MSSM Phenomenology and the muon g-2

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Outline

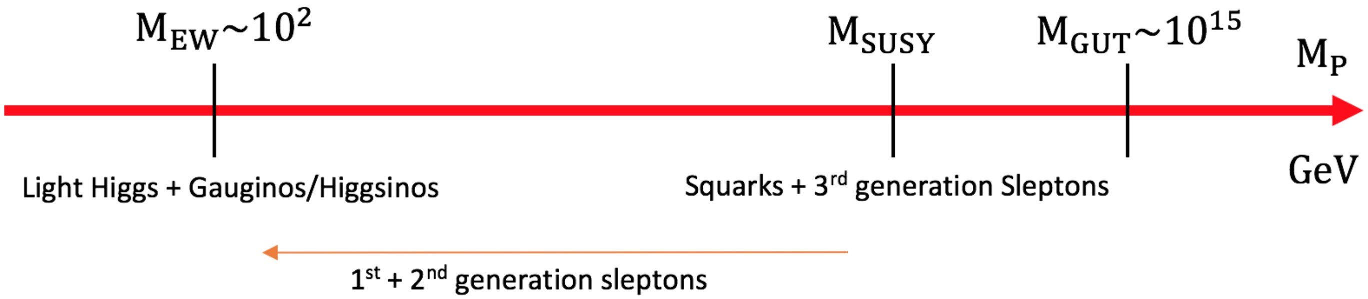
Introduction

The observation of a Higgs at 125 GeV has strengthened the need for SUSY to appear at the weak-scale.

- Tree-level higgs mass $\sim m_Z$
- Existence of electroweakinos (partners of EW gauge bosons)
- A light neutralino - great for DM!
- Composition of DM is important (Wino, Bino, Higgsino)

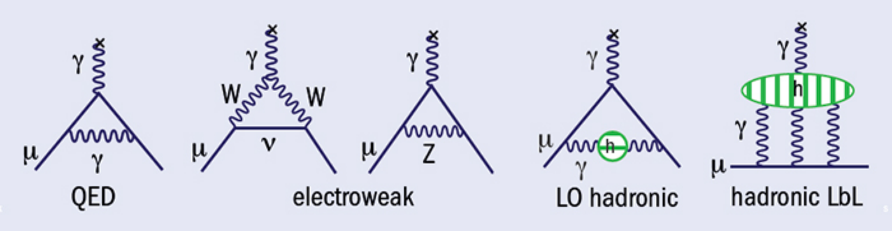
Minimal SUSY mass hierarchy

- Universal squark and slepton masses decoupled
- 125 GeV higgs finely-tuned
- Gauginos/higgsinos at weak scale, protected by chiral symmetry
- Light 1st and 2nd generation sleptons allowed by FCNC constraints
  $\rightarrow$ **muon g-2**



The muon $g-2$

Contributions to the SM:



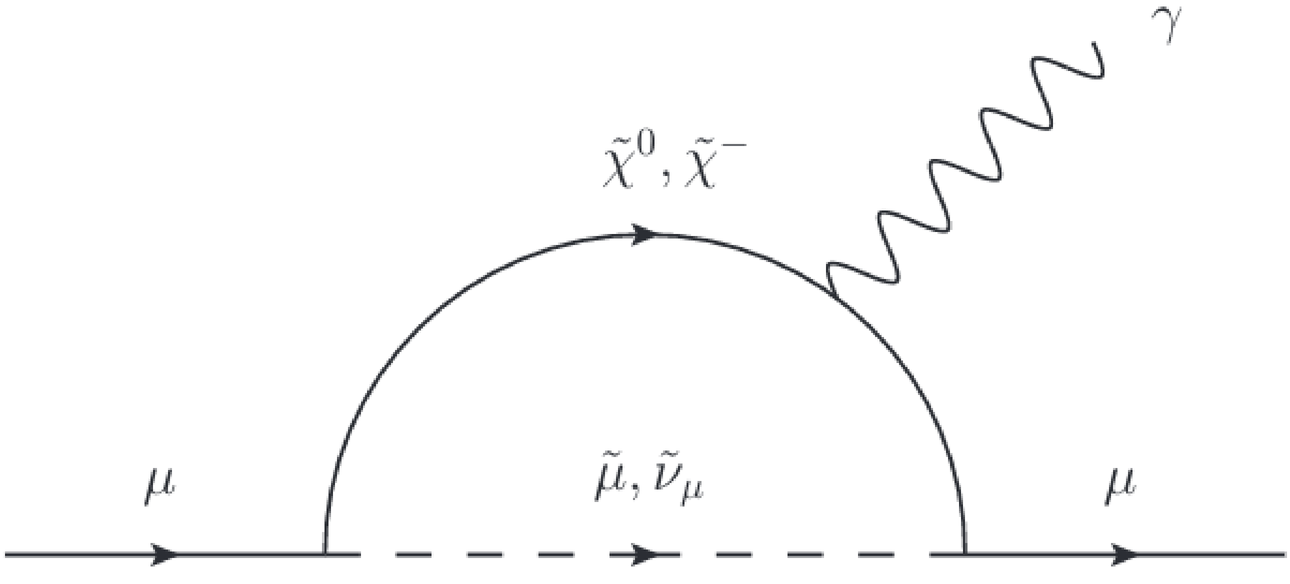
- Main theoretical uncertainty comes from LO Hadronic loop contributions (quarks and gluons)

$$20.6 \times 10^{-10} < \Delta a_\mu < 36.6 \times 10^{-10} \quad (1\sigma)$$
$$12.6 \times 10^{-10} < \Delta a_\mu < 44.6 \times 10^{-10} \quad (2\sigma)$$

where

$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM}$$

The muon $g-2$ in SUSY



The muon $g-2$ in SUSY

Contribution from the MSSM:

$$\Delta a_\mu = \frac{\alpha m_\mu^2 \mu \tan(\beta)}{4\pi} \left[\frac{M_2}{\sin^2\theta_W m_{\tilde{\mu}_L}^2} \left(\frac{f_\chi(M_2^2/m_{\tilde{\mu}_L}^2) - f_\chi(\mu^2/m_{\tilde{\mu}_L}^2)}{M_2^2 - \mu^2} \right) + \frac{M_1}{\cos^2\theta_W (m_{\tilde{\mu}_R}^2 - m_{\tilde{\mu}_L}^2)} \left(\frac{f_N(M_1^2/m_{\tilde{\mu}_R}^2)}{m_{\tilde{\mu}_R}^2} - \frac{f_N(M_1^2/m_{\tilde{\mu}_L}^2)}{m_{\tilde{\mu}_L}^2} \right) \right]$$

f_χ and f_N are loop functions:

$$f_\chi(x) = \frac{x^2 - 4x + 3 + 2\ln(x)}{(1-x)^3}, \quad f_\chi(1) = -2/3 \tag{1}$$

$$f_N(x) = \frac{x^2 - 1 - 2x\ln(x)}{(1-x)^3}, \quad f_N(1) = -1/3 \tag{2}$$

Explaining the muon $g-2$ in the MSSM

- We can heavily constrain the muon $g-2$ through slepton and chargino searches at colliders
- Smuons should be kept light (less than around 500 GeV) to increase contribution to the $(g-2)_\mu$
- Dark Matter (Direct/Indirect) searches can constrain neutralino LSPs in R-Parity conserving SUSY

Constraints from Experiment

- LEP constraints on Chargino and Slepton masses:

$$\begin{aligned} m_{\tilde{l}_L}, m_{\tilde{l}_R} &> 100\,\text{GeV} \quad (l = e, \mu) \\ m_{\tilde{\chi}_1^\pm} &> 105\,\text{GeV} \end{aligned}$$

