A large iron detector for the neutrino factory

by a Theorist

(The art of talking for 25 min about nothing)

Thanks are due to
Kenzo Nakamura
Mike Shaevitz
Adam Para
&
other organizers

A large iron detector in India as a far-end detector for a neutrino factory

(or)

Indian (→ India-based) Neutrino Observatory (INO) and its role in long-base-line experiments

(Talk at NuFact 03, New York, June 2003)

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- History & Introduction to INO
- Sites
- Detector
- Possible Physics

History

- Historically, the Indian initiative in Cosmic Ray and Neutrino Physics expts goes back several decades.
- In fact, atmospheric neutrinos were first detected in the Kolar Gold Fields (KGF) expts in India almost 4 decades ago.
- KGF were one of the deepest mines in the world. When the cosmic ray muon expts were set up at deeper and deeper levels in the mines, the counters fell silent at a particular depth. It was realized that at those depths and beyond, atmospheric neutrinos could be detected. They went ahead and detected them.

> That was in 1965 and it was the beginning of atmospheric neutrino physics.

- The deeper levels of KGF are now closed.

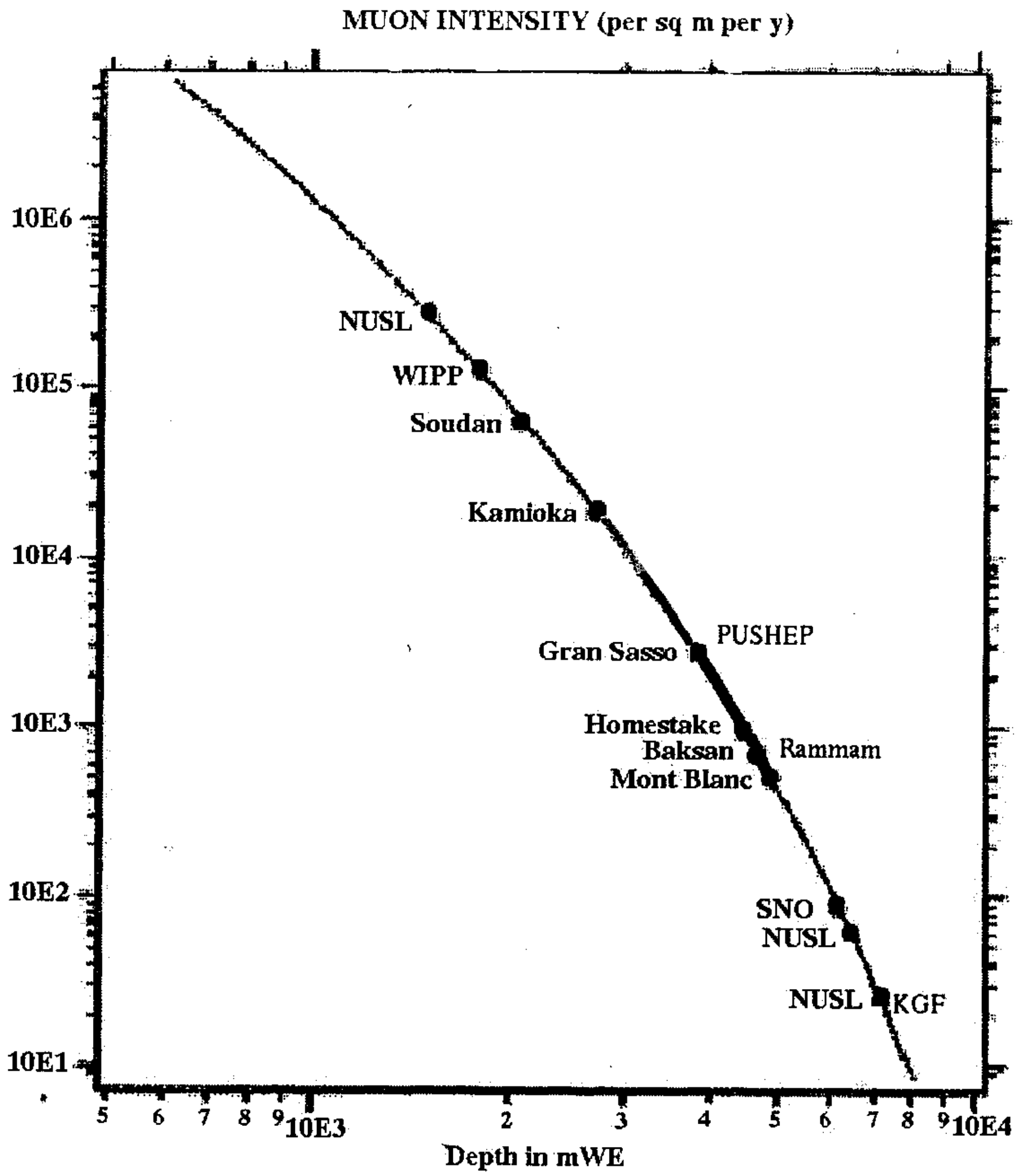


Figure 3: Muon background at likely depths for INO at PUSHEP and Rammam. The bands indicate the range of vertical depths.

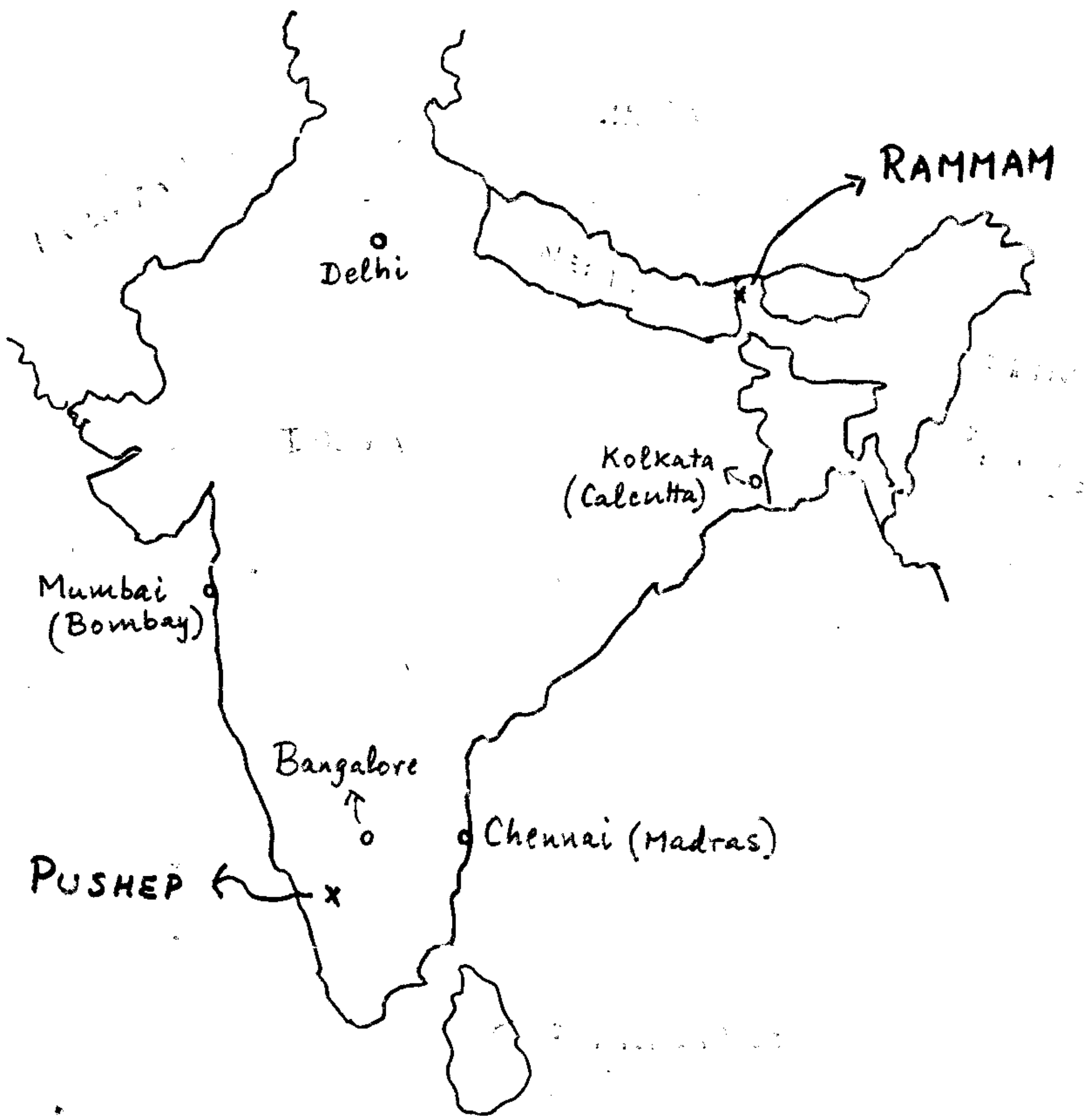
Indian Neutrino Observatory (INO)

- A major collaborative project involving many institutions. 12 institutions (TIFR, BARC, SINP ..... and a number of Universities) have already joined this National Neutrino Collaboration. About 60 Scientists are already in it and more will be required. MOU has been signed.
- Two sites for the underground laboratory have been located:
  1. PUSHEP near OOTY (Nilgiris)
  2. RAMMAM near Darjeeling

  One of These will be chosen.

  A huge cavern underneath the mountain (at least 1 Km cover) and a tunnel will be dug.
- A magnetised tracking iron calorimeter (of 30 – 50 K Ton) as neutrino detector is under design and prototyping.
- I Stage: Study of Atmospheric neutrinos

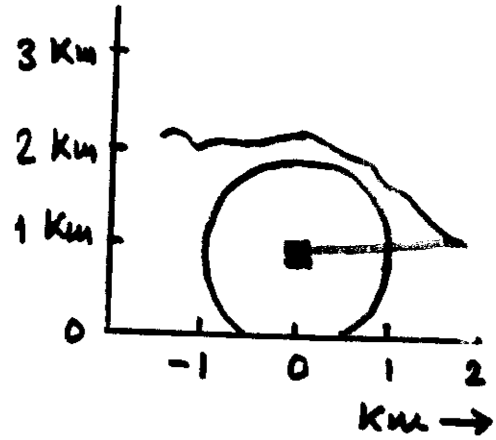
  II Stage: End detector for a Long-Base-Line Neutrino Expt (International)
- [illegible]


RAMMAM
Delhi
Kolkata
(Calcutta)
Mumbai
(Bombay)
Bangalore
Chennai (Madras)
PUSHEP

Tale of Two Sites (with apologies to Charles Dickens)

1. PUSHEP

- Under the Nilgiri Mountains near OOTY in S.I.
- Adjacent to a hydel project PUSHEP (Pykara Ultimate Stage Hydro Electric Project) of Tamil Nadu Electricity Board.



