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

Matti Heikinheimo

Helsinki Institute of Physics

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Dark Photons

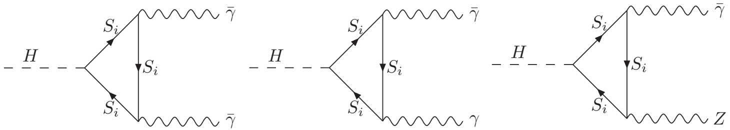
- Dark photons appear in several beyond the Standard Model physics scenarios, where a new $U(1)$ gauge group is added to the SM.
- Massive dark photons can be dark matter candidates, while massless dark photons can appear in models of self-interacting dark matter. (Cusp-vs-core, missing satellites...)
- 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 $U(1)' \times U(1)$.

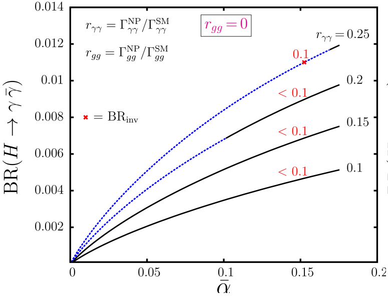


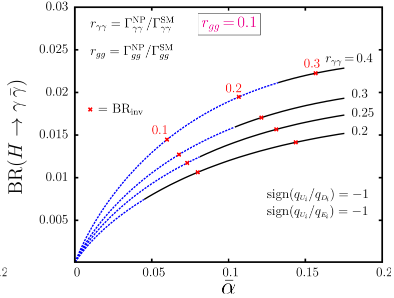
Similar diagrams will also contribute to the $H \to \gamma\gamma,\ H \to ZZ$ decay widths.
Effective Lagrangian:

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

$H\gamma\bar{\gamma}$-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 $H \to \gamma\bar{\gamma}$
- 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:

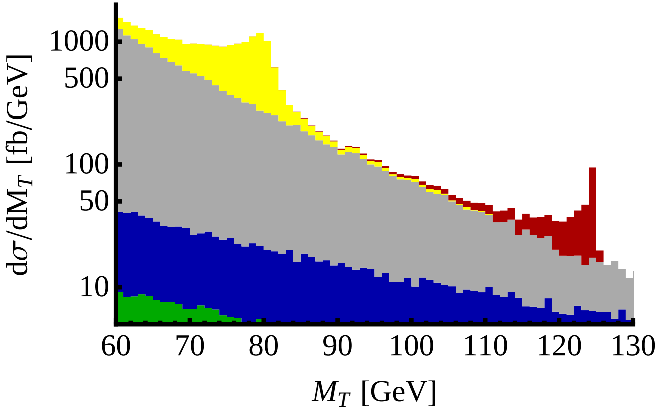
- One isolated ($\Delta R > 0.4$) photon with $p_T^\gamma > 50$ GeV, $|\eta^\gamma| < 1.44$.
- Missing transverse momentum $\not{E}_T > 50$ GeV.
- Transverse mass within 100 GeV $< M_T^{\gamma\bar{\gamma}} <$ 130 GeV, where $M_T^{\gamma\bar{\gamma}} = \sqrt{2p_T^\gamma \not{E}_T(1 - \cos(\Delta\phi^{\gamma\not{E}_T})}$.
- No isolated leptons.

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

We identify the following SM backgrounds:

- γj, 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.)
- $W \to e\nu$, where the electron is misidentified as a photon. (We assume 0.5% mis-tag rate.)
- $W(\to \ell\nu) + \gamma$, where the charged lepton is outside acceptence.
- $Z(\to \nu\nu) + \gamma$.

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



γj: grey, γZ: blue, W: yellow, signal ($BR(H \to \gamma\bar{\gamma}) = 5\%$): red.

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

- We simulated the electroweak backgrounds at parton level with MadGraph.
- For the γj and jj backgrounds we used MadGraph and Pythia for initial- and final state radiation, hadronization and detector resolution effects.
- The γj 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 γj 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]
$H \to \gamma\bar{\gamma}$ ($\mathrm{BR}_{\gamma\bar{\gamma}} = 1\%$)	101	236
γj	202	–
$jj \to \gamma j$	432	4738
$e \to \gamma$	93	169
$W(\to \ell\nu)\gamma$	123	239
$Z(\to \nu\nu)\gamma$	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]
$H \to \gamma\bar{\gamma}$ $(\mathrm{BR}_{\gamma\bar{\gamma}} = 1\%)$	66.6	139.1
γj	–	–
$jj \to \gamma j$	886	31235
$e \to \gamma$	93	169
$W(\to \ell\nu)\gamma$	123	239
$Z(\to \nu\nu)\gamma$	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 $H \to \gamma\bar{\gamma}$ branching ratio (in %) in the HL-LHC and HE-LHC:

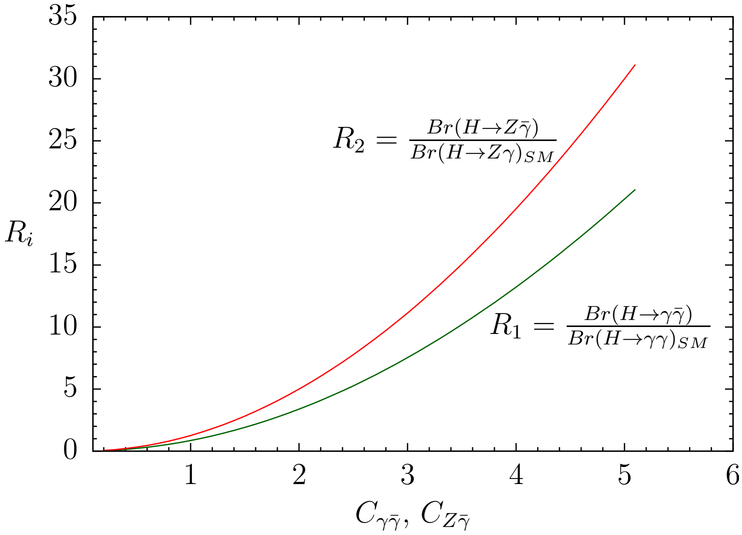
int. luminosity	3 ab^{-1}@14 TeV		15 ab^{-1}@27 TeV	
significance	2σ	5σ	2σ	5σ
CMS inspired	0.012	0.030	0.0052	0.013
jet veto in $\lvert\eta^j\rvert < 4.5$	0.020	0.051	0.021	0.053

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 $H \to \gamma\bar{\gamma}$ 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