The Higgs in Non-Minimal Gauge Mediation

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Cornell Theory Seminar

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Outline

- Motivation of Non-Minimal Gauge Mediation
- Gravitino LSP
- Higgs Decays to Neutralinos
- LEP/Tevatron Bounds
- Tevatron/LHC Searches

Supersymmetry

- SQCD can explain the Planck/EW Hierarchy
- Stabilize Planck/EW Hierarchy
- SUSY spontaneously Broken
- SUSY Breaking must be communicated to the partners of the Standard Model Fields

Minimal Gauge Mediation

$$\int d^4\theta \phi^\dagger e^{2gV} \phi$$

Predictive: Typically a Small number of free parameters

Communicates SUSY breaking with Minimal Flavor Violation

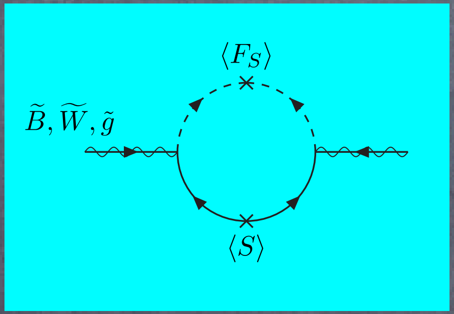
Minimal Gauge Mediation

$$W = \lambda' X \tilde{\phi} \phi$$

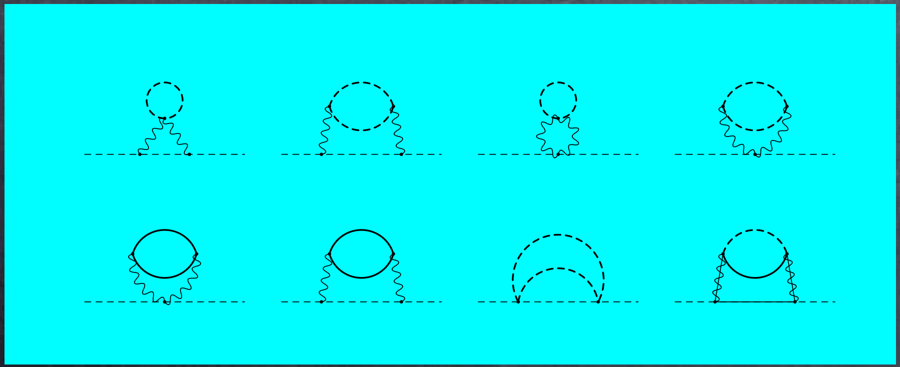
$$X = \langle X \rangle - \theta^2 F$$

$$m^2_{\psi_\phi} = \lambda'^2 \langle X \rangle^2$$

$$m^2_\phi = \begin{pmatrix} \lambda'^2 \langle X \rangle^2 & \lambda' F \\ \lambda' F & \lambda'^2 \langle X \rangle^2 \end{pmatrix}$$



$$M_\lambda^{(r)} = \frac{\alpha^{(r)}}{4\pi} \frac{F}{X}$$



$$m_f^2 = 2 \sum_{r=1}^{3} C_f^r \left(\frac{\alpha^{(r)}}{4\pi} \right)^2 \frac{|F|^2}{|X|^2}$$

The mu-Problem in MGM

$$W = \mu H_D H_U$$

1) Gives mass to Charginos $m_{\chi_1^\pm} > 105\mathrm{GeV}$

2) EWSB in MGM demands: $\mu \sim \mathrm{TeV}$

Therefore it is natural to expect a Dynamical origin to the mu-term connected to SUSY Breaking

Gauge Mediation requires some extension to explain this. Simplest models create a “B-term” that is too large.

“Little Hierarchy” in MGM

Automatic Hierarchy $$\frac{\tilde{m}_{squark}}{\tilde{m}_{slepton}} \sim \left(\frac{4}{5}\right)^{\frac{1}{2}} \frac{g_3^2}{g_1^2} \sim 10.2$$

Experimental Bounds $$m_{\tilde{e}_R} > 73\text{GeV} \rightarrow m_{sq} > 750\text{GeV}$$

Radiative Corrections $$\delta m_{H_U}^2 = -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln(\lambda' \langle X \rangle / m_{\tilde{t}}) < -(600\text{GeV})^2$$

EWSB $$\frac{m_Z^2}{2} = \frac{m_{H_D}^2 - m_{H_U}^2 \tan\beta^2}{\tan\beta^2 - 1} - \mu^2$$

$$\mu^2 > (600\text{GeV})^2$$ $$T = \frac{\mu^2}{\frac{m_Z^2}{2}} \sim 89 \rightarrow 1\%$$

Non-Minimal Gauge Mediation

"Squashing" the sparticle spectrum is needed for lighter stops

$$m_{sq} \sim \frac{g_3^2}{16\pi^2}\Lambda_q$$

$$m_{sl} \sim \frac{g_1^2}{16\pi^2}\Lambda_\ell$$

$$\frac{m_{sq}}{m_{sl}} \sim \frac{g_3^2}{g_1^2}\left(\frac{\Lambda_q}{\Lambda_\ell}\right) \sim 3$$

