University of DELHI

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University of DELHI, India

24.06.2012, GGI, Arcetri, Firenze

What is ν? Invisible ITN 1st General Meeting

University of DELHI

- ✓ *Founded in 1922*
  - ➢ *with 3 Colleges and 750 Students*
- ✓ *Today it has*
  - ➢ *16 Faculties*
  - ➢ *88 Departments*
  - ➢ *77 colleges*
  - ➢ *~150K regular students &*
  - ➢ *~250K distant learning students*
- ➢ *Largest University in India*

Department of Physics & Astrophysics since 1923

- ✓ *At present we have ~55 Faculty members (out of ~80 that we should have)*
- ✓ *Teaching - M.Sc - Two year - Four Semester Course – ~300 students/batch*
- ✓ *PhD ~about 170 students*
- ✓ *Research in HEP, EHEP, Nuclear Physics, Material Sciences, Condensed Matter (including soft), Nano Materials, Atomic & Molecular Physics, Plasma Physics, Bio Physics, Astrophysics & Cosmology*
- ✓ *EHEP Collaborations at Fermilab since : 1985 – 93- E706, 1992 – 2012 - D0.*
- ✓ *CERN (CMS) – since late 1990's - continuing*
- ✓ *INO – since 2004 - continuing*
- ✓ *FNAL Neutrino Program – MIPP, MINOS/MINOS+, NOνA, LBNE – since 2010*

DELHI Node in invisibles

neutrinos, dark matter & dark energy physics

Brajesh Choudhary

Debajyoti Choudhury

Poonam Mehta

In EHEP since 1987 –
E706 – Direct Photon production
D0 – EW, Top, Higgs
Neutrinos – MACRO, MINOS
CMS – QCD, Exotica
Neutrinos at FNAL - MINOS+, NOνA,
LBNE – Lead India-US ν Collaboration
Neutrinos in India - INO

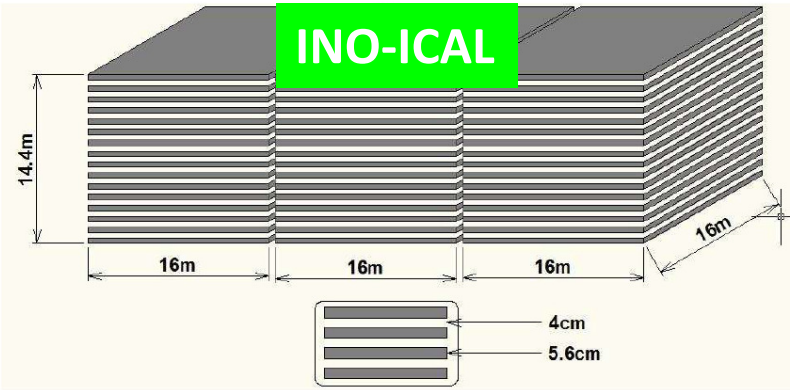
In HEP Theory since 1987 –
QFTs, Collider Theory & Phenomenology, B-Physics,
Neutrinos Theory & Phenomenology,
Cosmology
Dark Matter
Neutrinos in India - INO

In HEP Theory since 2000 –
Neutrino Oscillation – Theory & Phenomenology
BSM Topics – CPT violation, Neutrino Decay, Quantum Decoherence
Cosmo-Particle Physics - ν MH from Cosmology

