Measurement of Higgs boson cross sections with $H \rightarrow \gamma\gamma$ decays at CMS

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on behalf of the CMS Collaboration

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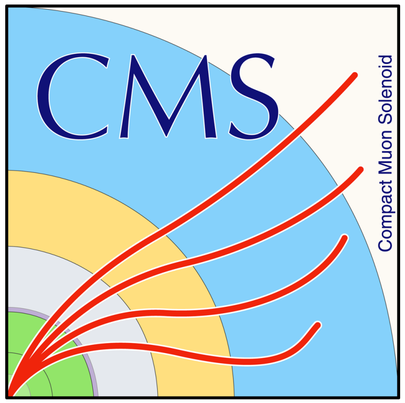
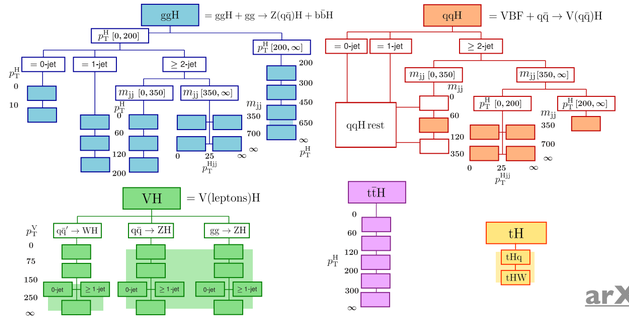


RWTH AACHEN UNIVERSITY

Introduction

- Cross section measurements essential for pinning down Higgs properties

- Simplifed template cross sections
  - optimized for reduced theory uncertainties
  - per production mode



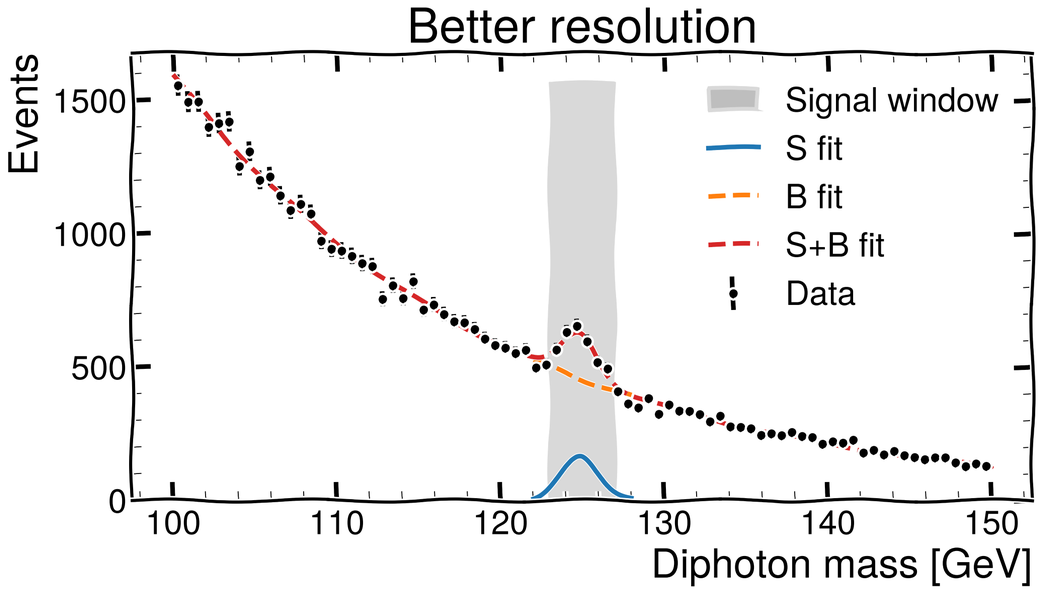
arXiv:2103.06956

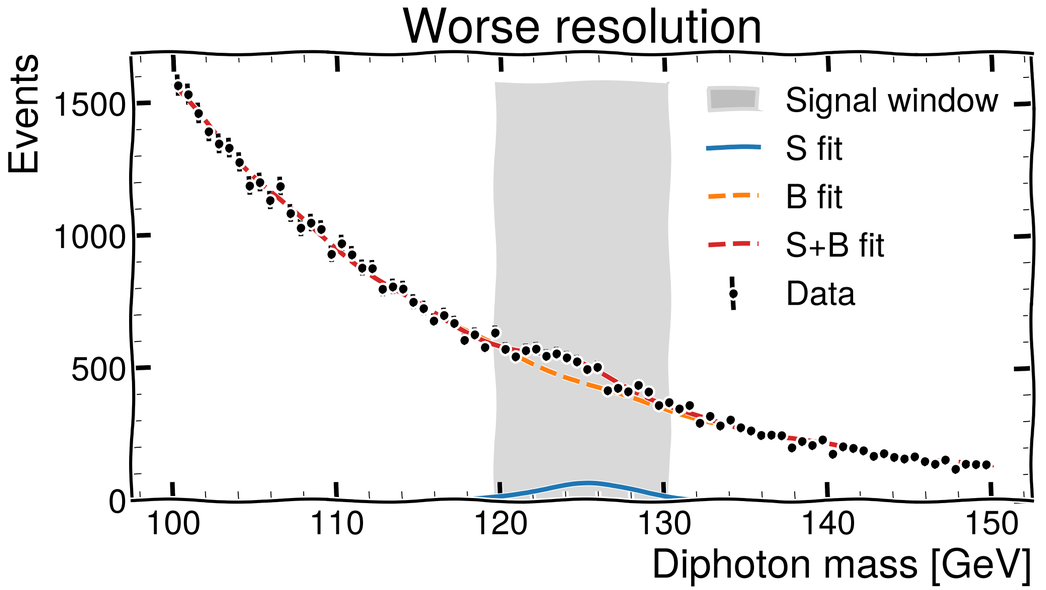
- Fiducial and differential cross sections (this talk)
  - designed to maximize model independence
  - inclusive in production modes
- Full Run-2 measurement arXiv:2208.12279 JHEP 07 (2023) 091

Analysis Strategy

- Fiducial phase spaces ~ reco. phase spaces
  - Inclusive
  - Motivated by production modes (ℓ, E_T^{miss}, b …)
  - Split into bins ($p_T^{\gamma\gamma}$, #jets, p_T^{jet}, …)

- Signal yields from fits to $m_{\gamma\gamma}$
- Additional categorization → model independent!
- Split only by:
  - $m_{\gamma\gamma}$ resolution
  - data-taking year





sketches: Florian Mausolf

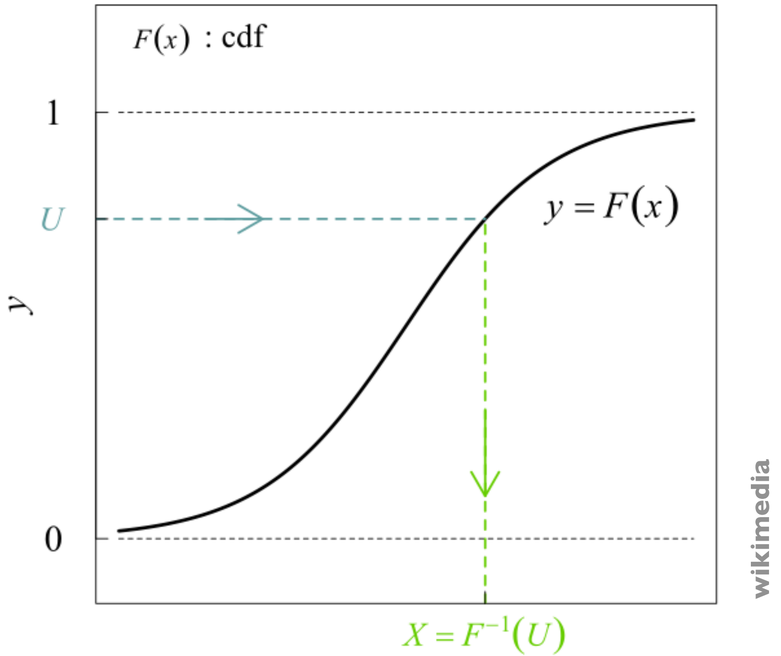
Quantile Morphing

- Energy resolution estimated by "semi-parametric regression"
- As resolution of calorimeters improves with energy $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$

