Scott Thomas

Lecture 3

Supersymmetry Breaking

Note on SUSY Gauge Coupling Unifications

For Pedagogical Reasons I Presented Prediction of Unif. in terms of The ratio of 1-loop β-fcn Coeffs:

$$B = \frac{b_3 - b_2}{b_2 - b_1}$$

Gives a Good fit to Data

$B^{SM} \approx 0.528$ $\qquad$ $B^{SUSY} = 0.714$

However This Comparison Assumes That 1-loop Supersymmetric b_i's Are Good Down to m_Z

This ignores

1. The fact That $m_\phi, m_\lambda \gtrsim m_Z$ so β-fcns must be Corrected below m_ϕ, m_λ

2. Two-loop β-fcn Effects

3. Finite Threshold Corrections at m_ϕ, m_λ From integrating out ϕ, λ (Two loop Matching Corrections)

When These Corrections Taken into Account
And $\alpha_1(m_Z)$ and $\alpha_2(m_Z)$ are used as inputs
SUSY unification Predicts

$\alpha_3(m_Z) \approx 0.13$ SUSY unification

$\alpha_3(m_Z) = 0.1172 \pm .002$ Experiment

This is a 6σ Discrepency - But is at the
level One Could expect from Unknown
High Scale Threshold Effects

This Should be Compared with SM Unification
which Predicts

$\alpha_3(m_Z) \simeq 0.07$

which is a 12σ Discrepency

Discuss

Note: All The "Problems" of SUSY SM
Are Related to Symmetries of
The Low Energy Theory
Either in W or in Soft SUSY.

So Depend on How Symmetries Realized
in Full Theory

And There Are Well Motivated / Thought out
Scenarios / Specific Models in Which
Some / All "Problems" Emeliorated

So I Don't View These as intrinsic
Deficiencies of SUSY: Rather They Are
Telling us Something About The
Structure of The Underlying Theory

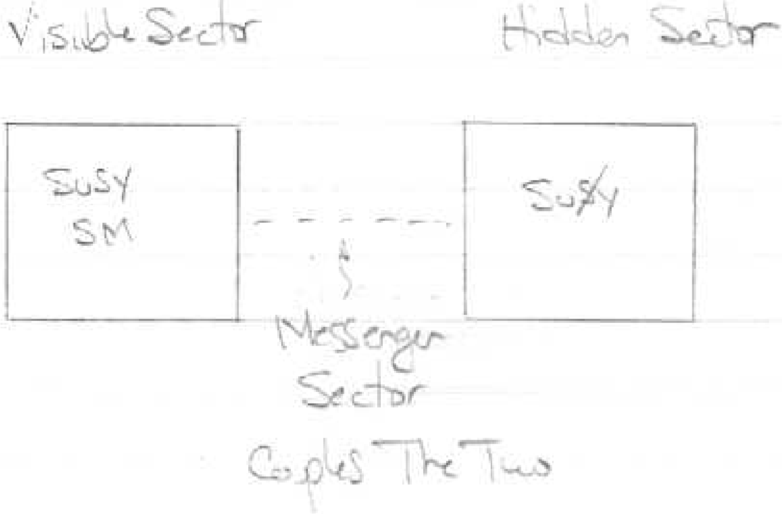
In particular giving Clues About How SUSY
is Broken.

[Any Way There is no Principle That Says All
(Approximate) Global Sym must be Accidental]

Also Note:

(Almost) All The "Indications" For SUSY Are Related to The Dynamics of SUSY Which are ~~Hard~~/Unnatural to modify

So in my opinion SUSY is by far The Leading Candidate for Physics Beyond The SM



- What is The S~~U~~SY Sector?
- What is The Messenger Sector?

Discussion Here in Context of $D=4$
Most Qualitative Features unchanged if Theory Becomes $D>4$ At an Intermediate Scale!

