Higgs property measurement in di-photon final state

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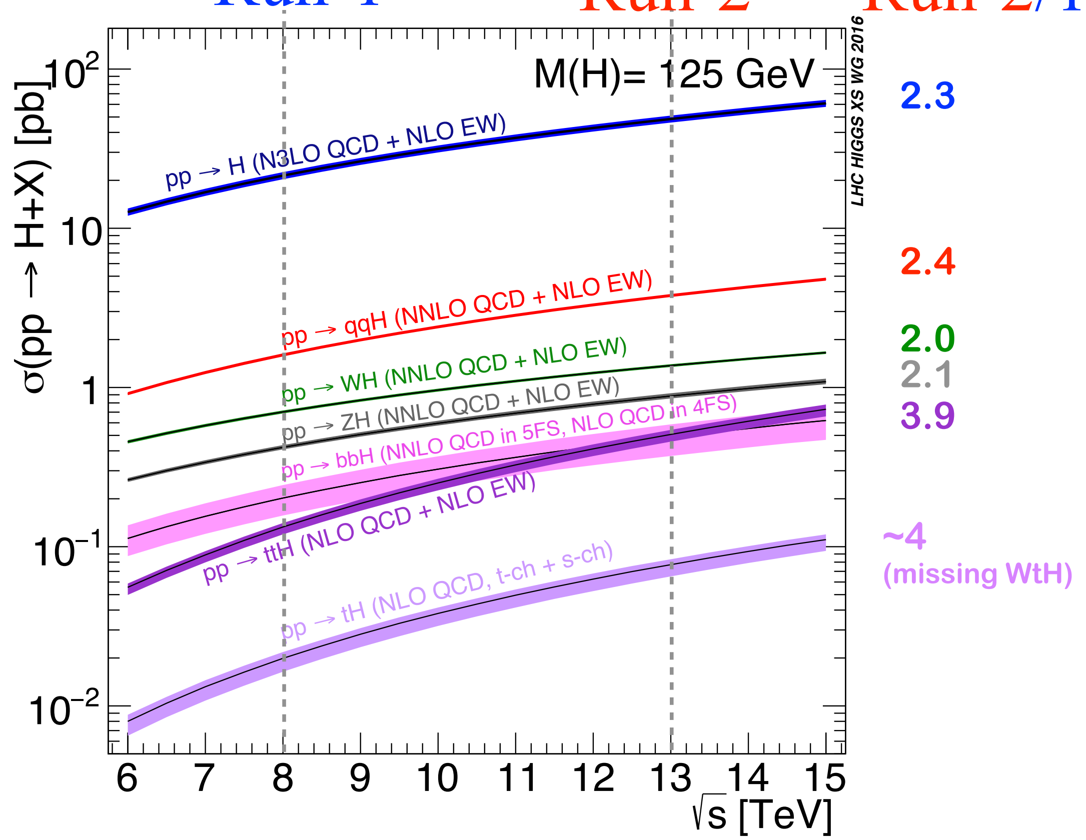
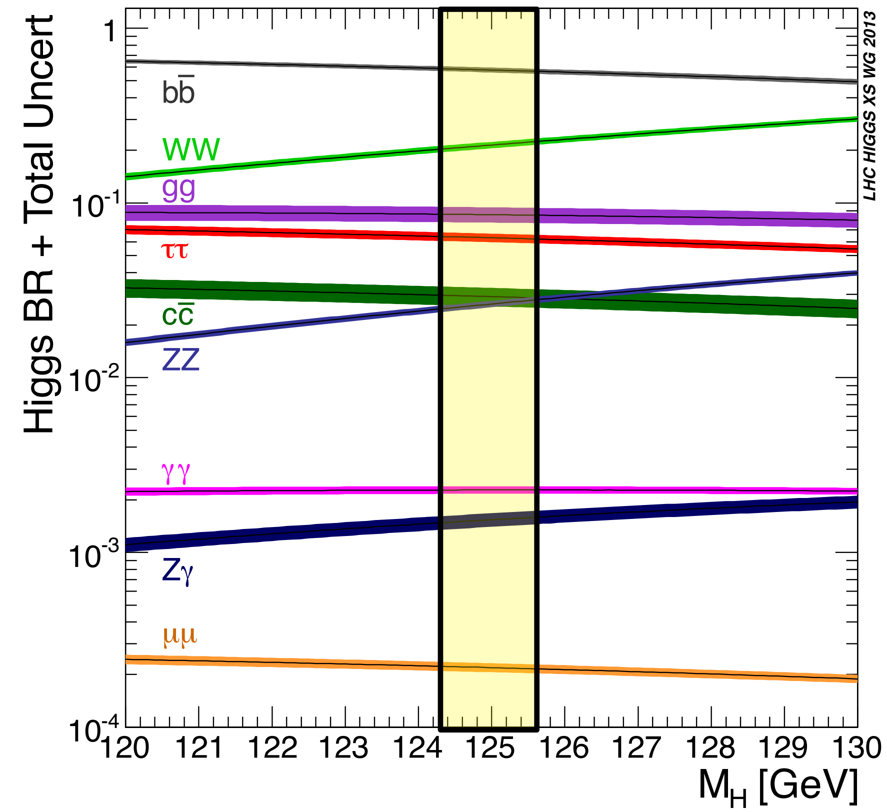
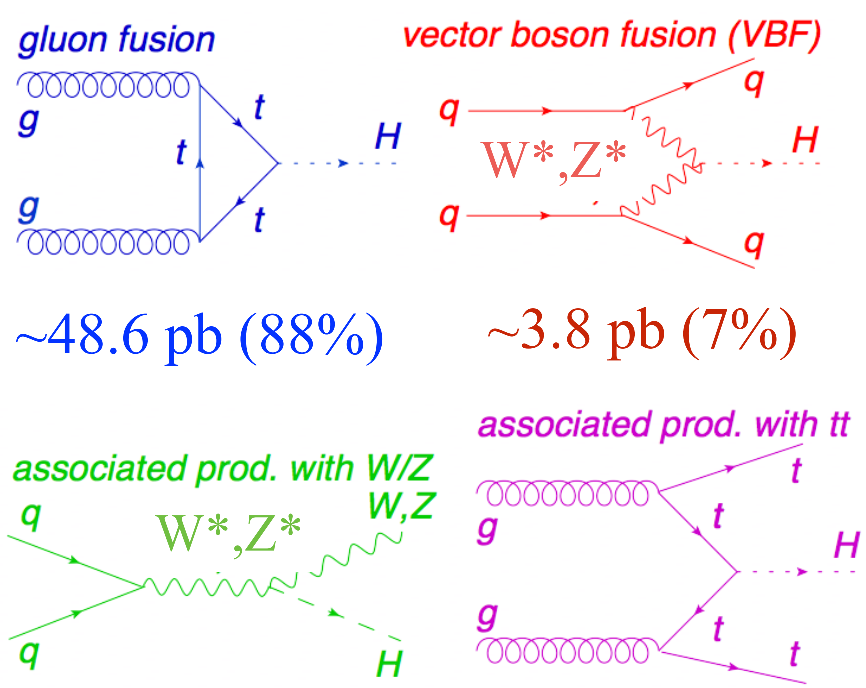
The Higgs @ LHC

Run-1 Run-2 Run-2/1





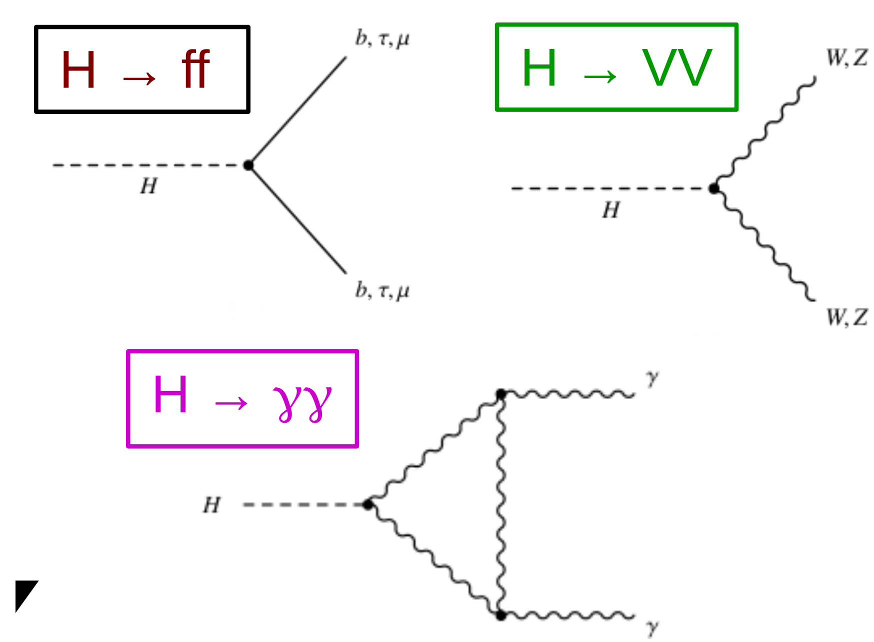


~48.6 pb (88%)

~3.8 pb (7%)

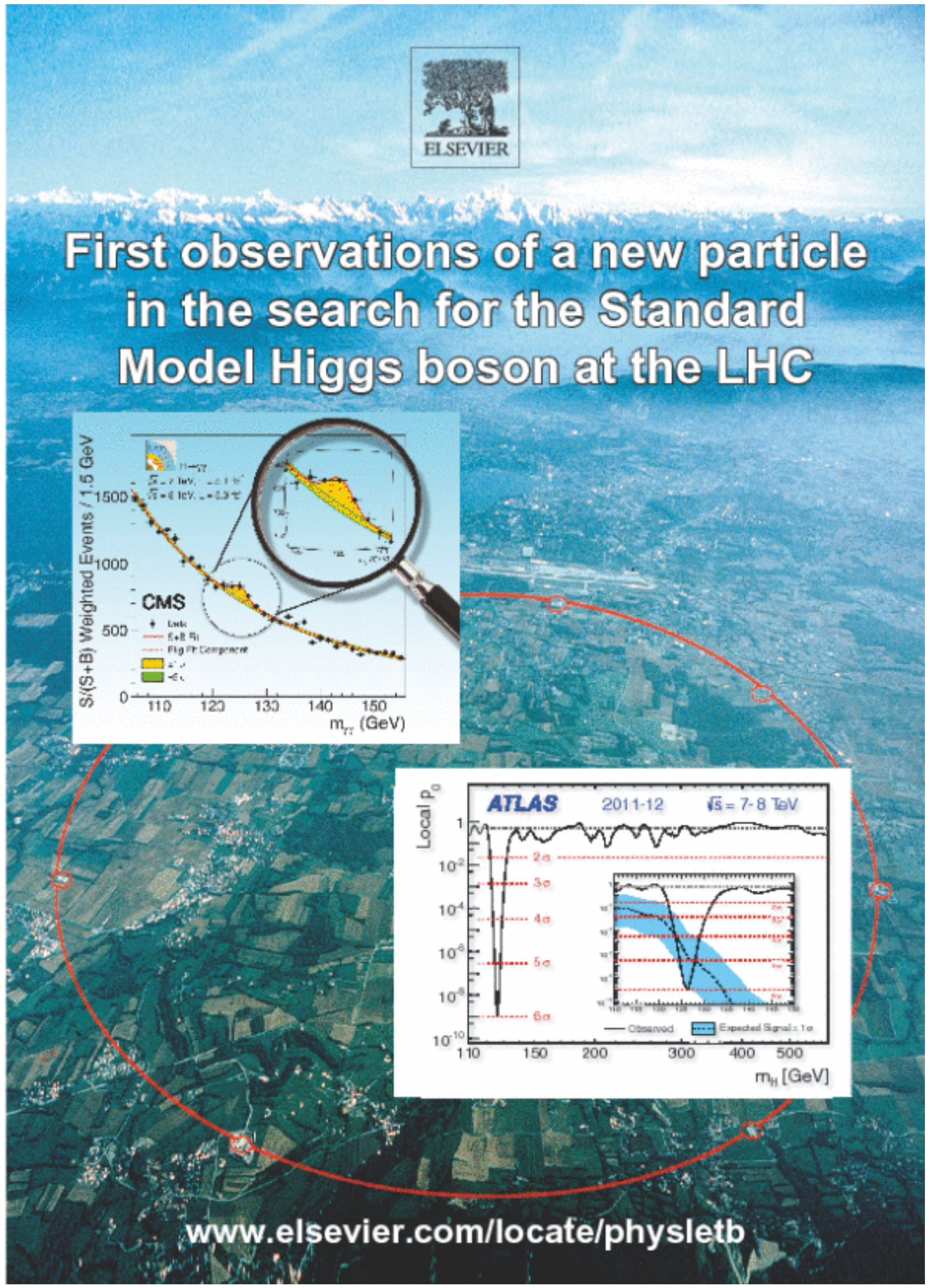
~2.3 pb (4%)

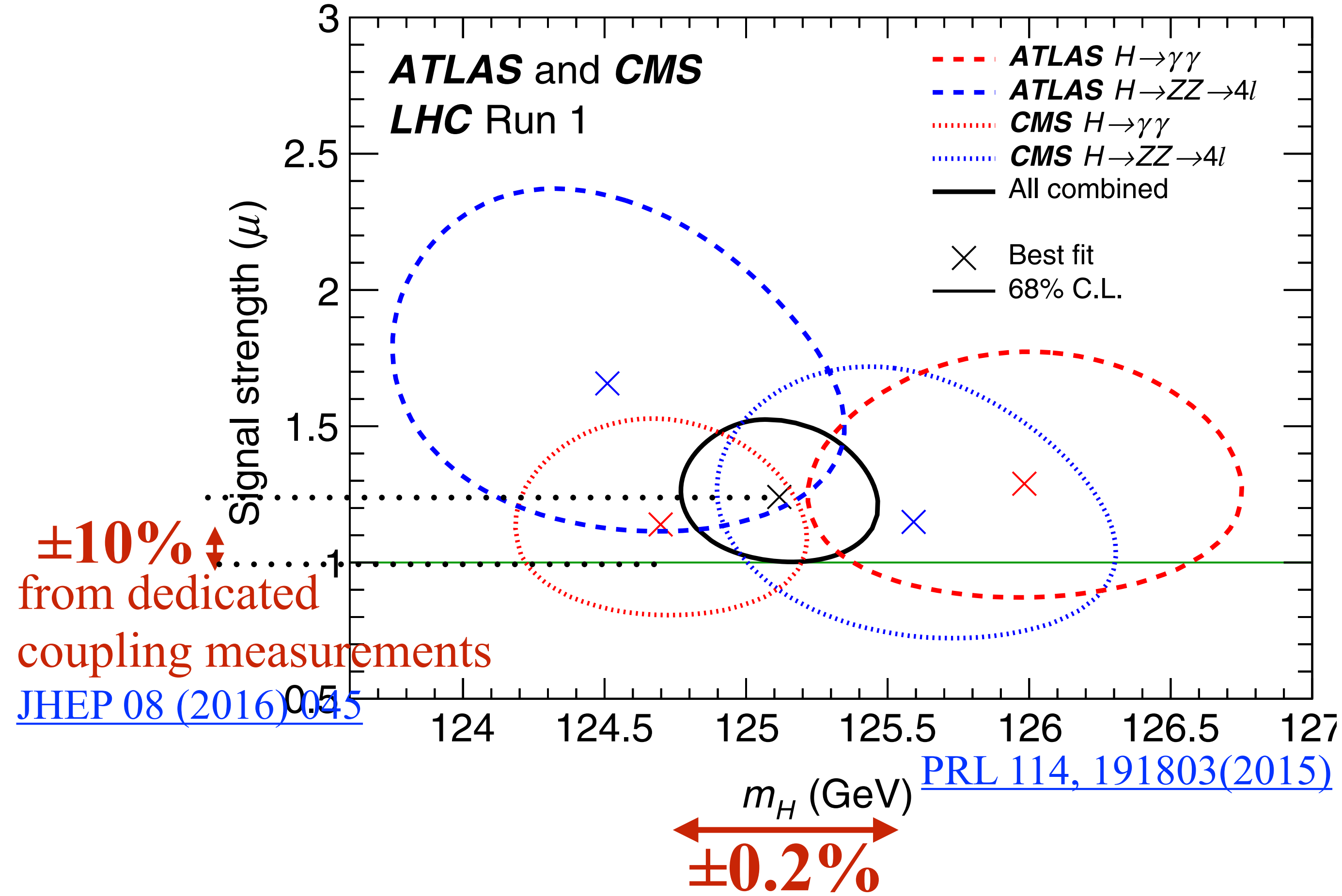
~0.5 pb (1%)