- Higgs mass from ATLAS/CMS:

$$123 < m_{h^0} < 127\,\text{GeV}$$

- Higgs precision constraints (LEP, Tevatron and LHC)
- Dark matter relic density (PLANCK 2013)

$$\Omega h^2 = 0.112 \pm 0.006$$

- WIMP-nucleon Spin-Independent Cross Section (LUX 2013)

MSSM Parameter Scan

We calculate the $(g-2)_\mu$ in the MSSM using `FeynHiggs`:

- Decoupled Squarks at 5 TeV (Ignore B-Physics constraints)
- Gluino mass $M_3 \sim 3000$ GeV
- Trilinear coupling A_t in range $|A_t| < 5000\,\text{GeV}$ (We keep $|X_t/M_S| < 2$ to avoid charge/colour-breaking minima)
- Rest of higgs sector decoupled with $m_{A^0} = 2000$ GeV

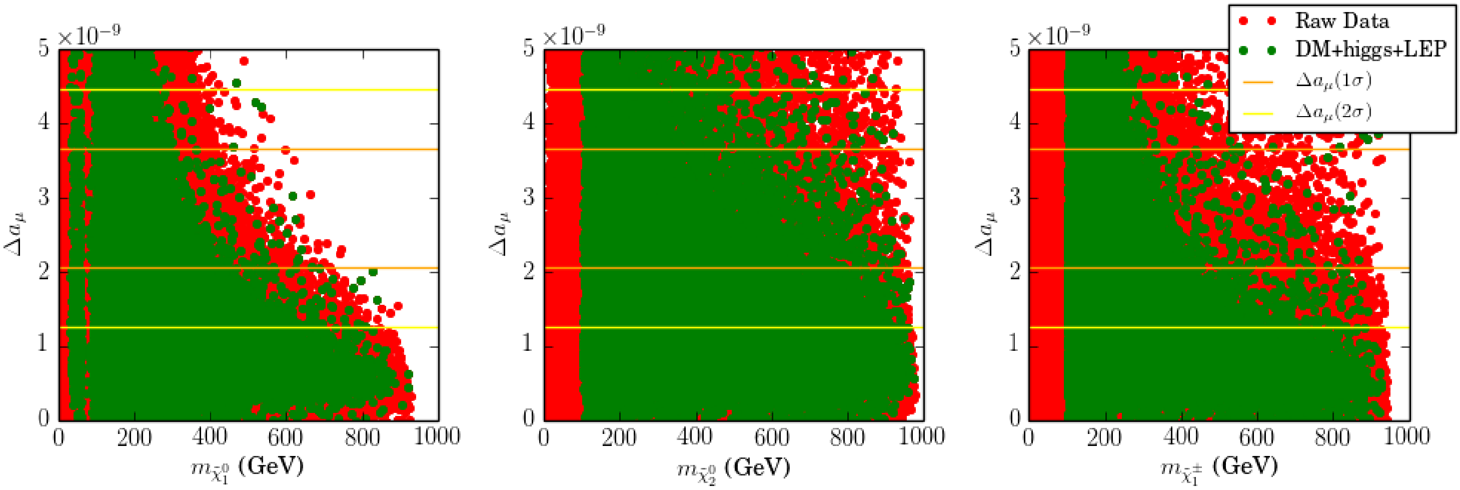
Parameter scan:

$$10 < \tan(\beta) < 50$$
$$|M_1|, |M_2|, |\mu| < 1000\,\text{GeV}$$
$$100 < m_{\tilde{l}_L}, m_{\tilde{l}_R} < 1000\,\text{GeV}$$

where $l = e, \mu$.

Higgs mass calculated in `FeynHiggs`, precision constraints in `HiggsBounds-4.2.1`. SUSY spectrum calculated in `SPheno`, `MicrOmegas` to calculate DM relic density and SI WIMP-nucleon CS.

