Zeroing in on Supersymmetric Radiation Amplitude Zeros

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August 30, 2011
SUSY11

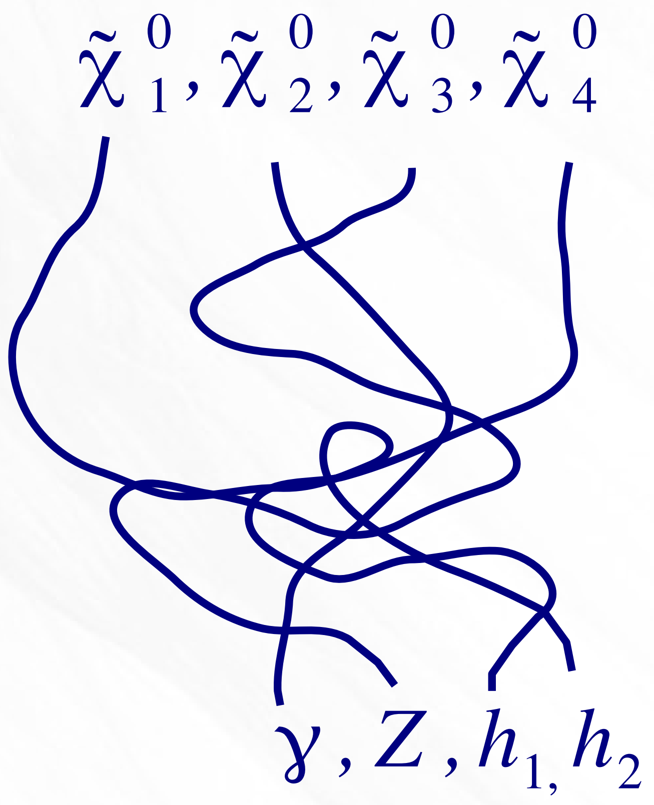
based on arXiv:1109.XXXX
(JoAnne Hewett, AI, Tom Rizzo)

Outline

- Motivation: neutralinos in the MSSM
- Radiation amplitude zeros (RAZ)
- Observing supersymmetric RAZ at the LHC

Motivation

- The neutralino sector of the Minimal Supersymmetric Standard Model has a rich phenomenology that is largely dependent on the mixing of the gaugino and Higgsino eigenstates



Motivation

- As the LHC makes more neutralinos, it will become important to know their properties
- While specific breaking scenarios predict various mixing arrangements for the neutralinos, bottom-up approaches to determining their content are few and far between (Kane et al., 1105.3742; Allanach et al., 1010.4261; Tata, talk on Sunday)
- How to untangle neutralino mixing in a model-independent fashion?

Radiation Amplitude Zeros

- Vanishing amplitudes in specific regions of phase space for processes with external gauge bosons
- RAZ were first seen, unexpectedly, in the calculation of $d\,\bar{u} \rightarrow W\,\gamma$ production

