Constraining Neutrino with KATRIN

Victor S. Basto-Gonzalez, Arman Esmaili and O. L. G. Peres[1]

[1] Instituto de Fisica Gleb Wataghin
UNICAMP

08 January 2012

Large extra dimensions

- It been proposed that a possible solution for the hierarchy problem can be the Large Extra Dimensions theories(LED) [1]
- *Large* flat extra-dimensions compactified in a torus
- Gravitacional strength diluted by volume of n extra compact spacial dimensions: $M_{\mathrm{Pl}}^2 \sim M_{\mathrm{Pl(4+n)}}^{2+n} R^n$, where the n-D Planck scale $M_{\mathrm{Pl(4+n)}}$ is the scale of gravity in the bulk.
- To account for hierarchy, $M_{\mathrm{Pl(4+n)}} \sim 1$TeV that implies $R \sim 100\mu m - 1mm$

[1] N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **429**, 263 (1998); N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Rev. D **59**, 086004 (1999); I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **436**, 257 (1998)

Large extra dimensions

- Inspired by these ideias we will test a specific model of LED, that include three massless right-handed 5-D neutrinos

$$
\begin{aligned}
S &= \int \mathrm{d}^4x\,\mathrm{d}y\, i\overline{\Psi}^{\alpha}\Gamma_{\mathsf{A}}\partial^{\mathsf{A}}\Psi^{\alpha} + \int \mathrm{d}^4x\,\{ i\bar{\nu}_{\mathsf{L}}^{\alpha}\gamma_{\mu}\partial^{\mu}\nu_{\mathsf{L}}^{\alpha} \\
&+ \kappa_{\alpha\beta} H \bar{\nu}_{\mathsf{L}}^{\alpha}\psi_{\mathsf{R}}^{\beta}(x, y=0) + \text{H.c.}\}, \qquad (1)
\end{aligned}
$$

where $A = 0, \ldots, 4$; H is the Higgs doublet, κ is the Yukawa coupling matrix and the right-handed neutrino field is decomposed to $(\psi_{\mathrm{L}}^{\alpha}, \psi_{\mathrm{R}}^{\alpha})$.

Large extra dimensions

- At the end of day we should write down in our boring 4D world then

$$R_{ED}\,M_i \quad = \quad \lim_{N\to\infty}\begin{pmatrix} m_i^D R_{ED} & 0 & 0 & \dots & 0 \\ \sqrt{2}\,m_i^D R_{ED} & 1 & 0 & \dots & 0 \\ \sqrt{2}\,m_i^D R_{ED} & 0 & 2 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \sqrt{2}\,m_i^D R_{ED} & 0 & 0 & \dots & N \end{pmatrix}$$

where m_i^D, i=1,2,3 came from the diagonalization of the left-handed flavor stated $\alpha = e, \mu, \tau$. and from this we can get the masses λ_i^n / R_{ED}, where the index n is for n-solution of the eigenvalue equation and the eigenstates are

$$\nu_{\mathrm{L}}^{\alpha} = \sum_{i=1}^{3} U^{\alpha i *} \sum_{n=0}^{\infty} L_i^{0n} \nu_{\mathrm{L}}^{i(n)} \, , \qquad (1)$$

where $\nu_{\mathrm{L}}^{i(n)}$ are the mass eigenstates composed of the n^{th} KK mode of ψ_{L} and the 3×3 matrix U is PMNS mixing matrix.

Large extra dimensions

- The smallest state of the tower, $\lambda_i^{(0)}/R_{ED}$ have values

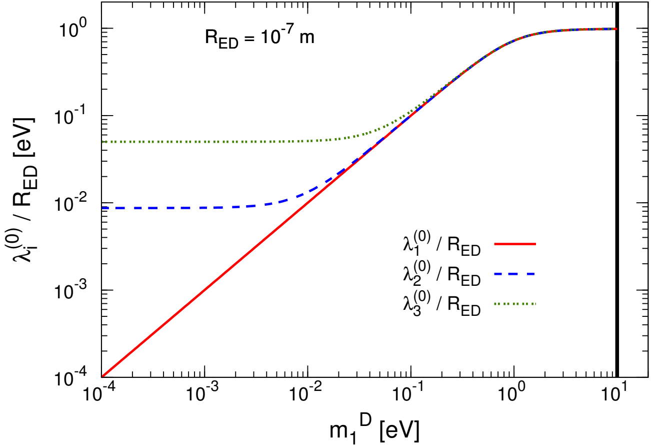
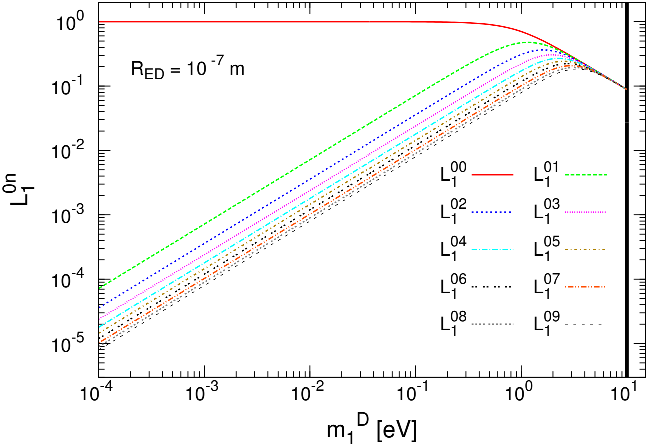


