Theory Xmas Workshop

Bari, 23/12/13

Constraints on very light sterile νs from reactor experiments

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Outline

The standard 3ν framework

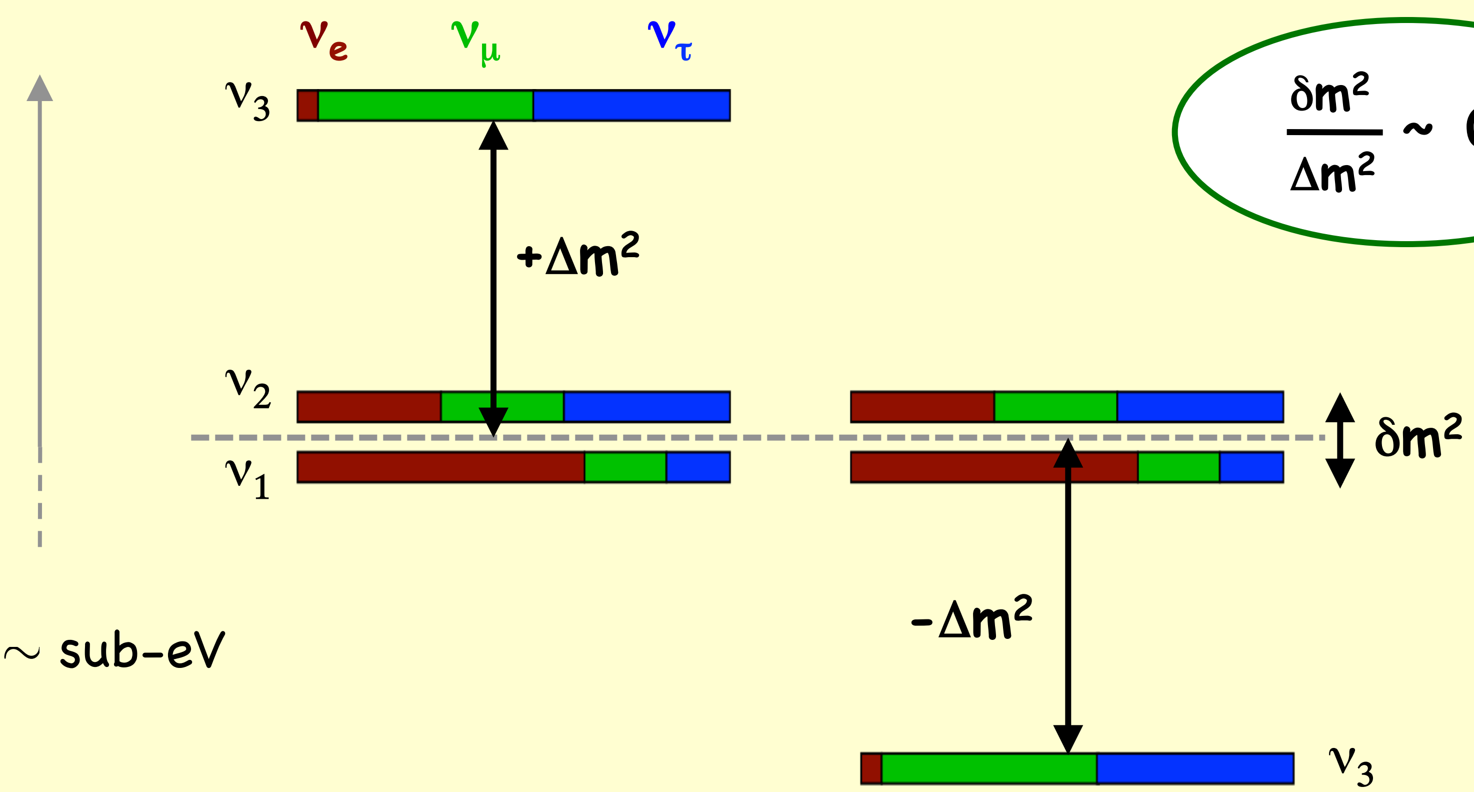
Beyond three neutrino families

Constraints on very light sterile neutrinos

Conclusions

The 3ν mass spectrum

NH or IH ?