· How Can Susy

Spont. Susy Means in Vacuum Non-Zero Order Parameter $Q^\alpha|0\rangle \neq 0$

In Global Susy $\{Q^\alpha, Q^\beta\} = 2H$

$Q|0\rangle \neq 0 \rightarrow \langle 0|H|0\rangle \neq 0$

∴ Vacuum Energy is The order Parameter In Global Susy

$V = \frac{1}{2}D^2 + F^{+}F$

Aux Component of Gauge mplet

Aux Comp. of X-mplet

So $\langle D\rangle \neq 0$ and/or $\langle F\rangle \neq 0 \rightarrow$ Susy

• So Aux Components are order Parameters for Susy

↳ Can See Another Way

For Global Sym ~~Goldstone Field Transforms~~
Inhomogenously under Sym like The Trans. Parameter
And in proportion to ⟨order Parameter⟩
Since SUSY Fermionic Sym Goldstone Field
Should be a Fermion / The Goldstino

Check SUSY Trans:

- Vector Superfield $\delta\lambda^\alpha = i\xi^\alpha D$
- χ-Superfield $\delta\psi^\alpha = i\xi^\alpha F$

Also indicates D, F are order parameters for Susy

• In Local Susy V no Longer Good order parameter but $\langle D\rangle$, $\langle F\rangle$ Are!

What ~~Sym~~

	SUSY	$U(1)_R$	$U(1)_{PQ}$
M_ϕ	✓		
m_λ	✓	✓	
μ			✓
M_d^2	✓	✓	✓
D	✓		
F	✓	✓	

$\langle D \rangle$ Leaves $U(1)_R$ D - uncharged

$\langle F \rangle$ Breaks $U(1)_R$ Spontaneously ← Good for m_λ

So $\langle F \rangle \neq 0$ most likely Although $\langle D \rangle \neq 0$ might be present

- Why Not Couple Some Φ to SUSY SM at Renormalizable Level and Arrange $F_\Phi \neq 0$. (What people Tried circa 1980)

$W = \Phi \Psi \Psi$, $F_\Phi \neq 0$

$\mathrm{Str}_\Psi M^2 = 0$ At Tree Level: Ferra - Giradelli. (Dimopolos - Georgi).

$\therefore \exists$ $m_0 < m_f$

But we Need $m_0 \gg m_f$

1) Violated QM: $\mathrm{Str}\, m_\Phi^2 \sim \left(\frac{g^2}{16\pi^2}\right)^2 m_{\not S}^2$

So if $\not S$USY Only Couples to SUSY SM
QM Through Radiative Corrections

And $m_{\phi_i} \sim \left(\frac{g^2}{16\pi^2}\right) m_{\not S} \sim m_Z$
MSSM Scalar Then OK

↳ Gauge Mediation ← Messenger Interactions Are Usual Gauge interactions.

2) Super Gravity $\mathrm{Str}\, m^2 = m_{3/2}^2$ Even Classically!

So if $\not S$USY Only Couples to SUSY SM
Through "Supergravity" (Planck Suppressed)
And

$m_{3/2} \sim m_Z$ Then OK!
↳ Gravity Mediation ← Messenger interactions Are M_p Suppressed Op.

So Can't Break SUSY Directly in Visible Sector
Must be Removed, Either Only Couples
Radiatively or Through Irrelevant Op.

- Either Case / General Setting:
  If int. of Messenger Interactions
  Get Eff Op. Coupling Visible and Hidden Sectors — Consider Global Susy for Simplicity:
  Susy SM to Susy Sector:

  ↓

  (Some Aux Comp of X - Sup Field)
  Call S in general

- $\mathcal{V} \supset m^2 \phi^\dagger \phi$

$$\frac{1}{M^2}\int d^4\theta\, \Phi^\dagger \Phi\, S^\dagger S \supset \frac{F^\dagger F}{M^2}\phi^\dagger\phi$$

Messenger Scale → M^2

m_ϕ^2 → $\frac{F^\dagger F}{M^2}$

- $\mathcal{V} \supset \frac{1}{2} m \lambda\lambda$

$$\frac{1}{M}\int d^2\theta\, S W^\alpha W_\alpha \supset \frac{F}{M}\lambda\lambda$$

m_λ → $\frac{F}{M}$

Note $m \sim F$, $m^2 \sim F^2$ } Good!

