Higgs Decays to Neutralinos

David E. Morrissey

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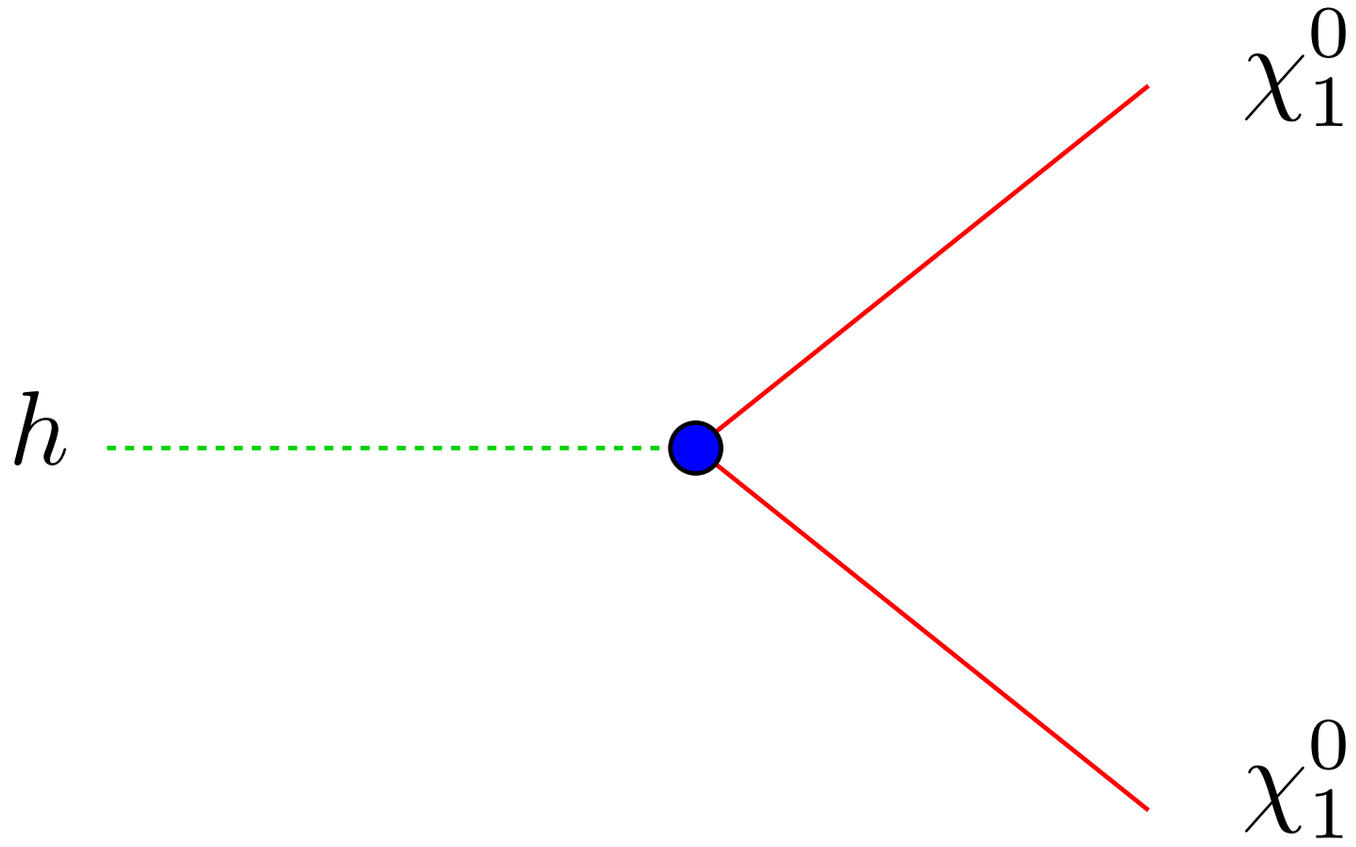
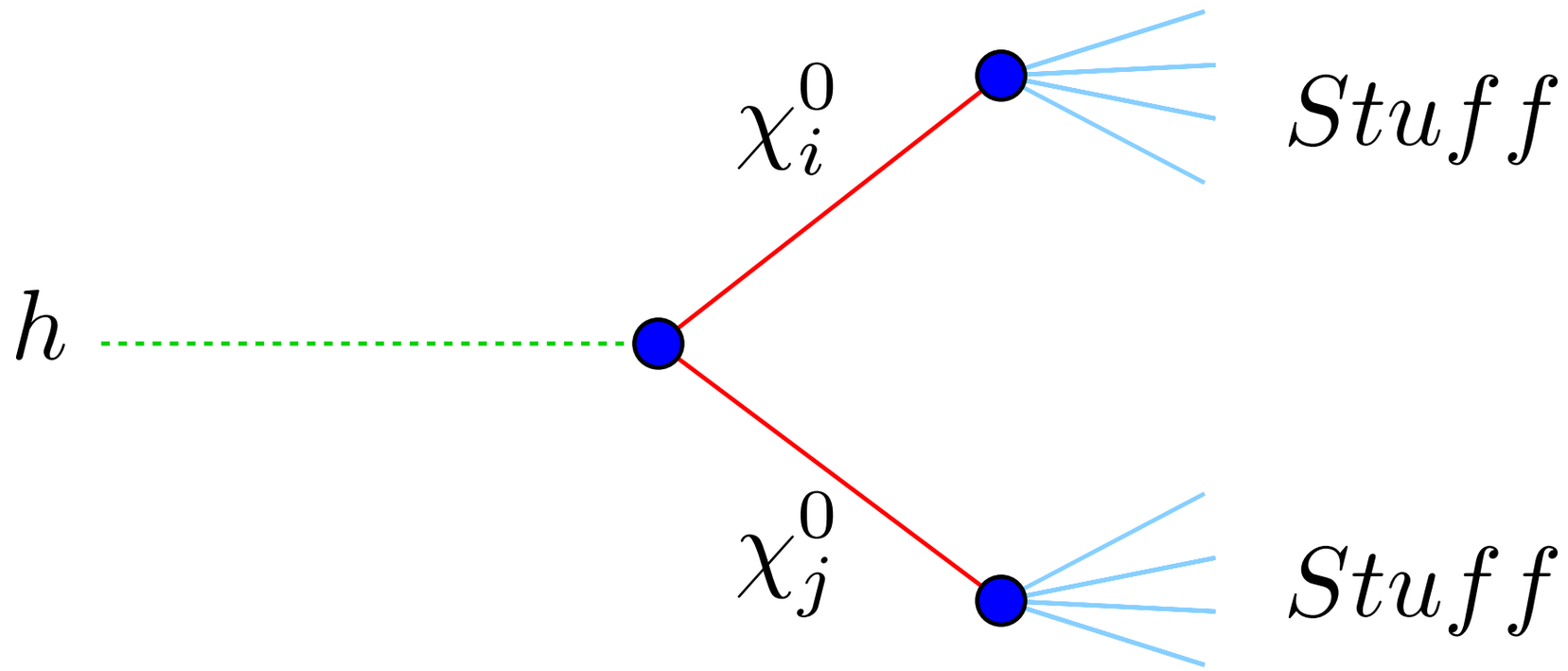
Exotic Higgs Decays @ Fermilab

