SU(5)-type unification of Yukawa couplings of fermions in MSSM

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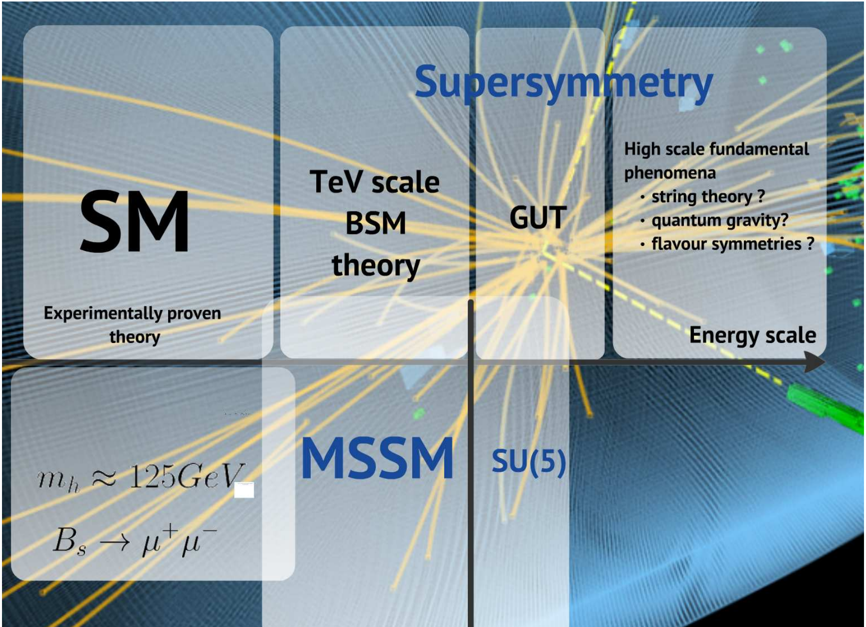
Planck 2013: From the Planck Scale to the Electroweak Scale
Bonn, 21.05.2013

MSSM: From the GUT scale to the Electroweak Scale



Problem's anatomy in SU(5)

In SM and MSSM the fermion masses are independent parameters and are given by 3 Yukawa matrices:

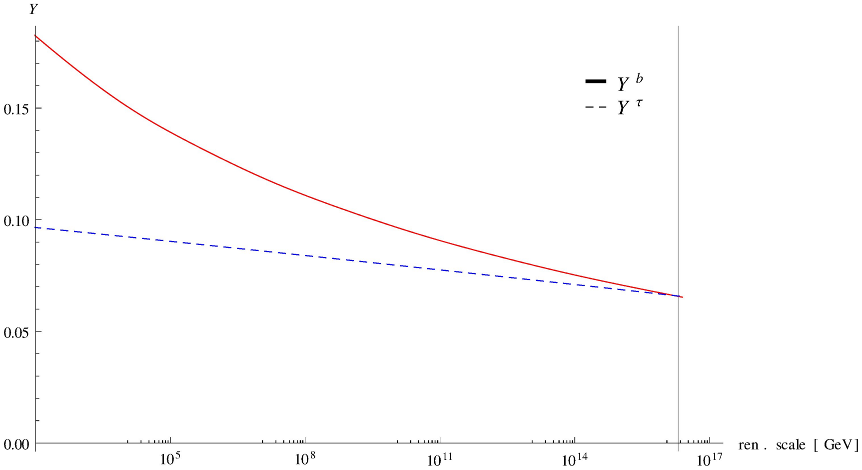
$$
\begin{aligned}
Y^u &\rightarrow m_u,\ m_c,\ m_t \\
Y^d &\rightarrow m_d,\ m_s,\ m_b \\
Y^e &\rightarrow m_e,\ m_\mu,\ m_\tau
\end{aligned}
$$

