NuMI Off-Axis Experiment (P929)

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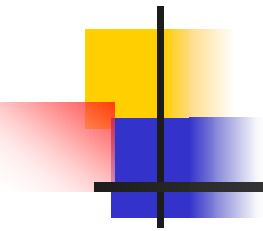
Rutherford Appleton Laboratory

Les Rencontres de Physique
de la Vallée d'Aoste
La Thuile, March 2004

CCLRC
Rutherford Appleton Laboratory



Content

- What is the physics?
- Why off-axis?
  - The beam
  - The site
- What experiment to build?
  - Scintillator
  - Resistive plate chambers
- Sensitivity

What is the Physics?

- Atmospheric neutrino anomaly
- Next generation of long baseline neutrino oscillation experiments
  - Precision measurements
    - Δm^2_{23}
    - $\sin^2 2\theta_{23}$

$$\nu_\mu \rightarrow \nu_\tau$$

- Look for sub-dominant oscillation mode
  - $\sin^2 \theta_{13}$

$$\nu_\mu \rightarrow \nu_e$$

  - Needed: low background
    - Low ν_e beam contamination
    - Few wrong energy neutrinos

- Beam Axis 3.32° into the ground at FNAL, exits at Canadian border.
- 2° off-axis in southern Canada or northern Wisconsin (L = 530 – 950 km)

- **NuMI has 400kW primary proton beam**
  - **120 GeV**
  - **8.67 μsec spill**
  - **1.9 sec rep rate**

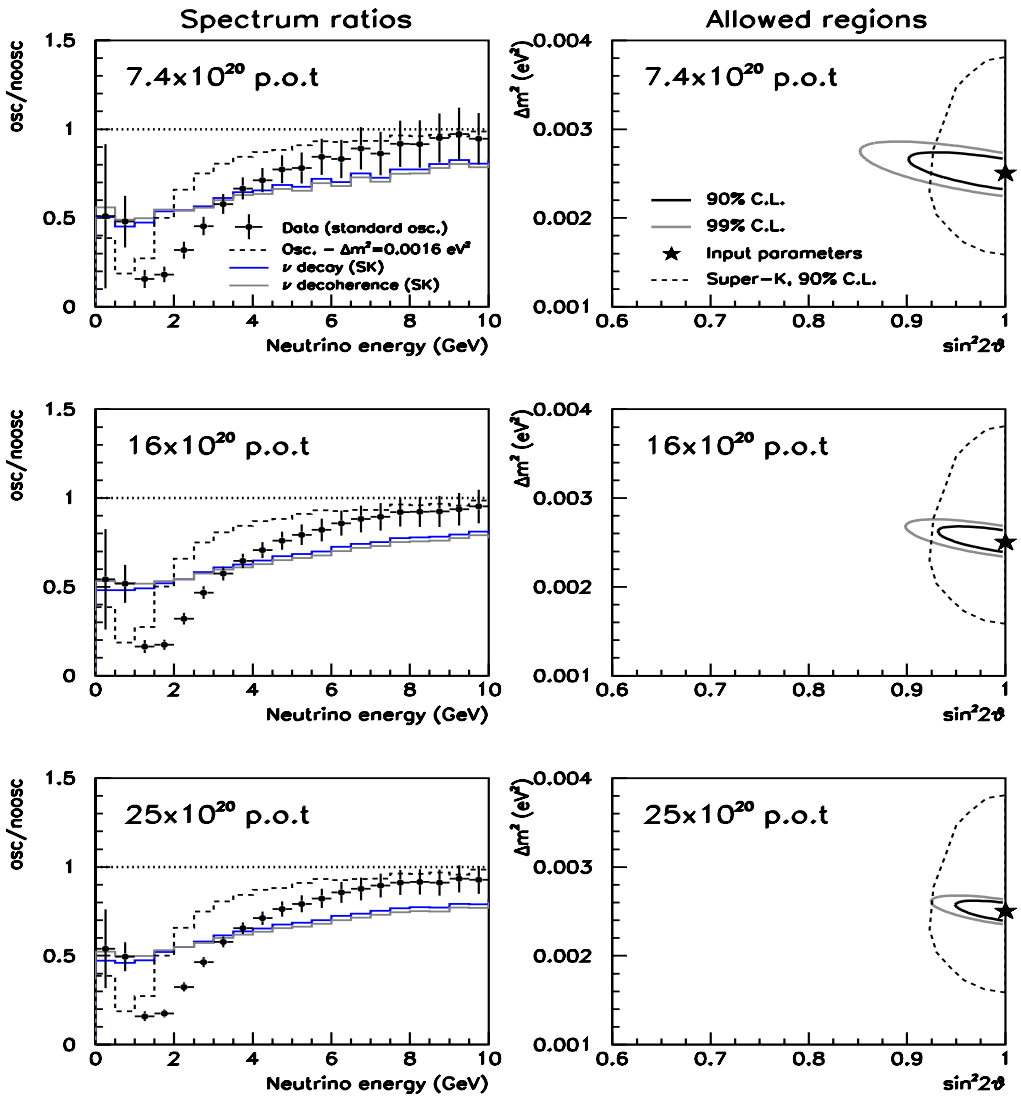
To Soudan Mine
MINOS Near Detector
Booster
Decay Enclosure
Target Enclosure
Tevatron
Main Injector

Minos Far Detector @ Soudan

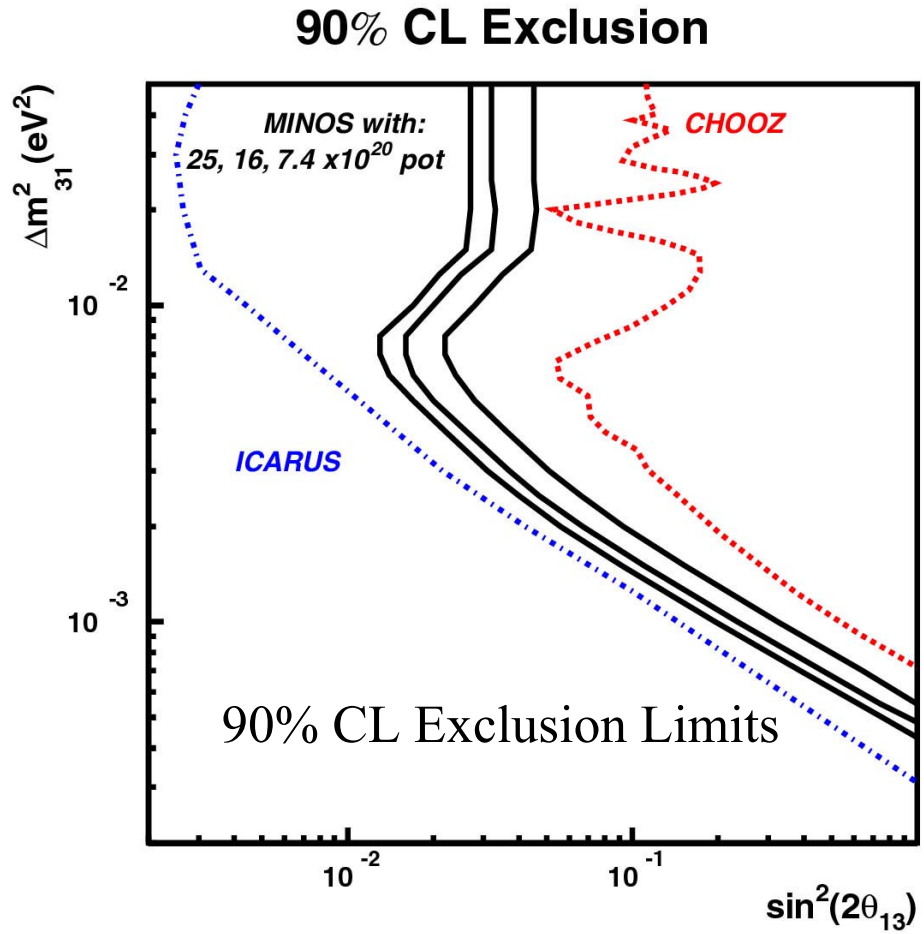
- Steel-scintillator tracking calorimeter
- Magnetized
- Half the detector has been running since mid 2002
- Completed July 2003
- Detector working well, up to or better than specifications in all respects
- Taking atmospheric neutrino data