Higgs Decays to Neutralinos: Invisible



Stable $\chi_1^0 \Rightarrow$ Invisible Higgs Decay

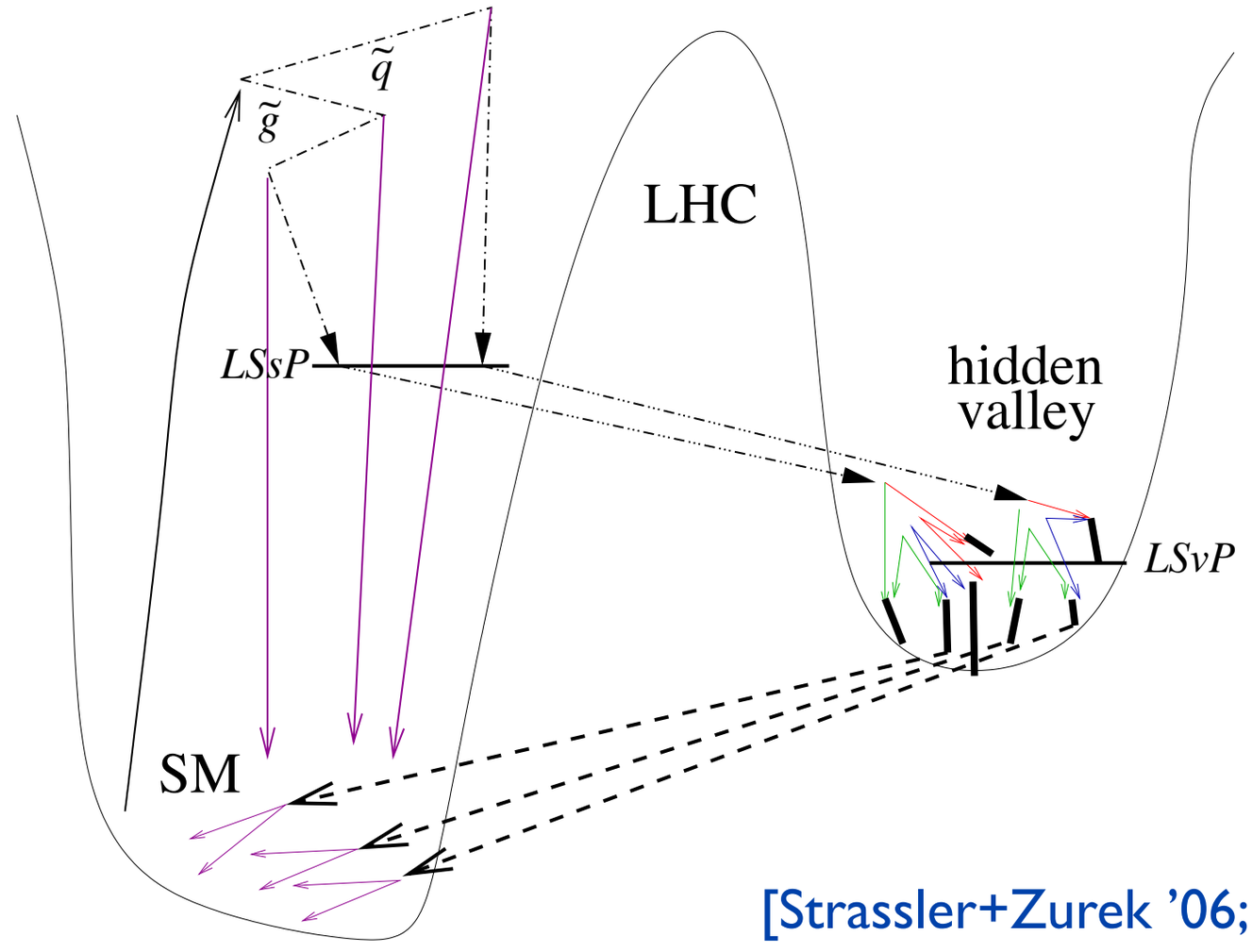
Higgs Decays to Neutralinos: Exotic



Unstable χ_i^0 $\Rightarrow$ Exotic Higgs Decay

Neutralinos as a Portal to Hidden Stuff

- Most viable SUSY models have (approximate) R-parity.
  ⇒ hidden superpartners from SM superpartner cascades



[Strassler+Zurek '06; Strassler '06]

Neutralinos: Minimal Supersymmetry

- Four Majorana fermions: $\chi_1^0,\ \chi_2^0,\ \chi_3^0,\ \chi_4^0$.
- Mixtures of superpartners of $B_\mu, W_\mu^3, H_u^0, H_d^0$.
- Mixing due to electroweak symmetry breaking .
  $\Rightarrow$ must couple to the Higgs!

- Lightest χ_1^0 state is often assumed to be stable (LSP).
- It doesn't have to be:
  - $\chi_1^0 \to \gamma + \widetilde{G}$ in low-scale gauge mediation
  - $\chi_1^0 \to SM\ stuff$ with R-parity violation

Neutralinos: Non-Minimal Supersymmetry

- Can get more than four neutralinos.
- New states come from new neutral superpartners, can be SM singlets or electroweakly charged.
- Mixing still due to electroweak symmetry breaking . ⇒ must couple to the Higgs!

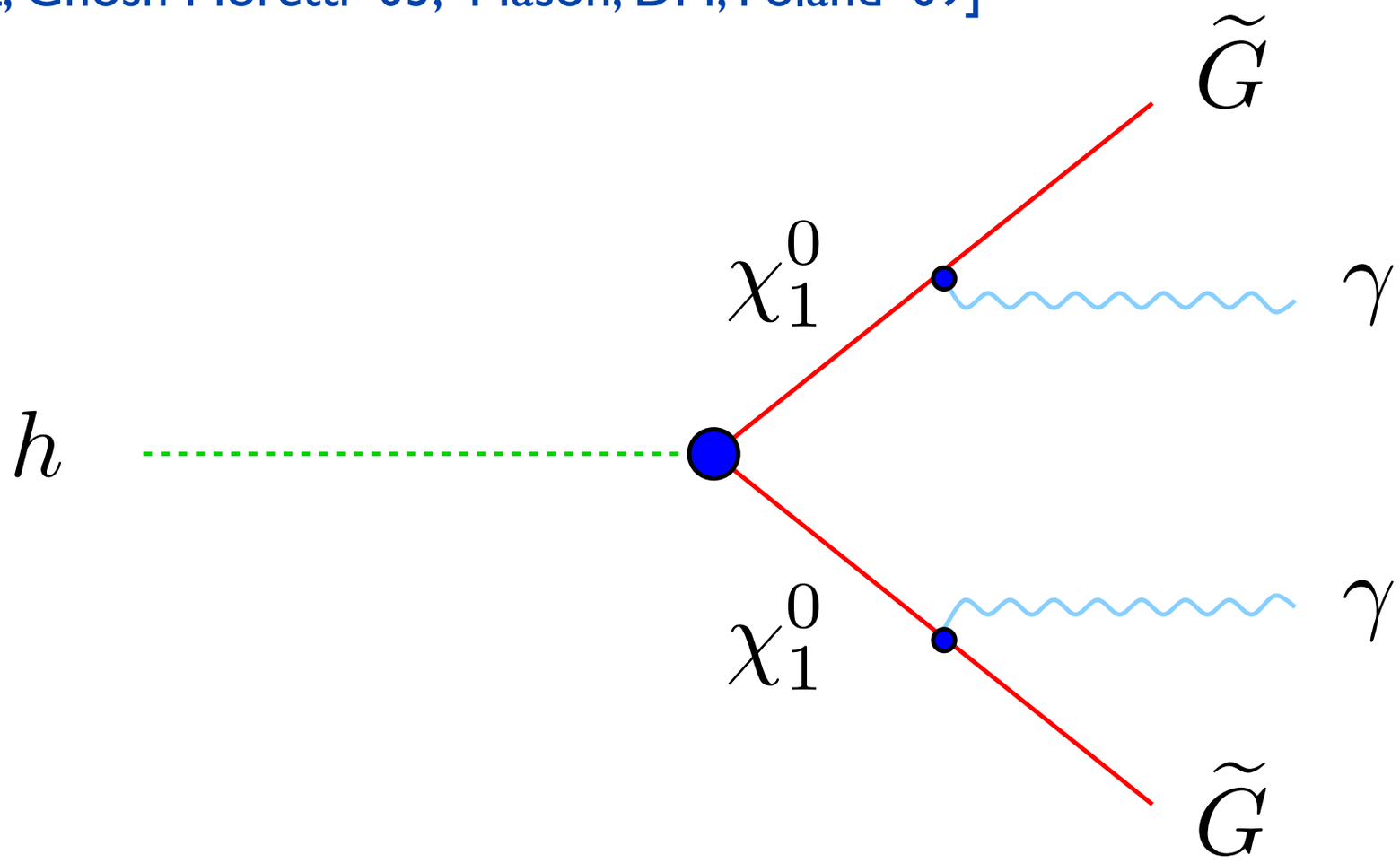
- Popular Examples:
  - singlino in MSSM + gauge singlet (NMSSM)
  - light dark-sector neutralinos from a dark gauged $U(1)_x$.
  - triplet fermion in MSSM + triplet (3MSSM)

MSSM Example:

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

MSSM $h \to \gamma\gamma + \not{E}_T$

[Díaz-Cruz, Ghosh Moretti '03; Mason, DM, Poland '09]



$\tilde{G}$ = stable gravitino (nearly massless)

Can arise in (very) general gauge mediation.

