Perspective from Fermilab

NRC-DUSEL, December 15, 2010

U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

- Summary
  - An underground laboratory for the US
  - Unique advantages of DUSEL
  - The importance of DUSEL in Fermilab's plans
- Overall particle physics perspective in the US
  - The three frontiers: energy, cosmic and intensity
  - The importance of the intensity frontier in Fermilab's future role
  - DUSEL as a key component of the intensity frontier

Summary: US underground lab

- There is a broad, world-leading program of science to be carried out in a deep underground laboratory
- It is several decades that we have been discussing creating such a laboratory in the US; the need will not go away
- Unless we want to keep talking about building a deep underground laboratory in the US for the next two decades, it is time to build it!

Summary: the advantages of DUSEL

- Ideal distance from Fermilab for the Long Baseline Neutrino Experiment (1300 km). Will benefit by future upgrades of the Fermilab accelerators (Project X)

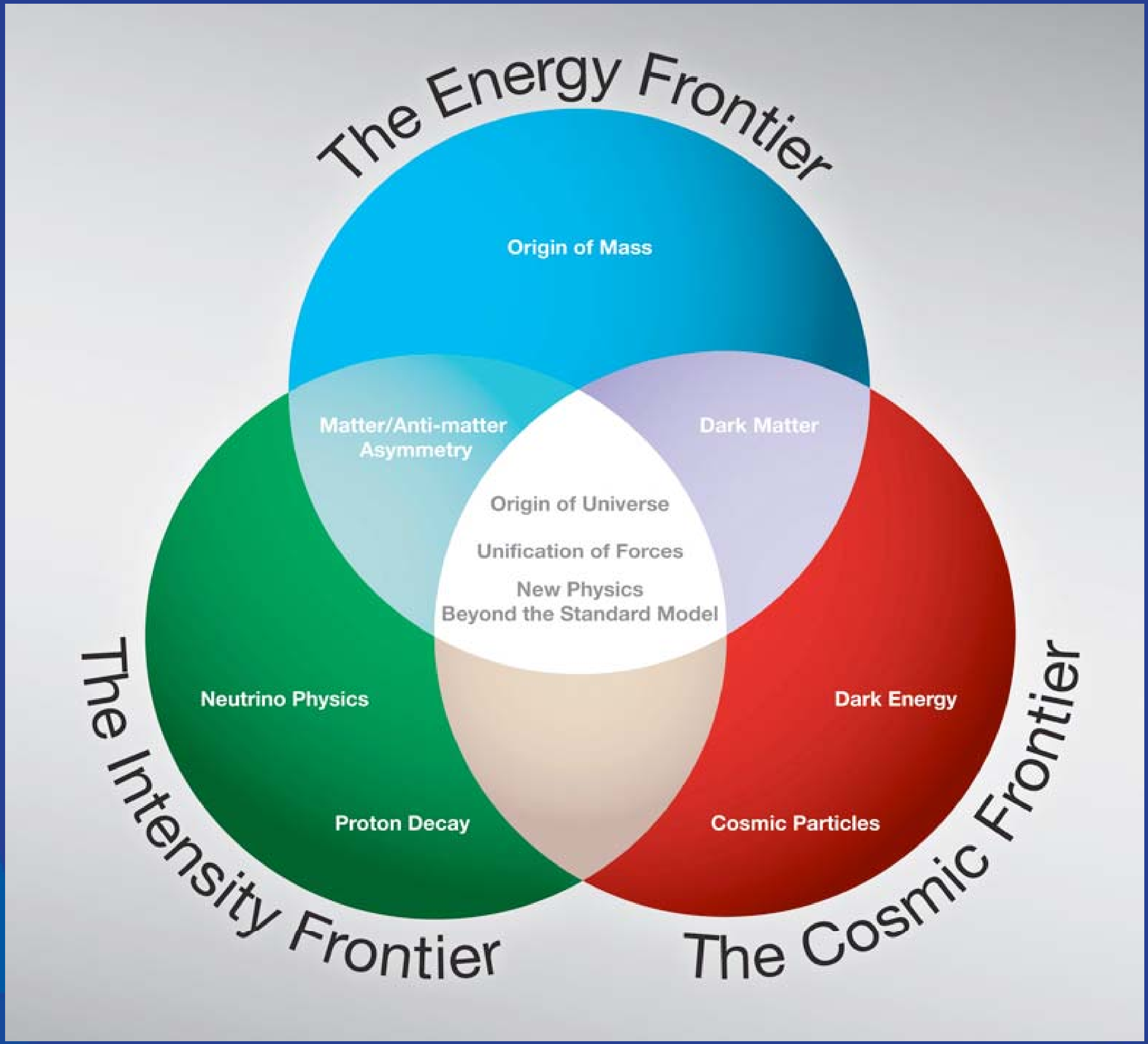
- Proven competent rock for large facilities at 4850 ft. depth; possibility of expansion to 7400 ft. level, the deepest in the world

- Large endowment (relative to other sites) in completed studies, permits, infrastructure, state support and ability to move quickly

Summary: role in Fermilab's plans

- LBNE is central in Fermilab's strategy
- Without DUSEL :
  - We could develop a shallow site at the 1300km → 2000km range. Would requires significant infrastructure, but it is unlikely to provide the possible future expansion for a deep underground lab. The opportunity is lost unless it is done at Homestake
  - For third generation dark matter or neutrino-less double Beta decay experiments, US led efforts would wait for approval/space in facilities abroad

A graph – not a list!



Frontiers of particle physics

- **Question: Why have we not seen all the particle physics phenomena yet?**
  - 1. **The phenomena involve objects that are hard to make (e.g. black holes, heavy gluinos)**
  - 2. **The phenomena involve interactions that are fundamentally weak – thus very rare**
  - 3. **The phenomena involve interactions that are very short range – thus very rare**

- **In case #1, proceed to Energy or Cosmic Frontiers**

- **In cases #2 and #3, we can use high intensities to observe rare phenomena**

Advancing the Frontiers: 1995 -2010

	Huge Surprising Discoveries	Evidence of New Fundamental Phenomena	First Observations or Strong Limits
Intensity	Neutrinos have mass! Lepton flavor not conserved!	g-2 anomaly (superpartners?) direct CP violation in kaons B -> tau nu anomaly + other B puzzles	Too numerous to enumerate here (hundreds)
Energy	Heavy top quark!	DZero muon asymmetry (new CP violation and quark flavor violation?)	Too numerous to enumerate here (hundreds)
Cosmic	Dark matter is nonbaryonic and mostly cold! Dark energy!?	Universe is flat (inflation?) Primordial density fluctuations (inflation?)	Too numerous to enumerate here (dozens)

J. Lykken, "Particle Physics and the Intensity Frontier"

Project X Briefing, DOE, 6 Dec 2010

Advancing the Frontiers: 2010 -2025

	Huge Surprising Discoveries	Evidence of New Fundamental Phenomena	First Observations or Strong Limits
Intensity	Neutrinos violate CP! Charged leptons mix! Neutrinos see a new force! etc!	Leptogenesis! Grand Unification! The origin of matter!	Too numerous to enumerate here (hundreds)
Energy	Nonstandard or No Higgs! Dark matter particles produced! New forces! New dimensions, etc!	Dark/hidden sectors! Grand Unification! The origin of matter!	Too numerous to enumerate here (hundreds)
Cosmic	Dark matter particles observed! Dark energy is dynamical! Footprints of inflation! etc!	The origin of the universe! The fate of the universe!	Too numerous to enumerate here (hundreds)

J. Lykken, "Particle Physics and the Intensity Frontier" Project X Briefing, DOE, 6 Dec 2010

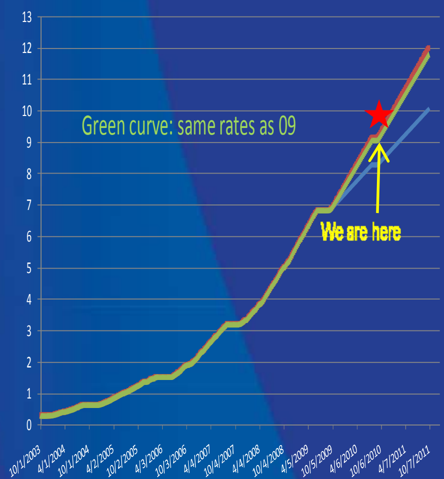
Gaps and roles: energy frontier

- 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: 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

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

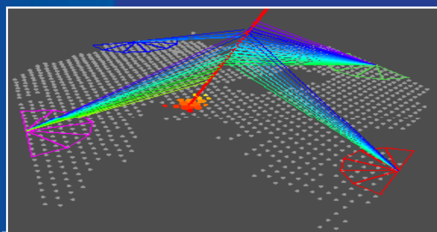
Now 2013 2016 2019 2022

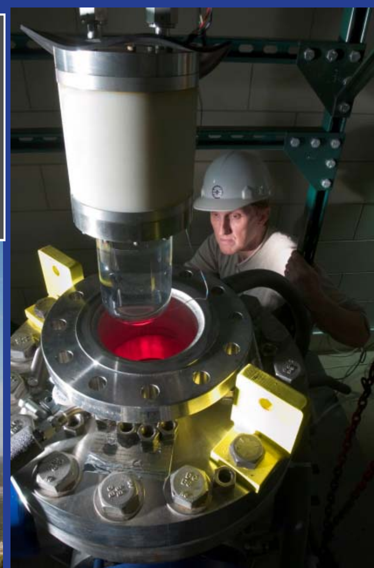


Gaps and roles: cosmic frontier

- The principal connection to particle physics: 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. Participate in future ground and space telescopes (the principal agencies are NSF and NASA, not DOE)

Roles: cosmic frontier





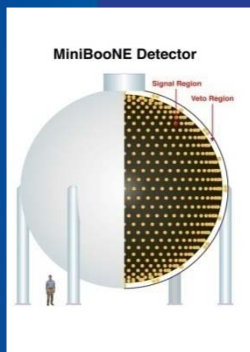
Now – 2013	2013 – 2016	2016 – 2019	2019 – 2022
DM: ~10 kg DE: SDSS P. Auger	DM: ~100 kg DE: DES P. Auger Holometer?	DM: ~1 ton DE: LSST WFIRST?? BigBOSS??	DE: LSST WFIRST??

