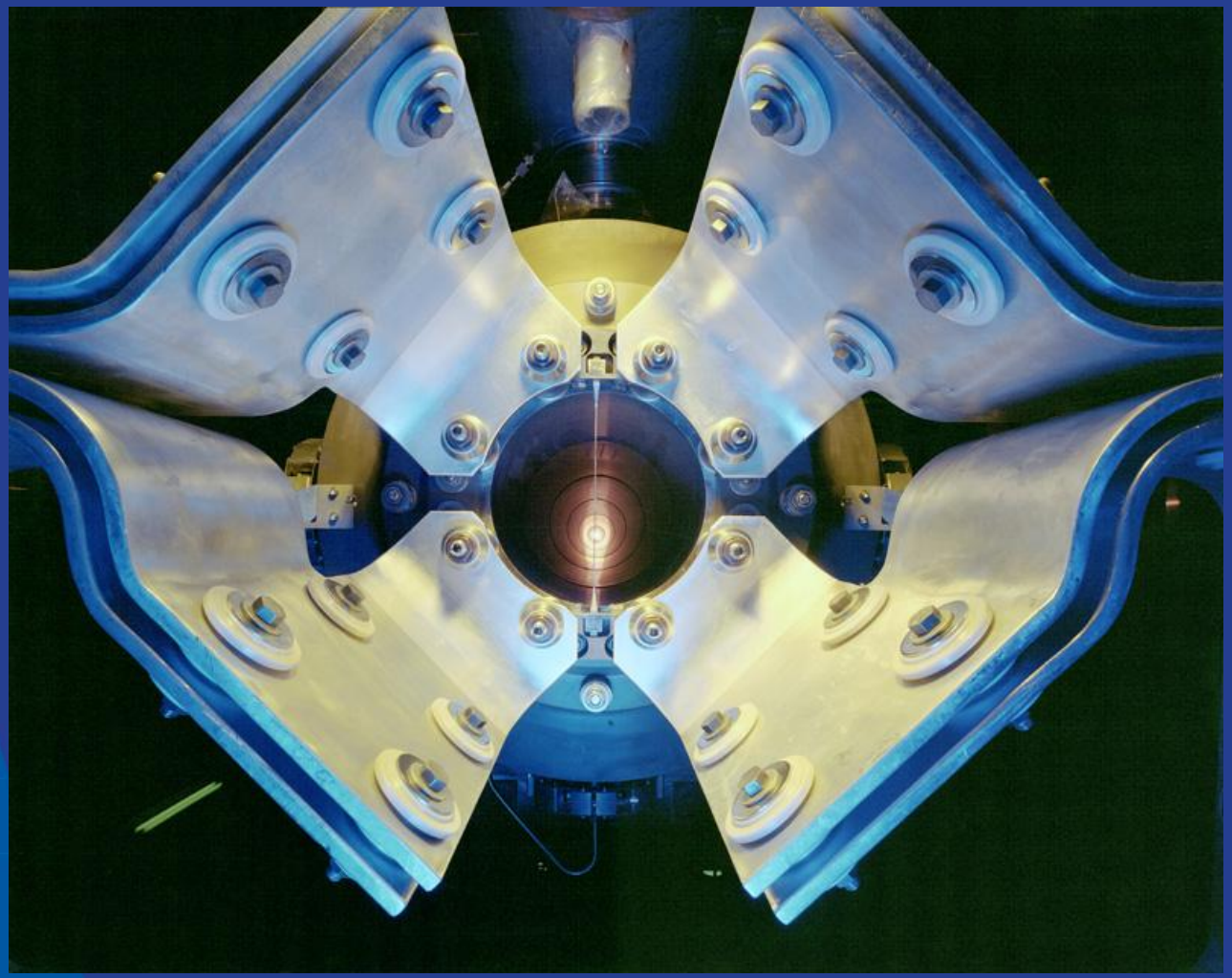
US Program and Goals

Proton Accelerator for Science and Innovation Workshop

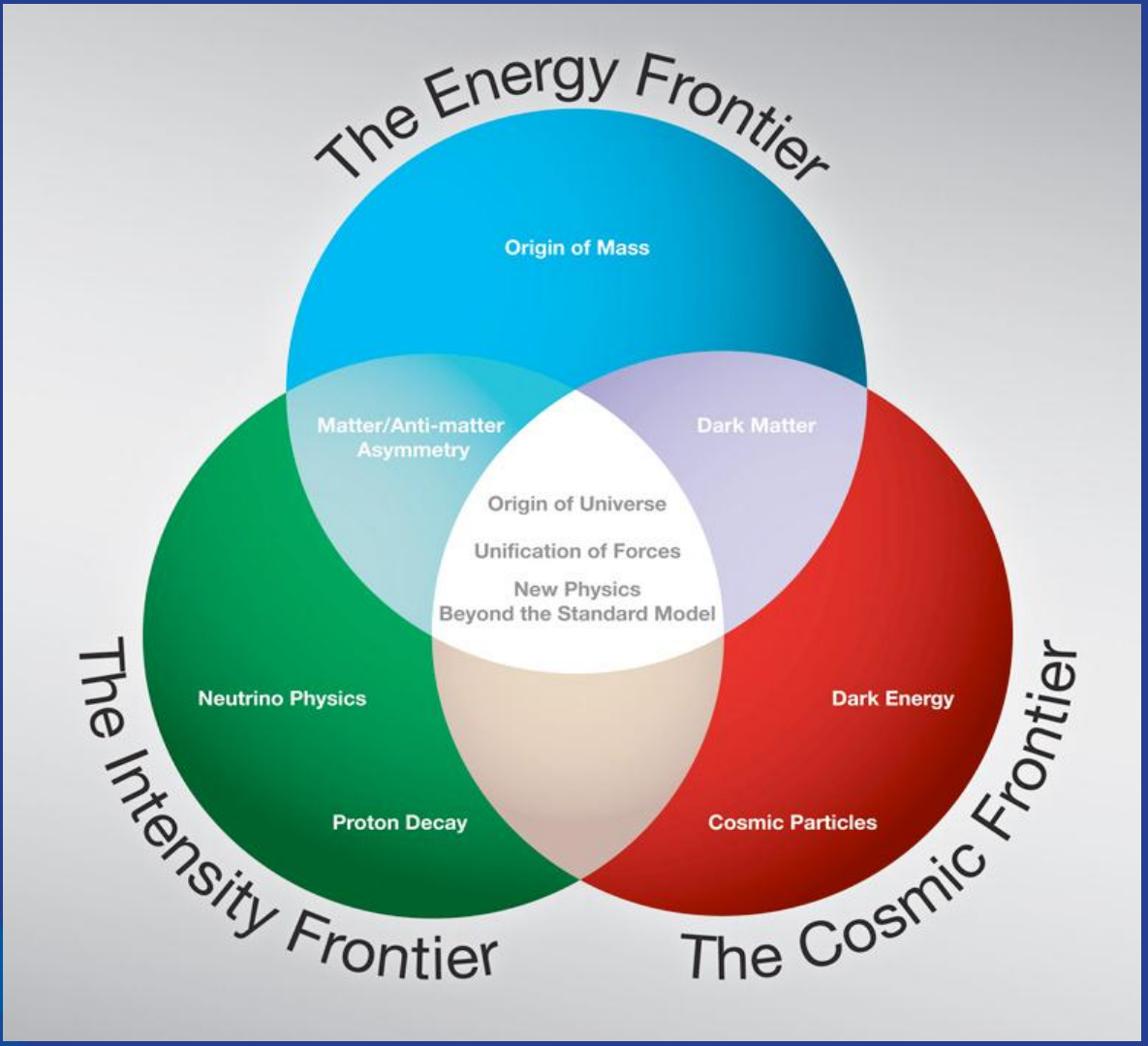
January 11 – 13, 2012



U.S. DEPARTMENT OF ENERGY

Fermilab

Program planned along three frontiers



The cosmic frontier

- Principal goals are the study of dark energy and the study of dark matter
- Dark energy:
  - DES being installed in the Blanco (4m) telescope, Cerro Tololo, Chile; supported by DOE and NSF
  - LSST (8m) in process of approval. First priority of the Decadal Survey for ground telescopes. Supported by DOE and NSF
  - BigBOSS proposed for the Mayall (4m) telescope to carry out a spectrographic survey. Going through review process as well as NSF Portfolio Review.

