Exotic Higgs Decays: Searches and Challenges at the LHC

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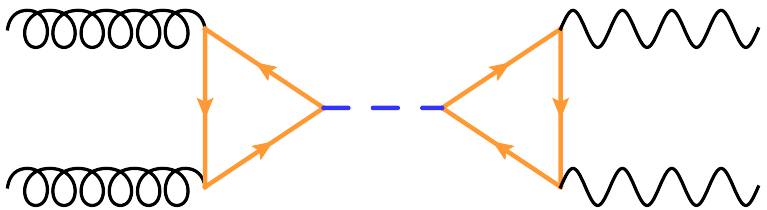
A light Higgs and physics beyond the Standard Model

A 125 GeV Higgs is an exquisitely sensitive window onto BSM physics.



- loop-induced production and decay vertices

A light Higgs and physics beyond the Standard Model

A 125 GeV Higgs is an exquisitely sensitive window onto BSM physics.

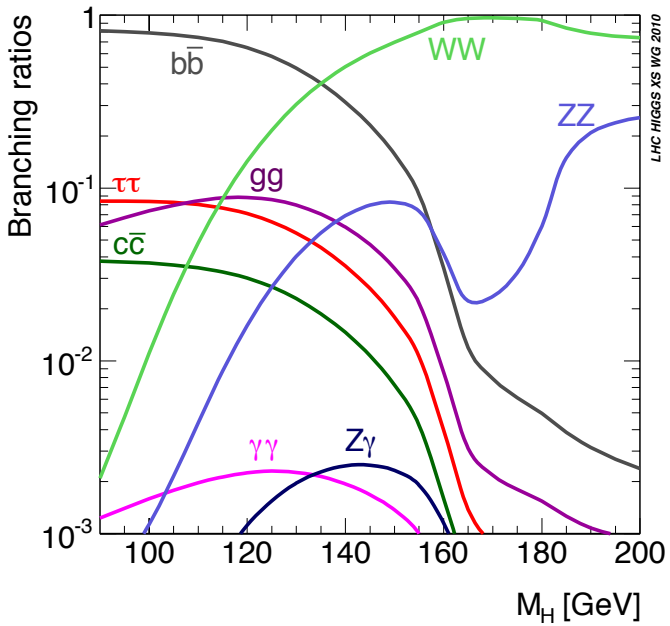
- Higgs portal: Higgs is leading place in SM to feel the effects of a hidden sector

$$\begin{aligned}\mathcal{L} &= \mathcal{L}_{SM} + \mathcal{L}_{HS} + \sum_i \frac{1}{\Lambda^{d_i-2}} |H|^2 \mathcal{O}^{(d_i)}_{HS,i} \\ &\quad + \sum_j \frac{1}{\Lambda^{d_j-2}} B_{\mu\nu} \mathcal{O}^{\mu\nu(d_j)}_{HS,j} + \dots\end{aligned}$$

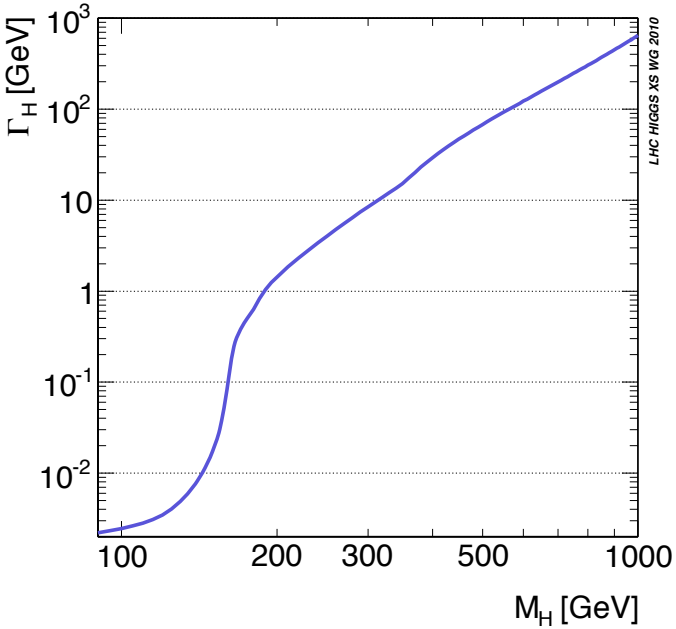
A light Higgs and physics beyond the Standard Model

A 125 GeV Higgs is an exquisitely sensitive window onto BSM physics.