Neutrino and Dark Matter - Interests

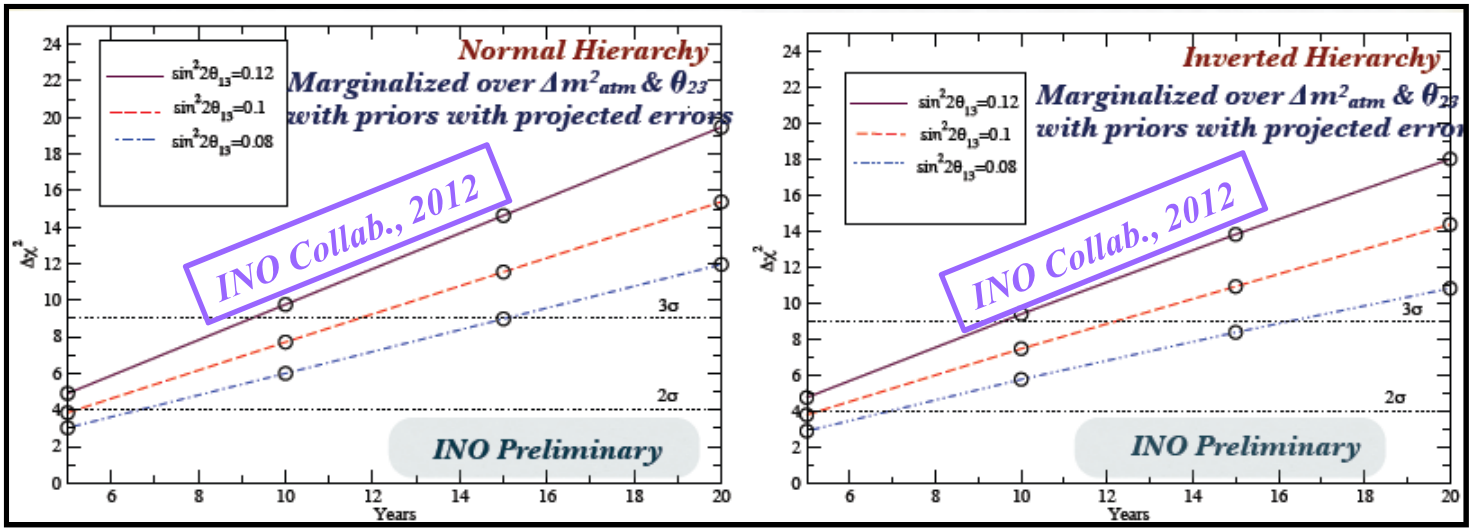
- *Neutrino Experiments – Neutrino Mass and Mixing*
  - *INO-ICAL*
  - *FNAL Neutrino Program – MIPP, MINOS/MINOS+, NOνA, LBNE*
- *Neutrino Phenomenology : New Physics effects in*
  - *Atmospheric Neutrinos*
  - *Long-baseline Neutrino Experiments*
  - *High Energy Astrophysical Neutrinos*
- *Leptogenesis*
- *Collider signature of Dark Matter*
- *Neutrino Mass Hierarchy from Cosmology*
- *+++ others……*

Experimental Neutrino Program at DU – INO-ICAL



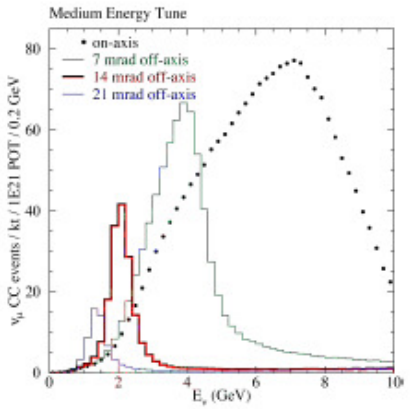
- *50kT magnetized (1.3T) Fe-RPC Calorimeter*
- *Atmospheric neutrino experiment*
- *Charge separation of μ+ and μ-*
- *Physics – Measure Mass hierarchy*
- *Octant Degeneracy*

