Higgs decay with γ + MET from low scale SUSY breaking

Riccardo Torre
IFT UAM/CSIC

LHCPhenoNet Annual Meeting,

Lumley Castle, Durham (UK)

21 March 2012

based on C. Petersson, A. Romagnoni and RT
to appear tomorrow (1203.xxxx [hep-ph])

Outline

- Introduction and theoretical motivations
- A simplified model for SUSY γ+MET
  - Search strategy
  - Signal vs Background
  - LHC@8 predictions
- SUSY γ+MET from explicit models
  - General goldstino couplings
  - Weakly vs Strongly coupled regime
- Conclusion

The goal of this talk

- In models with a low SUSY breaking scale the gravitino is very light and therefore it is the LSP
- The NLSP can be a neutralino which can therefore decay only into a goldstino and a gauge or 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 we can have a gauge or a Higgs boson decay into a neutralino and a goldstino with the former decaying to 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 discuss an explicit examples of a SUSY effective model giving rise to this signal

The 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 explicit SUSY models which predict the same signal
5. See if BRs and coupling interesting for discovery can be generated

Remarks

1. Of course in explicit models, the relevant BRs will depend on more than one parameter, therefore limits can be set only on combinations of parameters
2. However, even just the observation of some signals can give important qualitative information on the nature of the new physics

Simplified model for γ+MET

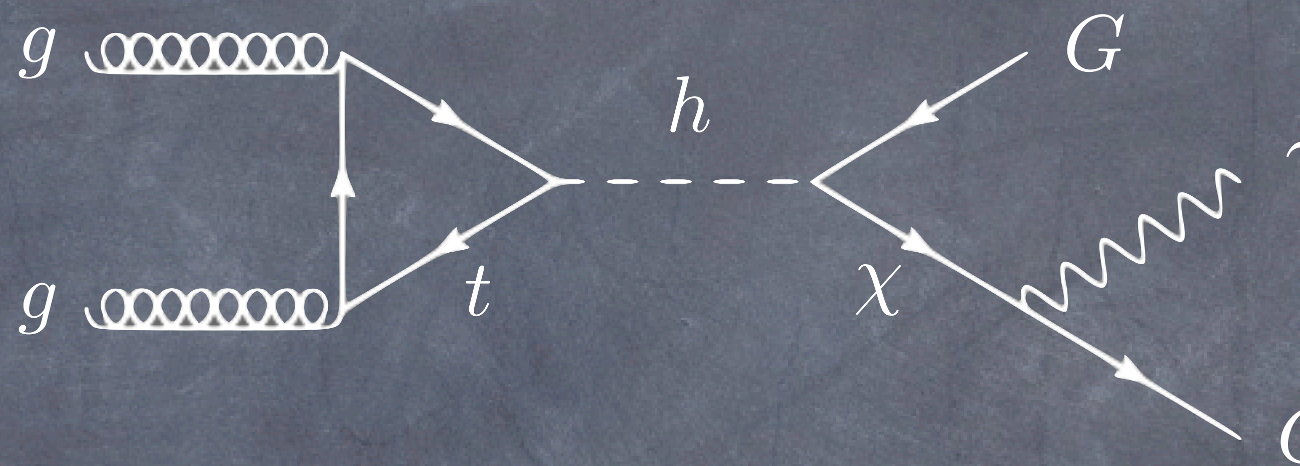
- The signal we are interested in is described by the following effective Lagrangian

