Higgsino LSP in ATLAS pMSSM

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KITP Experimental Challenges
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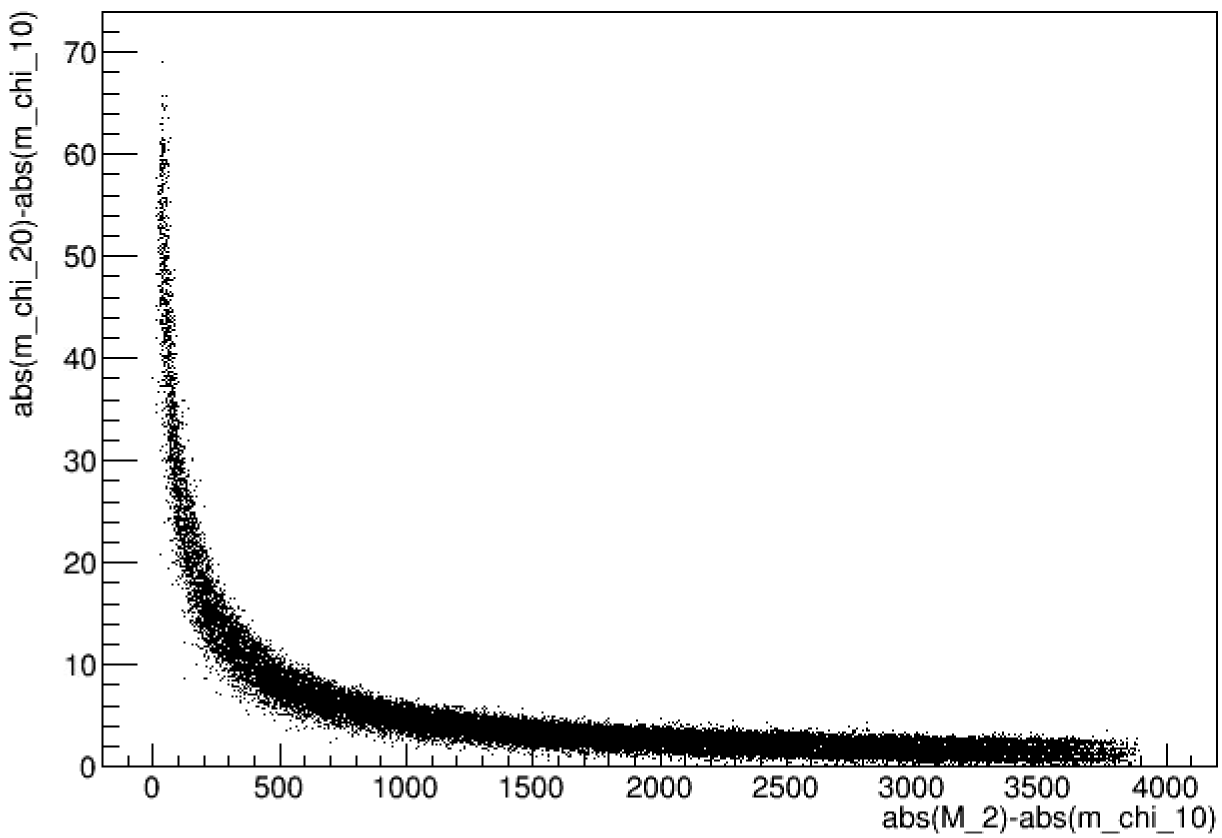
pMSSM scan

- ATLAS did scan over 19-parameter pMSSM in Run-1
  - Published in JHEP 10 (2015) 134 [arXiv:1508.06608]
- About 300k pMSSM models generated after pre-LHC SUSY constraints (see backup for details)
  - Generation done by T. Rizzo, M. Cahill-Rowley, J. Hewett and A Ismail
  - Use SoftSUSY 3.4.0 for spectrum generation
  - SUSY-HIT 1.3 for SUSY decays with some corrections
- About 40% of the models excluded by ATLAS Run-1
- All models and whether they are excluded available on HEPDATA: http://hepdata.cedar.ac.uk/view/ins1389857
- Used these to look at typical Higgsino mass splittings and decays when LSP is predominantly Higgsino-like