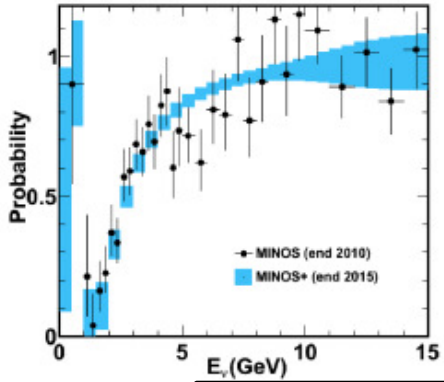
Mass Hierarchy with INO-ICAL



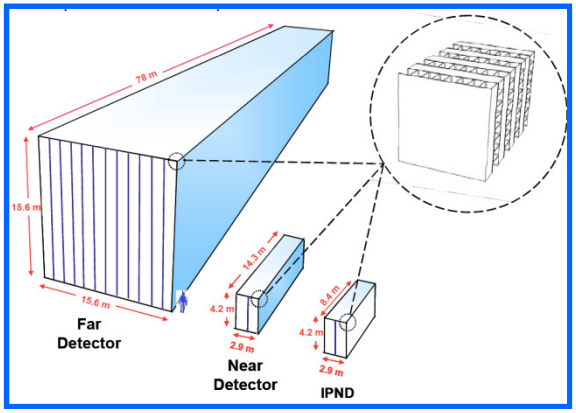
~2σ sensitivity for $\sin^2\theta_{23} = 0.5$, $\sin^2 2\theta_{13} = 0.1$ by 2022 (5 yrs)
~2.7σ sensitivity for $\sin^2\theta_{23} = 0.5$, $\sin^2 2\theta_{13} = 0.1$ by 2027 (10 yrs)

FNAL - Experimental Neutrino Program at DU





India-FNAL ν collaboration
8 Institutions
20+ Students
10+ Faculty



MINOS+ - Improved measurement of $|\Delta m^2_{23}|$, θ_{23}, $|\overline{\Delta} m^2_{23}|$, $\overline{\theta}23$, sterile ν's, tau ν's, high energy ν's, NSI, Search for ED
NOνA - Very precise measurement of $|\Delta m^2_{23}|$, θ_{23}, θ_{13}, MH, CPV, Octant Degeneracy
LBNE - θ_{13}, MH, CPV
Proton Decay, Atmospheric, Solar, Supernova, Relic & HE ν's etc.

- ***15kT LAr – underground at Soudan ↓↓***
- ***30kT LAr – on surface at Ash River ↓↓***
- ***10kT LAr – on surface at Homestake ↑↑***

CPT Violation using Atmospheric Neutrinos

- ***Atmospheric neutrinos and CPT violation***

$$L_{eff} = \bar{\nu}_L^{\alpha} b_{\alpha\beta}^{\mu} \gamma_{\mu} \nu_L^{\beta}$$

Colladay & Kostelecky – arXiv: hep-ph/9809521v1

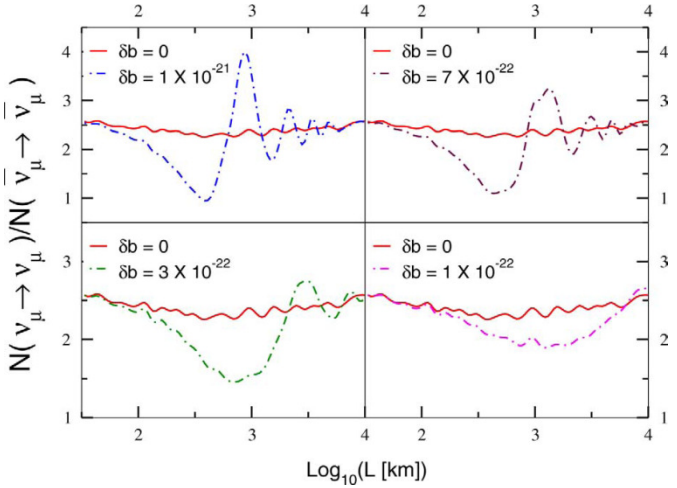
- ***Two-flavor muon survival probability***

