Higgs potential and BSM opportunity

Fiducial and differential cross-section measurements in $H \to \gamma\gamma$ channel at 139 fb-1 with ATLAS

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Motivation

- ***Differential Fiducial Higgs measurements:***
  - ***Test the SM Higgs boson properties in a wide variety of physics observables***
  - ***Probe for BSM contributions***:
    - compare measured differential cross-sections distributions to state-of-the-art SM theories
  - ***Measurements are inclusive in production mode (fiducial phase space)***
    - minimize model-dependence and comparisons with future and alternative theory calculations
- ***Presented in this talk:***
  - ***Studied observables and comparisons with SM predictions***
  - ***EFT interpretation of the measurements***
  - ***charm-Yukawa coupling probing through pT(H) distribution***

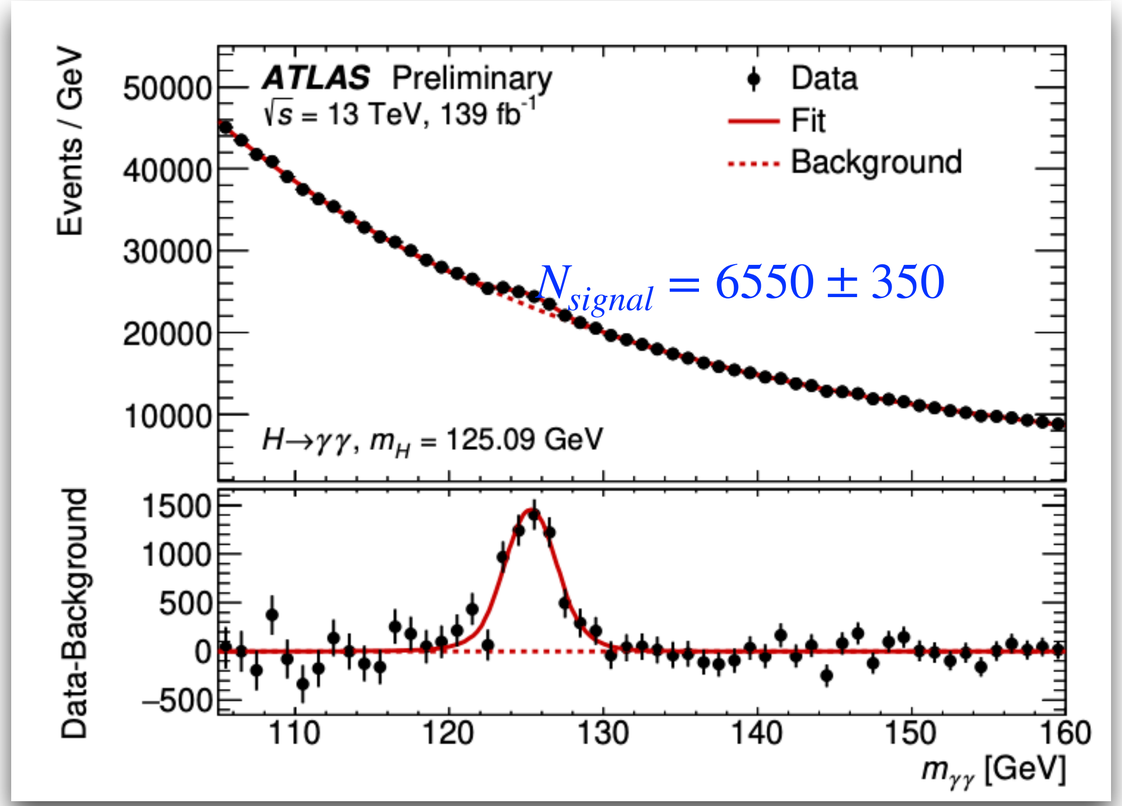
$H \to \gamma\gamma$ channel

ATLAS-CONF-2019-029

- ***Signature:*** two reconstructed isolated photons
  - ***kinematic selections:***
    - $pT(\gamma_1) > 0.35 m_{\gamma\gamma}$; $pT(\gamma_2) > 0.25 m_{\gamma\gamma}$
    - $|\eta| < 2.37$ (exclude 1.37-1.52 region)
    - Jets: pT > 30 GeV, |y| < 4.4
    - $105\ GeV < m_{\gamma\gamma} < 160\ GeV$
  - ***Signal Modelling*:**
    - double-sided Crystal Ball function: MC simulation