- Miniscule SM width: $\Gamma = 4$ MeV for 125 GeV Higgs



SM Higgs branching ratios

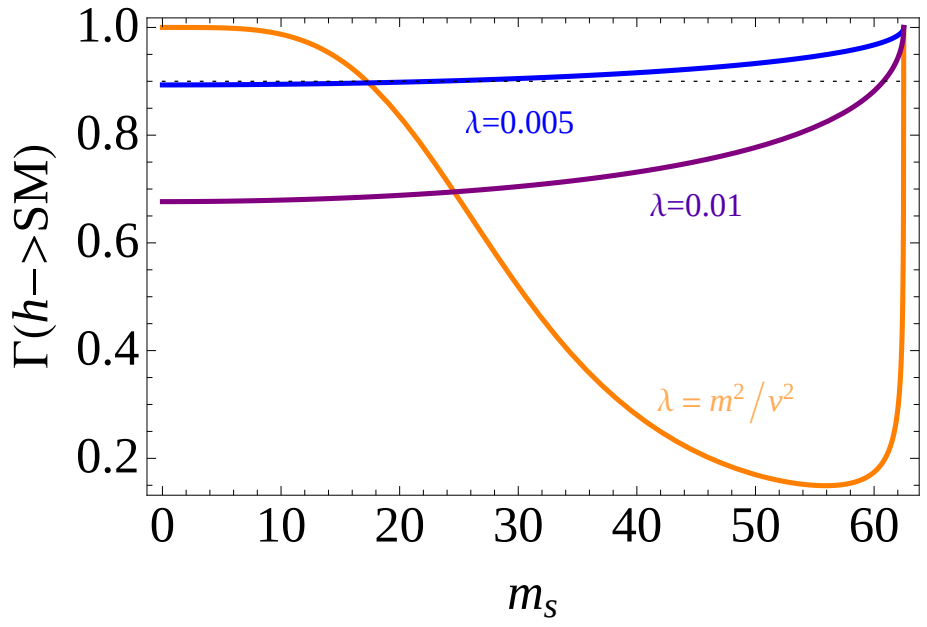


SM Higgs total width

Exotic Higgs decays

- Even very small couplings to new light degrees of freedom can give the Higgs an appreciable BSM branching ratio:

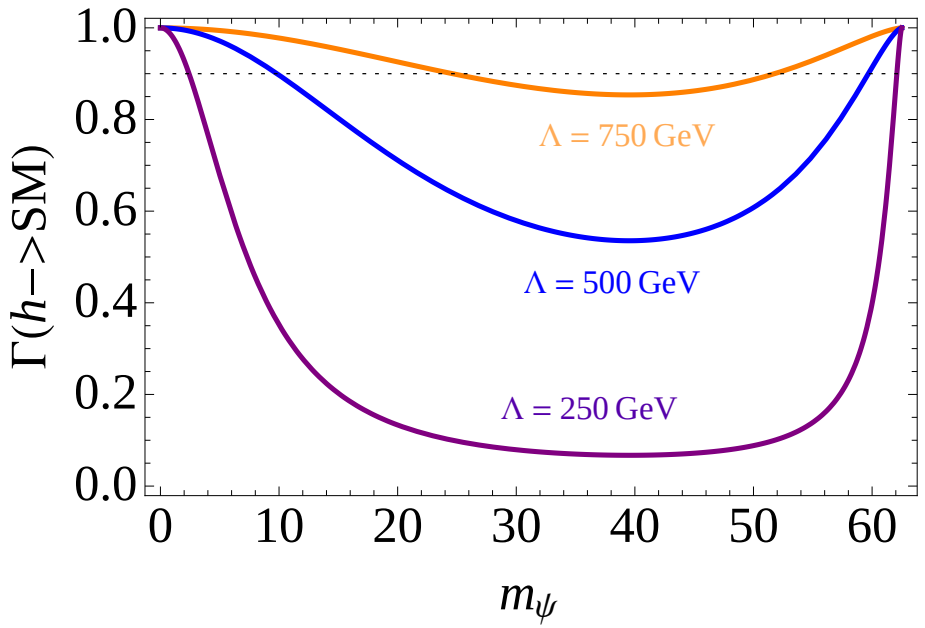
- Simplest example: new singlet scalar $\lambda S^2 |H|^2$



