Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Future of High Energy Physics in the U.S.

Joe Lykken

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40th Anniversary Symposium of the US-Japan Science and Technology Cooperation Program in High Energy Physics

Outline

- Delivering on the P5 plan
- Future colliders and other large scale HEP opportunities
- Discovery strategy of HEP experiment and theory
- Impact of technology breakthroughs on future HEP

2013: U.S. HEP community comes together

2014: The P5 plan

Building for Discovery

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

Report of the Particle Physics Project Prioritization Panel (P5)

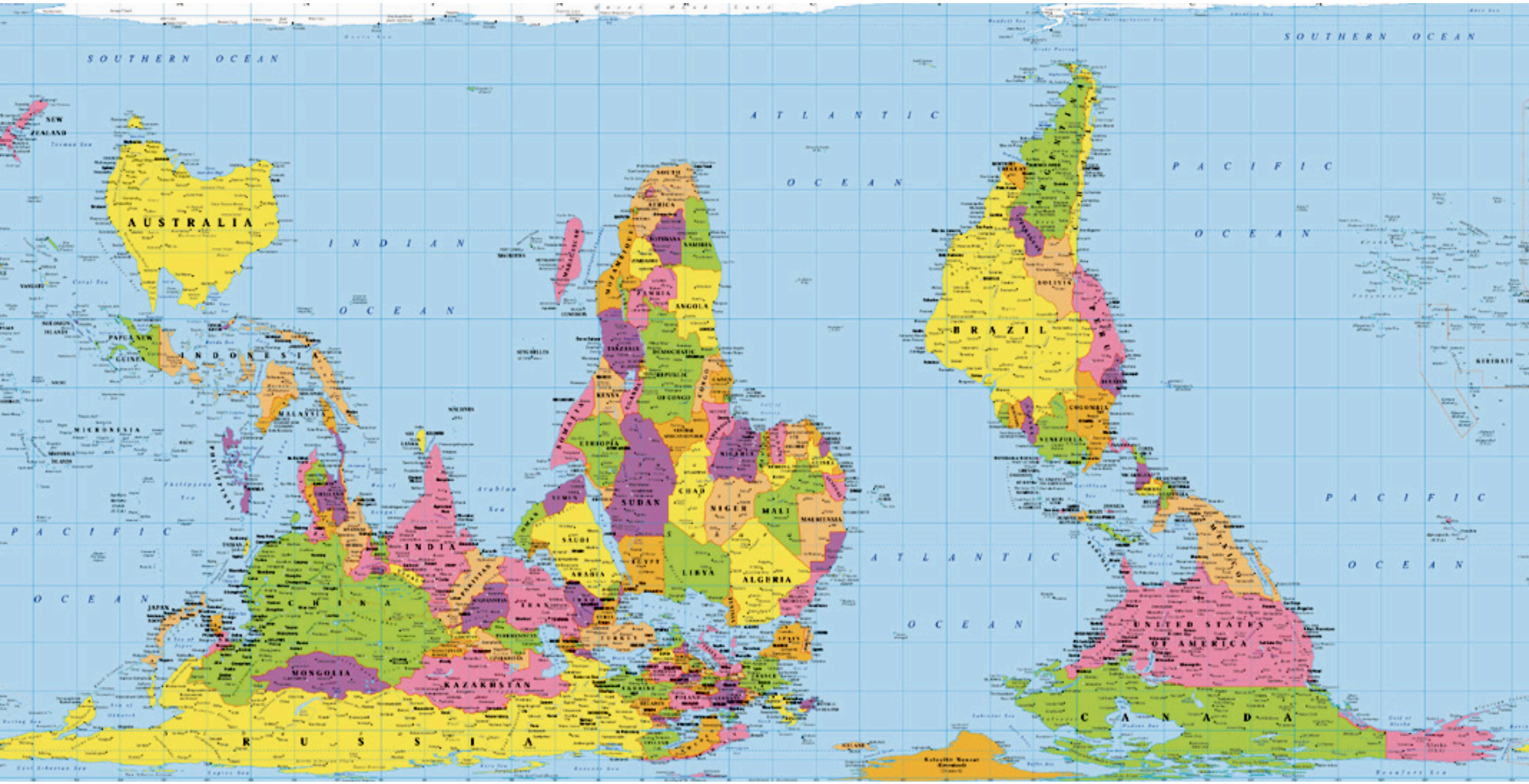
P5 plan: 10 year plan with a 20 year outlook

- Continue U.S. commitment and leading roles in the LHC
- Build a neutrino program at Fermilab that will attract the world community
- Continue U.S. leading efforts in dark matter, dark energy, and cosmic microwave background
- Pursue the Fermilab-based muon program
- Invest in the accelerator and detector technologies that we will need in the future

It is a feature of this plan that the major components reinforce each other

Strong support for P5 plan in DOE, Congress

P5 report: Particle Physics is Global



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Large international collaborations: neutrinos

The global neutrino community is now entering a new era of LHC-scale international collaboration

MiniBooNE collaboration, 2007:
77 people from 2 countries

Collaborator #1000

DUNE collaboration, 2019:
1,180 people from 31 countries

Benefits of large international science collaborations

It is widely recognized that the global advance in science is increasingly driven by large-scale, long-term international collaborations.

Such collaborations deliver lasting benefits to participating nations

These benefits include:

- Building science capability and science leadership
- Technology advances and tech transfer to industry
- Stronger and broader opportunities for STEM education, creating new pathways to the forefront of global science and research

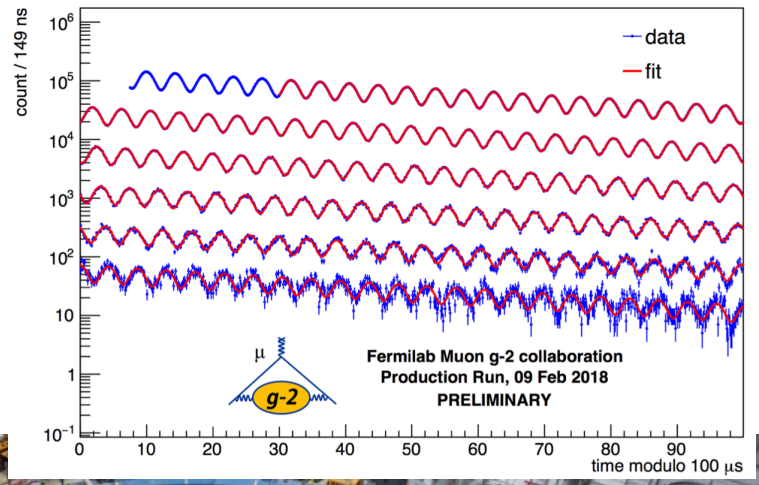
Erika Cataño Mur from Bogotá joined the NOvA experiment in 2013. Pictured in the Fermilab remote operations center

