HEP (and collider activities) in the Americas

Patricia McBride

FCC Workshop 2018
9 April 2018

Perspectives on Particle Physics today

- "Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community."

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

US High Energy Physics Strategic Plan: P5

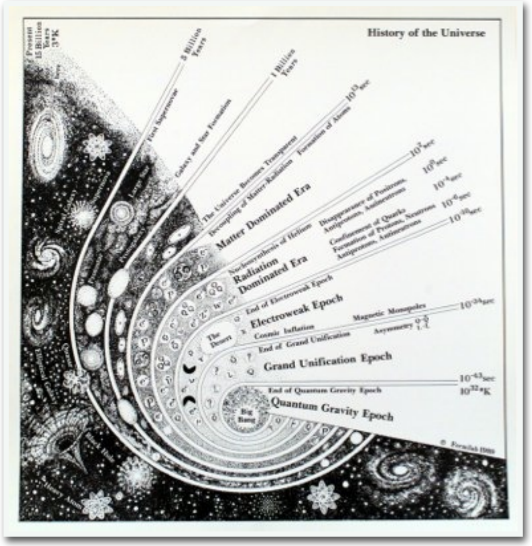
P5 outlined a strategic plan for U.S. High Energy Physics

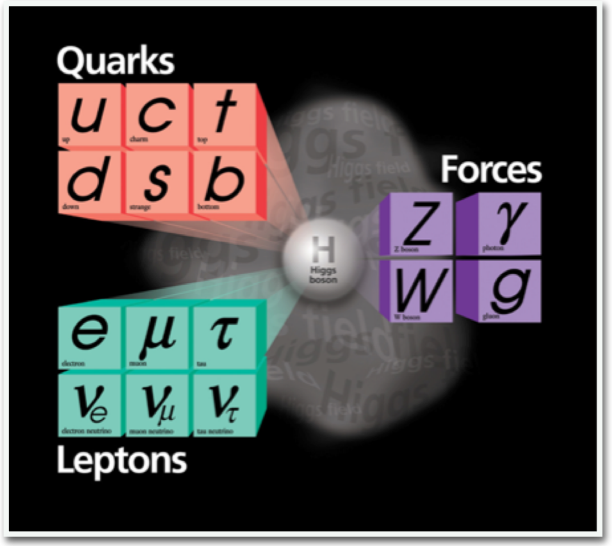
- Process: P5 Panel followed a year-long community-wide study organized by the APS Division of Particles and Fields.
  - Note: The P5 Plan does not include Heavy Ions, EIC, $0\nu 2\beta$.
  - P5 does include Astroparticle physics, Dark Matter (DM), and Dark Energy (DE)
- The P5 plan has had wide acceptance in the community and in Congress.

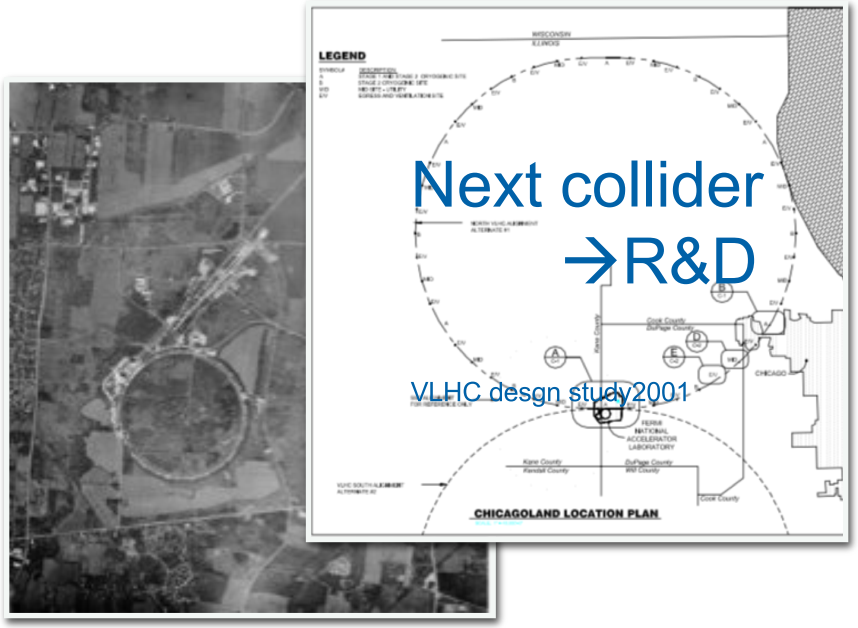
"Particle physics is global. The United States and major players in other regions can together address the full breadth of the field's most urgent scientific questions if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere." **(P5 report)**

Particle Physics Science Drivers

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles







Next collider
→R&D

VLHC desgn study2001

Fermilab

- What does the P5 Plan tell us?
  - Continue the U.S. commitment to the LHC program,
  - Build a neutrino program that will attract the world community,
  - Continue U.S. efforts in dark matter, dark energy, and cosmic microwave background.
  - **Invest in the accelerator and detector technologies that we will need in the future.**

The success of the plan depends on a **vital theory program.**

The plan is advanced though **the cooperation of the global science community**.

P5: Use the Higgs boson as a new tool for discovery

- The Large Hadron Collider, the largest global science program yet attempted, achieved the discovery of the Higgs boson in 2012
- Significant participation from U.S., Canada, and Latin America.
- Latin American collaboration in LHC experiments began around 2000 and grew steadily, helped by two mobility programs: HELEN (2005-2009) and EPLANET

Country	number of institutes
Argentina	9
Brazil	15
Canada	22
Chile	5
Colombia	6
Cuba	1
Ecuador	2
Mexico	9
Peru	2
U.S.	90

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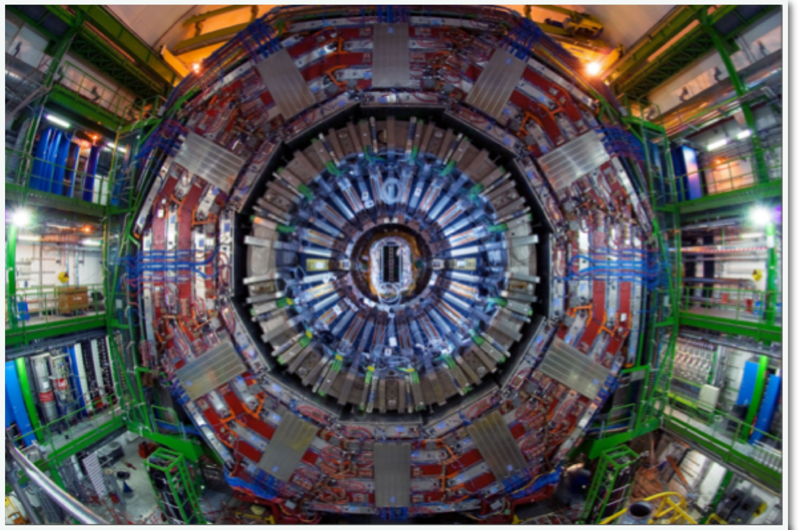
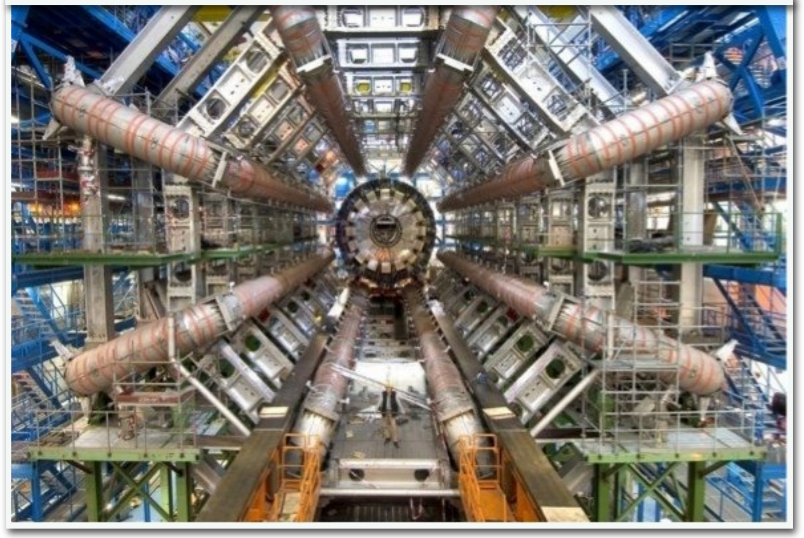
U.S. Participation in the ATLAS and CMS



