Differential Higgs cross section measurements

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On behalf of the ATLAS & CMS Collaborations
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Higgs @ LHC

- A **rich** set of measurements accessible at the LHC for m_H = 125 GeV
- All variety of production modes & final states accessible
  - Final states with large BR (H→bb, H→WW, H→ττ) have large backgrounds and limited mass resolution
  - Low BR channels (H→ZZ→4l, H→$\gamma\gamma$) are typically cleaner with good mass resolution
- But each channel brings complementary information and probes a different phase space

Higgs Production modes
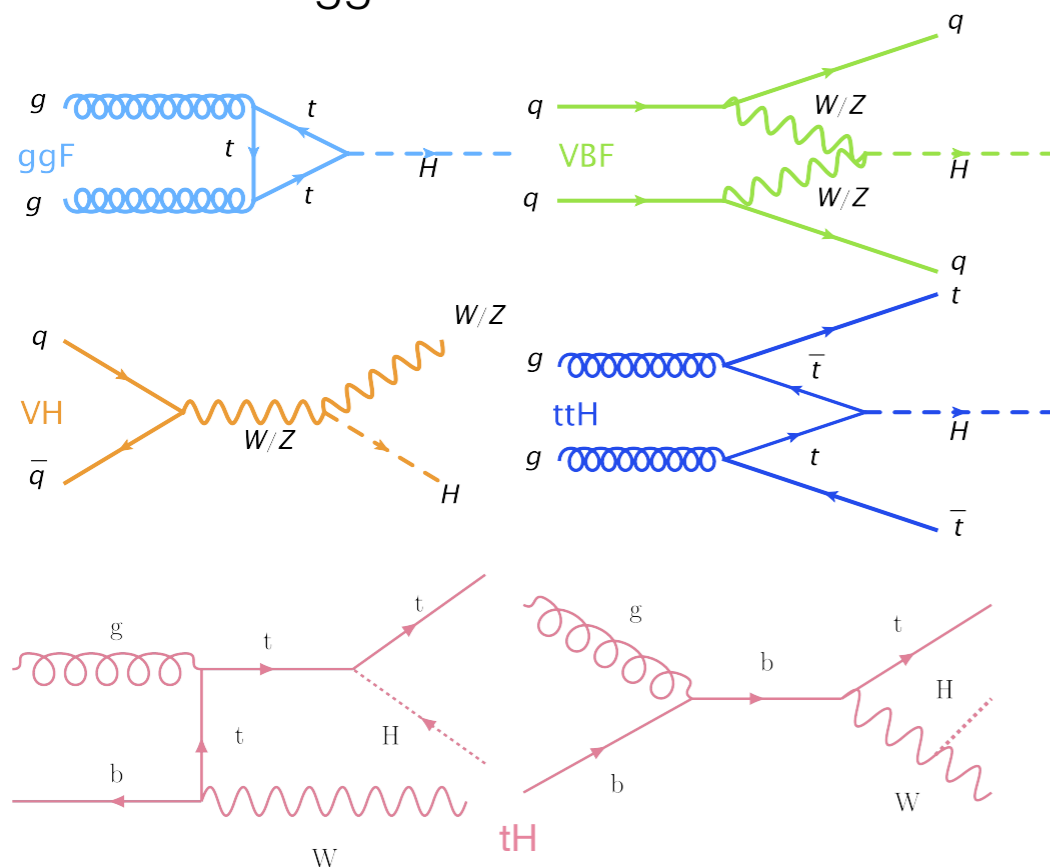
Higgs Decay mode
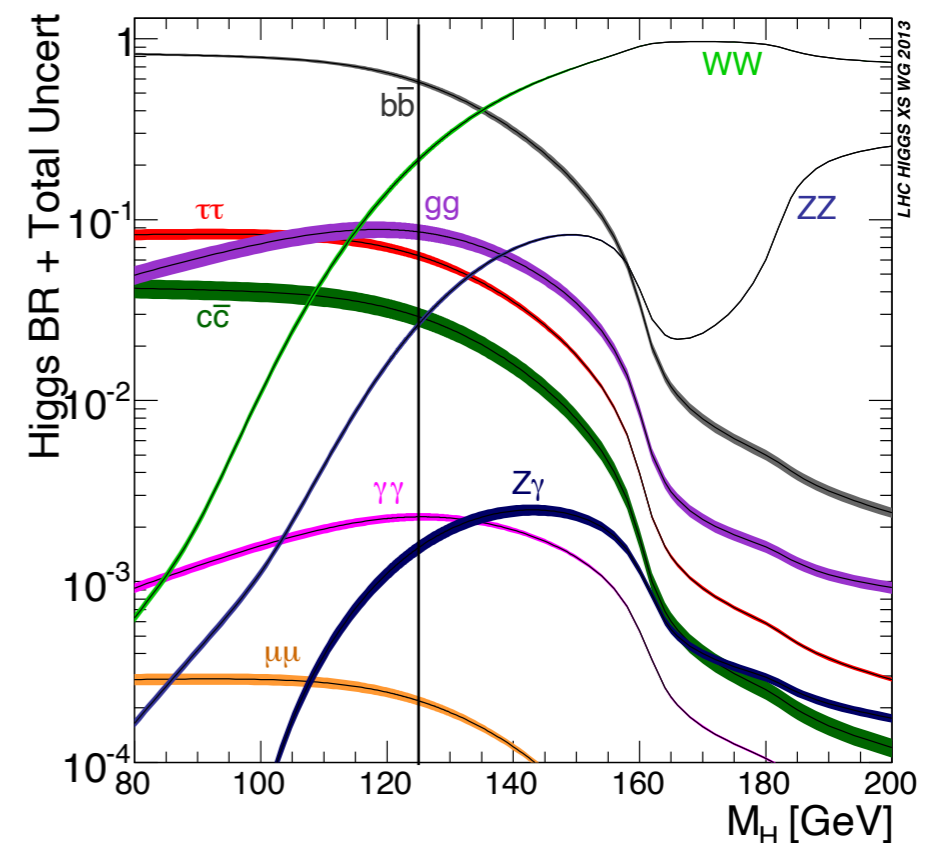
# Fiducial Differential Cross-section measurement

- Fiducial cross-sections are the **most model independent way** to measure Higgs interactions at LHC

- Fiducial phase space are based on the real detector **acceptance** and **extrapolation effects** are minimized

- Limitations:

  - To combine channels the extrapolation to the total phase space is needed (including BR)

  - Less sensitive BSM exclusion limits when compared to a dedicated analysis

- Typical unfolded quantities:

  - Higgs boson kinematics & decay observables

  - Jet produced in association with Higgs boson

  - Measure observables in phase space that are enriched in specific production mode

total phase space

detector/analysis acceptance

fiducial phase space
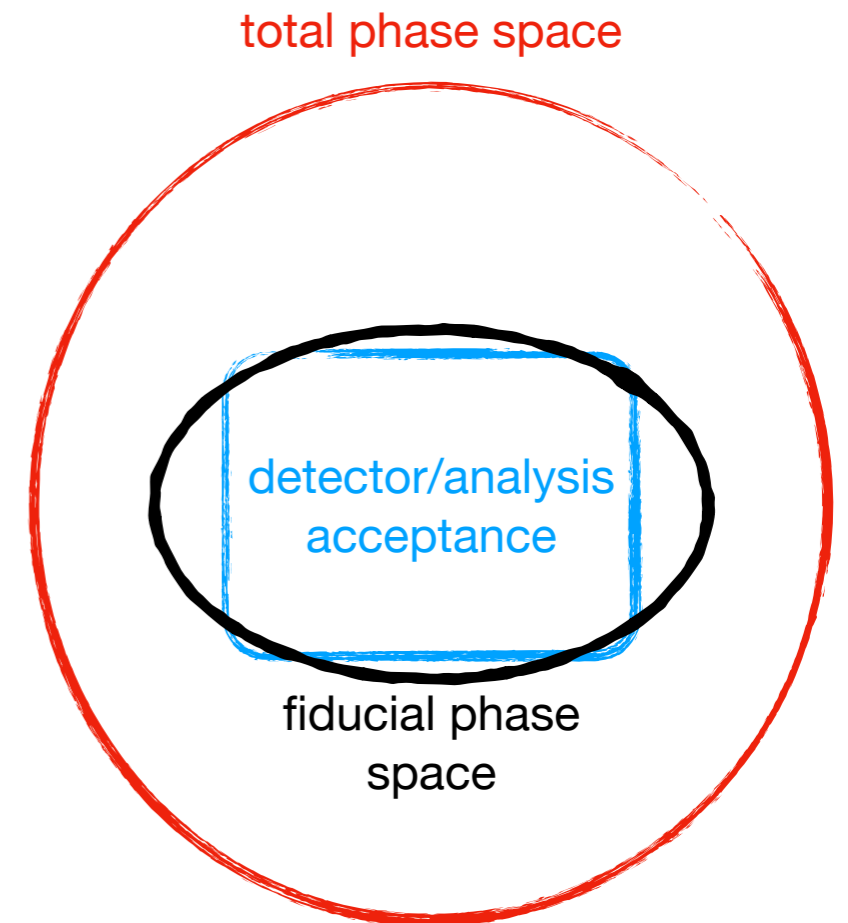
Analysis Flow

Step #1

Reconstructed quantity
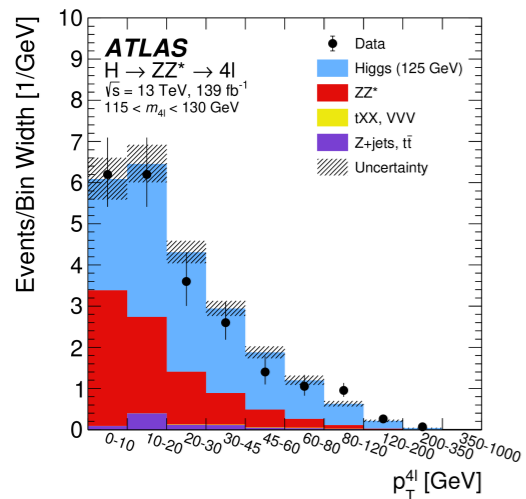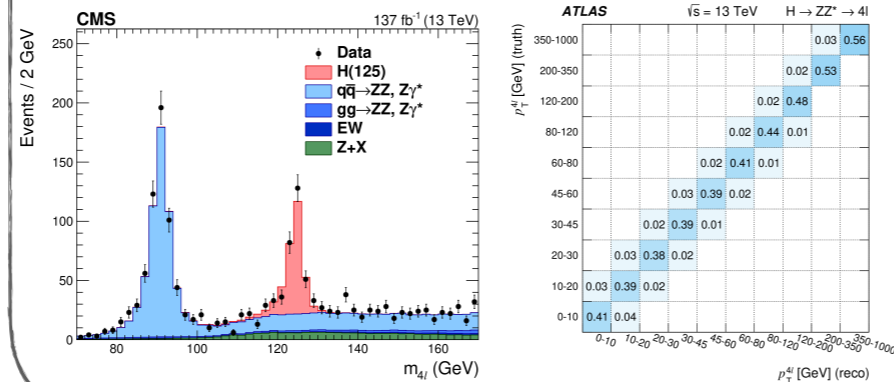
Binning choice:

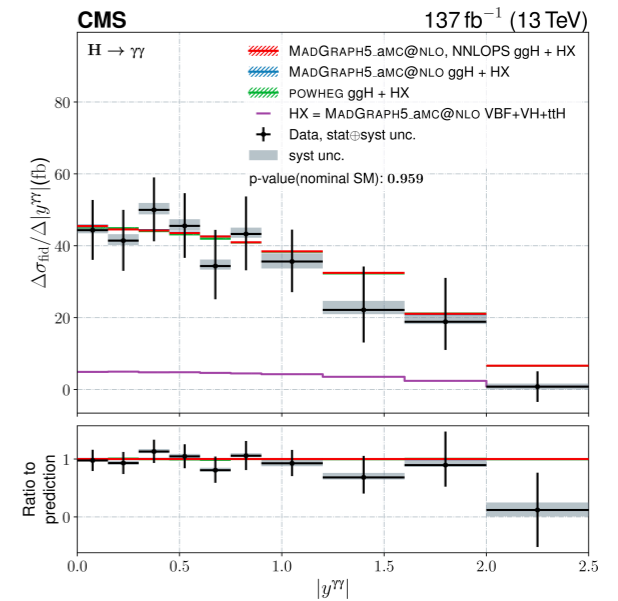expected number of events, detector resolution, S/B, …..

Step #2

Observable: $m_{4\ell}$, $m_{\gamma\gamma}$, m_T, counting, …

Unfolding method: matrix inversion, bin-by-bin correction, regularised, bayesian …
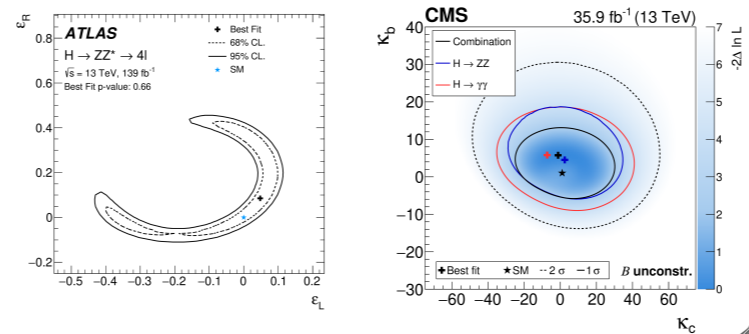
Step #3

Unfolded results

Step #4

**Interpretation:** k-framework, eft, PO

Current Measurements

- A wide range of decay modes probed with the 13/TeV dataset
  - New results are still coming!

	ATLAS	CMS
H→ZZ*	Eur. Phys. J. C 80 (2020) 942 CERN-EP-2023-030	PAS-HIG-21-009
H→yy	JHEP08 (2022) 027	2208.12279
H→WW*	2301.06822 CERN-EP-2023-025	JHEP 03 (2021) 003
H→ττ	-	PRL 128 (2022) 081805
H→bb	CONF-2022-015	PLB 792 (2019) 369
Combination (With partial channels)	2207.08615	

New (H→ZZ*)

New (H→WW*)

A small subset of results are highlighted in this talk!

H→γγ & H→ZZ*→4ℓ

More details in the YSF!
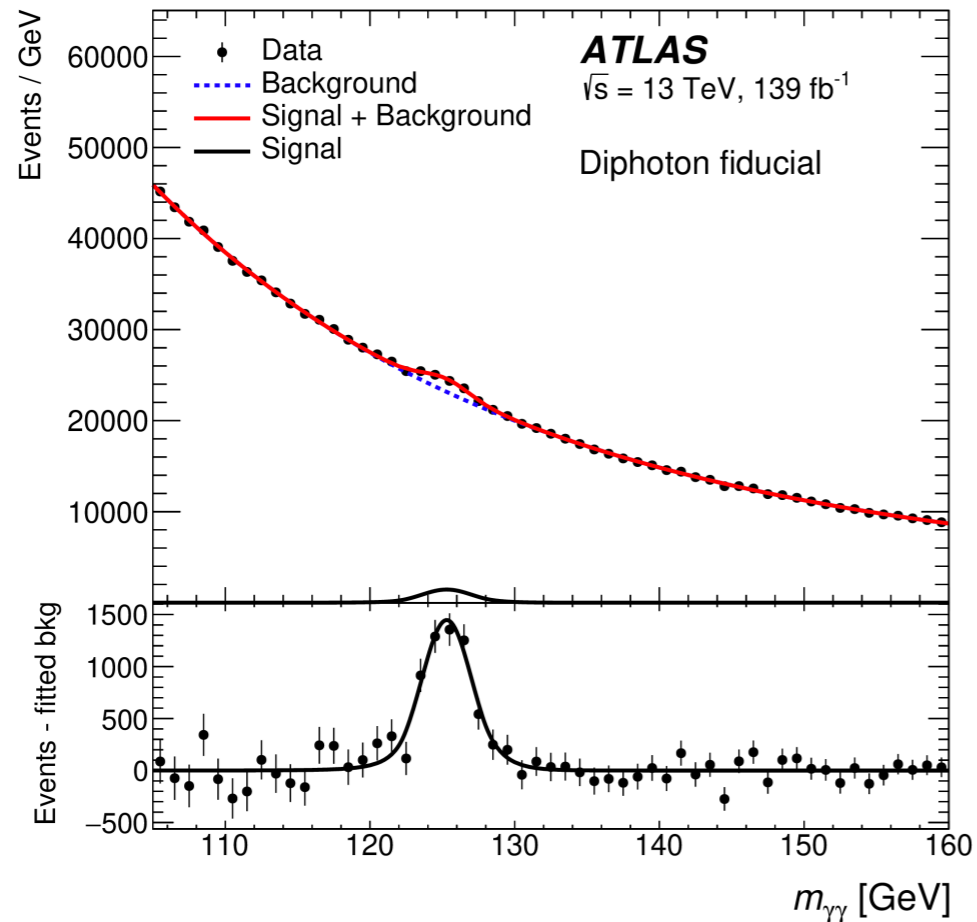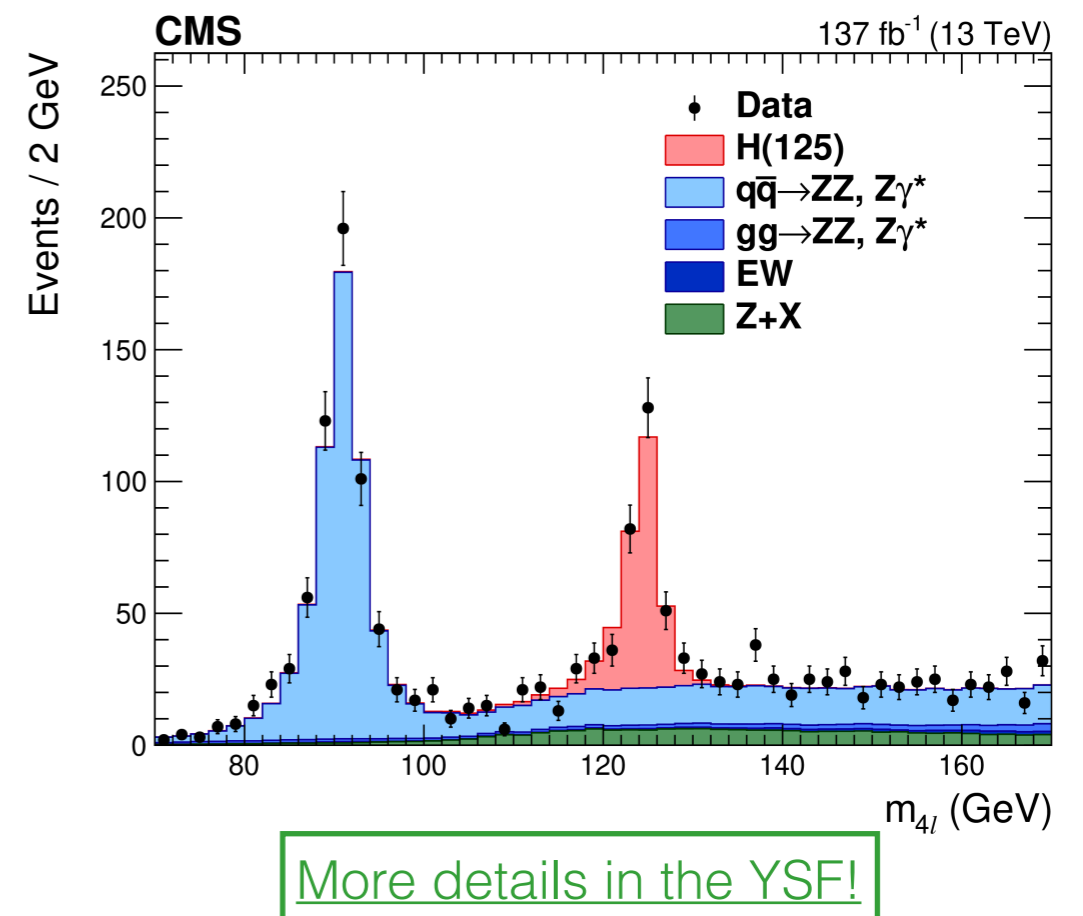
- Workhorse channels of Higgs measurements
  - Fully reconstructible final state: 4 isolated leptons (μ,e) or 2 photons
- Excellent mass resolution 1-2% m_H
- Main background:
  - γγ - Data driven fits
  - 4l: ZZ* estimated using MC (CMS) or data sidebands (ATLAS)