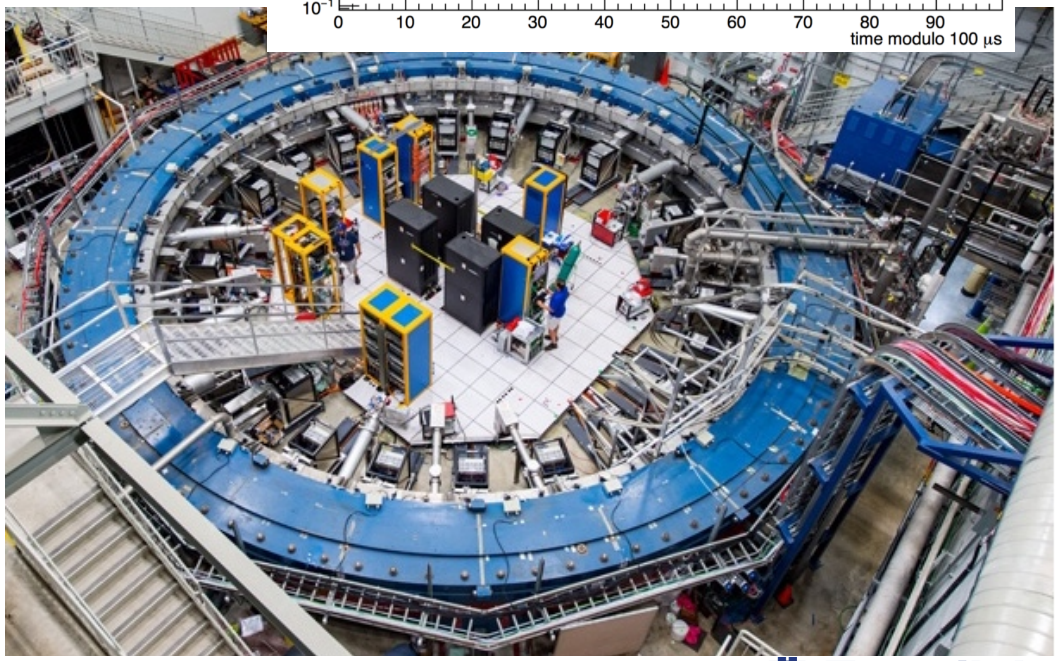
Delivering on the P5 plan

U.S. HEP Muon Program

Muon g-2 Experiment

- Running now
- Collaboration busy analyzing first physics data set
- Just completing major kicker upgrades to improve stored beam quality





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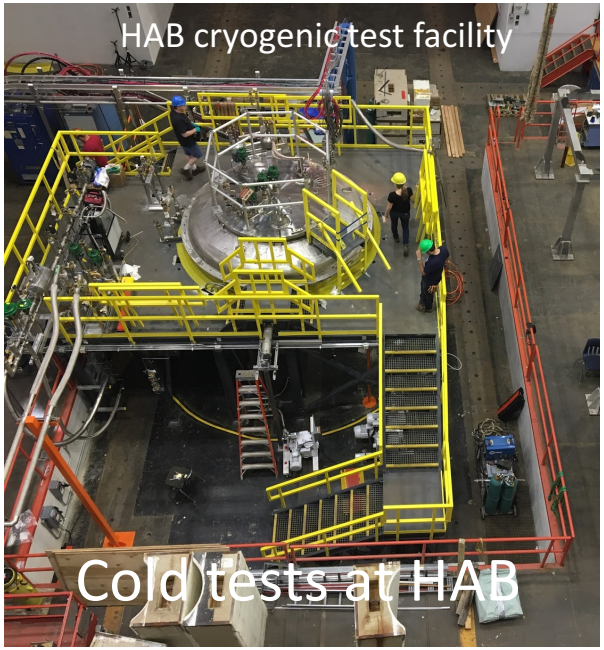
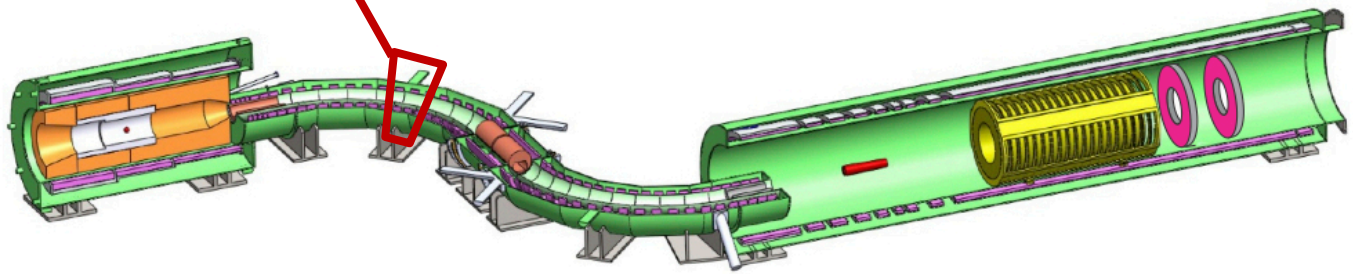
U.S. HEP Muon Program

Mu2e experiment: magnets and detectors under construction





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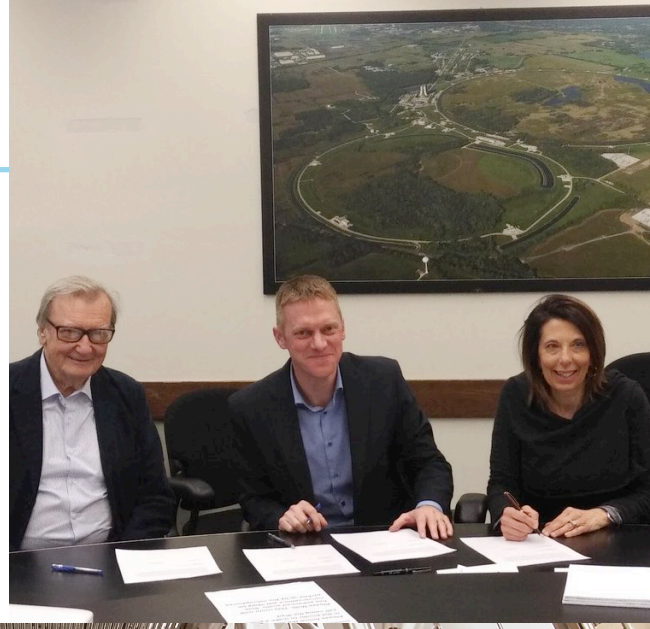
ICARUS @ Fermilab

