Searches for Dark Matter via Mono-Higgs signatures with the CMS experiment

Giorgia Miniello* **on behalf of the CMS Collaboration**

Università and INFN Bari

E-mail: giorgia.miniello@ba.infn.it

The Higgs boson discovery in 2012 represented not only one of the most important event occurred in the latest history of Physics, but also opened a new scenario in the detection of possible Dark Matter candidates that could be produced at colliders. In this context, the Higgs boson can be used as a probe for Dark Matter discovery. The study of the Dark Matter, whose cosmological evidence is definitely established, is one of the most promising and exciting frontier of the Physics research. The signature of the so-called Mono-Higgs analyses are typically characterized by a Higgs boson and missing transverse energy in the final state. Since the production of the Higgs via the initial state radiation is highly suppressed due to the small coupling with the quarks, an evidence of Mono-Higgs signal would probe directly the structure of the effective DM-SM coupling.

A complete overview of all the latest results from the Mono-Higgs analyses performed with the CMS experiment at the LHC will be provided using data collected during 2015 and 2016 at a luminosity of 2.3 fb^{-1} and 35.9 fb^{-1} respectively.

---

*Speaker.

1. The Mono-Higgs Analysis

The Higgs boson (H) discovery in 2012 opened a new interesting window for searching Dark Matter (DM) at the LHC via the Mono-Higgs signature. So far, no evidence of dark matter candidates have been found at colliders even though, starting from the assumption that DM is indeed associated with the scale of electroweak symmetry breaking [1, 2], it can be asserted that colliders are a natural place to search for Higgs-boson-related signatures. An exploration of possible DM-Higgs boson couplings have been already performed studying invisible Higgs decays but all the searches at LHC based on this sector led to null results [3]. The expected signature of DM at colliders is typically characterized by a large value of missing transverse energy, denoted E_T^{miss} or MET, due to DM candidates which do not interact with the detector. Mono-Higgs analyses search for final states with Higgs boson products plus a large value of missing transverse energy. They are characterized by a highly suppressed ISR due to the small coupling of the Higgs to quarks. Therefore, one Higgs boson is preferentially emitted from the new physics vertex. This would directly probe the effective DM-SM coupling and so it can be said that the Higgs is used as a probe.

2. The Signal Benchmark Models

For the Mono-Higgs analyses here presented two benchmark simplified models have been considered. The first one is the $Z'2HDM$, where a Z' is produced as an on-shell resonance decaying into a Higgs and a pseudoscalar A_0, with A_0 decaying into a pair of particle-antiparticle DM candidates. The other model used is the the Z' Baryonic, where a vector mediator Z'_B decays into $\chi\bar{\chi}$ after radiating a Higgs [4]. The main parameters of the two models considered are summarised in Table 1.

Model	Parameter	Description	Value
Z'2HDM	m_{A_0}	Mass of A_0	300 GeV
	$g_{Z'}$	Z' coupling strenght	0.8
	m_χ	Mass of DM candidate	100 GeV
	$m_{Z'}$	Mass of Z'	600 - 2500 GeV
	$\tan\beta$	Ratio between the two vevs of Higgs from $Z'2HDM$	1
Z' Baryonic	$g_{Z'_B}$	$DM - Z'_B$ coupling	1
	g_q	mediator-quark coupling	0.25
	$g_{hZ'_BZ'_B}/m_{Z'}$	coupling between Z'_B and the SM-like Higgs	1
	$sin\theta$	mixing angle between baryonic Higgs and the SM-like Higgs	0.3
	$m_{Z'_B}$	mass of Z'_B	10 − 1000 GeV
	m_χ	Mass of DM candidate	1 − 1000 GeV

Table 1: Main parameters of $Z'2HDM$ and Z' Baryonic models. In the Table *vevs* stands for *vacuum expectation values*.