The Legacy of Run-1

Higgs discovery

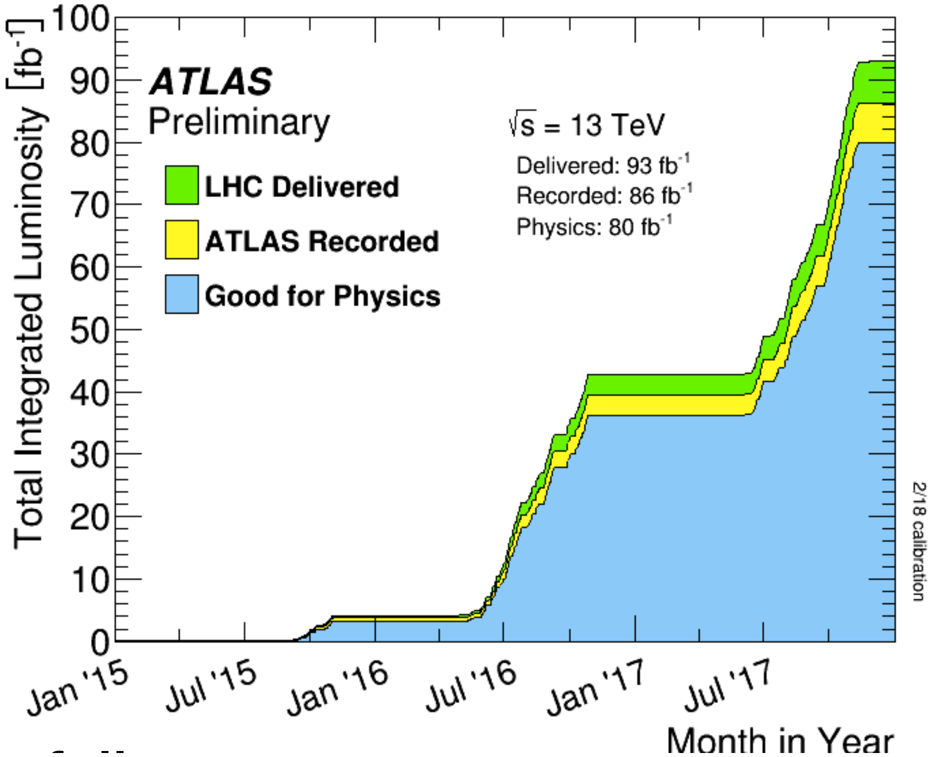


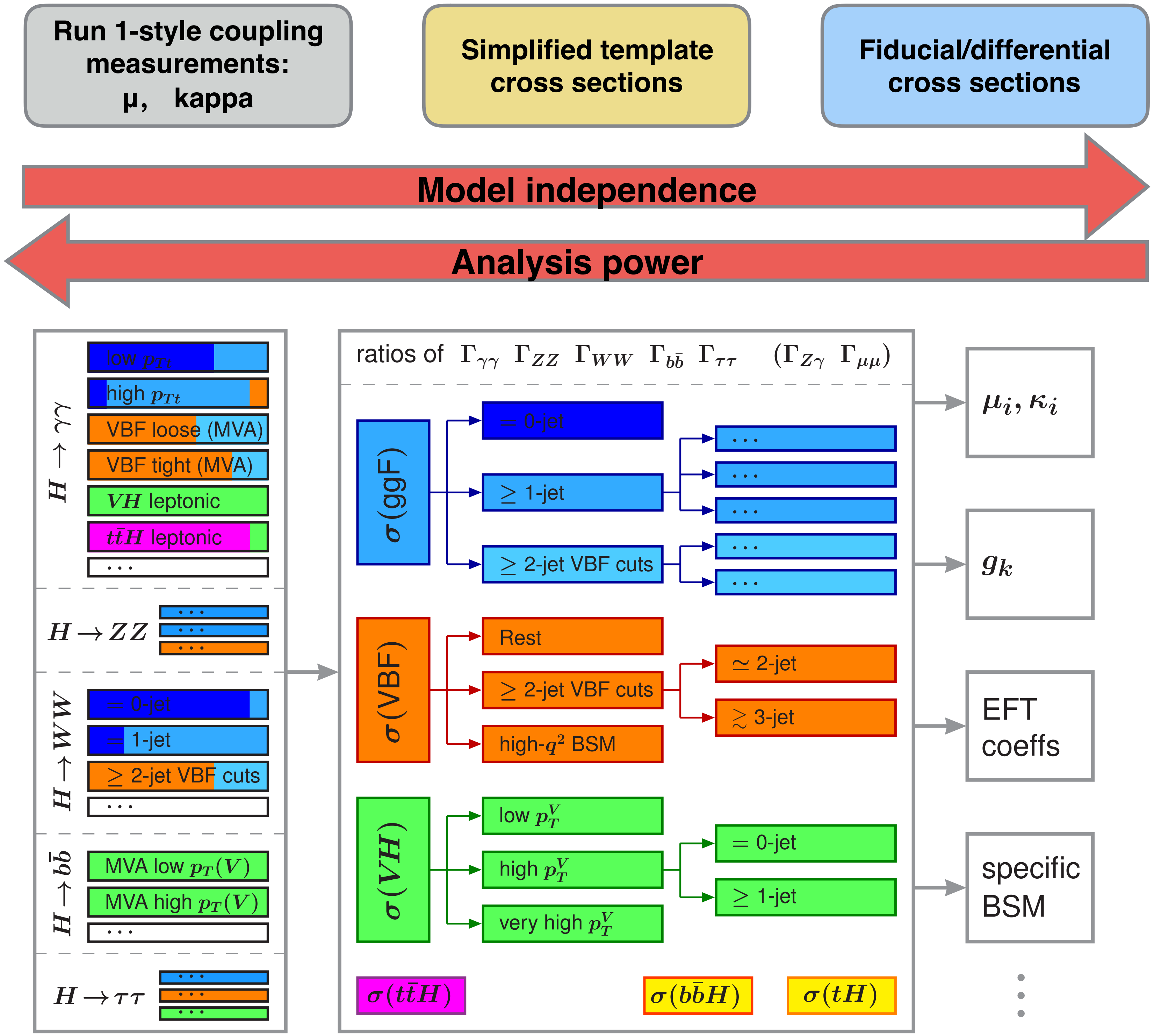


Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.6
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7

The first measurement of Higgs properties:
No significant deviation from SM.

How to Measure Higgs Property for Run2?

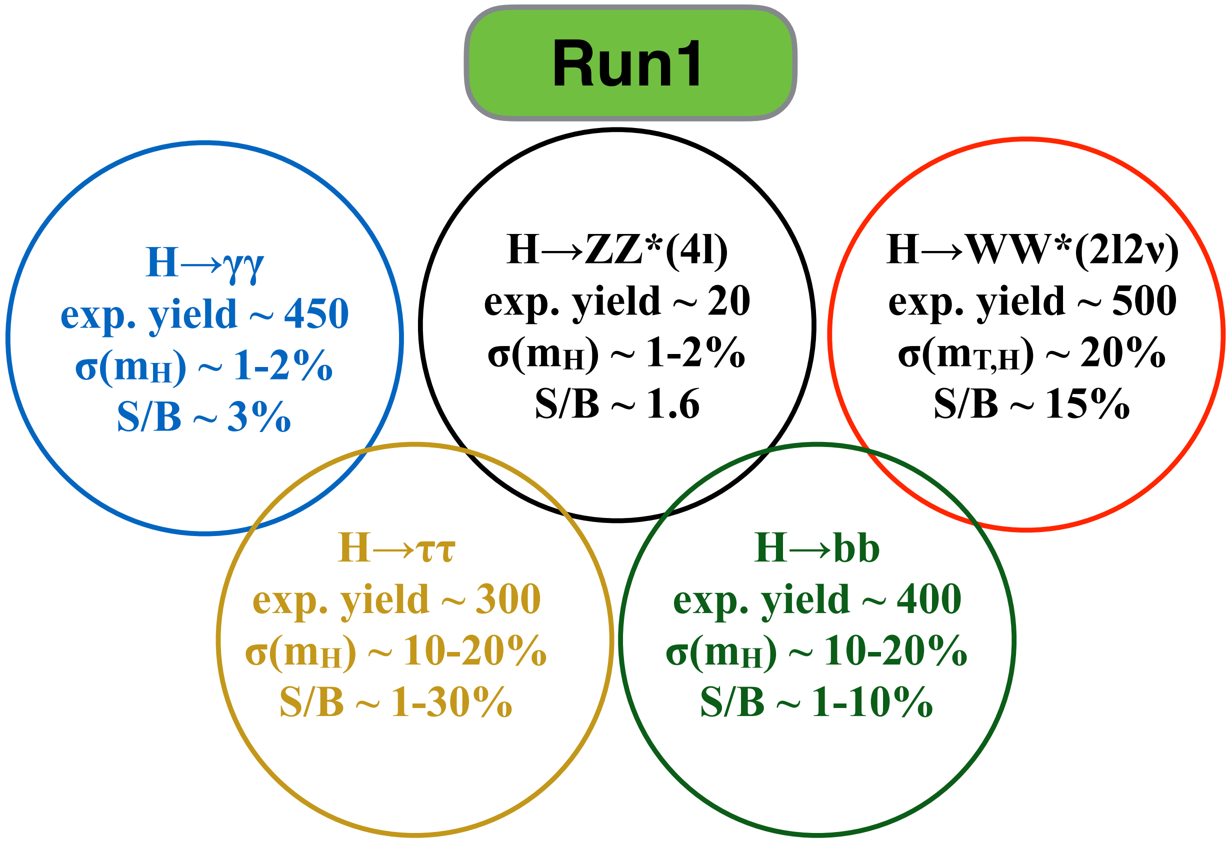


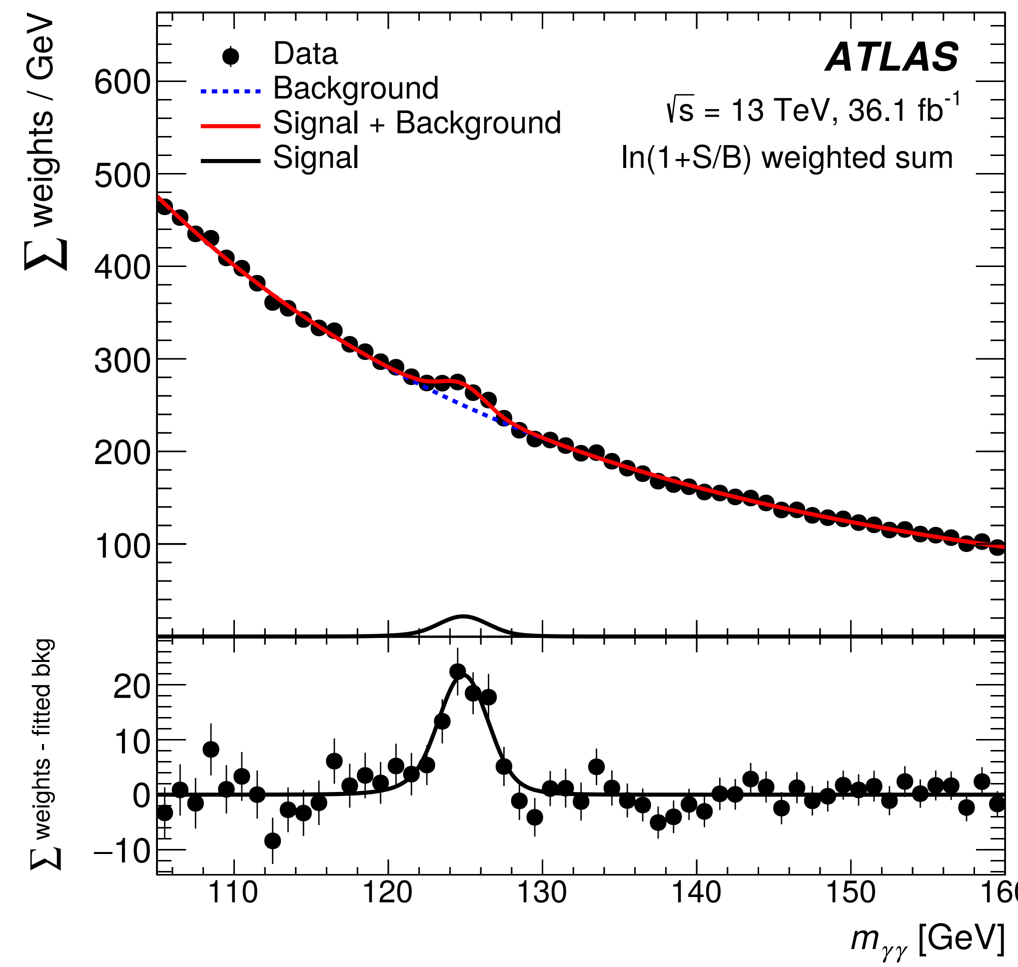


Higher collider energy
Higher data statistics

Comprehensive measurement methodologies including the new one of simplified template cross section measurement (STXS)

Why in $H\rightarrow\gamma\gamma$?

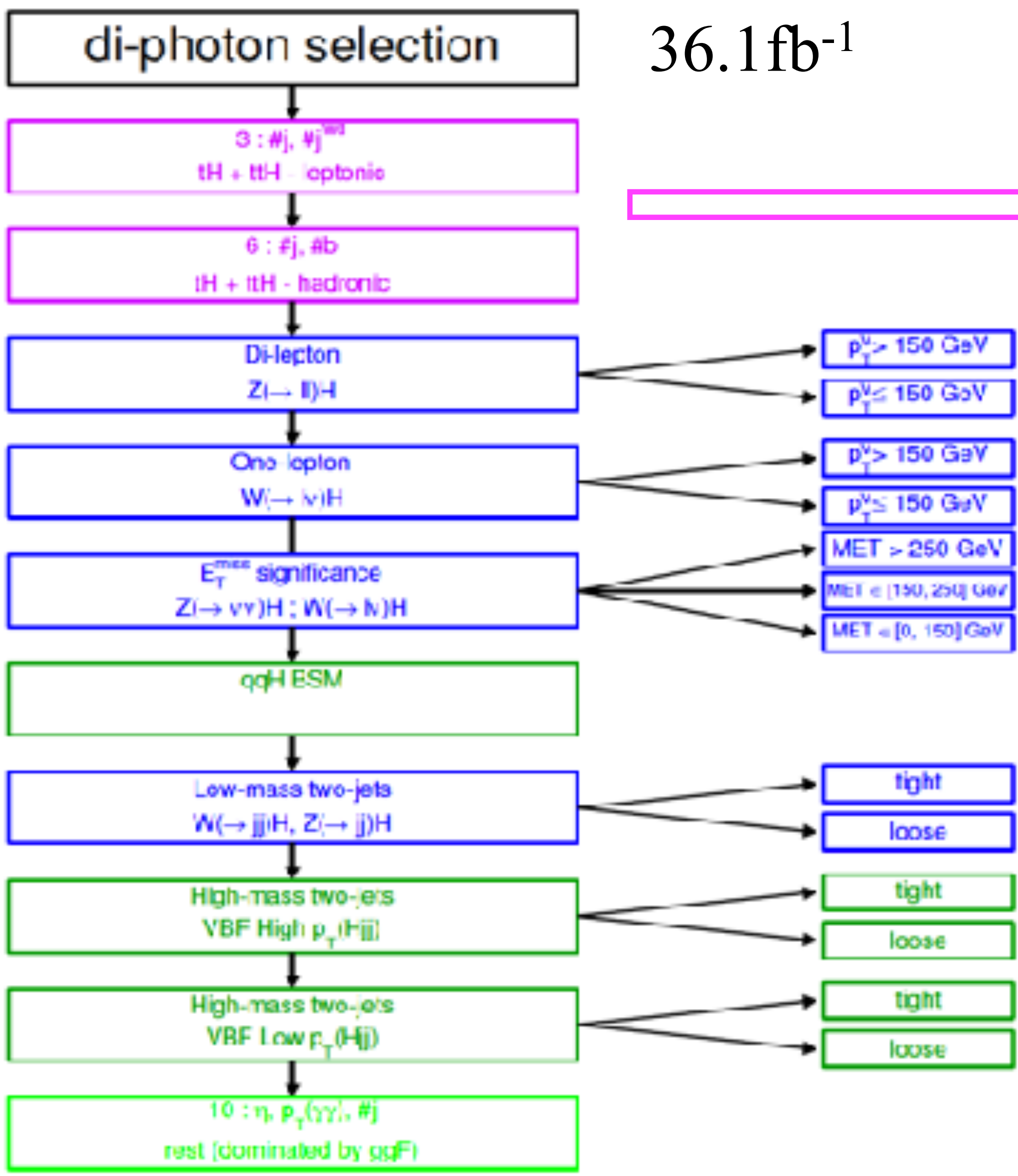




- **High photon reconstruction and identification efficiencies** lead to a sizable Higgs signal yield
- **Good photon resolution** exhibits the Higgs signal a peak on top of a smoothing falling background
- **Nice signal-background separation**

