



Fermilab's Science Priorities: A Vision for the Future

James Amundson

Users Meeting 2023

June 30, 2023

Fermilab's Future

2023 is an important year for the future of the Fermilab program

- Today Fermilab is a vibrant user facility
 - We are working very hard to welcome people back to site
- We are planning for the future of the US HEP Program
 - **The Particle Physics Projects Prioritization Panel (P5)**
- We are also planning for the future of the Fermilab facility
 - **Fermilab Accelerator Complex Evolution (ACE)**
 - Upgrades to the Main Injector
 - A replacement for the Fermilab Booster

The P5 Process

- <https://www.usparticlephysics.org/p5/>

2023 P5

P5 (Particle Physics Projects Prioritization Panel) reports to HEPAP (High-Energy Physics Advisory Panel) that advises High-Energy Physics of DOE Office of Science and Division of Physics of NSF. We will build on the “Snowmass” community study to hash out priorities for the next 10 years within 20-year context.

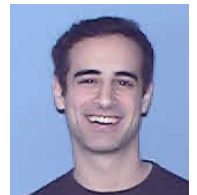
- P5 Town Hall at Lawrence Berkeley National Laboratory, February 22-24, 2023, with a focus on Cosmic Frontier (except for High-Energy Astrophysics)
- P5 Town Hall at Fermilab/Argonne, March 21-24, 2023, with a focus on Neutrino, Rare Processes and Precision Frontier, High-Energy Astrophysics
- P5 Town Hall at Brookhaven, April 11-14, 2023, with a focus on Energy, Instrumentation, Computational Frontiers
- P5 Town Hall at SLAC, May 2-5, 2023, with a focus on Underground, Accelerator, Theory Frontiers, Community Engagement

Fermilab's Science Priorities

May 30, 2022, charge from the Director:

In advance of the P5 meeting later this year, we are asking that you chair a Fermilab working group to help prepare the laboratory's input to the panel. Your deliverable should be a prioritized set of recommendations for the U.S. particle physics program and Fermilab's role over the next decade to be presented to the P5. The recommendations should integrate the broader community's scientific aspirations set in a global context.

Fermilab's Science Priorities Working Group Mugshots



The Science Priorities Working Group

- The working group met regularly starting summer of 2022
- Divided work into subgroups
 - **Neutrinos**
 - **Rare and Precision**
 - **Cosmic**
 - **Energy**
 - **Theory**
 - **Accelerator and Detector Science and Technology**
 - **Quantum**
 - **Computing and AI**

The P5 Town Hall presentation was the final summary of the group's work



Fermilab Program

Members of the Fermilab Science Priorities Working Group on behalf of Fermilab

J. Amundson, B. Benson, D. Berry, C. Boffo, S. Brice, A. Canepa, M. Carena, A. Drlica-Wagner, J. Estrada, F. Fahim, A. Fava, B. Flaugher, B. Fleming, A. Gaponenko, A. Grassellino, R. Harnik, P. Machado, P. Merkel, J. Ngadiuba, F. Pellemoine, C. Polly, S. Posen, A. Schukraft, A. Sonnenschein, P. Spentzouris, M. Toups, N. Tran, S. Valishev, T. Walton

Vision for US Particle Physics

- With our international partners, realize the full scope of the **best-in-class DUNE experiment** in a timely fashion
- With our international partners, participate as strong contributors in the **LHC and HL-LHC**
- Lay the foundation for an **international Higgs factory** and a **next-generation multi-TeV collider**
- Enable the accelerator complex to **probe the unknown** with a broad, balanced, diverse, discovery program
- Uncover the mysteries of the universe with **CMB-S4 and dark sector initiatives**
- Engage in enhanced **Accelerator R&D, Detector R&D, and Theory** efforts to enable the science
- Excel in National Initiatives in **Microelectronics, QIS, and AI/ML**

Engage, train, and support a **diverse community**

How to accomplish our science

Exploit the science of the current program to its fullest

Execute our current project portfolio with excellence

Lay the foundation for our future program

- **Continue to be a partner of choice** in international science
- **Serve as an excellent host** for our US-based world-leading international facilities
- **Find the right balance**
 - between executing the current program, laying the foundation for the future, and having free energy to respond to new discoveries;
 - between small, medium and large-scale experiments; and
 - between projects, operations, and research
- **Build and sustain the diverse workforce** for the next generation of everything we do

Commitment to Equity, Diversity, Inclusion, and Accessibility

The principles of equity, diversity, inclusion, and accessibility (EDIA) are crucial for maintaining a just and healthy work environment as well as for maximizing the scientific output of the basic research community; they constitute a core set of values of the community.
HEP is a global, open enterprise.

- Fermilab, as a focal point of the US HEP community, strives to be an exemplar for leading EDIA initiatives in HEP
- Fermilab believes that leadership in EDIA requires creating **a culture with real, actionable consequences**

Advancing EDIA

note: EDIA presentation at P5 superseded this slide

Fermilab is advancing EDIA by

- **Creating pathways** for members from marginalized backgrounds to participate in and remain in the field
- **Focusing EDIA funding on domain experts** with impactful EDIA proposals
- **Utilizing accountability, monitoring and transparency** as tools to obtain culture change
- **Enforcing common and actionable standards** for collaboration and institutional codes of conduct that can be linked back to funding
- **Tailoring** the implementation of DOE access rules in a way that is consistent with HEP's international pursuits

Vision for the Fermilab Facility

- The Fermilab Facility must have the capability to support
 - **The full DUNE program**, including both Phase I and Phase II
 - An ongoing program of **small- and medium-scale experiments**
 - **Research into future accelerators**
- ... all while maintaining enough **capacity to respond to developments** in the field

The Fermilab Accelerator Complex Evolution (ACE)

ACE has two components

- **Upgrades to the Main Injector and target station** will allow DUNE to achieve world-leading results on an accelerated schedule
- **A Booster replacement** will
 - Ensure high intensity for DUNE Phase II → CP Violation *measurement*
 - Enable the **capability** of the complex to serve precision experiments and searches for new physics with beams from 2-120 GeV
 - Create the **capacity** to adapt to new discoveries
 - Provide a robust and **reliable** platform for the future of the Fermilab accelerator complex
 - Supply the high-intensity proton source necessary for future multi-TeV accelerator research



