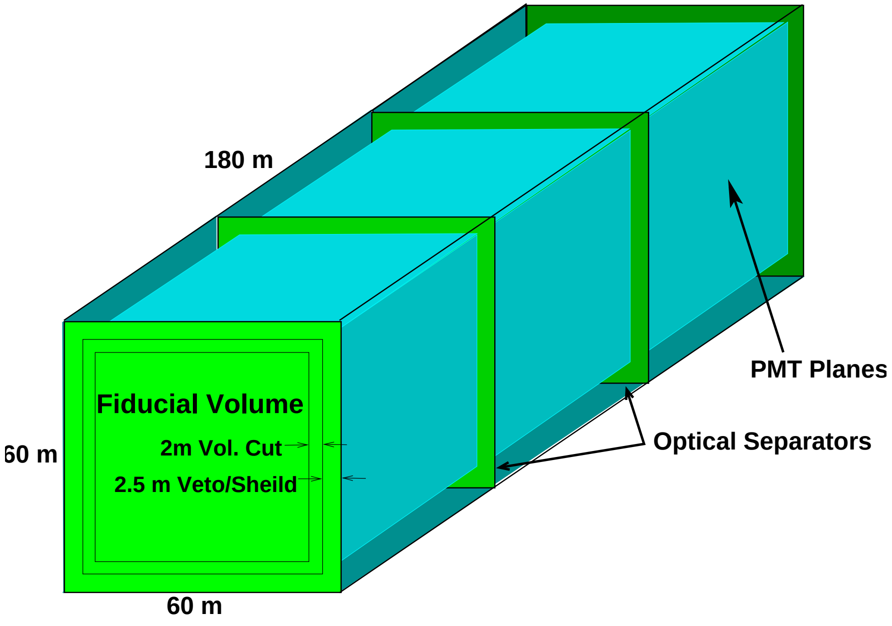


UNO:
Nucleon Decay
and
Neutrino
Observatory

Clark McGrew
CERN, Jan 2002

The UNO Concept

Build on well-established techniques

Explore broad range of physics

Provide a general purpose observatory

Balance between physics and costs

A Bigger Super-Kamiokande? Why?

Large Underground water Cherenkov Detectors have established a remarkable success record

- Exclusion of minimal SU(5)
- Real-time directional measurement of solar neutrinos
- Observation of supernova 1987A
- Discovery of neutrino oscillations (and hence neutrino mass)
- Detected first long baseline neutrinos
- Best limits on nucleon decay

What's left to be done? Wrong Question

This is just the beginning

Physics Opportunities

Nucleon Decay

Neutrino Oscillation

Neutrino Mass Measurements

Astrophysical Observations

The Experimentalists Point of View

Proton Decay

Atmospheric Neutrinos

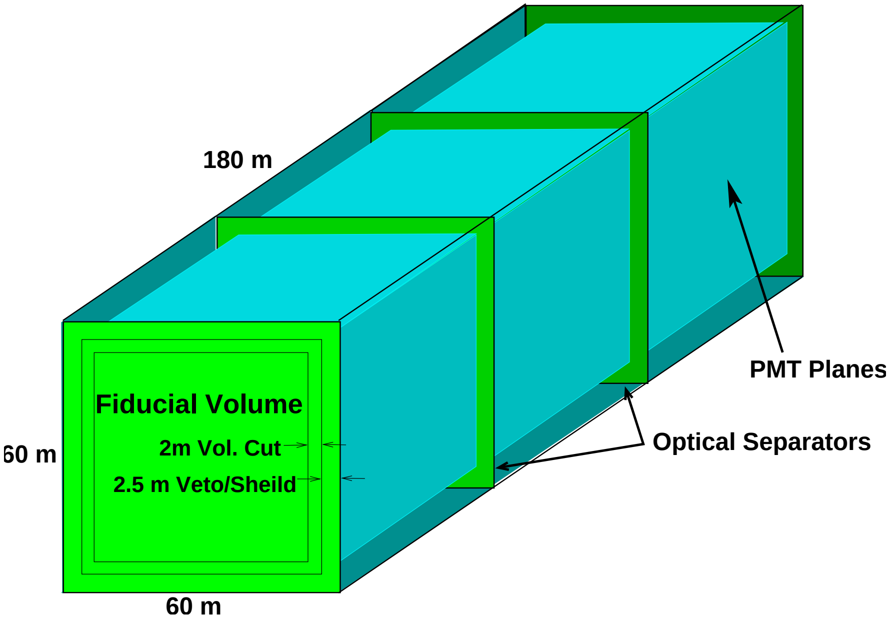
Long Baseline Neutrinos

Solar Neutrinos

Supernova Neutrinos

Neutrino Astronomy

A Baseline Design



- Total Mass: $648\ \mathrm{kt}$
- Fiducial Mass: $440\ \mathrm{kt}$
- Inner Region: $\sim 60,000$ 20 inch PMTs
  - Considering 10-40% PMT coverage
- Outer Region: ~ 15000 8 inch PMTs

a point of comparison, not a final design

Size Comparison

Parameters	Kam-III	IMB-3	SK	UNO
Total mass	4.5 kton	8 kton	50 kton	650 kton
Fiducial mass				
proton decay	1.0 kton	3.3 kton	22 kton	440 kton
solar	0.7 kton	–	22 kton	440 kton
supernova	2.1 kton	6.8 kton	32 kton	580 kton
Photocathode coverage	20%	4%	40%	1/3 40% 2/3 10%
Depth	$16m$	$18m$	$41m$	$60m$