"two-parameter Model" with Non-Minimal Messengers

S. Martin 98

$$W = (\lambda_1 X_1 + \lambda_2 X_2)\tilde{\phi}\phi$$

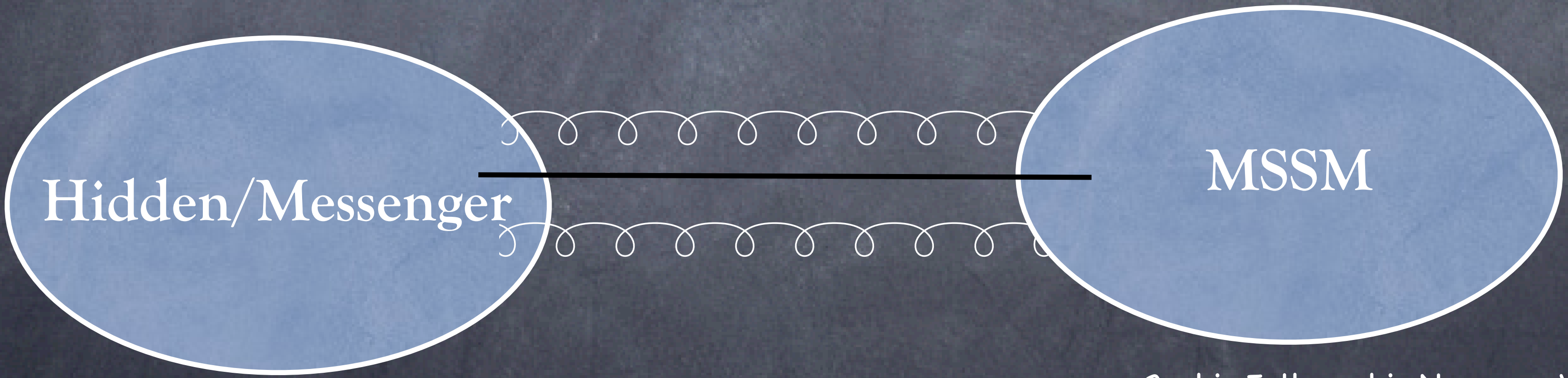
This fits into the broader framework of "General Gauge Mediation"

Meade, Seiberg, and Shih 08

Non-Minimal Gauge Mediation

Csaki, Shirman, Terning (07)
Carpenter, Dine, Festuccia, JM (08)
JM (09)

More Generally ...



Csaki, Falkowski, Nomura, Volansky (08)
Meade, Seiberg, Shih (08)
Komargodski, Seiberg (08)

General Soft Masses

Still Communicates SUSY breaking with Minimal Flavor Violation

The Gravitino is the LSP in GMSB

Spontaneously Broken global SUSY has a Goldstino: G_α

Combines with the Graviton multiplet and becomes the "gravitino."

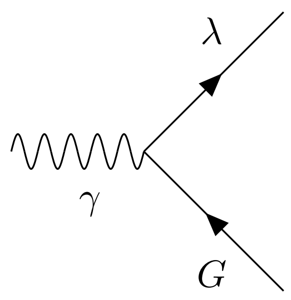
$$m_G = \frac{|F|}{\sqrt{3}M_p} \qquad \sqrt{|F|} = 100 \text{ TeV} \rightarrow m_G = 1 \text{ eV}$$

$$\mathcal{L} = \frac{1}{8M_p}\bar{\lambda}\gamma^\rho\sigma^{\mu\nu}\tilde{G}_\rho F_{\mu\nu} + \text{h.c.}$$

Fayet (76)

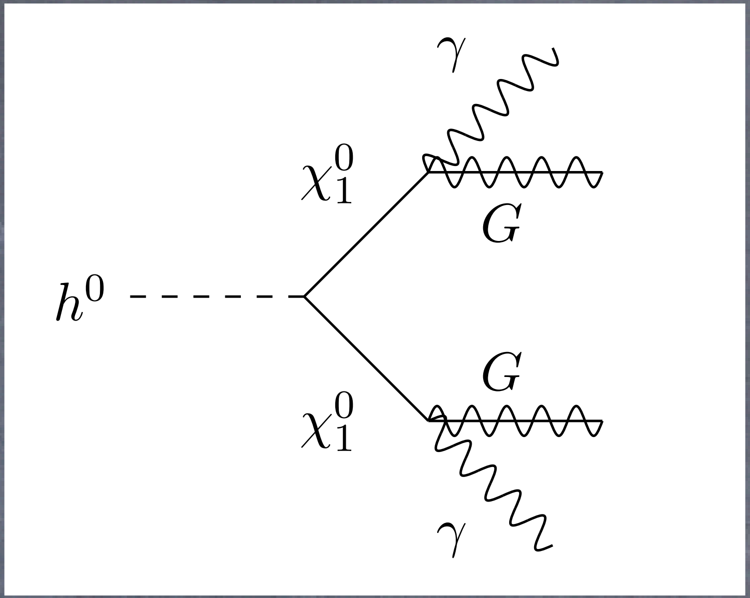
$E \gg m_G \rightarrow$ only the longitudinal mode remains coupled

$$\tilde{G}_\rho \rightarrow \frac{i}{m_G}\sqrt{\frac{2}{3}}\partial_\rho G \Rightarrow$$



$$= \frac{i}{\sqrt{2}F}\left((p_G \cdot p_\gamma)\gamma^\mu - \not{p}_\gamma p_G^\mu\right)$$

