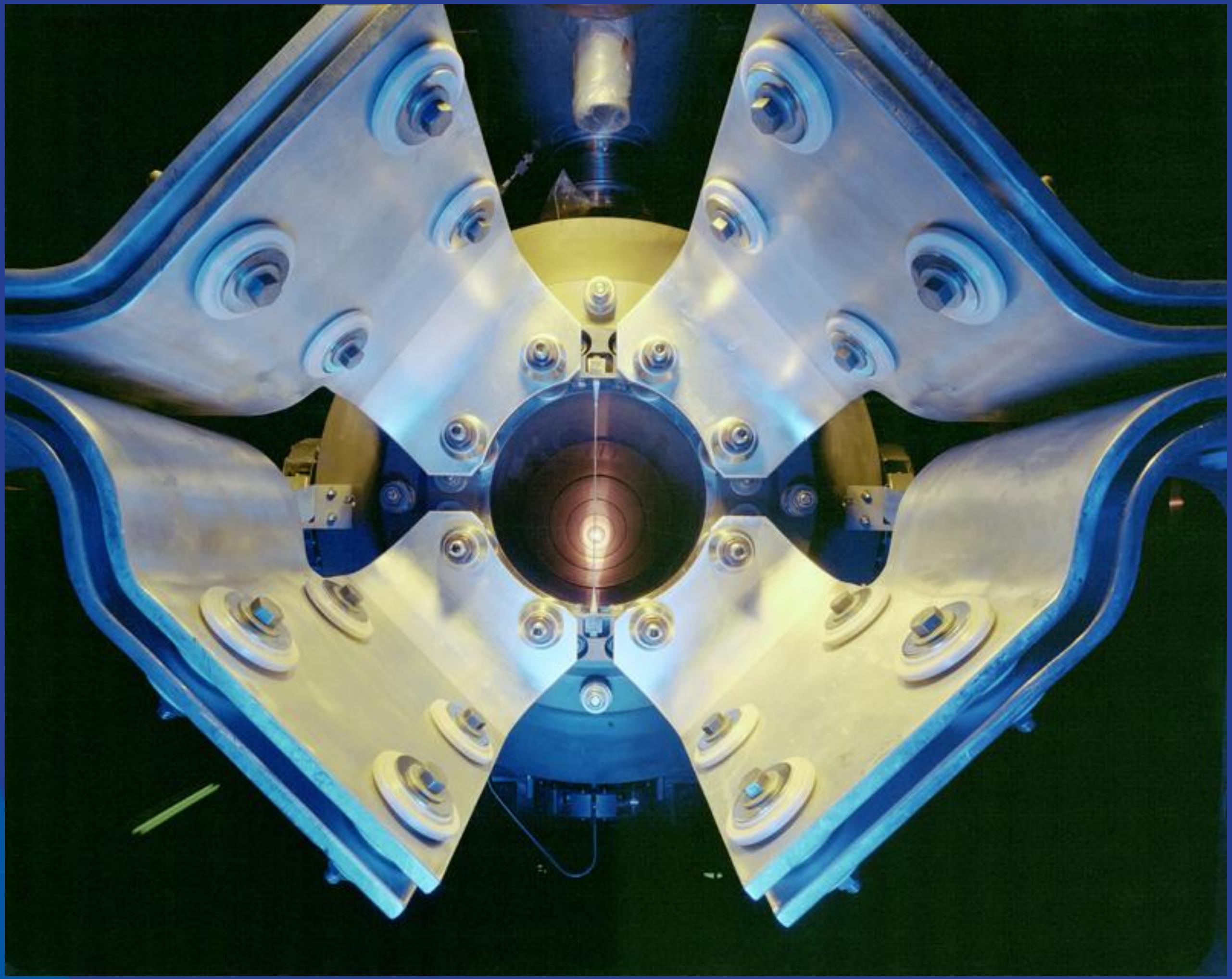
Intensity Frontier at Fermilab

HEPAP March 17, 2011



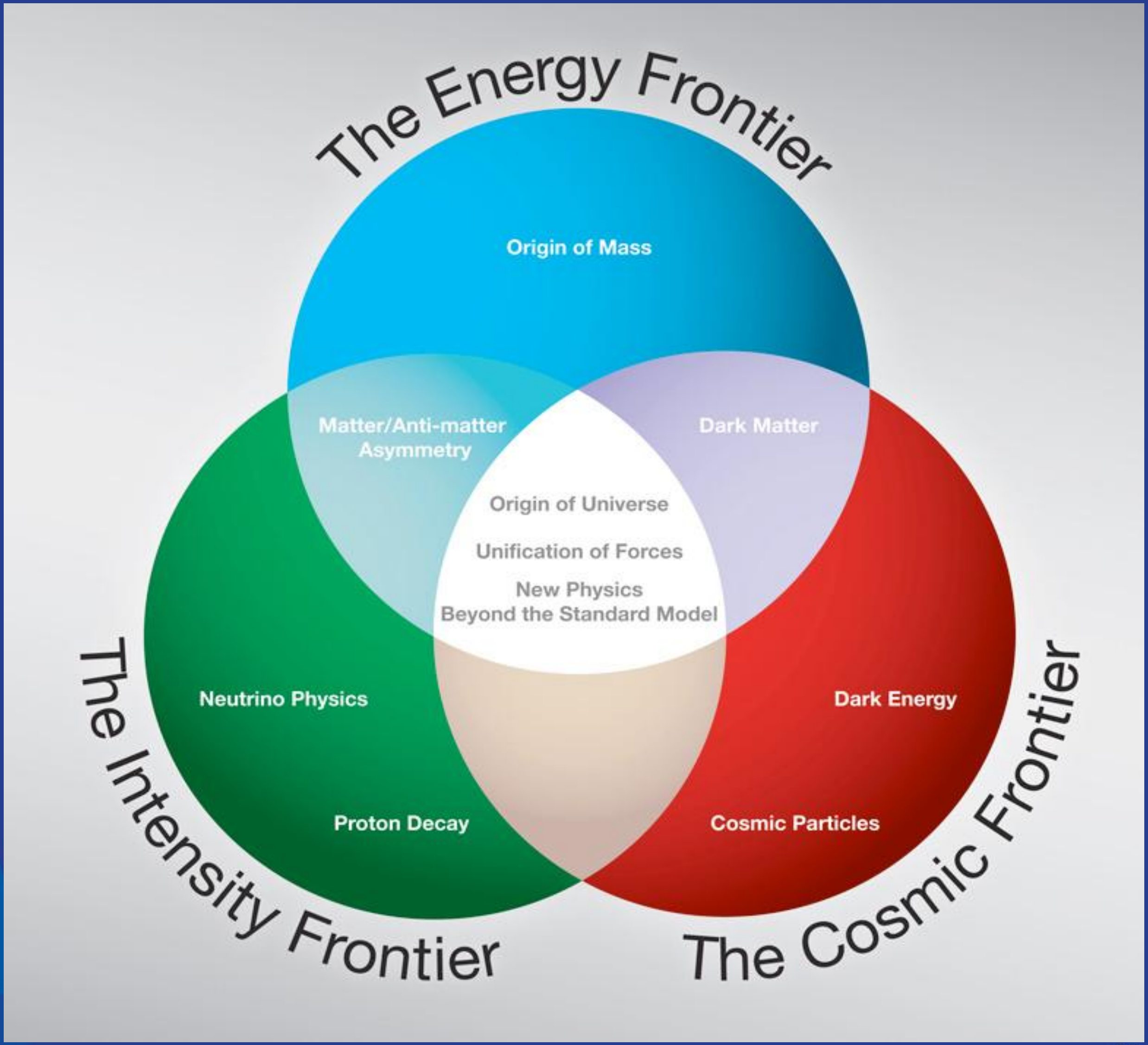
U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

- The intensity frontier in the context of the overall Fermilab strategy
- The intensity frontier:
  - Present (MINOS, MiniBooNE and MINERvA) and near term (NOvA,MicroBooNE, SeaQuest, g-2, MINOS)
  - The intermediate term: Mu2e, LBNE
  - Long term: LBNE, Project X, PX experimental program
- What will it take to get it done?

Future program: at the three frontiers



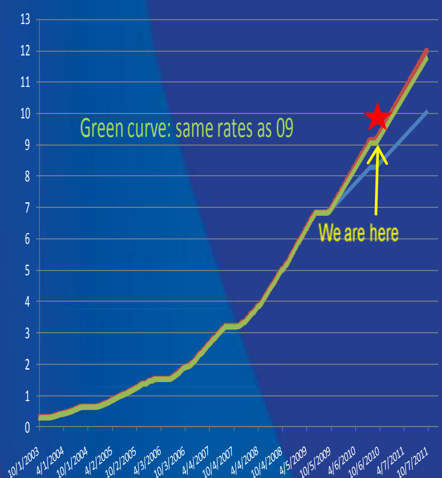
Gaps and roles: energy frontier

- Next two decades: dominated by LHC. Upgrades to machine and detectors
- Biggest gap: what follows the LHC? Depends on results and at what energy results occur
- Fermilab strategy: completion of the Tevatron program and physics exploitation and upgrades of LHC. R&D on future machines: ILC if at “low” energy; muon collider if at high energy; new high field magnets for extension of LHC or future proton colliders at ultra-LHC energies

Roles: energy frontier

Now – 2013	2013 – 2016	2016 – 2019	2019 – 2022
Tevatron LHC	LHC	LHC Upgrades ILC??	LHC ILC, CLIC or Muon Collider

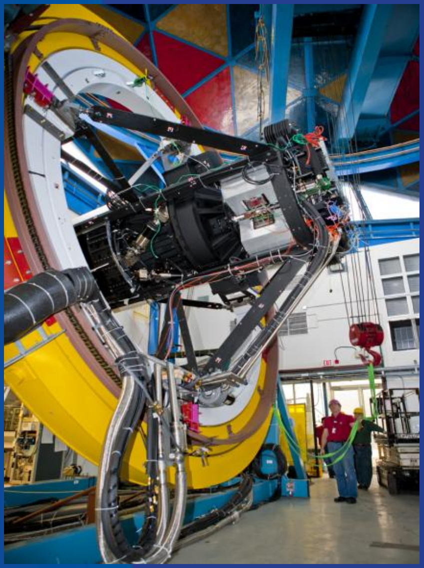
Now 2013 2016 2019 2022

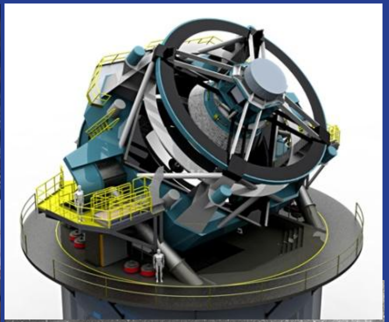


Gaps and roles: cosmic frontier

- The principal connection to particle physics today: the nature of dark matter and dark energy
- Gap in the direct search for dark matter: get to "zero—background" technology. Gap in understanding dark energy is establishment of time evolution of the acceleration: new major telescopes (ground and space)
- Fermilab strategy: establish scalable "zero-background" technology for dark matter. Commission and exploit DES. Participate in future ground and space telescopes (the principal agencies are NSF and NASA, not DOE)

Roles: cosmic frontier



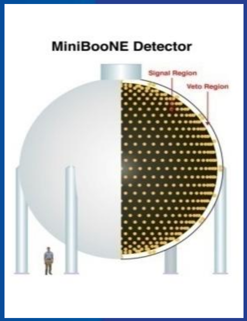

DM: ~10 kg DE: SDSS P. Auger	DM: ~100 kg DE: DES P. Auger Holometer?	DM: ~1 ton DE: LSST WFIRST?? BigBOSS??	DE: LSST WFIRST??