Exotic Higgs decays

- Even very small couplings to new light degrees of freedom can give the Higgs an appreciable BSM branching ratio:

- Using $\Delta\mathcal{L} = \frac{2\mu}{\Lambda^2}|H|^2\bar{\psi}\psi$ as a sample dim 6 hidden sector operator, and taking $2\mu \sim m_\psi$,

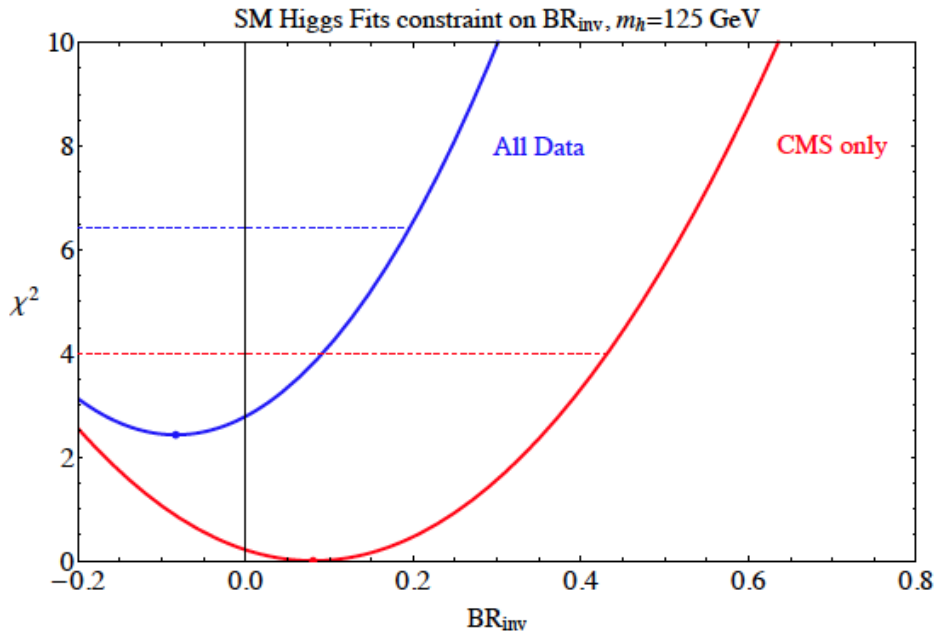


Exotic Higgs decays post-discovery

- Looking for BSM Higgs decays is a topic of longstanding interest
  - Precision electroweak motivation for a light, hidden Higgs
  - Many examples fall out naturally from extended Higgs sectors
- Discovery of a largely SM-like Higgs boson changes the nature of the searches
  - Know exactly where to look...
  - ...and that $BR(h \to SM)$ cannot be too small.

Constraining $BR(h \to BSM)$

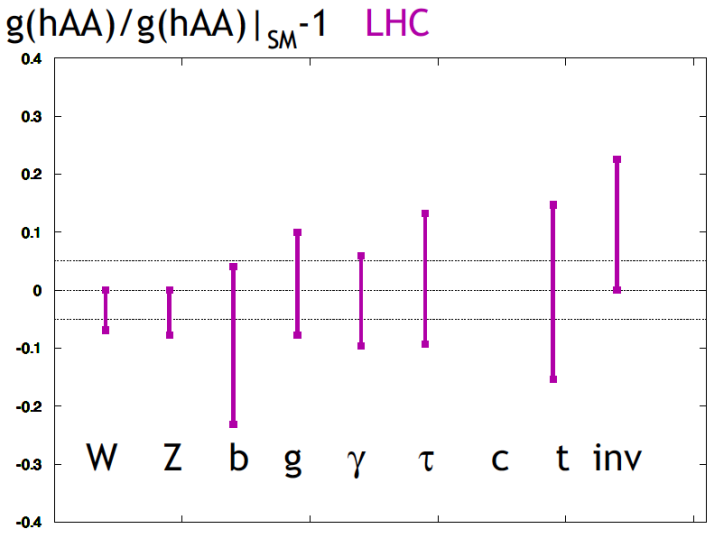
- For light Higgs: to excellent approximation, alter decays without altering production.