$m(\chi_2^0)$-$m(\chi_1^0)$ for M_1>3000 GeV

$m(\chi_2^0)$-$m(\chi_1^0)$

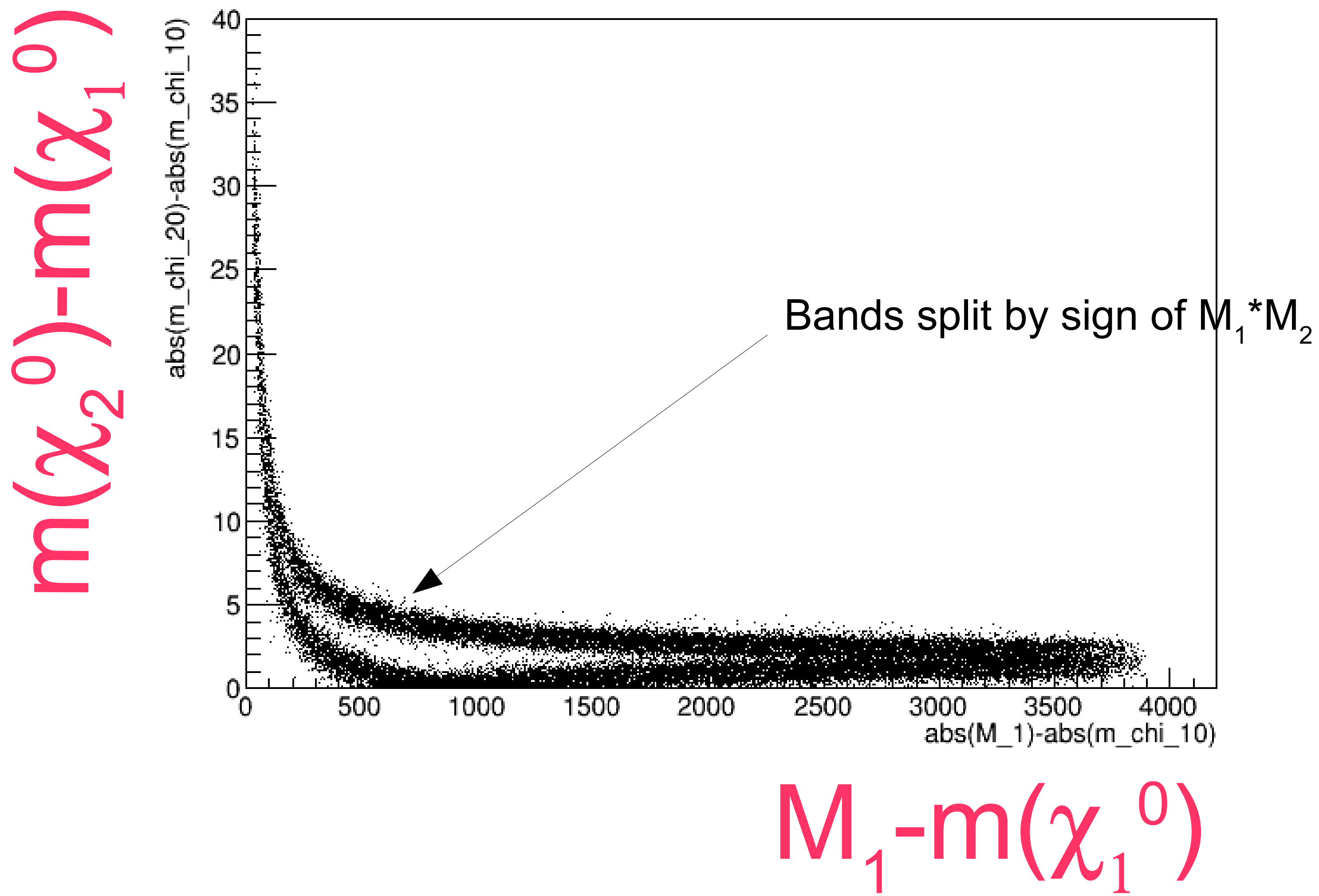


M_2-$m(\chi_1^0)$

Note:

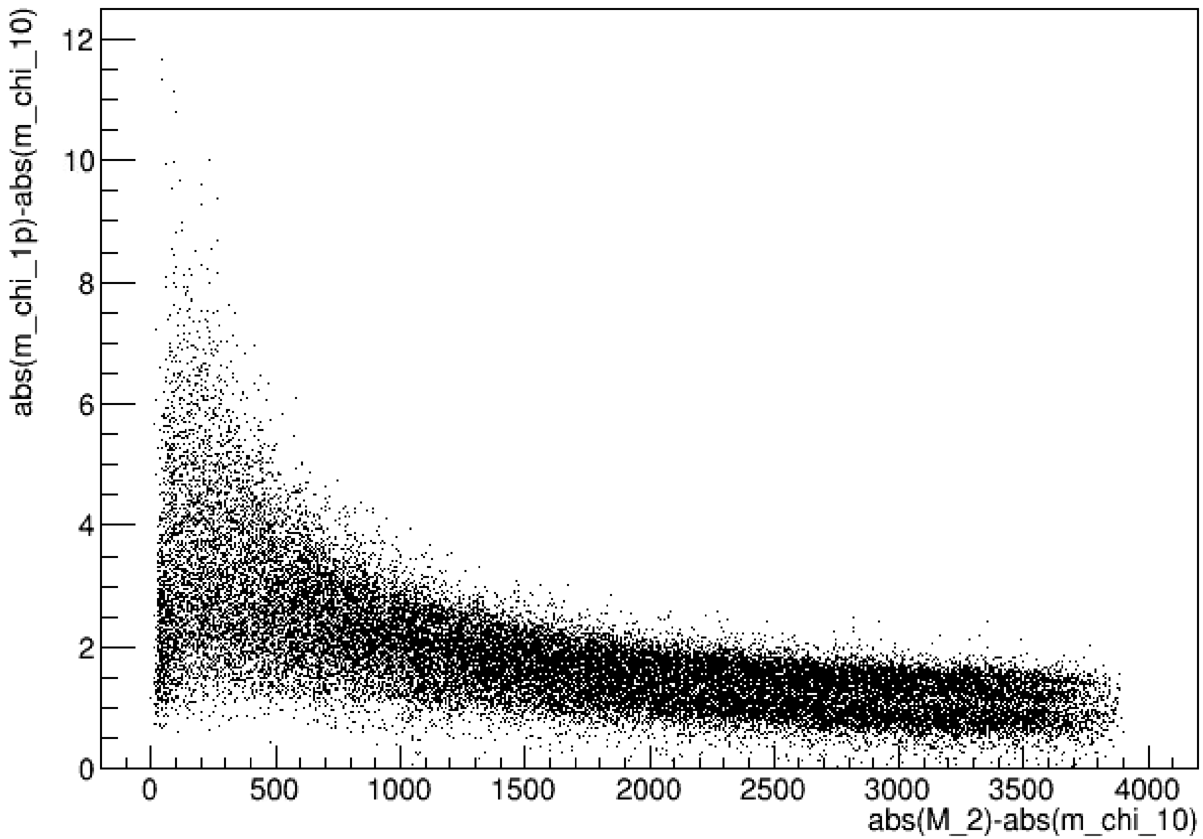
Looking at all models, not just the non-excluded ones

