Constrainig SUSY models from LHC +LC data - a preliminary look

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Exercise: perform fit on mSUGRA parameters from experimentally measurable quantities using input both from LHC and LC

Get example models for which full analysis for LHC with error estimate has been performed

For this preliminary exercise use Points 1 and 5 of original LHC study

For each example model, given N measurements of quantities x_i involving sparticle masses with estimated uncertainties σ_i:

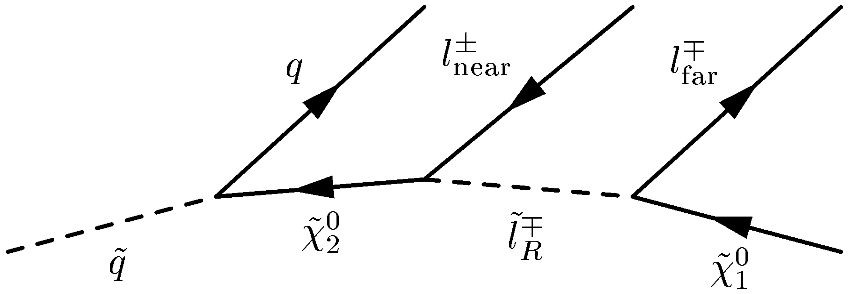
- Take the nominal value of variable at input point x_i^{input}
- Loop on a grid on m_0, $m_{1/2}$, $\tan\beta$ around input point, and calculate ifor each point in grid χ^2 as:

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i^{input} - x_i^{m_0,\ldots})^2}{\sigma_i^2}$$

- Draw contour in $(m_0 - m_{1/2})$ plane where $\chi^2/N < 1$
- For this exercise do not consider A

Main LHC measurements: decays of $\tilde{q}_L$:

(nice systematics in Allanach et al. hep-ph/0007009)



l^+l^- edge $\quad (m_{ll}^{\rm max})^2 = (\tilde{\xi}-\tilde{l})(\tilde{l}-\tilde{\chi})/\tilde{l}$

l^+l^-q edge $\quad (m_{llq}^{\rm max})^2 = (\tilde{q}-\tilde{\xi})(\tilde{\xi}-\tilde{\chi})/\tilde{\xi}$

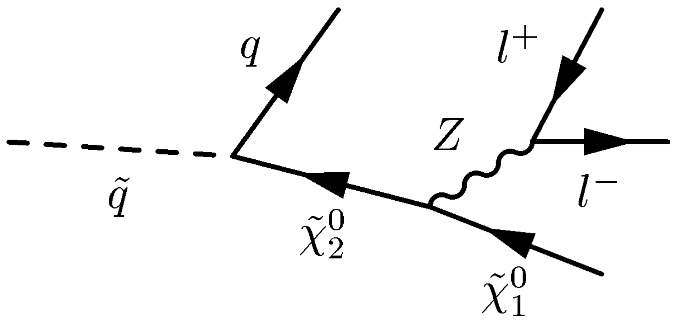
l^+l^-q thresh $\quad (m_{llq}^{\rm min})^2 = \begin{cases} [\ \ 2\tilde{l}(\tilde{q}-\tilde{\xi})(\tilde{\xi}-\tilde{\chi}) \\ +(\tilde{q}+\tilde{\xi})(\tilde{\xi}-\tilde{l})(\tilde{l}-\tilde{\chi}) \\ \quad -(\tilde{q}-\tilde{\xi})\sqrt{(\tilde{\xi}+\tilde{l})^2(\tilde{l}+\tilde{\chi})^2-16\tilde{\xi}\tilde{l}^2\tilde{\chi}} \ \ ] \\ /(4\tilde{l}\tilde{\xi}) \end{cases}$

