Flavor in supersymmetry with an extended R-symmetry

Erich Poppitz

University of Toronto

Graham Kribs, E.P., and ***Neal Weiner***

Oregon, Toronto, and New York U.

arXiv::0712.2039 [hep-ph]

Pointe Percée 2753 m.

base ~ 2100 m.

Graham Kribs, E.P., and **Neal Weiner**

Oregon, Toronto, and New York U.

arXiv::0712.2039 [hep-ph]

Graham Kribs, E.P., and ***Neal Weiner***

Oregon, Toronto, and New York U.

arXiv::0712.2039 [hep-ph]

the LHC is turning on soon ... what do we expect?

Standard Model is incomplete -
perhaps supersymmetry - the assumption of this talk

supersymmetry "doubles" the particle spectrum

but supersymmetry is broken

>100 "soft" supersymmetry-breaking parameters:
squark and slepton masses, gaugino masses, A-terms...

generic values of superparticle masses - e.g., nondegenerate squarks and sleptons are excluded by precision measurements
K-Kbar mixing still strongest constraint
- the "supersymmetric flavor problem"

who fixes the soft parameters?

- usually assume flavor blind mechanism of generating soft parameters (of "mediating" supersymmetry breaking)
  gauge mediation, anomaly mediation, gaugino mediation, mirage...
- or decouple flavor violation - as in "more minimal supersymmetry"
- flavor symmetries may solve problem - must be nonabelian

who fixes the soft parameters?

- usually assume flavor blind mechanism of generating soft parameters (of “mediating” supersymmetry breaking)
  gauge mediation, anomaly mediation, gaugino mediation, mirage...
- or decouple flavor violation - as in “more minimal supersymmetry”
- flavor symmetries may solve problem - must be nonabelian

an exciting and different possibility is to have large flavor violation in superpartner sector, but be “shielded” from its effects in low-energy experiments

who fixes the soft parameters?

- usually assume flavor blind mechanism of generating soft parameters (of "mediating" supersymmetry breaking)
  gauge mediation, anomaly mediation, gaugino mediation, mirage...
- or decouple flavor violation - as in "more minimal supersymmetry"
- flavor symmetries may solve problem - must be nonabelian

an exciting and different possibility is to have large flavor violation in superpartner sector, but be "shielded" from its effects in low-energy experiments

- turns out this is possible in a simple extension of the MSSM by postulating an enhanced R-symmetry - call it the "MRSSM"
  - will explain the "miracles" at work
  - new signatures at the LHC detailed study Kribs, Roy in progress

    new possibilities for dark matter e.g., Weiner et al in progress

    new avenues for model building e.g., Fox, E.P. in progress
- most importantly if this is true we will know soon!

who fixes the soft parameters?

- usually assume flavor blind mechanism of generating soft parameters (of "mediating" supersymmetry breaking)
  gauge mediation, anomaly mediation, gaugino mediation, mirage...
- or decouple flavor violation - as in "more minimal supersymmetry"
- flavor symmetries may solve problem - must be nonabelian

Outline/Summary/Conclusions:

an exciting and different possibility is to have large flavor violation in superpartner sector, but be "shielded" from its effects in low-energy experiments

- turns out this is possible in a simple extension of the MSSM by postulating an enhanced R-symmetry - call it the "MRSSM"
    - will explain the "miracles" at work
    - new signatures at the LHC detailed study Kribs, Roy in progress

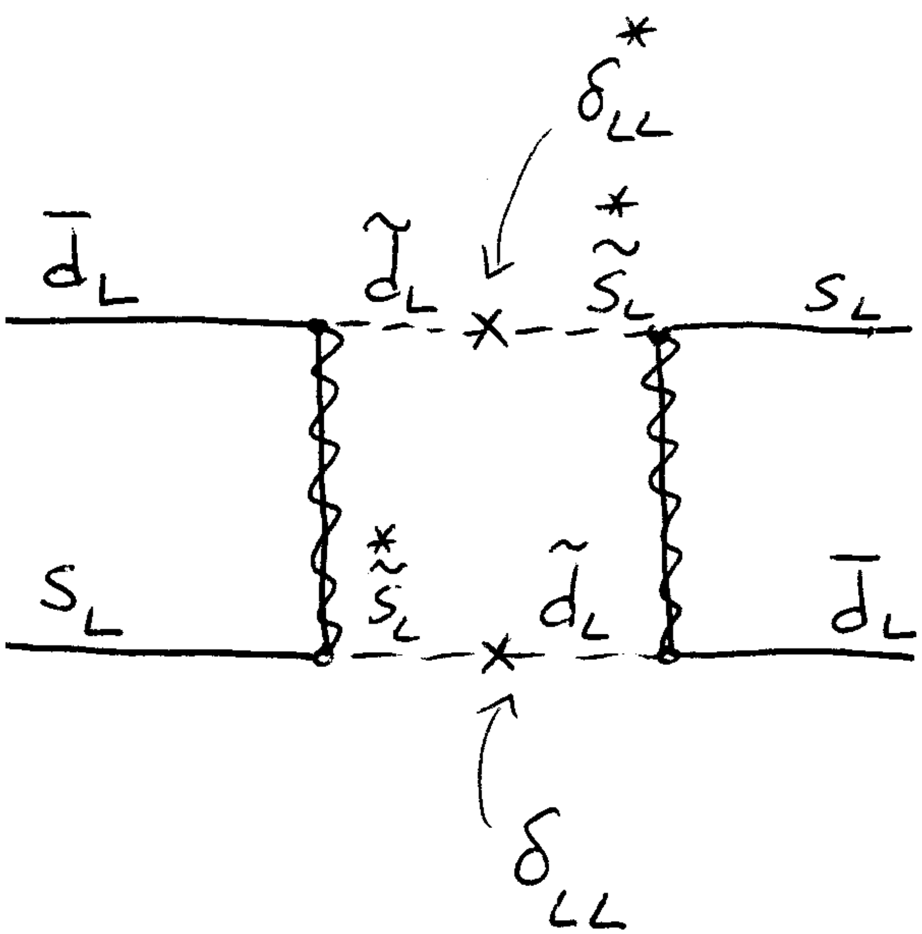
      new possibilities for dark matter e.g., Weiner et al in progress

      new avenues for model building e.g., Fox, E.P. in progress
- most importantly if this is true we will know soon!

to explain the “miracles” at work -

first recall constraints in squark nondegeneracy from Delta(S) = 2: $\delta_{ij} = \dfrac{m^2_{0\,ij}}{|m_0|^2}$

most favorable (least constrained) **case occurs** if $\delta_{RR} = \delta_{LR} = 0$