From Michael Trott's talk earlier this week: indirect limits on $BR(h \to BSM)$, assuming SM production

Constraining $BR(h \to BSM)$

- Determining Higgs couplings at the LHC is an $\mathcal{O}(10\%)$ program:

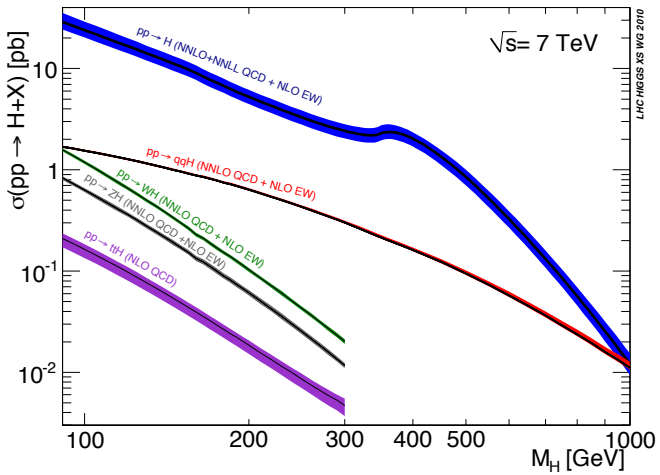


From Michael Peskin, 1207.2516

$\Rightarrow$ Benchmark BSM Higgs branching fractions of 10% are not only allowed by current LHC data but will remain reasonable targets for the long-term LHC physics program.

A direct search: Higgs to invisibles

- As an example, consider $h \to$ invisibles (Eboli, Zeppenfeld; Bai, Draper, JS; Djouadi, Falkowski, Mambrini, Quevillon)



SM Higgs production cross-sections

- gluon fusion : $h+ \geq 1j$: rate price for recoil
- WBF
- *WH*
- *ZH*

A direct search: Higgs to invisibles

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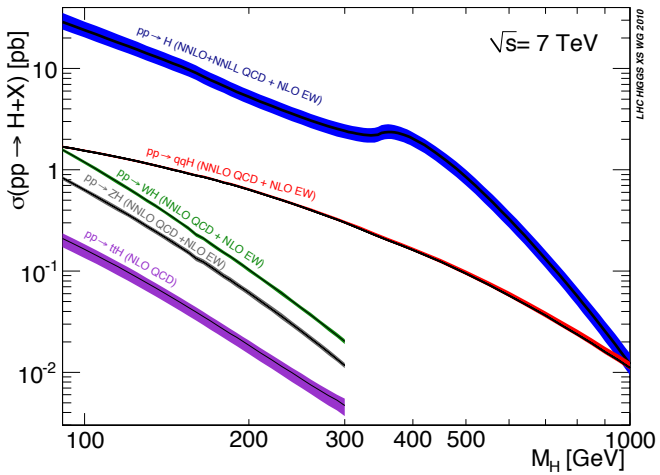
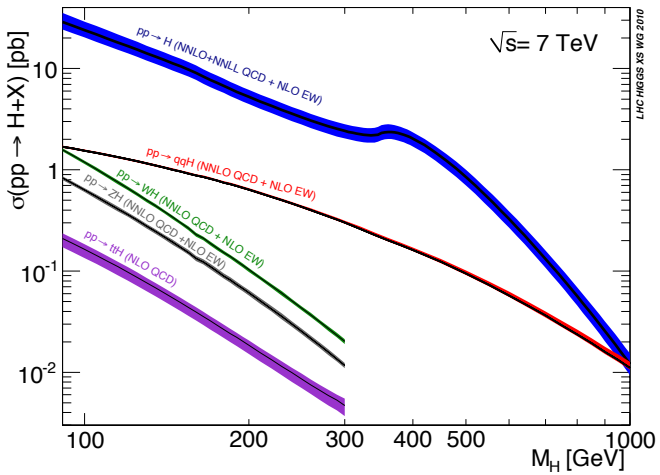


SM Higgs production cross-sections

- gluon fusion
- WBF : $h + 2j$, transverse boost
- WH
- ZH

A direct search: Higgs to invisibles

- As an example, consider $h \to$ invisibles (Eboli, Zeppenfeld; Bai, Draper, JS; Djouadi, Falkowski, Mambrini, Quevillon)