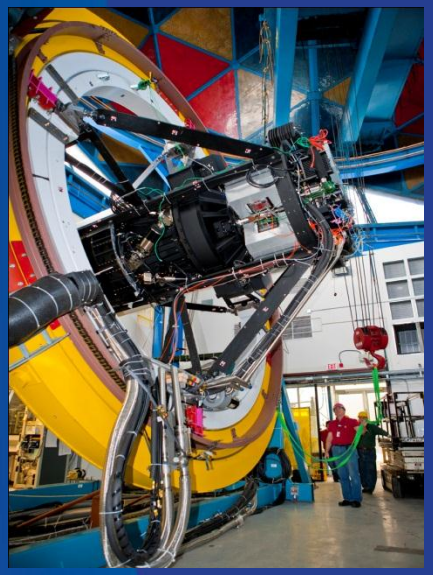
The cosmic frontier

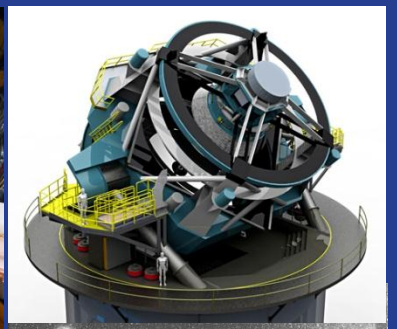
- Dark energy:
  - CMB: relevant to dark energy, dark matter and inflation; large number of approaches supported mostly by NSF: Atacama Cosmic Telescope, South Pole Telescope, QUIET, POLARBEAR……
  - WFIRST, a wide field IR survey, is the first priority of Decadal Survey for space; delayed due to NASA's budget restrictions while building the James Webb Telescope

The cosmic frontier: dark matter

- Direct detection: many efforts trying to achieve "zero background", i.e. discriminating against electromagnetic backgrounds, alpha particles and shielding against neutrons. Examples:
  - CDMS in various versions (Ge bolometers)
  - LUX (liquid Xenon)
  - MAX (depleted liquid Argon)
  - COUPP (bubble chamber)……
- Indirect detection: look for annihilation products such as in Fermi-GLAST and AMS

Cosmic Frontier



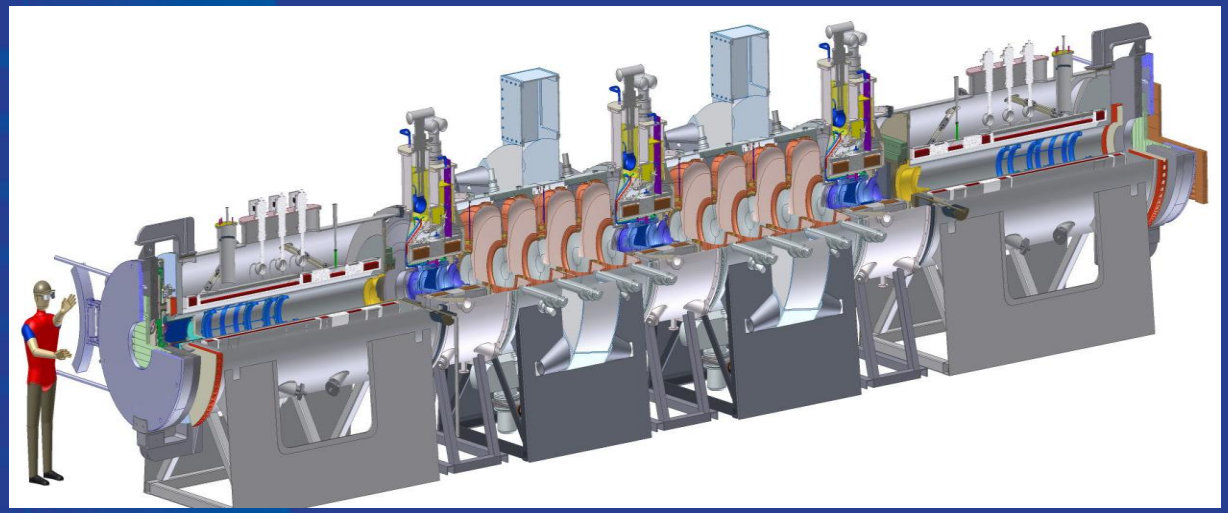

DDM: ~10 kg IDM: Fermi, AMS DE: BOSS, CMB P. Auger	DDM: ~100 kg IDM: Fermi, AMS DE: DES, CMB P. Auger	DDM: 1+ ton DE: LSST DE: BigBOSS??	DDM: 1+ ton DE: LSST DE: WFIRST??

The US at the energy frontier

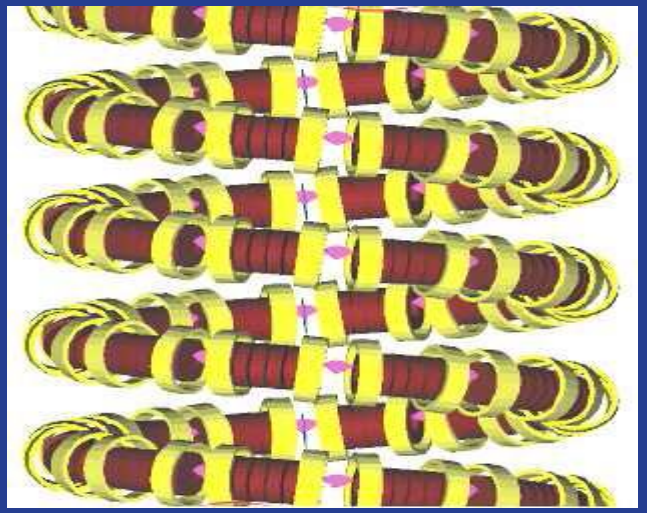
- Continued analysis of Tevatron data for the next few years
- The principal activity for the foreseeable future is exploitation of the LHC.
- The next steps will be to contribute to the High Luminosity LHC with both detector and accelerator upgrades.
- The biggest unknown is what follows the LHC?
  - ILC ?
  - CLIC ?
  - Muon Collider ?
  - Energy doubler ?

Fermilab HE program: ILC R&D

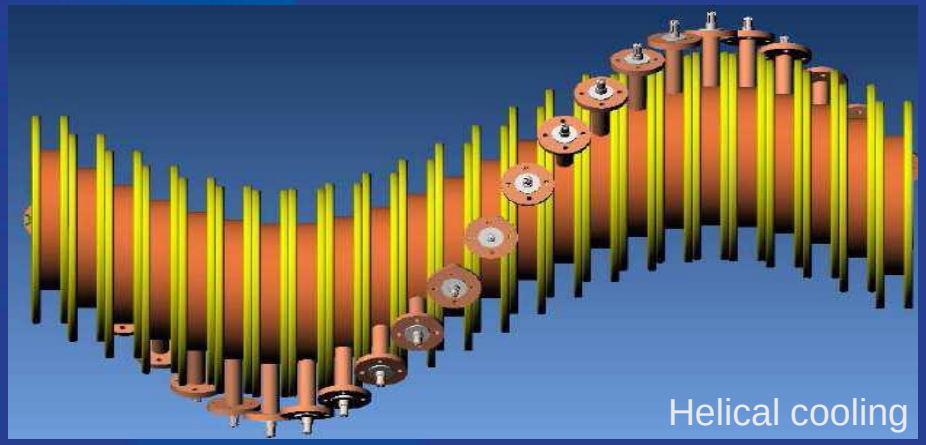
Fermilab HE program: muon collider

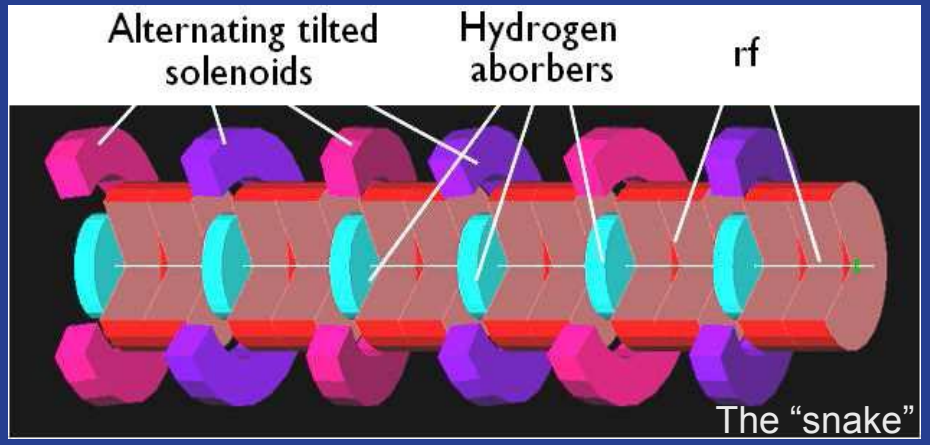


MICE



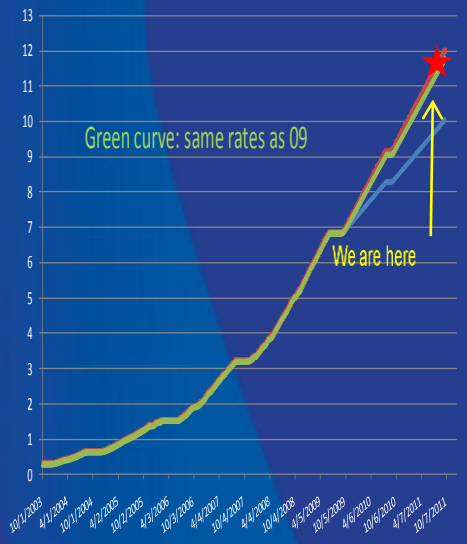
"Guggenheim"

