Atmospheric Neutrino Results from Soudan 2

Earl A. Peterson, University of Minnesota
for the
Soudan 2 Collaboration
Argonne, Minnesota, Oxford, Rutherford,
Tufts, Western Washington

Presented by
Geoff Pearce (Rutherford laboratory)

Outline of the talk

The Soudan 2 detector

Outline of data analysis

Neutrino Flavor Ratio from 5.1 kTy exposure

L/E analyses

Limits for neutrino oscillation parameters

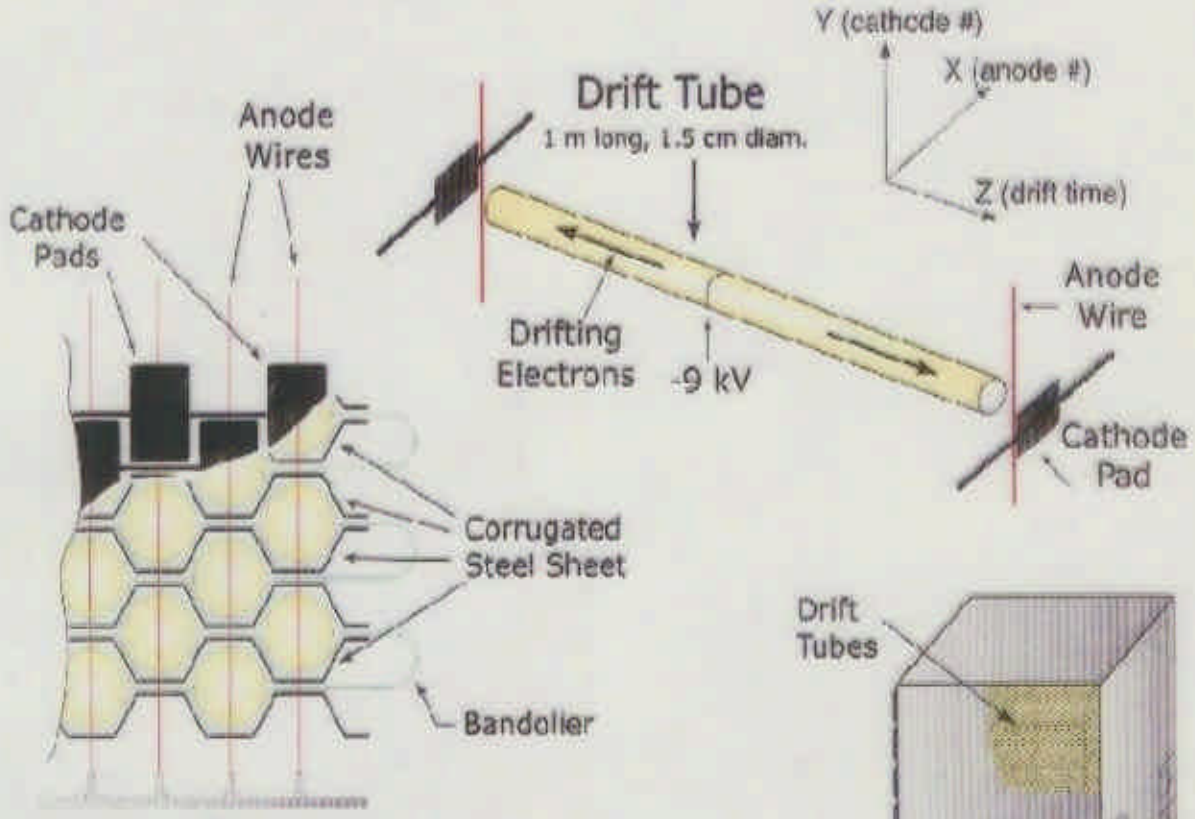
For the millennium:

- 4.6 ➡ 5.1 kTy
- Bartol '96 flux (not '89)

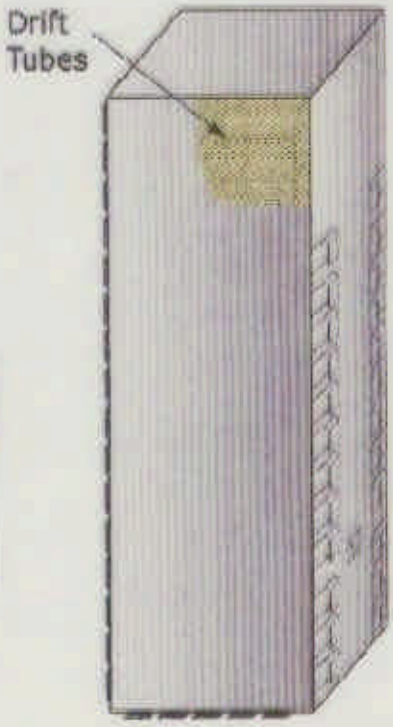
Soudan 2 Laboratory and Detector

The Soudan 2 Detector:

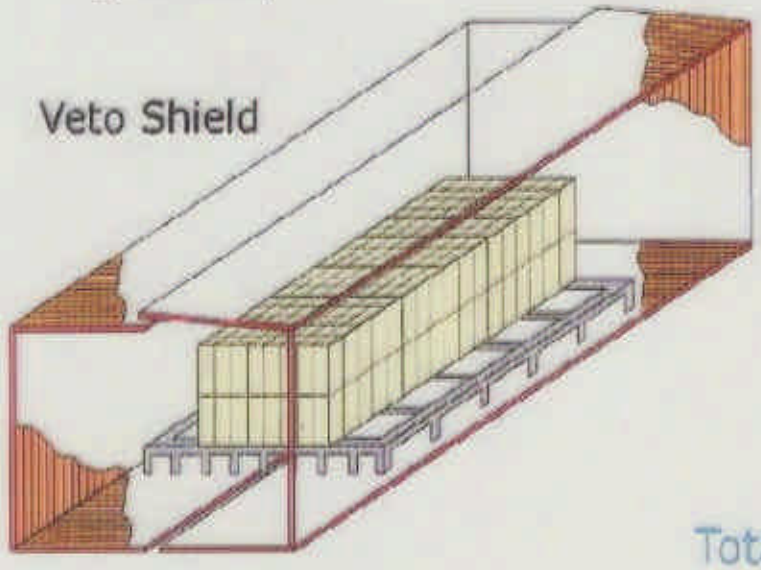
Slow-drift time projection chamber



Honeycomb lattice geometry

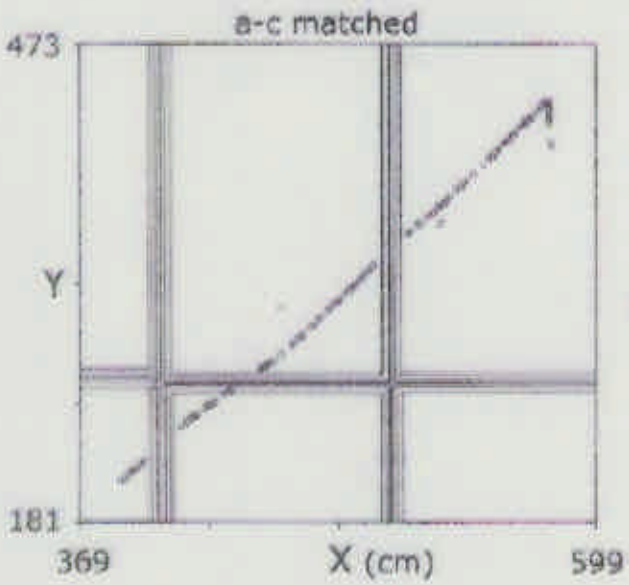


4.3 ton Module

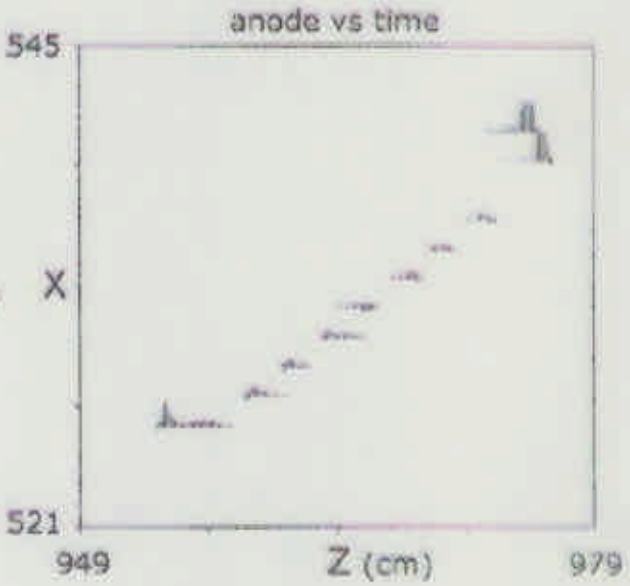


Total mass: 963 tons

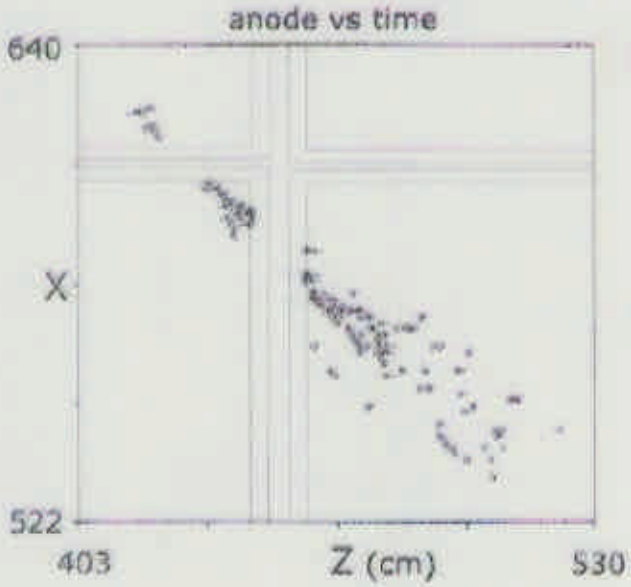
Track, Shower, Multiprong Events in Soudan 2:



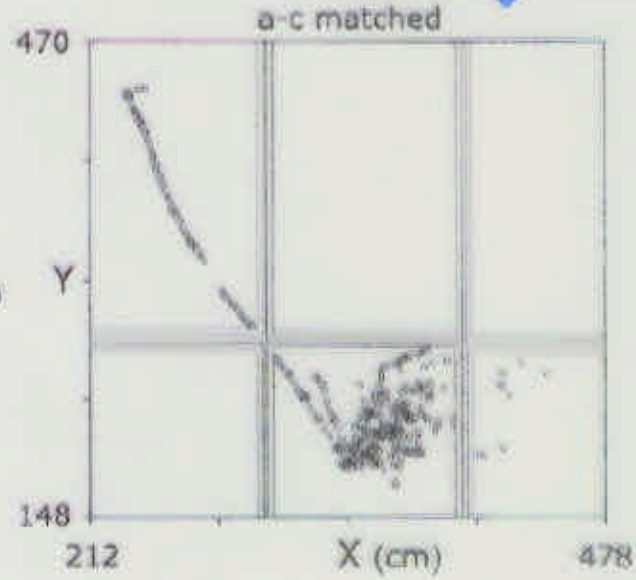
← TRACKS ↘



SHOWER ↘

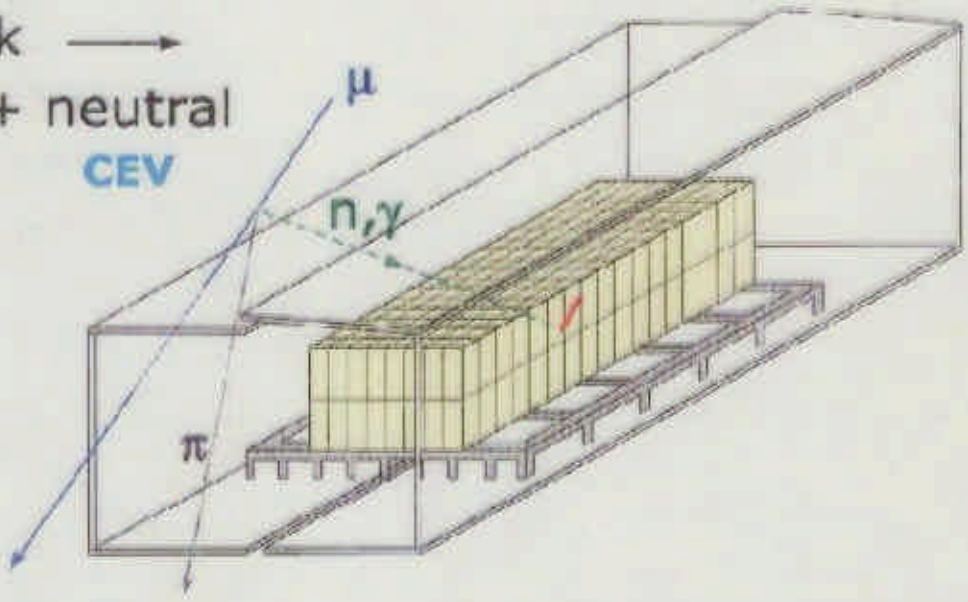


MULTIPRONG ↘



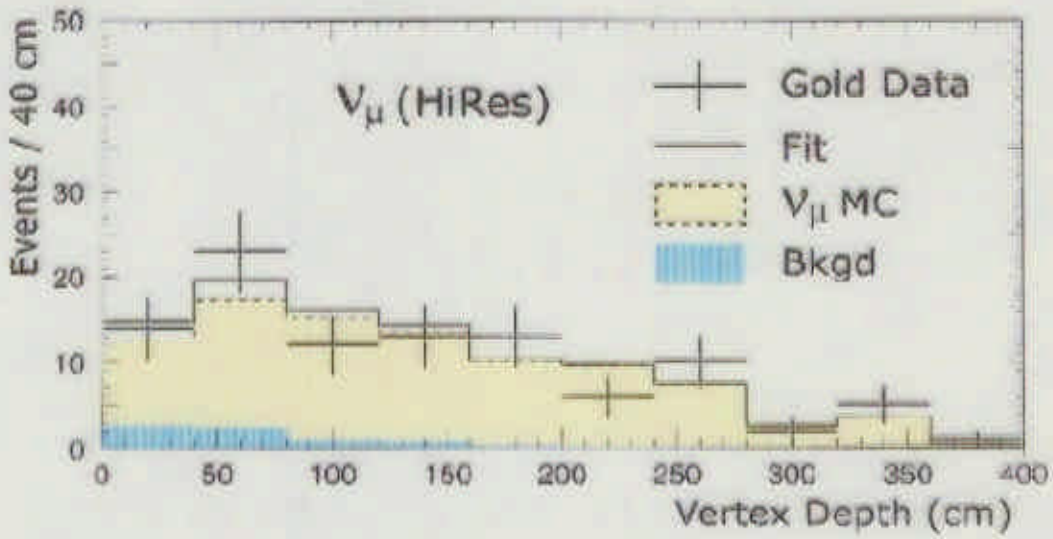
Non-neutrino cosmic-ray background:

μ + Rock ⟶
μ + charged + neutral
shield hits CEV



"Rock event" sample-
identified by presence of shield hits.

The residual zero-shield-hit background is calculated by fitting contained event vertex-depth distributions to a combination of Rock and ν Monte Carlo distributions:



Atm. ν flavor ratio:

Fully contained events (> 20 cm from det. edge)

Single Track and Single Shower Events

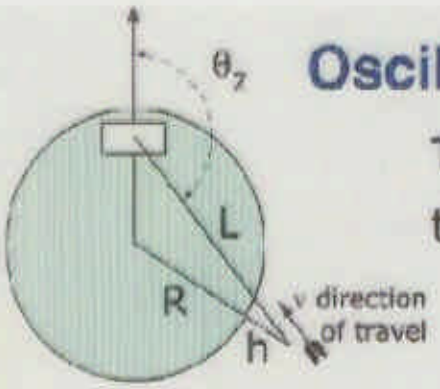
Cosmic-ray induced background:

Veto Shield tags most CR-induced bkgrd (n, γ)

Residual bkgrd estimated via vertex depth distr.

Number of Gold Tracks	133
Number of Gold Showers	193
Number of MC Tracks	1097 (193.1)
Number of MC Showers	1017 (179.0)
Corrected Number of ν Tracks	105.1 ± 12.7
Corrected Number of ν Showers	142.3 ± 13.9

