

The Fourth Generation in Extensions of the Standard Model

Erin De Pree

St. Mary's College of Maryland

Gardner Marshall, Marc Sher

The College of William & Mary

THE PUBLIC HONORS COLLEGE



St. Mary's College of Maryland
at Historic St. Mary's City



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Outline

- Fourth Generation
sequential, massive right-handed neutrino
 - History
 - Motivation
- Extensions
 - Warped Extra Dimensions
 - Two Higgs Doublet Models

History

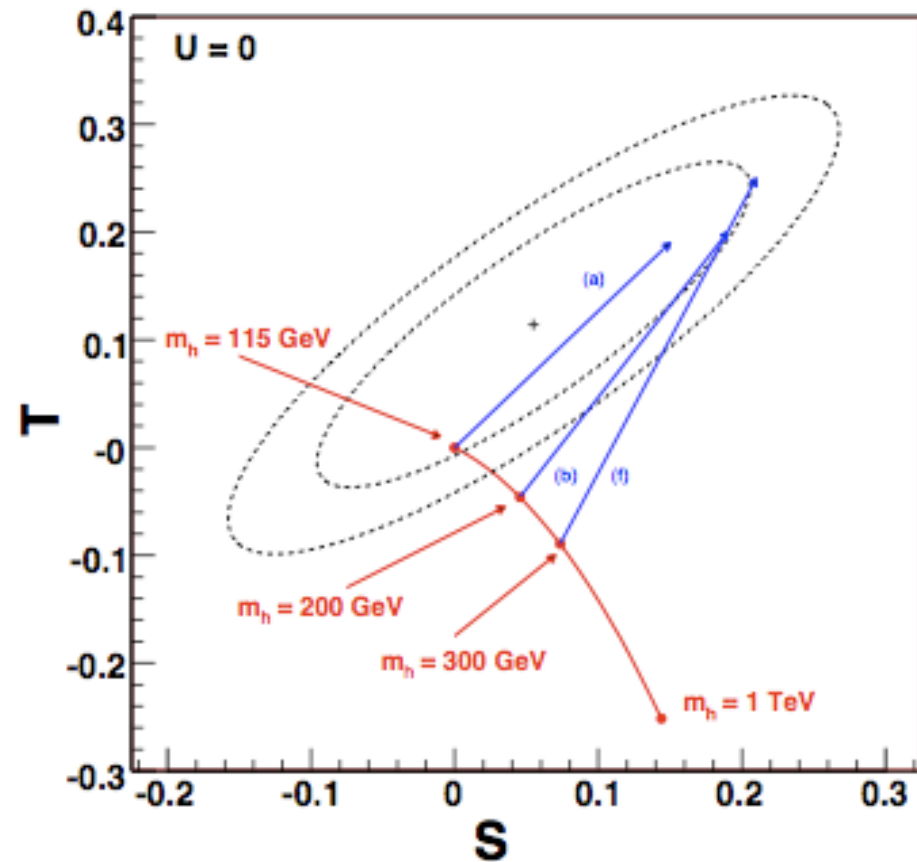
- late 1970's – 3rd family discovered, why not 4?
- 1990 – Z-boson limits number of massless neutrinos to 3
- late 1990's – neutrinos have mass
- early 2000's – precision electroweak fits

Precision electroweak fits

- PDG 2006
 - A fourth generation of ordinary fermions is excluded to 99.999% CL on the basis of the S parameter alone
 - For degenerate masses only
- Kribs, Plehn, Spannowsky, and Tait, 2007
 - Reminded that the PDG analysis assumed degenerate masses. Studied non-degenerate.

