Testing SUSY Unification

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work done in collaboration with G. Blair and P. Zerwas

Two Scale Picture of Nature

Electroweak Scale $<H> \simeq 10^2$ *GeV*	$\Leftarrow$	*SUSY*	$\Rightarrow$	*GUT/String/Planck Scale* 10^{16-19} *GeV*
$\Uparrow$				$\Uparrow$
Standard Model				*gravity* $\oplus$ *particle physics*

Exploring high scale structures (GUT,PL . . .)

- *Proton decay*
- *Cosmology at early time of the universe*
- *Neutrino physics (see-saw), fermion mass textures*
- *Extrapolation of high precision parameters:*
  gauge and Yukawa couplings
  SUSY parameters

Experimental information

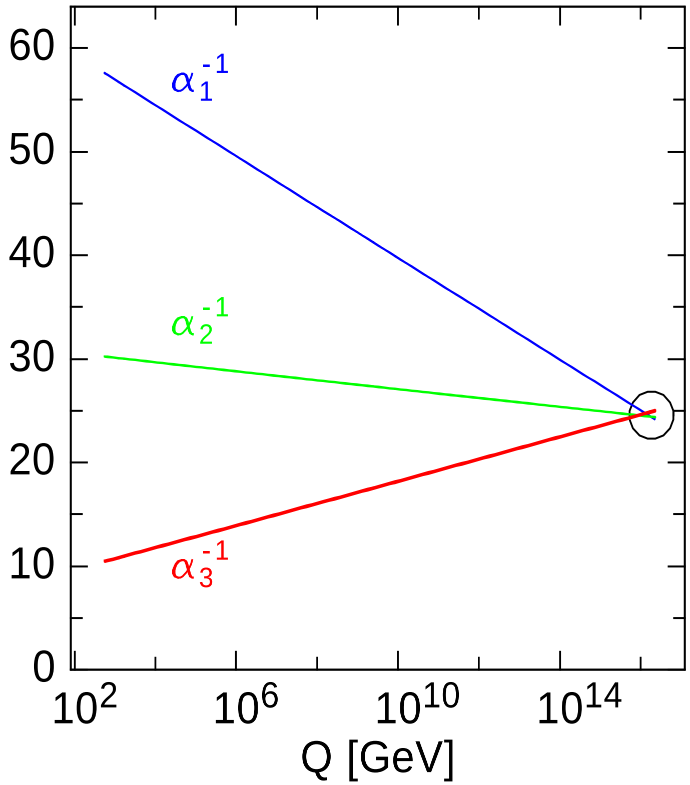
- *LEP/Tevatron:*
  Higgs heavier than 100 GeV
  charginos/sleptons heavier than 100 GeV
  squarks (except $\tilde{t}$,$\tilde{b}$), gluinos heavier than 200 GeV

- *rare decays:*
  bounds on flavour violation beyond CKM

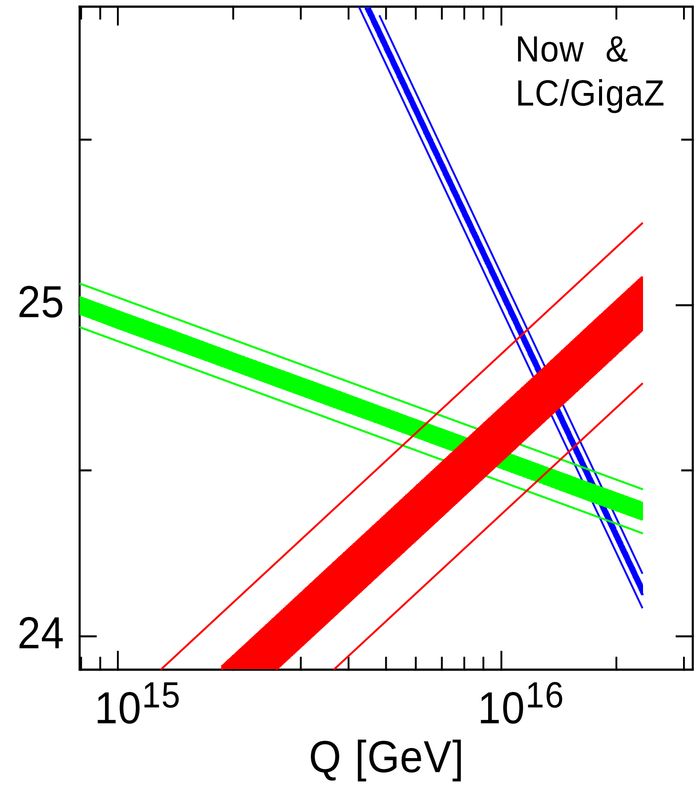
- *Cold dark matter:* $\Omega h^2 \lesssim 0.13$

