Fermilab Progress Report

Lia Merminga

Fermilab European Partners Meeting

University of Chicago Booth, London Campus

5 February 2024

Bottom-Line Up-Front Summary

- LBNF-DUNE-US continues to make excellent progress
  - Far Site cavern excavation is complete!
  - Completed DOE CD-2/3 review of FDC; established DUNE Coordination Office to execute the Host Lab Plan
  - Our national and international partners are advancing the prototyping, testing of DUNE detectors
- PIP-II construction has restarted, making excellent technical progress
- HL-LHC AUP first cryoassembly was shipped to CERN
- Muon g-2 experiment concluded data taking, published the world's most precise measurement
- Strong, experienced teams are addressing Accelerator Safety Order and Site Access
- 2023 P5 report endorses Fermilab's programs, vision, aspirations
- We have entered 2024 with renewed momentum and undisputed evidence of ***"cultural and functional change"***

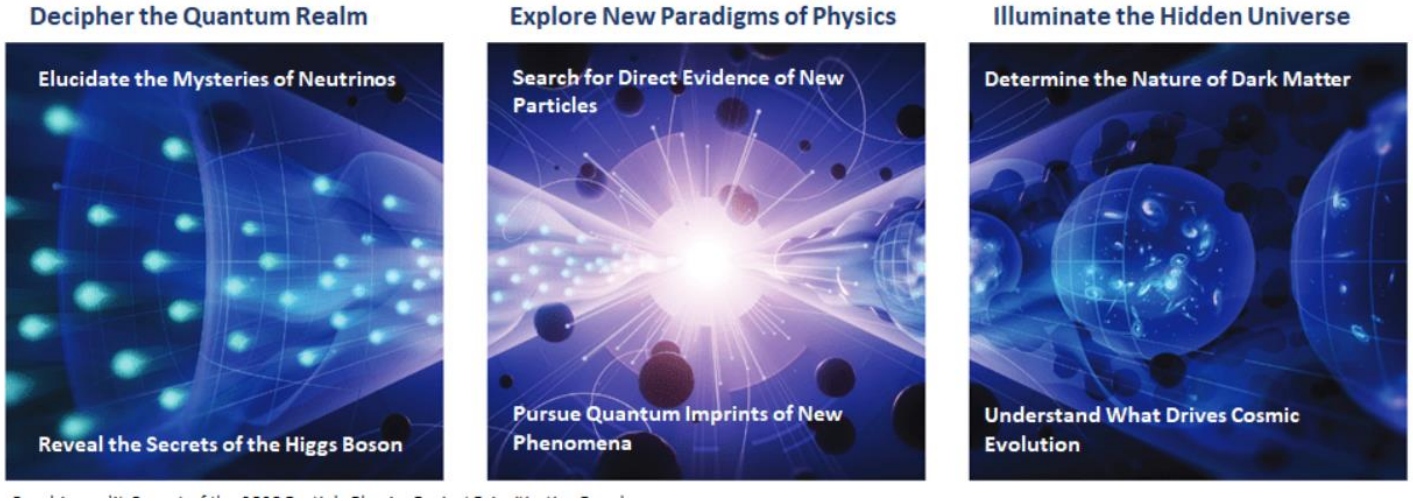
Fermilab at a Glance

- America's particle physics and accelerator laboratory
- Operates the largest US particle accelerator complex
- ~2,100 staff and ~$750M/year budget
- 6,800 acres of federal land
- Facilities used by 4,000 scientists from >50 countries

As we move into the next 50 years, our vision remains to solve the mysteries of matter, energy, space, and time for the benefit of all.

Fermilab Science Mission enables 2014 and 2023 P5 plans

- Higgs boson
- Neutrinos
- Dark matter
- Dark energy and inflation
- Exploring the unknown



Fermilab is delivering on the DOE/SC discovery science mission: Major particle physics breakthroughs from Fermilab experiments, major technology breakthroughs from Fermilab research

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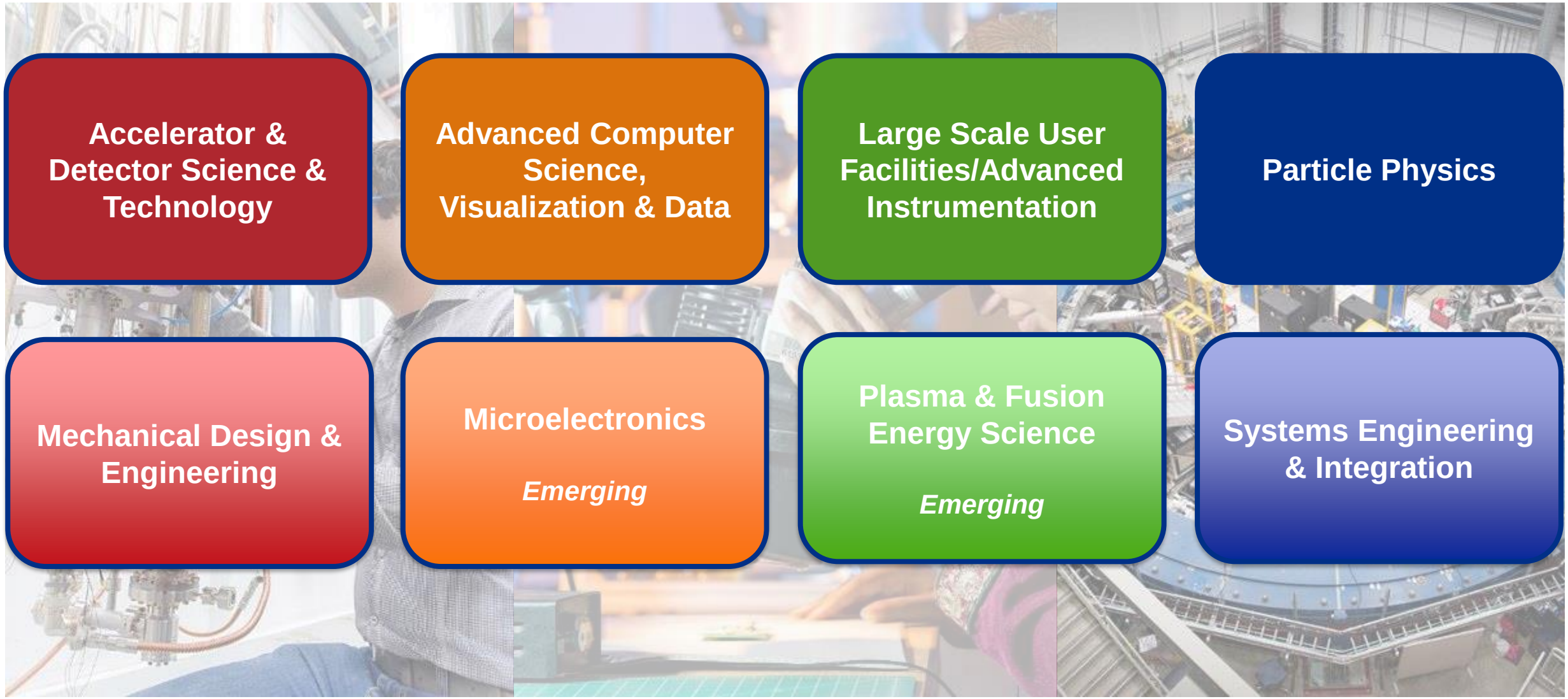
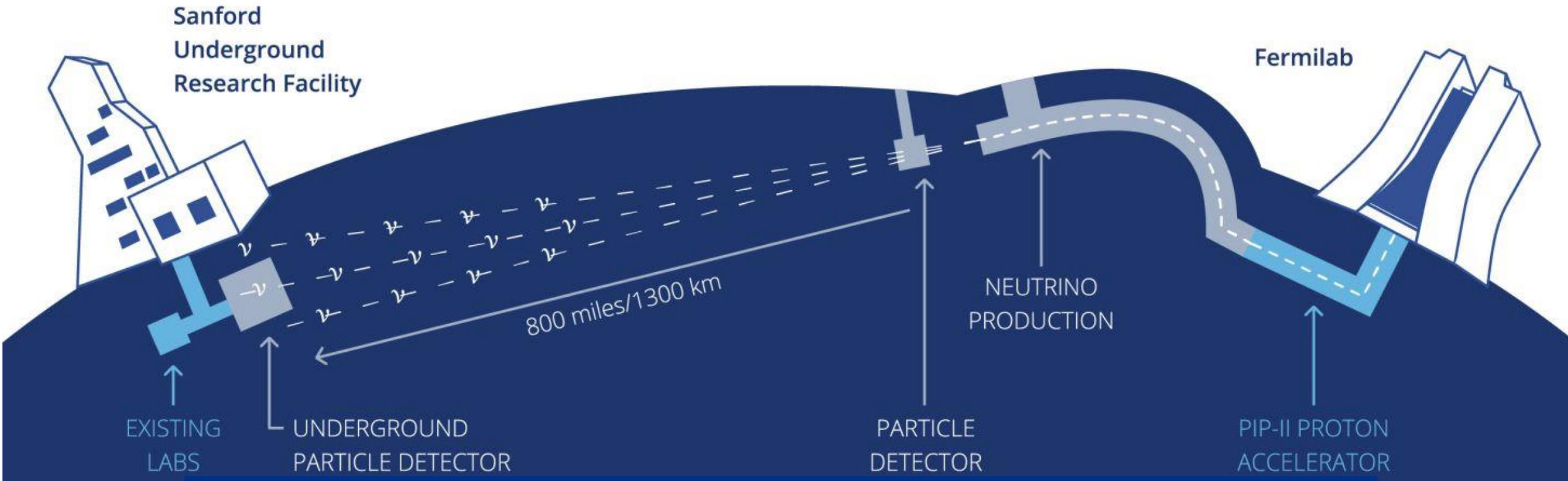
Fermilab Core Capabilities



