H -> $\gamma\gamma$ couplings and cross sections with the ATLAS detector

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on behalf of the ATLAS collaboration

Higgs Hunting 2017 – 24th July 2017

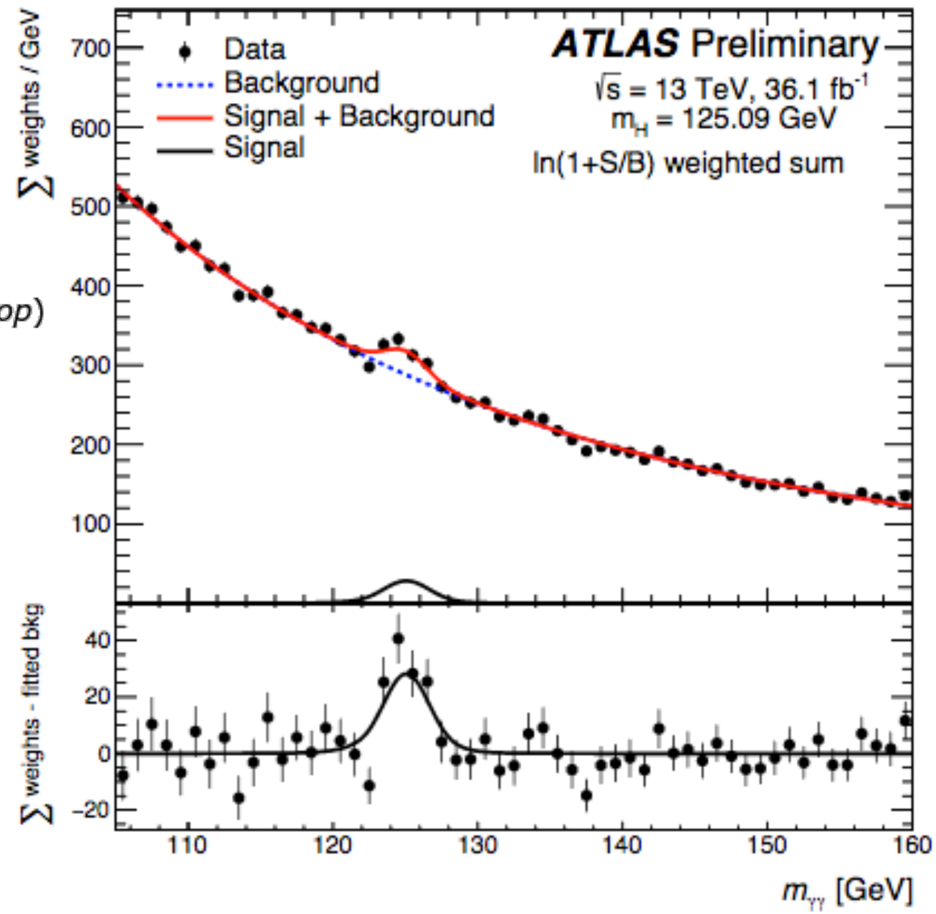
Analysis Overview

- Measure production rates and properties by splitting dataset into independent categories enriched in a target production mode or kinematic regions (bins)

- Perform simultaneous fit across all categories / bins while extracting various parameters of interest

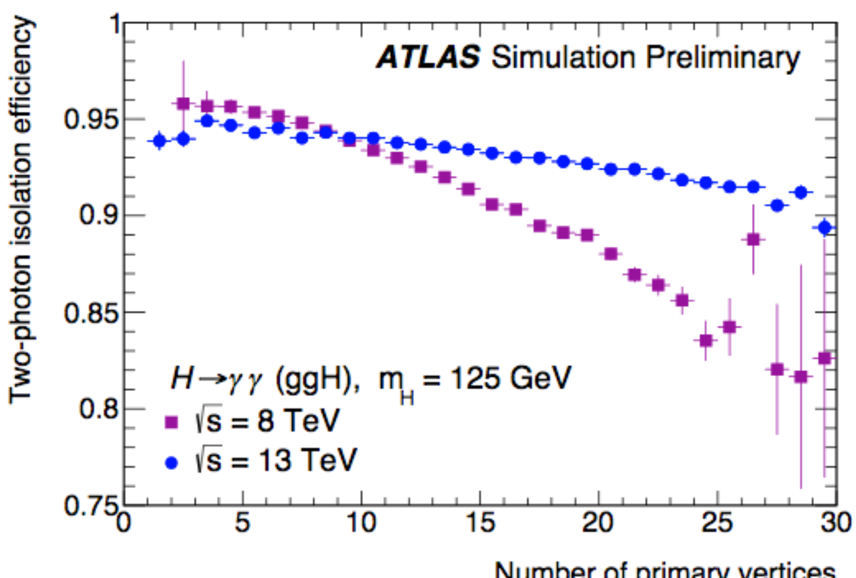
- Production Mode Measurements:
  - Signal strengths $\mu = \frac{\sigma \times BR}{(\sigma \times BR)_{SM}} (ggF, VBF, VH, top)$
  - Production XS = σ x BR (ggF, VBF, VH, top)
  - Simplified Template XS = σ x BR (ggF, VBF, VH, top), in smaller phase space regions
  - Coupling Strength modifiers κ

- Fiducial Measurements:
  - XS measurements in 5 fiducial regions
  - 5 differential XS



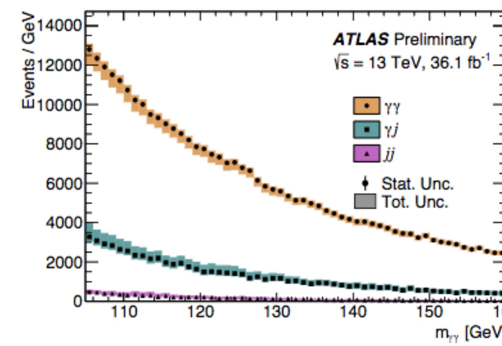
Diphoton Event Selection

- Preselection of two loose photons within $|\eta| < 2.37$
  - reject photons in barrel-endcap transition region: $1.37 < |\eta| < 1.52$
- Photon candidates must pass identification and isolation requirements
  - track and calorimeter isolation within $\Delta R < 0.2$
- Leading (sub-leading) photon with $p_T^{\gamma}/m_{\gamma\gamma} > 0.35$ (0.25)
- Diphoton mass window of 105 GeV $< m_{\gamma\gamma} <$ 160 GeV