[Cheung, Fitzpatrick, Shih '07; Meade, Seiberg, Shih '08]

Higgs Decays to Neutralinos

- $h^0 \to \chi_i^0 \chi_j^0$ requires $m_h > m_i + m_j$.
- MSSM: only possibility is mostly-Bino χ_1^0 .

  $\widetilde{B}^0$ does not couple to vector bosons

  $\widetilde{W}^0$, $\widetilde{H}_{u,d}^0$ do and have chargino friends

- State content:

$$\chi_1^0 \sim \widetilde{B}^0 - \epsilon \widetilde{H}^0 \ , \qquad \epsilon \sim s_\beta c_\beta \, (m_Z/\mu)$$

Higgs Decays to Neutralinos

- State content:

$$\chi_1^0 \sim \widetilde{B}^0 - \epsilon \widetilde{H}^0 \,, \qquad \epsilon \sim s_\beta c_\beta \, (m_Z/\mu)$$

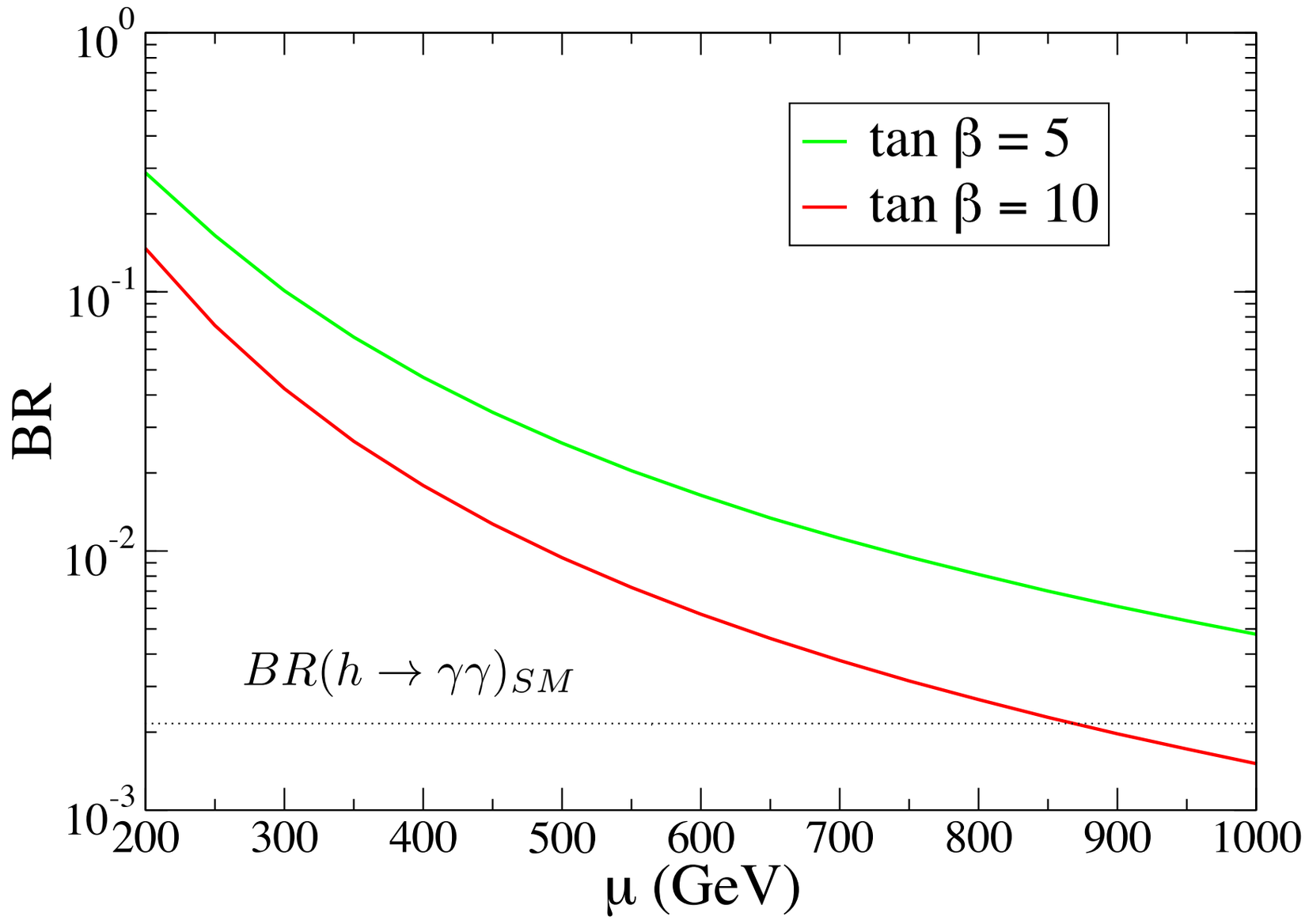
- Couplings:

$$-\mathcal{L} \supset g' H \, \widetilde{H}^0 \widetilde{B}^0 + \bar{g} Z_\mu^0 \, \widetilde{H}^{0\dagger} \bar{\sigma}^\mu \widetilde{H}^0$$