DUNE: “Best in Class” neutrino experiment, driven by LBNF and PIP-II

Vision for Neutrino Science

Fermilab with its partners is universally acknowledged as the world leaders in neutrino science for decades to come



Delivering on LBNF/DUNE is Fermilab’s highest priority

Science Objectives

- **Origin of Matter**
  Discover what happened after the Big Bang. Are neutrinos the reason the universe is made of matter?

- **Neutron Star and Black Hole Formation**
  Use neutrinos to look into the cosmos and watch the formation of neutron stars and black holes in real time

- **Unification of Forces**
  Move closer to realizing Einstein's dream of a unified theory of matter and energy by looking for proton decay

DUNE will be able to address many of the fundamental questions in Neutrino Physics!

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LBNF/DUNE Project

- Far site excavation is complete!
- Significant progress on DOE Critical Decision milestones
  - Five ESAAB approvals in 2023!
- Detector installation begins 2024; CERN and partners are ramping up production
- Current primary focus: baseline Far Detector and Cryogenic Infrastructure (FDC) subproject
- Site prep for near site CF has started

North Detector Cavern
Photo by Matt Kapust, SDSTA
Aug 2023

LBNF/DUNE-US: Central Utility Cavern

Excavation of Central Utility Cavern is complete!

90% of cavern concrete slab is in place

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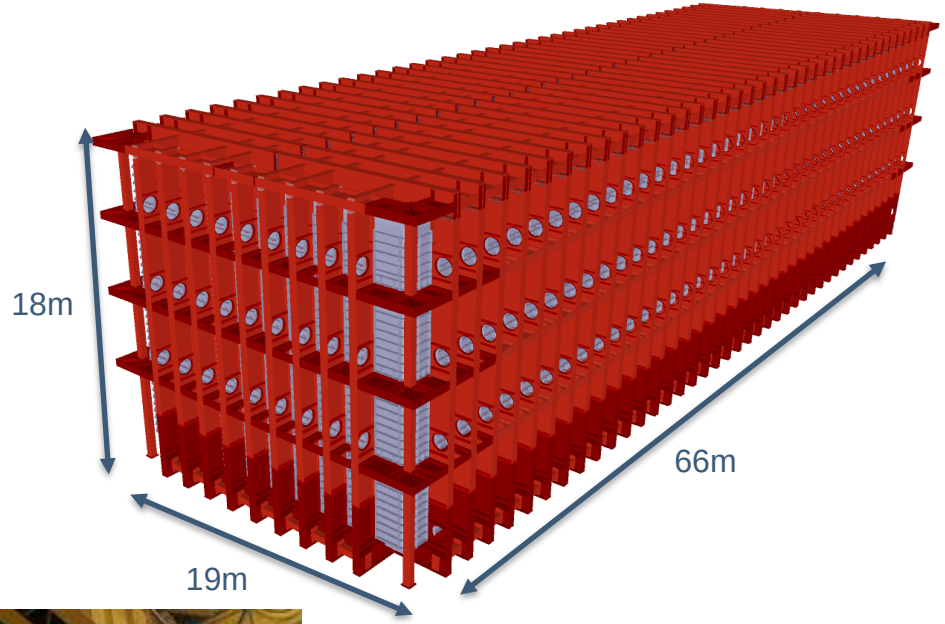
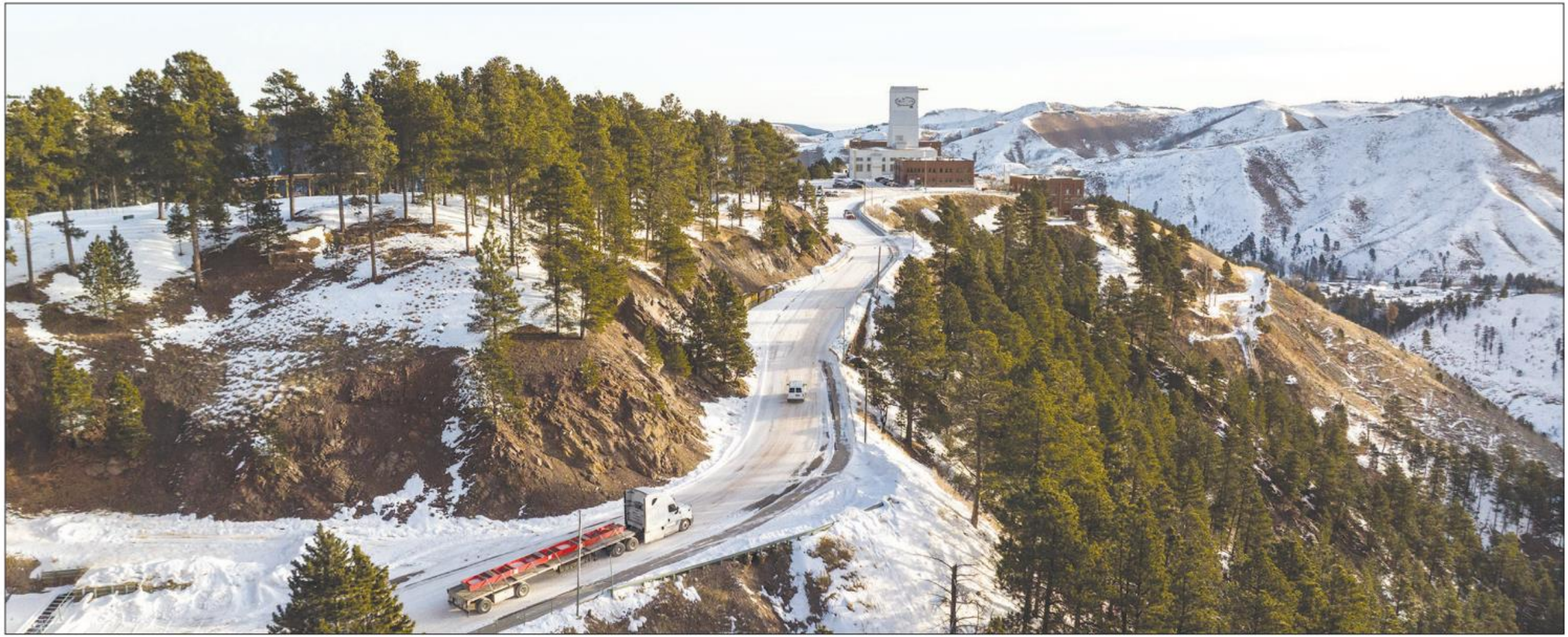
CERN moves forward with support for Fermilab-hosted neutrino experiment DUNE

- In September, Fermilab and CERN signed a project planning document to advance DUNE.
- This document follows two initial agreements signed in 2017 and 2021 in which CERN agreed to provide two large, approximately five-story-tall cryogenic vessels for the experiment.
- Far Detector cryostat in fabrication under CERN contract
  - First cryostat components (two photos far right) were shipped to SURF for lift tests



First components for DUNE experiment in Lead



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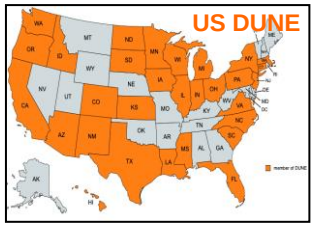
LBNF/DUNE near site prep work began!