Capability
Capacity
Reliability

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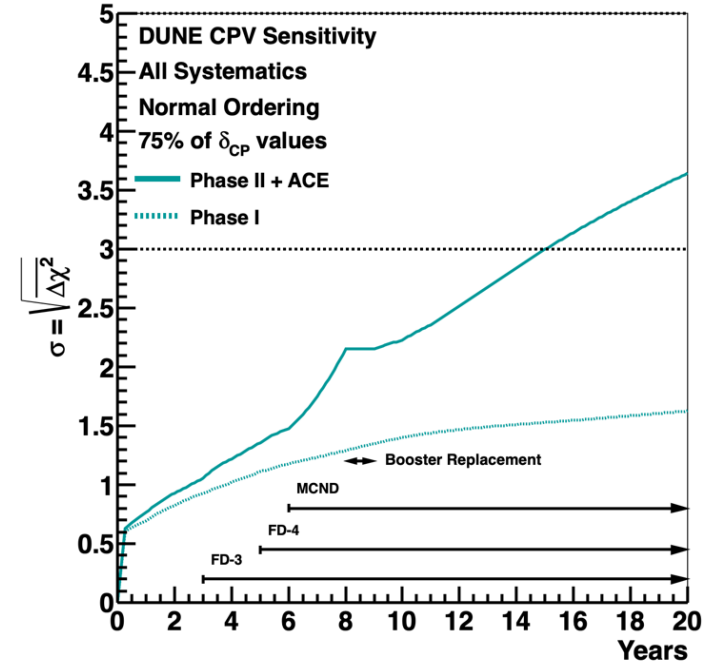
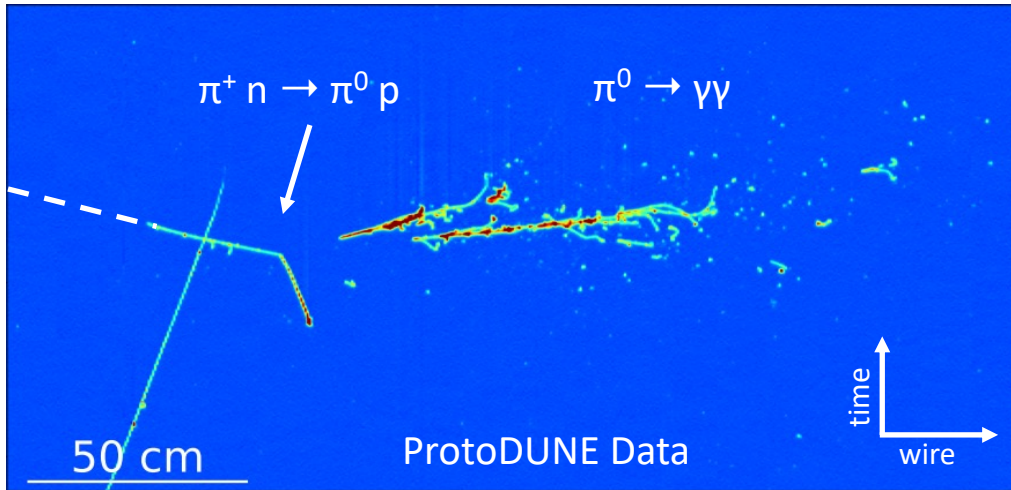
Capability
Capacity
Reliability

More on ACE later in this talk!

Commit to the Full DUNE Program

DUNE will be a best-in-class neutrino experiment and comprehensively test the 3-neutrino paradigm with the completion of its Phase II upgrades:

- Additional far detector mass to reduce statistical uncertainties
- More capable near detector to reduce systematic uncertainties

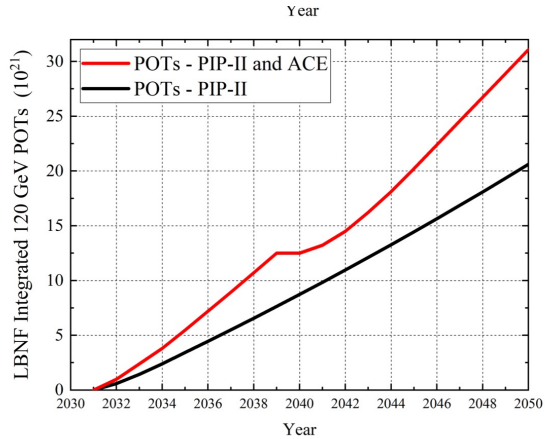


CP violation sensitivity to 75% of δ_{CP} values

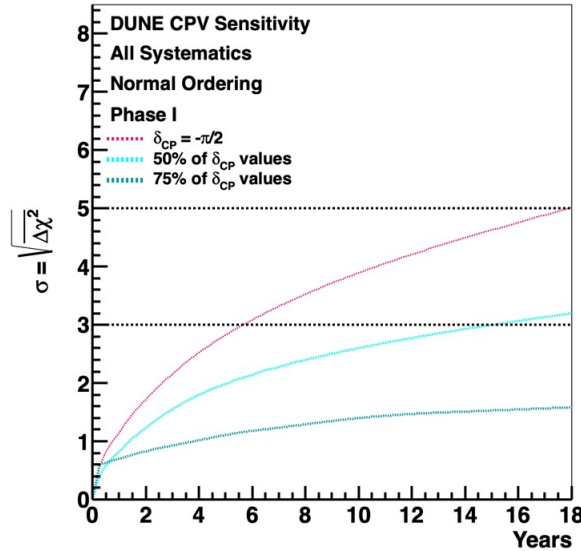
- Meets goal established in 2014 P5 recommendations

Enabling World-first Measurements from DUNE

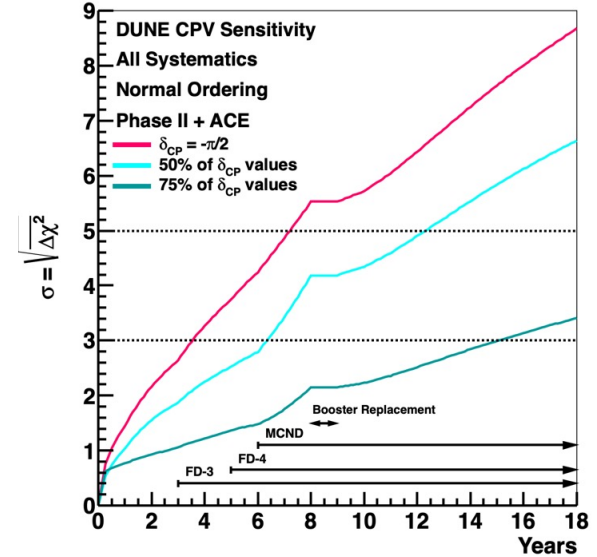
Early ACE upgrades to the Main Injector and target station, combined with completing DUNE Phase I puts DUNE and Hyper-K on a similar timescale for discovery



POT with ACE upgrades



Phase I



Phase II w/ ACE

Fermilab's Short-baseline Accelerator ν Program

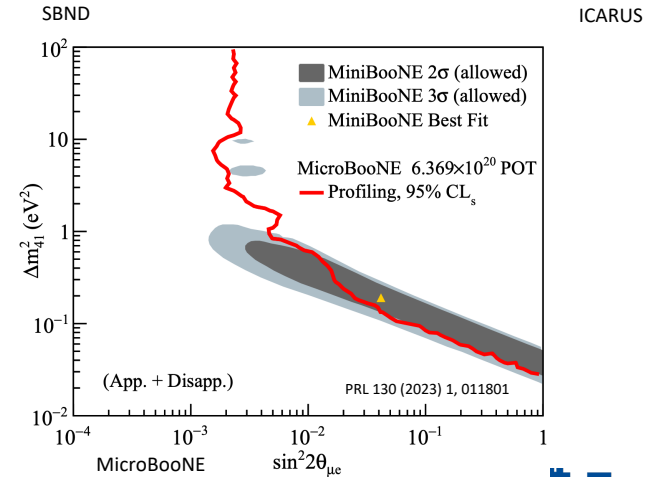
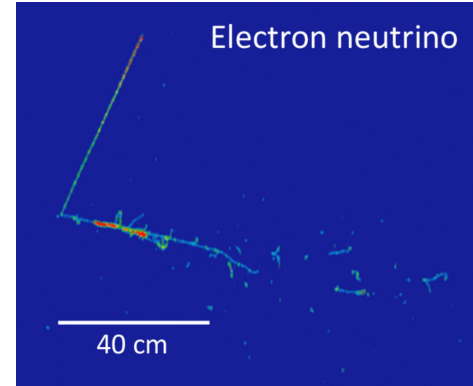
Suite of medium-scale neutrino experiments vital for the field

