Search for dark photons in Higgs boson production via vector boson fusion in proton-proton collisions at $\sqrt{s} = 13$ TeV

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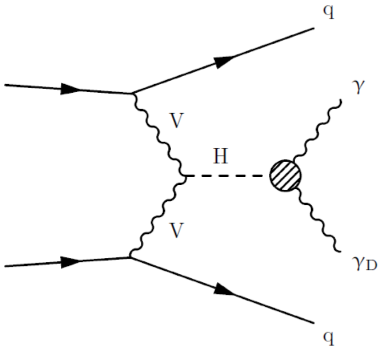
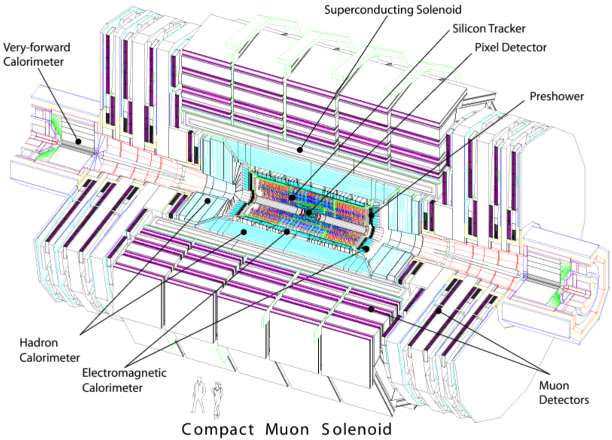
VBF production and Higgs decays



- jets with high $\Delta\eta_{jj}$ and high dijet m_{jj}
- λ and λ_D with high p_T
- λ_D detected indirectly through p_T^{miss}

The CMS detector

- $\sqrt{s} = 13\,TeV$ and $\mathcal{L} = 130 fb^{-1}$



CMS features

- $B = 3.8T$
- Tracker that detects up to $|\eta| < 2.5$
- EM calorimeter and Hadron calorimenter that detects up to $|\eta| < 3.0$
- Forward calorimeters extend detection up until $|\eta| < 5.0$
- Muon chambers detect up to $|\eta| < 2.4$
- Two level trigger system
- L1 - $100kHz$ in $4\mu s$
- HLT - $1kHz$ before data storage

Data samples and event reconstruction

Processes	**Program**
VBF, ggH, $t\bar{t}\gamma$, VVV, WZ, WW, ZZ	POWHEGv2
W+jets, Z+jets, γ + jets, $W(l\nu)+\gamma$, $Z+\gamma$	MADGRAPH5aMC@NLO
$H \rightarrow \gamma\gamma_D$, Parton Shower, Hadronization	Pythia

Table: Monte Carlo Simulations

- Simulation for H: $m_H = 125, 150, 200, 300, 500, 800, 1000 GeV$
- All events are processed by *Geant4*. Pileup interactions added with a distribution that matches observed results (23 for 2016, 32 for 2017-18)

CMS particle flow

- Information from subdetectors $\rightarrow$ Reconstruction and identification
- Jets analysed: $p_T > 30 GeV$ and $|\eta| < 4.7$
- Pileup mitigated by charged-hadron subtraction technique
- Electrons reconstructed from ECAL energy clusters, with with $|\eta| < 2.5$ and $p_T > 10 GeV$
- Muons reconstructed from tracks in muon system, with $|\eta| < 2.4$ and $p_T > 10 GeV$
- Photons reconstrcuted from ECAL energy deposits, with $|\eta| < 1.47$ and $p_T > 80 GeV$
- Isolated photon: $\sum p_T$ within cone of $\Delta R < 0.3$ below some bound
- Pixel-seed electron veto to exclude electrons misidentified as photons