To be completed in the next five months:

- Bring in equipment, trailers
- Removal of shrubs, trees on 5 acres (at present: average tree coverage 20%)
- Move soil and regrade
- Remove equipment, trailers by end of spring 2024

DUNE International Collaboration hosted by Fermilab



DUNE Collaboration meeting at CERN – January 2024

- DUNE collaboration comprises 1400 scientists and engineers at about 200 institutions
  - About 50% at U.S. institutions, 50% abroad (35 countries)
  - 350 students, 250 postdocs
- Fermilab is the host lab of DUNE: Established the **DUNE Coordination Office** in May 2023

DUNE Partners sign multi-institutional MOU

- International science organizations sign agreement to provide hardware for the Deep Underground Neutrino Experiment

DUNE Near Detector prototype installed in NOvA Beamline

Short Baseline Neutrino Detector (SBND)

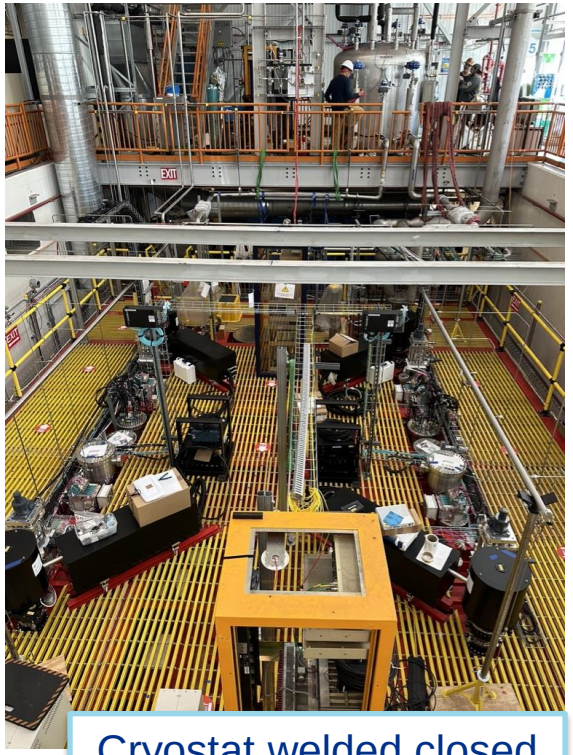
Detector arrival at SBN-ND

Completed SBND Cryostat

First physics run spring 2024

On 1/ 22 SBND received Operational Readiness Clearance (ORC) for the cryogenics system to start the purge of the cryostat then cooldown and fill with liquid argon. SBND has moved fully into commissioning mode with only the cosmic ray tagger system left to complete installation

Rigging detector into cryostat



Cryostat welded closed and cabling installed

CERN Neutrino Platform

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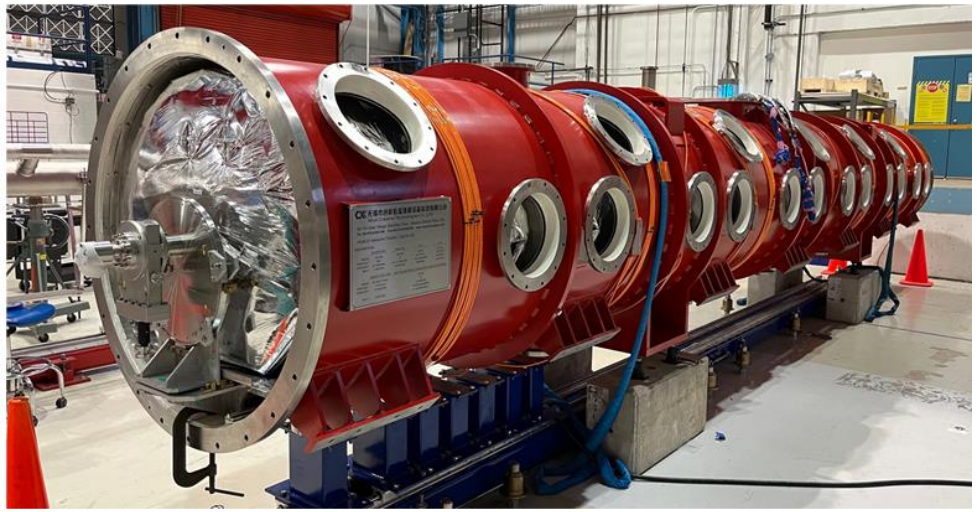
Proton Improvement Plan – II (PIP-II)

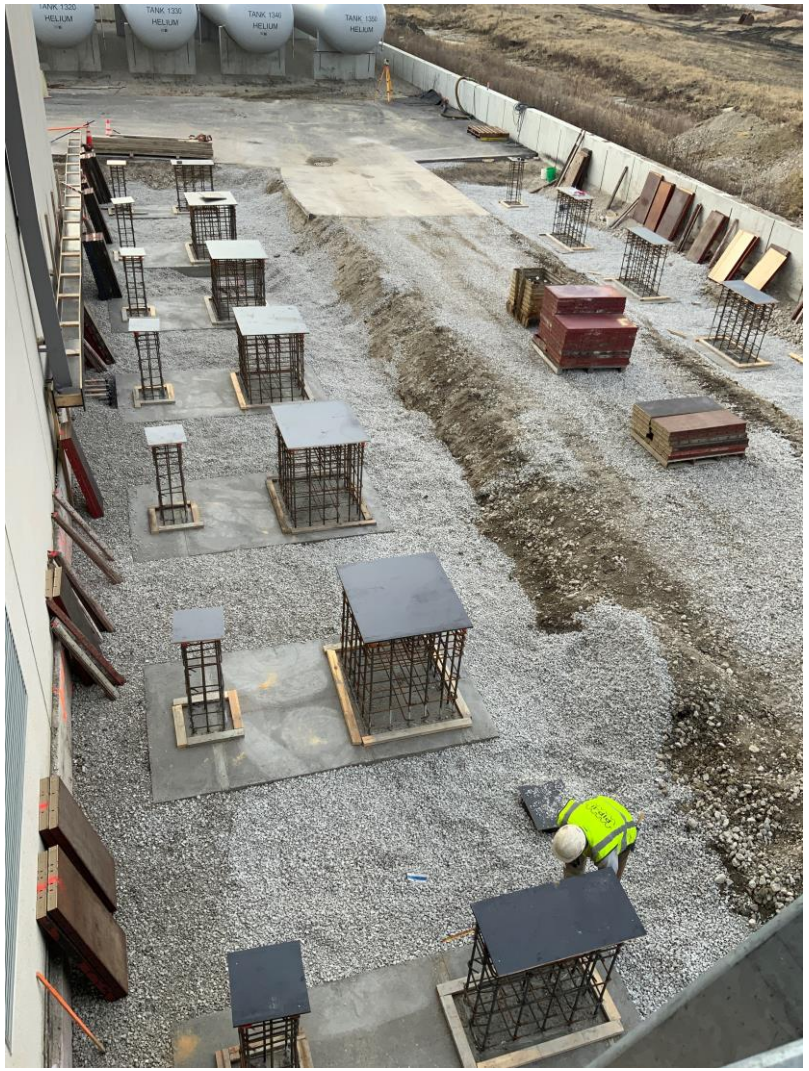
PIP-II is an essential upgrade to Fermilab accelerator complex to enable powerful, wideband neutrino beam to LBNF/DUNE, and a broad physics research program for decades to come

PIP-II particle accelerator complex is under construction



- Cryogenics Plant Building is complete
- Superconducting accelerator components have been successfully tested
- Groundbreaking for main building in April 2023

PIP-II Construction: All Linac Complex work restarted



Pantaleo Raimondi
New Project Director started!

PIP-II: Successful transportation test of HB650 cryomodule

US – Batavia, IL

UK - Daresbury

US – Batavia, IL

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Collider Science
and the
US CMS
Collaboration

Collider Science

- Fermilab is the host lab for US CMS (27% of CMS)
  - CERN is our European sister laboratory and our strong partner in many areas
- **Three major initiatives**
  - LHC CMS experiment operations – Run 3 – ROC is back in operations!
  - HL-LHC AUP Upgrade Project
  - HL-LHC CMS Detector Upgrade Project

LHC Remote Operations Center (ROC) at Fermilab - *CMS online shifts*

LQXFA/B-01 in preparation for shipment

US DOE/SC, Fermilab delegation visiting CMS – Sept 2022

First U.S.-built focusing magnet for LHC upgrades shipped to CERN

- CERN celebrates the arrival of a 13-meter-long assembly comprising two 5-meter-long magnets.
- These are the first U.S.-built magnets for the high-luminosity upgrade to the Large Hadron Collider.
- Over the next few years, another nine assemblies will follow, thus completing a two-decades' effort by a consortium of U.S. Department of Energy national laboratories—Fermilab, Brookhaven and Berkeley—to design and build new accelerator focusing magnets.
- These magnets, along with those from CERN, will be installed around two of the LHC's collision points in two years' time.

