

Search for Dark Matter in association with a
Higgs boson decaying to two photons at
 $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

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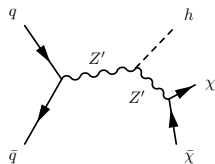
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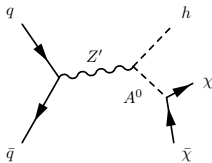
Introduction

- ▶ Many Dark Matter (DM) searches at the LHC involve missing transverse momentum associated with detectable particles
- ▶ Search for DM particles (χ) in association with the SM Higgs Boson (h) (arXiv:1706.03948)
- ▶ Aim for $E_T^{\text{miss}} + h \rightarrow \gamma\gamma$ decays
- ▶ Use 36.1 fb^{-1} of pp collision data at $\sqrt{s} = 13 \text{ TeV}$, collected by the ATLAS detector in 2015 and 2016

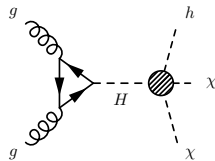
Z'_B model



Z' -2HDM model

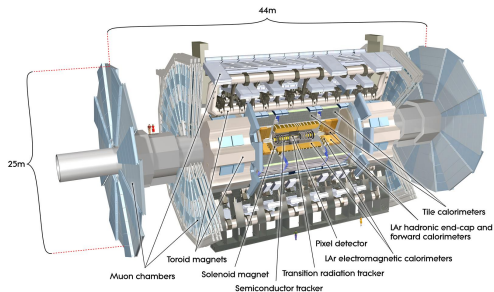


Heavy-scalar model



ATLAS detector

- ▶ Collect collision data at the LHC
- ▶ Three sub-detectors:
 - ▶ Inner detector, measure charged particle tracks
 - ▶ Calorimeters, measure particle energies
 - ▶ Muon detectors, measure muon tracks



Simulation samples

- ▶ DM signals: MadGraph_aMC@NLO+Pythia
 - ▶ Z'_B model: $m_{Z'}=1-2000$ GeV, $m_\chi=1-1000$ GeV
 - ▶ $Z'-2$ HDM model: $m_{Z'}=400-1400$ GeV, $m_A=200-450$ GeV, $m_\chi=100$ GeV
 - ▶ heavy scalar model: $m_H=260-350$ GeV, $m_\chi=60$ GeV
- ▶ SM $h \rightarrow \gamma\gamma$:
 - ▶ ggF, VBF: Powheg+Pythia
 - ▶ Wh , Zh : Pythia
 - ▶ $t\bar{t}h$, $b\bar{b}h$: MadGrpah_aMC@NLO+Pythia
- ▶ The generated events are processed through a detector simulation based on GEANT4

Event selection

- ▶ Di-photon trigger; at least two photons
- ▶ $p_T > 0.35$ (0.25) $\times m_{\gamma\gamma}$ for leading (subleading) photon
- ▶ $m_{\gamma\gamma}$ in [105, 160] GeV

Category	Requirements
Mono-Higgs	$S_{E_T^{\text{miss}}} > 7 \sqrt{\text{GeV}}$, $p_T^{\gamma\gamma} > 90$ GeV, lepton veto
High- E_T^{miss}	$S_{E_T^{\text{miss}}} > 5.5 \sqrt{\text{GeV}}$, $ z_{\text{PV}}^{\text{highest}} - z_{\text{PV}}^{\gamma\gamma} < 0.1$ mm
Intermediate- E_T^{miss}	$S_{E_T^{\text{miss}}} > 4 \sqrt{\text{GeV}}$, $p_T^{\text{hard}} > 40$ GeV, $ z_{\text{PV}}^{\text{highest}} - z_{\text{PV}}^{\gamma\gamma} < 0.1$ mm
Different-Vertex	$S_{E_T^{\text{miss}}} > 4 \sqrt{\text{GeV}}$, $p_T^{\text{hard}} > 40$ GeV, $ z_{\text{PV}}^{\text{highest}} - z_{\text{PV}}^{\gamma\gamma} > 0.1$ mm
Rest	$p_T^{\gamma\gamma} > 15$ GeV

- ▶ Signal and background are extracted by fitting analytic functions to the $m_{\gamma\gamma}$ distribution in each category