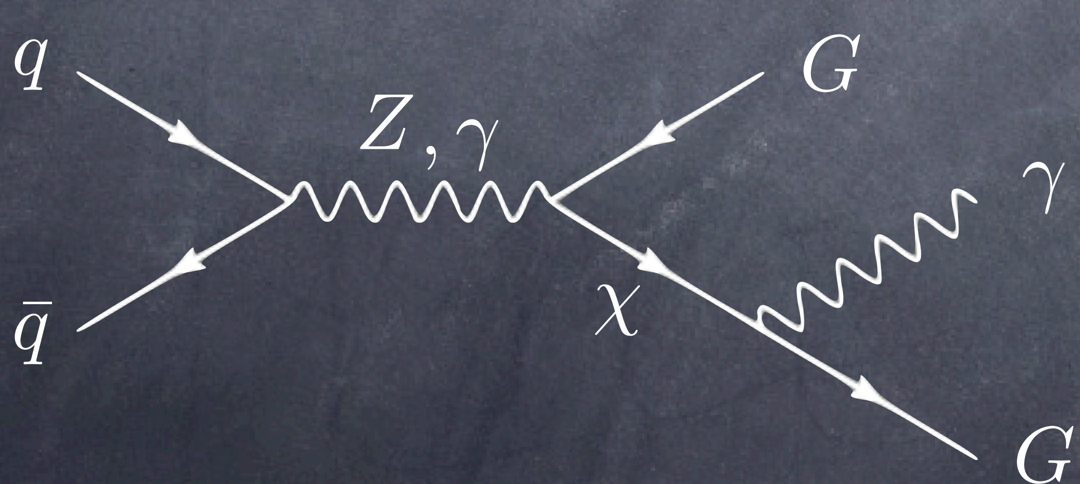
$$\begin{aligned}\mathcal{L}_{\rm eff} &= \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm NP}\\ \mathcal{L}_{\rm NP} &= \frac{m^2}{\sqrt{2}f}\Bigg[g_{h\chi} h\chi_1^0 G + \frac{g_{\chi\gamma}}{m} G\sigma^{\mu\nu}F_{\mu\nu}\chi_1^0\\ &\quad + \frac{g_{\chi Z\,1}}{m} G\sigma^{\mu\nu}Z_{\mu\nu}\chi_1^0 + g_{\chi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

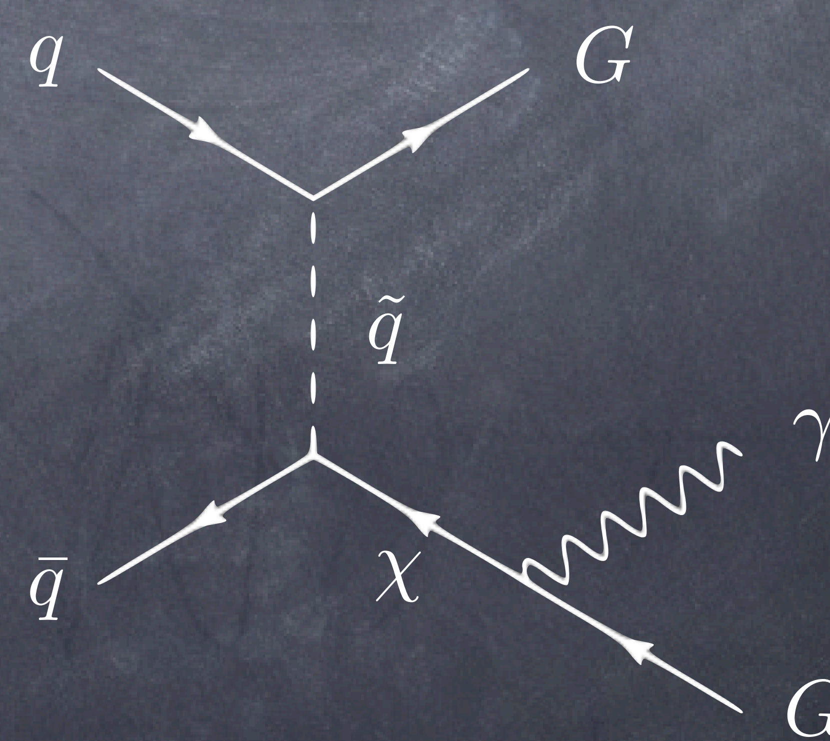
- We are interested in the case in which $\sqrt{f}$, which we interpret as the SUSY breaking scale, is at the TeV scale and m which is a mass scale that depends on the model is at the EW scale
- The g_i are dimensionless couplings
- The σ^μ, $\bar{\sigma}^\mu$ and $\sigma^{\mu\nu}$ are the usual combinations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