- A huge cavern under the mountain to be excavated, reachable by a tunnel of about 2 km length
- More than 1 Km of cover in all directions
- Most of the geotechnical studies already done
- The site is ready for INO.

2. RAMMAM

- In the Rammam Hydel Project area in the District of Darjeeling, West Bengal
- A tunnel of 4 km length can reach a site with a overburden of 1.5 Km or even more
- Geotechnical Studies going on.

Both sites are excellent. Of course each has its advantages & disadvantages. We have to make a critical evaluation and choose one pretty soon.

INO at PUSHEP [Lat 11·5°N, Long 76·6°E]

- Under the Nilgiri Mountains in South India
- Located in the Southern Peninsular Shield
- Good tunnelling medium for the creation of UG facility.
- Close to the Cosmic Ray Laboratory and the Radio Astronomy Centre, both situated at Ooty, both belonging to Tata Institute of Fundamental Research.
- Close to big cities, like Bangalore, with excellent industrial and academic infra-structure.
- Vertical overburden in the range 1·3 – 1·4 km & all-around cover of more than 1 km.
- Uniform rock medium of mean $\rho \sim 2.8$ gms/cc
- Lab cavern at the end of a tunnel of length ~ 2 km
- Seismic zone : 2
- Detailed survey of the region is complete.

INO at RAMMAM [Lat 27°N, Long 88°E]

- Under the Himalayas, in the Darjeeling Dist of West Bengal
- A tunnel of 3–5 km can reach an overburden of 1·5 – 1·85 km
- Seismic zone : 4
- Detailed survey is in progress

The Detector

- Magnetised, tracking iron calorimeter, weighing about 30 kTons, based on Monolith
- 15 m ⊗ 32 m ⊗ 12 m (ht) containing 140 layers of 6 cm thick iron plates interleaved with 2.5 cm airgap containing active detector elements
- Active detector elements made up of glass RPC's (Resistive Plate Chambers), with nanosecond timing, to provide up-down discrimination.
- Detector sensitive to $\boxed{\mu}$ and other charged particles
- Magnetic field of 1 – 1.3 Tesla, to provide efficient energy-momentum resolution, and more importantly, charge identification. The latter is an essential requirement for a far-end detector in a long-base-line expt.
- The design will be modular. The lab will be planned such that additional modules can be added in future, to increase its capability as a far-end detector.
- Emulsion sandwich being considered, (to improve detection efficiency for leptons $\neq \mu$).

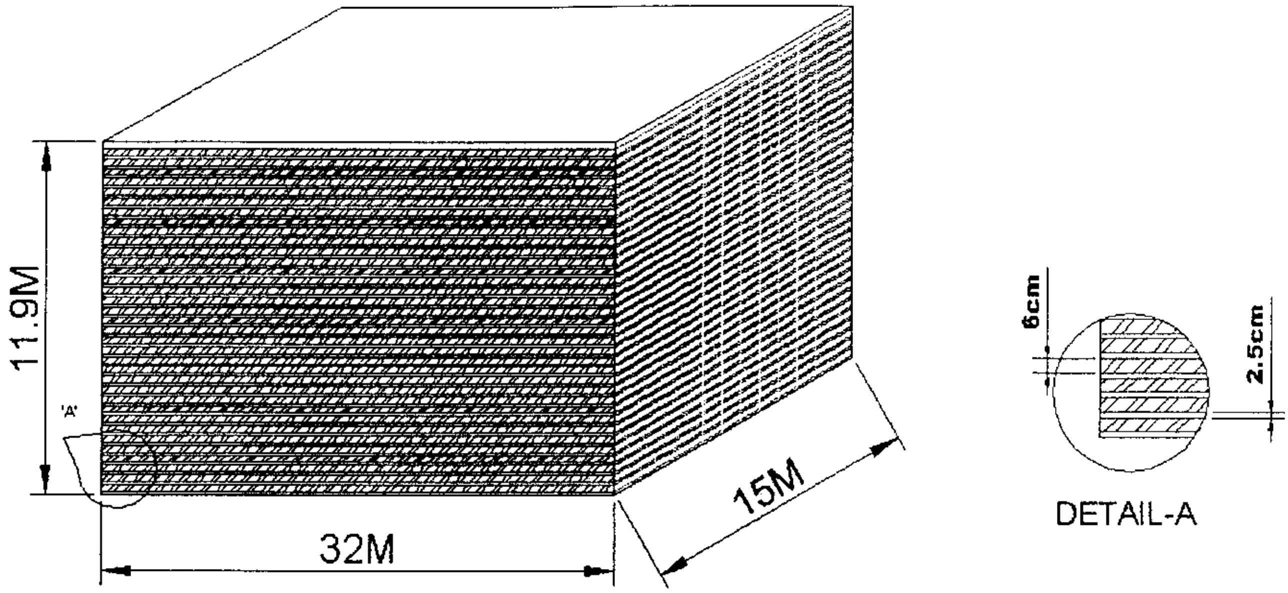


Figure 1: Sketch of the iron calorimeter detector.

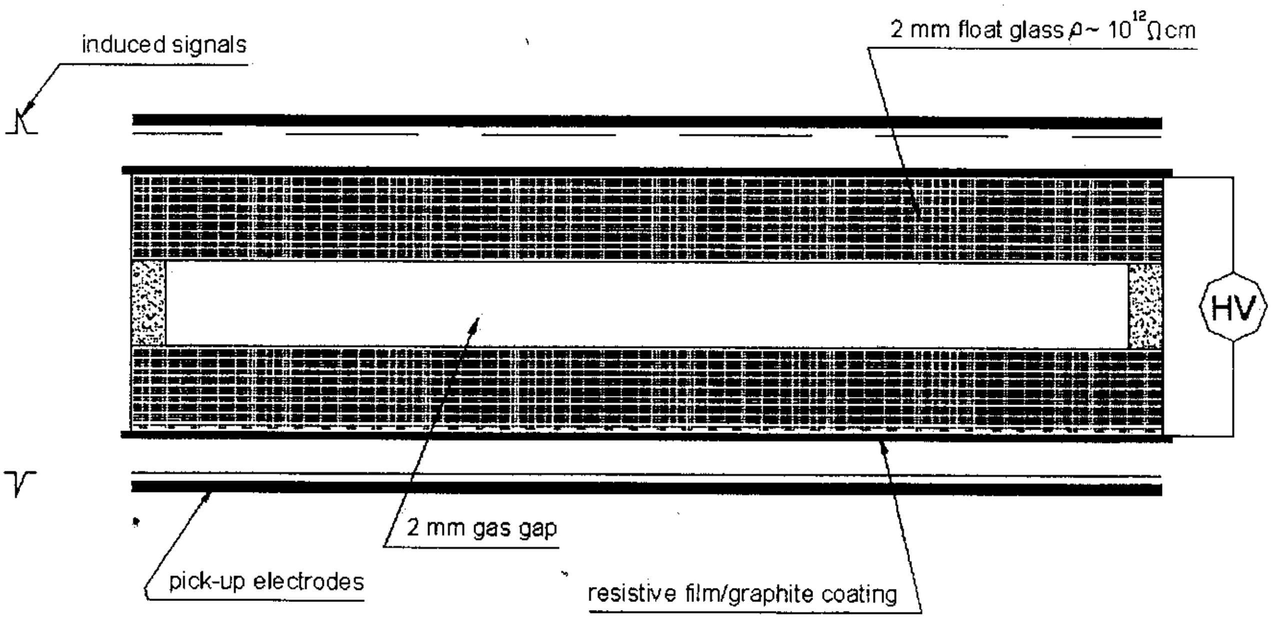


Figure 2: Sketch of a typical glass spark chamber.

Glass RPC or Glass Spark Chamber (GSC)

- GSC is a gaseous detector composed of 2 parallel electrodes made of float glass with a volume resistivity of about $10^{12}\ \Omega$.
- The two electrodes, 2 mm thick, are kept 2 mm apart, by means of suitable spacers.
- Under particular gas mixture and electric field configuration, the detector will operate in the spark mode providing typical signal amplitudes of about 100 – 200 mV on 50 Ω Cable.
- Use of high resistance glass as electrodes ensures that the spark discharges with a limited area around the spark.
- The high voltage will be applied to the electrodes either by means of a graphite coating or a resistive adhesive film.
- The detector unit will be inserted within an extended gas tight PVC/NORYL envelope for gas containment.
- The HV connections as well as gas inlet and outlet will be located in the end gap of the envelope.

Main characteristics of the detector

- Clean identification of μ
- Good Energy and time resolution
- $\boxed{\vec{B}}$ to distinguish +ve and −ve charged particles.

Long Base Lines

From ↓	To PUSHEP Km	To PUSHEP Dip angle	To RAMMAM Km	To RAMMAM Dip angle
Fermilab	11,300	62°	10,500	55°
CERN	7,145	34°	6,890	33°
JHF	6,595	31°	4,880	22°

- "Magic" base line ~ 7200 Km
- The very long base line of ~ 11,300 from Fermilab passes through ~ 3000 km of Earth's core.
- Multiple number of Long Base Lines important for Neutrino Physics

precision of observations, the lower mantle and the outer core were each homogeneous and obeyed the Adams-Williamson equation (see also Davies and Dziewonski, 1975). The density profile of one model is shown in Figure 6.17.

Inferences concerning the compositions of the interior zones of the Earth require extrapolation of the model densities to zero pressure.