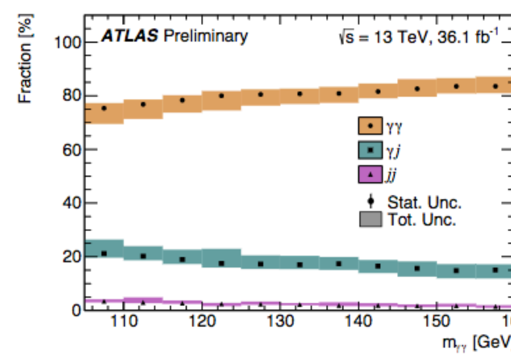


Background Decomposition

- Data-driven (using sideband method based on photon identification and isolation)



- Derived separately for each category / bin in the analysis



After final selection

Diphoton Event Selection

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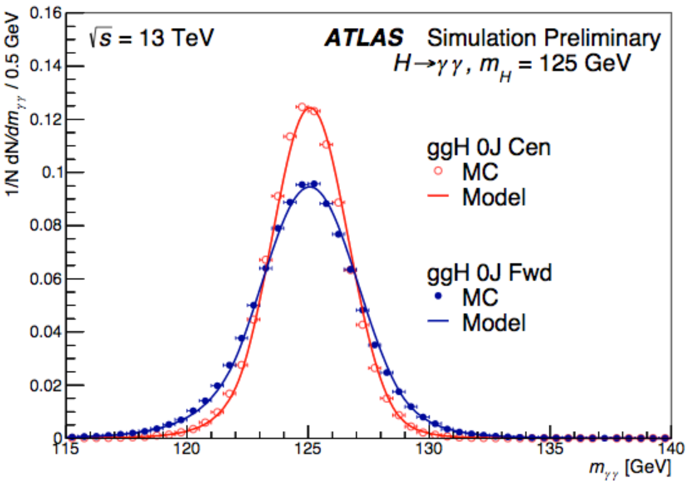
- Leading (sub-leading) photon with $p_T^{\gamma} / m_{\gamma\gamma} > 0.35$ (0.25)
- Diphoton mass window of $105\ \text{GeV} < m_{\gamma\gamma} < 160\ \text{GeV}$

Production process	Signal efficiency times acceptance (%)	Number of expected signal events (36.1 fb^{-1})
ggH	41.8	1518.4
VBF	41.3	119.1
WH	37.6	37.1
ZH	40.5	25.2
ttH	39.1	16.0
bbH	42.8	14.8
tHqb	38.9	2.2
tHW	44.5	0.5
All	41.8	1733.2

Signal Shape

- Signal shape described by a double sided crystal ball (DSCB)
- Parameterized for each reco category



Event Categorisation

- Used for the production mode measurements

H -> $\gamma\gamma$

ttH+tH leptonic (two tHX and one ttH categories)
ttH + tH hadronic (two tHX and four BDT ttH categories)

VH dilepton
VH one-lepton, $p_T^{l+MET} \geq 150$ GeV
VH one-lepton, $p_T^{l+MET} < 150$ GeV
VH E_T^{miss}, $E_T^{miss} \geq 150$ GeV
VH E_T^{miss}, $E_T^{miss} < 150$ GeV
VH+VBF $p_T^{j1} \geq 200$ GeV
VH hadronic (BDT tight and loose categories)

VBF, $p_T^{\gamma\gamma jj} \geq 25$ GeV (BDT tight and loose categories)
VBF, $p_T^{\gamma\gamma jj} < 25$ GeV (BDT tight and loose categories)

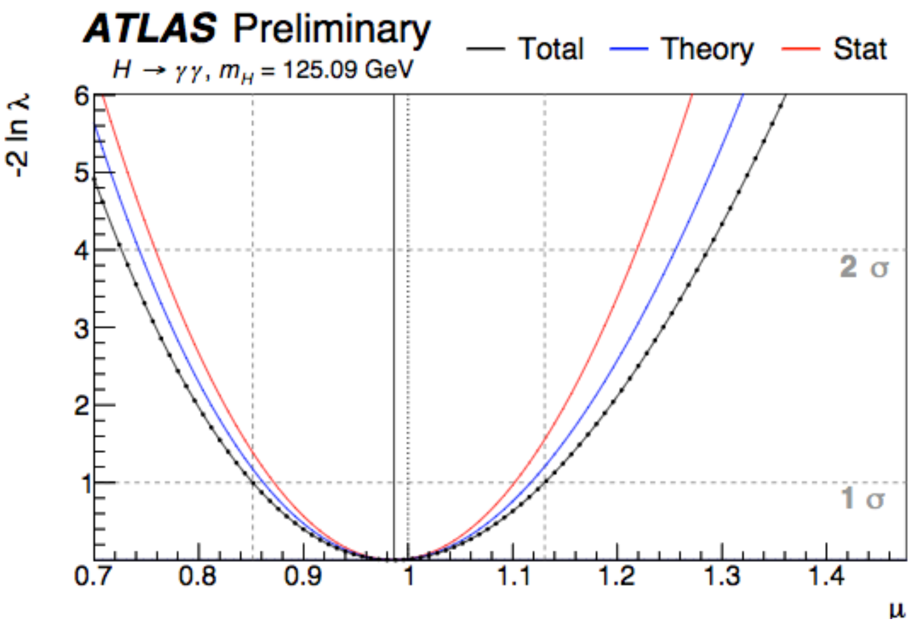
ggF 2-jet, $p_T^{\gamma\gamma} \geq 200$ GeV
ggF 2-jet, 120 GeV $\leq p_T^{\gamma\gamma} < 200$ GeV
ggF 2-jet, 60 GeV $\leq p_T^{\gamma\gamma} < 120$ GeV
ggF 2-jet, $p_T^{\gamma\gamma} < 60$ GeV
ggF 1-jet, $p_T^{\gamma\gamma} \geq 200$ GeV
ggF 1-jet, 120 GeV $\leq p_T^{\gamma\gamma} < 200$ GeV
ggF 1-jet, 60 GeV $\leq p_T^{\gamma\gamma} < 120$ GeV
ggF 1-jet, $p_T^{\gamma\gamma} < 60$ GeV
ggF 0-jet (central and forward categories)

