Proton decay in SUSY GUTs

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Outline

- SUSY/SUGRA
- B&L violation in SUSY
- SUSY GUT Models
- Proton decay in SUSY GUTs
- Conclusions/prospects

SUSY/SUGRA: Looking back

- An explanation of EWSB via RG
- Precision LEP data & gauge coupling unification
- A heavy top
- $b - \tau$ unification
- BNL result on $a_\mu = (g_\mu - 2)/2$

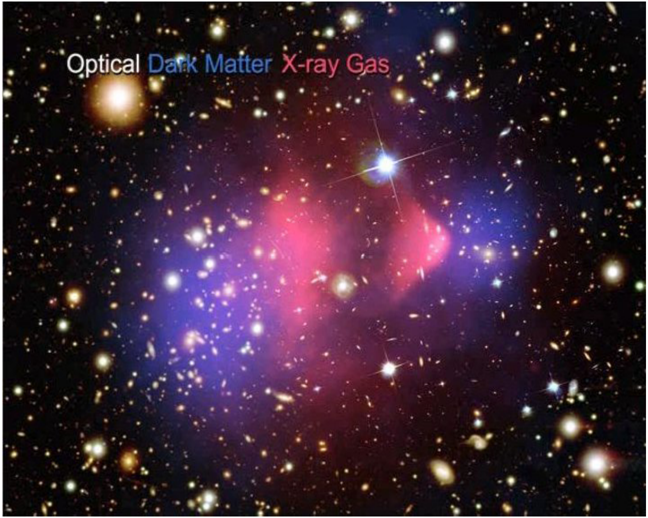
$$a_\mu^{exp} = 116592080(63) \times 10^{-11}$$

$$a_\mu^{SM} = 116592812(69) \times 10^{-11}$$

$$\Delta a_\mu = 26.8(9.3) \times 10^{-10} \quad 2.9\sigma \quad \text{discrepancy}$$

- Dark matter

Direct evidence for dark matter: Neutralinos? gravitinos? .. or ?. Need direct lab experiment such as CDMS to check.



Looking forward: Missing link- Sparticles

If the BNL experiment holds up, i.e., a $\mathbf{2.9\sigma}$ discrepancy is present, then within SUSY/SUGRA it is predicted that some of the **sparticles** have an upper bound and **must be seen at the LHC.**

Dim 4 and Dim 5 B&L violating operators in SUSY

- B&L violating dim 4 operators can appear in SUSY

$$QLD^C, U^C D^C D^C, LLE^C, LH$$

These may be suppressed by the constraint of R parity.

- **B&L violating dim 5 operators**.

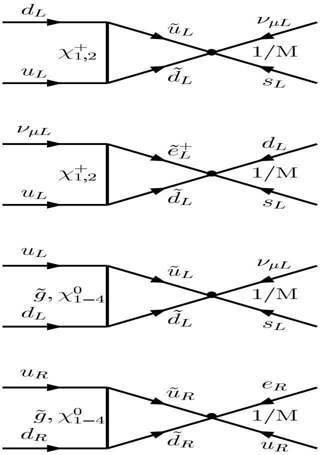
$$LLLL : C_{ikl}(Q_i.Q_i)(Q_k.L_l)/M_T$$

$$RRRR : C'_{ijkl} u_i^C e_j^C u_k^C d_l^C / M_T$$

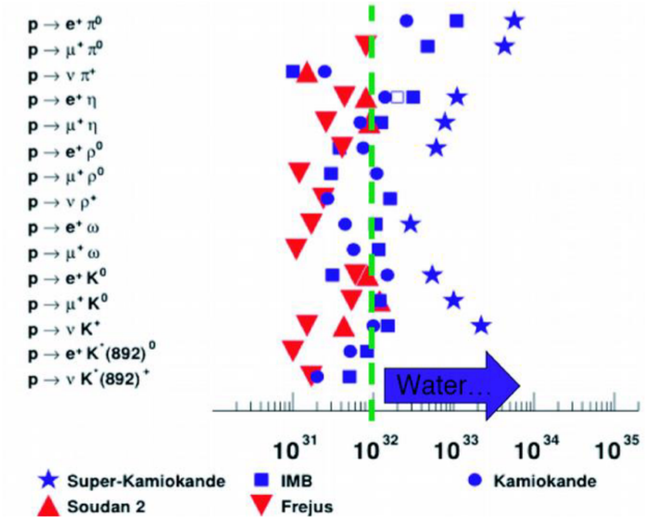
Dressing loops convert dim 5 to dim 6 operators involving quarks and leptons. Further, the quark -lepton lagrangian is converted to the one involving mesons and baryons using effective lagrangian techniques. These give rise to decay modes

$$p \longrightarrow \bar{\nu}_{e,\mu,\tau} K^+,\ \bar{\nu}_{e,\mu,\tau} \pi^+,\ \mu^+ K, ..$$

