Title: LHC Signals of MSSM Electroweak Baryogenesis

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Abstract: The Standard Model (SM) of particle physics provides an excellent description of nearly every collider physics experiment performed to date. However, the SM is unable to explain the observed cosmology. Among its cosmological shortcomings, the SM cannot account for the dark matter or explain why there is more matter than anti-matter. A well-motivated way to extend the SM is supersymmetry. In the minimal supersymmetric extension of the the SM, the MSSM, new superpartner particles can make up the dark matter and generate the matter-antimatter asymmetry. These two requirements place strong constraints on the mass spectrum of superpartners in the MSSM. In this talk, we will describe this cosmologically motivated spectrum, and discuss some of the interesting signatures it could create at the upcoming LHC experiments.

LHC Signals of MSSM Electroweak Baryogenesis

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Work in progress with:

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Baryons, not Anti-Baryons

- Baryon density of the universe: [WMAP '08]

$$\eta = \frac{n_B}{n_\gamma} = (6.5 \pm 0.3) \times 10^{-10}.$$

where $n_B = (\#\ baryons) - (\#\ anti-baryons)$.

- Only baryons, not anti-baryons.

  $\rightarrow$ Baryon Asymmetry of the Universe.

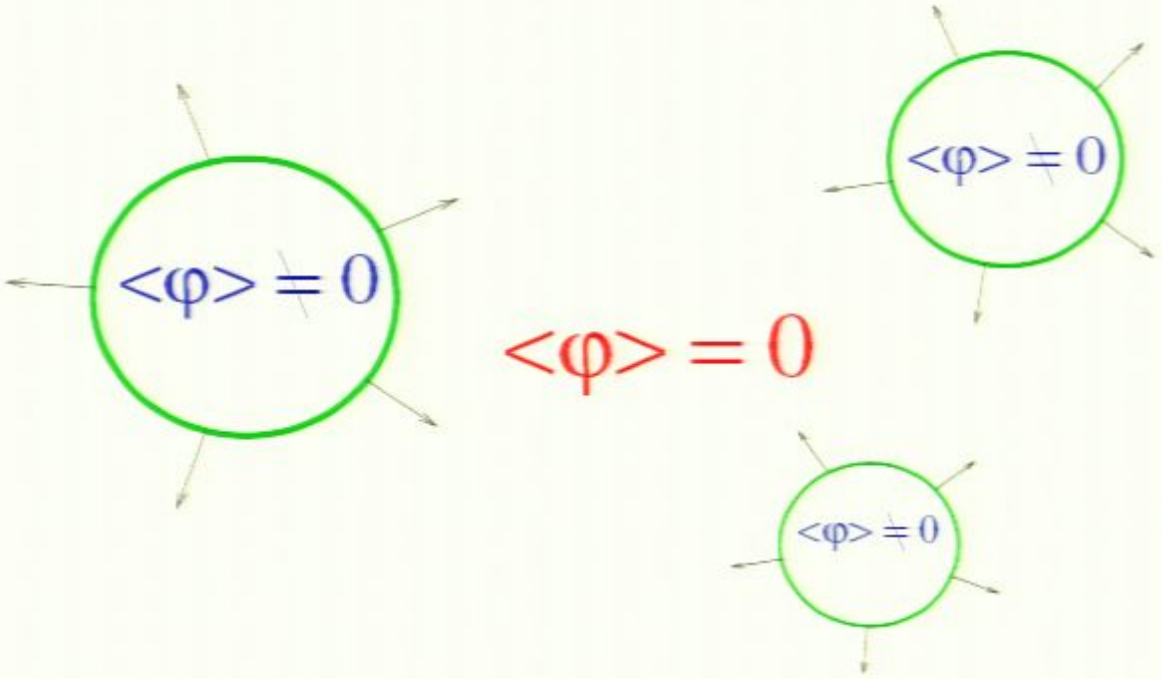
- No Standard Model (SM) explanation.

