Unusual Higgs Decays from Gauge Mediated Supersymmetry Breaking

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with

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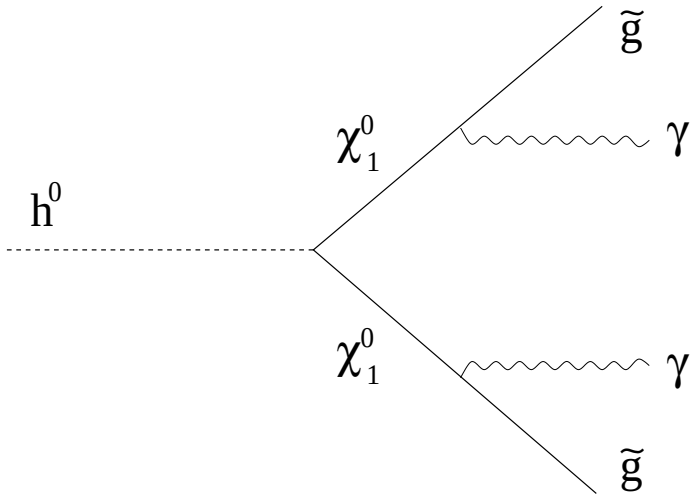
PRD80:115015,2009 – hep-ph/0909.3523

Pheno Symposium, May 10, 2010

The Big Picture

- 

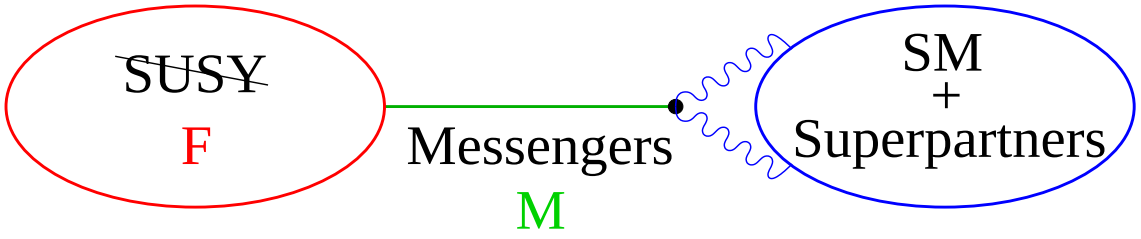
- $h^0 \rightarrow \chi_1^0 \chi_1^0$

  $\chi_1^0 \rightarrow \tilde{g}\,\gamma$ promptly in low-scale GMSB

- Three Questions:

  1. Is this possible in GMSB?
  2. Is it allowed by LEP and Tevatron data?
  3. Can we observe it at the Tevatron or the LHC?

Gauge Mediated SUSY Breaking (GMSB)



$$m_{soft} \sim \frac{g^2}{(4\pi)^2}\frac{F}{M} \qquad \text{(SM superpartners)}$$

$$m_{3/2} \sim \frac{F}{M_{\rm Pl}} \qquad \text{(Gravitino)}$$

- The gravitino is the lightest superpartner (LSP) if

$$M \ll \frac{g^2}{(4\pi)^2} M_{\rm Pl}.$$

- Gravitino = mixture of the gravitino and the goldstino.

  Effective Coupling: [Fayet '76]

$$\mathcal{L} \supset \frac{1}{4\sqrt{2}F}\,\bar{\lambda}\,\gamma^{\alpha}\sigma_{\mu\nu}\,\partial_{\alpha}\tilde{g}\,F^{\mu\nu} + \ldots$$

- This leads to

$$c\tau(\chi_1^0 \to \tilde{g}\gamma) \;\simeq\; \frac{48\pi}{c_W^2}\,\frac{m_{3/2}^2\,M_{\rm Pl}^2}{m_{\chi_1^0}^5}$$

$$\simeq\; (0.03\,\text{cm})\left(\frac{m_{3/2}}{0.6\,\text{eV}}\right)^2\left(\frac{50\,\text{GeV}}{m_{\chi_1^0}}\right)^5$$

- $D\emptyset$ ECAL can "point" photons to within 2 cm.

  (CDF does slightly worse.)