Figure : Assuming Normal Hierarchy

Large extra dimensions

And the L_1^{0n} couplings



Large extra dimensions

We are going to use the
• Chooz data (most of sensitivity for the R_{ED} parameter) [1]
• KATRIN sensitivity, expected to have put a upper bound $m_\beta \equiv \sqrt{\sum_i |U_{ei}|^2 m_i^2} < 0.23$ eV.
• The parameters of the model are the lightest state mass, m_0^D

$$m_0^D = \begin{cases} m_1^D & \text{for NH} \\ m_3^D & \text{for IH} \end{cases}$$

and R_{ED} (the others are fixed by $\left(\lambda_2^{(0)}\right)^2 = \left(\lambda_1^{(0)}\right)^2 + R_{\rm ED}^2 \Delta m_{\rm sol}^2$, and $\left(\lambda_3^{(0)}\right)^2 = \left(\lambda_1^{(0)}\right)^2 + R_{\rm ED}^2 \Delta m_{\rm atm}^2$,)

[1] P. A. N. Machado, H. Nunokawa and R. Zukanovich Funchal, Phys. Rev. D **84**, 013003 (2011)

ν masses in lab experiments

- Kinematics of β decay, absolute mass scale m_β

A effective neutrino mass can be used (for 3ν) $m_\beta^2 = \sum_i |U_{ei}|^2 m_i^2$.
Present limits are $m_\beta < 2.0$ eV.

KATRIN (2013?) expected to have sensitivity of $m_\beta = 0.23$ eV.

ν masses in lab experiments

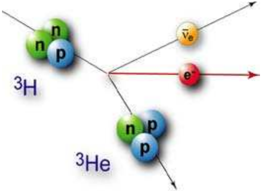
- Kinematics of β decay, absolute mass scale m_β

A effective neutrino mass can be used (for 3ν) $m_\beta^2 = \sum_i |U_{ei}|^2 m_i^2$.
Present limits are $m_\beta < 2.0$ eV.

KATRIN (2013?) expected to have sensitivity of $m_\beta = 0.23$ eV.

KATRIN

New generation (and probably the last) search for ν mass in β decay experiment. Lowest Q-value in β decay:Q$= 18571.8 \pm 1.2$ eV.



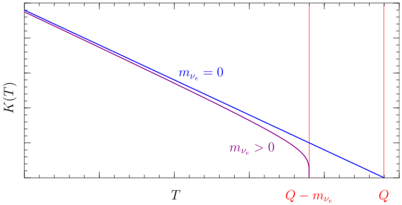
$$\beta(T_e, m_0, R_{\text{ED}}) = N_s F^Z \qquad (1)$$
$$\sum_k p_k \mathcal{E}_k \sum_{i=1}^{3} |U^{ei}|^2 \sum_{n=0}^{\infty} (L_i^{0n})^2 \sqrt{\mathcal{E}_k^2 - \left(\frac{\lambda_i^{(n)}}{R_{\text{ED}}}\right)^2} ,$$

where $F^Z)$ is the Fermi function, $\mathcal{E}_i = Q - W_i - K_e$, E_e and p_e; W_i and p_i are respectively the excitation energy and transition probability for the excited state i of the daughter nucleus.

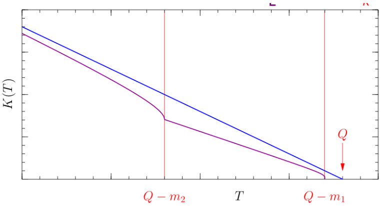
KATRIN experiment

Effect of neutrino mass in β spectrum. For 3ν we can use $m_\beta^2 = \sum_i |U_{ei}|^2 m_i^2$, for other cases for KATRIN it is not possible to use this expression.

3ν



>4ν



KATRIN experiment

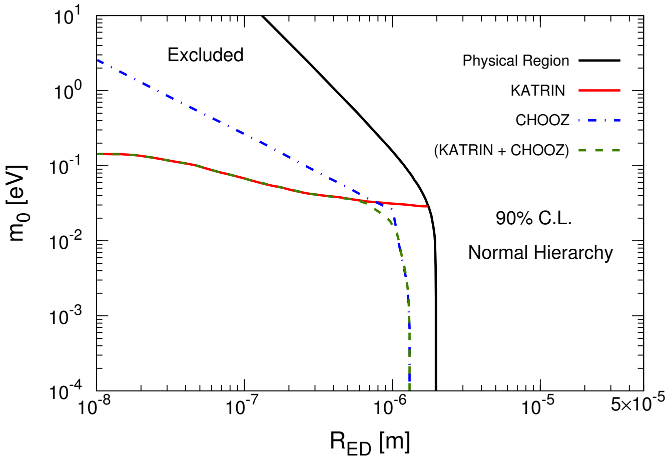
Integrated measurement

$$S(Q, qU, [U_{ei}], [m_\nu]) = \int_0^\infty \beta(K_e, Q, [U_{ei}], [m_\nu]) T'(K_e, qU)\, \mathrm{d}K_e\,,$$

