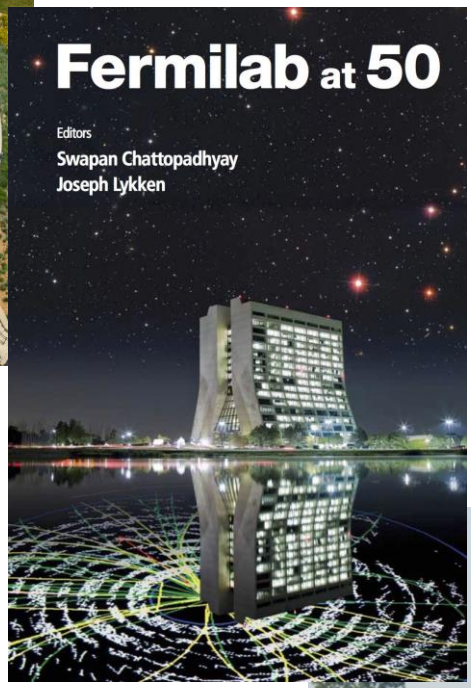
Fermilab Brief Overview

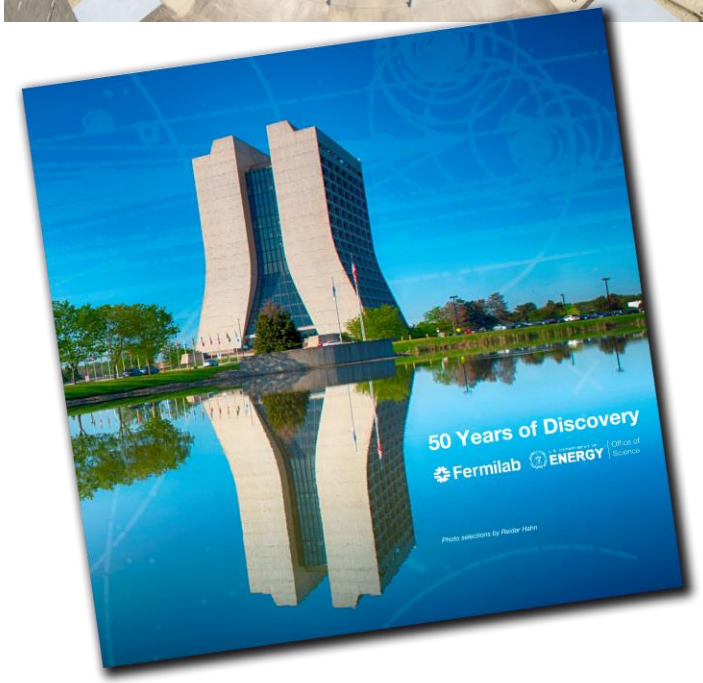
Tim I. Meyer

HEPAP

30 November 2017

50 Years (1967 – 2017)

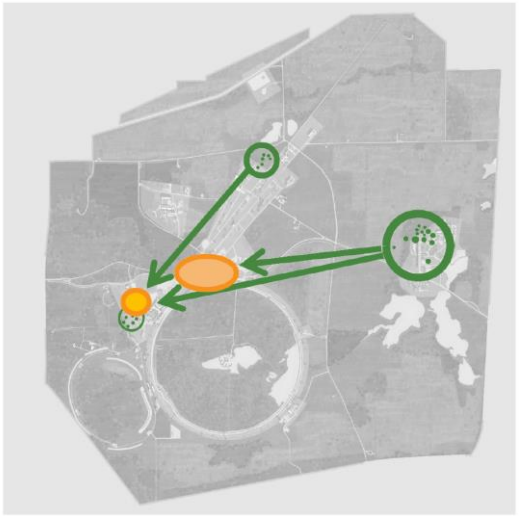




Before… During… After… Next?

- In response to forward thinking by SC, Fermilab has developed a Campus Master Plan that best positions the 6,800-acre campus to support our future science program

- Theme of the present investment strategy is:
  - "Consolidate, Centralize, Modernize" so that our community can "Eat, Sleep, and Work (safely) to Drive Discovery"



Community plan for U.S. particle physics: P5

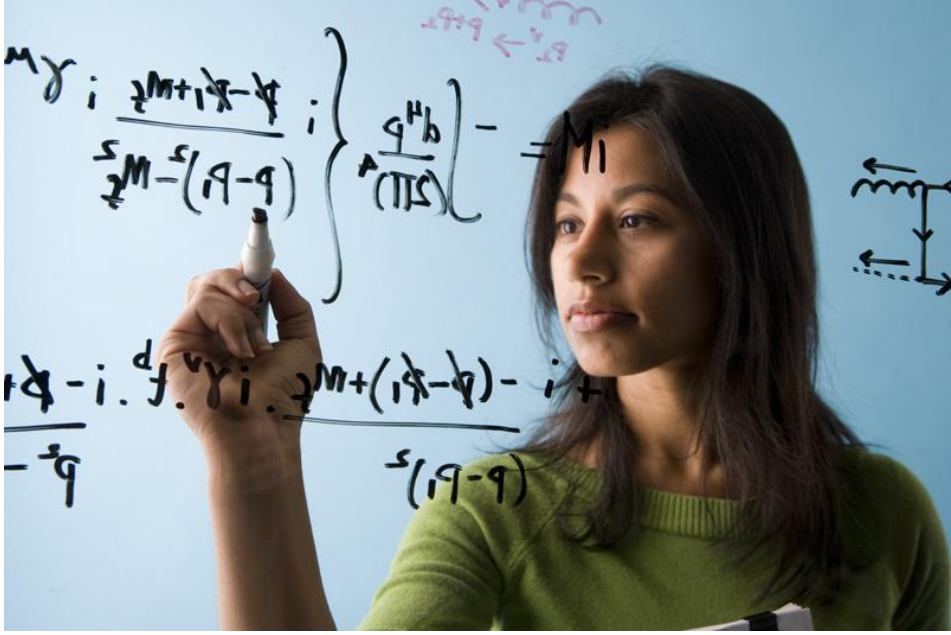
- P5 was an NSF/DOE prioritization panel using input from a year-long U.S. community exercise with global coordination
- Difficult choices were made; emphasis on the best opportunities for discoveries in fundamental science
- Fermilab is successfully executing the P5 plan for HEP as laid out in the May 2014 P5 report. Two (interconnected) highest priorities:
  - Fermilab hosts the world community at LBNF/DUNE for neutrino science
  - Fermilab continues strong partnership with CERN on LHC

Building for Discovery

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

Report of the Particle Physics Project Prioritization Panel (P5)

P5 science drivers



- Higgs boson
- Neutrinos
- Dark matter, dark energy

➔ What the above have in common:

- Fundamental roles in the universe
- Intertwined
- Very difficult to study -> little is known about them

- Exploring the unknown

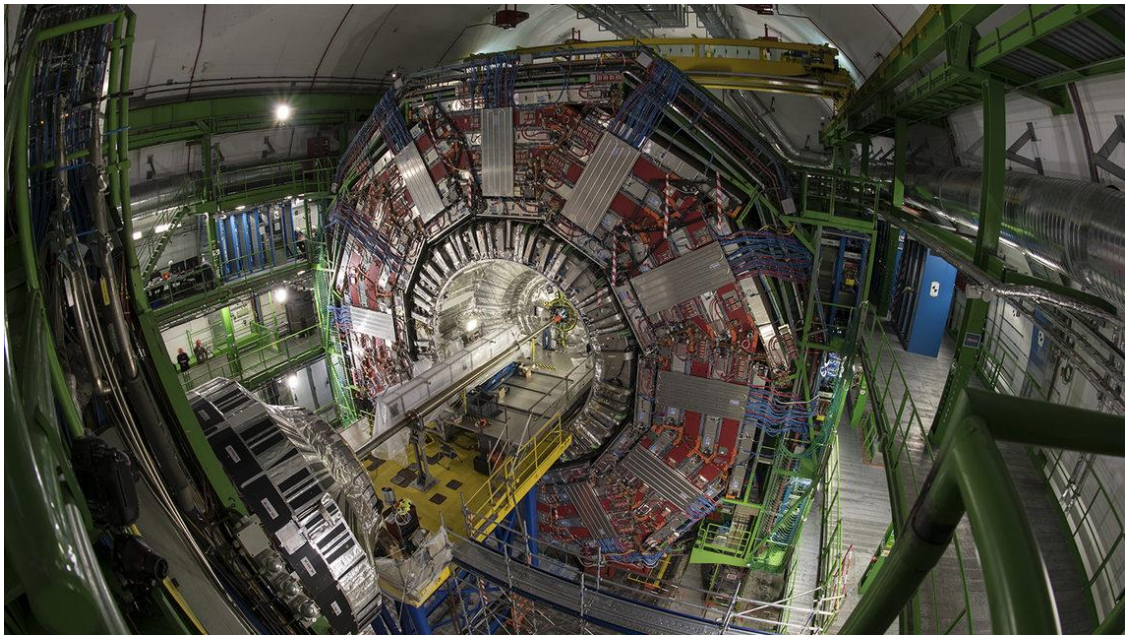
Higgs boson @ Fermilab

Higgs boson

- Discovered at CERN in 2012 by ATLAS and CMS collaborations
- Fermilab is U.S. host lab for CMS
- U.S. is by far the leading national contingent in CMS
- CMS spokesperson is Joel Butler of Fermilab