Culmination of years of effort by CERN and FNAL working as one team to realize high field Nb_3Sn magnets for HL-LHC

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HL-LHC Cryo-assembly at CERN

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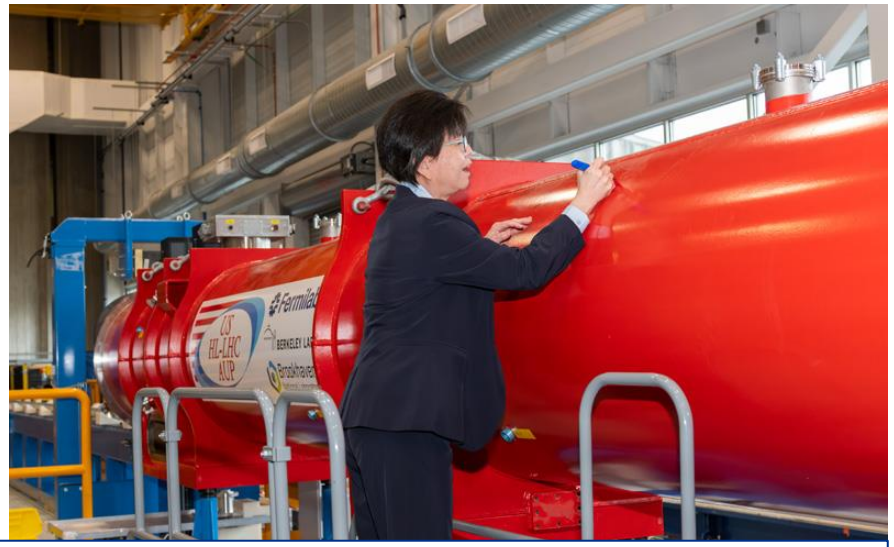
The Power of International Collaboration



HL-LHC AUP first cryoassembly is ready to be shipped to CERN - First deliverable from US to HL-LHC

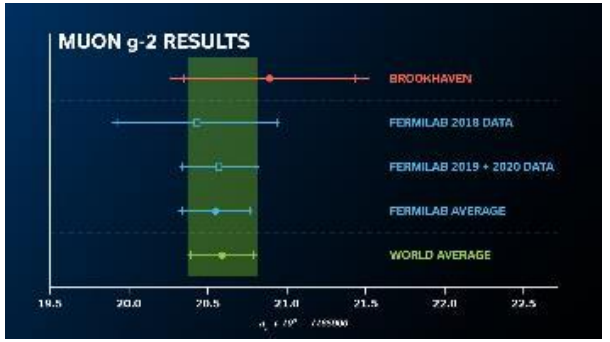
PIP-II HB650 prototype cryomodule preparing for shipment to UK

First DUNE components arrive from CERN

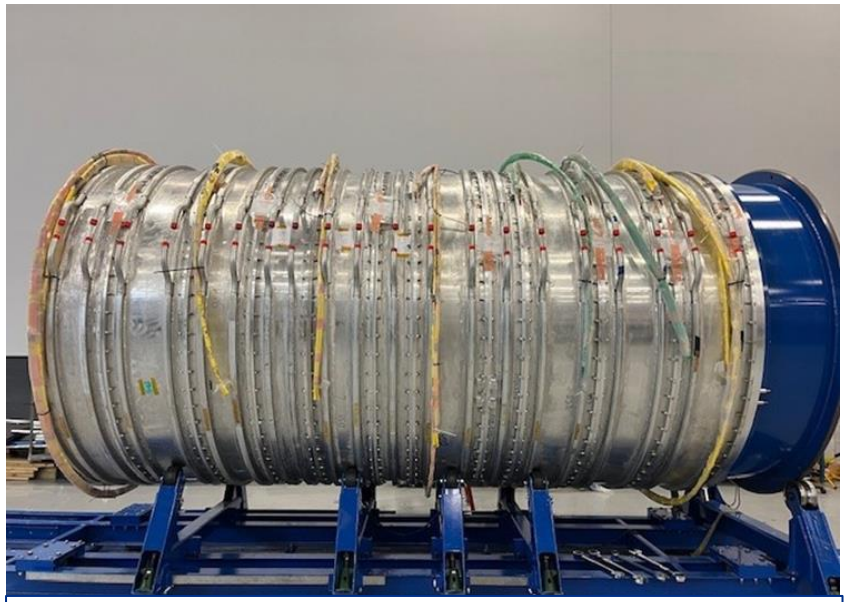
Physics with Muons

Two Major initiatives

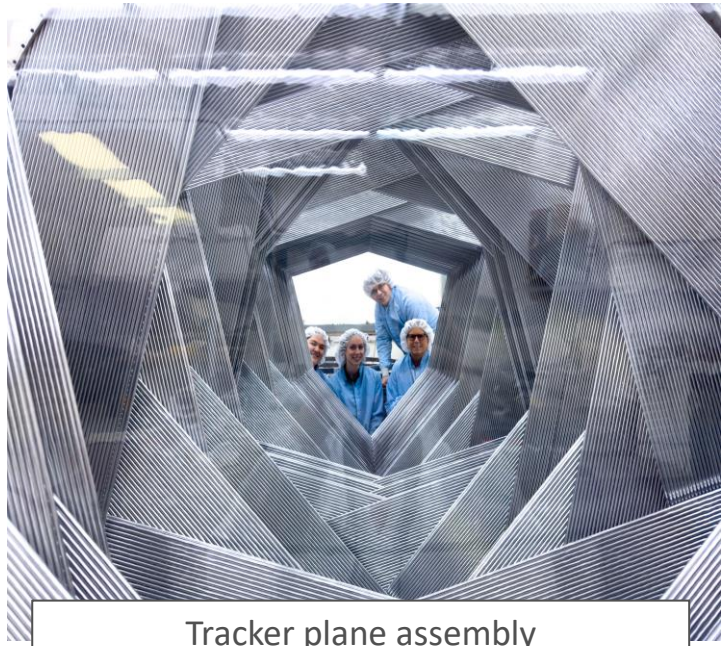
- **Muon g-2**: Data taking concluded, statistics goal achieved!
  - World's most precise measurement of muon g-2 was released in August
  - Final result, updates from Theory Initiative expected in 2025 timescale
- **Mu2e project**: Project under construction ~91% complete, start science in 2026



Movable collimator inserted into inner bore of downstream Transport Solenoid



Detector Solenoid in progress



Tracker plane assembly

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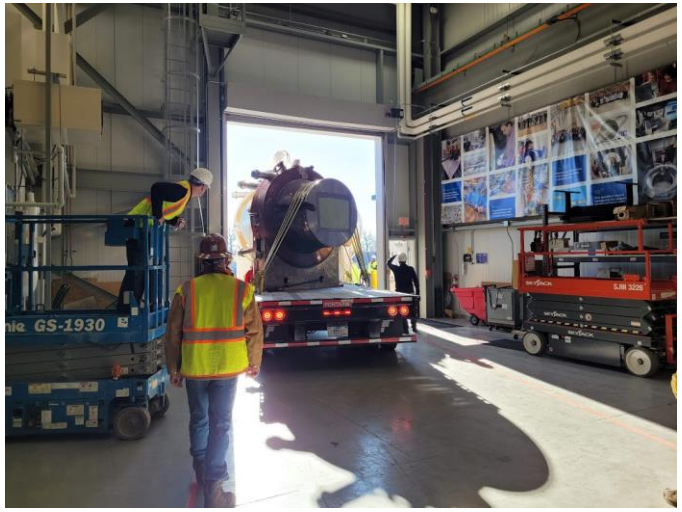
Mu2e: Upstream Transport Solenoid moves to the Mu2e Experimental Hall



Temporary stop downstairs to mark the footprint on the floor

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Cosmic Science

Vision: Fermilab is both a leader and essential partner in cosmic science experiments investigating the connections between phenomena on the very largest and smallest scales of the universe.