$$R' = 0.68 \pm 0.11\ (\text{stat}) \pm 0.06\ (\text{sys})$$



Oscillation analysis using L/E_ν:

To determine L, we reconstruct the neutrino zenith angle θ_z.

$$L(\theta_z) = \sqrt{R^2\cos^2\theta_z + 2Rh + h^2} - R\cos\theta_z$$

The high-resolution data selection:

1) Quasi-elastics (Tracks, Showers)

$P_{lept} > 150$ MeV/c if a recoil is measured

Or

$E_{vis} > 600$ MeV if a recoil is absent

2) Multiprongs

$E_{vis} > 700$ MeV

$|\Sigma\vec{p}_{vis}| > 450$ MeV/c (improve directionality)

$P_{lept} > 250$ MeV/c (improve flavor tag)

Resolutions:

	ν_μ CC	ν_e CC
Energy: $(\Delta E/E)$	20%	23%
Angle: $\angle\vec{p}_\nu(\text{true})\cdot\vec{p}_\nu(\text{recon})$	33.2°	21.3°
L/E: $\lvert\text{Log(true L/E)} - \text{Log(recon L/E)}\rvert$	0.49	0.43

Soudan-2 high-resolution event samples:

Exposure = 5.1 kty

Category	Data		MC
	Before bgr. subtraction	After	(Bartol x 0.79)
ν_μ	114.0 ± 10.7	106.3 ± 14.7	158.5 ± 4.8
ν_e	140.0 ± 11.8	132.8 ± 13.4	132.8 ± 4.4 (norm'ed)

Notes:

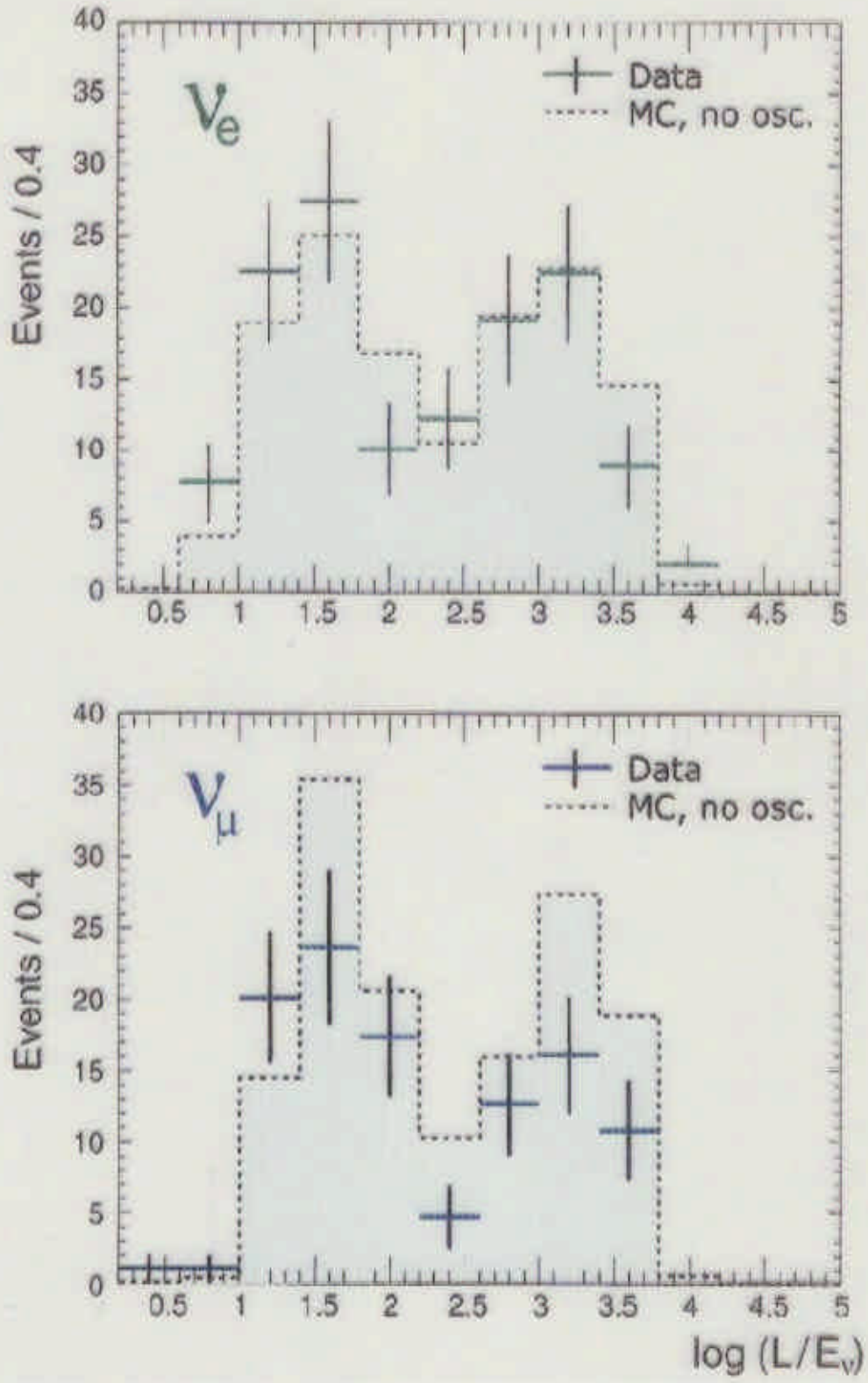
- Event identification matrix:

Data category	*Monte Carlo truth* ν_μ *CC*	ν_e *CC*	*NC*
ν_μ flavor	92.5%	3.1%	4.4%
ν_e flavor	2.6%	92.0%	5.4%

- Rock-muon associated background correction is 6.8% for ν_μ flavor and 5.1% for ν_e flavor.
- The Monte Carlo sample represents 28.2 kty of exposure; numbers given here are normalized to 5.1 kty.
- In this sample of mostly higher energy events, the ratio of ratios is R = 0.67 ± 0.12, also significantly below 1.

