Los Alamos Accelerator Science and Technology

Robert Garnett

Michigan State University

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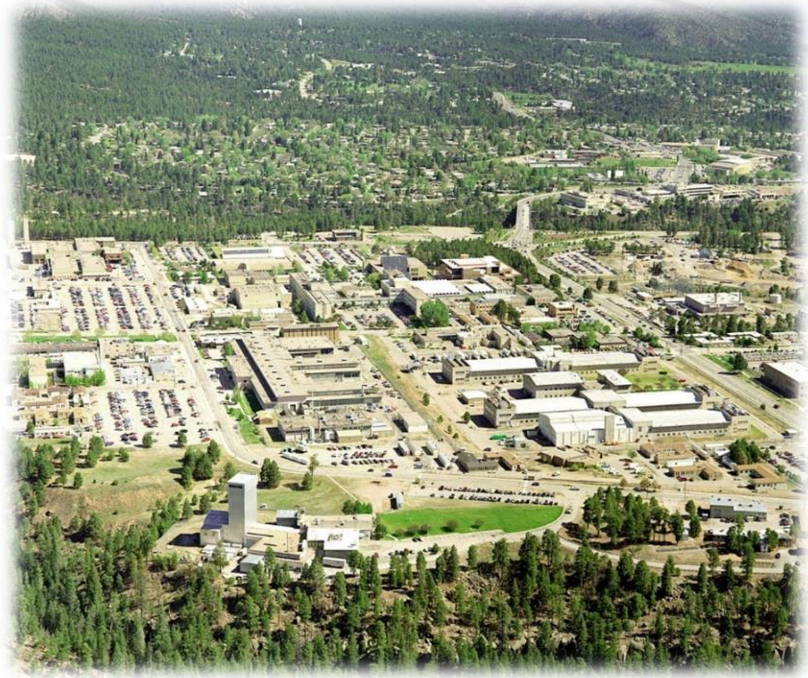
UNCLASSIFIED

Outline

- Introduction
- Accelerator Science & Technology Developments
- Large-Scale Accelerator Facilities
- Recent Accelerator Projects
- New Projects
- Opportunities

Los Alamos National Laboratory (LANL)



- Established 1943 during the Manhattan Project.
- Operated for the DOE National Nuclear Security Administration (NNSA).
- Operated by Triad National Security, LLC – UC, Battelle, Texas A&M.
- $2.2B Annual Budget
- 10,200 Staff
- LANL is one of the largest multidisciplinary science and technology institutions in the world – national security, space exploration, nuclear fusion, renewable energy, medicine, nanotechnology, and supercomputing.

LANL has specific strategic goals to meet it's mission requirements. Key to this is world-class talent.

GOALS

Deliver national nuclear security and broader global security mission solutions

We will maintain the nation's full confidence and trust through our technical prowess, scientific integrity, and reliable delivery of solutions.

Strategies

- Provide a safe, secure, and effective stockpile
- Protect against the nuclear threat
- Counter emerging threats and create new opportunities
- Provide solutions to strengthen energy security

by

Attracting, inspiring, and developing world-class talent to ensure a vital future workforce

We will shape our excellent technical, operational, and professional talent for evolving national security needs through recruiting, retention, and talent development.

Strategies

- Position the Laboratory to compete for and attract world-class talent
- Develop and mentor next-generation workforce and leadership talent
- Position the Laboratory as one of the best places to work

and

Foster excellence in science and engineering disciplines essential for national security missions

We will ensure agile mission responsiveness by advancing exceptional science and engineering in targeted strategic disciplines.

Strategies

- Sustain a culture of excellence to ensure the quality and integrity of our science and engineering solutions
- Strategically invest in breakthrough science and engineering
- Lead in transformational science at extremes

and

Enabling mission delivery through next-generation facilities, infrastructure, and operational excellence

We will create a modern workplace that is environmentally responsible, safe, and secure.

Strategies

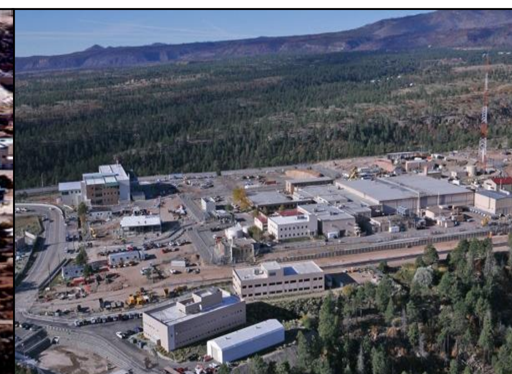
- Demonstrate leadership in environmental stewardship, commitment to sustainability, and social responsibility
- Transform our infrastructure to enable scientific breakthroughs
- Drive productivity and innovation in all aspects of operations, business systems, and information systems
- Protect our people, our assets, and our information

Modern Stockpile Stewardship: modeling and simulation, experimentation and surveillance

Stockpile stewardship today

Dual-Axis Radiographic Hydrotest Facility (DARHT)

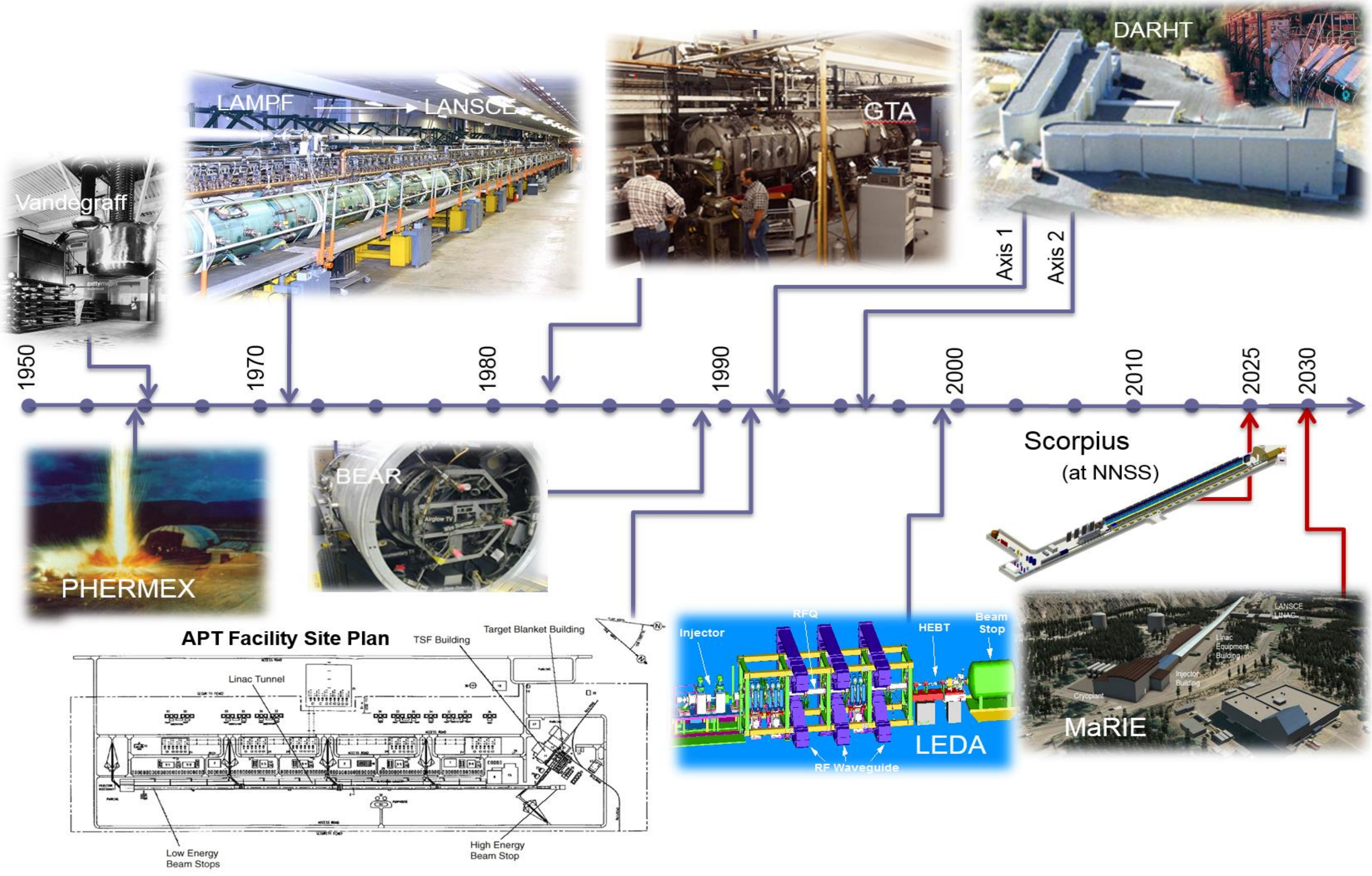
Los Alamos Neutron Science Facility (LANSCE)



Nuclear Material Facilities

Supercomputing

Accelerators have always been a part of supporting national security at LANL.



LANL supported the Strategic Defense Initiative Program ("Star Wars").

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Manufacturer
Los Alamos National Laboratory

Credit Line
Transferred from the Los Alamos National Laboratory.

Materials
Aluminum, Kapton (Polymide), Plastic, Copper, Stainless Steel, Rubber (Silicone), Paint, Acrylic (Plexiglas), Gold Plating, Fiberglas, Synthetic Fabric, Adhesive, Brass, Teflon, Phenolic Resin, Cadmium plating
foam
dolly - metal

Dimensions
Overall (BEAR) : 13ft 8in. x 3ft 7in. (416.56 x 109.22cm)
Overall (dolly) : 5ft 7in. x 4ft 7in. x 12ft (170.18 x 139.7 x 365.76cm)
Overall (arm of the dolly) : 7ft 1in. (215.9cm)

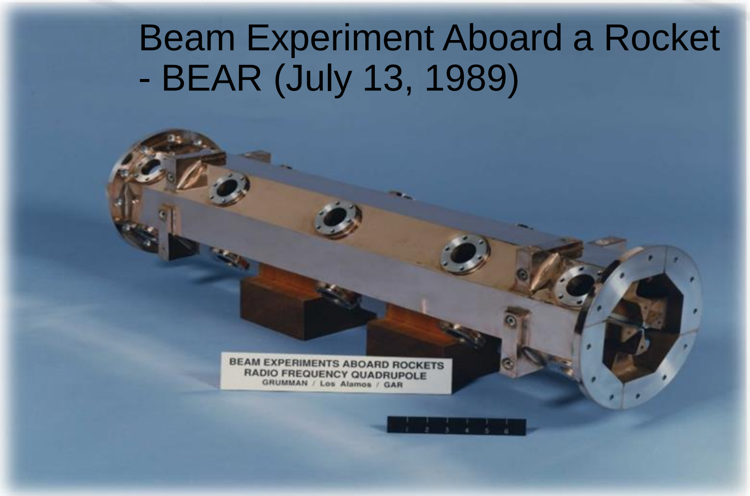
See more items in
National Air and Space Museum Collection

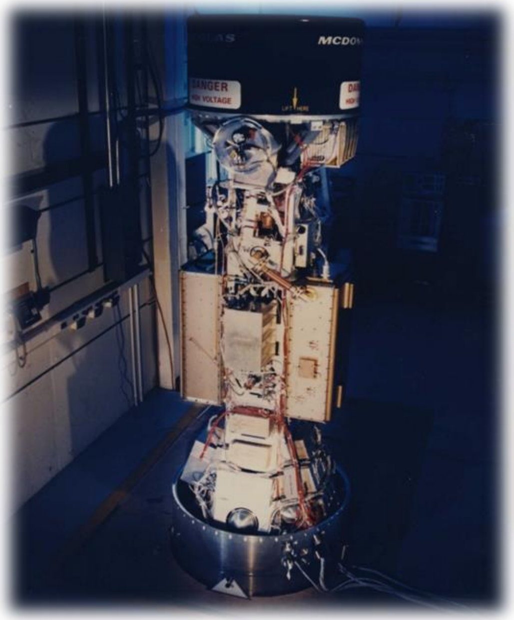
Country of Origin
United States

Type
SPACECRAFT-Unmanned-Instruments & Payloads

Inventory Number
A20070004000

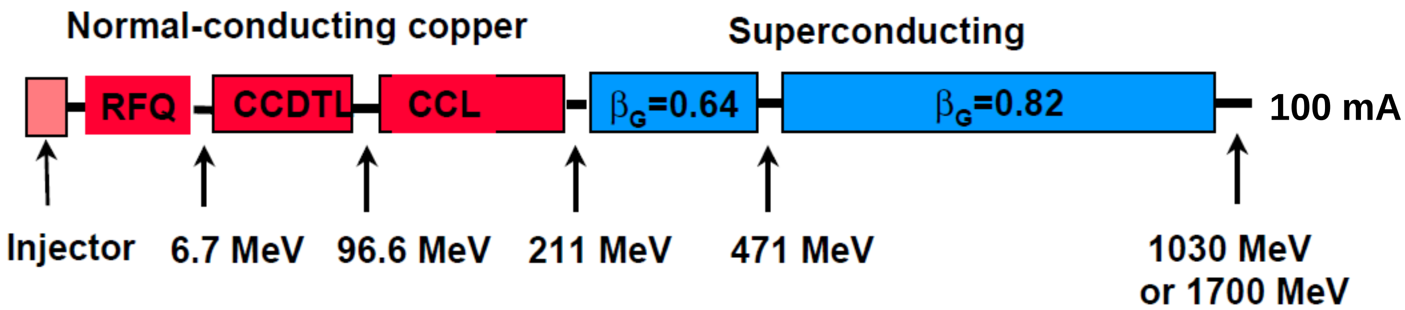
Beam Experiment Aboard a Rocket - BEAR (July 13, 1989)