Di-photon Selection / Categorization

- Preselection of two leading loose photons **within |η|<2.37 excluding crack region [1.37, 1.52]**
- Photon candidates must be **tight identification requirements + isolated** (track and calorimeter isolation within ΔR=0.2)
- Leading (sub-leading) photon with $\mathbf{p_T^{\gamma}/m_{\gamma\gamma}>0.35(0.25)}$
- Diphoton mass window of **105 GeV < $\mathbf{m_{\gamma\gamma}}$ < 160GeV**



36.1fb^{-1}

Dedicated BDTs to separate ttH signal with 79.8fb^{-1} for discovery of t-Yukawa coupling

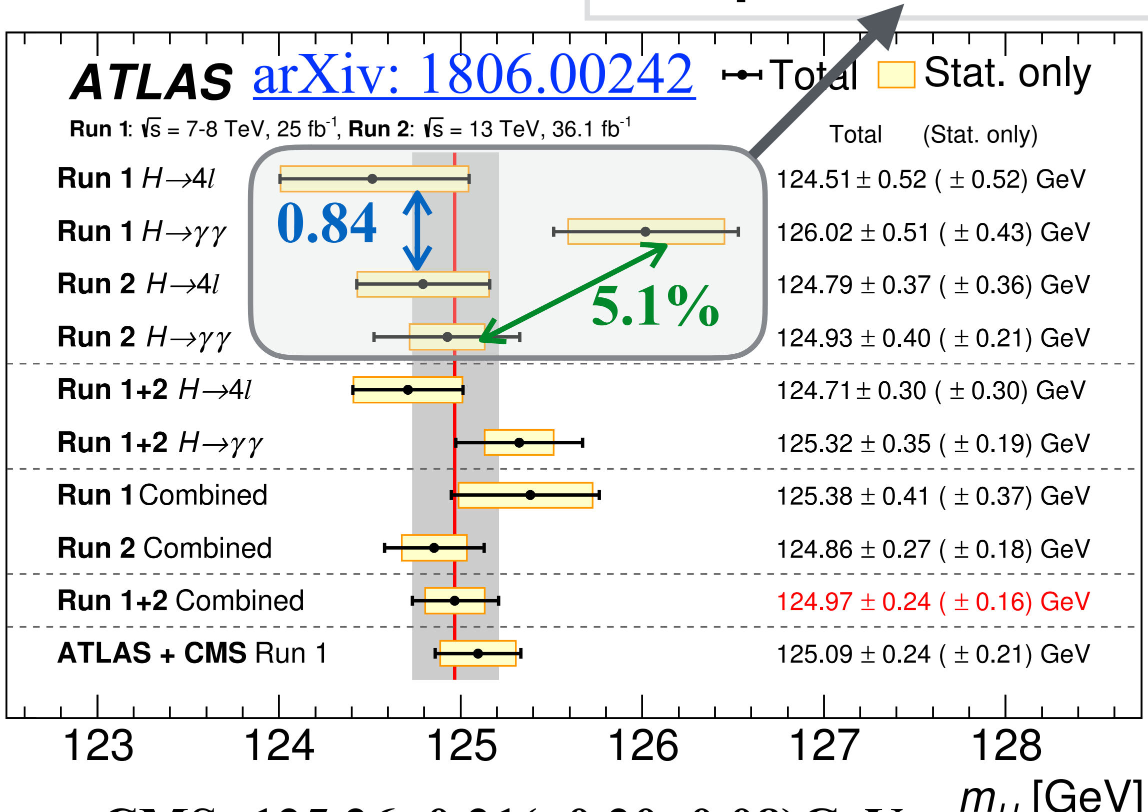
Full update with 79.8fb^{-1} will be available @ ICHEP

- Make use of **event kinematics and topologies of diff. production modes**
- Maximize the sensitivity to the **regions of STXS**

Mass measurement

- Dominant systematic uncertainties in $\gamma\gamma$ channel:
  - **Photon energy scale:** ±260MeV in “ggH 0J Cen” - 470MeV in “Jet BSM”
  - **Background modeling**: ±60MeV
  - **Event vertex selection**: ±40MeV
- ATLAS-only Combined result is **comparable w.r.t. ATLAS+CMS Run-1 combination**
- Uncertainty on coupling ~ 0.5%

Compatible with 12.3%



CMS :125.26±0.21(±0.20±0.08)GeV

$\sigma(m_H)/m_H \sim 0.17\%$

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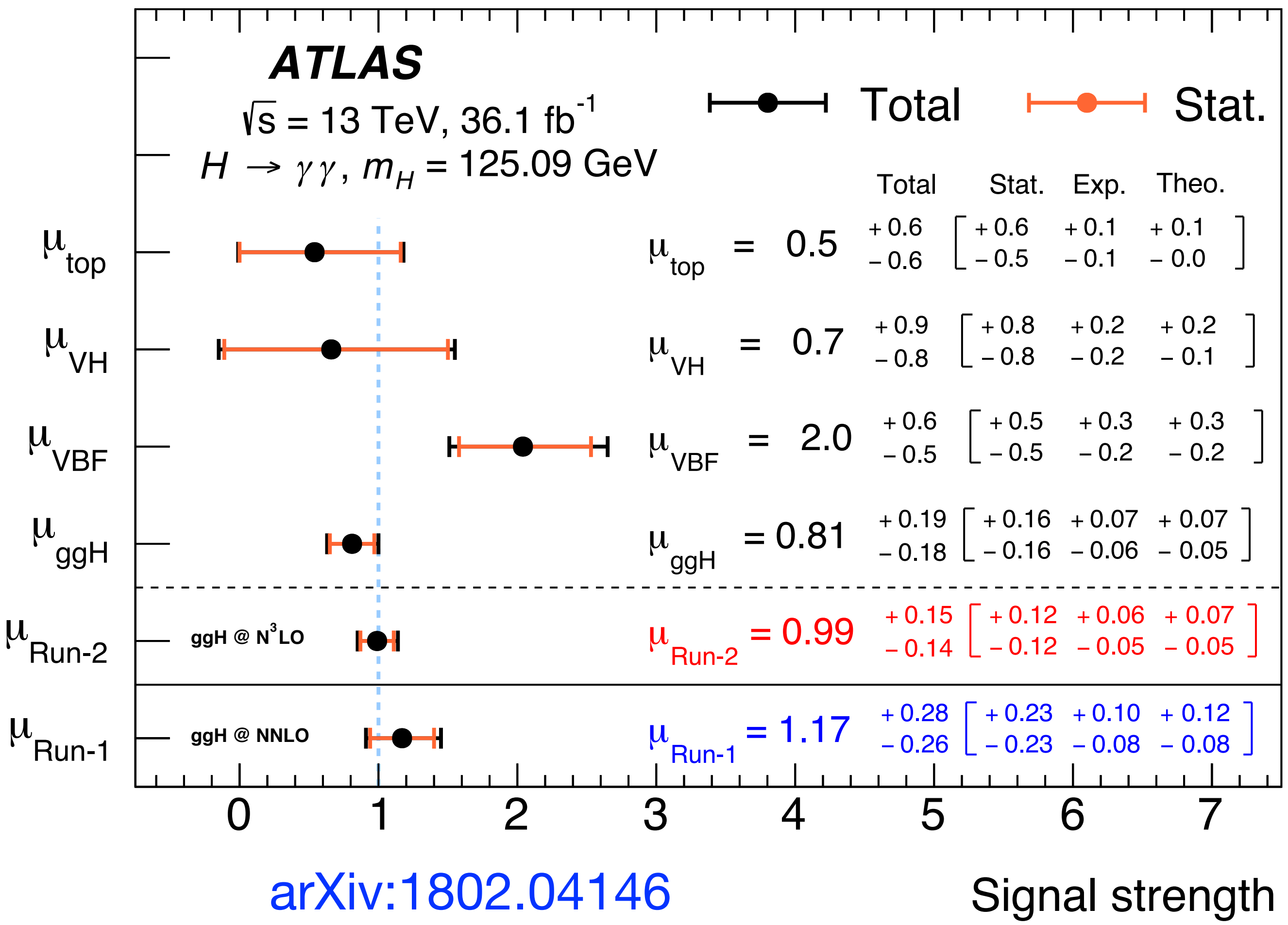
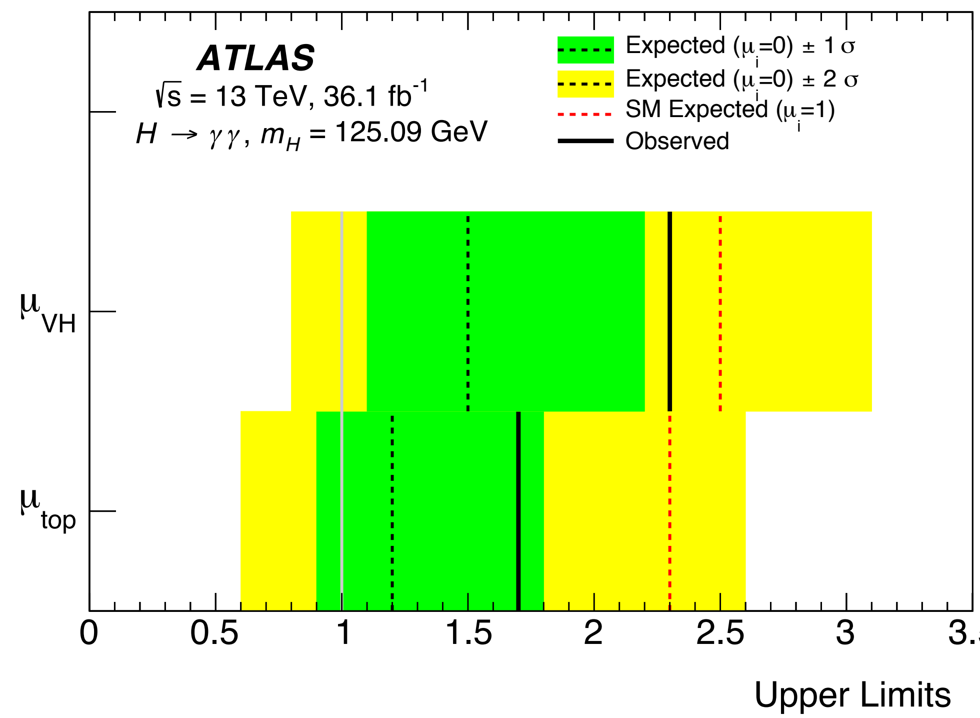
Source	Systematic uncertainty in m_H [MeV]
EM calorimeter response linearity	60
Non-ID material	55
EM calorimeter layer intercalibration	55
$Z \rightarrow ee$ calibration	45
ID material	45
Lateral shower shape	40
Muon momentum scale	20
Conversion reconstruction	20
$H \rightarrow \gamma\gamma$ background modelling	20
$H \rightarrow \gamma\gamma$ vertex reconstruction	15
e/γ energy resolution	15
All other systematic uncertainties	10

Signal strength



arXiv:1802.04146

Measurement	Exp. Z_0	Obs. Z_0
μ_{VBF}	2.6 σ	4.9 σ
μ_{VH}	1.4 σ	0.8 σ
μ_{top}	1.8 σ	1.0 σ



- $\mathbf{m_H}$**=125.09GeV** (ATLAS+CMS Run1 combination)
- The global signal strength measurement **improves on the Run1 precision with a factor of 2**.

Production mode cross section

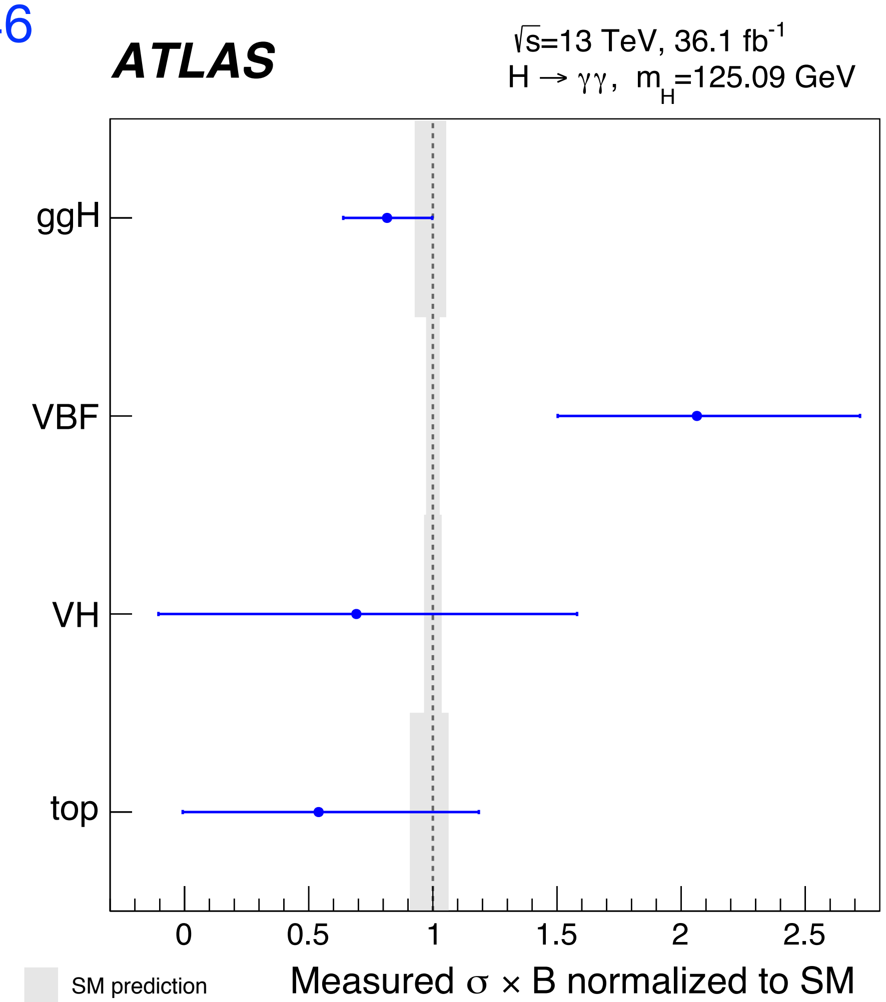
arXiv:1802.04146

Process ($\lvert y_H \rvert < 2.5$)	Result [fb]	Total	Stat.	Exp.	Th.	SM prediction [fb]
ggH	82	$^{+19}_{-18}$	$(\pm 16$	$^{+7}_{-6}$	$^{+5}_{-4})$	102^{+5}_{-7}
VBF	16	$^{+5}_{-4}$	$(\pm 4$	± 2	$^{+3}_{-2})$	8.0 ± 0.2
VH	3	± 4	$(^{+4}_{-3}$	± 1	$^{+1}_{-0})$	4.5 ± 0.2
top	0.7	$^{+0.9}_{-0.7}$	$(^{+0.8}_{-0.7}$	$^{+0.2}_{-0.1}$	$^{+0.2}_{-0.0})$	1.3 ± 0.1

$$\frac{\sigma_{\mathrm{VBF}}/\sigma_{\mathrm{ggH}}}{(\sigma_{\mathrm{VBF}}/\sigma_{\mathrm{ggH}})^{\mathrm{SM}}} = 2.5\,^{+1.3}_{-0.9} = 2.5\,^{+1.1}_{-0.8}\,(\mathrm{stat.})\,^{+0.5}_{-0.3}\,(\mathrm{exp.})\,^{+0.5}_{-0.3}\,(\mathrm{theory})$$

$$\frac{\sigma_{\mathrm{VH}}/\sigma_{\mathrm{ggH}}}{(\sigma_{\mathrm{VH}}/\sigma_{\mathrm{ggH}})^{\mathrm{SM}}} = 0.9\,^{+1.3}_{-1.0} = 0.9\,^{+1.2}_{-0.9}\,(\mathrm{stat.})\,^{+0.3}_{-0.3}\,(\mathrm{exp.})\,^{+0.2}_{-0.1}\,(\mathrm{theory})$$

$$\frac{\sigma_{\mathrm{top}}/\sigma_{\mathrm{ggH}}}{(\sigma_{\mathrm{top}}/\sigma_{\mathrm{ggH}})^{\mathrm{SM}}} = 0.7\,^{+0.8}_{-0.7} = 0.7\,^{+0.8}_{-0.7}\,(\mathrm{stat.})\,^{+0.2}_{-0.1}\,(\mathrm{exp.})\,^{+0.2}_{-0.0}\,(\mathrm{theory})$$