Fermilab's unique expertise and facilities are essential for major upgrades to:

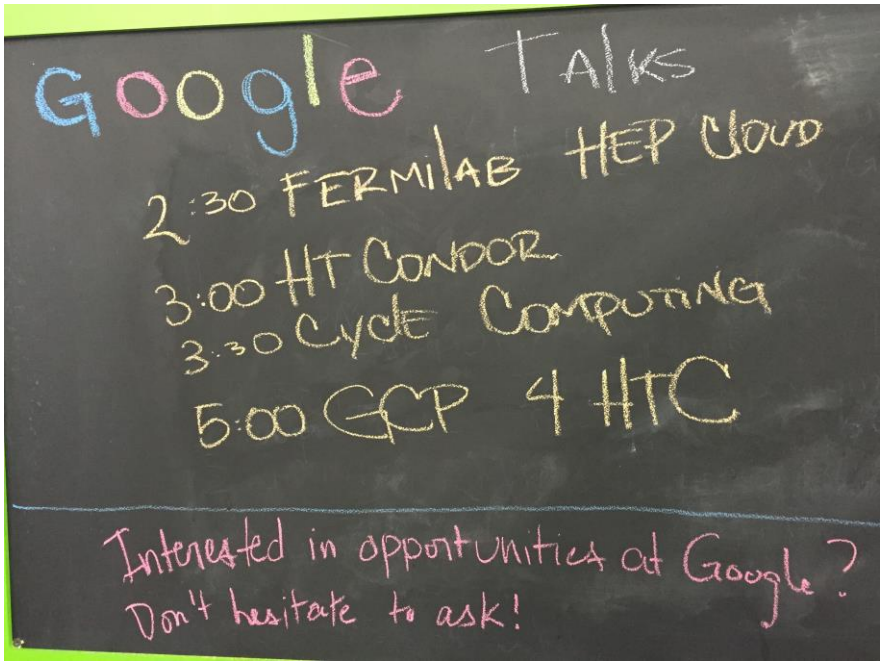
- The CMS detector
- CMS computing
- The LHC accelerator



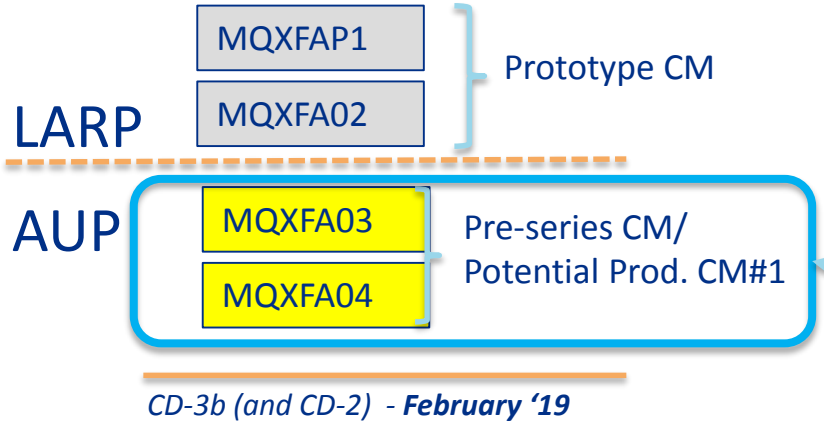
Higgs boson @ Fermilab @ Google

- Need to grow our Big Data distributed computing capacity by a factor of 100 for LHC

- Fermilab is creating a new system called HEPCloud, in collaboration with Google and Amazon

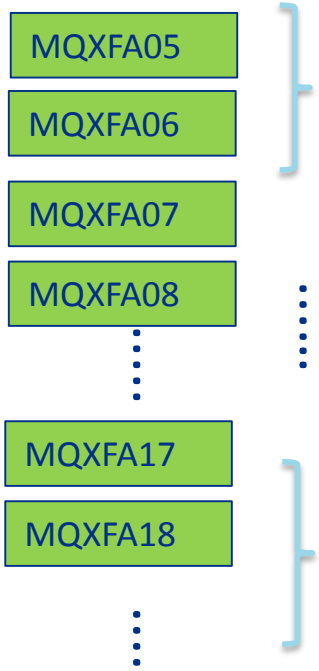


LHC AUP-CD-1 Baseline



Both Magnet MQXFA03 and MQXFA04 are fully conforming with AUP FRS. They are assembled in "Pre-Series CM"

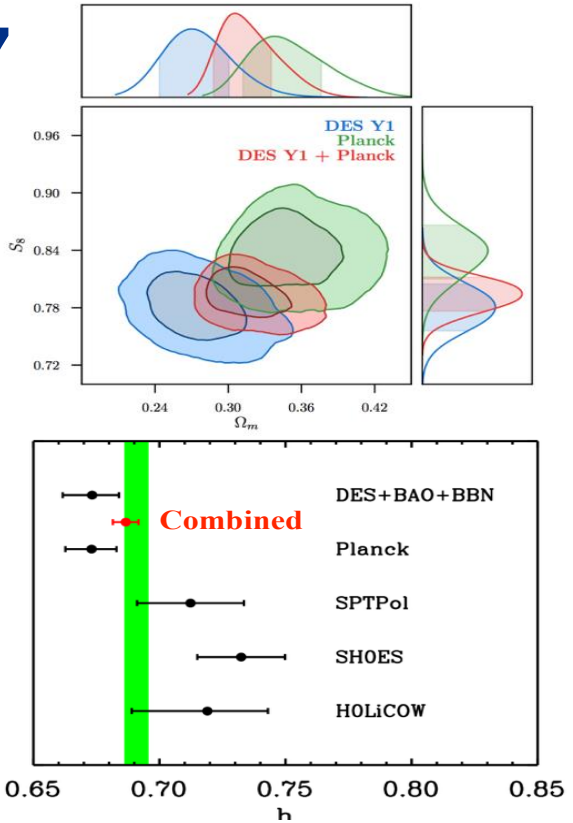
*CD-3b (and CD-2) - **February '19***

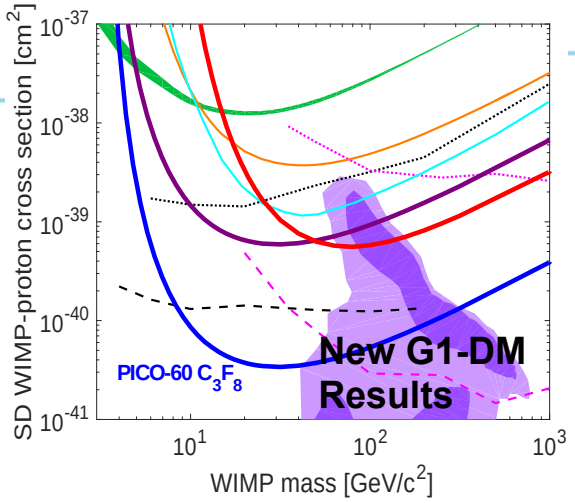


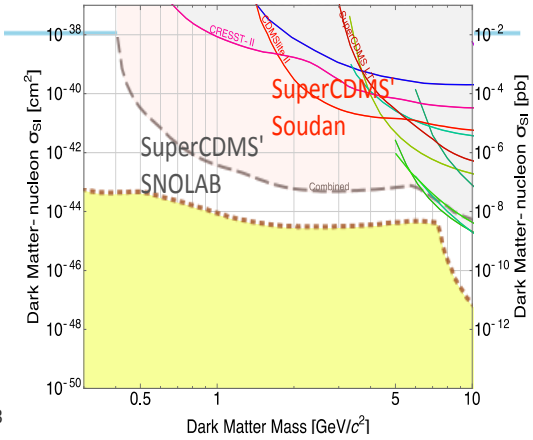
By maintaining same assembly rate, the opportunity offered by MQXFA03 can be capitalized in accelerating deliveries to CERN. ***Usage of MQXFA03 increases schedule float by ~2mo***

