COMMENT ON [INEXISTENT] KAMLAND FIRST RESULTS (JUST FOR FUN...)

KAMLAND WILL PRESENT ~100 DAYS DATA.

- EXPECTATION FOR NULL OSC.

$$\boxed{N_{NO} = 107 \pm \underset{SYS}{5} \text{ EVTS}}$$

- LMA $3\sigma \rightarrow N_{LMA} < 77 \pm \underset{SYS}{4}$ EVENTS

  LMA "BEST $\rightarrow N_{BEST} = 64 \pm \underset{SYS}{3}$ EVENTS

IF

$N_{OBS} = 107 \pm \underset{STAT}{10}$ => LMA DISFAVORED AT $\sim 3\sigma$ LEVEL !

F

$N_{OBS} = 64 \pm \underset{STAT}{8}$ => NULL HYPOTHESIS DISFAVORED AT $\gtrsim 4\sigma$!

STAY TUNED!!

AdG, A. FRIEDLAND, H. MURAYAMA, hep-ph/9910286

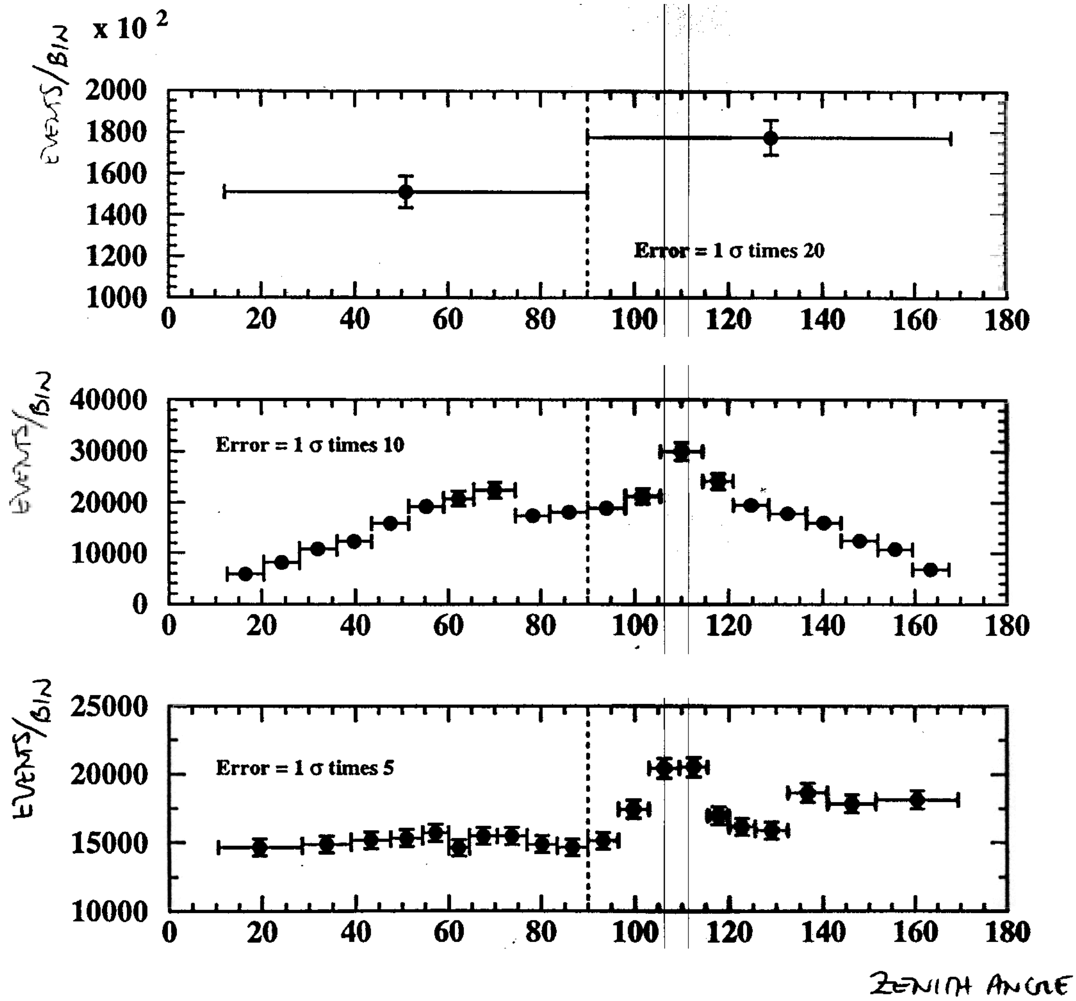

Figure 2: Different binning schemes, for $\Delta m^2 = 1.12 \times 10^{-7}\mathrm{eV}^2$, $\sin^2\theta = 0.398$: (a) $N = 1$ bin (the day-night asymmetry), (b) $N = 10$ equaly spaced zenith angle bins, and (c) $N = 10$ "uniform" bins, where the day-time data is (roughly) uniformly distributed. The error bars contain statistical uncertainties only. We assume three years of KamLAND running.

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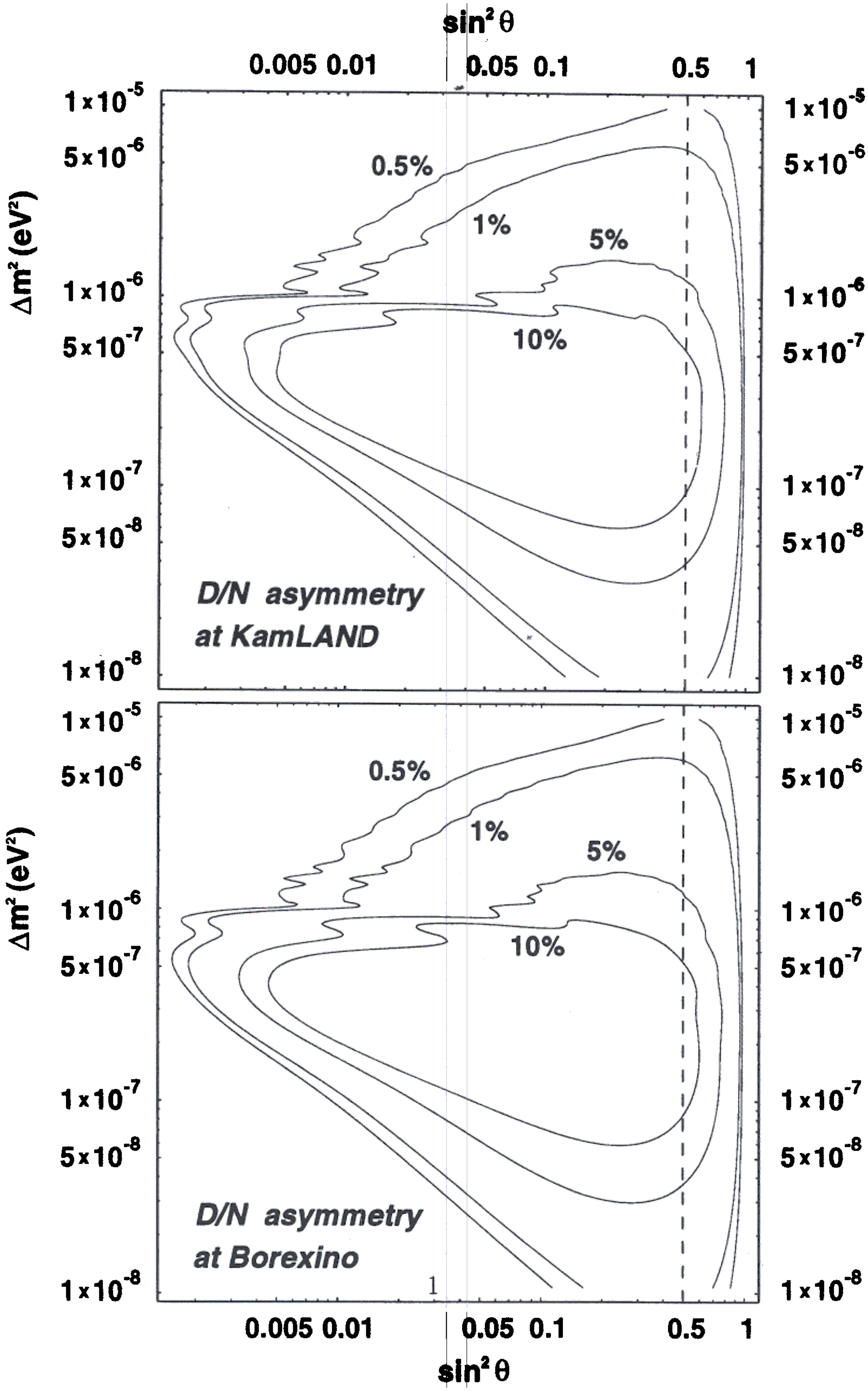

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Figure 1: CONSTANT DAY-NIGHT ASYMMETRY FOR ^{7}Be NEUTRINOS, AT THE BOREXINO AND KamLAND SITES

