Electroweak pMSSM reinterpretation of ATLAS searches for SUSY

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Electroweak pMSSM

MSSM → phenomenological MSSM (pMSSM)

- Assumes no CP violation, no flavor changing neutral currents, and first- and second-generation universality
- Reduces >100 to 19 parameters that influence SUSY particle masses and decays

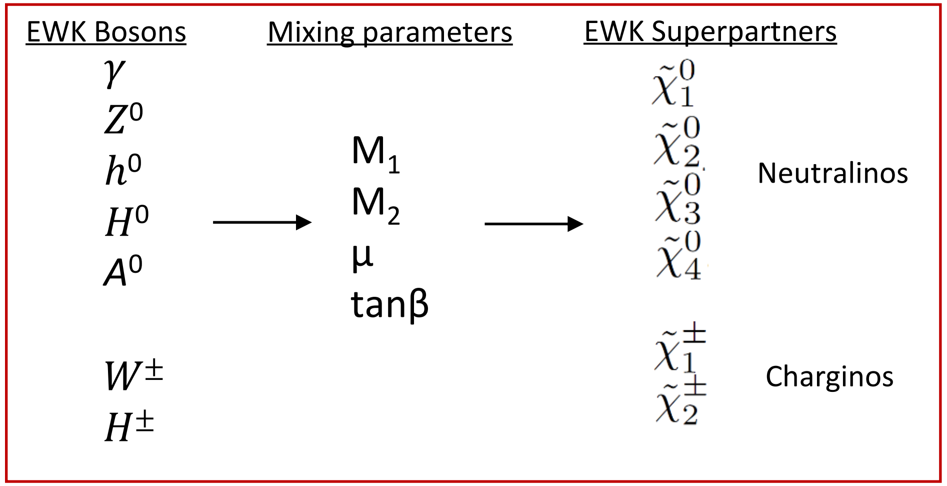
EWK pMSSM parameters

M_1 : bino mass parameter

M_2 : wino mass parameter

μ : bilinear higgs mass parameter

tanβ : ratio of the two higgs vacuum expectation values



pMSSM analysis for LHC Run 1 dataset[1] in ATLAS studied

- $M_1 \in$ [0 GeV, 4 TeV]
- $M_2 \in$ [70 GeV, 4 TeV]
- $\mu \in$ [80 GeV, 4 TeV]
- $\tan\beta \in$ [1, 60]

[1] arXiv:1508.06608 (Oct. 2015)

Motivation

No evidence of SUSY ?

- Naturalness suggests that the lightest electroweakinos should be accessible by current LHC searches
- Current LHC searches **assume a 100% branching ratio for targeted decay chains** to set mass limits

Goals:

1. Determine the dependence of the branching ratios of electroweakinos on pMSSM parameters

2. Restate mass limits from ATLAS searches that use a “simplified” model in terms of the pMSSM

3. Determine the importance of a more theory-based approach to SUSY searches

Model

<u>Chargino and neutralino production in the wino/bino+ scenario</u>

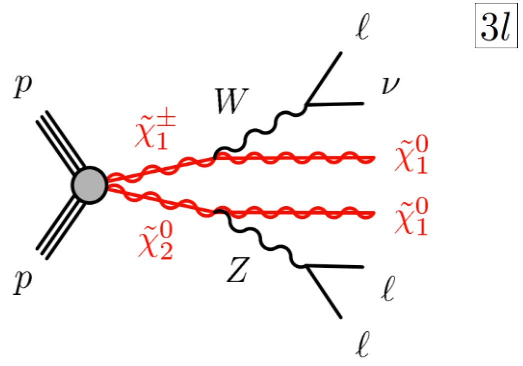
Bino-like LSP, wino-like next lightest SUSY particle (NLSP)

- $M_1 < M_2 << \mu$

"Simplified" searches assume a purely-bino LSP, purely-wino NLSP:

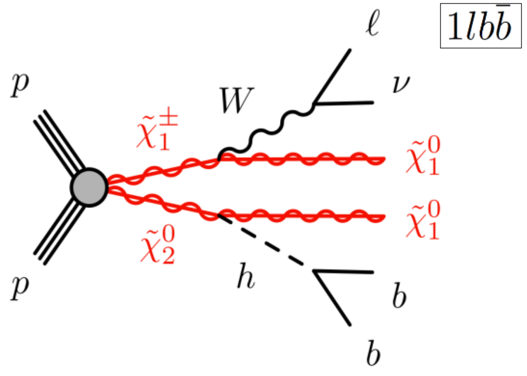
3 lepton (3*l*) final state search[2]

- on-shell *WZ* mediated decay
- LSPs/neutrino → large E_T^{miss}
- Selection assumes BR(C1 → N1 + *W*), BR(N2 → N1 + *Z*) = 1.00



1 lepton 2 *b*-jet (1*lbb̄*) final state search[3]

- LSPs/neutrino → large E_T^{miss}
- Selection assumes BR(C1 → N1 + *W*), BR(N2 → N1 + *h*) = 1.00



[2] arXiv:2106.01676 (Jun. 2021)
[3] arXiv:1812.09432 (Sep. 2019)

EWK Parameter Scan

Used SOFTSUSY 4.1.7[4] to generate electroweakino branching ratios from pMSSM parameters

Scan details:

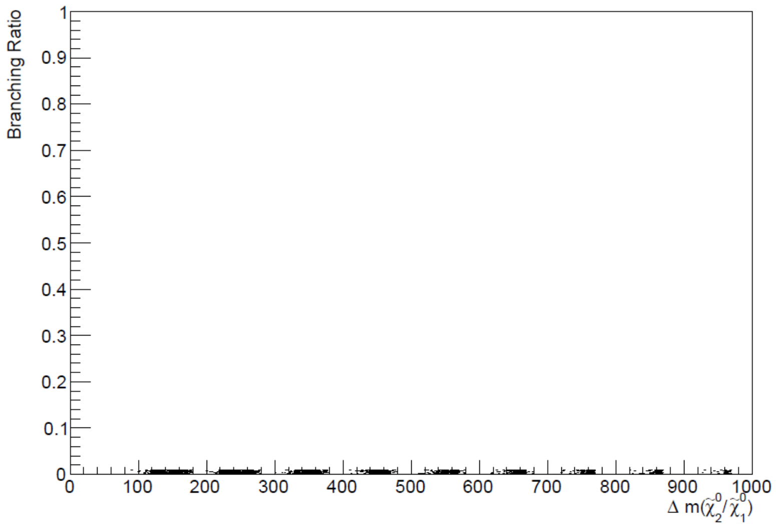
- **M_1** ∈ [100, 1000] GeV in steps of 100 GeV
- **M_2** ∈ (M1, 1000] GeV in steps of 100 GeV
- **μ** ∈ (M1, 3000] GeV in steps of 100 GeV
- **tanβ** ∈ {10, 50}