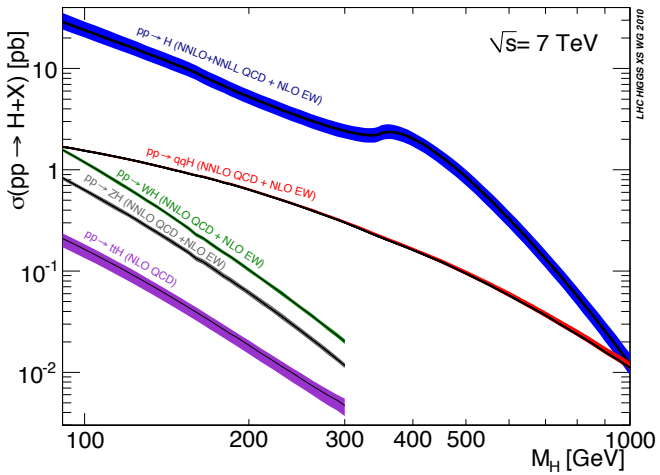


SM Higgs production cross-sections

- gluon fusion
- WBF
- WH : $\ell + h$: guaranteed trigger (not useful for $h \to \not{E}_T$)
- ZH

A direct search: Higgs to invisibles

- As an example, consider $h \to$ invisibles (Eboli, Zeppenfeld; Bai, Draper, JS; Djouadi, Falkowski, Mambrini, Quevillon)

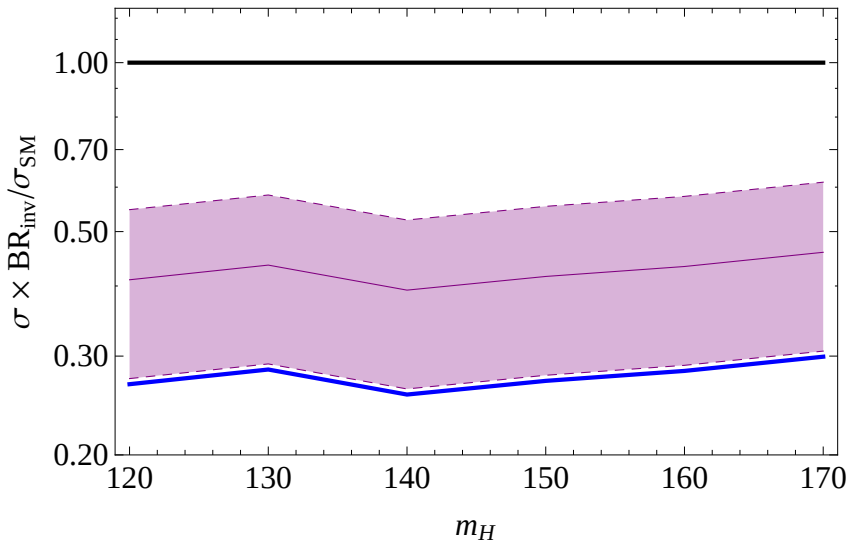


SM Higgs production cross-sections

- gluon fusion
- WBF
- *WH*
- *ZH* : $\ell\ell + h$: guaranteed trigger, but rate-limited

A direct search: Higgs to invisibles

- First question: how are events collected?
  - WBF: events arrive on $\not{E}_T$ trigger
  - Flat at $\not{E}_T = 120$ GeV: too high for best significance



Estimated 95% CL limits from WBF channel on $\Gamma(h \to \text{inv})$ with 20 fb^{-1} at 8 TeV

Triggering on Higgs daughters

- LHC triggers are designed for events with $\gtrsim$ hundreds of GeV
  - for good reasons!
  - poor acceptance for multibody decays of a 125 GeV Higgs (Strassler)
  - ...especially if produced near rest (ggF)
- There are baselines to fall back on:
  - Ex: buried Higgs (Falkowski, Krohn, JS, Thalapillal, Wang): Vh, $t\bar{t}h$
  - but rate limited: reach in BSM BRs dependent on yield

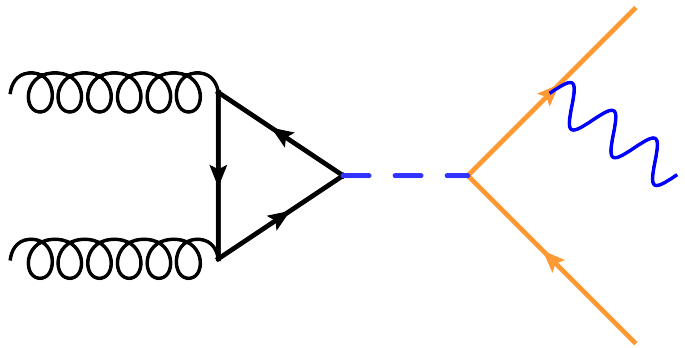
Target triggers for Higgs?

