Reconstructing Supersymmetric Theories near the Planck Scale

Werner Porod

Universität Würzburg

Two Scale Picture of Nature

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

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 $\bigoplus$ particle physics

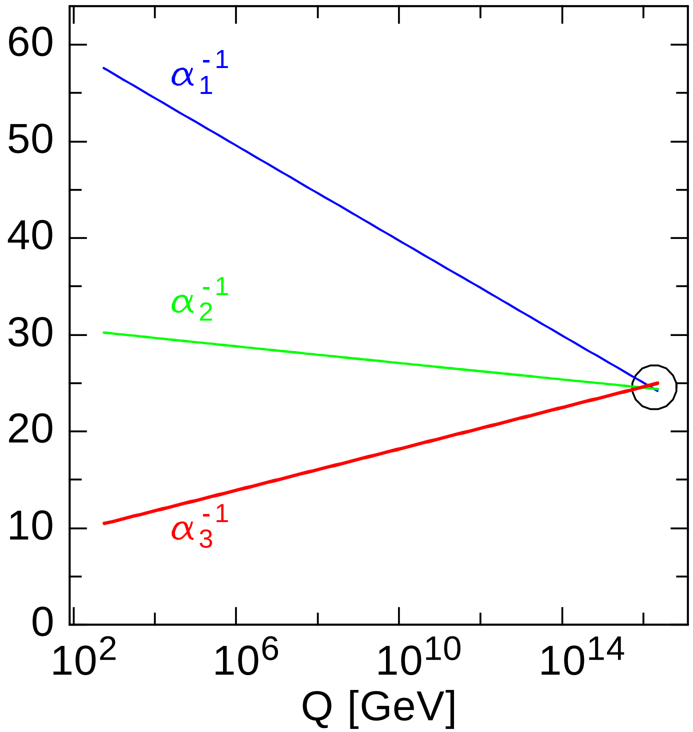
Exploring high scale structures (GUT,PL . . .)

- 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

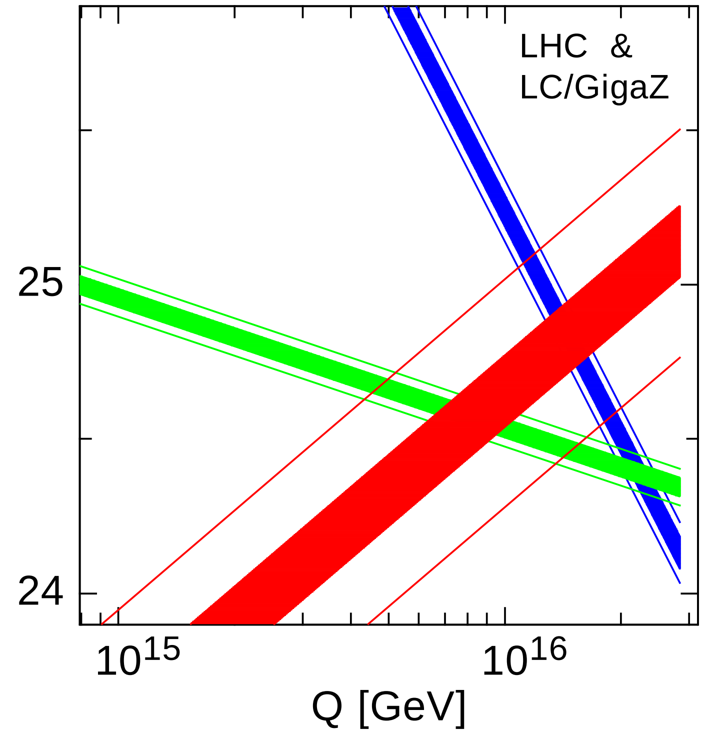
Experimental information

- LEP/Tevatron:
  - Higgs heavier than 100 GeV
  - charginos/sleptons heavier than 100 GeV
  - squarks (except $\tilde{t}, \tilde{b}$), gluinos heavier than 250 GeV
- rare decays:
  bounds on flavour violation beyond CKM
- Cold dark matter: $\Omega h^2 \lesssim 0.12$
- high precision measurments of gauge couplings
  $\Rightarrow$ unification if SUSY is present

