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Justin Evans
University of Manchester

The US long baseline neutrino programme

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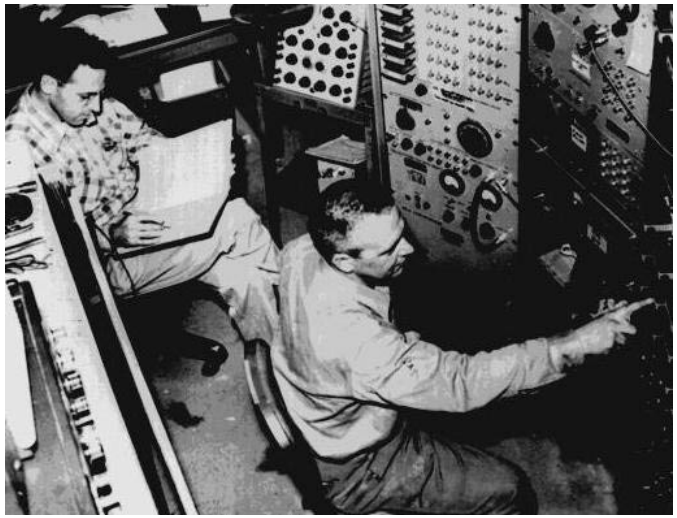
US neutrino physics highlights

Discovery of the neutrino



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US neutrino physics highlights

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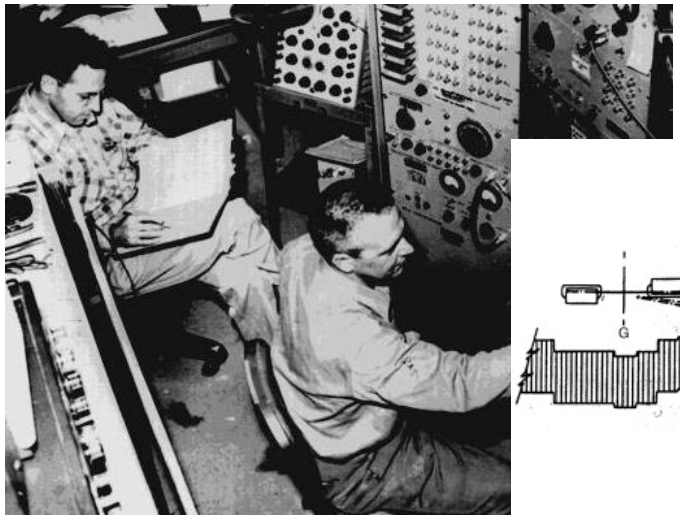
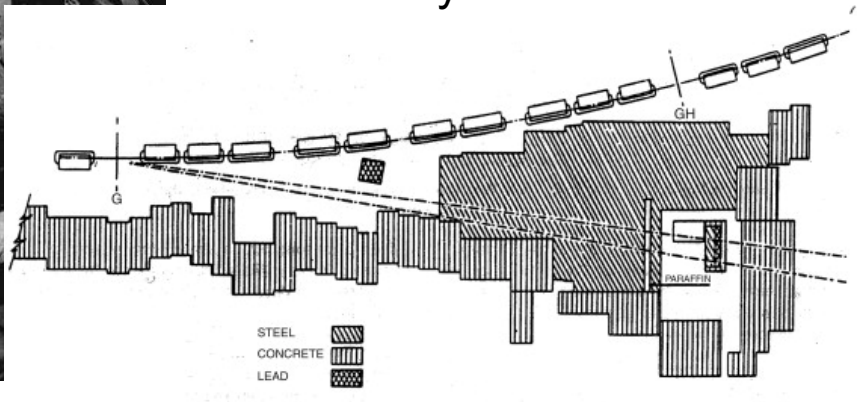


Discovery of muon neutrino



US neutrino physics highlights

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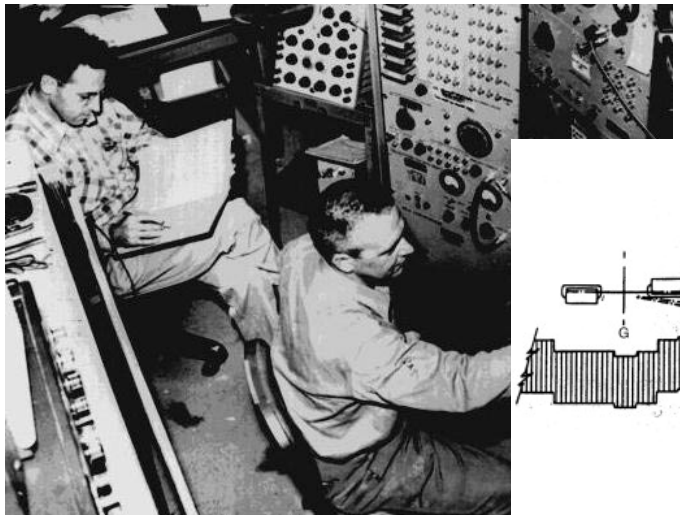
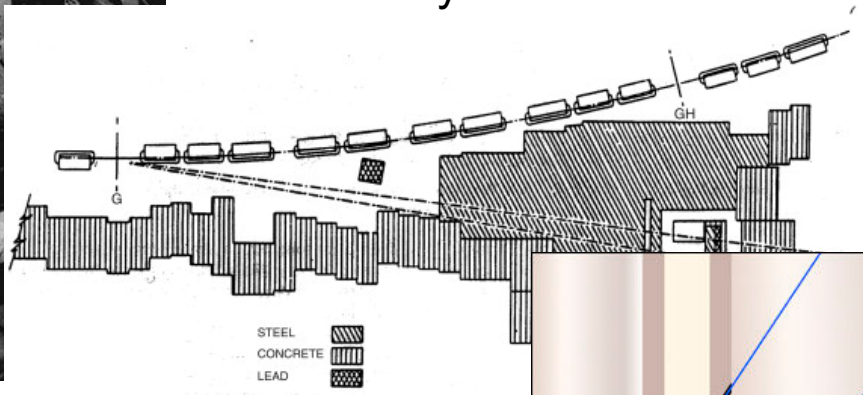
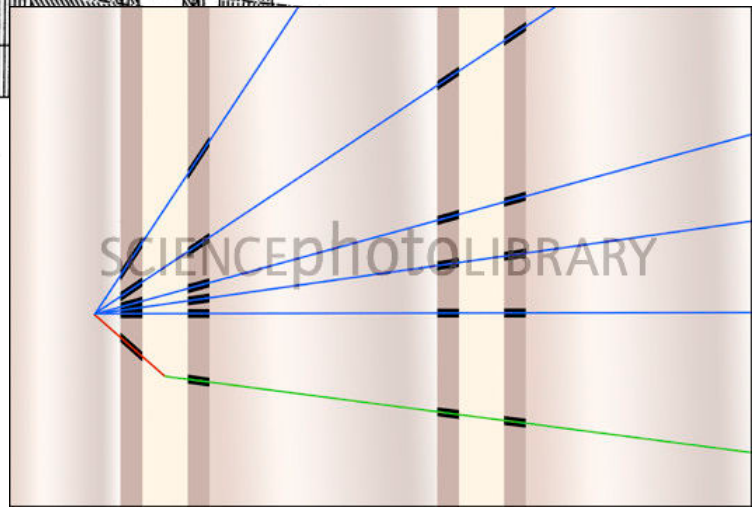


Discovery of muon neutrino

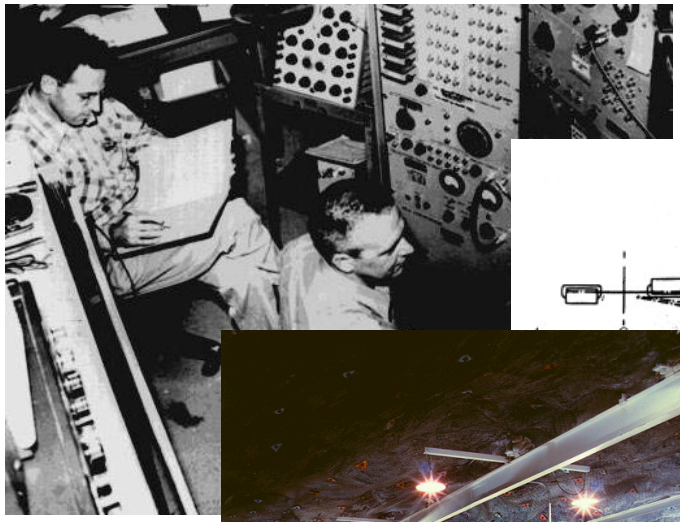




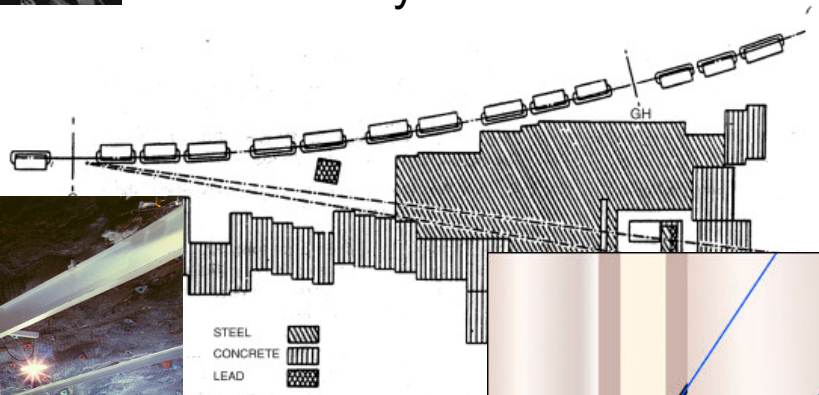
Discovery of tau neutrino

US neutrino physics highlights

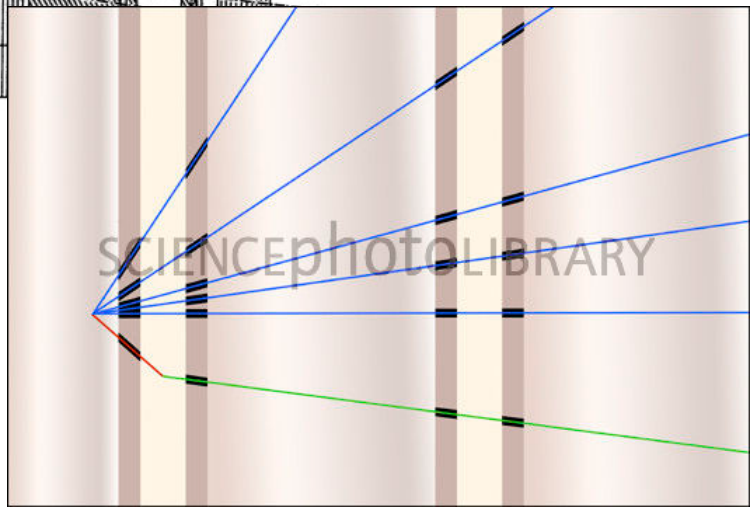
Discovery of the neutrino



Discovery of muon neutrino



Solar neutrino disappearance



Discovery of tau neutrino

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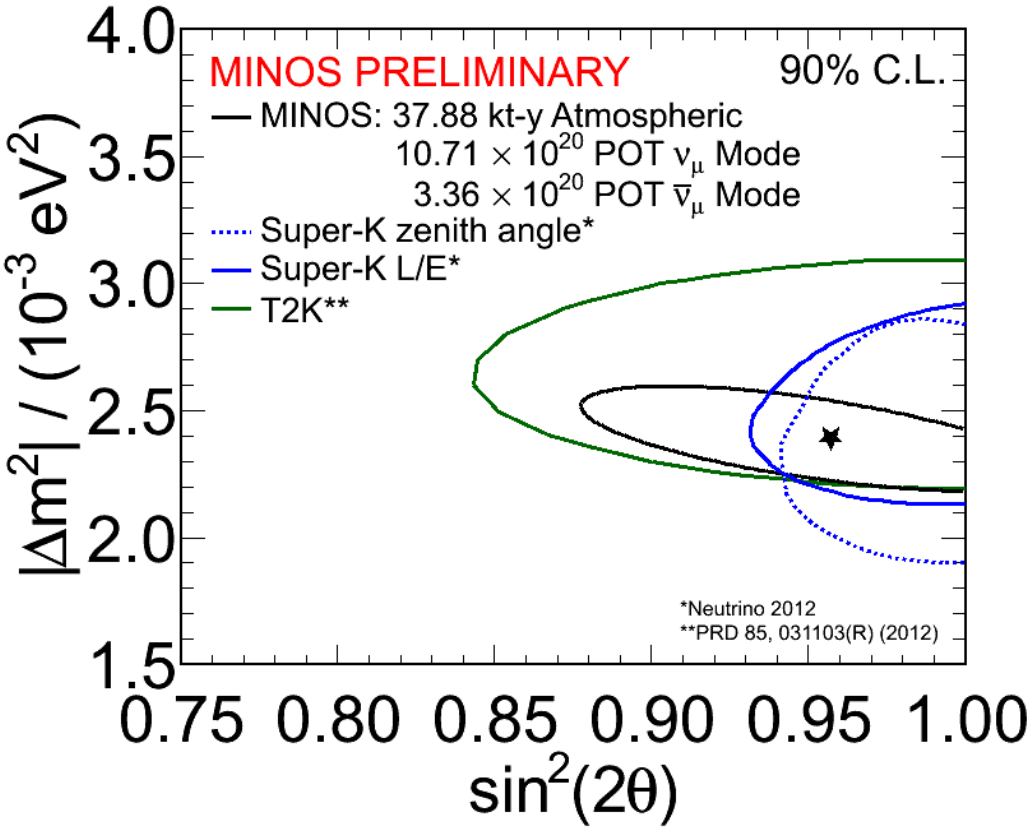
Recent neutrino physics: MINOS



World's most precise measurement of largest neutrino mass splitting

First precision measurements of the antineutrino mass splitting

Probing θ_{13}

Searches for sterile neutrinos

Strong UK involvement

- Cambridge, Manchester, Oxford, (RAL), Sussex, UCL

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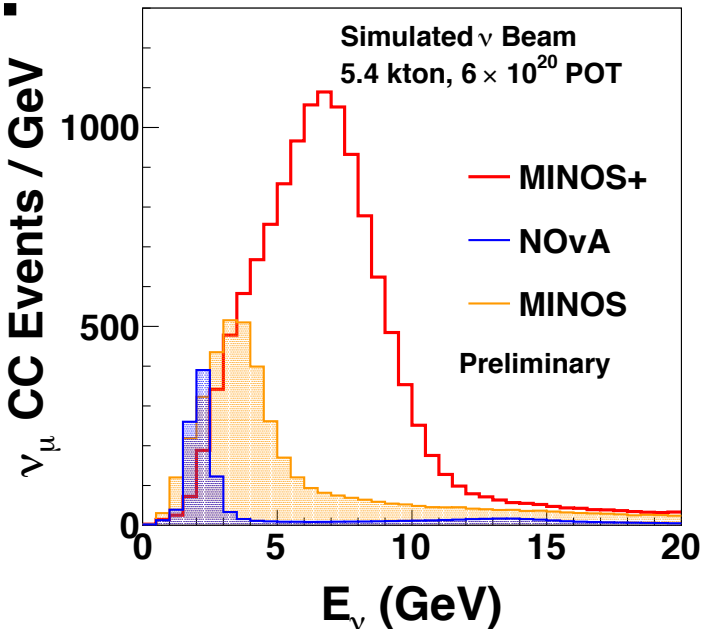
The near future: MINOS+

