Higgs boson cross section and coupling measurements at CMS

Jan Lukas Späh on behalf of the CMS Collaboration

III. Physikalisches Institut A, RWTH Aachen University

ICHEP 2024, 18th July 2024

Research Training Group
Physics of the Heaviest
Particles at the LHC

RWTH AACHEN UNIVERSITY

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Institute III A

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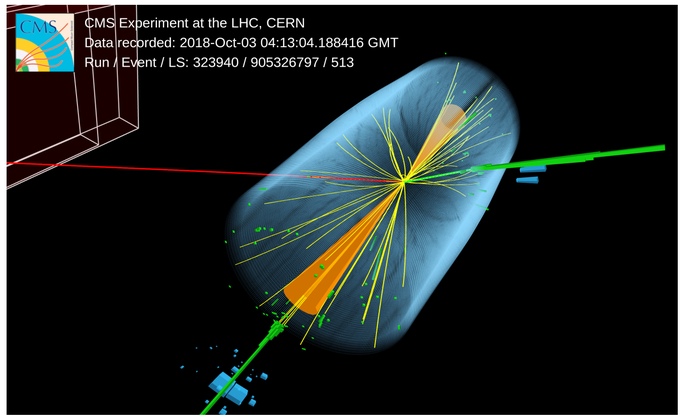
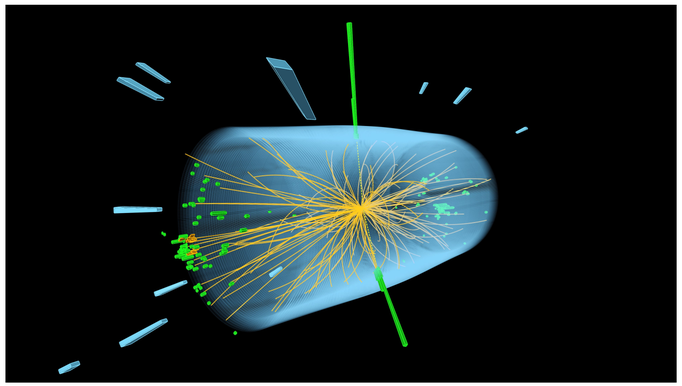
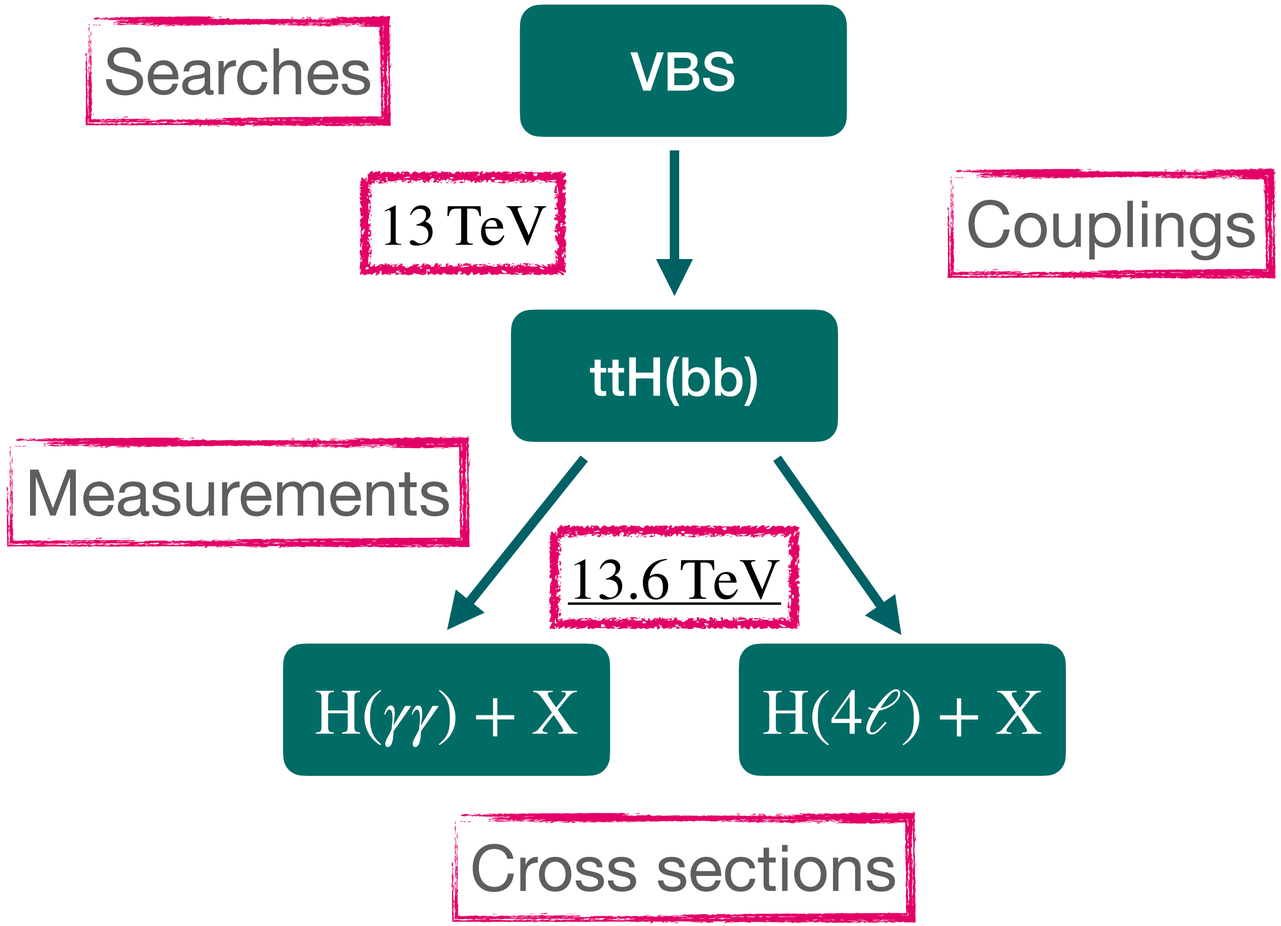
Overview



VBS WW candidate



$H \rightarrow \gamma\gamma$ candidate

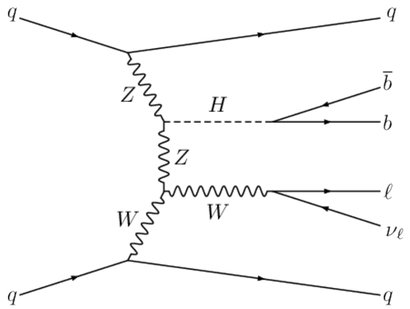


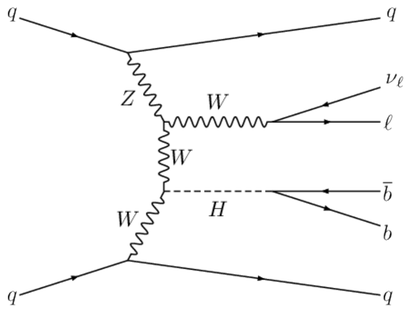
More information on differential results in Benedetta's talk at 10:45am

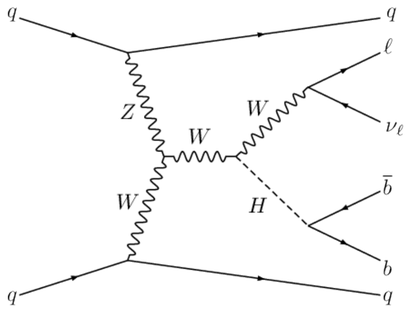
WH in vector-boson scattering

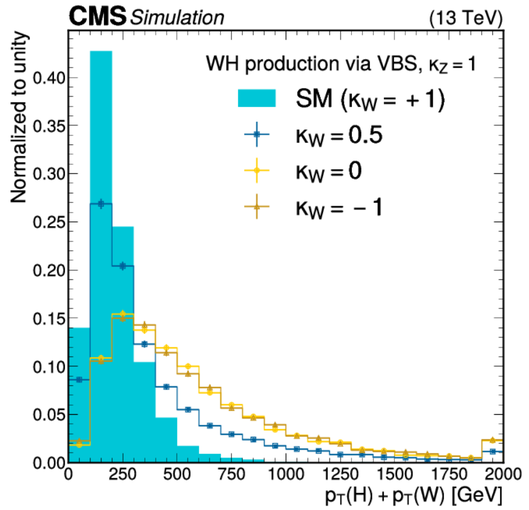
HIG-23-007
(sub. to Phys. Lett. B)

Recent

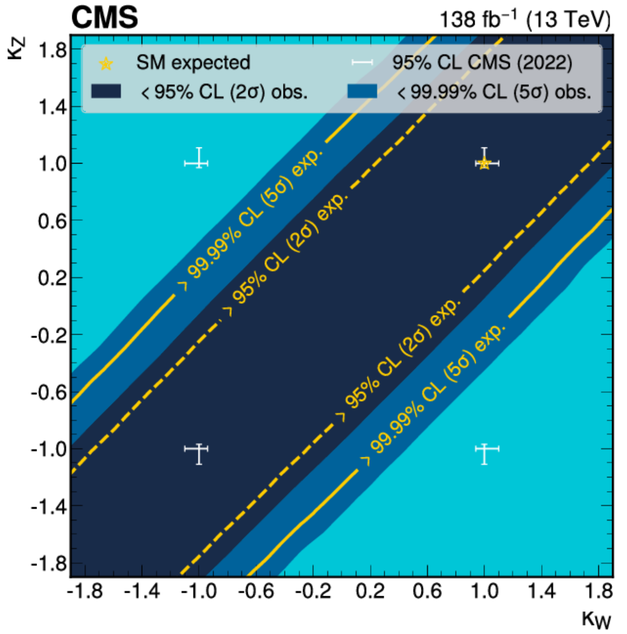








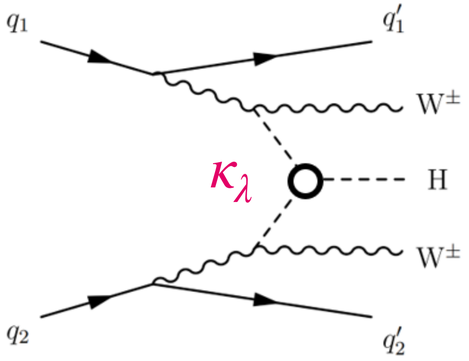
- Probe sign of $\lambda_{WZ} = \kappa_W/\kappa_Z$ with interference in WH VBS
- Deviation of couplings from SM prediction leads to significant Lorentz boost of W and Higgs bosons
- Observed (expected) upper limit of 14.3 (9.0) times SM
- All opposite sign scenarios with κ_W and κ_Z compatible with current measurements excluded with CL > 99.99%