- Supersymmetric SM (MSSM) $\rightarrow$ Electroweak Baryogenesis

Electroweak Baryogenesis (EWBG)

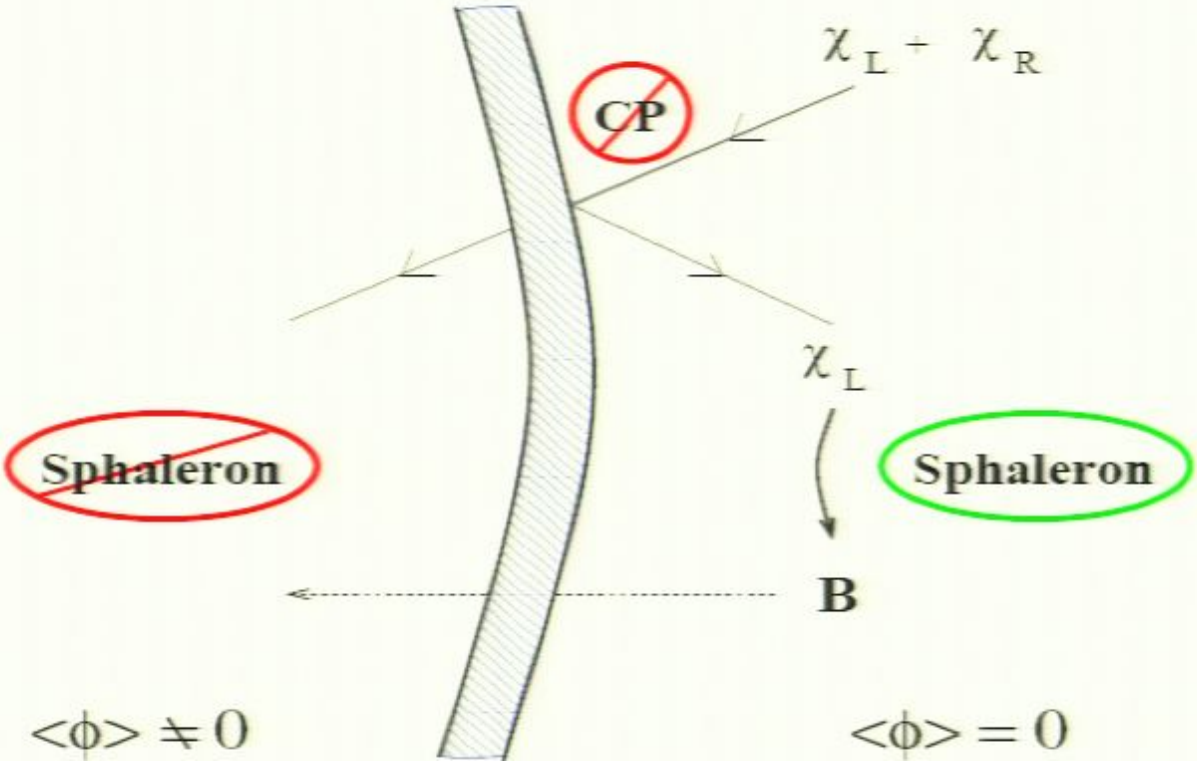
[Kuzmin,Rubakov,Shaposhnikov '85]

- $SU(2)_L \times U(1)_Y \to U(1)_{em}$ as the universe cools.
- First-order phase transition $\Rightarrow$ bubbles of broken phase.



Electroweak Baryogenesis (EWBG)

- CP violation in the bubble wall creates a chiral asymmetry.
- Sphalerons transform the chiral charge into baryons.
- These baryons are swept up into the bubbles.



EWBG in the MSSM

- SM Problem #1: No First-Order Phase Transition

- The MSSM scalar top can make the transition first-order if:

  – It is very light and mostly right-handed

$$125\,\text{GeV} \lesssim m_{\tilde{t}_1} \lesssim 170\,\text{GeV}$$

  – Large stop-Higgs coupling $\Longleftrightarrow$ small stop mixing:

$$g_{h\tilde{t}_1\tilde{t}_1^*} \simeq |y_t|^2 \left(1 - \frac{|X_t|^2}{m_{Q_3}^2}\right) \leq |y_t|^2$$