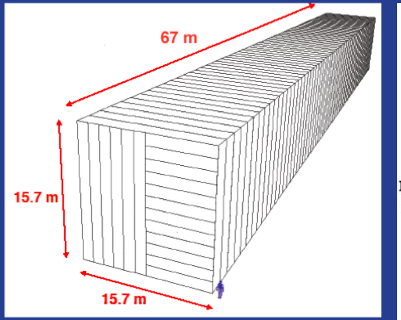
Now 2013 2016 2019 2022

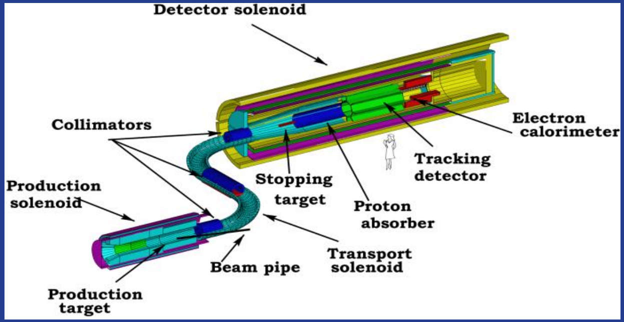
Gaps and roles: intensity frontier

- Two principal approaches: 1) proton super-beams to study neutrinos and rare decays and 2) quark factories: in e^+e^- and LHCb
- Principal gap is the understanding of neutrinos and the observation of rare decays coupled to new physics processes
- Fermilab strategy: develop the most powerful set of facilities in the world for the study of neutrinos and rare processes, well beyond the present state of the art. Complementary to LHC and with discovery potential beyond LHC. DOE has the central role. Will define the role of US facilities in the world's program.

Roles: intensity frontier

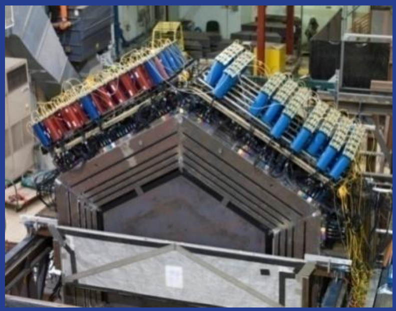


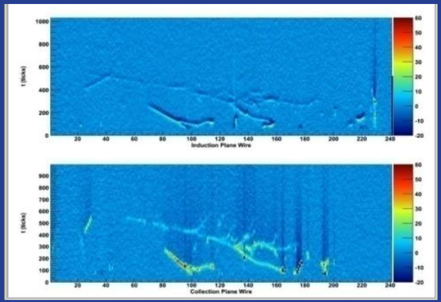


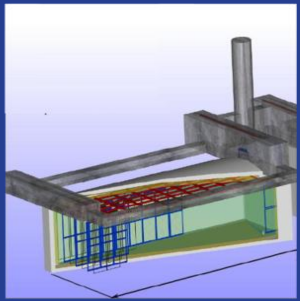


MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2 MINERvA MINOS SeaQuest	NOvA g-2 LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??

