Fermilab Neutrino Program

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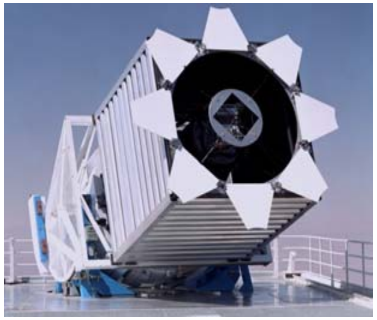
HEPAP Fermilab Meeting
April , 2002

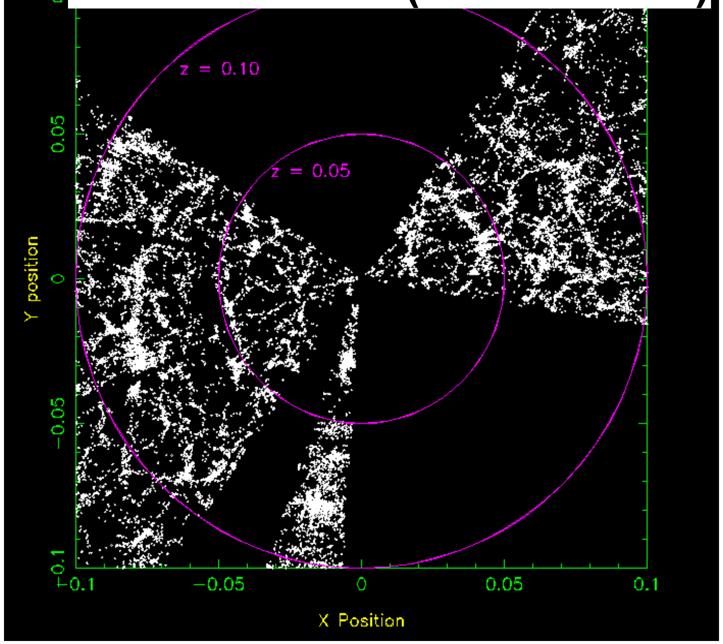
- Introduction
- NuMI / MINOS
- MiniBooNE



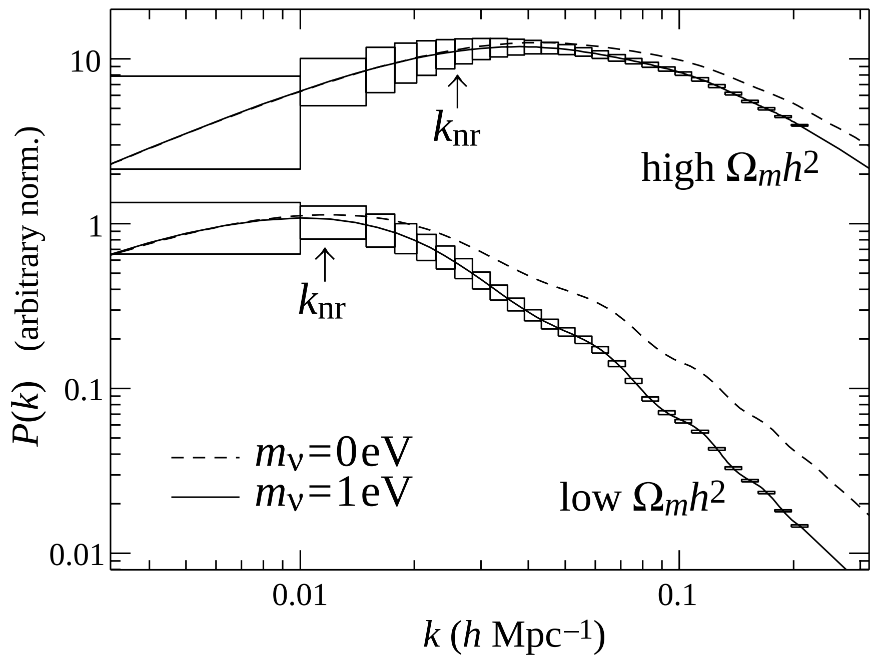
Sloan Digital Sky Survey

- Mapping the universe
  - Large imaging and spectroscopy survey about 1/4 of sky
  - Digitize 100 million objects and spectra for million galaxies

Galaxy Clustering in SDSS Redshift Data (Zehavi et al.)

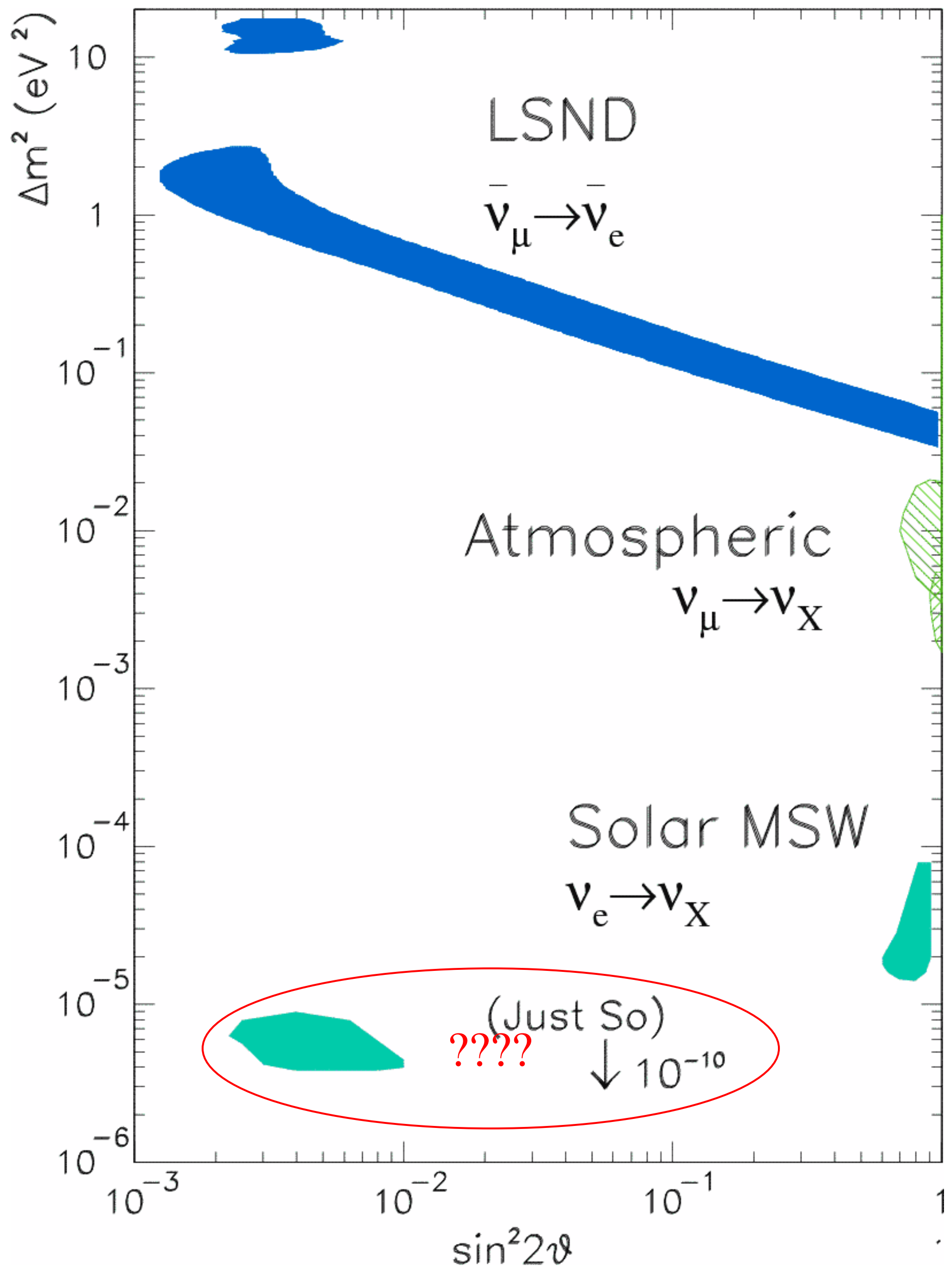


Neutrino Mass Density and Large Scale Structure



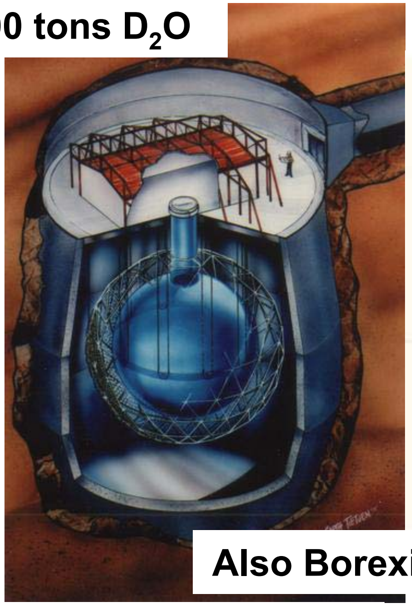
Current Neutrino Oscillation Signals

- Three Positive Signals
  - Solar Neutrinos
  - Atmospheric Neutrinos
  - Low-E Accelerator Neutrinos
- Many negative searches



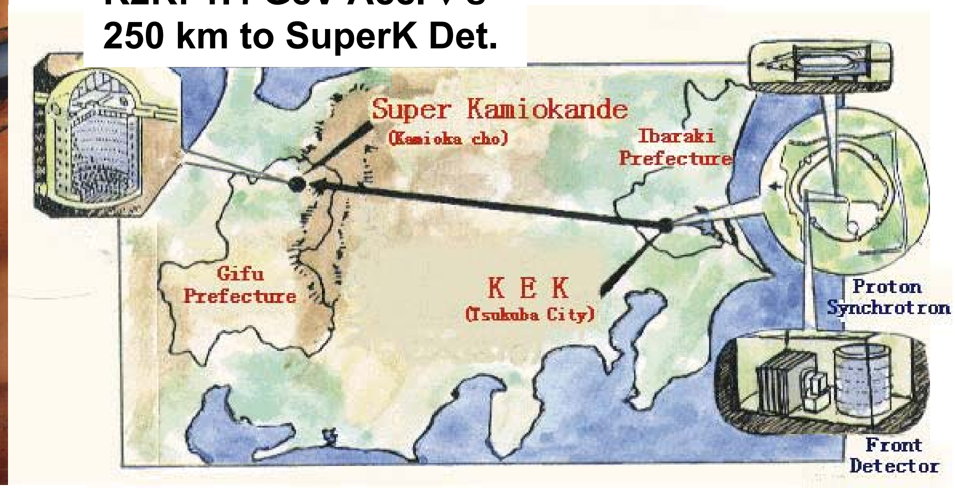
Upcoming Experiments

SNO: Solar ν's
1000 tons D_2O

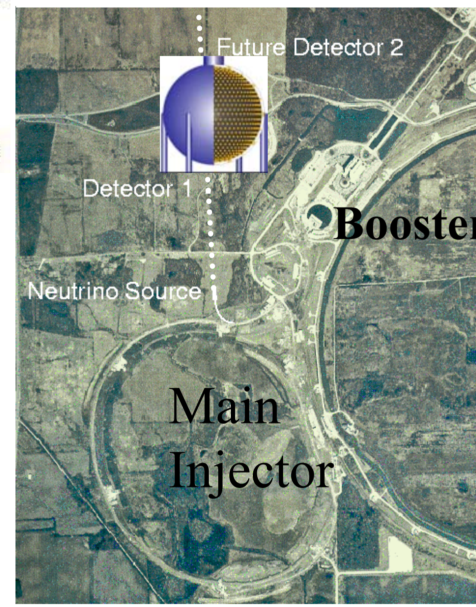


Also Borexino

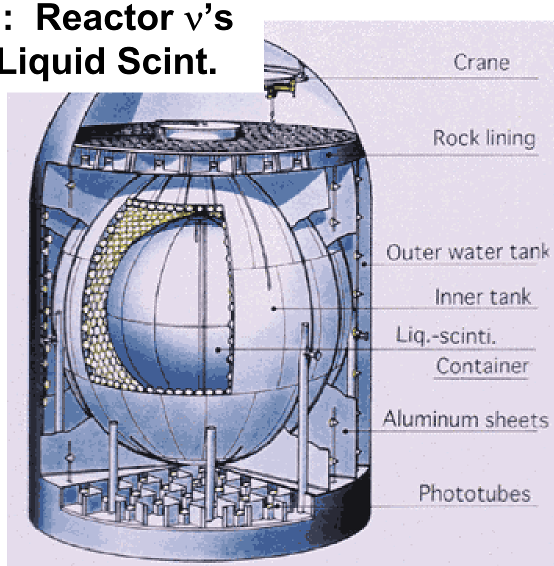
K2K: 1.4 GeV Acc. ν's
250 km to SuperK Det.



