Jefferson Lab and the NP SBIR/STTR Program

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Accelerator Operations and R&D

DOE-NP SBIR/STTR Exchange Meeting
August 7 – 8, 2018

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Outline

- **Jefferson Lab Overview**
- **Accelerator Facilities**
  - *Continuous Electron Beam Accelerator Facility (CEBAF)*
  - *Low Energy Recirculator Facility (LERF)*
  - *Upgraded Injector Test Facility (UITF)*
  - *LERF Gun Test Stand (GTS)*
- **Accelerator R&D Major Directions**
  - *SRF technology*
  - *Sources*
  - *EIC*
  - *Positrons*
  - *Isotopes*
  - *Diagnostics*
- **SBIR Engagement**
  - *Internal Process*
  - *Ongoing Partnerships*
  - *Growing the program*
- **Summary**

Jefferson Lab Overview

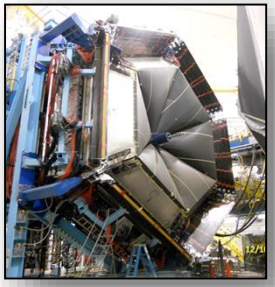
- DOE Office of Science Laboratory with a single program focused on Nuclear Physics.
- Created to build and operate the Continuous Electron Beam Accelerator Facility (CEBAF), world-unique user facility for Nuclear Physics.
- Mission is to gain a deeper understanding of the structure of matter:
  - Through advances in fundamental research in nuclear physics
  - Through advances in accelerator science and technology
- In operation since 1995

Jefferson Lab by the numbers:

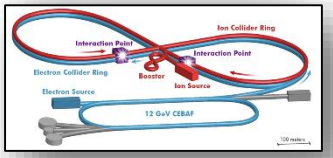
- 700 employees
- FY2018 Budget: $162.4M
- 169 acre site
- 1,600 Active Users
- 27 Joint faculty
- 608 PhDs granted to-date (211 in progress)
- K-12 programs serve more than 12,000 students and 950 teachers annually

Long-Term Vision for Jefferson Lab

Jefferson Lab supports the DOE Office of Science and serves the Nuclear Physics user community as a world-leading center for fundamental nuclear science and associated technologies



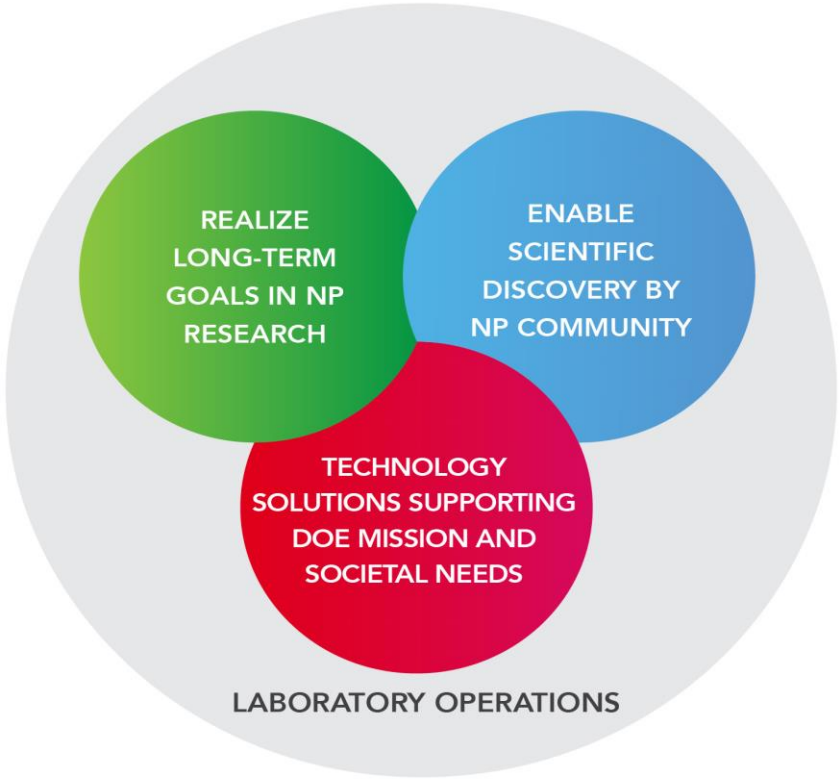
1. Deliver on 12 GeV Scientific Program



2. Provide a long-term path for the field

3. Provide technology solutions supporting DOE mission

4. Enable world-class science through excellence in Laboratory Operations



Jefferson Lab

Mission and Strategic Plan

MISSION		**We support the DOE Office of Science and serve the Nuclear Physics User Community as a world-leading center for fundamental nuclear science and associated technologies**		
SCIENCE & TECHNOLOGY	STRATEGIC OUTCOMES	Enable scientific discoveries by the Nuclear Physics User Community through our unique, world leading facilities and capabilities	Plan for future facilities and capabilities to realize the long-term scientific goals in Nuclear Physics research	Provide technology solutions that support the NP community, the larger DOE mission and societal needs
	MAJOR INITIATIVES	1. Operate CEBAF accelerator and experimental facilities to execute the FY18 experimental nuclear physics program 2. Prepare CEBAF accelerator and experimental equipment for future 3-5 year experimental physics program 3. Perform R&D to enable enhanced performance and future new capabilities for CEBAF and experimental halls 4. Perform theoretical research in support of the CEBAF 12 GeV program 5. Perform theoretical and experimental research in support of the broader NP research community 6. Provide software and computational resources for theoretical and experimental nuclear physics research	1. Continue to develop the MOLLER and SoLID initiatives 2. Perform Accelerator R&D towards an Electron Ion Collider 3. Perform Detector R&D towards an Electron Ion Collider 4. Pre-project design and planning for an Electron Ion Collider 5. Engage with the EIC user community and further develop the anticipated scientific program for a future Electron Ion Collider 6. Develop and expand expertise in Scientific Computation and Data Science	1. Execute LCLS-II activities to produce project deliverables 2. Perform R&D to enable other future (non-CEBAF, non-EIC) accelerator capabilities and enhance the reputation of JLab in SRF and large-scale cryogenics 3. Perform R&D on topics with potential commercial applications to facilitate transfer of the Lab's technology beyond nuclear physics
OPERATIONS	STRATEGIC OUTCOMES	Provide, protect, and improve the human, physical and information resources that enable world class science		
	MAJOR INITIATIVES	1. Business Process Streamlining 2. IT Service Modernization 3. Cyber Operations Laboratory	4. Facilities Engineering and Reliability Enhancement 5. Alternate Work Schedule 6. Website Redesign and Upgrade	7. ISMS Performance Enhancement 8. Enhanced Self-Assessment 9. Reduced Material and Supply Cost Through Improved Commodity Sourcing 10. Total Time Accounting

Mission and Strategic Plan

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Jefferson Lab Plays a Vital SRF Stewardship Role

Jefferson Lab is a world-leader in Superconducting Radiofrequency particle accelerators and cryogenic technologies

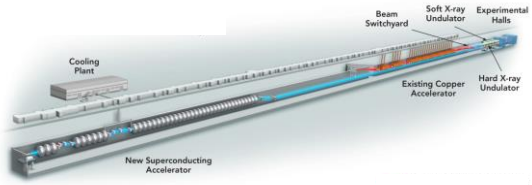
CEBAF - 1994
12 GeV Upgrade - 2017

Spallation Neutron Source (ORNL) - 2006

Facility for Rare Isotope Beams (MSU) - 2021

Linac Coherent Light Source II (SLAC) 2021

SNS Proton Power Upgrade

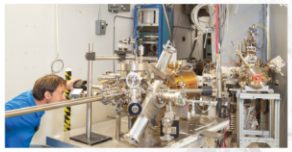


LCLS-II High Energy Upgrade

Jefferson Lab

CEBAF AT JEFFERSON LAB

Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) enables world-class fundamental research of the atom's nucleus. Like a giant microscope, it allows scientists to "see" things a million times smaller than an atom.