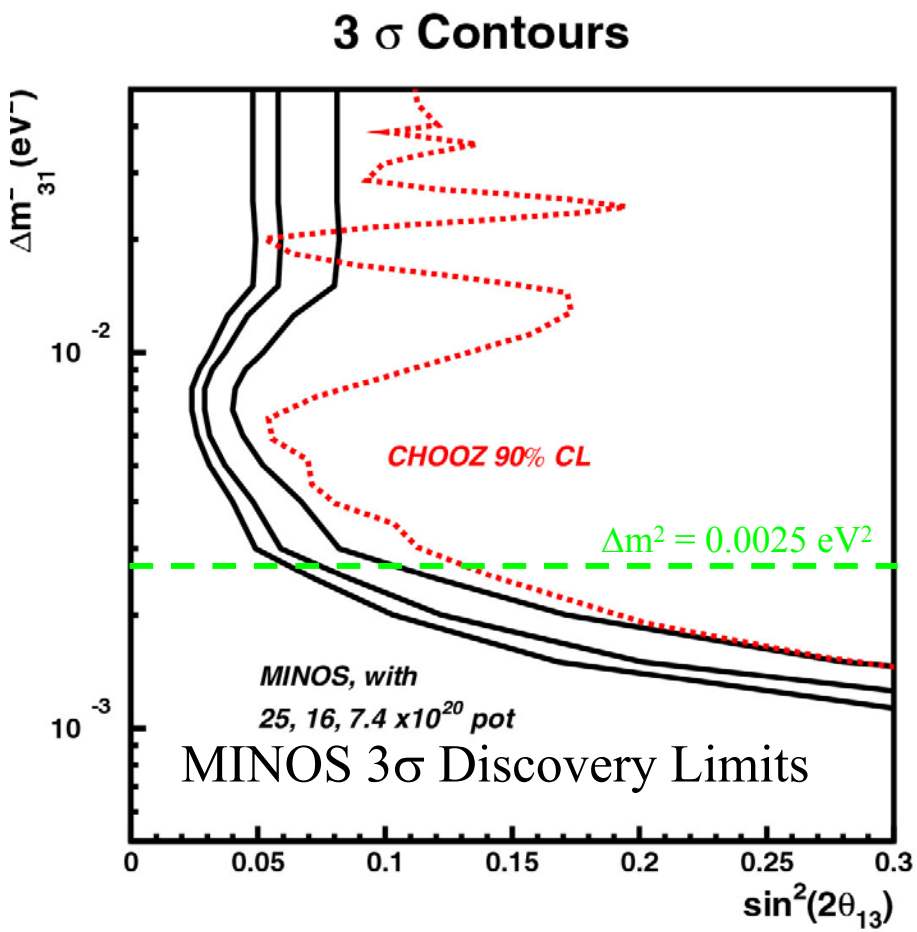
MINOS: CC Measurement

- Three proton intensities
- Points with errors: ratio of measured to expected ν_μ cc events ($\sin^2 2\Theta=1$, $\Delta m^2=0.0025$)
- Blue line neutrino decay hypothesis
- Dashed line oscillations ($\sin^2 2\Theta=1$, $\Delta m^2=0.0016$)
- 90% and 99% confidence allowed regions, compared with old Super-K



