Probing Higgs boson couplings in H+Photon production @ the LHC

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(arXiv:1702.05753)

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Outline

- Motivations
- SM EFT
- Higgs + photon production @ the LHC
- Analysis strategy and obtained limits
- Summary

Motivations

- After the discovery of Higgs → SM : a complete and successful framework.
- SM shortcomings → construct new models beyond the SM.
- New Models → modifications of the SM parameters: Higgs couplings.
- Strong motivation → precise measurements of the Higgs couplings.
- So far no significant deviation from SM expectations.
- The scale of new physics is well separated from the electroweak scale.

Effective Field Theory Approach

- There are **2 different approaches**, depend on new physics energy scale :

1. *The energy scale of new physics is **accessible** in the experiments,* $\Lambda \leq E_{\text{exp}}$
2. *The new degrees of freedom are **heavier** than our energy scale in the experiments.* $\Lambda >> E_{\text{exp}}$

Look for BSM

New Particles **New Interactions**

Dimensionless Coefficients

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{n=1}^{\infty} \frac{1}{\Lambda^n} \sum_{i=1} C_i^{(n)} \mathcal{O}_i^{(n)}$$

Higher order Operator

4+n

New Physics Scale

SILH Basis

$$\boxed{L_{eff} = L_{\rm SM} + \sum_i \frac{c_i O_i}{\Lambda^2},}$$

$$\begin{aligned}
\mathcal{L}_{\rm SILH} = &\frac{g_s^2\ \bar{c}_g}{m_W^2}\Phi^\dagger\Phi G^a_{\mu\nu}G_a^{\mu\nu} + \frac{g'^2\ \bar{c}_\gamma}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{ig'\ \bar{c}_B}{2m_W^2}\big[\Phi^\dagger \overleftrightarrow{D}^\mu \Phi\big]\partial^\nu B_{\mu\nu} \\
&+ \frac{ig\ \bar{c}_W}{2m_W^2}\big[\Phi^\dagger \sigma_k \overleftrightarrow{D}^\mu \Phi\big] D^\nu W^k_{\mu\nu} + \frac{ig\ \bar{c}_{HW}}{m_W^2}\big[D^\mu\Phi^\dagger\sigma_k D^\nu\Phi\big]W^k_{\mu\nu} - \frac{\bar{c}_6\lambda}{v^2}\big[\Phi^\dagger\Phi\big]^3 \\
&+ \frac{ig'\ \bar{c}_{HB}}{m_W^2}\big[D^\mu\Phi^\dagger D^\nu\Phi\big]B_{\mu\nu} + \frac{\bar{c}_H}{2v^2}\partial^\mu\big[\Phi^\dagger\Phi\big]\partial_\mu\big[\Phi^\dagger\Phi\big] + \frac{\bar{c}_T}{2v^2}\big[\Phi^\dagger \overleftrightarrow{D}^\mu \Phi\big]\big[\Phi^\dagger \overleftrightarrow{D}_\mu \Phi\big] \\
&- \left[\frac{\bar{c}_l}{v^2} y_\ell\ \Phi^\dagger\Phi\ \Phi\bar{L}_L e_R + \frac{\bar{c}_u}{v^2} y_u \Phi^\dagger\Phi\ \Phi^\dagger\cdot\bar{Q}_L u_R + \frac{\bar{c}_d}{v^2} y_d \Phi^\dagger\Phi\ \Phi\bar{Q}_L d_R + \text{h.c.}\right],
\end{aligned}$$

