Material zur

Vorlesung ”Flavorphysik”

Gudrun Hiller, Dortmund

Running fermion masses (SM)

TABLE IV. Running quark and lepton masses above M_Z in the SM with $m_H = 140$ GeV, where the uncertainties of $m_f(\mu)$ result from those of $m_f(M_Z)$. Here we have used $\Lambda_{\rm GUT} = 2 \times 10^{16}$ GeV. Case A and case B represent two different neutrino mass patterns with $m_1(M_Z) = 0.001$ eV and $m_1(M_Z) = 0.2$ eV, respectively.

	$\mu = M_Z$	$\mu = 1$ TeV	$\mu = 10^9$ GeV	$\mu = 10^{12}$ GeV	$\mu = \Lambda_{\rm GUT}$
$m_u(\mu)$ (MeV)	$1.27^{+0.50}_{-0.42}$	$1.10^{+0.43}_{-0.37}$	$0.67^{+0.27}_{-0.23}$	$0.58^{+0.24}_{-0.20}$	$0.48^{+0.20}_{-0.17}$
$m_d(\mu)$ (MeV)	$2.90^{+1.24}_{-1.19}$	$2.50^{+1.08}_{-1.03}$	$1.56^{+0.69}_{-0.65}$	$1.34^{+0.60}_{-0.56}$	$1.14^{+0.51}_{-0.48}$
$m_s(\mu)$ (MeV)	55^{+16}_{-15}	47^{+14}_{-13}	30^{+9}_{-8}	26^{+8}_{-7}	22^{+7}_{-6}
$m_c(\mu)$ (GeV)	0.619 ± 0.084	$0.532^{+0.074}_{-0.073}$	$0.327^{+0.048}_{-0.047}$	$0.281^{+0.042}_{-0.041}$	$0.235^{+0.035}_{-0.034}$
$m_b(\mu)$ (GeV)	2.89 ± 0.09	2.43 ± 0.08	1.42 ± 0.06	1.21 ± 0.05	1.00 ± 0.04
$m_t(\mu)$ (GeV)	171.7 ± 3.0	150.7 ± 3.4	$99.1^{+4.0}_{-3.8}$	$86.7^{+4.0}_{-3.8}$	$74.0^{+4.0}_{-3.7}$
$m_e(\mu)$ (MeV)	$0.486570161 \pm 0.000000042$	$0.495901601 \pm 0.000000043$	$0.501014122 \pm 0.000000043$	$0.490856087^{+0.000000042}_{-0.000000043}$	$0.469652046 \pm 0.000000041$
$m_\mu(\mu)$ (MeV)	$102.7181359 \pm 0.0000092$	$104.6880645^{+0.0000094}_{-0.0000093}$	$105.7673562^{+0.0000095}_{-0.0000094}$	$103.6229311^{+0.0000092}_{-0.0000093}$	99.1466226 ± 0.0000089
$m_\tau(\mu)$ (MeV)	$1746.24^{+0.20}_{-0.19}$	1779.74 ± 0.20	$1798.11^{+0.21}_{-0.20}$	1761.67 ± 0.20	1685.58 ± 0.19

Xing et al, 0712.1419 [hep-ph]; assumption: desert (just SM) between m_Z and Λ_{GUT}.

Running fermion masses (MSSM)

TABLE V. Running quark and lepton masses above M_Z in the MSSM with $\tan\beta = 10$, where the matching effect between the MS and MSSM and the $\overline{\rm MS}$-to-$\overline{\rm DR}$ transition effect on the input parameters at M_Z have been taken into account.