Engine for advances in neutrino physics, detector R&D, and theory

- 80 SBN-related papers and counting
 - Over 2800 citations

Establishing FNAL-based LArTPC community, training the next generation

Results and discoveries from the current SBN program will inform future short-baseline neutrino physics program



The Energy Frontier - The LHC and HL-LHC Program

Fermilab is committed to maintaining its **leadership** role in fully exploiting the LHC and HL-LHC programs along with our partner CERN, USCMS, and international collaborators.

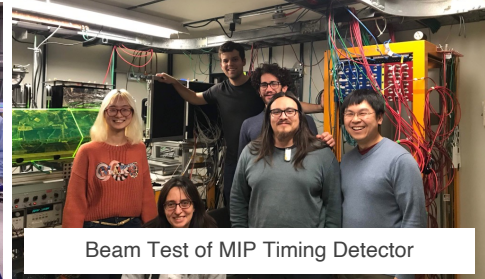
- Make the next set of **groundbreaking discoveries** and high-precision measurements using the LHC and HL-LHC data with over 1000+ publications to date.
- Complete the HL-LHC **detector and accelerator upgrades**.
- Play a critical role in CMS **operations** through the end of HL-LHC. Be the driver of S&C innovation aimed at facing the challenges foreseen at the end of the decade.
- Enhance the CMS detector and **explore new opportunities** including proposed high η experiments
- Enable the community through hosting the USCMS Collaboration, the LHC Physics Center, and facilities for detector construction and software and computing.



Outer Tracker Module



Prototype HGCAL Cassette



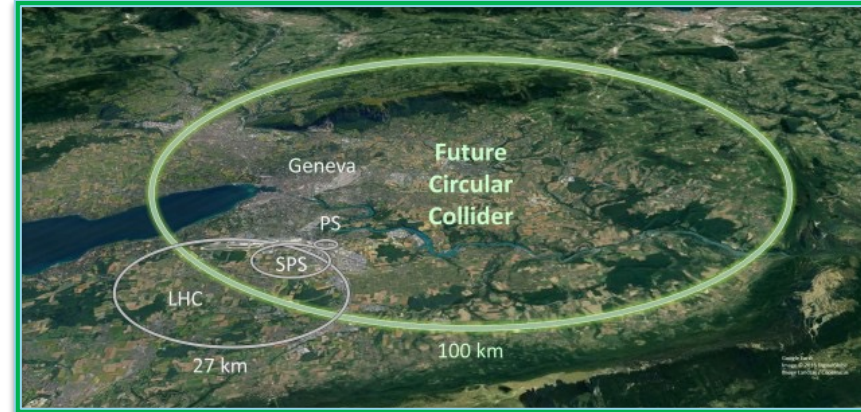
Beam Test of MIP Timing Detector


The Energy Frontier – Beyond the LHC and HL-LHC Programs

Precision measurements of the Higgs boson and EW sector and BSM searches at future colliders will shed light on key open questions in particle physics.

- This exploration will require an investment in accelerator technology research to
 - Contribute to the international effort to build a Higgs factory at CERN
 - Revitalize accelerator and detector R&D towards a next-generation multi-TeV energy frontier machine
 - Take advantage of emerging technologies
- *Fermilab is poised to host a next generation multi-TeV energy frontier collider, as a global endeavor, following the completion of DUNE*
- In order to make realistic progress, a substantial investment in **targeted accelerator research** as well as **associated detector research** will be required

These efforts should be organized through **national integrated accelerator R&D and detector R&D programs** that are aligned and coordinated with our international partners



 International MUON Collider Collaboration

March 15, 2022
<https://muoncollider.web.cern.ch>

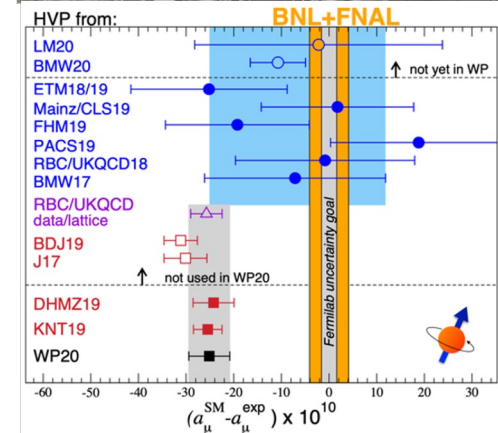
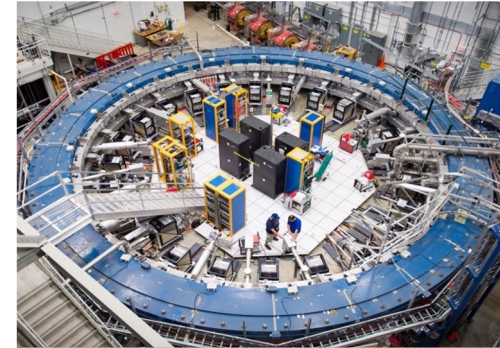
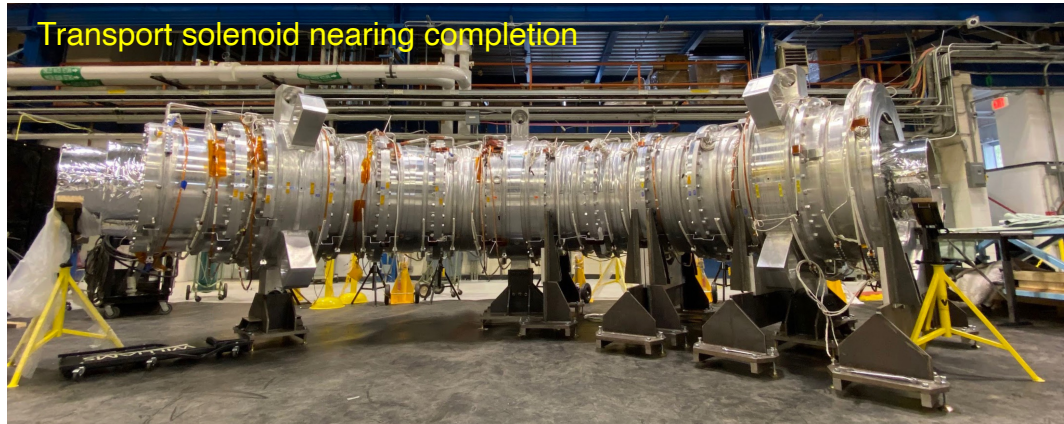
Promising Technologies and R&D Directions for the Future Muon Collider Detectors