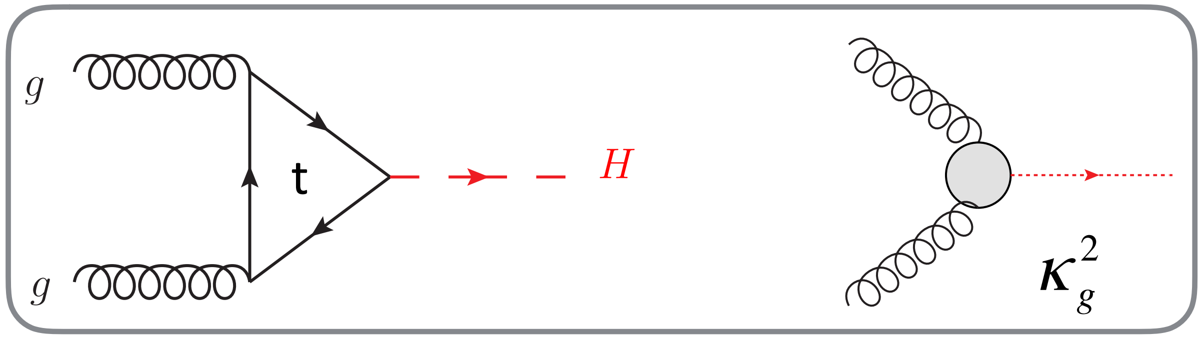
- The signal yield in each category c is parametrized with the cross section of each mode.

$$L \times \sigma_i^{\mathrm{SM}} \times B^{\mathrm{SM}}(H \to \gamma\gamma) \times (A \times \epsilon)_i^c$$

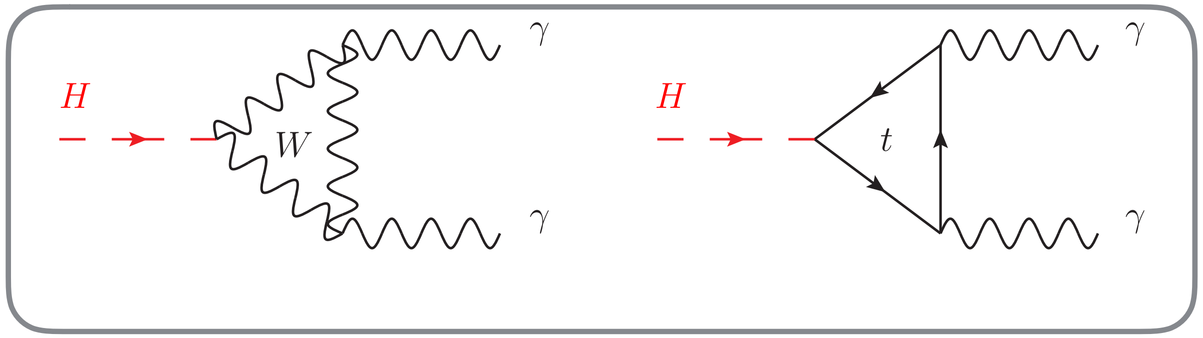
- **Direct measurement on the production mode cross section**, as well as **rate parametrization** to cancel out the impact of the possible branching ratio derivations.

κ - framework

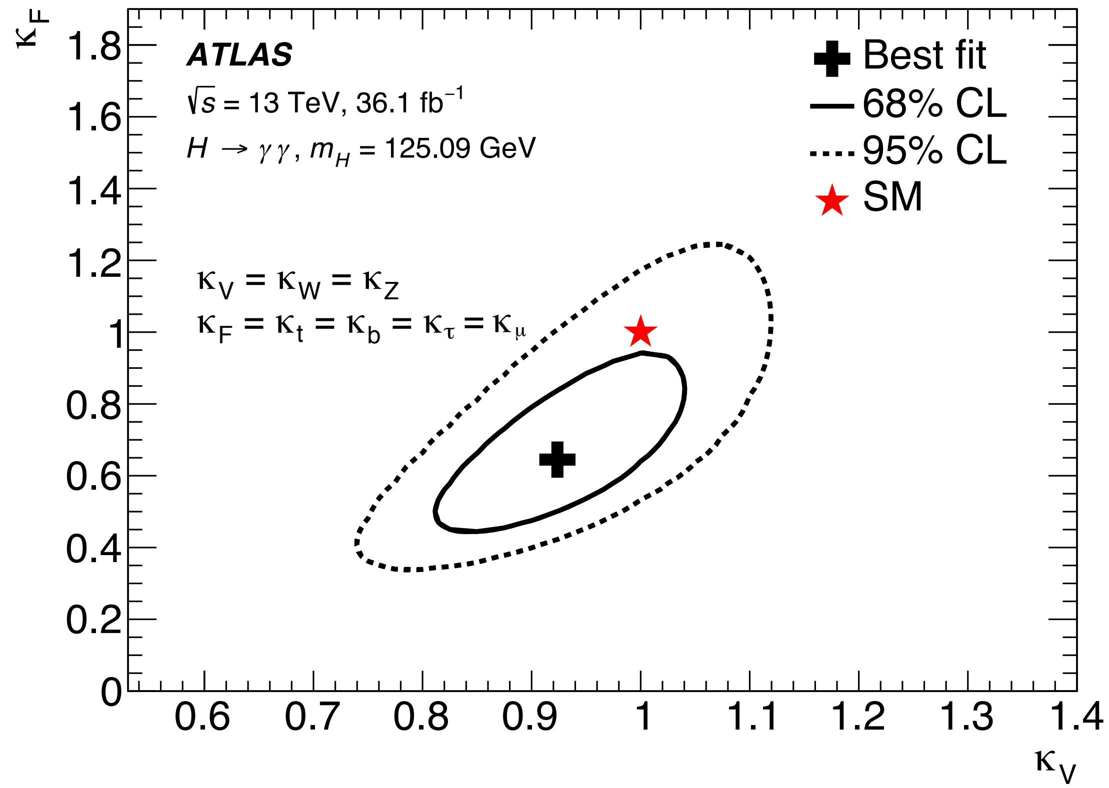
- **Assumptions:**
  - Single state, spin 0 and CP-even.
  - Narrow-width approximation: $(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$
- **Methodology:** parametrize deviations with coupling scale factors $\{\kappa_x\}$

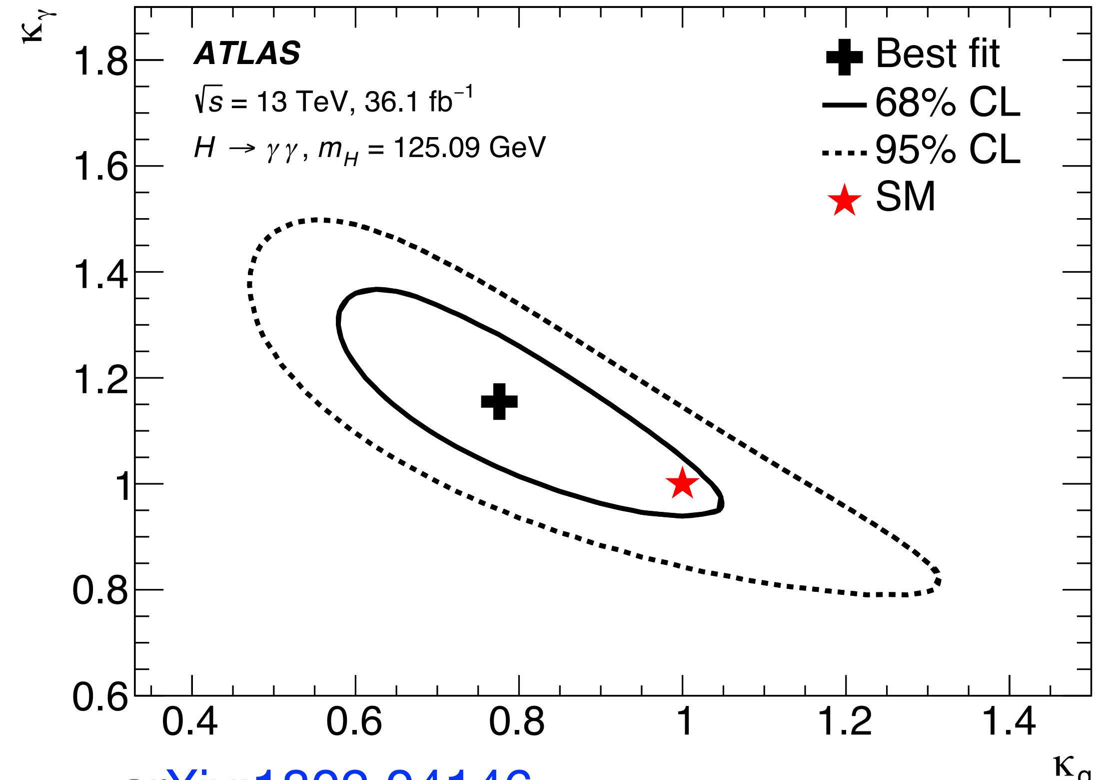


$\kappa_g^2 = 1.042\kappa_t^2 + 0.002\kappa_b^2 - 0.040\kappa_t\kappa_b - 0.005\kappa_t\kappa_c + 0.0005\kappa_b\kappa_c + 0.00002\kappa_c^2$



$\kappa_\gamma \propto 1.6 \times \kappa_W^2 - 0.7 \times \kappa_t \kappa_W + 0.1 \times \kappa_t^2$





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κ - framework

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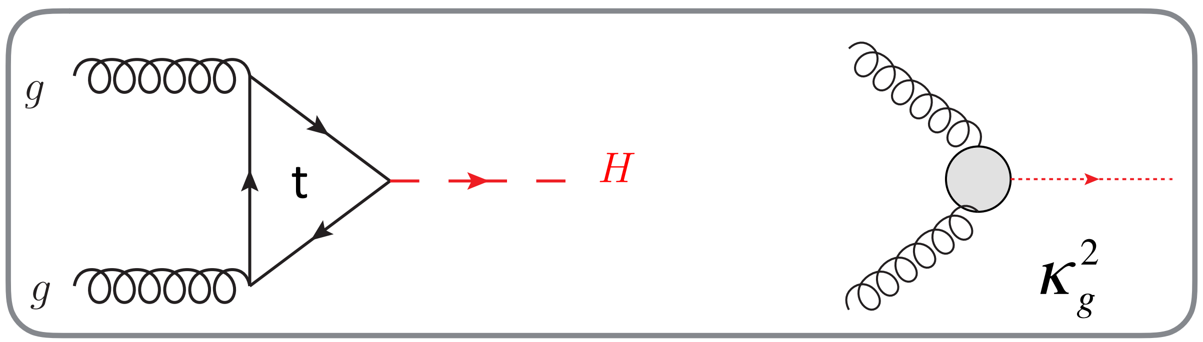
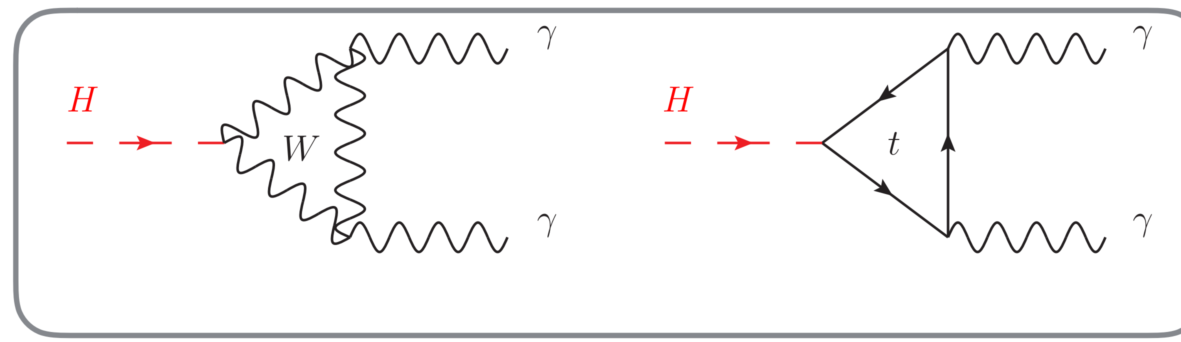
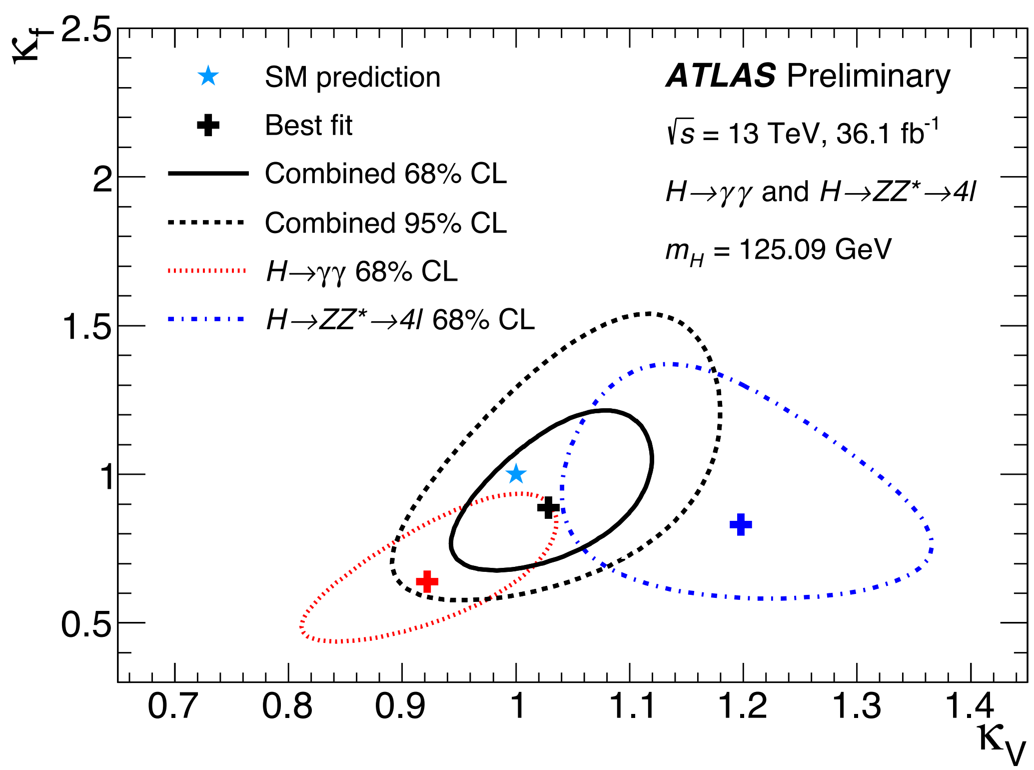
- **Methodology:** parametrize deviations with coupling scale factors $\{\kappa_x\}$

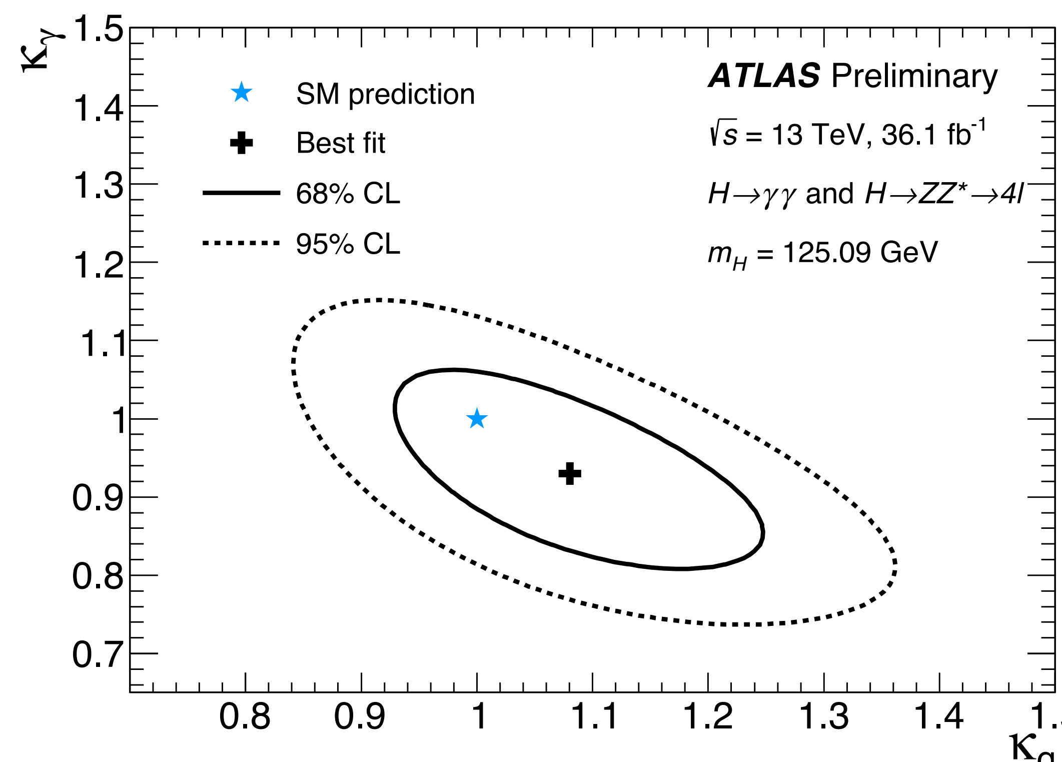




$\kappa_g^2 = 1.042\kappa_t^2 + 0.002\kappa_b^2 - 0.040\kappa_t\kappa_b - 0.005\kappa_t\kappa_c + 0.0005\kappa_b\kappa_c + 0.00002\kappa_c^2$