MiniBooNE: 1 GeV Acc.
ν's 500 m to Detector



Kamland: Reactor ν's
1000 m^3 Liquid Scint.



NuMI: 3 GeV Acc. ν's
750 km to MINOS Det.

Also CNGS (CERN)

Summary
Expectations for the Next ~5 years

- LSND Δm^2
  - Definitive determination if osc.
  - Measure $\Delta m^2/\sin^2 2\theta$ to 5-10%
  - If positive $\Rightarrow$ New round of experiments: $\nu_{\mu \text{ and } e} \rightarrow \nu_\tau$

$\Leftarrow$ ***Results from MiniBooNE***

- Atmospheric Δm^2
  - Know if $\nu_\mu \rightarrow \nu_\tau$ or ν_s
  - Measure $\Delta m^2/\sin^2 2\theta$ to 10% if $\Delta m^2 > 2\times10^{-3}$ eV^2
  - Maybe see $\nu_\mu \rightarrow \nu_e$

$\Leftarrow$ ***Results from K2K, MINOS , CNGS***

- Solar Δm^2
  - Restrictions to one solar solution
  - Know if $\nu_e \rightarrow \nu_{\mu,\tau}$ or ν_s

$\Leftarrow$ ***Results from Kamland, Borexino, SNO***

Recent SNO Results for Solar Neutrinos

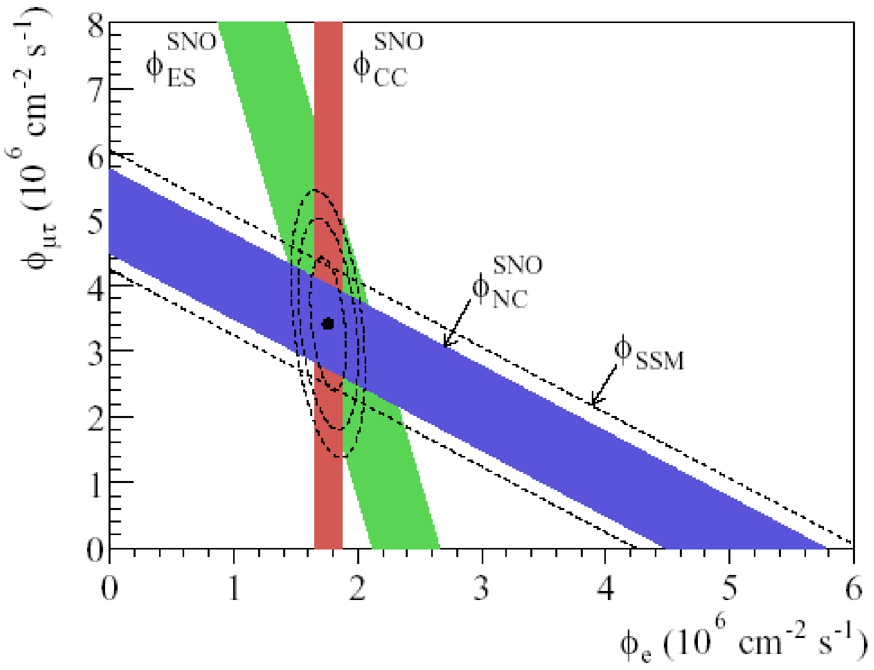
- SNO has measured the total active neutrino flux coming from the sun

SNO Measurements: Total flux = $5.09 \pm 0.64 \times 10^6$ cm^{-2}s^{-1}

ν_e flux = $1.76 \pm 0.10 \times 10^6$ cm^{-2}s^{-1}

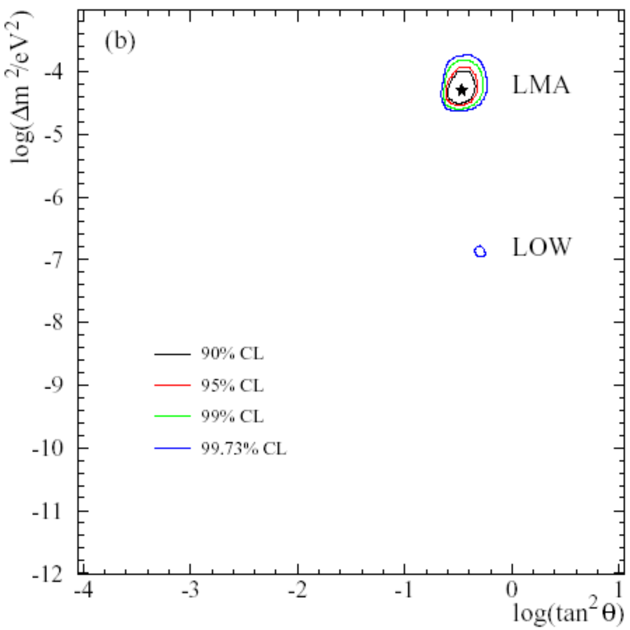
Solar Model Prediction: Total flux = $5.05 \pm 1.00 \times 10^6$ cm^{-2}s^{-1}

- – Conclusive indication of oscillations to active (ν_μ or ν_τ) neutrinos
- – Constrains amount of oscillations to sterile neutrinos



Also, CC day/night flux difference

- Constrains possible solar oscillation solutions from matter effects in the earth.



Next Step Driven by Near Term Results

- If MiniBooNE sees $\nu_\mu \rightarrow \nu_e$ oscillations then
  - Investigate the oscillation phenomenology at high Δm^2
    - Need at least 4 mass eigenstates … **Sterile Neutrinos!** What is the pattern … 2+2 , 3+1

- If MiniBooNE refutes LSND then Minos
  - Push to measure oscillation parameters with best precision
  - Search/measure $\nu_\mu \rightarrow \nu_e$ at the atmospheric Δm^2

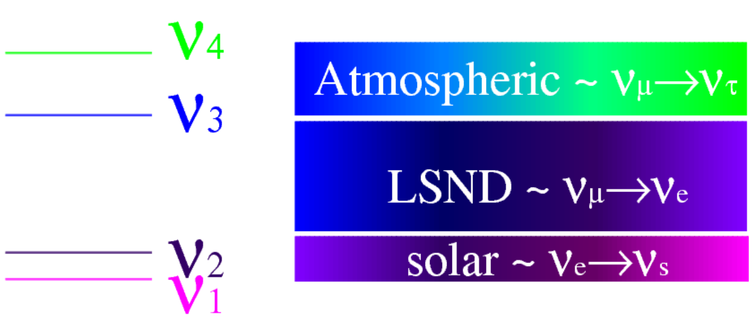
- If $\nu_\mu \rightarrow \nu_e$ at the atmospheric Δm^2 is below the Minos sensitivity then
  - Design new exp's to measure θ_{13} (also sign of Δm^2)
    - Offaxis beams at NuMI or JHF
    - Long-baseline "Superbeams" or ν–factory sources

- If parameters are reasonable, then move to a CP violation experiment
  - Experiment must be sensitive to
    - Δm^2_{23} and Δm^2_{12} $\Rightarrow$ requires the LMA
    - mixing at the θ_{13} level $\Rightarrow$ requires θ_{13} large enough to see

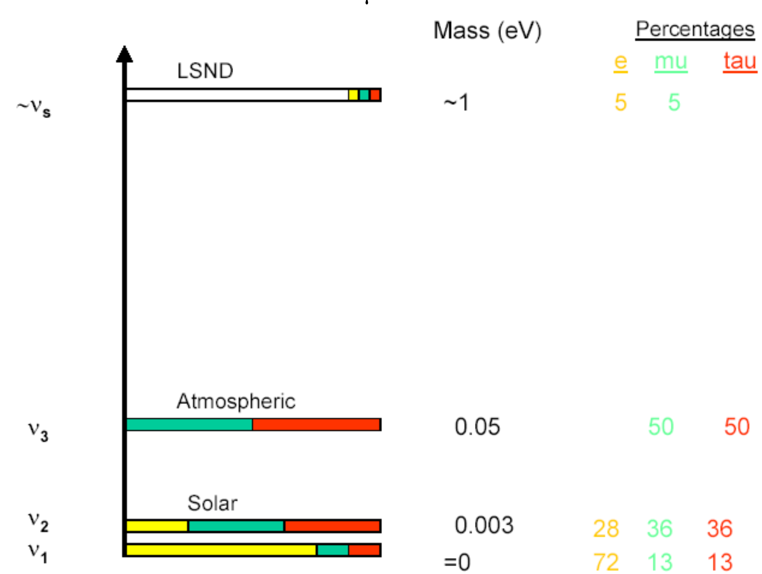
Scenario: MiniBooNE Confirms LSND
Three Δm^2_{solar}, Δm^2_{atm}, Δm^2_{LSND}

Possible Explanation: Introduce a 4th (or more) sterile neutrino

- 2+2 Model:
  - Atmospheric or Solar (or both) have oscillation fractions to ν_s such that $f_{Solar} + f_{Atmos} = 1$
    - Super-K Atmospheric: $f_{Atmos} < 0.25$ @ 90%CL
    - SNO + Super-K Solar: $f_{Solar} < 0.50$ @ 90%CL
  - Model still possible but at the edge (Also, 3active +3sterile models can work)



- 3+1 Model:
  - Atmospheric: $\nu_\mu \rightarrow \nu_\tau$
  - Solar: LMA $\nu_e \rightarrow \nu_{\mu,\tau}$
  - LSND: $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$
- Solar oscillations are to a 50%/50% mixture of ν_μ and ν_τ
- LSND $\nu_\mu \rightarrow \nu_e$ oscillations are through high mass, mainly ν_s state with small admixture of ν_μ and ν_e