H→ZZ*→4ℓ: differential cross-sections

- High p_T region is sensitive to heavy additional particles in the ggF loop
- Dedicated results for VBF-like phase space & BSM sensitive observables
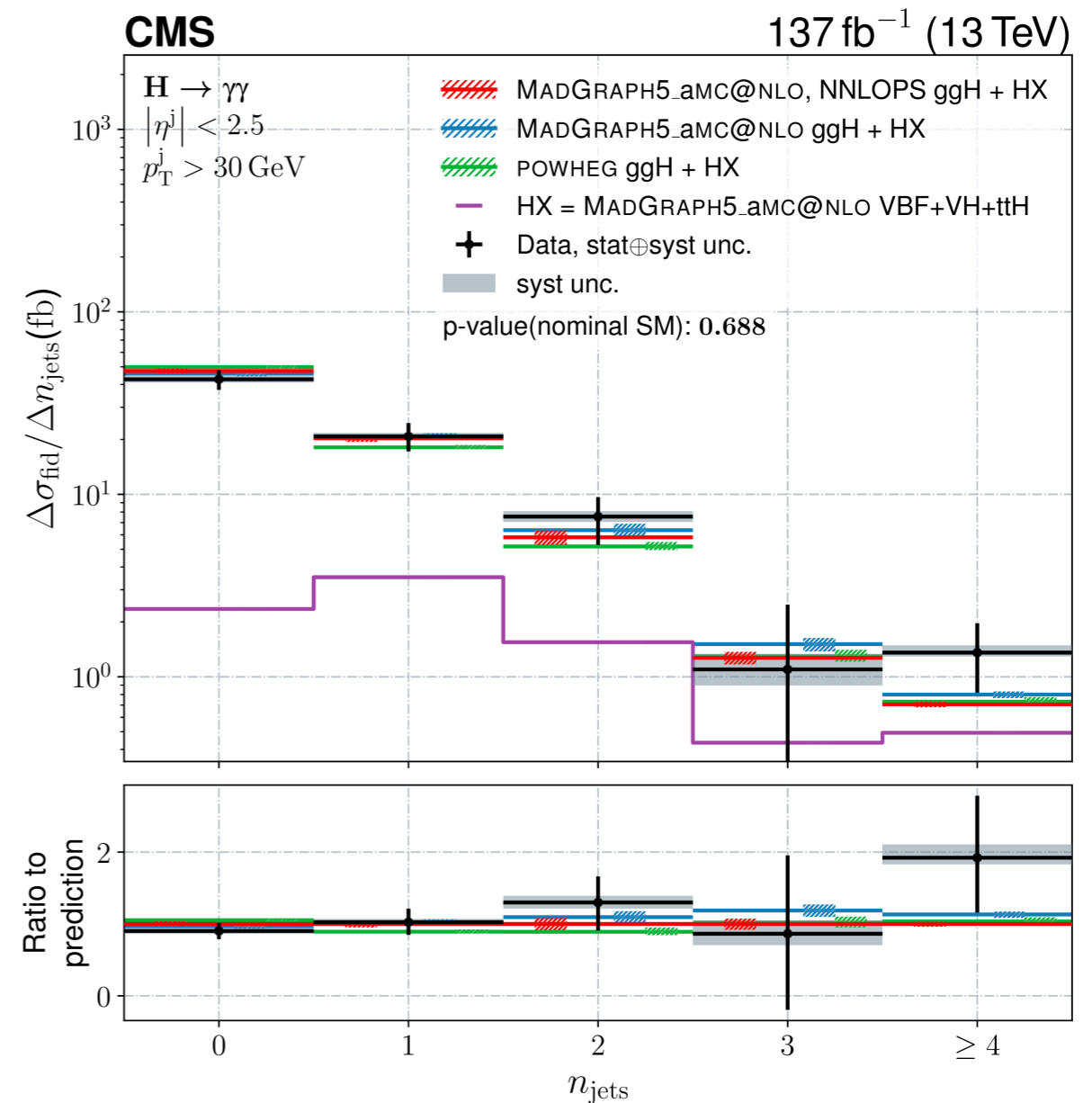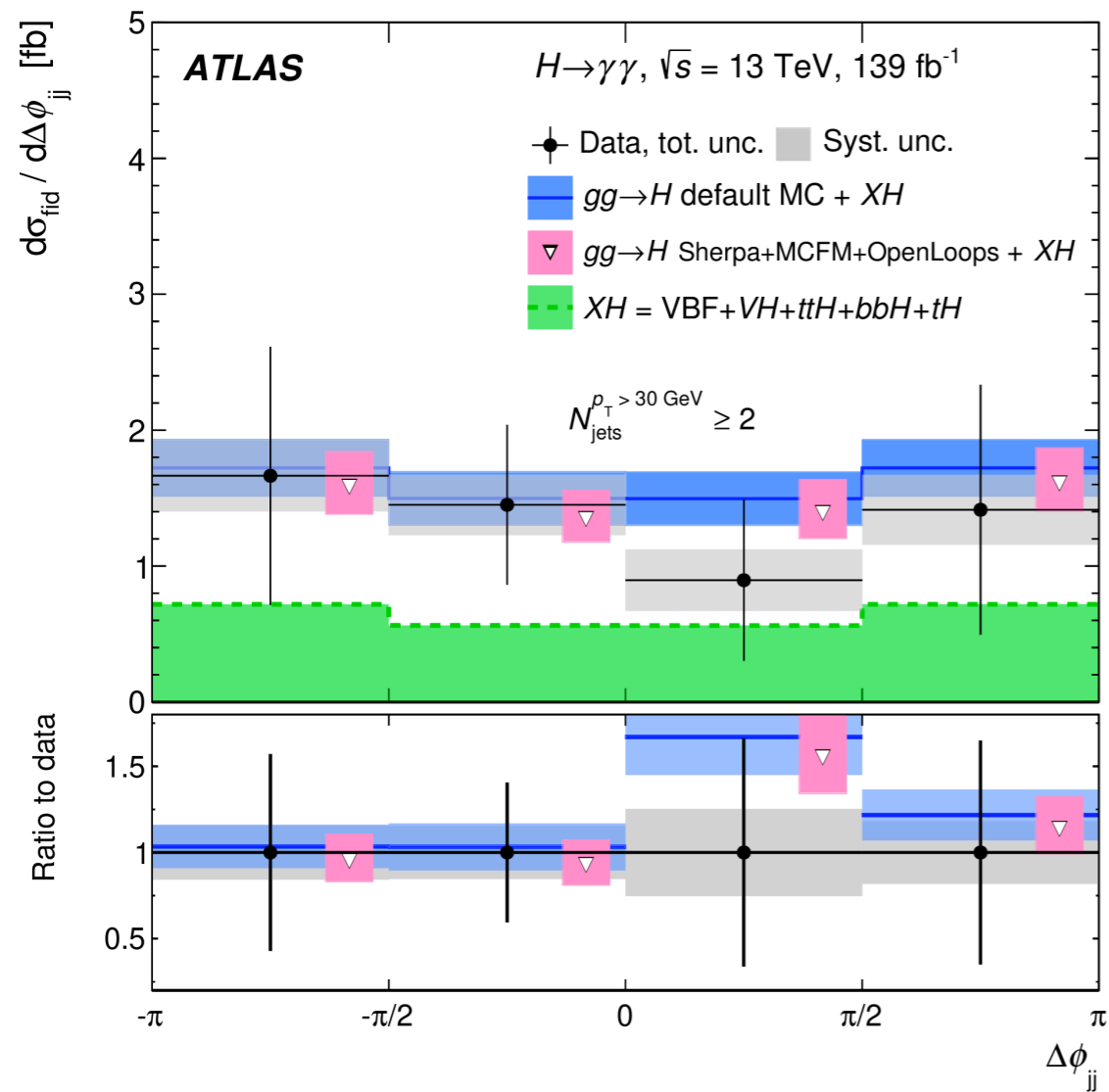
New

More results in next talk
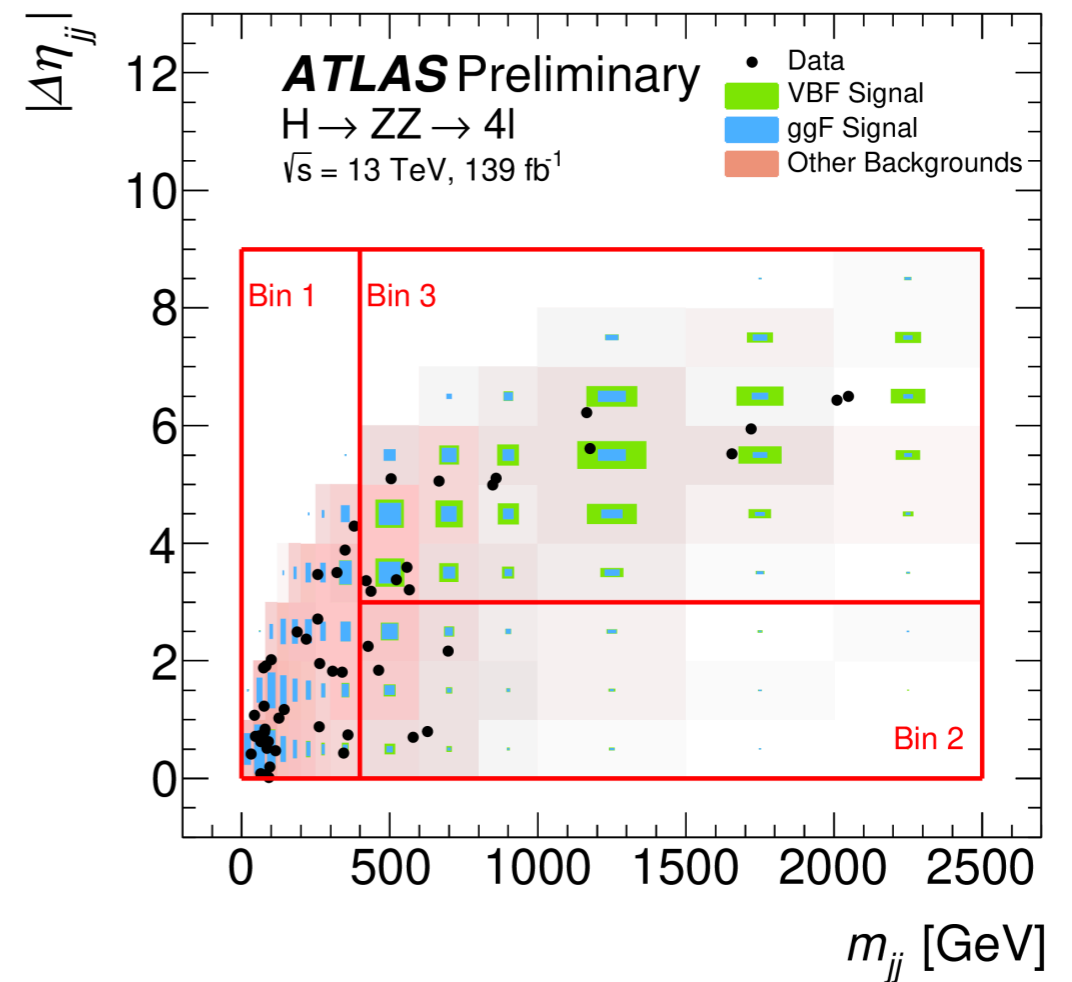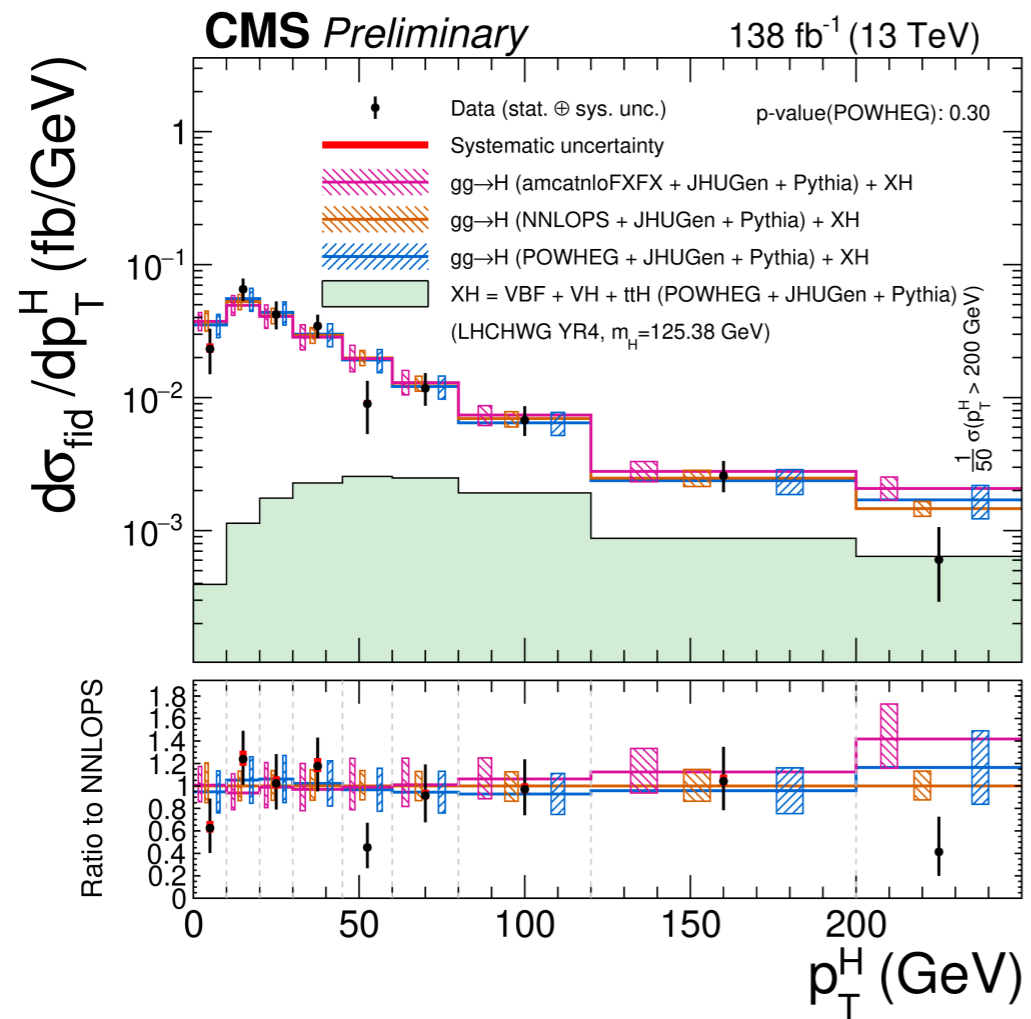
VBF enriched: Bin 3