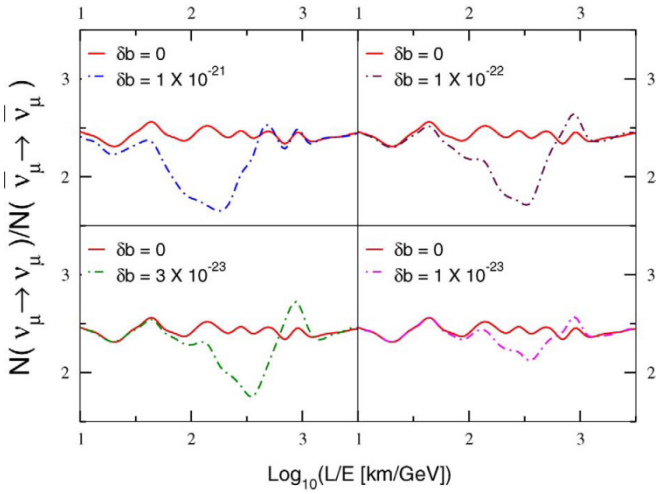
$$P_{\alpha\alpha}(L) = 1 - \sin^2 2\theta \sin^2\left[\left(\frac{\delta m^2}{4E} + \frac{\delta b}{2}\right)L\right]$$

E-independent part

$$\Delta P_{\alpha\alpha}^{\mathrm{CPT}} = -\sin^2 2\theta \sin\left(\frac{\delta m^2 L}{2E}\right) \sin(\delta b L).$$

- ***Observable: a muon to anti-muon events in a magnetized detector that can identify charge (ex: INO-ICAL)***
- ***Sensitivity – studied in context of INO – with 400kT-yr - similar to neutrino factory***



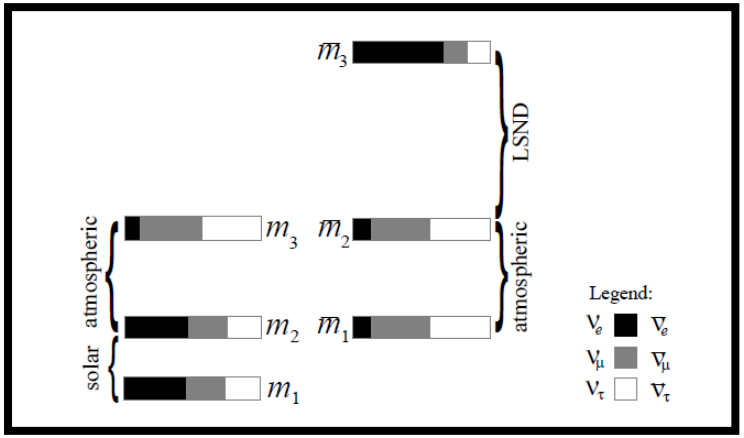


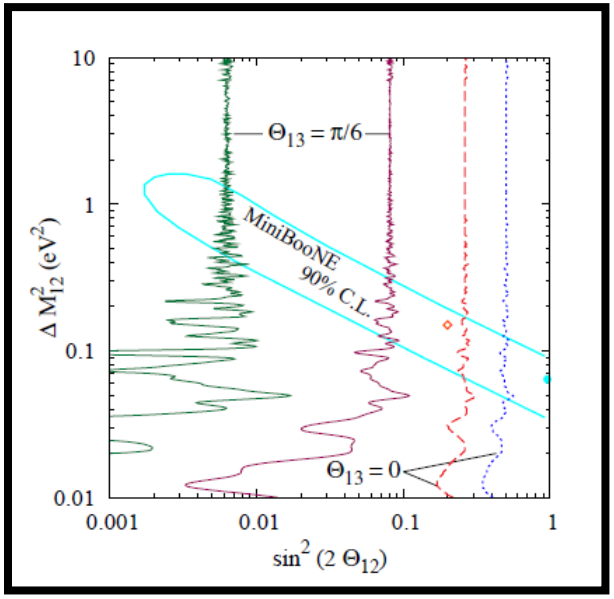
A. Dutta, R. Gandhi, **P. Mehta,** S. Uma Sankar **– PLB 597 (2004) 356**