$\kappa_\gamma \propto 1.6 \times \kappa_W^2 - 0.7 \times \kappa_t \kappa_W + 0.1 \times \kappa_t^2$





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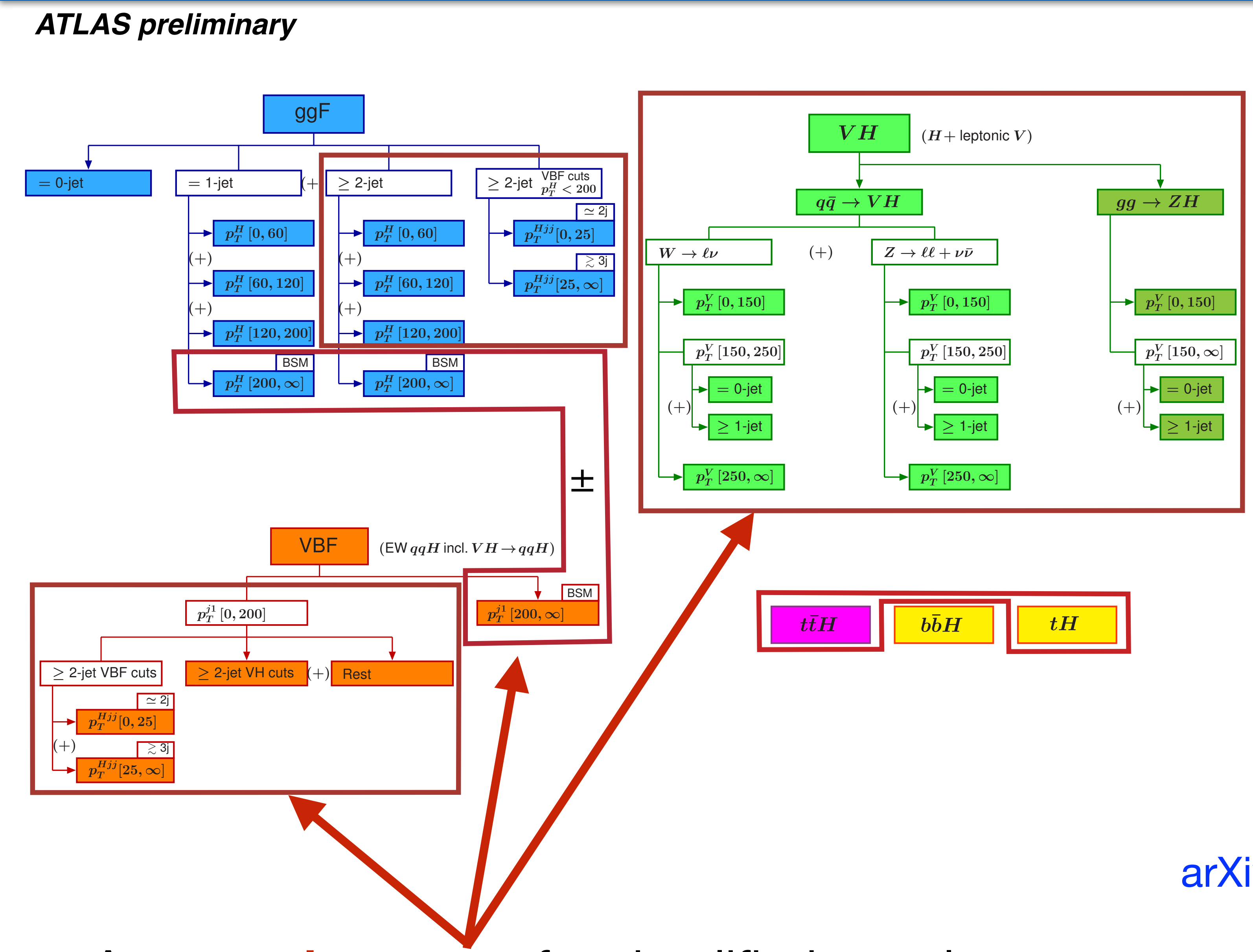
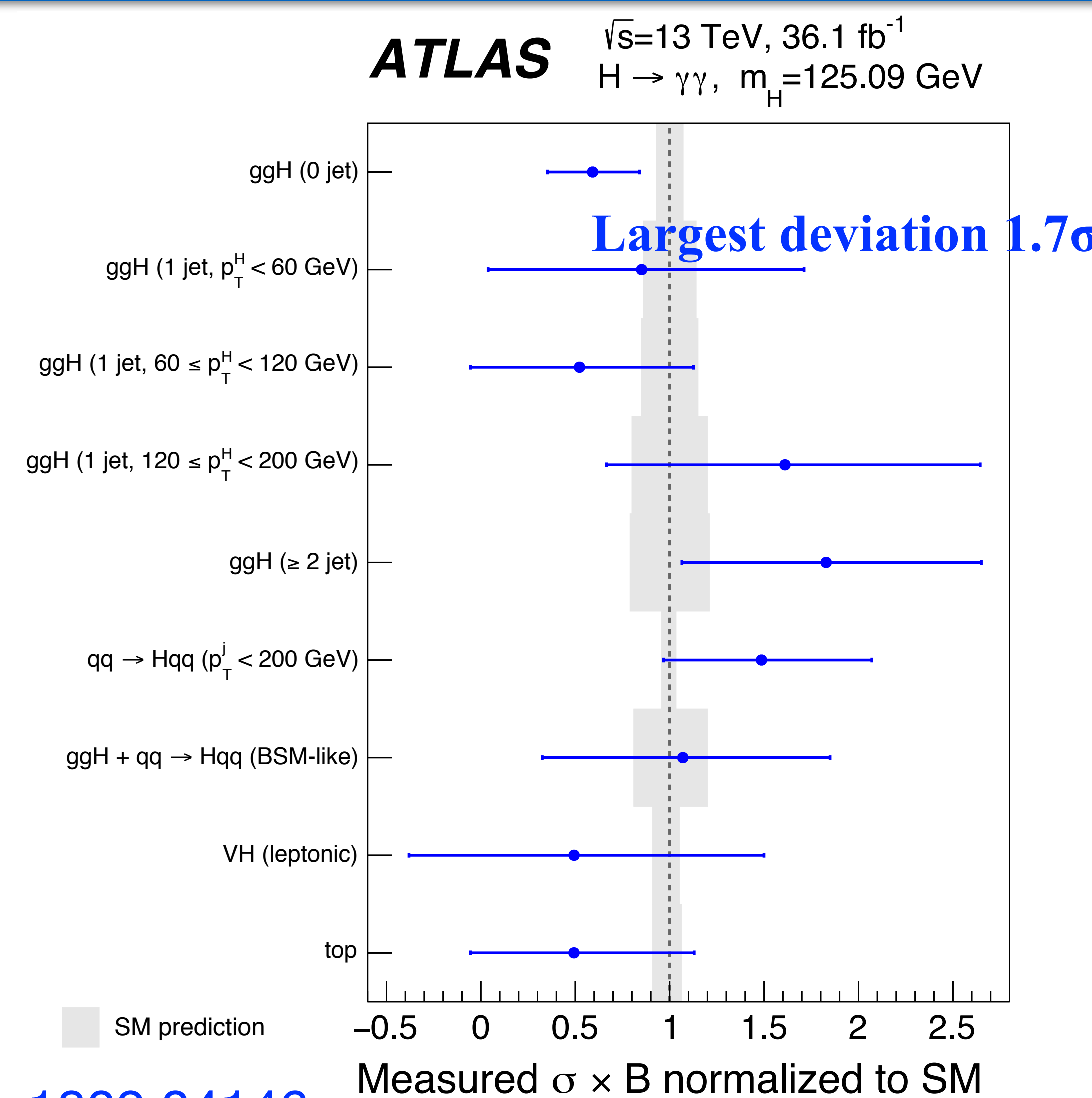
Simplified template cross section





arXiv:1802.04146

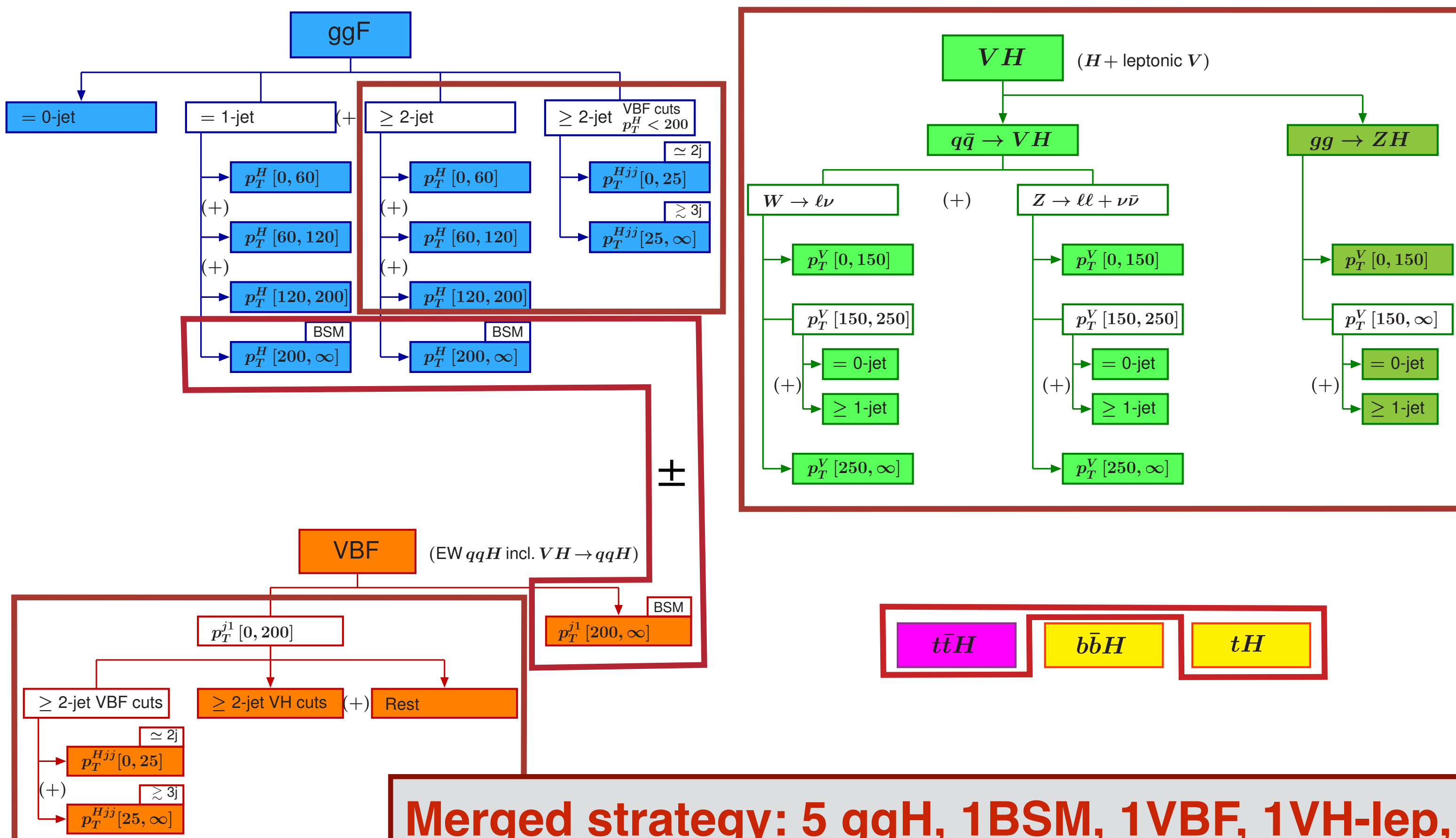
- A **merged strategy** for simplified template cross section measurement is used to **reduce strong correlations** and **keep total uncertainty near or below 100%**
- The signal yield in each category c is the sum over the yields from the simplified template regions

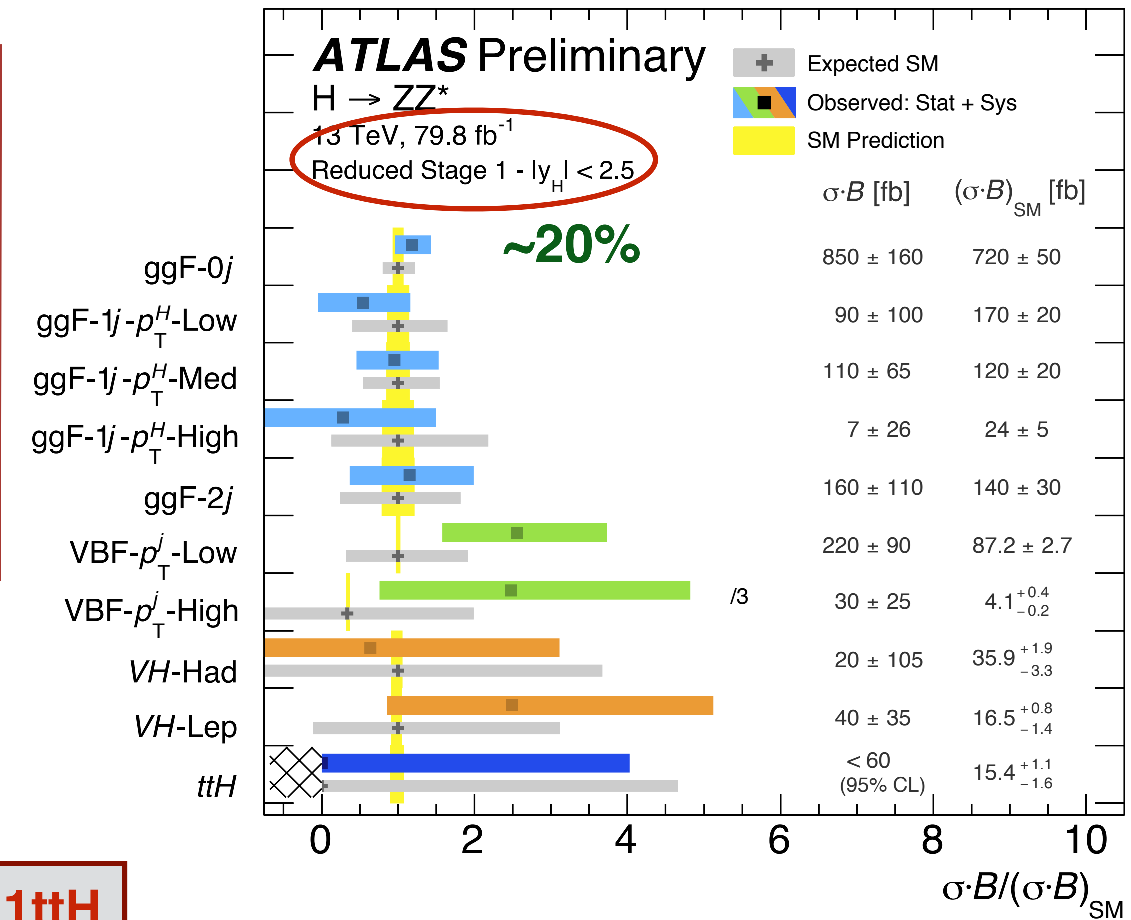
$$L \times \sigma_t^{SM} \times B^{SM}(H \to \gamma\gamma) \times (A \times \epsilon)_t^c$$

- Since defined to minimize theoretical uncertainty, the measurements are strongly dominated by experimental uncertainty

