Reconstructing the "Fundamental" Theory from LHC and LC data

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- mSUGRA, GMSB, String
- Procedure
- Numerical Results

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Phys. Rev. D 63 (2001) 017703; in preparation

Supersymmetry breaking

mSUGRA

Universal input Parameters:

M_0, $M_{1/2}$, A_0, $\tan\beta$, sign(μ)

GMSB

Messenger scale: $M_m = \lambda S$

$\Lambda = F/S$ where $< X >= S + F\theta\theta$

$M_{1/2} \to g(x)\alpha_i\Lambda$,

$M_0^2 \to f(X)\sum C_i\alpha_i^2\Lambda^2$,

$x = \Lambda/M_m$, $f(x), g(x) = (n_5 + n_{10})O(1)$

A_0, $\tan\beta$, sign(μ)

String

vevs of dilaton $< s >$ and moduli fields $< t_i >$

give determine the parameters $M_i, M_{0,j}, A_{0,k}$.

In general non-universal boundary conditions.

In addition $\tan\beta$, sign(μ)

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

$\boxed{\textbf{Assumption}}$

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

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

*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.

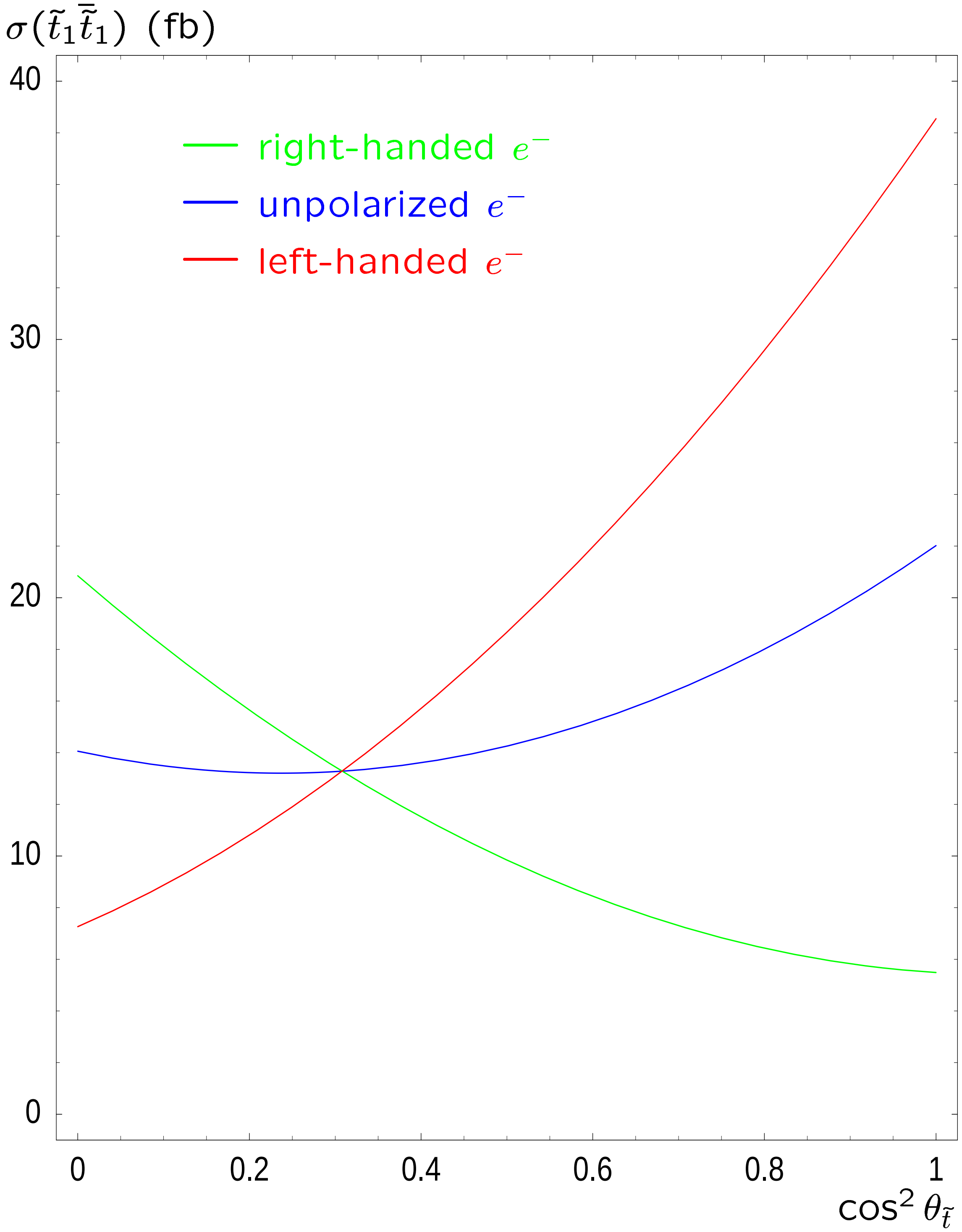
- Fit the masses and production cross sections within given experimental errors by varying the low energy parameters: M_{E_k}, M_{L_k}, M_{D_k}, M_{Q_k}, M_{U_k}, A_τ, A_b, A_t, M_{H_1}, M_{H_2}, M_i, $\tan\beta$, $k = 1, 3$, $i = 1, 2, 3$