  → $\frac{\sigma_{m_{\gamma\gamma}}}{m_{\gamma\gamma}}$ improves with energy
  - Produces turn-ons in $m_{\gamma\gamma}$ spectrum…

- Solution: decorrelate vs. $m_{\gamma\gamma}$ by quantile morphing to $m_{\gamma\gamma}$ = 125 GeV
  - *aka Smirnov transform*
  - *aka inverse transform sampling*

$$y_{\text{corr}} = F'^{-1}_{Y}\left(F_Y(y)\right)$$



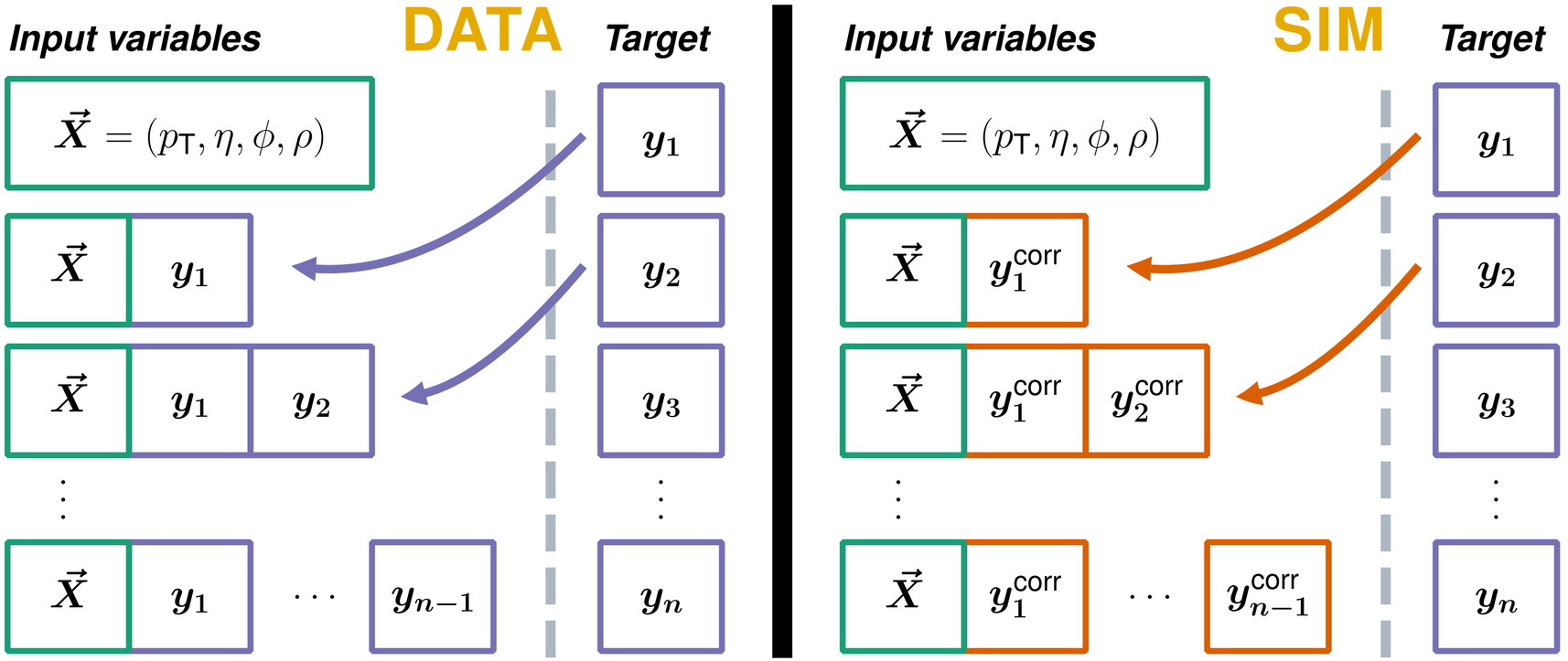
Chained Quantile Regression

- Conditional quantile morphing → quantile regression with loss

$$q_Y(\tau) = \underset{u}{\operatorname{argmin}} \left\{ (\tau - 1) \int_{-\infty}^{u} (y - u)\, \mathrm{d}F_Y(y) + \tau \int_{u}^{\infty} (y - u)\, \mathrm{d}F_Y(y) \right\}$$

- Extension to several correlated variables

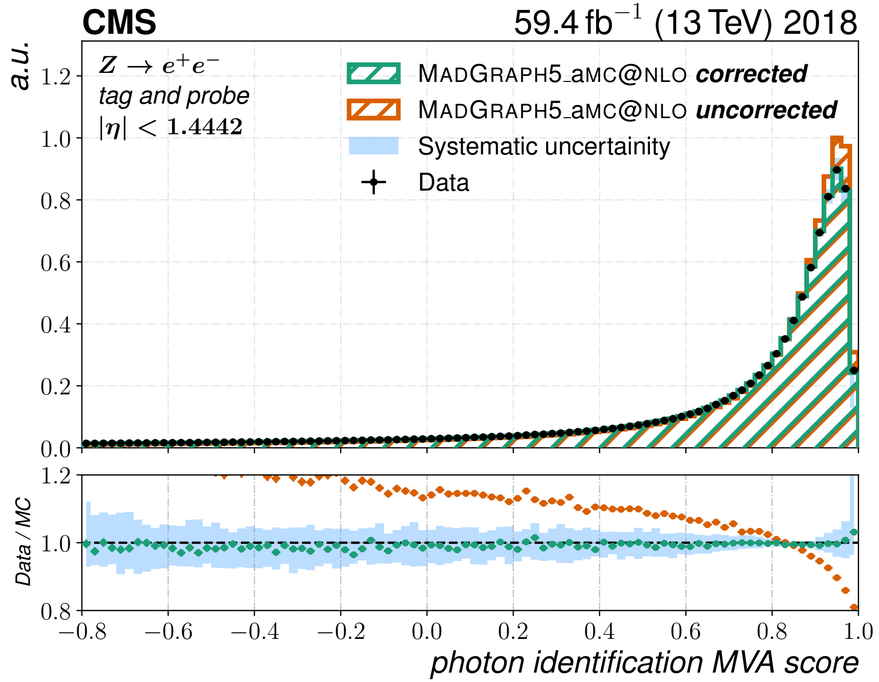
  → chained quantile regression:

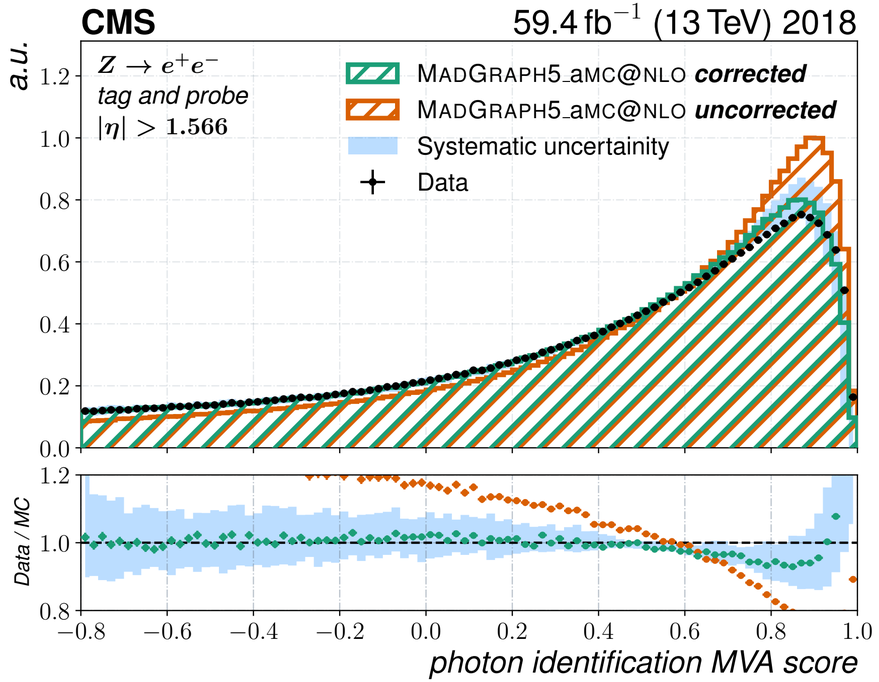


Chained Quantile Regression

- Used to correct modeling of input features to photon identification BDT

barrel:
~1% (!)





endcaps:
~5% (!)

