Ambiguities in the interpretation of SUSY observables

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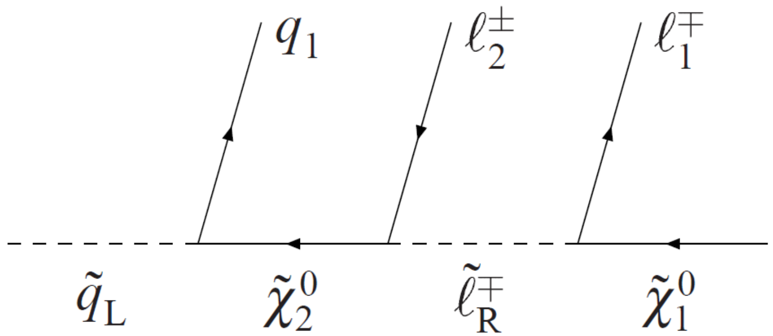
Introduction

- SUSY parameter determination with LHC data
  - SUSY parameter determination with existing measurements
    - Low energy observables, Ω_{CDM}, $(g-2)_\mu$
  - Expect measurements on kinematic end-points (edges) of invariant mass distributions

- Ambiguities in the interpretation of SUSY observables
  - Ambiguities in the kinematic edge measurement
  - Formalism used in the fit
  - Impact on the fit

Ambiguities in particle assignment

- Measurements from the standard cascade decay
  - We don't detect the SUSY particle directly
  - Separate observables for l=e,μ and 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
  - How do they affect the parameter determination?
  - Can we distinguish them by the fit and select the correct interpretation?



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

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

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

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

Fit incorporating several interpretations

Observables
- Kinematic edges
- Branching ratios
- …

compare

SUSY calculator
- Different assumptions on intermediate particles give different predictions of the observables

$$f\left(m_0, m_{1/2}, A_0, \tan\beta; s\right)$$

s : Discrete parameter for various interpretations

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

- Find the best fit point including ‘s’
- How different are the predictions with different ‘s’?
- What are the effects on the fit parameters
- Note that predictions are not a smooth function of ‘s’
    - Technically, it is useful to quickly find out non-interesting cases

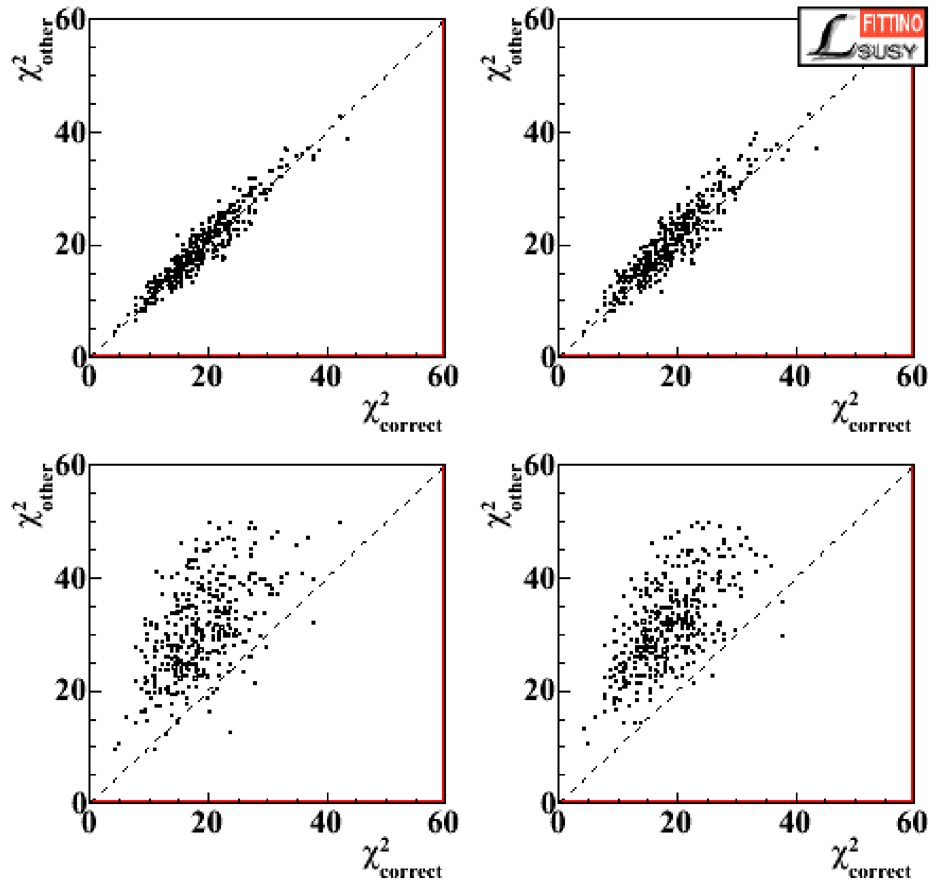
Fit incorporating several interpretations