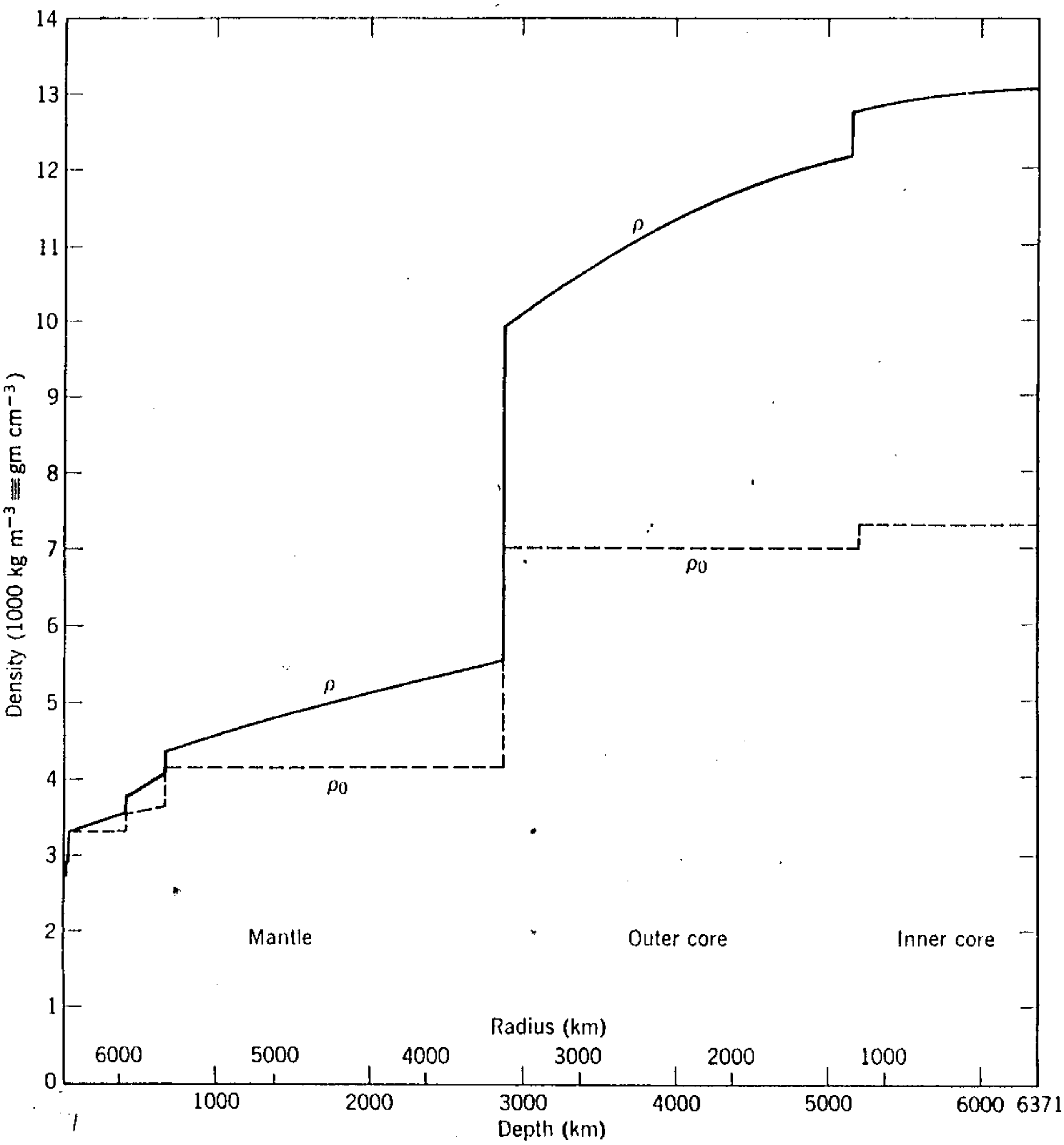


Figure 6.17. Density profile of Earth model by Dziewonski et al. (1975) (solid line) with corresponding extrapolated zero pressure (and room temperature) density (broken line).

Experimental Results so far (at 90% CL)

Atmos ν (SuperK, K2K)

$$|\Delta m^2_{32}| = (1.2 - 5) \times 10^{-3}\ eV^2$$

$$\sin\theta_{23} = 0.54 - 0.83$$

Solar ν (Cl, Ga, SuperK, SNO, KamLAND)

$$\Delta m^2_{21} = (2 - 50) \times 10^{-5}\ eV^2$$

$$\sin\theta_{12} = 0.40 - 0.70$$

Reactor ν (CHOOZ, Palo Verde)

$$\sin\theta_{13} \leqslant 0.16$$

2 Comments

1. **Race for θ_{13} (U_{e3})**

CHOOSE (1998, 99) : $\sin\theta_{13} < 0.16$

Narayan, GR & Umasankar, Phys Rev D58, 031301 (1998).

2. **What is the value of θ_{13} ?**

Our answer : $\sin\theta_{13} = 0.08$

Quark-Lepton Unification :

$U_{CKM} = U_{PMNS}$ at High Energies

Little Change ↓ (CKM) Big Change ↓ (PMNS) Renormalization Group Running

$$\begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} \qquad \begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

at Low Energies

$\theta_{13} = O(\lambda^3) \Rightarrow 0.08$ at Low energies

(or) $U_{e3} = U_{ub} = O(\lambda^3)$

R. Mohapatra, Parida & GR, hep-ph/0301234

Physics Questions

- Seeing Oscillations
- θ_{13}
- Sign of Δ_{32}
- δ
- 4^{th} ν ?
- Physics Beyond Oscillations (K°–$\bar{K}$° complex)
- ν technology of the future

Physics Tasks for INO

Phase I : Atmospheric neutrinos

1. See oscillations
2. Reduce the present range of Δm^2_{32}

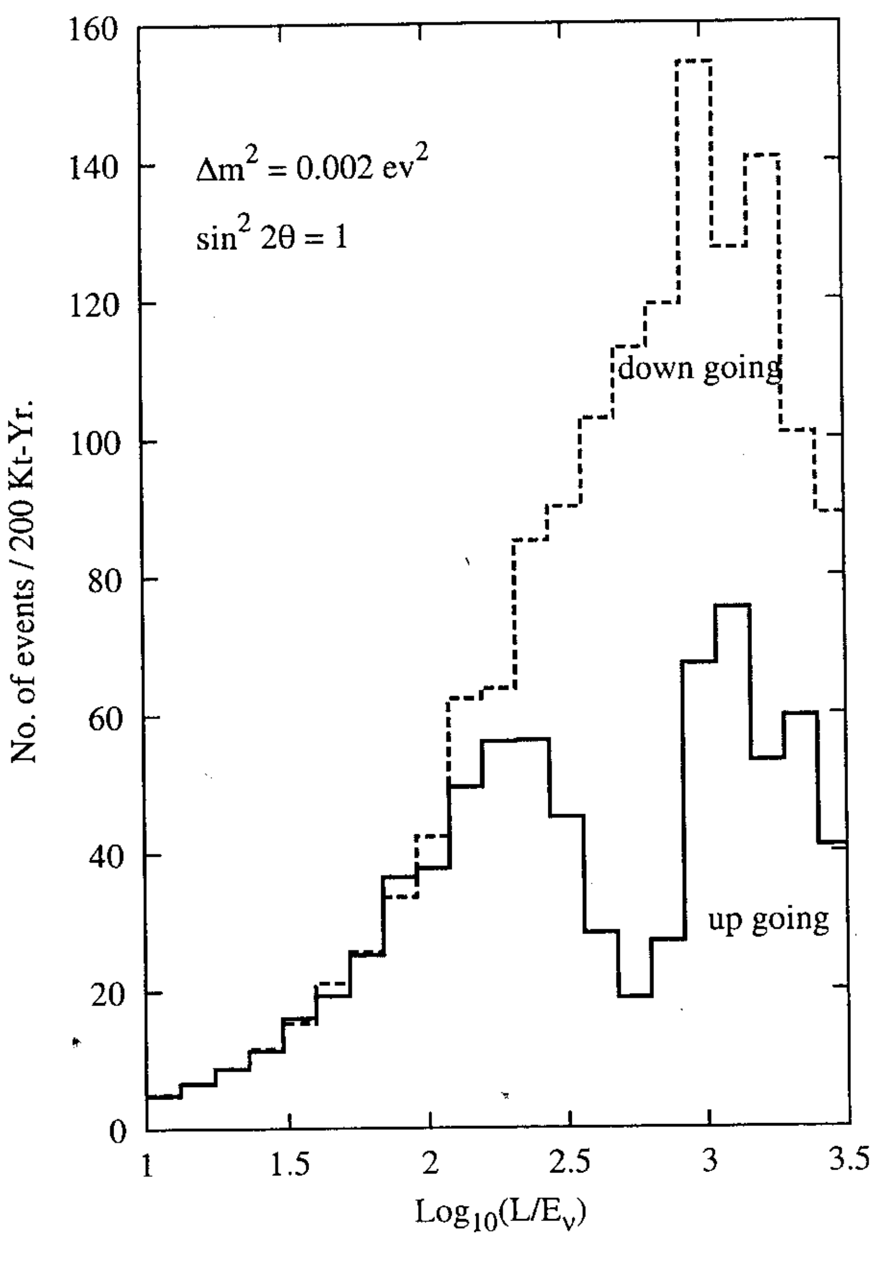
Phase II : Factory Neutrinos

1. Probe θ_{13}
2. Determine the sign of Δm^2_{32}
3. First glimpse of δ

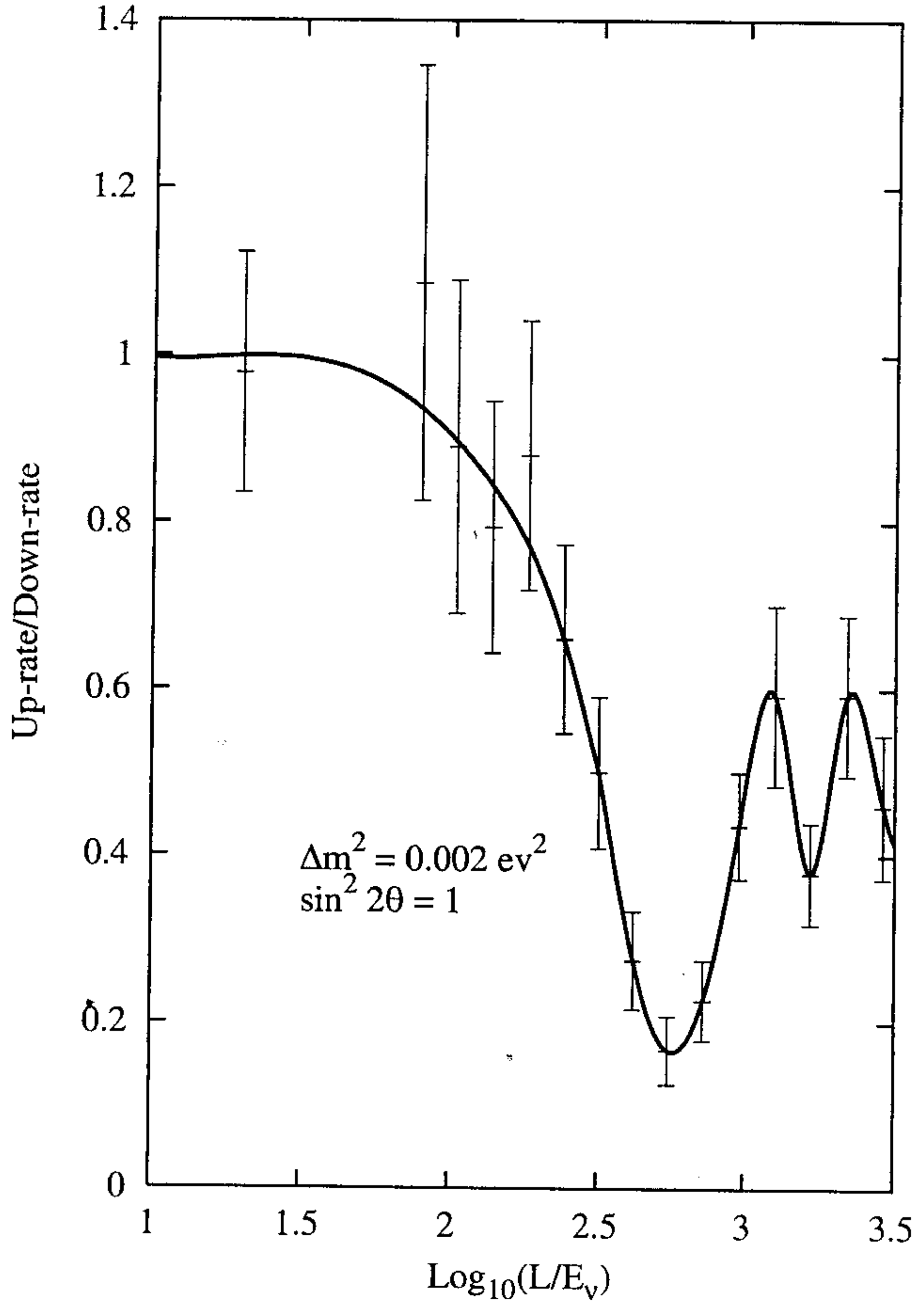
I will show a few results of preliminary calculations by Raj Gandhi & Anindya Datta on the Physics capabilities of INO.