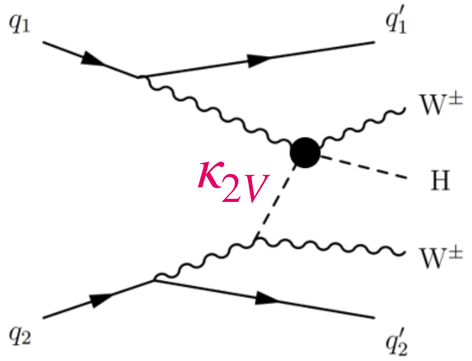


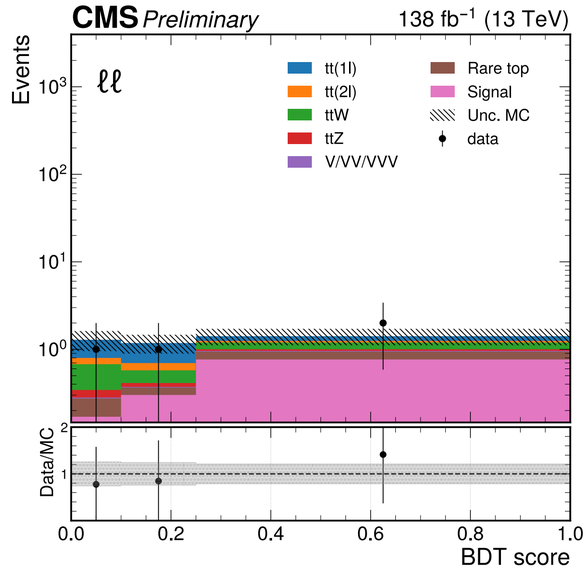
WWH in vector-boson scattering

CMS-PAS-HIG-24-001

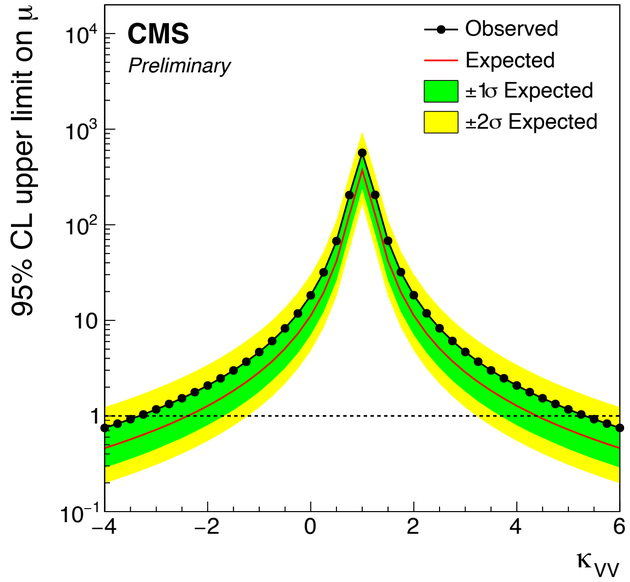
New for ICHEP







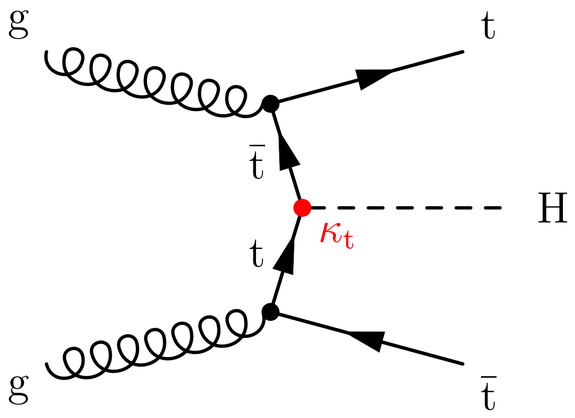
- Same-sign final state: $\mathrm{W^{\pm}W^{\pm}H + 2j}$
  → Target $\ell\ell/\ell\tau_\mathrm{h} + \mathrm{H(b\bar{b})}$ with large-radius jet
- BDT to suppress background from top processes
- Complementary constraint: $\kappa_{2V} \in [-3.3, 5.3]$ at 95% CL
- Discussed in more detail tomorrow morning by Andrea

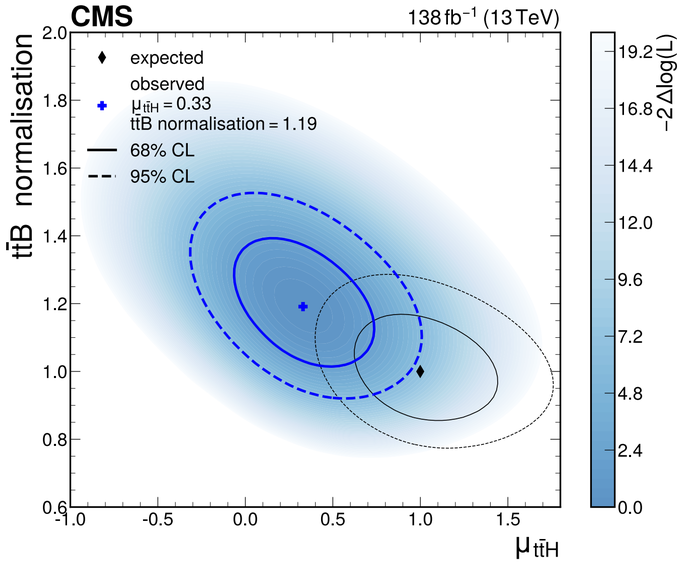


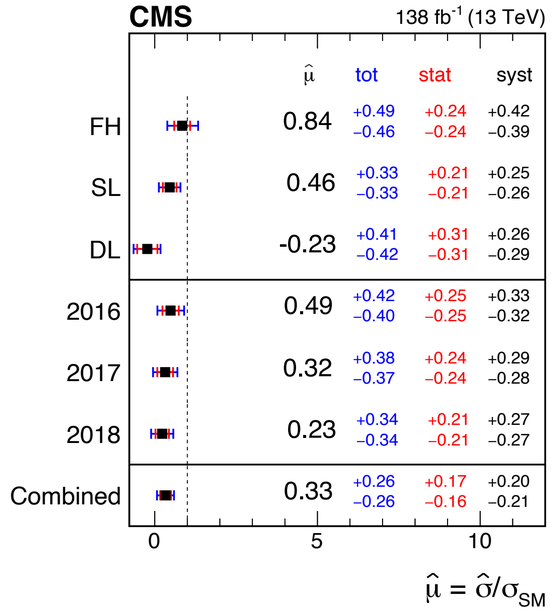
Measurement of $t\bar{t}H(b\bar{b})$

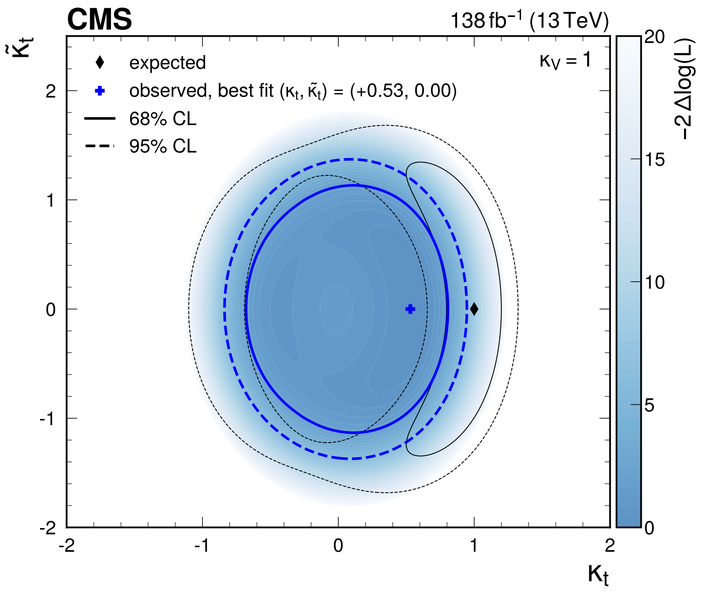
HIG-19-011
(sub. to JHEP)

- $t\bar{t}H$ offers direct access to coupling of top and Higgs
- Challenging measurement in particular due to irreducible background from $t\bar{t}b\bar{b}$
- Deficit of events is observed
  → Anticorrelation with $t\bar{t}B$
- Constraints on κ_t, $\tilde{\kappa}_t$, κ_V
- Limit of 14.6 times SM on tH





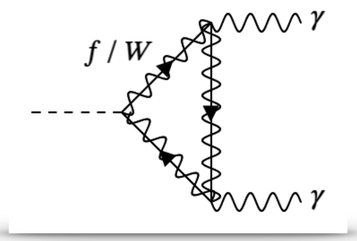




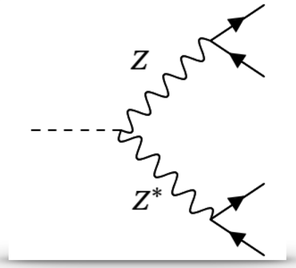
$\mathrm{H} \to \gamma\gamma$ and $\mathrm{H} \to \mathrm{ZZ}^* \to 4\ell$

JHEP 07 (2023) 091

JHEP 08 (2023) 040

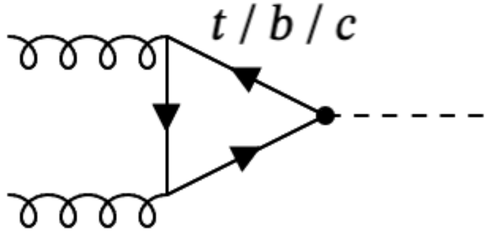


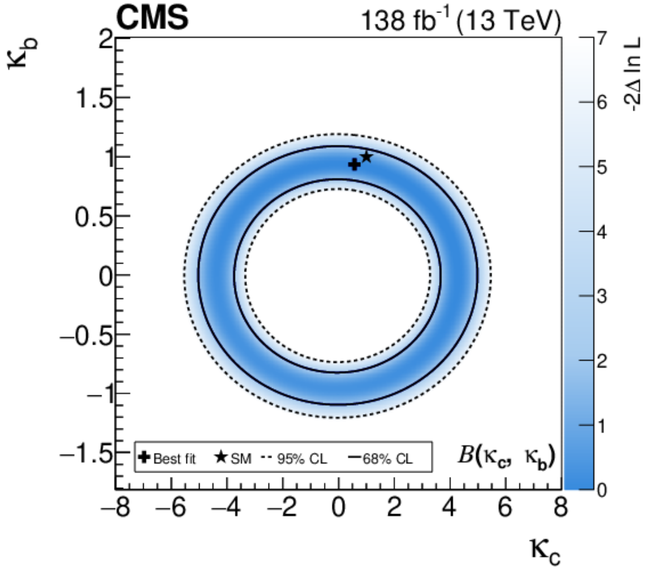
- Decay channels $\mathrm{H} \to \gamma\gamma$ and $\mathrm{H} \to \mathrm{ZZ}^* \to 4\ell$ well suited for inclusive and differential measurements
  → Fiducial: reduces extrapolation uncertainties
  → Analysis strategy reduces model-dependence