- The other stop must be very heavy for $m_h > 114\,\text{GeV}$,

$$m_{\tilde{t}_2} \gtrsim 2\,\text{TeV}.$$

EWBG in the MSSM

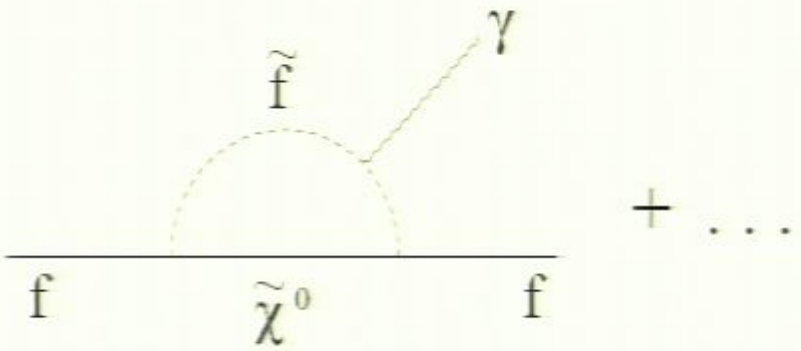
- SM Problem #2: Not Enough CP Violation
- Main MSSM source: Higgsinos and Gauginos.

  [Carena,Quirós,Seco,Wagner '02; Lee,Cirigliano,Ramsey-Musolf '04]

$$Arg(\mu M_{1,2}) \gtrsim 10^{-2}$$

$$\mu,\ M_{1,2} \lesssim 400\,\text{GeV}$$

- New CP violation $\longrightarrow$ electric dipole moments (EDM)



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- EDM bounds $\Rightarrow m_{\tilde{f}_{1,2}} \gtrsim 5\,\text{TeV}$ (unless cancellations)

A Light Stop at the Tevatron?

- Why hasn't the Tevatron seen a light stop with $m_{\tilde{t}_1} < m_t$?
- Not if the light stop is close in mass to the LSP:

$$(m_{\tilde{t}_1} - m_{LSP}) \lesssim 30\,\text{GeV}$$

$\Rightarrow$ decay products are soft and difficult to find.

- Dark Matter Motivation: [Balázs, Carena, Menon, Morrissey, Wagner '05]
  - Bino LSP $\rightarrow$ too much dark matter.
  - Coannihilation with a light stop reduces the DM density.
  - Requires $(m_{\tilde{t}_1} - m_{LSP}) \lesssim 30\,\text{GeV}$.

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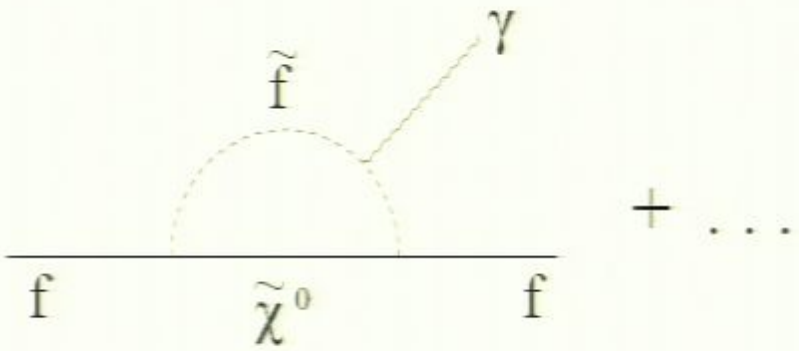

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MSSM EWBG Direct Searches at the LHC

- $\tilde{t}_1$ are produced copiously but are hard to see.

- Stop Decay Modes:
  - $\tilde{t}_1 \to c\,\chi_1^0 \qquad (\chi_1^0 = LSP)$

    Requires flavor violation.

    $(m_{\tilde{t}_1} - m_{\chi_1^0}) < 30\,\text{GeV} \Rightarrow$ soft charm

    [Balázs,Carena,Wagner '04]

  - $\tilde{t}_1 \to b\,W^{(*)}\,\chi_1^0, \quad \tilde{t}_1 \to b\,\chi_1^{+(*)}$

    Often kinematically impossible, soft decay products.