	$\mu = M_Z$	$\mu = 1$ TeV	$\mu = 10^9$ GeV	$\mu = 10^{12}$ GeV	$\mu = \Lambda_{\rm GUT}$
$m_u(\mu)$ (MeV)	$1.27^{+0.50}_{-0.42}$	$1.15^{+0.45}_{-0.38}$	$0.75^{+0.30}_{-0.25}$	$0.62^{+0.26}_{-0.21}$	$0.49^{+0.20}_{-0.17}$
$m_d(\mu)$ (MeV)	$2.90^{+1.24}_{-1.19}$	$2.20^{+0.96}_{-0.91}$	$1.21^{+0.54}_{-0.51}$	$0.96^{+0.43}_{-0.40}$	$0.70^{+0.31}_{-0.30}$
$m_s(\mu)$ (MeV)	55^{+16}_{-15}	42 ± 12	23 ± 7	18^{+6}_{-5}	13 ± 4
$m_c(\mu)$ (GeV)	0.619 ± 0.084	$0.557^{+0.077}_{-0.076}$	$0.363^{+0.053}_{-0.052}$	$0.303^{+0.046}_{-0.045}$	$0.236^{+0.037}_{-0.036}$
$m_b(\mu)$ (GeV)	2.89 ± 0.09	2.23 ± 0.08	1.30 ± 0.05	1.05 ± 0.05	0.79 ± 0.04
$m_t(\mu)$ (GeV)	171.7 ± 3.0	$161.0^{+3.7}_{-3.6}$	$125.2^{+7.1}_{-6.5}$	$111.0^{+8.5}_{-7.4}$	$92.2^{+9.6}_{-7.8}$
$m_e(\mu)$ (MeV)	$0.486570161 \pm 0.000000042$	$0.418436115 \pm 0.000000036$	$0.358332424 \pm 0.000000031$	$0.327996884^{+0.000000028}_{-0.000000029}$	$0.283755495^{+0.000000024}_{-0.000000025}$
$m_\mu(\mu)$ (MeV)	$102.7181359 \pm 0.0000092$	88.3347018 ± 0.0000079	75.6468538 ± 0.0000068	69.2429377 ± 0.0000062	59.9033617 ± 0.0000054
$m_\tau(\mu)$ (MeV)	$1746.24^{+0.20}_{-0.19}$	1502.25 ± 0.17	1288.68 ± 0.15	$1180.38^{+0.13}_{-0.14}$	$1021.95^{+0.11}_{-0.12}$

Xing et al, 0712.1419 [hep-ph]; assumption: desert (just MSSM) between m_Z and Λ_{GUT}.

