Rewriting the Probability for Neutrino Oscillations in the model of Large Extra Dimensions (LED, 5D)

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Victor Basto-Gonzalez

Universidad de Pamplona (NdeS)

Goal of poster

$$P_{\nu_\alpha \to \nu_\beta}(E_\nu, L, R, m_0) = \left| \sum_{j=1}^{3} U_{\alpha j} U^*_{\beta j} \sum_{n=0}^{\infty} \left(L_j^{0n} \right)^2 \exp\left(i \frac{\lambda_j^{(n)^2} L}{2 E_\nu R^2} \right) \right|^2$$

$$P_{\nu_\alpha \to \nu_\beta}(L, E) = \delta_{\alpha\beta} - 4 \sum_{k>j} \Re\mathrm{e}\left[U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j} \right] \sin^2\left(\frac{\Delta m^2_{kj} L}{4E} \right)$$

$$+ 2 \sum_{k>j} \Im\mathrm{m}\left[U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j} \right] \sin\left(\frac{\Delta m^2_{kj} L}{2E} \right) .$$

$$P_{\nu_\alpha \to \nu_\beta}(L, E) = \delta_{\alpha\beta} - 2 \sum_{k>j} \Re\mathrm{e}\left[U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j} \right] \left[1 - \cos\left(\frac{\Delta m^2_{kj} L}{2E} \right) \right]$$

$$+ 2 \sum_{k>j} \Im\mathrm{m}\left[U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j} \right] \sin\left(\frac{\Delta m^2_{kj} L}{2E} \right) ,$$

Giunti, and Kim “Fundamentals of Neutrino Physics and Astrophysics”

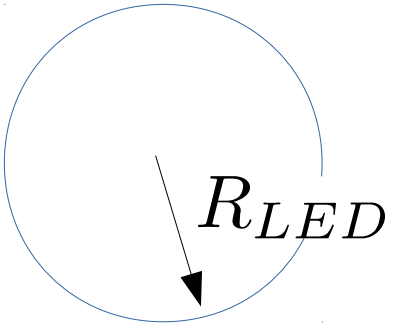
Assumptions LED

- Our world has 5 dimension:

$$(t, x, y, z, 2\pi R_{LED})$$

Flat

Compactified on a circle



- Neutrinos are Dirac particles

- Dominant effects are oscillations amongst the three active states

Oscillation probability in LED

$$P_{\nu_\alpha \to \nu_\beta}(E_\nu, L, R, m_0) = \left| \sum_{j=1}^{3} U_{\alpha j} U^*_{\beta j} \sum_{n=0}^{\infty} \left(L_j^{0n}\right)^2 \exp\left(i \frac{\lambda_j^{(n)^2} L}{2 E_\nu R^2} \right) \right|^2$$

$$\boxed{\xi_j = \sqrt{2} m_j R} \qquad \left(L_j^{0n}\right)^2 = \frac{2}{1 + \pi^2 \xi_j^2/2 + 2\lambda_j^{(n)^2}/\xi_j^2}; \qquad \lambda_j^{(n)} - \frac{\pi}{2}\xi_j^2 \cot\left(\pi \lambda_j^{(n)}\right) = 0$$

- Dominant effects are oscillations amongst the three active states

$$0 < \xi_i < 1$$

$n = 0$

$$\lambda_j^{(0)^2} = \frac{\xi_j^2}{2} - \frac{\pi^2 \xi_j^4}{12}$$

$$\left(L_j^{00}\right)^2 = 1 - \frac{\pi^2 \xi_j^2}{6} + \frac{\pi^4 \xi_j^4}{60}$$

$n = k = 1, 2, 3, \cdots$

$$\lambda_j^{(k)^2} = k^2 + \xi_j^2 - \frac{\xi_j^4}{4k^2}$$

$$\left(L_j^{0k}\right)^2 = \frac{\xi_j^2}{k^2} - \frac{3\xi_j^4}{2k^4}$$

PhysRevD.65.105015
Davoudiasl, Langacker, and Perelstein

Rewriting the oscillation probability in LED

$$P_{\nu_\alpha \to \nu_\beta}(E_\nu, L, R, m_0) = \delta_{\alpha\beta} - \sum_{j=1}^{3} |U_{\alpha j}|^2 |U_{\beta j}|^2 A_j$$
$$- 2 \sum_{j>i}^{3} \mathbf{Re}[U^*_{\alpha j} U_{\beta j} U_{\alpha i} U^*_{\beta i}] \left\{ 1 - \left[(1 - B_{ij}) \cos\left(\frac{\lambda_i^{(0)2} - \lambda_j^{(0)2}}{R^2} \frac{L}{2E_\nu} \right) + C_{ij} \right] \right\}$$
$$- 2 \sum_{j>i}^{3} \mathbf{Im}[U^*_{\alpha j} U_{\beta j} U_{\alpha i} U^*_{\beta i}] \left\{ (1 - B_{ij}) \sin\left(\frac{\lambda_i^{(0)2} - \lambda_j^{(0)2}}{R^2} \frac{L}{2E_\nu} \right) + D_{ij} \right\}$$