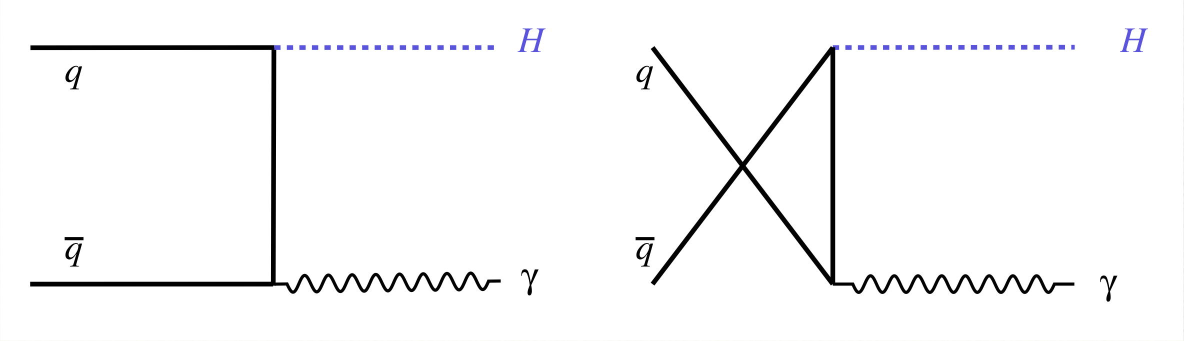
The per-mille bounds on **T and S parameters** strongly constrain:

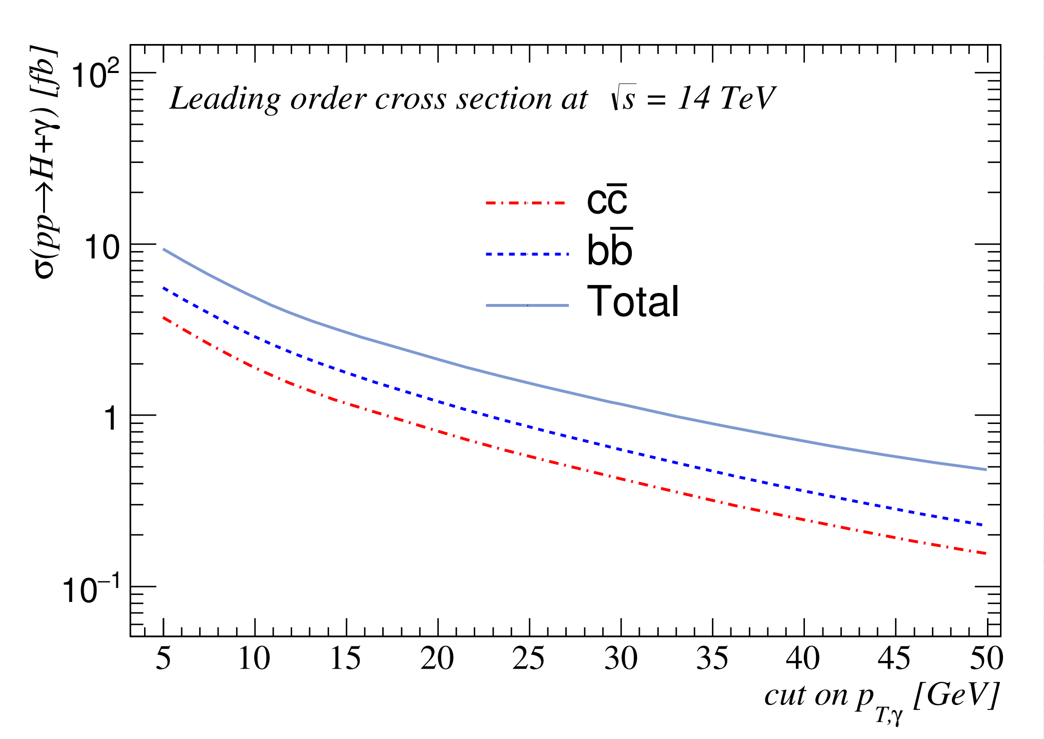
$$\bar{c}_T \ \text{ and } \ \bar{c}_B + \bar{c}_W$$