- Precision in σ_{fid}: $8\,\%$ in $\gamma\gamma$, $9.5\,\%$ in 4ℓ

- Comprehensive set of differential measurements
  → Allows robust coupling measurements
  → $p_{\mathrm{T}}^{\mathrm{H}}$ distribution used to constrain κ_{b} and κ_{c}



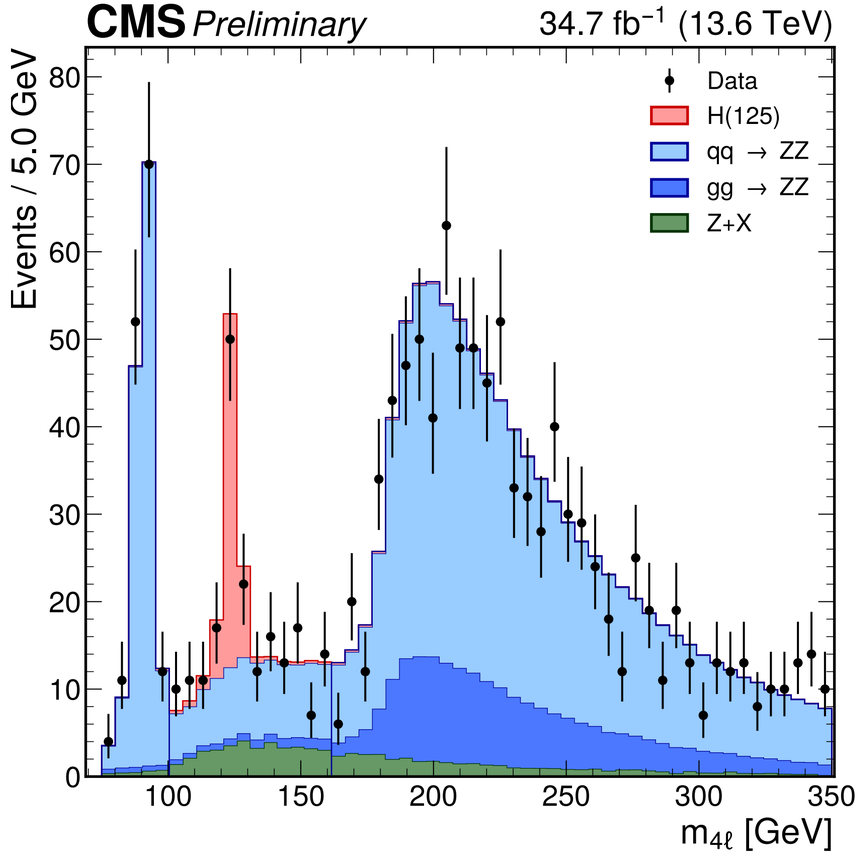


$H \to 4\ell$ at 13.6 TeV: Results

CMS-PAS-HIG-24-013

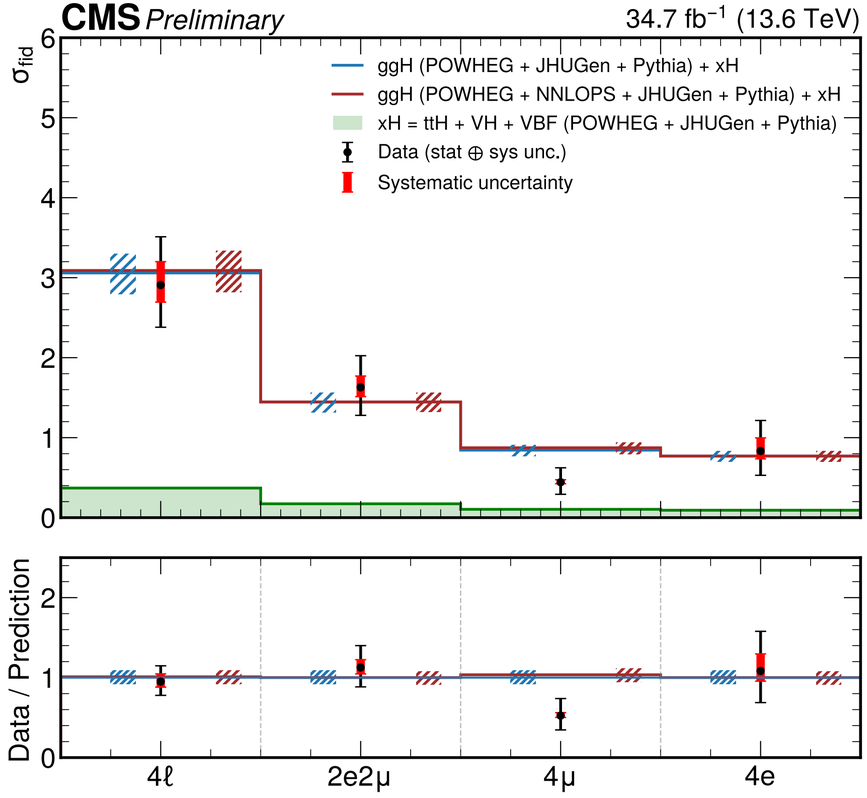
New for ICHEP

- $H \to 4\ell$ well-suited for measurement with 2022 dataset: Clean signal
  → Unbinned maximum-likelihood fit
- Overall, same strategy as in Run 2 measurement
- $\sigma_{\text{fid}} = 2.94^{+0.53}_{-0.49}\ (\text{stat.})^{+0.29}_{-0.22}\ (\text{syst.})\ \text{fb}$
  → Most relevant systematic: Electron efficiency
- Excellent validation of muon and electron performance of CMS in Run 3



$H \to 4\ell$ at 13.6 TeV: Performance

- Trigger efficiency larger than $99\,\%$ for events that satisfy selection
- Dedicated BDT for electron identification. For $5\ \text{GeV} < p_\text{T} < 10\ \text{GeV}$:
  $\to\ \varepsilon_\text{signal} \approx 80\,\%$, $\varepsilon_\text{bkg} \approx 4\,\%$ (barrel)
- Also use "tracker muons": inner tracks matched to muon detector segments
- Measurements per lepton category consistent with each other
- Systematic uncertainty smallest for 4μ final state (benefit from J/ψ)

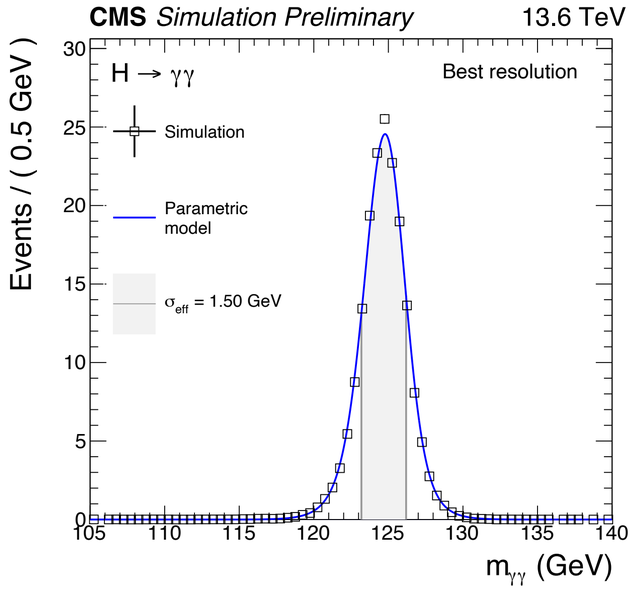


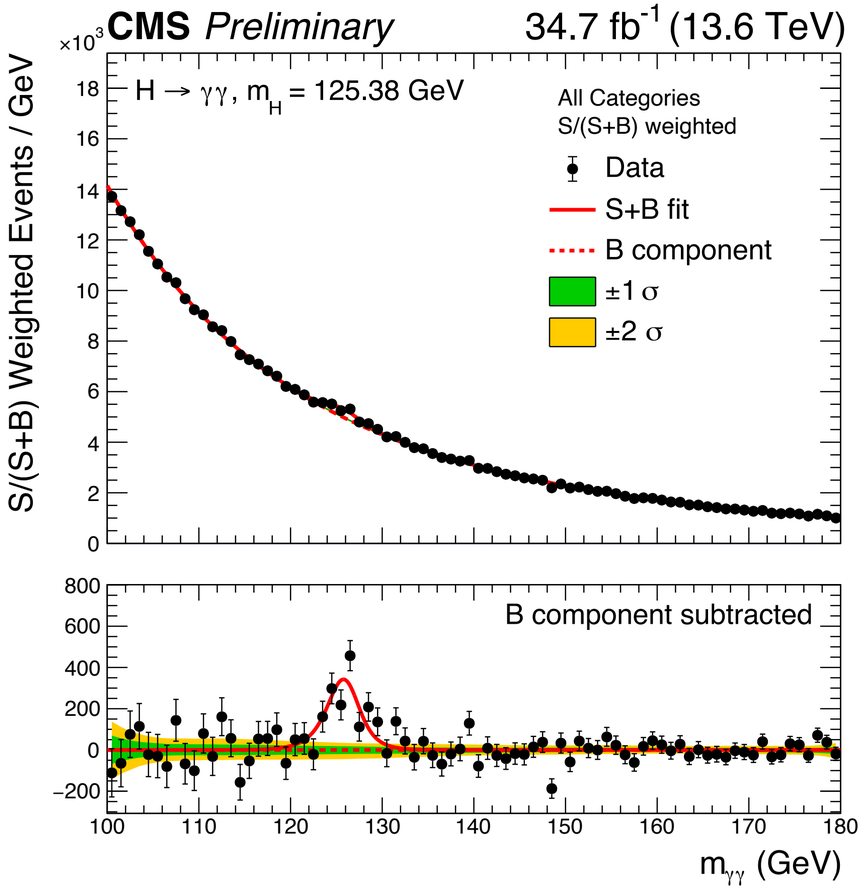
$H \to \gamma\gamma$ at 13.6 TeV: Overview