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Muon program well underway at Fermilab

- FNAL's accelerator infrastructure is a key enabler of world-leading IF experiments such as Muon g-2 and Mu2e
- Muon g-2 just completed TDR goal collecting 21x BNL stats
- Mu2e experiment first physics run in 2026, prior to the long shutdown for LBNF construction

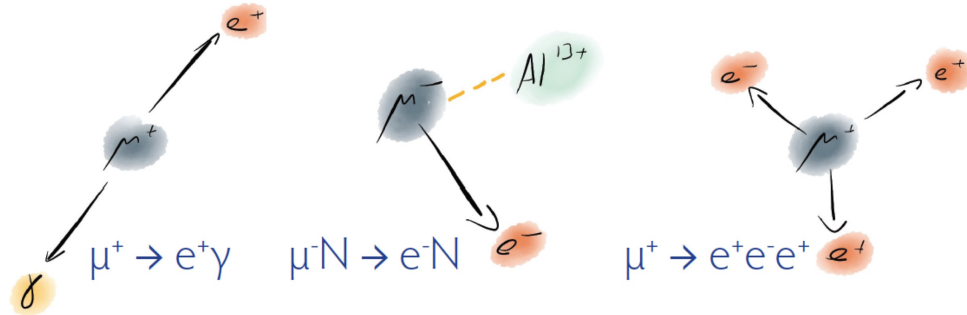
–Healthy transition from data analysis on g-2 to data taking on mu2e



Recent and ongoing results from g-2 expt. and theory community

Muon Charged Lepton Flavor Violation for the Future

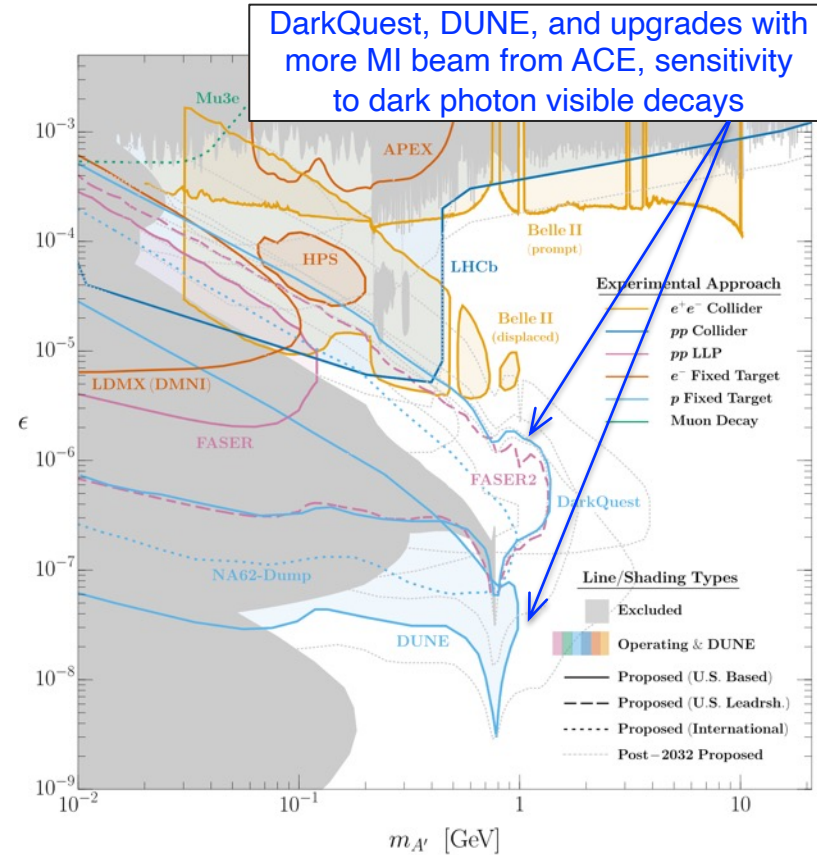
- Mu2e-II is designing for another 10x in sensitivity with direct injection of PIP-II beam
 - Relies on continuous wave capability of PIP-II
- Future muon experiments could leverage the PIP-II linac and ACE to power next-generation charged lepton flavor violation experiments
 - Up to 100x gains



- Precision muon experiments have synergies with muon collider R&D and Fusion Energy Science, including target design, rad-hard solenoids, and accumulation ring

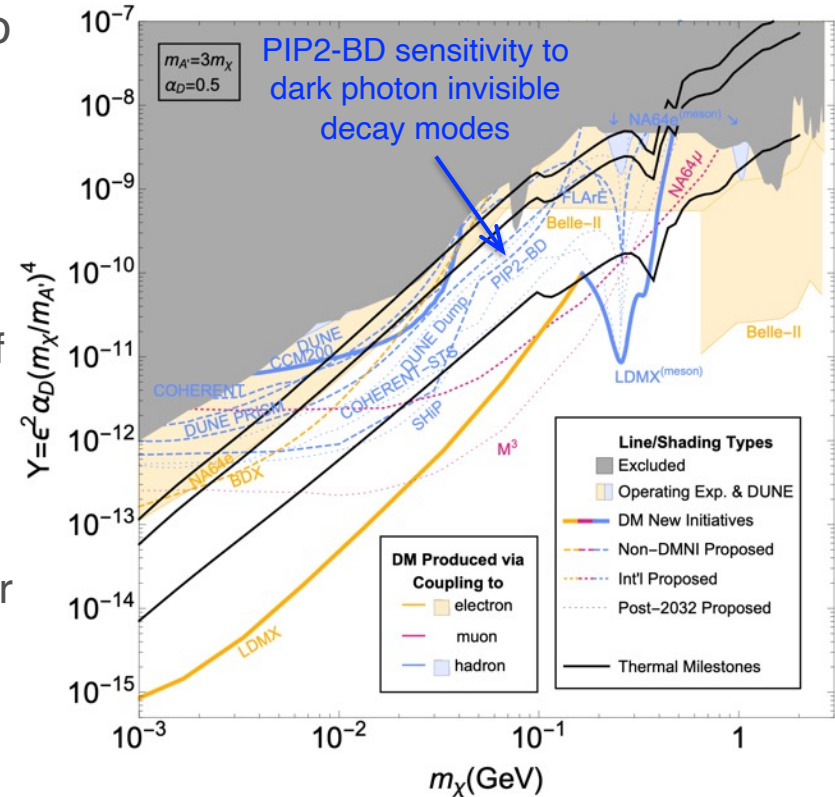
High Intensity Proton Beam to Explore Dark Matter Portals

- ACE will also enable excellent opportunities for accelerator-based dark sector searches at modest cost and scale
 - **At high energy**, proton beam dump searches can probe new parameter space making use of existing accelerator infrastructure and experiments (120 GeV beam)
 - At low energy, proton beam dump searches can form part of a new neutrino and dark sector facility that leverages the full power of the PIP-II beam coupled to an accumulator ring