Science Goals

1. Cosmic Surveys → Transition from DES to DESI, LSST
2. Cosmic Microwave Background → Major role in CMB-S4
3. Dark Matter Detection → Axions, Sub-GeV

South Pole Telescope during 2022 Austral winter survey observations (Credit: Aman Chokshi)

Cosmic Frontier

SuperCDMS SNOLAB

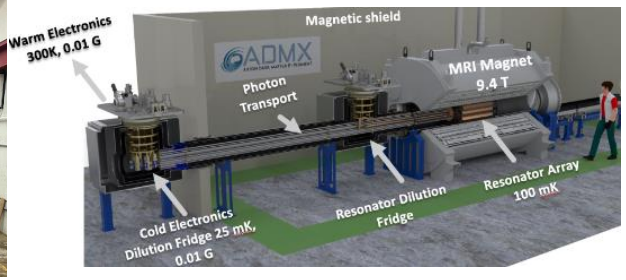
- Project completed. 60+ pallets of equipment shipped!
- Installation in Progress at SNOLAB

SENSEI publishes World leading result on search for Millicharged particles at NUMI

Dark Matter New Initiatives projects

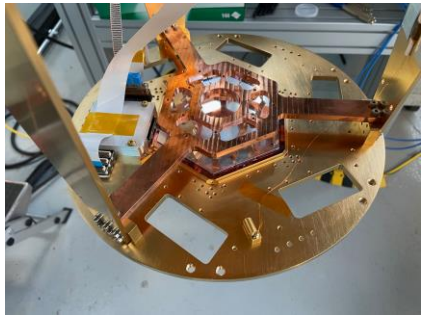
ADMX-EFR and OSCURA receive P5 support

- PW8 cleaned out for ADMX-EFR installation



CMB-S4 receives strong recommendation from P5 – Fermilab group leads Module Assembly and Testing

CMB-S4 Module testing framework



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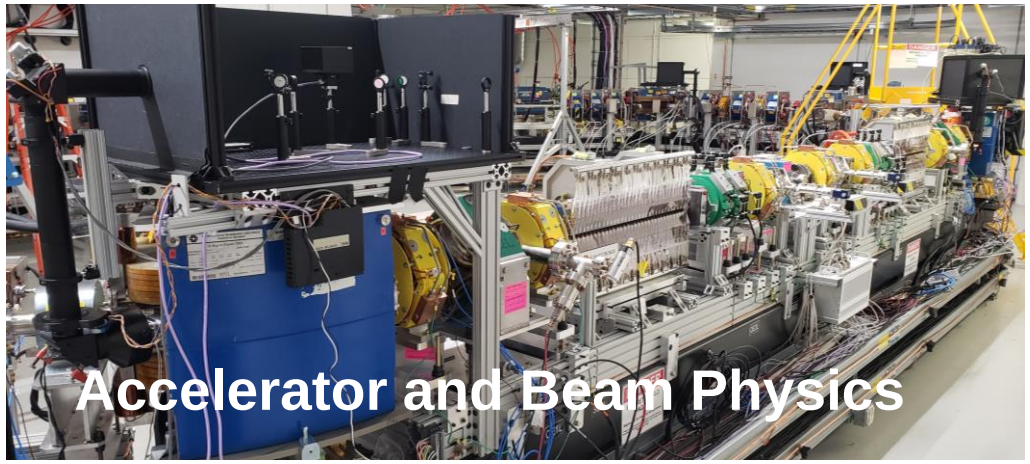
Accelerator Science & Technology

Vision: Fermilab is a world-leader in Accelerator Science & Technology R&D that enables the next generation of particle accelerators and advances the HEP and Office of Science mission. Fermilab is an essential partner of choice to future large-scale accelerators.



Fermilab is addressing the needs of many SC program offices

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New record beam power of 960 kW!

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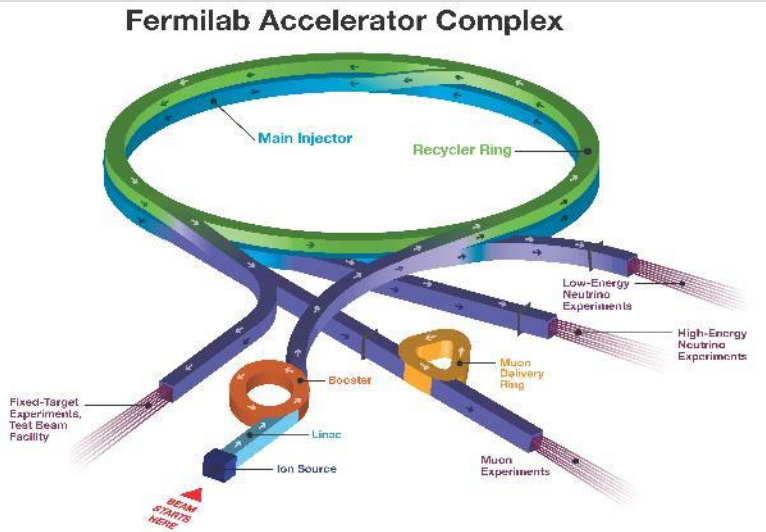
Accelerator Operations

Safety of Accelerators

We are updating our accelerator safety documents [Safety Assessment Document (SAD) and Accelerator Safety Envelope (ASE)] under DOE Order 420.2D “Safety of Accelerators.” This enables safe and effective operations of our accelerator complex and research mission, and ensures adequate protection of workers, the public, and the environment

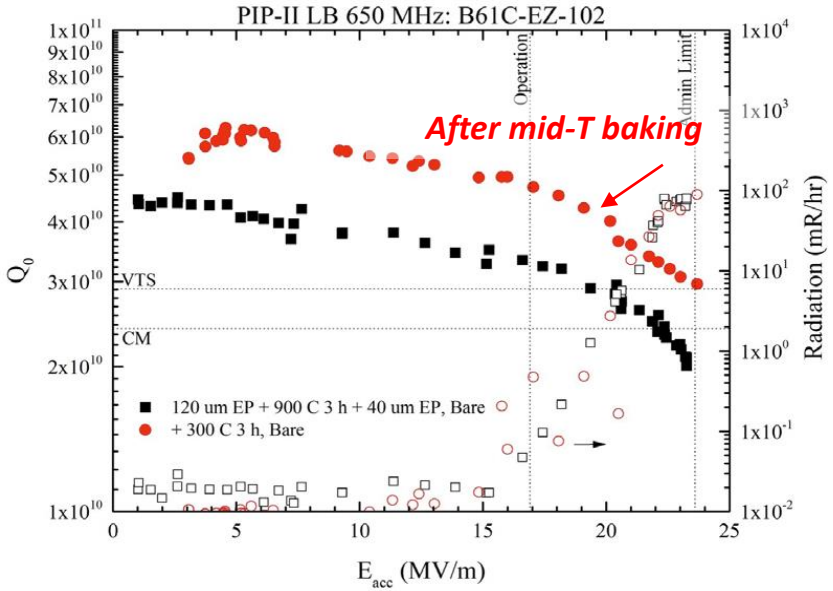


- Staged approach to turning on machines and resuming beam to experiments as soon as possible
- First 3 reviews completed on schedule
  - Reviews validated our approach for determining credited controls and flow of information from the SAD to the ASE
- The Linac has resumed beam operations on schedule
  - MTA requires additional radiation detectors before we can run
- Downstream machines are set to receive approval and resume operations

Machine	Review	Approval to run beam
Linac / MTA	SAD/ASE review Nov 29-Dec 1 ✓	January 11 ✓
Booster/MI8/BNB/MI/NuMI	SAD/ASE review Jan 9-11 ✓	February
Muon/SY120/Meson	SAD/ASE review Jan 23-25 ✓	February
NM/SpinQuest	SAD/ASE review Jan 23-25 ✓ ARR Feb 13-15	March
Accelerator Complex	ARR Feb 13-15	validate compliance
FAST	SAD/ASE review Jan 30 – Feb 1 ARR Feb 20-22	validate compliance
Test stand accelerators	SAD/ASE review Feb 6-8 ARR Feb 27-29	validate compliance