G. F. Giudice, et al. JHEP 0706:045

R. Contino, et al. , JHEP 1307 (2013) 035

Higgs + Photon Channel in the SM





Yukawa couplings

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{\alpha_{em} Q_q^2 \lambda_q^2}{12} \times \left[\frac{\hat{t}\hat{u}(1+r_H^2) + 8r_q^2(\hat{t}+\hat{u})^2 - 2r_q(4\hat{t}\hat{u} + r_H(\hat{t}+\hat{u})^2)}{(1-4r_q)\times \hat{t}^2\hat{u}^2}\right]$$

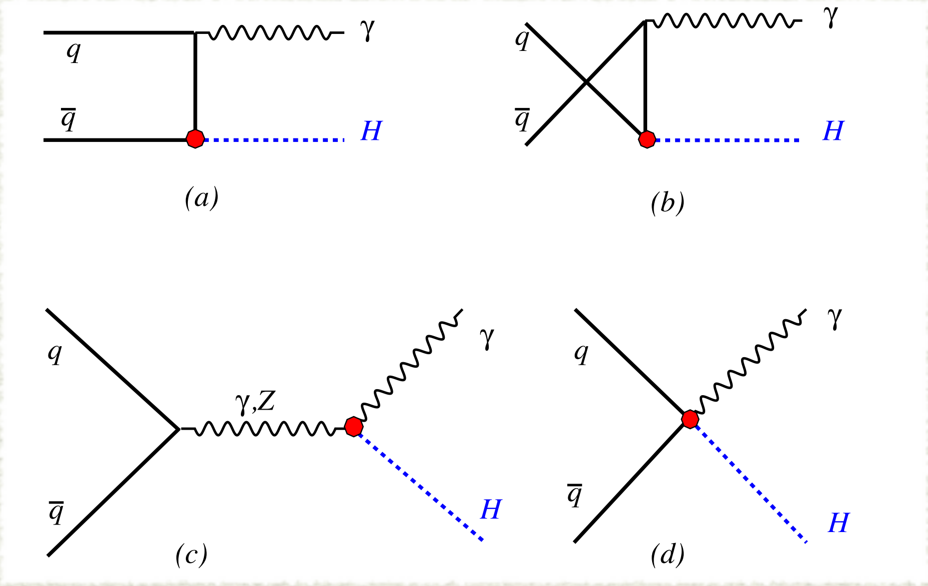
- The main source come from $c\bar{c}$ and $b\bar{b}$ annihilation because of their **larger Yukawa couplings**.
- The contributions of $c\bar{c}$ and $b\bar{b}$ are **suppressed by PDF**

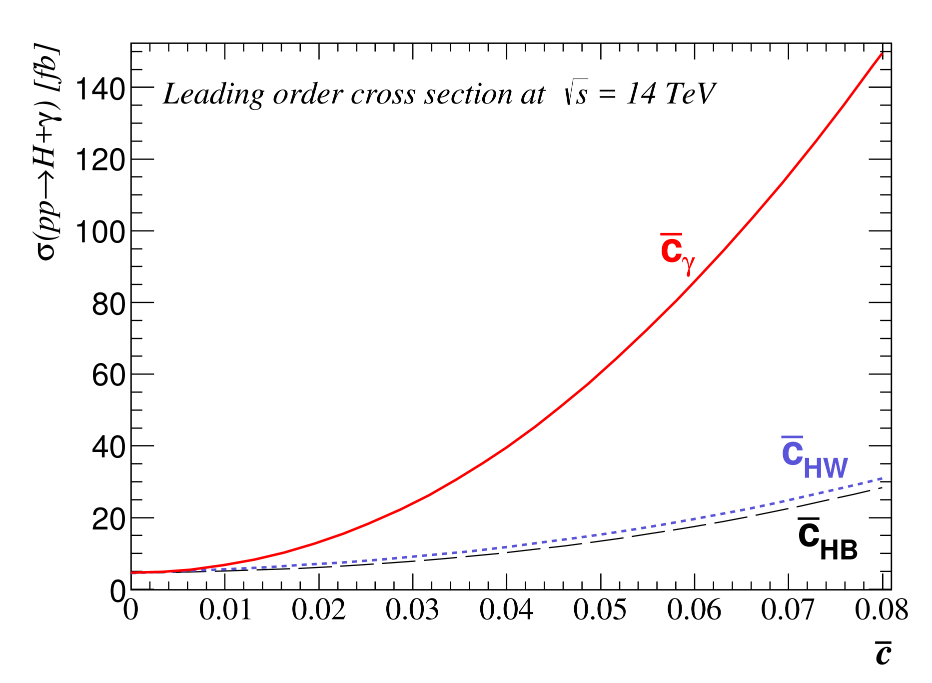
E. Gabrielli, et al. Phys. Rev. D 77, 015007