Higgs Decays to Neutralinos



"Prompt" Decays : $c\tau < 2\ \mathrm{cm}$

$$c\tau = 16\pi \frac{|F|^2}{m_{\chi_1^0}^5} \frac{1}{|P_{1\gamma}|^2}$$

$|F|^{\frac{1}{2}} < 100\ \mathrm{TeV}$ ⇒ Low-Scale Gauge Mediation

Kinematics requires $m_{h^0} > 2m_{\chi_1^0}$

Minimal Gauge Mediation $\Rightarrow$ $m_{\chi_1^0} > 70 \text{ GeV}$

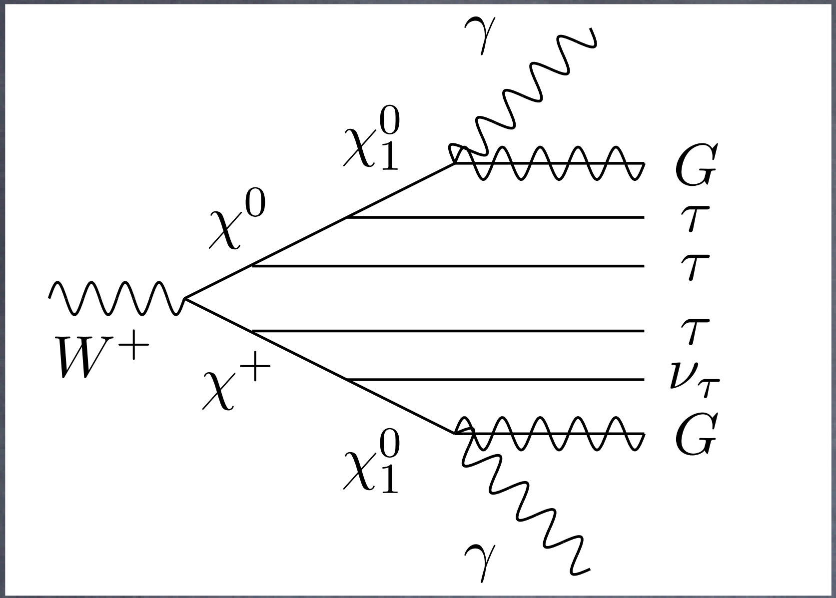
$$M_1 = \frac{5}{3}\frac{\alpha'}{4\pi}\Lambda$$

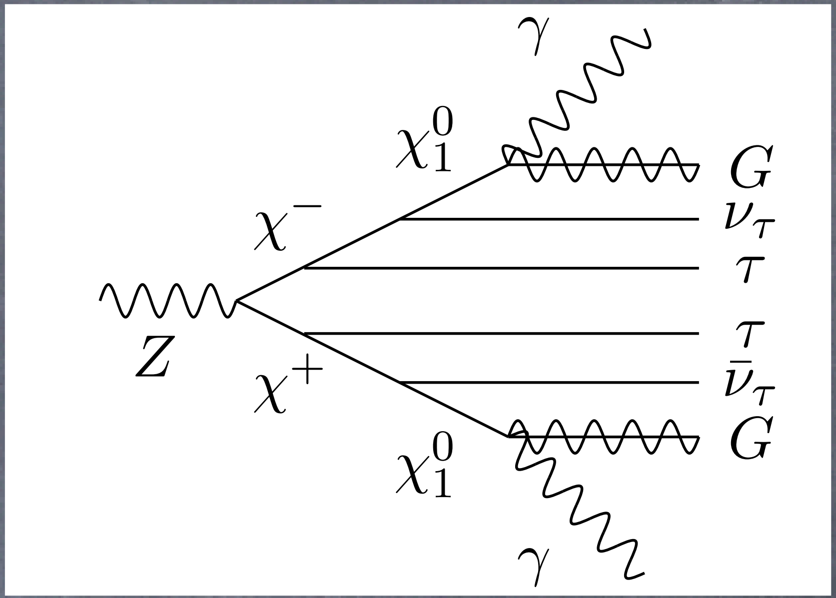
Non-Minimal Gauge Mediation (Neutralino sector is the MSSM) $\Rightarrow$ $m_{\chi_1^0} > 0 \text{ GeV}$