$$\frac{\delta m^2}{\Delta m^2} \sim 0.03$$

$\sum m_i \sim$ sub-eV

The 3ν mixing matrix

$$|\nu_\alpha\rangle = \sum_{i=1}^{3} U^*_{\alpha i}|\nu_i\rangle$$

$$U = O_{23}\Gamma_\delta O_{13}\Gamma^\dagger_\delta O_{12}$$

$$\Gamma_\delta = \mathrm{diag}(1, 1, e^{+i\delta})$$

$$\delta \in [0, 2\pi]$$

Dirac CP-violating phase δ

U is non-real if δ ≠ (0, π)

Explicit form

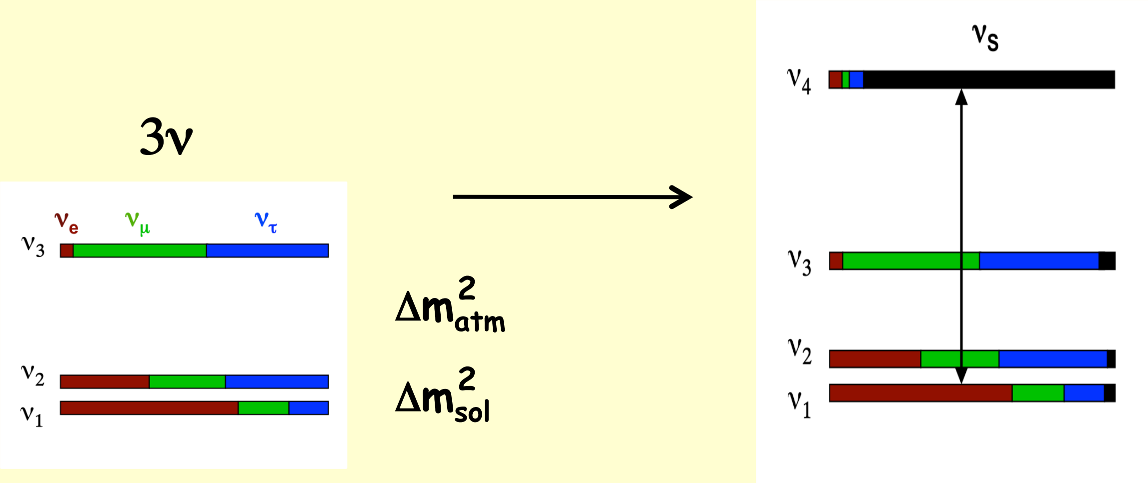
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\theta_{23} \sim 41°$ $\theta_{13} \sim 9°$ $\theta_{12} \sim 34°$

Weak preference (< 2σ) for δ ∈ [π, 2π] (i.e., sinδ < 0)

Beyond three neutrino families

Introducing a very light sterile neutrino (VLSν)



3ν

4ν

Δm^2_{atm}

Δm^2_{sol}

$|U_{s4}| \sim 1$

$\Delta m^2_{14} \in [10^{-3}, 10^{-1}]$ eV^2

Small mixing of active flavors with the 4th state

I will focus on the electron neutrino mixing U_{e4}

Motivations for investigating VLSνs

In the recent years most of the attention attracted by "heavier" sterile neutrinos (mass ~ 1 eV) because of a few anomalies recorded at very short baseline experiments.