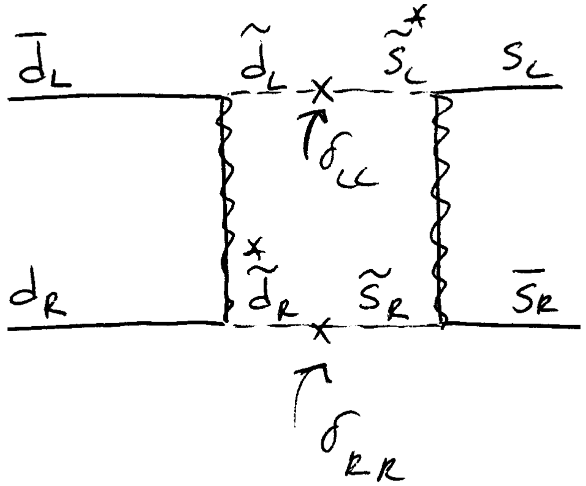
two-component notation:
undotted R-handed fermions are antiparticles

$$\sim \frac{1}{m_0^2} |\delta_{LL}|^2 \; \bar{d}_L \cdot \bar{d}_L \;\; s_L \cdot s_L$$

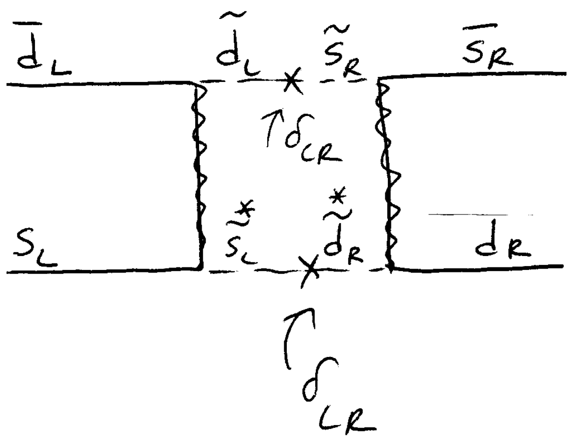
then, for “natural” ~ 500 GeV squark and gauginos $\Delta M_{K\bar{K}} < 10^{-6}\,\mathrm{eV}$

implies $|\delta_{LL}| < 6 \times 10^{-2}$

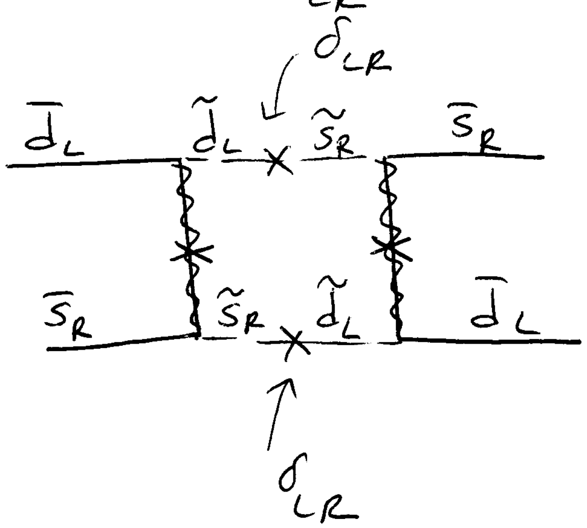
for general nondegeneracy, we also have:



$$\sim \frac{1}{m_0^2}\,\delta_{LL}\,\delta_{RR}\;\bar d_L\cdot\bar s_R\;s_L\cdot d_R$$



$$\sim \frac{1}{m_0^2}\,|\delta_{LR}|^2\;\bar d_L\cdot\bar s_R\;d_R\cdot s_L$$



$$\sim \frac{1}{m_0^2}\,\delta_{LR}^2\;\bar d_L\cdot\bar d_L\;\bar s_R\cdot\bar s_R$$

the **"supersymmetric flavor problem"** - small numbers below need explanation:

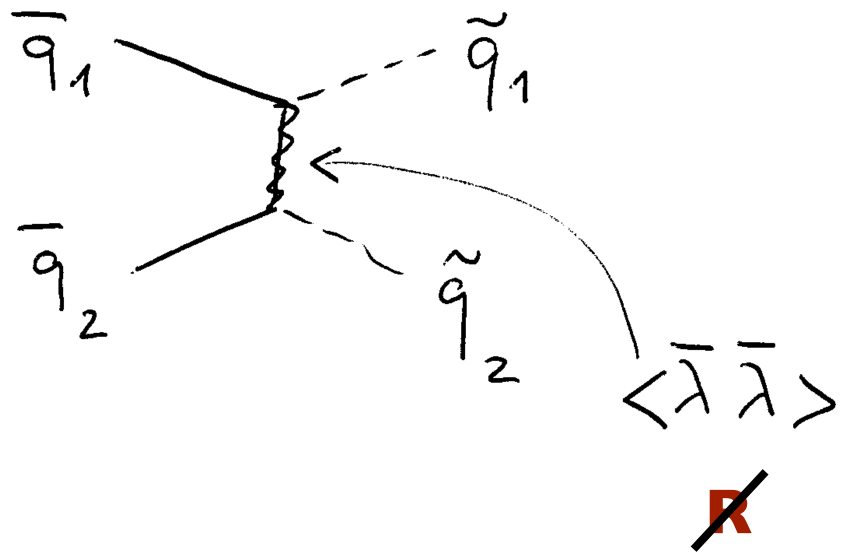
$$\sqrt{|\delta_{LR}\,\delta_{RL}|} < 2\times 10^{-3} \qquad \sqrt{|\delta_{LL}\,\delta_{RR}|} < 10^{-3}$$

detailed bounds in
e.g., Gabbiani Masiero, 1989 + ...

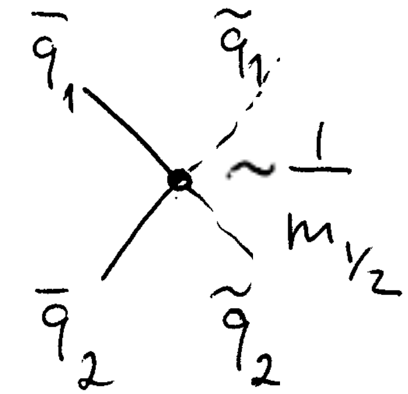
explain the "miracles" at work -

Dirac **(R)** vs Majorana **(no R)** gauginos?