Part of the new Short Baseline Neutrino program, with SBND and MicroBooNE



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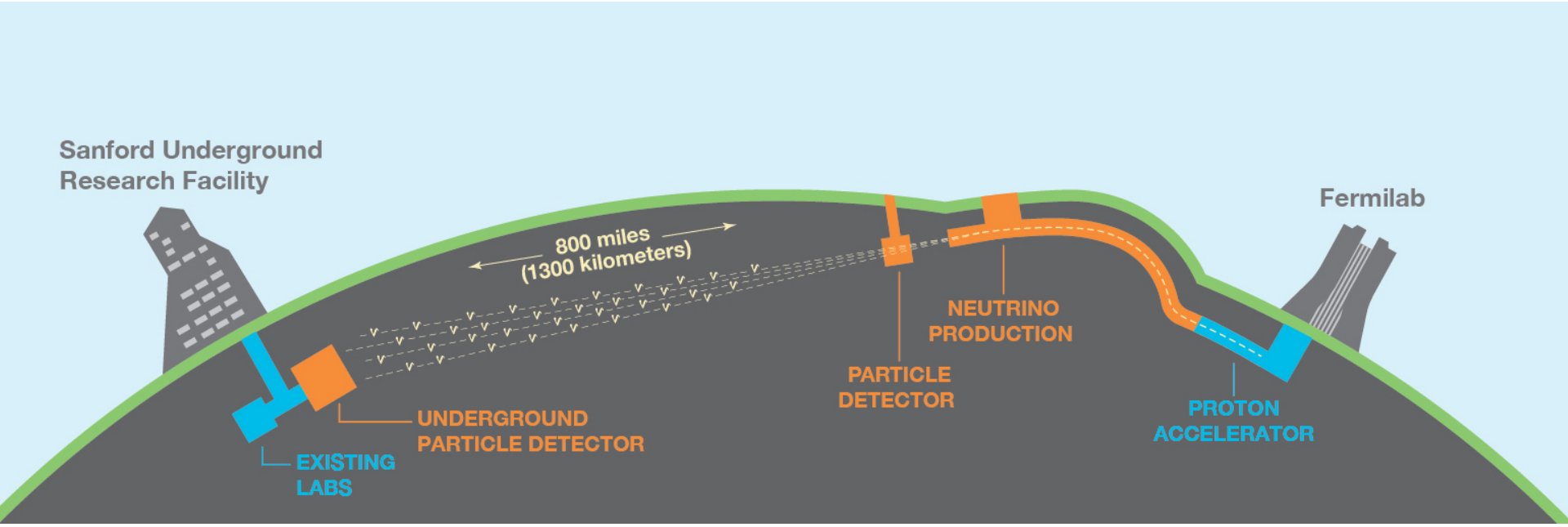
LBNF/DUNE: from concept to reality



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

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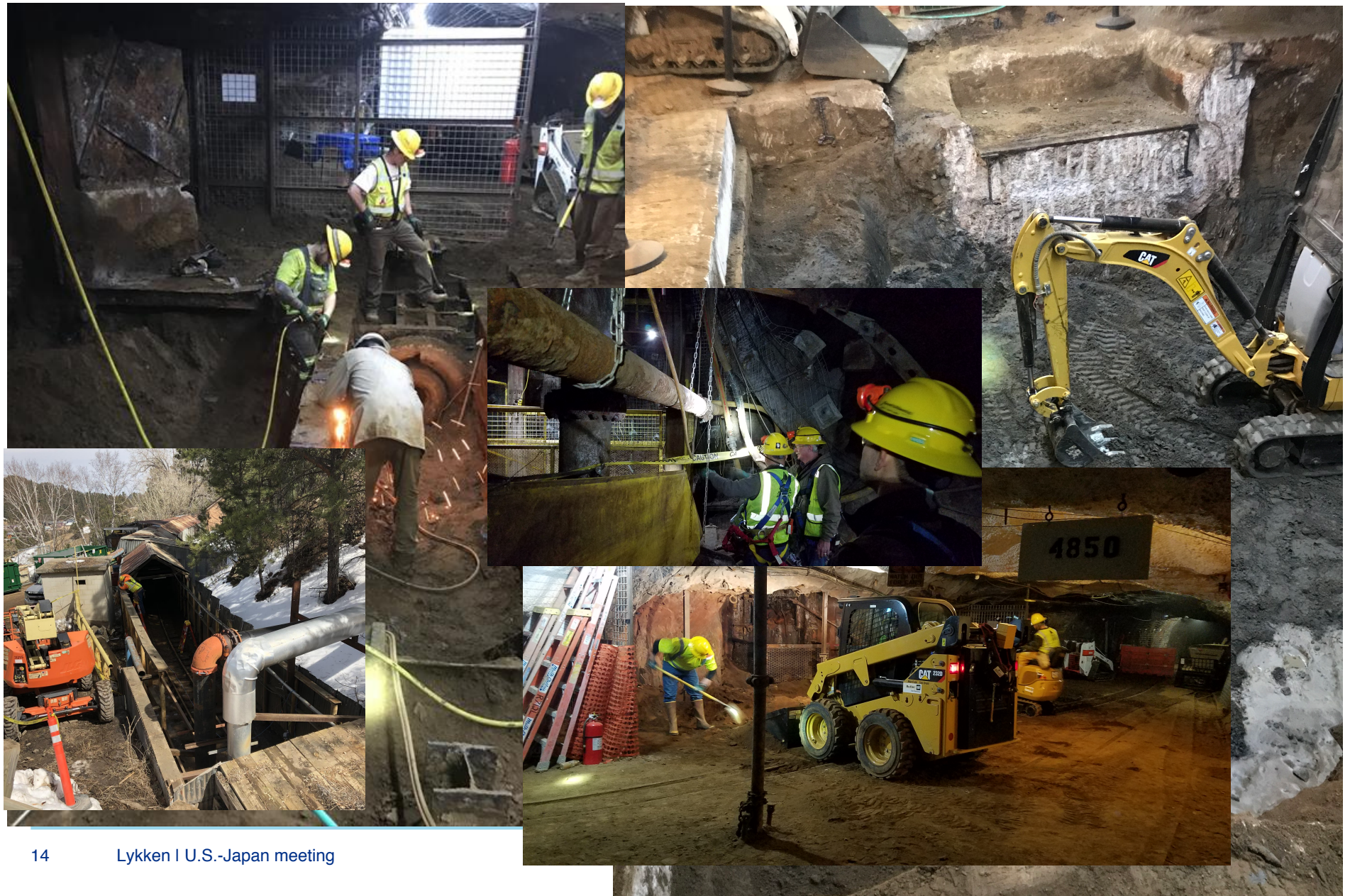
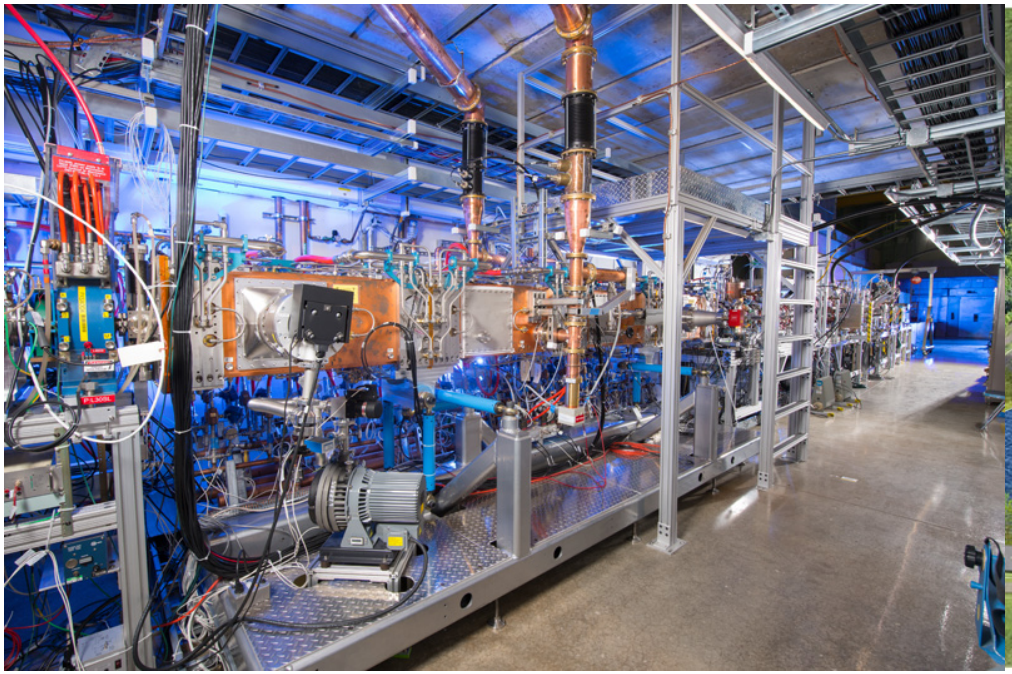
Pre-Excavation Construction at LBNF Far Site