3 YEARS OF KAMLAND

NOTE SCALE

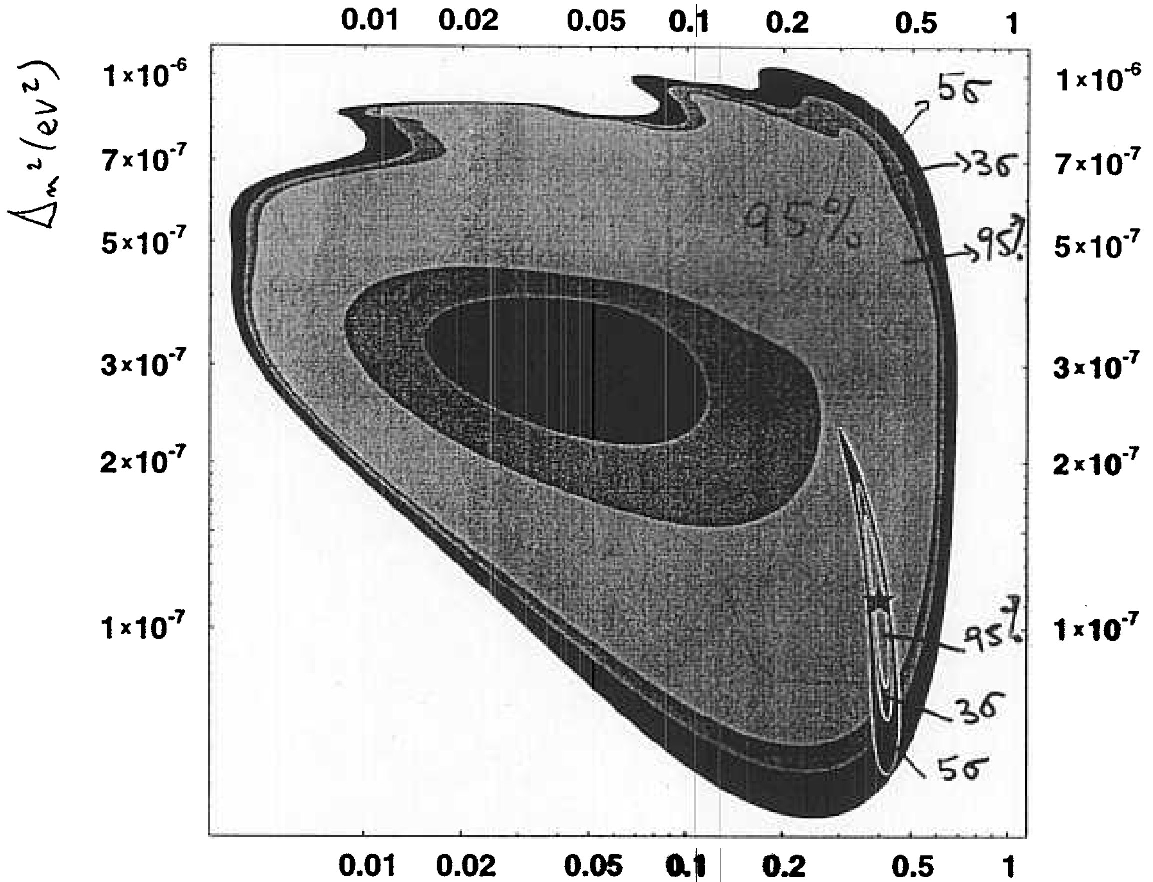
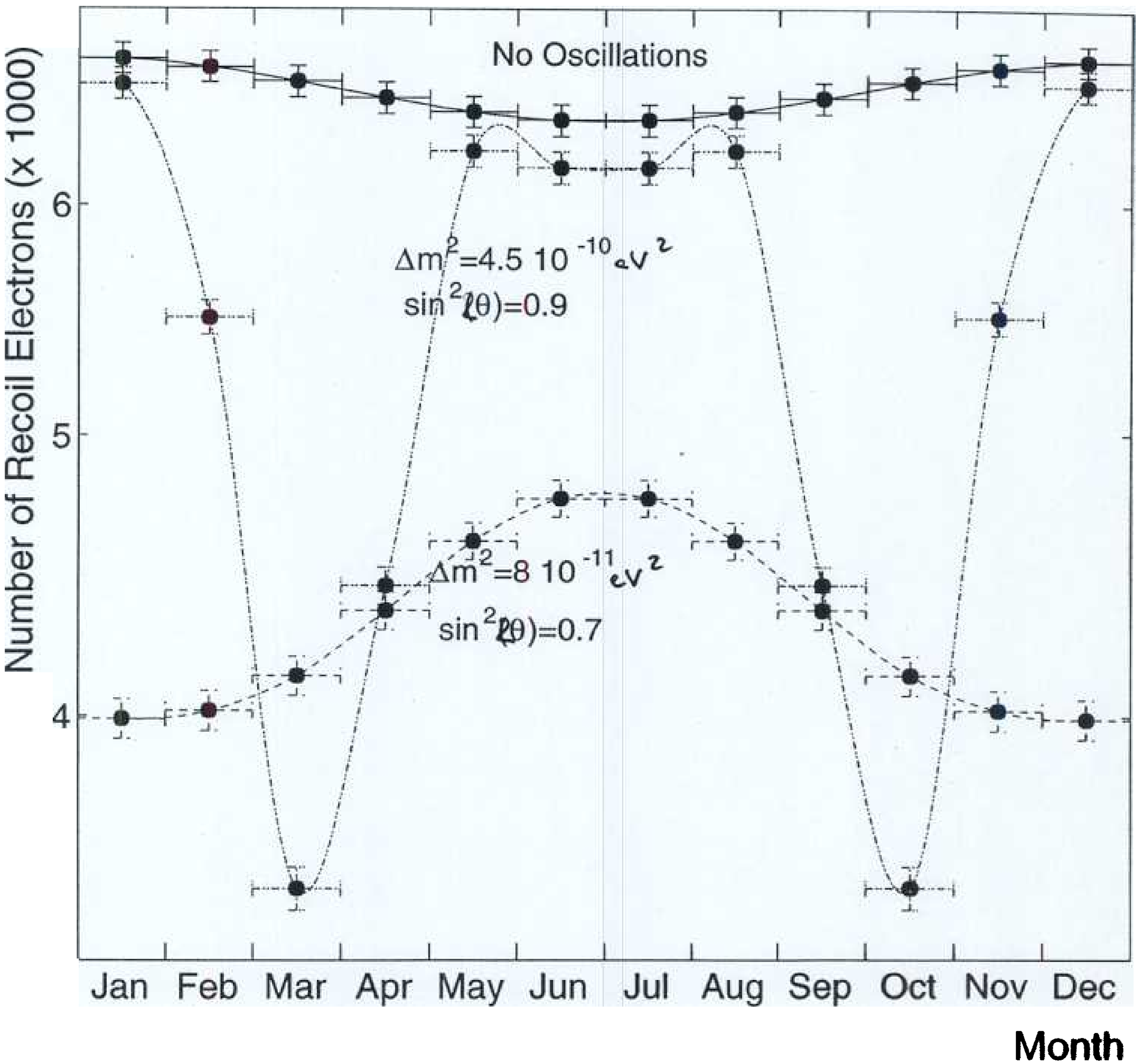


Figure 5: Measured values of $(\Delta m^2, \sin^2\theta)$ with seasonal variation of the day data and ten uniform night bins.

MEASUREMENT OF OSCILLATION PARAMETERS, INPUT = LOW (★)

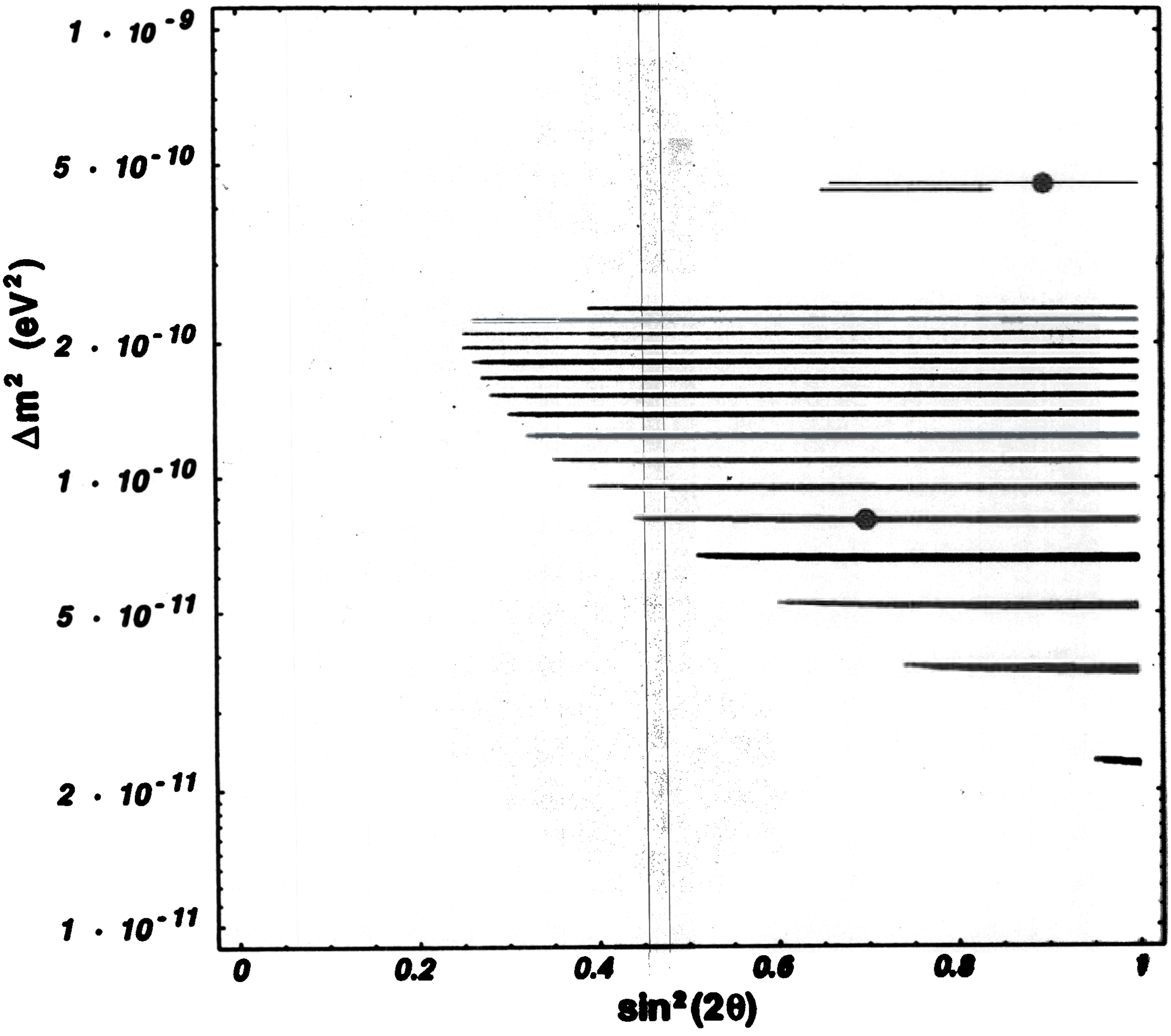
RING ◎ WITH A_{DN},

THIN STRIP 0 WITH 10 UNIFORM BINS.