Obs: $0.215^{+0.077}_{-0.064}$

Exp: $0.134^{+0.065}_{-0.053}$

H→γγ: differential cross-sections

- Δϕ_jj angle between two leading jets: sensitive to the CP structure of the Higgs
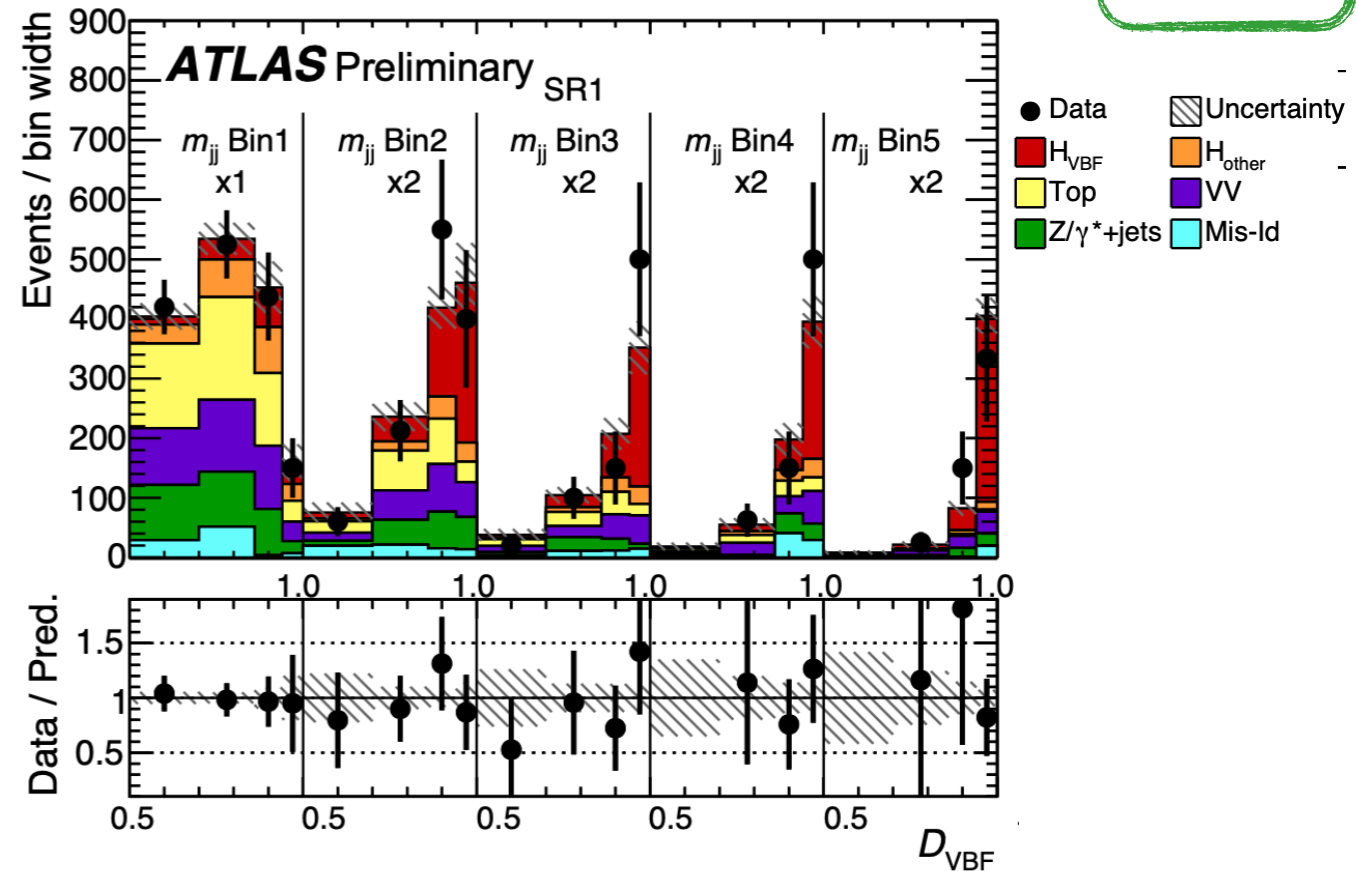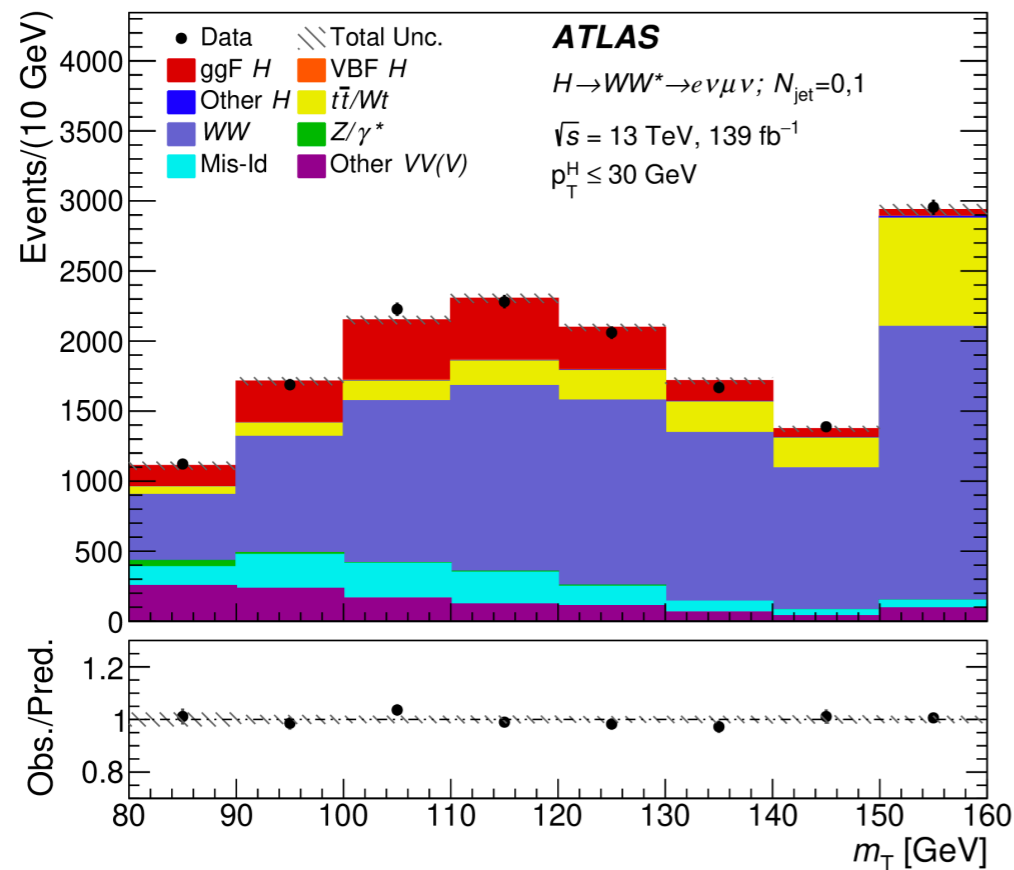- n_jets is sensitive to production mode composition and gluon emission

