Search for Dark matter in MonoHiggs signature at CMS

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On behalf of the CMS collaborations

November 29th 2023

Introduction

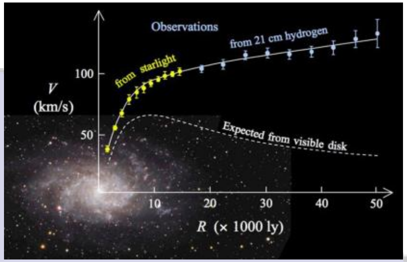
Dark Matter:

Electrically Neutral

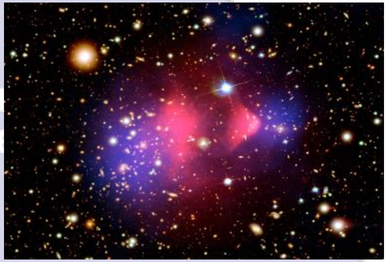
Interact only through gravity

Weakly Interacting Massive Particles (WIMPs)

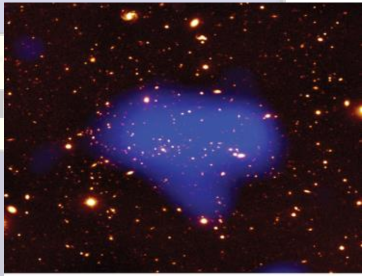
Rotation Curve Galaxy



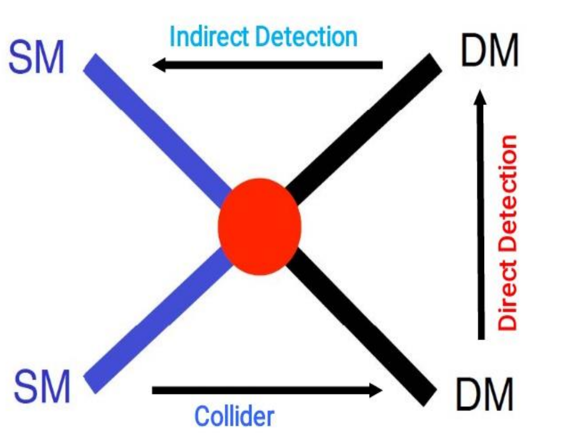
Bullet Cluster



Hot gas in clusters of galaxies



How to Detect Dark matter?



Colliders: Collision of SM particles (p-p at LHC) DM may produced, appear as **Missing Transverse Momentum**

Why Mono-Higgs Search?

Canonical mono-jet/photon/W/Z from initial state radiation (ISR)

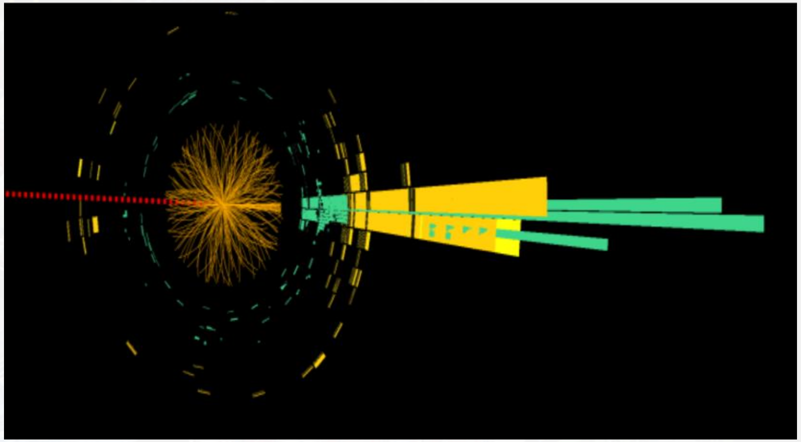
Mono-Higgs (Mono-h)

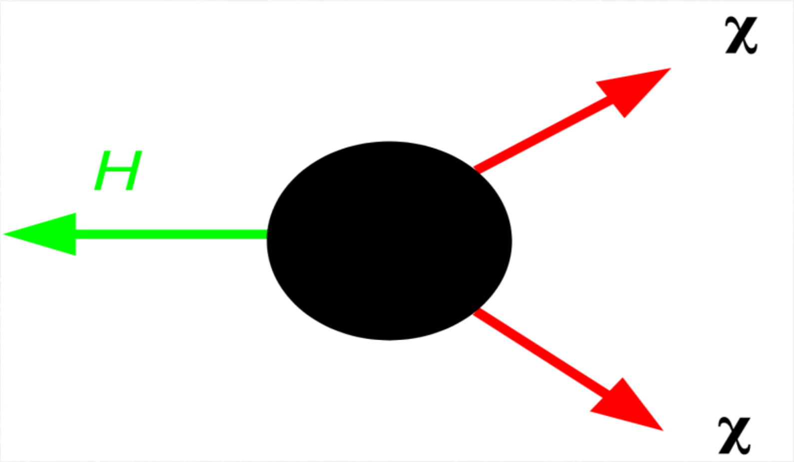
-“h” produced in ISR is highly suppressed

-The FSR of DM particles or the Beyond SM (BSM) interaction of DM particles with “h”, typically via a mediator particle