- *high precision measurments of gauge couplings*
  $\Rightarrow$ *unification if SUSY is present*

Evolution of gauge couplings



$\Rightarrow$



Supersymmetry breaking

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

GMSB: $M_m = \lambda S$, $\Lambda = F/S$, $\tan\beta$, *sign*(μ)

$M_{1/2} = g(x) n_5 \alpha_i \Lambda$, $M_i^2 = f(x) n_5 \sum C_i \alpha_i^2 \Lambda^2$, $x = \Lambda / M_m$

String effective field theories: $m_{3/2}$, s, t_i, $\sin\theta$, n_i, $\tan\beta$, *sign*(μ)

$M_{1/2} = -\sqrt{3} g^2 m_{3/2} s \sin\vartheta$, $M_i^2 = m_{3/2}^2 (1 + n_i \cos^2\vartheta)$

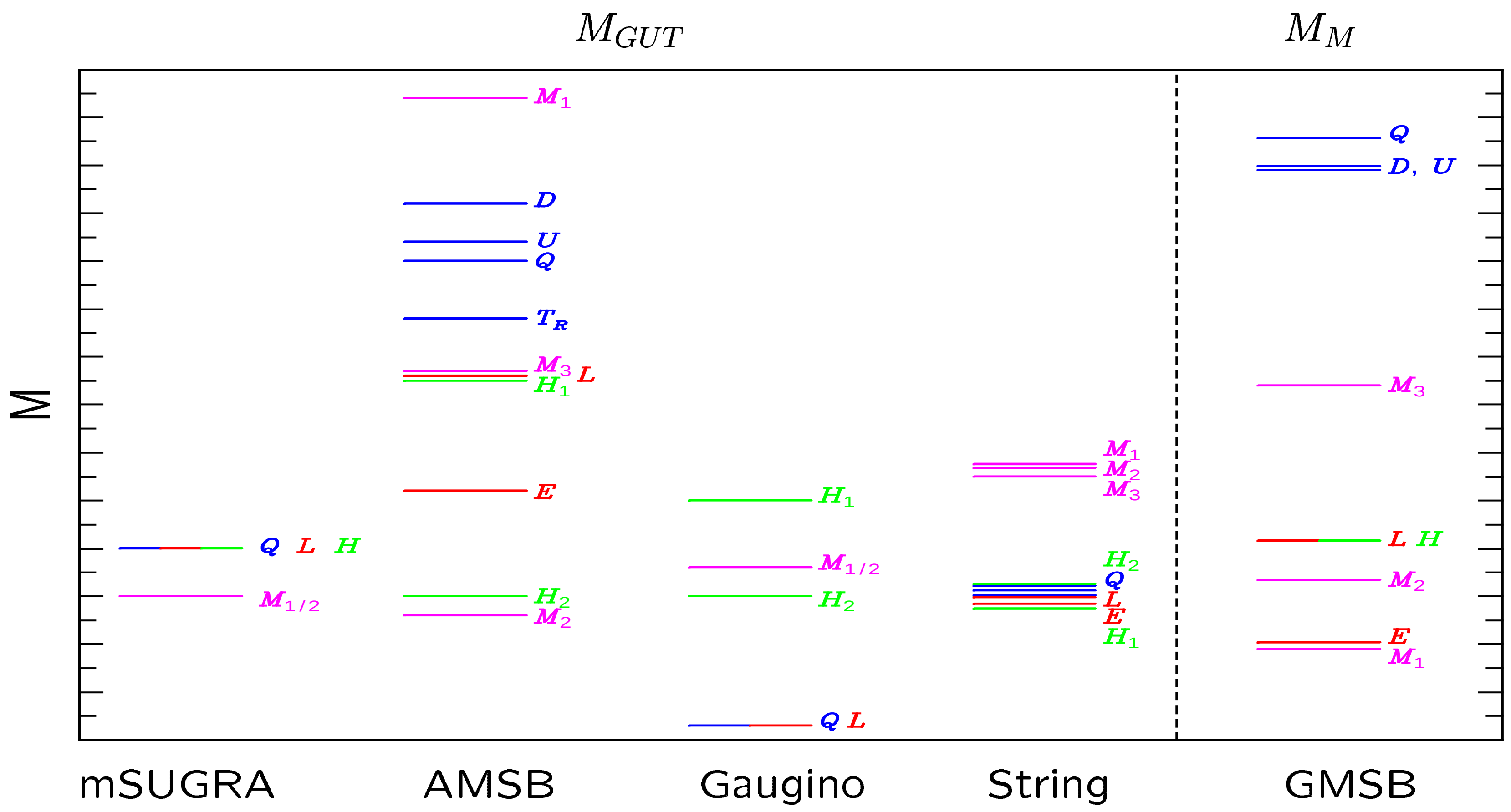
AMSB: $m_{3/2}$, M_0, $\tan\beta$, *sign*(μ)