Inputs used in the Calculations

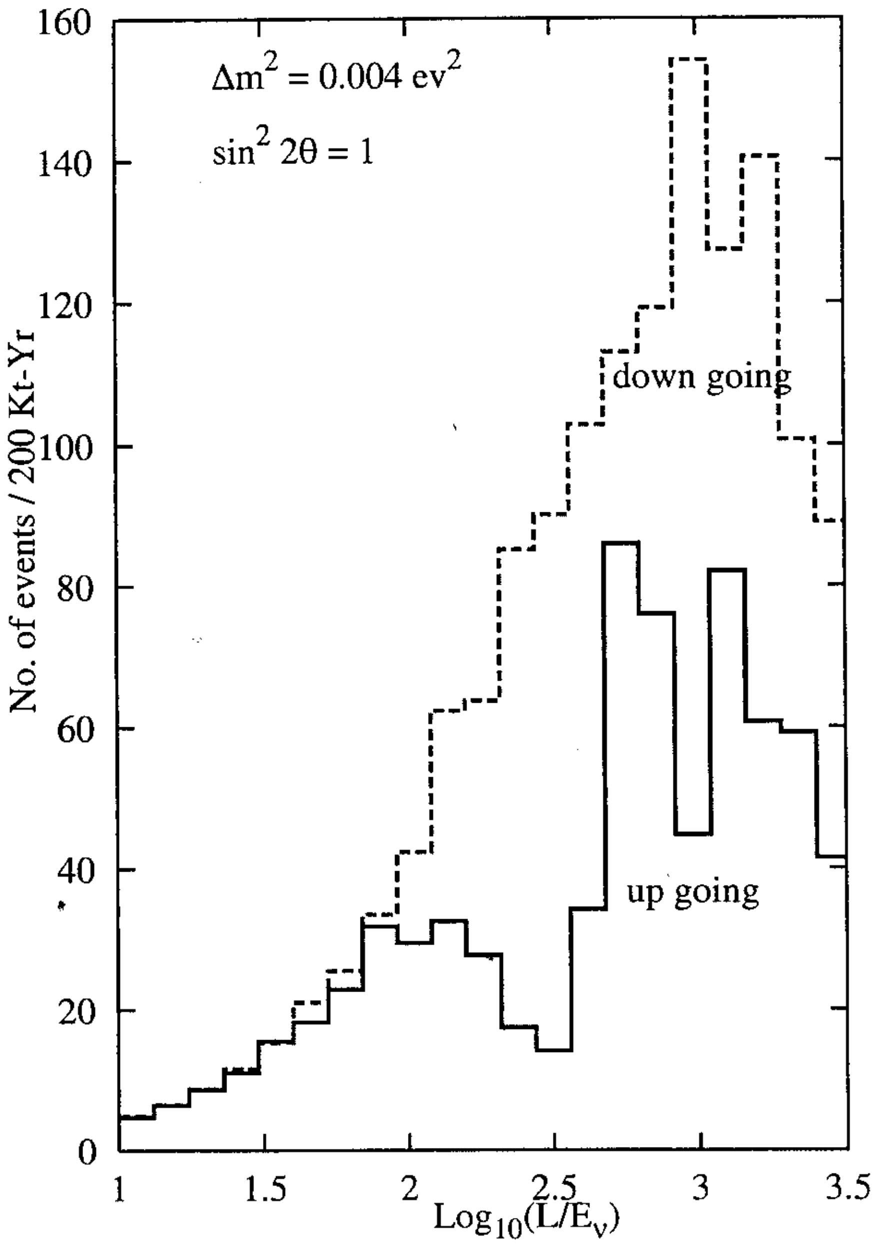
- μ energy resolution < 5%
- μ detection threshold = 2 GeV
- All measurements (for ν Fact) involve wrong sign muon detection, thus BG's are low.
- BG due to decays of Charm, π & K taken into account.
- p_T^2 cut invoked to reduce BG
- Matter effects incorporated using full PREM model of Earth
- Present best fit values from solar/atm/reactor data used.
- 100 % charge id capability assumed.



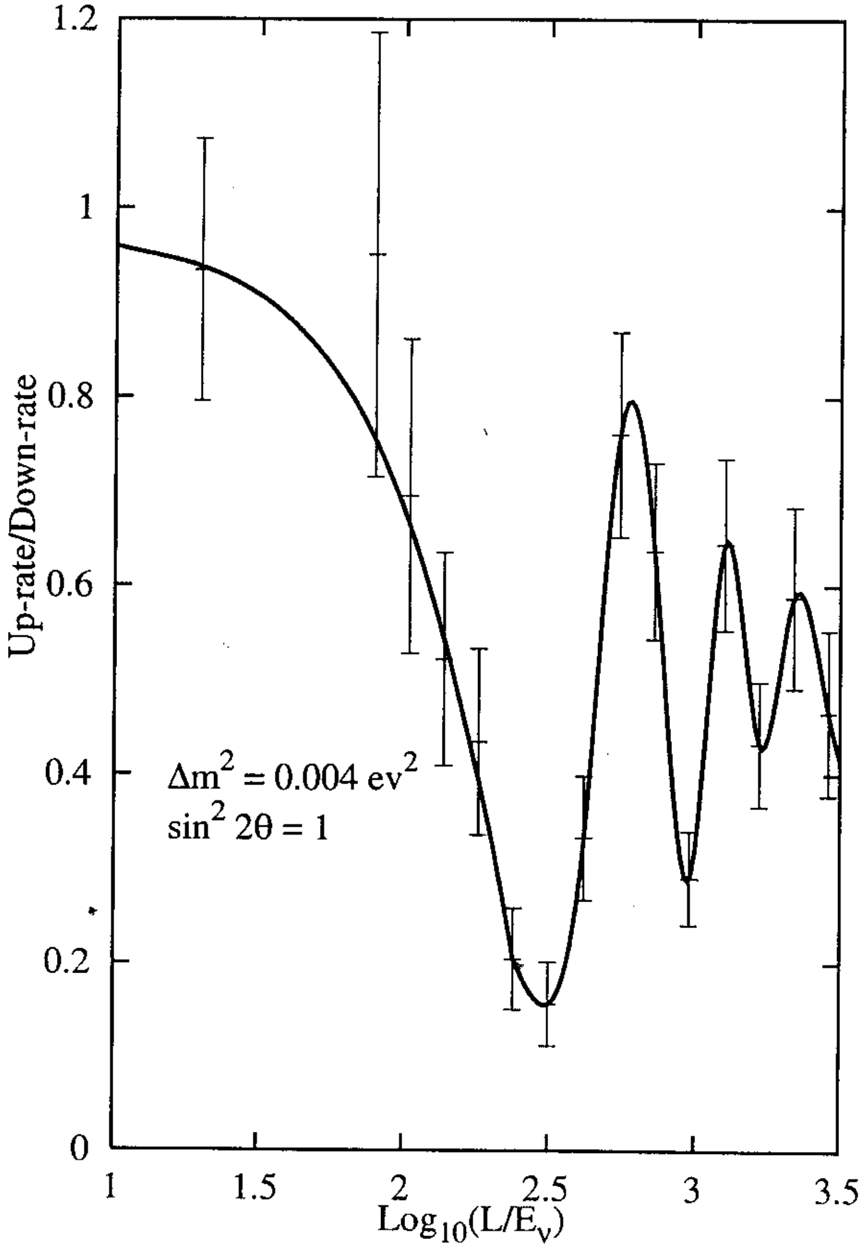
160
140
120
100
80
60
40
20
0
No. of events / 200 Kt-Yr.
$\Delta m^2 = 0.002$ ev^2
$\sin^2 2\theta = 1$
down going
up going
1
1.5
2
2.5
3
3.5
$\mathrm{Log}_{10}(L/E_\nu)$



