中国科学院高能物理研究所
Institute of High Energy Physics
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ATLAS EXPERIMENT

Early Run3 $H \to \gamma\gamma$ fiducial Cross-Section measurement

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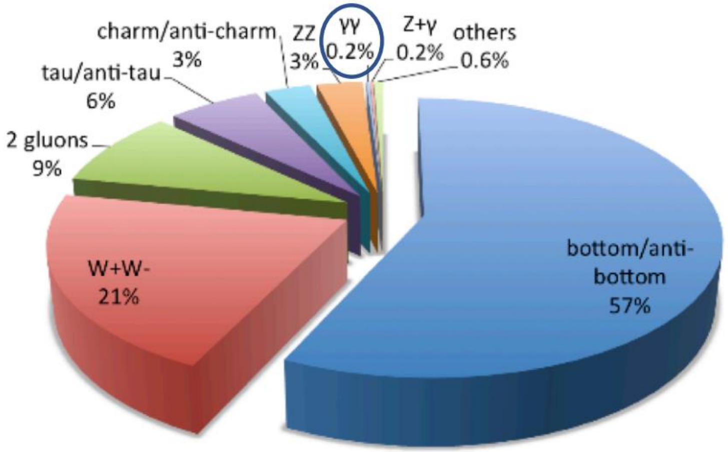
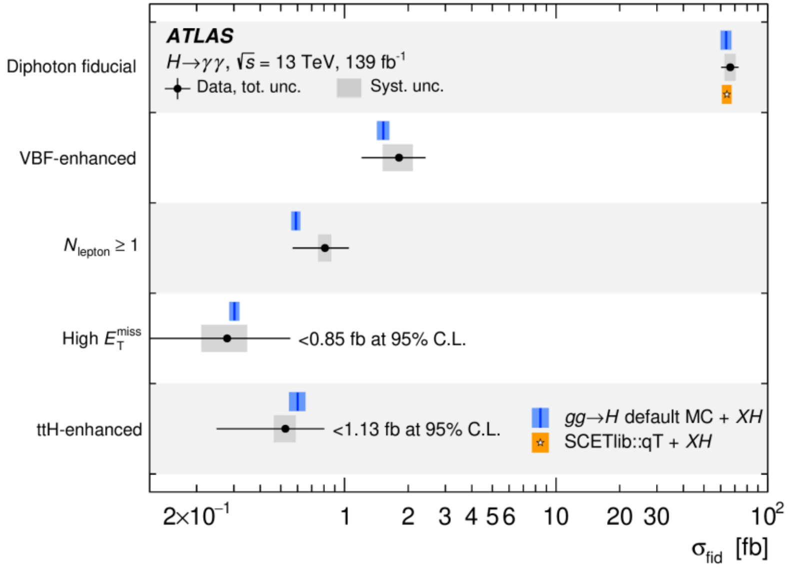
Introduction

- $H \to \gamma\gamma$ **cross-section measurement is a key probe of Higgs properties.**
  - Good photon resolution, photon reconstruction and identification efficiency
  - High Higgs signal yield and clear signal peak on top of a smoothly-falling background
- **This measurement closely follows the** $pp \to H \to \gamma\gamma$ **Run 2 analysis of 2015-2018 data**
- **We have the reconstruction methodology using Run 3 data at 13.6 TeV and upgraded software**
  - Focus on the inclusive fiducial cross section measurement.
- **It's interesting to check the compatibility with SM predictions under the new** E_{cm}**.**