Magnetic Moment of Weak Bosons Produced in pp and $p\bar{p}$ Collisions

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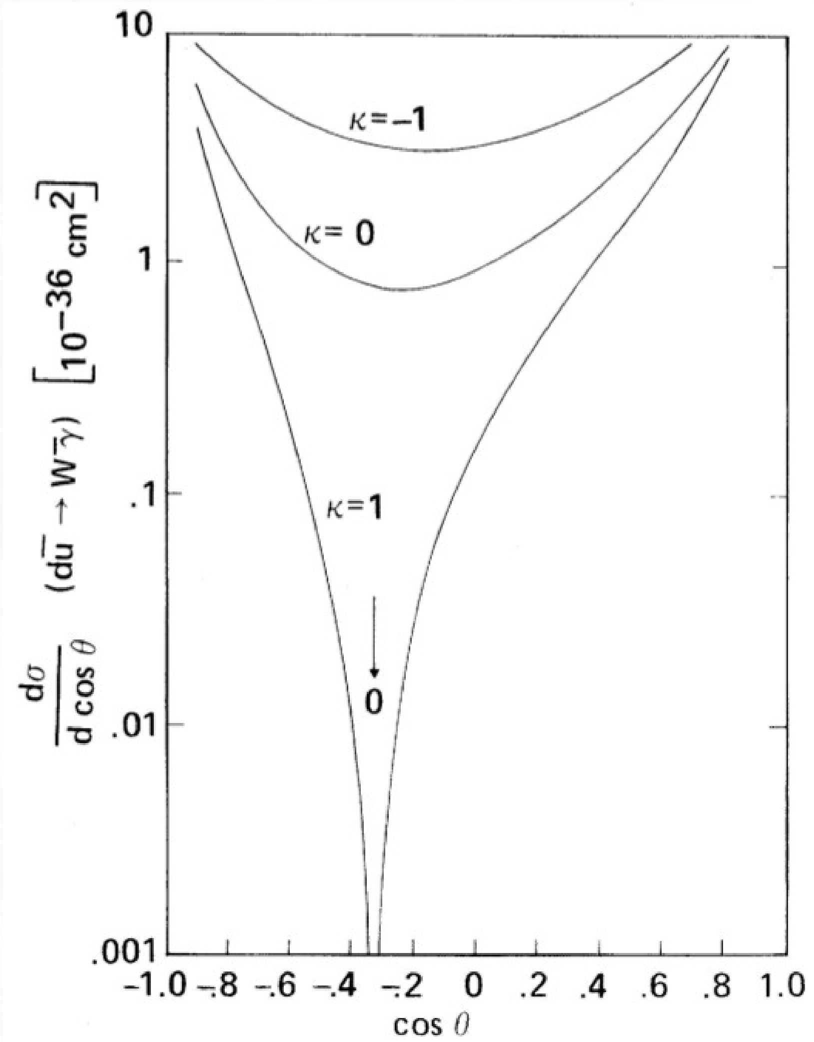
We suggest that the reactions $pp \rightarrow W^{\pm}\gamma X$ and $p\bar{p} \rightarrow W^{\pm}\gamma X$ are good candidates for measuring the magnetic moment parameter κ in $\mu_W = (e/2M_W)(1+\kappa)$. The angular distribution of the W bosons in $p\bar{p} \rightarrow W^{\pm}\gamma X$ is particularly sensitive to this parameter. For the gauge-theory value of $\kappa = 1$, we have found a peculiar