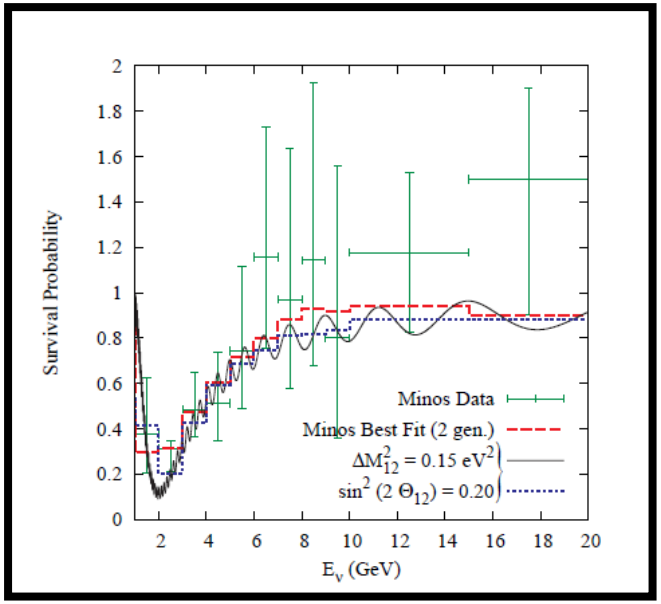
CPT Violation with MINOS + MiniBoonE

H. Murayama, T. Yanagida PLB 520 (2001)
Barenboim et al. JHEP 0210 (2001)

- *MINOS $\bar{\nu}_\mu$ disappearance & Mini-BoonE $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ results*
- *Can be reconciled by using different mass parameters for ν_μ and $\bar{\nu}_\mu$ → CPT violation*







D. Choudhary, A. Datta, A. Kundu - **arXiv:1007.2923**

Since then MINOS ν_μ & $\bar{\nu}_\mu$ difference has been resolved

NSI Effects during Propagation

$$\mathcal{L}_{NSI} = -2\sqrt{2}G_F\epsilon^{ff'C}_{\alpha\beta}(\bar{\nu}_\alpha\gamma^\mu P_L\nu_\beta)(\bar{f}\gamma_\mu P_C f')$$

$$P_L = 1-\gamma_5 \quad P_C = 1\pm\gamma_5$$

- *Flavor "preserving" or "violating" terms, f=f' for ν's*
- *NSI in 3-flavor context in the e-τ sector for atmospheric and LBL neutrinos*

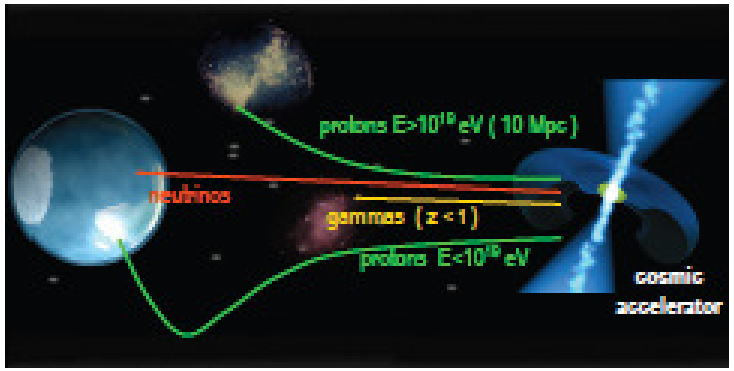
$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \frac{1}{2E}\left(U\begin{pmatrix}0 & 0 & 0\\ 0 & \delta m^2 & 0\\ 0 & 0 & \delta m^2_{31}\end{pmatrix}U^\dagger + A\begin{pmatrix}1+\epsilon_{ee} & 0 & \epsilon_{e\tau}\\ 0 & \epsilon_{\mu\mu} & 0\\ \epsilon^\star_{e\tau} & 0 & \epsilon_{\tau\tau}\end{pmatrix}\right)\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

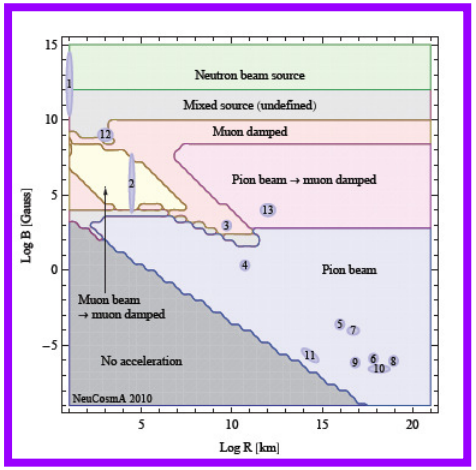
S.Davidson, C.Pena-Garay and N.Rius, **JHEP 0303:011,2003**