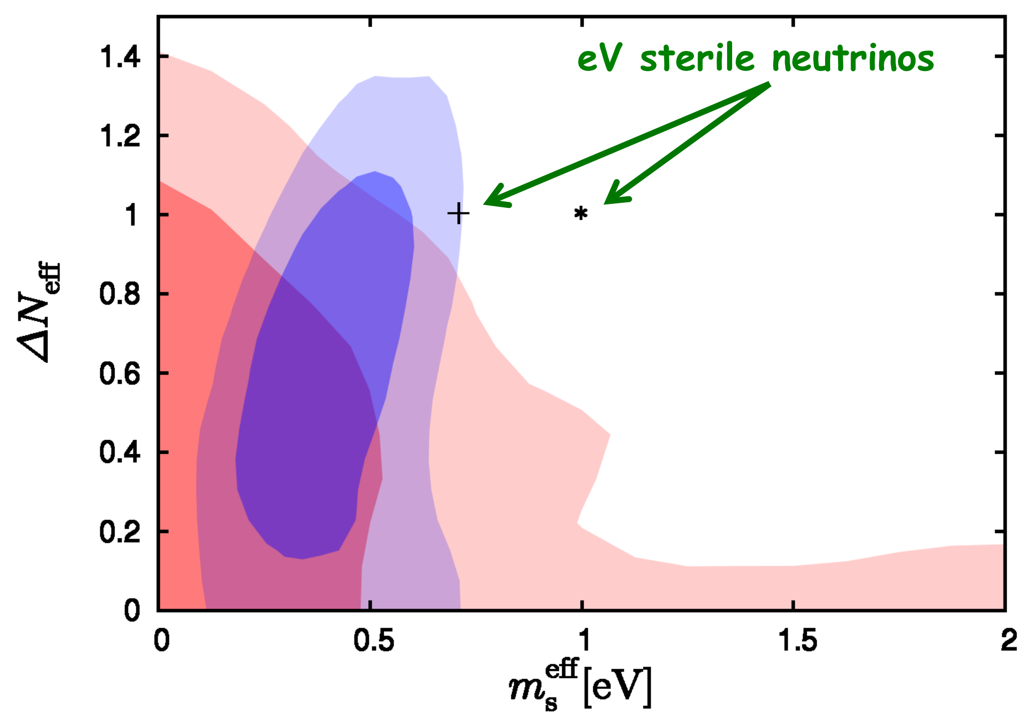
However, the latest cosmological data present features which cannot be explained by a new particle with mass of ~ 1 eV. Differently, particles with a smaller mass can explain them.

Theory does not provide solid information on ν_s mass-mixing. These parameters should be investigated without prejudice.

For the first time new reactor experiments, born for other purposes (to measure θ_{13}) allow us to probe small values of Δm^2_{14} opening a new window in the search of sterile neutrinos.

New trends in cosmological data

ΔN_{eff} ~ 0.6



m_ν ~ 0.4 eV

Haman and Hasenkamp [1308.3255 astro-ph]

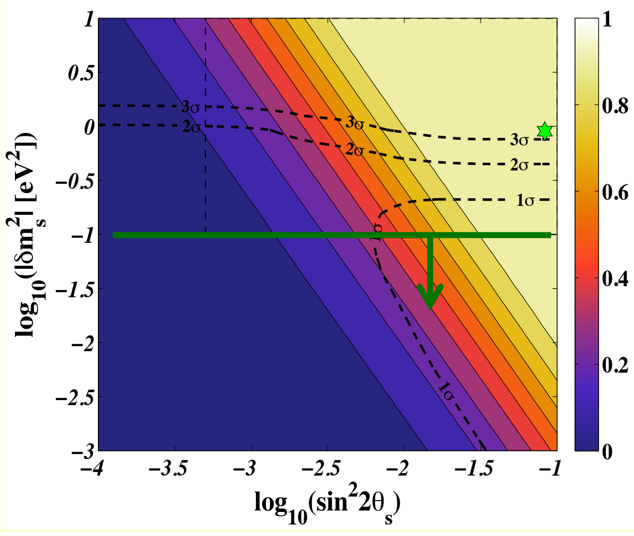
Similar findings in: Wyman et al. [1307.7715 hep-ph]
Giunti et al. [1309.3192 astro-ph]

A VLSν provides both features

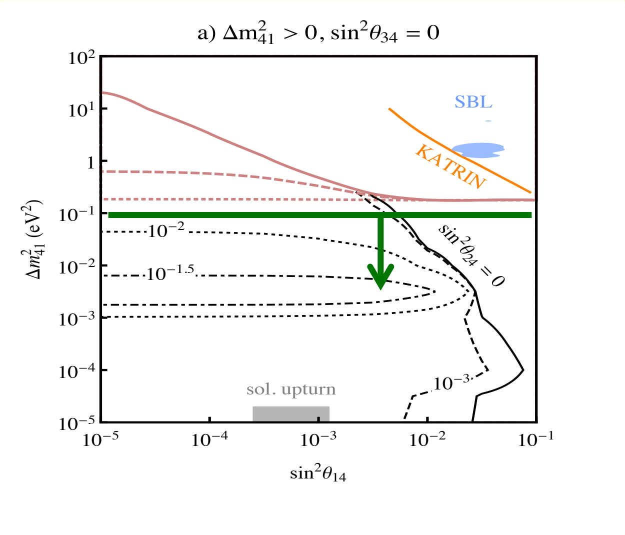
1) Contribution to the absolute ν mass in the sub-eV range

2) Only partial thermalization is expected to occur:

$0<\Delta N_{eff}<1$ for $\Delta m^2_{14} \in [10^{-3}, 10^{-1}]$ eV^2 and $U^2_{e4}<10^{-2}$



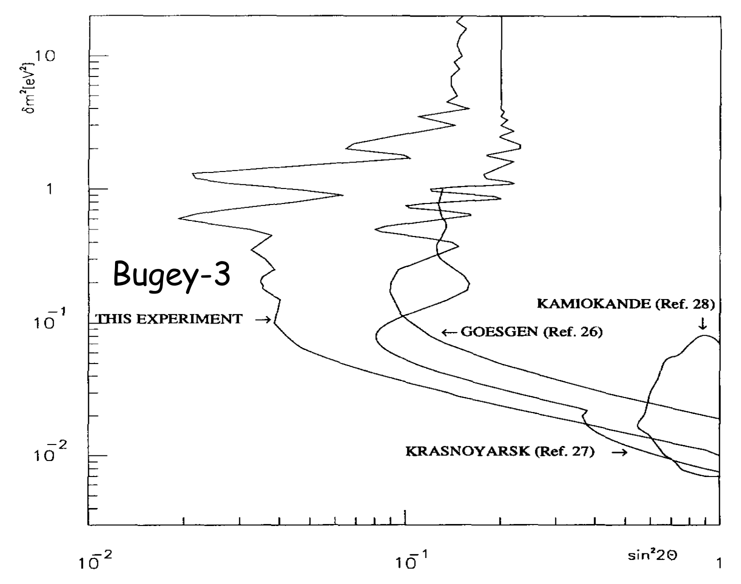
Hannestad, Tamborra, Tram
JCAP 1207 (2012) 025



Mirizzi et al.
Phys. Lett. B 726 (2013) 8

Constraining VLSνs with reactor experiments

Reactor experiments are sensitive to the mixing of the electron (anti-)neutrino with the sterile species ($|U_{e4}|^2 = \sin^2\theta_{14}$)



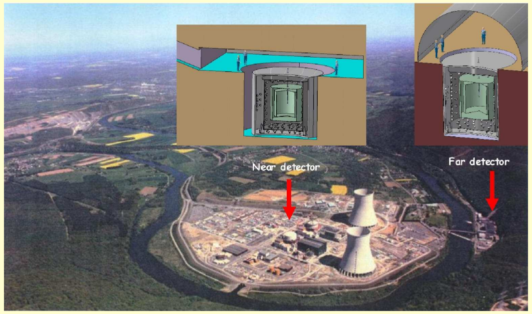
Non zero θ_{14} induces a "leakage" of $\overline{\nu}_e$'s

Existing constraints limited to Δm^2_{14} > few x 10^{-2} eV^2 due to baselines' limitations ($L < 100$ m)

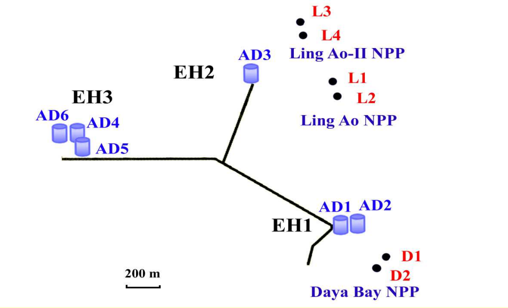
New experiments with longer baselines are now operating and make it possible to probe smaller values of Δm^2_{14}

θ_{13}-dedicated reactor experiments

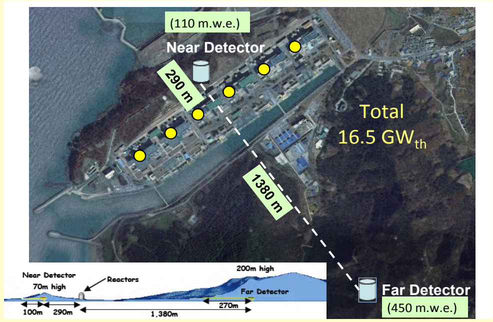
Double CHOOZ



Daya Bay



RENO



Observed far/near deficit implies θ_{13} is different from zero

$$P_{ee} \simeq 1 - 4|U_{e3}|^2\left(1 - |U_{e3}|^2\right)\sin^2\frac{\Delta m_{13}^2 L}{4E}$$

