$H+\gamma$ resonance search and interpretation with ATLAS detector

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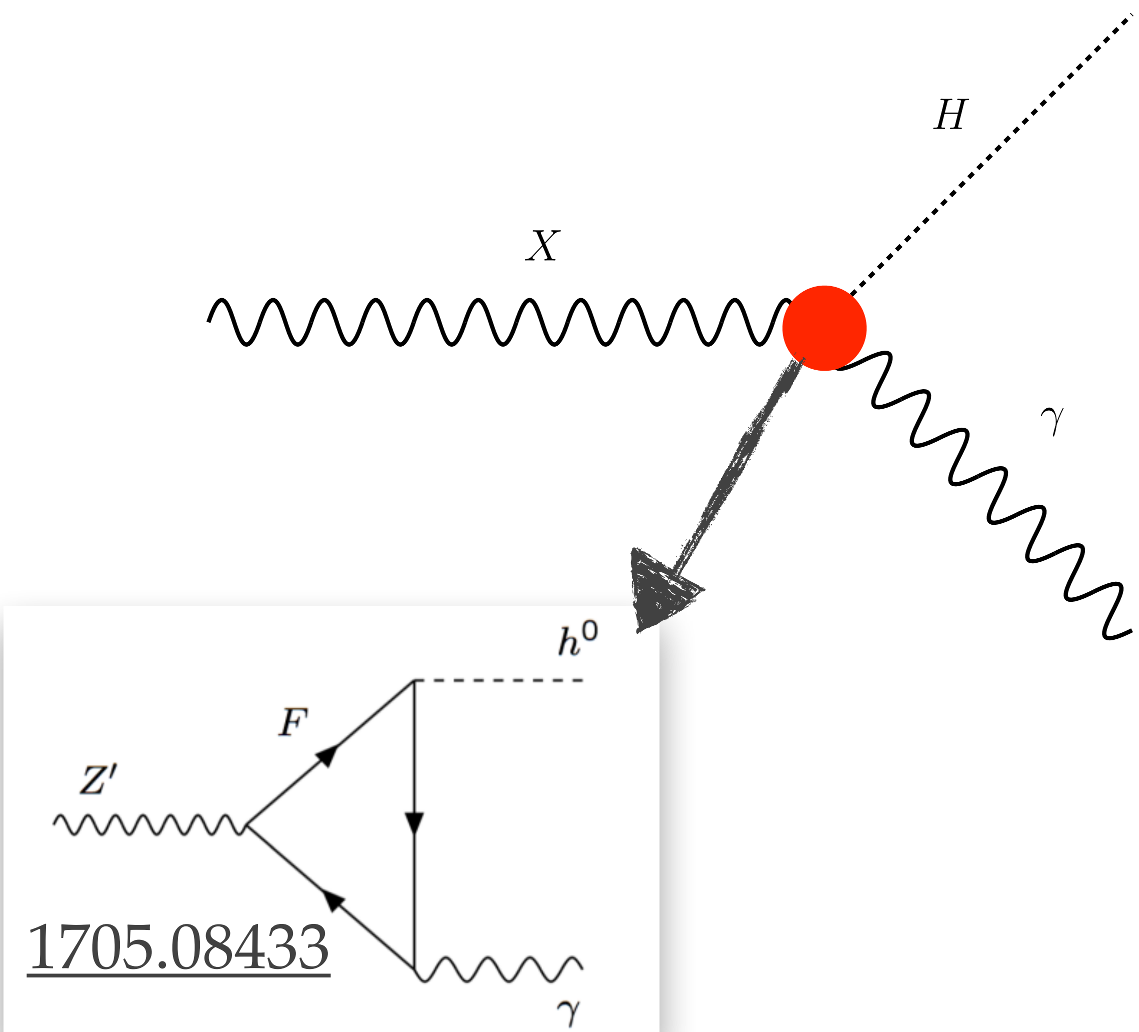
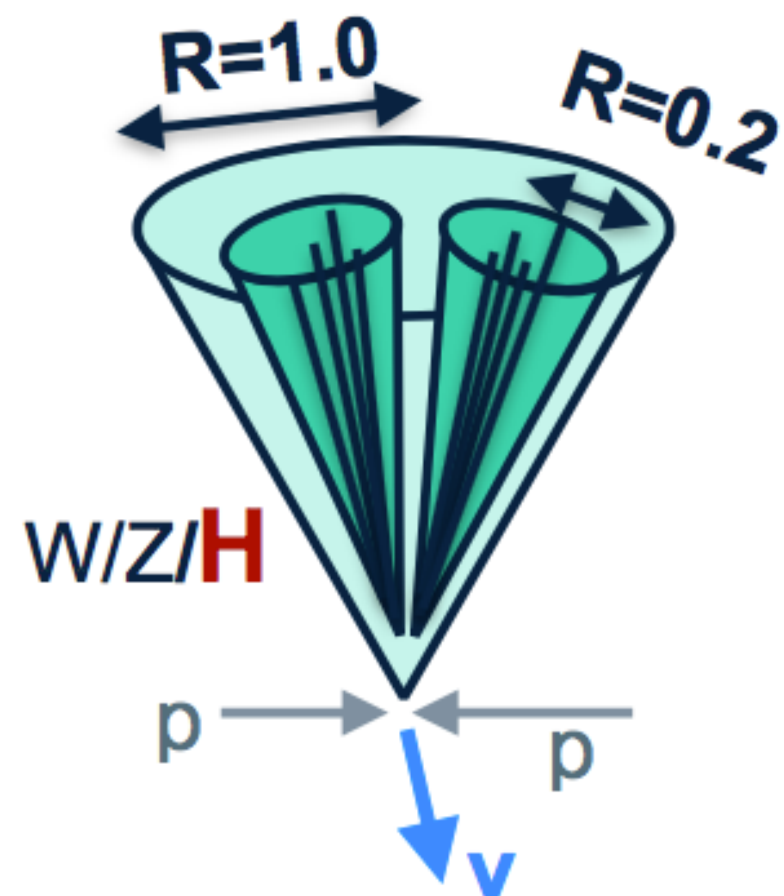
ATLAS EXPERIMENT

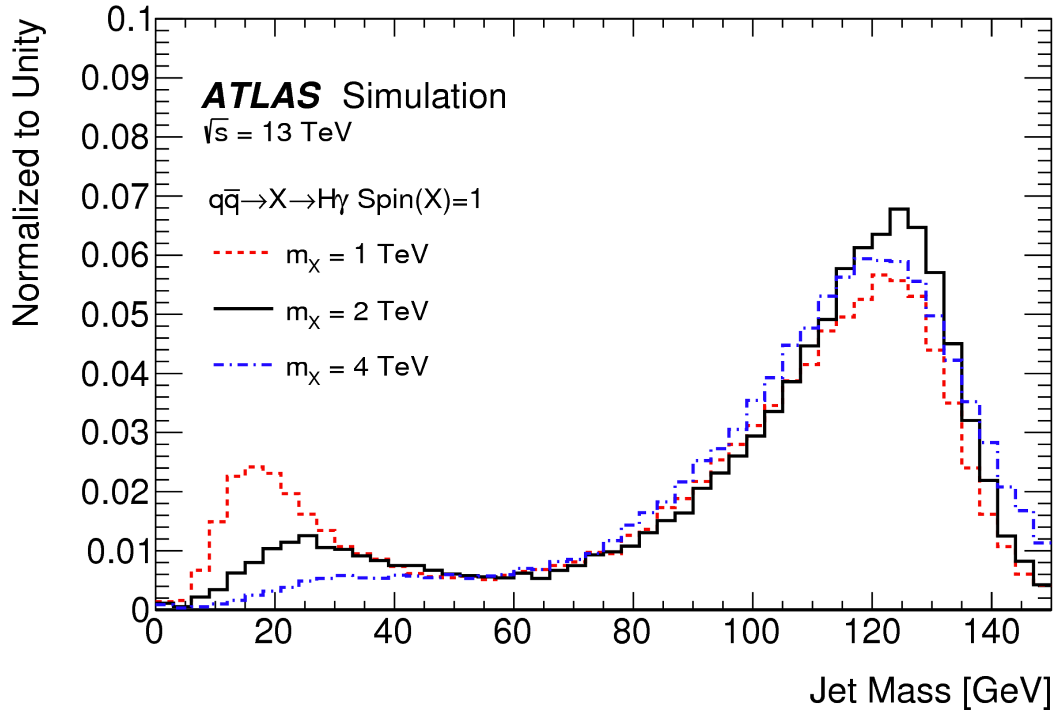
Introduction

- Search for heavy resonance decaying to H+γ:
  - Only considered bbar decay mode (~58%) and merge/boosted regime
    - Fat jet (R=1.0) and high p_T photon in final state
- Signals considered
  - Hγ is induced by Higgs effective coupling model
- Given high pT search, results can be further interpreted with new physics searches





Analysis selections



- Photon:
  - p_T>250 GeV and |η|<2.37 (without crack region [1.37, 1.52])
  - Pass tight photon ID selection and tight calorimeter only isolation
- Jet:
  - Anti-k_T large-R jet (R=1.0), Trimmed (f_{cut}<5%, R_{sub}=0.2)
  - p_T>200 GeV and |η|<2.0
  - Apply mass window cut 93-134 GeV
  - Anti-k_T R=0.2 trackjet btagging using MV2c10 algorithm @70% efficiency.

