Measurements of inclusive and differential Higgs boson production cross sections at 13.6TeV in the $H \to \gamma\gamma$ decay channel

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Motivation

- Determine the Higgs properties and test the Higgs compatibility with the standard model (SM) predictions.
- Measure the fiducial cross sections of Higgs boson production.
- First $H \to \gamma\gamma$ result with Run3 data @ $13.6\mathrm{TeV}$ in CMS.

Samples

- Signal modelling: ggH, VBF, VH and ttH.
- Three mass points are used: $120\mathrm{GeV}$, $125\mathrm{GeV}$, $130\mathrm{GeV}$
- Optimisation of categories: diphoton and γ + jets.
- Corrections: Drell-Yan sample.
- Data: 2022 dataset$=34.7/\mathrm{fb}$.

Photon selection and identification

- Preselections:
  - Requirements on p_T^γ, η_{SC}, photon ID, and shower shape and isolation observables to match the HLT requirements.
- ID:
  - Optimised cut at MVA score > 0.25.

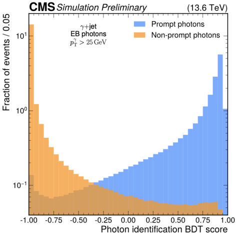


Fig. 1: Normalised distributions of the photon identification BDT scores for Barrel(left) and Endcap(right)

Photon scale and smearing corrections

- Residual shift in the photon energy scale between data and MC.
- $Z \rightarrow ee$ electrons are reconstructed as photons.

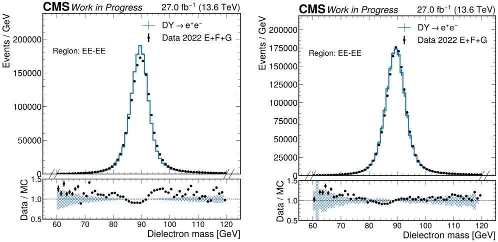


Fig. 2: EGamma Scale and Smearing corrections: before(left) and after(right)

Event categorisation

- Three categories are defined according to σ_m/m to enhance S/B. (With the MVA ID)

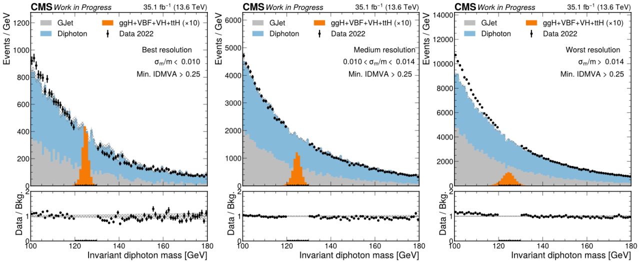


Fig. 3: Event categorisation

Correcting photon variables

- Photon mismodelling in the simulation is important.
- Shower shape and isolation observables(inputs to photon ID BDT), as well as the energy resolution are corrected with a novel method based on normalising flows. paper

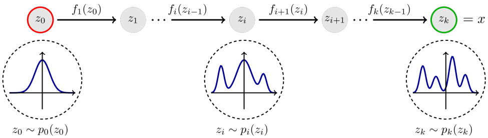


Fig. 4: Normalizing-flow

Correcting photon variables

- Flows achieve excellent data/MC agreement.
- The score of the photon ID MVA is reevaluated with the corrected input variables.
- The event categorisation based on the mass resolution is optimized .

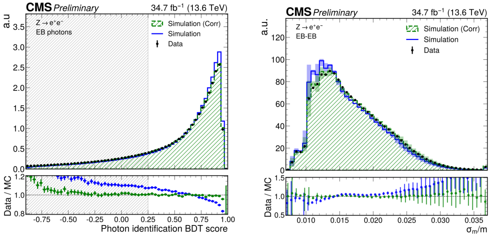


Fig. 5: BDT score and energy resolution after correcting

Jet definition and Fiducial phase space

- Jet definition:
  - Anti-κ_T clustering of stable particle.
  - Jets cleaning:
    - Distance parameter: $\Delta R < 0.4$. (With both photon and electron, muon)
    - Electrons: $p_T^e > 15\mathrm{GeV}$, $|\eta^e| < 2.5$, $I < 0.2$.
    - Muon: $p_T^\mu > 10\mathrm{GeV}$, $|\eta^\mu| < 2.4$, $I < 0.2$.
  - Add jet veto map: signal efficiency reduce by 1.5%.
  - Matches jet definition at reco level.
- Fiducial phase space:
  - $p_T^\gamma > 10\mathrm{GeV}$ and $|\eta^\gamma| < 2.5$.
  - $1.4442 < |\eta^\gamma| < 1.566$ region is masked.
  - $\mathrm{Iso} = \sum_{\mathrm{i}}^{\mathrm{R}<0.3} \frac{\mathrm{p_{T,i}}}{\mathrm{p_T}} \times \mathrm{p_T^\gamma} < 10\mathrm{GeV}$.
  - $\sqrt{p_T^{\gamma_1} p_T^{\gamma_2}}/m_{\gamma\gamma} > 1/3$ and $p_T^{\gamma_2}/m_{\gamma\gamma} > 1/4$.