- ***Background sources and modelling:***
  - SM $\gamma\gamma$ production (irreducible) and $\gamma - jet$ and $jet - jet$ (reducible ones)
  - choice of the background model: signal+background fits to $m_{\gamma\gamma}$ background-only templates:
    - function's choice uncertainty ('spurious signal')

Fits to $m_{\gamma\gamma}$ to extract the signal yields



Measurement (inclusive fiducial)

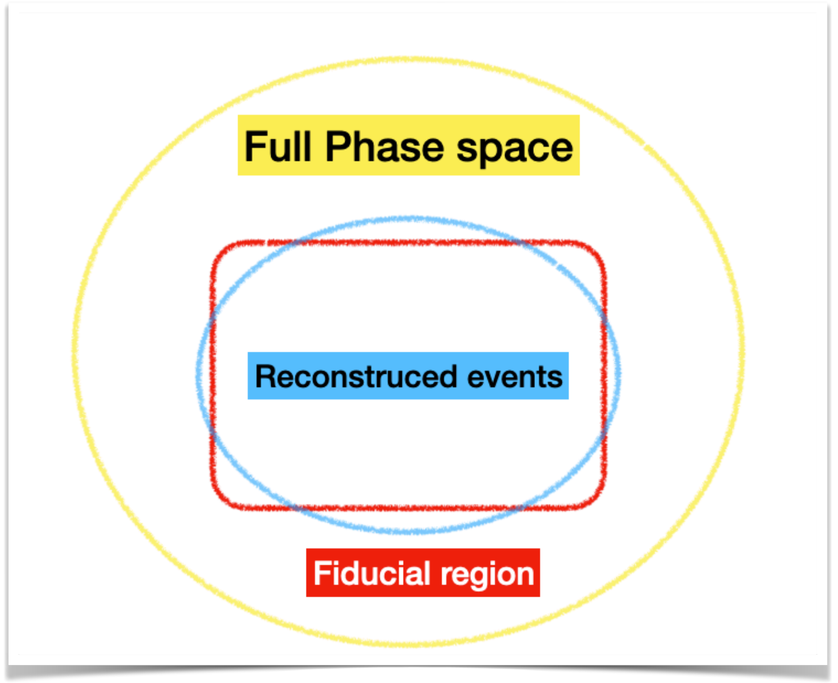
$$\sigma_{fid}^{inclusive} = 65.2 \pm 4.5(stat.) \pm 5.6(syst.) \pm 0.3(theo.) fb$$

Consistent with SM prediction: 63.6 ± 3.3 fb

Largest systematic uncertainty from background modelling

Measurement methodology

- ***Fiducial region:*** defined to closely match the detector-level analysis and object selections
- *Differential fiducial cross-section* are measured in bins of the studied observable (bin i of a variable x)
  - ✓ N_i^{sig} ***(measured signal yield):*** extracted signal events in data
  - ✓ Δx ***(bin width):*** choice based on significance (more than 2σ) and minimize migrations
  - ✓ c_i ***(correction factor):*** accounts for detector inefficiencies and resolutions effects as well as migrations in and out of fiducial region
    - estimated from MC simulation
    - bin-by-bin method and matrix-inversion (as a check)