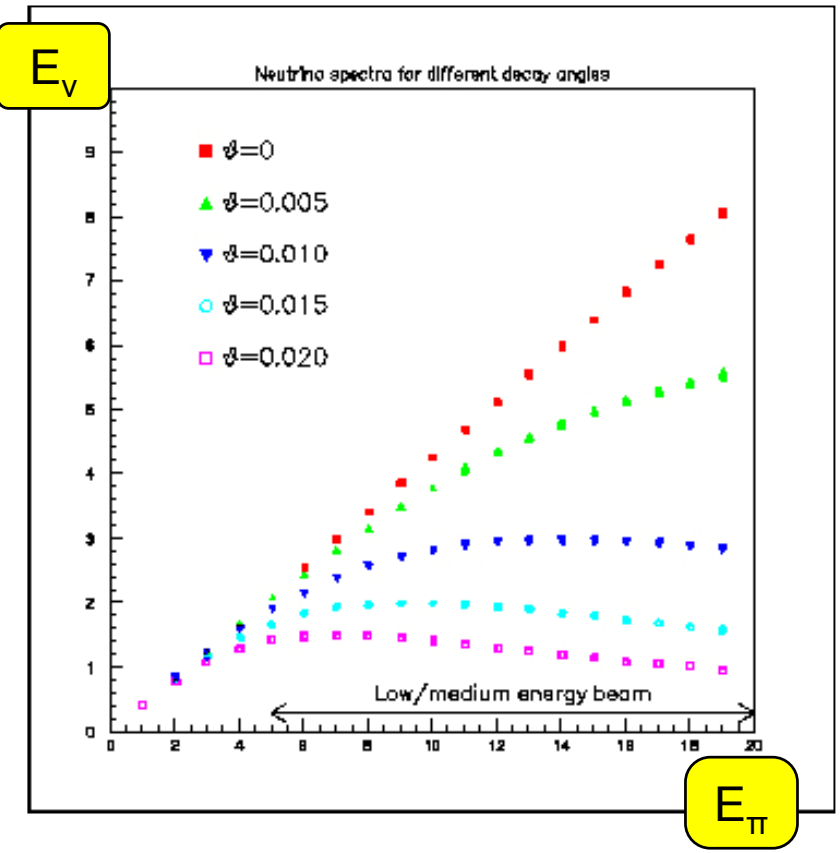
MINOS: Electron Appearance

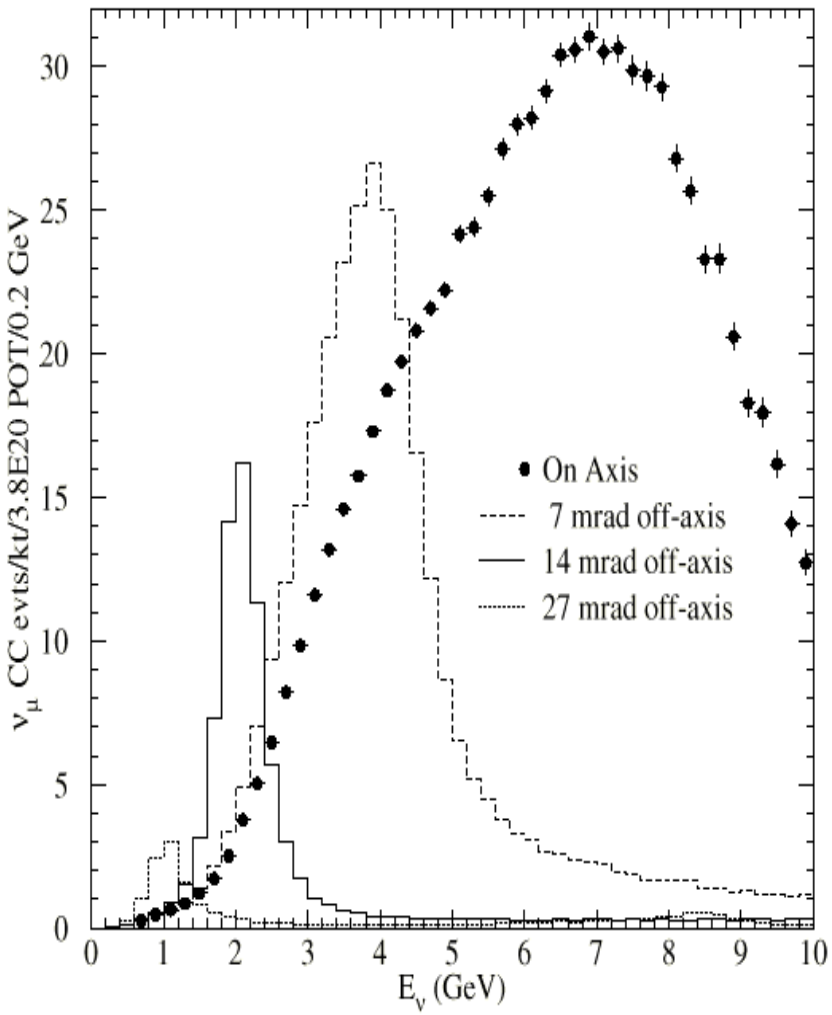




- MINOS sensitivities based on varying numbers of protons on target

Why Off-Axis

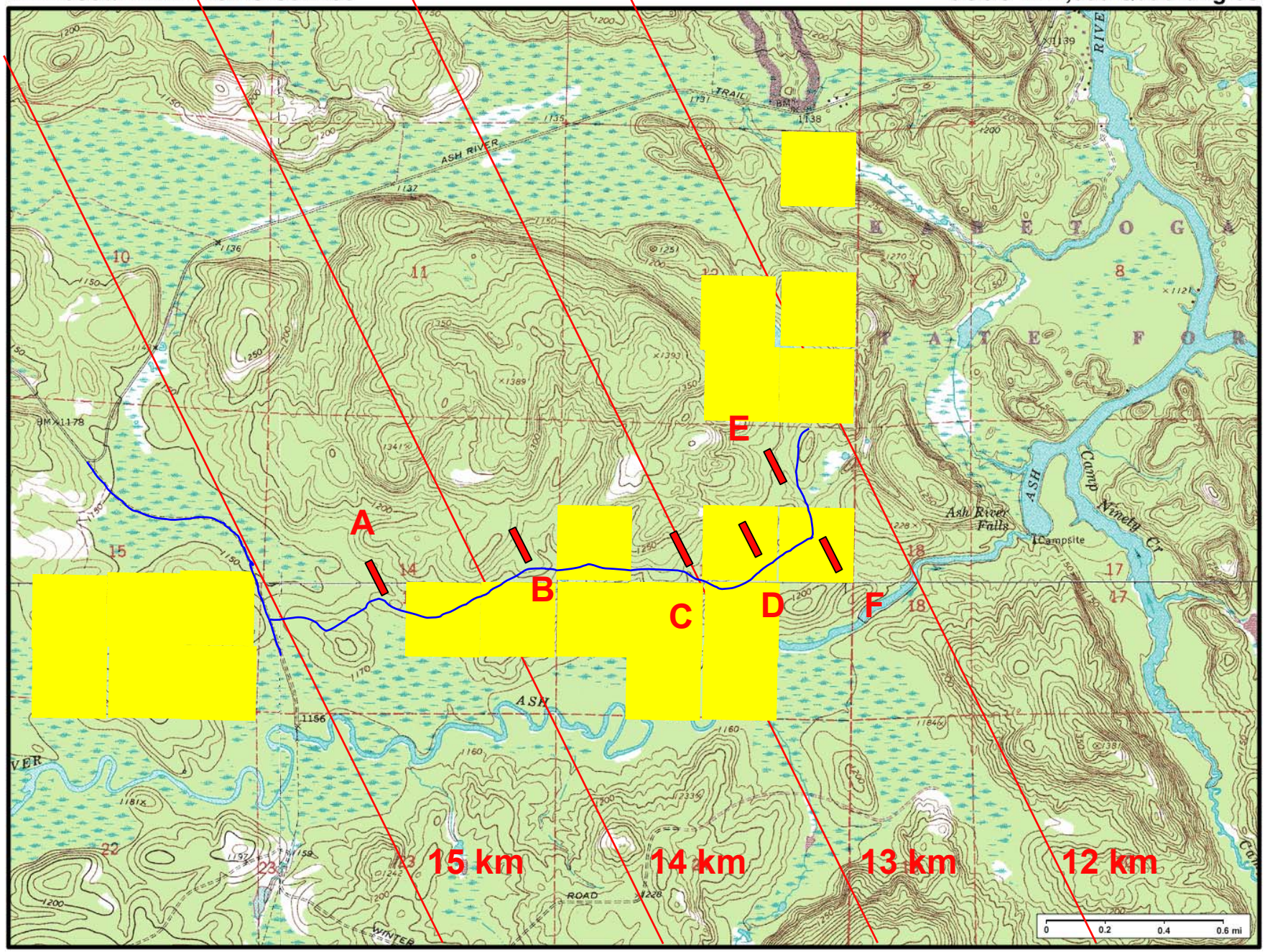




NuMI beam can produce 1-3 GeV intense beams with well defined energy in a cone around the nominal beam direction

Possible Sites

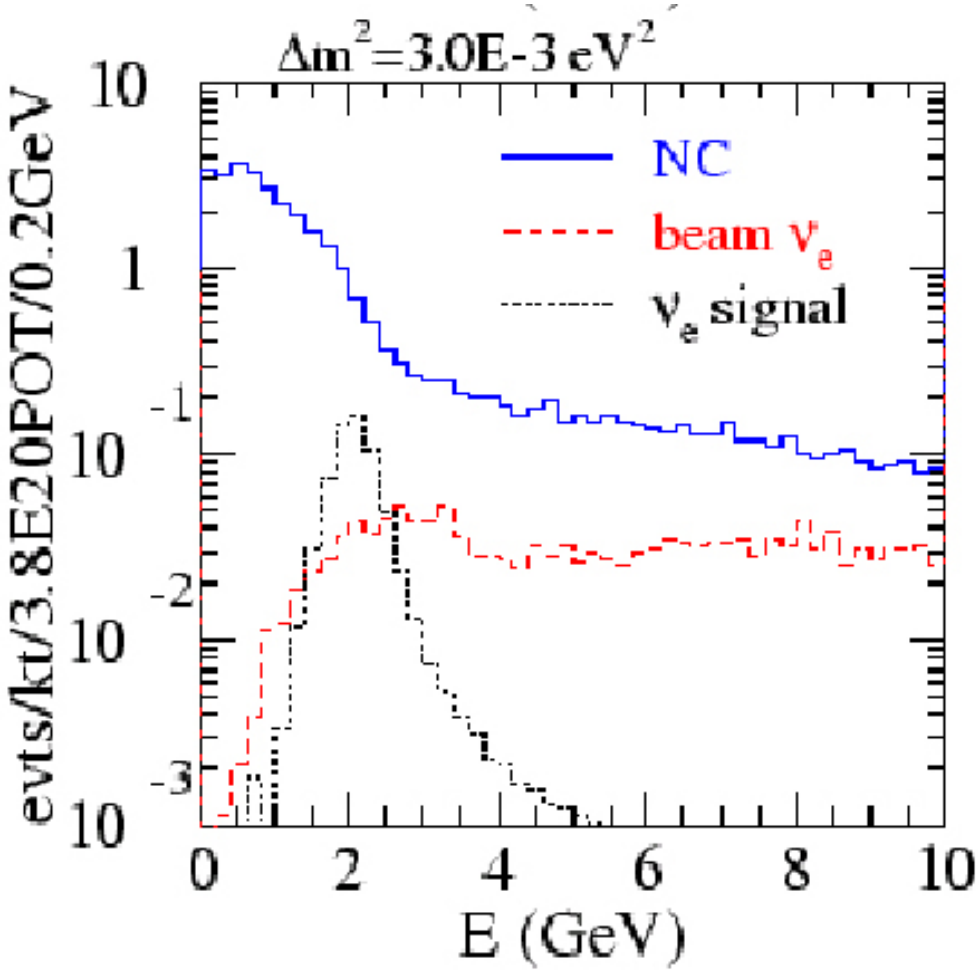
Minnesota DNR - ToMO Service **USGS 1:24,000 Quadrangles**