Now 2013 2016 2019 2022

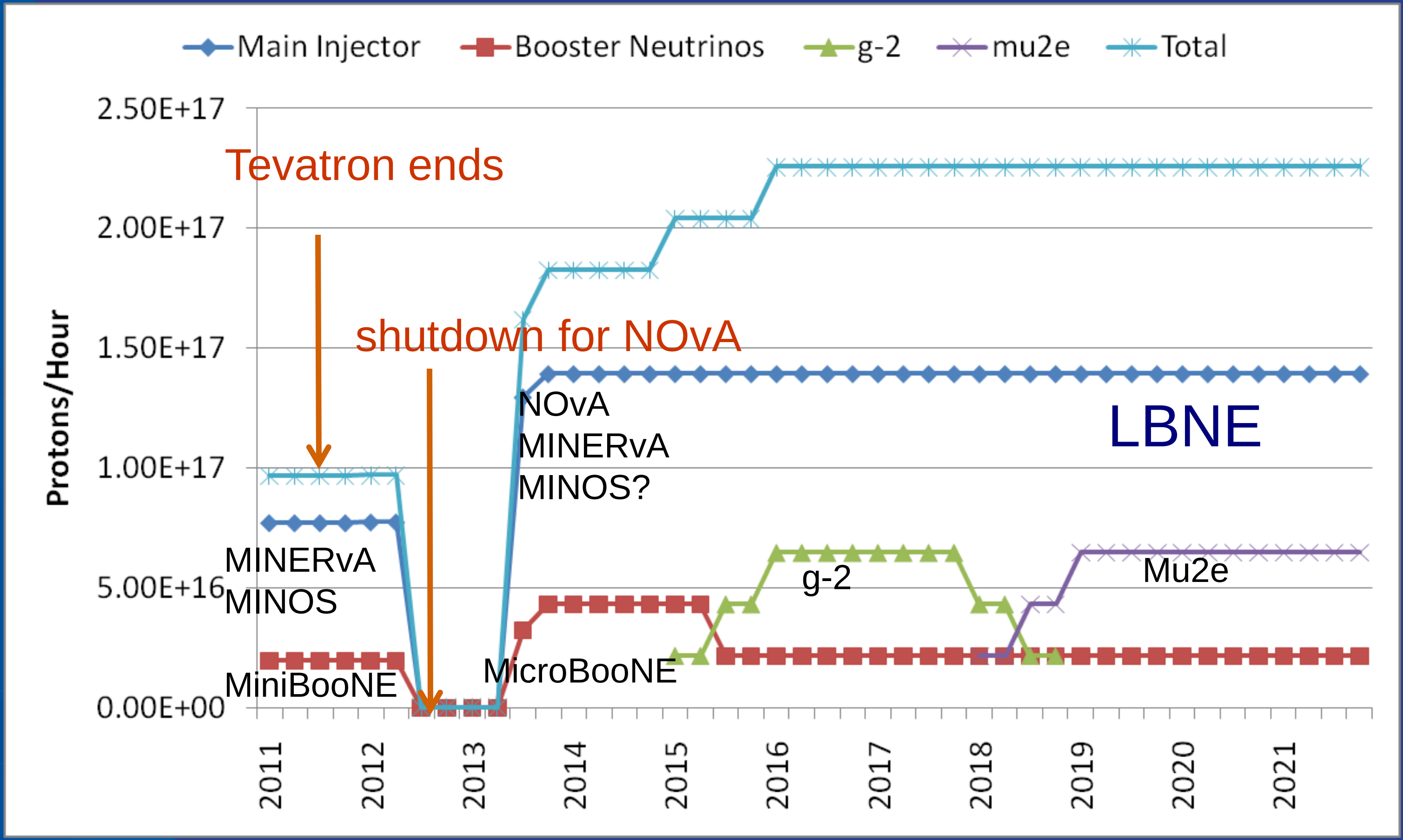






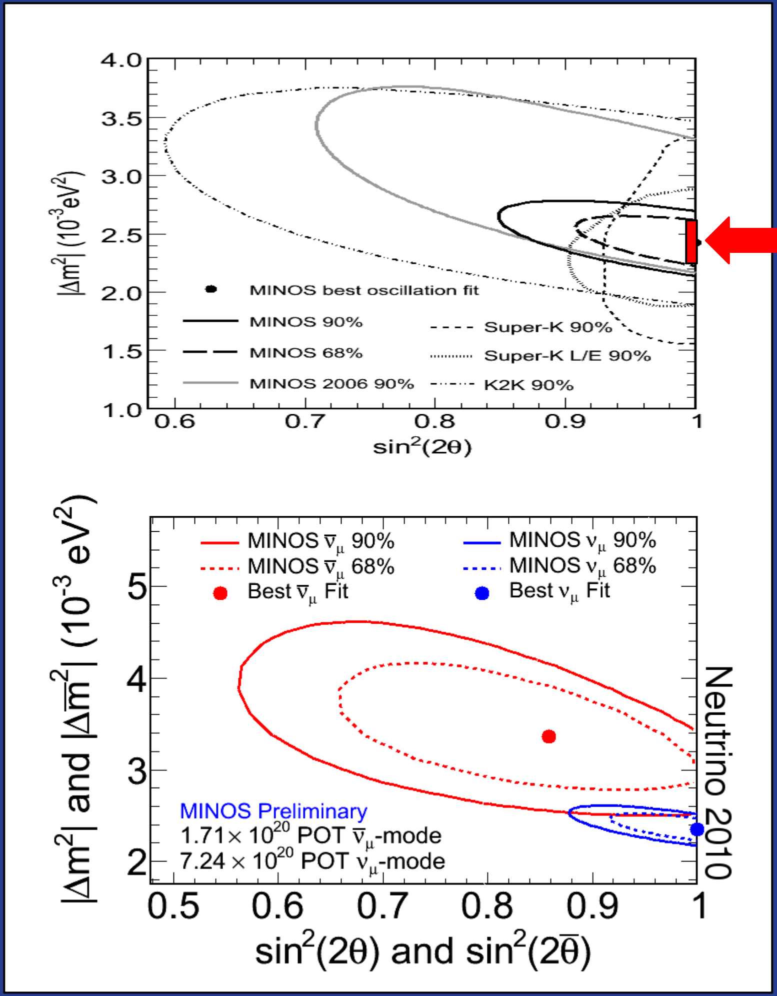
Near and intermediate stage

This decade



Next Decade *Project X*: 100 times

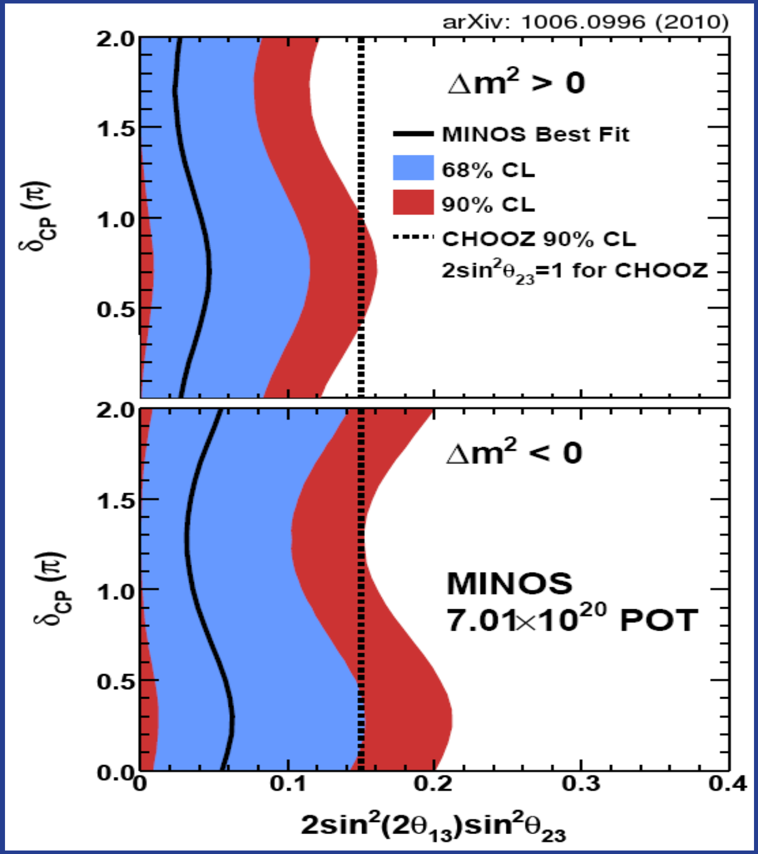
MINOS Results on Δm^2_{23} and θ_{23}



- Neutrino runs
  - best Δm^2_{23}
- Anti-neutrino runs
  - Tension between ν's and anti-ν's

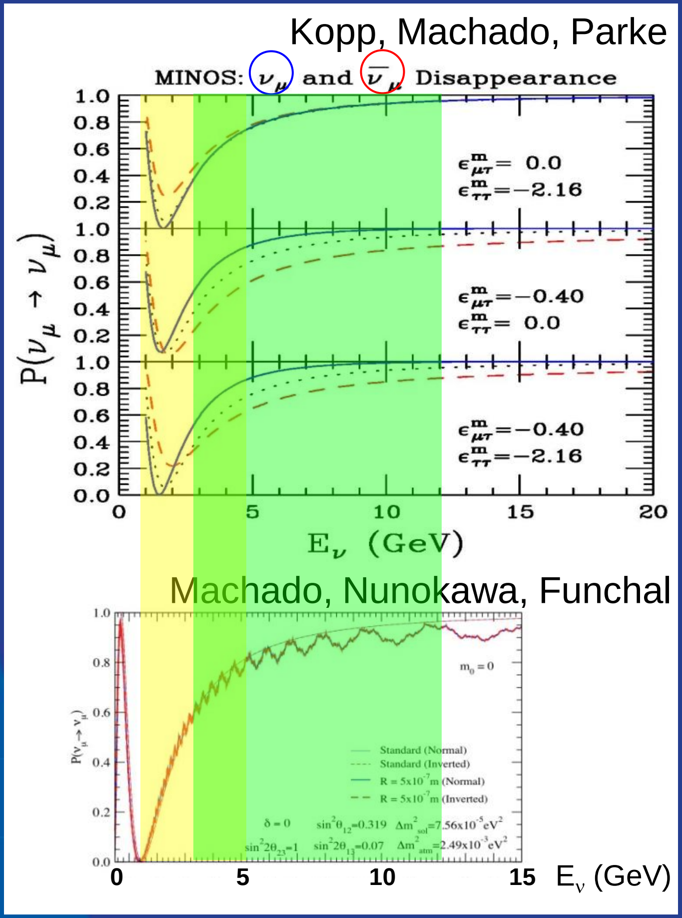
MINOS Results on θ_{13}

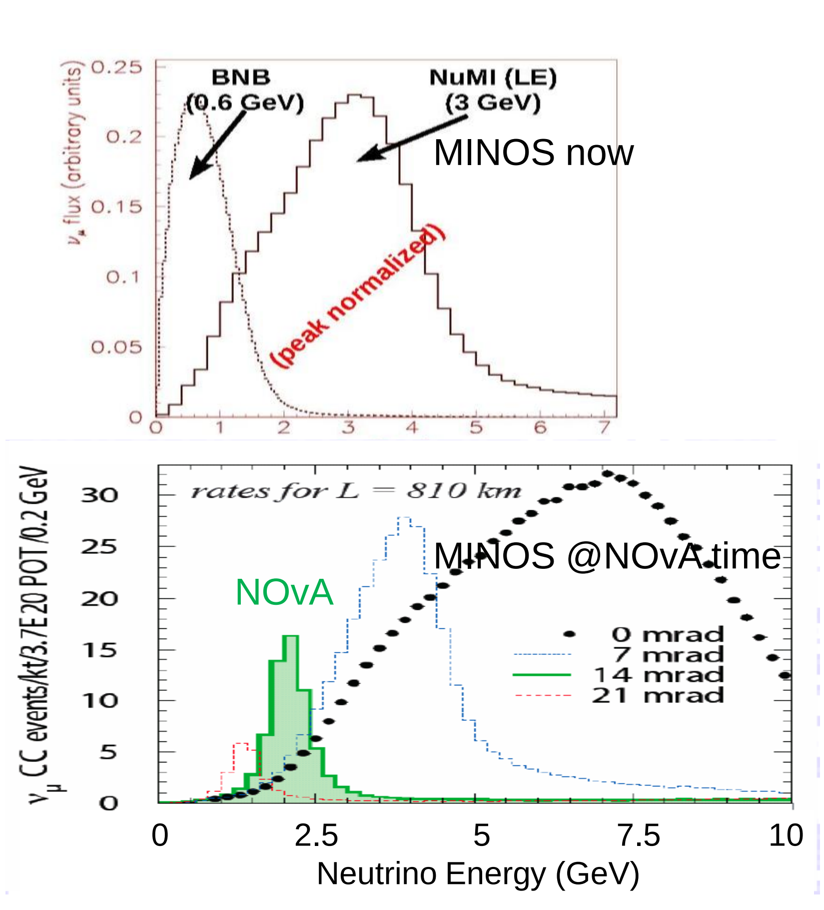
- Electron appearance measurement
- Comparable and consistent with the CHOOZ limit



MINOS Run extension (FY13-14) – TBD

Sensitivities to new physics





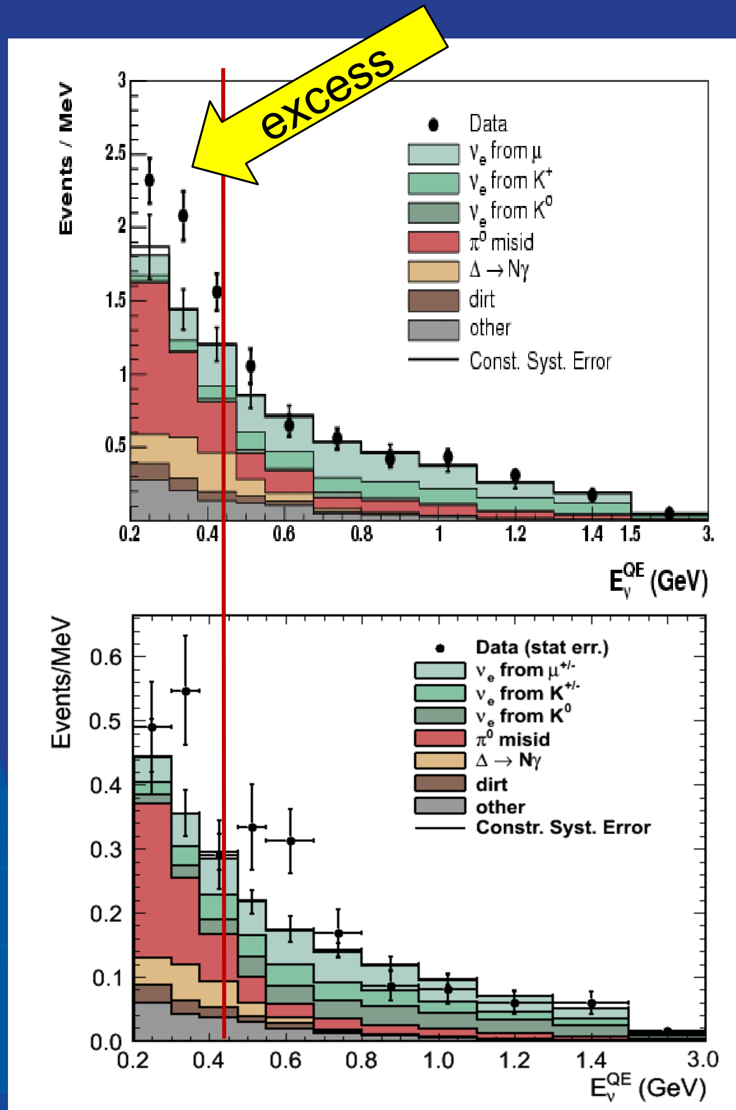
Will be discussed at the June 2011 PAC meeting

