IceCube bounds on sterile neutrinos above 10 eV

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3rd September 2018

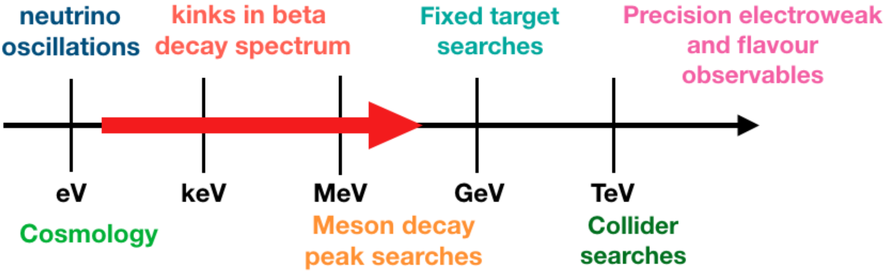
Based on arXiv:1803.02362, submitted to EPJC
in collaboration with
Mattias Blennow, Enrique Fernandez-Martinez, Josu Hernandez-Garcia and Jordi Salvado.

Introduction

neutrino masses most easily accommodated with sterile neutrinos ν_R

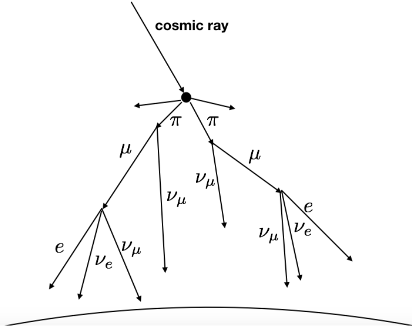
$$-\mathcal{L}_\nu = \underbrace{Y\overline{l_L}\phi\nu_R}_{\text{Dirac mass after SSB}} + \underbrace{M_N\overline{\nu_R^c}\nu_R}_{\text{Majorana mass}} + \text{h.c.}$$

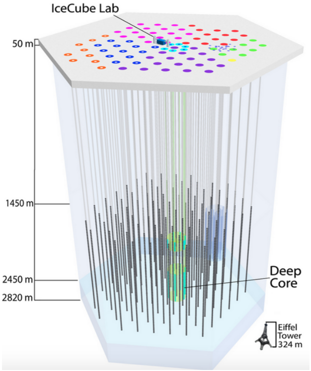
scale M_N unknown and not related to EW scale different phenomenology depending on M_N scale



IceCube

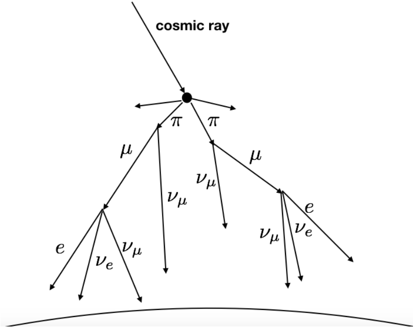
- km^3 detector at Southpole
- analyse muon neutrino disappearance with atmospheric neutrinos

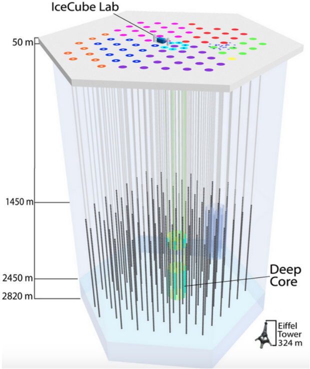




IceCube

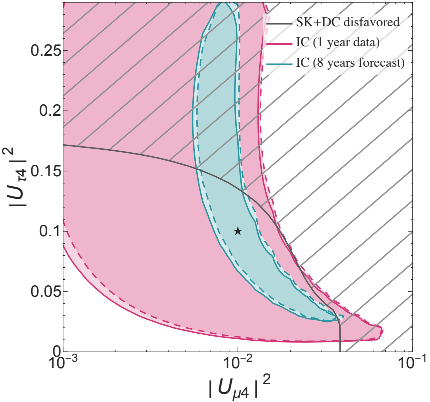
- average out regime for sterile oscillations ($\Delta m^2 L/E \gg 1$)
- first time this range of parameter space is probed with IceCube data