zero in $d\sigma(d\bar{u} \rightarrow W^{-}\gamma)/d\cos\theta$ at $\cos\theta = -\frac{1}{3}$, the location of this zero depending on the quark charge through $\cos\theta = -(1+2Q_d)$. A similar zero occurs in $d\sigma(u\bar{d} \rightarrow W^{+}\gamma)/d\cos\theta$. We can offer no explanation for this behavior.

Radiation Amplitude Zeros

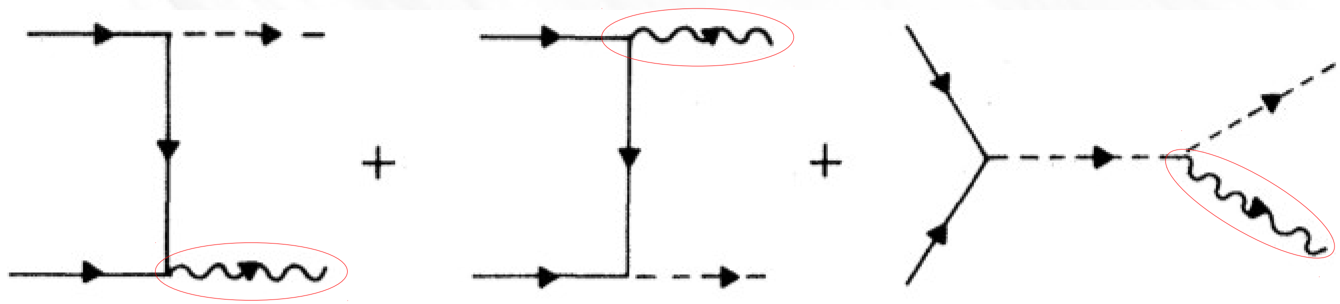
- This amplitude zero has been studied at the Tevatron
- Presence of the RAZ at $\cos\theta = -\frac{1}{3}$ allows us to constrain anomalous couplings of the W



Why do RAZ happen?