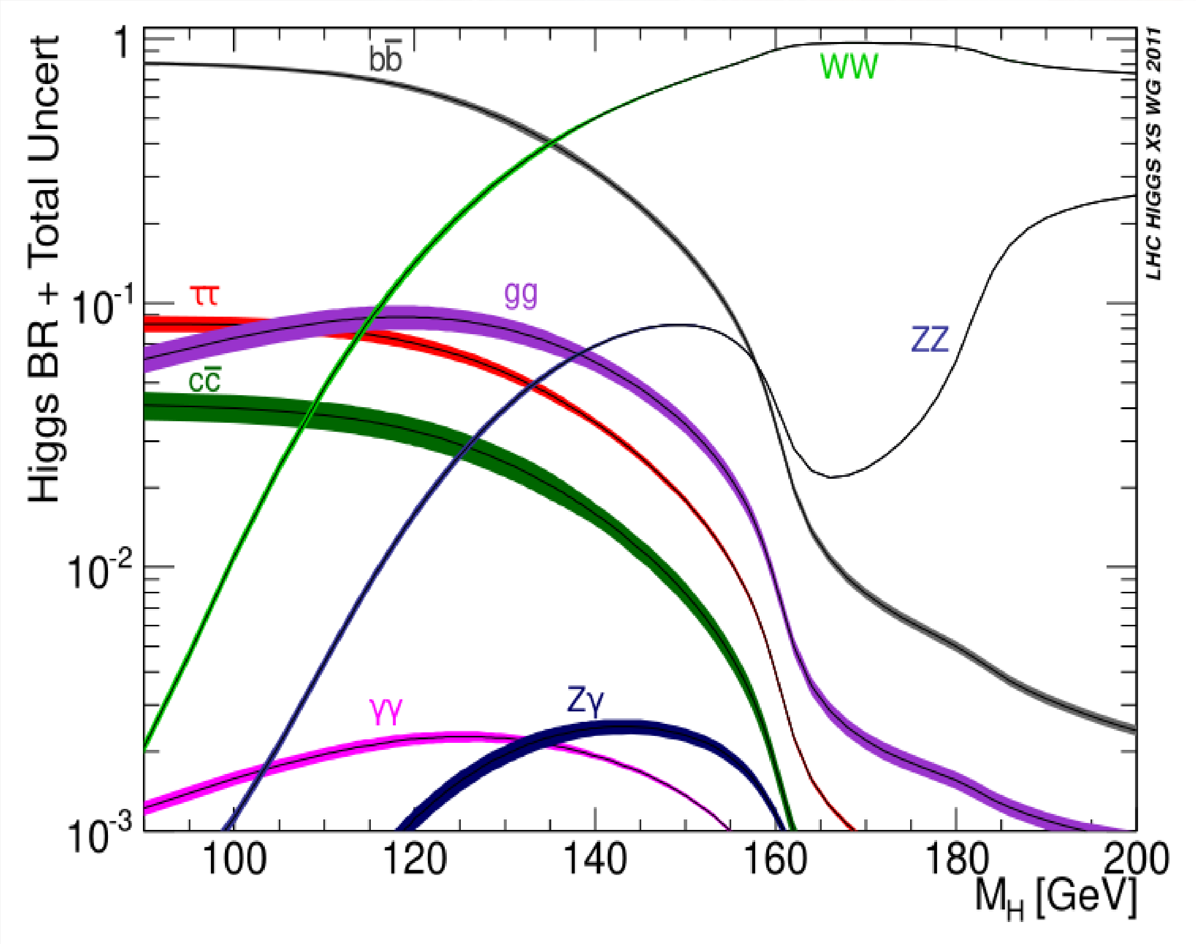
Signature:

-Reconstruct Higgs and search for excess of events with high MET





Which decay mode is best in Mono-Higgs Search?



The SM Higgs branching ratios as a function of Higgs mass

bb: High BR but large in background

ZZ: clean but low BR

Mono- Higgs searches

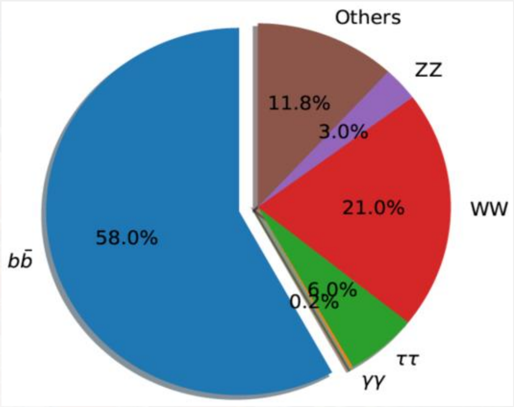


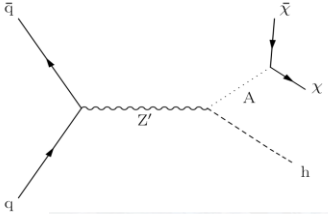
Table: Mono-Higgs analysis in different decay modes

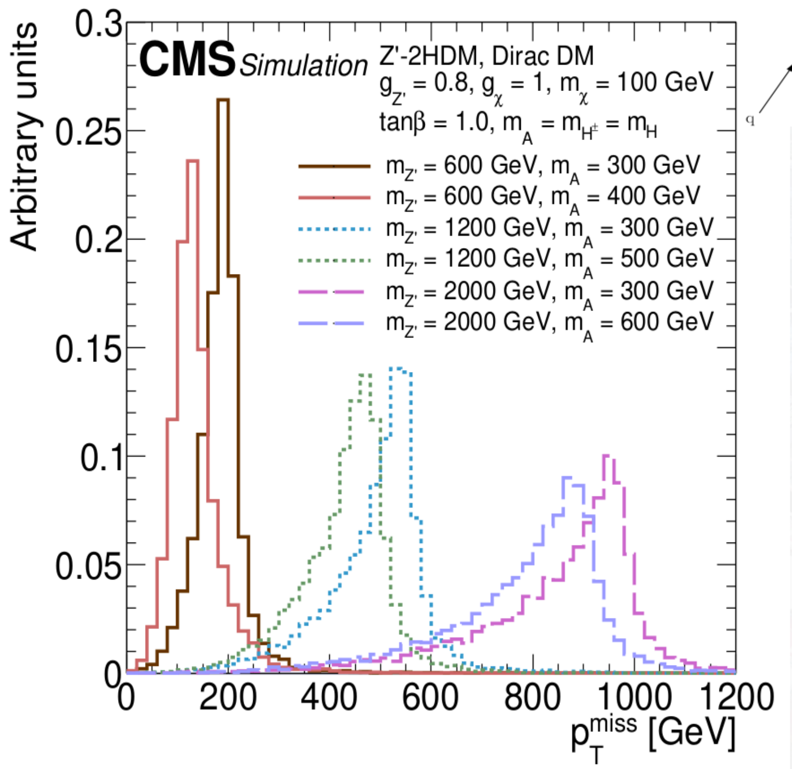
Decay channel	Final state or category	Publication
$h \to bb$	AK8 jet (Z′-2HDM) CA15 jet (Baryonic Z′)	Eur. Phys. J. C79 (2019) 280
$h \to \gamma\gamma$	$p_T^{miss} \in 50–130\,GeV$ $p_T^{miss} > 130\,GeV$	JHEP09(2018)046
$h \to \tau\tau$	$\tau_h\tau_h$ $\mu\tau_h$ $e\tau_h$	JHEP09(2018)046
$h \to WW$	$e\nu\mu\nu$	JHEP03(2020)025
$h \to ZZ$	4e 4μ $2e2\mu$	JHEP03(2020)025

Mono- Higgs searches

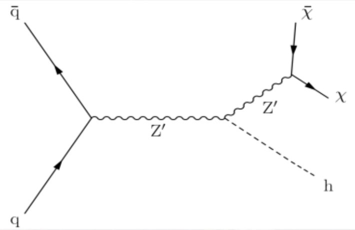
Experimental signature: Higgs (h) + Missing Transverse Momentum(MET)