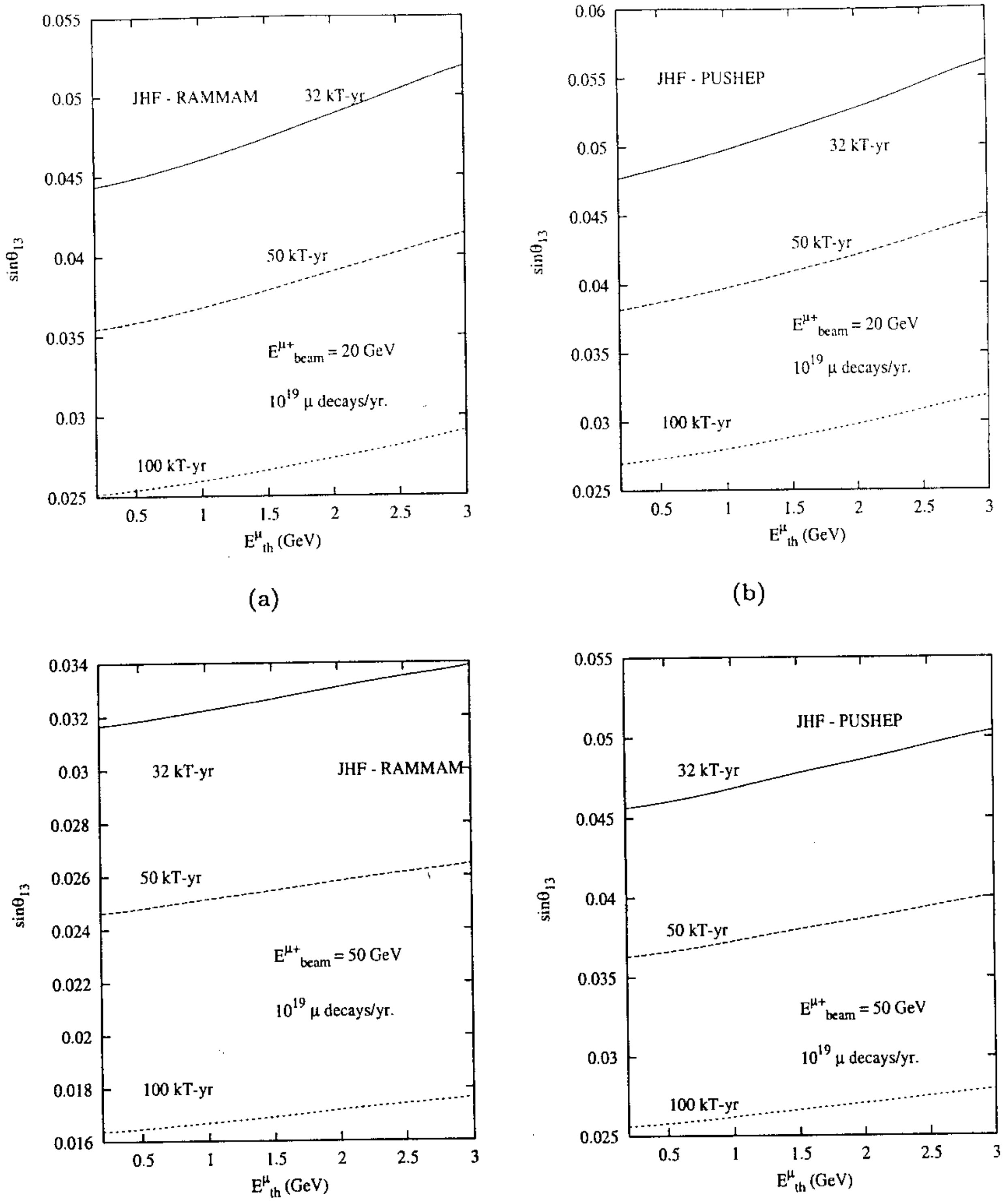
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Up-rate/Down-rate
$\Delta m^2 = 0.002$ ev^2
$\sin^2 2\theta = 1$
1
1.5
2
2.5
3
3.5
$Log_{10}(L/E_\nu)$



$\Delta m^2 = 0.004\ ev^2$
$\sin^2 2\theta = 1$
down going
up going
No. of events / 200 Kt-Yr
$Log_{10}(L/E_\nu)$
160
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
3.5


1.2
1
0.8
0.6
0.4
0.2
0
Up-rate/Down-rate
1
1.5
2
2.5
3
3.5
Log10(L/Eν)
Δm² = 0.004 ev²
sin² 2θ = 1

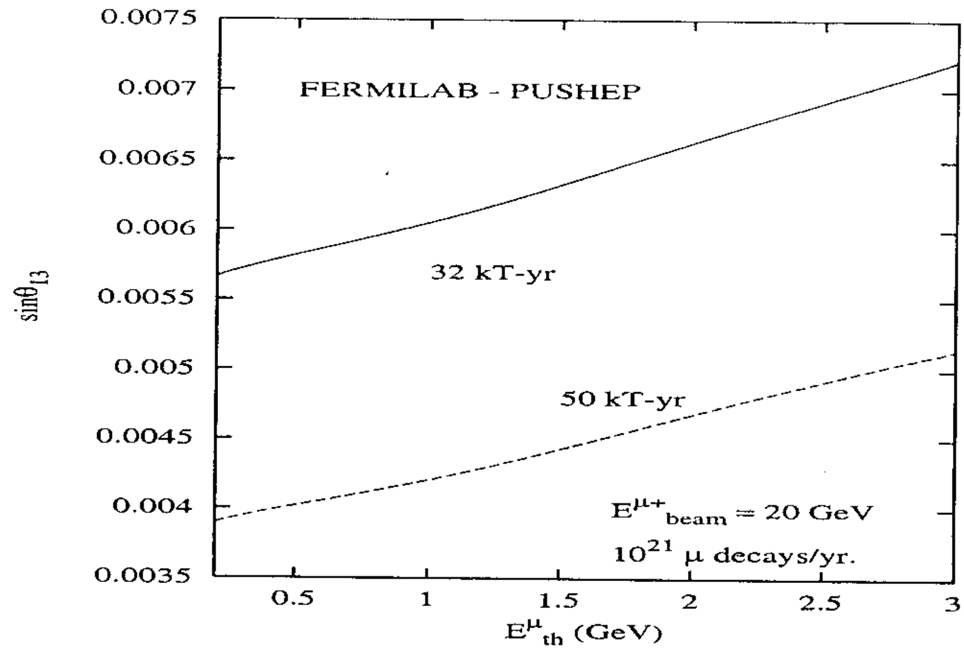
21



(c) (d)

Figure 5: *The $\sin\theta_{13}$ reach for detector exposures of 32 kT-yr, 50 kT-yr and 100 kT-yr for an entry-level neutrino factory configuration with $E_\mu = 20$ GeV for the (a) JHF-RAMAM baseline, the JHF-PUSHEP baseline (b). In (c) and (d) we show the improvement in reach if the storage muon energy is increased to 50 GeV, keeping the number of decays per year the same, i.e, $10^{19}/yr$.*

– The reach is defined as the value required to collect 10 signal events for a given kT-yr exposure



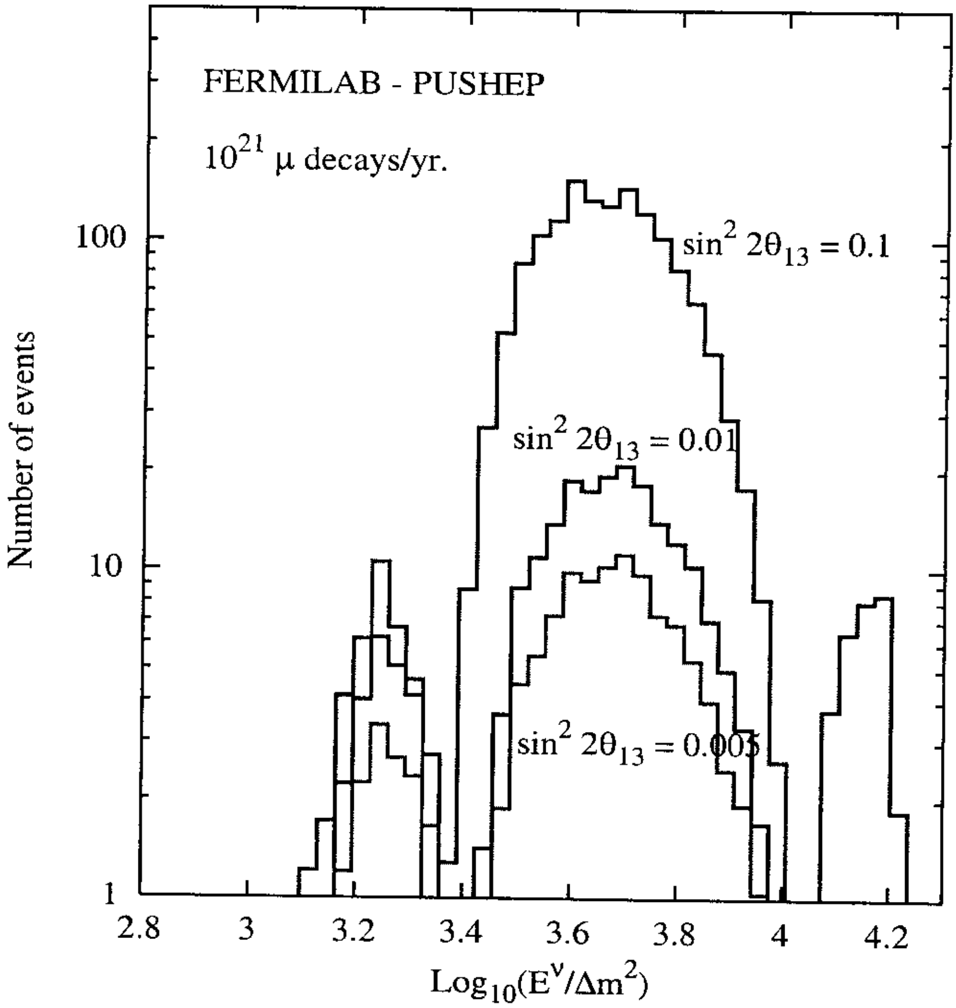
– Fermilab-Pushep baseline is 11296 km

– CHOOZ bound is $sin^2 2\theta_{13} < 0.1$

–Reach is $sin^2 2\theta_{13} = 8.8 \times 10^{-5}$ for 50 kT-yr exposure and 2×10^{-4} for 32 kT-yr

– Wrong sign muon rate sensitive to $sin^2 2\theta_{13}$

– Matter effects important for long baselines



– Note event rate peaks nicely in 10-20 Gev range for currently favoured values of Δm^2_{32}