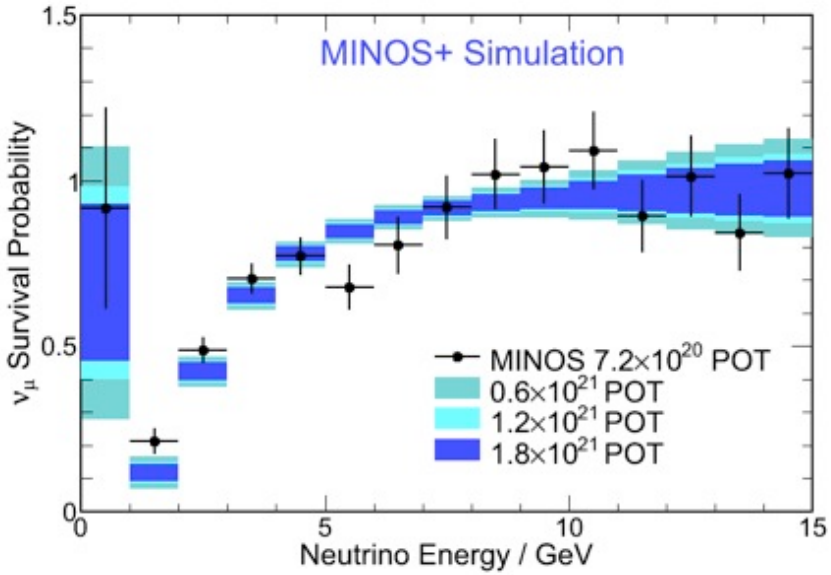
NuMI beam is being upgraded in energy and intensity

- Will restart in 2013

Expect ~4000 ν_μ CC events per year in the Far Detector

Offers a unique high precision test of the three flavour oscillation paradigm





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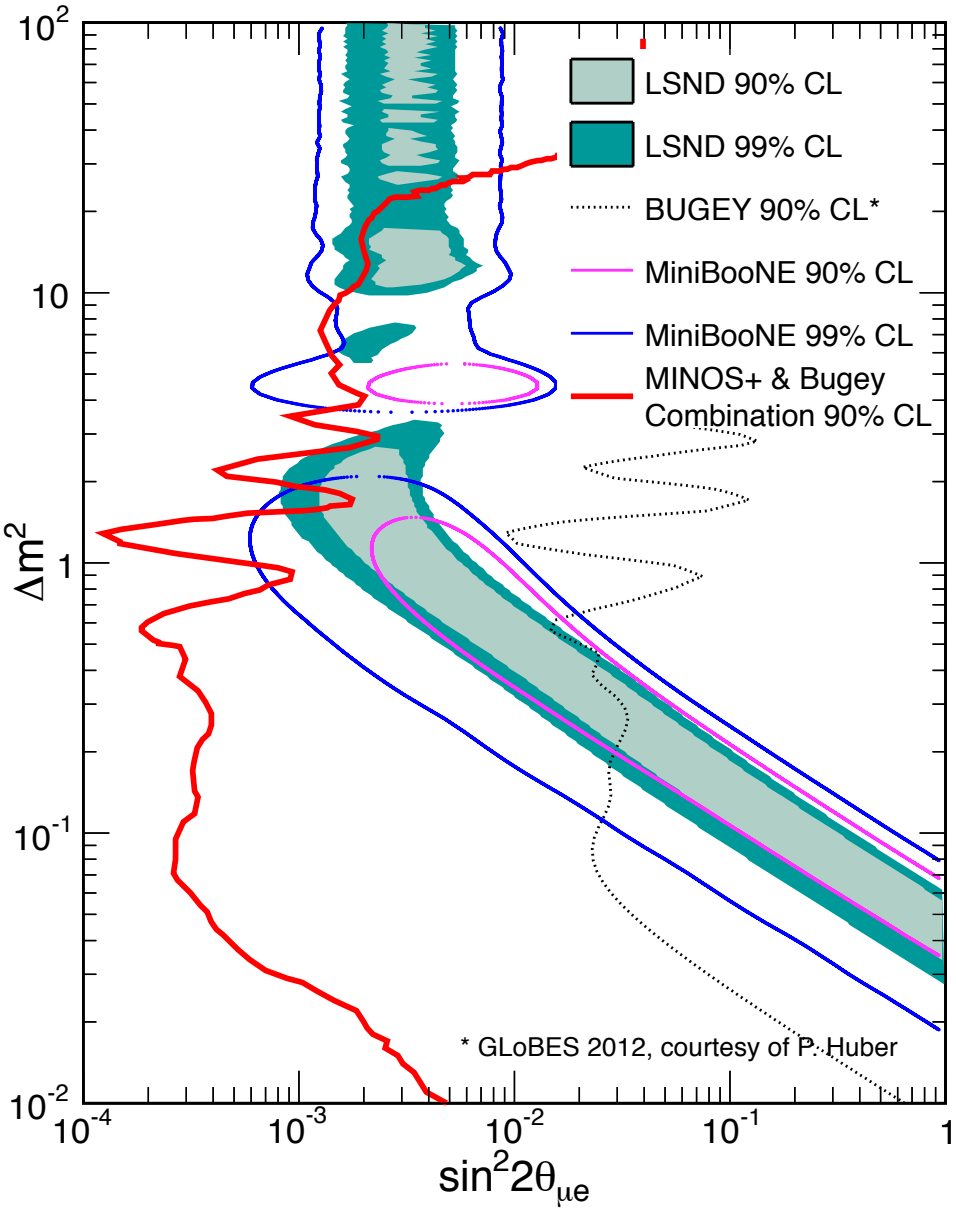
MINOS+ sterile neutrinos

- In combination with sterile neutrino searches from Bugey reactor experiment, MINOS+ can rule out most of the low mass LSND region



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The near future: NOνA

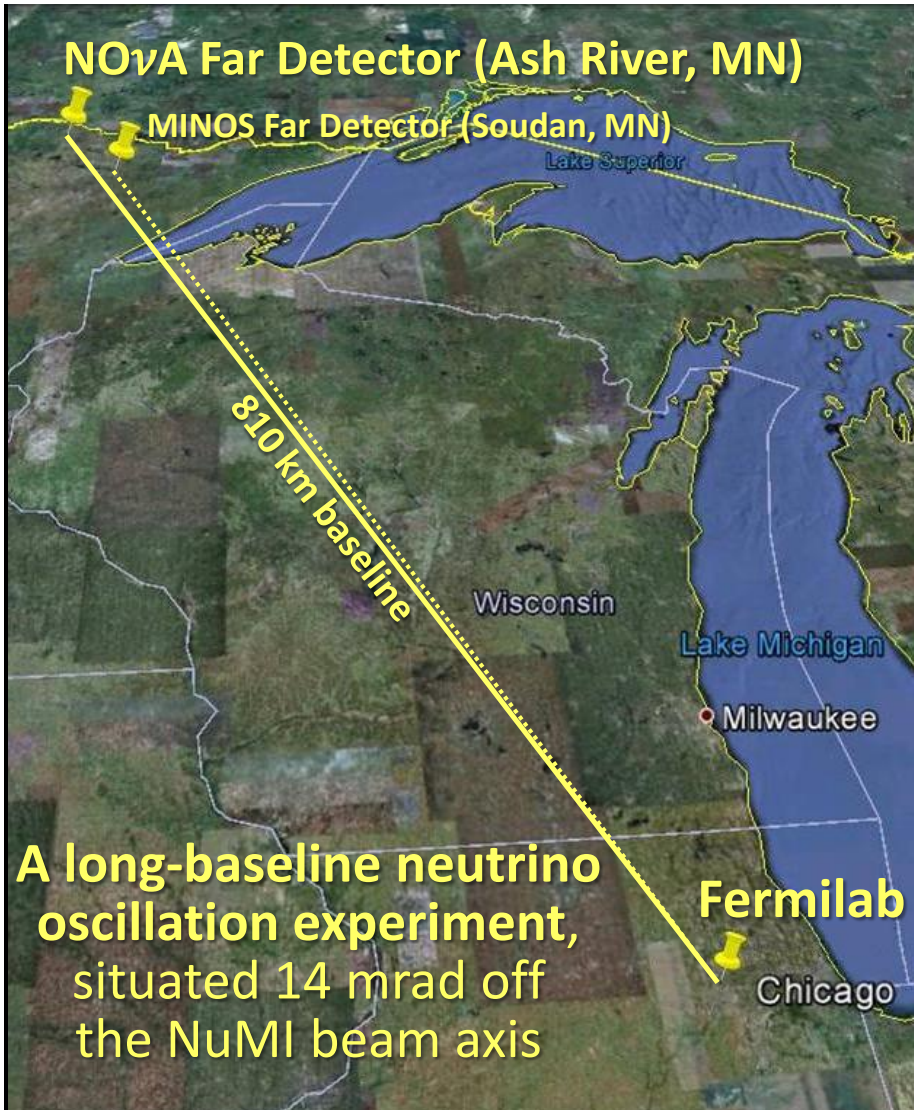
77% active, low-Z liquid scintillator detector

Upgraded NuMI beam

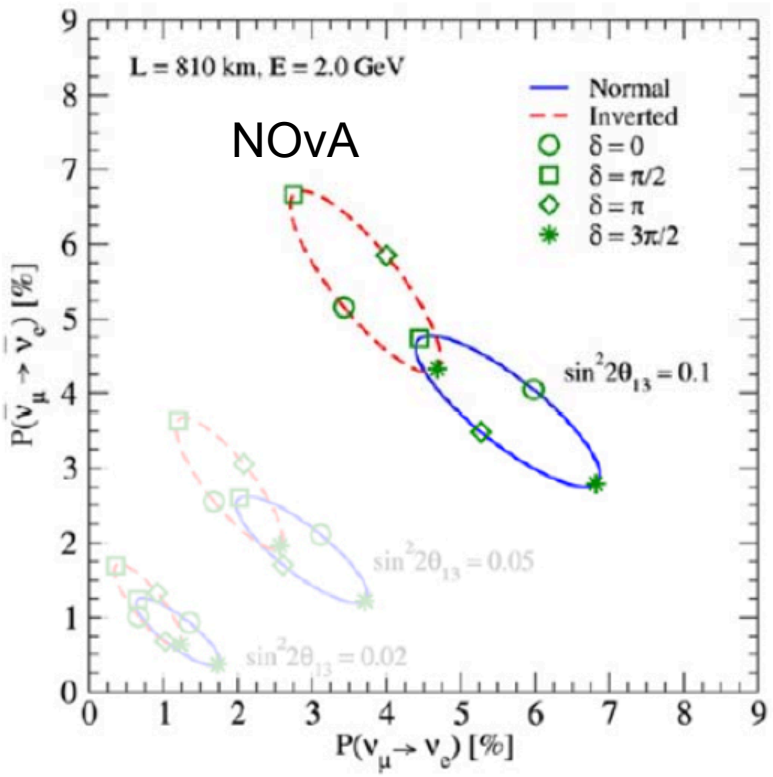
- 810 km baseline, off-axis

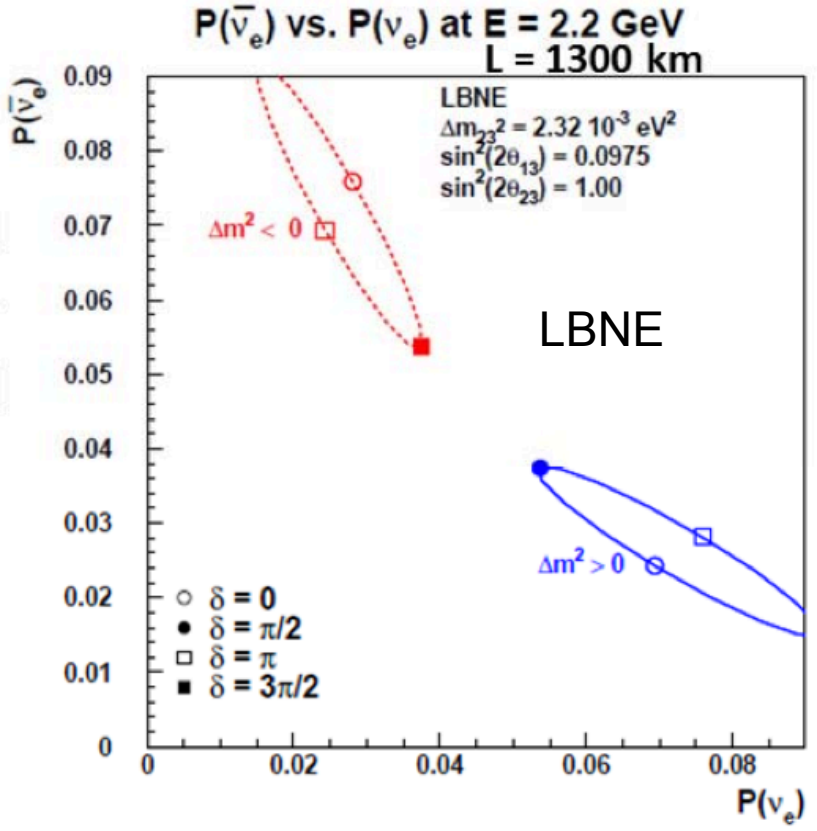
$\nu_\mu \rightarrow \nu_e$, $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$

- Measure θ_{13}
- Possibly determine the ν mass hierarchy
- Search for CP violation
- Determine the θ_{23} octant



Beyond NOvA: LBNE





Increase the baseline from 810 km to 1300 km

- Increased matter effect allows mass hierarchy determination
- Baseline is short enough that CP-violating effects can still be observed

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Liquid Argon TPC development

Next major technological revolution in neutrino physics

- Millimetre-scale spatial resolution over kiloton masses

Fermilab has a coherent, staged LAr R&D programme

Building on the experience from ArgoNeut

- In the NuMI beam

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Liquid Argon Purity Demonstrator

Primary aim is to demonstrate that required electron lifetimes can be achieved without evacuation