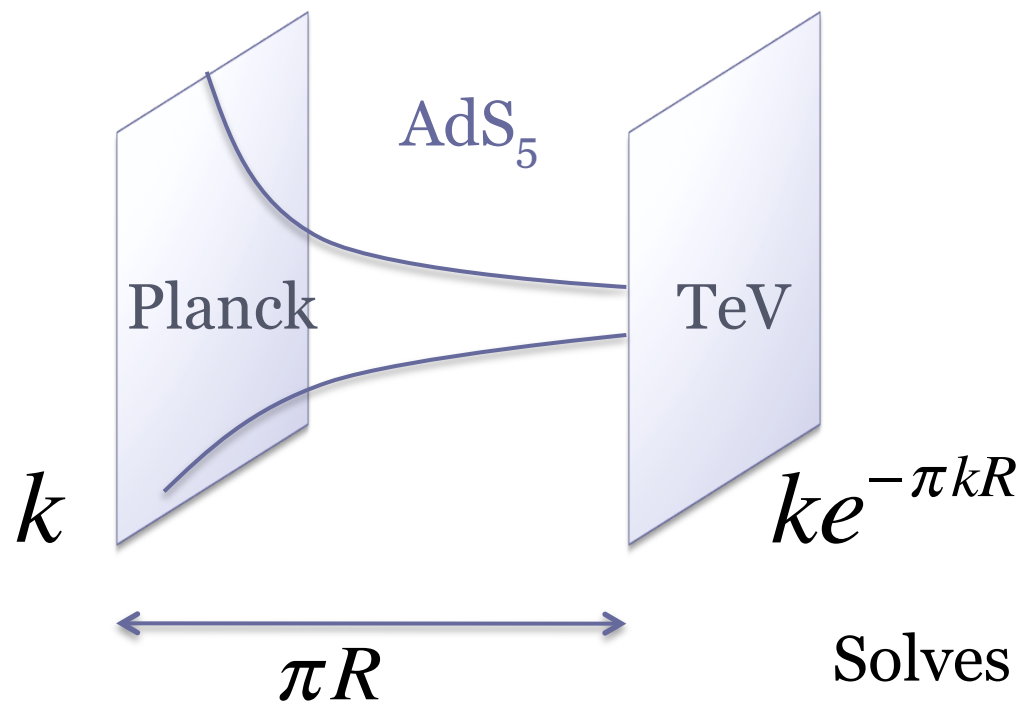
Non-degenerate masses

- For example:
 - $M_{\text{avg}} = 350 \text{ GeV}$
 - $\Delta m = 50 \text{ GeV}$



Warped extra dimension

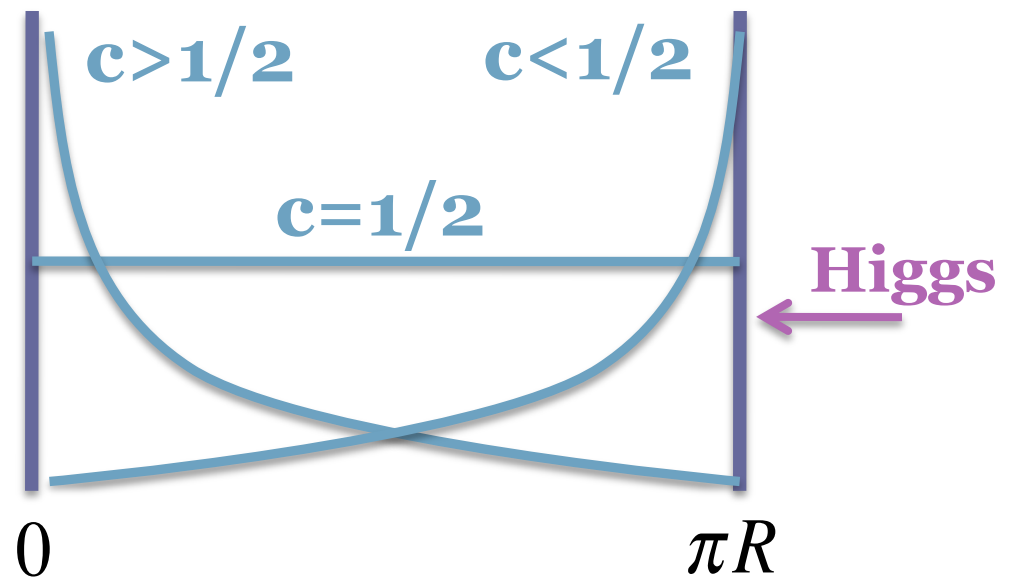
$$ds^2 = e^{-2k|z|} \eta_{\mu\nu} dx^\mu dx^\nu - dz^2$$