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

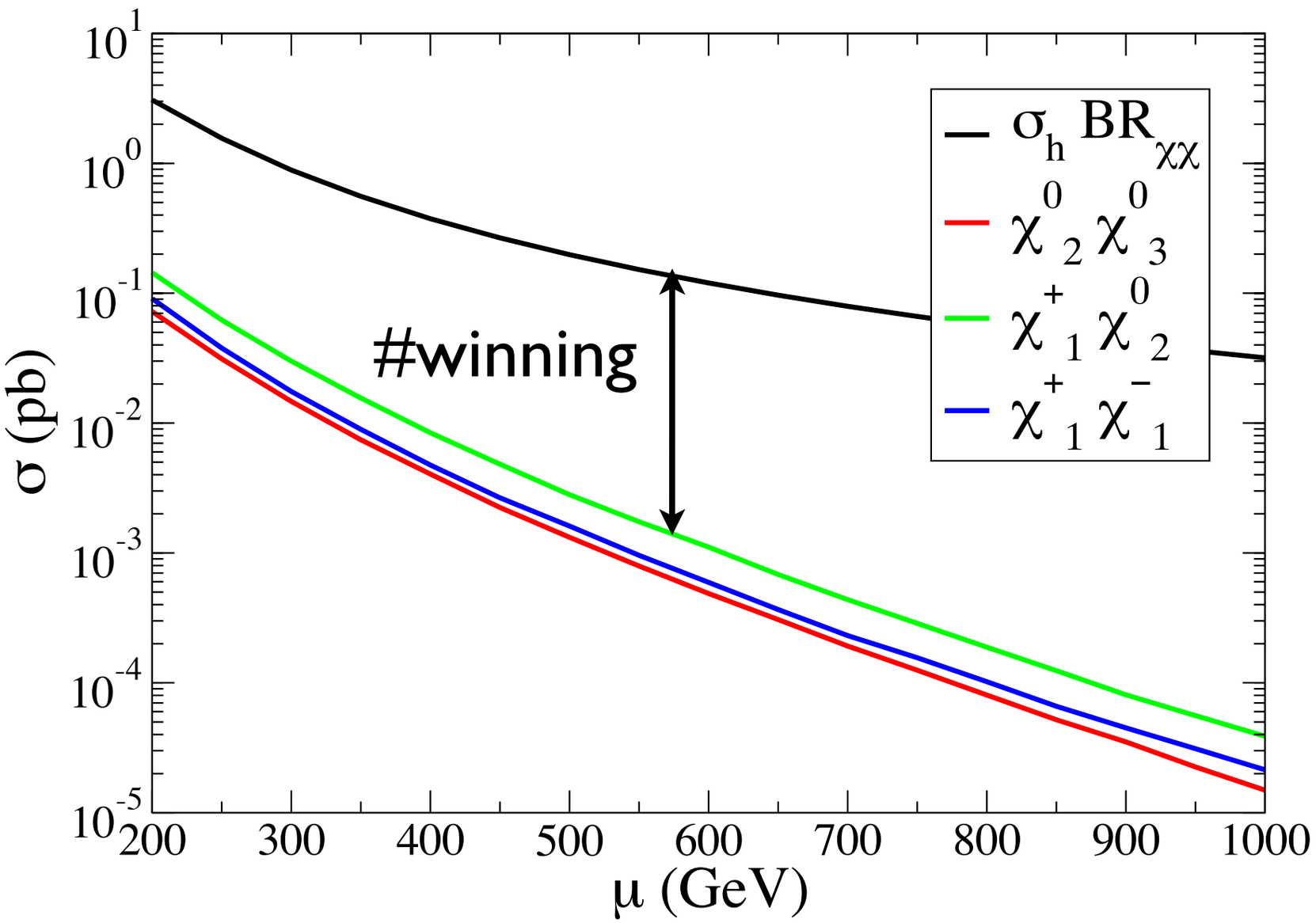
Higgs Decays to Neutralinos

- Branching Fractions ($M_1 = 50\,\mathrm{GeV}$):



Comparison to Neutralino Production

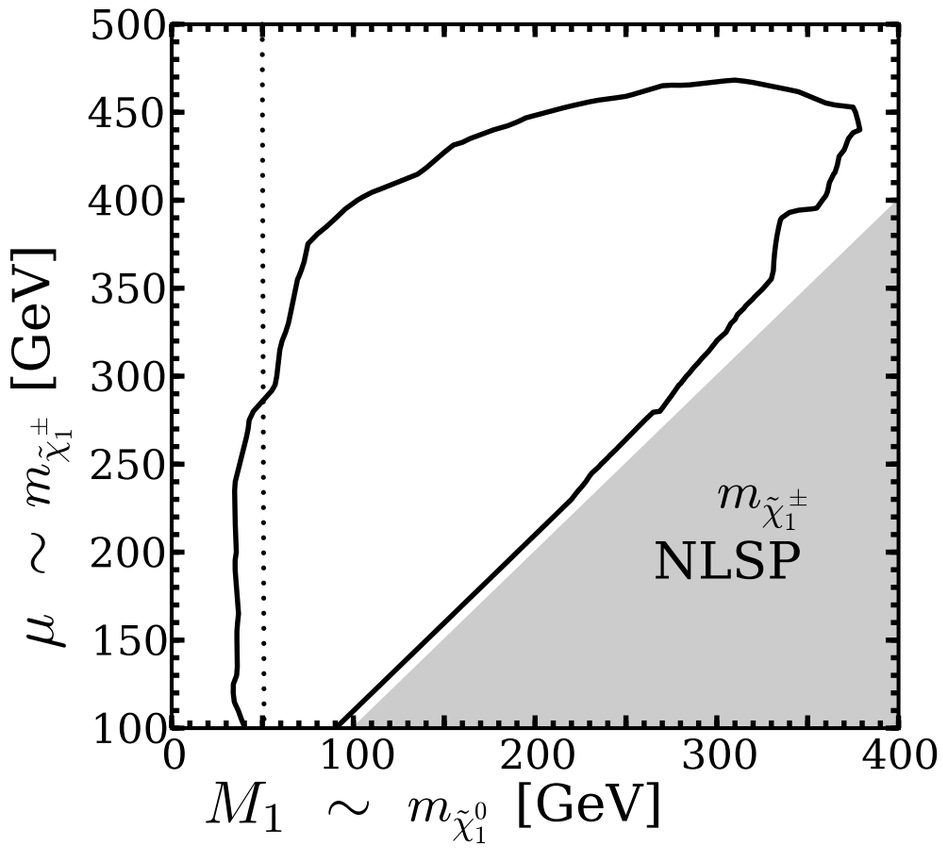
- LHC8 Production ($M_1 = 50\,\mathrm{GeV}, \tan\beta = 10$):



Direct Neutralino Limits

- Limits derived from LHC7 (4.8 fb^{-1} in ATLAS):

[Barnard, Farmer, Gherghetta, White '12]



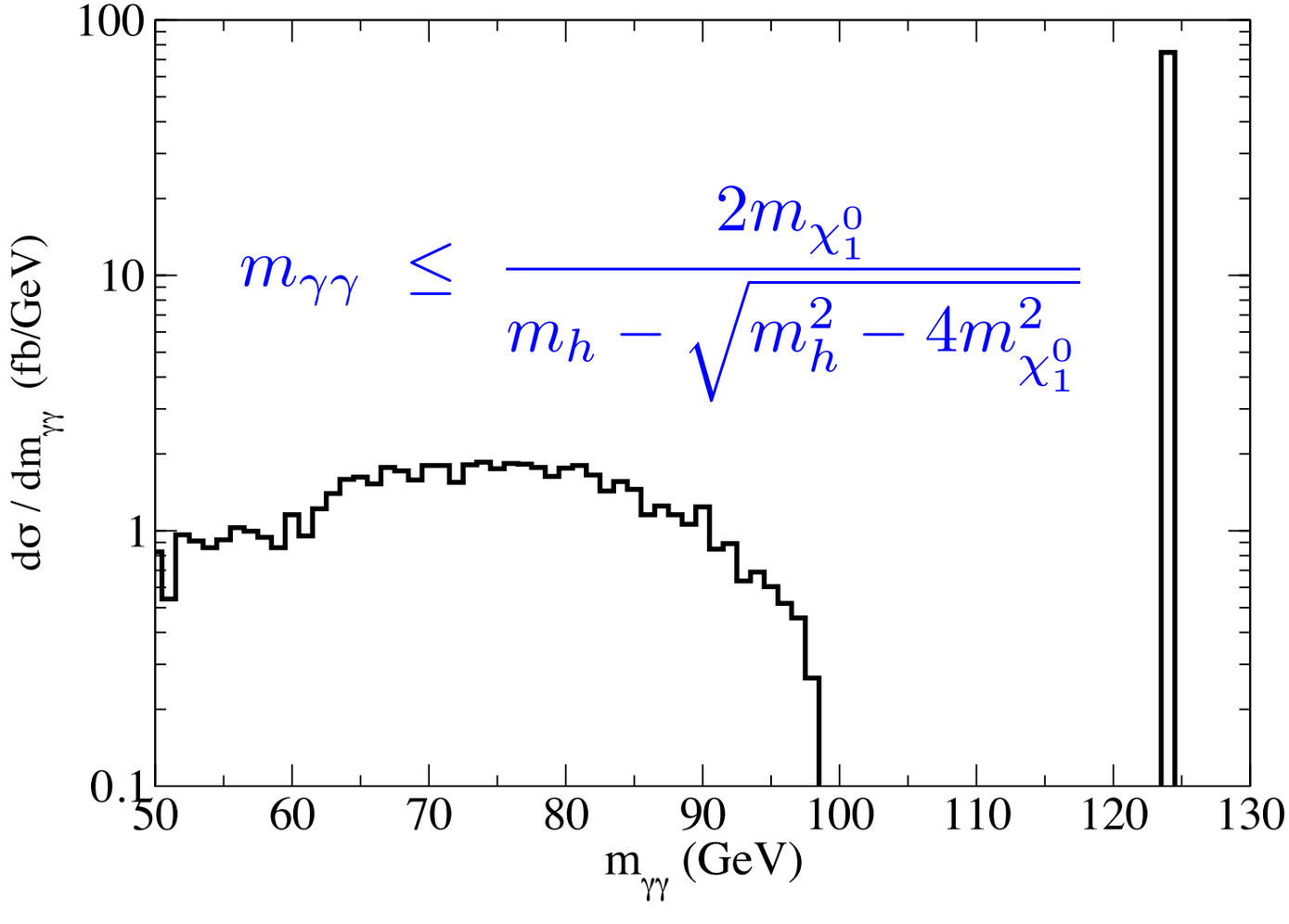
- LHC8 data should be able to limit $\mu \gtrsim 500-600\,\mathrm{GeV}$. Allows $BR(h \to \chi_1^0 \chi_1^0) \lesssim 5-10\%$ in the MSSM.