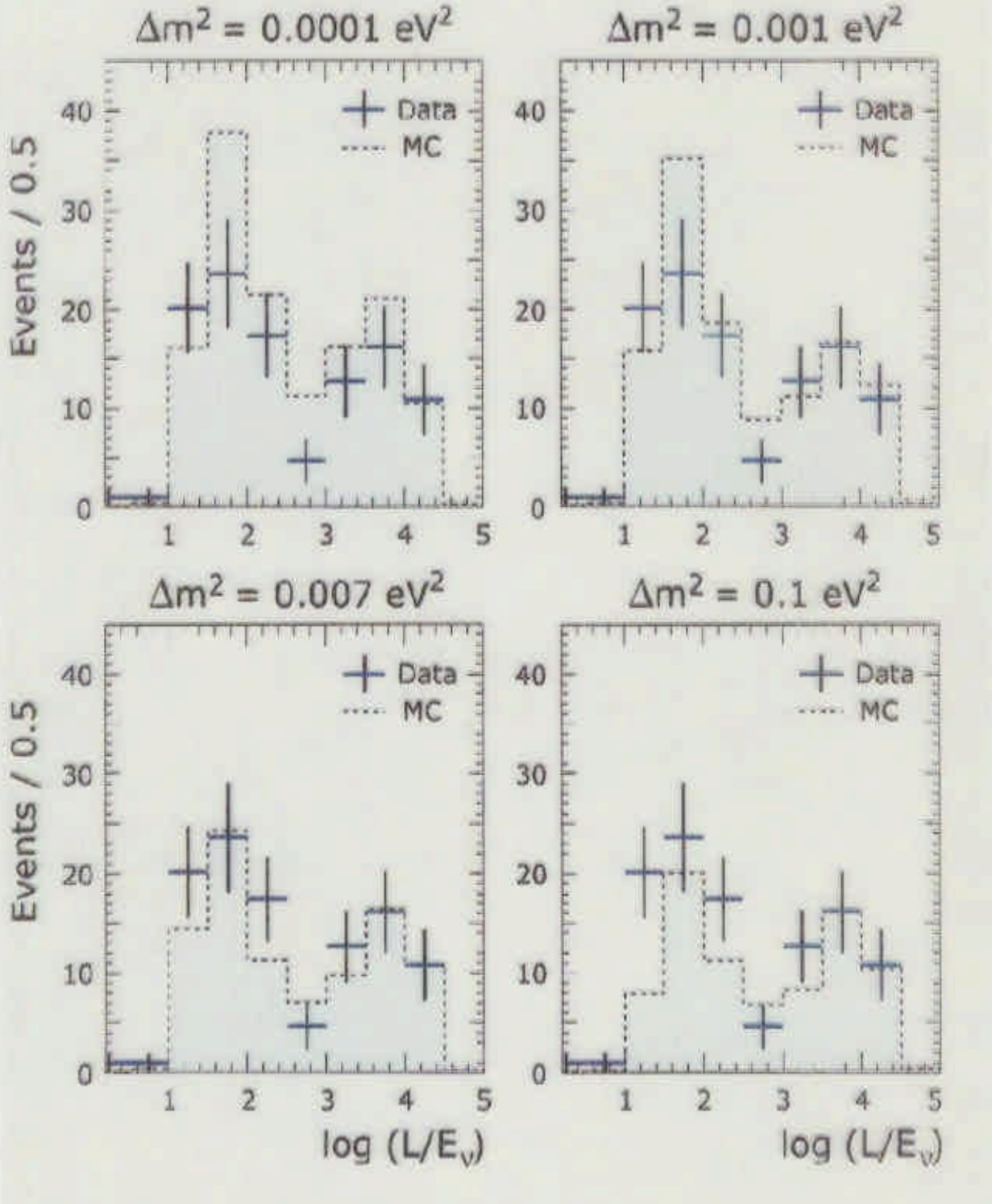
L/E Distributions:

Soudan 2 at 5.1 kty

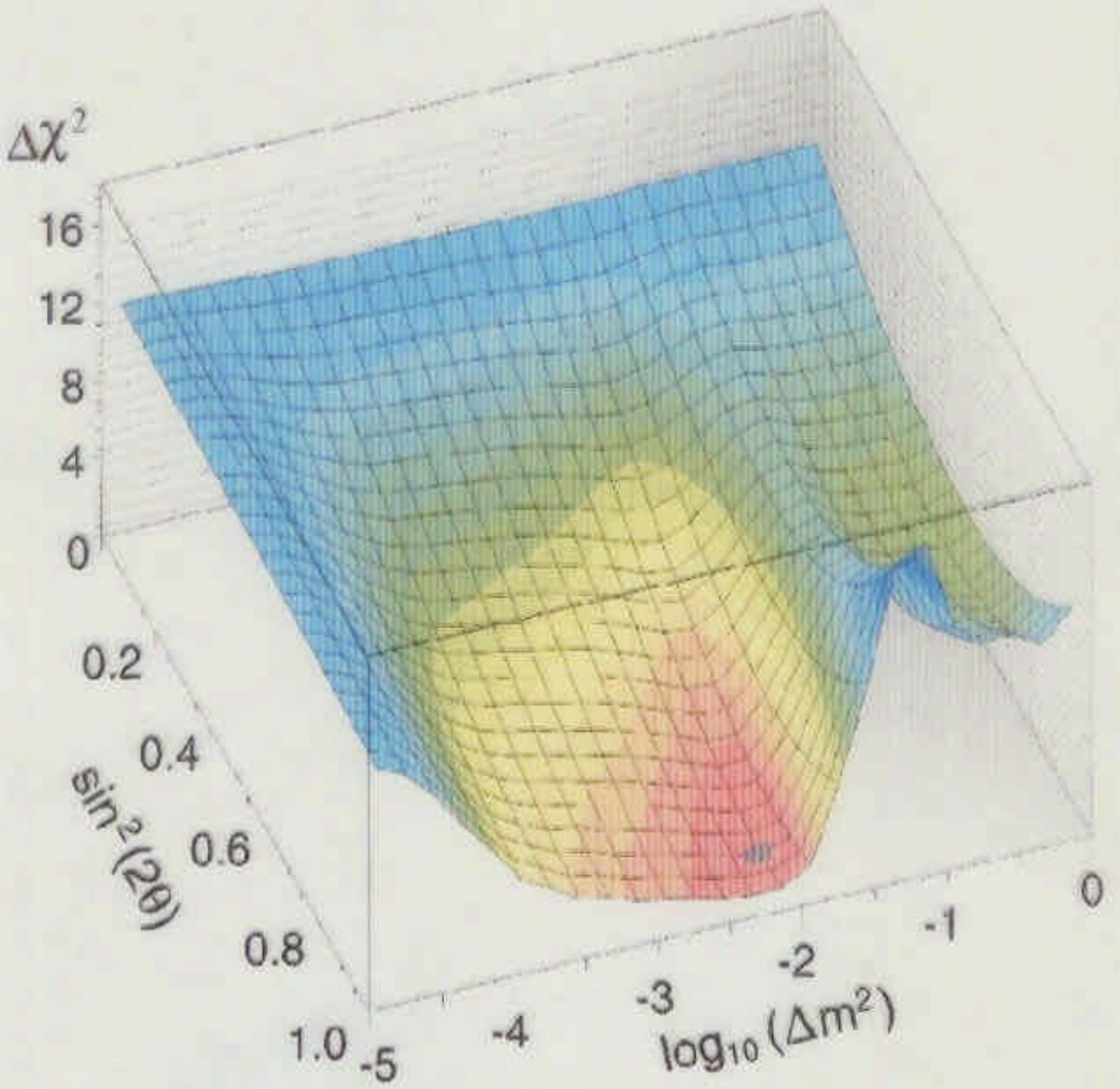


L/E Distributions for ν_μ - Flavor Events:

$\sin^2 2\theta = 1$



$\Delta\chi^2$ surface using L/E_ν distributions:



χ^2_{min} at

$\sin^2 2\theta = 0.90$

$\Delta m^2 = 7.9 \times 10^{-3}\ eV^2$

($f_\nu = 0.78$)

Feldman and Cousins procedure to find the 90% confidence region:

At each of 2500 points $(i, j) = (\sin^2 2\theta_i, \Delta m^2_j)$ in the physical region, run 1000 simulated experiments.

Find $(\Delta\chi^2_{90})_{ij}$ such that $(\Delta\chi^2_{sim})^s_{ij} < (\Delta\chi^2_{90})_{ij}$

for 90% of the simulated experiments at (i, j).

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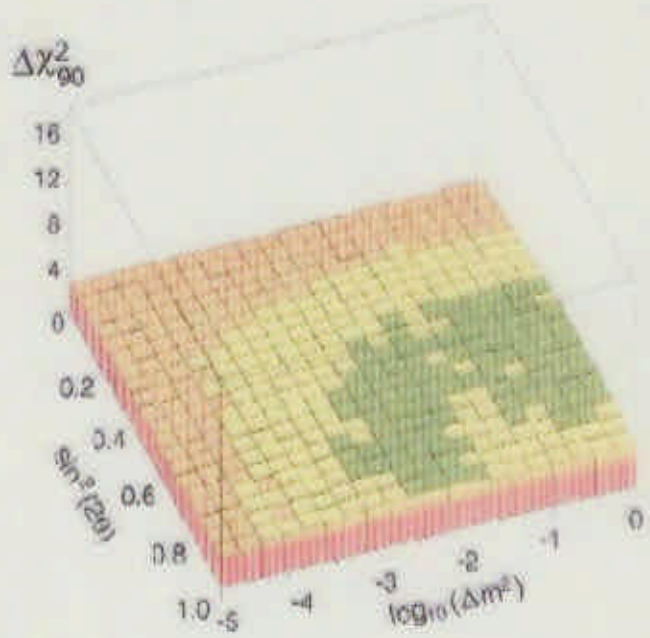
The surface defined by local $\Delta\chi^2_{90}$ over the oscillation parameters plane: $\Longrightarrow$