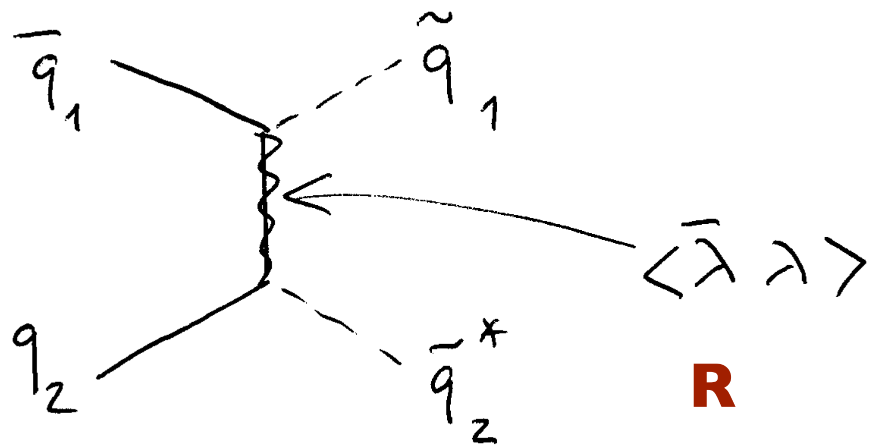
consider the box diagram in the **gauginos heavier than squarks** limit:



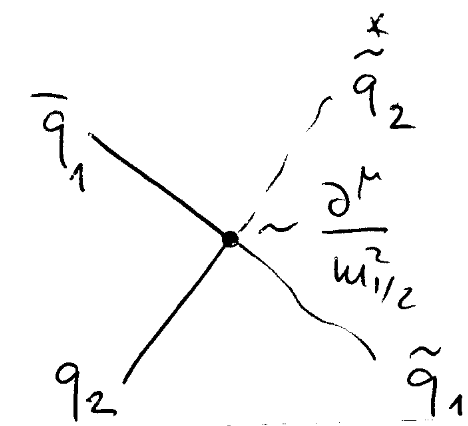
$$\sim \frac{1}{m_{1/2}} \bar{q}_1 \cdot \bar{q}_2 \; \tilde{q}_1 \tilde{q}_2$$



- Majorana
  dim-5 operator
  R-violating



$$\sim \frac{1}{m_{1/2}^2} \bar{q}_1 \bar{\sigma}^\mu q_2 \, \partial_\mu \tilde{q}_1 \tilde{q}_2^*$$

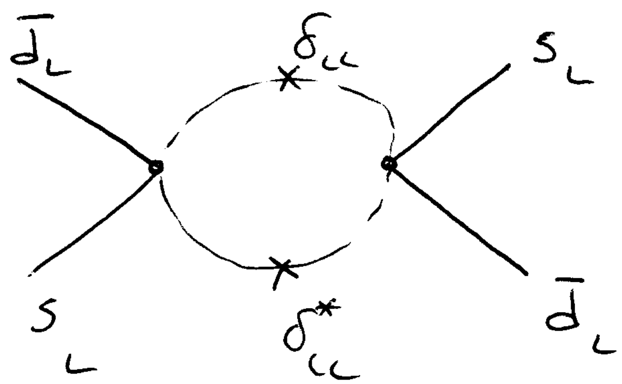


- Dirac
  dim-6 operator
  R-preserving

explain the “miracles” at work: in Dirac gaugino **(R)** case,

contract two $\frac{\partial^\mu}{m_{1/2}^2}$ vertices to get Delta(S)=2 transition

finite loop dominated by IR ~ m $_{squark}$ momenta:

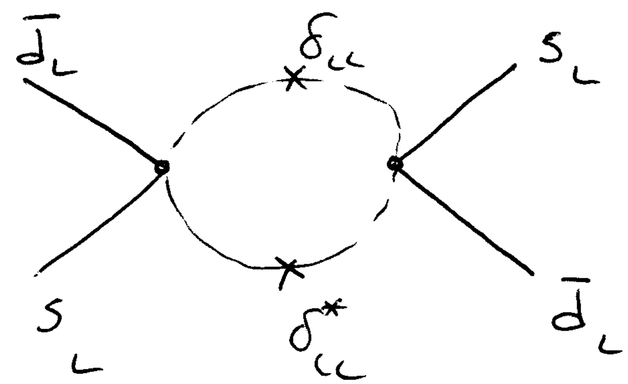


$$\sim \frac{1}{m_0^2}\left(\frac{m_0}{m_{1/2}}\right)^4 \bar{d}_L \cdot \bar{d}_L \; s_L \cdot s_L \, |\delta_{LL}|^2$$

explain the “miracles” at work: in Dirac gaugino **(R)** case,

contract two $\frac{\partial^\mu}{m_{1/2}^2}$ vertices to get Delta(S)=2 transition

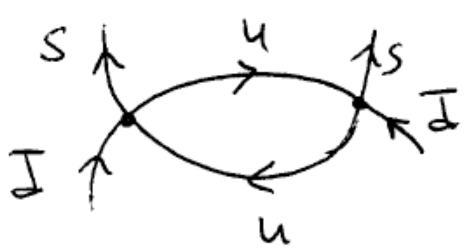
finite loop dominated by IR ~ m $_{\text{squark}}$ momenta:



$$\sim \frac{1}{m_0^2}\left(\frac{m_0}{m_{1/2}}\right)^4 \bar d_L \cdot \bar d_L \; s_L \cdot s_L \; |\delta_{LL}|^2$$

now, recall that a generic weak-strength/weak-cutoff Delta(S)=2 contribution,

e.g.:



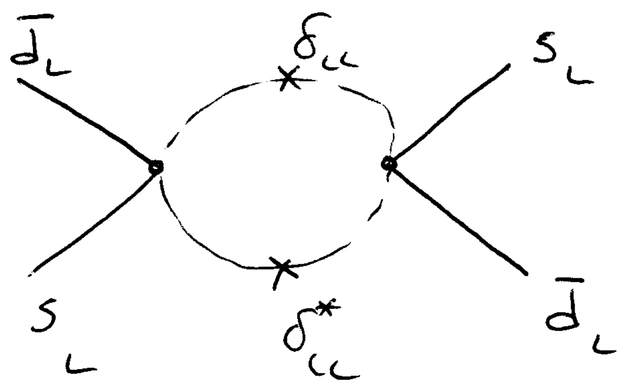
$$\sim (\bar d s)(\bar d s)\frac{G_F^2 \Lambda_{UV}^2}{16\pi^2} \quad \text{with} \quad \Lambda_{UV} \sim \frac{1}{\sqrt{G_F}}$$

gives $\Delta M_{K\bar K} \sim 10^{-2}\, eV \gg 10^{-6}\, eV$ (~ the measured value)