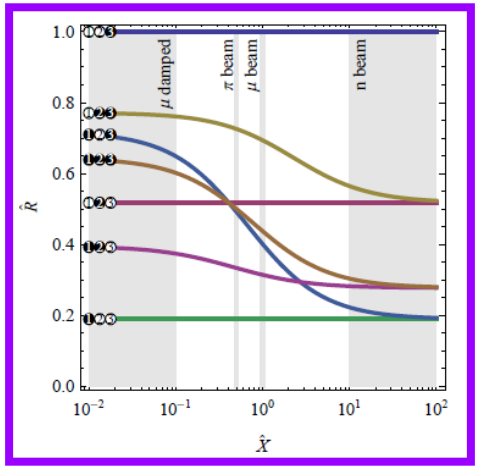
- *ν_μ interactions are strongly constrained*
- *With high precision on oscillation parameters – try to constrain NSI parameter effects*

DURHAM + DELHI+ HRI

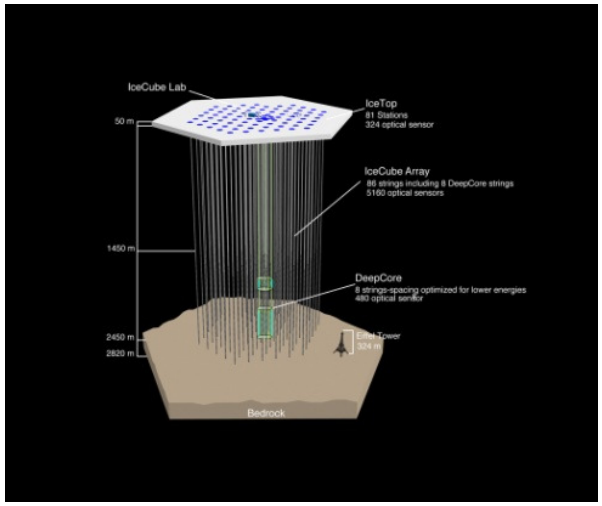
HE Astrophysical Neutrinos & New Physics Effect







- *Cosmic accelerator*
- *E and L beyond terrestrial experiments*
- *With Ice-cube like experiments allows for precise tests of new physics*
- *Flavor ratio of muon tracks to cascade carries imprint of new physics scenarios such as decay and decoherence in propagation from energy dependent source flavor ratios*
- *Scan parameter space on new physics*



P. Mehta and W. Winter
JCAP03 (2011) 041

Radiative Leptogenesis at the TeV scale

- ***Electromagnetic (radiative) leptogenesis: An idea with explicit models proceeding via the radiative decay of heavy RH ν into a light LH ν and a γ***

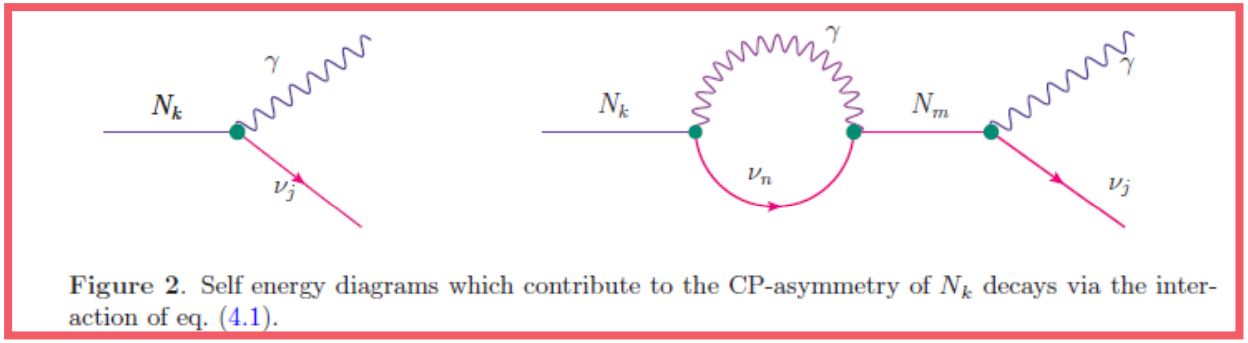


Figure 2. Self energy diagrams which contribute to the CP-asymmetry of N_k decays via the interaction of eq. (4.1).