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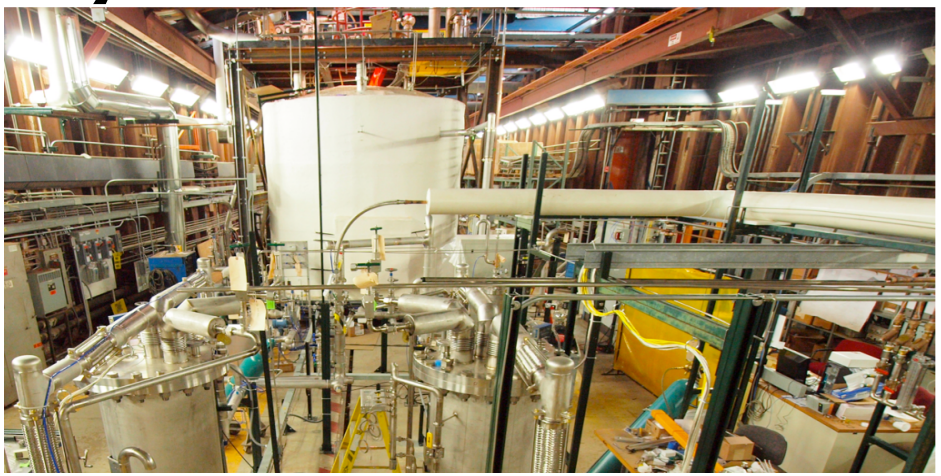
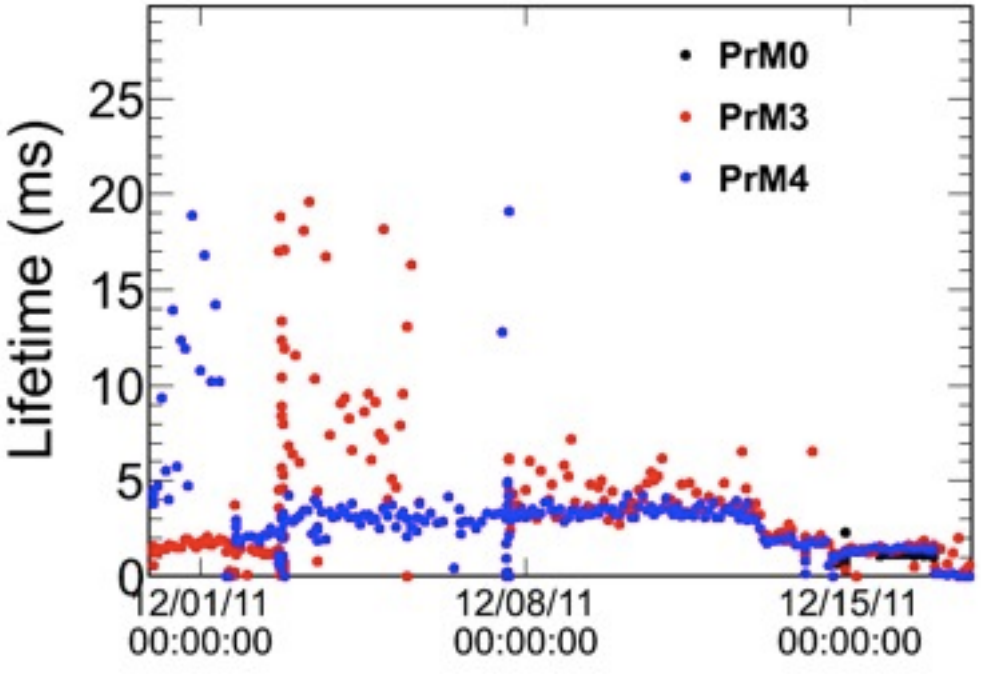
Liquid Argon Purity Demonstrator

Primary aim is to demonstrate that required electron lifetimes can be achieved without evacuation

In its first runs this spring, electron lifetimes of 3 ms or better were achieved in an empty vessel (30 t)

- LBNE requires 1.5 ms





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Liquid Argon Purity Demonstrator

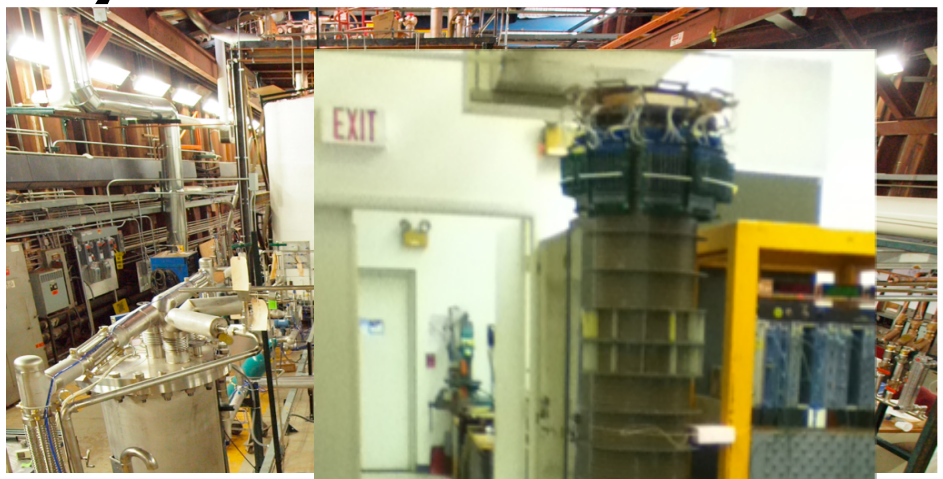
Primary aim is to demonstrate that required electron lifetimes can be achieved without evacuation

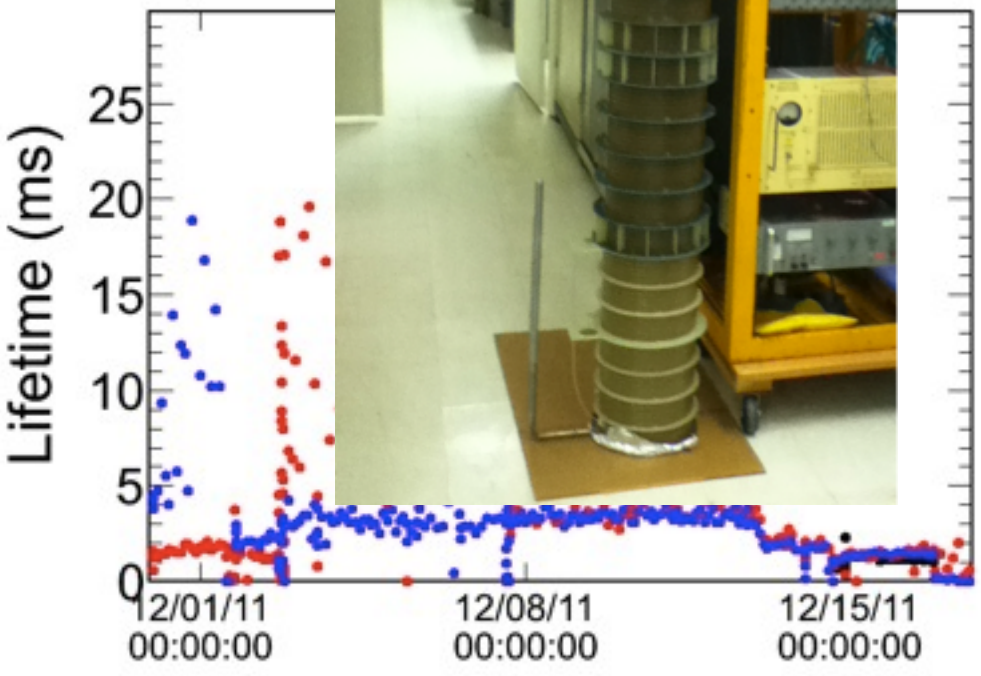
In its first runs this spring, electron lifetimes of 3 ms or better were achieved in an empty vessel (30 t)

- LBNE requires 1.5 ms

A TPC is about to be installed in the volume

- LongBo: 2 m drift





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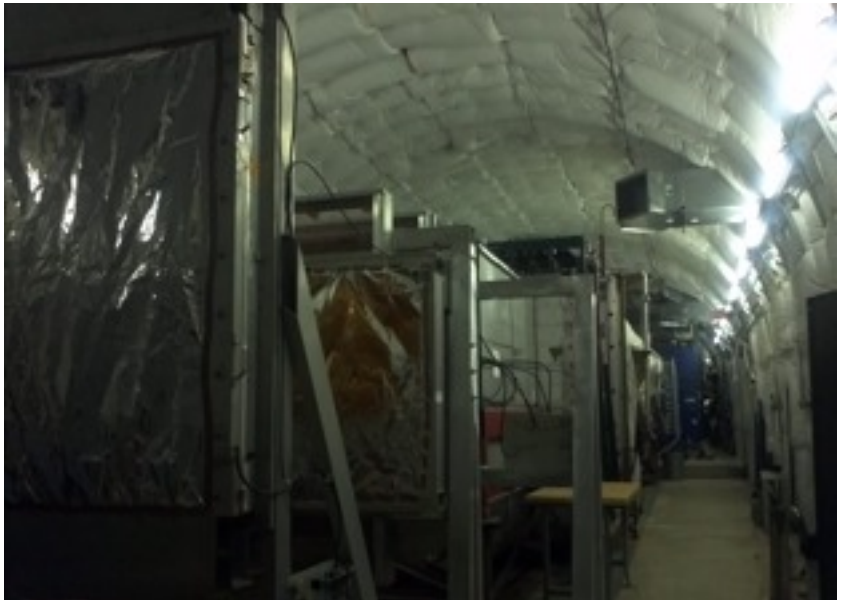
LArIAT



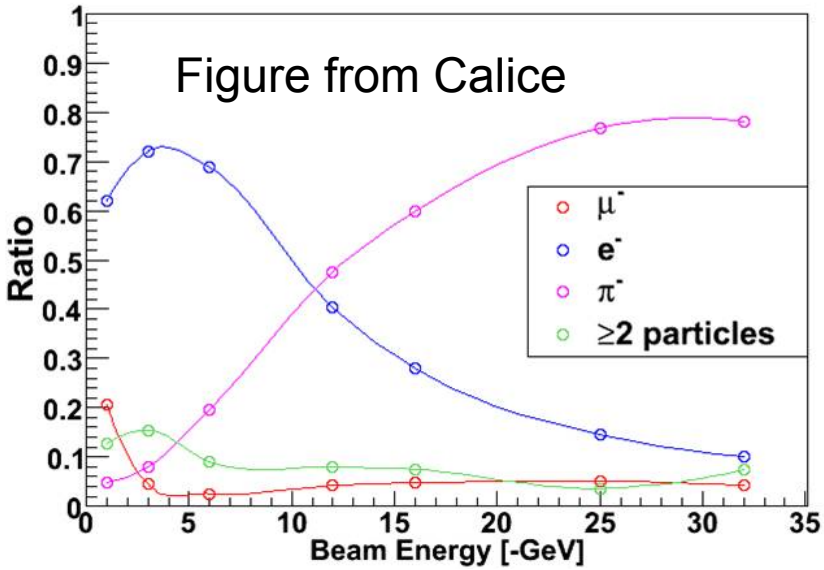
Liquid Argon In A Test beam

- Place a 5m x 1.5 m TPC in the Fermilab test beam facility

Characterise the response of a LArTPC to the particles and energies expected in neutrino interactions

- e, p, π, μ

- EM shower resolution
- Hadronic shower resolution
- Particle ID
- dE/dx
- Light collection efficiencies
- …



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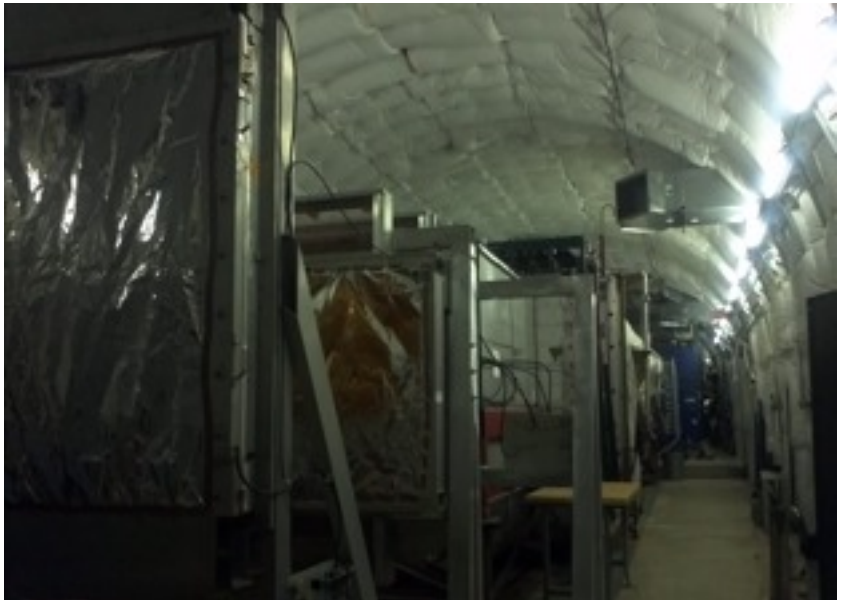
LArIAT

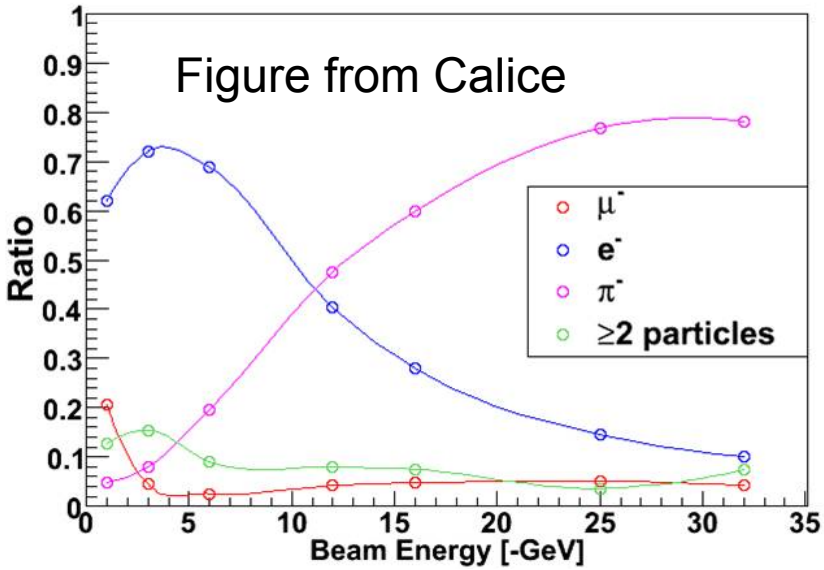


LArIAT will produce a dataset that is invaluable for all future LArTPC projects

Fermilab will provide facilities and cryostat, university groups will provide the active detector

