Reconstructing Supersymmetric Theories at High Energy Scales

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ICHEP2000, Osaka

- mSUGRA, GMSB
- Procedure
- Numerical Results
- Summary

G. Blair, W. Porod, P. Zerwas, hep-ph/0007107

Supersymmetry breaking

mSUGRA*

Supergravity coupled with a GUT theory.

- gauge unification at GUT scale
- Universal input Parameters (at GUT scale): M_0, $M_{1/2}$, A_0, $\tan\beta$, $\text{sign}(\mu)$

GMSB†

Transfer of SUSY breaking via gauge interactions.

- Messenger scale: $M_m = \lambda S$
- $\Lambda = F/S$ where $< X >= S + F\theta\theta$
  $M_{1/2} \to g(x)\alpha_i\Lambda$, $M_0^2 \to f(X)\sum C_i\alpha_i^2\Lambda^2$,
  $x = \Lambda/M$, $f(x), g(x) = (n_5 + n_{10})O(1)$
- $A_0, \tan(\beta)$, $\text{sign}(\mu)$

*H.P.Nilles, Phys.Rep. 110, 1 (1984)

†G.F.Guidice and R.Rattazzi, Phys.Rep. 322, 419 (1999)

Parameters

- The unbroken MSSM

  1. μ: mixing parameter for the Higgs Superfields
  2. Y_u, Y_d, Y_e: Yukawa couplings of Matter Superfields with Higgs Superfields
  3. g_1, g_2, g_3: gauge couplings

- Soft Susy Breaking Terms

  1. gaugino masses: $M_a \, \lambda_a \lambda_a + h.c.$ $(a = U(1), SU(2), SU(3)$
  2. scalar masses: $M^2_{\tilde{Q}ij} \tilde{q}^*_{Lj} \tilde{q}_{Li}$, $M^2_{\tilde{U}ij} \tilde{u}^*_{Rj} \tilde{u}_{Ri}$, $M^2_{\tilde{D}ij} \tilde{d}^*_{Rj} \tilde{d}_{Ri}$, $M^2_{\tilde{L}ij} \tilde{l}^*_{Lj} \tilde{l}_{Li}$, $M^2_{\tilde{E}ij} \tilde{e}^*_{Rj} \tilde{e}_{Ri}$, $M^2_{H1} h^*_1 h_1$, $M^2_{H2} h^*_2 h_2$
  3. bilinear coupling: $-\epsilon_{jk} B\mu h^j_1 h^k_2 + h.c.$

4. trilinear couplings:
$\epsilon_{jk}(h_1^j(\tilde{e}_R^* a_l \tilde{l}_L^k + \tilde{d}_R^* a_d \tilde{q}_L^k) - h_2^j \tilde{u}_R^* a_u \tilde{q}_L^k) + h.c.$

Assumption

1) real Parameters

2) The generation mixing for sfermions is the same as for fermions:

$M^2_{\tilde{f}ij} = \delta_{ij} M^2_{\tilde{f}i}$,
$a_{f,ij} = \delta_{ij} A_{f,i} Y_{f,i}$

$\Rightarrow$ Each of the three $(\tilde{l}, \tilde{u}, \tilde{d})$ generally 6×6 matrices can be decomposed into three 2×2 matrices

Procedure*

- Input at m_Z: $g_1, g_2, g_3, h_l, h_d, h_u, \tan\beta$ in $\overline{DR}$ scheme
- Using 2-loop RGEs to get the above parameters at the high scale: M_{GUT} (in mSUGRA defined via $g_1 = g_2$) or M_m (in GMSB)
- Evaluating mass parameters down to electroweak scale using 2-loop RGEs†, including threshold effects**
- radiative electroweak symmetry breaking

$$\Rightarrow |\mu|^2 = \frac{m^2_{H_2}\sin^2\beta - m^2_{H_1}\cos^2\beta}{\cos 2\beta} - \frac{m_Z^2}{2} + \text{rad.corr.}$$

*for details see e.g. Arason et al., Phys.Rev.D **46** 3945 (1992)

†S. Martin and M. Vaughn, Phys. Rev. **D50**, 2282 (1994); Y. Yamada, Phys. Rev. **D50**, 3537 (1994); I. Jack, D.R.T. Jones, Phys. Lett. **B333**, 372 (1994)

J. Bagger, K. Matchev, D. Pierce, and R. Zhang, Nucl. Phys. **B491, 3 (1997)

- Calculate SUSY masses at the electroweak scale. Attach experimental errors to the masses.