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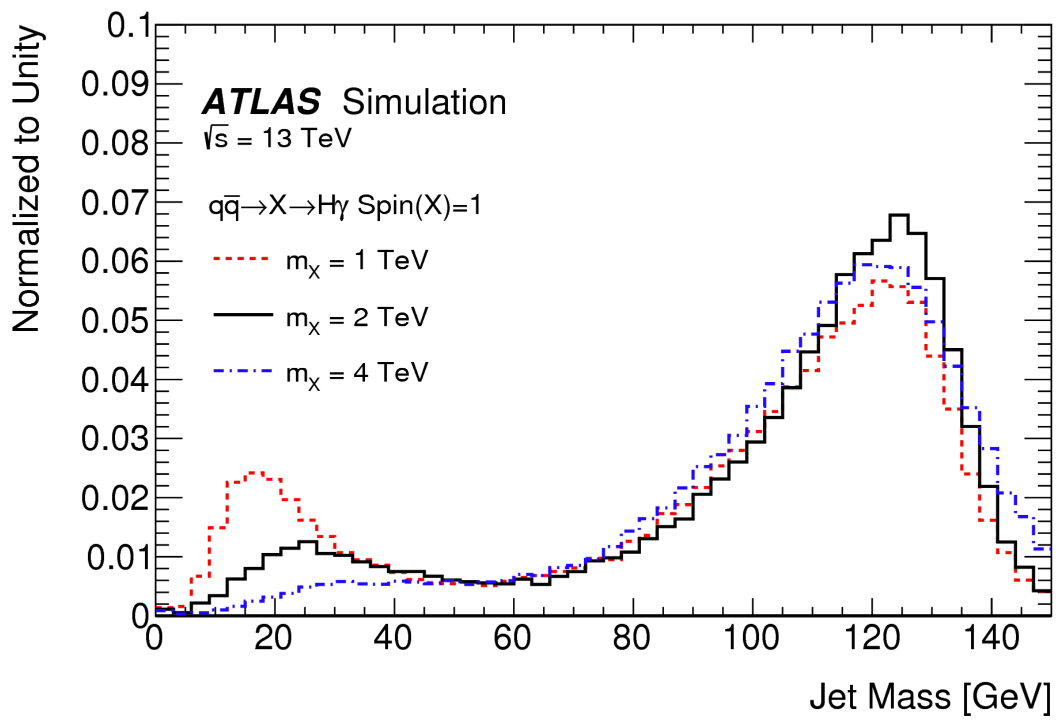

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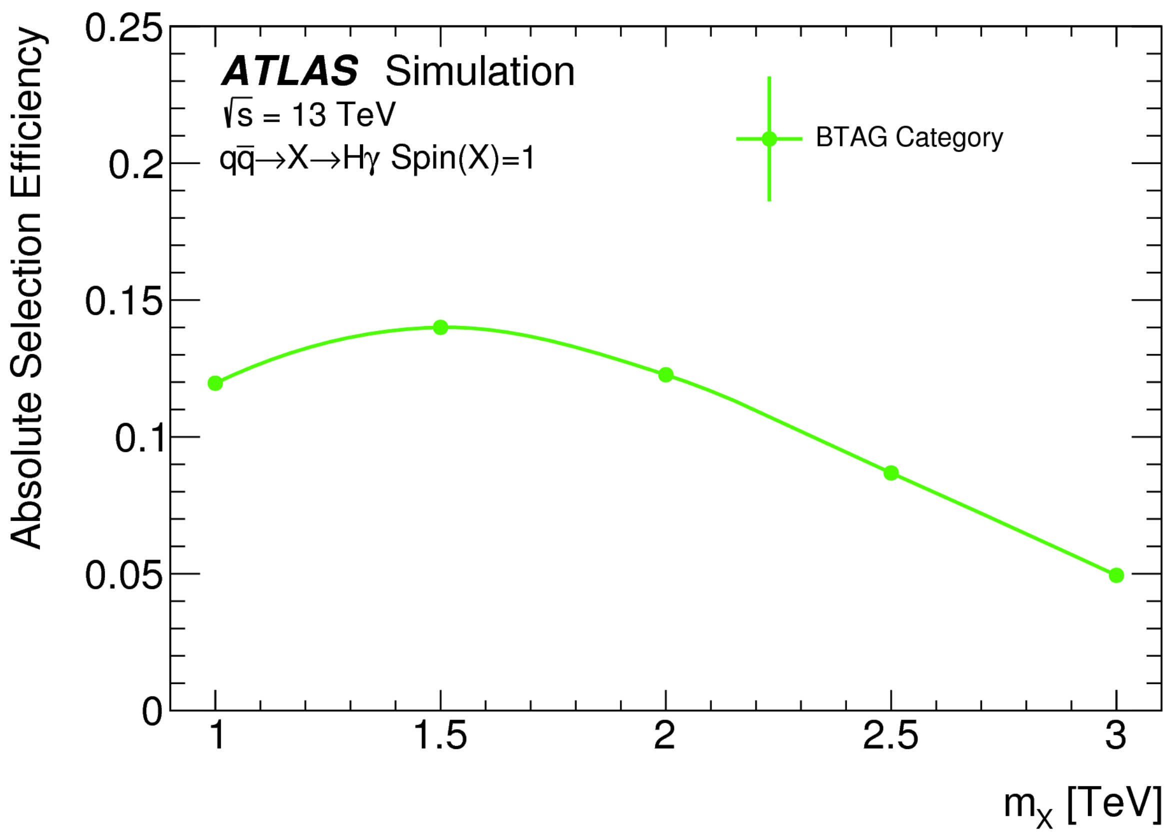
- Preselections
  - Trigger: HLT_g140_loose
  - One good PV by require at lease two associated track.
  - At least one photon in barrel calorimeter (|η| <1.37)
  - $\Delta R(J, \gamma)$>1.0.
  - Event should present at least one large R jet and at least one photon.
    - The leading p_T object will be used to form $m(J\gamma)$.
- Categorisation:
  - **btag (2btagged)**



Signal and background modelling

Signals are modelled by the *CrystalBall+Gaussian* function

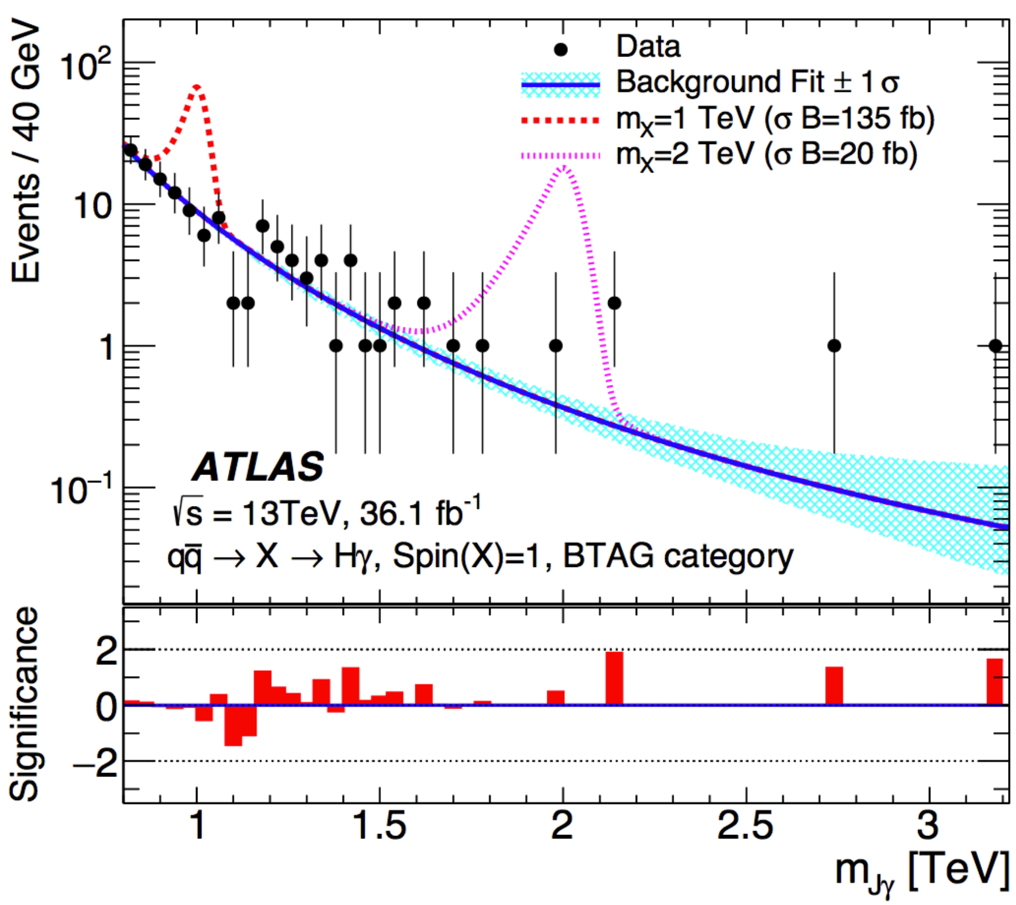
$$S(m_{J\gamma}) = f_C \cdot C(m_{J\gamma}; \mu, \sigma_C, \alpha_C, n_C) + (1 - f_C) \cdot \mathcal{G}(m_{J\gamma}; \mu, \sigma_{\mathcal{G}})$$