$$A_j = A_j(E_\nu, L, R, m_0)$$
$$C_{ij} = C_{ij}(E_\nu, L, R, m_0)$$
$$D_{ij} = D_{ij}(E_\nu, L, R, m_0)$$

$$B_{ij} = B_{ij}(R, m_0)$$

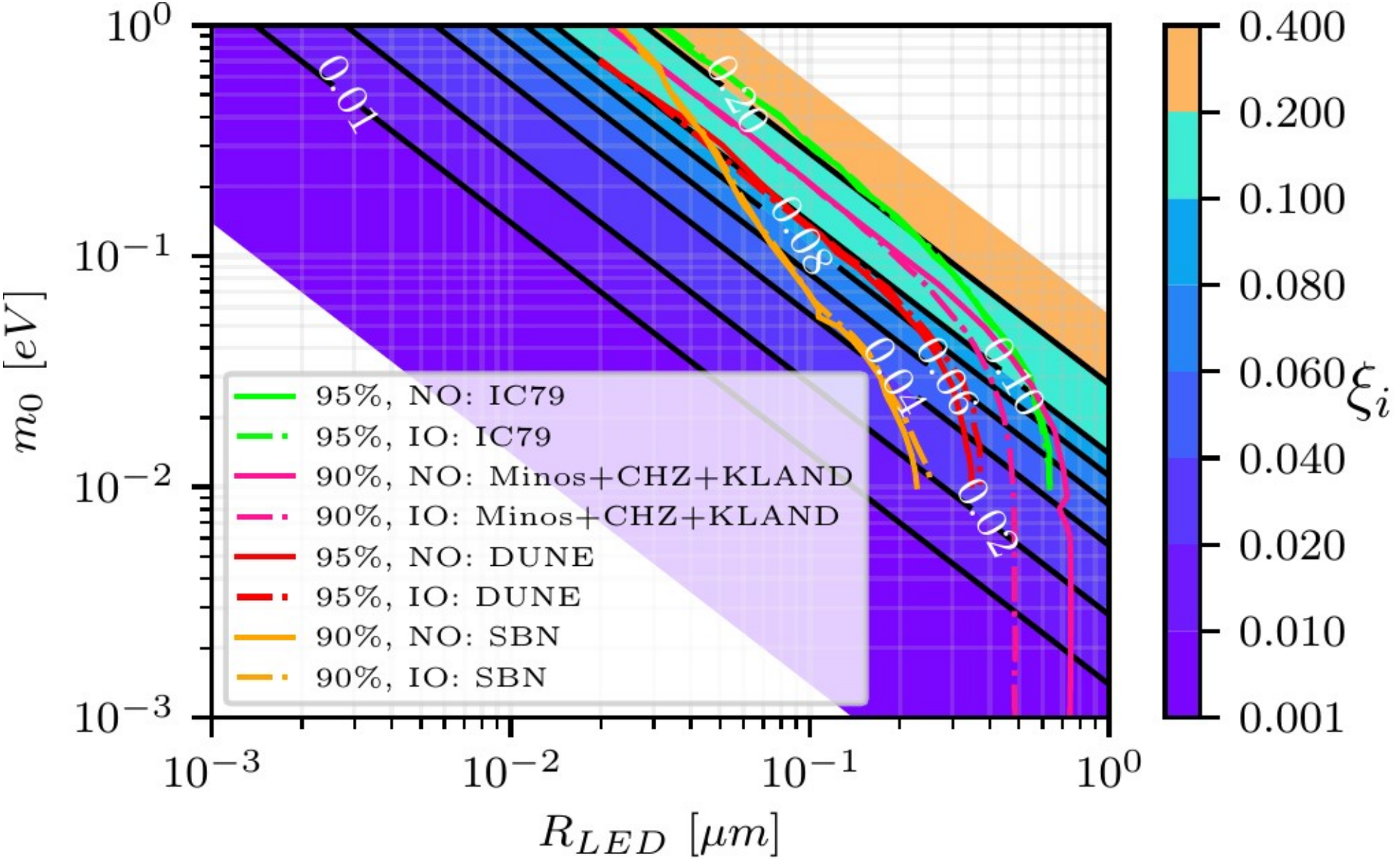
NO

$$m_2^2 = m_1^2 + \Delta m_{21}^2$$

IO

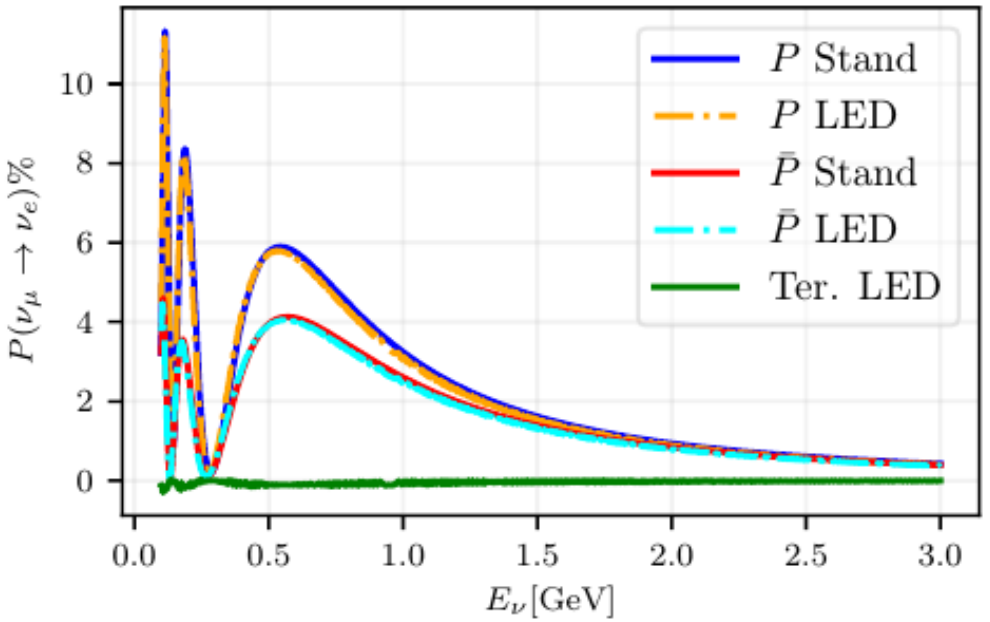
$$m_1^2 = m_3^2 - \Delta m_{31}^2$$

Excluded regions

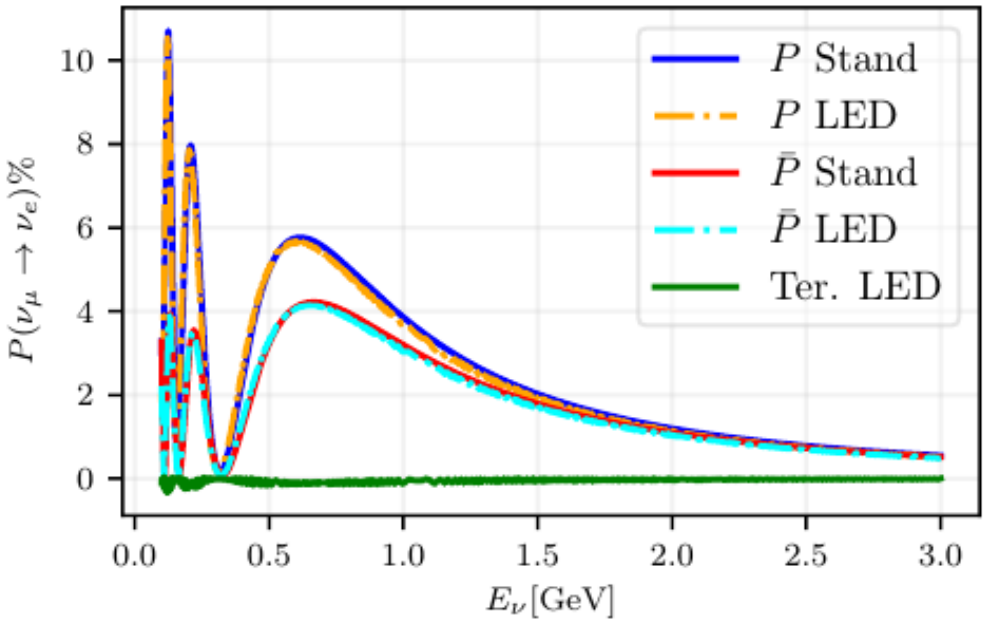


JCAP,1412(12):002,2014 PhysRevD.84.013003 PhysRevD.94.033006 JHEP11(2018)155

LED in T2K