UK involvement

- Imperial, Manchester, UCL
- Simulation, DAQ



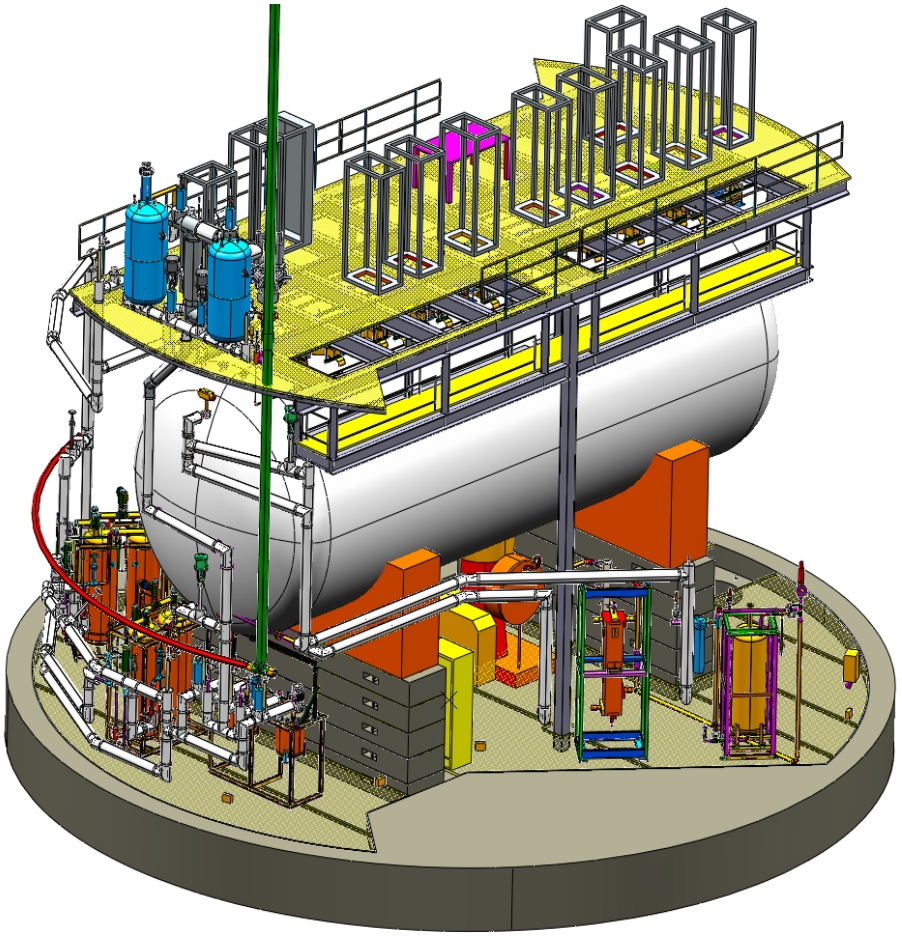
MicroBooNE

100 ton LAr TPC

- 60 tons fiducial
- 30 PMTs

Placed in front of MiniBooNE

- 470 m baseline



MicroBooNE

100 ton LAr TPC

- 60 tons fiducial
- 30 PMTs

Placed in front of MiniBooNE

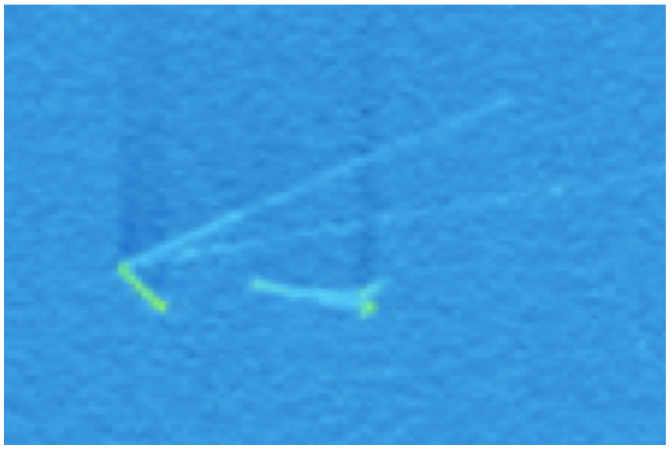
- 470 m baseline

Investigate the MiniBooNE low-energy excess

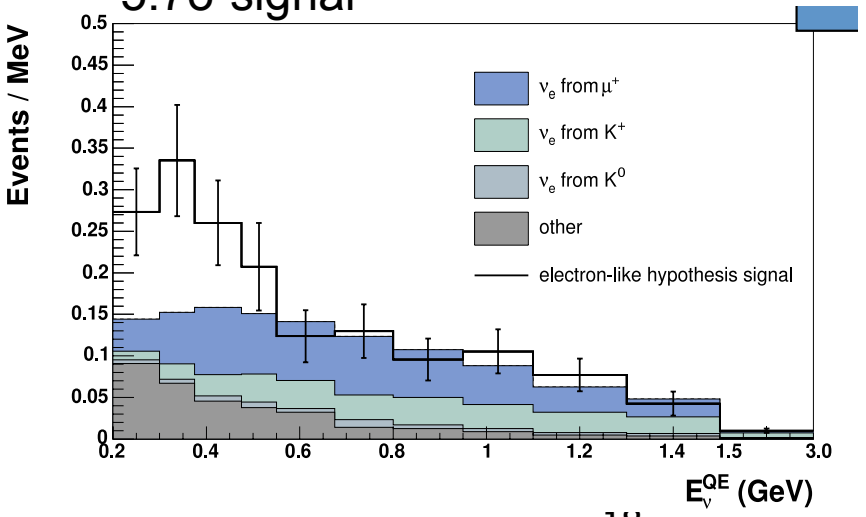
- Clear photon-electron separation

TPC is under construction

- Data-taking will begin in early 2014



Electron hypothesis for MiniBooNE: 5.7σ signal



LAr1

1 kt liquid argon TPC

- Membrane cryostat technology

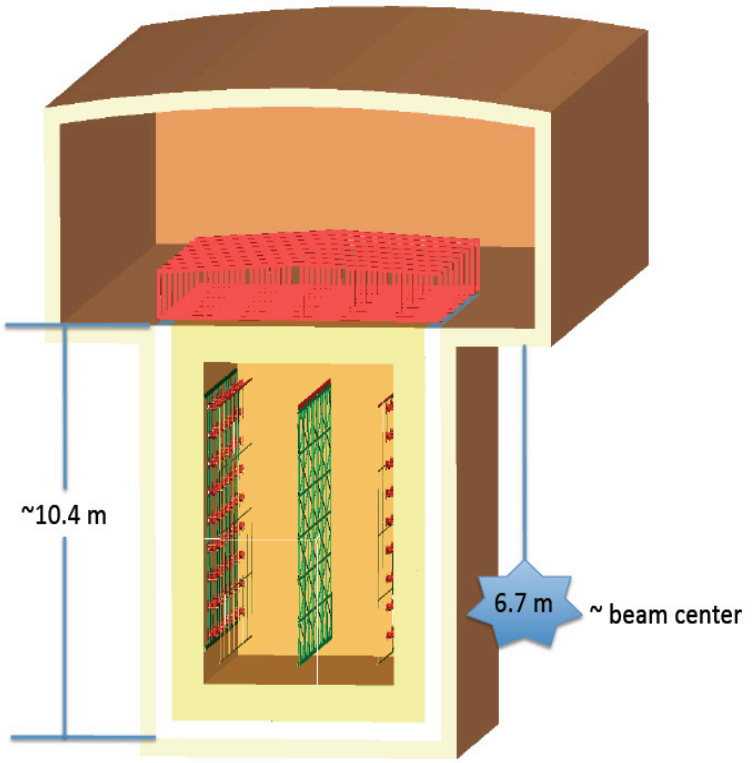
Engineering prototype for LBNE

800 m baseline in booster neutrino beam

- Move MicroBooNE to 200 m

Rule out entire LSND region at 5 σ

Proposal is currently under development



LBNE: the original plan

Fermilab to Homestake (DUSEL)

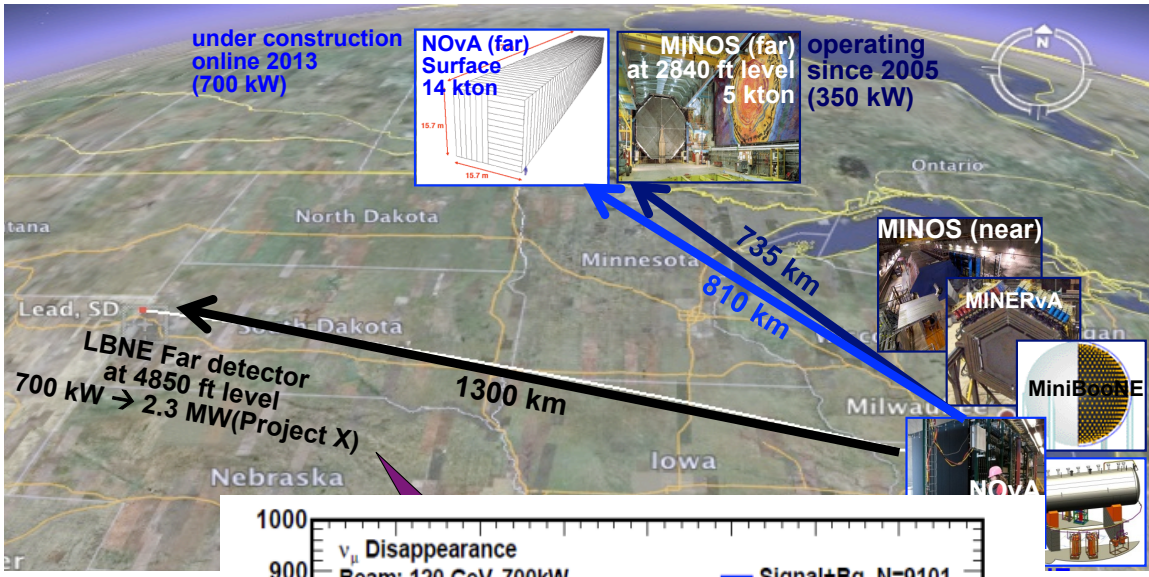
- 1300 km baseline
- 700 kW beam (up to 2.3 MW with project X)
- Original plan: 34 kt underground detector

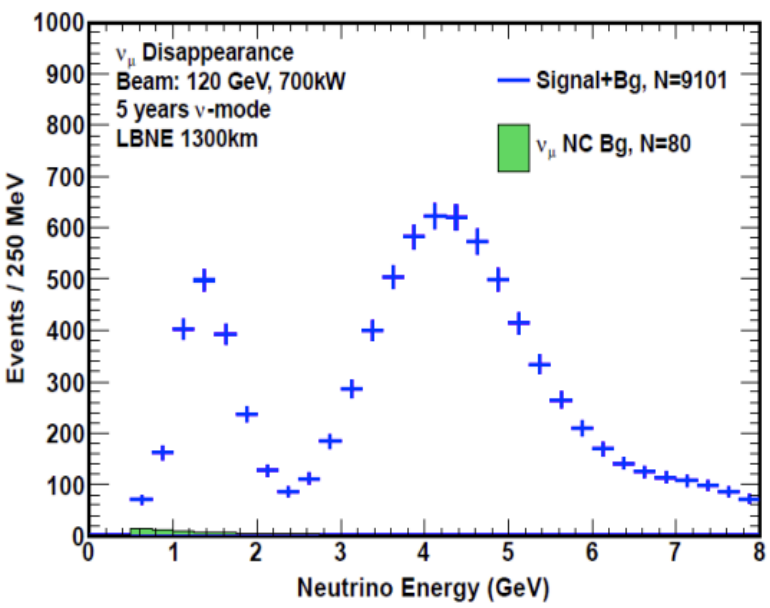
Broadband beam

- First two oscillation maxima at 2.5 GeV and 0.8 GeV

Underground physics programme

- Proton decay through $p \rightarrow K^{+}\nu$
- Precisely measure ν spectrum from galactic supernova
- Measurements with atmospheric neutrinos





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Staged LBNE

Politics and funding…

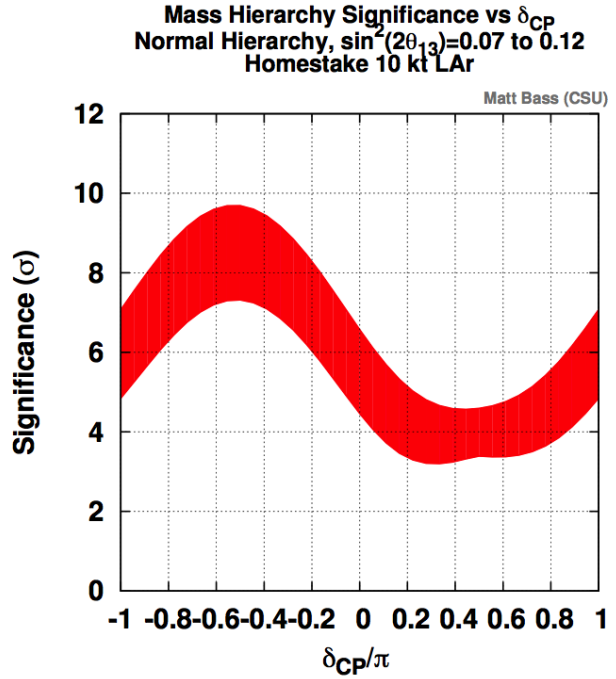
- NSF pulls out of DUSEL
- DoE must pay the bill
- DoE requests a phased programme

