Yukawa unifications and SUSY thresholds

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Overview

- SUSY and finite radiative corrections.
- Motivation for non universality in SU(5) GUT.
- SUSY spectrum and the threshold corrections to quark masses.
- FCNC constraints on the spectrum: strange and charm sector.
- Rare decays: $K^+ \to \pi^+ \nu$, $D^+ \to \pi^+ \nu$.
- Summary and conclusions.

Supersymmetry

- Motivation for SUSY
  1. stabilize gauge hierarchy
  2. better gauge coupling unification
  3. dark matter
- SUSY breaking
  1. Over 100 new parameters beyond the SM
  2. new FCNC: $K\bar{K}$ mixing, $\mu \to e\gamma$
  3. new CPV phases $\to$ EDM.s for p, n and e^-
- To avoid the FCNC and CPV, SUSY breaking scenarios
  1. universal (mSUGRA, gauge mediation etc)
  2. decoupling (heavy sfermions)
  3. alignment (no off diagonal elements)
- In this talk
  1. Yukawa unification for all generations $\to$ deviation from universality

SUSY SU(5) GUT

- RGE $\rightarrow$ Gauge coupling & b–τ unifications :

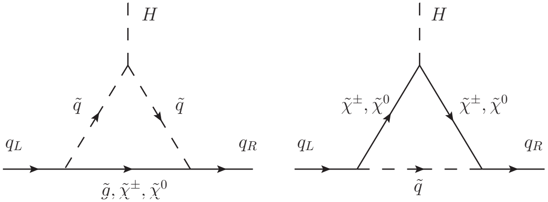
$$\alpha_U = \alpha_i \text{ and } Y_b \simeq Y_\tau \ (\sim 13 \div 24\%)$$

- For lighter generations $\rightarrow$ Wrong GUT relations

$$\frac{m_d}{m_s} \simeq \frac{m_e}{m_\mu} \quad \text{:GUT prediction}$$
$$\frac{m_d}{m_s} \sim O(10)\frac{m_e}{m_\mu} \quad \text{:Experiment}$$

- Solutions
  1. Extend Yukawa like interactions [Georgi Jarlskog, 1979] or higher dimensional operators.
  2. In this talk: Radiative corrections from threshold of heavy fields: Superpartners provide finite SUSY corrections to fermion masses [Buchmuller and Wyler 1983, Hall, Kostelecky and Raby 1986].

- Finite SUSY corrections to quark masses:
  gluino, neutralino, chargino – squark loops



The induced correction by gluino-loop (universal case) :

$$\begin{aligned} \delta m_d &\simeq -\frac{2}{3}\frac{\alpha_s}{\pi}\left(A_d - \mu Y_d \tan\beta\right) v_d m_{\tilde{g}} I(m_{\tilde{g}}^2, m_{\tilde{d}_1}^2, m_{\tilde{d}_2}^2) \\ &\simeq -\frac{\alpha_s}{3\pi}\frac{\left(a_0 - \mu\tan\beta\right) m_{\tilde{g}}}{\tilde{m}^2} m_d^0 \ \text{ for } \ A_f = Y_f a_0 \end{aligned}$$

where $\tilde{m} = Max(m_{\tilde{g}}, m_{\tilde{d}_1}, m_{\tilde{d}_2})$

- For universal soft parameters (usually the case for the lighter generations)

$$\frac{\delta m_d}{m_d^0} \simeq \frac{\alpha_s}{3\pi}\frac{\mu m_{\tilde{g}}}{\tilde{m}^2}\tan\beta \sim \mathsf{sign}(\mu m_{\tilde{g}})\frac{\alpha_s}{3\pi}\tan\beta \sim \pm O(1)$$

  Soft mass universality $\rightarrow$ the induced percentage is universal.