- $W = \mu H_u H_d$

$$\frac{1}{M}\int d^4\theta\, S H_u H_d \supset \underset{\mu}{\underbrace{\frac{F}{M}}} \int d^2\theta\, H_u H_d$$

- $V = m_d^2 H_u H_d$

$$\frac{1}{M^2}\int d^4\theta\, S^\dagger S H_u H_d \supset \frac{F^* F}{M^2} H_u H_d$$

μ-Problem Easy to "Solve" if write Down General Op.
— c.f. High Scale: just writing Down All Possible Op. Anyway

- Exercise

- Write Down Op for A-terms
- Write Down Op for a Hard Breaking That Would introduce Quad Div in Low Energy Theory — Estimate effect of Quad Div on Higgs Mass — Cutoff Div at Scale M — What is The Answer?

$$\frac{1}{M^4}\int d^4\theta\, S^\dagger S (H_u^\dagger H_u)^4$$

All Hard Breaking Terms Suppressed by Additional Powers of $\frac{F^\dagger F}{M^2}$

— To Avoid Destroying w Structure of Theory

So Requirement of only Soft Terms Results from Eff. Op Analysis

**

Arises Automatically in Eff op Analysis

· SFlavor Problem: — Challenging / Interesting Problem
Many Solutions: -- Discuss Two Main Ones:

↳ Viol. Depends on Structure / Couplings of Messenger Interactions:
↳ if Commute with Flavor — No Problem!

— Gauge Mediation

Massive Sector in which SUSY Broken
And Fields in This Sector Transform
under $SU(3) \times SU(2) \times U(1)$

$$W = S \bar{\Phi} \Phi \qquad S \neq 0, \; F_S \neq 0$$

$$m_\phi^2 \sim \left(\frac{g^2}{16\pi^2}\right)^2 \left|\frac{F}{S}\right|^2 \qquad m_\lambda \sim \frac{g^2}{16\pi^2}\,\frac{F}{S}$$

No Flavor Problem !! — SM Gauge interactions Commute With Flavor !!

$100\ \text{TeV} \lesssim S \lesssim M_p$

$\frac{F}{S} \sim 100\ \text{TeV}$ $\qquad 100\ \text{TeV} \lesssim F \lesssim 10^{11}\ \text{GeV}$

[Called Low Scale Models] "μ-Problem Difficult" to Build Model

Misnomer

- "Gravity" Mediation: $M \sim M_{GUT}$ or M_p

Just effective Op. Suppressed by

If not forbidden Expect Viol of (Global) Flavor Sym. --

Flavor Problem:

Without AnyThing Restricting Eff Ops. Expect General Flavor Structure Especially if $M \sim M_p$

Problem is That only Symmetry That Could Forbid off Diag Flavor Violation is Flavor itself.

However, The Yukawa Matrices Show Definite Patterns

First Gen < 2nd Gen << 3rd Gen Masses!

Moderate Mixing

Small Mixing

Seems (to me) Likely That This Pattern is Result of Flavor Symmetries - Not just Random #s.

At The Least it is Certainly True That The Flavor Viol in The Yukawas is Hierarchical in Generation.

Could turn it Around and Say Approximate Flavor Sym in First Two Generations.

Maybe Whatever Protected/Enforced Small Yukawas Protects Flavor Violation to Sufficient Degree is Squark/Slepton Mass Matrices

- Squark / Slepton Mass Matrices must either be

  1. (Approximately) Degenerate (So That No particular Directions picked out in Flavor Space)

And/or

  2. Aligned with Quark / Lepton Yukawa Couplings (Nir, Seiberg)

Possible for This to Arise in

- Froggatt-Nielsen Mechanism for Yukawa Couplings)

$\lambda_{ij} = 0$ $\quad G = \prod SU(3)$

Imagine Subgroup is a Gauge Sym - G'
Discrete or Continuous
So Quark / Lepton χ- SuperFields Transform
(Flavor or Horizontal Syms)

Then In general $\lambda_{ij}\, Q H_u \bar{u} + \cdots$
May not be Allowed by Sym!

$\lambda_t \approx 1$ So Should be Allowed $\lambda_t Q H_u \bar{t}$

* DisAllow others by G' Symmetry

↳ Good Start - App The IR world
Single Massive top, Rest massless)

If Broke G' Sym Spont, might Then
Allow other masses Since it was The
Sym That forbid Them

If $\langle \Phi \rangle$ Field That Breaks Sym Then
There Should exist Op of Form:

$$\frac{\Phi}{M} Q_i H_u \bar{U}_j \quad , \quad \frac{\Phi^2}{M^2} Q_i H_u \bar{U}_j \quad , \quad \frac{\Phi^3}{M^3} L_i H_d \bar{e}_j + \cdots$$