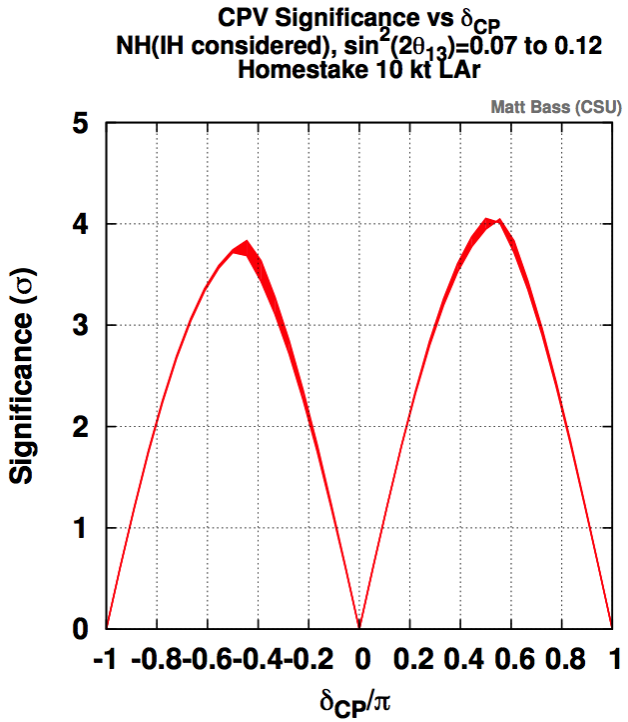
Phase 1

- 10 kt Lar TPC on surface at Homestake
- 700 kW beam
- No Near Detector

Reduced beam physics potential

No underground physics programme





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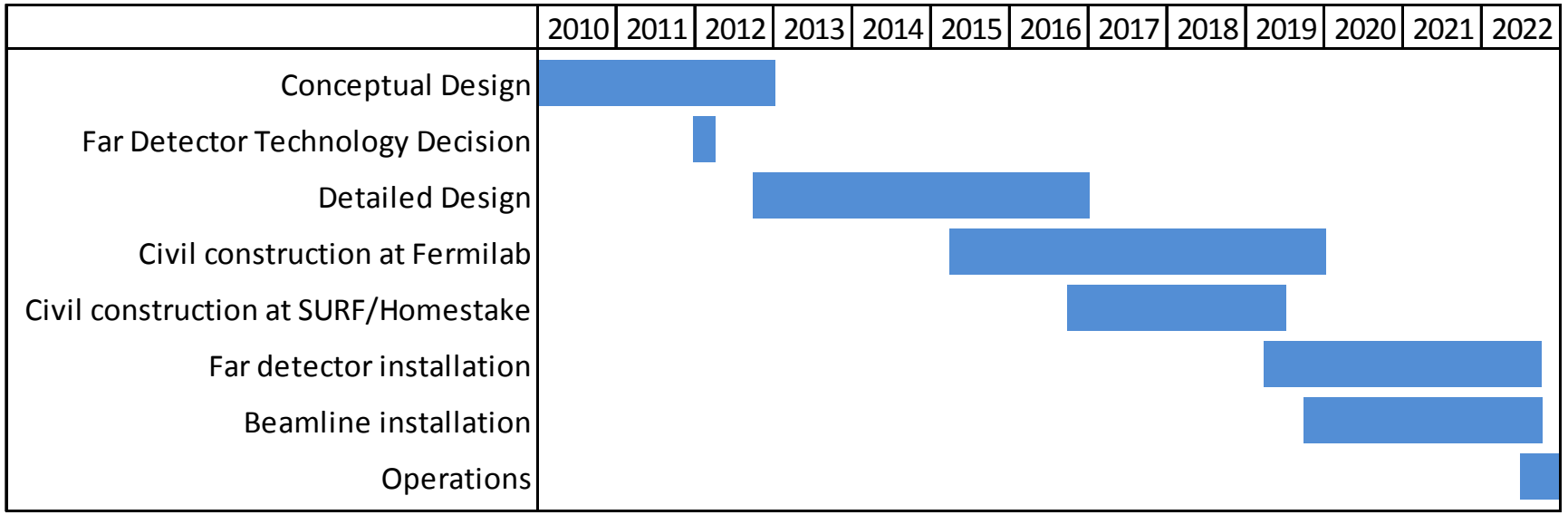
LBNE phase 1 timescale



Phase 1 design and construction covers the next 10 years

- Data taking estimated for 2022

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LBNE: International involvement

Existing UK involvement

Cambridge

- LAr reconstruction software

Oxford

- Triggering in LAr surface detector
- Cerenkov detector calibration
- Cosmic muon fluxes

Sheffield

- Co-convener of cosmics working group
- Simulation for 10 kt LAr detector
- Development of light collection in LAr

Sussex

- Just joined, interested in DAQ and calibration

UCL

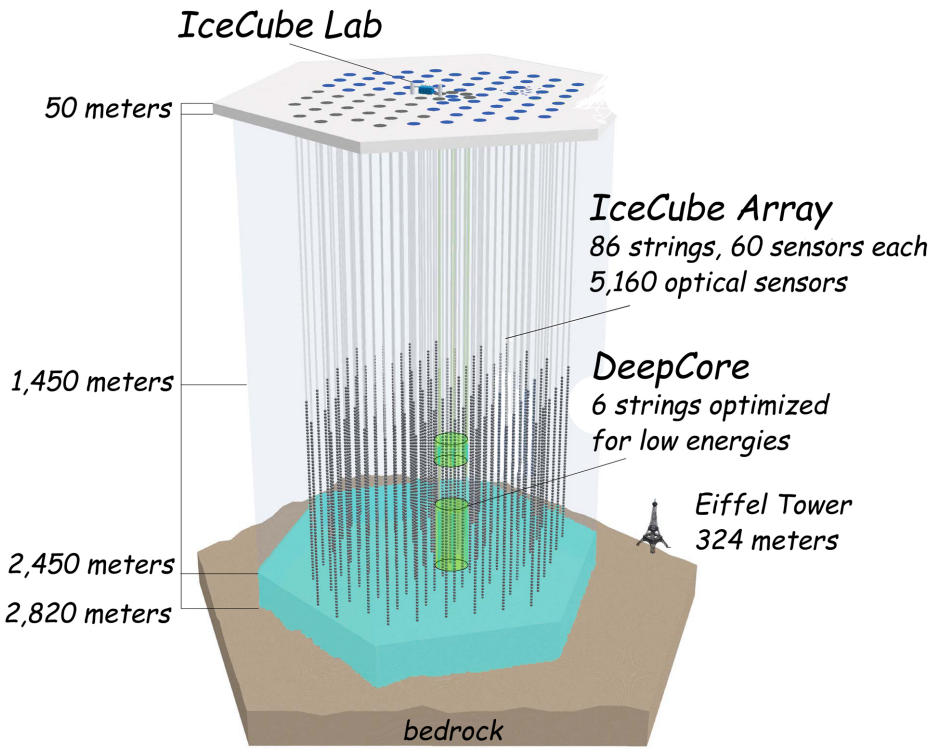
- Beam simulations

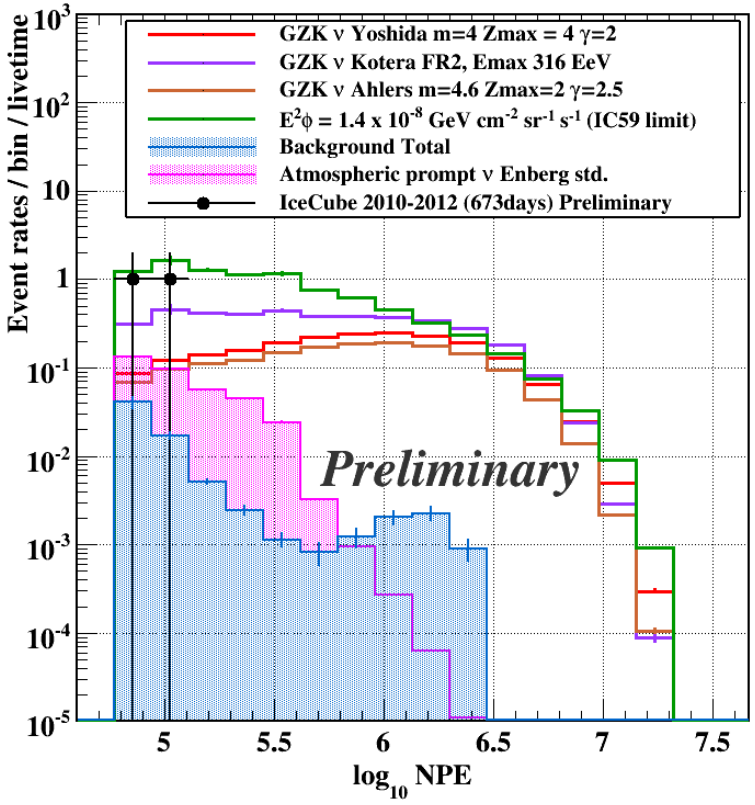
Scope	Cost (TPC)
LBNE 34 kTon@4850L and near detector	$1.440B
LBNE Phase I, 10 kTon surface	$0.789B
+Place Underground	$0.924B
+ Near Detector	$1.054B

Possibilities for significant impact from international involvement

- Provide a Near Detector
- Take the 10 kt detector underground

Antarctica





IceCube has turned the Antarctic ice shelf into the world's biggest neutrino detector

- Has seen the highest energy neutrinos ever observed

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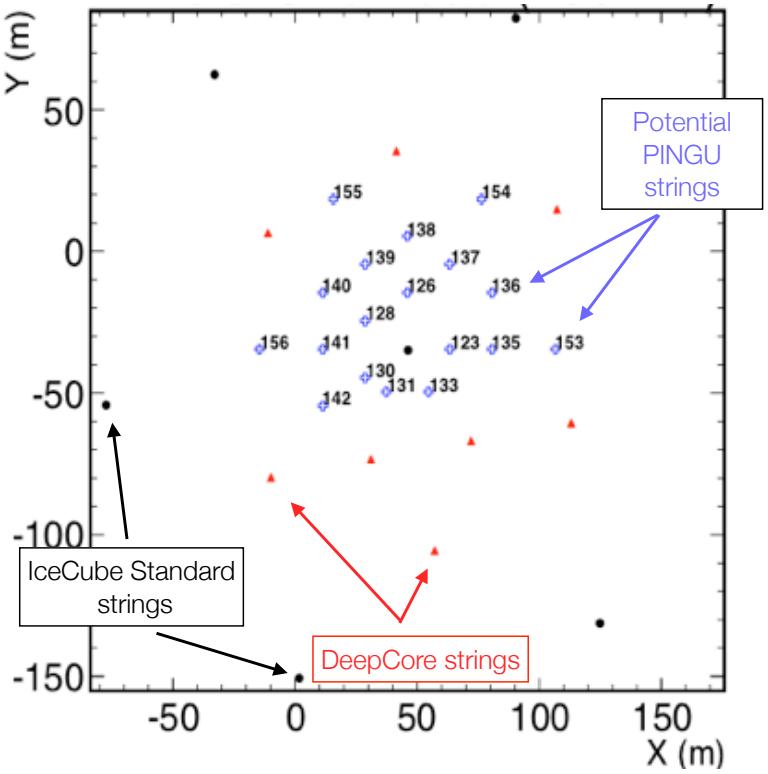
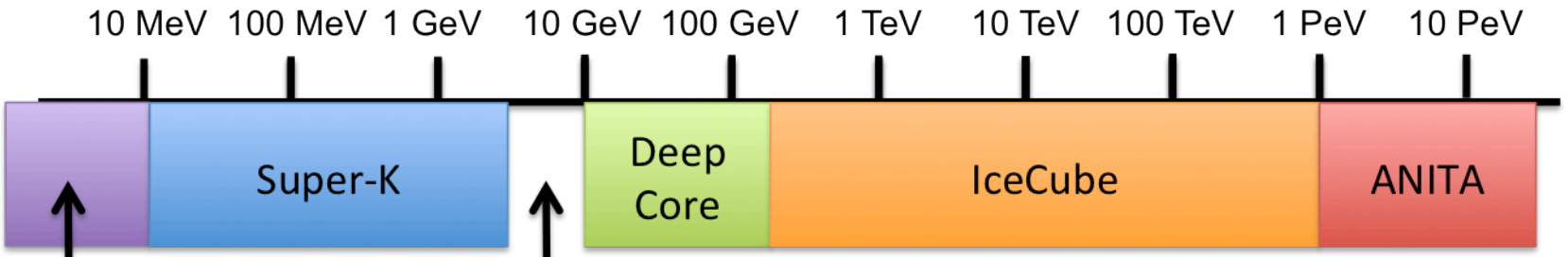
PINGU

Add 20 additional strings to the central region of IceCube

- Spaced by 6-7 m
- Take the neutrino energy threshold down to 1 GeV
- Measurements of atmospheric neutrino oscillations
- Searches for low-mass WIMPS





Borexino
KamLAND
Double Chooz
Daya Bay
SNO

PINGU fills this gap

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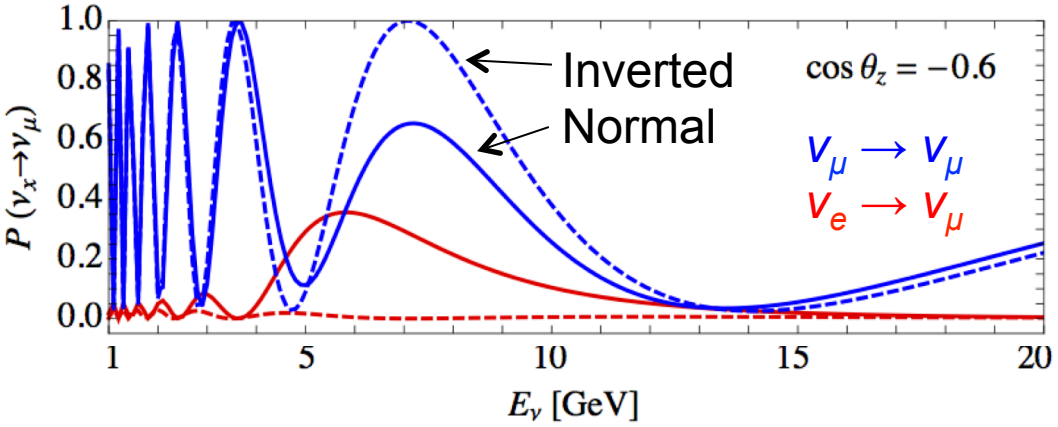
PINGU

5 GeV neutrinos traveling through the Earth are close to an MSW resonance

- Oscillations are enhanced
- The effect depends strongly on the mass hierarchy



A paper by Akhmedov et al. calculates PINGU's ability to determine the mass hierarchy