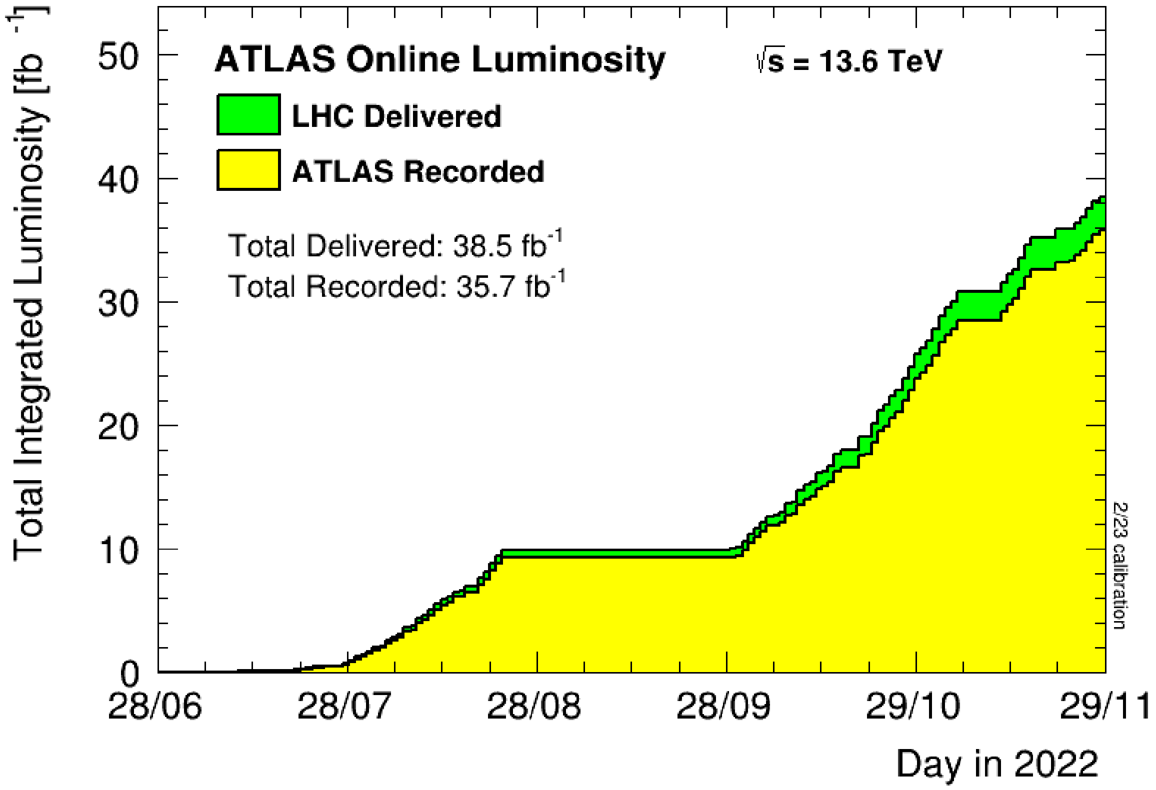


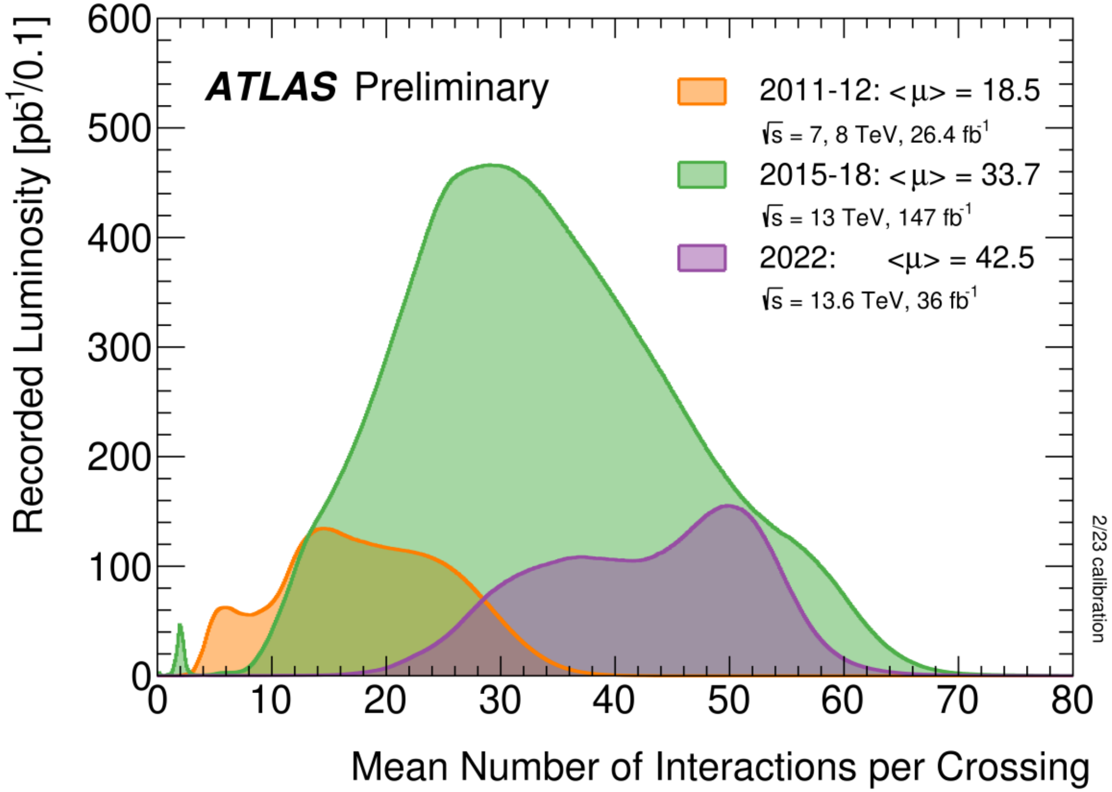
Why H → γγ important?



