INO and its Physics Possibilities

Raj Gandhi*

Harish-Chandra Research Institute, Allahabad, India

* For the INO Collaboration

Introduction . . .

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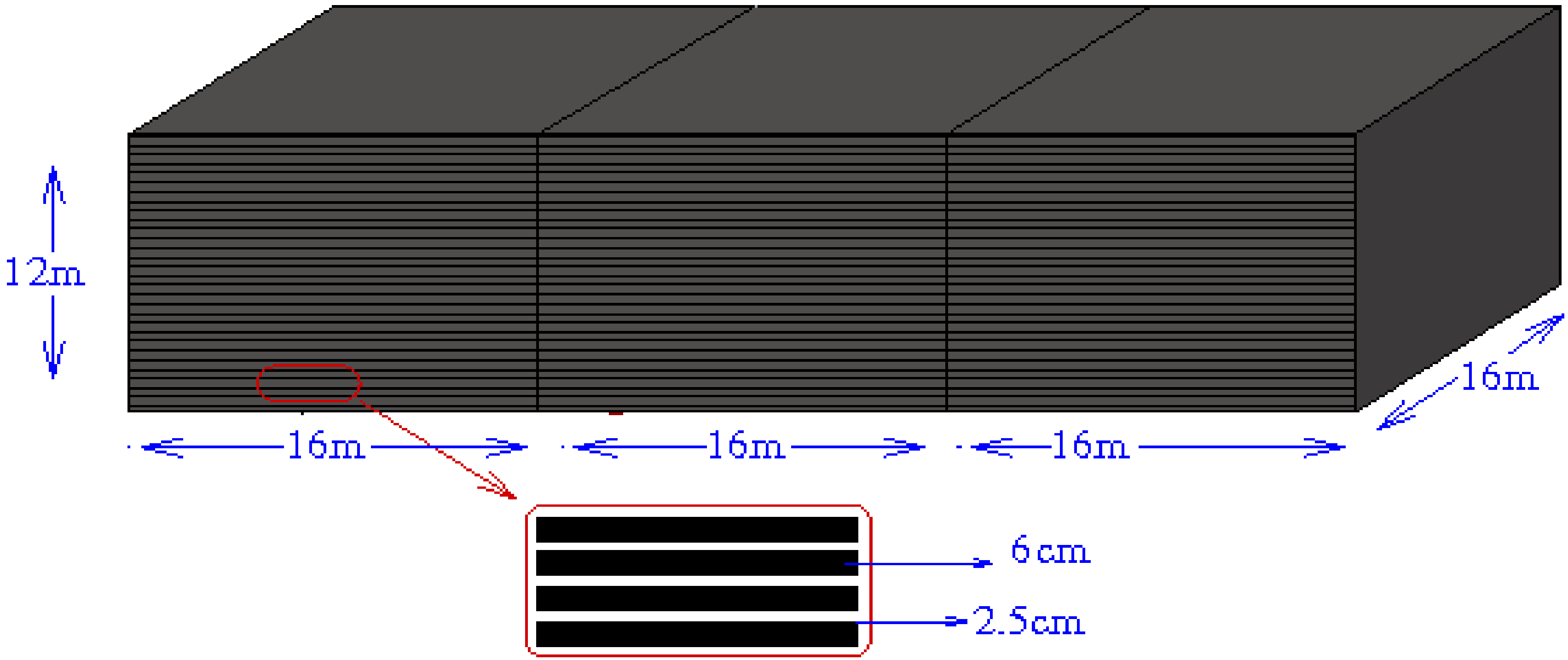
- The proposal is under review both domestically and by an International panel and a final funding decision is expected very soon.



- Magnetized calorimeter.
- 140 horizontal iron plates each 6 cm thick, interspersed with Glass RPC.
- Modular structure.

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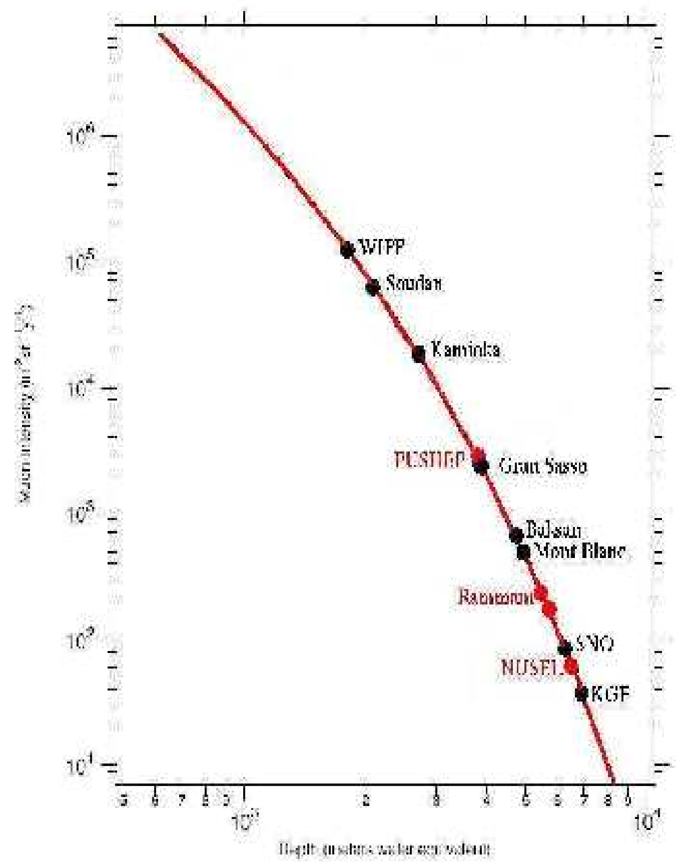
- Estimated cost is about USD 100 million

The Site



- Height of peak is 2207 m.
- Hydroelectric power project with access roads,large caverns at 500 m depth and 13 km of tunnels already adjoin the proposed site, thus Geotechnical knowledge of area exists.
- Few hours drive from Bangalore International Airport.

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  - Test for CPT violation, Lorentz Invariance and the presence of long-range forces

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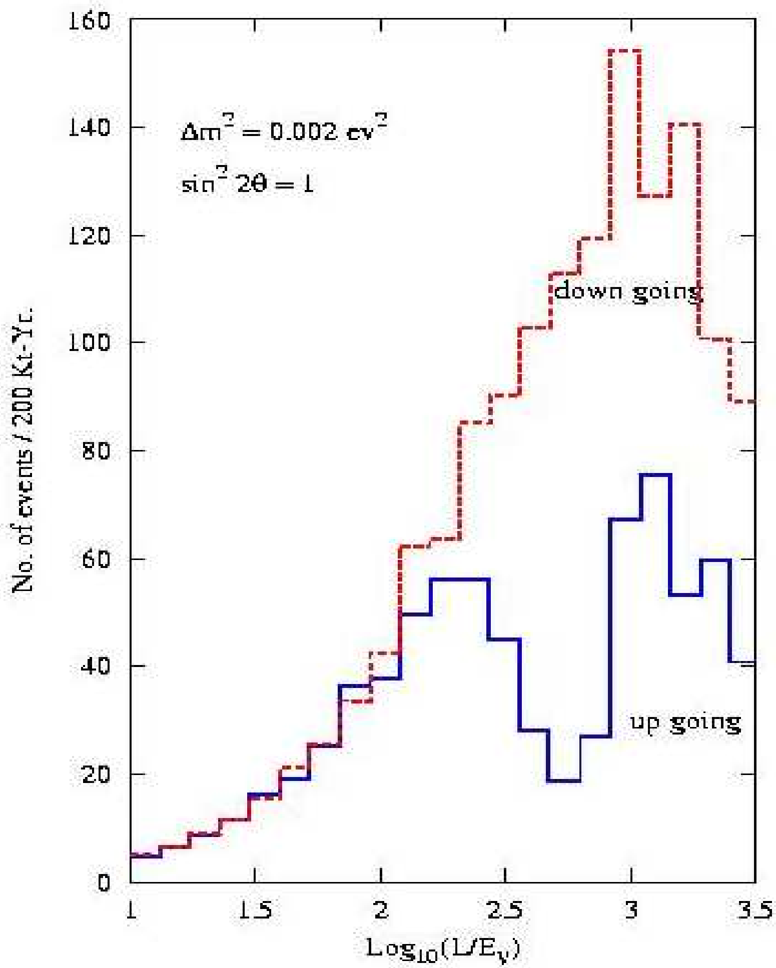
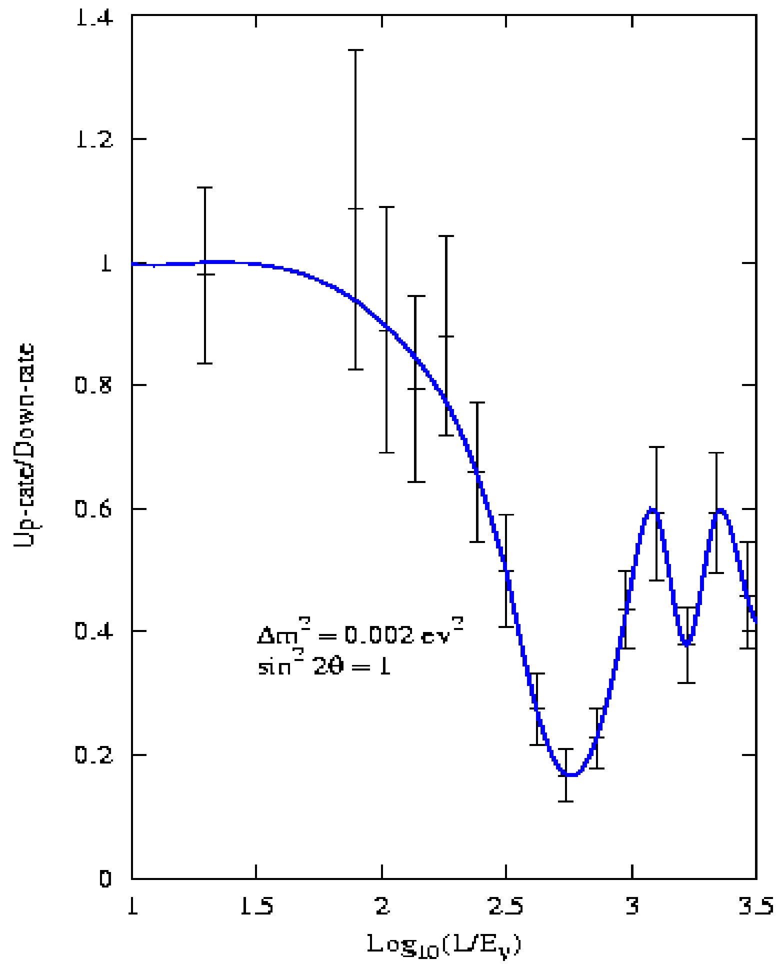
  - Improve the precision on θ_{13} considerably

Measurements of Atmospheric Oscillation Parameters

L/E Dip





- Clean detection of L/E dip possible within about 2 years of running.

Comparison with Long Baseline Experiments

- 3σ spread ($\Delta m^2{}_{13}$ = 2×10^{-3} eV^2, $\sin^2\theta_{23} = 0.5$).