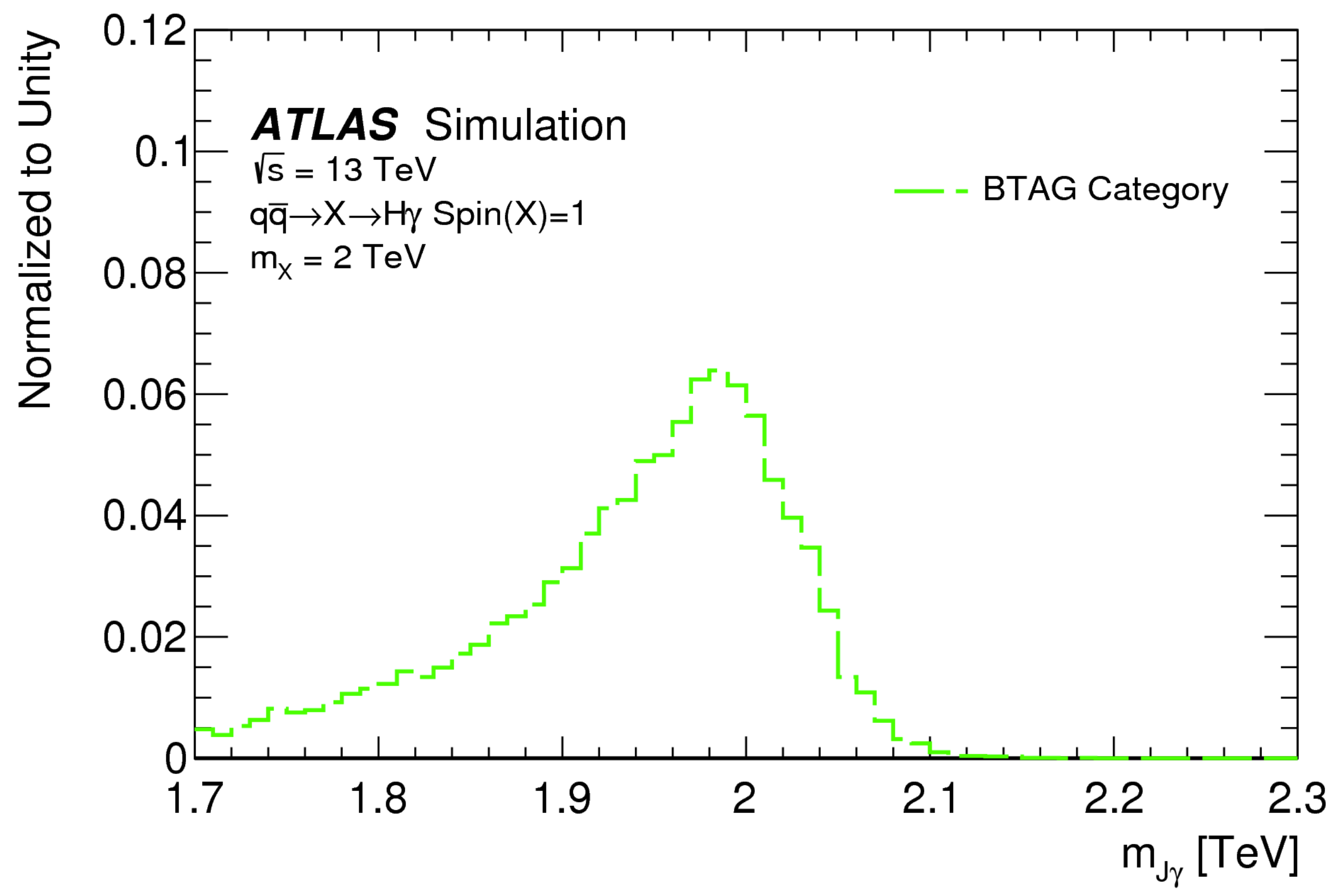
Where *CrystalBall* function can be written as:

$$C(m_{J\gamma}; \mu, \sigma_C, \alpha_C, n_C) = N_C \cdot \begin{cases} \exp\left(-\frac{(m_{J\gamma}-\mu)^2}{2\sigma_C^2}\right) & \frac{m_{J\gamma}-\mu}{\sigma_C} > -\alpha_C \\ \left(\frac{n_C}{\alpha_C}\right)^{n_C} \exp\left(-\frac{\alpha_C^2}{2}\right)\left(\frac{n_C}{\alpha_C} - \alpha_C - \frac{m_{J\gamma}-\mu}{\sigma_C}\right)^{-n_C} & \frac{m_{J\gamma}-\mu}{\sigma_C} \leq -\alpha_C \end{cases}$$

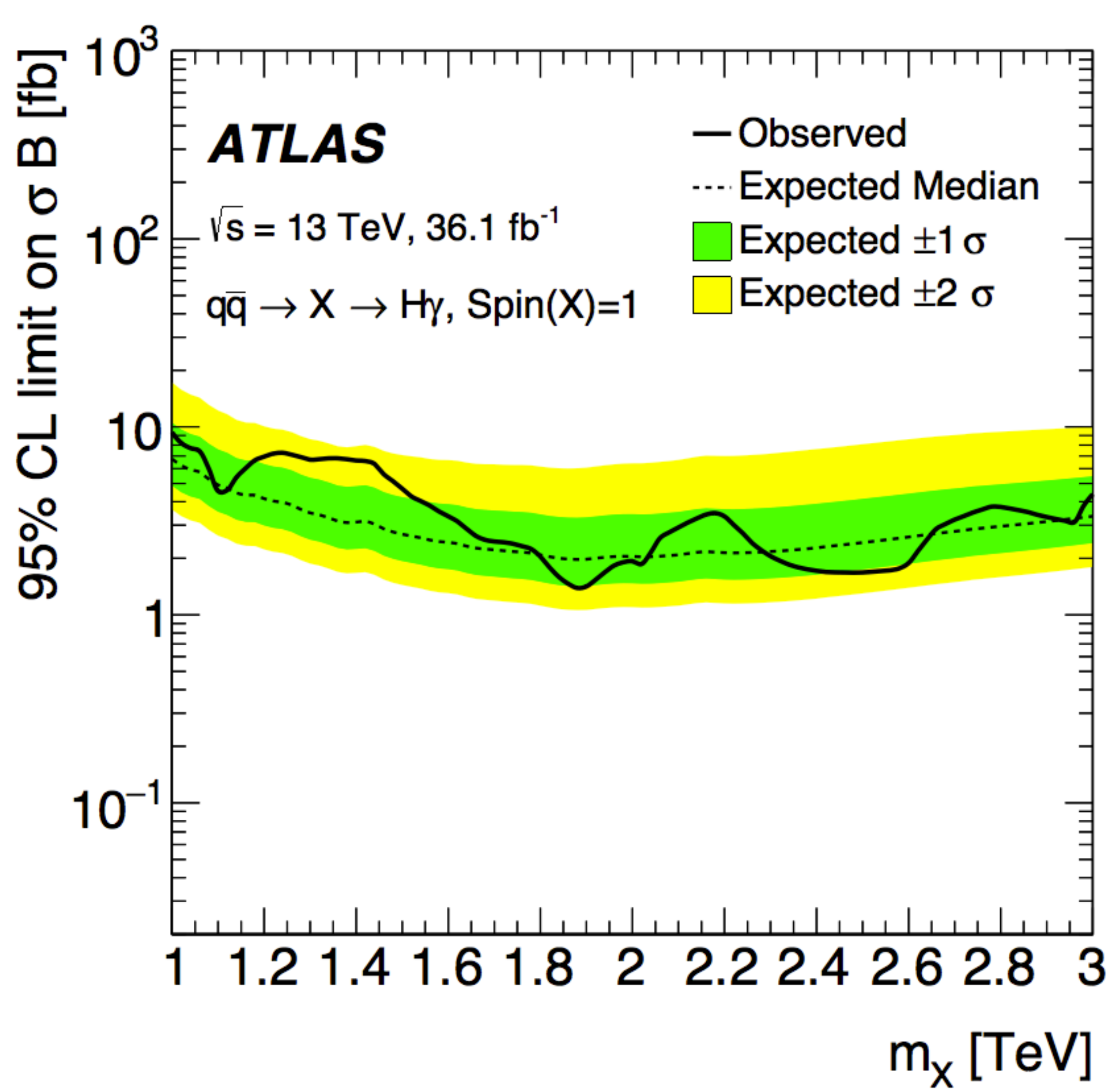
Background are modelled as:

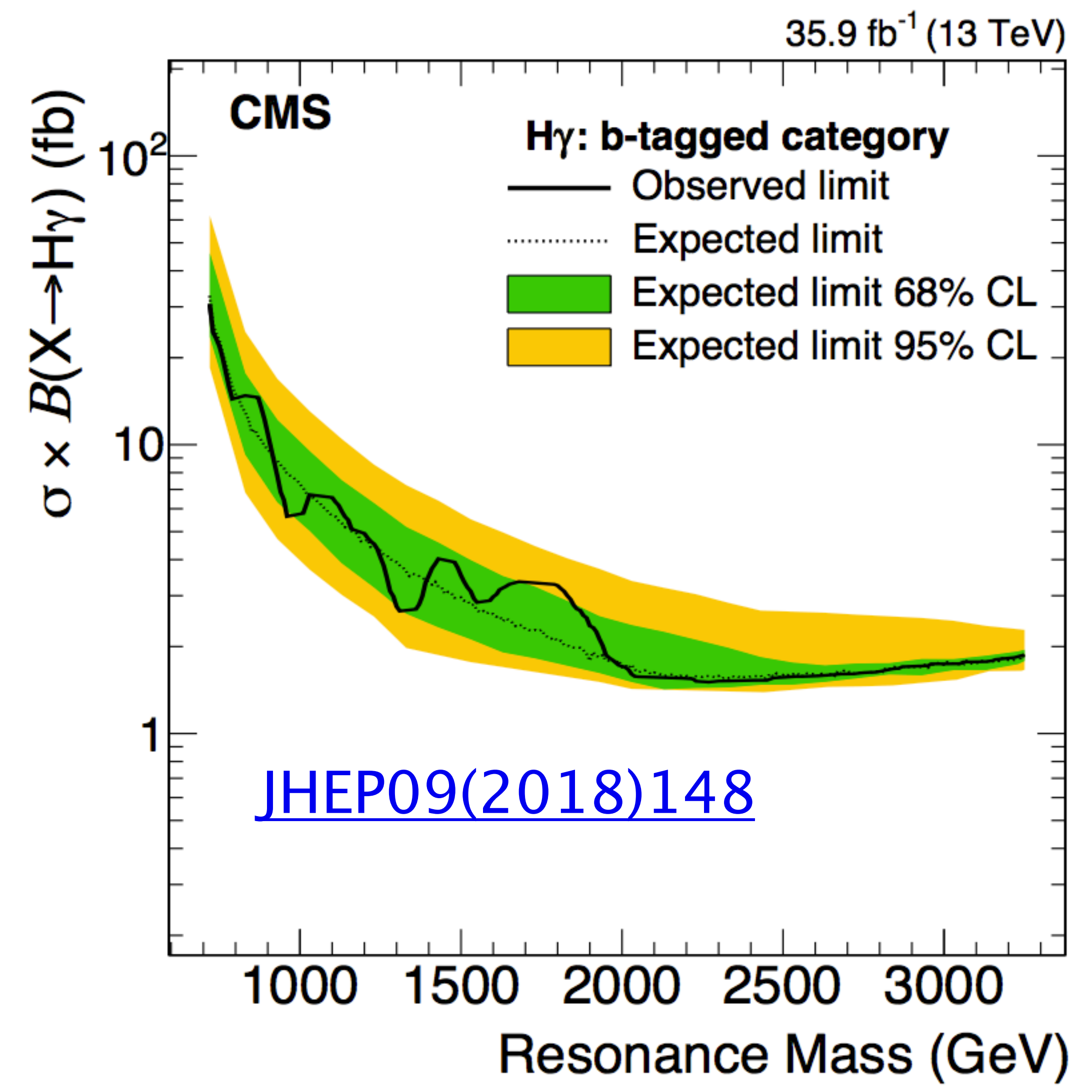
$$B(m_{J\gamma}; p_i) = (1-x)^{p_1} x^{p_2 + p_3 \log(x) + p_4 \log^2(x) + p_5 \log^3(x)}, x = m_{J\gamma}/\sqrt{s}$$





Results





- Similar sensitivity as CMS btagged region (CMS also explore untagged region)
- The difference in high mass due to better Higgs Tagger performance for CMS
- More advanced Tagger has been developed for ATLAS (ATL-PHYS-PUB-2017-010)
- Results to include new tagger is preparation with full run-II data

One more story: interpretation

- Article Phys.Lett. B773 (2017) 462-469 propose the potential way of constraint Higgs boson couplings via H+photon production channel and test new physics
- The HEFT model is used and mainly considered strongly interacting light Higgs (SILH) basis which strongly related to H+photon production

$$
\begin{aligned}
\mathcal{L}_{\mathrm{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}\left[\Phi^\dagger \overleftrightarrow{D}^\mu\Phi\right]\partial^\nu B_{\mu\nu} \\
& + \frac{ig\ \bar{c}_W}{2m_W^2}\left[\Phi^\dagger\sigma_k \overleftrightarrow{D}^\mu\Phi\right]D^\nu W^k_{\mu\nu} + \frac{ig\ \bar{c}_{HW}}{m_W^2}\left[D^\mu\Phi^\dagger\sigma_k D^\nu\Phi\right]W^k_{\mu\nu} - \frac{\bar{c}_6\lambda}{v^2}\left[\Phi^\dagger\Phi\right]^3 \\
& + \frac{ig'\ \bar{c}_{HB}}{m_W^2}\left[D^\mu\Phi^\dagger D^\nu\Phi\right]B_{\mu\nu} + \frac{\bar{c}_H}{2v^2}\partial^\mu\left[\Phi^\dagger\Phi\right]\partial_\mu\left[\Phi^\dagger\Phi\right] + \frac{\bar{c}_T}{2v^2}\left[\Phi^\dagger\overleftrightarrow{D}^\mu\Phi\right]\left[\Phi^\dagger\overleftrightarrow{D}_\mu\Phi\right] \\
& - \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 + \mathrm{h.c.}\right],
\end{aligned}
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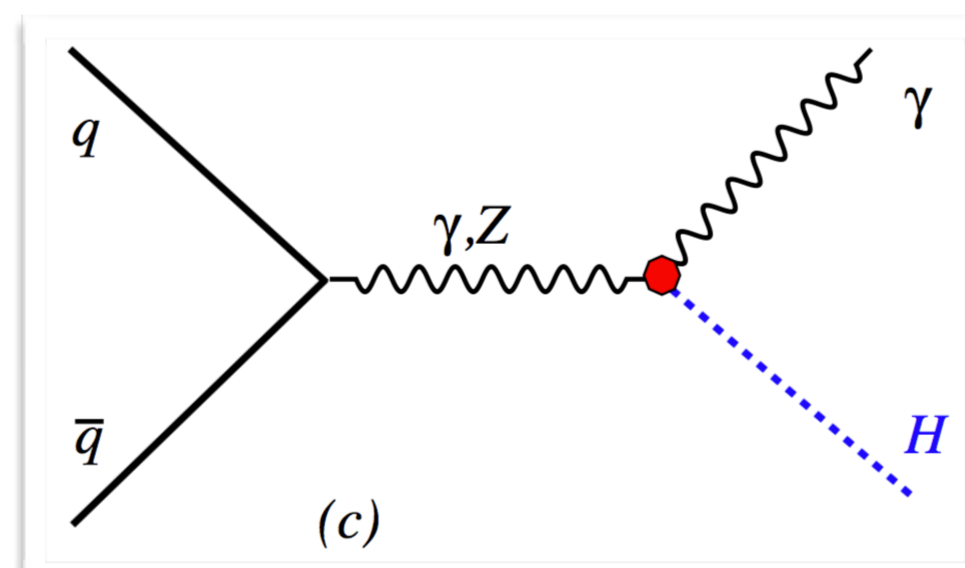
Mass basis	Gauge basis
$g_{h\gamma\gamma}$	$a_H - \frac{8gs_W^2}{m_W}\bar{c}_\gamma$
$g^{(1)}_{h\gamma z}$	$\frac{gs_W}{c_W m_W}(\bar{c}_{HW} - \bar{c}_{HB} + 8s_W^2\bar{c}_\gamma)$
$g^{(2)}_{h\gamma z}$	$\frac{gs_W}{c_W m_W}(\bar{c}_{HW} - \bar{c}_{HB} - \bar{c}_B + \bar{c}_W)$
y_u	$y_u[1 - \frac{1}{2}\bar{c}_H + \frac{3}{2}\bar{c}_u]$
$\tilde{y}_d$	$y_d[1 - \frac{1}{2}\bar{c}_H + \frac{3}{2}\bar{c}_d]$
$g^{(\partial)}_{h\gamma uu}$	$\frac{\sqrt{2}gs_W}{m_W^2}y_u[\bar{c}_{uB} + \bar{c}_{uW}]$
$g^{(\partial)}_{h\gamma dd}$	$\frac{\sqrt{2}gs_W}{m_W^2}y_d[\bar{c}_{dB} - \bar{c}_{dW}]$

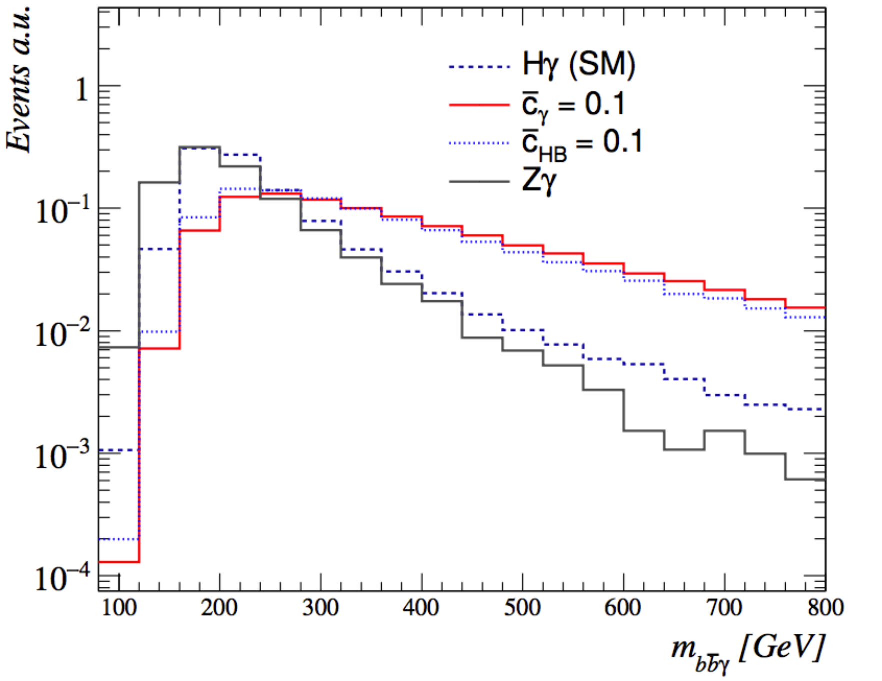
Constraints are only calculated for $\bar{c}_{HW}, \bar{c}_{HB}, \bar{c}_\gamma$
Other terms are found have small effect on results



Key diagram have leading contribution

Parametrization

- Based on pheno paper, the invariant mass of H+photon system is one of the sensitive variable to probe new couplings
  - Current resonance search paper only have mass distribution available



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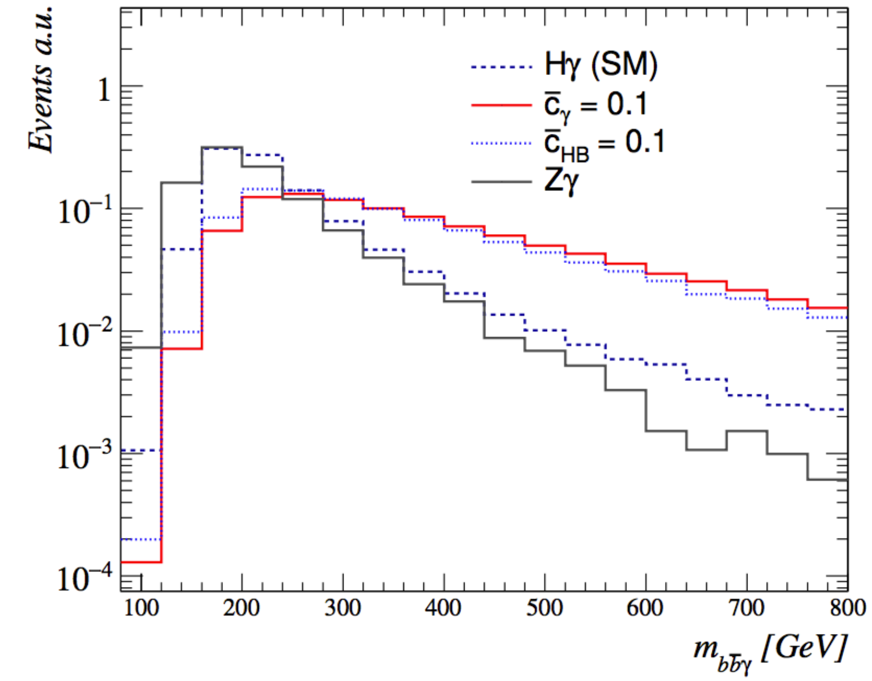
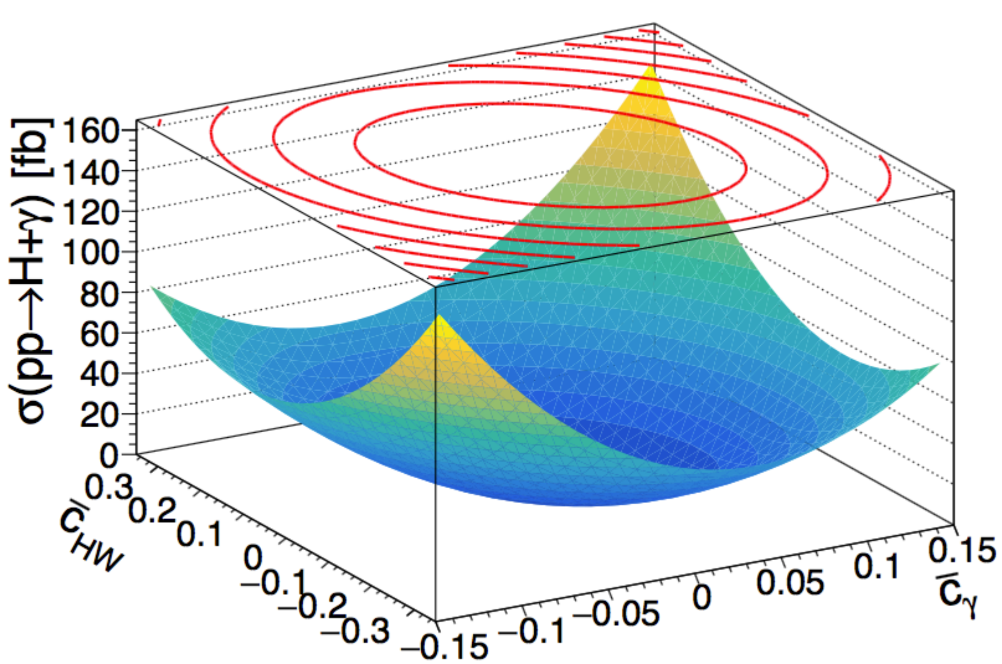
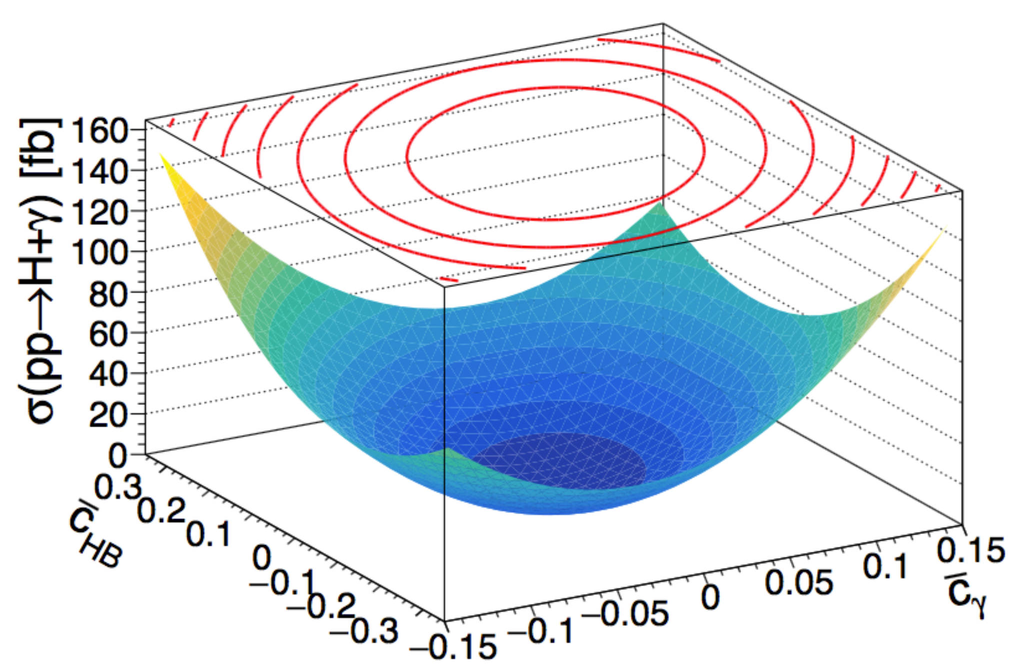


- Currently, SILH is implemented along with generic HEFT model in MadGraph

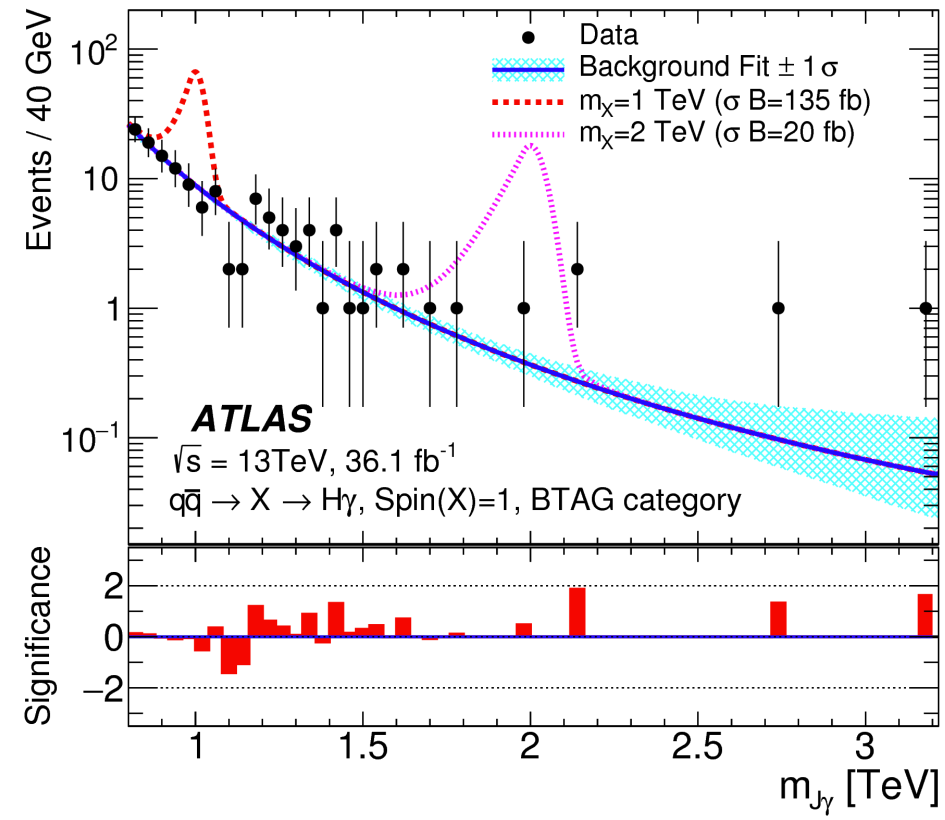
- A numeric relationship between EFT coefficients and H+photon crosssection with MadGraph calculation and parametrised with polynomial function for statistical analysis

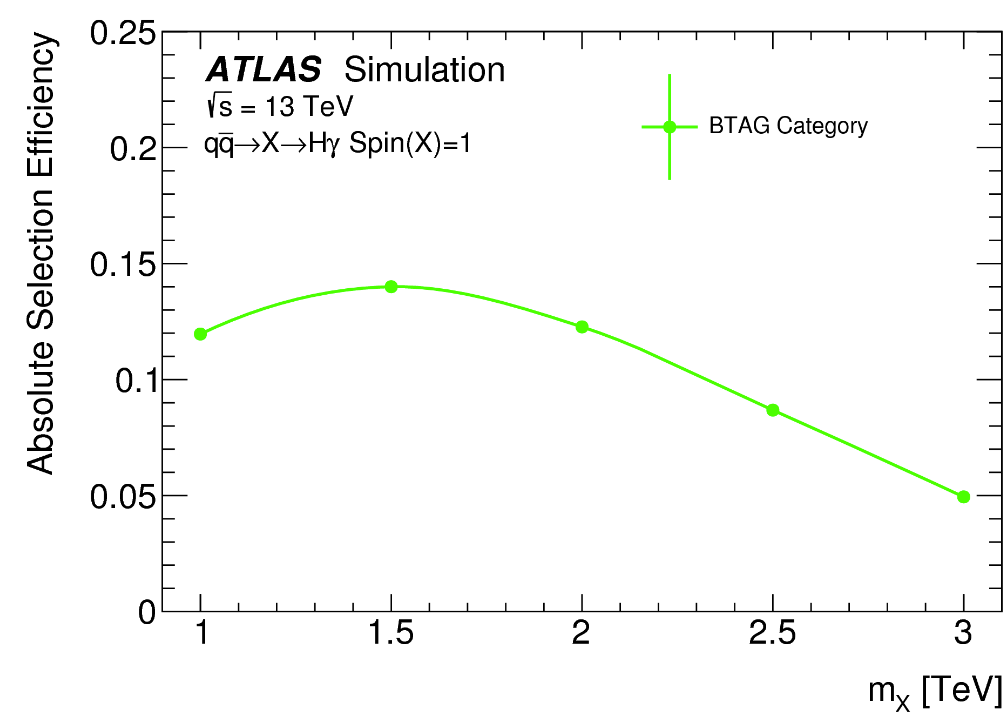




Statistical treatment

- Since we only have truth events for EFT signals, only the number counting analysis performed for $m_{H\gamma}$ in between 800-3200 GeV
- QCD background contribution is obtained from data fit along with uncertainty.
  - SM H+photon contribution is small and neglected
- The effects on signal efficiency due to acceptance, detector effect and selection efficiency are applied with efficiency parametrization on $m_{H\gamma}$





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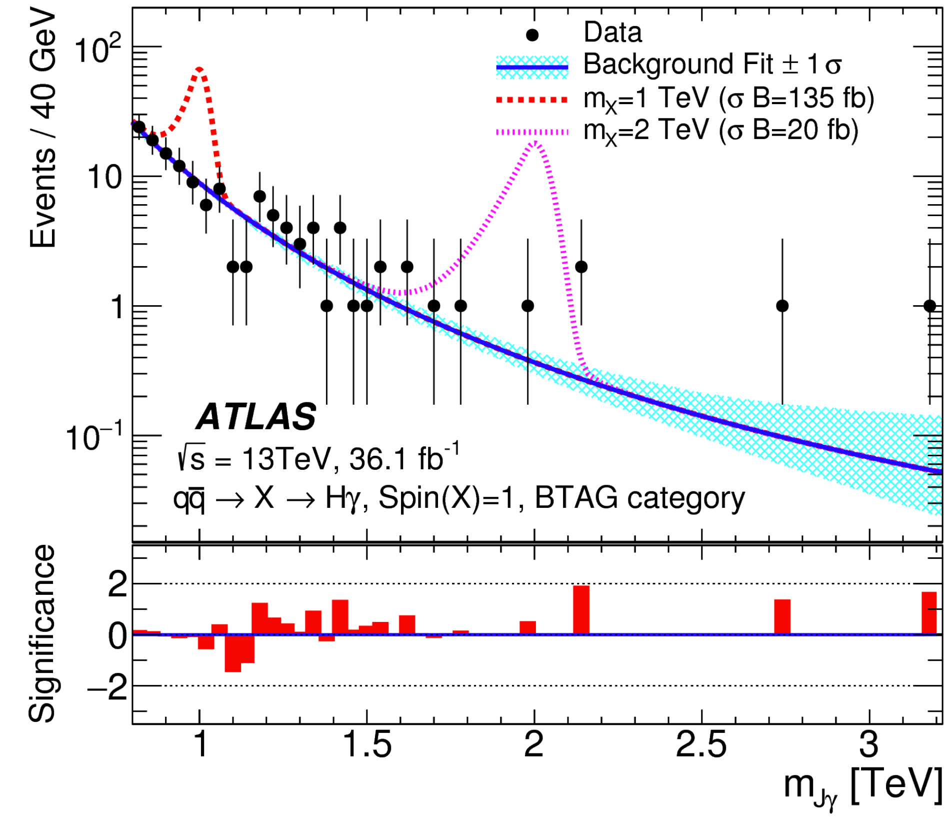
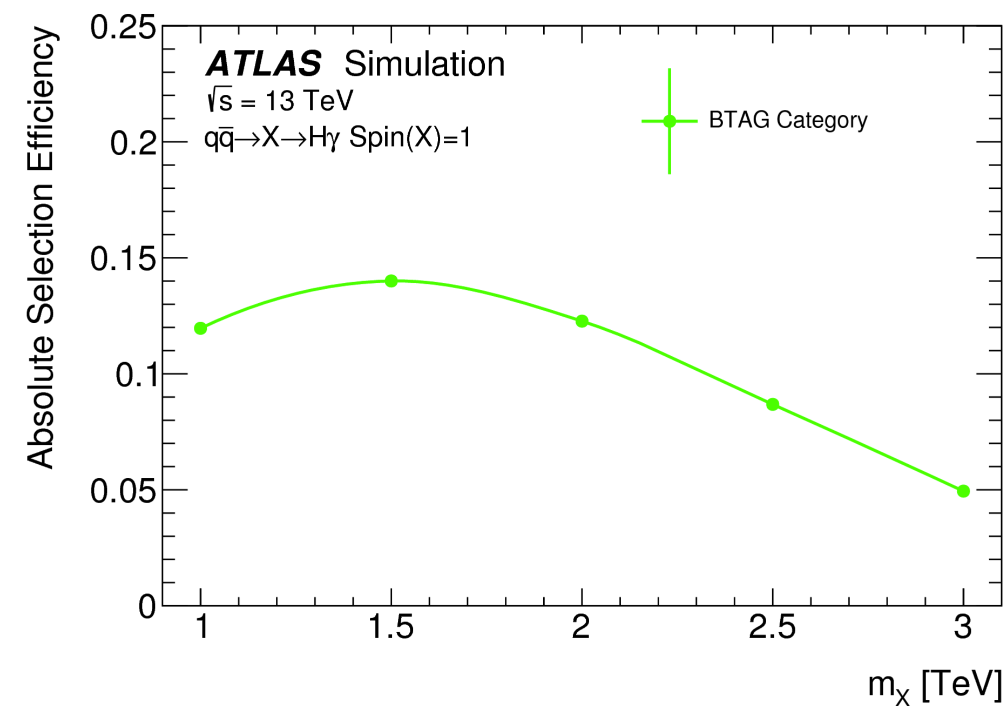




Statistical model is built as:

$$\mathcal{L} = \text{Pois}(n|s+b) \times \text{Gaus}(b_0|b,\sigma_b) \ .$$

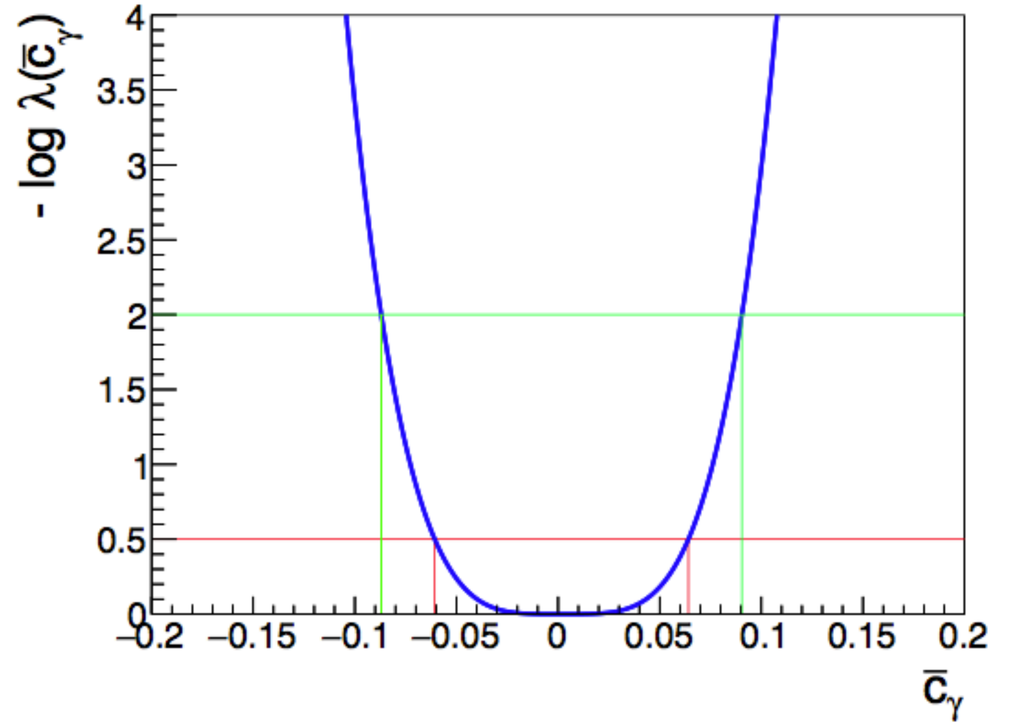
Constraints are obtained with PLR

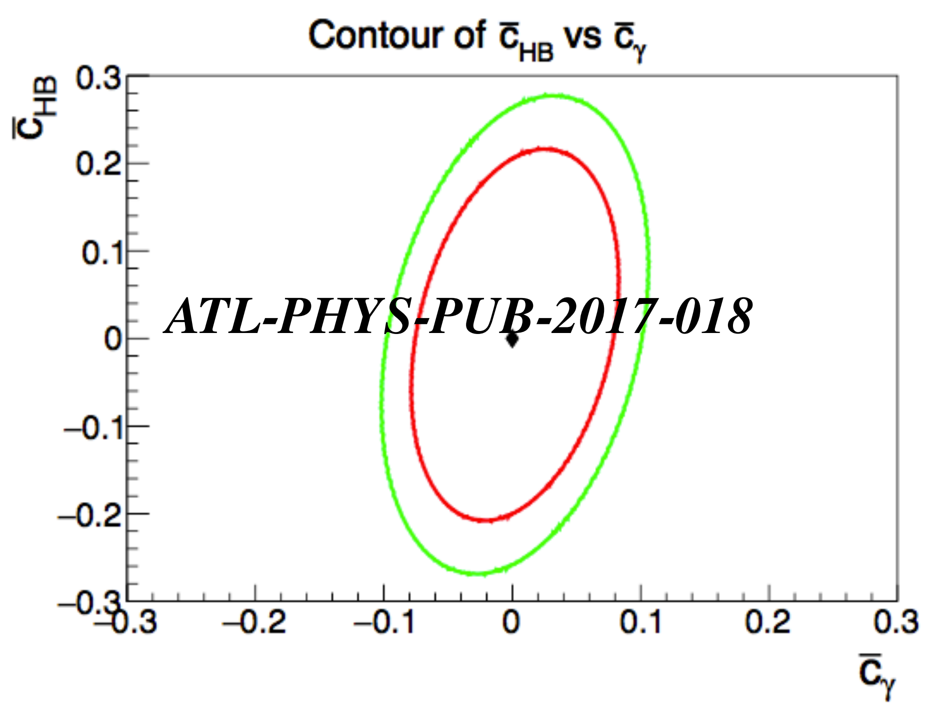
$$\lambda(\bar{c}_i) = \frac{\mathcal{L}(\bar{c}_i, \hat{\hat{b}})}{\mathcal{L}(\hat{\bar{c}}_i, \hat{b})}.$$

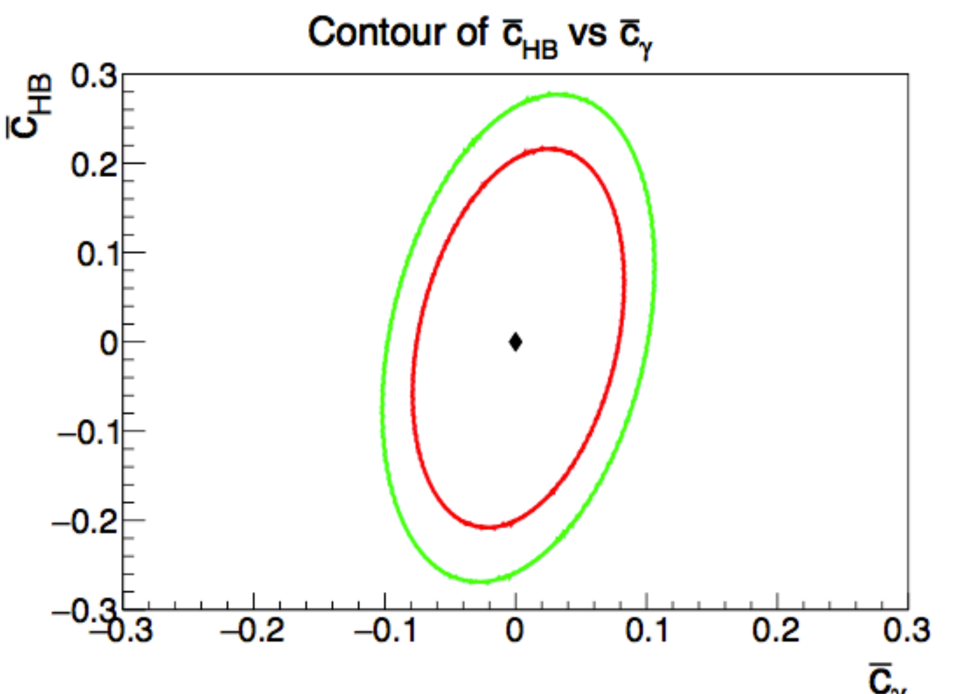
Constraints

- Results

Parameter	68% C.L.	95% C.L.
$\bar{c}_\gamma$	[-0.061, 0.064]	[-0.087, 0.090]
$\bar{c}_{HW}$	[-0.167, 0.161]	[-0.236, 0.231]
$\bar{c}_{HB}$	[-0.162, 0.167]	[-0.230, 0.236]







- Future potential shape analysis can further improve the constrains

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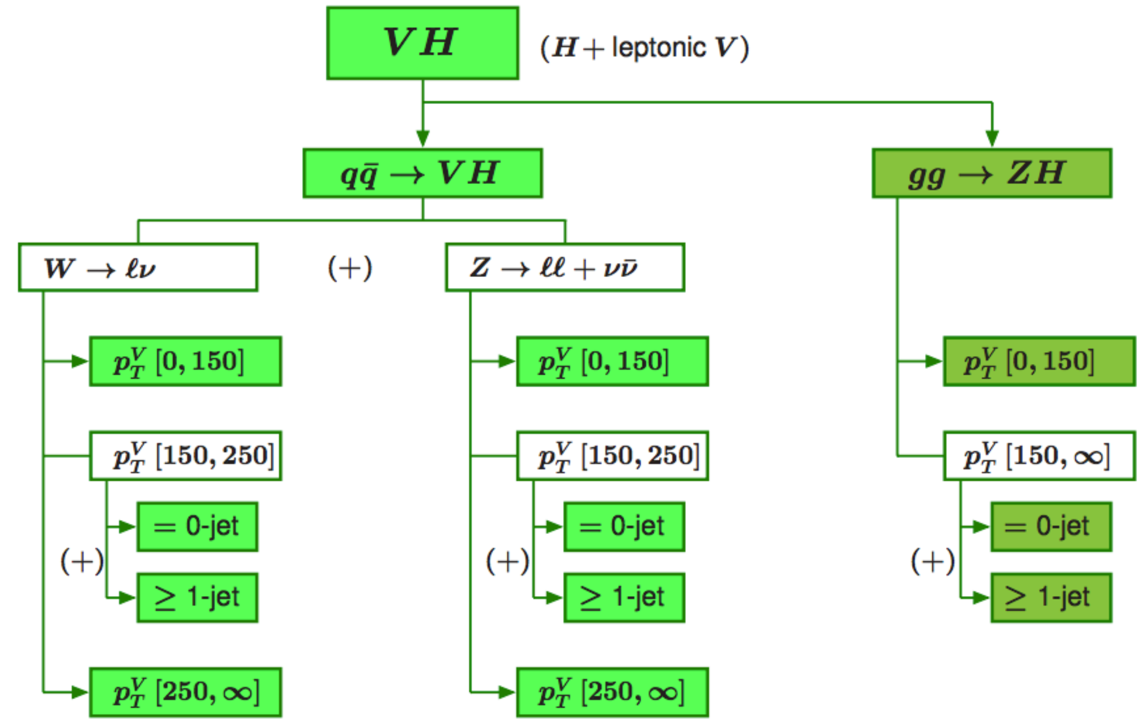
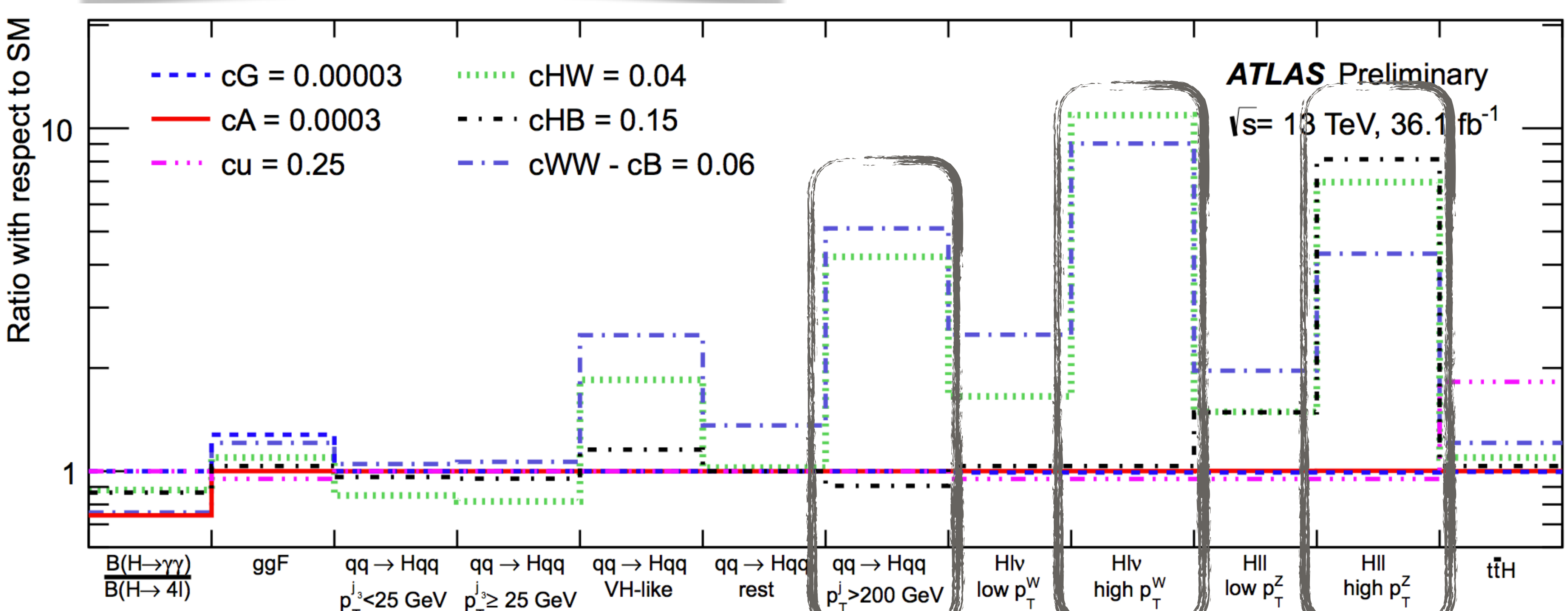
$$\bar{c}_\gamma \in [-1.5\times 10^{-4},\ 2.2\times 10^{-4}],$$
$$\bar{c}_{HW} \in [-0.080,\ -0.024],$$
$$\bar{c}_{HB} \in [-0.051,\ 0.103].$$



From ATL-PHYS-PUB-2017-018 (H→ZZ & H→γγ STXS)



Summary

- A search for heavy resonance decaying to Higgs boson and a photon has been presented
- Large-R jet is used to contain all the decay produces from the Higgs boson.
  - Search range limited in between 1-3 TeV for the performance of fatjet and flavour tagging
- No significant excess observed
- In addition to the model-independent search, an EFT interpretation has been made based on public dataset
- Similar constraint power as $H \rightarrow ZZ$ & $H \rightarrow \gamma\gamma$ combined results for few coefficients is obtained
- Potential shape analysis can future improve constraint power
- The study to improve the sensitivity with run-II dataset is ongoing