SUSY parameter determination

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Introduction

- SUSY parameter determination
  - Fittino program
  - SUSY parameter determination with existing measurements
    - Low energy observables, Ω_{CDM}, $(g-2)_\mu$

- Impact of LHC observables
  - Expected observables and mSUGRA fit
  - Ambiguities with the particle assignment in the cascade decay

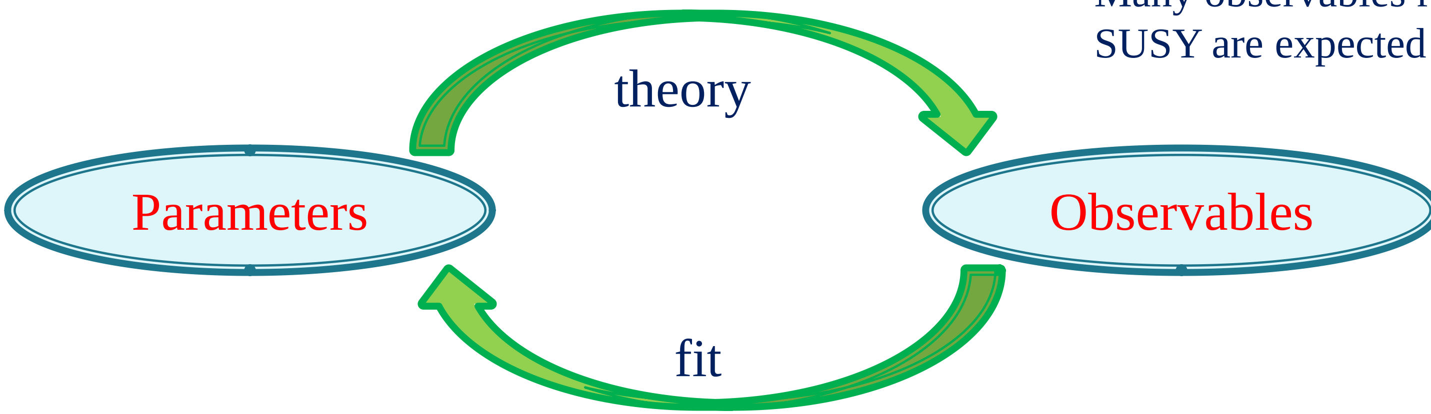
- Conclusion

SUSY parameter fit

<u>SUSY models</u>

• Determine the Lagrangian parameters for SUSY models

Many observables related to SUSY are expected at the LHC



<u>Mapping: observables → parameters</u>

• No direct calculation
• Perform a fit
• Prediction of observable values from external theory codes

$$\chi^2 = \sum_{i,j} \left(m_i^{\text{obs}} - m_i^{\text{pred}}\right)^T C_{ij} \left(m_j^{\text{obs}} - m_j^{\text{pred}}\right)$$

• MINUIT
• Simulated annealing
• Markov chain (parameter scan)

Fittino

- A C++ program to fit SUSY parameters to experimental measurements
- Models
  - Interface to any theory code via SUSY Les Houches interface
  - SPheno : SUSY mass spectrum and observables
  - MasterCode : Low energy observables
  - MicroMegas : Cosmological constraints
  - Available SUSY models:
    - mSUGRA, GMSB, AMSB, MSSM24, NMSSM etc.
- Fit methods
  - MINUIT
  - Simulated annealing
  - Toy fit for uncertainty estimation
  - Markov chain for parameter scan

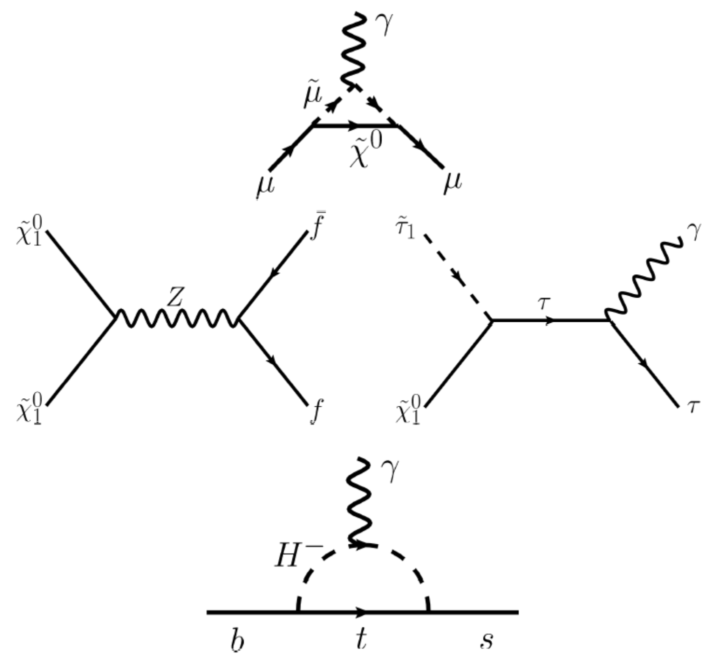
mSUGRA fit to available measurements

- Use existing data from
  - LEP, SLD
  - Tevatron
  - B/K physics
  - Astrophysics