Considered only on-shell electroweakino decays

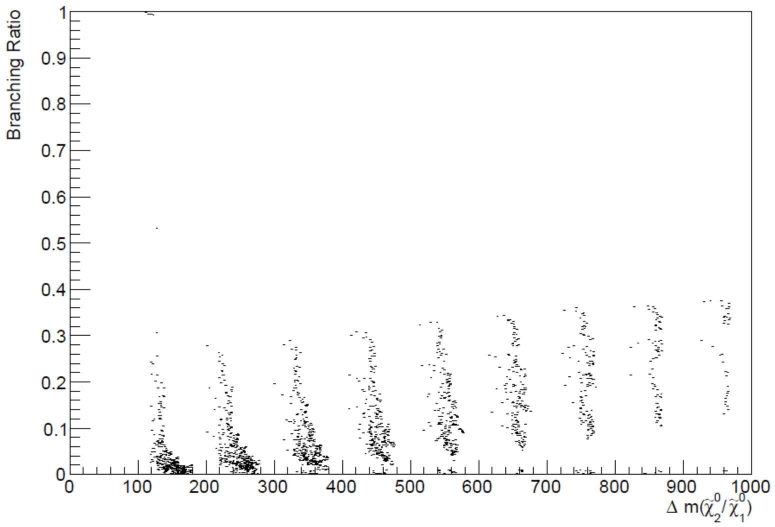
[4] arXiv:1703.09717v2 (Jul. 2017)

Results – Neutralino2 Branching Ratios

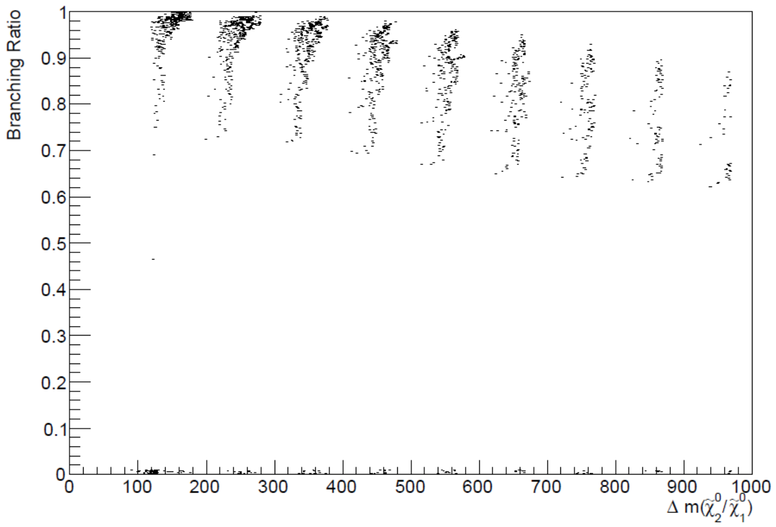
N2, C1 mass degenerate
on-shell N2 → *W* + C1 forbidden



$\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^\pm$



$\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0$



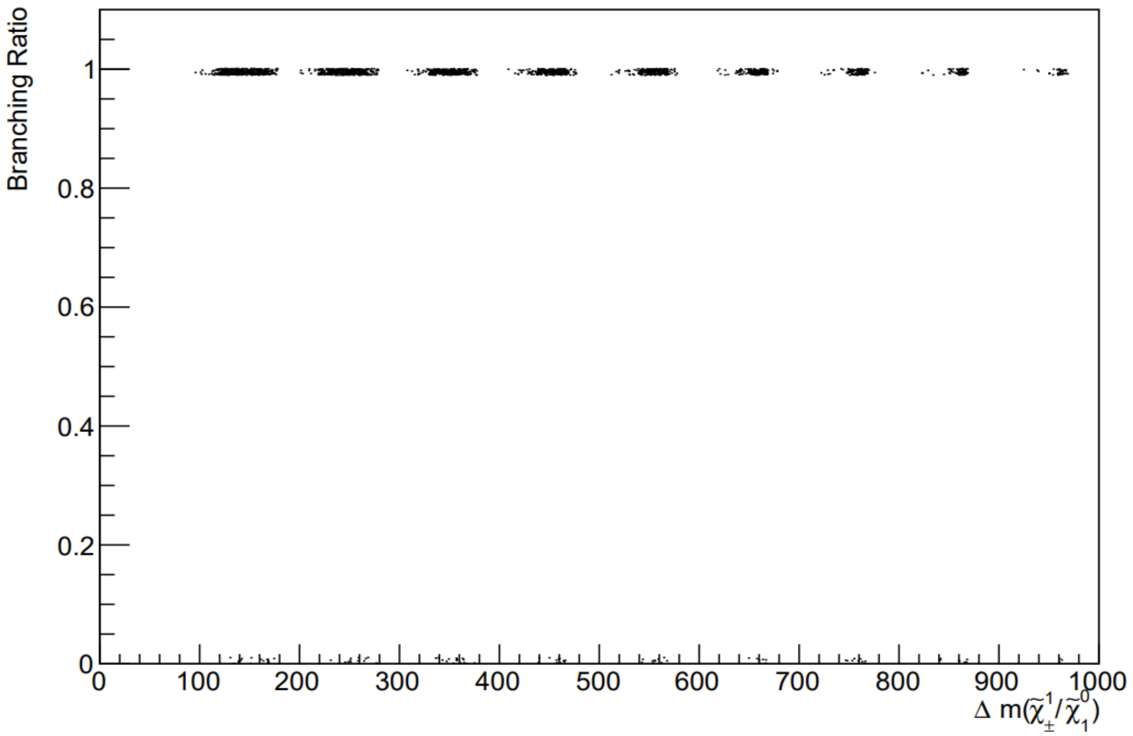
$\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$