Event selection

Data-taking year	2016	2017/2018	
Trigger	VBF+γ	Single-photon	$p_{\mathrm{T}}^{\mathrm{miss}}$
Number of photons		$\geq$1 photon	
p_{T}^{γ}	>80 GeV	>230 GeV	>80 GeV
Number of leptons		0	
$p_{\mathrm{T}}^{\mathrm{j}_1}$, $p_{\mathrm{T}}^{\mathrm{j}_2}$		>50 GeV	
$p_{\mathrm{T}}^{\mathrm{miss}}$	>100 GeV	>140 GeV	>140 GeV
Jet counting		2–5	
m_{jj}		>500 GeV	
$\lvert\Delta\eta_{\mathrm{jj}}\rvert$		>3.0	
$\eta_{\mathrm{j}_1}\eta_{\mathrm{j}_2}$		<0	
$\Delta\phi_{\mathrm{jet},\vec{p}_{\mathrm{T}}^{\mathrm{miss}}}$		>1.0 radians	
z_{γ}^{*}		<0.6	
$p_{\mathrm{T}}^{\mathrm{tot}}$		<150 GeV	

Figure: Signal Region Criteria

$$z_{\gamma}^{*} \equiv \left| \frac{\eta_{\gamma} - \left(\eta_{j1} + \eta_{j2}\right)/2}{\left|\Delta\eta_{jj}\right|} \right|$$

Background estimation

- Main: $W(e\nu) + jets$, where the γ is a misidentified e
- Larger p_T^{miss}, $Z(\nu\bar{\nu}) + \gamma /\ W(l\nu) + \gamma$
- $\gamma + jets$, with mismeasured p_T^{miss}
- Processes of electroweak are increasingly important with higher m_{jj}
- Normalized with control regions
- Minor contributions (VVV, VV, $t\bar{t}\gamma$, $t\gamma$) simulated with Monte Carlo methods.
- Normalization of pathological event reconstruction with mismeasured γ energy and of hadron as photon misidentification

Control regions

Control Region	Modifications
W($e\nu$) + jets	e selected, no γ found. e used in place of signal γ to build kinematic variables.
Z($\mu^+\mu^-$) + γ	Two μ selected with a γ. The $\Delta\phi_{\text{jet},p_T^{\text{miss}}}$ requirement not considered. μ added to $\vec{p}_T^{\text{miss}}$ to emulate the signal topology.
W($\mu\nu$) + γ	μ selected with a γ. μ added to $\vec{p}_T^{\text{miss}}$ to emulate the signal topology.
γ + jets	$\Delta\phi_{\text{jet},p_T^{\text{miss}}} < 0.5$.

Table: Control Regions

Event Selection

$$m_T = \sqrt{2p_T^{\text{miss}} p_T^{\gamma} \left[1 - \cos\left(\Delta\phi(\vec{p}_T^{\text{miss}}, \vec{p}_T^{\gamma})\right)\right]}$$

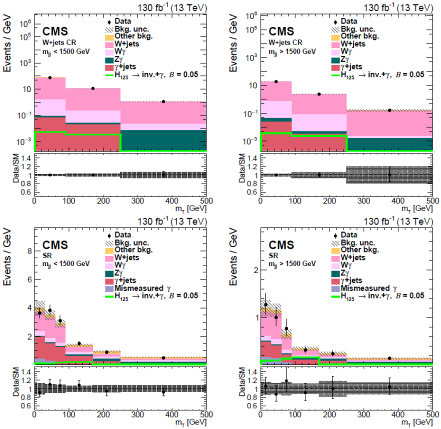
Region	Bins	m_T range (GeV)
SR, $m_{jj} < 1500$ GeV	6	[0, 30, 60, 90, 170, 250, ∞]
SR, $m_{jj} \geq 1500$ GeV	6	[0, 30, 60, 90, 170, 250, ∞]
$W(e\nu) +$ jets CR, $m_{jj} < 1500$ GeV	3	[0, 90, 250, ∞]
$W(e\nu) +$ jets CR, $m_{jj} \geq 1500$ GeV	3	[0, 90, 250, ∞]
$Z(\mu^+\mu^-) + \gamma$ CR, $m_{jj} < 1500$ GeV	1	[0, ∞]
$Z(\mu^+\mu^-) + \gamma$ CR, $m_{jj} \geq 1500$ GeV	1	[0, ∞]
$W(\mu\nu) + \gamma$ CR, $m_{jj} < 1500$ GeV	1	[0, ∞]
$W(\mu\nu) + \gamma$ CR, $m_{jj} \geq 1500$ GeV	1	[0, ∞]
$\gamma +$ jets CR, $m_{jj} < 1500$ GeV	1	[0, ∞]
$\gamma +$ jets CR, $m_{jj} \geq 1500$ GeV	1	[0, ∞]