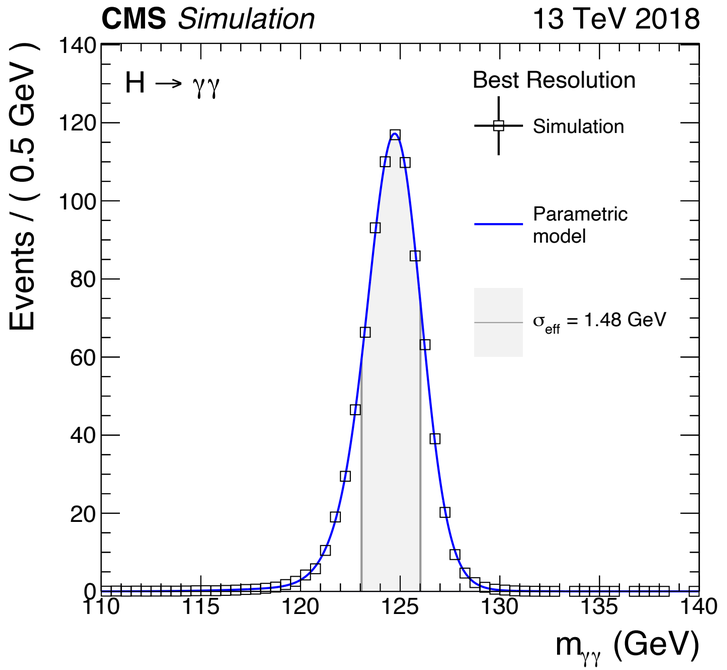
- CQR tedious: one BDT per quantile and per variable…
- Morphing proposals using deep learning: 2107.08648 (OT) 2309.15912 (CQR w/ NF)

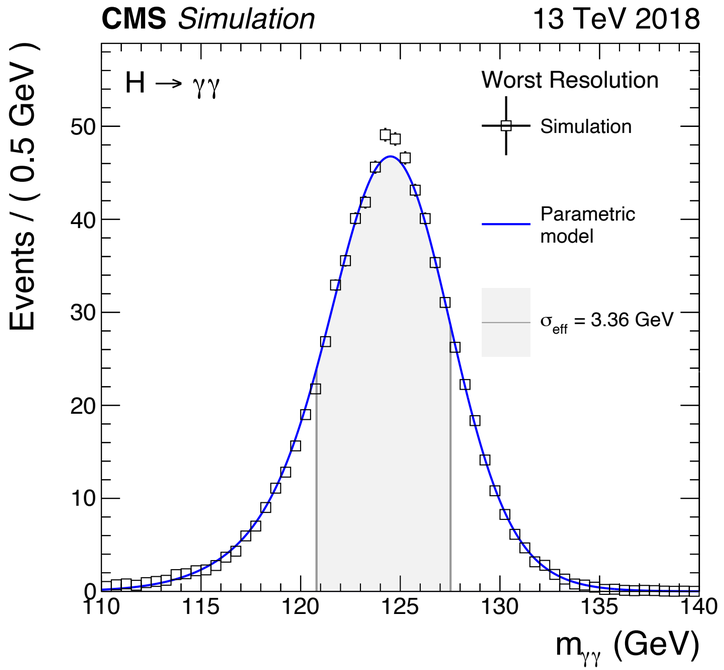
2304.14963 (NF for data) 2309.06472 (2-3 NFs) 2403.18582 (1 NF + switch)

Selections and Categorisation

	Reco Level	Particle Level
$p_T^{\gamma 1} / m_{\gamma\gamma}$	> 1/3	> 1/3
$p_T^{\gamma 2} / m_{\gamma\gamma}$	> 1/4	> 1/4
ID	minimum cut on ID BDT score	Iso^{γ}_{gen} < 10 GeV
$\lvert\eta^{\gamma}\rvert$	< 2.5 and not in [1.4442, 1.566]	< 2.5

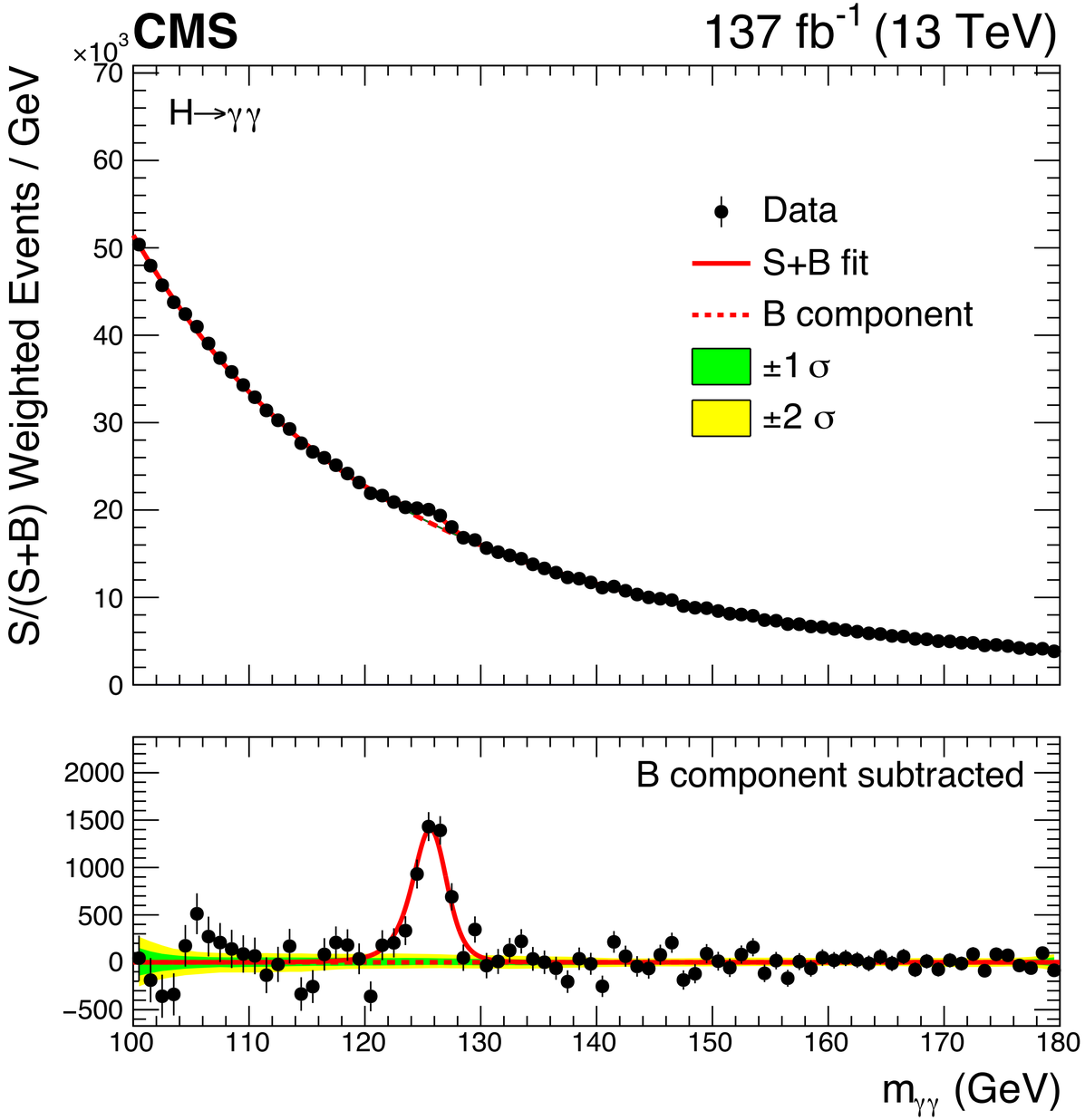
- 3 resolution categories
  + optimized cut on the photon ID BDT score (with efficiency from 63.5% to 90.4%)