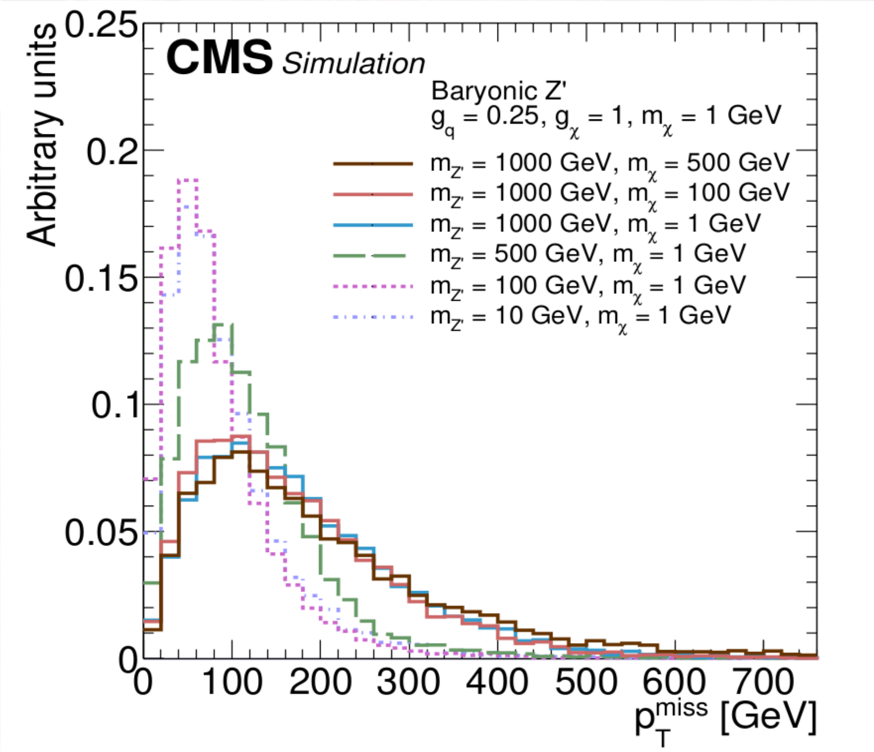
Z' 2HDM





Baryonic Z'



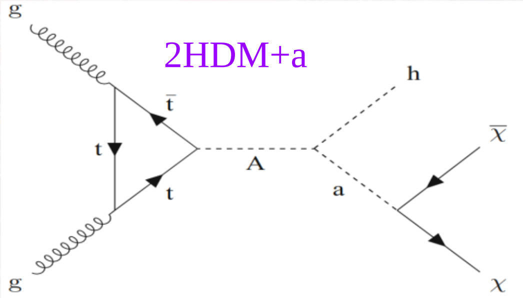


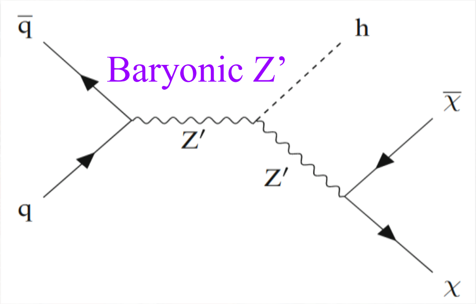
JHEP03(2020)025

Mono- Higgs searches:1. h→ bb (1/2)

Experimental signature: Higgs (h) + MET

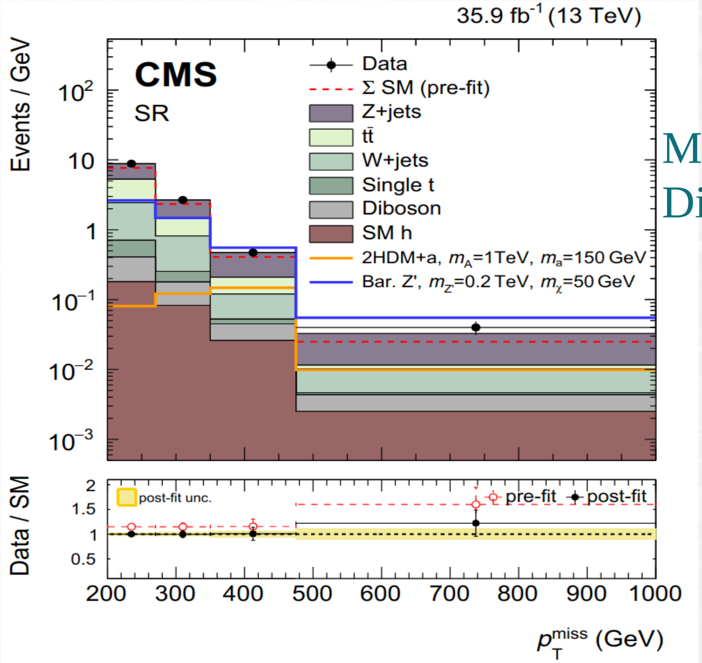
Most sensitive channel for most z' masses





Backgrounds:

-Dominant background: Z+jets, W+jets, ttbar



MET Distribution

Analysis strategy:

-Uses double b-tagger and jet substructure variables to isolate h to bb decays

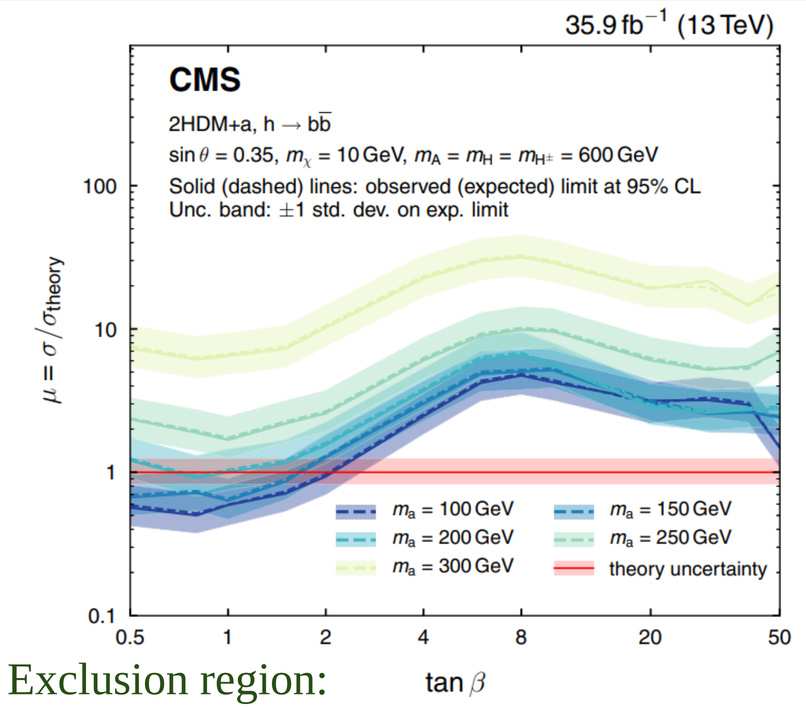
-Simultaneous fit is performed to MET in signal region and dedicated control regions (CR)