High Intensity Proton Beam to Explore Dark Matter Portals

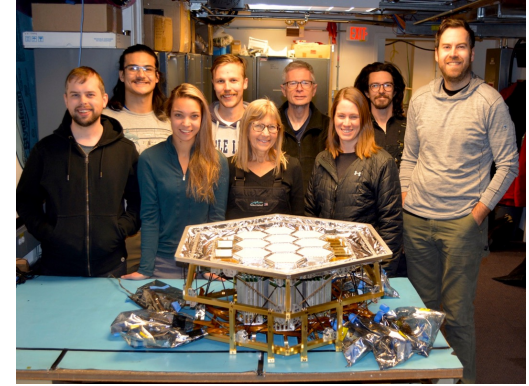
- New FNAL accelerator infrastructure will also enable excellent opportunities for accelerator-based dark sector searches at modest cost and scale
 - At high energy, proton beam dump searches can probe new parameter space making use of existing accelerator infrastructure and experiments
 - **At low energy**, proton beam dump searches can form part of a new neutrino and dark sector facility that leverages the full power of the PIP-II beam coupled to an accumulator ring (2-8 GeV beam)



Cosmic Science

- The Cosmic Frontier addresses fundamental questions by connecting the very small to the very large:
 - **What is the dark matter?**
 - **What is dark energy?**
 - **What is the physics of inflation?**

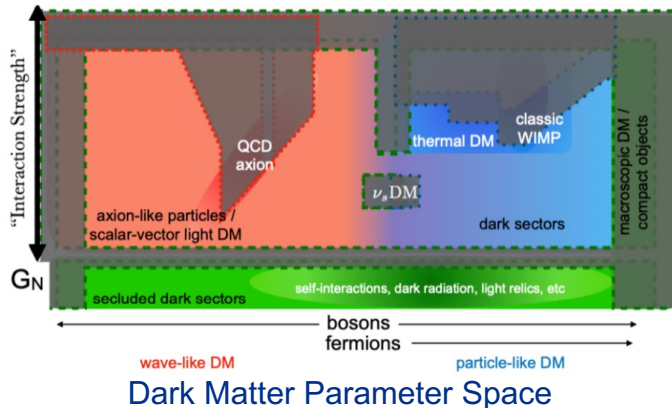
Aim high, search wide, delve deep



SPT-3G Focal Plane at the South Pole

Fermilab roles capitalize on unique strengths, core infrastructure, detector development support, facilities, and large talent pool

- Technical capabilities built up from accelerator program are applicable to Cosmic, including **largest HEP investment in detector development**
- **Large pool of engineers and technicians**, all available to User community



Cosmic Science at Fermilab in the Coming Decade

Operating Projects in the next decade include **Rubin LSST/DESC** and **SuperCDMS**

The highest priority future Cosmic Frontier effort at Fermilab in the next decade is **CMB-S4**

Other important projects are Axion DM (ADMX-EFR), Sub-GeV DM (Oscura), Dark Energy (Spec-S5)

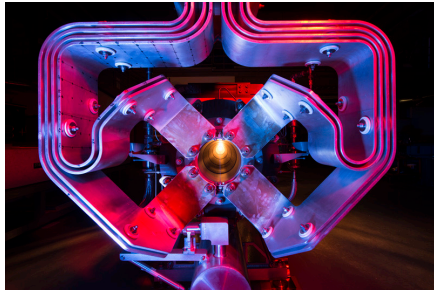
- **Partner with other labs and universities** to deliver the next generation of small projects
- Fermilab will **explore opportunities to build an axion center** with large magnets to serve the dark matter experimenter user community



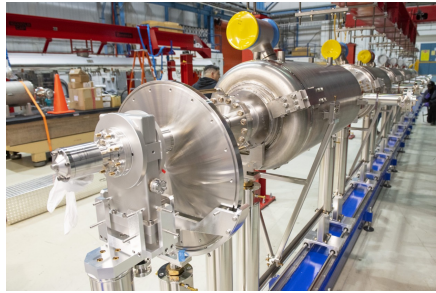
Accelerator Science and Technology

General Accelerator R&D: GARD Program

- Fermilab R&D under GARD has resulted in enabling advances for HEP



MW-Targets for **LBNF**



High Q SRF for **PIP-II**



Nb₃Sn magnets for **HL-LHC**

- Fermilab's key accelerator science & technology areas include **SRF**, **magnets**, **targets**, **accelerator & beam physics**; R&D is guided by GARD roadmaps
- Continued progress towards changing the cost/capability curve is key for the next generation of accelerators

Accelerator Science and Technology

Proposed: National Integrated Accelerator and Detector R&D Program on Future Colliders

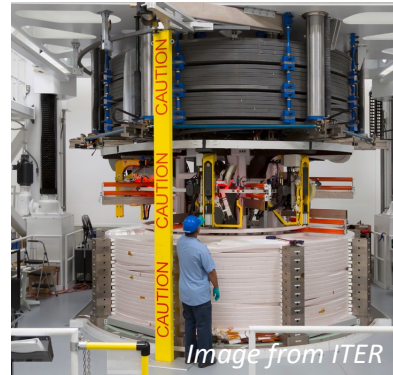
- Proposed future colliders include accelerator technologies that are not currently covered by GARD program but require substantial R&D
- **Accelerator R&D Program on Future Colliders** to provide new, targeted funding to solve technical challenges for new machines

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

July 14, 2022

U.S. National Accelerator R&D Program on Future Colliders

P.C. BHAT^{1,†}, S. BELOMESTNYKH^{1,5}, A. BROSS¹, S. DASU⁶, D. DENISOV⁴, S. GOURLAY⁷,
S. JINDARIANI¹, A.J. LANKFORD^{8,†}, S. NAGAITSEV^{1,2,†}, E.A. NANNI³, M.A. PALMER⁴,
T. RAUBENHEIMER³, V. SHILTSEV¹, A. VALISHEV¹, C. VERNIERI³, F. ZIMMERMANN⁹



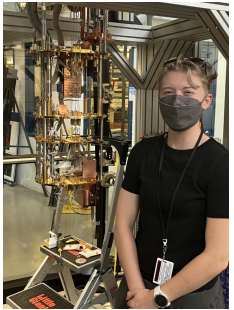
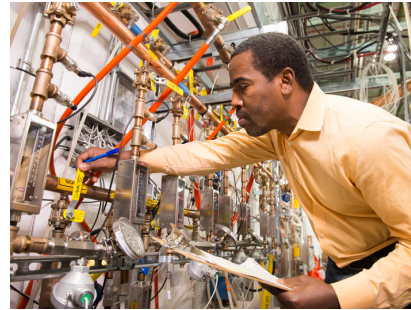
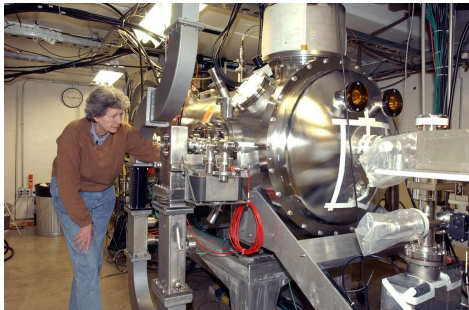
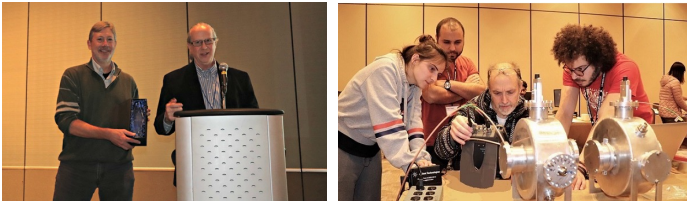
Examples may include high field and large bore solenoids, prototype cryomodules for FCC-ee, and accelerator lattice design studies

Also benefits cosmic, quantum, BES, NP, industry...