The statistical model and Systematic uncertainties

$$\mathcal{L}(\vec{\mu}, \vec{\theta}, m_H) =$$
$$\prod_{c}^{cat} \prod_{b}^{kinBins} Pois \left[n_{obs} | \sum_{j}^{genBin} \mu_j^{fid} S_j(\vec{\theta}, m_H) f_S(\vec{\theta}, m_H) + N^{out}(\vec{\theta}) f_S^{out}(\vec{\theta}, m_H) + B(\vec{\theta}) f_B(\vec{\theta}) \right] \times \prod_{k=1}^{n_k} p_k(\tilde{\theta}_k | \theta_k)$$

- $S = (\epsilon \cdot A) \cdot L \cdot \sigma \cdot BR$.
- Contribution from events outside of the fiducial phase space.
- Contribution from the background modelling.
- Including experimental and theoretical uncertainties.

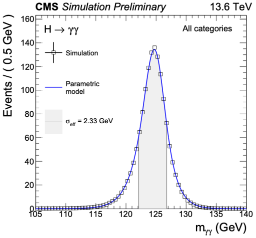


Fig. 6: Signal modelling

Inclusive fiducial cross section

- $\sigma_{fid} = 78 \pm 11(stat.)^{+6}_{-5}(syst.)\mathrm{fb} = 78^{+13}_{-12}\mathrm{fb}$
- Comparison with ATLAS result.
  - $\sigma_{fid}^{ATLAS} = 76 \pm 11(stat.) \pm 6(syst.)\mathrm{fb} = 76 \pm 13\mathrm{fb}$
- In agreement with SM prediction. $(67.8 \pm 3.8\mathrm{fb})$

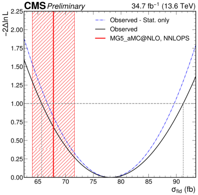


Fig. 7: Inclusive fiducial cross section

Impacts and Bin boundaries

- Dominated by energy scale and 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	$\pm 1.4\%$
Energy scale non-linearity	$+0.8\% / -1.6\%$
Photon identification efficiency	$\pm 1.0\%$
Pileup reweighting	$\pm 0.8\%$

Fig. 8: Impacts on fiducial inclusive results

Observable	Binning								
p_T^H	0	15	30	45	80	120	200	350	∞
$\|y^H\|$	0	0.15	0.3	0.6	0.9	2.5			
N_{jets}	0	1	2	3	4	∞			

Fig. 9: Bin boundaries for the differential cross sections.

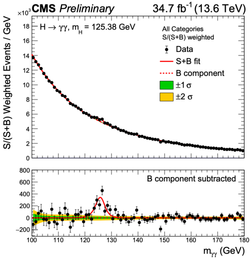
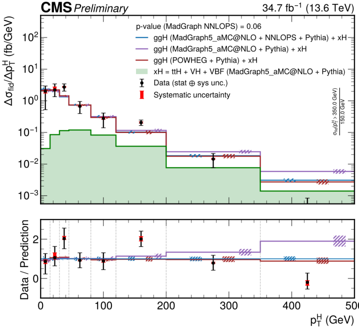
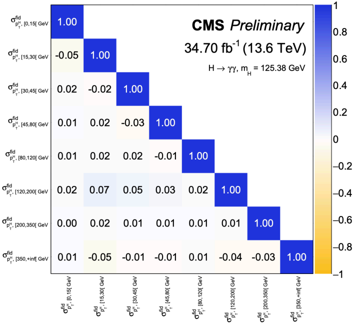


Fig. 10: Diphoton invariant mass distribution

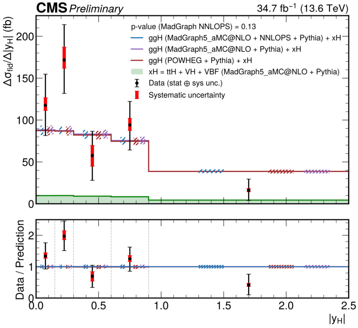
Differential fiducial cross section: pTH