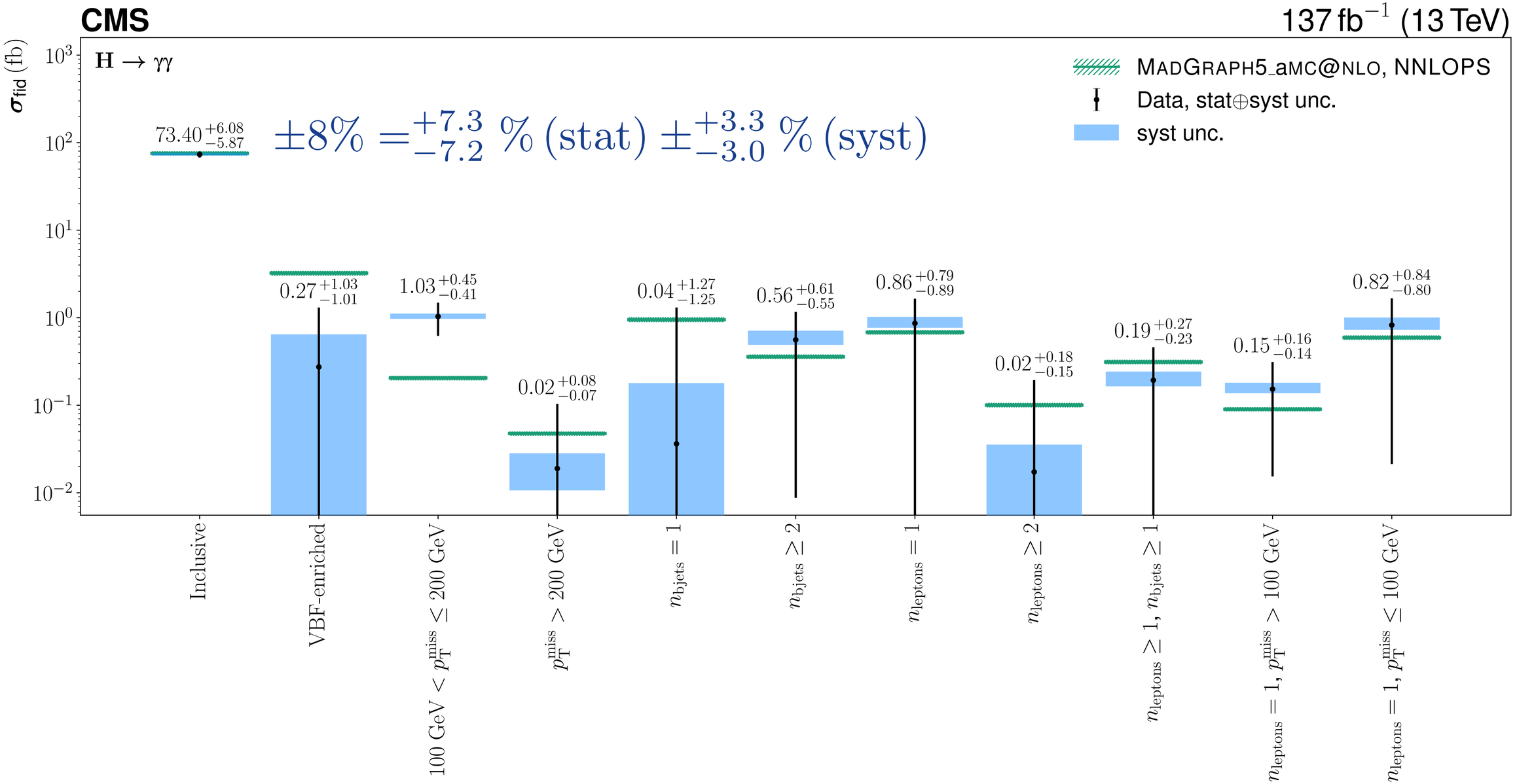


Statistical Treatment

- Binned profile likelihood fit to $m_{\gamma\gamma}$
- Signal modeled by up to four Gaussians
- Backgrounds from exp., power-law, Laurent and Bernstein polynomials included as nuisance parameter via discrete profiling