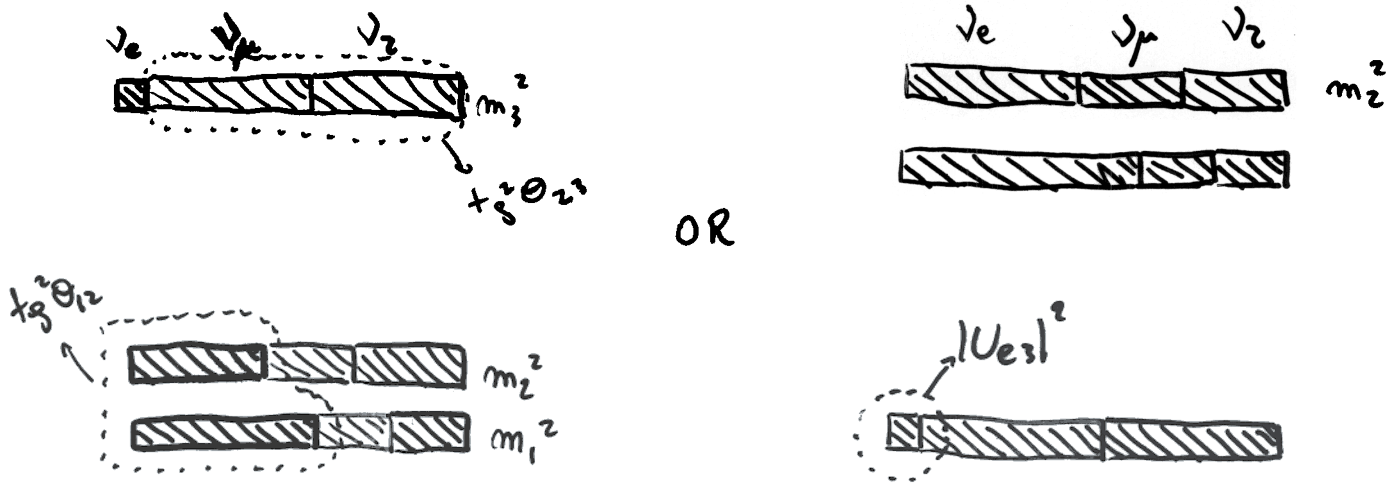


Number of Recoil Electrons (x 1000)
No Oscillations
Δm²=4.5 10⁻¹⁰ eV²
sin²2θ)=0.9
Δm²=8 10⁻¹¹ eV²
sin²2θ)=0.7
6
5
4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

AdG. A. Friedland, H. Murayama
PRD 60, 093011



WHAT IS LEFT?



$\Delta m^2_{13} > 0$ $\Delta m^2_{13} < 0$

1 - $|U_{e3}|^2$

2 - WHAT IS THE MASS HIERARCHY?

3 - WHAT IS THE CP-ODD PHASE?

[2] CAN BE ADDRESSED WITHIN OSCILLATIONS IF $|U_{e3}|^2$ IS BIG

[3] CAN BE ADDRESSED WITHIN OSCILLATIONS IF LMA + $|U_{e3}|^2$ BIG

LOOKING FOR $|U_{e3}|^2$ EFFECTS: $\nu_\mu \to \nu_e$ TRANSITIONS

WHY?

- IT'S EASY TO PRODUCE A ν_μ BEAM $[\pi \to \mu \nu_\mu]$ OF HIGH ENOUGH ENERGY

  APPEARANCE IS THE "RIGHT WAY" TO REACH VERY SMALL ANGLES (FOR DISCOVERY ANYWAY)... [x DISAPPEARANCE]

- SUCH A SETUP WILL PROVIDE (REQUIRED) PRECISE INFORMATION ON THE ATMOSPHERIC PARAMETERS.

$$
\begin{aligned}
P_{\mu e}^{VAC} = {} & 4 |U_{\mu 3}|^2 |U_{e3}|^2 \sin^2 \Delta_{13} - \\
& 4 \, \mathrm{Re}[U_{\mu 1} U_{e1}^* U_{\mu 2}^* U_{e2}] \sin^2 \Delta_{12} \\
& + 2 \, \mathrm{Re}[U_{\mu 2} U_{e2}^* U_{\mu 3}^* U_{e3}] [\cos 2(\Delta_{12} - \Delta_{13}) - \cos 2\Delta_{13}] \\
& - 8 \, \mathrm{Im}[U_{\mu 2} U_{e2}^* U_{\mu 3}^* U_{e3}] \sin \Delta_{12} \sin \Delta_{13} \sin(\Delta_{13} - \Delta_{12})
\end{aligned}
$$

$\to$ optimize $\Delta_{13} \sim \pi/2$ (for Δ_{13} in the first term)

$\sin^2 \Delta_{12} \dashrightarrow \Delta_{12}^2$ SUPP

last two terms: $|U_{e3}| \times \Delta_{12}$

Im term $\to$ CP-ODD

$$\Delta_{ij} \equiv \Delta m_{ij}^2 \frac{L}{4E}$$

MATTER EFFECTS MATTER! [PERO NO MUCHO...]

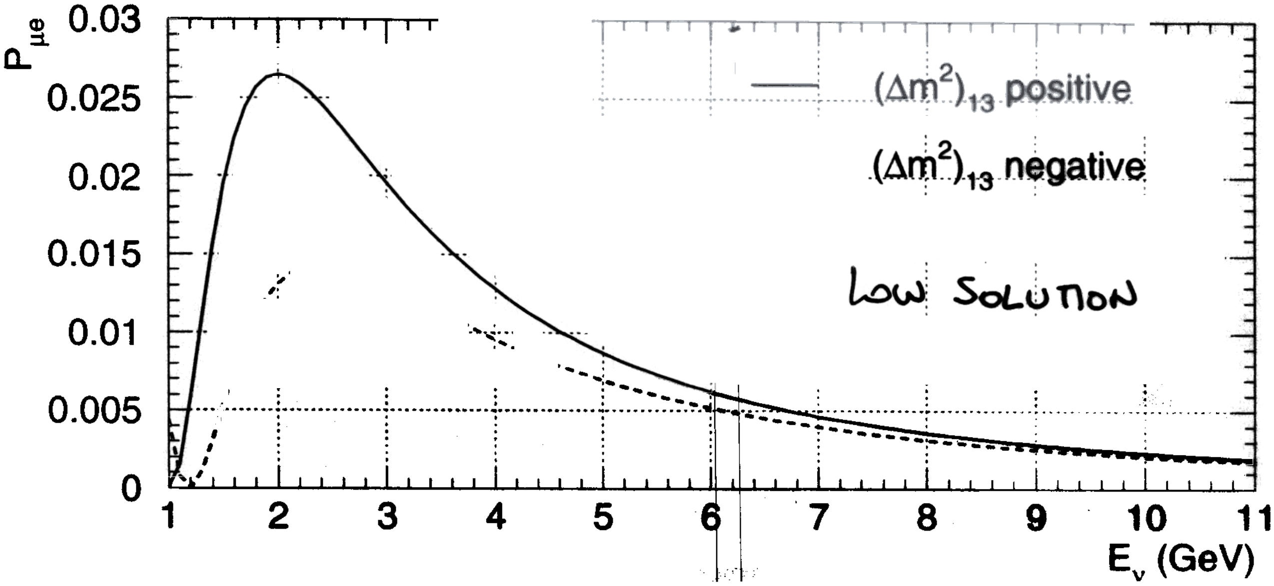


Figure 1: $\nu_\mu \to \nu_e$ oscillation probability for $\Delta m^2_{13} > 0$ (solid line) and $\Delta m^2_{13} < 0$ (dashed line). $|\Delta m^2_{13}| = 3 \cdot 10^{-3}$ eV^2, $\theta_{\rm atm} = \pi/4$, $\Delta m^2_\odot = 1 \times 10^{-7}$ eV^2, $\theta_\odot = \pi/6$, $|U_{e3}|^2 = 0.01$, and $\delta = 0$. $L = 900$ km

$$\frac{\Delta m^2}{2E} \times \quad \sqrt{2}\, G_F N_e \approx 1.4 \times 10^{-4}\ \frac{eV^2}{GeV}$$

AS LONG AS $E \lesssim 10$ GeV MATTER EFFECTS ARE AN IMPORTANT PERTURBATION. NOTE THAT FOR $E > 10$ GeV, WE NEED DISTANCES BIGGER THAN $\gtrsim 5000$ km