Dreiner et. al. (2009)

$$h^0 \to \gamma\gamma + \not{E}_T$$

Bounds





1) Bounds from LEP : $\sqrt{s} = 209 \text{ GeV}$

$$\sigma(e^+e^- \to \gamma\gamma + \not{E}_T) < 10^{-2} \text{ pb}$$

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

2) Bounds from Tevatron : $\sigma(p\bar{p} \to \chi\chi) < 20 \text{ fb}$

Satisfying Tevatron Bounds

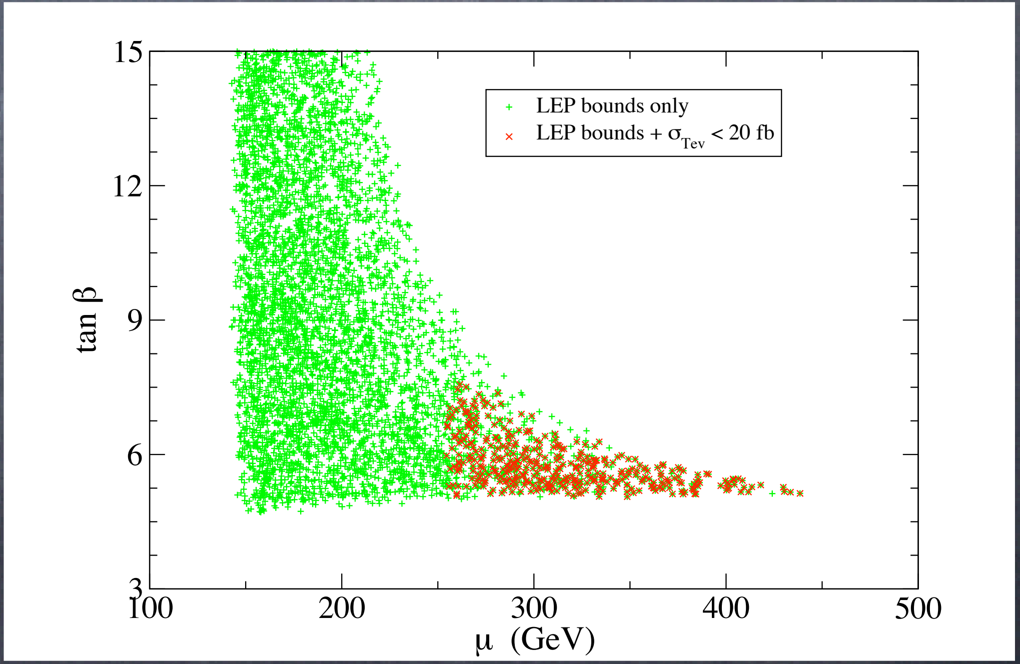
$$M_2,\ \mu >> M_1$$

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z s_\beta s_W & m_Z c_\beta s_W \\ 0 & M_2 & m_Z c_W s_\beta & -m_Z c_\beta c_W \\ -m_Z s_\beta s_W & m_Z c_\beta s_W & 0 & -\mu \\ m_Z c_\beta s_W & -m_Z c_\beta c_W & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} \lambda' \\ \lambda^3 \\ \psi^2_{H_u} \\ \psi^1_{H_d} \end{pmatrix}$$