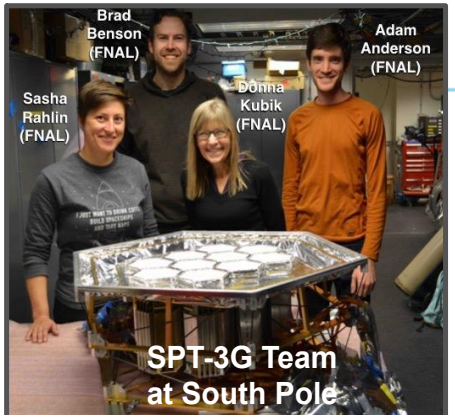
Fermilab Objectives achieved in 2017 in the Cosmic Frontier

- Extract Cosmological constraints on Dark Energy
- Complete the SPT-3G camera
- Develop leadership in axion dark matter research and associated technologies (became lead lab for ADMX and LDRD awarded for future axion search technology)
- Support G1 dark matter operations and improve on world-leading results
- Support Dark Energy and G2 Dark Matter projects (DESI, Super CDMS, LZ)









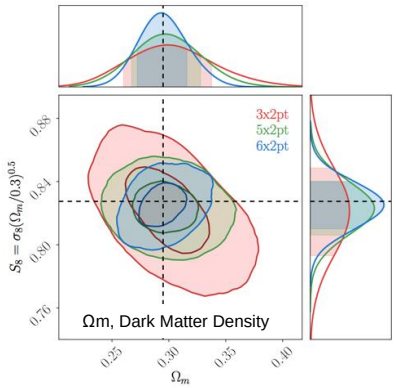
Dark Energy Survey

- This year first ever observation of a “kilonova” explosion from a merger of two neutron stars, also detected by LIGO with gravity waves

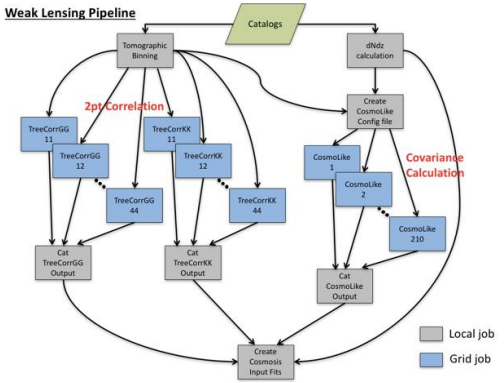
- More to come from imaging of 300 million galaxies

Cosmic Frontier: Building for the Future

- Build framework for combining and cross correlating Optical and CMB data: first with SPT+ DES to build foundation for LSST and CMB-S4

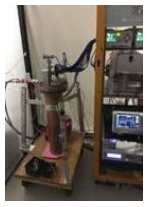


Simulation of projected cosmological constraints cross-correlating DES and SPT data to reduce systematics and maximize cosmological information

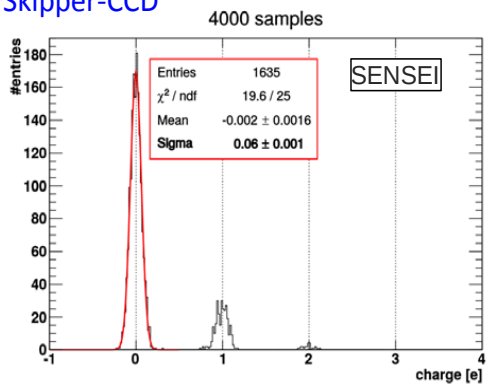


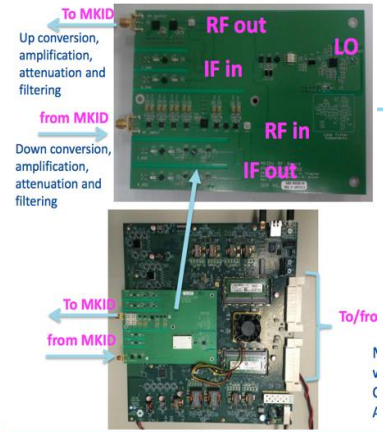
Weak lensing pipeline for LSST (WLPipe) interface with CosmoSIS software framework for combining cosmological probes

- Advance R&D for future optical and CMB surveys and technology for future dark matter experiments

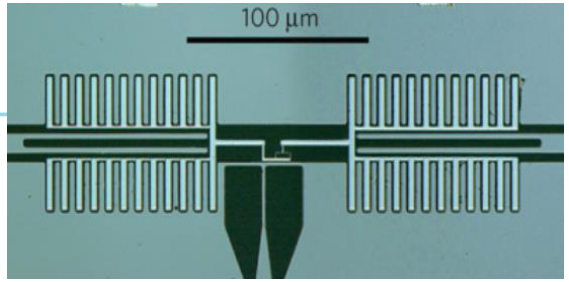


Skipper-CCD





10k pixel readout system for MKID detectors, (optical or CMB), benefitting from RF control experience at the Lab



Qubits act as amplitiude-to-frequency transducer to evade quantum noise limit – Work in collaboration with UChicago, funded by Heising-Simons grant

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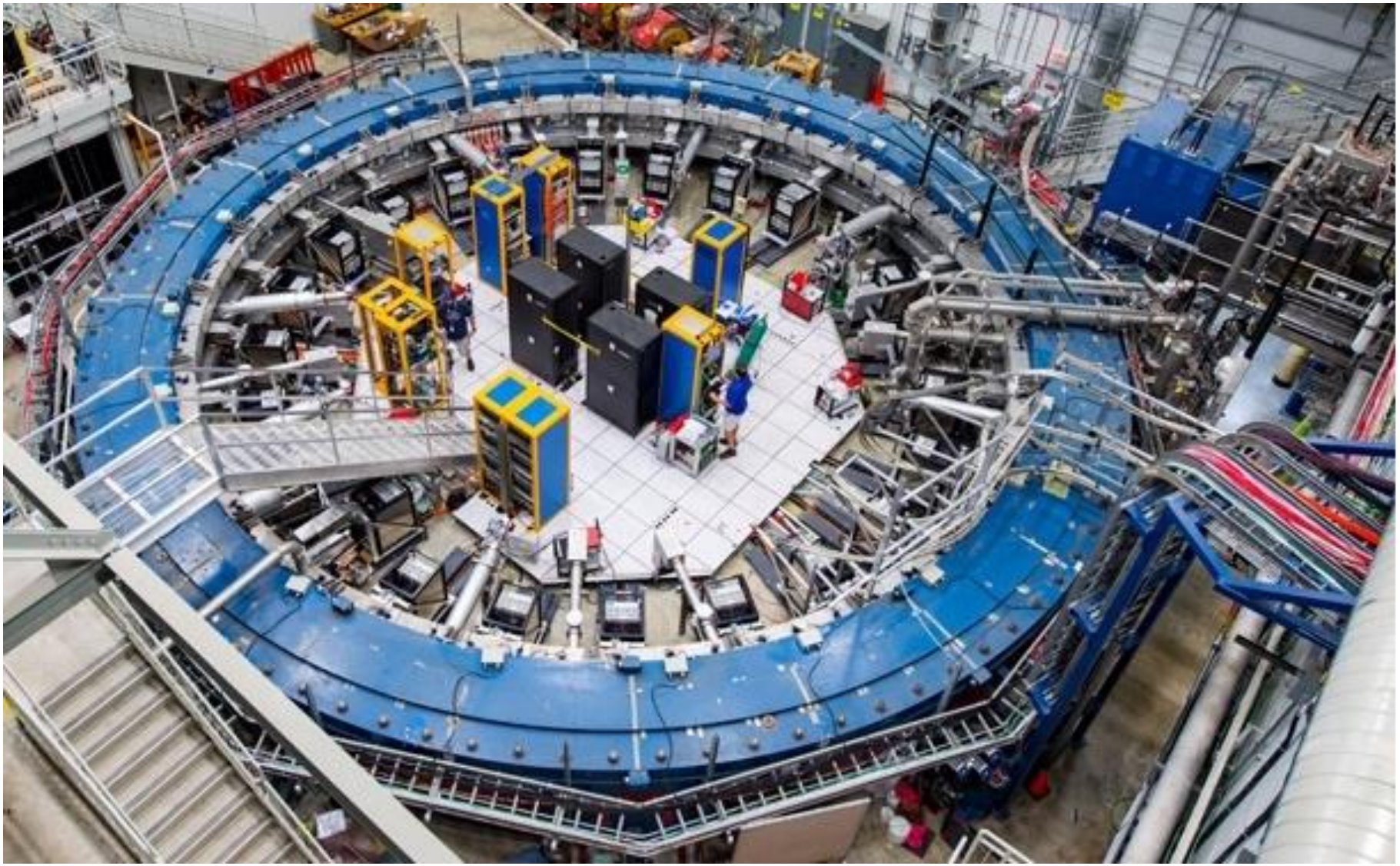
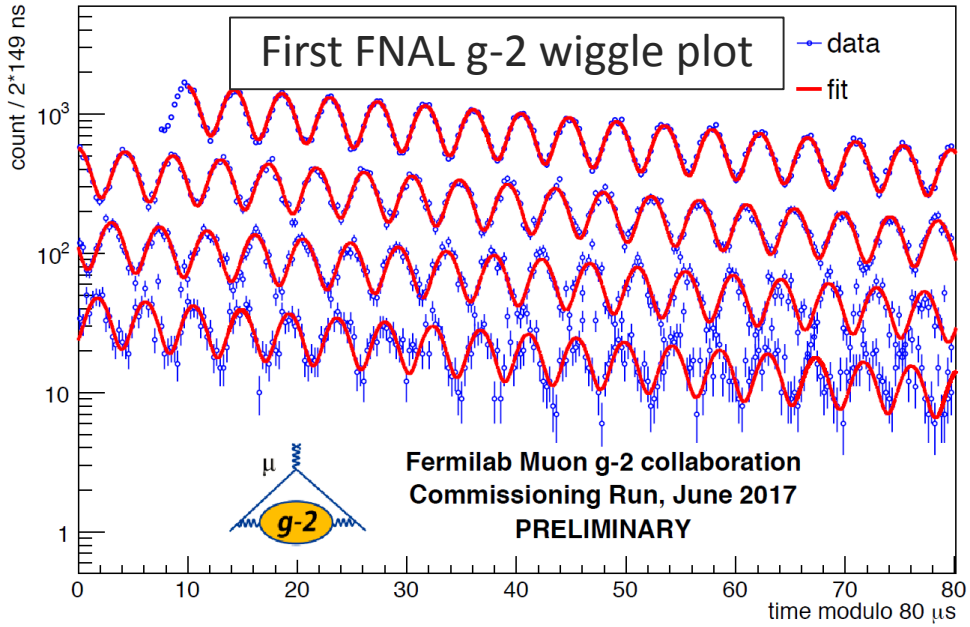
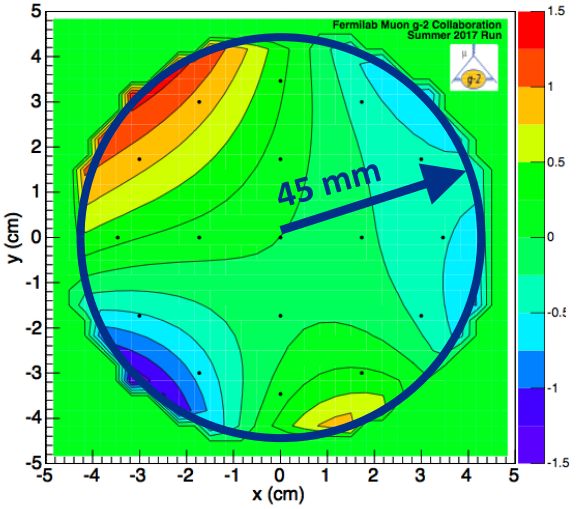
Muon g-2 commissioning…physics data hopefully January