AIM AT $\Delta_{13} \sim \pi/2 \ldots$

GNORING SOLAR EFFECTS [AdG, BARENBOIM HEP-PH/0209117]

$$P_{\mu e} = \sin^2\theta_{23} \frac{\sin 2\theta_{13}}{\left[1+\alpha^2-2\alpha\cos 2\theta_{13}\right]} \sin^2\left[\Delta_{13}\left(1+\alpha^2-2\alpha\cos 2\theta_{13}\right)^{1/2}\right]$$

DEPENDENCY ON SIGN (Δm^2_{13})

$$\alpha = \sqrt{2} G_F N_e \Big/ \frac{\Delta m^2_{13}}{2E}$$

$$P_{\bar\mu\bar e} = P_{\mu e}(-\alpha)$$

ALSO NOTE

$$P_{\bar\mu\bar\mu} = 1 \quad 4|U_{\mu 3}|^2(1-|U_{\mu 3}|^2)\sin^2\Delta_{13} + \mathcal{O}(|U_{e3}|^2\alpha)$$

MATTER EFFECTS IRRELEVANT FOR ν_μ DISAPPEARANCE

$$\sin^2 2\theta_{23}\left[-|U_{e3}|^2 \frac{\cos 2\theta_{23}}{\sin^2 2\theta_{23}} 4\sin^2\theta_{23} + \mathcal{O}(|U_{e3}|^4)\right]$$

THIS IS WHAT "ATM DISAPPEARANCE MEASURES"

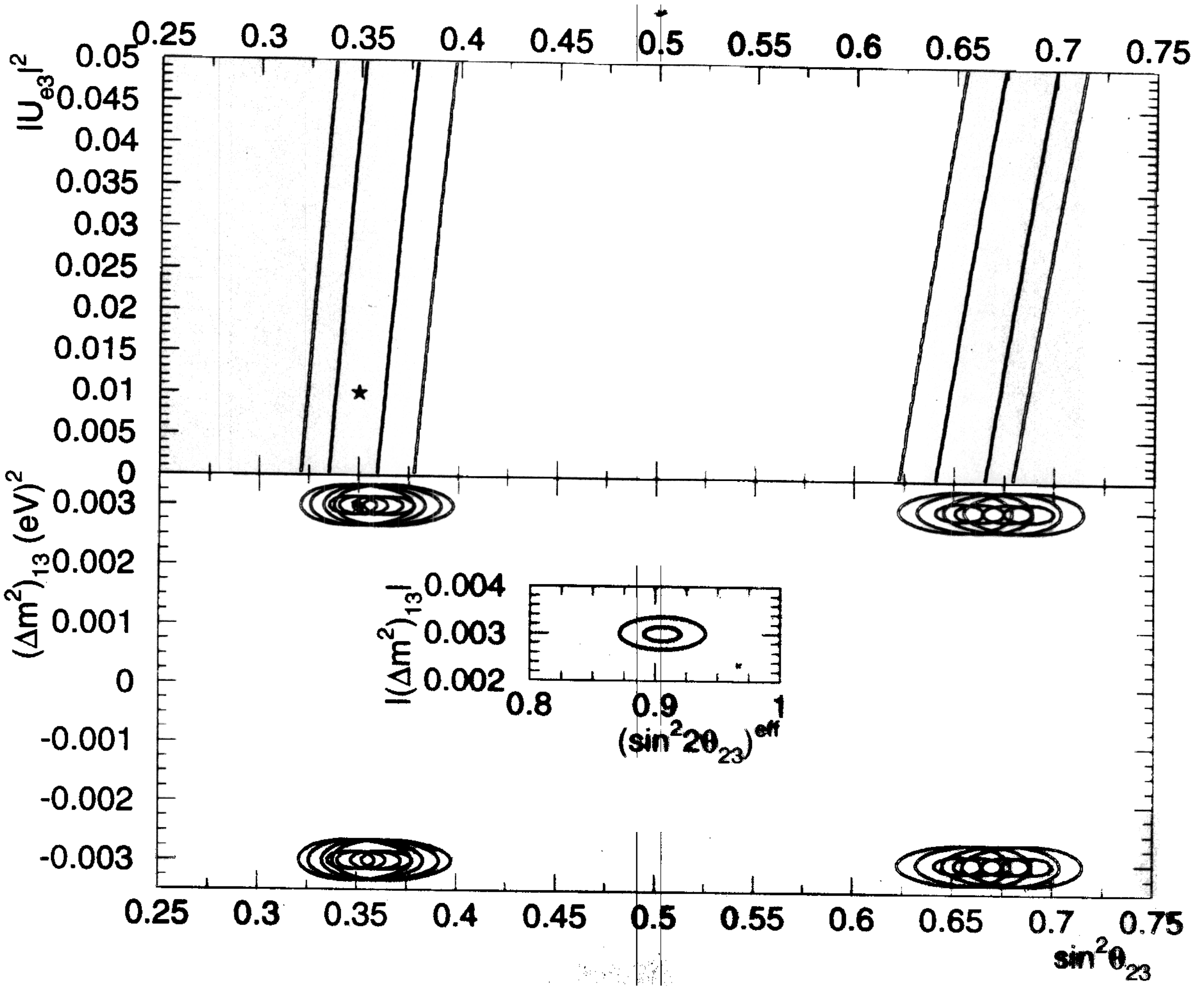


Figure 1: One and three sigma confidence level contours in the ($\sin^2\theta_{23} \times |U_{e3}|^2$) and ($\sin^2\theta_{23} \times \Delta m^2_{13}$)-planes, obtained from the "measurement" $|\Delta m^2_{13}| = (3 \pm 0.1) \times 10^{-3}$ eV^2 and $\sin^2 2\theta^{\rm eff}_{23} = 0.91 \pm 0.01$, depicted in the inset located in the center.

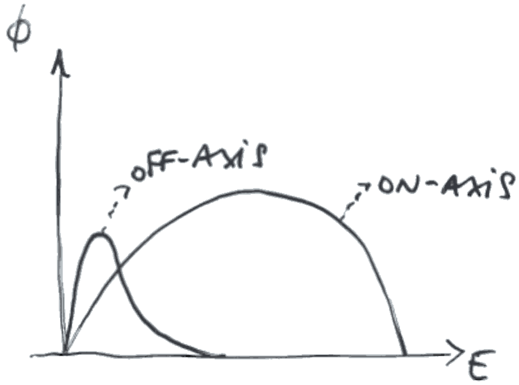
ONE "SAMPLE" EXPERIMENT

NUMI "OFF-AXIS"

- SOON-TO-BE EXISTING BEAMLINE +
- NEW 20 KTON MINOS-LIKE DETECTOR (OPTIMIZED FOR ν_e APPEARANCE)

OFF AXIS

- VERY NARROW BEAM TO BE CENTERED "AROUND" OSCILLATION MAXIMUM.
- BIGGEST DEAL: GET RID OF HIGH ENERGY TAIL IN ORDER TO SUPPRESS N.C. BACKGROUNDS



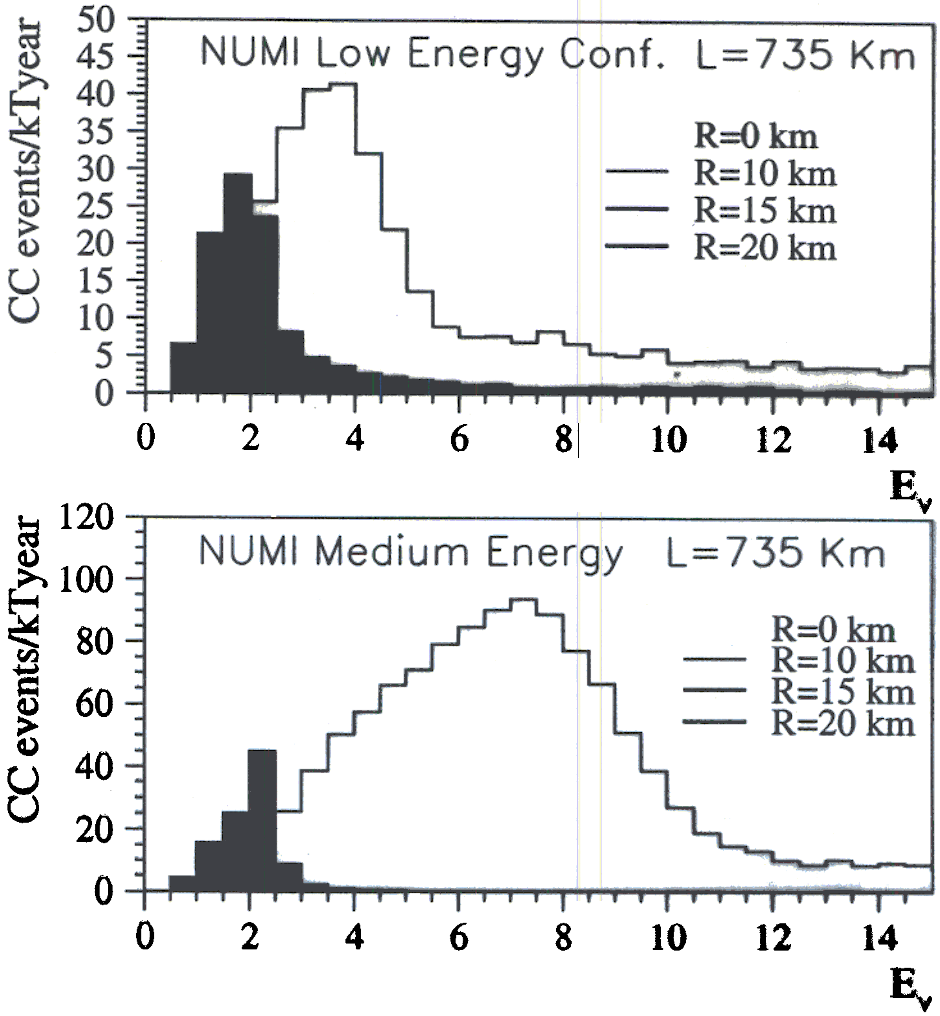


Figure 5: On and off-axis beams for the low and medium energy NuMI horns configuration. A full beam simulation was made using the GEANT based GNuMI Monte Carlo.