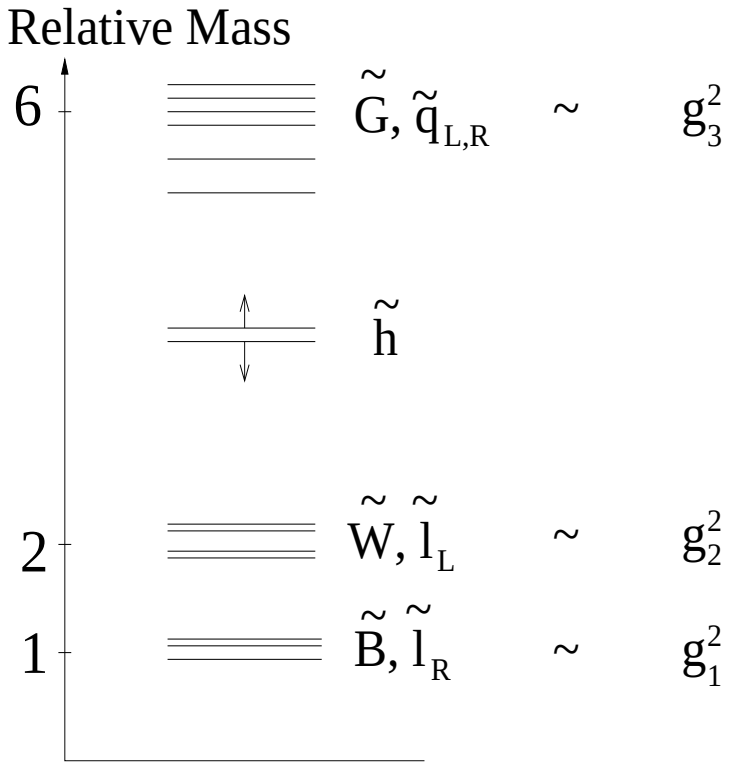
Minimal GMSB Spectra

$\Rightarrow N_m$ sets of $5 \oplus \bar{5}$ messengers

- Soft masses go like g_a^2.

  $M_1 \sim \sqrt{m^2_{\tilde{\ell}_R}}$ are the smallest.

- Mass Bounds:



$$m_{\chi_1^0} \sim m_{\tilde{\ell}_R} \gtrsim 100\,\text{GeV} \quad \text{from LEP searches}$$

$$m_{h^0} \lesssim 135\,\text{GeV} \quad \text{for } m_{soft} \lesssim 2\,\text{TeV}$$

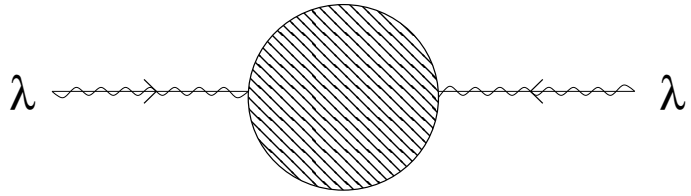
$\Rightarrow$ can't have $h^0 \to \chi_1^0\chi_1^0$ in minimal GMSB

(H^0, $A^0 \to \chi_1^0\chi_1^0$ is possible [Diáz-Cruz,Ghosh,Moretti '03])

General Gauge Mediation

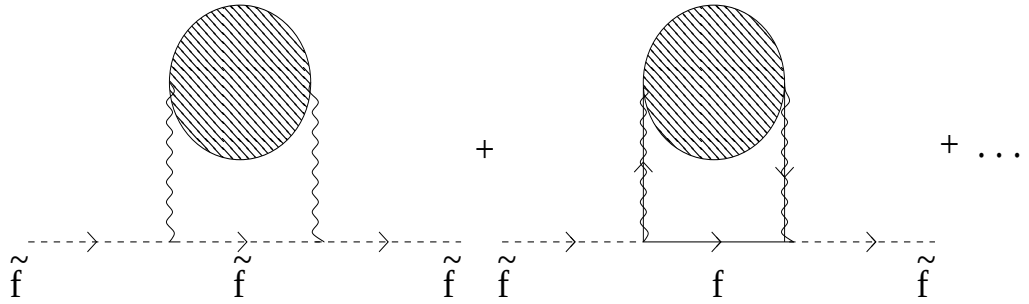
[Meade,Seiberg,Shih '08]

- Gaugino Mass Blob:



$$M_a = g_a^2 \, B_a$$

- Scalar Mass Blob:



$$m_i^2 = \Sigma_{a=1}^{3} \, g_a^4 C_a^i A_a$$

- Basis functions $\{A_a, \, B_a\}$ span the possibilities.

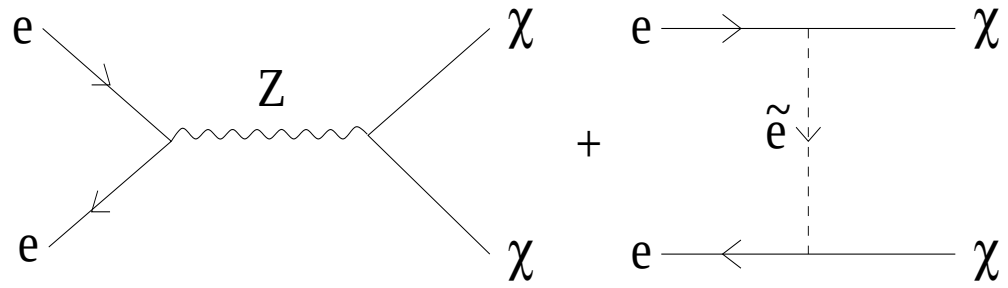
- M_1 and $m^2_{\tilde{\ell}_R}$ are independent in GGMSB.

  $\Rightarrow$ can have a light neutralino and heavier sleptons

  $\Rightarrow$ $h^0 \to \chi_1^0 \chi_1^0$ could be possible

Bounds on a Light Neutralino

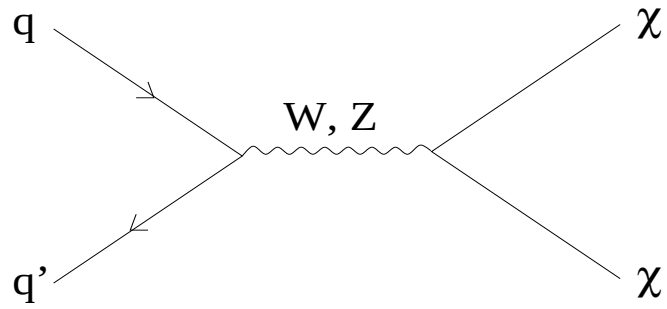
- LEP:



$\sigma(e^+e^- \to \chi_1^0\chi_1^0 \to \gamma\gamma + \not{E}_T) < 10 fb$

$BR(Z^0 \to \chi_1^0\chi_1^0 \to \gamma\gamma + \not{E}_T) < 3 \times 10^{-6}$

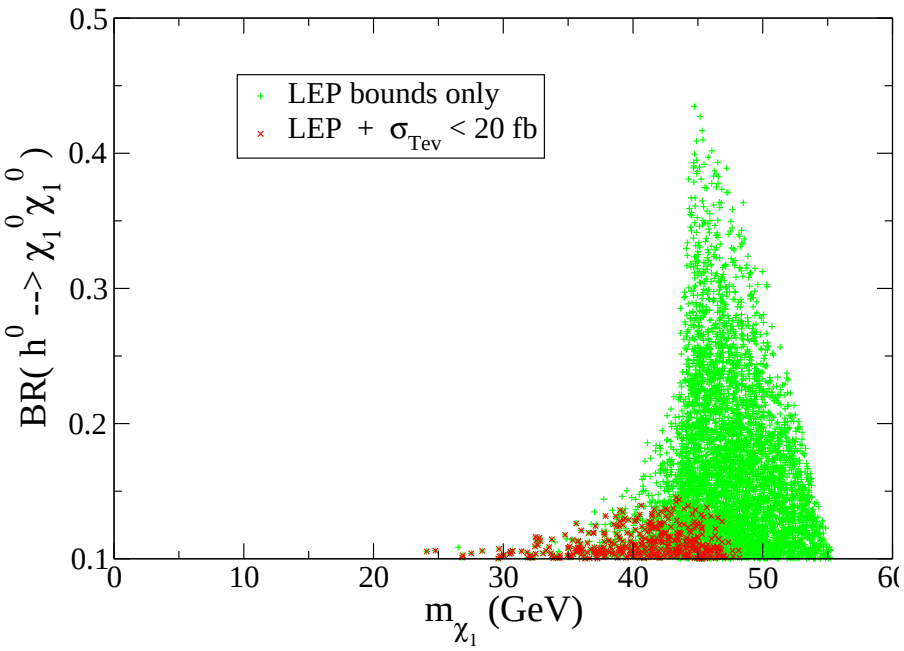
- Tevatron:

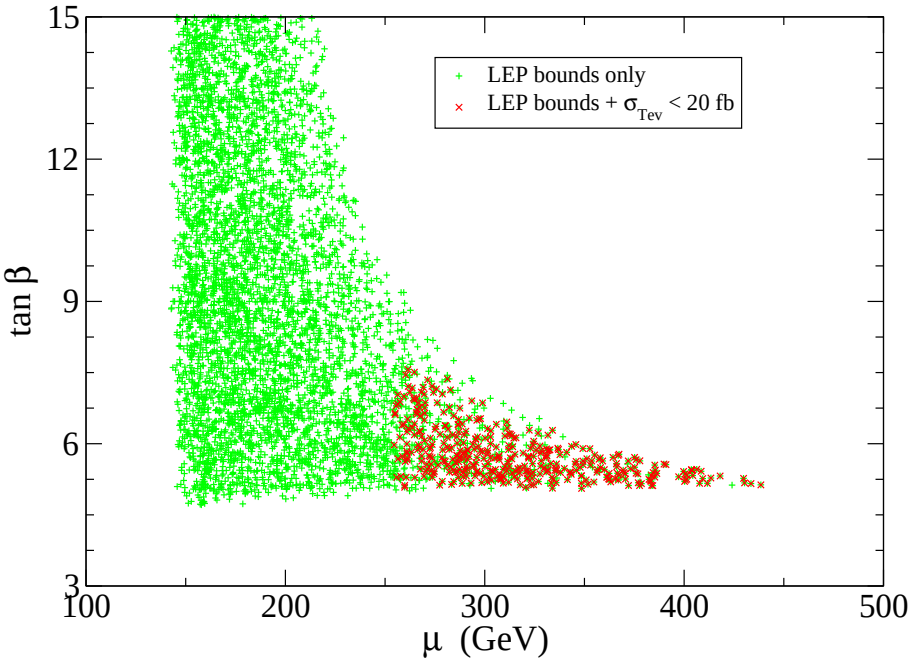


$\sigma_{tot}(p\bar{p} \to \chi_i^{0,\pm}\chi_j^{0,\mp} \to X + \gamma\gamma + \not{E}_T) < 20\, fb$ [CDF GMSB]

$\Rightarrow$ need small neutralino couplings to gauge bosons.

GGMSB Parameter Scans





- $BR(h^0 \to \chi_1^0\chi_1^0) \simeq 0.15$ is possible.

  Maximal for small $\tan\beta$, $|\mu|$.

- Tevatron bounds limit $|\mu| \gtrsim 250\,\text{GeV}$.

Tevatron Higgs Searches

- $BR(h^0 \to \gamma\gamma) \simeq 2 \times 10^{-3}$ in the SM

  Tevatron searches limit $(\sigma BR) \lesssim 15\,(\sigma BR)_{SM}$.

- $BR(h^0 \to \chi_1^0\chi_1^0 \to \gamma\gamma \not{E}_T) \simeq 0.15$ is possible.