3. Dark Matter produced in association with a Higgs boson decaying to Two Photons

The Mono-Higgs $\gamma\gamma$ analysis used 2016 data collected during p-p collisions at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity $\mathcal{L}$ = 35.9 fb^{-1}. Results are interpreted using both

$Z'2HDM$ and Z' Baryonic models. The analysis strategy includes many pre-selection requirements that must be applied to photon candidates. Among others, good photon candidates must be chosen in the fiducial ECAL range ($\eta < 1.4442$ or $1.566 < \eta < 2.5$), the transverse momentum of the photon p_T^γ must be chosen so that $p_T^\gamma > 30$ GeV for the leading one ($p_T^\gamma > 20$ GeV for the subleading), the mass of the diphoton must be $m_{\gamma\gamma} > 95$ GeV and the ratio between the mass of the transverse momentum and the mass of the diphoton must be $p_T^\gamma / m_{\gamma\gamma} > 1/3$ (1/4) for the leading (subleading) photon. The cut on transverse momentum p_T is chosen so that *the sculpting* of shape is avoided. Different photon identification criteria, relied on photon related variable (e.g. the ratio of hadronic to electromagnetic energy H/E) are applied to photons in the barrel and in the endcaps.

The selection criteria applied on the preselected candidates consist in choosing photon pairs to form a diphoton object. The analysis looks for an excess on the diphoton invariant mass spectrum plus a large missing transverse momentum. The missing transverse momentum of the selected events and the diphoton invariant mass are the two main variables used.

The main irreducible background source for this analysis is the associated production samples of the Higgs with a vector boson, VH (where V= Z,W), with Z decaying into two neutrinos and W decaying into a lepton and a neutrino.

The reducible backgrounds can be classified into resonant (ggF, VBF, ttH) and non-resonant sources (QCD, EWK processes).

Figure 1 shows on the *left* the 95% Confidence Level (CL) upper limits on the cross section for the $Z'2HDM$ scenario as a function of $m_{Z'}'$ for $m_{A_0} = 300$ GeV (at which signal cross section has the maximum value). 95% CL upper limits on the cross section for the Z' Baryonic model as a function of $m_{Z'_B}$ for $m_\chi = 1$ GeV is shown on the right. For more details on the analysis see [5].
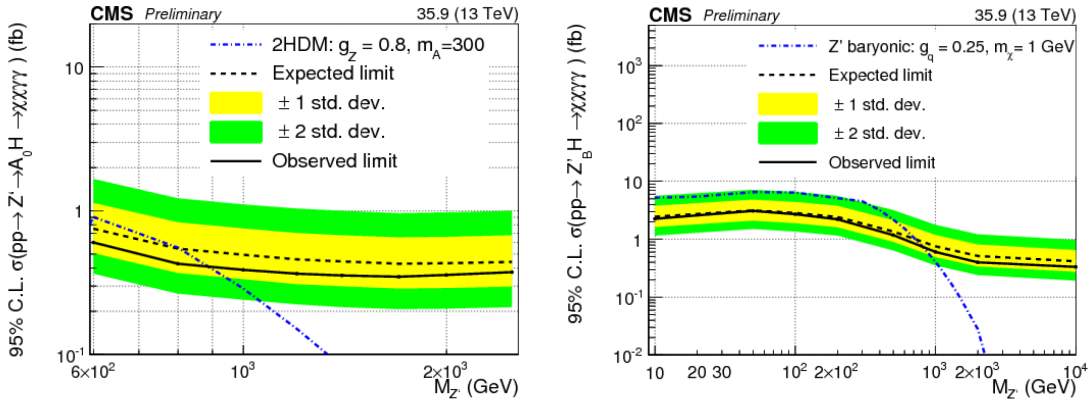

Figure 1: The upper limits on cross section for the $Z'2HDM$ scenario (*left*) and for the Z? Baryonic model (*left*) for Mono-Higgs $\gamma\gamma$