The signal: γ+MET

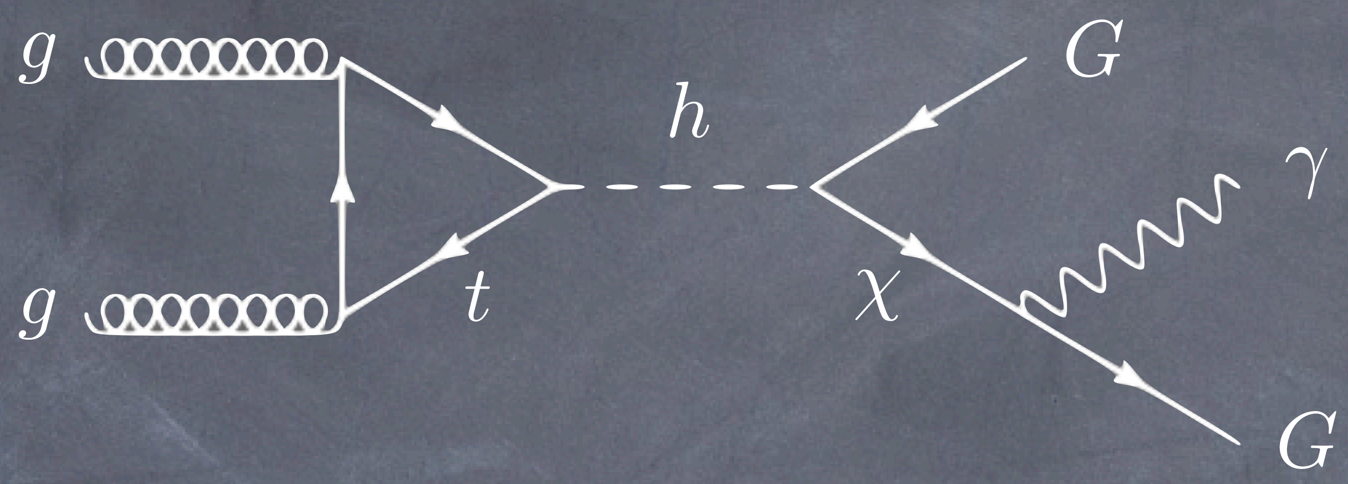
- We are interested in signals with a single isolated photon and missing transverse energy
- This final state arises from our Simplified Model through the following Feynman diagrams







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

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

- 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 $\text{BR}\left(h \to \chi_1^0 G\right) \times \text{BR}\left(\chi_1^0 \to \gamma G\right)$ but we always use the complete matrix elements for the calculations
- Where we expect the NWA to break down we define the "effective" BR

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

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
- 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