What Op Appear And with What flavor
Structure Depends crucially on
How Φs, Q, $\bar{U}$, ... Transform under G'

if $\frac{\Phi}{M} \sim \epsilon < 1$ Then Can Get Hierarchical Structure...

$$\lambda_{ij} \sim \begin{pmatrix} \epsilon^4 & \epsilon^3 & \epsilon^2 \\ \epsilon^3 & \epsilon^2 & \epsilon^2 \\ \epsilon^2 & \epsilon^2 & 1 \end{pmatrix} \leftarrow \text{Yukawa Textures.}$$

Certain Textures are known to
Approximately Reproduce
Quark masses / Mixings

Lots of Freedom

Independ of SUSY Flavor Problem

For Scalars:

$m^2 \phi^\dagger \phi$ Allowed by Any Symmetry

$m^2 \frac{\Phi^n}{M^n} \phi_i^\dagger \phi_j$

Also Get Scalar mass Matrix Texture:

$$\begin{pmatrix} 1 & \epsilon^2 & \epsilon^3 \\ \epsilon^2 & 1 & \epsilon \\ \epsilon^3 & \epsilon & 1.5 \end{pmatrix}$$

large λ_t Corrections – Dangerous ⋯→
At High Scale

1. off Diag Elements Small
~ Approximate Degeneracy

cf. predictions

-or-

2. Flavor Viol. Aligned Sufficiently with λ_{ij}

$$G = \prod_{q} SU(3)$$

- For A-terms:

Viol Same X-Sym as λ_{ij} $(3_a, \bar{3}_b)$

So Proportionality $A_{ij} \propto \lambda_{ij}$
Not Hard to Imagine

- Flavor Struct. of Yukawas Probably not an Accident.

- FN Mech. Elegant way to Generate

- With High Scale Mediation Most likely
Hope for Understanding lack of SUSY Flavor

Lot's of Work from Bottom up on Flavor Sym
Not much From Top Down

(Probably is Some But None Comes to Mind)

So if There were Scenarios for Realizing FN idea - Would be interesting.

- Note if There Are Flavor Sym
  Might be Very interesting levels of Slepton Oscillations at NLC

Slepton Flavor Physics at Linear Colliders

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If low energy supersymmetry is realized in nature it is possible that a first generation linear collider will only have access to some of the superpartners with electroweak quantum numbers. Among these, sleptons can provide sensitive probes for lepton flavor violation through potentially dramatic lepton violating signals. Theoretical proposals to understand the absence of low energy quark and lepton flavor changing neutral currents are surveyed and many are found to predict observable slepton flavor violating signals at linear colliders. The observation or absence of such sflavor violation will thus provide important indirect clues to very high energy physics. Previous analyses of slepton flavor oscillations are also extended to include the effects of finite width and mass differences.

I. INTRODUCTION

If supersymmetry is discovered at the Tevatron or LHC, much of the focus of particle physics research will turn to measuring and understanding the 105 (or more) soft breaking parameters. While this problem may seem, at first, more daunting than understanding the pattern of quark and lepton masses and mixings, we know, a priori, that these parameters must show striking regularities. Otherwise, supersymmetry would lead to large, unobserved flavor violation among ordinary quarks and leptons.

From the perspective of string theory, for example, the prospect of discovering supersymmetry and measuring the soft breaking parameters is extremely exciting. Indeed, in most pictures of supersymmetry breaking, squark and slepton masses arise from non-renormalizable operators associated with some new scale of physics. This could well be, for example, the scale of string or M-theory. Thus, collider measurements of the soft breaking parameters are potentially indirect probes of extremely high energy physics, physics we might hope to eventually unravel!

To date, there are only a few theoretical proposals for the origin of the requisite regularities of the soft parameters which lead to acceptably small low energy flavor violation among the quarks and leptons. Each has important implications for the physics discoveries of future colliders. In this note, we will survey these proposals, and discuss some of their implications for collider phenomenology. One particularly exciting possibility, is the existence of dramatic flavor violating phenomena in slepton production. This can occur even given the strong bounds from the non-observation to date of flavor violation in low energy lepton decays.

We also call attention to previous work on slepton flavor violating collider phenomenology [1, 2] and extend it to include the effects of finite width and mass differences. Our motivation is the realization that, in a first phase, a linear collider is likely to have a center of mass energy of 500 GeV. As a result, one can well imagine that supersymmetry will have been discovered at the LHC, but that we will have only limited information about the spectrum, and a first generation linear collider will have access to only a few of the lightest superpartner states. In many theories these include sleptons. Even with this limited set of states, the observation – or not – of slepton flavor violation will provide important clues to the underlying supersymmetry breaking structure.

The reason that observable sflavor violation at a linear collider is possible is easy to understand. In many proposals to solve the supersymmetric flavor problem, a high degree of degeneracy among sleptons (and squarks) is predicted. As a result, there is the potential for substantial mixing of flavor eigenstates. This can lead to substantial and observable sflavor violation. To be readily observable, it is necessary that mass splittings between the states not be too much smaller than the decay widths, and that the mixing angles not be terribly

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small. In some of these proposals, and in particular gauge mediation, the predicted degree of degeneracy is extremely high, and the mixing probably unobservable. However, in most other proposals, the splittings can be comparable or even larger than the widths, and the mixing angles may be of order the Cabbibo angle or larger. In this case, dramatic collider signatures are possible.

II. MEDIATION MECHANISMS

It is instructive to review the various proposed mechanisms for understanding the suppression of flavor changing processes in supersymmetric theories. We should start by noting that most analyses of collider experiments work in the framework of what has become to known as Gravity Mediation. In such models, one simply assumes exact degeneracy of squarks and sleptons at some very high energy scale. This assumption is not natural since it is violated by quantum corrections (and is in fact scale dependent), and so surely breaks down at some level. Without some theory, or more detailed assumptions, one cannot assess the degree to which this assumption is viable. In other words, degeneracy in this case is a puzzle to be explained rather than a mechanism in itself.

There are a number of more serious proposals of which we are aware for understanding the suppression of supersymmetric contributions to quark and lepton flavor violating processes. These fall into three broad classes. The first are mechanisms which seek to ensure a high degree of degeneracy as the result of dynamics without specific assumptions about flavor. The second are flavor symmetries which enforce either a high degree of degeneracy or alignment of the squark and slepton mass matrices with those of the quarks and leptons. The third invokes heavy superpartner masses to kinematically suppress low energy processes.

- Gauge Mediation: In its simplest form, any flavor violation in gauge mediation occurs at a high order in the loop expansion, or due to non-renormalizable operators. In the former case, the suppressions are typically by powers of small Yukawa couplings and extra loop factors. These effects are automatically aligned with flavor violation in the Yukawa sector and are therefore not dangerous and do not give rise to interesting processes. In the latter case, the suppression is by powers of Λ^2/M^2, where Λ represents some typical scale associated with the supersymmetry-breaking interactions, and M some large scale associated with new physics such as a flavor scale at which flavor is spontaneously broken or the Planck or string scale. For $\Lambda \ll M$ the distinctive feature is the absence of sflavor violating processes.

- Dilaton Domination: At weak coupling in the heterotic string there is a regime in which a gravity-mediated spectrum with a high degree of degeneracy is obtained. If the weak coupling picture is valid, one might hope that generic flavor violating corrections to squark and slepton mass matrices are of order $\alpha_{\rm GUT}/\pi$. Numerically this is just enough to understand the suppression of flavor changing neutral currents [3]. It suggests that mass splittings among the lightest sleptons will be at least of order a few parts in 10^{-3}. We will see that this is within the range (albeit at the low end) of what one might hope to measure directly at a linear collider. Without further assumptions about flavor, one expects mixings of squarks and sleptons to be of order one. Such a mass splitting is comparable to the expected decay widths of these states, so this sflavor violating mixing might well be observable. In the strongly coupled limit, it seems likely that the violations of degeneracy are larger [4].

- Anomaly Mediation: The anomaly-mediated hypothesis superficially has some features in common with gauge mediation. However, the mediation scale is now comparable to the Planck scale, and one has to ask about the magnitude of flavor violating corrections to squark and slepton mass matrices. It has been argued that brane world realizations of supersymmetry breaking might naturally provide a context for anomaly mediation with small corrections to degeneracy [5]. However, anomaly mediation turns out not a robust feature of brane world supersymmetry breaking, and violations of degeneracy are generally large [4]. Still, the degeneracy might be small enough to suppress low energy flavor violating processes in very special circumstances.

- Gaugino Domination (and the closely related idea of gaugino mediation): With no-scale boundary conditions one assumes that scalar masses vanish or are very small compared to gaugino masses at the high messenger scale. Without a detailed underlying model, it is hard to know how large the violations of degeneracy might be at this scale, but it seems reasonable to suppose that at the high scale, the magnitude of the squark and slepton mass matrices are suppressed relative to gaugino masses by an amount of order $\alpha_{\rm GUT}/\pi$. At lower scales, renormalization group evolution gives a flavor independent gaugino mass contribution to slepton masses which leads to a high degree of degeneracy. As in the case of dilaton domination, without further assumptions about flavor, the violations of degeneracy are expected to be maximally flavor violating, and to lead to large mixings in the high scale squark and slepton masses which in turn leads to large mixings at the electroweak scale.

- Conformal Sequestering: Another possibility for obtaining a high degree of degeneracy is to postulate that the first two generation squarks and sleptons are coupled to an approximately conformal sector over a few orders of magnitude in renormalization group evolution [6]. This has the effect of exponentially suppressing squark and slepton masses as well as fermion Yukawa couplings. Below this approximately conformal range of scales further renormalization group evolution gives a flavor independent gaugino mass contribution to slepton masses which leads to a high degree of degeneracy much as with no-scale boundary conditions. Violations of conformal invariance by standard model gauge interactions limit the degree of slepton degeneracy to roughly $\alpha_W/\pi \sim 10^{-2}$. Without further assumptions about flavor in the high scale theory above the approximately conformal scale, slepton mixings are related to ratios of lepton masses by roughly $\sin\phi_{ij} \gtrsim \sqrt{m_{\ell_i}/m_{\ell_j}}$.

- Non-Abelian Flavor Symmetries: If the explanation of squark and slepton degeneracy lies in non-abelian flavor symmetries, it is reasonable to expect that violations of degeneracy are correlated with the values of quark and lepton masses and the KM angles. In this case, one might hope to obtain tighter predictions in a given model for the pattern of flavor violation in the slepton sector. The level of degeneracy is model dependent, but again a few parts times 10^{-3} is a reasonable expectation for the violations of degeneracy, with values for the mixings of order Cabbibo angles $\sin\phi_{ij} \sim \sqrt{m_{\ell_i}/m_{\ell_j}}$ [7].

- Abelian Flavor Symmetries: As an alternative to degeneracy among squarks and sleptons, it has been suggested that the squark and slepton mass matrices might be approximately aligned with the quark and lepton matrices [8]. This can come about in theories with Abelian (discrete) flavor symmetries. In this case, one does not expect any approximate degeneracy among sleptons. In order to suppress flavor changing lepton decays the mixings need to be somewhat small. Still, the mixing can be large enough, in particular for mixing involving taus, such that sflavor violation can be observable at colliders.

- First Two Generations Heavy: Another possibility to suppress dangerous levels of supersymmetric contributions to low energy quark and lepton flavor violation is to postulate that the superpartners are very heavy. The first two generation squarks and sleptons can have masses up to of order 20 TeV without introducing significant tuning of electroweak symmetry breaking [9]. In this case only the (mostly) stau slepton(s) would be kinematically accessible at future colliders. Without additional assumptions about flavor, naturalness of the full slepton mass matrix implies that mixing of this light state(s) among the flavor eigenstates would be of order m/M where m and M are the light and heavy slepton masses.

In sum, of the various proposals to understand the absence of flavor violation at low energies, several predict dramatic violations of flavor at colliders. Among those which don't, there tend to be distinctive predictions for the spectrum. Models of gauge mediation, for example, tend to be highly predictive. While there is no one compelling model of this type, many models exist, and one can imagine detailed measurements distinguishing between them. In the case of alignment mechanisms, while there should flavor mixing it will not be so dramatic, one should observe correlations between the squark and slepton and the ordinary quark and lepton masses.

In the case of non-Abelian flavor symmetries, not only does one expect significant mixing, but one can hope to obtain, given some assumptions about the form of flavor symmetry breaking, precise predictions for some of the violations of flavor symmetry. Moreover, these are likely to be correlated with quark, lepton and neutrino mass matrices. In such a case, precision measurements might ultimately permit distinguishing between different models. Clearly, all of these are directions for further theoretical work, but the discovery of supersymmetry and unraveling the pattern of symmetry breaking would provide important insights into the nature of physics at very high energy scales. The observation of flavor violation – or its absence – at linear colliders will provide important clues to the nature of the underlying mechanisms of supersymmetry breaking and mediation.