Dressing loops: dim 5 $\rightarrow$ dim 6



Experimental data on lower limits on partial proton decay lifetimes



SUSY GUT Models

- SU(5) models
  - Minimal
  - Non-minimal: Planck slop, additional Higgs

    Dimopoulos, Georgi; Ellis, Nanop, Rudas; Arnowitt, PN; Hisano, Murayama, Yanagida; Pierce, Murayama; Dermisek, Mafi, Rabi; Babu, Barr, Bajc, Perez, Senjanovic, Dorsner, ··
- E(6) models:
  - Typically too many exotics.
  - The problem of exotics is significantly reduced or even removed in more recent Calabi-Yau compactifications of heterotic strings.
- SO(10) models
  - These are phenomenologically the most successful of the grand unified models. Considerable literature in this area

    Anderson, Hall, Dimopoulos, Raby; Babu, Pati, Wilczek; Aulakh, Senjanovic; Lucas, Raby; Dutta, Mimura, Mohapatra; PN, Syed; Fukuyama; Wiesenfeldt, ··

Conventional $SO(10)$ schemes

- Several Higgs reps needed
  - 16+$\overline{\mathbf{16}}$ or 126+$\overline{\mathbf{126}}$ to reduce the rank
  - $\mathbf{45}$, $\mathbf{54}$ or $\mathbf{210}$ to break it further to $\boldsymbol{SU(3)_C \times SU(2)_L \times U(1)_Y}$. $\mathbf{10}$-plet to break it to $\boldsymbol{SU(3)_C \times U(1)_{em}}$.
  - The arbitrariness of the Higgs sector allows for a huge number of possibilities for building models. So the advantage of unification in the matter sector is to a degree vitiated by the proliferation of the Higgs fields.
- An ideal scenario
  - Unification of matter in one irreducible representation
  - Unification of Higgs fields in one irreducible representation.

A new path to SO(10) unfication

Babu, Gogoladze, PN, Syed
Computational techniques: PN, Syed (2001); Mohapatra, Sakita (1980); Wilczek, Zee (1982)

Quite remarkably it is possible to break $SO(10)$ with a single irreducible rep. This is done by use of a vector-spinor 144 which under $SU(5) \times U(1)$ decomposes as

$$144 = \bar{5}_3 + 5_7 + 10_{-1} + 15_{-1} + 24_{-5} + 40_{-1} + \overline{45}_{-3}$$

- The 24-plet has a $U(1)$ charge which means that once the 24-plet gets a VEV, there is a change in the rank. Spontaneous symmetry breaking does occur and one finds

$$SO(10) \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y$$

- A fine tuning is required to get a light Higgs. All Higgs triplets are heavy.

Proton decay via dimension 5 operators

Review: Phys. Rep: PN & PF Perez

- Nature and strength of $B\&L$ violating interactions at the GUT scale.
- Nature of soft breaking enters in the dressing loop diagrams.
- Constraints from gauge coupling unification which constrain the heavy thresholds and the Higgsino triplet mass.
- $b-\tau$ unification, $g_\mu - 2$, and $b \to s\gamma$.
- Quark-lepton textures.
- Dark matter constraint
- Planck slop corrections
- Gravitational warping effects
- Uncertainties of effective lagrangian approximation which converts operators such as $QQQL$ and $U^C U^C D^C E^C$ into lagrangian for mesons + baryons.

Conditions for suppression of dim 5 proton decay

GUT/string theories contain not only color triplet (anti-triplet) Higgsinos $H^a(H'_a)$ with charges $Q = -1/3(1/3)$ which couple with sources J_a, K^a, but also Higgsino triplets (anti-triplets) with charges $-4/3(4/3)$ $\tilde{H}^a(\tilde{H}_a)$ which couple with sources $\tilde{J}, \tilde{K}$.

$$H'\mathcal{M}H + H'K + HJ + \tilde{H}'\tilde{\mathcal{M}}\tilde{H} + \tilde{H}'\tilde{K} + \tilde{H}\tilde{J}$$

The conditions for suppression of dim 5 operators including Planck scale corrections are (PN, R Syed, arXiv:0707.1332 [hep-ph])

$$LLLL: \ (U\mathcal{M}V^T)^{-1}_{11} + \Lambda_{\mathrm{Planck}} = 0$$

$$RRRR: \ (U\mathcal{M}V^T)^{-1}_{11} + (\tilde{U}\tilde{\mathcal{M}}\tilde{V}^T)^{-1}_{11} + \tilde{\Lambda}_{\mathrm{Planck}} = 0$$

U, V etc take us to the basis where only H_1 and H'_1 couple with matter.