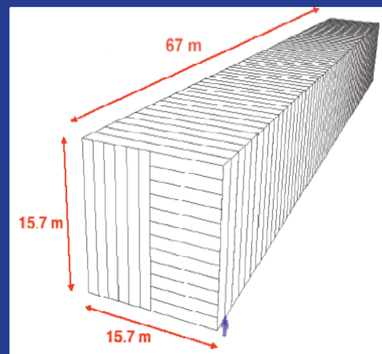
Now 2013 2016 2019 2022

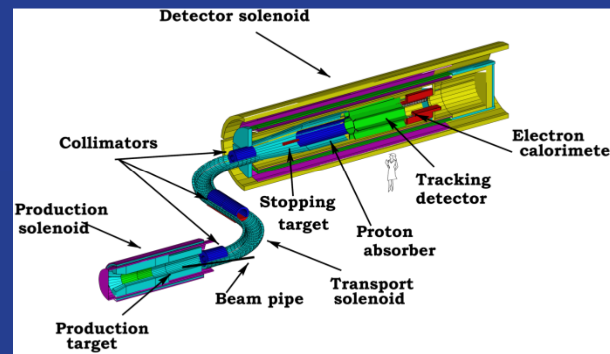
Gaps and roles: intensity frontier

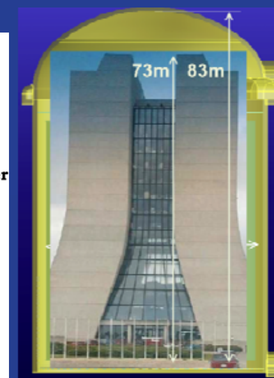
- Two principal approaches: 1) proton super-beams to study neutrinos and rare decays and 2) quark factories: in e^+e^- and LHCb
- Principal gap is the understanding of neutrinos and the observation of rare decays coupled to new physics processes
- Fermilab strategy: develop the most powerful set of facilities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

Roles: intensity frontier



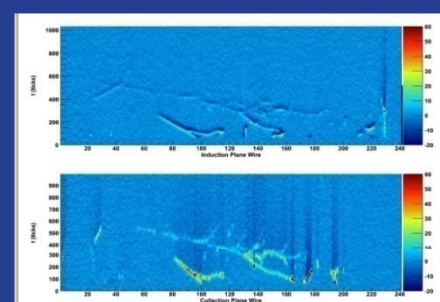


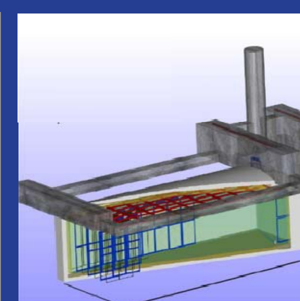




MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2? SeaQuest	LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??

Now 2013 2016 2019 2022





Fermilab

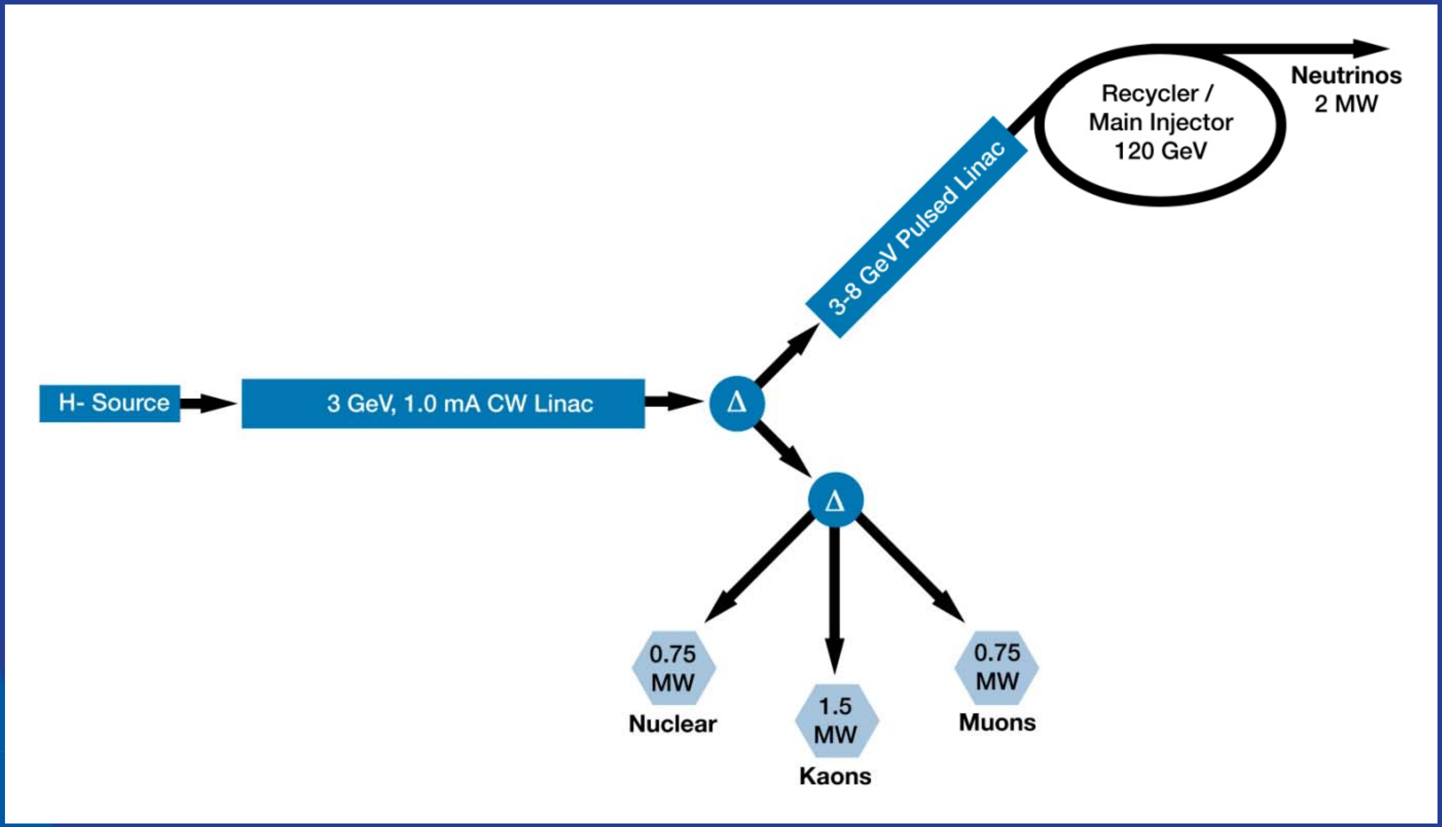
Implementing the vision

- 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
- Present existing and proposed sources elsewhere are pulsed linacs and synchrotrons, both with fundamental limitations for a comprehensive program at the intensity frontier
- Project X would be the dominant facility in the world with a very broad program