	$\|\Delta m^2{}_{13}\|$	$\sin^2\theta_{23}$
current	44%	39%
MINOS+CNGS	13%	39%
T2K	6%	23%
Nova	13%	43%
INO, 50 kton, 5 years	10%	30%

M. Lindner, hep-ph/0503101

Table refers to the older NOνA proposal; the revised March 2005 NOνA detector is expected to be competitive with T2K.

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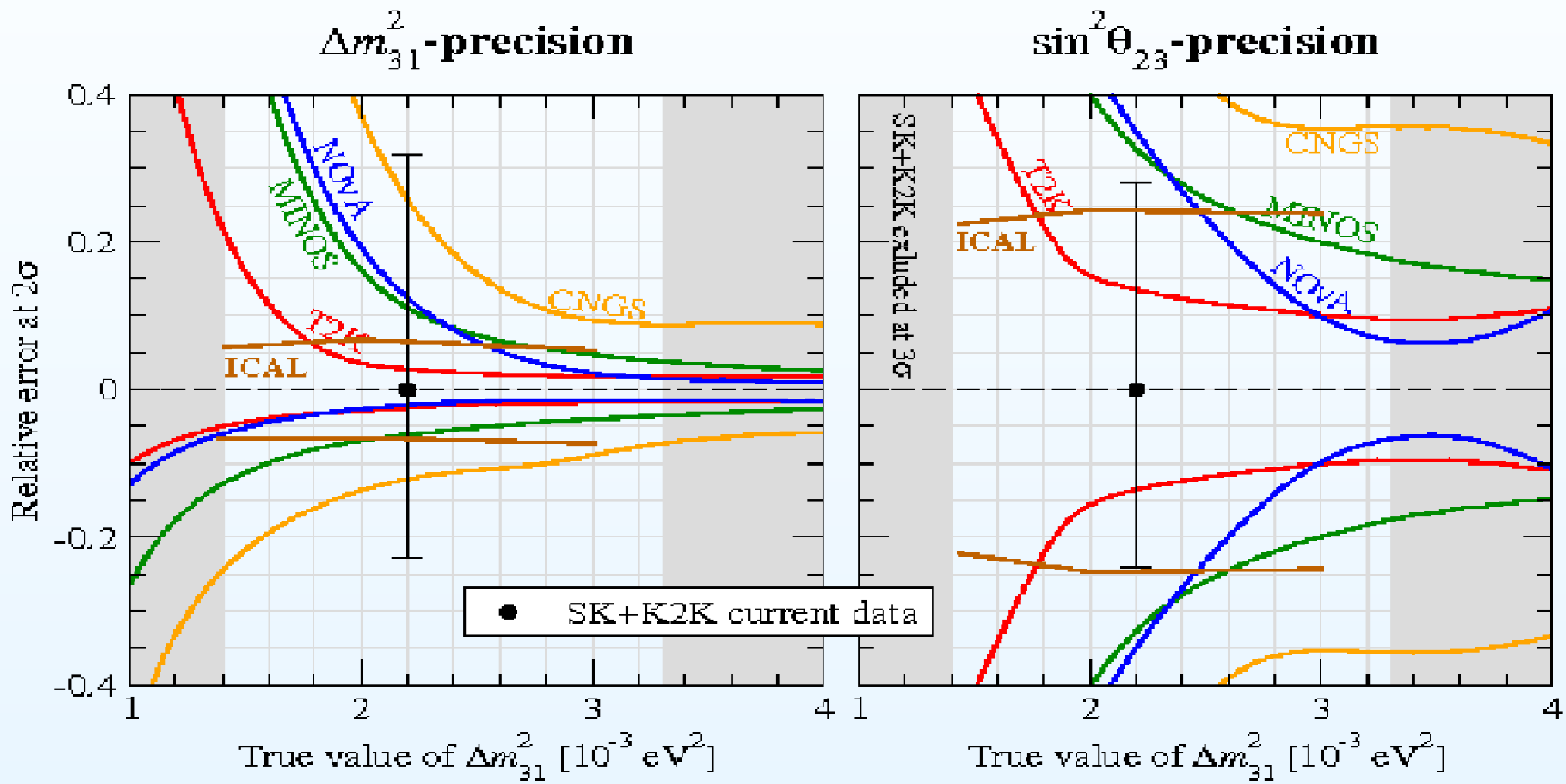

Is θ_{23} maximal?

Measuring the Deviation of θ_{23} from maximality . . .

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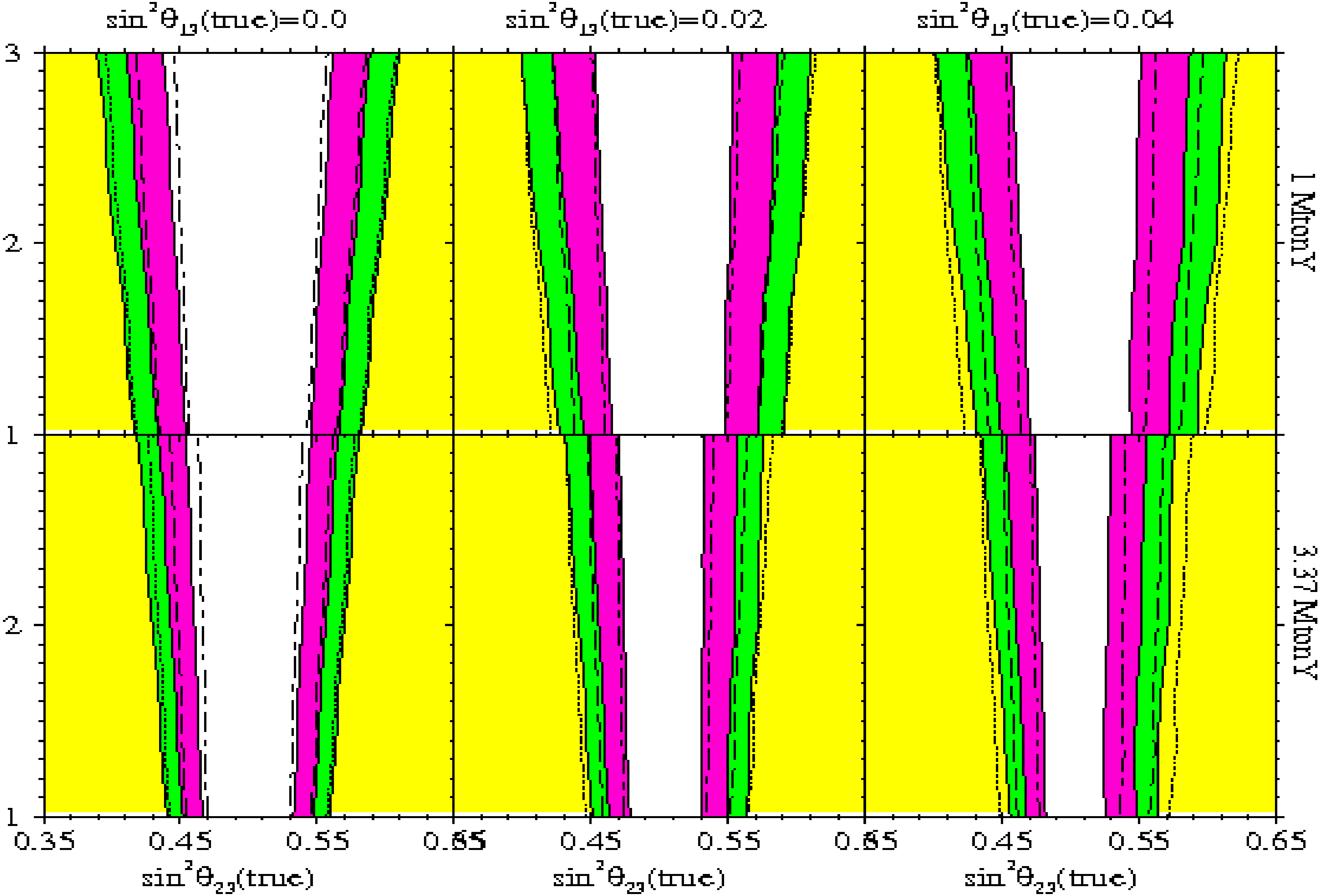
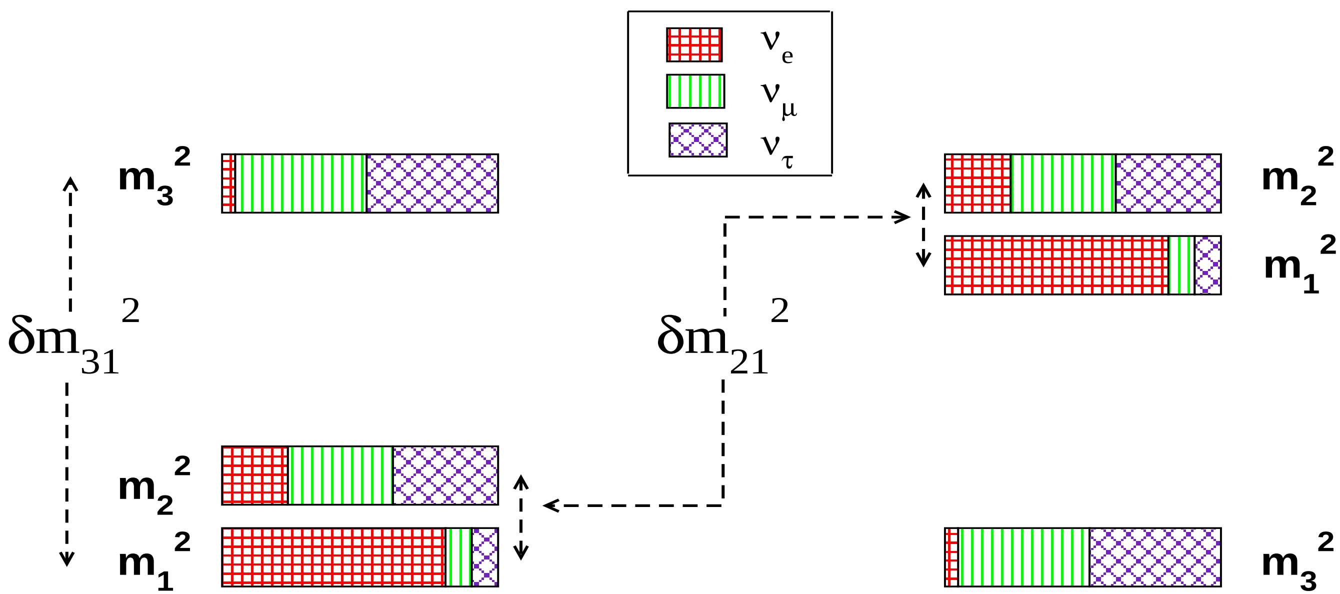
- The difference between U/D ratios for neutrinos and anti-neutrinos is sensitive to the deviation of θ_{23} from maximality.
- A non maximal θ_{23} has important implications for model building.



