CPAD 2025 at Penn

Oct 7 – 10, 2025
Inn at Penn, University of Pennsylvania
US/Eastern timezone

HEP Facility Status and Needs

Gabriella Carini

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Facilities

- Future experiments will operate in demanding environments: temperature, magnetic field, radiation, low-background, low-power, …
- It is vital to develop and maintain critical facilities, centers and capabilities for the sharing of common knowledge and tools

Test Beams

Test beams with expanded capabilities

Irradiation

High-flux irradiation facilities using different particle types

Magnet

General-purpose high-field magnet platform

Noble Liquid

Noble Liquid platform for neutrino and other cryogenic experiments

Quantum Systems

General-purpose platform for quantum sensors

Low-Background

Assay and low-background facilities

Characterization

Platforms for fundamental properties studies

Calibration

Platform for calibration and systems design

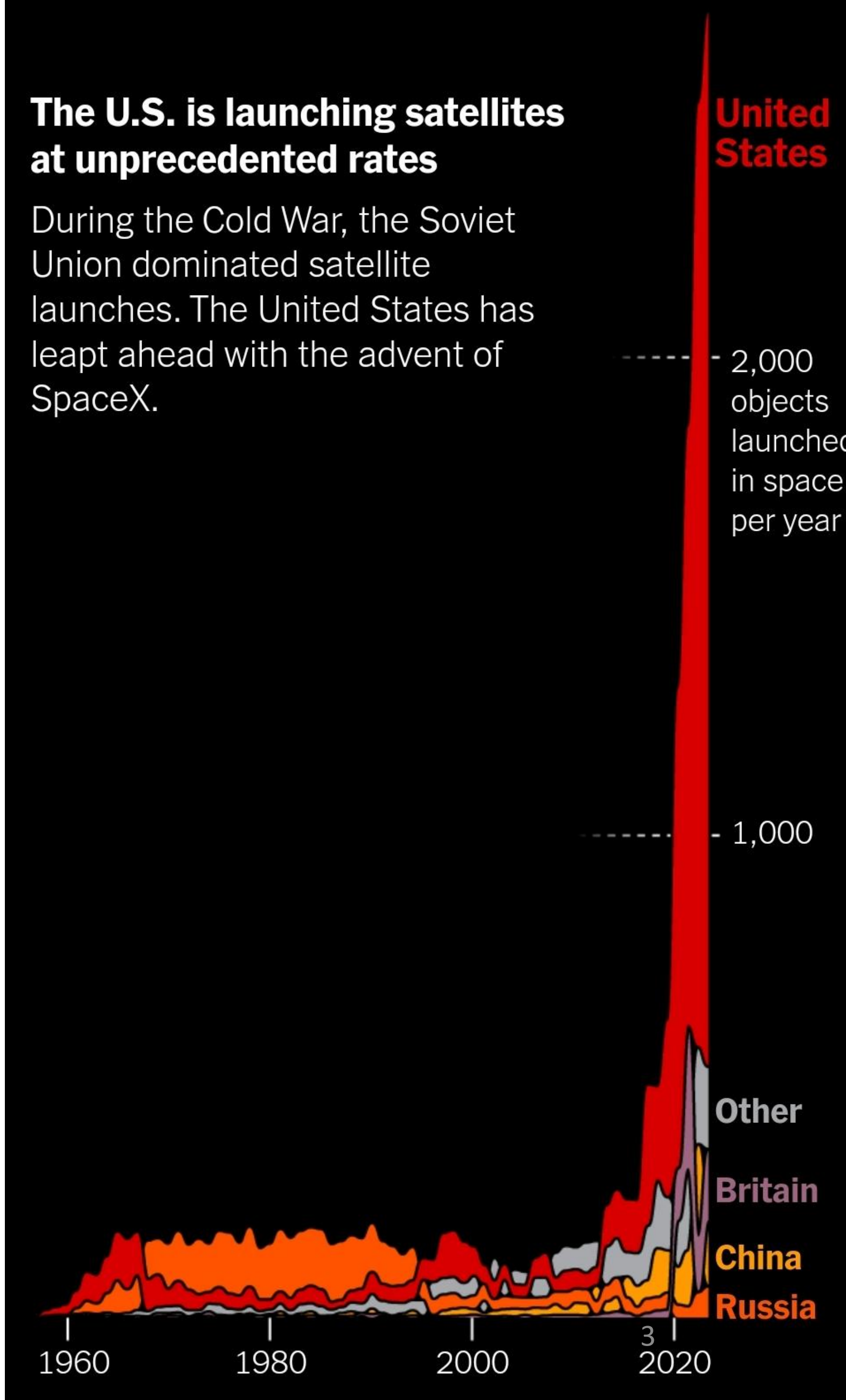
Testbeam Facilities – why?

Vital for the HEP (and NP) community

- How to test the performance of detectors (systems and components) under operational conditions?
- How to calibrate detector response?
- How to evaluate new technologies?

Synergies with other applications (e.g., instrumentation for space)

[Snowmass White Paper: "Test Beam and Irradiation Facilities"](https://arxiv.org/abs/2203.09944)
https://arxiv.org/abs/2203.09944



The U.S. is launching satellites at unprecedented rates

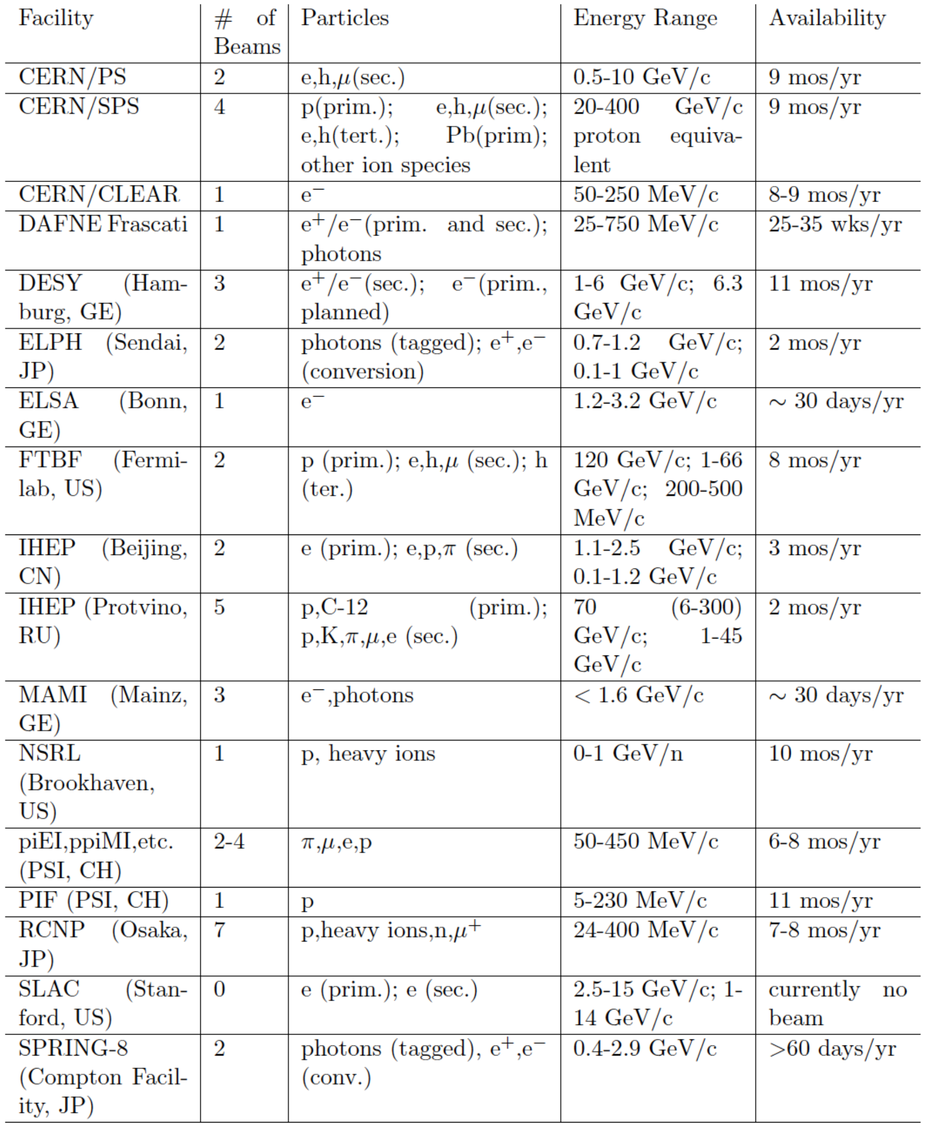
During the Cold War, the Soviet Union dominated satellite launches. The United States has leapt ahead with the advent of SpaceX.

Testbeam Facilities – what?

Broad range of energies and particle species with precise and robust control.

Accessibility!