4. Dark Matter produced in association with a Higgs boson decaying into a pair of bottom quarks

The Mono-Higgs analysis with H decaying in $b\bar{b}$ used 2015 data collected during p-p collisions at $\sqrt{s} = 13$ TeV corresponding to a luminosity $\mathscr{L} = 2.3\ fb^{-1}$. The results are interpreted using

the $Z'2HDM$ approach. This study uses the *resolved* regime for lower values of $m_{Z'}$ (from 600 to 1000 GeV) in which the Higgs boson gives rise to two separate b-*jets* with a minimum angular distance between the decay products of $H(b\bar{b})$ $\Delta R = 0.4$ and the boosted one for higher values of $m_{Z'}$ (> 1000 GeV), in which the Higgs boson is reconstructed by one single jet with a *jet* radius $\Delta R = 0.8$. This analysis search for final events with large E_T^{miss}, trigger requirements both on E_T^{miss} and H_T^{miss}[1] and cut on multijets. The main irreducible background source for this analysis is Z+*jets*, with Z decaing in two neutrinos, while the reducible background sources come from multijet events, W+*jets* plus top quark production, Z+*jets*, diboson production and VH. Figure 2 shows the 95% CL upper limits on the cross section for the $Z'2HDM$ scenario as a function of m_Z' for $m_{A0} = 300$ GeV. For $m_Z' = 600, 800, 1000$ GeV resolved regime has been used while for the other higher mass points the boosted approach has been chosen. For more details on the signal event selection for both the regimes of this analysis see [6].
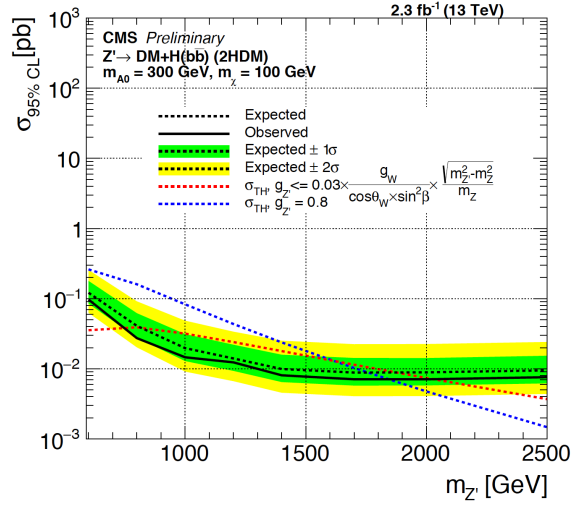

Figure 2: Expected and observed 95% CL limits on dark matter production cross section for Mono-Higgs $b\bar{b}$ analysis. For $m_Z' = 600, 800, 1000$ GeV resolved analysis has been used while the other higher mass points have been chosen for the boosted regime.

5. Conclusions

No evidence for DM production has been observed from both the Mono-Higgs studies here presented . For Mono-Higgs $\gamma\gamma$ the $Z'2HDM$ signals with $m_{A_0}=300$ GeV are excluded at 95% CL for $m_{Z'} < 900$ GeV while the Z' Baryonic signals with $m_\chi=1$ GeV are excluded at 95% CL for $m_{Z'} < 800$ GeV. The Mono-Higgs $b\bar{b}$ analysis results for $Z'2HDM$ approach shows that the range $600 < m_{Z'} < 1777$ GeV is expected to be excluded at 95% CL, while the range $600 < m_{Z'} < 1863$ GeV is excluded from the observed data.

---

[1]H_T^{miss} is the vectorial sum of the transverse momenta of all jets with $p_T > 20$ GeV

References

[1] G. Jungman, M. Kamionkowski, K. Griest, *Supersymmetric Dark Matter*, 10.1016/0370-1573(95)00058-5, 1995

[2] G. Bertone, D. Hooper, J. Silk, *Particle Dark Matter: Evidence, Candidates and Constraints*, 10.1016/j.physrep.2004.08.031, 2004

[3] L. Carpenter *et al*, *Mono-Higgs: a new collider probe of dark matter*, 10.1103/PhysRevD.89.075017, 2013

[4] Abercrombie *et al.*, *Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum*, arXiv:1507.00966v1 [hep-ex], 2015

[5] The CMS Collaboration, *earch for Dark Matter Produced in Association with a Higgs Boson Decaying to Two Photons*, CMS PAS EXO-16-054, 2016

[6] The CMS Collaboration, *Search for dark matter in association with a Higgs boson decaying into a pair of bottom quarks at $\sqrt{s}$ = 13 TeV with the CMS detector* CMS PAS EXO-16-012, 2016

PoS(EPS-HEP2017)711