LHC Signatures of Light Gauginos in String Motivated Models

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Based on work done in collaboration with
Gordon Kane and Ran Lu arXiv:1204.2795 (.v2 coming soon)

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Outline

- I. Motivation for MSSM with heavy scalars and Wino-LSP
- II. Review of canonical search strategy for gauginos at LHC
- III. Physics of disappearing chargino tracks
- IV. Implications of current ATLAS search for disapearing tracks
- V. Conclusion and outlook

Motivation for Heavy Scalars and Wino-LSP

Heavy scalars:

- In theories with moduli fields, cosmological moduli problem avoided if $m_\phi > \mathcal{O}(10)$ TeV. In generic SUGRA theories, $m_\phi = \mathcal{O}(1) m_{3/2}$.

  Ellis, Nanopoulos, Quiros Phys. Lett B174(1986)

  Moroi, Yamaguchi, Yanagida arXiv: 9409367

- In addition, heavy scalars mitigate SUSY flavor and CP problems

  Cohen, Kaplan, Nelson arXiv:9607394; Wells arXiv: 0411041

Wino-LSP:

- For Wino-LSPs produced non-thermally via decay of heavy moduli, proper relic densities can be achieved for $m_{LSP} <$TeV.

  Randall, Moroi arXiv: 9906527

- Wino-LSP generic in AMSB models.

Motivation for Heavy Scalars and Wino-LSP: G2-MSSM

Concrete M-theory motivated framework: G2-MSSM

Acharya, Kane et. al arXiv:0801.0478

- Cosmological moduli problem requires $m_{3/2} \gtrsim 30$ TeV

  Acharya, Kane, Kumar et. al arXiv:0804.0863

  Acharya, Kane Kuflik arXiv:1006.3272

- Can accomodate Wino-LSP which accounts for PAMELA and FERMI LAT results

  Kane, Lu, Watson arXiV:0906.4765

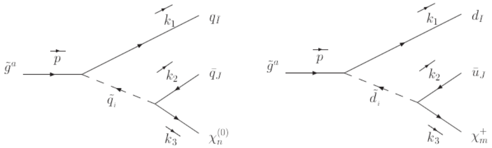
- Predicted m_h agrees with recent LHC result.

  Kane, Kumar, Lu, BZ arXiv:1112.1059

- **See Ran Lu's talk in String/GUTs... going on right now!**

Canonical Gaugino Search Strategies

Gluino Decays:



- $pp \to \tilde{g}\tilde{g} \to \ \geq 4$ hard jets + MET, large effective mass
- In particular, decays to third generation quarks have low SM background Kane, Kuflik, Lu, Wang arXiv:1101.1963
- Care must be taken in interpreting recent LHC limits, as they are **model dependent**.

Direct production of neutralinos and charginos can also potentially be observable with large luminosity.

- E.g. For Bino-LSP, $pp \to \tilde{Z}_2^0 \tilde{W}_1^\pm \to 3\ell$'s + $\not{E}_T$ is potential discovery channel. Baer, Tata et. al arXiV: 1201.5382

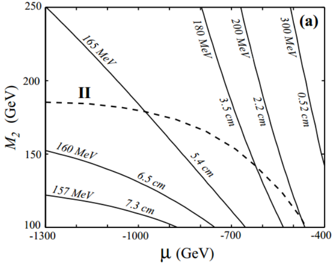
LHC Signatures of a Wino-LSP: Dissapearing Chargino Tracks

For $\mu \gtrsim$ TeV and heavy scalars, mass splitting between $\tilde{W}^0$ and $\tilde{W}^{\pm}$ is largely model independent:

$\Delta M =$

$$\frac{\alpha_2 M_2}{4\pi}\left[f\left(\frac{m_W}{M_2}\right) - {c_W}^2 f\left(\frac{m_Z}{M_2}\right) - {s_W}^2 f\left(0\right)\right]$$