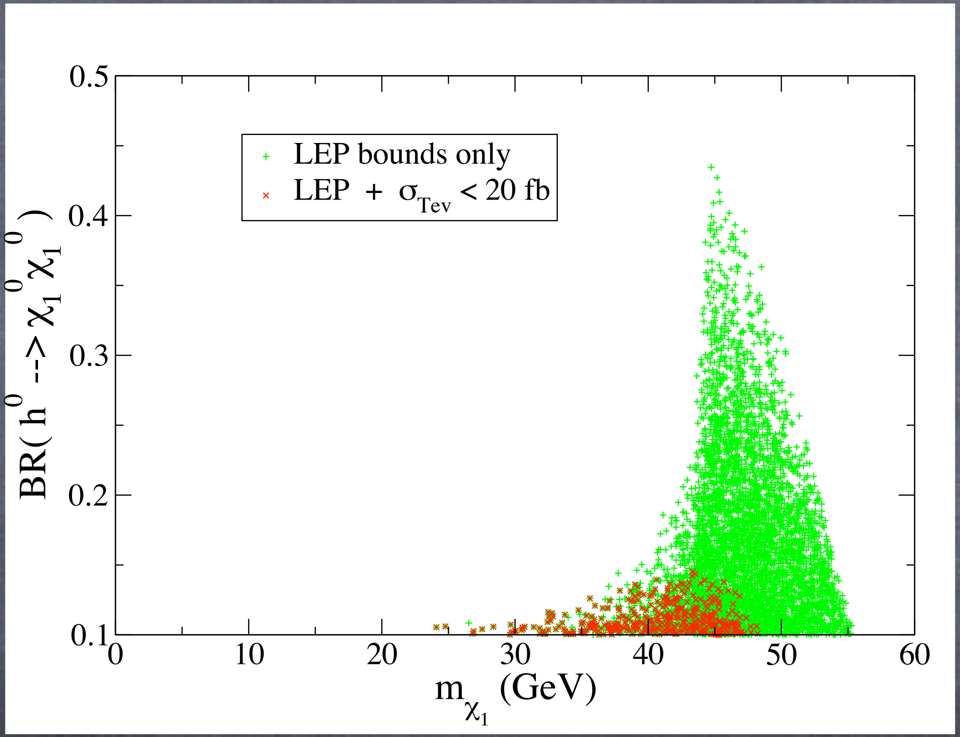
$$g_{Z\chi_1\chi_1} \sim \epsilon^2$$

$$\mu > 250 \text{ GeV}$$



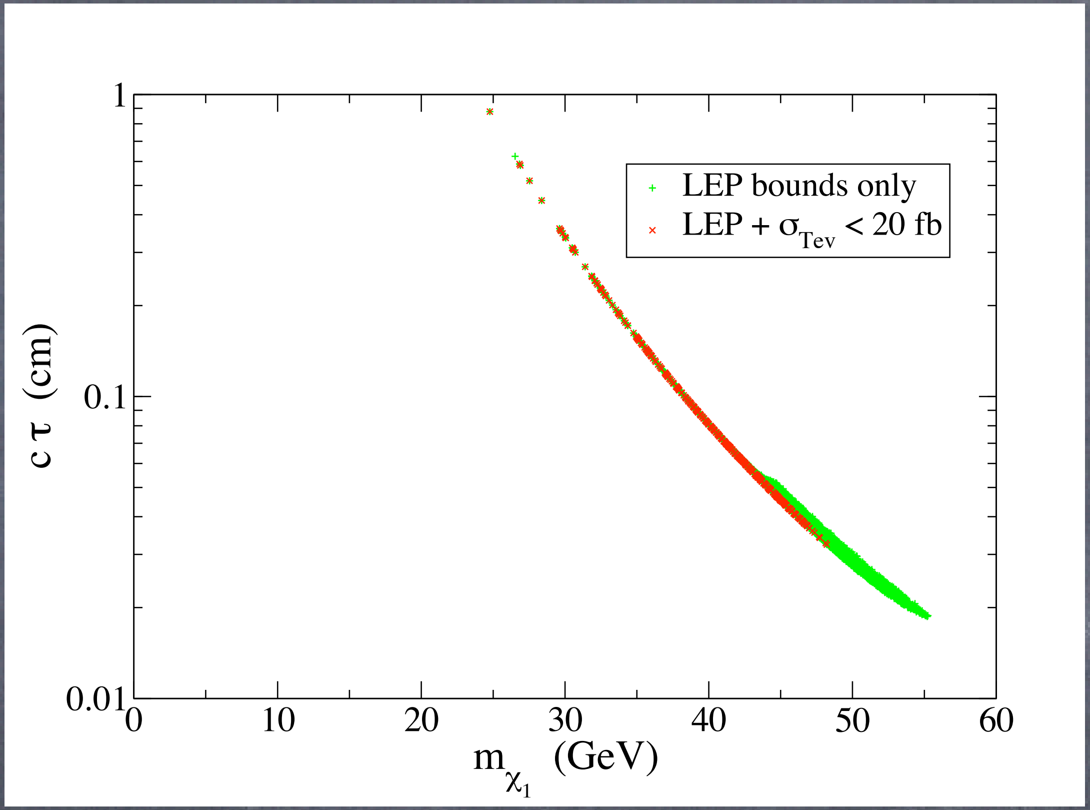
Higgs Branching Ratio

$$\mathcal{L} = \sqrt{2}\lambda' \psi^i_{H_u} H_u^{i*} \Rightarrow g_{h^0 \chi_1 \chi_1} \sim \epsilon$$