In SU(5) Supersymmetric Grand Unified Theory the symmetry requires:

$$Y_d = Y_e,\ Y_s = Y_\mu,\ Y_b = Y_\tau$$

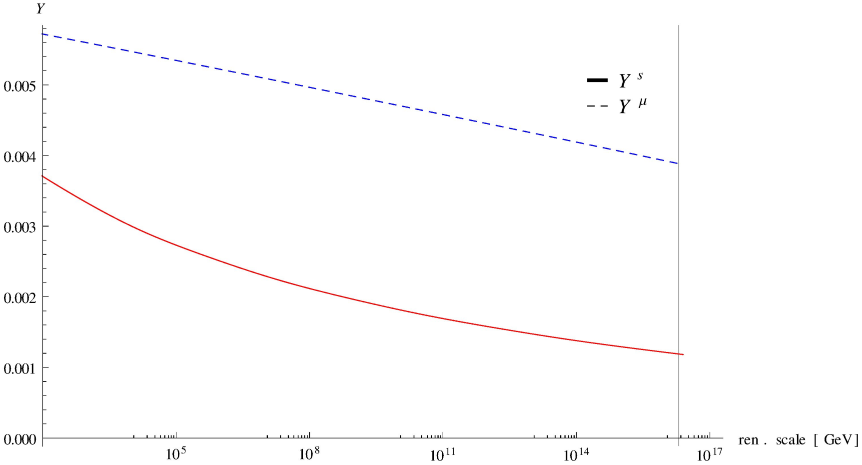
Yukawa unification

Succesful unification of bottom and tau Yukawa couplings: $\tan\beta = 10$, $M_{1/2} = m_0 = 600\,GeV$, $A^{de} = 0$



Yukawa unification

Unsuccesful unification of strange and mu Yukawa couplings:
$\tan\beta = 10$, $M_{1/2} = m_0 = 600\,GeV$, $A^{de} = A^{u} = 0$



Yukawa unification - Solution 1 - fix GUT structure

Change the boundary condition at the high scale

- non-minimal representations of Higgs superfields
- correction O(1) from higher-dim. operators
  - original idea accompanying GUTs in '70s
  - many modern treatments: 0903.2793, 1009.6000, 1101.5423, 1109.3396, 1211.0516
  - also with other mechanisms: 1211.6529, 1202.4012

Yukawa unification - Solution 2

Manipulate the boundary condition between SM and MSSM - play with treshold corrections

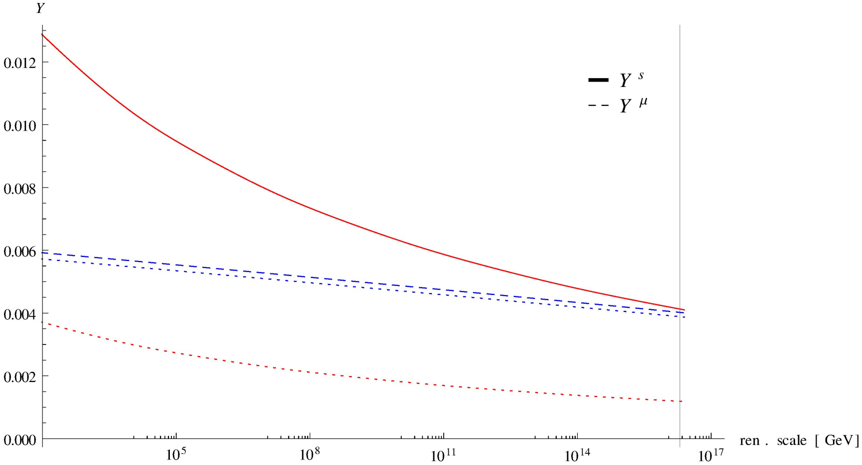
'06 Diaz-Cruz, Murayama, Pierce, arXiv: hep-ph/0012275

Our analysis:

- full 1-loop chirality changing treshold corrections in MSSM (implemented as modification to Softsusy 3.3.5 Allanach, hep-ph/0104145)
- simpler ansatz
- no tension with flavour observables - heavy gluino (calculated with SUSY Flavor 2.02 Crivellin, Rosiek, Chankowski, Dedes, Jaeger, Tanedo, 1203.5023)

Yukawa unification - Solution 2

Manipulate the boundary condition between SM and MSSM - play with treshold corrections



(dotted - running for unadjusted lower boundary condition)

Relevant parameters

Soft-supersymmetry breaking terms in MSSM:

$$\mathcal{L}_{soft} \ni \tilde{q}\mathbf{A}^u\tilde{u}h_u + \tilde{q}\mathbf{A}^d\tilde{d}h_d + \tilde{l}\mathbf{A}^e\tilde{e}h_d$$

Yukawa couplings can be unified within MSSM

with big diagonal A terms

making MSSM vacuum metastable

Dependencies on MSSM parameters

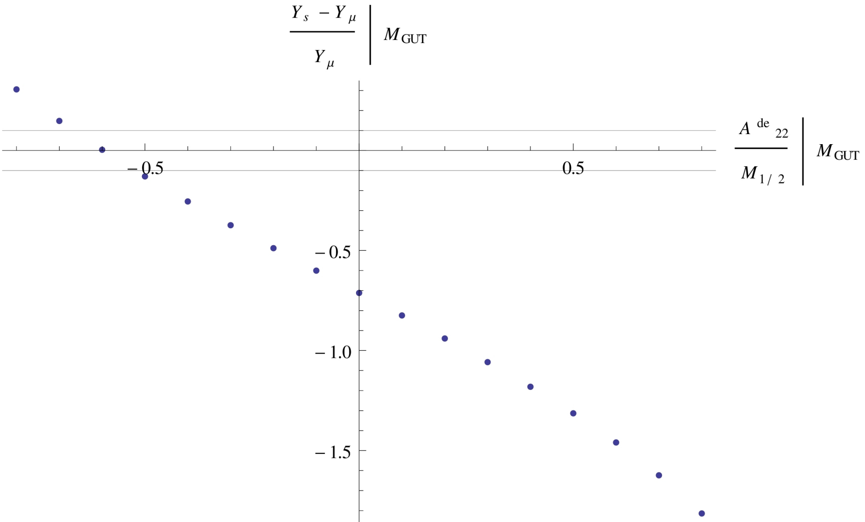
$\mathbf{A}^d_{ii}$ can be used to adjust the magnitude of treshold correction to achieve unification for given values of other parameters

$$Y^d_{ii} = \frac{m^d_i - \Sigma^{d_L R}_{\gamma}(\alpha_s m_{\tilde{g}} \mathbf{A}^d_{ii}, m_{\tilde{q}_i}, m_{\tilde{d}_i})}{v_d[1 + \tan\beta \cdot \epsilon^d(\mu, M1, M2, m_{\tilde{q}_i}, m_{\tilde{d}_i})]}$$

A. Crivellin, L. Hofer, J. Rosiek, JHEP 1107 (2011) 017 [arXiv:1103.4272]

Strange quark and muon

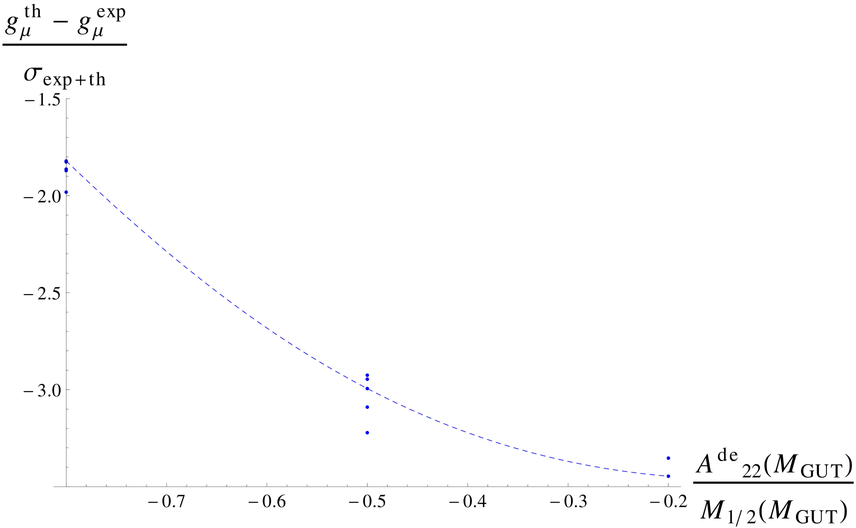
Yukawa couplings can be unified within MSSM with big A terms



for the 2nd family the shift has to be the biggest

Positive impact on $(g-2)_\mu$

$\tan\beta = 10,\ M_{1/2} = m_0 = 600\,GeV,\ \mu \in [-1000, -200]$



Relevant stability condition

Along the direction in space of scalar fields of MSSM where

$$|H_1| = |\tilde{s}_L| = |\tilde{s}_R|$$

a deeper, charge and color breaking minimum develops if A^d_{22} is of the order considered here. The absolute stability conditions (given by Casas, Lleyda, Munoz, arXiv: hep-ph/9507294)

$$\frac{A_{ii}}{Y_{ii}\tilde{m}} < O(1)$$

are violated:

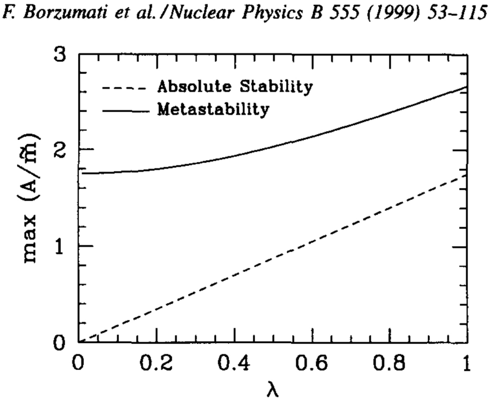
$$\rightarrow \frac{A_{22}}{Y_{22}\tilde{m}_2}(Q_{EWSB}) \approx 2 * 10^2$$

Metastable but durable

The decay time of the correct MSSM vacuum were longer than the age of the Universe if

$$\frac{A_{22}}{\tilde{m}} < 1.75$$

Borzumati, Farrar, Polonsky, Thomas Nuclear Physics B 555 (1999) 53-115:
is still satisfied in the considered model of Yukawa unification.



Conclusion

Yukawa couplings can be unified within MSSM

with big diagonal A terms

making MSSM vacuum metastable

Unavoidable?

Could we unify Y_s and Y_μ satisfying absolute stability bound, for which $A^{de}/\tilde{m} \leqslant 0.01$?

$$Y^d_{ii} = \frac{m^d_i - \Sigma^{d_L R}_{\tilde{\gamma}}(\alpha_s m_{\tilde{g}} \mathbf{A}^d_{ii}, m_{\tilde{q}_i}, m_{\tilde{d}_i})}{v_d[1 + \tan\beta \cdot \epsilon^d(\mu, M1, M2, m_{\tilde{q}_i}, m_{\tilde{d}_i})]}$$

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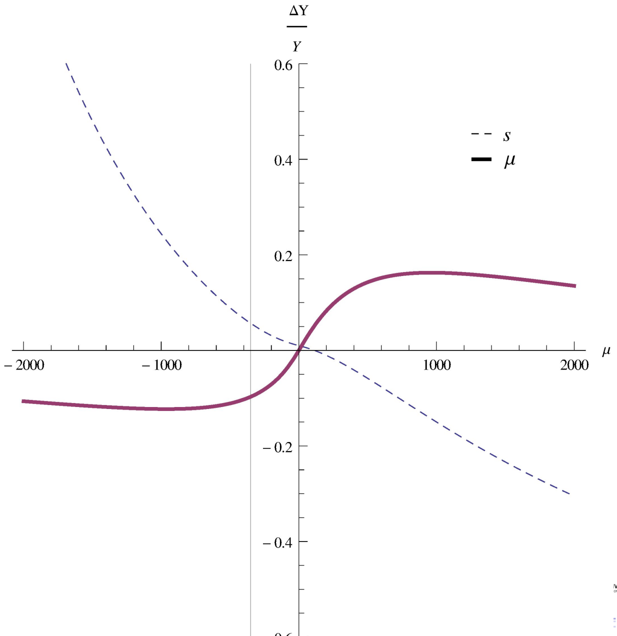
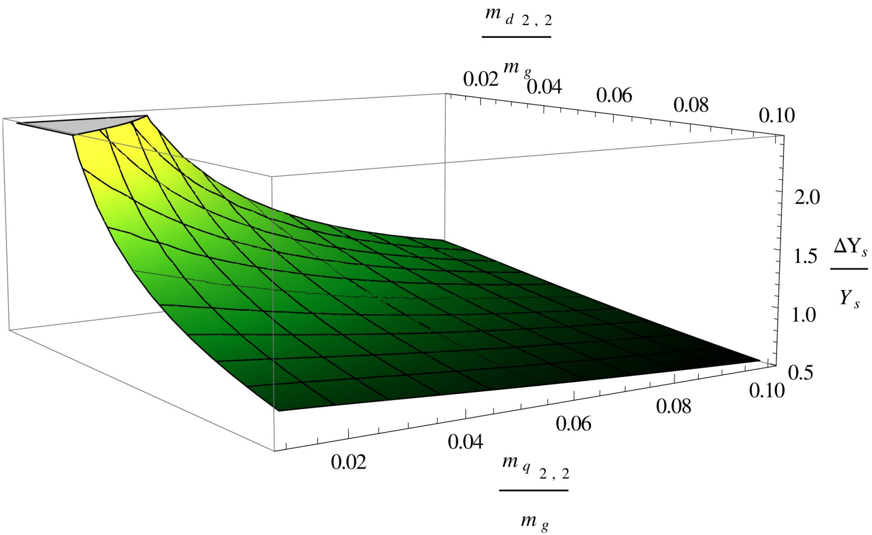
Just treshold corrections

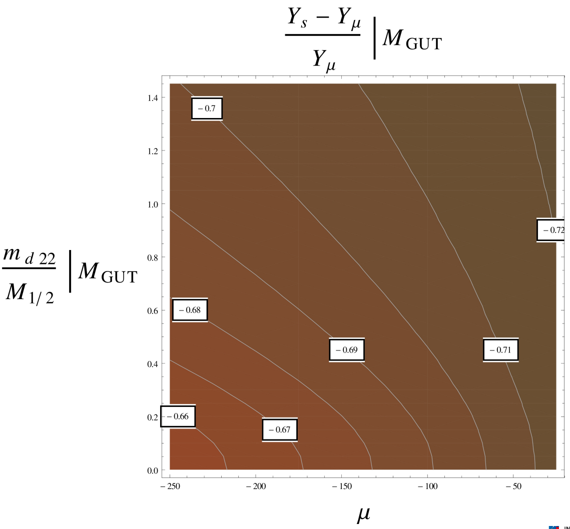


Impact of squark masses



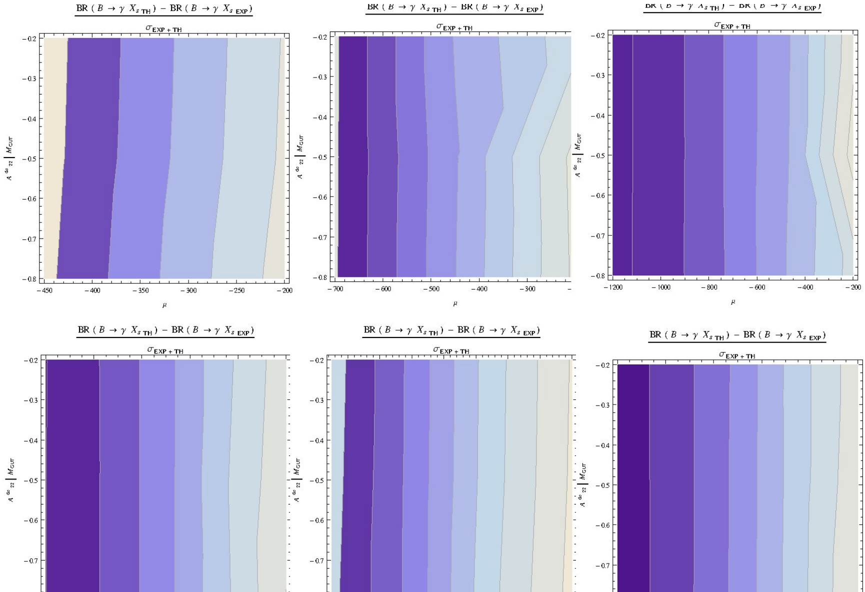
The actual scan

$\tan\beta = 40,\ M_{1/2} = m_0 = 600\,GeV,\ A^{de} = 0$



B to s gamma unaffected by Ade22

$\tan\beta = 10..40,\ M_{1/2} = m_0 = 600\,GeV$



Dominant corrections in complete form

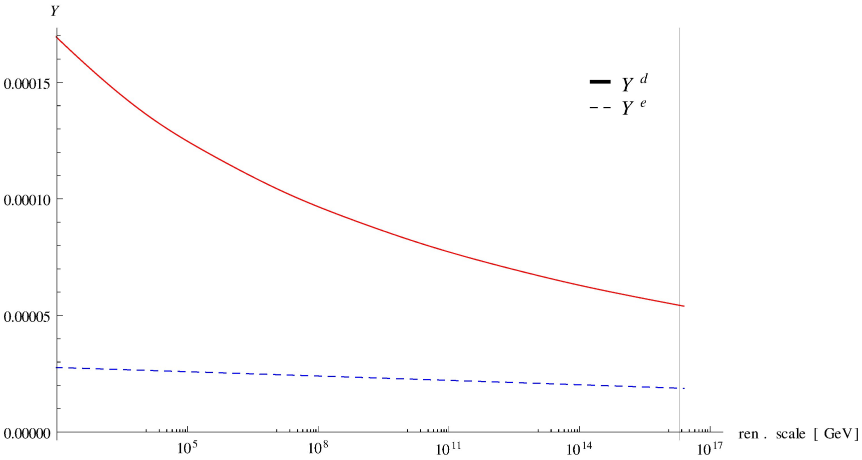
i - generation
Σ, ϵ - self-energies

$$m_{q_i} = v_q Y^{q_i} + \Sigma_{ii}^{q,LR}(Y^q)$$

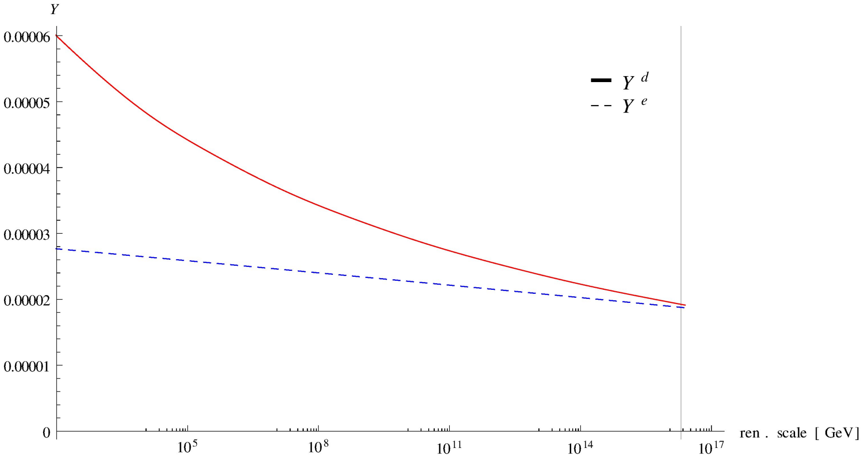
$$m_{d_i} = v_d Y^{d_i} + \Sigma_{ii}^{\not{Y}} + v_u Y^{d_i} \epsilon_i^d + O(\frac{v^2}{M_{SUSY^2}})$$

$$Y_{ii}^d = \frac{m_i^d - \Sigma_{\not{Y}}^{d_L R}}{v_d[1 + \tan\beta \cdot \epsilon^d]}$$

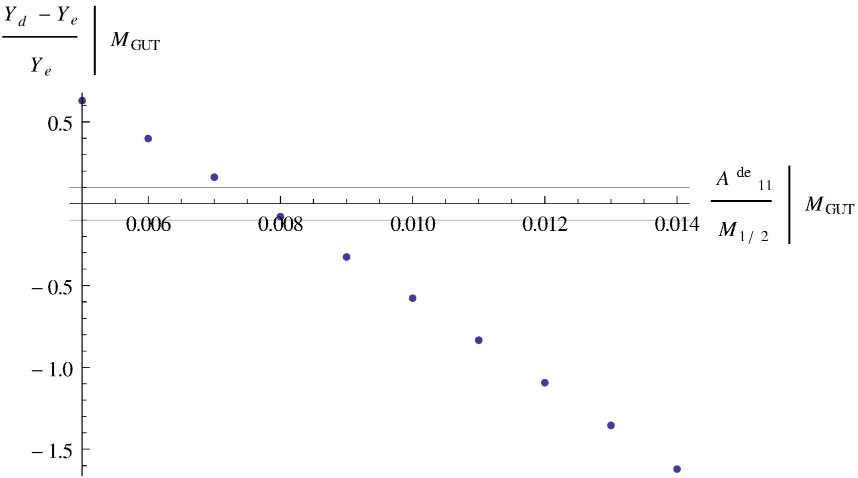
Down quark and electron 1



Down quark and electron 2



Down quark and electron 3



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