Signal Strength

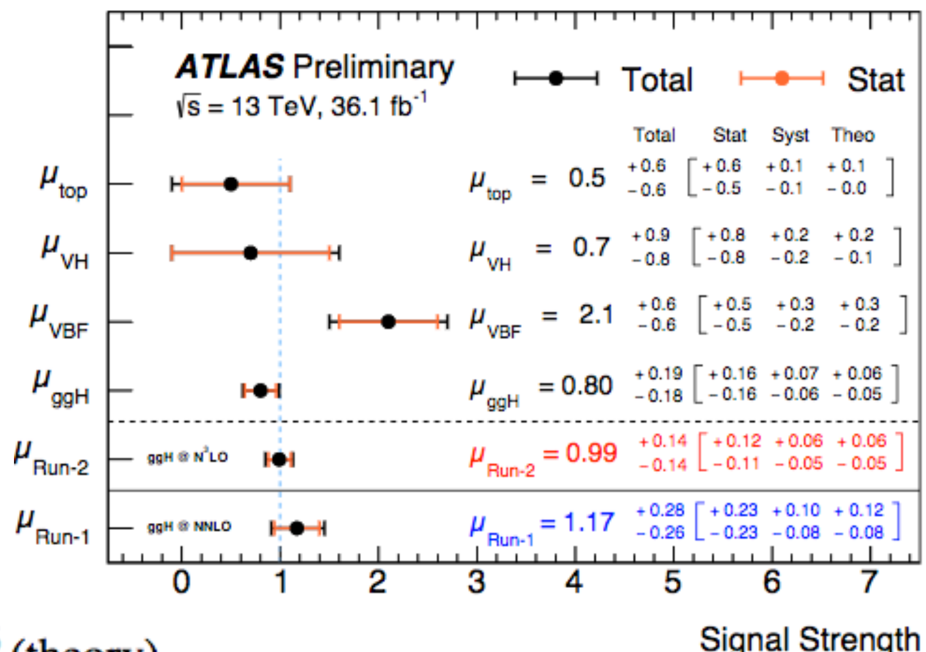
- Signal Strength Measurements : well in agreement with SM
  - ggH (VBF) production is measured to be 1σ below (2σ above) the SM expectation

- Dominant Systematic Uncertainties : Mass Scale and Resolution, Background Shape and Luminosity.