X-axis: N2, N1 mass splitting

M_1/M_2 noncontinuous → Stepwise structure
μ → Vertical structure

Results – Chargino1 Branching Ratios

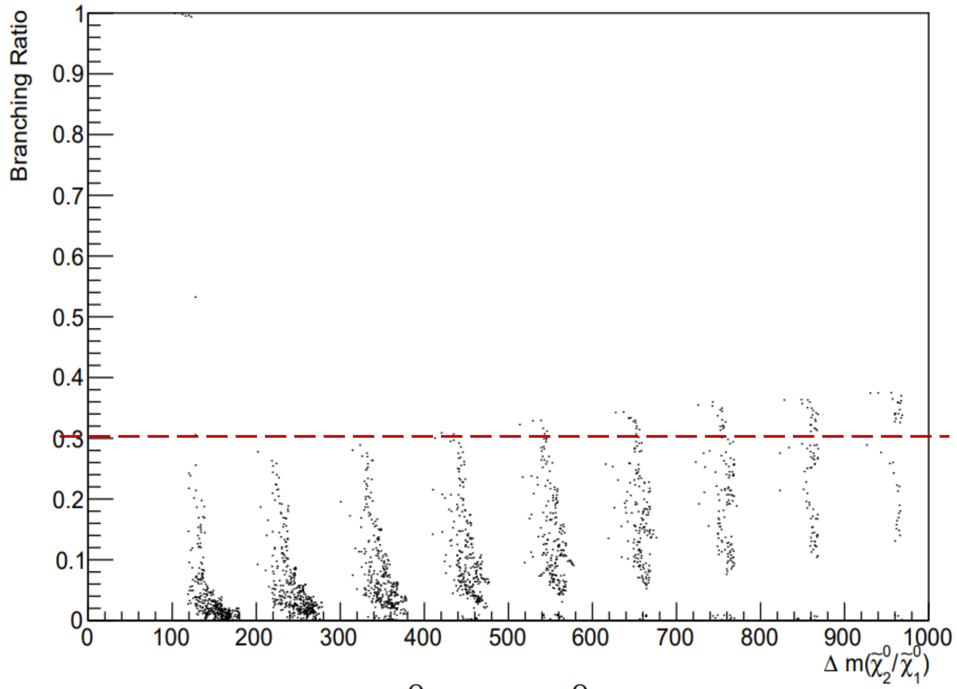
C1 → *Z/h* + chargino forbidden



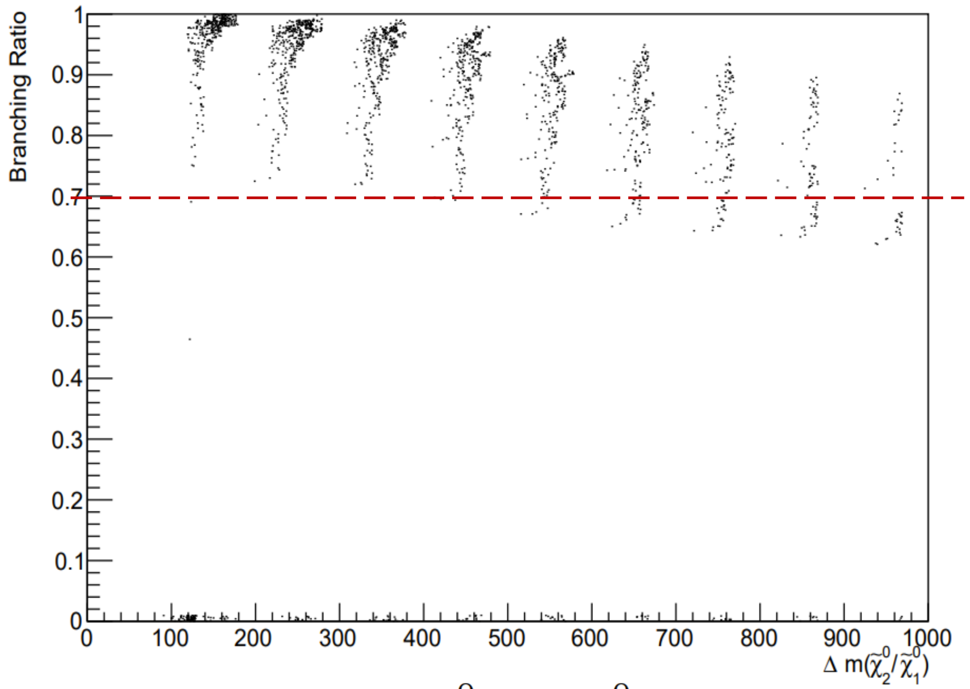
$$\tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0$$

X-axis: C1, N1 mass splitting

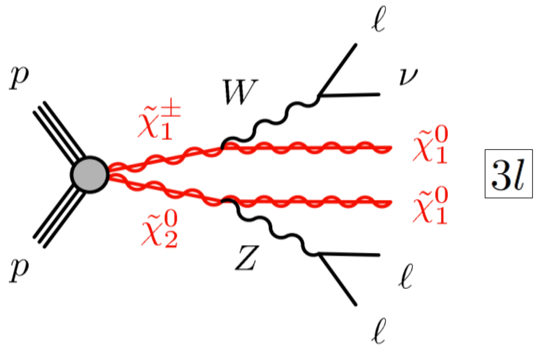
BR(N2)