Data from 5-week FY17 engineering run



- All subsystems commissioned
- FY18 Challenge → Ramping up to physics production rates
  - Beam transmission and injection efficiency x10



0.25 ppm contours ~3x more uniform than BNL

a_μ stat error 126 ppm in FY17
…ultimate goal 140 ppb!

Mu2e – Good Progress on all Fronts

(For more info: http://mu2e.fnal.gov)

Current status:

- Full CD-3 approval in July 2016
  - Project is 60% complete
- All major procurements placed
- New detector hall completed and transitioned to operations
  - Installing infrastructure
- Beamline magnets in position
- Construction underway for all three solenoids (PS, TS, DS)
- Detector preproduction prototypes constructed & tested


Mu2e Experimental Hall


Left bend magnets in Mu2e beamline


31/52 TS coils fabricated


Prototype Production Target

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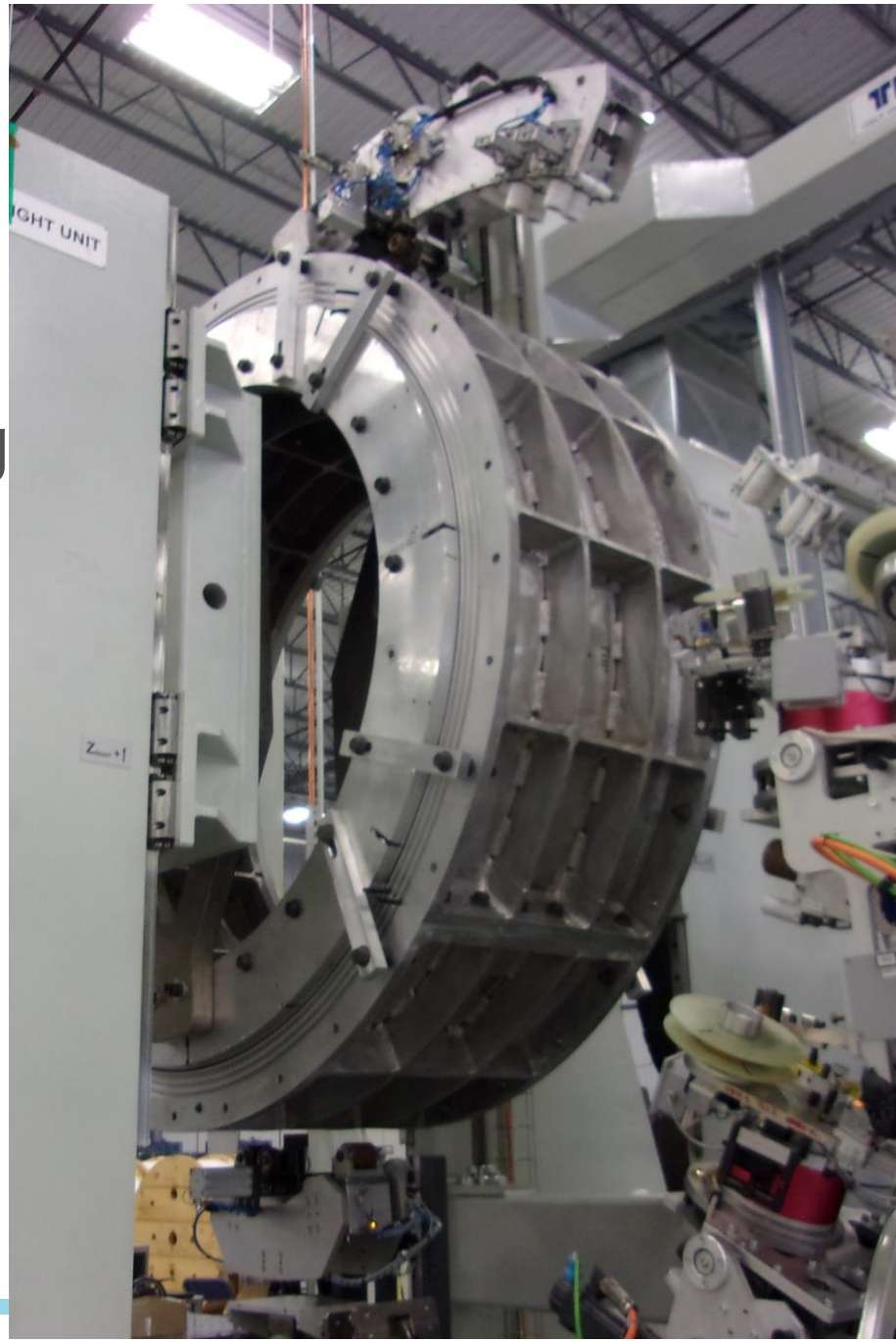
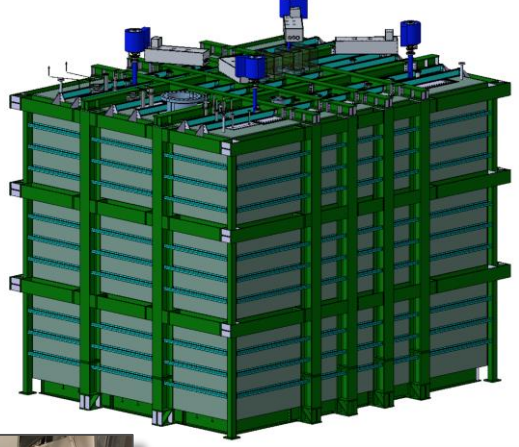
Production & Detector Solenoid Status

