Searching for Large Extra Dimensions with MINOS and MINOS+

Three singlet fermion fields in an extra dimension compactified on a circle with radius $R$ arise as Kaluza-Klein (KK) states in 3+1 spacetime.

Sterile masses set by $R$

$$m^{(k)}_{KK,i} \propto \frac{k}{R}$$

Active masses set by $m_0$, $\Delta m^2_{21}$, and $\Delta m^2_{32}$

$$R = 0.60 \mu m \quad m_1 = m_0 = 0.010 \text{ eV}$$

$$P(\nu_\mu \rightarrow \nu_\mu) = \left| \sum_{j=1}^{3} \sum_{n=0}^{+\infty} U_{\mu j} U^*_{\mu j} \left( W_j^{(0n)} \right)^2 \exp \left[ i \left( \frac{\lambda_j^{(n)}}{R} \right)^2 \left( \frac{L}{2E} \right) \right] \right|^2$$

Active mixing

Mixing in towers

Neutrino masses

Baseline Energy

Three-flavor

735 km baseline

MINOS FD

$R = 0.60 \mu m$, $m_0 = 0.010 \text{ eV}$

$\Delta m^2_{21} = 7.54 \times 10^{-5} \text{ eV}^2$

$\Delta m^2_{32} = 2.37 \times 10^{-3} \text{ eV}^2$

$\sin^2 \theta_{12} = 0.308$

$\sin^2 \theta_{13} = 0.022$

$\sin^2 \theta_{23} = 0.410$

$\delta_{CP} = 0$
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Vegetables

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MINOS/MINOS+ Near and Far Detector Charged and Neutral Current data set constraints on model:

\[ R < 0.30 \mu m \text{ at } 90\% \text{ C.L. for vanishing } m_0 \]