S. Choubey and P. Roy, hep-ph/0509197

The Mass Hierarchy, its Significance and Detection

So far we only know $|\Delta m^2_{31}|$ and not its Sign



Normal ordering ($\delta m_{31}^2 > 0$) **Inverted ordering** ($\delta m_{31}^2 < 0$)

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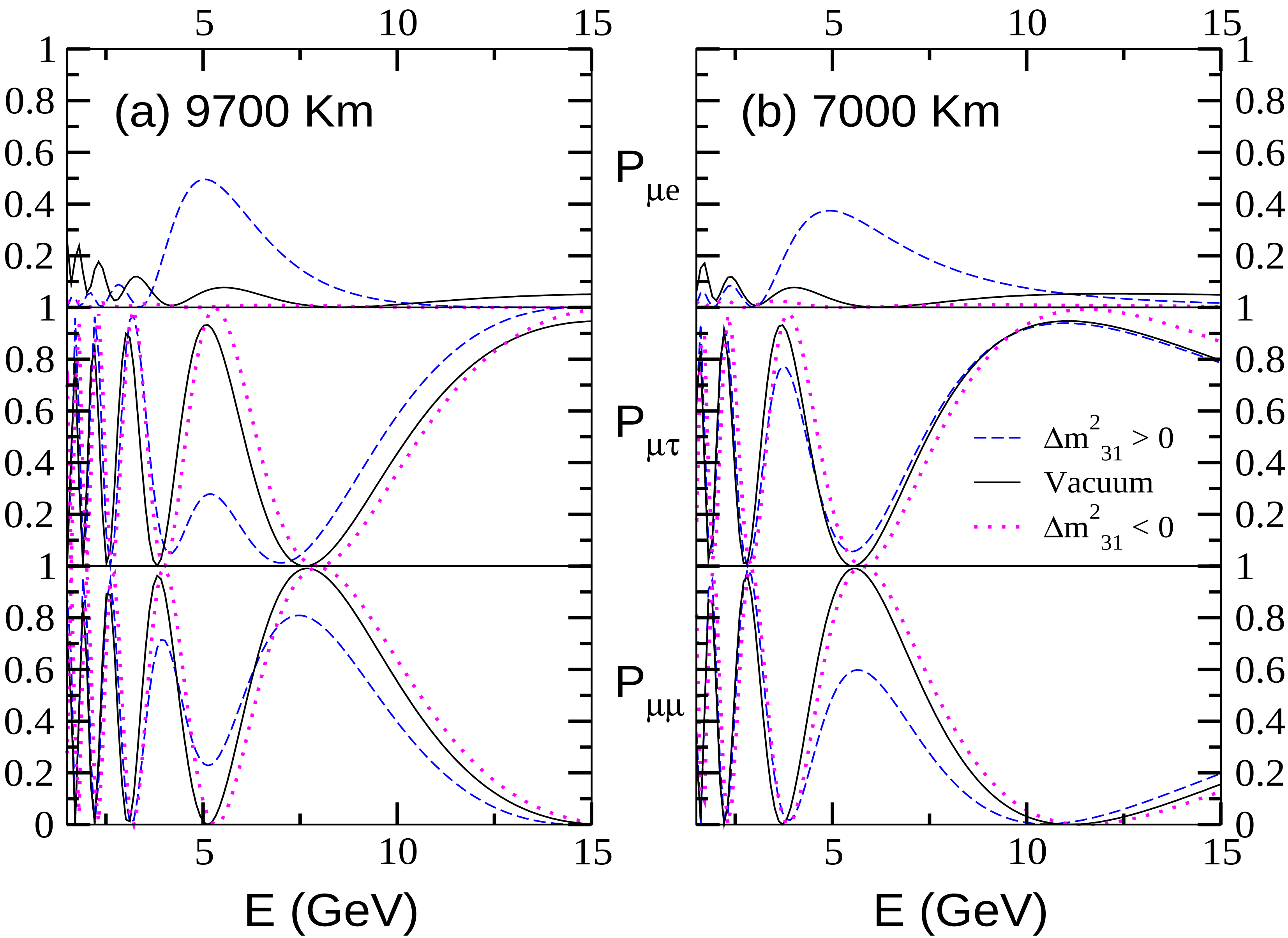
- It would also favour theories utilising *the Type II seesaw mechanism* with additional *Higgs triplets*.
- The type of hierarchy impacts the effectiveness of *leptogenesis* in most theoretical models.

Plot of Probabilities . . .

R. Gandhi *et al.*, Phys. Rev. Lett. **94**, 051801 (2005); hep-ph/0411252



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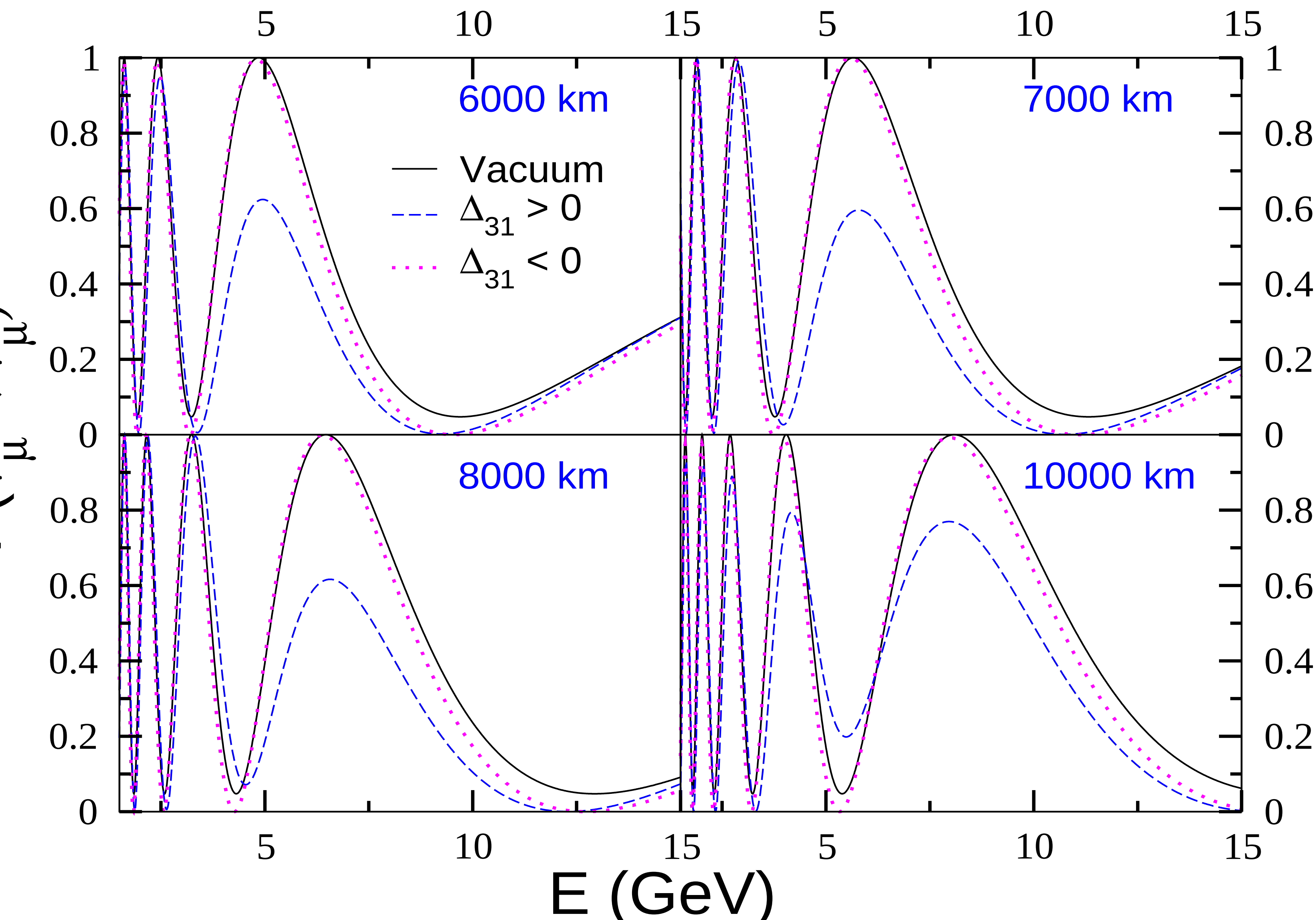
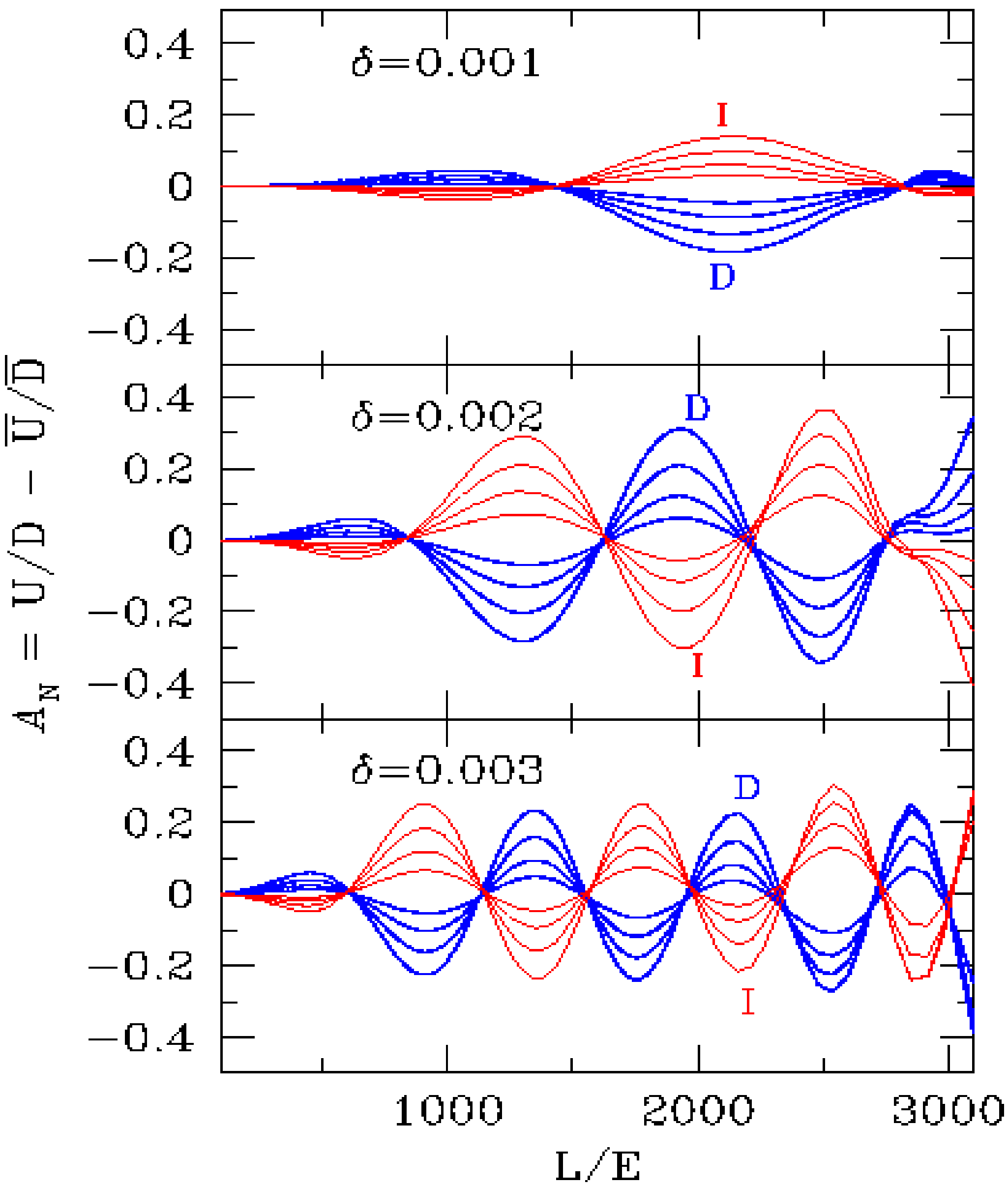


