Measurement of Higgs boson inclusive and differential fiducial production cross sections in the diphoton decay channel at CMS

Muhammad Aamir Shahzad

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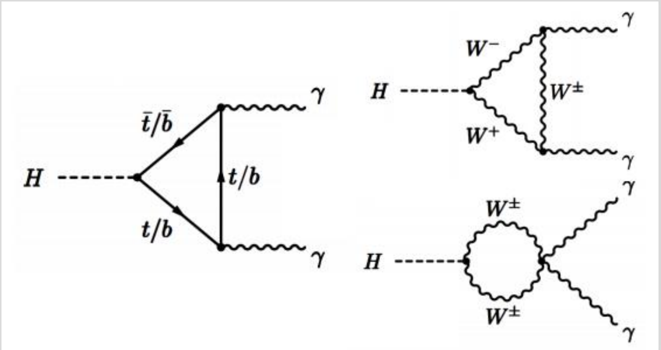
Higgs Boson decaying into $\gamma\gamma$

- At LHC, $H \rightarrow \gamma\gamma$ channel plays a key role first in the discovery of the Higgs boson, and then in the measurements of Higgs boson properties and also in searches for new physics

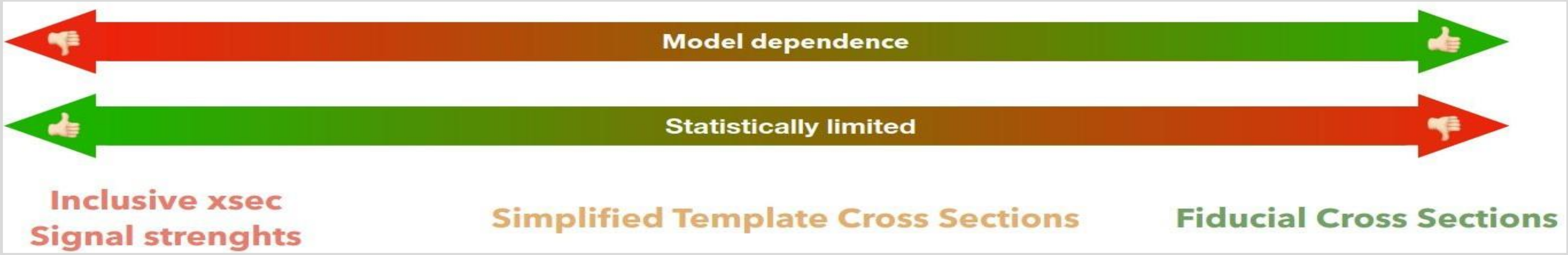


- Small branching fraction (0.2%), but clean final state with two highly energetic and isolated photons, so final state can be fully reconstructed with excellent mass resolution (1-2%)

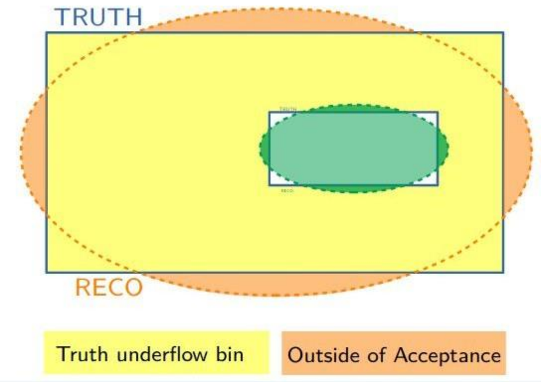
- Large backgrounds
  - ✓ Continuum $\gamma\gamma$ (irreducible)
  - ✓ Fakes from γj and jj (reducible)

- Measurement of Higgs boson inclusive and differential fiducial production cross sections in the diphoton decay channel at CMS has been submitted in JHEP (arXiv:2208.12279)

Introduction



- Measurement of binned cross sections is one of the aspects of precision study of the Higgs boson properties
- All of the approaches aim to minimize the dependence on theory predictions without losing sensitivity
- The inclusive and differential measurements of the fiducial cross sections is to provide a set of model-independent results



- Cross-sections measured in the **STXS** approach treat different production modes separately
- In the fiducial differential cross-section measurement:
  - ✓ looks for the deviation in the distribution of kinematic variables for the characterization of Higgs production
  - ✓ Various topologies are accepted to reduce model dependence
  - ✓ For BSM effects, provides better sensitivity

- Differential Cross-sections: Exhibit more information than inclusive cross-section and more powerful to models validation

- Outside of acceptance: Treated as production processes, with signal strength fixed to SM prediction

Analysis Strategy

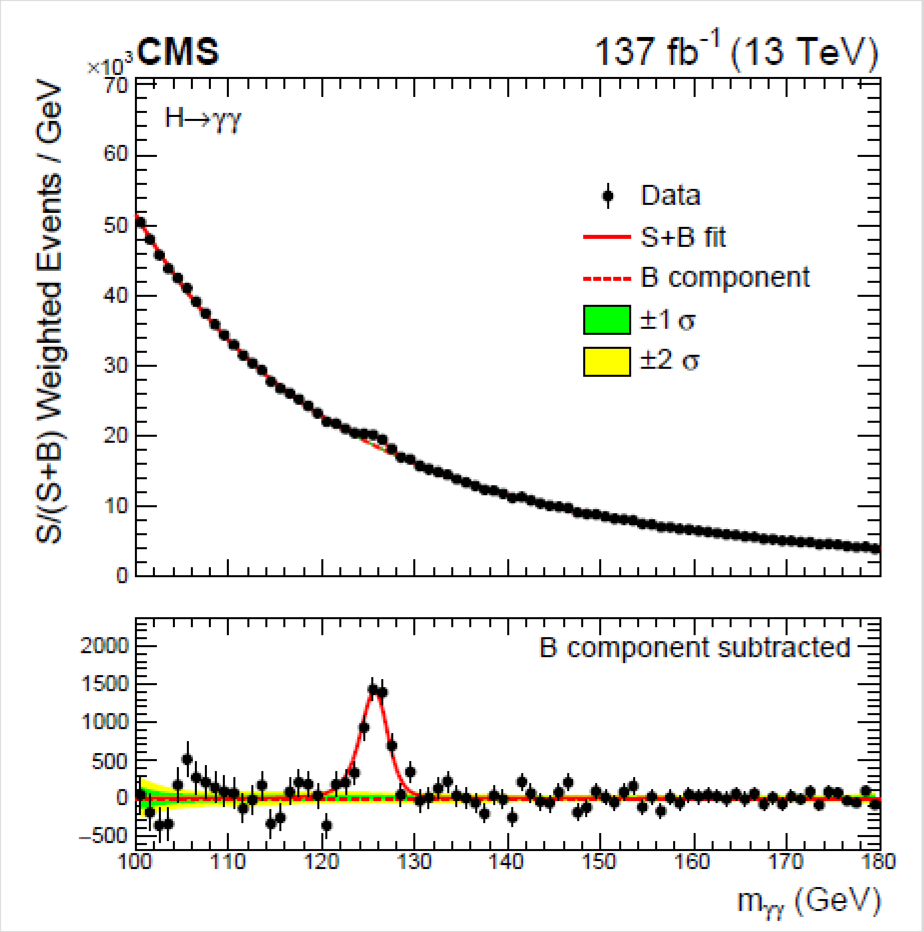
Inclusive fiducial phase space

- $p_T^{\gamma 1} > m/3$
- $p_T^{\gamma 2} > m/4$
- $|\eta^{\gamma}| < 2.5$
- $Iso_{gen}^{\gamma} < 10$ GeV

Observables

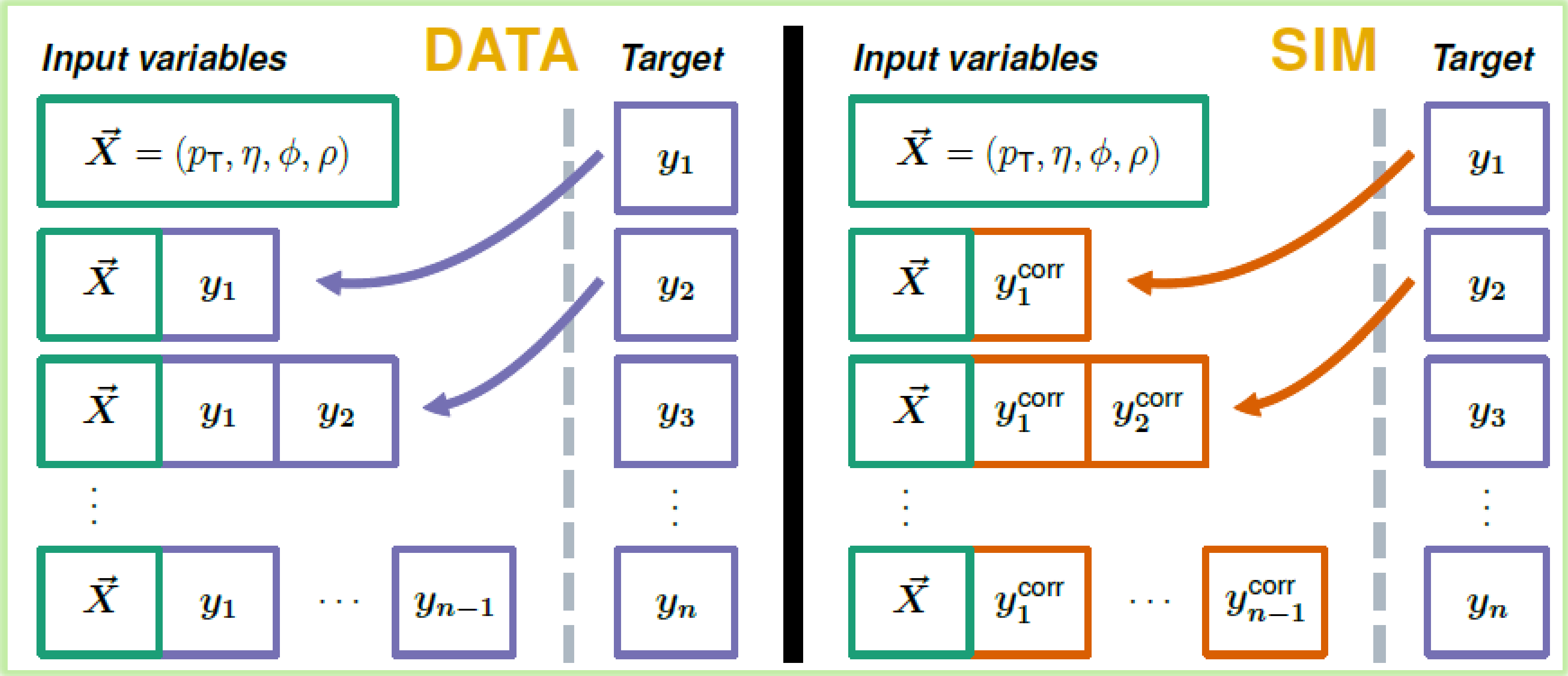
- Diphoton system
- Leading & Subleading jet
- jj-system
- Double differential