Neutralinos, Charginos and Smuons



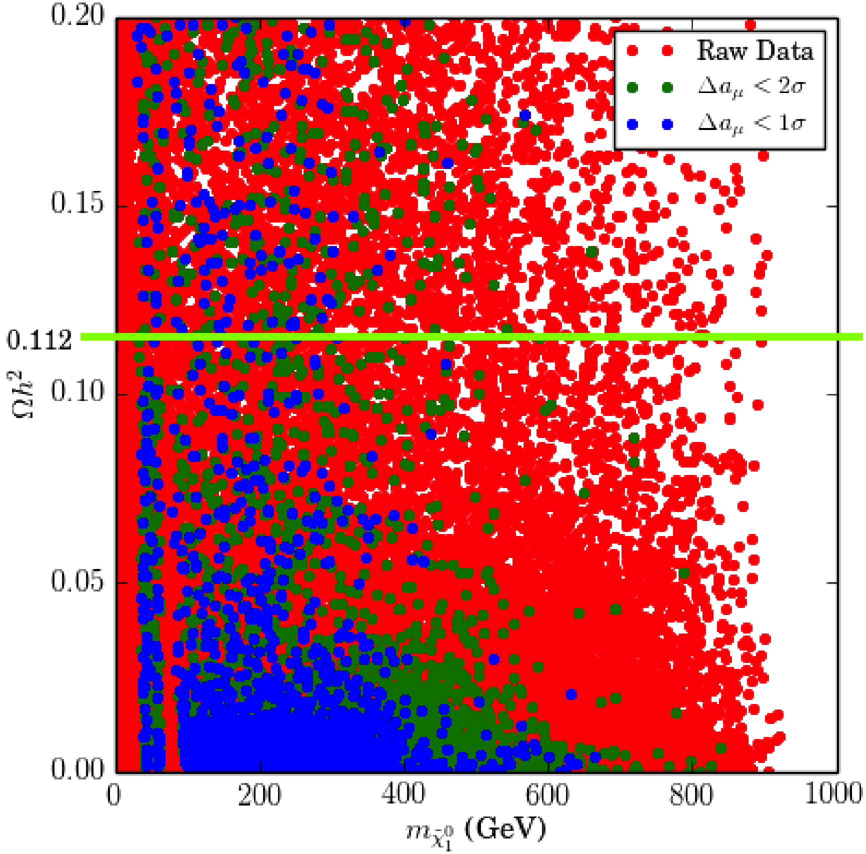
χ_1^0 component

Parameters	**LSP**	**NLSP**
$M_1 > M_2 > \mu$	Higgsino	Wino
$M_1 > \mu > M_2$	Wino	Higgsino
$M_2 > \mu > M_1$	Bino	Higgsino
$\mu > M_2 > M_1$	Bino	Wino

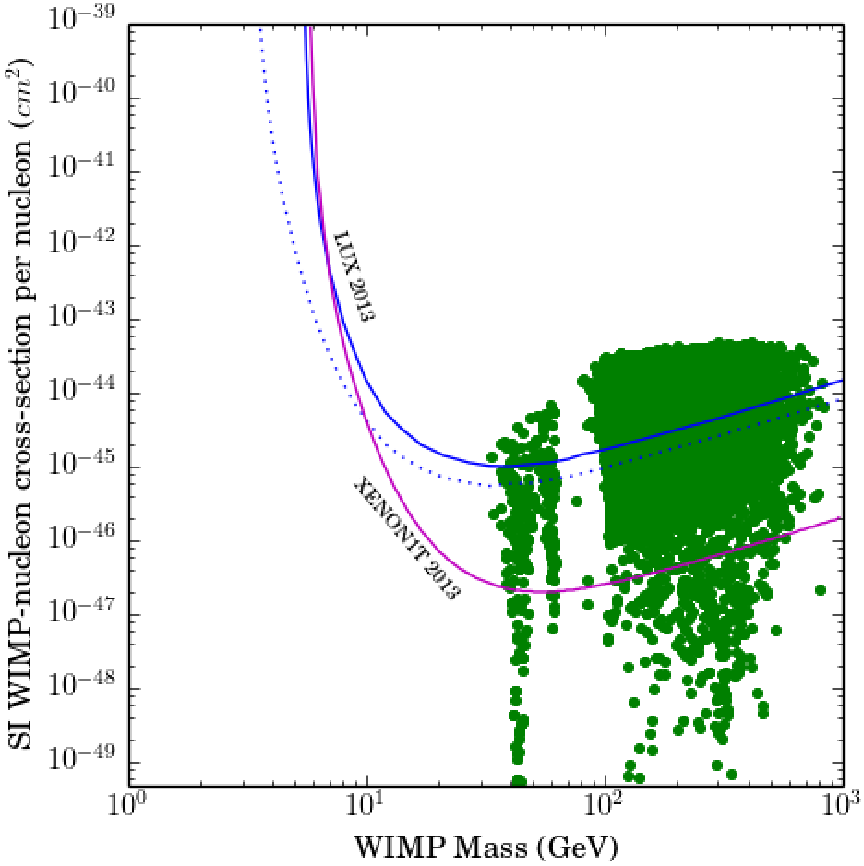
Constraints on χ_1^0 vary for different compositions of Bino, Wino and Higgsinos