MiniBooNE

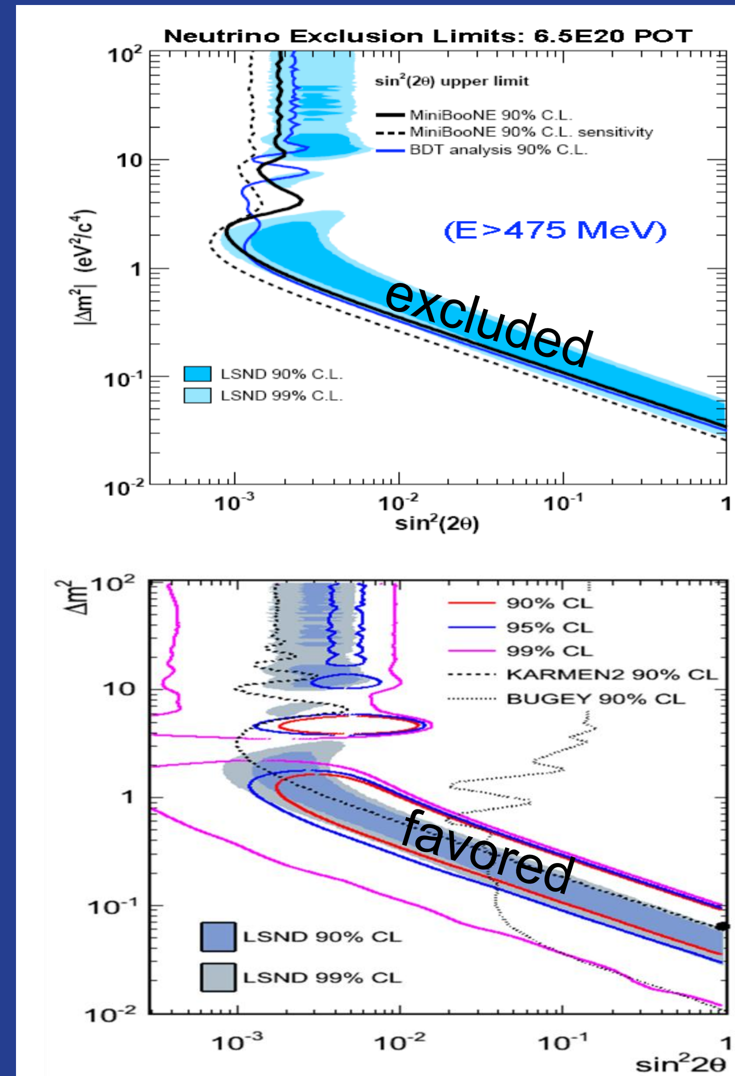
- Anomaly in low momentum neutrinos
- Neutrinos and antineutrinos may be different: neutrinos exclude LSND, antineutrinos consistent with LSND

MiniBooNE

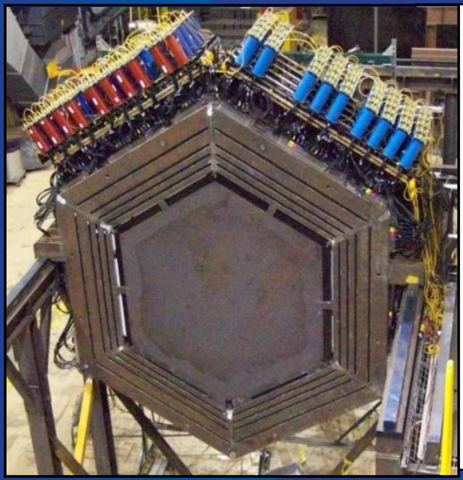
ν

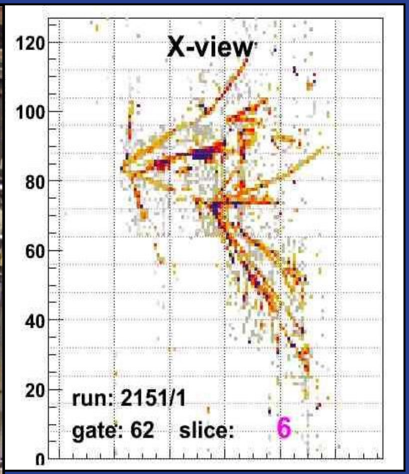


$\bar{\nu}$

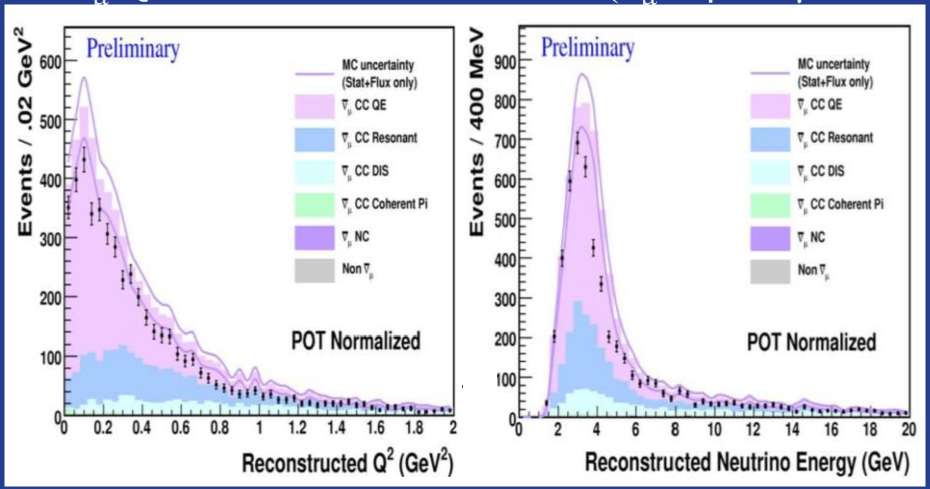


MINERvA program of cross sections





$\bar{\nu}_\mu$ Quasi-Elastic Kinematics ($\bar{\nu}_\mu + p \rightarrow \mu^+$



Deficit is flat in Q^2, not flat in neutrino energy

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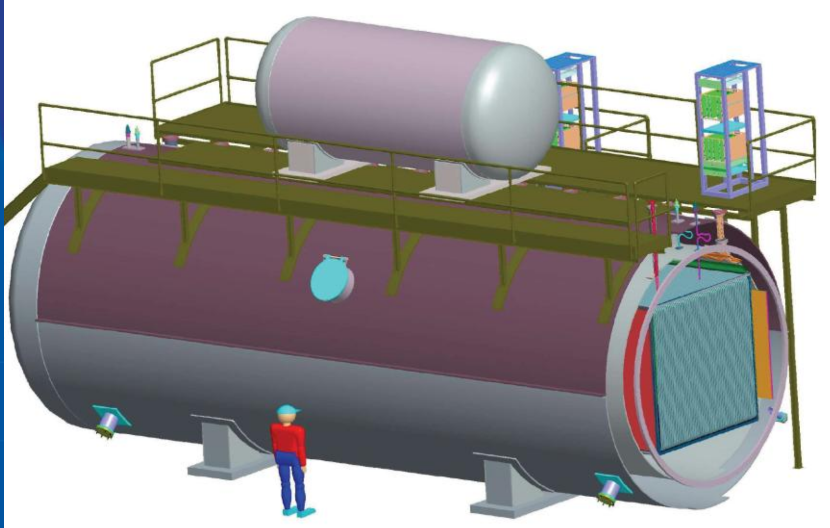
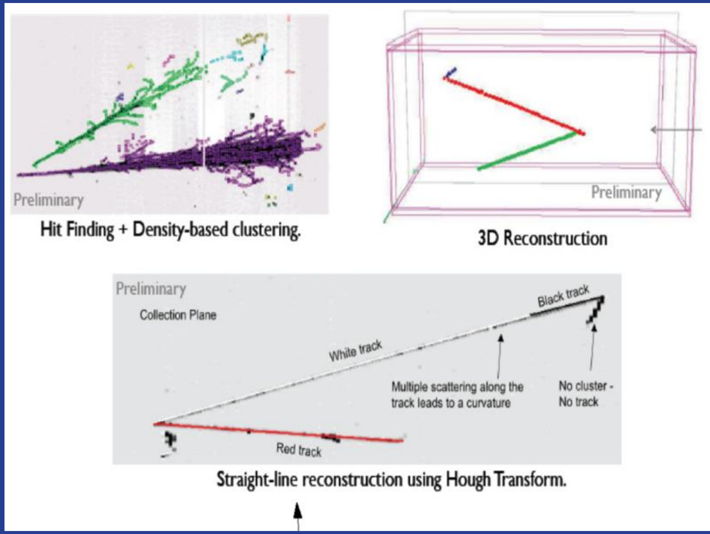
MicroBooNE

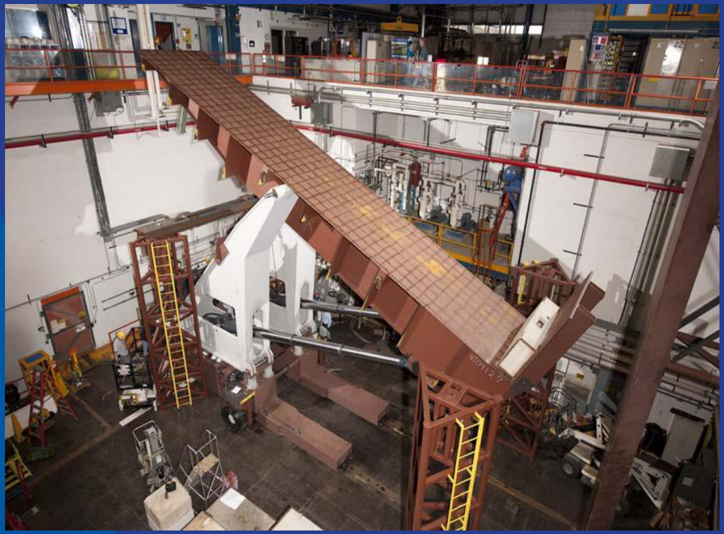
- Follow excess in MicroBooNE data. Critical to determine is it electrons or photons?
- Use Liquid Argon TPC: physics + further development of the technology

