Direct detection of Higgs-portal Dark Matter at the LHC

Jérémie Quevillon, LPT Orsay

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Introduction

- Starting point: Higgs boson of 125 GeV.
- The Higgs particle may have other decay channels that are not predicted by the SM.
- Existing LHC data already constrains the invisible width.
  - I. Monojet constraints on the invisible width
- Interesting interplay between LHC and direct dark matter detection in the context of Higgs portal models.
  - II. LHC and direct dark matter detection
Monojet constraints on the invisible width

Composition of the $H(\rightarrow \text{Inv}) + 1\text{jet}$ signal:

Principal backgrounds: $Z \rightarrow \nu\nu + \text{jets}$ and $W \rightarrow \nu l + \text{jets}$ (with systematics $\sim 10\%$)
CMS monojet search [1206.5663] updated to 5 fb-1:
- at least 1 jet with PT > 110 GeV and |η| < 2.4
- at most 2 jets with PT > 30 GeV
- no isolated lepton
- missing PT ≥ 200-400 GeV

A Higgs produced with a significant PT and decaying to invisible can lead to the topology targeted by monojet searches.

For example, for PTmiss ≥ 350 GeV CMS observes 1142 events vs predicted background 1225 ± 101

For Higgs with SM cross section fully invisible additional ~100 events, comparable to errors

⇒ Monojet searches may already provide interesting constraints
What is the sensitivity of the CMS monojet-search to the invisible Higgs signal?

\[ R_{\text{ggF}}^{\text{inv}} = \frac{\sigma(gg \rightarrow H) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(gg \rightarrow H)_{\text{SM}}} \leq 1.83 \text{ @95\%CL} \]

\[ R_{\text{VBF}}^{\text{inv}} = \frac{\sigma(qq \rightarrow Hqq) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(qq \rightarrow Hqq)_{\text{SM}}} \leq 4.13 \text{ @95\%CL} \]

Combining (assuming SM proportions of ggF and VBF):

\[ R_{\text{inv}} = \frac{\sigma(pp \rightarrow H) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(pp \rightarrow H)_{\text{SM}}} \leq 0.94 (1.27) \text{ @90 (95)\%CL} \]
Monojet constraints on the invisible width

With CMS data [1206.5663]

| $p_T^{\text{miss}}$ [GeV] | $N_{\text{ggF}}^{\text{inv}}$ | $N_{\text{VBF}}^{\text{inv}}$ | $\Delta N_{\text{Bkg}}$ | $R_{\text{inv}}^{\text{exp}}$ | $R_{\text{inv}}^{\text{obs}}$ |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 200                      | 630                      | 260                      | ~1200                    | 2.6                      | 1.8                      |
| 250                      | 250                      | 110                      | 367                      | 2.0                      | 1.3                      |
| 300                      | 110                      | 50                       | 167                      | 2.1                      | 2.2                      |
| 350                      | 46                       | 25                       | 101                      | 2.8                      | 1.6                      |
| 400                      | 22                       | 13                       | 65                       | 3.7                      | 2.2                      |

$R_{\text{inv}}^{\text{ggF}} = \frac{\sigma(gg \rightarrow H) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(gg \rightarrow H)_{\text{SM}}}$

$R_{\text{inv}}^{\text{VBF}} = \frac{\sigma(qq \rightarrow Hqq) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(qq \rightarrow Hqq)_{\text{SM}}}$

$\leq 1.83$ @95%CL

$\leq 2.22$ @95%CL

$\leq 0.94$ (1.27) @90 (95)%CL

$\leq 1.18$ (1.49) @90 (95)%CL

With ATLAS data [ATLAS-CONF-2012-084]

| $p_T^{\text{miss}}$ [GeV] | $N_{\text{ggF}}^{\text{inv}}$ | $N_{\text{VBF}}^{\text{inv}}$ | $\Delta N_{\text{Bkg}}$ | $R_{\text{inv}}^{\text{exp}}$ | $R_{\text{inv}}^{\text{obs}}$ |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 120                      | 1870                     | 700                      | 4000                     | 3.0                      | 3.3                      |
| 220                      | 280                      | 140                      | 400                      | 1.9                      | 1.5                      |
| 350                      | 30                       | 18                       | 60                       | 2.5                      | 3.2                      |
| 500                      | 3.8                      | 2.7                      | 14                       | 4.3                      | 3.3                      |

$\leq 2.22$ @95%CL

$\leq 4.49$ @95%CL

$\leq 1.18$ (1.49) @90 (95)%CL
Monojet constraints on the invisible width

Projection of the CMS study to the ongoing 8 TeV run:

- We assume the error on the $Z \rightarrow \nu \nu +\text{jets}$ background dominated by the statistics of the $Z \rightarrow \mu \mu +\text{jets}$ control sample (as in the current run).

- We assume the systematic error on the $W \rightarrow \nu l +\text{jets}$ background will be brought down to 5%.

\[ R_{\text{inv}} = \frac{\sigma(pp \rightarrow H) \times \text{BR}(H \rightarrow \text{inv.})}{\sigma(pp \rightarrow H)_{\text{SM}}} \leq 0.9 \quad 95\% \text{CL with 15 fb}^{-1} \text{ @ LHC 8 TeV} \]

- Just a crude estimate, depends on experiments’ ability to control systematic errors on the $V +\text{jets}$ backgrounds.
Monojet constraints on the invisible width

- no direct constraints on the visible branching fraction if Higgs produced with the SM rate.