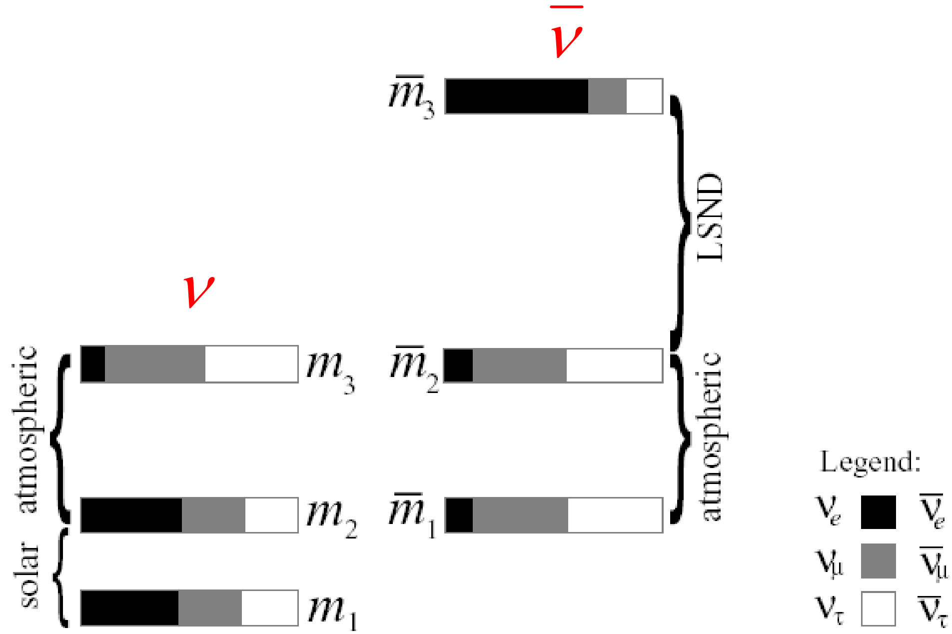
CPT Violation

- If CPT is violated the

  $$Mass(\nu_i) \neq Mass(\bar{\nu}_i)$$

  $\Rightarrow$ LSND sees $\bar{\nu}_\mu \to \bar{\nu}_e$

  but Solar sees $\nu_e \to \nu_\mu$



(Barenboim, Borissov, Lykken, Smirnov, Murayama, Yanagida; hep-ph 0201080)

- Model accommodates solar, atmospheric, and LSND without sterile neutrinos
  - Just allow the antineutrino Δm^2 to be bigger than the neutrino

- Tests
  - Kamland uses $\bar{\nu}_e$'s from a set of reactors
    - In this model, Kamland will see no oscillation signal
  - MiniBooNE can run with both ν_μ and $\bar{\nu}_\mu$
    - In this model, will see no oscillations for $\nu_\mu \to \nu_e$ but oscillations at the LSND rate for $\bar{\nu}_\mu \to \bar{\nu}_e$

Scenario: MiniBooNE Refutes LSND

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Atmospheric: θ_{23} | ??? | Solar: θ_{12}

Need to measure: Sign of Δm_{23}^2 , ~~CP~~ phase δ , θ_{13} ($\nu_e \rightarrow \nu_\mu$)

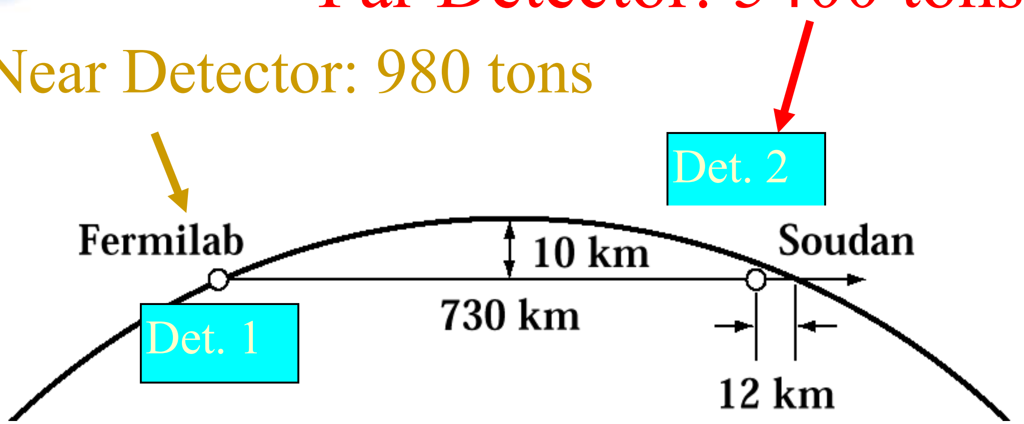
- θ_{13} key parameter for osc. phenomenology since θ_{12} and θ_{23} are both large
  - Determines whether CP violation might be accessible
- Measurements of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ yields θ_{13} and δ