1 INJECTOR

The injector produces electron beams for experiments.

2 LINEAR ACCELERATOR

The straight portions of CEBAF, the linacs, each have 25 sections of accelerator called cryomodules. Electrons travel up to 5.5 passes through the linacs to reach 12 GeV.

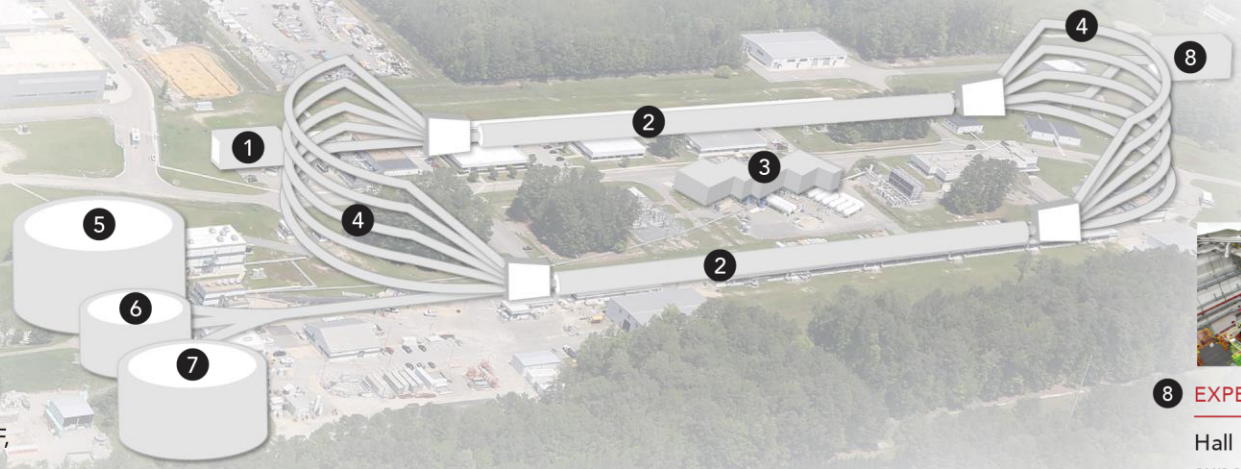
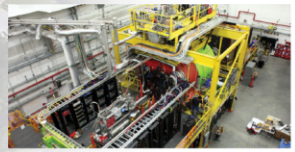


Diagram representational of below ground structure



8 EXPERIMENTAL HALL D

Hall D is configured with a superconducting solenoid magnet and associated detector systems that are used to study the strong force that binds quarks together.

3 CENTRAL HELIUM LIQUEFIER

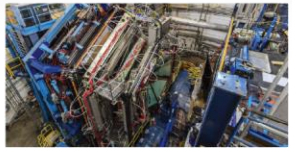
The Central Helium Liquefier keeps the accelerator cavities at -456 degrees Fahrenheit.

4 RECIRCULATION MAGNETS

Quadrupole and dipole magnets in the tunnel focus and steer the beam as it passes through each arc.

5 EXPERIMENTAL HALL A

Hall A is configured with two High Resolution Spectrometers for precise measurements of the inner structure of nuclei. The hall is also used for one-of-a-kind, large-installation experiments.



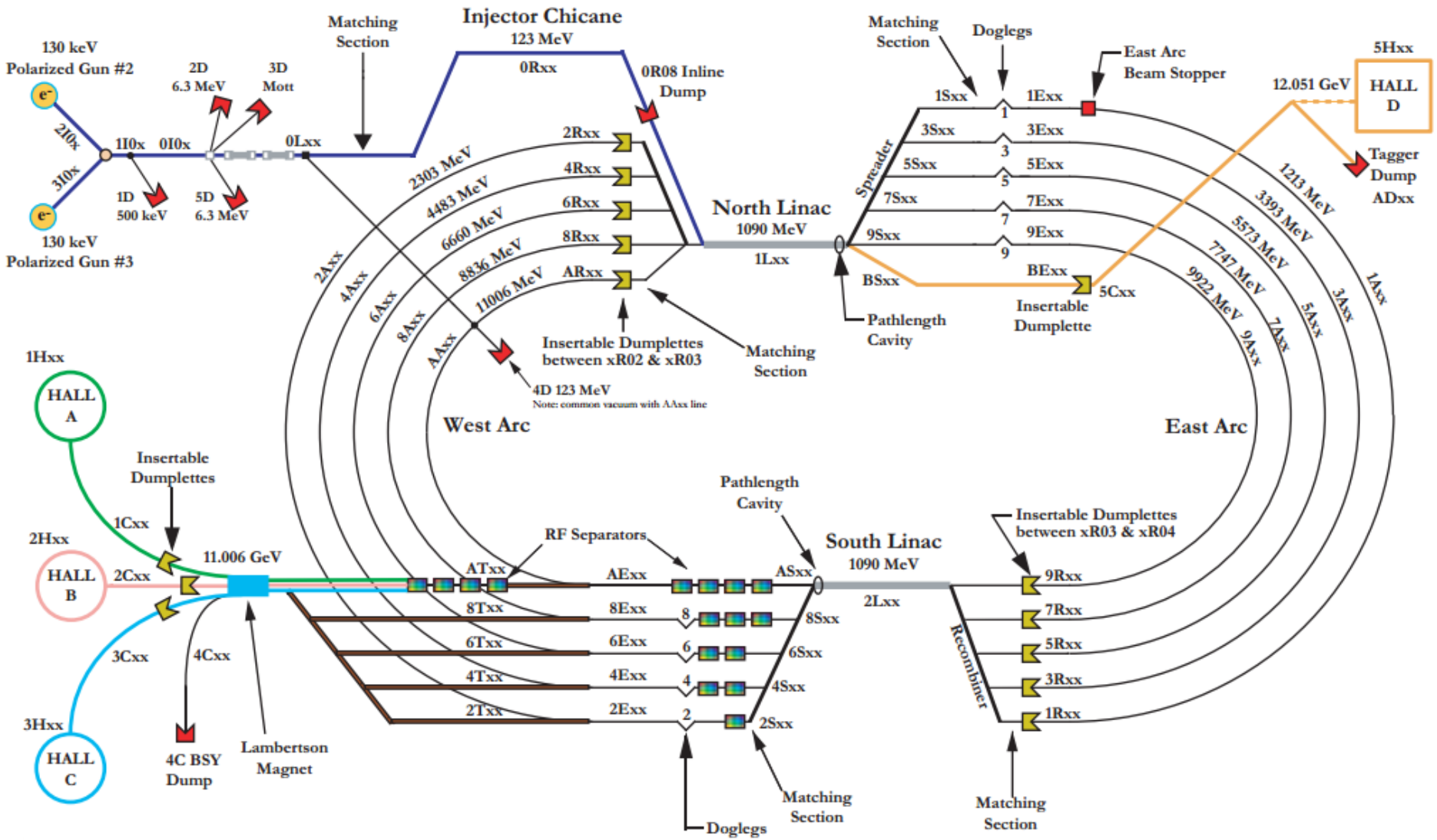
6 EXPERIMENTAL HALL B

The CEBAF Large Acceptance Spectrometer surrounds the target, permitting researchers to measure simultaneously many different reactions over a broad range of angles.

7 EXPERIMENTAL HALL C

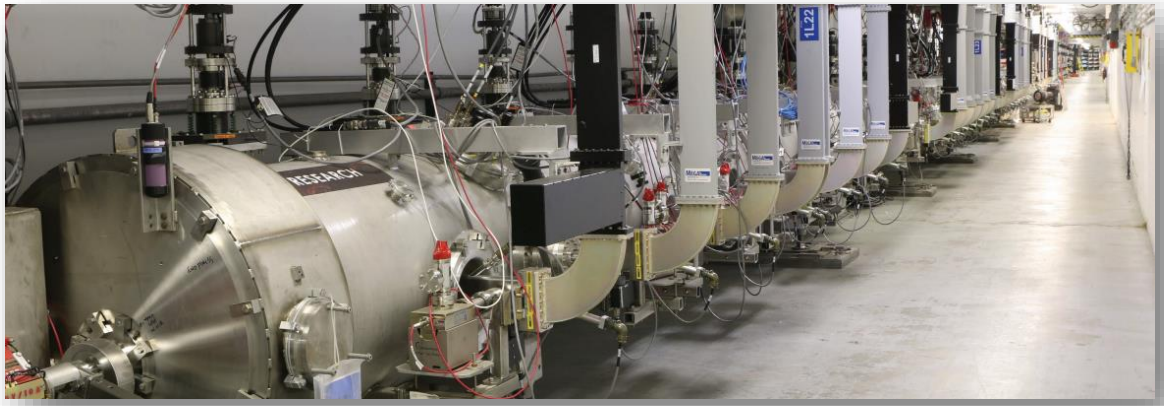
The Super High Momentum Spectrometer and the High Momentum Spectrometer make precise measurements of the inner structure of protons and nuclei at high beam energy and current.

Continuous Electron Beam Accelerator Facility



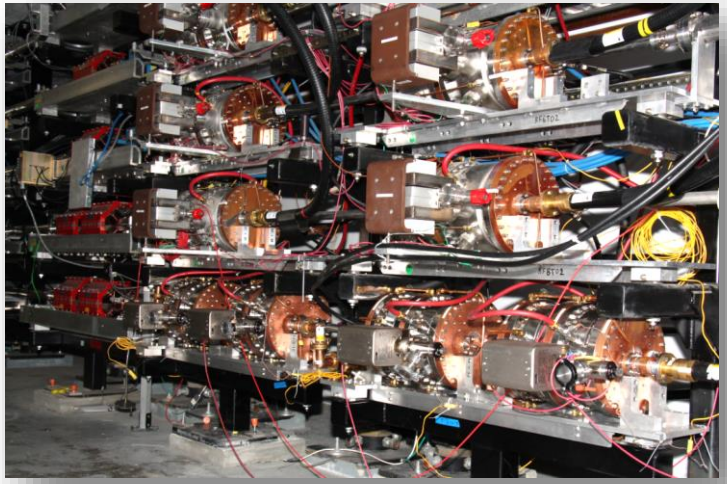
Jefferson Lab

Continuous Electron Beam Accelerator Facility

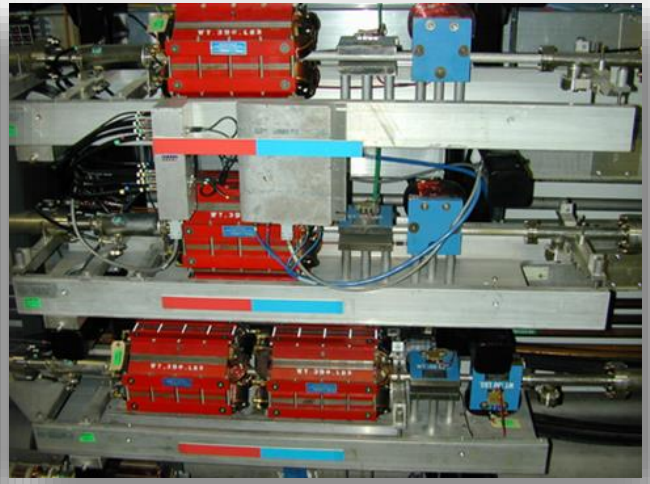


52-1/4 Cryomodules with 418 SRF Cavities to Accelerate Electrons in CEBAF

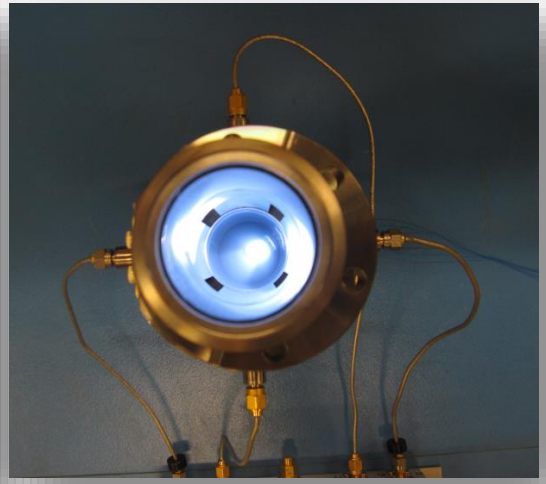
~500 Large Dipoles powered by >40 HVPS



16 RF Deflectors for Extracting Beams



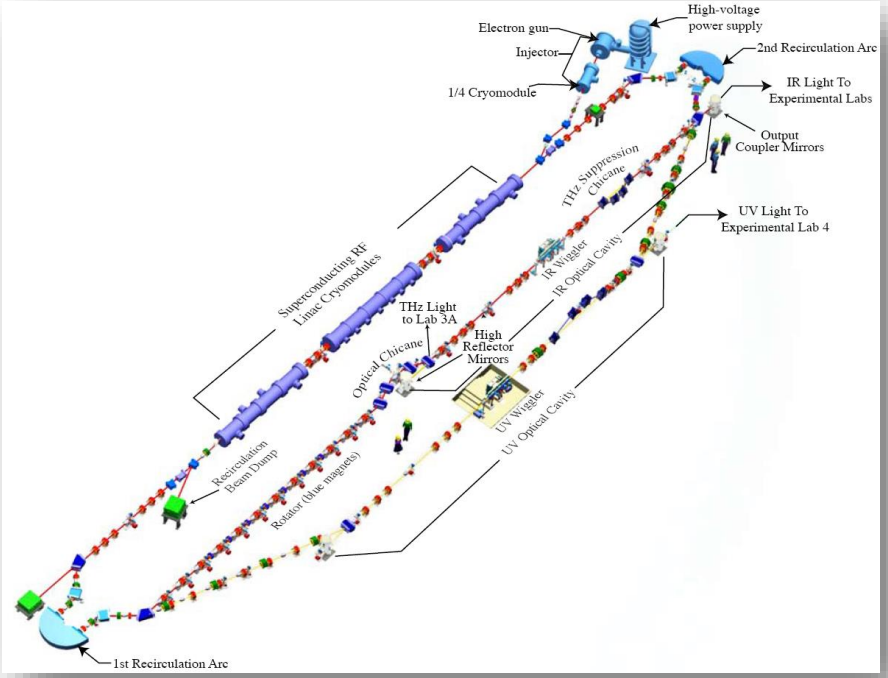
>2800 Magnets to Focus and Steer Beam



>800 Beam Position Monitors

Low Energy Recirculator Facility (LERF)

- LERF facility initially funded through DOD (Navy) program to develop high power Free Electron Lasers.
- Navy program terminated in 2014.
- LERF, laboratory spaces and Gun Test Stand are available to be used in support of R&D programs:
  - Magnetized Beam LDRD for JLEIC
  - Diagnostic Development for CEBAF upgrades
  - Ultra-high vacuum component assembly
  - Laser R&D
  - Magnetic hygiene for SRF cryomodules
- Main LERF accelerator is available to support R&D under a cost recovery model when opportunities arise.



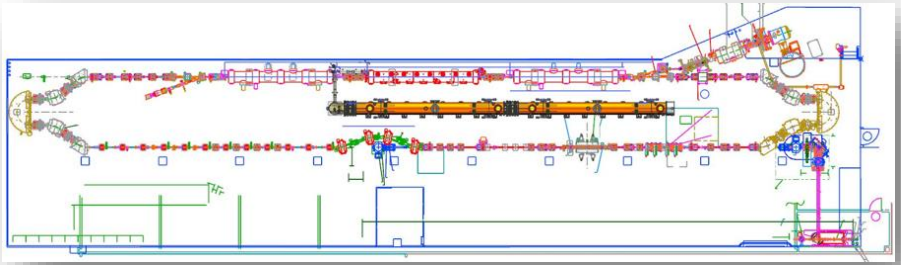
Parameter	Value
Max. Energy	170 MeV
Bunch Charge	150 pC
Bunch Frequency	75 MHz
Current (Fixed Target)	0.5 mA
Current (ERL)	8 mA
Long Axis Length	64 meters

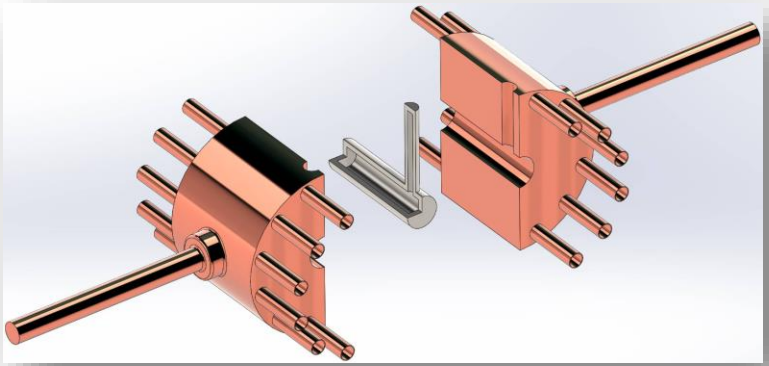
Low Energy Accelerator Facility (LERF)

LERF facility supporting two programs in the near term:

- LCLS-II cryomodule testing – DOE/BES funded effort to gain schedule contingency for cryomodule qualification
- Two LCLS-II cryomodules will be tested at a time on a ~2 month cycle and will repeat ~4 times.
- Sixteen Solid State Amplifiers, LLRF and Cryo controls on loan from SLAC to commission the cryomodules

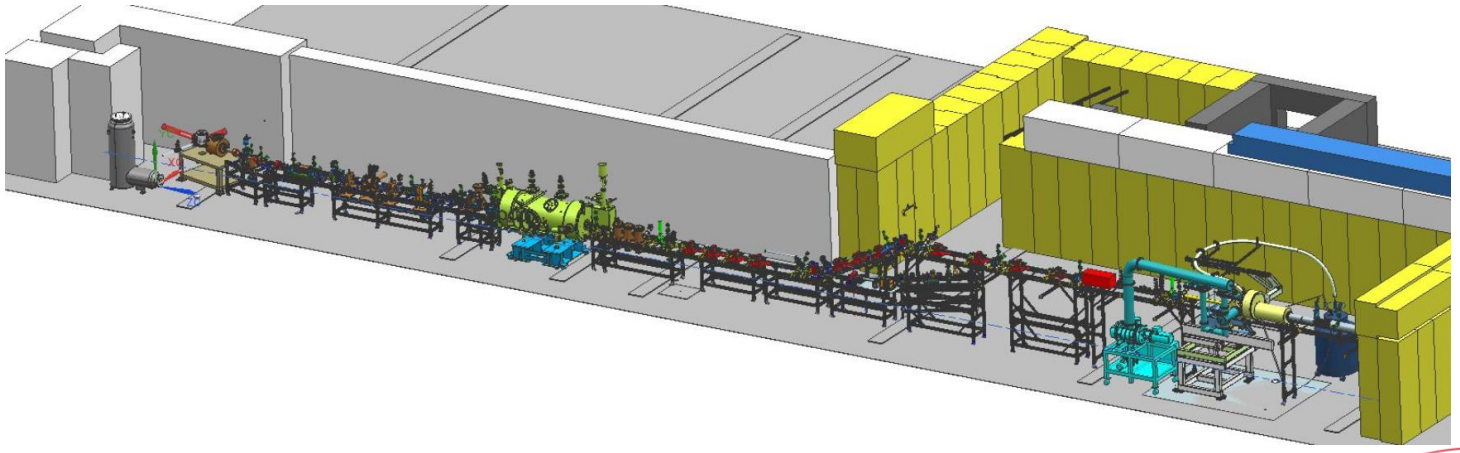
- Isotope Research and Development – DOE/NP Isotope program funded two year R&D plan to address national need for high-priority research isotopes.
- Program will specifically study the generation of ^{67}Cu by photo-production using bremsstrahlung photons from the LERF high power electron linac.





Upgraded Injector Test Facility (UITF)

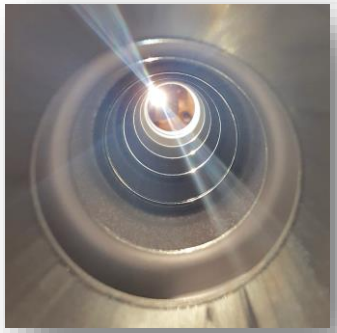
- The Injector Test Facility was established in the very early days of Jefferson Lab to build and commission the CEBAF warm injector while tunnel construction was underway. The facility was recently upgraded with cryogenics capabilities.
- Ongoing and planned R&D include:
  - Full Injector Upgrade: 200 kV gun, Wien filters, new Quarter Cryomodule
  - Polarize solid targets for the Physics Program and commissioning the HDIce target system for a future experiment in Hall B
  - Magnetized beam tests for EIC
  - Polarized positron source development for CEBAF and EIC
  - R&D in support of Environmental Applications of Accelerators



JLAB R&D Major Directions

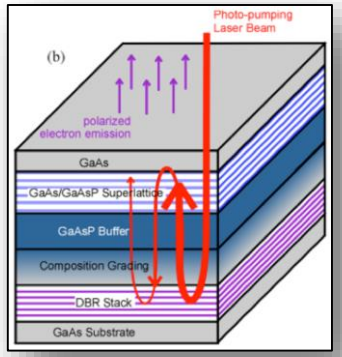
- Superconducting RF R&D
  - Improving SRF performance of CEBAF
  - New SRF technologies for an EIC
  - Next-generation SRF for high quality factor, high-gradient, higher temperature
  - New materials and processes for higher efficiency, lower cost, safer operations
- Electron Source R&D
  - Extend state-of-art for world record quantum efficiency for high polarization photocathodes
  - Parity quality beam program - CEBAF Injector Full-Energy Upgrade to 200 kV gun
  - Magnetized source for JLEIC cooler
  - Advanced cathode materials
- JLEIC R&D activities
  - Pre-conceptual R&D
  - R&D on high-priority topics identified by Jones panel

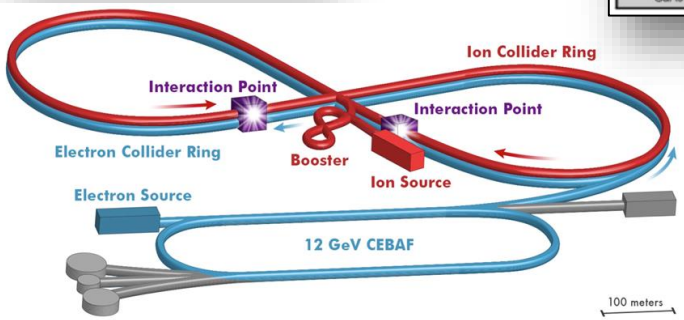
C75 cavity



Nb_3Sn coated 5-cell cavity

World Record High Polarization Photocathode





These activities are essential for forming the technological base for future Nuclear Physics research as well as the broader DOE mission

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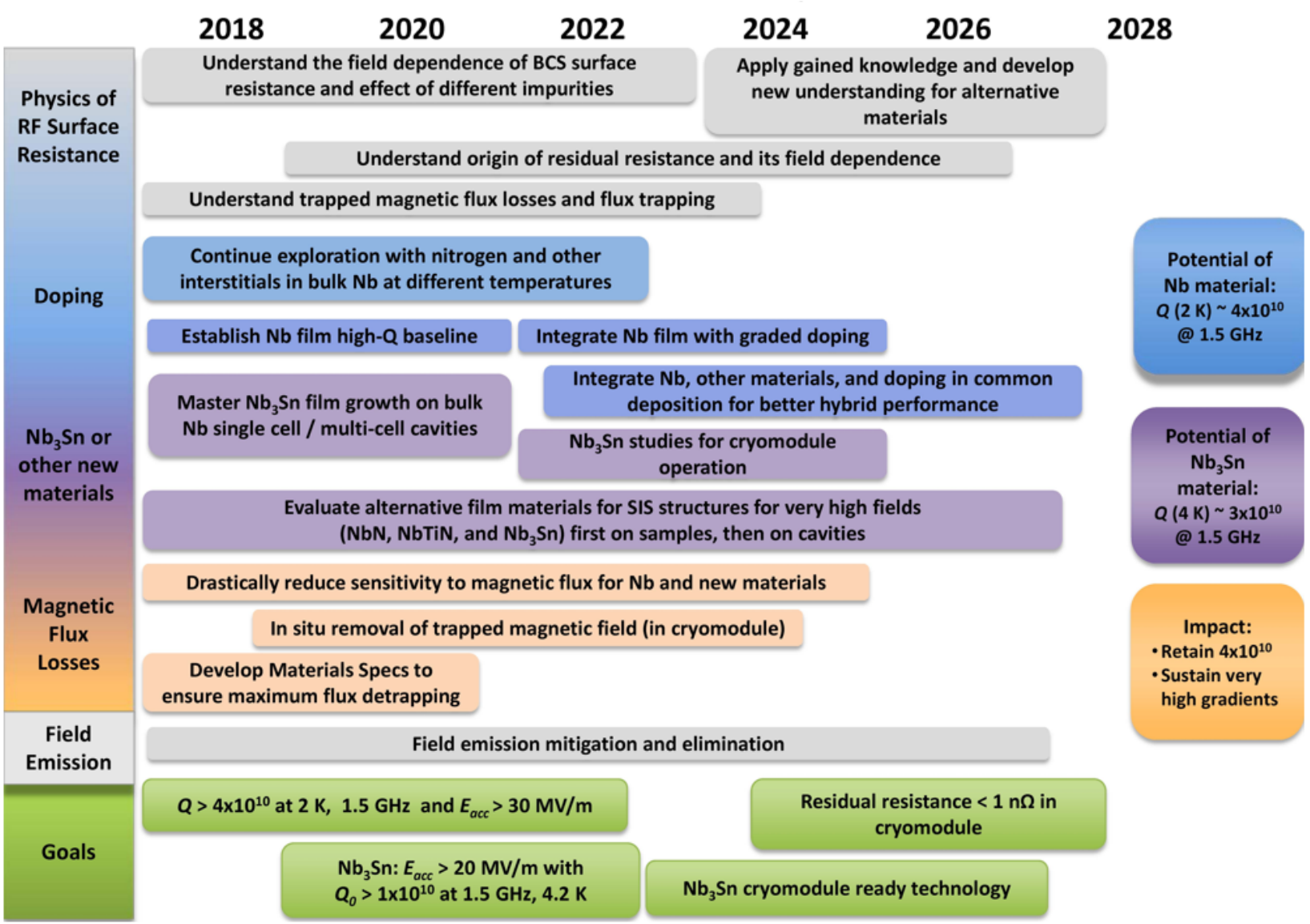
SRF R&D Roadmap



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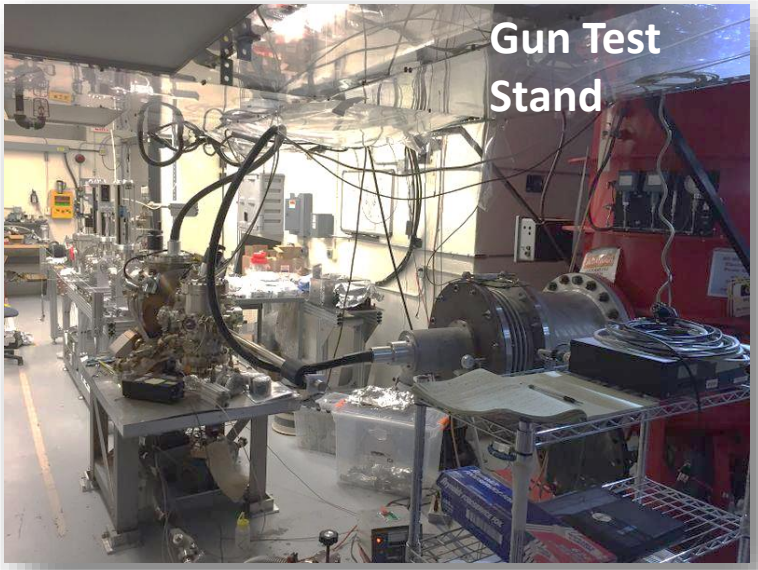
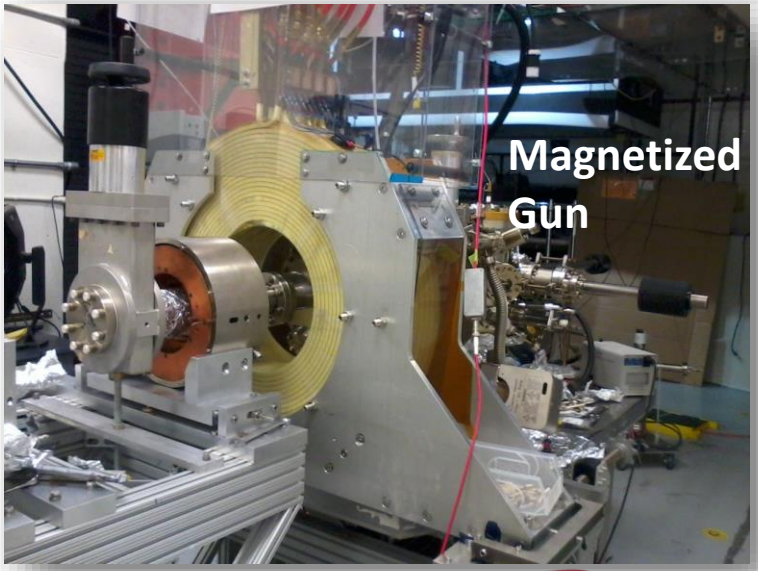
Source Group R&D

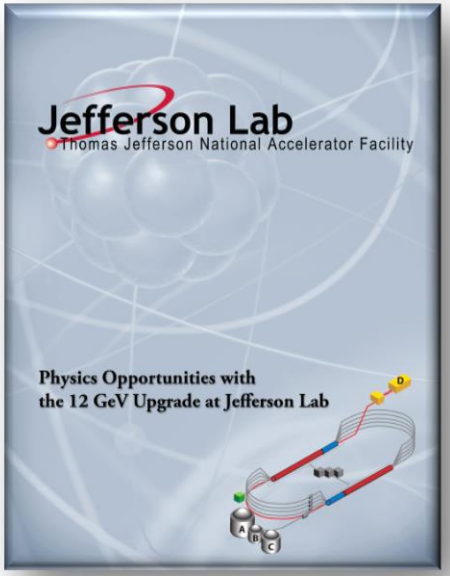
- Magnetized beam transport (LDRD, JLEIC)
- Bunchlength monitor and fast kicker using harmonically-resonant cavity, harmonic arbitrary waveform generator and amplifier (SBIR)
- Non-invasive electron beam polarimeter, RF-cavity to detect polarization (SBIR)
- High Polarization and High QE Photocathodes (SBIR)
- Improving vacuum to 10^{-13} Torr (funded via *Research and Development for Next Generation Nuclear Physics Accelerator Facilities*)
- Thermionic gun with RF time structure, for generating magnetized beam (SBIR, JLEIC)
- Powerful drive laser for photoguns, wavelength near 532 and/or 780 nm, with variable repetition rate, ~ 50ps laser pulses via gain-switching (SBIR)



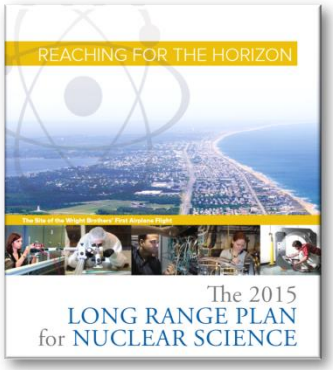


Looking Towards the Future - EIC

Decade of Experiments Approved
First 12 GeV Science Experiment Complete!

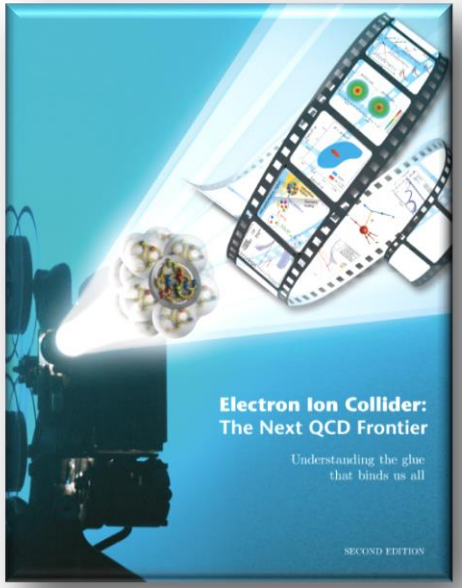


- **Confinement**
- **Hadron Structure**
- **Nuclear Structure and Astrophysics**
- **Fundamental Symmetries**



2015 NSAC Long Range Plan
Strong support for TJNAF program

Electron Ion Collider
The Next QCD Frontier



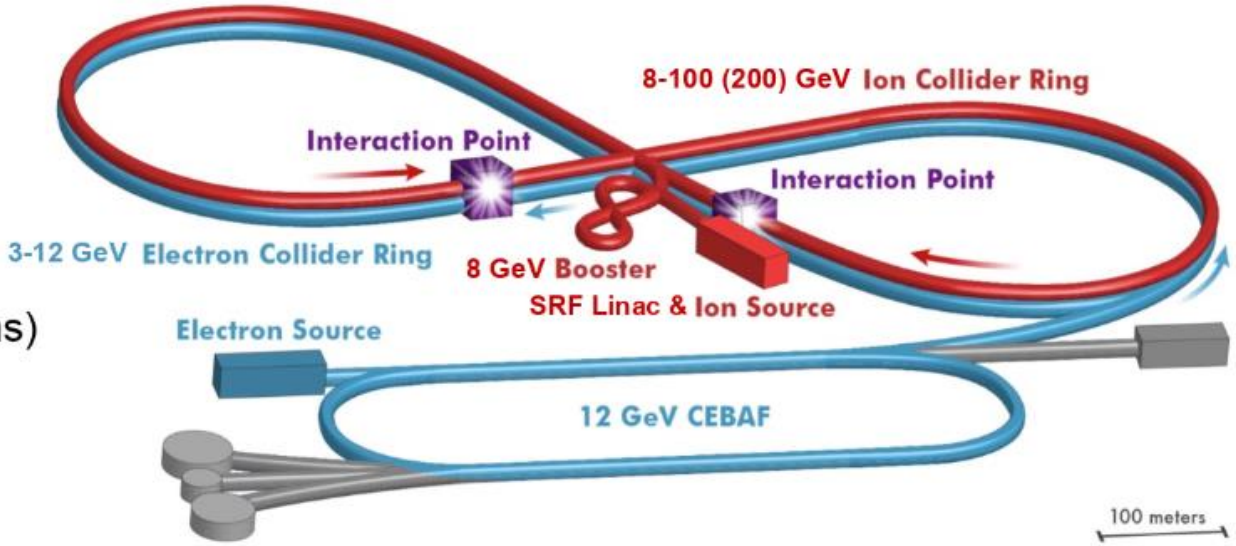
- **Role of Gluons in Nucleon and Nuclear Structure**

Exploring the Glue that Binds Us All

Jefferson Lab

Jefferson Lab Electron Ion Collider (JLEIC)

- Electron complex
  - CEBAF
  - Electron collider ring
- Ion complex
  - Ion source
  - SRF linac (285 MeV/u for protons)
  - Booster
  - Ion collider ring
- Up to two detectors at minimum background locations

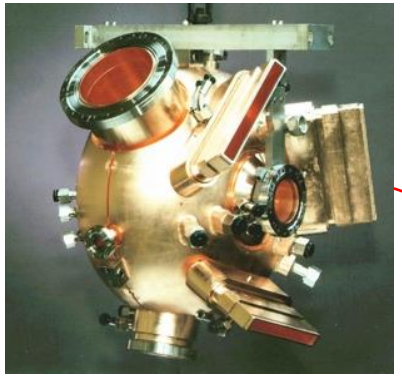


arXiv:1209.0757
arXiv:1504.07961

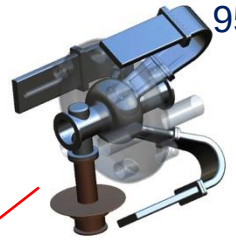
Completed by October 2018

May 17 parameter update:
https://eic.jlab.org/wiki/index.php/Main_Page

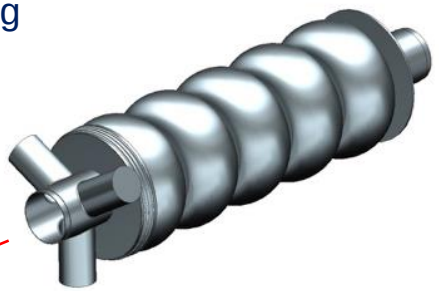
RF Structures for JLEIC



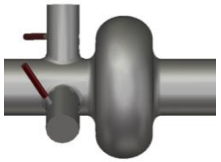
476.3 MHz electron-ring
(NCRF PEP-II)



952.6 MHz ion-ring
(SCRF)



952.6 MHz cooler
ERL (SCRF)



952.6 MHz booster
(SCRF)

952.6 MHz crab
(SCRF)

Harmonic Fast kicker
for cooling ring

JLEIC
Collider
Rings

i-SRF +
NCRF

Cooling

Crab

IP

e-RF

Crab

e-RF

Future IP

Booster

SRF Linac

Ion Source

Electron Injector

12 GeV CEBAF

Hall D

Halls A, B, C

Jefferson Lab

EIC R&D Topical Areas

- Polarized proton sources and polarimeters
- RF Structures
- Charge strippers for heavy ions
- Magnetized electron source development
- Electron Cooling
- Bunch formation development
- Feedback systems for beam stabilization
- Magnet R&D for:
  - Fast cycling 3-4 T Supercondcuting magnets
  - High field large aperture Interaction Region magnets
  - 20 m long solenoid magnets for e-cooling (1-2 T)

EIC Topics in Modeling and Simulation

- Study of non linear dynamics in the presence of beam beam interactions
  - Effect of beam beam in the presence of non-linearities
  - Effect of coherent and incoherent beam beam on the working point
  - Implications of utilizing a multi bunch scheme (gear changing) for synchronization
  - Effect of crab crossing in the presence of beam beam, synchro-betatron resonances
- Chromaticity compensation and dynamic aperture optimizations in the presence of higher order multipoles and magnet non-linearities
- Ion beam generation, acceleration, injection into the booster ring in the presence of space charge
- Estimation of electron cloud effects in the ion ring
- Design of a cooler for bunched beam cooling for the ion beam
- Development of a GPU accelerated code for beam cooling simulation

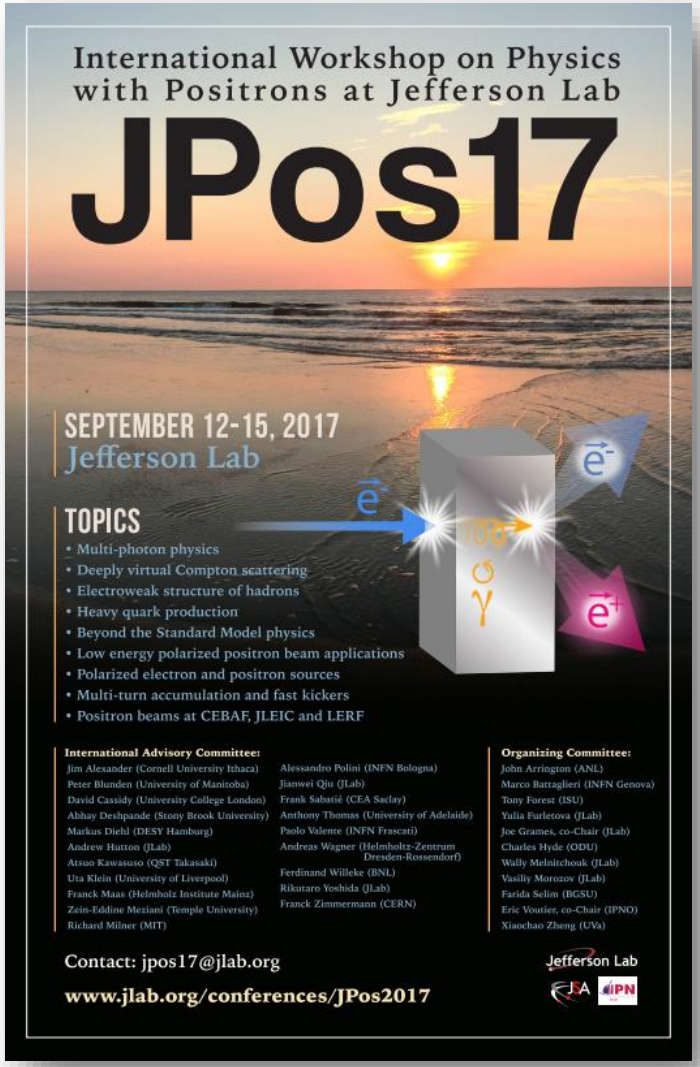
NP Next Generation Facilities R&D

- Funded through peer-reviewed proposals
- Next Generation Facilities R&D funded effort should be considered in context of the SBIR program
- Industrial partners benefit from working with laboratories to identify areas of overlap for potential SBIR R&D proposals

R&D Topic	Collaborators
Development and test of simulation tools for EIC beam-beam interaction	BNL, LBNL, MSU
Theoretical and experimental study of spin transparency mode in an EIC	BNL
Validation of EIC IR Magnet Parameters and Requirements Using Existing Magnet Results	LBNL, SLAC
Crab Cavity Operation in a Hadron Ring	ODU, BNL
Strong hadron cooling with micro-bunched electron beams	BNL, ANL, SLAC
High Gradient Actively Shielded Quadrupole	BNL, LBNL
High Bandwidth Beam Feedback Systems for a High Luminosity EIC	ANL
Development of innovative high-energy magnetized electron cooling for an EIC	ODU, FNAL, BNL

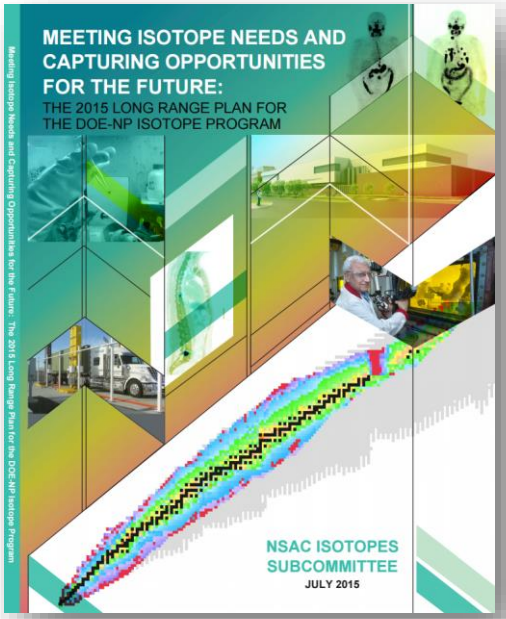
Positron R&D At Jefferson Lab

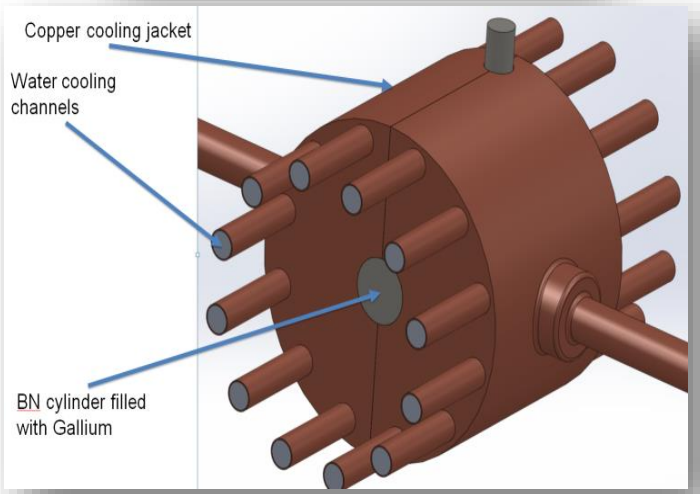
- Conducted a 4-day workshop to explore the scientific basis for polarized and unpolarized positron beams at JLAB in context of:
  - 12 GeV CEBAF
  - Jefferson Lab Electron Ion Collider (JLEIC)
  - Low Energy Applications
- An accelerator session dedicated to positron production and beam formation for each scenario was included in the scientific program.
- Collected the motivation and requirements for a positron physics experimental program
- Developing a Jefferson Lab Positron Physics white paper was a key goal of the meeting
- White paper expected to be released this summer
- Many R&D tracks to pursue



Isotope R&D at JLab

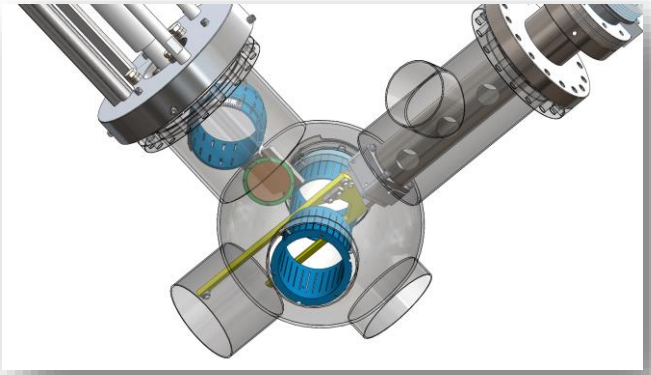
- High power electron accelerators are ideal for producing high-value isotopes
- Recently received funding to study the feasibility of producing Cu-67 via photo-production in Gallium
- High demand for Cu-67 as a high specific activity theranostic radionuclide. Therapy from 141 keV beta-emitter. Diagnostic from 185 keV photons for imaging.
- Two-year program just getting underway will use the LERF 40 MeV CW electron beam to study Cu-67
- Collaboration with Virginia Commonwealth University and New Mexico Tech
- Challenges:
  - High power target system development
  - Remote handling systems development
  - Yield modeling



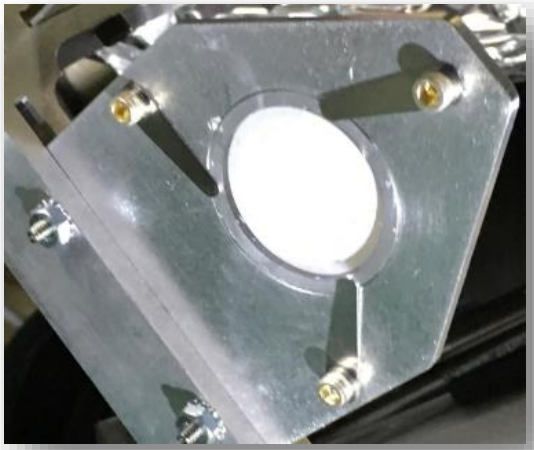


Diagnostics Development

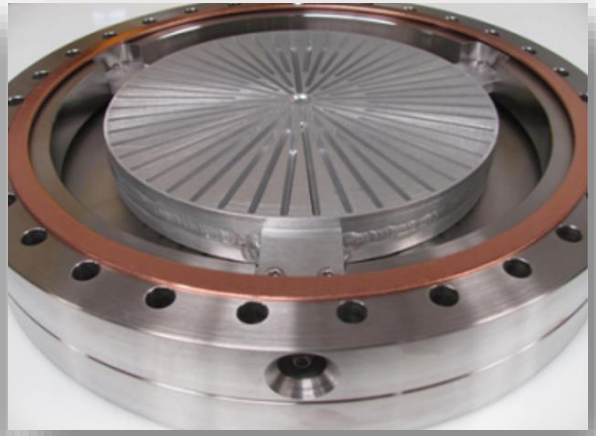
- BNNT Diagnostic Development
- Laser Wire Scanner
- Large Dynamic Range Transverse Diagnostics
- Large Dynamic Range Longitudinal Diagnostics
- Non-invasive Polarimetry