Signal and background parameterization

- ▶ DM signal and SM Higgs background: normalization and shape (double sided crystal ball) extracted from MC
- ▶ Non-resonant background: normalization and shape extracted by fitting the $m_{\gamma\gamma}$ distribution in data for each category
- ▶ The non-resonant background modeling uncertainty ($\Delta N_{bkg}^{non-res}$) is estimated as the signal event yield extracted from a signal-plus-background fit to a background-only $m_{\gamma\gamma}$ distribution

Category	Function	$\Delta N_{bkg}^{non-res}$	$\Delta N_{bkg}^{non-res} / N_{bkg}^{non-res}$ [%]	$\Delta N_{bkg}^{non-res} / N_{signal}$ [%]
Mono-Higgs	$\exp(a \cdot x)$	1.2	9.8	6.0
High- E_T^{miss}	$(1 - x^{1/3})^b \cdot x^a$	2.7	4.0	11
Intermediate- E_T^{miss}	$\exp(a \cdot x + b \cdot x^2)$	5.8	1.3	14
Different-Vertex	$\exp(a \cdot x + b \cdot x^2)$	8.4	0.5	26
Rest	$\sum_{j=0}^3 C_3^j x^j (1-x)^{3-j} b_{j,3}$	61	< 0.1	28

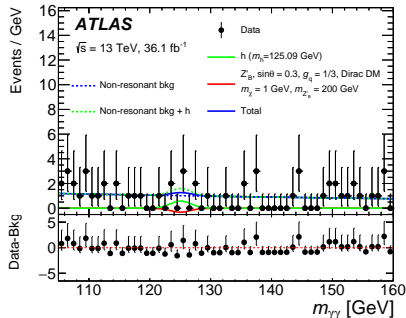
Systematic uncertainties

Source	Signals [%]	Backgrounds [%]	
		SM Higgs boson	Non-resonant background
Experimental			
Luminosity		3.2	-
Trigger efficiency		0.4	-
Vertex selection		< 0.1	-
Photon energy scale	0.1-2.0	0.1-1.4	-
Photon energy resolution	0.1-0.2	0.1-1.1	-
Photon identification efficiency	2.9-4.3	1.9-3.8	-
Photon isolation efficiency	1.2	0.8-1.6	-
E_T^{miss} reconstruction (diphoton vertex)	< 0.1	0.5-1.9	-
E_T^{miss} reconstruction (jets, soft term)	1.0-1.4	0.8-23	-
Diphoton vertex with largest Σp_T^2	< 0.1 -1.9	< 0.1-6.0	-
Pileup reweighting	0.2-5.6	0.7-11	-
Non-resonant background modeling	-	-	0.1 – 9.8
Theoretical			
Factorization and renormalization scale	0.6-11	2.5-6.0	-
PDF+ α_S	11 – 25	1.2-2.9	-
Multiple parton-parton interactions	<1	0.4-5.8	-
$B(H \rightarrow \gamma\gamma)$		1.73	-

Results: Z'_B and Z' -2HDM models

- ▶ For both the Z'_B and Z' -2HDM signals, the results are only obtained from the Mono-H category
- ▶ No significant excess is observed in this category
- ▶ A two-dimensional exclusion region is obtained

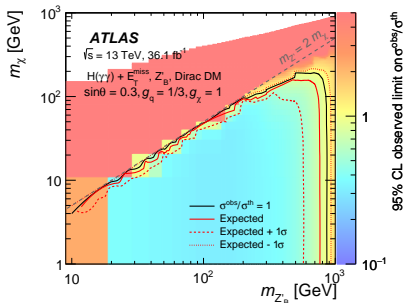
Mono-H category



arXiv:1706.03948

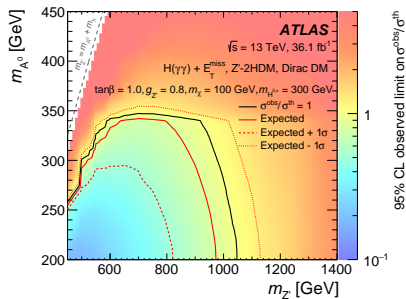
Results: Z'_B and Z' -2HDM models

Z'_B model



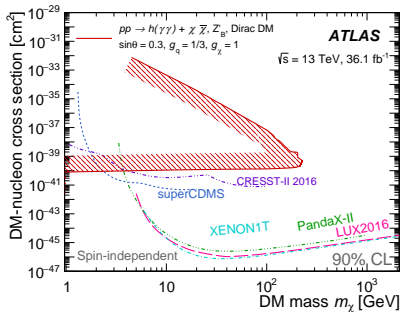
arXiv:1706.03948

Z' -2HDM model



Results: Z'_B and Z' -2HDM models

- ▶ Compare the inferred limits on the spin-independent DM–nucleon cross section to the constraints from direct detection experiments
- ▶ The comparison is model-dependent and solely valid in the context of the Z'_B simplified model with vector couplings