explain the "miracles" at work: in Dirac gaugino **(R)** case,

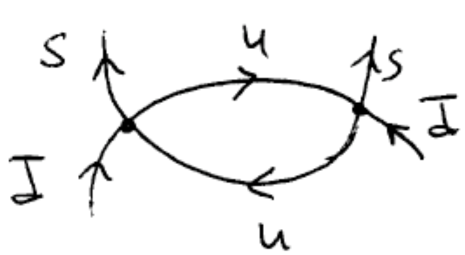
contract two $\frac{\partial^\mu}{m_{1/2}^2}$ vertices to get Delta(S)=2 transition

finite loop dominated by IR ~ m $_{\text{squark}}$ momenta:



$$\sim \frac{1}{m_0^2}\left(\frac{m_0}{m_{1/2}}\right)^4 \bar{d}_L \cdot \bar{d}_L \; s_L \cdot s_L \, |\delta_{LL}|^2$$

now, recall that a generic weak-strength/weak-cutoff Delta(S)=2 contribution,

e.g.: 

$$\sim (\bar{d}s)(\bar{d}s)\,\frac{G_F^2\Lambda_{UV}^2}{16\pi^2}$$ with $\Lambda_{UV} \sim \frac{1}{\sqrt{G_F}}$

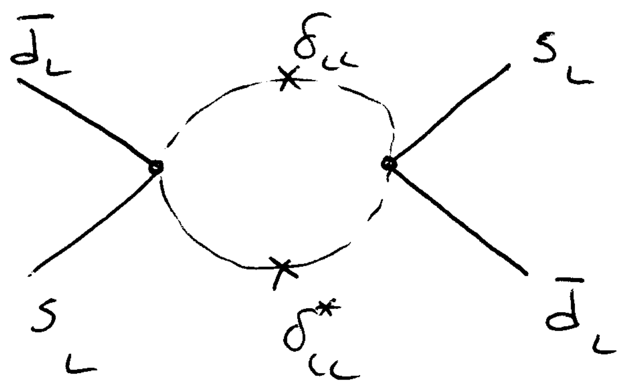
gives $\Delta M_{K\bar{K}} \sim 10^{-2}\,eV \gg 10^{-6}\,eV$ (~ the measured value)

so, we have **"miracle" #1:** if $\left(\frac{m_0}{m_{1/2}}\right)^4 \sim 10^{-4}$ for Dirac gluinos nondegenerate squarks compatible with K-Kbar mixing

explain the "miracles" at work: in Dirac gaugino **(R)** case,

contract two $\frac{\partial^\mu}{m_{1/2}^2}$ vertices to get Delta(S)=2 transition

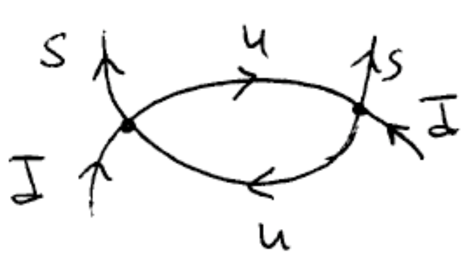
finite loop dominated by IR ~ m_{squark} momenta:



$$\sim \frac{1}{m_0^2}\left(\frac{m_0}{m_{1/2}}\right)^4 \bar d_L \cdot \bar d_L \;\; s_L \cdot s_L \; |\delta_{LL}|^2$$

now, recall that a generic weak-strength/weak-cutoff Delta(S)=2 contribution,

e.g.:



$$\sim (\bar d s)(\bar d s)\,\frac{G_F^2 \Lambda_{UV}^2}{16\pi^2}$$ with $$\Lambda_{UV} \sim \frac{1}{\sqrt{G_F}}$$

gives $\Delta M_{K\bar K} \sim 10^{-2}\,eV \gg 10^{-6}\,eV$ (~ the measured value)

so, we have **"miracle" #1:** if $\left(\frac{m_0}{m_{1/2}}\right)^4 \sim 10^{-4}$ for Dirac gluinos nondegenerate squarks compatible with K-Kbar mixing

we also have **"miracle" #2:** with Dirac gauginos, $\frac{m_0}{m_{1/2}} \sim \frac{1}{10}$ is natural

"miracle" #2: with Dirac gauginos, $\frac{m_0}{m_{1/2}} \sim \frac{1}{10}$ is natural

Dirac gauginos have N=2 vector multiplet structure: m_D $\lambda^{a\alpha}$ ψ^a_α / $\uparrow$ $\uparrow$ / V^a φ^a

Dirac gaugino mass from D-term supersymmetry breaking spurion: $[\theta^\alpha m_D]$ or $\bar{D}^2 D^\alpha \theta^4 m_D$

via operator: $\int d^2\theta \, [\theta^\alpha m_D] W^a_\alpha \, \phi^a$ *Polchinski, Susskind, 1985*

realizing ***"supersoft"*** *supersymmetry breaking* *Fox, Nelson, Weiner, 2002*

"supersoft" - *as can be seen in many ways, e.g., at one loop due to N=2 structure* - finite, instead of log-divergent contribution of gaugino mass to scalar mass: $\delta m_0^2 \sim \frac{m_D^2}{16\pi^2}$