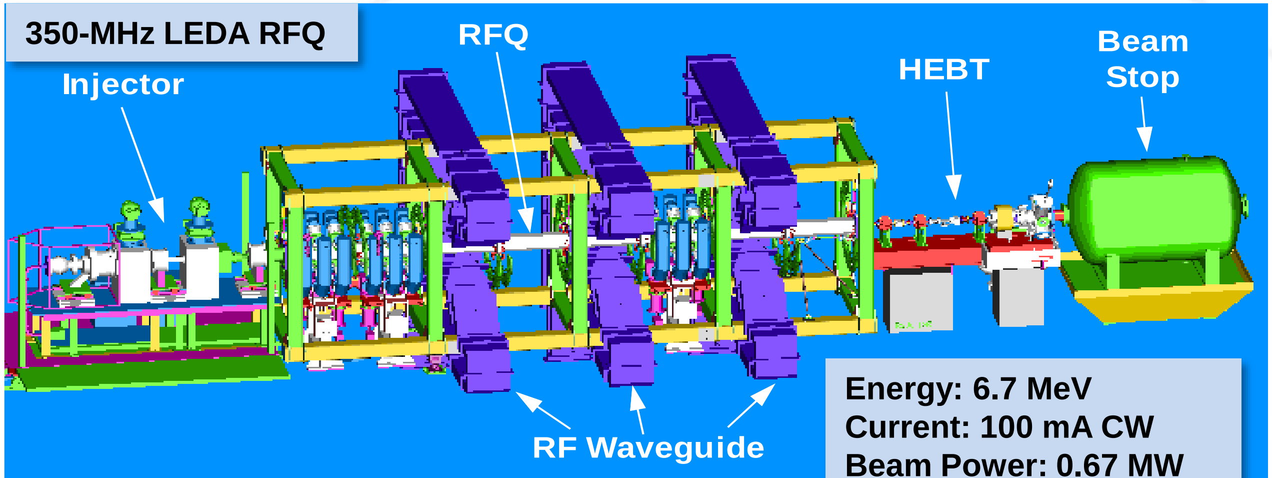
https://airandspace.si.edu/collection-objects/neutral-particle-beam-accelerator-beam-experiment-aboard-rocket

The Accelerator Production of Tritium (APT) project in the 1990s established a new technology base for high-average power proton linac technology.



- **Superconducting cavities were used above 200 MeV.**
- High availability (90%) was an important APT design goal. Required new approach to the low-energy part of the linac – LEDA facility demonstrated 100-mA, CW, DC injector/RFQ technology.
- **Became the basis for most new high-average power designs that followed such as the SNS and ESS.**

The Low-Energy Demonstration Accelerator (LEDA) for the Accelerator Production of Tritium - world record for highest average power RFQ



Energy: 6.7 MeV
Current: 100 mA CW
Beam Power: 0.67 MW

LEDA RFQ with the injector rolled back.

Major injector components

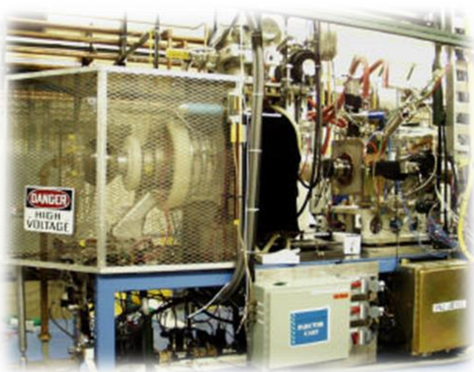
- 2.45-GHz microwave ion source
- single-gap extractor
- dual magnetic solenoid, gas-neutralized LEBT

Pertinent ion source parameters

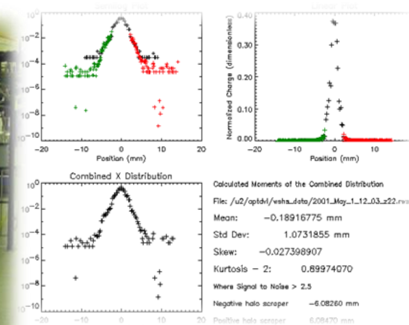
- 800-1200 W of 2.45-GHz microwave power
- 85% ≤ proton fraction ≤ 95%

Key injector beam parameters

- proton current >110 mA at 75-keV
- emittance <0.2 ≤ mm-mrad (normalized)



LEDA H^+ injector including LEBT (Low Energy Beam Transport)



The LEDA Halo Experiment was used to understand halo growth and associated beam-loss mechanisms.

Significant developments have resulted from LANL national security applications of accelerator science and technology.

- Invention of side-coupled accelerating structure for high velocities $\beta > \sim 0.4$ (1968).
- First high power (~1 MW average beam power) proton linac: 800-MeV LAMPF (first beam in 1972).
- Linear accelerator design and simulation codes (~1970 on) – MESSYMESH, SIMILAC, PARMELA, PARMILA, RFQUICK/CURLI, PARMTEQM.
- High-current beam dynamics including space-charge, emittance growth, and beam-halo physics (~1977 on; GTA, APT, ATW, SNS; extended to ESS, CADS, and others).
- RFQ proof of principle experiment (1980) - enabling higher beam currents.
- RFQs for CERN, FMIT, BEAR (operated in space), GTA, SSC.
- Invention of the RF photoinjector (Sheffield; FEL program; 1986)
- EPICS control system developed (1987 on).
- Invention of Emittance Compensation (Carlsten; 1989)
- Invention of the Proton Radiography (pRad) microscope (1995)
- Application of SCRF to high-energy/high-power proton linacs (APT, ATW, SNS; 1996 on).
- SNS linac design and construction (1997 on).
- 6.7-MeV 100-mA CW LEDA RFQ (1999).
- MW RF power coupler (APT; 2001)

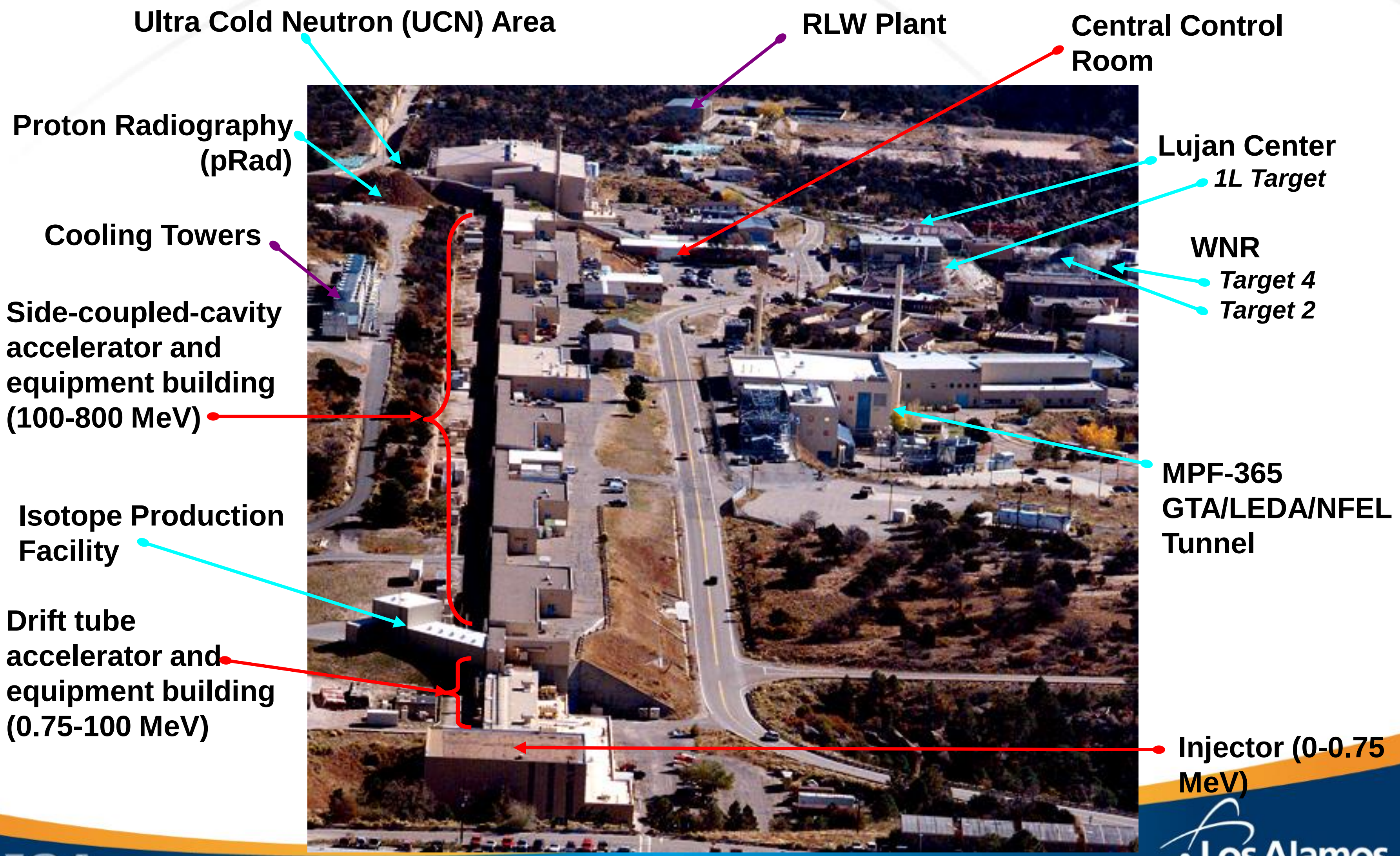
LANL is currently active in many accelerator technology target areas, including:

- ***Next generation FELs*** *– Motivated primarily by the MaRIE Project*
  - *- Beam physics (CSR, µBI, IBS)*
  - *- Emittance exchange*
  - *- High-performance photoinjectors*
  - *- Advanced cathodes (graphene coated; quantum dots; "cathodes by design")*
  - *- Smith-Purcell and other EM/optical beam diagnostics*
- ***Compact accelerators*** *(electrons and ions)*
  - *- Dielectric Wake and Dielectric Laser Acceleration*
  - *- Photonic Band-gap Structures (NCRF and SCRF)*
  - *- Compact Microtrons/Inverse Compton Scattering Sources*
  - *- High-brightness Sources*
  - *- High-temperature SCRF materials (MgB_2 coatings, etc.)*
  - *- Compact muon sources*
  - *- Compact linac structures*

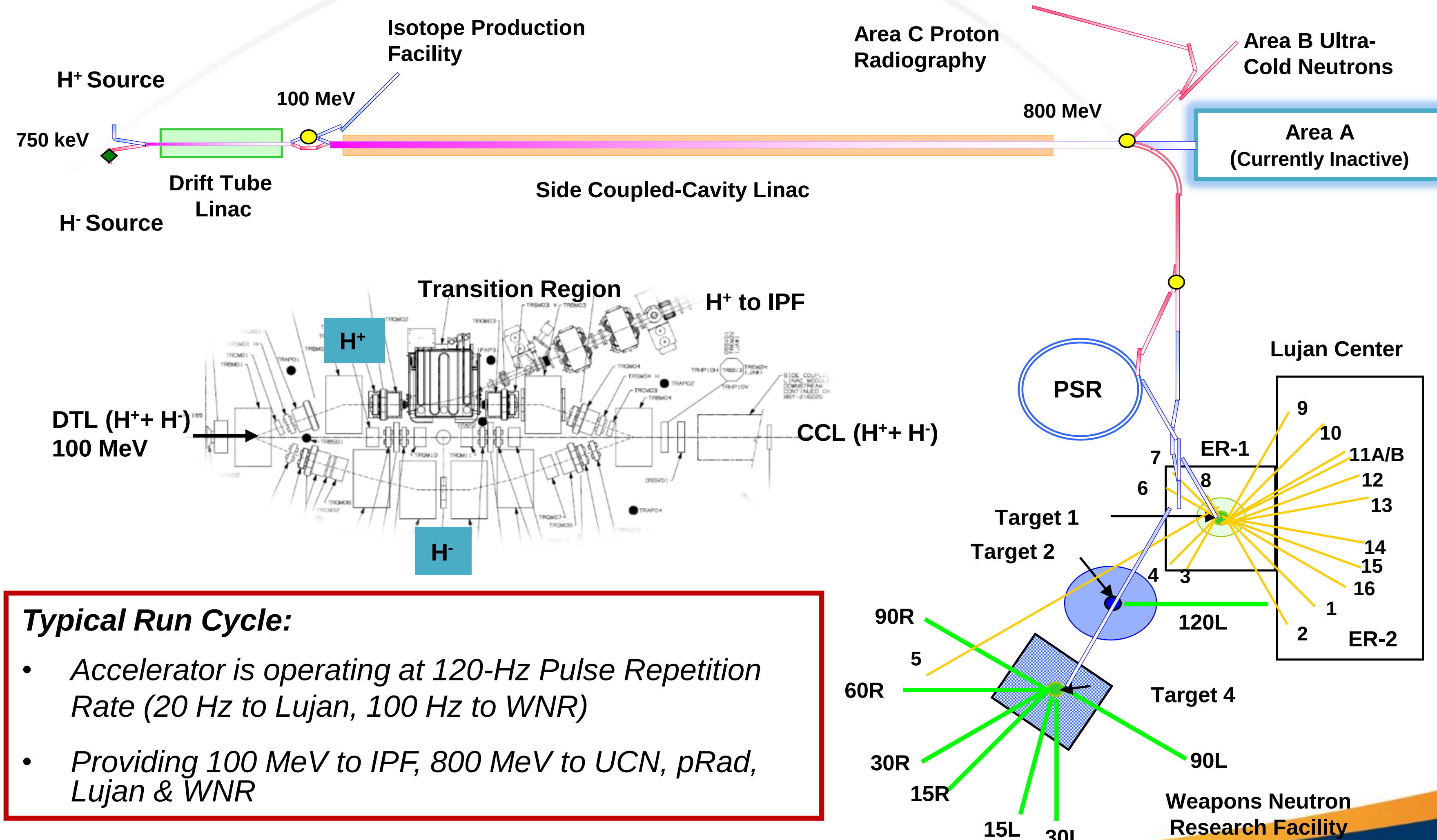
Large-Scale Accelerator Facilities

- Los Alamos Neutron Science Center (LANSCE)
- Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT)

The LANSCE LINAC provides flexible time-structured H^+ / H^- beams serving 5 experimental areas.