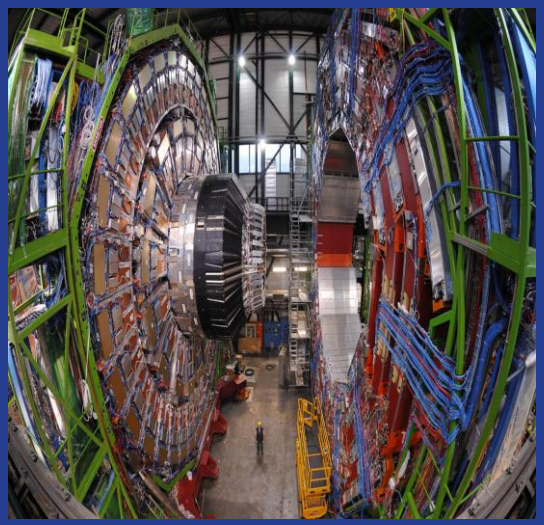


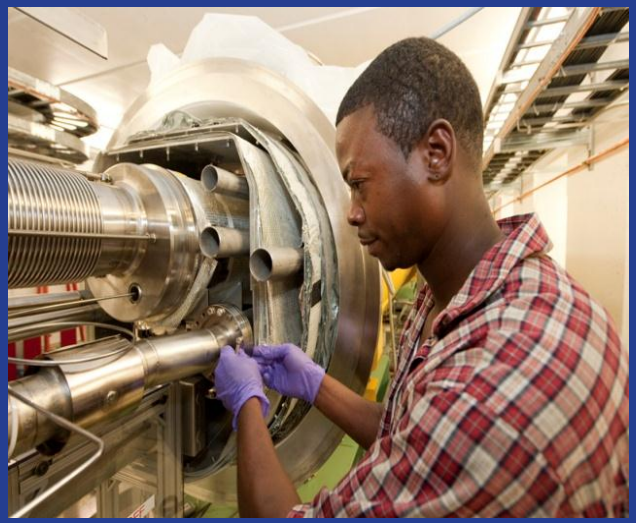


The US at the energy frontier

Tevatron LHC	LHC	LHC Upgrades ILC??	LHC HE-LHC ILC, CLIC or Muon Collider







Fermilab facilities → intensity frontier Neutrinos

ν SM: Pattern of neutrino masses and mixings

- Long baseline experiments: MINOS → NOvA → (LBNE)

Beyond ν SM: Explore cracks in our understanding: sterile neutrinos? Anomalous interactions?

- Short baseline experiments: MiniBooNE → MicroBooNE
- Long baseline experiments: MINOS → MINOS+

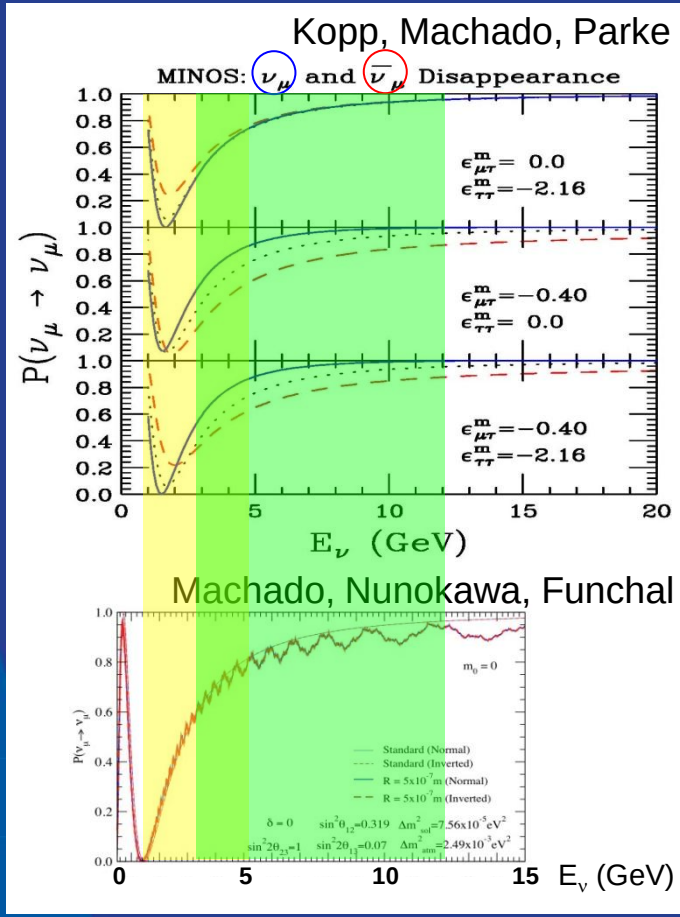
Neutrino physics measurements as a probe of nuclear structure and support of oscillation experiments

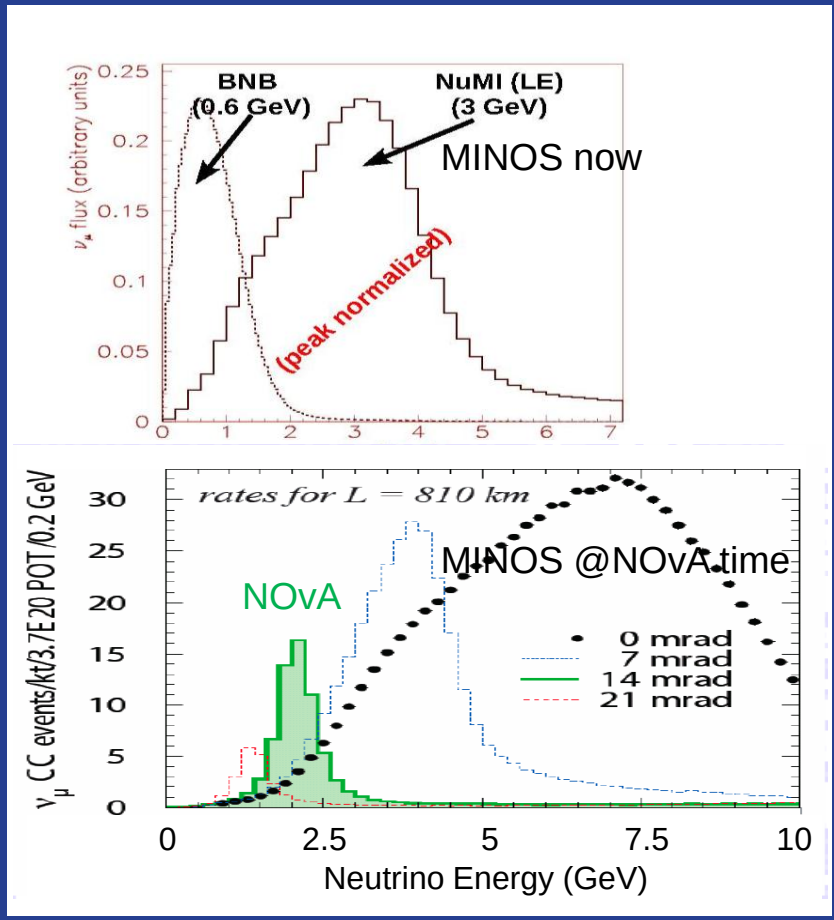
- Dedicated experiment: MINERvA

MINERvA

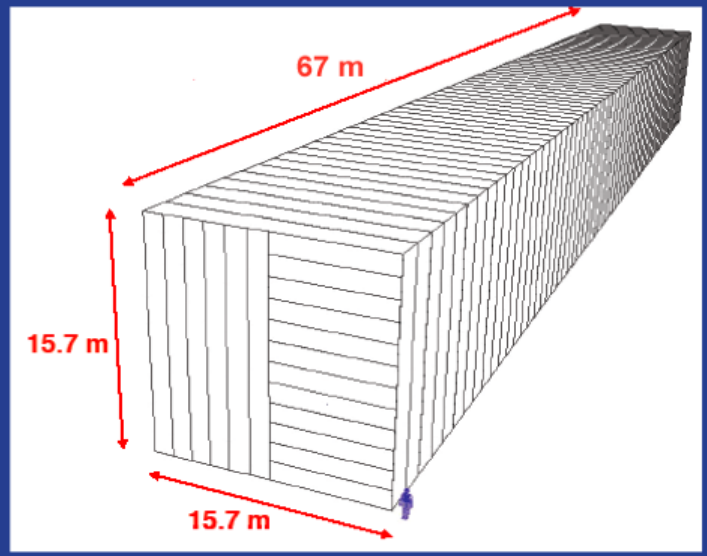
MINOS + (FY13-14)