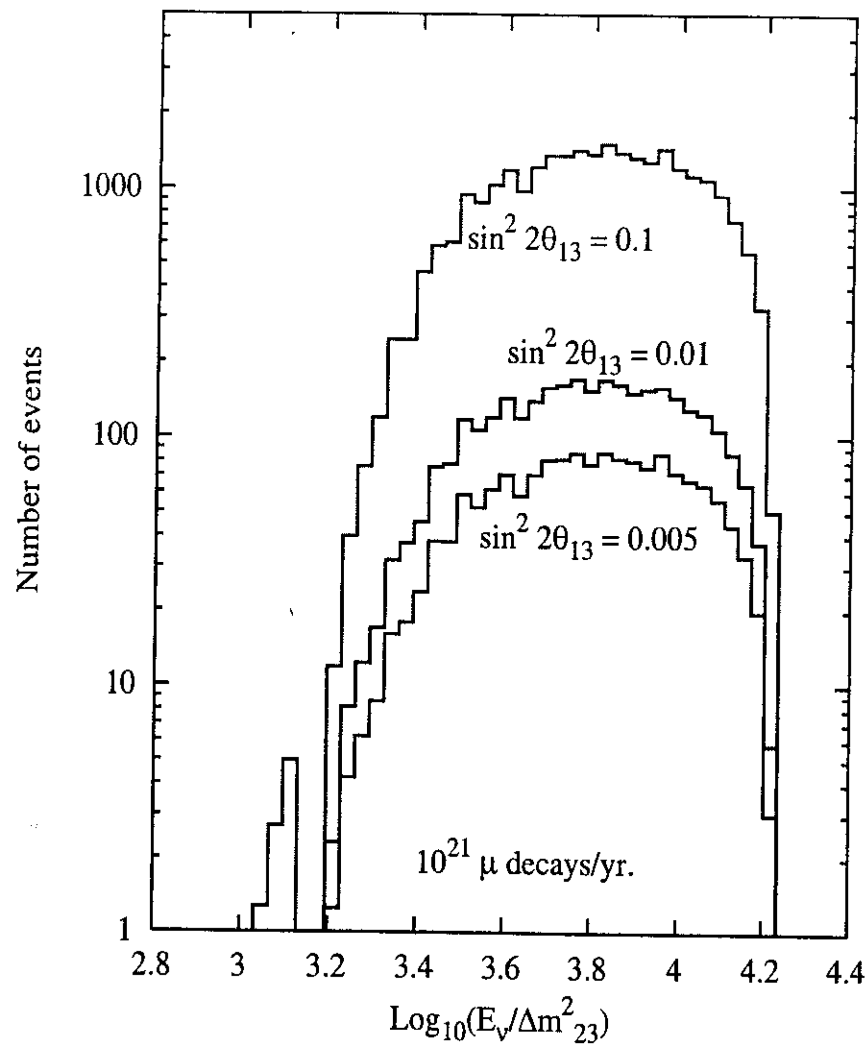


Figure 6: The number of right-sign muon events as a function of $E_\nu/\Delta m^2_{32}$ for the JHF-PUSHEP baseline. The dip to the left of the distribution is due to a minimum of the oscillation probability.

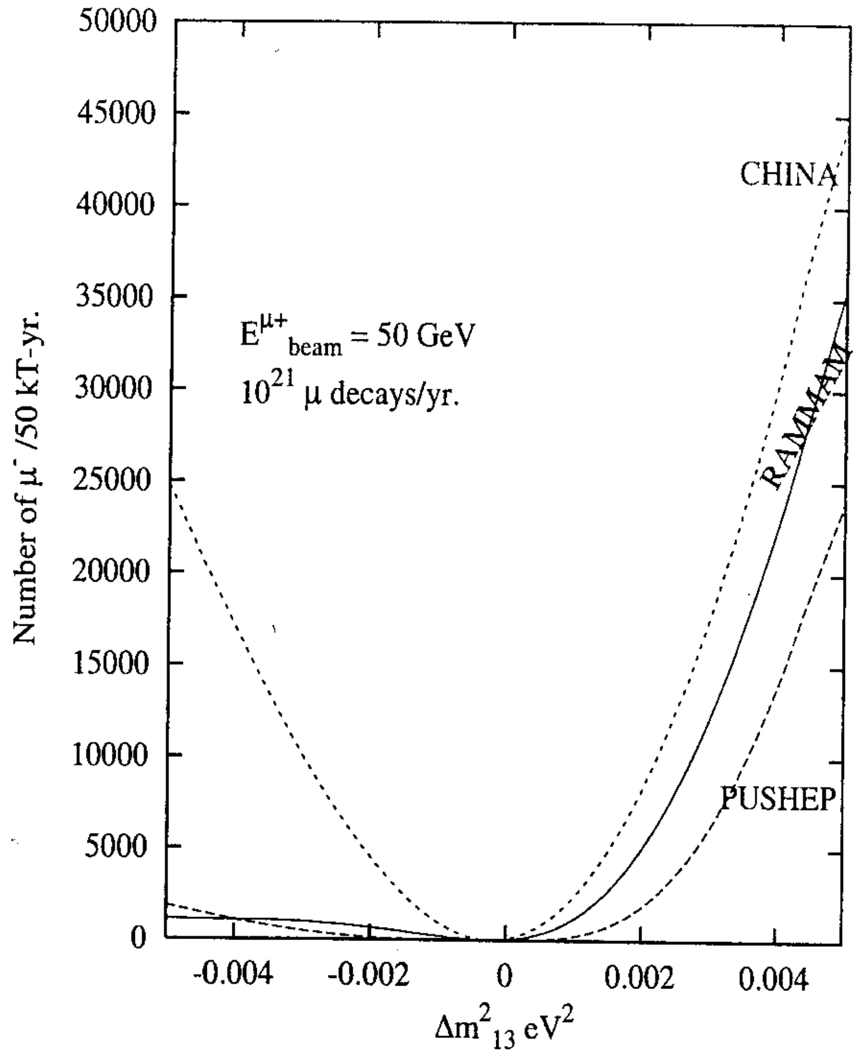
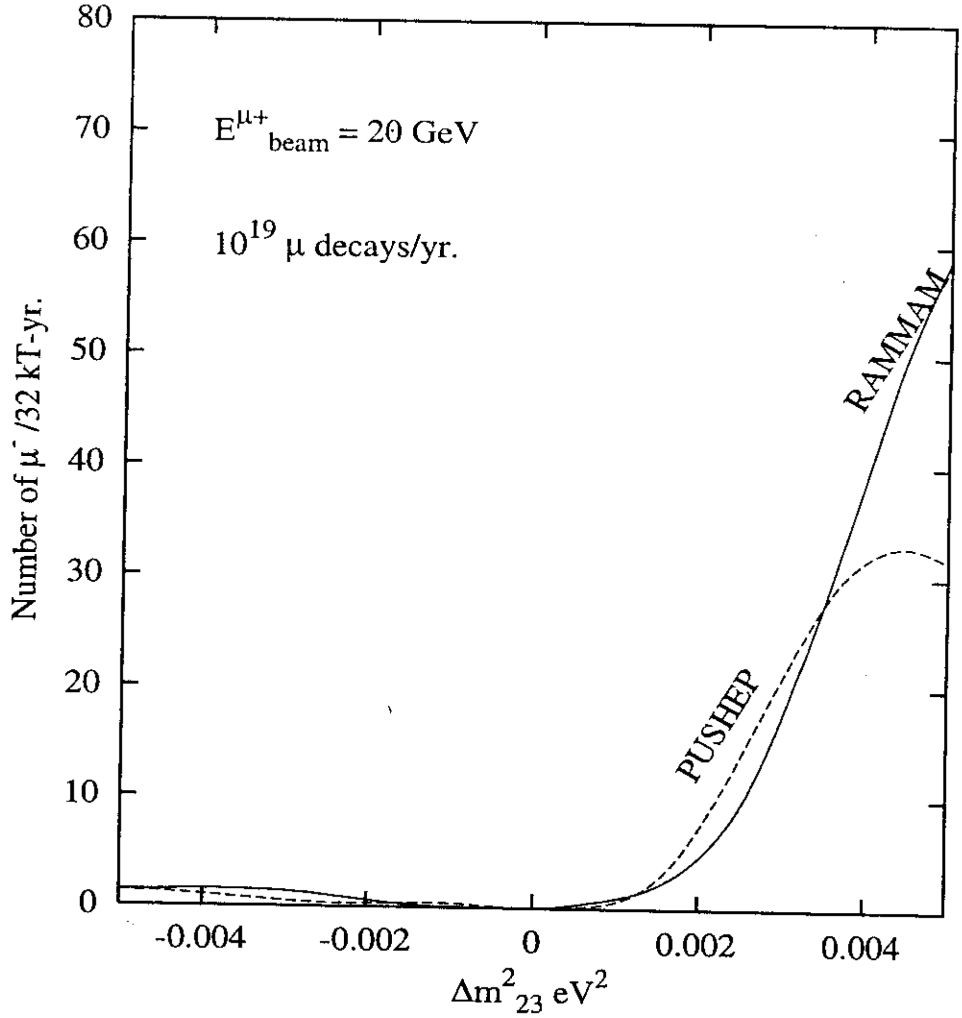


Figure 8: The same as Figure 7, but for a upgraded neutrino factory configuration with a 50 kT-yr exposure.

Sign of Δm^2_{32}

– For anti-neutrino oscillations, A changes sign

– $P_{\nu_e \to \nu_\mu}$ is enhanced and $P_{\bar{\nu}_e \to \bar{\nu}_\mu}$ suppressed