Broad range of energies and

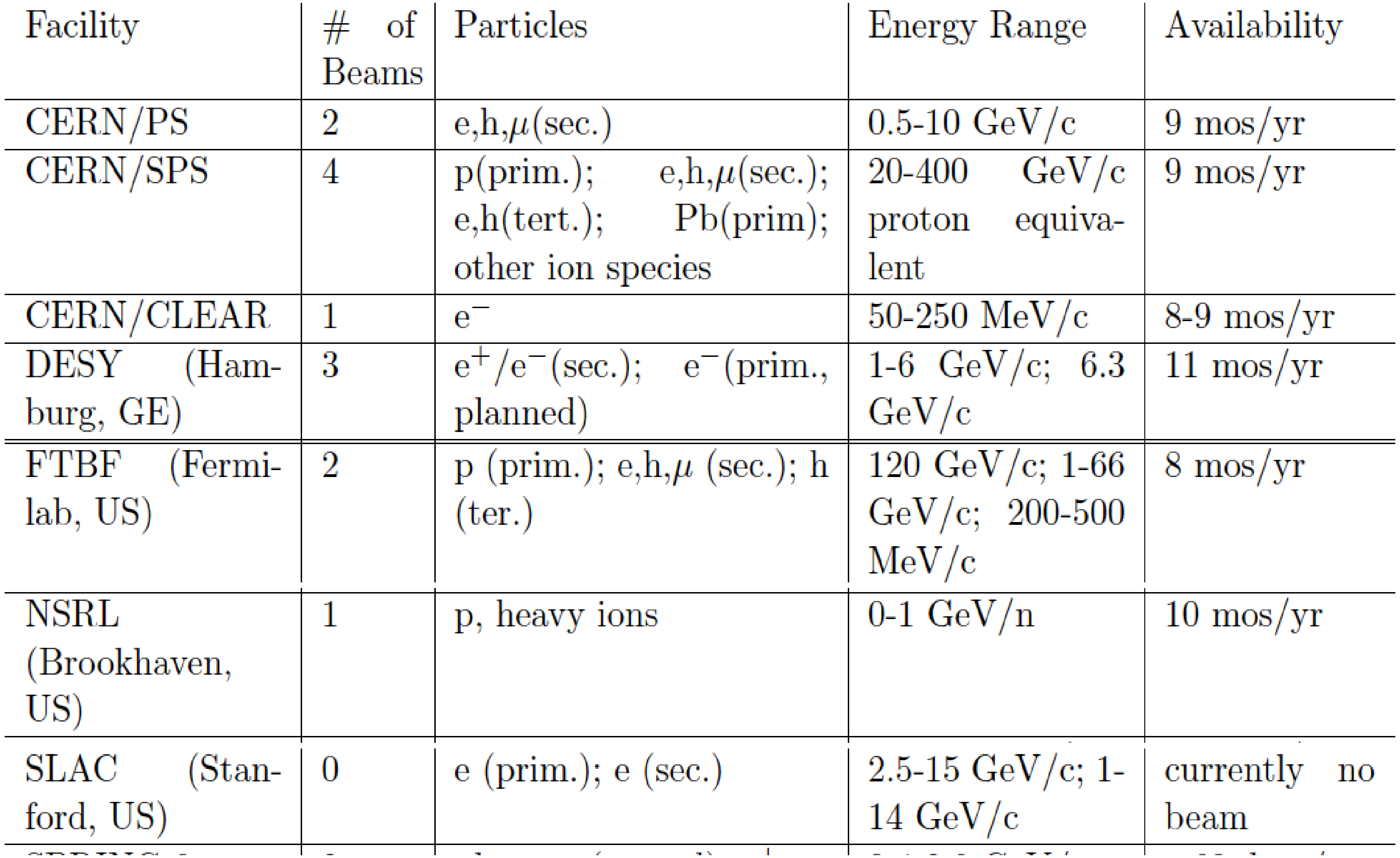


Facility	# of Beams	Particles	Energy Range	Availability
CERN/PS	2	e,h,μ(sec.)	0.5-10 GeV/c	9 mos/yr
CERN/SPS	4	p(prim.); e,h,μ(sec.); e,h(tert.); Pb(prim); other ion species	20-400 GeV/c proton equivalent	9 mos/yr
CERN/CLEAR	1	e^-	50-250 MeV/c	8-9 mos/yr
DAFNE Frascati	1	e^+/e^-(prim. and sec.); photons	25-750 MeV/c	25-35 wks/yr
DESY (Hamburg, GE)	3	e^+/e^-(sec.); e^-(prim., planned)	1-6 GeV/c; 6.3 GeV/c	11 mos/yr
ELPH (Sendai, JP)	2	photons (tagged); e^+,e^- (conversion)	0.7-1.2 GeV/c; 0.1-1 GeV/c	2 mos/yr
ELSA (Bonn, GE)	1	e^-	1.2-3.2 GeV/c	$\sim$ 30 days/yr
FTBF (Fermilab, US)	2	p (prim.); e,h,μ (sec.); h (ter.)	120 GeV/c; 1-66 GeV/c; 200-500 MeV/c	8 mos/yr
IHEP (Beijing, CN)	2	e (prim.); e,p,π (sec.)	1.1-2.5 GeV/c; 0.1-1.2 GeV/c	3 mos/yr
IHEP (Protvino, RU)	5	p,C-12 (prim.); p,K,π,μ,e (sec.)	70 (6-300) GeV/c; 1-45 GeV/c	2 mos/yr
MAMI (Mainz, GE)	3	e^-,photons	$<$ 1.6 GeV/c	$\sim$ 30 days/yr
NSRL (Brookhaven, US)	1	p, heavy ions	0-1 GeV/n	10 mos/yr
piEI,ppiMI,etc. (PSI, CH)	2-4	π,μ,e,p	50-450 MeV/c	6-8 mos/yr
PIF (PSI, CH)	1	p	5-230 MeV/c	11 mos/yr
RCNP (Osaka, JP)	7	p,heavy ions,n,μ^+	24-400 MeV/c	7-8 mos/yr
SLAC (Stanford, US)	0	e (prim.); e (sec.)	2.5-15 GeV/c; 1-14 GeV/c	currently no beam
SPRING-8 (Compton Facility, JP)	2	photons (tagged), e^+,e^- (conv.)	0.4-2.9 GeV/c	>60 days/yr

Table 1: Overview of existing test beam facilities

Snowmass White Paper: "Test Beam and Irradiation Facilities"
https://arxiv.org/abs/2203.09944

Testbeam Facilities – landscape



Facility	# of Beams	Particles	Energy Range	Availability
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DESY (Hamburg, GE)	3	e^+/e^-(sec.); e^-(prim., planned)	1-6 GeV/c; 6.3 GeV/c	11 mos/yr
FTBF (Fermilab, US)	2	p (prim.); e,h,μ (sec.); h (ter.)	120 GeV/c; 1-66 GeV/c; 200-500 MeV/c	8 mos/yr
NSRL (Brookhaven, US)	1	p, heavy ions	0-1 GeV/n	10 mos/yr
SLAC (Stanford, US)	0	e (prim.); e (sec.)	2.5-15 GeV/c; 1-14 GeV/c	currently no beam

shutdown for HL-LHC upgrade

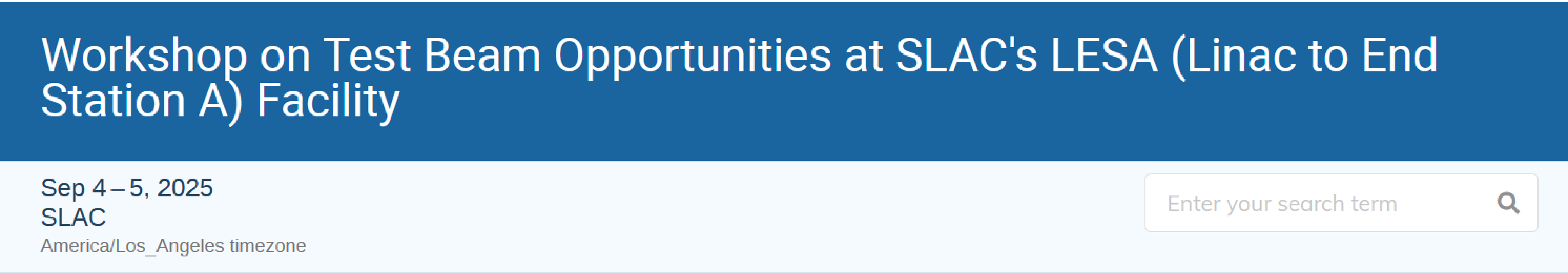
shutdown for PETRA IV/DESY IV

shutdown for LBNF/PIPII

Most relevant facilities for US community

Testbeam Facilities – future?