Hierarchies from geometry

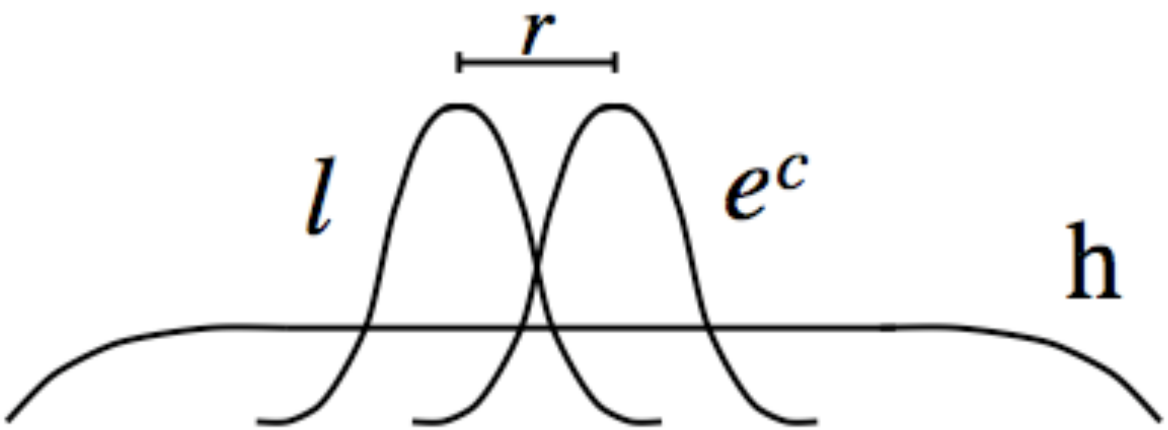
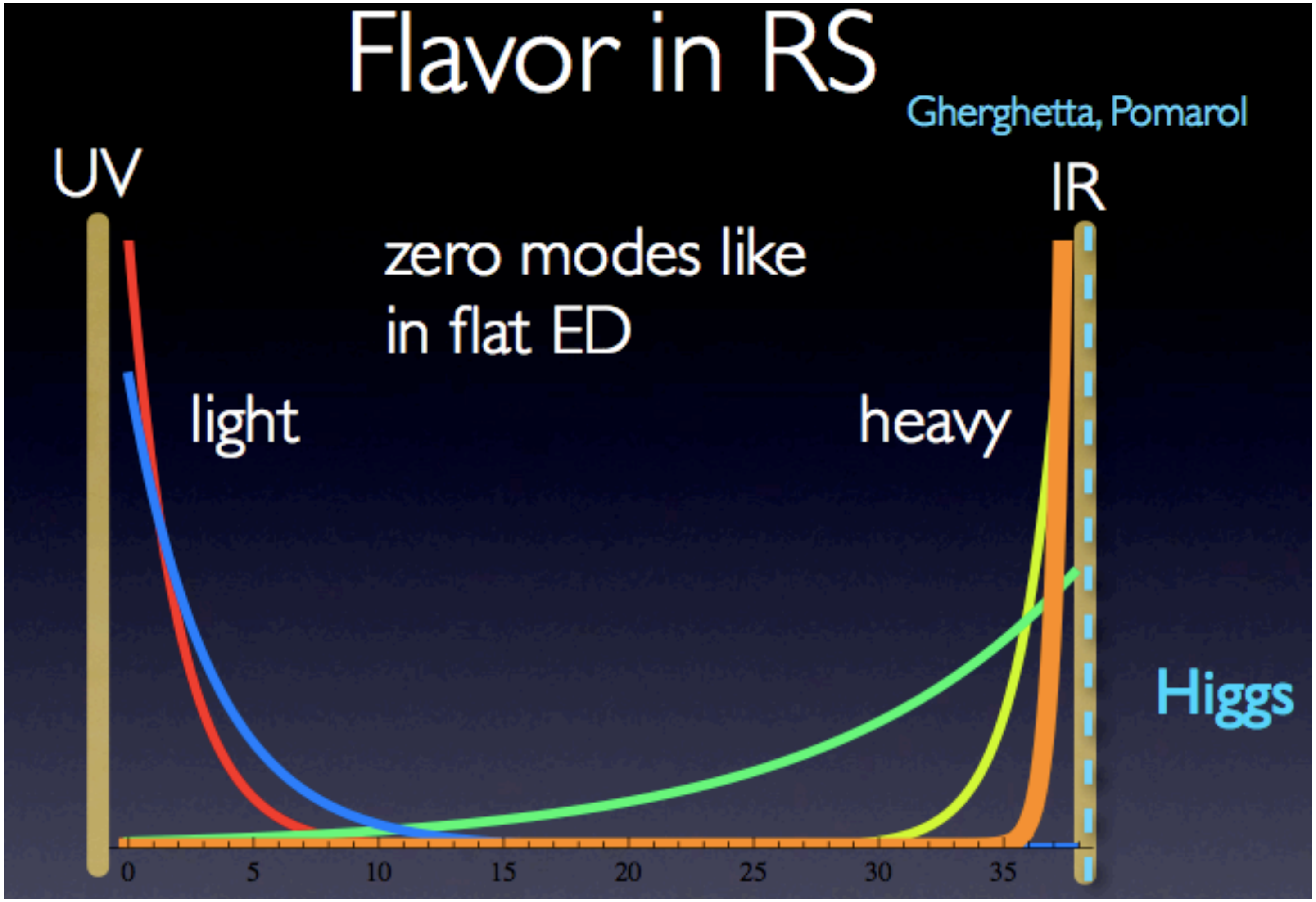


Figure 3: *Yukawa coupling: the Gaussian wave functions of the fermions* l *and* e^c *overlap only in an exponentially small region, suppressing the effective Yukawa coupling exponentially.*

Arkani-Hamed and Schmaltz, 9903417 [hep-ph]

Hierarchies from geometry/Warped Metric

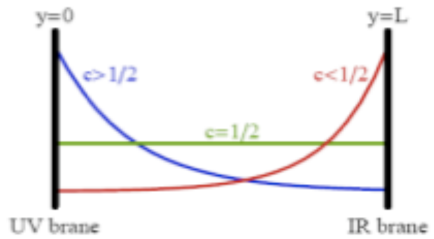


Andreas Weiler, Talk at Ringberg Workshop '09

RS= Randall, Sundrum

Flavor Problem & its Solution (2)

- Zero Modes of Fermions:



$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2 \ , \qquad 0 \le y \le L$$

$$f^{(0)}(y,c) = \sqrt{\frac{(1-2c)\,kL}{e^{(1-2c)kL}-1}}\,e^{\left(\frac{1}{2}-c\right)ky}$$