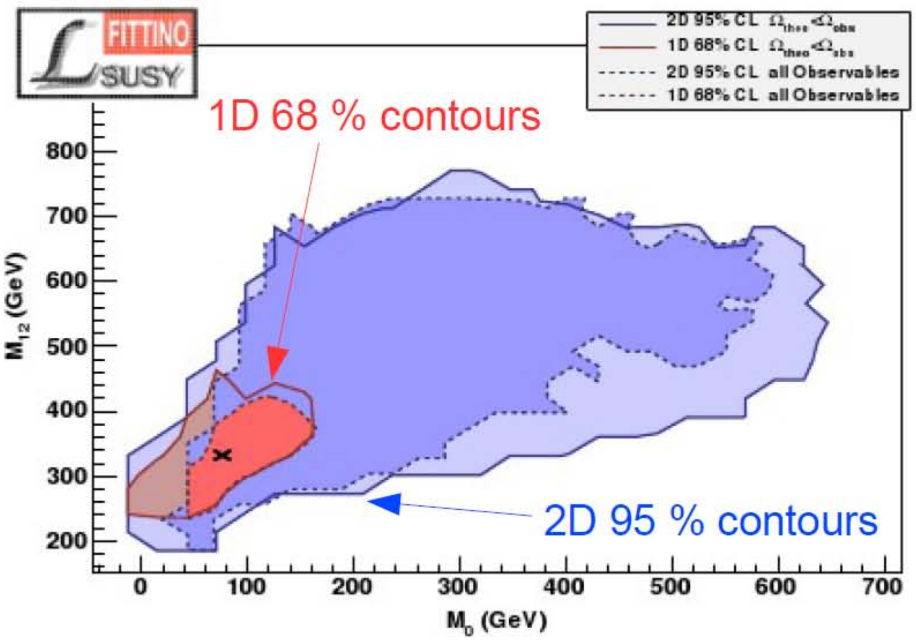
<u>Observables sensitive to SUSY</u>

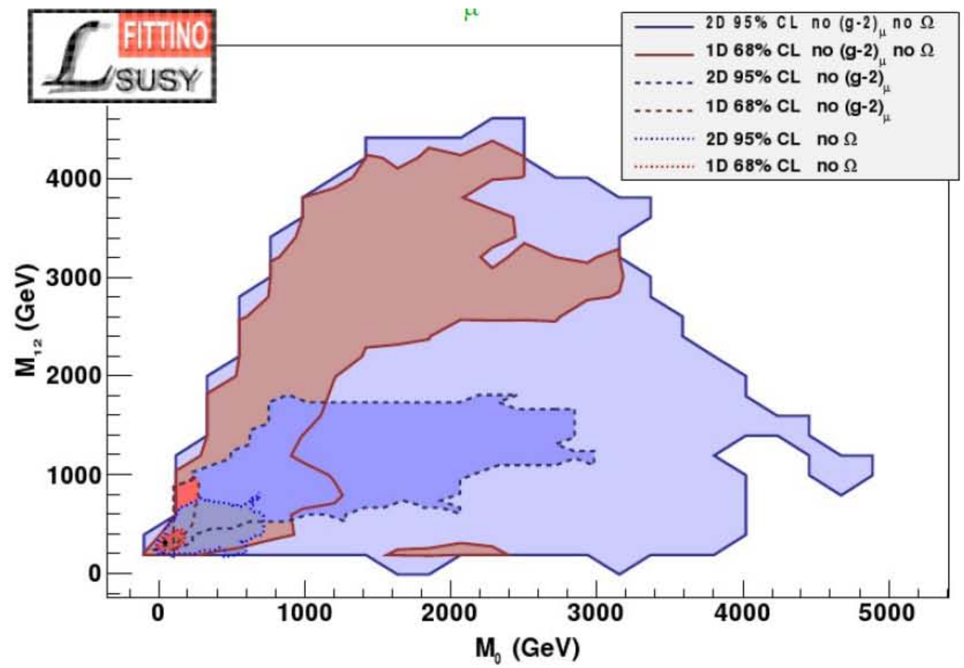
Diagram examples:

- $(g-2)_\mu$
- $\Omega_{CDM}\ h^2$
- $BR(b \to s\ \gamma)$



mSUGRA fit results





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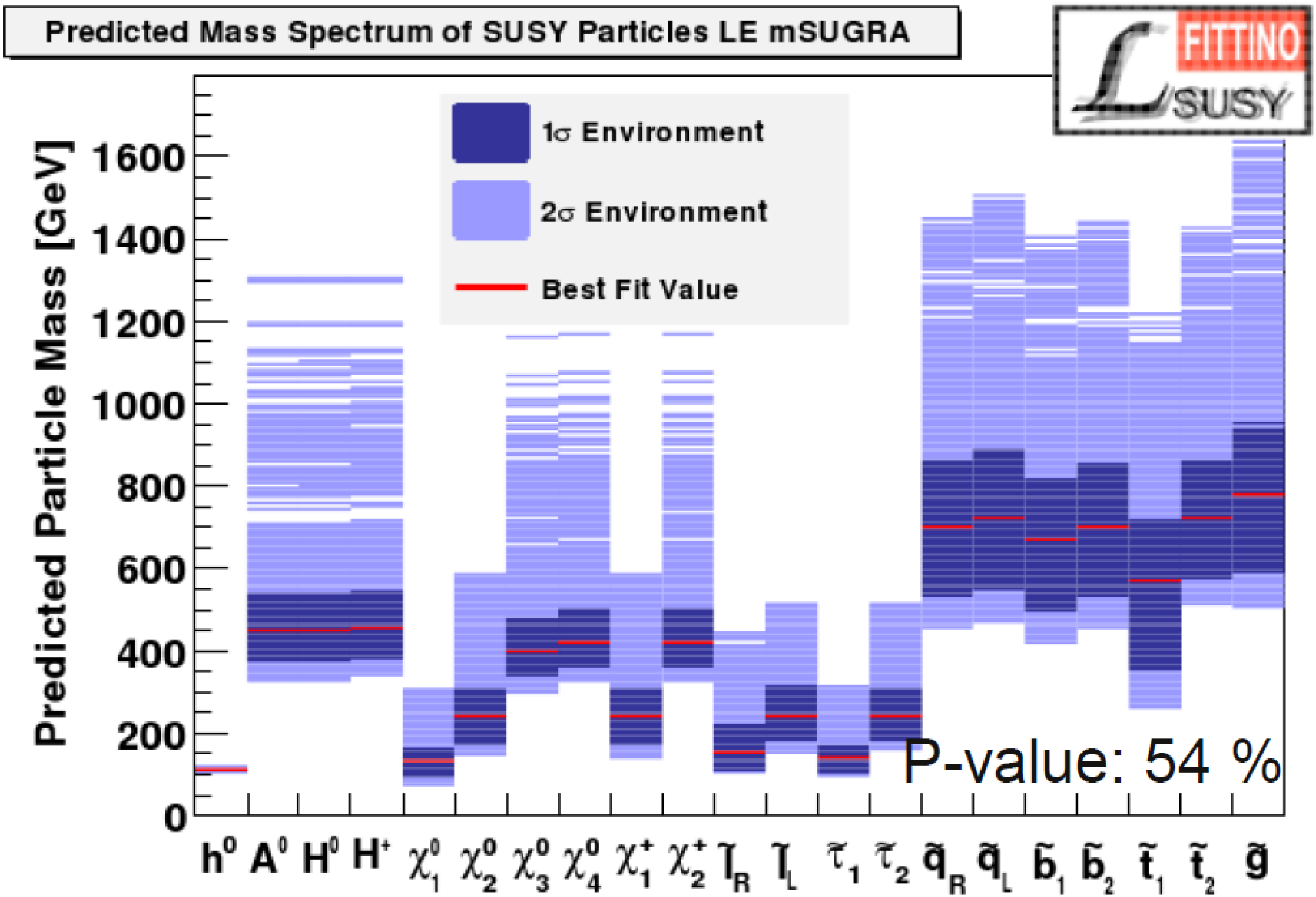
- Most constraining observables are $(g-2)_\mu$ and Ω_{CDM}
- Best fit point of mSUGRA fit to available observables is accidentally close to the well-studied SUSY benchmark point