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

This is a pure bottom-up approach!

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

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



Assumptions for the Fits*

1. $\mathcal{L} = 100\ \text{fb}^{-1}$ for each scanned point
2. $\mathcal{L} = 500\ \text{fb}^{-1}$ for each polarized cross-section measurement
3. $\Delta m_{\tilde{g}} = 10$ GeV from LHC†
4. 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
5. Error on squark masses $\Delta m_{\tilde{q}} = 10$ GeV

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

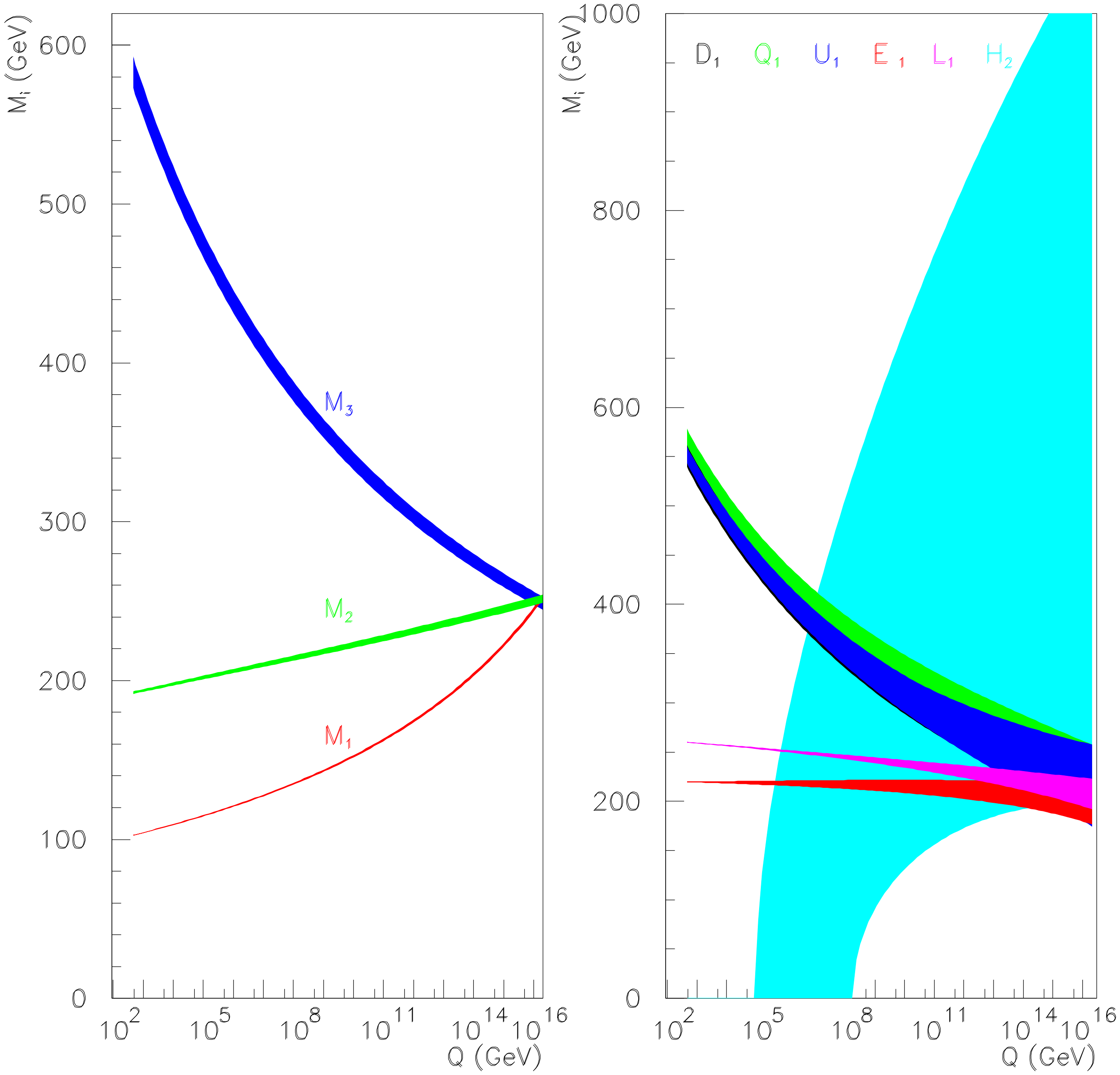
†ATLAS TDR, CERN/LHCC/99-15

Typical Errors on parameters

$M_{1,2}$	$O(10^{-3})$
M_3	$O(10^{-2})$
$M^2_{E_i}$	$O(10^{-3})$
$M^2_{L_i}$	$O(10^{-3})$
$M^2_{Q_i}$	$O(10^{-3})$
$M^2_{U_i}$	$O(10^{-3})$
$M^2_{D_i}$	$O(10^{-3})$
$M^2_{H_1}$	$O(10^{-3}) - O(10^{-2})$
$M^2_{H_2}$	$O(10^{-3})$
$A_{b,\tau}$	$O(1)$
A_t	$O(10^{-2})$

