Invisible neutrino decay at DUNE

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Invisible neutrino decay

One of the active neutrino mass eigenstates decays into some lighter states. This is invisible neutrino decay. Such decay can happen in two ways. If the neutrinos are Dirac particle, the neutrinos will decay in the following way:

$$\nu_j \to \bar{\nu}_{iR} + \chi$$

χ is iso-singlet scalar and ν_{iR} is right-handed singlet.

If neutrinos are Majorana particle, the decay will be following:

$$\nu_j \to \nu_s + J$$

J is Majoron and ν_s is a sterile neutrino.

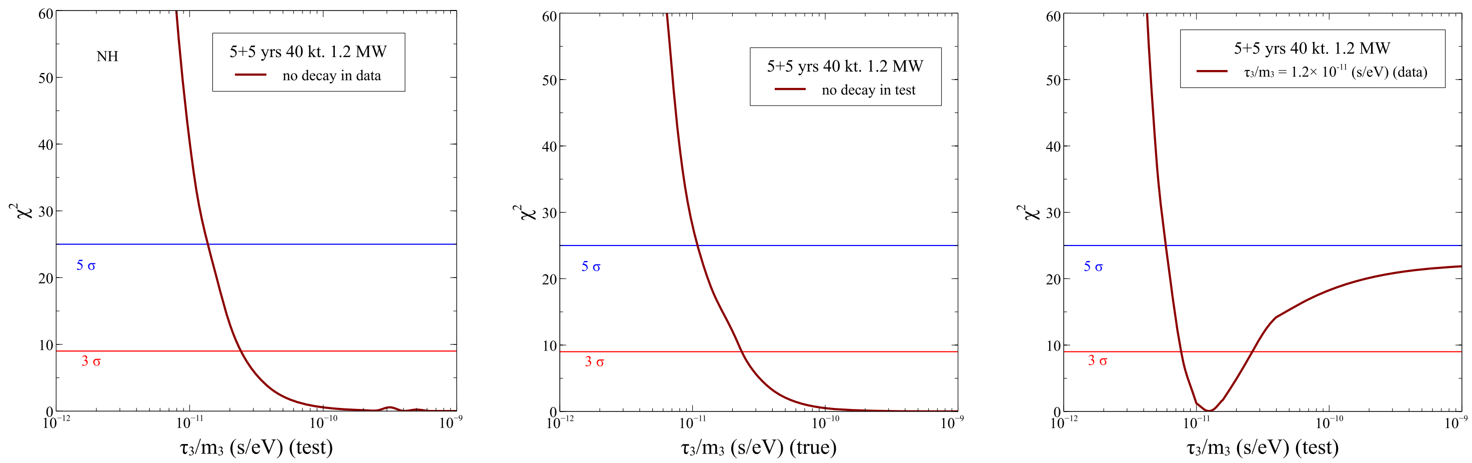
Mixing matrix in presence of decay

$$\begin{pmatrix} \nu_\alpha \\ \nu_s \end{pmatrix} = \begin{pmatrix} U & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_4 \end{pmatrix}.$$

Note the block diagonal form of the mixing matrix. This shows that there is no mixing between the active and the sterile states.

$$i\frac{d}{dx}\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \left[U \left[\frac{1}{2E} \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} - i\frac{m_3}{2E\tau_3} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right] U^\dagger + \begin{pmatrix} A & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \right] \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}, \tag{2.2}$$

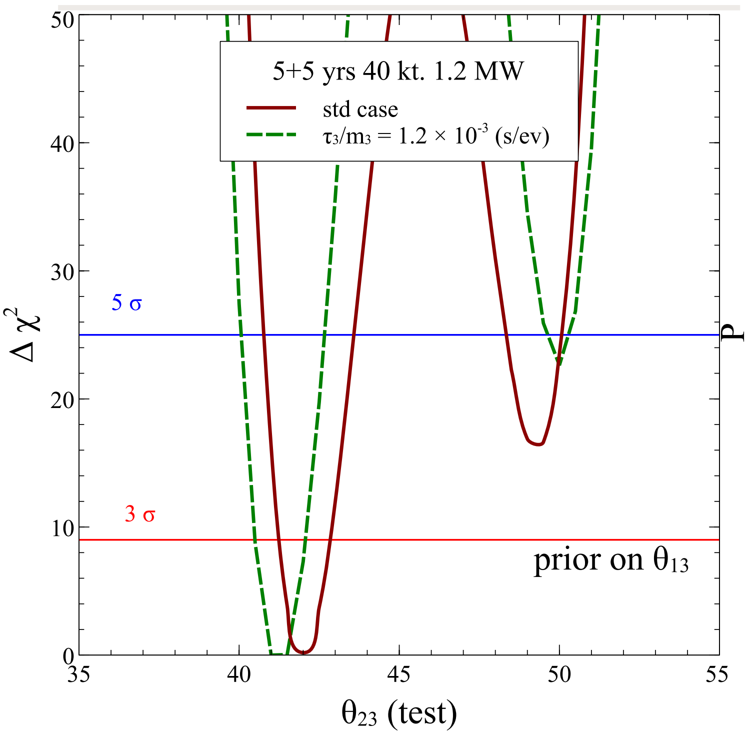
The τ_3 is the lifetime of the decaying state and $A = 2\sqrt{2} G_F n_e E$

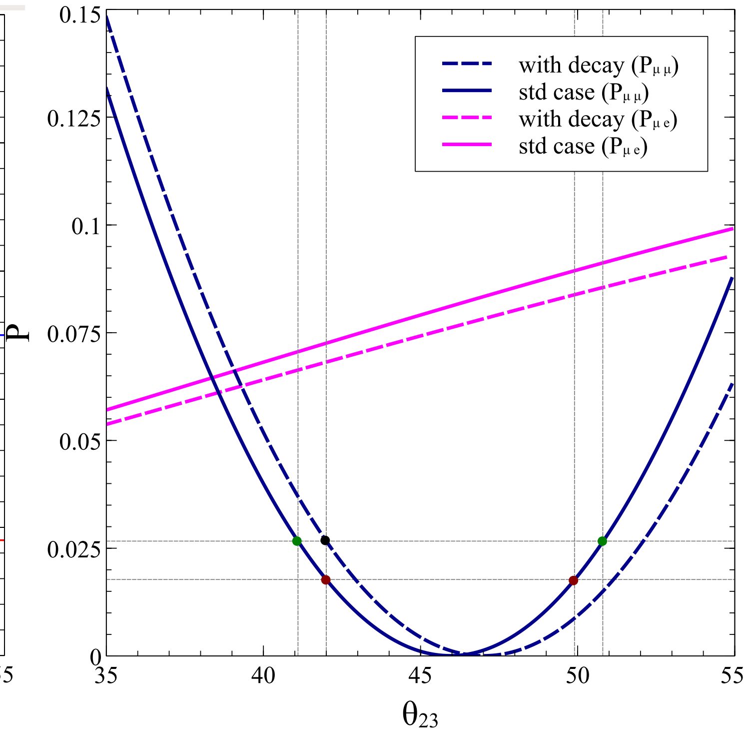


The figures show the sensitivity, discovery potential and measurement capability of DUNE for τ_3/m_3 from left to right. DUNE can put bound on neutrino lifetime of $\tau_3/m_3 > 2.38 \times 10^{-11}$(s/eV) .DUNE can discover neutrino decay at more than 3σ for $\tau_3/m_3 < 2 \times 10^{-11}(s/eV)$ and for true $\tau_3/m_3 = 1.2 \times 10^{-11}(s/eV)$, the expected precision will be $2.63 \times 10^{-11} > \tau_3/m_3 > 7.62 \times 10^{-12}(s/eV)$

The effect of decay in measuring of θ_{23} :

The figure in the left shows the effect of decay in measuring θ_{23} , here the dark red solid curve shows the standard case. For the green dashed curve, we assumed decay in the data and then we fitted with standard 3+0 scenario. Here we can see that the **best-fit of θ_{23} shifts towards lower value in the lower octant and towards higher value in higher octant** compared to the original value.





The shift in the θ_{23} can be explained in terms of the right figure. The magenta curves show the variation of appearance probability in θ_{23} for std (decay) for solid (dashed) curves. And the blue curves depict the variation of disappearance probability for std (decay) case for solid (dashed) curves. The dark-red dot shows the disappearance probability for $\theta_{23} = 42^o$, for the standard 3+0 case without decay. For decay case the probability is given by the black dot. When this is fitted with the standard case ignoring decay, the probability follows the blue solid curve. Therefore the probability is matched at a lower value of θ_{23} , shown by the green dot in the lower octant.

Conclusion:

1) DUNE is expected to increase the bound of τ_3/m_3 by one order of magnitude from the current bound of presently running experiments.
2) DUNE is expected to rule out the no decay scenario by more than 3σ .
3) If decay is present in nature and if this is ignored in the analysis of DUNE data, the measurement of will be erroneous and the value of θ_{23} will be shifted to a lower value from the actual value of θ_{23} in the lower octant.