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

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The CMS Experiment

The CMS experiment is a multipurpose detector hosted at the LHC. It was mainly designed for Higgs boson search and to explore physics beyond Standard Model. It mainly consists of:

- Inner tracking system ($|\eta| < 2.5$)
- Electromagnetic Calorimeter – ECAL ($|\eta| < 3$)
- Hadronic Calorimeter – HCAL (Barrel: $|\eta| < 1.3$, Endcaps: $1.3 < |\eta| < 3$, Forward HCAL: $3 < |\eta| < 5.2$)
- Solenoidal Magnet
- Muon System (Drift Tube: $|\eta| < 1.2$, Cathod Strip Chamber: $0.9 < |\eta| < 2.4$, RPC: $|\eta| < 1.6$)

The main parameters of the CMS detector are summarised in **Fig. 1a-b** and **Tab.1**.

CMS	
Magnetic Field	3.8 T Solenoid + return yoke
Tracker	Silicon pixel and strip chambers $\sigma/p_T \approx 5*10^{-4} p_T + 0.005$
ECAL	$PbWO_4$ Crystals + $\sigma/E \approx 3\%/\sqrt{E} + 0.003$
HCAL	Brass + scintillator (7 λ + tail catcher HO) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV
Muons	Inner Tracker + muon chambers $\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV
Trigger	L1 +HLT (L2 + L3)

Tab.1

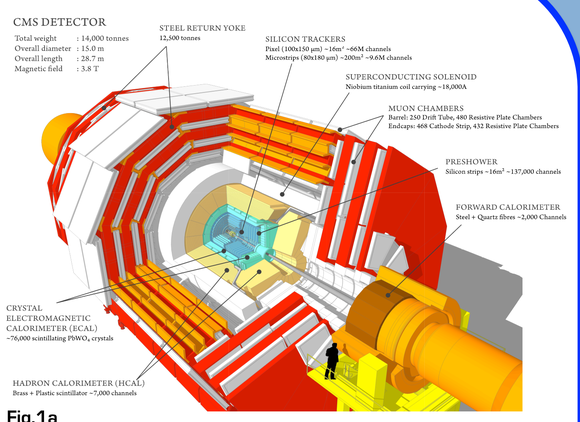

Fig.1a

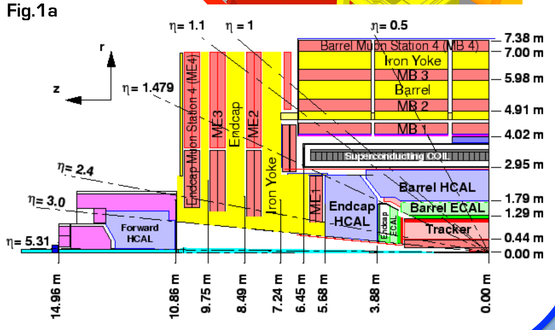

Fig.1b

H→γγ + MET full 2016 dataset

The MonoHiggs $\gamma\gamma$ search:

- Searching for final events with a Higgs decaying into two photons + MET
- 2016 data collected during p-p collisions @ $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity $\mathcal{L}$ = 35.9 fb^{-1}
- Results interpreted using both Z'-2HDM and Z' Baryonic models

Analysis strategy:

Pre-selection requirements to photon candidates:

- γ in the fiducial ECAL range: $\eta < 1.4442$ or $1.566 < \eta < 2.5$
- $p_T^{\gamma} > 30$ GeV for leading γ, $p_T^{\gamma} > 20$ GeV for subleading γ
- $m_{\gamma\gamma} > 95$ GeV
- $p_T/m_{\gamma\gamma} > 1/3$ for leading γ, $p_T/m_{\gamma\gamma} > 1/4$ for subleading γ
- p_T cut chosen so that the sculpting of $m_{\gamma\gamma}$ shape is avoided
- Different photon identification criteria, relied on photon related variable (e.g. the ratio of hadronic to electromagnetic energy H/E), applied to photons in the barrel and in the endcaps

Selection:

- Pairs of γ are combined to form a diphoton object
- Looking for an excess on the diphoton mass spectrum
- 2 main variables to distinguish the expected signals:
  - p_T^{miss} (**Fig.5**)
  - Diphoton invariant mass $m_{\gamma\gamma}$
- Diphoton invariant mass distribution of backgrounds fitted directly in data
- Fit performed using 2 categories :
  - Low - p_T^{miss} (**Fig.6a**)
  - High - p_T^{miss} (**Fig.6b**)

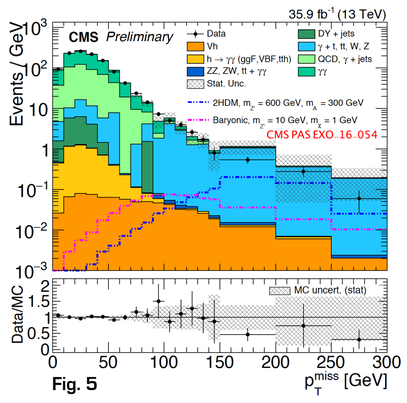

Fig. 5

Main backgrounds:

Irreducible:

- VH (V= Z,W) with Z→νν and W→lν

Reducible:

- Resonant: ggF, VBF, ttH
- Non-resonant: QCD (dijet, multijet events), EWK processes (Z, ZZ, $\bar{t}$, tt or W associated production with one or two photons, $\gamma\gamma$, γ + jet, Drell-Yan production associated with jets, with Z→ee, νν)

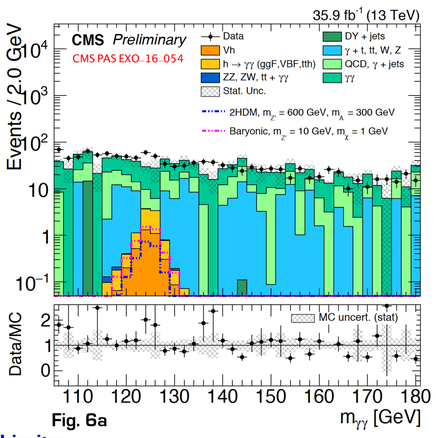

Fig. 6a

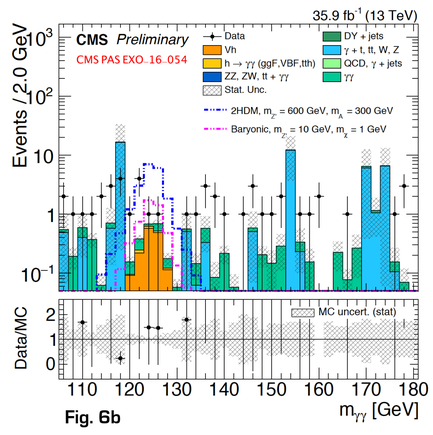

Fig. 6b

Results: Limits

- **Fig. 7a** shows the 95% C. L. upper limits on the cross section for the Z'-2HDM scenario as a function of $m_{Z'}$ for m_{A0} = 300 GeV (at which signal cross section has the maximum value)
- **Fig. 7b** the 95% CL upper limits on the cross section for the Z' Baryonic model as a function of $m_{Z'B}$ for m_χ = 1 GeV

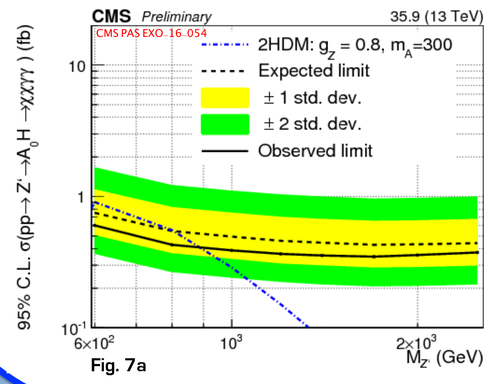

Fig. 7a

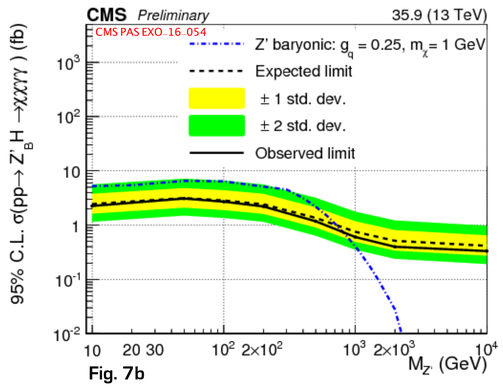

Fig. 7b

Conclusions

H→γγ+MET:

- 2016 data collected in pp collisions at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity $\mathcal{L}$ = 35.9 fb^{-1} used
- Results interpreted in terms of Z'-2HDM and Z' baryonic simplified models of dark matter production where the final signature is the SM Higgs boson decaying into two photons + MET
- No evidence for Dark Matter candidates production observed:
  - Z'-2HDM signals with m_{A0} = 300 GeV excluded at 95 % C. L. for $m_{Z'} < 900$ GeV
  - Z' Baryonic signals with m_χ = 1 GeV excluded at 95 % C. L. for $m_{Z'B} < 800$ GeV

H→bbar+MET:

- 2015 data collected in pp collisions at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity $\mathcal{L}$ =2.3 fb^{-1} used
- Results interpreted in terms of Z'-2HDM simplified model of dark matter production where the final signature is the SM Higgs boson decaying into a pair of bottom quarks + MET
- No deviation from Standard Model background is observed:
  - Range $600 < m_{Z'} < 1777$ GeV expected to be excluded at 95% C.L.
  - Range $600 < m_{Z'} < 1863$ GeV excluded from the observed data

The Mono Higgs Analysis

Main Feature of a Mono-Higgs search:

- Small coupling of a Higgs to quark → ISR production highly suppressed → a Mono-H emitted at the effective vertex $H\chi\bar{\chi}$
- Looking for Higgs boson decay products + MET → **Higgs particle used as a PROBE**

Goals:

- derive sensitivity of Mono-Higgs analyses to probe DM mass hypotheses for different benchmark models
- direct test of the SM-DM coupling structure (**Fig. 2**).

Theoretical Simplified Models used as benchmarks:

- Z'-2HDM: Z' produced as an on-shell resonance decaying into a Higgs and a pseudoscalar A_0, with $A_0 \rightarrow \chi\bar{\chi}$ (**Fig.3**)
- Z' Baryonic: a vector mediator Z'_B decays into $\chi\bar{\chi}$ after radiating a H (**Fig. 4**)

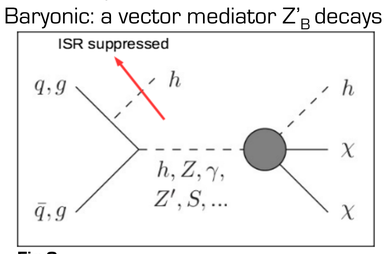

Fig.2

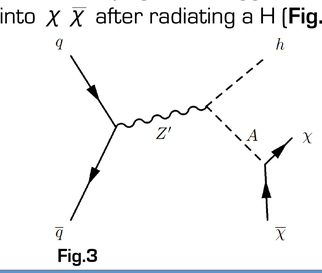

Fig.3

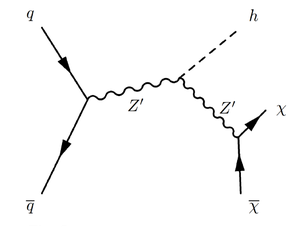

Fig.4

Model	Parameter	Description	Value
Z'-2HDM	m_{A0}	Mass of the pseudoscalar Higgs A_0 decaying into two DM candidates	300 GeV
	g_Z	Coupling costant between A_0 e DM	0.8
	m_χ	DM candidate mass	100 GeV
	$m_{Z'}$	Z' mass	600 - 2500 GeV
	tan β	Ratio between the vacuum expectation values for the two Higgs doublets expected from Z'-2HDM	1
Z'-Baryonic	$g_{Z'B}$	mediator-DM coupling	1
	g_q	mediator-quark coupling	0.25
	$g_{hZ'BZ'B}/m_{Z'}$	coupling between the heavy mediator Z'_B and the SM-like Higgs	1
	sinθ	mixing angle between baryonic Higgs and the SM-like Higgs boson	0.3
	$m_{Z'}$	Z'_B mass	10 - 1000 GeV
	m_χ	DM candidate mass	1 - 1000 GeV

Tab. 2

H→bb̄ + MET

The MonoHiggs $b\bar{b}$ search:

- Searching for final events with a Higgs decaying into a pair of bottom quarks + MET
- 2015 data collected during p-p collisions @ $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity $\mathcal{L}$ = 2.3 fb^{-1}
- Results interpreted using the Z'-2HDM model

Analysis strategy:

Two regimes of analysis used:

- **RESOLVED**: the Higgs boson gives rise to two separate b-jets with a minimum angular distance between the decay products of H ($b\bar{b}$) ΔR= 0.4. It is used for lower values of $m_{Z'}$ (from 600 to 1000 GeV).
- **BOOSTED**: Higgs boson reconstructed by one single jet with a jet radius ΔR = 0.8. It is used for higher values of $m_{Z'}$ (> 1000 GeV)

Selection:

Main requirements for this study are:

- High p_T^{miss}
- Trigger: $E_T^{miss} > 90$ GeV ($E_T^{miss} > 170$ GeV to get higher efficiency) and $H_T^{miss} > 90$. H_T^{miss} is the vectorial sum of the transverse momenta of all jets with $p_T > 20$ GeV
- Cut on multijets: azimuthal angle difference between vectors p_T^{miss} and E_T^{miss} less than 0.7

RESOLVED:

- At least two AK4 jets
- Jet with $p_T > 30$ GeV within $|\eta| < 2.4$ regime
- The two jets then used to reconstruct the Higgs boson with $p_T > 150$ GeV

BOOSTED:

- only one AK8 jet with $p_T > 200$ GeV needed to reconstruct the Higgs

A more detailed signal region event selections for resolved and boosted regimes is presented in **Tab. 3**

Cut Variable	Resolved	Boosted
AK4 Jet Kinematics	2 jets with $p_T > 30$ GeV and $\lvert\eta\rvert < 2.4$	-
AK8 Jet Kinematics	-	$p_T > 200$ GeV, $\lvert\eta\rvert < 2.4$
E_T^{miss}	> 170 GeV	> 200 GeV
p_T^{bb}	> 150 GeV	-
b tagging	Medium WP for both jets	Loose WP for two subjets
$m_{corrected}^{pruned}$	-	100 to 150 GeV
m_{bb}	100 to 150 GeV	-
$\Delta\phi$(AK4 Jet, E_T^{miss})	> 0.4	> 0.4
$\Delta\phi(\vec{p}_T^{miss}, E_T^{miss})$	< 0.7	-
additional isolated lepton (e, μ, τ_h)	0	0
additional AK4 jet	not more than one	not more than one
additional AK4 b jet	0	0

Tab. 3

Main backgrounds:

Irreducible:

- Z+jets, with Z→ ν ν

Reducible:

- Multijet events
- W[→l ν]+jets + top quark production
- Z[→ll]+jets, diboson production and associated production VH

Results: Limits

Fig. 8 shows the 95% C.L. 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 analysis has been used while for the other higher mass points boosted analysis has been used.

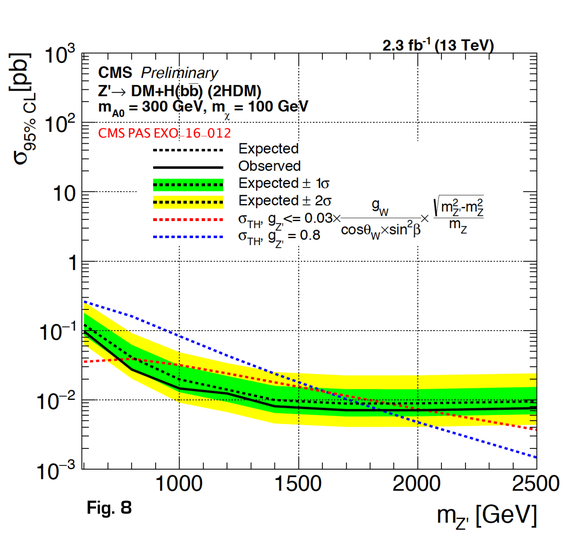

Fig. 8

References

- Abercrombie *et al.*: "Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum", arXiv:1507.00966v1
- Carpenter *et al.*: "Mono-Higgs: a new collider probe of dark matter", 10.1103/PhysRevD.89.075017
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