Dobrescu et. al arXiv:9811316



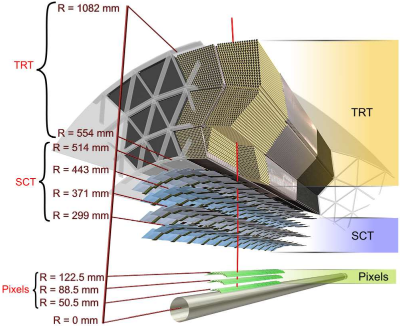
Moroi, Randall et. al arXiv:9904250

- For $\Delta M \gtrsim 140$ MeV, $\tilde{W}^{\pm} \rightarrow \tilde{W}^0 \pi^{\pm}$ dominates, resulting in $c\tau \sim \mathcal{O}(5)$ cm.
  Thomas, Wells arXiv:9804359
  These $\tilde{W}^{\pm}$'s travel a macroscopic distance from the primary vertex.
- This corresponds to a charged, high p_T particle track disappearing within a detector, a striking signal with little SM physics background.

Detecting Dissapearing Chargino Tracks

See Christopher Marino's talk, SUSY I

Fig. 4.2 of https://twiki.cern.ch/twiki/bin/view/AtlasPublic/AtlasTechnicalPaperListOfFigures



- For track reconstruction, $\tilde{W}^{\pm}$ must go past fourth SCT layer, 51.4 cm from beam pipe.
- $\tilde{W}^{\pm}$ must then decay in TRT at distance $d < 86.3$ cm from beam pipe, "disappearing" inside detector.

ATLAS arXiv:1202.4847

Observing direct $\tilde{W}^{+}\tilde{W}^{-}$ production requires large luminosity even for $\sqrt{s} = 14$ TeV, due to small cross section and triggering difficulties

Moroi, Nakayama arXiv:1112.3123.

Look to SUSY decay cascades as potential source of chargino tracks.

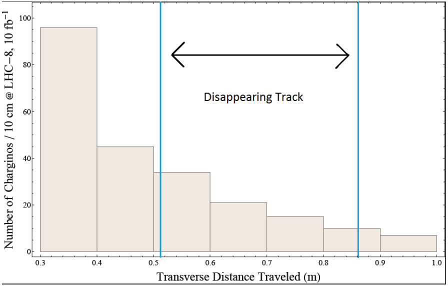
Disappearing Tracks as a Probe of Gluino Production

- Assuming no large squark hierarchy, gluinos have an $\mathcal{O}(50\%)$ B.R. to $\tilde{q}q'\tilde{W}^{\pm}$.
- NLO $\sigma_{\tilde{g}\tilde{g}}$ (PROSPINO) for $m_{\tilde{g}} = 750$ (900) GeV:

$$\sigma_{\tilde{g}\tilde{g}} = 114 \ (24) \ \mathrm{fb}^{-1} \text{ at } \sqrt{s} = 7 \text{ TeV}$$
$$\sigma_{\tilde{g}\tilde{g}} = 235 \ (54) \ \mathrm{fb}^{-1} \text{ at } \sqrt{s} = 8 \text{ TeV}$$

At 10 fb^{-1} of LHC-8 Data (from MadGraph 5):

$m_{\tilde{g}} = 750$ GeV, $m_{\tilde{W}^{\pm}} = 150$ GeV

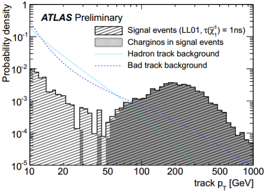


For $m_{\tilde{g}} = 750$ GeV, number of $\tilde{W}^{\pm}$'s traveling past SCT layers:

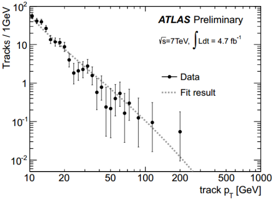
$m_{\widetilde{W}}$	1st SCT Layer	2nd SCT Layer	3rd SCT Layer	4th SCT Layer
100 GeV	416.3	292.6	208.2	147.9
150 GeV	232.2	150.6	98.9	69.5
200 GeV	125.3	76.5	46.4	30.8
250 GeV	85.2	42.2	24.7	14.8
300 GeV	49.7	27.6	17.0	9.4