$M_j = \frac{\beta_i}{g} m_{3/2}$, $M_i^2 = -\frac{\dot{\gamma}_i}{4} m_{3/2}^2 + c_i M_0^2$, $A_k = -\frac{\gamma_k}{2} m_{3/2}$

Gaugino mediated / brane induced: $M_{1/2}$, $\tan\beta$, *sign*(μ)

$$M_{H_i} = O(M_{1/2}),\ M_F^2 = O\left(\frac{M_{1/2}^2}{16\pi^2}\right),\ A = O\left(\frac{M_{1/2}}{16\pi^2}\right)$$

Regularities at High Scales



Low Energy Parameters

Measurements:

masses
cross sections
polarization

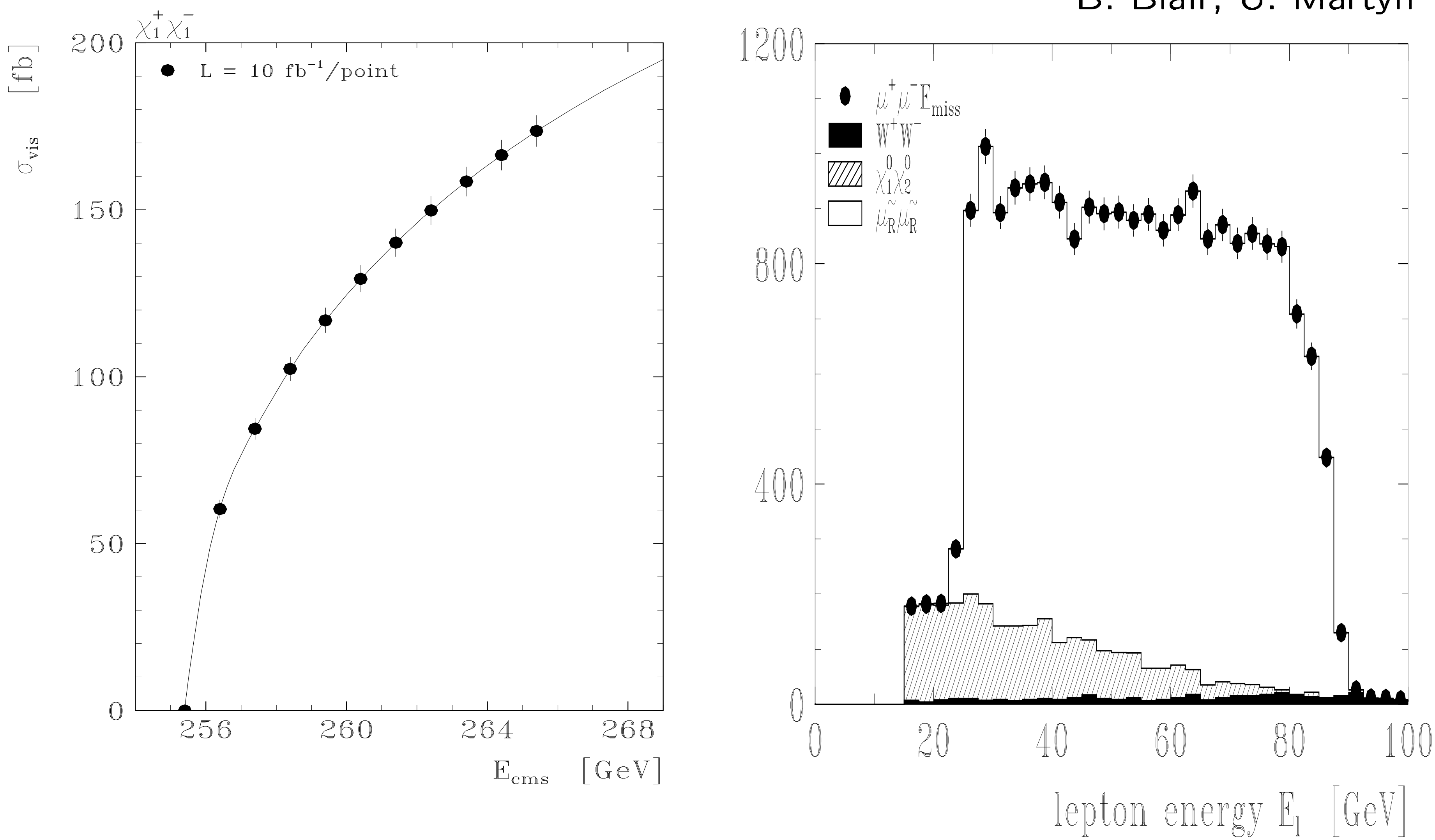
$\Downarrow$

SUSY parameters:

gaugino parameters M_i
scalar masses: $M^2_{H_i}$, M^2_E, M^2_L, ...
Higgs/Higgsino parameters: μ, $\tan\beta$
trilinear couplings: A_t, A_b, A_τ

Mass measurements

B. Blair, U. Martyn



Expected Accuracies

LHC: *masses of squarks, gluinos, winos, bino within a few per–cent*

LC: *sleptons, winos, bino within per–mile*

typical values for mSUGRA scenario

$\tilde{\chi}_1^+$	183.05 ± 0.15	0.08 %	$\tilde{e}_R$	224.82 ± 0.15	0.06 %
$\tilde{\chi}_2^+$	385.28 ± 0.28		$\tilde{e}_L$	269.09 ± 0.28	
$\tilde{\chi}_1^0$	97.86 ± 0.20	0.2 %	$\tilde{u}_R$	572.0 ± 10.0	1.8 %
$\tilde{\chi}_2^0$	184.65 ± 0.30		$\tilde{u}_L$	589.0 ± 10.0	

LHC + LC: *combining data of both machines can improve accuracies on some masses considerably, e.g. $\Delta m_{\tilde{\chi}_2^0}$ up to an order of magnitude. (B.K. Gjelsten, D. Miller, P. Osland and G. Polesello)*

RGE structures

implicit solutions:

$$M_i = Z_i M_{1/2}$$
$$M^2_{\tilde{j}} = M_0^2 + c_j M^2_{1/2} + c'_{j\beta}\Delta M^2_\beta$$
$$A_k = d_k A_0 + d'_k M_{1/2}$$

explicit solutions:

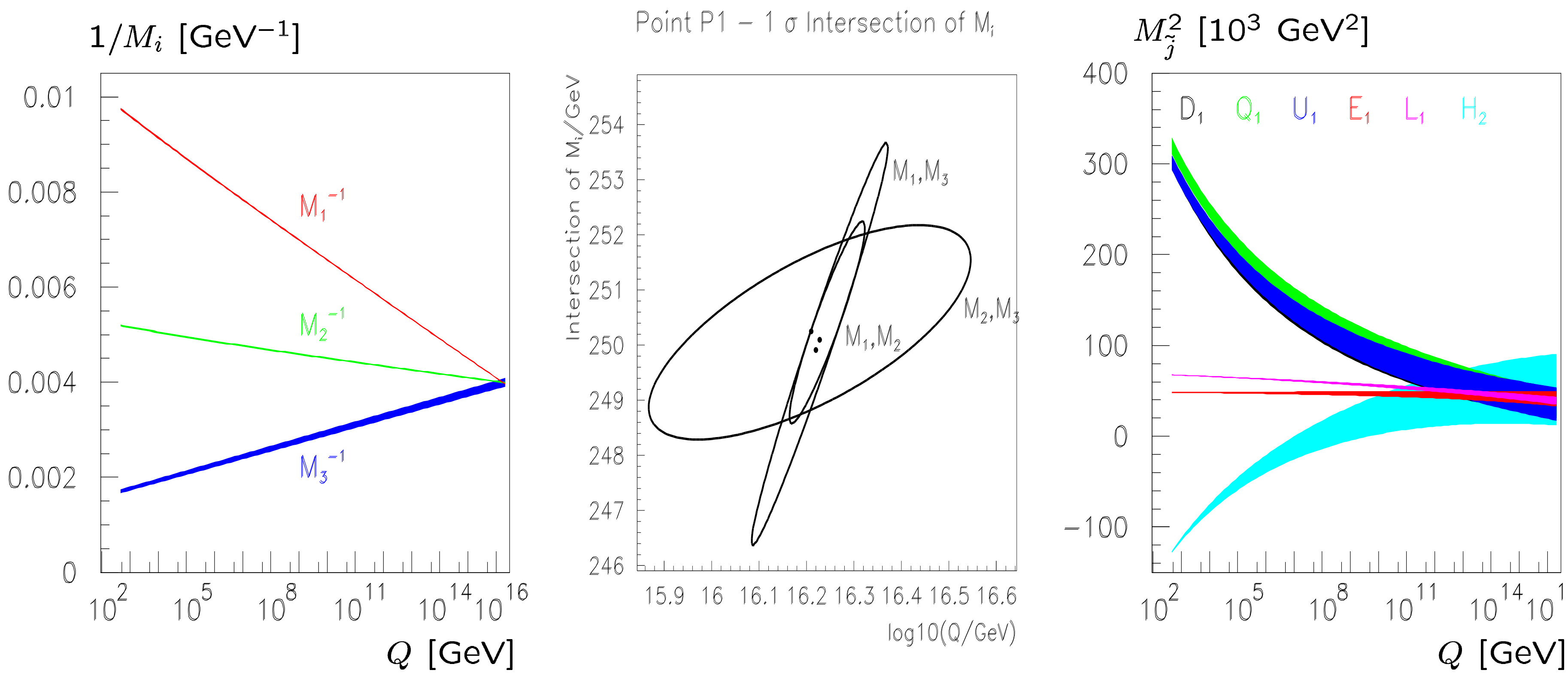
$$M_1 = 0.41 M_{1/2} \quad \Rightarrow M_{1/2} \text{ easy}$$
$$M^2_L = M^2_0 + 0.47 M^2_{1/2} \quad \Rightarrow M_0 \text{ easy}$$
$$M^2_Q = M^2_0 + 5.1 M^2_{1/2} \quad \Rightarrow M_0 \text{ difficult}$$
$$M^2_{H_2} = -0.03 M^2_0 - 1.34 M^2_{1/2} + \ldots \quad \Rightarrow M_0 \text{ very difficult}$$