Strong dependence on bulk masses

- The Solution of the Flavor Problem:

I. 4D Yukawas in terms of shape functions:

$$Y_{ij} \propto \int_0^L \frac{dy}{L^{3/2}} \lambda_{ij} h(y) f_L^{(0)}(y,c^i)\, f_R^{(0)}(y,c^j)$$

5D Yukawas

λ_{ij} assumed to be **anarchical** and O(1)

Higgs localized on the IR brane: $h(y) = \sqrt{2(\beta-1)kL}\; e^{kL} e^{\beta k(y-L)} \ , \quad \beta > 1$

II. Result: slightly different c parameters of O(1) lead to a large hierarchy in Y_{ij}

Hierarchy of quark masses and mixings explained by a purely geometrical approach!

BUT Still missing a theory for the bulk masses

Numerical example:

$c_1 = 0.66 \ , \ c_2 = 0.59 \ , \ c_3 = 0.41$

$Y_1 = 0.0017 \ , \ Y_2 = 0.017 \ , \ Y_3 = 0.42$

Anthropic fermion masses

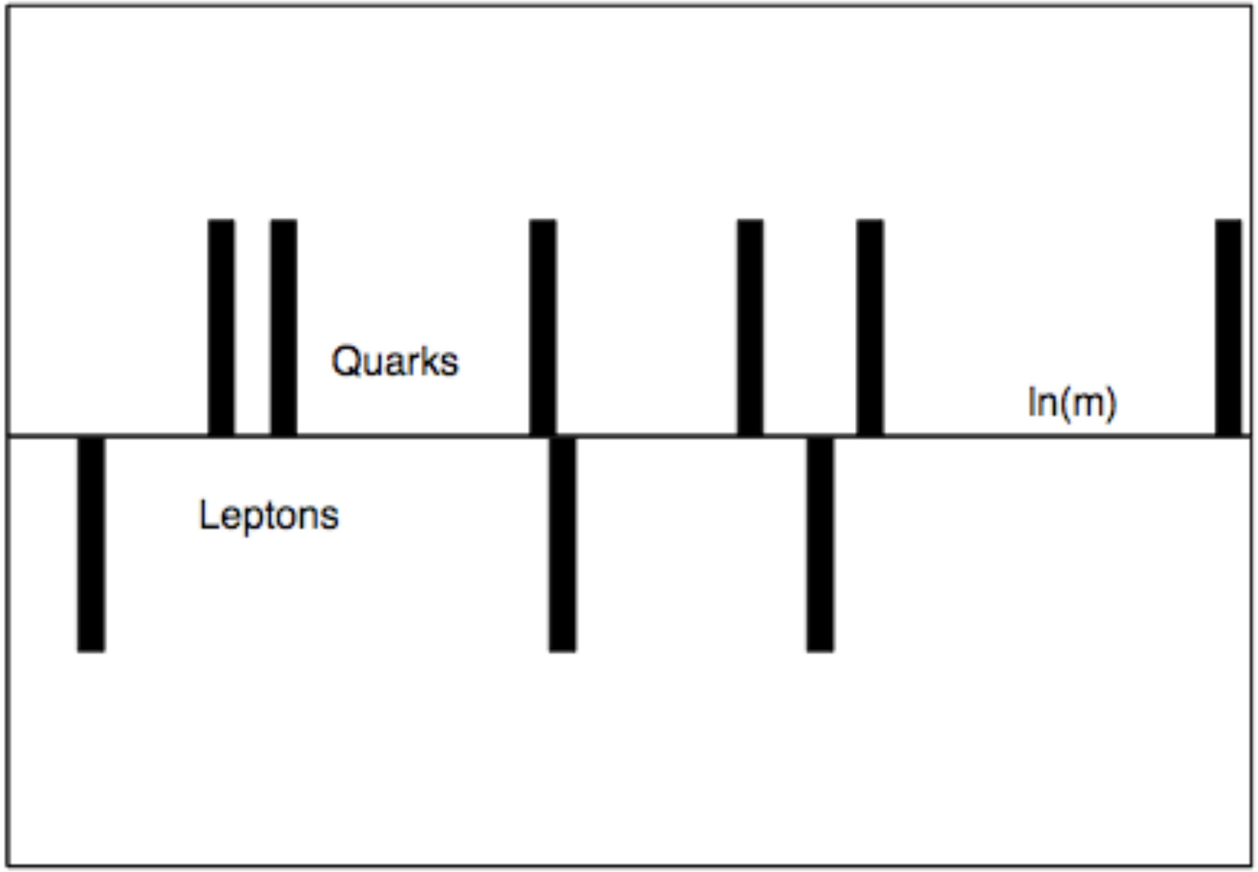


Figure 1: The quark and lepton masses on a log scale. The result appears visually to be consistent with a random distribution in $\ln m$, and quantitative analysis bears this out.