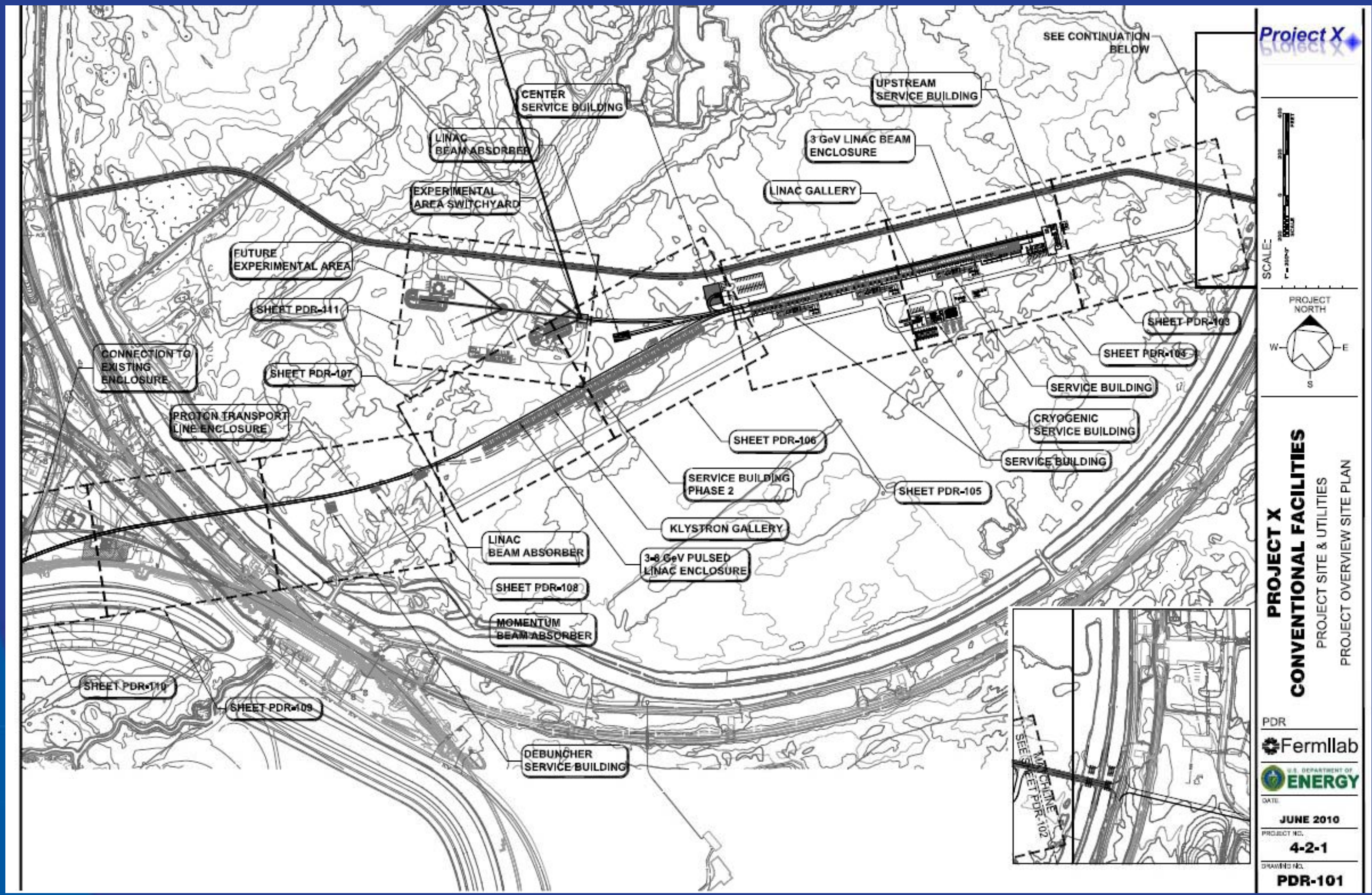
Implementing the vision

- LBNE is the 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

Project X Reference Design



Project X Siting



Project X Capabilities

- > 2 MW delivered to a neutrino target at any energy between 60 – 120 GeV
- Simultaneous delivery of ~3 MW of high duty factor beam power to the 3 GeV program
  - Variable beam formats to multiple users
  - CW beam at time scales >1 μsec
  - 10% duty factor on time scales < 1 μsec
- Potential for development of additional programs at:
  - 1 GeV for nuclear energy experimentation
  - 8 GeV for neutrino or muon experimentation

Project X is central to the strategy

- 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

Project X is central to the strategy

- 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

LBNE and DUSEL

Neutrinos are Messengers of New Physics

Neutrinos, unlike quarks:

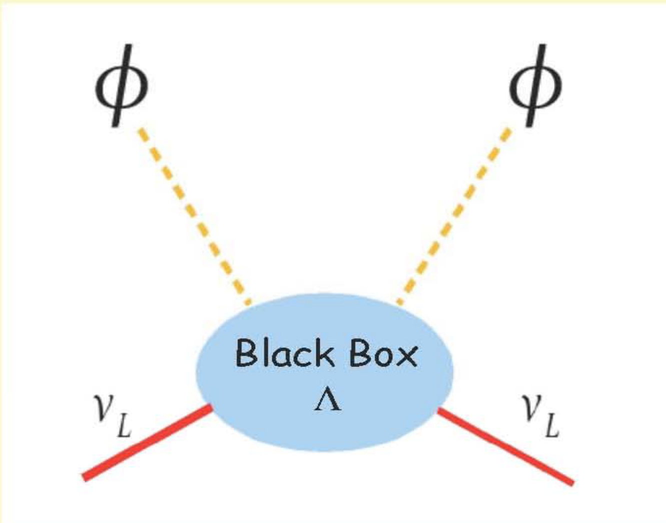
- **Have tiny masses**
- **May have "inverted" mass splittings**
- **Have large mixings**
- **Might be mixed with additional light fermions ("steriles")**
- **Might be their own antiparticles ("Majorana")**
  - **thus violating L and B - L**
  - **and having extra CP phases**
  - **and having superheavy partners**

Furthermore:

- **They oscillate flavors over macroscopic distances**
- **This oscillation phase is sensitive to the medium (matter effects)**
- **They are part of the dark matter and may be related to dark energy**
- **They may experience new interactions or exotic effects**

J. Lykken, "Particle Physics and the Intensity Frontier" Project X Briefing, DOE, 6 Dec 2010

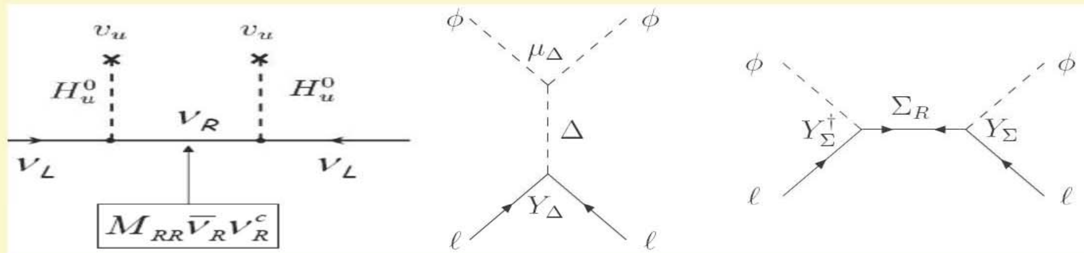
How do neutrinos talk to the Higgs?



Type I,
fermion singlet
N, charge 0

Type II,
scalar triplet
Δ, charge 0, 1, 2

Type III,
fermion triplet
Σ, charge 0, 1



+ variants (inverse, +SUSY, +LR, +radiative,…)

- **Either neutrinos couple to the Higgs via superheavy partners, or via new TeV particles accessible at the LHC**
- **Need to nail down the neutrino masses, mixings, and possible CP phases**
- **Even more so if neutrinos have one or more sterile components**

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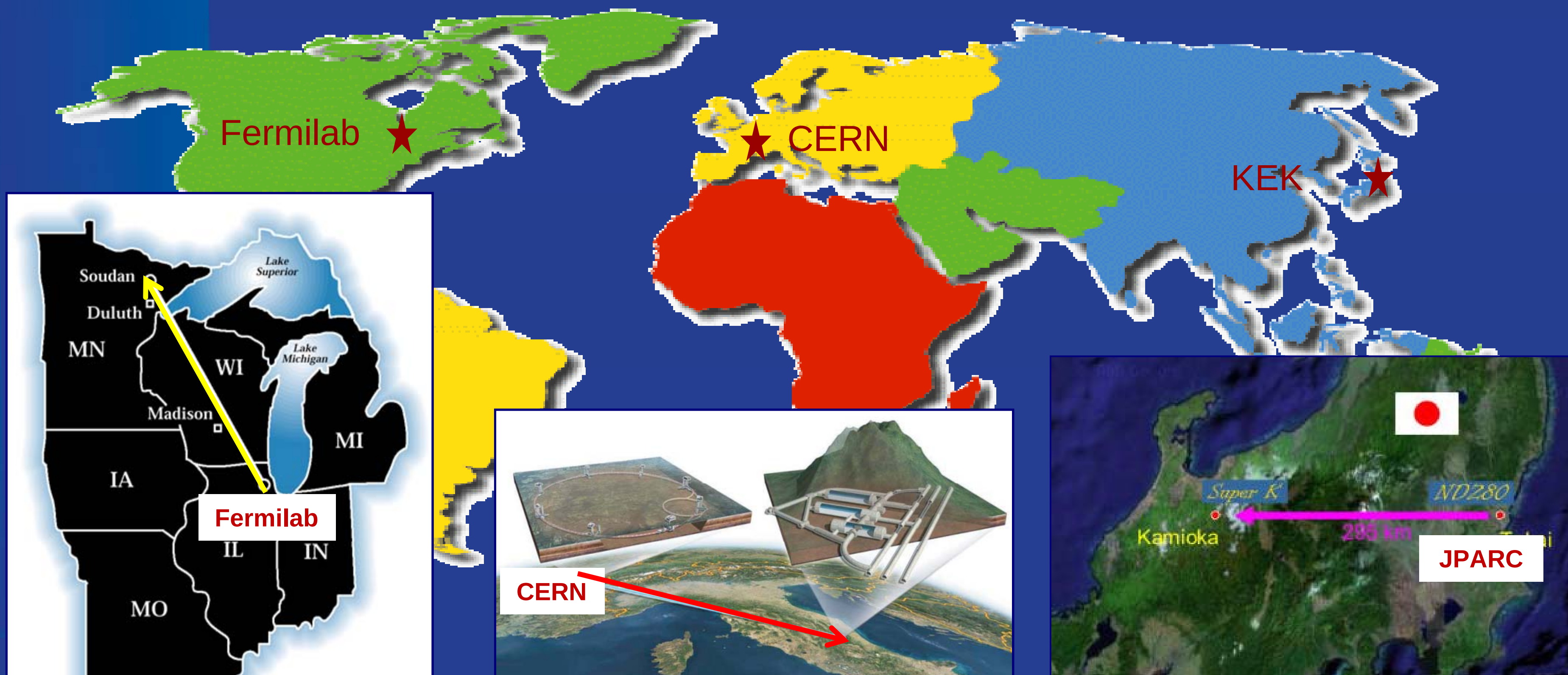
Intensity Frontier: Neutrino Beams



Fermilab → Soudan (735km)
Ash river(810km)
300 kW → 700 kW

MINOS, MINERvA, MiniBooNE
NOvA

CERN → Gran Sasso (732km)

