



Welcome and Overview of the Fermilab Program

Lia Meringa, Laboratory Director
55th Annual Users Meeting
Fermilab
13 June 2022

Welcome back to Fermilab!



Wilson Hall and IERC at dawn. The sloped roof on IERC is intended to mimic the curve of Wilson Hall rotated 90 degrees; this is especially evident when the image of IERC is doubled in the reflecting pond. Photo credit: Brian Rubik

Fermilab at a Glance

- America's particle physics and accelerator laboratory
- Fermilab operates the largest US particle accelerator complex

- ~1,900 staff and ~\$600M/yr budget
- 6,800 acres of federal land
- 4,000 scientists from >50 countries use Fermilab facilities

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.

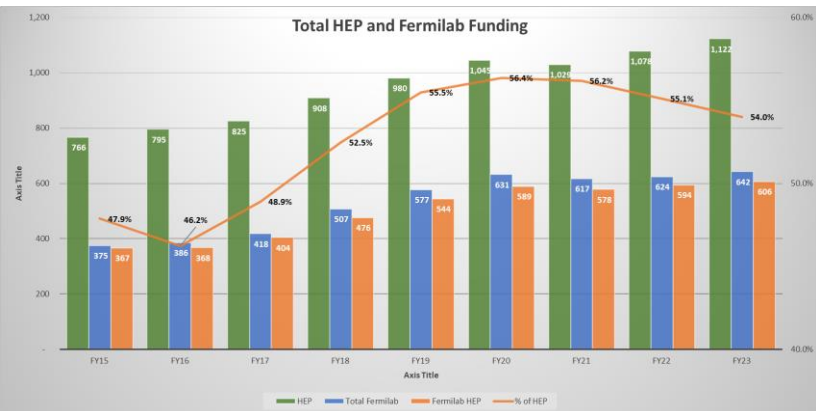
The Fermilab research community

- More than 4,000 scientists in 55 countries use Fermilab and its particle accelerators, detectors and computers for their research
- That includes more than 2,200 scientists from 175 U.S. universities and labs in 41 states
- Fermilab is attracting and training the next generation of a diverse HEP scientific workforce: 114 postdocs, 273 graduate students, 52 undergraduate interns
- Fermilab scientists also work at CERN, Sanford Underground Research Facility, SNOLAB, Cerro Tololo Inter-American Observatory, South Pole Telescope, NOvA Ash River Laboratory, Matter-wave Atomic Gradiometer Interferometric Sensor



Fermilab following the P5 strategy

- The flagship projects LBNF/DUNE/PIP-II, HL-LHC anchor the program but take many years to realize
- Fermilab simultaneously pursues a broad research effort in HEP
- The goal is a continuous stream of exciting results that attract/build/retain a diverse user community and scientific workforce
- Fermilab projects drive funding growth for HEP



Building for discovery: Project execution

Vision: Safely and successfully complete ~\$5.6B portfolio of projects in a timely manner and deliver P5 vision. Engage with community in next planning exercise.

DOE Project	TPC (\$M)	Program	Total (\$M)
LBNF/DUNE	\$3130	SBN	\$50
PIP-II	\$978	MAGIS-100	\$10
UIP	\$314	SQMS	\$115
Mu2e	\$274		
HL-LHC AUP	\$243		
HL-LHC CMS	\$181		
ACORN	\$142		
IERC	\$86		
LCLS-II HE	\$56		
SuperCDMS	\$40		