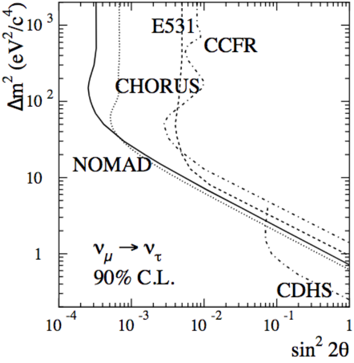
See also Josu's talk later

- contours @ 90 % C.L
- bounds for $\Delta m^2_{41} > 100$ eV^2
- zero sterile mixing disfavoured at 2.3 σ (1.6 - 3.0 σ with different models for initial flux)



NOMAD & CHORUS [arXiv: 0106102]

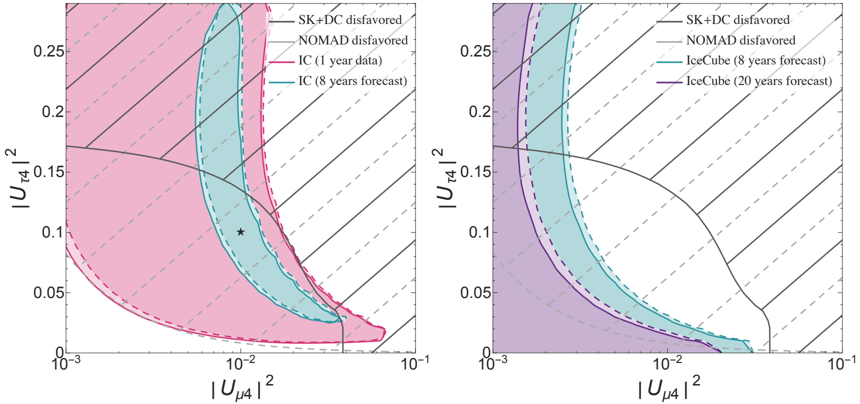
- same parameter space probed by CHORUS and NOMAD via appearance of ν_τ in a ν_μ beam through vacuum oscillations



- channel and underlying physics explored are very different

Summary of IceCube results [Blennow, Fernandez-Martinez, JG, Hernandez-Garcia, Salvado '18]

contours @ 90 % C.L



CHORUS & NOMAD rule out the favoured region of 1 year data

End of the talk

Thanks for your attention!

This project has received funding/support from the European Union's Horizon 2020 research and innovation programme

under the Marie Sklodowska-Curie grant agreement No 674896.

Backup: Details of the simulation

- neutrino flux computed with the analytic air shower code using cosmic ray flux from HondaGaisser model with Gaissser-Hillas H3a correction with the hadronic model QGSJET II-04
- propagation of the neutrinos simulated using the nuSQuIDS software (with PREM earth profile)
- Monte Carlo provided with the data release used to compute the expected number of events in every bin of reconstructed zenith angle
- nuissance parameters: uncertainty in the pion-kaon ratio of initial flux (prior: $\sigma_{\pi/k} = 0.05$), DOM efficiency, overall flux normalization
- one energy bin, 40 bins for zenith angle
- Poisson log-likelihood

Backup: Analytical oscillation probability

ν_e decoupled (θ_{13} small, 1-2 oscillation not developed, θ_{14} tightly constrained already)

$$P_{\mu\mu} = \underbrace{(1-\alpha_{\mu\mu})^4}_{\text{normalisation}} \left(1 - \sin^2(2\theta_m)\sin^2\left(\frac{\Delta_m L}{2}\right)\right) + \underbrace{\sum_{i=4}^{n} |U_{\mu i}|^4}_{\text{leaking term}} ,$$

with

$$\Delta_m^2 = \left[\frac{\Delta m_{31}^2}{2E}\cos(2\theta_{23}) + 2V_{\text{NC}}(\alpha_{\mu\mu} - \alpha_{\tau\tau})\right]^2 + \left|\frac{\Delta m_{31}^2}{2E}\sin(2\theta_{23}) - 2V_{\text{NC}}\alpha_{\tau\mu}\right|^2 ,$$

$$\sin^2(2\theta_m) = \frac{1}{\Delta_m^2}\left|\frac{\Delta m_{31}^2}{2E}\sin(2\theta_{23}) - 2V_{\text{NC}}\alpha_{\tau\mu}\right|^2 ,$$