Top-Down (taking mSUGRA as example)

$$M_{1/2} = 250 \pm 0.08 \text{ GeV}$$
$$M_0 = 200 \pm 0.09 \text{ GeV}$$
$$A_0 = -100 \pm 1.8 \text{ GeV}$$

mSUGRA

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



1 σ error bands

mSUGRA + $\tilde{\nu}_R$

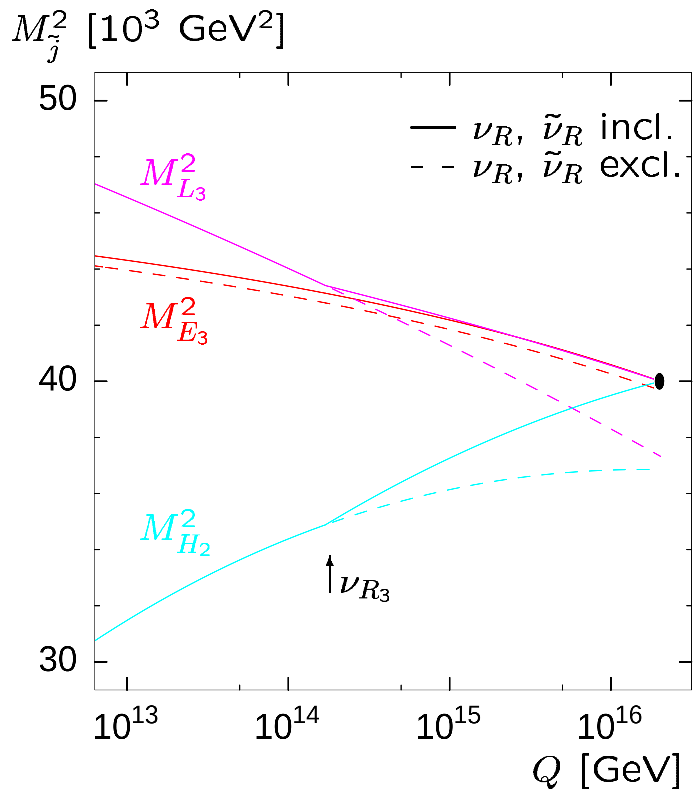
$\tan\beta = 10$, $M_0 = 200$ *GeV*, $M_{1/2} = 250$ *GeV*, $A_0 = -100$ *GeV*, *sign*$(\mu) = 1$, $m_{\nu_{R,3}} = 1.7 \cdot 10^{14}$ *GeV*

$$m^2 = \begin{pmatrix} M^2_{\tilde{L}} + \mathrm{D\,term} & M^2_{LR} \\ M^2_{LR} & M^2_{\tilde{R}} + M^2_{\nu_R} \end{pmatrix}$$