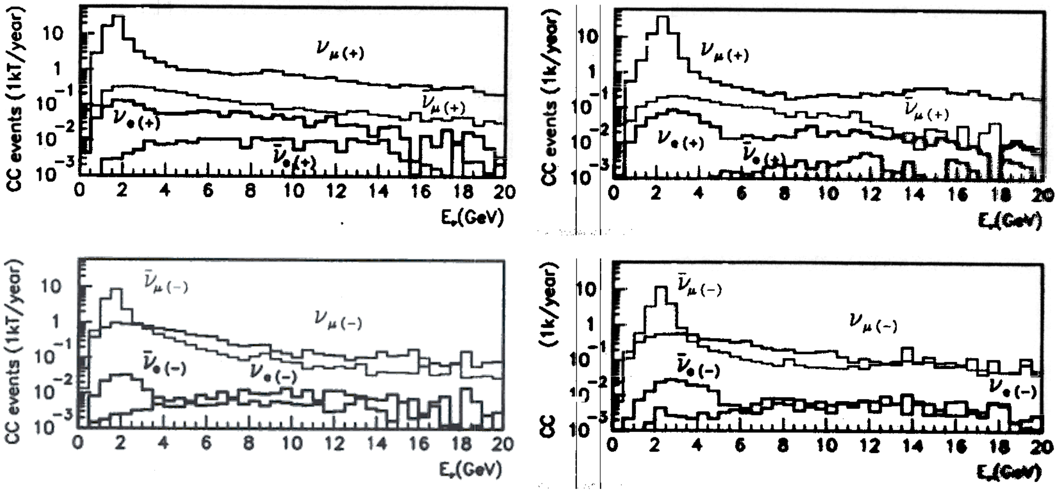


Figure 9: Beam composition for positive (+) and negative (-) horn currents. left: for the a low energy configuration at $L = 735$ km and $R = 10$ km. right: for the a medium energy configuration at $L = 900$ km and $R = 12$ km.

the picture. Nonetheless, the FOM is flat enough that any "reasonable" choice of baseline and opening angle should be "close" to optimal. We, therefore, will do all our analyses for a baseline of 900 km and at a radius of 11.5 km.

3.1 NuMI Off-Axis Beams With A New Proton Driver

The Proton Driver design described in [23, 24] will allow us to bring the NuMI neutrino beam power up from 0.4 MW to 1.6 MW. This design is based on an 8 GeV circular machine with a circumference of 473.2 m, and it will provide 2×10^{13} protons per pulse instead of the assumed 5×10^{12} of the current booster. In addition, the total luminosity could be further increased by 30% if the current linac gets a 200 MeV upgrade. In this case, we would get 3×10^{13} protons per pulse. This machine is estimated to cost US$160M.

An alternative design made out of only a linac to accelerate protons up to 8 GeV, using SNS and Tesla style superconducting cavities, is also under consideration [25].

4 Detector Simulation and Expected Signal Efficiencies

To determine our $\nu_\mu \to \nu_e$ detection capabilities, we are considering a highly segmented iron-scintillator detector. A full study of the expected detector performance, event reconstruction efficiencies, and background contamination was performed.

The detector is made up of 4.5 mm thick iron foils (one quarter of one radiation length)

3σ SENSITIVITY TO OBSERVE ν_e EXCESS.

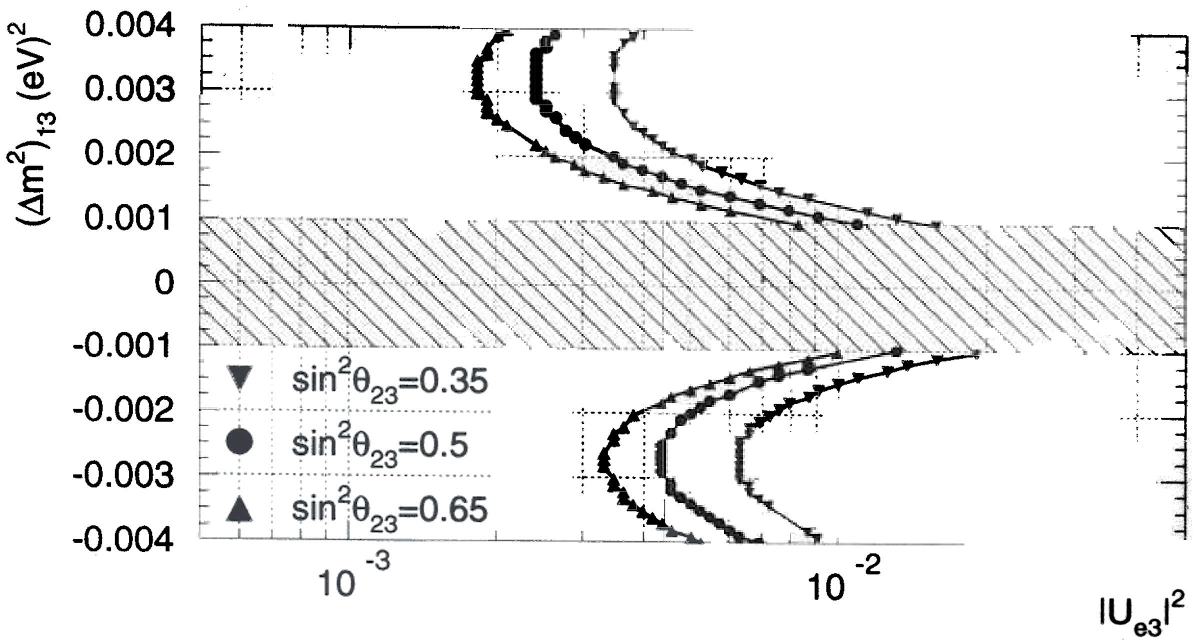


Figure 2: Three sigma confidence level sensitivity of 120 kton-years of “neutrino beam” data, 12 km off-axis and 90 km away from the NuMI beam, as a function of Δm^2_{13} and $|U_{e3}|^2$, for $\sin^2\theta_{23} = 0.35, 0.5, 0.65$. The hatched region is currently ruled out by the atmospheric neutrino data at the three sigma confidence level.

Ad6, BARENBOIM
HEP-PH/0209117

DEGENERACIES TRYING TO MEASURE $|U_{e3}|^2$

EVEN IF LMA IS RULED OUT THE FACT THAT WE ONLY HAVE PARTIAL INFORMATION FROM DISAPPEARANCE CHANNEL LEADS TO AMBIGUITIES MEASURING $|U_{e3}|^2$

- "HIERARCHY" AMBIGUITY

$$\Delta m^2_{23} > 0, \quad |U_{e3}|^2 \text{ "SMALL"} = \Delta m^2 < 0 \quad |U_{e3}|^2 \text{ "BIG"}$$

- "ATMOSPHERIC ANGLE" AMBIGUITY

$$|U_{e3}|^2, \ \sin^2\theta_{23} = |U_{e3}|^2 \, tg^2\theta_{23}, \ \cos^2\theta_{23}$$

$$P_{\mu e} \propto \sin^2\theta_{23} \, |U_{e3}|^2$$

HOWEVER, DEGENERACIES ARE GOOD IF THEY CAN BE LIFTED...

DEGENERACIES: MORE INFORMATION = MORE MEASUREMENTS

HOW TO "LIFT" DEGENERACIES

- RUN EXPERIMENT AT "SHORT" BASELINE, SO THAT MATTER EFFECTS DON'T MATTER
  - → MEANS LOWER ENERGY ν'S $E \lesssim 500\,MeV$
  - → CAN'T "SEE" THE HIERARCHY

COMBINE TWO EXPERIMENTS AT DIFFERENT L/E,
  - → REQUIRES TWO DISTINCT BEAMS, DETECTORS...
  - → MIGHT NOT BE SO UNREALISTIC IF DIFFERENT PROPOSALS MATERIALIZE

* RUN SAME EXPERIMENT WITH ANTI-NEUTRINO BEAM
  - → SAME SETUP
  - → $\bar{\nu}_\mu$ ARE HARDER TO PRODUCE AND DETECT
  - → NEED REALLY BIG DETECTOR OR INTENSE BEAM
    - ↳ P-DRIVER UPGRADE AT FNAL!