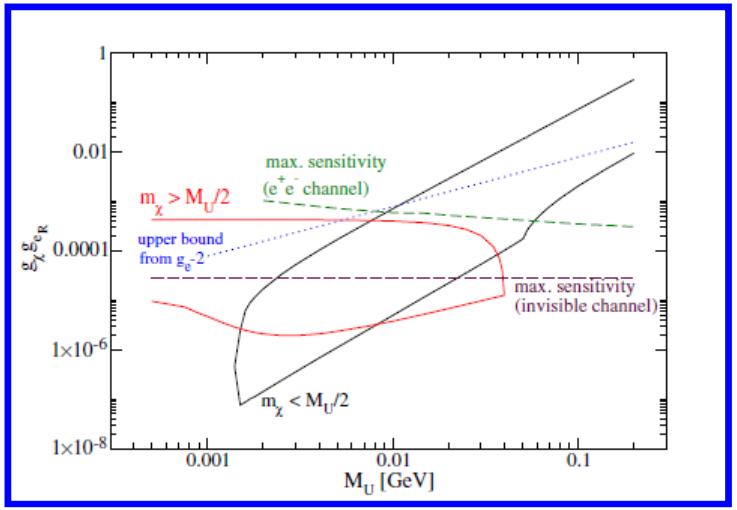
D. Choudhury, N. Mahajan, S. Patra & U. Sarkar - **JCAP04 (2012) 017**

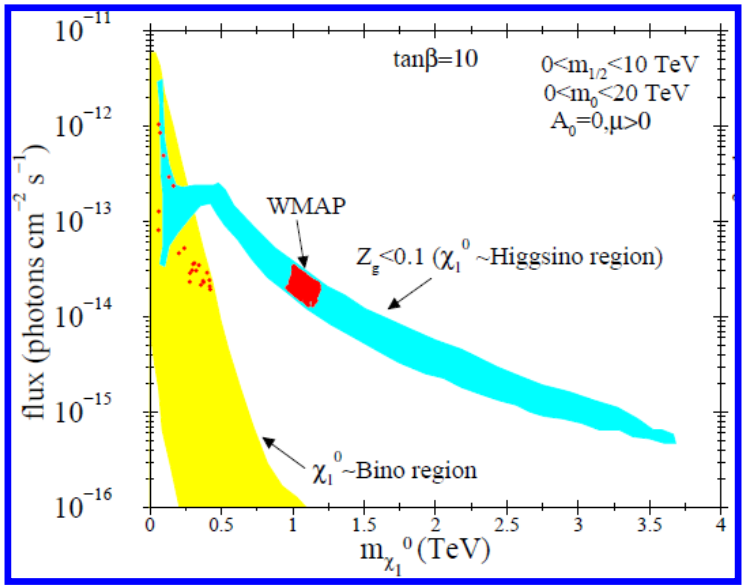
- ***Generates correct leptogenesis with resonant enhancement & required neutrino mass - via TeV scale seesaw mechanism***
- ***Consistent with low energy phenomenology***
- ***Signatures at future colliders or even at LHC***

Collider Signatures of Dark Matter

N. Borodatchenkova, **D. Choudhrury** & M. Drees – PRL 96, 141802 (2006)

- ***INTEGRAL saw an excess of 511 keV photons from center of our galaxy:***
  - ***MeV dark matter particles can annihilate into e+e- pairs***
  - ***Signals in B-factories and DAφNE***
- ***Search for heavy Higgsino LSP in collider and dark matter experiments***