Inclusive Cross Sections



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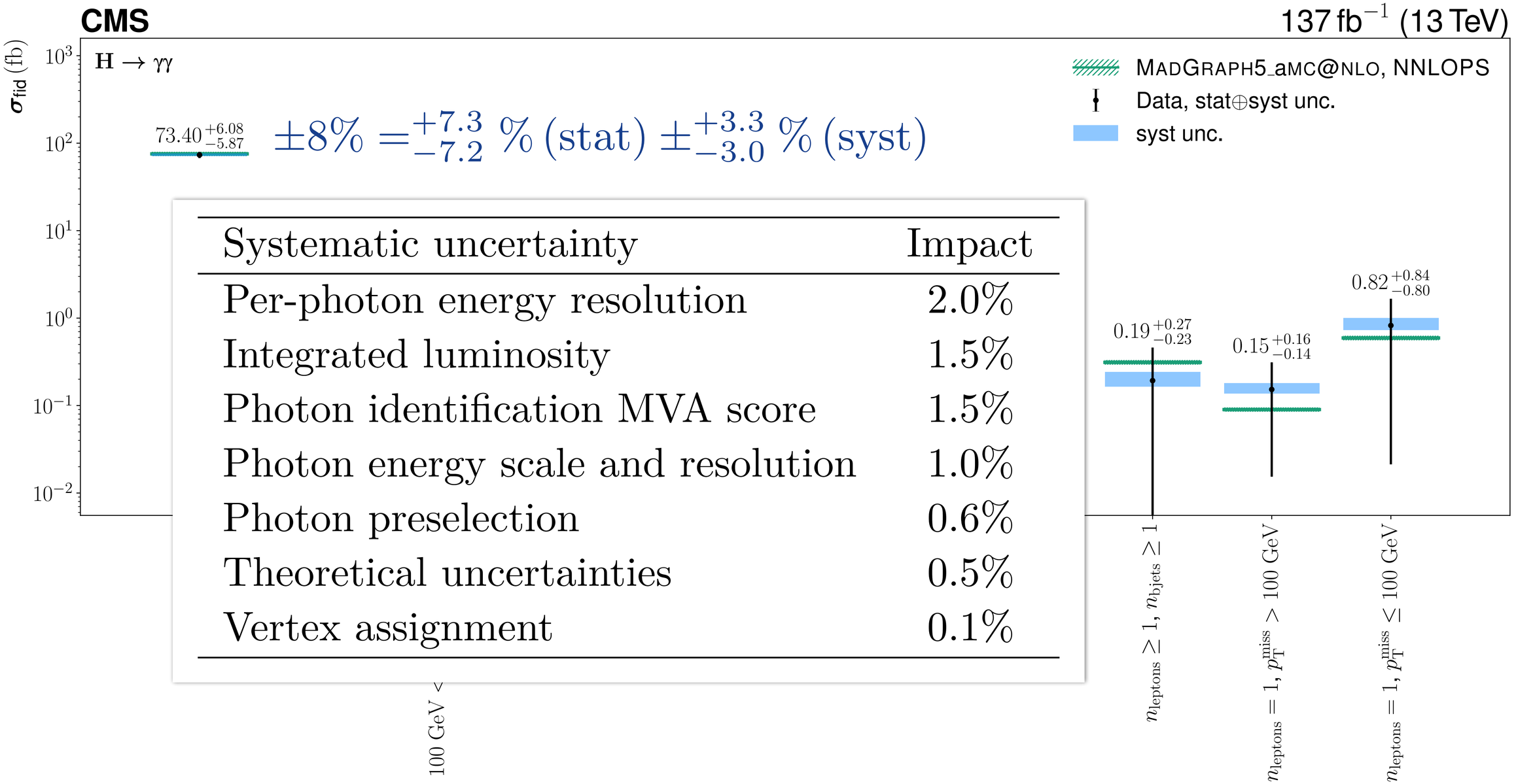
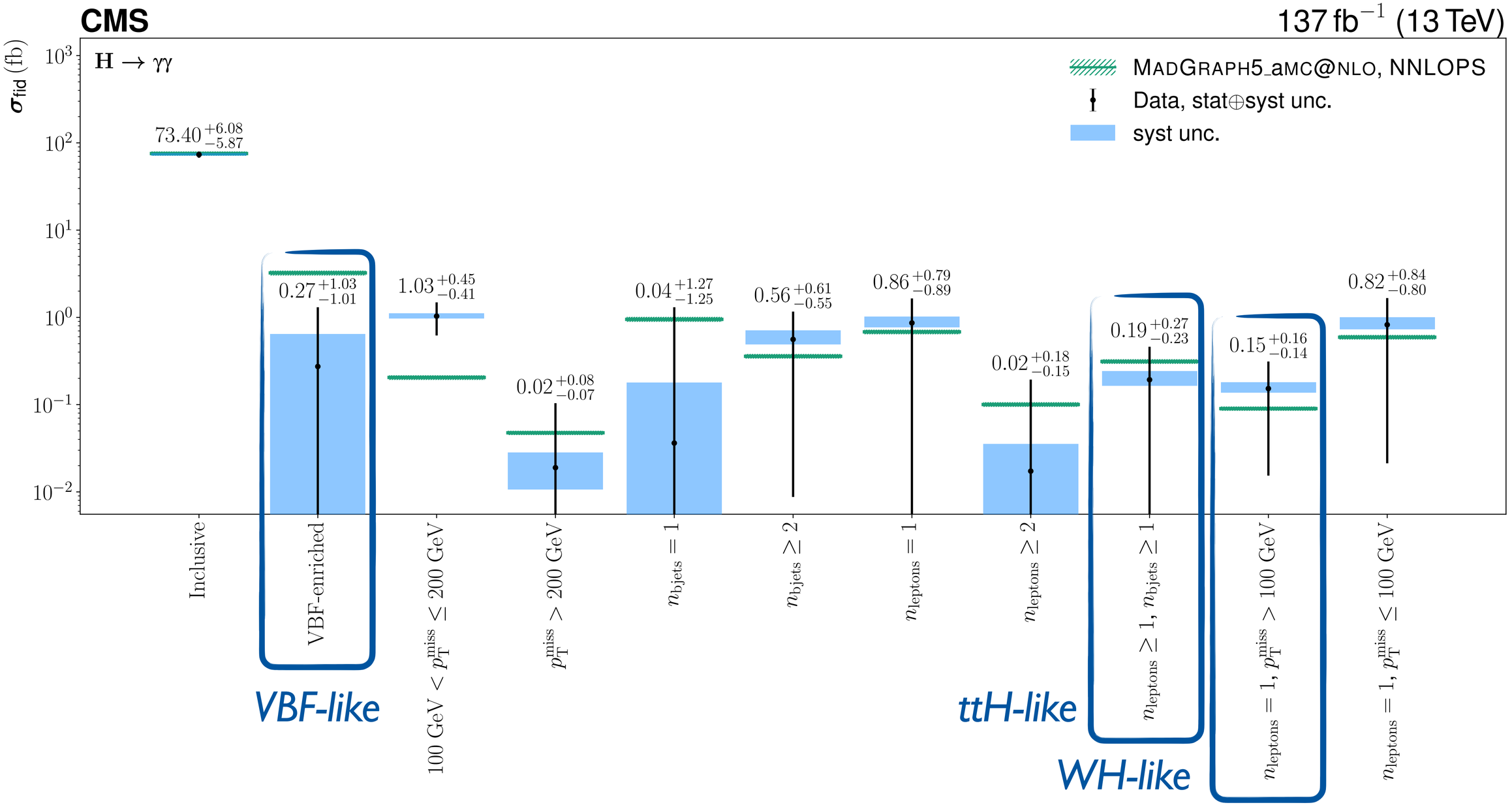


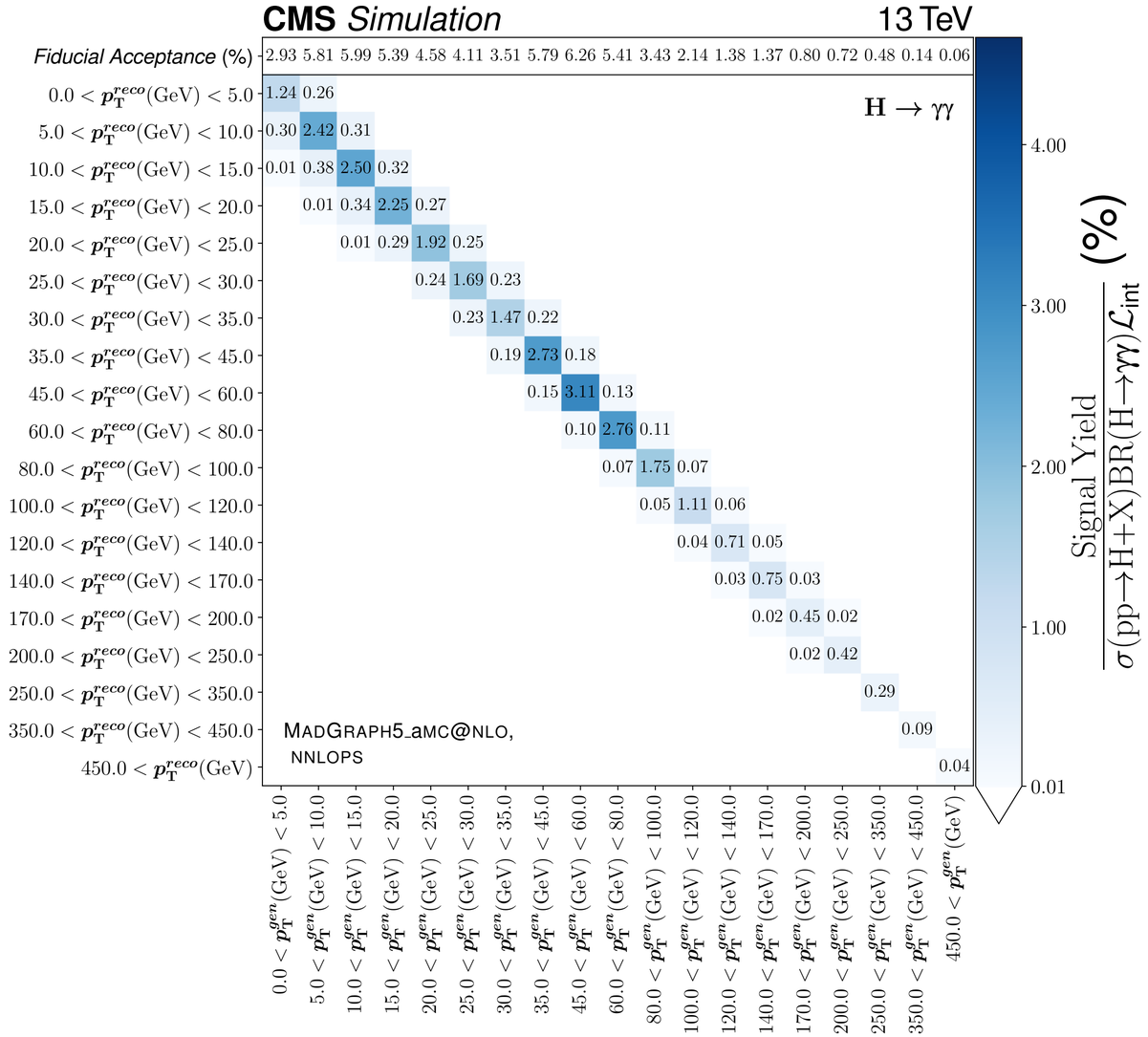
Systematic uncertainty	Impact
Per-photon energy resolution	2.0%
Integrated luminosity	1.5%
Photon identification MVA score	1.5%
Photon energy scale and resolution	1.0%
Photon preselection	0.6%
Theoretical uncertainties	0.5%
Vertex assignment	0.1%