Mechanisms for suppression of dim 5 proton decay

- Various mechanisms for suppression include
  - Dim 5 is non-vanishing but naturally small and consistent with data in specific models (ideal scenario).
  - Group theoretic suppression: Couplings to one or both of the Higgsino triplets vanish and no dim 5 operators are generated.
  - If the sfermions are all very heavy such as when REWSB occurs far on the HB/FP branch, or as in split supersymmetry, then dim 5 are naturally small.
  - The cancellation mechanism: It can operate if there are more than one set of irreducible reps contributing to the dim 5 operators.

An illustration of the cancellation mechanisms for suppression of dim 5 proton decay

Consider an $SU(5)$ model with the Higgs content $\mathbf{24}, \mathbf{5}, \bar{\mathbf{5}}, \mathbf{45}, \overline{\mathbf{45}}$ with the color triplets (anti-triplets) as follows

$$H^a(5; q = -1/3), P^a(45; -1/3), Q^a(\overline{45}; -4/3)$$

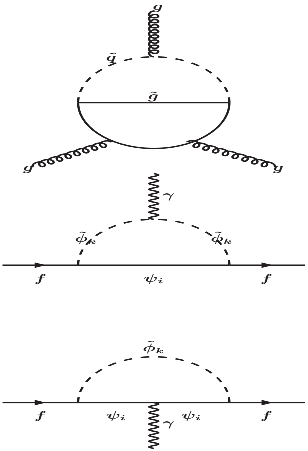
$$H'_a(\bar{5}; q = 1/3), Q_a(\overline{45}; 1/3), P_a(45; 4/3)$$

$$\begin{array}{cc} & \begin{array}{ccc} H^\alpha & P^\alpha & Q^\alpha \end{array} \\ \begin{array}{c} H'_\alpha \\ Q_\alpha \\ P_\alpha \end{array} & \begin{pmatrix} M_{11} & M_{12} & 0 \\ M_{21} & M_{22} & 0 \\ 0 & 0 & M_{33} \end{pmatrix} \end{array}$$

P decay suppression: Assume couplings of $\mathbf{45}(\overline{\mathbf{45}})$ have the same flavor dependence as couplings for $\mathbf{5}(\bar{\mathbf{5}})$: $\mathbf{45} \sim \lambda \mathbf{5}$, $\overline{\mathbf{45}} \sim \lambda' \bar{\mathbf{5}}$.

$$(i)\lambda' = 0, M_{11}^{-1} + \lambda M_{12}^{-1} = 0;\ (ii)\lambda = 0, M_{21}^{-1} + \lambda' M_{22}^{-1} = 0$$

Analogous to the cancellation mechanism for SUSY EDMs among electric dipole, chromoelectric dipole, and purely gluonic dimension six operators.



The cancellation mechanisms in $SO(10)$ for suppression of dim 5 proton decay

- $\boldsymbol{SO(10)}$ models with couplings of type $\mathbf{16.16.10}$, $\mathbf{16.16.120}$, and $\mathbf{16.16.\overline{126}}$ do not give a cancellation, since 10 plet couplings symmetric, 120 plet couplings anti-symmetric and $\mathbf{\overline{126}}$ do not contribute.
- The cancellation possibility arises in $\mathbf{144(\overline{144})}$ plet couplings

$$\mathbf{144 - Higgs : 5(3) + \bar{5}(7) + \overline{45}(3) + ..}$$

$$\mathbf{\overline{144} - Higgs : \bar{5}(-3) + 5(-7) + 45(-3) + ..}$$

  - Two pairs of color triplets (anti-triplets) from $\mathbf{5(\bar{5})}$.
  - Two pairs of color triplets (anti-triplets) from $\mathbf{45(\overline{45})}$.
  - An internal cancellation can occur in the dim 5 operators originating from the two types of contributions.

Conclusion/prospects

- The LHC results will hopefully provide us with a concrete evidence of sparticles and a measurement of some of the sparticle masses which will lead to improved proton lifetime predictions.

- Proton stability experiments should continue as they probe the nature of fundamental interactions at extremely short distances which the accelerators can never hope to reach. Several proposals under consideration include HyperK, UNO, LANNDD, LENA, MEMPHYS,..

  The goal of the new generation nucleon stability experiments is to improve the lower limits by a factor of 10 or more, e.g.,

$$\boldsymbol{\tau_p / B(p \rightarrow \bar{\nu} K^+) > (2.3) \times 10^{33}\mathrm{y} \ \rightarrow \ (> 4) \times 10^{34}\mathrm{y}}$$

Conclusion/prospects

Further work is also needed in reducing the uncertainties in theoretical predictions. This requires better fix on GUT parameters, sparticle spectrum, lattice gauge calculations of β_p, as well as further improvements in connecting fundamental supergravity/string theory to effective low energy Lagrangian including baryons and mesons.