Measuring the Up/Down Asymmetry



D. Indumathi and M. Murthy,
hep-ph/0407336

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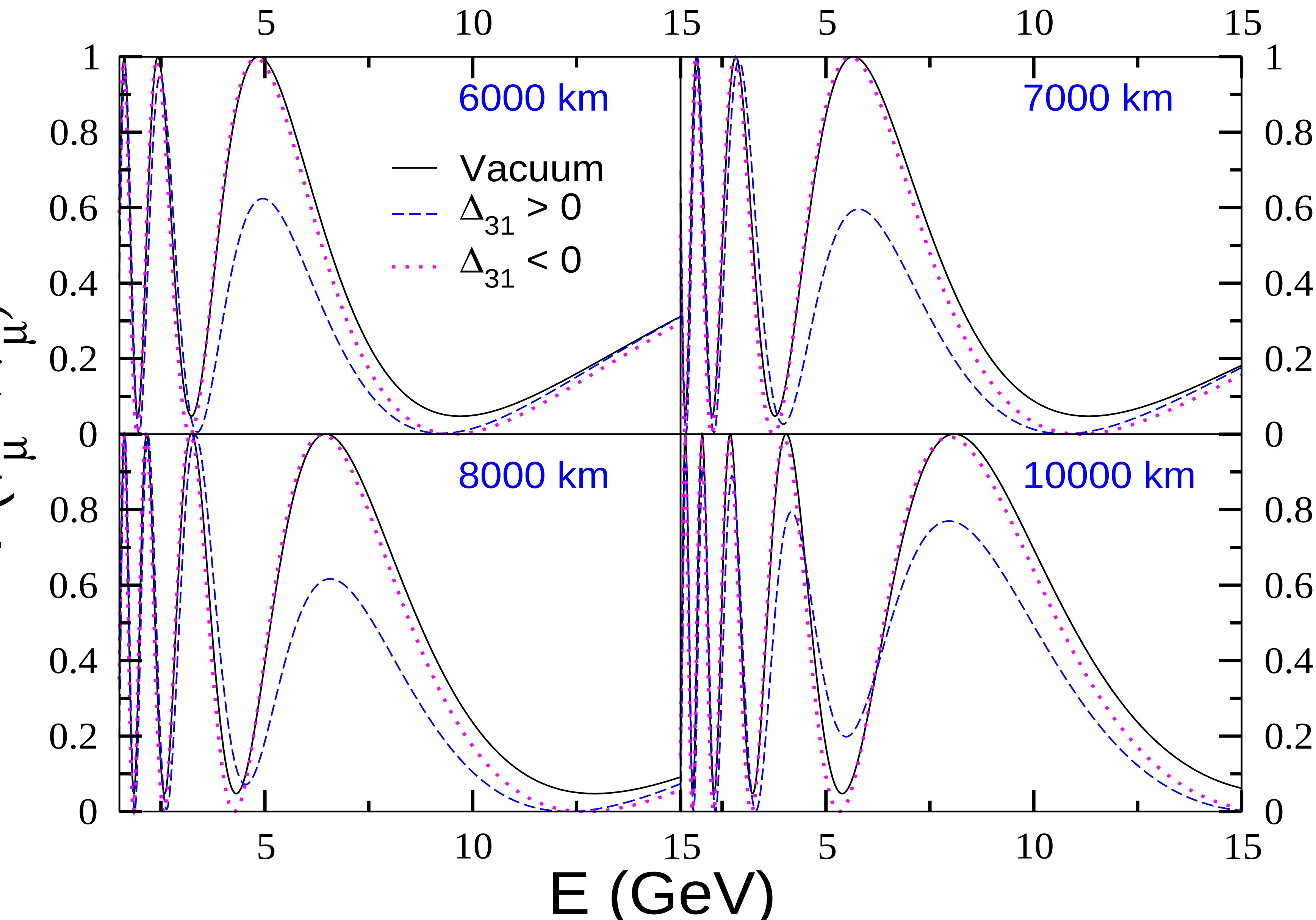
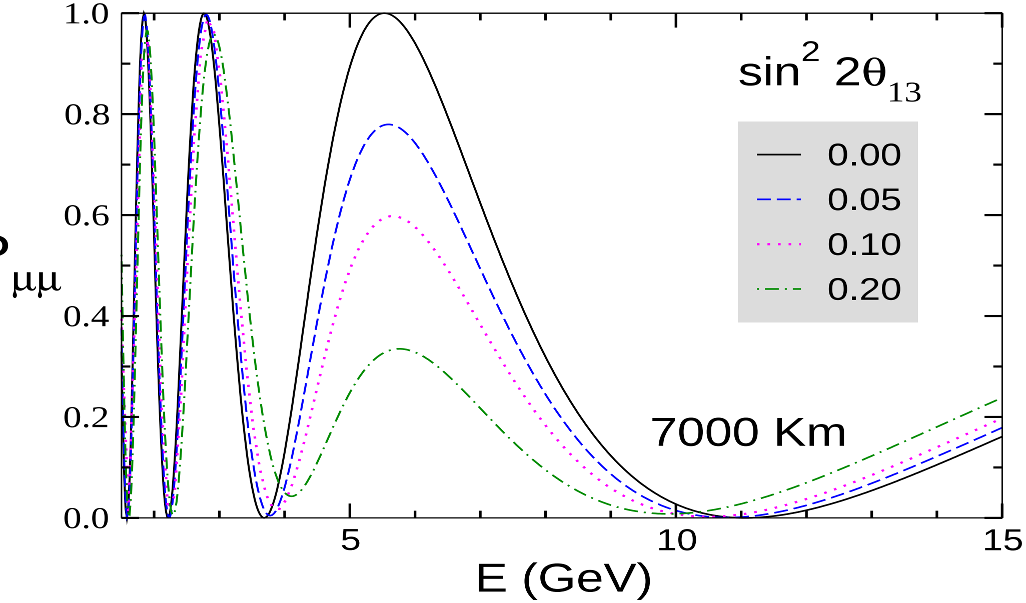


Survival Probability : θ_{13} sensitivity . . .



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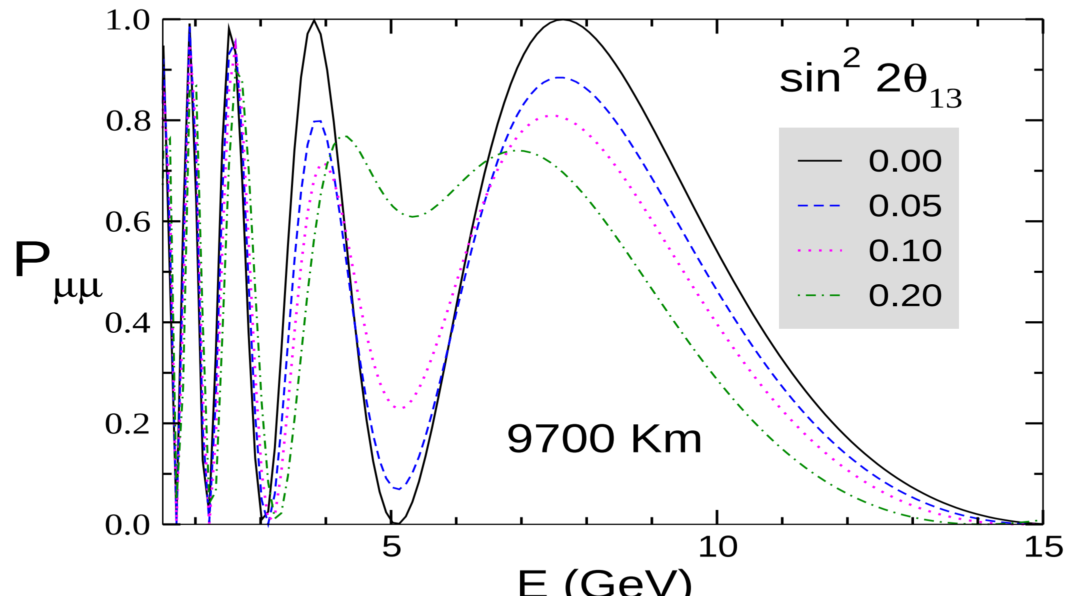
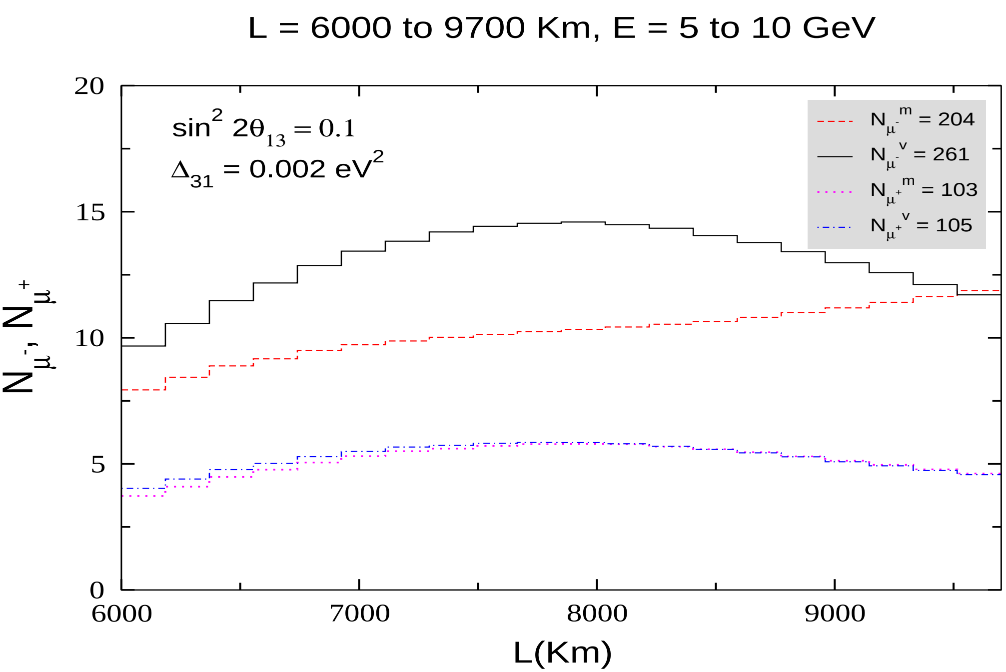


Results for an Iron Calorimeter type detector

Results : Iron Calorimeter, 1000 kt-yr . . .