- Using full Run 2 dataset (137 fb^{-1})
- Select diphoton events that fall into fiducial phase space
- Events are categorized using estimated diphoton mass resolution per year (avoid model dependence in event categorization)
- Signal is extracted making fit to diphoton invariant mass spectrum
- Background model data driven using discrete profiling method
- Maximum likelihood fit performed using signal strength per particle level bin as POIs



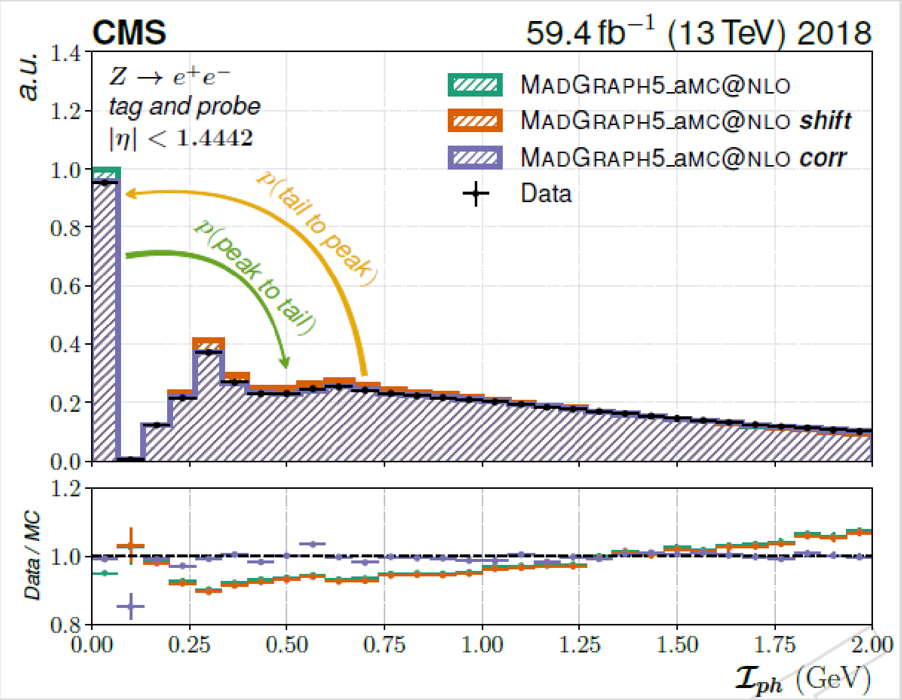
Diphoton invariant mass distribution of all categories combined used for the inclusive fiducial cross section measurement

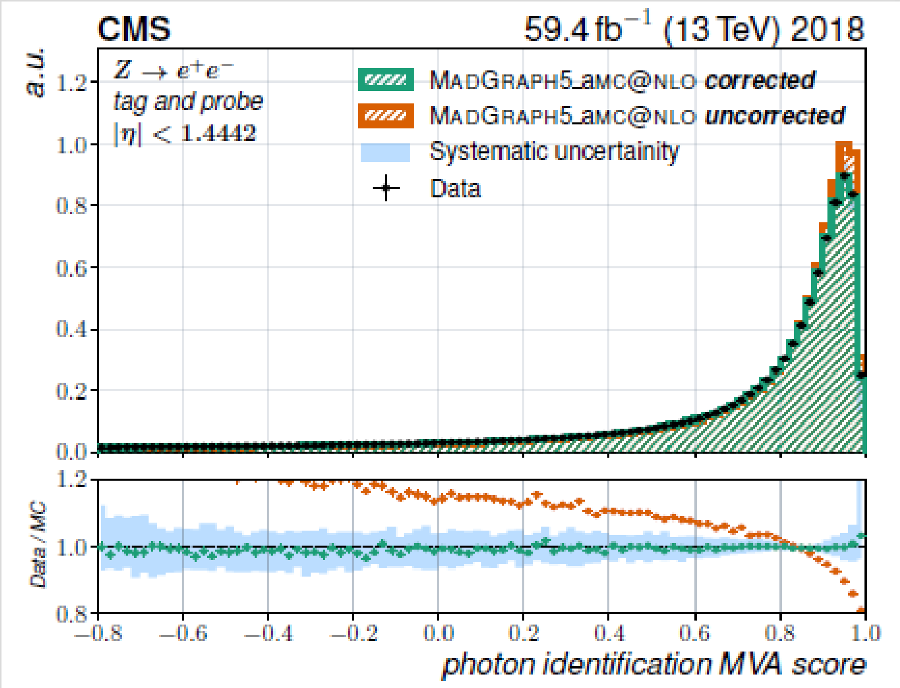
Differential MC corrections



- Dedicated method (chained quantile morphing) to compute per-photon correction to match simulation to data
  - Results in much better data/MC agreement of phoIDMVA output
- Order of correction is determined and variables corrected become inputs to BDTs for correlations among variables corrected (Separate order for shower shapes and isolations)
- Additionally, a stochastic procedure is applied for discontinuous isolation variables

Isolation Correction and Photon Identification





- For the isolation correction: Used stochastic and chained quantile morphing method to match simulation to data
  - ✓ Differential in *pT, η, ϕ* and *ρ*
  - ✓ Match number of events in peak where *Iso=0* in simulation with number in data
  - ✓ Probability of events shifted from peak to tail (or vice versa) is calculated using probability of event to be in peak/tail in simulation and data (A BDT is trained to estimate the probability to have an isolation sum of zero)
  - ✓ Event shifted to tail assigned a new value sampled from tail distribution

- A TMVA based BDT is trained for photon identification **γ**+Jet sample to discriminate photons against jets faking photons
  - Shower shape, isolation and kinematic variables are used as input for this BDT
  - All of these variables (Shower shape, isolation, kinematic) corrected in simulation to match data and validated with $Z \to \mu\mu\gamma$ and and $Z \to ee$
  - Systematic uncertainty corresponding to data/simulation mismatch for IDMVA score was significantly reduced by using shower shape and isolation corrections

Phase spaces

Fiducial phase space

- $p_T^{\gamma 1} > m_{\gamma\gamma}/3$
- $p_T^{\gamma 2} > m_{\gamma\gamma}/4$
- $|\eta^{\gamma}| < 2.5$
- $Iso_{gen}^{\gamma} < 10$ GeV

1 jet phase space

- $>= 1$ Jet
- $|\eta^{j1}| < 2.5$
- $p_T^{j1} > 30$ GeV

2 jet phase space

- $>= 2$ Jets
- $|\eta^{j1,j2}| < 4.7$
- $p_T^{j1,j2} > 30$ GeV

VBF-enriched phase space:

- $>=2$ Jets
- $|\Delta\eta^{j1,j2}| > 3.5$
- $m^{j1j2} > 200$ GeV

Dedicated fiducial xs measurement

ttH-like phase space:

- $>= 1$ lepton
- $>= 1$ b-jet

VH-like phase space:

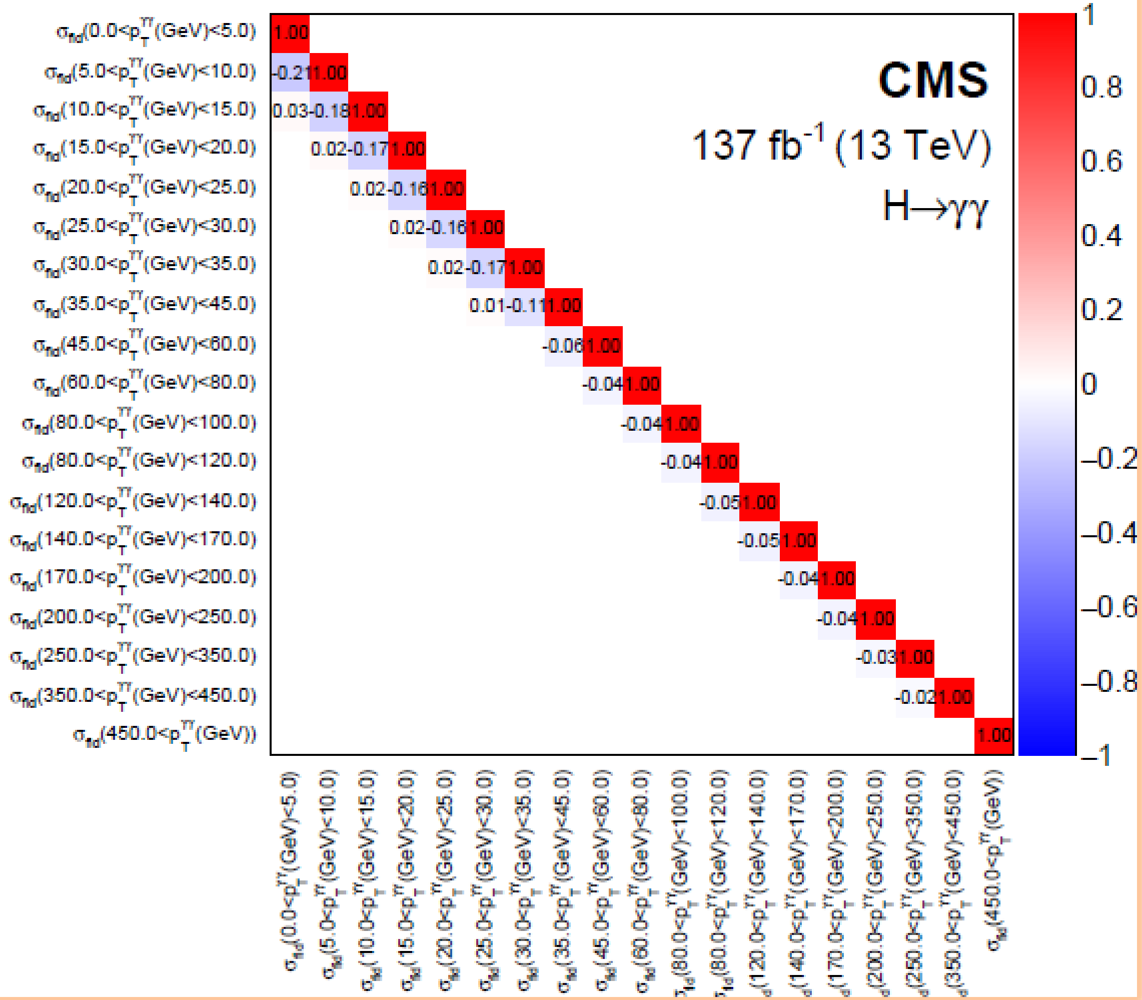
- 1 lepton
- $p_T^{Miss} < 100$ GeV

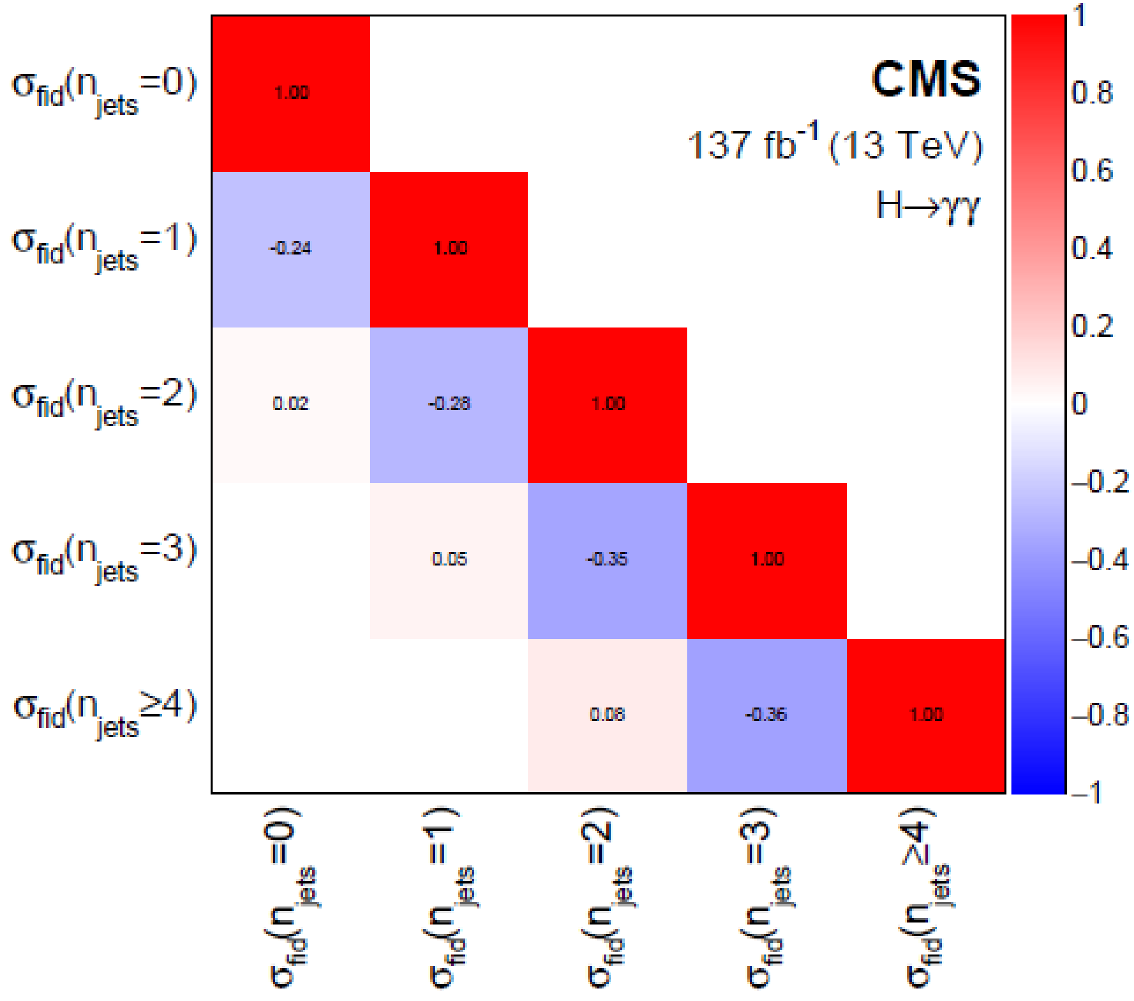
WH-like phase space:

- 1 lepton
- $p_T^{Miss} > 100$ GeV

- **Fiducial phase space** requirements are applied to all phase spaces
- **VBF-enriched phase space** for differential measurement having dedicated 2-jet observables
- **Dedicated fiducial xs** measurement in 3 special phase spaces

Correlation Matrix

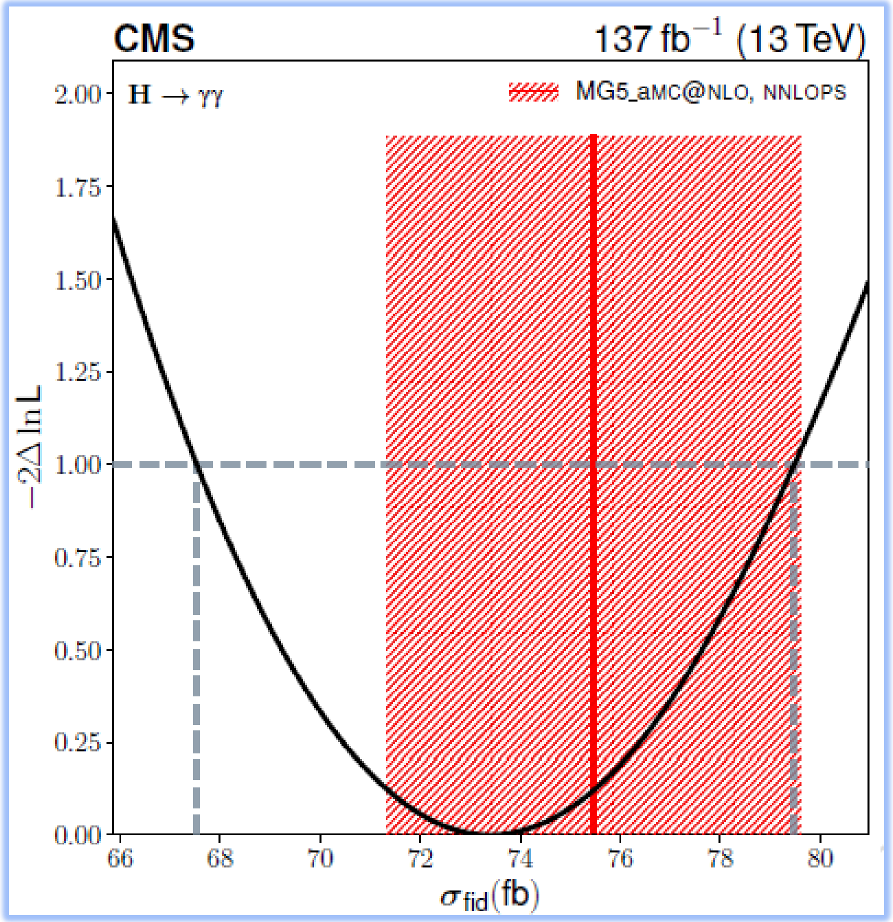


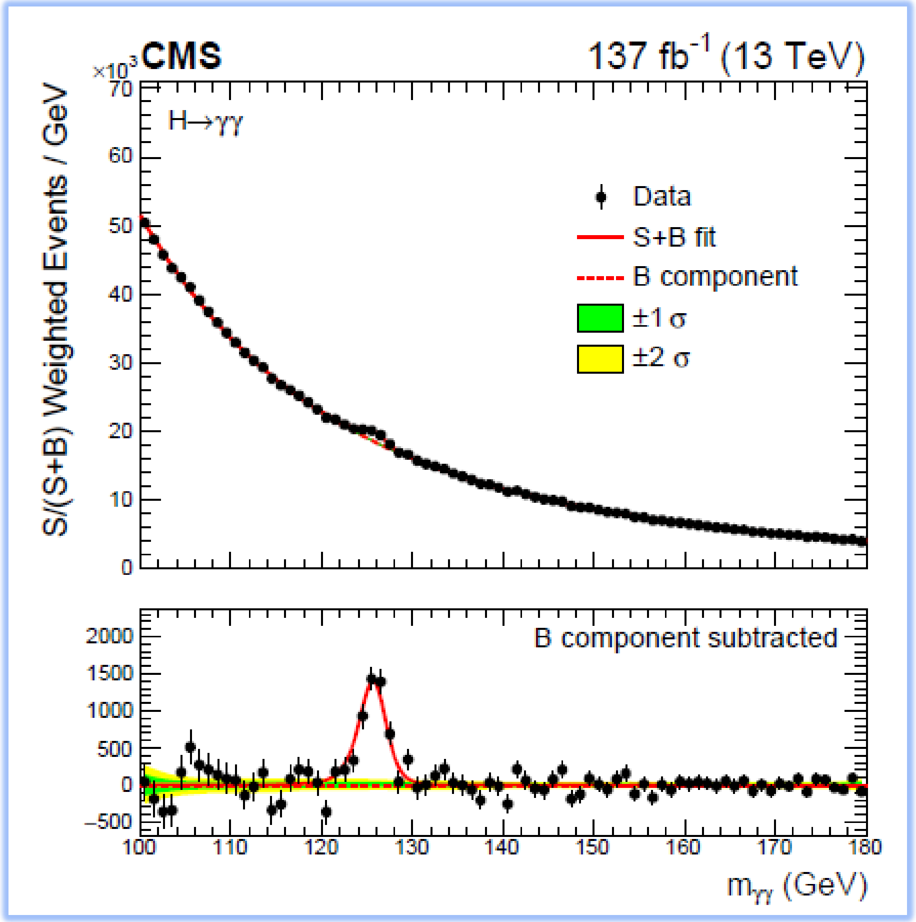


- The correlation matrices for the fiducial cross sections per particle level bin of $\mathbf{P_T^{\gamma\gamma}}$
- The correlation matrices for the fiducial cross sections per particle level bin of $\mathbf{n_{jets}}$

Fiducial Cross-section

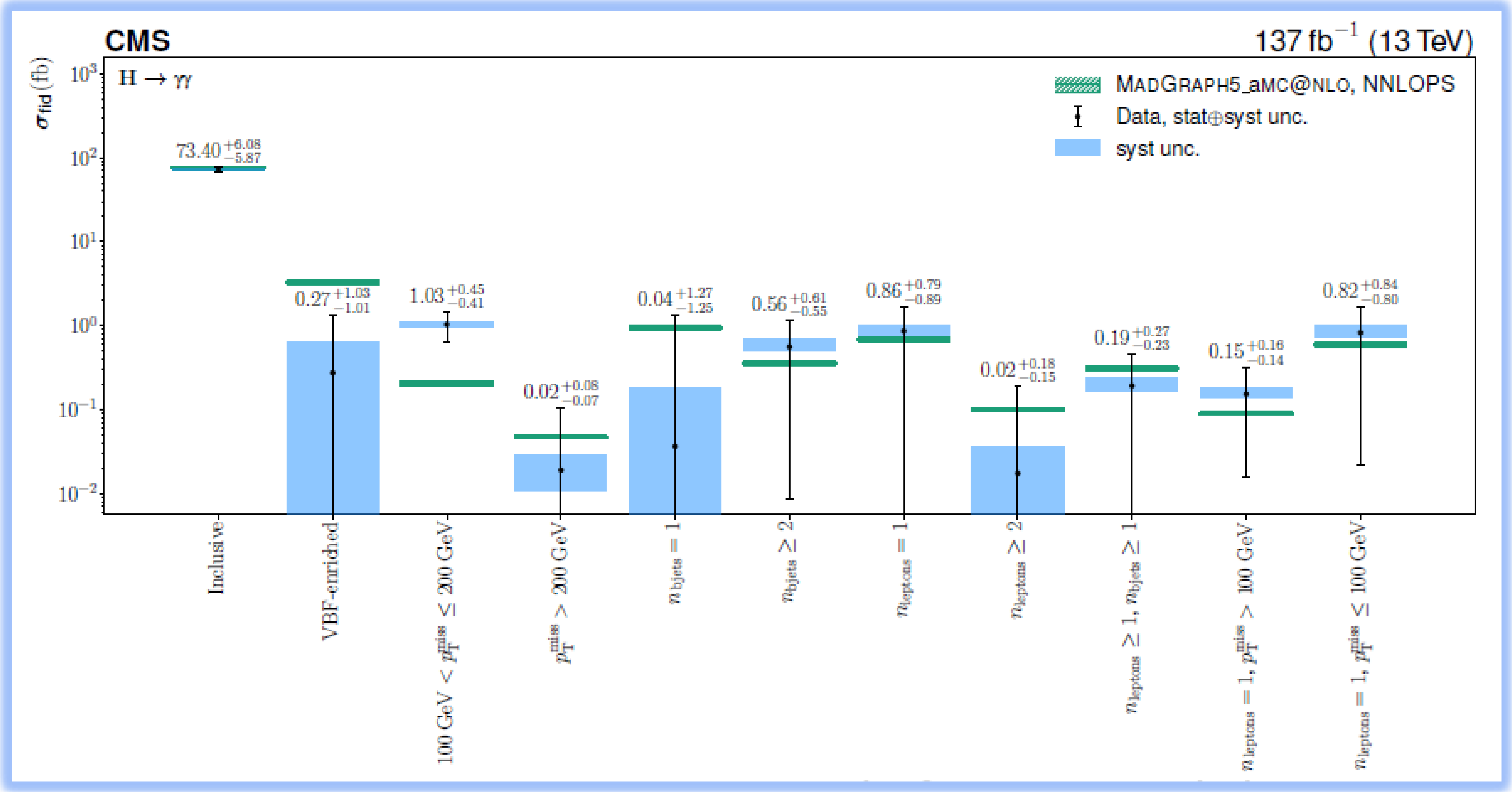
$$\sigma_{\text{fid}} = 73.4^{+5.4}_{-5.3}\,(\text{stat})^{+2.4}_{-2.2}\,(\text{syst})\,\text{fb} = 73.4^{+6.1}_{-5.9}\,\text{fb}.$$