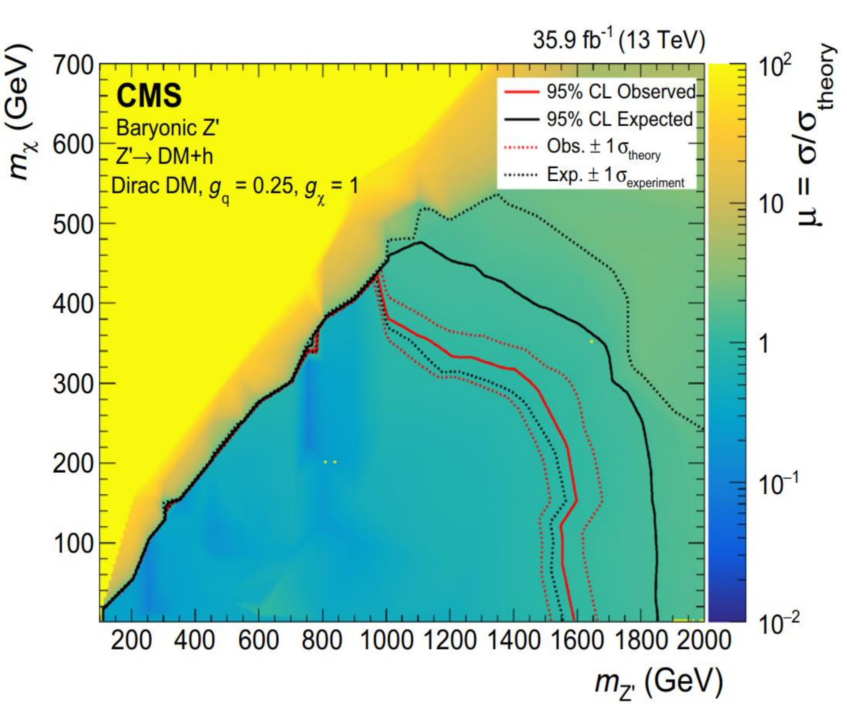
Eur. Phys. J. C79 (2019) 280

Mono- Higgs searches:1. h⟶ bb (2/2)

1d scan of tanβ

2d scan of Mz' and mchi





Exclusion region:

2HDM+a tanβ*: ~ 0.5-2, ma 100 GeV*

[Eur. Phys. J. C79 (2019) 280]

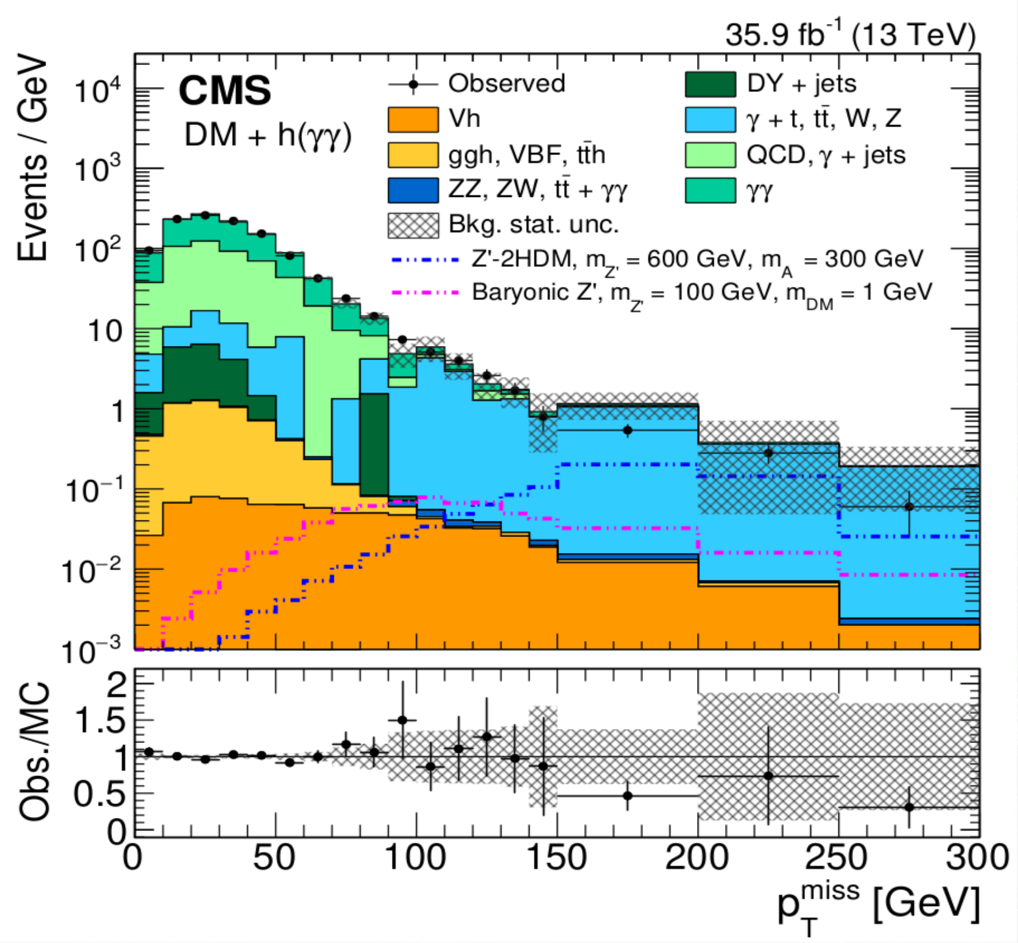
Exclusion region:

Baryonic Z': ~ 1600 GeV, mass of DM: ~ 1 GeV

~ 960 GeV, mass of DM: ~ 430 GeV

Mono- Higgs searches:2. h→ γγ

MET Distribution:



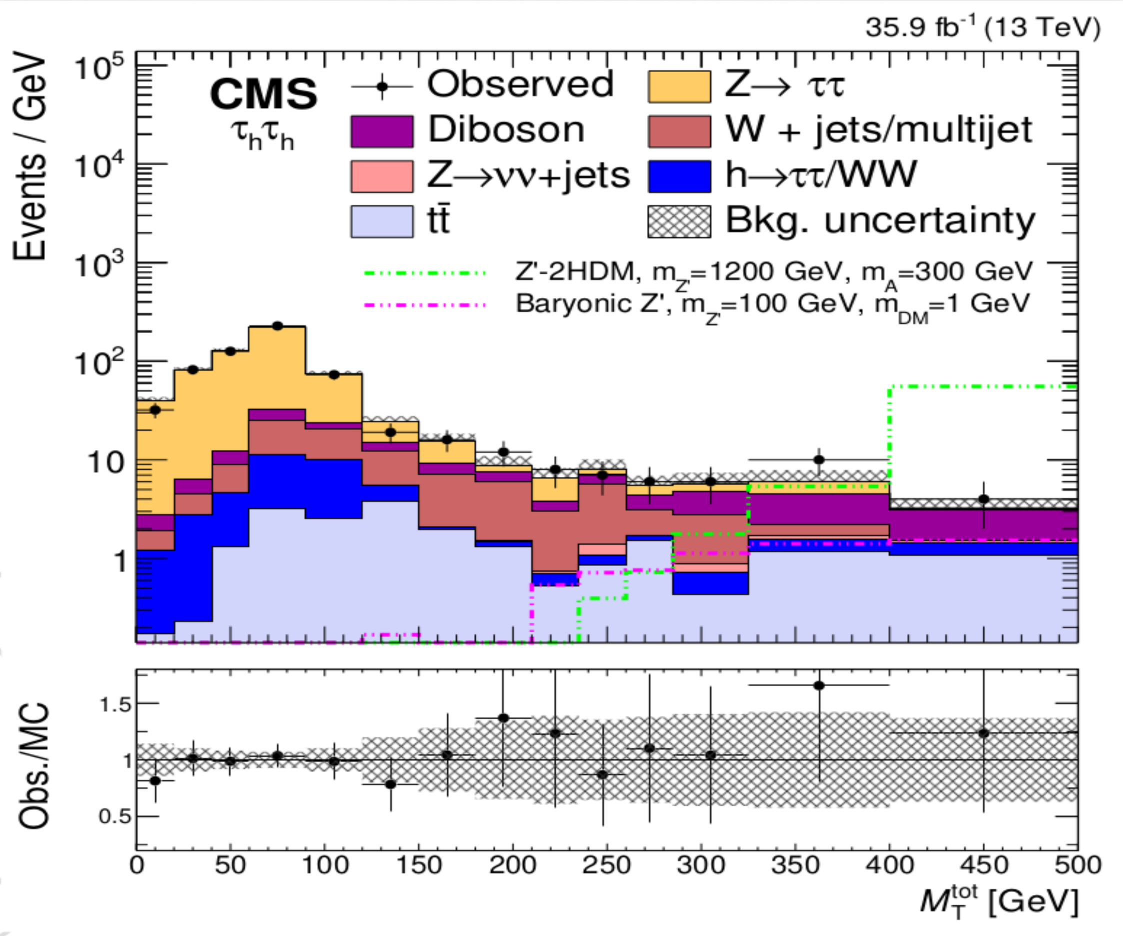
- Improved resolution on the reconstructed Higgs invariant mass

- Fit is performed to the diphoton invariant mass distribution.

JHEP09(2018)046

Mono- Higgs searches:3. h⟶ ττ

Transverse mass Distribution:

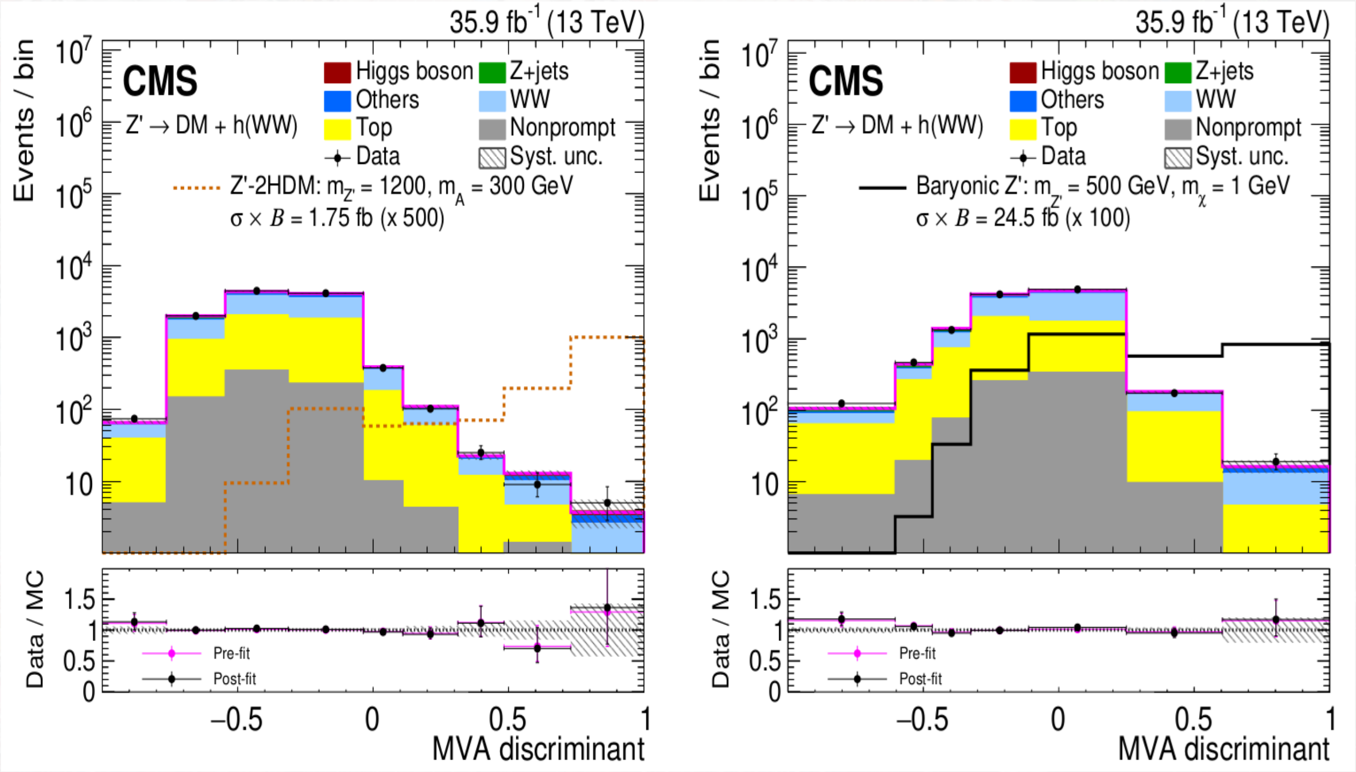


- Improved sensitivity for low values of $m_{Z'}$
- Combination of $\tau_h\tau_h$, $e\tau_h$, and $\mu\tau_h$.
- Simultaneous fit in control and signal regions to the transverse mass

JHEP09(2018)046

Mono- Higgs searches:4. h⟶ WW

Z' 2HDM　　　　Baryonic Z'



