24-26 July 200

J. Schneps

NO-VE

ATMOSPHERIC and LONG BASELINE EXPERIMENTS

	ACCELERATOR	ATMOSPHERIC
APPROVED	K2K (cont.) *MINIBOONE (2001) MINOS (2004) OPERA (2005) ICARUS (2005) (? kton)	SuperK (cont) MINOS (2002) ICARUS (soon, ? kt) SNO
PROPOSED	JHF-SK *BOONE (if MINIB. positive)	MONOLITH ~Mton H_2O $\check{C}$ (Aquarich, UNO, HyperK

Superbeams (~5× conventional)

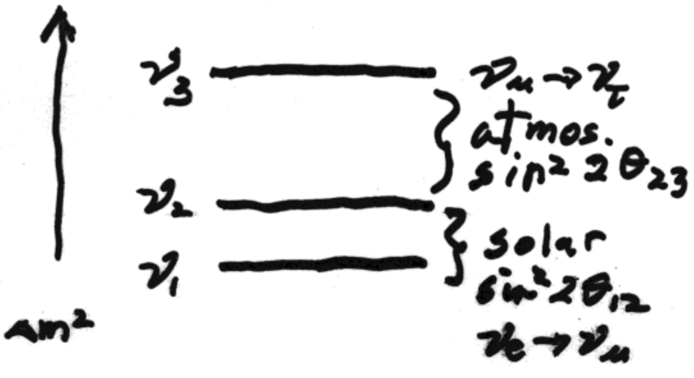
- JHF
  - SK
  - CHINA
  - KOREA
  - ?
- FNAL
  - Soudan
  - SLAC
  - Japan
  - ?
- CERN
  - Frejus
  - N. America
  - ?

Detectors ?

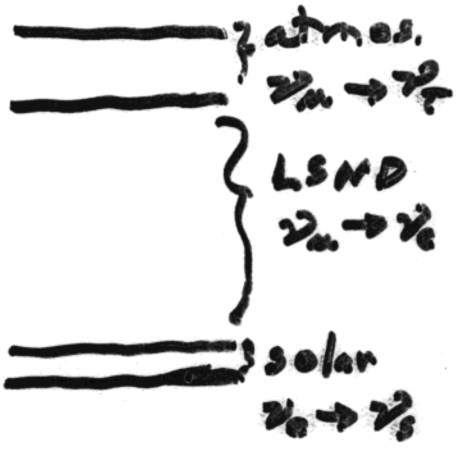
Massive $\gtrsim$ 50 kto

Two recent "popular" models for ν oscillations

3 Generations
ν_e, ν_μ, ν_τ



4 Generations
$\nu_e, \nu_\mu, \nu_\tau, \nu_s$



SNO + negative MINIBOONE will favor the 3ν model strongly

This gives focus to LBL experiments which, in fact, already are 3ν focused.

Positive MINIBOONE, however, will require a deeper look into the aims

In 3ν scenario

What needs to be measured?

now

1. Δm^2_{23}
2. $\sin^2 2\theta_{23}$

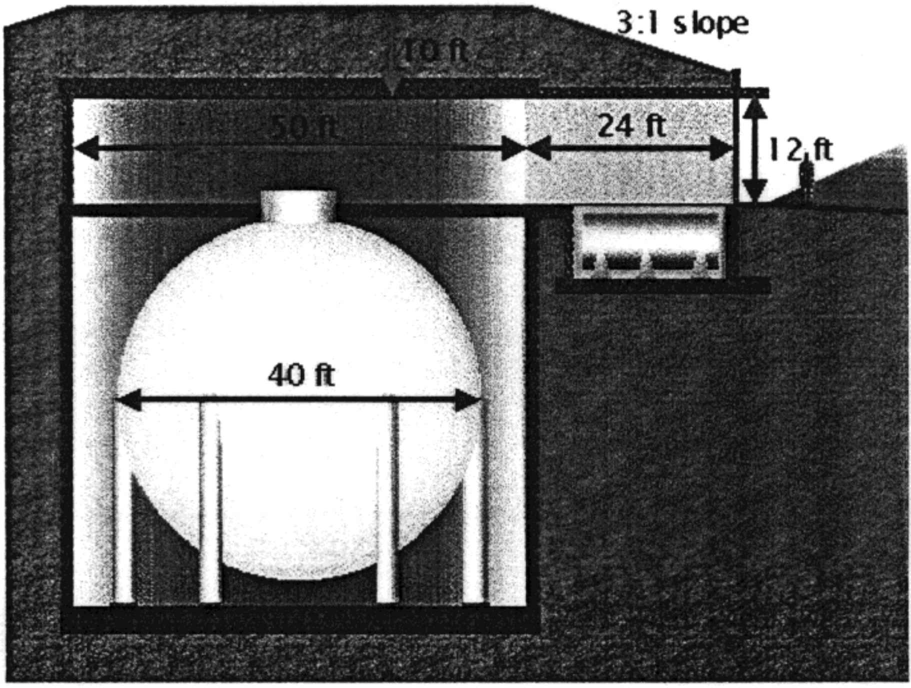
$\Big\}$ more precisely — Superk $1.6 < \Delta m^2 < 4\times10^{-3}\,eV^2$, $\sin^2 2\theta_{23} > .88$

3. $\sin^2 2\theta_{13}$
   $\nu_\mu \to \nu_e$ at Δm^2_{atm}
4. matter effects in the earth $\nu_\mu \to \nu_e$
5. sign of Δm^2_{23} e.g. $\nu_\mu \to \nu_e$ vs. $\bar{\nu}_\mu \to \bar{\nu}_e$
6. CP violation

ν factor

But first, is LSND right or wrong?

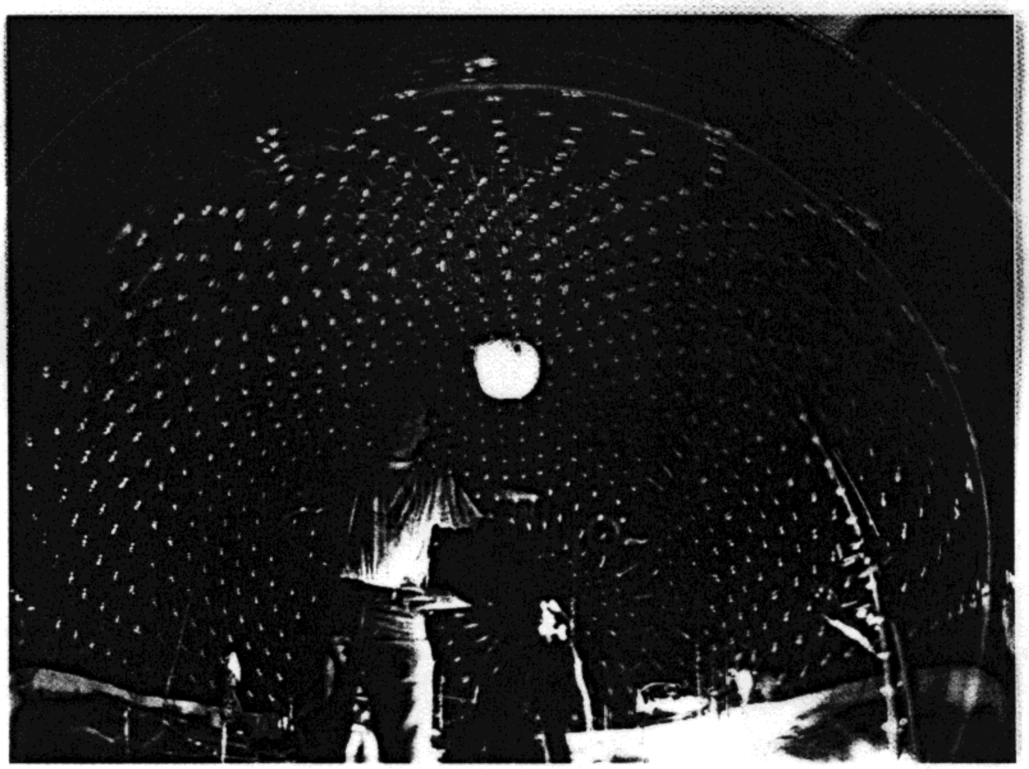
Did it see $\nu_\mu \to \nu_e$ oscillations?