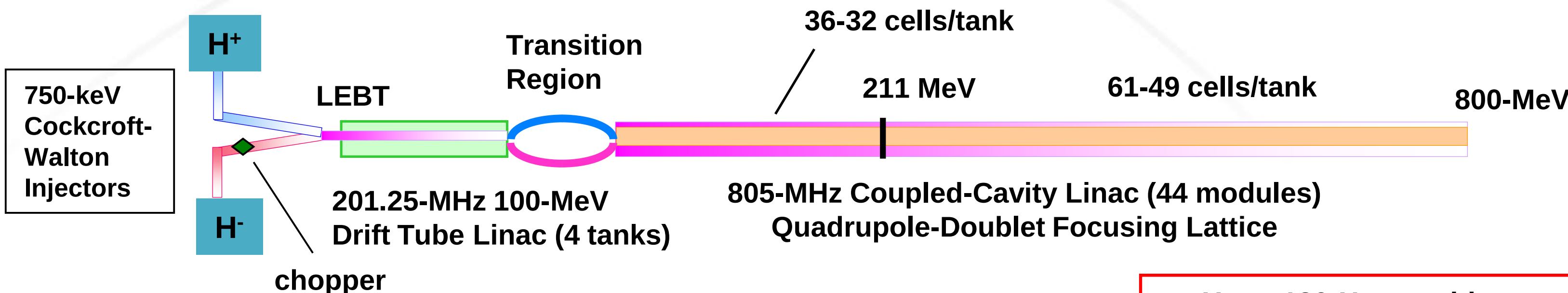
The LANSCE accelerator and beam delivery complex continues to provide multi-beam operations to many users.

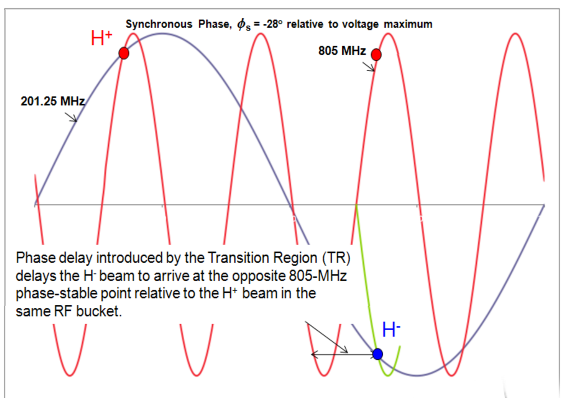


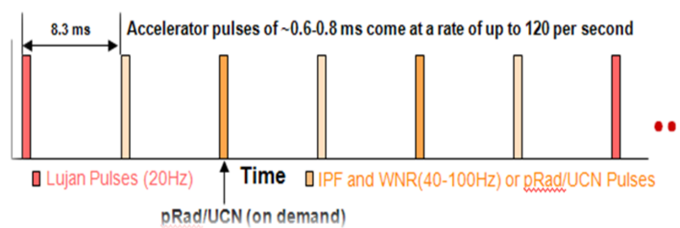
Typical Run Cycle:

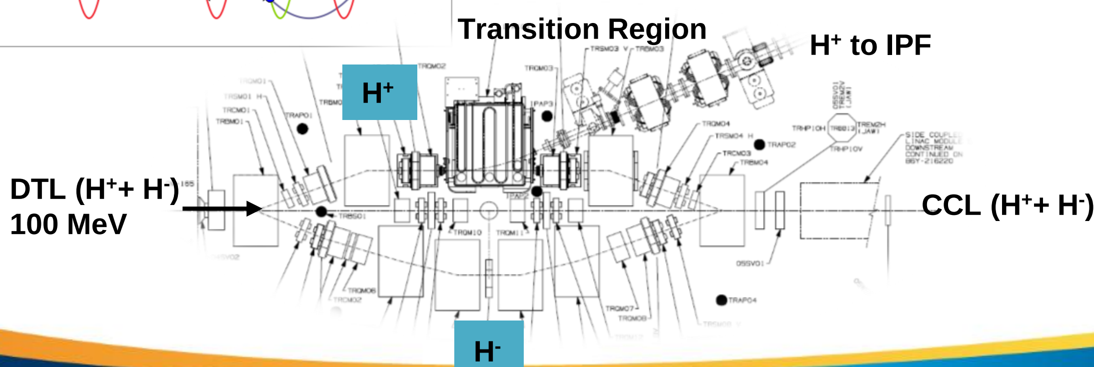
- *Accelerator is operating at 120-Hz Pulse Repetition Rate (20 Hz to Lujan, 100 Hz to WNR)*
- *Providing 100 MeV to IPF, 800 MeV to UCN, pRad, Lujan & WNR*

Multiple beams are accelerated by sharing machine cycles and accurate timing.



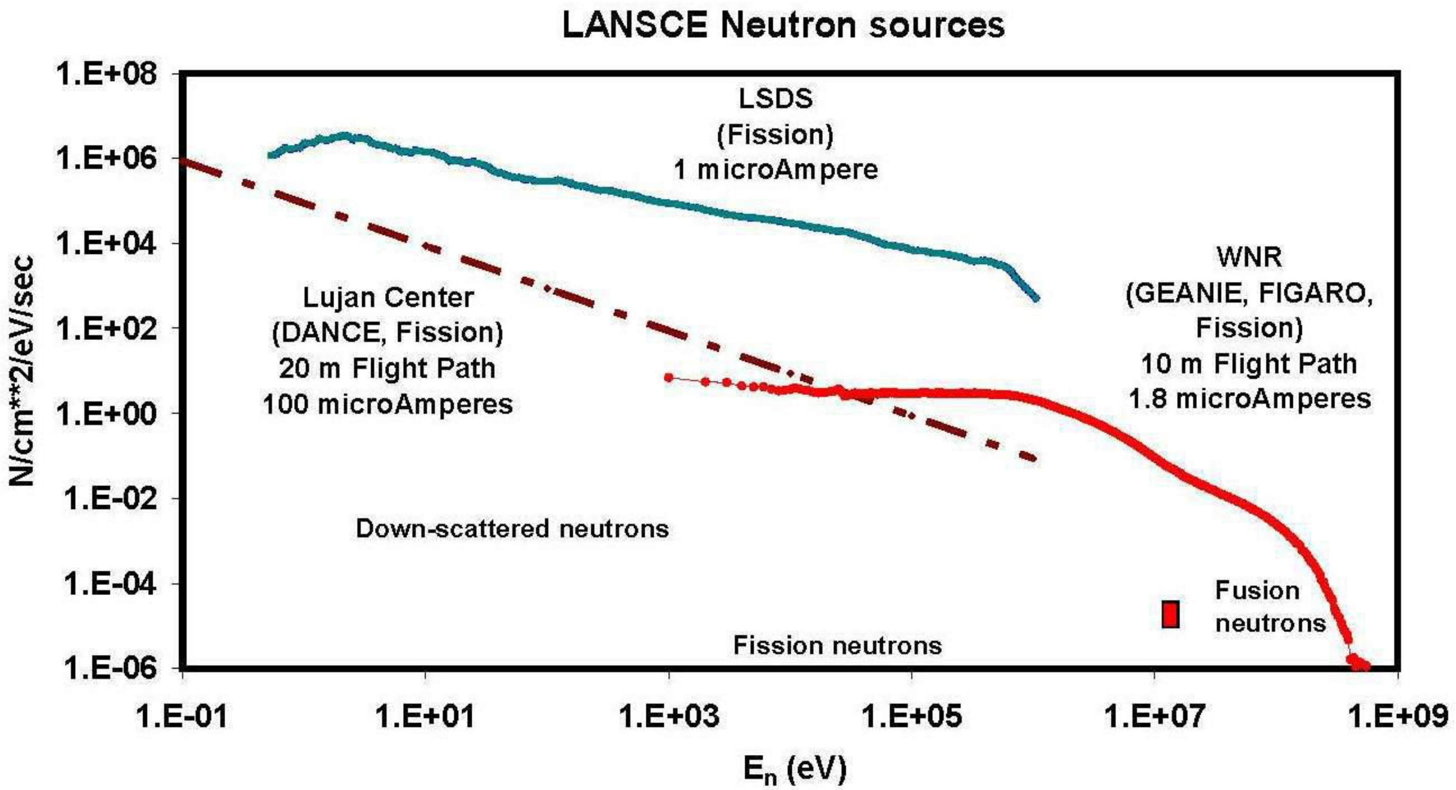






- Up to 120-Hz repetition rate; pulse length of 625-825 μs; single-pulse capability of 1225 μs
- 800-MeV micro-pulse width approx. 1 ns; micro-pulse separation = 5 ns (201.25 MHz)
- 20 Hz dedicated for the Lujan Center
- 40-100 Hz can be multiplexed for pRad, WNR, IPF, or UCN
- High-peak-current IPF (H+) and WNR (H-) beams share machine cycles
- pRad and UCN "steal" on-demand machine cycles from WNR

LANSCE delivers neutron energies spanning nearly 10 orders of magnitude.



LANSCE operations supports a broad range of users and experiments.

- Strontium-82 produced for ~120,000 cardiac images; Actinium-225 investigated for **cancer therapy**. Other research isotopes also generated.
- Supports dynamic **proton radiography** experiments.
- Supports WNR and Lujan Center experiments advancing knowledge of total **fission cross sections** for U and Pu.
- **Materials science** experiments have focused on understanding additively manufactured materials.
- Increased beam delivery and improved neutron storage have now made the Ultracold Neutron (UCN) facility best in the world.
- WNR Blue Room (Target 2) experiments contribute to developing **rad-hard electronics**.
- WNR supports **single-event-upset** measurements for the semiconductor industry.

Science-Based Stockpile Stewardship, Homeland Security, Defense, Medical, Fundamental Science

Planned and Ongoing LANSCE Upgrades:

- H^+/ H^- RFQs to replace CW injector – H+ RFQ Test Stand
- H^- Ion Source Upgrade – longer lifetime, higher peak current; collaboration with ORNL on RF-driven source
- Control System
- Digital LLRF
- Linac & Storage Ring diagnostics
- Machine Learning/Automation – injectors, interlocks and machine protection checks, beam tuning, upset event recovery
- Next Generation Spallation Target

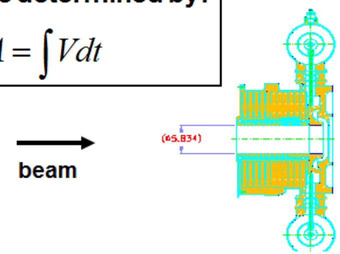
Approximately $110M invested in 2009-2015 to assure LANSCE continues to operate successfully.

The Dual-Axis Radiographic Hydrotest (DARHT) Facility supports Science Based Stockpile Stewardship and large-scale Homeland Security applications.

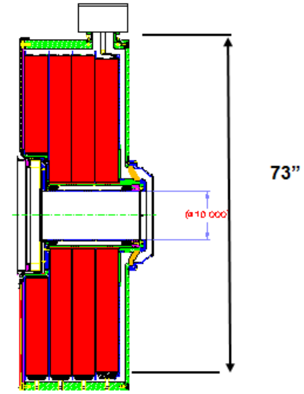
LANL DARHT Facility

Core volume determined by:

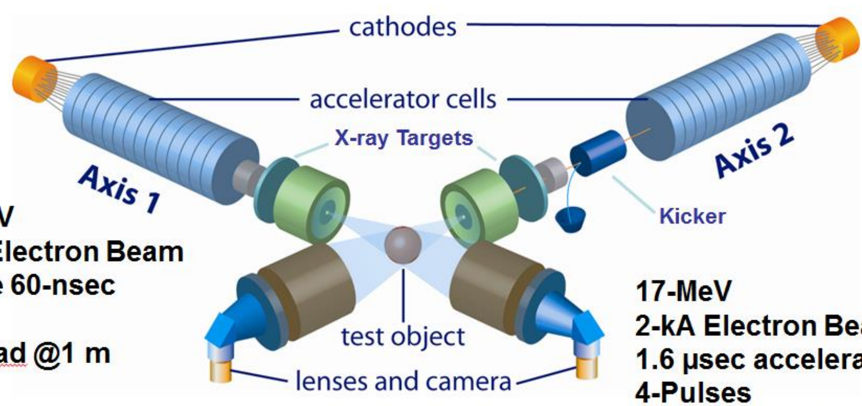
$$2B_{sat}A = \int V dt$$



DARHT I - single 0.06 μs pulse (1,430 lbs)

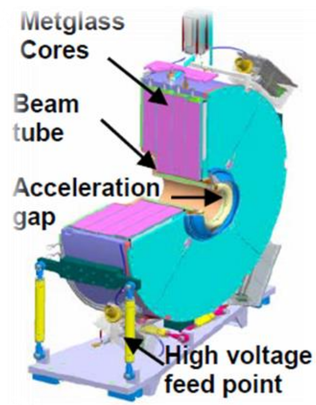


DARHT II - four pulses extracted from a 2 μs beam (16,000 lbs, core wt. 2,300-2,800 lbs each)