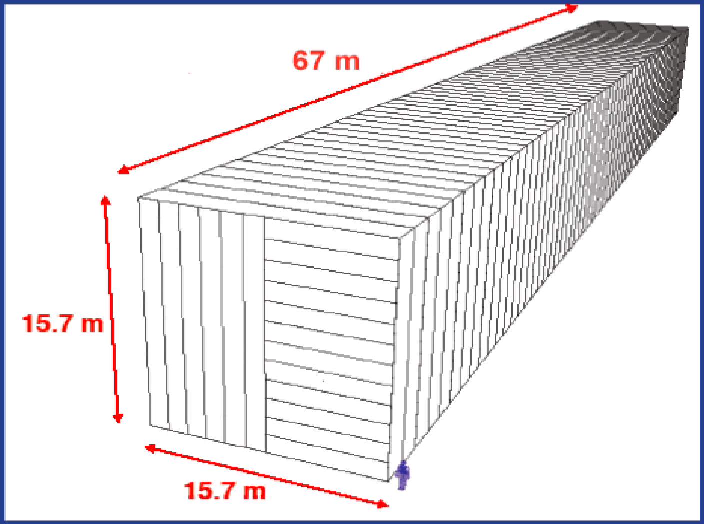




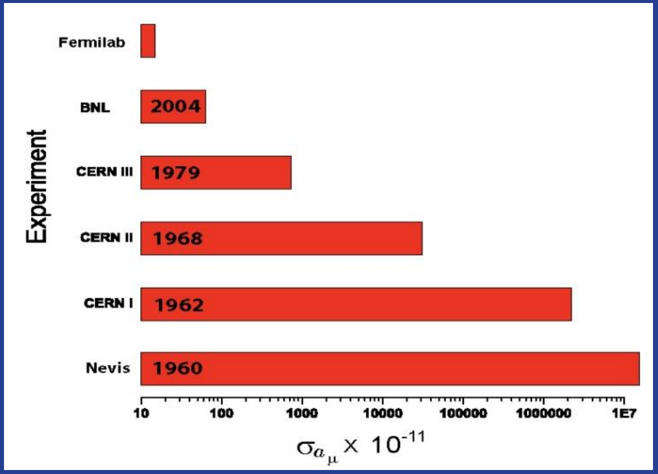
NOvA

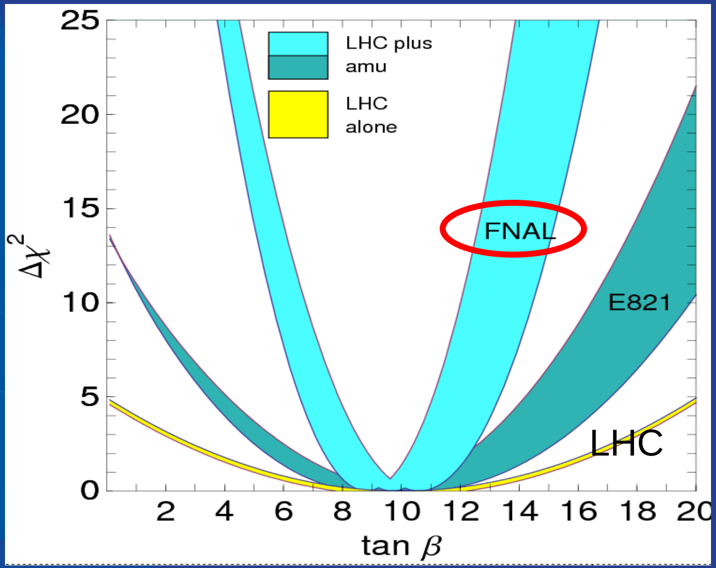
- Electron appearance and next step in oscillation parameters. Neutrinos vs. antineutrinos: different parameters?

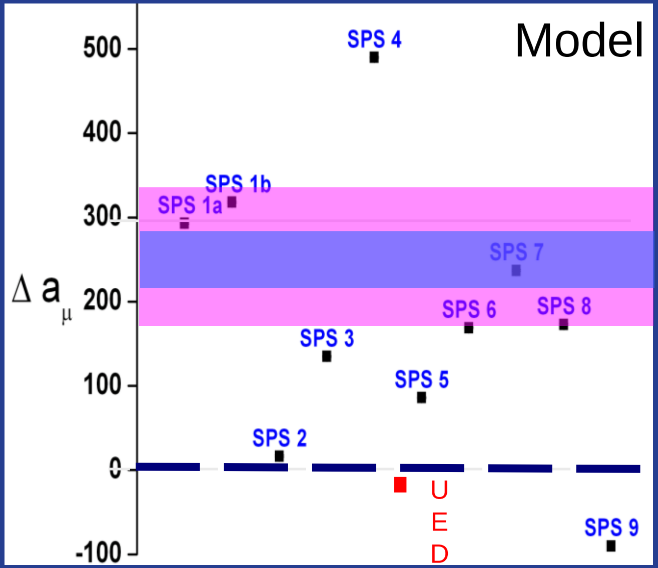




A new (g-2) to uncertainty $0.14 * 10^{-11}$







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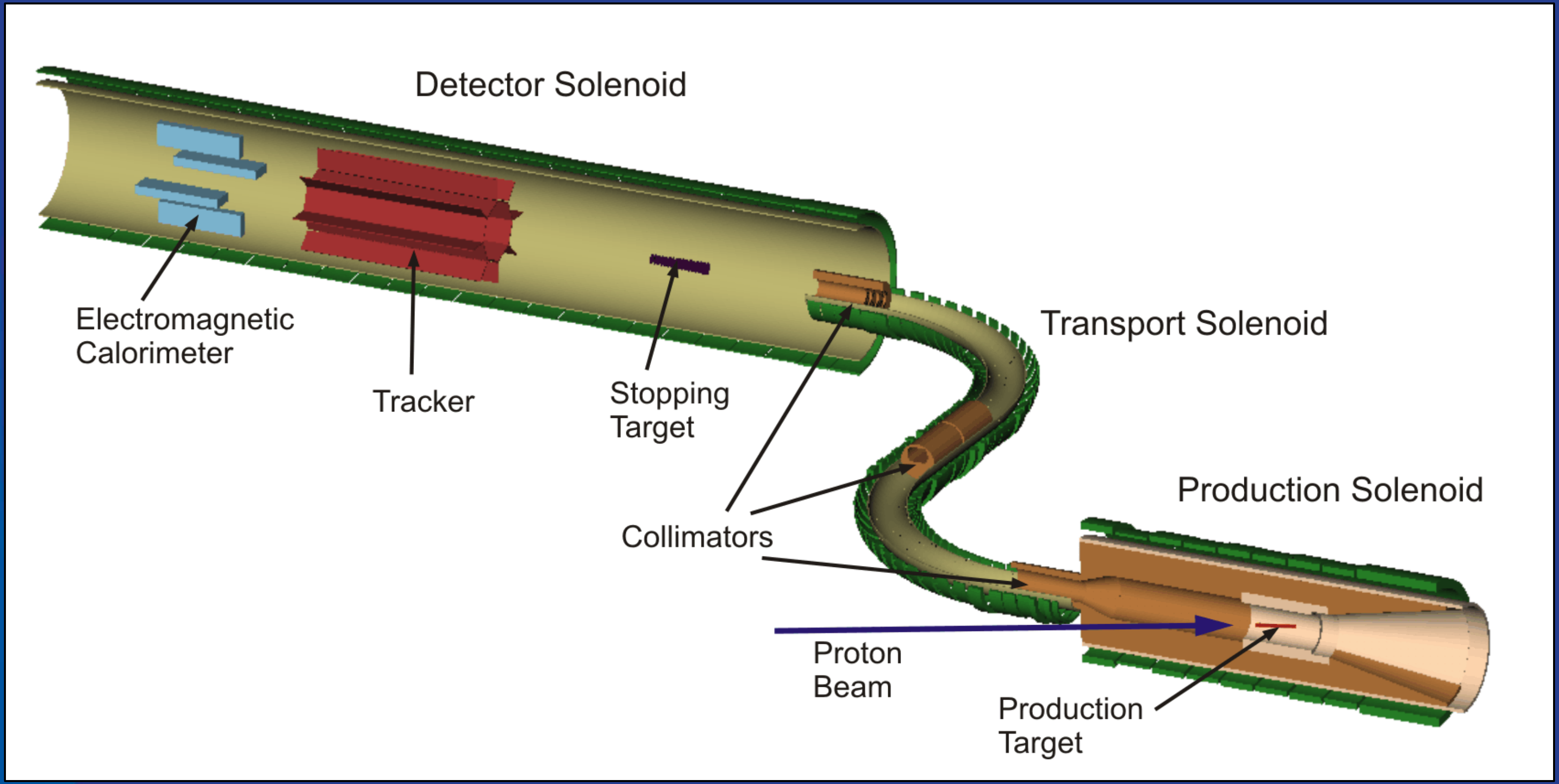
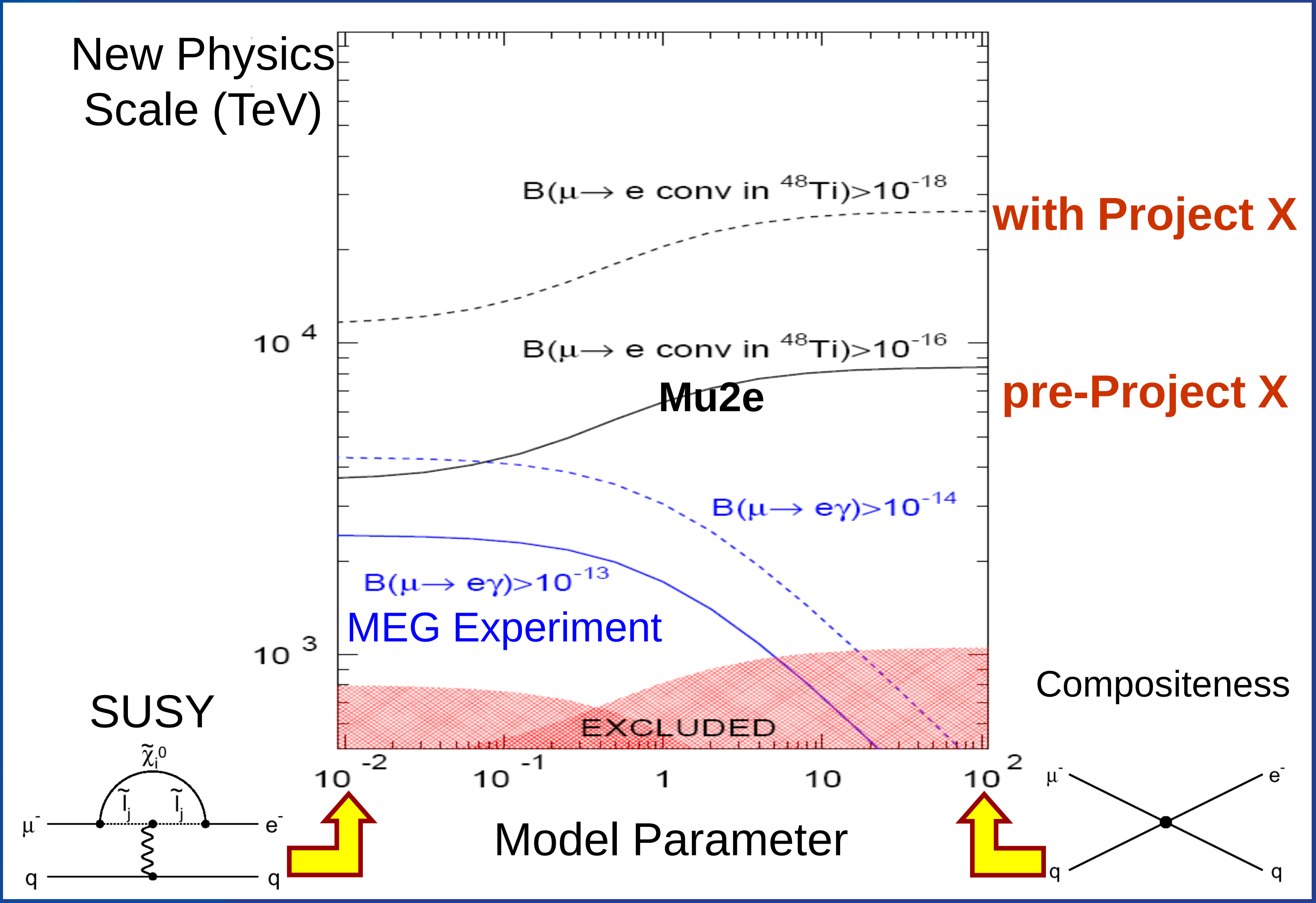
Mu2e….