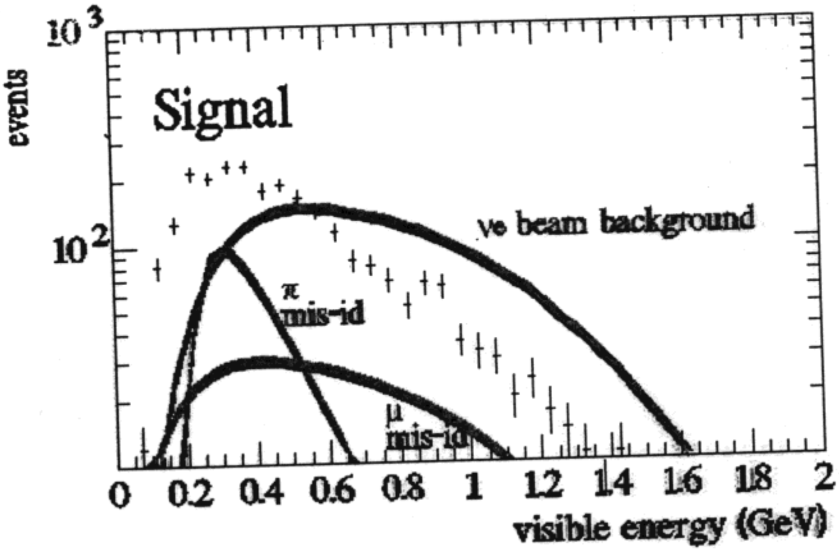
MINIBOONE

ν_μ beam from 8 GeV bo

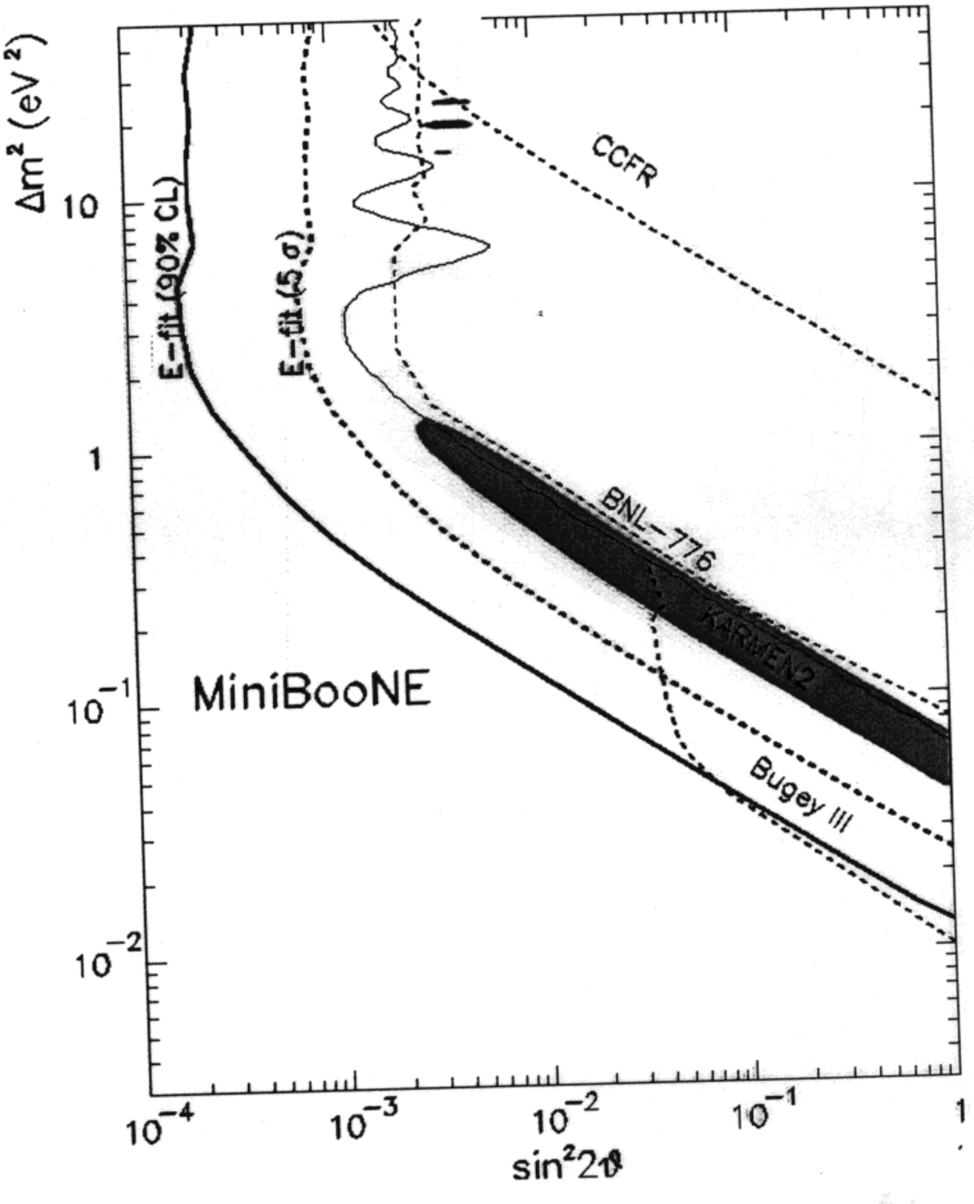
look for $\nu_\mu \to \nu_e$

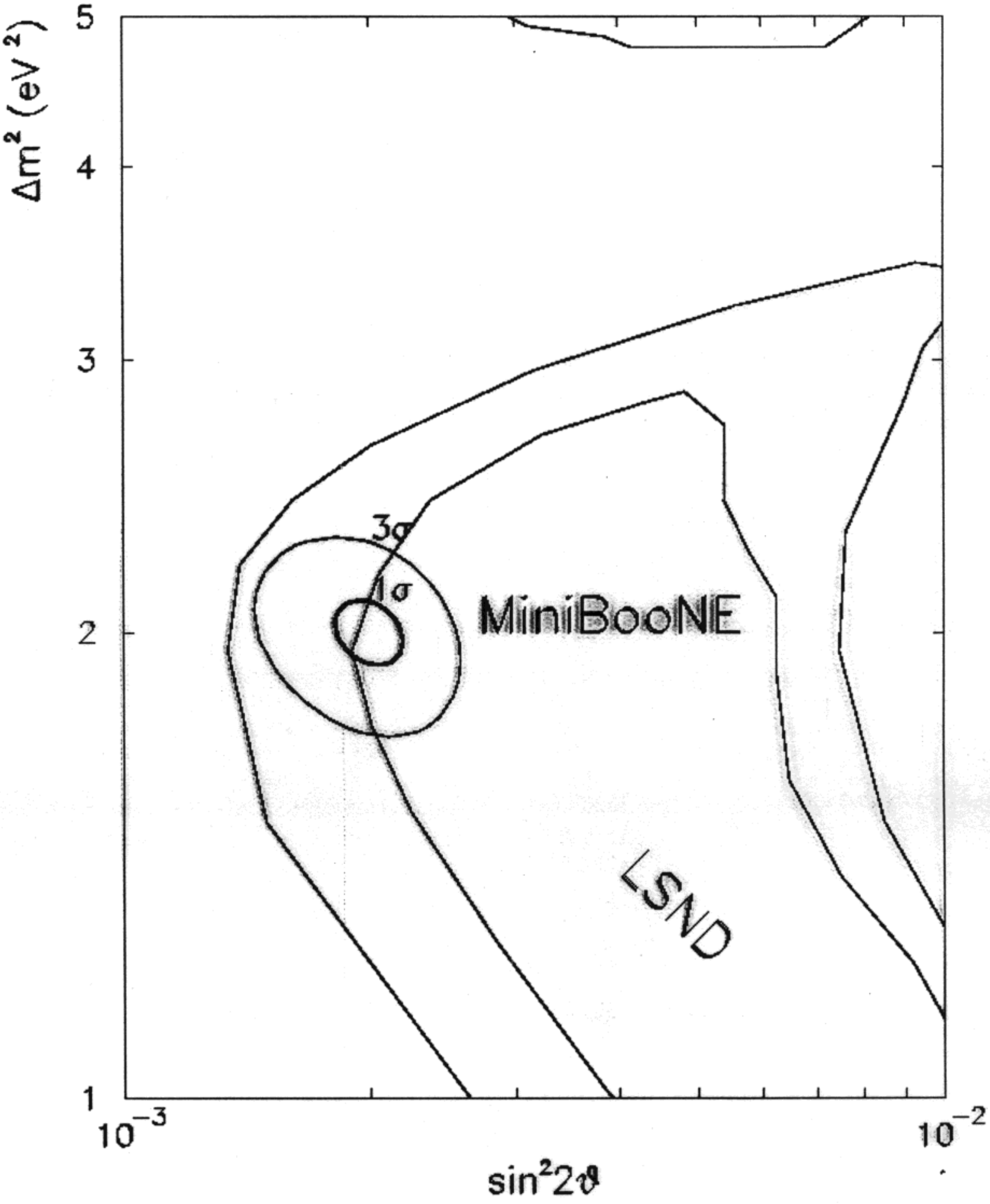


As of June 2001



If LSND
is right
MINIBOONE
sees ~1000
excess ν_e /year

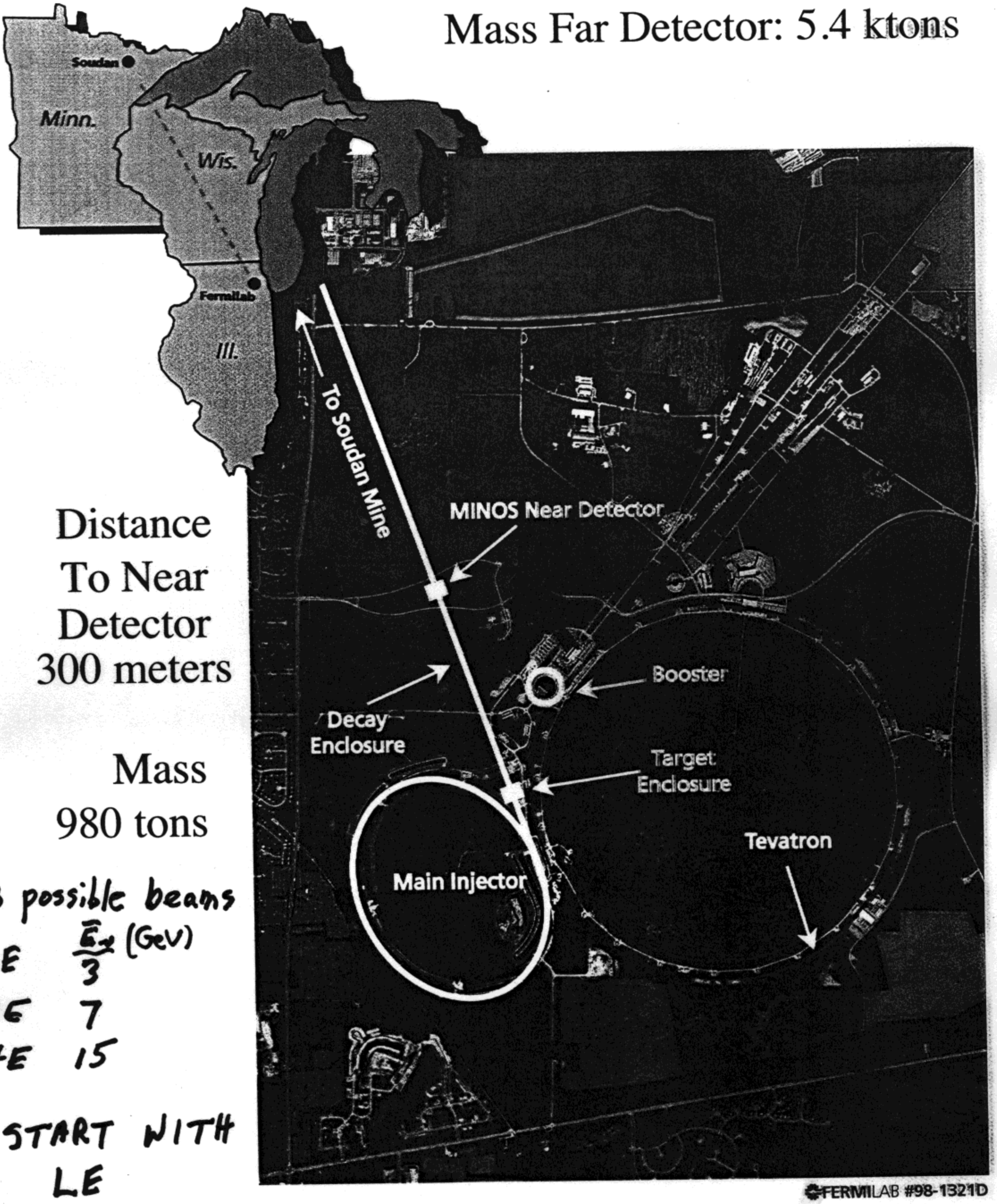




MINIBOONE START ~DEC 2001

Fermilab - Soudan: 732 km

Mass Far Detector: 5.4 ktons