- Diagrams for processes with external photons can be thought of as arising from attaching photons to a simpler diagram in all possible places
- Adding a photon introduces a factor to a diagram which only depends on the spin structure, charges, and momenta

$$M(d\bar{u} \rightarrow W\gamma) \sim f(Q_i, p_i^{\mu}) \cdot M(d\bar{u} \rightarrow W)$$



Why do RAZ happen?

- In specific regions of phase space, this extra factor vanishes since it corresponds to a Lorentz transformation (Brown, Kowalski, Brodsky)
- For 2-2 scattering with a photon in the final state, the kinematic region with an amplitude zero is given by $\cos\theta = \frac{Q_1 - Q_2}{Q_1 + Q_2}$
- e.g. for $W\gamma$ production, we have $Q_d = -\frac{1}{3}, Q_{\bar{u}} = -\frac{2}{3}$

Why do RAZ happen?

- Amplitude zeros also happen for processes with external gauge bosons other than photons

$$\cos\theta = \frac{g_1 - g_2}{g_1 + g_2}$$

- For massive gauge bosons, RAZ are only approximate, because of production of longitudinally polarized bosons
- e.g. $q_1 \overline{q_2} \rightarrow W Z$ production (Baur, Han, Ohnemus)

RAZ in Supersymmetry

- Given the zero in $W\gamma$ production, it's natural to expect a zero in chargino-neutralino production
- But the existence of a RAZ here depends on the neutralino composition! (need RAZ at $\cos\theta < 1$)

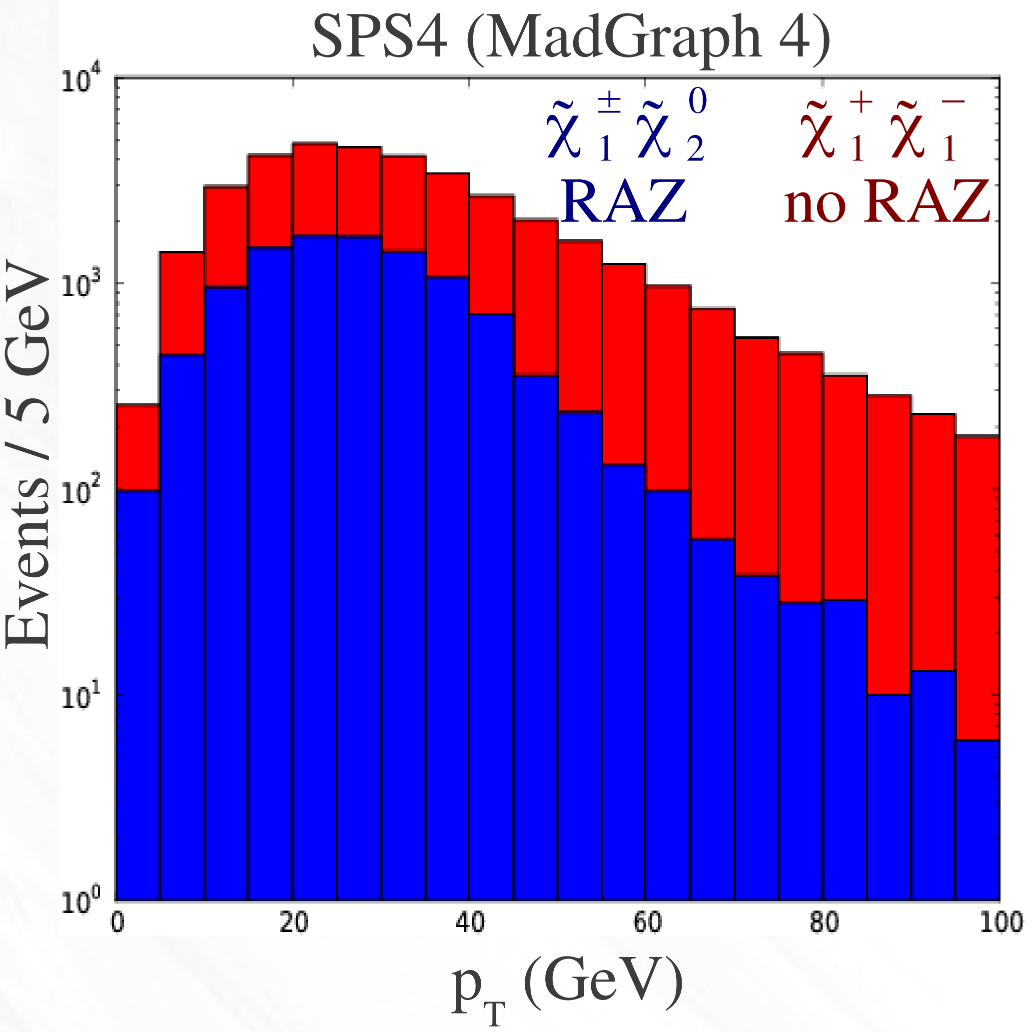
	$\tilde{W}^{\pm}$	$\tilde{H}^{\pm}$
$\tilde{B}$	No physical RAZ	No tree level diagrams
$\tilde{W}^{3}$	RAZ at $\cos\theta^{*} = 0$	No tree level diagrams
$\tilde{H}_{1,2}$	No tree level diagrams	No physical RAZ

RAZ in Supersymmetry

- There is no amplitude zero in chargino-neutralino production except when the neutralino is a wino, so we can use the presence of a RAZ to probe the wino content of the neutralino
- We now turn to methods of observing the zero experimentally in $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow 3l + MET$
- Clean signal (WZ background), can't do with $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$
- We assume 1 ab^{-1} of LHC data at 14 TeV; not for discovery but exploration after SUSY is found

Turning to Trileptons

- Consider chargino-neutralino production with trilepton decay
- When the neutralino is wino-like, we expect fewer events at low $\cos\theta$ because of the amplitude zero, and hence a lower number of high-p_T leptons



Turning to Trileptons

- We choose to look at the softest lepton p_T, seeing how many trilepton events from chargino-neutralino production remained as the minimum lepton p_T was increased
- To calibrate how fast the number of events drops with increasing p_T cut, we compare to a process that never exhibits an amplitude zero, chargino pair production

$$R_{23}(p_T) = \frac{N(\tilde{\chi}_1^+ + \tilde{\chi}_1^- \rightarrow 2l + MET)}{N(\tilde{\chi}_1^+ + \tilde{\chi}_2^0 \rightarrow 3l + MET)}$$

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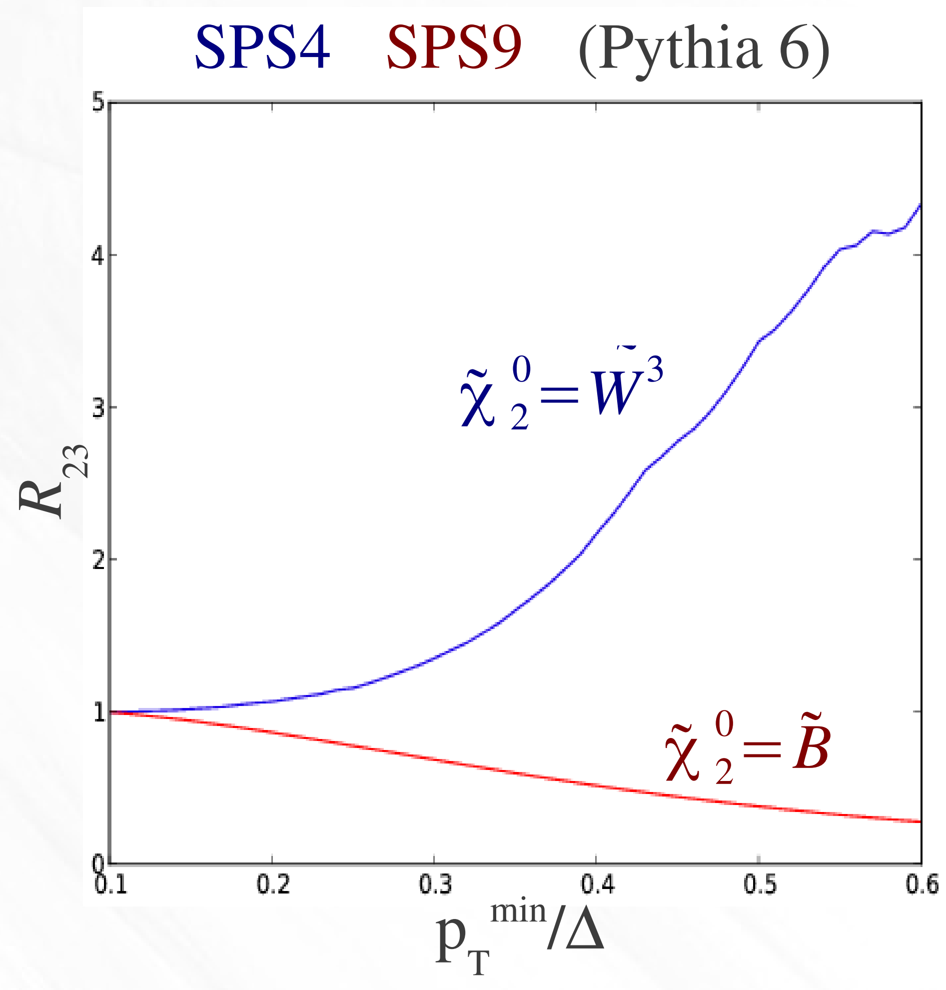
- Events without ISR, FSR, or fragmentation (negligible effect)
- Require that leptons have rapidity < 2.5
- Δ is chargino-LSP mass splitting
- Ratio rises with increasing cut when neutralino is wino-like



A Potential Problem?

- When the chargino-LSP mass splitting is much greater than the neutralino-LSP mass splitting, R_{23} compares the spectra of leptons that are generally coming from different decays
- To account for different possible SUSY spectra, we also construct an analogous ratio comparing chargino-neutralino associated production to neutralino pair production

$$R_{43}(p_T) = \frac{N(\tilde{\chi}_2^0 + \tilde{\chi}_2^0 \rightarrow 4l + MET)}{N(\tilde{\chi}_1^+ + \tilde{\chi}_2^0 \rightarrow 3l + MET)}$$

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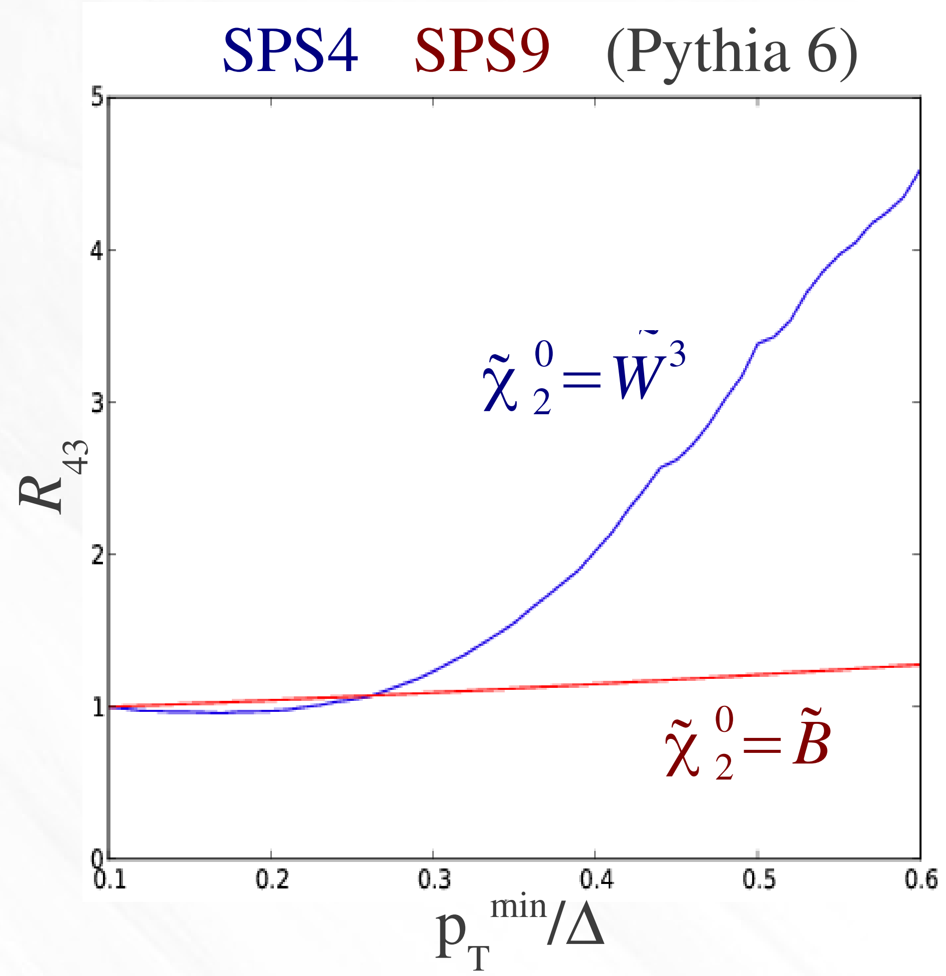
- R_{23} and R_{43} complement each other
- For a wino-like neutralino, both ratios tend to rise sharply with increasing leptonic transverse momentum cut



Investigating Neutralino Mixing

- The more leptons there are in the final state, the more events a transverse momentum cut removes

$$R_{23}(p_T) = \frac{N(\tilde{\chi}_1^+ + \tilde{\chi}_1^- \rightarrow 2l + MET)}{N(\tilde{\chi}_1^+ + \tilde{\chi}_2^0 \rightarrow 3l + MET)}$$

$$R_{43}(p_T) = \frac{N(\tilde{\chi}_2^0 + \tilde{\chi}_2^0 \rightarrow 4l + MET)}{N(\tilde{\chi}_1^+ + \tilde{\chi}_2^0 \rightarrow 3l + MET)}$$

- Low $R_{23} \rightarrow$ low $|N_{22}|$
- High $R_{43} \rightarrow$ high $|N_{22}|$

N_{22} = wino content of $\tilde{\chi}_2^0$

Using the pMSSM

- To test our techniques, we applied them to the results of a previous scan of the phenomenological MSSM, which imposes only those constraints on the full MSSM parameter space that are experimentally motivated, e.g. minimal flavor violation
- This large set of pMSSM models contains a wide variety of neutralino mixing schemes, providing an ideal testing ground for our method
- For more details, see Berger et al., arXiv:0812.0980