CMS-PAS-HIG-23-014

New for ICHEP

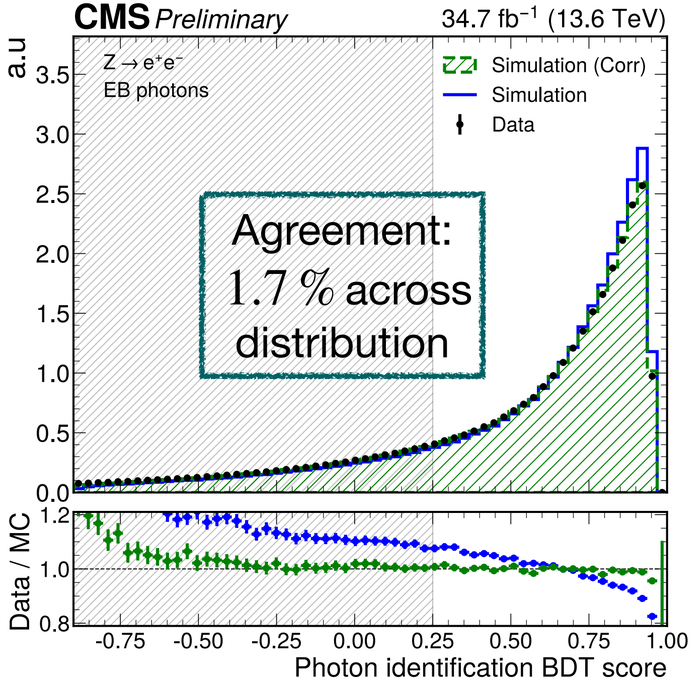
- Overall, same strategy as in Run 2
  → Suppression of non-prompt photons with BDT
  → In contrast to $H \to 4\ell$, S/B is lower
  → However, excellent data-driven background estimation under the peak
- Categorisation based on mass resolution
- New columnar analysis framework, processing lightweight datasets

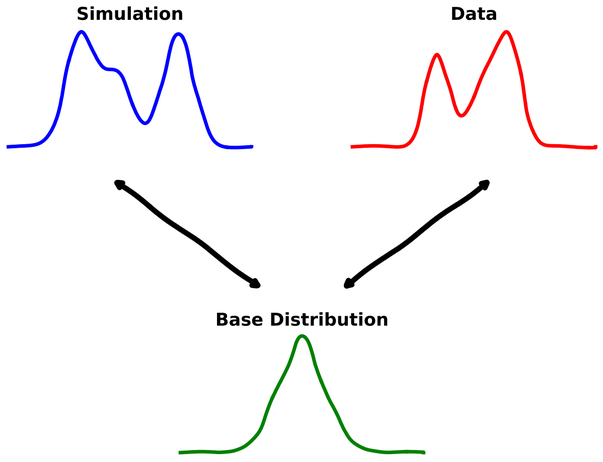


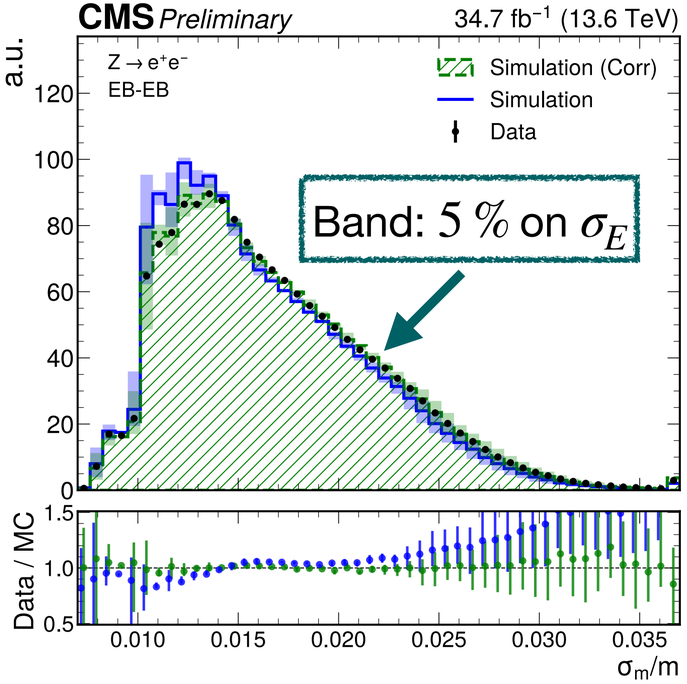


$H \to \gamma\gamma$ at 13.6 TeV: Corrections to simulation

- Disagreement in input variables for photon ID BDT propagates to output score
- Corrected with single normalising flow (2403.18582) conditioned on kinematics
  → Trained using $Z \to ee$ probes, simplified compared to Run 2 BDT approach
- Excellent agreement after correction in ID score and also mass resolution



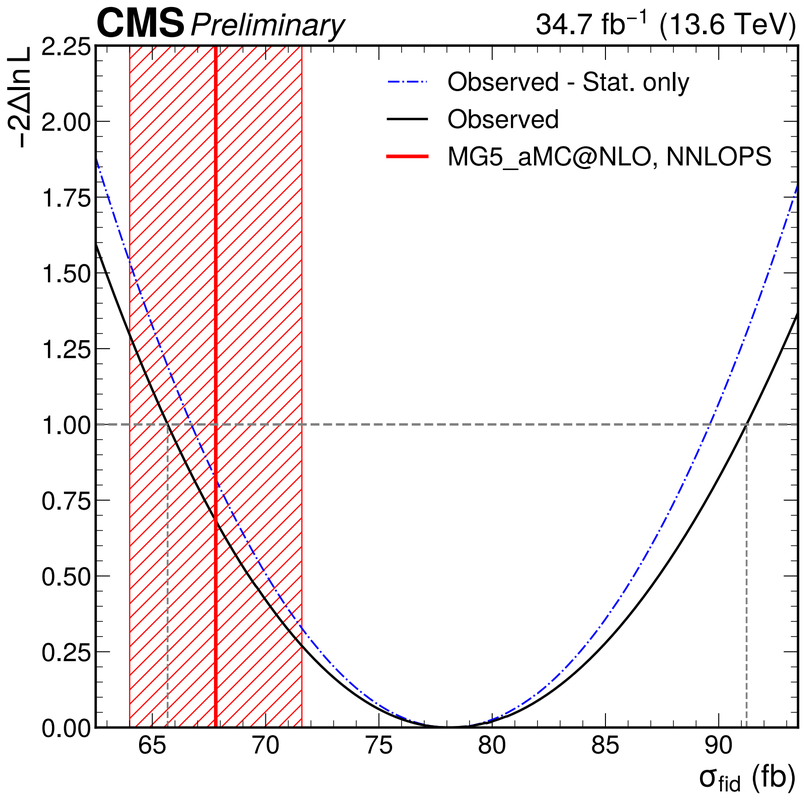




$H \to \gamma\gamma$ at 13.6 TeV: Inclusive cross section

- Apply fiducial requirement on geometric mean: $\sqrt{p_T^{\gamma_1} p_T^{\gamma_2} / m_{\gamma\gamma}} > 1/3$
  → Improved perturbative convergence in phase space (2106.08329)
- $\sigma_{fid} = 78 \pm 11\ (stat.)^{+6}_{-5}\ (syst.)\ fb = 78^{+13}_{-12}\ fb$
- Systematics dominated by photon scale/resolution

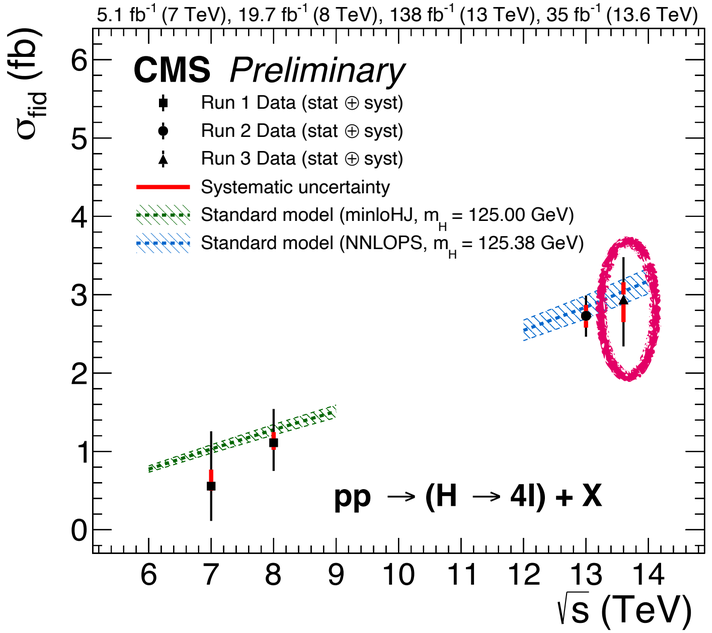
Systematic uncertainty	Magnitude
Photon energy scale and resolution group	$+5.8\%/-4.9\%$
Category migration from energy resolution	$+3.5\%/-3.9\%$
Integrated luminosity	$\pm 1.4\%$
Photon preselection efficiency	$\pm 1.4\%$
Non-linearity	$+0.8\%/-1.6\%$
Photon identification efficiency	$\pm 1.0\%$
Pileup reweighting	$\pm 0.8\%$