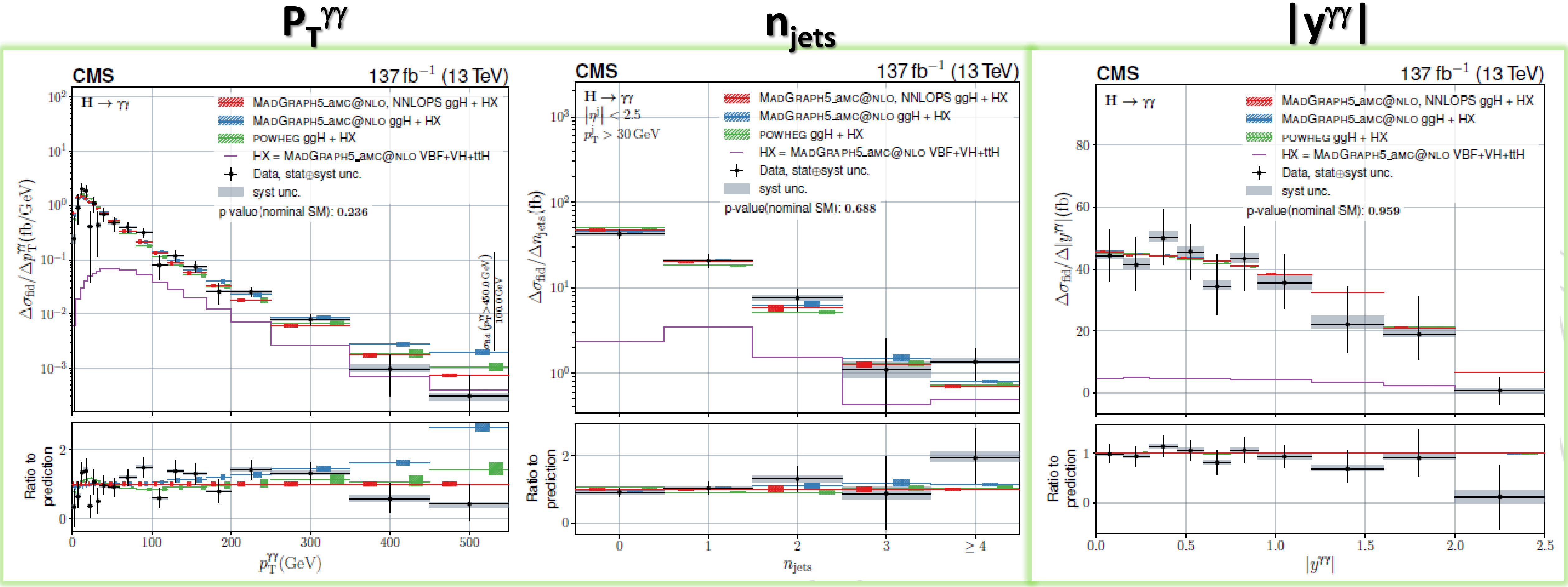
- ➢ Measured signal strength for inclusive fit is **μ**=0.973
- ➢ Translates to measured fiducial xs **σ**=73.40 fb (expected σ=75.44 fb)

Fiducial Cross-section in dedicated phase space regions



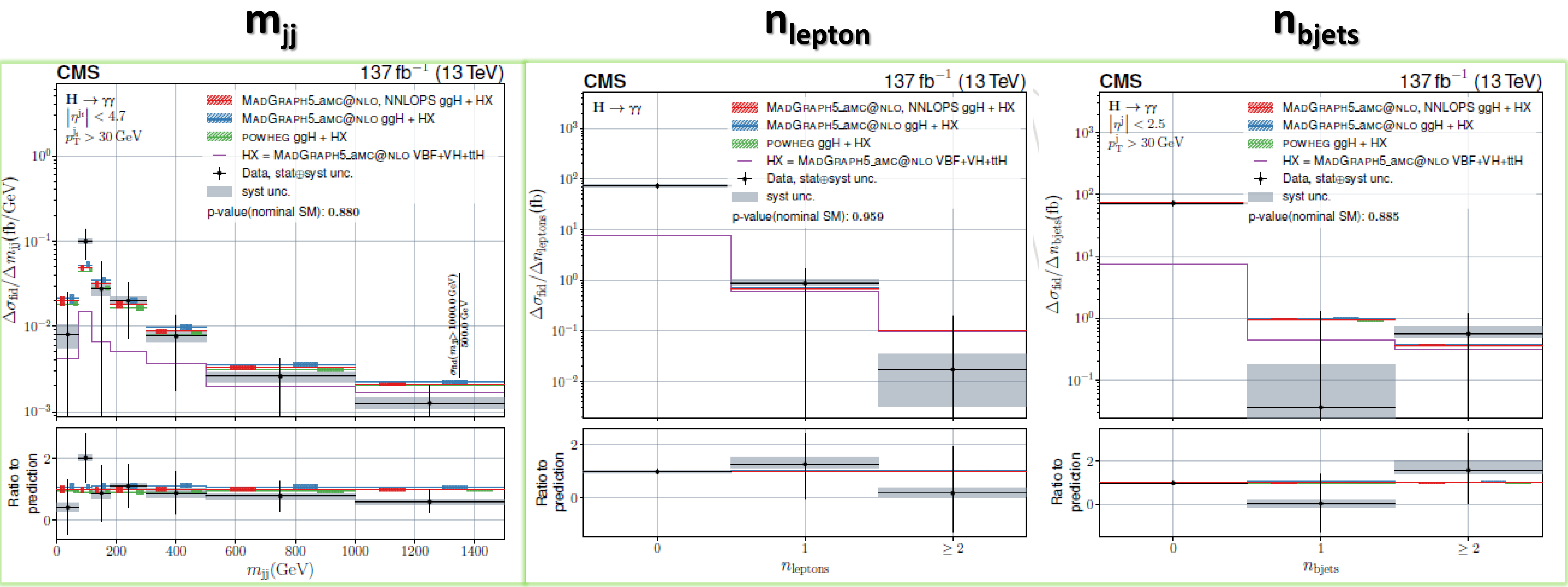
➢ Fiducial cross-section measured in dedicated phase space regions i.e. VBF-enriched, at least one lepton, at least on b-tagged jet, exactly one lepton, high missing p_T Exactly one lepton, low missing p_T

Differential Cross-section for $P_T^{\gamma\gamma}$, n_{jets} and $|y^{\gamma\gamma}|$



- ➢ Cross-section shown as function of observable of interests
- ➢ Bottom panel shows ratio to nominal prediction

Differential Cross-section for m_{jj}, $n_{leptons}$, n_{bjets}

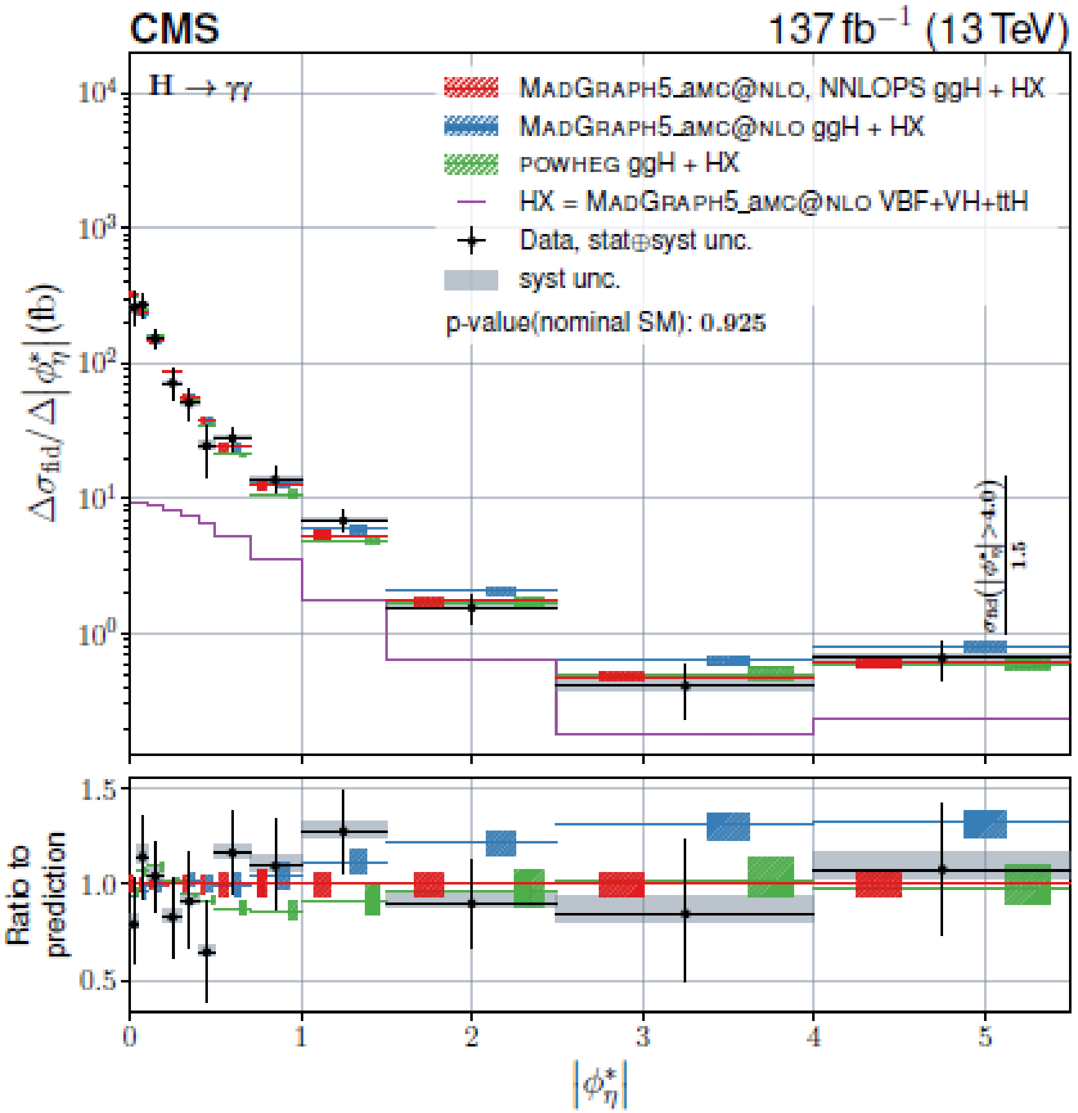


➢ Cross-section shown as function of observable of interests
➢ Bottom panel shows ratio to nominal prediction