Evolution of gauge couplings



$\Rightarrow$

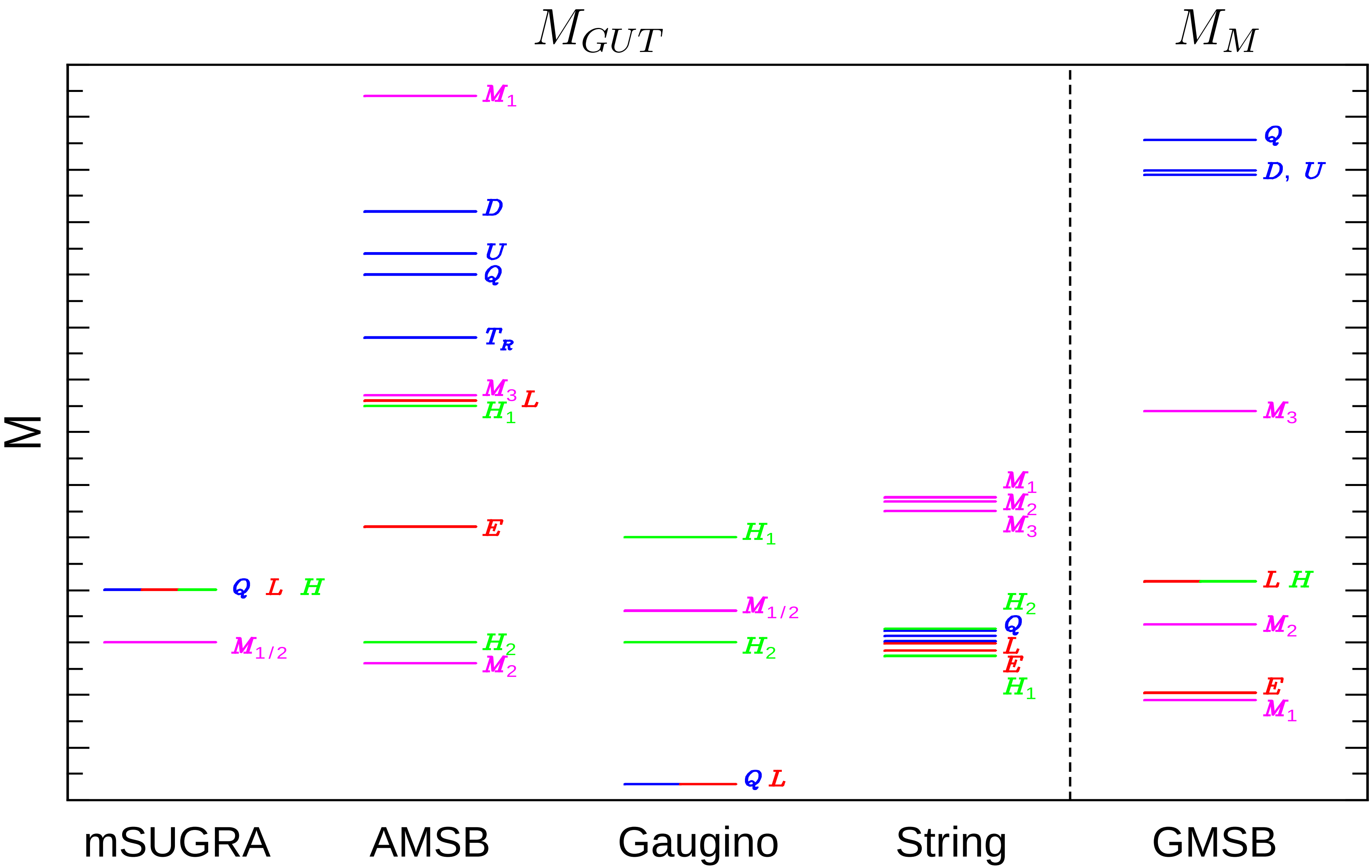


	Today/"LHC"	GigaZ/"LHC+LC"
M_U	$(2.36 \pm 0.06) \cdot 10^{16}$ GeV	$(2.360 \pm 0.016) \cdot 10^{16}$ GeV
α_U^{-1}	24.19 ± 0.10	24.19 ± 0.05
$\alpha_3^{-1} - \alpha_U^{-1}$	0.97 ± 0.45	0.95 ± 0.12