- MEASURE THINGS REALLY WELL!
  - → MORE INFO ON THE SPECTRUM OF ν_e APPEARANCE, DISAPPEARANCE

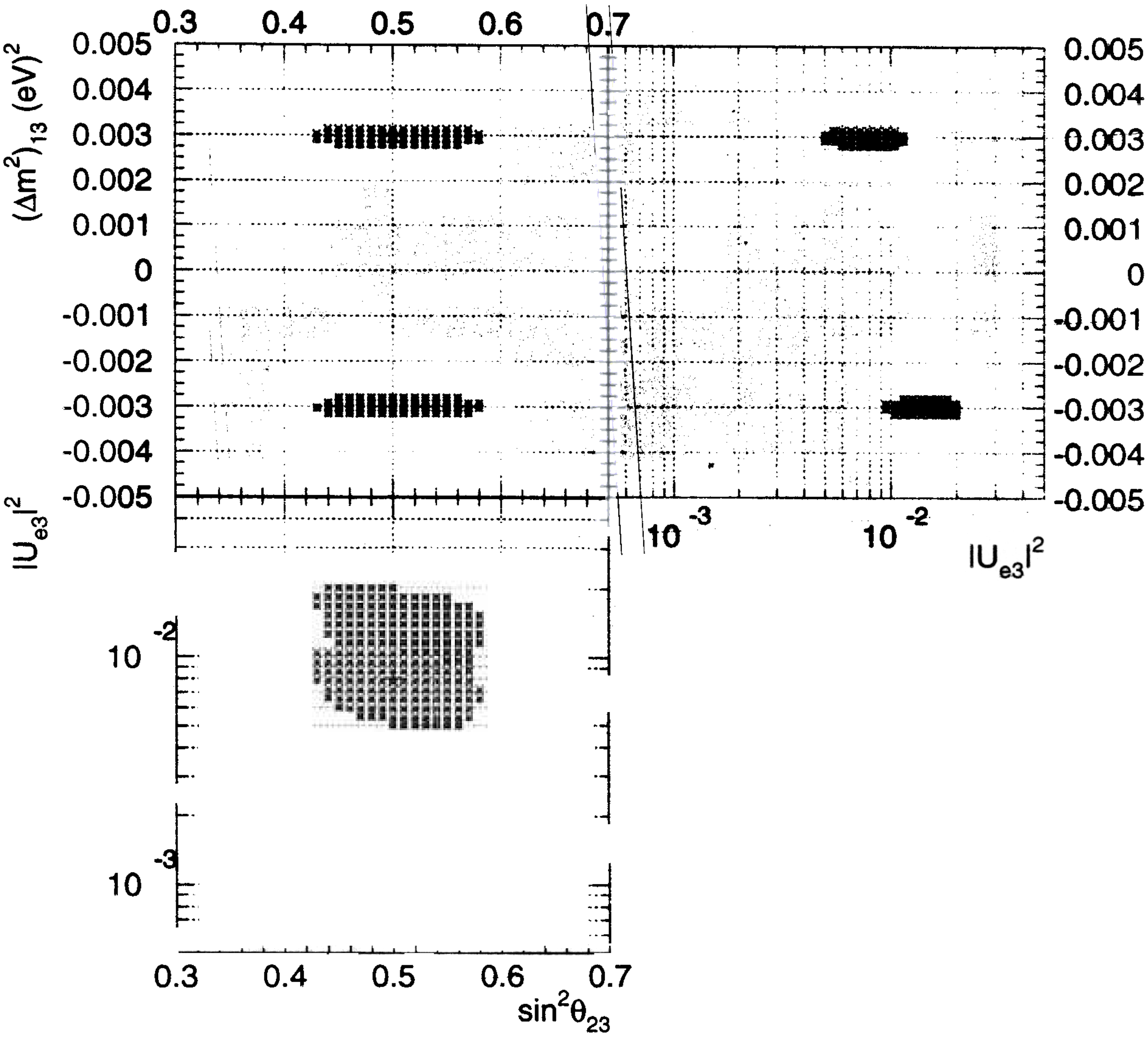


Figure 3: Two-sigma confidence level regions in the $(\Delta m^2_{13} \times |U_{e3}|^2)$, $(|U_{e3}|^2 \times \sin^2\theta_{23})$, and $(\Delta m^2_{13} \times \sin^2\theta_{23})$-planes obtained after 120 kton-years of "neutrino-beam data" (dark squares) combined with 300 kton-years of "antineutrino-beam data" (light [green] circles) for the following input value for the mixing parameters (indicated by the [blue] stars): $\Delta m^2_{13} = 3 \times 10^{-3}$ eV^2, $|U_{e3}|^2 = 0.008$, and $\sin^2\theta_{23} = 0.5$.

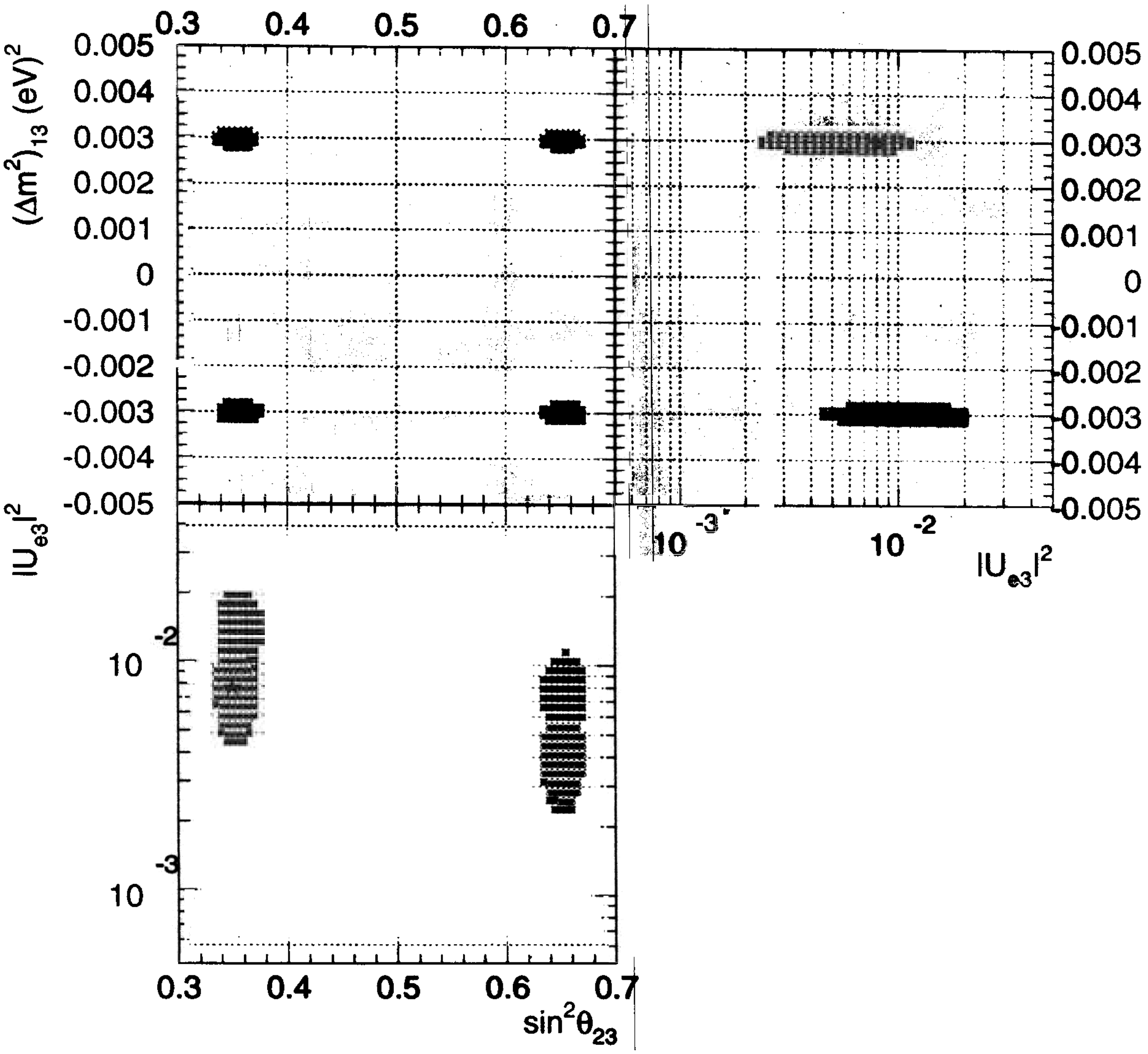


Figure 4: Two-sigma confidence level regions in the $(\Delta m^2_{13} \times |U_{e3}|^2)$, $(|U_{e3}|^2 \times \sin^2\theta_{23})$, and $(\Delta m^2_{13} \times \sin^2\theta_{23})$-planes obtained after 120 kton-years of "neutrino-beam data" (dark squares) combined with 300 kton-years of "antineutrino-beam data" (light [green] circles) for the following input value for the mixing parameters (indicated by the [blue] stars): $\Delta m^2_{13} = 3 \times 10^{-3}$ eV^2, $|U_{e3}|^2 = 0.008$, and $\sin^2\theta_{23} = 0.35$.