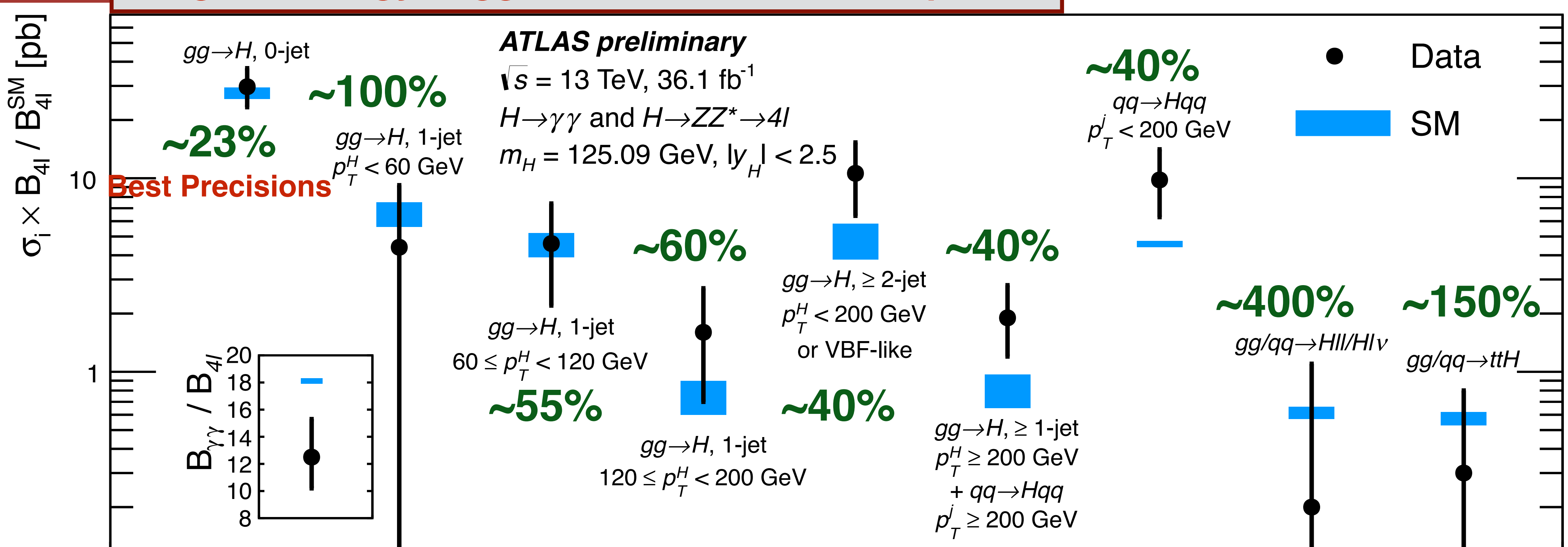
Simplified template cross section

ATLAS preliminary



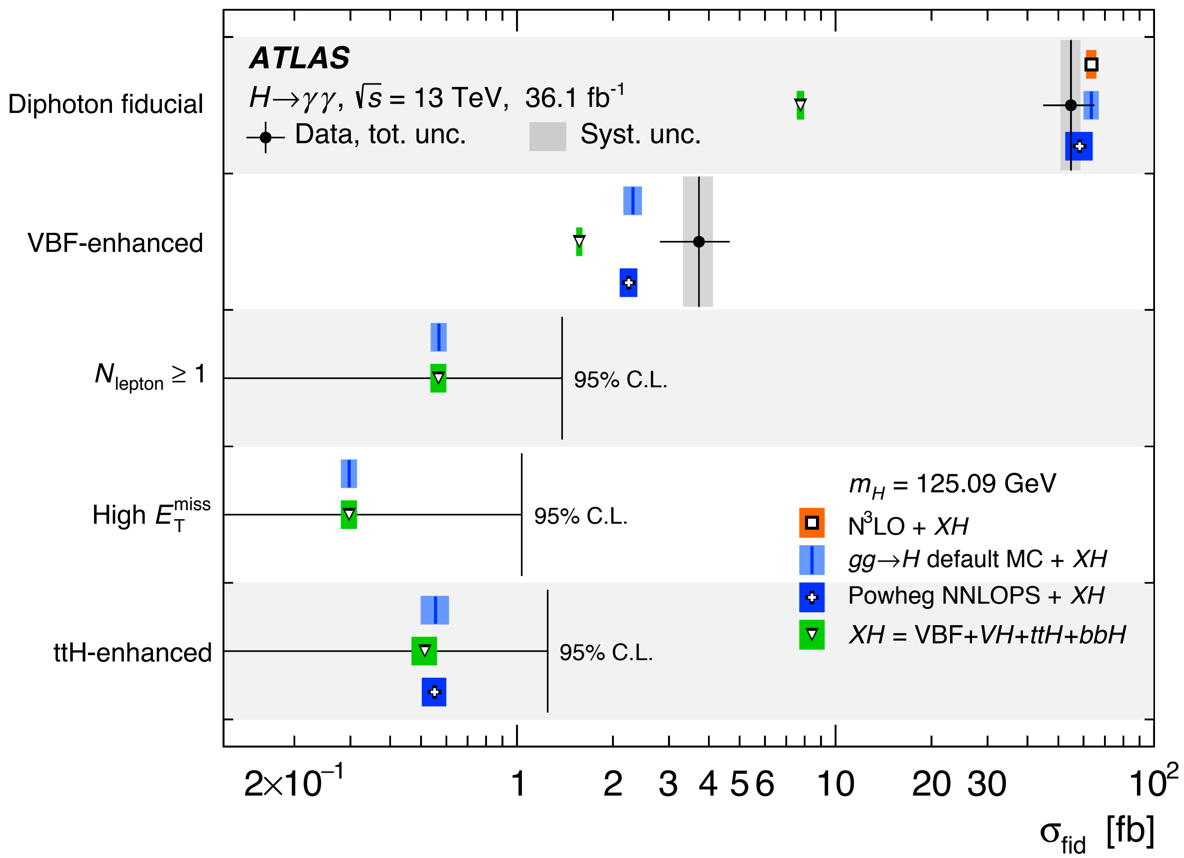


Merged strategy: 5 ggH, 1BSM, 1VBF, 1VH-lep, 1ttH



ATLAS-CONF-2017-047 Simplified template cross section measurements

Fiducial cross section measurement



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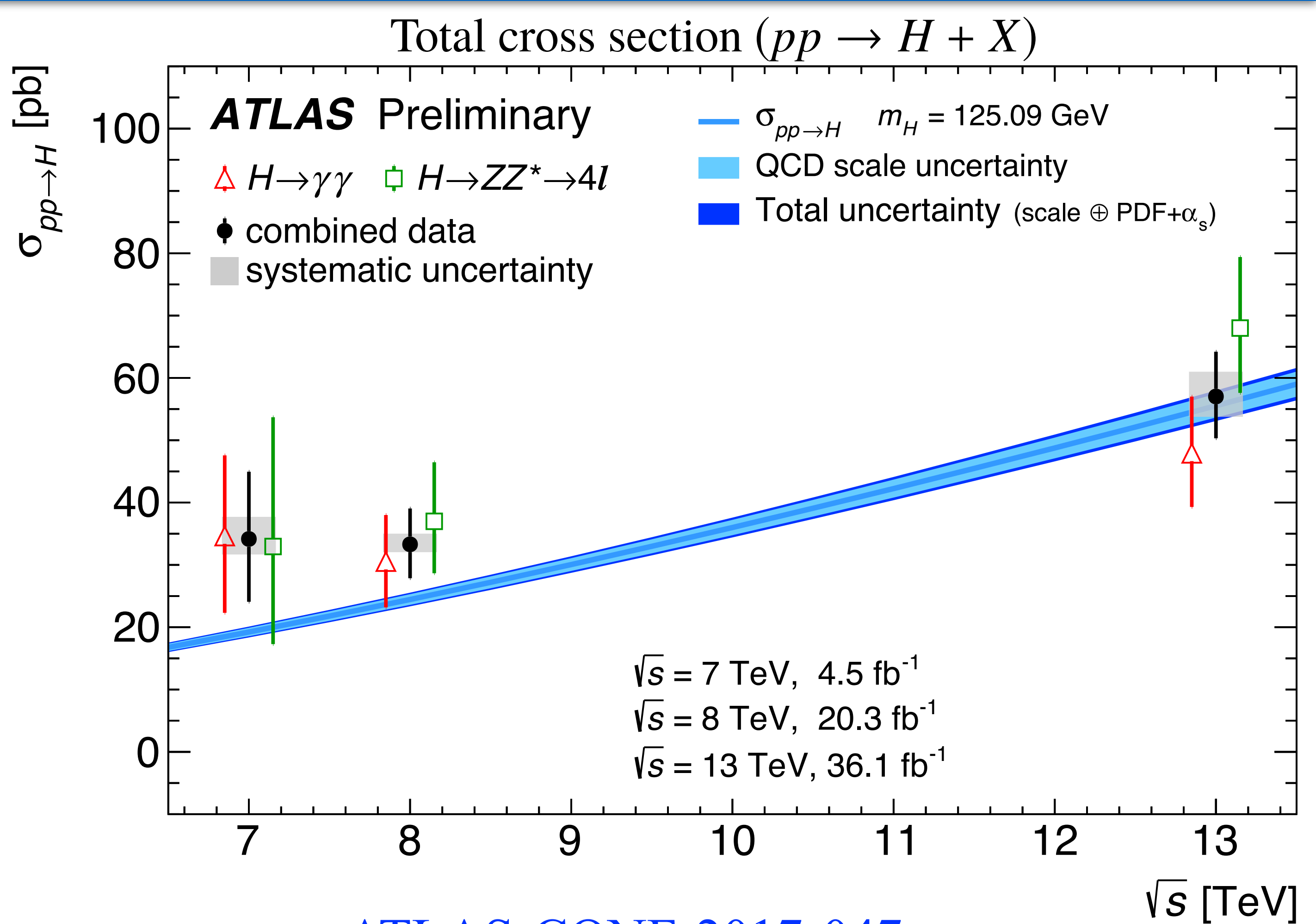


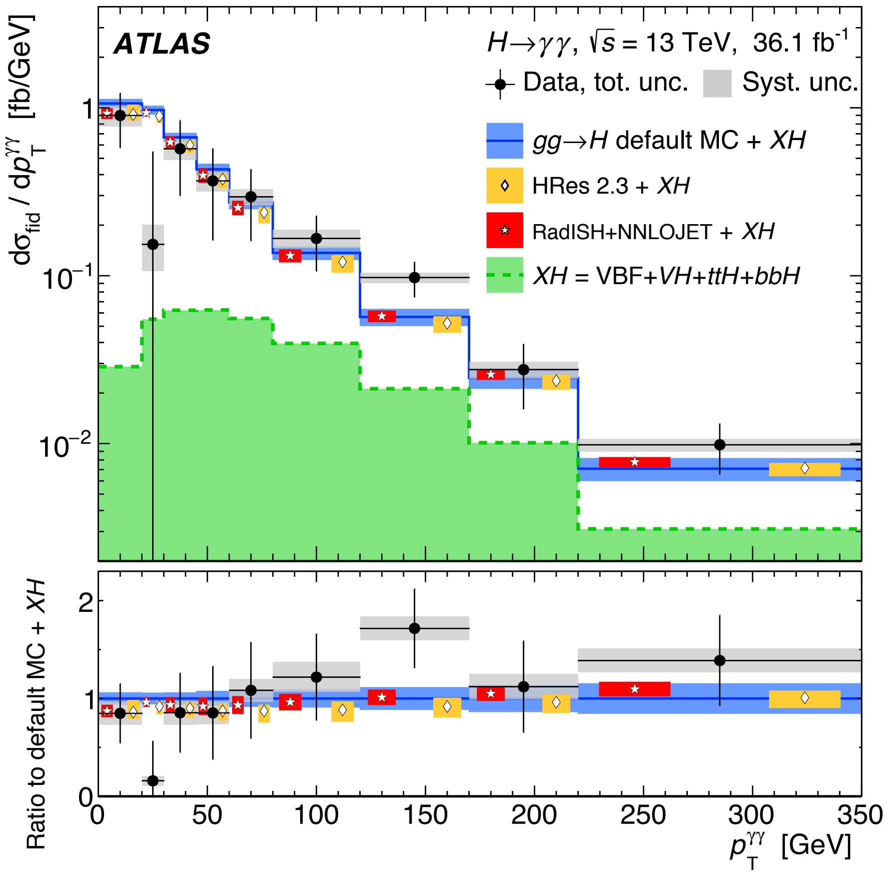
ATLAS-CONF-2017-047

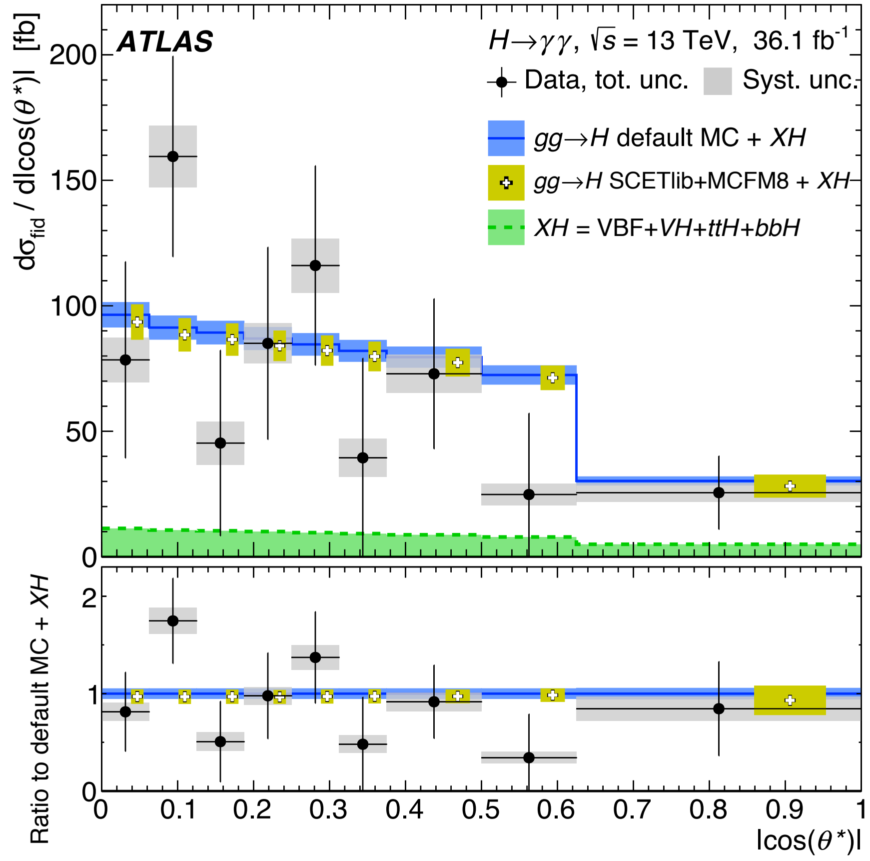
Fiducial region	Measured cross section	SM prediction	
Diphoton fiducial	$55 \pm 9\,(\text{stat.}) \pm 4\,(\text{exp.}) \pm 0.1\,(\text{theo.})$ fb	64 ± 2 fb	[N^{3}LO + XH]
VBF-enhanced	$3.7 \pm 0.8\,(\text{stat.}) \pm 0.5\,(\text{exp.}) \pm 0.2\,(\text{theo.})$ fb	2.3 ± 0.1 fb	[default MC + XH]
$N_{\text{lepton}} \geq 1$	≤ 1.39 fb 95% CL	0.57 ± 0.03 fb	[default MC + XH]
High E_T^{miss}	≤ 1.00 fb 95% CL	0.30 ± 0.02 fb	[default MC + XH]
$t\bar{t}H$-enhanced	≤ 1.27 fb 95% CL	0.55 ± 0.06 fb	[default MC + XH]