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

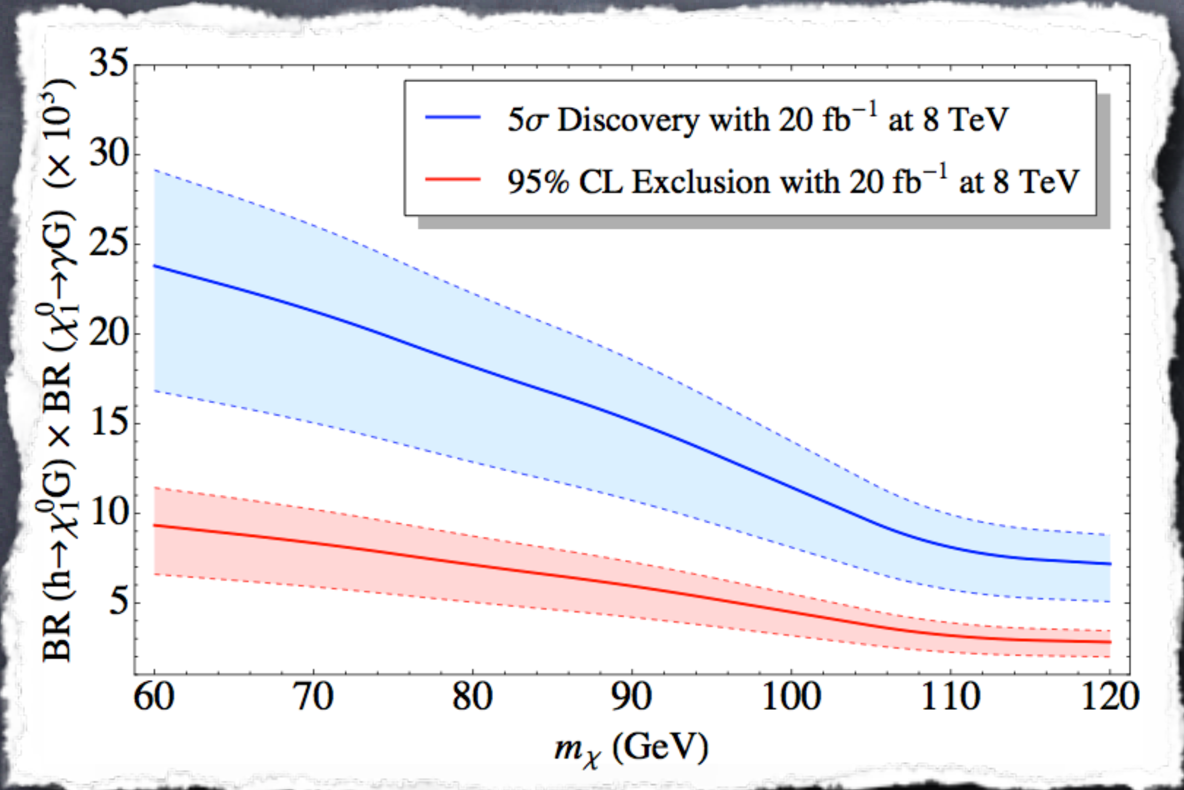
- Notice that $\mathrm{BR}\left(\chi_1^0 \to \gamma G\right) = 1$ for $m_\chi < m_Z$ but is expected to be close to one in the whole range $m_\chi < m_h$
- Therefore all the bounds can simply be applied to $\mathrm{BR}\left(h \to \chi_1^0 G\right)$ for neutralino masses lower than the Z boson mass