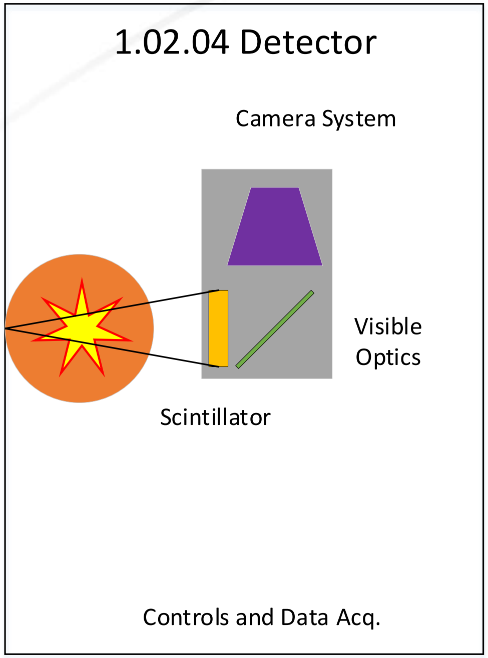
20-MeV
2-kA Electron Beam
Single 60-nsec pulse
550 Rad @1 m

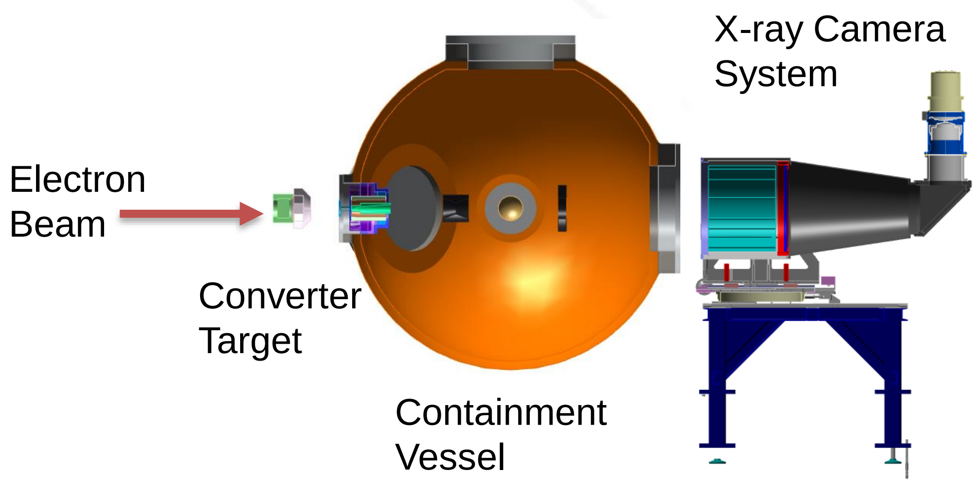
17-MeV
2-kA Electron Beam
1.6 μsec accelerator pulse
4-Pulses
Variable Dose Format



Axis-2 Induction Cells

Experiments using surrogate materials are done at DARHT with special containment vessels and x-ray cameras.





- The converter target generates a nearly point source of x-rays that propagate through the object.
- A thick, large-area, pixelated, LSO scintillator converts the x-rays to visible light.
- Multi-frame CCD cameras capture and record the images.

The primary mission of the DARHT facility is to support national security.

Capabilities

- The main purpose of DARHT is to provide radiographic data for verification of computer codes.
- Radiographic images are used to evaluate nuclear weapons through non-nuclear hydrodynamic testing of full-scale mock implosions of the primary stage of a nuclear weapon system.
- DARHT is the world's most powerful x-ray machine for analysis of mock nuclear weapon implosions.

National Security

- Critical tool for nuclear weapons development and stockpile stewardship.
- DARHT provides radiographs that help ensure weapons in the stockpile are safe, effective, and will perform as designed.
- Tests of improvised devices are also performed.

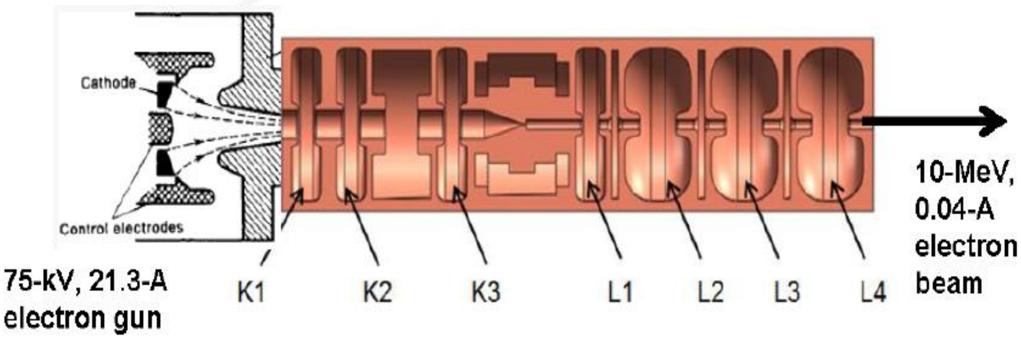
Planned DARHT Upgrades:

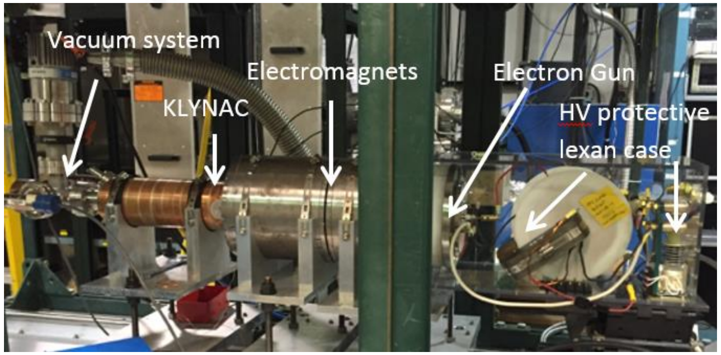
- **Axis 1:**
  - New target design to reduce background noise improving radiographic image quality
  - New cathodes to improve beam profile, reduce emittance and improve spot size
  - Investigate multi-pulse operation (single-pulse operation now; requires pulsed-power, injector and induction cell modifications)
- **Axis-2:**
  - Increase number of pulses from 4 to 8 – includes new 8-frame camera, configure kicker for 8 pulses

Recent Projects

- Includes everything from concepts to prototype testing and technology demonstrations
- Funding sources: LDRD, DOE-Office of Science, DTRA, DoD…

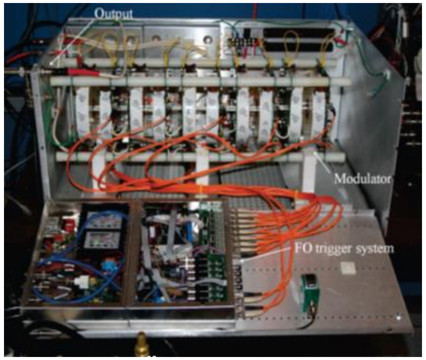
KLYNAC – Combined Klystron and Linac (LDRD funded)





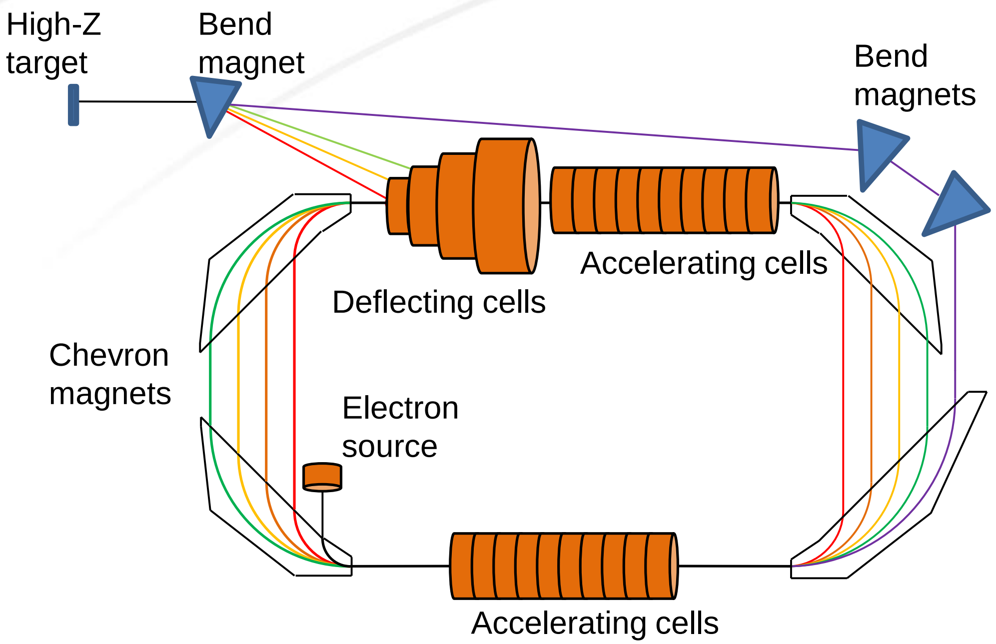
8-cell, 1-MeV KLYNAC being tested at LANL.

- K1-K3 are klystron cells; L1-L4 are linac cells
- f = ~3 GHz (S-band)
- Klystron section extracts approximately 850 kW (pulsed) from the electron beam which is coupled to the linac section.
- Iris between K3 and L1 limits accelerated beam to 40 mA.
- Klystron section driven by 75-keV, 21.3-A electron beam
- 44 linac cells required to reach 10 MeV.
- Goal: 10 MeV, 40 mA, 5% duty (20-kW average power, 10-µs pulse length, 5-kHz rep rate)
- **Potential applications include active interrogation.**



Solid-state, diode-directed Marx assembly mounted in the modulator chassis.

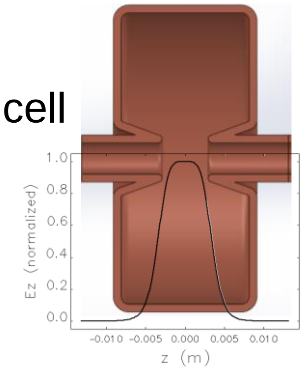
Compact Microtron for Department of Homeland Security Applications



Dual-Axis Microtron

- Uses chevron bend magnets
- Accelerates beam on both axes
- Can make use of RF deflectors
- **Lightweight source of up to 10-MeV γ-rays**

C-band accelerating cell

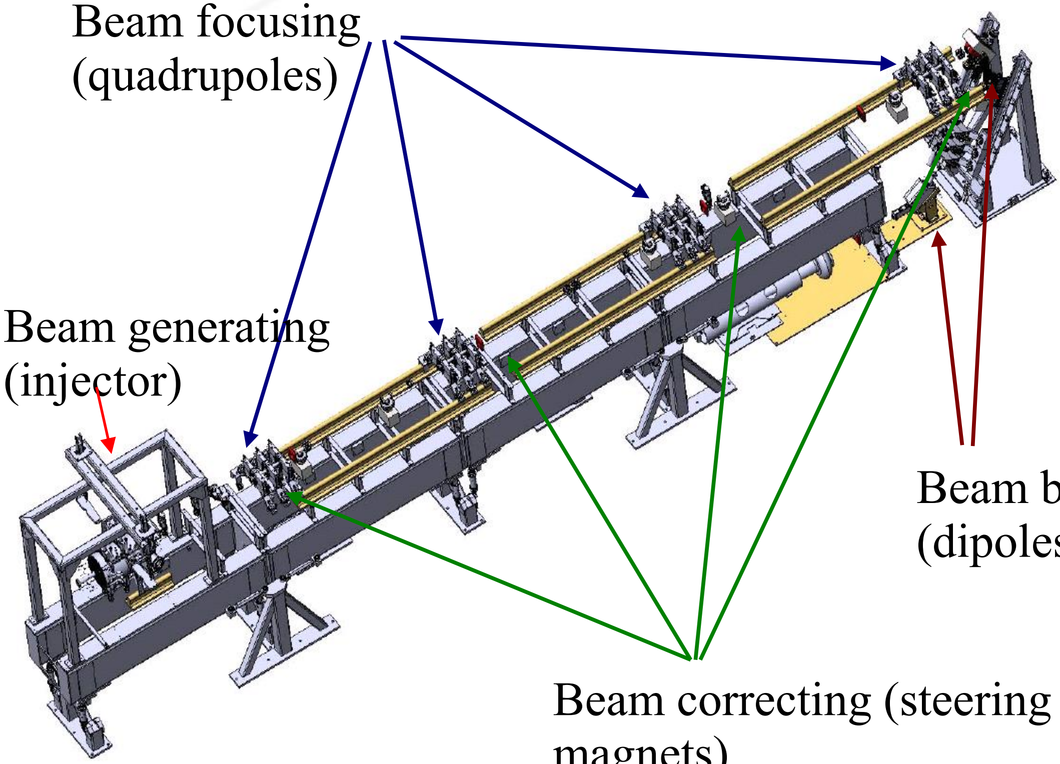


Parameters	Values
Linac type	Microtron
Beam energy	<10 MeV
Total length	~3 m
Total weight	~100 kg
RF frequency	5.1 GHz
# of accelerating cells	110
# of passes	<10

High-Current (100 mA) Beam Demonstration – S&T in Support of INP (Innovative Naval Prototype)

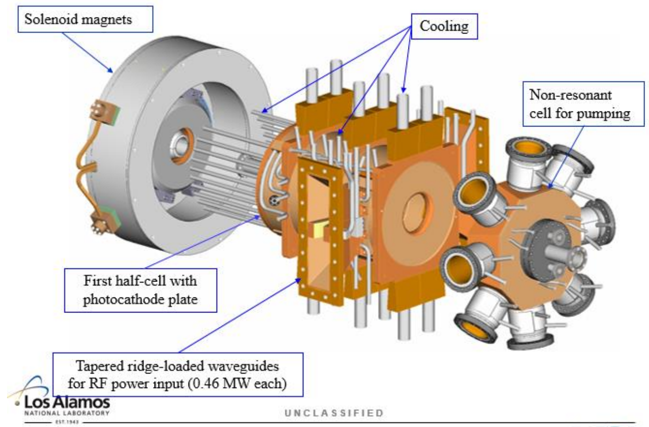
Beam focusing (quadrupoles)