\$5.6B DOE funded

Major Science & Technology Initiatives



Higgs boson



Neutrinos



Dark matter



Dark energy and inflation



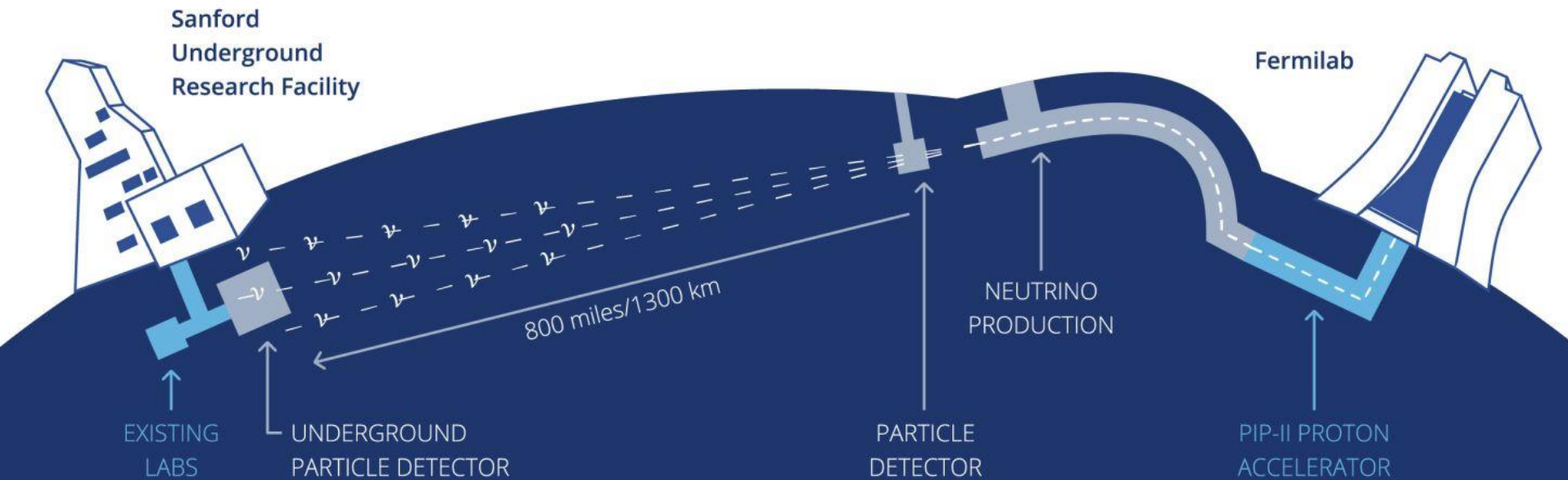
Exploring the unknown



DUNE: The world's most capable neutrino experiment, driven by LBNF and PIP-II

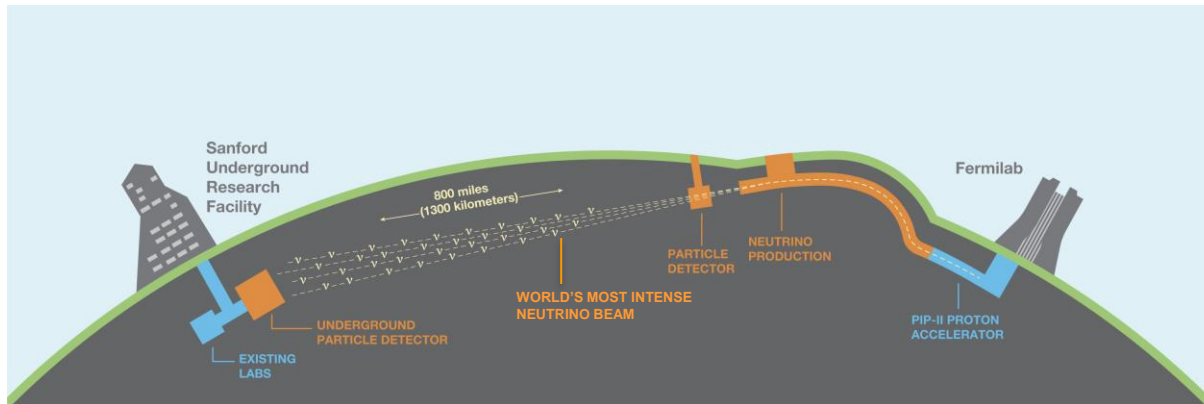
Vision

Fermilab is universally acknowledged as the world leader in neutrino science for decades to come



Fermilab's primary goal: establish a world-leading neutrino science program led by LBNF and DUNE, powered by PIP-II

- Powerful proton beams (**PIP-II**) using superconducting RF technology
 - 1.2 MW upgradable to multi-MW to enable world's most intense neutrino beam
- Dual-site detector facilities (**LBNF**)
 - Deep underground caverns (1.5 km) to support four huge liquid argon detectors
 - A long baseline (1300 km) and wideband beam neutrino beam
- Deep Underground Neutrino Experiment (**DUNE**)
 - The next-generation neutrino experiment with powerful liquid argon technology



LBNF/DUNE-US: Status and recent achievements

- Project will be executed through 5 subprojects - total TPC stable at \$3130M
- Far site excavation proceeding on time and on budget, over 30% complete and in baseline approval process – ESAAB expected in July
- Detector installation begins 2024; CERN and partners ready for production
- DOE provided new funding profile that accelerates “beam on date” to Mar 2031
- CD-1RR review in July; successful Director’s Review in May



Proton Improvement Plan – II (PIP-II)



PIP-II will provide a highly capable, reliable, upgradeable and expandable scientific infrastructure with significant savings to DOE

PIP-II Project construction begins!