  A potential signal?

- Study Sample Point:

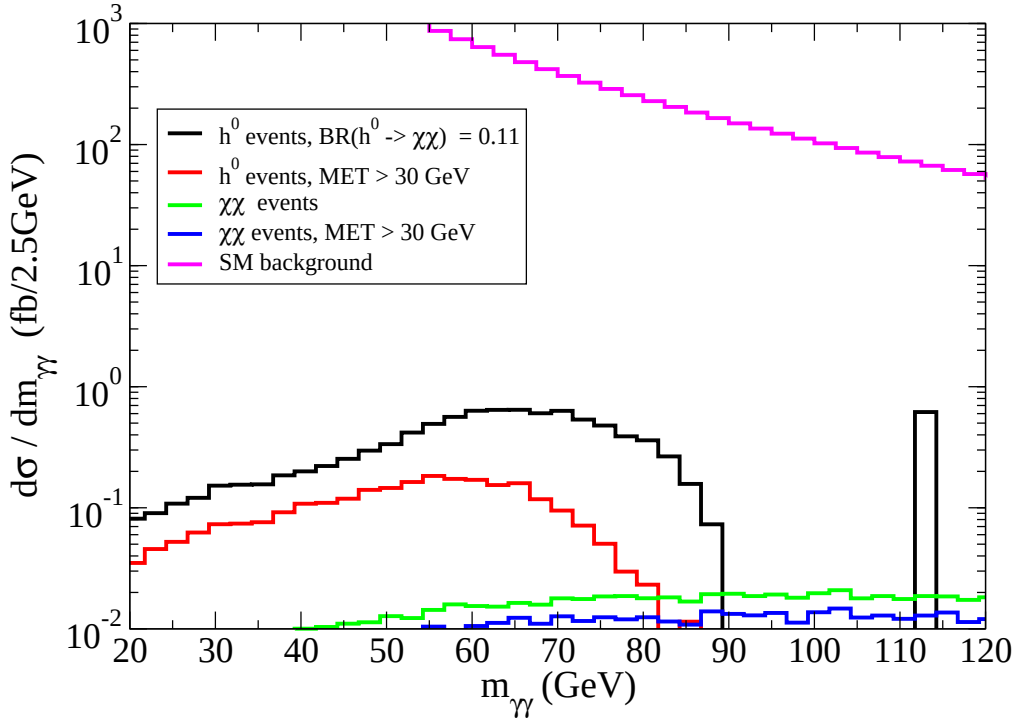
$$M_1 = 50\,\text{GeV},\ \mu = 300\,\text{GeV},\ \tan\beta = 5.5,$$

$$m_{\tilde{t}} \simeq 2000\,\text{GeV},\quad A_t = 0,\quad m_{A^0} = 1000\,\text{GeV}.$$

This is consistent with LEP+Tevatron and gives

$$BR(h^0 \to \chi_1^0\chi_1^0) \simeq 0.11,\ m_{h^0} \simeq 114.7\,\text{GeV},\ m_{\chi_1^0} \simeq 46.6\,\text{GeV}.$$

- Tevatron (DØ) search: $p_T^\gamma > 25\,\text{GeV}$, $|\eta| < 1.1$



- This inclusive channel is swamped by background.

- Kinematic End-Point:

$$m_{\gamma\gamma} \leq \frac{2\,m^2_{\chi_1^0}}{m_h - \sqrt{m_h^2 - 4m^2_{\chi_1^0}}}.$$

Tevatron (DØ) GMSB Searches

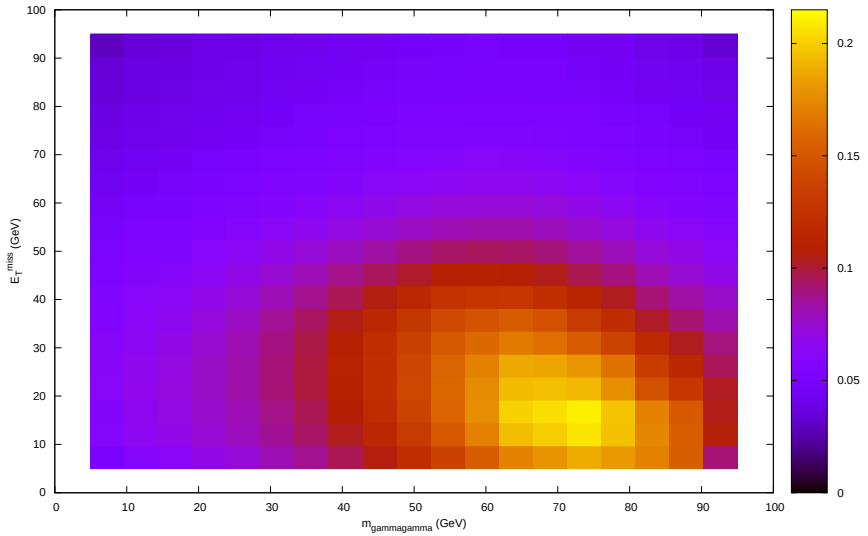
- Cuts: $p_T^\gamma > 25\,\text{GeV}$, $|\eta| < 1.1$, $\not{E}_T > 30,\, 60\,\text{GeV}$.
- With $\not{E}_T > 30\,\text{GeV}$,