UNO and Proton Decay

Size Matters

- For $1\ \mathrm{Mt}\cdot\mathrm{yr}$ exposure (no background)
  - $\tau_{sens} \sim \frac{1}{4}\epsilon \times 10^{35}\ \mathrm{yr}$
  - $\tau_{90\%} \sim \epsilon \times 10^{35}\ \mathrm{yr}$
- Want multi-$\mathrm{Mt}\cdot\mathrm{yr}$ exposures

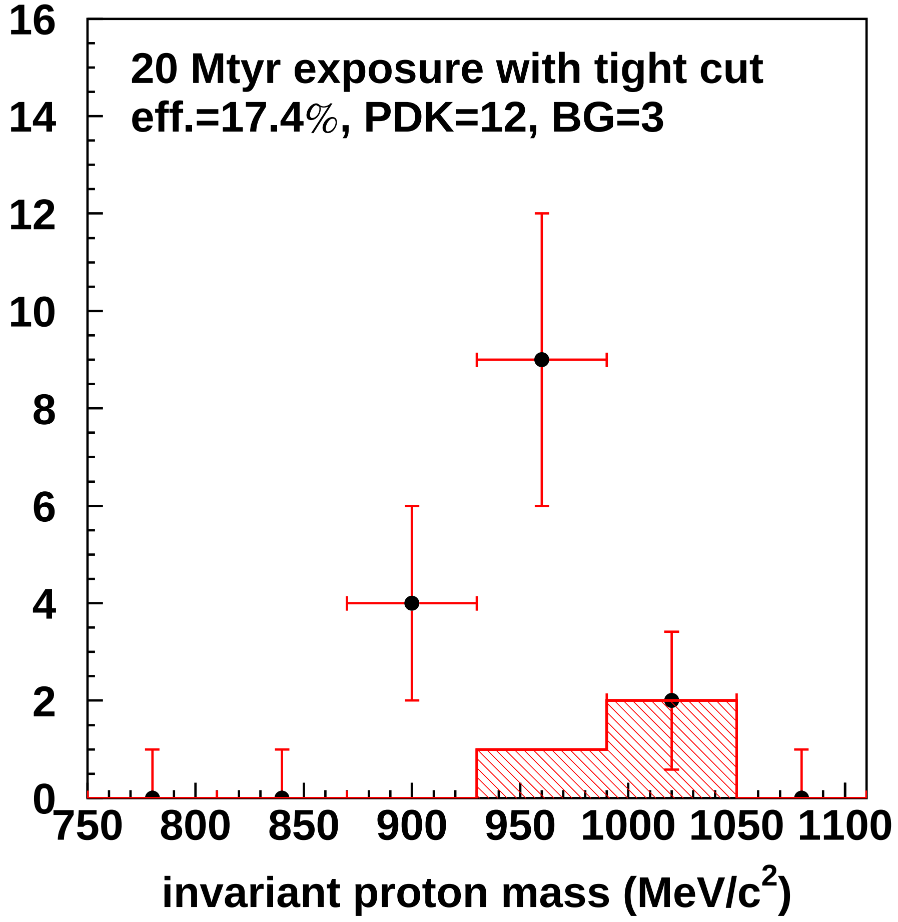
Background spoils the limit

- Must be low background

There are no sure thing decay modes

- UNO is sensitive to many modes

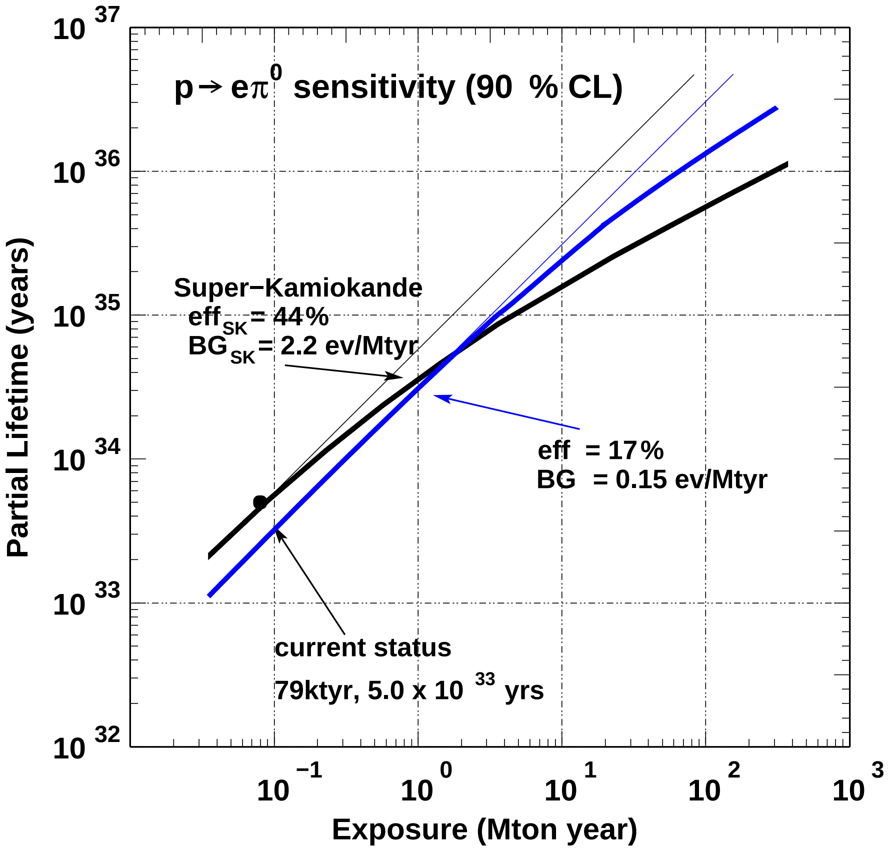
$p \rightarrow e^+\pi^0$ Signature



- $p \rightarrow e^+\pi^0$
- Optimized for free protons
  - $P_{tot} < 100$ MeV
- $\tau = 1 \times 10^{35}$ yr

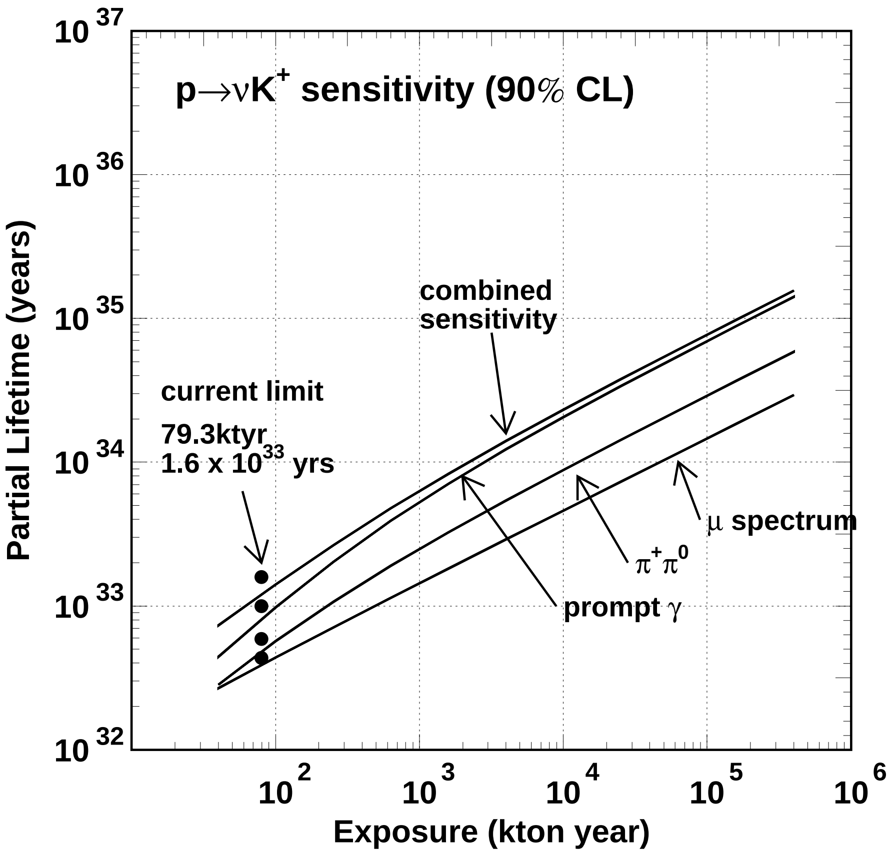
A clear discovery signal

$p \rightarrow e^+\pi^0$ Sensitivity



- $\tau_{90\%}$ =∼6×10^{34} yr in 5 yr
- No background in 10 yr
- Small background in 20 yr

$p \to \nu K^+$ Sensitivity



- Search Methods:
  1. $K^+ \to \mu^+\nu$ μ–spectrum
  2. $K^+ \to \pi^+\pi^0$
  3. $K^+ \to \mu^+\nu \oplus$ “6 MeV γ”
- Limiting Background: $\nu p \to \nu \Lambda K^+$
  - ~ 1 event/Mtyr (current: $\sim$6 event/Mtyr)
- $\tau_{90\%} = \sim 1 \times 10^{34}$ yr in 5 yr

This decay mode determines the PMT coverage requirement

Nucleon Decay Sensitivity

	Super-Kamiokande		UNO	
Mode	Current	After 10 yr	5 yr	15 yr
$p \rightarrow e^+\pi^0$	5×10^{33} yr	3×10^{34} yr	6×10^{34} yr	2×10^{35} yr
$p \rightarrow \nu K^+$	1.6×10^{33} yr	5×10^{33} yr	1×10^{34} yr	2×10^{34} yr

Background estimation is important. The K2K experiment is currently collecting a $\sim 20\ \mathrm{Mtyr}$ equivalent exposure.

Atmospheric Neutrinos

"Phenomena start as a signal, become a calibration, and end up as a background."