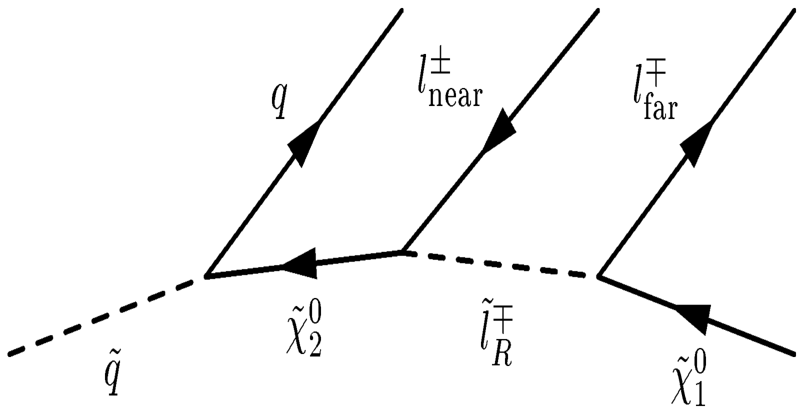
Supersymmetry breaking

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

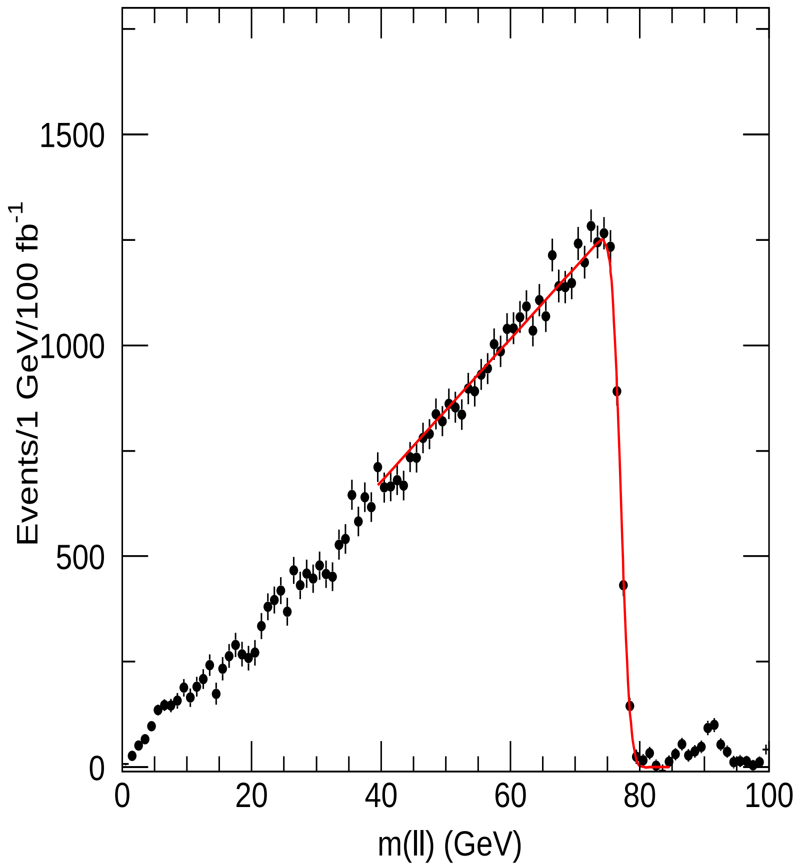
Regularities at High Scales



Mass measurements, LHC



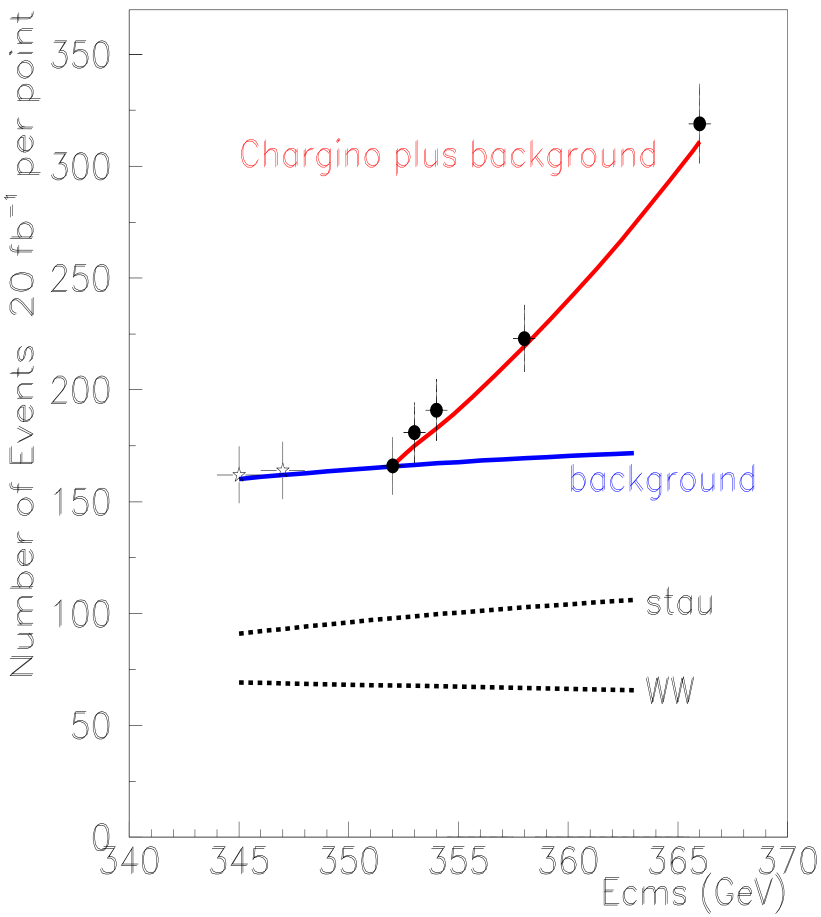
G. Polesello



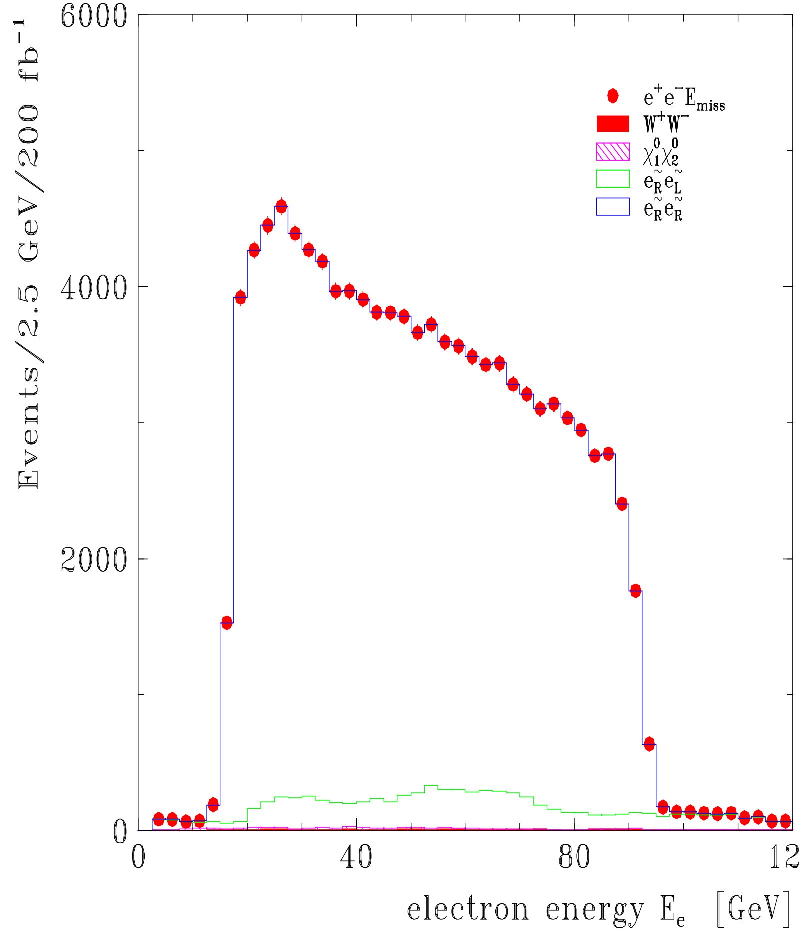
5 kinematical observables
depending on 4 SUSY masses
$\Rightarrow$ masses within 2-5%
using various assumptions

Mass measurements, ILC

$$e^+_R e^-_L \longrightarrow \tilde{\chi}^+_1 \tilde{\chi}^-_1$$



$$e^+_L e^-_R \longrightarrow \tilde{e}^+_R \tilde{e}^-_R \longrightarrow e^+ \tilde{\chi}^0_1 \, e^- \tilde{\chi}^0_1$$



G. Blair, U. Martyn

Expected experimental accuracies

	Mass, ideal	"LHC"	"LC"	"LHC+LC"
h^0	116.0	0.25	0.05	0.05
H^0	425.0		1.5	1.5
$\tilde{\chi}_1^0$	97.7	4.8	0.05	0.05
$\tilde{\chi}_2^0$	183.9	4.7	1.2	0.08
$\tilde{\chi}_4^0$	413.9	5.1	3-5	2.5
