

# Searching for dark photons via Higgs production at the HL-LHC and HE-LHC

Matti Heikinheimo

Helsinki Institute of Physics

Phys. Rev. D93, 093011 [1603.01377 [hep-ph]], Sanjoy Biswas, Emidio Gabrielli,  
M. H., Barbara Mele

May 22, 2018

# Dark Photons

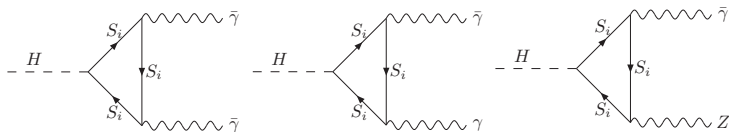
- Dark photons appear in several beyond the Standard Model physics scenarios, where a new  $U(1)$  gauge group is added to the SM.
- Massive dark photons can be dark matter candidates, while massless dark photons can appear in models of self-interacting dark matter. (Cusp-vs-core, missing satellites...)
- Unbroken  $U(1)$  results in a massless dark photon. Motivated e.g. in a model for radiative origin of the SM Yukawa couplings. Gabrielli and Raidal: [arXiv:1310.1090 [hep-ph]]

# Coupling to the SM

- Dark photons can couple to the SM particles via the kinetic mixing operator  $F'_{\mu\nu} F^{\mu\nu}$ , or via loop-induced dimension 5 operators.
- The kinetic mixing of massless Dark Photons can be transformed away by field redefinitions. Generally this results in millicharges for the particles initially charged under the hidden  $U(1)$ .
- If the tree-level kinetic mixing is set to zero, the possible loop-induced mixing vanishes on-shell.
- If there are particles charged under both the hidden and the SM  $U(1)$ , there will be loop-induced couplings between the dark photon and the SM.

# Coupling to the SM

Couplings to the Higgs can be generated via messenger particles charged under  $U(1)' \times U(1)$ .



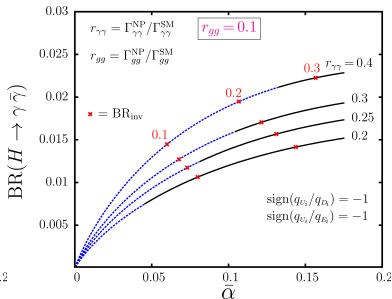
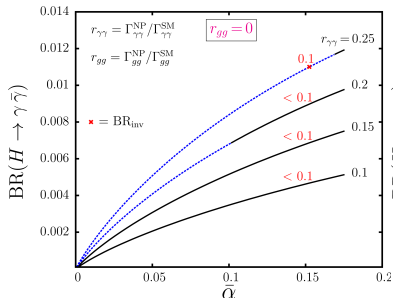
Similar diagrams will also contribute to the  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow ZZ$  decay widths.

Effective Lagrangian:

$$\mathcal{L}_{\text{DPH}} = \frac{\alpha}{\pi} \left( \frac{C_{\gamma\bar{\gamma}}}{v} \gamma^{\mu\nu} \bar{\gamma}_{\mu\nu} H + \frac{C_{Z\bar{\gamma}}}{v} Z^{\mu\nu} \bar{\gamma}_{\mu\nu} H + \frac{C_{\bar{\gamma}\gamma}}{v} \bar{\gamma}^{\mu\nu} \bar{\gamma}_{\mu\nu} H \right)$$

# $H\gamma\bar{\gamma}$ -Coupling

- For this study, the relevant effective coupling is the  $C_{\gamma\bar{\gamma}}$ .
- Equivalently, we can express the expected signal strength in terms of the exotic branching ratio  $H \rightarrow \gamma\bar{\gamma}$
- In new physics models, (e.g. [1310.1090]), values of the branching ratio up to a few percent can be expected. (See also arxiv:1503.05836).



# $H\gamma\bar{\gamma}$ Search; Gluon Fusion

The Higgs decay into a SM photon and a dark photon results in a signal of one photon and missing  $E_T$ . In [1603.01377] we proposed the event selection criteria:

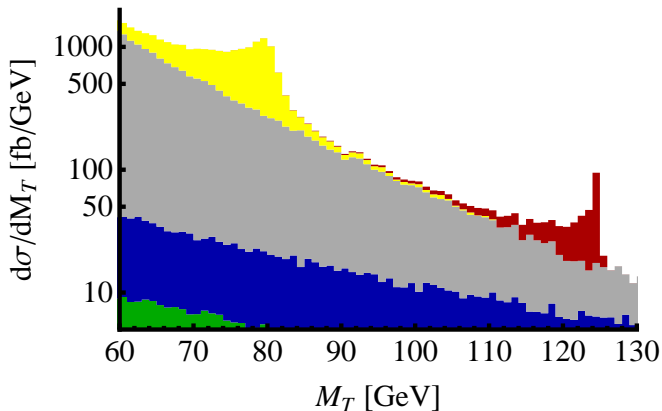
- One isolated ( $\Delta R > 0.4$ ) photon with  $p_T^\gamma > 50$  GeV,  $|\eta^\gamma| < 1.44$ .
- Missing transverse momentum  $\cancel{E}_T > 50$  GeV.
- Transverse mass within  $100 \text{ GeV} < M_T^{\gamma\bar{\gamma}} < 130 \text{ GeV}$ ,  
where  $M_T^{\gamma\bar{\gamma}} = \sqrt{2p_T^\gamma \cancel{E}_T (1 - \cos(\Delta\phi^{\gamma\cancel{E}_T})}$ .
- No isolated leptons.