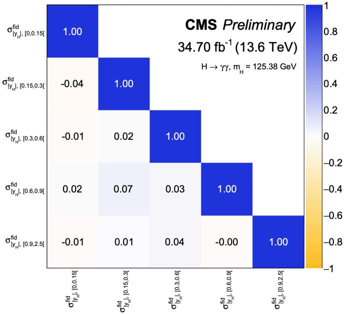




- Spectrum and correlation matrix for the transverse momentum of the Higgs boson.
- Agreement with SM prediction.

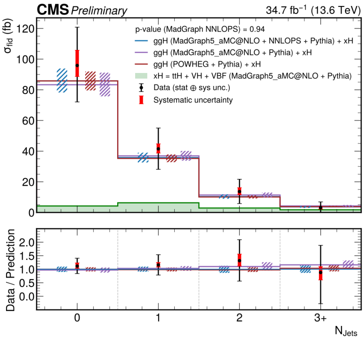
Differential fiducial cross section: rapidity

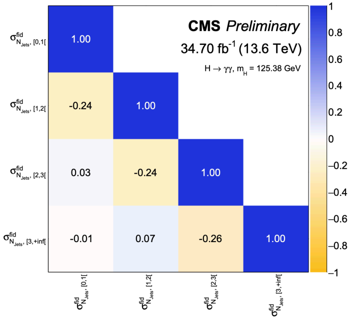




- Spectrum and correlation matrix for the absolute value of the rapidity of the Higgs boson.
- Agreement with SM prediction.

Differential fiducial cross section: number of jets





- Spectrum and correlation matrix for the absolute value of the number of associated jets.
- Nice agreement with SM prediction.

Summary

- First CMS Higgs result in Run 3, important validation of Run 3 performance. PAS link
- New method to correct photon observables using normalising flows.
  - Correct all ingredients for BDT and mass resolution.
- Fiducial inclusive and differential cross sections.
  - In agreement with SM prediction.

Back Up

From miniAOD to NanoAOD

- The mass resolution in the $H \to \gamma\gamma$ is driven by:
  - photon energy resolution.(ECAL)
  - precision measurement of the opening angle between the two photons.(vertex choice)
- $H \to \gamma\gamma$ vertex previously assigned by means of a BDT and all MiniAOD variables were recomputed wrt to the chosen diphoton vertex.
- Hgg vertex cannot be used with central NanoAOD $\to$ private NanoAOD.

Normalizing flows

- Train a single normalizing flow on both MC and data simultaneously.
- Events are conditioned on an "IsData" boolean, which allows the flow to learn both distributions.

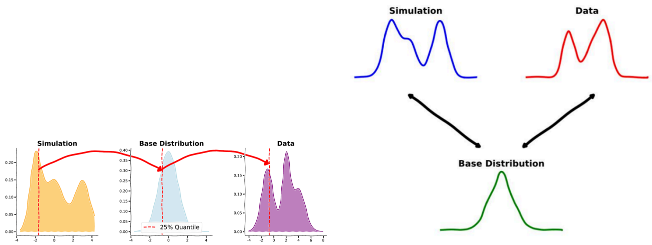


Fig. 11: The normalizing flows

Fraction of out-of-fiducial events

$$\mathcal{L}(\vec{\mu}, \vec{\theta}, m_H) =$$

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Fraction of out-of-fiducial events

	Best resolution	**Medium resolution**	**Worst resolution**
ggH	0.06%	0.19%	1.62%
VBF	0.17%	0.50%	1.97%
VH	0.31%	0.57%	2.16%
ttH	0.57%	0.83%	2.30%

Frame Title

- Consider photons in acceptance with $p_T > 25\mathrm{GeV}$.
- Apply BDT to reduce background.
- Retain the $p_T^{\gamma\gamma}$-leading diphoton system if $p_T^{\gamma 1} > 35\mathrm{GeV}$.

Category	R9	H / E	sieie	Hollow cone track isolation	PF photon isolation
Barrel, high R9	> 0.85	< 0.08	–	–	–
Barrel, low R9	[0.5, 0.85]	< 0.08	< 0.015	< 6 GeV	< 4 GeV
Endcap, high R9	> 0.9	< 0.08	–	–	–
Endcap, low R9	[0.8, 0.9]	< 0.08	< 0.035	< 6 GeV	< 4 GeV