- Calculation of production cross sections for $\tilde{t}_{1,2}$, $\tilde{b}_{1,2}$, $\tilde{\tau}_{1,2}$ with polarized e^- and e^+ beams.

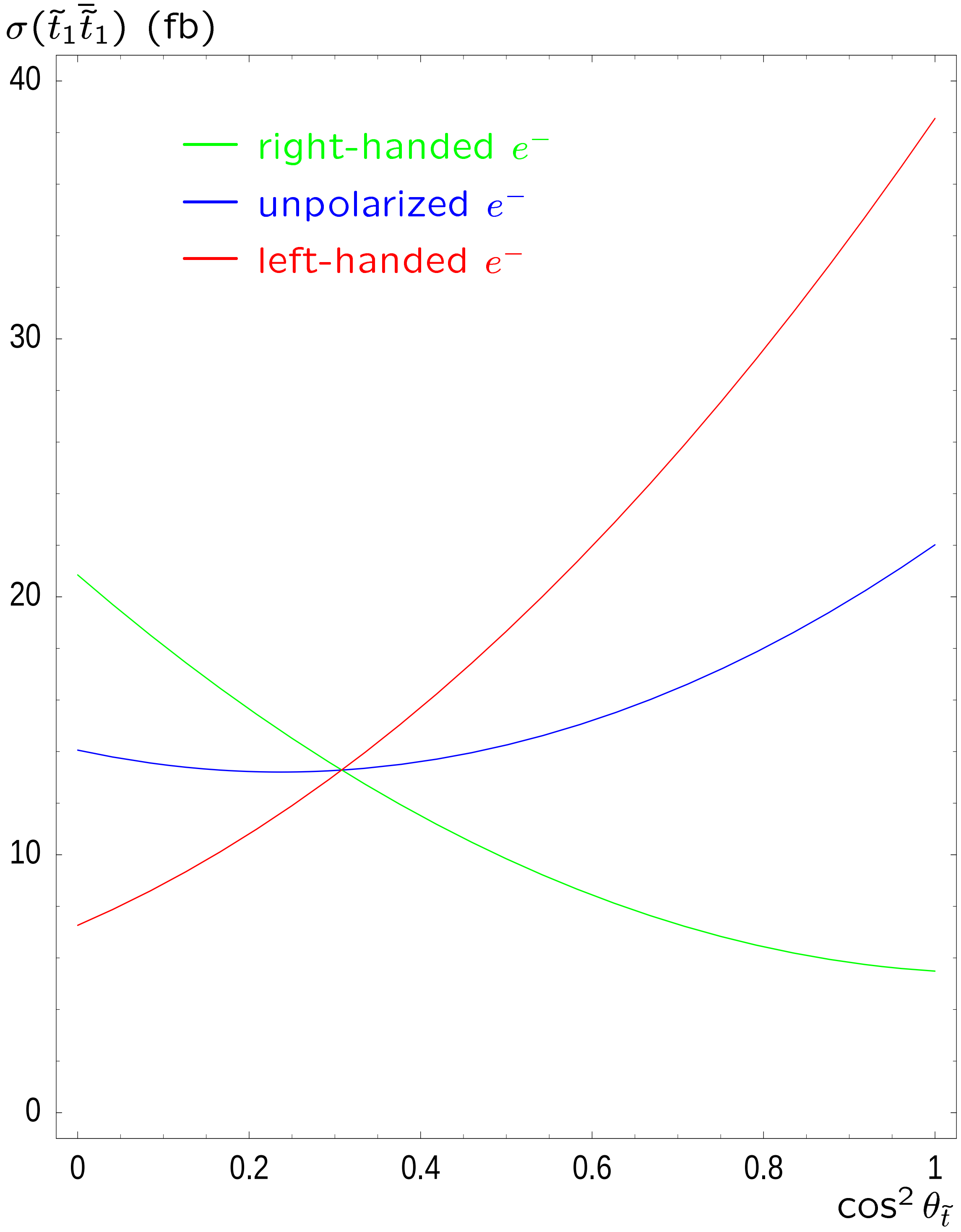
- Fit the masses and production cross sections within given experimental errors by varying the low energy parameters: M_{E_k}, M_{L_k}, M_{D_k}, M_{Q_k}, M_{U_k}, A_τ, A_b, A_t, M_{H_1}, M_{H_2}, M_i, $\tan\beta$, $k = 1, 3$, $i = 1, 2, 3$

- use again RGEs to get high scale parameters within the errors.