- Large $\tan\beta$:
  1. motivated by $SO(10)$ GUT
  2. induce large threshold corrections to m_{d_i}
     [Hall, Rattazzi and Sarid 1994].
  3. large FC effects: Higgs mediated $B_s \rightarrow \mu^+\mu^-$: [Babu and Kolda 1998].

$$Br(B_s \rightarrow \mu^+\mu^-) \sim \tan\beta^6$$

- In this talk : low and medium $\tan\beta$
  1. the threshold effects from A–term are easier to induce.

Non universality

- The SUSY thresholds are more prominent for quarks due to strong interaction $\rightarrow$
- $SU(5)$ condition: at M_{GUT} Y_{d_i} are set to Y_{l_i}
  1. The needed changes for light flavors (at $M_{SUSY} = 500$ GeV)

$$\frac{m_d^{exp}}{m_d^0} \simeq 2.5 \;\rightarrow\; \delta m_d \sim \text{ 1.5 MeV(-3.5 MeV) } \rightarrow\; \frac{\delta m_d}{m_d^0} \sim \text{ 1.5(-3.5)}$$

$$\frac{m_s^{exp}}{m_s^0} \simeq 0.25 \;\rightarrow\; \delta m_s \sim \text{-150 MeV } \rightarrow\; \frac{\delta m_s}{m_s^0} \sim \text{-0.75}$$

  2. Correcting the wrong GUT ratios by SUSY thresholds requires non universality!

     [Babu, Dutta and Mohapatra 1999]. , [Diaz Cruz,Murayama and Pierce 2001], [Antusch et al 2009].

- Two choices for non universality:
  1. Using different soft masses $\rightarrow$ large mass splitting in first two generation squarks. FCNC constraints may push the masses beyond the reach of LHC.
  2. Choice in this talk: Large A–terms subject to local stability condition.

Local vs Global MSSM minimum

- MSSM has many color/charge breaking vacua along D–flat directions.

  1. Condition for global minimum

     $$A_{ij} \lesssim \frac{Y_{ij}}{\sqrt{3}}\sqrt{\tilde{m}_i^2 + \tilde{m}_j^2 + \mu^2 + m_H^2} \text{ for interaction } A_{ij}\tilde{f}_i\tilde{f}_j H$$

     more stringent than $K^0 - \bar{K}^0$ mixing (not necessary)

     [Dimopoulos et al 1996]. .

  2. If the condition of local minimum

     $$A_{ij} \lesssim 1.75\sqrt{\tilde{m}_i^2 + \tilde{m}_j^2 + \mu^2 + m_H^2} \text{ for interaction } A_{ij}\tilde{f}_i\tilde{f}_j H$$

     satisfied, the lifetime of the vacuum is longer than the age of the universe.

     [Kusenko, Langacker and Segre 1995], [Borzumatti et al 1999].

Choice for soft terms

- Yukawas A-terms

$$
\begin{aligned}
W_Y &= Y_{10} 10\, 10\, \bar{5}_H + Y_5 10\, \bar{5}\, \bar{5}_H \\
L_A &= A_{10} \tilde{10}\, \tilde{10}\, \tilde{\bar{5}}_H + A_5 \tilde{10}\, \tilde{\bar{5}}\, \tilde{\bar{5}}_H
\end{aligned}
$$

- GUT conditions on soft paramenters (not essential)

$$
\begin{aligned}
&(Y_5)_{ji} \equiv (Y_d)_{ji} = (Y_l)_{ij}, \\
&(A_5)_{ij} \equiv (A_l)_{ji} = (A_d)_{ij} \\
&(m^2_{\tilde{\bar{5}}})_{ij} \equiv (m^2_{\tilde{L}})_{ij} = (m^2_{\tilde{d}^c})_{ij}, \\
&(m^2_{\tilde{10}})_{ij} \equiv (m^2_{\tilde{e}^c})_{ij} = (m^2_{\tilde{u}^c})_{ij} = (m^2_{\tilde{Q}})_{ij}
\end{aligned}
$$

- In the basis Y_5 diagonal we choose
  1. $m^2_{\tilde{10}}$, $m^2_{\tilde{\bar{5}}}$ and A_5 are diagonal.
  2. $A_5 \neq a_0 Y_5$ to induce the needed threshold corrections

