mSUGRA topdown

testing the scalar mass universality

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GDR SUSY: Probing SUSY Models at Colliders

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Motivation

- We hope to discover SUSY at the LHC (+LC), measure sparticle masses, etc.
- As the next step we will want to relate observations to the underlying model parameters and ultimatly determine the high-scale structure of the theory !

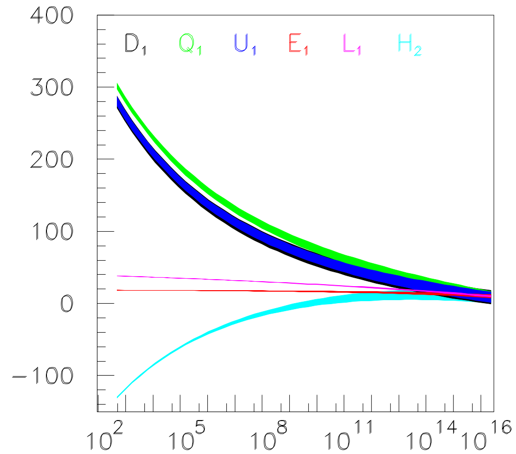
  $\rightarrow$ turn sparticle properties measured at the EW/TeV scale into SUSY-breaking parameters at the high-energy scale

  - RG evolution, loop corrections
  - sophisticated computational tools
  - good strategy, relevant measurements
  - careful assessment of uncertainties
- 2 possible strategies: top-down or bottom-up

Bottom-up evolution

Extract the SUSY Lagrange parameters from measurements at the EW/TeV scale and extrapolate them to the GUT scale.

[Blair, Porod, Zerwas, hep-ph/0007107]



- Model-independent test of high-scale boundary conditions!
- RGEs = highly coupled set of differential equations, at 2-loops "everything feeds into everything" ...

$\rightarrow$ needs almost complete spectrum information

$\rightarrow$ needs good precision to avoid that errors blow up

needs LHC + LC

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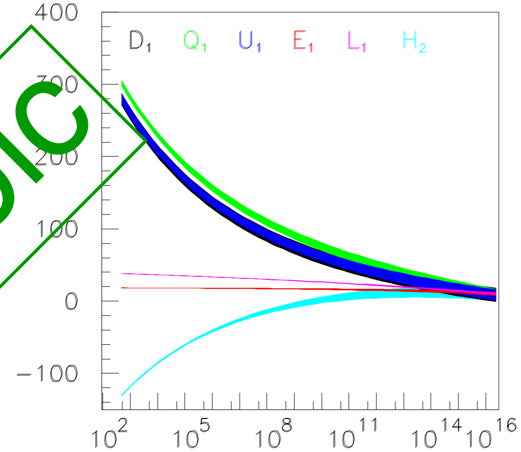

see talk by Jean-Loic

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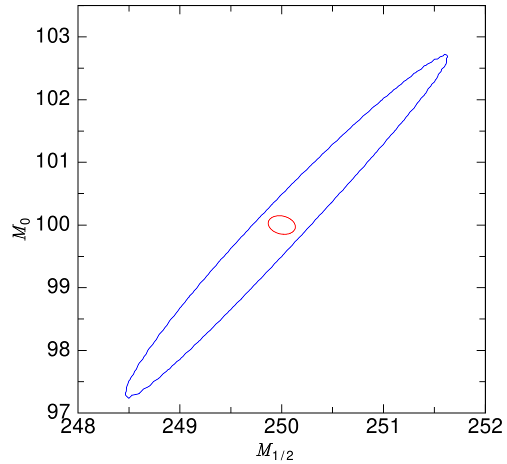
Top-down Fit

Quite simple idea: take all available data and fit a particular model, e.g. mSUGRA, to them. [e.g. ATLAS Physics TDR]

