Gamma + MET Higgs decay from low scale SUSY breaking

Riccardo Torre

IFT UAM/CSIC

Planck 2012, Warsaw, Poland

29 May 2012

based on C. Petersson, A. Romagnoni and RT

arXiv:1203.4563 [hep-ph]

Outline

- Introduction and Summary of previous talk
- A simplified model for SUSY γ+MET
  - Search strategy
  - Signal vs Background
  - LHC@8 predictions
- Conclusion

Summary of Petersson's talk

- In models with a low SUSY breaking scale the gravitino (goldstino) is very light and can be the LSP
- The lightest neutralino can be the NLSP and can therefore decay only into a goldstino and a gauge or a Higgs boson
- If the neutralino is also lighter than the Higgs and the gauge bosons, it can only decay into a goldstino and a photon
- In this case the Higgs boson can decay into a neutralino and a goldstino with the former decaying into a photon and a second goldstino
- This process gives rise to a signature with one isolated photon and missing transverse energy in the region $p_T^\gamma \leq 100\,\mathrm{GeV}$
- I will present a study of this signature within a simplified model and then I will comment on how the effective SUSY model introduced by Petersson can give rise to this signal

The bottom-up approach

Our approach

1. Define a simplified model (effective Lagrangian) giving rise to the signal we want to study
2. List and compute all the SM backgrounds for the corresponding signal
3. Study the sensitivity of the LHC@8 TeV with the integrated luminosity expected for the next run (15÷20/fb) to the relevant BRs (and couplings)
4. Look at effective low scale SUSY breaking models that can account for this signal and see if BRs and coupling interesting for discovery are allowed

Remarks

1. Of course in effective SUSY models, the relevant BRs will depend on more than one parameter (e.g. scalar and fermion masses and mixings), therefore limits can be set only on combinations of parameters
2. However, even just the observation of a signal can give important qualitative information on the nature of the new physics

Simplified model for γ+MET

- The signal we are interested in is described by the following effective Lagrangian

$$
\begin{aligned}
\mathcal{L}_{\rm eff} &= \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm NP} \\
\mathcal{L}_{\rm NP} &= \frac{m^2}{\sqrt{2}f}\Bigg[g_{h\chi} h \chi_1^0 G + \frac{g_{\chi\gamma}}{m} G\sigma^{\mu\nu} F_{\mu\nu}\chi_1^0 \\
&\quad + \frac{g_{\chi Z\,1}}{m} G\sigma^{\mu\nu} Z_{\mu\nu}\chi_1^0 + g_{\chi Z\,2}\bar{G}\bar{\sigma}^{\mu} Z_{\mu}\chi_1^0 + \text{h.c.}\Bigg]
\end{aligned}
$$

- We are interested in the case in which $\sqrt{f}$, which we interpret as the SUSY breaking scale, is at the TeV scale and m represents a typical soft-mass parameter depending on the model
- The g_i are dimensionless couplings
- The σ^{μ}, $\bar{\sigma}^{\mu}$ and $\sigma^{\mu\nu}$ are the usual combinations of the Pauli matrices and the two dimensional identity matrix

Our assumptions

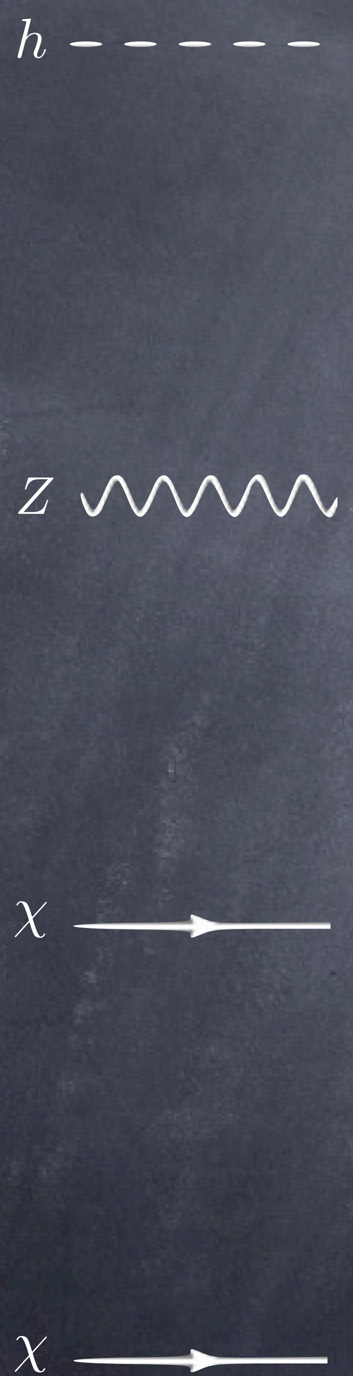
1. The goldstino is the LSP, the neutralino the NLSP and they are the only s-particles relevant for the phenomenology of γ+MET
2. The Higgs is SM like with $m_h = 125\,\mathrm{GeV}$ as suggested by the last LHC results
3. The Higgs and Z boson widths are negligibly modified with respect to the SM ones by the new decay channels

$$\Gamma(h \to \chi_1^0 G) \ll \Gamma_h^{\mathrm{SM}} \qquad \Gamma(Z \to \chi_1^0 G) \ll \delta\Gamma_Z = 2.3\ \mathrm{MeV}$$