$$M^2_{LR} = \frac{1}{\sqrt{2}} Y_\nu (A_\nu v_2 - \mu v_1)$$

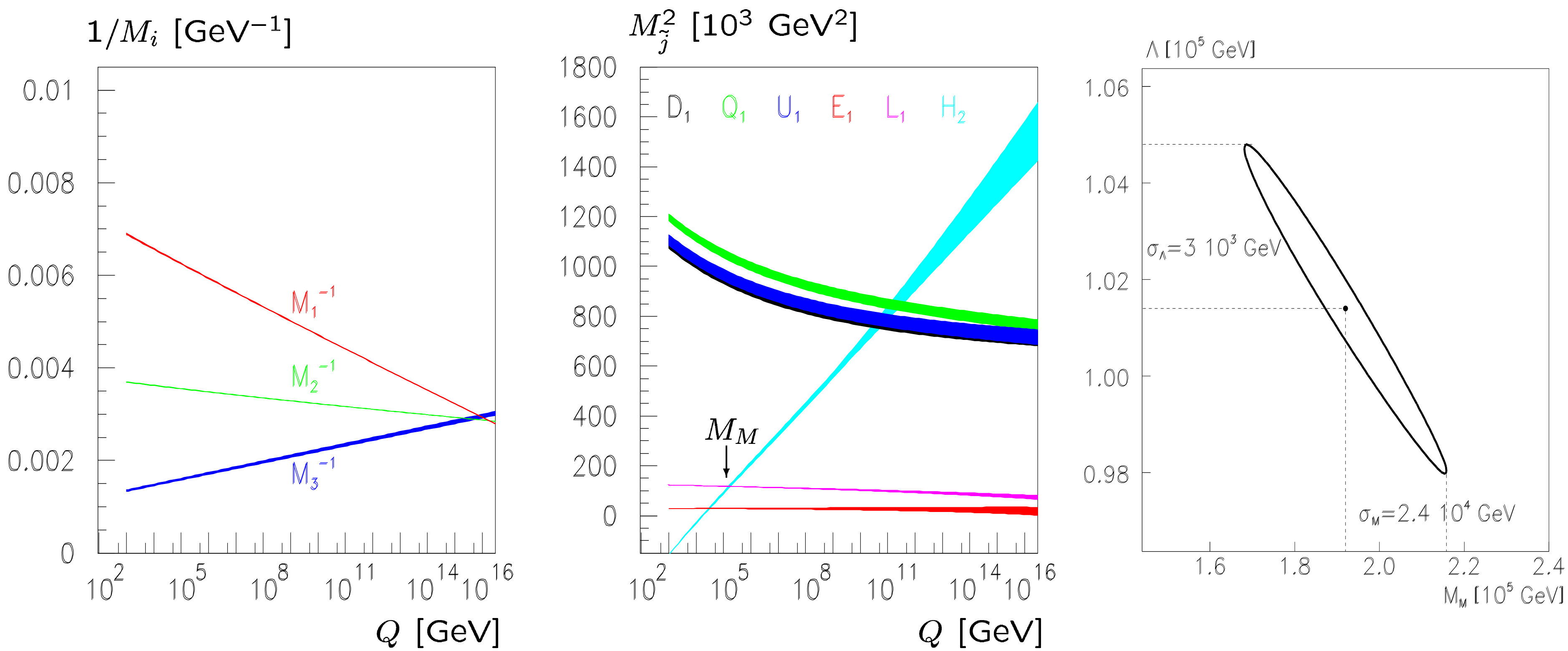
$$m^2_{\tilde{\nu}_1} \simeq M^2_{\tilde{L}} + \mathrm{D\,term} - \mathrm{M}^4_{\mathrm{LR}}/\mathrm{M}^2_{\nu_\mathrm{R}}$$

$$m^2_{\tilde{\nu}_2} \simeq M^2_{\nu_R} + M^2_{\tilde{R}} + M^4_{LR}/M^2_{\nu_R}$$



GMSB

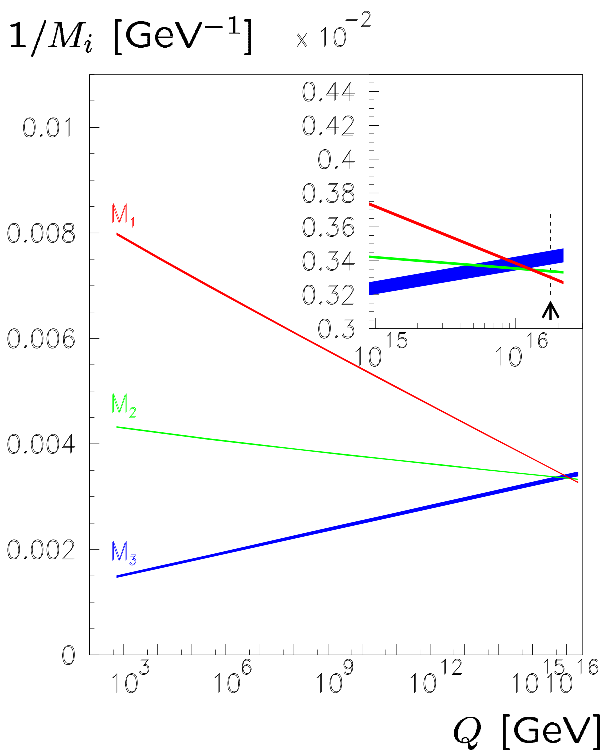
$M_M = 200$ *TeV*, $\Lambda = 100$ *TeV*, $N_5 = 1$, $\tan\beta = 15$, $A_0 = 0$, *sign*$(\mu) = 1$