H→WW*

2301.06822

CERN-EP-2023-025

New

- Large signal but not fully reconstructible final state and low S/B ~ 10^{-1}-10^{-2}
- Main backgrounds: WW*, tt shapes evaluated with MC and normalization from data -> reduces impact of theory modelling uncertainties
- Split into two phase spaces to target different production modes
  - Gluon Fusion: =0, =1 jet fiducial phase space
  - Vector boson fusion: >= 2 jets fiducial phase space

ggF enriched H→WW*: differential cross-section

Sensitive to BSM contributions
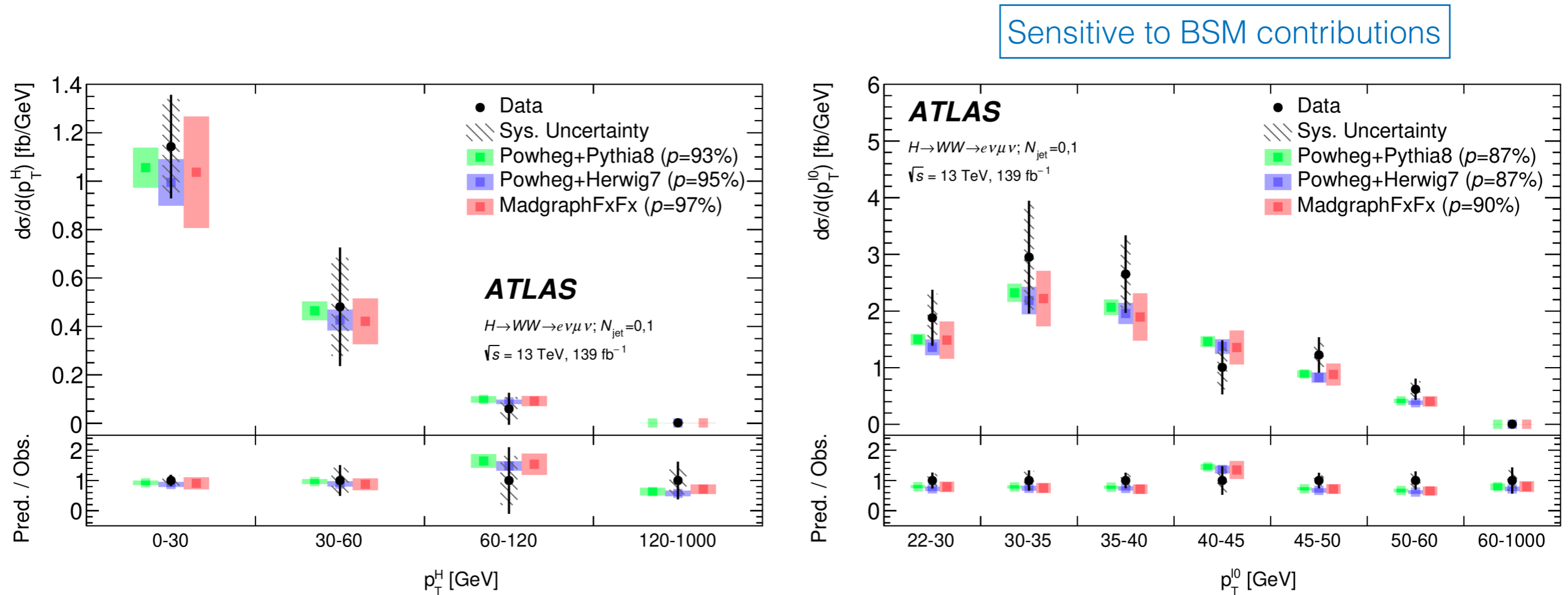
- Cross section extracted by fitting m_T dimensional distribution in each bin, with control regions for background estimation

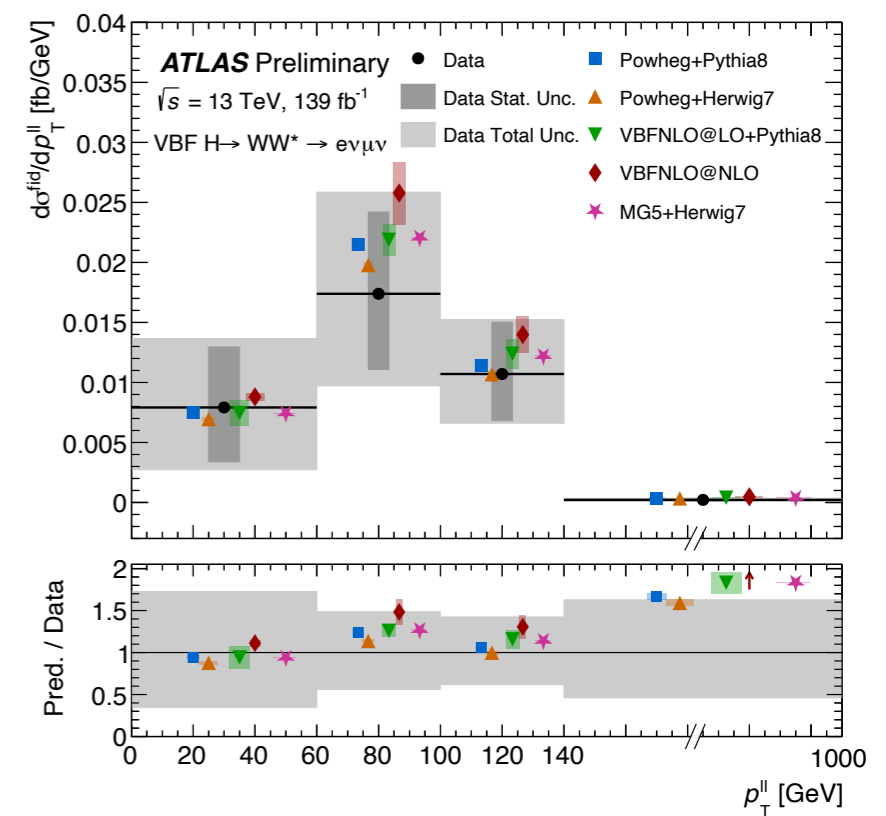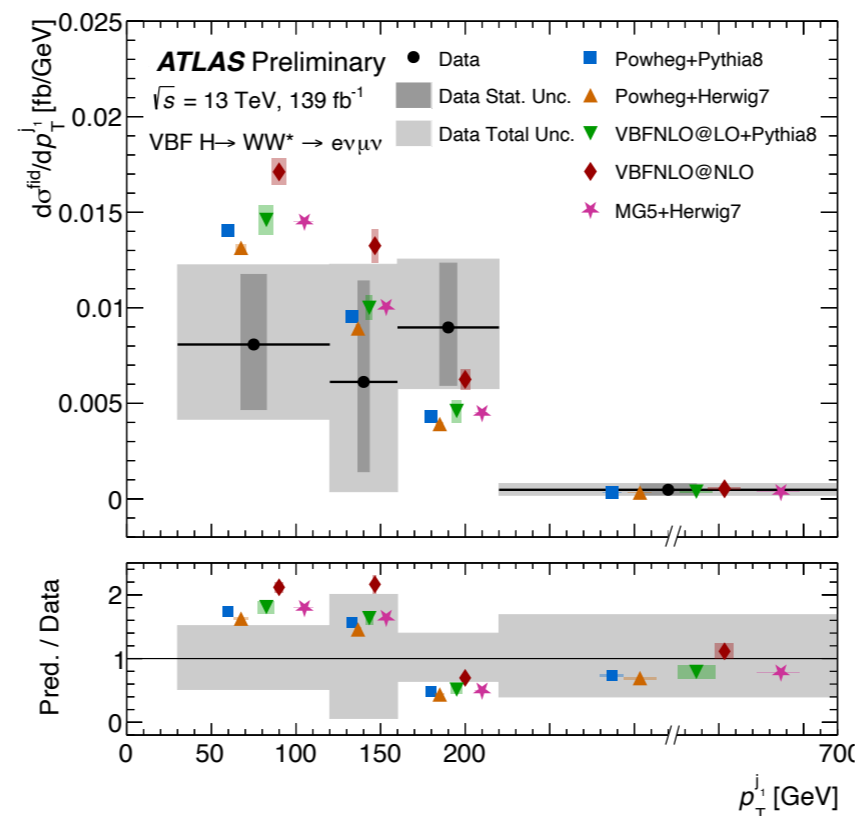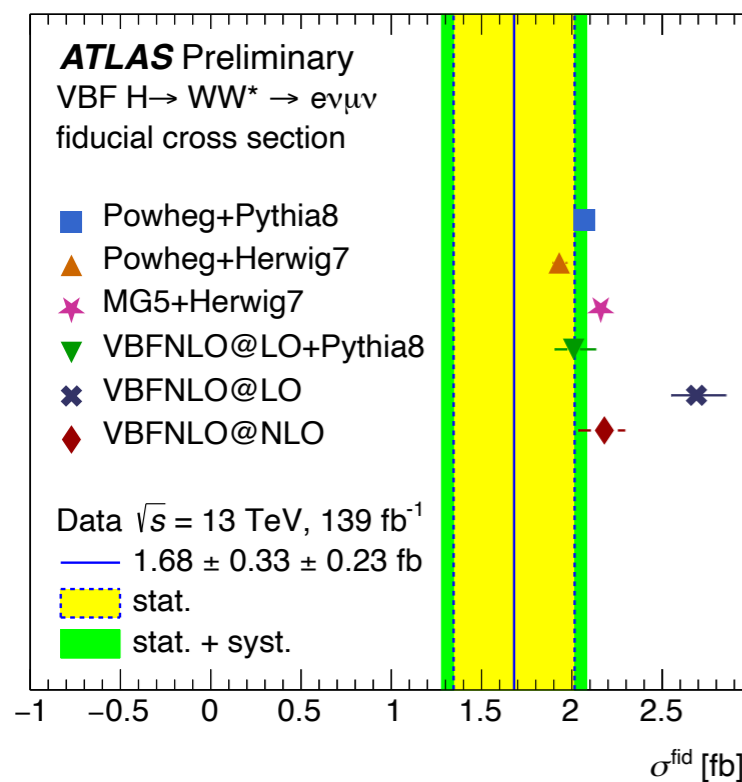$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\mathrm{miss}})^2 - |\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\mathrm{miss}}|^2}$$

- **Competitive channel at high Higgs p_T:** uncertainties < 100% p_T > 120 GeV

VBF enriched H→WW*: differential cross-section

New

Sensitive to BSM contributions & theoretical modelling

More details in the YSF!

- Cross section extracted from signal region with background estimated form both signal and control regions
  - ggF contribution is taken from a fit to dedicated control region
  - Sensitivity improved by using BDTs to separate the processes
- Detailed studies of second largest production mode at LHC!

