MANCHESTER 1824
The University of Manchester

Measurements of the properties of the Higgs boson with ATLAS

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(University of Manchester)

On behalf of the ATLAS Collaboration

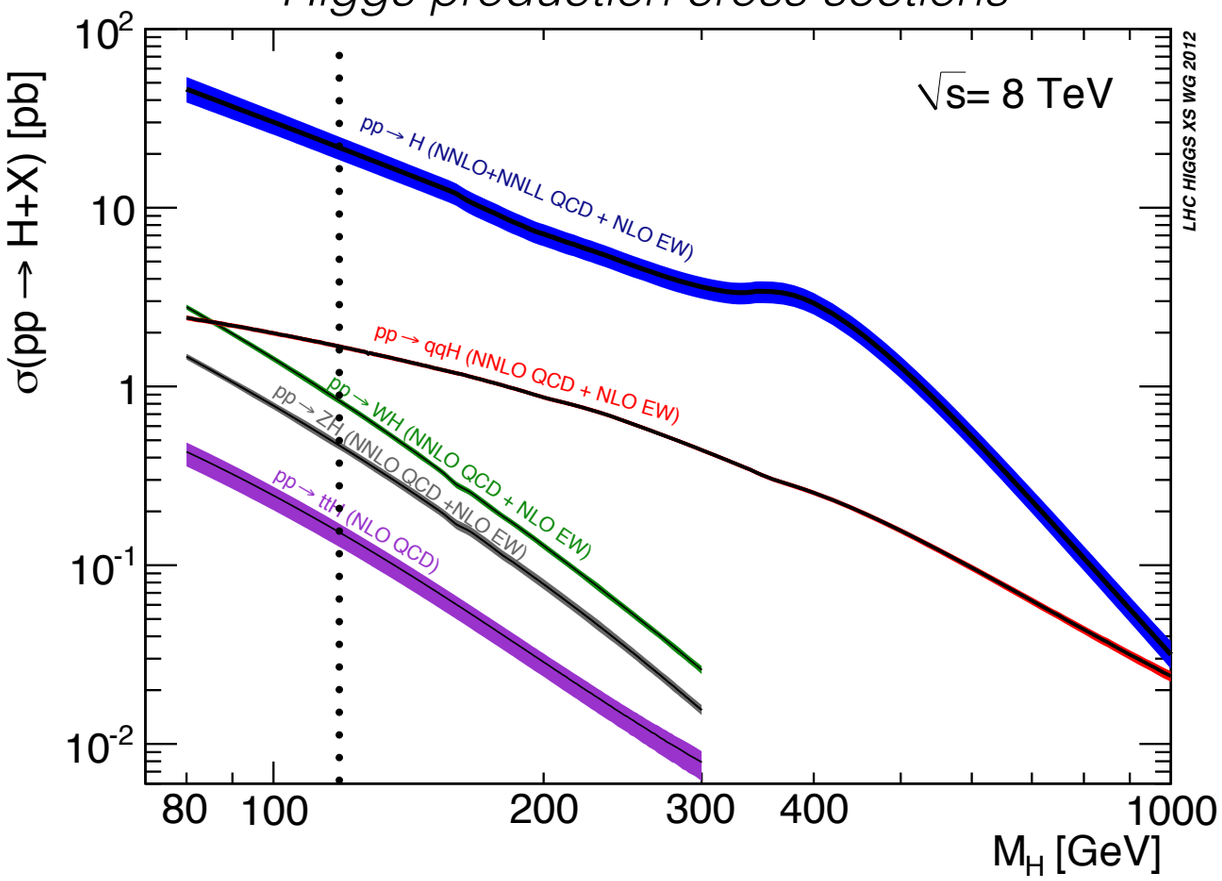
ICNFP2015
23rd-30th August
Kolymbari, Crete

ATLAS EXPERIMENT

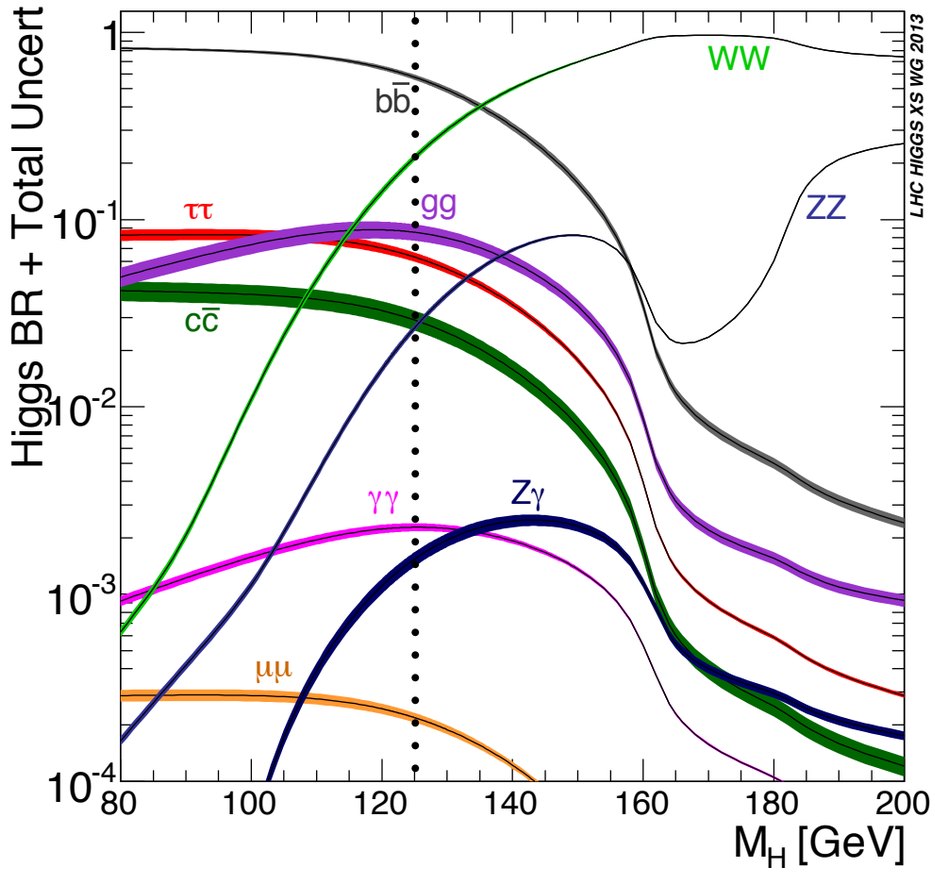
Higgs boson production at the LHC

The University of Manchester

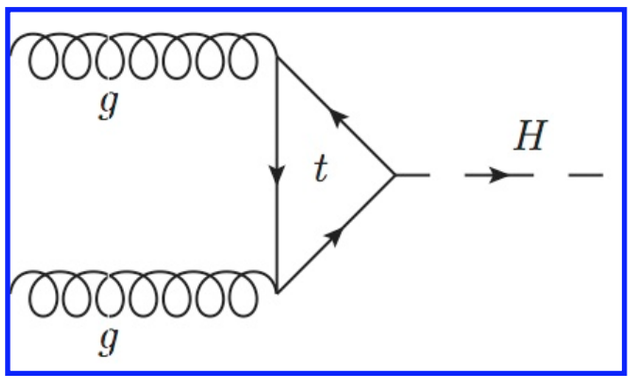
Higgs production cross sections



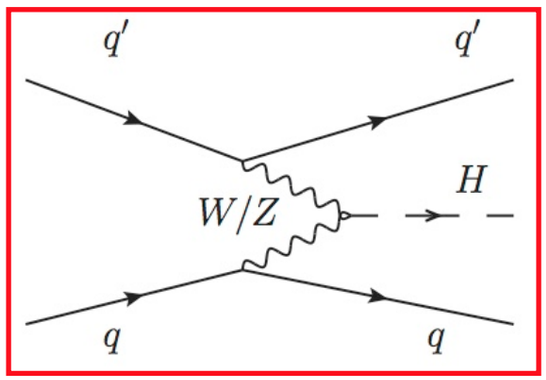
Higgs production branching ratios



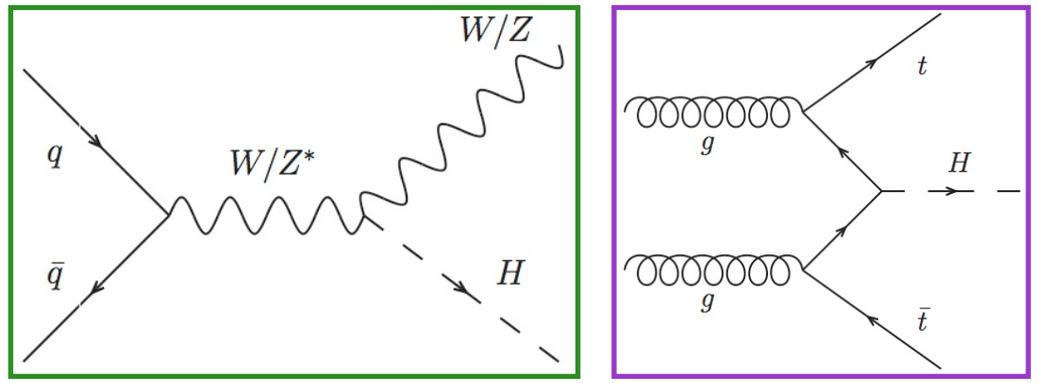
Gluon fusion



Vector boson fusion



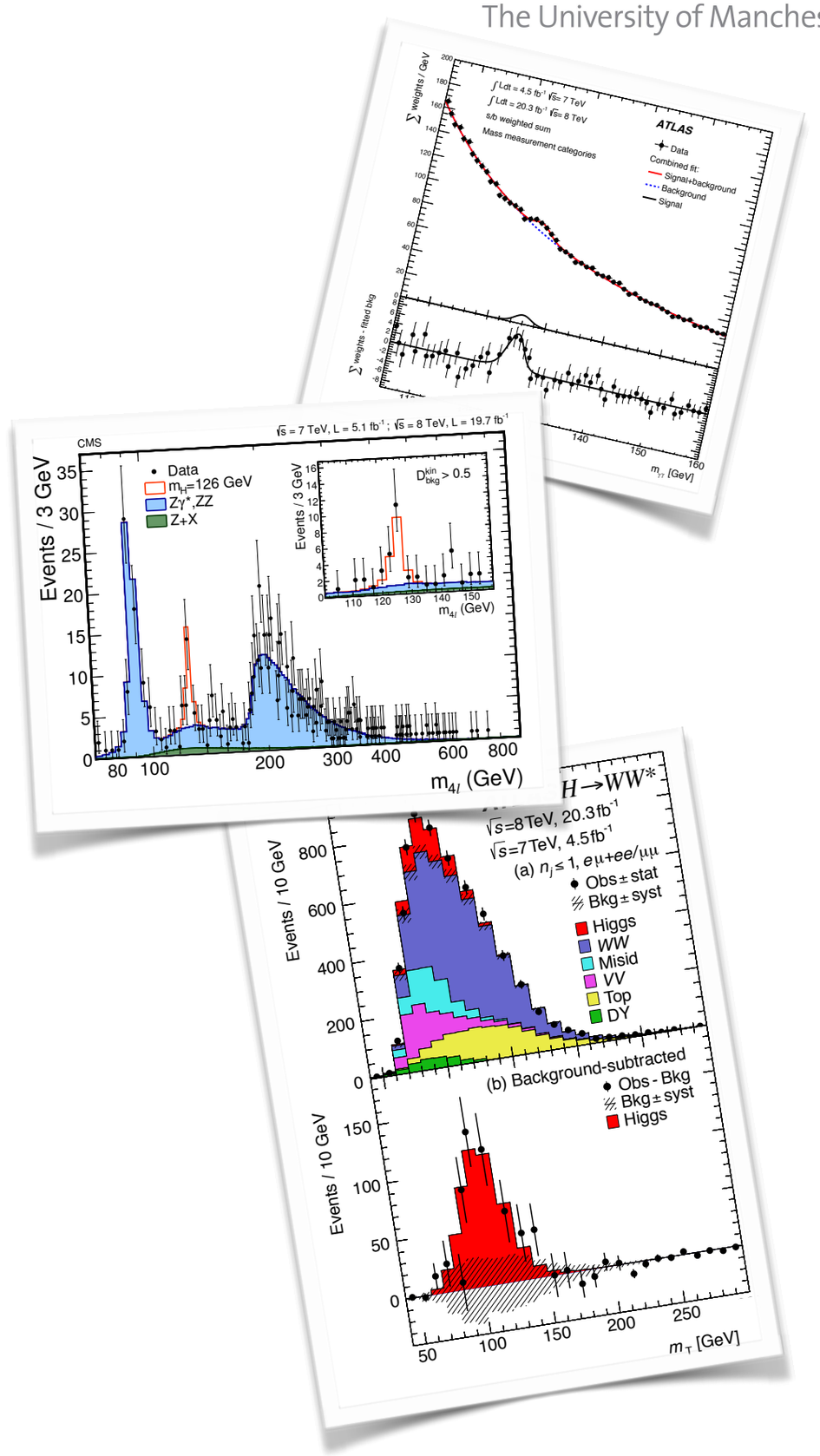
Associated production



Property measurements

- Very successful Run-1 at the LHC has allowed us to go from discovery towards precision measurements of the properties of the Higgs boson in diboson channels.
  - Mass
  - Width
  - Couplings

  } *See next talk by N. Lu*
  - **Spin & parity**
  - **Fiducial and differential cross sections**



Spin and parity ($\gamma\gamma$, ZZ^*, WW^*)

arXiv:1506.05669, submitted to EPJC

Eur. Phys. J. C75 (2015) 231

- Study spin and CP properties using the *Higgs characterisation model* described in arXiv:1306.6464, which uses an *effective field theory* (EFT) approach.

$$\mathcal{L}_0^V = \Big\{\cos(\alpha)\kappa_{\rm SM}\Big[\tfrac{1}{2}g_{HZZ}Z_\mu Z^\mu + g_{HWW}W_\mu^+ W^{-\mu}\Big] - \tfrac{1}{4}\tfrac{1}{\Lambda}\Big[\cos(\alpha)\kappa_{HZZ}Z_{\mu\nu}Z^{\mu\nu} + \sin(\alpha)\kappa_{AZZ}Z_{\mu\nu}\tilde{Z}^{\mu\nu}\Big] - \tfrac{1}{2}\tfrac{1}{\Lambda}\Big[\cos(\alpha)\kappa_{HWW}W_{\mu\nu}^+ W^{-\mu\nu} + \sin(\alpha)\kappa_{AWW}W_{\mu\nu}^+ \tilde{W}^{-\mu\nu}\Big]\Big\} X_0$$

- Discriminant observables sensitive to spin and parity of the signal used to probe spin-0 and spin-2 hypotheses:
  - **SM Higgs boson**
  - **BSM spin-0 CP-even**
  - **BSM spin-0 CP-odd**
  - **Mixtures of SM + spin-0 BSM CP-even or CP-odd**
  - Graviton-like spin-2 particle with universal and non-universal couplings

Spin and parity

- Study spin and CP properties using the *Higgs characterisation model* described in arXiv:1306.6464, which uses an *effective field theory* (EFT) approach.

$$\mathcal{L}_2 = -\frac{1}{\Lambda}\left[\sum_V \kappa_V \mathcal{T}^V_{\mu\nu} X^{\mu\nu} + \sum_f \kappa_f \mathcal{T}^f_{\mu\nu} X^{\mu\nu}\right]$$

Strength of vector boson coupling

Strength of fermion coupling

Universal couplings

$$\kappa_q = \kappa_g$$

Non-universal couplings

$$\kappa_q \neq \kappa_g$$

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  - SM Higgs boson
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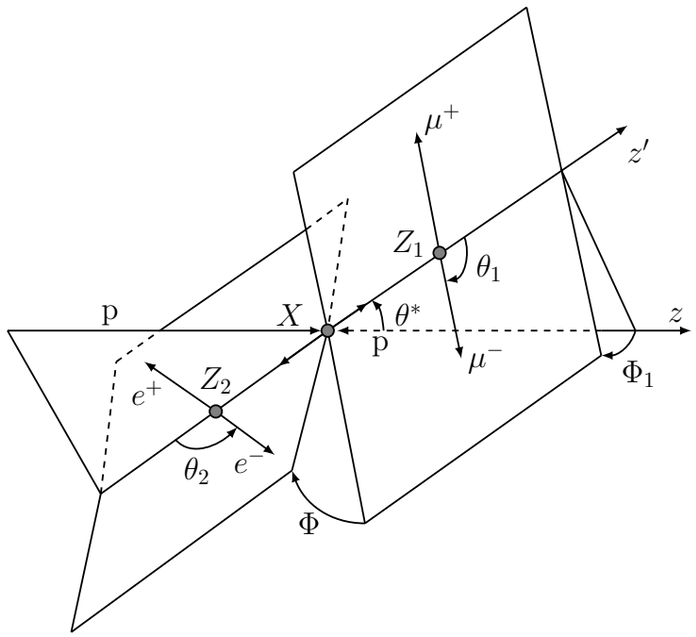
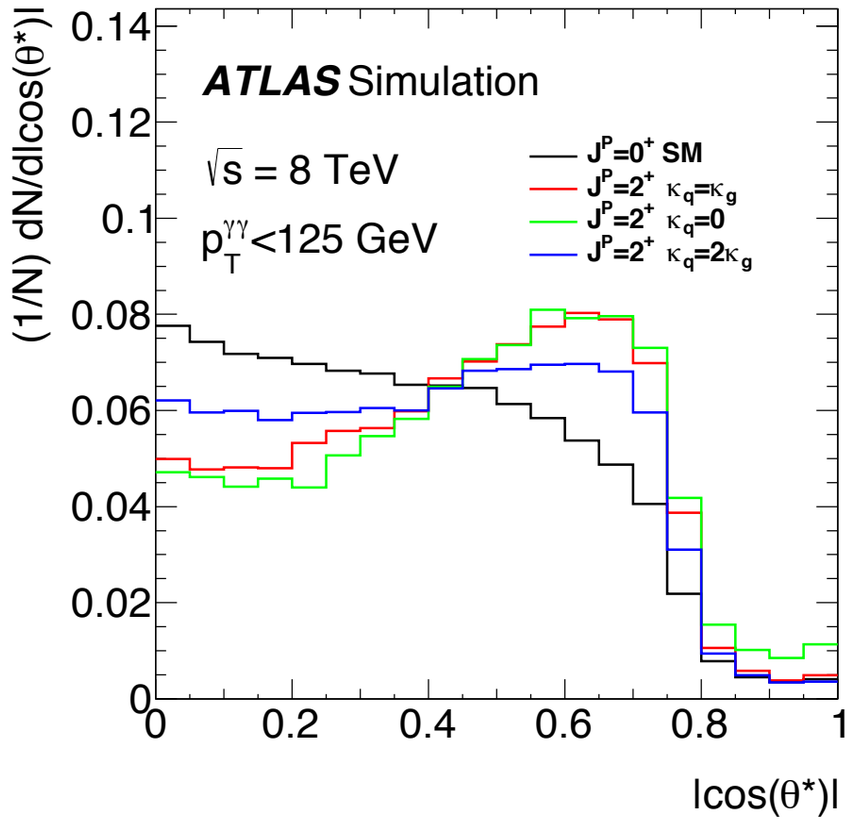
Spin and parity: discriminant observables



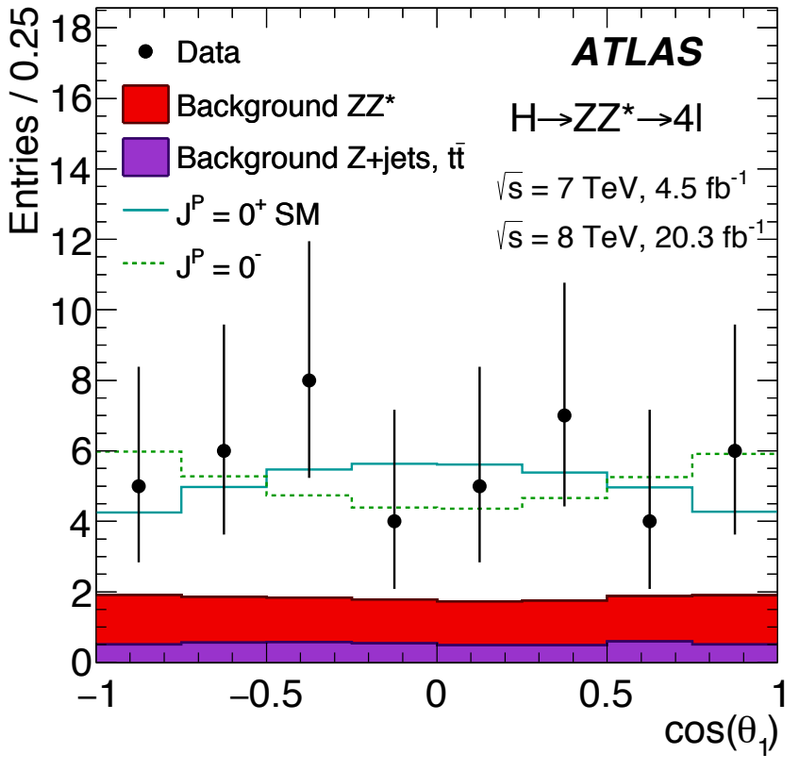
$H \to \gamma\gamma$

Categories in bins of $|\cos\theta^*|,\ p_{\mathrm{T}}^{\gamma\gamma}$



$H \to ZZ^*$

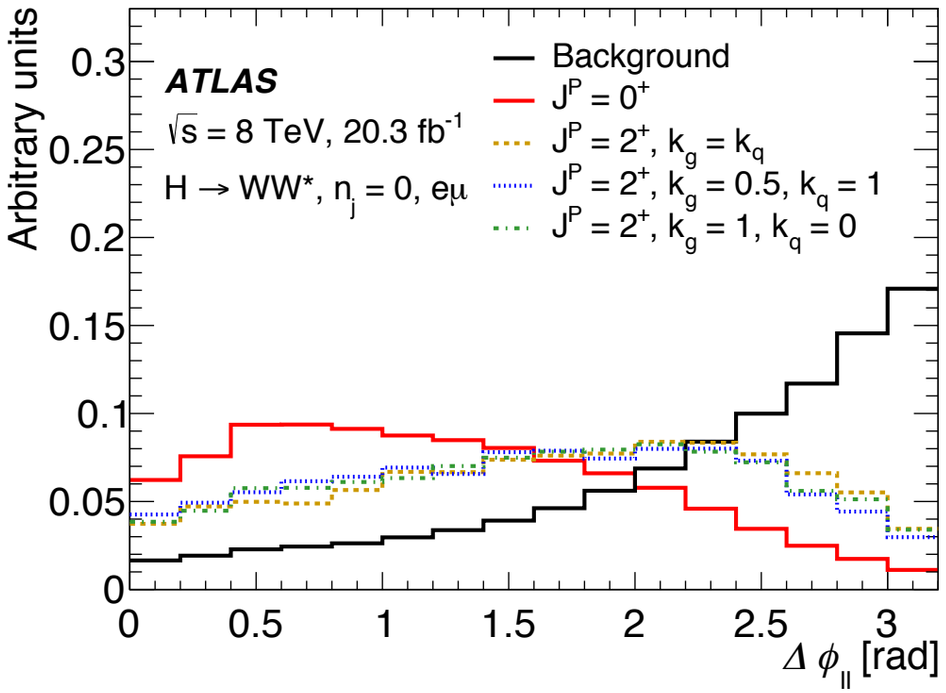
Matrix element based discriminant



$H \to WW^*$

BDTs trained on

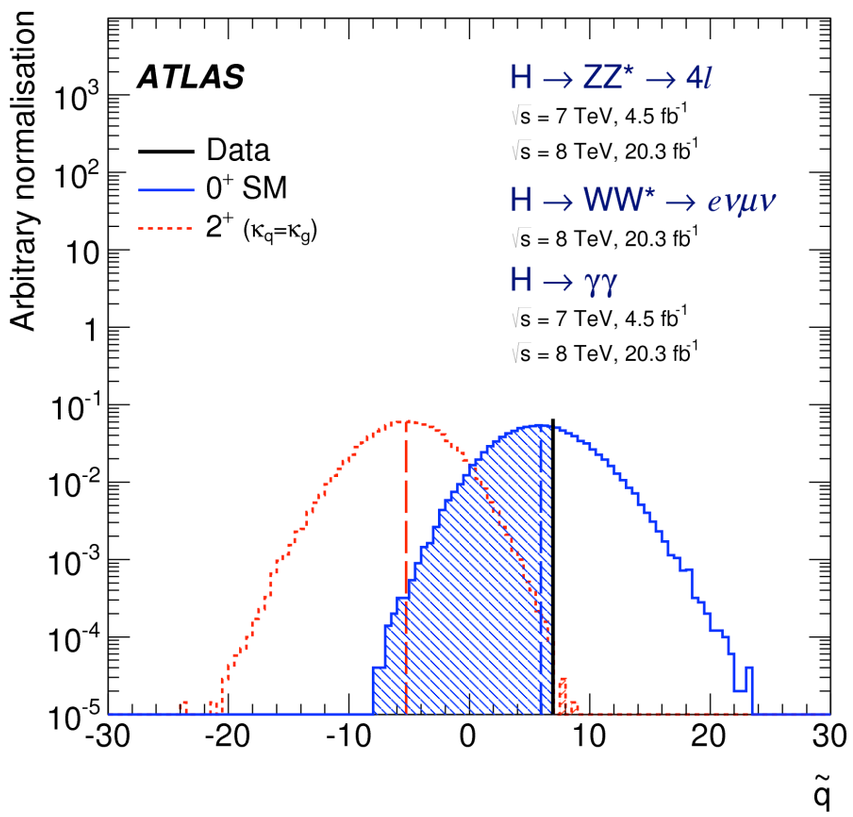
$p_{\mathrm{T}}^{\ell\ell},\ m_{\ell\ell},\ \Delta\phi_{\ell\ell},$
$m_{\mathrm{T}},\ p_{\mathrm{T}}^{miss},\ E_{\ell\ell\nu\nu}$

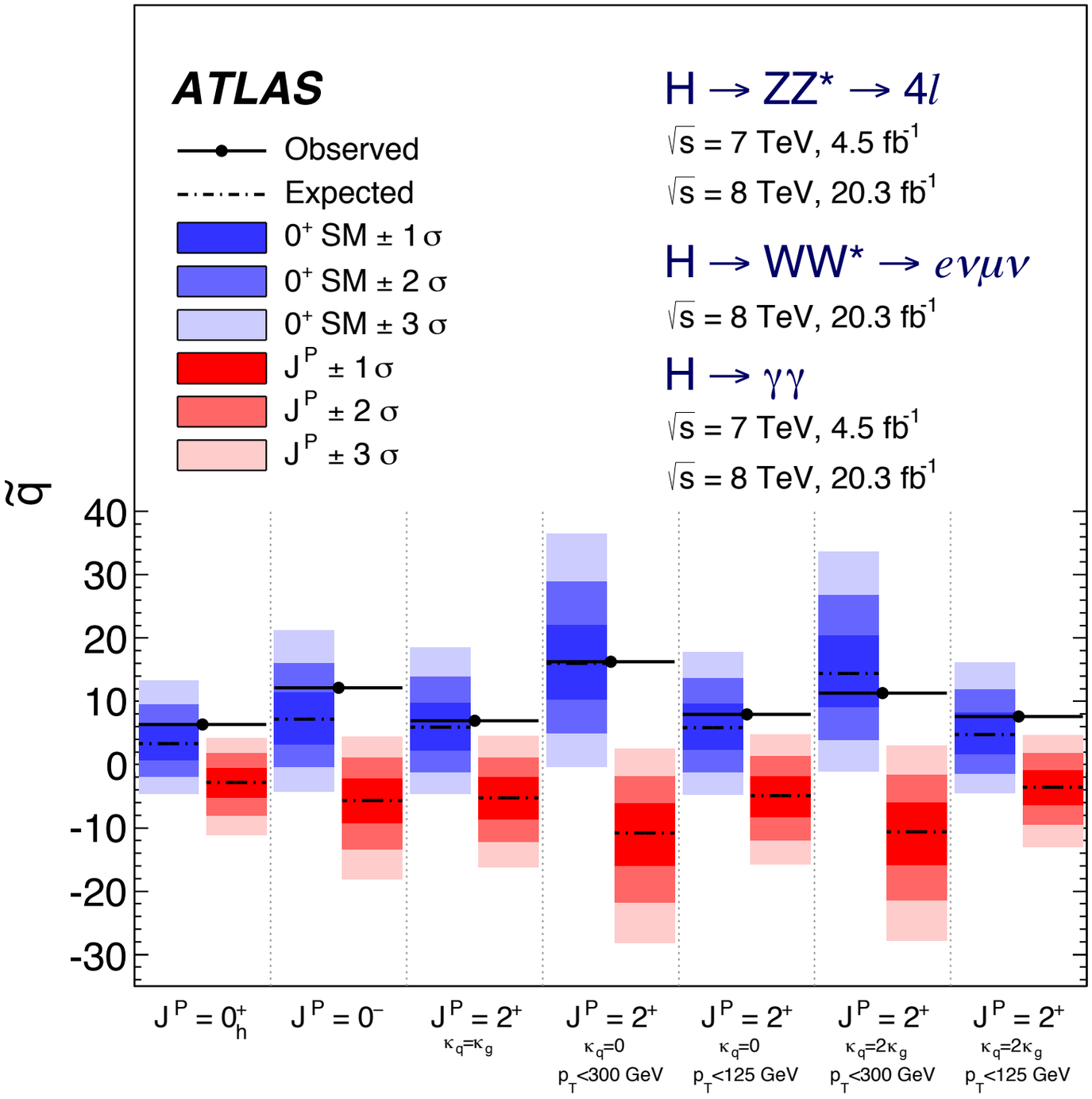


Spin and parity: non-SM hypotheses

- All considered non-SM spin hypotheses excluded at more than 99.9% CL.

$$\tilde{q} = \log \frac{\mathcal{L}(J^P_{\mathrm{SM}}, \hat{\hat{\mu}}_{J^P_{\mathrm{SM}}}, \hat{\hat{\theta}}_{J^P_{\mathrm{SM}}})}{\mathcal{L}(J^P_{\mathrm{alt}}, \hat{\hat{\mu}}_{J^P_{\mathrm{alt}}}, \hat{\hat{\theta}}_{J^P_{\mathrm{alt}}})}$$

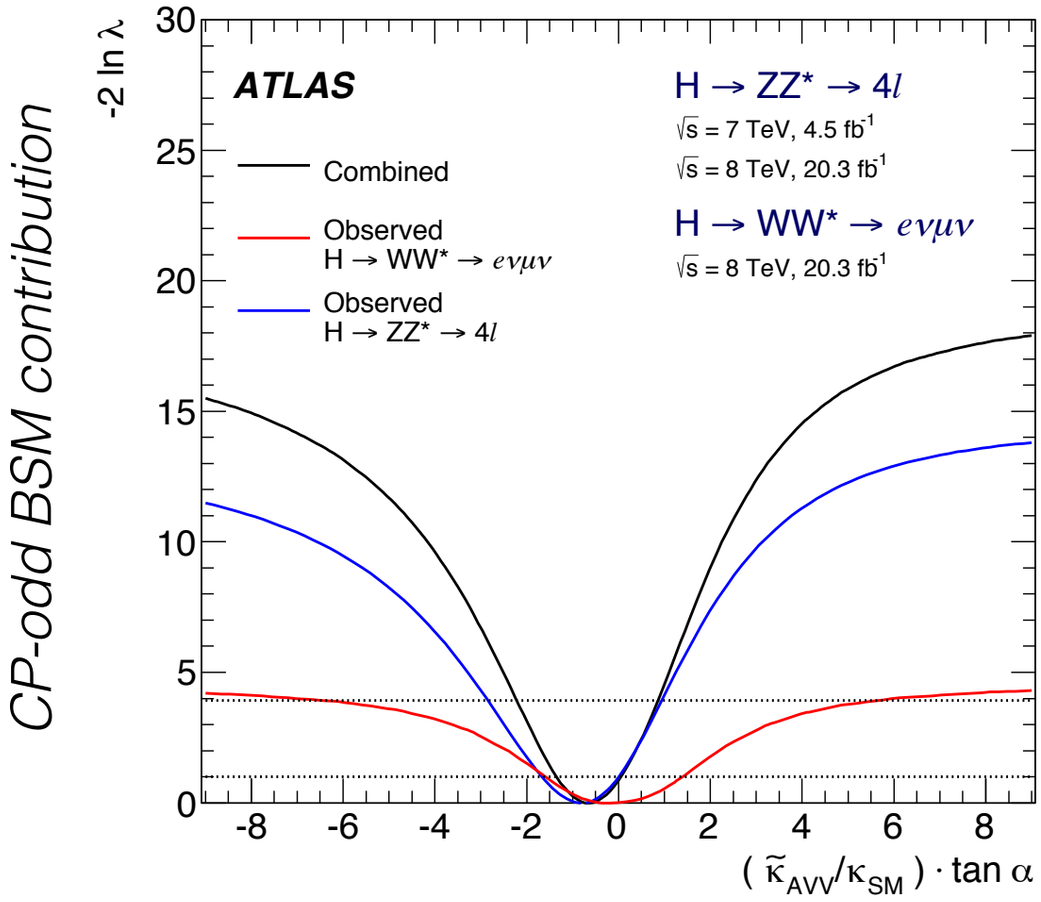




Spin and parity: HVV tensor coupling

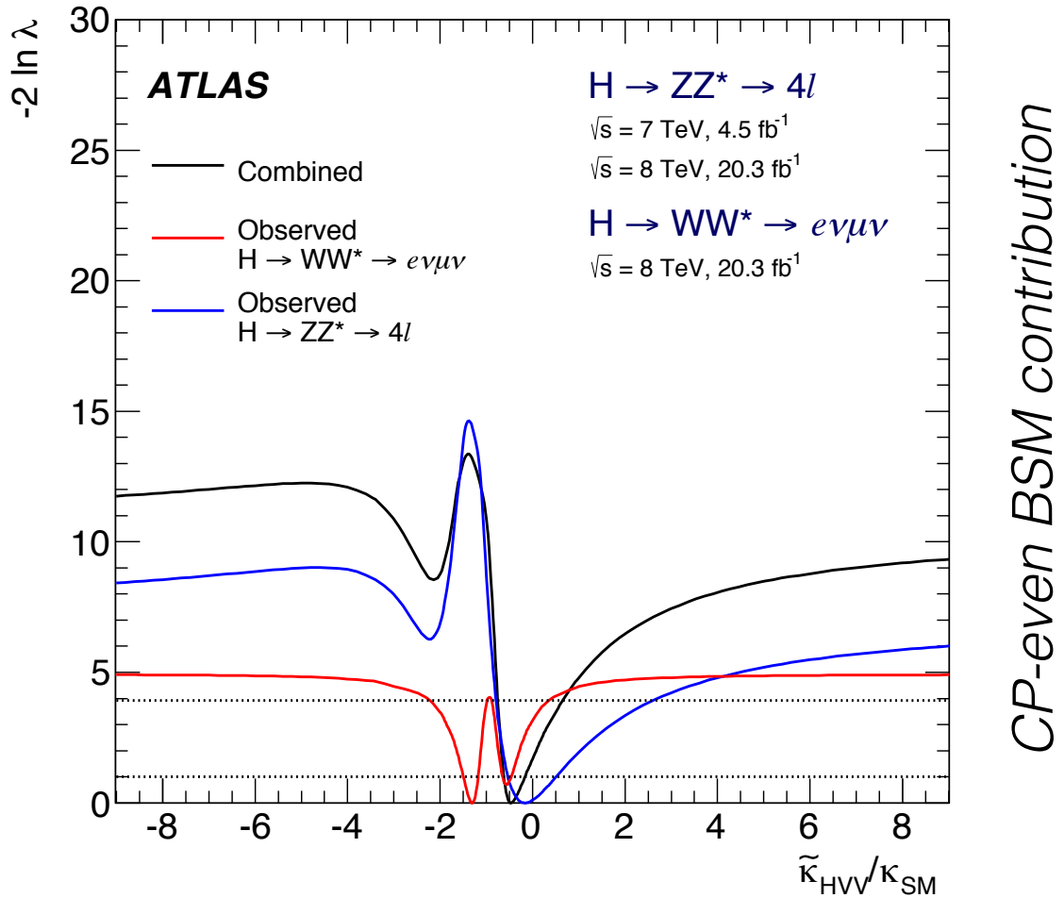
- Tensor structure of HVV interaction investigated assuming spin-0 hypothesis.
- Mixture of SM + BSM CP-even/CP-odd terms tested independently.
- Consistent with SM expectations.

$$\tilde{\kappa}_{AVV} = \frac{1}{4}\frac{\mathrm{v}}{\Lambda}\kappa_{AVV}$$



$$-2.18 < (\tilde{\kappa}_{AVV}/\kappa_{SM}) \cdot \tan\alpha < 0.83$$

$$\tilde{\kappa}_{HVV} = \frac{1}{4}\frac{\mathrm{v}}{\Lambda}\kappa_{HVV}$$



$$-0.73 < \tilde{\kappa}_{HVV}/\kappa_{SM} < 0.63$$

Fiducial and differential cross sections ($\gamma\gamma$, ZZ^*)

JHEP09(2014)112

Physics Letters B 738 (2014) 234-253

arXiv:1504.05833, accepted by PRL

arXiv:1508.02507, submitted to PLB

Fiducial and differential cross sections

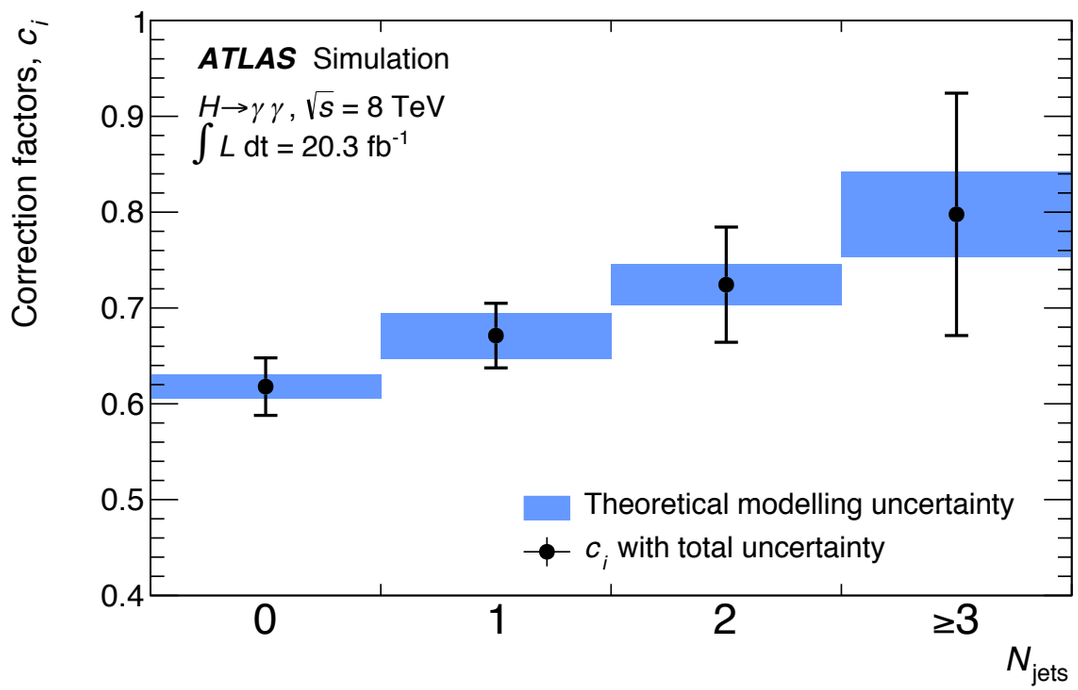
- *Cross sections*: direct measurement of Higgs production rates with minimal assumptions on the underlying model.
- Differential cross sections probe various properties of the Higgs boson: theoretical modelling of gluon fusion, spin/CP, jet activity.
- Corrected for efficiency and resolution of detector to *particle level* within a *fiducial volume* to reduce model dependence.

Fiducial cross section — *Signal yield*

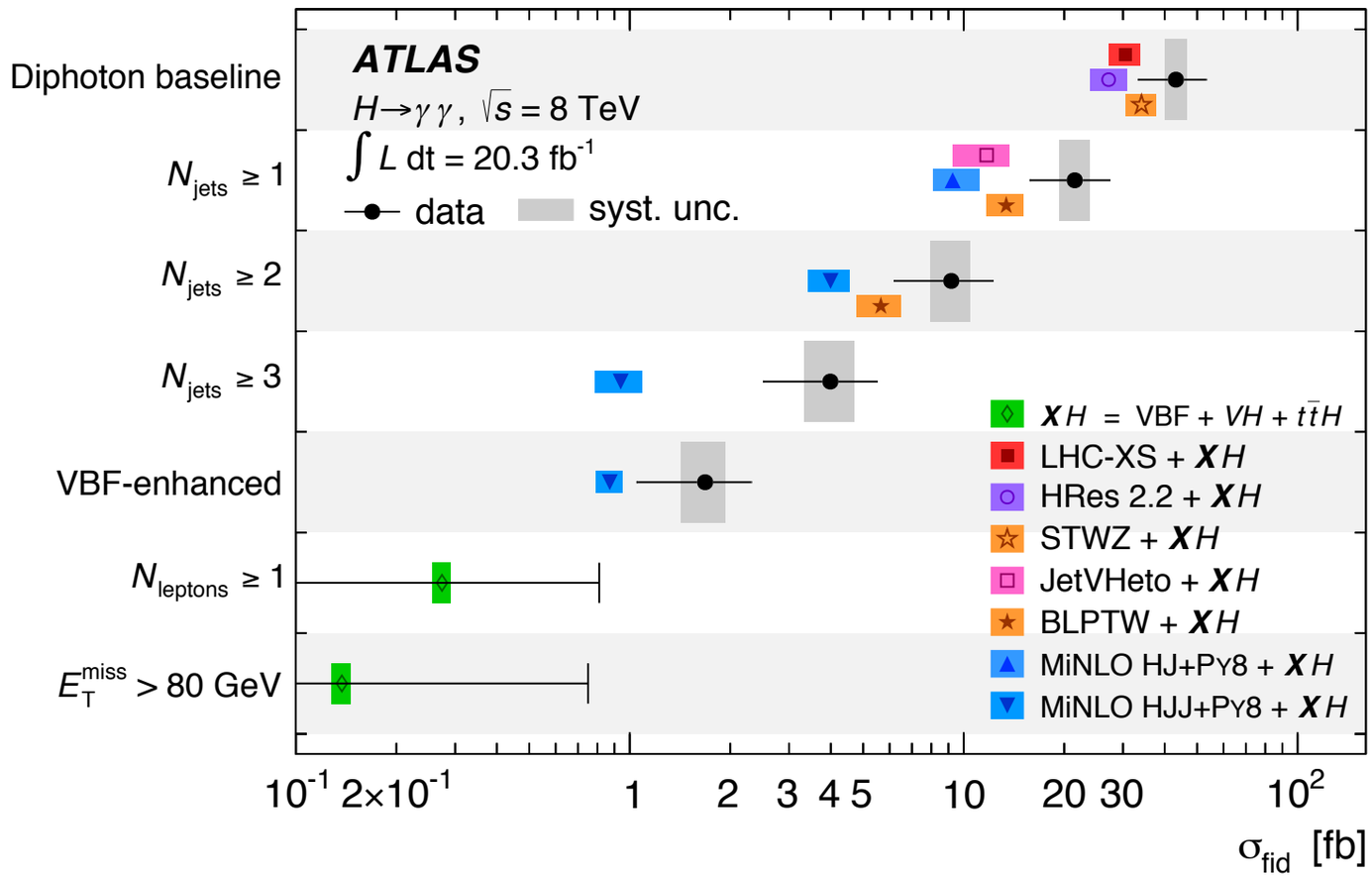
$$\sigma_i^{fid} = \frac{\nu_i^{sig}}{c_i \int L\mathrm{d}t}$$

Correction factor — *Integrated luminosity*

$$c_i = \frac{N_i^{det}}{N_i^{ptcl,fid}}$$



Fiducial cross sections



$$pp \to H \to \gamma\gamma$$

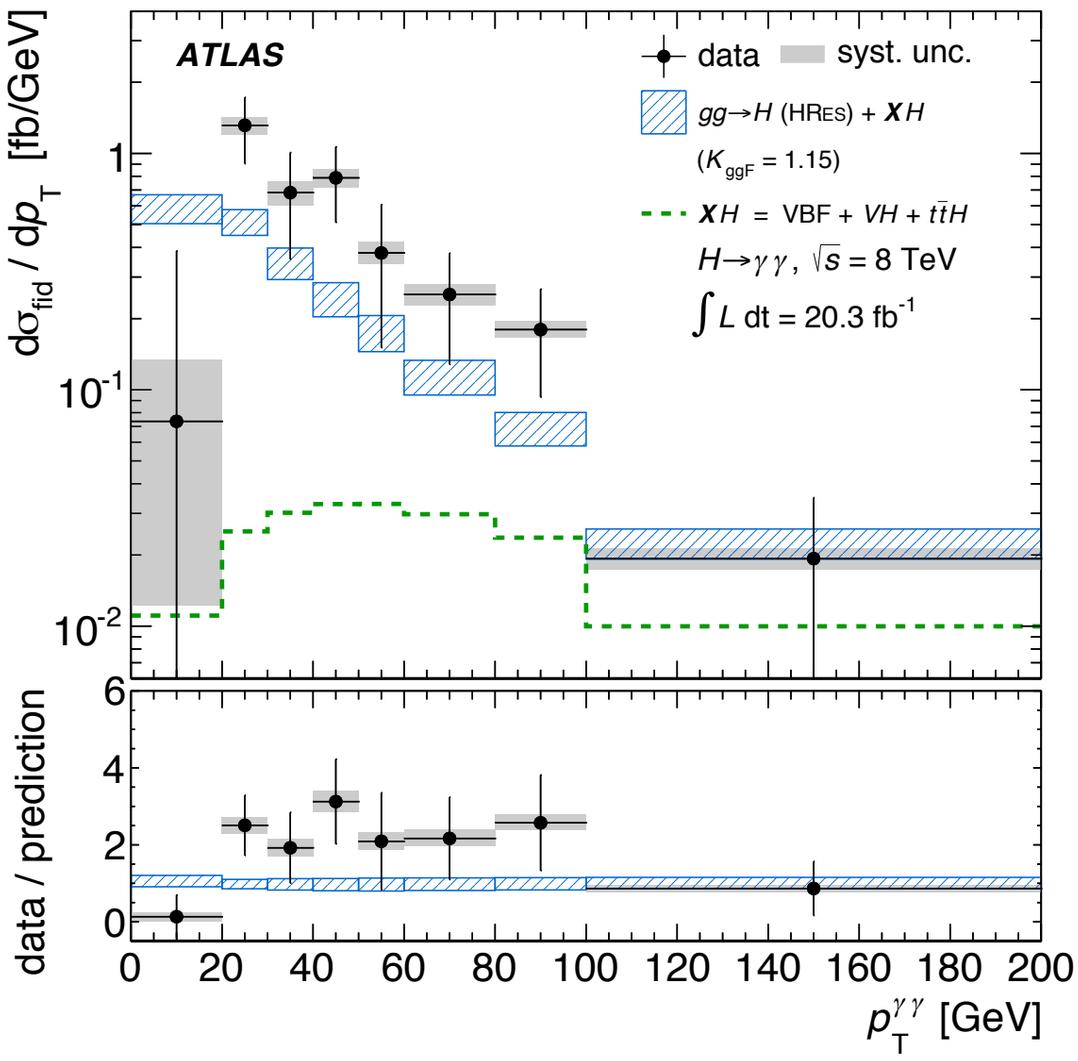
$$\sigma_{fid} = 43.2 \pm 9.4\ (\text{stat.}) \pm {}^{+3.2}_{-2.9}\ (\text{syst.}) \pm 1.2\ (\text{lumi})\ \text{fb}$$
$$\sigma_{\text{LHC-XS}} = 30.5 \pm 3.3\ \text{fb}$$

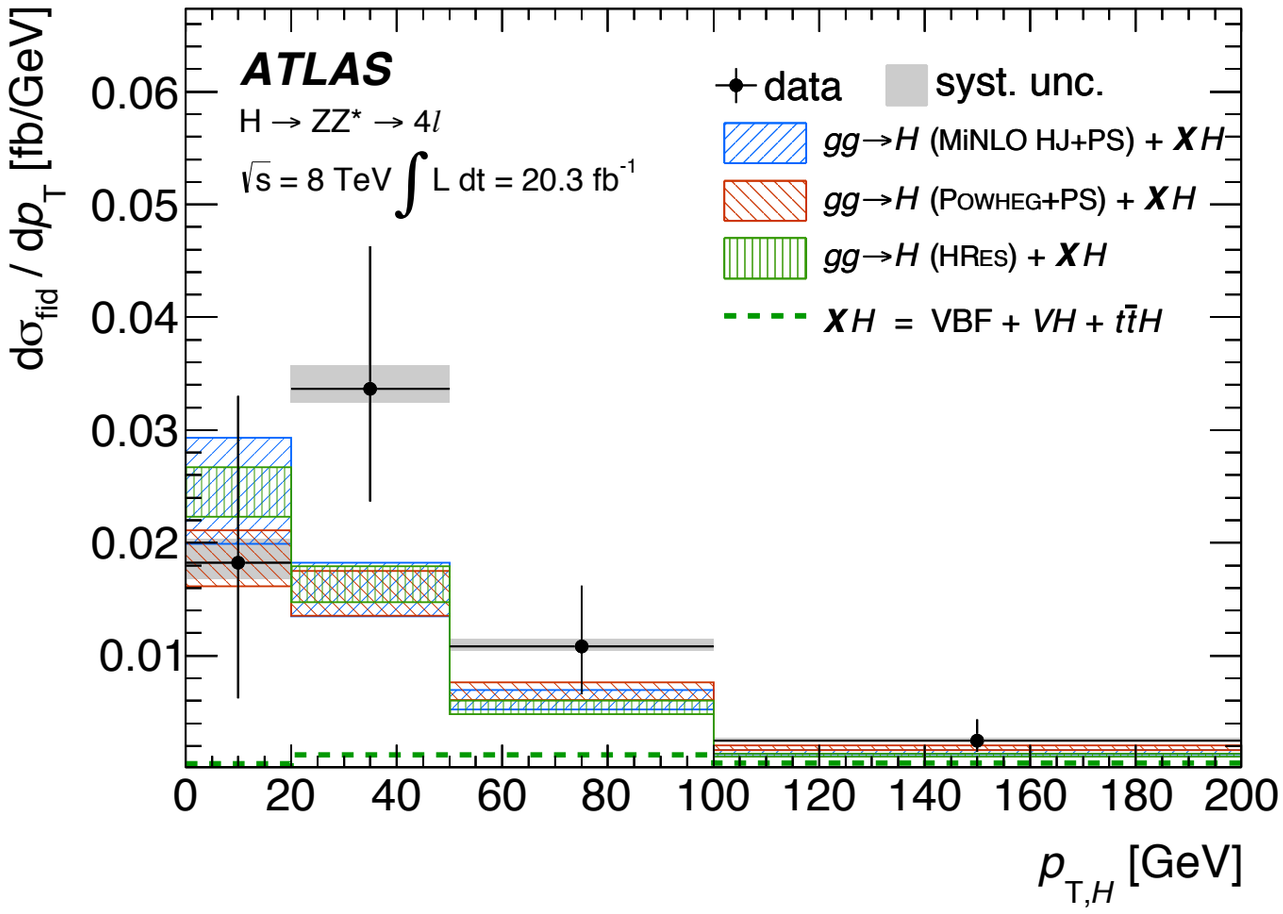
$$pp \to H \to ZZ^* \to 4l$$

$$\sigma_{fid} = 2.11\ {}^{+0.53}_{-0.47}\ (\text{stat.}) \pm 0.08\ (\text{syst.})\ \text{fb}$$
$$\sigma_{\text{LHC-XS}} = 1.3 \pm 0.13\ \text{fb}$$

Differential cross sections

- Differential distributions broadly in line with SM expectations and compatible between $\gamma\gamma$ and ZZ* channels.
- Many observables measured, unfolded data and uncertainties available on HepData.





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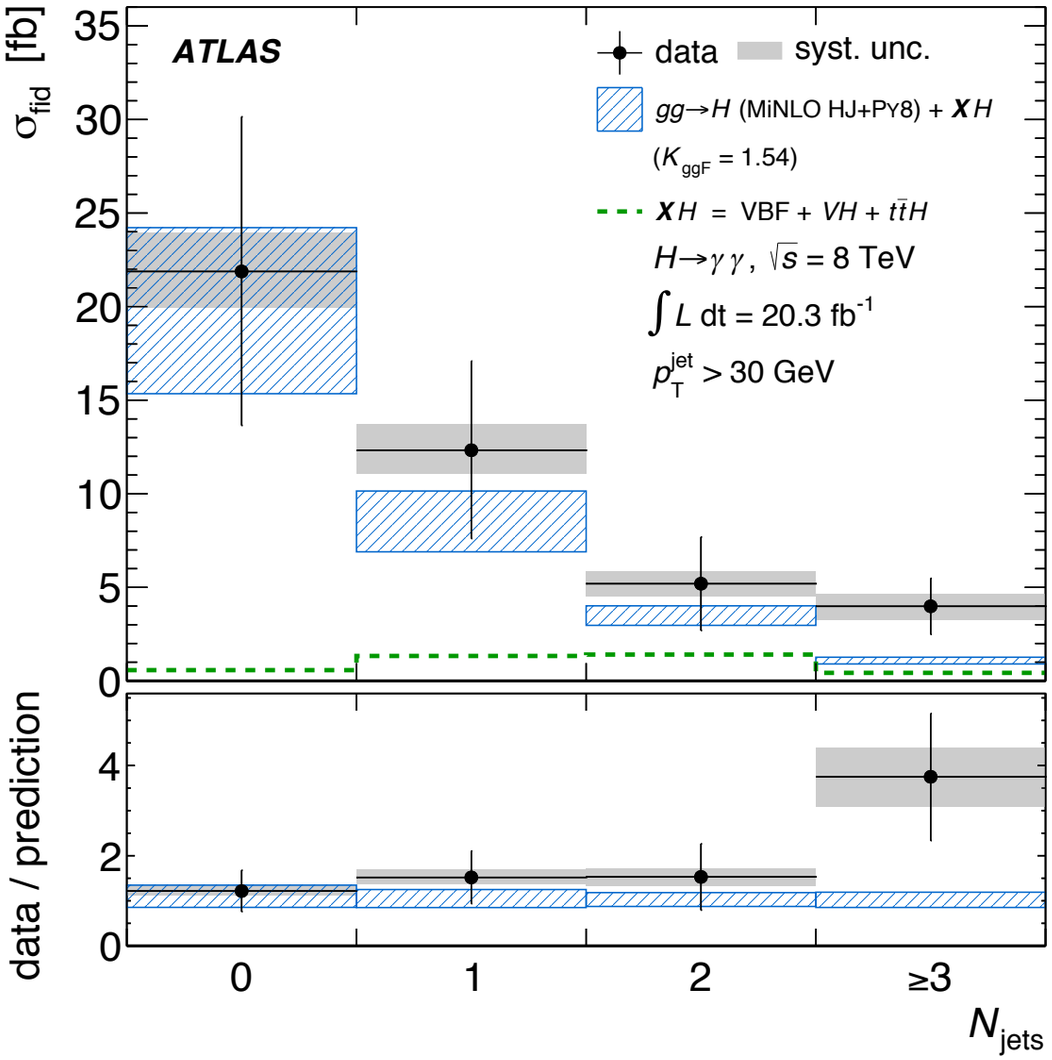
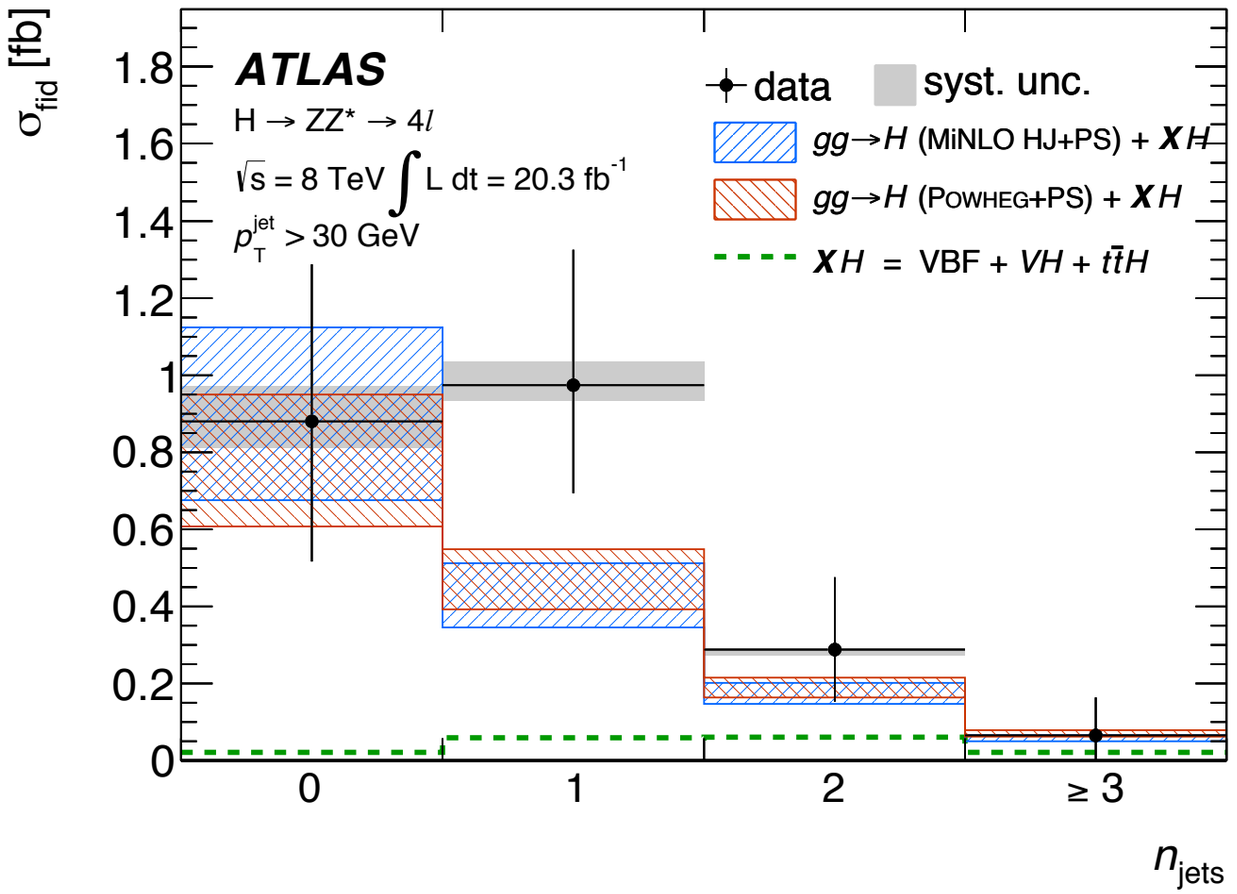
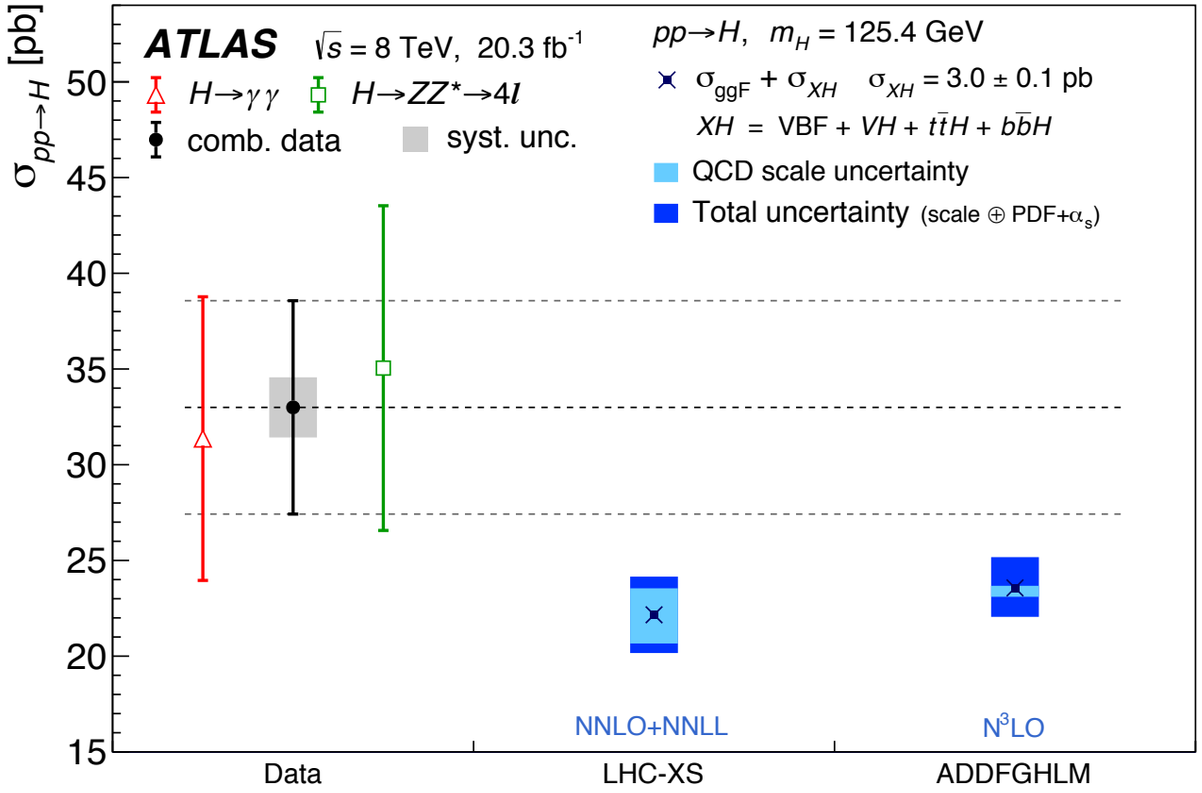




Total cross section and combined differential distributions

- Total cross section and differential distributions from combining data in the $\gamma\gamma$ and ZZ* channels.
- Corrected for branching fraction and fiducial acceptance.
- Overall normalisation higher, but shapes of distributions consistent with SM.



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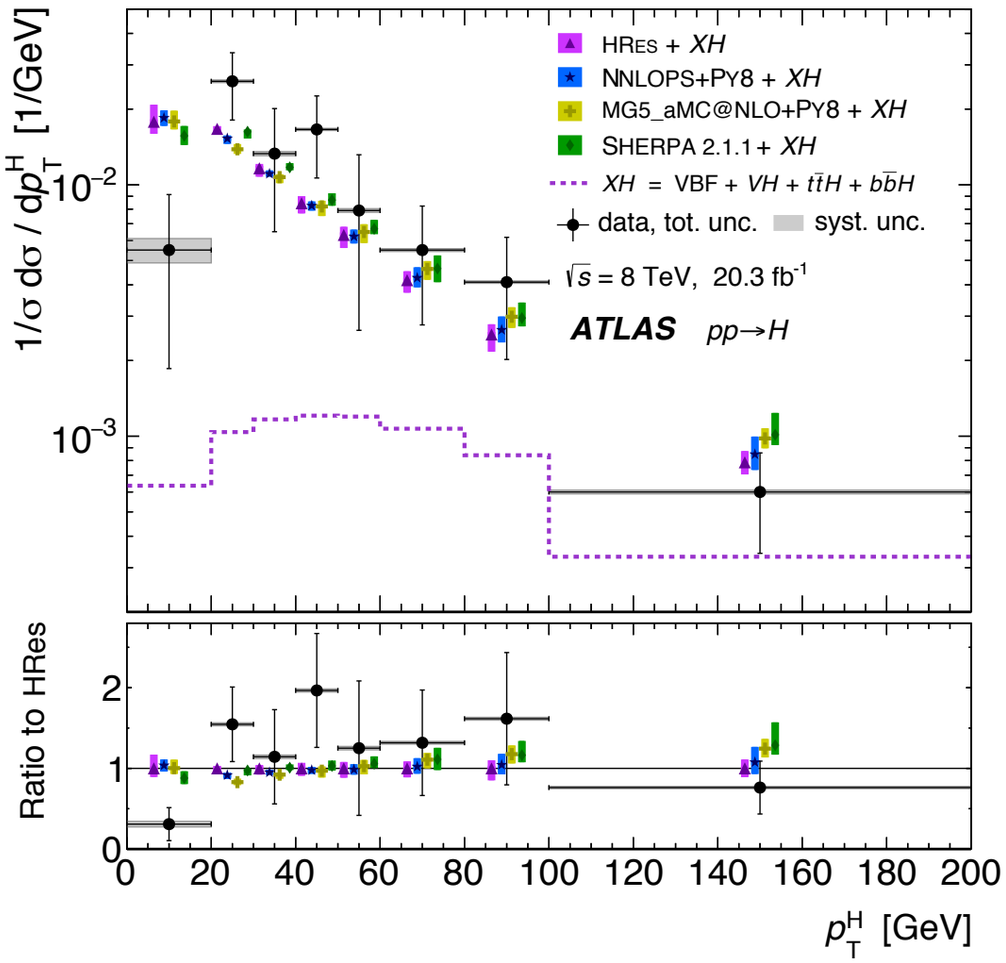
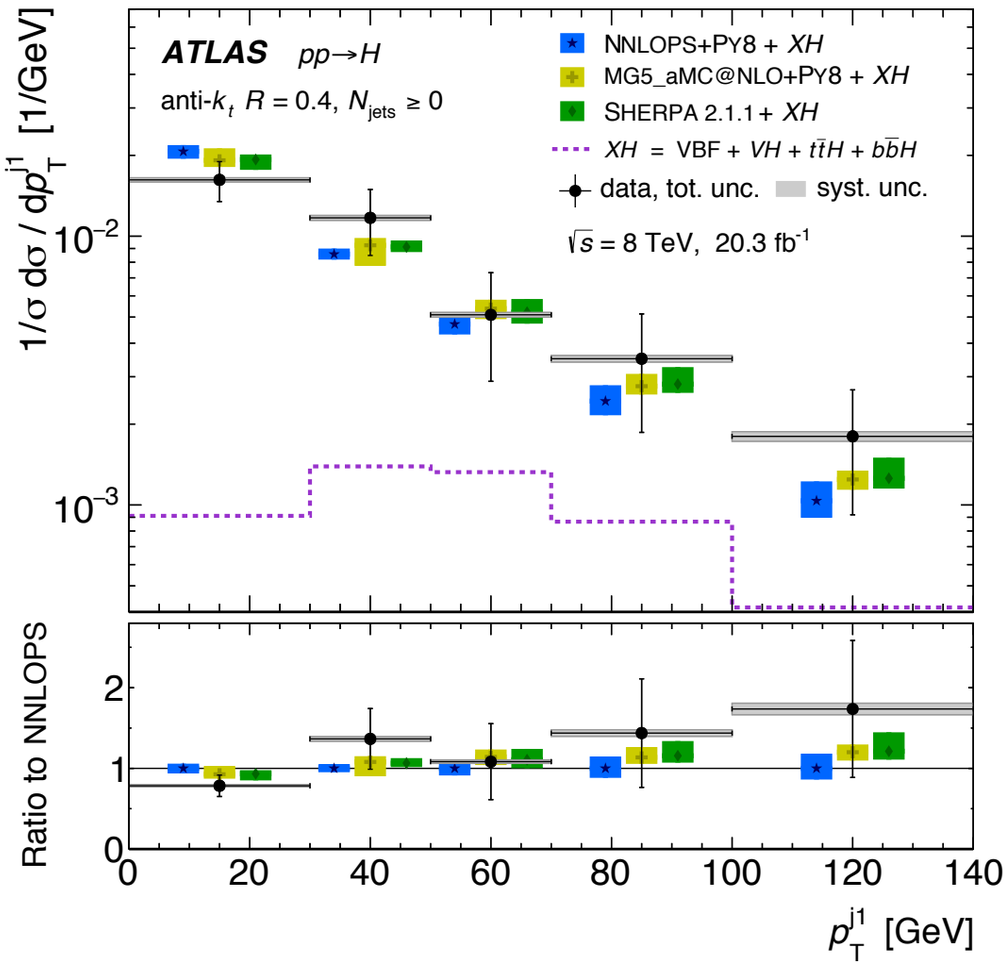
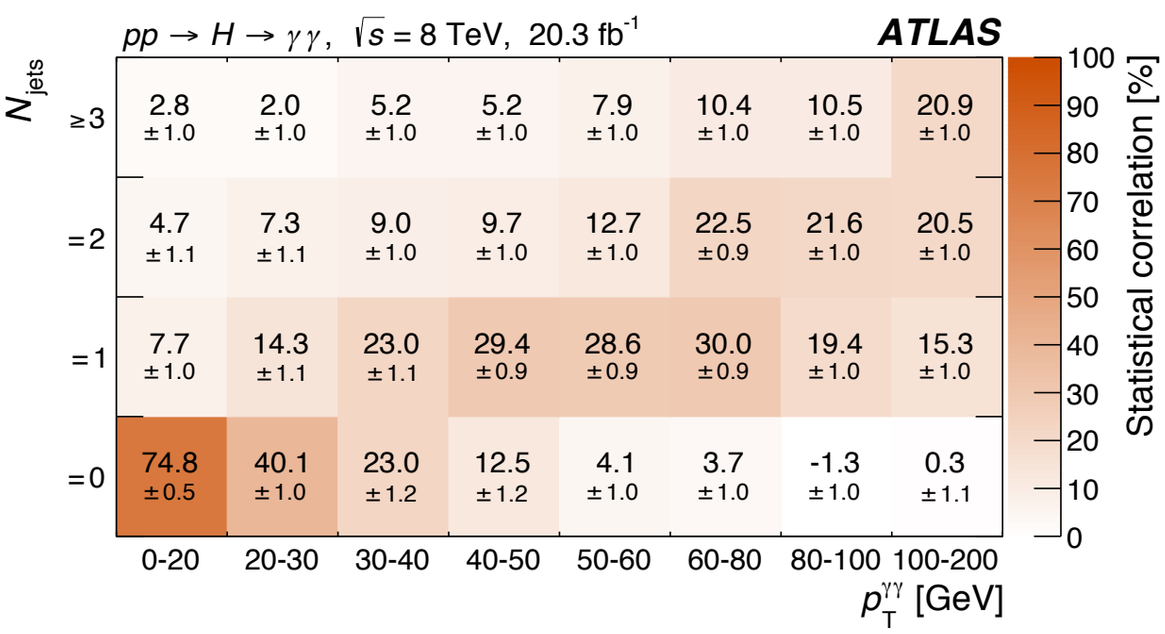


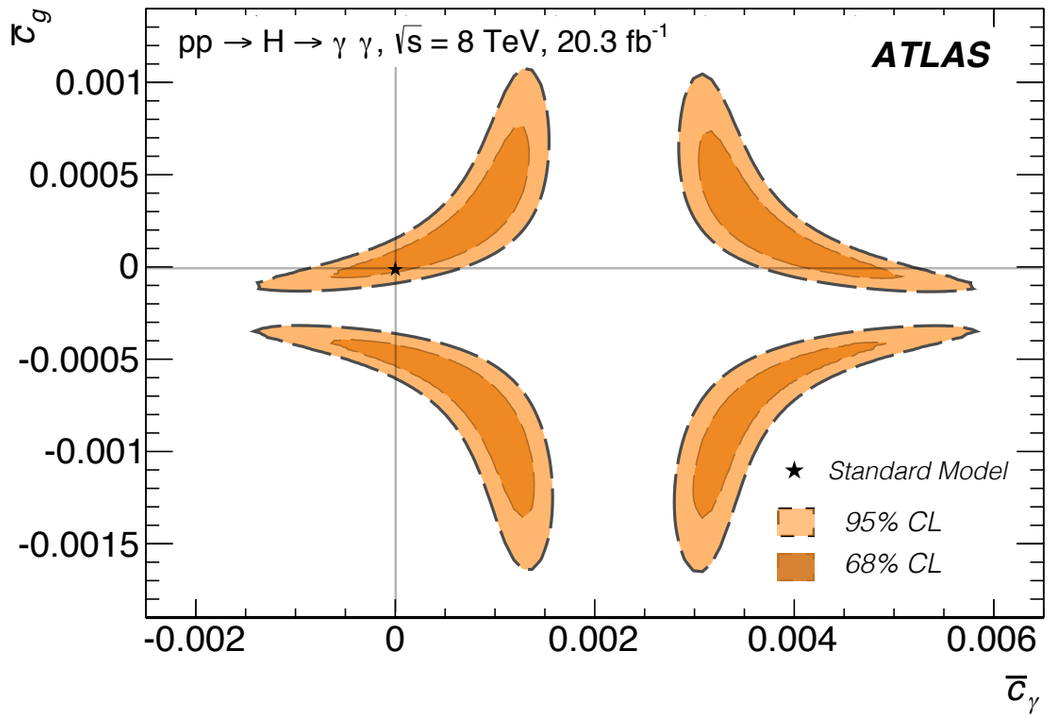


Constraints on HEFT using differential distributions

- Set limits on *Wilson coefficients* for *strongly interacting light Higgs* (SILH) EFT formulation, from arXiv:1303.3876.
- Analyses 5 differential distributions from γγ measurement ($p_T^{\gamma\gamma}$, N_{jets}, p_T^{j1}, m_{jj}, $\Delta\phi_{jj}$).
  - Statistical correlations between observables produced from toys.
- Results consistent with expectations for a SM Higgs boson.

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





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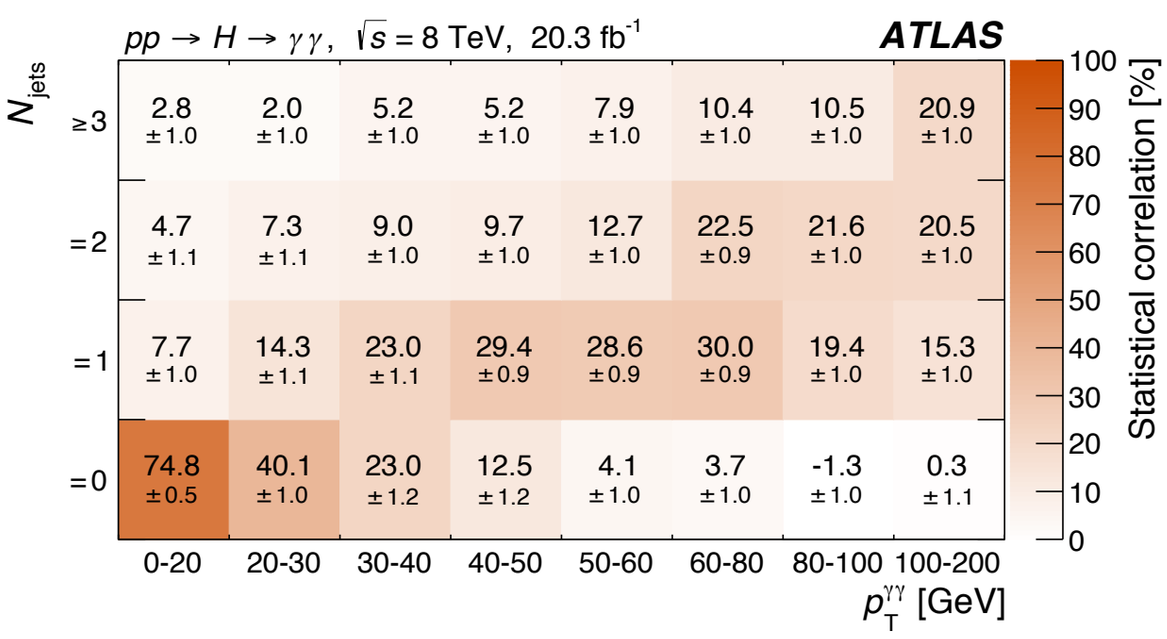
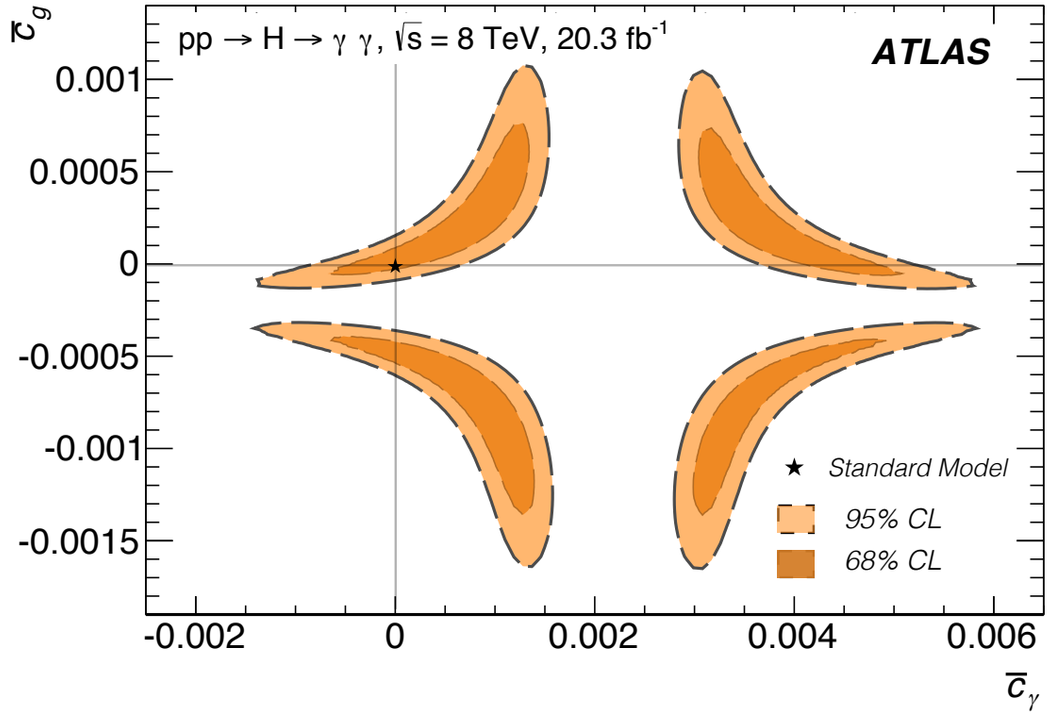
$$+ \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_g \tilde{O}_g + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB} \quad \textit{CP-odd}$$





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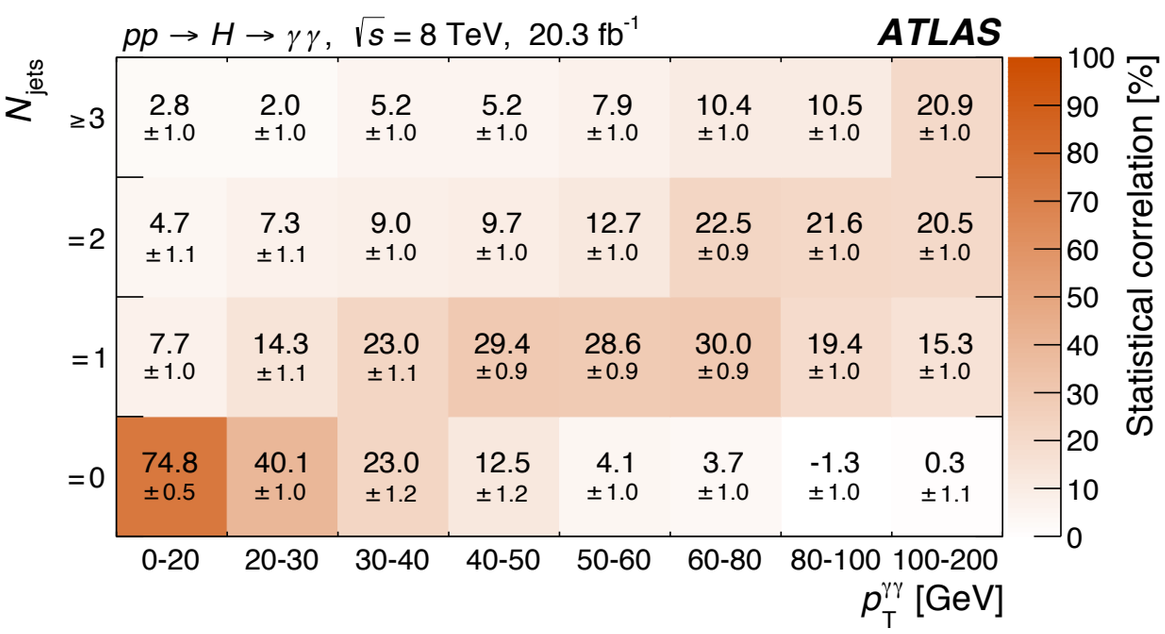

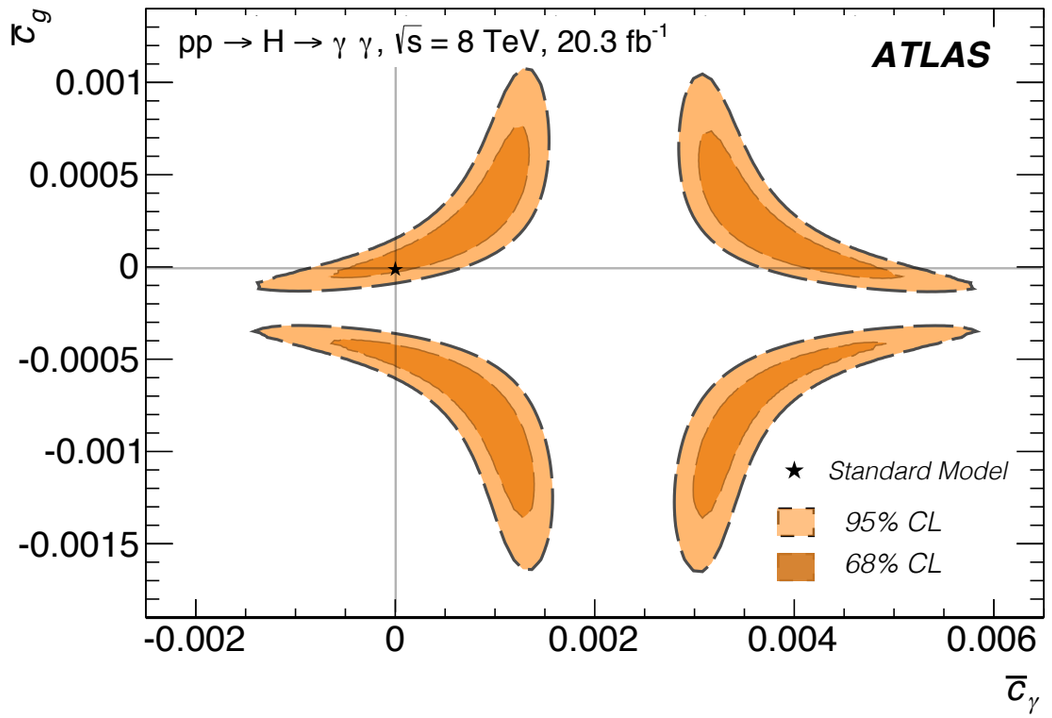

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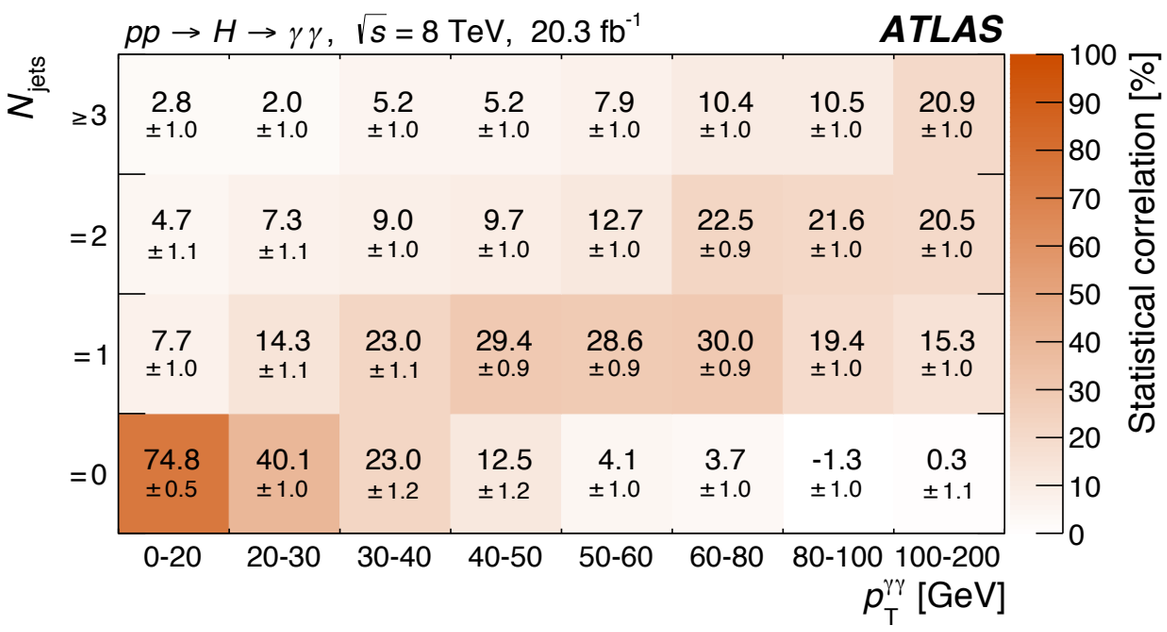
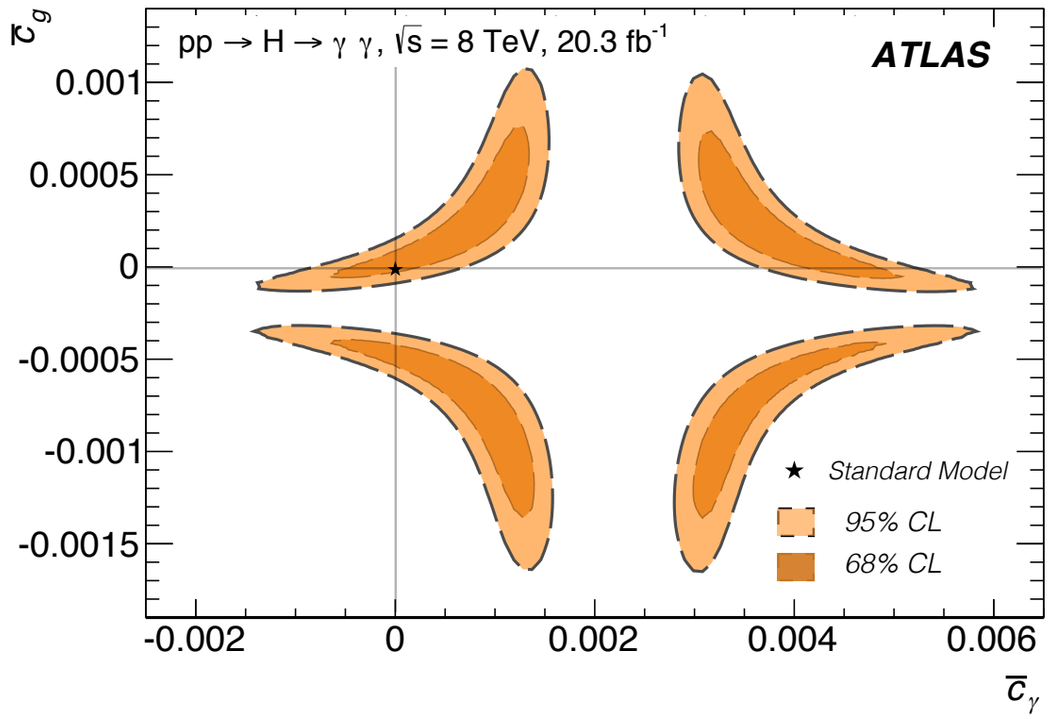
Terms affect coupling of Higgs to photons, gluons and vector bosons