- Several opportunities at BNL, DESY, FNAL, SLAC
- Precision timing capabilities



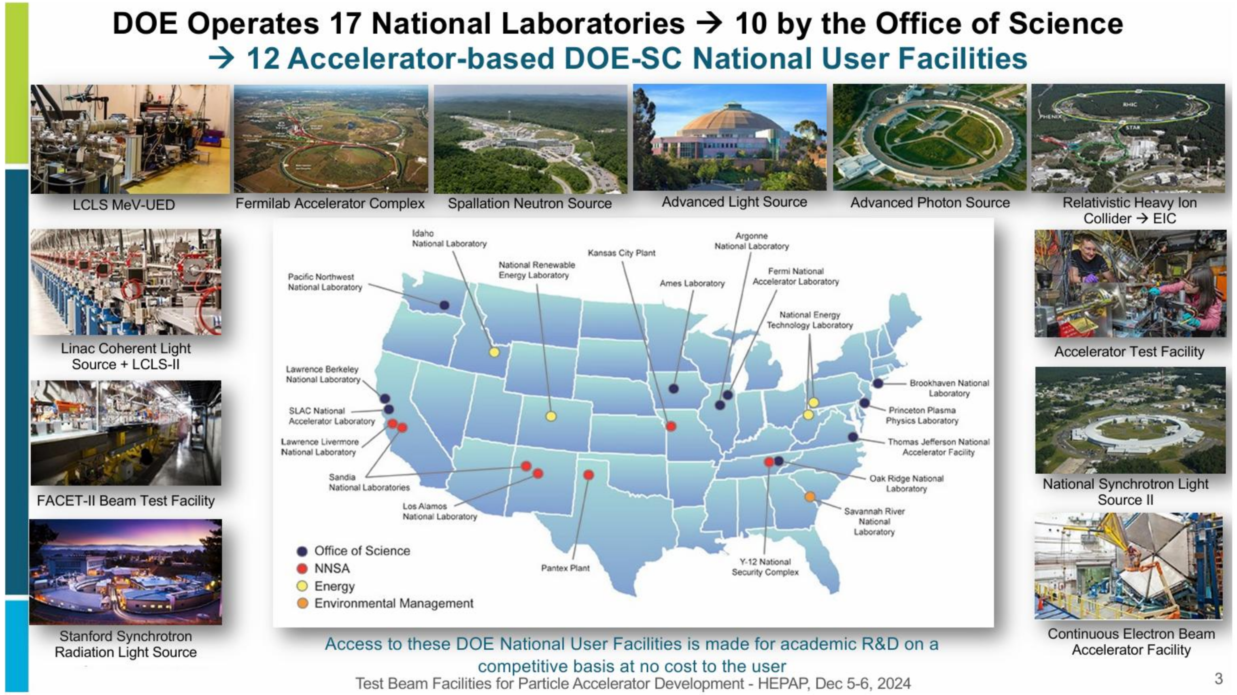
Workshop on Test Beam Opportunities at SLAC's LESA (Linac to End Station A) Facility

Sep 4 – 5, 2025
SLAC
America/Los_Angeles timezone

The LESA beamline, which is currently nearing completion, will deliver low current 8 GeV electron beams from the LCLS-II-HE superconducting linac to End Station A. Commissioning is planned to begin in late 2025 and continue during the first 2 months of SC Linac beam availability in 2027.

…planned dedicated lasers at the injector, to be commissioned around 2028.

Test Beam Facilities for Particle Accelerator Development in the US



DOE Operates 17 National Laboratories → 10 by the Office of Science
→ 12 Accelerator-based DOE-SC National User Facilities

LCLS MeV-UED
Fermilab Accelerator Complex
Spallation Neutron Source
Advanced Light Source
Advanced Photon Source
Relativistic Heavy Ion Collider → EIC
Linac Coherent Light Source + LCLS-II
FACET-II Beam Test Facility
Stanford Synchrotron Radiation Light Source
Accelerator Test Facility
National Synchrotron Light Source II
Continuous Electron Beam Accelerator Facility

Access to these DOE National User Facilities is made for academic R&D on a competitive basis at no cost to the user

Test Beam Facilities for Particle Accelerator Development - HEPAP, Dec 5-6, 2024 3

- Maintain and improve existing accelerator capabilities
- Develop new capabilities
- Design next-generation facilities
- Train a new generation of accelerator specialists

Maintaining and updating the DOE Accelerator Complex requires test beams!

Building National User Facilities requires developing the accelerator technology and underlying science

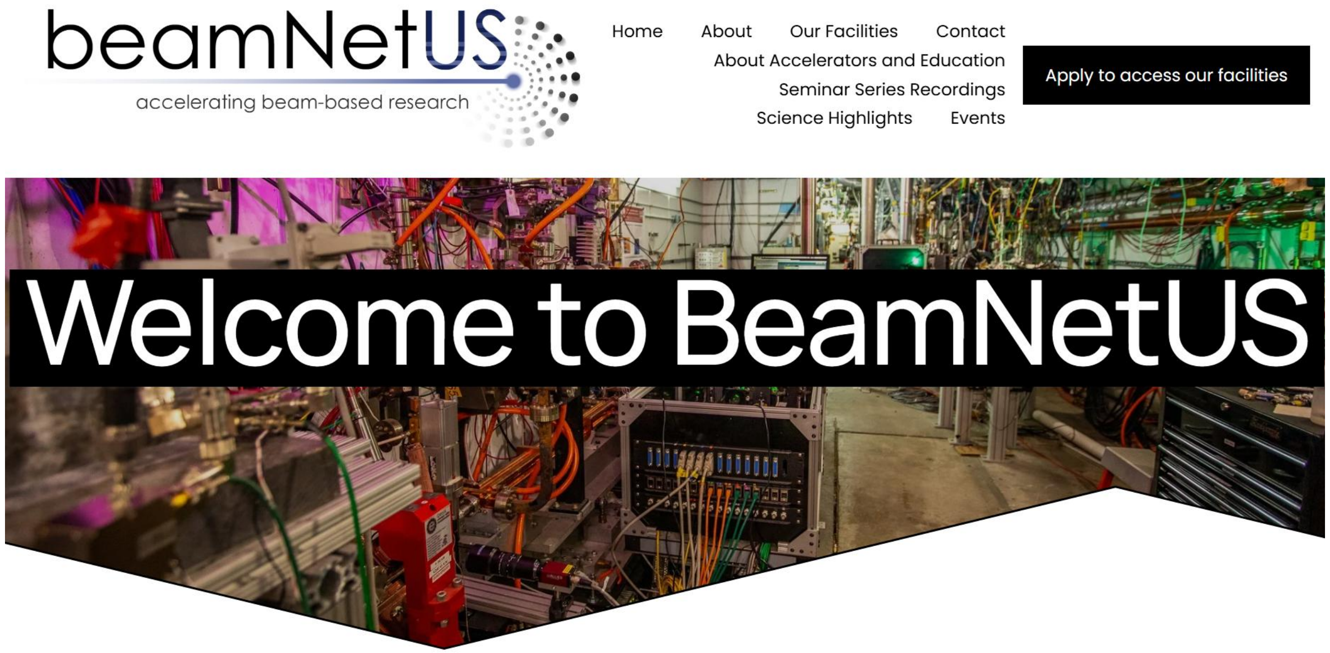
Over 50 specialized accelerator R&D Capabilities exist across the DOE Office of Science complex

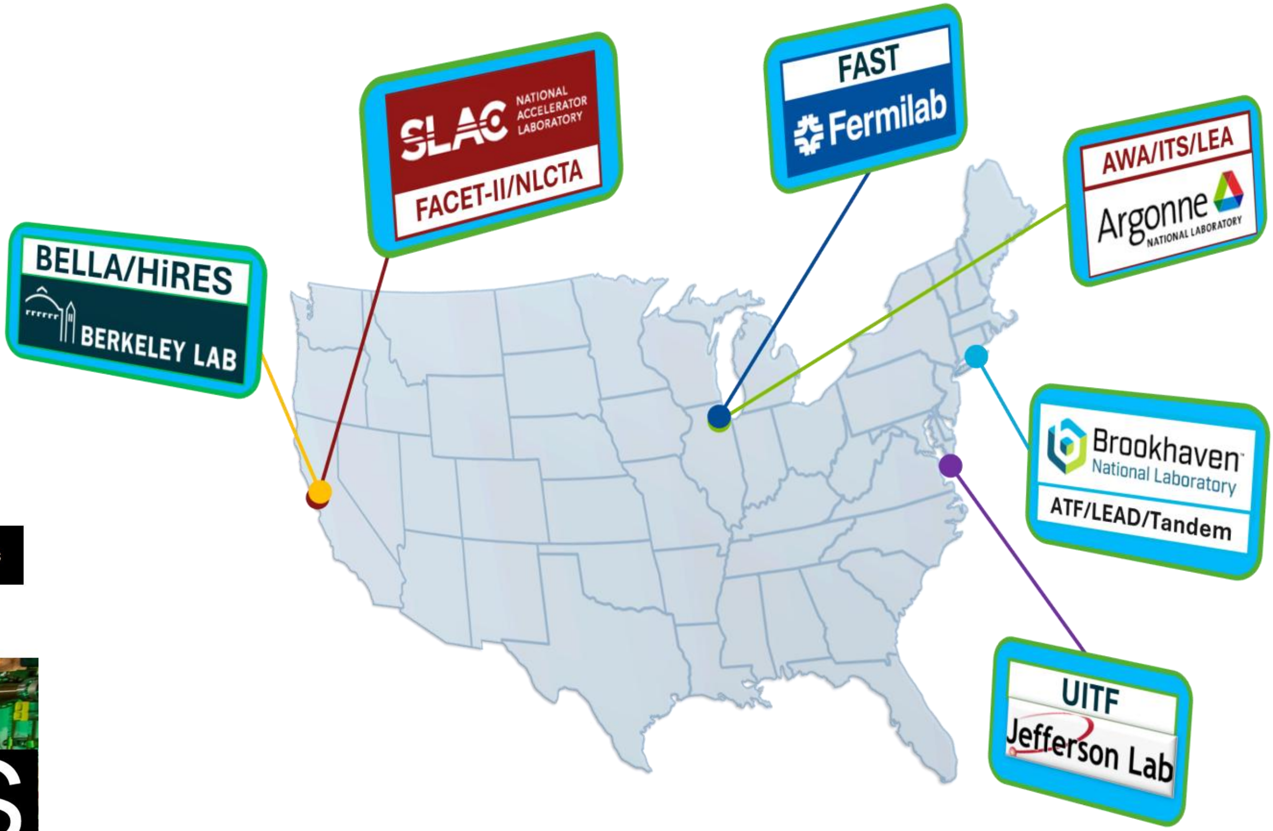
5

Test Beam Facilities for Particle Accelerator Development - HEPAP, Dec 5-6, 2024

Test Beam Facilities for Particle Accelerator Development in the US

BeamNetUS is a network of facilities united in a common mission to advance accelerator research and applications of accelerator technology through improving awareness and access to these unique facilities.





These facilities provide complementary capabilities enabling research in plasma physics, beam physics, material science, radiofrequency sources and structures, nuclear physics and electron beam irradiation.

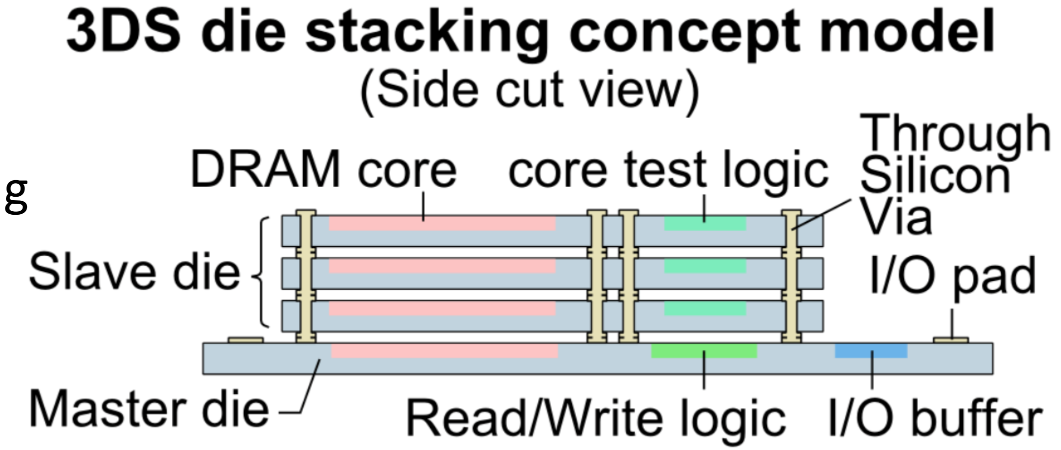
https://www.beamnetus.org/

Irradiation Facilities – applications

Study and characterize damaging effects that detectors (systems and components) will experience when in operation (HEP and NP):

- Sensors (silicon and more) bulk and surface damage
- Scintillators (crystal and plastic)
- Materials for integration and packaging
- Electronics including live Single Event Effect [SEE] testing

System In a Package (SIP)



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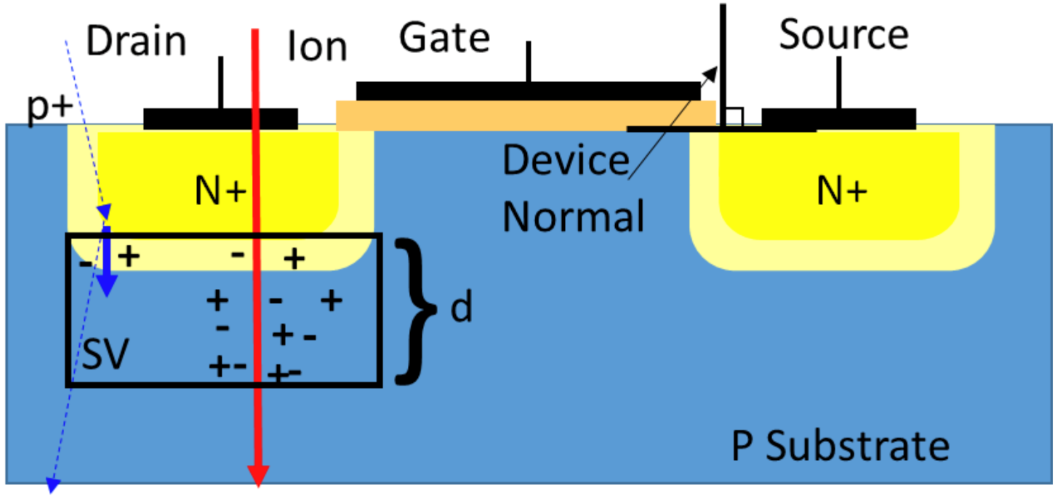


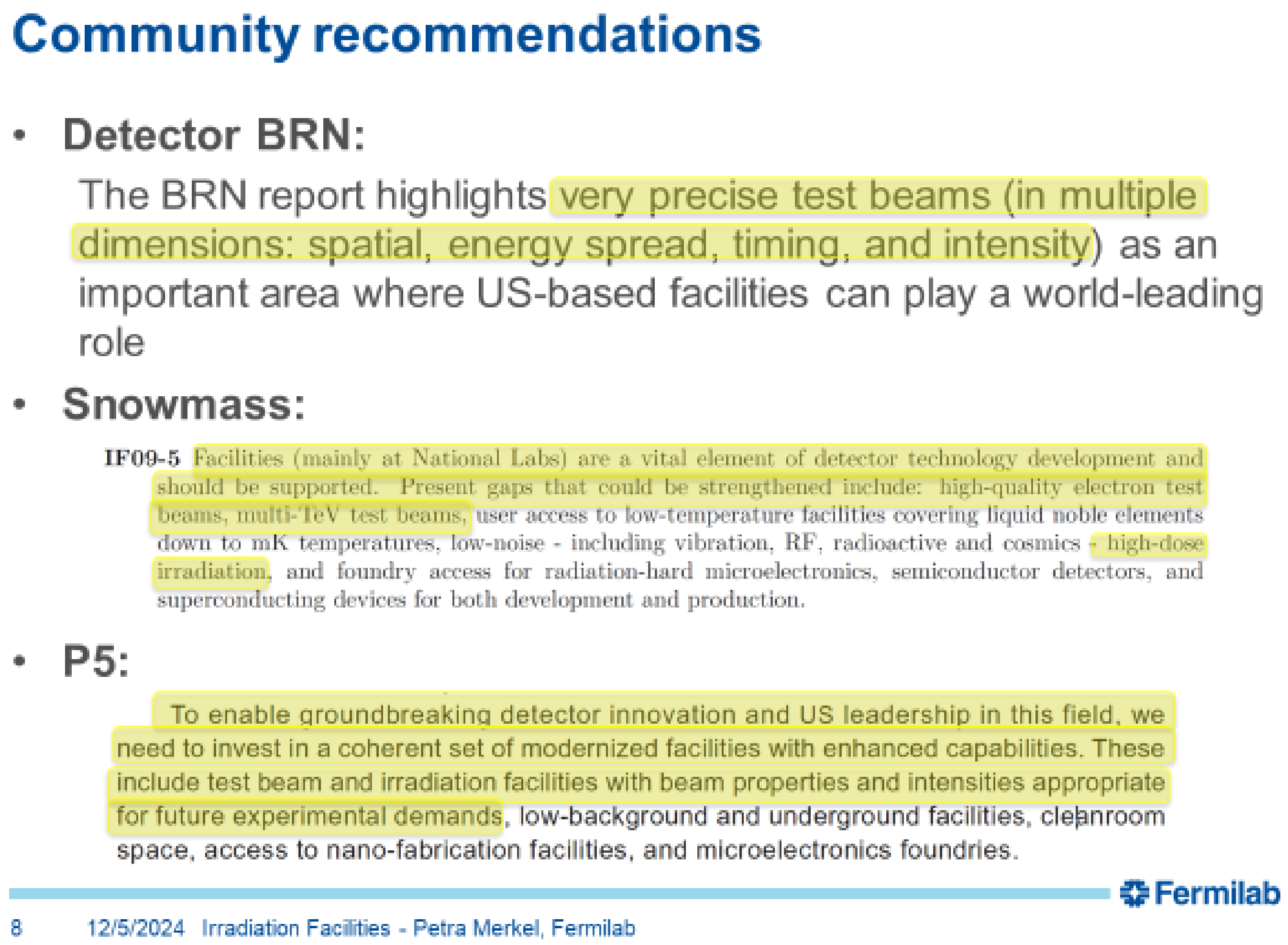
Single Event Effects

Modern, more complex integrated circuits are multilayered and require higher energy beams to test (since only higher energy particles can penetrate the chips).

main workhorse e.g. for HL-LHC

Facility	Particles	Energy Range	SEE Testing
BASE (LBNL, US)	p, n, heavy ions	1-55 MeV	yes
CERN (Geneva, CH)	p	24 GeV	yes
CNL (UC Davis, US)	p, n	1-67.5 MeV	yes
CYCLONE (Louvain, BE)	p, heavy ions	14.4-65 MeV	yes?
FACET-II (SLAC, US)	e^-	10 GeV	n/a
GIF (Sandia, US)	n/gamma, heavy ions	1.17-1.33 MeV	yes
HFIR (ORNL, US)	gamma	-	yes
ITA (FNAL, US)	p	400 MeV	yes
KAZ (Karlsruhe, GE)	p	23 MeV	yes?
LANSCE (LANL, US)	p	800 MeV	no
NSRL (BNL, US)	p, heavy ions	50-2500 MeV	yes
PIF (TRIUMF, CA)	p	5-500 MeV	no
RINSC (Rhode Island, US)	n	-	no
SEUTF (BNL, US)	heavy ions	1-350 MeV	n/a
TRIGA (Ljubljana, SI)	n	few MeV	no

Irradiation Facilities – future?



Community recommendations

- **Detector BRN:**

  The BRN report highlights very precise test beams (in multiple dimensions: spatial, energy spread, timing, and intensity) as an important area where US-based facilities can play a world-leading role

- **Snowmass:**

  IF09-5 Facilities (mainly at National Labs) are a vital element of detector technology development and should be supported. Present gaps that could be strengthened include: high-quality electron test beams, multi-TeV test beams, user access to low-temperature facilities covering liquid noble elements down to mK temperatures, low-noise - including vibration, RF, radioactive and cosmics - high-dose irradiation, and foundry access for radiation-hard microelectronics, semiconductor detectors, and superconducting devices for both development and production.

- **P5:**

  To enable groundbreaking detector innovation and US leadership in this field, we need to invest in a coherent set of modernized facilities with enhanced capabilities. These include test beam and irradiation facilities with beam properties and intensities appropriate for future experimental demands, low-background and underground facilities, cleanroom space, access to nano-fabrication facilities, and microelectronics foundries.

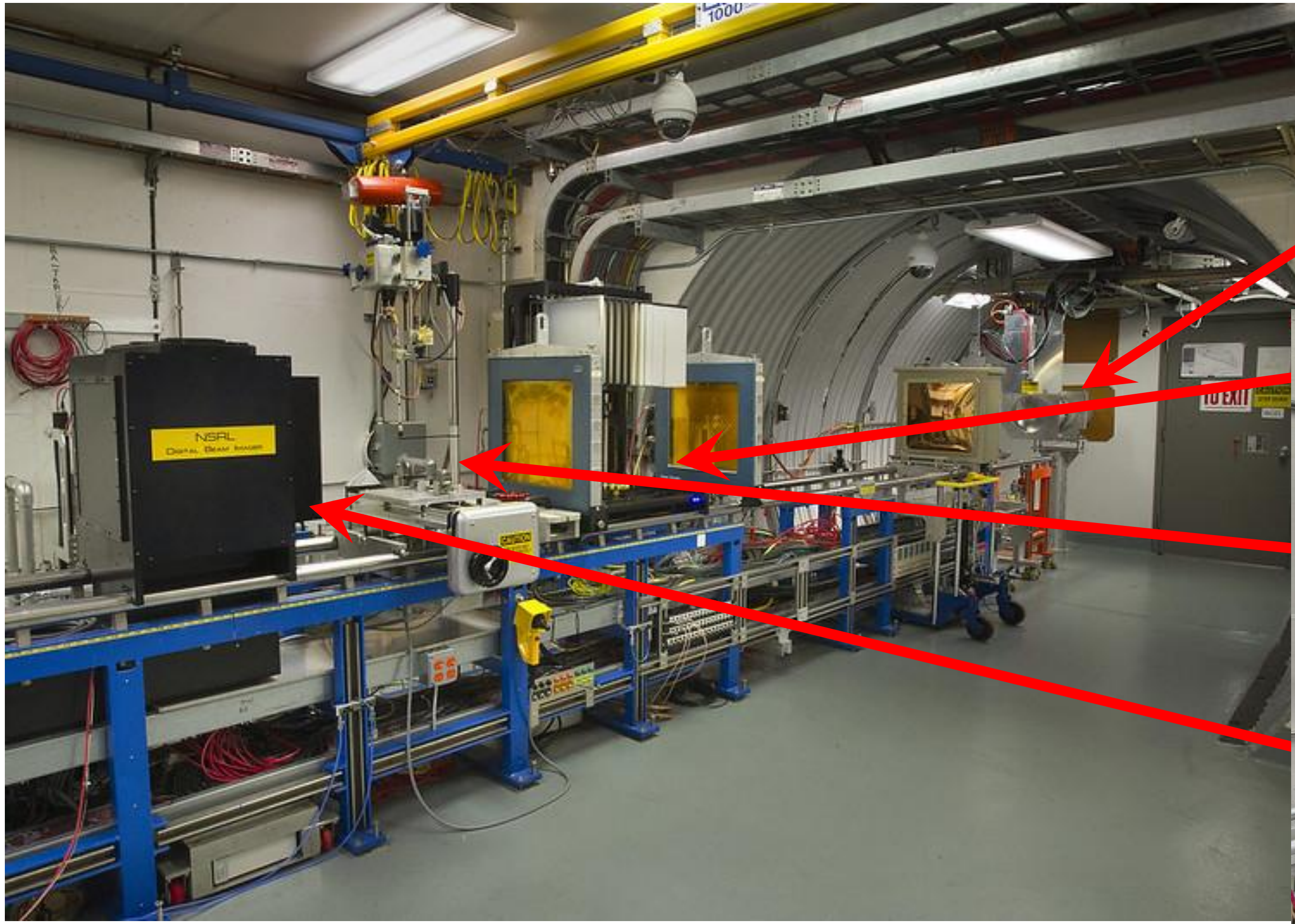
Fermilab

8 12/5/2024 Irradiation Facilities - Petra Merkel, Fermilab

Future collider-based experiments:

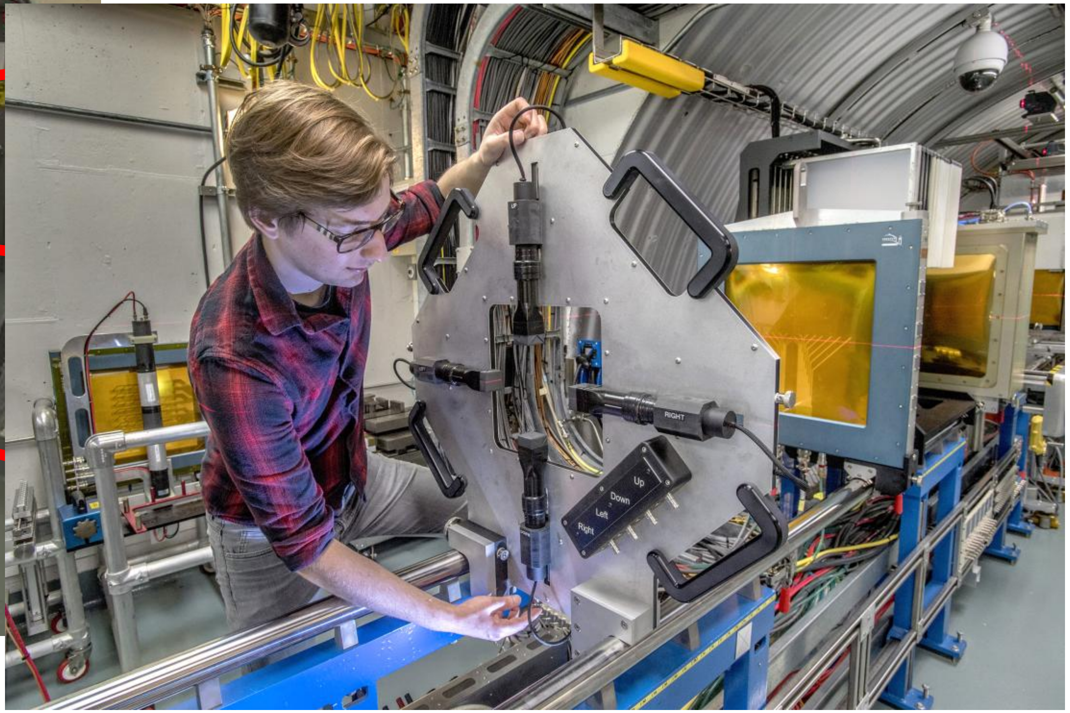
- Unprecedented radiation exposures
- Rates and integrated doses (two orders of magnitude greater than systems operating today)
- Will require high-dose-rate environments for accelerated testing
- Activation of the detector materials may require robotics handling
- Benefit from expertise with accelerator and other fields (FES)