Higgs + Photon Channel in the SM-EFT

$$
\begin{aligned}
\mathcal{L} &= -\frac{1}{4} g_{h\gamma\gamma} F_{\mu\nu} F^{\mu\nu} h - \frac{1}{2} g^{(1)}_{h\gamma z} Z_{\mu\nu} F^{\mu\nu} h - g^{(2)}_{h\gamma z} Z_\nu \partial_\mu F^{\mu\nu} h \\
&- \Big(\frac{\tilde{y}_u}{\sqrt{2}} [\bar{u} P_R u] h + \frac{\tilde{y}_d}{\sqrt{2}} [\bar{d} P_R d] h \\
&+ g^{(\partial)}_{h\gamma uu} [\bar{u} \gamma^{\mu\nu} P_R u] F_{\mu\nu} h + g^{(\partial)}_{h\gamma dd} [\bar{d} \gamma^{\mu\nu} P_R d] F_{\mu\nu} h + h.c. \Big),
\end{aligned}
$$

Mass basis	Gauge basis
$g_{h\gamma\gamma}$	$a_H - \frac{8 g s_W^2}{m_W} \bar{c}_\gamma$
$g^{(1)}_{h\gamma z}$	$\frac{g s_W}{c_W m_W} (\bar{c}_{HW} - \bar{c}_{HB} + 8 s_W^2 \bar{c}_\gamma)$
$g^{(2)}_{h\gamma z}$	$\frac{g s_W}{c_W m_W} (\bar{c}_{HW} - \bar{c}_{HB} - \bar{c}_B + \bar{c}_W)$
$\tilde{y}_u$	$y_u [1 - \frac{1}{2} \bar{c}_H + \frac{3}{2} \bar{c}_u]$
$\tilde{y}_d$	$y_d [1 - \frac{1}{2} \bar{c}_H + \frac{3}{2} \bar{c}_d]$
$g^{(\partial)}_{h\gamma uu}$	$\frac{\sqrt{2} g s_W}{m_W^2} y_u [\bar{c}_{uB} + \bar{c}_{uW}]$
$g^{(\partial)}_{h\gamma dd}$	$\frac{\sqrt{2} g s_W}{m_W^2} y_d [\bar{c}_{dB} - \bar{c}_{dW}]$