$$\frac{d\sigma_i}{dx} = \frac{N_i^{sig}}{c_i \Delta x \mathcal{L}}$$

Differential fiducial cross-section

pT(H) and y(H) differential measurements

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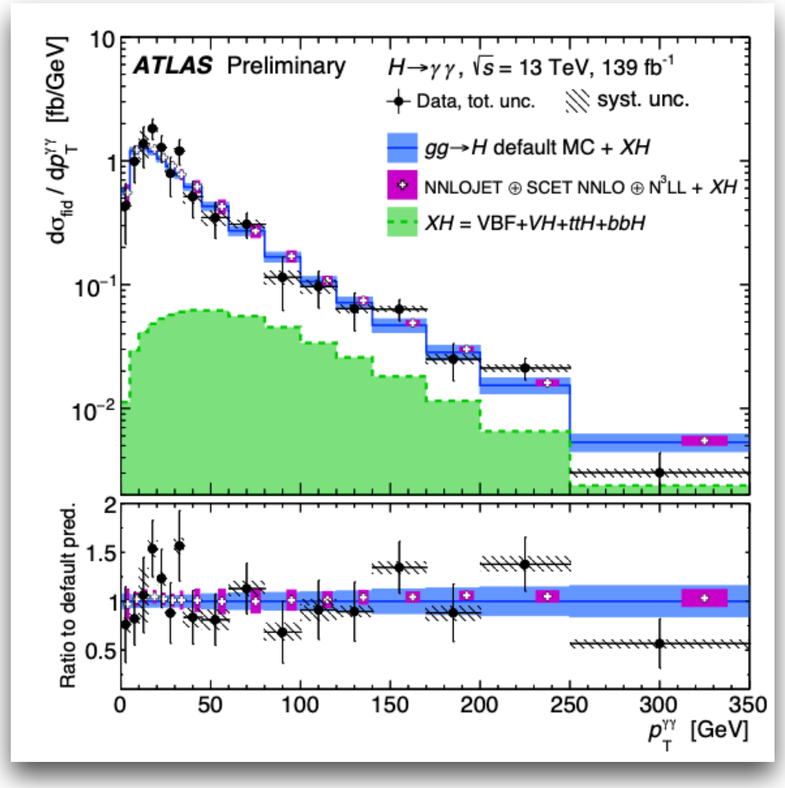
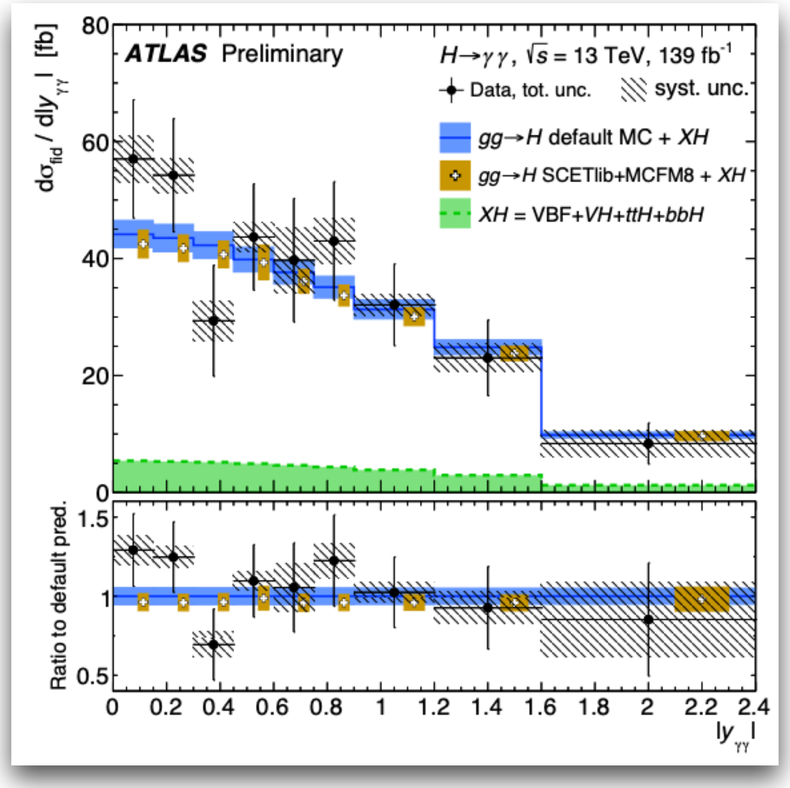
$p_T(H)$: ***Low pT(H): sensitive to bottom and charm Yukawa couplings***
High pT(H): sensitive to new heavy particle coupling to the Higgs boson and top-quark mass effects