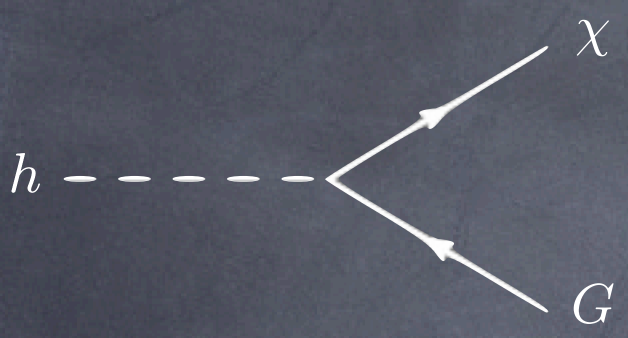
4. The neutralino is lighter than the Higgs boson (bounds on the neutralino mass in general models can be made very weak)
5. The neutralino decays promptly and within the detector (not an invisible Higgs boson decay)

$$L_\chi = \frac{1}{g_{h\chi}^2}\frac{(100\,\mathrm{GeV})^5}{m_\chi^3 m^2}\left(\frac{\sqrt{f}}{1\,\mathrm{TeV}}\right)^4\sqrt{\left(\frac{E^2}{m_\chi^2}-1\right)}\cdot 10^{-10}\,\mathrm{cm}$$

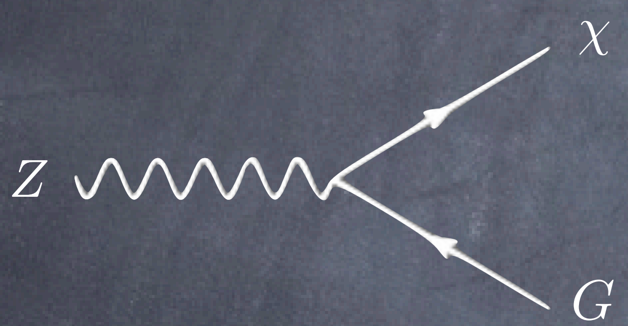
New decay channels



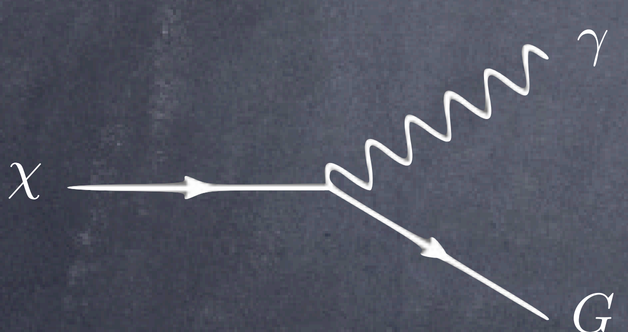
New decay channels



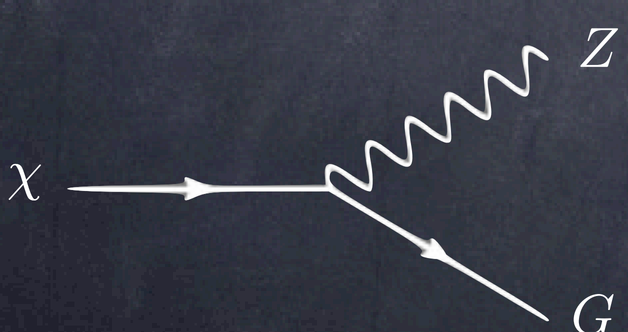
$$\Gamma(h\to\chi_1^0 G)=\frac{m_h}{16\pi}\frac{g_{h\chi}^2 m^4}{f^2}\left(1-\frac{m_\chi^2}{m_h^2}\right)^2$$



$$\begin{aligned}\Gamma(Z\to\chi_1^0 G) \quad = \quad & \frac{1}{48\pi m_Z}\left(1-\frac{m_\chi^2}{m_Z^2}\right)\frac{m^4}{f^2}\Bigg[g_{\chi Z\,2}^2\left(2m_Z^2-m_\chi^2-\frac{m_\chi^4}{m_Z^2}\right)\\ &+6\frac{g_{\chi Z\,1}g_{\chi Z\,2}}{m}m_\chi(m_Z^2-m_\chi^2)+\frac{g_{\chi Z\,1}^2}{m^2}(m_Z^4+m_\chi^2 m_Z^2-2m_\chi^4)\Bigg]\end{aligned}$$

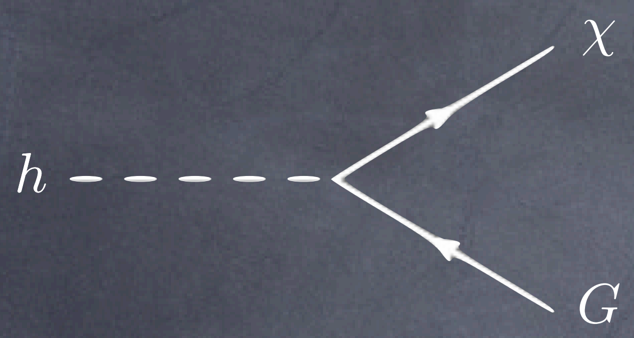


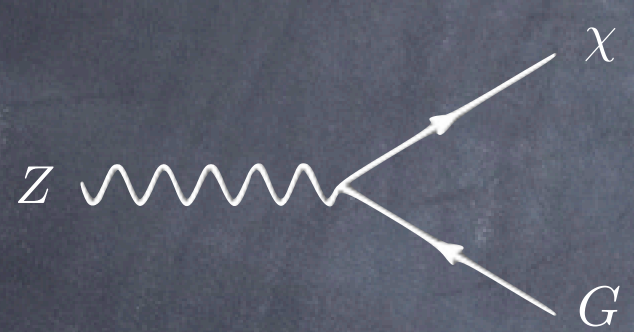
$$\Gamma(\chi_1^0\to\gamma G)=\frac{m_\chi^3}{16\pi}\frac{g_{\chi\gamma}^2 m^2}{f^2}$$