H→ττ

Distribution taken from couplings measurement
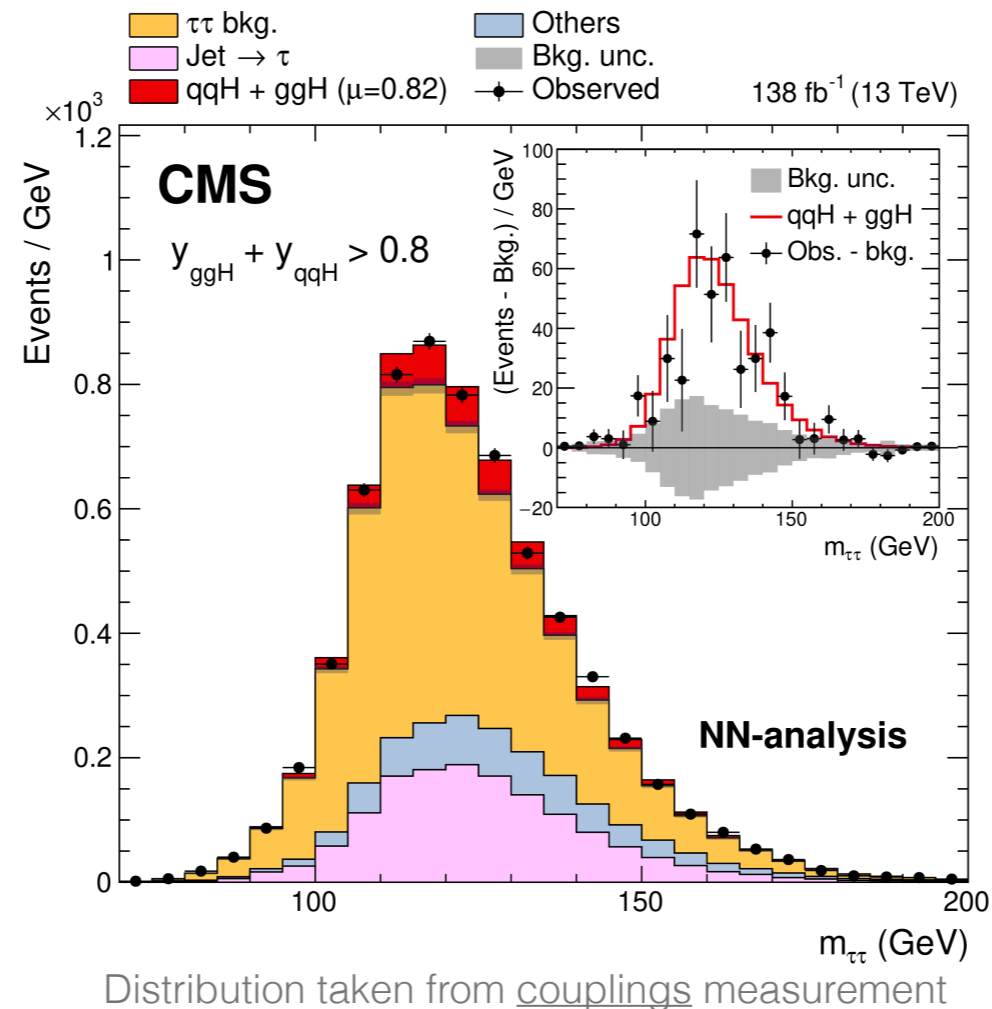
- Similar as HWW: Large signal but not fully reconstructible final state and low S/B ~ 10^{-1}-10^{-2}

- Main backgrounds: Z and mis-idenfitication of jets as τ

- Competitive channel at high p_T and high jet multiplicity: $p_T > 200$ GeV region similar to HZZ and Hyy & uncertainties < 100% for $n_{jet} \geq 3$

H→ττ: differential cross-section
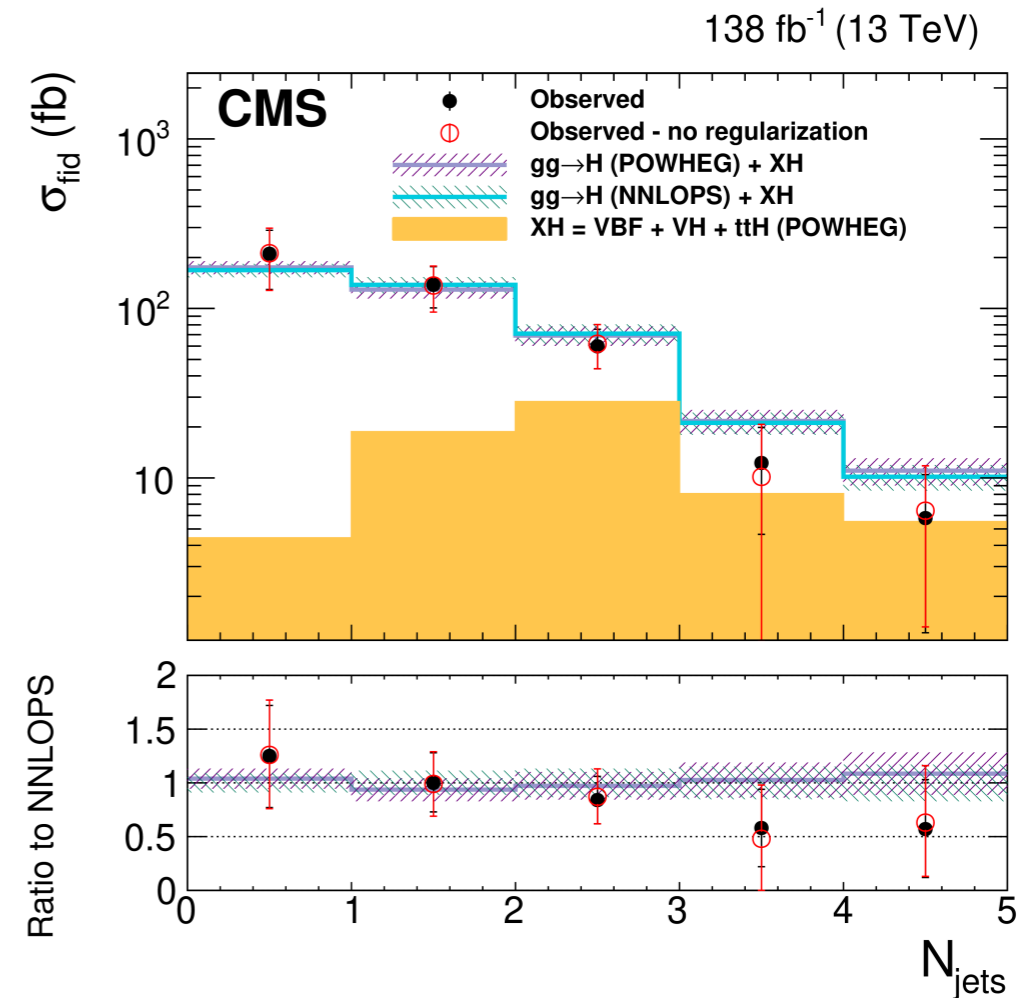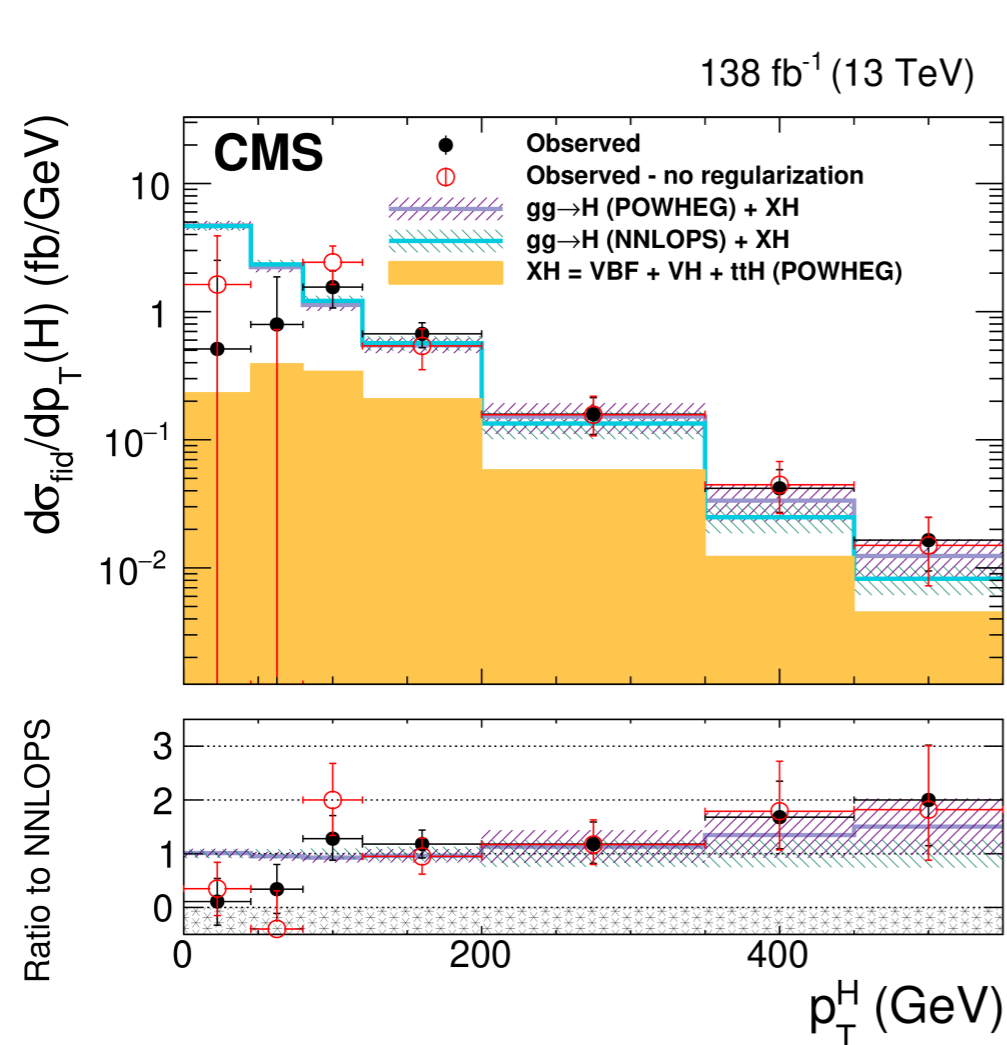
- Cross section extracted by fitting $m_{\tau\tau}$ in each bin with background estimated from MC and data driven techniques
- Results extracted **with and without regularization** - the former is more model dependant but less sensitive to statistical fluctuations
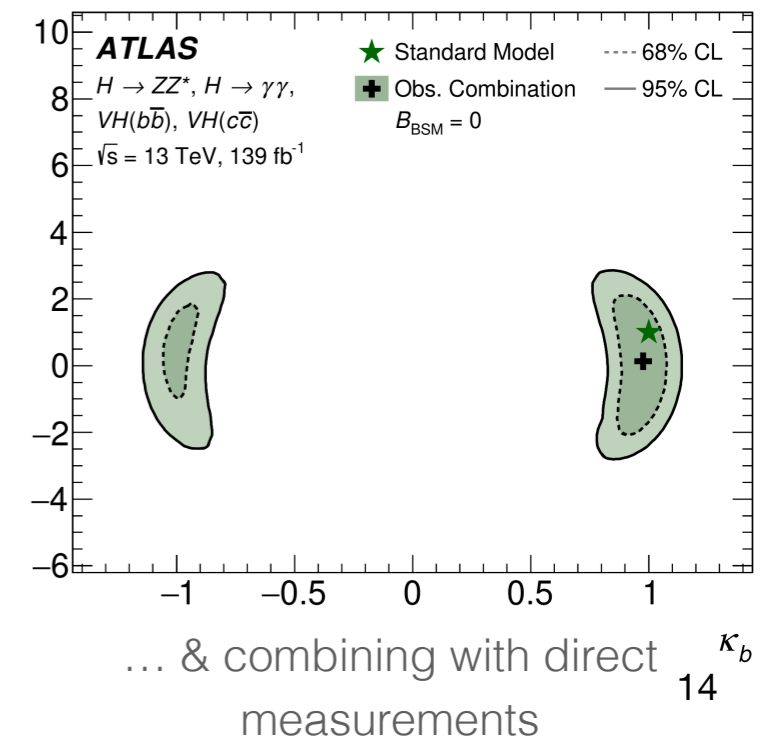
Combined differential cross sections