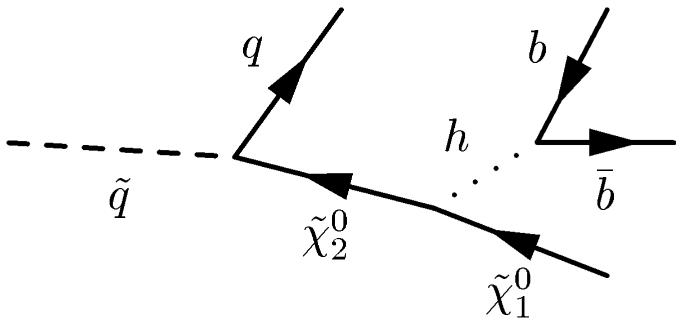
$l^{\pm}_{\rm near}q$ edge $\quad (m_{l_{\rm near}q}^{\rm max})^2 = (\tilde{q}-\tilde{\xi})(\tilde{\xi}-\tilde{l})/\tilde{\xi}$

$l^{\pm}_{\rm far}q$ edge $\quad (m_{l_{\rm far}q}^{\rm max})^2 = (\tilde{q}-\tilde{\xi})(\tilde{l}-\tilde{\chi})/\tilde{l}$

With $\quad \tilde{\chi} = m^2_{\tilde{\chi}^0_1}, \qquad \tilde{l} = m^2_{\tilde{l}_R}, \qquad \tilde{\xi} = m^2_{\tilde{\chi}^0_2}, \qquad \tilde{q} = m^2_{\tilde{q}}$

"Branched decays"





$$X q \text{ edge} \quad (m_{Xq}^{\text{max}})^2 = \begin{cases} X + (\tilde{q} - \tilde{\xi})[\, \tilde{\xi} + X - \tilde{\chi} \\ + \sqrt{(\tilde{\xi} - X - \tilde{\chi})^2 - 4X\tilde{\chi}}\,]/(2\tilde{\xi}) \end{cases}$$

$$X q \text{ thresh} \quad (m_{Xq}^{\text{min}})^2 = \begin{cases} (\tilde{q} - \tilde{\xi})[\, \tilde{\xi} + X - \tilde{\chi} \\ + \sqrt{(\tilde{\xi} - X - \tilde{\chi})^2 - 4X\tilde{\chi}}\,]/(2\tilde{\xi}) \end{cases}$$

With X is m_h^2 or m_Z^2 depending on which particle participates in the "branched" decay.

Besides $\tilde{\chi}_2^0$ decays, additional mass measurements possible at the LHC

Often model-dependent, and requiring knowledge of $m_{\tilde{\chi}_1^0}$

Fits performed using these signatures as straight measurements of concerned mass

Two examples, which will be used in the following

- $m_{\tilde{q}_R}$ from measurement of high pt jet spectrum from $\tilde{q}_R \longrightarrow \tilde{\chi}_0^1$ (high jet mass points)
- $m_{\tilde{g}}$ and $m_{\tilde{t}}$ from decay $\tilde{g} \longrightarrow \tilde{t}_1 t$

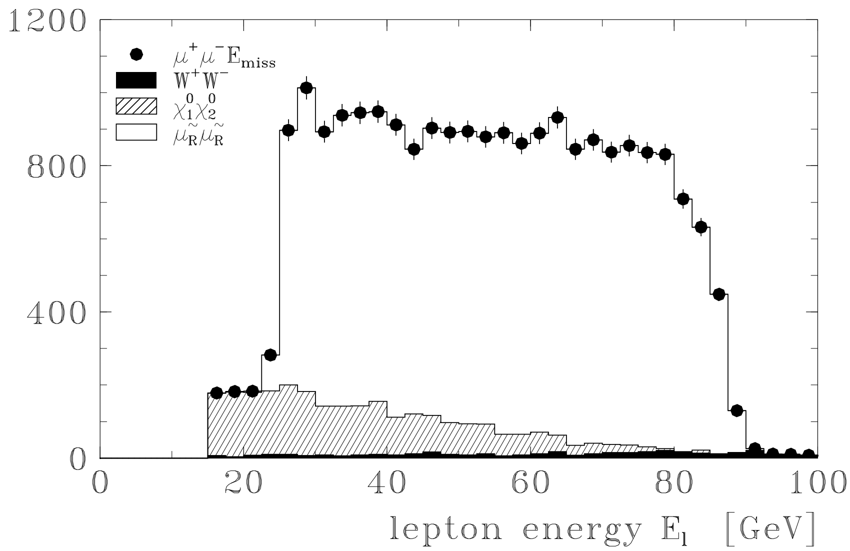
Take error on the mass of the h as 3 GeV from theoretical uncertainty

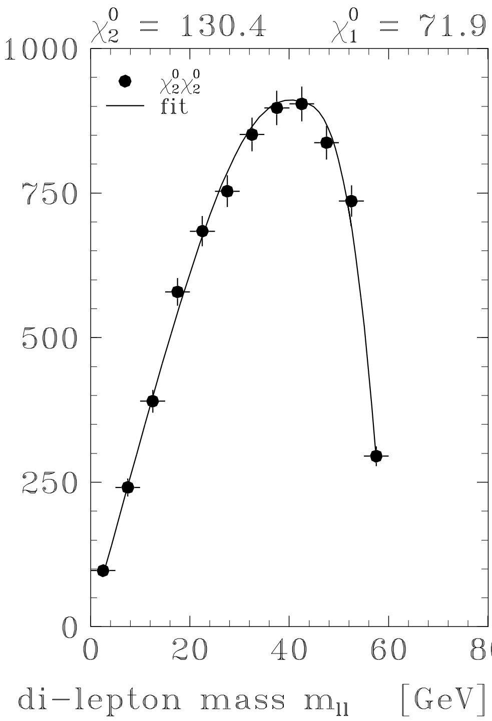
I neglect some recent promising work on stop mass measurement (Kawagoe Nojiri)

Precision on masses at LC from Blair-Martyn (hep-ph 9910416)

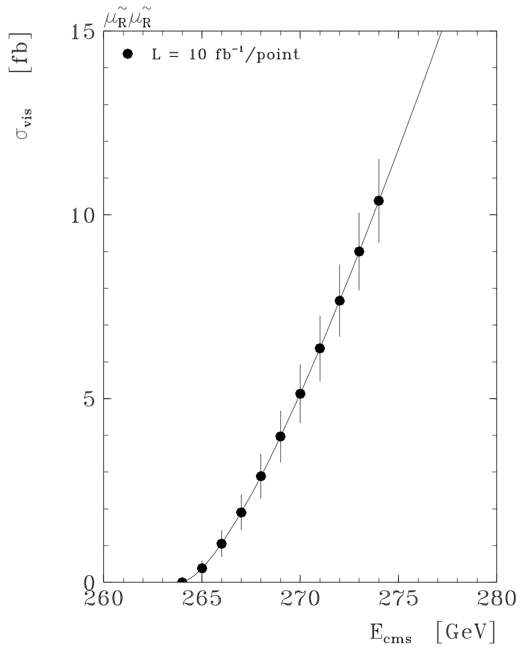
particle	mass [GeV]	δm_{cont} [GeV]	δm_{scan} [GeV]
$\tilde{\mu}_R$	132.0	0.3	0.09
$\tilde{\mu}_L$	176.0	0.3	0.4
$\tilde{\nu}_\mu$	160.6	0.2	0.8
$\tilde{e}_R$	132.0	0.2	0.05
$\tilde{e}_L$	176.0	0.2	0.18
$\tilde{\tau}_1$	131.0		0.6
$\tilde{\tau}_2$	177.0		0.6
$\tilde{\nu}_\tau$	160.6		0.6
$\chi_1^\pm$	127.7	0.2	0.04
$\chi_2^\pm$	345.8		0.25
χ_1^0	71.9	0.1	0.05
χ_2^0	130.3	0.3	0.07
χ_3^0	319.8		0.30
χ_4^0	348.2		0.52

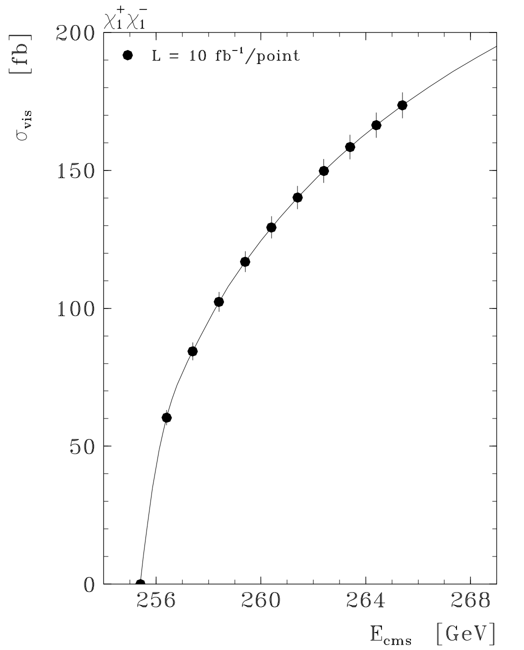
LC: direct reconstruction





LC: threshold scan





Adopt following prescription for LC:

For each model Point consider measured the following sparticles:

- Each sfermion $\tilde{f}$ such that $m_{\tilde{f}} < 250$ GeV,
- Each neutralino $\tilde{\chi}^0_j$ such that $m_{\tilde{\chi}^0_j} + m_{\tilde{\chi}^0_1} < 500$ GeV
- Each chargino with mass<250 GeV

Errors assigned to the measurement taking the best between direct reconstruction, and threshold scan

Typical assigned error between per mil and a few per mil

As for the LHC case, take error on the mass of the h as 3 GeV from theoretical uncertainty

Example 1: LHC Point 5

$$m_0 = 100 \text{ GeV}, m_{1/2} = 300 \text{ GeV}, \tan\beta = 2.1,$$

$$A = 300 \text{ GeV}, \mu > 0$$

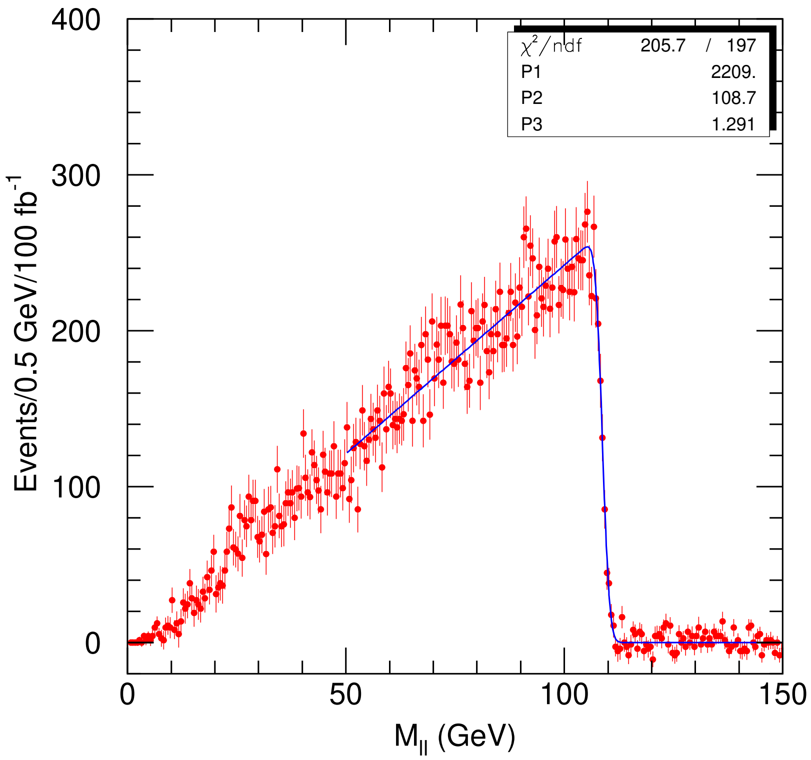
Mass spectrum

$m_{\tilde{q}} = 680$ GeV	$m_{\tilde{\chi}_1^0} = 121$ GeV
$m_{\tilde{g}} = 760$ GeV	$m_{\tilde{\chi}_2^0} = 232$ GeV
$m_{\tilde{t}_1} = 490$ GeV	$m_h = 93$ GeV
$m_{\tilde{\ell}_R} = 157$ GeV	$m_H = 640$ Gev
$m_{\tilde{\ell}_L} = 240$ GeV	

Point excluded by LEP mass searches, would be OK for $\tan\beta = 10$, use original point, as detailed error estimate depends on detail of model.

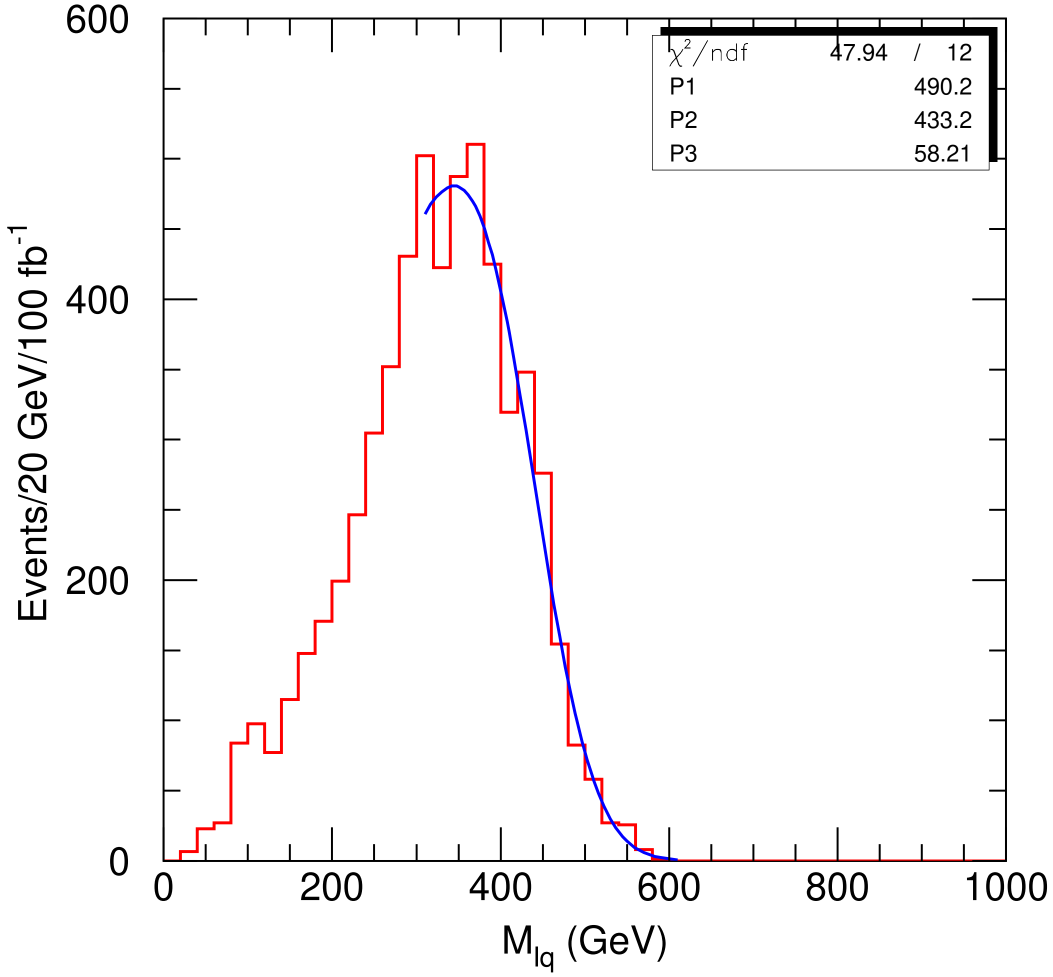
Both decays $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ and $\tilde{\chi}_2^0 \to \tilde{\ell}\ell$ are open and have a significant branching fraction

Different variables have different measurement errors, depending on the type of structure, and on involved particles:



Lepton-lepton edge very sharp due to well-measured lepton energy

Error dominated by energy scale uncertainty on sleptons, permille level



Lepton-quark invariant mass end point estimate affected by smearing in jet energy measurement and uncertainity in converting jet momentum to parton momentum.

Conservative uncertainties at 5-10% level.

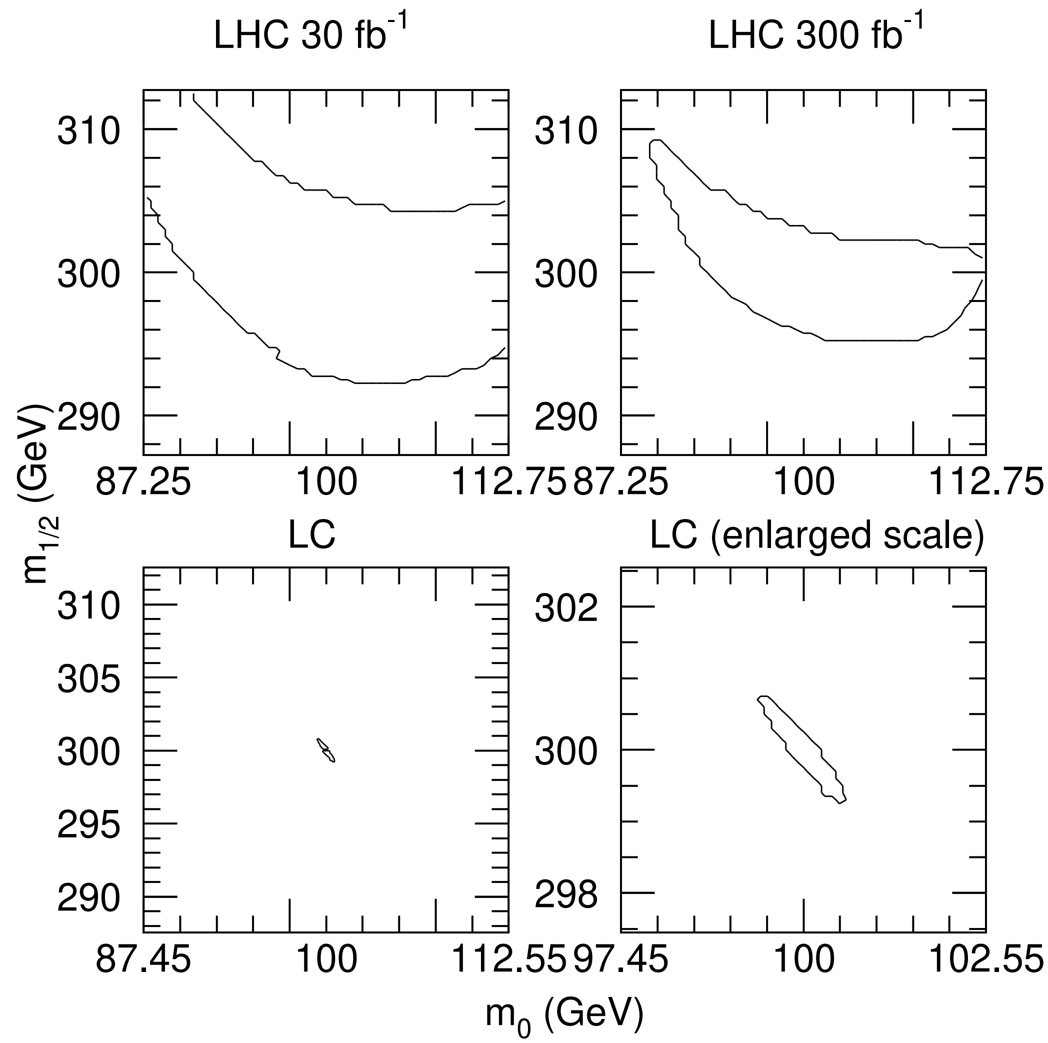
Point studied in ATLAS TDR, Allanach et al., Hinchliffe Paige.