Except Atmospheric Neutrinos:

- Started as a signal
- Became a background
- Became a signal

  1988 Kamiokande reports the "too few ν_μ" problem

  1989 IMB confirms the "problem"

  1990 Fréjus and NUSEX don't see a "problem"

  1998 Super-Kamiokande solves the "problem"

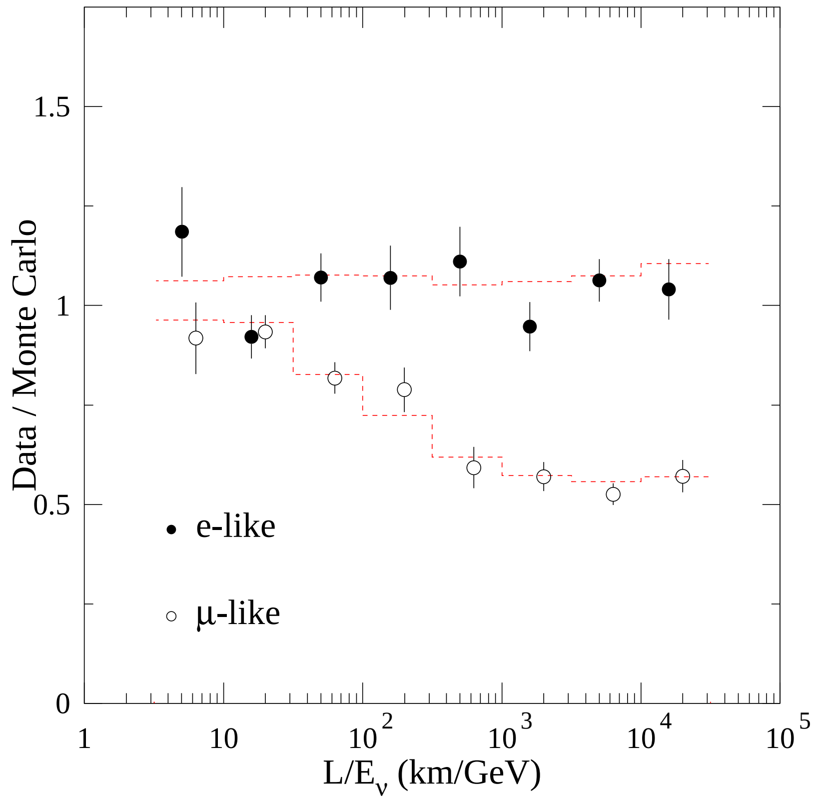
  201? UNO begins

UNO and Atmospheric Neutrinos

- UNO is big
  - Truly Colossal Atmospheric Neutrino Rate
    - UNO: ~ 60000 evt$/\mathrm{yr}$ (165 evt$/\mathrm{d}$)
    - SK: ~ 3000 event$/\mathrm{yr}$ (8.2 evt$/\mathrm{d}$)

    $\sim 400\ \nu_\tau$ events per year
  - Rate with $E_\nu > 100\ \mathrm{GeV}$
  - Fully contain $E_\mu \sim 35\ \mathrm{GeV}$
- Water is a good Hadron Calorimeter
  - $\frac{\Delta E}{E} = 9\% + \frac{30\%}{\sqrt{E}}$

Current L/E Measurement



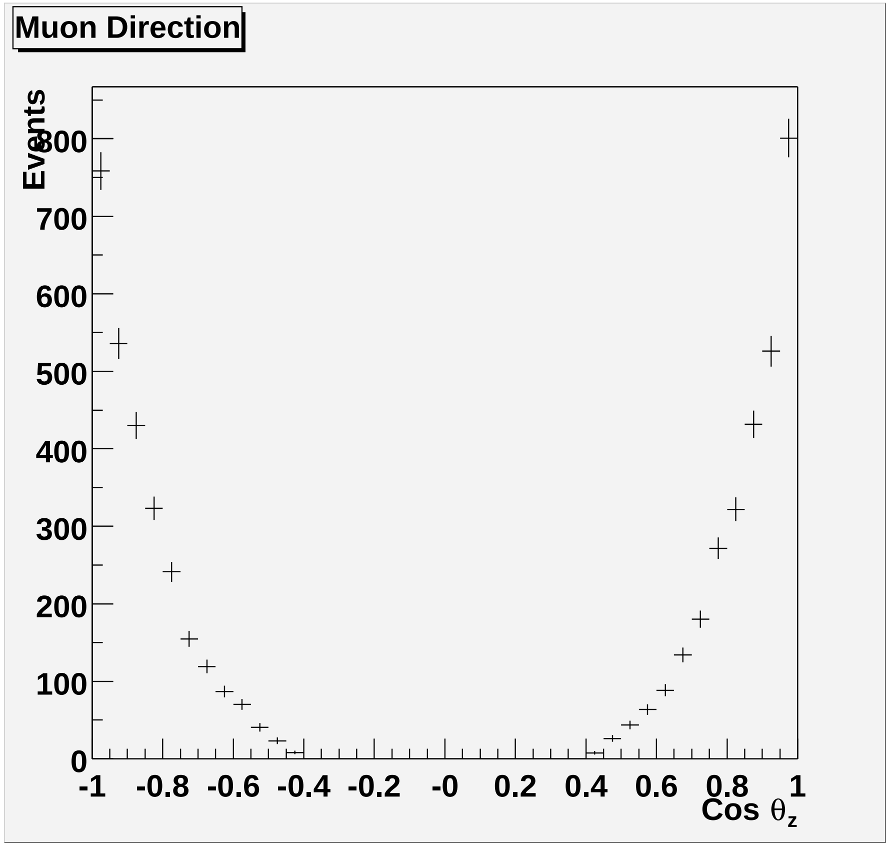
The Super-Kamiokande oscillation analysis is limited by