$$S \simeq 2.7/fb^{-1}, \quad B \simeq 10/fb^{-1}$$

$\Rightarrow S/\sqrt{B} \simeq 3$ with $10\,fb^{-1}$ of data

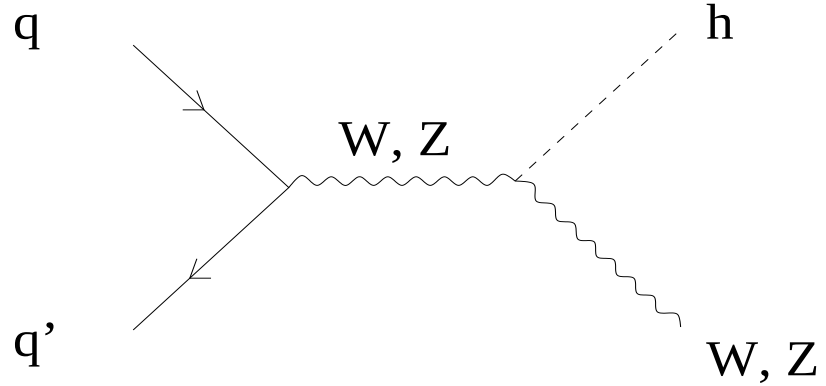
$\Rightarrow$ better than SM Higgs sensitivity for $m_h \lesssim 125\,\text{GeV}$

- Could be improved with smarter cuts:



LHC Searches

- Use same sample point: $m_h = 114.7\,\text{GeV}$, $m_{\chi_1^0} = 46.6\,\text{GeV}$.
- Inclusive $h^0 \to \gamma\gamma$ is swamped by background.
- Exclusive $(W/Z)\,h^0 \to \gamma\gamma + n\,\ell$:



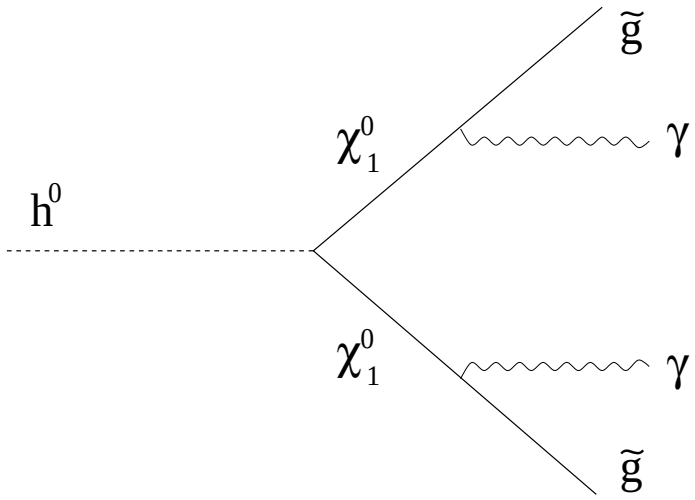
- CMS Search: $p_T^\gamma = 35,\, 20\,\text{GeV}$, $|\eta| < 2.5$, $N_\ell \geq 1$, ...
- With $20\,\text{GeV} < m_{\gamma\gamma} < 90\,\text{GeV}$ we find (after cuts)

$$S \simeq 7\ fb,\ B \simeq 28\ fb \quad \Rightarrow S/\sqrt{B} \simeq 1.26 \quad \text{with } 1\ fb^{-1}.$$

$\Rightarrow$ discovery with about $16\ fb^{-1}$ of data

Summary

- $h^0 \to \chi_1^0 \chi_1^0$ with $\chi_1^0 \to \gamma\, \tilde{g}$ promptly.



- This does not occur in minimal MSSM GMSB.

  It is possible in generalized GMSB scenarios.

- Might be visible at the Tevatron and the LHC.

Extra Slides

Neutralino Decays to Photons and Gravitinos

- Gravitino = mixture of the gravitino and the goldstino.
- Goldstino Equivalence Theorem: [Fayet '76]