Sensitivities to new physics



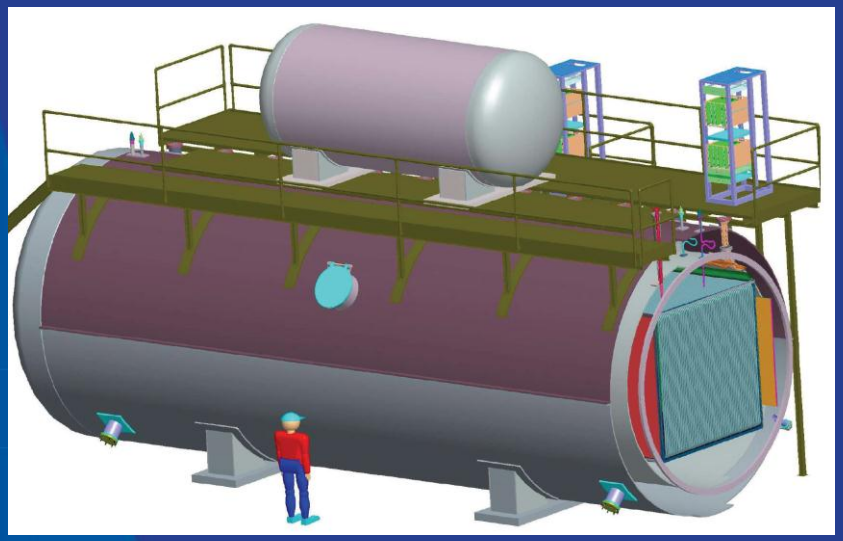


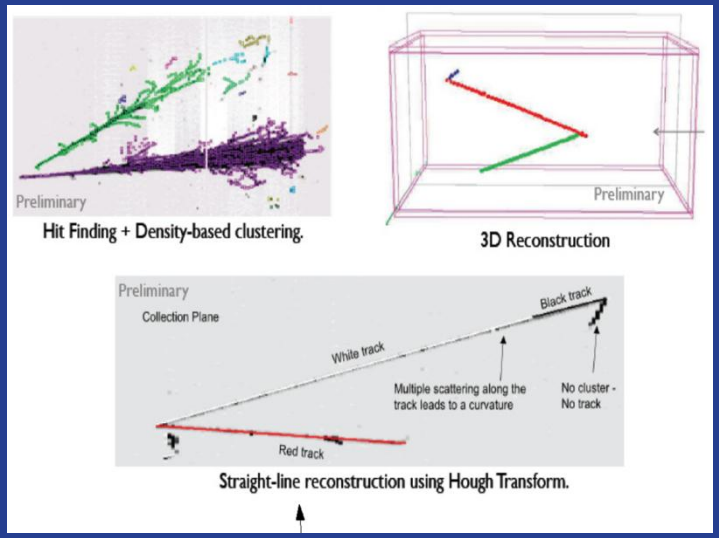
NOvA: electron appearance



MicroBooNE

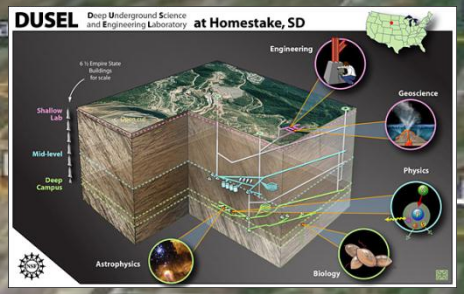
- Follow excess in MicroBooNE data. Critical to determine is it electrons or photons?
- Use Liquid Argon TPC: physics + further development of the technology





Long Baseline Neutrino Experiment

CD 0: January 2010



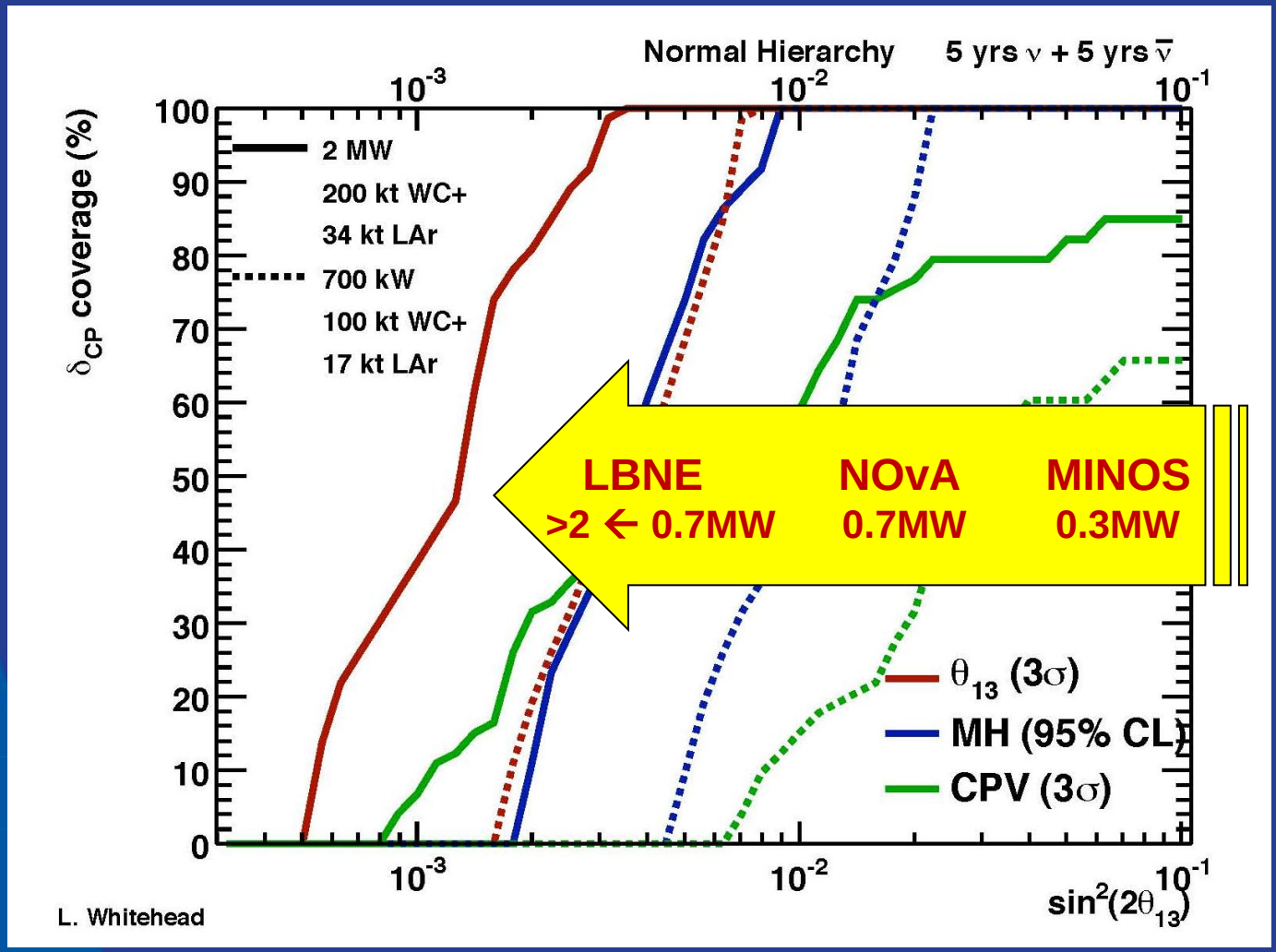
1300 km

Collaboration: 306 members

58 institutions (6 US labs) and 5 countries (India, Italy, Japan, UK, US)

Continue to grow!

Evolution of Neutrino Sensitivities



Technology recommendation: LAr

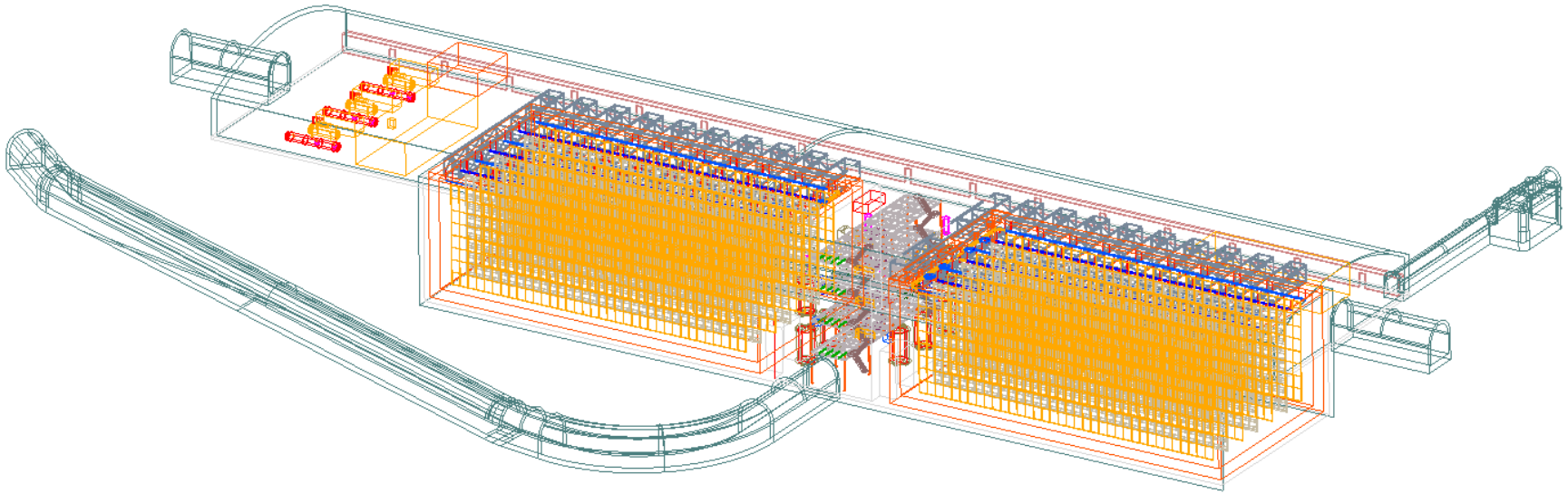
- Needs DOE concurrence: expected very soon
- The proposal is to build 33 kton TPC in two modules at the 4850' level
- DOE would assume full control of the facility with NSF contributing to scientific instruments
- Goals: neutrino mass hierarchy and CP violation. Proton decay into the k-mode, supernova explosion