# $H\gamma\bar{\gamma}$ Search; SM backgrounds

We identify the following SM backgrounds:

- $\gamma j$ , where missing energy is due to neutrinos following heavy-flavor decays in the jet and/or mismeasurement of jet energy.
- $jj$ , where in addition to the above, a jet in the central region is misidentified as a photon. (We assume 0.1% mis-tag rate.)
- $W \rightarrow e\nu$ , where the electron is misidentified as a photon. (We assume 0.5% mis-tag rate.)
- $W(\rightarrow \ell\nu) + \gamma$ , where the charged lepton is outside acceptance.
- $Z(\rightarrow \nu\nu) + \gamma$ .

# $H\gamma\bar{\gamma}$ Search; $M_T^{\gamma\bar{\gamma}}$ distribution (parton level, $\sqrt{s} = 8$ TeV)



$\gamma j$ : grey,  $\gamma Z$ : blue,  $W$ : yellow, signal ( $BR(H \rightarrow \gamma\bar{\gamma}) = 5\%$ ): red.



# $H\gamma\bar{\gamma}$ Search; SM backgrounds

- We simulated the electroweak backgrounds at parton level with MadGraph.
- For the  $\gamma j$  and  $jj$  backgrounds we used MadGraph and Pythia for initial- and final state radiation, hadronization and detector resolution effects.
- The  $\gamma j$  and  $jj$  background samples (for 8 TeV) were matched to the CMS analysis (Phys. Lett. B **753** (2016) 363, arXiv:1507.00359), resulting in rescaling factors of  $k = 0.11$  for the  $\gamma j$  background and  $k = 0.058$  for the  $jj$  background.
- In our analysis [1603.01377] we applied the same rescaling factors for these backgrounds at 14 TeV.

# $H\gamma\bar{\gamma}$ Search; Signal and background rates

Repeating our analysis procedure from [1603.01377] for 27 TeV, we obtain the following event rates (in fb):

	$\sigma \times A$ [14 TeV]	$\sigma \times A$ [27 TeV]
$H \rightarrow \gamma\bar{\gamma}$ ( $\text{BR}_{\gamma\bar{\gamma}} = 1\%$ )	101	236
$\gamma j$	202	–
$jj \rightarrow \gamma j$	432	4738
$e \rightarrow \gamma$	93	169
$W(\rightarrow l\nu)\gamma$	123	239
$Z(\rightarrow \nu\nu)\gamma$	283	509
total background	1133	5655

# $H\gamma\bar{\gamma}$ Search; Signal and background rates

In attempt to mitigate the dijet background that grows rapidly with collision energy, we imposed a jet veto within  $|\eta^j| < 4.5$ , yielding event rates [fb]:

	$\sigma \times A$ [14 TeV]	$\sigma \times A$ [27 TeV]
$H \rightarrow \gamma\bar{\gamma}$ (BR $_{\gamma\bar{\gamma}} = 1\%$ )	66.6	139.1
$\gamma j$	—	—
$jj \rightarrow \gamma j$	886	31235
$e \rightarrow \gamma$	93	169
$W(\rightarrow l\nu)\gamma$	123	239
$Z(\rightarrow \nu\nu)\gamma$	283	509
total background	1385	32153

# $H\gamma\bar{\gamma}$ Search; reach

Based on the two event selection criteria discussed above (the event selection adapted from the CMS analysis [1507.00359], and the jet veto), we estimate the reach for the  $H \rightarrow \gamma\bar{\gamma}$  branching ratio (in %) in the HL-LHC and HE-LHC:

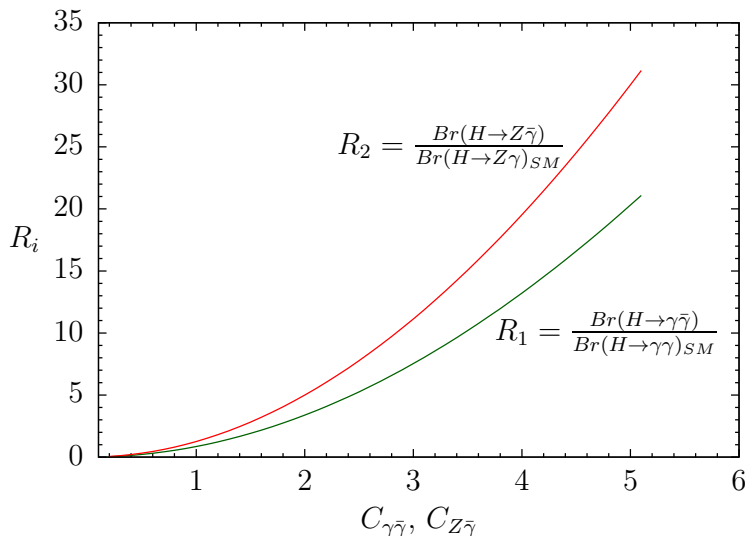
int. luminosity	3 ab <sup>-1</sup> @14 TeV		15 ab <sup>-1</sup> @27 TeV	
	2 $\sigma$	5 $\sigma$	2 $\sigma$	5 $\sigma$
CMS inspired	0.012	0.030	0.0052	0.013
jet veto in $ \eta^j  < 4.5$	0.020	0.051	0.021	0.053

These are our initial attempts to estimate the reach: A full detector simulation is required to better understand the QCD background.

# Conclusions

- The exotic decay mode of the Higgs  $H \rightarrow \gamma\bar{\gamma}$  results in a final state of one photon and missing energy.
- The main background is the QCD multijet where one jet is misidentified as a photon.
- The multijet background grows rapidly with collision energy. Better modelling and reduction of this background at HE-LHC is crucial.

# Backup: BR versus eff. theory couplings



# Backup: Photon $p_T$ spectrum