more details on spectra: Blechman, Kaplan, Weiner...., in progress

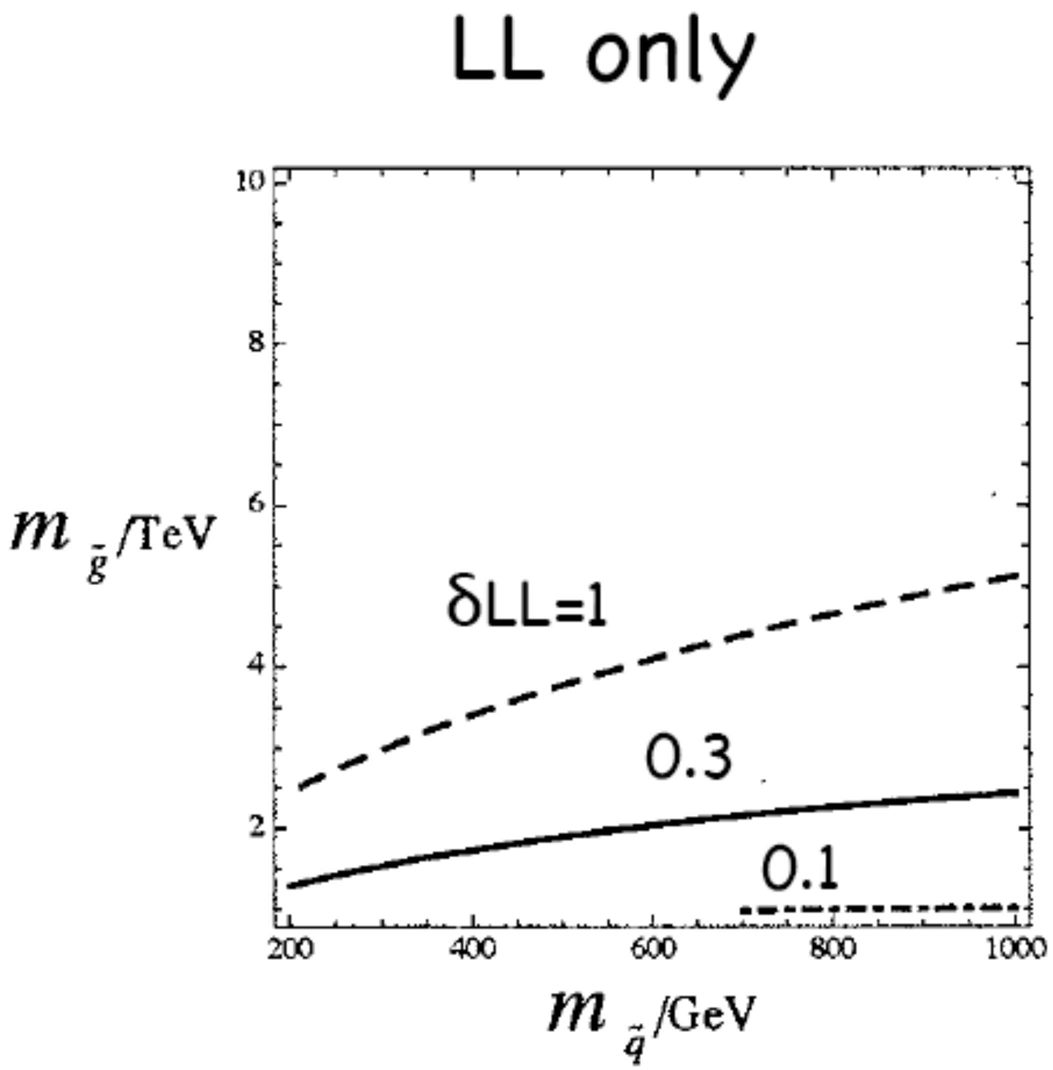
thus, the "miracles" at play, due to "supersoft"/Dirac nature

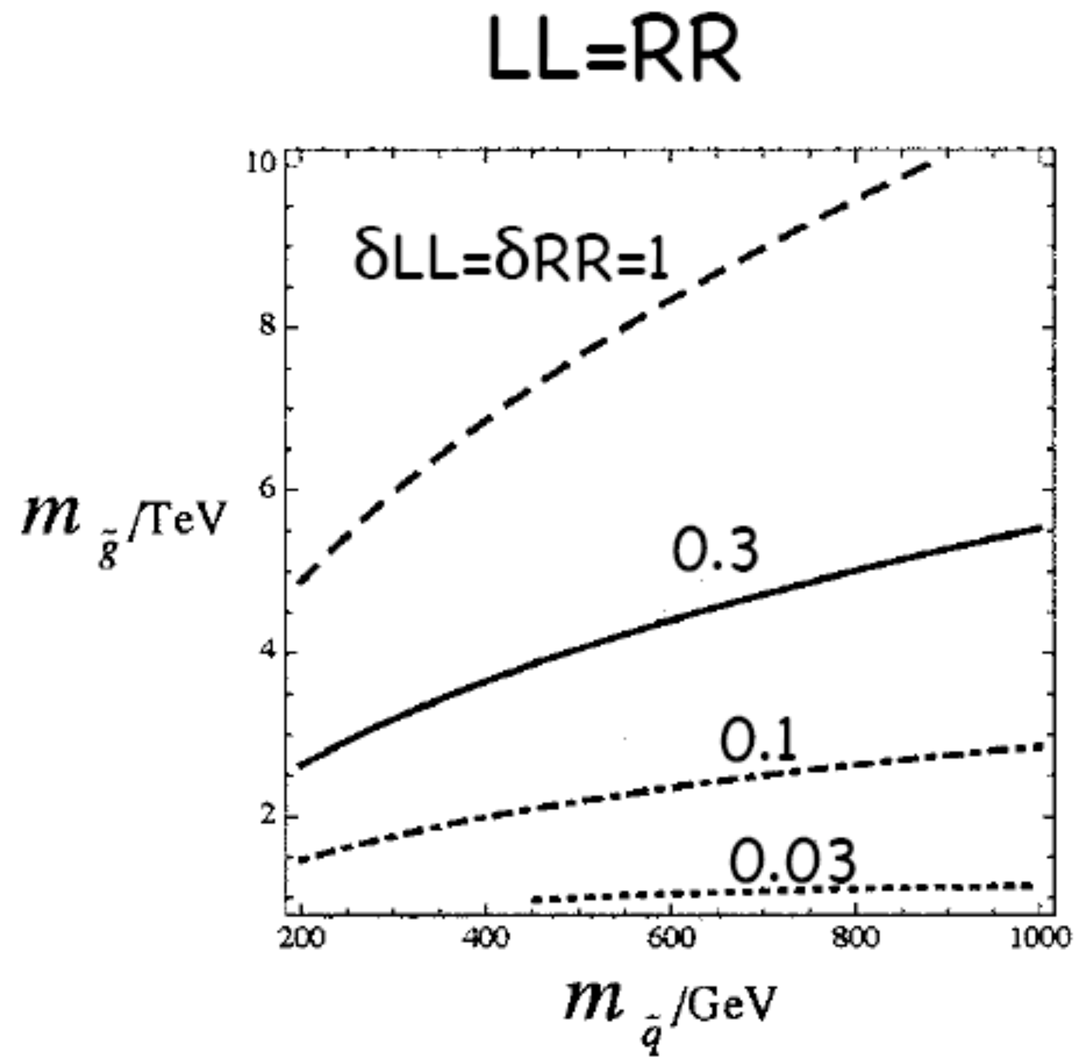
= weak K-Kbar constraints

(weaker ones from B_d, and even less from B_s oscill.)

how weak are the K-Kbar constraints, really?

Kribs, EP, Weiner





cf. MSSM:
squarks, gluinos >500 TeV
for delta=1!