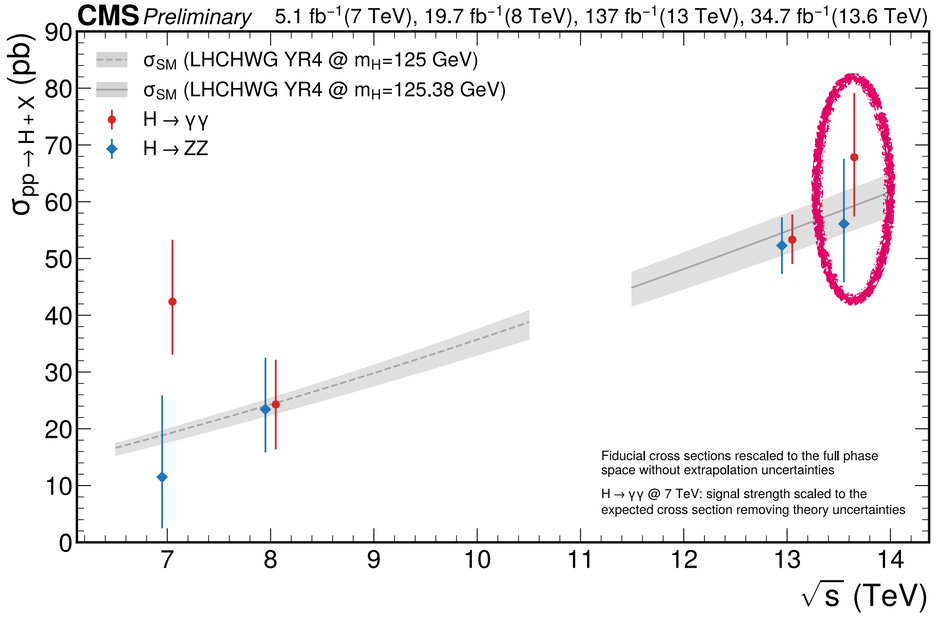


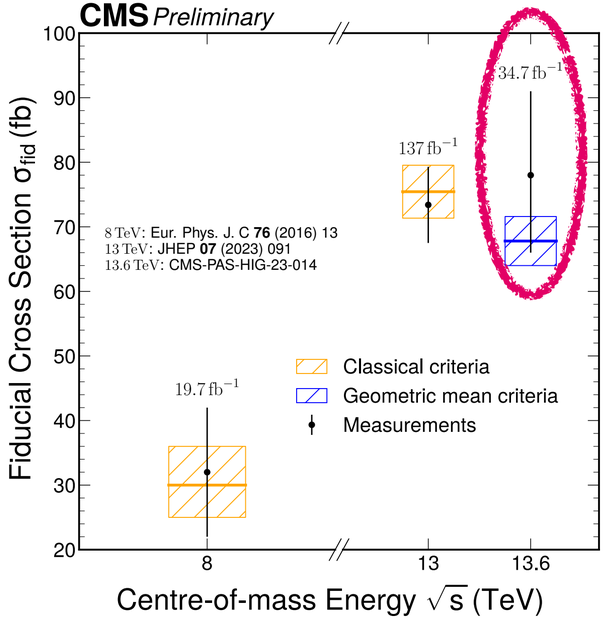
Summary

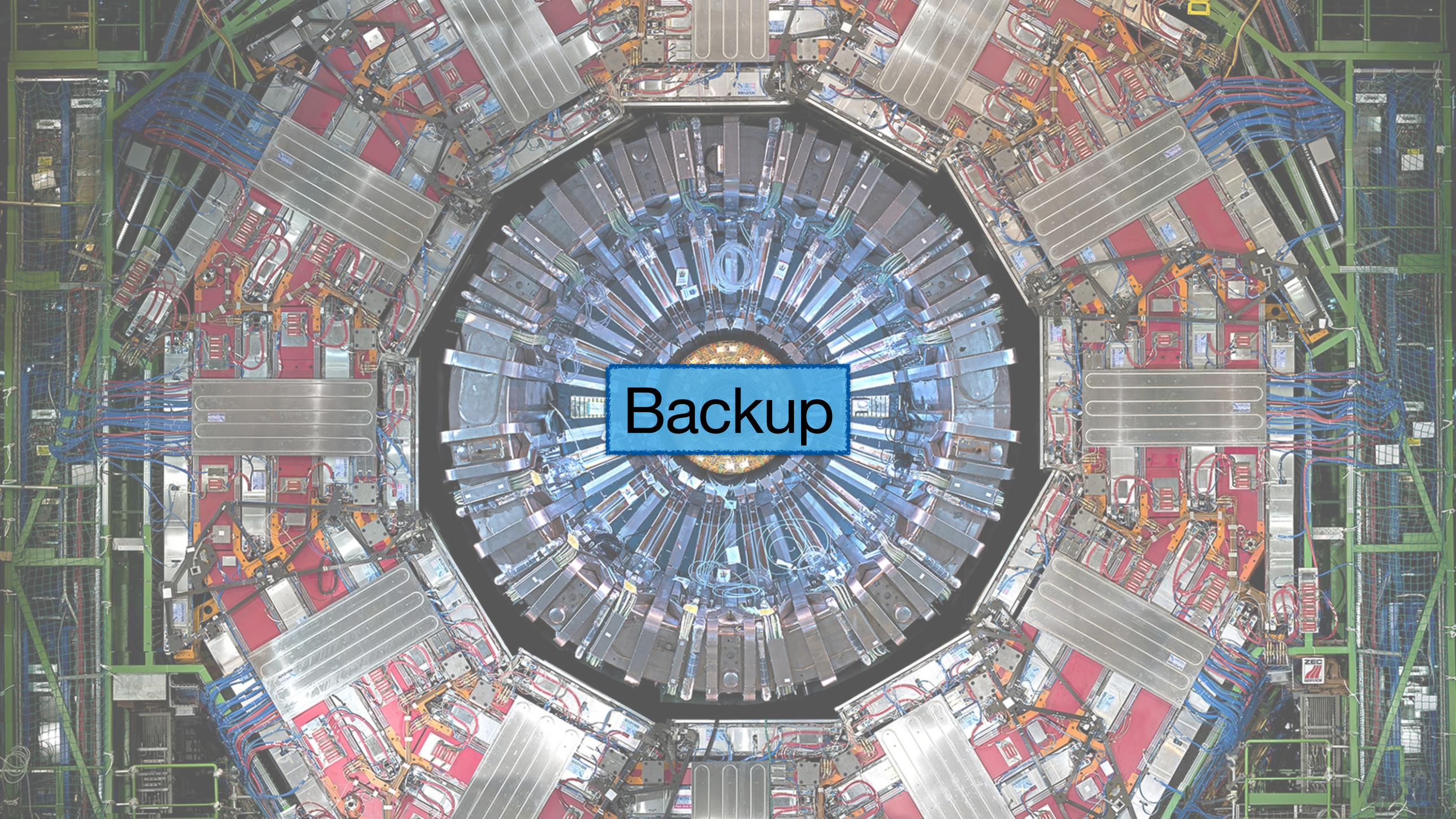
- Wealth of results provided with Run 2 dataset
  → Showcased two VBS searches and $\mathrm{t\bar{t}H}$ measurement

- Presented two new measurements at $13.6\,\mathrm{TeV}$
  → Inclusive/differential measurements in $\mathrm{H} \to \gamma\gamma$ and $\mathrm{H} \to 4\ell$
  → Using $\sim 35\,\mathrm{fb}^{-1}$, measurements statistically limited