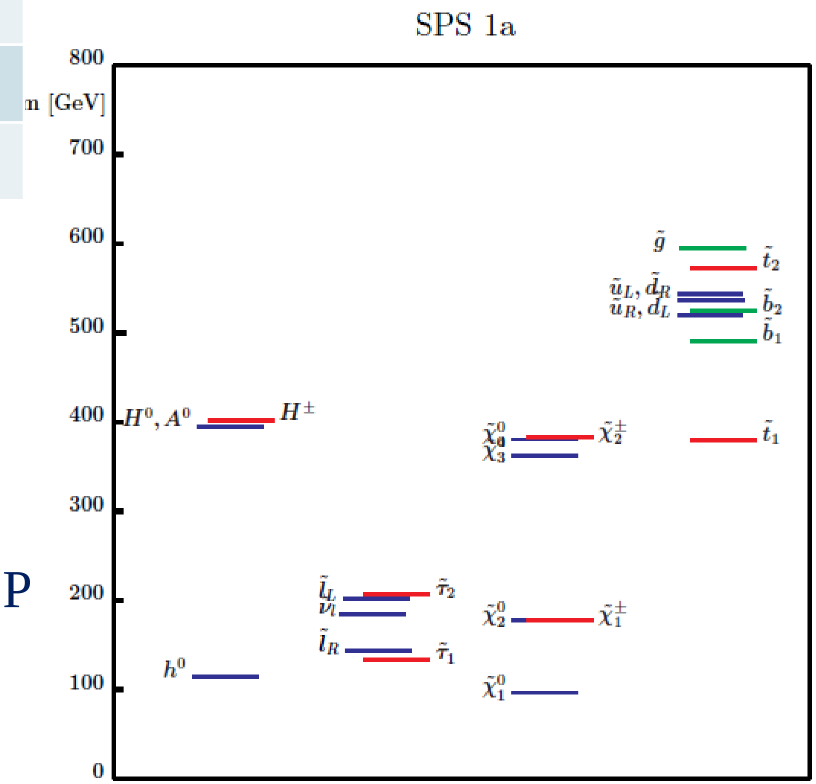
→ Use the SPS1a point to study the impact of LHC

Particle mass spectra



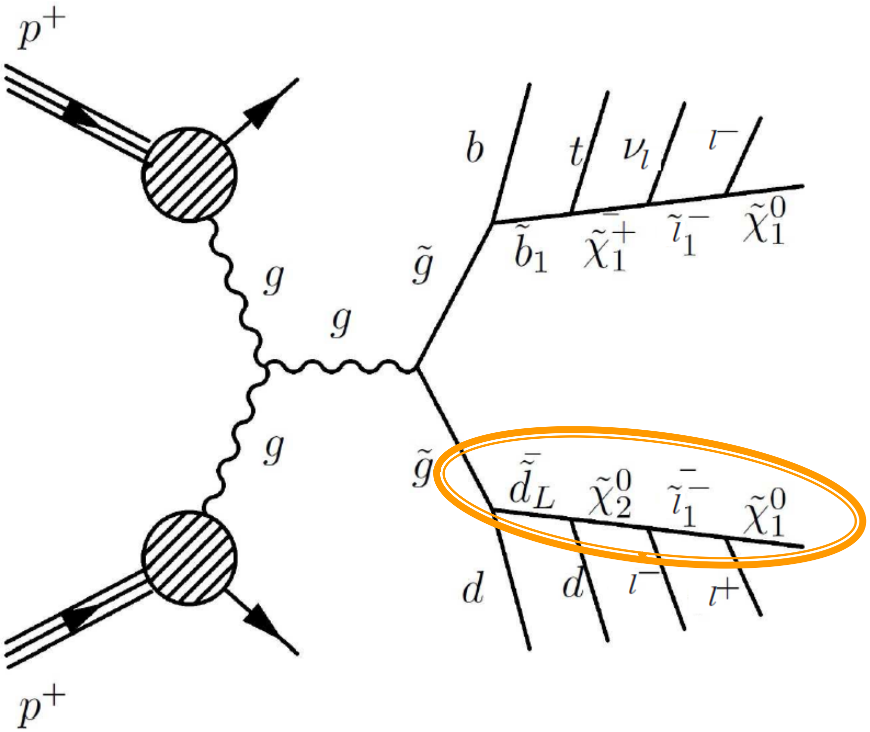
SPS1a benchmark point

Parameter	best fit value	SPS1a value
M_0 (GeV)	$76.2^{+79.2}_{-29.1}$	100
$M_{1/2}$ (GeV)	331.5 ± 86.6	250
A_0 (GeV)	383.8 ± 647	-100
$\tan\beta$	13.2 ± 7.2	10



Neutralino is the LSP and stau becomes the NLSP

LHC observables for SUSY fit



- SUSY particles are not directly measured
- Kinematic edges of various combinations of invariant mass distributions are related to SUSY particle masses
- Ambiguities in the particle assignment in the cascade decay

$$m^2_{l^+l^-}\left(m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}, m^2_{\tilde{\chi}_1^0}\right)$$
$$m^2_{ql^+l^-}\left(m^2_{\tilde{q}}, m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}, m^2_{\tilde{\chi}_1^0}\right)$$
$$m^2_{ql_{\text{near}}}\left(m^2_{\tilde{q}}, m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}\right)$$
$$m^2_{ql_{\text{far}}}\left(m^2_{\tilde{q}}, m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}, m^2_{\tilde{\chi}_1^0}\right)$$
$$m^2_{ql_{\text{low}}} = \min\{(m^2_{ql_{\text{near}}}),(m^2_{ql_{\text{far}}})\}$$
$$m^2_{ql_{\text{high}}} = \max\{(m^2_{ql_{\text{near}}}),(m^2_{ql_{\text{far}}})\}$$