Differential Cross-section for $|\phi_\eta^*|$

$$\phi_\eta^* = \tan\left(\frac{\phi_{\text{acop}}}{2}\right)\sin(\theta_\eta^*)$$

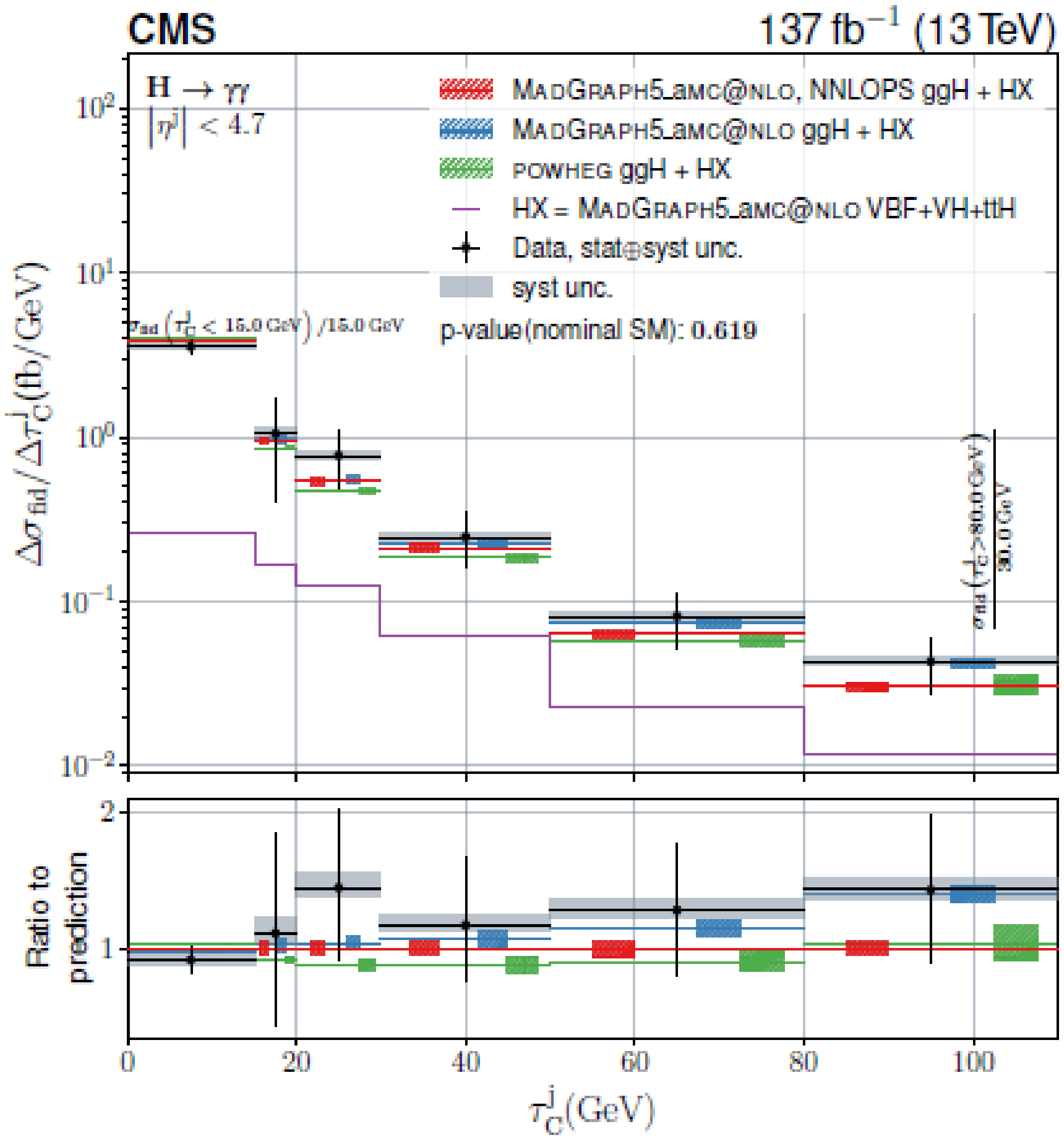
- **"Back-to-backness"** of the diphoton system
- Designed to probe the low p_T region while minimizing the impact of experimental uncertainties
- **Acoplanarity angle**: Angle between the photons in the transverse plane, **Δϕ** and **acop = π − Δϕ**
- θ^*_η: Scattering angle of the two photons with respect to the proton beam in the reference frame in which the two particles are back to back in the (r, θ) plane
- Measured "first time" for the Higgs production



Differential Cross-section for τ^{j}_{c}

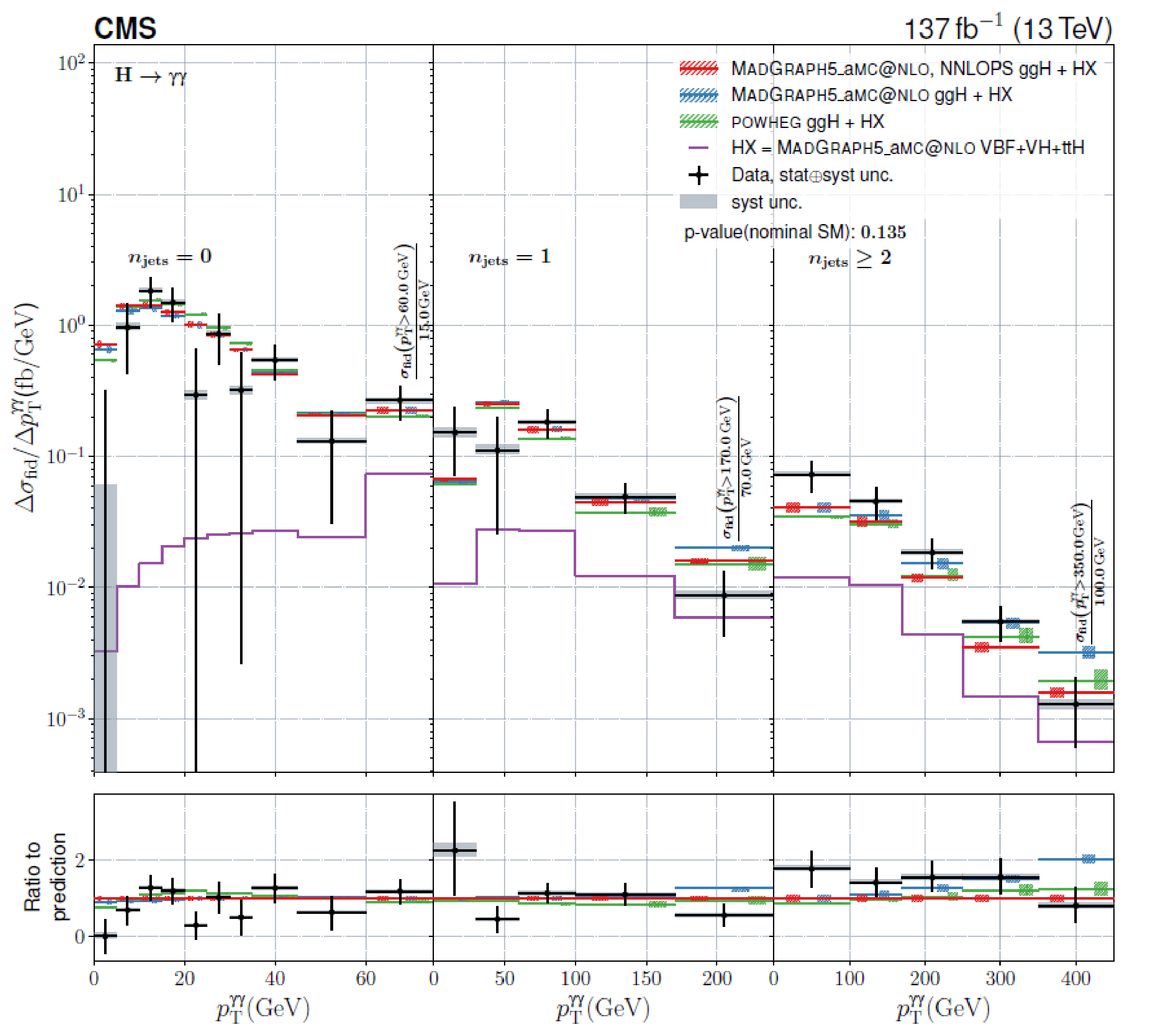
$$\tau_C^j = \max_{k \in \text{jets}} \left(\frac{\sqrt{E_k^2 - p_{z,k}^2}}{2\cosh\left(y_k - y_H\right)} \right)$$

- **Rapidity weighted jet p_T**
- Maximum six largest p_T jets in the event considered
- **τ^{j}_{c}**: Transverse momentum of the jet weighted by a function that depends on the rapidity of the jet and smoothly suppresses the contribution from forward jets
- **τ^{j}_{c}** is calculated in the frame where $y_H = 0$
- Measuring the Higgs boson production cross section with respect to **τ^{j}_{c}** is sensitive to QCD resummation
- Measured "first time" for the Higgs production