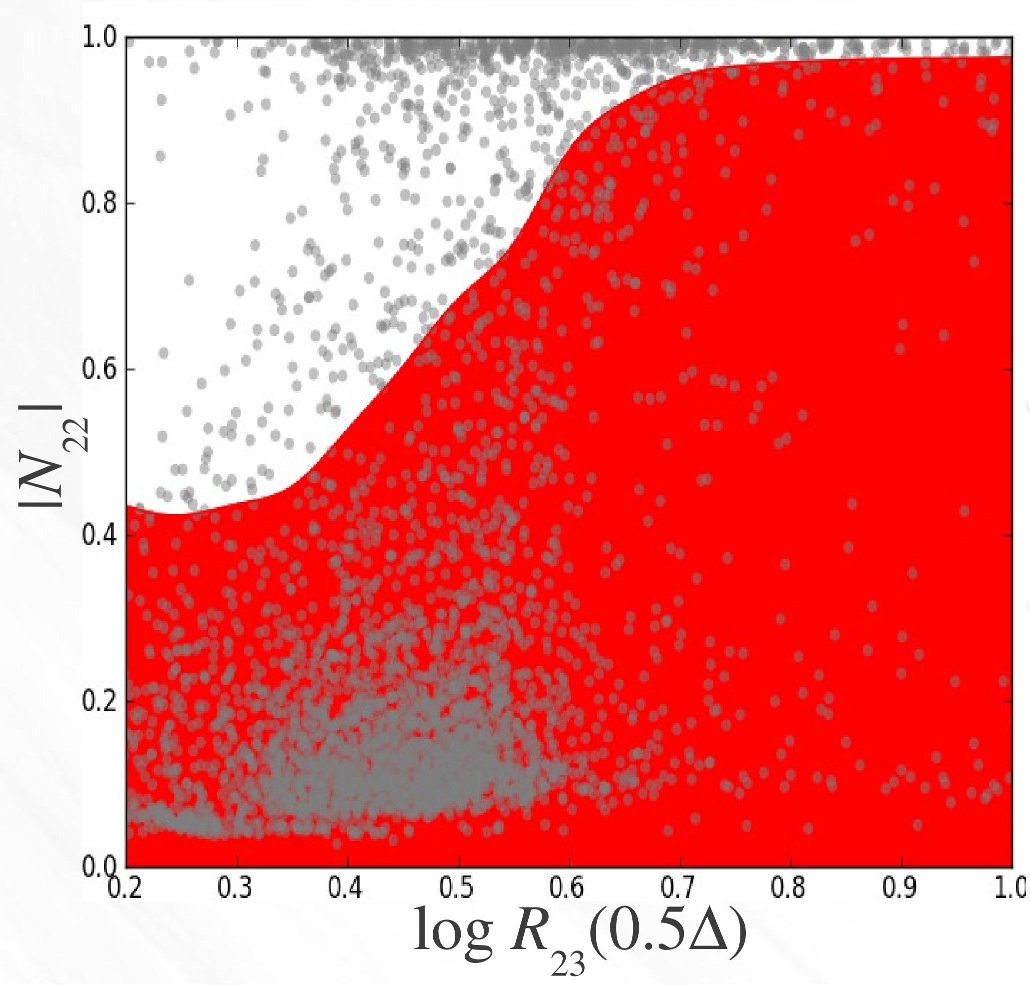
Using the pMSSM

- 50 GeV ≤ $|M_{1,2}, \mu|$ ≤ 1 TeV
- 100 GeV ≤ M_3 ≤ 1 TeV
- 1 ≤ tan β ≤ 50
- 43.5 GeV ≤ m_A ≤ 1 TeV
- 100 GeV ≤ m_f ≤ 1 TeV
- $|A_{t,b,\tau}|$ ≤ 1 TeV

- After applying many theoretical and experimental constraints, ~70000 models that were still viable before the LHC
- Here, we only consider models with chargino-LSP mass splittings above 50 GeV (~16%)

