

Invisible neutrino decay at ESSnuSB

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Based on: Choubey, Ghosh, Kempe, Ohlsson, JHEP 05, 133
(2021)

Invisible decay

Invisible decay: Active neutrinos decaying into sterile neutrinos

Dirac: $\nu_j \rightarrow \nu_{iR} + \chi$

ν_{iR} is a right-handed singlet, χ is an iso-singlet scalar. For

Majorana: $\nu_j \rightarrow \nu_s + J$

ν_s is a sterile neutrino, J is a Majoron

In principle: ν_1 , ν_2 , and ν_3 can decay invisibly

Decay of ν_2 and ν_1 is constrained from solar and supernova

In this Presentation: Decay of ν_3

Formalism

Assuming ν_3 decays

$$i \frac{d}{dt} \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \left\{ U \left[\frac{1}{2E} \text{diag} (0, \Delta m_{21}^2, \Delta m_{31}^2 - i\alpha_3) \right] U^\dagger + \text{diag}(V, 0, 0) \right\} \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

$$\alpha_3 \equiv m_3/\tau_3$$

$$P_{\mu e} \simeq s_{13}^2 c_{13}^2 s_{23}^2 \left[4 \sin^2 \frac{\Delta_{\text{atm}}}{2} - (1 - e^{-\Gamma_3}) + 2 \cos \Delta_{\text{atm}} \left(1 - e^{-\frac{\Gamma_3}{2}} \right) \right]$$

$$P_{\mu \mu} \simeq 1 - c_{13}^2 s_{23}^2 \left[4(1 - c_{13}^2 s_{23}^2) \sin^2 \frac{\Delta_{\text{atm}}}{2} + c_{13}^2 s_{23}^2 (1 - e^{-\Gamma_3}) + 2(1 - c_{13}^2 s_{23}^2) \cos \Delta_{\text{atm}} \left(1 - e^{-\frac{\Gamma_3}{2}} \right) \right]$$

$$\Gamma_3 \equiv \alpha_3 L/E$$

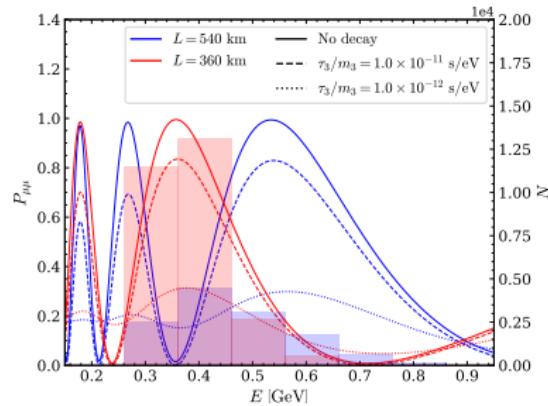
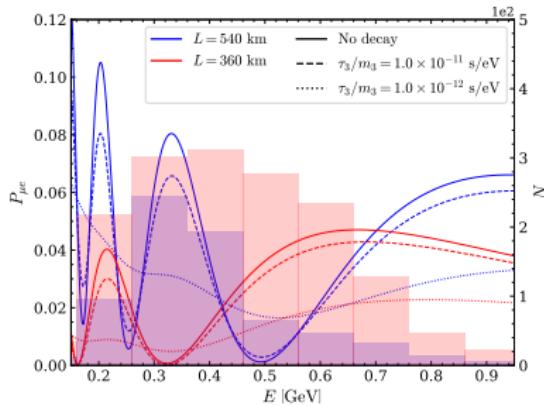
- Decay leads to a depletion in the number of events
- Decay parameter appears together with the quantity L/E .