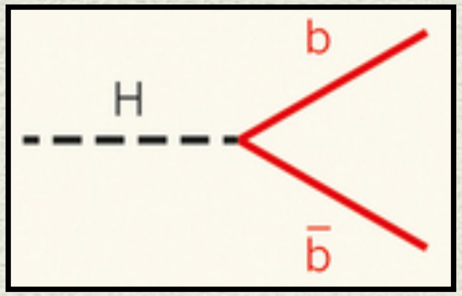




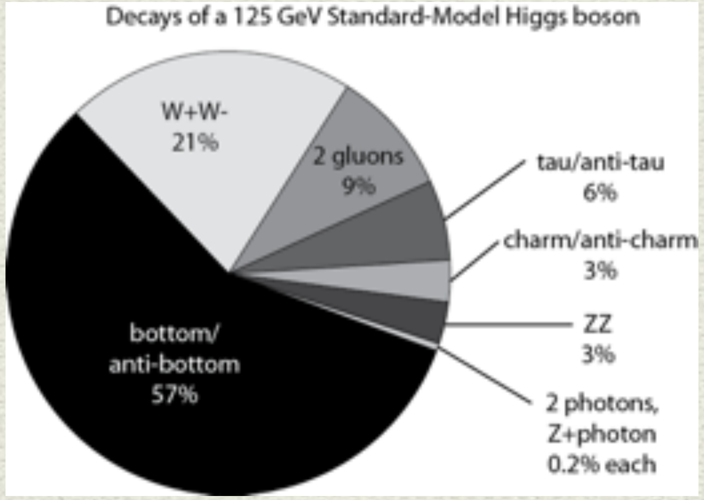
Adam Alloul, Benjamin Fuks, Veronica Sanz, JHEP 1404 (2014) 110

Event Simulation

- Final state: **one energetic photon** together with **two b-jets.**



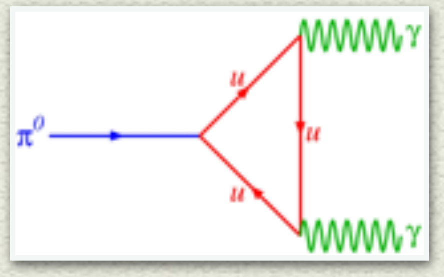
- The main sources of **background** processes: **Wγ+jets, Zγ+jets, γ+jets, top+γ+jets, $t\bar{t}$ + γ.**
- Generate events: **MadGraph5-aMC@NLO.**
- The center-of-mass energy of **14 TeV** at the LHC .



- Showering and hadronization: **PYTHIA 8.**
- Detector simulation: **Delphes.**

Multijet Background

- Multijet production where jets are **misidentified as photons**.
- In the jet fragmentation, **neutral pions** appear and decay into **two photons with a large boost**.



- The two photon showers will overlap in the ECAL and they appear as **a single photon** in the detector.
- The cross section of multijet background is around **10^3 pb.**
- The **jet fake photon probability** is at the order of **$10^{-4,-5}$** for the high p_T fake photons ($p_T > 200$ GeV).
- We **neglect this background** in this analysis.