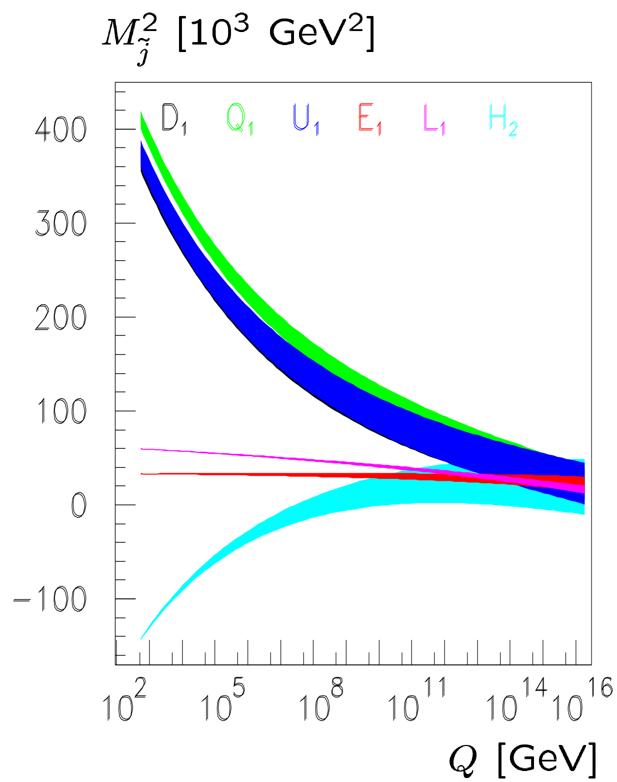


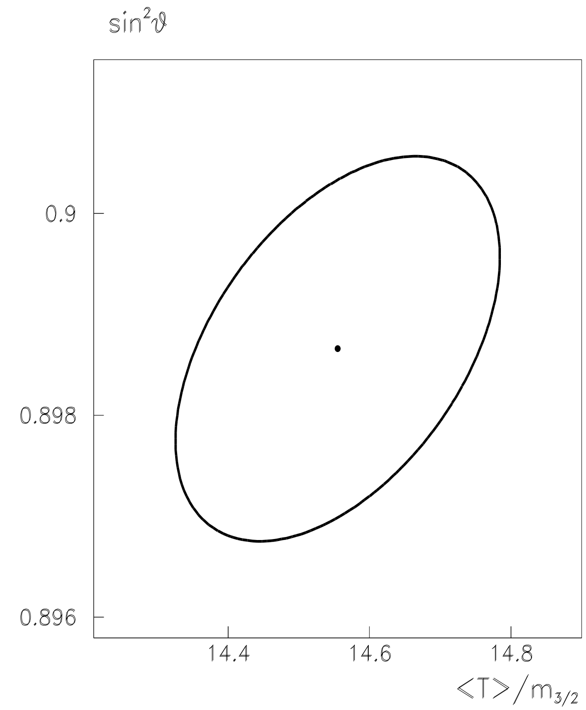
1 σ error bands

String Effective Field Theory

$\tan\beta = 10$, $M_{3/2} = 180$ *GeV*, $\sin^2\vartheta = 0.9$, *O–I*, $n_Q = 0$, $n_D = 1$, $n_U = -2$, $n_L = -3$, $n_E = -1$, *and* $n_{H_1} = n_{H_2} = -1$, *sign*$(\mu) = -1$







1 σ error bands

String Parameter Determination

$m_{3/2}$	*180*	179.9 $\pm$ 0.4
t	*14*	*14.6 $\pm$ 0.2*
$< s >$	*2*	*1.998 $\pm$ 0.006*
δ_{GS}	*0*	*0.1 $\pm$ 0.4*
$\tan\beta$	*10*	*10 $\pm$ 0.1*
n_{H_2}	*-1*	*-1.00$\pm$ 0.02*
n_L	*-3*	*-2.94$\pm$ 0.04*
n_E	*-1*	*-1.00$\pm$ 0.05*
n_Q	*0*	*0.02$\pm$ 0.02*

Trying OII scheme:
$n_E = -1.4 \pm 0.02$, *similar for other* n_i, *and* $\chi^2 = O(10^2)$

Trying mSUGRA scheme: errors in the per–cent range, $\chi^2 = O(10^2)$

Summary

- *Reconstruction of the underlying high scale theory is feasible*
- *High precision measurements at future e^+e^- colliders are necessary*