This is a <u>pure bottom-up approach</u>!

$\sigma(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1)$

$m_{\tilde{t}_1} = 350$ GeV, $E = 1$ TeV
Polarization degree: 80%



Assumptions for the Fits*

1. $\mathcal{L} = 100$ fb^{-1} for each scanned point
2. $\mathcal{L} = 500$ fb^{-1} for each polarized cross-section measurement
3. $\Delta m_{\tilde{g}} = 10$ GeV from LHC†
4. Errors on masses for particles which decay predominantly to τ channels** are inflated conservatively
5. The errors $\Delta\sigma$ on the cross sections σ are statistical only: $\Delta\sigma = \sqrt{\frac{\sigma}{\mathcal{L}\epsilon}}$, where ϵ (=20%) is the efficiency and $\mathcal{L}$ the integrated luminosity
6. Measurement of squark masses at LC require $\sqrt{s} = 1$ TeV for mSUGRA and $\sqrt{s} = 1.5$ TeV for GMSB

*for details see e.g. G.A. Blair and U. Martyn, hep-ph/9910416

†ATLAS TDR, CERN/LHCC/99-15

M.M. Nojiri, K. Fujii, and T. Tsukamoto, Phys.Rev. **D54, 6756 (1996).

Particle	M(GeV) Mass	Δ M(GeV) LHC	LHC+LC
h^0	109	0.2	0.05
A^0	191	3	1.5
χ_1^+	133	3	0.11
χ_1^0	72.6	3	0.15
$\tilde{\nu}_e$	233	3	0.1
$\tilde{e}_1$	217	3	0.15
$\tilde{\nu}_\tau$	214	3	0.8
$\tilde{\tau}_1$	154	3	0.7
$\tilde{u}_1$	466	10	3
$\tilde{t}_1$	377	10	3
$\tilde{g}$	470	10	10

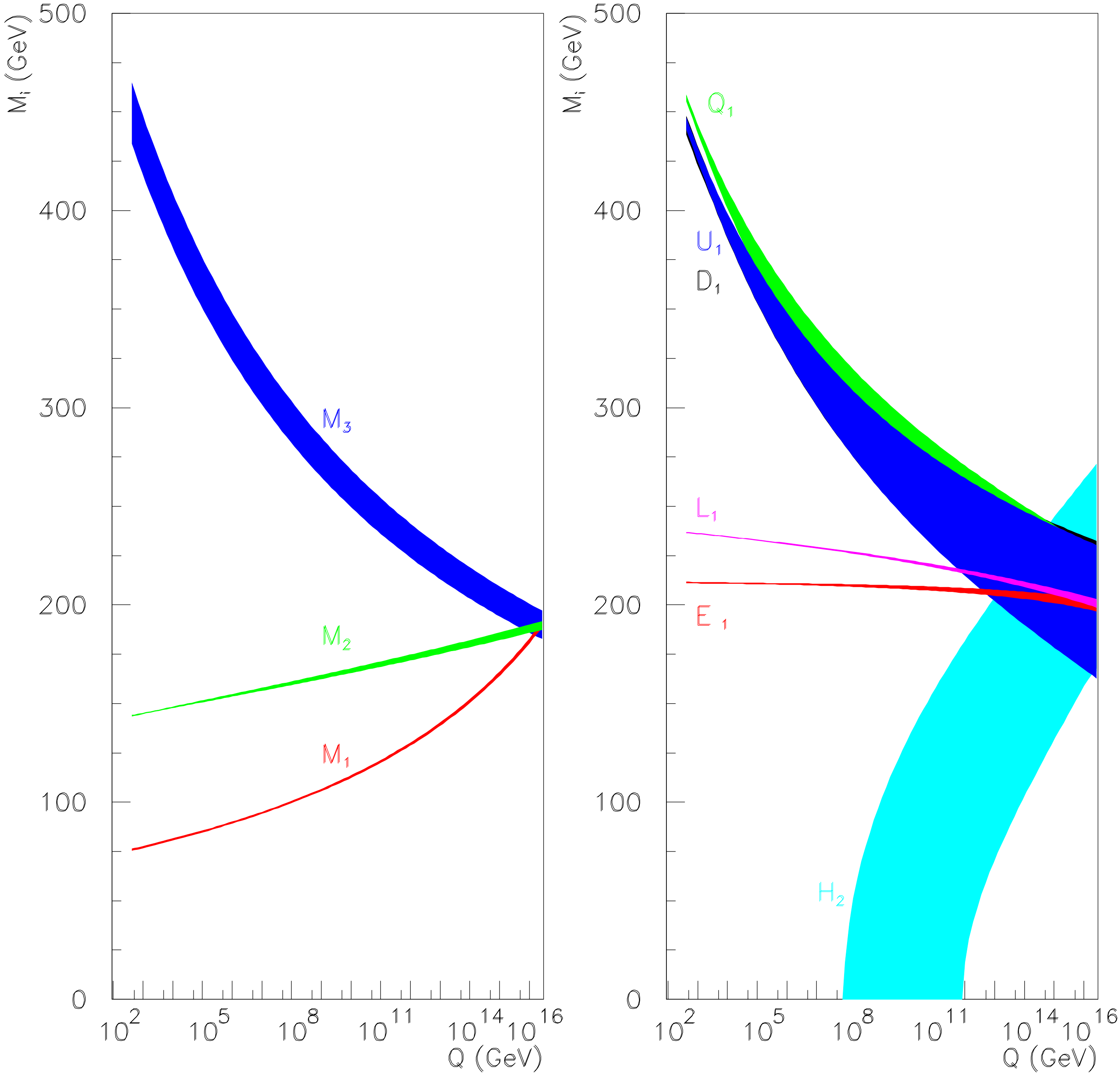
Representative experimental mass errors used in the fits to the mass spectra. Starting point: $M_0 = 200$ **GeV**, $M_{1/2} = 190$ **GeV**, A_0 **= 550 GeV**, $\tan\beta = 30$, **and** $\mathrm{sign}(\mu) = (-)$.