The NuMI/MINOS Experiment

Two Detector Neutrino Oscillation Experiment

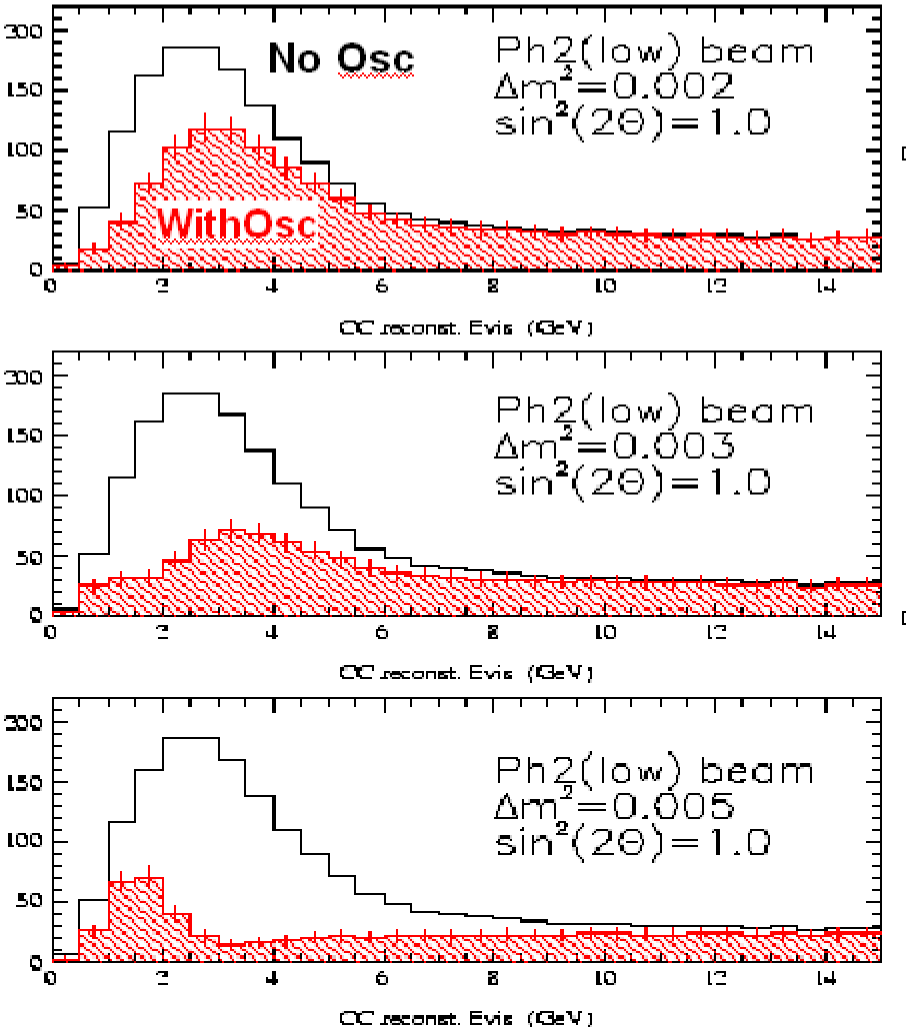
Far Detector: 5400 tons

Near Detector: 980 tons

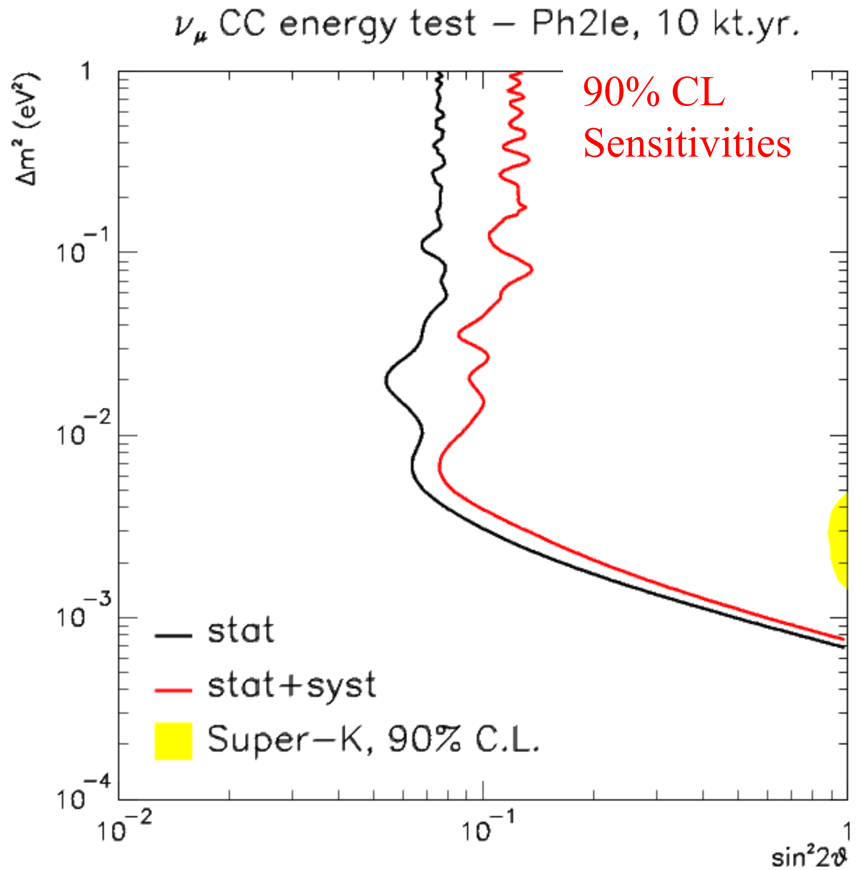


Minos Oscillation Sensitivity

Minos will see oscillatory behavior

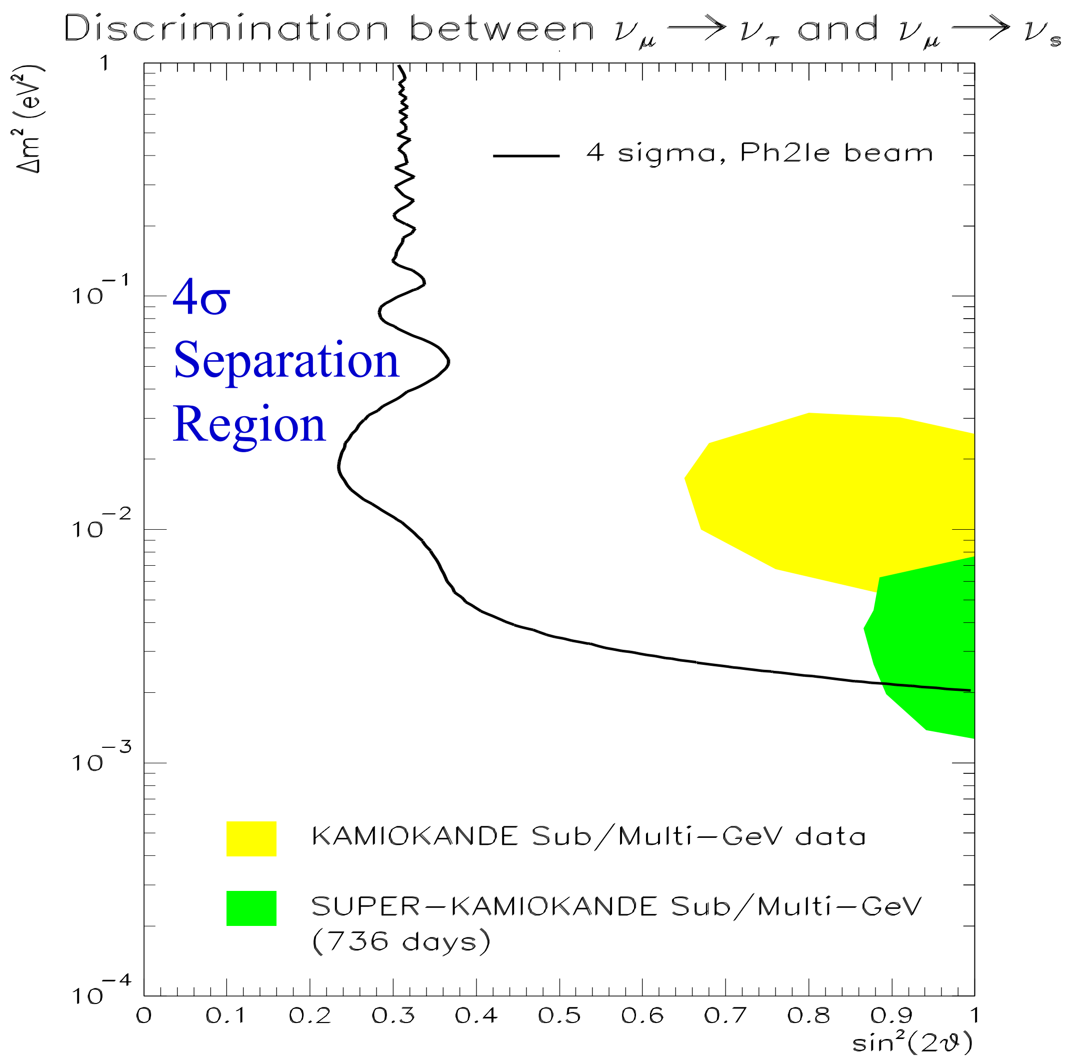


Minos can measure Δm^2 and $\sin^2 2\theta$ over the complete Super-K region



10 kt-yr Exposure
(~1400 CC events/yr)

MINOS Oscillation Mode Sensitivity
(Discriminate $\nu_\mu \rightarrow \nu_\tau$ vs. $\nu_\mu \rightarrow \nu_{sterile}$)

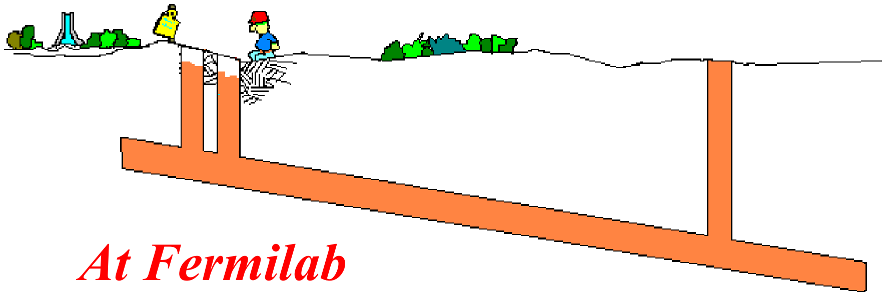


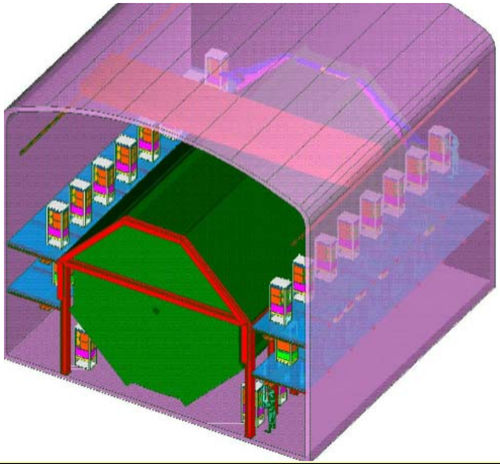
- Use CC/NC Ratio to distinguish between oscillations to ν_τ or $\nu_{sterile}$
- For $\nu_\mu \rightarrow \nu_\tau$, CC production of τ's will look like NC ~80% of the time

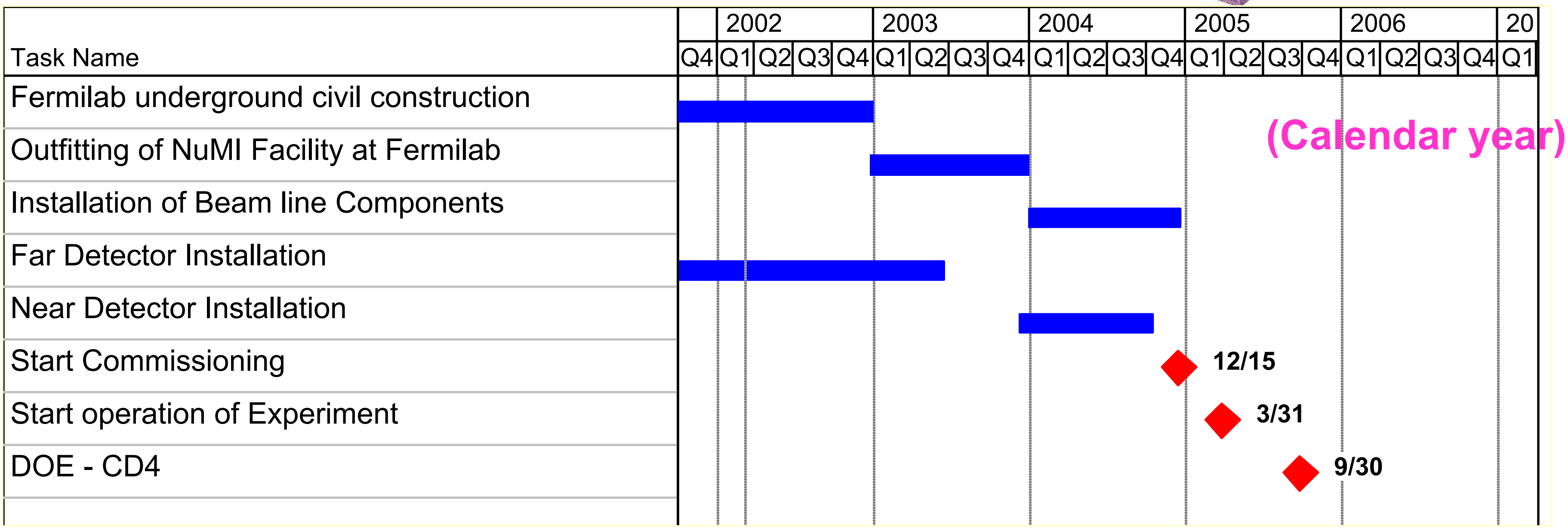
  CC/NC $\rightarrow$ down
- For $\nu_\mu \rightarrow \nu_{sterile}$, both CC and NC will be suppressed.

  CC/NC stays ~ constant

NuMI/Minos Project







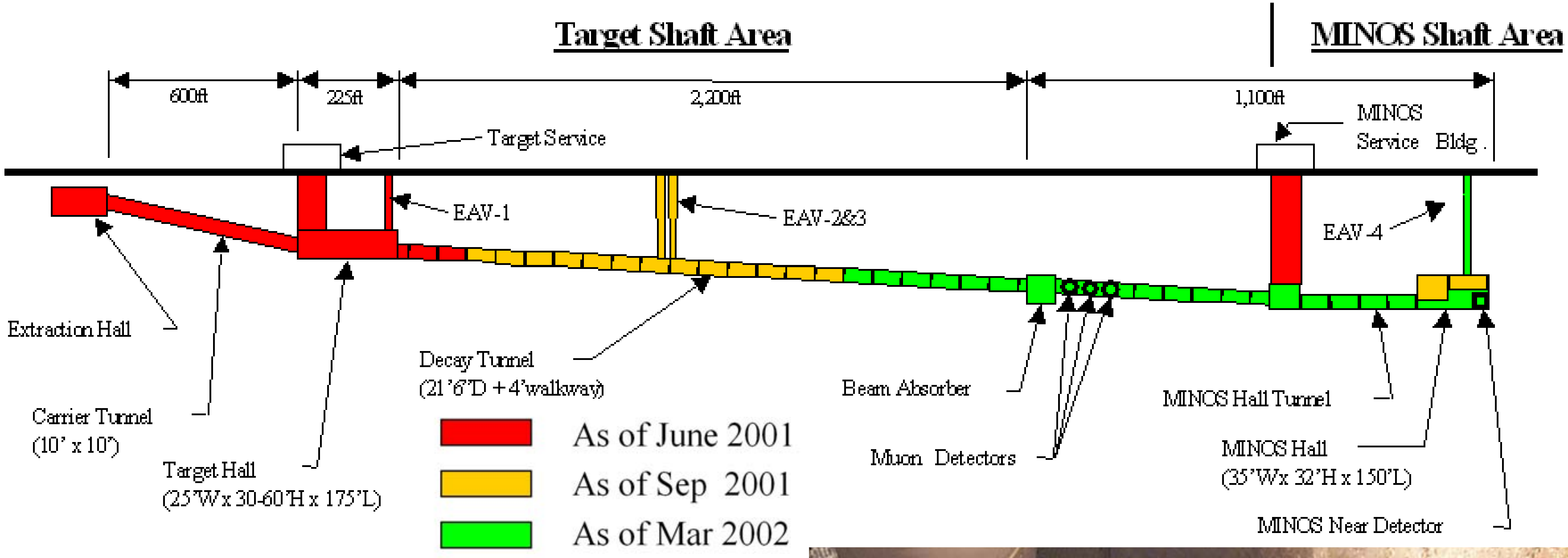
New Cost and schedule baseline Approved Dec. 01

	Nov '98 baseline	New Baseline	Increase
TEC	$76.2M	$109.2M	$33M
OPC	$62.2M	$62.2M	0
TPC	$138.4M	$171.4M	$33M

NuMI/MINOS: Progress

Completion schedule has been constant since new baseline developed in July 2001
⇒ Start operations of NuMI/Minos experiment is Feb., 2005

- Civil Construction
  - NuMI facility at Fermilab
    - TBM Excavation completed — Dec '01
    - Remaining excavation & decay pipe installation to be completed — Nov '02
    - Outfitting bid package sent out — Feb '02
  - MINOS hall at Soudan
    - Outfitting completed — July '01
- Beamline Components
  - Engineering fully staffed & 12 FNAL scientific staff added to various tasks
  - Design & engineering >80% completed
- MINOS Detector
  - Started to move detector components underground — Apr '01
  - Erected 1st Far detector plane — July '01
  - First cosmic muon observed in Far detector planes — Aug '01
  - 33% (~160 planes) of Far detector installed — Mar '02