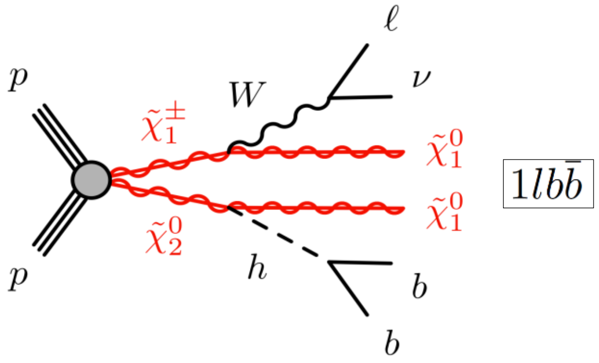


$$\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0$$

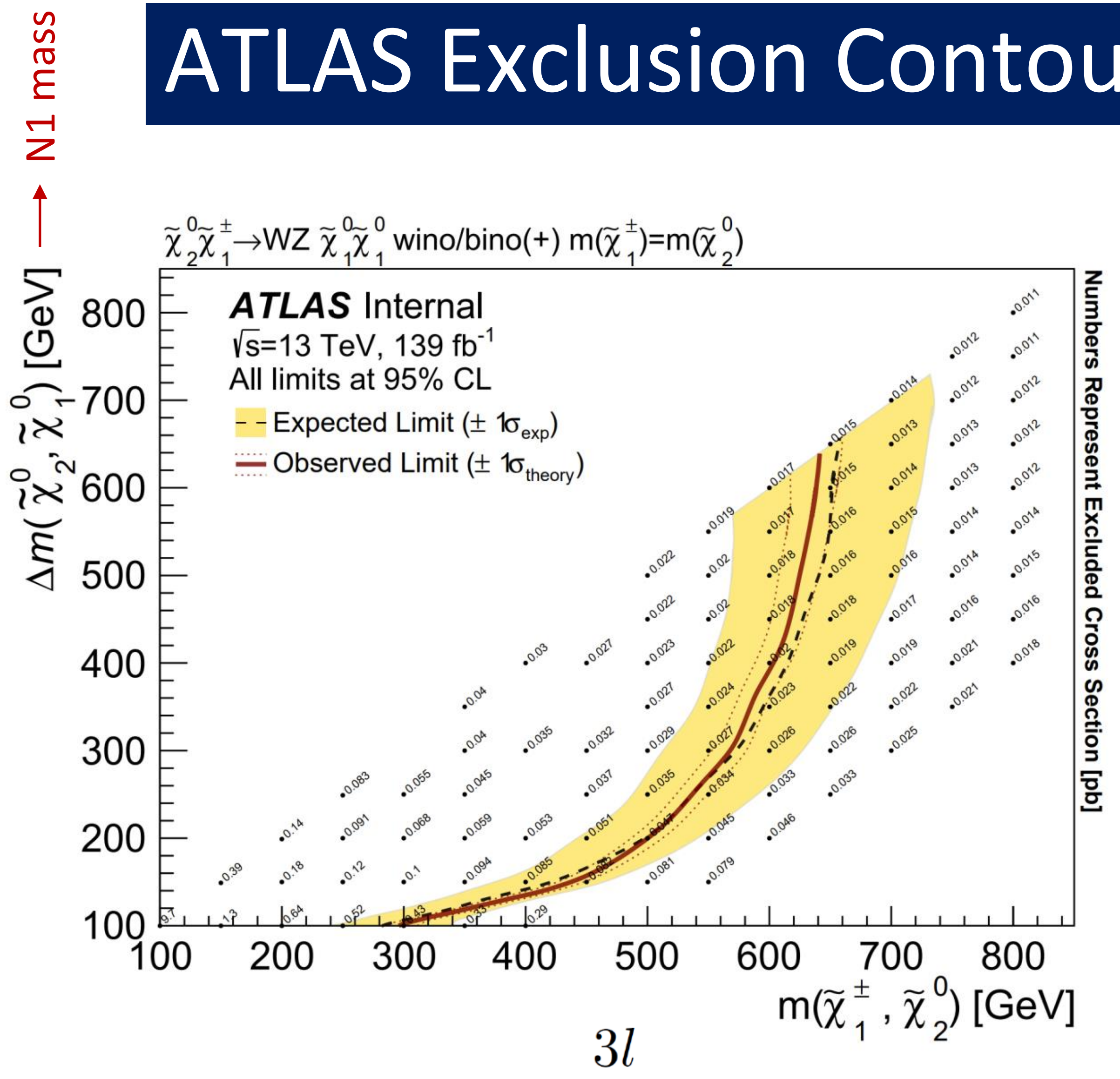


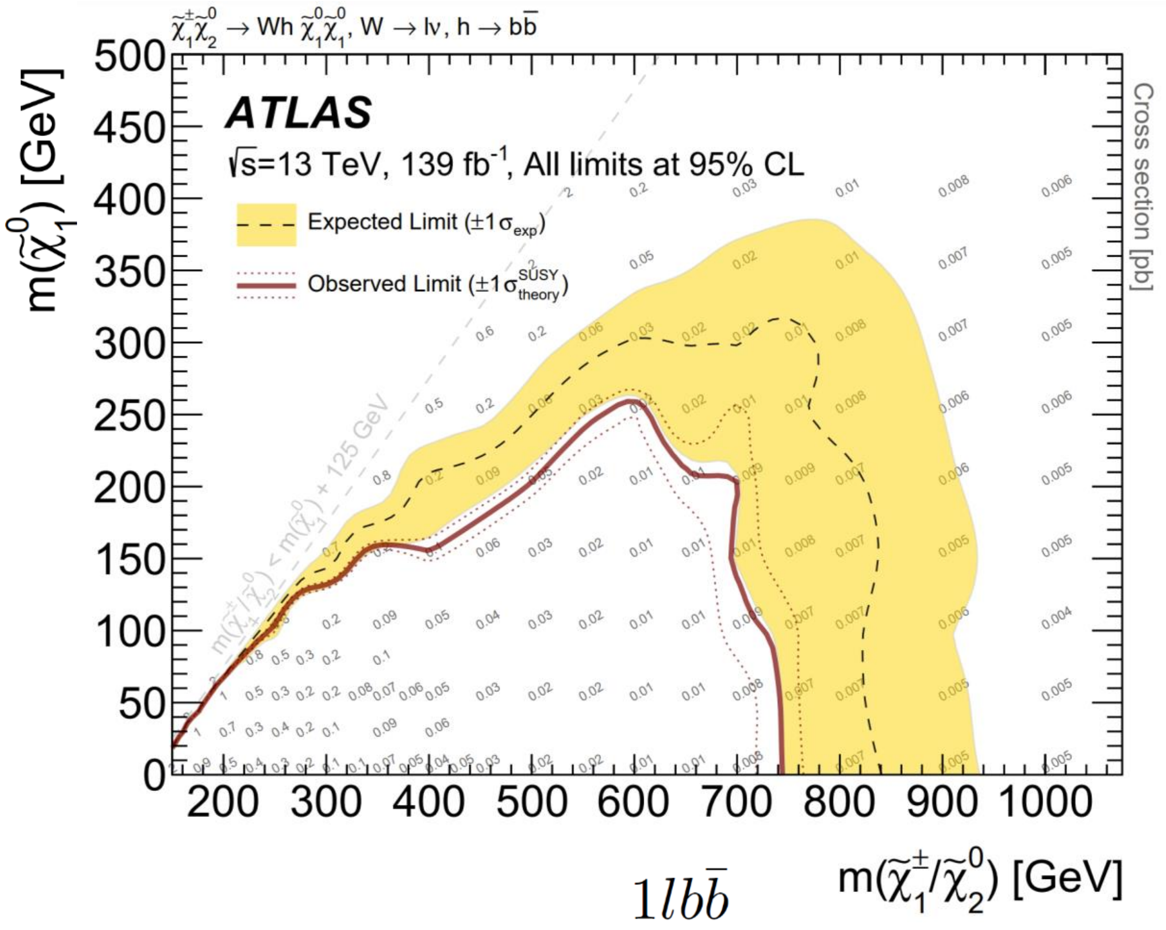
$$\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$$