- Thick Tritium source: atomic/molecular levels
- Energy loss of electrons inside source
- Sanity test: We recover the quoted limite for 3ν neutrinos:

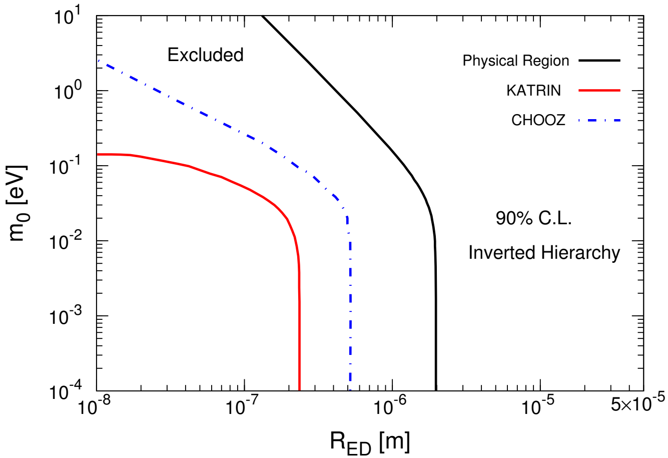
$m_\beta < 0.23$ at 90 % C.L.

Results

- 

Excluded
Physical Region
KATRIN
CHOOZ
(KATRIN + CHOOZ)
90% C.L.
Normal Hierarchy
m_0 [eV]
R_{ED} [m]
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
5×10^{-5}

Results


Excluded
Physical Region
KATRIN
CHOOZ
90% C.L.
Inverted Hierarchy
m_0 [eV]
R_{ED} [m]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
5×10^{-5}

Conclusions

- Large Extra Dimension models can be tested in neutrino experiments: complementary role of oscillation experiments and β decay experiments
- β decay expts can imptove bounds on the lightest mass, m_0 and on the radius R_{ED}
- For normal hierarchy, we can get $m_0 < 0.2$ eV at 90 % C.L. and for inverted hierarchy we improve the bound on $R_{ED} : 610^{-7} \to 2 \times 10^{-7}$ m and also improve bounds on m_0

Conclusions

- Large Extra Dimension models can be tested in neutrino experiments: complementary role of oscillation experiments and β decay experiments
- β decay expts can imptove bounds on the lightest mass, m_0 and on the radius R_{ED}
- For normal hierarchy, we can get $m_0 < 0.2$ eV at 90 % C.L. and for inverted hierarchy we improve the bound on $R_{ED} : 610^{-7} \rightarrow 2 \times 10^{-7}$ m and also improve bounds on m_0

Conclusions

- Large Extra Dimension models can be tested in neutrino experiments: complementary role of oscillation experiments and β decay experiments
- β decay expts can imptove bounds on the lightest mass, m_0 and on the radius R_{ED}
- For normal hierarchy, we can get $m_0 < 0.2$ eV at 90 % C.L. and for inverted hierarchy we improve the bound on $R_{ED} : 610^{-7} \to 2 \times 10^{-7}$ m and also improve bounds on m_0

Rigid body dynamics

- Coriolis acceleration

$$\vec{a}_p = \vec{a}_o + \frac{{}^b d^2}{dt^2}\vec{r} + \boxed{2\vec{\omega}_{ib} \times \frac{{}^b d}{dt}\vec{r}} + \vec{\alpha}_{ib} \times \vec{r} + \boxed{\vec{\omega}_{ib} \times (\vec{\omega}_{ib} \times \vec{r})}$$

- Transversal acceleration
- Centripetal acceleration

Rigid body dynamics

- Coriolis acceleration

$$\vec{a}_p = \vec{a}_o + \frac{{}^b d^2}{dt^2}\vec{r} + \boxed{2\vec{\omega}_{ib} \times \frac{{}^b d}{dt}\vec{r}} + \vec{\alpha}_{ib} \times \vec{r} + \boxed{\vec{\omega}_{ib} \times (\vec{\omega}_{ib} \times \vec{r})}$$

- Transversal acceleration
- Centripetal acceleration

Rigid body dynamics

- Coriolis acceleration

$$\vec{a}_p = \vec{a}_o + \frac{{}^b d^2}{dt^2}\vec{r} + \boxed{2\vec{\omega}_{ib} \times \frac{{}^b d}{dt}\vec{r}} + \vec{\alpha}_{ib} \times \vec{r} + \boxed{\vec{\omega}_{ib} \times (\vec{\omega}_{ib} \times \vec{r})}$$

- Transversal acceleration
- Centripetal acceleration