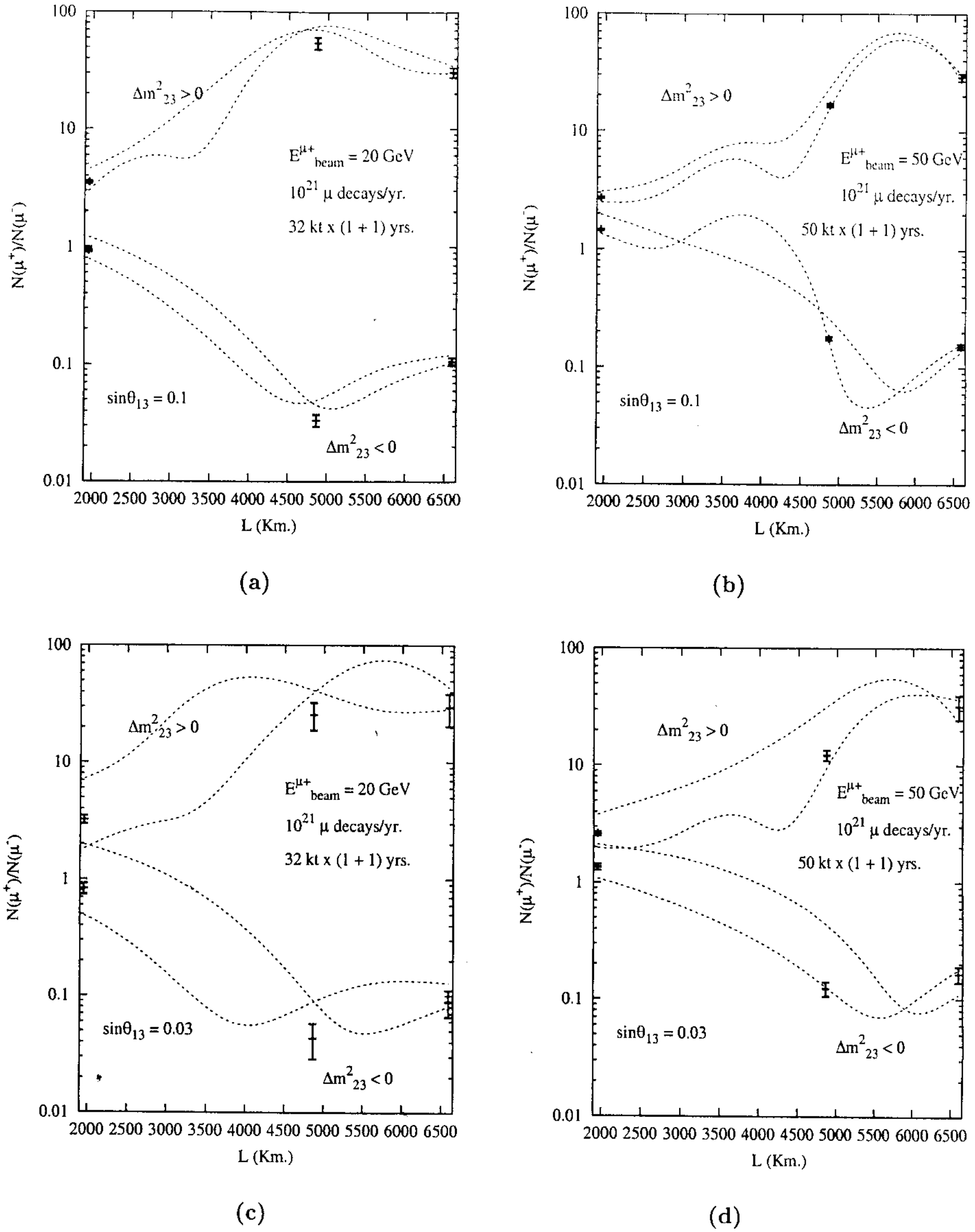
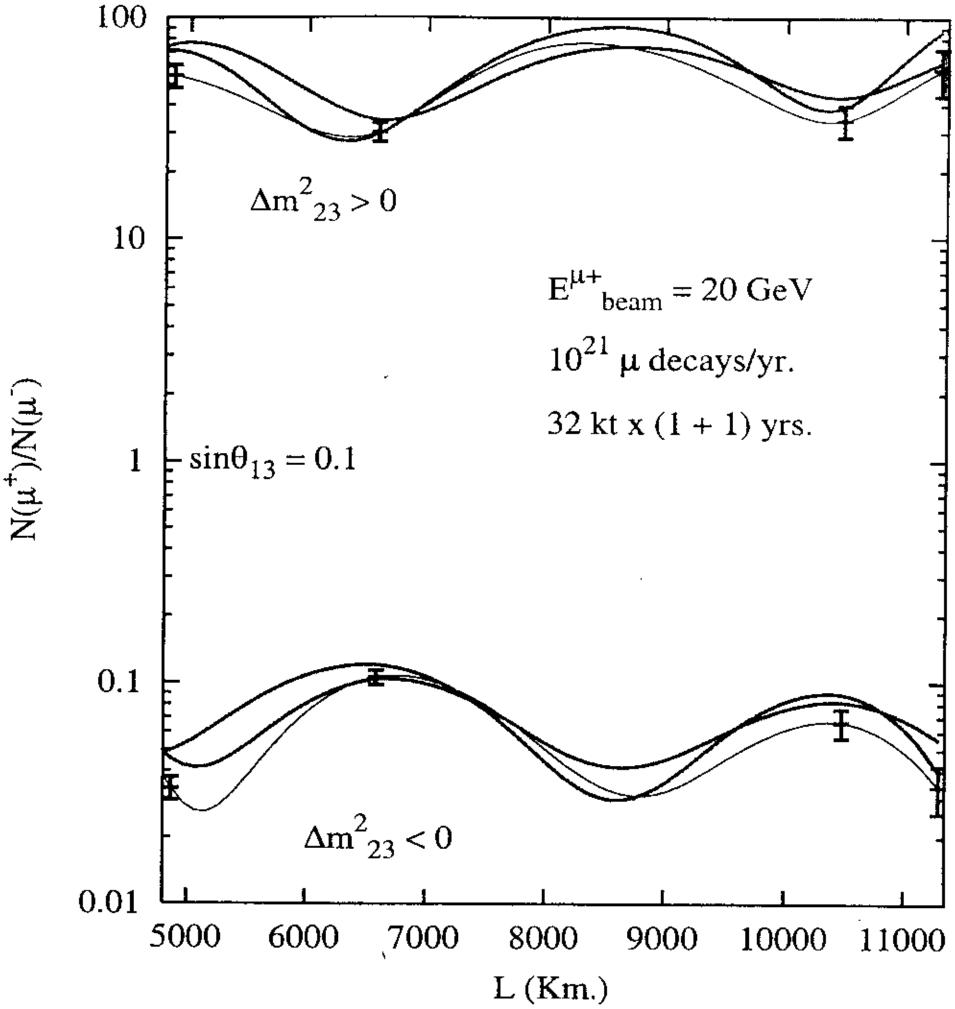
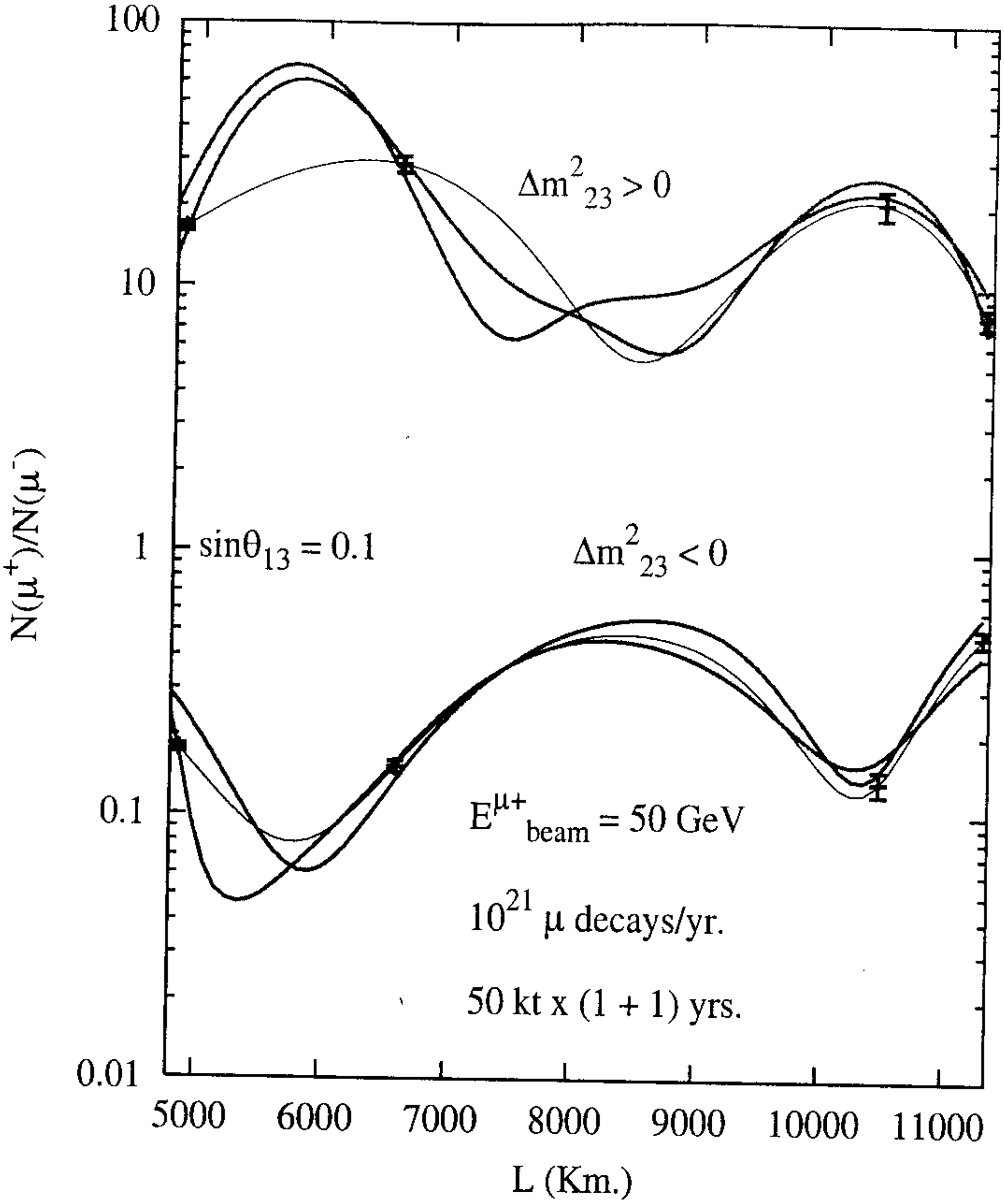