2207.08615

PLB 792 (2019) 369

Higgs p_T interpretation …

… & combining with direct measurements
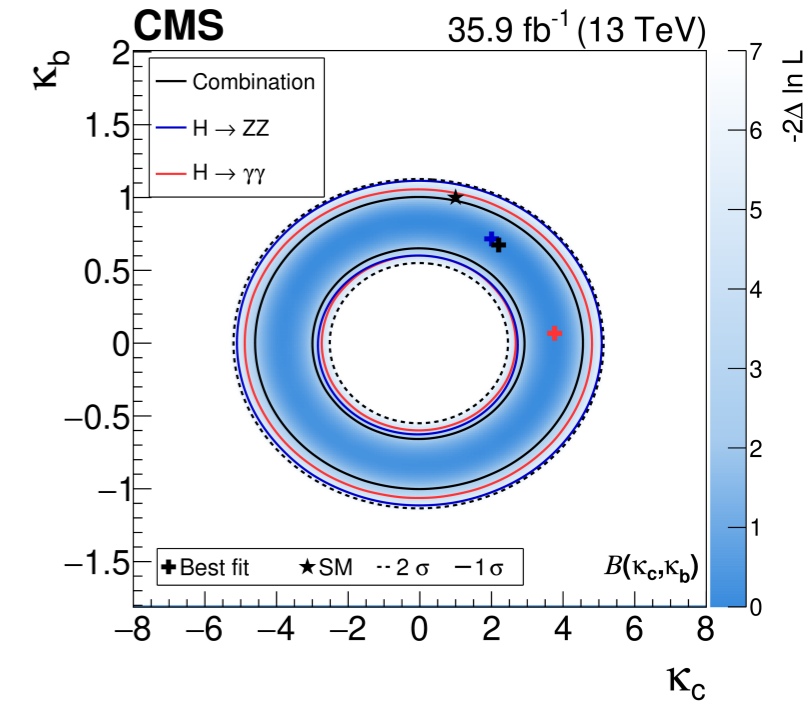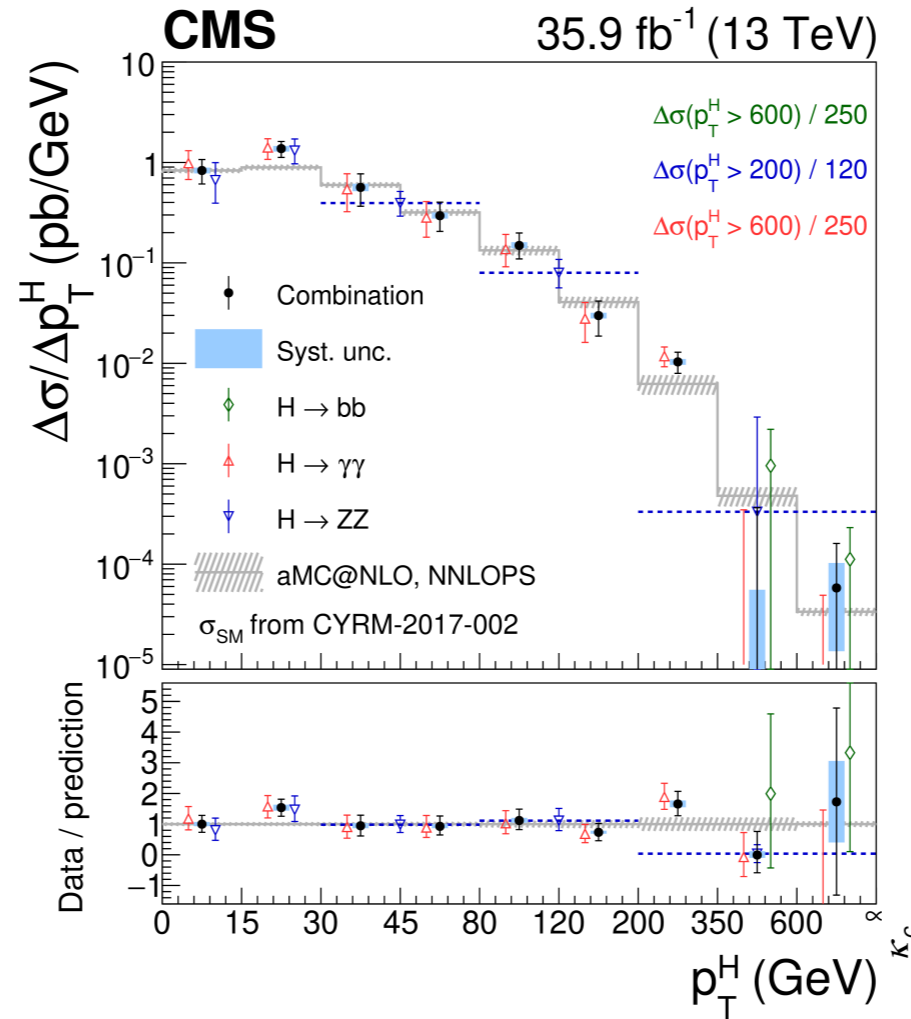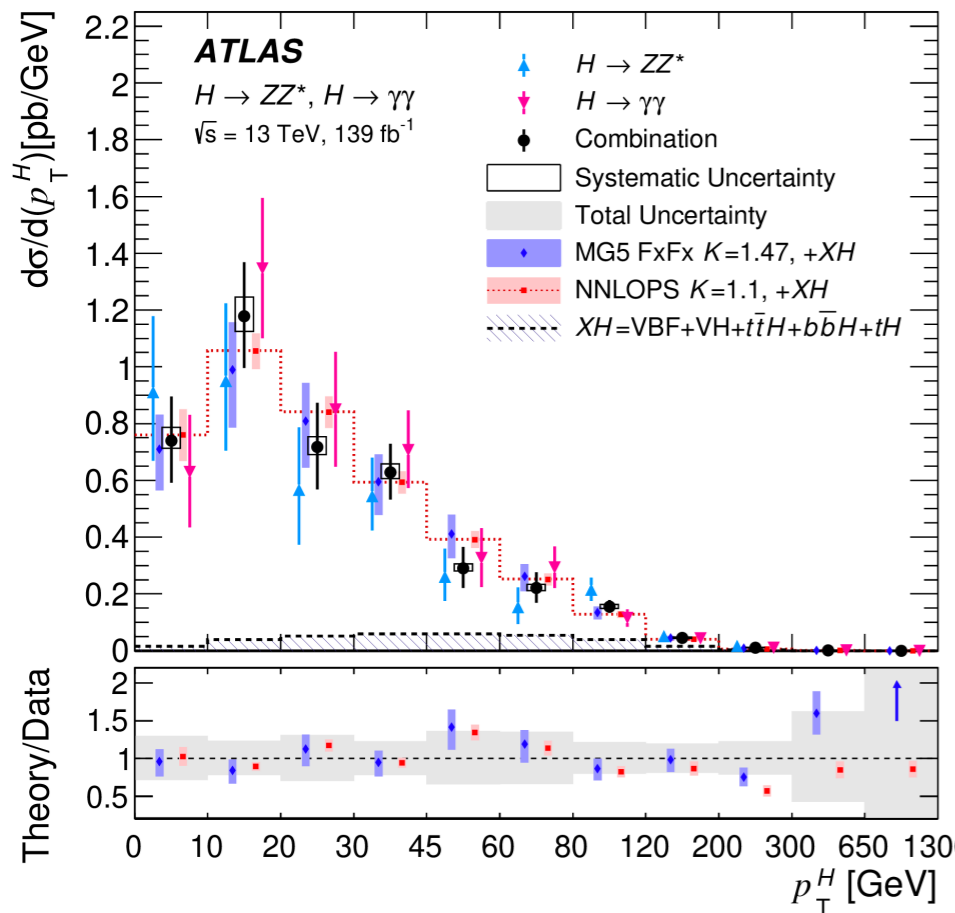
- **Extrapolation to the full phase space: larger theory uncertainties with respect to fiducial measurements**

- ATLAS: 4ℓ and $\gamma\gamma$ @ 139 fb^{-1}

- CMS: 4ℓ, $\gamma\gamma$ and bb @ 36 fb^{-1}

- Light Yukawa couplings interpretation using 4ℓ, $\gamma\gamma$ + other channels

Conclusions

- Several differential cross sections measurements of the Higgs Boson have been performed in ATLAS and CMS (dominated by statistical uncertainties)

- Good agreement between Standard Model predictions and experimental results

    - Few tensions that point for more detailed measurements and theoretical calculations

- Run 3 dataset is slowly accumulating - already have ~ 30/fb

    - Expected to have similar as full Run 2 next year!

    - First results to be presented tomorrow!

- A rich program with many new results still to come: stay tuned!