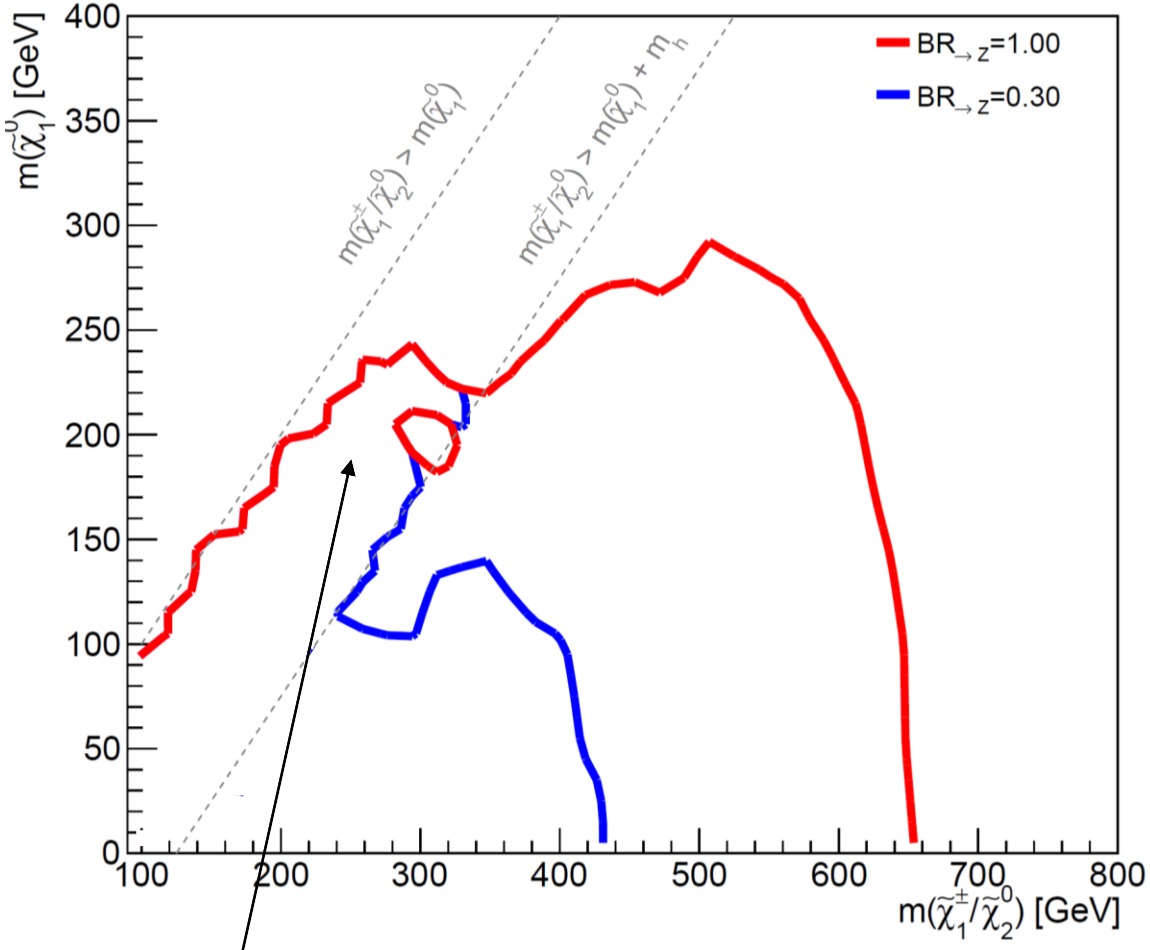
ATLAS Exclusion Contours



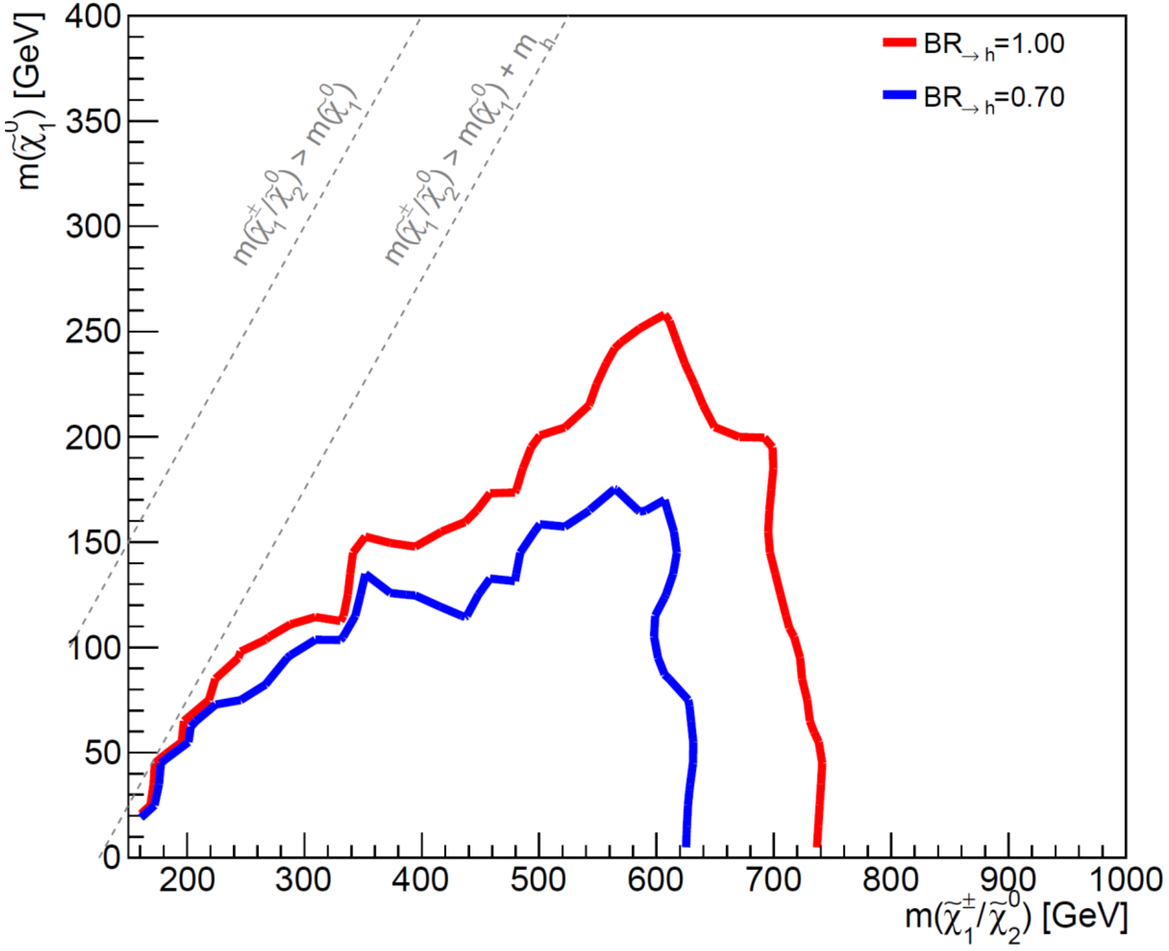


1. **Scaled excluded cross-section values observed (overlaid points) by BR(N2 → *Z/h*)**
2. **Compared ^ to the upper-limit signal production cross section for each mass point**

Results – Reinterpreted Exclusion Limits



$3l$



$1lb\bar{b}$

on-shell N2 → *h* + LSP forbidden

C1/N2 mass exclusions drop by >100 GeV !