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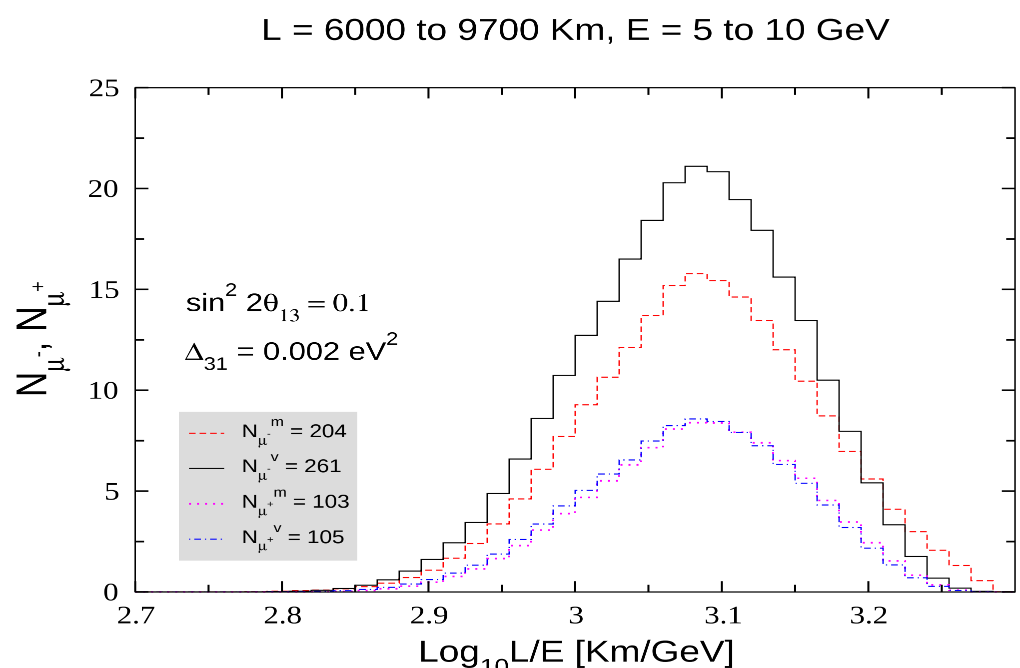
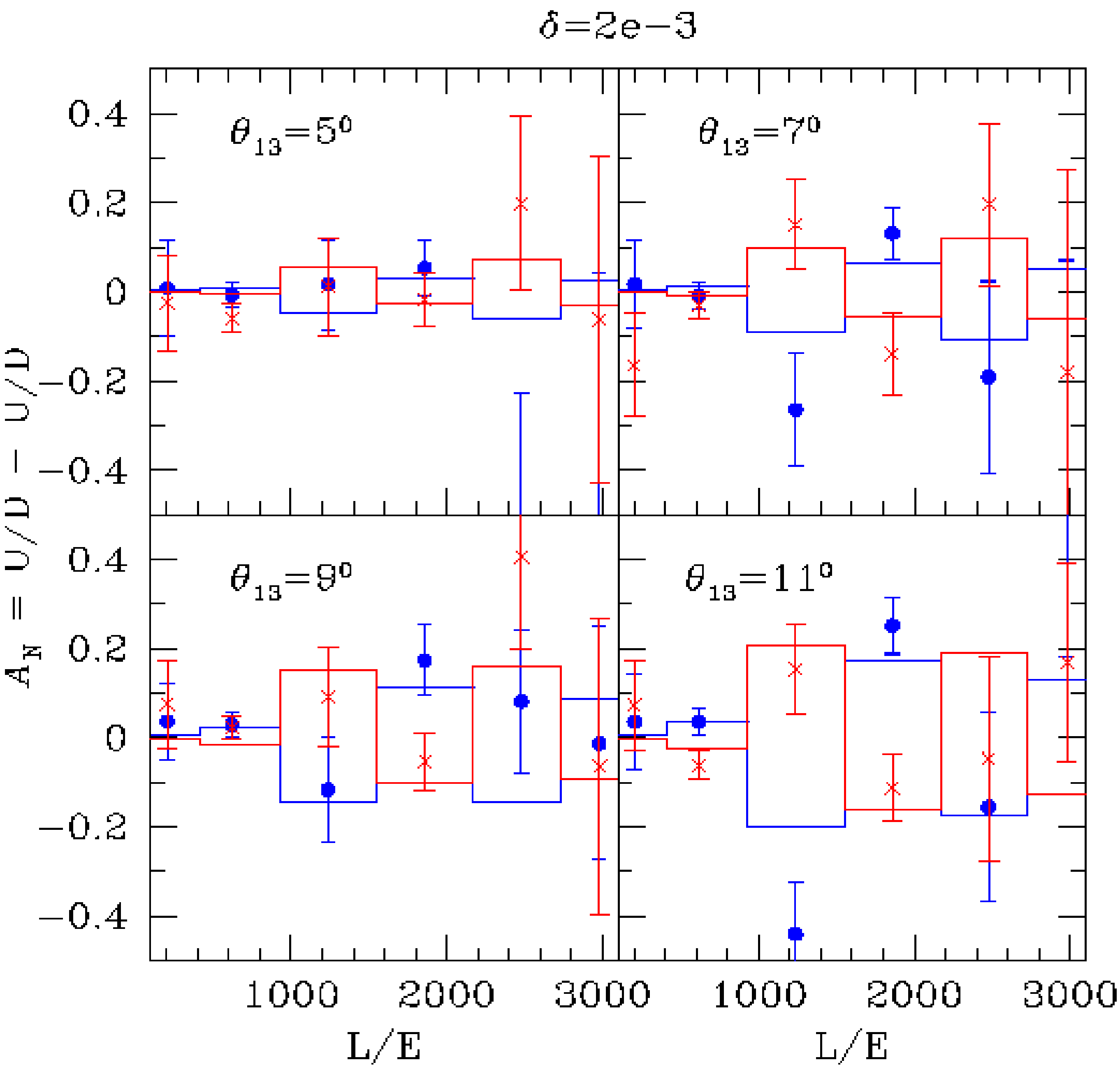


Asymmetry in Up-Down Event Rates . . .



D. Indumathi and M.V.N. Murthy; hep-ph/0407336

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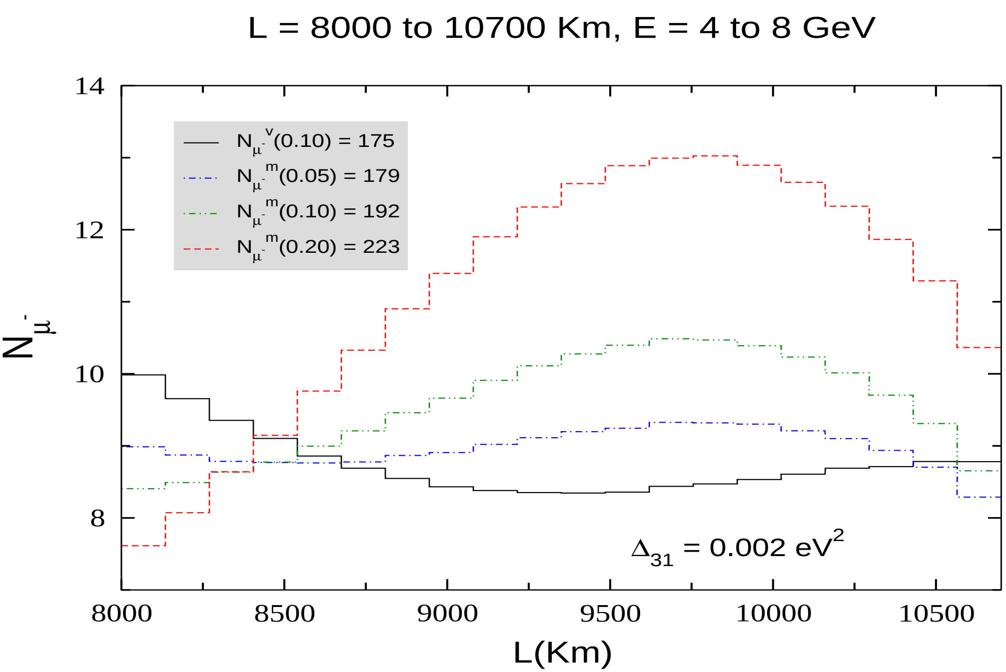
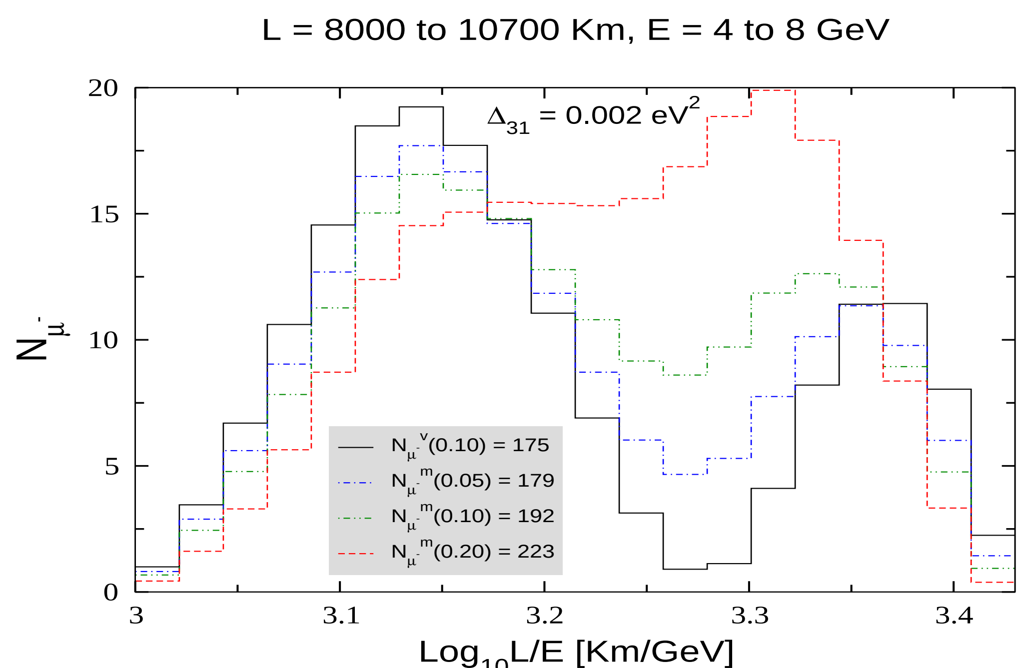