- It is well known that pure Bino-like DM relics are typically overabundant (suppressed annihilation cross section), except in the case where the bino co-annihilates with other sparticles
- We can suppress the cross-section with a wino or higgsino component to χ_1^0
- To avoid significant constraint, for any LSP abundance less than the relic density, we assume additional DM component (possibly axion-like DM)

Relic Density, Ωh^2



WIMP-nucleon SI Cross Section

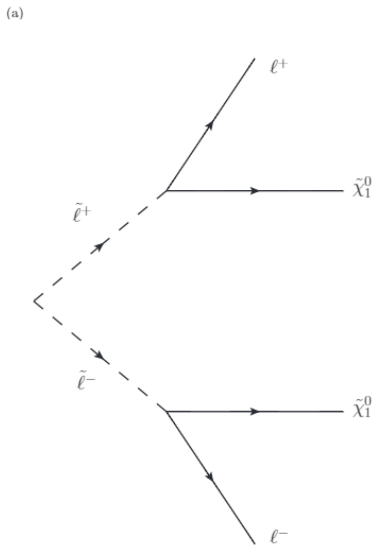


Collider Simulation

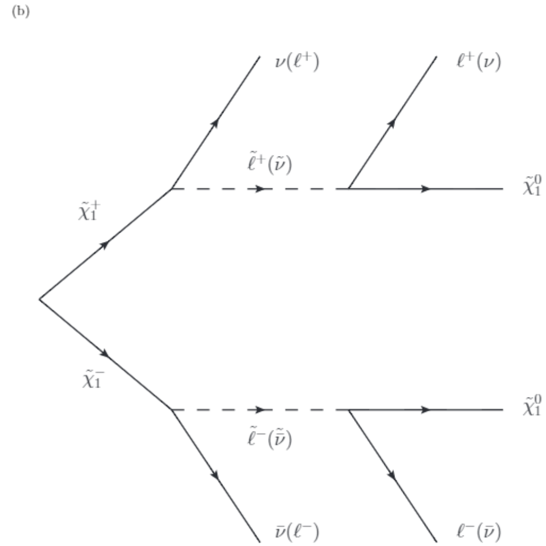
We study constraints from multilepton + MET searches at the LHC.

- We study electroweakinos at $\sqrt{s} = 8$ TeV LHC from slepton/sneutrino and W/Z decays
- Parameter sets that pass the previous collider and direct/indirect dark matter searches are considered
- Points are considered within the 2σ limit of Δa_{μ}
- We also present the prospects for electroweakino searches with a 100 TeV collider
- Events are simulated using `MadGraph 5` interfaced with `Pythia 6`
- These are passed to `CheckMATE-1.2.2` to check exclusion limits at 95% CL

$2\ell + \not{E}_T$ (2 leptons + missing energy) [1]