$$4|U_{e3}|^2\left(1 - |U_{e3}|^2\right) \equiv \sin^2 2\theta_{13}$$

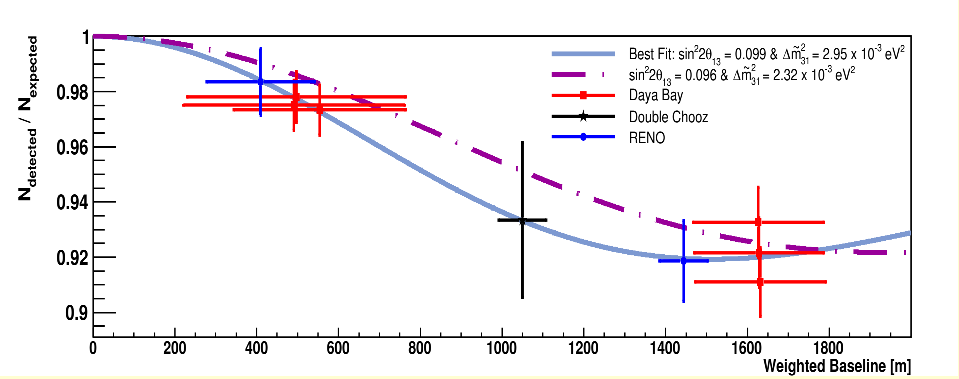


Figure from Bezerra et al., Phys Lett. B 725 (2013) 271

4ν formulae valid at θ_{13}-experiments

Neglecting terms $\propto |U_{e3}|^2 |U_{e4}|^2$ or $\propto \Delta m^2_{sol}$ we have

$$P_{ee} \simeq 1 - \sin^2 2\theta_{13} \sin^2 \left(\frac{\Delta m^2_{13} L}{4E_\nu} \right) - \sin^2 2\theta_{14} \sin^2 \left(\frac{\Delta m^2_{14} L}{4E_\nu} \right) .$$

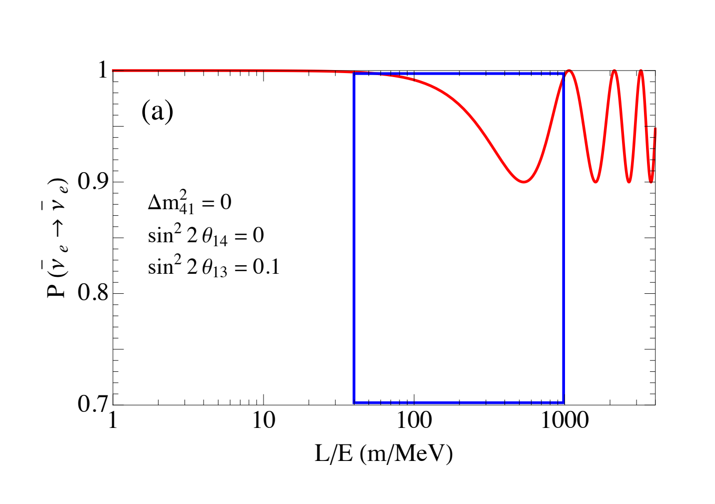
where

$$\frac{\Delta m^2_{14} L}{4E_\nu} \simeq 1.267 \left(\frac{\Delta m^2_{14}}{10^{-2}\ \mathrm{eV}^2} \right) \left(\frac{L}{400\ \mathrm{m}} \right) \left(\frac{4\ \mathrm{MeV}}{E_\nu} \right) .$$

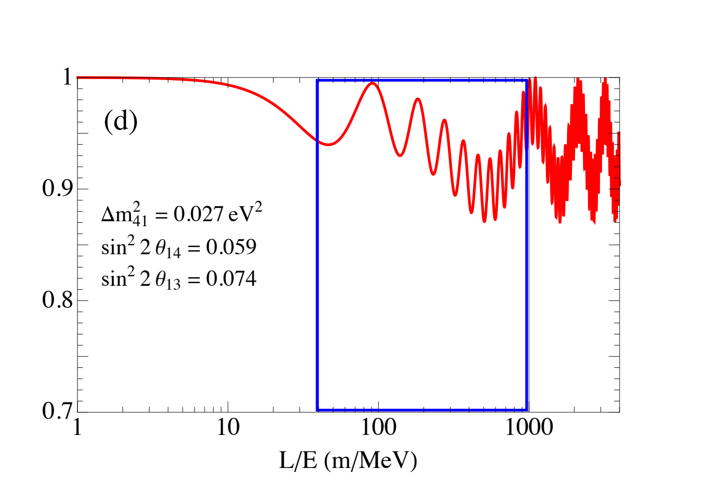
Sizable effects expected both at
near (few hundreds m) and far (1-2 km) detectors