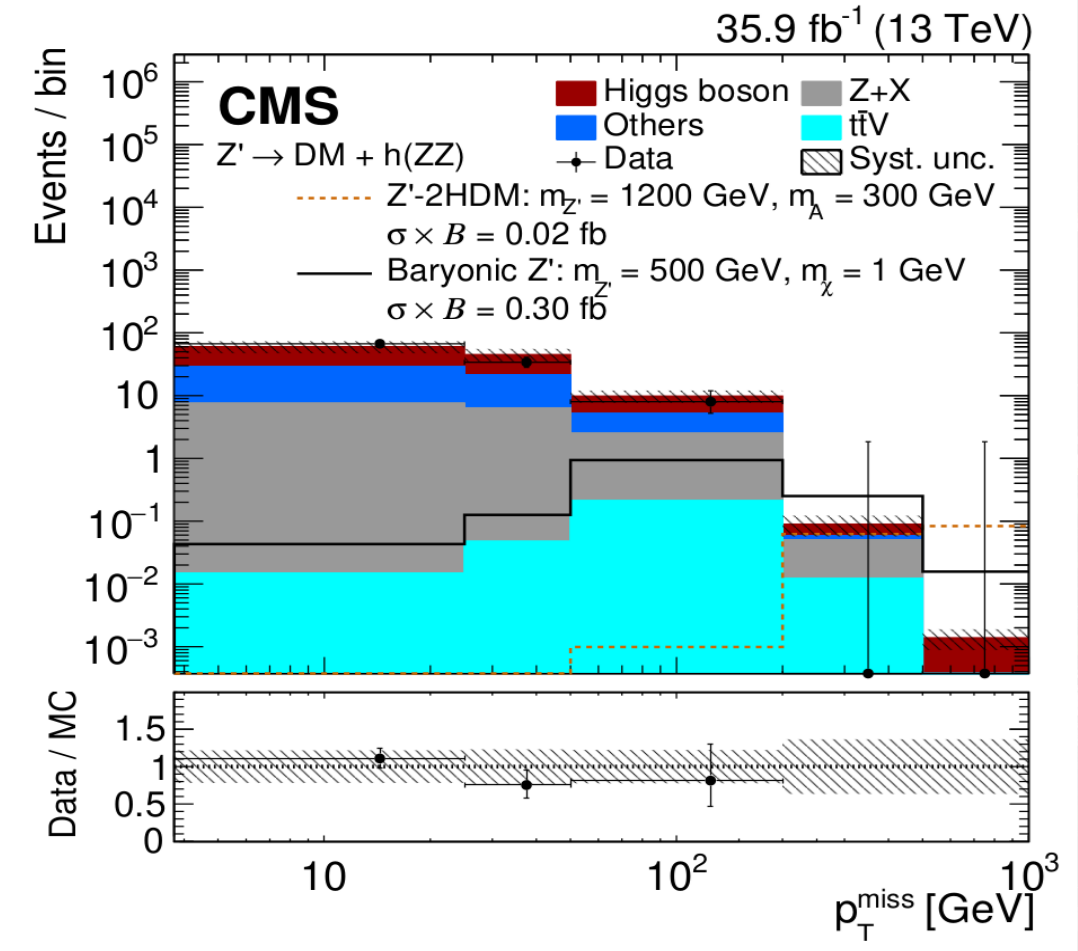
- Use eμ final state to avoid backgrounds from Z boson
- Major backgrounds: ttbar, non-resonant WW, nonprompt leptons
- Different MVA discriminant used for each of the signal models

JHEP03(2020)025

Mono- Higgs searches:5. h⟶ ZZ

MET Distribution:

- Use 4l final state to reconstruct Higgs invariant mass
- Major backgrounds: SM Higgs boson, nonresonant ZZ production, "Z+X" backgrounds from non-prompt leptons inside jets
- Misidentification rate estimated from data CRs.



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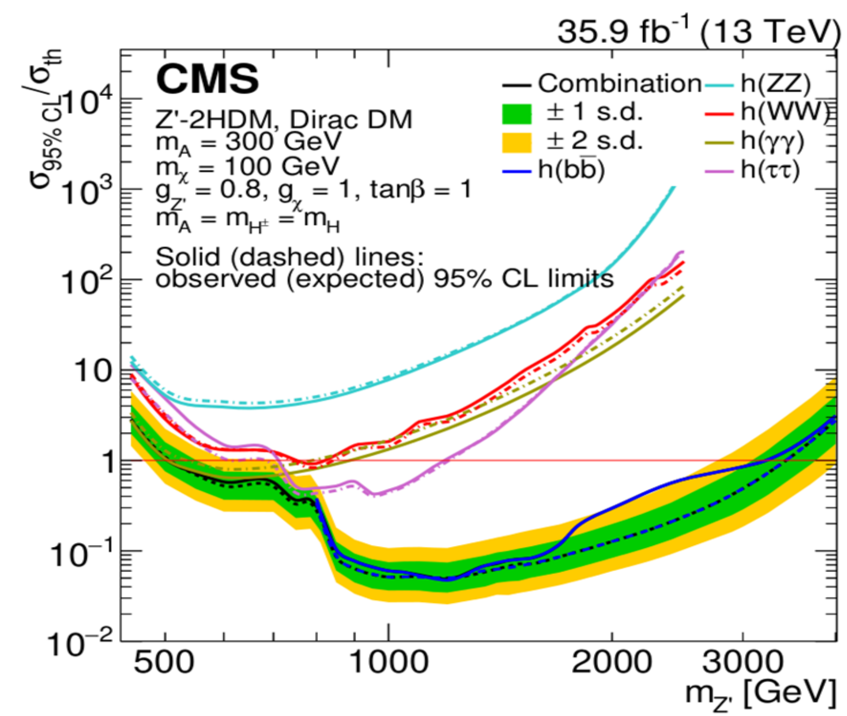
Combination of H→ bb, ττ, γγ, WW, ZZ