BR(N2) Dependence on μ

Previously, only $\mu > 0$ was considered…

- no MSSM constraints on the sign of μ

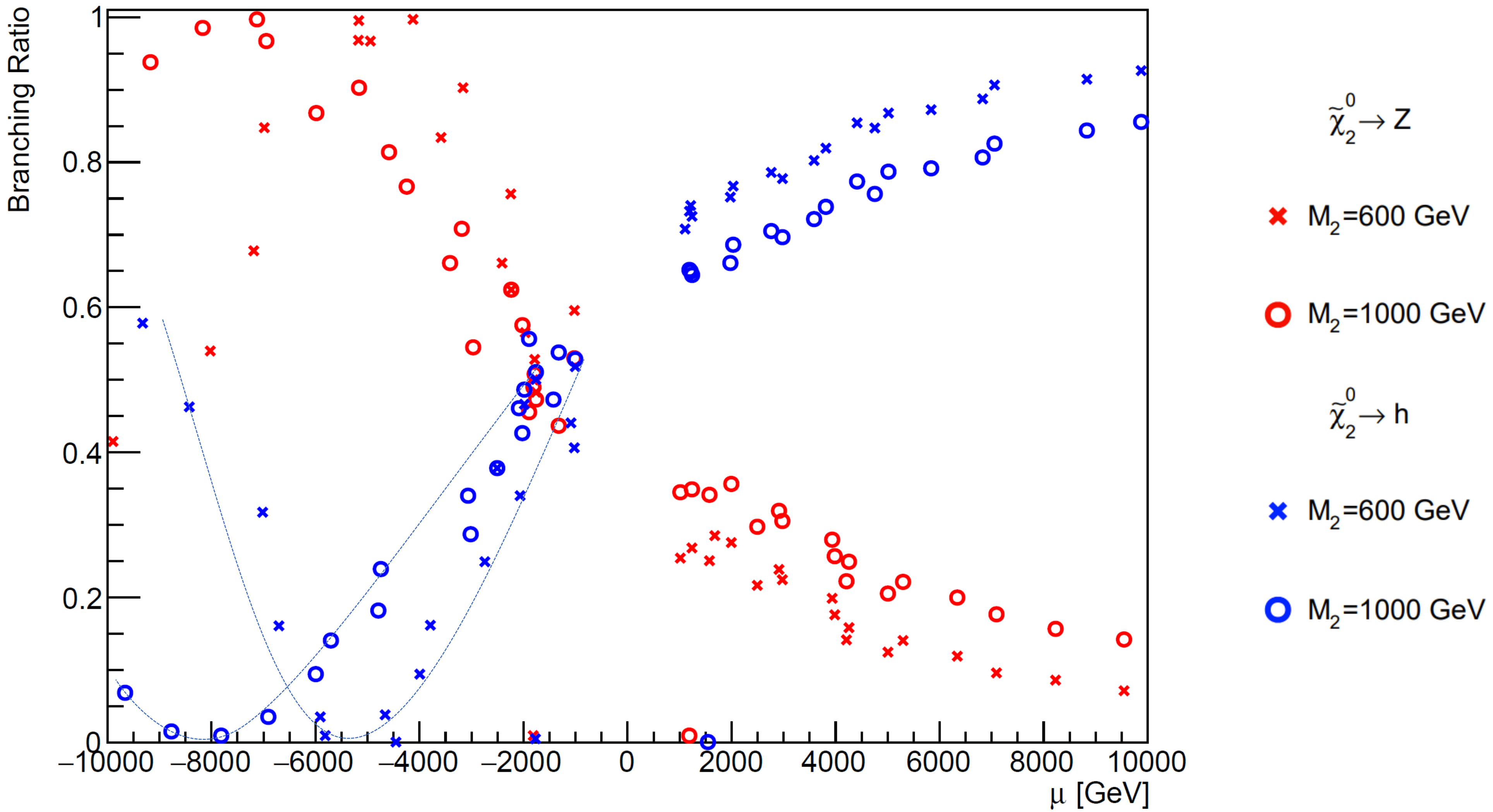
Now $\mu < 0$ will be studied,

Scan Details:

- $\mathbf{M_1} \in \{100\}$ GeV
- $\mathbf{M_2} \in \{600, 1000\}$ GeV
- $\boldsymbol{\mu} \in [-10, 10]$ TeV in steps of 100 - 1000 GeV where $|\mu|>1000$ GeV
- $\mathbf{tan\beta} = \{30\}$

Results – μ

N2 begins to favor decays through *Z* at μ < 0



BR values at μ < - 6 TeV ??

Conclusions

For $0 < M_1 < M_2 < \mu$, **BR(N2 → *Z* + LSP) ≲ 0.30** and **BR(N2 → *h* + LSP) ≳ 0.70**

- BR(C1 → *W* + LSP) = 1.00 - consistent with simplified assumptions
- 0.30 BR(N2 → *Z* + LSP) for the $3l$ analysis reduces excluded C1/N2 masses by **~225 GeV**
- 0.70 BR(N2 → *h* + LSP) for the $1lb\bar{b}$ analysis reduces excluded C1/N2 masses by **~115 GeV**

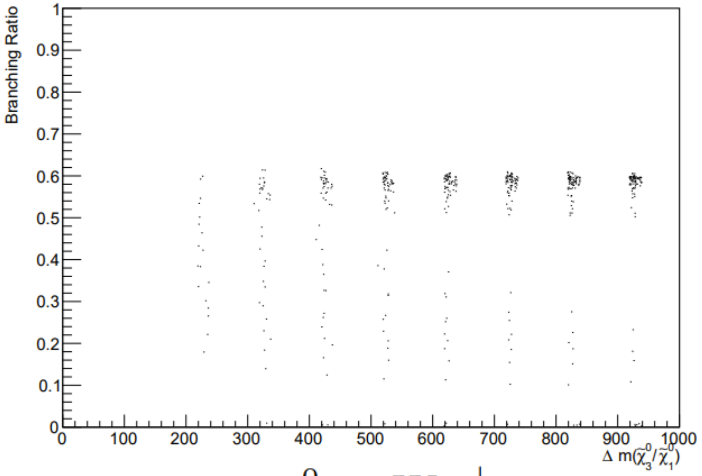
However, BR(N2) is highly dependent on the sign of μ

Future considerations :

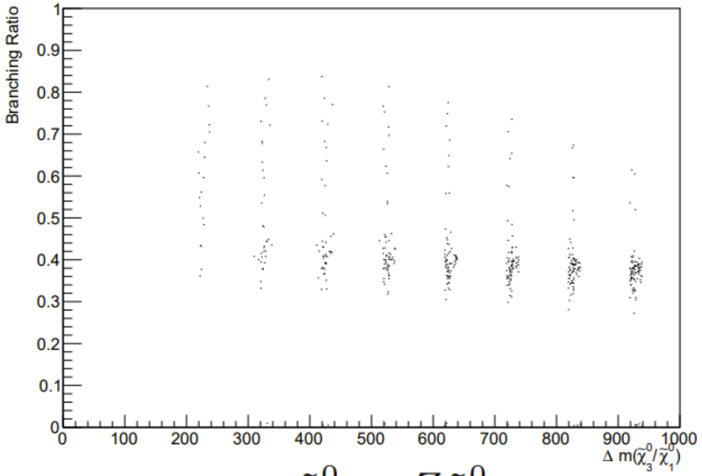
- Model space where M_1 and M_2/μ have opposite signs within wino/bino scenario $|M_1|<|M_2|<|\mu|$
- Decays involving off-shell bosons

pMSSM space will become more important with LHC Run 3 and HL-LHC and will better inform the direction of future searches and the comparison of reach for future colliders