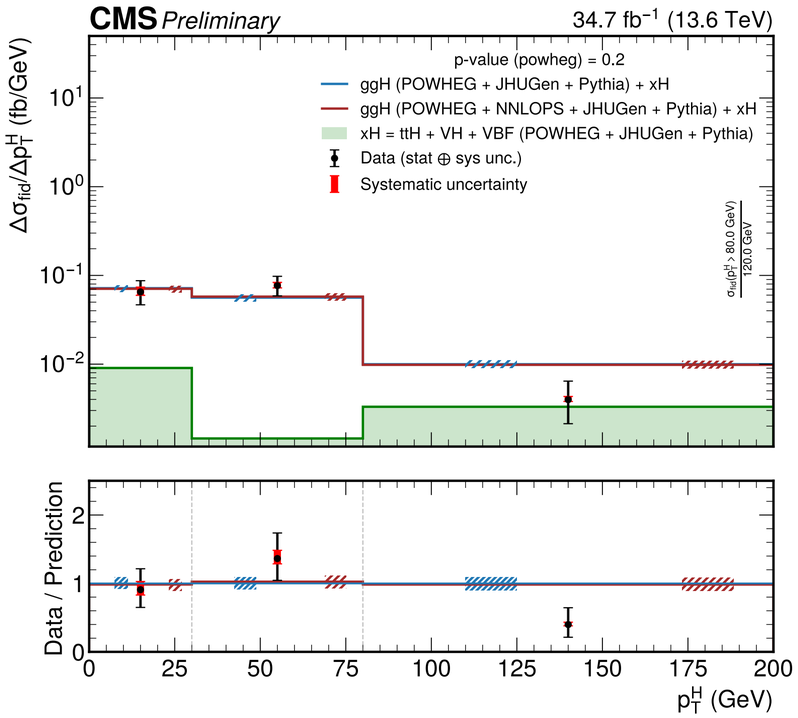


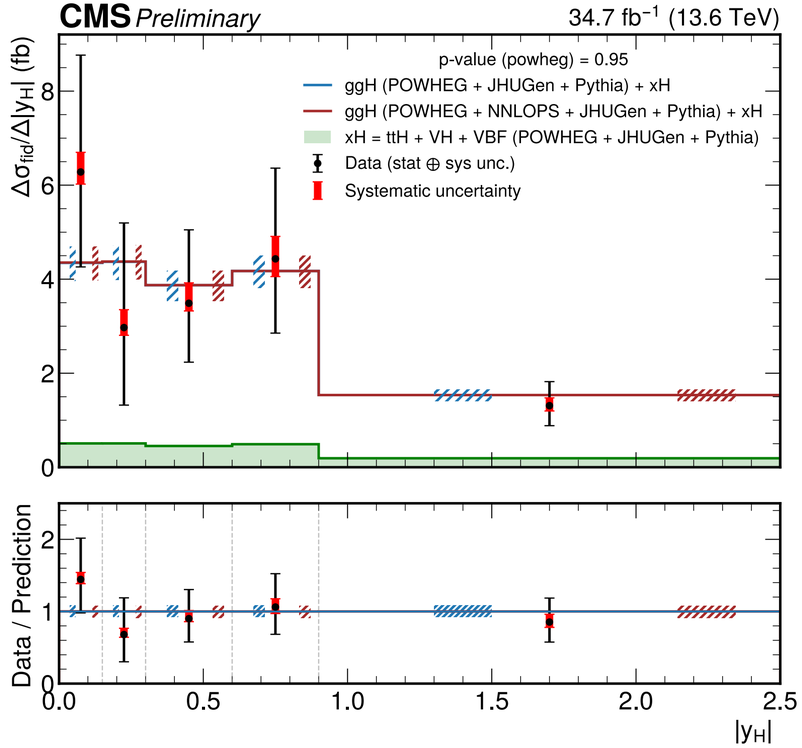



Backup

$H \to 4\ell$ at 13.6 TeV: Results

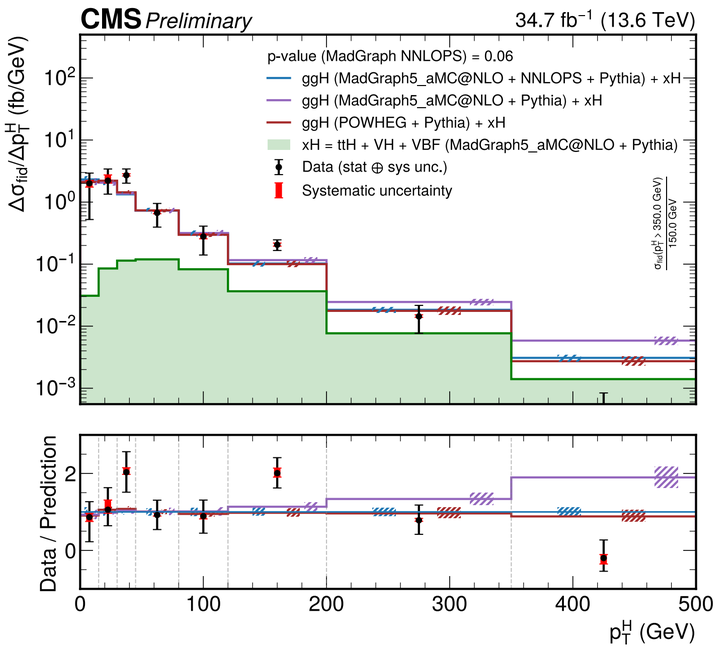
- Measured cross section in coarse bins of $p_{\mathrm{T}}^{\mathrm{H}}$ and $|y_{\mathrm{H}}|$
- Differential measurements in good agreement with SM predictions

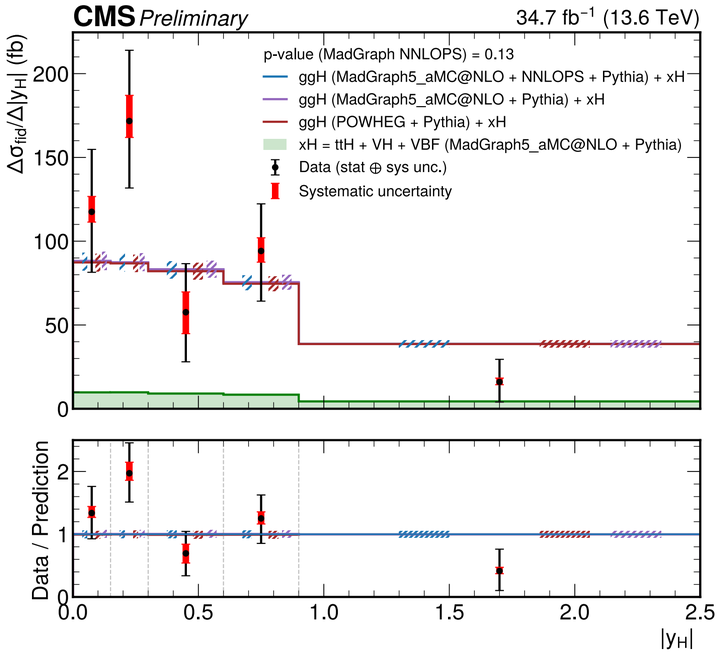


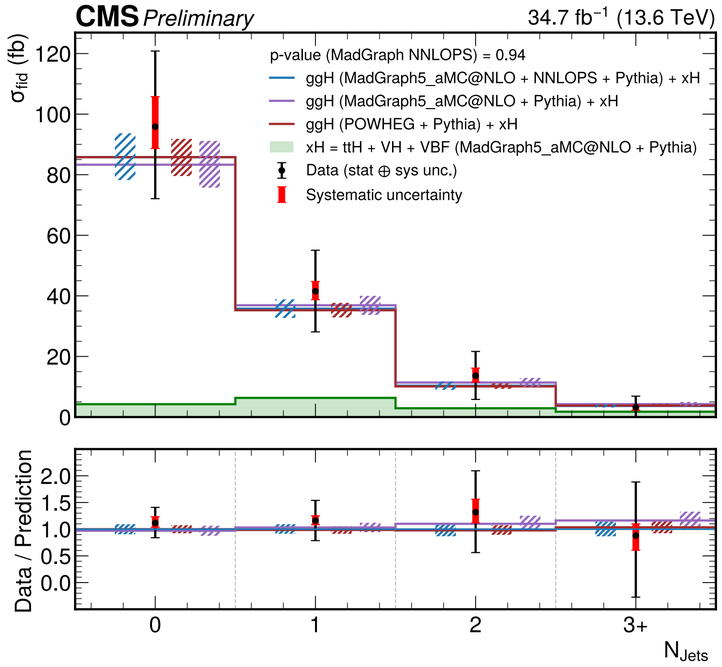


$H \to \gamma\gamma$ at 13.6 TeV: Differential cross sections

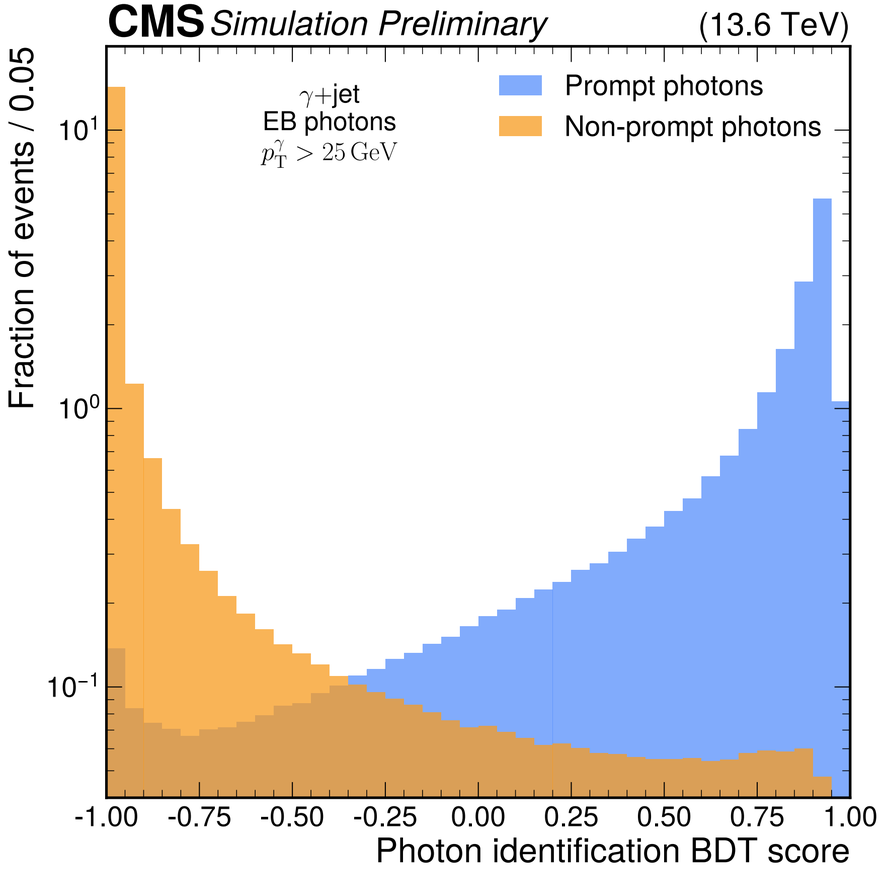
- Differential cross sections measured for p_T^H, $|y^H|$, and N_{jets}
- Agreement within uncertainties with the MadGraph+NNLOPS prediction
- Statistically limited, will benefit from full Run 3 dataset
  → More granular binning