The following values and estimated errors are used for the fit in Phys. Rev. D62 (2000) 015009 :

$$
\begin{aligned}
(M_{hq}^{\text{max}})^2 &= (552.6 \pm 40\,\text{GeV})^2\,; \\
M_{\ell\ell}^{\text{max}} &= 108.9 \pm 0.1\,\text{GeV}\,; \\
R = \frac{M_{\ell q}^{\text{max}}}{M_{\ell\ell q}^{\text{max}}} &= 0.865 \pm 0.02\,; \\
M_{\ell q}^{\text{max}} &= 478.1 \pm 40\,\text{GeV}\,; \\
(M_{\ell\ell q}^{\text{min}})^2 &= (271.8 \pm 5.4\,\text{GeV})^2\,; \\
(M_{hq}^{\text{min}})^2 &= (346.5 \pm 17\,\text{GeV})^2\,.
\end{aligned}
$$

Most pessimistic estimates, use these one for High Luminosity

Lots of information from LC, as both leptons and charginos/neutralinos measured



Constraints on both m_0 and $m_{1/2}$ from the LHC, much higher precision from LC

Error on $\tan\beta$ at the LHC determined by large error assigned to m_h

$\tan\beta$ fixed to ± 0.1 at the LC

Example 2: LHC Point 2

$$m_0 = 400 \text{ GeV}, \; m_{1/2} = 400 \text{ GeV}, \; \tan\beta = 10,$$

$$A = 0 \text{ GeV}, \; \mu > 0$$

Mass spectrum

$m_{\tilde{q}} = 940$ GeV $\quad m_{\tilde{\chi}_1^0} = 168$ GeV

$m_{\tilde{g}} = 1000$ GeV $\quad m_{\tilde{\chi}_2^0} = 325$ GeV

$m_{\tilde{\ell}} = 490$ GeV $\quad m_{\tilde{t}_1} = 710$ GeV

$m_h = 115$ GeV

$m_H = 740$ GeV

Only decay $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 h$ available

Take measurements from ATLAS TDR,

respectively for 30 (300) fb^{-1}

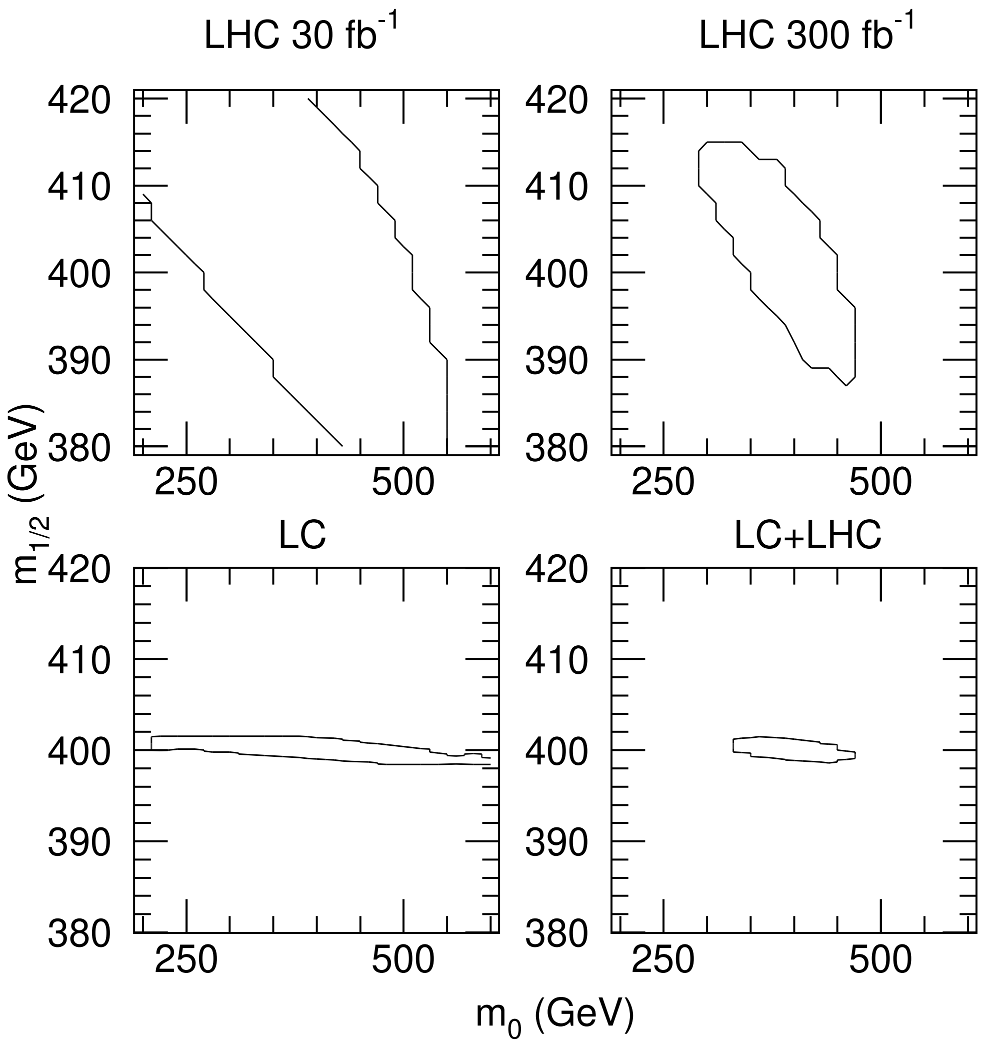
$$(M_{hq}^{\text{max}})^2 = (758.3 \pm 25(13)\ \text{GeV})^2\,;$$

$$M_{\tilde{q}_R} = 959 \pm 40(15)\text{GeV}$$