FERMILAB #98-1321D

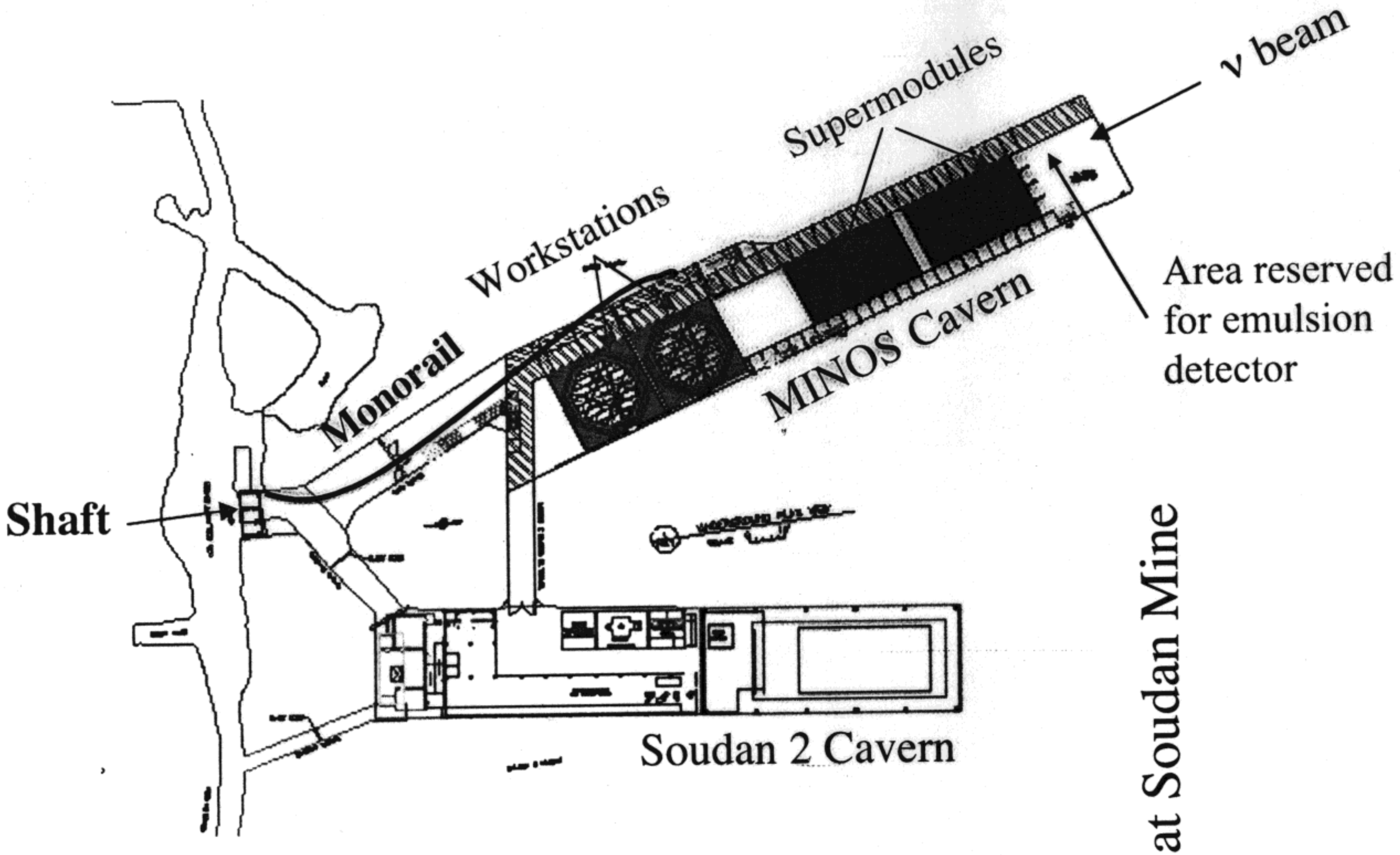
Distance
To Near
Detector
300 meters

Mass
980 tons

3 possible beams

	$\bar{E}_\nu$ (GeV)
LE	3
ME	7
HE	15

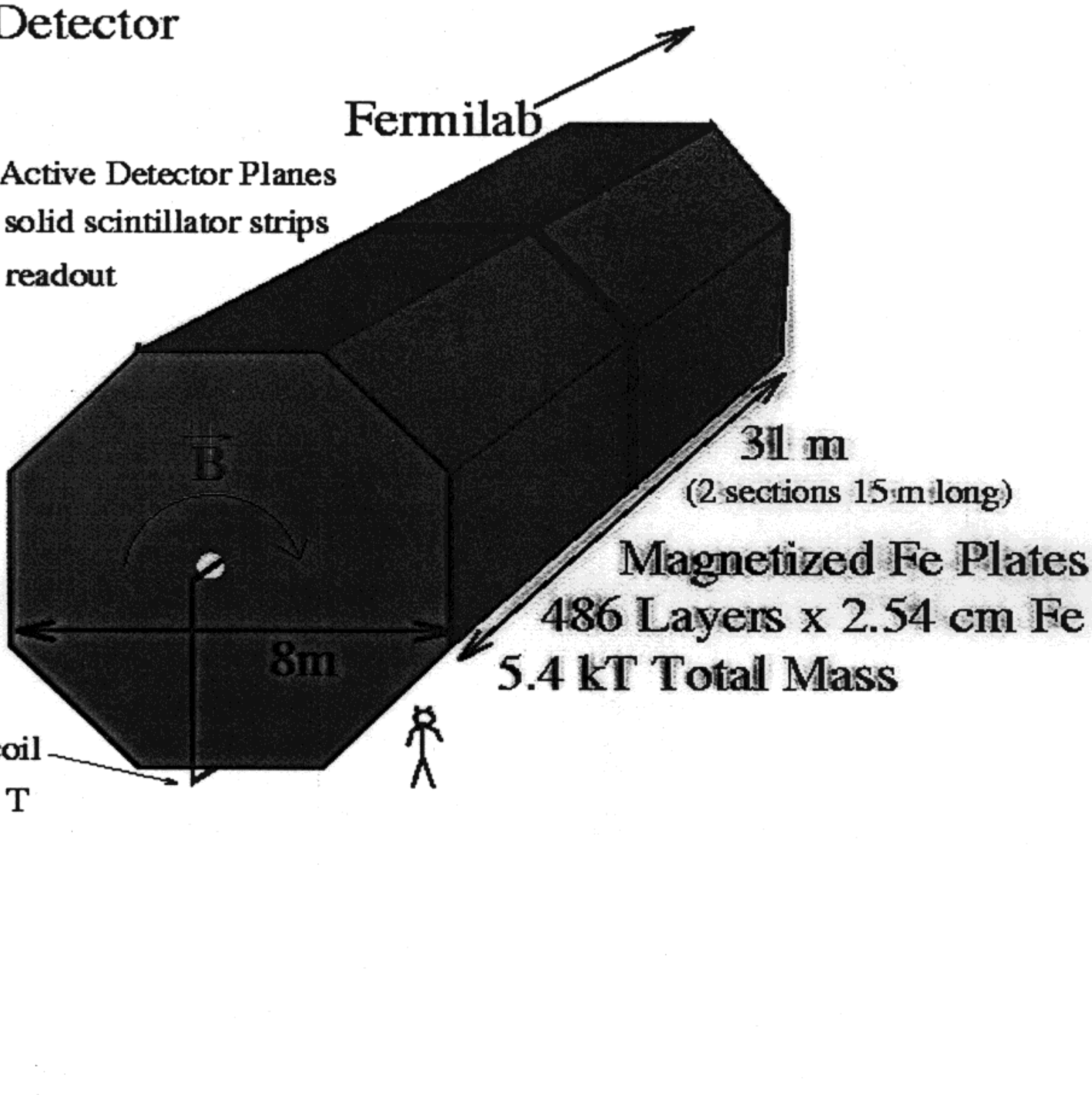
START WITH LE



Layout at Soudan Mine

Far Detector

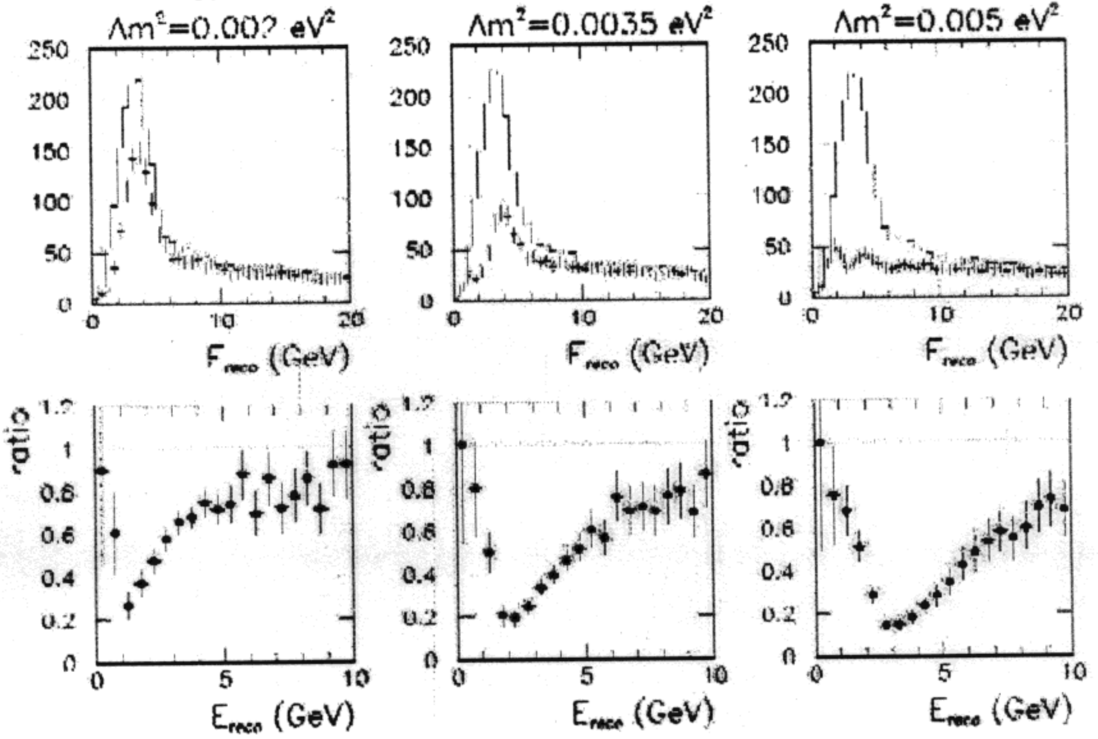
25,800 m^2 Active Detector Planes
4 cm wide solid scintillator strips
WLS fiber readout