Accelerator and Detector Science and Technology

Accelerator and Detector Workforce

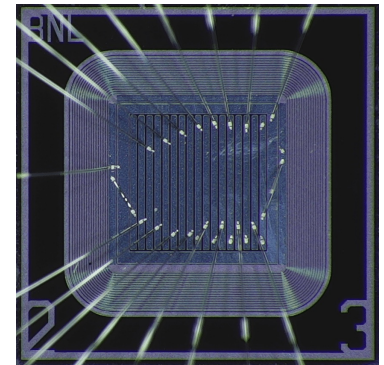
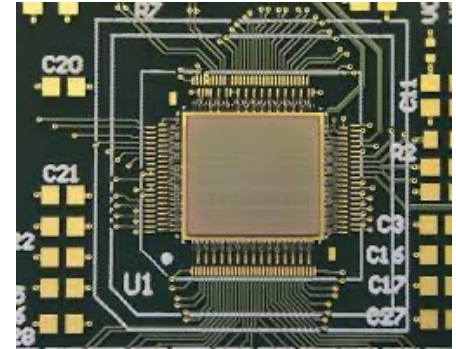
- Support has been crucial for programs to attract and train accelerator and detector workforce at all levels: undergrads, grad students, postdocs, fellows, engineers and technicians
- **US Particle Accelerator School (USPAS)**, traineeship programs, summer student programs, early career awards, fellowships...
- EDIA efforts in AS&T are extremely important, including programs like the Accelerator Engineering Fellowships for Underrepresented Minorities (ASPIRE) fellowship
- **Today's training will enable tomorrow's accelerators and detectors**



Detector R&D

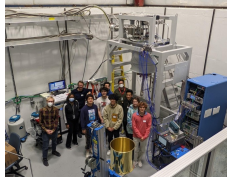
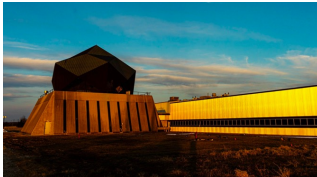
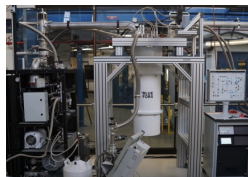
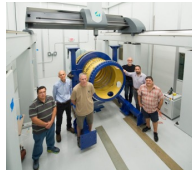
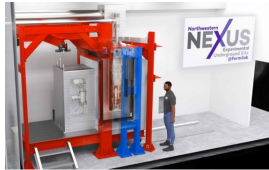
A strong program in detector research is necessary to enable planned experiments and explore new directions

- **Fermilab enables targeted R&D including**
 - DUNE
 - Targeted R&D for Far Detectors 3 and 4, building on recent R&D that led to FD 1 and 2
 - Short baseline
 - Near detector
 - Future Collider Detectors – coordinating with international partners
 - Silicon tracking including picosecond timing and low-mass
 - 5D and dual readout calorimetry
 - Synergies between e+e- and muon collider requirements
- **Fermilab enables blue-sky R&D**
 - Addressing four grand challenges of the DOE Detector and Instrumentation Basic Research Needs
 - Opening roads to ground-breaking technologies



Fermilab Facilities Enable Advances

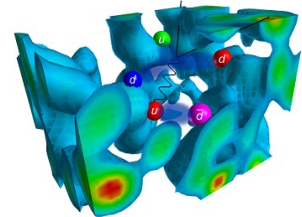
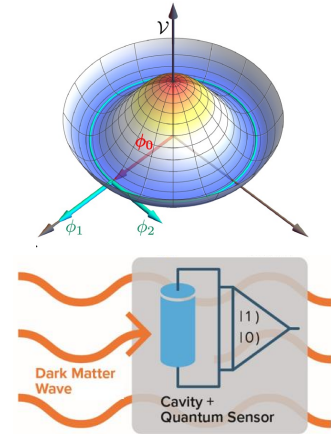
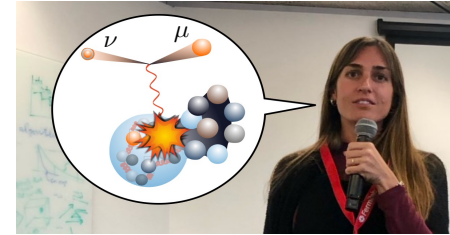
- **Fermilab facilities enable advances**
 - Helen Edwards Engineering Research Center
 - Test beam and irradiation facility
 - Micro- and macro-packaging and testing
 - Noble element detector facility
 - Scintillators: unique HEP facility with high demand



US HEP Theory

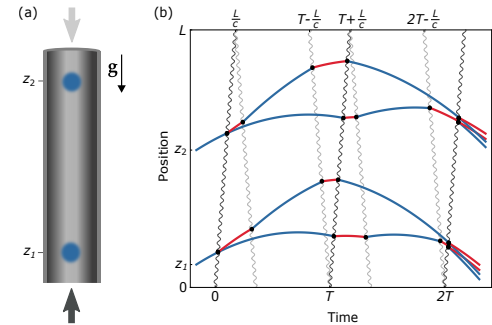
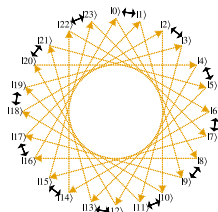
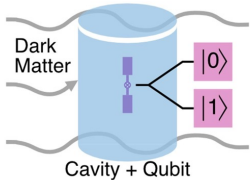
Fermilab is committed to providing critical theory needs of the HEP program in the coming decade, through both in-house efforts and consortia with universities and other labs:

- Further ramp up **theory support for DUNE and the ongoing neutrino program** to maximize the physics output, as was done for the LHC
- **Invigorate theory initiatives** to explore the frontiers of the **HL-LHC reach** and stimulate a **future collider program worldwide**
- Develop a **coordinated theory effort** towards shaping a broader **dark matter and dark sector search** program
- Guide the interpretation of precision **multi-messenger cosmology** data
- Continue expanding the scope and capabilities of **lattice gauge theory** to meet the needs of the HEP experimental program