LAr Purity Demonstrator

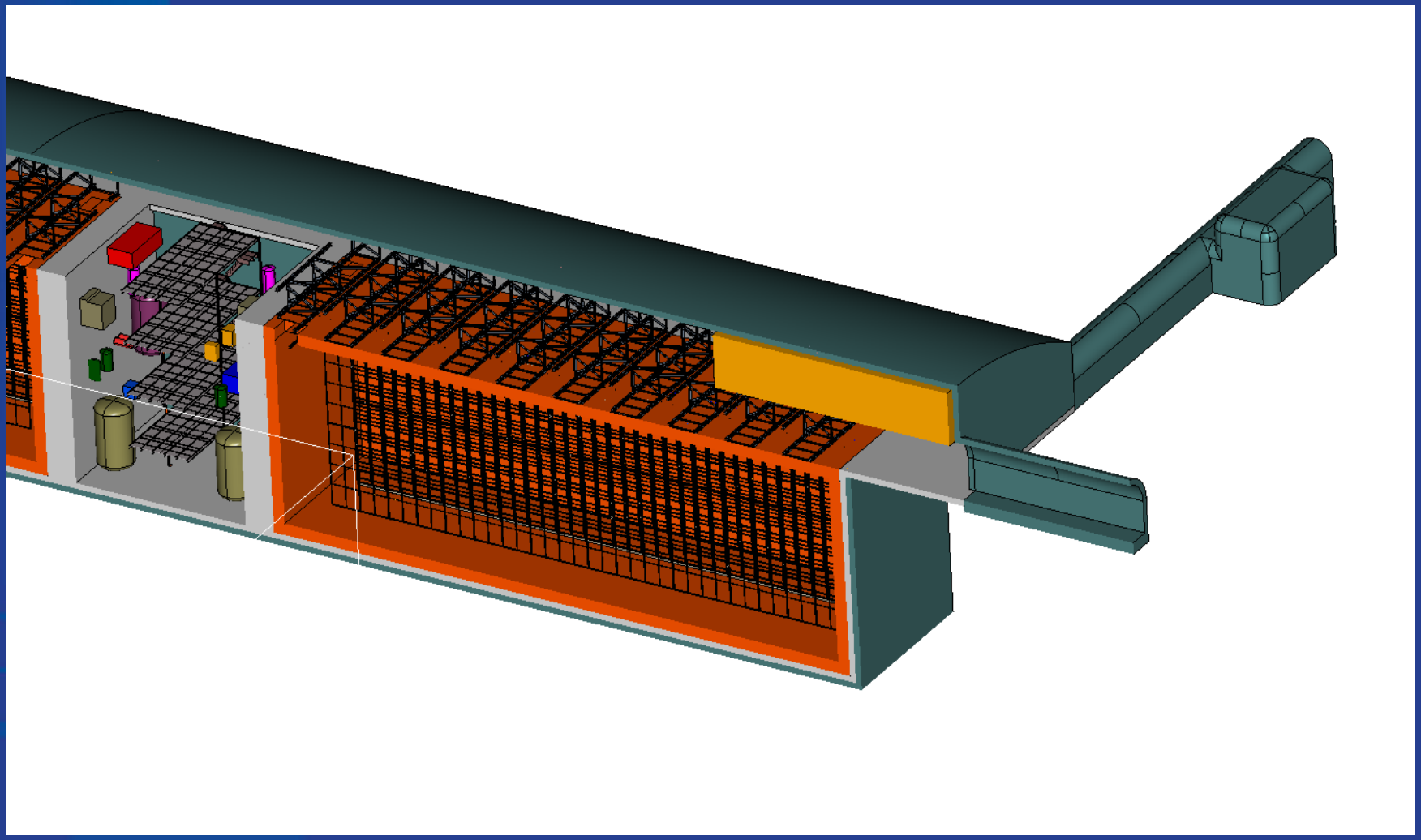
- LAPD has now run its liquid through the filters and continues to take data
- Now measuring lifetimes > 5 ms after 8 volume exchanges, and still rising

(1.4 ms is needed for the LBNE drift)

Underground LAr TPC

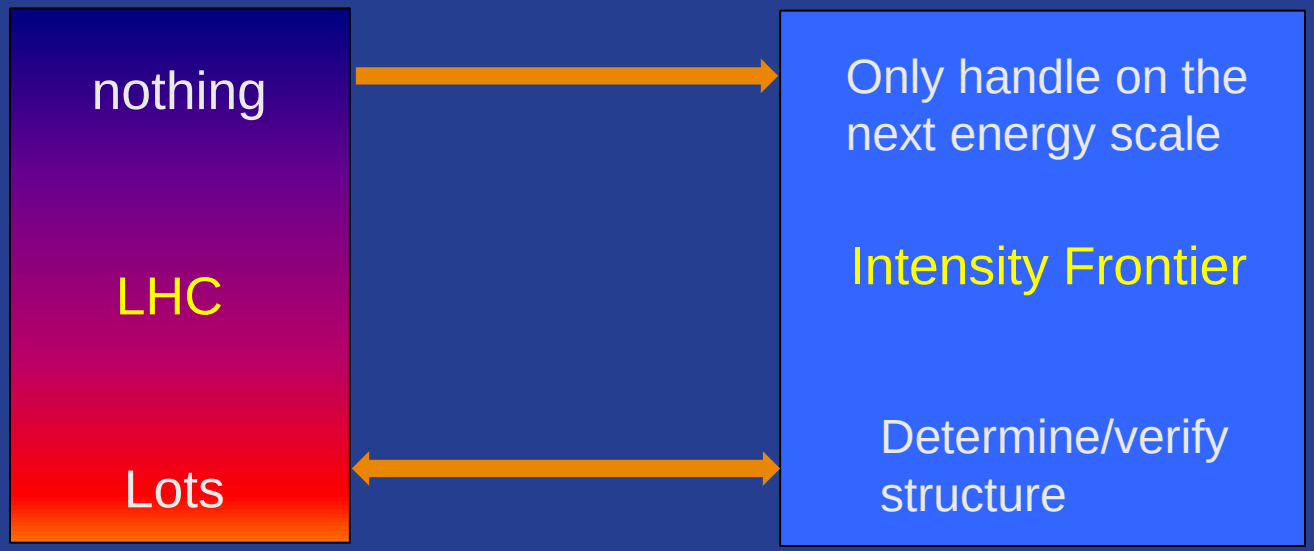


Underground LAr TPC

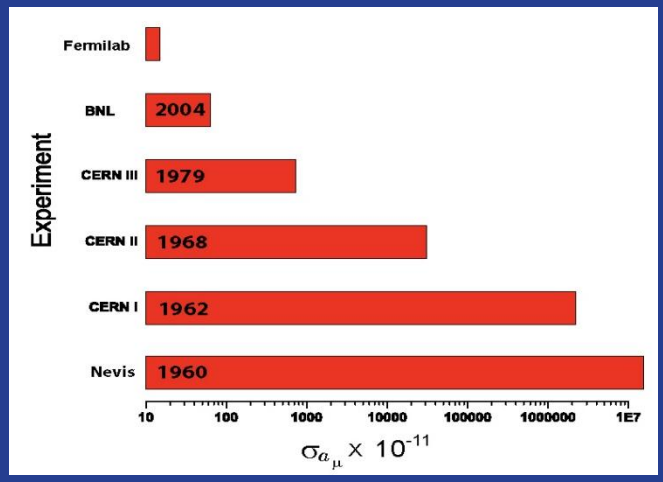


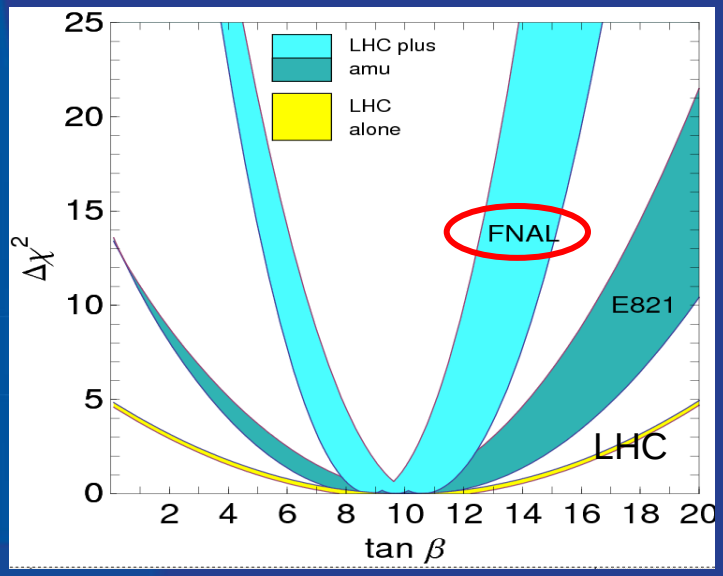
Fermilab facilities → intensity frontier Rare Decays

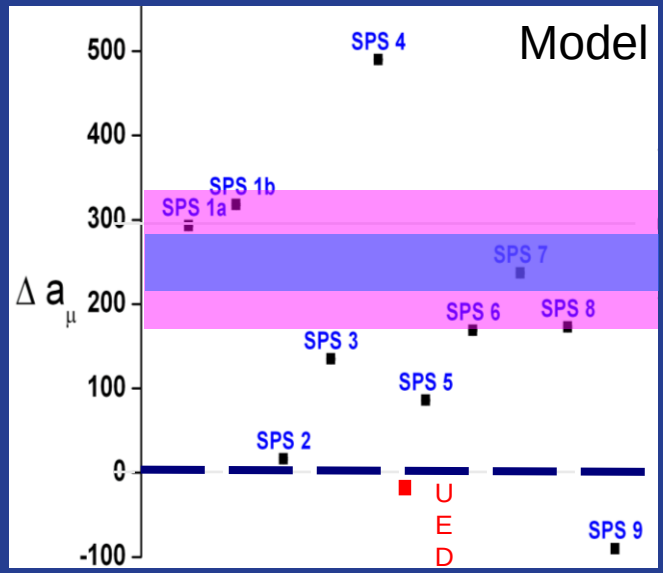
- Also in the intermediate term, a series of world-class experiments exploiting the present beams:
  - g-2: anomalous magnetic moment of the muon x20 statistics
  - Mu2e: direct muon to electron conversion - huge sensitivity to NP
  - SeaQuest: nuclear physics Drell-Yan process to study the structure of the nucleon in the nuclear environment