(a) via direct slepton decays

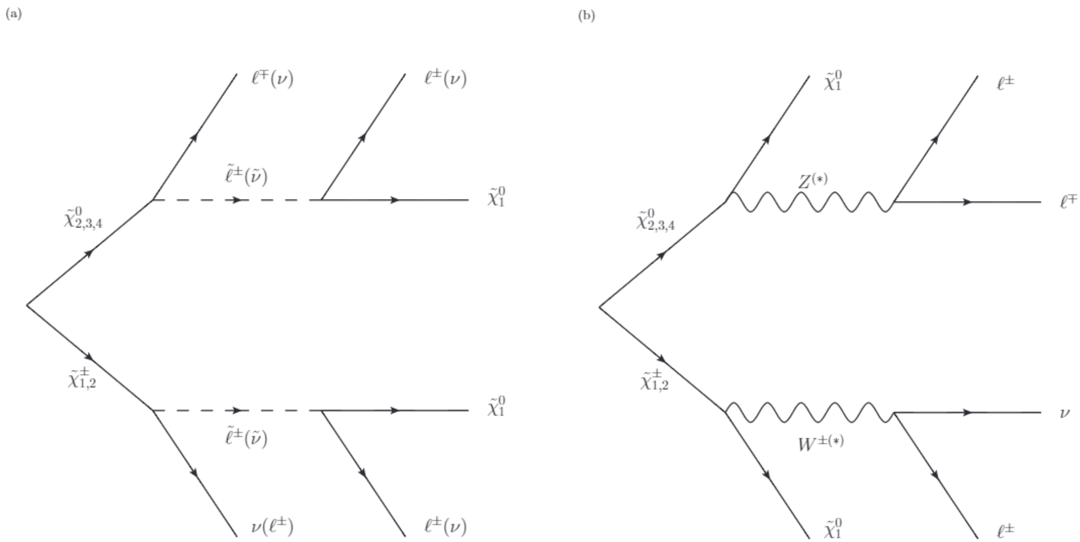


(b) via sleptons/sneutrinos

[1] atlas_conf_2013_049

Electroweakinos and sleptons at colliders

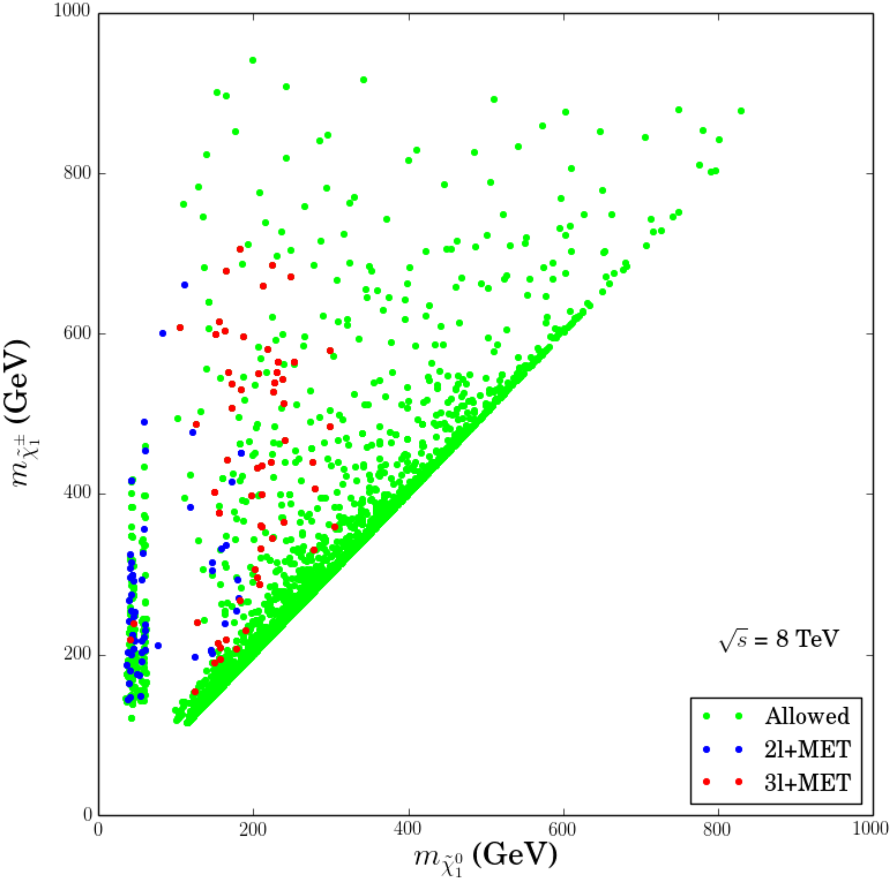
$3\ell + \not{E}_T$ (3 leptons + missing energy) [2]



