

# Dissecting the SUSY Breaking Mechanism Using Renormalization Group Invariants

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# Outline

- Introduction.
- RGEs for sparticle masses and gauge couplings in the MSSM .
- 1-Loop RG Invariants constructed.
- 1-Loop RG Invariants used to constrain and extract information about SUSY breaking.
- 2-Loop effects invariants analyzed and always included.
- High scale extraction of parameters using RGIs:
  - Generic Flavor Blind Models
  - GGM
  - CMSSM with NUHM
- Numerical simulation: scan over model space of GGM,
  - Certain invariants may be used to test FB/GGM hypothesis.
  - If data consistent with model, RGIs may be used to extract information about soft SUSY breaking parameters.
  - Expected determination of parameters depends on experimental errors at LHC in measuring the physical sparticle masses.
- Outlook and Conclusions.

- Assumptions:

- Effective theory at electroweak scale is MSSM.
- No new physics alters 1-loop MSSM  $\beta$  functions below messenger scale, at which SUSY breaking is transmitted to visible sector.

- MSSM:

- Particle content governed by SUSY, and couplings by SM gauge and Yukawa couplings.
- Soft SUSY breaking parameters governing sparticle masses unknown.
  - Highly dependent on SUSY breaking scheme.
- If sparticles light, flavor physics strongly constrains structure of soft masses.
  - Flavor Blind Models of SUSY breaking favored.

Could LHC measurements determine :  
Messenger scale?  
Soft SUSY breaking parameters ?

- TOOL:

- 1-Loop RG Invariants in the MSSM.
  - Do 2-loop effects spoil invariance?
  - Effect on extraction of high scale parameters?
  - Experimental constraints need to be satisfied to extract information?

# The Minimal Supersymmetric Standard Model.

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# 1-Loop RG Evolution

## Assume

- soft sfermion masses flavor diagonal.
- 1<sup>st</sup> and 2<sup>nd</sup> generation masses degenerate at the messenger scale.
- Neglect 1<sup>st</sup> and 2<sup>nd</sup> generation yukawa and trilinear couplings.

$$16\pi^2 \frac{dm_i^2}{dt} = \sum_{jk} y_{ijk}^* y^{ijk} (m_i^2 + m_j^2 + m_k^2 + A_{ijk}^* A^{ijk}) - 8 \sum_a C_a(i) g_a^2 |M_a|^2 + \frac{6}{5} Y_i g_a^2 D_Y,$$

- First sum: degrees of freedom available to run in self-energy loop.
- Second sum: gauge groups.
- $C$  is quadratic Casimir.
- Trace in  $D_Y$  : all chiral multiplets.

$$\begin{aligned} D_Y &\equiv \text{Tr}_i(Y_i m_i^2) \\ &= \sum_{gen} \left( m_Q^2 - 2m_u^2 + m_d^2 - m_L^2 + m_e^2 \right) + m_{H_u}^2 - m_{H_d}^2. \end{aligned}$$

## Gauge couplings: homogenous RGEs at 1-loop:

$$16\pi^2 \frac{dg_r}{dt} = g_r^3 (\text{Tr}_n I_r(n) - 3C_r(G)),$$

- Here  $C$  is the quadratic Casimir of the adjoint representation.

## Three soft gaugino masses evolve:

$$16\pi^2 \partial_t M_r = g_r^2 M_r (2 \text{Tr}_n I_r(n) - 6C_r(G)).$$

# Constructing 1-Loop Renormalization Group Invariants

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# Sfermion dependant Invariants.

- Construct linear combinations of soft masses,  $D_i$ , evolving only with  $D_Y$

- Six combinations:

$$D_i \equiv \sum_j Q_j m_j^2, \quad \frac{dD_i}{dt} = a_i D_Y,$$

- For yukawa terms to vanish,

- $Q_i$ s must correspond to charges of global symmetry of classical yukawa potential.
  - Implies three independent constraints on the 12  $Q_i$ s.

- For gaugino terms to cancel,

- Symmetry must have vanishing mixed anomalies with SM gauge groups.
  - Supplies three more independent constraints on the  $Q_i$ s.

- Can construct basis in which 5 of 6 combinations also satisfy  $\text{Tr}QY=0$ ,

- Cancels  $D_Y$  dependence.
- Promotes them to 1-loop RG Invariants, independent of vanishing of  $D_Y$ .

## Invariants Testing Flavor Structure

- Baryon Number ( $Q=B$ ) and Lepton Number ( $Q=L$ )

- Classical symmetries, anomalous in the MSSM.
- Our approximation:  $B$  and  $L$  anomalies flavor independent.
- Difference between the first (second) and third generation is anomaly free.

$$D_{L_{13}} \equiv D_{L_1} - D_{L_3}$$

- We can then generate two invariants:

$$D_{B_{13}} \equiv D_{B_1} - D_{B_3}$$

# Anomalous U(1)s and Invariants involving Gauge Couplings/Gaugino Masses

Obvious choice:  $Y$  and  $(B-L)$ :

- Evolve with  $D_Y$ .

Use similar idea for  $Y$  as with  $B$  and  $L$ .

- Must include Higgs doublet with 3<sup>rd</sup> generation, since evolution linked with yukawas.

The RG Invariant is given by:

$$D_{Y_{13H}} \equiv D_{Y_1} - \frac{10}{13} D_{Y_{3H}}$$

For  $(B-L)$ , generation subtraction redundant: can already be constructed out of  $B_{13}$  and  $L_{13}$ .

Restricted to one generation,  $D_Y$  and  $D_{(B-L)}$  evolve only with  $D_Y$

- Construct RGI depending only on 1<sup>st</sup> generation soft masses:

$$D_{\chi_1} \equiv 4D_{Y_1} - 5D_{(B-L)_1}$$

- Identified with U(1) <sub>$\chi$</sub>  generated in breaking of  $E_6$  to  $SU(5) \times U(1)_\chi \times U(1)$ .

Anomalous combination of both U(1)s, setting 1<sup>st</sup> generation left handed slepton charges to zero: obtain additional anomaly free U(1) <sub>$Z$</sub> :

$$D_Z \equiv 3m_{\tilde{d}_3}^2 + 2m_{L_3}^2 - 2m_{H_d}^2 - 3m_{\tilde{d}_1}^2.$$

$D_Y$  vanishes only in minimal GGM.