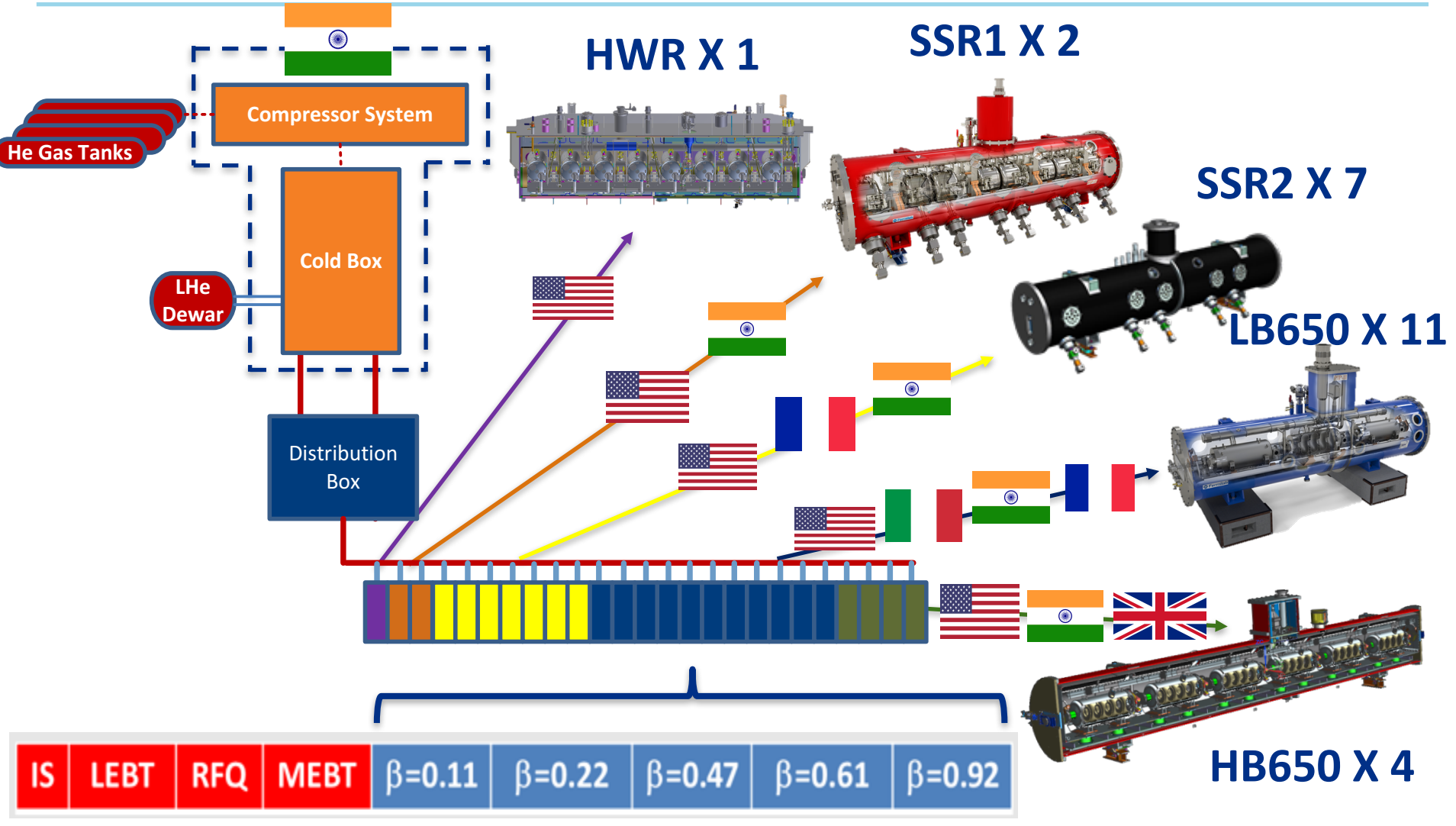
PIP-II accelerator

PIP-II will deliver the world's most intense beam of neutrinos to the international LBNF/DUNE project, and enable a broad physics research program, powering new discoveries for decades to come.

Building the world's most powerful neutrino beam cost-effectively



PIP-II international collaborators



PIP-II is the first accelerator project in the U.S. with substantial international contributions

New international agreements for HEP collaboration

U.S. Department of Energy and Indian Department of Atomic Energy Sign Agreement for Neutrino Physics Collaboration

APRIL 16, 2018

Home » U.S. Department of Energy and Indian Department of Atomic Energy Sign Agreement for Neutrino Physics Collaboration

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U.S. Cosmic Frontier Program

- G2 dark matter experiments proceeding well
- Dark energy probed by powerful cosmic surveys: DES, DESI, LSST
- The final major piece of the P5 plan still to launch is CMB-S4, a large multi-lab, multi-agency initiative that will probe cosmic inflation and the cosmic effects of neutrinos, among other things

Future colliders and other large scale HEP opportunities

Future Colliders: some facts

- Currently there is no organized effort in the U.S. HEP community to propose a future collider hosted in the U.S.
- The P5 plan positions U.S. HEP to participate strongly in an ILC hosted by Japan
- The very strong ties between U.S. HEP and CERN imply strong interest in the European Strategy update, including the possibility of a future collider hosted by CERN
- U.S. HEP has strong accelerator and detector R&D programs relevant to a variety of future collider options
- For example, ILC Cost Reduction activities proceeding at full speed - research and lessons learnt via US-DOE GARD program and LCLS-2 paved the way for cavity performance improvement for ILC

Future Colliders: some opinions

- It seems unlikely that a future energy frontier collider can be built anywhere if funding has to come entirely from current baseline budgets
- Thus somebody is going to have to make an “overtarget ask” at a high political level
- For success at this high level, it will be necessary to **show value beyond** -- and in addition to -- a strong HEP science case
- U.S. HEP has been using such arguments successfully already for LBNF/DUNE and PIP-II
- I am optimistic that a global collaboration can do this for a future collider
- ILC is the most immediate opportunity

Other large scale HEP opportunities

- New large neutrino detectors with new/improved technologies at existing sites?
- New accelerator-based high-power neutrino sources?
- Large G3 dark matter experiments?
- Post-LSST spectroscopic galaxy survey?
- New large scale muon expt?
- Large scale entangled quantum sensor array?