Magnetized Fe Plates
486 Layers x 2.54 cm Fe
5.4 kT Total Mass

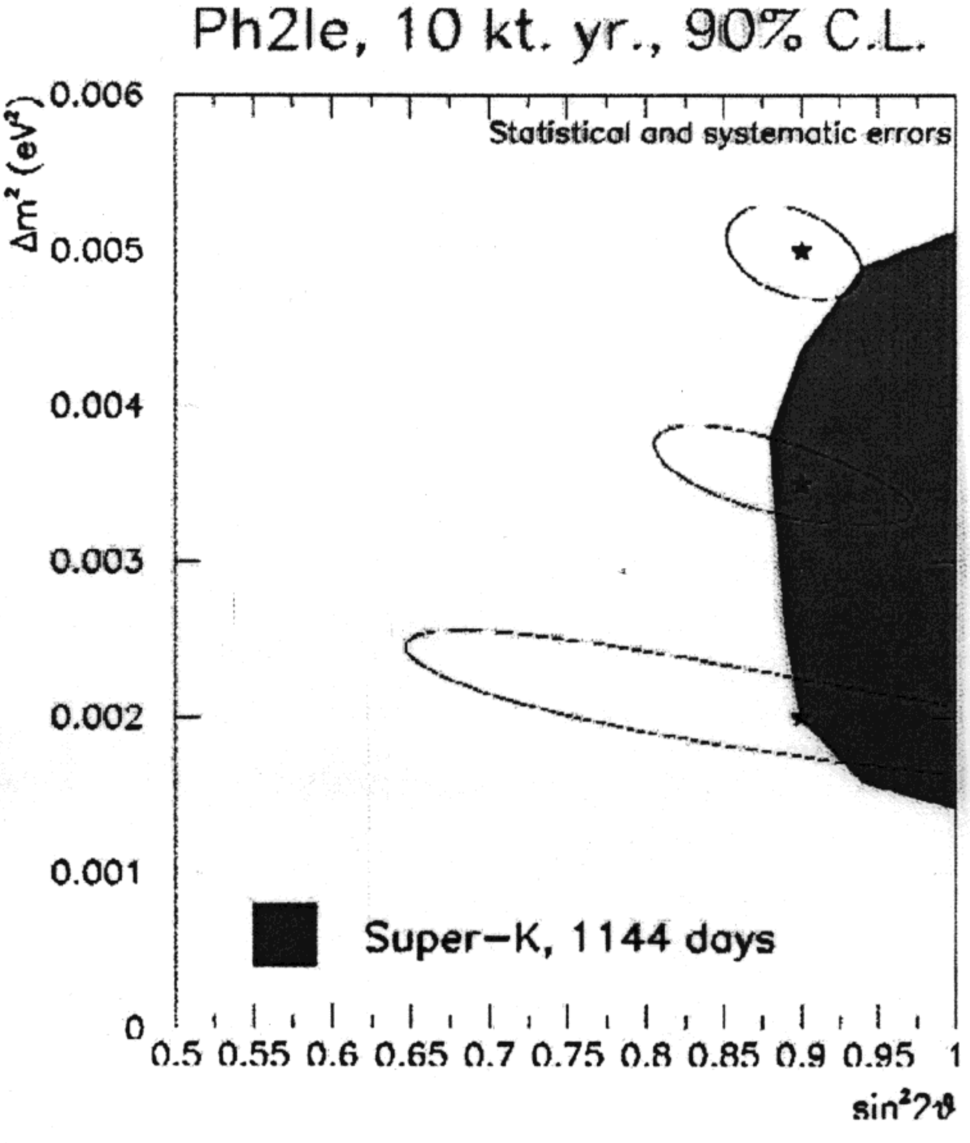
<B>=1.5 T

CC energy distributions – Ph2le, 10 kt.yr., $\sin^2(2\vartheta)=0.9$

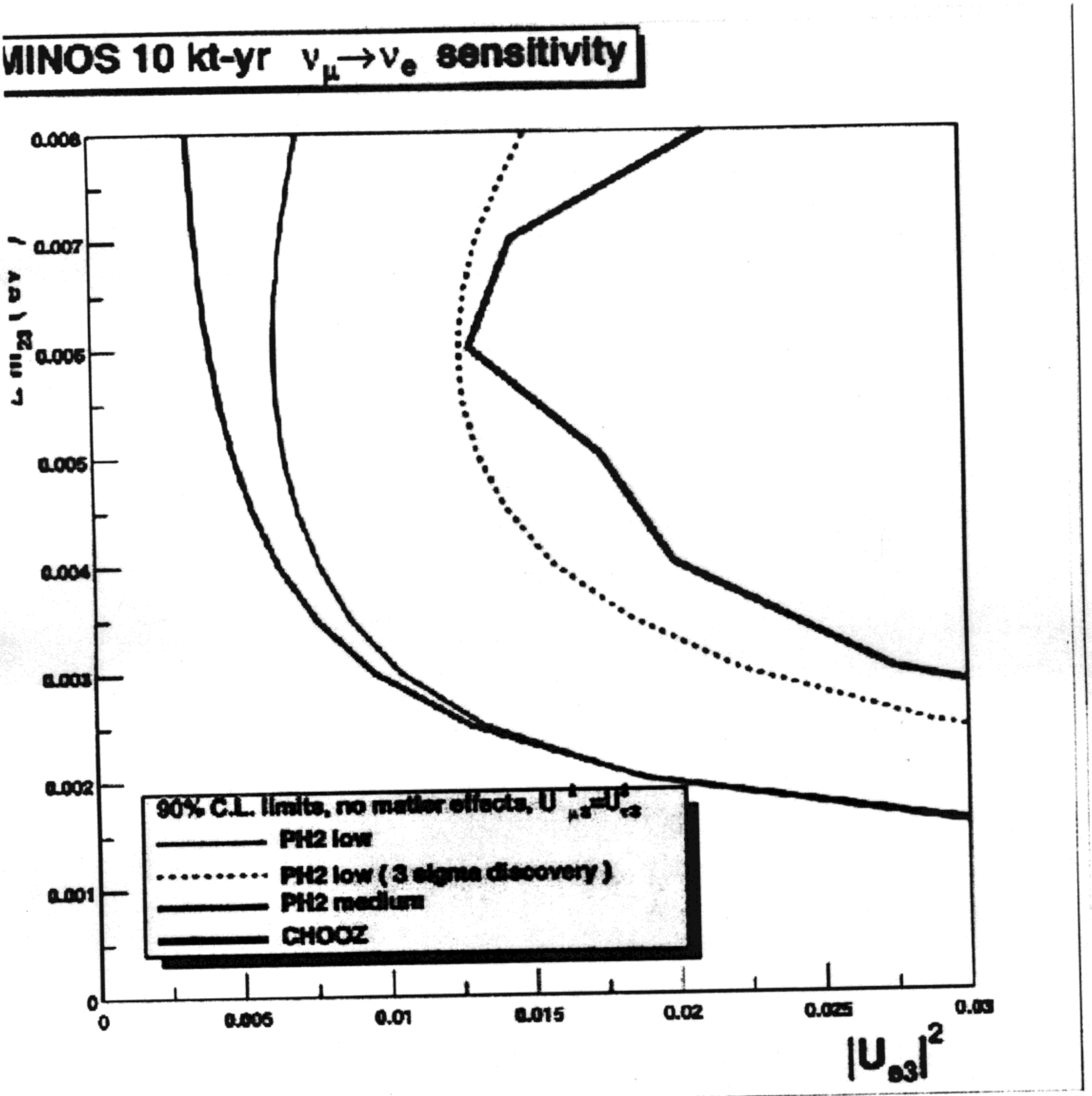


$\Delta m^2=0.002$ eV^2 $\Delta m^2=0.0035$ eV^2 $\Delta m^2=0.005$ eV^2

2 years run

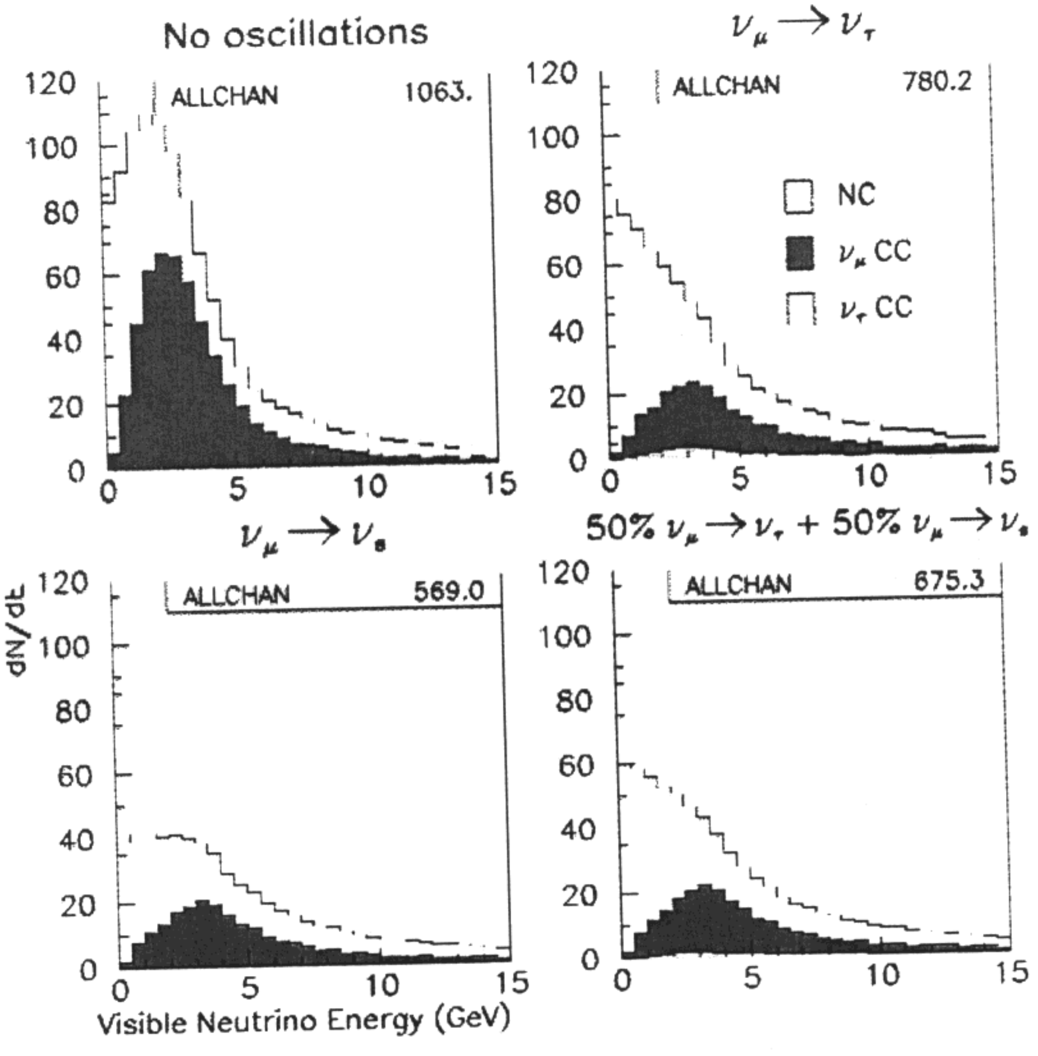

Ph2le, 10 kt. yr., 90% C.L.
Statistical and systematic errors
Δm^2 (eV^2)
0.006
0.005
0.004
0.003
0.002
0.001
0
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
$\sin^2 2\vartheta$
Super−K, 1144 days

$\nu_\mu \to \nu_e$

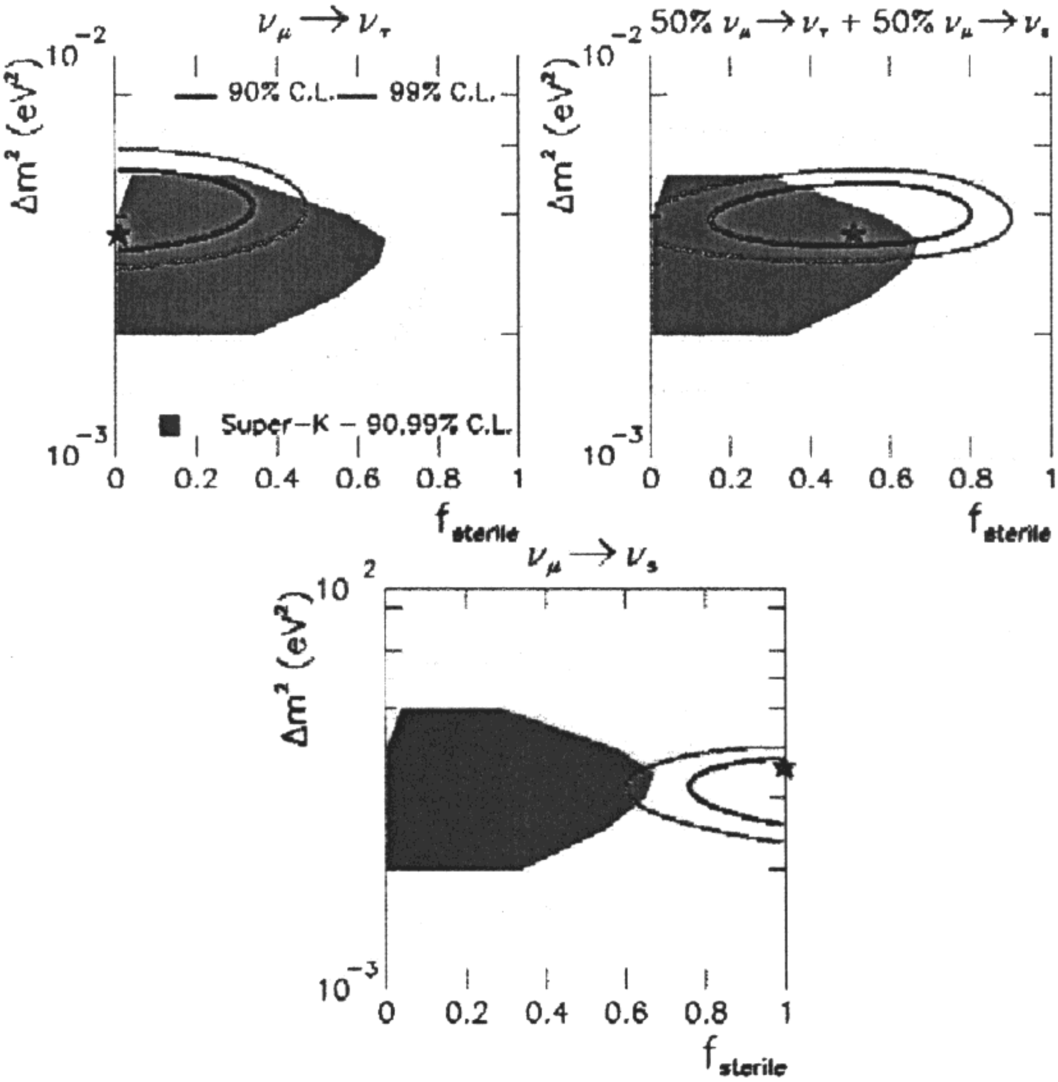

MINOS 10 kt-yr $\nu_\mu \to \nu_e$ sensitivity
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
0.005
0.01
0.015
0.02
0.025
0.03
$|U_{e3}|^2$
90% C.L. limits, no matter effects, $U^2_{\mu 3}=U^2_{\tau 3}$
PH2 low
PH2 low (3 sigma discovery)
PH2 medium
CHOOZ

ν_s

NC energy distributions, Ph2le, Δm^2=0.0035 eV^2



Ph2le, 10 kt. yr., Δm^2=0.0035 eV^2



Status of MINOS

Good News

Construction of the detector is on schedule.

Cavern available on July 19, 2001

First steel plane is going up now.

1st Supermodule completion - August 2002
2nd " " - August 2003

Not as good news

Excavation for beam and near detector hall well under way at Fermilab

but

delays due to cost underestimates, safety concerns, etc. put startup date back to

end 2004

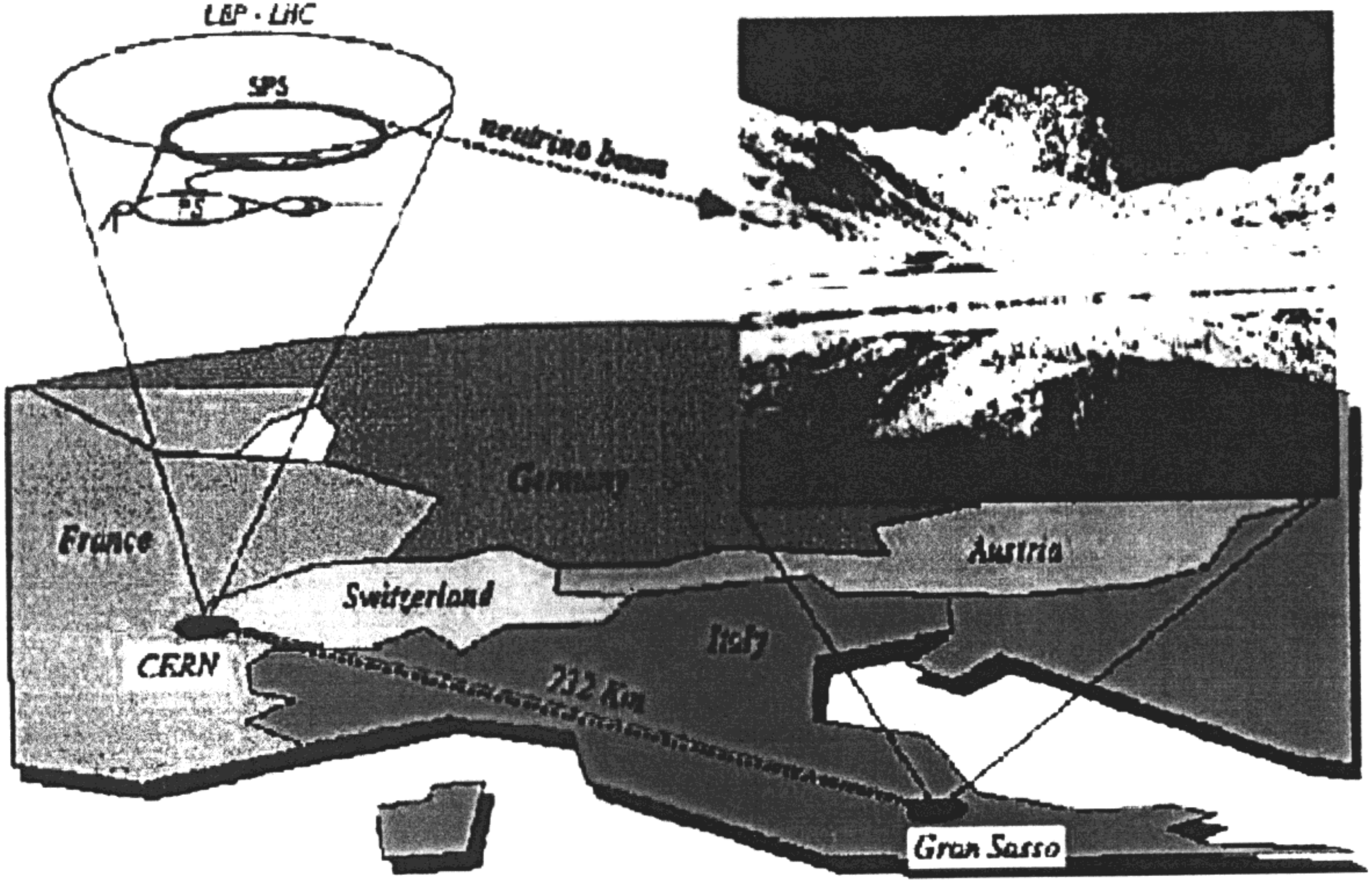
MINOS Atmospheric ν's beginning in 2002

1. MINOS has good sensitivity to ν_μ CC events at high energies
   $p_\mu > 1$ GeV/c
2. Results comparable to Super K can be obtained in a few years running

   Magnetic field compensates for lower mass and statistics
3. Sensitivity to ν_e CC is limited

Detailed simulations are still to be carried out.