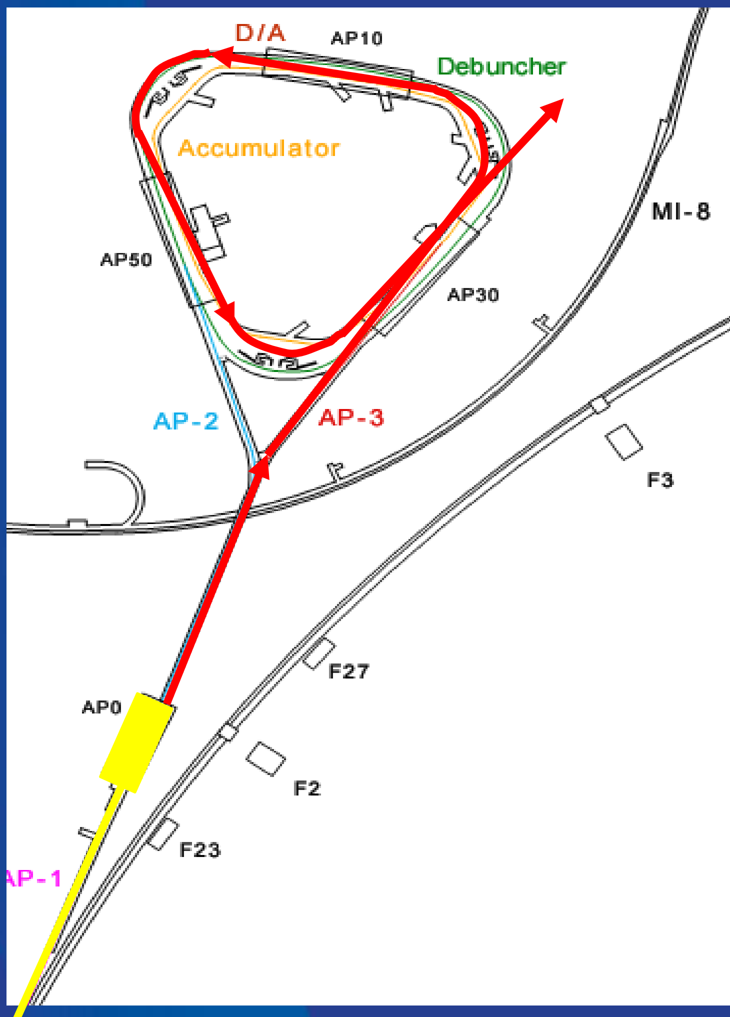


Conversion of a muon into an electron in the field of a nucleus: negligible rate in the SM and measurable in almost any extension of the SM

Mu2e experiment can probe 10^3–10^4 TeV



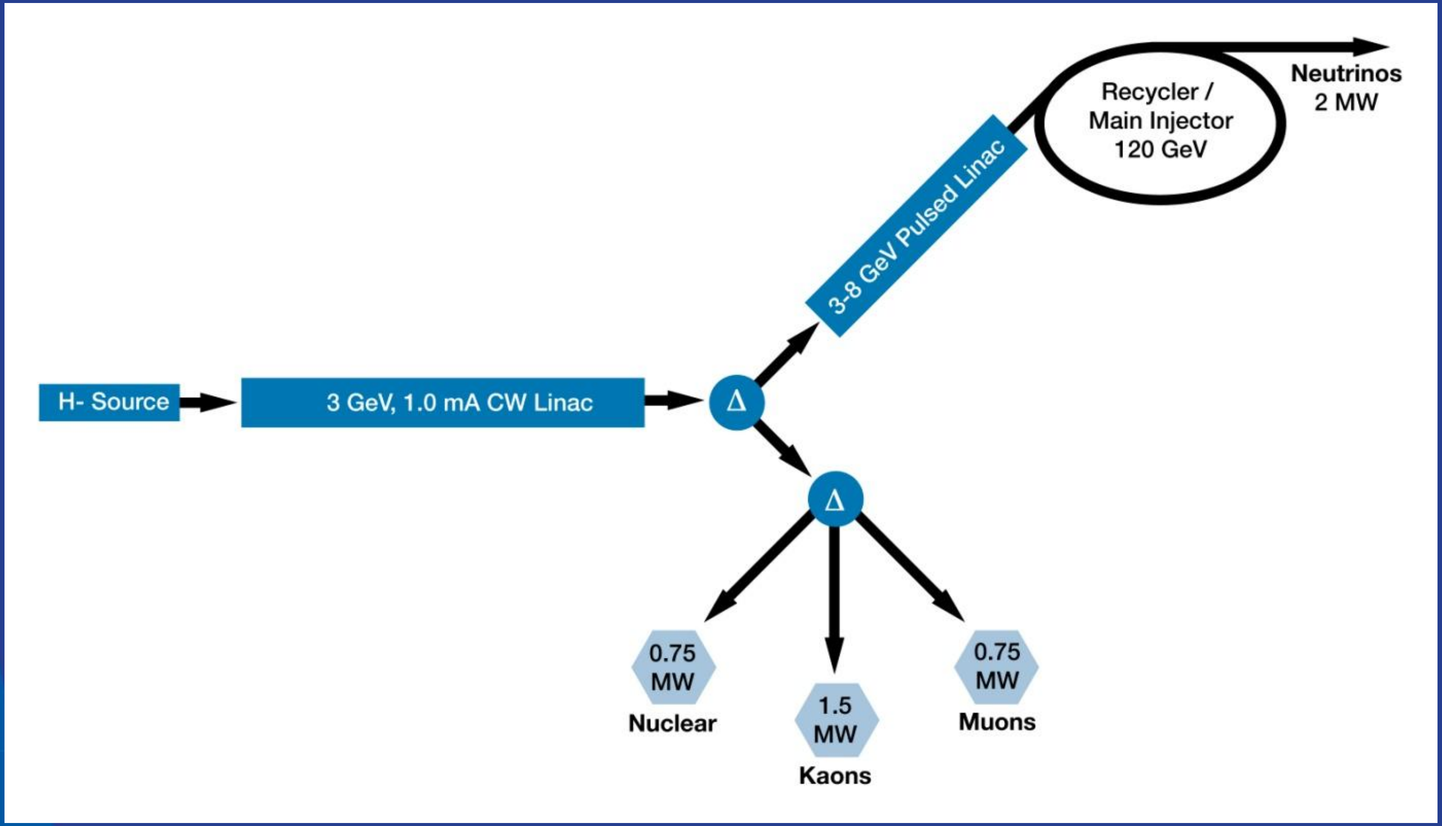
First stage of a muon program…..



Implementing the long term vision

- The most important foundation is to commit to building the most intense and flexible source. The foundation CANNOT be the present front end of Fermilab that is 40 years old; LBNE and important driver.
- Existing and proposed sources elsewhere are pulsed linacs and synchrotrons, both with fundamental limitations in usable intensity
- Project X would unique facility in the world with a very broad program

Project X Reference Design



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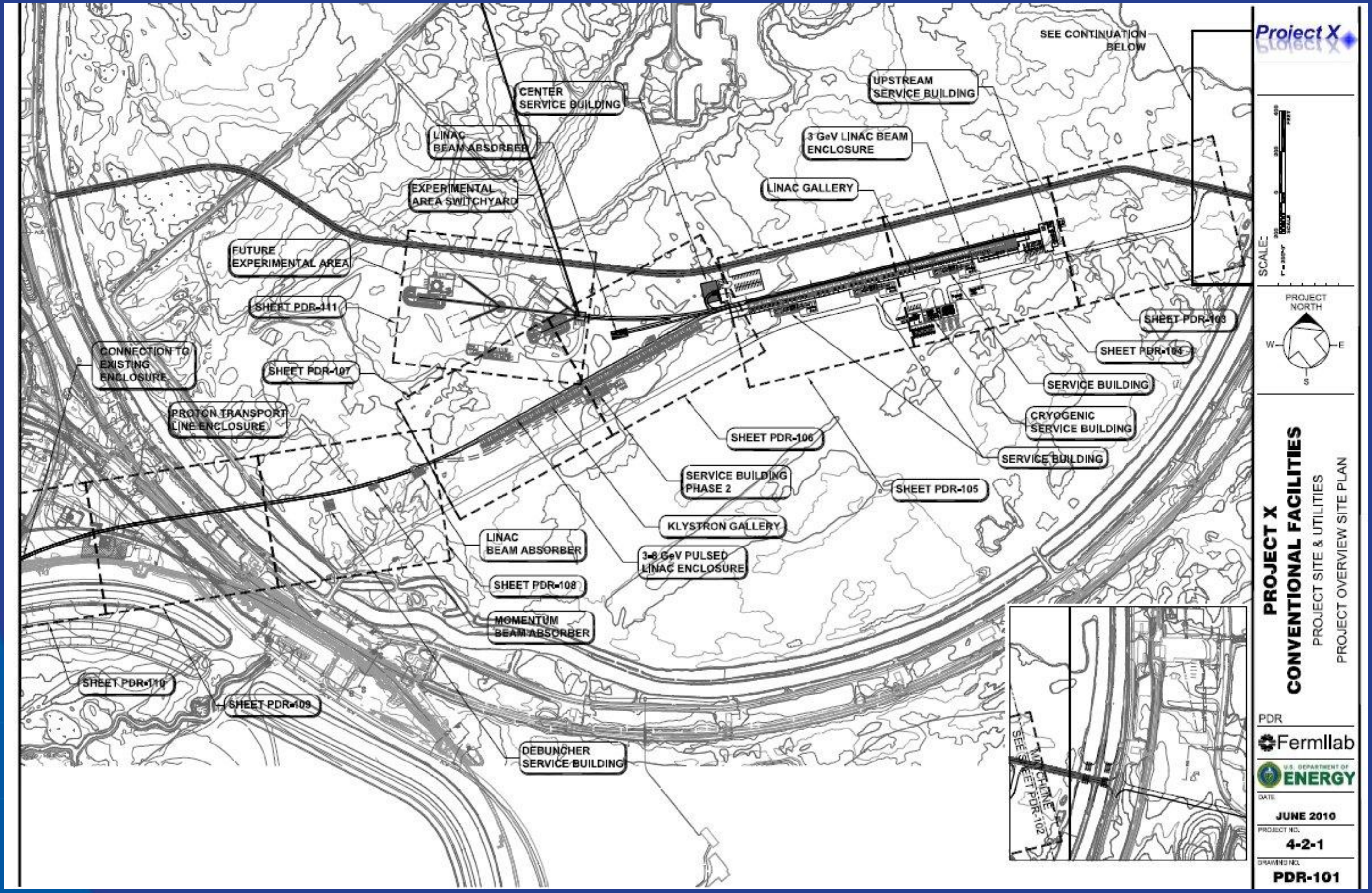
Project X Siting