- Also include some measurements on branching ratios

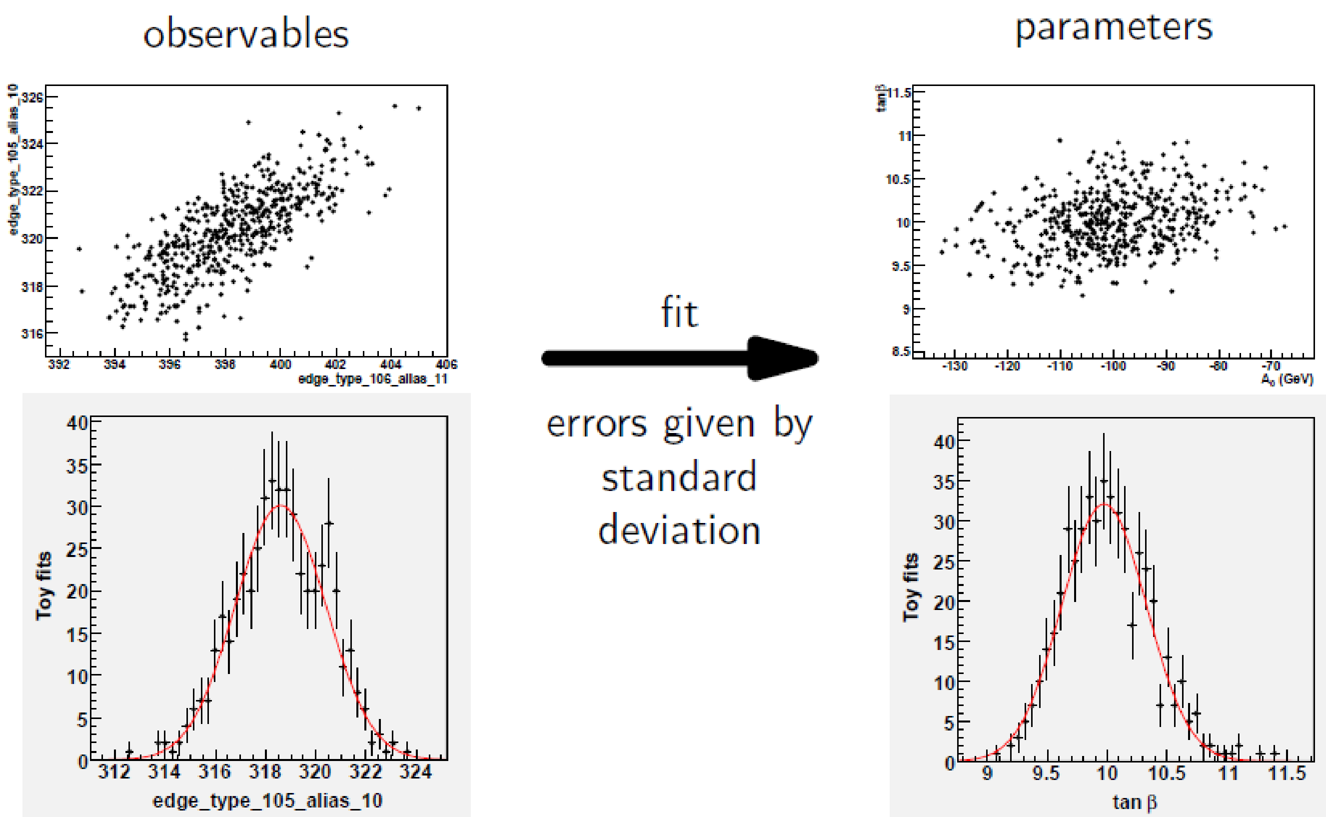
$$\frac{Br\left(\tilde{\chi}_2^0 \to \tilde{l}_R l\right)\cdot Br\left(\tilde{l}_R \to \tilde{\chi}_1^0 l\right)}{Br\left(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau\right)\cdot Br\left(\tilde{\tau}_1 \to \tilde{\chi}_1^0 \tau\right)}$$

- A list of possible measurements and uncertainties are taken from hep-ph/0410364