- PIP-II received DOE CD-3 approval for start of construction/execution on April 18
 - Linac complex RFP issued
- Front end of PIP-II linac constructed and successfully tested with beam
- PIP-II cryoplant building 98% complete – Ribbon-cutting July 11th!
- HB650 prototype cryomodule in assembly – first of its kind



PIP-II is the first particle accelerator built in the U.S. with significant international contributions

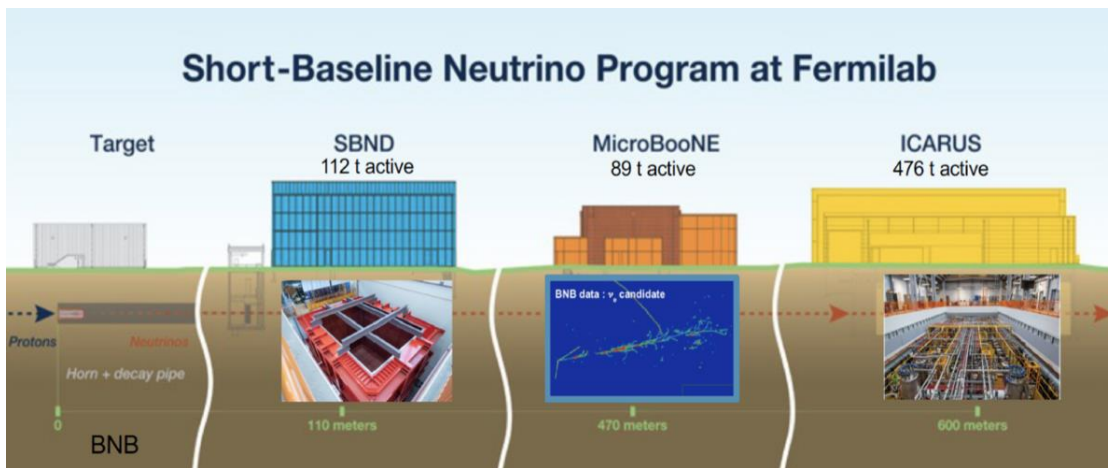
Short Baseline Neutrino (SBN) program

The SBN program is a P5 report recommendation:

Pursue an exciting accelerator-based short baseline neutrino program at Fermilab, SBN

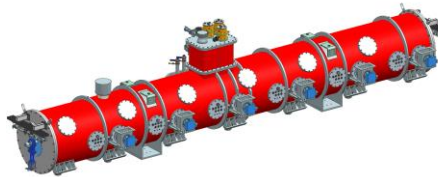
- to attract national and international neutrino community to Fermilab
- perform experiments using liquid argon detector technology – basis of DUNE
- establish and train diverse community of researchers needed for DUNE era

Science target: resolve the 4.8σ MiniBooNE low energy excess, with the possibility of discovering sterile neutrinos or other exotic neutrino physics



Major milestones in Neutrino Science

- **Deliver LBNF/DUNE**
 - Begin TSIB construction (FY23)
 - Execute “Host Lab” Plan (FY23)
 - Complete cavern excavation at SURF (FY24)
- **Deliver PIP-II**
 - Complete/test first ever HB650 prototype cryomodule (FY23)
 - Begin linac complex construction (Q1FY23)
- **Fully exploit SBN program**
 - Install and commission the SBND detector and begin taking data (FY23)



Target Systems Integration Building



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

Discovery Potential

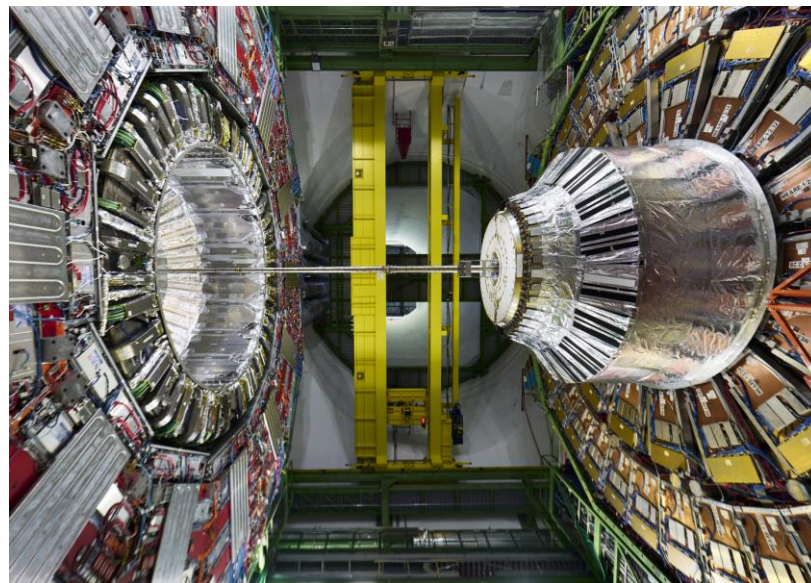
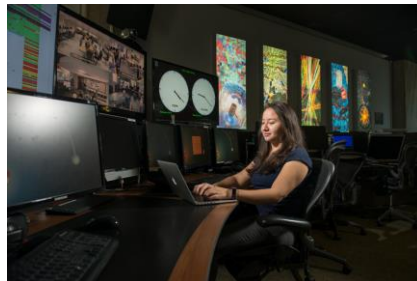
New insights into the building blocks of the universe, searching for new particles including those that could make up dark matter