- $E_c{}^{ont} < 10\ \mathrm{GeV}$
- “Small” Statistics
  - poor L/E resolution
  - limits systematic studies
  - Very MC dependent

Precision Atm. ν Measurements

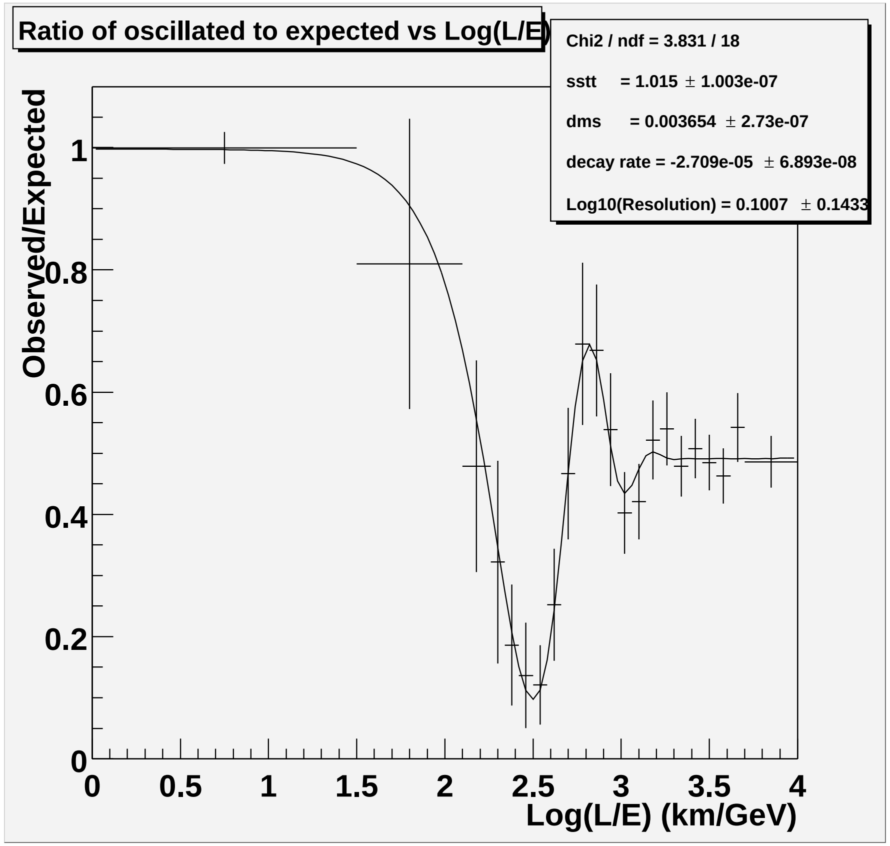
- High Statistics
  - Select high resolution sub-samples
  - Detector systematic studies
  - Detailed verification of Atm. ν models
- Measure total event energy in a wide energy range.

Direct Observation of L/E



- Select good L/E resolution events
- Only muon events ($E_\mu > 1$ GeV)
- Fully Contained
- Determine spectrum with down-going
- Measure L/E with up-going

Direct Observation of L/E



Assume $\Delta m^2 = 3 \times 10^{-3}\,\mathrm{eV}^2$

Provides a Laboratory for:

- Clear test of neutrino oscillation
- Sensitive to non-standard disappearance

(eg. ν decay)

Limiting Δm^2 Systematic Errors

Energy Scale	4%
Atmospheric Neutrino Zenith Angle	5%
Angular Resolution	5%
Total	$< 10\%$

i.e. $\Delta m^2 = 0.003 \pm 0.0003$ eV^2

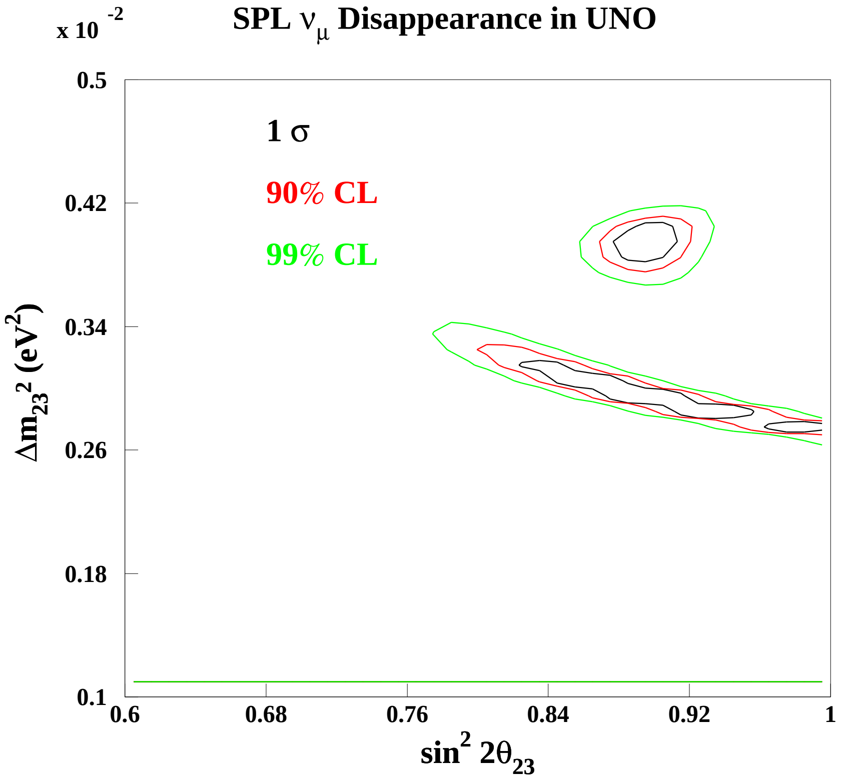
Systematic errors will be studied with data.