The ESSnuSB experiment



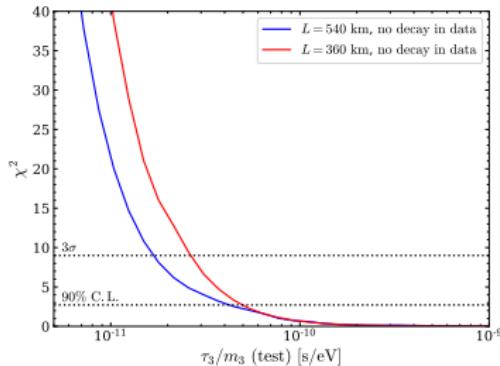
- $L = 540 \text{ km}/360 \text{ km}$
- $E = 0.35 \text{ GeV}$
- 538 kt WC detector
- **Unique:** Probes Second oscillation maximum

Probability and events



- $P_{\mu e}$: 540 ~second oscillation maximum, 360 ~both the first and second oscillation maxima
- $P_{\mu \mu}$: 540 ~second oscillation minimum, 360 ~both the first and second oscillation maximum
- Change in the probability is much larger for a shorter τ_3

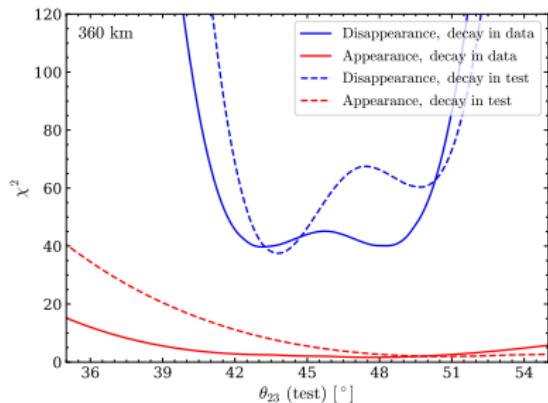
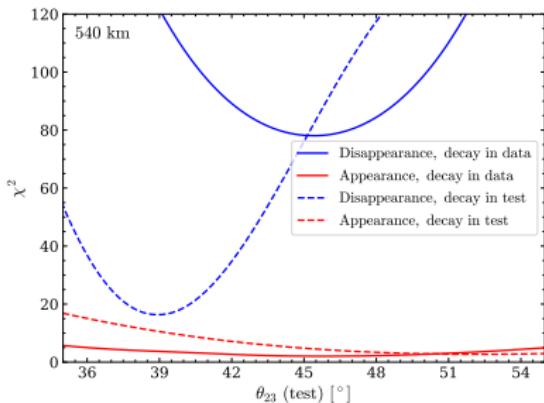
Bound



Experiment	90 % C.L. (3σ) bound on τ_3/m_3 [s/eV]
T2K + NO ν A	$2.3 (1.5) \times 10^{-12}$
T2K + MINOS	$2.8 (1.8) \times 10^{-12}$
SK + MINOS	$2.9 (0.54) \times 10^{-10}$
MOMENT	$2.8 (1.6) \times 10^{-11}$
ESSnSB (540 km)	$4.22 (1.68) \times 10^{-11}$
DUNE (CC)	$4.50 (2.38) \times 10^{-11}$
ESSnSB (360 km)	$4.95 (2.64) \times 10^{-11}$
DUNE (CC + NC)	$5.1 (2.7) \times 10^{-11}$
JUNO	$9.3 (4.7) \times 10^{-11}$
INO	$1.51 (0.566) \times 10^{-10}$
KM3NeT-ORCA	$2.5 (1.4) \times 10^{-10}$

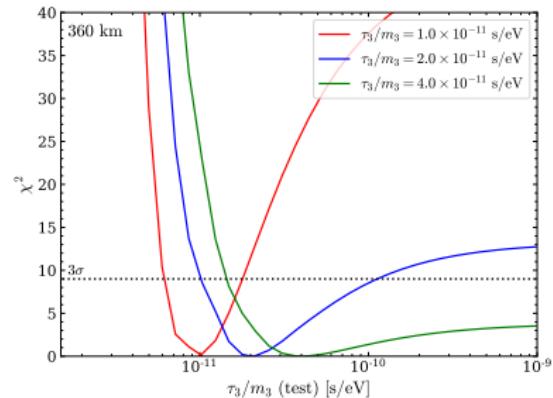
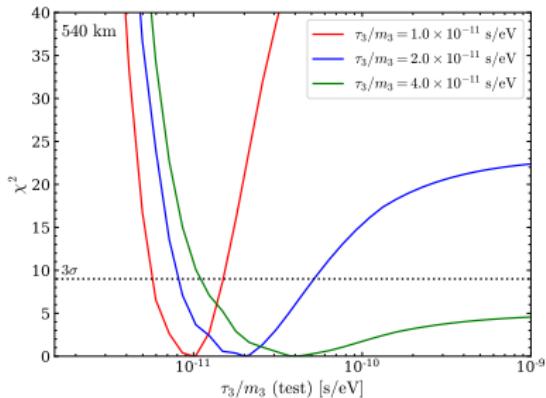
- 360 is better than 540
- ESSnSB is comparable to DUNE
- Atmospheric experiments are better