- A χ^2 analysis gives the 1-, 2-, 3-σ errors on the input parameters.
- The $\chi^2_{min}/n.d.o.f.$ is a measure for the goodness of the fit (probabiliy that the model is wrong) $\longrightarrow$ hypothesis test
- Advantage: works [in principle] with any amount and precision of experimental data
  $\longrightarrow$ convenient for LHC studies



SUSY signatures @ LHC

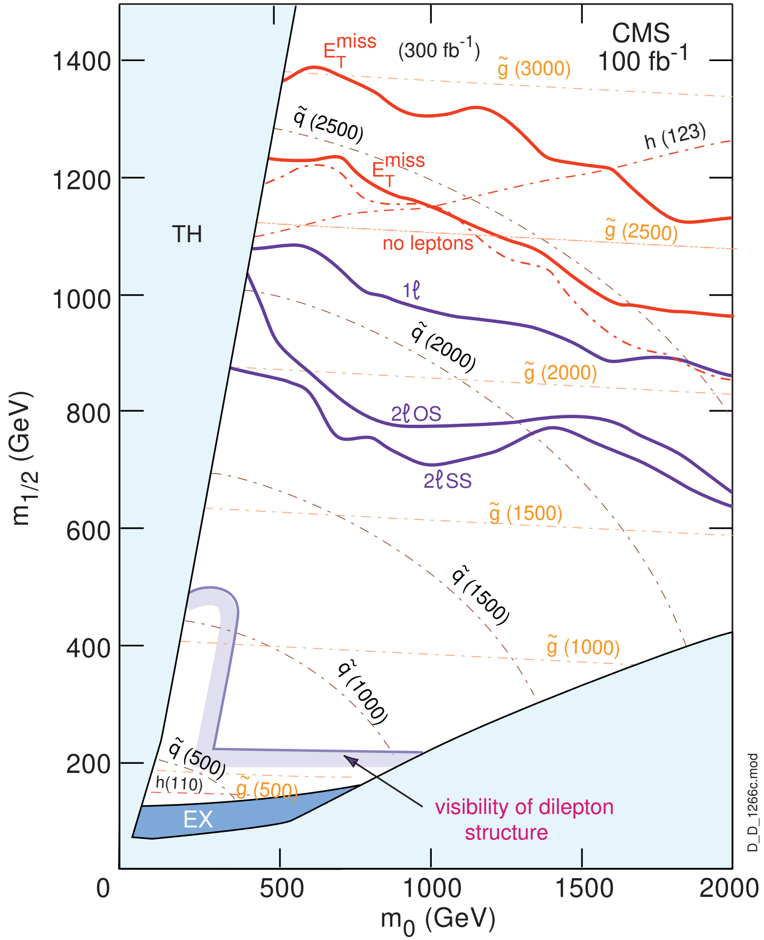
- $pp \to \tilde{q}\tilde{q},\ \tilde{g}\tilde{q},\ \tilde{g}\tilde{g}$ production with $\tilde{g} \to q\tilde{q}$, $\tilde{q} \to q\tilde{\chi}^0, q'\tilde{\chi}^\pm$
  - jets $+\ \not{E}_T$ signature
  - covers squark and gluino masses up to 2–3 TeV.
- $\tilde{q} \to q\tilde{\chi}_2^0 \to qZ\,\tilde{\chi}_1^0$, $\tilde{q} \to q'\tilde{\chi}_j^\pm \to q'W\,\tilde{\chi}_1^0$: jets + leptons + $\not{E}_T$

  SFOS or SS dilepton, 1l inclusive signatures
- If $m(\tilde{l}) < m(\tilde{\chi}_2^0)$: $\tilde{q} \to q\tilde{\chi}_2^0 \to ql^\pm\tilde{l}^\mp \to ql^\pm l^\mp\,\tilde{\chi}_1^0$

