Vision and Plans for Fermilab’s Next 10-20 Years

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Snowmass Community Summer Study
University of Washington, Seattle
25 July 2022
This is an exciting time for Particle Physics

- Profound science questions and discovery potential
  - Higgs boson
  - Neutrinos
  - Dark matter
  - Dark energy and inflation
  - Exploring the unknown

- Significant advances in technology and other enabling drivers
  - Accelerator science & technology
  - Detectors & Microelectronics
  - Computing, AI/ML
  - Quantum science & technology
  - Theory
This is a defining moment for Fermilab

- With the successful completion of LBNF/DUNE/PIP-II, Fermilab will become host to the first internationally conceived, constructed, and operated mega-science experiment on U.S. soil
  - US/Fermilab is universally acknowledged as the world leader in neutrino science

- As it enters its next 50 years, Fermilab remains America's premier Particle Physics and Accelerator Laboratory, delivering groundbreaking science and technology innovation, underpinned by a world-class and diverse workforce, excellence in business and operations, a renewed and sustainable campus and strong and lasting regional, national and international partnerships
Over the next decade, Fermilab plans to:

- Continuously deliver groundbreaking discovery science and technology innovation
  - Addressing the 2014 P5 science drivers and science priorities informed by the next P5 report
  - NOvA, SBN; LHC; Muon g-2; LSST-DESC, ….
- Successfully complete the 2014 P5 plan, begin scientific exploitation consistent with P5 timeline
  - LBNF/DUNE; PIP-II; HL-LHC; Mu2e; CMB-S4
  - Host Lab for DUNE
- In collaboration and coordination with the US community and international partners, ensure the success and impact of the new P5 strategic plan
  - Booster Replacement (BR), DUNE Phase II
  - Lay the groundwork for the next major facility onsite, as an international project, conceived and executed as a global endeavor
- Pursue accelerator and detector R&D
  - BR, DUNE Phase II, FCC @CERN, next major facility @Fermilab
  - As sciences in their own right
- Advance emerging science & technology capabilities → further enhancing lab’s core mission
  - Quantum Information Science & SQMS Center
  - Artificial Intelligence / Machine Learning
  - Microelectronics
Over the next decade, Fermilab also plans to:

- Diversify and empower our workforce
  - Develop and execute a workforce and diversity strategic plan
  - Foster a culture of respect, inclusion, transparency, integrity and excellence that is essential to ground-breaking science
  - Partner with Chicagoland and nationwide colleges and universities, including minority serving institutions, to host upwards of 100s of students and advanced degree programs
- Achieve excellence in business & operations, and renew our campus infrastructure with sustainability goals, integrated with science vision
- Forge strong regional, national, international partnerships: with University of Chicago, Argonne, Universities Research Association and other national and international institutions
- Launch a strategic plan for Fermilab’s next 20 years
Strategic Thrusts: Pillars of our vision for Fermilab

Deliver groundbreaking science and technology innovation

Building for Discovery: Project Execution

Diversify and empower our workforce

Transform business systems & operations, execute sustainable campus strategy integrated with science vision

Forge strong alliances with UChicago, ANL, URA and other national/international institutions

Develop Strategic Plan for Fermilab’s next 20 Years
Delivering on LBNF/DUNE is Fermilab’s highest priority
Proton Improvement Plan – II (PIP-II)
LBNF/DUNE-US Project Scope

Near Site – Batavia, IL

Far Site – SURF, Lead, SD

Over 50% of scope is at final design maturity
Definition of Phases

- Originally envisioned in the 2014 P5 plan

- **Phase I**
  - Accomplished with PIP-II, LBNF/DUNE-US, and DUNE International Partners
  - Meets P5 minimum requirements to proceed by 2035 timeframe
  - **Same project scope as proposed at CD-1R in July 2015**

- **Phase II**
  - Increased mass at Far Detector
  - More Capable Near Detector (MCND)
  - Increased beam power by Booster replacement

### Capability Description

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**Note 1:** requires upgrades to LBNF neutrino target and upgrades to Fermilab accelerator complex. The LBNF facility is built to support 2.4MW in Phase I.

**Note 2:** Near Detector Subproject threshold scope provides “day 1” requirements to start the DUNE experiment.
**Booster Replacement**

PIP-II provides a platform for extended physics program and future facility upgrades. Booster replacement scenarios are developed informed by input from Snowmass/P5:

- Cost-effective and fastest path to increased power to 2.4MW for LBNF.
- Capture options for additional medium and small-scale experiments.
- Enable long-term vision.