Completed model coil winding

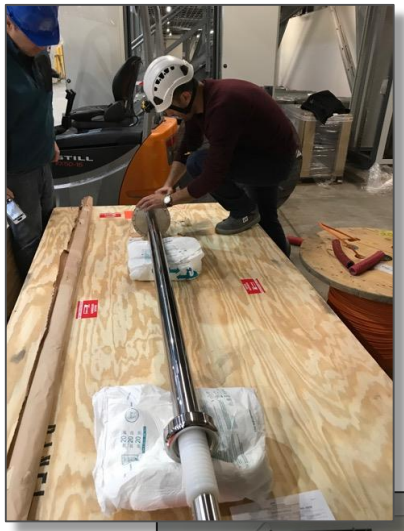


Short Baseline Near Detector (SBND)

- Near detector building completed in early 2017
- TPC components in fabrication:
  - About to start anode plane wire winding (UK & US)
  - Cathode plane nearly complete
  - 1st HV feedthrough delivered to Yale
- TPC cold electronics prototyping near end:
  - Same cold front-end ASIC as protoDUNE
  - Plan to use commercial off the shelf ADC in LAr
  - Very promising ADC lifetime study in LN2 near completion – decision January 2018
- Cosmic ray tagger panels >50% complete
  - Testing in the SBN ND building: see BNB ν interactions!
- Cryostat and cryogenics starting final design
- Upcoming milestones:
  - Start TPC assembly at FNAL mid-2018
  - Start cryostat assembly in late 2018
  - Installation in 2019



SBND Cryostat



HV Feedthrough at Yale

Cosmic ray tagger testing in SBND Building

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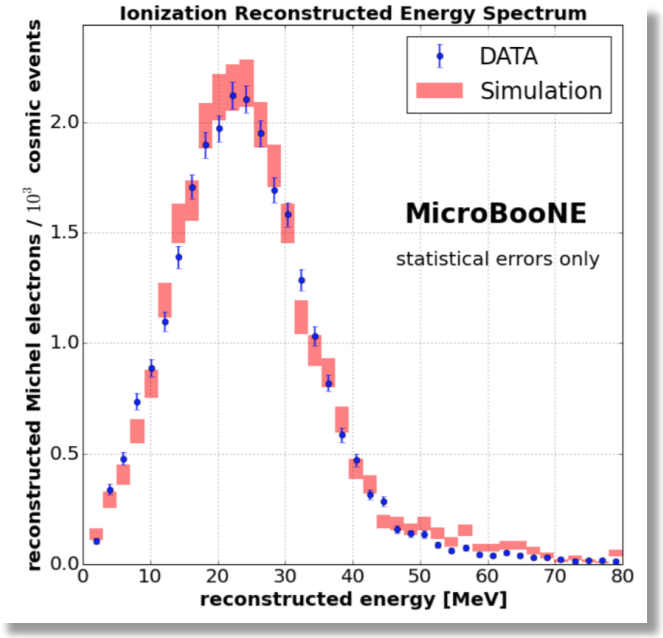
MicroBooNE

- Detector & beamline are running well
- MicroBooNE has developed many new techniques using data & is providing crucial input for SBN and DUNE
- 7 papers so far this year - more coming

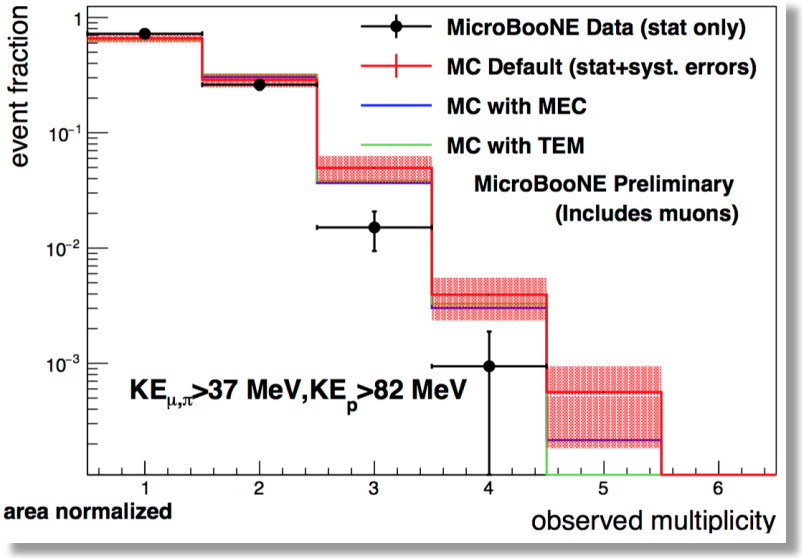
)

- 19 public notes

Michel electrons:



ν_μ charged current interactions:



SBN: ICARUS at Fermilab

- Far detector building completed in early 2017
- ICARUS detector vessels successfully delivered to Fermilab in July.
  - No damage to TPC or PMTs
- “Warm” outer vessel installation completed
- Cryogenics fabrication near completion in Europe (CERN deliverables) and US
- Readout electronics fabrication in progress
- Next steps for installation:
  - Installation of LN2 cold shields (Feb 2018)
  - Final preparation of vessels
  - Rig vessels into the building (Mar 2018)
- Complete installation and transition to commissioning in late CY 2018

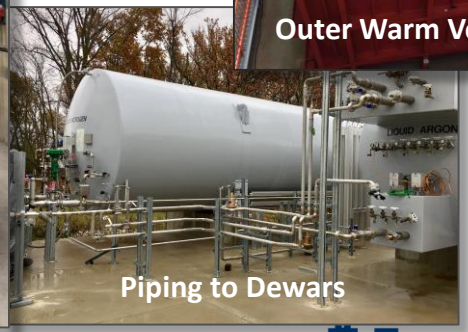
- SBN joint analysis group progressing on common tool framework


Vessel Ready to Leave CERN June 12

Vessel 2 parked west of SBN FD Building


Outer Warm Vessel


Cryogenic components @ Vendor in Holland


Piping to Dewars

PIP-II: The accelerator driving LBNF/DUNE

- Modern, 800-MeV superconducting linac
  - Replace current, 47-year-old, linac
- Responsive to the P5 plan
  - Sustained U.S. leadership in accelerator-based neutrino physics

- Goals:
  - 1.2 MW beams at startup of LBNF/DUNE
  - Platform for eventual 2+ MW

- Status
  - CD-0 November 2015
  - CD-1 DOE Rvw Dec 12-14

PIP-II: Driving Accelerator Technologies

- Superconducting radio-frequency (SRF) technologies are the enabling technology of high-power accelerators
  - SNS (ORNL)
  - LCLS-II (SLAC, under construction)
- Fermilab: world leader, based on investment over last decade
  - Development of "high G/high Q_0" techniques
  - Providing ~50% of LCLS-II acceleration modules
- PIP-II will inherit the LCLS-II workforce and infrastructure

PIP-II: International Partners

- India/DAE
  - Long-standing R&D collaboration with four DAE laboratories
    - BARC, IUAC, RRCAT, VECC
  - Engaged in nearly all major systems
  - In-kind contributions authorized in formal agreements
- Italy/INFN
  - Draft agreement for construction stage under discussion
- UK/STFC
  - Oct 2017 announcement of significant contribution to LBNF/DUNE/PIP-II
  - Construction phase deliverables under review by UK gov't
- France/CEA, IN2P3
  - Technical discussions underway; agency discussions initiated

India : Dept Atomic Energy, Chairman Sekhar Basu, & Bhabha Atomic Research Center, Director Vyas

- Annex-I : Agreement for PIP-II, Accelerator projects
- Annex-II: discussion ongoing– Neutrino program (anticipating signing the agreement in early 2018)