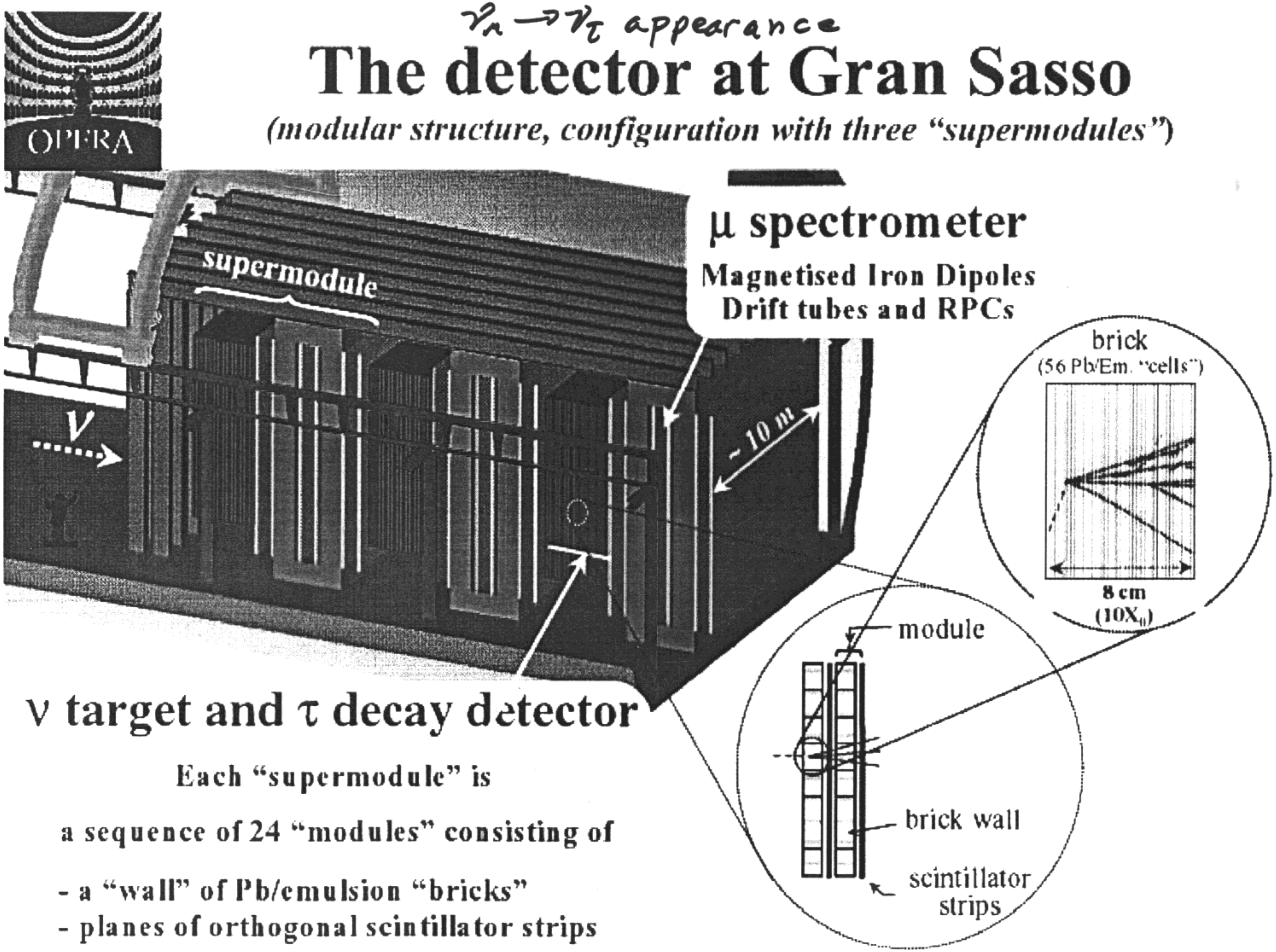
CERN to Gran Sasso Neutrino Beam



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

The detector at Gran Sasso

(modular structure, configuration with three "supermodules")



μ spectrometer

Magnetised Iron Dipoles
Drift tubes and RPCs

ν target and τ decay detector

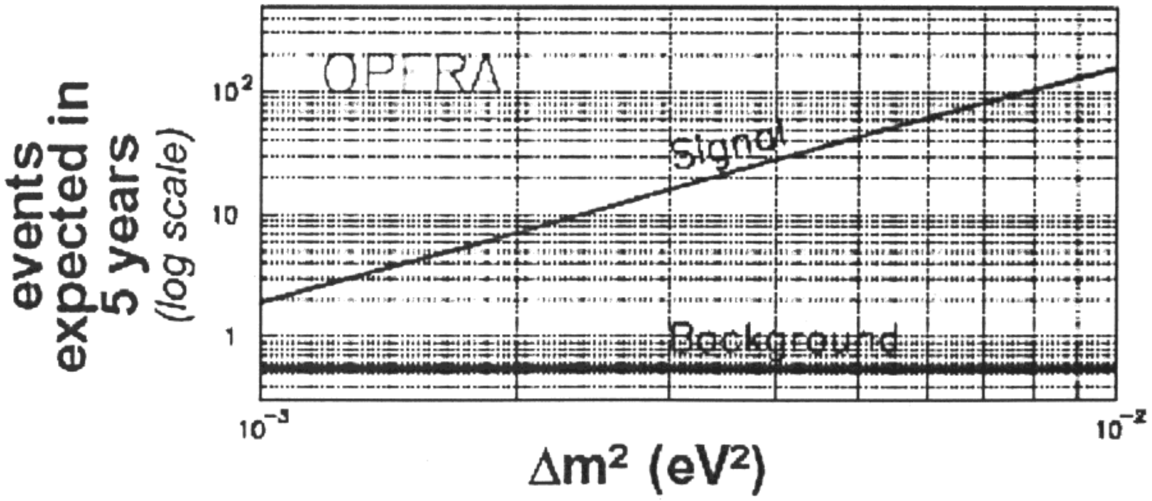
Each "supermodule" is

a sequence of 24 "modules" consisting of

- **a "wall" of Pb/emulsion "bricks"**
- **planes of orthogonal scintillator strips**

Expected events

τ decay	ν_τ events Δm^2 (10^{-3} eV^2)			b.g.
	1.5	3.2	5.0	
e	1.7	7.7	18.5	0.19
μ	1.3	5.7	13.8	0.13
h	1.1	4.9	11.8	0.25
Total	**4.1**	**18.3**	**44.1**	**0.57**



- **Full mixing**
- **5 years with shared SPS operation (2.25×10^{20} pot)**
- **Average target mass = 1.8 kton**

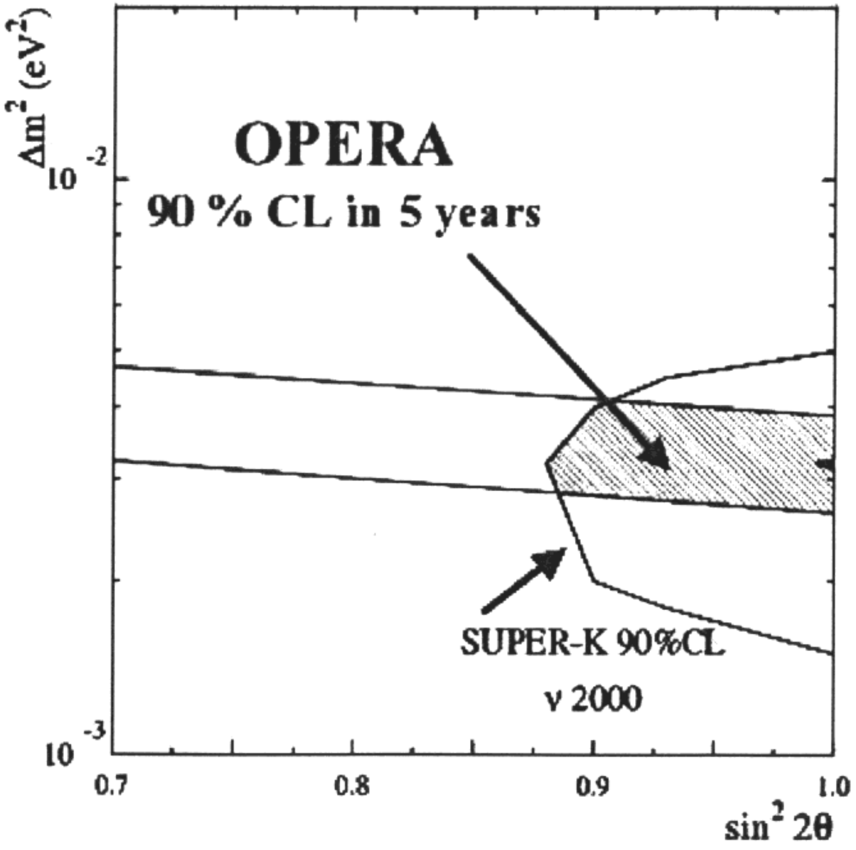
  (accounting for mass reduction with time, due to brick removal for analysis)
- **Uncertainties on background and efficiencies accounted for in the following**

Determination of Δm^2

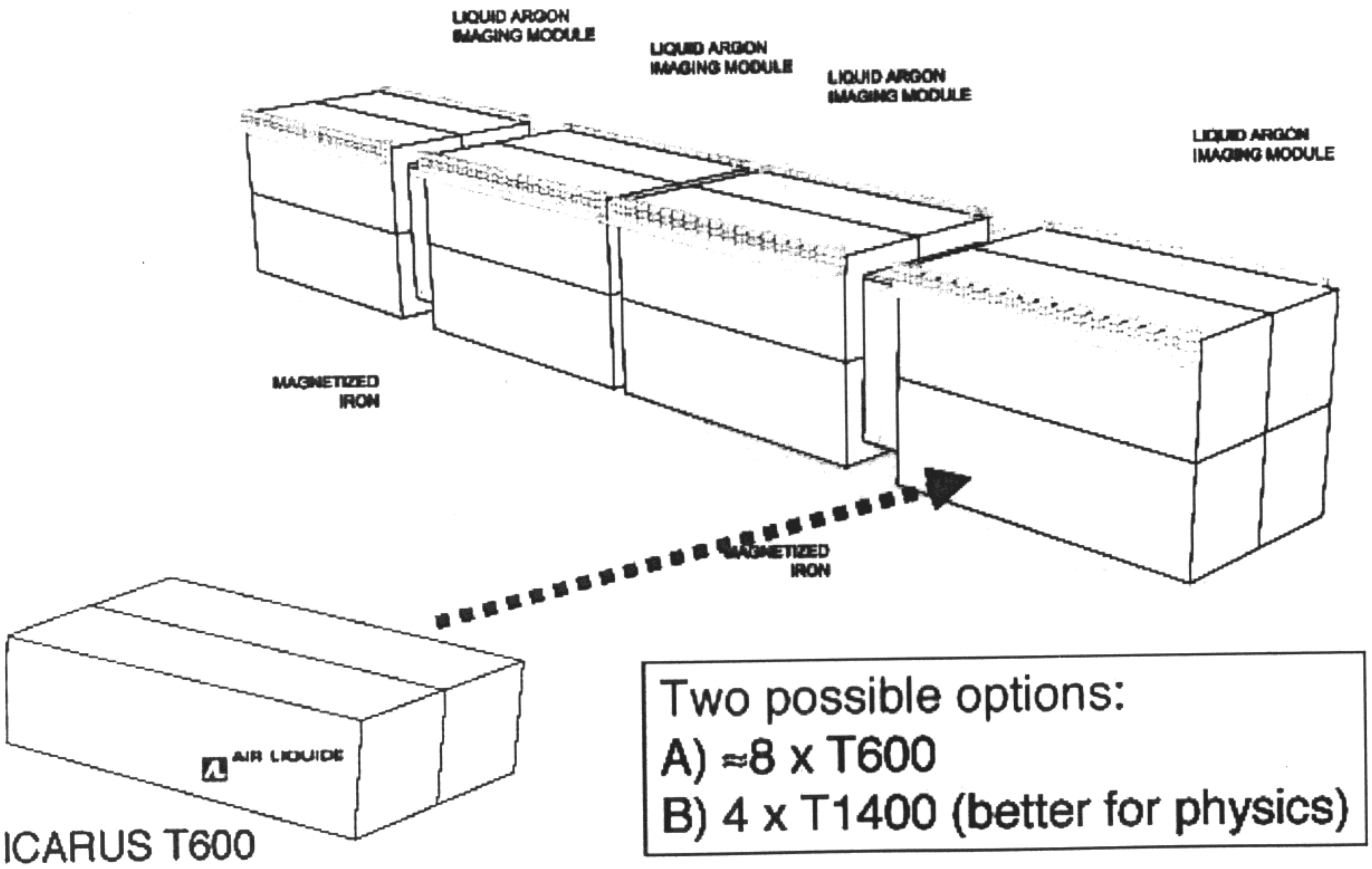
(mixing constrained by SuperK)

90 % CL limits *	Δm^2 (10^{-3} eV^2)		
	1.5	3.2	5.0
Upper limit	2.1	3.8	5.6
Lower limit	0.8	2.6	4.3
(U - L) / True	41 %	19 %	12 %

* assuming the observation of a number of events corresponding to those expected for the given Δm^2



Proposed setup ICARUS 5kt in LNGS Hall B

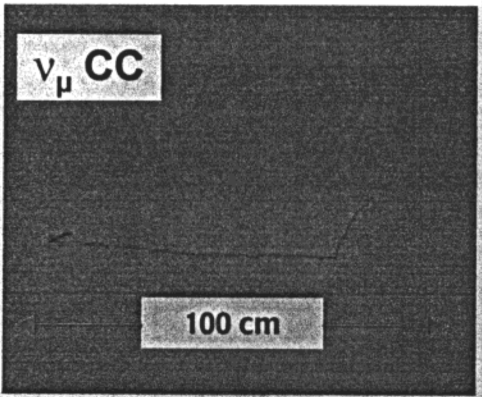


Two possible options:
A) ≈8 x T600
B) 4 x T1400 (better for physics)