R. Gandhi *et al.*, hep-ph/0411252



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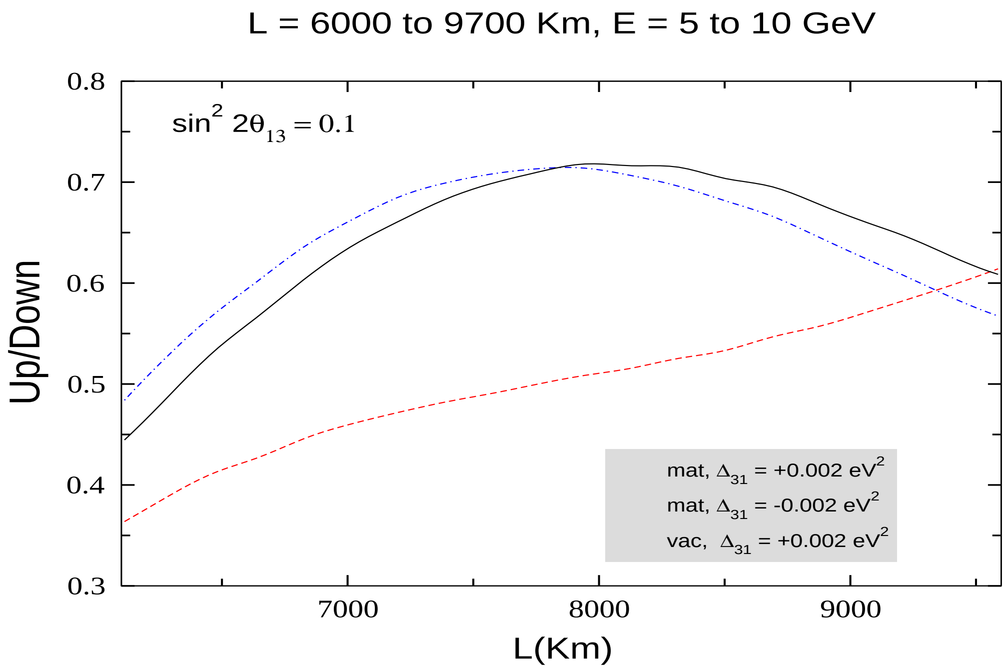

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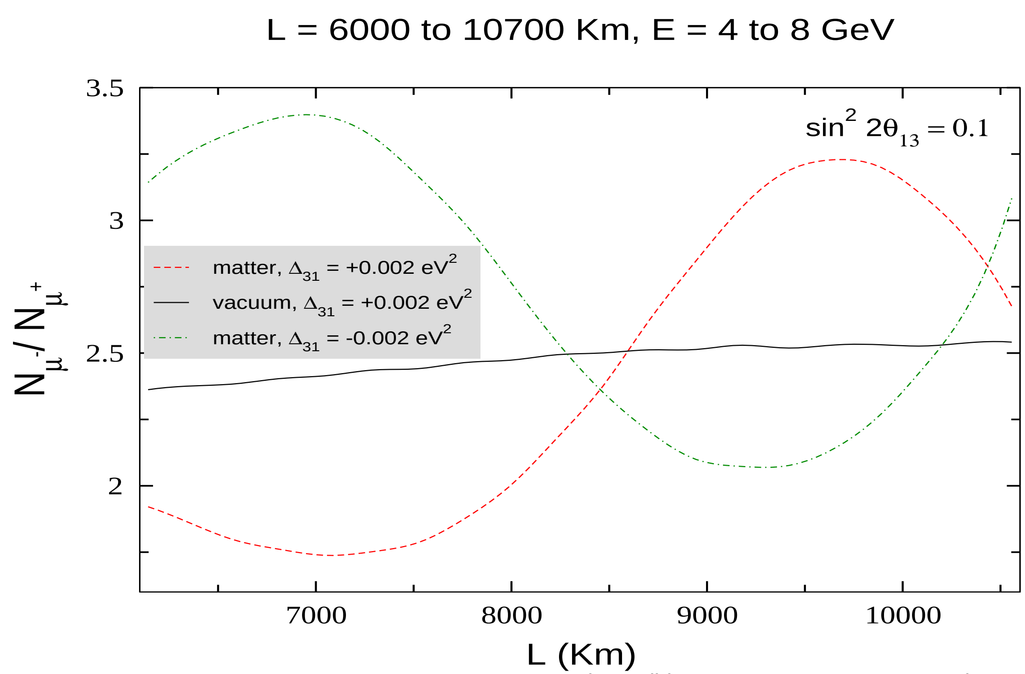

Bin by bin χ^2-analysis

- Results for a iron calorimeter detecto
  - χ^2 analysis of μ^- event in 24 L/E bins
  - 15% energy and 15^o angular resolution
  - 10% systematic error
  - 85% efficiency
  - Marginalized over Δm^2_{31}, $\sin^2\theta_{13}$, $\sin^2\theta_{23}$

$\sin^2 2\theta_{13}$	$\chi^2_{\rm min}$ 500 kt yr	$\chi^2_{\rm min}$ 1000 kt yr
0.05	2.7	3.7
0.1	6.6	8.9

Gandhi et al. work in progress.

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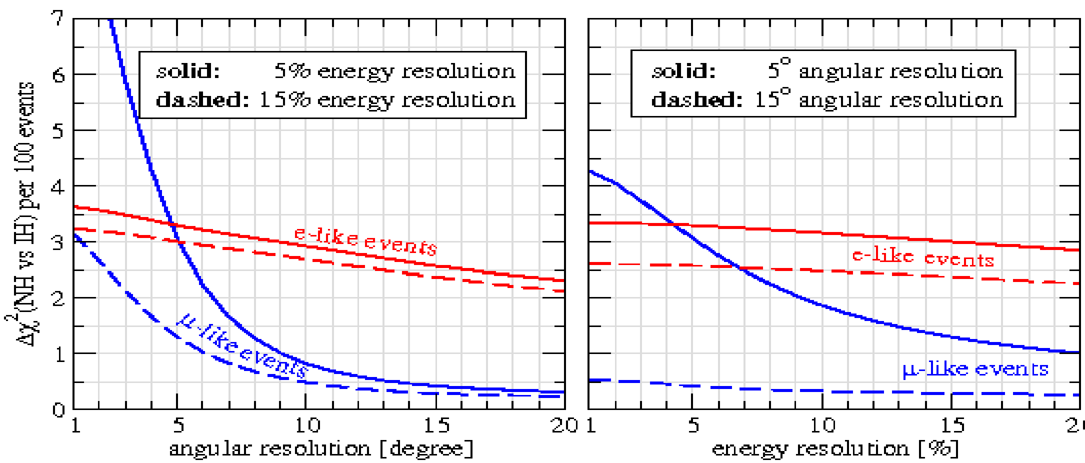
Gandhi et al. work in progress.

- The Importance of Detector Resolution



Petcov and Schwetz,hep-ph/0511277

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Gandhi et al. work in progress.

- Comparison with water-Cerenkov detector
  - No charge sensitivity: $N_\mu = N_\mu^+ + N_\mu^-$

$\sin^2 2\theta_{13}$	$\chi^2_{\rm min}$ (6 Mt yr)
0.05	1.9
0.1	4.4

Gandhi et al., hep-ph/0406145

INO as a Detector for VHE Cosmic Ray Muons

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- These studies would provide crucial data towards understanding the prompt contribution to VHE muon fluxes

The Pair Meter Technique

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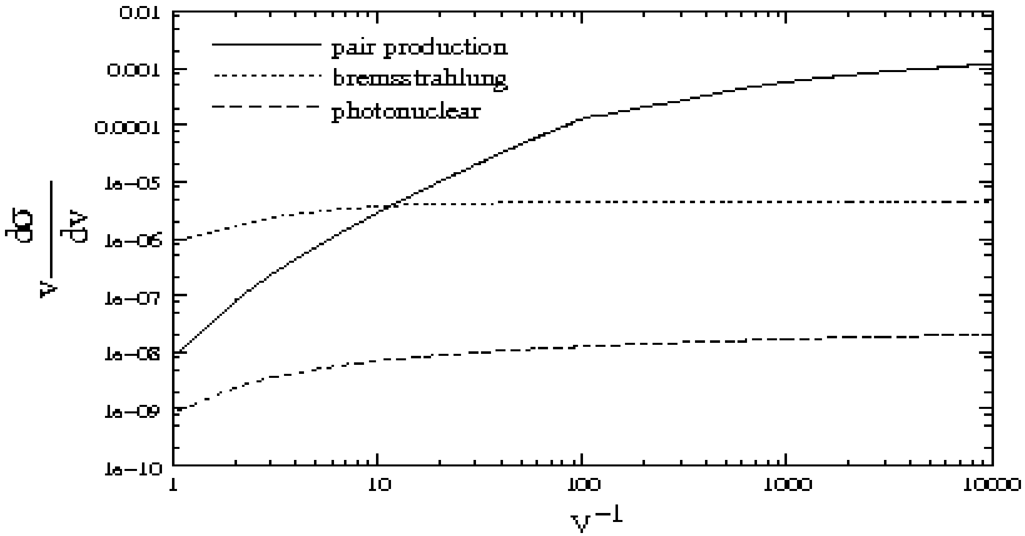
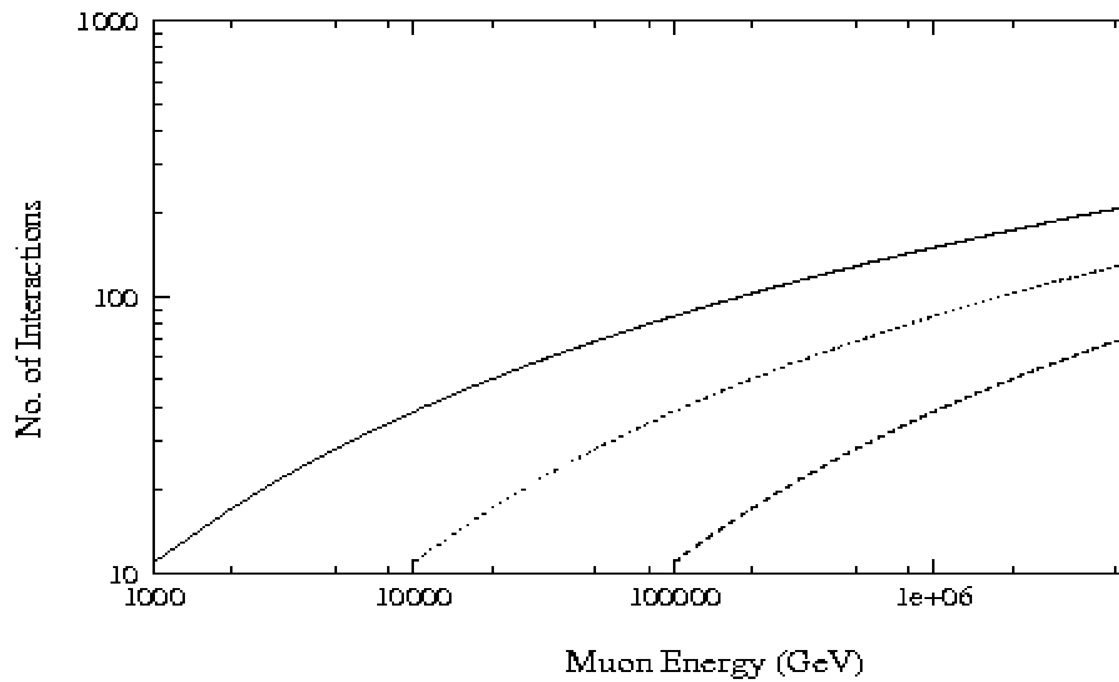
- The cross section for e^+e^- pair production by a muon with energy E_μ with energy transfer above a threshold E_0 grows as $ln^2(2m_eE_\mu/m_\mu E_0)$, where m_μ and m_e are the muon and electron masses respectively.

VHE Muon Detection in INO . . .