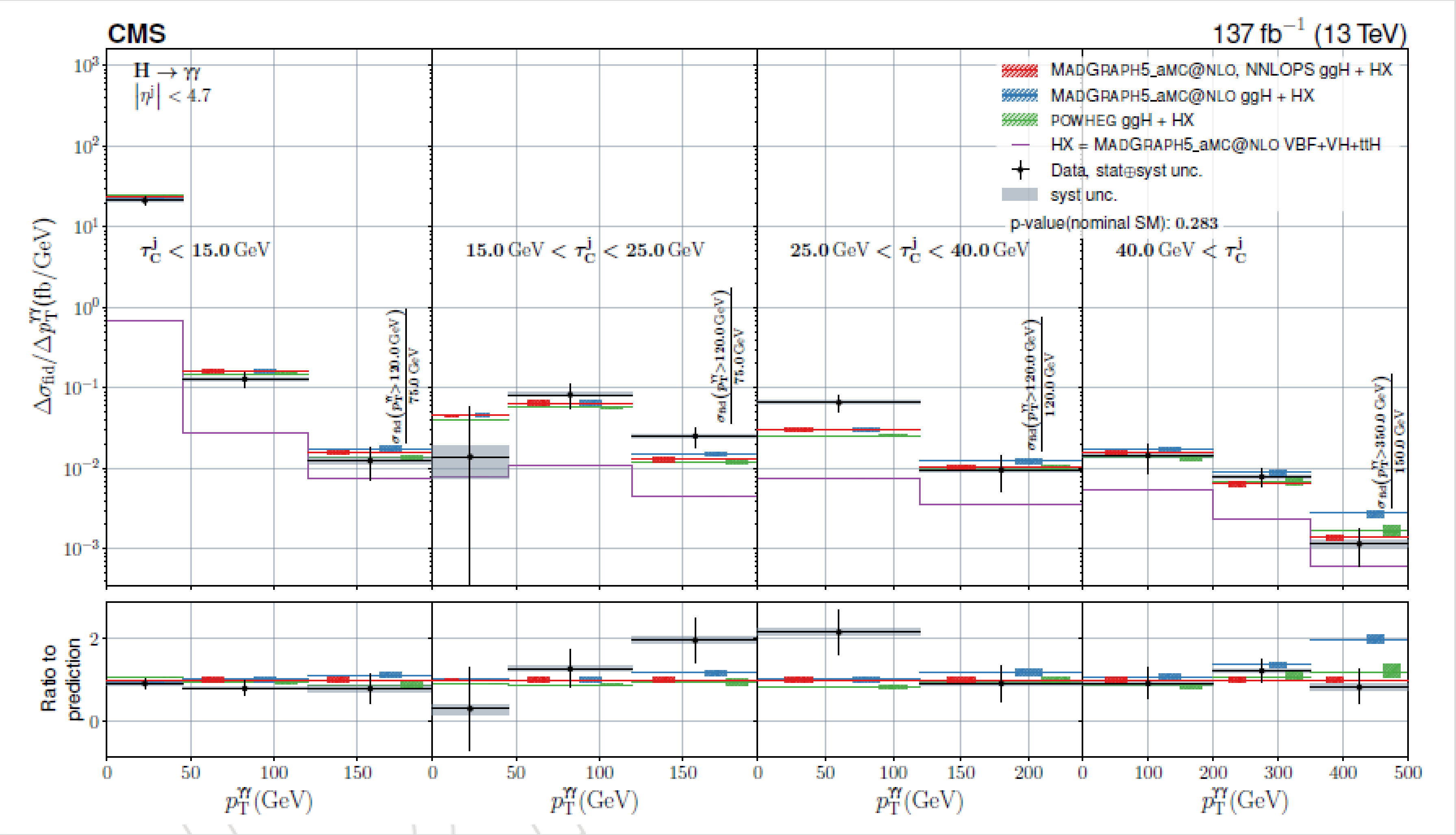


Double Differential Cross-section in bins of $P_T^{\gamma\gamma}$ and n_{jets}

$P_T^{\gamma\gamma}$ VS n_{jets}



Double Differential Cross-section in bins of $P_T^{\gamma\gamma}$ and τ^j_c



$P_T^{\gamma\gamma}$ VS τ^j_c

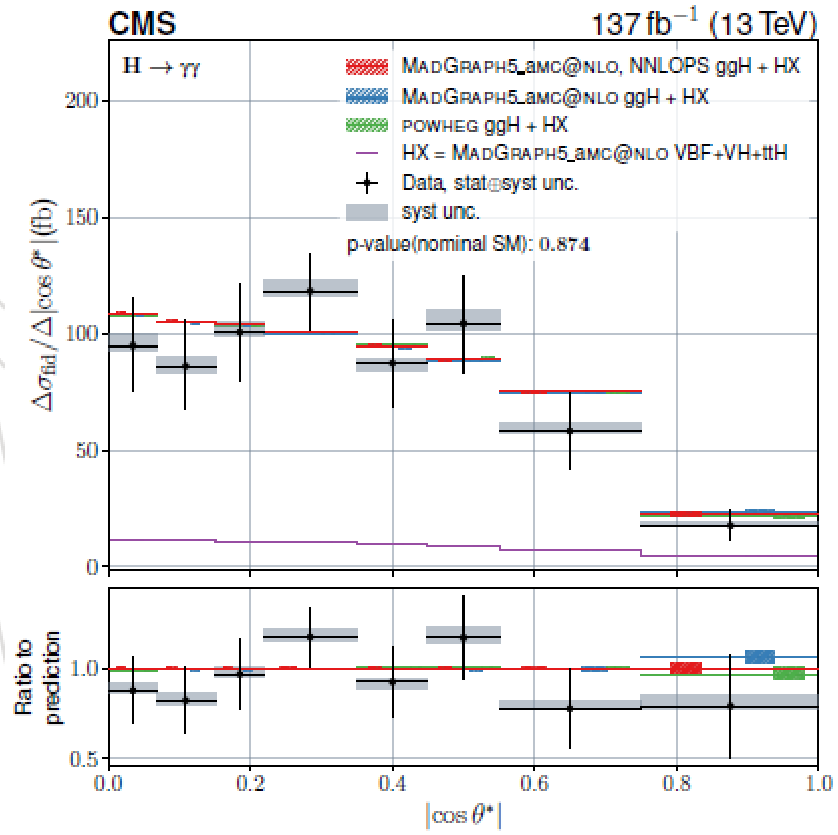
Summary

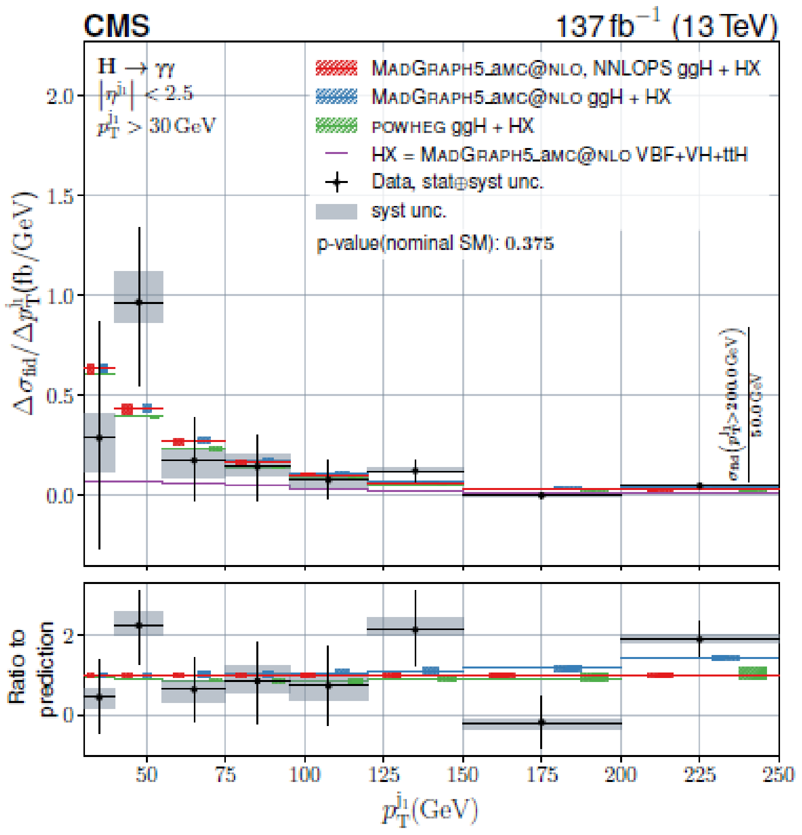
- $H \rightarrow \gamma\gamma$ Differential fiducial cross-section measurement for full Run 2 data are presented
- Measured inclusive fiducial XS as a function of 20 variables
- True cross section values extracted after unfolding, efficiency and acceptance correction
- Two double differential measurements are done
- Fiducial XS measurement done in three special phase space regions targeting ttH, VBFH processes
- All the results are compatible with SM prediction