  SFOS dileptons, gold-plated decay chain

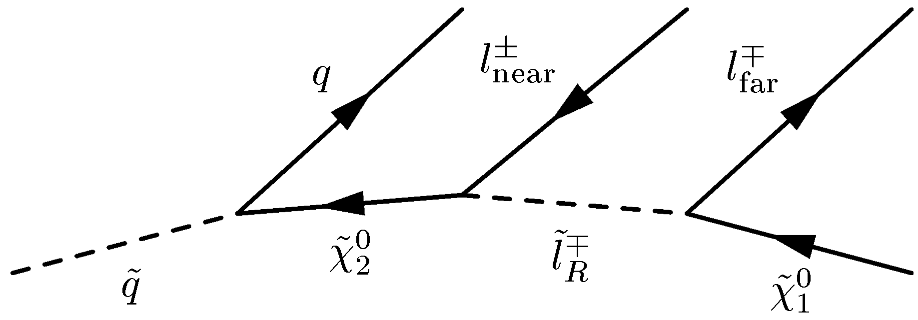
  - Mass determinations through kinematic endpoints
  - Large $\tan\beta$: $l \to \tau$, challenging!
  - Stau co-annihilation: $\Delta M(\tilde{\chi}_1^0\tilde{\tau}_1) \lesssim 10$ GeV, soft τ's !!!

LHC reach in mSURGA



[CMS, Abdullin et al, hep-ph/9806366]

Kin. endpoint in cascade decays



Can construct various kinematic endpoints:

$l^+ l^-$	edge	m_{ll}^{max}
$l^+ l^- q$	edge	m_{llq}^{max}
$l^+ l^- q$	threshold	m_{llq}^{min}
$l^{\pm} q$	high-edge	m_{lq}^{high}
$l^{\pm} q$	low-edge	m_{lq}^{low}

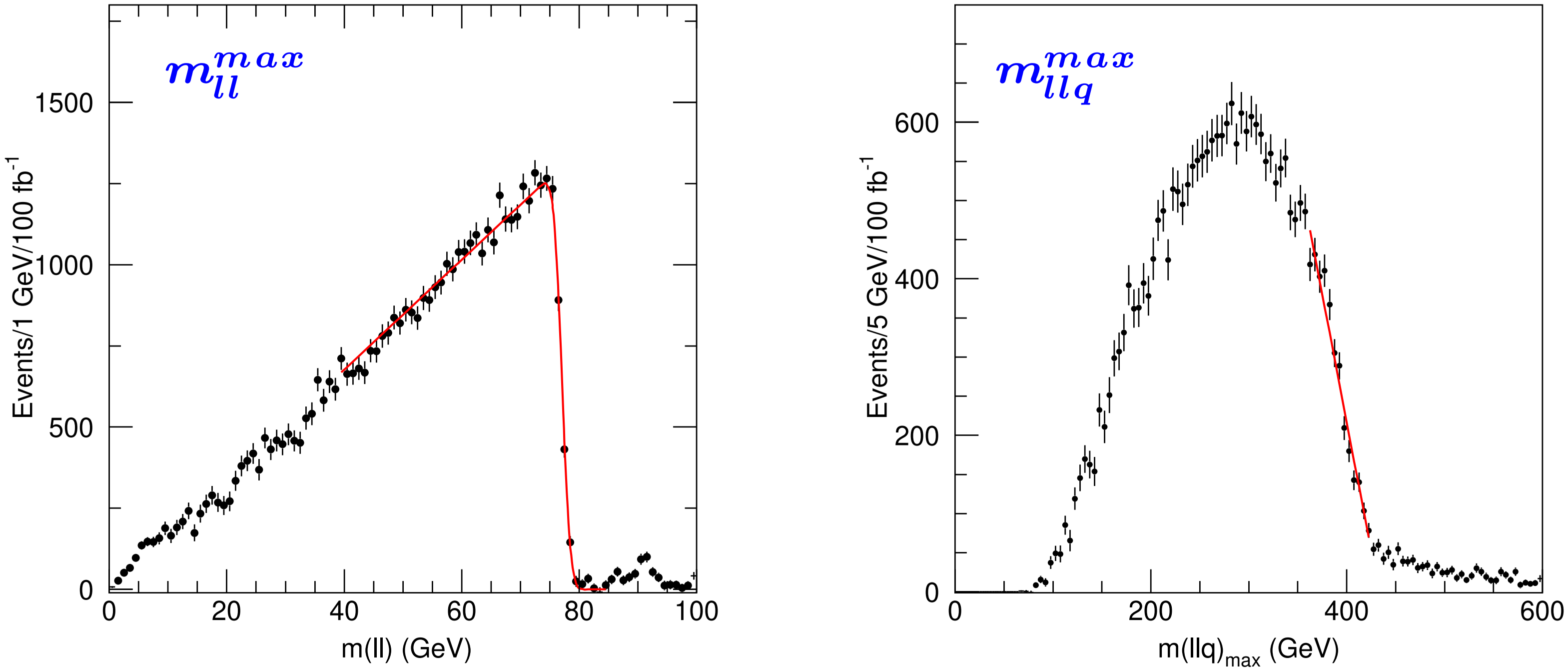
$$(m_{ll}^{max})^2 = (m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R})(m^2_{\tilde{l}_R} - m^2_{\tilde{\chi}^0_1})/m^2_{\tilde{l}_R}$$