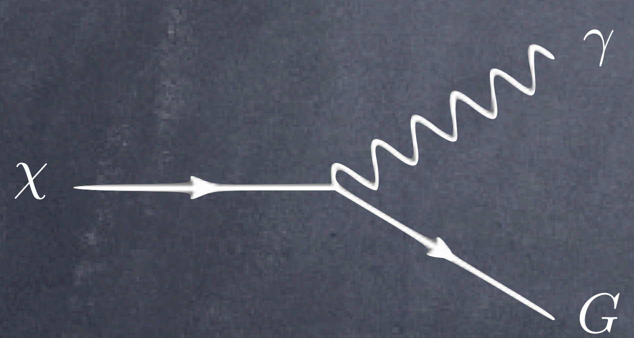


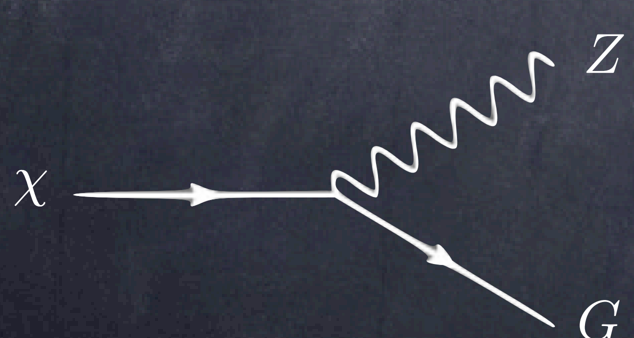
$$\begin{aligned}\Gamma(\chi_1^0\to ZG) \quad = \quad & \frac{1}{32\pi m_\chi}\left(1-\frac{m_Z^2}{m_\chi^2}\right)\frac{m^4}{f^2}\Bigg[g_{\chi Z\,2}^2\left(m_\chi^2+\frac{m_\chi^4}{m_Z^2}-2m_Z^2\right)\\ &+6\frac{g_{\chi Z\,1}g_{\chi Z\,2}}{m}m_\chi(m_\chi^2-m_Z^2)+\frac{g_{\chi Z\,1}}{m^2}(2m_\chi^4-m_Z^4-m_\chi^2 m_Z^2)\Bigg]\end{aligned}$$