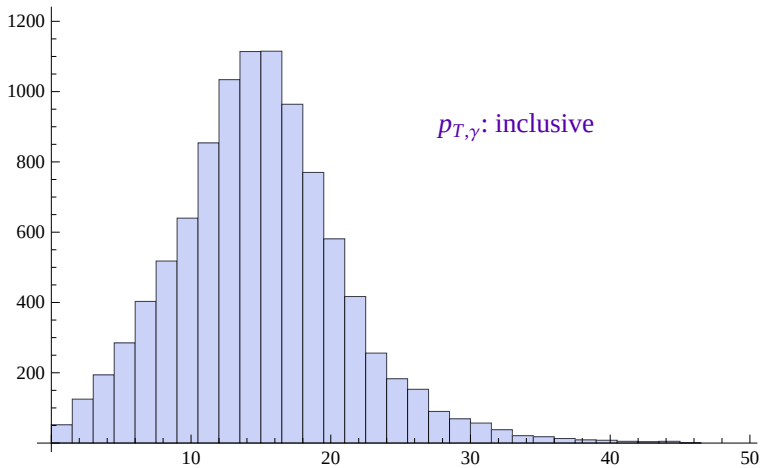
- Possibilities with WBF? (Shelton, Strassler, Volansky: informal study)
- Data parking: additional 300-350 Hz of data recorded on additional trigger streams for offline analysis
- CMS has two data parking triggers of particular interest for Higgs:
  - WBF jets: thresholds $M_{jj} > 650$ GeV, $|\Delta\eta_{jj}| > 3.5$
  - Monojet + $\not{E}_T$: thresholds $p_{T,\gamma} > 30$ GeV, $\not{E}_T > 25$ GeV

* Numbers as of communication in September; subject to change, update; contact your friendly local CMS member!

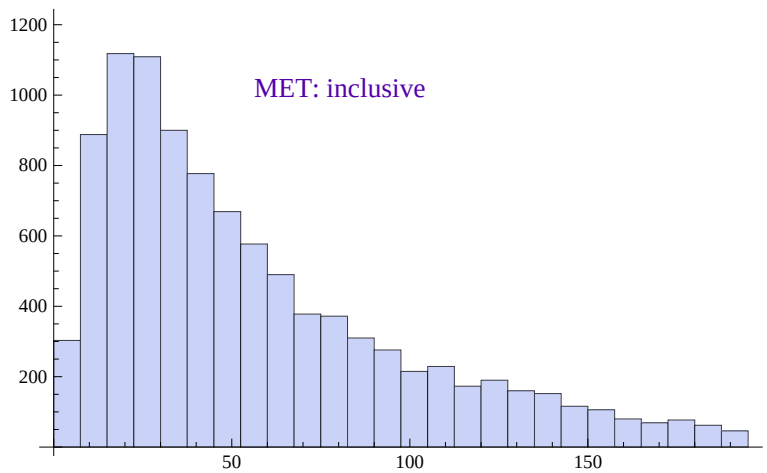
Illustration: photon + $\not{E}_T$

- Consider 10% branching fraction into $h \to \chi_2^0 \chi_1^0$, followed by $\chi_2^0 \to \chi_1^0 \gamma$: "mostly invisible"
- Reference working point $m_{\chi_2^0} = 70$ GeV, $m_{\chi_1^0} = 50$ GeV





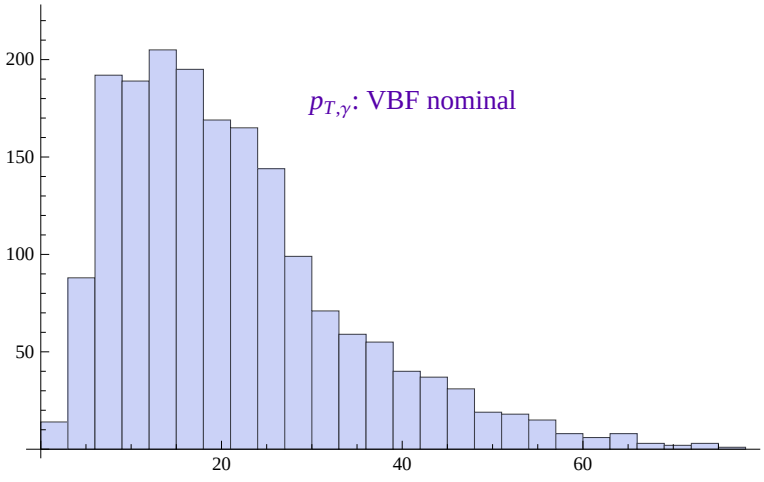
$p_{T,\gamma}$ distribution for signal in gluon fusion