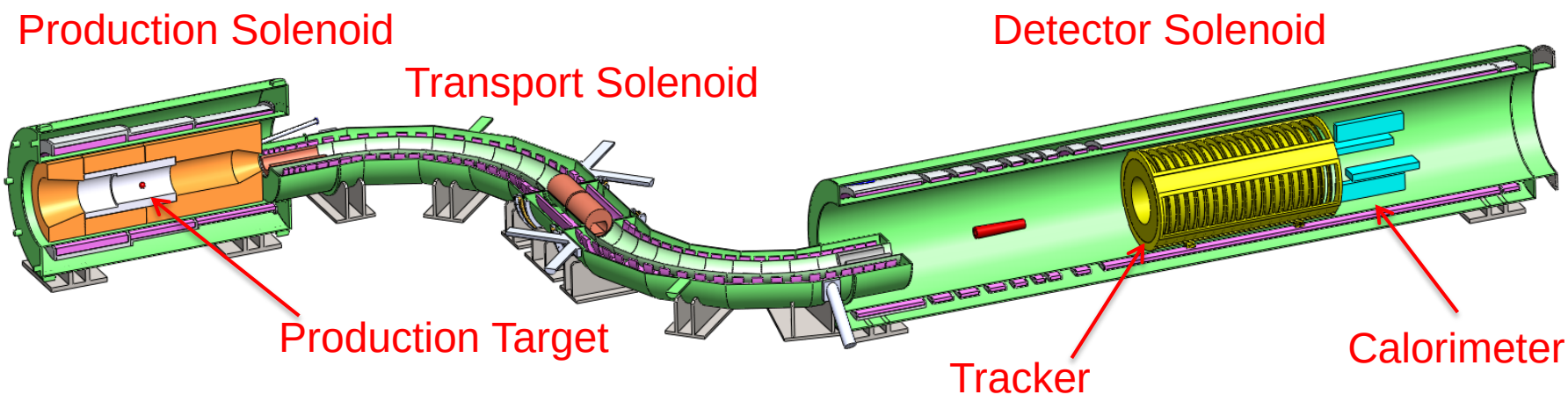
A new (g-2) to uncertainty $0.14*10^{-11}$





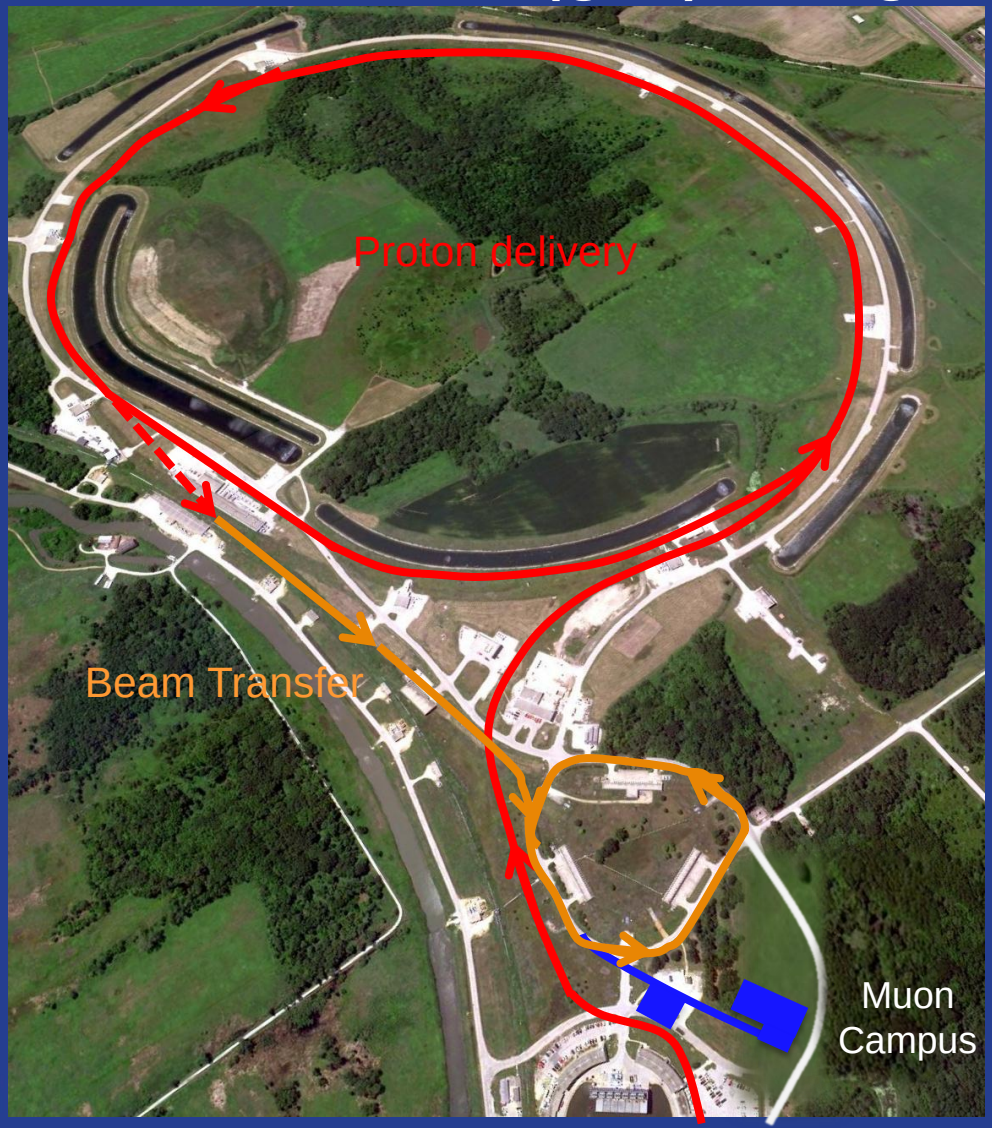


Some examples: Mu2e….



Conversion of a muon into an electron in the field of a nucleus: negligible rate in the SM and measurable in almost any extension of the SM