$|y(H)|$: ***Sensitive to the gluon distribution in the proton and QCD radiative corrections***

default MC prediction: ggF MC Powheg NNLOPS scaled to N^3LO





- ***Good agreement with the SM predictions within the uncertainties:***
  - **pT(H)** ATLAS $p(\chi^2) = 44\%$ (default MC prediction)
  - **y(H)** ATLAS $p(\chi^2) = 68\%$ (default MC prediction)
- Measurement is ***statistically dominated***

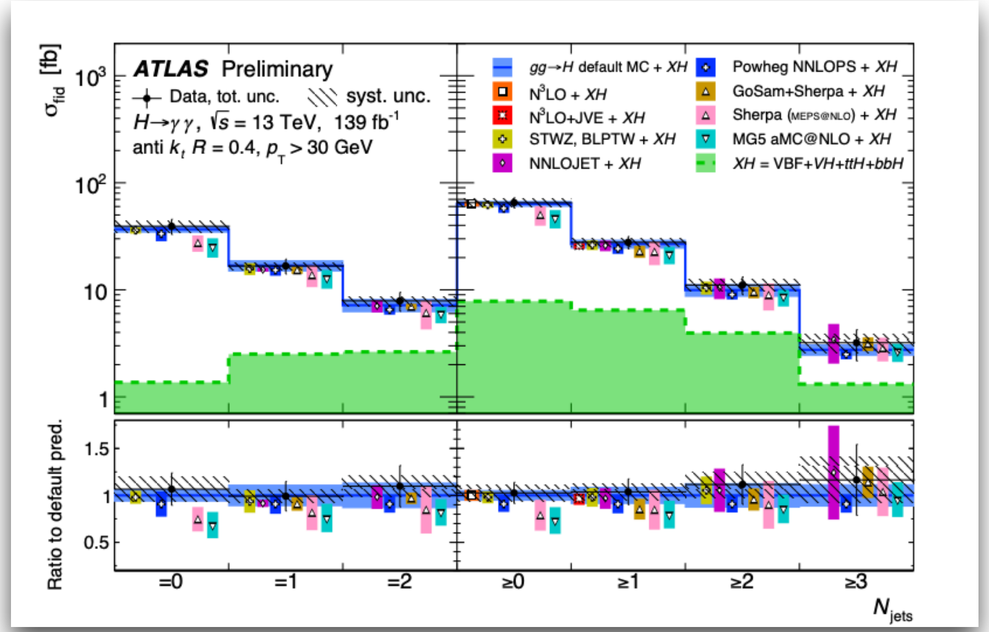
- ***Systematic uncertainties:***
  - photon energy scale and resolution and background modelling

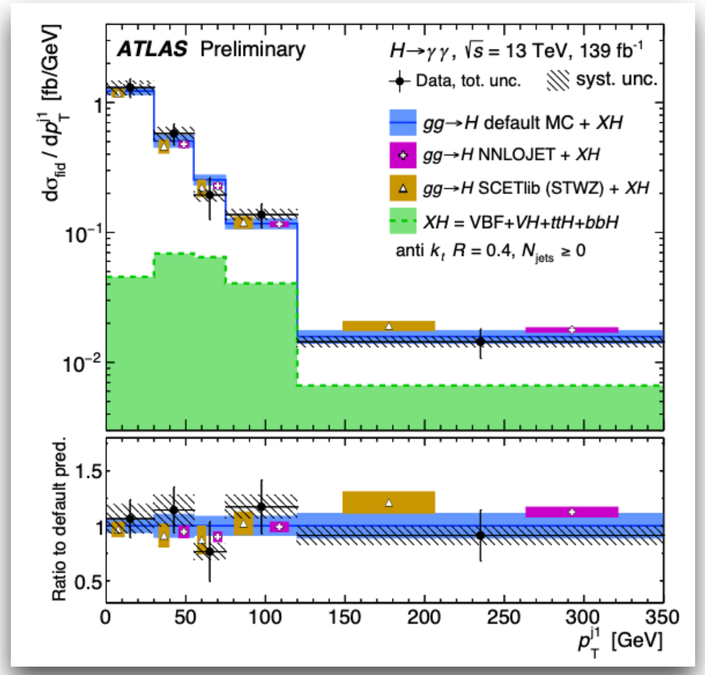
N_jets and pT(j1) differential measurements

N_{jets}, $p_T^{j_1}$:

Jet multiplicity provides sensitivity to Higgs boson production mechanism and theoretical modelling of high pT quark and gluon emissions

Jet transverse momentum offers direct probe to quark and gluon radiation





- ***Good agreement with the SM predictions within the uncertainties:***
  - N_jets $p(\chi^2)$ = 96% (default MC prediction)
    - N^3LO scaling improves agreement with data
  - pT_j1(($p(\chi^2)$ = 77%) (default MC prediction)
    - same kinematic range as pT(H): coarse bins at low pT

- **Important systematics uncertainties*:***
  - jet energy scale and resolution (6%-25%)

$H \to \gamma\gamma$: interpretations

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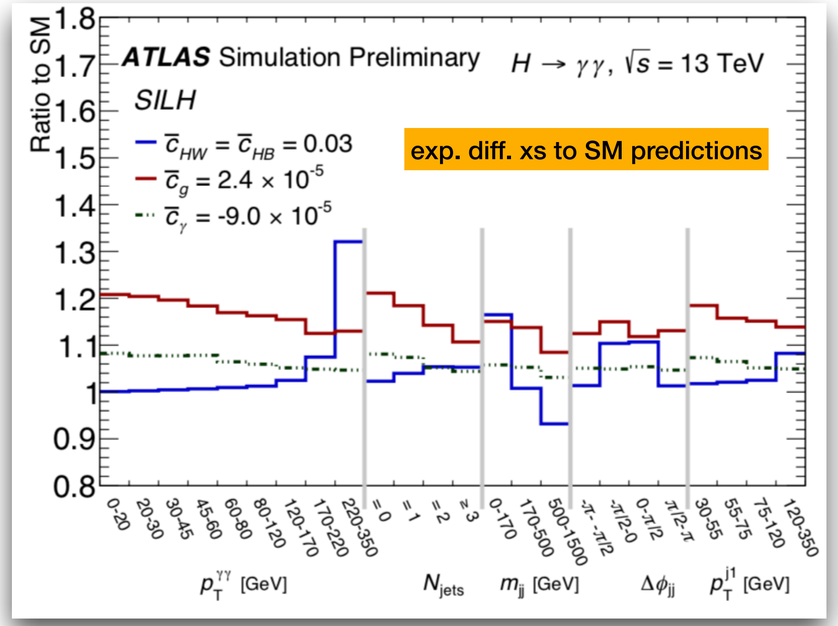
- ***Strength and Tensor structure of the interactions of the Higgs boson:*** Effective Field Theory (addition of new interactions CP-even and CP-odd)
  - Constraints derived for the variables: $p_T^{\gamma\gamma}$, **N_jets,** m_{jj}, $\Delta\phi_{jj}$ **and** p_T^{j1}
  - BSM contributions probed as non-zero Wilson coefficients
  - Basis of parametrization SILH and SMEFT: $c_i/\tilde{c}_i$ (Wilson coefficients); $O_i/\tilde{O}_i$ (6d operators that introduce new interactions)

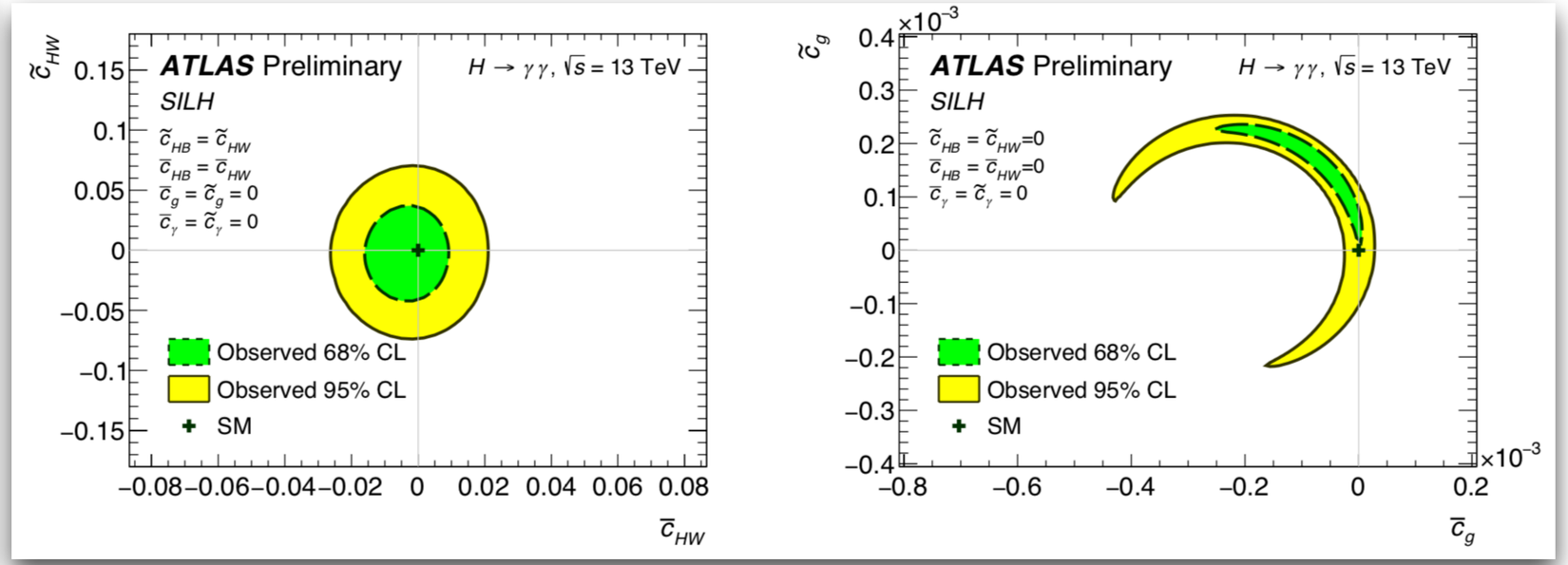
- ***Limits setting on*** $c_{HW}/\tilde{c_{HW}}$:
  - $c_{HB} = c_{HW}$ *and* $\tilde{c_{HB}} = \tilde{c_{HW}}$ (SM decay rate for H->Zy)
- ***Limits setting on*** $c_g/\tilde{c}_g$:
  - Destructive interference: ggF production mode cross-section is zero at $c_g \sim -2.2 \times 10^{-4}$ for $\tilde{c}_g \sim 0$

CP-even **CP-odd**

$$\mathcal{L}_{eff}^{SILH} \supset \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g \tilde{O}_g + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_{HW} \tilde{O_{HW}} + \tilde{c}_{HB} \tilde{O_{HB}}$$

No significant BSM physics contributions are observed





Charm-Yukawa coupling interpretation

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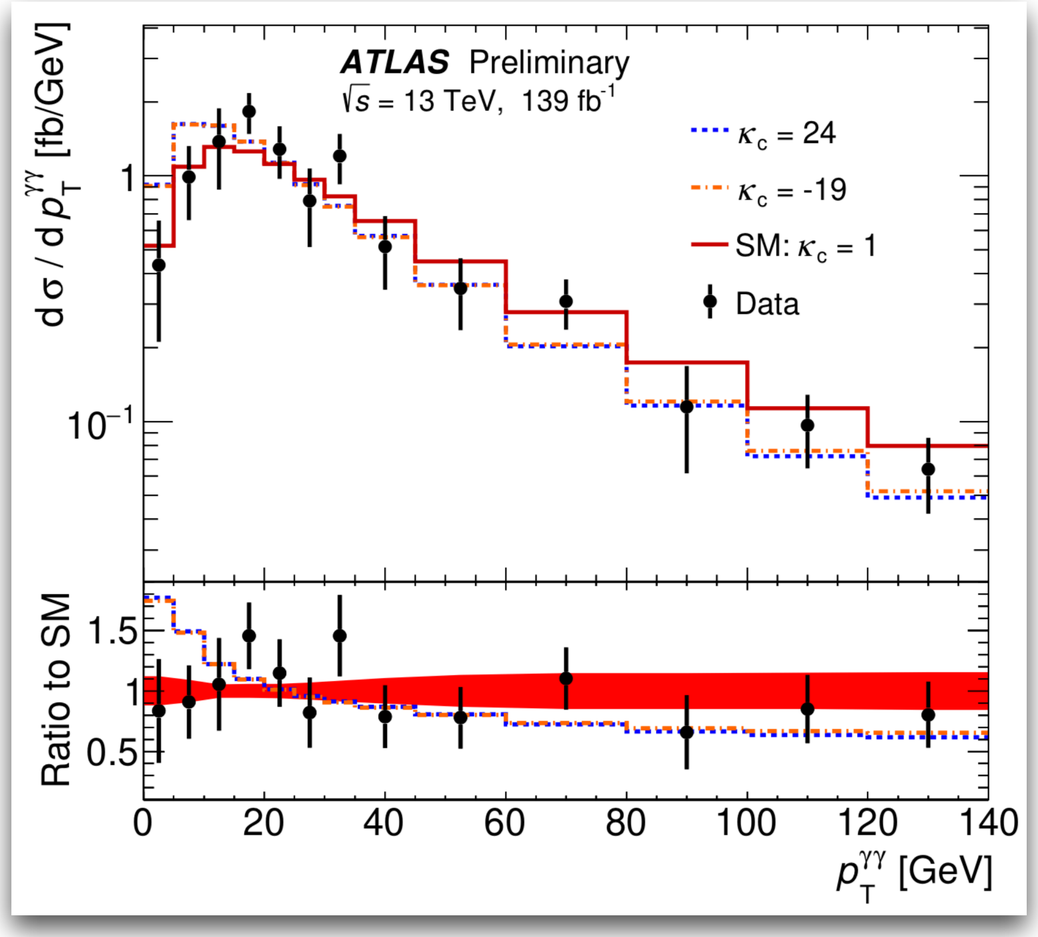
◉ *Low pT(H) region provides sensitivity to Yukawa coupling of charm quark:*

- Indirect constraint on $\kappa_c (= Y_c/Y_c^{SM})$ using **pT(H) shape information only**
  - Loop-induced ggF and quark-initiated production of the Higgs boson are sensitive to modifications of κ_c
  - ***pT(H) < 140 GeV*** (most sensitive region)
  - Profile likelihood fit: measured cross-sections and predicted cross-sections (**ggF: Radish** and **cc/cg->H:** Madgraph)
- Statistical uncertainty dominates

◉ Less stringent limits compared to direct searches ($VH, H \to c\bar{c}$, ***PRL_120_2018***) but still complementary

Coefficient	Observed 95% CL limit	Expected 95% CL limit
κ_c	[−19, 24]	[−15, 19]



Summary

✓ ***Higgs Fiducial and differential measurements in ATLAS experiment have been presented in the $H \rightarrow \gamma\gamma$ channel:***

- Higgs boson properties and probe to new physics contributions in many observables exploring ***Higgs kinematic and jet-kinematic activity in the events***
- ***Very good agreement between the measurements and SM predictions:***
  - Statistical uncertainty still the dominant uncertainty source in most channels
- ***Measurements are interpreted in the context of:*** EFT framework and pT(H) shape for charm-quark coupling
  - No significant BSM contributions are observed
  - Loose limits on κ_c are set compared to direct searches but still complementary