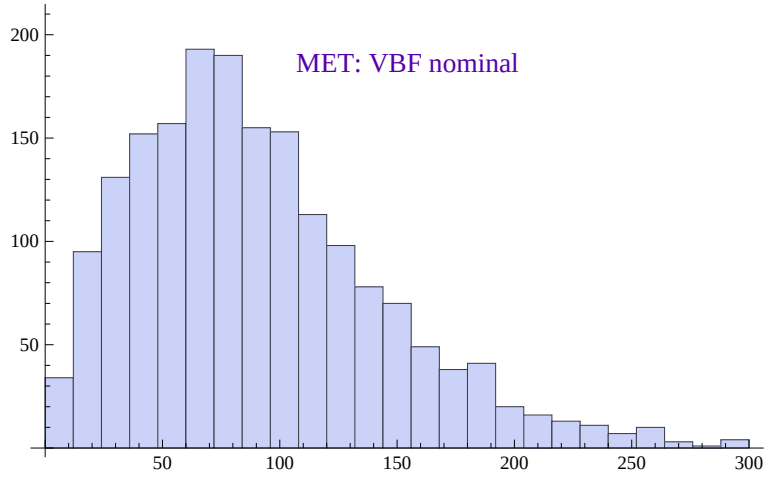
MET distribution for signal in gluon fusion

Illustration: photon + $\not{E}_T$

- WBF reference selection cuts: $M_{jj} > 750$ GeV, $|\Delta\eta_{jj}| > 4.0$



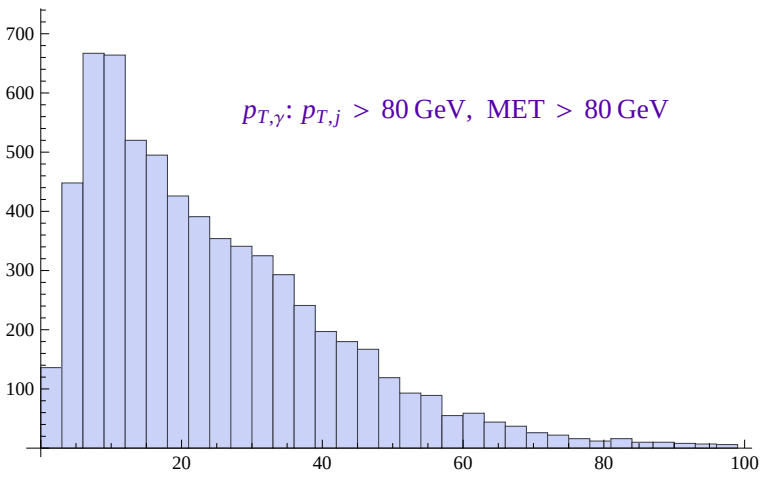
$p_{T,\gamma}$ distribution for signal with WBF trigger cuts



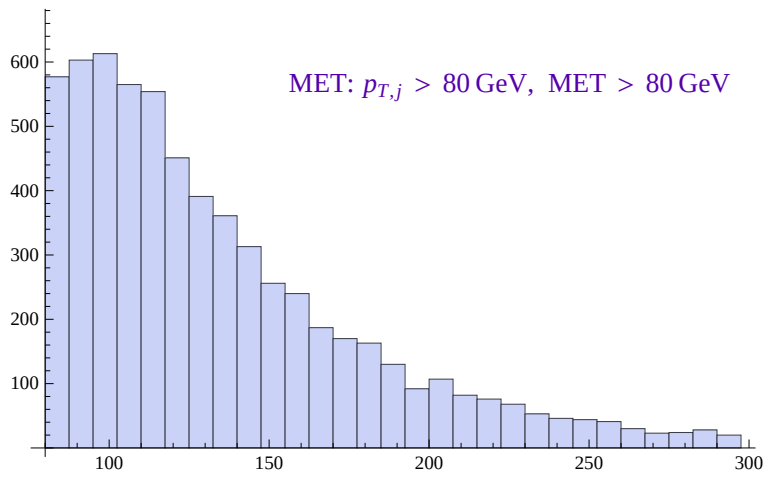
MET distribution for signal with WBF trigger cuts