mSUGRA

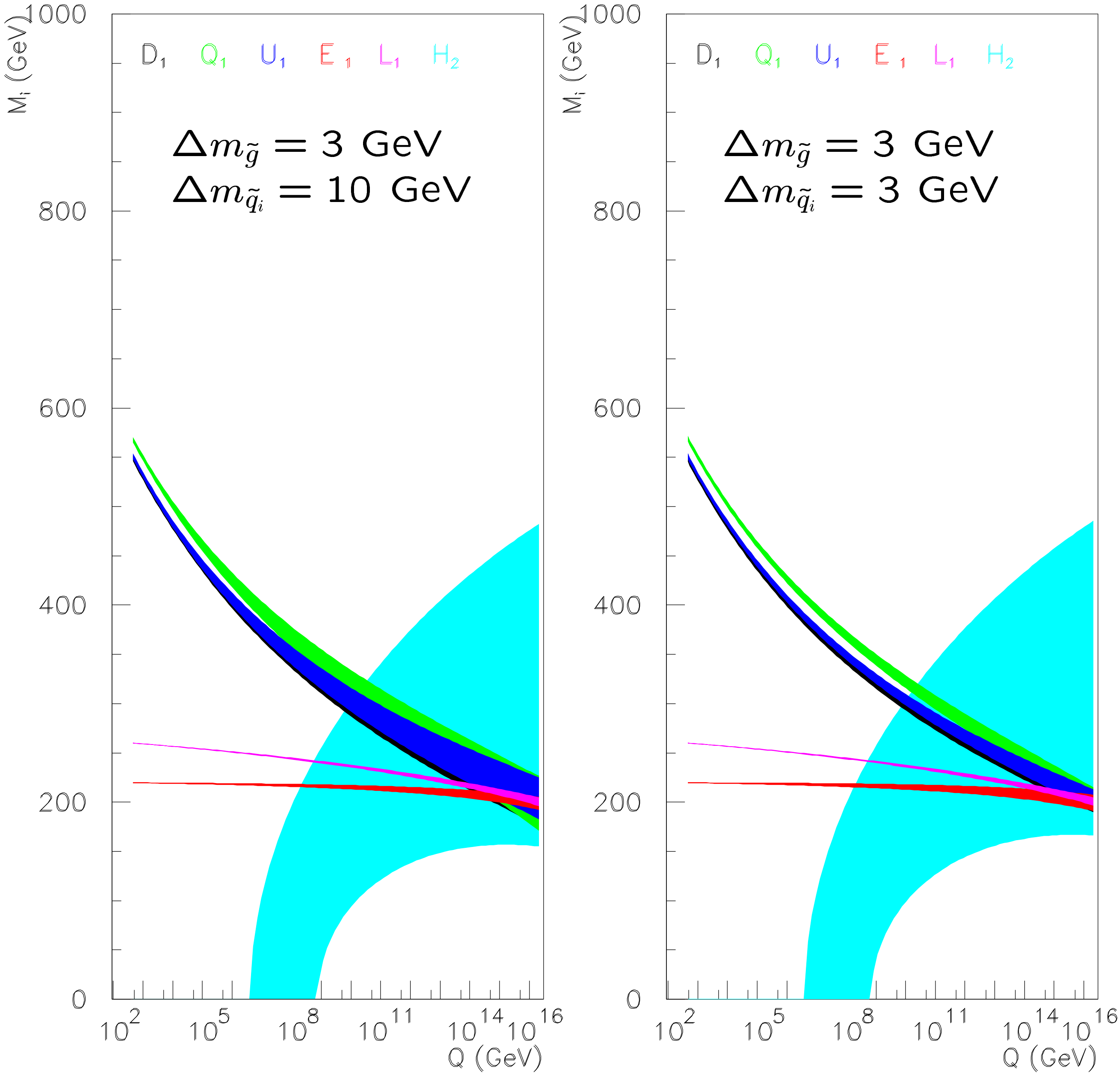
$\tan\beta = 10,\ M_0 = 200$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$, sign$(\mu) = 1$



1 σ error bands

mSUGRA

$\tan\beta = 10$, $M_0 = 200$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$, sign$(\mu) = 1$



1 σ error bands

Gaugino mass Parameters

$$
\begin{aligned}
M_1 &\simeq 0.41 M_{1/2} \\
M_2 &\simeq 0.82 M_{1/2} \\
M_3 &\simeq 2.82 M_{1/2}
\end{aligned}
$$