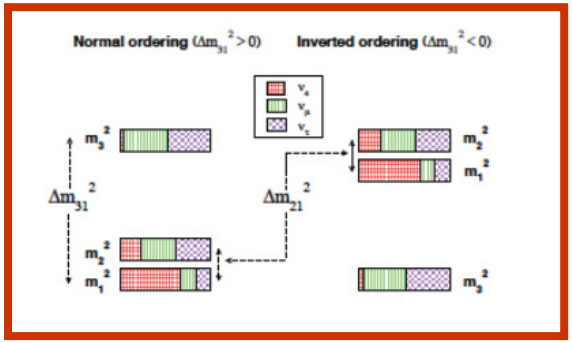


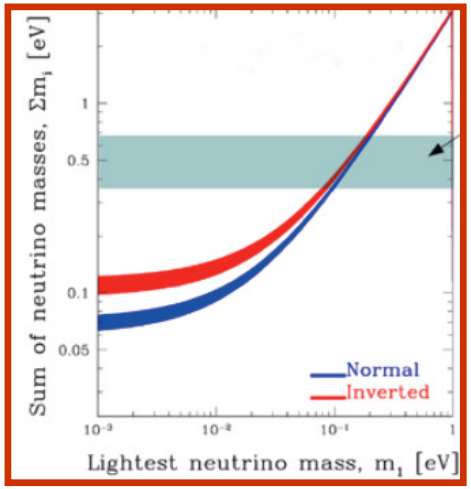


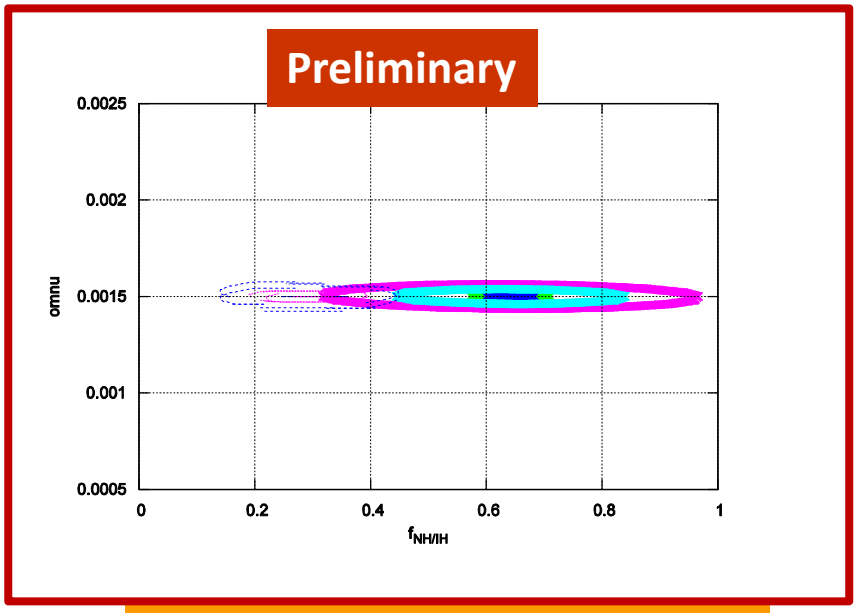
U. Chattopadhyay, **D. Choudhrury,** M. Drees, P. Konar & D. P. Roy **PLB 632, 114 (2006)**

Neutrino Mass Hierarchy – via Cosmology

- ***Complementary approach***
  - ✓ $\Omega_\nu h^2 = \sum m_\nu / 94\ eV$
- ***Lab limits:***
  - ✓ $Min \sum m_\nu \sim 0.05\ eV$
    $\rightarrow$ $min\ \Omega_\nu \sim 0.1\%$
  - ✓ $Max \sum m_\nu \sim 7.0\ eV$
    $\rightarrow$ $min\ \Omega_\nu \sim 12\%$
- ***Future***
  - ✓ ***PLANK + LSST***
- ***Model-dependent***







P. Mehta and S. K. Sethi **in preparation**

AND Other Studies

Looking forward to collaborate within "Invisibles"

THANK YOU