ATLAS Luminosity Results for Run-3 of the LHC

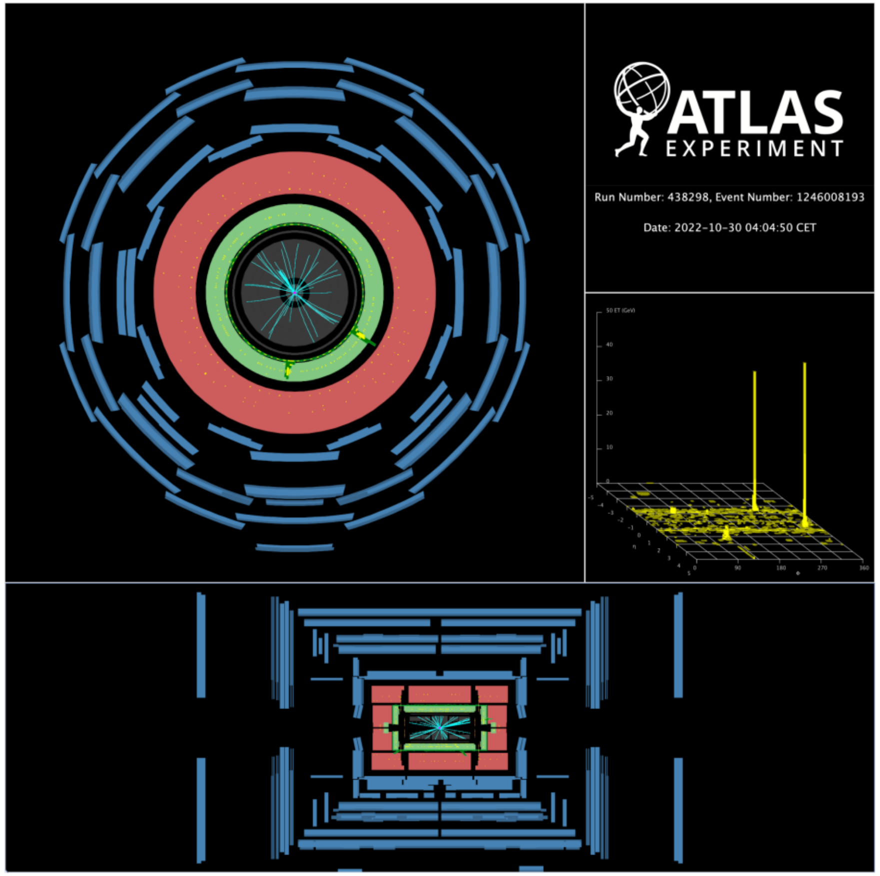
- **The total integrated luminosity of pp Run3 data set, collected in 2022, is 31.4 /fb.**
- **Higher pile-up comparing to Run2.**





Fiducial Region & Strategy

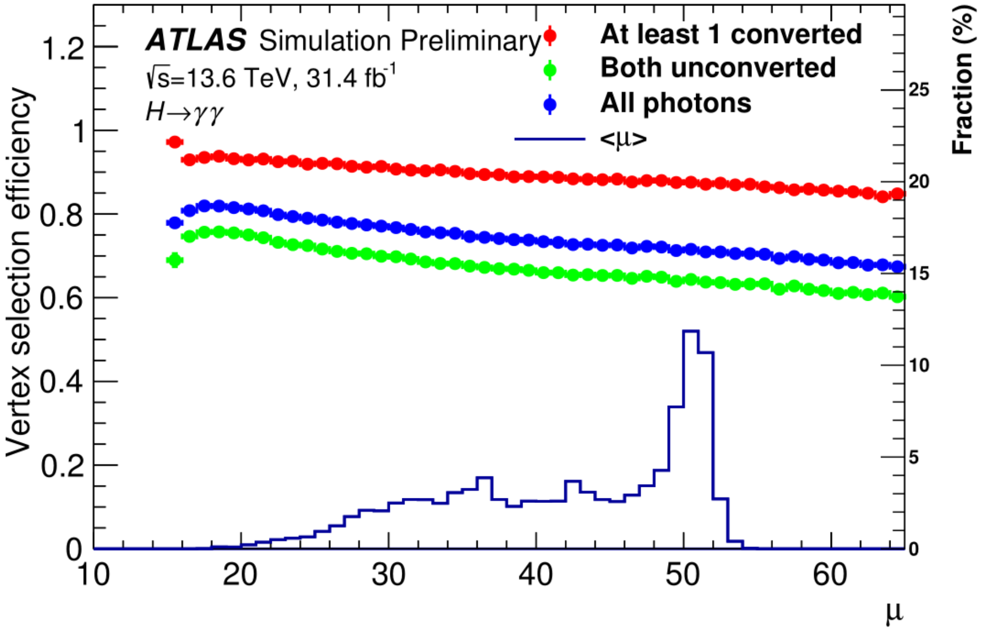
- **Baseline Diphoton fiducial volume (to mimic detector-level acceptance region)**
  - At least 2 isolated prompt photons with $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$
  - Relative pT cuts: $p_T/m_{\gamma\gamma} > 0.35(0.25)$ for leading (subleading) photon
- **Analytic parametrizations on diphoton mass for signal and background shapes**
- **Maximum likelihood method to extract the fiducial cross section by performing a signal plus background fit**