Maps shown: Ash River NE, Daley Bay, Ash River SE, Ash River SW.

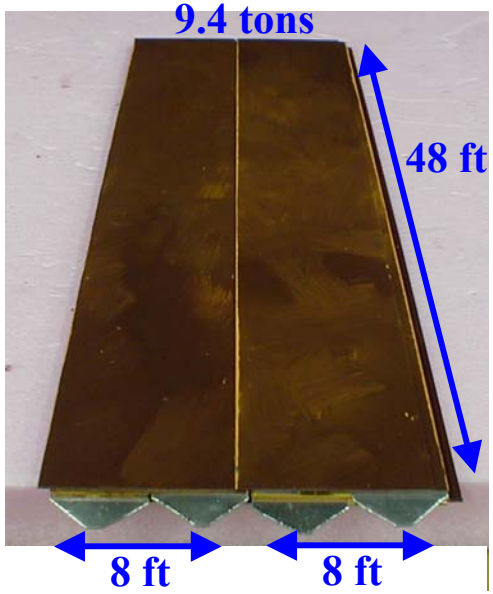
Experimental Challenge

- Small signal
  - huge # NC
- Surface detector
  - No or light overburden
  - cosmic μ
  - μ induced n
  - But:
    Duty factor 10^{-5}
- Technology
  - Liquid Scintillator
  - RPSs



Liquid Sintillator

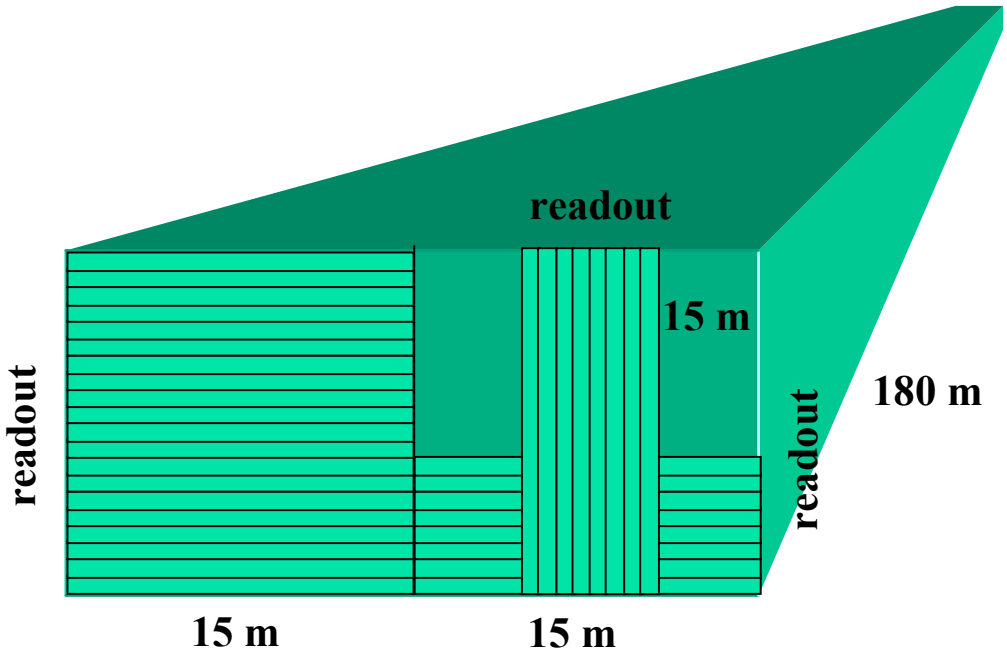
- Alternating horizontal and vertical scintillator planes
- Passive material: wood Oriented Strand Board (density .6 - .7 g/cm^3)
- Sampling: 1/3 rad. length



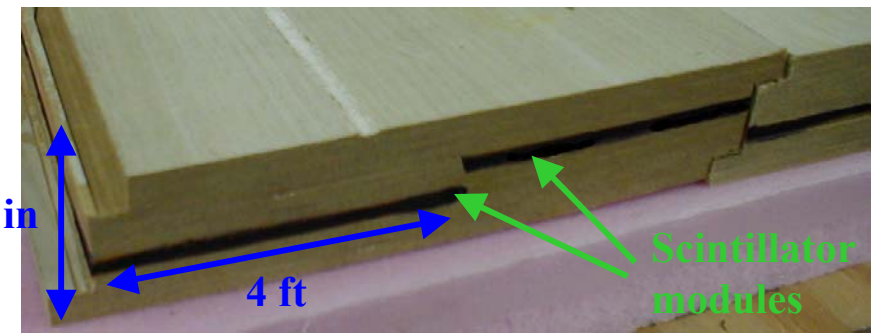
6 = 1 plane

5300 = detector

Fiducial fraction (1 m cut at all edges) 80%



885 planes = detector

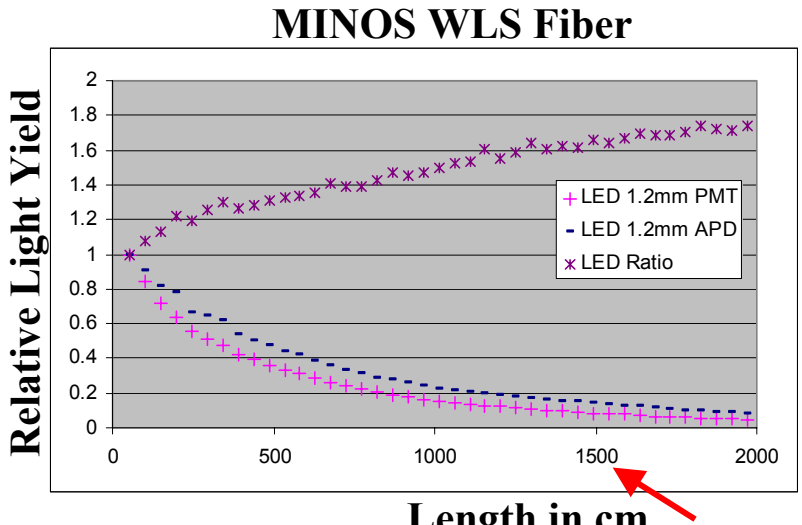


Scintillator and WLS Fibre

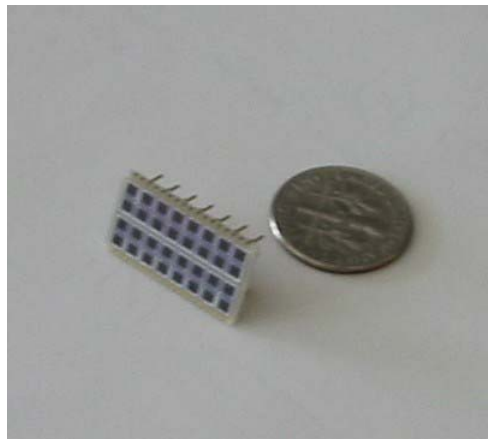
- Scintillator Length 15 m
  - Looped fibre readout
- Scintillator Material
  - Liquid
    - Bicron 517 L (3.8x2.9 cm^2)
- WLS Fiber
  - Kuraray (0.7 mm ø)
- Photodetector
  - APD
  - PMT: M64