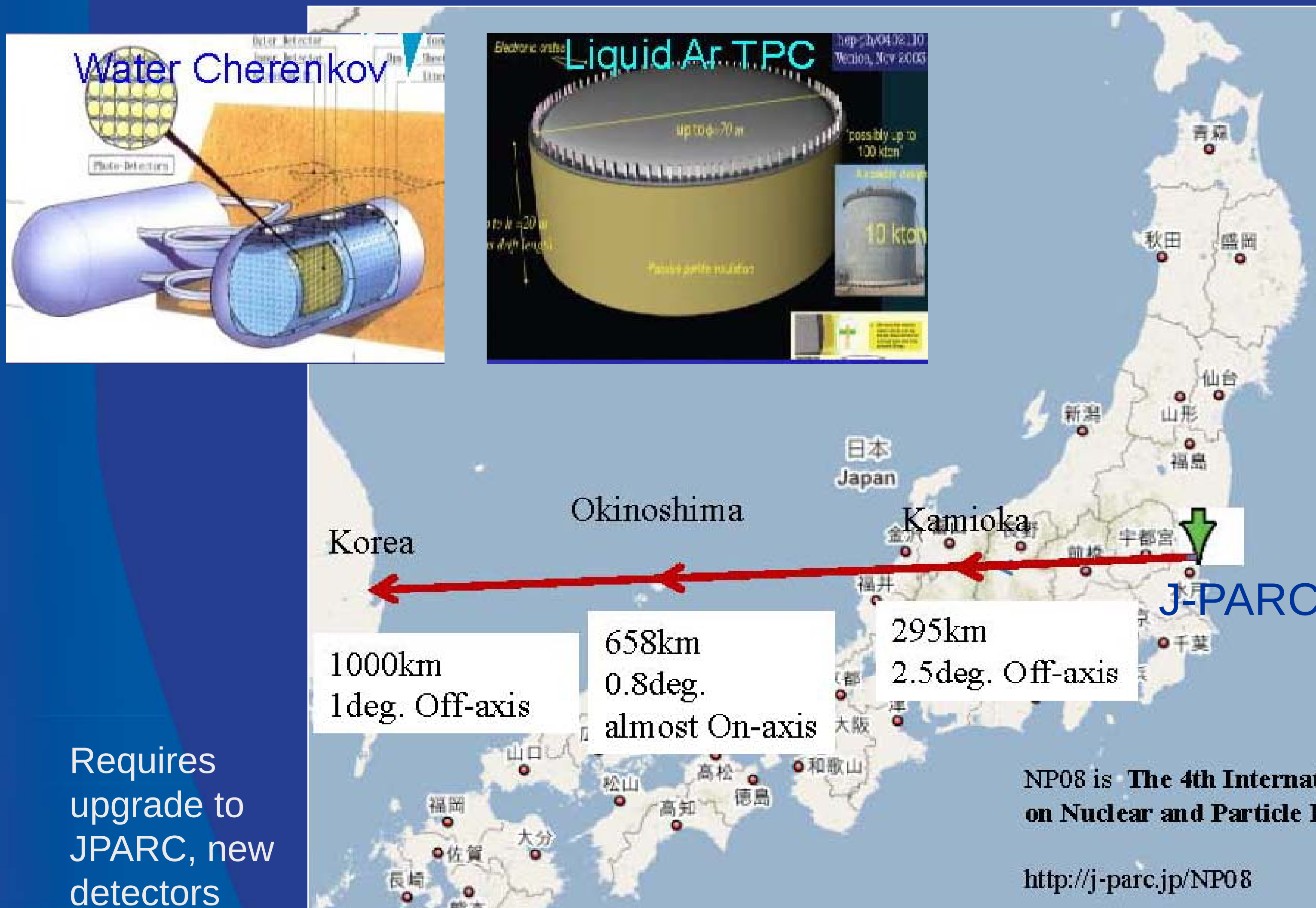
OPERA

J-PARC → Kamioka (295km)

50 kW → 100 kW (→ 750 kW)

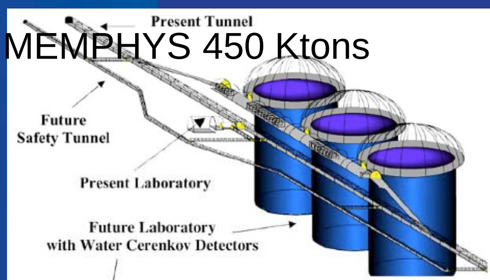
T2K

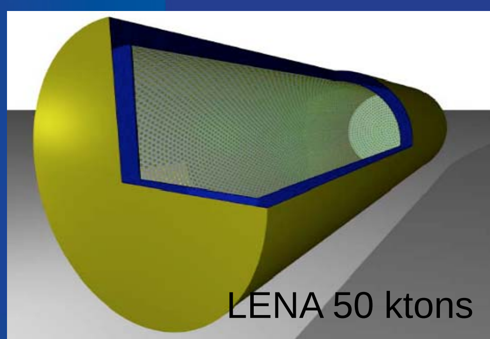
Comparative situation: Asia

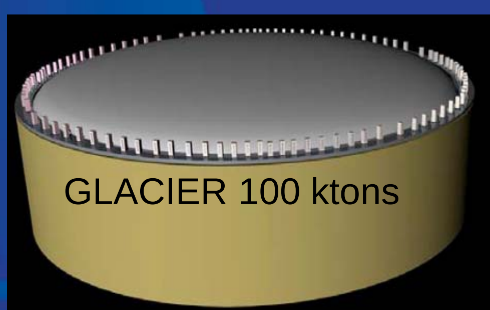


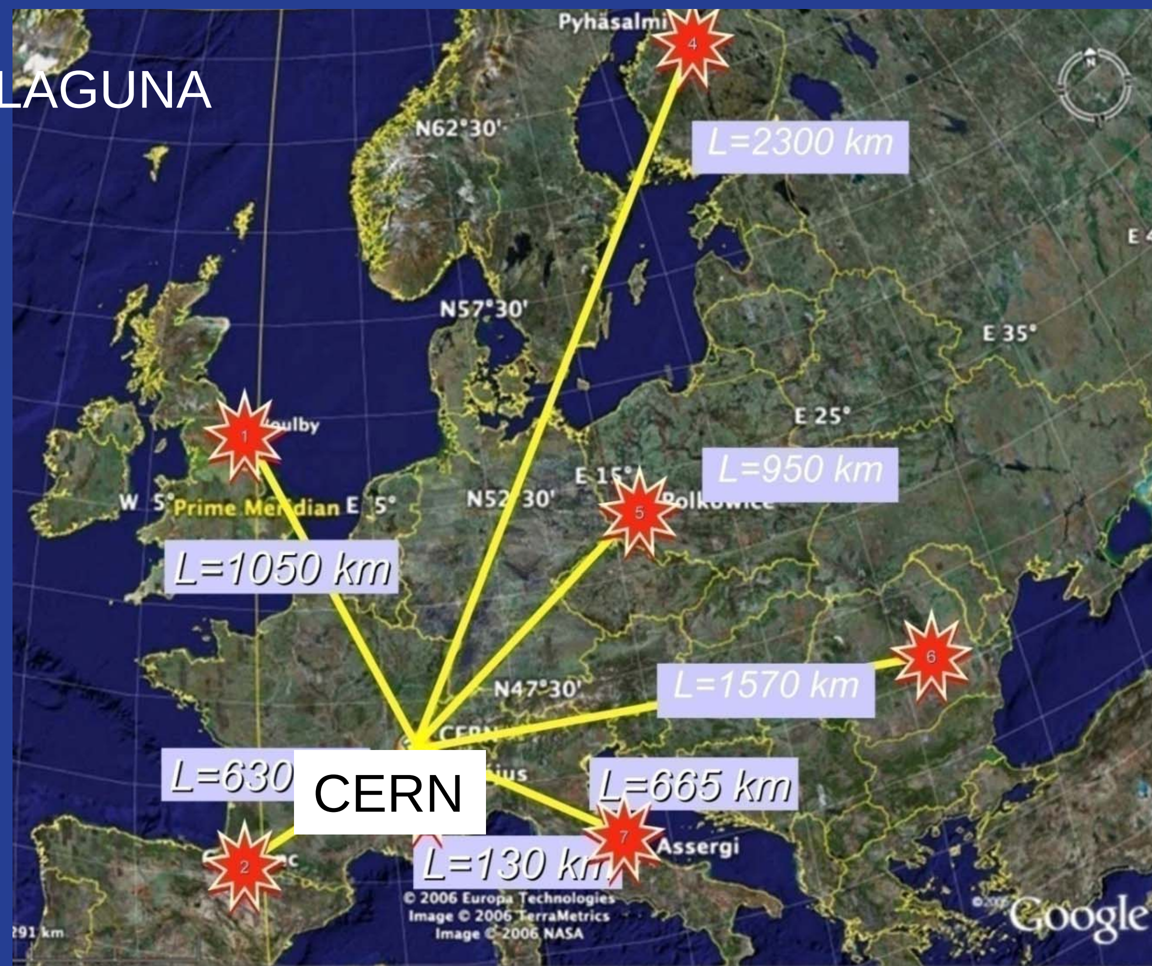
Requires upgrade to JPARC, new detectors