Illustration: photon + $\not{E}_T$

- ggF reference selection cuts: $p_{T,j} > 80$ GeV, $\not{E}_T > 80$ GeV



$p_{T,\gamma}$ distribution for signal with monojet+MET trigger cuts

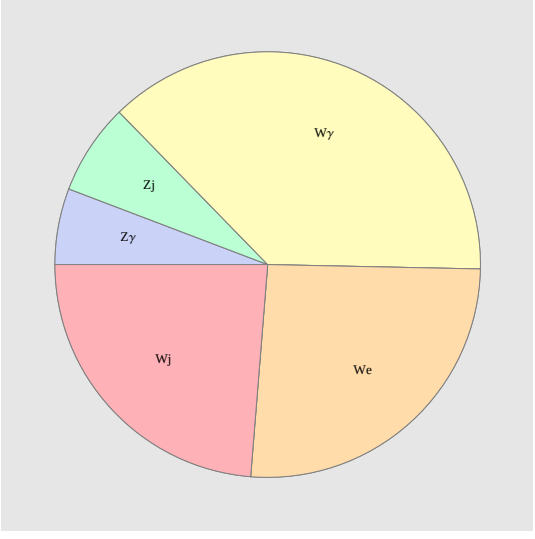


MET distribution for signal with monojet+MET trigger cuts

Illustration: photon + $\not{E}_T$

- Signal is fairly clean: single photon, sharp kinematic correlations with $\not{E}_T$
- However, many backgrounds:

- $Z + \gamma$
- $W + \gamma$, lost lepton; treat ℓ, τ separately!
- $Z + (j \to \gamma)$
- $W + (j \to \gamma)$, lost lepton
- $W \to e\nu$, $e \to \gamma$



non-VBF background processes in the VBF channel.

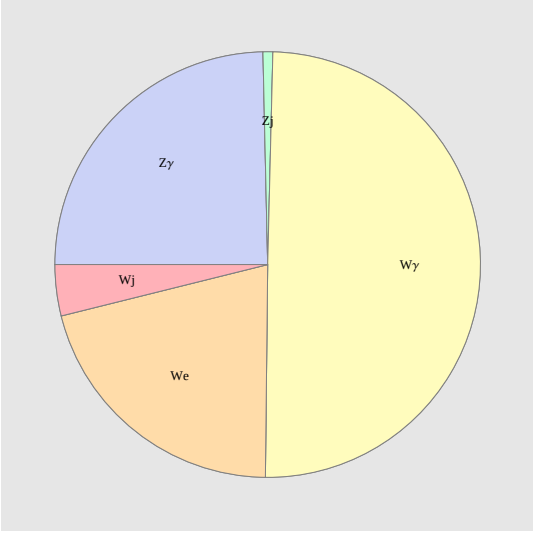
Total: $\sim$ 15 fb

- Use simple estimates for photon efficiencies and fake rates for $j \to \gamma$, $e \to \gamma$

Illustration: photon + $\not{E}_T$

- Signal is fairly clean: single photon, sharp kinematic correlations with $\not{E}_T$
- However, many backgrounds:

- $Z + \gamma$
- $W + \gamma$, lost lepton; treat ℓ, τ separately!
- $Z + (j \to \gamma)$
- $W + (j \to \gamma)$, lost lepton
- $W \to e\nu$, $e \to \gamma$



VBF background processes in the VBF channel.

Total: $\sim$ 9 fb

- Use simple estimates for photon efficiencies and fake rates for $j \to \gamma$, $e \to \gamma$

Illustration: photon + $\not{E}_T$

- Kinematic features of signal allow good suppression of backgrounds in both channels
- Estimate 5.5σ in $5\ \text{fb}^{-1}$ for ggF
- In statistically more limited WBF channel, estimate 3.5σ in $5\ \text{fb}^{-1}$
- Key: signal acceptance not dependent on details of decay mode

Summary and discussion questions

- Exotic Higgs decays: possibly best hope for BSM at LHC?

  Though we are all hoping for TeV scale discoveries!

- Branching fractions below 10% to exotic modes can in many cases be seen or excluded, but reach can be dramatically extended if dedicated Higgsy triggers are in place and functional.

- How practical will low threshold $1j + \not{E}_T$, $1\gamma + \not{E}_T$, *WBF* jet triggers be?

- What other options for (potentially soft and high multiplicity) Higgs decays can be exploited?