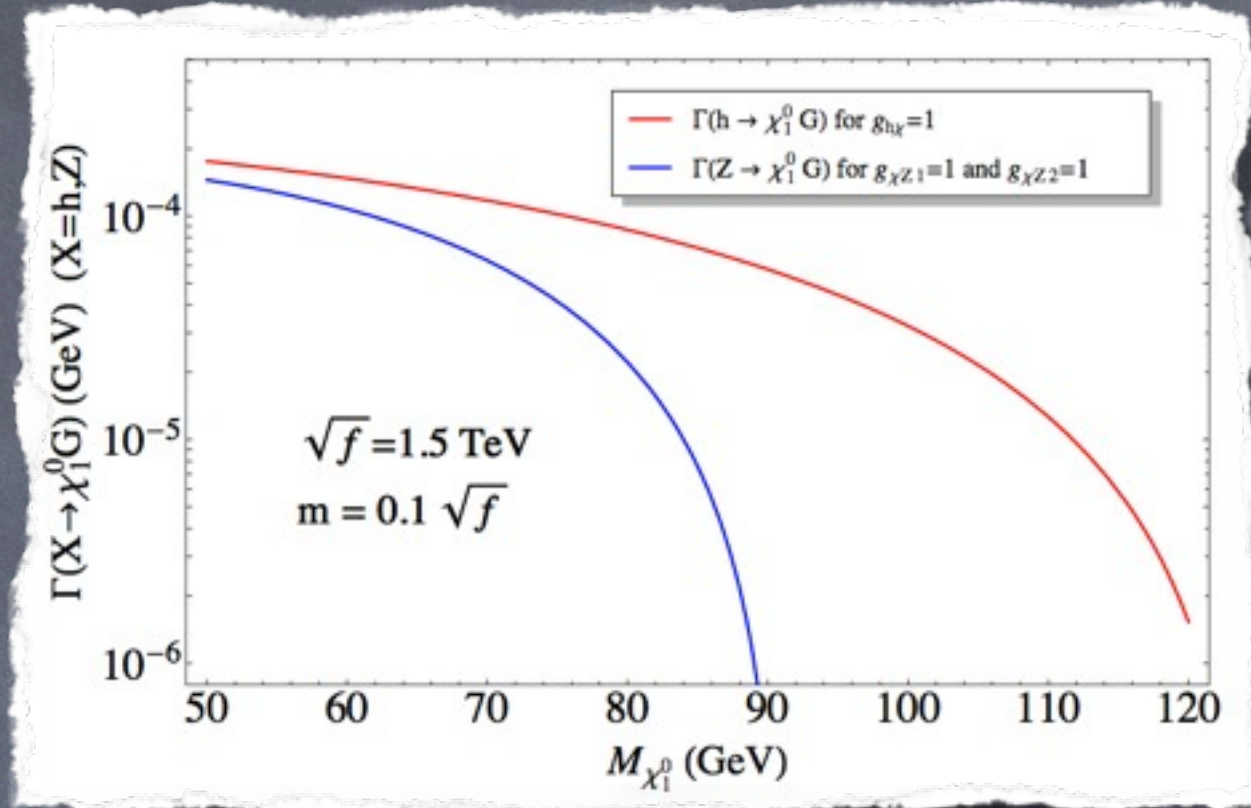
New decay channels

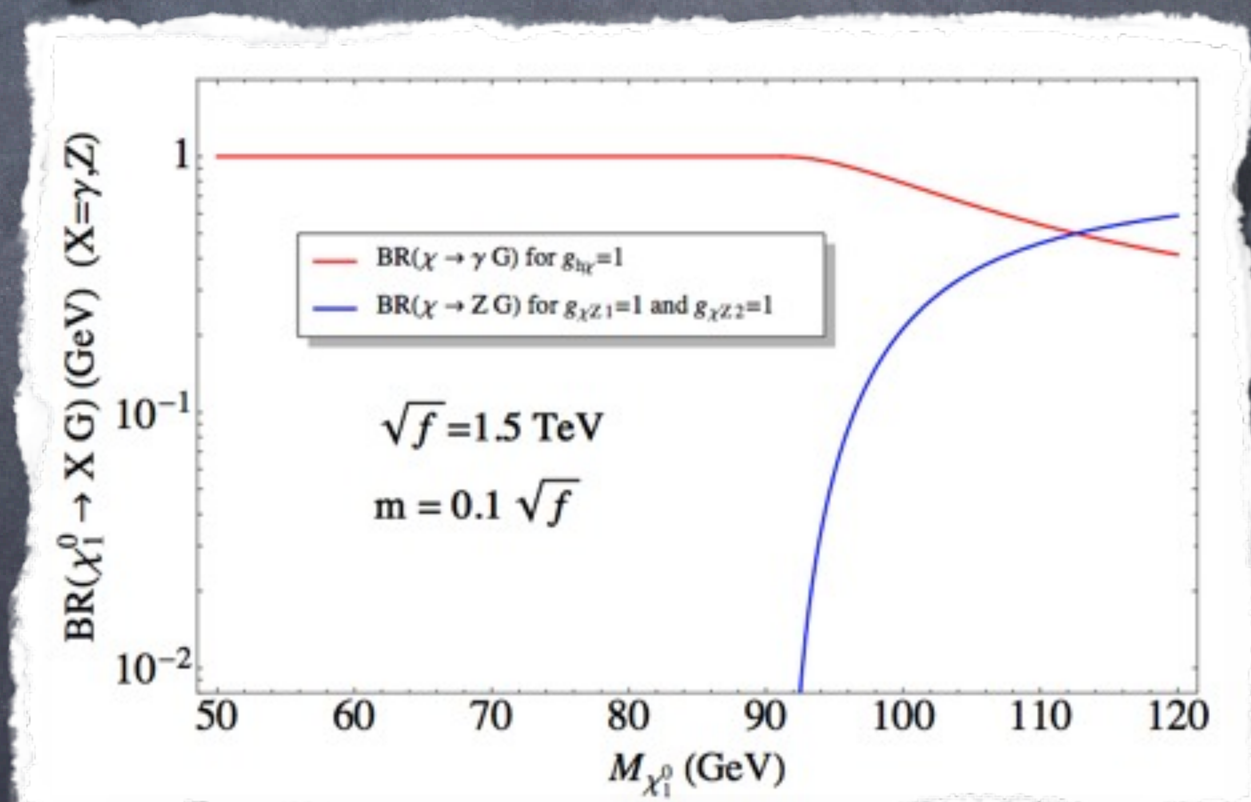






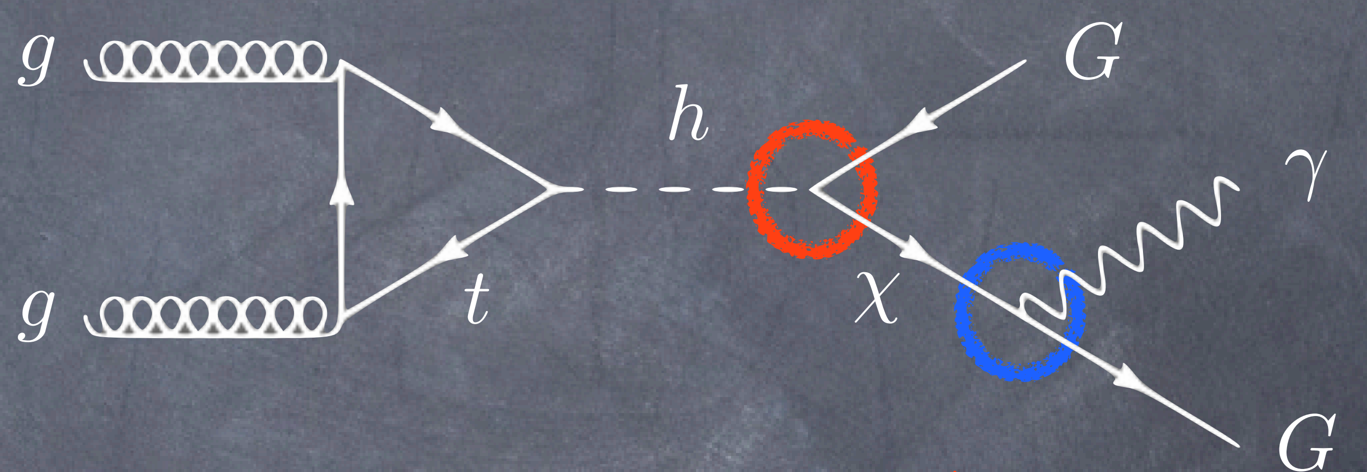






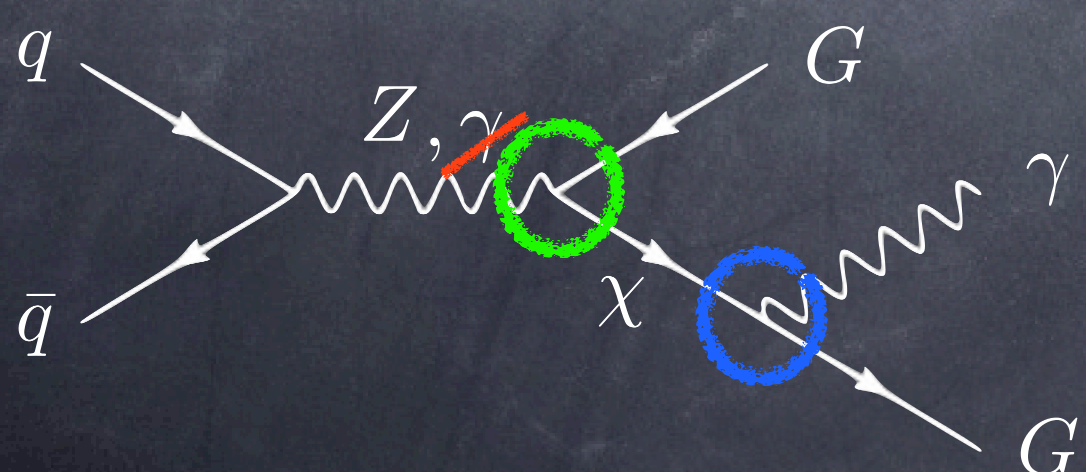
The signal: γ+MET

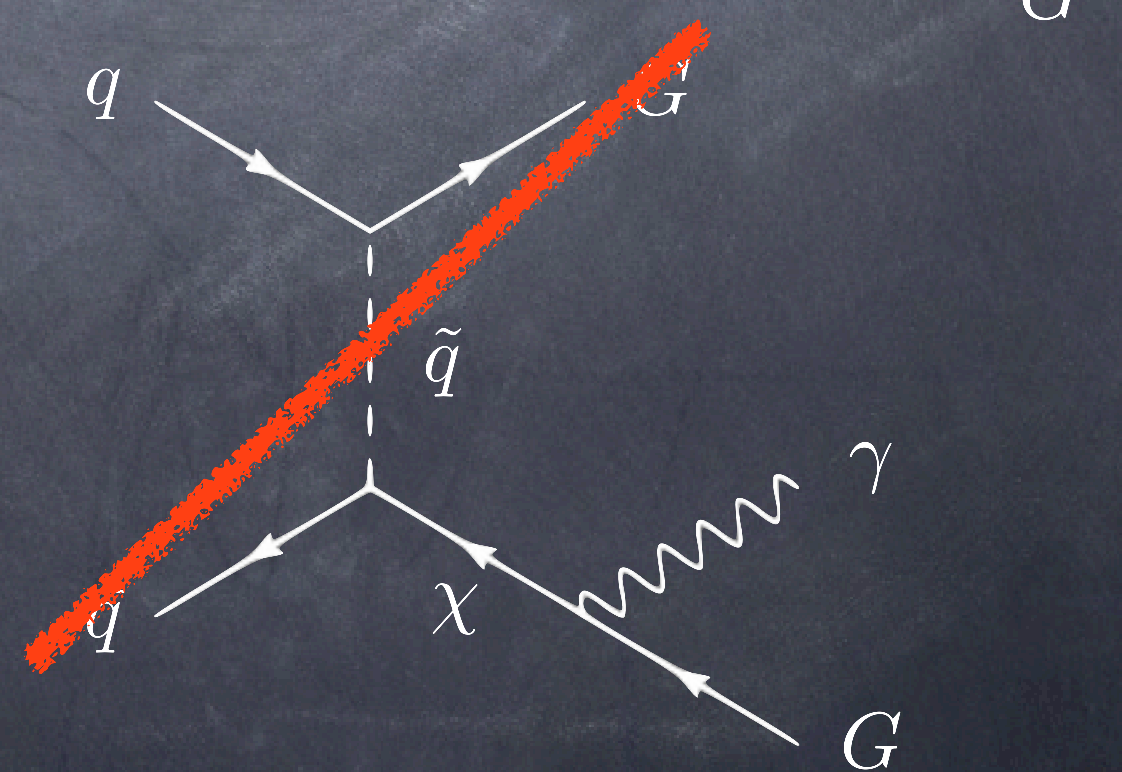