Beam generating (injector)



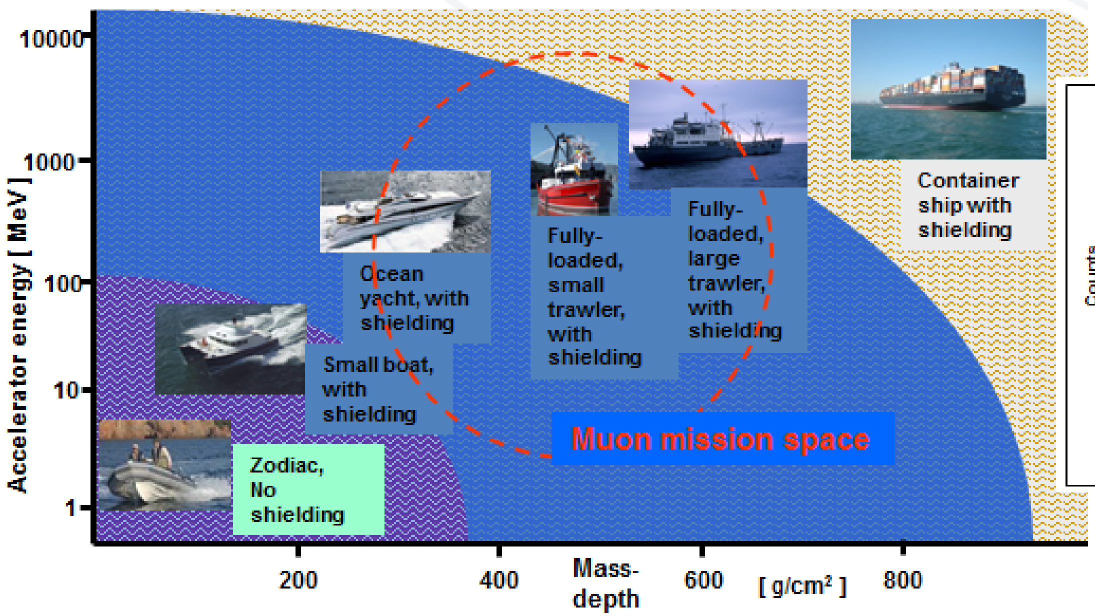
Beam bending (dipoles)

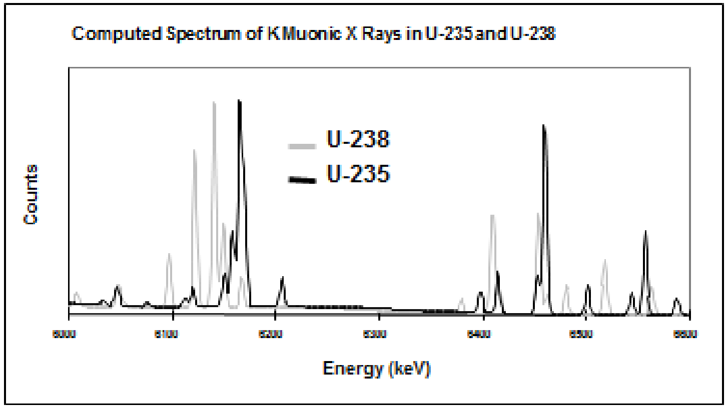
Beam correcting (steering magnets)



Project goal was to generate MW-scale IR beam with a Free-Electron Laser

Large stand off active-interrogation systems require high-energy beam sources (DTRA funded study).



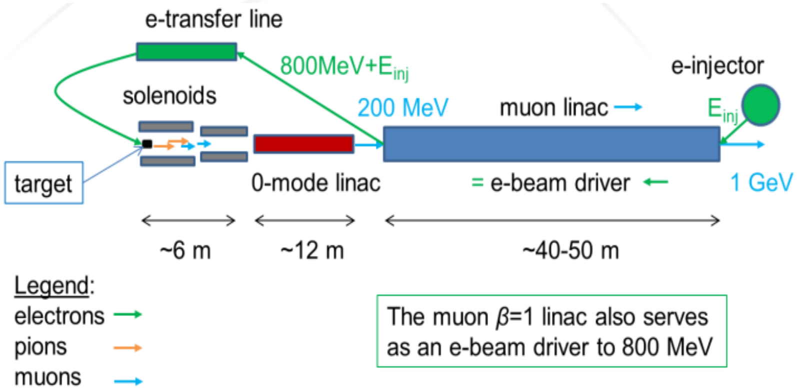


For 12-m diameter beam, and average density of 0.33 g/cm^3, photons attenuate by >10^6 before reaching shielded HEU (50cm PE, 2.5cm Pb)

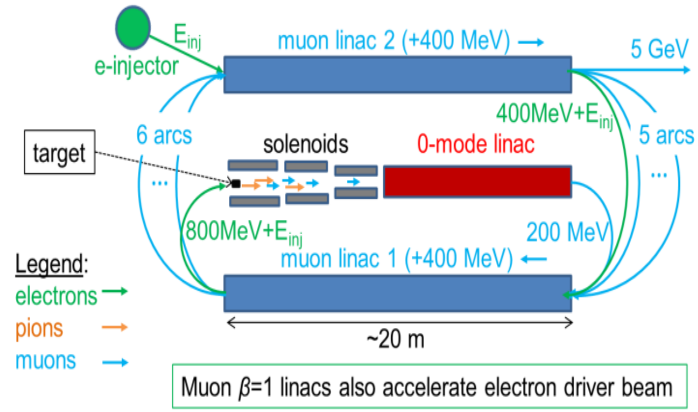
- Active interrogation using protons or muons.
- 100-m+ stand-off distances
- Requires beam energies of 500 MeV–1000 MeV.
- Ave. Beam Current = 1mA

- Technology currently not available.
- Needs innovative approach for compact, stable, and portable high-energy proton accelerator.

Compact electron linac generated muon beams can be used for radiography or tomography.



1-GeV electron linac based system for muon tomography



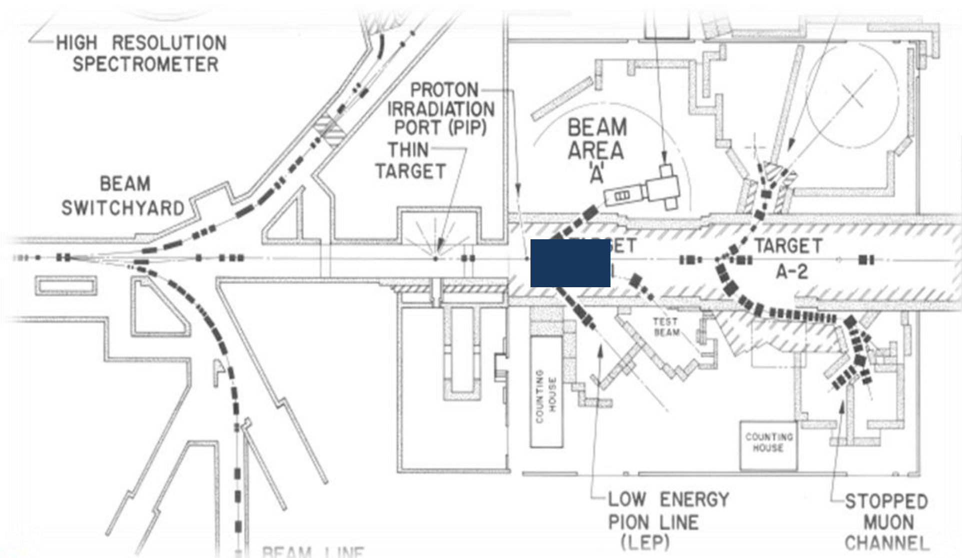
5-GeV system for muon tomography of large objects

- **We expect attainable muon fluxes of 10^5/s at 1 GeV** – compared to an estimated flux of 10^3/s required for high resolution tomography of the Fukushima reactor building within minutes.
- Such systems are applicable for imaging **SNM**, **well-shielded devices**, and contraband including concealed **humans or animals**.

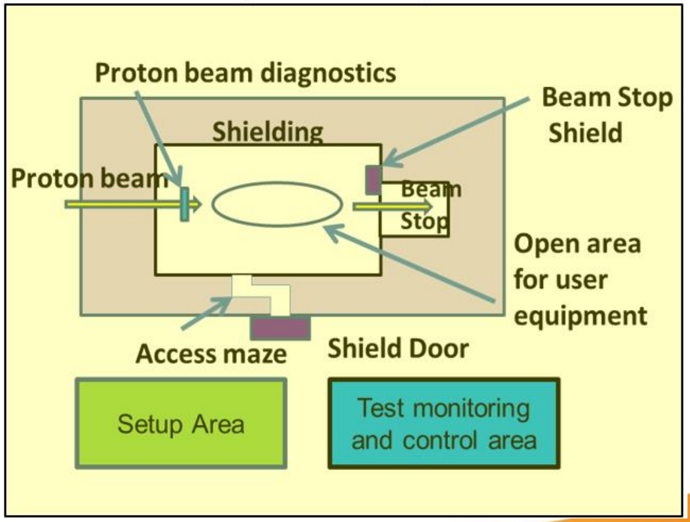
See R. Garnett et al., "A Compact Muon Accelerator for Tomography and Active Interrogation, *Proc. LINAC 2016*.

There is renewed interest in restoring 800-MeV proton beam operations to the LANSCE Area-A experimental area.

- **Primary users will be the Space Radiation Effects community**
- 200-MeV and 800-MeV operations expected
- H+, 1 Hz, 625-µs macropulse
- 100 nA average current (6.25 x 10^{11} protons/sec)
- Experimental area approximately 5 m x 7 m within ~3,000 m^2 Area A
- Project presently under review
- Expect 2-3 years to implement



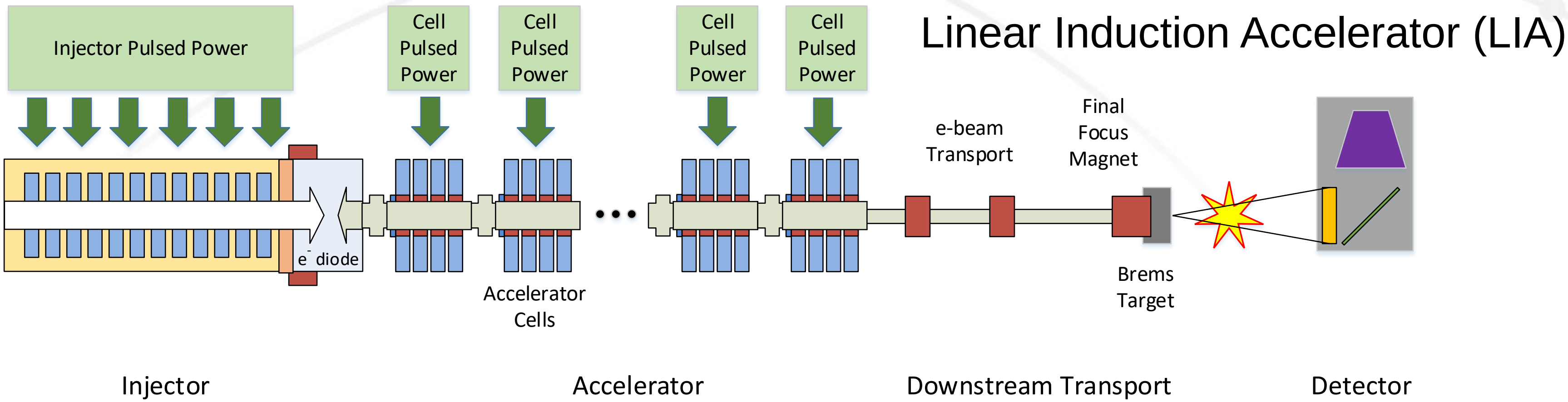
Low-Power Proton Source



New Projects

- ASD-Scorpius/Enhanced Capabilities for Subcritical Experiments (ECSE)
- Accelerators in Space
- Matter-Radiation Interactions in Extremes (MaRIE)