$\tilde{\chi}_1^\pm$	183.7		0.55	0.55
$\tilde{e}_R$	125.3	4.8	0.05	0.05
$\tilde{e}_L$	189.9	5.0	0.18	0.18
$\tilde{\tau}_1$	107.9	5-8	0.24	0.24
$\tilde{q}_R$	547.2	7-12	-	5-11
$\tilde{q}_L$	564.7	8.7	-	4.9
$\tilde{t}_1$	366.5		1.9	1.9
$\tilde{b}_1$	506.3	7.5	-	5.7
$\tilde{g}$	607.1	8.0	-	6.5

$m_0 = 70$ GeV

$m_{1/2} = 250$ GeV

$A_0 = -300$ GeV

$\tan\beta = 10$

sign$(\mu) = +$

The SPA Project

- accurate theoretical calculations to match experimental data
- model independent reconstruction of Lagrange parameters
- extrapolation to high scale

SPA
SUPERSYMMETRY PARAMETER ANALYSIS

J. A. Aguilar-Saavedra *et al.*
Eur. Phys. J. C **46** (2006) 43
http://spa.desy.de/spa

- SPA Convention:
  renormalization scheme / LE parameters / decay widths / cross sections
- Programme Base: theo + exp analyses / ILC + LHC
- Theoretical and Experimental Tasks
- References point SPS1a’
- Future Extensions: MSSM-CP, NMSSM, . . .