(a) via sleptons/sneutrinos (b) via gauge bosons

[2] atlas_1402_7029

Results in $m_{\chi_1^0} - m_{\chi_1^\pm}$ plane



100 TeV preliminary Analysis

The 3 lepton + MET events at 100 TeV are expected to have the largest reach over the MSSM parameter space [3].

Taking the expected and observed events, we scale the SM background sources by $\sigma^{100\ \mathrm{TeV}}/\sigma^{8\ \mathrm{TeV}}$:

- WZ
- ZZ
- $ttV + ttZ$
- VVV
- H
- Reducible (t single/pair, WW, single W/Z with jets or photons)

[3] Gori, S., Jung, S., Wang, L., Wells, J.D., 1-31 JHEP (2014)

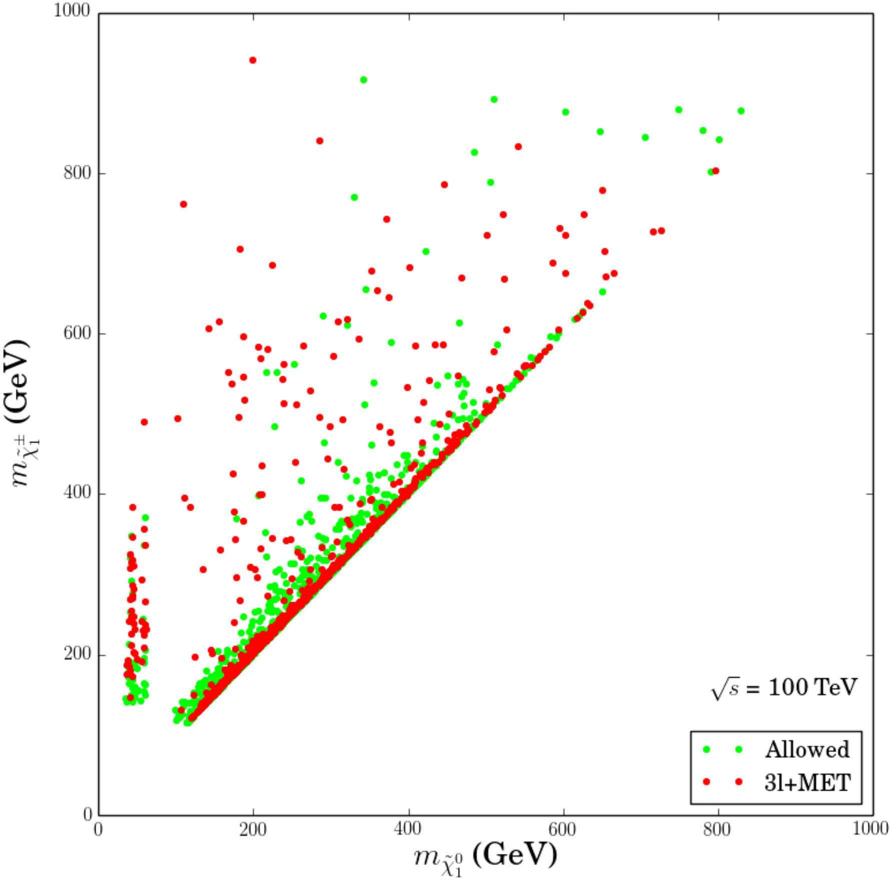
Important cuts

- Exactly 3 lepton final state
- Minimal Same Flavour Opposite-Sign (mSFOS) - The invariant mass of the same-flavour and opposite-sign lepton pair closest to the Z mass
- Missing energy E_T^{miss}
- Transverse mass of non-mSFOS lepton pair - $m_T\left(\overrightarrow{p}^{\ell}_T, \overrightarrow{p}^{miss}_T\right) = \sqrt{2\overrightarrow{p}^{\ell}_T E_T^{miss} - 2\overrightarrow{p}^{\ell}_T \cdot \overrightarrow{p}^{miss}_T}$