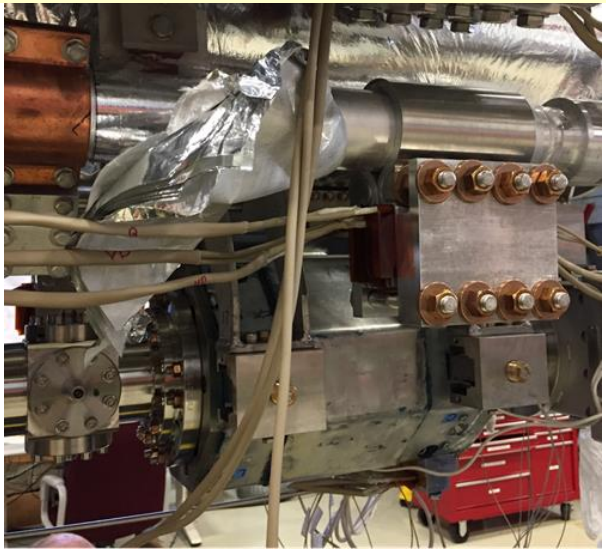
LCLS-II CM Assembly Status

All cavities for CM10 are

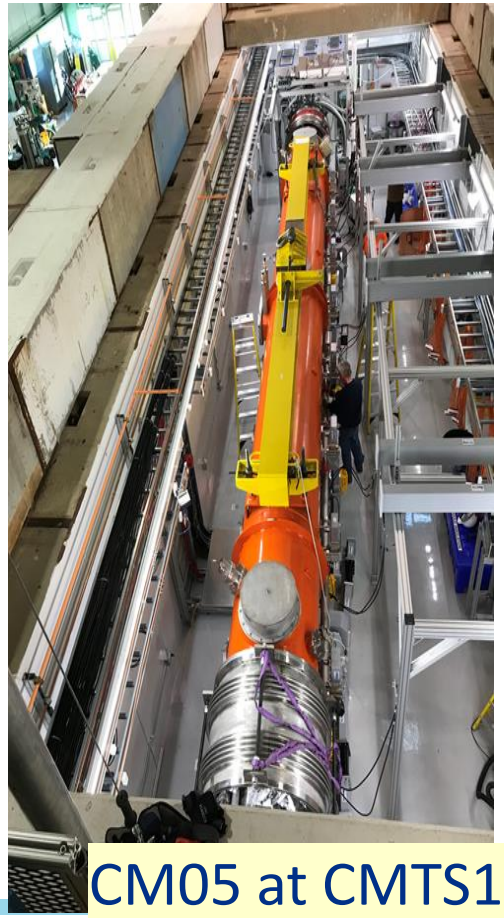
CM03 disassembly

FC-1 in SLAC tunnel

CM08 assembly – SC magnet



CM09 at WS2

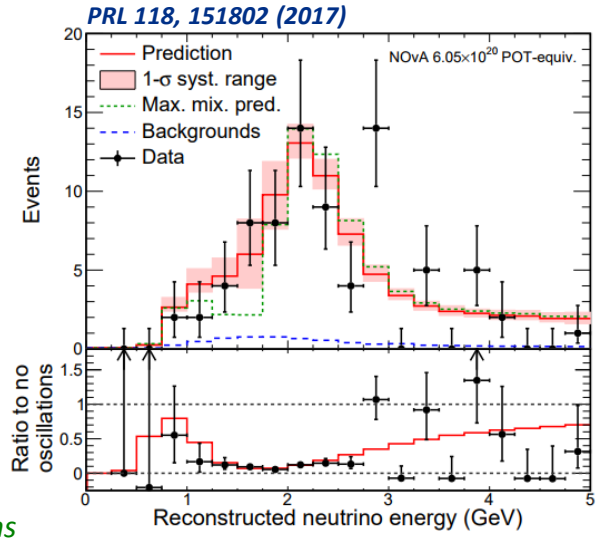


CM05 at CMTS1

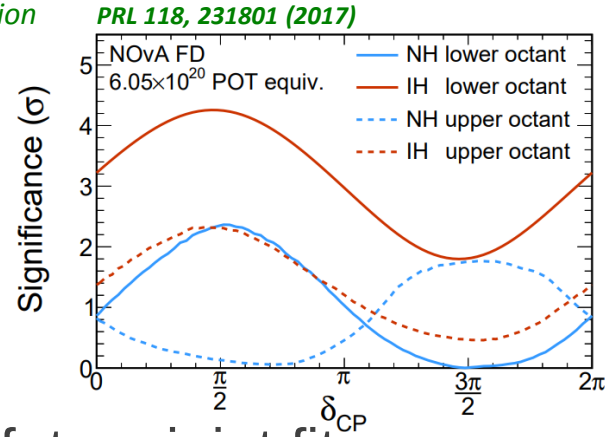
NOvA Updates

- Accelerator and detectors performing well
  - FY17 record year with 5.2E20 protons-on-target (POT) delivered
  - To-date collected 9E20 POT neutrino mode, 3.8E20 POT antineutrino mode
- Published results on ν_μ disappearance, ν_e appearance, and long-baseline sterile neutrinos search with 6E20 POT
- Upcoming results
  - Full 9E20 POT in neutrino mode this winter.
  - First antineutrino results with 7-8E20 POT planned for Neutrino2018
    - ~2σ mass hierarchy sensitivity.

Hint of non-maximal 2-3 mixing

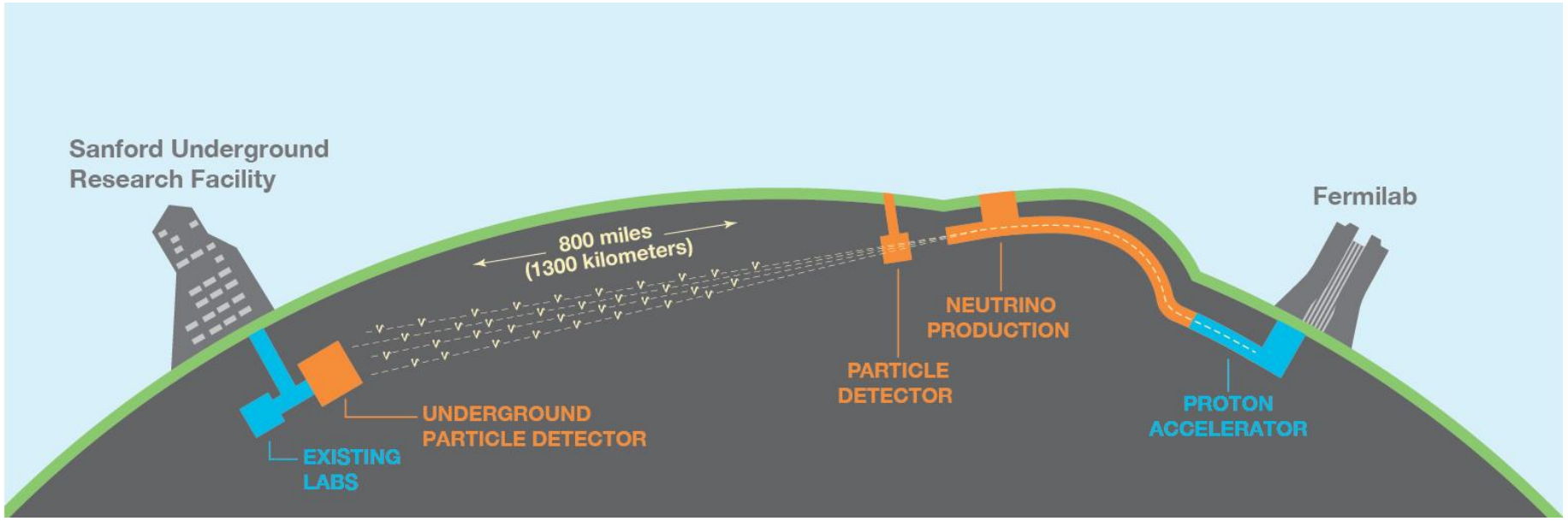


Constrains allowed combination of mass hierarchy and CP-violating phase



- Held 3 meetings to-date with T2K in pursuit of future joint fits

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



LBNF/DUNE is the world's flagship neutrino project and an international experiment that could change our understanding of the universe.

The project will send particles from the world's most powerful neutrino beam, located at Fermilab in Illinois, to the world's most precise neutrino detectors, located a mile underground at Sanford Lab in South Dakota.

The LBNF/DUNE project will be the first internationally conceived, constructed, and operated mega-science project hosted by the Department of Energy in the U.S.

discovery opportunities

Neutrino CP violation

- the origin of matter in the universe

Supernova neutrinos

- origins of neutron stars and black holes

Neutrino surprises

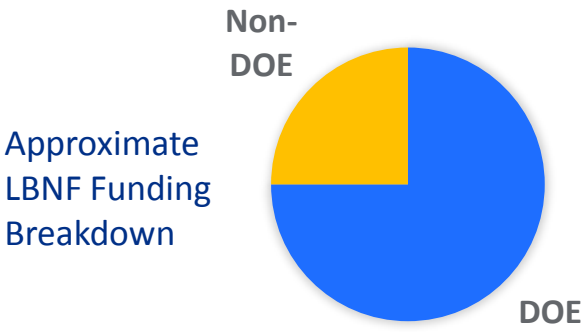
- new forces, particles, or laws of nature connected to neutrinos

Proton decay

- unified origins of particles and forces

Overview of the LBNF Project

The LBNF Project provides the **infrastructure** necessary for the DUNE experiment. DOE, as the host funding agency, will fund all civil construction, and will fund significant parts of other critical LBNF systems, including cryogenics, primary and neutrino beamlines, and other components.