- We are interested in signals with a single isolated photon and missing transverse energy
- This final state arises from our Simplified Model through the following Feynman diagrams



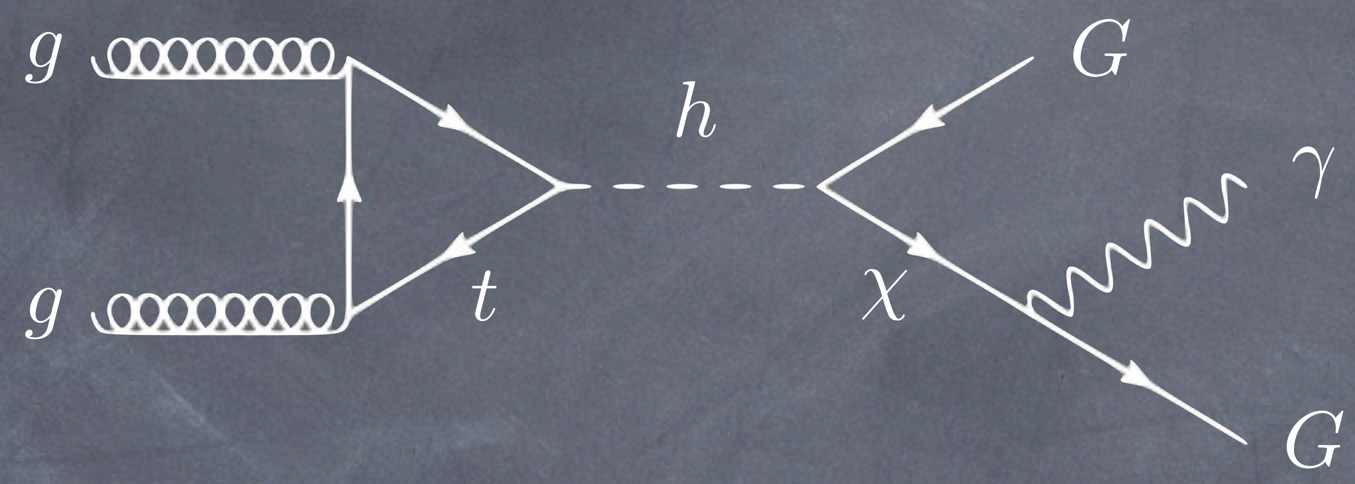
- Contributes in the region $p_T^\gamma \lesssim m_h/2$
- Focus on this region
- Need only the new vertices:

$h\chi G, \chi\gamma G, \chi Z G$





The signal: h -> γ+MET



- We can use the Narrow Width Approximation (NWA) to describe this process and write the number of signal events in the form

$$N_{\rm sig}^{h} = \sigma_{h}^{\rm SM} \times {\rm BR}\left(h \to \chi_1^0 G\right) \times {\rm BR}\left(\chi_1^0 \to \gamma G\right) \times \mathcal{A}_{\rm sig}^{h} \times \epsilon_\gamma \times L$$

- The NWA is reliable unless we're close to the kinematic threshold $m_\chi \sim m_h$ and we have verified that it is ok up to $m_\chi \sim 110$ GeV
- We use the NWA only to put a bound on ${\rm BR}\left(h \to \chi_1^0 G\right) \times {\rm BR}\left(\chi_1^0 \to \gamma G\right)$ but we always use the complete matrix elements for the calculations
- Where we expect the NWA to break down we define the "effective" BR

$${\rm BR}_{\rm eff}\left(A \to BC\right) = \frac{\sigma\left(pp \to BC\right)}{\sigma\left(pp \to A\right)}$$

The SM background: γ+MET

Name	Process	Source
bg1	$pp \to Z\gamma \to \gamma 2\nu$	Irreducible background
bg2	$pp \to Zj \to j2\nu$	Jet fakes a photon
bg3	$pp \to W \to e\nu$	Electron fakes a photon
bg4	$pp \to \gamma j$	Missing jet
bg5	$pp \to W\gamma \to \gamma l\nu$	Missing lepton
bg6	$pp \to \gamma\gamma$	Missing photon

Search strategy

- The $|\eta|$ cut is chosen to be $|\eta| < 1.44$ which represents the barrel ECAL fiducial region for the CMS experiment (almost the same for ATLAS)
- The p_T^γ distributions coming from the Higgs and Z boson on shell productions have an end point at $m_h/2$ and $m_Z/2$ respectively
- Therefore we can choose as upper p_T^γ cut $p_T^\gamma < m_h/2$
- To optimize the lower p_T^γ cut we have studied the signal significance as a function of this cut for LHC@8 with 20/fb of integrated luminosity

p_T^γ	Total bg	Signal	$N_S/\sqrt{N_B}$
30	$27.4 \cdot 10^3$	138	3.7
35	$15.5 \cdot 10^3$	107	3.8
40	5539	80	4.8
45	1975	55	5.5
50	942	33	4.8

$$m_\chi = 80\,\mathrm{GeV}$$

$$\mathrm{BR}\left(h \to \chi_0^1 G\right) = 2 \cdot 10^{-2}$$

- The signal significance is optimized for $p_T^\gamma|_{\min} = 45\,\mathrm{GeV}$

Signal acceptances

- The sensitivity of the LHC@8 to $\mathrm{BR}\left(h \to \chi_1^0 G\right) \times \mathrm{BR}\left(\chi_1^0 \to \gamma G\right)$ is only a function of the background and of the signal kinematic acceptance

$$\mathrm{BR}(h \to \chi_1^0 G) \times \mathrm{BR}(\chi_1^0 \to \gamma G)\Big|_{\min} = \frac{\mathcal{S}\sqrt{N_B}}{\sigma_h^{\mathrm{NNLO}} \times \mathcal{A}_{\mathrm{sign}}^h \times \epsilon_\gamma \times L}$$