Test of high scale models

Two methods:

- Top-Down
  - + a handful of observables are sufficient
  - - model-dependent

  e.g. mSugra
  - $M_{1/2} = 250 \pm 0.2$ GeV
  - $M_0 = 70 \pm 0.2$ GeV
  - $A_0 = -300 \pm 13$ GeV
- Bottom-Up
  - + does not depend on high scale model
  - - requires several observables,
    e.g. nearly complete spectrum

RGE structures

implicit solutions:

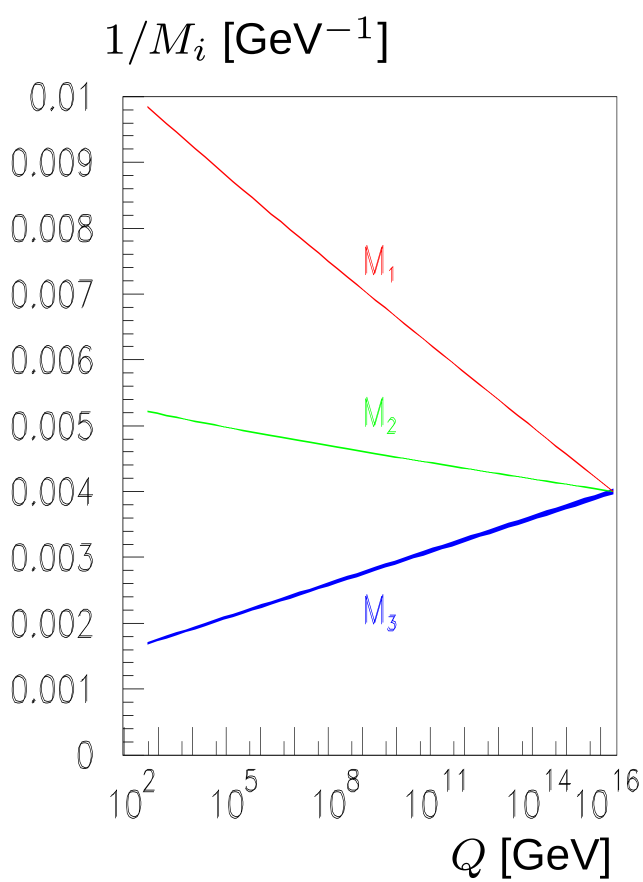
$$M_i = Z_i M_{1/2}$$
$$M_{\tilde{j}}^2 = M_0^2 + c_j M_{1/2}^2 + c'_{j\beta} \Delta M_\beta^2 (M_0, M_{1/2}, A_0)$$
$$A_k = d_k A_0 + d'_k M_{1/2}$$

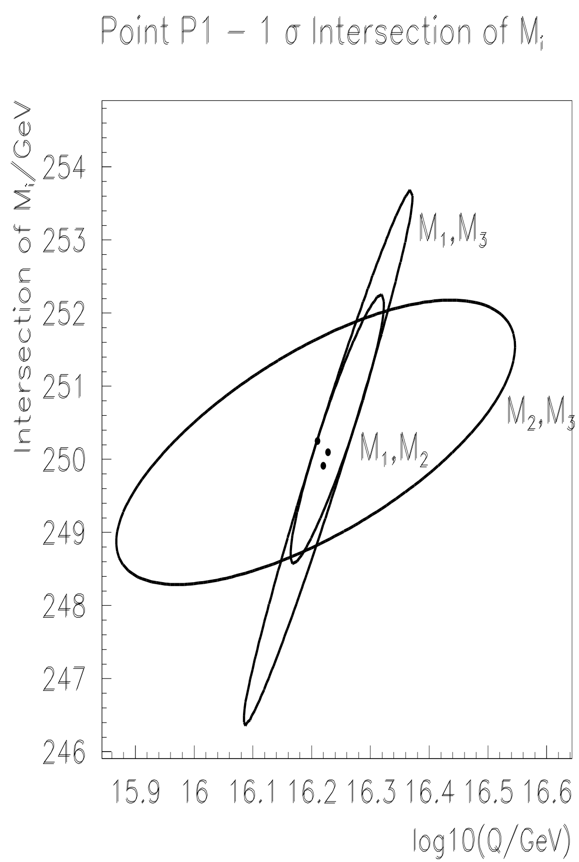
explicit solutions:

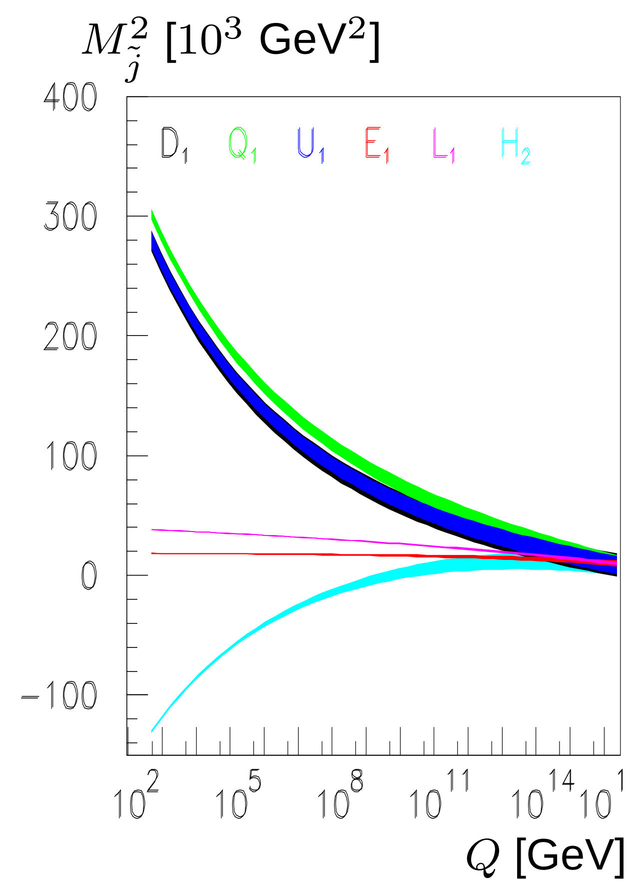
$$M_1 = 0.41 M_{1/2} \quad \Rightarrow \quad M_{1/2} \text{ easy}$$
$$M_L^2 = M_{0,L}^2 + 0.47 M_{1/2}^2 \quad \Rightarrow \quad M_{0,L} \text{ easy}$$
$$M_Q^2 = M_{0,Q}^2 + 5.1 M_{1/2}^2 \quad \Rightarrow \quad M_{0,Q} \text{ difficult}$$
$$M_{H_2}^2 = -0.03 M_{0,H}^2 - 1.34 M_{1/2}^2 + \ldots \quad \Rightarrow \quad M_{0,H} \text{ very difficult}$$

Bottom-Up: mSugra

$\tan\beta = 10$, $M_0 = 70$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -300$, sign$(\mu) = +$