Diphotons from the Higgs

- $M_1 = 50\,\mathrm{GeV}, \quad \tan\beta = 10, \quad \mu = 400\,\mathrm{GeV}$

  $(BR(h \to \chi_1^0\chi_1^0) \simeq 2.5\%)$

- **Selection:** $p_{T_1}^{\gamma} > 35\,\mathrm{GeV}, \quad p_{T_2}^{\gamma} > 25\,\mathrm{GeV}, \quad |\eta_\gamma| < 2.5$

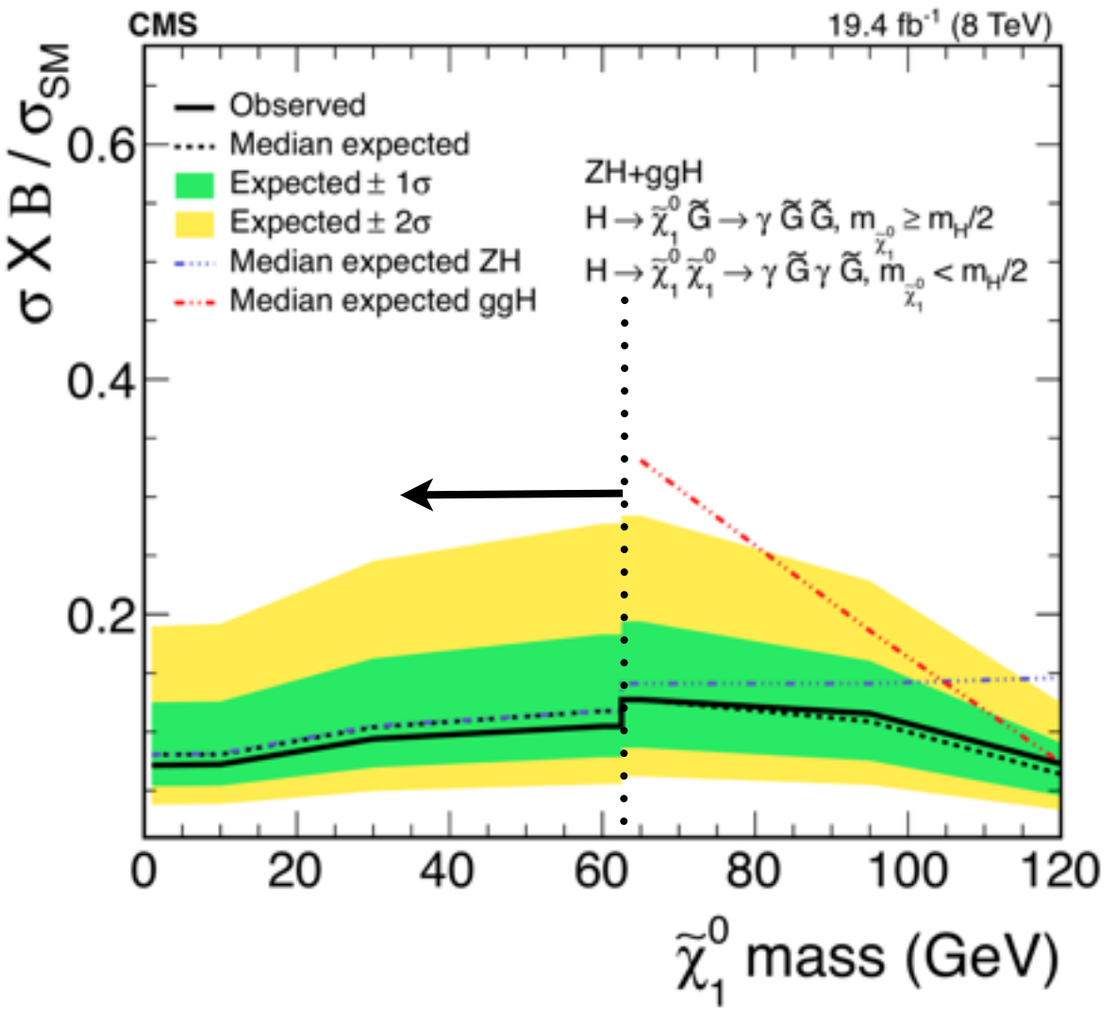


Searches

- Inclusive diphotons is swamped by background.
- Large event rate ⇒ exclusive channels promising:
  - Zh (leptonic) selection plus diphotons
  - VBF selection plus diphotons
  - monojet plus diphotons
- Generalizes to other rare Higgs modes...

Searches: Zh plus Diphotons

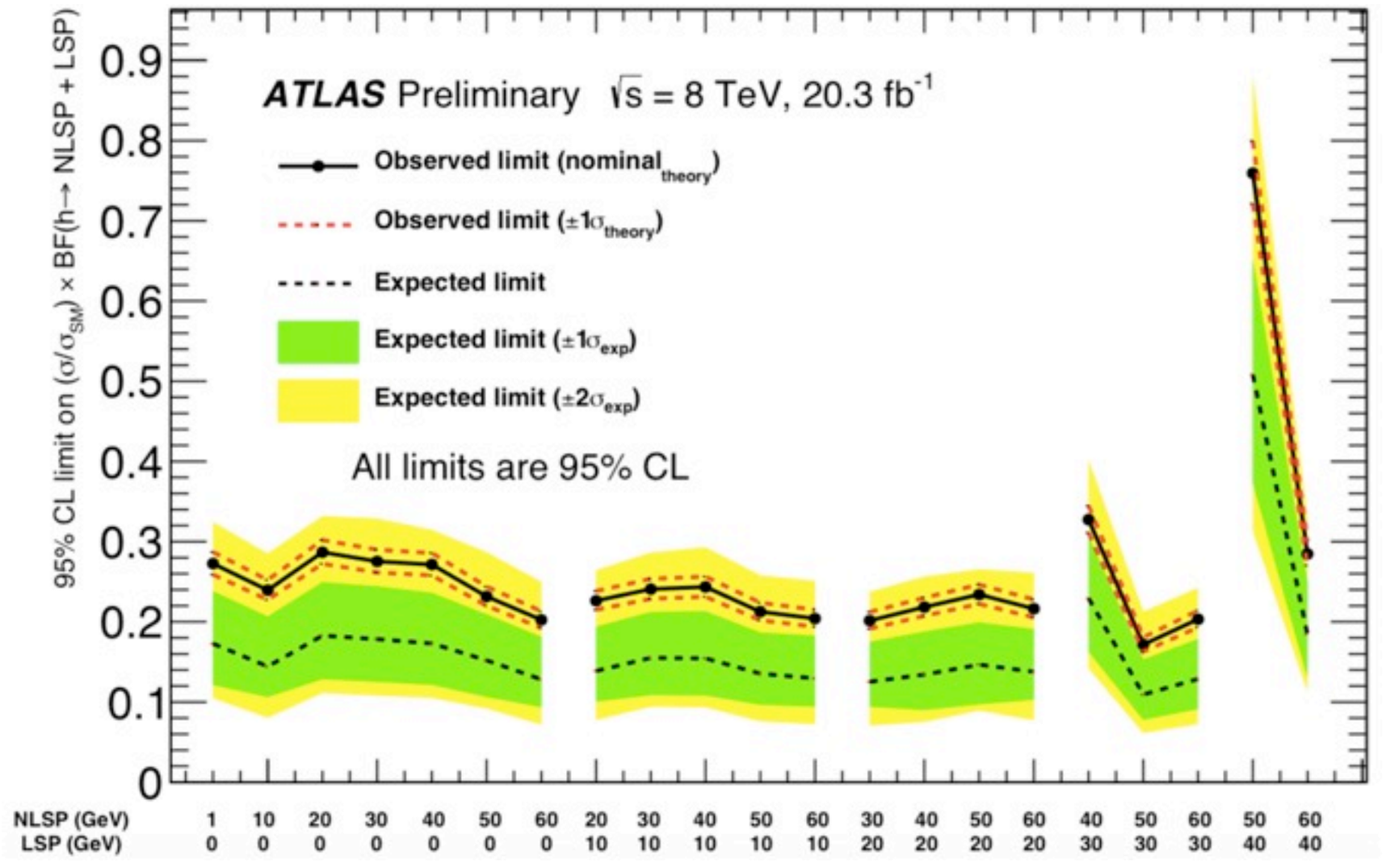
- Talk by A. Mohammadi (CMS) at the last meeting:



- (Still no CMS PAS?)

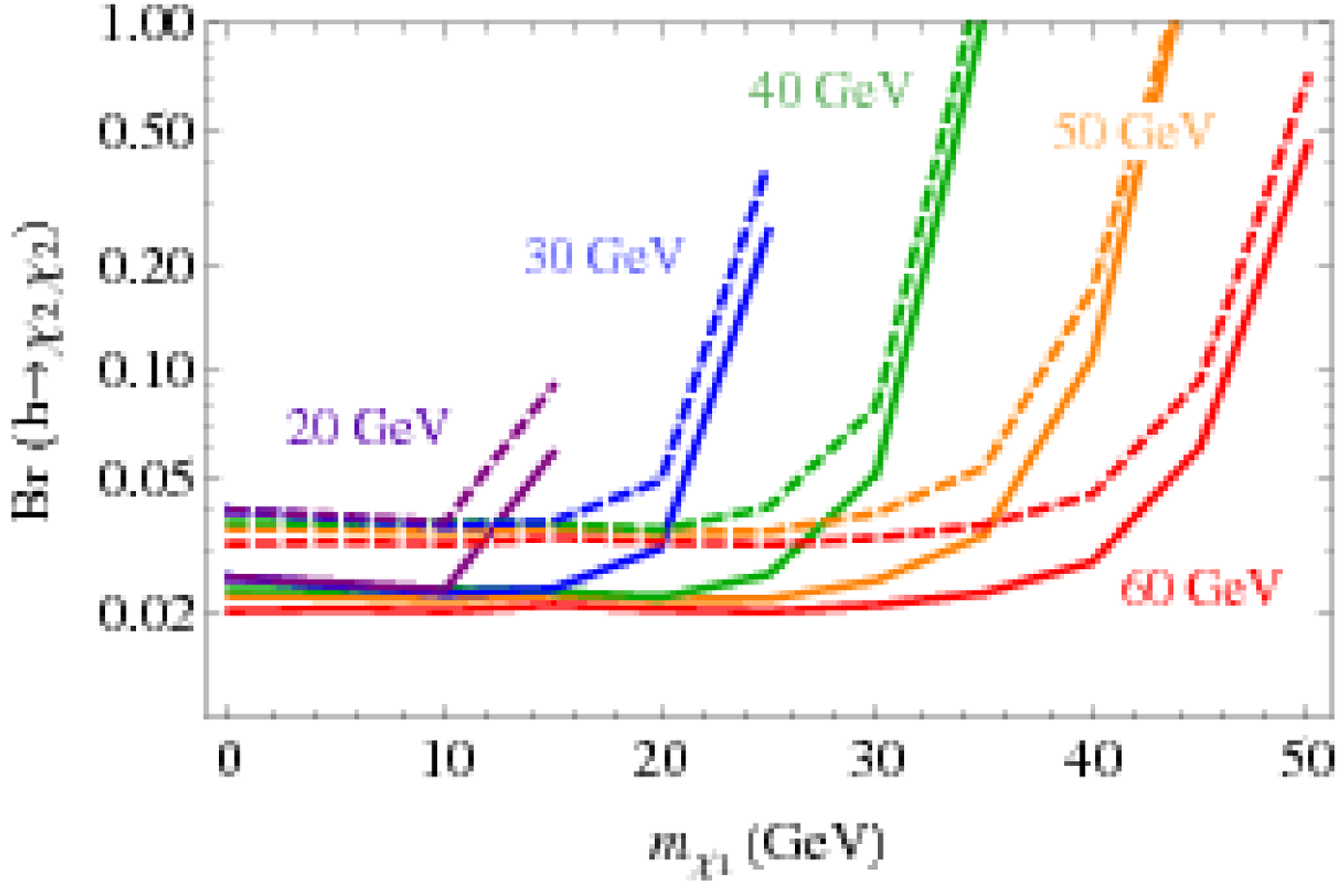
Searches: VBF with Photon and MET

- ATLAS-CONF-2015-001
- VBF dijets, one photon with $p_T^\gamma > 40\,\mathrm{GeV}$, $\not{E}_T > 50\,\mathrm{GeV}$.



Searches: Monojet plus Diphoton

- Recast of CMS PAS-SUS-12-018 by Curtin *et al.* [1312.4992] .
- Based on 4 fb^{-1} at 8 TeV.
- $p_T^{\gamma_{1,2}} > 40(25)\,\mathrm{GeV}, \quad p_T^j > 30\,\mathrm{Gev}, \quad \not{E}_T > 50-100\,\mathrm{GeV}$



Non-Prompt Photons

- Neutralino decay length:

$$c\tau = \frac{48\pi}{c_W^2}\frac{m_{\widetilde{G}}^2 M_{\rm Pl}^2}{m_{\chi_1^0}^5}$$
$$\simeq (1\,{\rm mm})\left(\frac{m_{\widetilde{G}}}{1\,{\rm eV}}\right)^2\left(\frac{50\,{\rm GeV}}{m_{\chi_1^0}}\right)^5$$

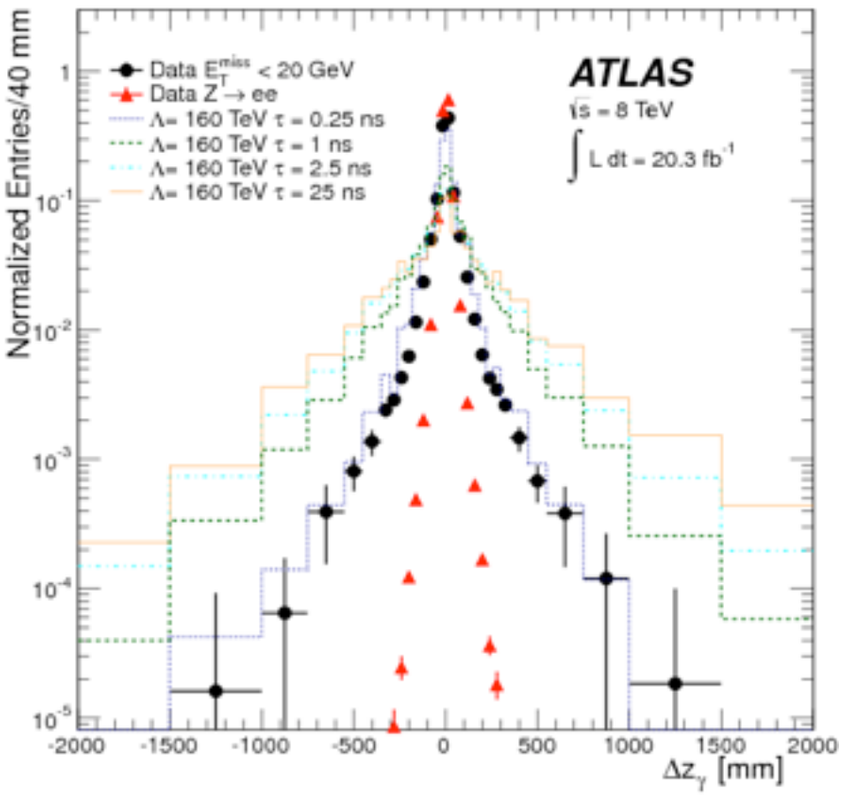
- The gravitino mass can span a wide range.
  Delayed or non-pointing photons are natural to consider.
  (Note: this is also why we assumed $m_{\widetilde{G}} \to 0$.)