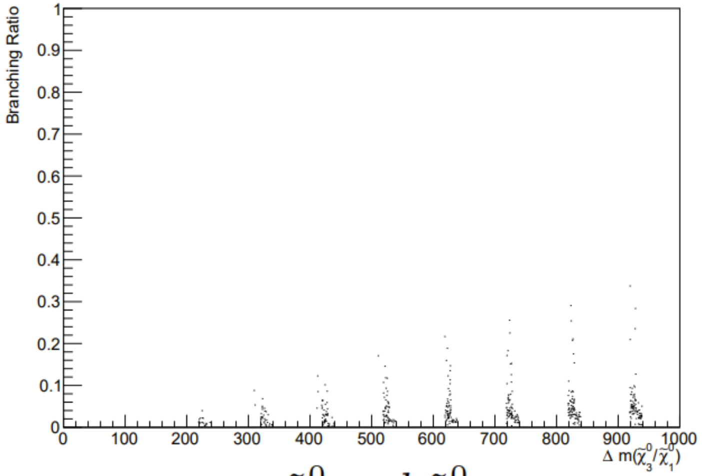
Results – Neutralino Branching Ratios



$\tilde{\chi}_3^0 \rightarrow W\tilde{\chi}_i^{\pm}$

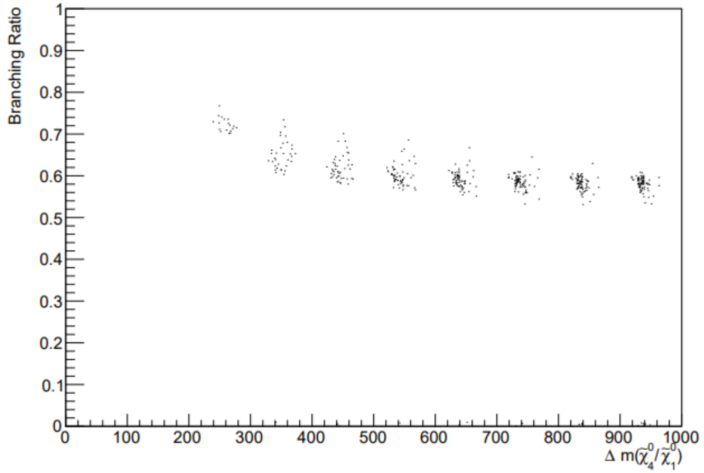


$\tilde{\chi}_3^0 \rightarrow Z\tilde{\chi}_i^{0}$

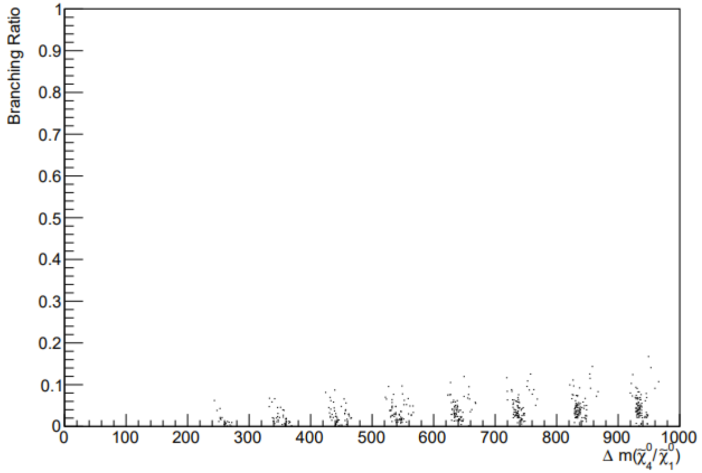


$\tilde{\chi}_3^0 \rightarrow h\tilde{\chi}_i^{0}$

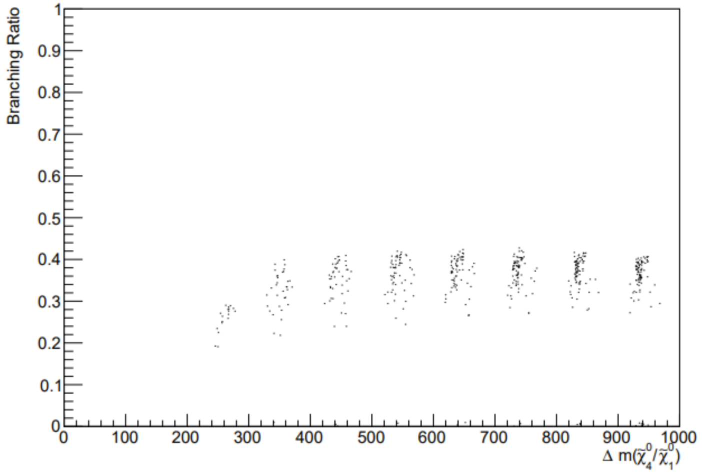
X-axis: N3/N4, N1 mass splitting



$\tilde{\chi}_4^0 \rightarrow W\tilde{\chi}_i^{\pm}$



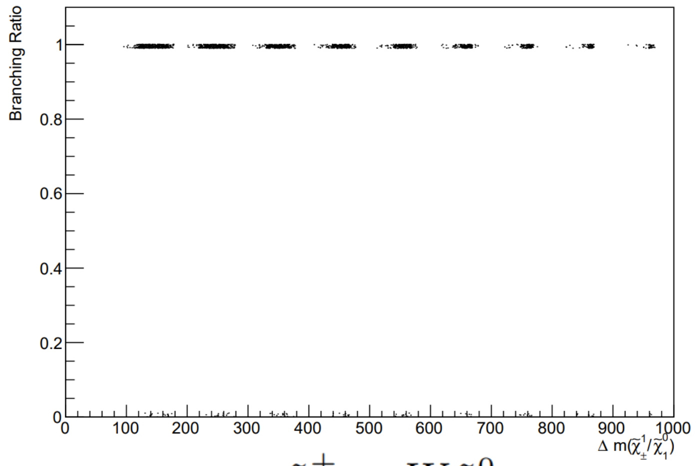
$\tilde{\chi}_4^0 \rightarrow Z\tilde{\chi}_i^{0}$



$\tilde{\chi}_4^0 \rightarrow h\tilde{\chi}_i^{0}$

Results – Chargino Branching Ratios

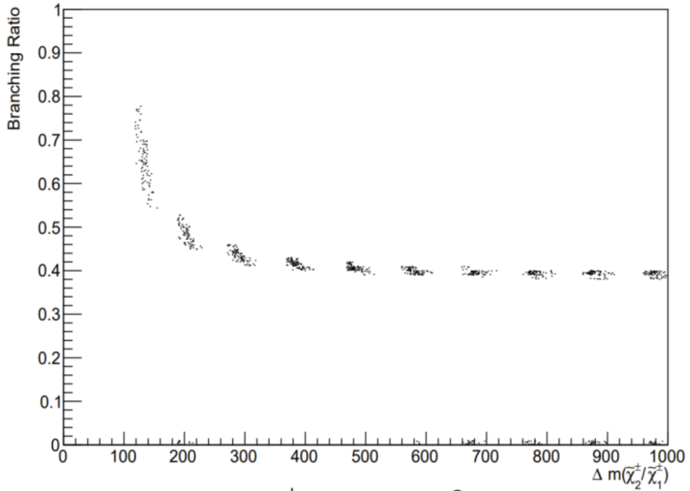
C1 → *Z/h* + chargino forbidden



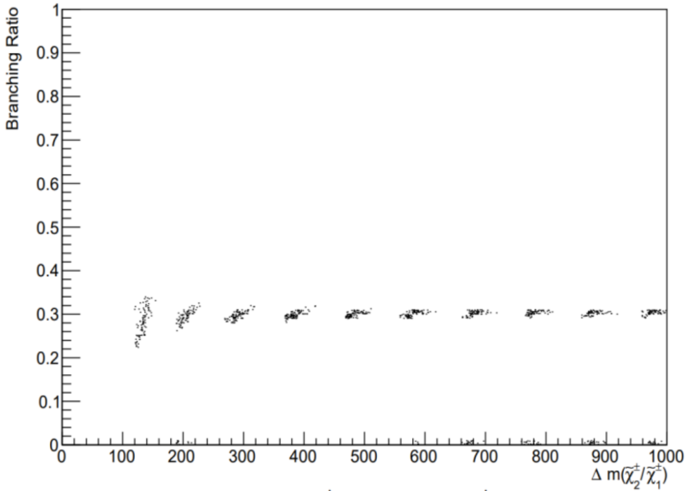
$\tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0$