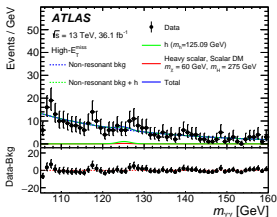


arXiv:1706.03948

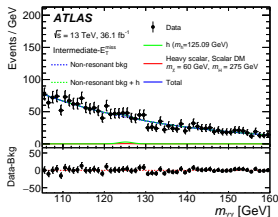
Results: heavy-scalar model

- ▶ Results for the heavy-scalar model are obtained from a simultaneous fit of all the categories

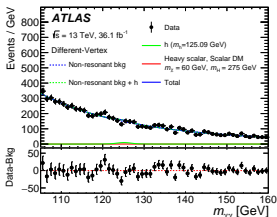
High E_T^{miss} category



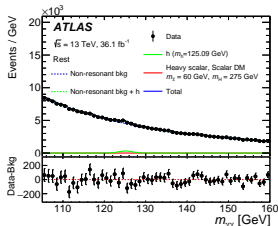
Intermediate E_T^{miss} category



Different vertex category



Rest category

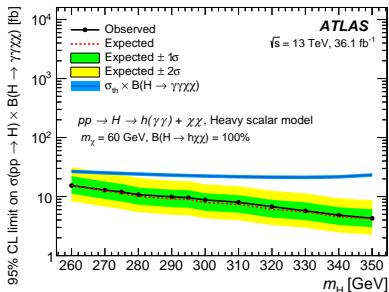


arXiv:
1706.03948

Results: heavy-scalar model

- ▶ No significant excess is observed in any category
- ▶ Set 95% CL upper limits on the cross section \times branch ratio as a function of m_H for $m_\chi = 60$ GeV

Heavy-scalar model



arXiv:1706.03948

Results: visible cross section limits

- ▶ Set upper limits (at 95% CL) on the visible cross section for BSM physics processes producing missing transverse momentum and a SM Higgs boson decaying into two photons

Category	$\sigma_{\text{vis}}^{\text{BSM}}$ [fb]		$\mathcal{A} \times \epsilon$ [%]		
	Observed	Expected	Z' -2HDM	Z'_B	Heavy scalar
Mono-Higgs	0.19	$0.23^{+0.11}_{-0.07}$	53 – 74	15 – 63	1.0 – 4.0
High- $E_{\text{T}}^{\text{miss}}$	0.67	$0.52^{+0.23}_{-0.15}$	0.2 – 12	1.3 – 7.1	1.8 – 8.4
Intermediate- $E_{\text{T}}^{\text{miss}}$	1.6	$1.2^{+0.5}_{-0.3}$	0.05 – 5.0	0.6 – 5.5	3.9 – 6.6
Different-Vertex	1.5	$2.5^{+1.1}_{-0.7}$	0.04 – 11	0.9 – 10	2.5 – 7.4
Rest	11	15^{+6}_{-4}	0.06 – 5.5	1.1 – 22	14 – 27

arXiv:1706.03948

Summary

- ▶ A search for dark matter in association with a Higgs boson decaying to two photons is presented
- ▶ No significant excess over the expected background is observed
- ▶ Limits on visible cross section, as well as the Z'_B , Z' -2HDM and heavy-scalar models, are set at 95% CL
- ▶ Paper (arXiv:1706.03948) submitted to Phys. Rev. D
- ▶ Reinterpretation of other models and combination with E_T^{miss} + $h \rightarrow bb$ are upcoming

Backup

Object reconstruction

- ▶ Photons: $p_T > 25\text{GeV}$, $|\eta| < 2.47$ (veto $1.37 < |\eta| < 1.52$)
- ▶ Electrons: $p_T > 10\text{GeV}$, $|\eta| < 2.47$ (veto $1.37 < |\eta| < 1.52$)
- ▶ Muons: $p_T > 10\text{GeV}$, $|\eta| < 2.7$
- ▶ Jets: $p_T > 25\text{ GeV}$, $|\eta| < 4.4$
- ▶ E_T^{miss} : negative vectorial sum of the transverse momenta of calibrated photons, electrons, muons and jets, as well as additional tracks