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

- For more than two decades, Fermilab has played a significant role in the LHC
- Now CERN playing a significant role in DUNE
- Fermilab is host lab for US CMS (27% of CMS)



Fermilab's Patty McBride elected next CMS spokesperson



Fermilab as the Host Laboratory for US CMS

- **Forefront for Computing and Software in HEP Community**
 - Tier-1 facility - World's largest CMS Tier-1 facility outside CERN
 - Infrastructure to exploit HPC
 - Cutting-edge R&D
- **Host of the LHC Physics Center (LPC)** established center of excellence - Research, training, user support



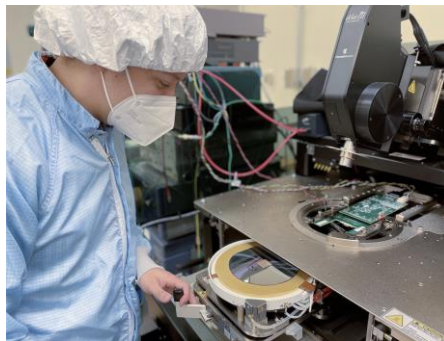
- **Remote Operations Center is Back in Operations!**



- First ROC in the World to be qualified for online DQM shifts
- Unique facility that enables USCMS members to take shifts in the US
 - Efficient knowledge exchange thanks to large critical mass at the lab
 - Allowing USCMS members to perform research at the LPC while taking shifts

Major milestones in Collider Science

- **Maximize science from LHC Runs 2 and 3 data**
 - Publish high priority analyses based on Run 2 dataset (FY24)
 - Ensure successful restart of detector and computing operations at Run 3 (FY23)
 - Restart in-person operations of the LHC Physics Center (FY23)
- **Execute HL-LHC CMS Detector Upgrade Project**
 - Complete prototyping and start pre-production phase for the detector upgrades and achieve CD-2/3c (FY23)
- **Execute HL-LHC AUP Upgrade Project**
 - Re-baseline project (FY23)
 - Successful magnet demonstration (4 or 5 in FY23)
- **Advance FCC R&D**



Scientist Douglas Berry testing FNAL-designed detector components

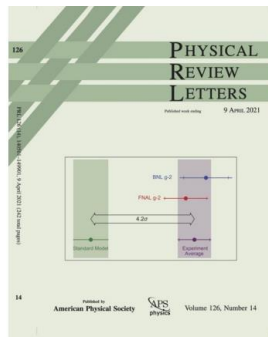


FNAL cavity using FNAL SRF technology

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

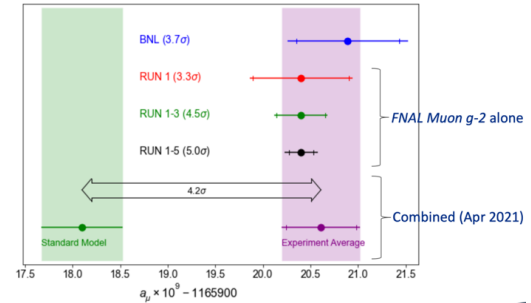
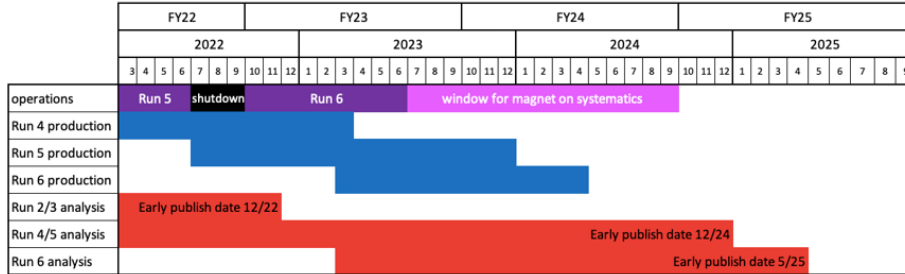
Discovery Potential

The Muon g-2 and Mu2e experiments use muons, particles that we can produce and control, as a probe of possible new forces or quantum phenomena that could have tiny or rare effects on how muons behave.



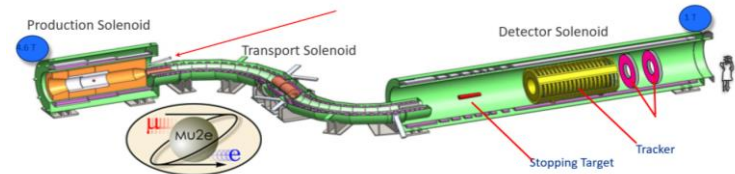
Major milestones in Precision Science

Muon g-2



Mu2e

- Baseline Change Review (Q1FY23)
- Production solenoid delivery (Q2FY23)
- Delivery of first electrostatic septum (Q1FY24)
- Project complete CD-4 (Q3FY25)
- Working toward conceptual design for Mu2e-II, enabled by PIP-II



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. The Cosmic Physics Center will unify the activities at the laboratory and in the Chicagoland area, in particular UChicago and ANL, while serving a national cosmic user community.