  "longitudinal" $s = 1/2$ goldstino components couple as $1/F$

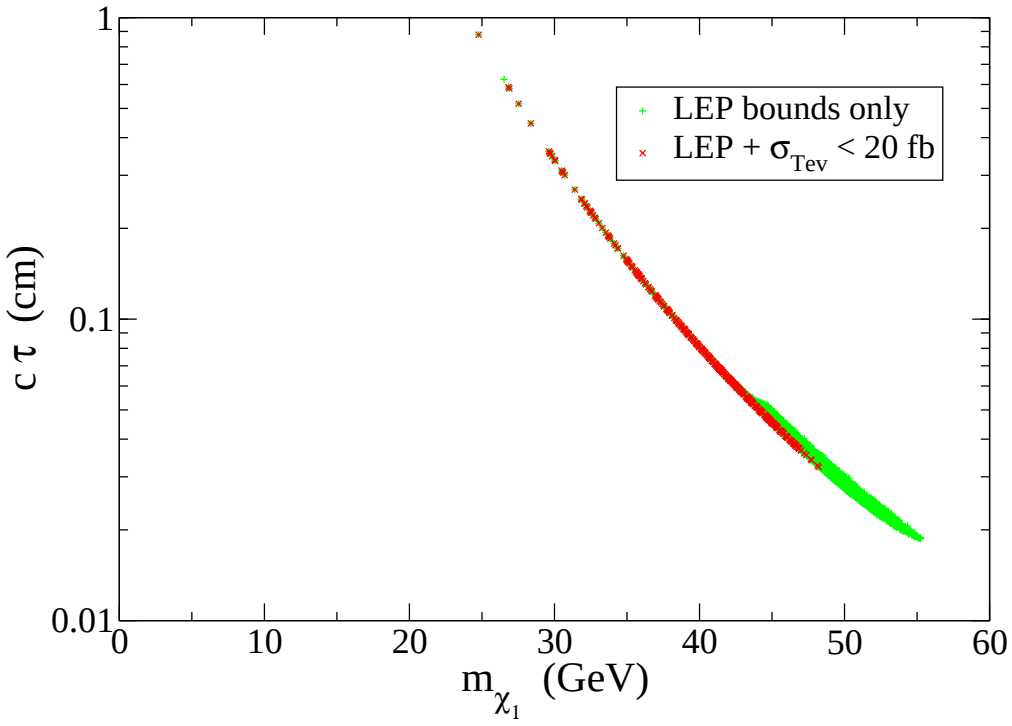
  "transverse" $s = 3/2$ SUGRA components couple as $1/M_{\rm Pl}^2$
- Effective Goldstino Coupling:

$$\mathcal{L} \supset \frac{1}{4\sqrt{2}F}\,\bar{\lambda}\,\gamma^{\alpha}\sigma_{\mu\nu}\,\partial_{\alpha}\tilde{g}\,F^{\mu\nu} + \ldots$$

- This leads to

$$c\tau(\chi_1^0 \to \tilde{g}\gamma) \simeq \frac{48\pi}{c_W^2}\,\frac{m_{3/2}^2\,M_{\rm Pl}^2}{m_{\chi_1^0}^5},$$

- $m_{3/2} \simeq 0.6\,\mathrm{eV}$ ($F \simeq 50\,\mathrm{TeV}$) gives "prompt" decays:



- $D\emptyset$ ECAL can "point" photons to within $2cm$.
  (CDF does slightly worse.)

Higgs Decays to Neutralinos

- LEP+Tevatron $\Rightarrow$ light neutralino must be mostly Bino:

  $\tilde{B}^0$ doesn't couple directly to gauge bosons,

  $\tilde{H}_u$, $\tilde{H}_d$, $\tilde{W}^3$ do couple directly.

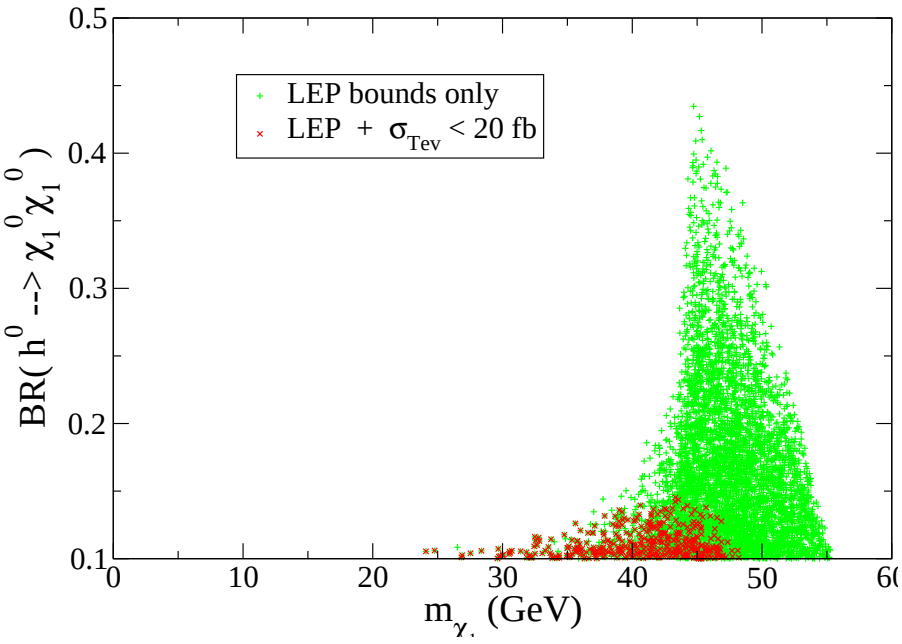
$$\chi_1^0 \simeq \tilde{B}^0 - \epsilon \tilde{H}, \quad \text{with} \quad \epsilon \sim s_\beta c_\beta \left(\frac{v}{\mu}\right)$$