UNO and Long Baseline Neutrinos

Assumes a particular beam and baseline to get a flavor of what is possible

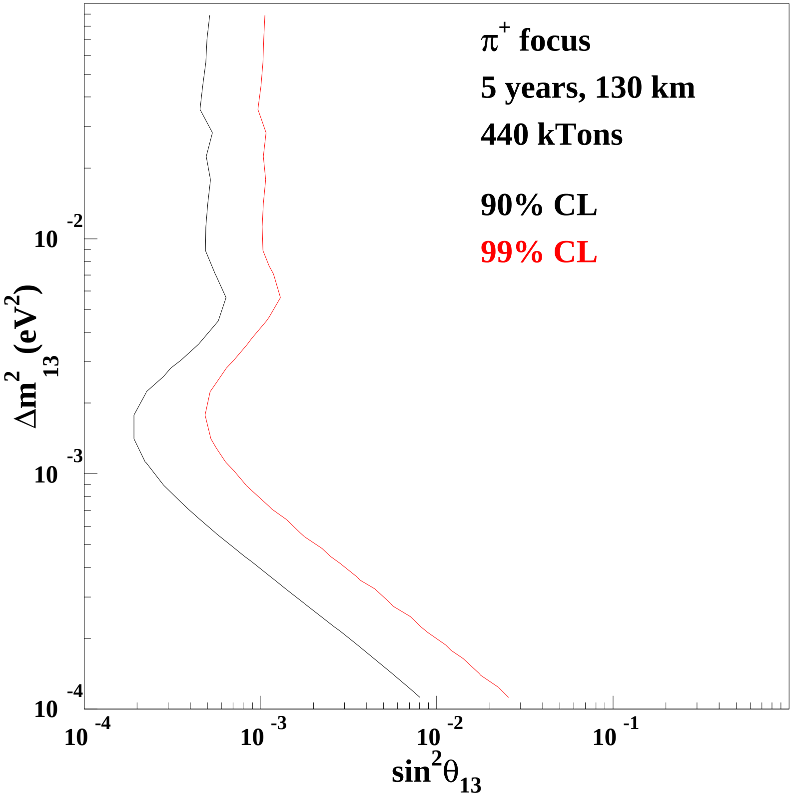
- The CERN SPL beam: $E_\nu \sim 300\ \mathrm{MeV}$
- Detector in Fréjus tunnel
  - Baseline: $130\ \mathrm{km}$
- Assume Super-Kamiokande efficiencies.

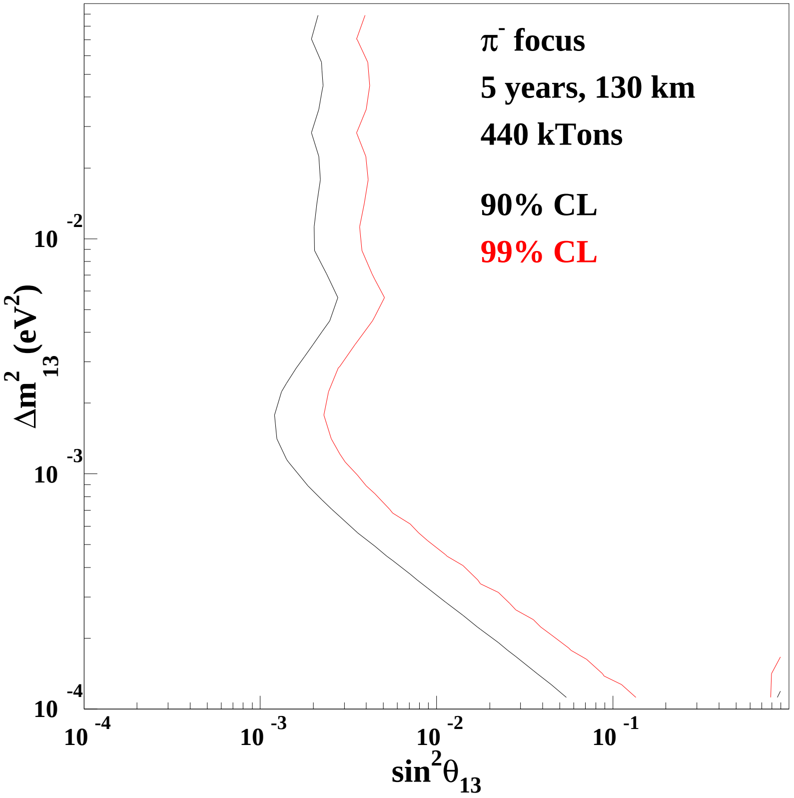
Δm^2 Sensitivity



- Δm^2 at 3 or 4 $\times 10^{-3}$
- Expect ~10000 events in 5 years
- Sensitivity is a few % statistical.