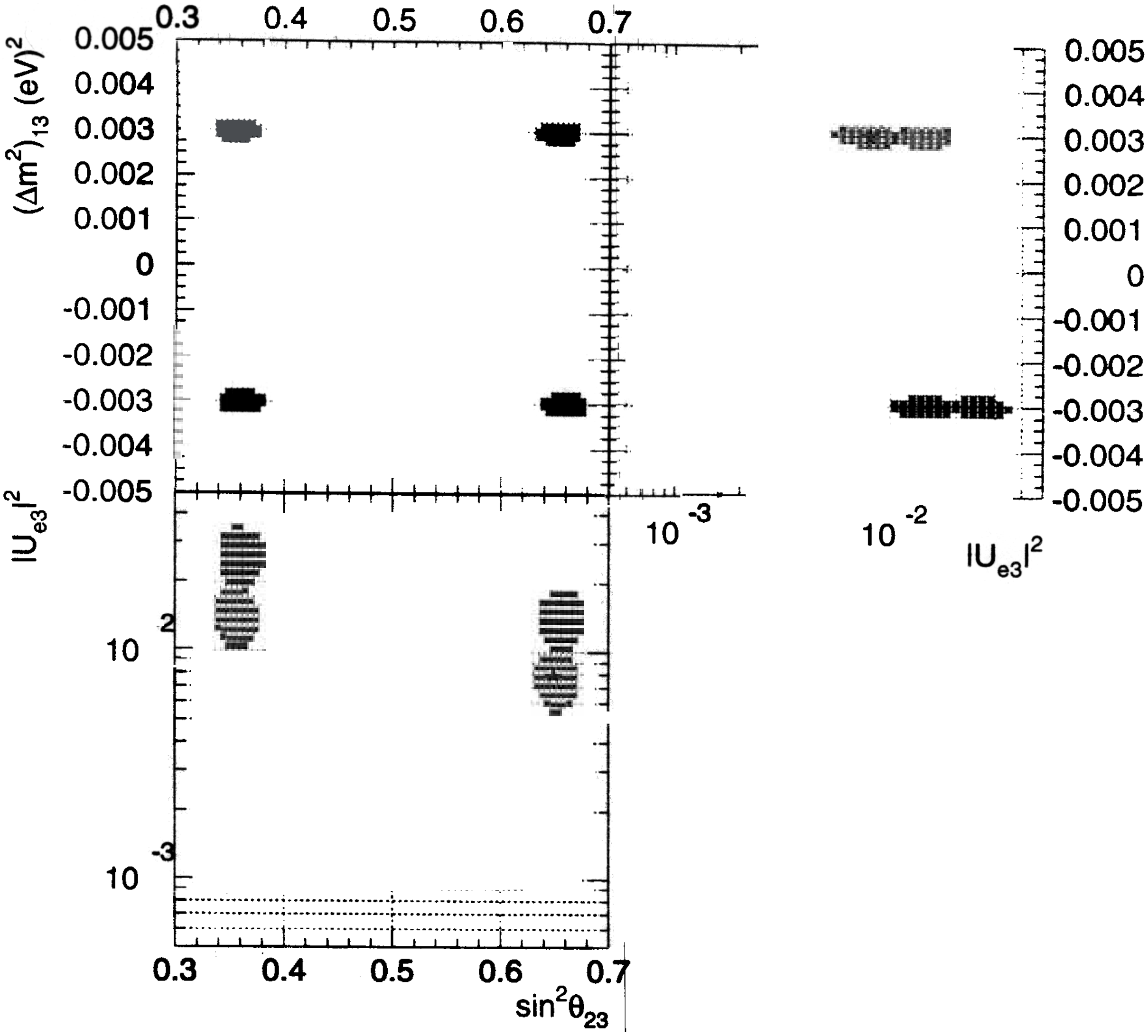


Figure 5: Two-sigma confidence level regions in the $(\Delta m^2_{13} \times |U_{e3}|^2)$, $(|U_{e3}|^2 \times \sin^2\theta_{23})$, and $(\Delta m^2_{13} \times \sin^2\theta_{23})$-planes obtained after 120 kton-years of "neutrino-beam data" (dark squares) combined with 300 kton-years of "antineutrino-beam data" (light [green] circles) for the following input value for the mixing parameters (indicated by the [blue] stars): $\Delta m^2_{13} = 3 \times 10^{-3}$ eV^2, $|U_{e3}|^2 = 0.008$, and $\sin^2\theta_{23} = 0.65$.

Barenboim, AdG

hep-ph/0209117

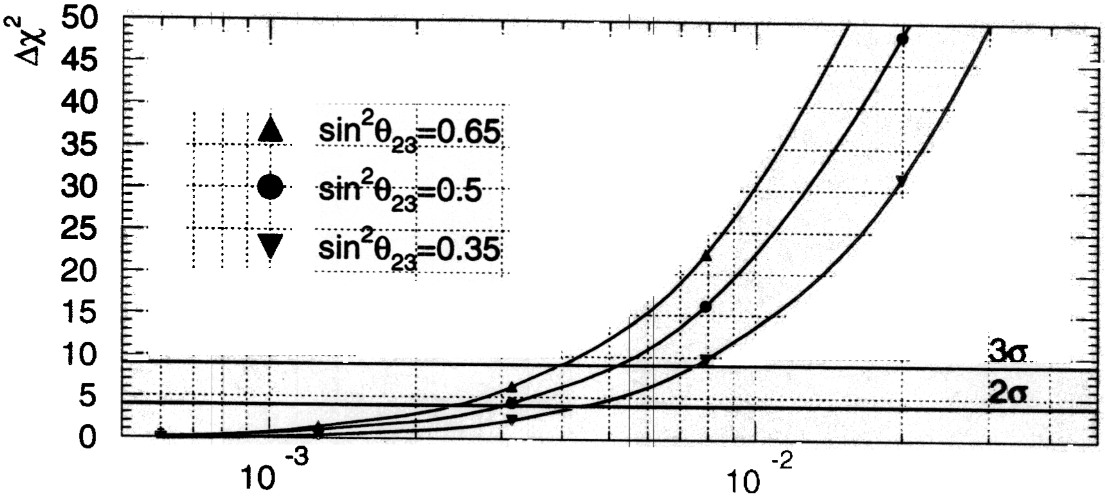


Figure 6: $\Delta\chi^2 \equiv |\chi^2_{min}(\Delta m^2_{13} < 0) - \chi^2_{min}(\Delta m^2_{13} > 0)|$ as a function of $|U_{e3}|^2$, for $\Delta m^2_{13} = +0.003$ eV^2 and $\sin^2\theta_{23} = 0.35, 0.5, 0.65$, obtained after 120 kton-years of "neutrino beam data" and 300 kton-years of "antineutrino beam data." The solid horizontal lines indicate the two- and three-sigma confidence levels for determining the sign of Δm^2_{13}.

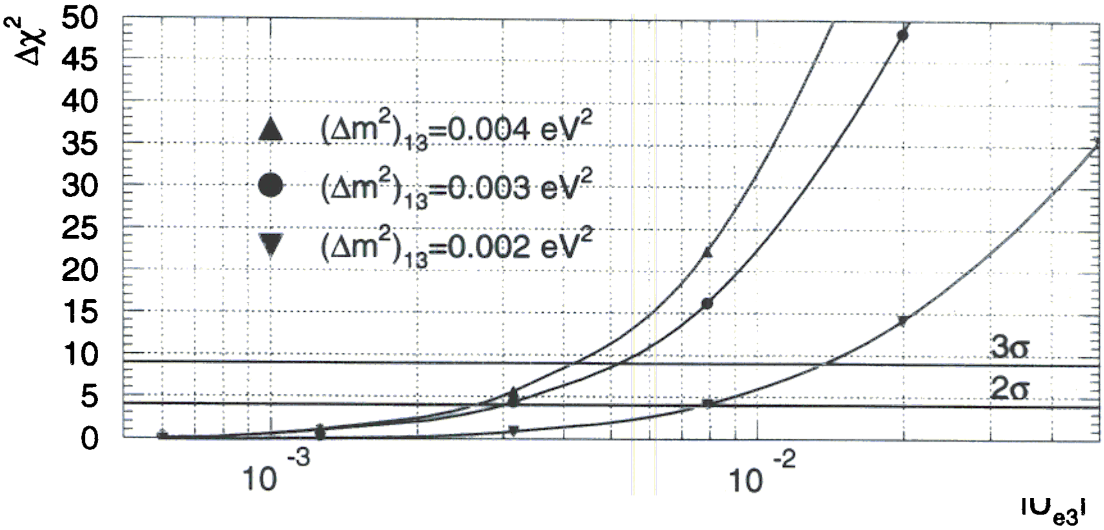


Figure 7: Same as Fig. 6, for $\sin^2\theta_{23} = 0.5$ and $\Delta m^2_{13} = 0.002, 0.003, 0.004$ eV^2.

OTHER SSUES

ETTING RID OF ATMO HERIC ANGLE AMBIGU TY
S TRICKY

IDEA $P(\nu_e \quad \nu_e) \propto U_e{}^2(U_e$ PER S GEY REACTOR EXPT.

$P(\nu_e \quad \nu_2) \propto \cos^2\theta \quad U_e{}^2$ WHERE DO WE GET HIGH ENERGY ν_e BEAM

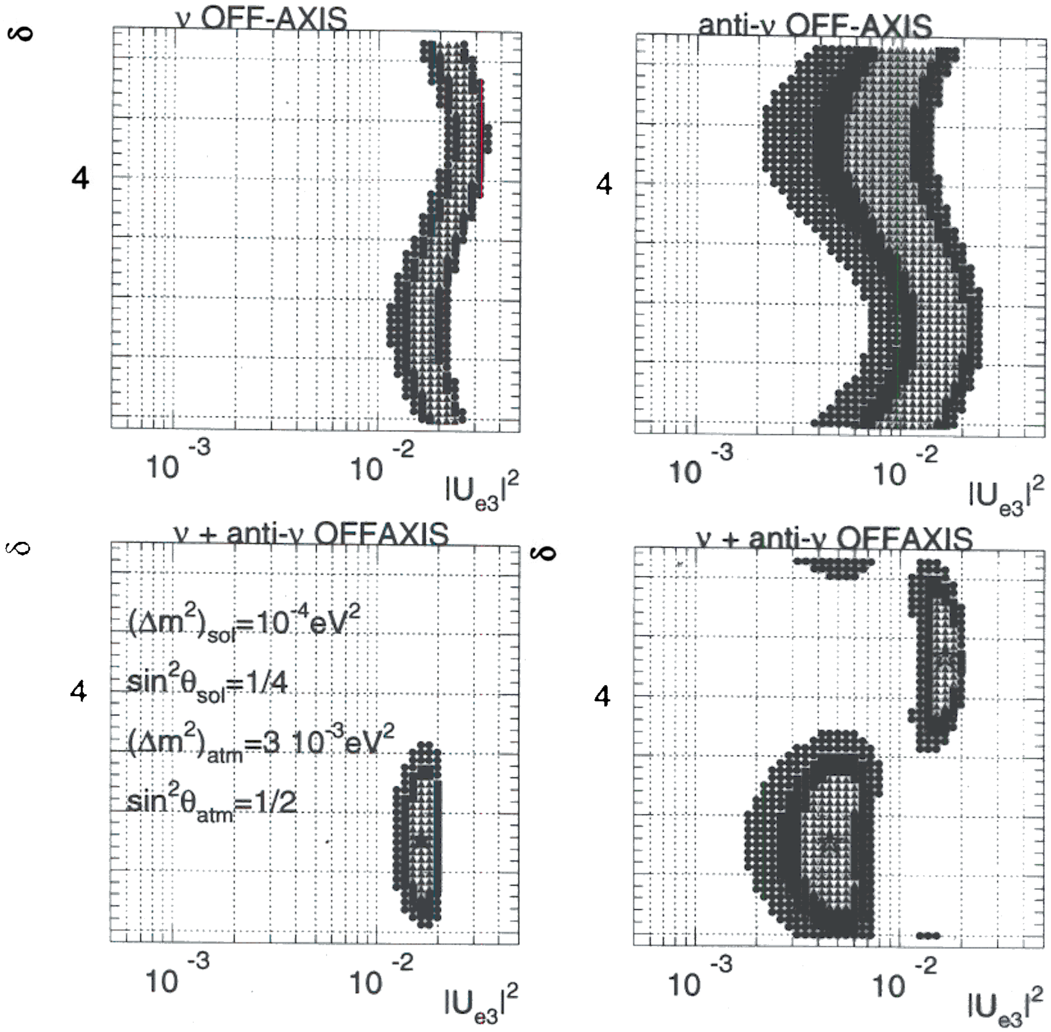
HOW ELL DO WE HAVE TO KNOW THE ATM PARAMETER ?
WHEN?