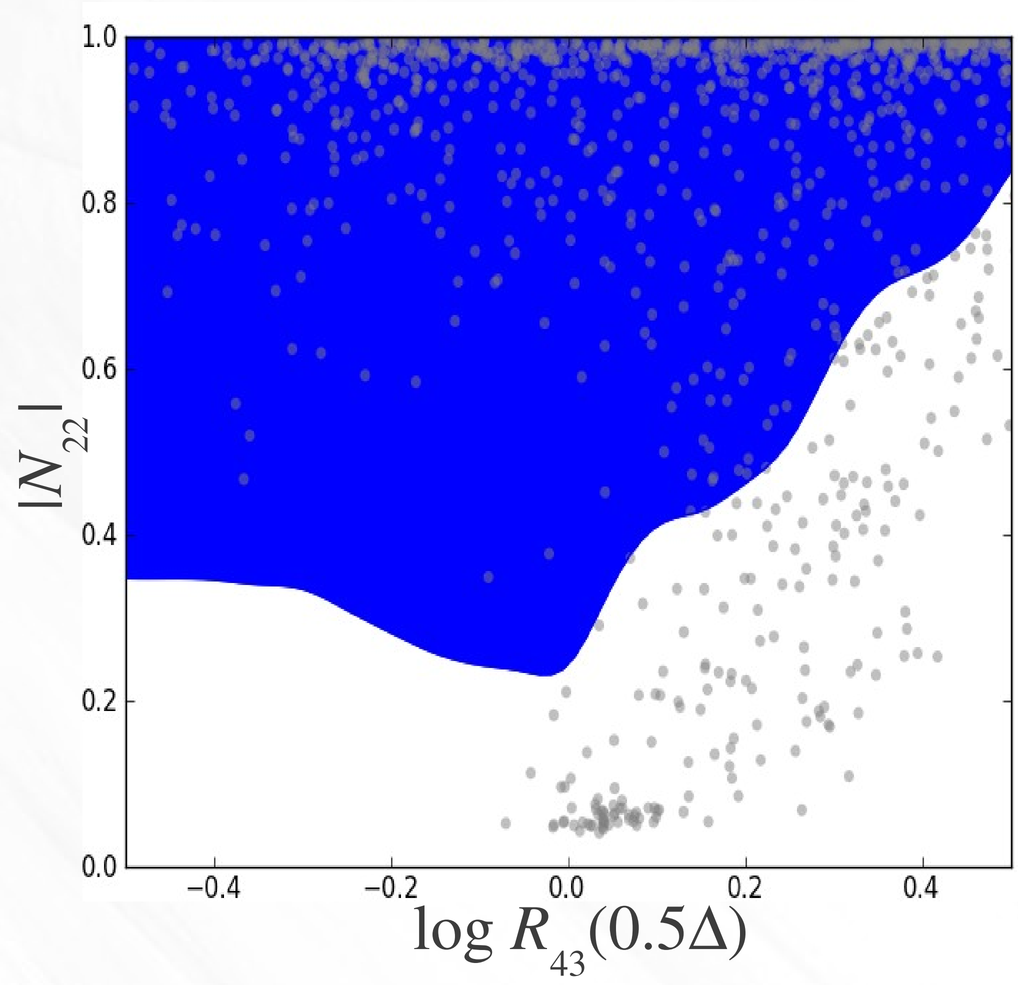
Results from the pMSSM

- Only use models that should have sufficient statistics with 1 ab^{-1} (~4400) at LHC-14
- Within our model set, the 90% upper limits on the wino content of the second neutralino are indicated by the shaded region



Results from the pMSSM

- Second neutralino tends to be heavier than lightest chargino in the model set, so only ~1200 models for looking at R_{43}
- R_{23} and R_{43} are useful for setting upper and lower bounds on the wino-ness of the second neutralino, respectively



Summary

- Radiation amplitude zeros, having previously been used to test the Standard Model, show promise in probing the coupling structure of supersymmetry
- Looking at the potential effects of a RAZ in associated chargino-neutralino production, we have demonstrated the power of a technique to investigate the neutralino mixing matrix
- As the LHC ramps up, RAZ should prove useful once again in testing SUSY gauge theory