[B.C. Allanach et al., hep-ph/0007009]

Case study of SPS1a

$\tilde{g}, \tilde{q} \sim 600$ GeV
$\tilde{\chi}^0_2 \sim 180$ GeV
$\tilde{l}_R \sim 140$ GeV
$\tilde{\chi}^0_1 \sim 100$ GeV

$$m_0 = 100, \qquad \tan\beta = 10, \qquad \mu > 0,$$
$$m_{1/2} = 250, \quad A_0 = -100, \quad m_t = 175$$



[G. Polesello, ATLAS]

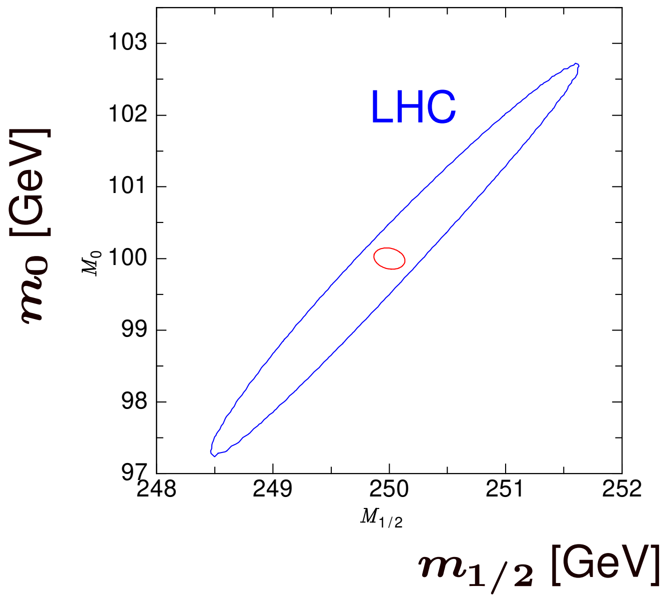
Mass determination at SPS1a

	mass, ideal	Δ_{abs}	Δ_{rel}
$\tilde{\chi}_1^0$	97.2 GeV	4.8 GeV	5 %
$\tilde{\chi}_2^0$	180.7 GeV	4.7 GeV	3 %
$\tilde{\chi}_4^0$	381.9 GeV	5.1 GeV	1 %
$\tilde{l}_R$	143.9 GeV	4.8 GeV	3 %
$\tilde{l}_L$	207.1 GeV	5.0 GeV	2 %
$\tilde{\tau}_1$	134.8 GeV	5–8 GeV	5 %
$\tilde{q}_R$	547.6 GeV	7–12 GeV	1–2 %
$\tilde{q}_L$	570.6 GeV	8.7 GeV	1–2 %
$\tilde{b}_1$	515.1 GeV	7.5 GeV	1–2 %
$\tilde{b}_2$	547.1 GeV	7.9 GeV	1–2 %
$\tilde{g}$	604.0 GeV	8.0 GeV	1–2 %
h^0	110.8 GeV	0.25 GeV	0.2 %