Quantum

- Quantum science and technology at Fermilab is growing
 - Quantum for HEP and HEP for Quantum
 - Host of the SQMS National Quantum Initiative Center
 - Record-breaking systems for quantum computing and sensing
 - Strong presence in **ORNL-led Quantum Science Center**
 - Leading in quantum sensors
 - **MAGIS 100** (gravitational wave and dark matter searches)
 - **Quantum theory**
 - **Control and readout electronics**



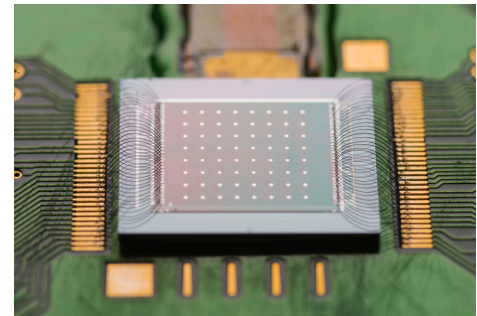
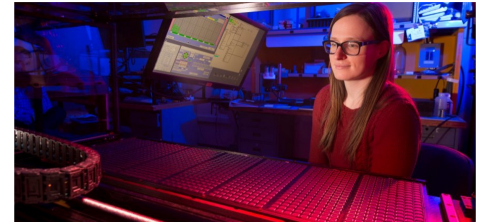
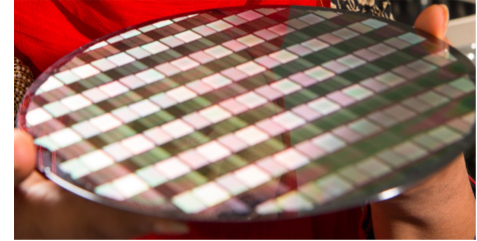
- In the coming years Fermilab will deploy its first quantum computer onsite, develop quantum sensing opportunities, advance quantum networks research, and advance quantum simulations of QFT.

Microelectronics

Fermilab, together with other national labs, academic and industry partners, wants to **establish and co-lead a major US Microelectronics Co-design center**

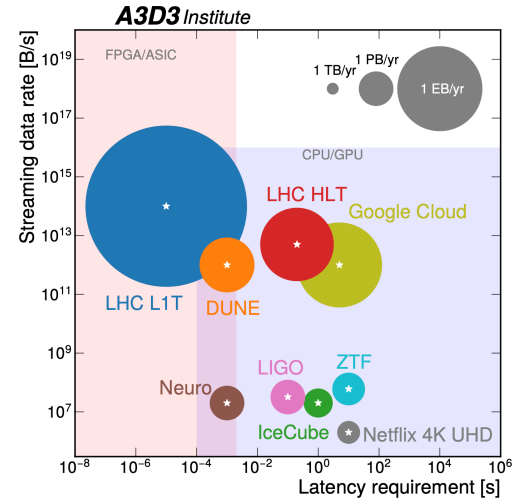
Future Detector Development heavily relies on advances in microelectronics

- Support the community for **extreme environment microelectronic development**
- Further advance expertise in **state-of-the art integrated circuit design and testing** to enable precision science measurements
- Further develop **Collaboration and Partnerships** to leverage and advance transformative technologies
 - Cross Office of Science partnerships to enable co-design with new materials (BES), novel algorithms (ASCR), energy efficient processes (EERE)
 - Across federal government collaboration with NASA, DARPA, DOD enabled by the CHIPS act
 - Engage with industry on production scale processing, heterogeneous integration and advanced packaging solutions



Computing & AI

- HEP faces **unique** high-throughput computing challenges from **massive data rates**
- Advanced computing techniques
 - Enable deeper insights and improve performance
 - Improve operational efficiency
 - Ultimately accelerate time-to-physics and discovery



Support formation of
**Coordinating Panel for
Software and Computing**
to promote, coordinate, and assist
in developing HEP software &
computing community

Evolve HEP computing infrastructure

Storage technologies, analysis facilities, heterogeneous computing (e.g. GPUs)

Leverage multidisciplinary computational & domain science expertise

Federal HPC facilities and commercial cloud, specialized services, modern software stacks

Embrace AI/ML for HEP and also HEP for AI/ML

Develop AI capabilities for HEP science, support HEP contributions to broader AI advances

Fermilab and the Accelerator Complex Evolution (ACE)

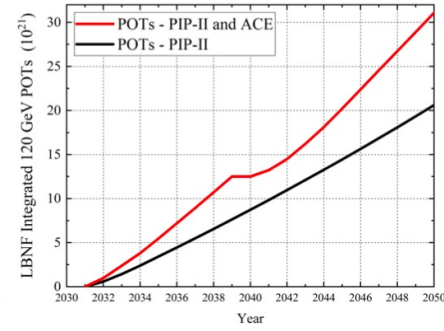
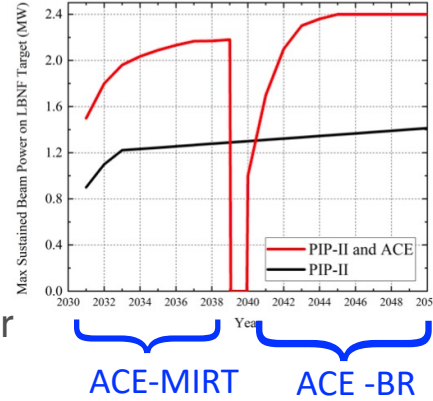
- ACE has two components
 - Main Injector Ramp and Targetry (**ACE-MIRT**)
 - Increases the beam to DUNE Phase I
 - **Capability**
 - Upgrades components
 - **Reliability**
 - Booster Replacement (**ACE-BR**)
 - Achieves DUNE/LBNF Phase II goal of 2.4 MW
 - **Capability**
 - Provides beam for a physics program beyond DUNE
 - **Capacity**
 - Fixes the bottleneck in the future Fermilab complex
 - **Capacity and Reliability**



Capability
Capacity
Reliability

Main Injector Cycle Time Reduction

- Why
 - More beam to DUNE
 - Plan includes completing Mu2e
 - Reliability
 - Replace aging equipment in the Main Injector
- What



Scenario	Present	PIP-II Booster Intensity		
		PIP-II	A	B
MI 120 GeV ramp time (s)	1.333	1.2	0.9	0.7
Booster intensity (10^{12})	4.5	6.5		
Booster ramp rate (Hz)	15	20		
Number of batches	12	12		
MI power at 120 GeV (MW)	0.865	1.25	1.666	2.142

Booster Replacement Addresses Fundamental Limitations

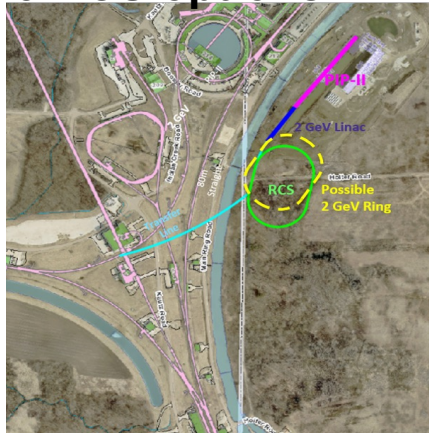
- Why?
 - There are **fundamental limitations** in operating the Booster in the ACE era:
 - The Booster cannot handle $> 1\%$ of PIP-II beam
 - $6.5E12$ PPP absolute maximum
 - The Booster cannot support > 2.1 MW from the Main Injector
 - **The Booster cannot support DUNE and any other ≥ 8 GeV physics program simultaneously**
 - Radiation losses
 - e.g., at transition - no upgrade can alleviate this
 - Tunnel too restrictive - size, depth