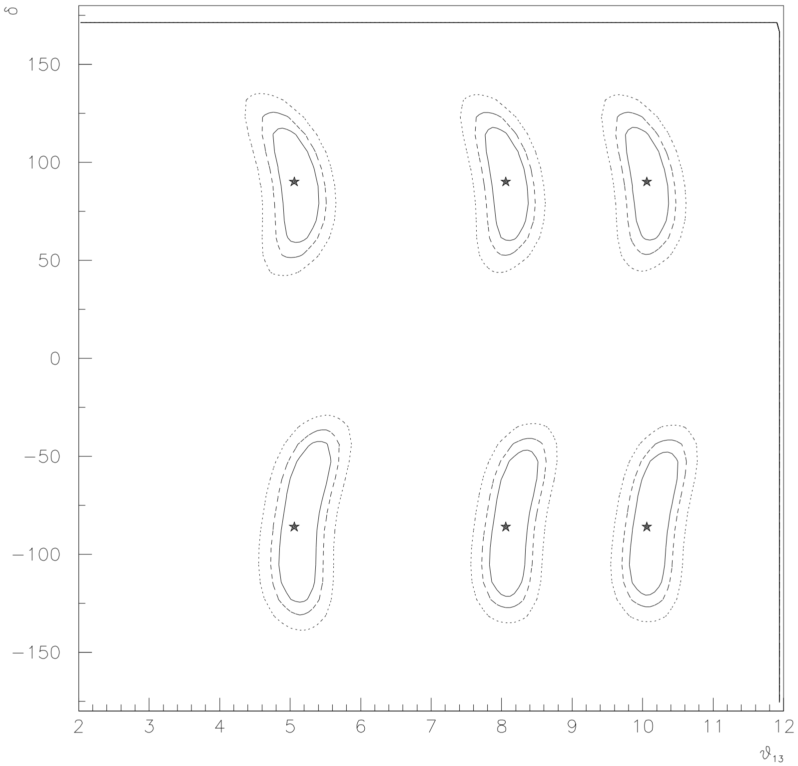
$\sin^2\theta_{13}$ Sensitivity





5 years of beam.

CP Violation



- 2 years π^+
- 10 years π^-
- Assume the LMA
  - Δm^2 = 1.0$\times 10^{-4}$ eV^2
  - $\theta_{12} = 45$ °

UNO and Supernova Neutrinos

A Supernova at 10 kpc

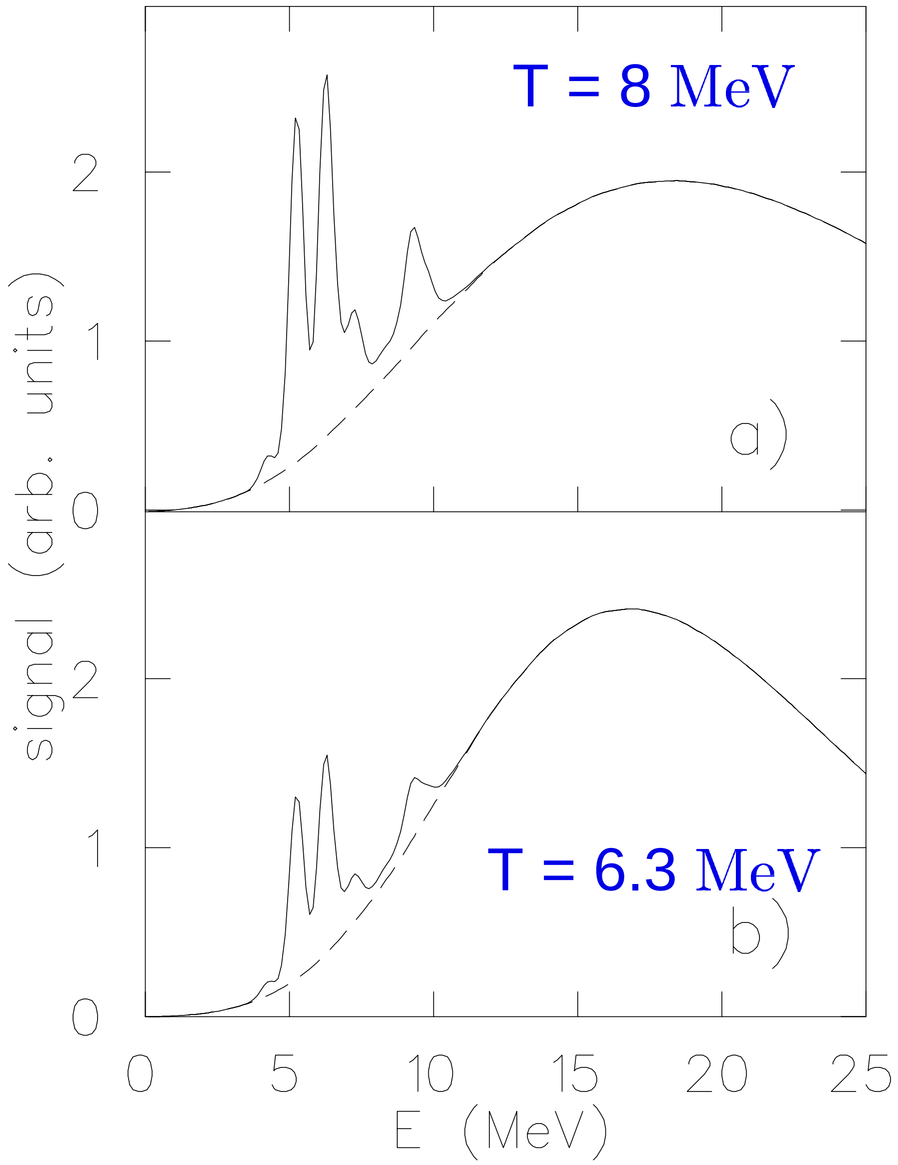
Detector	Method	Mass	Events
UNO	water Cherenkov	400 kt	140,000
Super-Kamiokande	water Cherenkov	22.5 kt	9,000
OMNIS	neutron capture	several kt	$\sim$2,000
SNO	water Cherenkov	1 kt	1,000
KamLAND	scintillation	1 kt	$\sim$500
Borexino	scintillation	1 kt	$\sim$500
LVD	scintillation	0.5 kt	$\sim$200