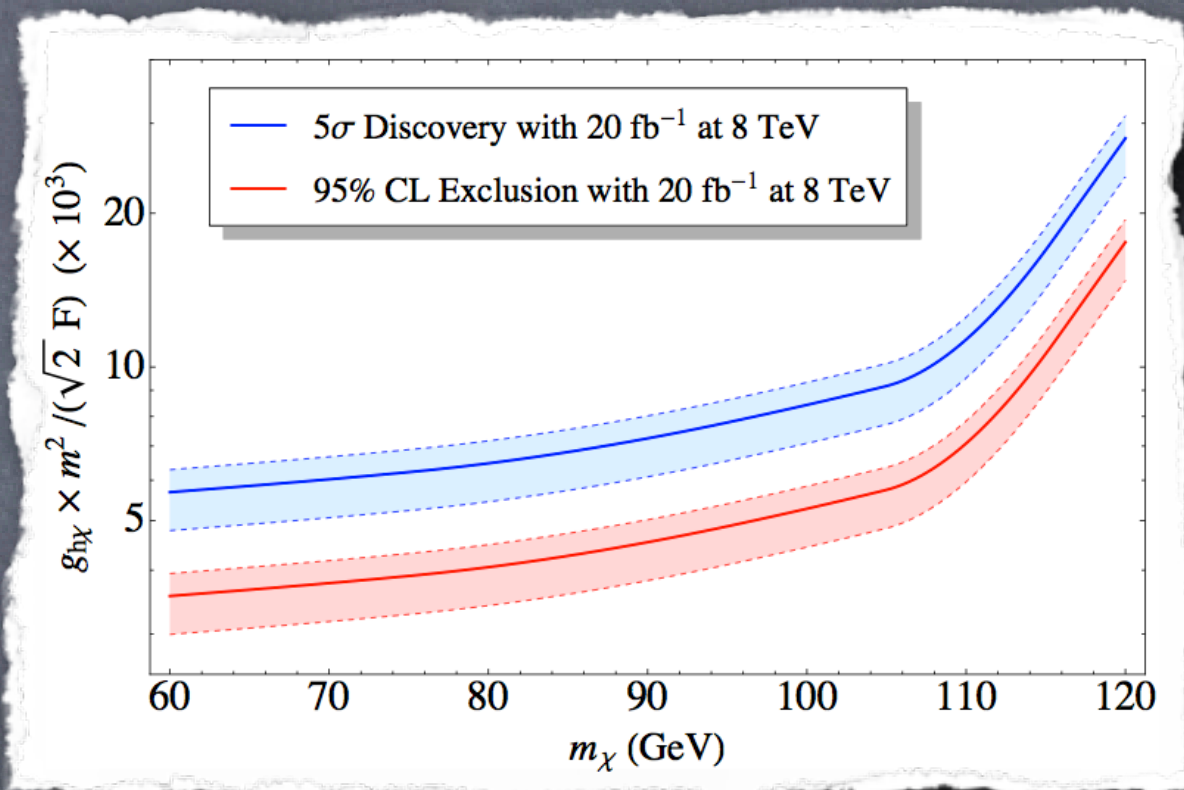
m_χ	A^h_{sign}
60	0.126
70	0.141
80	0.165
90	0.198

m_χ	A^h_{sign}
100	0.262
110	0.370
120	0.418

Final model independent results

- We have plotted the sensitivity of the LHC@8 with 20/fb of integrated luminosity to $\mathrm{BR}\,(h \to \chi_1^0 G) \times \mathrm{BR}\,(\chi_1^0 \to \gamma G)$ 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

Explicit SUSY model

- The complete Lagrangian of the model is given by

$$\mathcal{L} = \mathcal{L}_{\text{SUSY}} + \mathcal{L}_X$$
$$\mathcal{L}_{\text{SUSY}} = \mathcal{L}_{\text{kin}} + \mathcal{L}_g + \mathcal{L}_\mu + \mathcal{L}_{\text{Yuk}}$$
$$\mathcal{L}_X = \mathcal{L}_{\text{kin},X} + \mathcal{L}_{g,X} + \mathcal{L}_{\mu,X} + \mathcal{L}_{\text{Yuk},X} + \mathcal{L}_X$$

- X is the Goldstino superfield, usually treated as a spurion only containing a VEV in its auxiliary F-term component
- Since we assume SUSY to be broken at very low energy (TeV scale) we treat X as a dynamical chiral superfield

$$X = x + \sqrt{2}\theta\psi_X + \theta^2 F_X$$

- Where ψ_X becomes the Goldstino at low energies (modulo corrections due to EWSB), x its complex scalar superpartner (the s-goldstino) and F_X the auxiliary field which acquires the non vanishing VEV that breaks SUSY
- Here we assume the s-goldstinos to be parametrically heavier than the Higgs so that they dont affect the phenomenology we discussed

Minimal goldstino couplings

- We get all the X couplings just by coupling X to every MSSM chiral interaction and $X^\dagger X$ to the non chiral ones

1. $$\mathcal{L}_{\mathrm{kin},X} = -\int d^4\theta \left(\frac{m_u^2}{f^2} X^\dagger X H_u^\dagger e^{gV} H_u + \frac{m_d^2}{f^2} X^\dagger X H_d^\dagger e^{gV} H_d + \sum_{\Phi} \frac{m_\Phi^2}{f^2} X^\dagger X \Phi^\dagger e^{gV} \Phi \right)$$