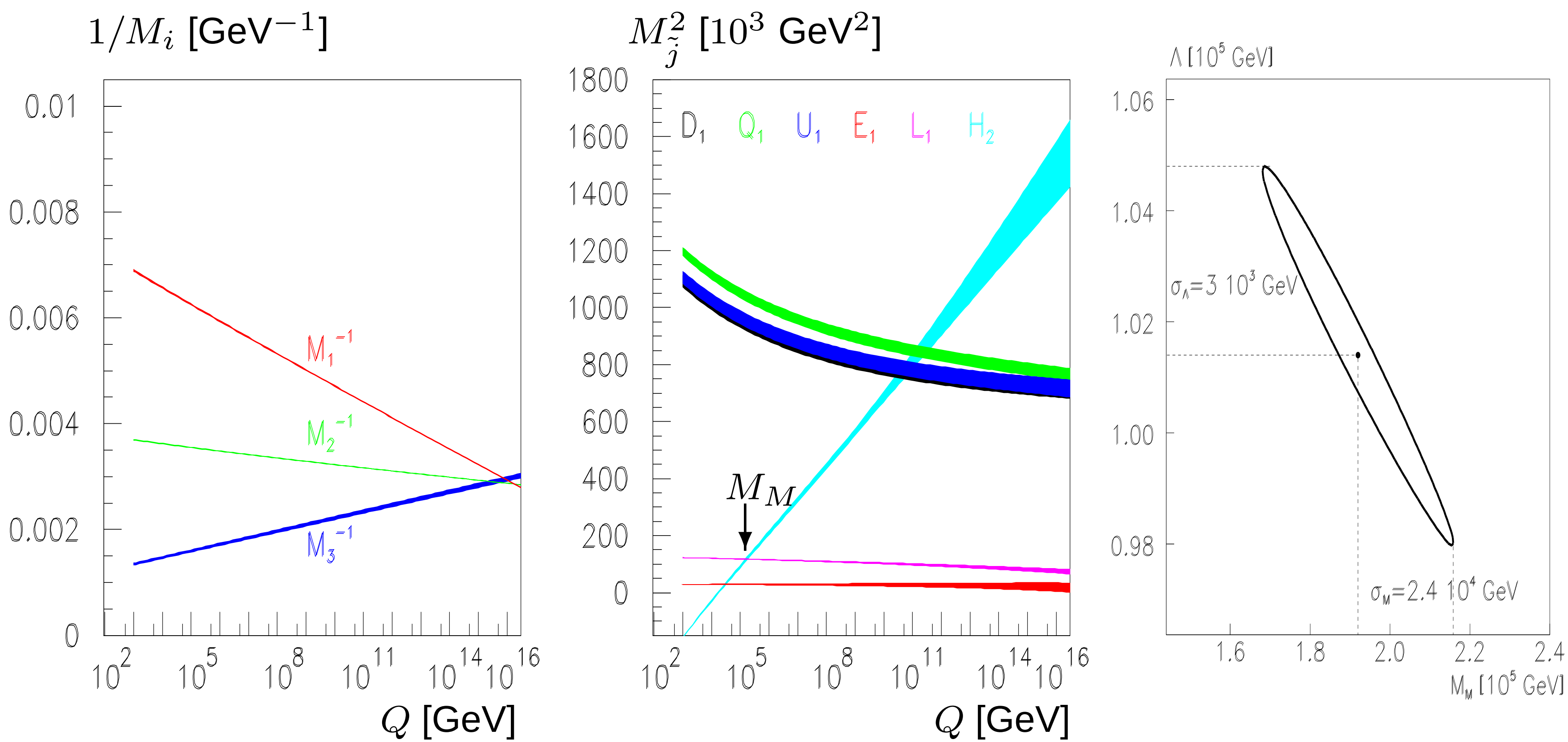




1 σ error bands

Bottom-Up: GMSB

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

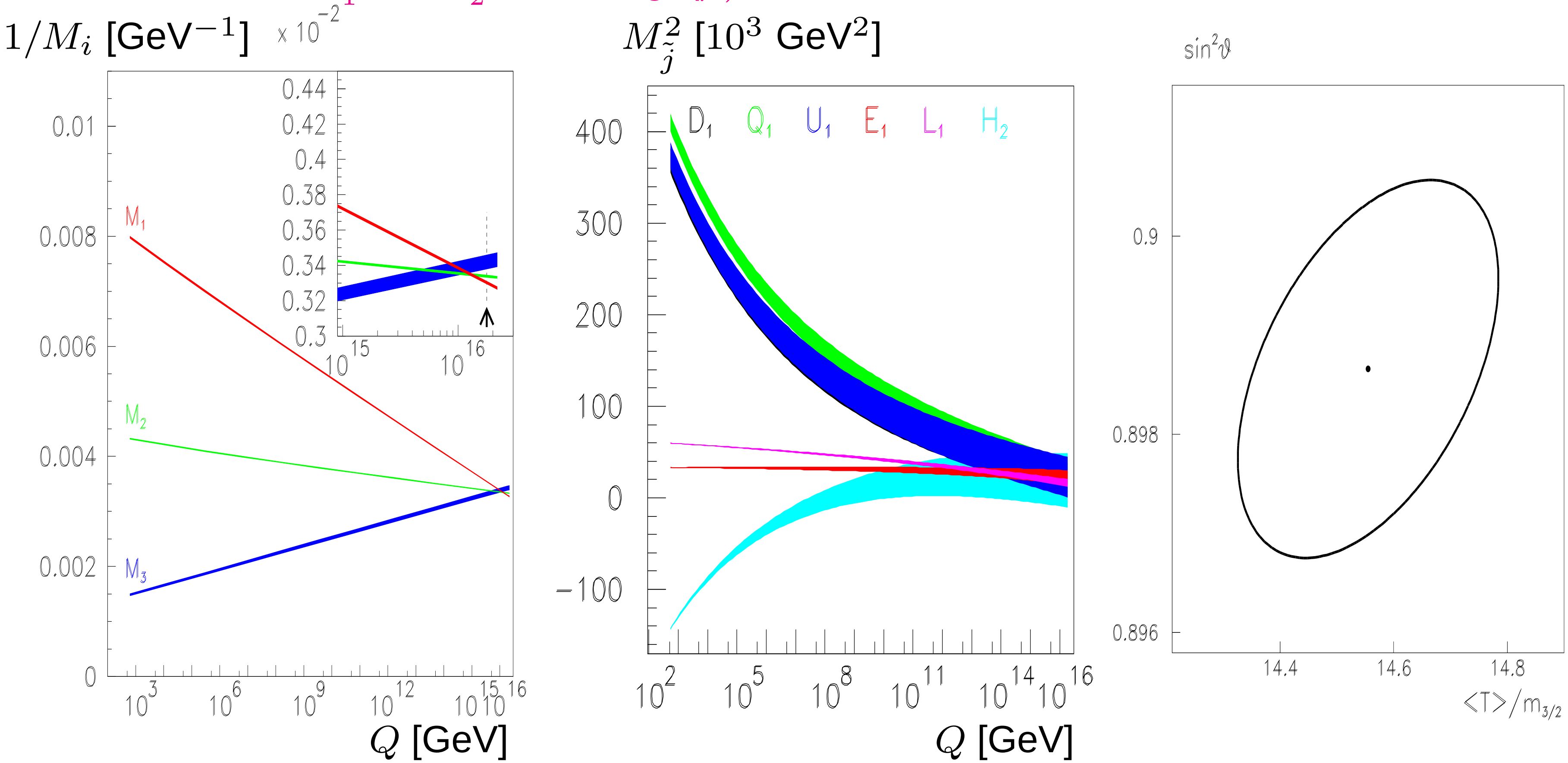


1 σ error bands

G. A. Blair, W.P., P.M. Zerwas, Phys. Rev. D **63** (2001) 017703; Eur. Phys. J. C **27** (2003) 263

Bottom-Up: 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(μ) $= -$



1 σ error bands

G. A. Blair, W.P., P.M. Zerwas, Eur. Phys. J. C **27** (2003) 263

Bottom-Up: String Parameter Determination

Trying OI scheme:

$m_{3/2}$	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, $\chi^2 = O(10^2)$

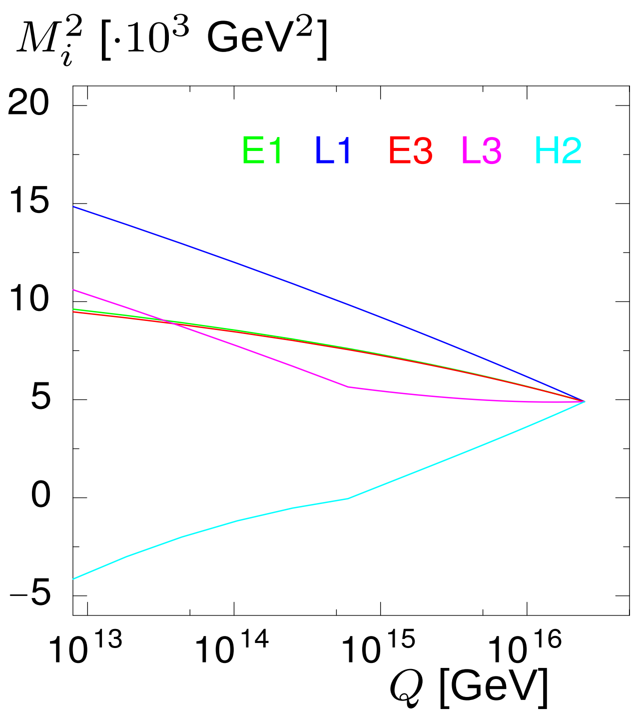
Bottom-Up: mSugra + $\hat{\nu}_R$

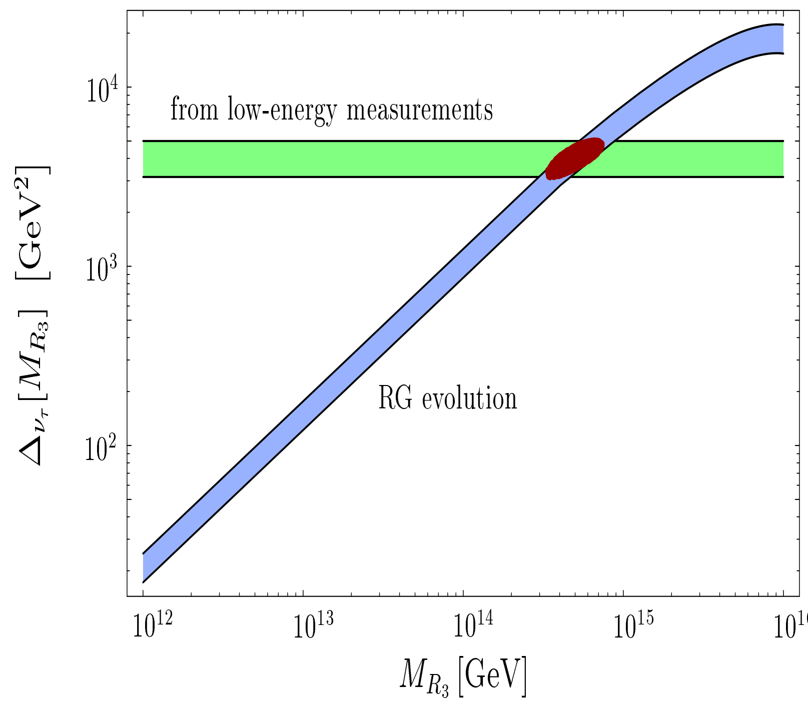
$m_\nu \neq 0$ neutrino masses via seesaw mechanism

$\Rightarrow$ seesaw scale $M[\nu_R] \sim 10^{10}/10^{14}$ GeV in SO(10)

$\Rightarrow$ influences the evolution 3rd generation parameters $\Rightarrow$ kink

$\oplus$ information from neutrino sector $\Rightarrow$ $M[\nu_{R3}] \sim 10^{14}$ GeV [30%]





A. Freitas, W. P., P. M. Zerwas, Phys. Rev. D **72** (2005) 115002

Summary

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

$\Rightarrow$ LHC + ILC yield a telescope to Plank Scale Physics