Backup: Analytical oscillation probability

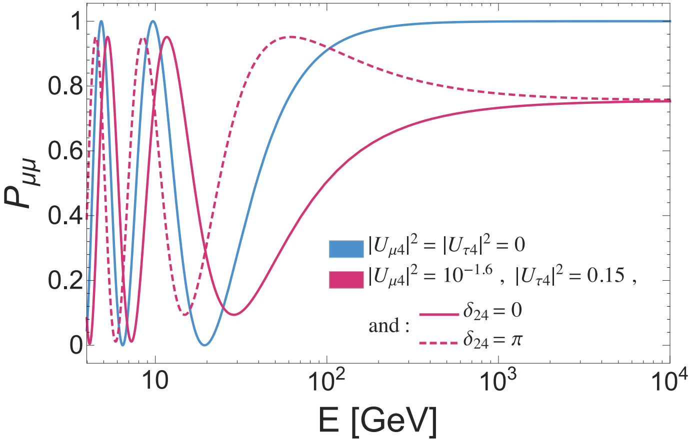
- expression for α for a single sterile neutrino:

$$\alpha_{\mu\mu} \simeq |U_{\mu 4}|^2/2, \quad \alpha_{\tau\tau} \simeq |U_{\tau 4}|^2/2, \quad \alpha_{\tau\mu} = s_{24} s_{34} e^{i\delta_{24}} \simeq U_{\tau 4} U^*_{\mu 4}\,,$$

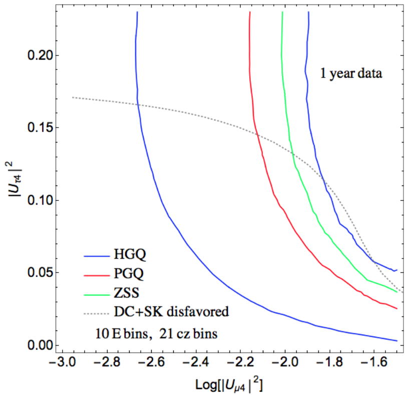
- in analysis: free normalization and no sensitivity to the leaking term, which does not depend on energy nor baseline
- at leading order in α and neglecting Δm^2_{31}

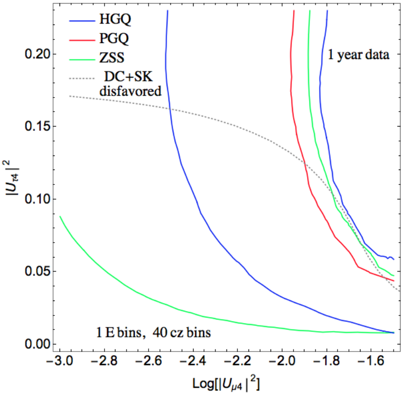
$$P_{\mu\mu} \simeq 1 - V^2_{\rm NC} |U_{\tau 4}|^2 |U_{\mu 4}|^2 L^2\,.$$

Backup: Effect of sterile phase



Backup: Effect of binning/initial fluxes





result compatible with [Dentler, Hernández-Cabezudo, Kopp, Machado, Maltoni, Martinez-Soler, Schwetz '18]

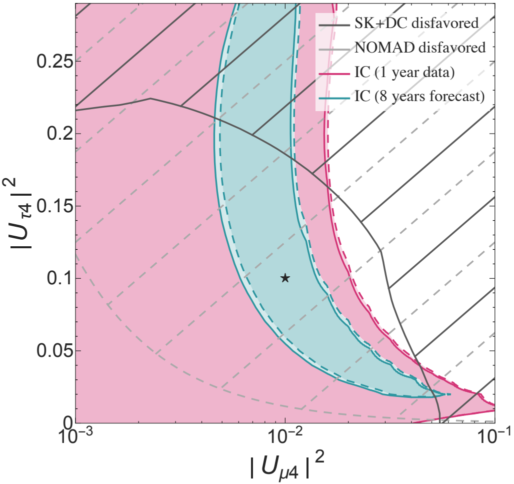
Backup: Chorus & Nomad

- CERN wide-band neutrino beam produced by the 450 GeV proton synchrotron
- distance between the neutrino source and the detector $\sim$ 600 m
- neutrino energies $\sim$ 40 GeV $\Rightarrow$ sensitivity for $\Delta m^2_{41} > 1$ eV^2
- constraints in $\Delta m^2_{41} - |U_{\mu 4}|^2 |U_{\tau 4}|^2$ plane

[NOMAD: arXiv: 0106102, CHORUS: arXiv: 0710.3361]

Backup: IceCube results [Blennow, Fernandez-Martinez, JG, Hernandez-Garcia, Salvado '18]

contours @ 99 % C.L



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