LBNF will provide facility infrastructure at two locations:

- **Near site**: Fermilab, Batavia, IL – facilities to create the neutrino beam and support the DUNE near detector
- **Far site**: Sanford Underground Research Facility, Lead, SD – caverns and facilities to support the DUNE far detectors

Partnerships/in-kind contributions are critical to LBNF's success: ~25% of project

Fermilab's LBNF will drive neutrino science forward the way CERN's Large Hadron Collider drove the Nobel Prize-winning Higgs discovery

Overview of the DUNE Collaboration

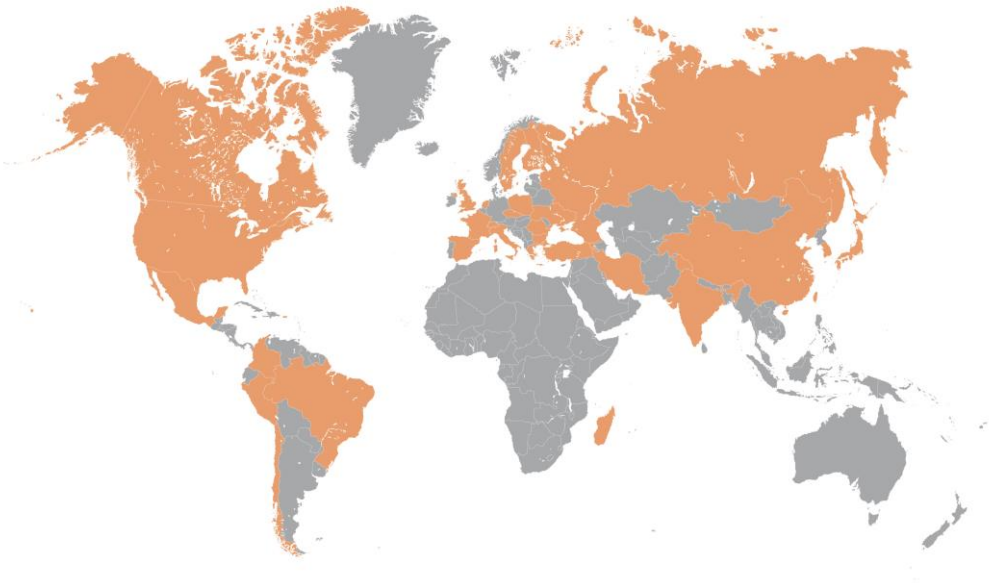
The international DUNE Collaboration is responsible for managing the design, funding, construction, and operation of the neutrino detectors at both the near and far sites.

As of today:

>60 % non-US

1041 collaborators from 176 institutions in 31 nations

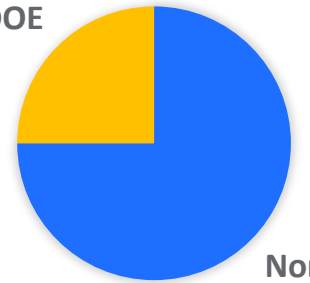
Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Paraguay, Peru, Poland, Romania, Russia, South Korea, Spain, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE has broad international support and is growing

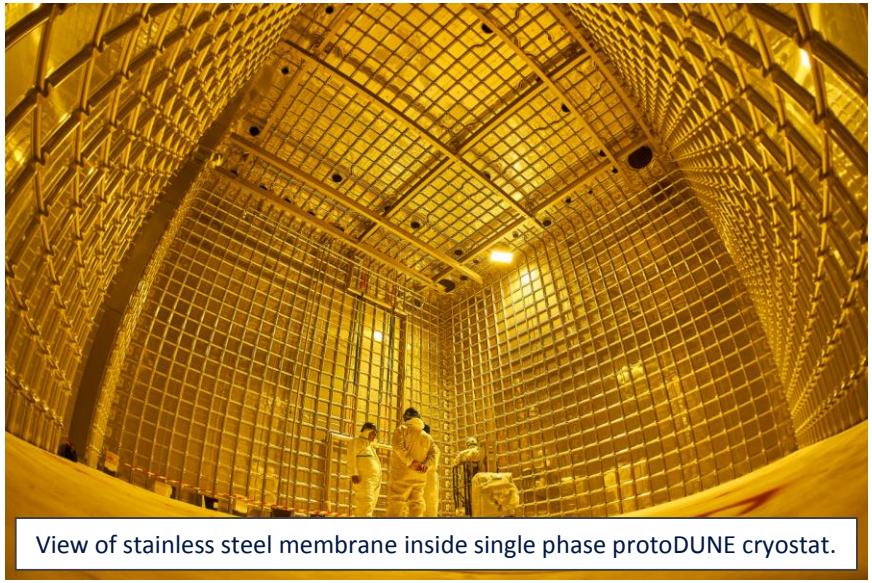
Overview of DUNE Experiment

Approximate DUNE Funding Breakdown



- The DUNE experiment will consist of:
  - four 17,700 ton liquid argon time projection chambers at the South Dakota site
  - a neutrino detector at Fermilab

View protoDUNE Single Phase detector (near) and Dual Phase detector (far) at CERN. The prototypes are 1/25 scale.



View of stainless steel membrane inside single phase protoDUNE cryostat.

- In order to build the massive DUNE detectors, two 700-ton scale prototype liquid-argon detectors are currently under construction at CERN - will take data in fall 2018.
- The DUNE Collaboration is organizing and overseeing institutional consortia that will have responsibility for design and construction of different detector elements.

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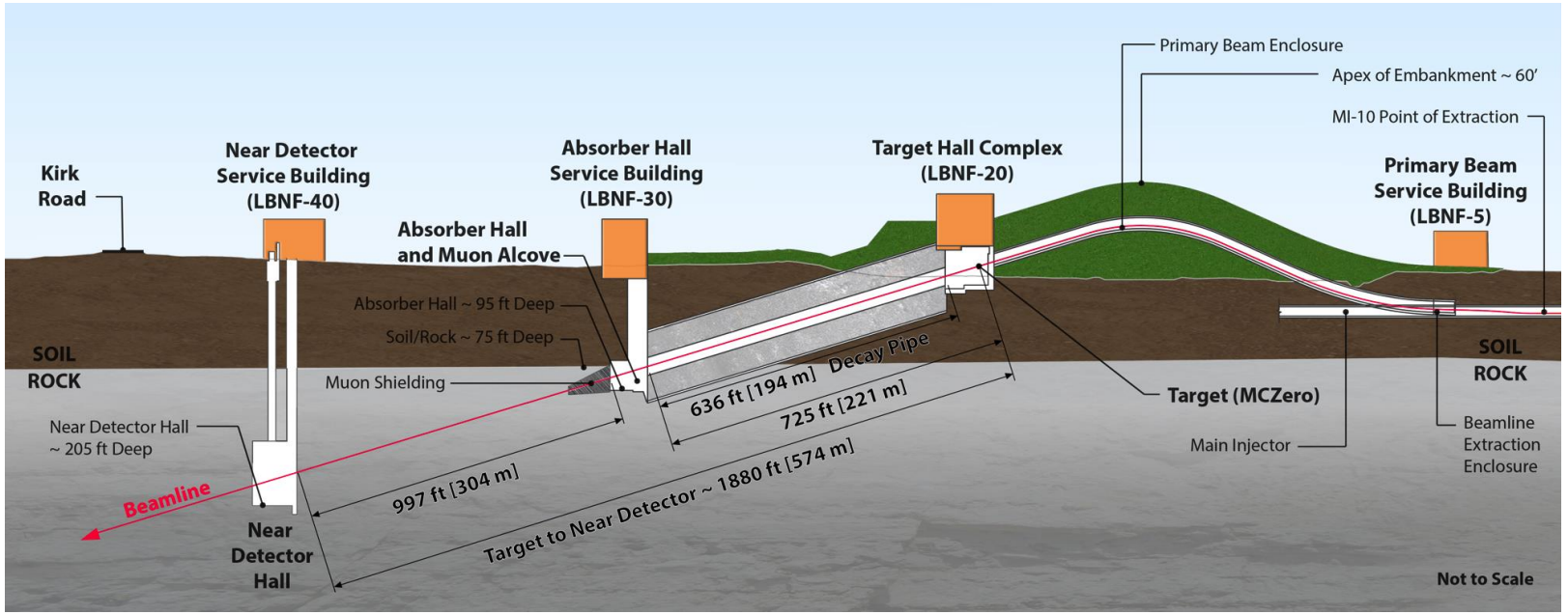
LBNF/DUNE Overview - Near Site at Fermilab, Batavia, IL



- Primary proton beam extracted from existing Main Injector
- Initial 1.2 MW beam power, upgradable to 2.4 MW
- Embankment allows target complex to be at grade and neutrino beam to be aimed to South Dakota
- Decay region followed by absorber
- Four surface support buildings, including an underground hall to support DUNE near detector