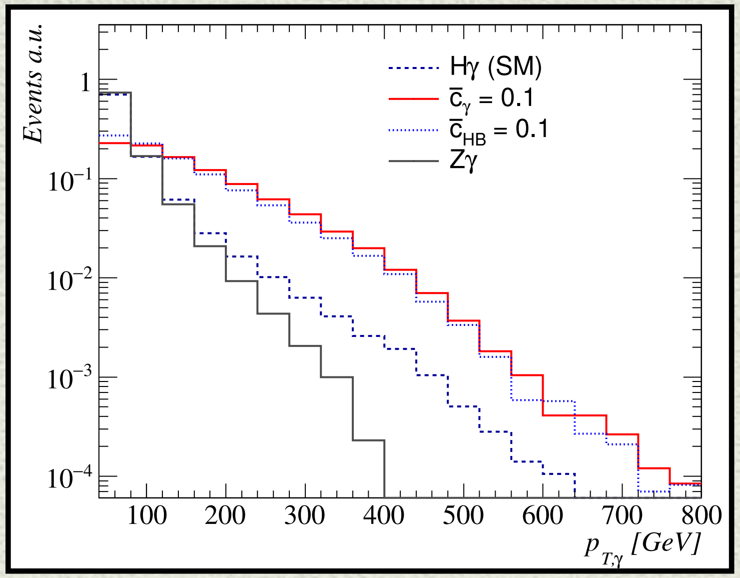
Event Selection

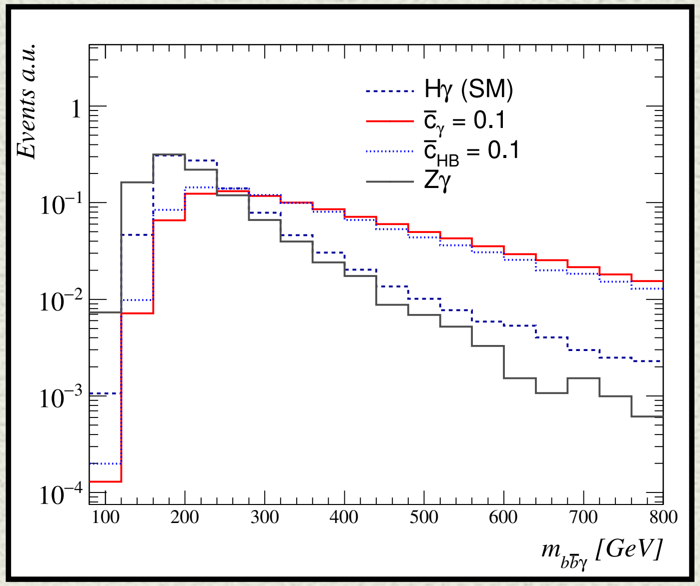
preselection cuts:

Photon: $p_T > 40$ GeV and $|\eta| < 2.5$

b-jets: $p_T > 20$ GeV and $|\eta| < 2.5$

$$\Delta R(\gamma, \mathrm{b-jets}) = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} > 0.4$$