    [Demina, Lykken, Matchev, Nomerotski '99]

- Same-sign tops ($\tilde{t}_1 \to c\chi_1^0$) [Kraml+Raklev '05,'06]

  $\tilde{g}\,\tilde{g} \to t\,t\,\tilde{t}_1^*\,\tilde{t}_1^* \to b\,b\,\ell^+\ell^+ + (jets) + \not{E}_T$

  $\Rightarrow$ same sign tops $\to$ same-sign leptons

  LHC discovery with 30 fb^{-1} for $m_{\tilde{g}} < 1000\,\text{GeV}$

- Stoponium? $\tilde{t}_1\,\tilde{t}_1^* \to \eta_{\tilde{t}_1} \to \gamma\gamma$ [Martin '08]

- New signals if $\tilde{t}_1 \to b\,W^{(*)}\chi_1^0$ dominates?

- Look for electroweak-inos directly? [Carena+Freitas '06]

$$\chi_{1,2}^{\pm} \to \tilde{t}_1\,b \quad \text{(if possible)}$$
$$\chi_{(i>1)}^0 \to Z\,\chi^0,\ h\,\chi^0,\ W^{\pm}\,\chi^{\mp}$$

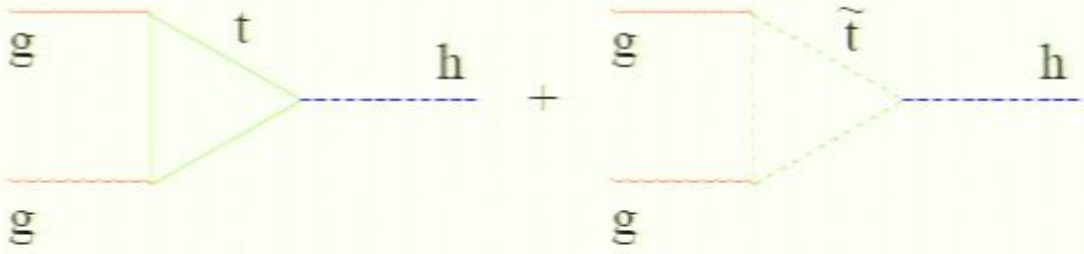
LHC Higgs Signals of MSSM EWBG

- A light stop can modify Higgs production and decay.

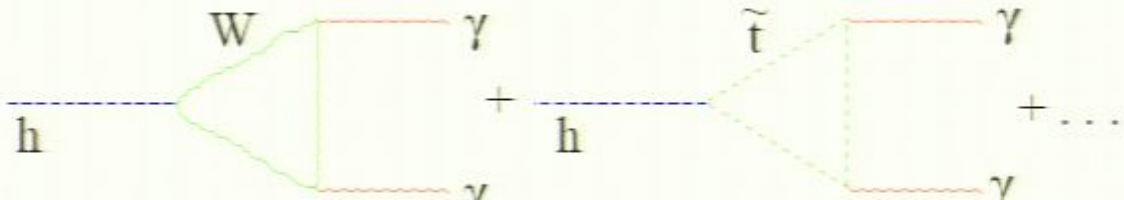
  [Kane,Kribs,Martin,Wells '95; Dawson,Djouadi,Spira '96;Djouadi '98;Dermisek+Low '0

- $h\,\tilde{t}_1\,\tilde{t}_1^*$ coupling: $g_{h\tilde{t}_1\,\tilde{t}_1} \simeq |y_t|^2 \left(1 - \frac{|X_t|^2}{m^2_{\tilde{Q}_3}}\right) \overrightarrow{EWBG} |y_t|^2$