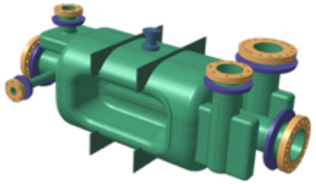


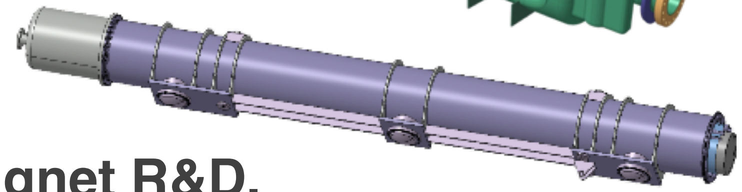
- **The U.S. contributed to the construction of the LHC.**
- **LHC is expected to be a part of the U.S. program for next ~20 year.**
- **The U.S. is very active in the ATLAS and CMS detector upgrades.**
  - The detector upgrades plans for the HL-LHC are undergoing the project funding review process.
- **High luminosity to LHC will extend the discovery potential (2025-2035).**
  - Increase LHC luminosity by a factor of 10.
  - Explore new physics and new dynamics for W/Z, top, and Higgs at TeV energies.

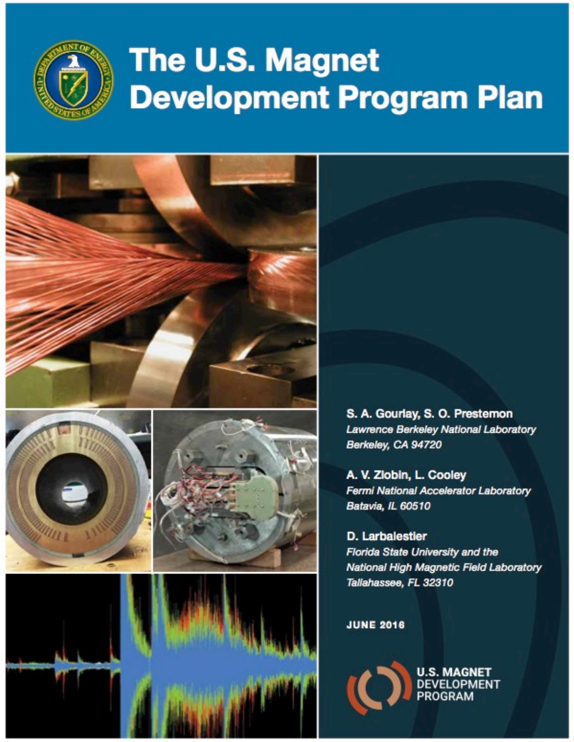
The High Luminosity LHC Upgrade and beyond

> "Future high energy colliders will be expensive and complex. Optimization studies will be key to lowering the construction cost and maximizing the operating efficiency. Optimized superconducting magnet design both in field intensity and manufacturability will require R&D for a very high-energy proton-proton collider. For e^+e^- colliders, more efficient RF sources as well as much higher accelerating gradients could lower operating costs." -- U.S. GARD Directions and Opportunities

- **The U.S. HL-LHC Accelerator Upgrade Project is moving ahead towards final project approval.**
  - Cryomodules: ~8m long Cold Masses with Nb3Sn focusing quadrupoles for the CMS and ATLAS interaction regions.
  - Dressed Radio Frequency Dipoles (RFD): Crab Cavities

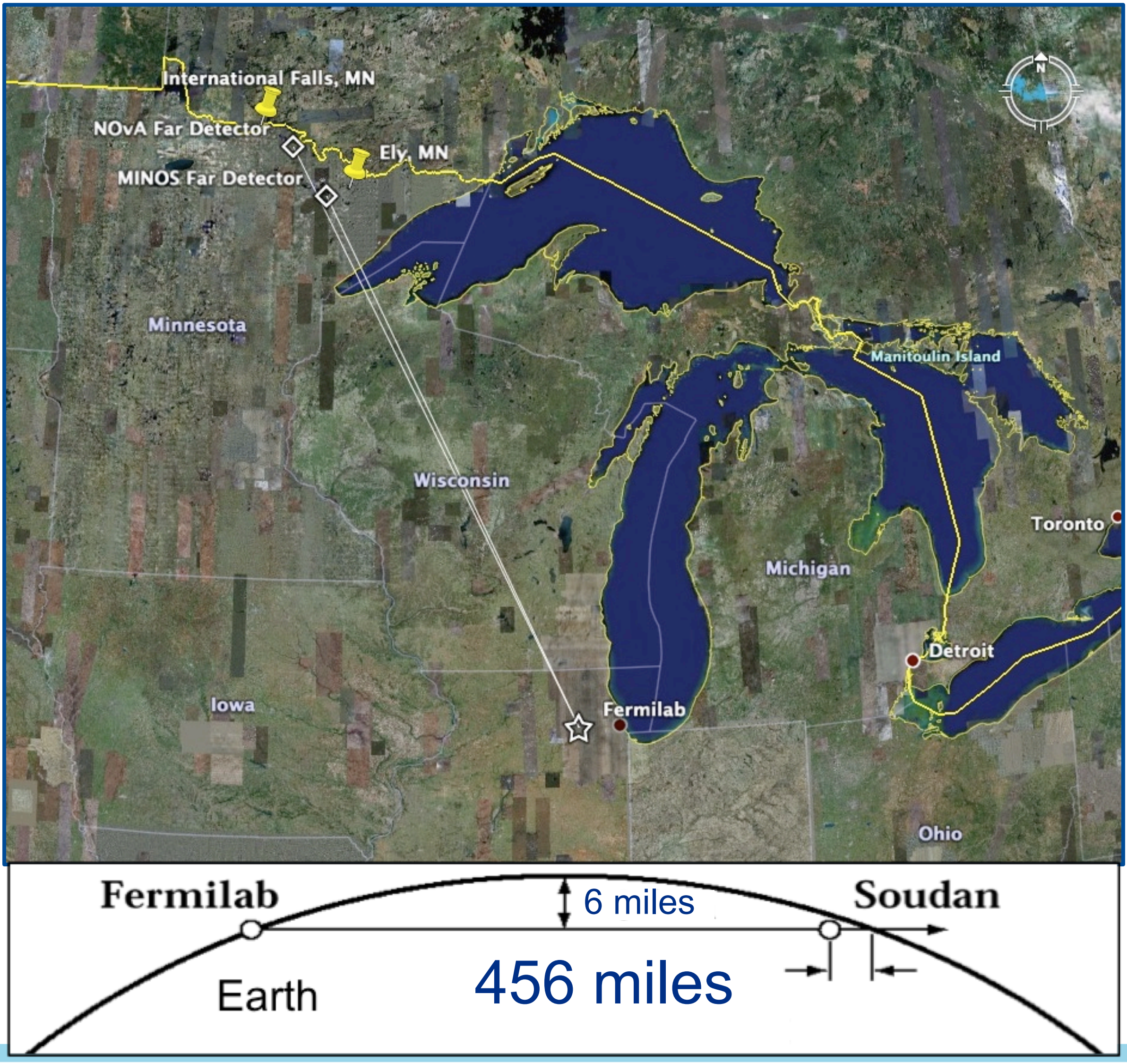






- **The U.S. plans to continue high field magnet R&D.**
  - R&D on magnets for future machines is a nationwide collaboration.
  - 15 Tesla prototype under final assembly. First test results soon.

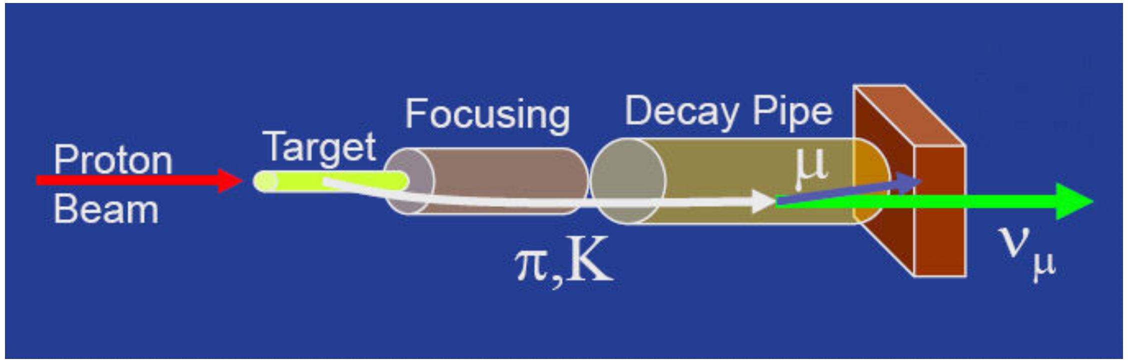
P5: Pursue the physics associated with neutrino mass



Fermilab delivers high energy neutrinos 810 km through the Earth to the NOνA experiment in Minnesota.