R. Gandhi and S. Panda , hep-ph/05



VHE muons entering INO in 5 years

	Number of muons per solid angle entering the detector in 5 years					
$E_\mu(TeV)$	conv+TIG	conv	TIG	PRS1	PRS2	PRS3
1	1.035×10^7	1.03×10^7	37461	55482	95489	136871
10	52486	51282	1204	2952	5341	10443
50	770	696	74	236	431	1104
100	127	106	21	73	134	387
200	22	16	6	22	40	129
300	8	5	3	11	19	66
400	4	2	2	6	11	41
500	2	1	1	4	7	28
600	1.5	1	.5	3	5	20
700	1	.5	.5	4	7.5	31
800	.8	.35	.5	1.5	3	12
900	.65	.25	.37	1.25	2.5	10
1000	.5	.2	.3	1	2	4
10000	.0025	.0003	.0022	.007	.013	.08

Table 2: Number of muons per solid angle entering the detector over 5 years fo
of the entering muon, E_μ.

R. Gandhi and S.Panda, hep-ph/0512179

Cascade production above various thresholds by VHE muons i

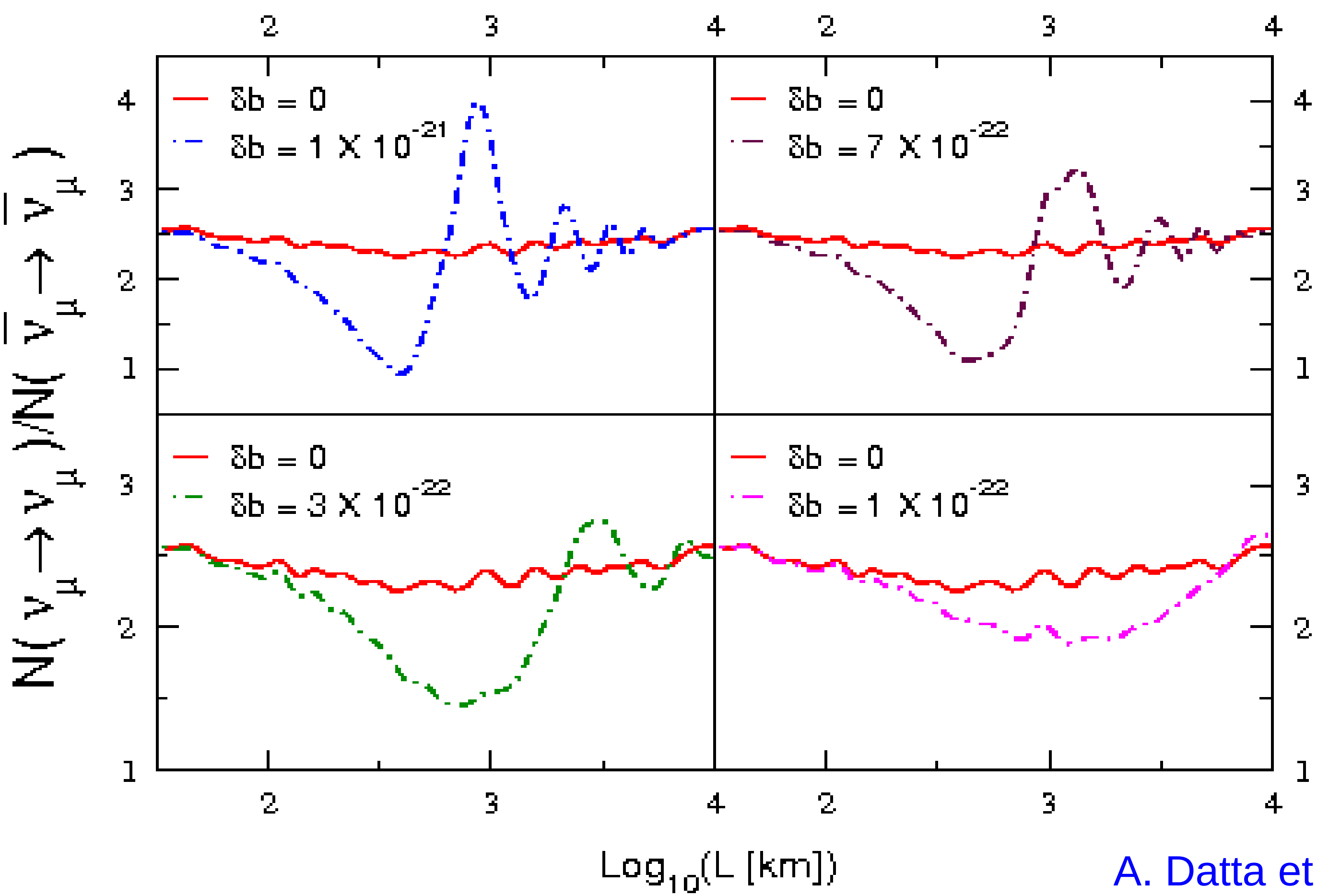
		Number of cascades per muon for different thresholds E_0 in GeV								
E_μ	E_μ^s	5	10	20	50	100	300	500	1000	5000
1	6.1	3.08	2.56	3.78						
10	40.26	17.28	10.99	6.43	3.08	2.56				
20	83.16	25.3	17.28	10.99	5.34	3.08				
50	205	38.58	28.26	19.67	10.99	6.43	2.78	2.56		
100	407.58	50.63	38.58	28.26	17.28	10.99	4.58	3.08	2.56	
200	813	64.43	50.63	38.58	25.30	17.28	8.11	5.34	3.08	
300	1218	73.3	58.49	45.42	30.8	21.76	10.99	7.46	4.19	
400	1624	79.96	64.43	50.63	35.06	25.3	13.39	9.33	5.34	
500	2029	85.33	69.24	54.89	38.58	28.26	15.45	10.99	6.43	2.56
600	2435	89.85	73.3	58.49	41.58	30.8	17.28	12.47	7.46	2.58
700	2841	93.76	76.83	61.64	44.21	33.05	18.91	13.82	8.43	2.6
800	3246	97.23	79.96	64.43	46.56	35.06	20.4	15.06	9.33	2.72
900	3652	100.33	82.77	66.95	48.69	36.9	21.76	16.21	10.18	2.89
1000	4057	103.16	85.33	69.24	50.63	38.58	23.02	17.28	10.99	3.08
10000	40554	174.84	151.24	129.38	103.16	85.33	60.63	50.63	38.58	17.28

Table 3: Number of cacades above thresholds $E_0 = 5, 10, 20, 50, 100, 300, 500, 1000, 5000$ GeV p muon. Here E_μ is the energy of the muon in TeV entering the detector, and E_μ^s is its correspondi energy in TeV at the surface of the earth, assuming it traversed a depth of rock corresponding $3.5 \times 10^5 gm/cm^2$.

R. Gandhi and S. Panda, hep-ph/0512179

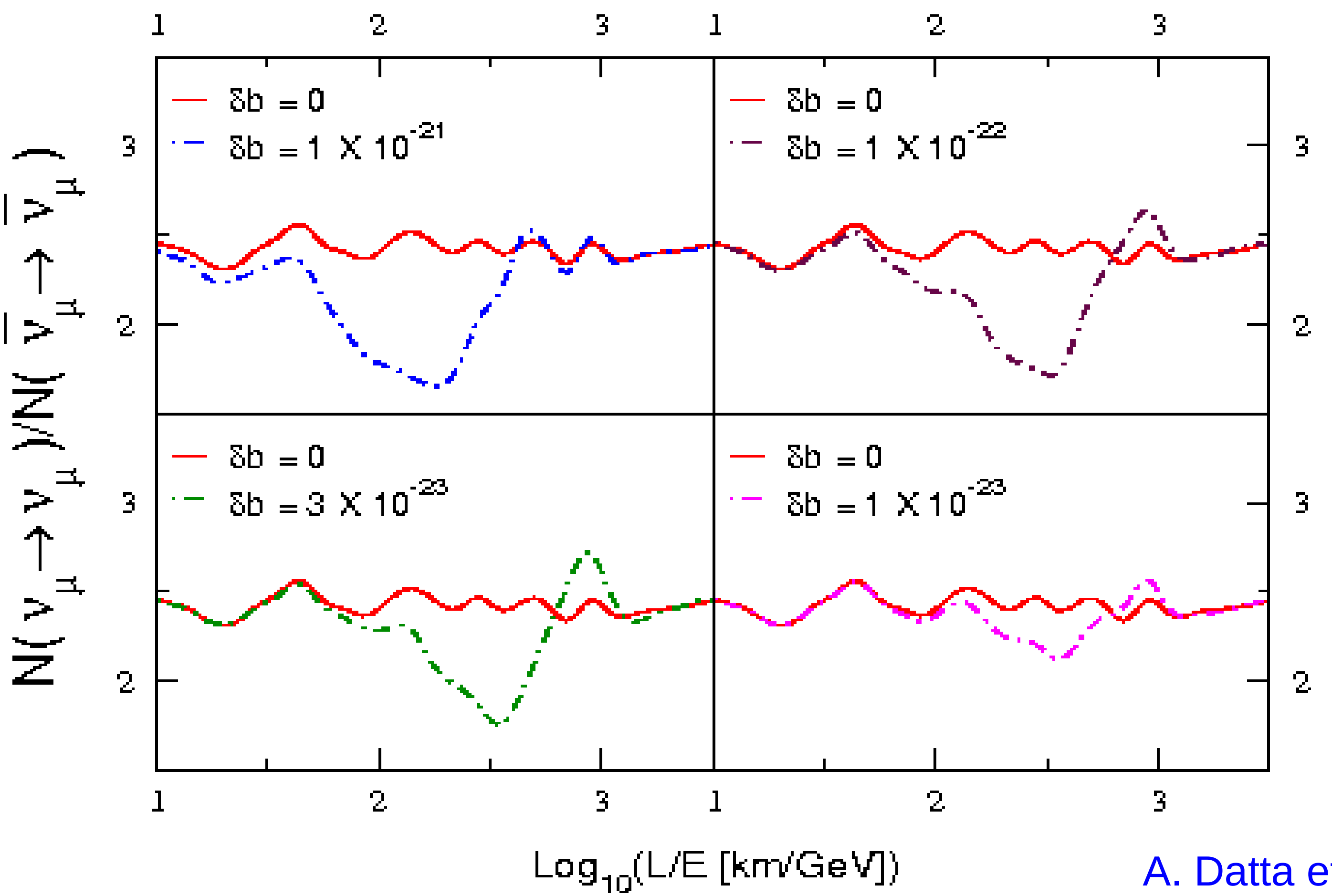
Bounds on CPT/Lorentz Violation

Sensitivity of Neutrino-Antineutrino Event Ratios to CPT.....