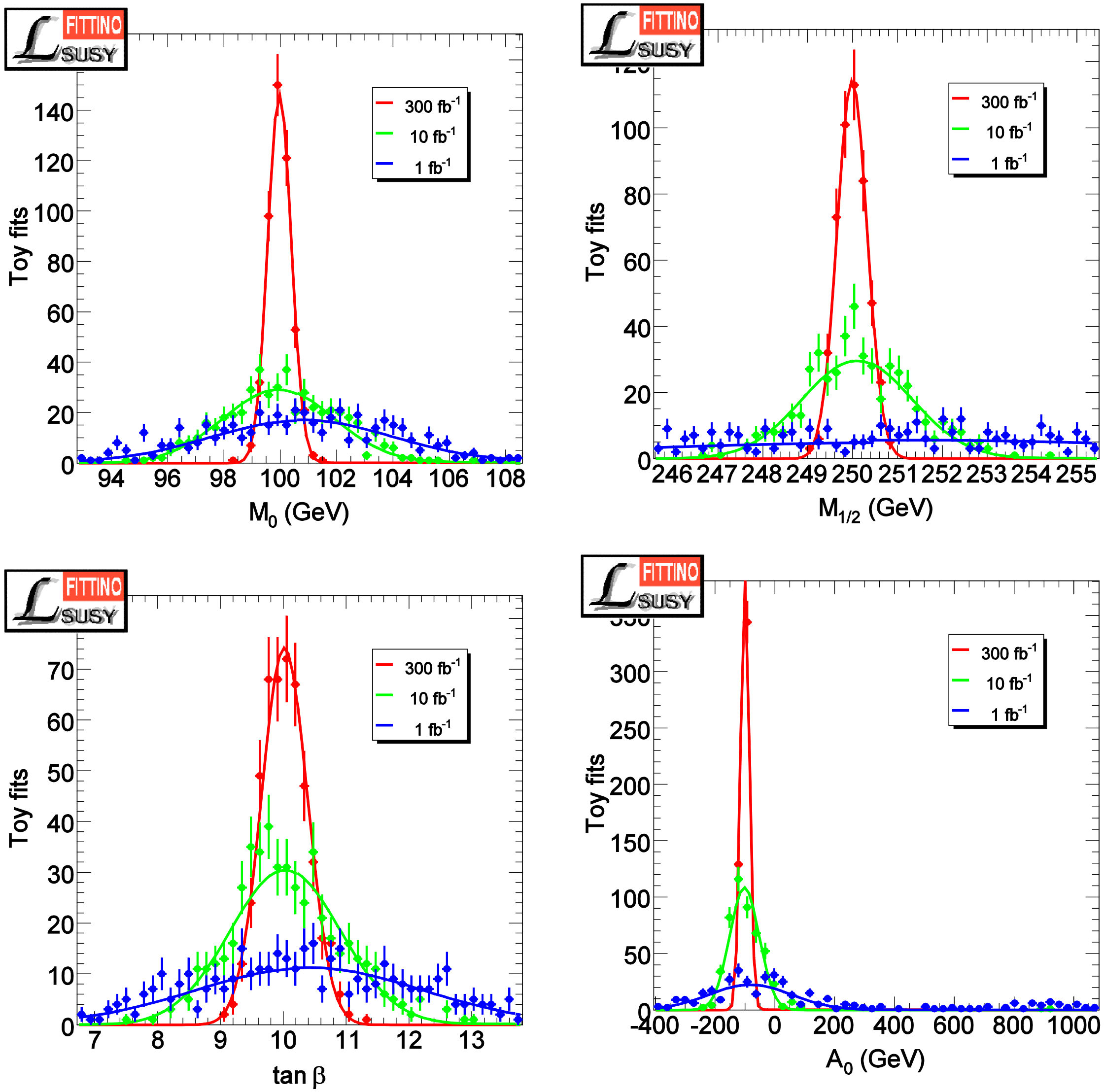
Toy fit

• Smear observables around the central value according the uncertainties and correlation

• Perform a fit for each smeared point. Resulting distribution on fit parameters gives the uncertainty and correlation on the parameters



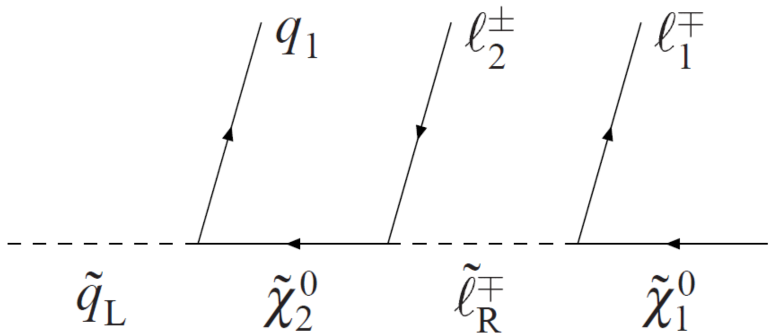
Fit to Low energy + LHC observables



- mSUGRA parameters from a fit to low energy and LHC observables with L=1, 10 and 300 fb^{-1}
- Typical uncertainties on LHC observables are assumed to be 5-10 % at L=10 fb^{-1} and statistical uncertainties are scaled by the luminosity

Ambiguities in particle assignment

- We consider measurements from the standard cascade decay
  - Separate observables for l=e,μ and l=τ
- Ambiguities in the SUSY particles in the decay chain
  - Neutralinos involved in the decay chain
  - Slepton (right- or left-handed)
- These ambiguities may lead to wrong interpretations of data
  - Can we distinguish them by the fit and select the correct interpretation?



$$\tilde{\chi}_2^0 \leftrightarrow \tilde{\chi}_i^0, i = 1,2,3,4$$

$$\tilde{\chi}_1^0 \leftrightarrow \tilde{\chi}_j^0, j = 1,2,3\left(\mathrm{i} > \mathrm{j}\right)$$

$$\tilde{l}_R^{\pm} \leftrightarrow \tilde{l}_L^{\pm}$$

$$\tilde{\tau}_R^{\pm} \leftrightarrow \tilde{\tau}_L^{\pm}$$

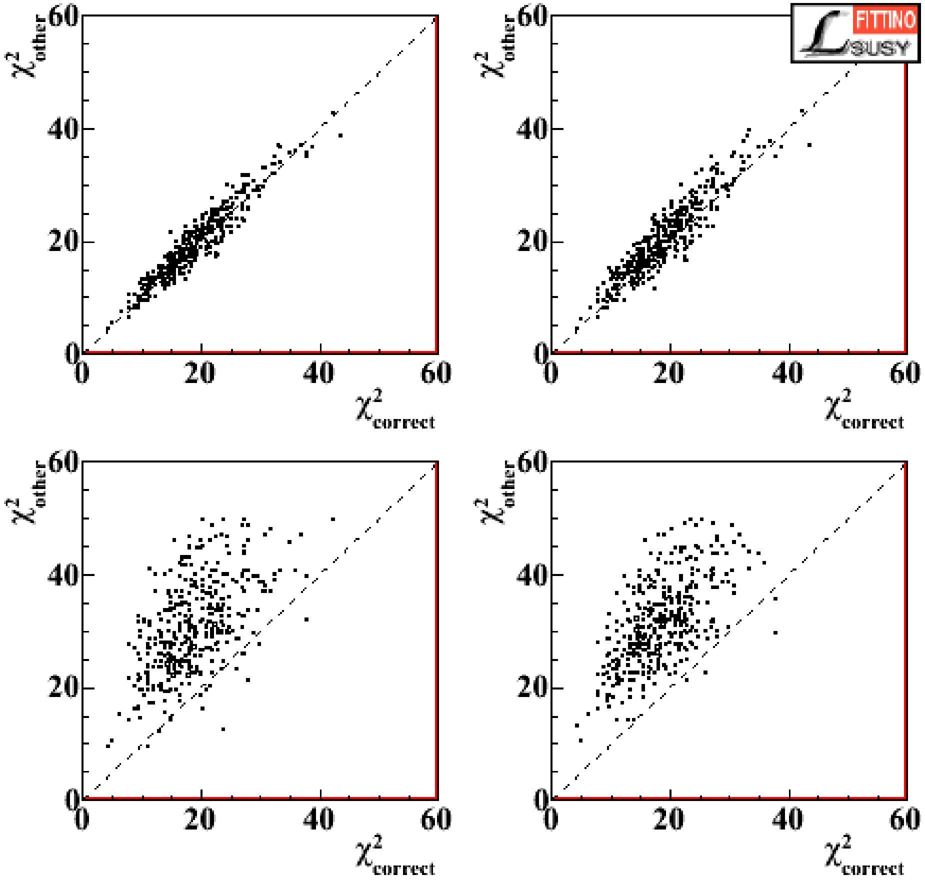
Particle assignment ambiguities (2)

