Running neutrino masses and extra dimensions

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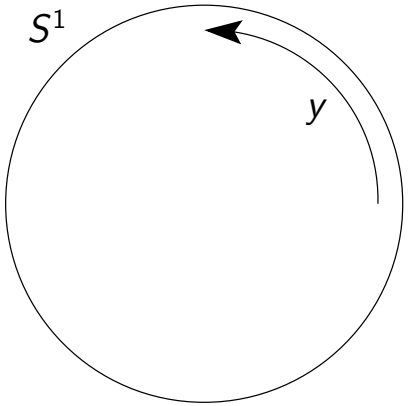
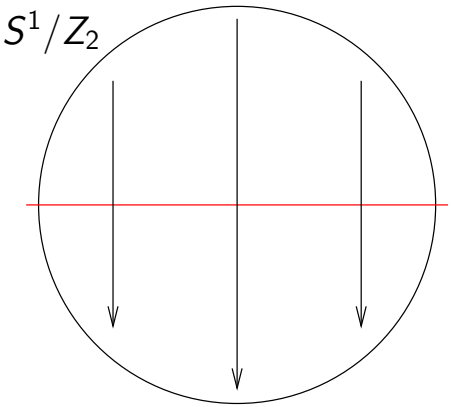
Mainly based on MB, Melbéus, Ohlsson, Zhang, submitted to JHEP, arXiv:1101.2858

1 Kaluza–Klein models

KK models

- Simplest Kaluza–Klein model: One extra dimension compactified as the circle S^1
  - Quantized extra-dimensional momentum
  - KK masses as
    $m_n^2 = m_0^2 + p_5^2 = m_0^2 + (n/R)^2$





- Orbifold compactification: $S^1/\mathbb{Z}_2$
  - Non-conservation of extra-dimensional momentum - remaining $\mathbb{Z}_2$ KK parity
  - Fix points at boundaries $\Rightarrow$ boundary localized terms (BLTs)

Two example models

Universal Extra Dimensions (UED)

Appelquist, Cheng, Dobrescu, PRD64, 035002 (2001), hepph/0012100

- All particles propagate in bulk
- KK towers for all particles

Fermions on the brane

Dienes, Dudas, Gherghetta, NPB537, 47 (1999), hep-ph/9806292

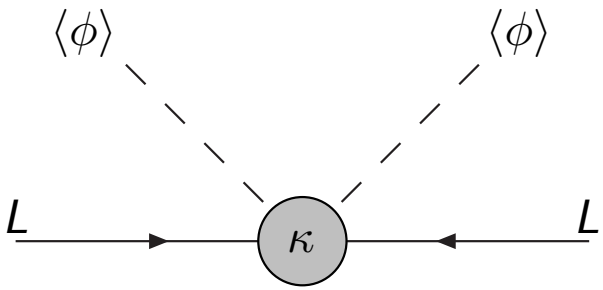
- Fermions restricted to a brane
- Only bosons have KK towers

KK theories are non-renormalizable, we will use a cutoff scale such that the height of the towers is 50 and take $R^{-1} = 1$ TeV

RGE running of neutrino masses and mixings

- Neutrino masses are described by the Weinberg operator

$$\mathcal{L}_{m_\nu} = -\frac{1}{2}\overline{L}\phi\kappa\phi^T L^c + \text{h.c.}$$



$$m_\nu = \kappa v^2$$

- Running is given by

$$16\pi^2 \frac{\mathrm{d}\kappa}{\mathrm{d}\ln\mu} = \beta_\kappa^{\mathrm{SM}} + \beta_\kappa^{\mathrm{ED}}$$

- The standard model contribution

$$\beta_\kappa^{\mathrm{SM}} \propto \kappa$$

Running in extra dimensions

- With extra dimensions

$$\beta_\kappa^{\mathrm{ED}} \propto s(\mu)\kappa$$

$s(\mu)$ counts accessible KK modes and grows linearly with μ
$\Rightarrow$ effective powerlaw running of ν parameters above KK scale

Dienes, Dudas, Gherghetta, NPB537, 47 (1999), hep-ph/9806292

General questions:

See also: Bhattacharyya et al., NPB760, 117 (2007); Cornell, Liu (2010), arXiv:1010.5522; Abel, King, PRD59, 095010 (1999); Bhattacharyya, Goswami, Raychaudhuri, PRD66, 033008 (2002)

- How fast can the running be?
- What high-energy models (mixing patterns) are possible?