ASD-Scorpius Accelerator Conceptual Design

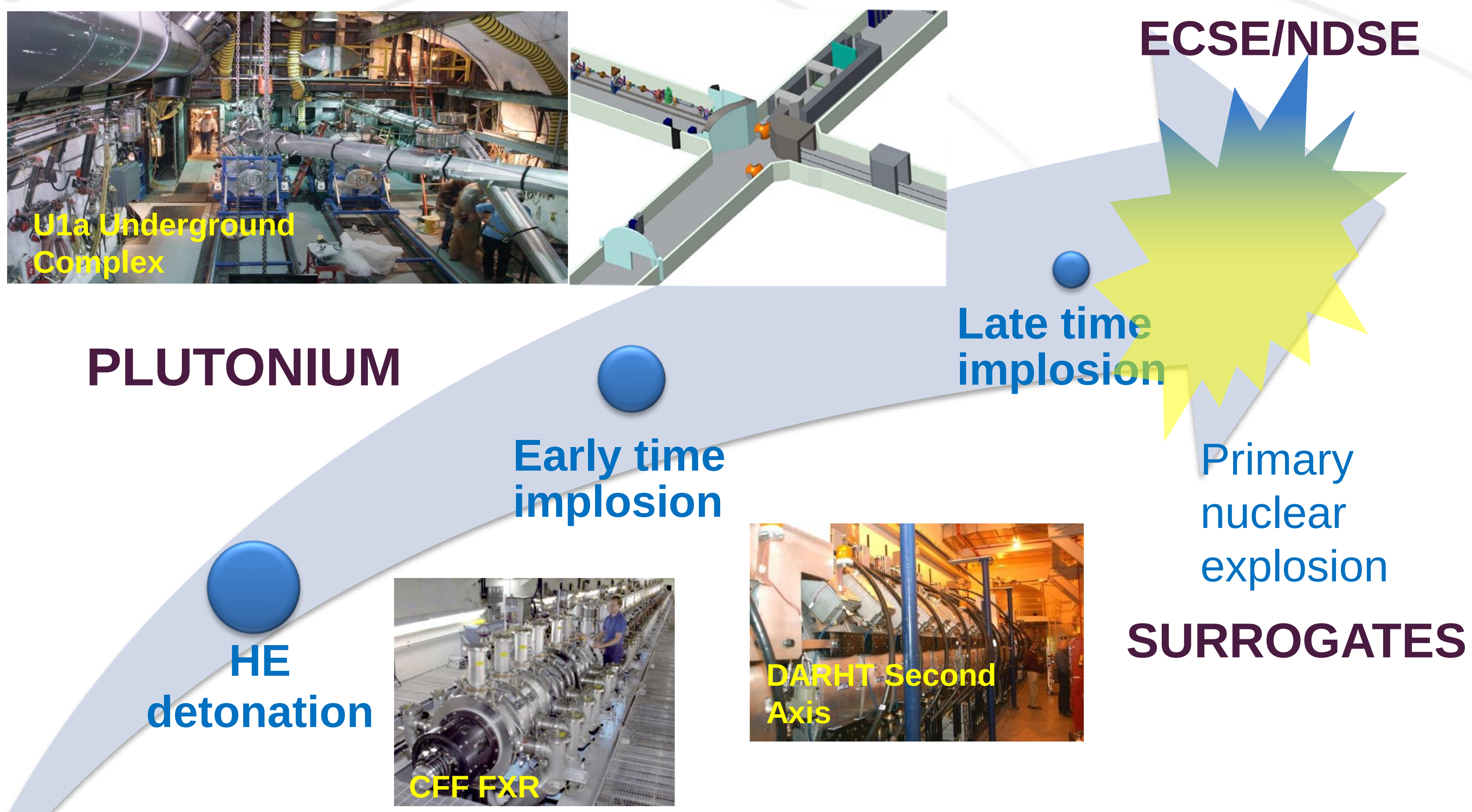


- Injector – Four-pulse, 2 MV, 2 kA, 85ns
  - Vacuum IVA with thermionic cathode driven completely by solid state pulsers
- Accelerator – 9, 2-MeV Blocks, Four-pulse, 250 kV cells
  - Based on DARHT-1 cell (multi-pulse performance validated) and 2x2 SPFL pulsed power architecture
- Downstream Transport
  - 4 to 1 dose control,
- Detector System
  - Based on DARHT-2 system, with updated camera development

Enhanced Capabilities for Subcritical Experiments (ECSE)

- ECSE is critical to the **certification and assessment** of the current and future stockpile.
- By adding world-class diagnostics to the U1a facility in Nevada – the only place in the nation where we can couple **plutonium with high explosives** – we close an important capability gap.
- ECSE will provide new capabilities (ASD Radiography and Neutron Diagnosed Subcritical Experiments (NDSE)) to assess **aging and manufacturing effects** on the stockpile.
- ECSE will provide vital data supporting **future stockpile options**.

Nuclear performance depends on the way plutonium implodes. There is no true surrogate for plutonium.



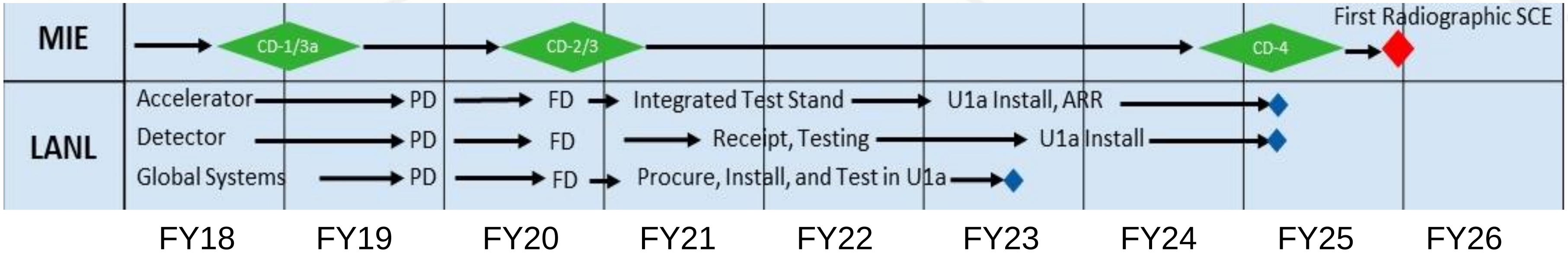
ECSE's Radiographic and NDSE measurements will fill a critical gap in experimental capabilities: the ability to measure plutonium in the final stages of primary implosion.

Scorpius beam physics requirements are based on meeting DARHT-1 source performance for multiple pulses

- Nine different transport and instability issues were evaluated and well-defined requirements for each system were established

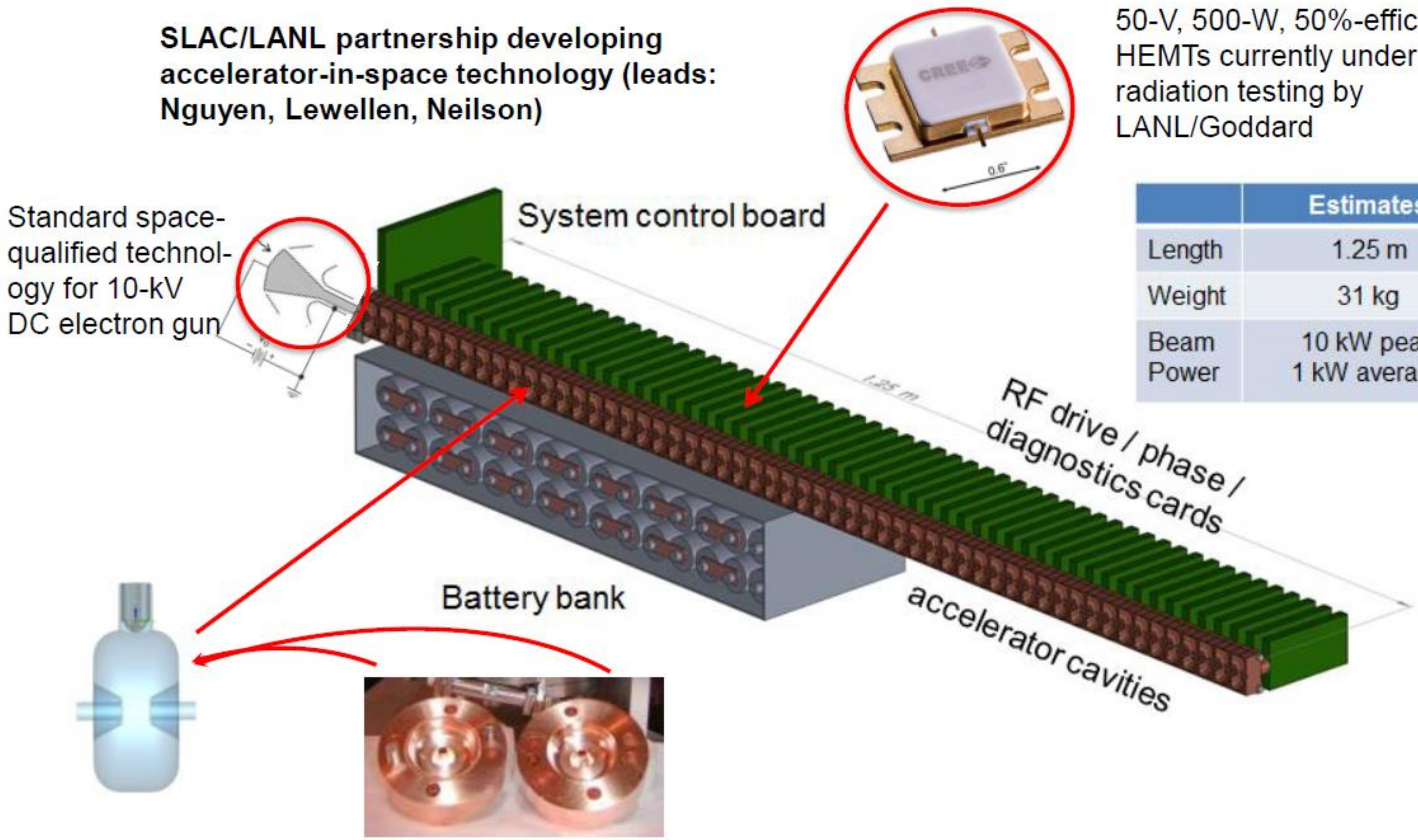
Beam Transport Issue	Mitigating Measure	System Requirement	Applies to
Emittance Growth	Matched beam tune for small size Steering dipoles to center beam	Dipoles in Cells (10 G on axis) ±1% Bz reproducibility	Accelerator
Beam Breakup (BBU)	Accelerating gap and cavity design Transport Magnetic field	Cell Zperp < DARHT-1 Mod2a Bz > 2 kG on axis ±1%	Accelerator
Image Displacement Instability (IDI)	Transport Magnetic field	Cell Bz > 0.2 kG	Accelerator
Corkscrew motion	Tight alignment tolerance Quiet pulsed-power Corrector dipoles in cells	Cell Alignment < 0.2 mm RMS dE/E < 5% RMS (~ ±7%) Dipoles in Cells (10 G on axis)	Accelerator Injector
Ion Hose Instability	High throughput distributed vacuum pumping Transport Magnetic Field	Vacuum < 200 nTorr	Accelerator, Downstream
Resistive Wall Instability	High-conductivity Beam Tubing Transport Magnetic Field	High σ (Al or Cu) Tubing Bz > 2 kG on axis ±1%	Accelerator, Downstream
Diocotron Instability	Diode design to produce convex profile High energy diode	Non-hollow beam Injector>1.5 MV	Injector
Final Focus Chromatic Aberration	Minimal beam energy variation	Total beam energy variation at entrance to FF magnet < 2% rms	Injector Accelerator Downstream
Parametric Envelope Instability	High- energy matched-beam tune	None	All

Scorpius Project



- Project Milestone Schedule supports execution of the first radiographic Sub-Critical Experiment (SCE) in FY2025
- Technology Maturation required for:
  - Multi-pulse Thermionic Cathode
  - Solid State Pulse Power
  - Diode Isolation
  - Series Pulse Forming Water Lines
  - Scorpius Accelerator Cell
- Preliminary Design in FY19; Final Design in FY20.

Accelerators in Space – Compact Accelerators



	Estimates
Length	1.25 m
Weight	31 kg
Beam Power	10 kW peak 1 kW average

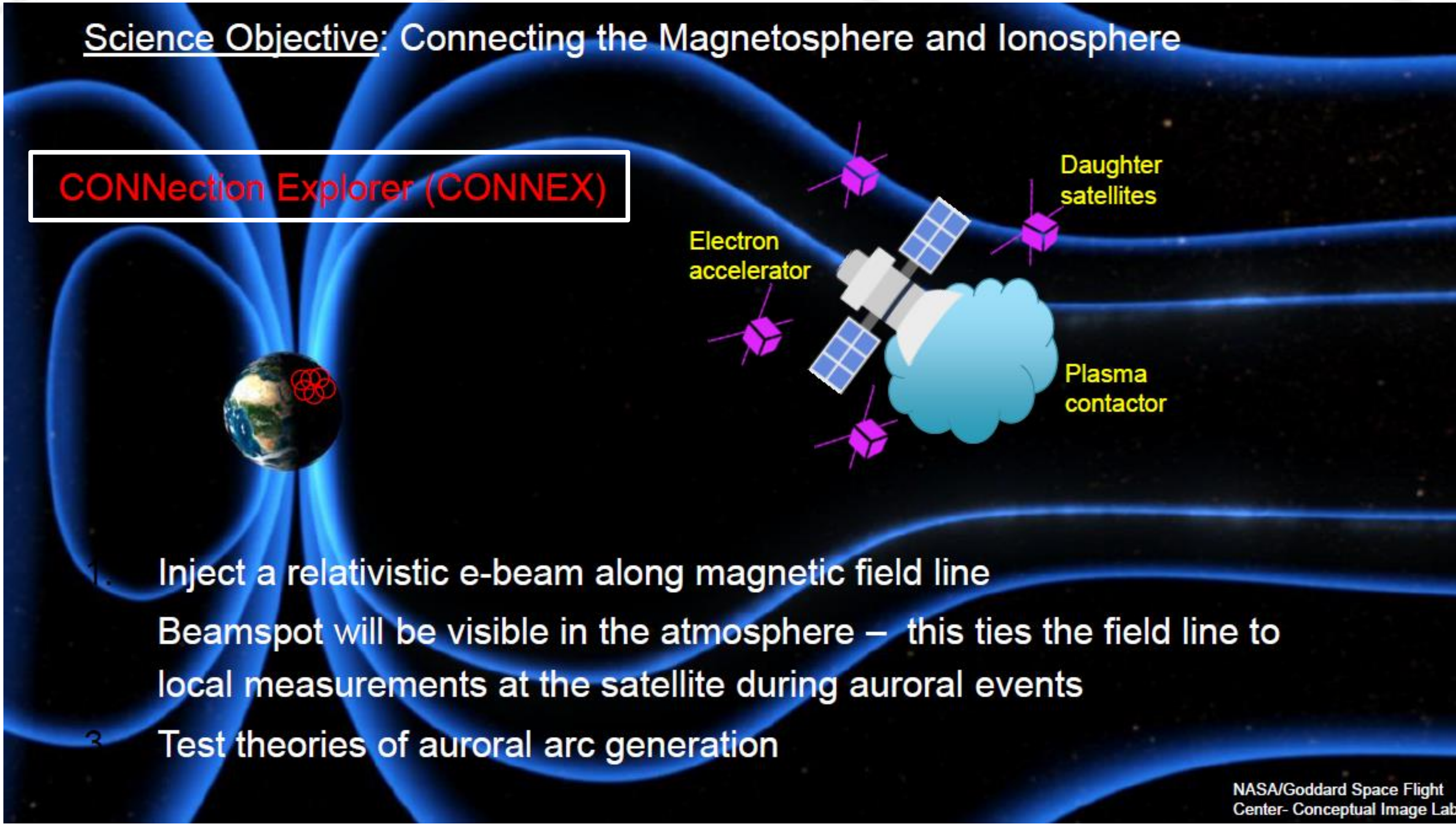
- **5-GHz cavities driven by solid-state HEMTs are a practical accelerator technology for space.**