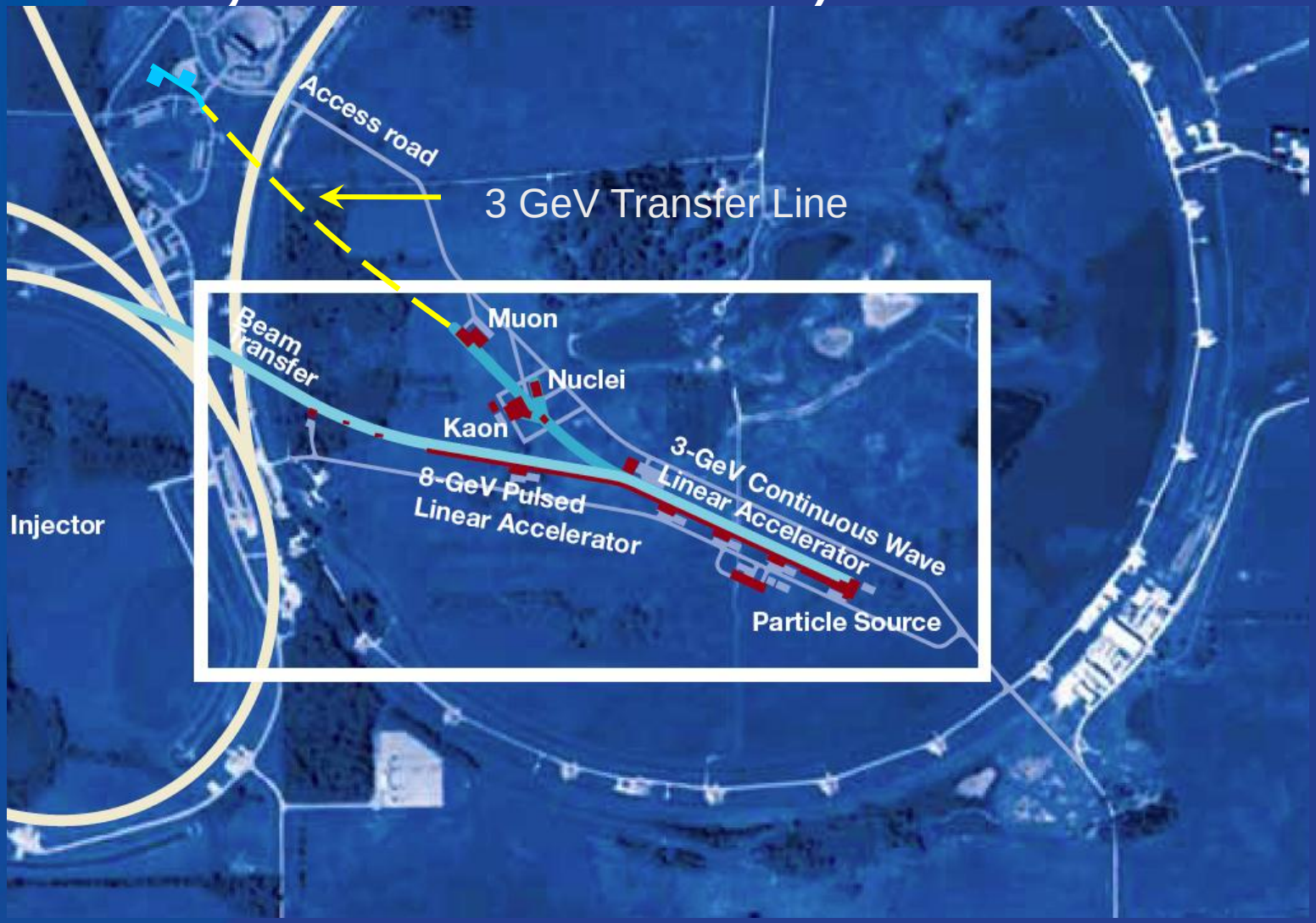
Mu2e and Muon (g-2) Programs



Muon Campus

- Mu2e and Muon (g-2) will use common beam line enclosure and infrastructure

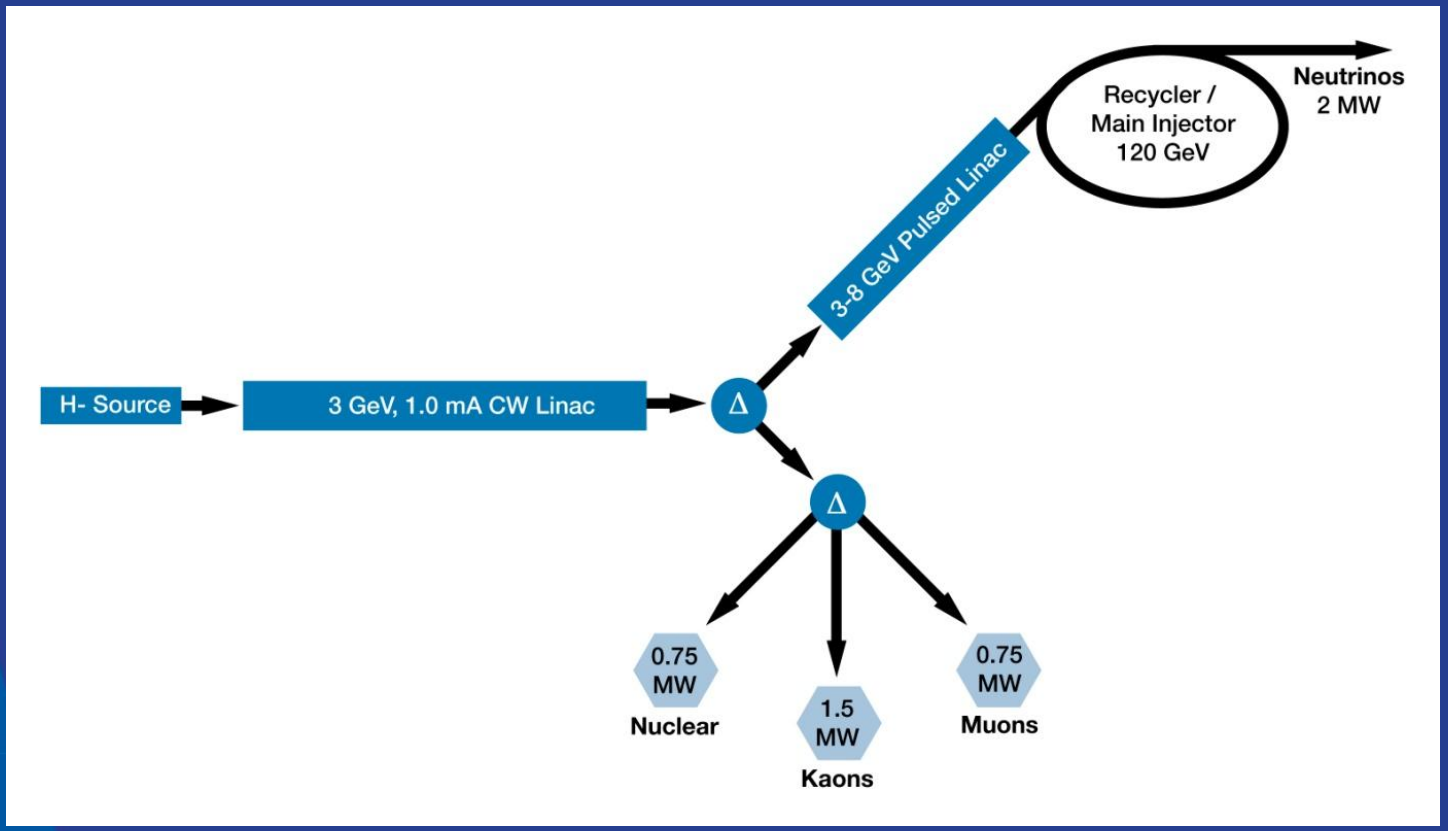
Mu2e and (g-2) with Project X (First day: 3 GeV or 8 GeV)



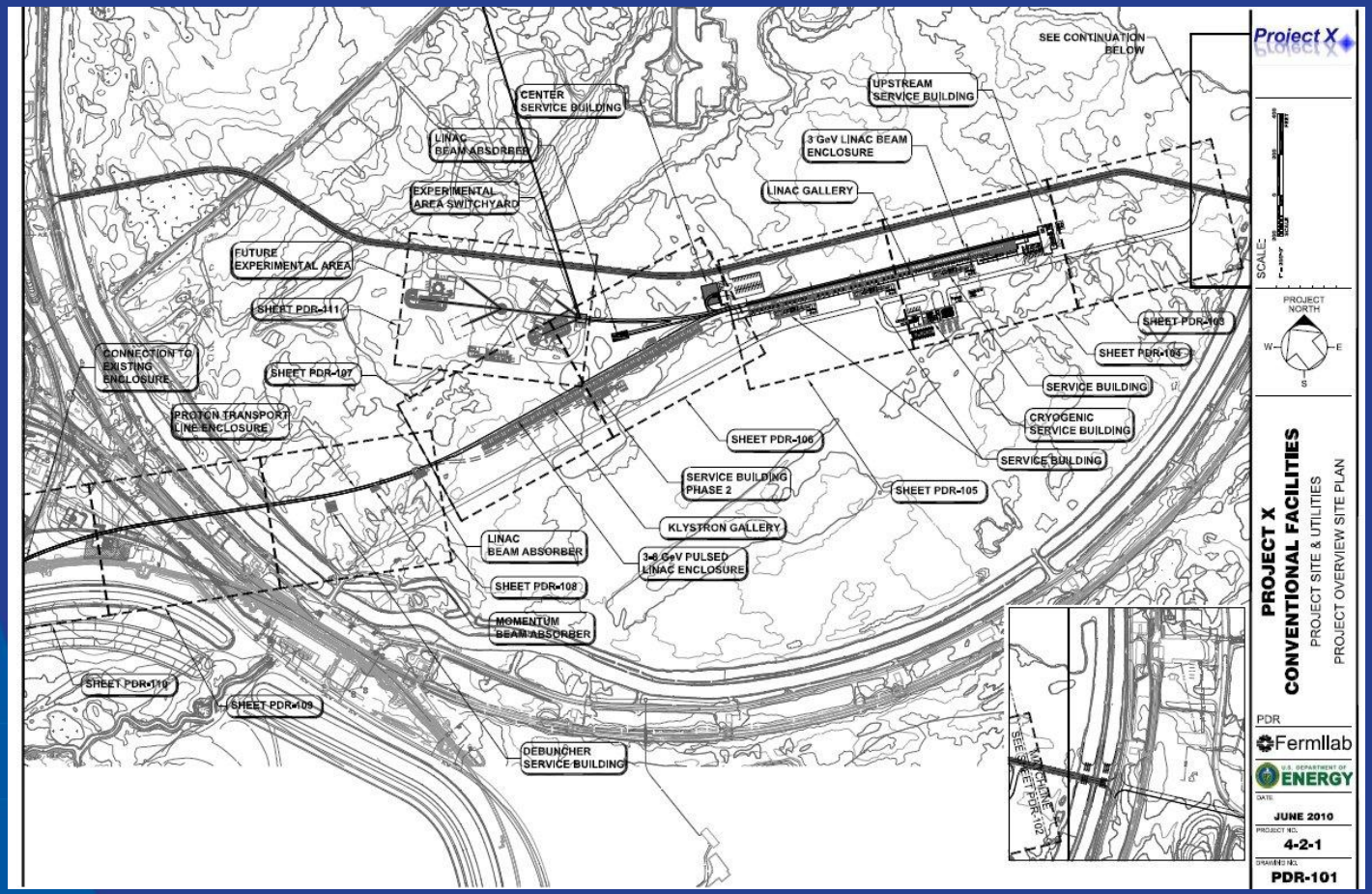
Program next decade

- LBNE (2+ MW): the long-base line experiment
  - Neutrino mass spectrum (mass hierarchy)
  - Matter-antimatter symmetry
  - Neutrino/antineutrino differences
  - Anomalous interactions
- Project X: a broad program with megawatts of continuous beam, ideal to lead at the intensity frontier
  - Neutrino, long/short base-lines, more than 2 MW to LBNE
  - Kaons where the Standard Model backgrounds are minimal and we are sensitive to many models
  - Rare muon decay with sensitivity to masses 10000 TeV
  - Symmetry violations through electric dipole moments in nuclei
  - Applications to transmutation, spallation targets, ADS