Numerical examples

3ν: ($\theta_{13} \neq 0$, $\theta_{14} = 0$)



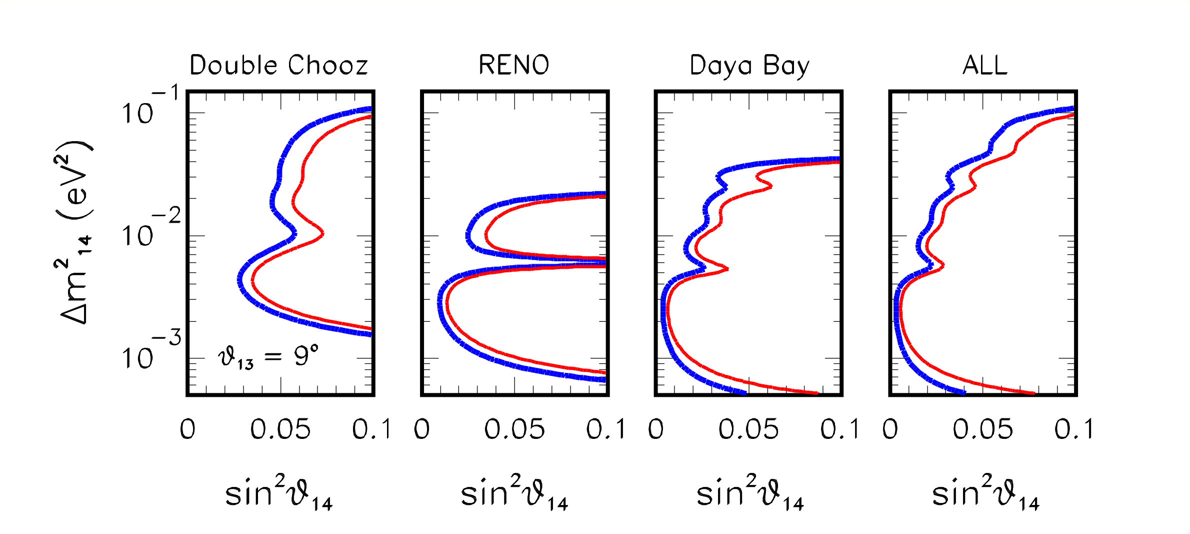
4ν: ($\theta_{13} \neq 0$, $\theta_{14} \neq 0$)



Figures from Esmaili et al., Phys. Rev. D 88, 073012 (2013)