Assume a reasonable energy and angular resolution

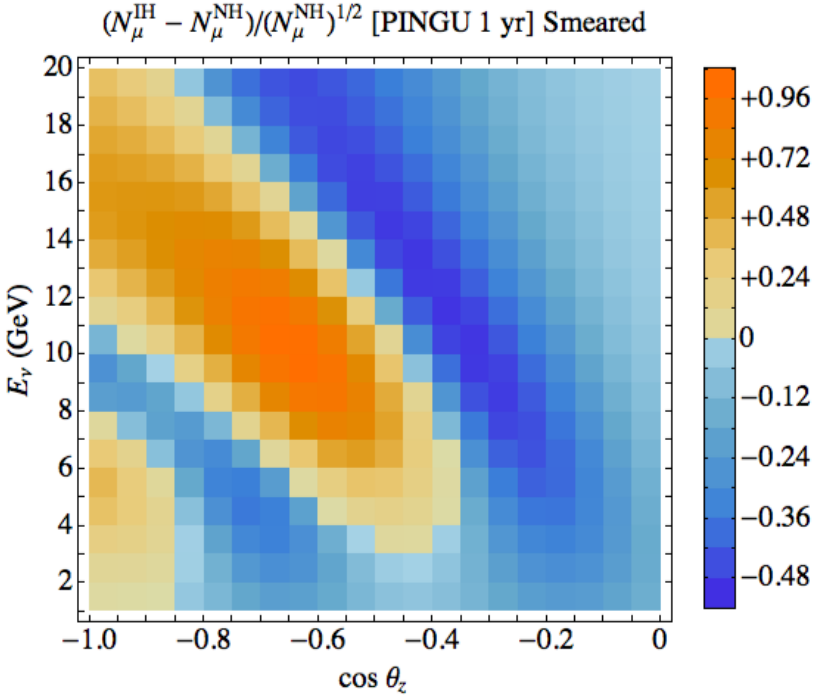
- σ_E = 3 GeV, σ_φ = 15°

Mass hierarchy determination at 4.5σ – 7σ

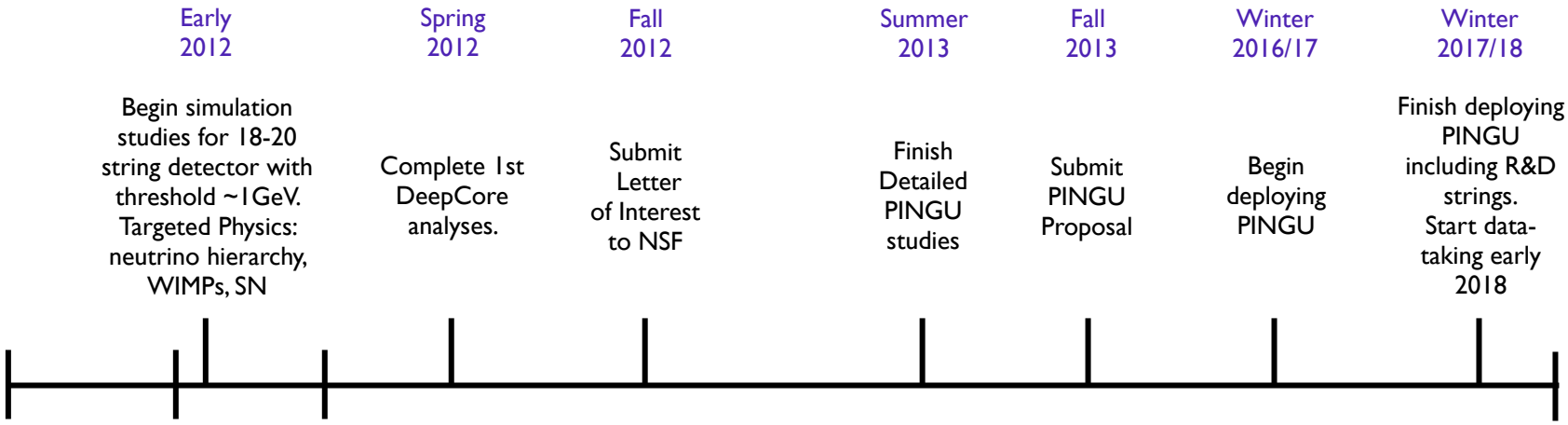
- Assuming uncorrelated systematics at 5% – 10%

Fairly independent of δ_{CP}

hep-ph/1205.7071



A possible PINGU timescale



The PINGU collaboration are currently working on a full detector simulation

- Aiming to submit a letter of intent to NSF soon

Akhmedov et al. paper assumes 5 years of data taking

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E-NuMI: Exploiting NuMI

A new group will study ideas for further exploiting the NuMI neutrino beam

- The beam exists, why not instrument it further?

Looking for ideas of $10 m – $100 m

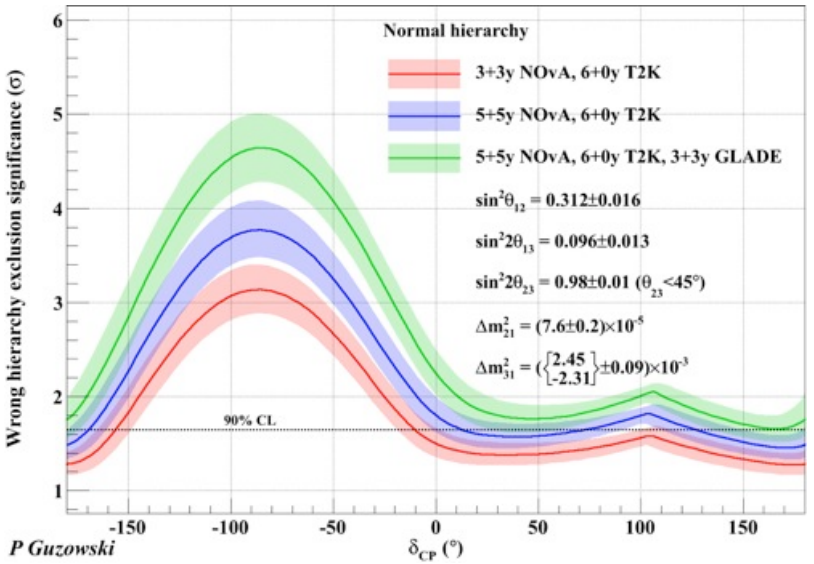
- 5 kt LAr at Ash River?
- A water Cerenkov detector?
- …?

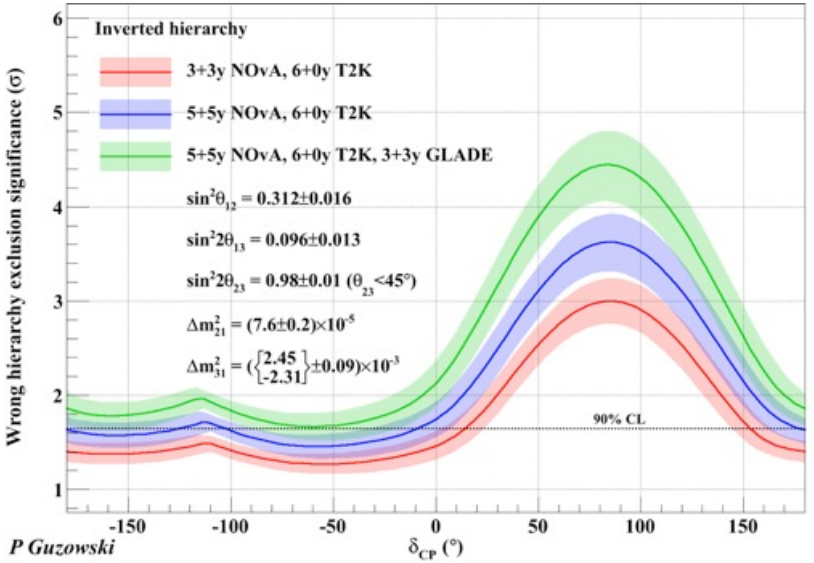
Monthly phone calls planned

Two-day meeting in Minneapolis, 11th–12th March 2012

- Develop input for the Snowmass 2013 meeting

UK contact is Jenny Thomas





Summary

Current US neutrino programme

- MINOS, MiniBooNE and MINERvA

The near future

- MINOS+, MINERvA and NOvA

Liquid argon TPC development

- LAPD, MicroBooNE, LArIAT, LAr1

The long-term future

- Phased LBNE: 10 kt LAr TPC on the surface
- PINGU

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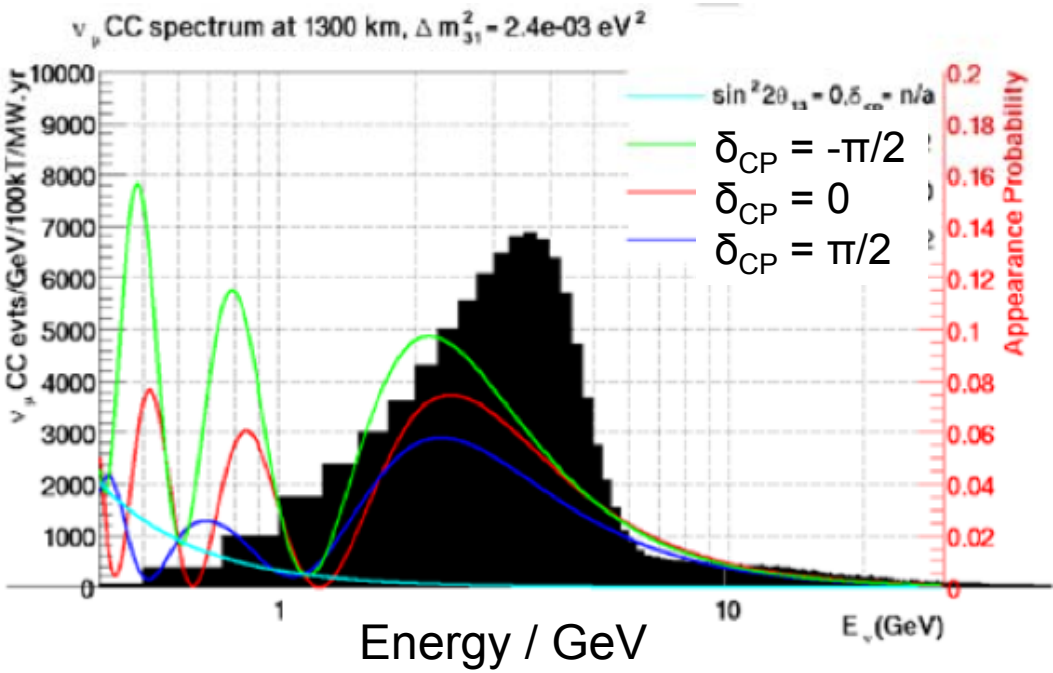
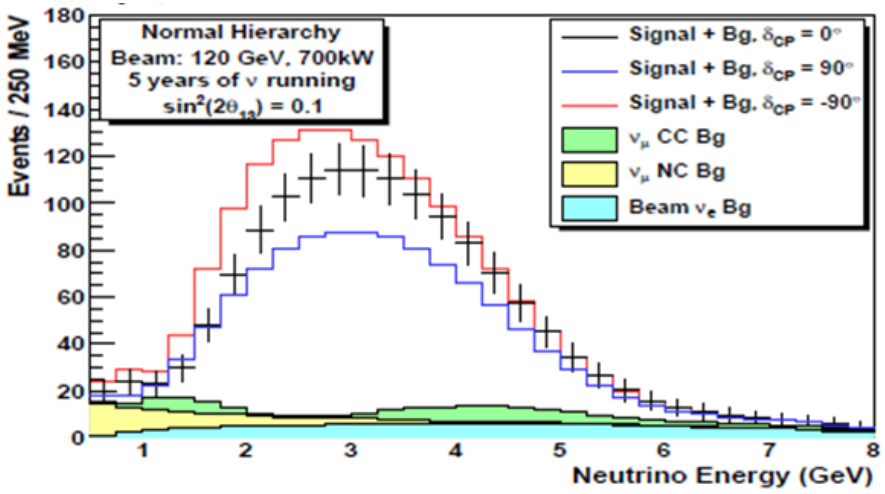
LBNE

Broadband beam

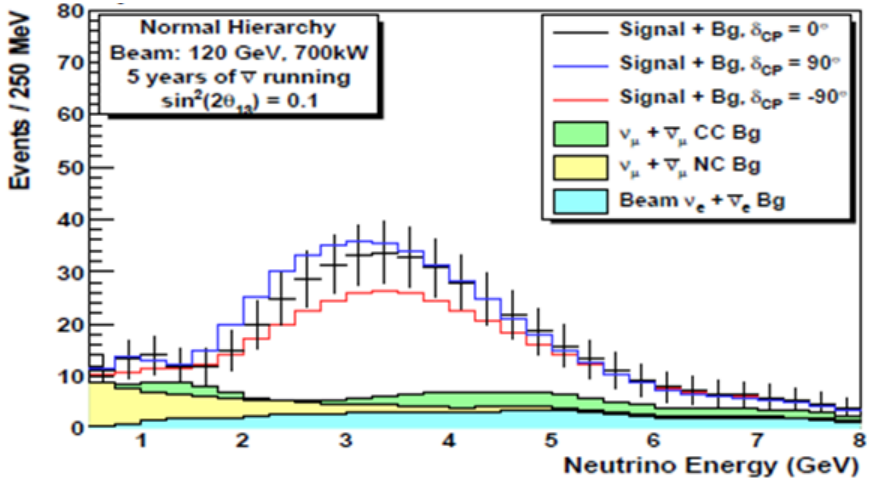
- First two oscillation maxima at 2.5 GeV and 0.8 GeV
- Low energy events vital for detecting CP violation