[M. Chiorboli et al., LHC/LC study, hep-ph/0410364]

Fit of mSUGRA to SPS1a

Top-down fit of mSUGRA parameters to LHC ‘data’ at SPS1a:



$$\begin{aligned} m_0 &= 100 \pm 2.8 \\ m_{1/2} &= 250 \pm 2.1 \\ A_0 &= -100 \pm 34 \\ \tan\beta &= 10.0 \pm 1.8 \end{aligned}$$

$$\chi^2_{min}/14\, d.o.f. \sim 10^{-5}$$

Good precision, looks very promising ....
[Allanach et al., hep-ph/0403133]

Fit of mGMSB to the same data gives $\chi^2_{min}/14 d.o.f. \sim 68$:-)

Note however:

- top-down approach requires model-by-model test
  $\longrightarrow$ fit of mGMSB to SPS1a gives $\chi^2_{min}/14dof \sim 68$
  but cannot exclude other options

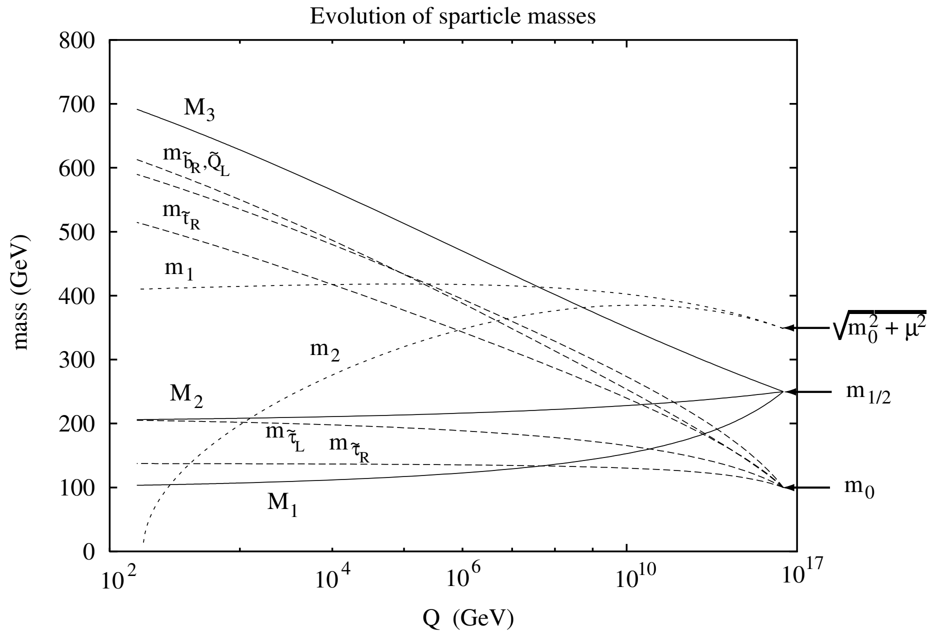
- care needed not to make too strong assumptions
  e.g. scalar mass universality in mSUGRA:

$$m_L^2 \sim m_0^2 + 0.5\, m_{1/2}^2, \qquad m_Q^2 \sim m_0^2 + 6.3\, m_{1/2}^2,$$
$$m_E^2 \sim m_0^2 + 0.15\, m_{1/2}^2, \qquad m_{U,D}^2 \sim m_0^2 + 5.8\, m_{1/2}^2.$$

  $\longrightarrow$ squark masses dominated by $m_{1/2}$
  $\longrightarrow$ fit of m_0 dominated by sleptons !

- no theoretical uncertainties are taken into account

Can we test the assumption of scalar mass universality?