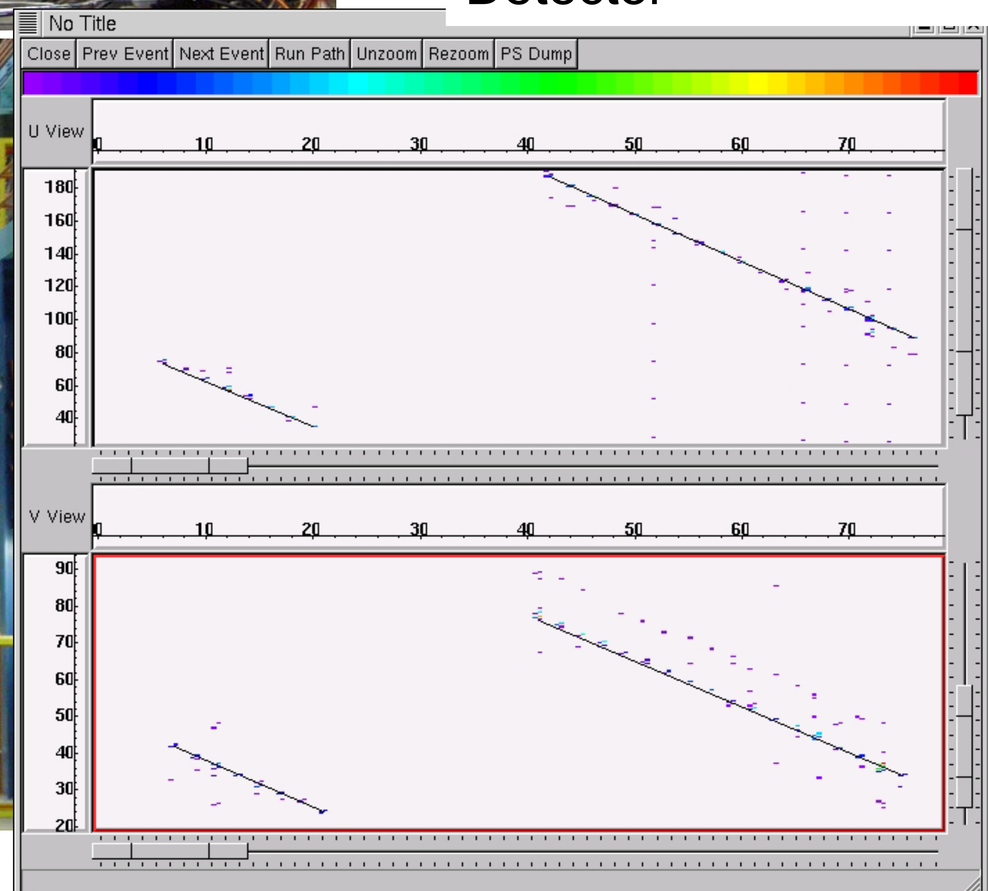


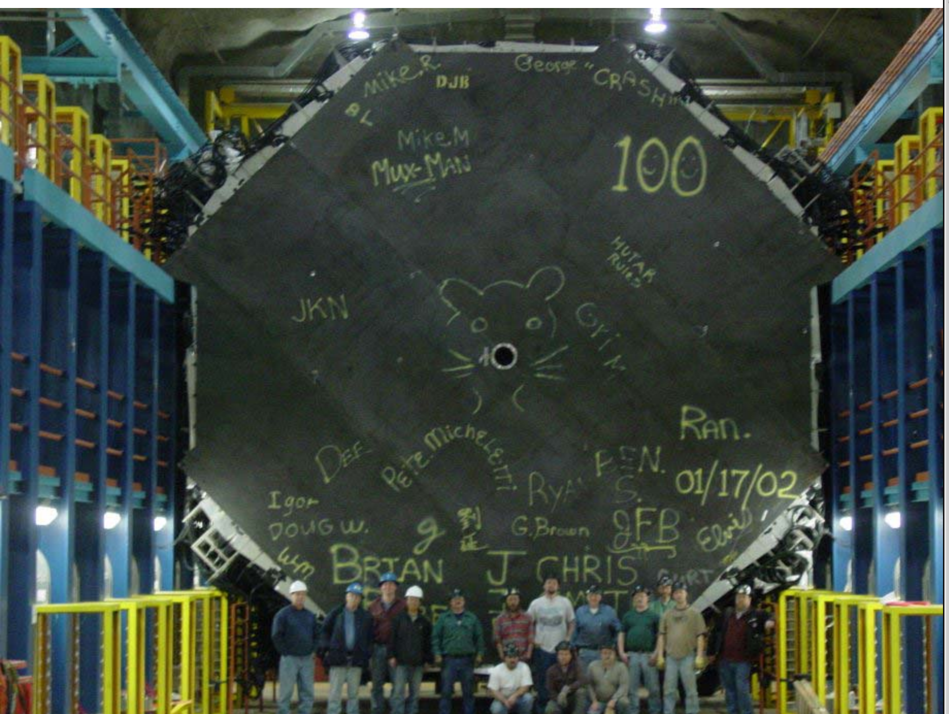
Tunnel Boring Machine

NuMI Decay Tunnel - July 2001

MINOS Far Detector

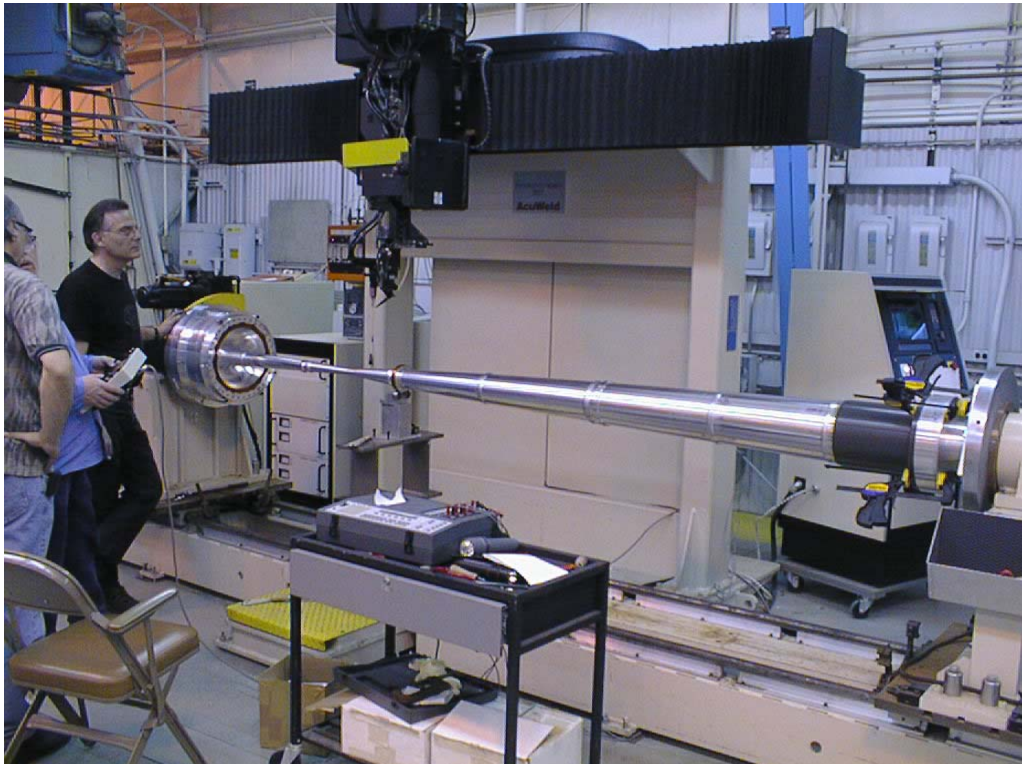
Double Cosmic- Ray Muon in MINOS Far Detector





Far Detector Installation Plane #100 on Jan. 17, 2002!

Horn 1 Prototype



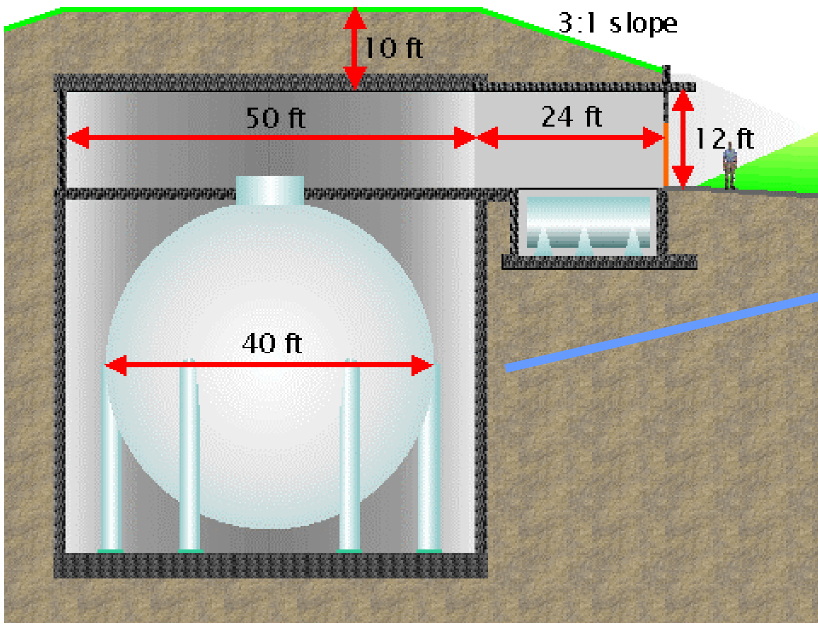
Welding inner conductor

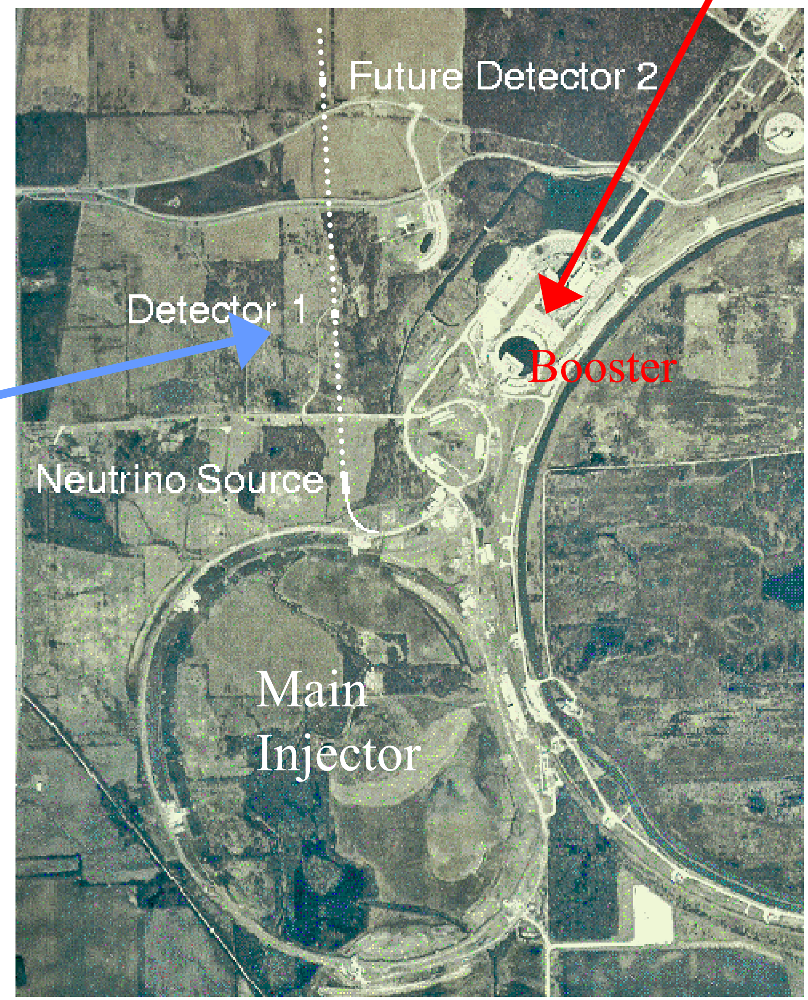
Prototype tested
with 7 million pulses

Assembled for testing

MiniBooNE Experiment

Use protons from the 8 GeV booster
$\Rightarrow$ Neutrino Beam
$\langle E_\nu \rangle \sim 1$ GeV