- Construct genuine invariant using RGE for  $g_i$ :

$$I_{Y\alpha} \equiv \frac{D_Y}{g_1^2}.$$

From RGEs for gauge couplings, we can further obtain:

$$I_{g_2} \equiv \frac{1}{g_1^2} - \frac{33}{5g_2^2}$$

$$I_{g_3} \equiv \frac{1}{g_1^2} + \frac{33}{15g_3^2},$$

From RGEs for gaugino masses, can construct:

$$I_{B_r} \equiv M_r / g_r^2.$$

3 invariants mixing sfermion and gaugino masses can be obtained from the 1<sup>st</sup> generation:

$$I_{M_1} \equiv M_1^2 - \frac{33}{8}(m_{\tilde{d}_1}^2 - m_{\tilde{e}_1}^2 - m_{\tilde{u}_1}^2)$$

$$I_{M_2} \equiv M_2^2 - \frac{1}{24}(-9m_{\tilde{d}_1}^2 - 16m_{L_1}^2 + m_{\tilde{e}_1}^2 + 9m_{\tilde{u}_1}^2)$$

$$I_{M_3} \equiv M_3^2 - \frac{3}{16}(5m_{\tilde{d}_1}^2 - m_{\tilde{e}_1}^2 + m_{\tilde{u}_1}^2).$$



# 2-Loop Effects?

- All RGEs defined so far have vanishing  $\beta$ -functions only at 1-loop level.
- Can easily check invariance not preserved at 2-loops.
  - Important to estimate 2-loop effects.
  - How do they compare to expected experimental errors in measurements of invariants?
  - How does this constrain experimental accuracy required to determine any high scale model parameters?
- Implemented full 2-loop RGEs for evolution of soft SUSY breaking parameters, gauge and Yukawa couplings when performing numerical simulations in Mathematica.
- Compared our mass spectrum to one obtained from SUSPECT and obtained excellent agreement.

# Extraction of High Scale Parameters using RGIs.

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Invariant	Generic Flavor Blind Model	GGM	CMSSM with NUHM
$D_{B_{13}}$	0	0	0
$D_{L_{13}}$	0	0	0
$D_{X_1}$	$9m_d^2 - m_e^2 + 6m_L^2 - 6m_Q^2 - 3m_u^2$	0	$5m_0^2$
$D_{Y_{13H}}$	$\frac{1}{13} \left( 3(m_d^2 + m_e^2 - m_L^2 + m_Q^2 - 2m_u^2) + 10(m_{H_d}^2 - m_{H_u}^2) \right)$	$-\frac{10}{13}(\delta_u - \delta_d)$	$-\frac{10}{13}(\delta_u - \delta_d)$
$D_Z$	$2(m_L^2 - m_{H_d}^2)$	$-2\delta_d$	$-2\delta_d$
$I_{Y\alpha}$	$\frac{1}{97} \left( 3(m_d^2 + m_e^2 - m_L^2 + m_Q^2 - 2m_u^2) - m_{H_d}^2 + m_{H_u}^2 \right)$	$\frac{1}{97}(\delta_u - \delta_d)$	$\frac{1}{97}(\delta_u - \delta_d)$
$I_{B_r}$	$M_r/g_r^2$	$MB_r$	$m_{1/2}/g_r^2$
$I_{M_1}$	$M_1^2 + \frac{33}{8} \left( m_e^2 + m_u^2 - m_d^2 \right)$	$g_1^4 \left( \frac{33}{10} A_1 + (MB_1)^2 \right)$	$m_{1/2}^2 + \frac{33}{8} m_0^2$
$I_{M_2}$	$M_2^2 + \frac{1}{24} \left( 9m_d^2 - m_e^2 + 16m_L^2 - 9m_u^2 \right)$	$g_2^4 \left( \frac{1}{2} A_2 + (MB_2)^2 \right)$	$m_{1/2}^2 + \frac{5}{8} m_0^2$
$I_{M_3}$	$M_3^2 - \frac{3}{16} \left( 5m_d^2 - m_e^2 + m_u^2 \right)$	$g_3^4 \left( (MB_3)^2 - \frac{3}{2} A_3 \right)$	$m_{1/2}^2 - \frac{15}{16} m_0^2$
$I_{g_2}$	$\approx -10.9$	$\approx -10.9$	$\approx -10.9$
$I_{g_3}$	$\approx 6.2$	$\approx 6.2$	$\approx 6.2$

## High Scale Parameters

Three gauge couplings,  $g_r$

Flavor Blind Models

- 5 sfermion masses
- 3 Gaugino masses
- 2 Higgs Parameters

Under-constrained:

- have 1 undefined parameter

CMSSM with NUHM

- $m_0$ : sfermion masses
- $m_{1/2}$ : Gaugino masses
- 2 Higgs Parameters.

Over-constrained:

- Need to satisfy consistency equations.

GGM:

- $A_r$ : defining sfermion masses
- $B_r$ : defining Gaugino masses
- 2 Higgs Mass Parameters

Exactly right number of parameters.

# Numerical Simulations and Results.

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# Procedure

- Scan messenger scale parameter space of models for GGM.

- $A_r$ : 0.1, 0.55, 1 (TeV)<sup>2</sup>
- $B_r$ : 0.1, 0.55, 1 (TeV)
- $\delta_u$ : 0, 0.5, 1 (TeV)<sup>2</sup>
- $\delta_d$ : 0, 0.5, 1 (TeV)<sup>2</sup>
- $\text{Log}[\mu_f/m_Z]$ : 12, 21, 30
- $\text{Tan}(\beta)$ : 2, 9, 16, 26, 50

- Compute invariants, soft masses and gauge/yukawa couplings at messenger scale.

- Using 2-loop RGEs, run down to TeV scale.

- Compute invariants, soft masses and physical masses at TeV scale.

- Assume each point in model space maybe an experimental measurement for the soft masses at TeV scale, with error of 1%:

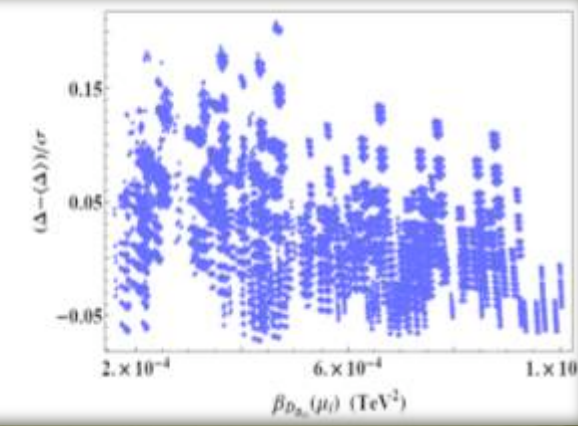
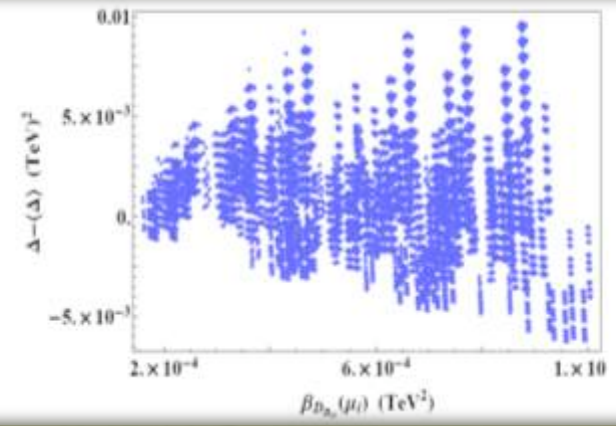
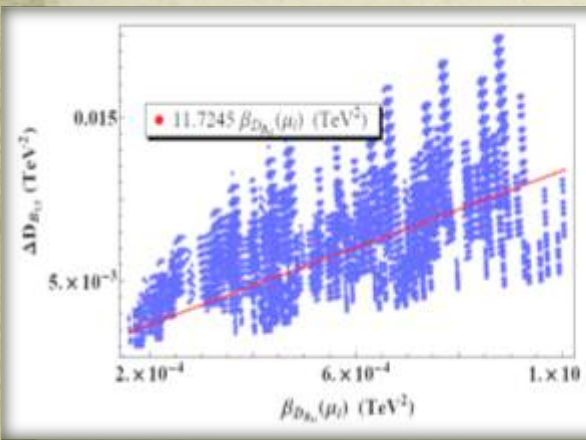
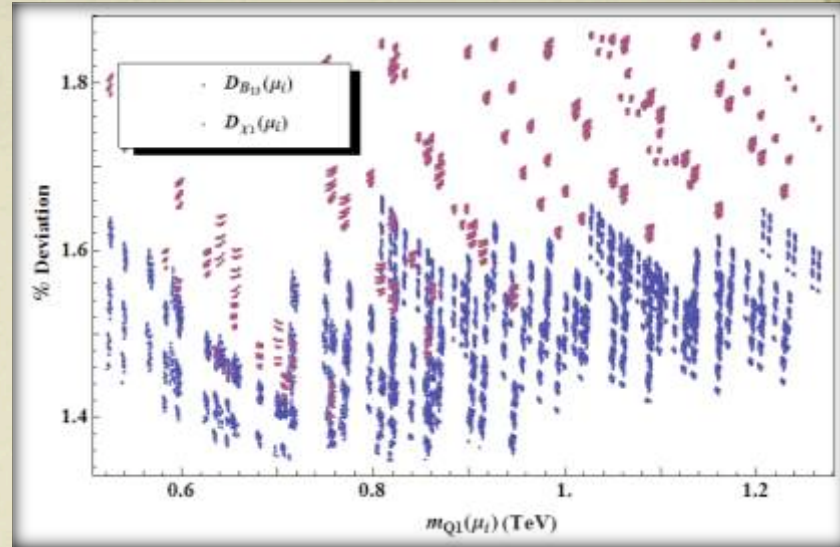
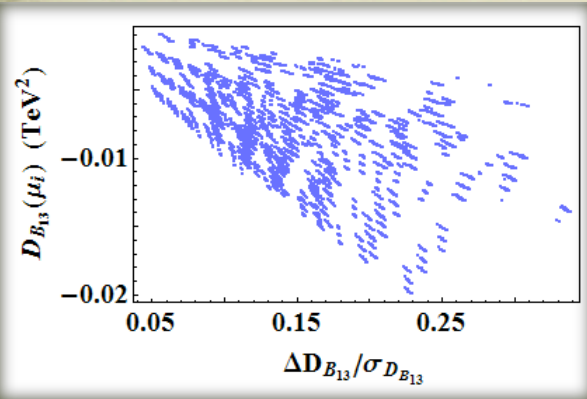
- Test hypothesis of flavor blindness using first 2 invariants.
- Test GGM using 3<sup>rd</sup> Invariant
- Extract messenger scale parameters from the rest.
- Check consistency of CMSSM with NUHM using over-constrained equation.

- Considered flat 1% experimental error in measurement of all soft masses at TeV scale.

- Probably highly optimistic
- In reality would be highly dependant on exact decays chains depending on mass hierarchy, etc used to measure masses experimentally.
- Since we assume flat % errors, easy to see from plots what change in % error would imply.

# $\sigma_{\text{soft mass}} = 1\%$ : 2-loop Running Preserves Invariance within Error.

$D_{B_{13}}$ , expected to be zero in FBMs, plotted as function of ratio of 2-loop running and expected experimental errors. Can invert relationship to extract % deviation in soft masses that could be detected when any of them are non-zero within error.

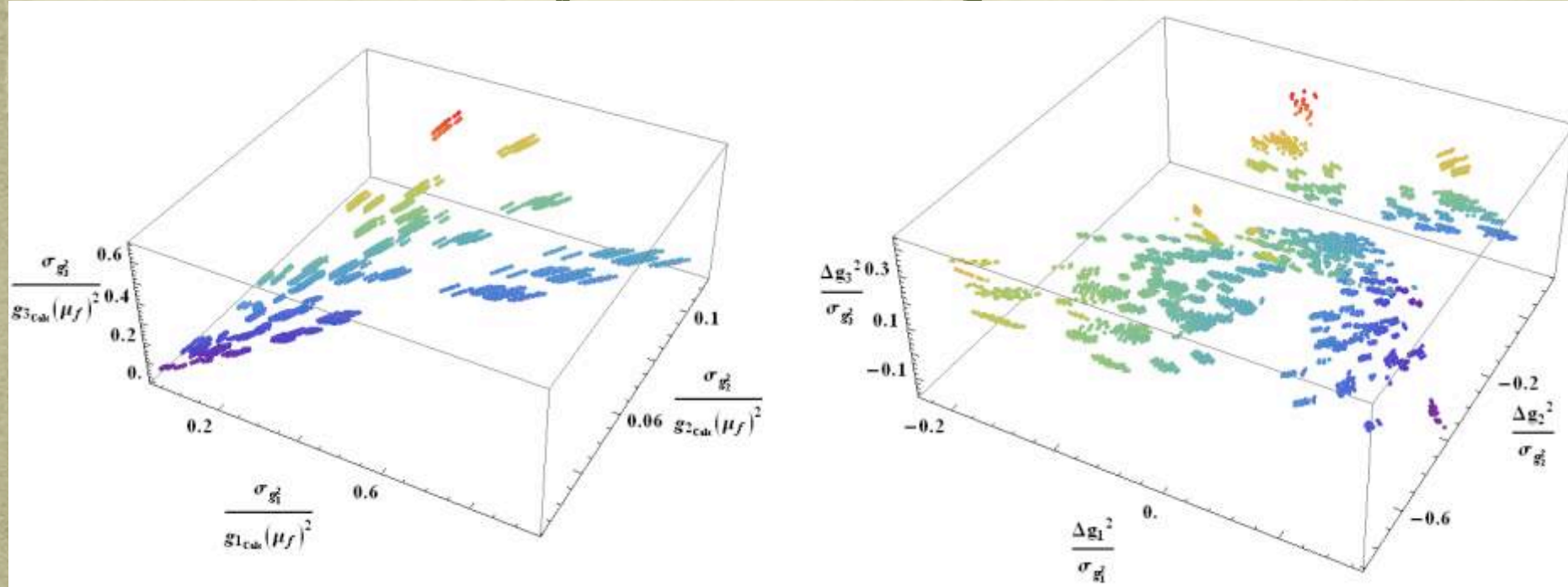


Treatment of 2-loop running:

Approximate  $\beta$ -function, and subtract expected value from Invariant calculated. All RGIs 2-loop running then  $\sim < 1 \sigma$ . Hence, after shifting invariants, can ignore 2-loop effects. 14

# Determination of $g_r$ at the messenger scale:

$$g_1^2(\mu_f) = -13/10 D_{Y13H} / I_{Y\alpha}$$

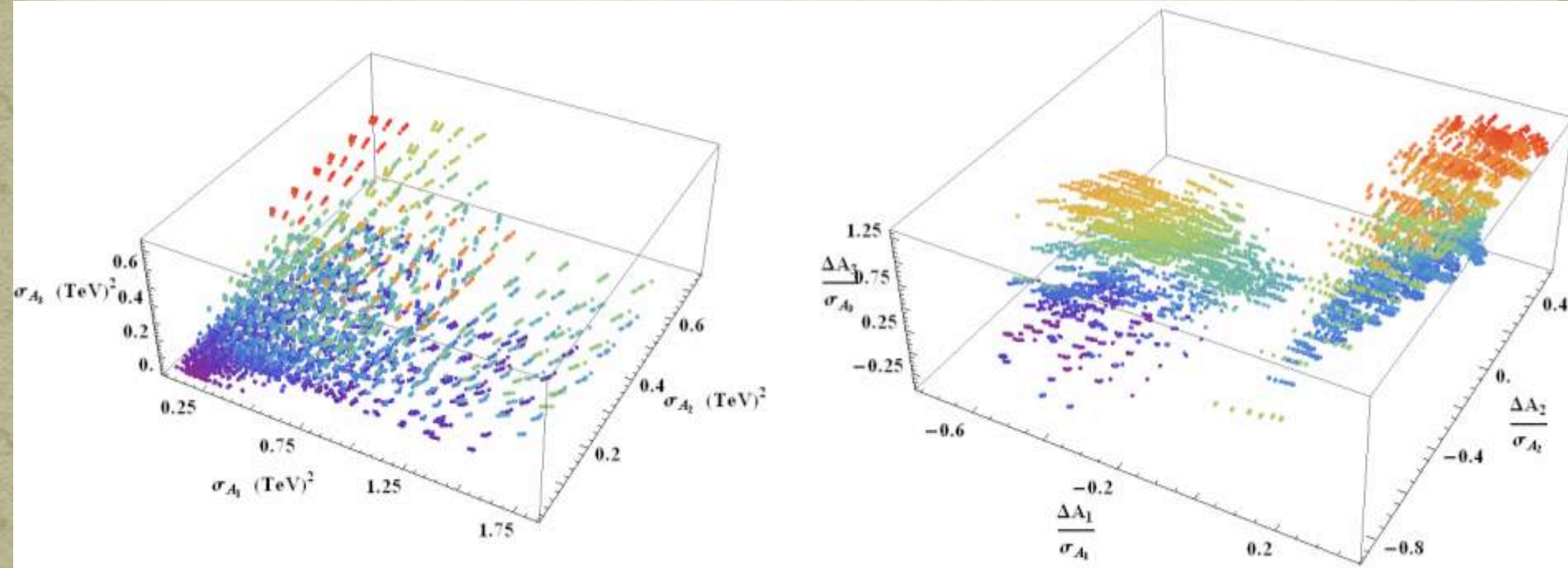


If the difference between the corrections to the Higgs up and down sector are determined to be zero within error, there will be large errors associated with the determination of the gauge couplings at the messenger scale.

However, actual value of  $g_i^2(\mu_f)$  within **0.6 $\sigma$**  of the calculated value of  $g_i^2(\mu_f)$  :  
Can still determine a range for the couplings at the high scale.

# Example:

Determination of GGM parameters  $A_r$ ,  
 $A_r$  extracted using  $B_r$  and  $g_r$ : indeterminacy for  $g_r$  transmits to  $A_r$ .



Actual value of  $A_r$  within **1.25  $\sigma$**  of the calculated value of  $A_r$ : Can extract a range of consistent  $A_r$ .

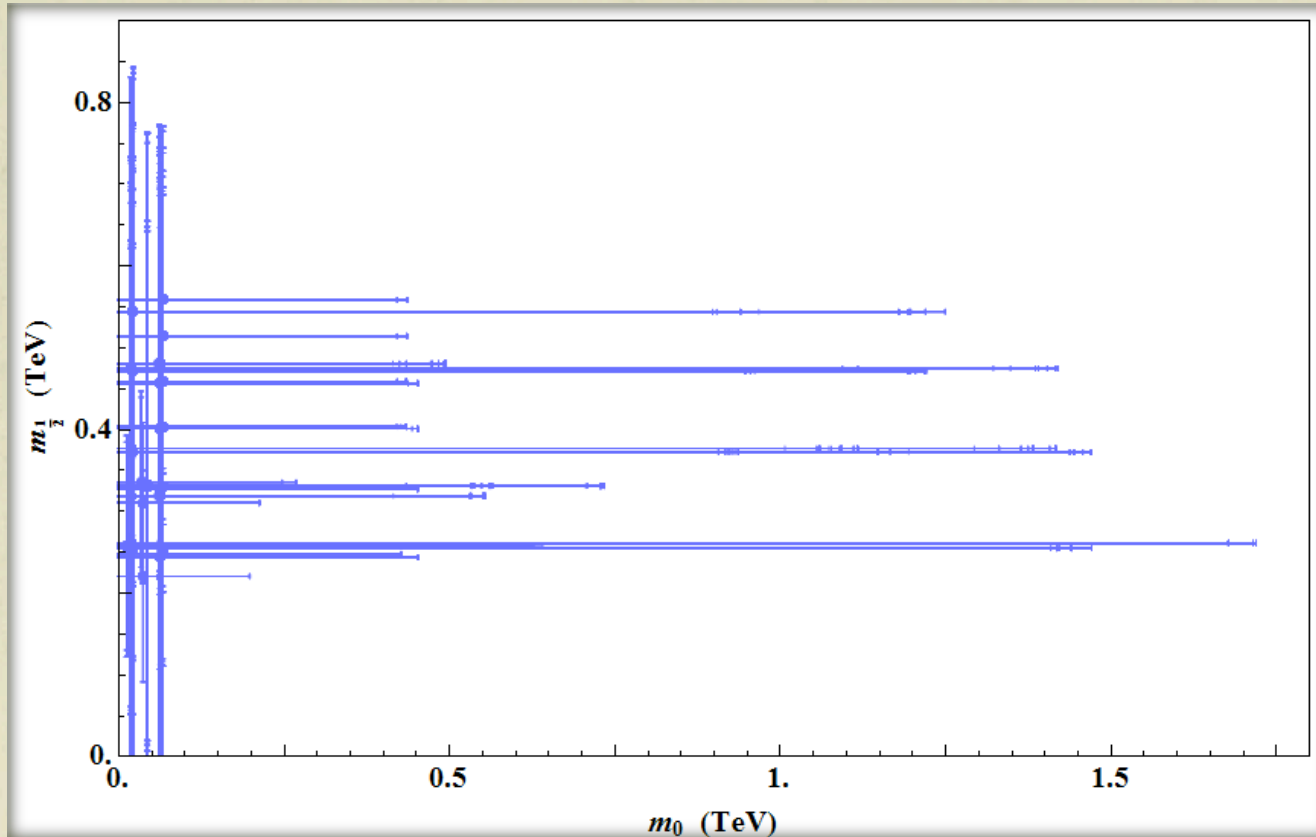
Additionally, can find correlation between  $A_{1,2}$  and  $g_{1,2}$  with very small errors, using linear combination of invariants mentioned before:

$$g_1^4 \frac{33}{10} A_1 + g_2^4 \frac{11}{2} A_2 = I_{M12} - g_1^4 I_{B1}^2 - 11 g_2^4 I_{B2}^2$$



# Example:

## Determination of CMSSM parameters $m_{1/2}$ and $m_0$



$D_{\chi^2=0}$  within error (required for GGM), forces  $m_0$  very small, for consistency with CMSSM.  
Plotted above, CMSSM with NUHM spectrum obtained as a subspace of GGM models :  
 $m_0$  with central values  $< 100$  GeV, and upto about 1.75 TeV with errors,  
 $m_{1/2}$  with central values between 200-600 GeV, upto about 850 GeV with errors.

# Outlook and Conclusions

- If SUSY discovered at the LHC: raises the question of SUSY breaking scheme at some high scale.
- One would like to be able to probe this high scale phenomenon using TeV scale measurements.
- 1-loop RG Invariants provide a powerful tool to probe the high energy parameter space of models.
- Assuming an optimistic estimate of 1% measurement for the soft masses at the TeV scale, we checked that the 2-loop running does not destroy the invariance within experimental errors.
- These RGIs may determine the high energy scale.
- We can also check generic features like flavor blindness.
- Additionally, consistency with model parameter space can be probed.
- We ran numerical simulations scanning the parameter space of GGM, demonstrating the power of using these invariants to probe physics beyond the reach of the LHC.
- This methodology may be used for other models, hence building subset of SUSY breaking scenarios which satisfy an experimentally measured low energy spectrum.

# Back Up Slides

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# Particle Content

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks (×3 families)	$Q$	$(\tilde{u}_L \tilde{d}_L)$	$(u_L d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
	$\bar{u}$	$\tilde{u}_R^*$	$u_R^\dagger$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\bar{d}$	$\tilde{d}_R^*$	$d_R^\dagger$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons (×3 families)	$L$	$(\tilde{\nu} \tilde{e}_L)$	$(\nu e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
	$\bar{e}$	$\tilde{e}_R^*$	$e_R^\dagger$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	$H_u$	$(H_u^+ H_u^0)$	$(\tilde{H}_u^+ \tilde{H}_u^0)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	$H_d$	$(H_d^0 H_d^-)$	$(\tilde{H}_d^0 \tilde{H}_d^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

- ❖ Chiral supermultiplets in MSSM:
  - ❖ Spin-0 fields are complex scalars,
  - ❖ Spin-1/2 fields are left-handed two-component Weyl fermions.

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\tilde{g}$	$g$	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\tilde{W}^\pm \tilde{W}^0$	$W^\pm W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\tilde{B}^0$	$B^0$	$(\mathbf{1}, \mathbf{1}, 0)$

- ❖ Gauge supermultiplets in the MSSM.

**Table 1:** U(1) Representations in the MSSM

Particle	Y	B	L
$Q = \begin{pmatrix} u \\ d \end{pmatrix}_L$	1/6	1/3	0
$L = \begin{pmatrix} \nu \\ l \end{pmatrix}_L$	-1/2	0	1
$u = u_R^C$	-2/3	-1/3	0
$d = d_R^C$	1/3	-1/3	0
$e = l_R^C$	1	0	-1
$H_u$	1/2	0	0
$H_d$	-1/2	0	0

# Soft SUSY Breaking Masses

- GGM provides class of models in which perhaps flavor blindness is most natural.

## At the Messenger Scale

- Soft sfermion masses are parameterized in terms of three numbers  $A_r$ , originating from hidden sector current-current correlation functions.

$$m_{\tilde{f}}^2 = g_1^2 Y_{\tilde{f}} \xi + \sum_{r=1}^3 g_r^4 C_r(f) A_r$$

- Assume Fayet Iliopoulos term is zero.
- Gaugino masses given in terms of three more numbers  $B_r$ :

$$M_r = g_r^2 M B_r,$$

- To generate Higgsino mass parameter,  $\mu$ , may need supplemental SUSY breaking in the Higgs sector, modifying Higgs mass parameters:

$$\begin{aligned} m_{H_u}^2 &= m_{\tilde{L}_3}^2 + \delta_u \\ m_{H_d}^2 &= m_{\tilde{L}_3}^2 + \delta_d. \end{aligned}$$

Invariant	Symmetry	Expression	GGM Value
$D_{B_{13}}$	$B_1 - B_3$	$2m_{Q_1}^2 - m_{u_1}^2 - m_{d_1}^2 - 2m_{Q_3}^2 + m_{u_3}^2 + m_{d_3}^2$	0
$D_{L_{13}}$	$L_1 - L_3$	$2m_{L_1}^2 - m_{e_1}^2 - 2m_{L_3}^2 + m_{e_3}^2$	0
$D_{X_1}$	$X_1$	$-6m_{Q_1}^2 - 3m_{u_1}^2 + 9m_{d_1}^2 + 6m_{L_1}^2 - m_{e_1}^2$	0
$D_{Y_{13H}}$	$Y_1 - \frac{10}{13}Y_{3H}$	$\frac{m_{Q_1}^2 - 2m_{u_1}^2 + m_{d_1}^2 - m_{L_1}^2 + m_{e_1}^2}{-13} \left( \frac{m_{Q_3}^2 - 2m_{u_3}^2 + m_{d_3}^2 - m_{L_3}^2 + m_{e_3}^2}{-13} (m_{H_u}^2 - m_{H_d}^2) \right)$	$-\frac{10}{13}(\delta_u - \delta_d)$
$D_Z$	$Z$	$3m_{d_3}^2 + 2m_{L_3}^2 - 2m_{H_d}^2 - 3m_{d_1}^2$	$-2\delta_d$
$I_{Y_\alpha}$	$Y$	$\frac{\sum_{gen} (m_Q^2 - 2m_u^2 + m_d^2 - m_L^2 + m_e^2) + m_{H_u}^2 - m_{H_d}^2}{g_1^2}$	$\frac{\delta_u - \delta_d}{g_1^2}$
$I_{B_r}$		$\frac{M_r}{g_r^2}$	$MB_r$
$I_{M_1}$		$M_1^2 - \frac{33}{8}(m_{d_1}^2 - m_{e_1}^2 - m_{u_1}^2)$	$g_1^4 \left( \frac{33}{10}A_1 + (MB_1)^2 \right)$
$I_{M_2}$		$M_2^2 - \frac{1}{24}(-9m_{d_1}^2 - 16m_{L_1}^2 + m_{e_1}^2 + 9m_{u_1}^2)$	$g_2^4 \left( \frac{1}{2}A_2 + (MB_2)^2 \right)$
$I_{M_3}$		$M_3^2 - \frac{3}{16}(5m_{d_1}^2 - m_{e_1}^2 + m_{u_1}^2)$	$g_3^4 \left( (MB_3)^2 - \frac{3}{2}A_3 \right)$

$$\delta_u = -\frac{1}{2}D_Z - \frac{13}{10}D_{Y_{13H}}$$

$$\delta_d = -\frac{1}{2}D_Z.$$

$$A_1 = \frac{10}{33} \left( \frac{I_{M_1}}{g_1^4} - I_{B_1}^2 \right)$$

$$A_2 = 2 \left( \frac{I_{M_2}}{g_2^4} - I_{B_2}^2 \right)$$

$$A_3 = \frac{2}{3} \left( \frac{-I_{M_3}}{g_3^4} + I_{B_3}^2 \right)$$

$$MB_r = I_{B_r}.$$

If  $I_{Y_\alpha}$  and  $D_{Y_{13H}}$  non-zero, from their ratio we can extract value of  $g_r$ , at the high scale,  $\mu_f$

Hence, using the running of  $g_r$ , one could determine  $\mu_f$ .

When errors in the determination of  $A_r$  large, can still determine certain correlations between the  $A_r$  and  $g_r$  with high accuracy:

$$g_1^4 \frac{33}{10} A_1 + g_2^4 \frac{11}{2} A_2 = I_{M_{12}} - g_1^4 I_{B_1}^2 - 11g_2^4 I_{B_2}^2$$

# Example LHC Accuracy

Soft and other basic parameters, plus sparticle pole masses for SPS1a input (with  $m_{\text{top}} = 175$  GeV), calculated with SuSpect ver 2.41, for two illustrative optional choices:

basic par.	2-loop RGE +full R.C.	1-loop RGE +approx. R.C.	relevant pole masses	2-loop RGE +full R.C.	1-loop RGE +approx. R.C.
$Q_{EWSB}$	465.5	468.2			
$M_1$	101.5	108.8	$m_{\tilde{N}_1}$	97.2	105.1
$M_2$	191.6	208.9	$m_{\tilde{N}_2}$	180.8	189.9
$M_3$	586.6	603.8	$m_{\tilde{g}}$	606.1	603.8
$\mu$	356.9	340.6	$m_{\tilde{N}_4}$	381.8	369.6
$\tan \beta$	9.74	9.75			
$m_{H_d}^2$	$(179.9)^2$	$(187.3)^2$	$m_h$	110.85	111.28
$m_{H_u}^2$	$-(358.1)^2$	$-(341.7)^2$			
$m_{e_L}$	195.5	201.5			
$m_{\tau_L}$	194.7	200.6			
$m_{e_R}$	136	138.6	$m_{\tilde{e}_2}$	142.8	145.4
$m_{\tau_R}$	133.5	136.2			
$m_{Q_L 1,2}$	545.8	554.1	$m_{\tilde{u}_1}$	562.3	551.6
$m_{Q_L 3}$	497	502.9	$m_{\tilde{b}_1}$	516.2	502.1
$m_{u_R}$	527.8	531.6			
$m_{t_R}$	421.5	421.6			
$m_{d_R}$	525.7	528.7			
$m_{b_R}$	522.4	525.4	$m_{\tilde{b}_2}$	546.3	530.1
$-A_t$	494.5	501.0			
$-A_b$	795.2	791.3			
$-A_\tau$	251.7	255.0			
$-A_u$	677.3	686.6			
$-A_d$	859.4	857.2			
$-A_e$	253.4	256.7			

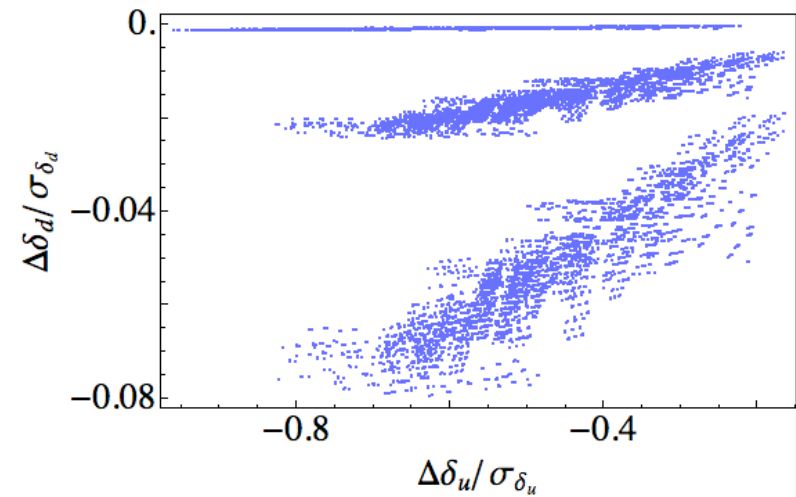
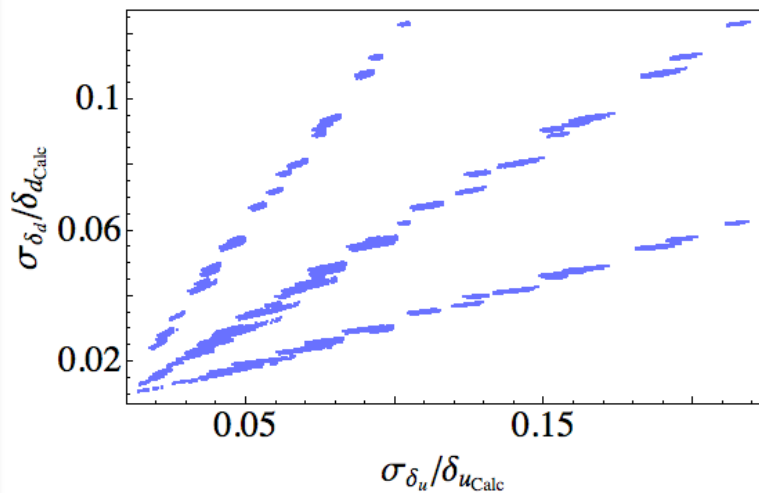
- full two-loop in RGE and full radiative corrections to sparticle masses (second and fifth columns);
- one-loop RGE, no radiative corrections to squarks, gluino, neutralinos, charginos masses, simple approximation for  $m_h$  radiative corrections (third and sixth columns).

Experimental accuracies on mass determinations from LHC gluino cascade and other decays.

mass	expected LHC accuracy (GeV)	decay or process
$m_{\tilde{g}}$	7.2	$\tilde{g}$ cascade decay
$m_{\tilde{N}_1}$	3.7	" "
$m_{\tilde{N}_2}$	3.6	" "
$m_{\tilde{q}_L}$	3.7	" "
$m_{\tilde{l}_R}$	6.0	" "
$m_{\tilde{N}_4}$	5.1	$\tilde{q}_L \rightarrow \tilde{\chi}_4^0 + ..$ cascade
$m_{\tilde{b}_1}$	7.5	$\tilde{g}$ cascade decay
$m_{\tilde{b}_2}$	7.9	" "
$m_h$	0.25 (exp)-2 (th)	$h \rightarrow \gamma\gamma$ (mainly)

J.-L. Kneur, N. Sahoury, Phys.Rev.D79:075010,2009.  
 B.Allanach, C.Lester, M.Parker and B.Webber, JHEP 0009 (2000) 004.  
 G. Weiglein et al, Phys. Rept. 426 (2006) 47.

# Corrections to the Higgs mass parameters and their expected experimental determination



Large % errors in corrections to Higgs mass parameters expected when either is zero at input scale.

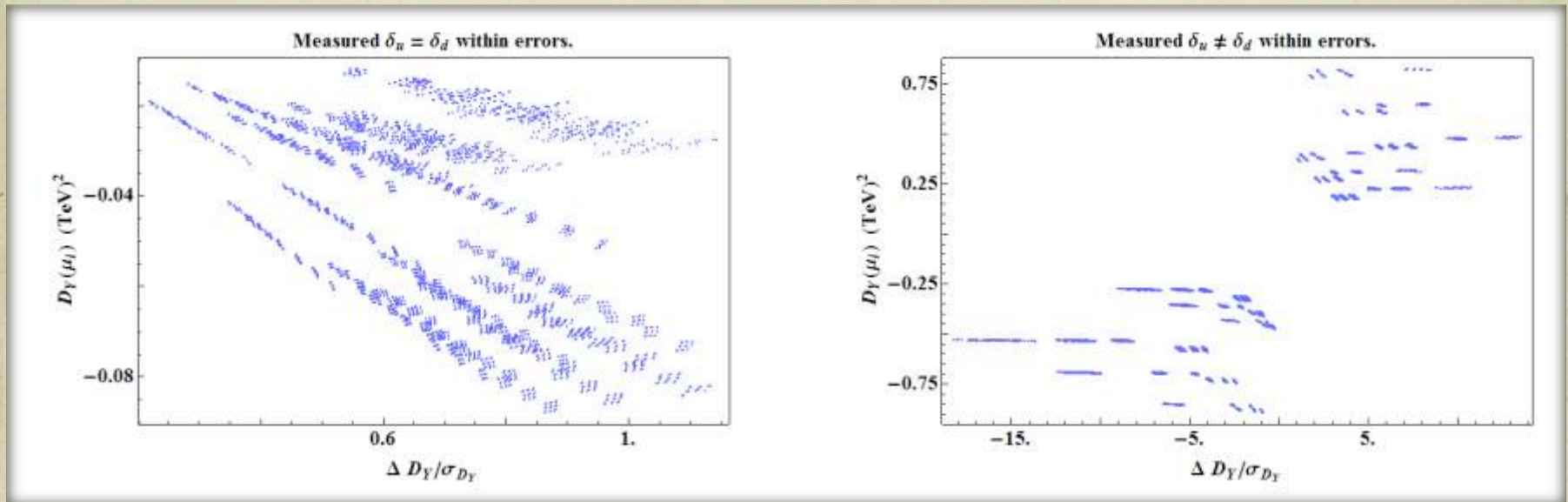
In above plots, Higgs mass parameter corrections are different with in error.

As seen from plot on the right, 2-loop contributions can be ignored for the extraction of these parameters.

This is true for both zero and non-zero corrections.



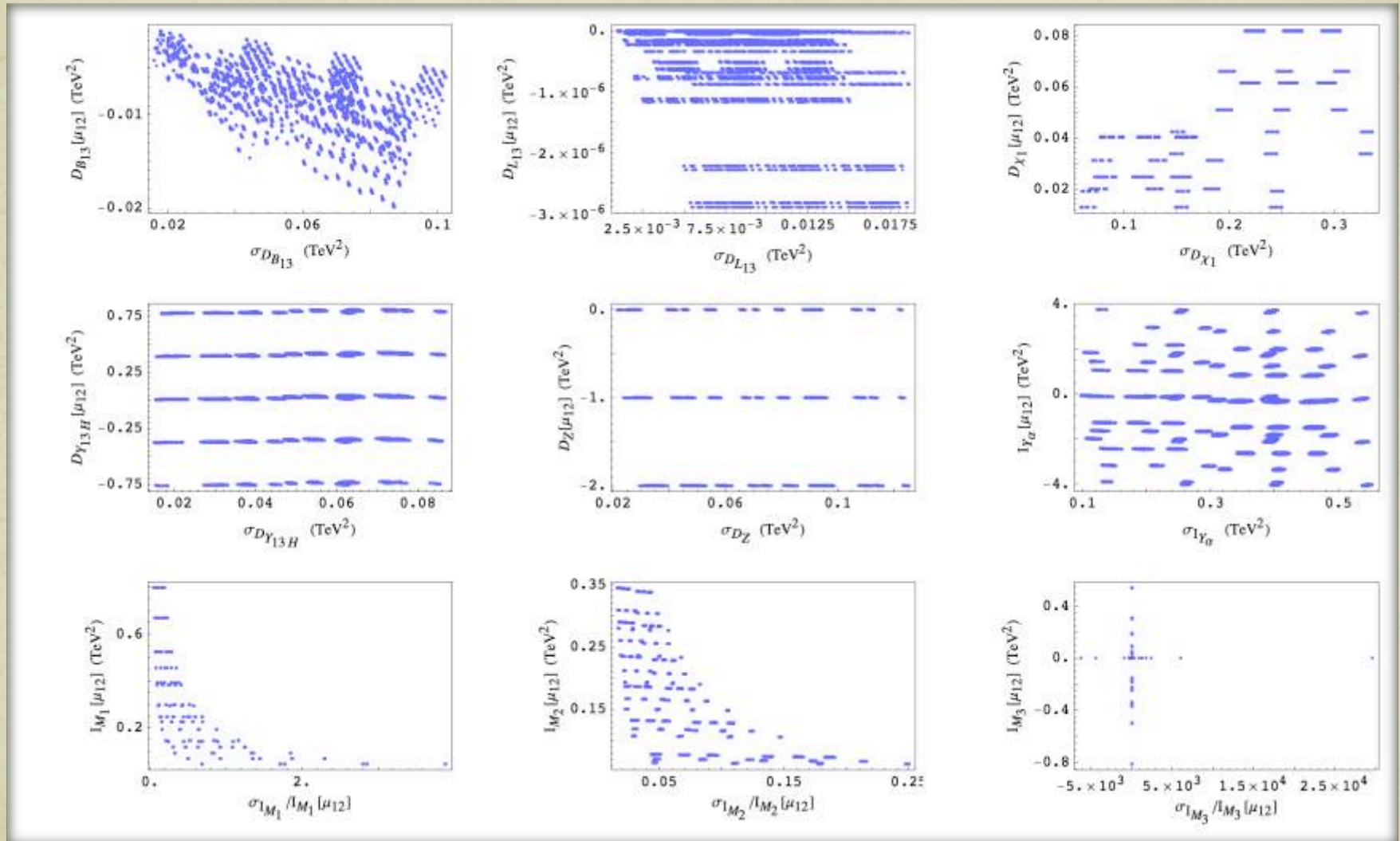
# $D_Y$ vs. the ratio of the running of $D_Y$ and its expected error in measurements



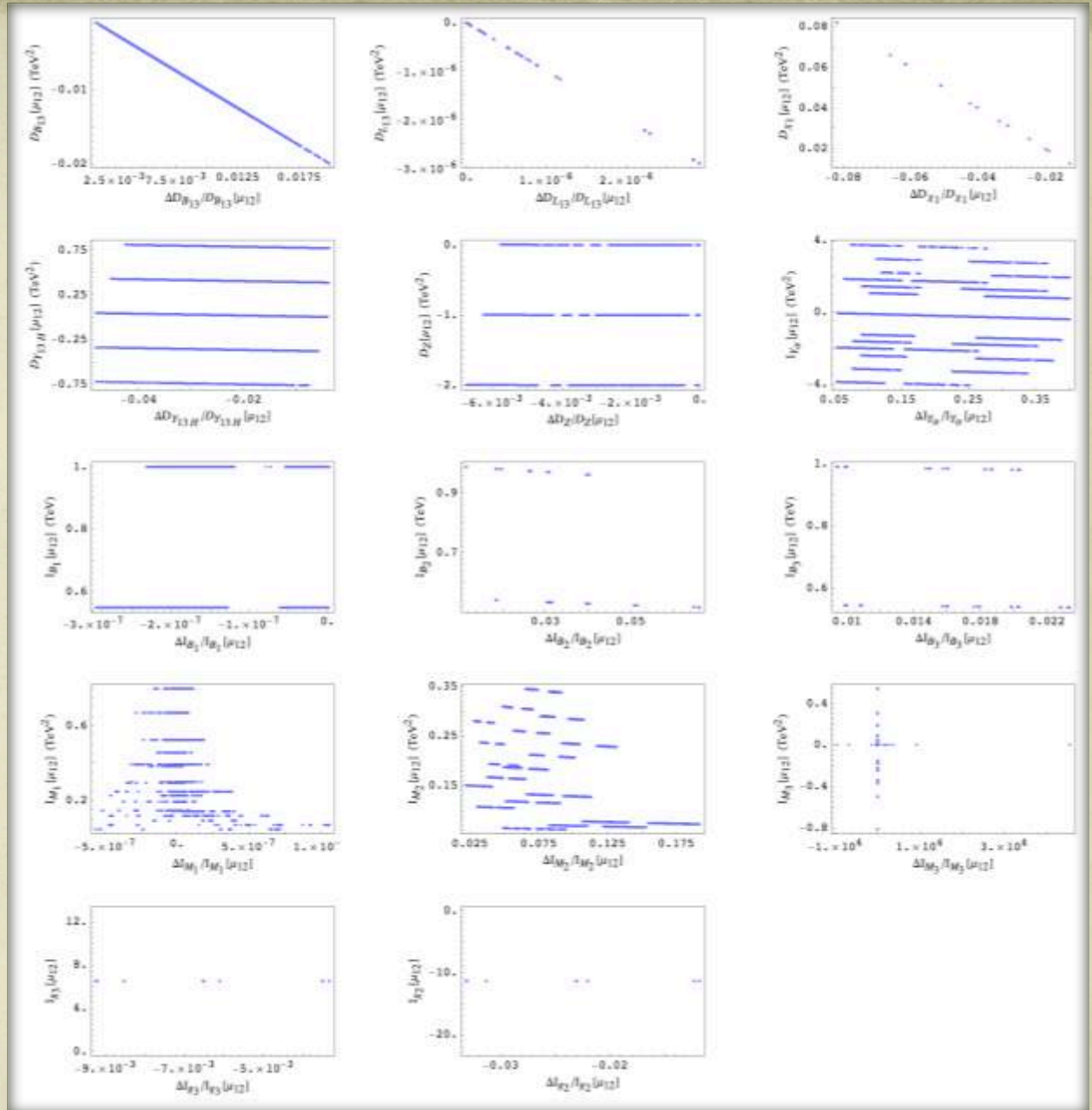
If minimal GGM, i.e., the Higgs mass parameters don't get corrections from supplemental SUSY breaking,  $D_Y$  running is smaller than the expected error in its measurement.

In non-minimal GGM,  $D_Y$  is not an invariant, hence as can be seen from the plot on the right, the running is comparable to or larger than the expected error. However, this would still give us information about whether it is consistent with zero or not.

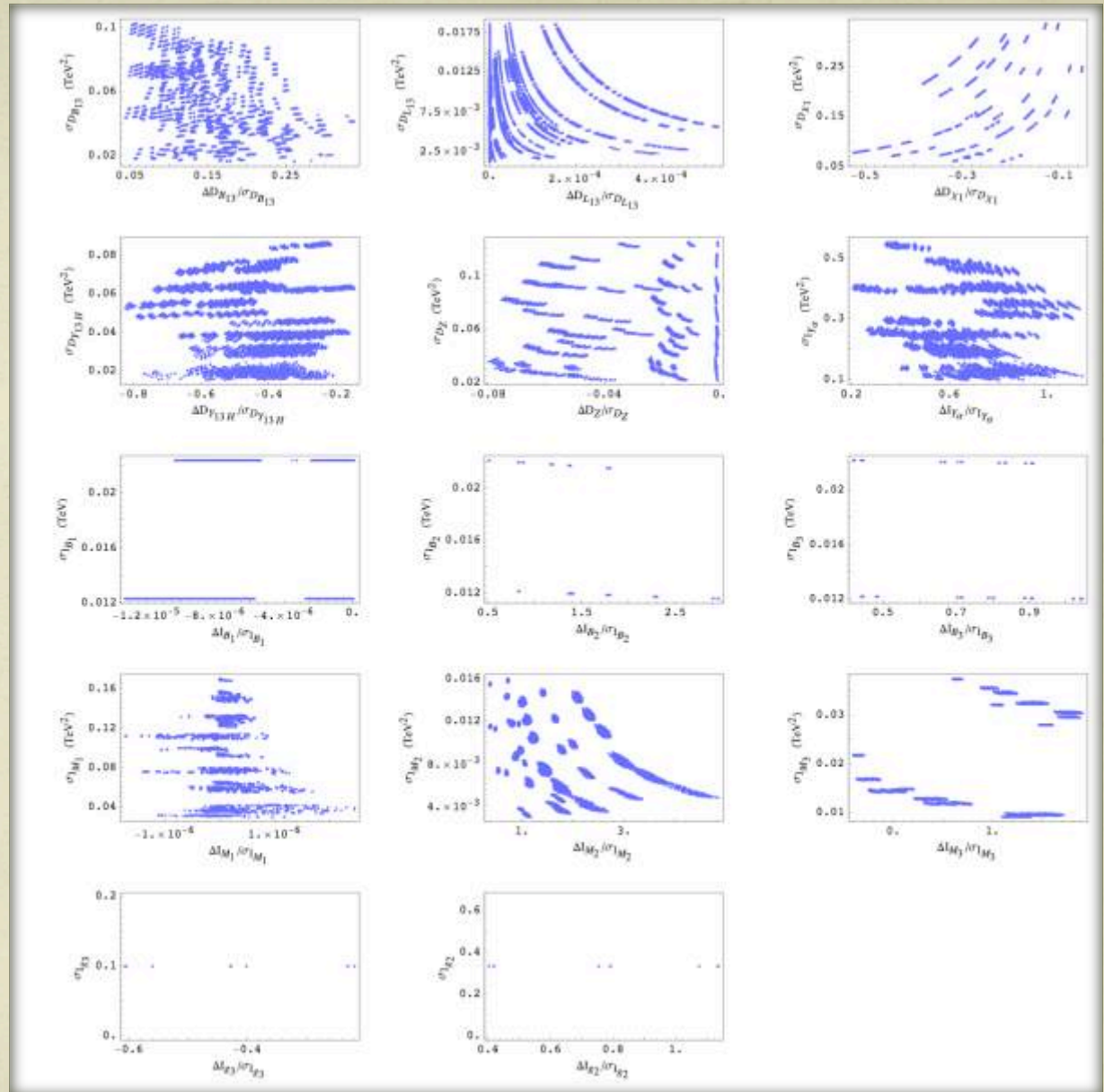
# Invariants vs. $\sigma$



# Invariants vs. 2-loop



$\sigma$  vs.  $\Delta/\sigma$



$\sigma$  vs.  $\Delta$