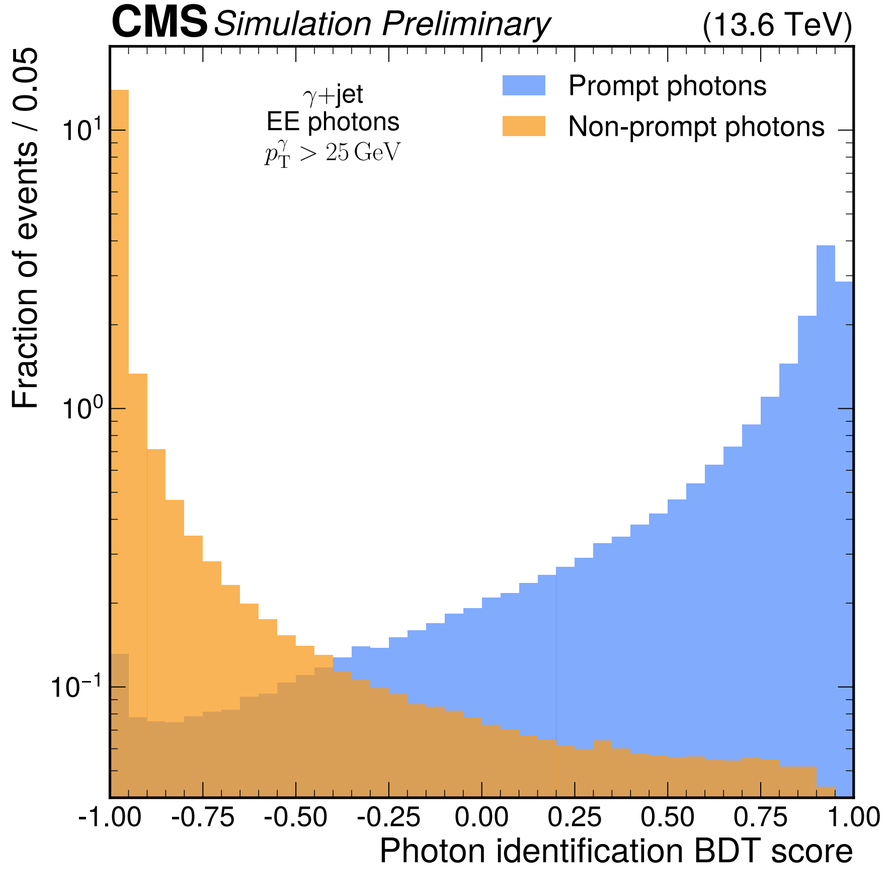




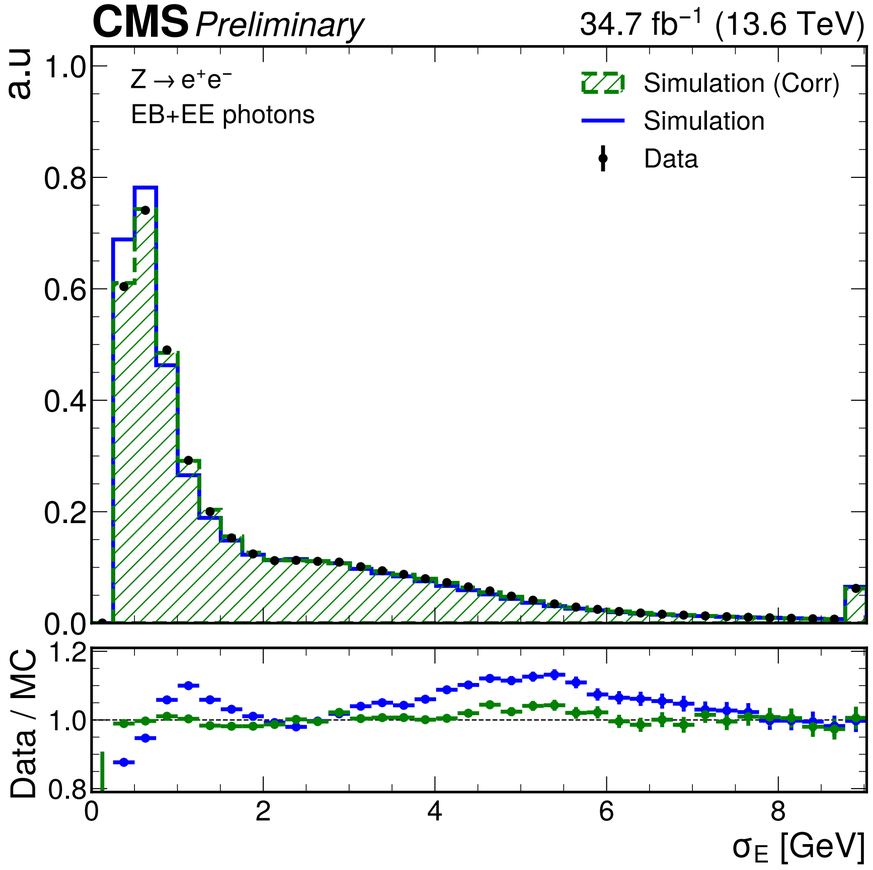


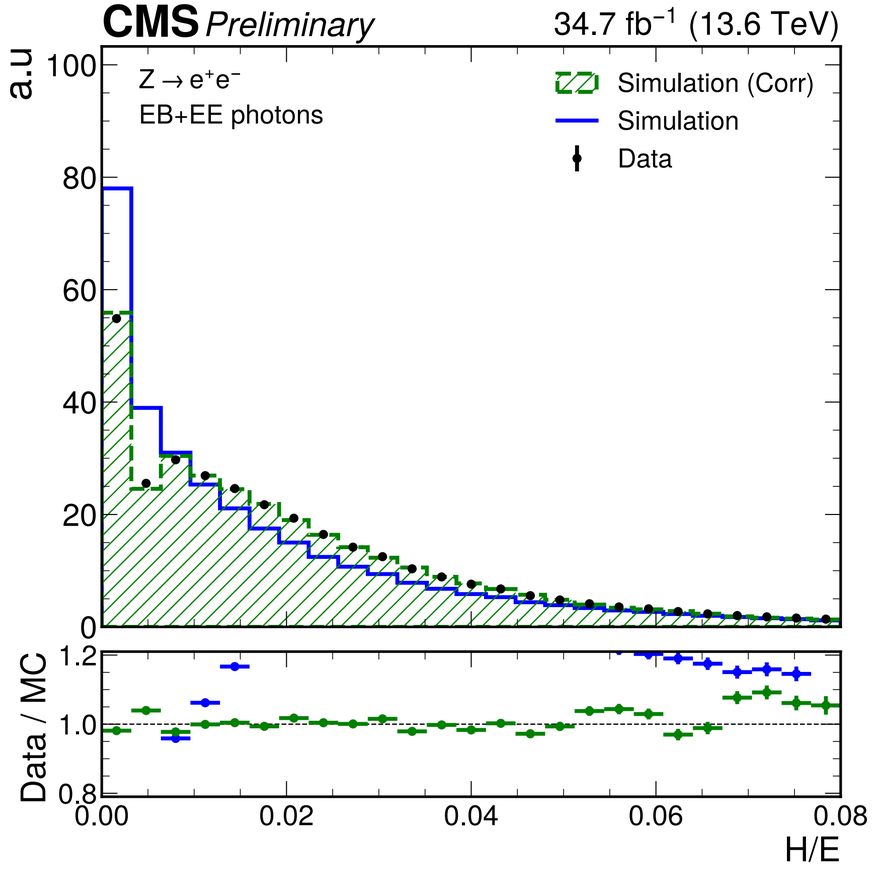
$H \to \gamma\gamma$ at 13.6 TeV: Photon ID score in simulation



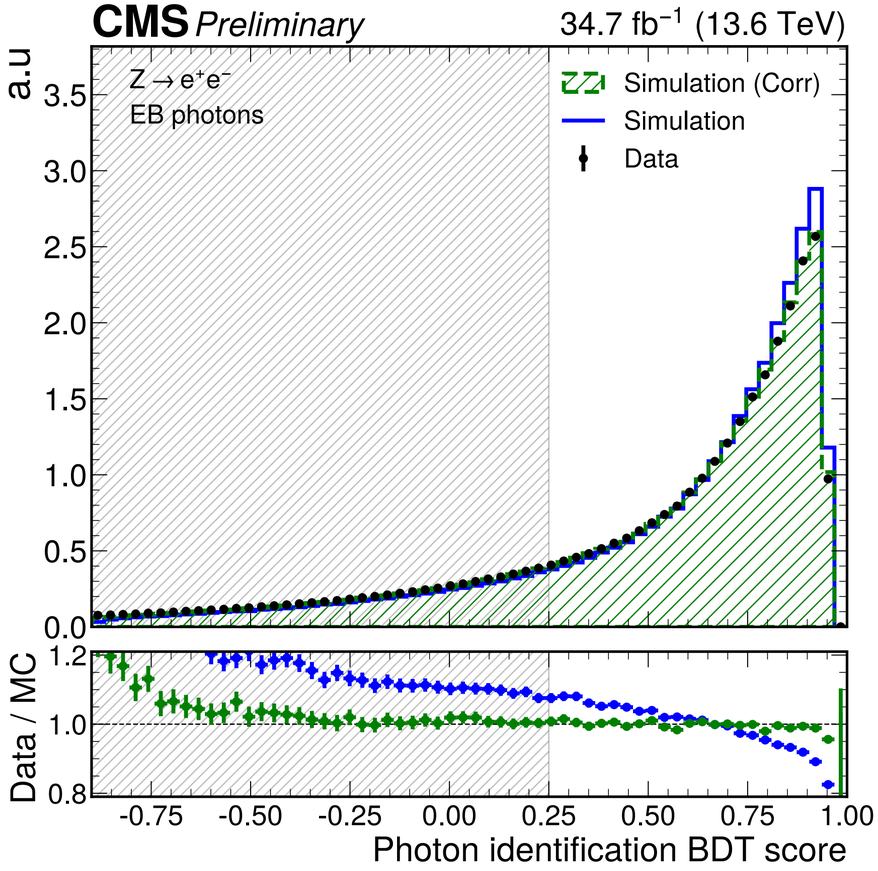


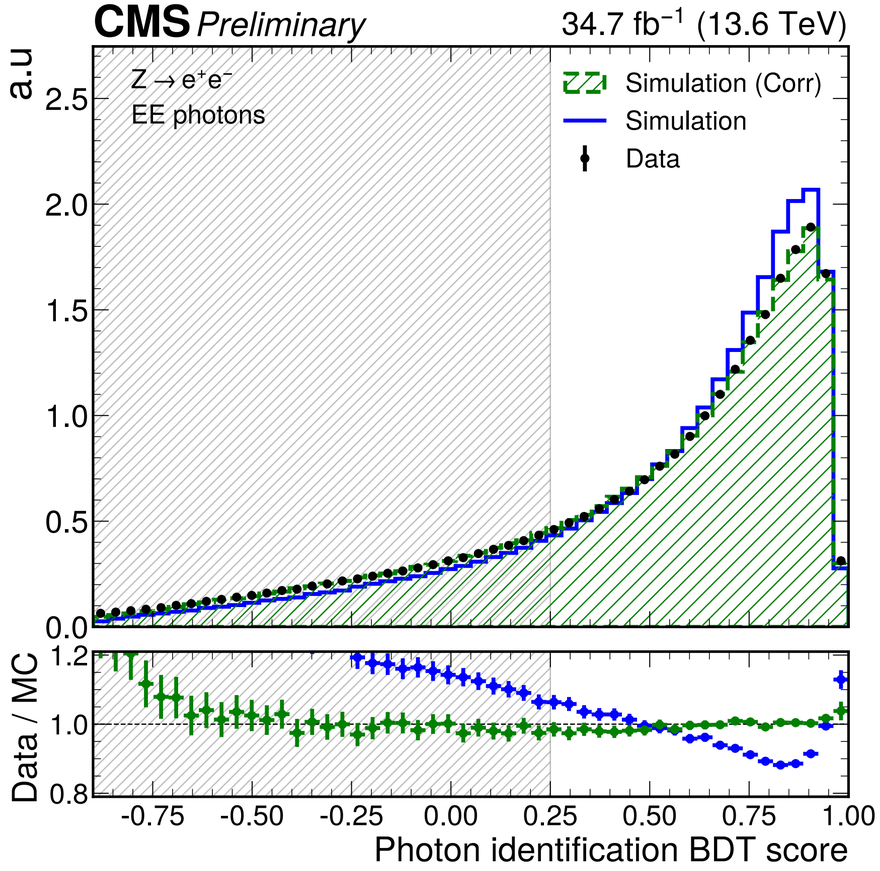
H → $\gamma\gamma$ at 13.6 TeV: σ_E, H/E in Z → ee