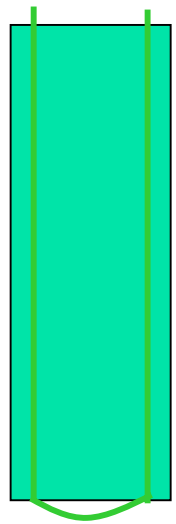
400,000 m^2
(16 x MINOS)

680,000 channels
(30 x MINOS)



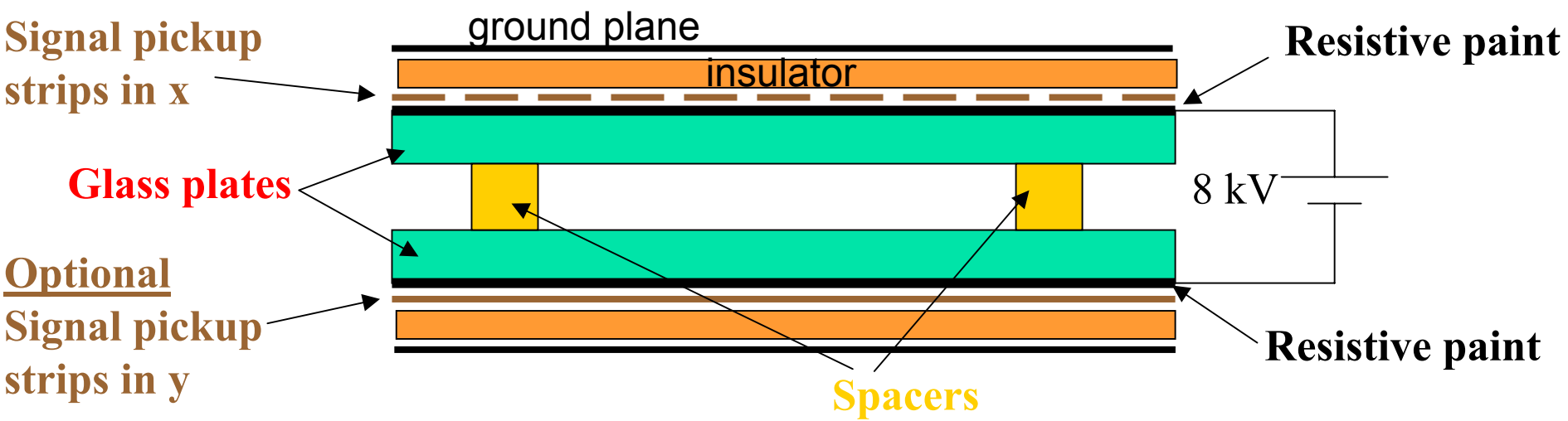
(2 x MINOS)





The basic RPC unit

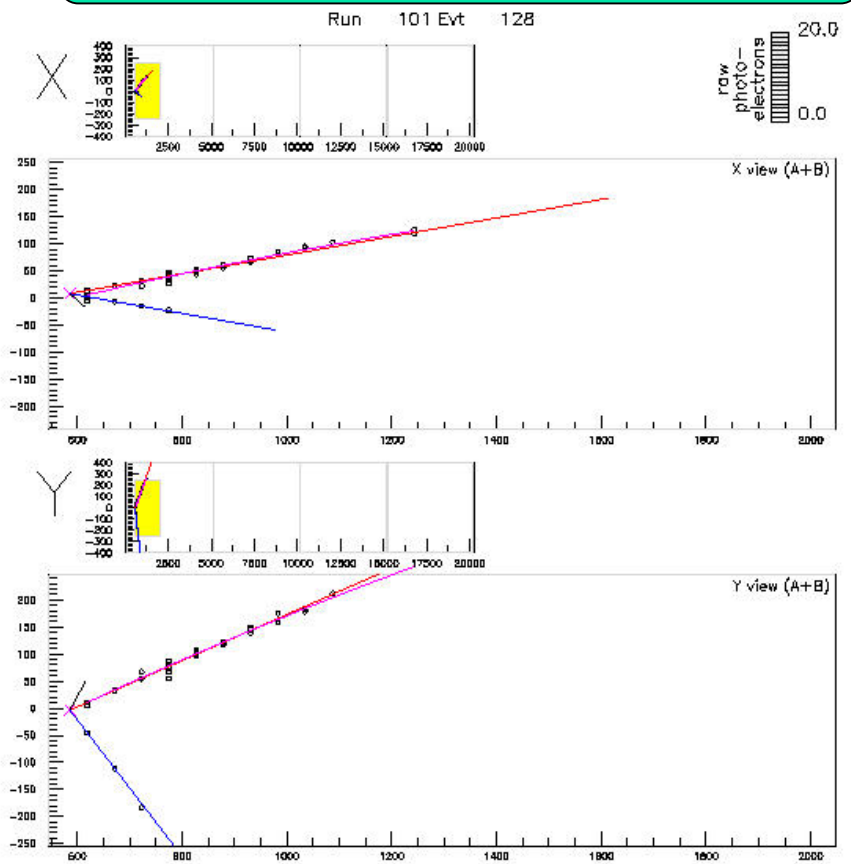
- Glass RPCs are our design baseline
  - This is a conservative choice based on the successful BELLE experience with their barrel and endcap muon systems
    - BELLE has 5,000 m2 of such chambers
    - BELLE has operated them without problems for 5 years