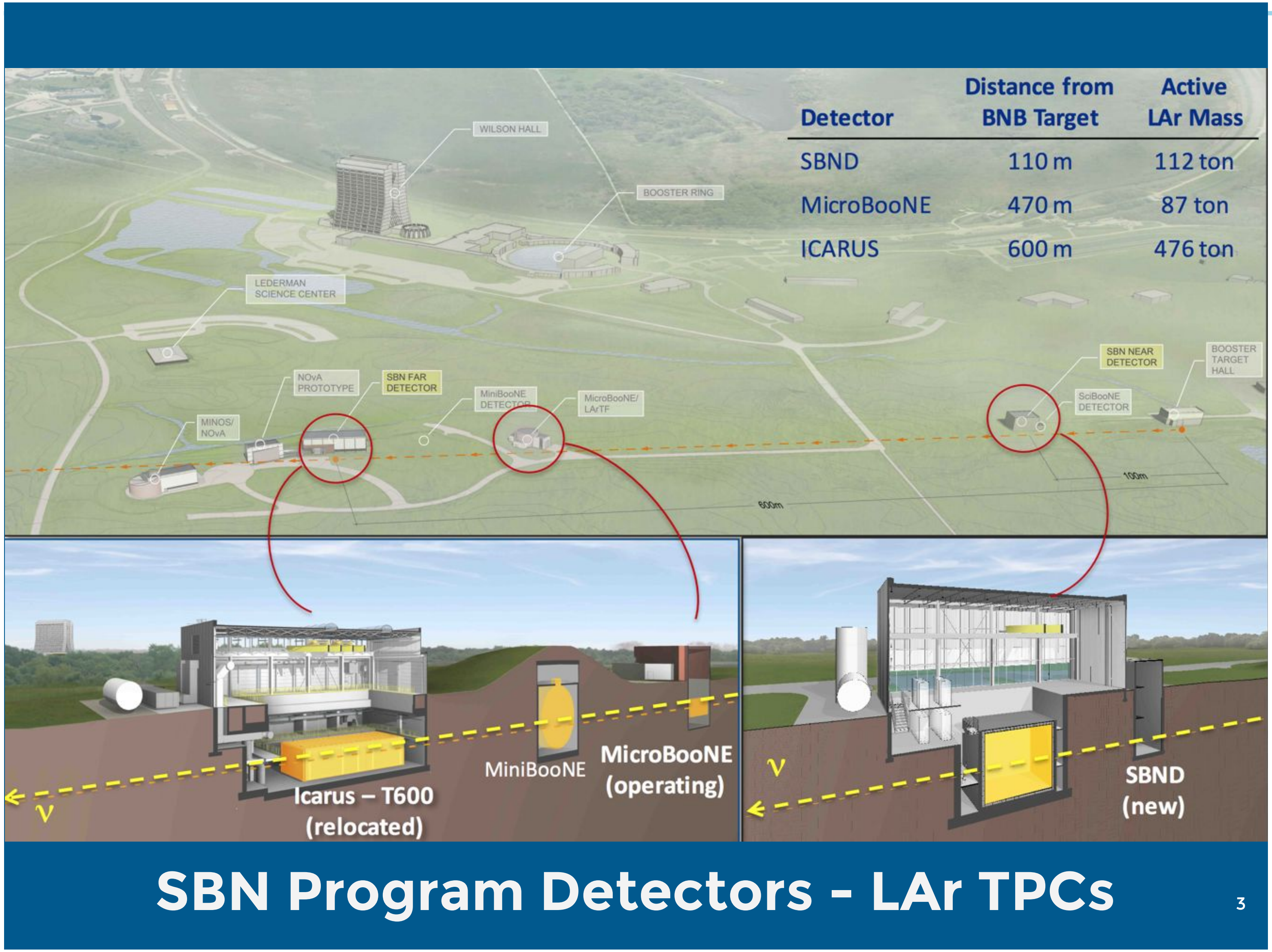
Beam is routinely running at the design power of 700 kW

NOνA has been improving the analysis through deep learning techniques.



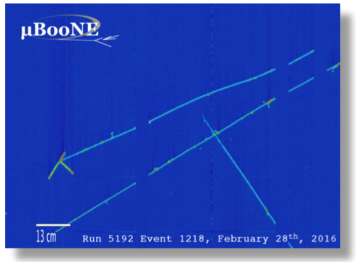
The NOvA neutrino detector….14,000 tons liquid scintillator

Short Baseline Neutrino program



The Short-Baseline Neutrino Program:

Emerged from a joint proposal by three collaborations to use their detectors to perform sensitive searches for ν_e appearance and $\nu_\mu$disappearance in the Booster Neutrino Beam.



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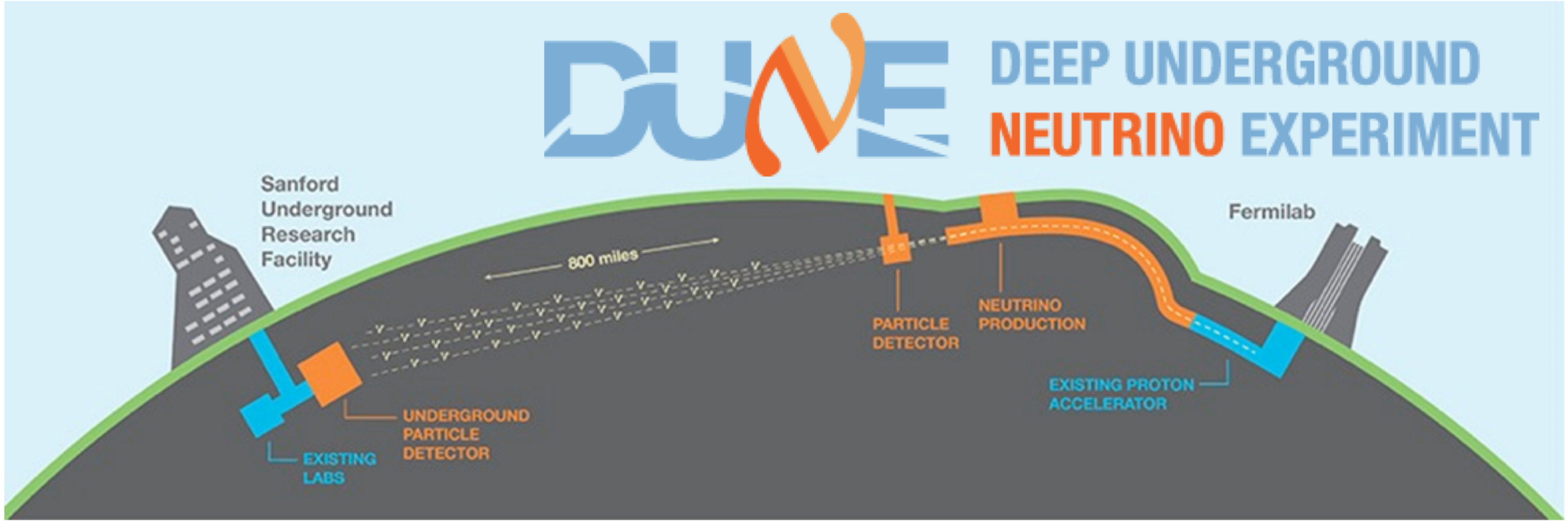
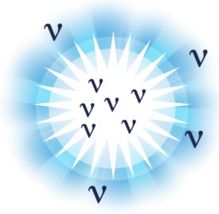
Long-Baseline Neutrino Facility / Deep Underground Neutrino Experiment (LBNF/DUNE)

- A 1.2 MW (2.4 MW phase 2) wide-band neutrino beam
- Detector deep underground (1.5 km) 70kt liquid argon
- A long baseline (1300 km)
- Liquid Argon is next generation neutrino detector technology



DUNE Science Objectives

Neutrinos – most ubiquitous matter particle in the universe, yet the least understood. Opportunities for game changing physics discoveries:



- **Origin of matter**
  Investigate **leptonic CP violation, mass hierarchy, and precision oscillation physics**
  - Discover what happened after the big bang: Are neutrinos the reason the universe is made of matter?