High-Power Neutrino Beams

- Next-generation facilities being designed to accommodate MW scale beam power in the DUNE/HyperK era
  - Minimize beam loss in the accelerator ring to keep radiation effects manageable
  - Increase capacity of neutrino production facility (robustness of target/horn, radioactive equipment/waste handling)
- Consortium inclu
  KEK, SLAC
  - Grew out of ex
    mutual interest
  - In-person meet
    2019, several t

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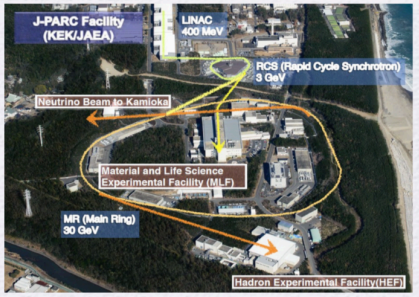

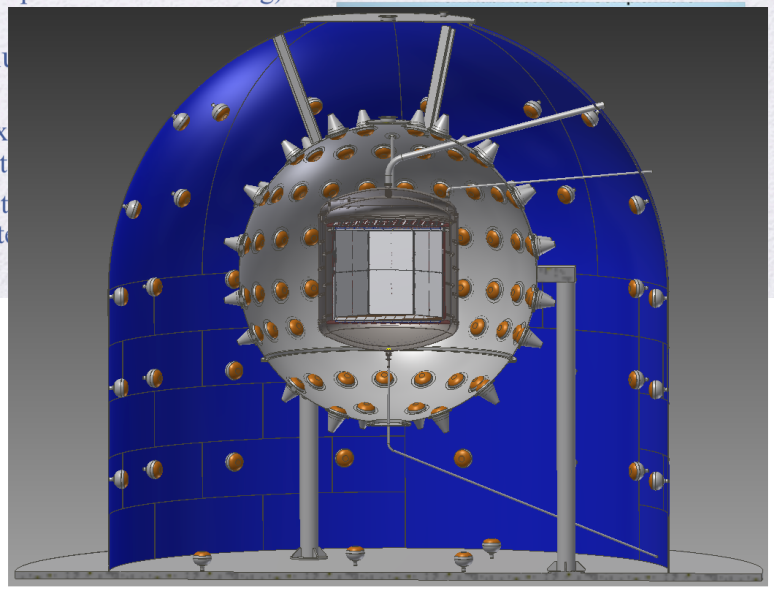

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Not all big cutting edge accelerators are for HEP…

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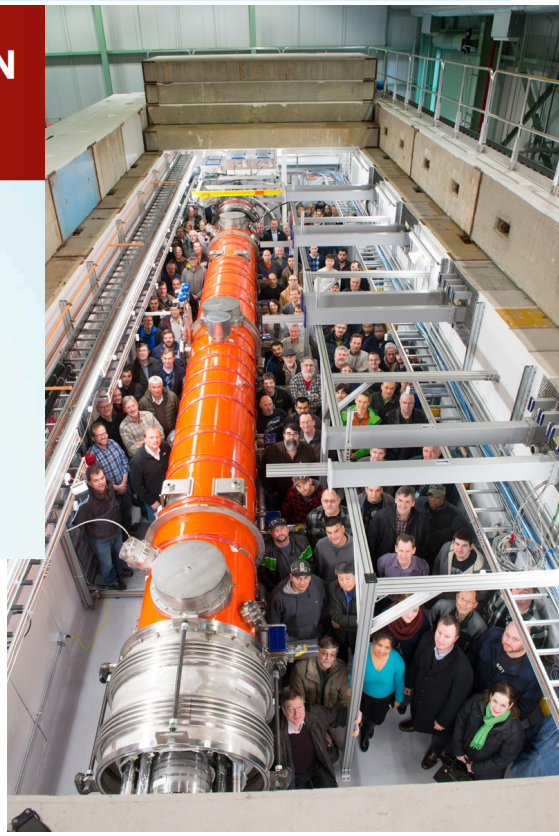
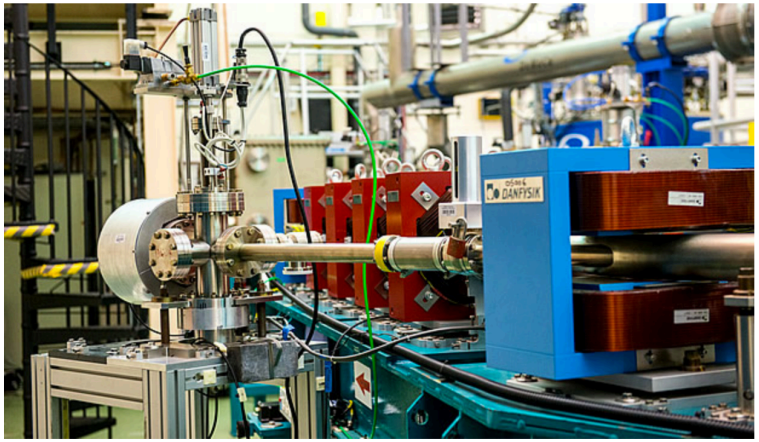
XFEL : ACHIEVEMENT OF THE CRYOMODULES INTEGRATION

LAST CRYOMODULE LEFT SACLAY IN JULY 2016



UK's Daresbury Lab Gears Up for High-Beta Cavity Series Production

MAY 3, 2017



Video. ESS interviews team members at Daresbury Lab in England. The STFC facility is responsible for series production and testing of the 84 high-beta cavities that will form the bulk of the European Spallation Source's superconducting Accelerator.

e.g. XFEL, ESS, LCLS-II, EIC

Discovery strategy of HEP experiment and theory

Discovery strategy of HEP experiment and theory

"The revolution is not an apple that falls when it is ripe. You have to make it fall" -- Ernesto Guevara de la Serna

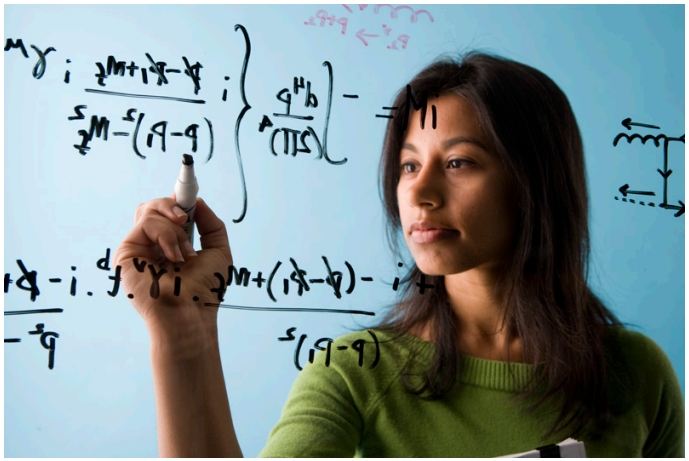
- To escape the tyranny of the Standard Model, it will not be sufficient just to discover new physics - this we already have (neutrino masses, dark matter, dark energy, inflation, baryogenesis, and quantum gravity are all BSM)
- It is also not sufficient to build consistent compelling BSM frameworks – we already have a lot of these too
- We seem to be missing some key clues that will propel us into new ways of thinking and new connections

