into 5.7-GHz rep-rate bunches.
- For space-borne RF electron accelerators.
  - Compactness: EPD approach**.
  - Minimizing beam waste: Ballistic + nonlinear space-charge bunching.
  - Minimizing power consumption: Tunable periodic permanent magnet focusing***.









*) H. Xu *et al.*, *IEEE Trans. Electron Device*, 68(4), pp. 1930-1936, 2021.
**) M. Sanchez Barrueta, *abstract #285 for LINAC 2024*, 2024.
***) K. A. Shipman *et al.*, *in Proc. IPAC 2024*, no. MOPC41, 2024.