Discovery Potential

Surveys of galaxies and cosmic background radiation use precise measurements of cosmic structure to learn about fundamental physics of cosmic acceleration, new forms of matter, and properties of cosmic neutrinos. A coordinated campaign of experiments seek to directly detect and study the properties of dark matter particles in the laboratory.



Major milestones in Cosmic Science

	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
	DES										
Surveys		Dark Energy Spectroscopic Instrument (DESI)									
			Rubin Observatory/LSST/DESC								
CMB	SPT-3G									CMB-S4	
Dark Matter	ADMX-G2										
axions						ADMX-EFR					
	SENSEI										
sub-GeV			SuperCDMS				OSCURA				

Near-term Deliverables / Milestones

- Develop new ways to probe cosmos
 - Advance R&D on new technologies for future large surveys and CMB experiments (FY24)
- Exploit new quantum sensor technologies to broaden search for particle and wave-like dark matter
 - Design experiment to search for axion dark matter in 2-4 GHz frequency band (FY22)
 - Design 10-kg Skipper CCD dark matter experiment (FY23)
 - Build and commission SuperCDMS at SNOLAB (FY23)
- Use cosmos to understand cosmic acceleration and physics of neutrinos
 - Support operations for LSST (Rubin Ops and DESC) to enable science at first light (FY23)
 - Complete science analysis from full DES dataset (FY24)
 - Complete operations of SPT-3G survey (FY24)

Late Breaking News

From Dark Energy Survey (E-939)

- The three URA Awards were presented at the 55th Annual Fermilab User's Meeting to three Dark Energy Survey Collaborators:
 - The Early Career Award was presented to **Dr. Elisabeth Krauss** (U. Arizona) for her leadership in DES's Y3 multi-probe cosmology results.
 - The Graduate Thesis Award went to **Dr. Maria Vincenzi** for her U. Portsmouth Ph. D thesis "*Core-collapse contamination in photometric samples of Type Ia Supernovae*"
 - The Alvin Tollestrup Post-Doc Award to **Dr. Alex Amon** (Stanford U.) for her leadership in DES Weak-Lensing Science

DES Hybrid Collaboration Meeting at Duke U. May 2022



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.

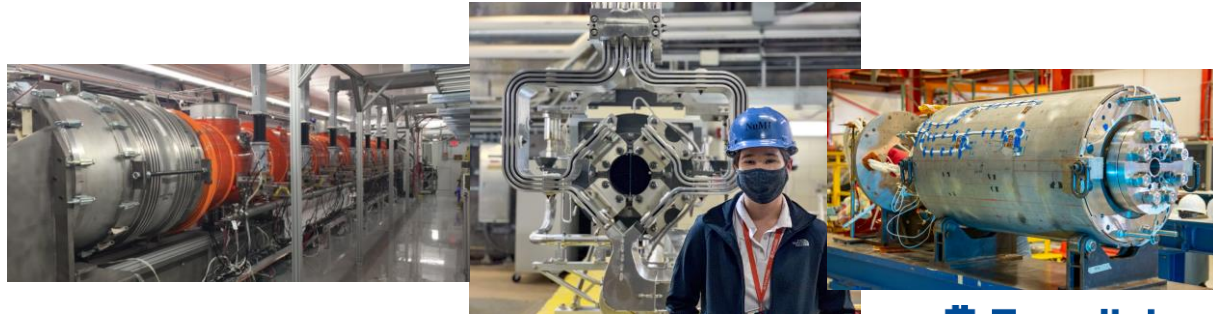
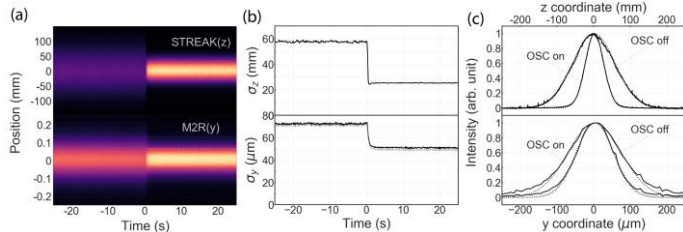
Fermilab is an essential partner of choice to future large-scale accelerators.

Discovery Potential

Future accelerator-based experiments will be enabled by more intense beams, higher accelerating gradients and more power accelerator magnets.