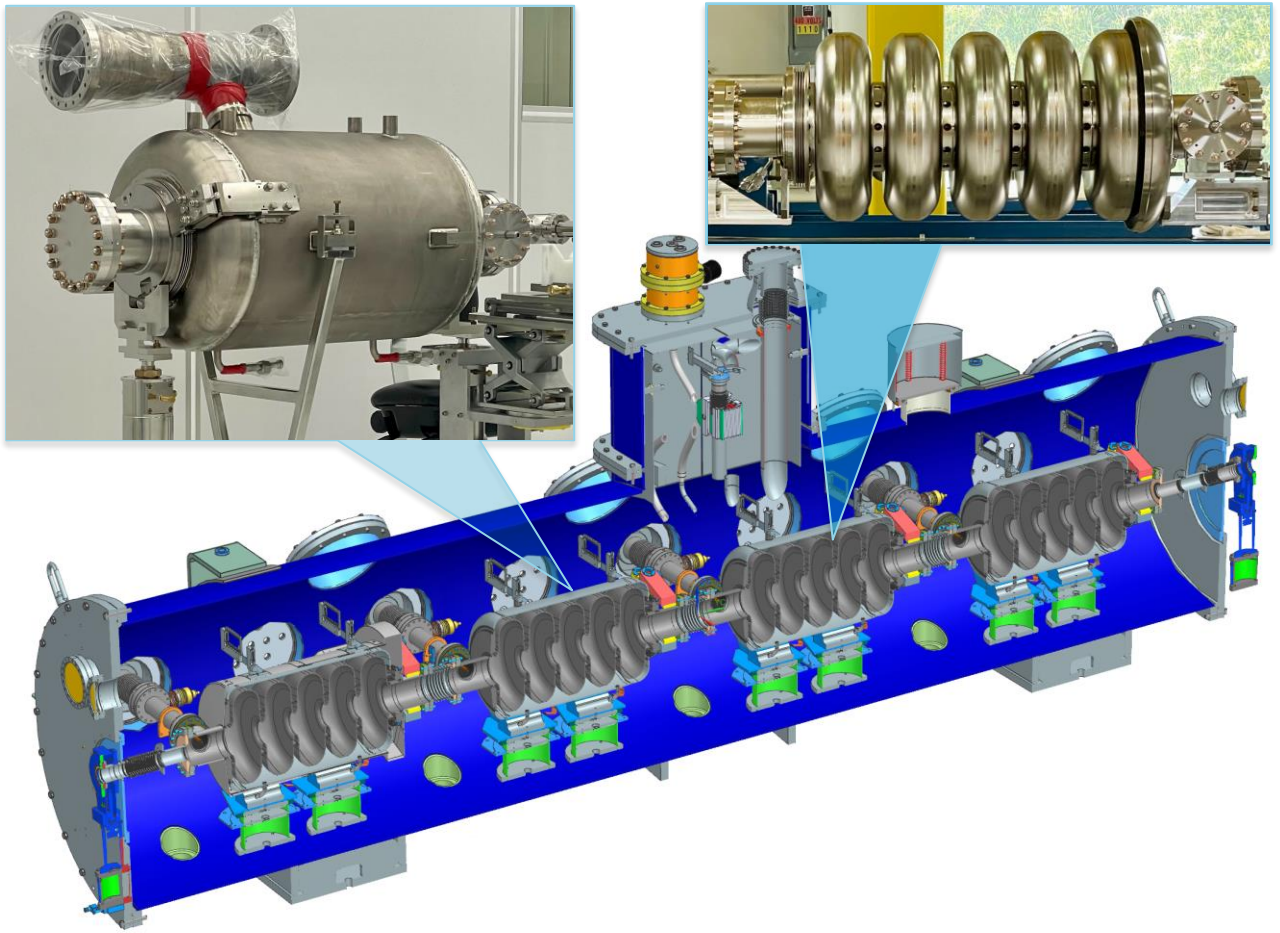
Accelerator S&T Highlight: Mid-T Bake and PIP-II LB650 Cryomodule

- Mid-T baking developed at Fermilab is a simple process to improve Q and has been widely adopted by SRF community
- Mid-T bake was adopted for PIP-II LB650 cryomodules
- Promising approach for high-Q 800 MHz cavities for FCC-ee!



Jacketed Cavity

Bare Cavity



Leveraging Fermilab accelerator research advances for PIP-II and FCC-ee

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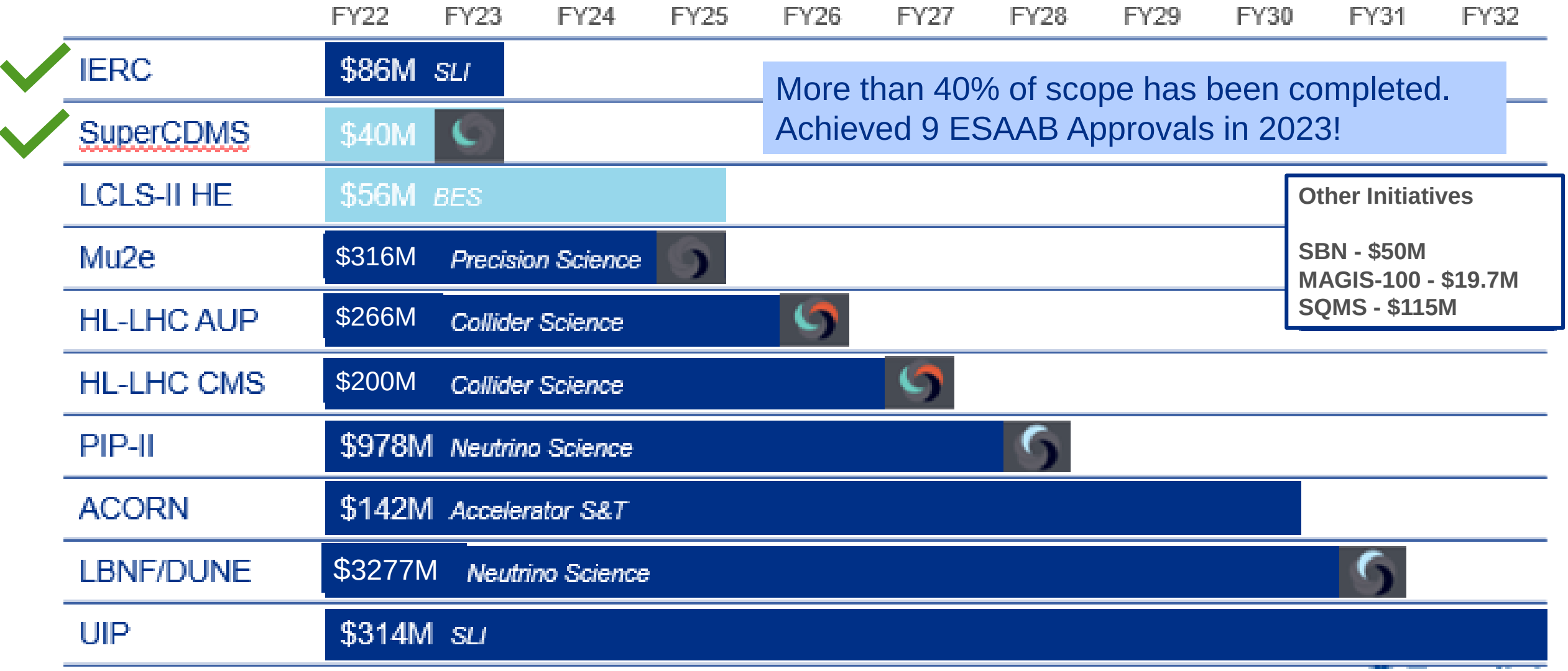
Fermilab executes the 2014 P5 plan

Investment
$5.6B DOE,
$1.1B International



More than 40% of scope has been completed.
Achieved 9 ESAAB Approvals in 2023!

Other Initiatives

SBN - $50M
MAGIS-100 - $19.7M
SQMS - $115M

IRA funding of $260M in FY22 "forward funded" our major construction projects

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IERC achieved CD-4 approval and Project Award

New group accelerates Fermilab's sustainability practices

- Establishing sustainability as a lab priority, Fermilab's formed a team of four, full-time sustainability specialists to direct the efforts of the lab's already established Sustainability Management Team.

- In addition to making buildings, such as IERC, more sustainable, other initiatives to improve sustainability have been put into practice on campus.

Emerging Science & Technology Capabilities

Quantum Information Science & SQMS
Artificial Intelligence / Machine Learning
Microelectronics

Emerging Science & Technology Initiatives

Quantum Information Science

Fermilab is pursuing a multi-pronged and vibrant QIS&T program:

- Lead **SQMS -** 1/5 DOE National QIS Centers
- Strong participation at QSC
- Broad research program

aiming to enable HEP science and advance QIS&T. Our approach:

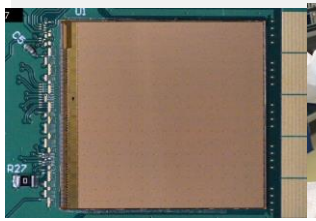
- Quantum sensors; systems; simulation; computing

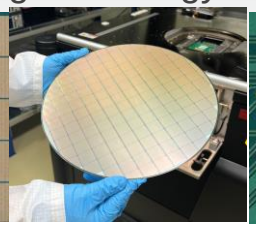
Microelectronics

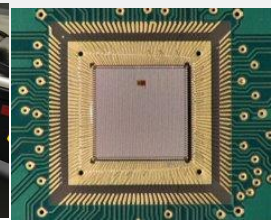
HEP experiments set the grand challenge for enabling next generation microelectronics.