NOTE THAT WE CAN T KNOW T EXACTL BECAUSE OF THE HIERARCHY AMB GU TY.

I D DN T TELL YOU HOW EXITING (AND CONFUSING THING ARE F LMA S CORREC

LOOKING FOR CP VIOLATION (δ)

[A uni HIERARCHY KNOWN $\sin^2\theta$ ½
ATM + SOL PARAMETERS PERFECTLY MEASURED]



gure Cap

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BARENBOIM, AdG
ZLEPER VELASCO

HLMA

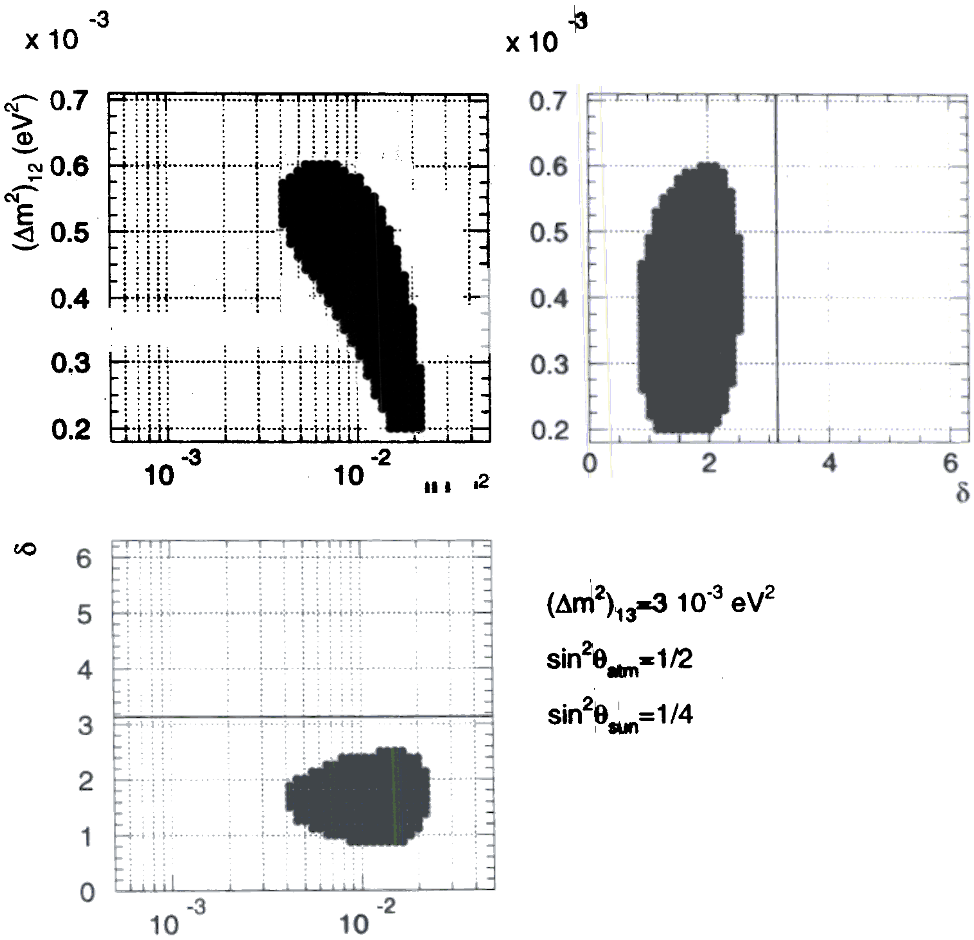


Figure 19: Projections of the three sigma measurement surface in the $(|U_{e3}|^2 \times \delta \times \Delta m^2_{12})$-space, after 120 kton-years of neutrino-beam running and 300 kton-years of antineutrino-beam running. The simulated data is consistent with $|U_{e3}|^2 = 0.012$, $\delta = \pi/2$ and $\Delta m^2_{12} = 4 \times 10^{-4}$ eV^2. $\Delta m^2_{13} = +3 \times 10^{-3}$ eV^2, $\sin^2\theta_{\rm atm} = 1/2$, $\sin^2\theta_\odot = 1/4$.

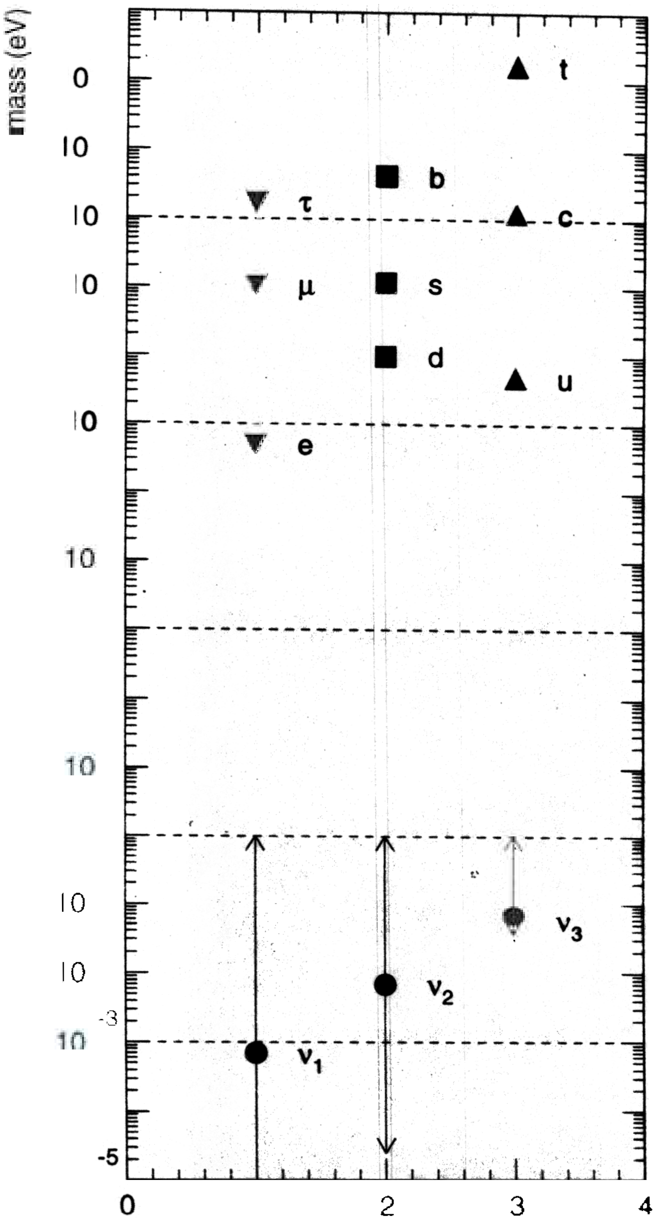
HEP-PH/0204208

CONCLUDING THOUGHTS

- NEUTRINO OSCILLATION EXPERIMENTS: ONLY EVIDENCE FOR PHYSICS BEYOND THE SM
  [+ IT IS PROBABLY MORE THAN JUST AN EXTRA PIECE OF THE FLAVOR PUZZLE]
  ↳
- SEVERAL KEY EXPERIMENTAL RESULTS TO APPEAR IN THE NEXT COUPLE OF YEARS: GUARANTEED!
  I DID NOT TALK ABOUT OTHER ν-EXPT'S ($0\nu\beta\beta$-DECAY, TRITIUM-DECAY, SUPER NOVAE...)
- EVEN IF THE CURRENTLY ACCEPTED SCENARIO IS TRUE (3 FLAVOR OSCILLATIONS, LSND IS WRONG) THERE ARE PLENTY OF UNANSWERED QUESTIONS; WE NEED NEW EXPERIMENTS TO ADDRESS THEM. (UNDER ANY CIRCUMSTANCES) [LMA OR NO LMA

THERE IS PLENTY OF ROOM FOR SURPRISES!

NEUTRINO MASSES ARE REALLY TINY



$m_e \gg m_{\nu_3}$

$m_t \quad m_e$

← ASSUMING NORMAL HIERARCHY

WHY?