Electron neutrinos



Electron antineutrinos



MicroBooNE Goals

Rule out much of the LSND region

Galactic supernovae

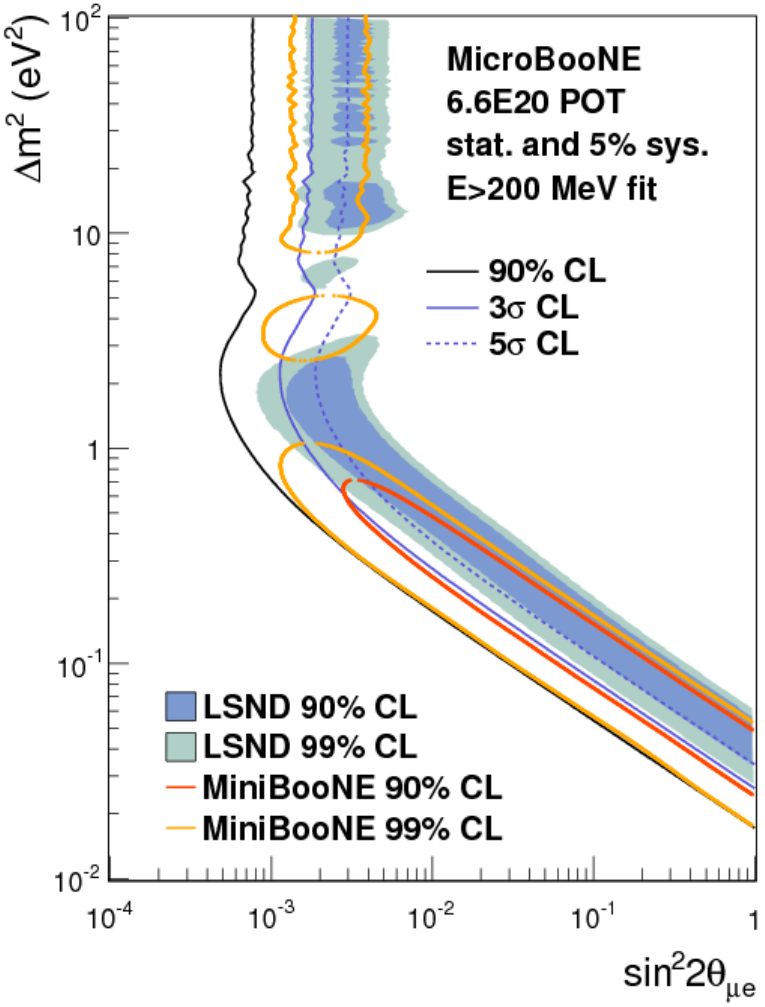
- 10–20 events expected

Neutrino–argon cross section measurements

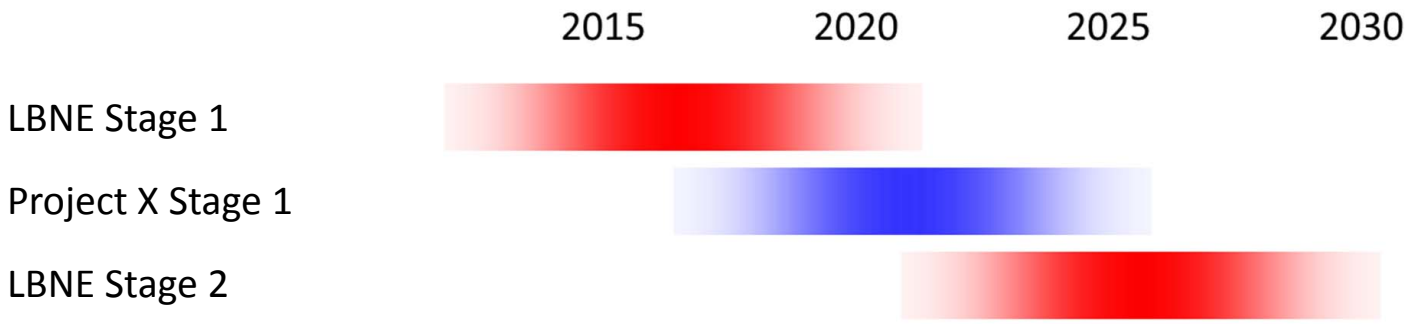
Background measurements for proton decay

- $K^0_L \rightarrow K^+$ charge exchange

Testing cold electronics



Possible future LBNE scenarios



LBNE still aims to reach its final goal of a large underground LArTPC

LBNE stage 1

- 10 kt on surface, 700 kW beam

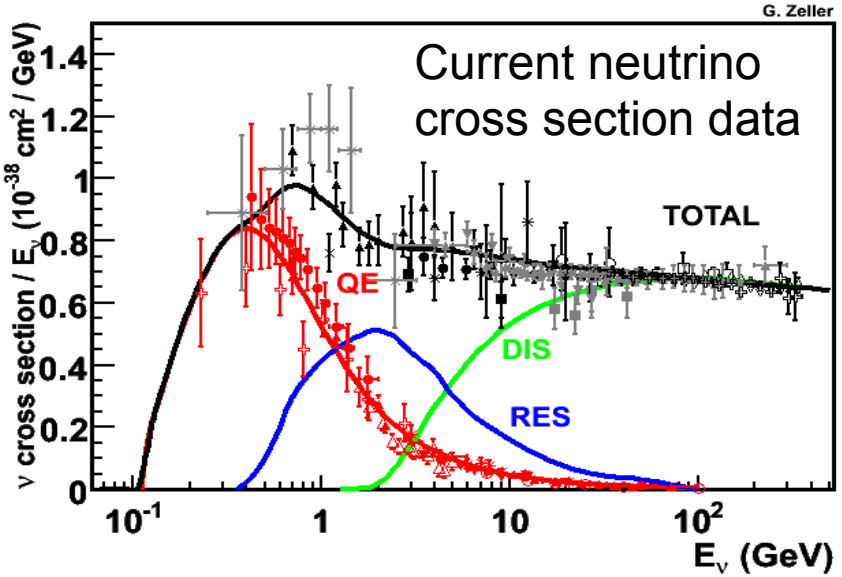
Project X stage 1

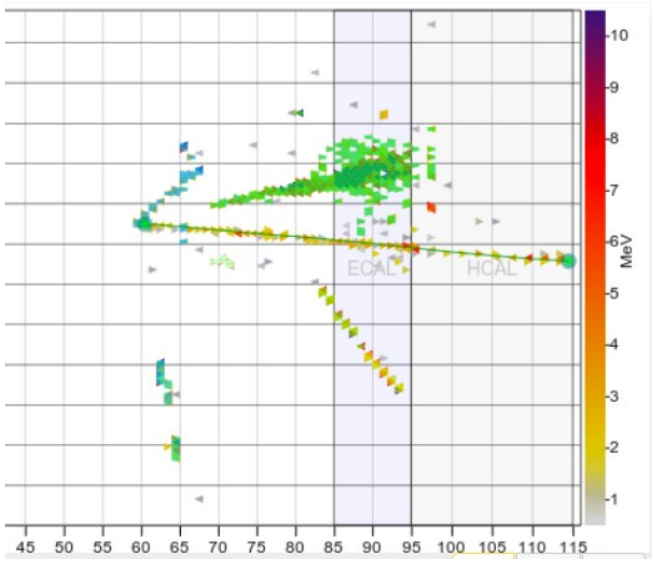
- Upgrade neutrino beam to 1.1 MW; perhaps install a Near Detector at this point

LBNE stage 2

- Additional 30 kt detector on surface or 15-30 kt underground

The near future: MINERvA





Large uncertainties on neutrino cross sections

- 20–50%

MINERvA aims to reduce this to 5–10%

- In the 1–10 GeV region

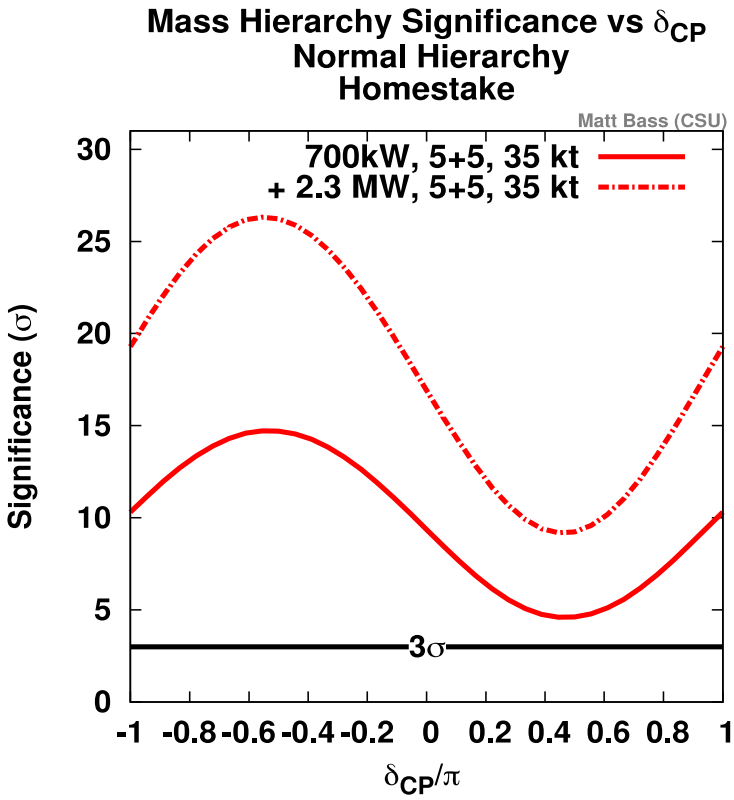
A number of neutrino target materials

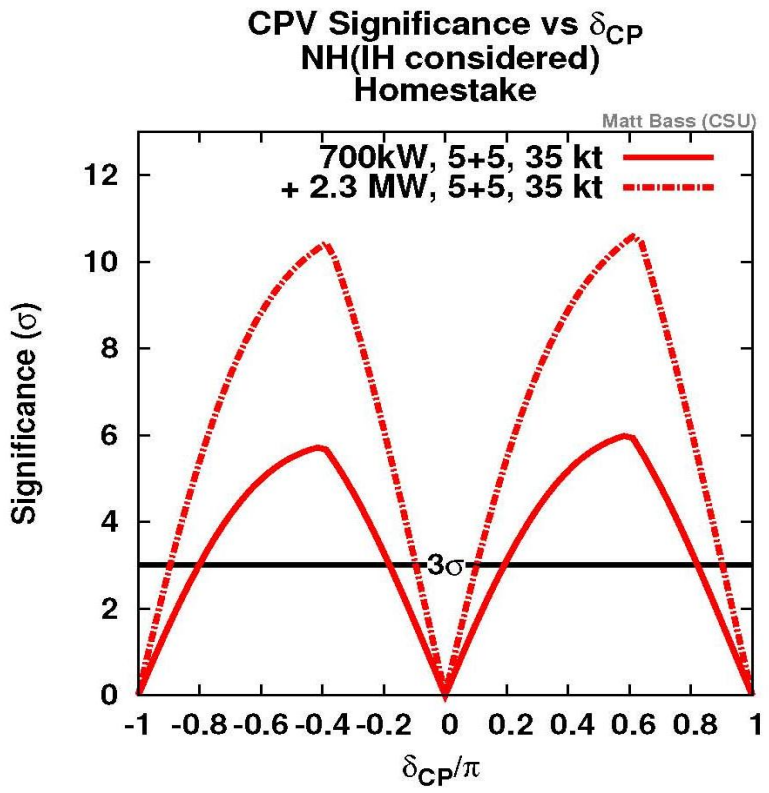
- C, Pb, Fe, H_20, He

Located in the NuMI neutrino beam

- In front of MINOS Near Detector

35 kt Underground LBNE





Original LBNE design has excellent physics potential

- Good sensitivity to mass hierarchy and CP violation

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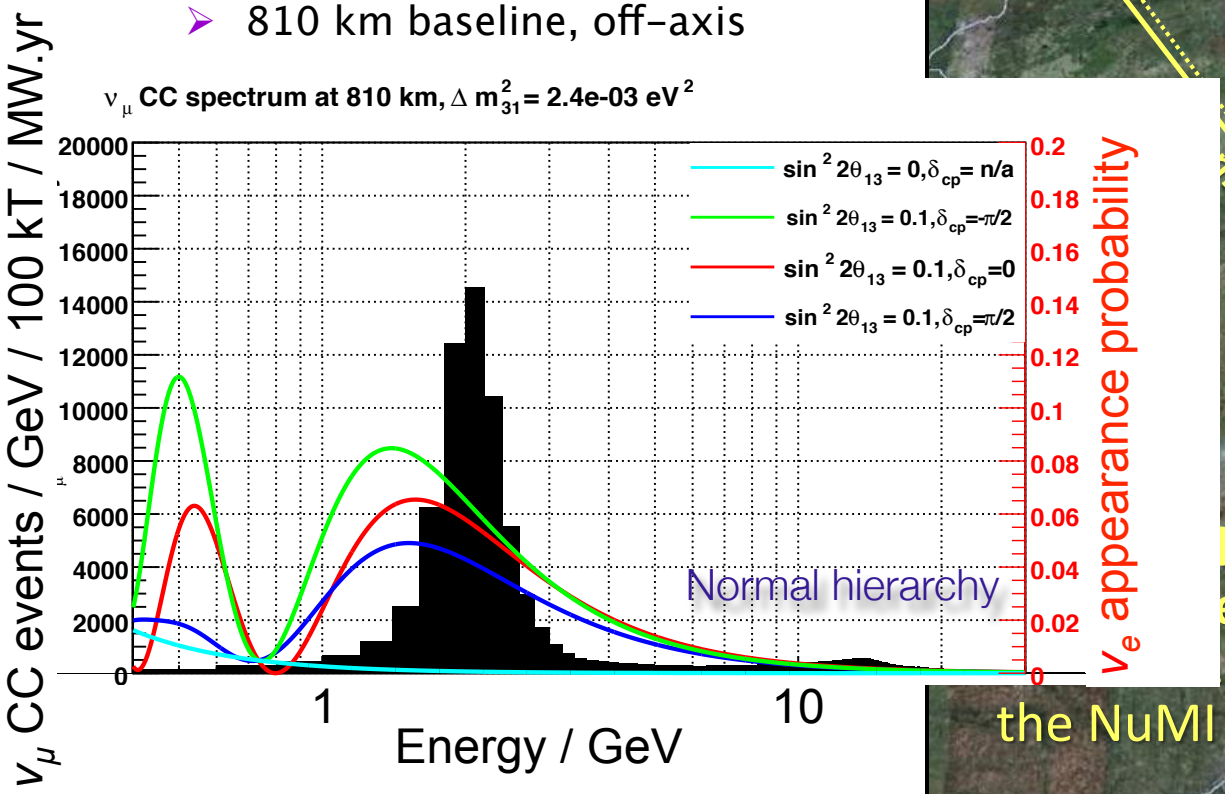
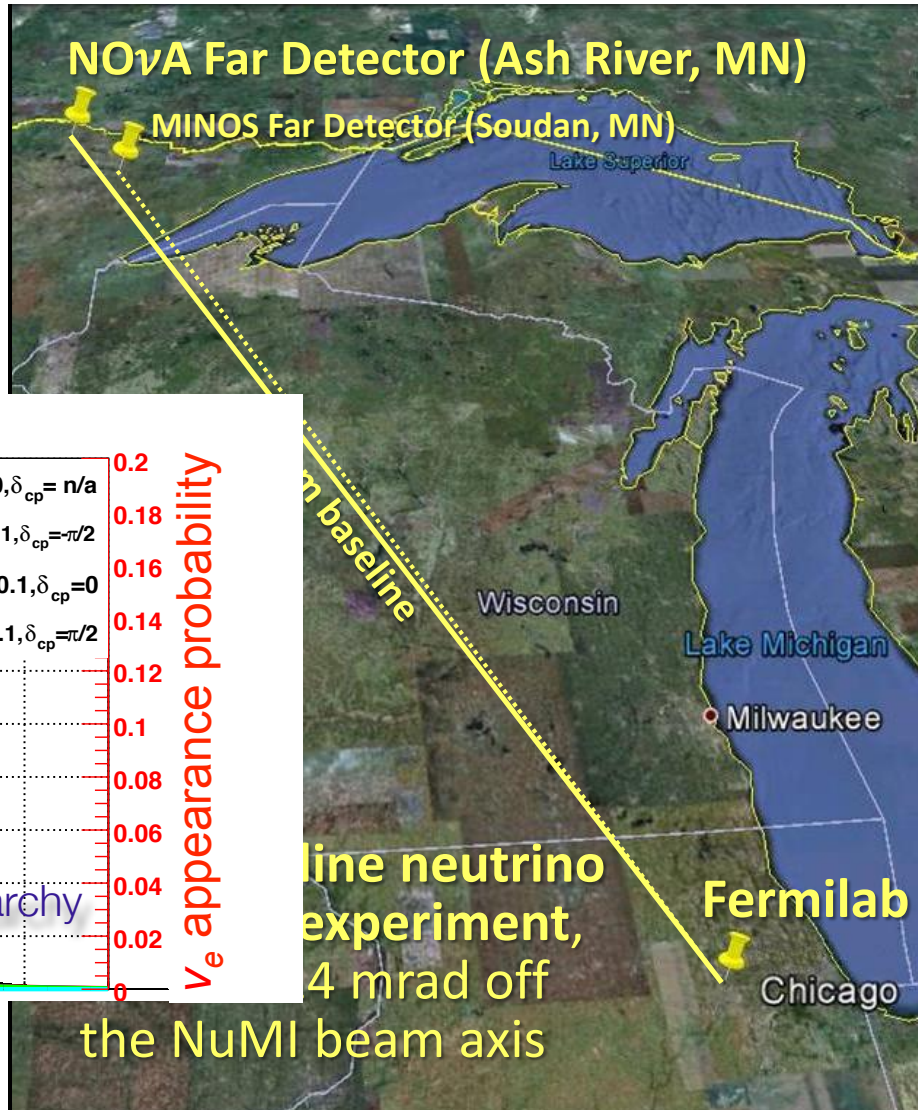
The near future: NOvA