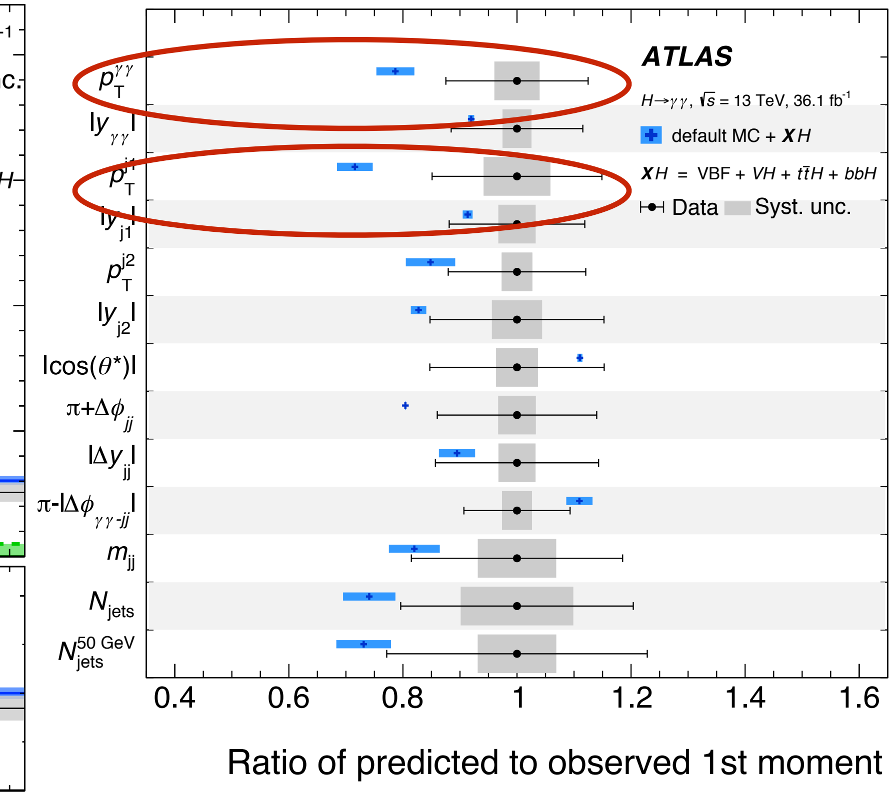
In good agreement with SM prediction

Differential cross section measurement

Higgs boson production / Jet kinematics, Spin-CP, VBF production mode







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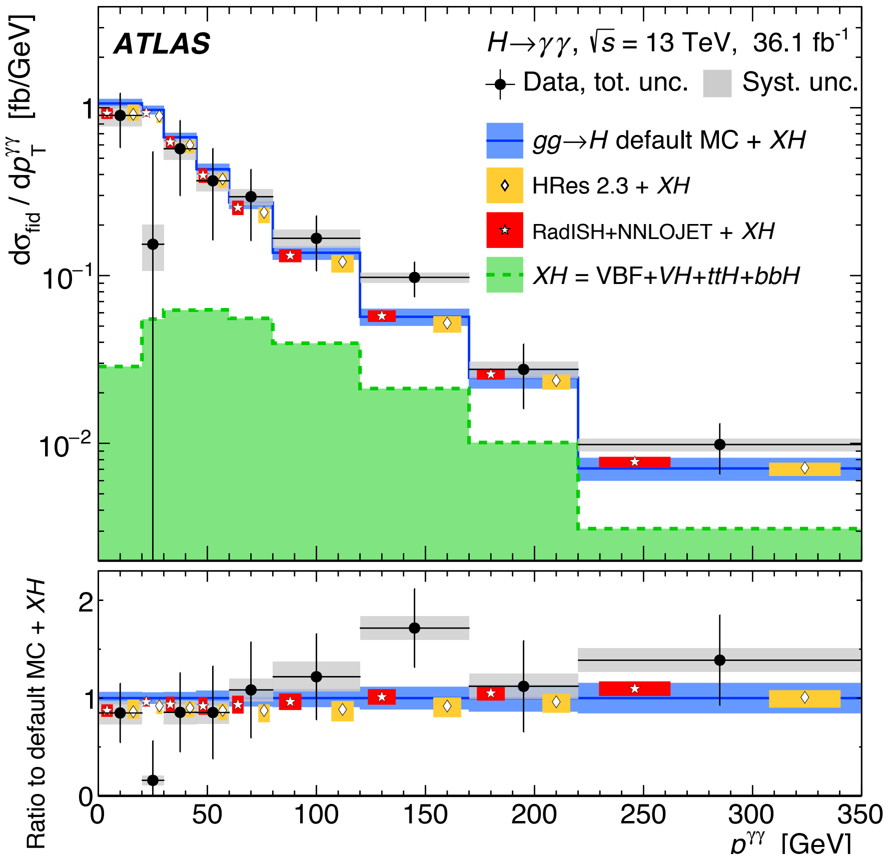
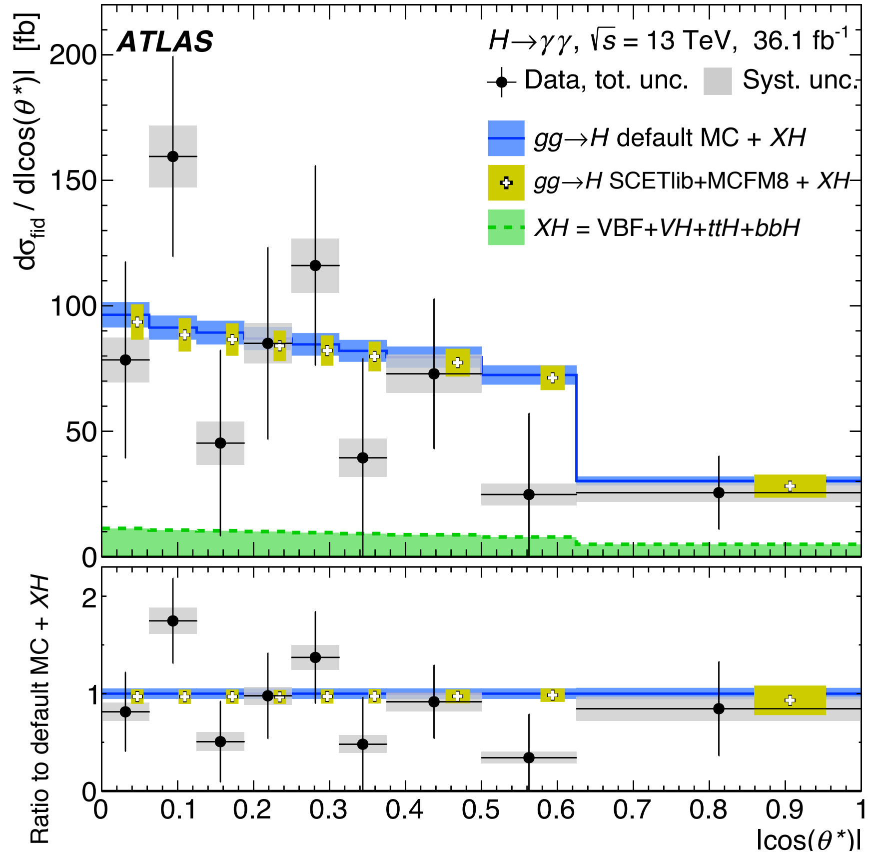
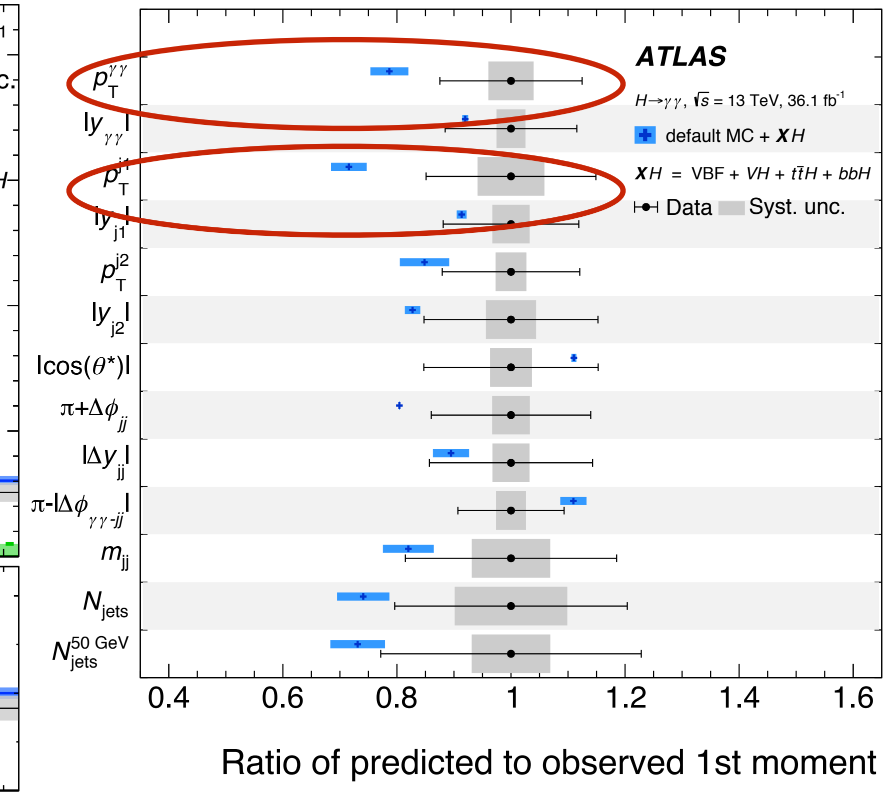
- The data slightly undershoot (overshoot) the SM prediction at low (large) transverse momentum.
- The compatibility is tested with the probability from χ^2 test and first/second moment, shows a good agreement.

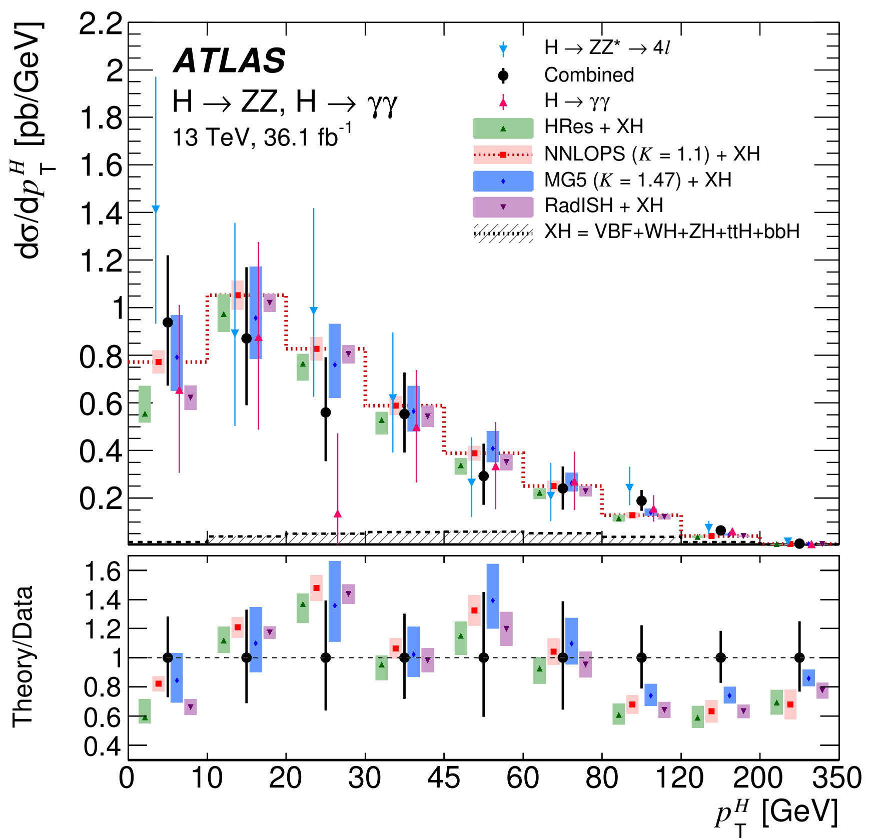
Differential cross section measurement

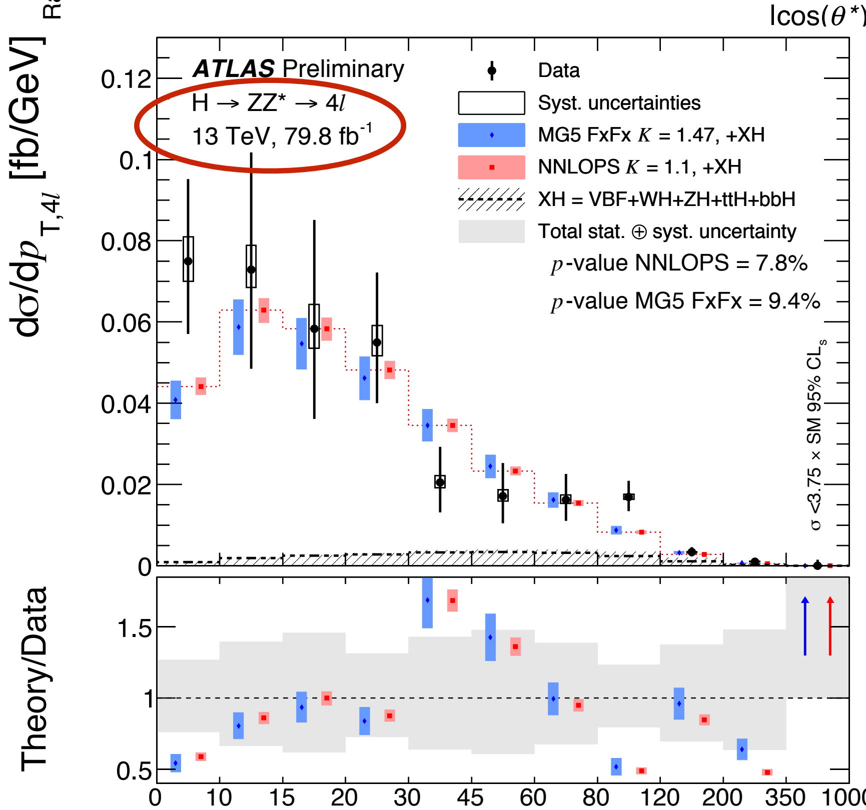
Higgs boson production / Jet kinematics, Spin-CP, VBF production mode



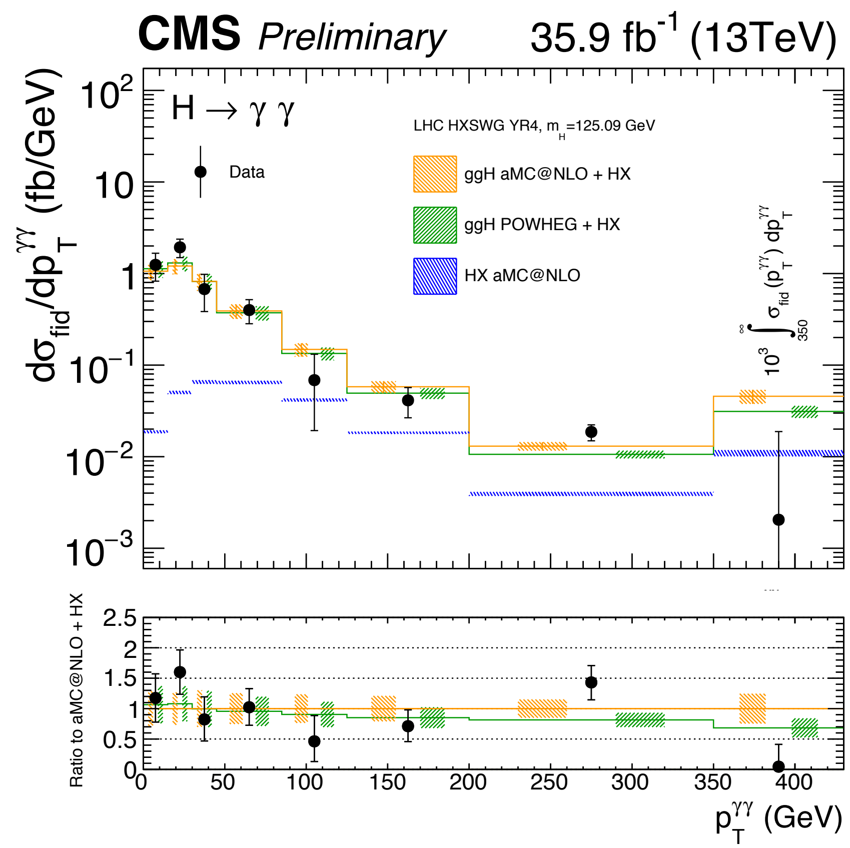




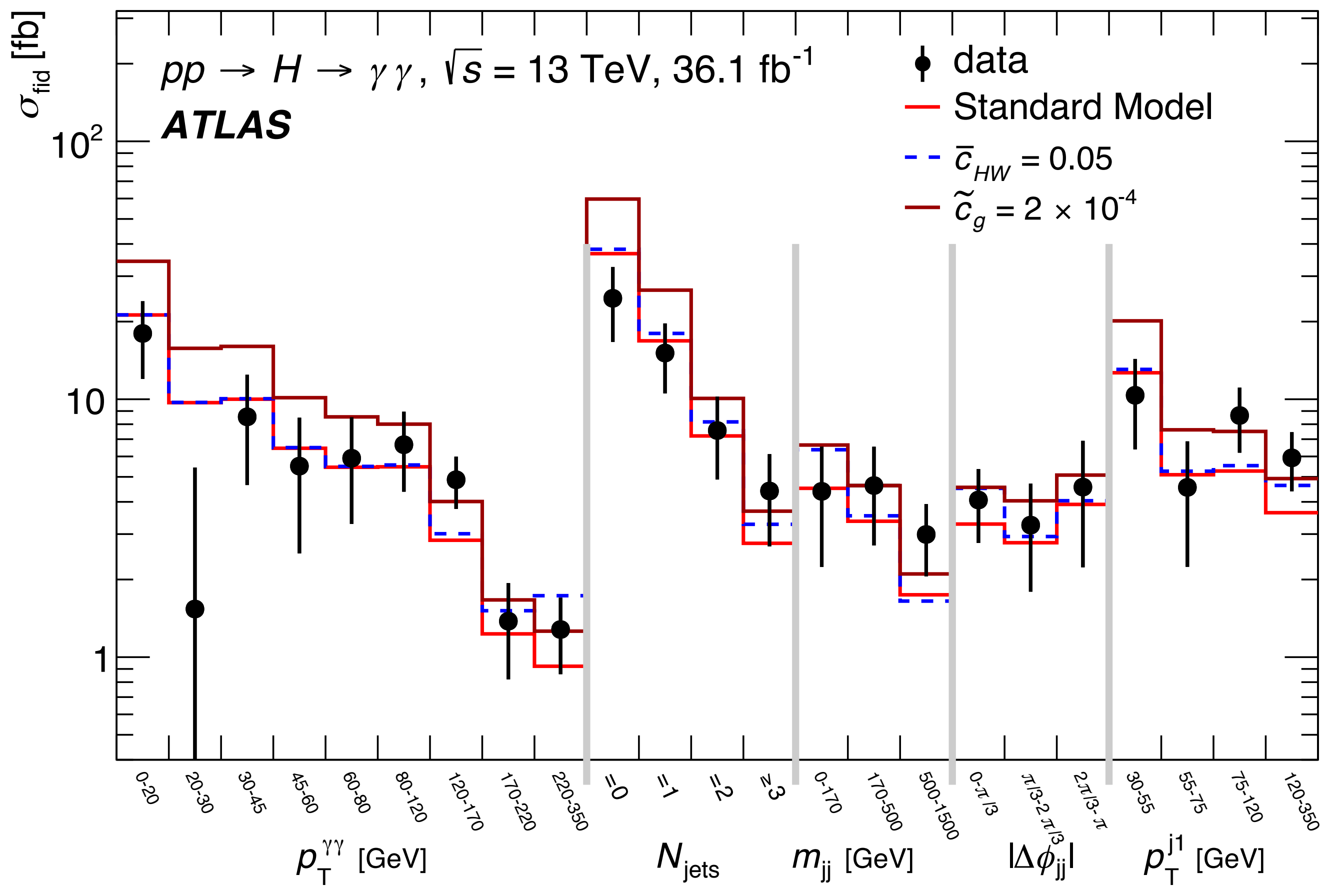




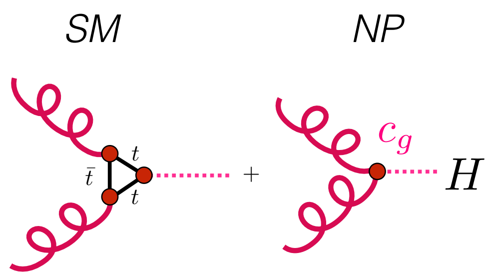
ATLAS-CONF-2018-018 $p_{T,4l}$ [GeV]