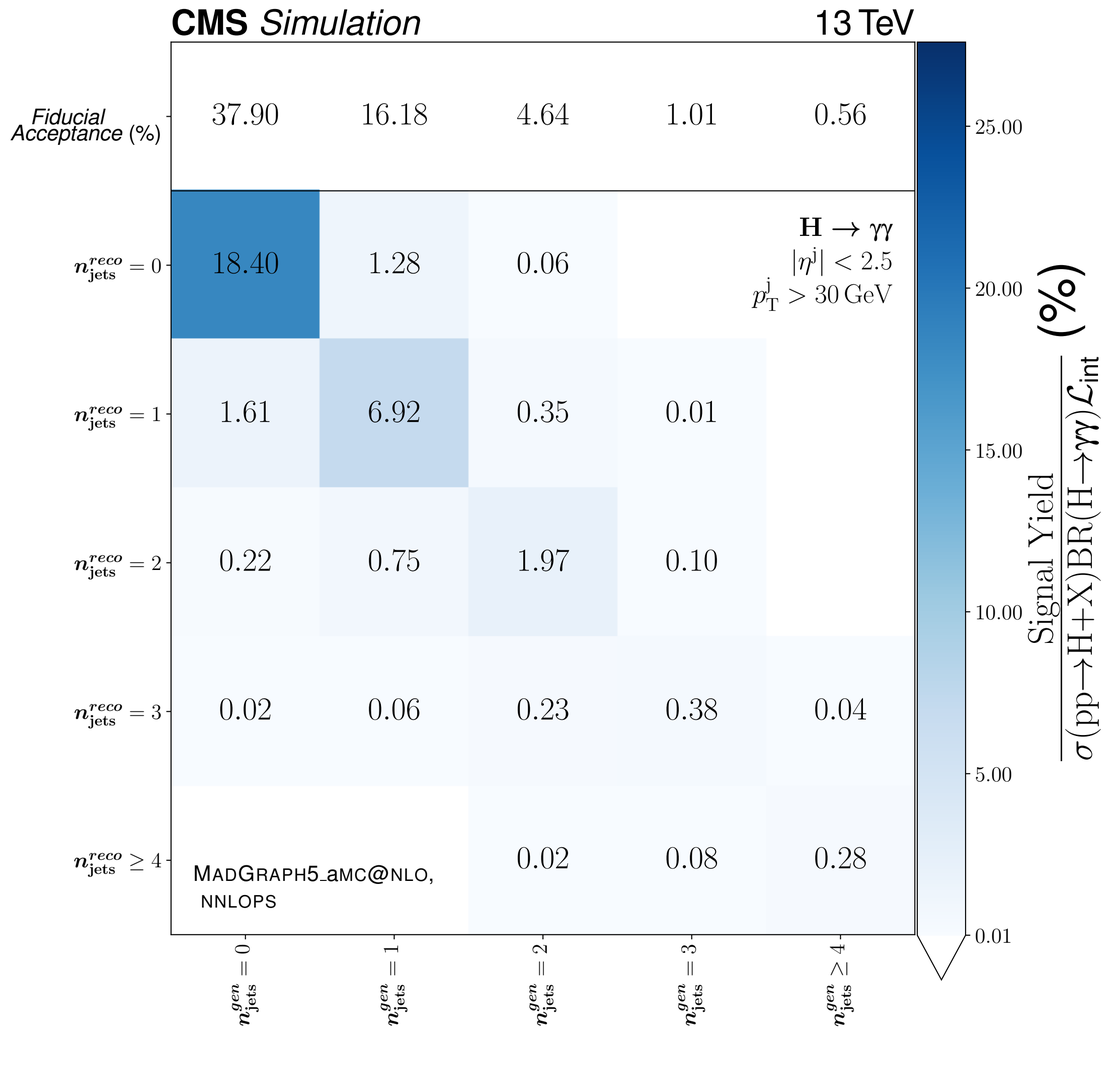
Inclusive Cross Sections



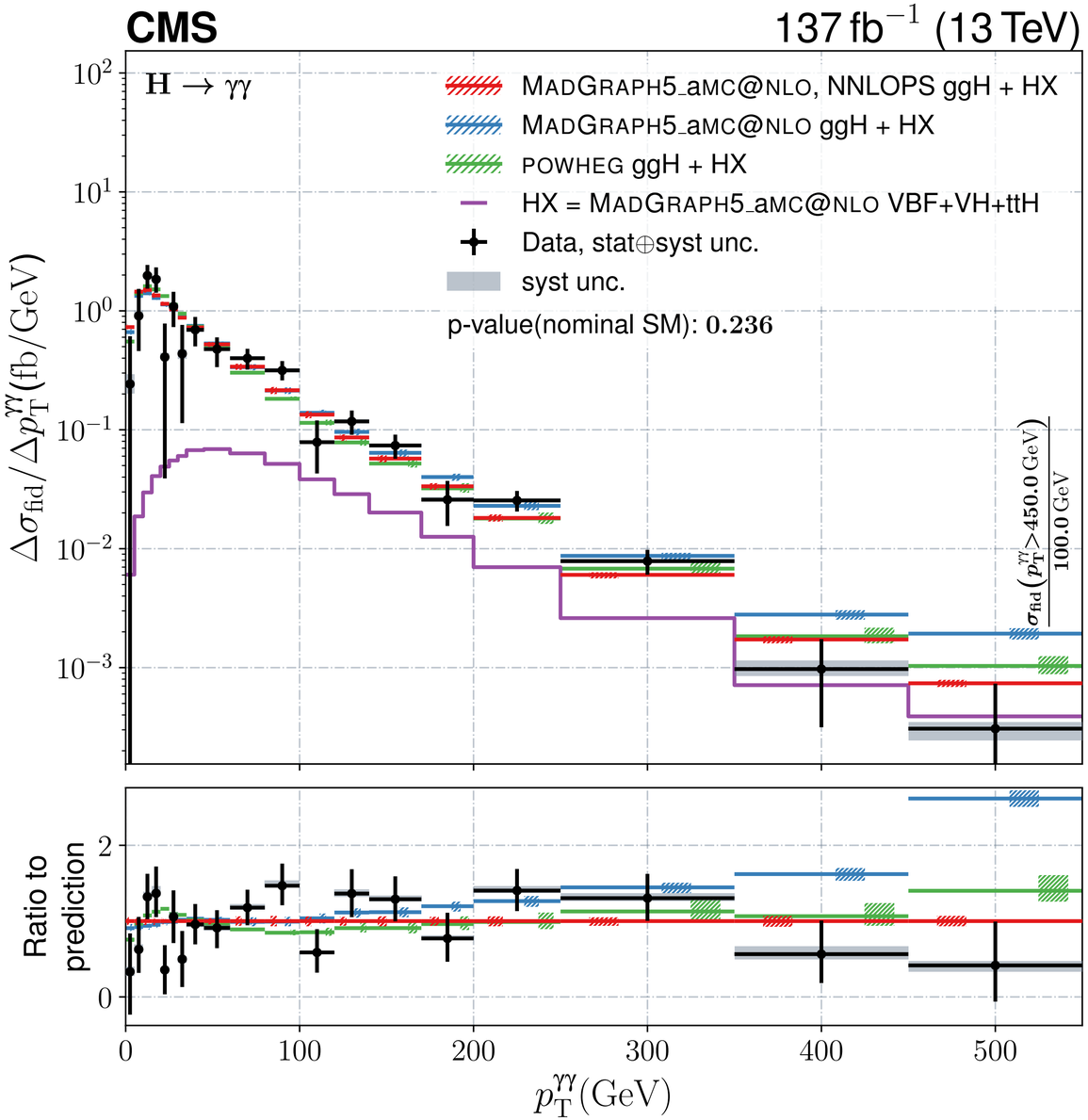
Differential Cross Section: Migrations

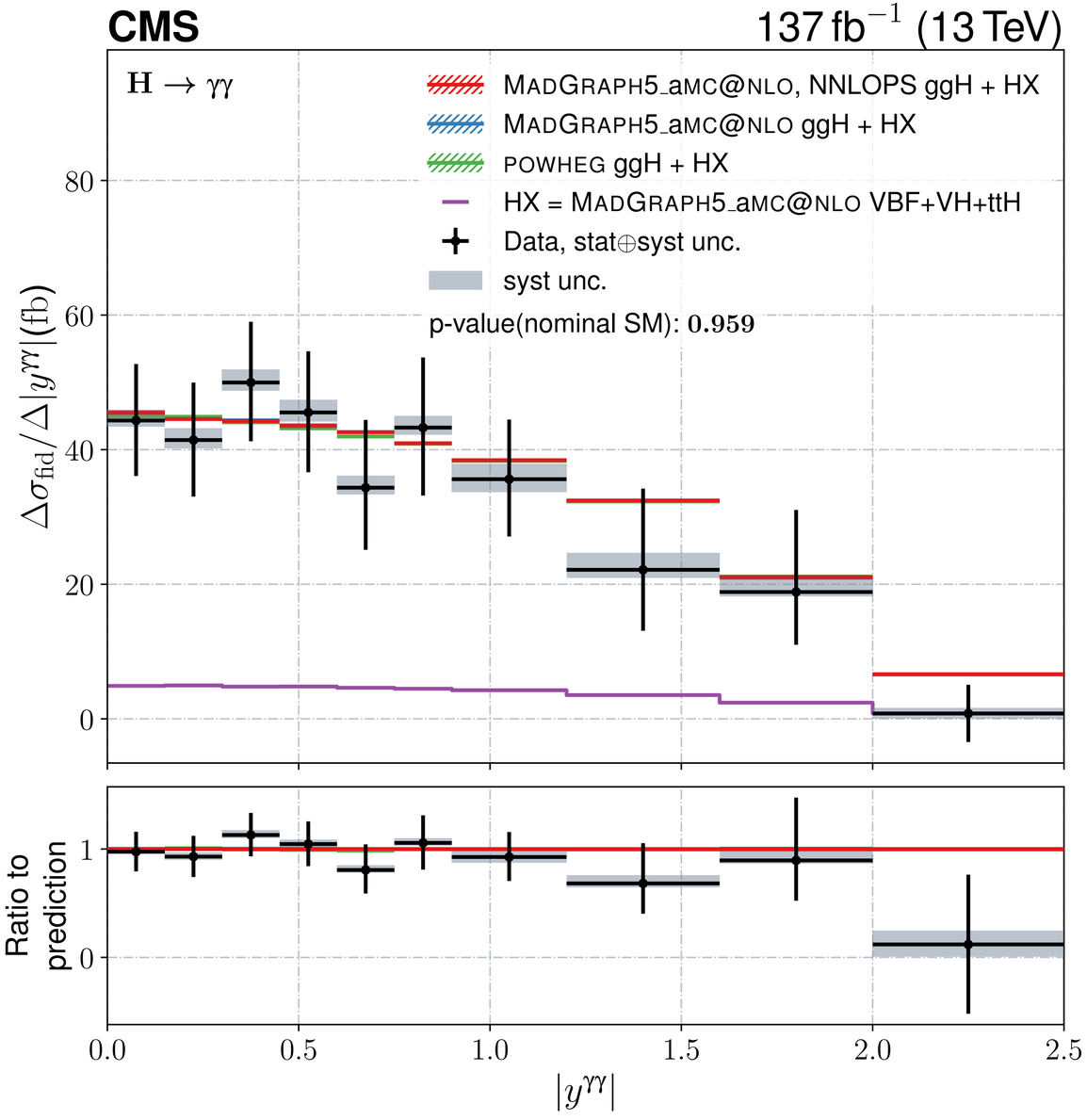
- As expected: small migrations for $p_T^{\gamma\gamma}$, stronger migrations for #jets