Project X Reference Design



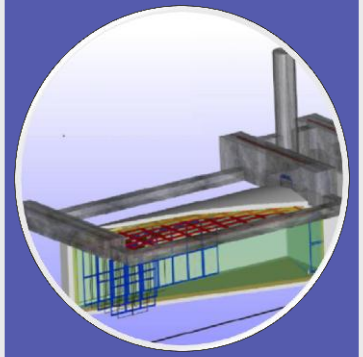
Project X Siting



Project X

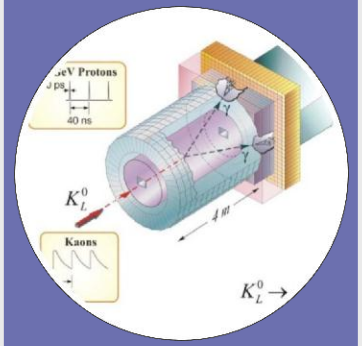
- Unique facility with 3 MW, continuous wave (CW) linac. Multiplies low energy flux of protons at Fermilab by 100 with flexible timing patterns, ideal for rare decays
- Solves “proton economics”. Experiments run simultaneously at 3 GeV, 8 Gev and 60-120 GeV at high power
- Delivers 2+ MW to LBNE
- To be developed consistently to serve as front end of neutrino factory or muon collider

Project X: new experiments



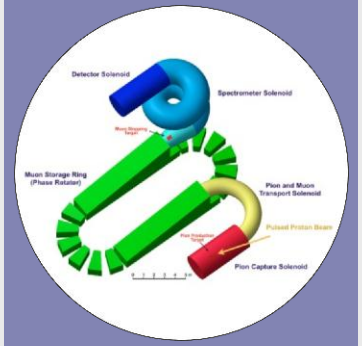
Neutrinos

- Matter-antimatter asymmetry
- Neutrino mass spectrum
- Neutrino-antineutrino differences
- Anomalous interactions
- Proton decay
- SuperNova bursts



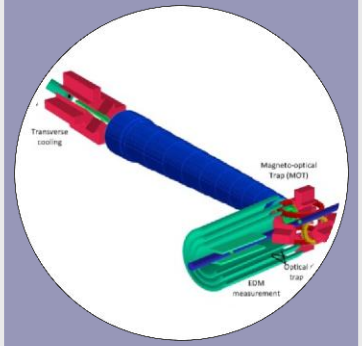
Kaons

- Physics beyond the Standard Model
- Elucidation of LHC discoveries
- Two to three orders of magnitude increase in sensitivity



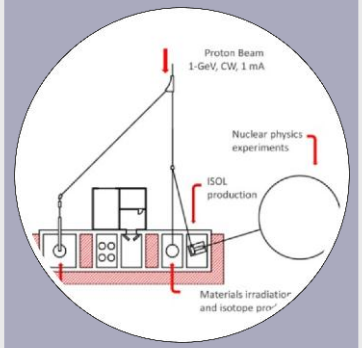
Muons

- Oscillation in charged leptons
- Physics beyond the Standard Model
- Elucidation of LHC physics
- Sensitive to energy/mass scales three orders of magnitude beyond LHC



Nuclei

- New generation of symmetry-test experiments
- Electric Dipole Moments
- Three or more orders of magnitude increase in Francium, Radium, Actinium isotopes



Energy Applications

- Transmutation experiments with nuclear waste
- Spallation target configurations
- Materials test under high irradiation
- Neutron fluxes under various configurations relevant to ADS

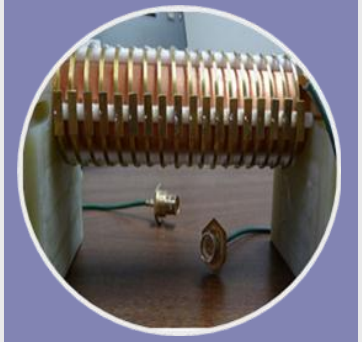
Project X: technology innovation

CW Linac Design

- Multi-MW/high duty factor (continuous wave) proton linac
- First of a kind, all superconducting RF design
- Low beam loss/high reliability

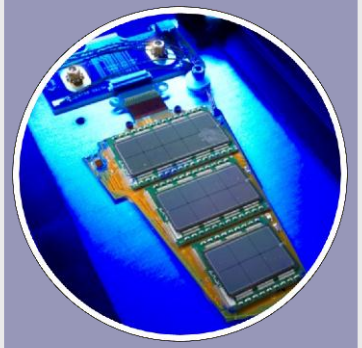
SRF Accelerating Modules

- State-of-the-art performance
- High Q_0/high gradient
- Low-β spoke resonators
- Medium-β elliptical resonators
- U.S. industrial development



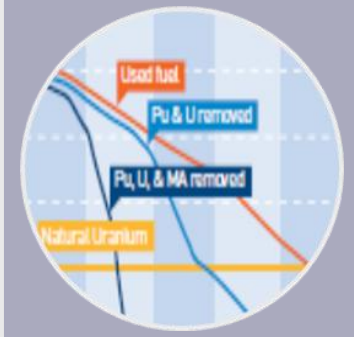
Fast Chopper

- Revolutionary concept
- Programmable bunch patterns at 162 MHz
- Applications beyond HEP



Detector Development

- High speed electronics & triggering
- Rad hard detectors
- Large Liquid Argon Time Projection Chambers
- Cryo-electronics
- High power targeting



Transmutation

- MW-class CW beams at 1 GeV
- Technology demonstration
- Benchmarking experiments to validate concepts

Project X and the big questions

Where does mass come from?

Why is matter dominant?

What are the neutrino masses and what do they say?

Where are the heavy neutrino partners?

Why are there three families of quarks and leptons?

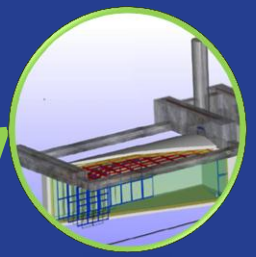
Do the forces unify?

Does nature use supersymmetry or other new symmetries?

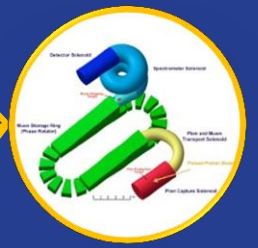
Are there extra dimensions of space?

What is dark matter?

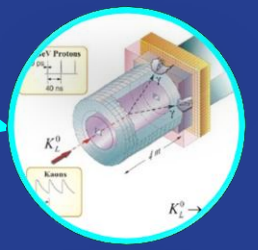
What is dark energy?



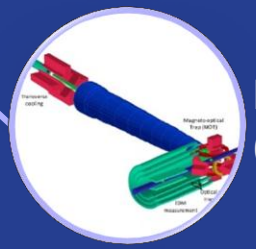
neutrinos



muons

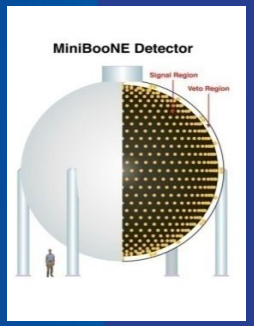


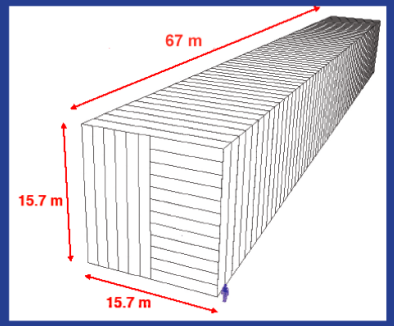
kaons

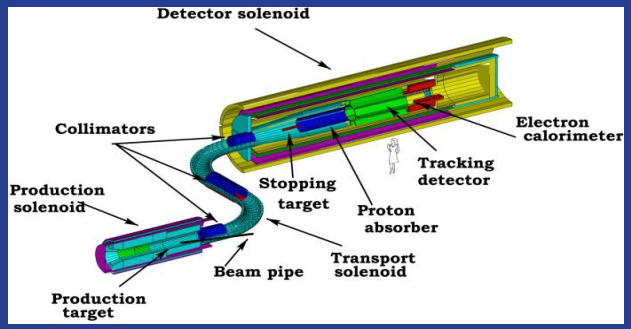


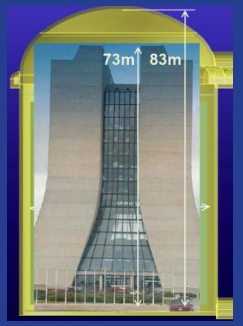
Nuclei (EDMs..)

Fermilab and the intensity frontier

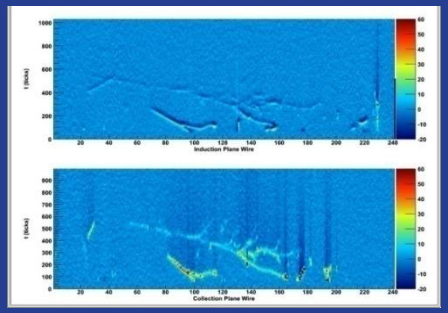


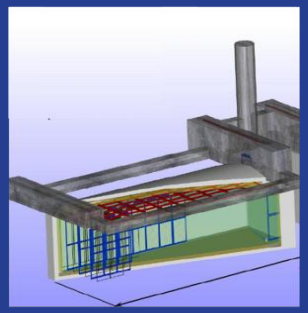






MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2 MINERvA MINOS+ SeaQuest	NOvA g-2 LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??





From *Project X* to Neutrino Factory and Muon Collider

Project X
Accelerate hydrogen ions to 8 GeV using SRF technology.

Compressor Ring
Reduce size of beam.

Target
Collisions lead to muons with energy of about 200 MeV.

Muon Cooling
Reduce the transverse motion of the muons and create a tight beam.

Initial Acceleration
In a dozen turns, accelerate muons to 20 GeV.

Recirculating Linear Accelerator
In a number of turns, accelerate muons up to 2 TeV using SRF technology.

Collider Ring
Located 100 meters underground. Muons live long enough to make about 1000 turns.