ICANOE physics program

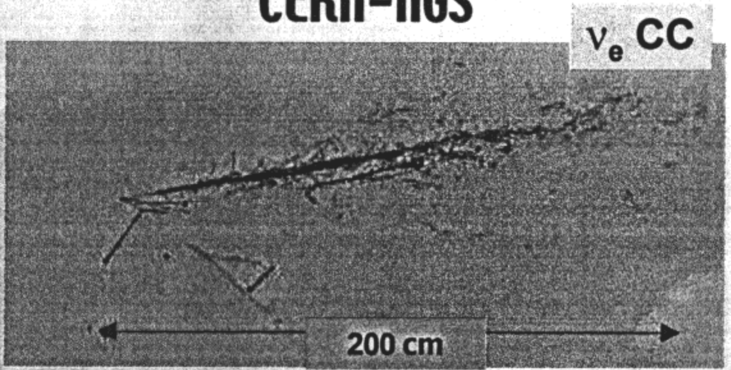
Looking for rare events:

Atmospheric neutrinos



- ✓Detection of all neutrino flavors, CC & NC modes
- ✓Study of L/E distributions for e and μ
- ✓Clean NC/CC
- ✓Direct tau appearance
- ✓Upward going muons
- ✓Very low energy electrons

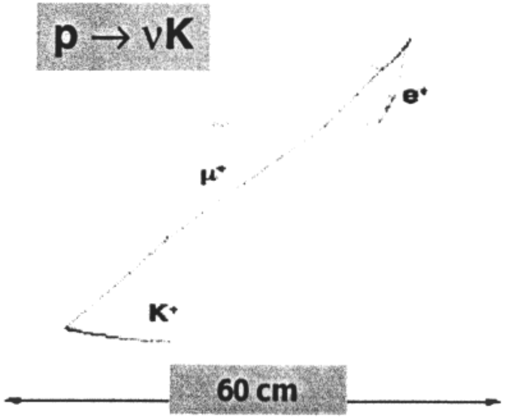
CERN-NGS



- ✓Direct tau and electron appearance
- ✓Muon disappearance

Nucleon decay

$p \rightarrow \nu K$



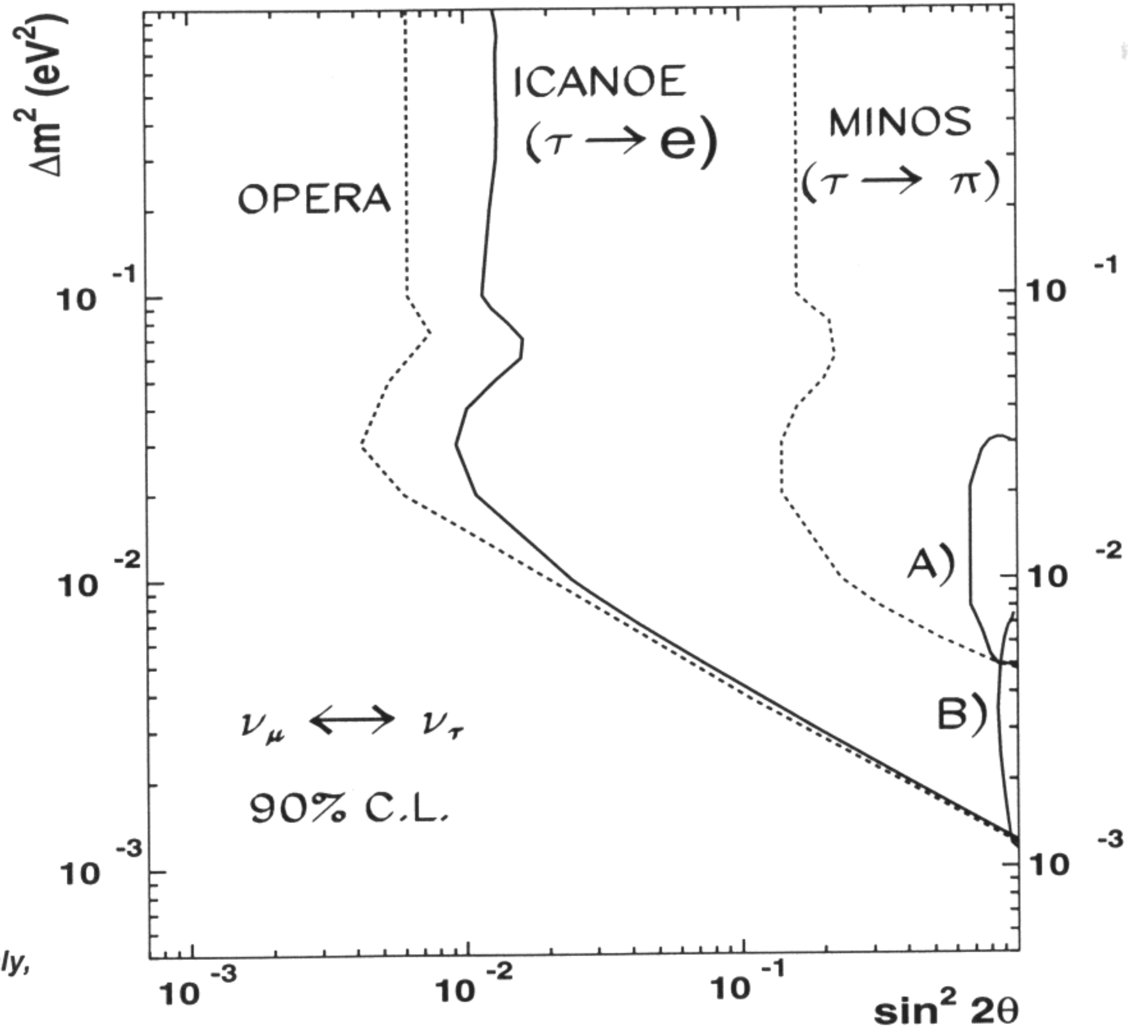
- ✓Background free searches
- ✓Sensitivity >10^{33} years

ν_τ appearance

Two-family $\nu_\mu \rightarrow \nu_\tau$ oscillations: sensitivity

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

4 years

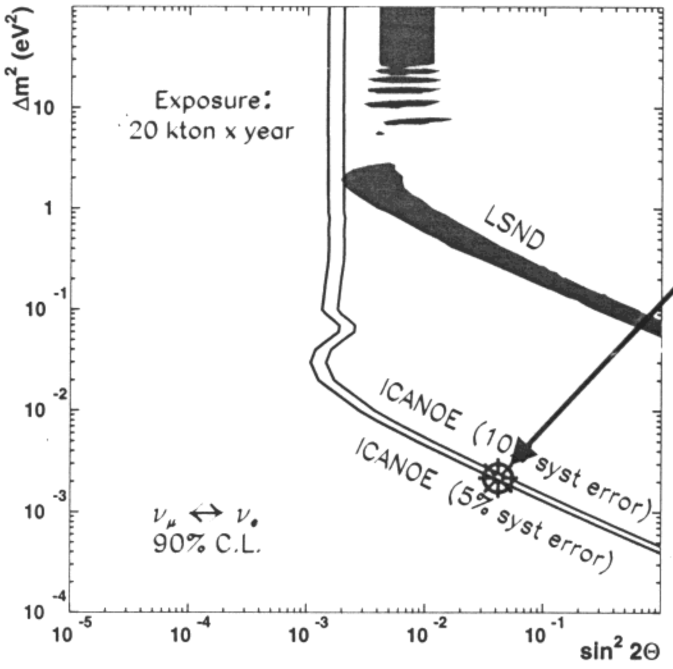


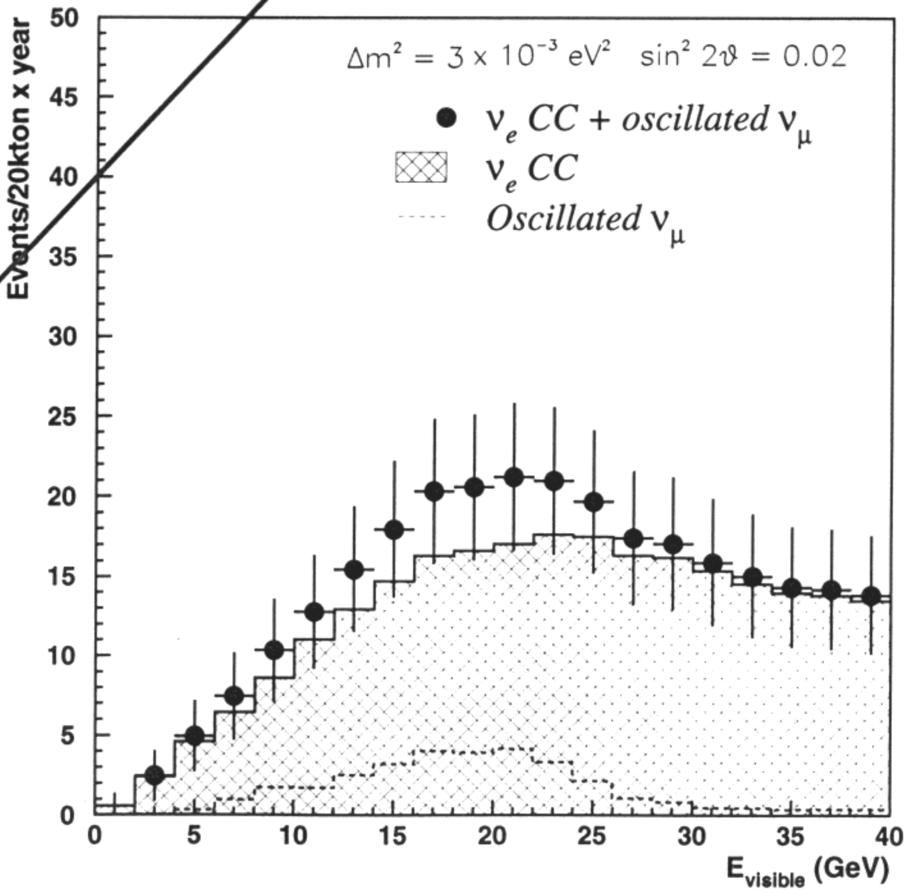
(MINOS high energy beam (PH2high) configuration, NUMI-L228 & TDR)
(OPERA, CERN/SPSC 99-20)
(ICANOE, tau appearance, electron channel only, optimized for low Δm^2)

Two-family $\nu_\mu \rightarrow \nu_e$ oscillations

Exploit the small intrinsic ν_e contamination of the beam (0.8% of ν_μ CC)
Exploit the unique e/π^0 separation
Excess at low energy

$$\Delta m^2 = 3\times 10^{-3}\, eV^2;\ \sin^2 2\theta = 0.02$$





Search for $\theta_{13} \neq 0$

ICANOE
4 years

$\Delta m^2_{32} = 3.5\text{x}10^{-3}$ eV^2; $\sin^2 2\theta_{23} = 1$

Cuts: Fiducial, $E_e > 1$ GeV, $E_{vis} < 20$ GeV

$\Delta m^2_{23} = 3.5 \times 10^{-3}$ eV^2, $\theta_{23} = 45^o$

θ_{13} (degrees)	$\sin^2 2\theta_{13}$	ν_e CC	$\nu_\mu \to \nu_\tau$ $\tau \to e$	$\nu_\mu \to \nu_e$	Total	Statistical significance
9	0.095	79	74	84	237	6.8σ
8	0.076	79	75	67	221	5.4σ
7	0.058	79	76	51	206	4.1σ
5	0.030	79	77	26	182	2.1σ
3	0.011	79	77	10	166	0.8σ

$P(\nu_\mu \to \nu_\tau) = \cos^4 \theta_{13} \sin^2 2\theta_{23} \Delta^2_{32}$

$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{13} \sin^2 \theta_{23} \Delta^2_{32}$

ICANOE atmospheric event rates

☆ **Complete data set:**

- → 5.6 kton LAr sensitive mass
- → 3.2 kton calorimeter mass

Events/year

1150 } 1650
500 }

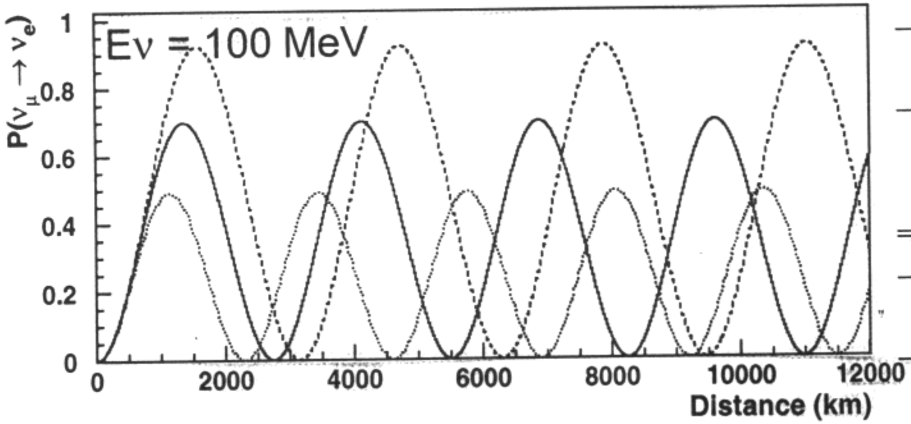
Process	Exposure		
	5 kton× year	20 kton×year	50 kton× year
ν_μ CC	535	2140	5350
$\bar{\nu}_\mu$ CC	135	545	1350
ν_e CC	300	1200	3000
$\bar{\nu}_e$ CC	59	235	585
ν NC	325	1300	3250
$\bar{\nu}$ NC	150	590	1500