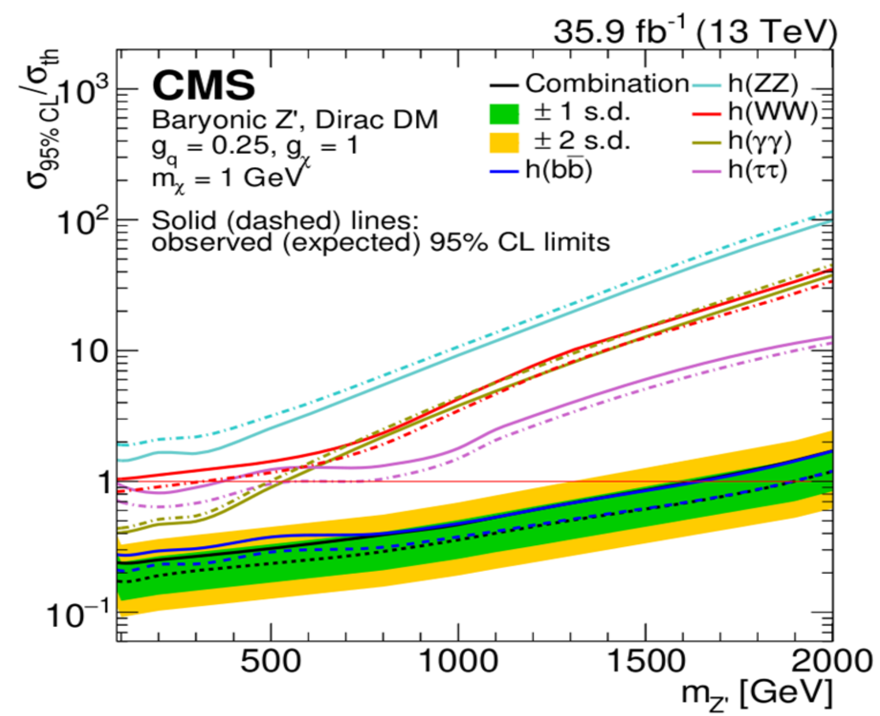
1d scan of Mz’ in Z’ 2HDM model



Exclusion region:

Z’-2HMD: mZ’ ~ 500-3200 GeV, mass A: 300 GeV

1d scan of Mz’ in Baryonic Z’ model



Exclusion region:

Baryonic Z’: mZ’ ~ 100- 1600 GeV, mass of DM: ~ 1 GeV

JHEP03(2020)025

Dark Higgs

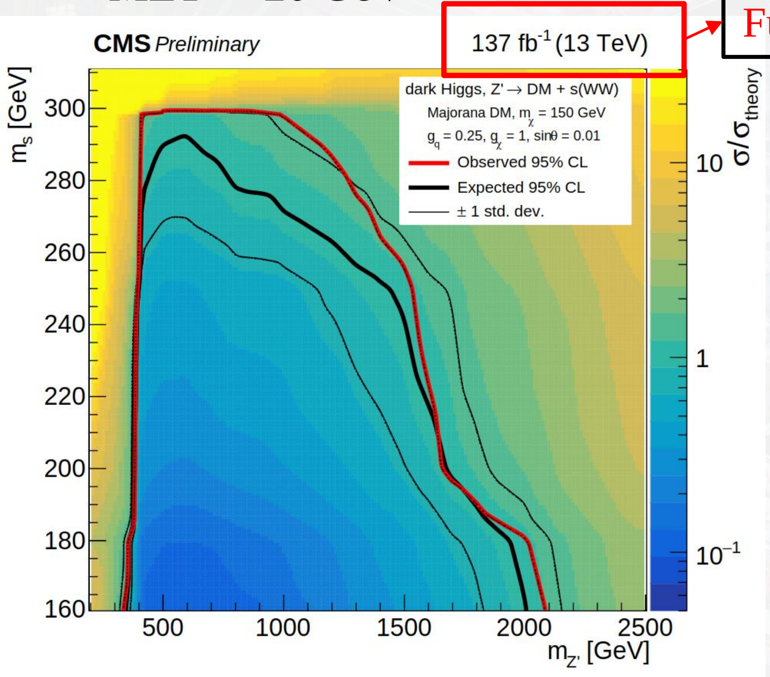
Experimental signature: s → WW → (ℓ+ℓ) + Missing Transverse Momentum (MET)

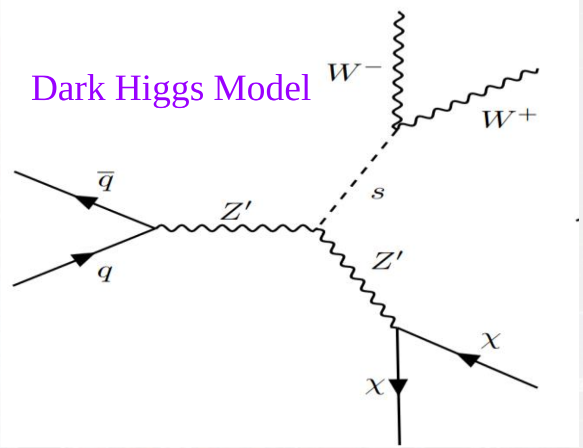
Event selections:

-Final state: leptons (e/μ) with opposite charge and different flavor

-MET > 20 GeV

Full RunII result





coupling constant $g_q = 0.25$, $g_\chi = 1$, $m_{DM} = 150$

2d scan of Mz’ and Ms

Exclusion region:

ms ~ 300 GeV, mZ’ ~ 480-1200 GeV

ms ~ 160 GeV, mZ’ ~ 2000 GeV

CMS-PAS-EXO-20-013

Summary

- Interesting results for the search of dark matter performed with Mono-higgs with CMS detector are discussed
- No signal is observed yet
- With large RunII dataset and good improvement on analysis techniques, more complete signal & background modeling and estimation led to more stringent exclusions
- **Stay tuned for the new results with Run3…**

For more results on DM searches visit CMS

Thank you for your attention…

Backup

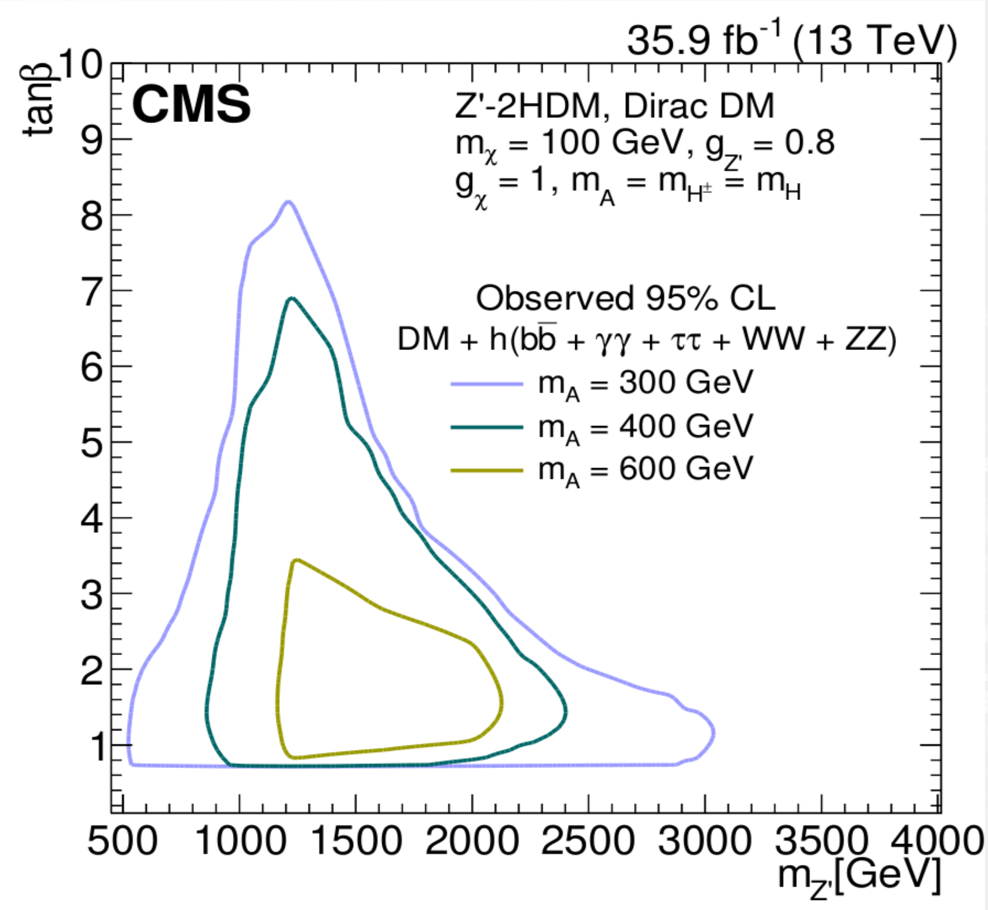
Combination Limits, in the $m_{Z'}$ - tanβ