Fermilab needs a Booster replacement in order to enable a physics future in addition to DUNE as well as to meet the design goals of DUNE/LBNF

What: Replacing the Fermilab Booster

- Proton Intensity Upgrade Central Design Group (PIU-CDG)
 - Chartered by Director Merminga at the same time as the Science Priorities Working Group
 - Led by Steven Brice and Brenna Flaugher
 - Charged with doing a preliminary exploration of Booster replacement options to support the future Fermilab facility

3 RCS options



3 Linac options



Physics Potential of the Fermilab Complex with the Booster Replacement

- Physics opportunities at 800 MeV, 2 GeV, 8 GeV, and 120 GeV
- Many sources of discussion
 - Snowmass
 - P5
 - Multiple workshops held
 - **Physics Opportunities Beam Dump Facility at PIP-II and Beyond Workshop**
 - **ACE Science Workshop series**
 - others, e.g., “Workshop on a future muon program at Fermilab”
- Provides beam for accelerator research

Need to start now in order to enable physics in the
late 2030s!

Science Opportunities in the PIP-II Era

PIP-II will provide 2 mA current at 800 MeV

Workshop on “Physics Opportunities Beam Dump Facility at PIP-II and Beyond”

- May 10-13, 2023, at Fermilab
- Discussed possible experimental programs and theory directions with a focus on dark sectors enabled by a possible PIP-II based beam dump facility
- Included theorists and experimental ideas, including taking advantage of new detector technologies
- eV-scale to MeV-scale detection thresholds
- Output of the workshop is a whitepaper on the accelerator and physics opportunities



Matt Touns
Fermilab



Jae Yu
UT Arlington



Juan Estrada
Fermilab



Jacob Zetlemoyer
Fermilab

Physics Opportunities at Beam Dump Facility in PIP-II and Beyond

May 10, 2023, 12:00 AM → May 13, 2023, 11:59 PM America/Chicago

Jacob Zetlemoyer (Fermilab), Jacob Yu (University of Texas at Arlington), Juan Vigil, Matthew Touns

Description This workshop is to explore physics opportunities, including dark sector particle (DSP) searches, at PIP-II beam dump and future facilities. The PIP-II ring at Fermilab is capable of accelerating up to 1 mA of protons to 800 MeV and is a fundamental element in providing a large flux of neutrons essential for precision measurements at future long-baseline neutrino experiments. The large proton current that will be provided by the PIP-II ring and the proton interactions in the beam dump also provide an excellent opportunity to search for dark sector particles produced via various portals. The aim of this workshop is to discuss the potential for DSP searches and other physics opportunities that can take full advantage of the beam power of this facility. We anticipate that a white paper will be produced at the end of the workshop. The workshop will be held from 1 pm CDT on Wednesday, May 10 and run through 12 pm CDT on Friday, May 12.

A discussion on the proposed DAMSA experiment will take place starting the afternoon of Friday May 12 and run through the morning of Saturday, May 13, immediately following the workshop.

<https://indico.fnal.gov/event/59430/>

ACE Science Workshop Series

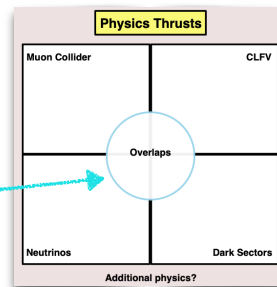
- Workshop held June 14 – June 15
- This was the first in a series of workshops to co-design physics case and technical design
- Continue development of ACE towards CD-0 in ~2-year timescale

Two exciting days of talks and discussions

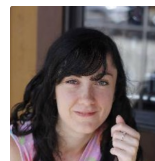
Physics thrusts

- Muon Collider; Muon program; Charged Lepton Flavor Violation (CLFV); Neutrino program; Dark Matter and Dark Sectors; New Physics ideas
- Additional potential physics programs and R&D
- Parallel session discussing accelerator topics

Complementarity



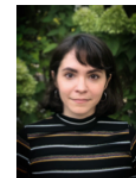
From N. Tran, Fermilab PAC meeting, June 2023



S. Gori



N. Tran



K. DiPetrillo



B. Echenard



J. Eldred



R. Harnik



P. Machado



M. Toups

Fermilab ACE Science Workshop
Jun 14, 2023, 12:00 AM → Jun 15, 2023, 11:59 PM US/Central
Wilson Hall - One West
Bertrand Echenard (CERN), Jeffrey Eldred (Fermilab), Karri DiPetrillo (The University of Chicago), Nhan Tran (FNAL), Pedro Machado (Fermilab), Roni Harnik (FNAL), Stefania Gori (UC Santa Cruz)

Description Over the past year Fermilab has developed the Accelerator Complex Evolution (ACE) plan to ensure quality, high intensity beam delivery for a diverse set of experiments, including the flagship DUNE experiment, and for upgrades necessary for a potential future multi-TeV collider. The ACE plan begins with modifications to the Main Injector and the DUNE Target that will improve reliability and provide up to 2.1 MW of beam for DUNE through the mid-late 2030s. The second phase of ACE involves replacement of the booster to expand the scientific capabilities of the complex beyond LBNF/DUNE, improve overall complex capacity and reliability while providing a platform for detector development and serving as a front end for future colliders.

<https://indico.fnal.gov/event/59663/>

Conclusion: Vision for the Fermilab Facility

- The Accelerator Complex Evolution
 - **ACE-MITR**
 - Capability
 - DUNE to achieve world-leading results on an accelerated schedule
 - Reliability
 - Replace aging portions of the Fermilab Accelerator Complex
 - **ACE-BR**
 - Capability
 - To Realize the DUNE Phase II design goals
 - Capacity
 - Provide beam for a rich physics program beyond DUNE
 - Respond to new ideas in the coming decades
 - Reliability
 - Ensure a robust platform for the future of the complex

Conclusion: Vision for US Particle Physics

- With our international partners, realize the full scope of the **best-in-class DUNE experiment** in a timely fashion
- With our international partners, participate as strong contributors in the **LHC and HL-LHC**
- Lay the foundation for an **international Higgs factory** and a **next-generation multi-TeV collider**
- Enable the accelerator complex to **probe the unknown** with a broad, balanced, diverse, discovery program
- Uncover the mysteries of the universe with **CMB-S4 and dark sector initiatives**
- Engage in enhanced **Accelerator R&D, Detector R&D, and Theory** efforts to enable the science
- Excel in National Initiatives in **Microelectronics, QIS, and AI/ML**

Engage, train, and support a **diverse community**