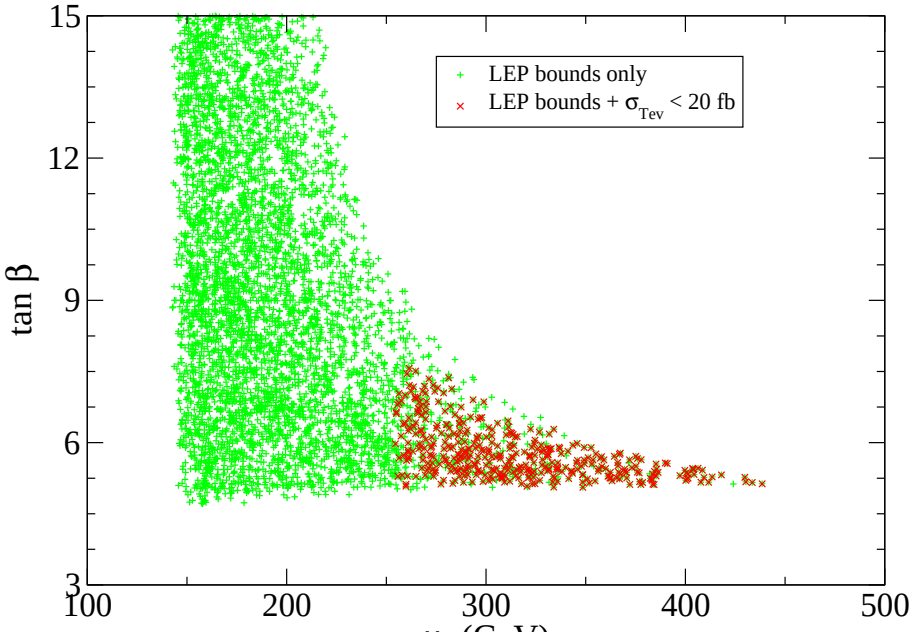
- Higgs-neutralino couplings come from

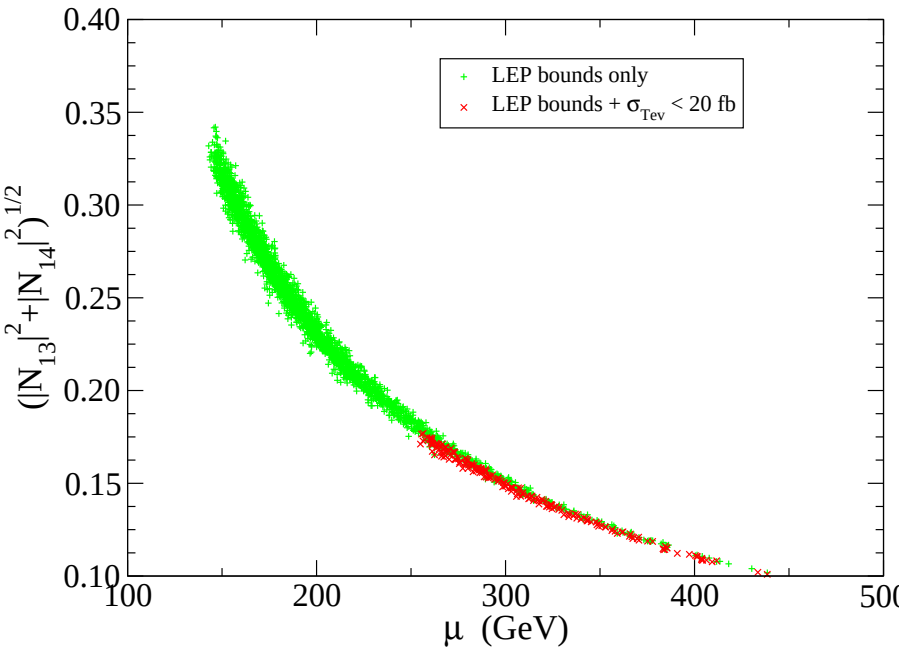
$$-\mathcal{L} \supset \pm \frac{1}{\sqrt{2}} g_Y \tilde{B}_0 \tilde{H}_i H_i^0$$

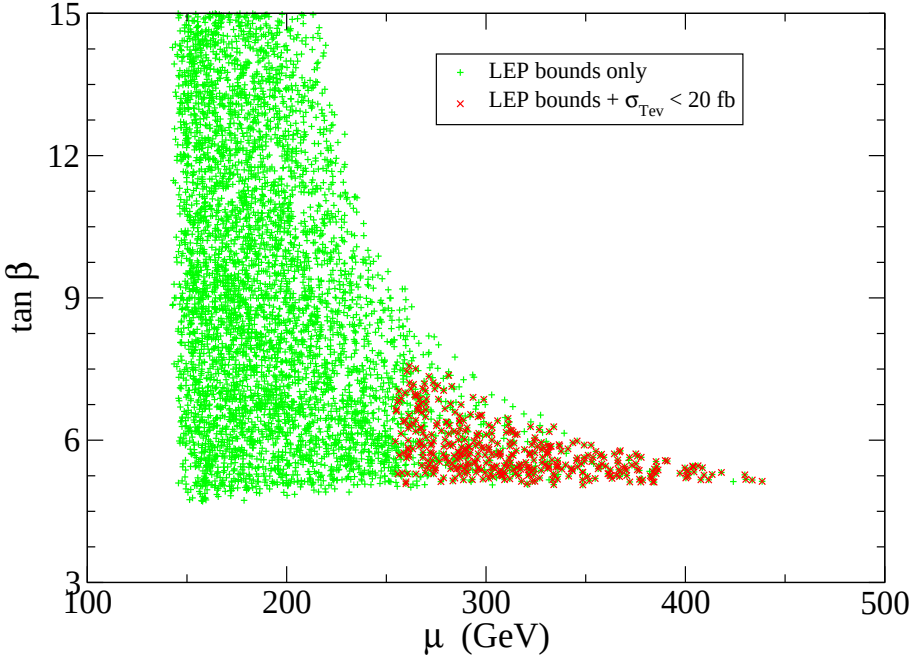
- $W^\pm/Z^0\, \chi_1^0 \chi_1^0$ coupling $\propto \epsilon^2$
- $h^0\, \chi_1^0 \chi_1^0$ coupling $\propto \epsilon$