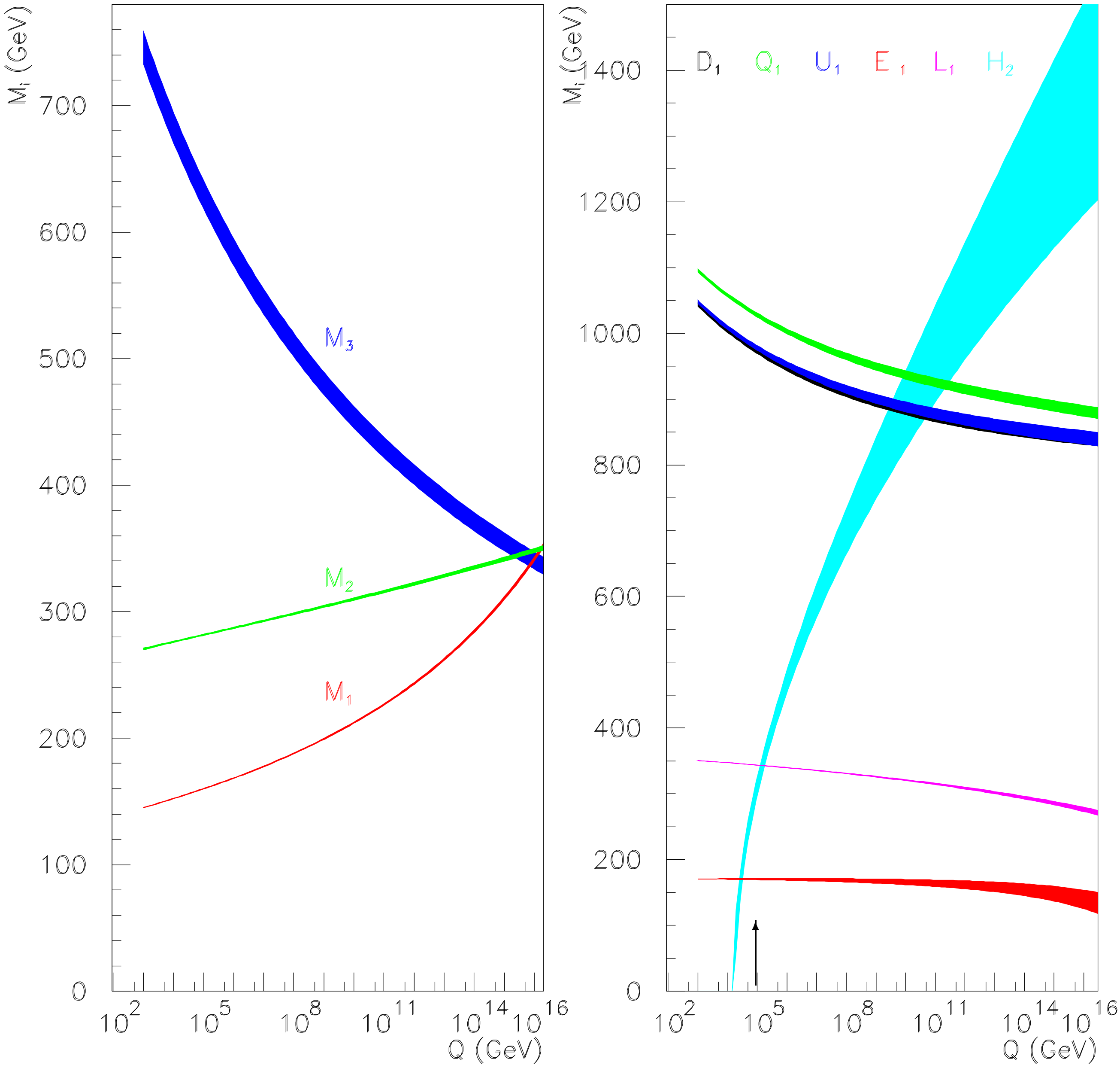
Sfermions + Higgs ($\tan\beta = 30$)