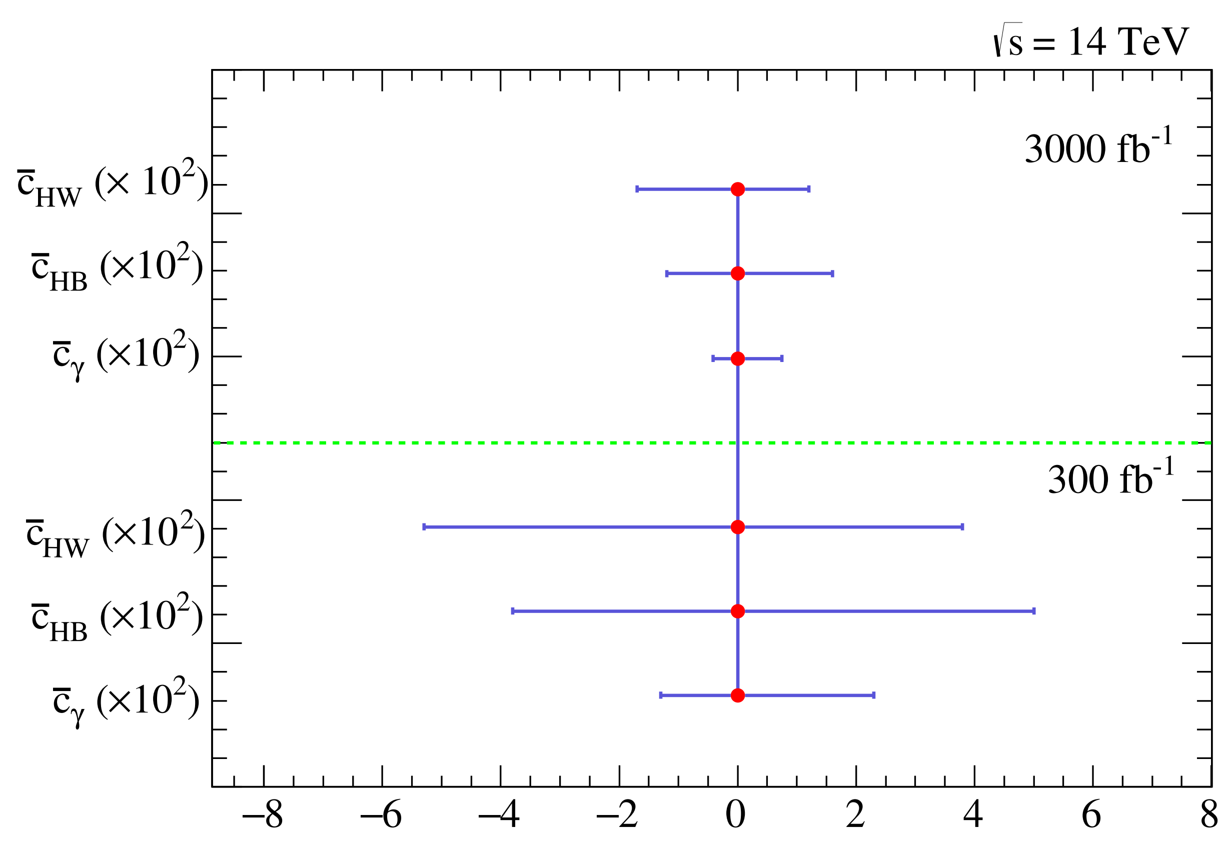


$\sqrt{s} = 14$ TeV	Signal		Background processes			
Cuts	$\bar{c}_\gamma$	$\bar{c}_{HB}$	γ+jets	$tj\gamma + t\bar{t}\gamma$	$W\gamma + Z\gamma$	SM (Hγ)
One photon and lepton veto	126.3	20.99	4.443×10^6	164.92	10286.4	0.450
Only 2 b-jets, $\Delta R_{i,j} > 0.4; i,j = \gamma, b$	19.77	3.41	13026.2	0.0312	119.57	0.080
$90 < m_{b\bar{b}} < 160$ GeV and $\Delta R(H,\gamma) > 2.4$	17.88	3.06	6397.6	0.0165	58.41	0.067
$m_{b\bar{b}\gamma} > 250$ and $p_T^\gamma > 400$ GeV	0.51	0.076	0.0	0.0	0.0	0.0003

Limits on DIM-6 coefficients

- Using of the **tail of photon transverse momentum**.
- Only one coefficient is considered in the fit at a time.
- Predicted bounds at 95% CL for the LHC with an integrated luminosity of **300 fb^{-1}** and **3000 fb^{-1}**.

Coefficient	$\mathcal{L} = 300$ fb^{-1}	$\mathcal{L} = 3000$ fb^{-1}
$\bar{c}_\gamma$	$[-0.013, 0.023]$	$[-0.0042, 0.0075]$
$\bar{c}_{HB}$	$[-0.038, 0.050]$	$[-0.012, 0.016]$
$\bar{c}_{HW}$	$[-0.053, 0.038]$	$[-0.017, 0.012]$



- Compare the results obtained in this study with the expected bounds at high luminosity LHC with **other channels**.

Different Higgs Production modes →

$$pp \to t\bar{t} + H$$

$$pp \to H + j \quad pp \to W + H$$

$$pp \to H + 2j \quad pp \to Z + H$$

$$-0.027 < \bar{c}_{HW} < 0.028, \quad -0.026 < \bar{c}_{HB} < 0.027, \quad -0.00029 < \bar{c}_{\gamma} < 0.00027$$

Englert , et al. Eur. Phys. J. C76, 393

There are possibilities for improvement of our results:

1. To use the complete next-to-leading order predictions for the process of H+γ . with the dimension-six couplings.
2. The incorporation of the H+γ+jet process into our analysis.
3. The inclusion of other decay modes of the Higgs boson such as WW, ZZ, etc.
4. Including the Higgs+γ process in a global fit with other production processes at the LHC

Summary

- According to the measurements of the LHC, so far **no considerable sign of new physics** has been found.
- To search for the possible effects of new physics one can focus on the **SM effective theory.**
- In this work, we have studied the impact of dimension-six operators of the SM effective field theory related to the **Higgs boson production in association with a photon** at the LHC.
- $H+\gamma$ production allows us to probe **$\bar{c}_{\gamma}$ and $\bar{c}_{HW}$($\bar{c}_{HB}$) down to 10^{-3} and 10^{-2}**, respectively, with an integrated luminosity of **3000 fb^{-1}**