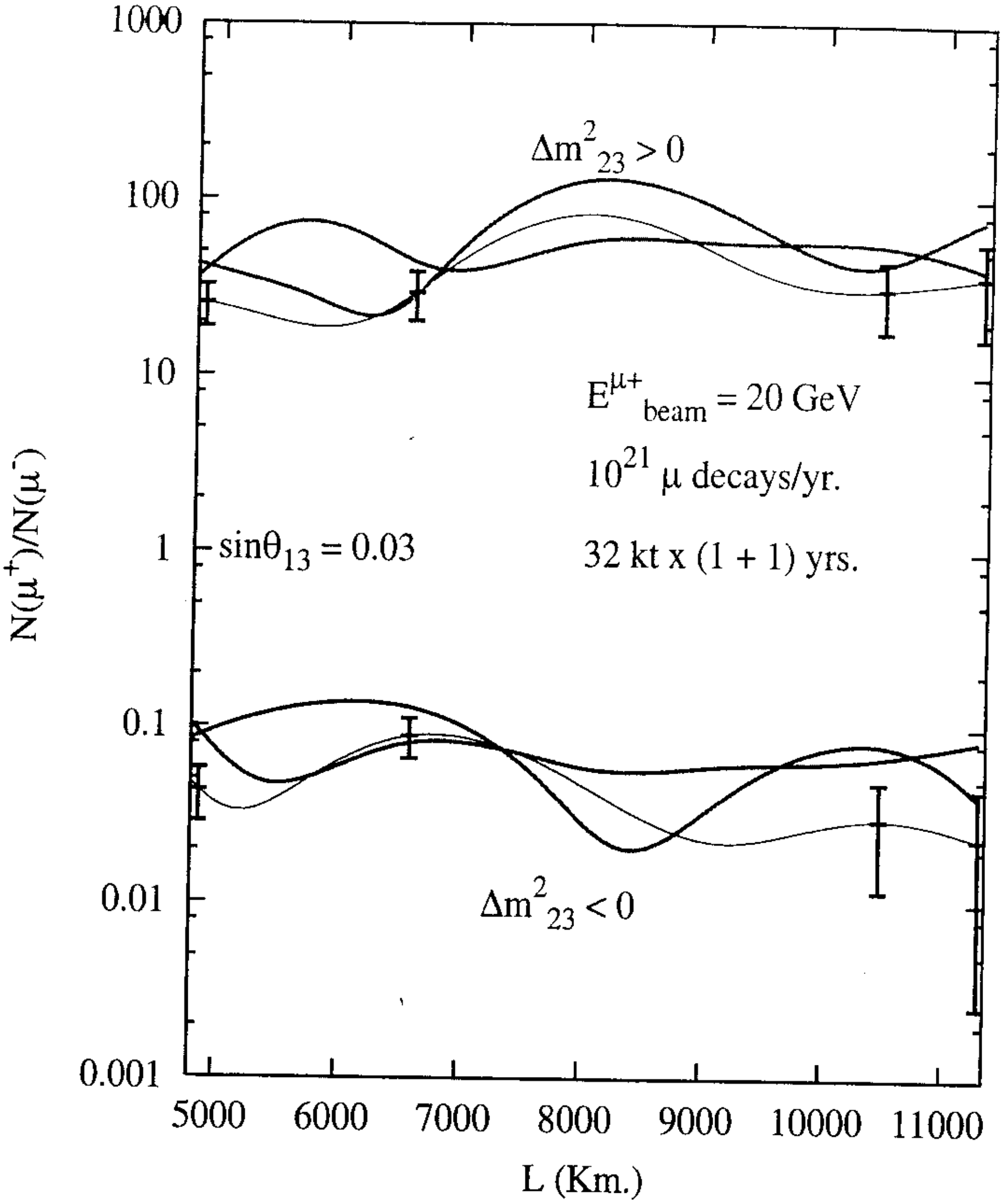
Figure 9: *The $sin\theta_{13}$ reach for detector exposures of 32 kT-yr, 50 kT-yr and 100 kT-yr for an entry-level neutrino factory configuration with $E_\mu = 20$ GeV for the (a) JHF-RAMAM baseline, the JHF-PUSHEP baseline (b). In (c) and (d) we show the improvement in reach if the storage muon energy is increased to 50 GeV, keeping the number of decays per year the same, i.e, $10^{19}/yr$.*

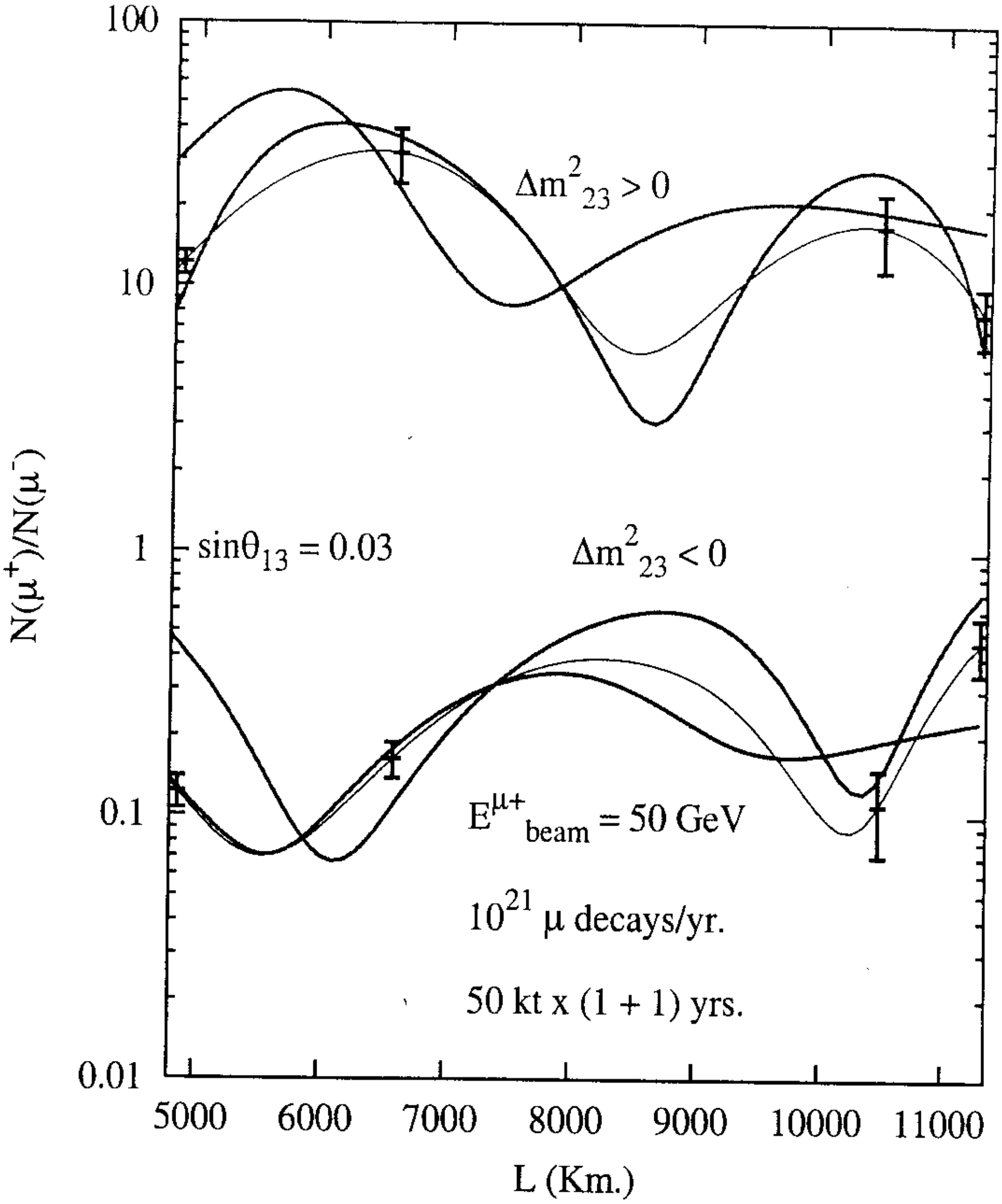


100
10
1
0.1
0.01
$\Delta m^2_{23} > 0$
$E^{\mu+}_{beam}$ = 20 GeV
10^{21} μ decays/yr.
32 kt x (1 + 1) yrs.
$\sin\theta_{13} = 0.1$
$N(\mu^+)/N(\mu^-)$
$\Delta m^2_{23} < 0$
5000
6000
7000
8000
9000
10000
11000
L (Km.)



100
10
1
0.1
0.01
$N(\mu^+)/N(\mu^-)$
$\Delta m^2_{23} > 0$
$\sin\theta_{13} = 0.1$
$\Delta m^2_{23} < 0$
$E^{\mu+}_{beam} = 50$ GeV
10^{21} μ decays/yr.
50 kt x (1 + 1) yrs.
5000
6000
7000
8000
9000
10000
11000
L (Km.)


1000
100
10
1
0.1
0.01
0.001
N(μ+)/N(μ-)
Δm²₂₃ > 0
Δm²₂₃ < 0
E^μ+ beam = 20 GeV
10^21 μ decays/yr.
32 kt x (1 + 1) yrs.
sinθ13 = 0.03
5000
6000
7000
8000
9000
10000
11000
L (Km.)


100
10
1
0.1
0.01
$N(\mu^+)/N(\mu^-)$
$\Delta m^2_{23} > 0$
$\sin\theta_{13} = 0.03$
$\Delta m^2_{23} < 0$
$E^{\mu+}_{beam} = 50$ GeV
10^{21} μ decays/yr.
50 kt x (1 + 1) yrs.
5000
6000
7000
8000
9000
10000
11000
L (Km.)

- Spokesperson : Naba Mondal (TIFR)

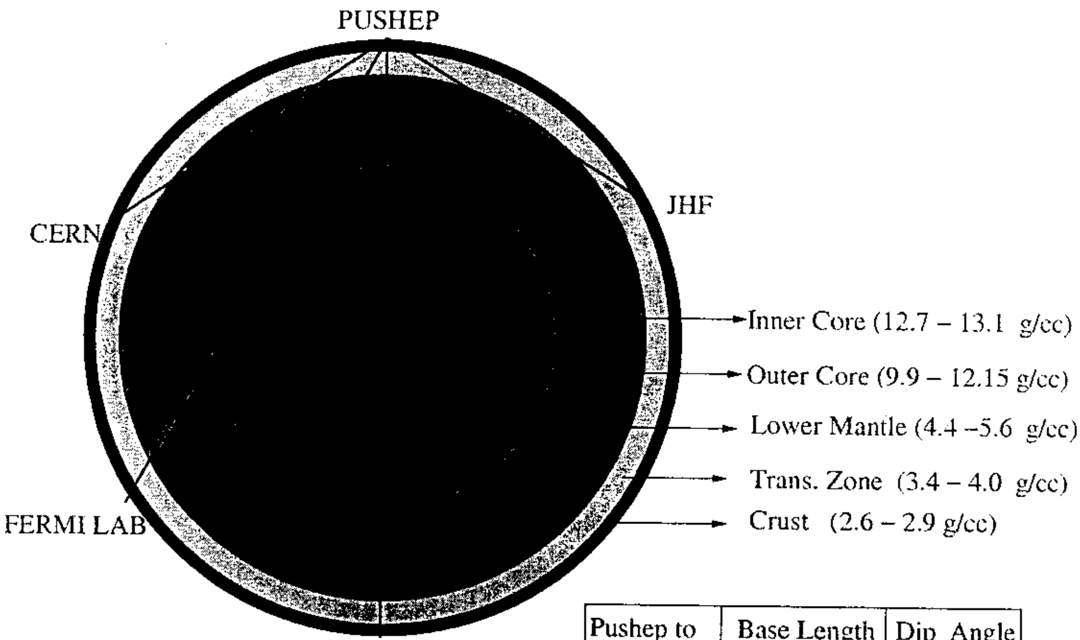
  nkm@tifr.res.in

- Website : www.imsc.ernet.in/~ino

- International Collaboration invited

- We need the support & cooperation of neutrino enthusiasts all over the world.

The Ultimate Neutrino Collaboration



Pushep to	Base Length	Dip Angle
Fermi Lab	11300 km	62 deg
CERN	7145 km	34 deg
JHF	6595 km	31 deg