Project X: CW linac

- Unique facility for rare decays: a continuous wave (CW), very high power, superconducting 3 GeV linac. Will not exist anywhere else
- CW linac greatly enhances the capability for rare decays of kaons, muons
- CW linac is the ideal machine for other uses: Standard Model tests with nuclei (ISOL targets), possible energy and transmutation applications, cold neutrons

$K \rightarrow \pi\bar{\nu}\nu$...Past, Present, Future

Facility (Experiment)	Proton Power	Kaon decay rate	Kaon Properties	$K \rightarrow \pi\nu\bar{\nu}$ Sensitivity
BNL AGS (E787/E949)	50kW	1×10^6 K^+/sec	Pure stopped K^+ source	7 events (charged)
CERN (NA62)	20kW	10×10^6 K^+/sec	Un-separated 1- GHz $K^+/\pi^+/p^+$ beam	80 events (charged)
Project-X $K^+ \rightarrow \pi\nu\bar{\nu}$	1500 kW	100×10^6 K^+/sec	Pure stopped K^+ source	>1000 events (charged)
JPARC (KOTO)	<300 kW	$<0.5 \times 10^6$ K_L/sec	Pencil beam	1 event (neutral)
Project-X $K_L \rightarrow \pi\nu\bar{\nu}$	1500kW	50×10^6 K_L/sec	Pencil beam & Precision TOF	1000 events (neutral)

$\mu^-A \rightarrow e^-A$ Conversion… Past, Present, Future

Facility (Experiment)	Proton Power	Stopped Muon rate	Muon Properties	$\mu A \rightarrow eA$ Sensitivity
PSI (SINDRUM II)	1000kW	10^7 μ/sec	"DC" (50 MHz cyclotron) 52 +/-1 MeV/c	3×10^{-13}
Booster & JPARC (Mu2e/COMET)	25kW	5×10^{10} μ/sec	1 MHz Pulsed 10-70 MeV/c	2×10^{-17}
Project-X (PRISM-like)	1000kW	$>10^{12}$ μ/sec	Pulsed, narrow-band (30 +/- 1 MeV/c)	$<10^{-18}$

Mu2e/COMET breakthrough technology:

- Large muon yield from production target *inside* of high field solenoid.
- Pulsed beam strongly suppresses pion backgrounds.

Project-X breakthrough technology:

- Collapse the high flux wide-band muon beam to a narrow-band beam with cooling techniques.

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Project X is central to the strategy

- The CW linac coupled to an 8 GeV pulsed LINAC and to the Recycler and Main Injector, gives the most intense beams of neutrinos at high energy (LBNE) and low energy (for the successors to Mini and MicroBooNE)
- Makes use of modern accelerators at Fermilab (Recycler and Main Injector) and its scope would be difficult to reproduce elsewhere without this established base
- Eliminates proton economics as the major limitation: all experiments run simultaneously

Project X and other projects

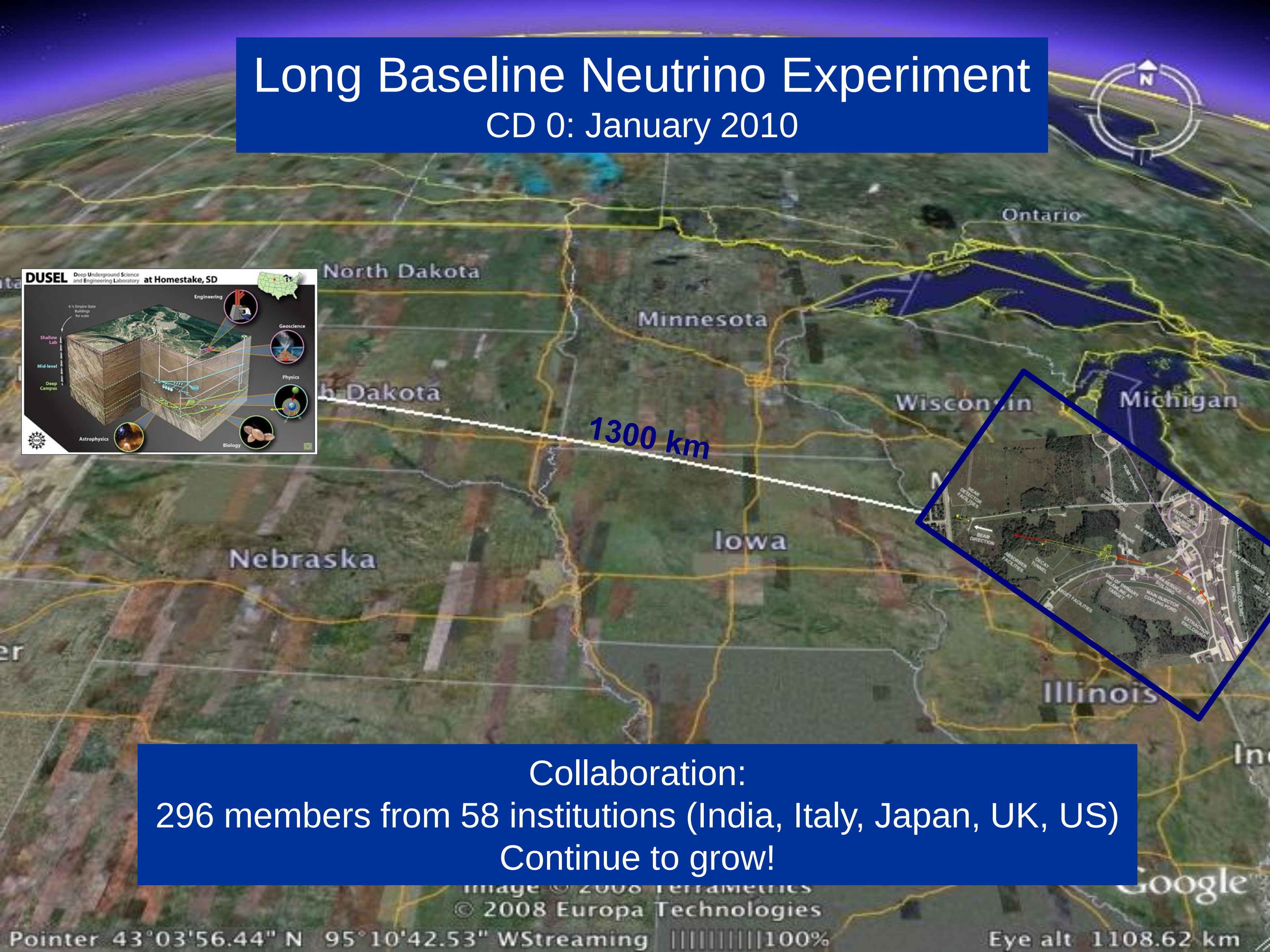
- Project X benefits from the word-wide ILC R&D: SCRF and photo-e cloud. SCRF R&D positions the US to play a leading role in ILC.
- Capabilities and infrastructure developed for Project X will be useful for other domestic non HEP projects.
- Project X with upgrades can be the front end of a neutrino factory or a muon collider, opening paths for development of the intensity frontier and a road back to the energy frontier

Implementing the vision: LBNE

- LBNE is a key experiment in the neutrino area and already engages a very broad collaboration
- It can start with the 700kW beam developed for NOvA (facilities have to be built towards the DUSEL direction)
- It would ultimately deliver over >2000kW in the Project X era

Long Baseline Neutrino Experiment

CD 0: January 2010

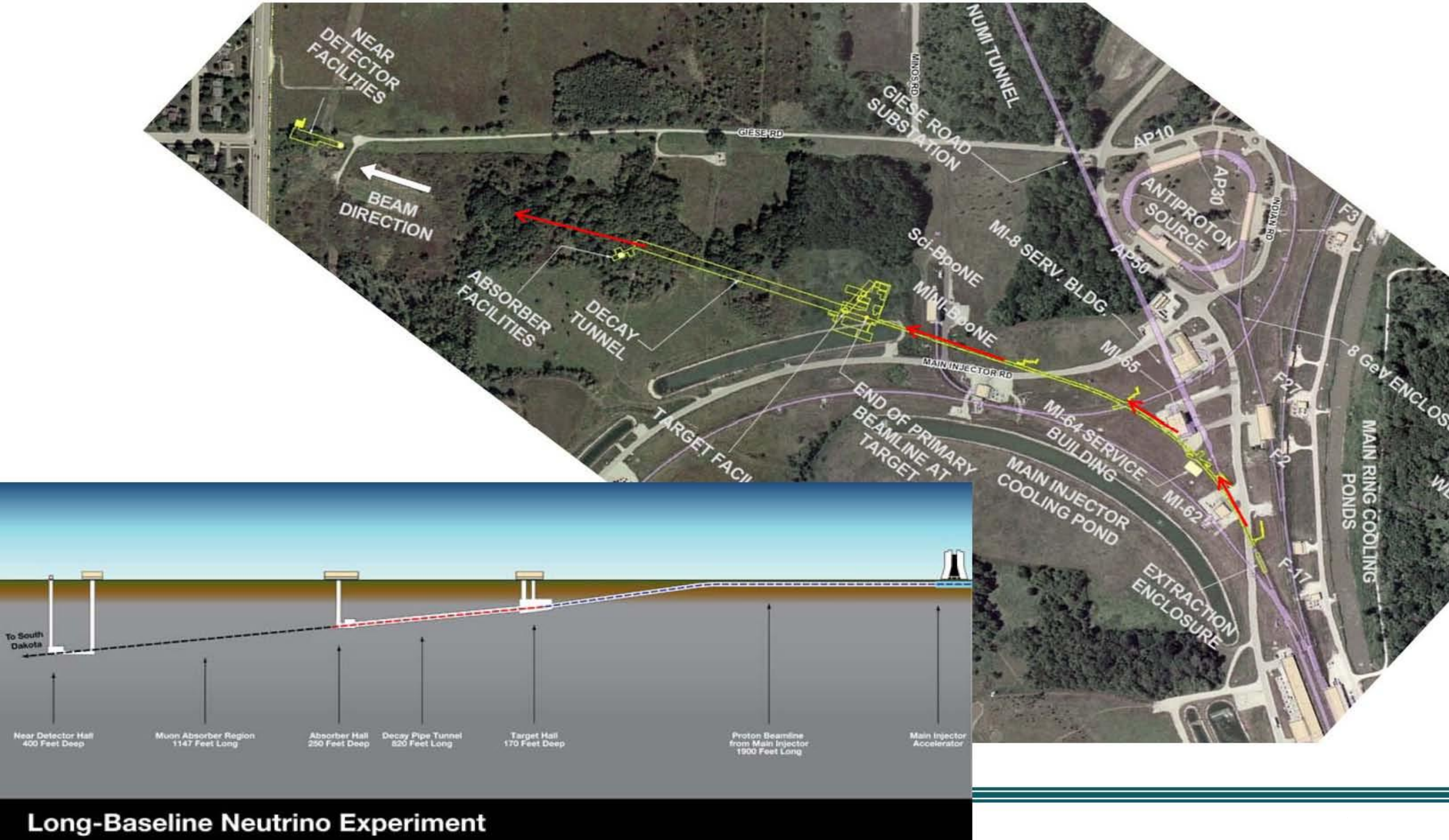


Collaboration:

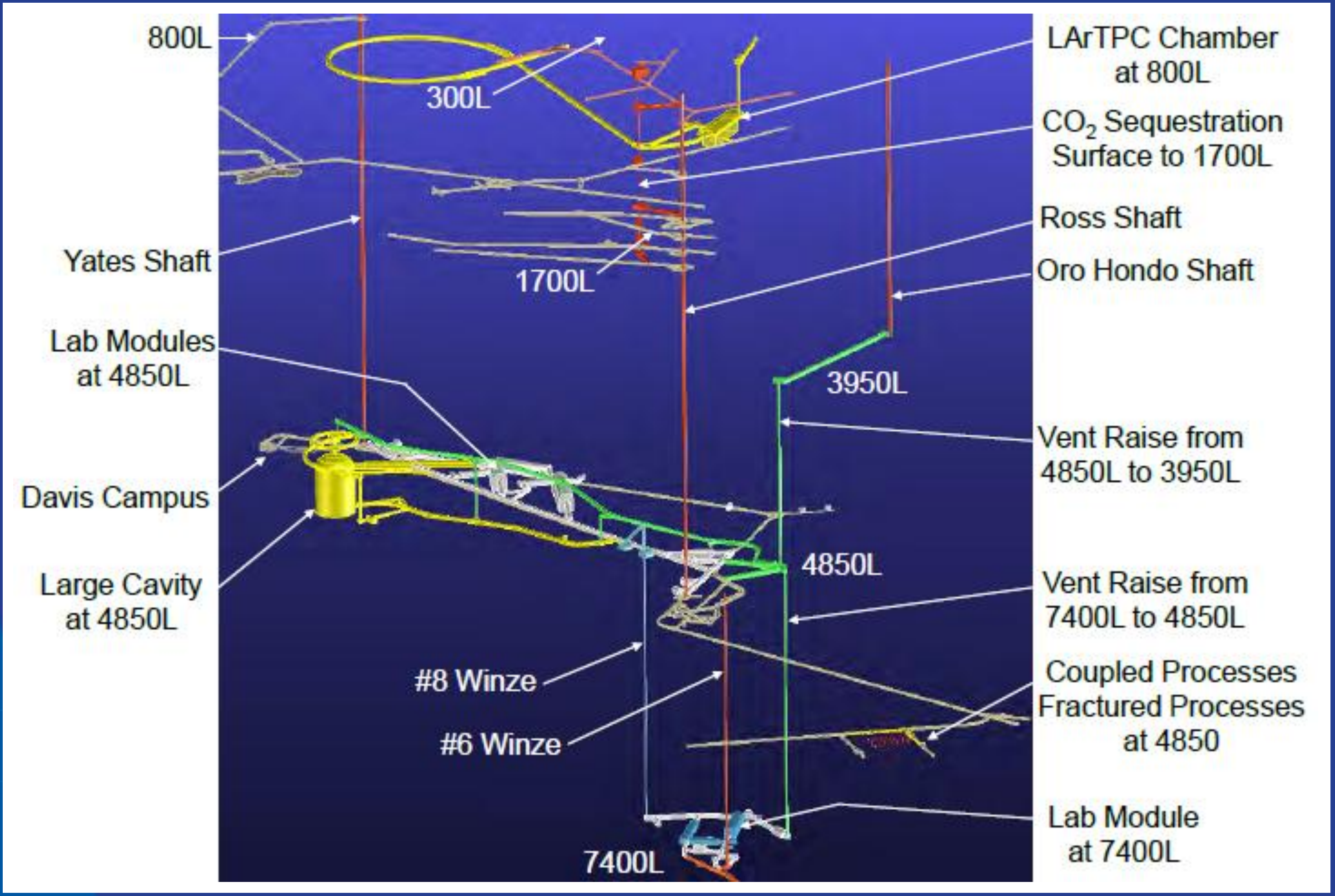
296 members from 58 institutions (India, Italy, Japan, UK, US)

Continue to grow!

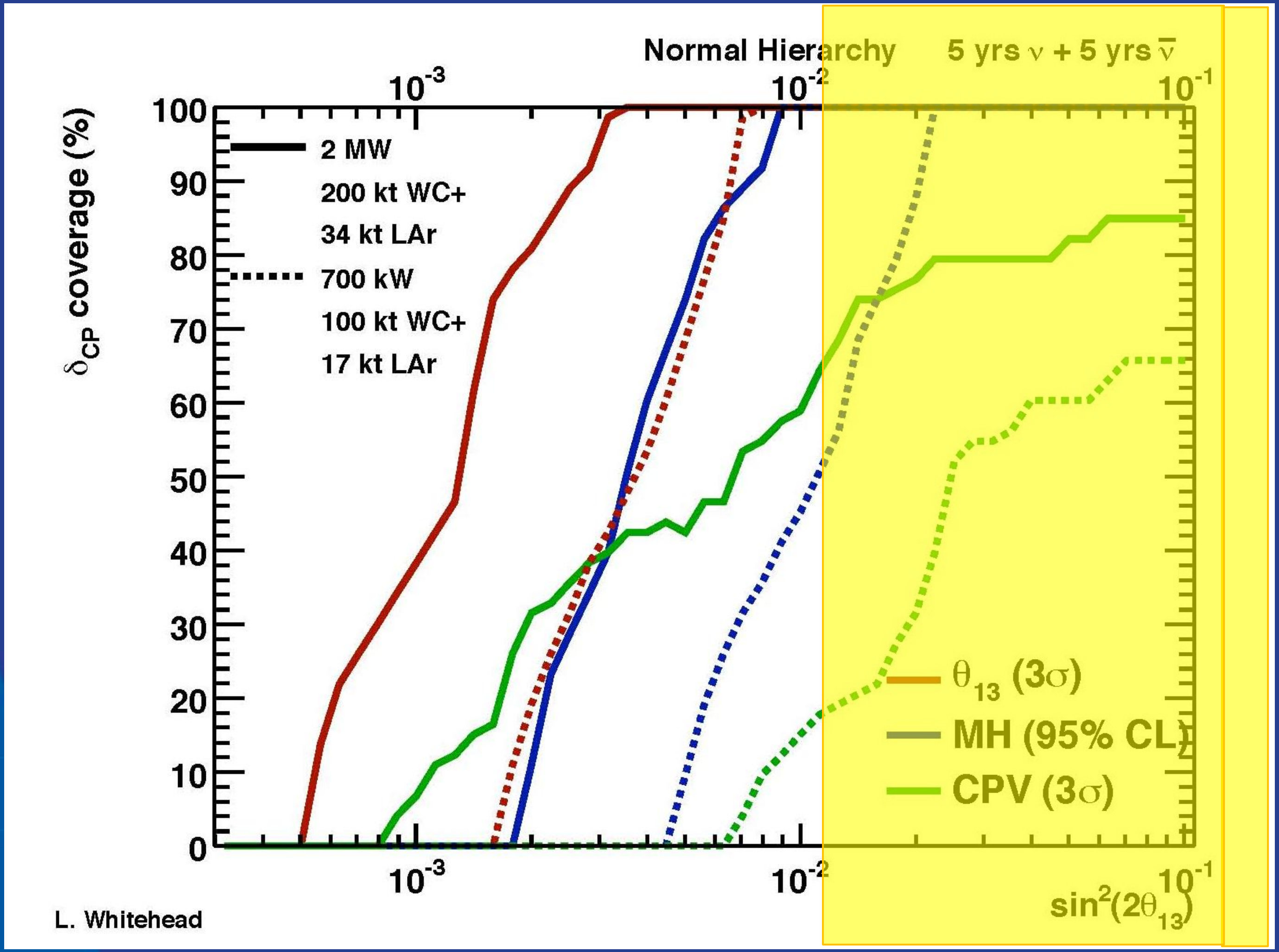
Conceptual Design Overview – Neutrino Beam



DUSEL Lab Layout



Neutrino physics sensitivities



With Project X

"Plug and play" - physics

3 GeV CW linac	• Muons • Kaons • Nuclei (ISOL) • Materials (ADS)
3-8 GeV pulsed linac	• Neutrinos vs. antineutrinos • Muons
8-120 GeV existing machines	• Long base line neutrino oscillations

Sequencing is flexible

LBNE at 700 kW | 3 GeV initial program | 8 GeV initial program | LBNE at 2300kW

3 GeV initial program | 8 GeV initial program | LBNE at 2300kW

We are capable of doing the whole program at once in the next ten years, or it can be sequenced over a longer period

What will it take? – cost to day one

With full contingency and escalation
(P5 Cost were in FY08$)

3 GeV CW linac	Accelerator	$1.2B
	Experiments	$0.2B
3-8 GeV pulsed linac	Accelerator	$0.5B
	Experiments	$0.2B
8-120 GeV existing machines	Accelerator	$0.1B
	Experiment	$1.0B

What will it take? – cost and offsets

	TPC		Offsets: foreign+NSF	
3 GeV CW linac	Accel	$1.2B	Accel	$0.3B
	Exp	$0.2B	Exp	$0.1B
3-8 GeV pulsed linac	Accel	$0.5B	Accel	$0.1B
	Exp	$0.1B	Exp	$0.05B
8-120 GeV existing machines	Accel	$0.1B	Accel	$0
	Exp	$1.0B	Exp	$0.2B

How should you think about this ?

• Total cost of Project X + LBNE + day one intensity frontier experiments (on the same time frame SNS would be $2.2B)….	$3.1B
• Offsets: India + Europe + China(?) + NSF	($0.75B)
• Net cost for the DOE………………………..	$2.35B
• In present Fermilab budget: ramp down of NOvA and Tevatron times ten years……...	($0.9B)
• Net additional investment on HEP over ten years for the entire program	$1.45B