- **Neutron Star and Black hole formation**
  Ability to **observe supernovae events**
  - Use neutrinos to look into the cosmos and watch the formation of neutron stars and black holes in real time

- **Unification of forces**
  Investigate **nucleon decay** targeting SUSY-favored modes
  - Move closer to realizing Einstein's dream of a unified theory of matter and energy

Overview of the DUNE Collaboration

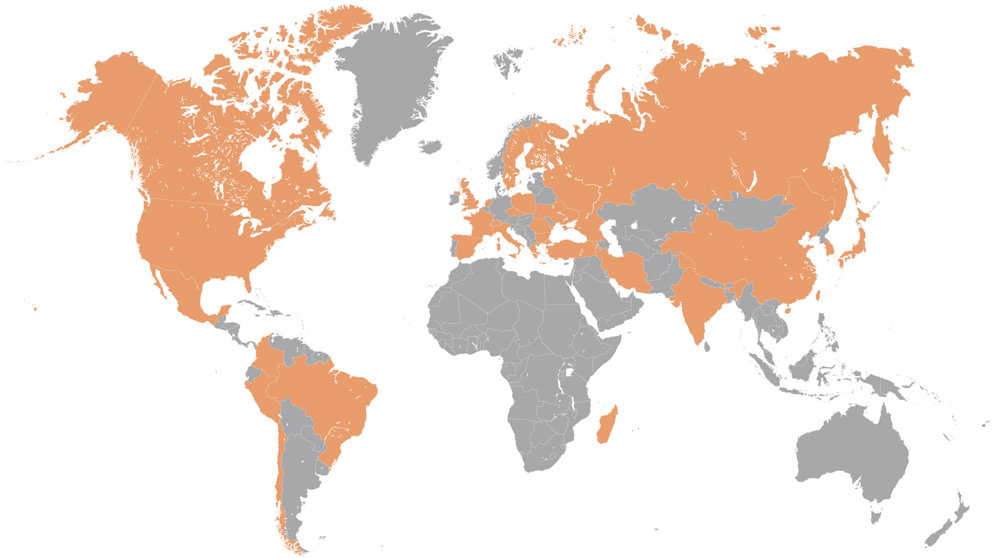
The international DUNE Collaboration is responsible for managing the design, funding, construction, and operation of the neutrino detectors at both the near and far sites.

As of today:

>60 % non-US

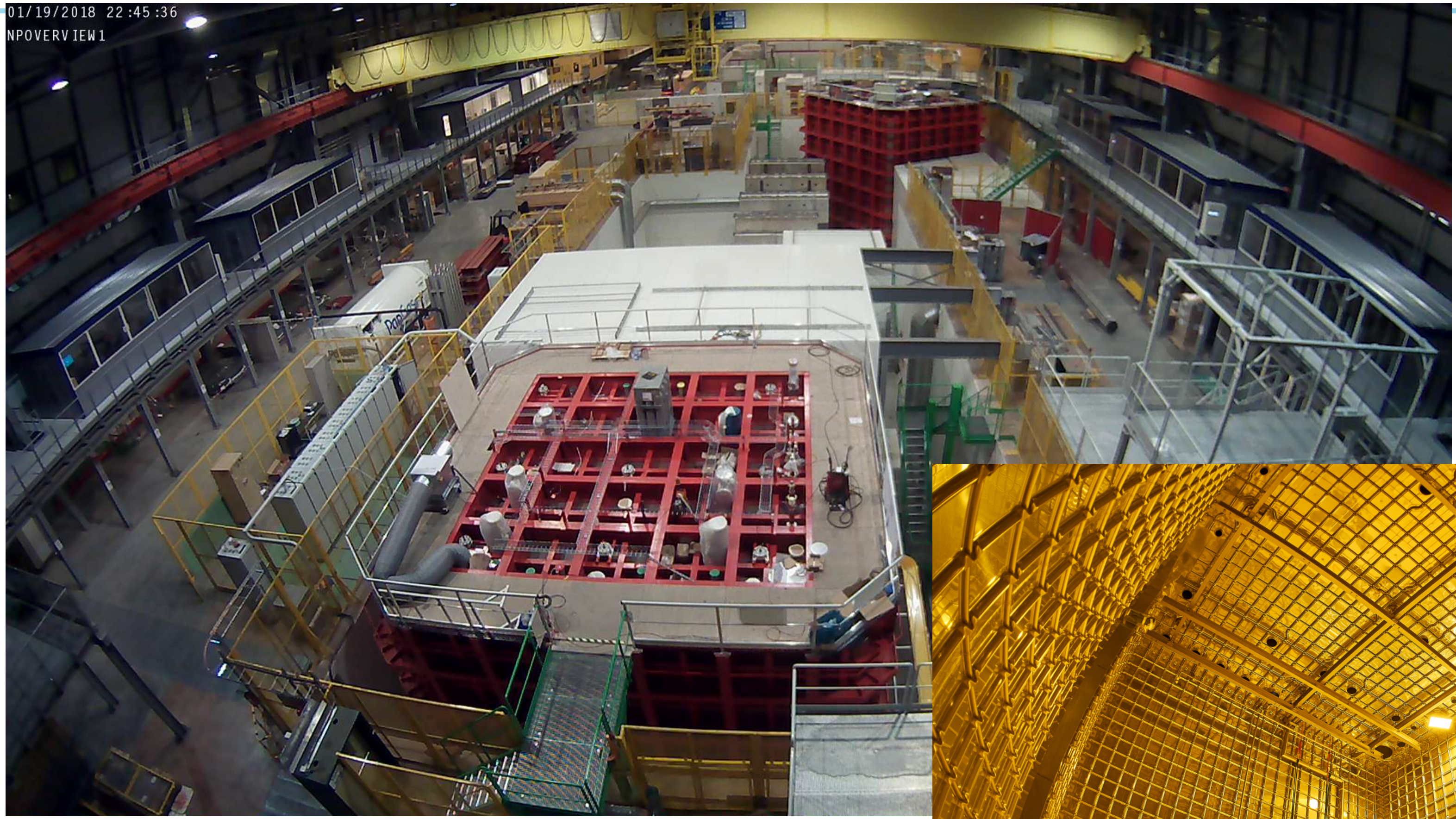
1065 collaborators from 177 institutions in 31 nations

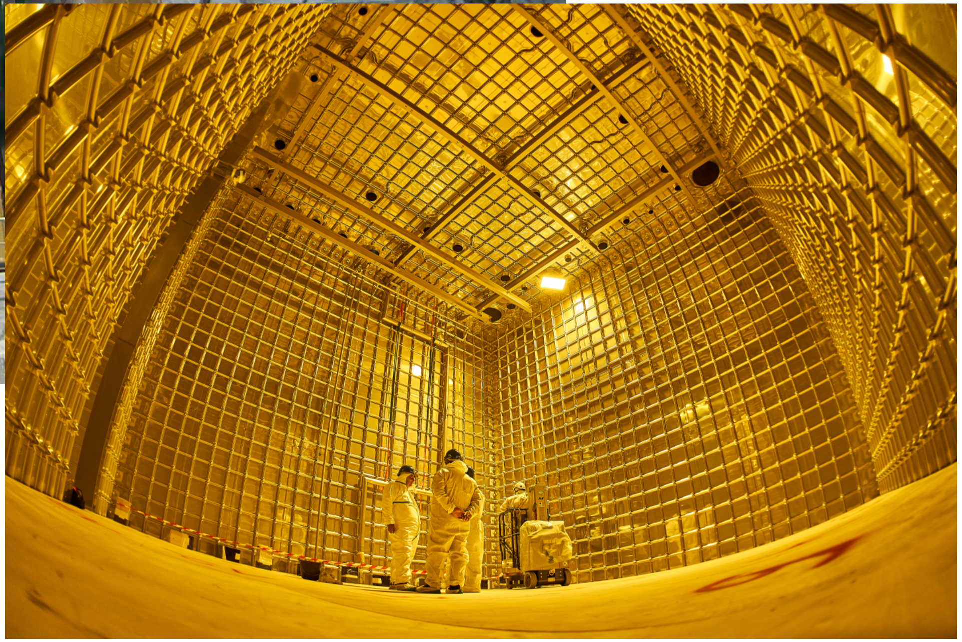
Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Paraguay, Peru, Poland, Romania, Russia, South Korea, Spain, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE has broad international support and is growing