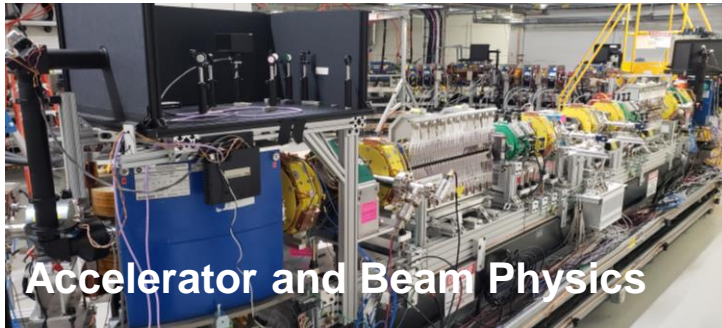
Fermilab's IOTA/FAST Facility provides a unique platform for accelerator science.

- World's first experimental demonstration of Optical Stochastic Cooling at the IOTA ring (accepted to *Nature*)



World-leading capabilities

Accelerator Science & Technology



Fermilab Accelerator Complex User Facility Modernization

Vision/Goals

- Highly effective, efficient accelerator operations with a modernized control system, work and lab spaces and integration of emerging technologies like robotics and AI/ML for accelerators



Key Initiatives

- **ACORN:** DOE O413 project to modernize the accelerator control system and replace end-of-life power supplies; partnership with INL for user interface and human factors expertise
- **Robotics Initiative:** Motivated by need to increase worker safety and efficiency for accelerator and target operations
- **CAST:** Proposed building to potentially include updated Main Control Room, co-located controls and instrumentation staff and space for USPAS, visiting scientists and engineers

Recent Achievements

- Completed Accelerator Operations Requirements Workshops – broad labwide participation; documented requirements for AI/ML for accelerator ops, cyber security, ES&H, software development, etc.
- Completed Robotics Strategic Plan and initiated partnership with National Robotics Engineering Center (NREC) at Carnegie Mellon

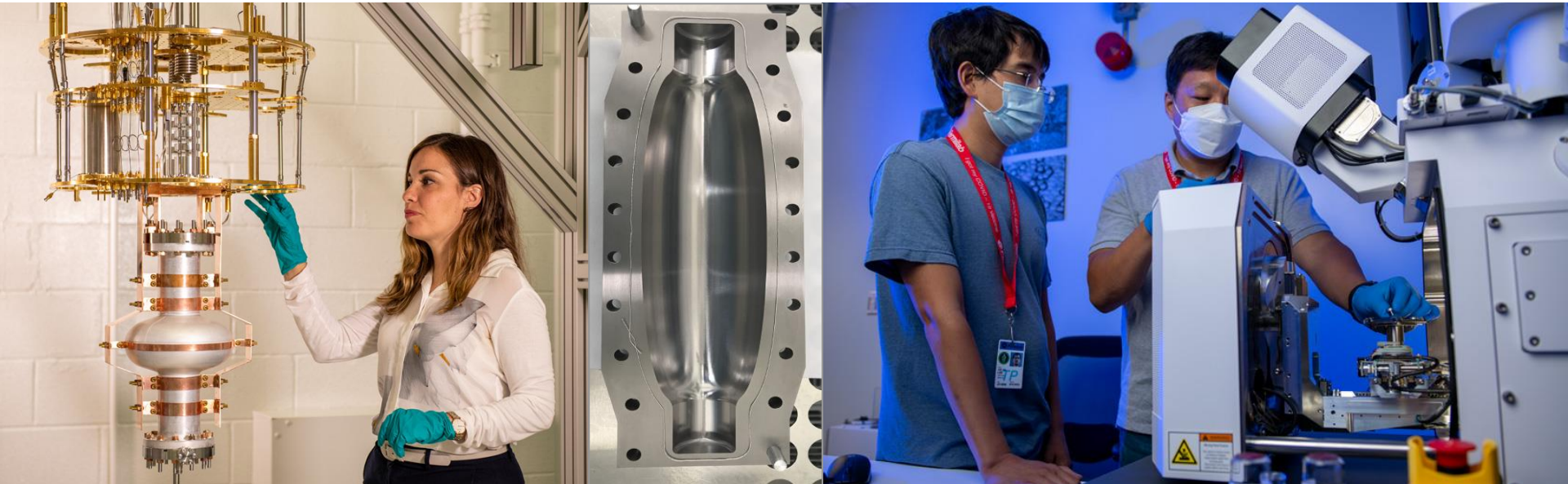
Fermilab visitors Tia Miceli, Adam Watts, and Mayling Wong-Squires with CHIMP (CMU Highly Intelligent Mobile Platform) at NREC



Largest accelerator complex in the U.S. and the only one in the world to produce both low- and high-energy neutrino beams and enable precision science experiments

Emerging Technologies and Capabilities

Vision: Fermilab, together with Chicagoland partners, is a major US quantum center; hosts user facilities for Quantum Information Science and Technology.