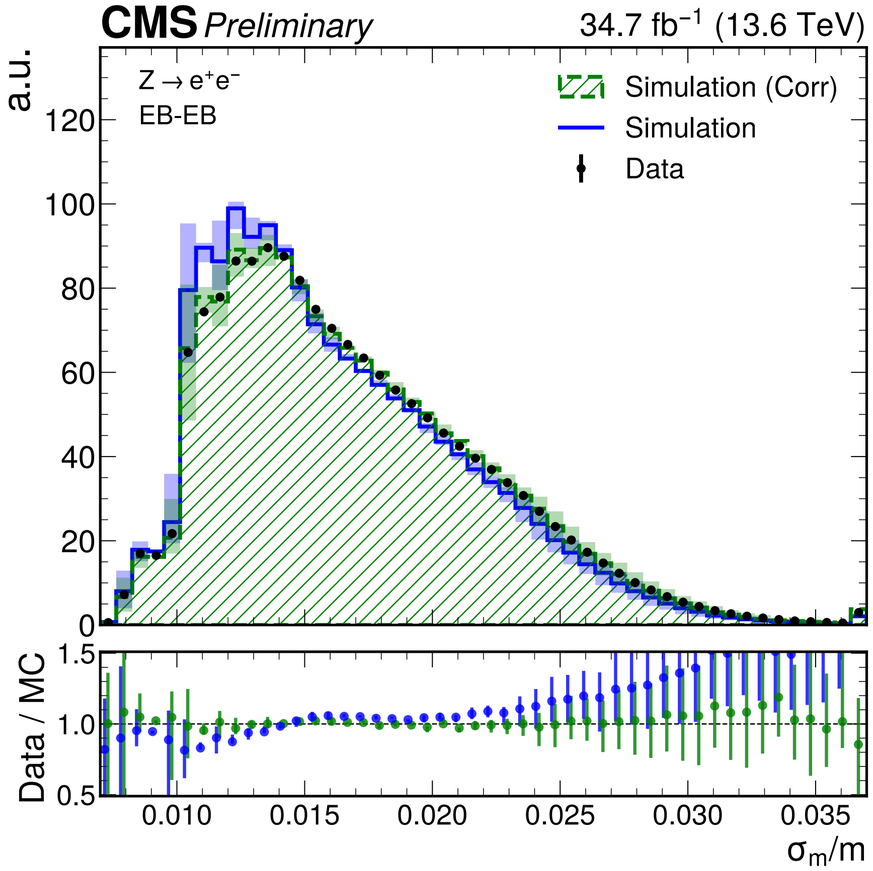


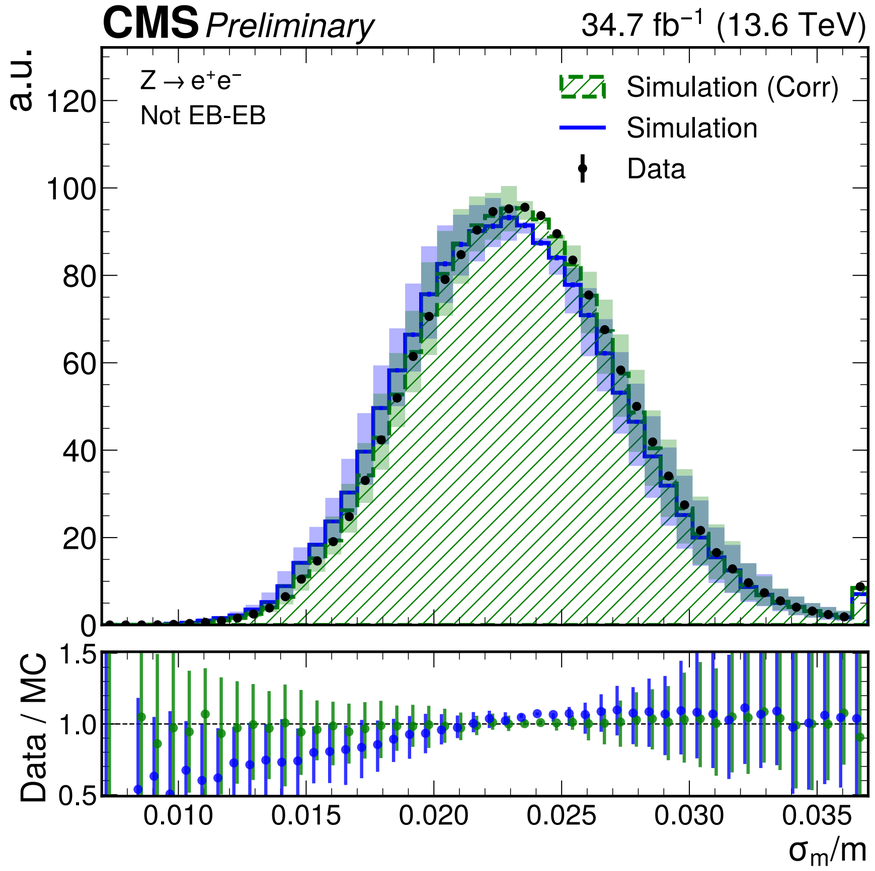
$H \to \gamma\gamma$ at 13.6 TeV: Photon ID score in $Z \to ee$





$H \to \gamma\gamma$ at 13.6 TeV: Mass resolution in $Z \to ee$





H → $\gamma\gamma$ at 13.6 TeV: σ_E, H/E in Z → $\mu\mu\gamma$

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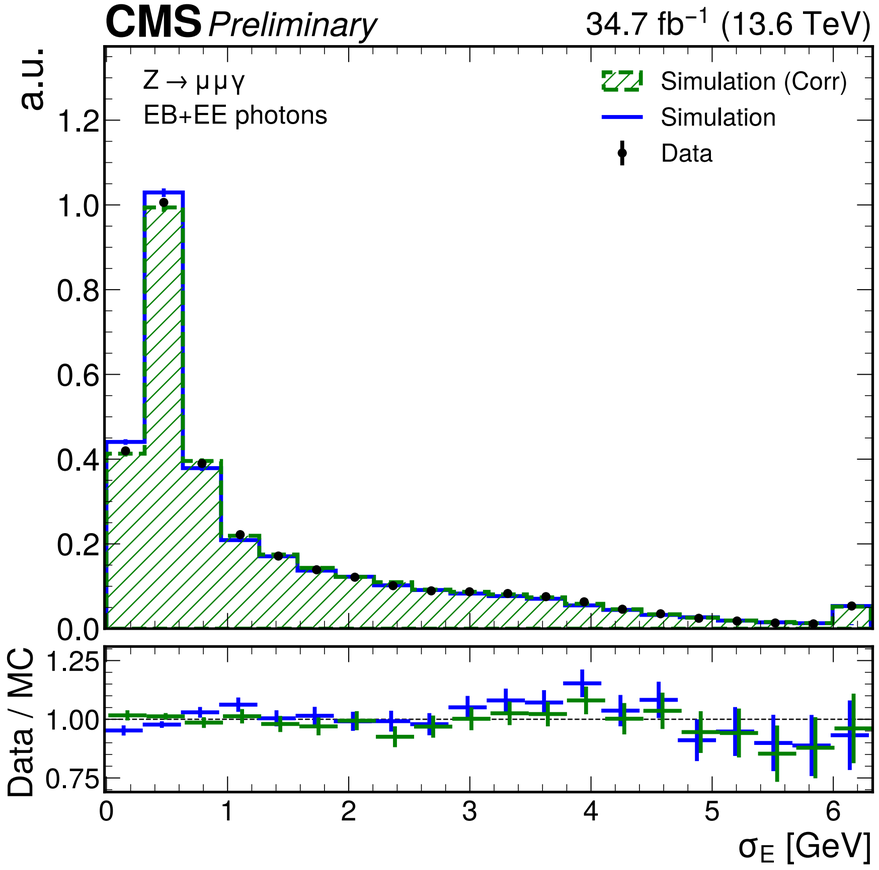

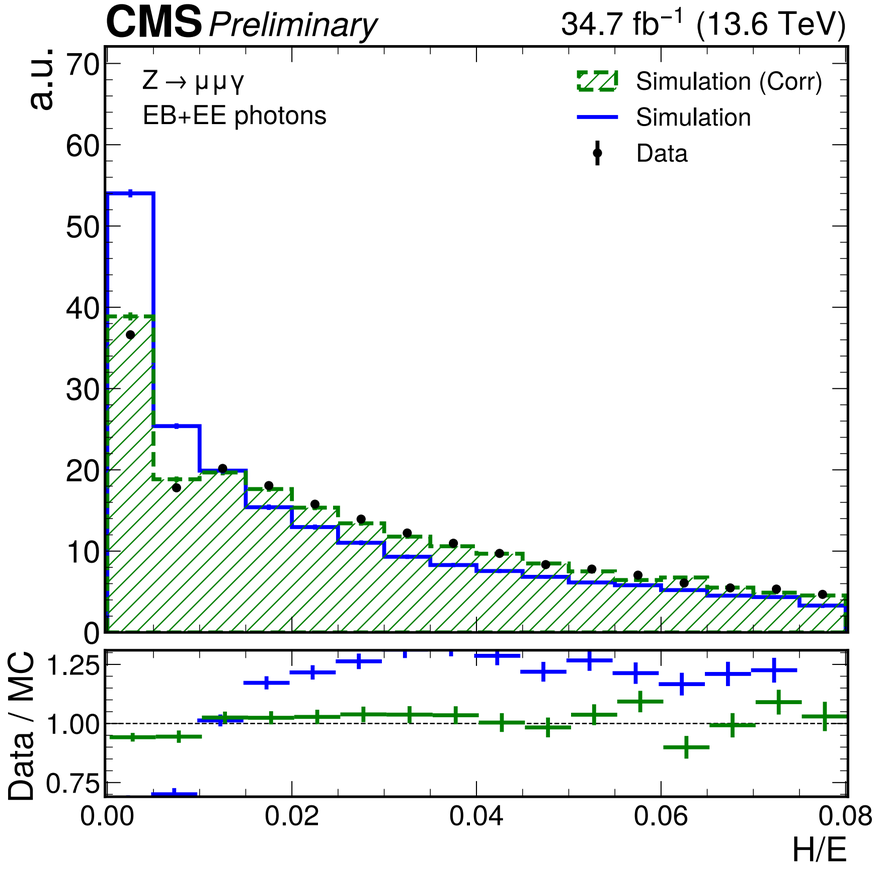

$H \to \gamma\gamma$ at 13.6 TeV: Photon ID score in $Z \to \mu\mu\gamma$

Points in ratio panel offset for visibility only