- A way to incorporate the decay chain ambiguities in the fit
  - Modify the interpretation of the observables
  - Consider different interpretations as a ‘discrete parameter’
  - Perform a toy fit taking into account the discrete parameter
  - Scan parameter space for each model first in order to check the validity of the interpretation since the toy fit is computationally expensive

- Is there a possibility of interpreting the observed edges with wrong SUSY particle assignment?
  - Can the fit eliminate all wrong interpretations?
  - How often can it happen that a wrong interpretation has smaller χ^2?
  - How does it affect the uncertainties of model parameters

LHC with L=10 fb^{-1} @14 TeV

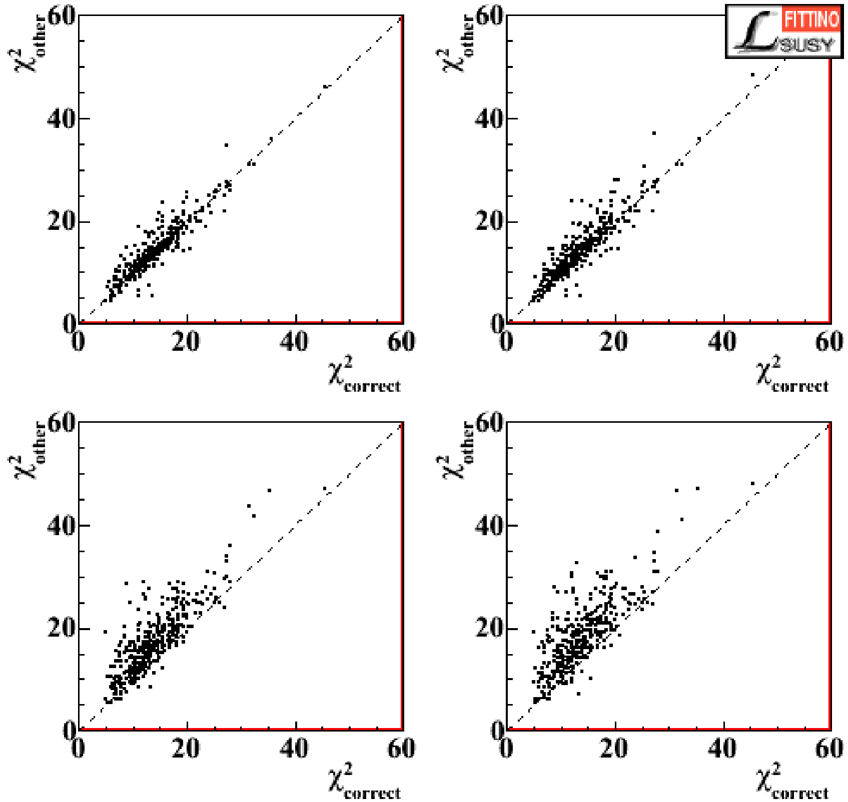
Particle assignment	Fraction (%)
Correct interpretation	69
$\chi^1_0 \leftrightarrow \chi^2_0$ (e,μ-channel)	16
$l_R \leftrightarrow l_L$ (e,μ-channel)	12
$\chi^1_0 \leftrightarrow \chi^3_0$, $l_R \leftrightarrow l_L$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^4_0$, $l_R \leftrightarrow l_L$ (τ-channel)	3
$\chi^1_0 \leftrightarrow \chi^2_0$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^2_0$ (τ-channel)	<0.1



- Wrong interpretation is chosen when the calculated mass edges are accidentally close to the observed value
- Including the cross section for a particular final state would be useful
- Little effect on parameter uncertainties

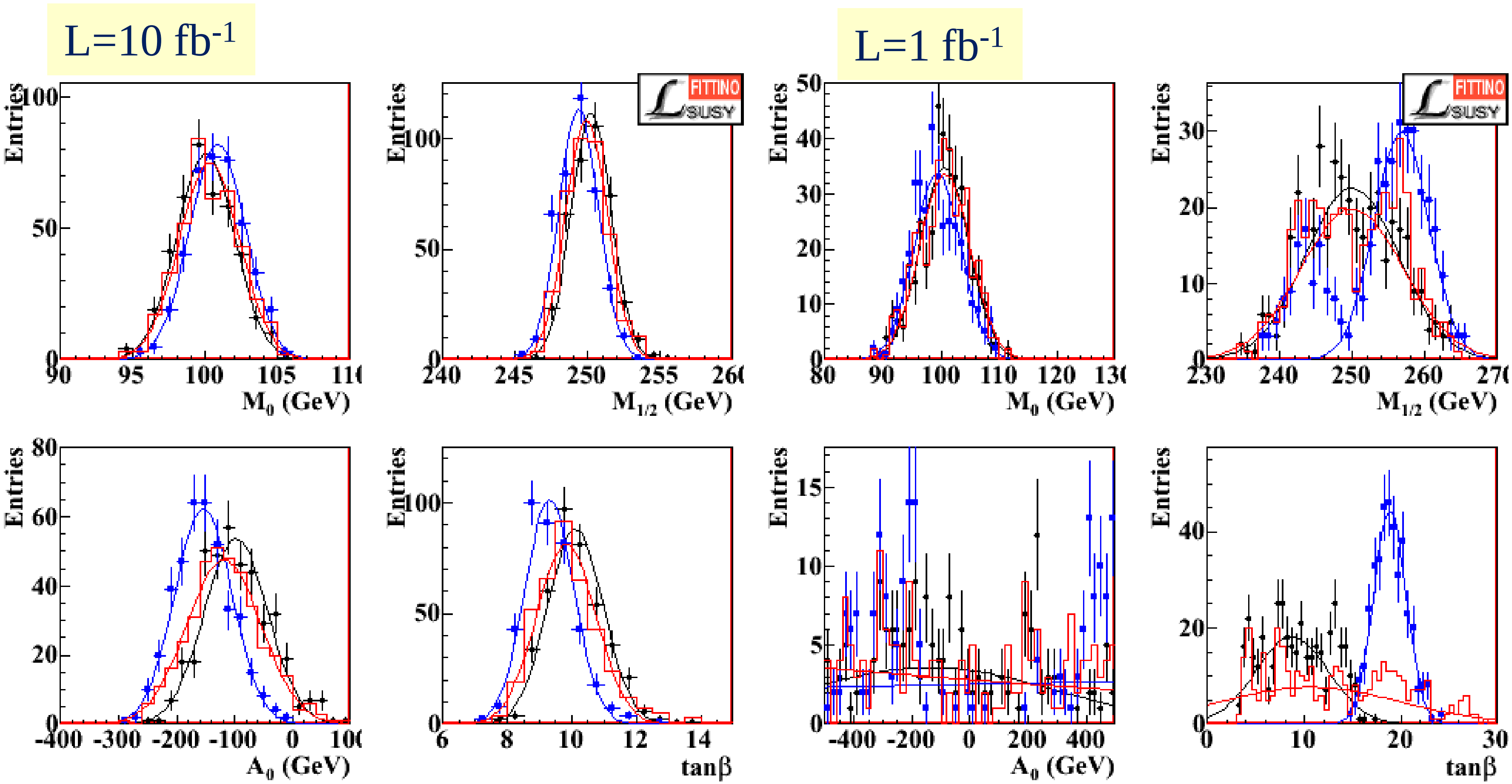
LHC with $L=1\ fb^{-1}$ @14 TeV

Particle assignment	Fraction (%)
Correct interpretation	48
$\chi^1_0 \leftrightarrow \chi^2_0$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^2_0$ (τ-channel)	21
$\chi^1_0 \leftrightarrow \chi^2_0$, $l_R \leftrightarrow l_L$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^3_0$ (τ-channel)	19
$\chi^1_0 \leftrightarrow \chi^2_0$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^3_0$ (τ-channel)	3.6
$\chi^1_0 \leftrightarrow \chi^3_0$, $l_R \leftrightarrow l_L$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^2_0$, $\chi^2_0 \leftrightarrow \chi^3_0$, $l_R \leftrightarrow l_L$ (τ-channel)	2.5
$\chi^1_0 \leftrightarrow \chi^2_0$ (e,μ-channel) $\chi^1_0 \leftrightarrow \chi^2_0$, $l_R \leftrightarrow l_L$ (τ-channel)	1.8



- Experimental uncertainties are increased for estimating the fit performance with $L=1\ fb^{-1}$
- The probability of selecting a wrong interpretation increases as expected

Parameter uncertainties



- Particle assignment ambiguity has little effect on parameter uncertainties
- $L=1fb^{-1}$ case: Problem with fitting $\tan\beta$ and A_0. Also different features of parameter distributions

Correct interpretation
Wrong interpretation
Combination (best χ^2)

Parameter determination

$L=10\ fb^{-1}$

Parameter	Nominal fit	with particle assignment ambiguities
M_0 (GeV)	100.0±2.0	100.2±2.1
$M_{1/2}$ (GeV)	250.2±1.4	249.9±1.4
A_0 (GeV)	-98±54	-118±264
tanβ	10.1±0.85	9.8±0.92

The effect on the parameter uncertainty is small when we have precise measurements

$L=1\ fb^{-1}$

Parameter	Nominal fit	with particle assignment ambiguities
M_0 (GeV)	100.6±4.1	100.7±4.3
$M_{1/2}$ (GeV)	249.9±6.4	249.9±7.1
A_0 (GeV)	-138±430	-118±3060
tanβ	8.7±3.7	9.8±9.2

- Difficult to fit tanβ and A_0 in this case
- Effect on M_0 and $M_{1/2}$ are small

Conclusion

- mSUGRA fit to available data
  - Low energy observables and measurements of (g-2) and Ω constrain the mSUGRA model to relatively low-mass SUSY

- mSUGRA fit with LHC observables
  - Many new observables related to SUSY particles are expected such as kinematic edges and branching ratios
    - Several observables with good precision (5-10 %) are needed to constrain even the mSUGRA model
  - Ambiguities of the particle assignment in the decay chain can be treated in the fit to discriminate those interpretations
    - The effect in the mSUGRA model seems to be small when the fit works
    - Moderate increase of uncertainties and the shift is within the uncertainty

- Outlook
  - Extend the study to a more general SUSY models, e.g. MSSM18, taking into account the particle assignment ambiguity
  - Different SUSY models can be compared in the same as we compared possible interpretations of observables using the toy fit