Combined Signal Strength



Production Mode Signal Strength

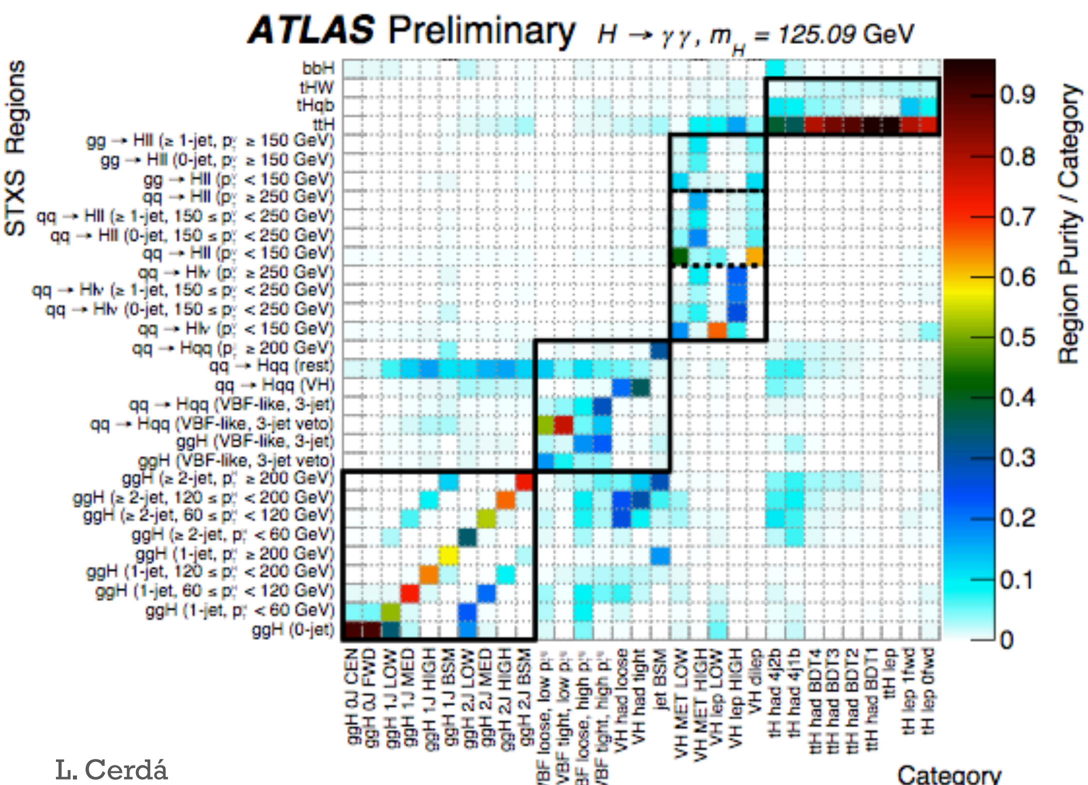


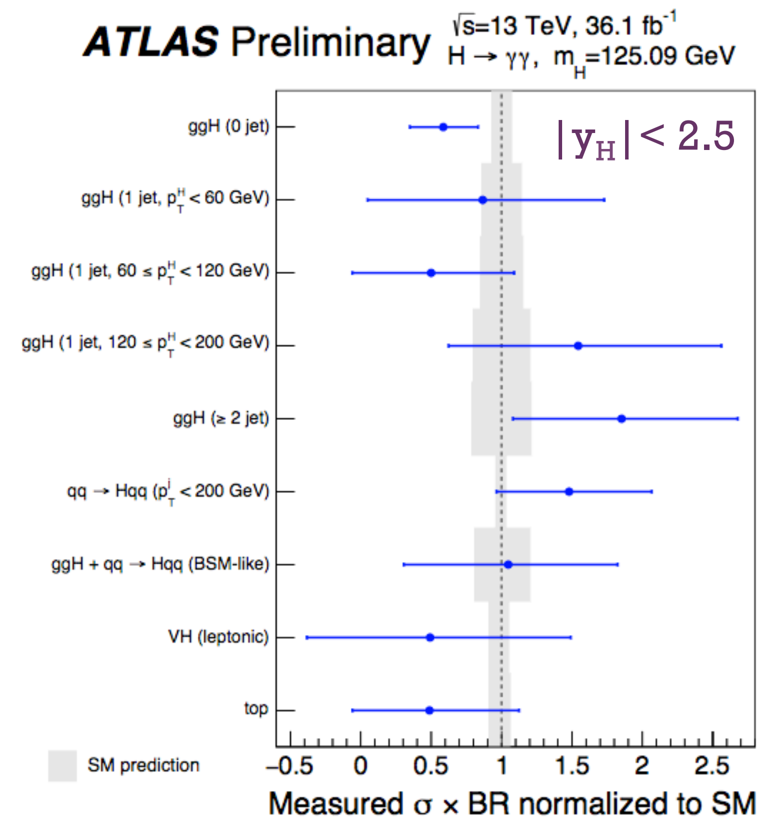
$$\mu = 0.99\,^{+0.14}_{-0.14} = 0.99\,^{+0.12}_{-0.11}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{exp.})\,^{+0.06}_{-0.05}\,(\text{theory})$$

- This result confirms the ATLAS Run-1 diphoton Signal Strength Measurement of $\mu = 1.17 \pm 0.27$ with around a factor of 2 improvement in the uncertainty (Run-1 ggH: NNLO, Run-2 ggH: N^{3}LO; k-factor of ~10%)

+ STXS Measurement

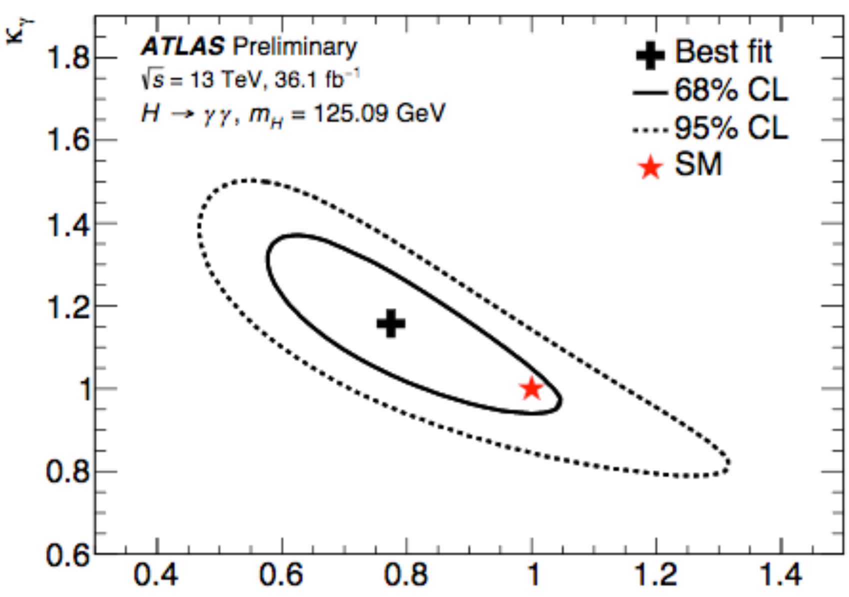
- Allows to maximise experimental sensitivity while minimising theory dependence
- Measure cross sections in mutually exclusive regions of phase space split by production mode
- Template cross sections reported for 9 phase space categories (by merging the initial 31 categories)
- Results are in agreement with the SM

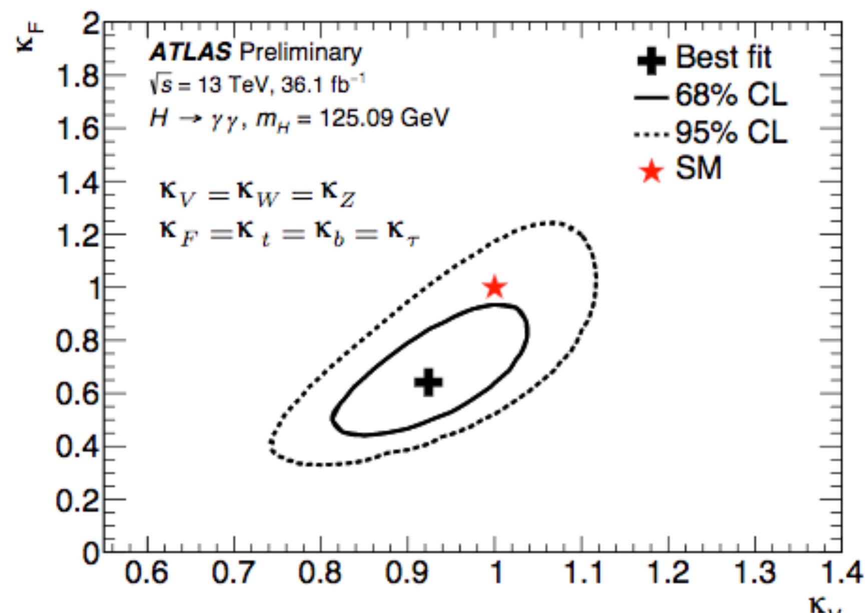




+ Coupling Strength Measurements

- Measurement and limit setting on Higgs coupling modifiers within κ - framework
- SM prediction within 68% CL two-dimensional contour for $\kappa_g - \kappa_\gamma$ as well as for $\kappa_V - \kappa_F$ plane





- Fit effective couplings to gluons (κ_g) and to photons (κ_γ)
  - Capture all loop contributions to Higgs interaction with gluons and photons
  - New loop effects would appear here instead of resolved in terms of (κ_V, κ_F)
- Fit couplings to fermions (κ_F) and to vector bosons (κ_V)
  - Loops are resolved
  - Higgs productions depends on κ_V^2, κ_F^2