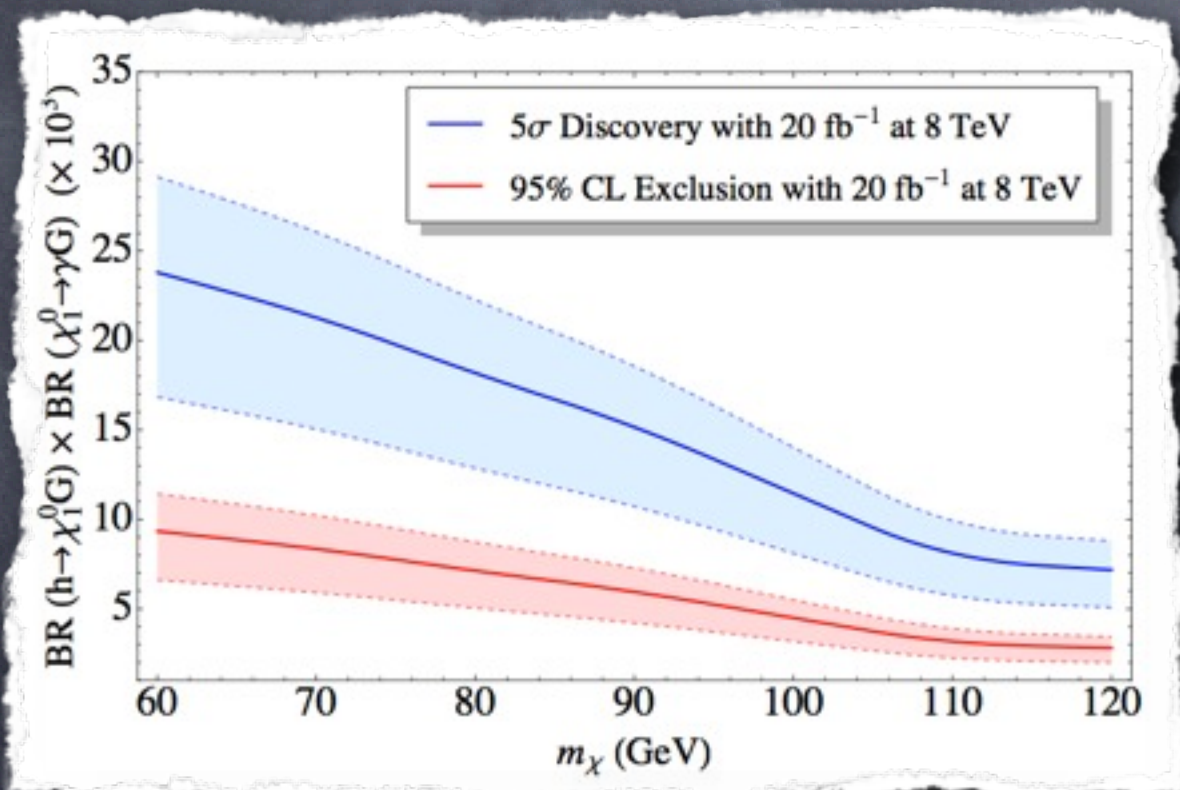
- Notice that $\mathrm{BR}\left(\chi_1^0 \to \gamma G\right) = 1$ for $m_\chi < m_Z$ but is expected to be close to one in the whole range $m_\chi < m_h$
- Therefore all the bounds can simply be applied to $\mathrm{BR}\left(h \to \chi_1^0 G\right)$ for neutralino masses lower than the Z boson mass

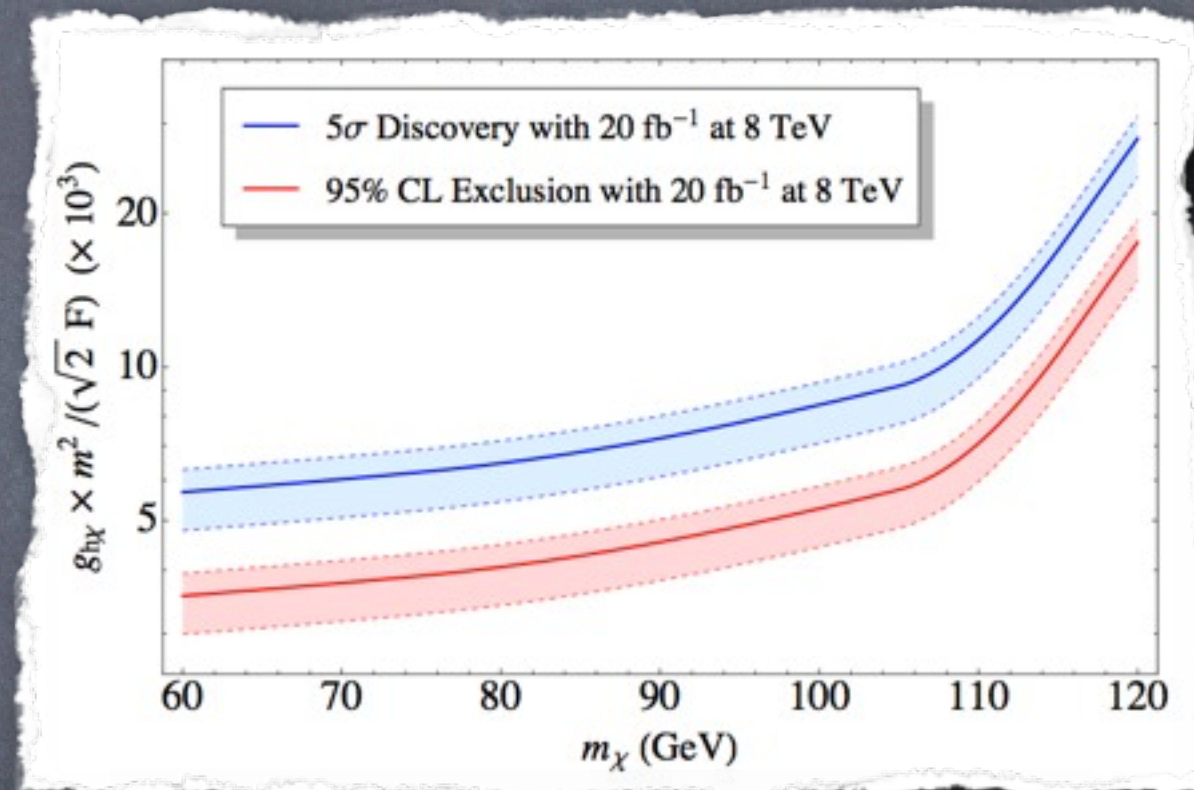
m_χ	A_{sign}^h
60	0.126
70	0.141
80	0.165
90	0.198

m_χ	A_{sign}^h
100	0.262
110	0.370
120	0.418

Model independent results

- We have plotted the sensitivity of the LHC@8 with 20/fb of integrated luminosity to $\mathrm{BR}\left(h \to \chi_1^0 G\right) \times \mathrm{BR}\left(\chi_1^0 \to \gamma G\right)$ and to the $h\chi_1^0 G$ coupling both for 5σ discovery and 95% CL exclusion