- Estimate 3 ± 1 Supernova per century in our galaxy (Beacom et al. PRD63,073011).
- UNO would detect $\sim$10 events for a supernova in Andromeda.

Neutronization Pulse

- ~ 1% of ν energy in a 1 ms pulse
  - perhaps 1 evt in SK
  - identifiable pulse in UNO
- Sensitive to
  - stellar collapse physics
  - neutrino mass ($m_\nu > 1\ \mathrm{eV}$)
  - oscillation

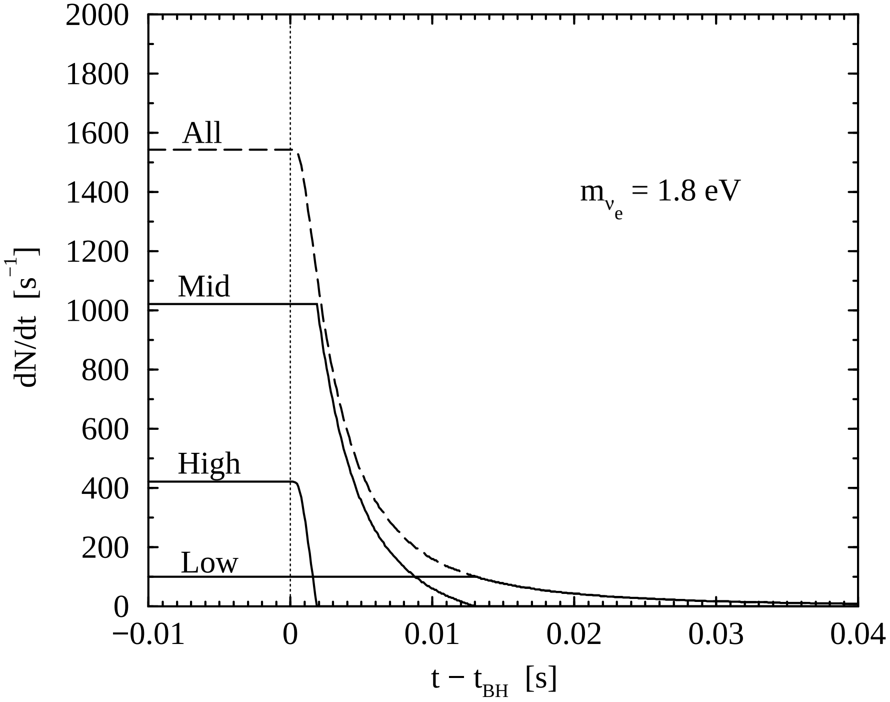
Temperature of a Supernova



- $\nu_x + {}^{16}O \rightarrow \nu_x + X + \gamma$
  - $\sim$ 3% of the events.
- Produces mono-energetic γ between 5–10 MeV.

Blackhole Formation

Roughly half of Supernova may end in black hole formation.



- Formation is predicted during neutrino generation phase.
- Sensitive to collapse for tens of seconds.
- “Direct” evidence of blackhole formation.
- Can be used to measure neutrino kinematic mass.

Summary

- UNO is a General Purpose Detector
- Excellent Physics Opportunities
  - Sensitive to a wide variety of proton decay modes
    τ/B to $\sim 10^{35}$
  - Atmospheric Neutrinos:
    $\delta(\Delta m^2_{23}) \sim$ several%, $\delta(\sin^2 2\theta_{23}) \sim$ several%
  - Long Baseline Neutrinos:
    $\delta(\Delta m^2_{23}) \sim$ few%, $\sin^2\theta_{13} > 2\,^\circ$
  - Sensitive to Supernova in Andromeda
- Builds on 20 Years of Continuous Water Cherenkov Detector Operation