Fiducial Cross Sections

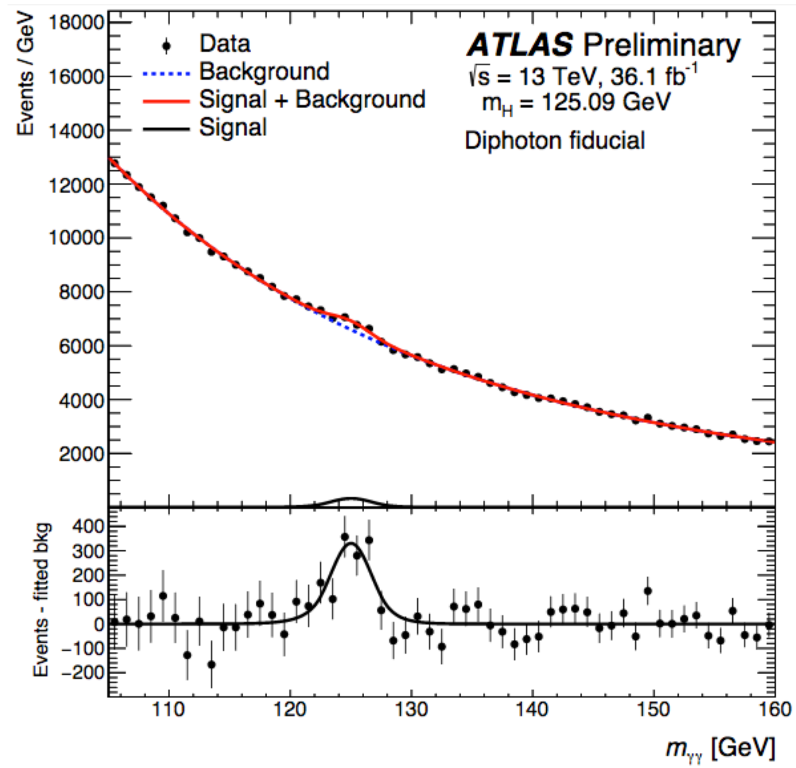
- Fiducial definition closely mimics reco selection for minimal model dependence
  - Fiducial photon selection ("$\gamma\gamma$ baseline"):
    $N_\gamma \geq 2$,
    $p_T^{\gamma 1} > 0.35\, m_{\gamma\gamma}$, $p_T^{\gamma 2} > 0.25\, m_{\gamma\gamma}$,
    $|\eta| < 1.37$ OR $1.52 < |\eta| < 2.37$,
    $p_T^{iso,0.2} / p_T^{\gamma} < 0.05$

- Unfolding factors correct for detector efficiency and resolution

- Cross section:

$$\sigma_i = \frac{N_i^{sig}}{c_i \int L\,\mathrm{d}t}$$

  - N_i^{sig} : number of signal events observed
  - c_i : correction for detector eff. and resolution
  - $\int Ldt$: integrated luminosity of the data set



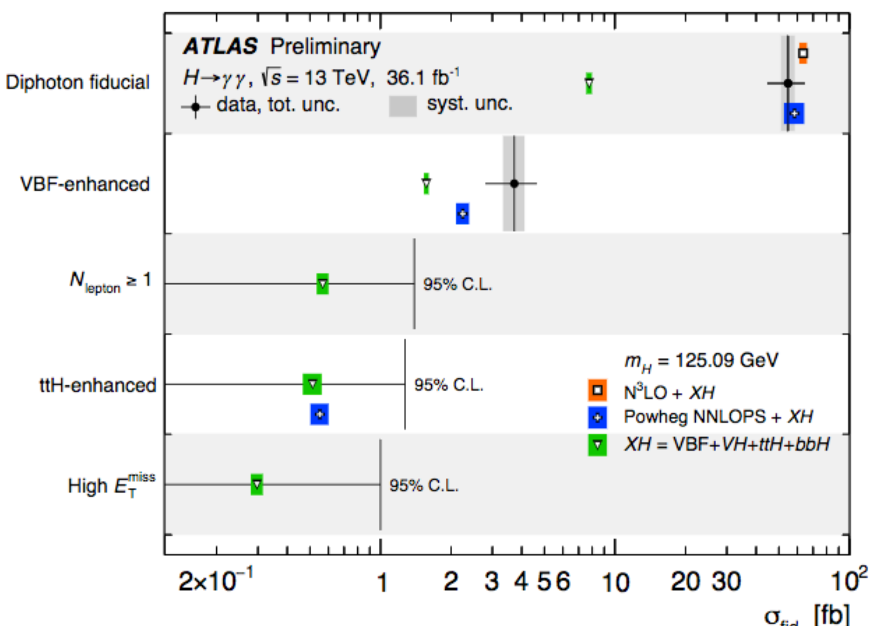
$\sigma_{fid} = 54.7 \pm 9.1$ (stat.) ± 4.5 (syst.) fb