Far/near ratios are expected to provide information on VLSνs

4-flavor analysis performed at fixed θ_{13}



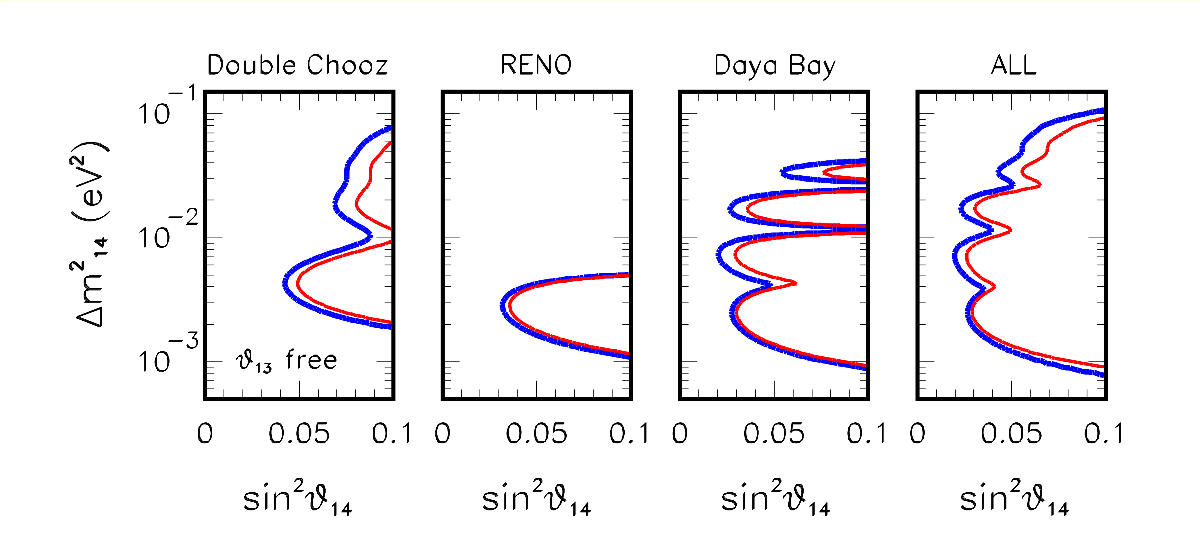
A.P. JHEP 1310 (2013) 172

All the three experiments exclude a lobe around the atm. splitting (far site sees the oscillating phase, at near site negligible effects)

All the three experiments exclude a second lobe around 10^{-2} eV^2 (at far site oscillations averaged, near site sees oscillating phase)

D-Chooz used Bugey-4 (15 m) as an anchor, limits up to 10^{-1} eV^2

4-flavor analysis performed for free θ_{13}



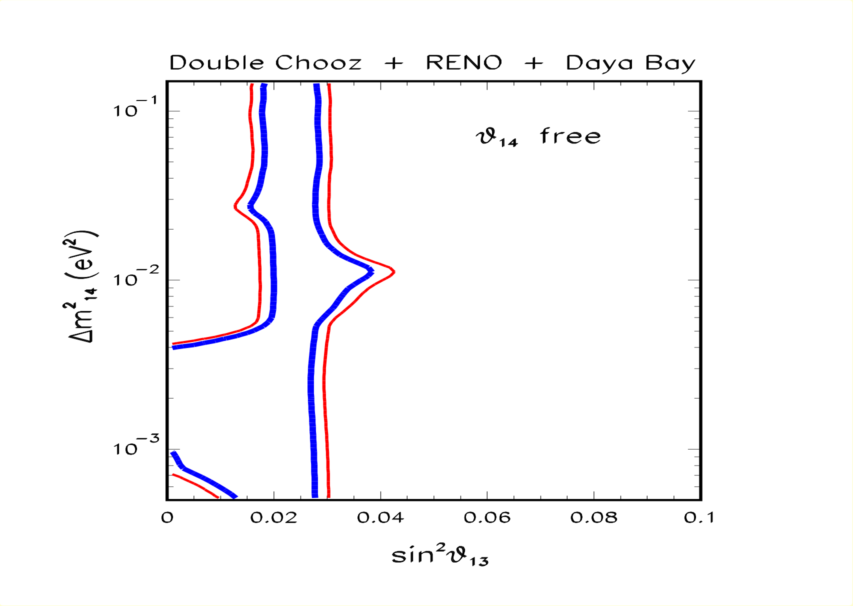
A.P. JHEP 1310 (2013) 172

General degradation of sensitivity in each of the three experiments

Entire lobes disappear due to strong degeneracies among θ_{13} and θ_{14}

Noticeable synergy in the global combination

Estimate of θ_{13} in a 4-flavor framework



A.P. JHEP 1310 (2013) 172

Standard 3ν estimate is robust provided that $\Delta m^2_{14} > 6 \times 10^{-3}$ eV^2

No lower bound for smaller Δm^2_{14} due to degeneracy of θ_{13} and θ_{14}

However, in this region lower bound by T2K (4ν effects negligible)

Conclusions

The 3ν scheme may not constitute the ultimate description of the ν oscillatory phenomena. Sterile νs may alter the standard picture

Very light sterile neutrinos with $\Delta m^2 \sim [10^{-3}, 10^{-1}]$ eV^2 offer an option for cosmo hints (dark radiation and hot-dark-matter)

First constraints on VLSνs obtained with θ_{13}-dedicated experiments

Further information on VLSνs can be gained by spectral analysis and from LBL accelerator experiments and atmospheric neutrinos

Not unreasonable to think that several sterile νs can co-exist and explain some observations: (SBL,eV), solar spectrum (10^{-3} eV), dark radiation (sub-eV), DM (keV), leptogenesis (TeV), small ν mass (GUT)

ALL MASS SCALES SHOULD BE PROBED WITHOUT PREJUDICES!