Radiation-Belt Remediation (RBR)

- **What is Radiation Belt Remediation (RBR)?**
  - Enhanced electron flux in the radiation belts can happen ***naturally*** or be induced by a ***high-altitude nuclear detonation***
- **Why do we care about RBR?**
  - Enhanced electron flux can lead to a rapid degradation/loss of satellites in low-Earth orbit (LEO)
  - There are enough electrons to damage electronics
- **RBR is a "no-kidding" national mission**
  - The problem has been recognized for a long time but no solution has been implemented
- **How do we fix this?**
  - Driving VLF waves in the ionosphere can drive electrons out of the radiation belt (VLF=Very Low Frequency, 3-30 kHz) – whistlers, low-hybrid waves, Bernstein modes, etc.
  - VLF waves can be generated by antennas and **electron beams**
- **Proposed CONNEX MidEx NASA experiment will further advance accelerator-in-space technology.**
- **Starfish Prime (part of Operation Fishbowl) - July 8, 1962, 400-km altitude, launched from Johnston Island 1200 miles SW of Hawaii**
  - Starfish detonation created a belt of ~ MeV electrons that lasted for >5 years (~60 rad/day for 4 months)
  - Starfish detonation damaged or destroyed 7 satellites within 7 months (1/3 of all satellites in LEO), including Telstar (first commercial communications satellite), Ariel-1 (the UK's first satellite), and a Soviet satellite (Transit 4B, Traac, Ariel damaged by solar cell degradation, Telstar by command decoder failure by Nov, 1962)

See B. Carlsten, "Applications of Compact Accelerators in Space for National Security," Proc. IPAC'18.

Electron Beam In Space – Proposed NASA Experiment



Science experiment supports the technology development needed for the RBR mission

Project Goals – Develop an RBR Strategy

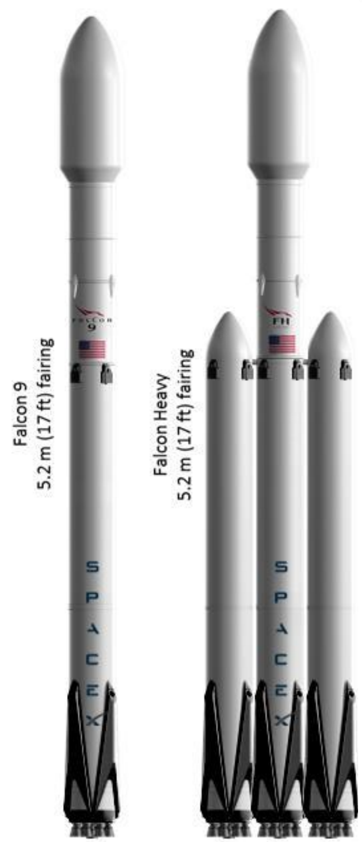
- **Understand VLF wave generation**
  - Antenna and electron beam generation (ongoing)
- **Understand VLF wave propagation/conversion**
  - Non-ideal effects will stimulate loss of power in desired VLF modes (ongoing)
- **Understand wave-particle interactions**
  - This understanding may be already mature enough
- **Advance the technology components**
  - First HEMT-driven accelerator in space in 2 years
  - Funded e-beam/plasma interaction experiments will close science/technology gaps:
    - NSF - MeV beam at UCLA Large Area Plasma Device (2018 through 2020)
    - NASA – BeamPIE (Low Cost Ascent to Space, launch in 2020)
  - Proposed CONNEX MidEx NASA experiment will further advance accelerator-in-space technology

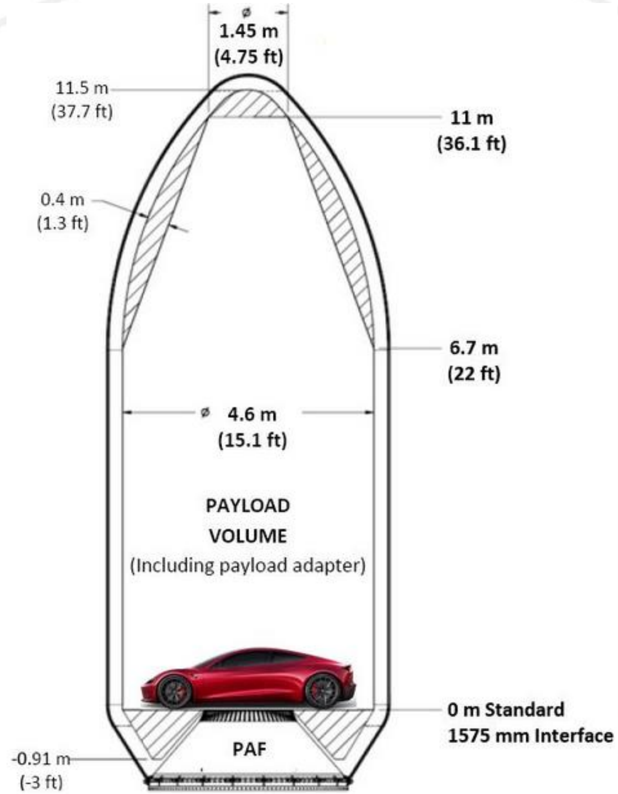
Accelerators in Space – Neutral Particle Beams

- Evaluate appropriate technologies for insertion into a modern updated NPB system conceptual design.
- Unique accelerator design and operational challenges exist for accelerators operating in space. SWaP – Size, weight, and performance need to be optimized:
  - Electron and Ion Sources
  - Accelerating Structures
  - Beam Steering & Pointing
  - Diagnostics
  - Prime Power
  - Thermal Management
  - RF Systems
  - Controls and Automation
- Project may lead to ground and space testing.

High-power accelerators in space requires solving challenging beam physics and engineering problems.

Test launch will most likely be on a Space-X vehicle.

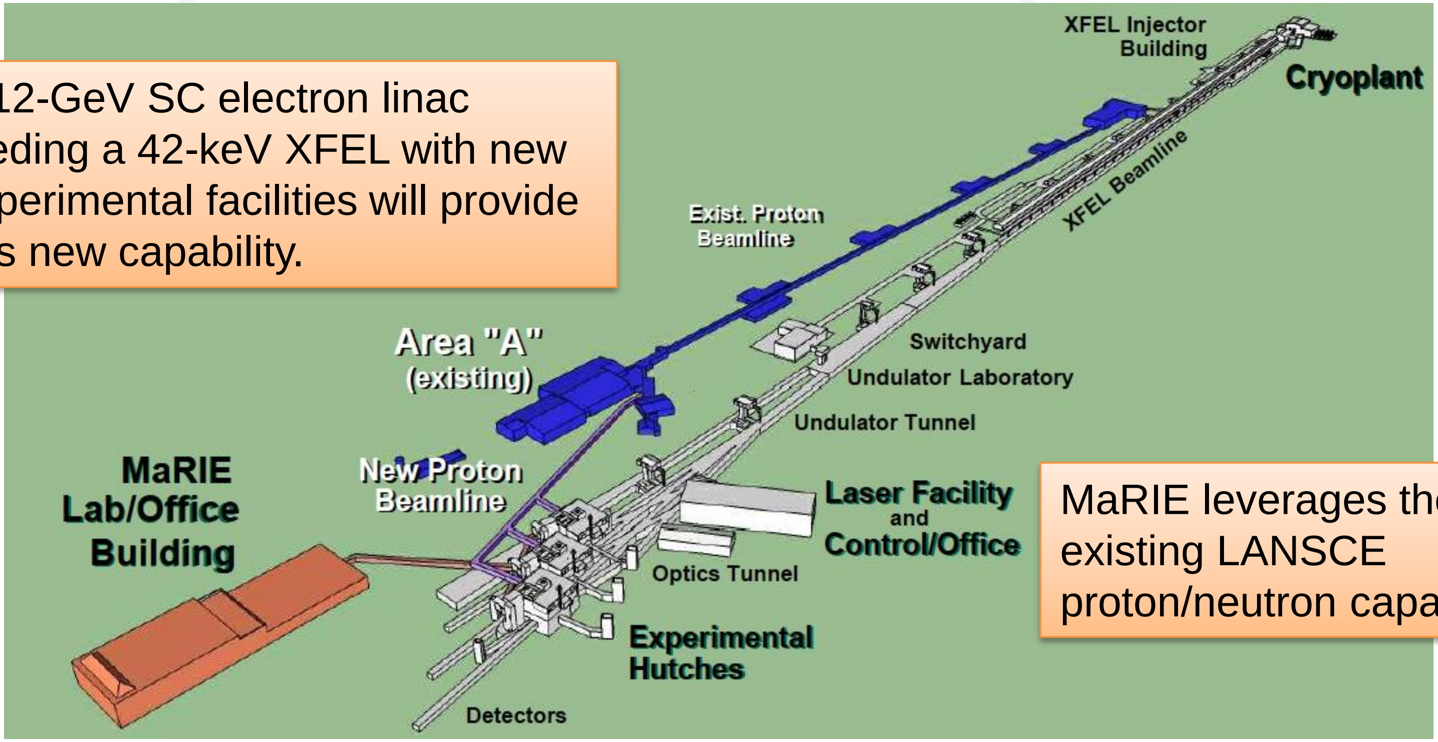




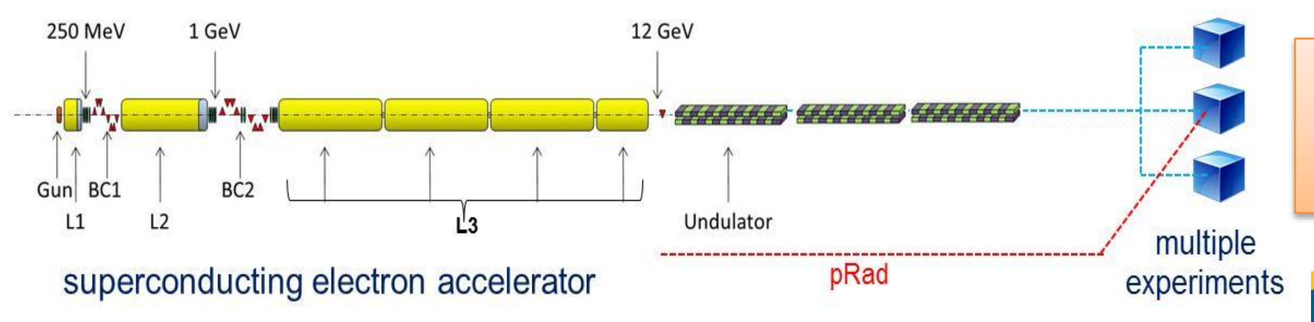
Launch Vehicle	Payload Size, LEO (kg)	Payload Height (m)	Payload Diameter (m)
Aries (Bear)	1,545	7.2	1.1
Falcon 9	22,800	11.0	4.6
Falcon 9 Heavy	63,800	11.0	4.6

Matter-Radiation Interactions in Extremes (MaRIE) – the Long-term Plan for LANSCE

A 12-GeV SC electron linac feeding a 42-keV XFEL with new experimental facilities will provide this new capability.



MaRIE leverages the existing LANSCE proton/neutron capabilities.



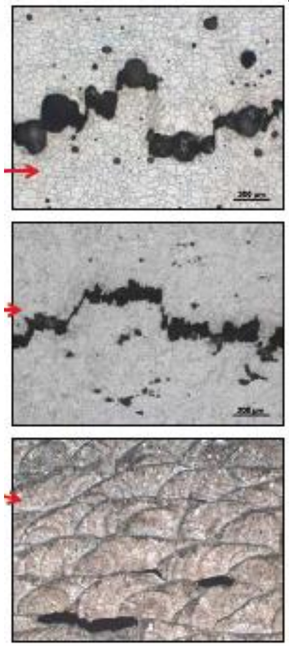
Baseline accelerator design assumes LHC cryomodules.

MaRIE will be a revolutionary capability

- The **brilliance** of an XFEL
- Transformative **imaging techniques with coherence** – “ordered light for disordered systems”
- ★ Designed for **time-dependence** from electronic motion (picosecond) through sound waves (nanosecond) through shock transit across samples (microseconds) through thermal diffusion (millisecond) to manufacturing (seconds and above)
- ★ **High-energy** to not destroy mesoscale samples with that brilliance and give that time-dependence (and perhaps provide larger reciprocal space resolution)
- ★ Not just x-ray facility, but designed for **multiple simultaneous probes**
- Designed with strong connection to the needs of scientific predictive capability from theory, modeling, and computation
- Providing comprehensive materials discovery capability to collaborative teams
- Enables science-based qualification and certification, leading to the “revolution in manufacturing science”

MaRIE will address the control of performance and production of materials for national security science at the mesoscale.