- Find the best fit point including ‘s’
  - Since predictions are not smooth in terms of ‘s’, we need to run the fit on usual parameters for each ‘s’
  - Otherwise, Markov chain, Minuit or Simulated Annealing
  - → Best interpretation + parameter values

- What are the effects on the fit parameters?
  - Parameter values and uncertainties can be evaluated running toy fits
  - Toy fit also tells you how other interpretations are compatible with the best one

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

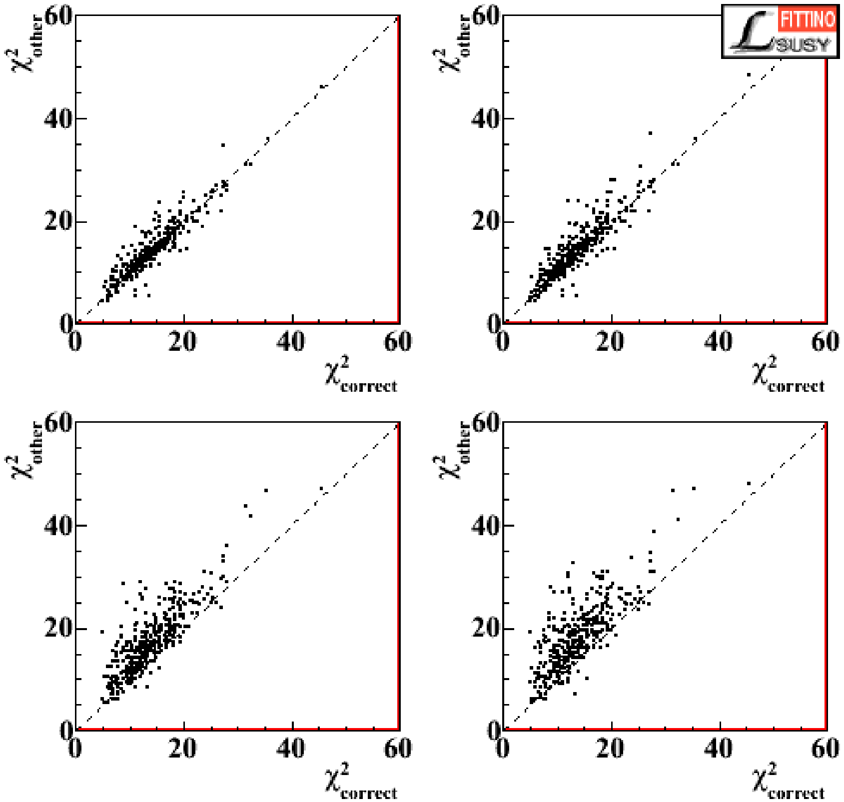
Particle assignment	Fraction (%)
Correct interpretation	69
$\chi^2_0 \leftrightarrow \chi^3_0$ (e,μ-channel)	16
$l_R \leftrightarrow l_L$ (e,μ-channel)	12
$\chi^2_0 \leftrightarrow \chi^3_0$, $l_R \leftrightarrow l_L$ (e,μ-channel) $\chi^2_0 \leftrightarrow \chi^4_0$, $l_R \leftrightarrow l_L$ (τ-channel)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