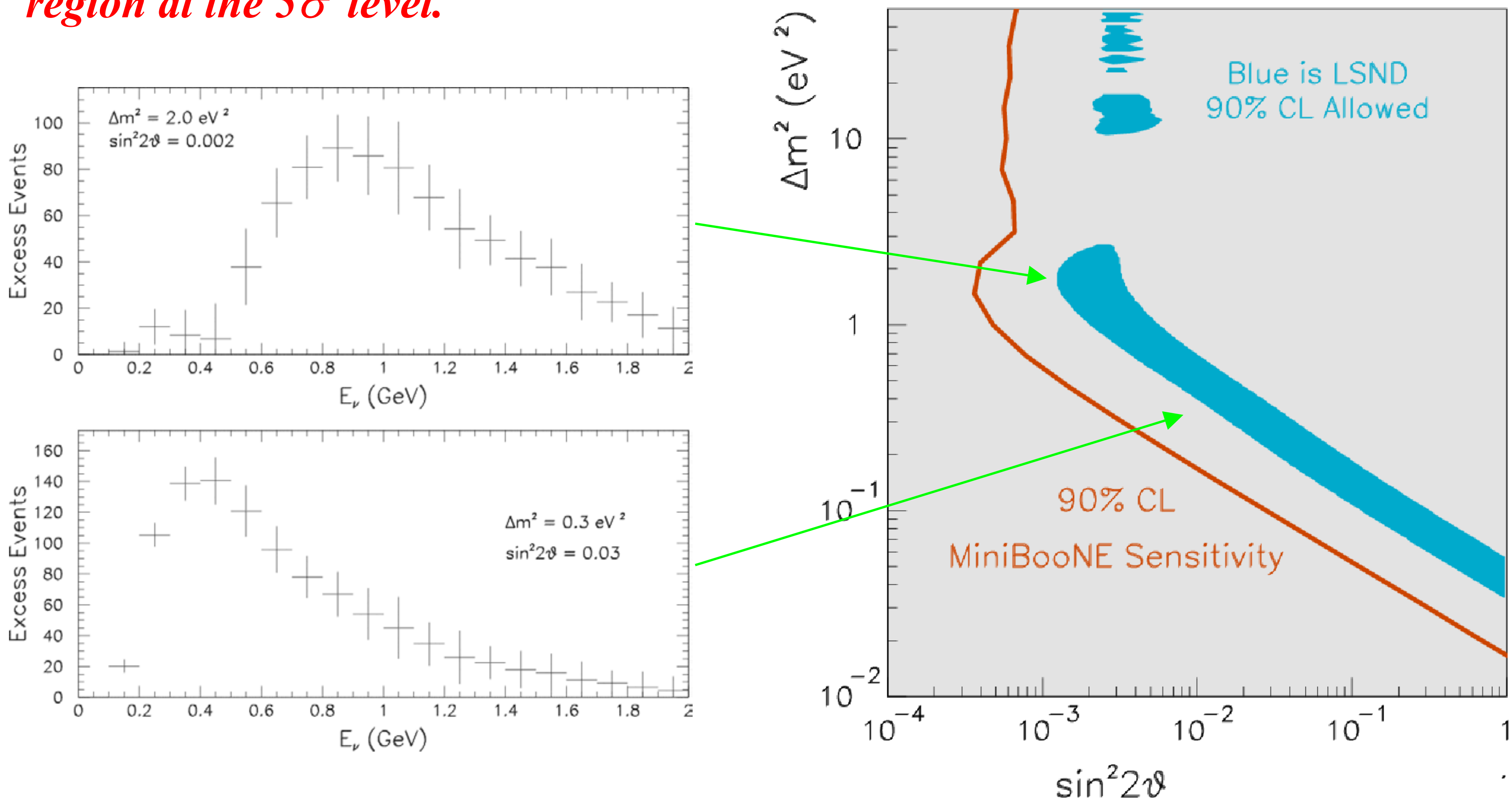
12m sphere filled with mineral oil and PMTs located 500m from source

MiniBooNE Sensitivity to LSND

With two years of running MiniBooNE will completely include or exclude the entire LSND signal region at the 5σ level.

Expected events

- 500,000 ν_μ CC quasi-elastic
- **~1000 ν_e if LSND correct**

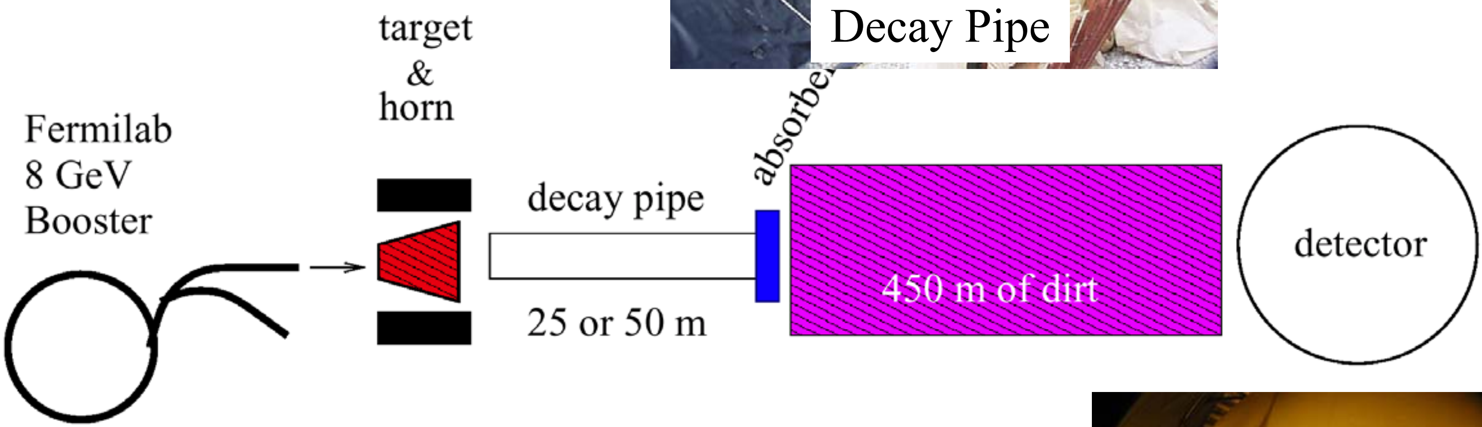


MiniBooNE Neutrino Beam

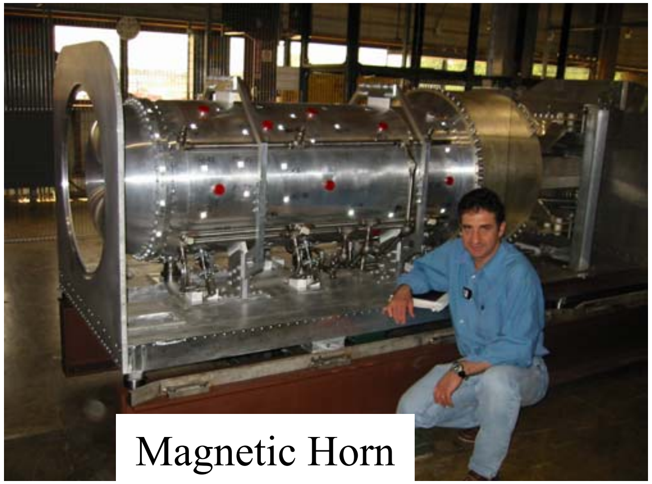

8 GeV Beam Transport

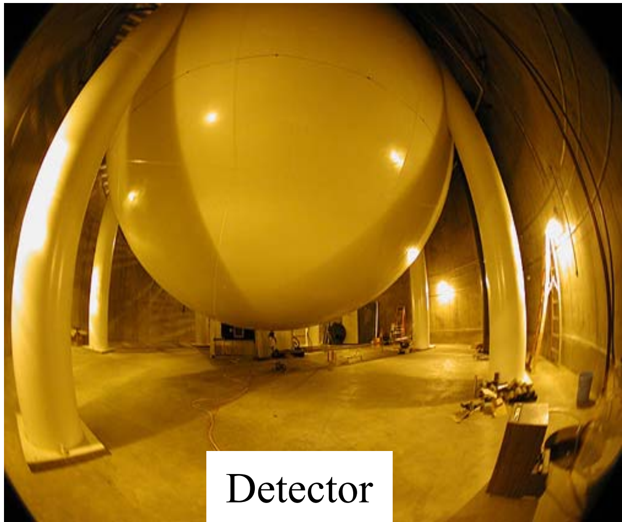

Decay Pipe

Variable decay pipe length (2 absorbers @ 50m and 25m)