Performance of additively-manufactured (AM) structural components



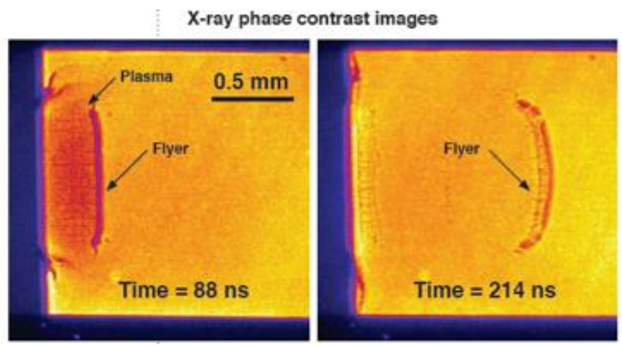
Wrought

AM Annealed

AM

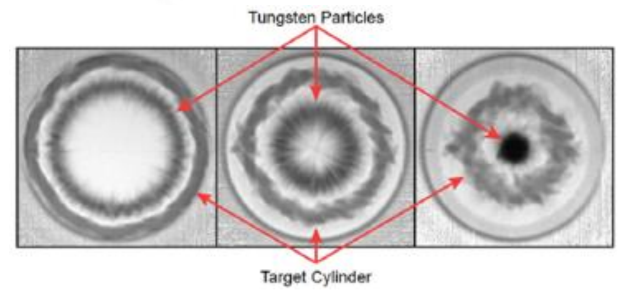
Damage in wrought vs. additively-manufactured steel

High Explosive performance and safety



Movies of functioning slapper detonators

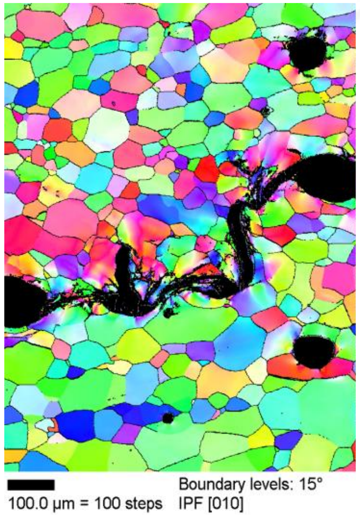
Ejecta and Mix



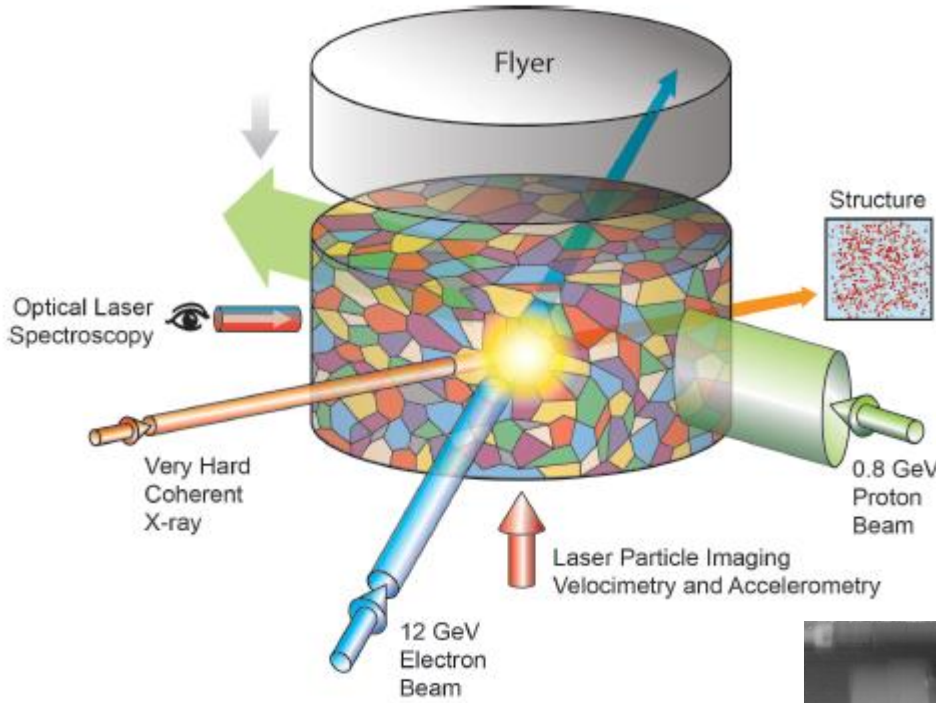
Movies of ejecta in convergent geometry

MaRIE fills a critical gap in length scale between the atomic scale (small laboratory-scale experiments and simulations) and and the integral scale addressed by other capabilities (DARHT, pRad, etc.).

Challenging experiments are planned to observe the dynamic microstructure and phase evolution in materials down to the sub-granular level while connecting to the macroscale.



Requirements:
Sub-µm space resolution
100's – 1000's-µm samples
Sub-ns time resolution,
~30 frames in
1−1000-µs duration



The model:

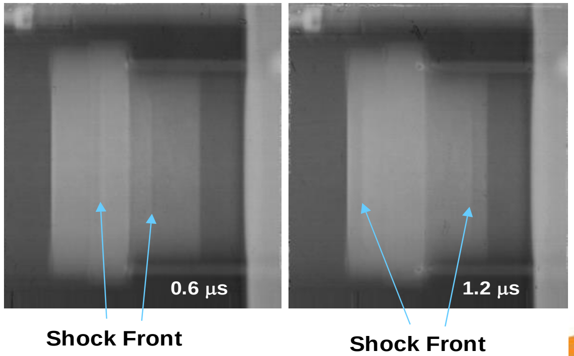
Accurate sub-grain models of microstructure evolution coupled to molecular dynamics.

The goal

Predict dynamic microstructure and damage evolution.

The first experiment

Multiple, simultaneous dynamic *in situ* diagnostics with resolution at the scale of nucleation sites (< 1 µm; ps – ns)

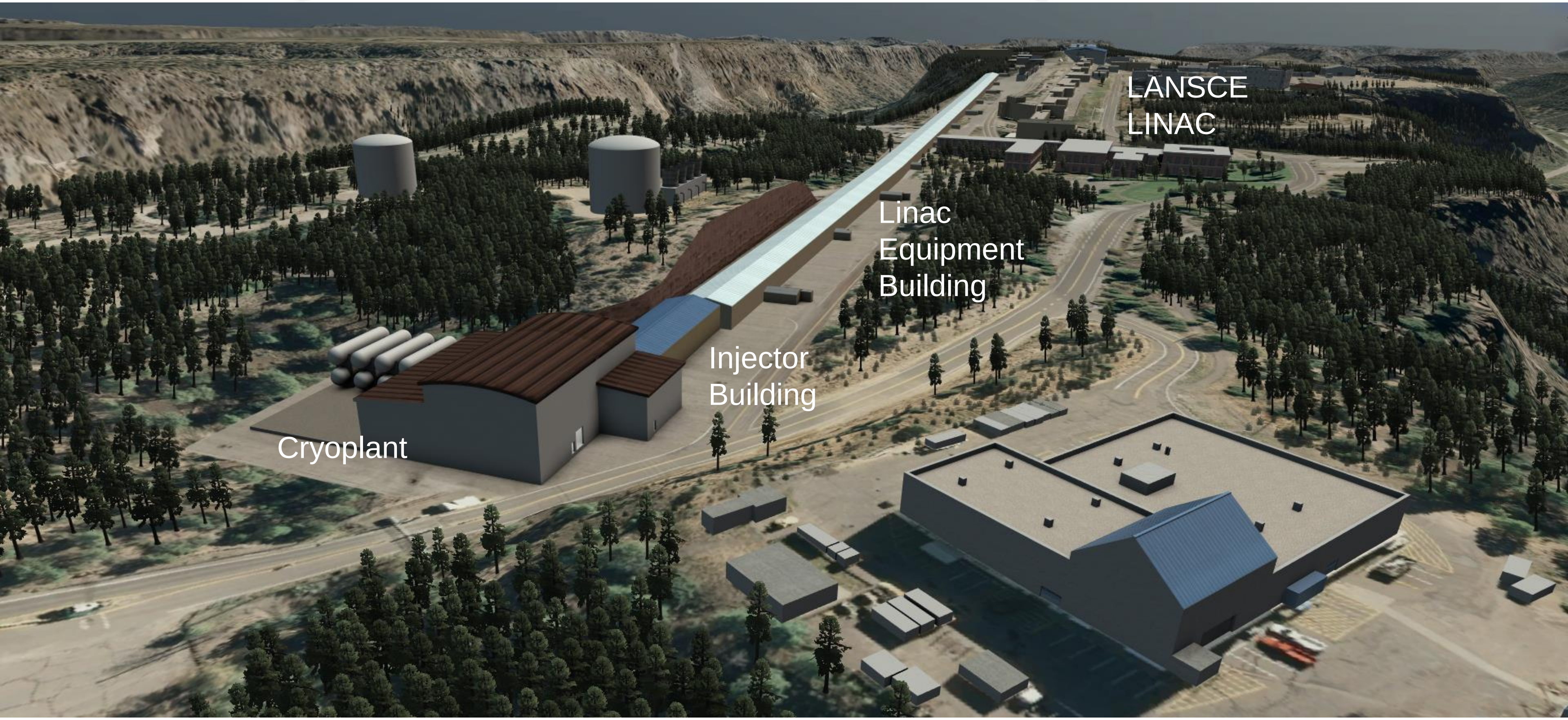


MaRIE will allow us to break apart the problem.

Hard X-ray FEL Parameters

	LCLS-I	SACLA	EXFEL 2016	PAL XFEL 2016	SwissFEL 2017	LCLS-II 2019 SRF / NCRF	**MaRIE 202x**
X-ray energy Pulse energy photons/pulse	12.8 keV 0.93 mJ 5E11	19.5 keV 0.03 mJ 1E10	24.7 keV 1 mJ 2.5E11	20.6 keV 0.08 mJ 2.5E10	12.4 keV 1.4 mJ 7E11	5 / 25 keV 0.025 / 0.3 mJ 3E10 / 7E10	**42 keV** **0.35 mJ** **5E10**
Undulator period K_{rms}	3.0 cm 2.5	1.8 cm 0.94	4.0 cm 1.4	2.44 cm 0.94	1.5 cm 1.1	2.6 cm 0.43 / 1.5	**1.86 cm** **0.86**
Electron beam energy	16.9 GeV	8.5 GeV	17.5 GeV	10 GeV	5.8 GeV	4 / 15 GeV	**12 GeV**
Linac type Linac length	NCRF S-band 1 km	NCRF C-band 0.4 km	SRF L-band 1.7 km	NCRF S-band 0.78 km	NCRF C-band 0.46 km	SRF / NCRF 0.4 / 1 km	**TBD**
Gun type Cathode	NCRF S-band Cu photo	Pulsed DC CeB_6	NCRF L-band Cs_2Te photo	NCRF S-band Cu photo	NCRF S-band Cu photo	VHF / S-band Cs_2Te / Cu	**TBD**
RF pulse Rep. rate	<1 ms 120 Hz	<1 ms 30 Hz	600 ms 10 Hz	< 1 ms 60 Hz	< 1 ms 100 Hz	CW / <1 ms 930 kHz / 120 Hz	**TBD**
# pulses/RF	1-2	1-2	2,700	1-2	1-2	N/A / 1-2	**TBD**
Bunch charge	150 pC	30 pC	250 pC	100 pC	200 pC	20 / 130 pC	**100 pC**
Bunch length	43 fs	<10 fs	50 fs	43 fs	42 fs	20 / 33 fs	**33 fs**
Norm. slice emittance	0.4 mm	0.6 mm	0.6 mm	<0.5 mm	0.2 mm	0.14 / 0.48 mm	**0.2 mm**

Artist Rendition of MaRIE Conventional Facilities



Opportunities

Opportunities – Students, Postdocs, Early-Career Staff (and possible collaborations)

- **Scorpius Project** – 2018 to 2025; in the preliminary design phase
- **Accelerators in Space** – 2018 to 2022; proof-of-principle, conceptual design, technology risk mitigation
- **MaRIE** – 2018 to 2030; pre-conceptual design completed; preliminary design phase and technology risk mitigation to begin in 2019; photoinjector test stand planned to start in late 2019
- **LANSCE, DARHT** – on-going hiring to support long-term operations and upgrades
- Opportunities, include physics and engineering design, fabrication, installation & commissioning, and integration of all major accelerator subsystems

Our needs include the full spectrum of accelerator engineers and scientists.

Opportunities align well with the MSU ASET Program: Physics & Engineering of Large Accelerators, SCRF Technology, Large-Scale Cryo Systems

Opportunities – Students, Postdocs, Early-Career Staff (and possible collaborations)

- Proton/Ion Beam Dynamics
- Accelerator Simulation & Design
- Model-Independent Control & Optimization
- Digital LLRF Systems
- Magnet & Wiggler Design
- High-Performance Ion Sources
- Non-Interceptive Diagnostics/Plasma Diagnostics
- Induction Linacs
- Applications – Materials damage, single-event upset
- Applied Electromagnetics – structures, sources, magnets

Projects and programs are willing to make investments in developing these capabilities that will sustain long-term Accelerator Science & Technology at LANL.

Contact Information

- **LANL website** at www.lanl.gov – General LANL stuff and what we do, Careers: students, postdocs, apply for a job
- **For more information**:
  - **LANSCE & Accelerators in Space** - Bob Garnett, Accelerator Operations & Technology Division, rgarnett@lanl.gov
  - **DARHT** – Chris Rose, DARHT Physics & Pulse Power, crose@lanl.gov
  - **Scorpius** – Mark Crawford, Accelerator System Technical Development, mtc@lanl.gov
  - **MaRIE** – Cris Barnes, MARIE Division, cbarnes@lanl.gov