Irradiation Facilities – synergies & accessibility



End station for testing

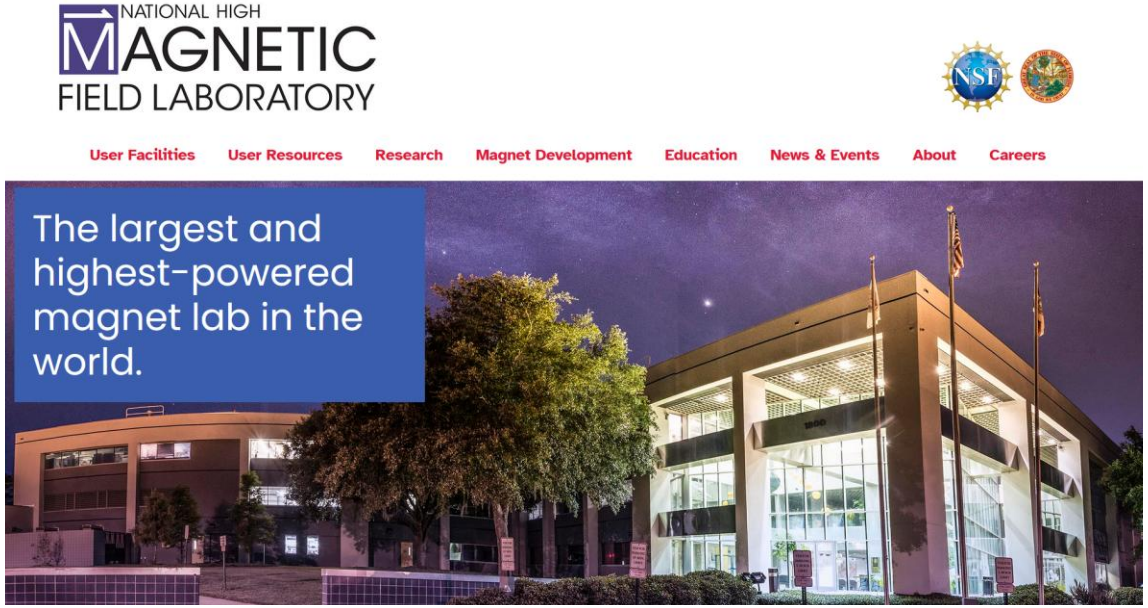
- Beam enters from particle accelerator



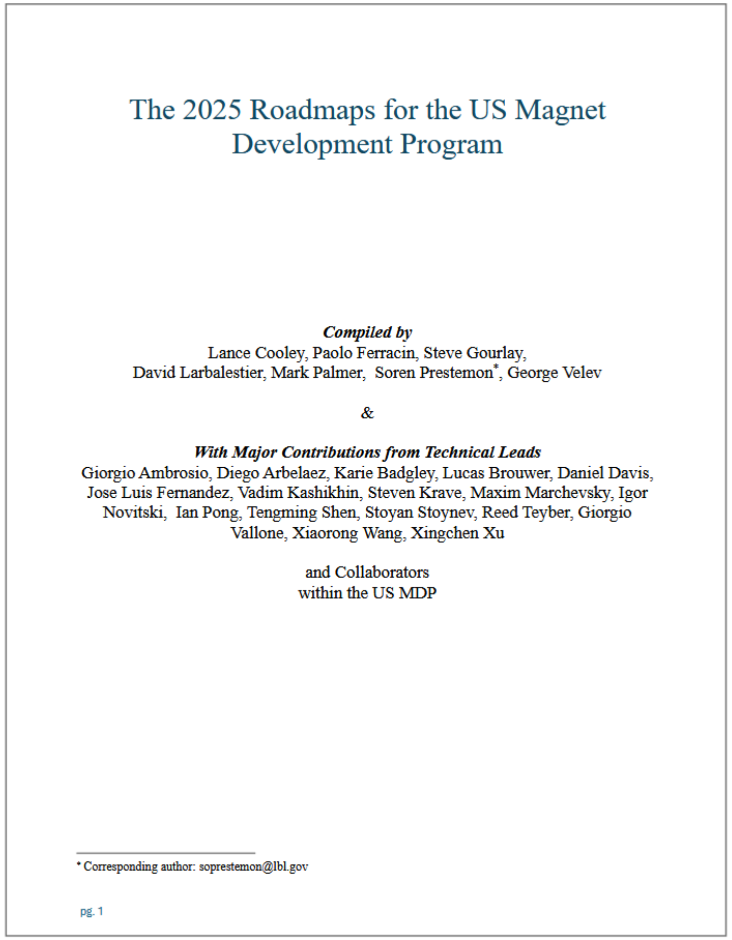
- >50 ion species
- From 1 MeV p to 337 MeV Au

Magnets – meeting future needs

‘A major element of MDP since its inception is the investment in ***core technologies****, including* ***advanced modeling****, the development of* ***unique diagnostics and instrumentation****, the exploration of novel means to* ***enhance training rate in LTS magnets****, and* ***materials research*** *to support industry advances in conductor performance. These investments continue, with increased focus on integrating* ***advances into magnet prototypes****. As an example, for HTS magnets we expect* ***diagnostics and instrumentation*** *to evolve from tools of discovery and understanding, to* ***tools integral to the magnet operation and protection****.’*



The largest and highest-powered magnet lab in the world.



The 2025 Roadmaps for the US Magnet Development Program

Compiled by
Lance Cooley, Paolo Ferracin, Steve Gourlay,
David Larbalestier, Mark Palmer, Soren Prestemon*, George Velev

&

With Major Contributions from Technical Leads
Giorgio Ambrosio, Diego Arbelaez, Karie Badgley, Lucas Brouwer, Daniel Davis, Jose Luis Fernandez, Vadim Kashikhin, Steven Krave, Maxim Marchevsky, Igor Novitski, Ian Pong, Tengming Shen, Stoyan Stoynev, Reed Teyber, Giorgio Vallone, Xiaorong Wang, Xingchen Xu

and Collaborators
within the US MDP

---

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pg. 1

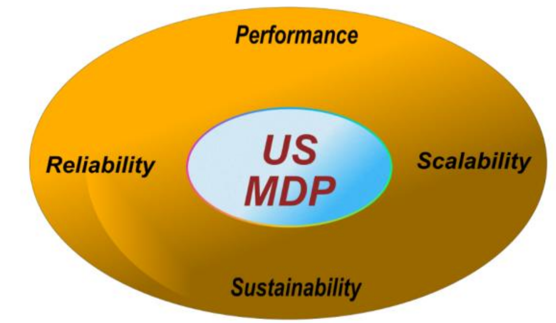
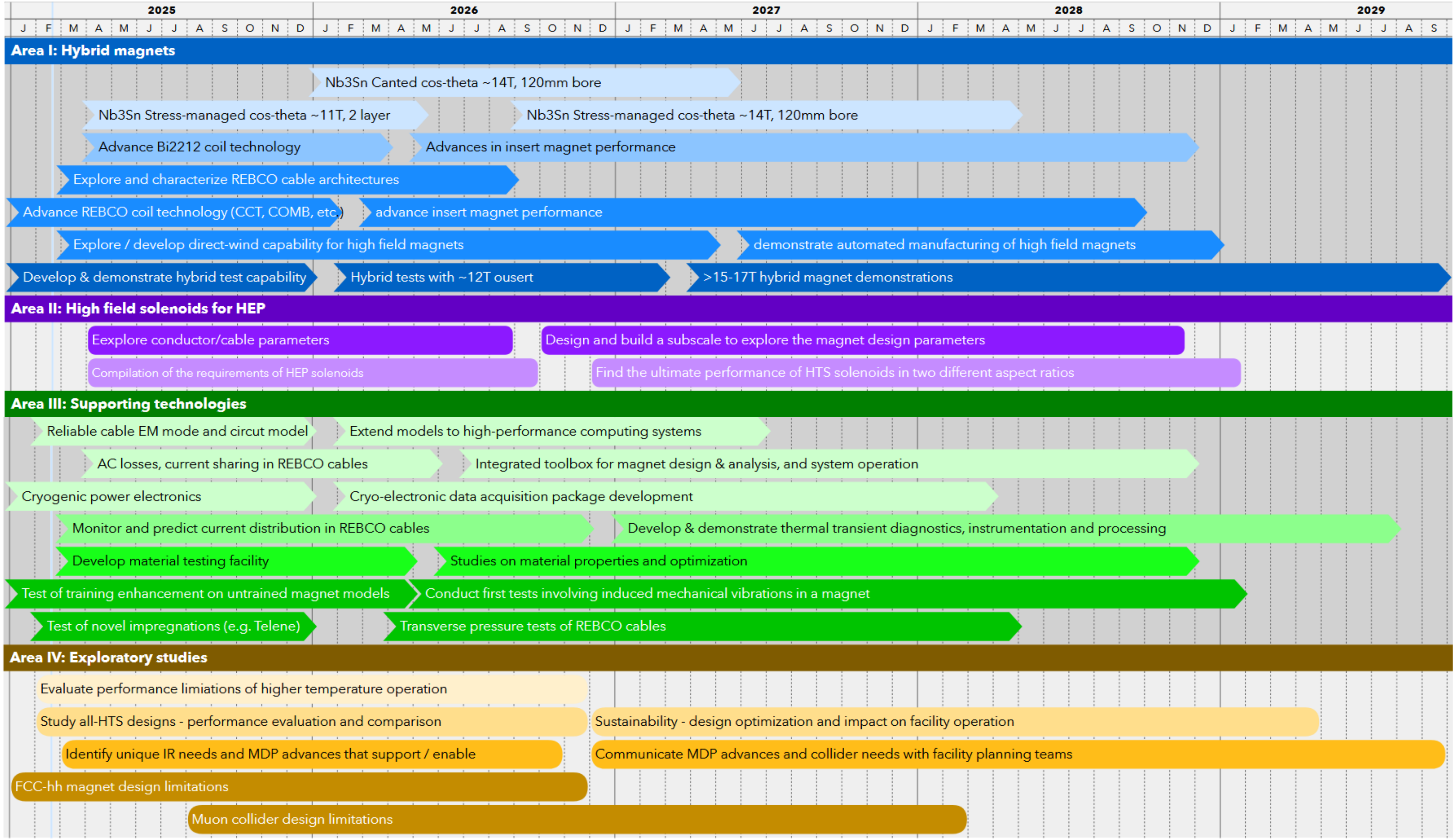