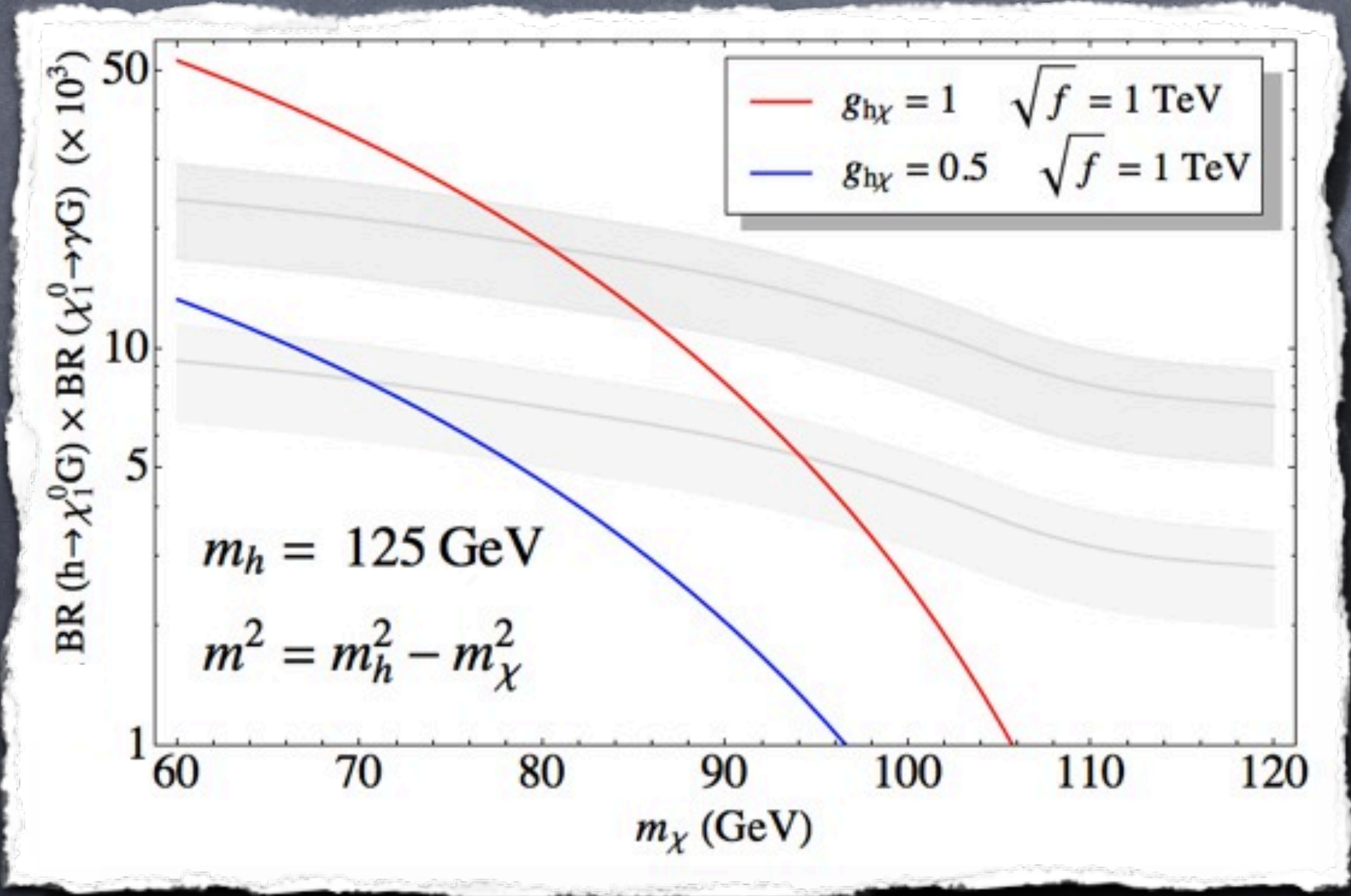
- The behavior of the plots for $m_\chi > 110\,\mathrm{GeV}$ is due to the deviation from the NWA

$h\chi G$ coupling from theory

- We have seen that the $h \to \chi_1^0 G$ width can be written in the form

$$\Gamma(h \to \chi_1^0 G) = \frac{m_h}{16\pi} \frac{g_{h\chi}^2 m^4}{f^2} \left(1 - \frac{m_\chi^2}{m_h^2}\right)^2$$

- Of course here everything depends on m and $g_{h\chi}$
- They are related to the soft-masses and scalar and fermion mixing angles



Conclusion

- Supersymmetry provides a fascinating solution to the Hierarchy Problem and is an important candidate to extend the SM far above the Fermi scale in a natural way
- However it suffers of strong experimental constraints summarized by the non observation of s-particles at colliders
- The hint for a Higgs boson with a mass around 125 GeV also pushes minimal models in a region of fine-tuning
- This motivates to go beyond the minimal possibilities (MSSM)
- We have explored the possibility in which SUSY breaking happens at the TeV scale giving rise to a peculiar phenomenology in the Higgs sector
- In particular we have also studied the sensitivity of the LHC@8 to the decay of the Higgs into γ + MET finding that a discovery in this channel will point to low scale SUSY breaking

Thanks

To my collaborators Alberto Romagnoni and Christoffer Petersson for having patiently introduced me to the topic

To Damiano Tommasini, Vincent Giangiobbe and Roberto Franceschini for discussions related to the project