$m(\chi_2^0)-m(\chi_1^0)$ for M_2>3000 GeV



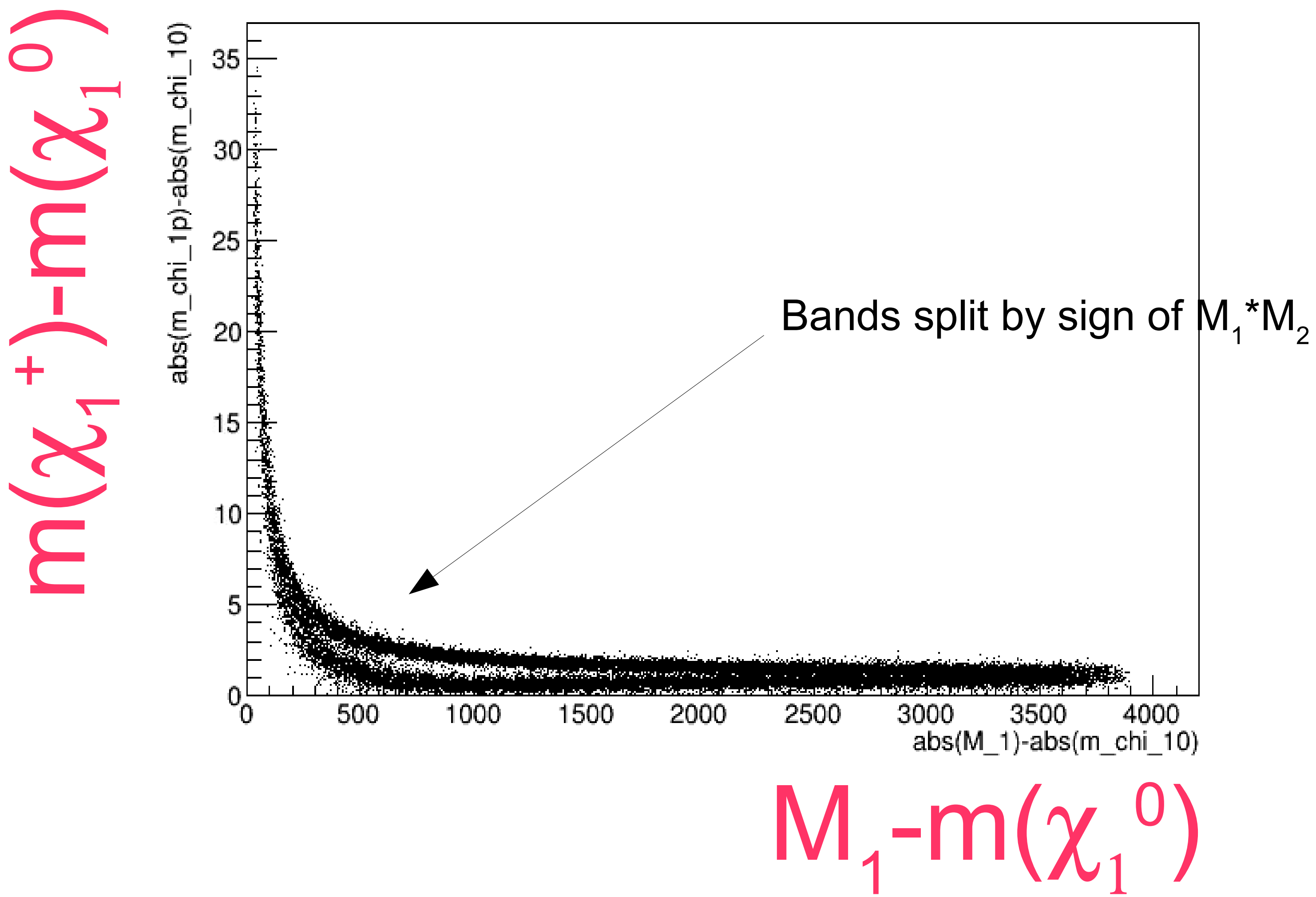
$m(\chi_1^+)-m(\chi_1^0)$ for $M_1>3000$ GeV