Event display

Diphoton vertex performance

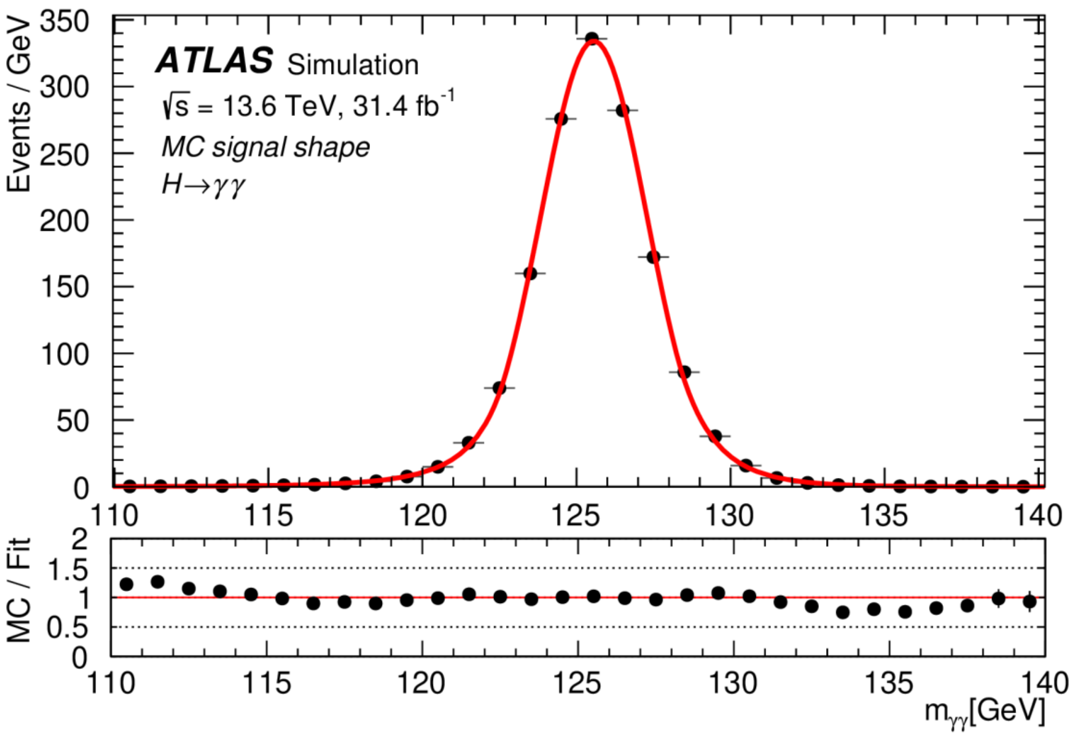
- **The photon pointing method use vertex and energy deposit in first layer of calorimeter to reconstruct the pseudorapidity.**
- **Traditional primary vertex selection: hardest vertex (highest Σp_T of track)**
  - No charged tracks for ggF $H \rightarrow \gamma\gamma$ process, so hardest vertex is not suitable.
- **Neural net (NN) method is performed to select the primary vertex**
  - The NN model from last round analysis is validated to be powerful for Run 3 at 13.6 TeV sample.
  - The NN vertex selection efficiency reaches to 71.4% for the most abundant ggF process, to be compared with an efficiency of 52.2% using hardest vertex.