Comparative situation: Europe





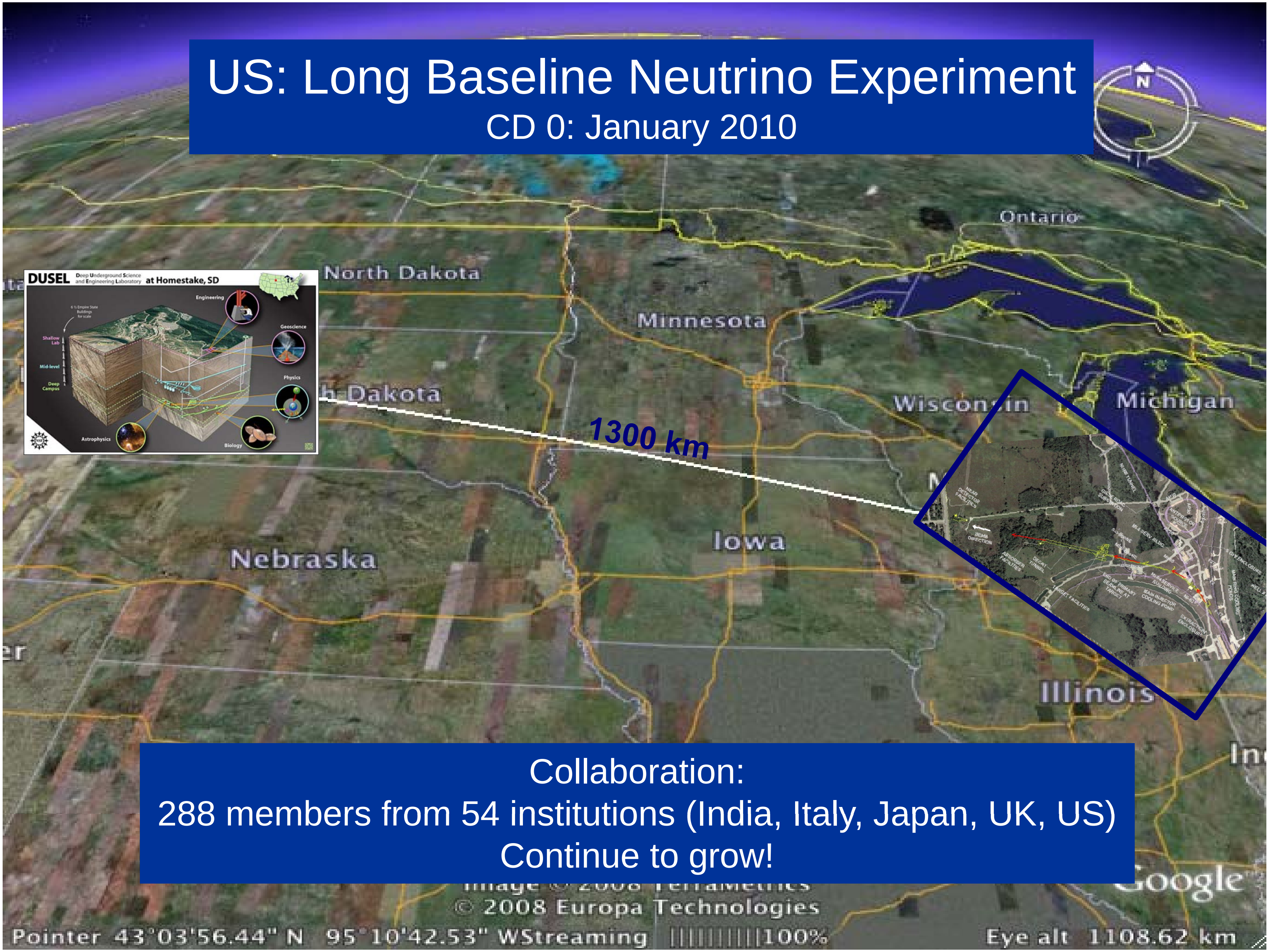




Reuires Project X and new synchrotron at CERN

US: Long Baseline Neutrino Experiment

CD 0: January 2010

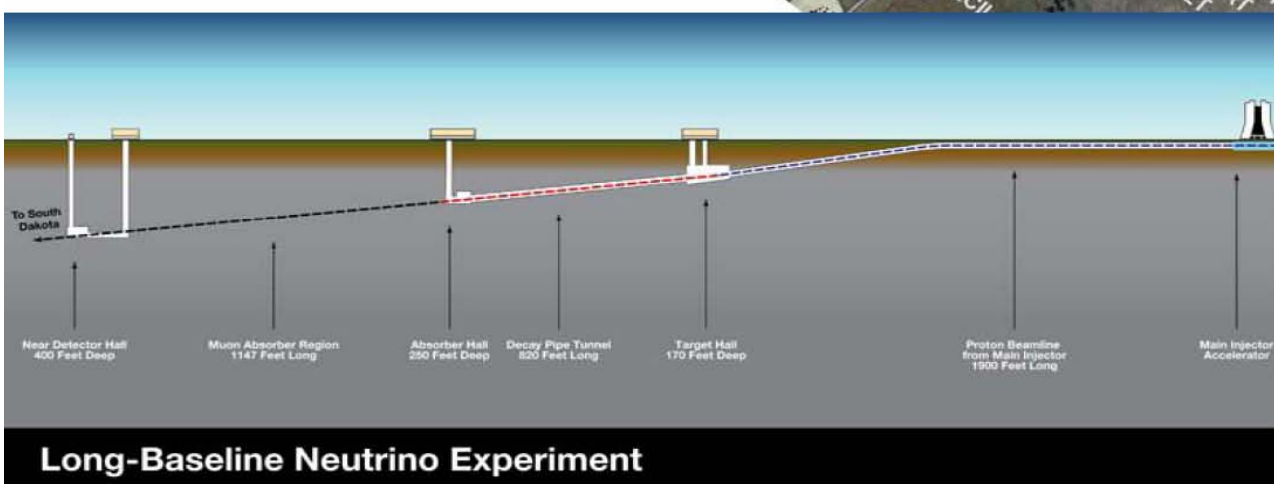


Collaboration:

288 members from 54 institutions (India, Italy, Japan, UK, US)

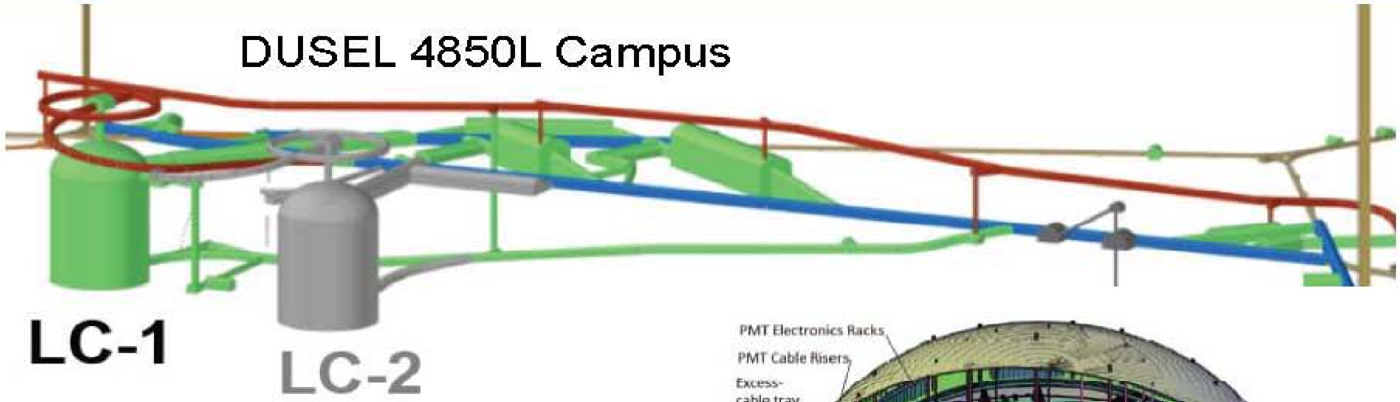
Continue to grow!

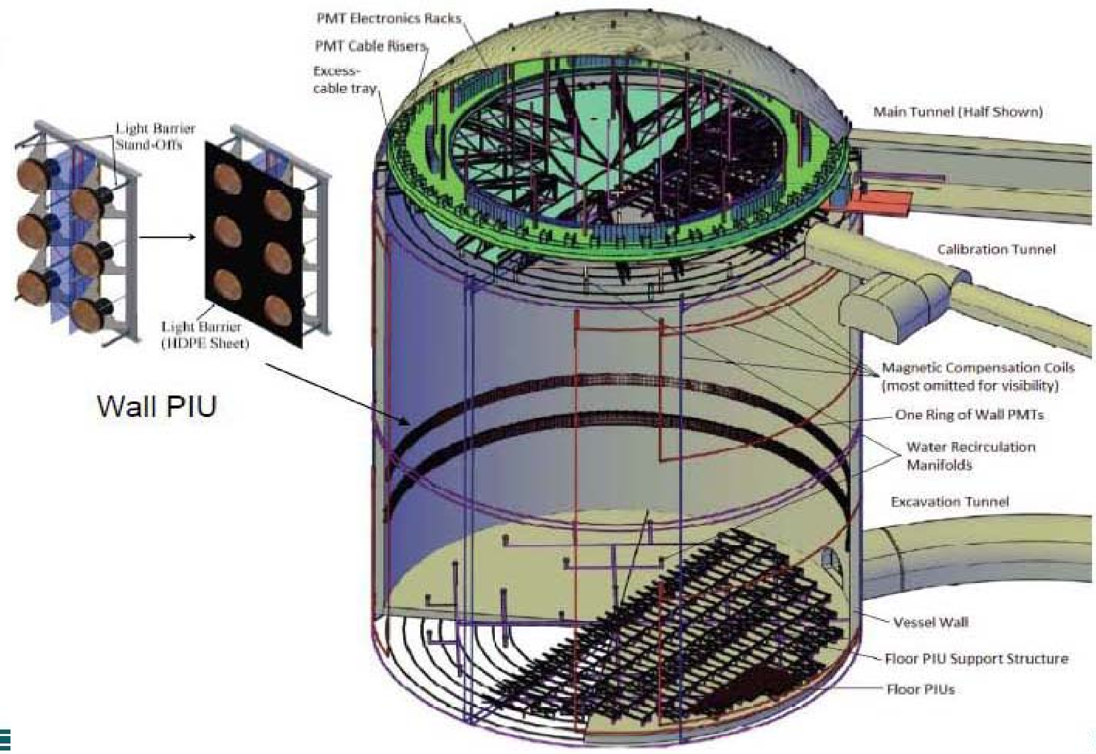
Conceptual Design Overview – Neutrino Beam