Figure 4. Technology developments are critical to enable major advances in performance, reliability, and scalability of magnet technology, and to address sustainability concerns of future colliders.



Area I: Hybrid magnets

Nb3Sn Canted cos-theta ~14T, 120mm bore

Nb3Sn Stress-managed cos-theta ~11T, 2 layer

Nb3Sn Stress-managed cos-theta ~14T, 120mm bore

Advance Bi2212 coil technology

Advances in insert magnet performance

Explore and characterize REBCO cable architectures

Advance REBCO coil technology (CCT, COMB, etc.)

advance insert magnet performance

Explore / develop direct-wind capability for high field magnets

demonstrate automated manufacturing of high field magnets

Develop & demonstrate hybrid test capability

Hybrid tests with ~12T ousert

>15-17T hybrid magnet demonstrations

Area II: High field solenoids for HEP

Eexplore conductor/cable parameters

Design and build a subscale to explore the magnet design parameters

Compilation of the requirements of HEP solenoids

Find the ultimate performance of HTS solenoids in two different aspect ratios

Area III: Supporting technologies

Reliable cable EM mode and circut model

Extend models to high-performance computing systems

AC losses, current sharing in REBCO cables

Integrated toolbox for magnet design & analysis, and system operation

Cryogenic power electronics

Cryo-electronic data acquisition package development

Monitor and predict current distribution in REBCO cables

Develop & demonstrate thermal transient diagnostics, instrumentation and processing

Develop material testing facility

Studies on material properties and optimization

Test of training enhancement on untrained magnet models

Conduct first tests involving induced mechanical vibrations in a magnet

Test of novel impregnations (e.g. Telene)

Transverse pressure tests of REBCO cables

Area IV: Exploratory studies

Evaluate performance limiations of higher temperature operation

Study all-HTS designs - performance evaluation and comparison

Sustainability - design optimization and impact on facility operation

Identify unique IR needs and MDP advances that support / enable

Communicate MDP advances and collider needs with facility planning teams

FCC-hh magnet design limitations

Muon collider design limitations

Figure 6. Roadmap for the program for the 2025-2030 period, aligned with the research Areas described above.

Magnets – synergies and collaborations

NASEM Report: The Current Status and Future Direction of High-Magnetic-Field Science and Technology in the United States (2024) DOI 10.17226/27830

“A concerted effort from multiple agencies will bring both scientific and commercial advantages for the United States. **Without higher magnetic fields**, we will not have compact fusion devices, next-generation MRI, high-field nuclear magnetic resonance (NMR), or the **muon collider**.”

2020 UPDATE OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS Technical Report CERN-ESU-015

“The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for **high-field superconducting magnets**, including **high-temperature superconductors**.”

Noble liquids

Platforms for neutrino and other cryogenic experiments

Cryogenic User Facilities for R&D on Noble Liquid Detectors and Low Temperature Devices

A White Paper for Snowmass 2021

March 15, 2022

arXiv:2203.06146v2 [physics.ins-det] 14 Mar 2022

Y. Li, C. Zhang, M. Diwan, X. Qian, S. Martynenko, C. Thorn, J. Stewart, S. Kettell
Brookhaven National Laboratory
M. Hollister, A. Chou, J. Theilacker
Fermi National Accelerator Laboratory
S. Golwala
California Institute of Technology
R. Khatiwada
Illinois Institute of Technology
N. A. Kurinsky
Stanford Linear Accelerator Center
C. Bromberg
Michigan State University
V. Paolone
University of Pittsburgh

Abstract

Cryogenic test facilities are critical infrastructure for physics experiments in a variety of fields, perhaps most notably for particle detection with noble liquid detectors, low-temperature device development, and quantum information research. However, considerable investment and technical knowledge are required to construct and operate such facilities. This white paper discusses proposals for user facilities aimed at broadening the availability of testing capabilities for the scientific community.

1 Introduction

Cryogenic test facilities are critical infrastructure for physics experiments in a variety of fields. Some notable examples include studying noble liquid properties for particle detection, low-temperature device development, and research in quantum information. However, the required technical knowledge and infrastructure capacity, including the cost of setting up and operating the test facilities, can place these studies out of reach of many individual group laboratories. As such, these research areas would greatly benefit from cryogenic user facilities with suitable access for university and laboratory research groups. This white paper discusses concepts of such facilities, using the liquid argon test facilities and millikelvin test

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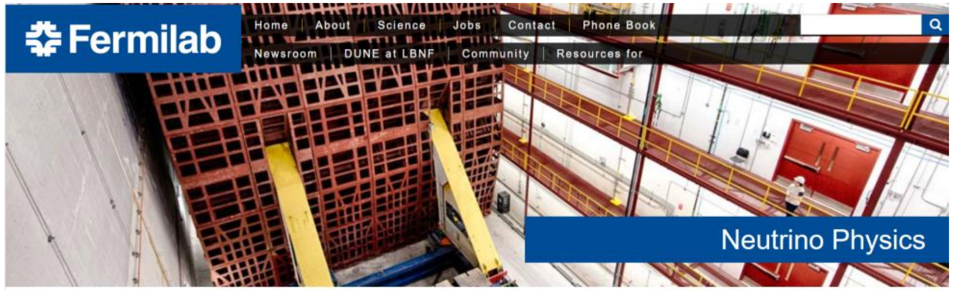
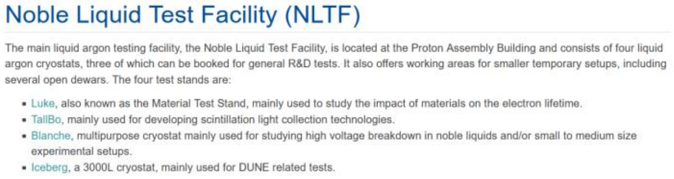



NP02 vertical drift cryostat and associated cryogenic system in CERN's EHN1 test beam hall @CERN

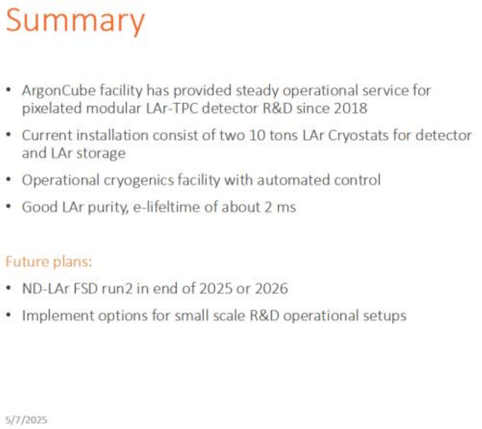


Noble Liquid Test Facility (NLTF)

The main liquid argon testing facility, the Noble Liquid Test Facility, is located at the Proton Assembly Building and consists of four liquid argon cryostats, three of which can be booked for general R&D tests. It also offers working areas for smaller temporary setups, including several open dewars. The four test stands are:

- Luke, also known as the Material Test Stand, mainly used to study the impact of materials on the electron lifetime.
- TallBo, mainly used for developing scintillation light collection technologies.
- Blanche, multipurpose cryostat mainly used for studying high voltage breakdown in noble liquids and/or small to medium size experimental setups.
- Iceberg, a 3000L cryostat, mainly used for DUNE related tests.