- Indirectly a better bound from observation of visible Higgs decays:
  \[ \text{BR}(h \to \text{inv}) < 0.4 \text{ Giardino,Kannike,Raidal,Strumia [1203.4254]} \]
  \[ \text{BR}(h \to \text{inv}) < 0.20 \text{ (with 2012 data), Carmi,Falkowski,Kuflik,Volansky,Zupan [1207.1718]} \]
However, if Higgs rate enhanced (4th chiral generation or in many BSM models) then our analysis provides non-trivial constraints.

Monojet searches are sensitive mostly to the ggF mode, thus they can probe invisible Higgs in models where the Higgs couplings to the W,Z bosons are reduced (complementarity to invisible Higgs searches in VBF mode).

Sensitivity of monojet searches to invisible Higgs turns out to be much better than expected $\Rightarrow$ LHC is already sensitive to $R_{\text{inv}} \sim 1$. 

Figure 2: 

- The "Combined" region (green) shows the 95% CL preferred region arising from all channels. 
- The red-line shows the trajectory of the cross of the dashed lines is the SM point. 
- The plots characterize composite Higgs models in which loops containing beyond the SM fields contribute to the effective 5-dimensional operators, while leaving the lower-dimension Higgs operators, while leaving the lower-dimension Higgs
Higgs-portal models

\[ \mathcal{L}_S = \mathcal{L}_{SM} - \frac{1}{2} m^2_S S^2 - \frac{1}{4} \lambda_S S^4 - \frac{1}{4} \lambda_{h SS} H^\dagger H S^2 \]

\[ \mathcal{L}_V = \mathcal{L}_{SM} + \frac{1}{2} m^2_V V_\mu V^\mu + \frac{1}{4} \lambda_V (V_\mu V^\mu)^2 + \frac{1}{4} \lambda_{h V V} H^\dagger H V_\mu V^\mu \]

\[ \mathcal{L}_f = \mathcal{L}_{SM} - \frac{1}{2} m_f \bar{\chi} \chi - \frac{1}{4} \frac{\lambda_{h f f}}{\Lambda} H^\dagger H \bar{\chi} \chi \]

Key of the portal $\lambda$

Scalar DM
Vector DM
Fermion DM

LHC

WMAP

XENON
Higgs-portal models

\[ \mathcal{L}_S = \mathcal{L}_{SM} - \frac{1}{2} m_S^2 S^2 - \frac{1}{4} \lambda_S S^4 - \frac{1}{4} \lambda_{hSS} H^+ H S^2 \]

\[ \mathcal{L}_V = \mathcal{L}_{SM} + \frac{1}{2} m_V^2 V_\mu V^\mu + \frac{1}{4} \lambda_V (V_\mu V^\mu)^2 + \frac{1}{4} \lambda_{hVV} H^+ H V_\mu V^\mu \]

\[ \mathcal{L}_f = \mathcal{L}_{SM} - \frac{1}{2} m_f \bar{\chi} \chi - \frac{1}{4} \frac{\lambda_{hff}}{\Lambda} H^+ H \bar{\chi} \chi \]

\[
\begin{align*}
\Gamma_{h \rightarrow SS}^{\text{inv}} &= \frac{\lambda_{hSS}^2 v^2 \beta_S}{64 \pi m_h^3} \left( 1 - 4 \frac{M_S^2}{m_h^2} + 12 \frac{M_V^4}{m_h^4} \right) \\
\Gamma_{h \rightarrow VV}^{\text{inv}} &= \frac{\lambda_{hVV}^2 v^2 m_h^4 \beta_V^3}{256 \pi M_V^4} \\
\Gamma_{h \rightarrow \chi \chi}^{\text{inv}} &= \frac{\lambda_{hff}^2 v^2 m_h^4 \beta_f^3}{32 \pi \Lambda^2} \\
\end{align*}
\]
LHC and direct dark matter detection

For a given $M_\chi$, the invisible branching fraction probed at the LHC is connected to the dark matter-nucleon cross section probed by XENON100:

$$\text{BR}_{\chi}^\text{inv} = \frac{\sigma_{\chi p}^{\text{SI}}}{\Gamma_{H}^{\text{SM}}/r_{\chi} + \sigma_{\chi p}^{\text{SI}}}$$

Strongest (weakest) bound is derived in the vectorial (scalar) case

$\Rightarrow$ the LHC is currently the most sensitive dark matter detector *

* in the context of simple Higgs-portal models
Conclusion

- Monojet searches at the LHC already provide interesting limits on invisible Higgs decays, constraining the invisible rate to be less than the total SM Higgs production rate at the 90%CL.

- This constrains the invisible branching fraction in models where the Higgs production cross section is enhanced.

- We expect that the monojet data which will be collected in the ongoing 8 TeV LHC run will place non-trivial constraints on the Higgs invisible branching fraction even if the Higgs production rate is SM-like.

- We also analyzed in a model-independent way the interplay between the invisible Higgs branching fraction and the dark matter scattering cross section on nucleons.

- The limits $\text{BR}^{\text{inv}} < 0.4$ suggested by the combination of Higgs data in the visible channels, implies a limit on the direct detection cross section that is stronger than the current bounds from XENON100 for scalar, fermionic, vectorial DM.

- Hence in the context of Higgs-portal models the LHC is currently the most sensitive DM detection apparatus.
Merci de votre attention!