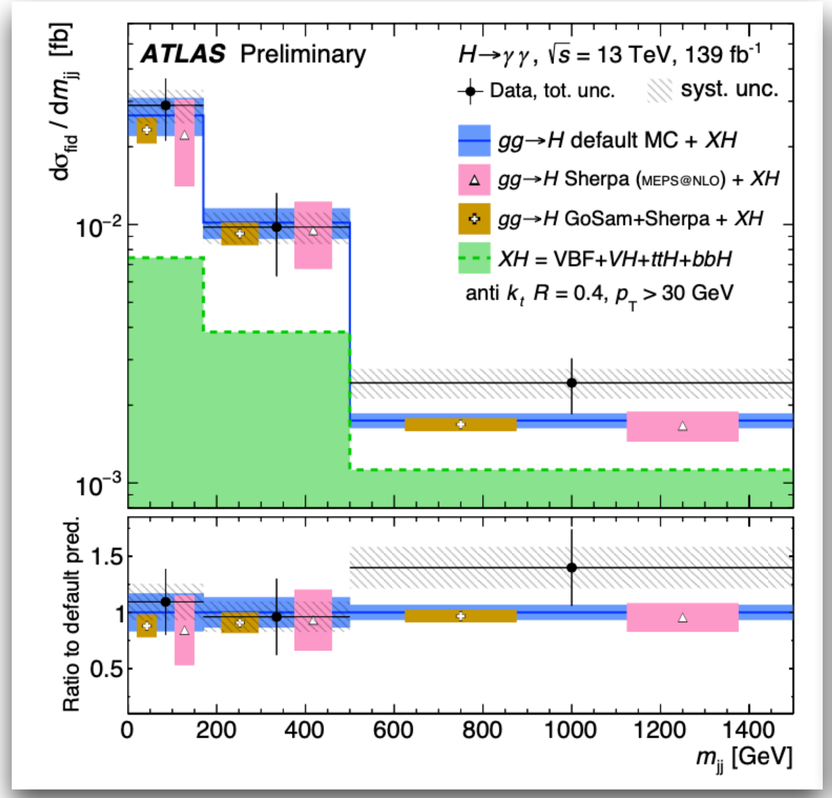
Thank you for the attention!

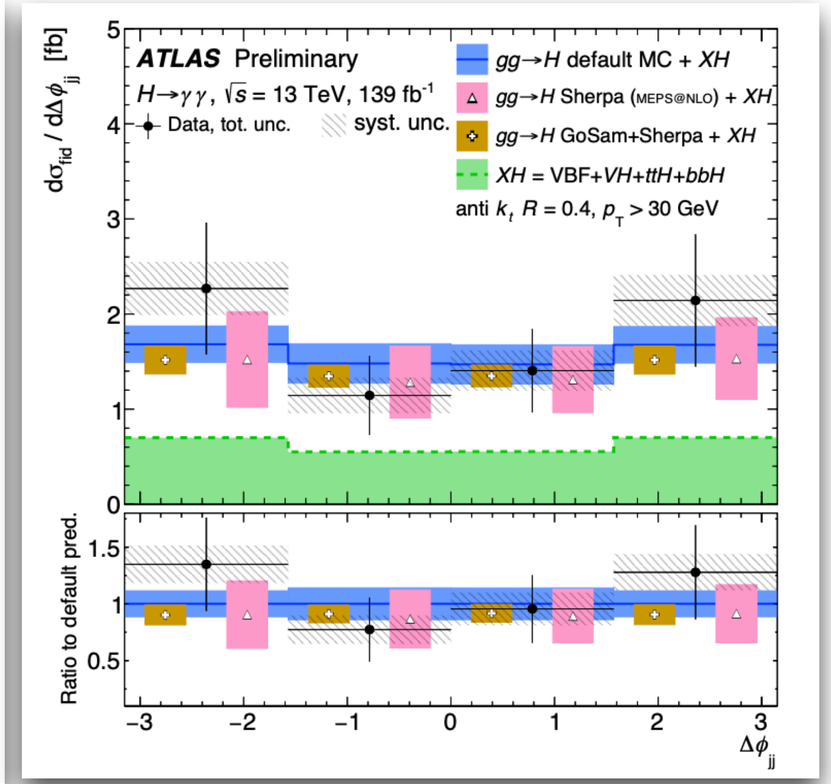
Back-up slides

m(jj) and $\Delta\phi(jj)$ differential measurements

$m(jj)$: ***sensitive to the VBF production mode in the high mass bin***

$\Delta\phi(jj)$: ***sensitive to the CP properties of the Higgs boson***





- ***Level of agreement with the SM predictions:***
  - m(jj) $p(\chi^2) = 75\%$ (default MC prediction)
  - $\Delta\phi(jj)$ $(p(\chi^2) = 82\%)$ (default MC prediction)
- Measurement is ***statistically dominated***

- **Important systematics uncertainties*:***
  - jet energy scale and resolution (6%-25%)