$$BR(h^0 \to \chi_1^0 \chi_1^0) \sim 0.1$$

Prompt Decays



$$c\tau = 16\pi \frac{|F|^2}{m^5_{\chi^0_1}} \frac{1}{|P_{1\gamma}|^2}$$

$$|F| = (50\ \text{TeV})^2$$

Tevatron Higgs Search

SM : $BR(h^0 \to \gamma\gamma)_{SM} = 2 \times 10^{-3}$

GMSB : $BR(h^0 \to \chi_1\chi_1 \to \gamma\gamma + \not{E}_T) = 0.15$

Tevatron Limits : $\sigma BR < 15(\sigma BR)_{SM}$

Can this give a signal ? ⇨ $(\sigma BR)_{GMSB} = 50(\sigma BR)_{SM}$

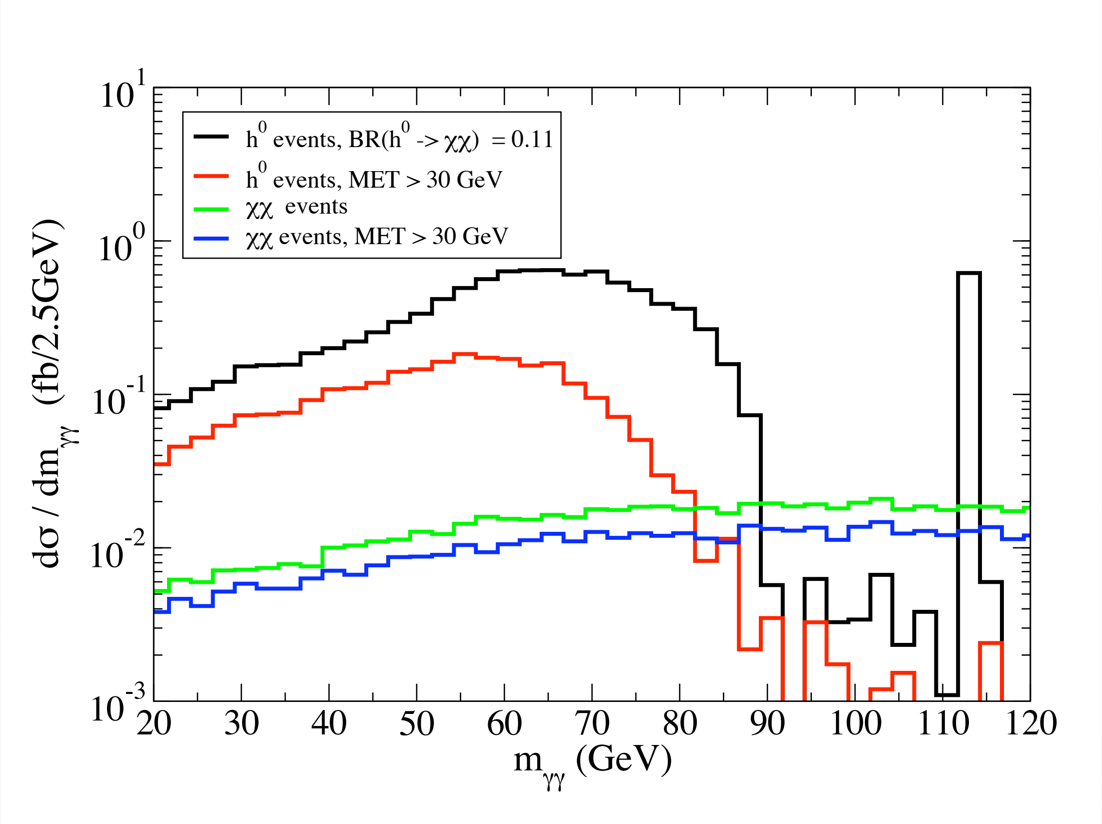
Study a parameter point consistent w/ LEP and Tevatron :

$$M_1 = 50 \text{ GeV}, \quad \mu = 300 \text{ GeV}, \quad \tan\beta = 5.5, \quad m_{A^0} = 1000 \text{ GeV},$$

$$BR(h^0 \to \chi_1\chi_1) = 0.11 \qquad m_{h^0} = 114.7 \text{ GeV} \qquad m_{\chi_1} = 46.6 \text{ GeV}$$

Tevatron Search (D0-Higgs-type)

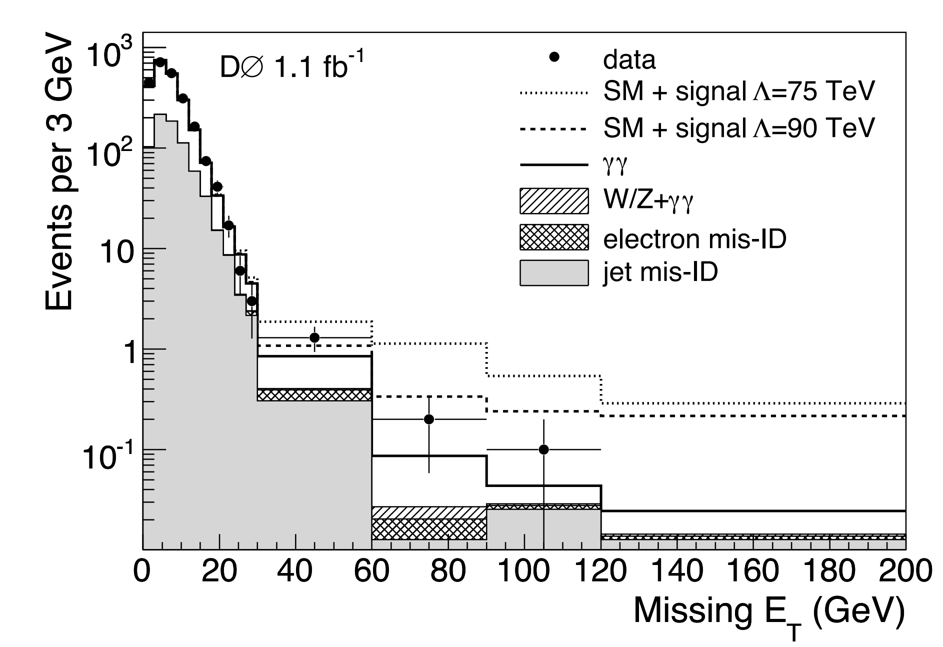
$p_T^\gamma > 25$ GeV $\quad |\eta| < 1.1$



$50 \text{ GeV} < m_{\gamma\gamma} < 90 \text{ GeV}$ ⇒ $\frac{S}{\sqrt{B}} < 0.08$

Tevatron Search (D0-GMSB-type)