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Large A term, initial conditions

- The choice at GUT scale (simultaniously diagonalized with Yukawas but not proportional)

$$(A_5)_{ij} = a_i \delta_{ij} \neq a_0 Y_{5_i}$$

- [Diaz Cruz, Murayama and Pierce, 2001].

$$(A_5)_{2\times 2} = a_0 \begin{pmatrix} 0 & \lambda_c \\ \lambda_c & 1 \end{pmatrix} + \begin{pmatrix} 0 & 0 \\ 0 & A \end{pmatrix}$$

  1. $\mu \to e\gamma$: $m_{\tilde{l}} \gtrsim 6$ TeV
  2. Beyond the reach of LHC

- In this work, in the basis Y_5 diagonal $Y_{10} = V_{CKM} Y_{10}^{diag}$:
  1. $m^2_{\tilde{10}}$, $m^2_{\tilde{5}}$ and A_5 are diagonal
  2. $A_5 \neq a_0 Y_5$ while $A_{10} = a_0 Y_{10}$
  3. This choice leads to light SUSY spectrum below 1 TeV.

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PARAMETERS

- Parameter choice at GUT scale:

$\tan\beta$	5	10	15	25
$m_{1/2}$	-0.20	-0.21	-0.23	-0.23
$m^2_{\tilde{Q}_i} \equiv m^2_{\tilde{10}}$	0.392	0.28	0.28	0.392
$m^2_{\tilde{d}_i} \equiv m^2_{\tilde{5}}$	0.448	0.32	0.32	0.448

- Parameter choice at M_{SUSY}:

$\tan\beta$	5	10	15	25
μ	0.30	0.30	0.30	0.85
A_d	3.1	7.7	8.5	22.0
A_s	-0.34	-0.78	-0.76	-0.86

- A_s and soft masses are in TeV and TeV^2, A_d is in GeV.

Induced finite corrections

- The threshold corrections to light down type quark masses at $(M_{SUSY}) = 500$ GeV

$\tan\beta$	5	10	15	25
δm_d MeV	1.48	1.61	1.32	1.61
δm_s GeV	-0.157	-0.163	-0.157	-0.154

- We used publicly available SOFTSUSY, C++ code for our calculation.
- We have performed RGE calculation taking into account full flavor structure.
- All relevant SUSY threshold corrections are resummed including subleading effects.

- RGE to $M_{EW} \longrightarrow$ Non universal soft masses:

$\tan\beta$	5	10	15	25
$m^2_{\tilde{Q}_1}$	0.807	0.466	0.506	0.613
$m^2_{\tilde{Q}_2}$	0.715	0.401	0.429	0.496
$m^2_{\tilde{Q}_3}$	0.520	0.270	0.294	0.327
$m^2_{\tilde{d}^c_1}$	0.795	0.487	0.525	0.650
$m^2_{\tilde{d}^c_2}$	0.610	0.357	0.349	0.414
$m^2_{\tilde{d}^c_3}$	0.777	0.474	0.493	0.542

The soft mass params are in TeV^2

- Non-universal A–term for Unifications $Y_{e_i} = Y_{d_i}$ split the soft masses.

- Slepton mass parameters in TeV^2:

$\tan\beta$	5	10	15	25
$m^2_{\tilde{L}_1}$	0.386	0.346	0.349	0.471
$m^2_{\tilde{L}_2}$	0.342	0.316	0.306	0.414
$m^2_{\tilde{L}_3}$	0.383	0.343	0.341	0.442
$m^2_{\tilde{e}^c_1}$	0.264	0.263	0.270	0.389
$m^2_{\tilde{e}^c_2}$	0.175	0.202	0.186	0.274
$m^2_{\tilde{e}^c_3}$	0.258	0.257	0.255	0.331