So we need to keep shaking the tree…

Shaking the tree

There are lots of ways to do this:

- Looking for new phenomena in accelerator-based experiments
- Shaking the tree of standard cosmology
- Dark matter/ dark sector direct and indirect detection
- Quantum simulations and experiments on the Entanglement Frontier
- Pushing on the two particles that we can produce but know the least about, namely:
    - The Higgs boson
    - Neutrinos

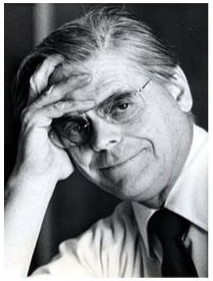


Impact of technology breakthroughs on future HEP

HEP science drives technology innovation

Superconducting magnets for the Tevatron, first industrial scale use of such magnets

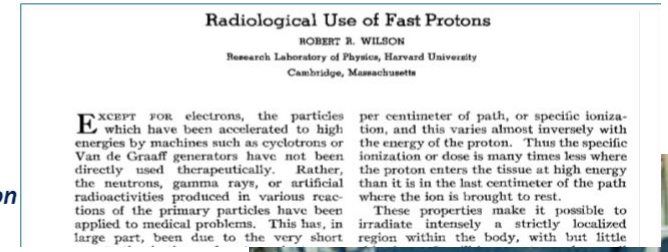
MRI machines from GE and Siemens USA



Robert Rathbun Wilson

1946: R. Wilson first proposed a possible therapeutic application of proton and ion beams

R. Wilson, Radiologial use of fast protons, Radiology 47, 487-491, 1946



Radiological Use of Fast Protons

ROBERT R. WILSON

Research Laboratory of Physics, Harvard University

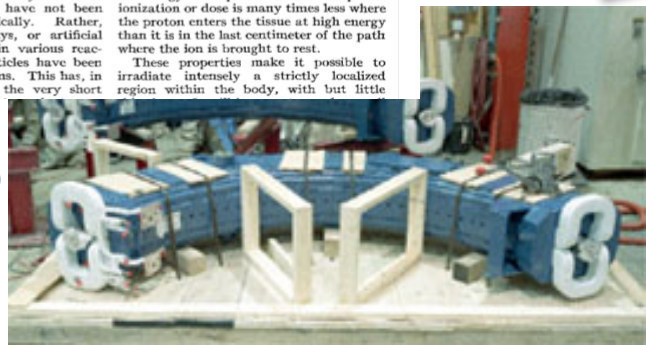
Cambridge, Massachusetts

EXCEPT FOR electrons, the particles which have been accelerated to high energies by machines such as cyclotrons or Van de Graaff generators have not been directly used therapeutically. Rather, the neutrons, gamma rays, or artificial radioactivities produced in various reactions of the primary particles have been applied to medical problems. This has, in large part, been due to the very short

per centimeter of path, or specific ionization, and this varies almost inversely with the energy of the proton. Thus the specific ionization or dose is many times less where the proton enters the tissue at high energy than it is in the last centimeter of the path where the ion is brought to rest.

These properties make it possible to irradiate intensely a strictly localized region within the body, with but little

Loma Linda proton cancer therapy



Invented by Fermilab Director, first working system built here

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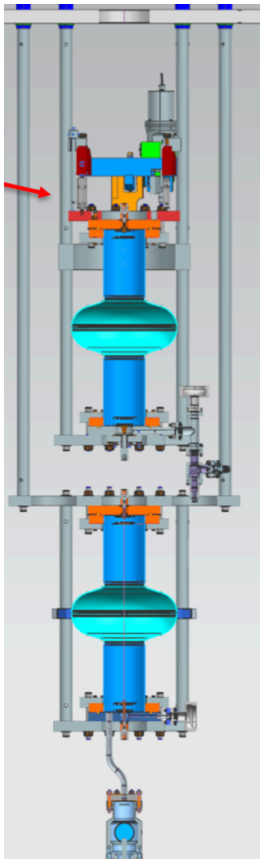
Fermilab quantum teleportation (FQNET)

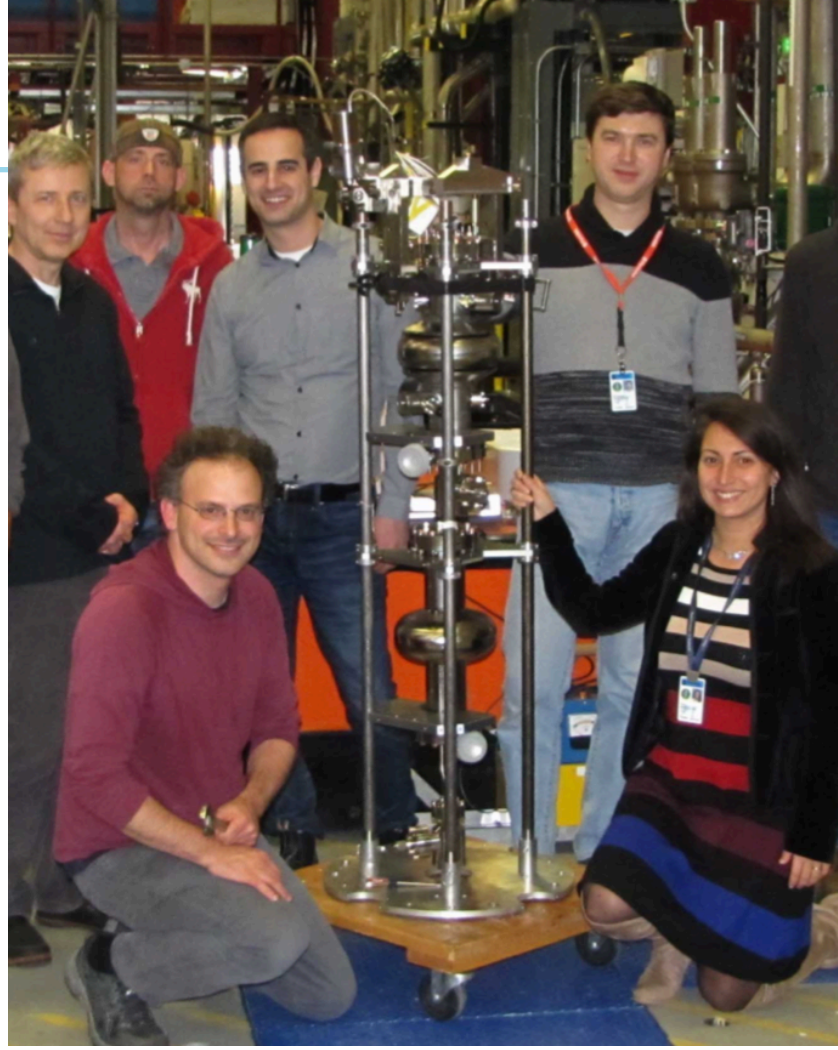
- Quantum teleportation over commercial fiber
- Experiments on long-range entanglement
- First steps towards a quantum internet