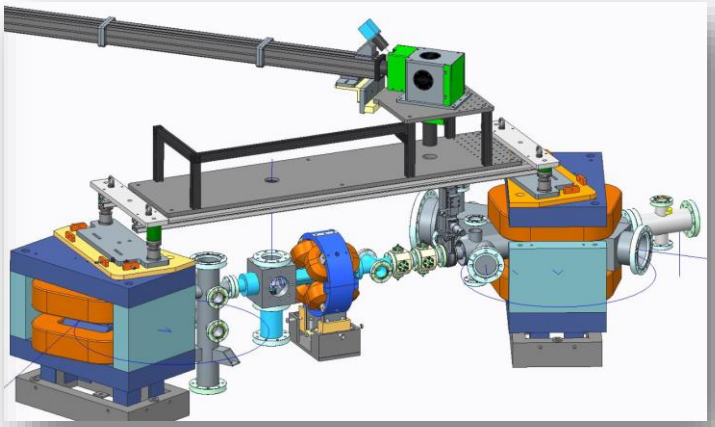
Large Dynamic Range Transverse Diagnostics



40 mm BNNT Viewer Flag



Polarimeter Cavity



Laser Wire Scanner Beam Diagnostic

BNNT PIONEERING REVOLUTIONARY MATERIALS

U.S. DEPARTMENT OF ENERGY | Office of Science

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

CORNELL UNIVERSITY FOUNDED A.D. 1865

LHeC

Muons, Inc. Innovation in Research

OLD DOMINION UNIVERSITY IDEA FUSION

NIOWAVE Accelerating Your Particles

SLAC NATIONAL ACCELERATOR LABORATORY

radiabeam TECHNOLOGIES

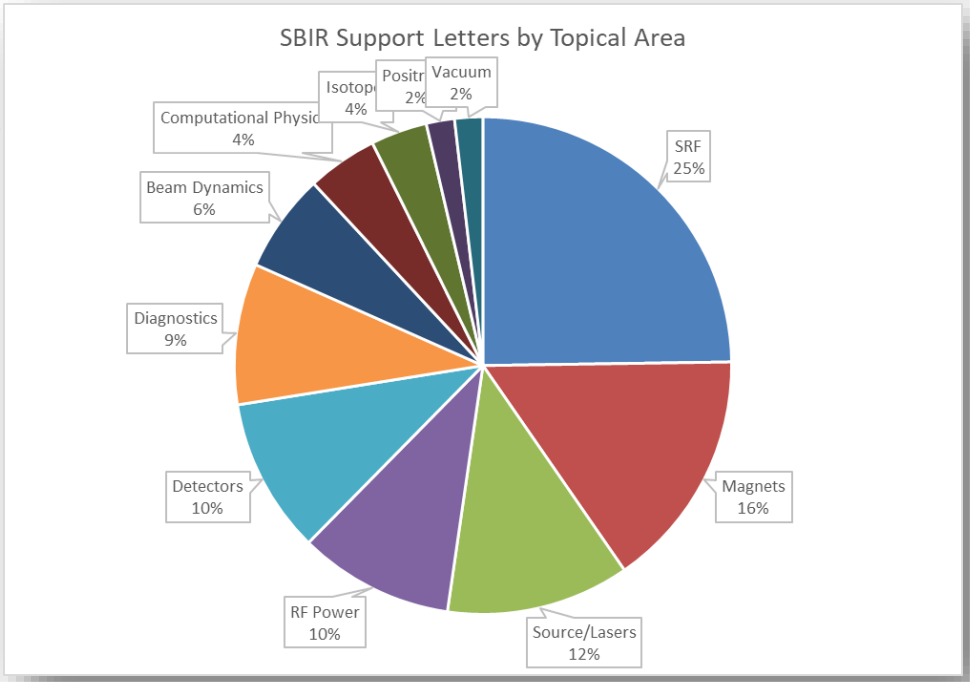
BTG Brookhaven Technology Group

ALPHACORE ANALOG & RF ELECTRONICS

JLAB SBIR Program Overview

- Jefferson Lab actively seeks opportunities with **Industrial Partners** to conduct research that is aligned with our Laboratory Agenda
- Laboratory staff work with the **SBIR Program Manager** to edit topical areas for the different Funding Opportunity Announcements

- Solicitations received from Industry cover a broad spectrum of potential opportunities
- We monitor awards for potential synergies with our Strategic Plan
- Interested in growing the program along R&D tracks consistent with the Laboratory Agenda
- Shoring up internal processes to streamline industry engagement with Jefferson Lab
- Planning an Industry Event this Fall



Jefferson Lab

Ongoing SBIR R&D at Jefferson Lab

Topic	Title	Industrial Partner	Phase
Magnets	Micro-aligned 1 Tesla solenoid for high-energy bunched-beam electron cooling	Accelerator Technology Corp.	I
Magnets	Fast Beam-Switching Kickers	Electrodynamic	I
Magnets	Field Compensation in Electron-Ion Collider Magnets with Passive Superconducting Shield	Particle Beam Lasers Inc.	I
Magnets	Novel Design for High Field, Large Aperture Quadrupoles for Electron-Ion Collider	Particle Beam Lasers Inc.	I
Polarized Source	Precise and ultra-stable laser polarization control for polarized electron beam generation	Raytum Photonics LLC	I
RF Power	High-Efficiency 952.6-MHz Power Amplifier for JLEIC	Green Mountain Radio Research Company	I
SRF	HOM Load Development	Muons Inc.	I
SRF	Boron Nitride Nanotube Vibration Damping for SRF Structures	BNNT LLC	I
SRF	Modeling Plasma Discharge Cleaning of SRF Cavities	Tech-X Corp.	I
Beam Physics	Accurate Spin Tracking on Modern Computer Architectures for Electron-Ion Colliders	RadiaSoft LLC	II
Diagnostics	Radiation Hard High Speed Camera System for Accelerator Beam Diagnostics	Alphacore Inc.	II
Diagnostics	Resonant Polarimetry and Magnetometry	Electrodynamic	II
Diagnostics	Robust Wire-Scanner for High Intensity Beam Profile Diagnostics	RadiaBeam	II
Lasers	High Power Extremely Narrow Linewidth Diode Laser for Polarizing 3He Target	Raytum Photonics LLC	II
Lasers	High Power, High Repetition Rate 700-850 nm Pulsed Laser	Q-Peak Inc.	II
RF Power	Magnetron 1497 MHz RF Power Source	Muons Inc.	II
Source	A Magnetized Injector for Ion Beam Cooling	Xelera Research LLC	II
SRF	Low RF loss DC conductive Ceramic for High Power Input Coupler Windows for SRF Cavities	Euclid Techlabs LLC	II
SRF	Acid-Free Electropolishing of SRF Cavities	Faraday Technologies	II

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Tech Center Coming Online

- **Located on 50 acres adjacent to Jefferson Lab**
- **Follows the proven business model at Virginia Tech Corporate Research Center (VTCRC)**
- **1 million square feet of research and office space**

Jefferson Lab

Summary

- **Jefferson Lab has multiple accelerator facilities spanning a broad range of parameter space that can be used to support R&D activities**
- **The SBIR program at Jlab has been growing over the last few years and covers a wide range of R&D topics**
- **The Laboratory is seeking to continue to grow the SBIR R&D program along topics that are consistent with the Lab Agenda and our Strategic Vision**

Thank you!