Non-universal scalar masses

- Different m_0's for different generations?
  For 1st vs 2nd generation strong constraints from FCNC.

  More freedom in 3rd generation.

- Squarks vs sleptons: $m_0(\tilde{q}) \neq m_0(\tilde{l})$?
  Disfavoured in various GUT models: SU(5), SO(10),...

  Don't forget GUT-scale threshold effects.

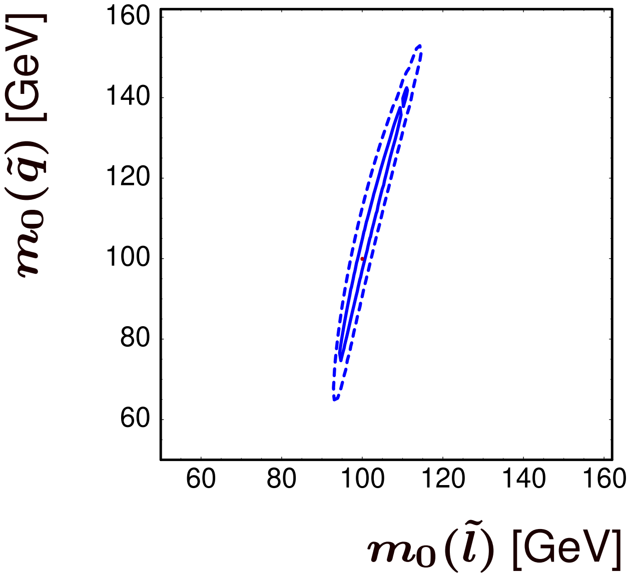
- Higgs sector: $m_{H_i}^2 = m_0^2(1 + \delta_i)$?
  μ and m_A become free parameters

  No restrictions, so why not.

need to test all possibilities

Fit with non-universal scalar masses

Fit to anticipated SPS1a data with SFITTER taking m_0's of the squark, slepton and Higgs sectors as independent variables gives