BNL 260-L LAr User Facility



Summary

- ArgonCube facility has provided steady operational service for pixelated modular LAr-TPC detector R&D since 2018
- Current installation consist of two 10 tons LAr Cryostats for detector and LAr storage
- Operational cryogenics facility with automated control
- Good LAr purity, e-lifetime of about 2 ms

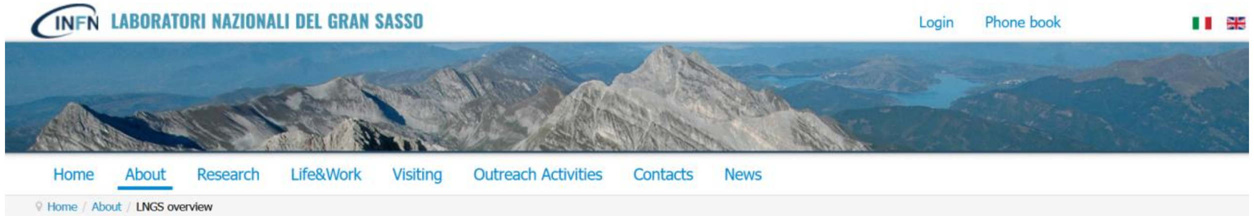
Future plans:

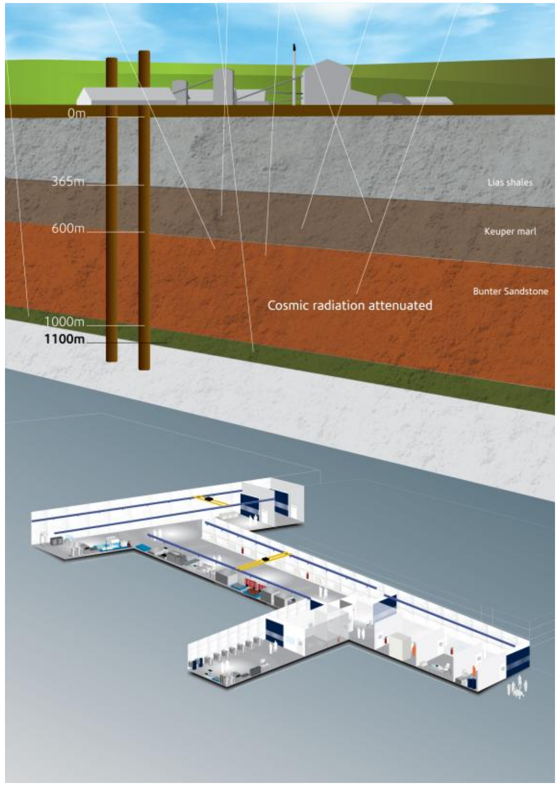
- ND-LAr FSD run2 in end of 2025 or 2026
- Implement options for small scale R&D operational setups

5/7/2025

ArgonCube test facility at Uni Bern
for testing pixelated LAr-TPCs
DRD2 meeting, 7 May 2025
Saba Parsa, University of Bern

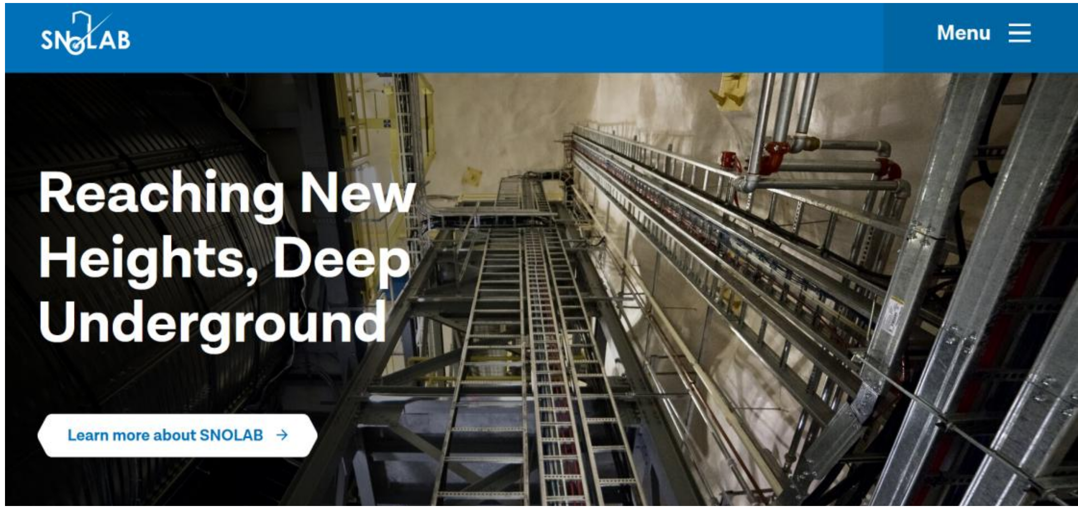
Low background

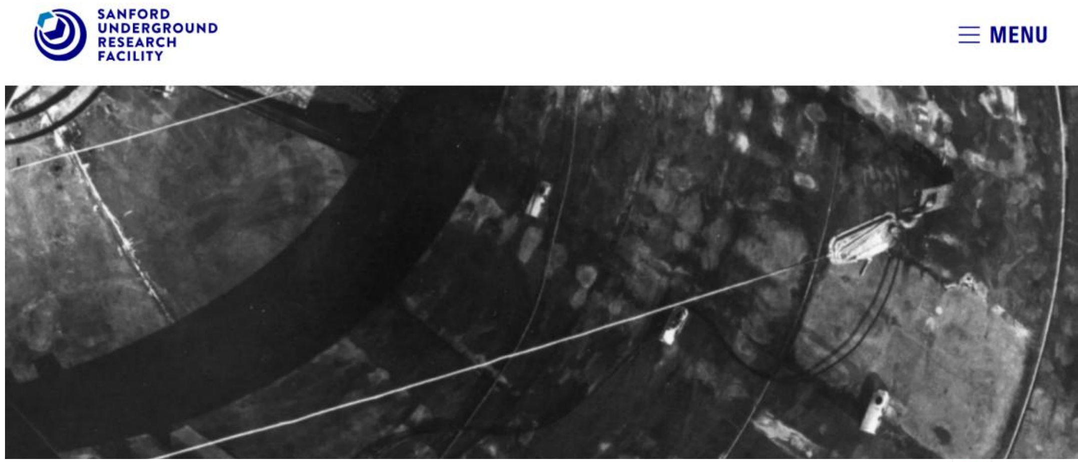




LNGS overview

UKRI Science and Technology Facilities Council | Boulby Underground Laboratory

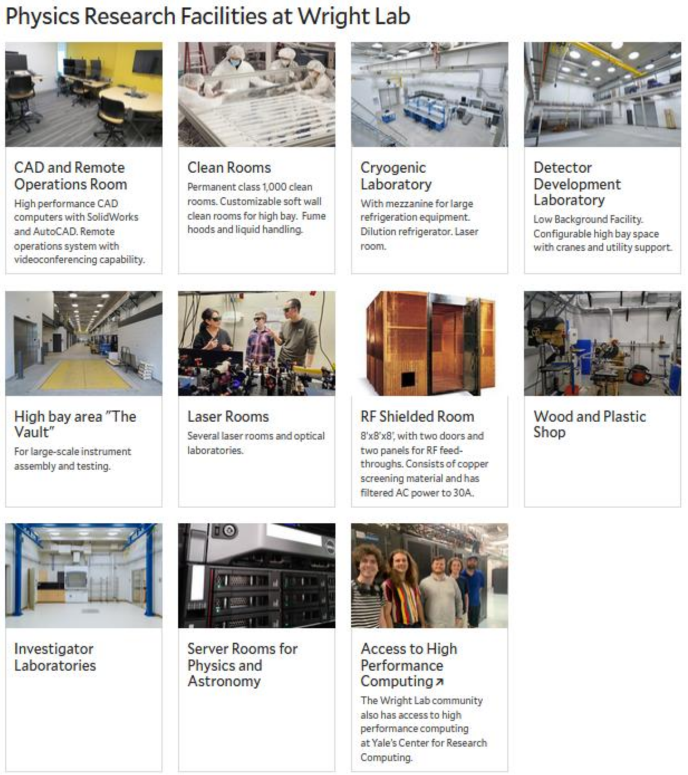




Ultralow-background test capabilities exists at PNNL and LLNL

Quantum, characterization, calibration

- All benefit from synergistic activities
- Benchmarking technologies provide the quality we need for advanced instrumentation
- Testbeds, ‘standards’, frameworks
- Good coordination across labs can lead to a virtual distributed lab
- Facilities provide excellent training opportunities for workforce development
- AI can help!



Physics Research Facilities at Wright Lab

CAD and Remote Operations Room
High performance CAD computers with SolidWorks and AutoCAD. Remote operations system with videoconferencing capability.

Clean Rooms
Permanent class 1,000 clean rooms. Customizable soft wall clean rooms for high bay. Fume hoods and liquid handling.

Cryogenic Laboratory
With mezzanine for large refrigeration equipment. Dilution refrigerator. Laser room.

Detector Development Laboratory
Low Background Facility. Configurable high bay space with cranes and utility support.

High bay area "The Vault"
For large-scale instrument assembly and testing.

Laser Rooms
Several laser rooms and optical laboratories.

RF Shielded Room
8'x8'x8', with two doors and two panels for RF feed-throughs. Consists of copper screening material and has filtered AC power to 30A.

Wood and Plastic Shop

Investigator Laboratories

Server Rooms for Physics and Astronomy

Access to High Performance Computing ↗
The Wright Lab community also has access to high performance computing at Yale's Center for Research Computing.

Thanks!

To those who willing or unaware help me with this overview…

…and apologies for all the great facilities and capabilities that are out there and I missed to report here.