Uncertainties

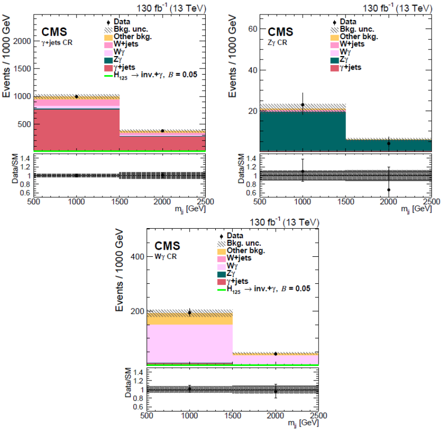
Source of uncertainty	Impact for scenario with signal (fb)	Impact for scenario without signal (fb)
Integrated luminosity	3.3	0.6
Lepton and trigger measurements	17	7.7
Jet energy scale and resolution	24	19
Pileup	9.7	8.5
Background normalization	25	18
Theory	6.0	3.0
Simulation sample size	36	36
Total systematic uncertainty	54	46
Statistical uncertainty	58	48
Total uncertainty	79	66

- With signal: $m_H = 125 GeV, \sigma = 0.05\sigma_{SM}$
- No signal: $\sigma = 0$

Results



(a) 0-500GeV

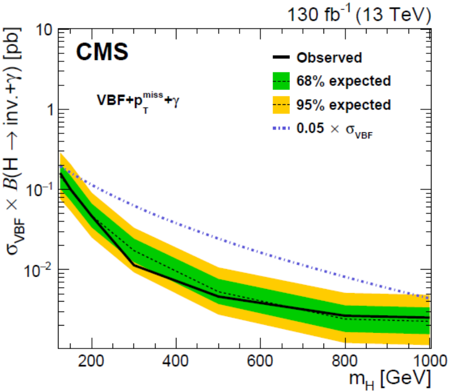


(b) 500-2500GeV

Results

	SR	$W(e\nu)+\text{jets}$ CR	$Z(\mu^+\mu^-)+\gamma$ CR	$W(\mu\nu)+\gamma$ CR	$\gamma+\text{jets}$ CR
$W+\text{jets}$	250 ± 17	10500 ± 100	—	—	180 ± 37
$W(\ell\nu)+\gamma$	98 ± 11	240 ± 36	—	190 ± 18	76 ± 8
$Z+\gamma$	98 ± 18	6.8 ± 1.5	25 ± 4	1.7 ± 0.4	46 ± 8
$\gamma+\text{jets}$	230 ± 22	12 ± 4	—	9.5 ± 2.3	1400 ± 58
Mism. γ	34 ± 15	—	—	—	—
$Z+\text{jets}$	41 ± 6	100 ± 10	—	6.3 ± 0.6	26 ± 3
Nonprompt	20 ± 4	1.1 ± 0.2	1.2 ± 0.2	4.4 ± 0.9	62 ± 13
Top quark	18 ± 5	16 ± 4	0.3 ± 0.1	30 ± 7	22 ± 5
VV	6.9 ± 1.0	200 ± 9	0.3 ± 0.3	4.4 ± 0.9	5.7 ± 0.5
VVV	3.1 ± 0.5	7.6 ± 1.0	—	8.1 ± 1.1	3.6 ± 0.5
Total background	800 ± 25	11100 ± 100	27 ± 4	250 ± 16	1800 ± 43
Data	801	11091	27	253	1830
$qqH_{125}(\gamma\gamma_D)$	50.5 ± 7.4	1.7 ± 0.3	—	—	4.5 ± 0.4
$ggH_{125}(\gamma\gamma_D)$	30.6 ± 14.3	1.2 ± 0.6	—	—	6.9 ± 2.9

Results



- Limits σ_{VBF} up to $160fb(2fb)$ for $m_H = 125GeV(1000GeV)$
- Upper for limit for branching ratio of 3.5% for $m_H = 125GeV$

The End