Numeric analysis

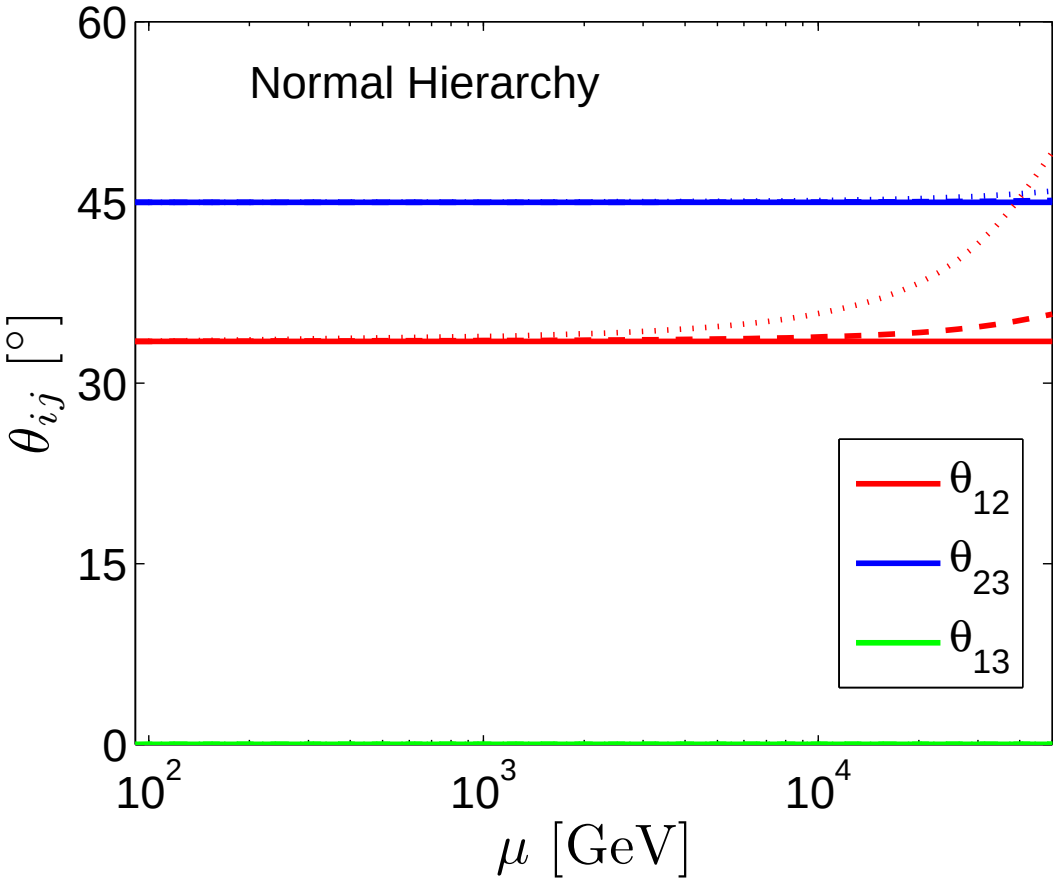
- We compute the running of the neutrino mixing matrix U

$$\kappa_{\text{diag}} = U^\dagger \kappa U^*$$

- We sample the (measured) low-energy parameters with a Markov Chain Monte Carlo to infer the possible high-energy values
- Approximately ($\zeta_{ij} = (m_i + m_j)/(m_i - m_j)$)

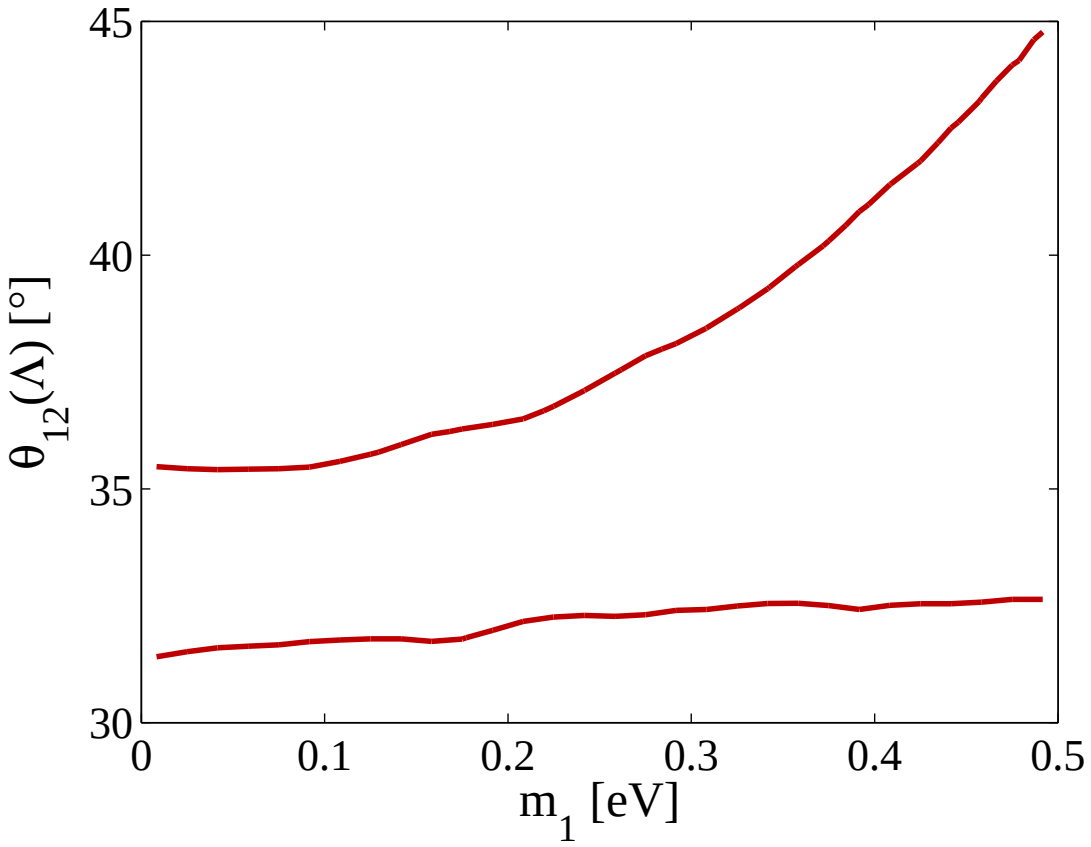
$$\begin{aligned}
\dot{\theta}_{12} &\propto \frac{3}{2} s \zeta_{12} s_{12} c_{12} s_{23}^2 c_{\rho-\sigma}^2 y_\tau^2 \,, \\
\dot{\theta}_{23} &\propto \frac{3}{2} s \zeta_{13} s_{23} c_{23} \left(s_{12}^2 c_\rho^2 + c_{12}^2 c_\sigma^2 \right) y_\tau^2 \,, \\
\dot{\theta}_{13} &\propto \frac{3}{2} s \zeta_{13} s_{12} c_{12} s_{23} c_{23} \left(c_\sigma c_{\delta+\sigma} - c_\rho c_{\delta+\rho} \right) y_\tau^2 \,,
\end{aligned}$$