Backup slides

Low energy observables

Observable	Experimental value	Uncertainty stat	syst	Exp. reference
$\mathcal{B}(B \to s\gamma)/\mathcal{B}(B \to s\gamma)_{SM}$	1.117	0.076	0.096	[48]
$\mathcal{B}(B_s \to \mu\mu)$	$<4.7 \times 10^{-8}$		0.02×10^{-8}	[48]
$\mathcal{B}(B_d \to \ell\ell)$	$<2.3 \times 10^{-8}$		0.001×10^{-8}	[48]
$\mathcal{B}(B \to \tau\nu)/\mathcal{B}(B \to \tau\nu)_{SM}$	1.15	0.40		[49–52]
$\mathcal{B}(B_s \to X_s\ell\ell)/\mathcal{B}(B_s \to X_s\ell\ell)_{SM}$	0.99	0.32		[48]
$\Delta m_{B_s}/\Delta m_{B_s}^{SM}$	1.11	0.01	0.32	[53]
$\frac{\Delta m_{B_s}/\Delta m_{B_s}^{SM}}{\Delta m_{B_d}/\Delta m_{B_d}^{SM}}$	1.09	0.01	0.16	[48, 53]
$\Delta\epsilon_K/\Delta\epsilon_K^{SM}$	0.92	0.14		[53]
$\mathcal{B}(K \to \mu\nu)/\mathcal{B}(K \to \mu\nu)_{SM}$	1.008	0.014		[54]
$\mathcal{B}(K \to \pi\nu\bar{\nu})/\mathcal{B}(K \to \pi\nu\bar{\nu})_{SM}$	<4.5			[55]
$a_\mu^{exp} - a_\mu^{SM}$	30.2×10^{-10}	8.8×10^{-10}	2.0×10^{-10}	[56–60]
$\sin^2\theta_{eff}$	0.2324	0.0012		[47]
Γ_Z	2.4952 GeV	0.0023 GeV	0.001 GeV	[47]
R_l	20.767	0.025		[47]
R_b	0.21629	0.00066		[47]
R_c	0.1721	0.003		[47]
$A_{fb}(b)$	0.0992	0.0016		[47]
$A_{fb}(c)$	0.0707	0.0035		[47]
A_b	0.923	0.020		[47]
A_c	0.670	0.027		[47]
A_l	0.1513	0.0021		[47]
A_τ	0.1465	0.0032		[47]
$A_{fb}(l)$	0.01714	0.00095		[47]
σ_{had}	41.540 nb	0.037 nb		[47]
m_h	>114.4 GeV		3.0 GeV	[61–63]
$\Omega_{CDM}h^2$	0.1099	0.0062	0.012	[64]
$1/\alpha_{em}$	127.925	0.016		[65]
G_F	1.16637×10^{-5} GeV^{-2}	0.00001×10^{-5} GeV^{-2}		[65]
α_s	0.1176	0.0020		[65]
m_Z	91.1875 GeV	0.0021 GeV		[47]
m_W	80.399 GeV	0.025 GeV	0.010 GeV	[65]
m_b	4.20 GeV	0.17 GeV		[65]
m_t	172.4 GeV	1.2 GeV		[66]
m_τ	1.77684 GeV	0.00017 GeV		[65]
m_c	1.27 GeV	0.11 GeV		[47]

LHC observables

Pair production of slepton and squarks

$$\tilde{g} \to b b_1 \to b b \tilde{\chi}_2^0$$
$$\to b b l^\pm \tilde{l}_R^\mp \to b b l^\pm l^\mp \tilde{\chi}_2^0$$
$$\tilde{q}_L \to q \tilde{\chi}_2^0 \to q l^\pm \tilde{l}_1^\mp \to q l^\pm l^\mp \tilde{\chi}_1^0$$
$$\tilde{q}_L \to q \tilde{\chi}_2^0 \to q \tau^\pm \tilde{\tau}_1^\mp \to q \tau^\pm \tau^\mp \tilde{\chi}_1^0$$

$$b_1 \to b \tilde{\chi}_2^0 \to b l^\pm \tilde{l}_1^\mp \to b l^\pm l^\mp \tilde{\chi}_1^0$$

$$\tilde{g} \to t \tilde{t}_1 \to t b \tilde{\chi}_1^\pm$$
$$\tilde{g} \to b \tilde{b}_1 \to b W \tilde{t}_1 \to b b W \tilde{\chi}_1^\pm$$
$$\tilde{g} \to b \tilde{b}_1 \to t b \tilde{\chi}_1^\pm$$

Observable	Nominal Value	1 fb^{-1}	10 fb^{-1}	300 fb^{-1}
m_h	109.6		1.4	0.1
m_t	172.4	1.1	0.05	0.01
$m_{\tilde{\chi}_1^\pm}$	180.2			11.4
$\sqrt{m_{\tilde{\ell}_L}^2 - 2m_{\tilde{\chi}_1^0}^2}$	148.8			1.7
$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$	507.7		13.7	2.5
$\sqrt{m_{\tilde{q}_R}^2 - 2m_{\tilde{\chi}_1^0}^2}$	531.0	19.6	6.2	1.1
$m_{\tilde{g}} - m_{\tilde{b}_1}$	88.7			1.5
$m_{\tilde{g}} - m_{\tilde{b}_2}$	56.8			2.5
$m_{\ell\ell}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R})$	80.4	1.7	0.5	0.03
$m_{\ell\ell}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_4^0}, m_{\tilde{\ell}_L})$	280.6		12.6	2.3
$m_{\tau\tau}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\tau}_1})$	83.4	12.6	4.0	0.73
$m_{\ell\ell q}^{\max}(m_{\tilde{\chi}_1^0}, m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0})$	452.1	13.9	4.2	1.4
$m_{\ell q}^{\mathrm{low}}(m_{\tilde{\ell}_R}, m_{\tilde{q}_L}, m_{\tilde{\chi}_2^0})$	318.6	7.6	3.5	0.9
$m_{\ell q}^{\mathrm{high}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{q}_L})$	396.0	5.2	4.5	1.0
$m_{\ell\ell q}^{\mathrm{thres}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{q}_L})$	215.6	26.5	4.8	1.6
$m_{\ell\ell b}^{\mathrm{thres}}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{b}_1})$	195.9		19.7	3.6
$m_{tb}^{\mathrm{w}}(m_t, m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{g}}, m_{\tilde{b}_1})$	359.5	43.0	13.6	2.5
$\frac{\mathcal{B}(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell) \times \mathcal{B}(\tilde{\ell}_R \to \tilde{\chi}_1^0 \ell)}{\mathcal{B}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) \times \mathcal{B}(\tilde{\tau}_1 \to \tilde{\chi}_1^0 \tau)}$	0.076	0.009	0.003	0.001
$\frac{\mathcal{B}(\tilde{g} \to \tilde{b}_2 b) \times \mathcal{B}(\tilde{b}_2 \to \tilde{\chi}_2^0 b)}{\mathcal{B}(\tilde{g} \to \tilde{b}_1 b) \times \mathcal{B}(\tilde{b}_1 \to \tilde{\chi}_2^0 b)}$	0.168			0.078