One magnetic Horn, with Be target

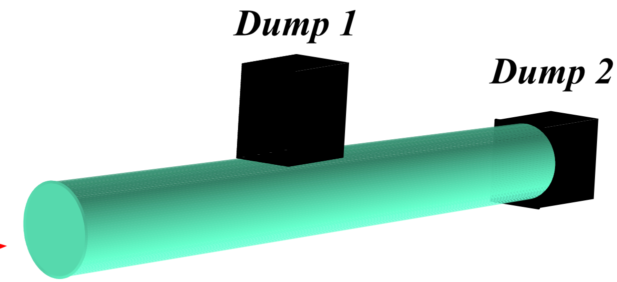

Magnetic Horn


Detector

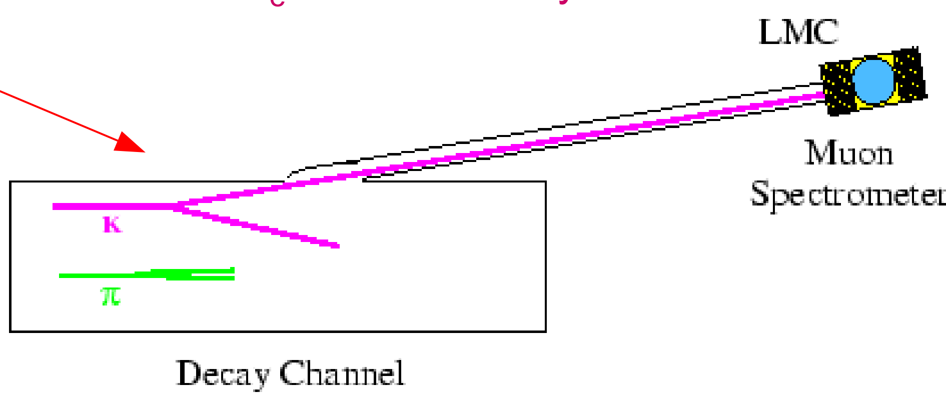
Background Controls

All Backgrounds can be related to data measurements

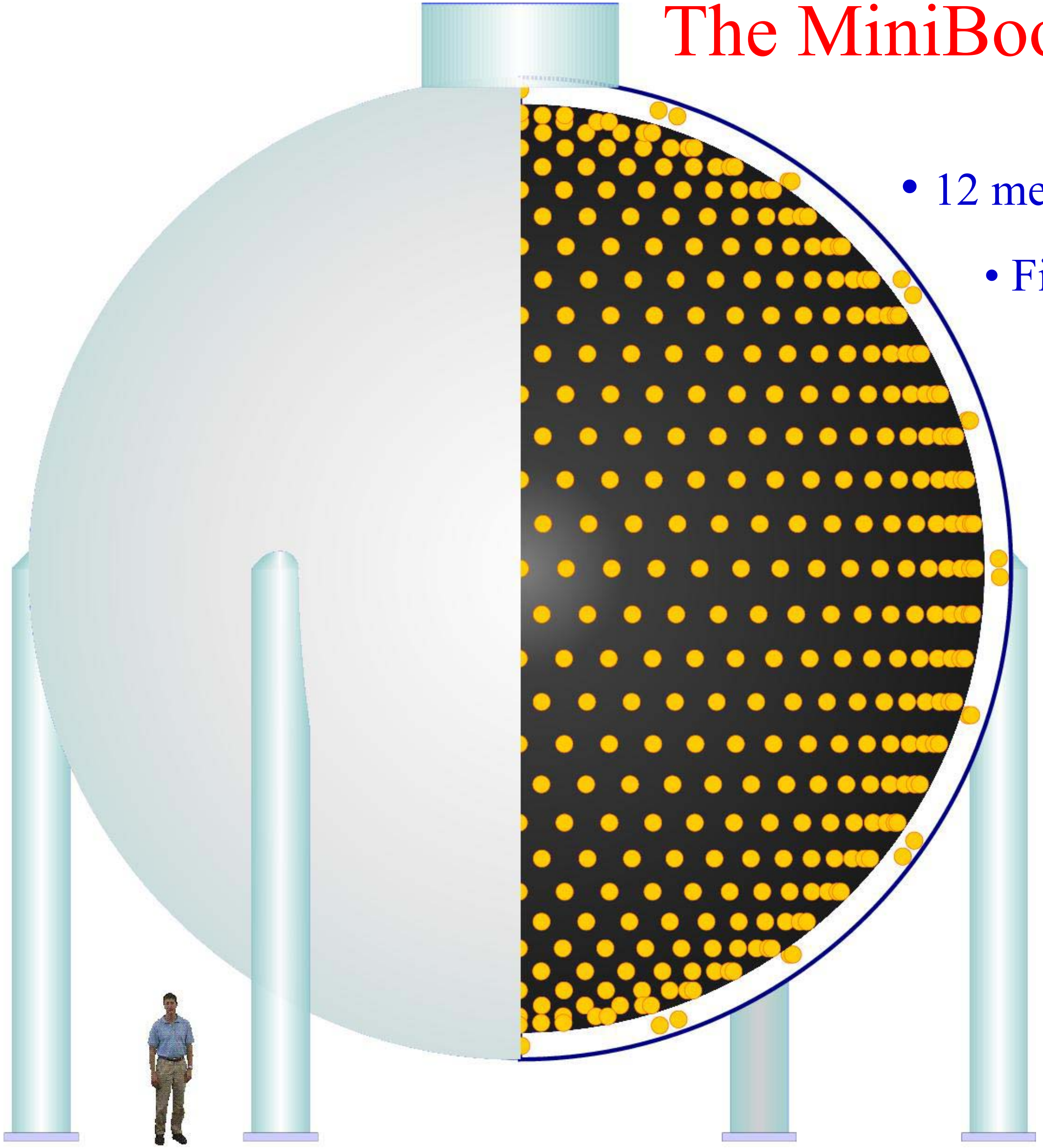
- Intrinsic Beam Backgrounds
  - ν_e from μ –decay (0.06%)
    - Directly tied to observed ν_μ rate
    - Quadratic DK-pipe Length dependence
  - ν_e from K–decay (0.06%)
    - Related to observed high E events
    - Beam surveys: BNL-910, HARP
    - "Little Muon Counters" (LMC)
- Mis-Identification
  - Neutral current π^0 production (0.1%)
    - Scaled from the 99% that are properly reconstructed
  - ν_μ mis-id'ed as ν_e's (0.03%)
    - Scaled from the 99.9% that are properly reconstructed



Can change decay pipe length:
- ν_e from μ–decay $\propto L^2$
- ν_μ from π–decay $\propto L$
- ν_e from K^+–decay $\propto L^{<1}$



The MiniBooNE Detector



- 12 meter diameter sphere
- Filled with 950,000 liters of undoped mineral oil
- Light tight inner veto region with 1280 photomultiplier tubes
- Outer veto region with 241 PMTs.

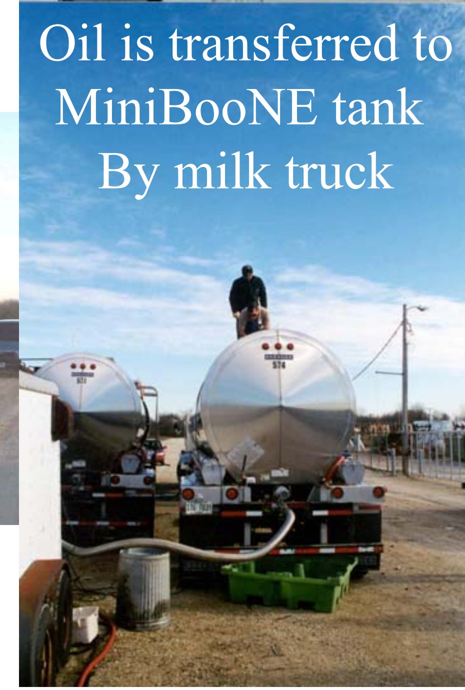
Neutrino interactions in oil produce:

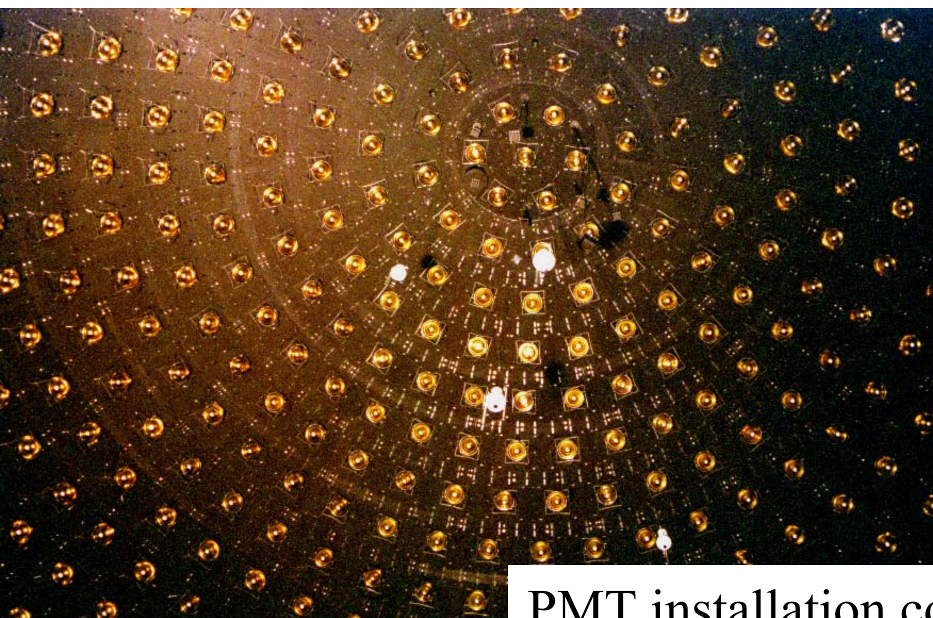
- Prompt Čerenkov light
- Delayed scintillation light

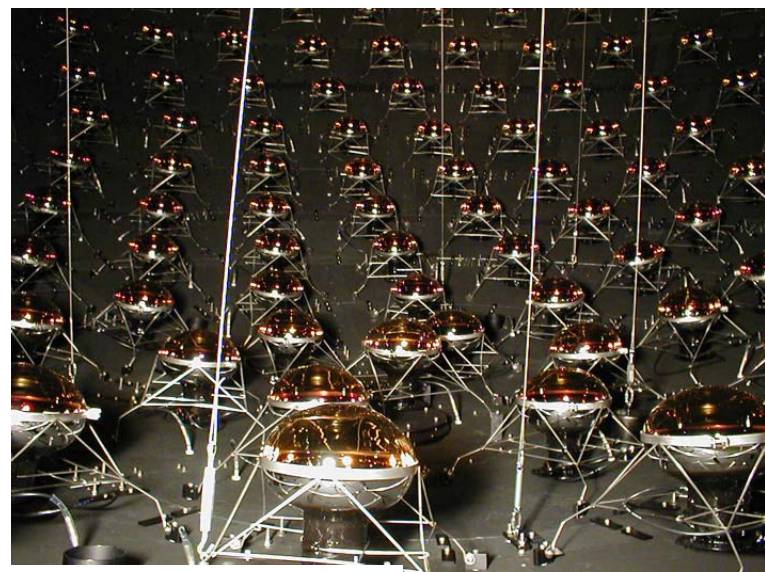
(Ratio ~ 5 Č to 1 Scint.)

MiniBooNE is about to Start

- Everything on schedule for *June , 2002 Start*
  - Detector ~83% filled with oil
  - Horn tested (10^7 pulses)
  - Proton extraction ready



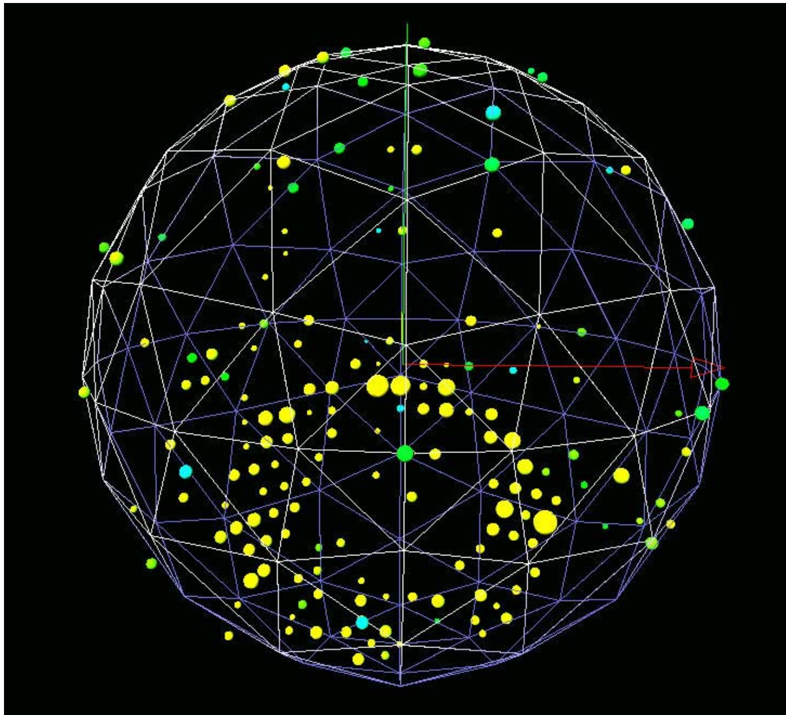




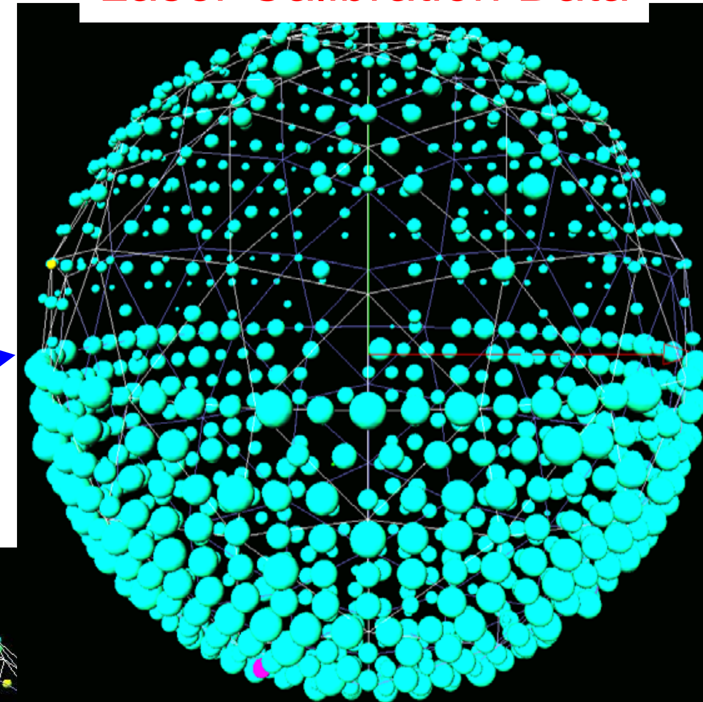
PMT installation completed in October.