Z'-2HDM: mDM = 100 GeV, g_χ = 1 and gZ' = 0.8

2d scan of Mz' and tanβ

- tan(β) runs from 0.5 to 10

- The area enclosed by the contours are for a given value of the pseudoscalar mass "A" and are excluded at 95% CL



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Mono- Higgs searches:2. $h \to \gamma\gamma$ Event selection

Variable	Low-p_T^{miss} category	High-p_T^{miss} category
p_T^{miss}	>50 GeV, <130 GeV	>130 GeV
$p_{T1}/m_{\gamma\gamma}$	>0.45	>0.5
$p_{T2}/m_{\gamma\gamma}$	>0.25	>0.25
$p_{T\gamma\gamma}$	>75 GeV	>90 GeV

Table 1. Optimized kinematic requirements for the low- and high-p_T^{miss} categories.

Mono- Higgs searches:2. h→ tautau

		Lepton selection		
Final state	Trigger type	p_T [GeV]	η	Isolation
$e\tau_h$	$e(25\,GeV)$	$p_T^e > 26$	$\|\eta^e\| < 2.1$	$I_{rel}^e < 0.1$
		$p_T^{\tau_h} > 20$	$\|\eta^{\tau_h}\| < 2.3$	Tight MVA τ_h
$\mu\tau_h$	$\mu(24\,GeV)$	$p_T^\mu > 26$	$\|\eta^\mu\| < 2.4$	$I_{rel}^\mu < 0.15$
		$p_T^{\tau_h} > 20$	$\|\eta^{\tau_h}\| < 2.3$	Tight MVA τ_h
$\tau_h\tau_h$	τ_h (35 GeV) & τ_h (35 GeV)	$p_T^{\tau_h} > 55\,\&\,40$	$\|\eta^{\tau_h}\| < 2.1$	Loose MVA τ_h

Table 2. Selection requirements for the three $\tau\tau$ decay channels. The p_T thresholds for the triggers are given in the second column in parentheses.

Mono- Higgs searches:4. h→ WW

Since full kinematic reconstruction of the Higgs boson mass and p_{T} is impossible in this decay channel because of the presence of undetected neutrinos and DM particles, to maximize the sensitivity of the search, a boosted decision tree (BDT) multivariate classifier has been trained for each of the two signal models. The BDT exploits the following input variables:

- transverse masses: $m_{\mathrm{T}}^{\mathrm{h}}$, $m_{\mathrm{T}}^{\mathrm{W}_1}$, $m_{\mathrm{T}}^{\mathrm{W}_2}$;
- lepton transverse momenta: $p_{\mathrm{T}}^{\ell\ell}$, $p_{\mathrm{T}}^{\ell_1}$, $p_{\mathrm{T}}^{\ell_2}$;
- missing transverse momenta: PF $p_{\mathrm{T}}^{\mathrm{miss}}$, tracker $p_{\mathrm{T}}^{\mathrm{miss}}$, $p_{\mathrm{T,mp}}^{\mathrm{miss}}$;
- angular variables: $\Delta R_{\ell\ell}$, $\Delta\phi_{\ell\ell}$, $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}}\ell_1}$, $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}}\ell_2}$; and
- dilepton invariant mass: $m_{\ell\ell}$.

Here, $m_{\mathrm{T}}^{\mathrm{W}_i} = \sqrt{2p_{\mathrm{T}}^{\ell_i}p_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}}\ell_i})}$, where $i = 1$ ($i = 2$) defines the transverse mass of $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ and the leading (subleading) lepton in the event, and $\Delta\phi_{\ell\ell}$ is the azimuthal angle between the directions of the two lepton momenta.

Mono- Higgs searches: combination systematics

Source	$h \to bb$ Z′-2HDM	$h \to bb$ Baryonic Z′	$h \to \gamma\gamma$	$h \to \tau\tau$	$h \to WW$	$h \to ZZ$
AK4 jet b tagging	3–11% (combined with b mistag)	Uncorr. (3–4%)	—	4%	Shape (1%)	1%
AK4 jet b mistag		Shape (5–7%)	—	2–5%	Shape (1%)	—
e ident. efficiency	4%	2%	—	2%	Shape (2%)	2.5–9.0%
μ ident. efficiency	4%	2%	—	2%	Shape (2%)	2.5–9.0%
τ_h ident. efficiency	3%	3%	—	4.5%	Shape (1%)	—
e energy scale	1%	—	—	—	Shape (1%)	3%
μ energy scale	1%	—	—	—	Shape (1%)	0.4%
JES	—	Uncorr. (4%)	—	Shape (<10%)	Shape (3%)	2–3%
Int. luminosity	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Signal (PDF, scales)	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%

Table 5. Systematic uncertainties in the combination of channels, along with the type (rate/shape) of uncertainty affecting signal and background processes, correlated amongst at least two final states. For the rate uncertainties, the percentage of the prior value is quoted, while for shape uncertainties an estimate of the impact of systematic uncertainties on the yield is also listed. A dash ("—") implies that a given uncertainty does not affect the analysis. Whenever an uncertainty is present but kept uncorrelated in a particular channel, this is mentioned explicitly. The effect of the b jet mistag rate uncertainty is very small in the $h \to bb$ Z′-2HDM analysis and hence it is added to the effect of the b tagging efficiency uncertainty in quadrature.

Mono- Higgs searches:2. h→ γγ