$$M^2 = a M_0^2 + b M_{1/2}^2 + c A_0^2 + d A_0 M_{1/2}$$

	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

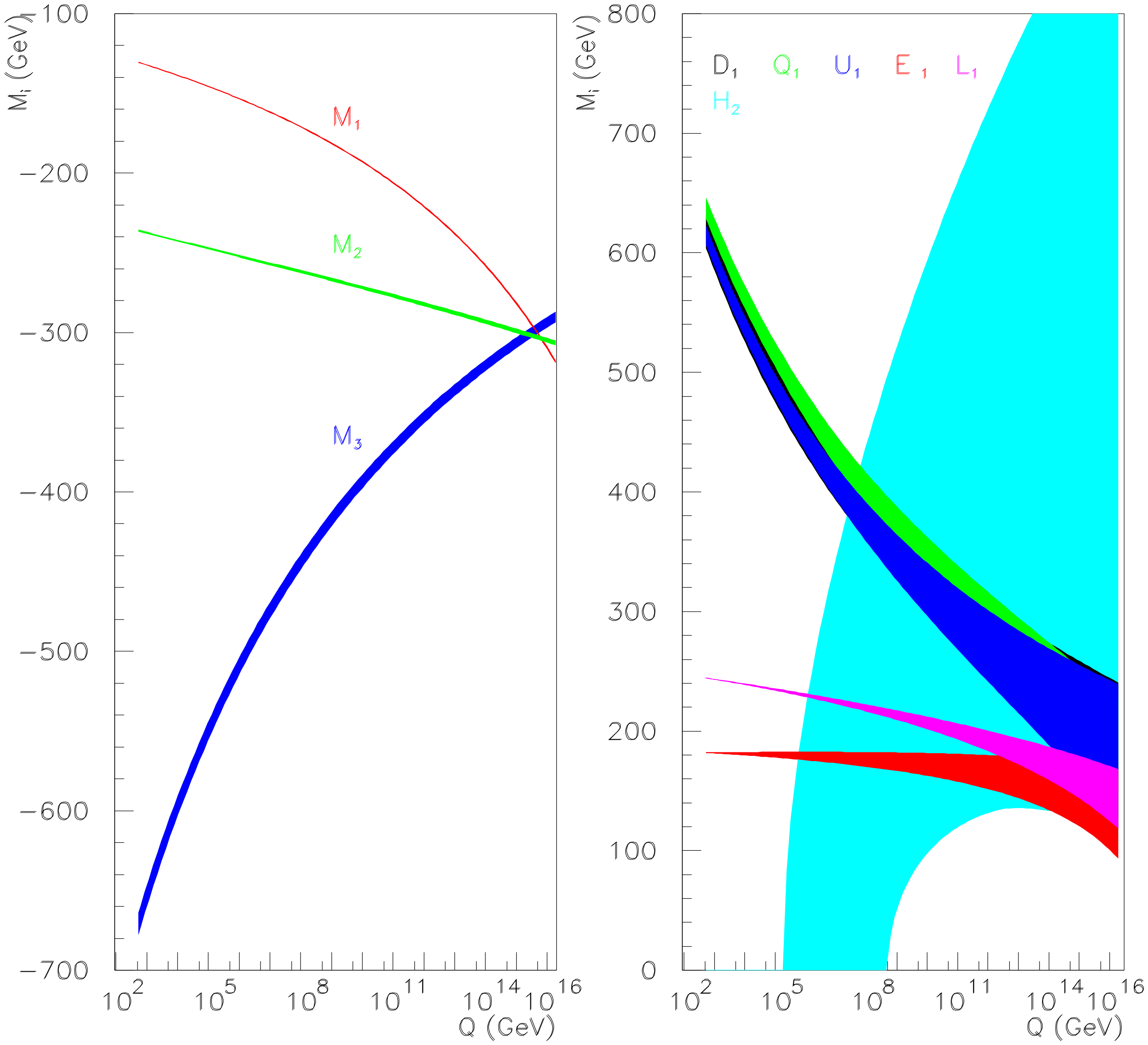
M_m = 200 TeV, Λ = 100 TeV, $N_5 = 1$, $\tan\beta = 15$, $A_0 = 0$, sign$(\mu) = 1$



1 σ error bands

String

$\tan\beta = 10$, $M_{3/2} = 180$ GeV, $\sin^2\theta = 0.85$, O–I, $n_Q = n_D = 0$, $n_U = -1$, $n_L = -3$, $n_E = -2$, and $n_{H_1} = n_{H_2} = -1$, sign$(\mu) = -1$



1 σ error bands

Things to work on

Theory

- Y_b (in particular for large $\tan\beta$),Y_t, α_s, 2-loop shift from $\overline{MS}$ to $\overline{DR}$ scheme
- $m_{\tilde{t}_1}$ at 2-loop to reduce Q dependence
- m_H, m_A for large $\tan\beta$ and/or large M_0 (2-loop Y_b corrections)
- calculation of μ at 2-loop for large $\tan\beta$ and/or large M_0

Experiment

- smallest possible Error on $m_{\tilde{g}}$
- smallest possible Error on $m_{\tilde{q}_i}$ in particular $q = t, b$.
- precise determination of $BR(A \to \tilde{f}_i \overline{\tilde{f}}_j)$ $BR(H^0 \to \tilde{f}_i \overline{\tilde{f}}_j)$, $BR(H^\pm \to \tilde{f}_i \overline{\tilde{f}}'_j)$, $BR(\tilde{f}_2 \to (h^0, A, H^0)\tilde{f}_1)$

Scale dependence

$\tan\beta = 10$, $M_0 = 200$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$, sign$(\mu) = 1$