- R-symmetric model has no LR mixing (from A- or mu- term), so bounds on LL and RR only
- LO QCD corrections recently computed yielding 2x stronger constraints (Blechman, Ng, 2008)
- from same plot, since ϵ_K down by 6 x10^{-3} - phases in squark masses should be small (or even exact CP) or else invoke moderate degeneracy...

how about Delta(F)=1? -

before describing limits, note that the R-symmetry of the Dirac gauginos can be **beneficially** promoted to an exact symmetry of the MSSM --- **"MRSSM"...**

why?

- because the vast majority of supersymmetric flavor problems arise from R-violation

  R-violating Majorana masses and mu-term: allow chirality flip on gaugino/higgsino lines

  R-violating A-terms allow LR scalar mass mixing

  Hall and Randall (1990) constructed an R-symmetric model and discovered the suppression of EDMs; as written their model is ruled out by LEP: $m_{wino} = m_W$, one-loop suppresed photino mass....

- many (metastable) vacua with broken supersymmetry preserve R (or a discrete subgroup)...

our proposal: U(1) or $Z_{2n,\, n>1}$ exact R-symmetry Kribs, EP, Weiner

our proposal: U(1) or $Z_{2n,\, n>1}$ exact R-symmetry

Kribs, EP, Weiner

usual R-charges of MSSM superfields:

R = 2 superpotential

1 W_α super field strength (and gaugino) - Dirac gaugino masses for *all* gauginos -

require adjoint chiral fields with supersoft operator

1 Q,u,d,L,e

0 H_u,H_d - R-symmetric Higgsino masses -

require two additional Higgs doublets of R=2: R_u and R_d - R_u, R_d do not couple to matter

the "MRSSM"

- **no** Majorana gaugino/higgsino masses
- $\Delta L = 2$ Majorana neutrino mass allowed (dim-5)
- **no** dim-5 proton decay, **no** $\Delta B = 1$ and $\Delta L = 1$
- **no** mu-term, instead two mu' terms: $\int d^2\theta\, \mu_u H_u R_u + \mu_d H_d R_d$
- B-mu term is allowed
- **no** LR scalar mass mixing through A- or mu- terms

benefits ?

Delta(F)=2:

- as explained

EDMs:

- counting of phases beyond flavor sector - *a priori* one more phase than in MSSM
- however, all 1- and 2-loop EDMs require A-, mu-, or Majorana insertions - *absent here!*

while MSSM electron and neutron EDMs require phases as small as < 0.001 for O(100) GeV supersymmetric mass...

- leading neutron EDM in "MRSSM" arises through the Weinberg operator, yields no significant constraint on flavor-diagonal phases

essentially, Dirac gaugino mass and mu' terms can be "rephased" without consequence

strong-CP:

- needs a solution as in MSSM ...

spontaneous CP violation a la Barr-Nelson or Hiller-Schmaltz can be incorporated naturally as both mechanisms require significant flavor violation to work Weiner et al in progress

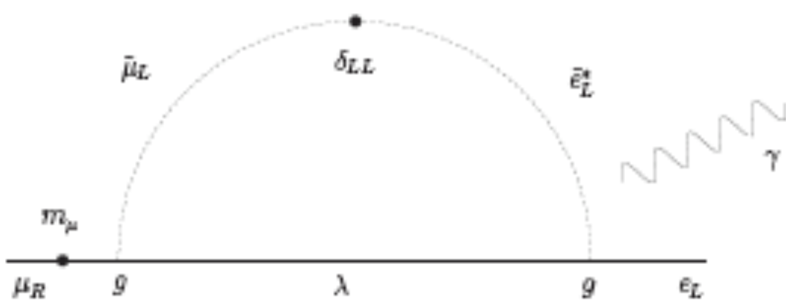
$b \to s\gamma$ and $\mu \to e\gamma$:

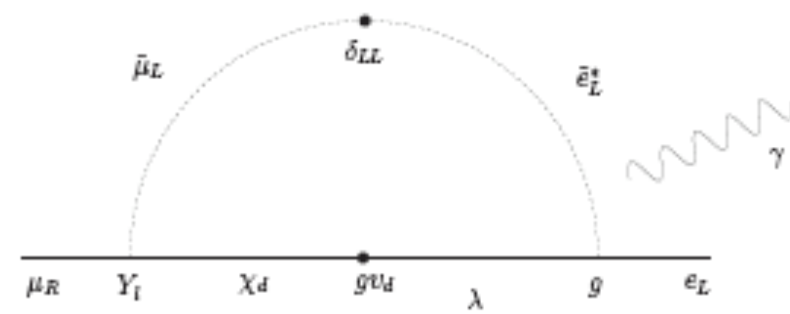
- both involve a helicity flip in diagram
- but for Dirac gauginos, opposite helicity state (chiral adjoint) has no coupling to matter