2. $$\mathcal{L}_{g,X} = -\sum_{i=1}^{3} \int d^2\theta \, \frac{m_i}{2f} X W_{A_i}^{\alpha} W_{\alpha}^{A_i} + \mathrm{h.c.}$$

3. $$\mathcal{L}_{\mu,X} = -\int d^2\theta \, \frac{B_\mu}{f} X H_d \cdot H_u + \mathrm{h.c.}$$

4. $$\mathcal{L}_{\mathrm{Yuk},X} = -\int d^2\theta \left(\frac{A_u}{f} X H_u Q U^c + \frac{A_d}{f} X Q D^c H_d + \frac{A_e}{f} X L E^c H_d \right) + \mathrm{h.c.}$$

5. $$\mathcal{L}_X = \int d^4\theta \, X^\dagger X \left(1 - \frac{m_x^2}{4f^2} X^\dagger X \right) + \left\{ \int d^2\theta f X + \mathrm{h.c.} \right\}$$

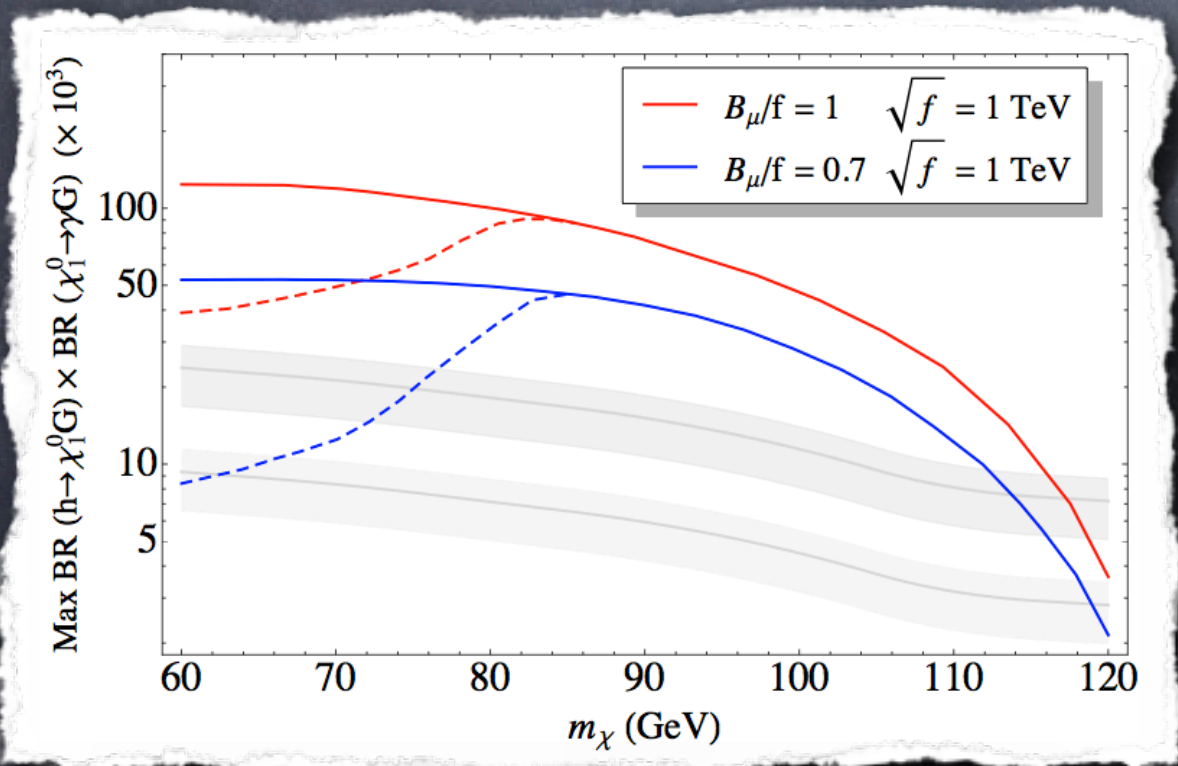
1. soft mass terms for the Higgs and the s-fermions
2. gaugino masses
3. B_μ-term
4. A-terms
5. Polonyi term (SUSY breaking) + s-goldstino soft mass