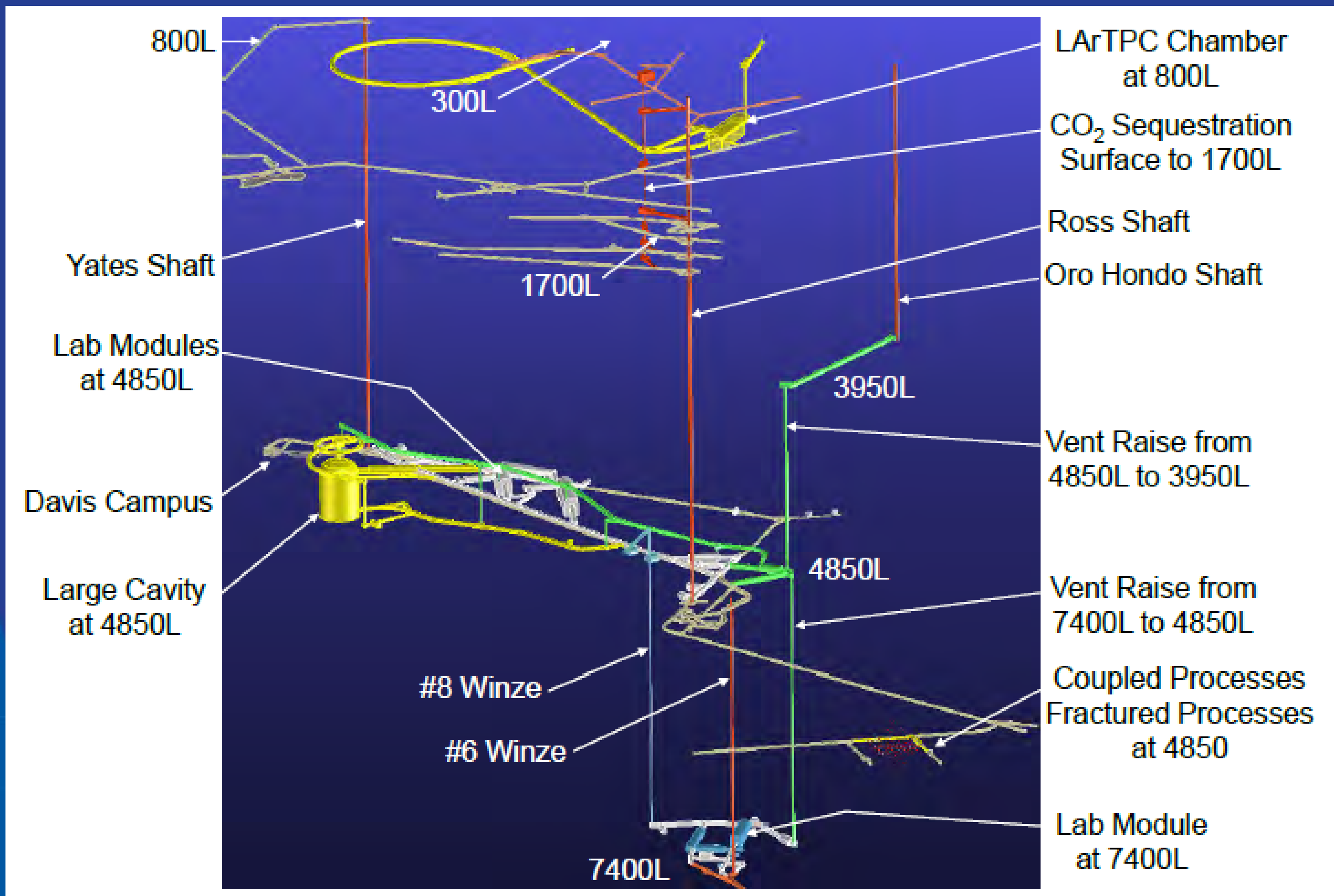
Conceptual Design Overview – Water Cherenkov

DUSEL 4850L Campus



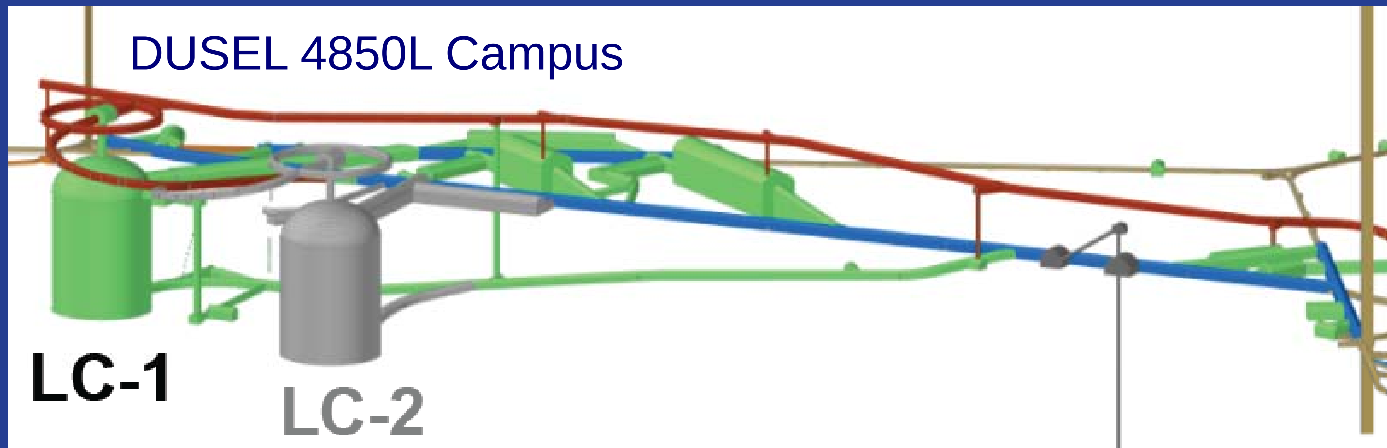


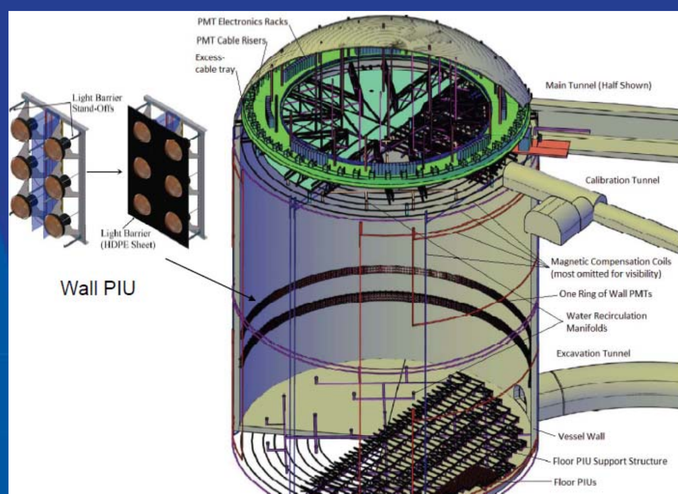
DUSEL Lab Layout



Fermilab

Far detector: Water Cherenkov at 4850L

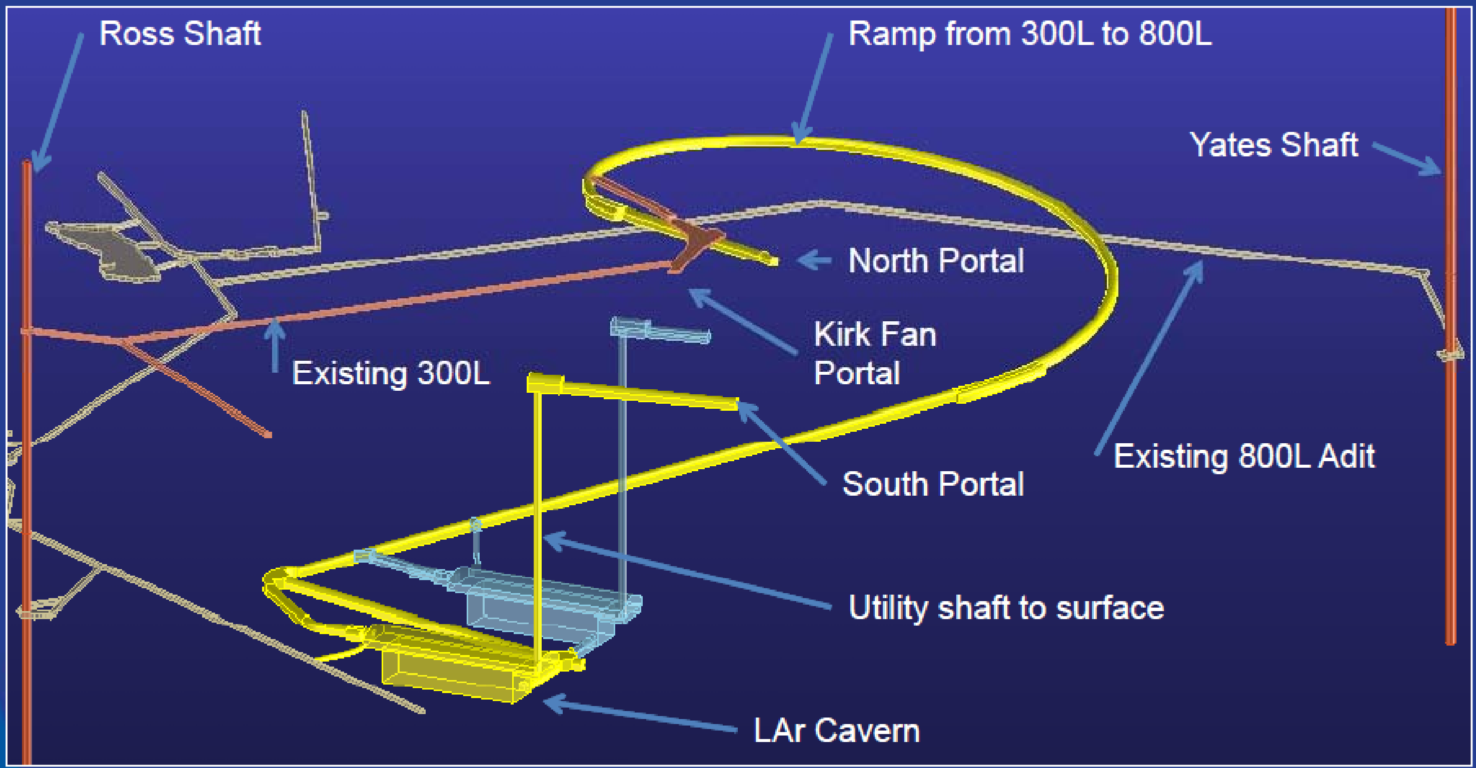




Fiducial mass for each: 100 kton

Proton decay limit > 6×10^{34} years for $e^{+}\pi^{\circ}$ final state in 10 years