- Gluino, charginos and neutralinos ($\tan\beta = 15$)
  1. $m_{\tilde{g}} = 593$ GeV
  2. $m_{\tilde{\chi}^{\pm}} = (173,\ \ 324)$ GeV
  3. $m_{\tilde{\chi}^0} = (92,\ \ 171,\ \ 308,\ \ 323)$ GeV

Results for mass splittings for different meson(here only non SM contributions):

$\tan\beta$	5	10	15	25
$\Delta M_D \times 10^{-14}$ GeV	0.578	1.23	1.48	1.18
$\Delta M_K \times 10^{-15}$ GeV	0.027	0.199	-0.447	0.0342
$\Delta M_B \times 10^{-16}$ GeV	1.9	1.46	1.07	1.37
$\Delta M_{B_s} \times 10^{-14}$ GeV	1.67	1.16	6.06	4.39

Experimental values (HFAG):

ΔM_D	$(1.57 \pm^{0.438}_{0.471}) \times 10^{-14}$ GeV
ΔM_K	$(3.483 \pm 0.033) \times 10^{-15}$ GeV
ΔM_B	$(3.337 \pm 0.006) \times 10^{-13}$ GeV
ΔM_{B_s}	$(1.17 \pm 0.008) \times 10^{-11}$ GeV

Rare decays

- The RGE induced mass splitting of first two generation sfermions lead to FCNCs.
- The results for $D^+ \to \pi^+ \nu \bar{\nu}$ and $K^+ \to \pi^+ \nu \bar{\nu}$ decays

$\tan\beta$	5	10	15	25
$Br(D^+)$	0.34	0.90	1.03	0.161
$Br(K^+)$	0.018	1.77	5.94	0.134

- Here

$$Br(D^+) \equiv B(D^+ \to \pi^+ \nu \bar{\nu}) \times 10^{11}$$
$$Br(K^+) \equiv B(K^+ \to \pi^+ \nu \bar{\nu}) \times 10^{11}$$

- The SM expectation for $B(D^+ \to \pi^+ \nu \bar{\nu})$ [G. Burdman eta al, 2001]
  1. short distance contribution $\sim 10^{-16}$
  2. long distance contribution $\sim 10^{-15}$
  3. Aim of BESIII experiment $\sim 10^{-8}$
- The SM expectation for
  1. $B(K^+ \to \pi^+ \nu \bar{\nu})_{SM} \sim (8.22 \pm 0.84) \times 10^{-11}$
  2. Experimental status [E787, E949 collaborations] $B(K^+ \to \pi^+ \nu \bar{\nu})_{Exp} = (15.7 \pm^{17.5}_{8.2}) 10^{-11}$

Comment on proton decay

- Minimal SUSY SU(5) $\rightarrow$ large proton decay rate .
  [Murayama and Pierce, 2001].
- Mass splitting between octet and triplet due to nonrenormalizable operator could suppress the proton decay
  [see eg. Bachas etal 1996
  Chkareuli and Gogoladze 1998
  Bajc, Perez and Senjanovic, 2001].
- Example of SUSY SO(10) with the SUSY threshold corrections studied by Aulakh et al.
  [Aulakh et al 2006 and his talk].
- For further discussions see Dorsner's talk.

Conclusions

- Finite radiative corrections for fermmion masses studied.
- Minimal SU(5) unifications for Yukawas of light charged leptons and down–type quarks can be achieved by finite SUSY corrections.
- To have unifications for lighter generations certain non universality is needed among soft parameters.
- For low and moderate $\tan\beta$ we obtain the needed corrections for light down type quarks d and s.
- All the sfermions have sub TeV masses: squarks can be observed at LHC.
- The sfermion spectrum displays flavor pattern reflecting a large A–term that could be probed at future colliders.
- The non universality in A_5 lead to rare charm decays.
- The branching fractions for $K^+ \to \pi^+ \nu \bar{\nu}$ could be at the level of the SM expectation.

GORAN, HAPPY BIRTHDAY TO YOU AND MAY W_R BE DISCOVERED AT LHC!