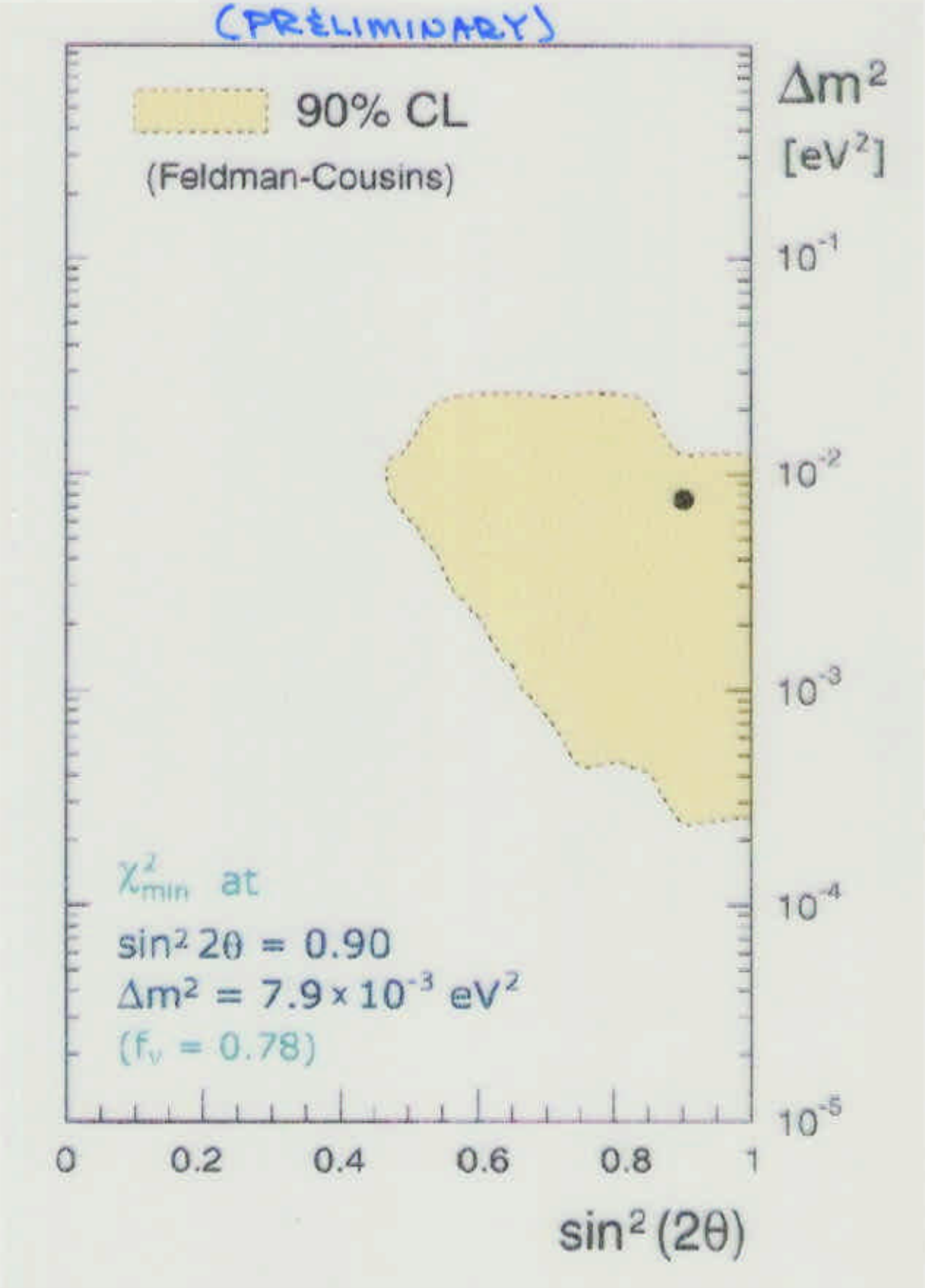


$\Delta\chi^2_{90} \neq 4.61$!

Finally,

if $(\Delta\chi^2_{data})_{ij} < (\Delta\chi^2_{90})_{ij}$, then (i, j) belongs to the allowed region of the 90% CL contour.

(PRELIMINARY)



Summary and Outlook

- Two more data sets to analyze:
  - Partially contained events
  - Upward muons
- Remove "Preliminary" !
- Keep the detector running:
  - a bit more data
  - high-resolution addition to MINOS