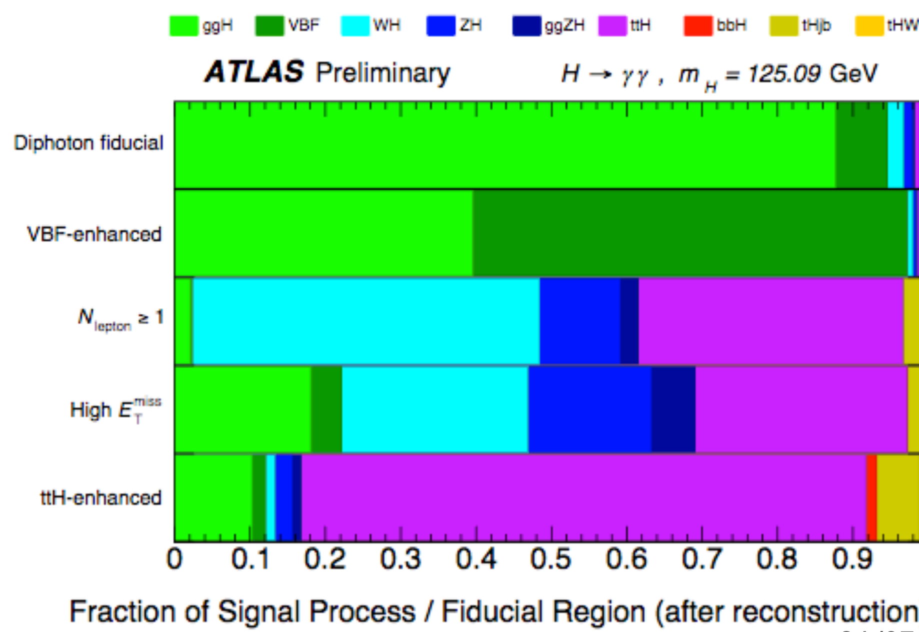
SM prediction: 63.5 ± 2.4 fb

Fiducial Regions

Fiducial Region	Definition
Diphoton Fiducial	$\gamma\gamma$ baseline
VBF-enhanced	$\gamma\gamma$ baseline, $N_j \geq 2$, $m_{jj} > 400$GeV, $\lvert \Delta y_{jj} \rvert > 2.8$, $\lvert \Delta \phi_{\gamma\gamma,jj} \rvert > 2.6$
$N_{lepton} \geq 1$	$\gamma\gamma$ baseline, $N_l \geq 1$
High E_T^{miss}	$\gamma\gamma$ baseline, $E_T^{miss} > 80$ GeV, $p_T^{\gamma\gamma} > 80$ GeV
ttH-enhanced	$\gamma\gamma$ baseline, ($N_j \geq 4$, $N_{b\text{-}jets} \geq 1$) OR ($N_j \geq 3$, $N_{b\text{-}jets} \geq 1$, $N_l \geq 1$)

- No significant deviations from the SM expectations are observed

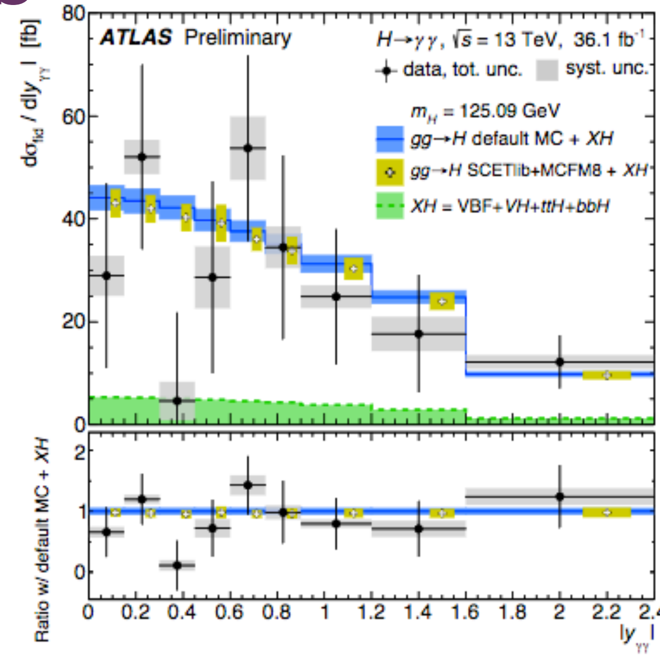


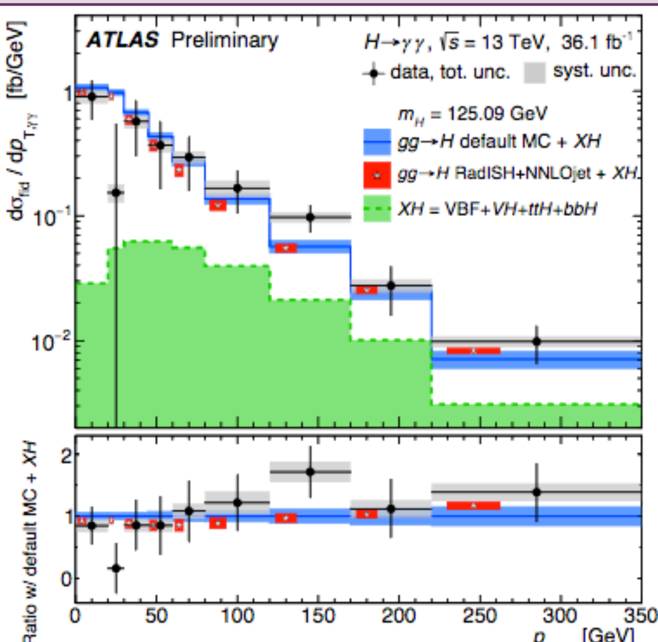


Differential Variables

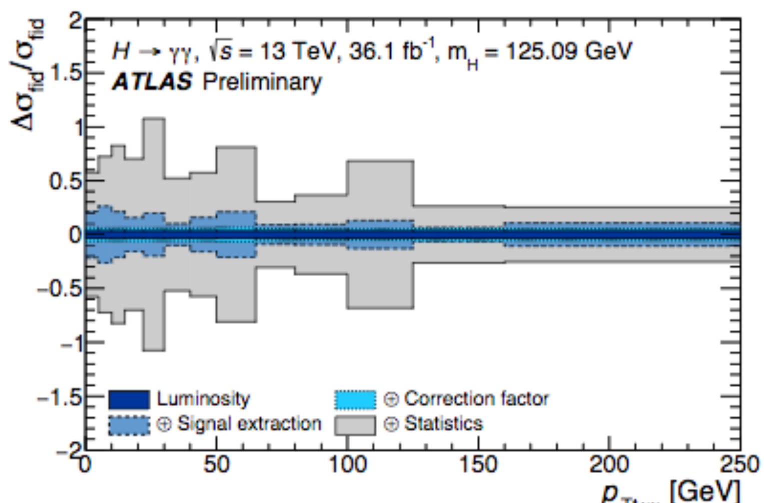
- Binning chosen to have a migration purity of >50%, width larger than resolution and ~2 σ significance in each bin

Observable	Definition
$p_T^{\gamma\gamma}$	Diphoton p_T
$\lvert y_{\gamma\gamma}\rvert$	Absolute diphoton rapidity
$\lvert\cos\ \theta^*\rvert$	Higgs boson helicity angle in CS frame
$p_{Tt}^{\gamma\gamma}$	Orthogonal component of the diphoton p_T when projected on the axis given by the difference of the 3-momenta of the two photons
$\lvert\Delta y_{\gamma\gamma}\rvert$	Rapidity separation of photons