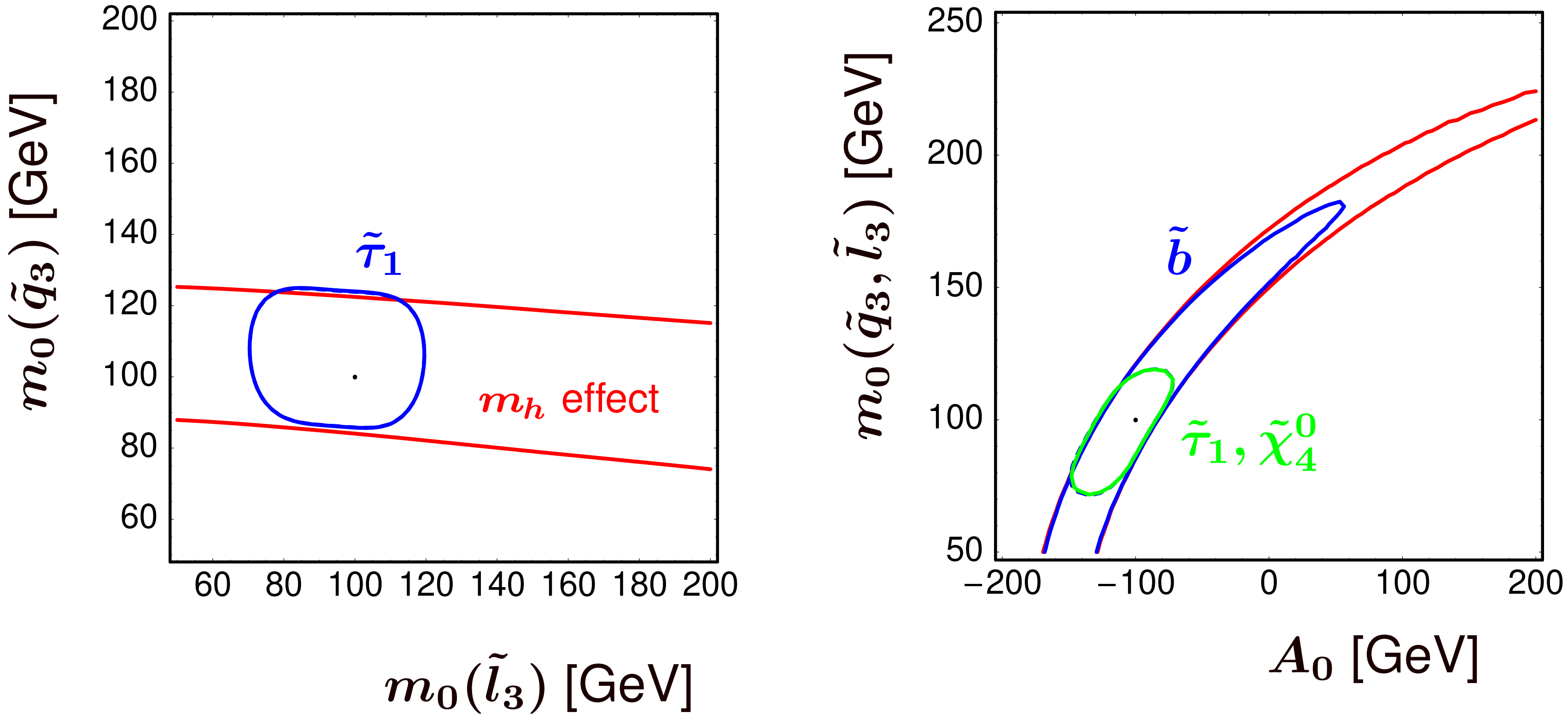
$$
\begin{aligned}
m_0(\tilde{l}) &= 100 \pm 4.6 \\
m_0(\tilde{q}) &= 100 \pm 50.2 \\
m_{1/2} &= 250 \pm 3.5 \\
A_0 &= -100 \pm 180 \\
\tan\beta &= 10 \pm 4.4
\end{aligned}
$$

The Higgs mass parameters stay undetermined.

[SFITTER: R. Lafaye, T. Plehn, D. Zerwas, hep-ph/0404282]

SK & SFITTER group, PRELIMINARY

Test of scalar mass universality: 3rd generation



Top-down summary

- Top-down fit of model parameters to data: useful if only limited experimental information (only part of the spectrum)

  case-by-case hypothesis test, (very) model dependent;
  care needed not to make too strong assumptions

- Typical LHC cascade decays:
  tightest constraints come from m_{ll} and m_h $\quad\longrightarrow \tilde{\chi}^0_{1,2},\ \tilde{l}_R,\ h^0$

  - need to separately test scalar masses

    ? squarks vs. sleptons, ? 3rd generation,
    ? non-universal Higgs mass parameters

  - study with SFITTER on the way for SPS1a test case

- Caution: can only favour or disfavour tested model(s) but not exclude other possibilities

Laundry List

- Assumed that masses of $\tilde{l}_L$, $\tilde{l}_R$ and $\tilde{q}_L$, $\tilde{q}_R$ can be determined. But we don't know which one is a L and which a R state....
- Take theoretical uncertainty on m_h into account!
  $\longrightarrow$ Errors in the fit increase a lot.
  $\longrightarrow$ Will additional measurement of $\tilde{t}_1$ help?
- Effect of $\tilde{b}$ and $\tilde{\tau}$ mass measurements on the parameter determination of the 3rd generation. What precision is needed?
- So far we are blind to $m^2_{H_1}$, $m^2_{H_2}$.
  $\longrightarrow$ need a handle on μ parameter and m_A
  $\longrightarrow$ measurement of heavy Higgses and heavy neutralinos
  (however, can't tell H from A or $\tilde{\chi}^0_3$ from $\tilde{\chi}^0_4$)
- Errors depend very much on the parameter point
  $\longrightarrow$ try move away from SPS1a