Typical running



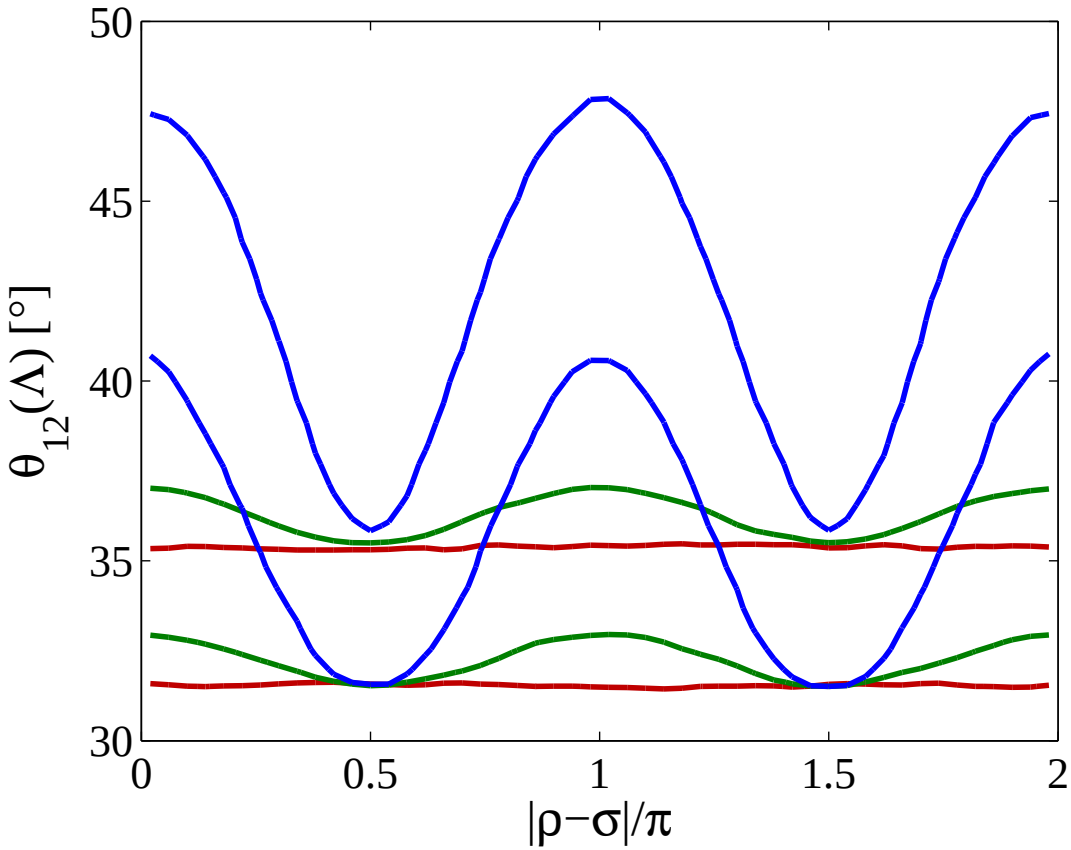
UED, normal mass hierarchy

Running dependence on neutrino masses



UED, normal mass hierarchy

Running dependence on majorana phases



UED, normal mass hierarchy, $m_1 = 0,\ 0.2,\ 0.5$ eV

Remarks

- Even if neutrino parameters run significantly at relatively low energies:
  - Neutrino experiments typically have very low energy scales in comparison
  - UHE neutrinos would be a possibility, but sources and interactions not under control

    See, e.g., Bustamante, Gago, Jones-Perez, arXiv:1012.2728
- Thus, results are mainly of theoretical/model building interest

Conclusions

- We have computed the running of neutrino mixing parameters in extra-dimensional models and inferred the allowed region for the high-energy parameters
- For the high-energy mixing, it is ...
  - ... possible to accomodate bi-maximal mixing or tri-bi-maximal mixing, depending on the Majorana phases
  - ... not possible to accomodate small θ_{12} at the high scale