ProtoDUNE at CERN





Fast track construction- excellent progress due to the expertise of collaborators at CERN

International Project Milestones

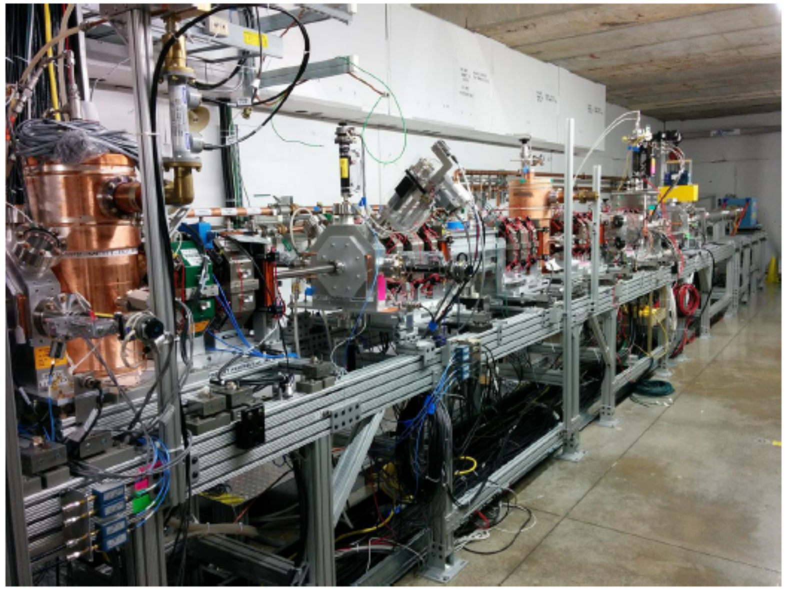
- LBNF, the DUNE collaboration and CERN, has established "international project milestones" that provide focus, establish confidence among the various partners, and serve to coordinate international deliverables.
- U.S. FY18 funding has been secured to move the project forward.

International Project Milestones	Date
Start Main Cavern Excavation	2019
Start Detector #1 Installation	2022
Neutrino beam on with two detectors	2026

Fermilab/DOE/U.S. must demonstrate to the world that we are reliable partners to ensure success

PIP-II Project

- PIP-II incudes a modern 800-MeV superconducting linear accelerator.
- Proceeding to baseline through the DOE review process.
- First time we will have built a major accelerator project in the US with international partners
  - Major partners at review: India, UK, France, Italy
- Aim is 1.2 MW of beam power day one for DUNE 2026



Building cutting edge accelerators

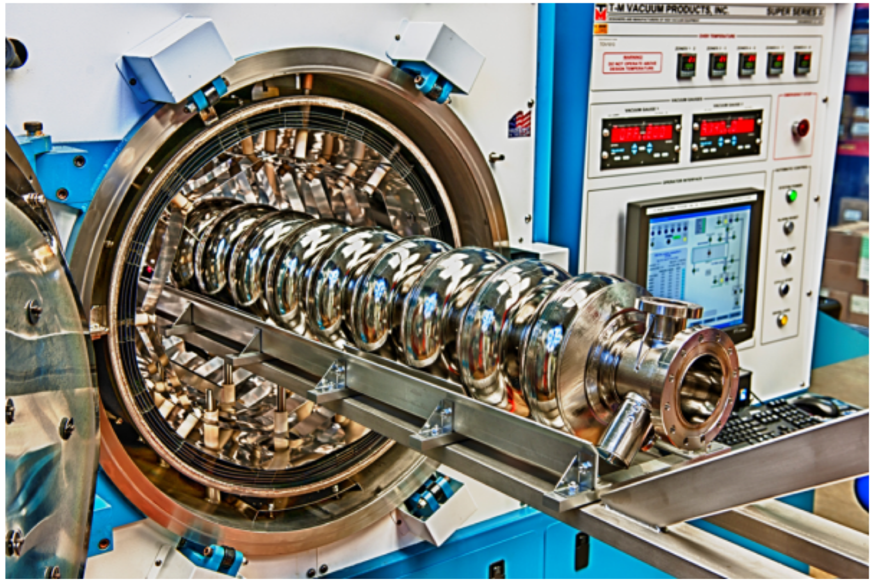
There has been significant investment in SRF infrastructure:

Enable modern accelerators:

➔ LCLS-II XFEL cryomodules

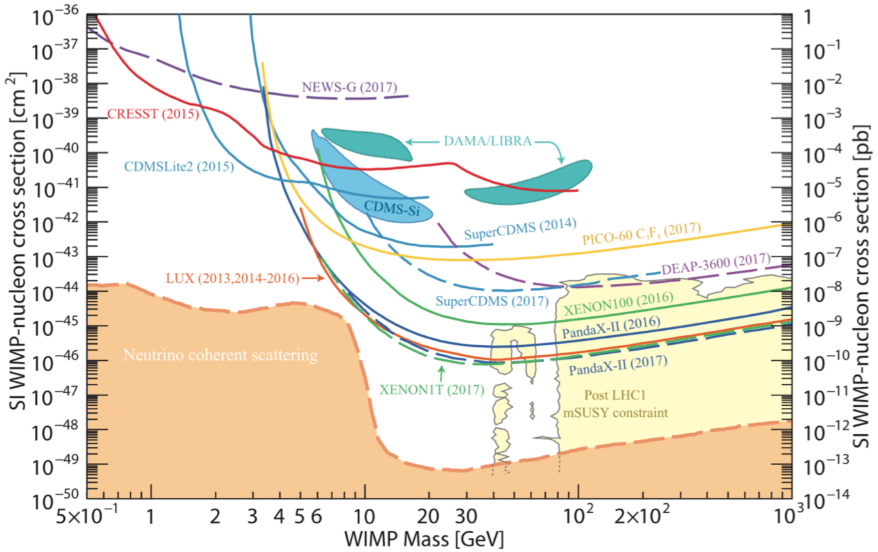
➔ PIP-II

R&D on cost savings underway.



P5: Identify the new physics of dark matter

- Very active field: Innovation and diversity in the DM program has been particularly effective.



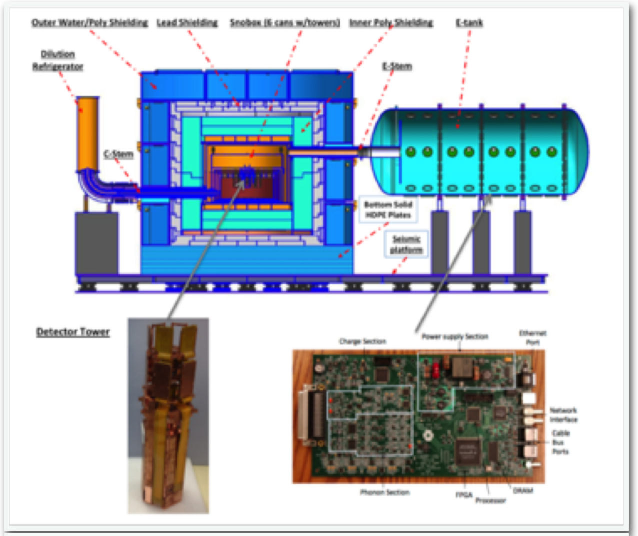
The G2 DM expts. are starting construction or in operation.

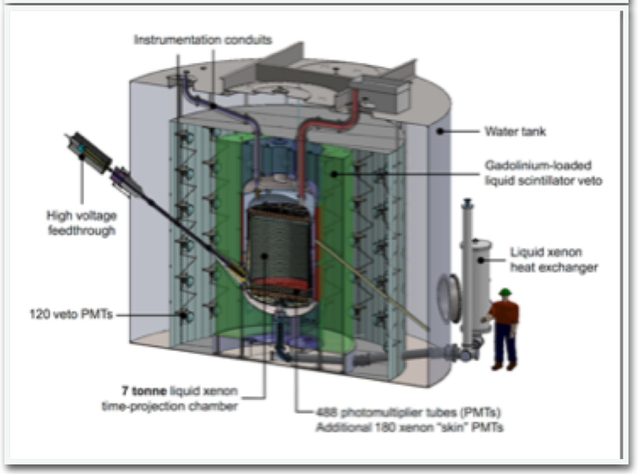
ADMX, LZ, SuperCDMS SNOLAB

Many ideas for the development of techniques for DM searches are under discussion in the community.