X-axis: C1, N1 mass splitting

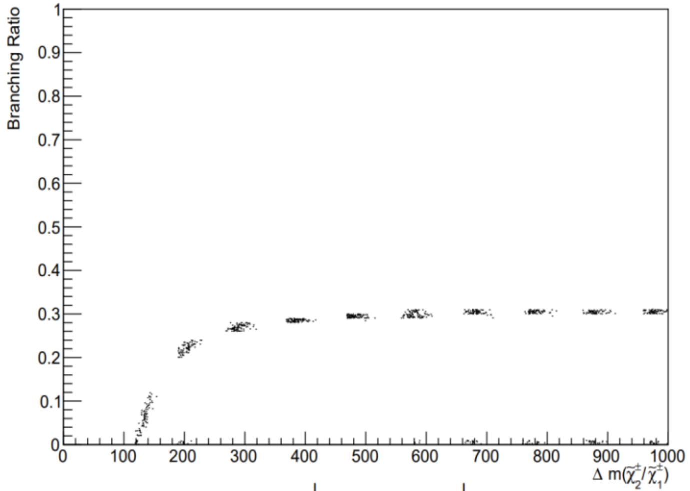
X-axis: C2, C1 mass splitting



$\tilde{\chi}_2^{\pm} \rightarrow W\tilde{\chi}_i^0$

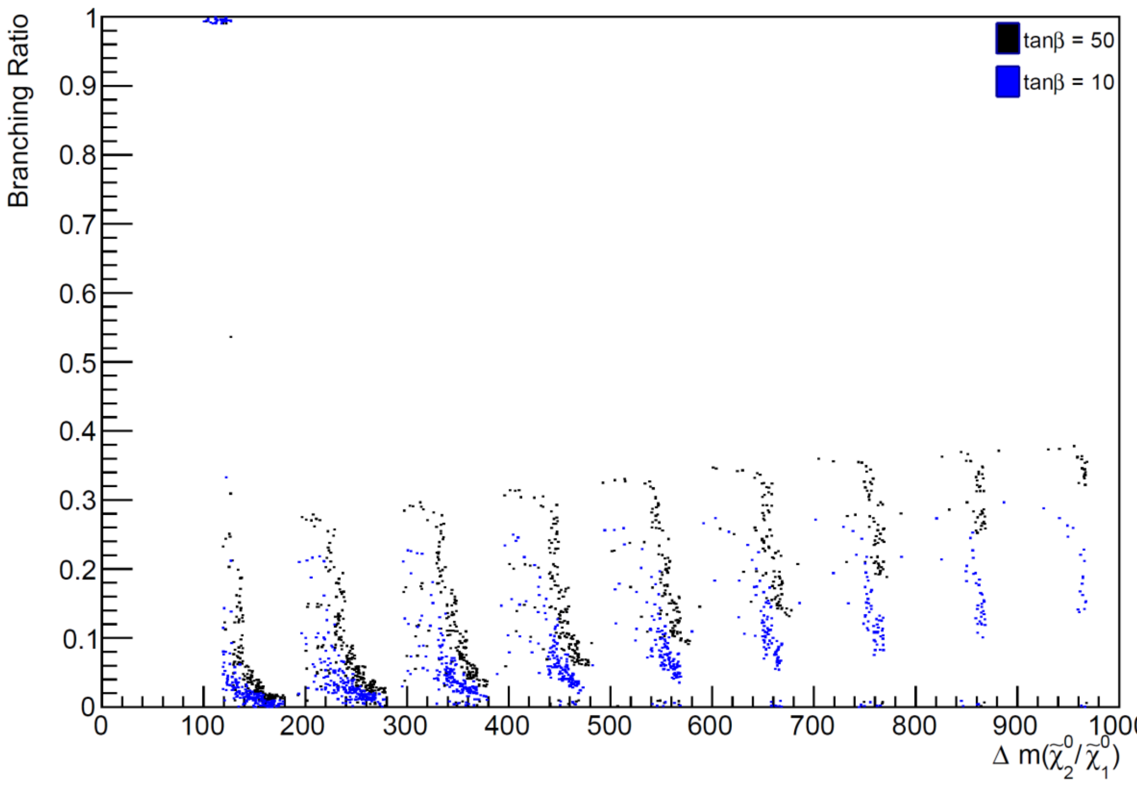


$\tilde{\chi}_2^{\pm} \rightarrow Z\tilde{\chi}_1^{\pm}$

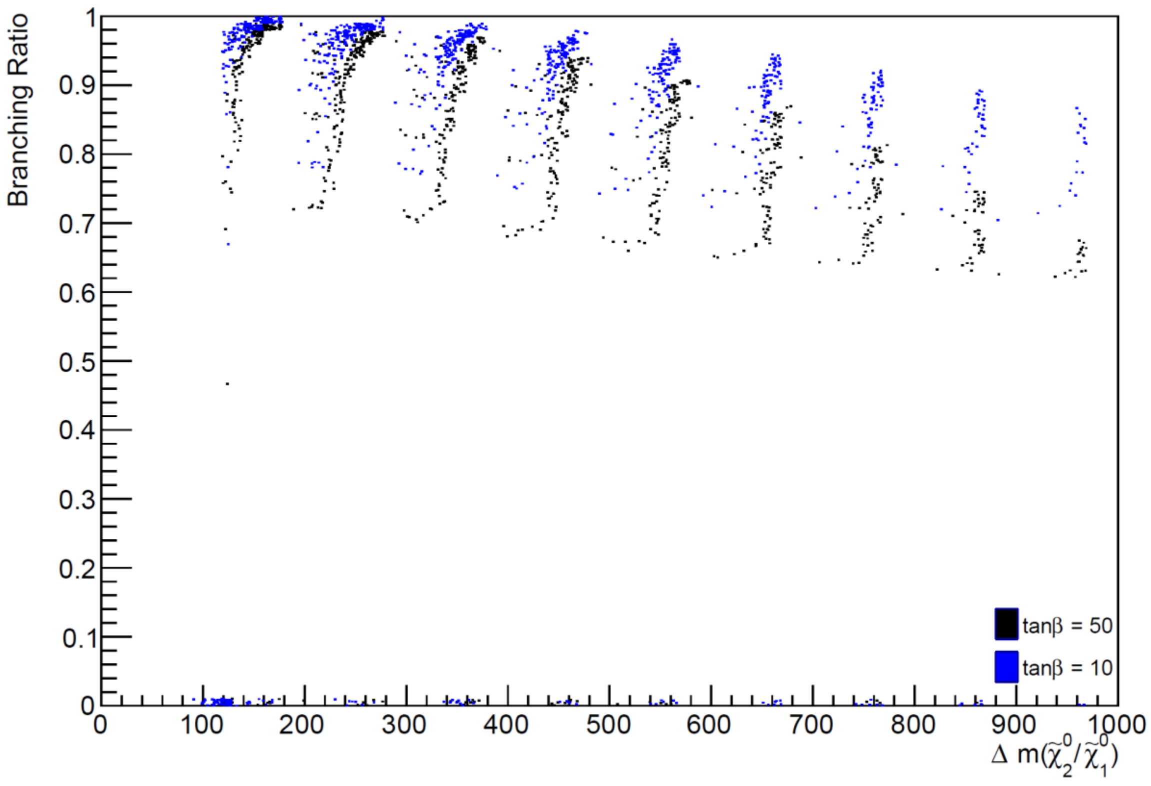


$\tilde{\chi}_2^{\pm} \rightarrow h\tilde{\chi}_1^{\pm}$

Results – tanβ



$$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$$



$$\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$$