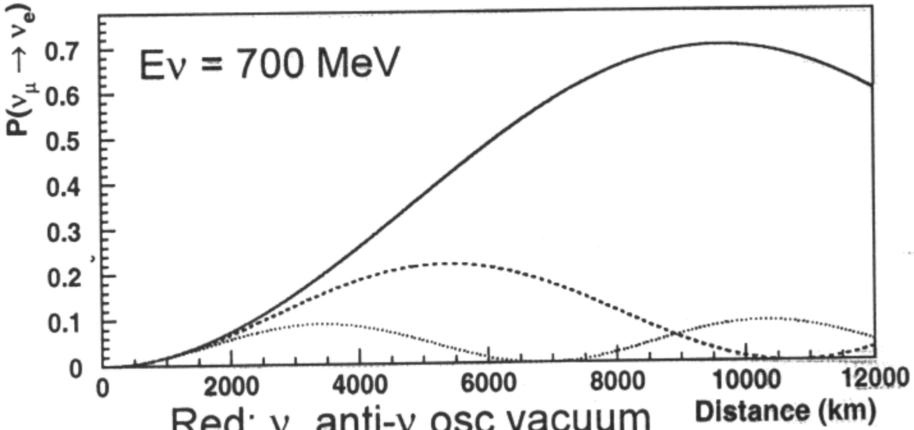
Flux: 3D calculation, Battistoni et.al., hep-ph/9907408

Data for L/E analysis:

Events/year	ICANOE liquid Evisible > 1 GeV	ICANOE solid Evisible > 1 GeV
ν_μ CC	380	260
ν_e CC	160	
ν NC	400	

Oscillations in matter





Red: ν, anti-ν osc vacuum
Black: ν osc matter
Blue: anti-ν osc matter

$\nu_\mu \leftrightarrow \nu_e$ oscillations in matter

Exposure ($kton \times year$)	ν_e CC no oscillations	ν_e CC oscillations	ν_e CC excess (%)
5	111	131	18 ± 10
20	442	523	18 ± 5
50	1104	1308	18 ± 3

$\nu_\mu \leftrightarrow \nu_e$ oscillations in vacuum

Exposure ($kton \times year$)	ν_e CC no oscillations	ν_e CC oscillations	ν_e CC excess (%)
5	111	134	21 ± 10
20	442	535	21 ± 5
50	1104	1338	21 ± 3

$\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$ oscillations in matter

Exposure ($kton \times year$)	$\bar{\nu}_e$ CC no oscillations	$\bar{\nu}_e$ CC oscillations	$\bar{\nu}_e$ CC excess (%)
5	14	15	7 ± 20
20	58	62	7 ± 13
50	145	155	7 ± 9

$\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$ oscillations in vacuum

Exposure ($kton \times year$)	$\bar{\nu}_e$ CC no oscillations	$\bar{\nu}_e$ CC oscillations	$\bar{\nu}_e$ CC excess (%)
5	14	19	34 ± 30
20	58	78	34 ± 15
50	145	195	34 ± 10

Cuts: $E_{vis} < 1$ GeV, $\cos\theta_{zenith} < -0.2$ ←
Oscillation parameters: $\Delta m^2 = 9 \times 10^{-5}$ eV^2, $\sin^2 2\theta = 0.7$

low E
upgoing ν_e's

André Rubbia, ETH/Zürich, 21/6/00, Neutrino 2000

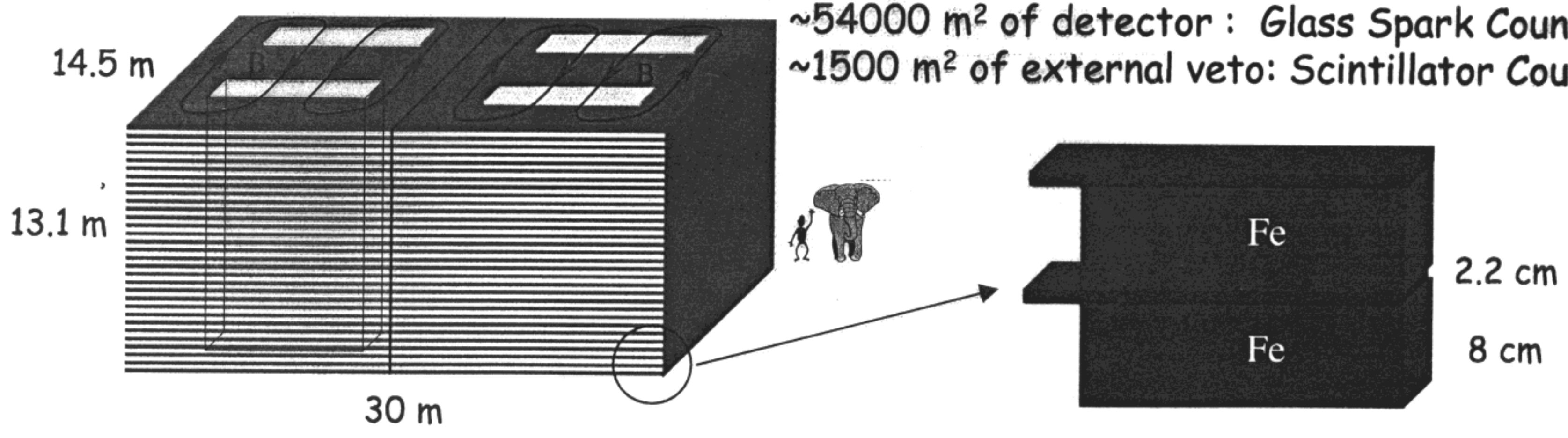
The MONOLITH Detector

Large mass		~ 35 kton
Magnetized Fe spectrometer		B = 1.3 Tesla
Space resolution		~ 1 cm (rms on X-Y coordinates)
Time resolution		~ 1 ns (for up/down discrimination)
Momentum resolution	σ_p/p	~ 20% from track curvature for outgoing m
		~ 6% from range for stopping muons
Hadron E resolution	σ_{E_h}/E_h	~ $90\%/\sqrt{E_h} \oplus 30\%$

$8.0 \times 3000 \times 1450\ \text{cm}^3 \times 7.87\ \text{g/cm}^3 = 285$ ton/plane   130 planes

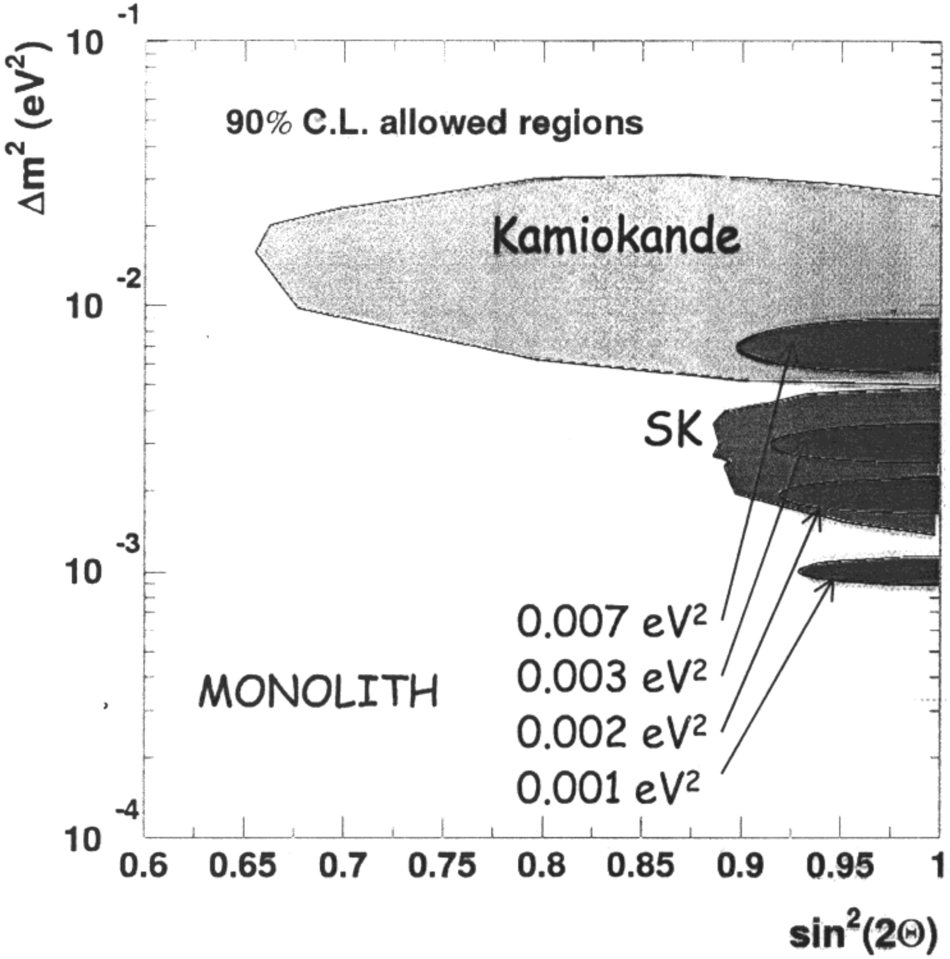
~54000 m^2 of detector : *Glass Spark Counters*

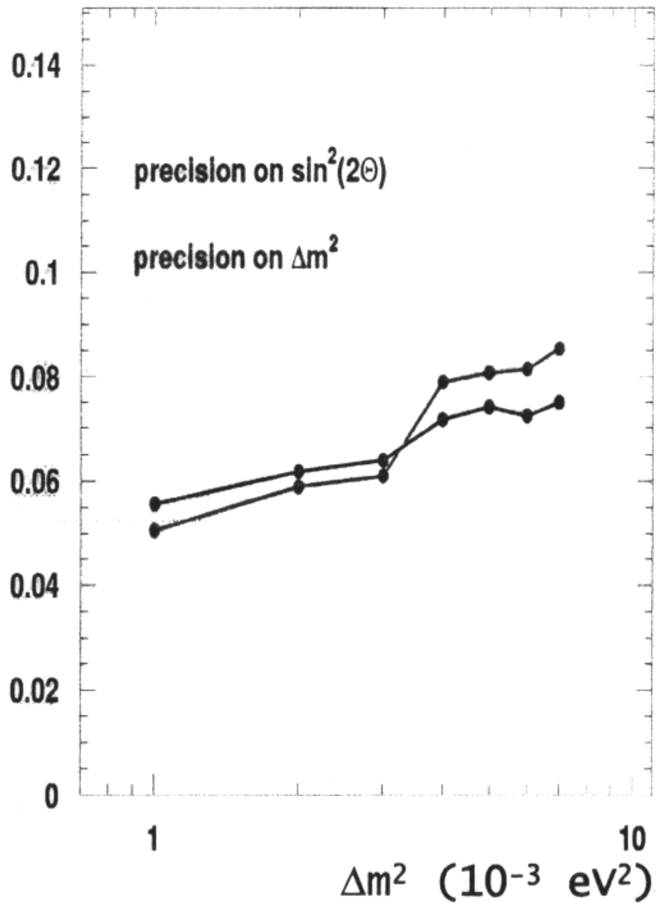
~1500 m^2 of external veto: *Scintillator Counters*



TTF, Roma, 20 giugno 2001

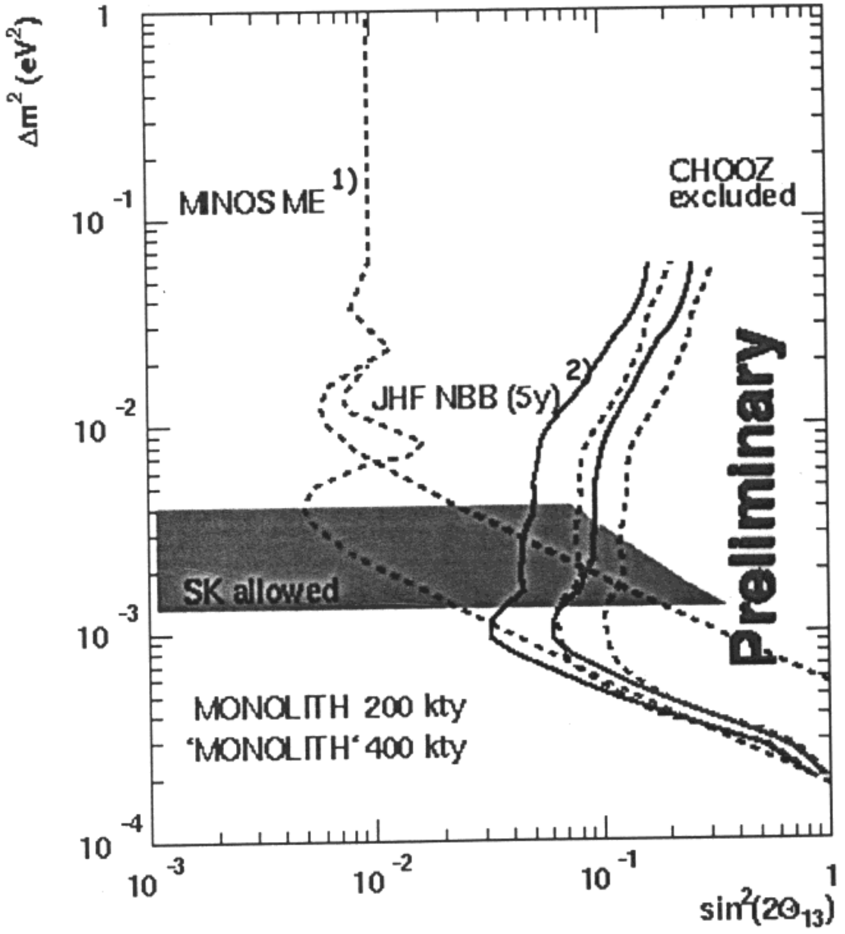
Monolith sensitivity (4 years)