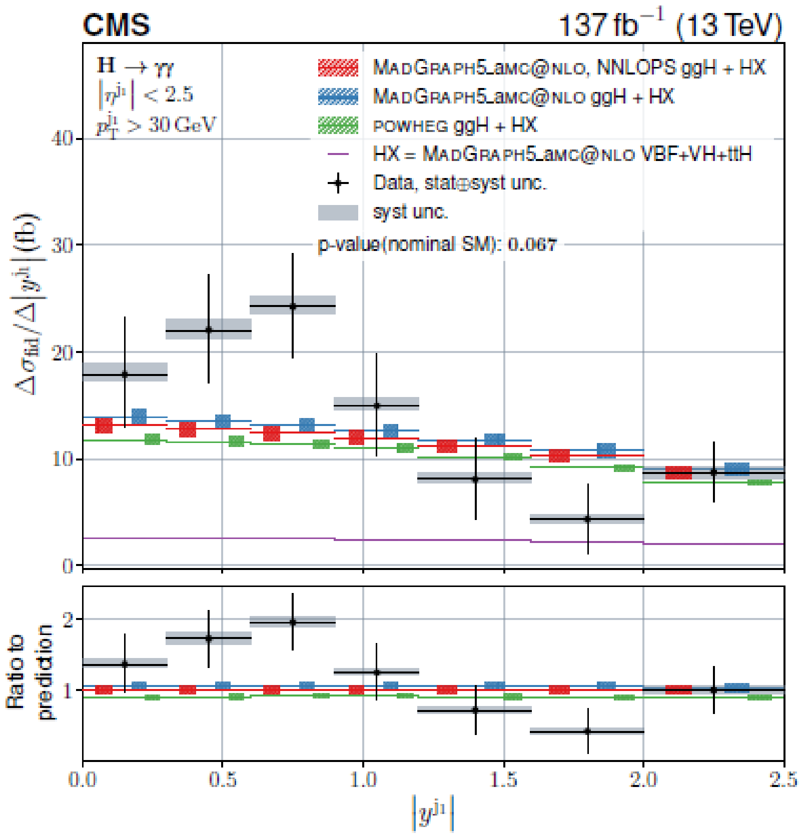
Thanks

Backup

Some other variables







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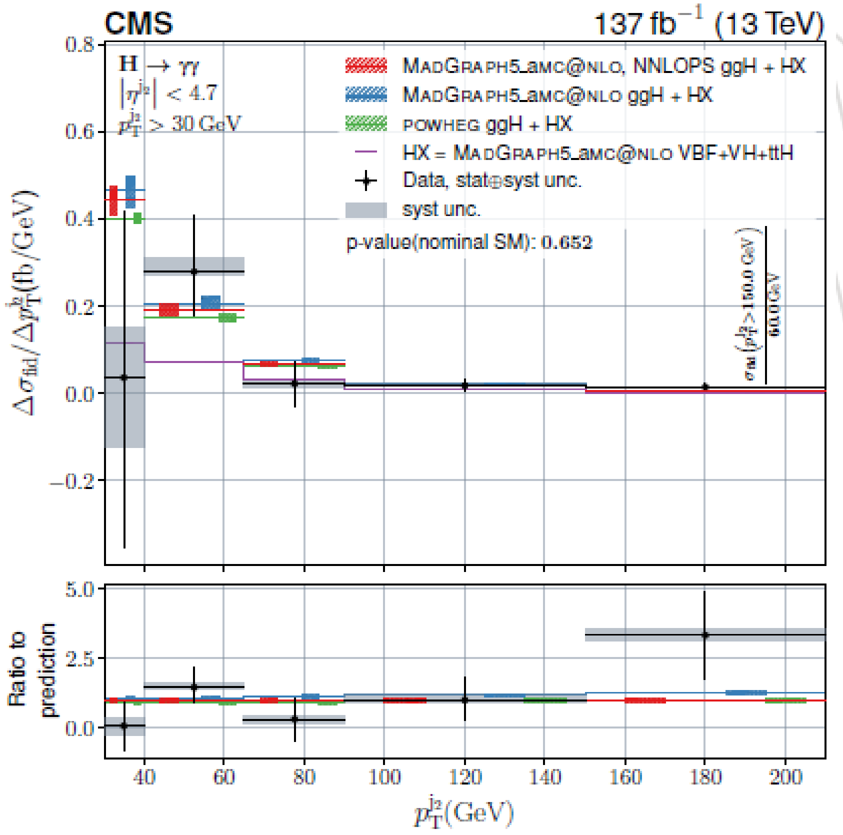

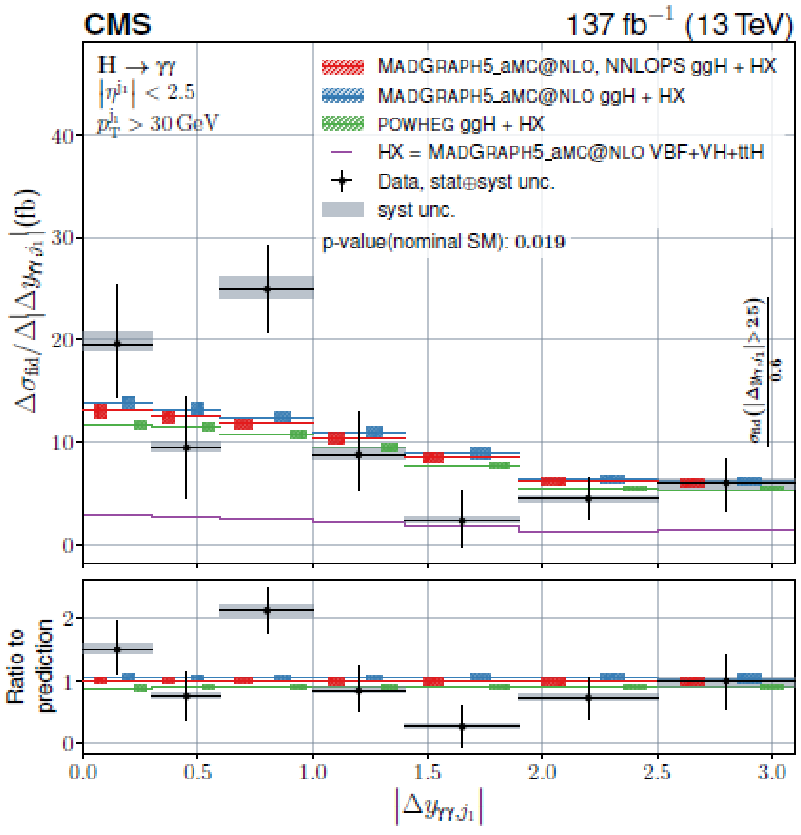

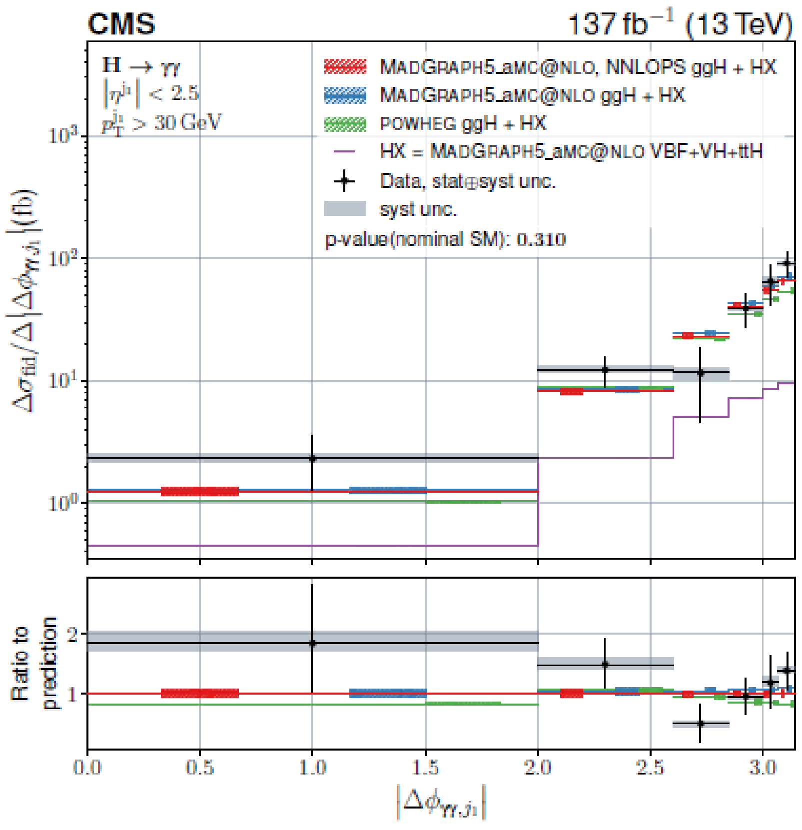

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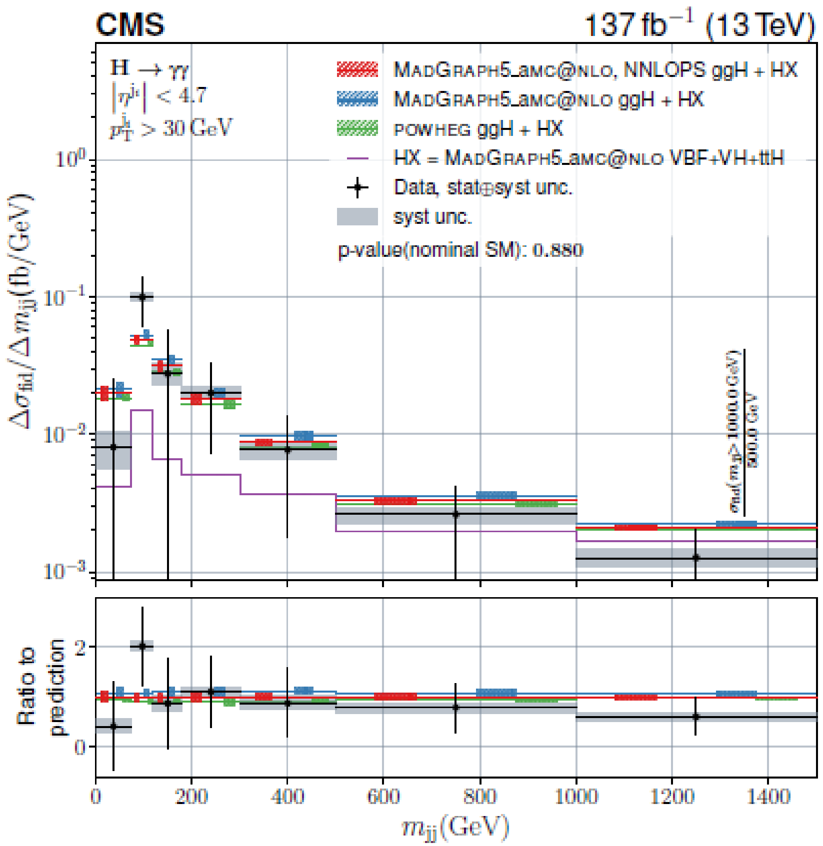