A. Datta et al, hep-ph/0408179

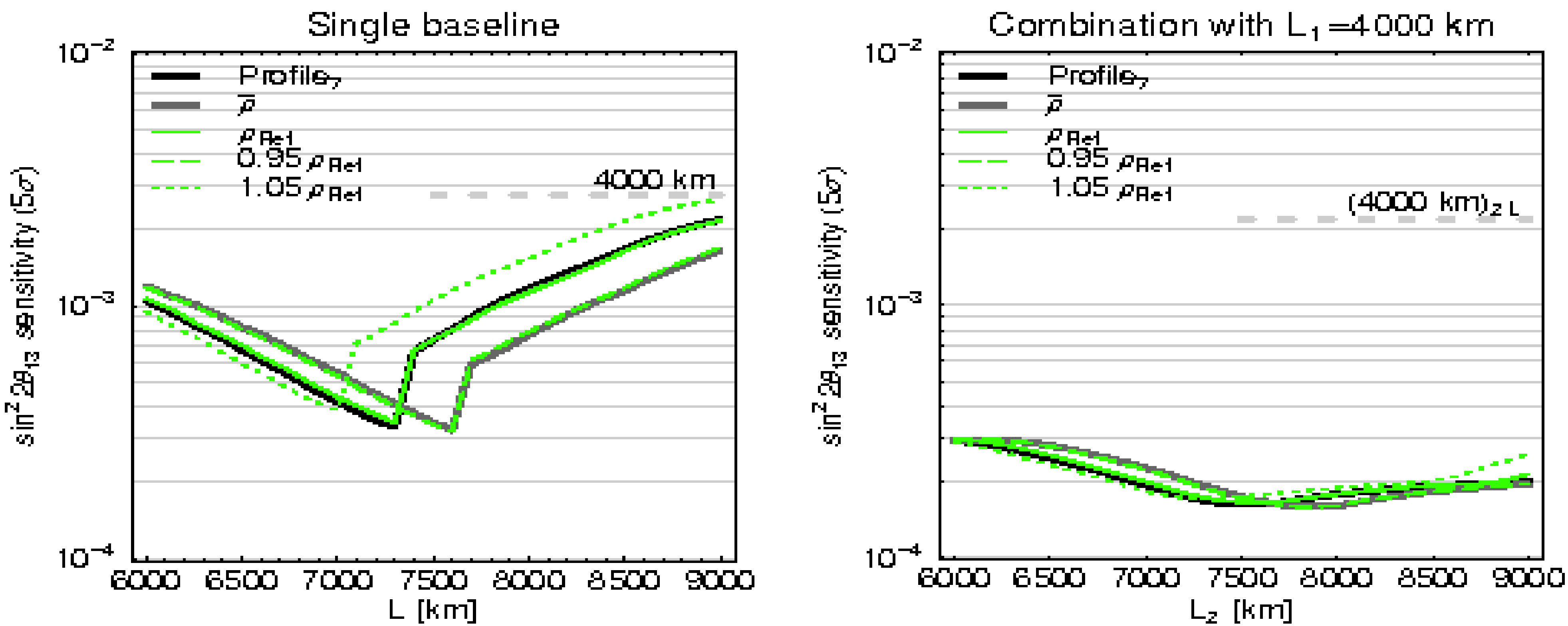
Sensitivity of Neutrino-Antineutrino Event Ratios to CPT.....



A. Datta et al, hep-ph/0408179

The Iron Calorimeter as an End- Detector for a Neutrino Factory

The Utility of a “Magic Baseline Detector”



R. Gandhi and W. Winter, work in progress

The Iron Calorimeter as an End- Detector for a Beta Beam

Physics from a Beta Beam . . .

- The proximity to the magic baseline distance leads again to physics uncluttered by CP degeneracies.
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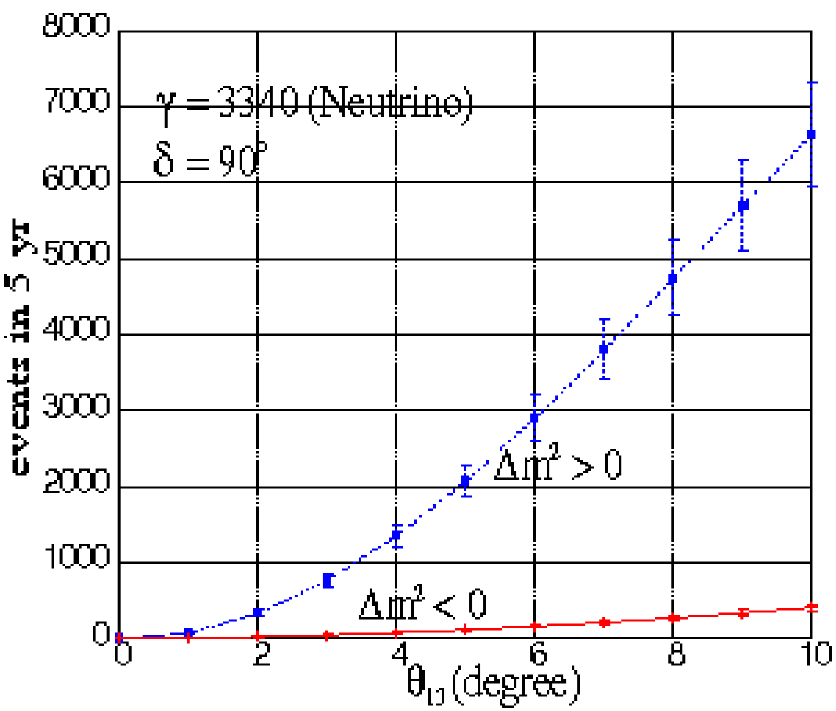
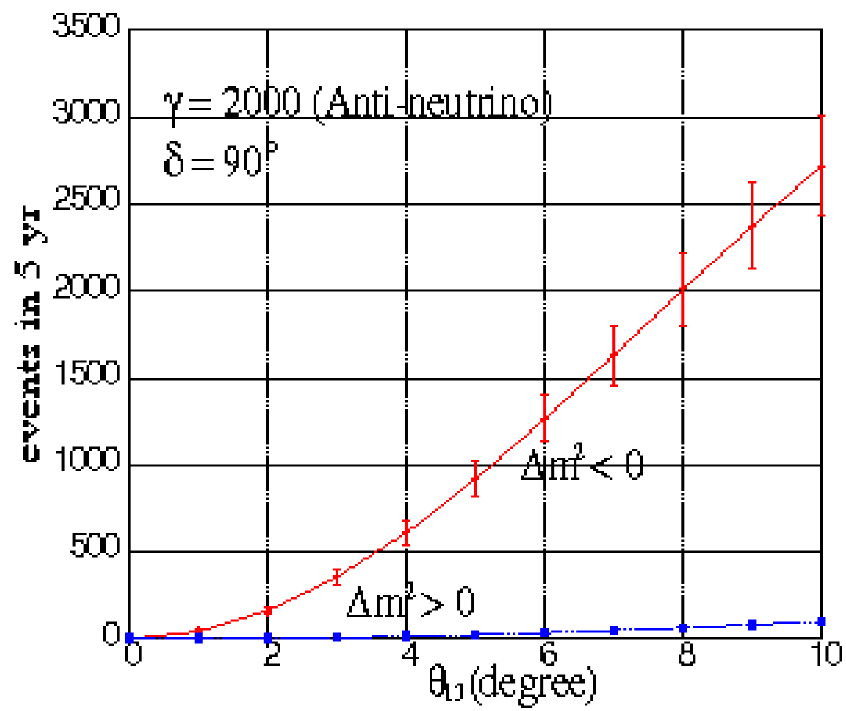
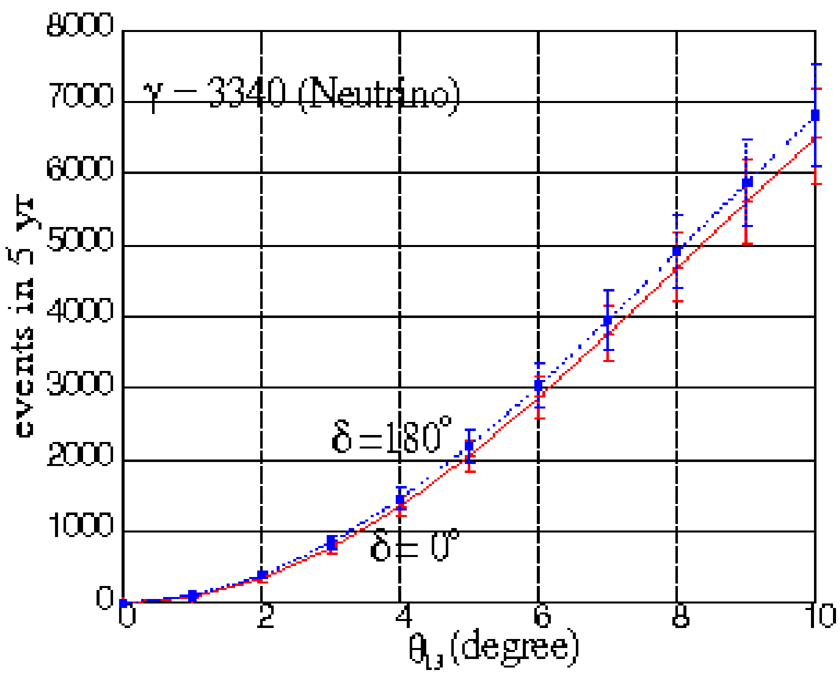
Beta Beam Results...

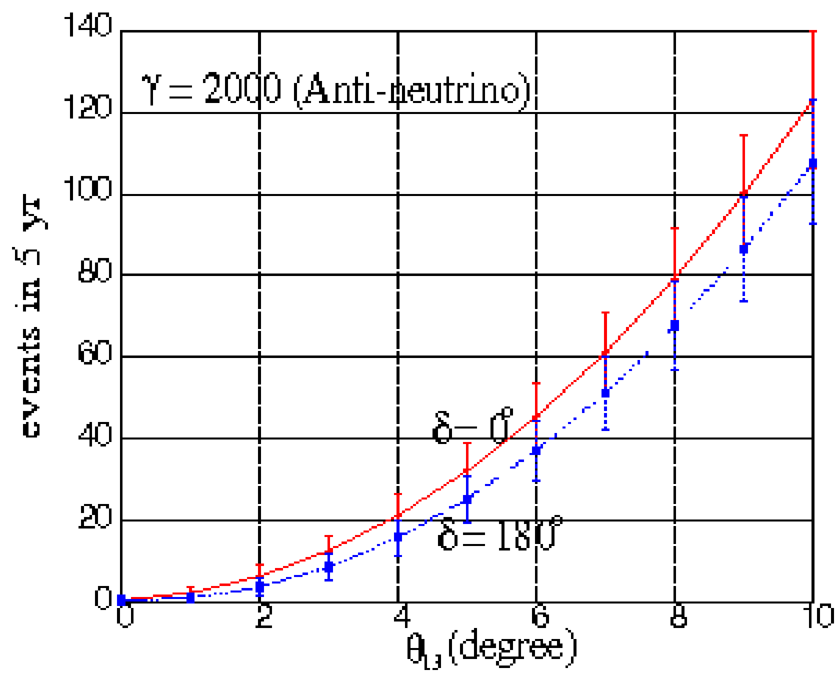




S. Agarwalla, A. Raychaudhuri and A. Samanta, hep-ph 0505015

Beta Beam results.....





S. Agarwalla, A. Raychaudhuri and A. Samanta, hep-ph 0505015

To Sum Up . . .

- INO, a 50-100 kT magnetized iron calorimeter would usefully buttress the presently planned program of neutrino experiments worldwide.
- Using atmospheric neutrinos, a 100 kT detector has the potential to illuminate one of the most important questions in neutrino physics, the mass hierarchy
- It would provide improved precision on atmospheric neutrino parameters,improved bounds on CPT/Lorentz violation,crucial data on VHE muons for the CR and PQCD communities and, in its second phase, be an excellent end detector for neutrino factories/beta beams.
- At present INO, after an intensive feasibility study, is close to a final funding decision.

Acknowledgements . . .

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