$$M_{\tilde{g}} = 1004 \pm 25(12)\text{GeV}$$

The theory error on the h mass is taken 3 GeV

LC in this case only contributes measurement of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$



LC alone $\sim$insensitive to m_0

$\tan\beta$ contrained to be $>$5

Combining LC and LHC, some gain also on m_0, as $m_{1/2}$ and m_0 correlated through squark mass measurement

Critical appraisal

Top-down approach, based on assuming mSUGRA roughly dominated by being able to measure precisely:

- gauginos ($m_{1/2}$)
- sleptons (m_0)
- higgs (stau) ($\tan\beta$)

Very useful approach in exploratory LHC studies to demonstrate we are able to measure variables which can close in on a model

Once fixed parameters of the model, use additional sparticle measurements (squarks, gluinos) to see if their values fit inside the proposed model

In this framework as soon one of above particles kinematically accessible at LC, LC takes over measurement $\Rightarrow$ model parameters constrained in a tight way $\Rightarrow$ precise predictions on additional particles

Compare with bottom-up approach: (talk by W. Porod)

Instead of throwing a set of disparate measurements into the fit, exploit wealth of measurements for less model-dependent approach:

- Try to reconstruct from physical masses MSSM parameters (see work on neutralino system)
- Compare result with pattern of masses parameters resulting from a given boundary condition on RGE equations

For both steps necessary combination of precise LC measurements and heavy /coloured particles from the LHC