$p_T^\gamma > 25$ GeV $\quad |\eta| < 1.1 \quad \not{E}_T > 30$GeV, 60 GeV



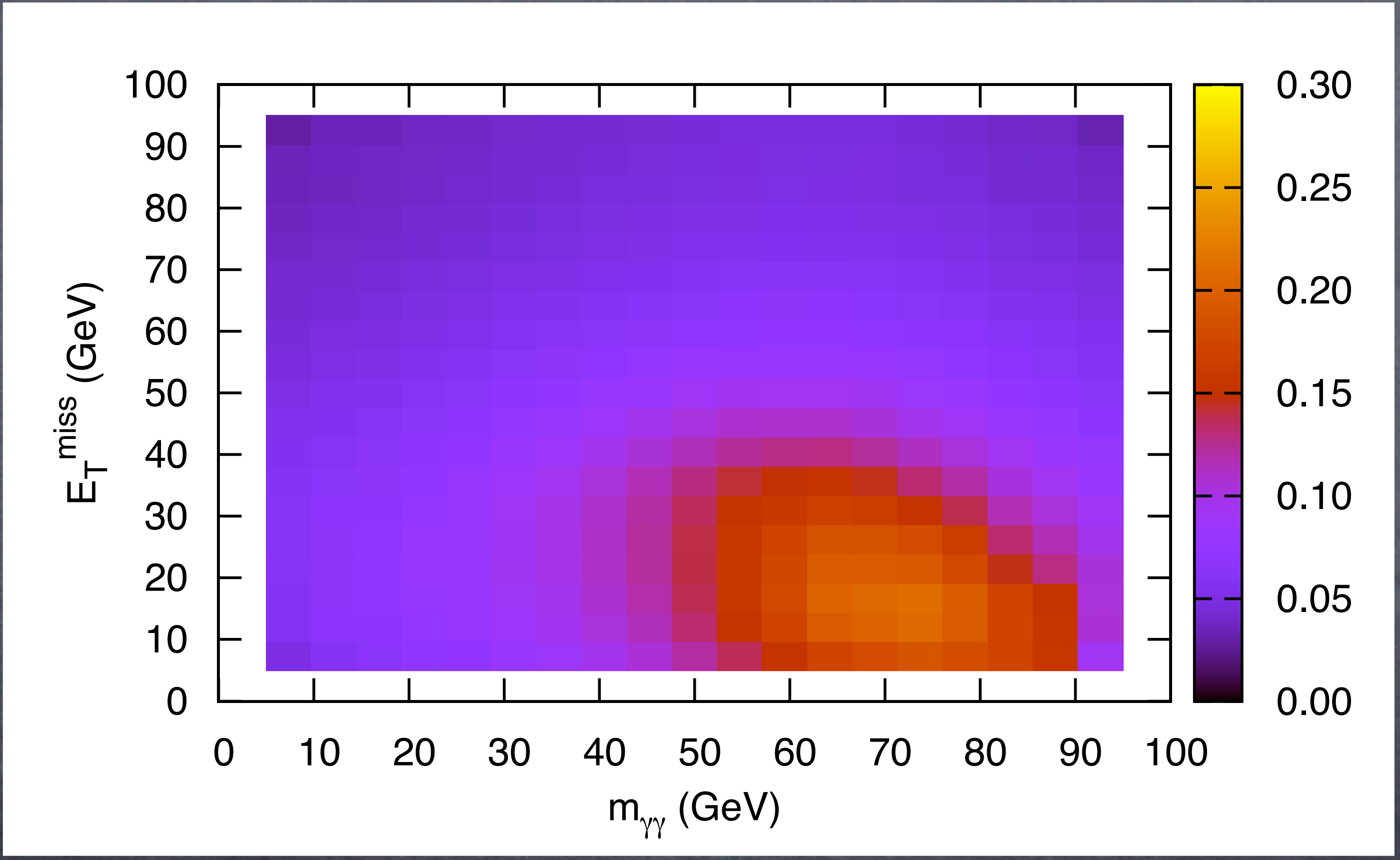
Abazov et. al. (2007) : 0710.3946 [hep-ex]