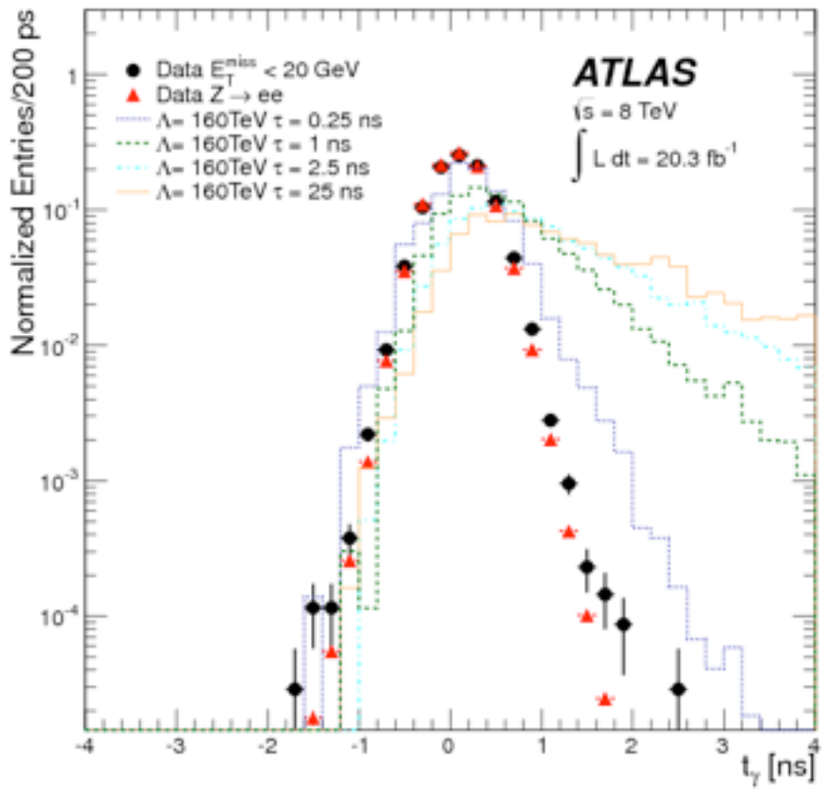
e.g. ATLAS Non-Prompt Diphoton Search

[1409.5542]

- Sensitive to $\tau(\chi_1^0) = 0.25 - 100\,\mathrm{ns}$.
  Uses a diphoton trigger (plus some prompt tracks).

- ECAL pointing and timing for photon displacement.





- Larger displacement ⇒ use monophoton plus MET.

[Mason+Toback '11]

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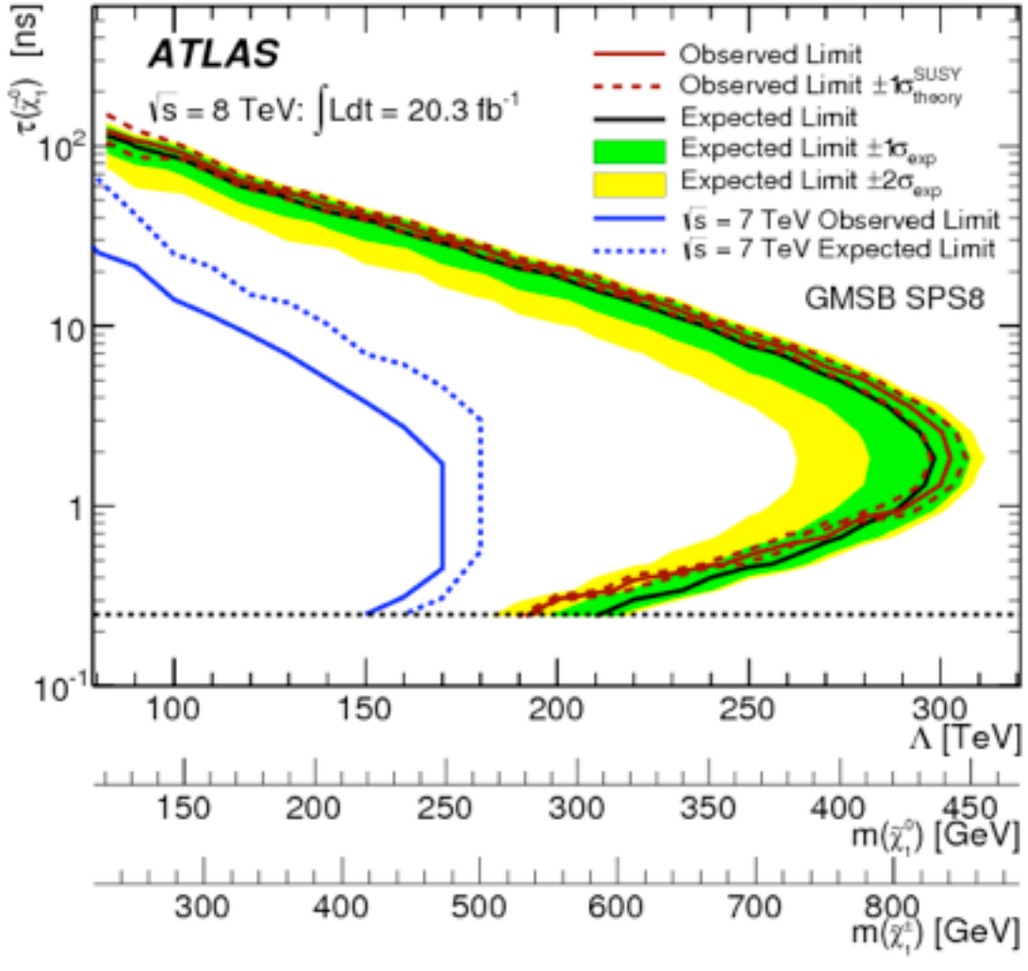


Beyond the MSSM

Many Other Possibilities

- NMSSM: new singlino neutralino $\widetilde{S}$, pseudoscalar a_S.
  - $h \to \widetilde{S}\widetilde{S},\ \widetilde{B}\widetilde{S},\ \widetilde{B}\widetilde{B}$, ...
    - $\widetilde{B} \to \widetilde{S} + a_S$, $\widetilde{S} \to \widetilde{G} + a_S$, ...
      - $a_S \to b\bar{b},\ \tau\bar{\tau},\ \mu\bar{\mu}$, ...