Recent ATLAS Search for Chargino Tracks at 4.7 fb^{-1} ATLAS-CONF-2012-034

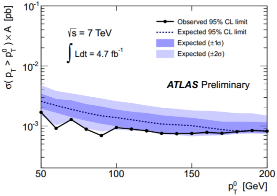
Expected p_T distribution:



Data:



95 % CL:



- No significant excess above SM background.
- 95 % CL: $\sigma A \lesssim 0.9\ \mathrm{fb}^{-1}$ for track $p_T > 50$ GeV.

Predicted σA for $m_{\tilde{g}} = 750$ GeV, $\sqrt{s} = 7$ TeV(preliminary):

MadGraph5/Pythia + PGS

$m_{\tilde{W}^{\pm}}$	100 GeV	150 GeV	200 GeV	250 GeV	300 GeV
$\sigma \times A\ \ (\mathrm{fb}^{-1})$	4.2	1.7	0.9	0.43	0.15

Speculations of a Naive Phenomenologist: Doubly Suppressed Background?

High p_T disappearing tracks have very low background rates.

- E.g. @ 4.7 fb^{-1}(ATLAS-CONF-2012-034):
  - After kinematic cuts (3 hard jets, $\not\!\!E_T > 130$ GeV):

    $\rightarrow$ **73433 events**

    $\rightarrow$ **304 disappearing track events**

    $\rightarrow$ **8 high p_T disappearing track events**

Speculations of a Naive Phenomenologist: Doubly Suppressed Background? cont.

Signal regions for typical $\tilde{g}\tilde{g}$ searches have small number of events after applying hard jet p_T, m_{eff} and $\not{E}_T$ cuts.

- E.g. jets + $\not{E}_T$ search @ 1.07 fb^{-1} (arXiv: 1109.6572):
  - 4 hard jets, $\not{E}_T > 130$ GeV, $m_{eff} > 500$ GeV $\rightarrow$ **1118 events**
  - 4 hard jets, $\not{E}_T > 130$ GeV, $m_{eff} > 1000$ GeV $\rightarrow$ **40 events**

Disappearing $\tilde{W}^{\pm}$ track signals from $\tilde{g}\tilde{g}$ events are robust under typical SUSY search cuts.

- E.g. @ 10 fb^{-1}, $m_{\tilde{g}} = 750$ GeV, $m_{\tilde{W}^{\pm}} = 150$ GeV:
  - No cuts $\rightarrow$ **34 disappearing chargino track events**
  - 4 hard jets, $\not{E}_T > 130$ GeV, $m_{eff} > 500$ GeV $\rightarrow$ **20 disappearing chargino track events**
  - 4 hard jets, $\not{E}_T > 130$ GeV, $m_{eff} > 1000$ GeV $\rightarrow$ **13 disappearing chargino track events**

Speculations of a Naive Phenomenologist: Doubly Suppressed Background? cont.

- By first applying gluino search cuts (4 hard jets, large $\not{E}_T$ and m_{eff}) and looking for disappearing tracks in the surviving events, the background could potentially be "doubly suppressed" without significantly reducing signal strength!
- May potentially increase kinematic reach of LHC for gluino detection at large luminosities.
- However, background is data driven and difficult to estimate. Only careful analysis by detector groups can determine how successful this approach will be at reducing the background.

Conclusions

- Heavy scalars can mitigate flavor and CP problems of the MSSM with a realistic Ω_χ, provided a non-thermal history with moduli decay and a Wino-LSP.
- In such theories, gluinos decaying to disappearing chargino tracks can give a signal reaching substantially into $m_{\tilde{g}} - m_{\tilde{W}^\pm}$ plane.
- Gluino searches complemented by searches for disappearing tracks can potentially give very low background signals in Wino-LSP models.
- Requires careful study by detector groups to determine true power of this signal.
- Analysis updated with latest LHC data forthcoming; Kane, Lu, BZ arXiv: 1202.4448v2
- **Thanks for listening!**