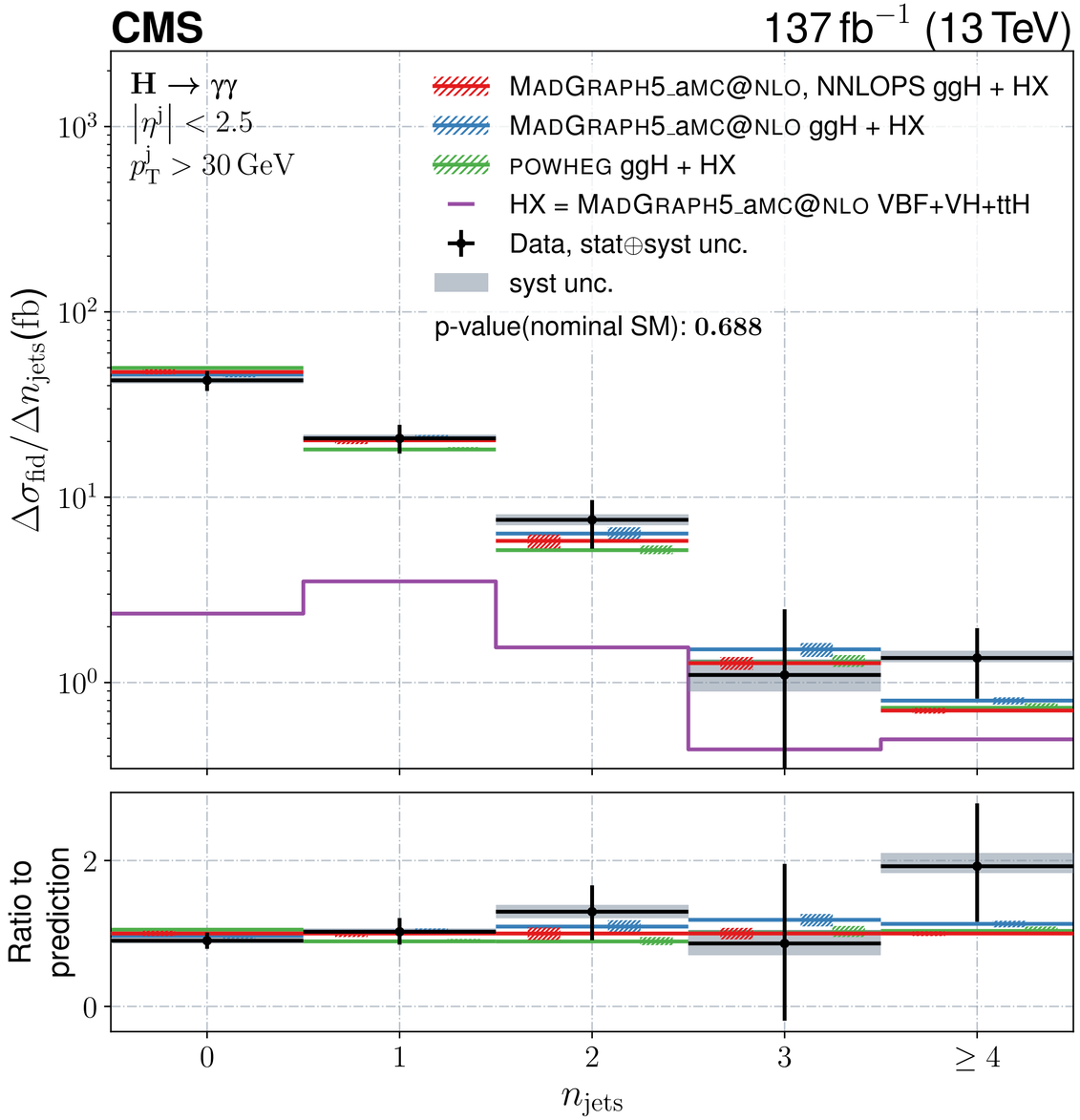


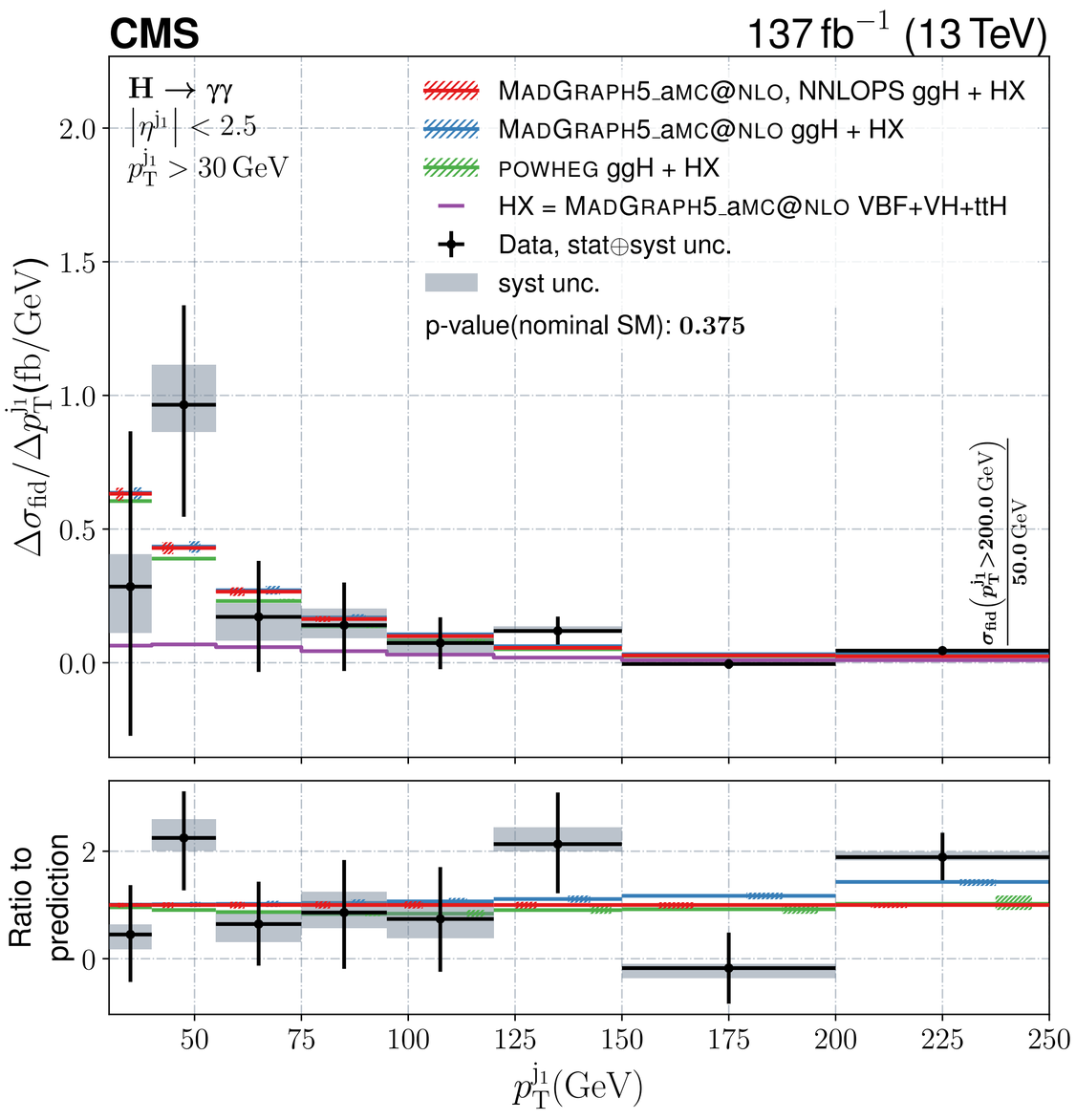
Differentials: Diphoton Kinematics



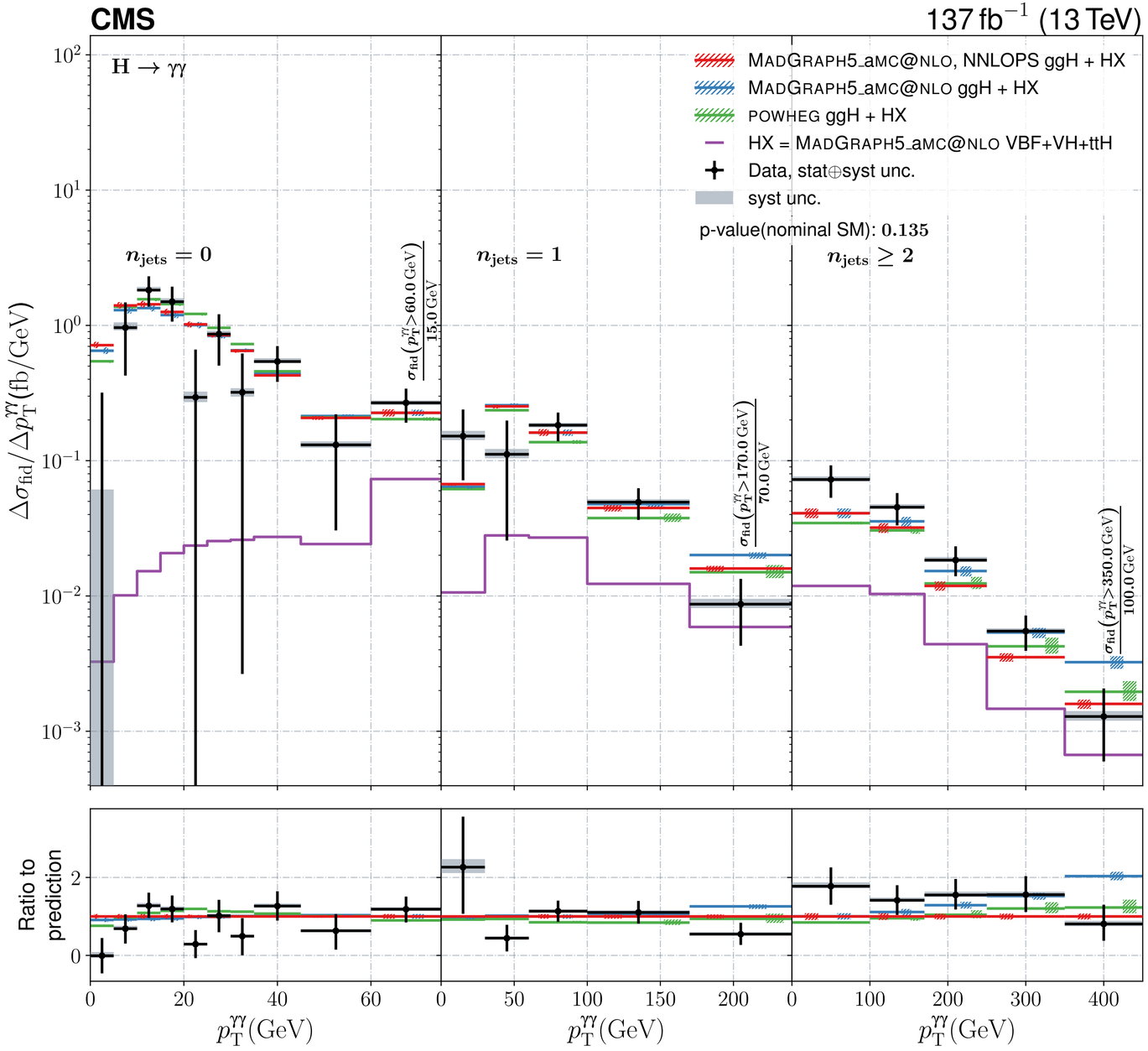


Differentials: Jets





Double Differential: #jets vs. $p_T^{\gamma\gamma}$



Summary

- Inclusive and fiducial cross sections with full Run-2 data

- Model-independent strategy based on expected $m_{\gamma\gamma}$ resolution & photon ID
- Quantile morphing to improve modeling of these variables

- Uncertainty on fiducial inclusive cross section: 8%
- 1D and 2D differential cross sections

- *For more CMS Higgs differential measurements:*
  - *Alessandra Cappati's talk later this morning !*