Fermilab quantum research

QIS for HEP: Quantum sensors for direct dark matter detection

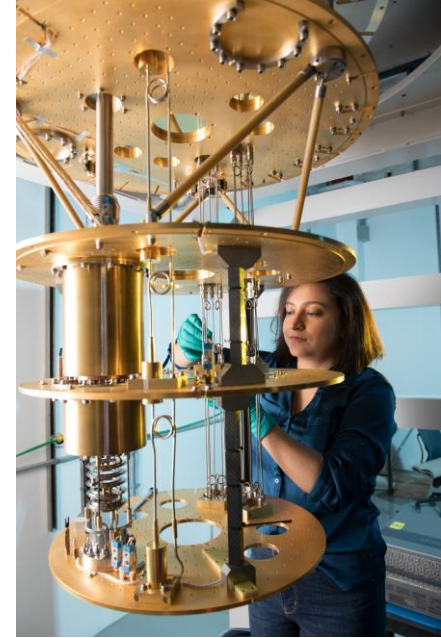
- MAGIS-100 cold atom interferometers
- Qubit-based sensors for axion detection
- Dark SRF cavity-based sensors for dark photon detection

QIS for HEP: Quantum computers to simulate HEP quantum dynamics

- Real-time QCD dynamics including neutrino-nuclear
- Early universe phase transitions
- Quantum gravity and emergent spacetime

HEP for QIS

- Better qubits from Fermilab's expertise in superconducting devices and materials
- Control and readout systems for quantum processors
- Picosecond synchronization for quantum communications



Fermilab leads one of five NQI Centers (SQMS) and has a major role in the ORNL led NQI Center (QSC)

SQMS: Fermilab hosts one of five national quantum centers

Vision/Goals

- Advance quantum technologies as new and **unique tools** for particle physics discovery
- Build upon Fermilab **technological strengths** to advance quantum technology
- Develop and deliver **new quantum platforms and testbeds** to enable a new decade of experiments in quantum computing and sensing for Fermilab and the broader physics community
- Make an impact in **technology transfer** and commercialization



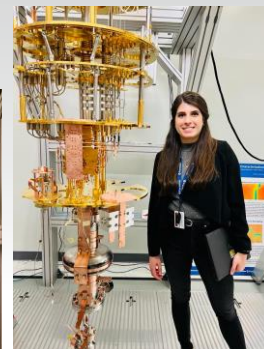
Key Initiatives

- **Develop and deploy Fermilab's first quantum computer:** enabled by our own expertise in superconducting RF technology and cryogenics, to solve pressing and currently unapproachable HEP physics problems
- **Develop and deploy quantum sensors for fundamental physics: realize pilot experiments,** searches for dark matter, precision experiments, gravitational waves, quantum physics
- **Demonstrate qubits of record performance with immediate tech transfer**



Recent Achievements

- **Record coherence** cavity-qubit integrated quantum system, quantum memory
- **World's best exclusion limit** for dark photon/dark matter at ~ 1.3 GHz frequency
- Launched unique **multi-institutional study** for materials characterization, nanofabrication and measurements of quantum devices
- > 40 publications, >100 students and postdocs supported



Microelectronics and Detector R&D



Farah Fahim
2021 DOE Early
Career Research
Award

Front-end implementation
of AI/ML neural networks
for on-detector radiation-
hard edge compute

Fermilab received a 2021 funding award from SC for **Microelectronics co-design research** on the topic

“Hybrid Cryogenic Detector Architectures for Sensing and Edge Computing enabled by new Fabrication Processes”

- Leverages and strengthens expertise in cold ASIC electronics developed for DUNE
- Partnership with ORNL, BNL, 6 universities, Qualcomm, and INFN

Fermilab’s **Detector R&D Strategic Plan** identified two other focus areas where the lab has special expertise and facilities as well as long-term programmatic interest

- Picosecond timing for advanced particle detectors
- Advances in detectors using liquid argon/xenon

Fermilab’s Test Beam Facility including the new **Irradiation Test Area** is essential for national detector R&D efforts including HL-LHC upgrade projects

Fermilab AI/ML research

Fermilab has identified three focus areas where our mission needs overlap with special expertise related to AI/ML:

- “Real-time” fast AI integrated into the sensor for data-intensive HEP experiments, includes FPGAs and “AI on a chip”
- AI/ML for optimal operations of accelerators and experiments - robust real-time controls with continuous and autonomous learning and calibration systems
- Uncertainty quantification and bias; essential to get a better quantification for HEP applications such as cosmology or theory → data mapping