Our vision is to leverage our core capabilities while working with academia and industry to develop microelectronics to meet our scientific goals and achieve societal impact through disruptive technologies. Our approach:

- Integrated precision sensing with computing and communication technologies
- Impactful hardware development for Quantum, AI at the edge, 6G and beyond
- Microelectronics workforce
- Support and develop US-based advance manufacturing technology







Artificial Intelligence

Unique HEP challenges will spur innovation in AI techniques and technology that will **transform HEP** and **advance discoveries in other sciences, society, industry**.
Major synergy with our strength in microelectronics and with the upgrade of the accelerator complex

- **Accelerators**
- **Experiments**
  - AI-enabled automation/optimization
  - Experiment design
  - Readout and control
  - Data processing and simulation
  - Automated data mining, analysis, and interpretation

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SQMS

>30 Partner Institutions

>500 Collaborators, $115M

A DOE National Quantum Information Science Research Center, led and host by Fermilab

Fermilab
Northwestern University
rigetti
AMES NATIONAL LABORATORY Creating Materials & Energy Solutions
NASA Ames Research Center
NIST
COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
FormFactor™
Goldman Sachs
ILLINOIS INSTITUTE OF TECHNOLOGY
INFN
Jefferson Lab
JOHNS HOPKINS UNIVERSITY
LOCKHEED MARTIN
LSU
NPL National Physical Laboratory
NYU
ROYAL HOLLOWAY UNIVERSITY OF LONDON
RUTGERS THE STATE UNIVERSITY OF NEW JERSEY
Stanford
Temple University
Unitary Fund
THE UNIVERSITY OF ARIZONA
University of Colorado Boulder
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
UNIVERSITY OF MICHIGAN
UNIVERSITY OF MINNESOTA Driven to Discover®
IN SUPREMÆ DIGNITATIS 1343
UNIVERSITÀ DI PISA
USC University of Southern California
UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

The U.S. largest quantum center, bringing together hundreds of experts from 30 DOE national labs, academia, industry and several other federal and **international** entities

Fermilab's SQMS Center hosts inaugural U.S. Quantum Information Science School to develop quantum workforce; inaugurates "Quantum Garage"

Mission: Attacking the Decoherence Cross-Cutting Challenge

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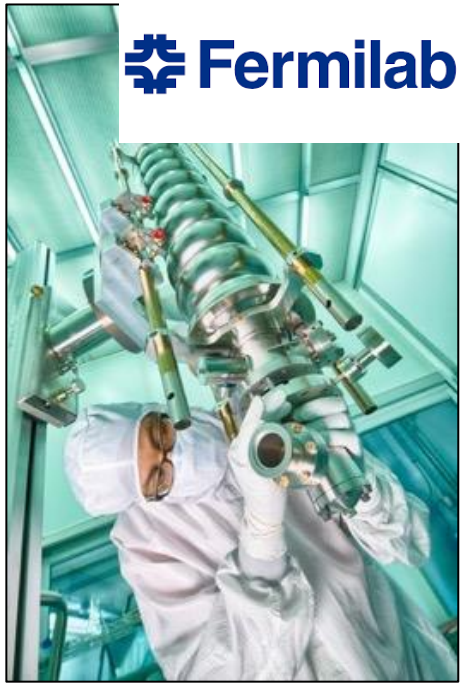
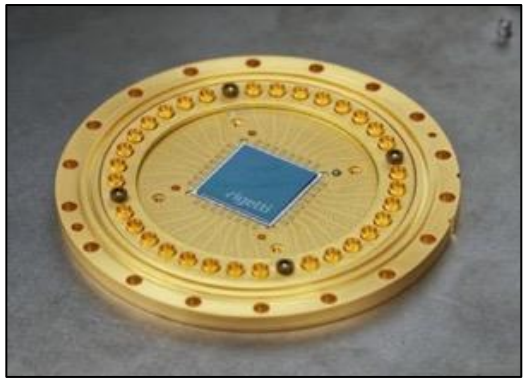
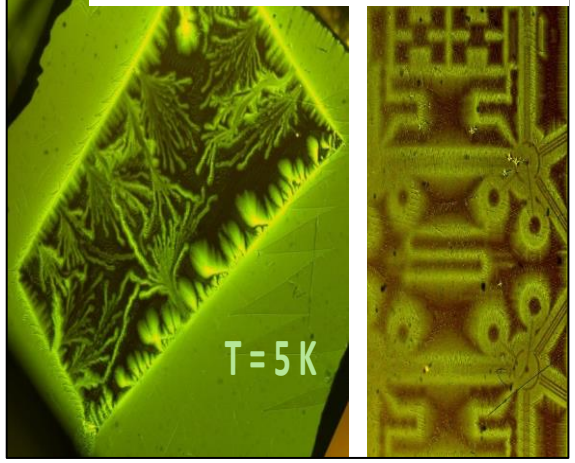




AMES LABORATORY
Creating Materials & Energy Solutions
U.S. DEPARTMENT OF ENERGY



SQMS Mission

"bring together the power of national labs, industry and academia to achieve transformational advances in the QIS **major cross-cutting challenge** of **understanding** and **eliminating** the **decoherence** mechanisms in superconducting 2D and 3D devices, with the goal of **enabling construction and deployment of superior quantum systems for computing and sensing.**"

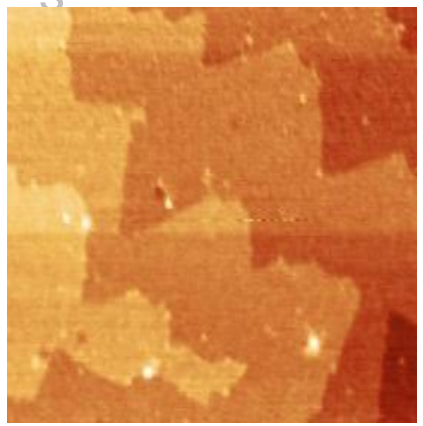
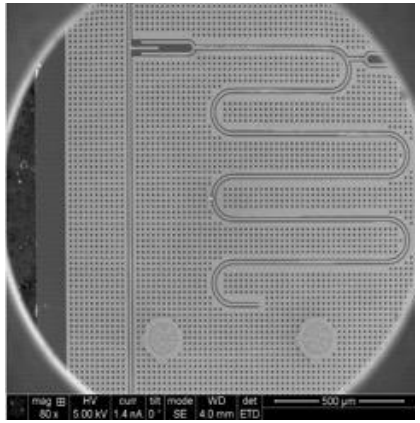
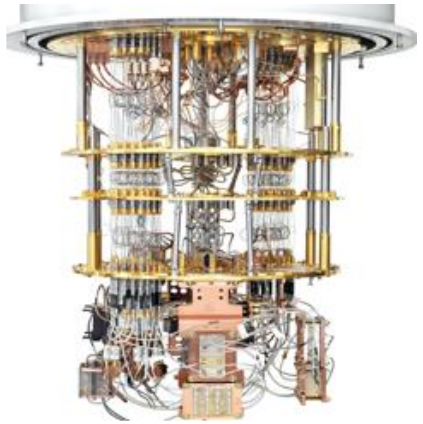
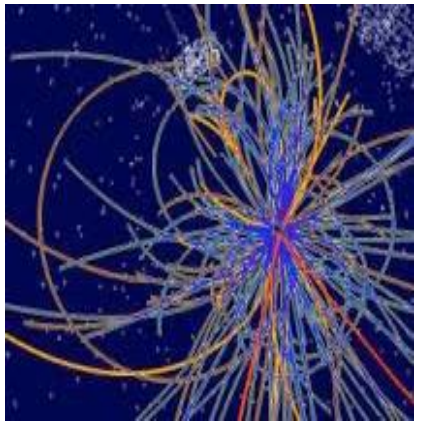
rigetti

INFN

NIST

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

SQMS Goals and Science & Technology Innovation Chain

Materials	High-coherence devices	Systems integration	New platforms for quantum computing & sensing	Quantum advantage
				