Fermilab Dark SRF Experiment

Fermilab Vertical Test Stand used for cryogenic tests of accelerator SRF cavities



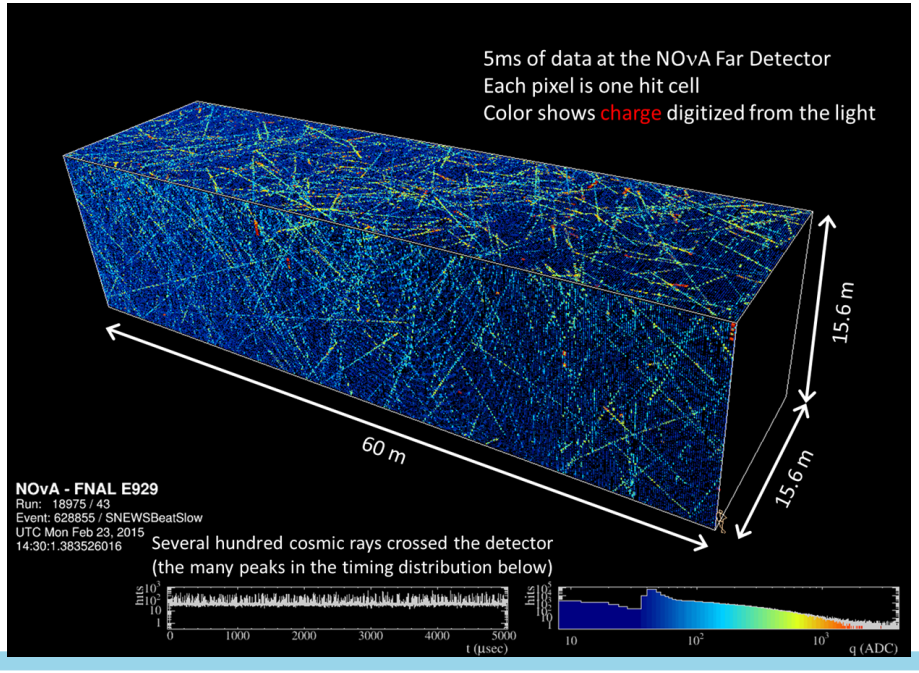
Tunable powered “Emitter” cavity and quiet “Receiver” cavity

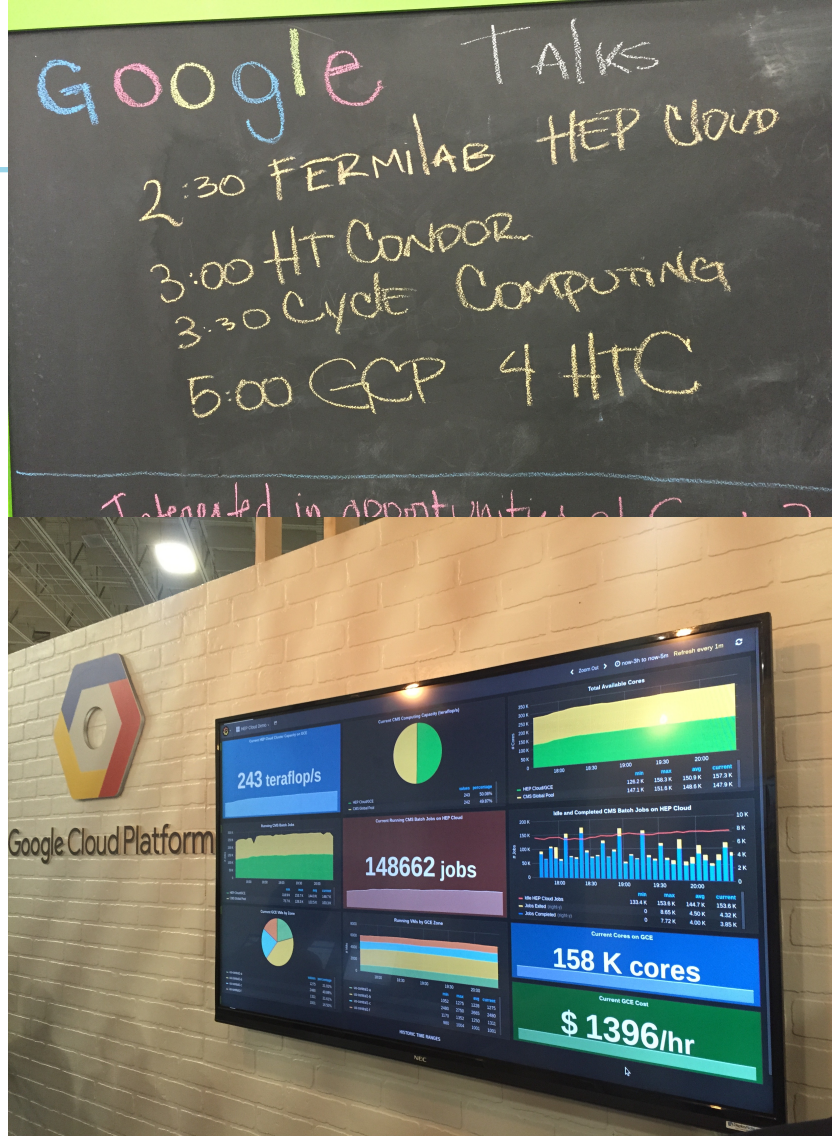


Prototype “R2D2” ready for testing: supported by the DOE QuantISED program

Big data computing

- Preparing for Exascale computing and ever-increasing Big Data needs
- Pushing the boundaries of AI machine learning applied to some of the world's most challenging data sets