Nhan Tran
2019 DOE Early Career Research Award

Deep Learning
Acceleration of the Boosted Higgs Program and HEP Computing



Brian Nord
2021 DOE Early Career Research Award

Simulation-based inference for cosmological parameter estimation and discovery



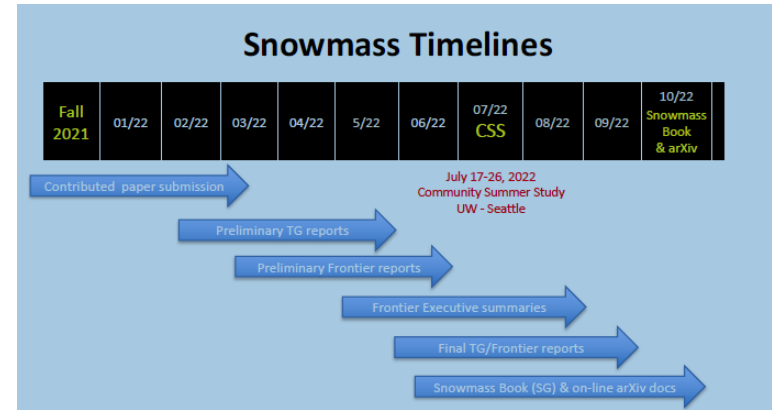
Alexandra Čiprijanović
Wilson Fellow, AI/ML principal investigator



Jennifer Ngadiuba
Wilson Fellow, AI/ML principal investigator

Fermilab engages in community planning via Snowmass and next P5

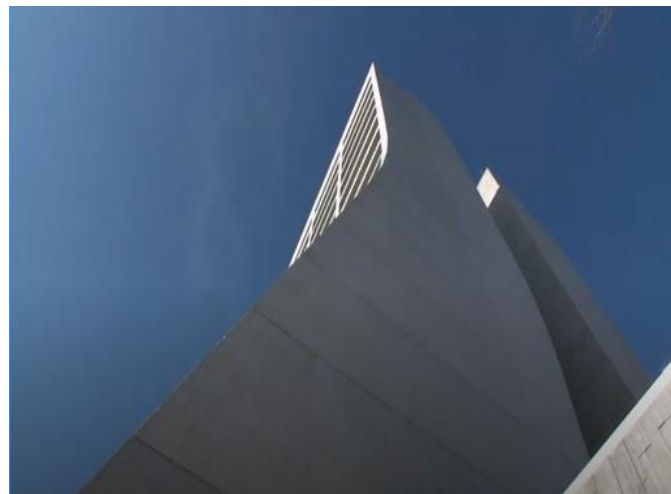
- The US Particle Physics Community Study (Snowmass), led by Fermilab distinguished scientist Joel Butler, is close to completion; opportune time to develop US strategy for timeframe beyond LBNF/DUNE/PIP-II
- **Great labwide participation in Snowmass** (whitepaper contributors, convenors, working group members) and in Fermilab Science Strategic Planning Workshops
 - Thank you to Scientist Advisory Council and SAC working group convenors for leading [All-Scientist Retreats and putting together an excellent summary!](#)
- **Two Fermilab working groups launched in preparation for the next P5**
 - Science Priorities Working Group, chaired by Jim Amundson
 - Proton Intensity Upgrade Central Design Group, chaired by Steve Brice and Brenna Flaughter



Thanks to URA for Snowmass Travel Awards!

Summary

- Our mission is strong, compelling and beautiful!
- Our people are world-class!
- We remain laser-focused on our science mission and executing the 2014 P5 Plan
- Ready for the future, actively involved in Snowmass toward the next P5
- Together with our user community and partners, we are defining a bold yet realistic vision and a strategic plan for Fermilab to remain a global leader in High Energy Physics



My commitment to the success and productivity of the Fermilab User community and to our responsibilities as host lab is unwavering

Thank you!



Wilson Hall and IERC at dawn. The sloped roof on IERC is intended to mimic the curve of Wilson Hall rotated 90 degrees; this is especially evident when the image of IERC is doubled in the reflecting pond. Photo credit: Brian Rubik

Site Access changes

- DOE requirements (many have changed in the last couple years)
- The security of the world has changed
 - International threats/risks
 - Domestic threats/risks
 - US competitiveness/Economic threats
- Increased efforts to protect the safety and security of FRA employees, users, subcontractors and members of the general public.
- Areas where Fermilab was not in compliance with Federal Regulations that prompted necessary modifications to the security posture.

Site Access changes

Retaining the lab's open culture as we implement the increased security requirements is of great importance to the lab and to the DOE.

To simplify site access, we have implemented a **site access and badging system** that will allow us to gather information in advance of a visit so the experience at the gate is more streamlined.

We are making additional changes to our security department and creating a plan that will further enhance the onboarding experience for users, affiliates, employees and subcontractors.

SoLita Greene is Fermilab's new Facility Security Officer. Soon she will provide more details of our plans to balance our security needs with our culture.

Finally, Fermilab has received funding for a new **Welcome and Access Center**. This facility will take us to the next level and enable us to more properly function as the host lab and create an easy, pleasant experience for our international users.

For more information about site access and badging please visit our website here:

<https://eshq.fnal.gov/security-site-access/>