- Dark SUSY $U(1)_x$: new hidden gaugino $\widetilde{X}$.
  - $h \to \widetilde{B}\widetilde{B},\ \widetilde{B} \to \widetilde{X} + Z^x,\ Z^x \to SM + SM$

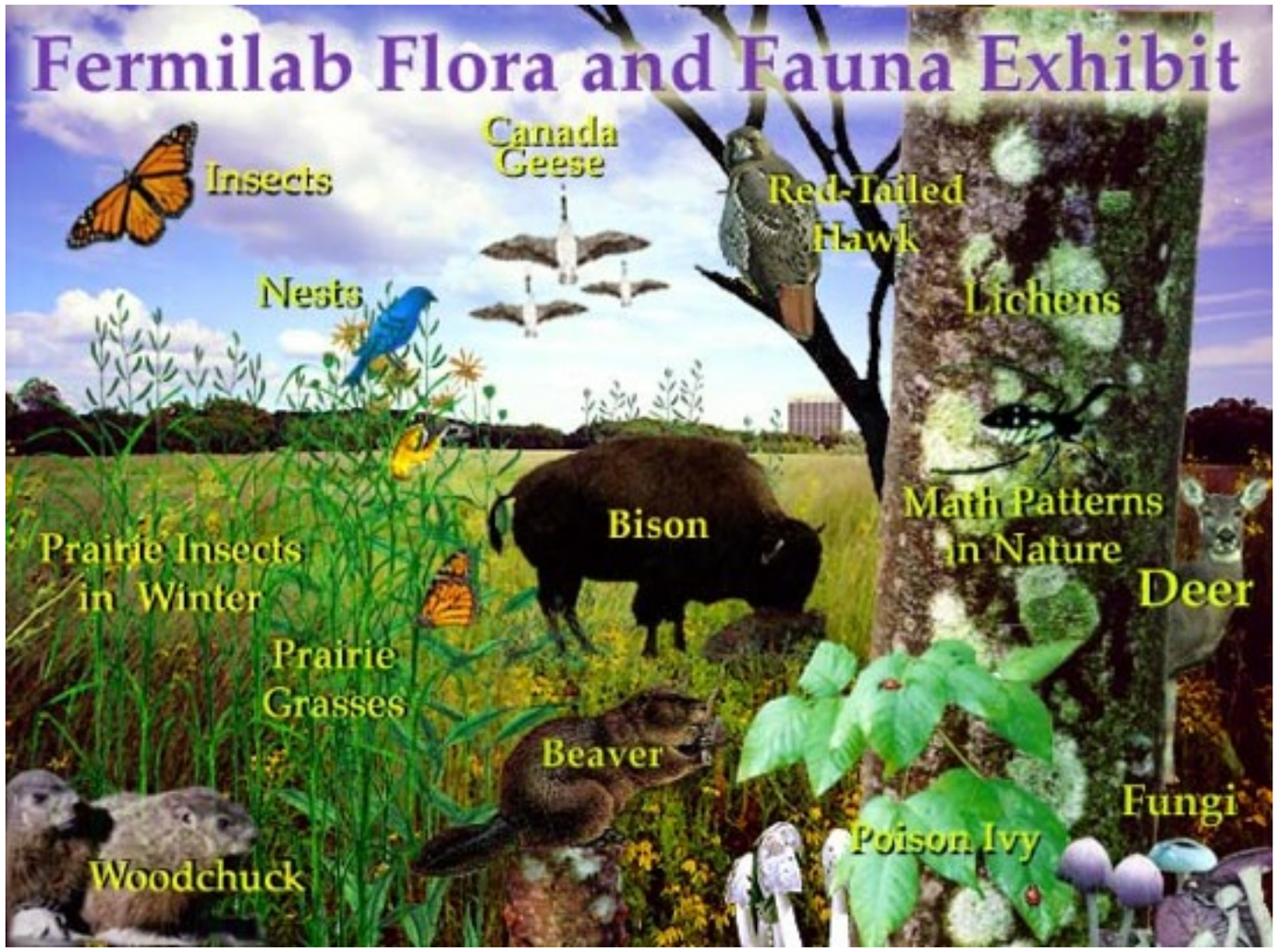
- And many more...

General Story

- $BR(h \to \chi^0\chi^0) \neq 0$ is possible if χ^0 is mostly singlet.
  But Higgs coupling requires EW non-singlet friends.
- Higgs-mediated production of χ^0 can win out over direct production of non-singlets.
- χ^0 can have interesting decays.
- Focus on Higgs-associated production modes:
  $h + 1j,\ h + 2j\,(\mathrm{VBF}),\ hZ, hW, \ldots$
- Search broadly for unusual final states in these data sets.
- Challenges: low p_T final states, displaced decays, ...

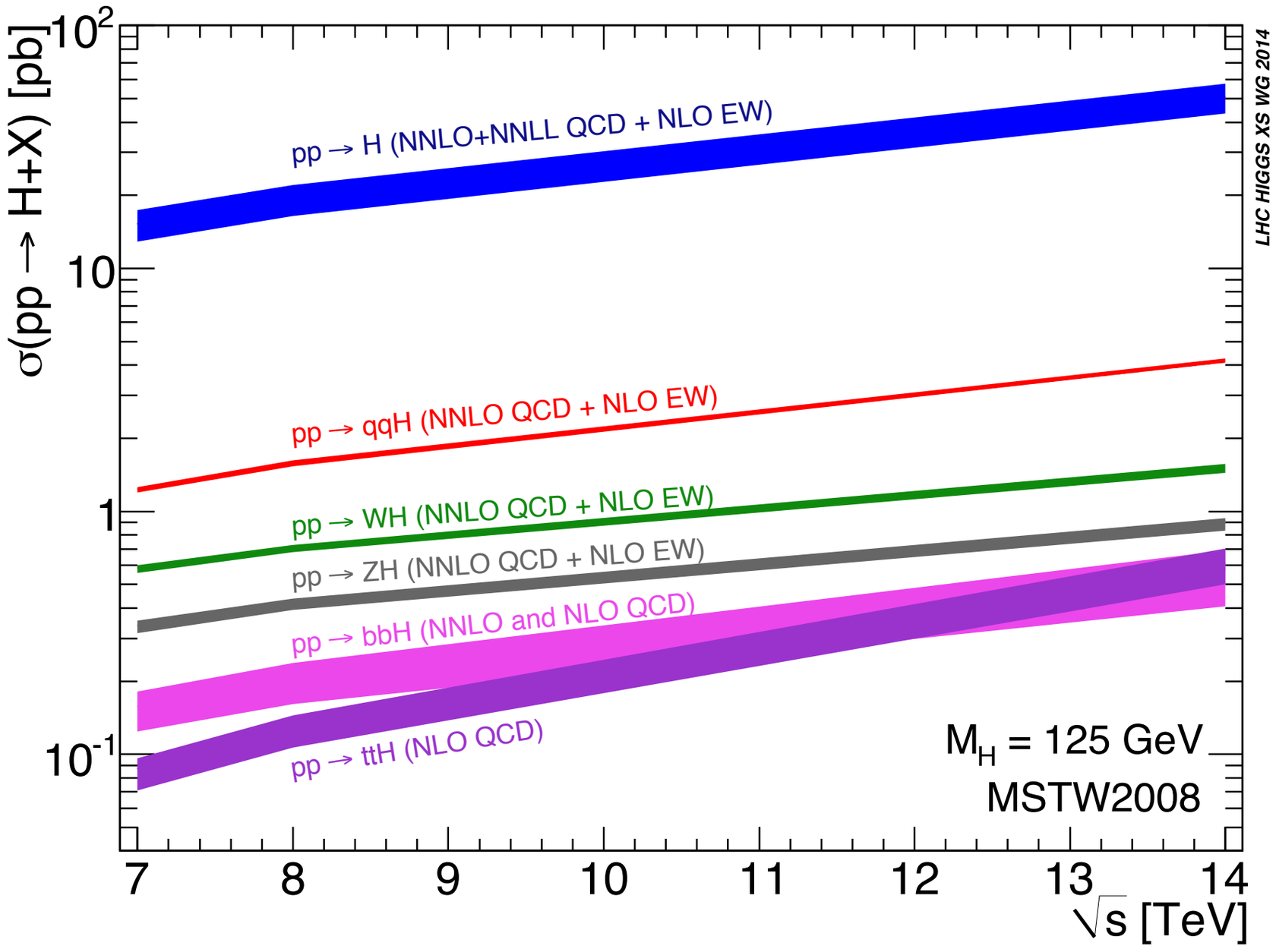
Higgs-Enriched Channels

- Motivated by $h + 1j,\ h + 2j\,(\mathrm{VBF}),\ hZ, hW, \ldots$
- Search broadly for unusual final states in these data sets.



Extra Slides

Higgs Production Cross Sections



Distributions for $h \to \gamma\gamma + \not{E}_T$

- Diphotons with $p_T^\gamma > 25\,\mathrm{GeV},\ |\eta| < 1.1$: