Constraints on non-SM Higgs boson interactions in an EFT using differential cross sections in the H→γγ channel with the ATLAS detector

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Introduction

- Interpretation of most Higgs results: “kappa” framework:
  - allow each coupling to be scaled by a constant value: $g_{H_{ii}} \rightarrow \kappa_i \cdot g_{H_{ii}}$

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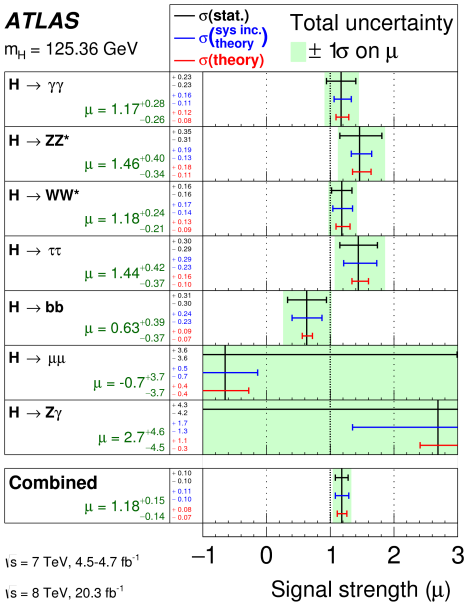
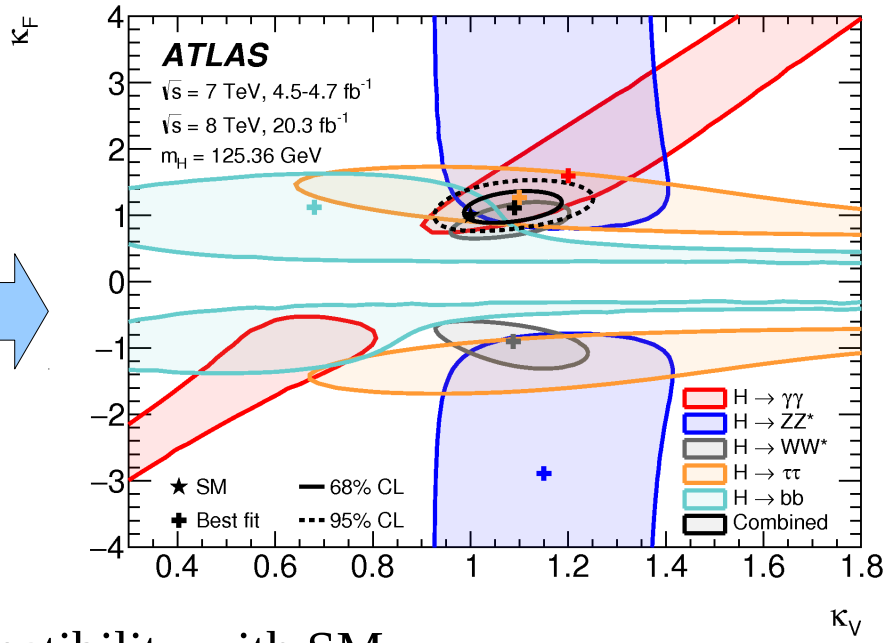




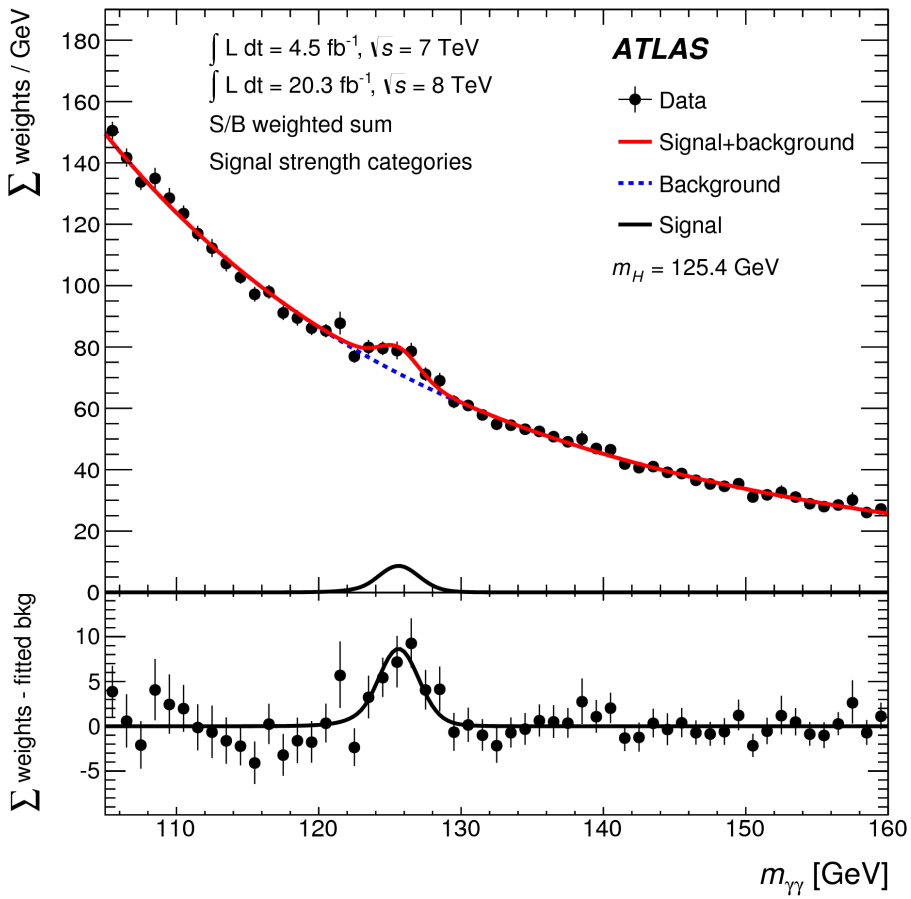
- Pros:
  - simple representation of data compatibility with SM
  - easy comparison between experiments
  - can be used to test BSM models in which strength of Higgs boson couplings are modified
- Cons:
  - does not test the structure of the Higgs boson couplings
  - data cannot be easily used to test models with different couplings structure and kinematics

H→γγ analysis

Phys. Rev. D. 90, 112015 (2014)

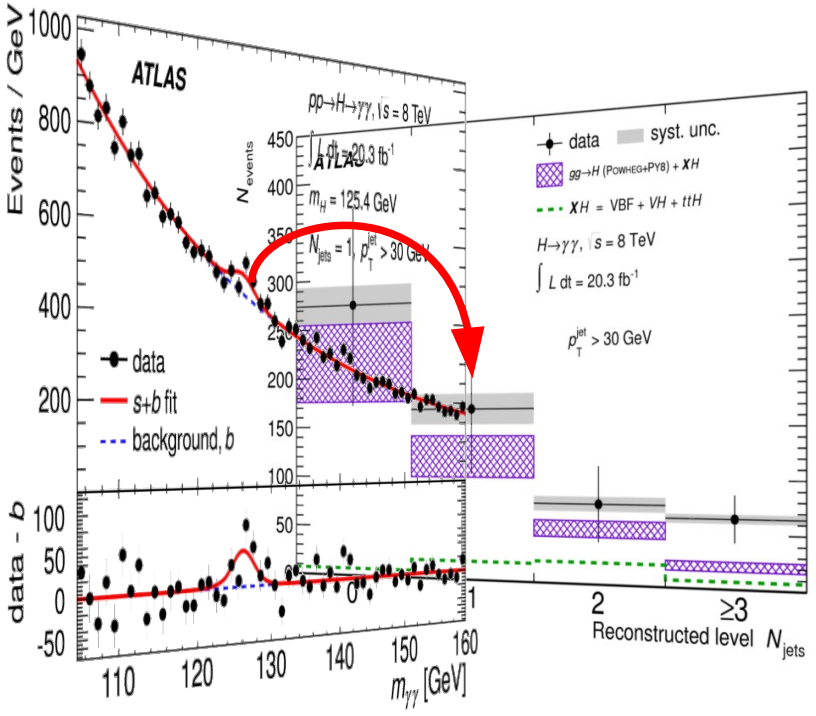
- Two well identified and isolated photons
  - $E_T^{\gamma 1} > 0.35 * m_{\gamma\gamma}$, $E_T^{\gamma 2} > 0.25 * m_{\gamma\gamma}$
- γγ purity: 77±3% at 8 TeV
- Signal+background fit of $m_{\gamma\gamma}$
- Number of expected signal events and measured background
  - window with 90% of signal

	signal	background	S/(S+B)
7+8 TeV	421.8	13196.4	0.03



H→γγ differential cross-sections (1)

- Extract signal events from fits of $m_{\gamma\gamma}$ in bins of variables of interest

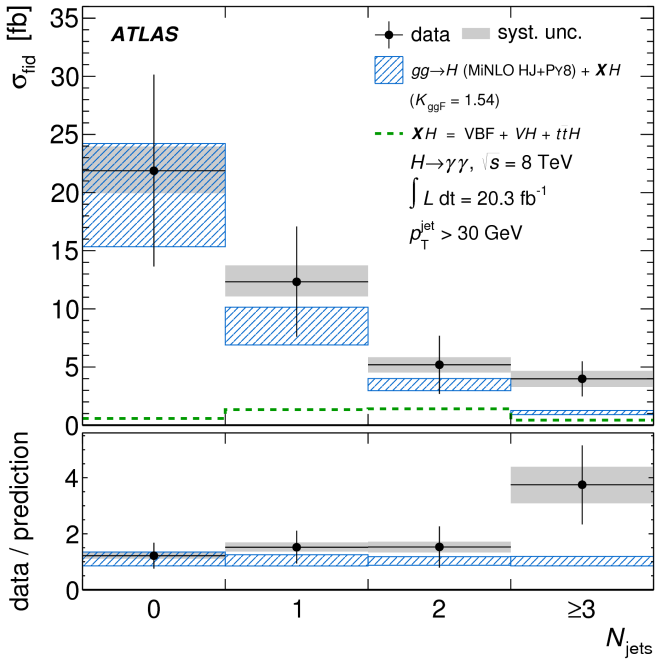


- Unfold to fiducial volume:

$$\sigma_{fid} \cdot BR = \frac{N^{sig,obs}}{C_H \cdot L}$$

  - C_H = detector correction factor
  - L = integrated luminosity

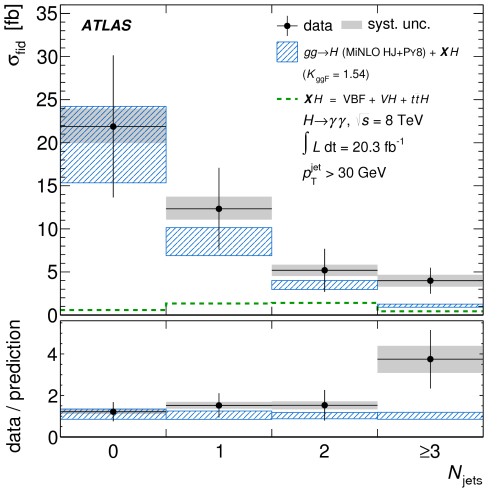
- Get fiducial cross sections:

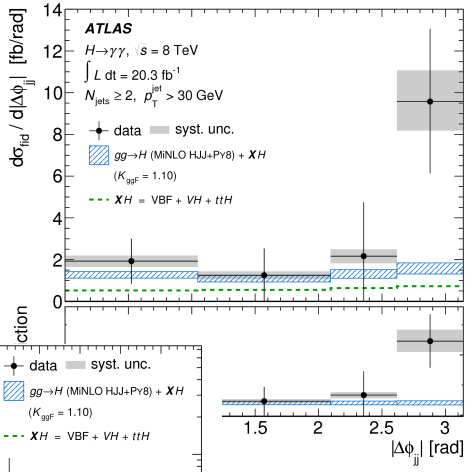


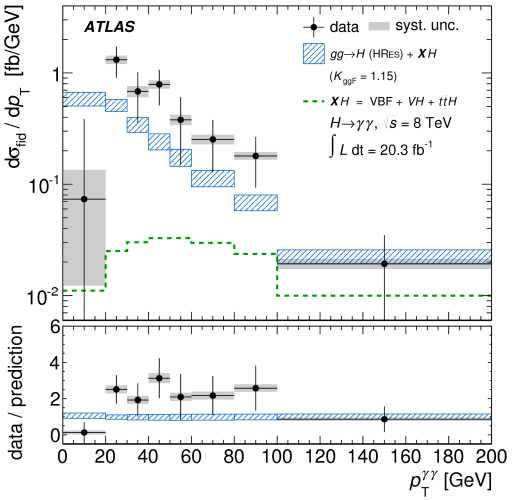
H→γγ differential cross-sections (2)

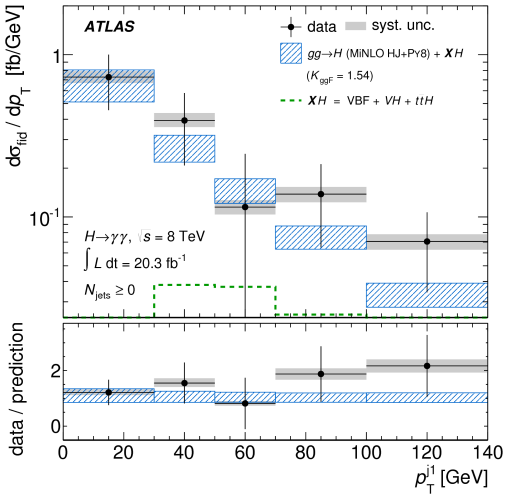
- Variables sensitive to
  - Higgs boson kinematics → $p_T^{\gamma\gamma}$, $y^{\gamma\gamma}$
  - Jet activity → N_{jets}, p_T^{j1}, y^{j1}, p_T^{j2}, H_T
  - spin/CP → $\cos\theta^*$, $\Delta\varphi_{jj}$
  - VBF-sensitive → m_{jj}, Δy_{jj}, $\Delta\varphi_{\gamma\gamma\text{-}jj}$

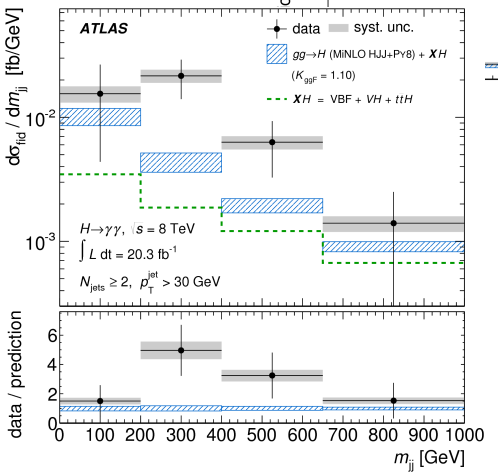
JHEP09(2014)112











- Data corrected for detector effects and preserved in HEPDATA
- Rivet routine provided to allow theorists to easily compare with the data
- In order to perform a simultaneous fit on several distributions, need the correlations between them (same events used)

Correlations between distributions

- Almost all of the statistical uncertainty originates from background pp → γγ
- Used to estimated the stat correlations between distributions by applying bootstrap procedure
  - i - assign each event of the pp → γγ events a Poisson weight from P(ν = 1)
  - ii - reconstruct the five observables
  - iii - re-extract the Signal yields
- Full table will be provided in HEPDATA
- Can be use to test Higgs EFTs

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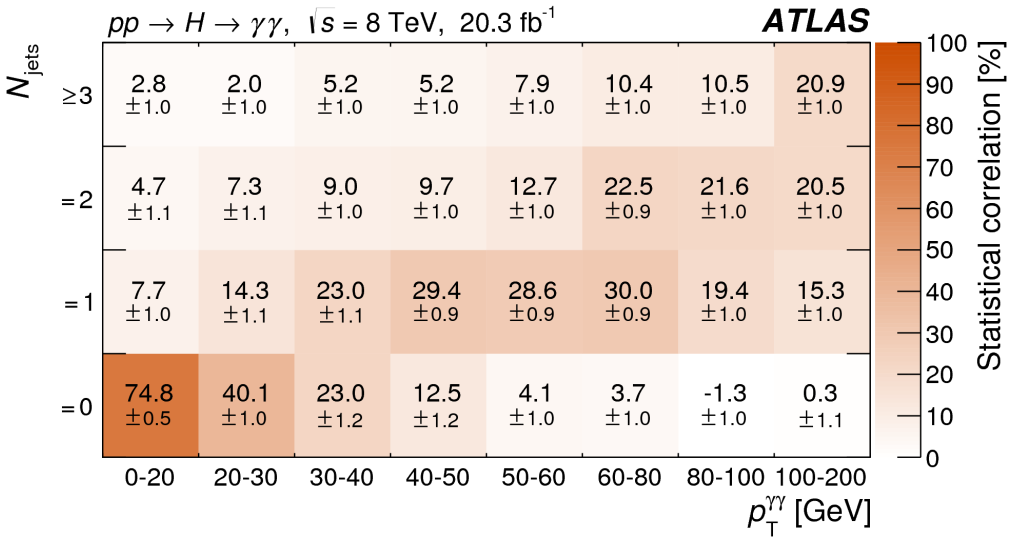


Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.8	7.7	4.7	2.8	5.1	2.0	0.8	0.3	-0.8	-0.1	3.7	6.8	9.8	3.5	0.5	2.7
2	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	40.1	14.3	7.3	2.0	5.3	4.9	1.7	0.1	1.1	1.2	4.7	6.9	18.5	3.9	2.4	2.4
3	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	23.0	23.0	9.0	5.2	10.0	4.5	0.8	-0.7	2.1	2.8	5.7	8.9	25.9	9.6	5.2	2.3
4	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	12.5	29.4	9.7	5.2	7.8	6.0	4.3	4.0	3.5	5.4	4.2	8.9	26.9	16.2	7.8	4.3
5	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	4.1	28.6	12.7	7.9	12.9	4.5	6.9	1.5	2.8	7.4	11.0	8.4	20.5	24.3	10.0	5.1
6	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	3.7	30.0	22.5	10.4	21.1	11.2	5.6	2.3	10.9	17.8	11.4	10.2	16.2	27.8	26.4	10.6
7	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	-1.3	19.4	21.6	10.5	17.0	13.7	8.3	3.7	15.7	14.4	9.9	8.9	7.0	15.4	26.1	17.3
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.3	15.3	20.5	20.9	22.6	14.3	8.8	6.4	23.9	17.9	11.4	6.2	1.0	5.4	19.8	32.9
9	74.8	40.1	23.0	12.5	4.1	3.7	-1.3	0.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	7.7	14.3	23.0	29.4	28.6	30.0	19.4	15.3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.9	38.9	23.4	12.4
11	4.7	7.3	9.0	9.7	12.7	22.5	21.6	20.5	0.0	0.0	100.0	0.0	73.1	35.7	20.3	13.4	35.1	43.3	38.4	50.7	18.5	26.4	29.6	21.2
12	2.8	2.0	5.2	5.2	7.9	10.4	10.5	20.9	0.0	0.0	0.0	100.0	33.9	38.3	16.9	6.8	20.9	22.8	25.0	33.5	3.8	12.1	20.4	24.2
13	5.1	5.3	10.0	7.8	12.9	21.1	17.0	22.6	0.0	0.0	73.1	33.9	100.0	0.0	0.0	0.0	42.5	41.9	39.3	38.2	17.7	30.2	30.2	17.7
14	2.0	4.9	4.5	6.0	4.5	11.2	13.7	14.3	0.0	0.0	35.7	38.3	0.0	100.0	0.0	0.0	7.7	21.5	20.8	44.4	6.4	6.3	19.4	23.3
15	0.8	1.7	0.8	4.3	6.9	5.6	8.3	8.8	0.0	0.0	20.3	16.9	0.0	0.0	100.0	0.0	8.0	12.3	10.3	20.2	0.9	3.9	5.8	13.9
16	0.3	0.1	-0.7	4.0	1.5	2.3	3.7	6.4	0.0	0.0	13.4	6.8	0.0	0.0	0.0	100.0	7.3	7.4	4.8	10.3	1.0	1.6	3.5	4.5
17	-0.8	1.1	2.1	3.5	2.8	10.9	15.7	23.9	0.0	0.0	35.1	20.9	42.5	7.7	8.0	7.3	100.0	0.0	0.0	0.0	9.9	16.2	12.2	3.7
18	-0.1	1.2	2.8	5.4	7.4	17.8	14.4	17.9	0.0	0.0	43.3	22.8	41.9	21.5	12.3	7.4	0.0	100.0	0.0	0.0	9.1	15.6	17.8	14.2
19	3.7	4.7	5.7	4.2	11.0	11.4	9.9	11.4	0.0	0.0	38.4	25.0	39.3	20.8	10.3	4.8	0.0	0.0	100.0	0.0	10.4	11.6	13.6	18.8
20	6.8	6.9	8.9	8.9	8.4	10.2	8.9	6.2	0.0	0.0	50.7	33.5	38.2	44.4	20.2	10.3	0.0	0.0	0.0	100.0	7.1	14.2	25.5	23.0
21	9.8	18.5	25.9	26.9	20.5	16.2	7.0	1.0	0.0	69.9	18.5	3.8	17.7	6.4	0.9	1.0	9.9	9.1	10.4	7.1	100.0	0.0	0.0	0.0
22	3.5	3.9	9.6	16.2	24.3	27.8	15.4	5.4	0.0	38.9	26.4	12.1	30.2	6.3	3.9	1.6	16.2	15.6	11.6	14.2	0.0	100.0	0.0	0.0
23	0.5	2.4	5.2	7.8	10.0	26.4	26.1	19.8	0.0	23.4	29.6	20.4	30.2	19.4	5.8	3.5	12.2	17.8	13.6	25.5	0.0	0.0	100.0	0.0
24	2.7	2.4	2.3	4.3	5.1	10.6	17.3	32.9	0.0	12.4	21.2	24.2	17.7	23.3	13.9	4.5	3.7	14.2	18.8	23.0	0.0	0.0	0.0	100.0

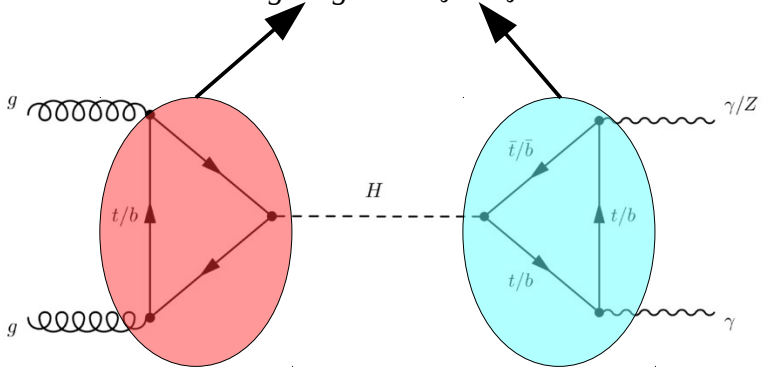
Higgs effective lagrangian (1)

- Parameterise BSM physics using an effective lagrangian that supplements the dim-4 Standard Model with all relevant dim-6 operators
  - Original paper: JHEP 0706 (2007)045

- Choice for the analysis: Higgs Effective Lagrangian
  - contains 39 relevant operators in a specific basis
  - Strongly Interacting Light Higgs formulation: dim-6 CP-even operators + corresponding CP-odd operators

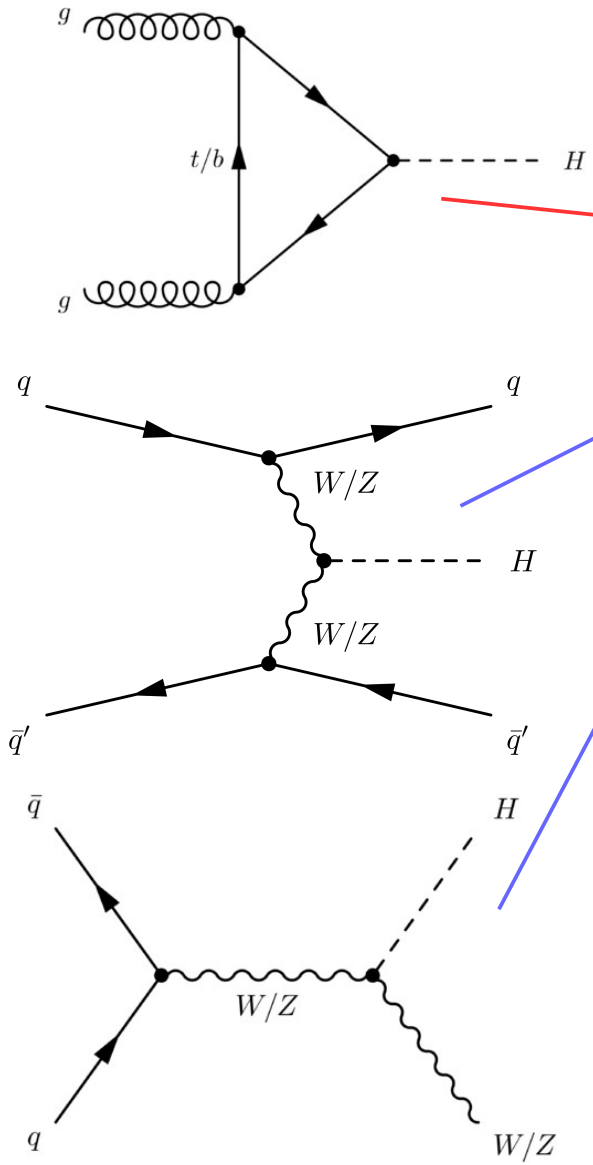
- H → γγ sensitive to operators that affect the Higgs boson interaction with gauge bosons
  - relevant terms in the Lagrangian:

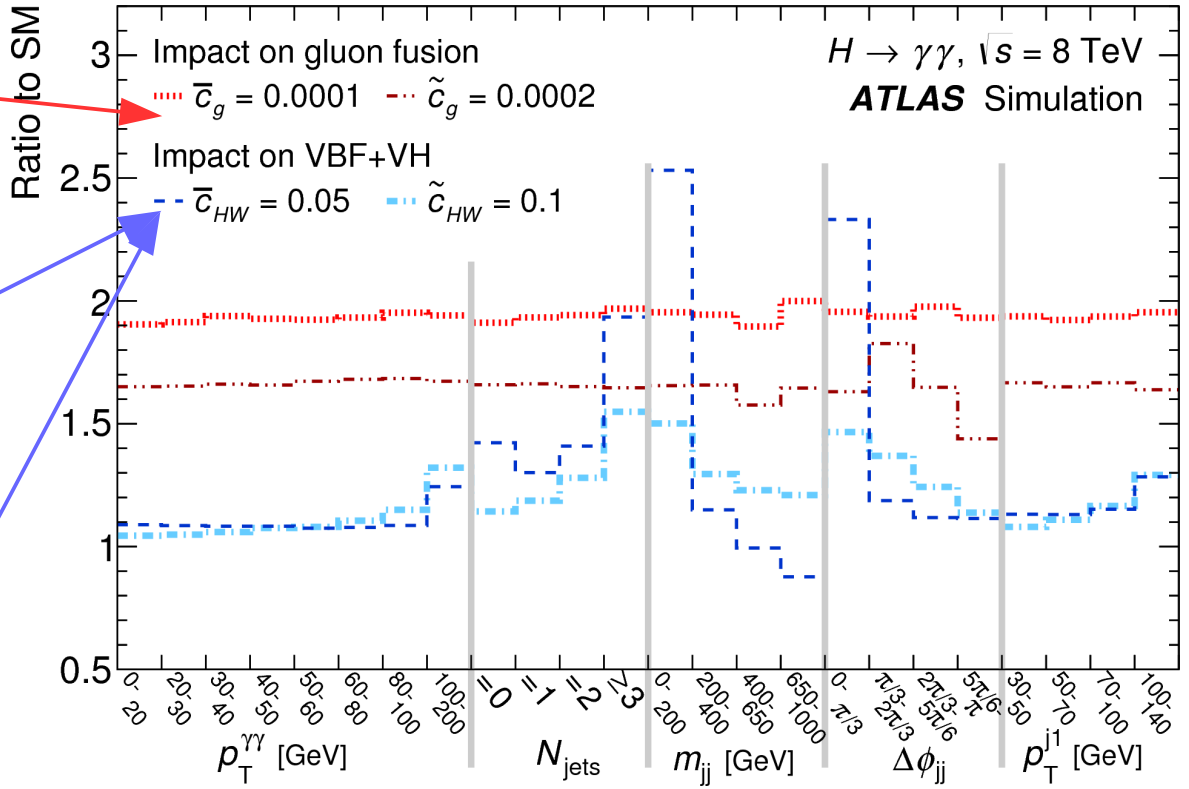
$$L = \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g O_g + \tilde{c}_\gamma O_\gamma + \tilde{c}_{HW} O_{HW} + \tilde{c}_{HB} O_{HB}$$



Higgs effective lagrangian (2)

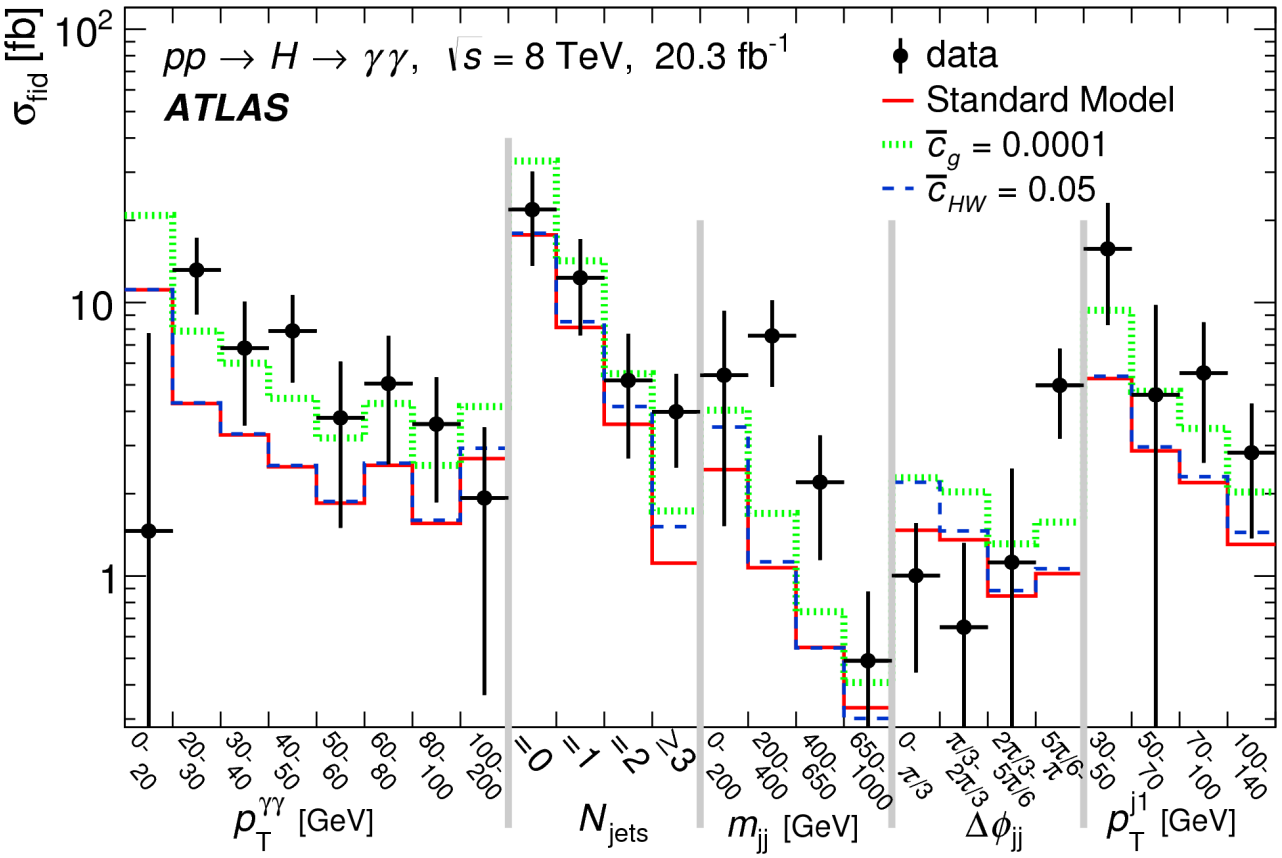
- Effect on the distributions for a few examples:





Fits to differential cross sections

- Example of distributions pre-fit:

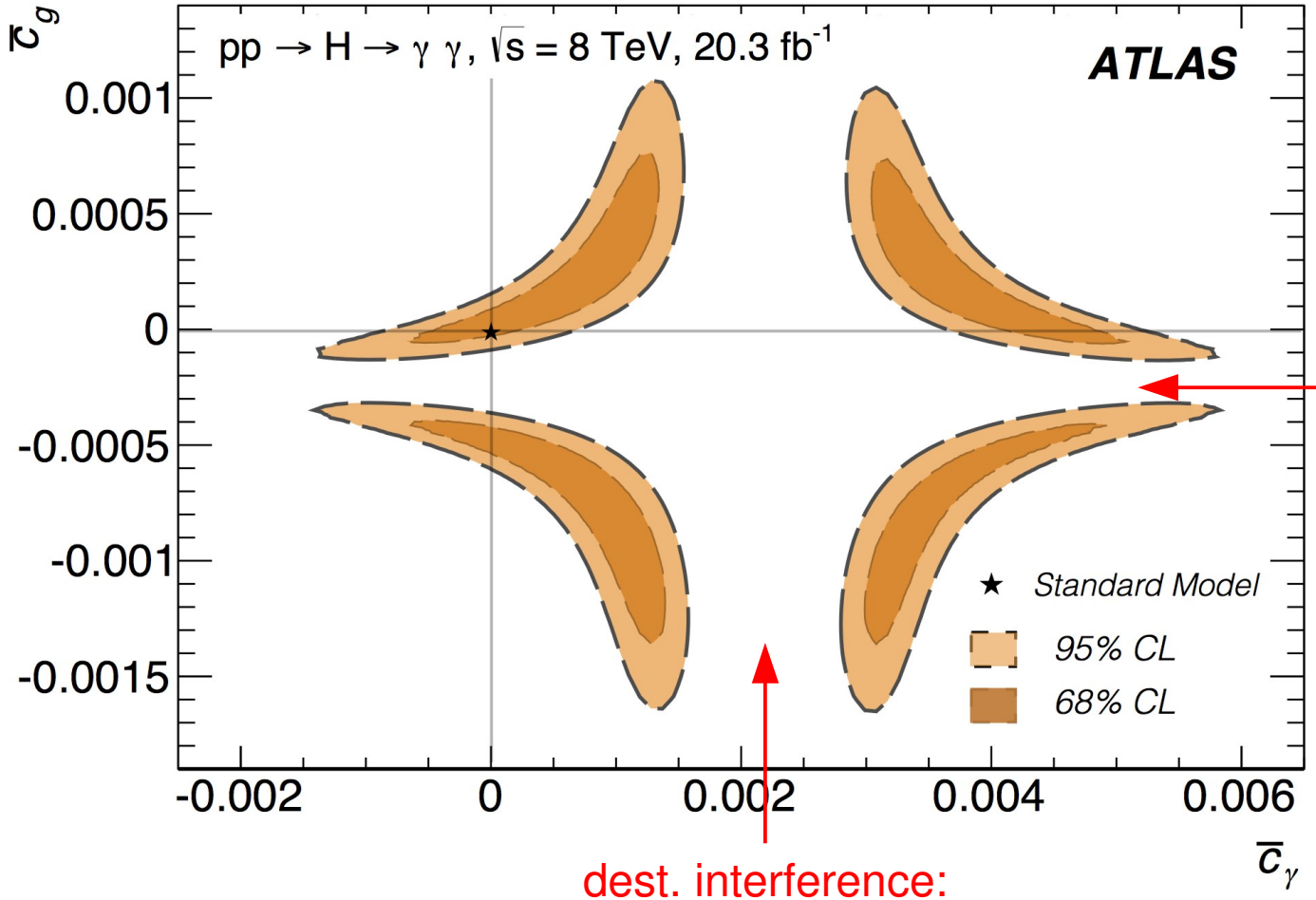


- Fit the 5 differential cross sections, taking into account the correlations
- Limits from χ^2 function: $\chi^2 = (\vec{\sigma}_{data} - \vec{\sigma}_{prediction})^T C^{-1} (\vec{\sigma}_{data} - \vec{\sigma}_{prediction})$
- Confidence Level for each mass point:

$$1 - CL = \int_{\chi^2(c_i) - \chi^2_{min}}^{\infty} dx\, \chi^2(x; m)$$

Results: $\bar{c}_g$-$\bar{c}_\gamma$

- Additional $gg \to H$ and $H \to \gamma\gamma$ contributions
  - all other coefficients are 0
- Additional interactions can interfere constructively or destructively with the corresponding SM interactions

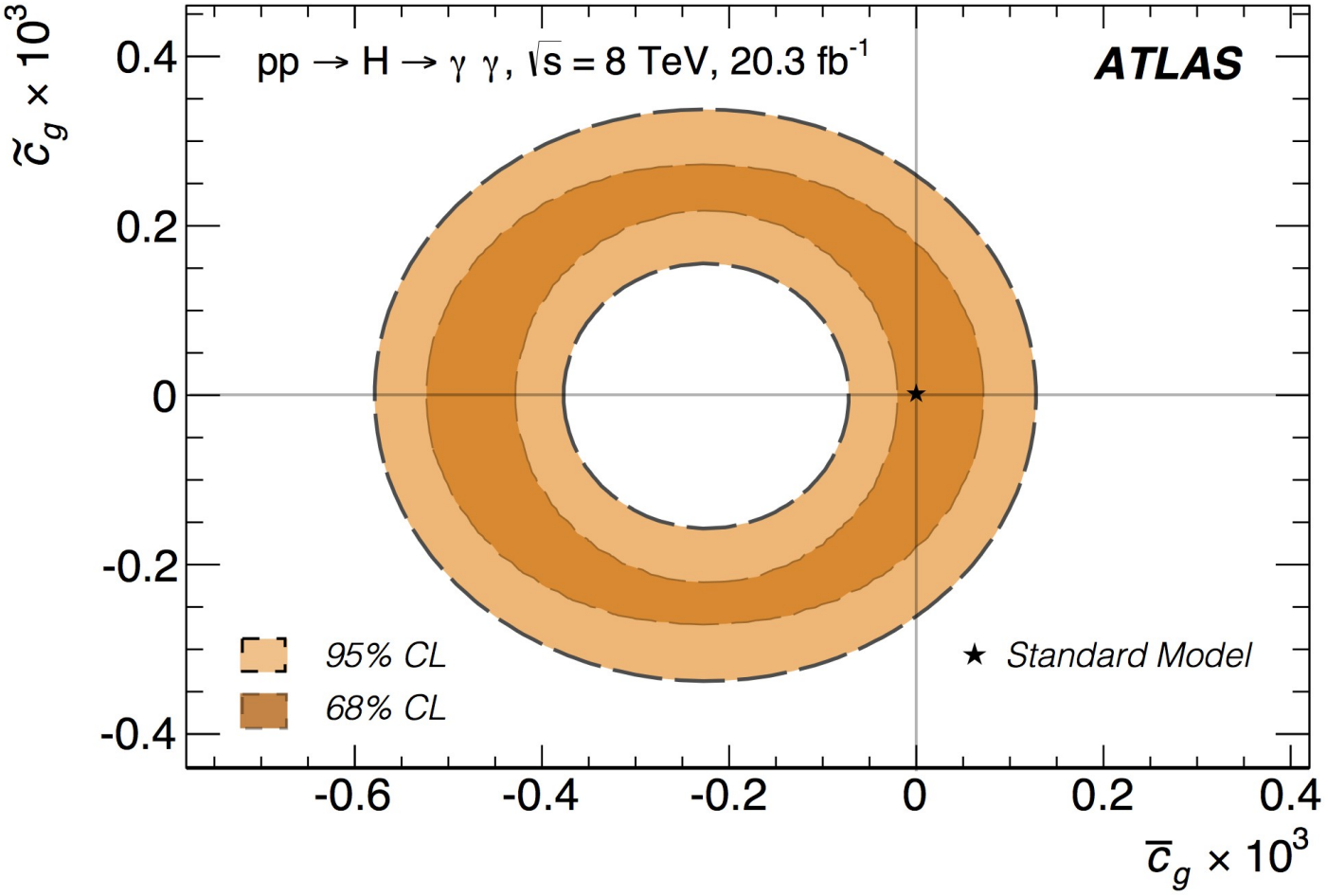


dest. interference: σ(gg → H) = 0

dest. interference: BR(H → γγ) = 0

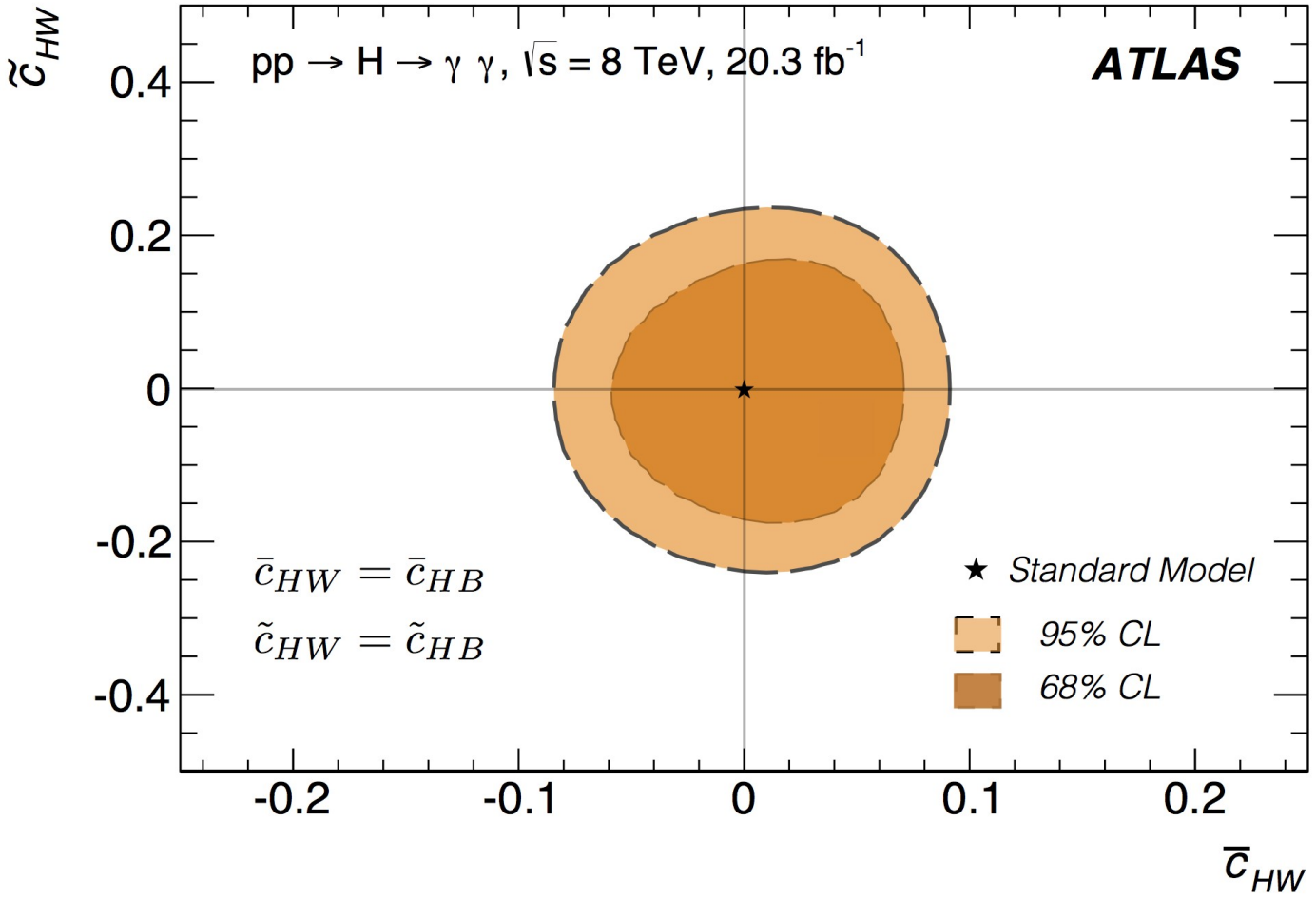
Results: $\bar{c}_g$ - $\tilde{c}_g$

- Additional $gg \rightarrow H$ contributions
  - all other coefficients are 0
- Better constraint on $\tilde{c}_g$ than $\bar{c}_g$ thanks to $\Delta\varphi_{jj}$ (distinguishes the CP-conjugate contributions)



Results: $\bar{c}_{HW}$ - $\tilde{c}_{HW}$

- Additional W/Z couplings
  - all other coefficients are 0
- Fix $c_{HW}=c_{HB}$ to ensure BR(H→Zγ) is the one of SM
- 18% improvement when using 5 variables instead of $\Delta\varphi_{jj}$ only



Conclusion

- Use full potential of H→γγ differential cross section measurements
  - with correlations between distributions

- Illustrated by fits with parameters from an Effective Lagrangian
  - summary of limits on coefficients:

Coefficient	$95\%\ 1-CL$ limit
$\bar{c}_\gamma$	$[-7.4, 5.7]\times10^{-4} \cup [3.8, 5.1]\times10^{-3}$
$\tilde{c}_\gamma$	$[-1.8, 1.8]\times10^{-3}$
$\bar{c}_g$	$[-0.7, 1.3]\times10^{-4} \cup [-5.8, -3.8]\times10^{-4}$
$\tilde{c}_g$	$[-2.4, 2.4]\times10^{-4}$
$\bar{c}_{HW}$	$[-8.6, 9.2]\times10^{-2}$
$\tilde{c}_{HW}$	$[-0.23, 0.23]$

- Higgs cross section measurements still limited by statistical error (20-60%)
  - looking forward for Run 2 results!

Back-up slides