in MSSM, most constrained are $\delta_{\ell e}$ insertions, absent here

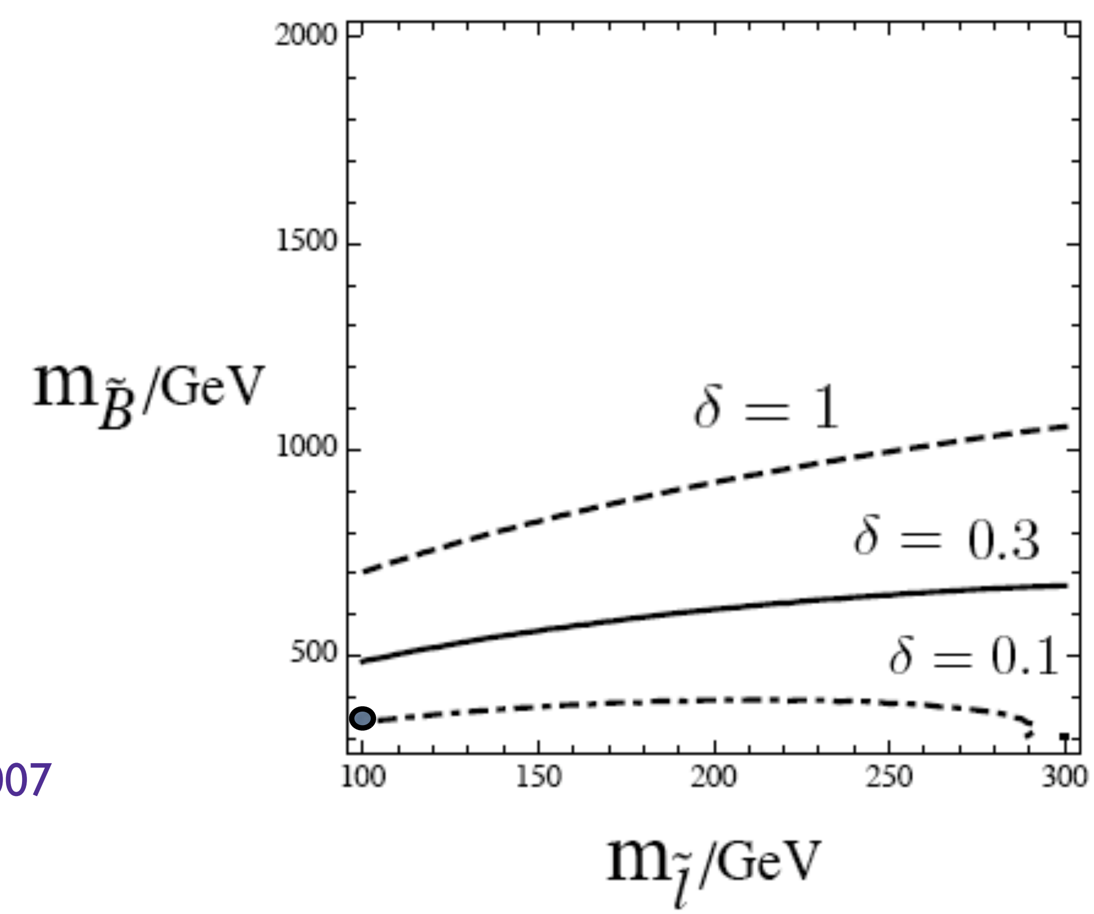
only (smaller) contributions with

external line helicity flip   or   gaugino-Higgsino (both Dirac) mixing





Contours of δ where $BR_{\mu\to e\gamma} = 1.2\times 10^{-11}$ for $\delta_{LL} = \delta$, $\delta_{RR} = 0$ $m_{\tilde{B}} = m_{\tilde{W}}/2$.



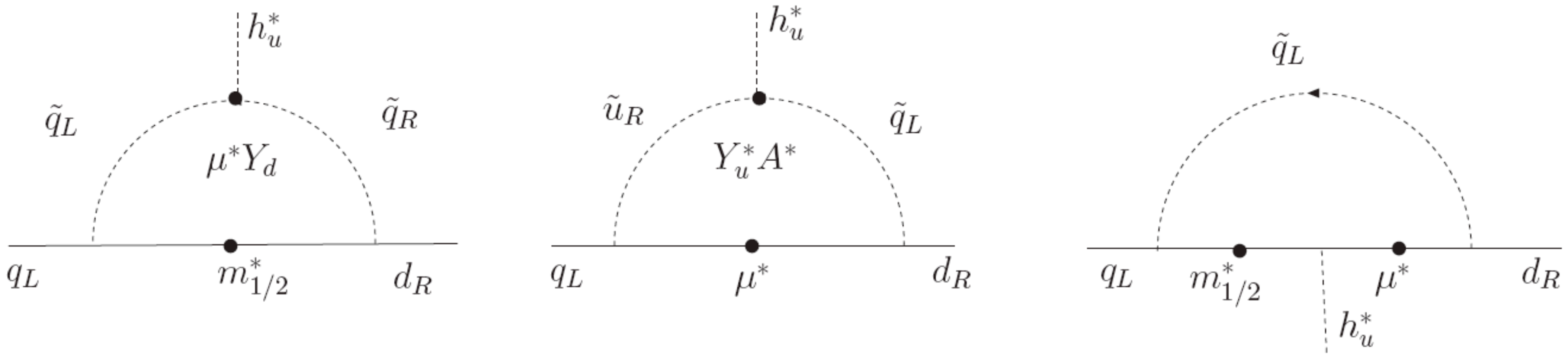
Kribs, EP, Weiner

cf. MSSM: for • $\delta < 0.007$

... MEG experiment ?

large tan(beta) flavor violation:

in MSSM, up-type Higgs can couple to down-type quarks at one loop -



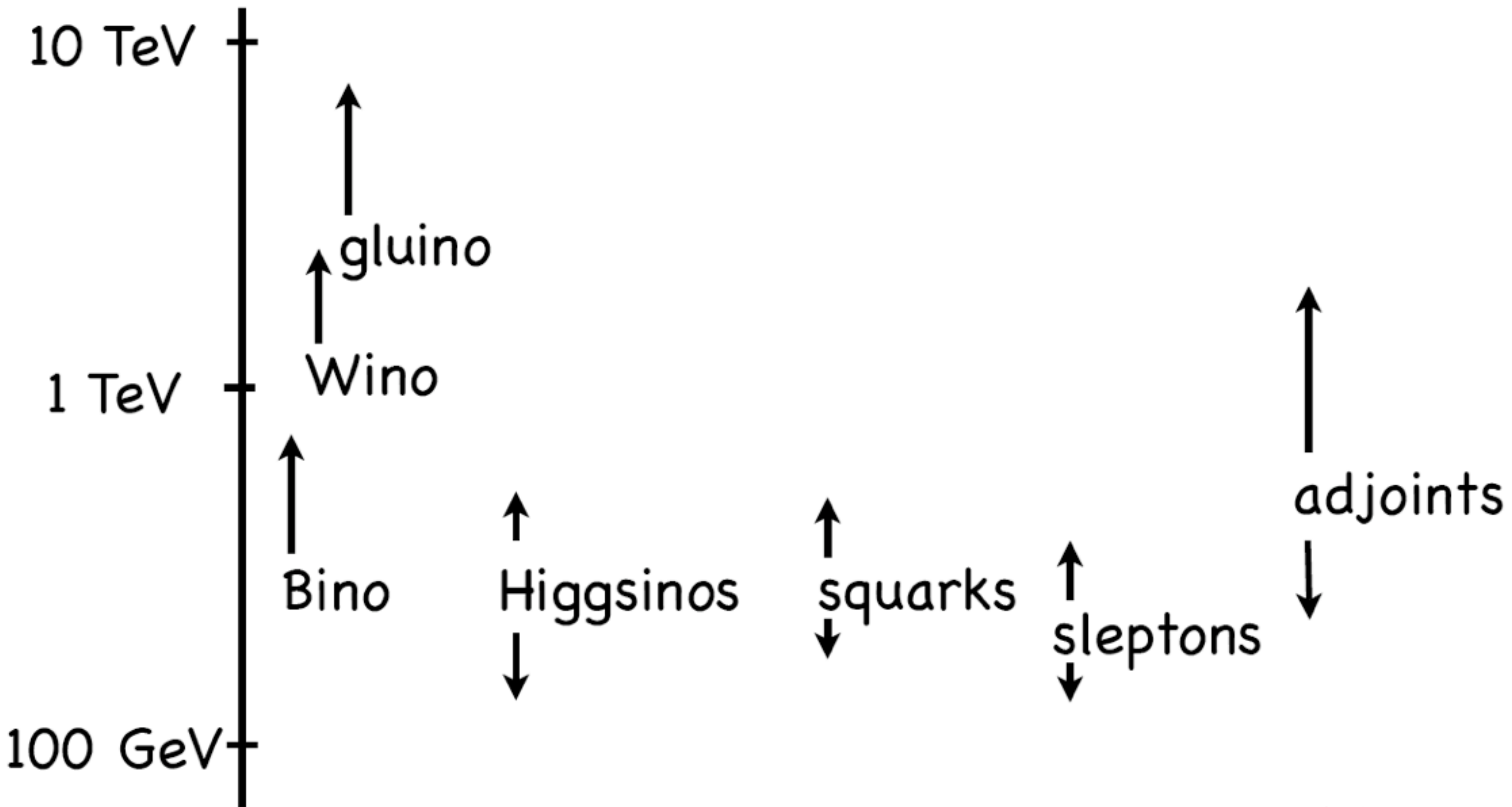
- this coupling can be the leading source of flavor violation at large tan(beta); in mixing as well as decays, i.e. B -> μμ *Hamzaoui, Pospelov, Toharia 1998*