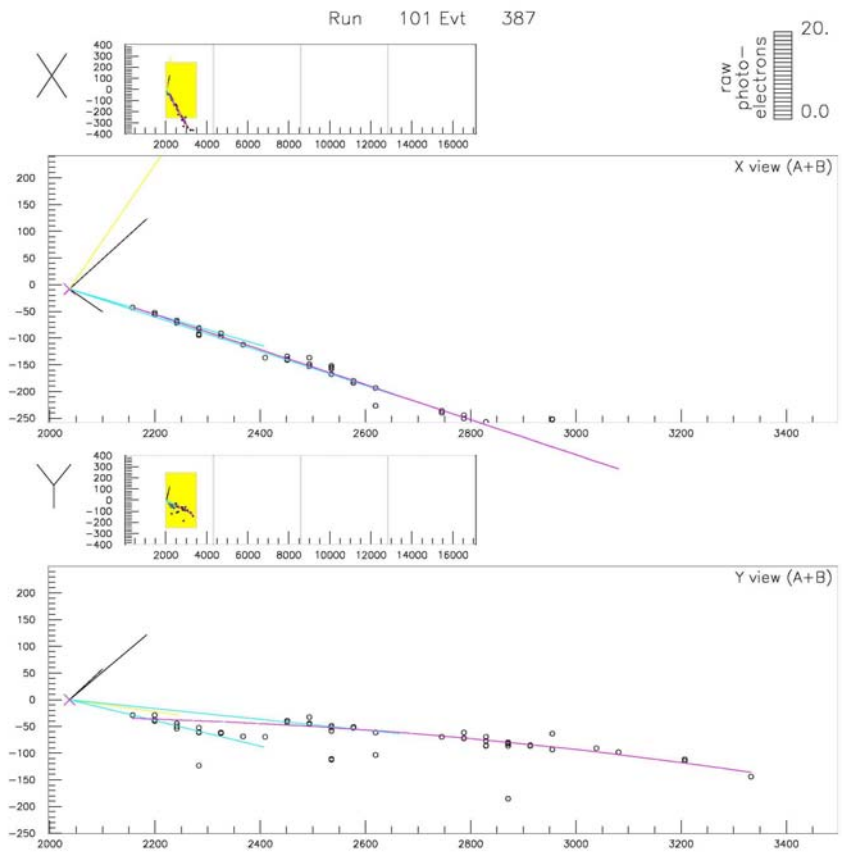
Container Solution

Signal & BG Events

typical signal event



BG event

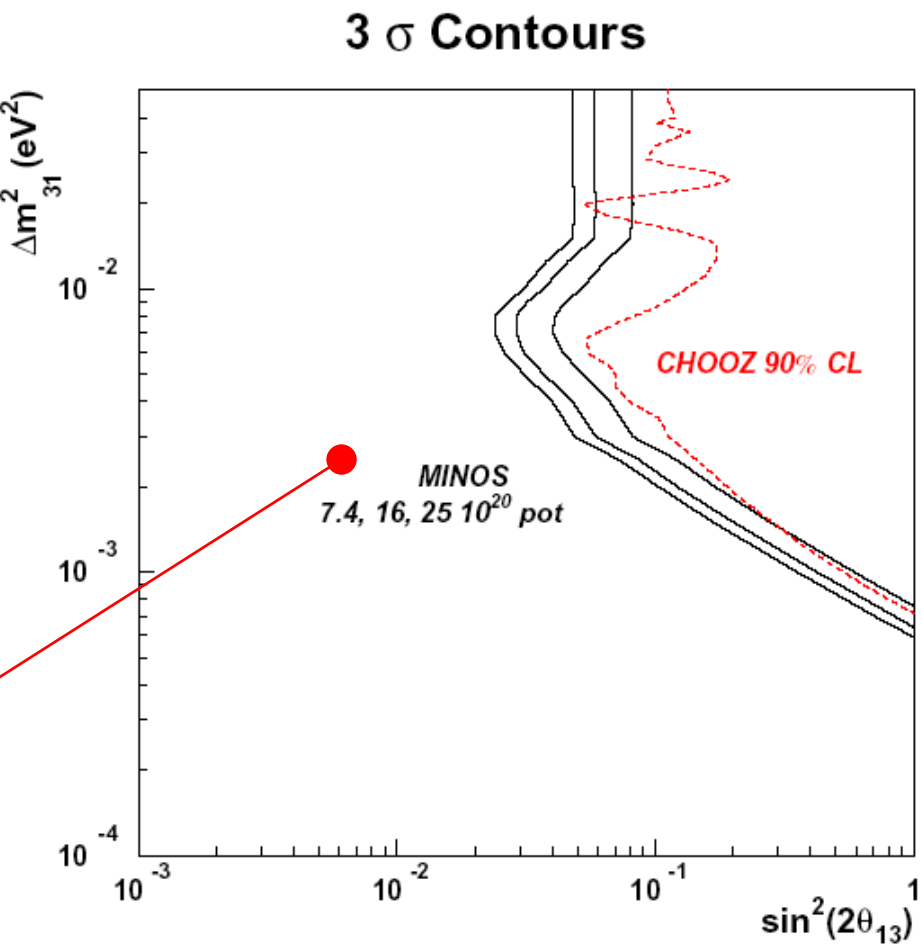


Fuzzy track = e^-

2 tracks = π^0

Sensitivity to $\nu_\mu \rightarrow \nu_e$ (3σ Discovery)

- Current Analysis
  - Based on
    - 50 kton detector
    - 4×10^{20} PoT/year
    - 5 year running
  - 25 σ signal at CHOOZ limit



Off-Axis Goal for discovery limit

Physics Reach

- Some Math:

$$P(\nu_\mu \to \nu_e) = P_1 + P_2 + P_3 + P_4$$

$$P_1 = \sin^2\theta_{23}\sin^2\theta_{13}\left(\frac{\Delta_{13}}{B_\pm}\right)^2\sin^2\frac{B_\pm L}{2}$$

$$P_2 = \cos^2\theta_{23}\sin^2\theta_{12}\left(\frac{\Delta_{12}}{A}\right)^2\sin^2\frac{AL}{2}$$

$$P_3 = J\cos\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\cos\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$

$$P_4 = J\sin\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\sin\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$

$$\Delta_{ij} = \frac{\Delta m^2_{ij}}{2E_\nu};$$

$$A = \sqrt{2}G_F n_e;$$

$$B_\pm = \left|A \pm \Delta_{13}\right|;$$

$$J = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

A. Cervera et al., Nuclear Physics B 579 (2000) 17 – 55,

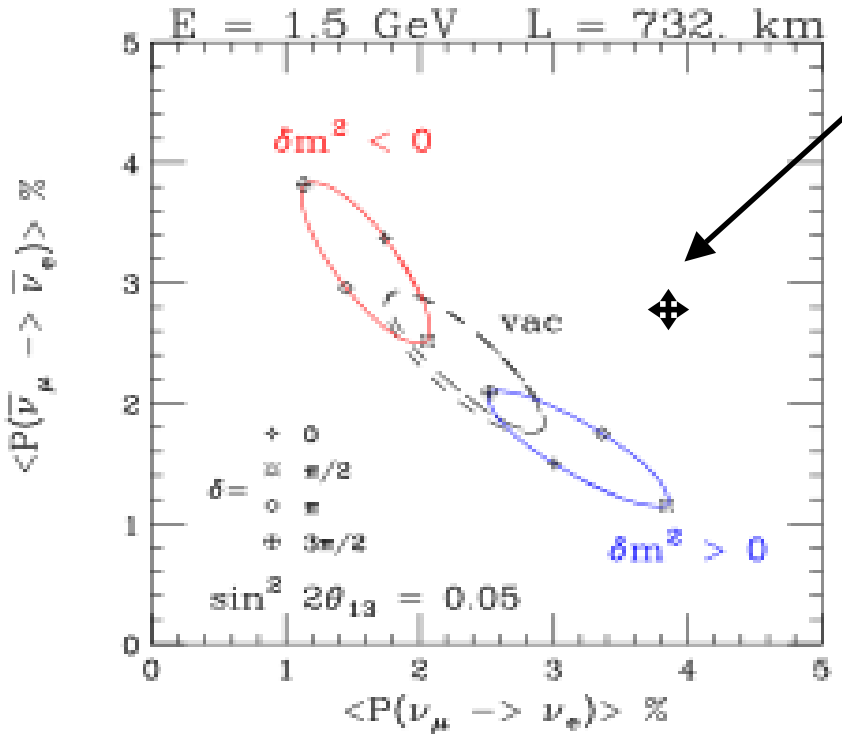
expansion to second order in $\theta_{13}, \frac{\Delta_{12}}{\Delta_{23}}, \frac{\Delta_{12}}{A}, \Delta_{12}L$