Optimized variables for 100 TeV search (future implementation):

- $H_T(jets)/M_{eff}$ where $M_{eff} = \sum_{jets,leptons,MET} p_T^i$
- $M'_{eff} \equiv M_{eff} - p_T(\ell_1)$
- $p_T(\ell_2)/p_T(\ell_1)$

Results for 100 TeV Analysis



Conclusions

- We studied constraints from direct/indirect measurements on the MSSM with heavy squarks
- A 100 TeV collider could potentially probe the entire mass range for electroweakinos in this model as an explanation for the muon g-2 (as well as simultaneously explaining higgs and part of DM)
- Such a study could be performed on CMSSM with GUT RGE evolution of non-universal sfermion/gaugino masses, expected to be even more constrained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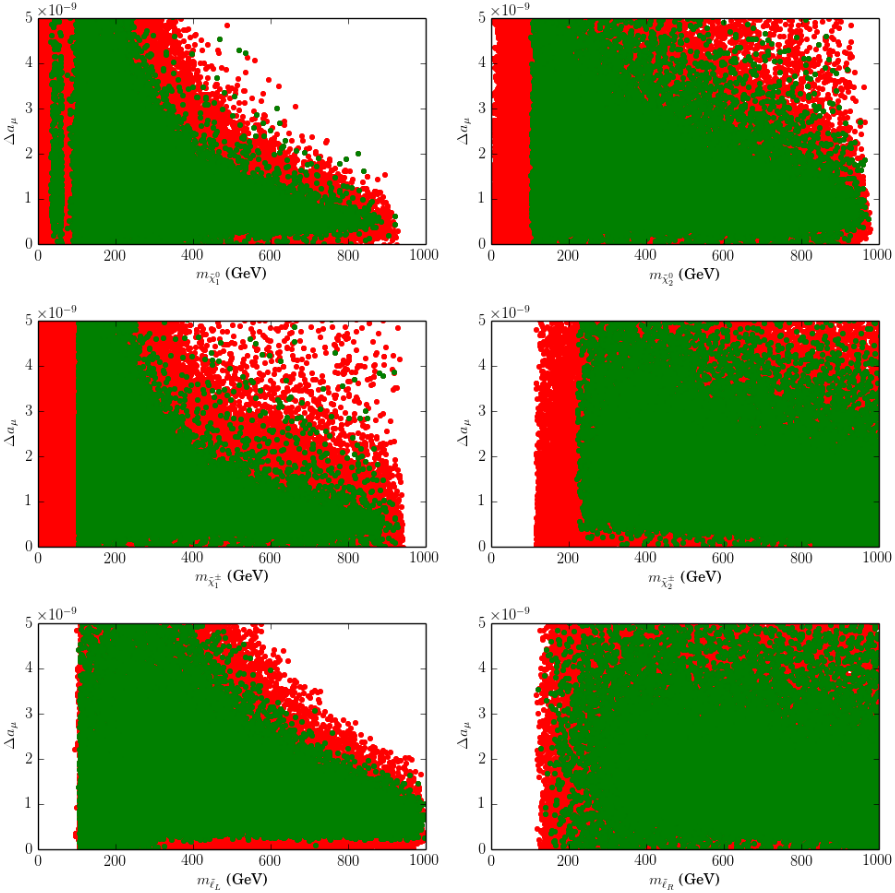

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