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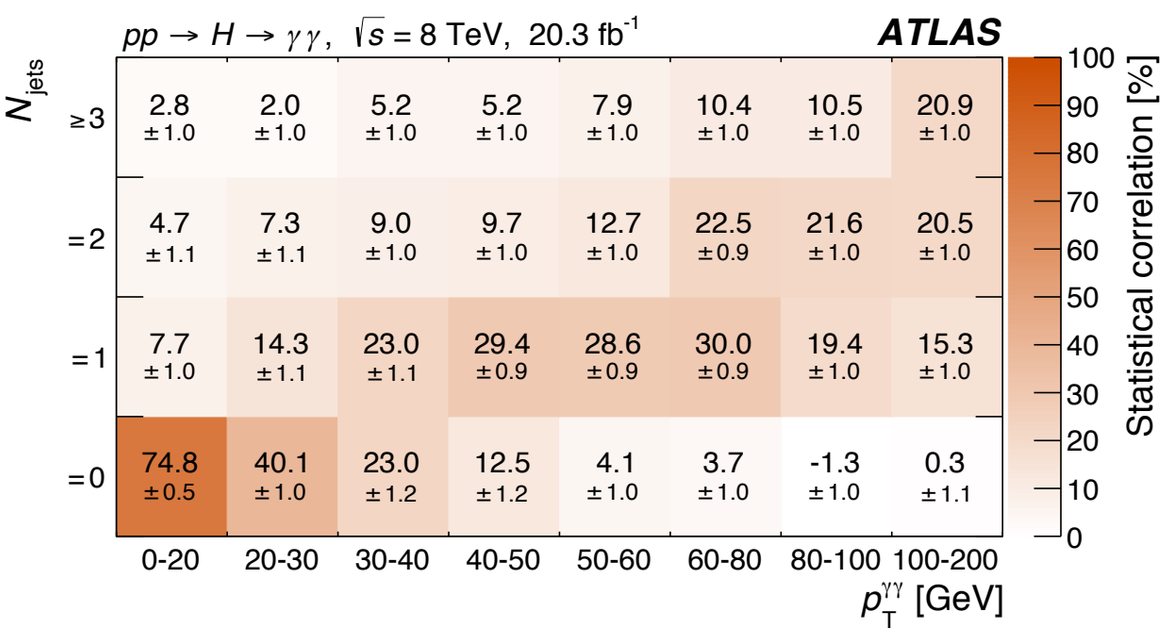

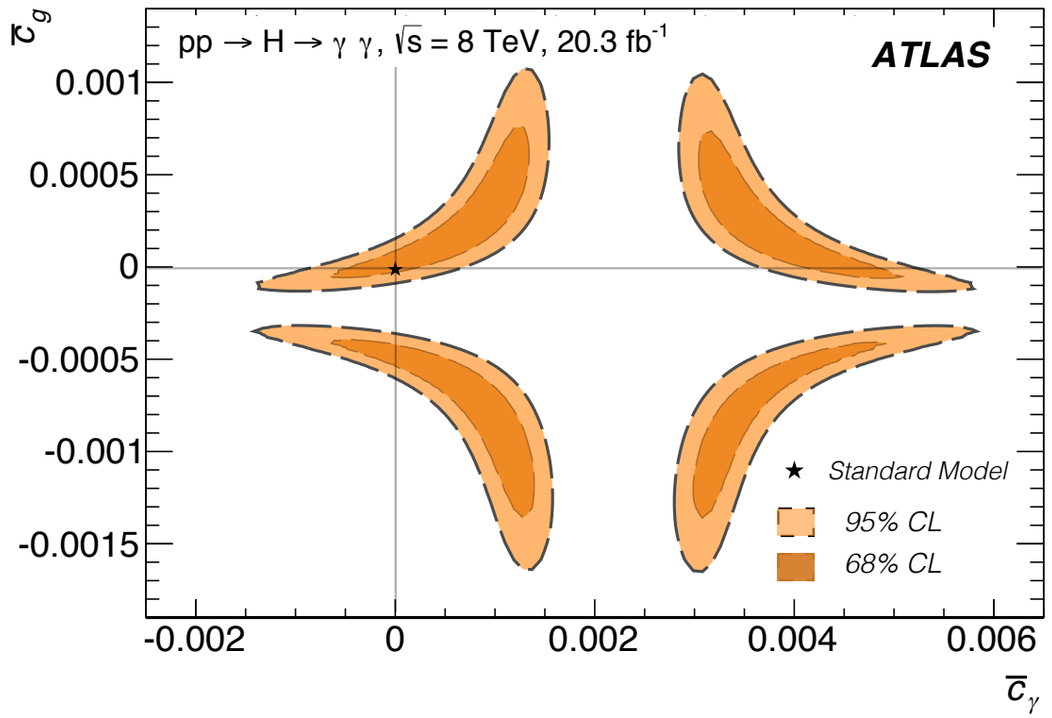

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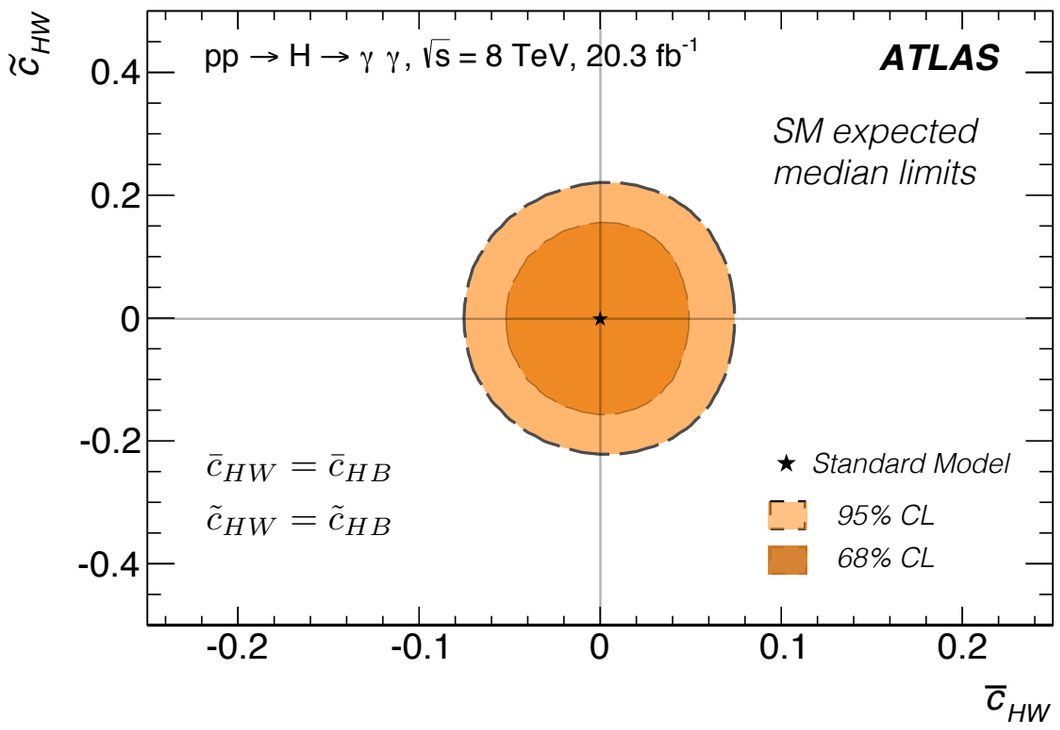
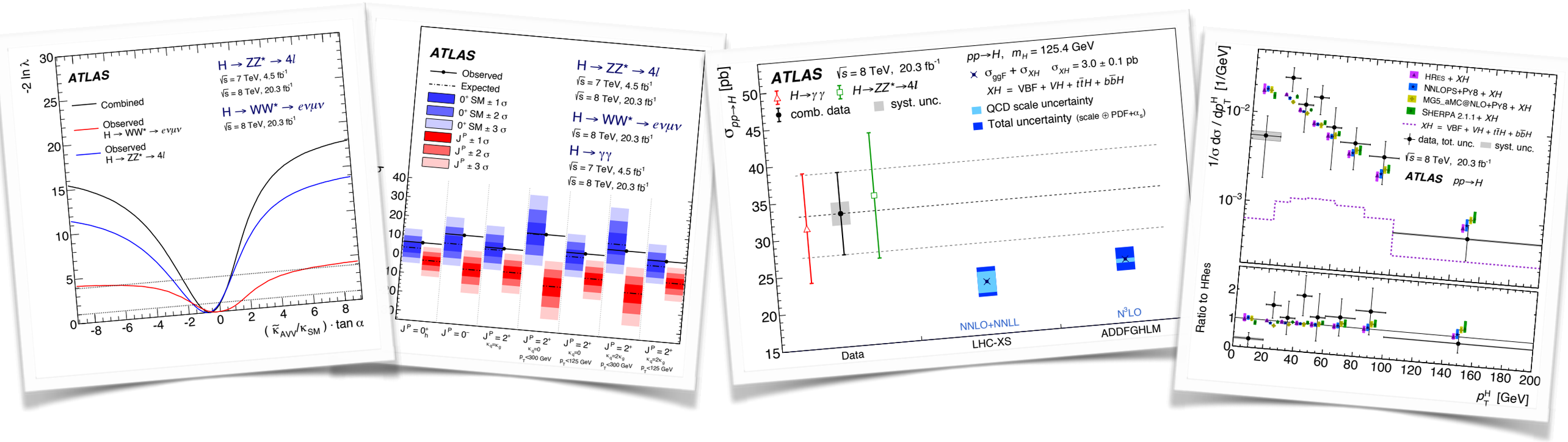


95% confidence intervals can be translated to Higgs characterisation framework

$$-0.08 < \tilde{\kappa}_{\mathrm{HVV}}/\kappa_{\mathrm{SM}} < 0.09$$

$$-0.22 < \tan(\alpha) \cdot \tilde{\kappa}_{\mathrm{AVV}}/\kappa_{\mathrm{SM}} < 0.22$$

Summary & Outlook



- Run-1 at the LHC has been very successful for physics in the Higgs sector.
  - Transitioned from search to discovery to begin precision measurements.
- Current measurements of spin & parity, fiducial and differential cross sections are reasonably consistent with SM expectations.
- Run-2 will allow for more precise measurements, and to extend to other channels.