III. SFLAVOR OSCILLATIONS OF UNSTABLE SLEPTONS

Slepton flavor oscillations arise if the sleptons mass eigenstates are not flavor eigenstates. Consider for simplicity the case in which leptons are produced initially in flavor eigenstates. If the mass eigenstates have distinct mass, then the flavor eigenstate oscillates in time and space with a frequency given by the mass splittings. If the slepton decay rate is much smaller than the mass splitting, oscillations average out and the probability of decay from a given flavor eigenstate is given simply by mixing angles, as implicitly assumed previously [1]. If the slepton decay is rapid compared with the oscillation frequency then the probability of decay to another flavor eigenstate is suppressed [2]. There are additional effects which can affect the flavor violating decay probability. First, different flavor eigenstates need not have the same decay width. This is particularly true for the $\tilde{\tau}$ slepton which can have a non-trivial decay amplitude to the Higgsino component of a neutralino at moderate to large $\tan\beta$. In addition, the probability amplitude or cross section for production of different mass eigenstates need

IV. CONCLUSIONS

If superpartners are discovered, there is good reason to expect that sleptons will have a high degree of degeneracy which enhances sensitivity to sflavor violating effects. It is quite possible then that significant sflavor violation could be observed at a linear collider. The observation – or non-observation – of such sflavor breaking would provide important indirect clues about flavor and supersymmetry physics at potentially extremely high energy scales.

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- What is SUSY Sector:

Non-Renorm Thm for $\underline{W}$:

Not Renormalized at Any order in Pert. Theory.

$\underline{\text{So}}$ if SUSY unbroken at Tree level
Remains unbroken at Any order in
Pert. Theory.

However Superpotential Can be Modified by
Non-Pert. $\underline{\text{effects}}$:

Effects which Are
In Gauge Theory: NP in gauge Coupling

$$e^{-8\pi^2/g^2}$$

but Dynamical Scale Generated by
Dimensional Transmutation in Asym Free Theory is

$$\Lambda = M e^{-8\pi^2/bg^2(M)}$$

So NP effects in W Can be written in
Terms of Dyn Scale.

e.g. Gauge Group G
Φ Matter in Adjoint Rep:

$$W_{\text{tree}} = \lambda S \Phi^2 \qquad \text{SUSY}$$

$$W = \Lambda^2 S \qquad\qquad F_S = \Lambda^2 \quad \text{S}\not{\text{U}}\text{SY}$$

(for $S \neq 0$)

So S$\not{\text{U}}$SY Can Result From Dim Transmutation

$$\Lambda = M e^{-8\pi^2/bg^2(M)} \ll M$$

Natural Large Hierarchy

If Theory Remains D=4 up to High Scale
This is likely The Way S$\not{\text{U}}$SY Occurs

If D>4 other Non-pert. Mechanisms
(may be Related to FT Dynamics by Dualities)

- Perturbative SUSY → Technically Natural Solution of Hierarchy Problem

  Softly Broken SUSY SM
  SUSY Scale Stable Against Corrections

- Non-Perturbative SUSY → Natural Solution of Hierarchy Problem

  The Scale of SUSY is Naturally exp Smaller Than Fundamental Scale Since Only Non-Perturbative Effects Related to Dimensional Transmutation Break SUSY.

- Fair / Good Chance Superpartners
  Will be Discovered at Fermilab
  (Now Running) - Next yr. Start to
  Probe new territory

- Susy Will be Discovered or Ruled out
  (At least Psychologically) by LHC
  Start Date 2007 (Only 5 yrs.)

Beyond Scope To Discuss How Susy will
be Discovered / Tested

Main Thing we Can Hope to Learn is

1. From Patterns of Soft masses
   ⇒ What are Messenger interactions

2. What is Scale of SUSY

If Lucky 3. Clues About Flavor from
   Sflavor Oscillations

(• ~~S&P~~ SPY Sector Pyramid)

(• What will we Learn) → ~~Shield~~ SPY

↳ ~~Robot~~ Eff. op Dipped 14 on (Assis and Scale
interaction — probably there got a word
Handle on

↳ But those interact could follow ~~dlt~~

- Really Hopeful (Teaches about Flaws Something)