See: U.S. Cosmic Visions: New Ideas in Dark Matter 2017: Community Report arXiv:1707.04591 **[hep-ph]**

SuperCDMS SNOLAB



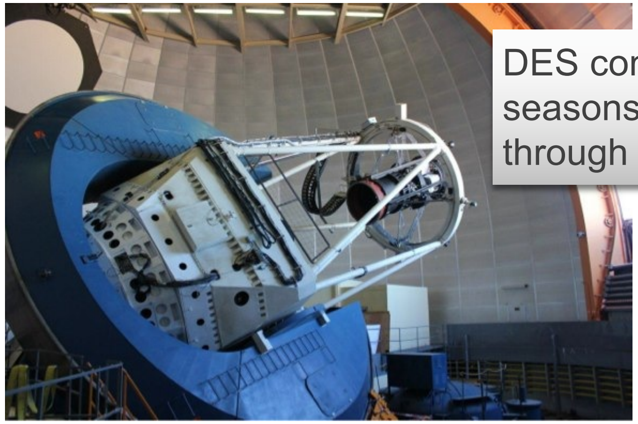


LZ at SURF

G2 DM program

ADMX

P5: Understand cosmic acceleration: dark energy and inflation



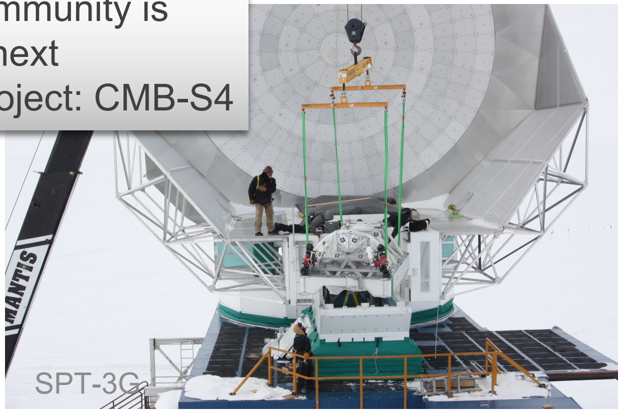
DES completed 5 seasons; extended through 2018

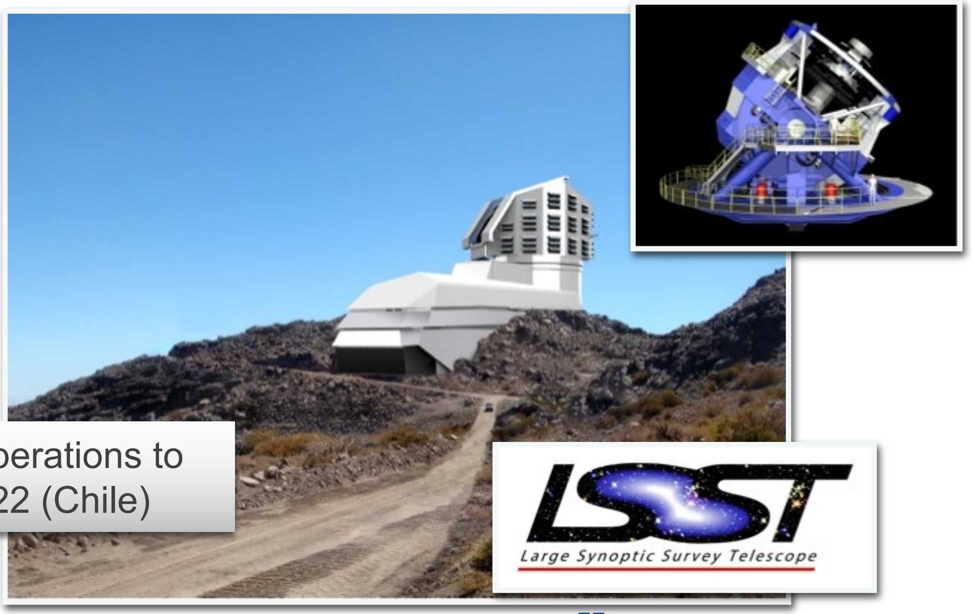
DES

DESI commissioning in 2019

DESI

U.S. CMB community is planning the next generation project: CMB-S4



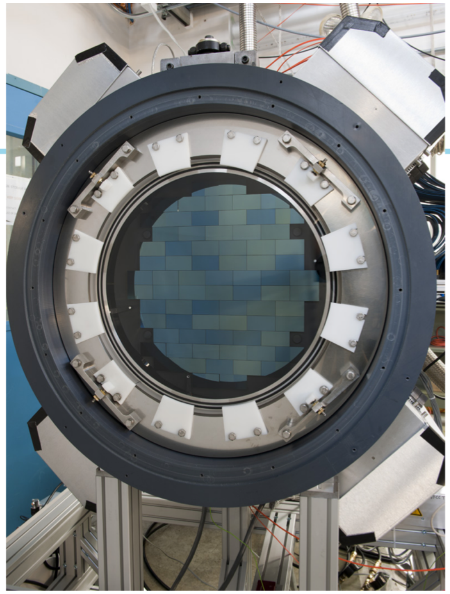


LSST operations to start 2022 (Chile)

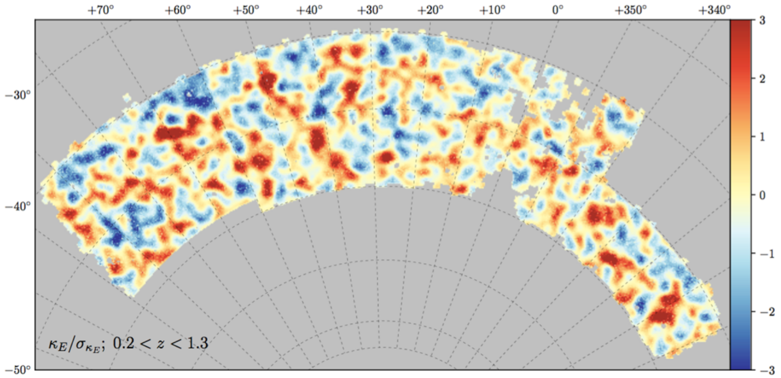
Large Synoptic Survey Telescope

DESI: (Dark Energy Spectroscopic Instrument)
Fiber-fed multi-object spectrograph using Baryon Acoustic Oscillation (BAO) technique to measure the expansion history of the Universe.
5000 robotically positioned optical fibers.

The Dark Energy Survey …. Exciting results



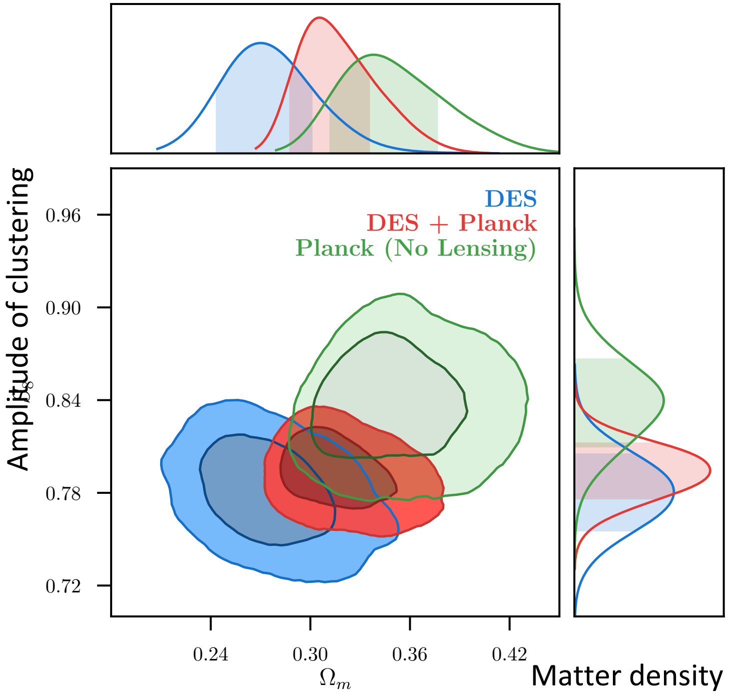
- Probing nature of Dark Energy via survey of 300 million galaxies and 3000 supernovae….telescope in Chile
- Now in 5th year (of 5) of observing. (extended through 2018)
- **Aug. 2017: Year 1 Cosmology results** (10+ papers) from galaxy clustering & weak lensing; constraints competitive with Planck CMB. Broad interest.