	LHC		LC	
	exp. input	GUT value	exp. input	GUT value
M_1	75.6 ± 3.2	189.6 ± 7.6	75.6 ± 0.2	189.6 ± 0.7
M_2	143.6 ± 3.1	190.6 ± 3.8	143.6 ± 0.2	189.4 ± 0.9
M_3	452.3 ± 11.9	190.1 ± 5.7	452.3 ± 9	190.0 ± 4.2
M_{L_1}	236.8 ± 2.1	200.6 ± 6.9	236.8 ± 0.1	200.5 ± 0.9
M_{Q_1}	459.6 ± 7.4	200.7 ± 30.5	459.7 ± 0.6	200 ± 18
M_{L_3}	218.6± 2.8	199.5 ± 12.3	218.6 ± 0.6	196.5 ± 7.2
M_{Q_3}	392 ± 45	192 ± 251	391.2 ± 1.0	233 ± 46
M_{H_1}	132.4 ±12	361 ± 324	132.4 ± 1.5	224 ± 90
$\|M_{H_2}\|$	(-)251.9 ±2.2	279 ± 98	(-)251.9±0.2	211 ± 27
A_τ	101 ± 2590	210 ± 432	100 ± 92	319 ± 340
A_b	-125 ± 3920	806 ± 1292	-126± 286	129 ± 571
A_t	-186 ± 39	608 ± 169	-186.3 ±3.2	505 ± 81

Representative mass parameters as determined at the electroweak scale and evolved to the GUT scale; the minus sign $(-)$ in front of M_{H_2} refers to the negative value of $M^2_{H_2}$ at the electroweak scale; The errors quoted correspond to 1σ; Starting point: $M_0 = 200$ GeV, $M_{1/2} = 190$ GeV, $A_0 = 550$ GeV, $\tan\beta = 30$, and $\text{sign}(\mu) = (-)$.

mSUGRA

$\tan\beta = 30$, $M_0 = 200$ GeV, $M_{1/2} = 190$ GeV, $A_0 = 550$, sign$(\mu) = -1$



The widths of the bands indicate the 95% CL.

Gaugino mass Parameters

$$M_1 \simeq 0.41 M_{1/2}$$
$$M_2 \simeq 0.82 M_{1/2}$$
$$M_3 \simeq 2.82 M_{1/2}$$

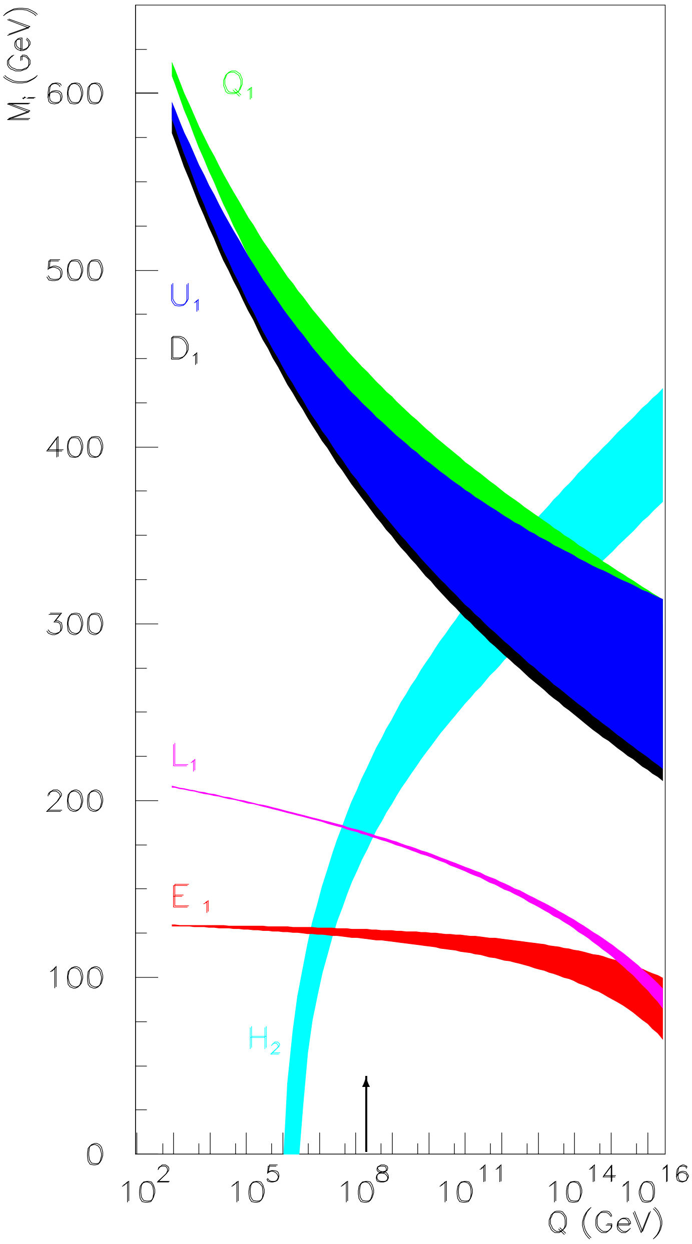
Sfermions + Higgs ($\tan\beta = 30$)

$$M^2 = aM_0^2 + bM_{1/2}^2 + cA_0^2 + dA_0 M_{1/2}$$

	a	b	c	d
$M^2_{\tilde{E}_{1,2}}$	1	0.15		
$M^2_{\tilde{L}_{1,2}}$	1	0.52		
$M^2_{\tilde{U}_{1,2}} \simeq M^2_{\tilde{D}_{1,2}}$	1	6.2		
$M^2_{\tilde{Q}_{1,2}}$	1	6.7		
$M^2_{\tilde{E}_3}$	0.94	0.14	-0.02	
$M^2_{\tilde{L}_3}$	0.97	0.52	-0.01	
$M^2_{\tilde{D}_3}$	0.78	5.7	-0.05	- 0.21
$M^2_{\tilde{U}_3}$	0.27	4.5	-0.07	-0.28
$M^2_{\tilde{Q}_3}$	0.53	5.6	-0.06	-0.25
$M^2_{\tilde{H}_1}$	0.65	-0.24	0.09	-0.32
$M^2_{\tilde{H}_2}$	-0.18	-2.2	0.08	-0.35

GMSB

$M_m = 2 \cdot 10^5$ TeV, $\Lambda = 28$ TeV, $N_5 = 3$,
$\tan\beta = 30$, $A_0 = 0$, $\mathrm{sign}(\mu) = -1$



The widths of the bands indicate the 95% CL.

Summary

- We have used the bottom-up approach for determining the high scale parameters assuming we know masses and cross sections within the experimental errors.
- The model–independent reconstruction of the fundamental supersymmetric theory at the high scale, the grand unification scale M_{GUT} in supergravity or the intermediate scale M_m in gauge mediated supersymmetry breaking, appears feasible.
- The accuracy is significantly improved if, in addition to the LHC input values, high–precision LC values are also included.