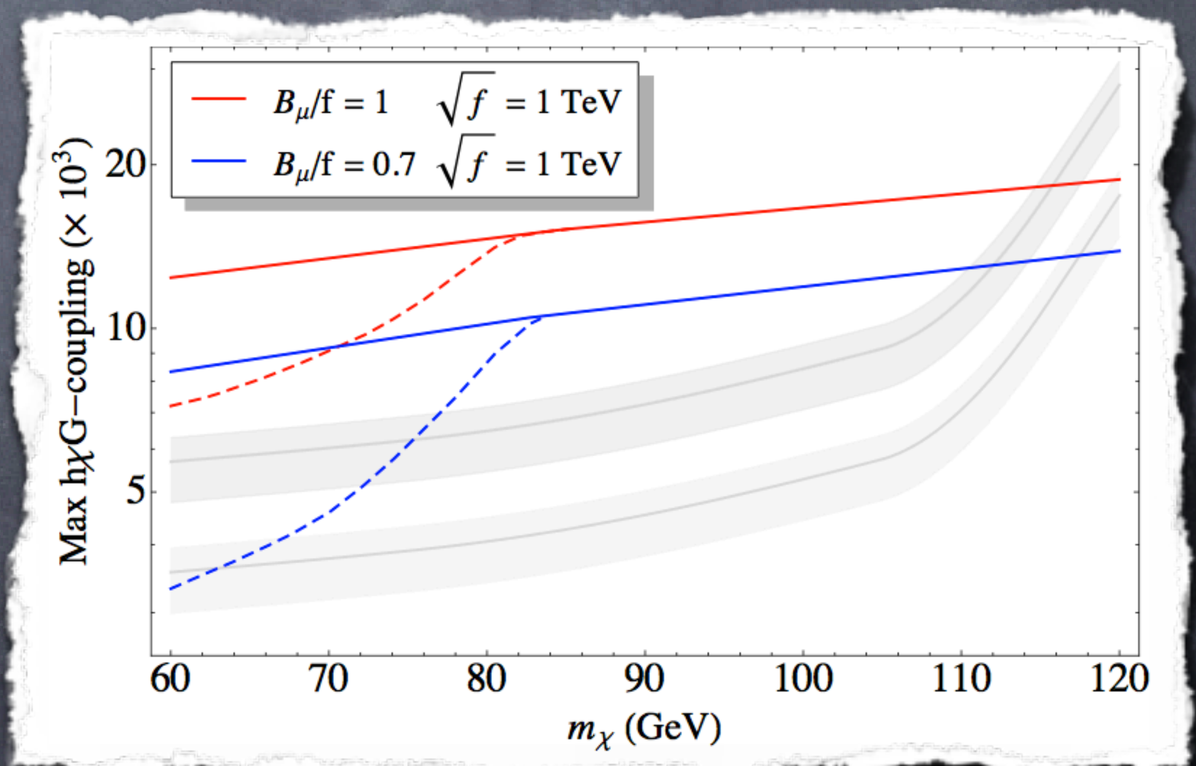
$h\chi G$ coupling

- The $h\chi G$ coupling strongly depends on B_μ/f (this is analogous to the λ of the NMSSM even if they have a very different nature)

$$\mathcal{L}_{\mu,X} = -\int d^2\theta \, \frac{B_\mu}{f} X H_d \cdot H_u + \text{h.c.}$$

- We can distinguish a weakly coupled regime (NMSSM like) and a strongly coupled regime (λ SUSY like)





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 large 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
- We have extended the MSSM to include the couplings of the goldstino by promoting the soft terms to supersymmetric operators
- We have also studied the sensitivity of the LHC@8 to the decay of the Higgs into γ + MET founding that a discovery in this channel will point to a non-minimal SUSY model

Thanks

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

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