Developing a full understanding of sources of decoherence via a systematic, fundamental science approach	Demonstrating devices with systematically and consistently higher coherence at different SQMS partners and industry	Preserving device high performance through the process of integrating into more complex systems	Deploying quantum computing and sensing facilities of innovative architectures and improved performance	Demonstrating quantum computing and sensing advantage for particle physics and other scientific and societal applications

The SQMS Center bridges the gap between ideas and large-scale realizations via the unique center-wide, multidisciplinary, co-design, coordinated approaches

US and UK team up to advance QIS

Dr. Alexander Tsalenzchuk (NPL)

Prof. John Saunders (RHUL)

NPL National Physical Laboratory

Unique materials characterization tools

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Unique qubit cooling capability (microkelvin)

Prof. Sir Peter Knight
SQMS Advisory Board member

Dr. Tobias Lindstrom (NPL)

Dr. Sebastian De Graaf (NPL)

Two PIs, six senior personnel, plus students and postdocs have joined the SQMS collaboration

SQMS

Prof. Jocelyn Monroe (RHUL/Oxford)

Dr. Andrew Casey (RHUL)

Dr. Ivan Rungger (NPL)

"Quantum has become a major part of the scientific adventure that everybody wants to participate in, and SQMS is going to be a beacon of getting stuff done." – Sir Peter Knight, chair of the U.K. National Quantum Technologies Programme

https://news.fnal.gov/2023/06/the-us-and-uk-team-up-to-advance-quantum-information-science/

Events at Fermilab

Inventor recognition ceremony Feb. 23, 2023

P5 Report Town Hall

DOE Deputy Secretary Turk, Gov. Pritzker, local legislators unveil new buildings to advance science at Fermilab

The 56th Annual Fermilab Users Meeting: New ideas for future projects

Fermilab

Outdoor Family Fair – First since 2019!

- Held on Sunday, October 22
- Engages community in Fermilab's physics and ecology efforts
- Brings STEM outside the classroom and into the community

- ~2000 people attended, ~1500 public attendees and ~500 employees and families
  - 3x attendees as the last Outdoor Fair in 2019
  - Over 35 volunteers, 20 EPE staff + security worked on the event

Site Access Progress to Date

September 2023

- DOE SC Site Access Assist Visit

October 2023

- Initiation of Site Access Steering Committee

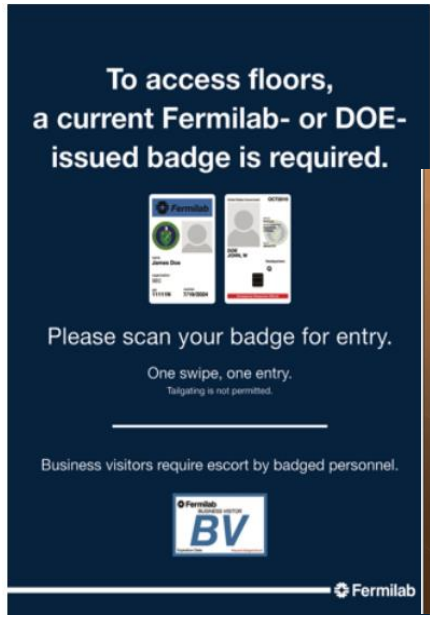
November 2023

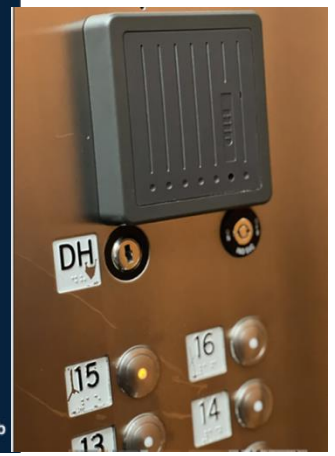
- SASC Workshop
- Security Accountability Procedure
- Enhanced Communications
  (includes 100s of comments/suggestions)

December 2023

- DOE Labs Benchmark Briefing & Recommendations
- Wilson Hall Access Control System operational
- P5 Town Hall event
- Site Access Single Form Release (including invite capability)
- Draft End State Proposal (to SLM)
- Expanded access to buildings (IERC, IARC, FCC, ICB)

Wilson Hall Access Control System
Allows for public access to Ground Floor, First Floor and 2nd Floor Exhibit area





Successful P5 Town Hall Dec 2013

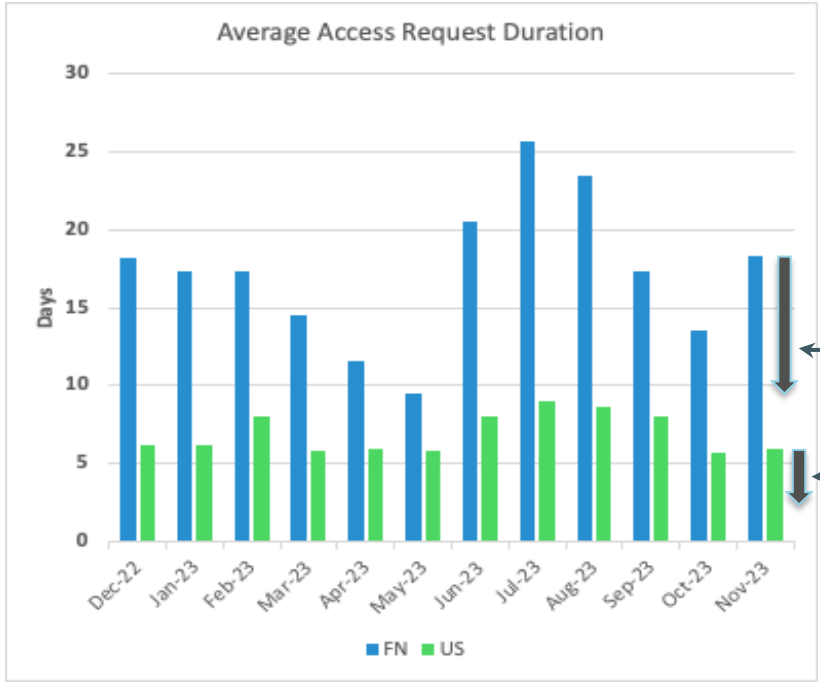
Site Access Near-term Actions

January 2024

- Site Access Website, including metrics dashboard
- Public Safety Access Gates
- Wilson Hall “Reopening” Event
- Office of Science Briefing

February-March 2024

- Changes to Foreign National Access process
- Further discussions with FSO on access improvements
- Finalize Site Access End-State Objectives



Site Access Approval Processing
Online form improvements expected to reduce average approval times by 3-4 days and to reduce errors/re-work.
Additional changes to UFNAP review and approval process will decrease average access time by several more days.

Wilson Hall has been re-opened to the public!
(Credit Union, Atrium & First Floor, Art Gallery and Second Floor Crossover)

Fermilab

Discovery on the Prairie: a new vision for Fermilab and its Communities

- State of IL recently approved a $30M appropriation to support housing at Fermilab – many thanks to UChicago!
- Develop an integrated vision of a “Discovery on the Prairie” concept that includes new housing facility as one element

The vision

- Create an integrated and sustainable site vision for Fermilab and its communities over the next 10 years and beyond that encompasses:
  - **Vision of the Village ten years from now**
  - **New housing facility and amenities** (State of Illinois grant)
  - **Welcome Center and Badging Facility** (in progress)
  - **STEM education and outreach** (Lederman Science Center)
  - **Technology hub/park for innovation and entrepreneurship**
- Steering Committee established, chaired by J. Jarvis
- Engaging Fermilab scientific user community throughout the process and formulation of new vision

Fermilab hosts 316 Interns this summer!

Largest summer internship cohort Fermilab has seen in our 44-year history of pipeline programs

P5 Report Presentation Town Hall at Fermilab – December 11

P5 Town Hall at Fermilab – Dec 11

2023 P5 report endorses Fermilab's programs, vision, aspirations

- The P5 (Particle Physics Project Prioritization Panel) report is a ten-year strategic plan for U.S. particle physics.
- The 2023 P5 report provides a bold and balanced vision and roadmap for US particle Physics for the next decade.
- The report
  - strongly endorses Fermilab's ongoing experiments and construction projects
  - recommends the early implementation of DUNE as *the definitive* neutrino-oscillation experiment (beam power increase through ACE-MIRT and FD3)
  - recommends delivery of a 20-year strategic plan for the Fermilab accelerator complex, compatible with a muon collider
  - Investing in the scientific workforce, broadening engagement, and supporting ethical conduct in our field, and the development of a Sustainability strategy for particle physics.


Thank you
for your partnership!