Solves the hierarchy problem if
 $kR \sim 11 - 12$

SM fields move into the bulk!

- Allowed
- c – mass parameter
- Flavor hierarchy is determined by fermion geography



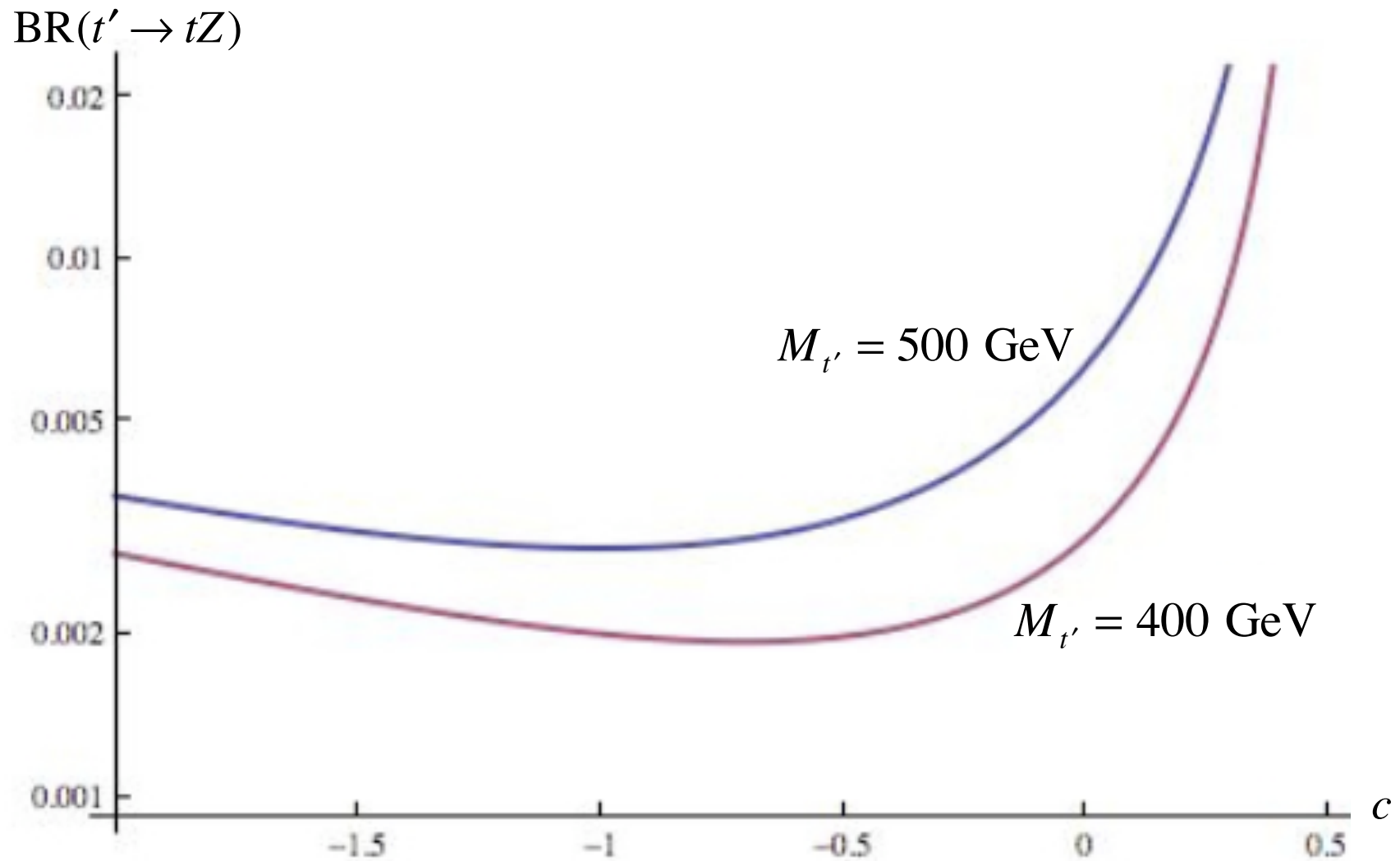
Consequences of fermions in the bulk

- t, b couple more strongly to KK- Z
 - KK- Z mixes with Z modifying $Zt\bar{t}$ and $Zb\bar{b}$ interactions
- $Zb\bar{b}$ coupling well measured, b must be kept away from TeV brane
- t_L also kept away from brane.
- Tension between large top mass and $Zb\bar{b}$ correction

More consequences of fermions in the bulk

- 5-D mass terms are diagonal
 - Not the same basis as 4-D mass basis
 - Allows flavor changing couplings in SM
- Add a 4th generation in the bulk
 - No EW precision constraints
 - Large flavor changing neutral currents

Warped extra dimension



Two Higgs doublet model

$$\langle \phi_1 \rangle = \begin{pmatrix} 0 \\ v_1 \end{pmatrix}$$

$$\langle \phi_2 \rangle = \begin{pmatrix} 0 \\ v_2 e^{i\xi} \end{pmatrix}$$

$$\tan \beta = \frac{v_2}{v_1}$$

- Higgs sector:
 - H^\pm – charged Higgs pair
 - H, h – neutral scalars
 - A – neutral pseudoscalar

Model II

- d, s, b, b' couple to ϕ_1
- u, c, t, t' couple to ϕ_2
- Limits $\tan \beta$

$$\frac{1}{\sqrt{2\pi(v/M)^2 - 1}} < \tan \beta < \sqrt{2\pi(v/M)^2 - 1}$$

for $M > 280 \text{ GeV}$

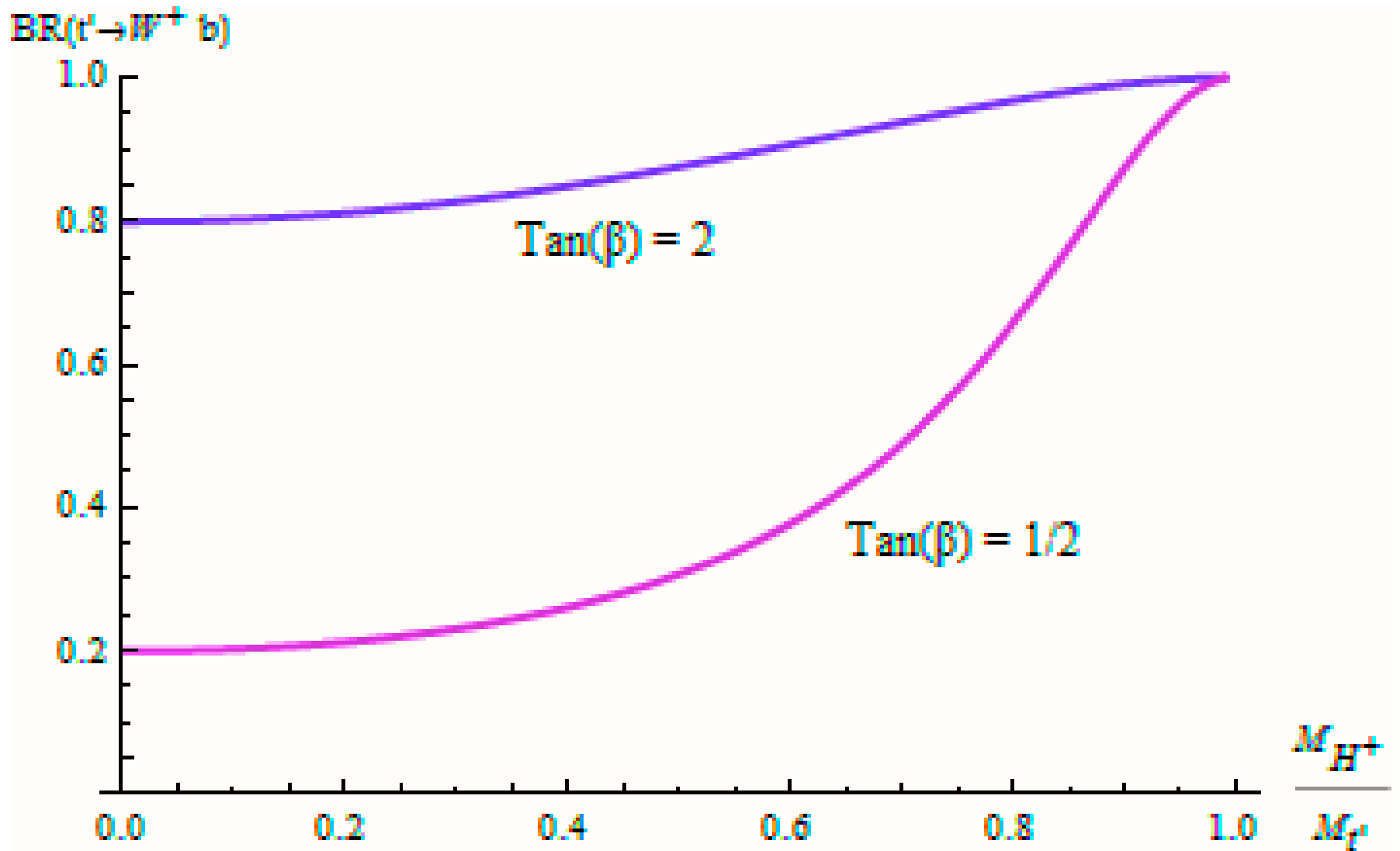
$$\frac{1}{2} < \tan \beta < 2$$

Model I

- All fermions couple to ϕ_2
- Only have a lower bound

$$\frac{1}{2} < \tan \beta$$

$$t' \rightarrow H^+ b$$



Model III

- All fermions couple to both ϕ_1 and ϕ_2
- Tree level FCNC:

$$\square \lambda_{ij} \frac{\sqrt{m_i m_j}}{v / \sqrt{2}} \bar{f}_i f_j \phi$$

- $\phi = h, H, \text{ or } A$ (scalar or pseudoscalar)

Model III

- $t' \rightarrow t\phi$ dominates (if allowed)
- Cross-section
 - For $t' = 400$ GeV
 - 15 pb (arXiv:hep-ph/9801375)
- Leads to $t\bar{t}\phi\phi$ signature

$$m_\phi < 140 \text{ GeV}$$

- Final state $6b \ 2W$
- LHC b tagging efficiency of 40%
 - Look for 3 or more tagged b 's
 - Background: $t\bar{t}b\bar{b}$ production – $4b \ 2W$ final state
 - Signal = 3150 fb
 - Background = 160 fb

$$m_{\phi} > 140 \text{ GeV}$$

- Final state: $2b$ $6W$
 - Look for: 3+ leptons
1+ b 's
 - No known background
 - Signal = 1.8 pb

Conclusions

- 4th generation is allowed
- Warped Extra Dimensions
 - Noticeable BR changes
- Two Higgs Doublet Model
 - Model III – dramatic signature

ekdepree@smcm.edu

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