Sensitivity to sin²(2Θ$_{13}$)

ν_μ / ν_e - 90% C.L. expected limit



Sensitivity curves computed assuming 15% uncertainty on flux predictions and perfect knowledge of the resolution function

Exclusion regions if no effect observed for positive (continuous line) and negative (dashed line) sign of Δm^2

Test statistics:

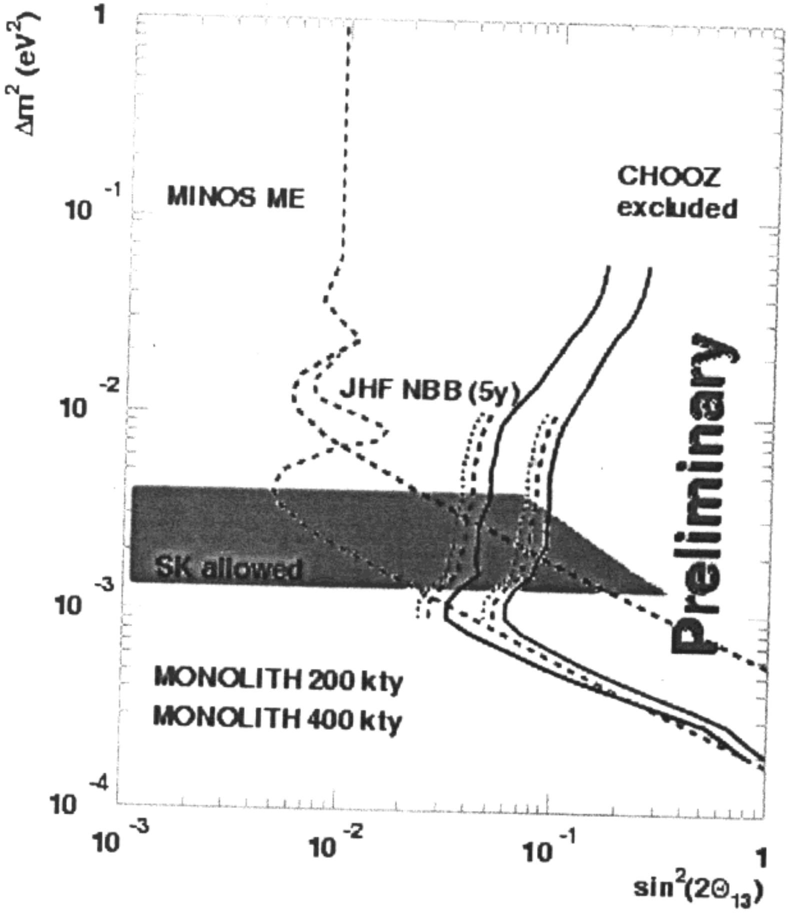
$$-2\ln \frac{\mathcal{L}(A, \Delta m^2, \sin^2(2\Theta_{23}), \sin^2(2\Theta_{13})=0)}{\mathcal{L}(A, \Delta m^2, \sin^2(2\Theta_{23}), \sin^2(2\Theta_{13}))}$$

1) A. Para, hep-ph/0005012

2) T. Kobayashi, talk in La Thuile, 2001

Sensitivity to the sign of Δm^2

sign of Δm^2 - expected sensitivity at 90% C.L.



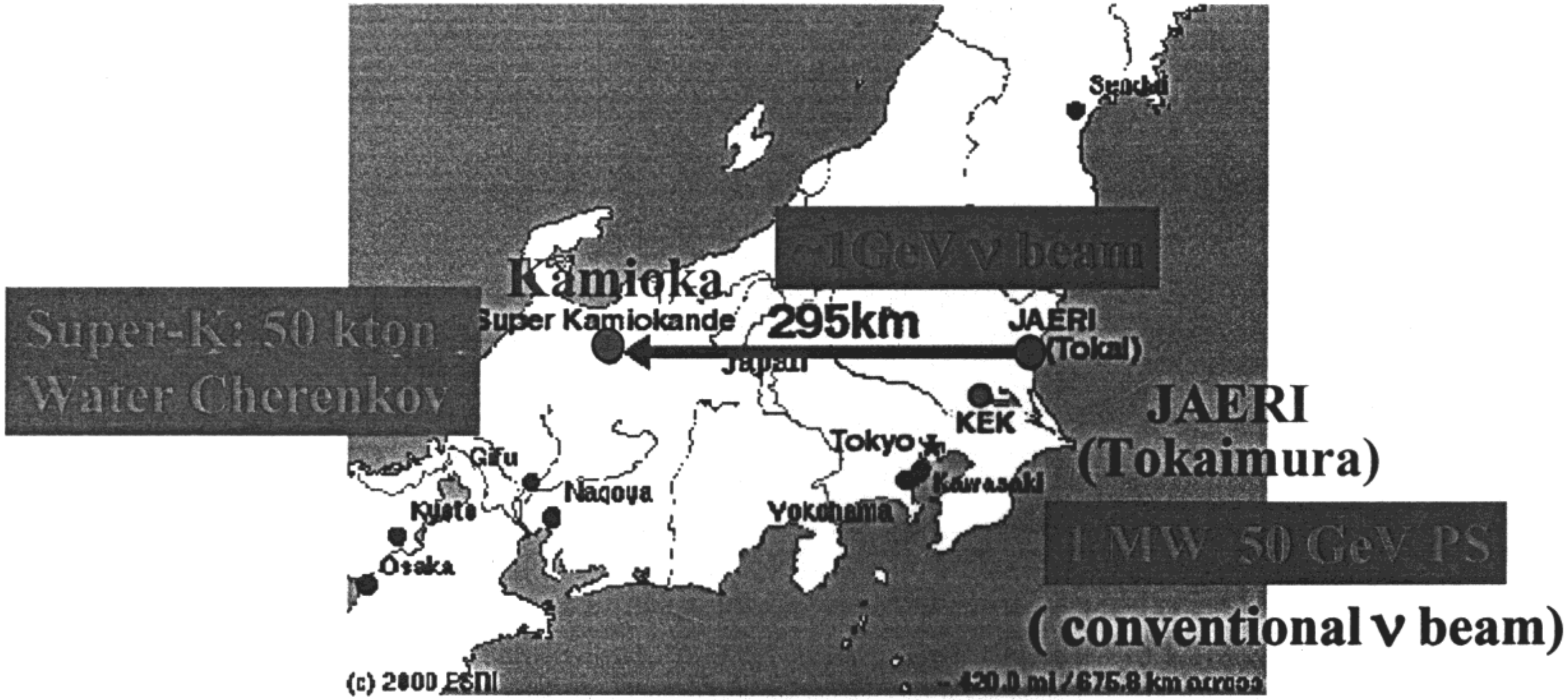
Region over which the sign of Δm^2 can be determined assuming that $\sin^2(2\Theta_{13})$ be known with a relative error of

- 20% (dotted)
- 1000% (dashed)
- Infinite (continuous)

(Measurement difficult for mixing below 0.01: the optimal baseline exceeds the Earth diameter)

NB: MINOS and JHF cannot measure the sign of Δm^2!

1. Overview of the experiment



- Precision measurement of ν oscillation parameters by $\nu_\mu \rightarrow \nu_x$ ($\sin^2 2\theta_{23}$、$\Delta m_{23}{}^2$).
- Discovery of $\nu_\mu \rightarrow \nu_e$ ($\sin^2 2\theta_{13}$)
- Confirmation of $\nu_\mu \rightarrow \nu_\tau$ with π^0 in Neutral Current (NC).

θ_{13} measurement

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(1.27\ \Delta m_{23}^2\ L/E)$$

- A mixing angle between 1st and 3rd generation in MNS.
  - θ_{13} may be just below the CHOOZ limit, and $\nu_\mu \rightarrow \nu_e$ is waiting to be discovered.

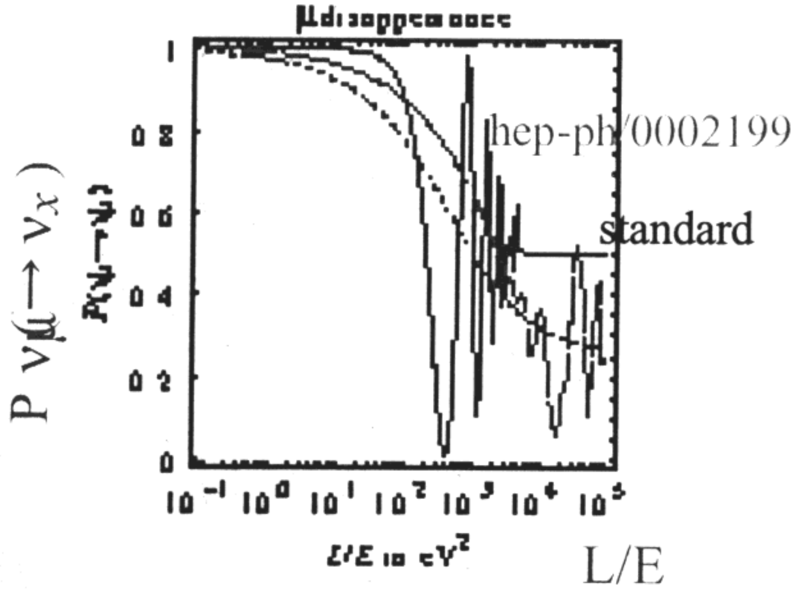
$$\begin{aligned} \sin^2 2\theta_{13} &= 0.014 \text{ (SU(5)-GUT, hep-ph/0007254)} \\ &= 0.01\text{-}0.09 \text{ if LMA (PRL84, 3535 (2000))} \\ &\sim 0 \end{aligned}$$

- A discovery of $\nu_\mu \rightarrow \nu_e$ can open the new window to study CP violation in this mode.

may be a source of baryogenesis in the universe.

Non standard ν oscillation

- Large Extra Dimension



- A sterile neutrino (LSND result? 3 or 4 ν's)
- non standard CP violation of **$\nu_\mu \rightarrow \nu_\tau$** .
  - (see Yasuda-san's talk at PA08d (neutrino), ICHEP 2000)
- Any other unexpected phenomena

4. Physics Sensitivity

- First 1 year WBB
  → pin down Δm_{23}^2 to ±10% level
- 5year NBB or OAB
  → precise measurement of θ_{23} and θ_{13}.

Sensitivity (goal):

$\delta \sin^2 2\theta_{23} \sim 0.01$
$\sin^2 2\theta_{13} \sim 5 \times 10^{-3}$ (90% CL)
$\delta \Delta m_{23}^2 \sim 1.5 \times 10^{-4} \mathrm{eV}^2$
at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)

ν_τ confirmation

- NC π^0 interaction
  - $\nu + N \rightarrow \quad \nu + N + \pi^0$
  - $\nu_\mu \rightarrow \nu_e$ CC + NC(~0.5CC) ~0 ($\sin^2 2\theta_{\mu e}$~0)
    - $\rightarrow \nu_\mu$ CC + NC(~0.5CC) ~0 (maximum oscillation)
    - $\rightarrow \nu_\tau$ **NC**

#π^0 is sensitive to ν_τ flux.

$\Downarrow$

Limit on the existence of sterile ν.

Additional Options

- JHF with **<u>1 Mton Water Cherenkov detector</u>**

  (for proton decay)

  - **If $\nu_\mu \rightarrow \nu_e$ is discovered in JHF-ν,** the study of CP violation becomes realistic.
    - #($\nu_\mu \rightarrow \nu_e$)~O(100) → Asymmetry ~ 10% .

      → sensitivity to δ ~ 10 degree.

- Very LBL experiment between Japan and China (or Korea).
  - **With a 100kt detector and a new beam line,** a matter effect **is measurable in $\nu_\mu \rightarrow \nu_e$ mode.**

    → sign of Δm_{23}^2

SUPERBEAMS

PROPOSALS TO UPGRADE PROTON INTENSITY AT

FNAL
CERN by ~ 5 (allows considering NBB, OAB)
JHF

COMBINED WITH MASSIVE DETECTORS GAIN order of magnitude in sensitivity

Example JHF → HyperKamiokande (1Mton)

measure $\sin^2 2\theta_{13}$ down to 10^{-3}

Set beam at oscillation peak energy, $E_\nu \sim .75$ GeV so matter effect is negligible. Then any $\nu_\mu \to \nu_e$ vs. $\bar{\nu}_\mu \to \bar{\nu}_e$ asymmetry due to CP violation.

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} = \frac{\Delta m^2_{12} L}{4E_\nu} \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \sin\delta$$

Using LMA solution $\Delta m^2_{12} \sim 5 \times 10^{-5}$ and $\theta_{12} \sim \pi/8$ and $\sin^2 2\theta_{13} \sim .01$, $A_{CP} \sim 25\%$

JHF → CHINA, KOREA

FEW × 1000 km baseline + 100 kton detector

Study matter effects, sign of Δm^2_{23}

Similar proposals at CERN, FNAL

e.g. CERN → Frejus

FNAL study group looks at

FNAL → Soudan

→ SLAC ~3000 km

→ Super K