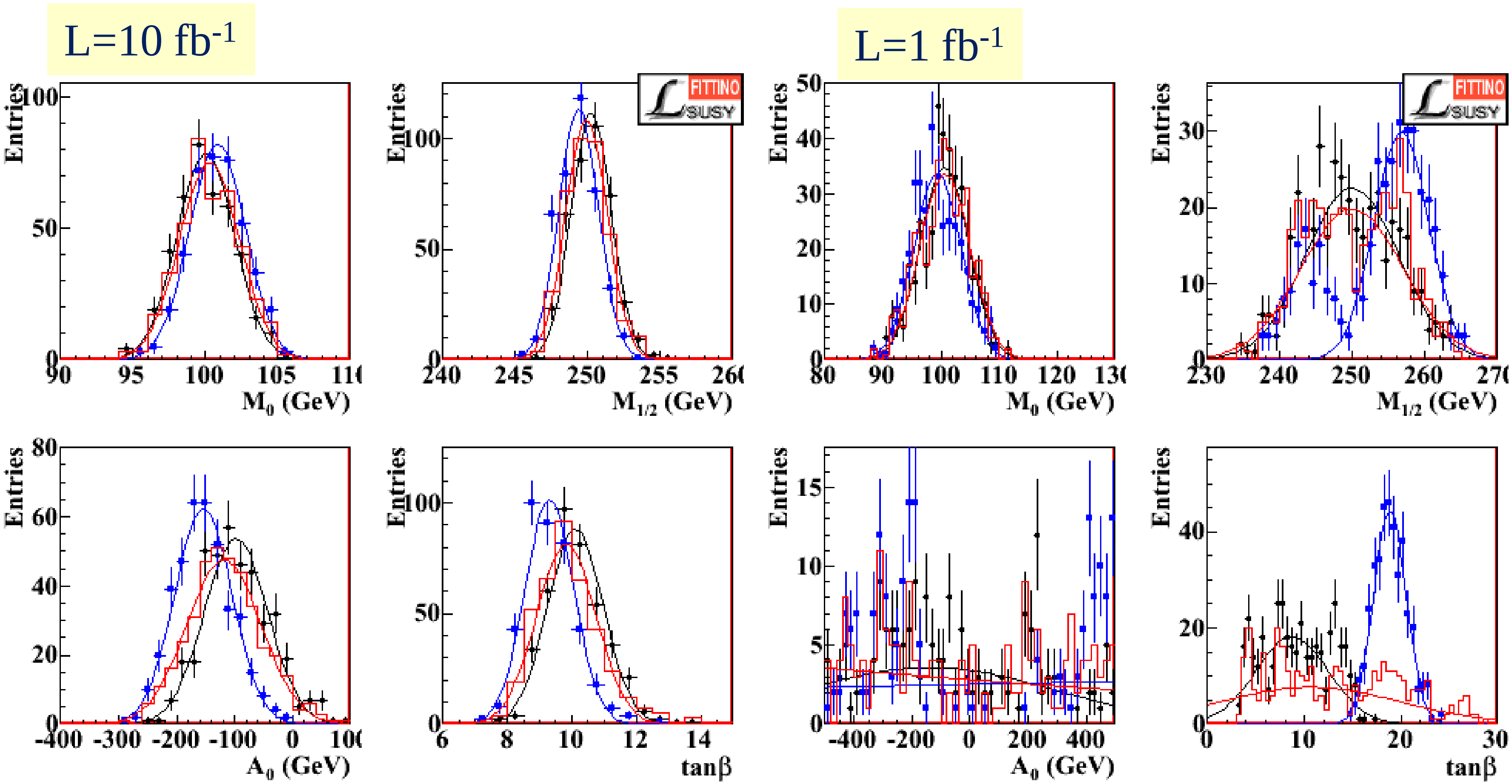
LHC with L=1 fb^{-1} @14 TeV

Particle assignment	Fraction (%)
Correct interpretation	48
$\chi^2_0 \leftrightarrow \chi^3_0$ (e,μ-channel) $\chi^2_0 \leftrightarrow \chi^3_0$ (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}
- Fewer observables used in the fit
- 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

Summary

- mSUGRA fit with LHC observables
  - 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