Donoghue, 0710.4080 [hep-ph]

Anthropic CP violation

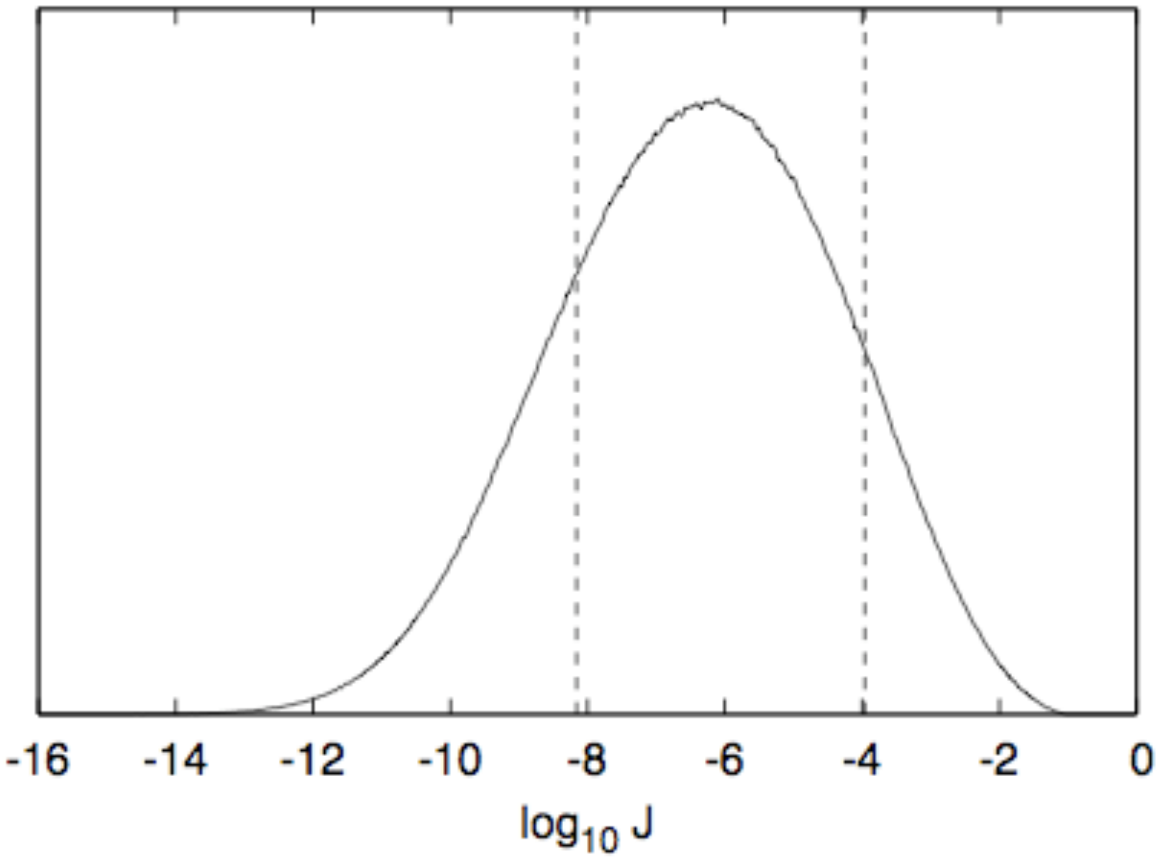


Figure 13: The Jarlskog invariant for quarks describing the magnitude of CP violation

Donoghue et al, 0511219 [hep-ph] $J = Im[V_{ud}V_{cs}V^*_{us}V^*_{cd}] = (2.9 \pm 0.3) \cdot 10^{-5}$