Far detector: LAr TPC at 800L

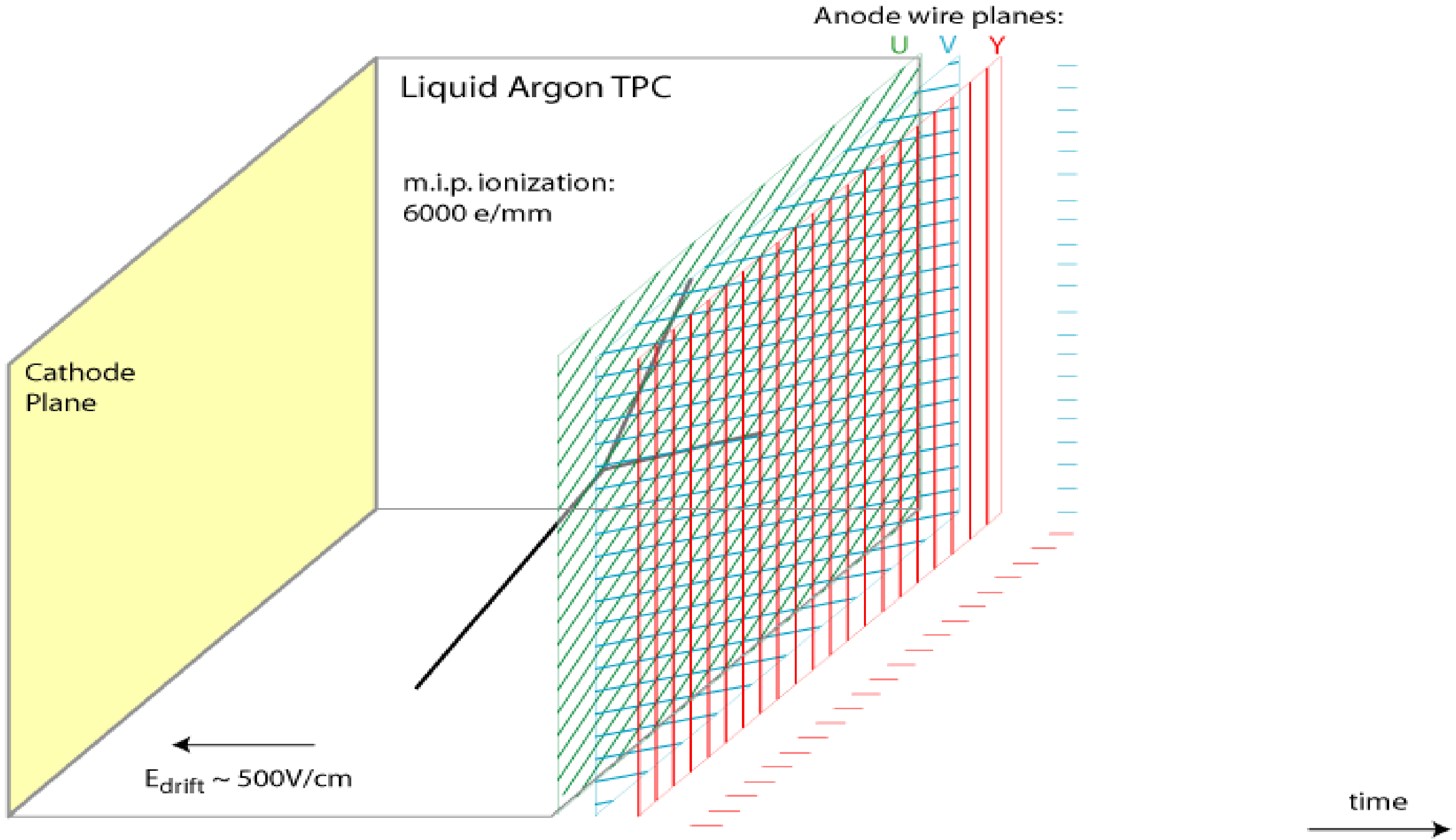


(Fiducial mass for each: 17 kton)

LAr TPC in 800L facility with cosmic ray veto to enable proton decay ($K^+\nu$) search.

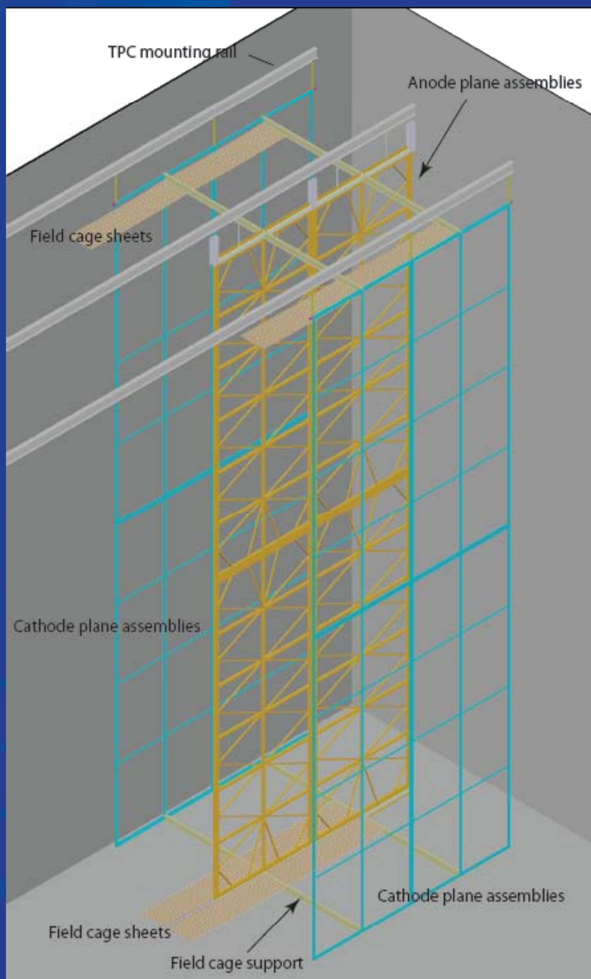
Proton decay limit > 3×10^{34} years for $K^+\nu$ final state in 10 years