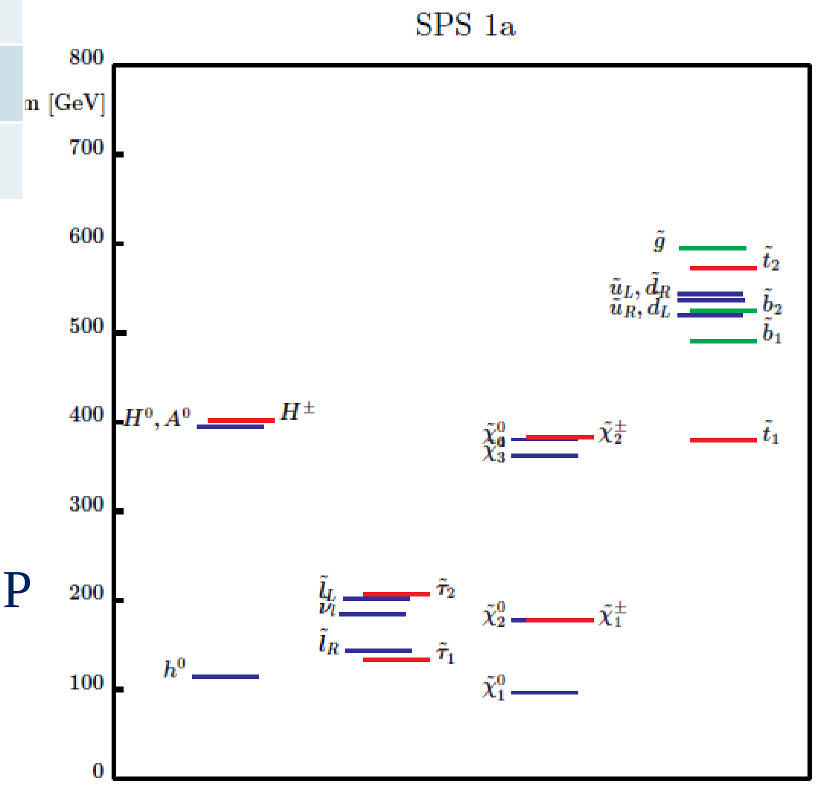
- Outlook
  - Extend the study to a more general SUSY models, e.g. MSSM18
  - Constraints from cross section measurements would help the interpretation of observables

Backup slides

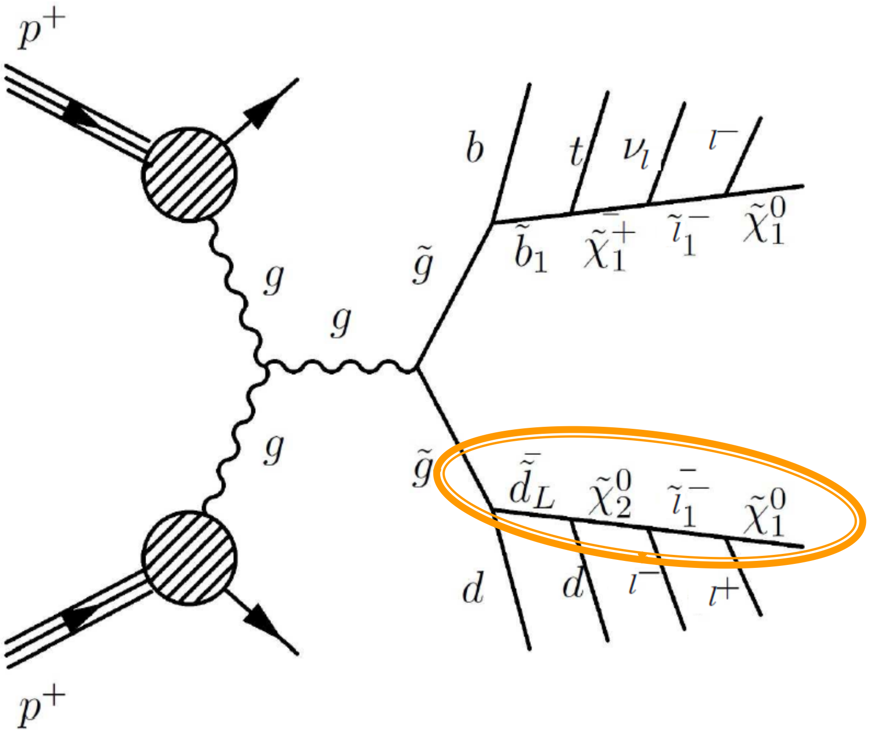
SPS1a benchmark point

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

$$m^2_{l^+l^-}\left(m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}, m^2_{\tilde{\chi}_1^0}\right)$$
$$m^2_{ql^+l^-}\left(m^2_{\tilde{q}}, m^2_{\tilde{\chi}_2^0}, m^2_{\tilde{l}_1}, m^2_{\tilde{\chi}_1^0}\right)$$
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- 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

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
$\frac{\mathcal{B}(\tilde{g} \to \tilde{b}_2 b) \times \mathcal{B}(\tilde{b}_2 \to \tilde{\chi}_2^0 b)}{\mathcal{B}(\tilde{g} \to b_1 b) \times \mathcal{B}(b_1 \to \tilde{\chi}_2^0 b)}$	0.168			0.078

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