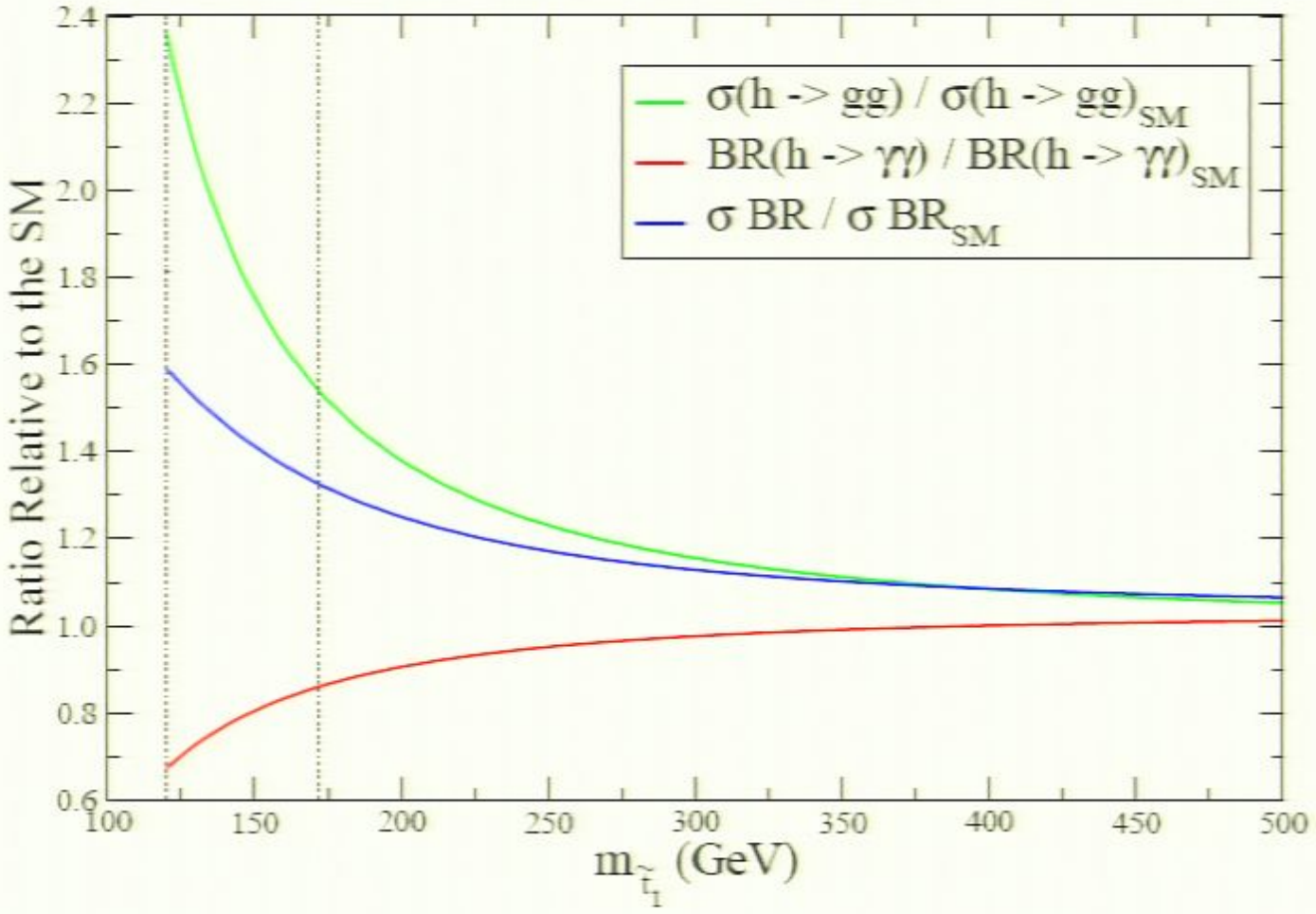
- $\sigma(gg \to h)$ is enhanced.



- $\Gamma(h \to \gamma\gamma)$ is suppressed.



- $|X_t| \simeq 0$, $\tan\beta = 10$, $M_a =$ large, $m_h = 120$ GeV



- $\Delta\sigma/\sigma \lesssim 30\%$, $\Delta BR/BR \lesssim 20\%$, $\Delta\sigma BR/\sigma BR \lesssim 15\%$

Summary

- On top of everything else, the MSSM can account for the baryon asymmetry.
- Baryon production $\rightarrow$ electroweak baryogenesis.
- EWBG requires a light stop, light -inos, heavy scalars.
- This scenario can be challenging at the LHC.
- Higgs boson production and decay gives an indirect probe.
- Connection between colliders and cosmology!?