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**PIP-II Linac**

8 GeV Linac

8 GeV storage ring

Optional Storage Ring

Main Injector

RCS

Optional 1-3 GeV Linac

Optional Storage Ring

H- Injection easier at lower energy

H- Injection is challenge at 8 GeV
Far Detector Modules 3 and 4
**Neutrino Science**

**Vision:** US/Fermilab is universally acknowledged as the world leader in neutrino science for decades to come

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2040
**Vision:** Fermilab continues to be the leading U.S. center for CMS and second leading center in the world after our partner CERN

**CERN is our European sister laboratory and our strong partner in many areas**

**Major decadal goals**

- Maximize science from LHC Runs 2 and 3 data – ROC is back in Operations!
- Execute HL-LHC AUP and CMS Detector Upgrade Projects
- Advance R&D towards FCC @CERN

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**Operations**, **Construction**, **R&D / Prototyping**, **Physics studies / Pre-conceptual designs**
**S&T Precision Science**

**Vision:** Fermilab is a world center for accelerator-based Charged-lepton flavor violation (CLFV) and Dark Matter experiments, driven by intense particle beams and PIP-II/Booster Replacement

**Major decadal goals**
- Muon g-2: Complete data production, analysis, theory to achieve 5σ
- Complete Mu2e project and start science
- Design and build Mu2e-II, other upgrades

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- **Operations/analysis**
- **R&D**
**Vision:** Fermilab is an essential partner in world-leading cosmic science experiments and is contributing innovative R&D efforts toward future dark energy, dark matter, and cosmic microwave background (CMB) experiments and a coordinated campaign of experiments seeking to directly detect and study the properties of dark matter particles in the laboratory.

**Major Decadal Goals**

1. **Cosmic Surveys → Transition from DES to DESI, LSST**

2. **Cosmic Microwave Background → Grow: Major role in CMB-S4**

3. **Dark Matter Detection → Consolidate: G2, Axions, Sub-GeV**

### Surveys

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Vision: Fermilab is a world-leader in Accelerator Science and 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 for future large-scale accelerators.

Major decadal goals:
1. Deliver 2.4 MW proton beam power to LBNF/DUNE
   - Design, develop Booster Replacement
   - Develop High Power Targetry capabilities
2. Advance R&D in high field magnets and Superconducting RF for FCC @CERN
3. Initiate physics studies and concepts towards next major facility on Fermilab site
4. Continue to advance accelerator science as science in its own right!
5. Continue to enable the mission of other Office of Science programs
Fermilab Magnet and SRF Technology & FCC

- Fermilab accelerator technology R&D programs are highly synergistic with ambitious goals of FCC-ee and FCC-hh
- Fermilab magnet and SRF innovations can be leveraged for FCC:

Fermilab Nb$_3$Sn conductor with APCs exceeding FCC $J_c$ spec for first time

"mid-T bake" for high $Q_0$ SRF cavities at medium fields

World record 14.5 T Nb$_3$Sn dipole magnet
Emerging Science & Technology Capabilities

Quantum Information Science & SQMS
Artificial Intelligence / Machine Learning
Microelectronics
**Vision:** Fermilab, together with Chicagoland partners, is a major US quantum center; hosts national facilities for Quantum Science, developing innovative approaches that enable HEP discovery.

**Major decadal goals:**

1. **Execute SQMS Center decadal roadmap:**
   - Utilizing SRF technology to develop record coherence for 3D cavities in quantum regime demonstrated at FNAL ~ 2 seconds → Quantum computer → Solving complex problems in HEP, CMP, medicine, climate, national security

2. **Quantum Networks towards a Quantum Internet:**
   - Fermilab together with Chicagoland and other collaborators to deploy a multi-node, multi-user metropolitan scale quantum network in the greater Chicago area → Urbana → ORNL

3. **Deep Cryogenic electronics for utility-scale Quantum Computers**
AI/ML to accelerate discovery science

**Vision:**
Develop powerful AI algorithms that are robust, interpretable, and explainable for reconstruction, simulation, and operations.

**Optimized accelerator and experimental facilities**
with real-time, continuous learning control.

Build software and hardware infrastructure to support community AI computing needs including open data, benchmarks, and training.

Advance world-leading capabilities in AI-on-chip for edge ML applications – strong connections with smart sensing, internet-of-things, and novel microelectronics.

ML advances foster a diverse AI-ready workforce with strong multi-disciplinary teams and collaborations.
**Microelectronics**

**Vision:** Fermilab together with other national labs, academic and university partners establishes a major US Microelectronics Co-design center

**Major decadal goals**

1. **Support the community for extreme environment microelectronic development**
   - Enable lab-university-industry collaboration

2. **Maintain and grow expertise in state-of-the art integrated circuit design and testing to enable precision science measurements**
   - Develop smart detectors with integrated sensing-edge computing - communication

3. **Engage with Industry on Heterogeneous Integration and Advanced packaging solutions**
   - Leverage transformative technologies
Final Thoughts

• Particle physics is global! The evolving international context remains essential

• In this decade, Fermilab will complete the 2014 P5 strategic plan and follow the next P5 plan
  – DUNE Phase I will be realized, Phase II will be launched

• **Fermilab’s role for the HEP Community is an integral part of the Fermilab mission**
  – as host of the USCMS and DUNE collaborations
  – as the nexus for US HEP, and the broader Snowmass Frontiers communities
  – as a resource for large-scale engineering, co-located expertise and capabilities, and intellectual vitality
  – as an International User Facility, dedicated to a diverse workforce and collaborative culture, and to enabling world-class scientific discovery
Thank you for your contributions to defining compelling future directions for our field!