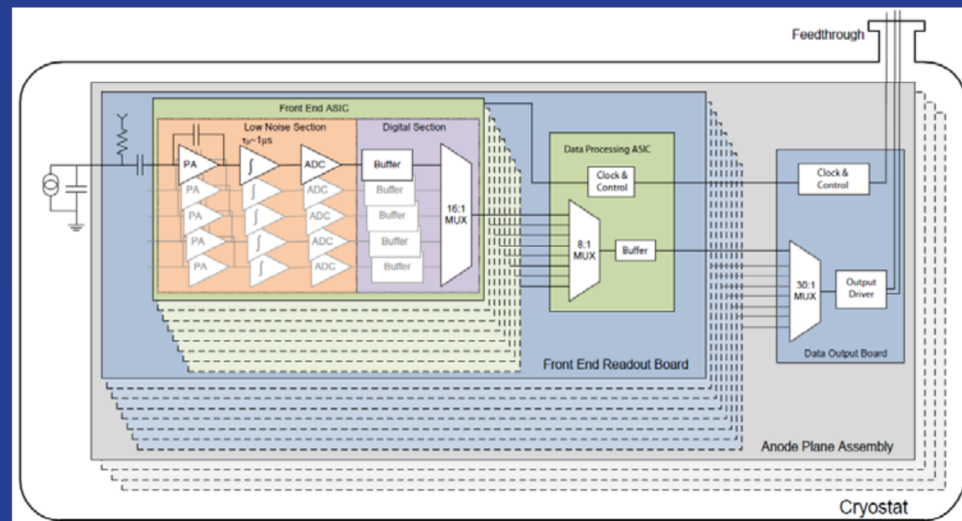
LAr TPC is a great choice



Need extremely good LAr purity, low convective flow

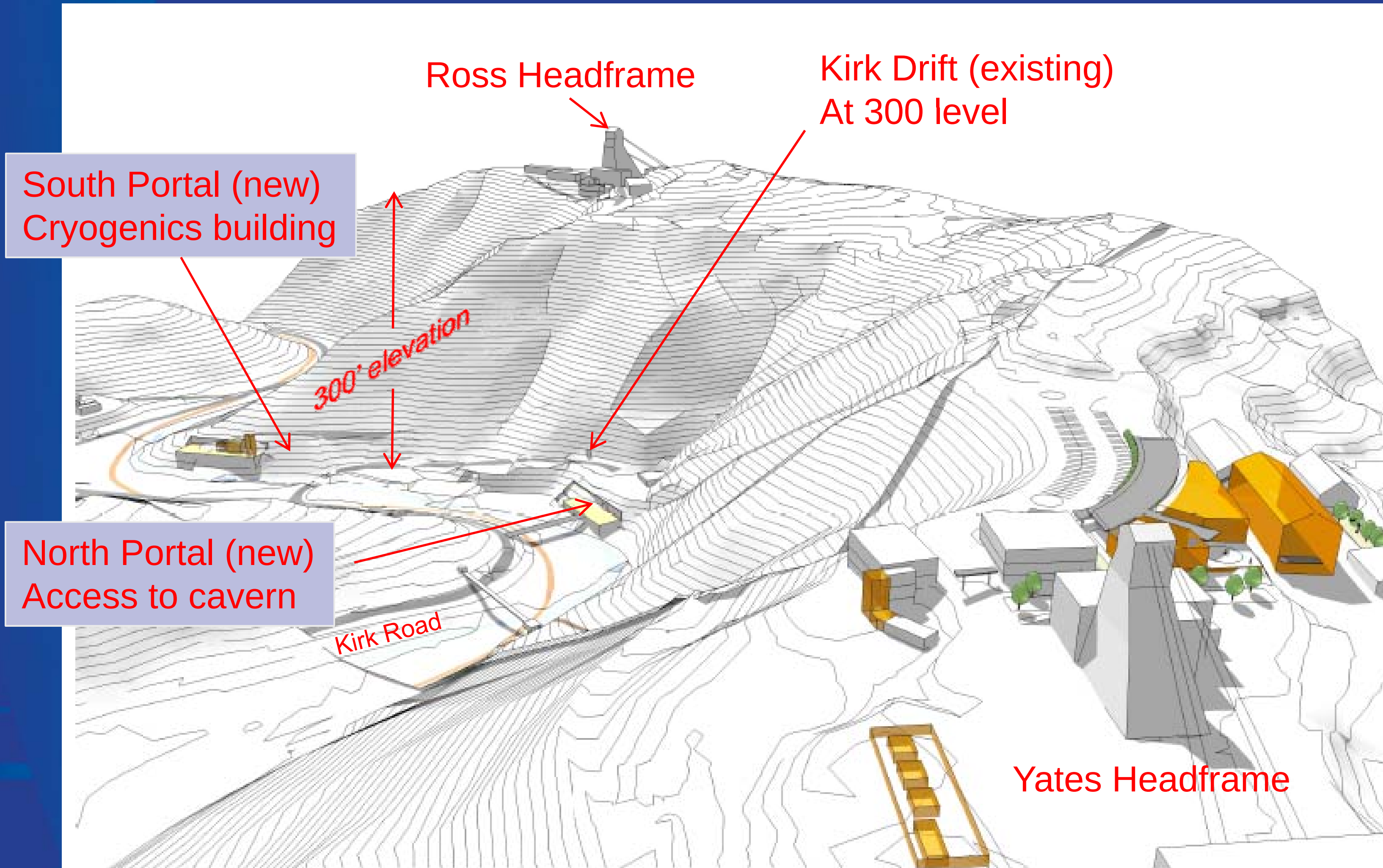
Time Projection Chamber (TPC)





168 APAs (each 250kg, 3840 chan)
224 CPAs (each 100kg, HV @125 kV)
Field cage
Cryogenic ASIC electronics
Power, signal cables, feedthroughs, HV

Facility Overview: LAr TPCs

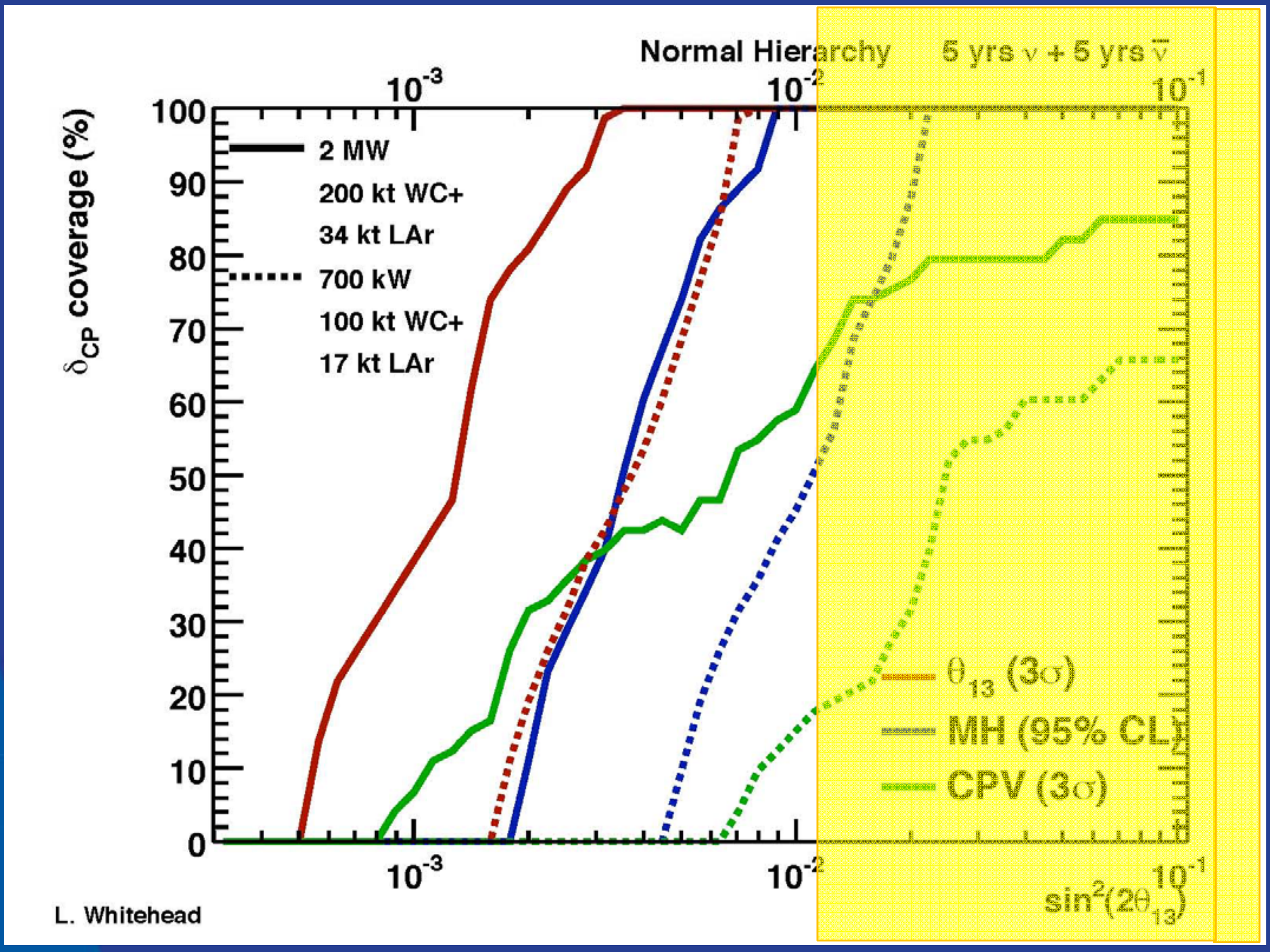


Various configurations: scorecard

#	Detector configuration	LBP	PDK		SNB	SRN	Atm	Sol
			$e\pi$	$K\nu$				
1	Three 100 kt WC, 15%	A1	C2	D4	B3	D4	B1	D3
1a	Three 100 kt WC, 30%	A1	C2	C3	B3	C4	B1	B1
1b	Three 100 kt WC, 30% with Gd	A1	B1	B2	B3	A1	B1	B1
2	Three 17kt LAr, 4850′, γ trig	A1	E5	A1	B4	E5	B1	E5
2a	Three 17kt LAr, 300′, no γ trig	A1	E5	A2	B4	E5	B1	E5
2b	Three 17kt, LAr, 800′, γ trig	A1	E5	A2	B4	E5	B1	E5
3	Two 100 kt WC, 15% + One 17 kt LAr, 300′, no γ trig	A1	D4	B4	A2	D4	B3	D3
3a	Two 100 kt WC, 30% + One 17 kt LAr, 300′, no γ trig	A1	D3	B4	A1	D4	B3	C2
3b	One 100 kt WC, 15% + One 100 kt WC, 30% & Gd + One 17 kt LAr, 300′, no γ trig	A1	C3	B3	A1	B2	B3	C2
4	Two 100 kt WC, 15% + One 17 kt LAr, 800′, γ trig	A1	D4	B4	A2	D4	B2	D3
4a	Two 100 kt WC, 30% + One 17 kt LAr, 800′, γ trig	A1	D3	B4	A1	D4	B2	C2
4b	One 100 kt WC, 15% + One 100 kt WC, 30% & Gd + One 17 kt LAr, 800′, γ trig	A1	C3	B3	A1	B2	B2	C2
5	One 100 kt WC, 30% & Gd + Two 17 kt LAr, 300′, no γ trig	A1	D4	A2	B2	B3	B3	C2
6	One 100 kt WC, 30% & Gd + Two 17 kt LAr, 800′, γ trig	A1	D4	A2	B2	B3	B2	C2

TABLE XXIX. Summary of the relative impact of the reference far detector configurations on the measurement sensitivity. Only topics where LBNE will make a competitive measurement are included. The entries consist of two parts: 1) a letter from A-E indicating the impact of the LBNE measurement made possible by a particular configuration as compared to the [expected] state of world knowledge, and 2) the relative ranking of the different configurations for the physics topic of interest. Highlighted boxes indicate the preferred option for that topic.

Neutrino physics sensitivities



With Project X

Fermilab