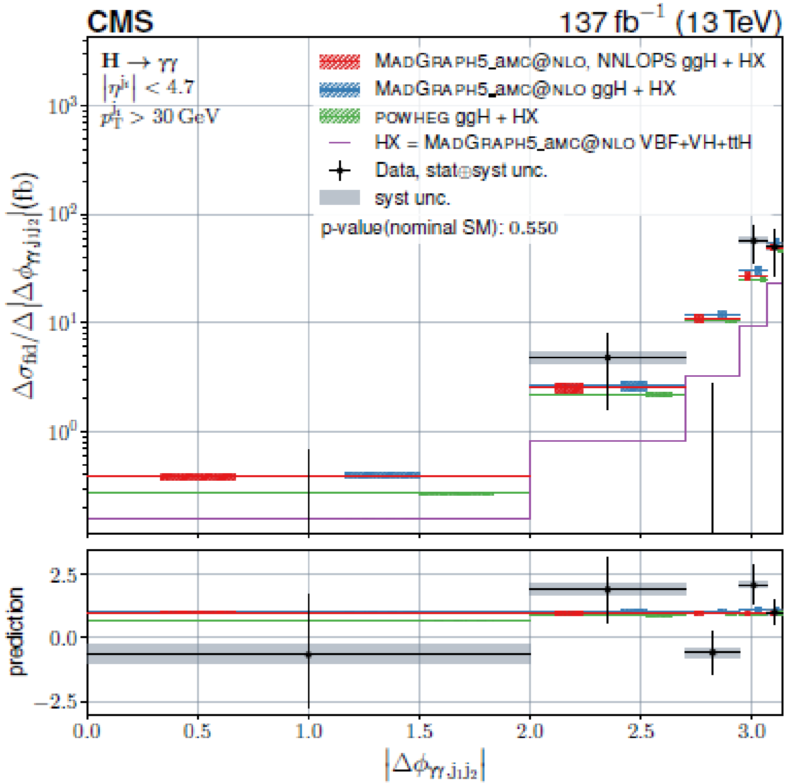

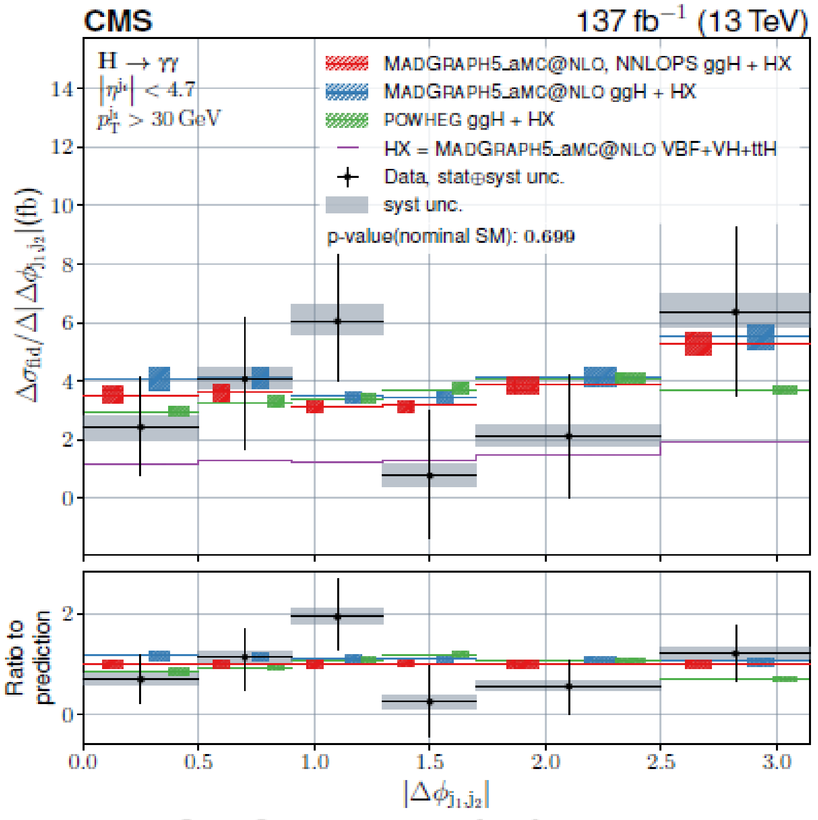

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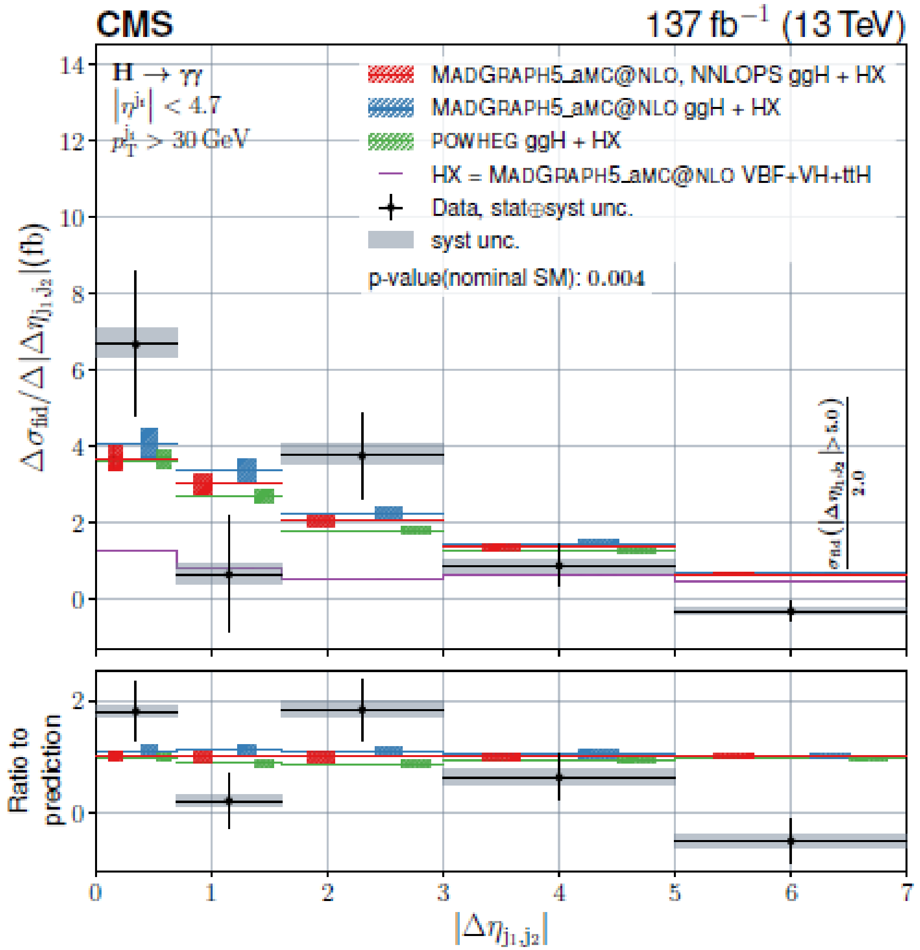

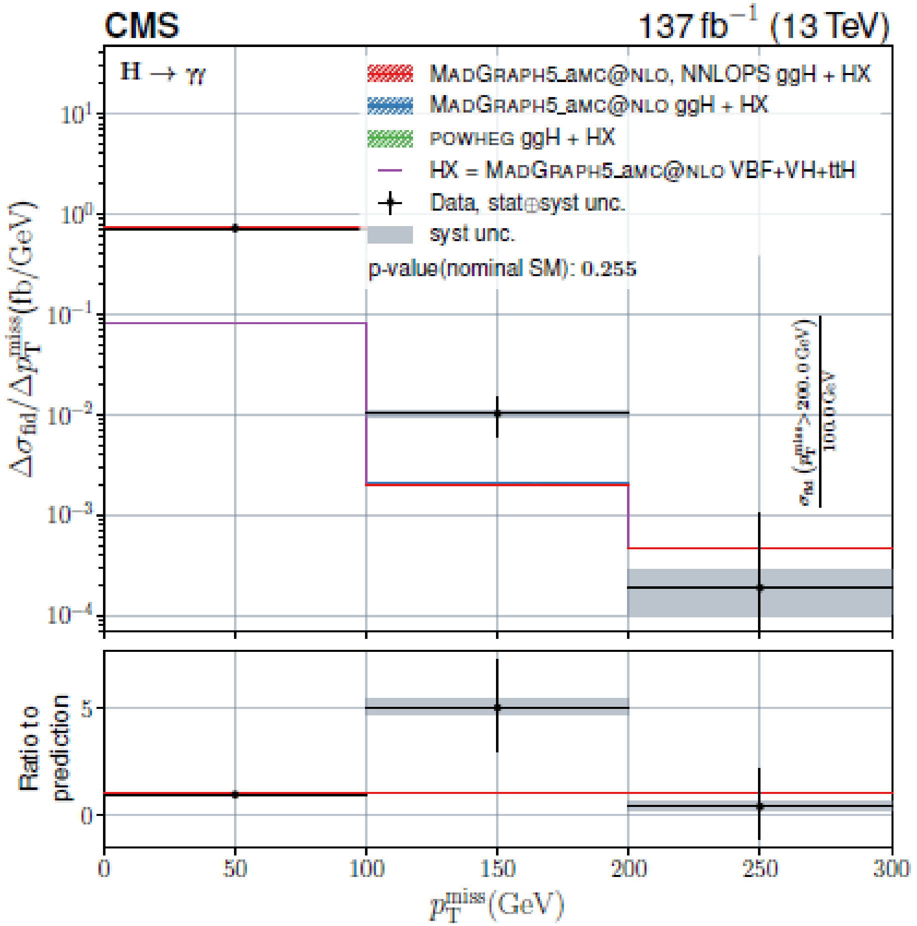

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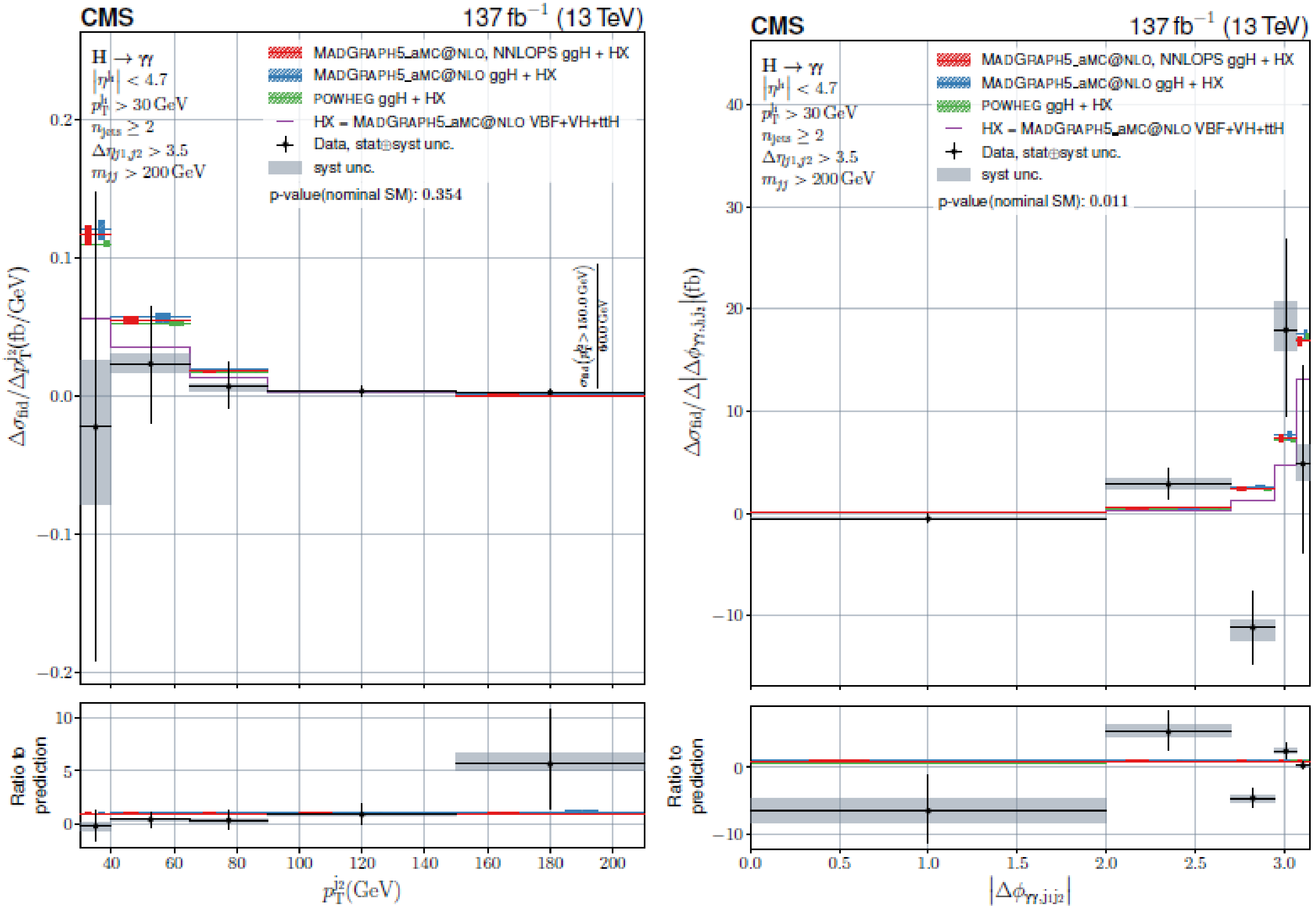

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