DES Year 1: largest map of dark matter in the Universe. Based on weak lensing shape measurements of ~30 million galaxies, this map spans ~2.5 billion light years. (Chang, et al. 2017)

DES Year 1: cosmology results from galaxy clustering and weak lensing (DES Collaboration 2017). Consistent with Planck CMB within ΛCDM. Combined wCDM constraints on dark energy with Planck, BAO, SN:

$$w = -1.00^{+0.04}_{-0.05}.$$



P5: Explore the unknown: new particles, interactions, and physical principles

Exploration of the unknown is at the heart of our work. Many examples… including the FCC.

Unknown known?

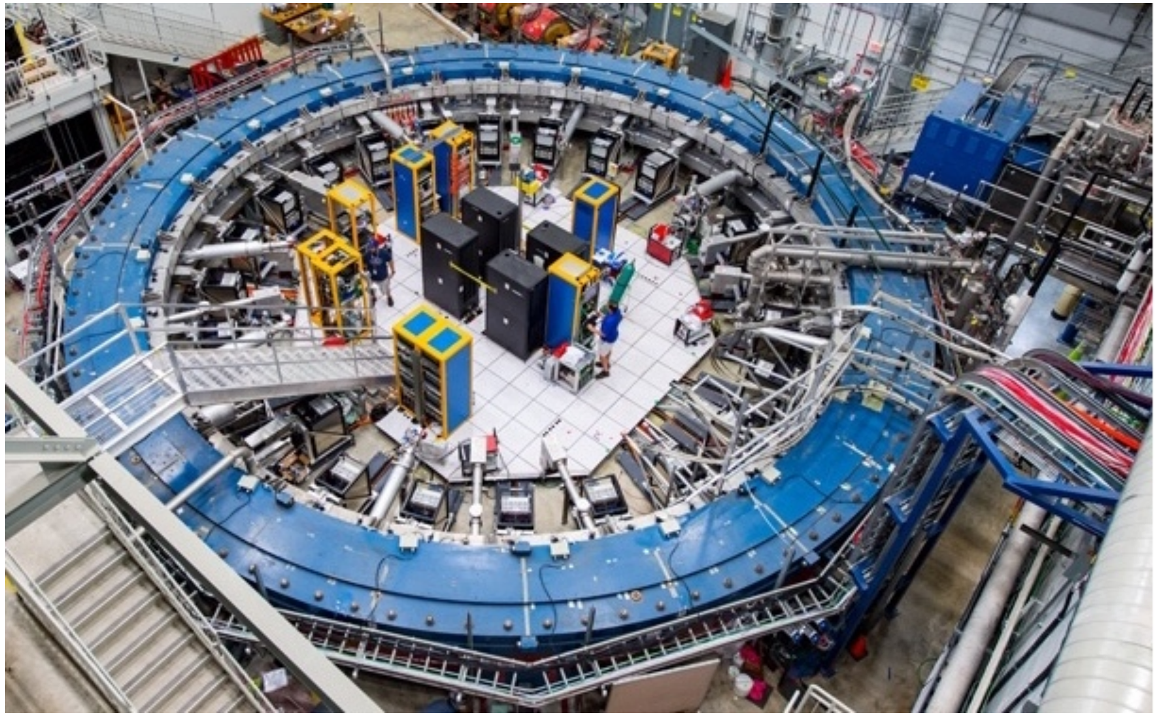
g-2 arriving at Fermilab from BNL

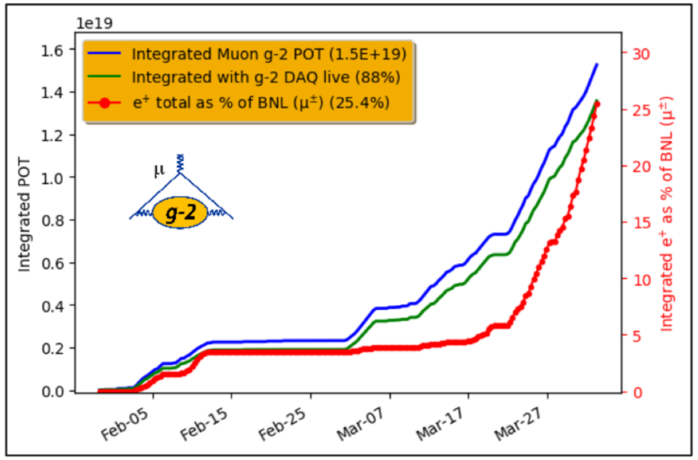
Muon g-2 experiment is underway

The Muon g-2 experiment at Fermilab: physics data run has begun!

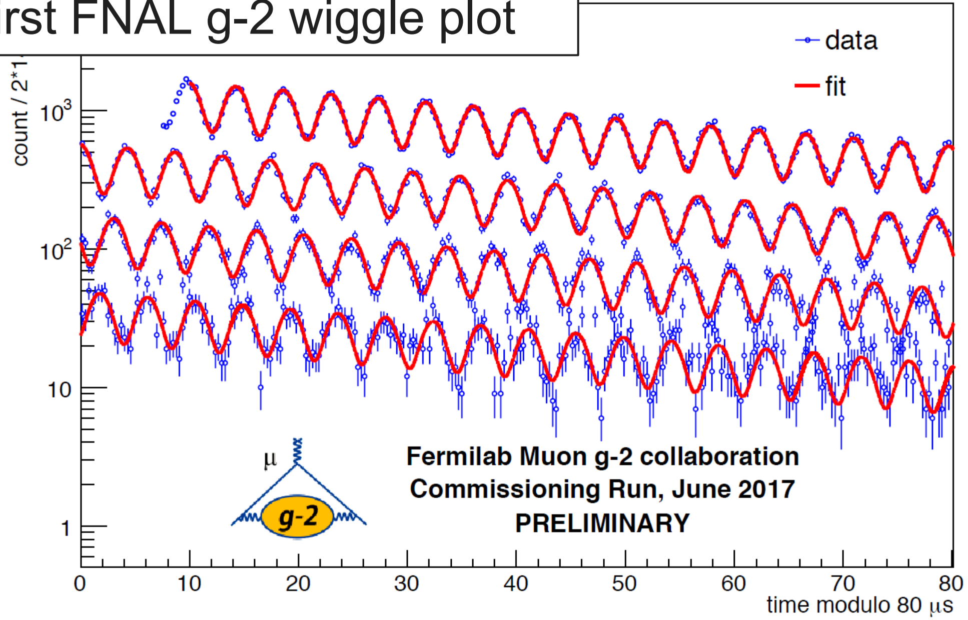
- systems commissioned; ramping up the production rates

The plan is to collect a BNL size data set before the summer shutdown.





First FNAL g-2 wiggle plot



The Mu2e experiment is under construction

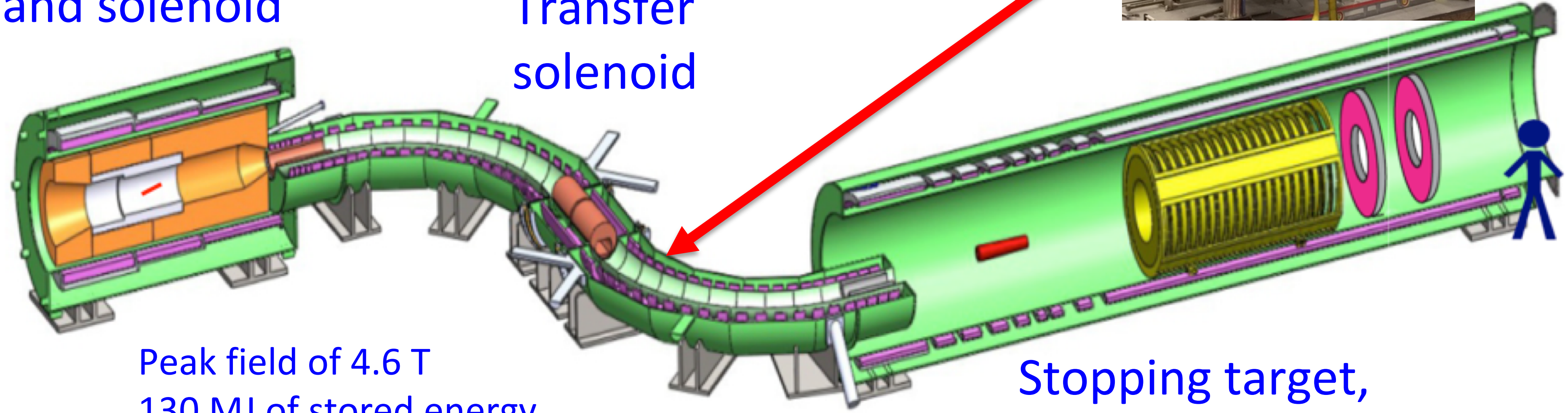
Construction activities going ahead at full speed;

- First beam expected 2020;
- Physics data starting in 2022.