Impact of Systematic Uncertainties



Conclusions

- Measurements of Higgs boson production cross sections times branching ratios presented for the $H \rightarrow \gamma\gamma$ analysis using full 2015+2016 dataset (36.1 fb^{-1})

- All measurements from production rates, STXS and κ framework in agreement with the SM

- First measurements using a simplified version of Stage 1 STXS
  - With higher statistics will be more sensitive to finer splitting of kinematics

- All reported results are statistically limited and their precision will further improve with the full data set to be recorded during Run 2 of the LHC

Back-up

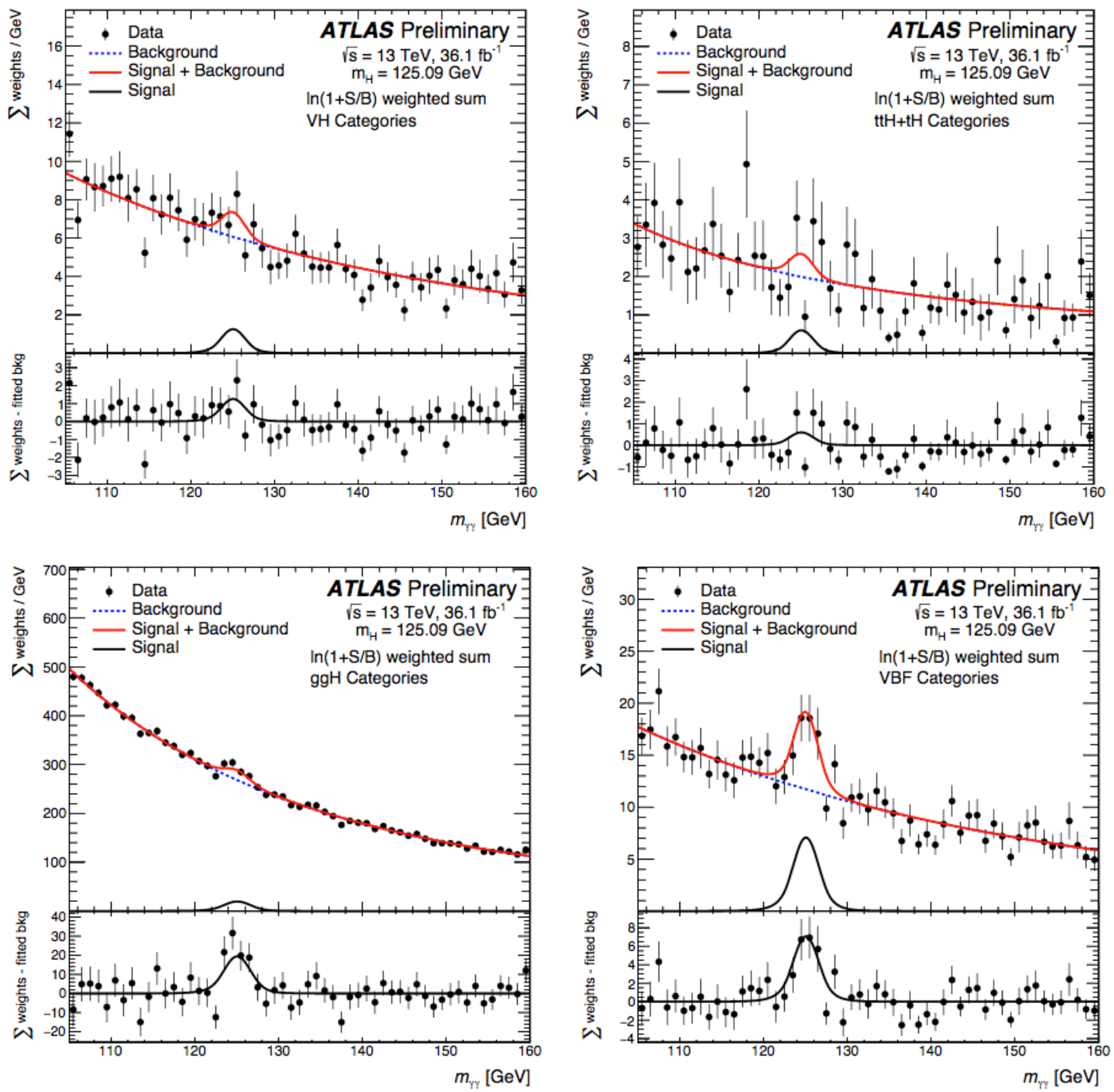
Systematic Uncertainties

		Syst. source	N_{NP}	Implementation
Yield	Theo.	Missing higher orders	6	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		$B(H \to \gamma\gamma)$	1	$N_{\mathrm{S}}^{\mathrm{tot}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
	Exp.	Heavy Flavor Content	1	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Luminosity	1	$N_{\mathrm{S}}^{\mathrm{tot}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Trigger	1	$N_{\mathrm{S}}^{\mathrm{tot}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Photon Identification	1	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Photon Isolation	2	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
Migrations	Theo.	ggH Theory	9	$N_{\mathrm{S}}^{\mathrm{ggH}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		UE/PS	5	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		PDF	30	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		α_{S}	1	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
	Exp.	Flavor Tagging	14	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Jet	20	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Jet Flavor Composition	7	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Jet Flavor Response	7	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Electron	3	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Muon	11	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		MET	3	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Pileup	1	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
		Photon Energy Scale	40	$N_{\mathrm{S}}^{\mathrm{p}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
Mass		ATLAS-CMS m_H	1	$\mu_{\mathrm{CB}}\,F_{\mathrm{G}}(\sigma_i,\theta_i)$
		Photon Energy Scale	40	$\mu_{\mathrm{CB}}\,F_{\mathrm{G}}(\sigma_i,\theta_i)$
		Photon Energy Resolution	9	$\sigma_{\mathrm{CB}}\,F_{\mathrm{LN}}(\sigma_i,\theta_i)$
Background		Spurious signal	31	$N_{\mathrm{spur},c}\,\theta_{\mathrm{spur},c}$