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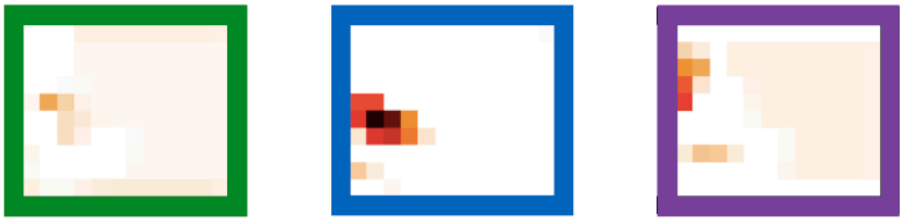
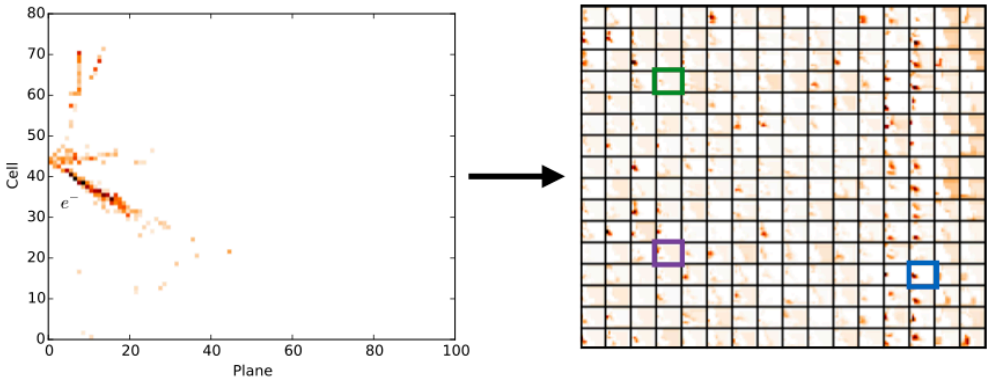
Artificial Intelligence and HEP: NOvA's big success

- This analysis features a new event selection technique based on ideas from computer vision and deep learning

- Calibrated hit maps are inputs to Convolutional Visual Network (CVN)
- Series of image processing transformations applied to extract abstract features
- Extracted features used as inputs to a conventional neural network to classify the event



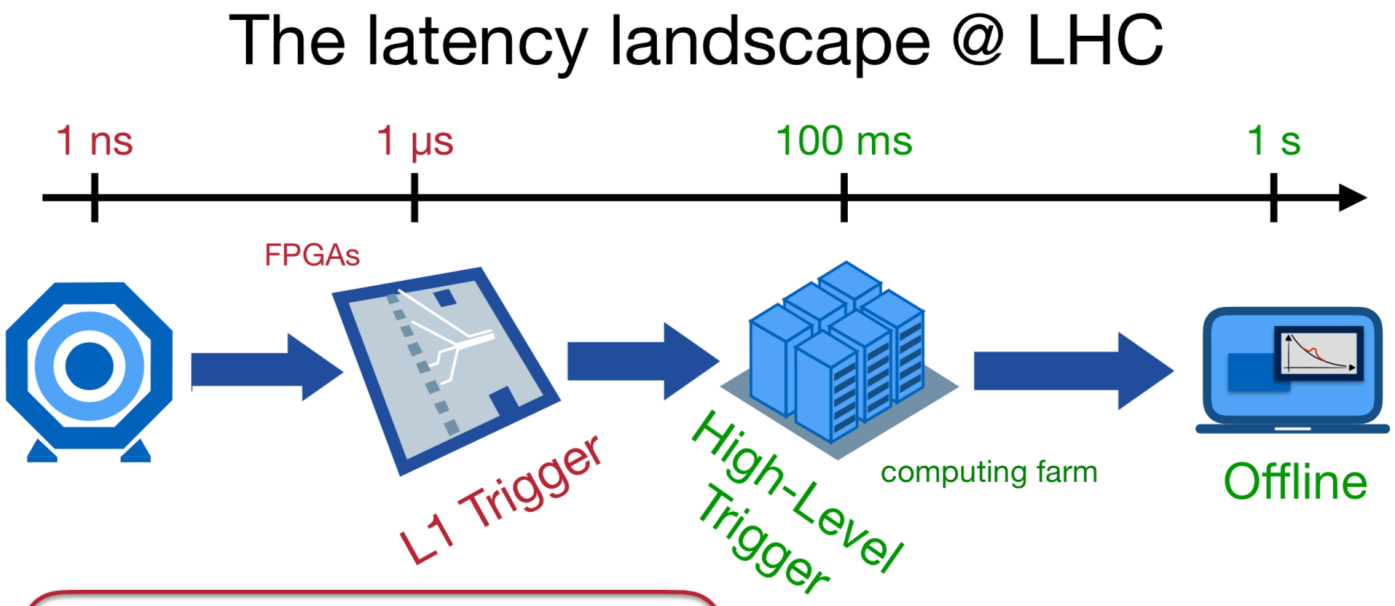


Improvement in sensitivity from CVN equivalent to 30% more exposure

Like adding 4,000 extra tons of detector mass!

Artificial Intelligence and HEP: edge computing

Deep learning on FPGAs for Trigger and DAQ



Exploration of ML algorithms in low-latency, real-time processing has just begun!

What can we do in ~1 us on one FPGA?

ML methods typically employed in offline analysis or longer latency trigger tasks

Many successes in HEP: identification of b-quark jets, Higgs candidates, particle energy regression, analysis selections, ….

Talk by Jennifer Ngadiuba

Artificial Intelligence and HEP: faster better simulation

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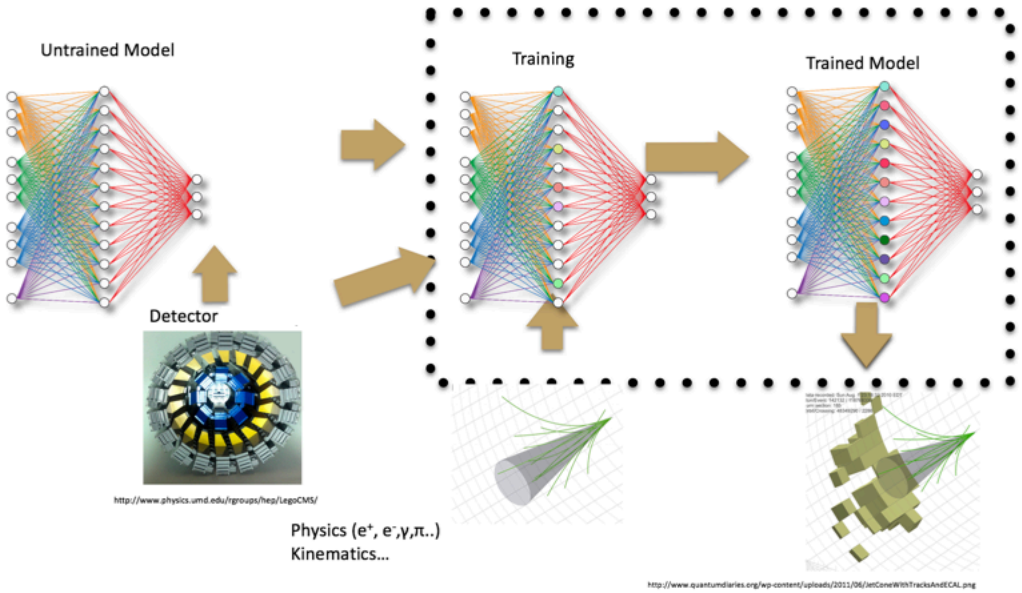
A DL ENGINE FOR FAST SIMULATION

INTEL PCC in 2017

- Focus on time consuming detectors
  - Reproduce particle showers in calorimeters
- Train on full simulation
  - Test training on real data
- Test different models
  - Generative Adversarial Networks, Recurrent Networks
- Embed inference (and training) step in GEANTV
  - Provide a configurable interface



Talk by Sofia Vallecorsa

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Any questions?