$S = 2.7/\text{fb}^{-1}$

$B = 9.8/\text{fb}^{-1}$

$$\frac{S}{\sqrt{B}} = 3, \; 10 \text{ fb}^{-1}$$

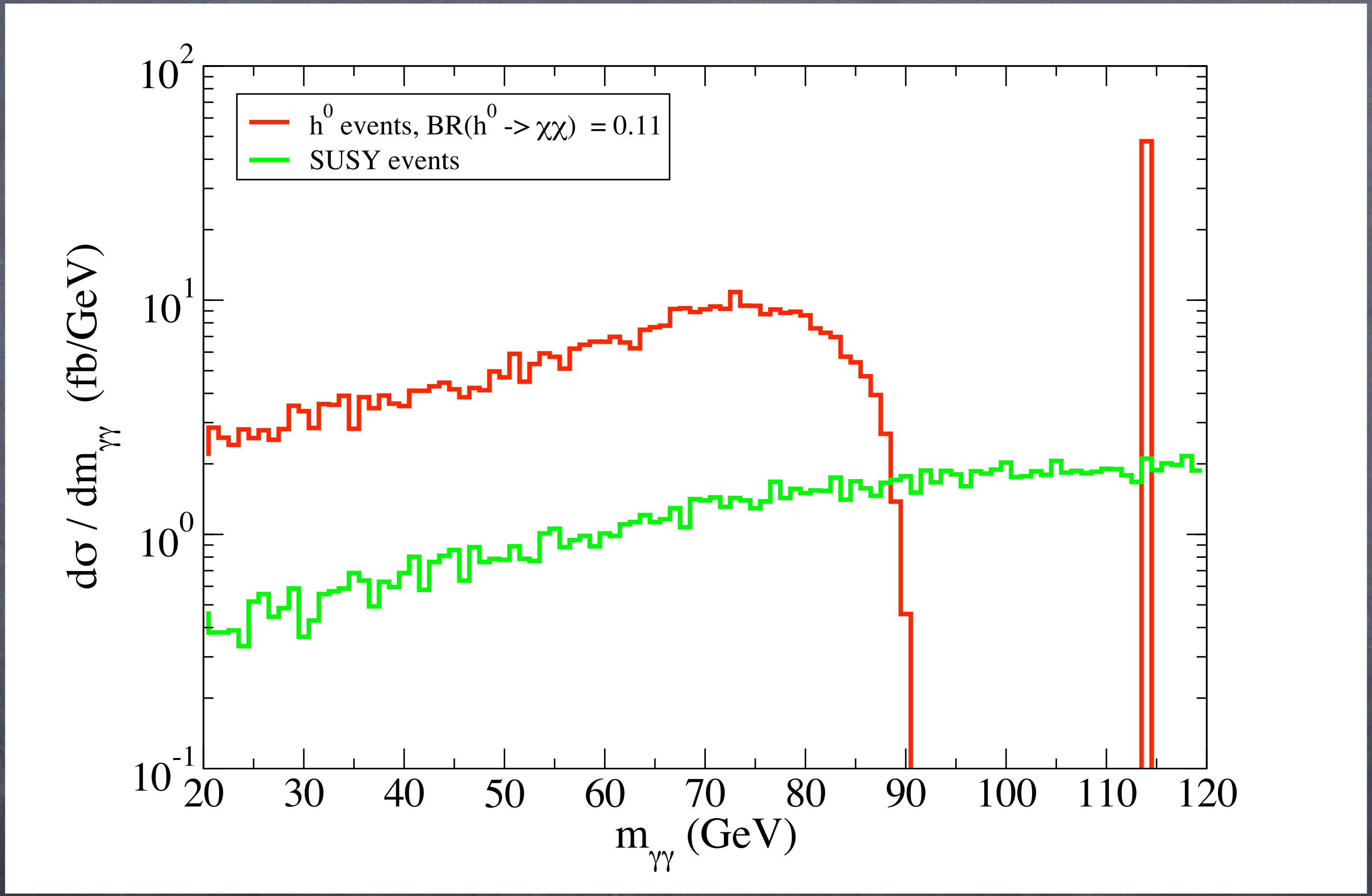
Tevatron Search (D0-hybrid-type)



Signal has more information; can we use this ?

LHC Search (ATLAS inclusive)

$p_T^\gamma = 40\ \mathrm{GeV},\ 25\ \mathrm{GeV}$ $\qquad$ $|\eta| < 1.37,\ 1.52 < |\eta| < 2.37$



$60\ \mathrm{GeV} < m_{\gamma\gamma} < 90\ \mathrm{GeV}$ ⇨ $\dfrac{S}{\sqrt{B}} = 5,\ 20\ \mathrm{fb}^{-1}$

LHC (CMS) Search (W/h, Z/h)

$$p_T^{\gamma} = 35\ \mathrm{GeV}\ ,\ 20\ \mathrm{GeV} \qquad |\eta| < 2.5$$

$$20\ \mathrm{GeV} < m_{\gamma\gamma} < 90\ \mathrm{GeV}$$

$$\frac{S}{\sqrt{B}} = 5,\ 16\ \mathrm{fb}^{-1}$$

Experimental Summary

- Future D0 GMSB and CMS $(W/Z)h^0 \to \gamma\gamma$ Searches are sensitive to this decay mode.
- CDF GMSB uses $H_T = \sum_i p_T^i + \not{E}_T > 200 \text{ GeV}$ which eliminates most of the signal
- Larger pT cuts in ATLAS ($p_T^\gamma > 50\ GeV$) (non-inclusive) searches eliminate the signal.

Conclusions

- Higgs may have an interesting Decay Channel to photons and missing energy.
- Realized in Non-Minimal GMSB
- Could be visible at Tevatron and LHC
- NMSSM Scenarios
  1) $BR(h^0 \to \chi_1 \chi_1) \sim 1, \text{ small } \tan\beta$
  2) $\chi_1^0 \to a^0 + G \qquad a^0 \to b\bar{b}, \tau\bar{\tau}$