77% active, low-Z liquid scintillator detector

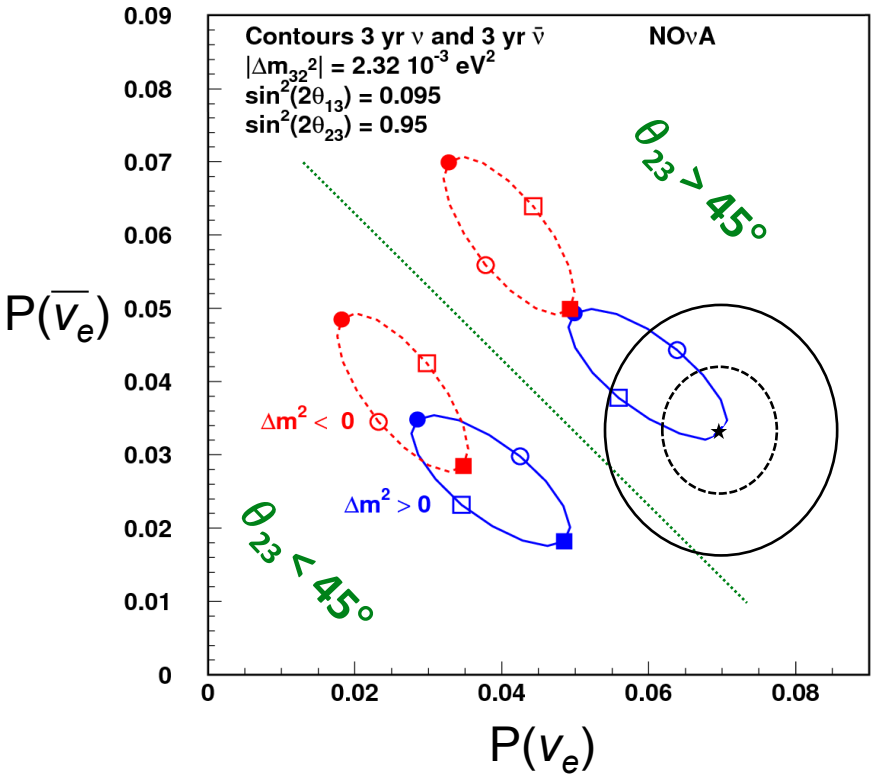
Upgraded NuMI beam

- 810 km baseline, off-axis



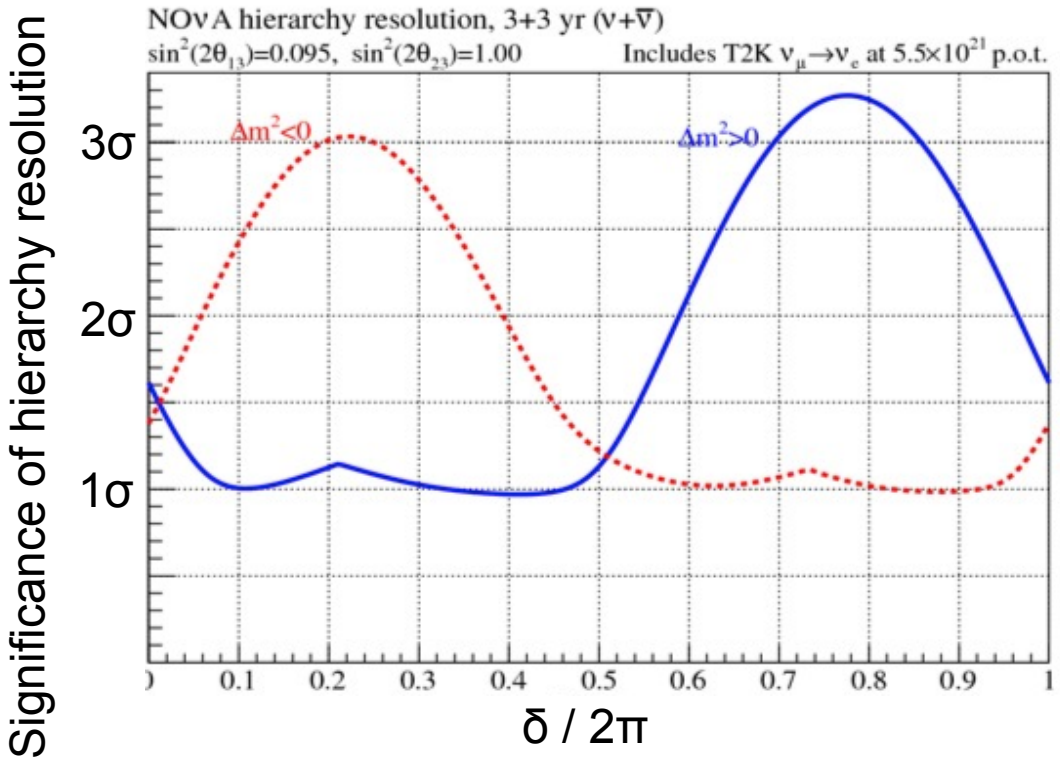


NOvA physics sensitivity



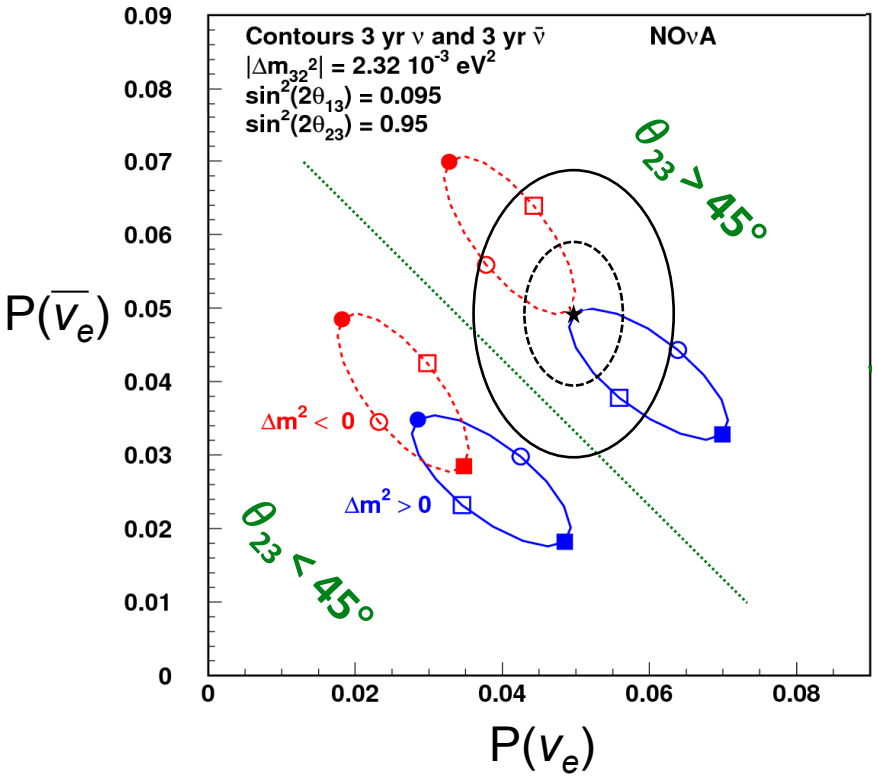
- Simultaneous sensitivity to hierarchy, octant and CP phase
- Resolution ability depends on the values of δ and θ_{23}

NOvA mass hierarchy resolution



- 3+3 years of neutrinos + antineutrinos
- Combination with T2K is important

NOvA physics sensitivity



Black contours are 1σ and 2σ

- Simultaneous sensitivity to hierarchy, octant and CP phase
- Resolution ability depends on the values of δ and θ_{23}

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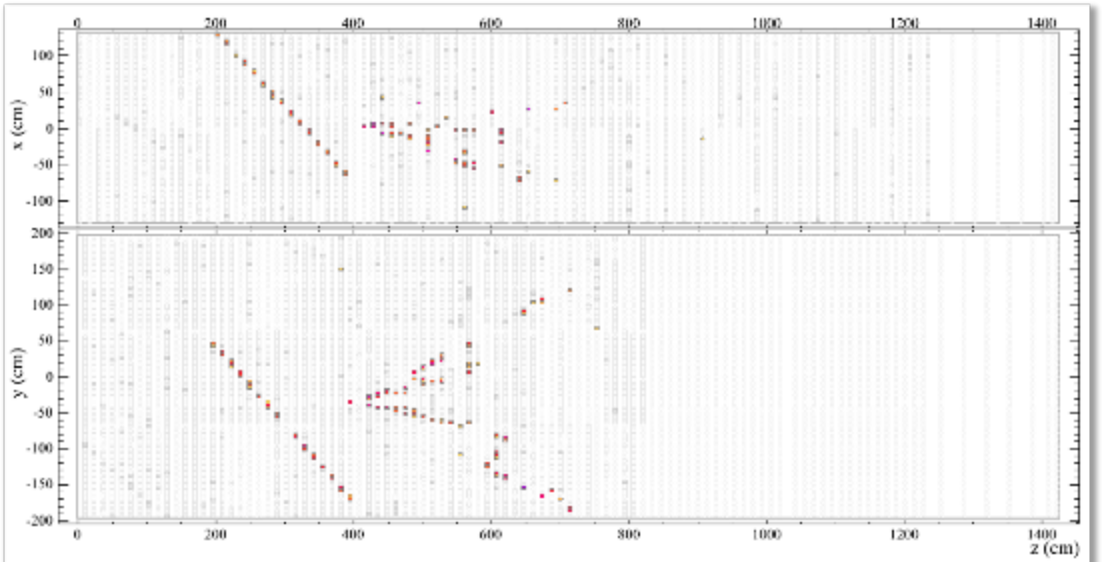
NOvA schedule and status

Prototype near detector has been operated

- DAQ development, calibrations, reconstruction, simulation…
- Detector assembly practice



Far detector assembly underway

- 5 kt when beam switches on
- 14 kt by May 2014

NuMI beam switches on in May 2013

- Reaches 700 kW by November 2013
- Baseline plan is 6 years' of running

UK involvement from Sussex University

- ERC starting grant

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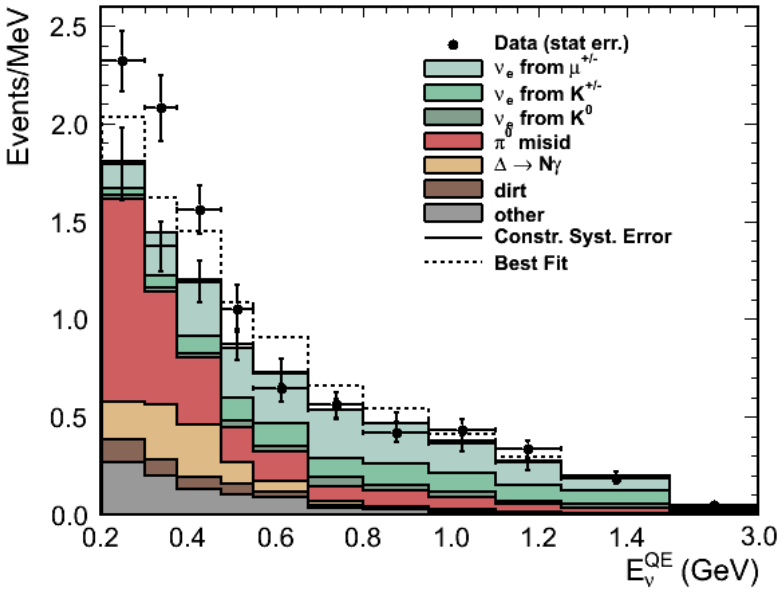
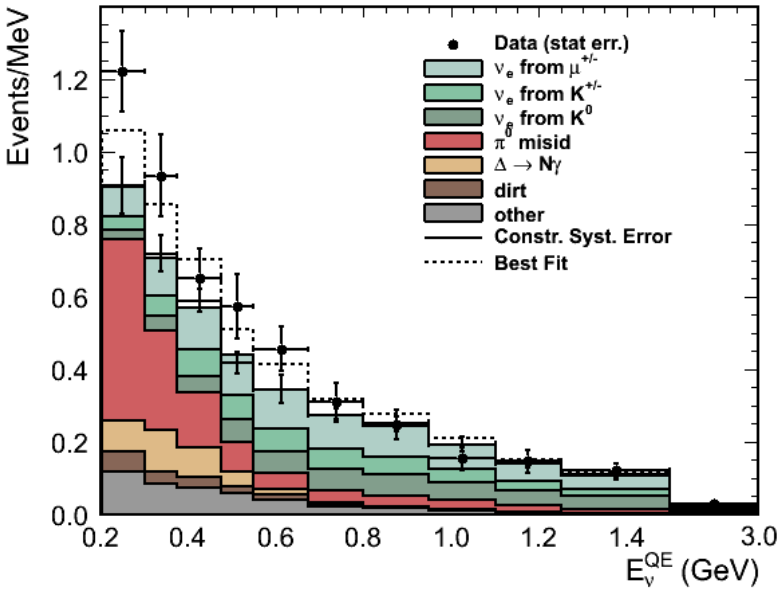
Recent neutrino physics: MiniBooNE

6.5e20 POT neutrino mode w/ 3+1 fit



11.3e20 POT anti-neutrino mode w 3+1fit



Aiming to address the LSND signal for sterile neutrinos

- Inconclusive results due to low energy excesses for neutrinos and antineutrinos