  $\Rightarrow h^0 \to \chi_1^0 \chi_1^0$ can compete with $h^0 \to b\bar{b}$


LEP bounds only
LEP + σTev < 20 fb
BR(h0 --> χ1 0 χ1 0)
mχ1 (GeV)

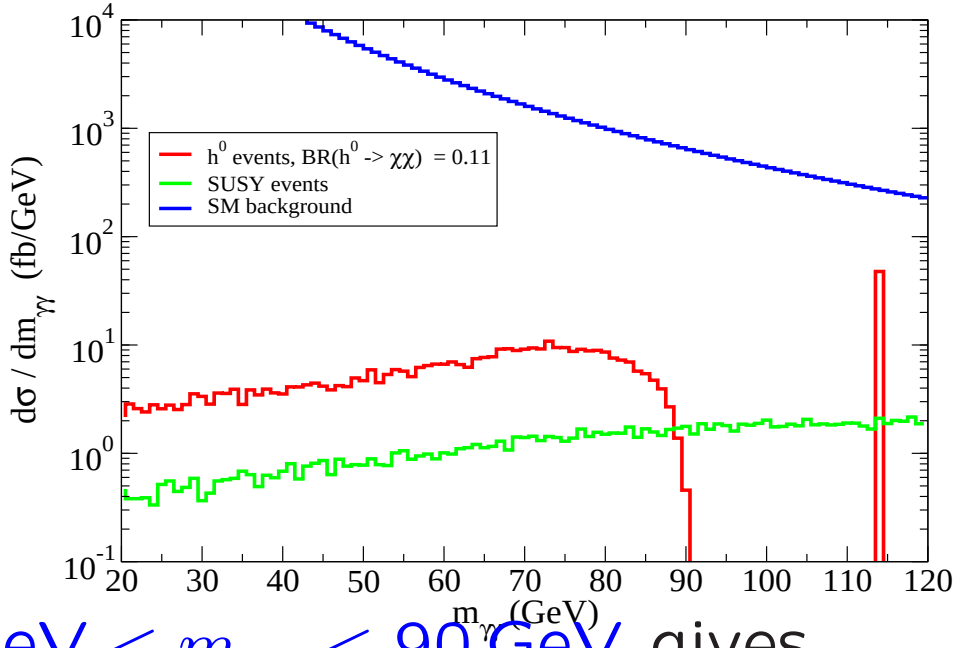

LEP bounds only
LEP bounds + σTev < 20 fb
tan β


LEP bounds only
LEP bounds + σTev < 20 fb
(|N13|2+|N14|2)1/2
μ (GeV)


LEP bounds only
LEP bounds + σTev < 20 fb
tan β
μ (GeV)

LHC Inclusive Diphotons

- ATLAS Inclusive Higgs: $p_T^\gamma > 40,\, 25\,\text{GeV},\ |\eta| < 2.5$

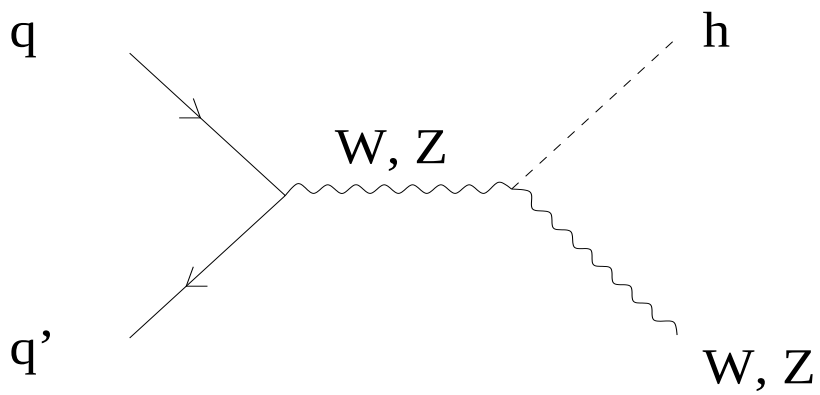


- Requiring $60\,\text{GeV} < m_{\gamma\gamma} < 90\,\text{GeV}$ gives

$$S/\sqrt{B} = 1.1 \quad \text{with } 1\, fb^{-1} \quad (S/B \sim 5 \times 10^{-4})$$

$\Rightarrow$ $20\, fb^{-1}$ needed for discovery (but systematics . . .)

Exclusive $(W/Z)\, h^0 \to \gamma\gamma + n\,\ell$

- 

- Requiring a lepton from the W/Z makes this channel clean.
- CMS Search: $p_T^\gamma = 35,\, 20\,\text{GeV},\ |\eta| < 2.5,\ N_\ell \geq 1,\ \ldots$
- With $20\,\text{GeV} < m_{\gamma\gamma} < 90\,\text{GeV}$ we find (after cuts)

$$S \simeq 7\ fb,\ B \simeq 28\ fb \quad \Rightarrow S/\sqrt{B} \simeq 1.26 \quad \text{with } 1\ fb^{-1}.$$

$\Rightarrow$ discovery with about $16\ fb^{-1}$ of data