Beamline design based on Fermilab's NuMI beam, currently the most powerful neutrino beam in the world

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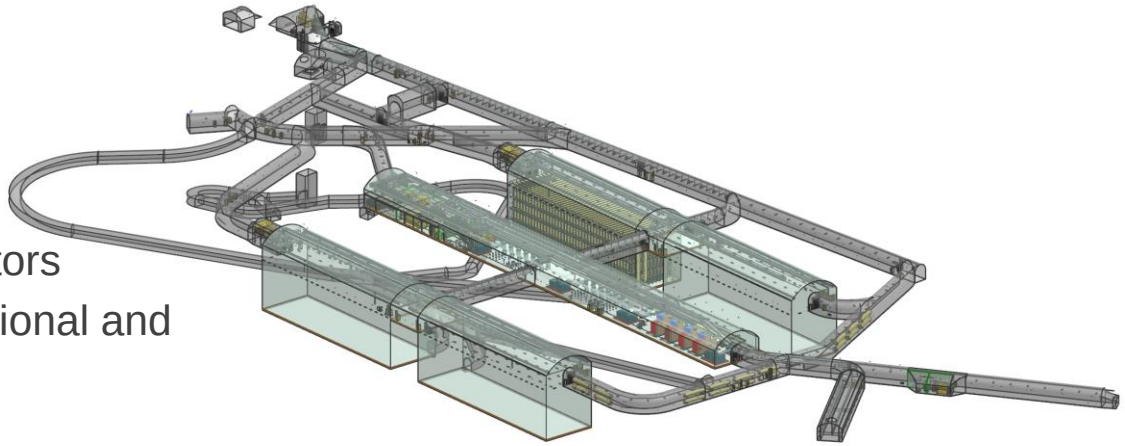
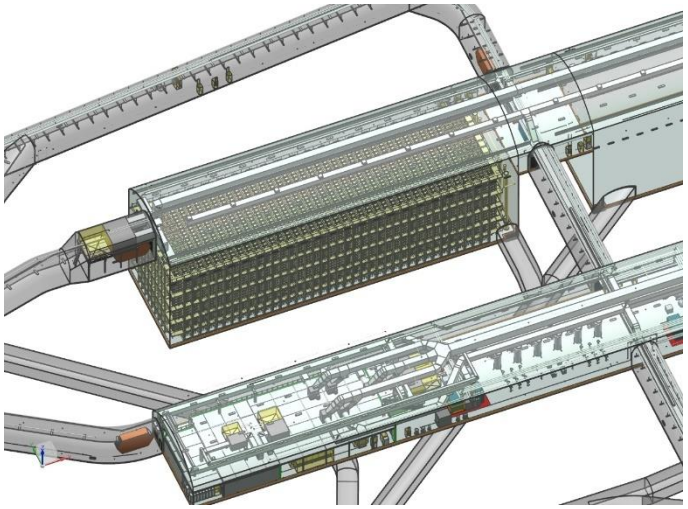
LBNF/DUNE Overview - Far Site at Sanford Lab, Lead, SD

- **Conventional Facilities:**
  - Surface and shaft Infrastructure including utilities
  - Drifts and two caverns for detectors
  - Central utility cavern for conventional and cryogenic equipment
- **Cryostats:**
  - Four membrane cryostats supported by external steel frames
- **Cryogenic Systems:**
  - Liquid nitrogen refrigeration system for cooling and re-condensing gaseous argon
  - Systems for purification and recirculation of liquid argon
- **Argon:**
  - 70,000 tons of liquid argon
- **DUNE neutrino detectors**



4850L caverns and drift layout



Single cryostat and portion of central utility cavern

LBNF facilities will support DUNE experiment

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LBNF and DUNE progressing rapidly…

- **July 2017**: LBNF groundbreaking in South Dakota

Participants included CERN, INFN, STFC, congressional delegations, SD governor, and Executive Office of the President

- **August 2017**: Contract awarded to Kiewit/Alberici Joint Venture (KAJV) to begin laying the groundwork for the excavation for LBNF
- **August 2017**: DUNE collaboration welcomes 1,000th member- Vitor Prestes Luzio from Brazil
- **August 2017**: Construction of protoDUNE cryostats at CERN nearly complete; first Anode Plane Assembly (major detector component) delivered to CERN by DUNE-US for installation

Rock Disposal System

- Future conveyor across US 85 in Lead (below) with Open Cut at right
- Geotech site investigation finished last week (right)

International Project Milestones

- The LBNF Project, working with the international DUNE collaboration and CERN, has established “international project milestones” that provide focus, establish confidence among the various partners, and serve to coordinate international deliverables.
  - For example, these dates help coordinate delivery of major in-kind deliverables from partners, such as the LBNF cryostat being supplied by CERN (first investment by CERN outside Europe in 60 years).
  - Detailed logistics planning and coordination is critical to LBNF/DUNE project success.

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

Agreement with CERN

- First time in history CERN investing outside of Europe
- Addenda signed May 2017:

Official Seal: On behalf of the U.S. Department of Energy, Chargé Theodore Allegra signed three amended protocols to the United States CERN 2015 cooperation agreement on May 2. The agreements will enable the U.S. and CERN to contribute technical equipment and scientific expertise to support the U.S. hosted Long Baseline Neutrino Facility in Illinois and South Dakota

UK Science and Technology Agreement

- First ever S&T agreement between U.S. and U.K. signed on September 20, 2017 by U.K. Science Minister Jo Johnson

- Commits £65M (about $88M) to DUNE, LBNF, and PIP-II

UK Minister Johnson Visits Fermilab

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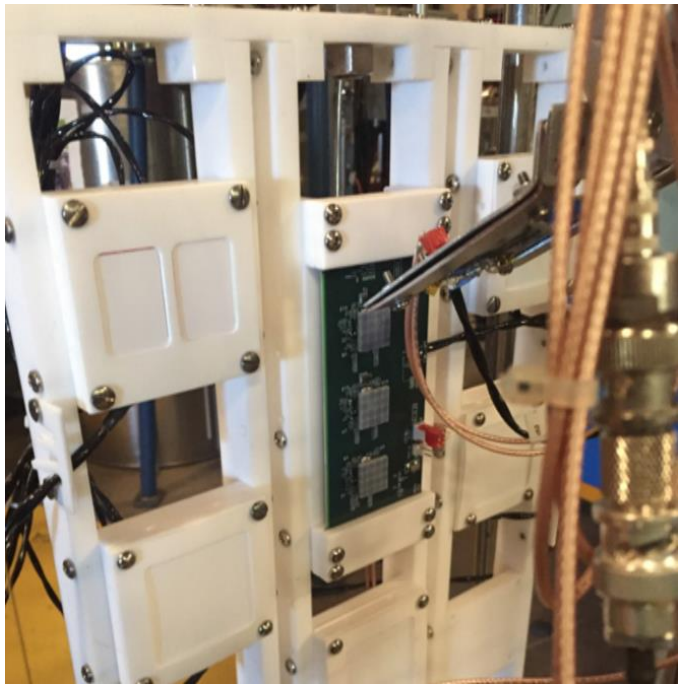
Italy: Funding Agency INFN

- Engaged in short baseline neutrino program, ICARUS Neutrino Detector, upgraded by CERN & INFN
- PIP-II R&D secure, production quantities good promise

Deep Underground Neutrino Experiment (DUNE)

- DUNE is building a regional collaborative effort in Latin America that focuses on leadership roles in high speed electronics, advanced computing, and a novel light detection technology: ARAPUCA

- ARAPUCA in the language of native Brazilian means a trap for birds; the new detector technology concept was invented at a Brazilian university with Brazilian funding



LBNF/Fermilab at the OAS ministerial and High authorities Science and Technology meeting. (Medellin, Nov.2, 2017)

Presentation to the Ministers and High Authorities jump-started/consolidated high interest in Fermilab's science and technology program

- Colombia: Intend of commitment from Colciencias President to support a consortium of Colombian university groups in DUNE in the next 4 years
- Mexico: following on letter of CONACYT's President to DOE, expressing strong interest in participation in the DUNE program, CONACYT's President offered to explore new venues within their institutes to support DUNE groups in Mexico
- Brazil: Leading group in DUNE ARAPUCA detectors, received support from Sao Paulo State funding agency
- Peru CONCYTEC and Paraguay CONACYT: Commitment from both Presidents, to financially support DUNE groups as part of ARAPUCA

Outlook

- Fermilab and US HEP program has unique strengths, a powerful network of partners around the world, and a good relationship with DOE, administration, and Congress

- All will need to be fully leveraged to realize the ambitions of the field…and then some

- The international dimensions have attracted significant positive attention and must be managed carefully to succeed

- US program healthy with many good projects and programs but we must stretch to succeed