Search for anomalous Higgs-boson interactions

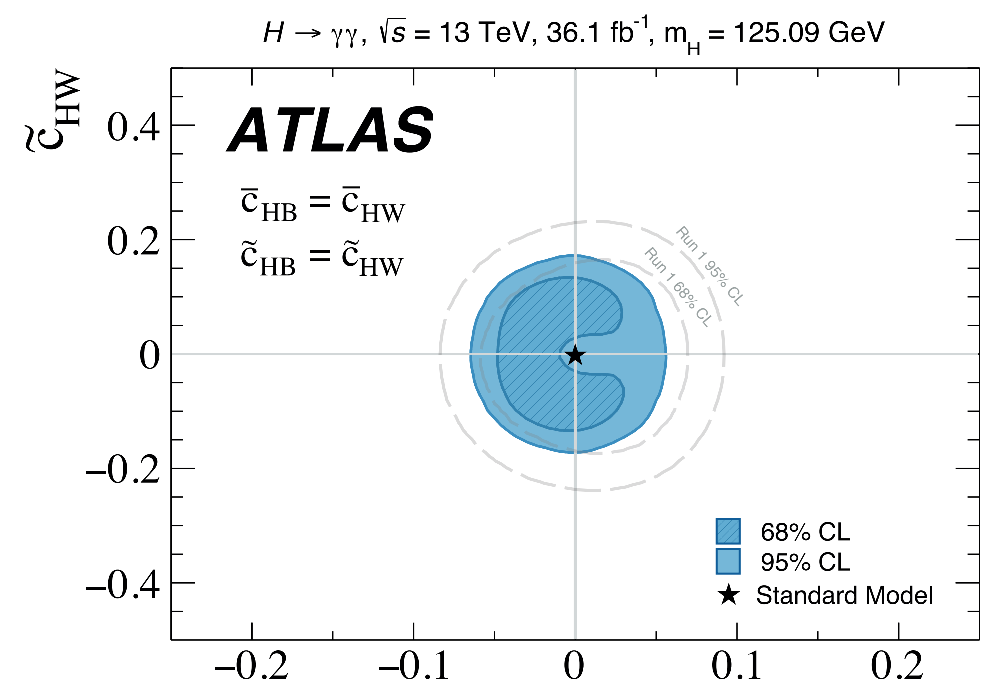


EFT approach with differential cross sections



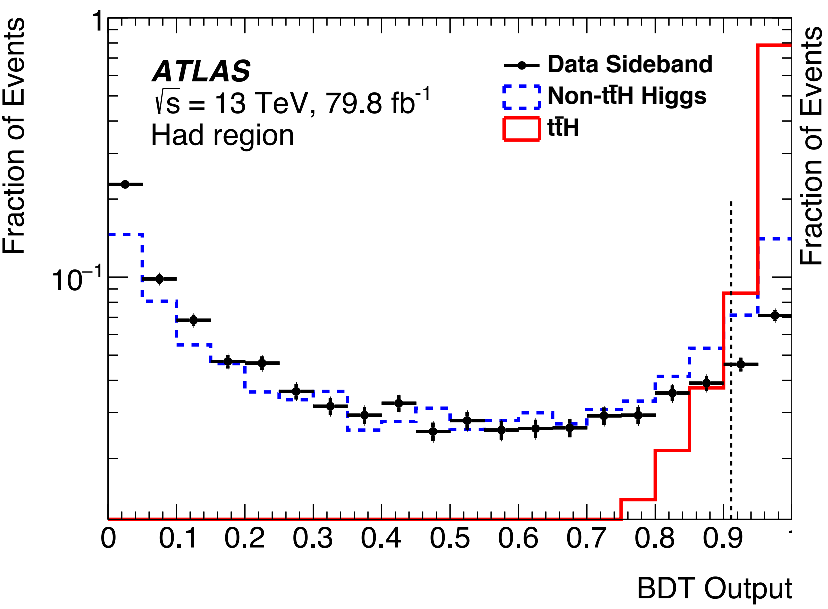
$$\mathcal{L} = \bar{c}_\gamma O_\gamma + \bar{c}_g O_g + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_g \tilde{O}_g + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB},$$

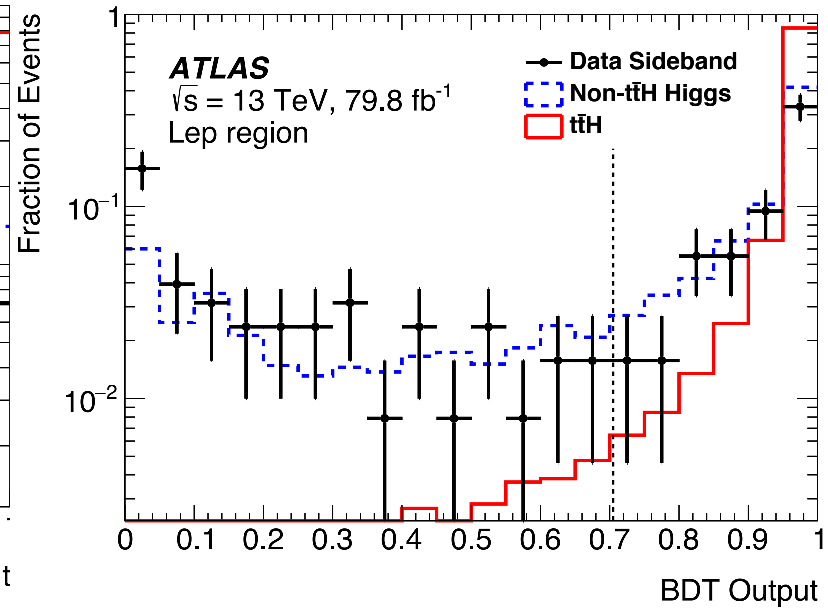
No significant deviation from SM

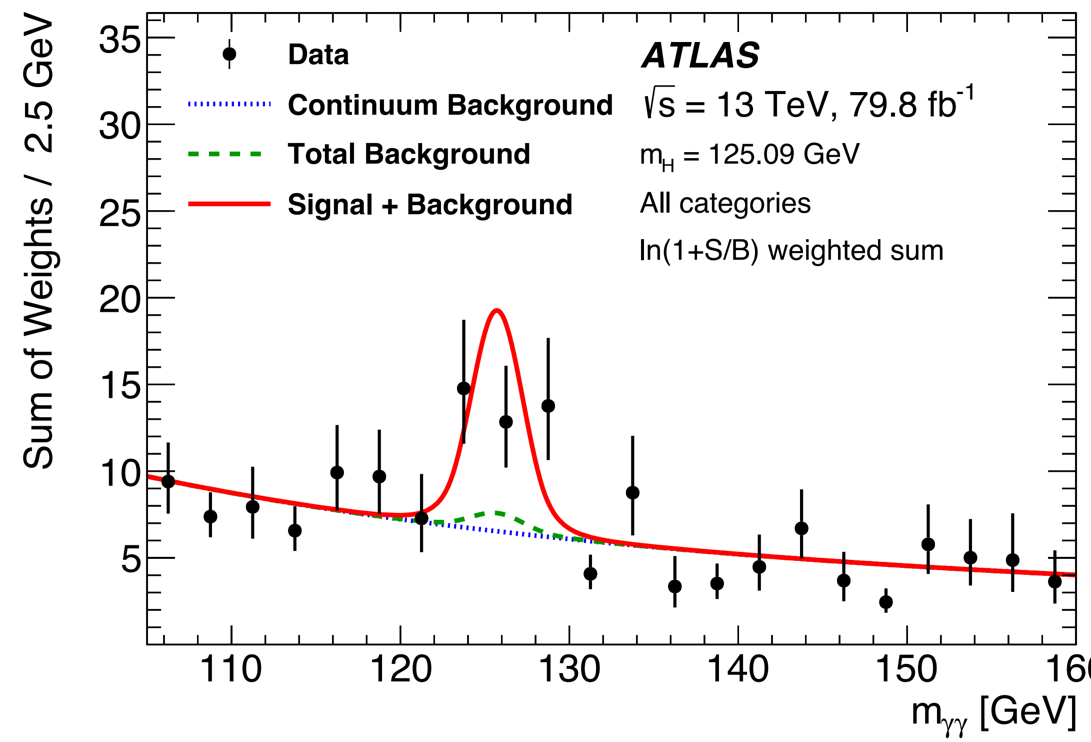


arXiv:1802.04146

top-quark Yukawa coupling

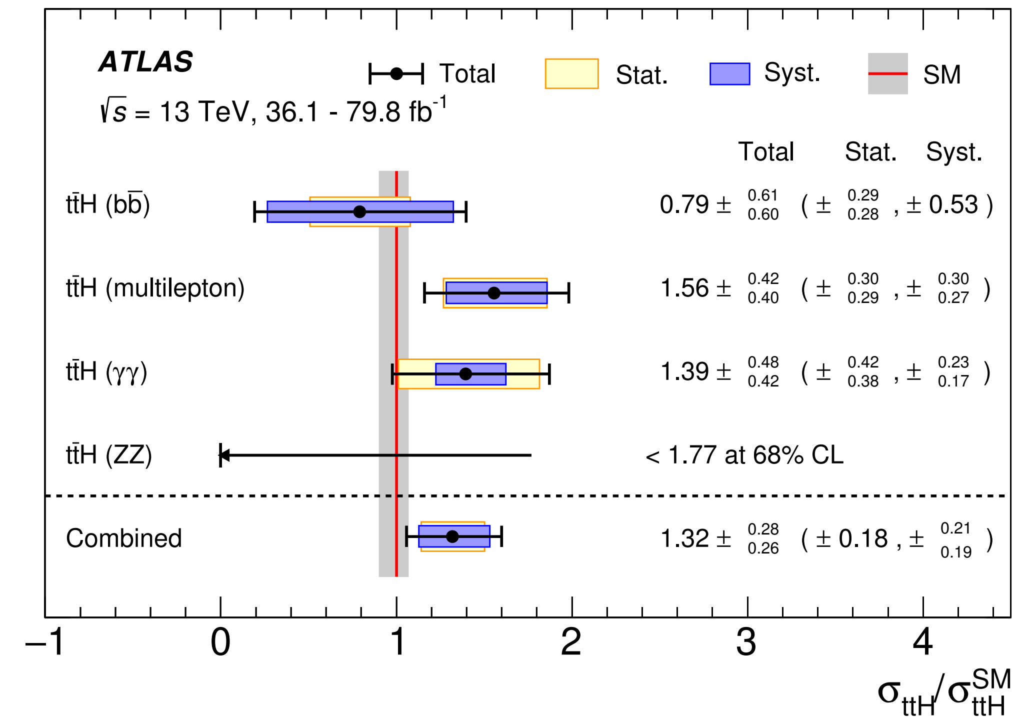






- Two dedicated boosted decision trees are trained to discriminate the signal from background. (Had region + Lep region)

Significance	Obs.	Exp.
Had region	3.8 σ	2.7 σ
Lep region	1.9 σ	2.5 σ
Total	4.1 σ	3.7 σ

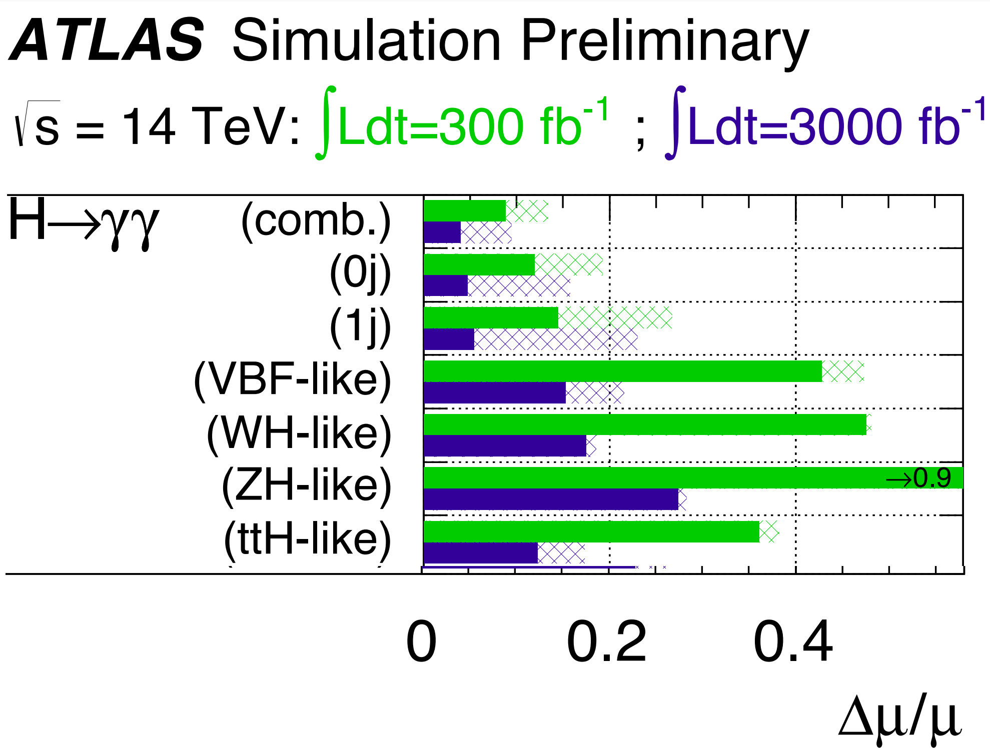


Obs. (Exp.) significance: 6.3 (5.1) σ

Summary

- **With Run2 2015+2016 data (36.1 fb^{-1}):**
  - Comprehensive measurement methodologies including Run-1 type coupling measurement, fiducial and differential cross section measurement and the new one of simplified template cross section measurement.
  - Extensive Higgs property measurement in $H \rightarrow \gamma\gamma$ and further combination with $H \rightarrow ZZ$.
  - Overall, all the results are in good agreement with the SM prediction.
- **With higher statistics data:**
  - More extensive and sensitivity measurement.
  - Looking forward to the update results with ~80 fb^{-1} @ ICHEP2018

Prospect



$\Delta\mu/\mu$	300 fb^{-1}		3000 fb^{-1}	
	All unc.	No theory unc.	All unc.	No theory unc.
$H \to \gamma\gamma$ (comb.)	0.13	0.09	0.09	0.04
(0j)	0.19	0.12	0.16	0.05
(1j)	0.27	0.14	0.23	0.05
(VBF-like)	0.47	0.43	0.22	0.15
(WH-like)	0.48	0.48	0.19	0.17
(ZH-like)	0.85	0.85	0.28	0.27
(ttH-like)	0.38	0.36	0.17	0.12

More challenge for theoretical precision