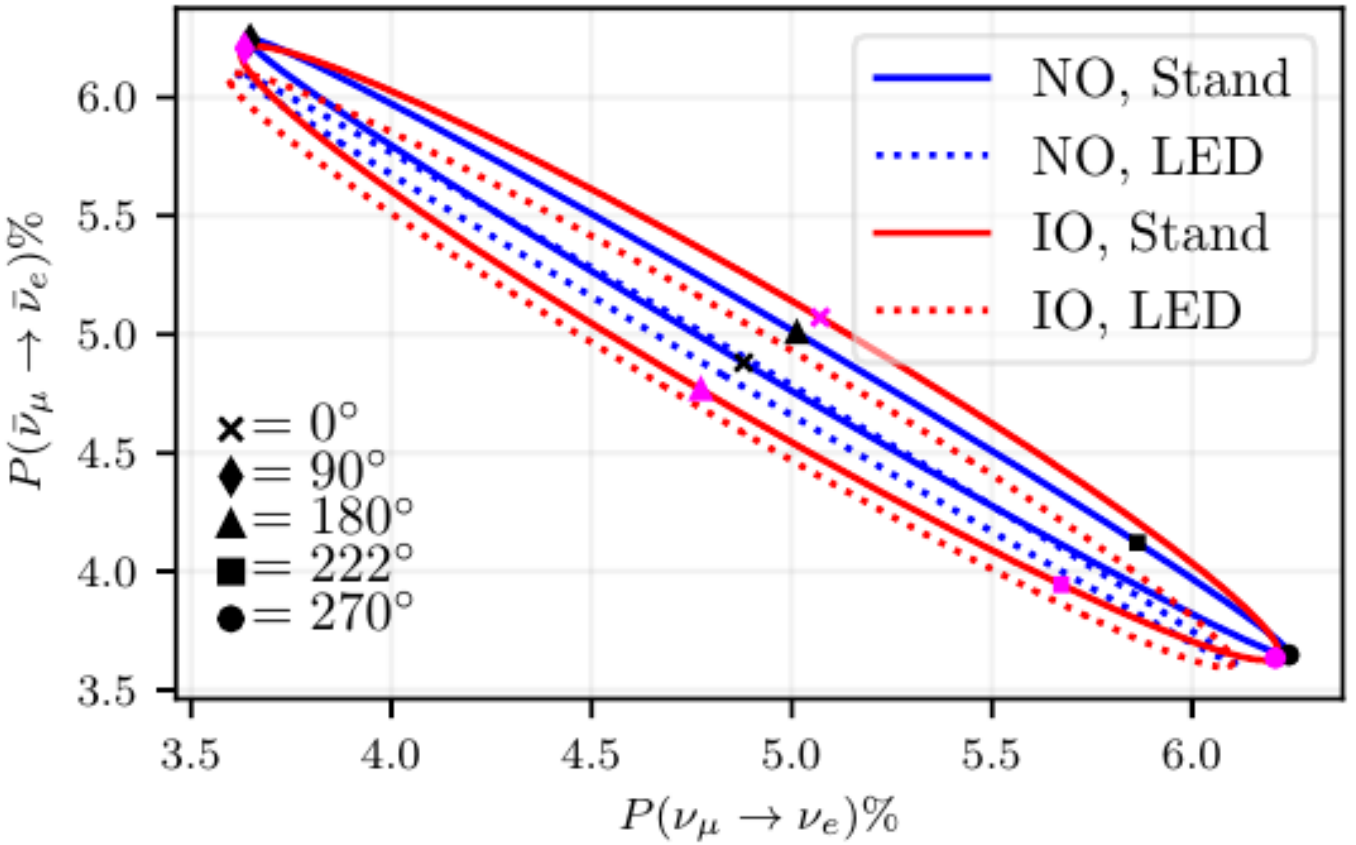
Normal Ordering



Inverted Ordering

$L = 295\ km$
$\delta = 222°$
$\theta_{12} = 33.82°$
$\theta_{13} = 8.61°$
$\theta_{23} = 48.3°$
$\Delta m^2_{21} = 7.390 \times 10^{-5}\ eV^2$
$(\Delta m^2_{31})_{NO} = 2.523 \times 10^{-3}\ eV^2$
$(\Delta m^2_{31})_{IO} = -2.523 \times 10^{-3}\ eV^2$
$R_{LED} = 0.1\ \mu m$
$m_0 = 0.1\ eV$
[6] NuFIT 4.1 (2019), www.nu-fit.org
Null matter effect.

LED in T2K



Bi-probability

$L = 295\ km$
$\delta = 222°$
$\theta_{12} = 33.82°$
$\theta_{13} = 8.61°$
$\theta_{23} = 48.3°$
$\Delta m^2_{21} = 7.390 \times 10^{-5}\ eV^2$
$(\Delta m^2_{31})_{NO} = 2.523 \times 10^{-3}\ eV^2$
$(\Delta m^2_{31})_{IO} = -2.523 \times 10^{-3}\ eV^2$
$R_{LED} = 0.1\ \mu m$
$m_0 = 0.1\ eV$

[6] NuFIT 4.1 (2019), www.nu-fit.org

Null matter effect.

Conclusions

- Goal was accomplished

- $A_i, B_{ij}, C_{ij}, D_{ij}$ can not be relevant to T2K.