Backup

H→ZZ*→4ℓ
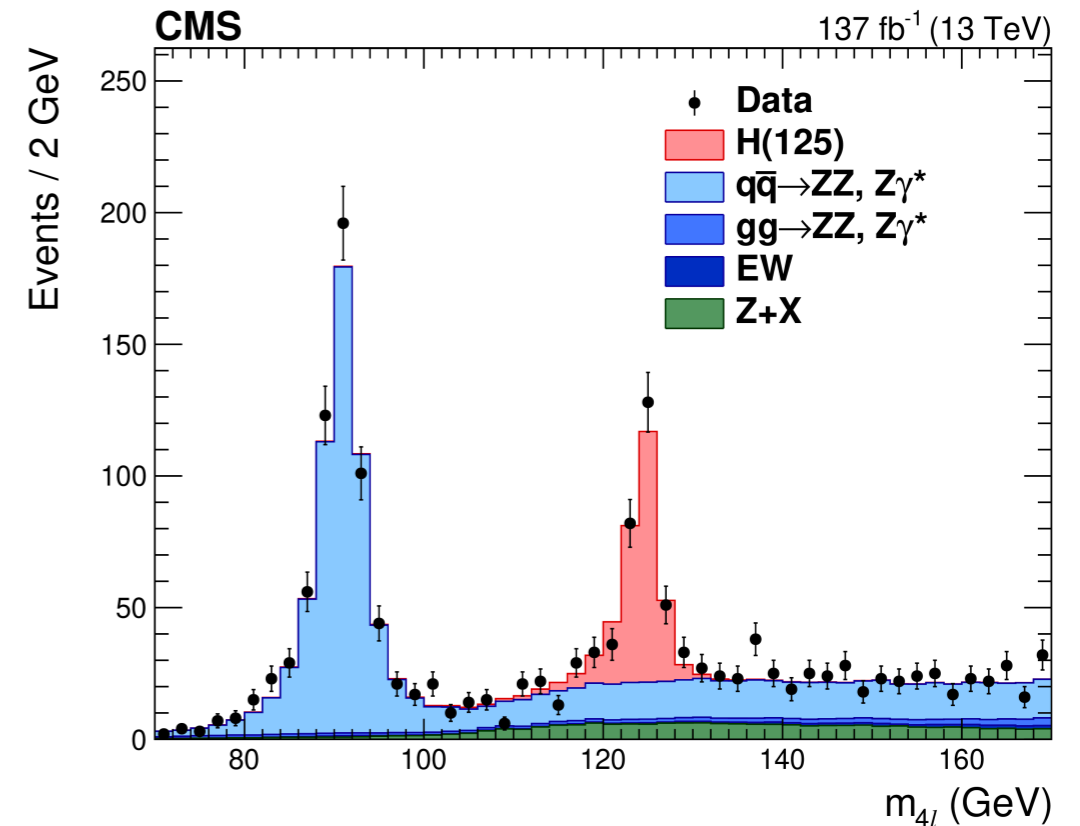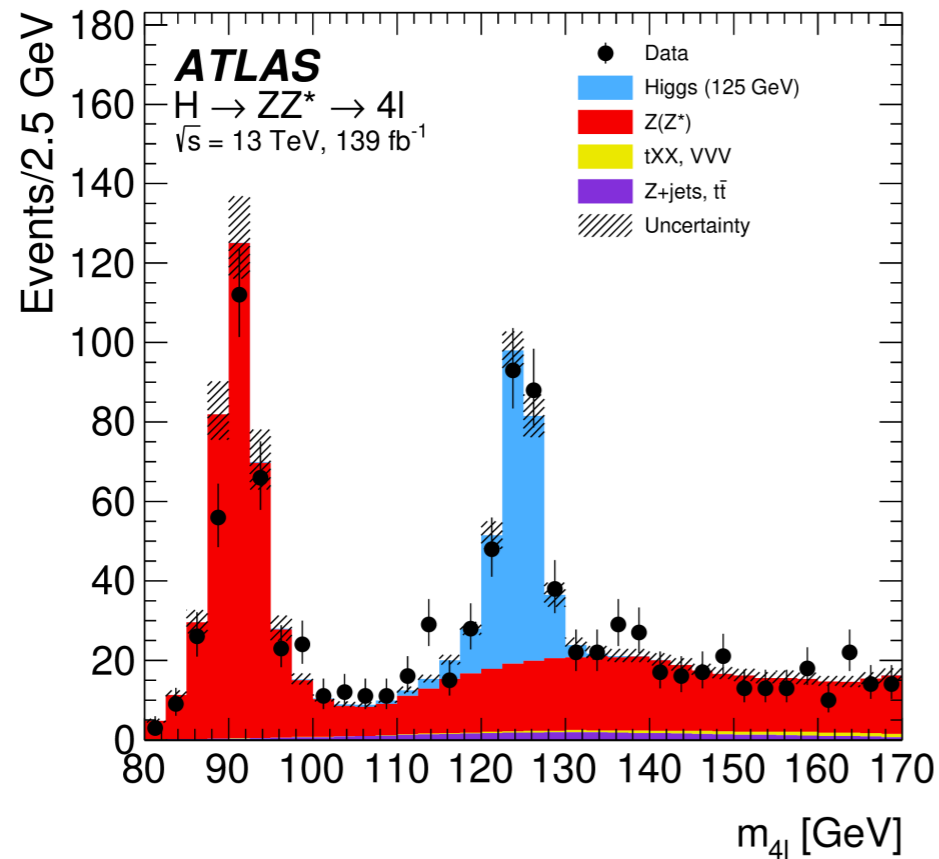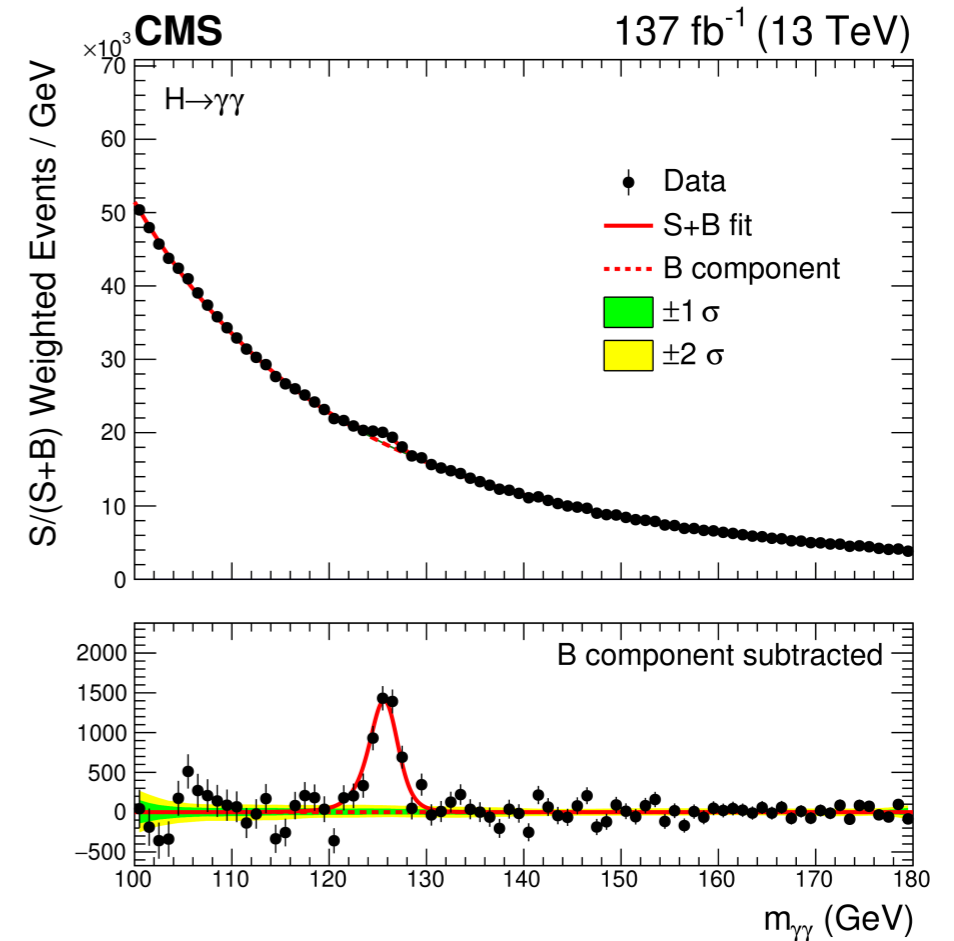
- Fully reconstructible final state and very high S/B ~ 2
- Signal signature: 4 isolated leptons (μ,e) at "low" p_T (5-20 GeV) 2 lepton pairs same flavour opposite sign
- Excellent mass resolution 1-2% m_H
- Main background: ZZ* estimated using only MC in case of CMS or data sidebands and MC for ATLAS

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H→γγ
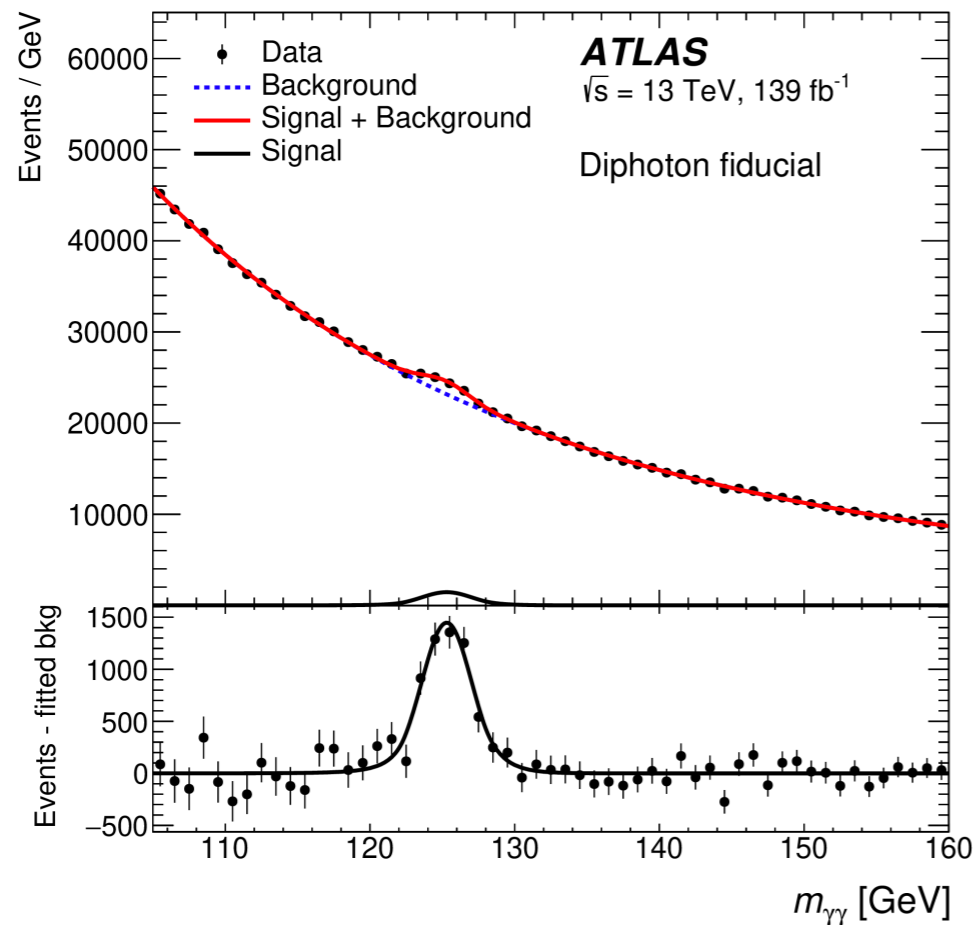
- Fully reconstructible final state but lower S/B compared to 4ℓ ~10^{-1}-10^{-2}
- Signal signature: 2 isolated photons
- Excellent mass resolution 1-2% m_H
- Main background: continuum γγ production estimated from data sidebands

H→γγ & H→ZZ*→4ℓ

- High p_T region is sensitive to heavy additional particles in the ggF loop
- n_{jets} is sensitive to production mode composition and gluon emission