$m(\chi_1^+)-m(\chi_1^0)$

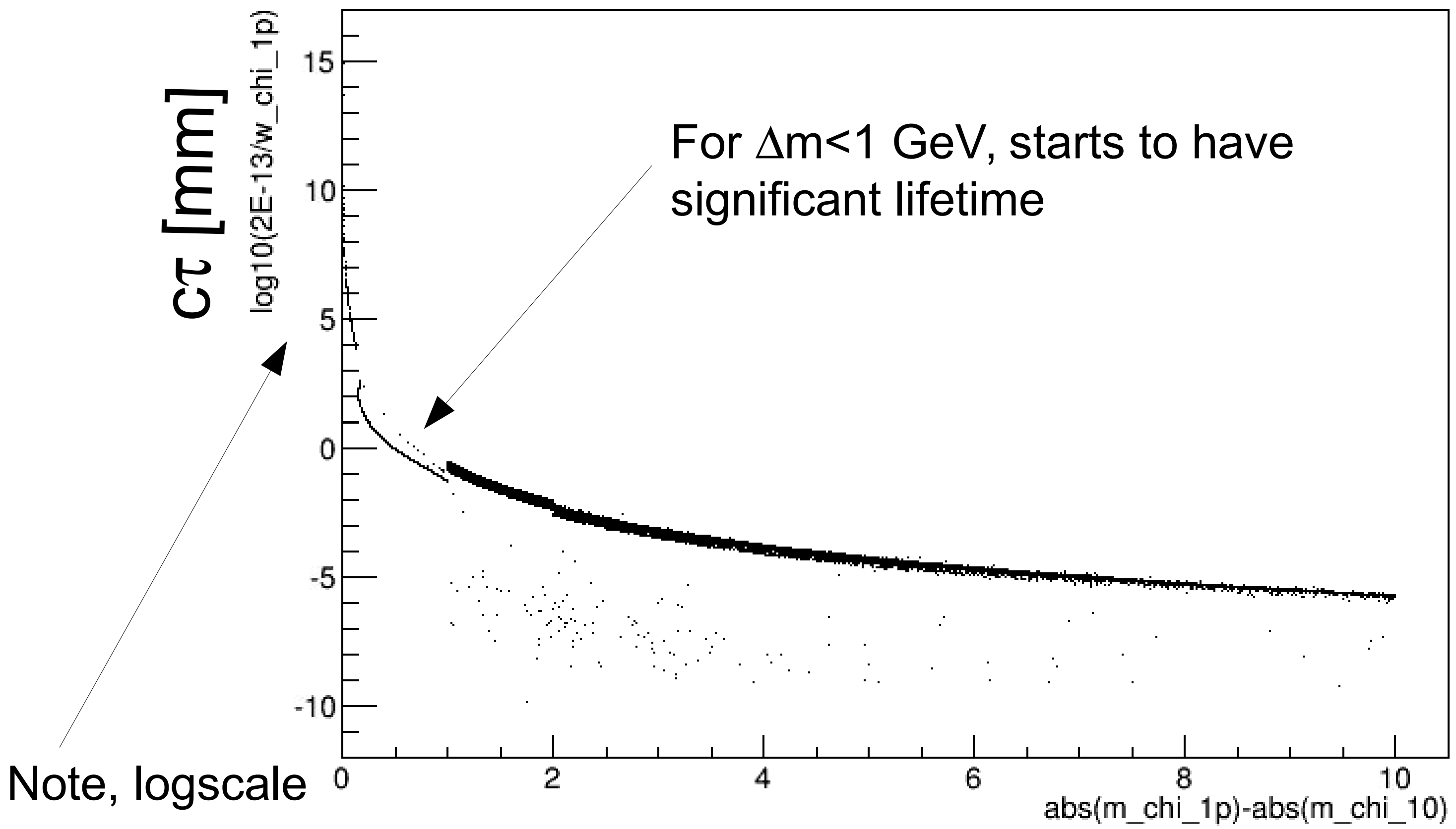


$M_2-m(\chi_1^0)$

$m(\chi_1^+)-m(\chi_1^0)$ for $M_2>3000$ GeV

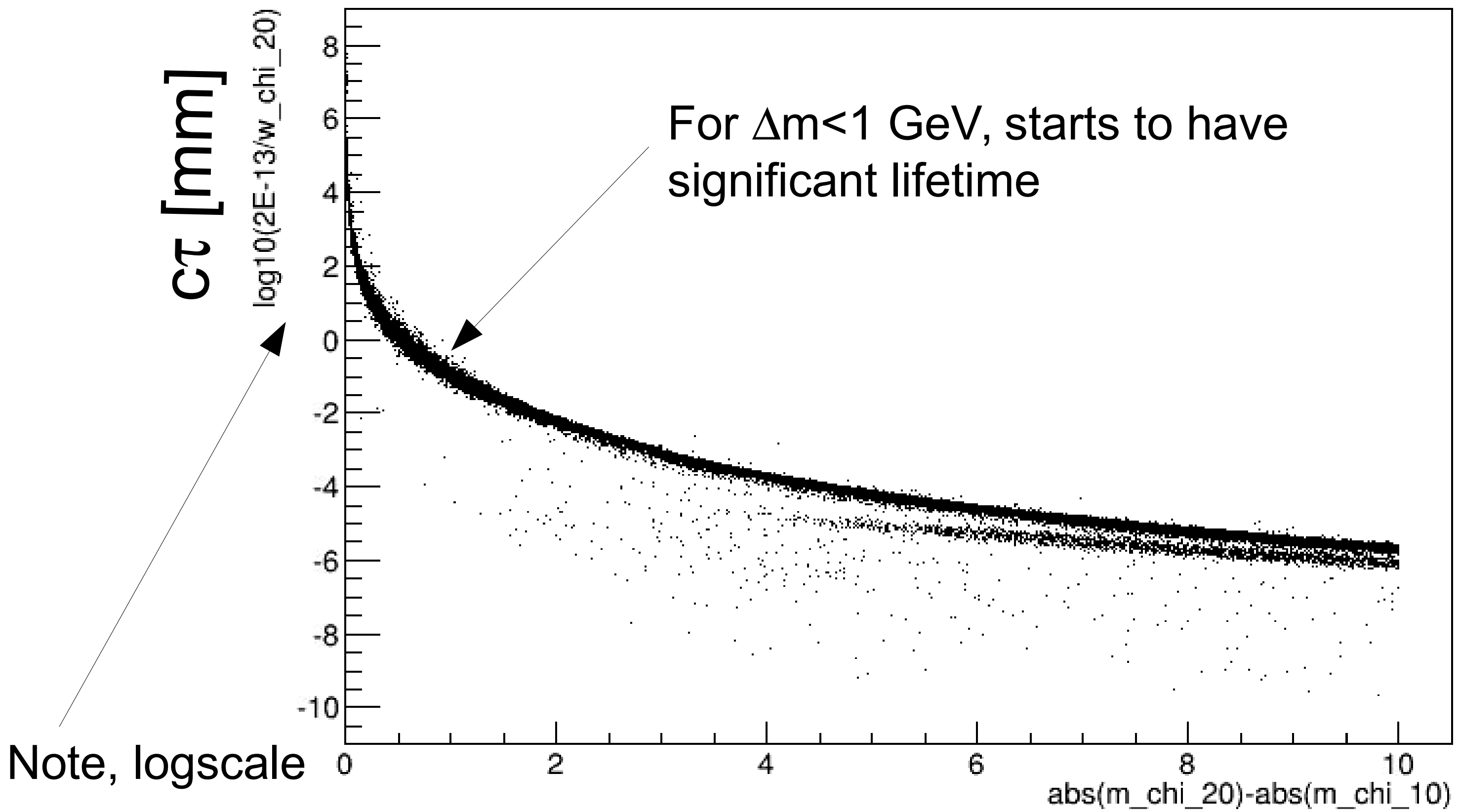


$c\tau$ for χ_1^+



$m(\chi_1^+)-m(\chi_1^0)$

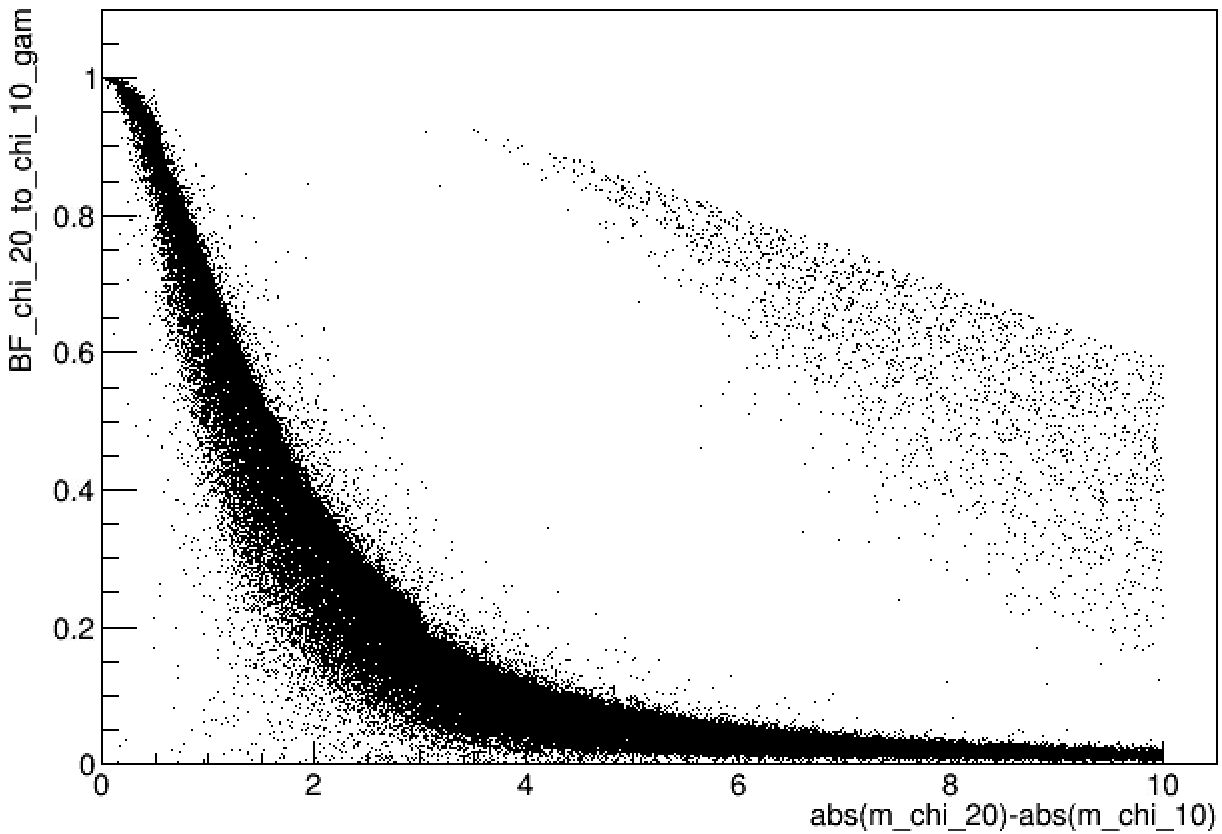
$c\tau$ for χ_2^0



$m(\chi_2^0)-m(\chi_1^0)$

Decays of χ_2^0

For low Δm, χ_2^0 also mainly decays through γ instead of Z^* (so no leptons)



$BF(\chi_2^0 \rightarrow \chi_1^0 + \gamma)$

$m(\chi_2^0) - m(\chi_1^0)$

Brief pMSSM Reminder

pMSSM Scan Parameters

- Using a 19 parameter pMSSM as basis model
  - No CP violating parameters
  - Minimal flavor violation
  - Degenerate 1st and 2nd generations sfermions
  - Lightest sparticle (LSP) is a neutralino