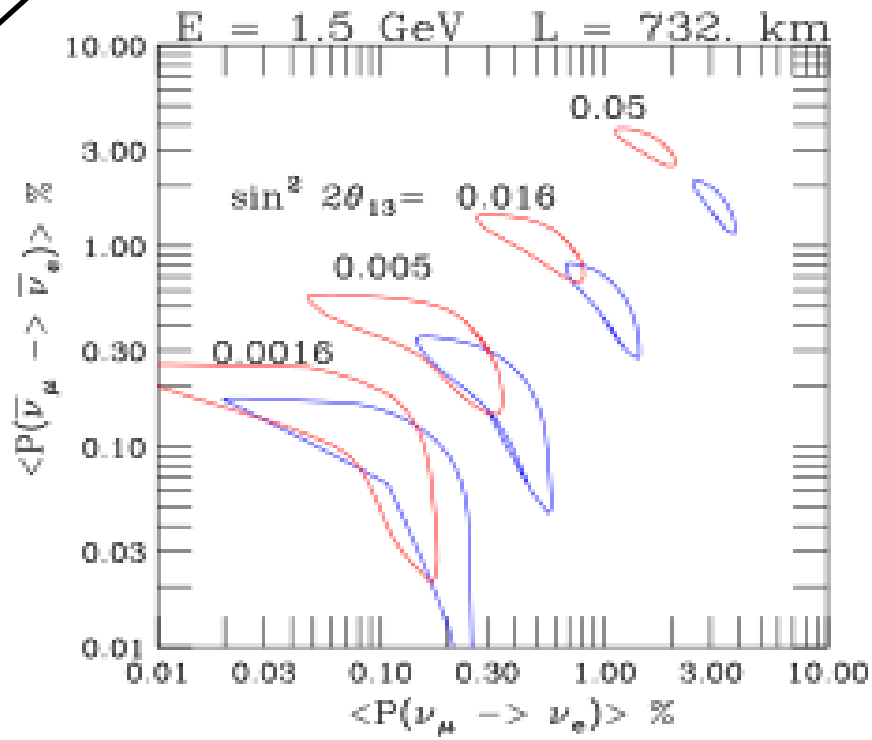
- need more than one experiment to determine oscillation parameters

Physics Reach (II)

- Measurement is oscillation probability
- Depends simultaneously on:
  - Mass hierarchy
  - CP phase
  - Mixing angles

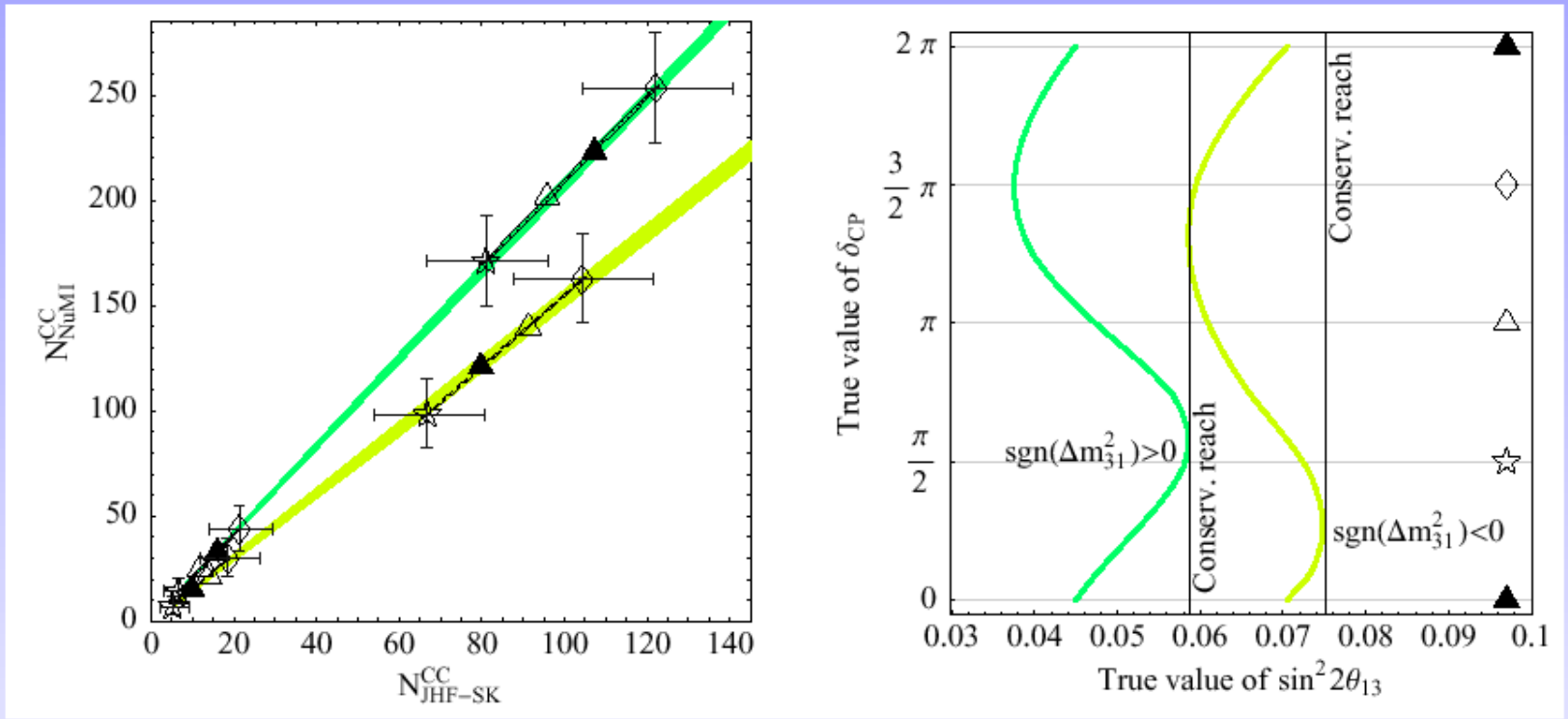
Typical Errors





Mass hierarchy sensitivity reach

JHF-SK + NuMI@890km, 50kt:



$\Delta m^2_{31} = 2.5 \cdot 10^{-3}\,\mathrm{eV}^2$, 90% CL

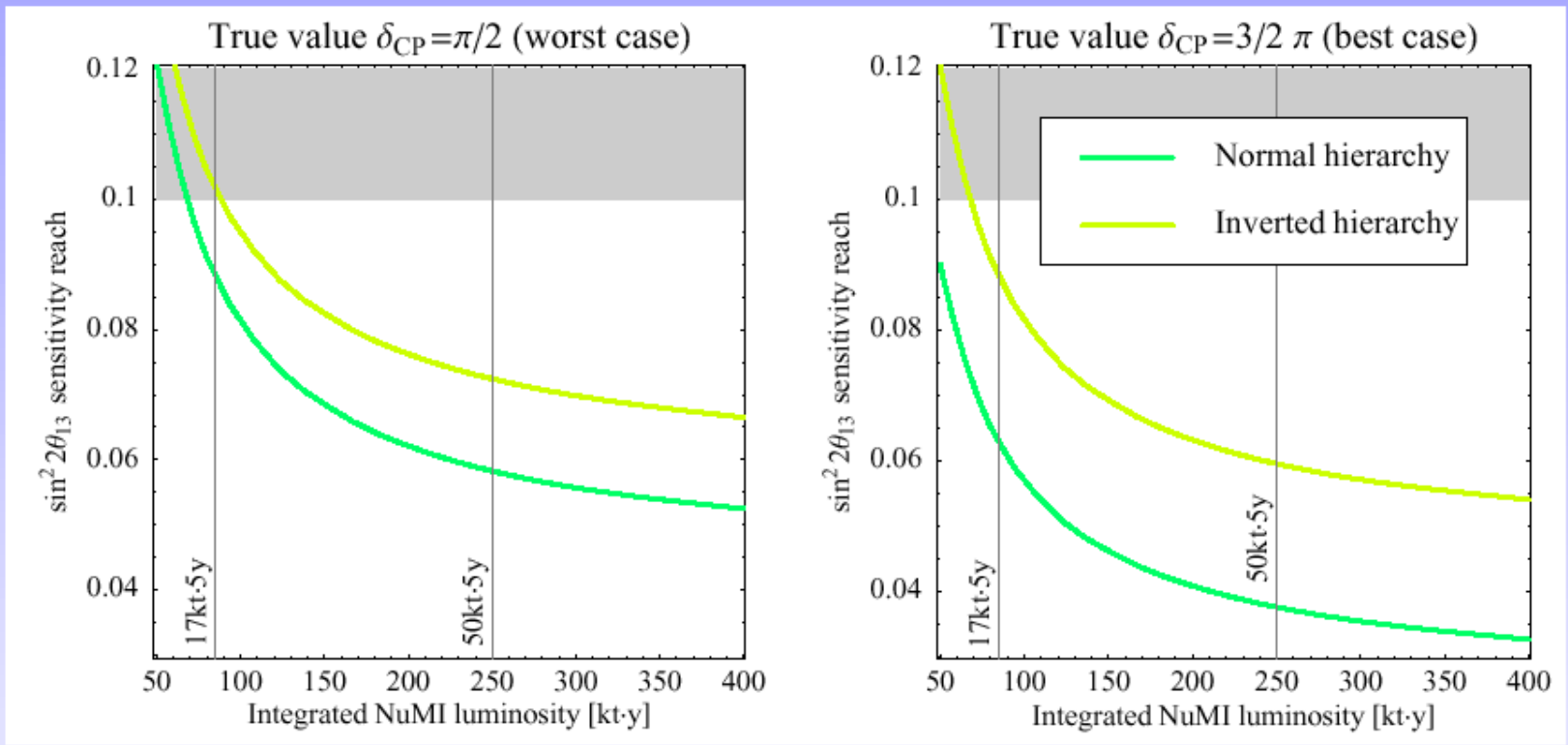
(Winter, hep-ph/0310307)

"Conservative reach": This can be done in any case!

For bi-probability graphs, see also Minakata, Nunokawa, Parke, hep-ph/0301210

Mass hierarchy: Luminosity scaling

JHF-SK + NuMI@890km, $\sin^2 2\theta_{13}$-sensitivity reach:

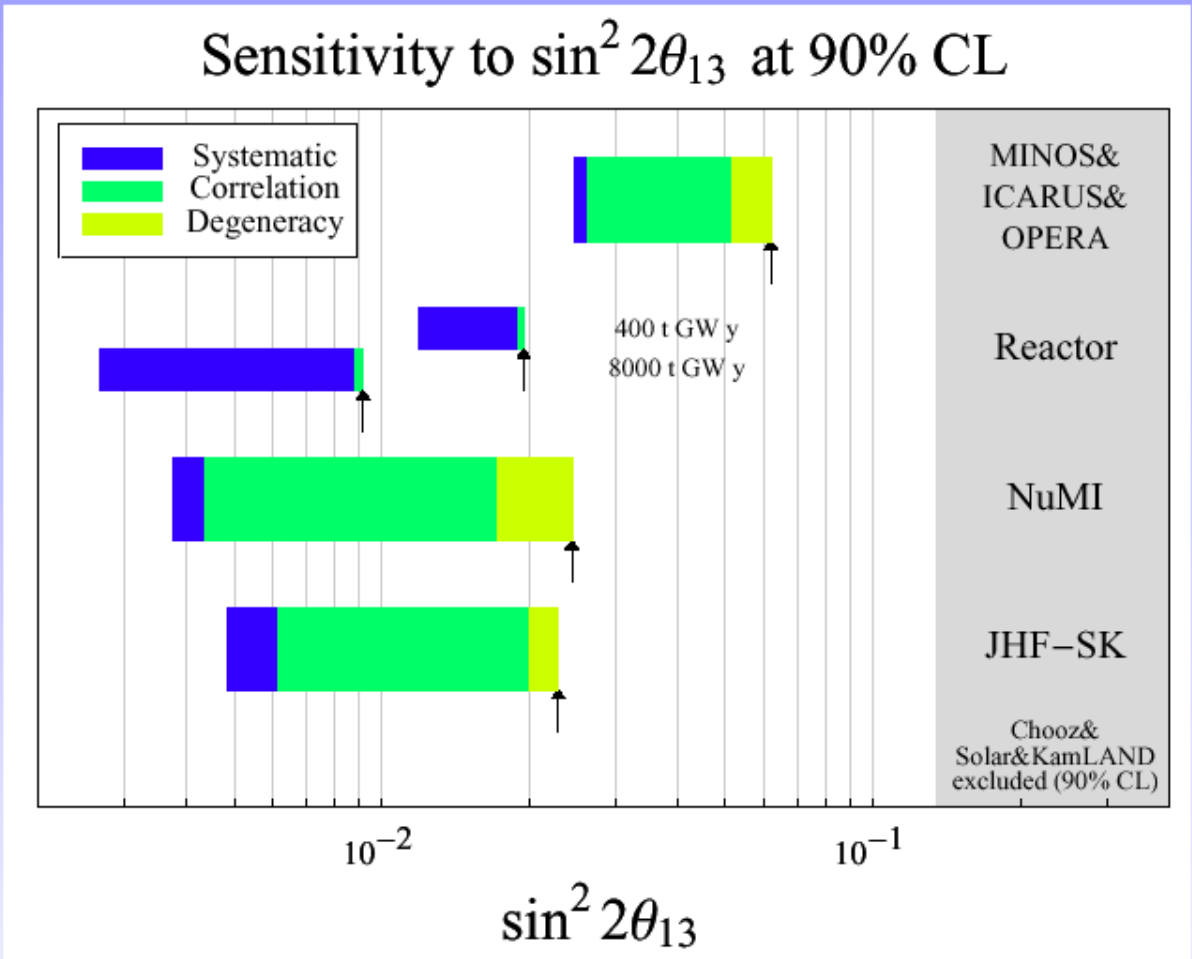


$\Delta m^2_{31} = 2.5 \cdot 10^{-3}\,\mathrm{eV}^2$, 90% CL

(Winter, hep-ph/0310307)

$\longrightarrow$ 50 kt detector very useful!

The $\sin^2 2\theta_{13}$-sensitivity limit



$\Delta m^2_{31} = 2 \cdot 10^{-3}\,\mathrm{eV}^2$,

NuMI as in proposal

(+8% target power),

MINOS etc.:

5 yr running time

(Huber et al,

in preparation;

Courtesy of

Marc Rolinec)

→ Superbeam (1st gen.) dominated by correlations and degeneracies

→ Reactor experiments dominated by systematics

Summary

- The NuMI OA group is seriously trying to bring froward a credible & affordable proposal
- Combination of
  - JPARC/SuperK and NuMI OA
  - neutrino and anti-neutrino running
  - reactor experient
- might reveal neutrino mixing parameters
  - Masses & hierarchy
  - Angles
  - CP phase
- For more information:

http://www-off-axis.fnal.gov