MiniBooNE Cosmic-ray Data with tank 55% full of oil

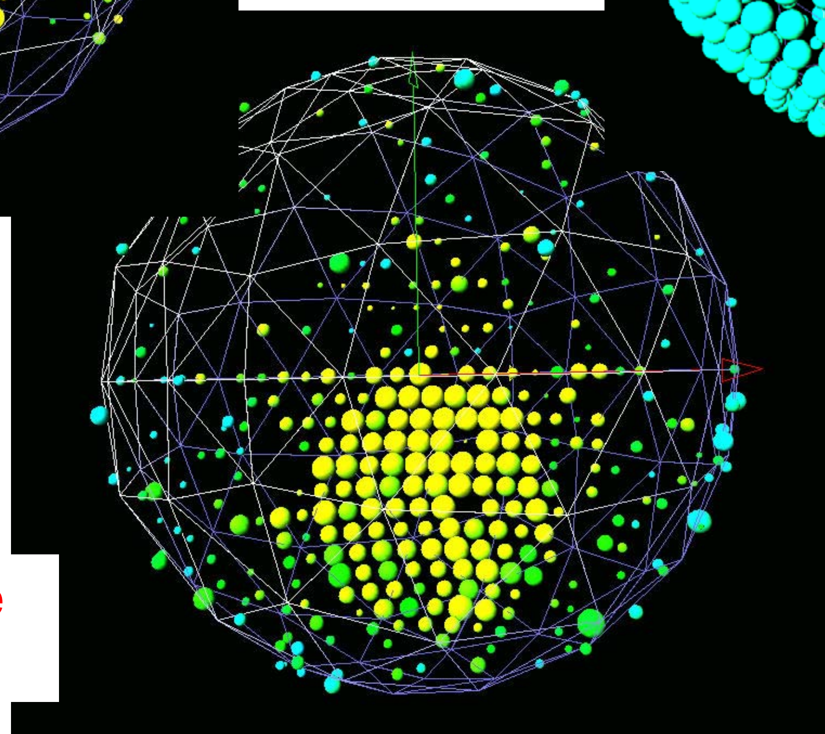
Stopping Muon Candidate Čerenkov Ring



Laser Calibration Data



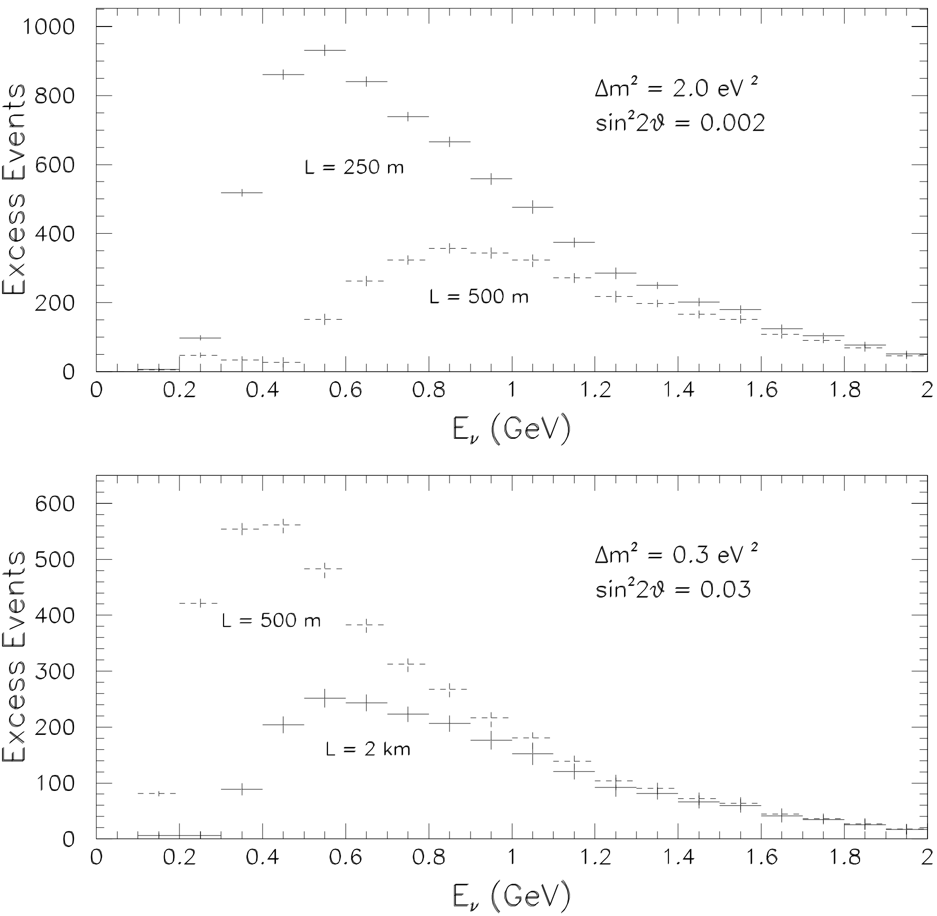
Oil level

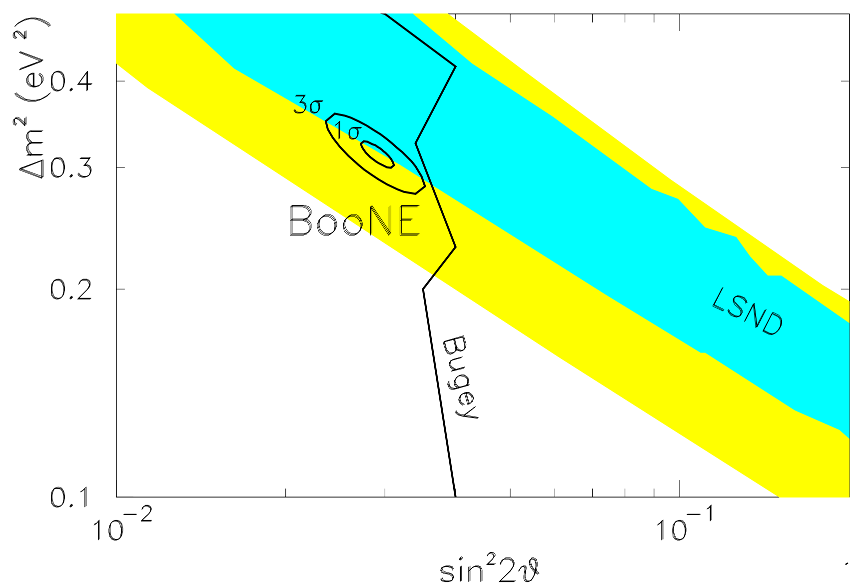


Exiting Muon Candidate Čerenkov Ring

MiniBooNE ⇒ BooNE

- If signal is observed in MiniBooNE, then add second detector at appropriate distance ⇒ **Two detector BooNE experiment**



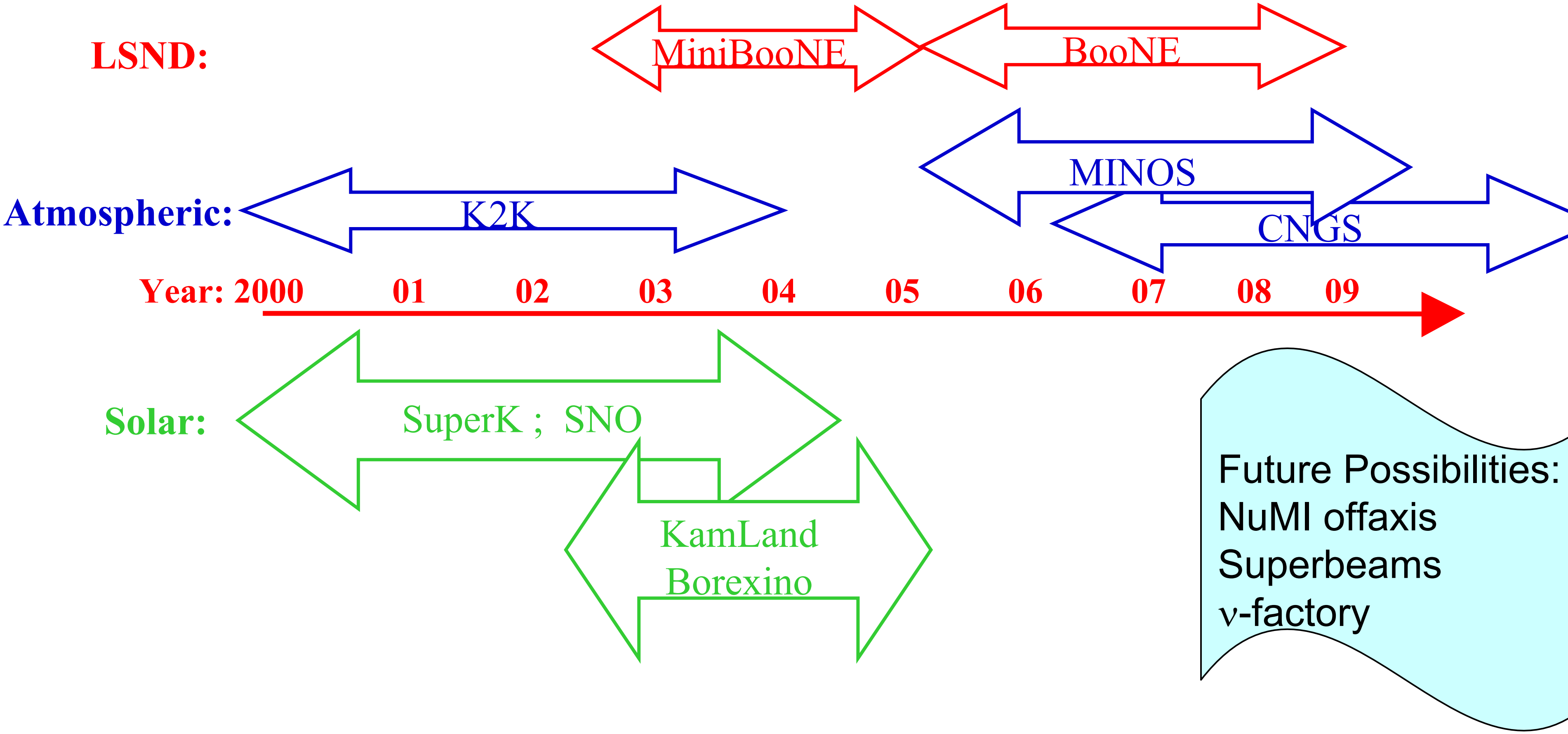


Measure:

Δm^2 to $\pm$ 0.014 eV^2

$\sin^2 2\theta$ to $\pm$ 0.002

Oscillation Experiment Timeline



Exciting Times for Neutrino Experimentation over the next decade !!