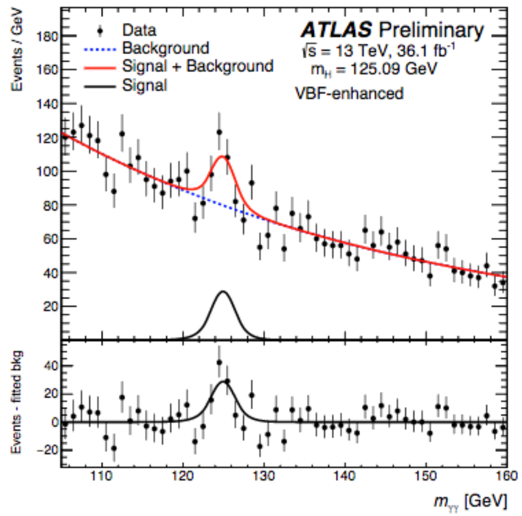
Impact on combined signal strength

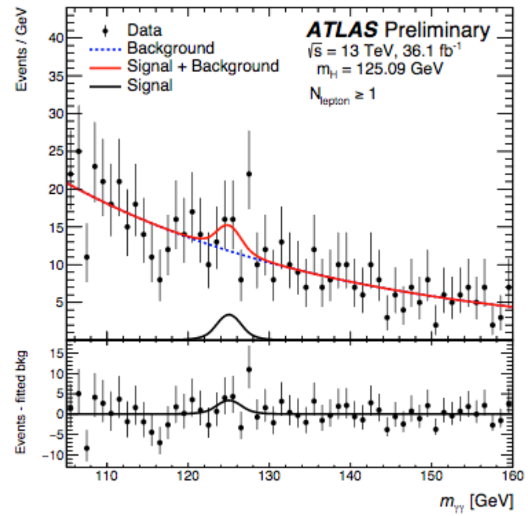
Uncertainty Group	$\sigma_{\mu}^{\mathrm{syst.}}$
Theory (yield)	0.03
Experimental (yield)	0.02
Luminosity	0.03
Theory (migrations)	0.05
Experimental (migrations)	0.01
Mass resolution	0.03
Mass scale	0.04
Background shape	0.03

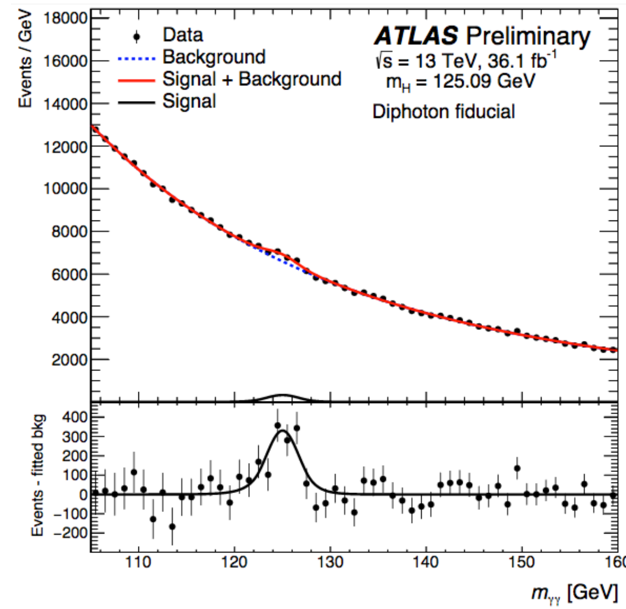
Observed data

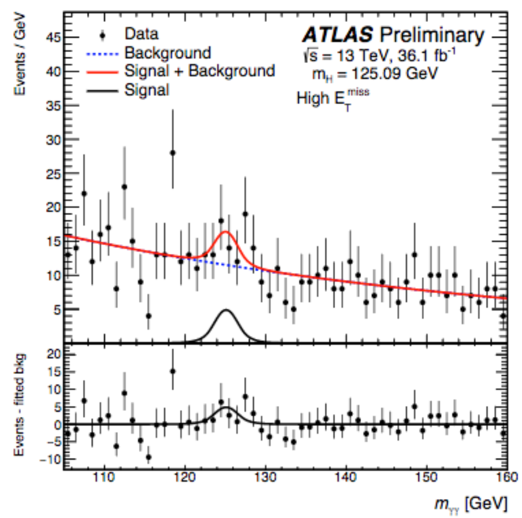


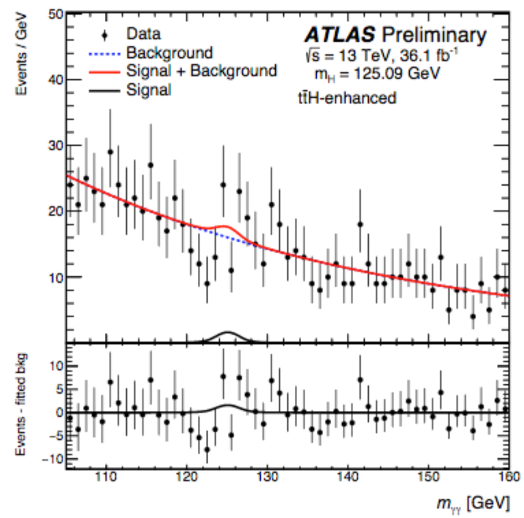
+ Fiducial regions











Differential Variables

- **Inclusive Higgs boson production is dominated by gluon fusion**, for which the transverse momentum of the Higgs boson is largely balanced by the emission of soft gluons and quarks.

- Measuring **$p^{\gamma\gamma}_{T}$ and $p^{\gamma\gamma}_{Tt}$** probes the **perturbative QCD modeling** of this production mechanism and is mildly sensitive to the bottom and charm quark Yukawa couplings of the Higgs boson. The distribution at high transverse momentum **is sensitive to new heavy particles coupling to the Higgs boson and to the top quark Yukawa coupling.**

- **The rapidity distribution of the Higgs boson** is also sensitive to the **modeling of the gluon fusion production mechanism**, as well as to the parton distribution functions (PDFs) of the colliding protons.

- Both **$|\cos\theta^*|$ and $|\Delta y^{\gamma\gamma}|$** are sensitive to **the spin of the Higgs boson.**