  - R-parity is exactly conserved (LSP is stable)

Flavor physics constraints

- Sample parameters uniformly over wide range (up to 4TeV)

Higgs sector parameters:

$1 < \tan\beta < 60$

$0.1\ \text{TeV} < M_A < 4\ \text{TeV}$

Neutralino/chargino mass parameters:

$-4\ \text{TeV} < \mu < 4\ \text{TeV}, \quad |\mu| > 80\ \text{GeV}$

$-4\ \text{TeV} < M_1 < 4\ \text{TeV}$

$-4\ \text{TeV} < M_2 < 4\ \text{TeV}, \quad |M_2| > 70\ \text{GeV}$

Slepton mass parameters:

$0.09\ \text{TeV} < m_{eL} = m_{\mu L} < 4\ \text{TeV}$

$0.09\ \text{TeV} < m_{eR} = m_{\mu R} < 4\ \text{TeV}$

$0.09\ \text{TeV} < m_{\tau L} < 4\ \text{TeV}$

$0.09\ \text{TeV} < m_{\tau R} < 4\ \text{TeV}$

Squark/gluino mass parameters:

$0.2\ \text{TeV} < M_3 < 4\ \text{TeV}$

$0.2\ \text{TeV} < m_{q1L} = m_{q2L} < 4\ \text{TeV}$

$0.2\ \text{TeV} < m_{uR} = m_{cR} < 4\ \text{TeV}$

$0.2\ \text{TeV} < m_{dR} = m_{sR} < 4\ \text{TeV}$

$0.1\ \text{TeV} < m_{q3L} < 4\ \text{TeV}$

$0.1\ \text{TeV} < m_{tR} < 4\ \text{TeV}$

$0.1\ \text{TeV} < m_{bR} < 4\ \text{TeV}$

Trilinear coupling parameters:

$-4\ \text{TeV} < A_b < 4\ \text{TeV}$

$-8\ \text{TeV} < A_t < 8\ \text{TeV}$

$-4\ \text{TeV} < A_\tau < 4\ \text{TeV}$

Non-ATLAS Search Constraints

- For each point evaluate whether it is a "viable" model
  - Model has to be theoretically "sound"
  - Model should not already be excluded by other measurements

Low energy constraints:

$g_\mu - 2$	$[-1.77 : 4.38] \times 10^{-9}$	±3σ union of theory and exp. meas.
$BF(b \to s\gamma)$	$[0.269 : 0.387] \times 10^{-3}$	±2σ union of theory and exp. meas.
$BF(B_s \to \mu\mu)$	$[1.6 : 4.2] \times 10^{-9}$	
$BF(B^+ \to \tau\nu_\tau)$	$[64 : 161] \times 10^{-6}$	

LEP constraints:

$\Gamma_{invis.}(Z)$	< 2 MeV	Invisible width in addition to neutrinos
$\Delta\rho$	$[-0.0005 : 0.0017]$	
Charged sparticles	> 100 GeV	Raised to 103 GeV for $\tilde{\chi}_1^+$ in most cases

Higgs mass constraints:

$m(h)$	124–128 GeV	Higgs mass range was set at end of 2013 Uncertainty is set by theory prediction

Dark matter constraints:

Relic density	$\Omega h^2 < 0.1221$	Relic dark matter density from Planck only used as upper limit (use +2σ) Allow other DM component than LSP
Direct SI	$< 4\times$ LUX	For direct detection use factor 4 looser limit to account for nuclear form factor uncertainties (also scale down by LSP relic density/DM density)
Direct SD, p	$< 4\times$ COUPP	
Direct SD, n	$< 4\times$ Xenon	

Sampling by LSP Type

- In total 500 million model points were generated and 311,209 viable models selected

LSP type	Definition	Sampled	Simulated Number	Simulated Fraction	Weight
'Bino-like'	$N_{11}^2 > \max(N_{12}^2,\ N_{13}^2 + N_{14}^2)$	480×10^6	104,201	35%	$1/24$
'Wino-like'	$N_{12}^2 > \max(N_{11}^2,\ N_{13}^2 + N_{14}^2)$	20×10^6	80,239	26%	1
'Higgsino-like'	$(N_{13}^2 + N_{14}^2) > \max(N_{11}^2,\ N_{12}^2)$		126,769	39%	1
Total		500×10^6	311,209		

- Models split by the dominant component of LSP
- Bino-like LSP suppressed by relic density constraint as most models have low annihilation cross section
  - Oversampled by factor 24 to get similar samples of each
  - In combined plots later, the Bino-like LSP models are weighted down by 1/24 to restore uniform scan prior

Fraction of Models Excluded

Analysis	All LSPs	Bino-like	Wino-like	Higgsino-like
0-lepton + 2-6 jets + E_T^{Miss}	32.06%	35.56%	29.65%	33.46%
0-lepton + 7-10 jets + E_T^{Miss}	7.82%	5.59%	7.63%	8.01%
0/1-lepton + 3 b-jets + E_T^{Miss}	9.03%	5.98%	7.17%	10.30%
1-lepton + jets + E_T^{Miss}	7.99%	5.47%	7.47%	8.40%
Monojet	6.93%	14.61%	6.32%	7.06%
SS/3-leptons + jets + E_T^{Miss}	2.43%	1.65%	2.35%	2.51%
Taus + jets + E_T^{Miss}	3.04%	1.30%	2.96%	3.14%
0-lepton, stop	9.34%	7.58%	8.26%	10.08%
1-lepton, stop	6.06%	3.62%	5.23%	6.66%
2b-jets + E_T^{Miss}	3.69%	3.37%	2.95%	4.17%
2-leptons, stop	0.23%	0.38%	0.33%	0.17%
Monojet, stop	3.11%	11.27%	2.48%	3.23%
Stop with Z boson	0.32%	1.01%	0.23%	0.36%
tb+E_T^{Miss},stop	5.30%	1.86%	4.28%	6.06%
ℓh, electroweak	0.00%	0.00%	0.00%	0.00%
2-leptons, electroweak	0.47%	0.91%	0.17%	0.64%
2-taus, electroweak	0.05%	0.06%	0.00%	0.07%
3-leptons, electroweak	0.34%	2.02%	0.39%	0.25%
4-leptons	0.53%	1.13%	0.55%	0.49%
Disappearing Track	11.41%	0.39%	29.91%	0.08%
Long-lived sparticles	0.06%	0.09%	0.02%	0.08%
$H/A \rightarrow \tau^+\tau^-$	1.85%	2.17%	0.87%	2.46%
Total	40.60%	39.59%	45.43%	37.58%