Mu2e Experimental Hall

Production target and solenoid

Transfer solenoid



Peak field of 4.6 T
130 MJ of stored energy
70 km conductor and 45 ton cold mass
8 kW power on production target
~100k readout channels

Stopping target, detector, and detector solenoid

Left bend magnets in Mu2e beamline

The age of quantum computing and quantum communications

- **DOE Office of Science has announced a new initiative in quantum science that includes HEP.**
- Even after allowing for media hype, there has been progress in the last two years on building real quantum computers and performing long-range quantum communication

Quantum Sensors: Adapt quantum technologies to enable new fundamental physics experiments.

Quantum Systems: Four companies now have functioning 50 qubit quantum computers, which is generally considered the threshold of "quantum supremacy" = quantum computers that can outperform supercomputers on at least one kind of problem. How to scale these devices from 50 qubits to 50,000 qubits involves challenges similar to those encountered with large detectors in HEP

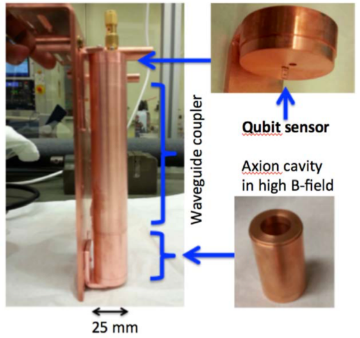
HEP Applications of Quantum Computing: Richard Feynman said use quantum machines to solve quantum problems. But the HEP community needs to learn how to use these devices and to identify the most promising HEP applications on near-term quantum computers

Foundational Quantum Science connections to HEP: Can we simulate black holes and quantum gravity on quantum computers?

Intel's New Chip Aims For Quantum Supremacy

How Google's Quantum Computer Could Change the World

The ultra-powerful machine has the potential to disrupt everything from science and medicine to national security—assuming it works



Canadian Particle Physics and Future Accelerators
Subatomic Physics Long Range Plan 2017-2021

Community-driven planning exercise captures aspirations of Canadian particle and nuclear physics research communities as guide to investment decisions of funding agencies

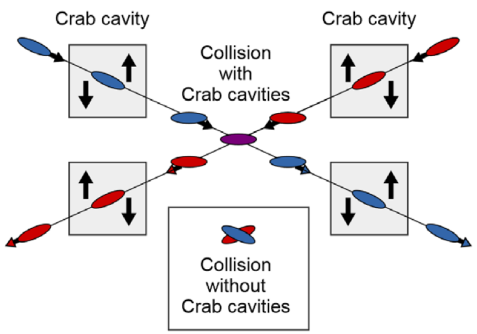
(Long Range Plan available at www.subatomicphysics.ca)

Scientific Recommendation highlights:

- **Provide continued support and resources to:**
  ATLAS; T2K; TRIUMF (radioactive beams, ARIEL);
  SNOLAB (dark matter and $0\nu2\beta$ searches);
- **Support strategic, smaller-scale Canadian efforts, giving breadth to the community's programme:** ALPHA, JLAB and offshore rare isotope beam experiments, and IceCube.
- **Support activities in potential *future* flagship endeavours having significant Canadian participation:**
  - ATLAS at the High-Luminosity LHC
  - Belle II at SuperKEKB
  - Hyper-Kamiokande
  - ILD at ILC
  - Moller and SOLID at JLAB
  - nEXO at SNOLAB
  - UCN/nEDM at TRIUMF (w/ significant Japanese contributions)

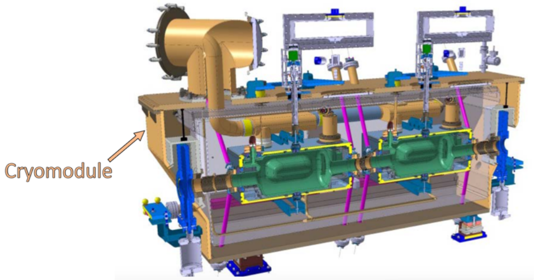
Canadian Particle Physics and Future Accelerators

Canadian HEP community will be engaged in next generation high energy collider projects for both detectors and accelerators



e.g. HL-LHC:

- ATLAS detector upgrades have federal funding
- IPP Canadian HEP community working to secure funding of cryomodules for crab cavities (partnerships TRIUMF, FNAL, CERN…)



International partnerships in all regions key to success:

- TRIUMF and KEK have offices in each others labs, joint programs/symposium series
- Long Range Plan recommends:
  - Stakeholders in Canadian government, universities, institutes, labs and industry work towards a more formal relationship between Canada and CERN.
  - Identify an office in federal government responsible for engaging with the international community in moving forward major new science initiatives.
- Canadian government now has a Chief Science Advisor – IPP HEP community working with her on engagement in international projects and partnerships.

U.S. Planning - P5 in 2018

The P5 recommended projects have made significant progress since the P5 plan was released in 2014.

At this moment, several large P5 projects are in the pipeline for approval of the baseline.

As a result, overall funding levels are up which is an essential component for success.

The importance of building a strategy for the long-term future is recognized and the community is beginning to discuss a possible update to P5.

FIGURE 1 Approximate construction (blue; above line) and expected physics (green; below line) profiles for the recommended major projects, grouped by size (Large [>$200M] in the upper section, Medium and Small [<$200M] in the lower section), shown for Scenario B. The LHC: Phase 1 upgrade is a Medium project, but shown next to the HL-LHC for context. The figure does not show the suite of small experiments that will be built and produce new results regularly.

Fermilab

Future U.S. Planning

The Future of U.S. Particle Physics

- **DOE HEP continues the implementation of the 2014 P5 global vision for particle physics**
  - Strong community support has been crucial to the successful implementation of the P5 strategy so far
  - Continued community support is necessary to maintain our momentum with the U.S. Administration and Congress
- **At an appropriate point, the strategy for U.S. particle physics will need to be reevaluated and updated**
  - Discoveries and results from upcoming experiments will impact the strategy for future investments
    - Next strategy should be informed by results from the 13-14 TeV run of the LHC, second generation dark matter experiments, precision muon experiments, and short- and long-baseline neutrino experiments
  - Further advance current R&D and planning activities conducted towards future projects (*e.g.,* high-field magnets, SRF cavities, CMB-Stage IV, and third generation dark matter)
  - Updated strategy for the future of particle physics should be available in time to guide next round of major investments
    - Guidance should be available as the current round of projects are being completed and the field seeks to make new investments
    - Updated strategy should incorporate results from current, ongoing studies of future collider initiatives by the international community

U.S. DEPARTMENT OF ENERGY | Office of Science

DOE HEP Status Update at HEPAP - March 2017 13

Summary/Conclusion

- The P5 and community based planning process has provided a robust roadmap for HEP which has enjoyed broad support.
- A diverse program has been launched that promises to advance the field over the next decade. Includes recommendations for accelerator R&D.
- There is a recognition that larger projects and programs require global collaboration, cooperation and coordinated planning.
- The planning for the planning for the next P5 is under discussion. The last plan was developed through a multi-year process.
  - Working groups are forming to provide input into these planning processes.
- The Canadian have also developed a long range plan through a community based exercise that relies on global partnerships.
- HEP has been growing in Latin American with involvement in the LHC program, DM, DE, and neutrinos.

Looking forward to the next 50 years

Thank you