- in MRSSM, absent - require mu- and Majorana- or A-term insertions

  PQ symmetry forbidding up-Higgs coupling to down quarks broken only by dim-2 B-mu term, no dim-3 mu-term contribution as in MSSM

hence, modified Higgs sector in "MRSSM" addresses large tan(beta) flavor problems as well

Rough Spectrum



... a ‘pre-QCD corrections’ slide stolen from Graham Kribs - in reality, for not-too-heavy, e.g., not >10 TeV but only a few TeV, gluinos ~ 30% nondegeneracy allowed

Squark and slepton mass matrices completely arbitrary in size and phase*!

Dirac gluino and Wino heavy.

New particles: color octet, weak triplet scalars
R_u,R_d scalars and fermions

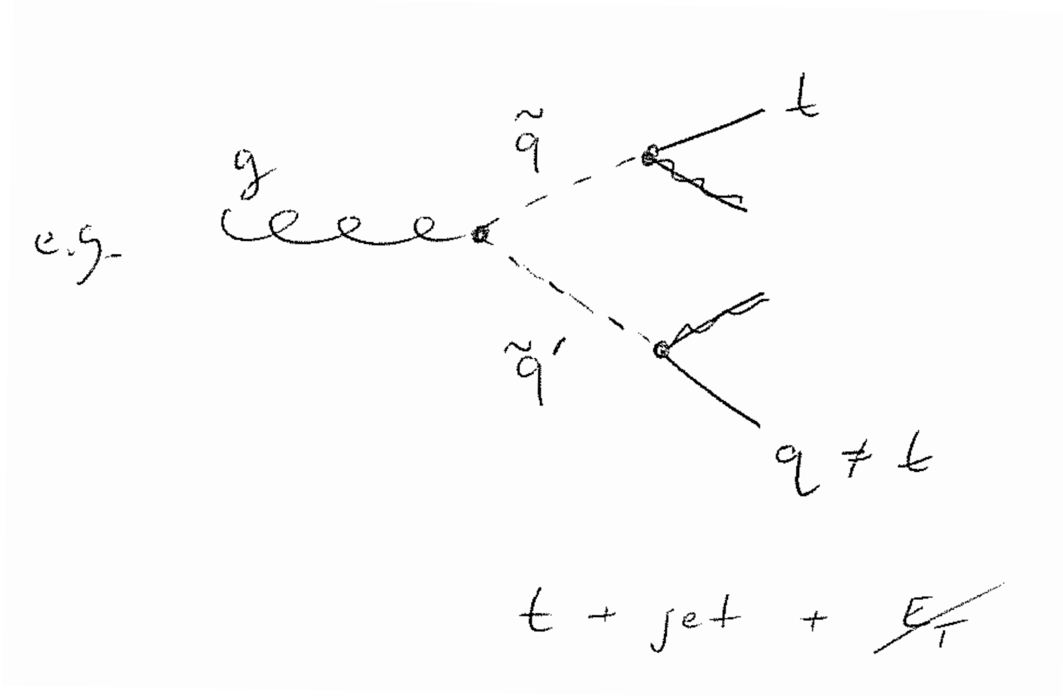
*[The only exception is ϵ_K that requires $\mathrm{Im}[\delta_{LL12}\delta_{RR12}] < 0.01$; so that, e.g., no more than 0.1 phase is permitted in LL and RR]

possible signatures at the LHC?

apart from seeing the new adjoint/R_u , R_d (R-charge 2 higgses) states charged under SM gauge group

Dirac nature of gauginos - no like-sign dilepton (signature of Majorana gauginos)
however, gauginos may be too heavy for pair production at LHC

signals of flavor nondegeneracy - e.g. single top production via squarks



detailed study needed
- G. Kribs, T. Roy, in progress

similarly, slepton production with unlike flavor final states
studied in the past, e.g. Bityukov, Krasnikov1997 + ...

some obvious issues I didn't go into...

not the usual unification - but $SU(3)^3$ naturally fits

Fox, Nelson, Weiner, 2002
Kribs, E.P., Weiner, 2007

where does it come from? -
for example, can be realized in R-symmetric supersymmetry-breaking vacua

$U(1)_Y$ "adjoint" (= SM singlet) tadpole?
- discrete symmetry easy to incorporate

supergravity R-breaking effects
- must be small, or absent...

Dirac gravitini, anyone?

note that all these are UV ...

...while staying in the IR, we

- found that much of flavor violation in supersymmetry is tied to R-violation
- showed that an R-symmetric extension of the MSSM:
    - allows for significant flavor non-degeneracy among squarks and leptons
    - opens the door for more model building...

...while staying in the IR, we

- found that much of flavor violation in supersymmetry is tied to R-violation
- showed that an R-symmetric extension of the MSSM:
    - allows for significant flavor non-degeneracy among squarks and leptons
    - opens the door for more model building...
- are these ideas relevant to nature?

...while staying in the IR, we

- found that much of flavor violation in supersymmetry is tied to R-violation
- showed that an R-symmetric extension of the MSSM:

  - allows for significant flavor non-degeneracy among squarks and leptons
  - opens the door for more model building...

- are these ideas relevant to nature?

... the near future will tell how
the pieces fit together...