Contribution of channels



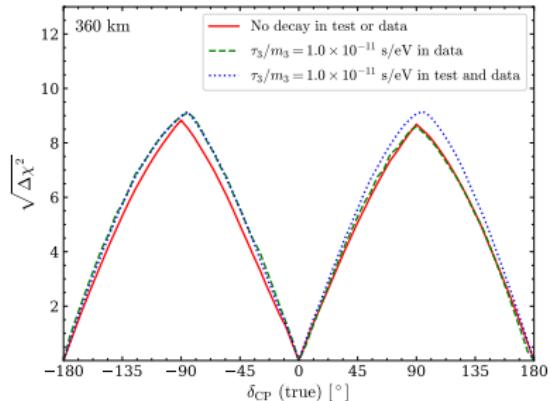
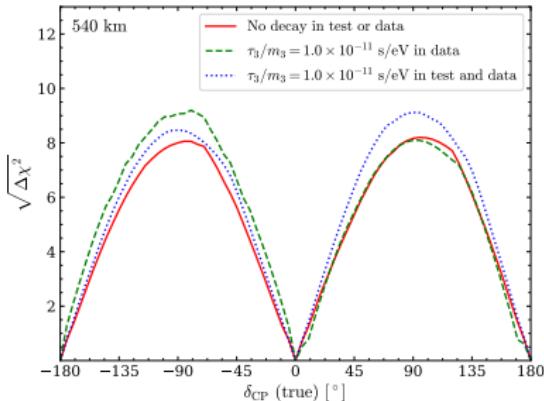
- $\tau_3/m_3 = 1.0 \times 10^{-11} \text{ s/eV}$.
- Sensitivity corresponds to χ^2 minimum
- Most of the sensitivity comes from the $P_{\mu\mu}$ channel.

Precision of τ_3



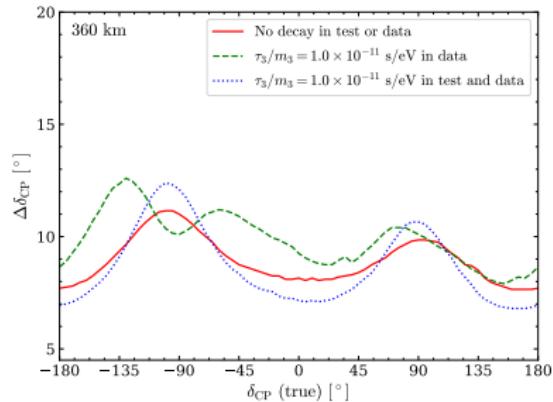
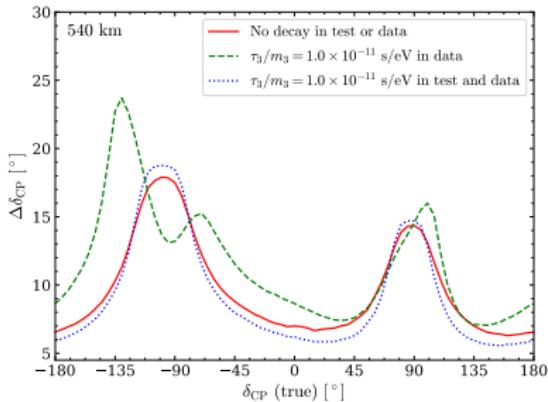
- Better for 540 km
- Good sensitivity for lower τ_3

CP violation



- Sensitivity is better in presence of decay
- Effect of decay is more for 540 km

CP precision



- Sensitivity is different if we fit data with decay with a theory without decay

Summary

- ESSnuSB can probe decay
- Bound on τ_3 comparable to DUNE
- CP precision is different in presence of decay

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Thank You