Vertex selection efficiency as a function of pile-up

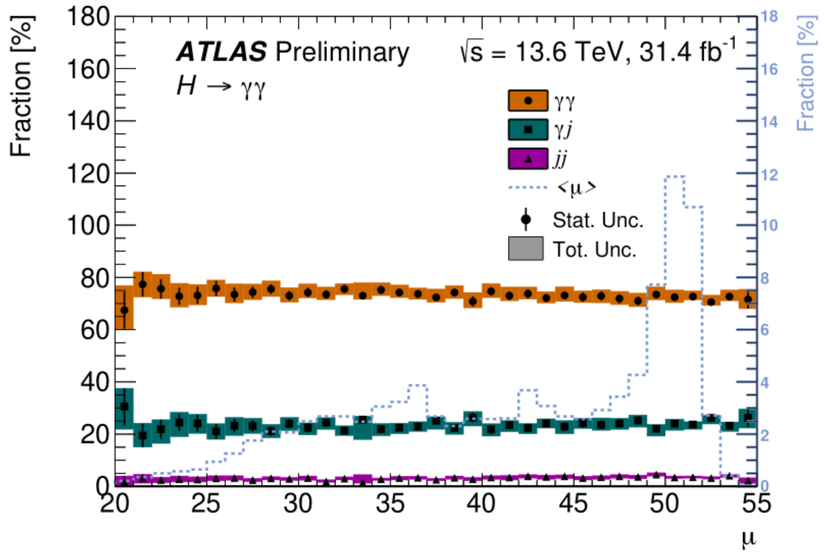
Signal Modeling

- **The mγγ distribution is modeled by fitting a double-sided Crystal Ball to MC simulation**
  - The simulated samples are generated at mH=125.0 GeV, so the peak position is shifted to 125.09 GeV
- **Uncertainties on signal shape is only affected by the photon energy scale (PES) and energy resolution (PER)**
  - Impact peak position and width respectively



Background modeling

- **The main backgrounds are non-resonant continuum backgrounds made up of γγ, γ-jet and jet-jet events.**
  - Two-dimensional double-sideband (2x2D method) to measure the fraction contributed by each background component.
- **The background templates are built with fractions and γγ samples:**
  - MadGraph γγ samples generated using full simulation
  - Based on MadGraph TRUTH sample, Normalizing flow (NF) method is introduced to produce large statistic samples
- **Functional form determined from studies on MC templates. The form is selected by spurious signal test.**



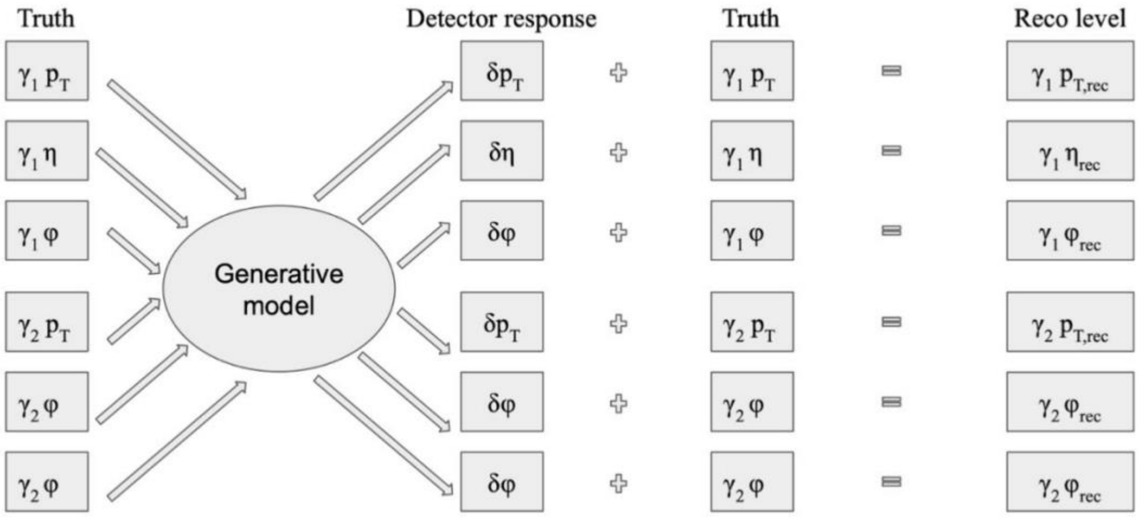
Fractions dependence on pile-up

Normalizing Flow (NF) method

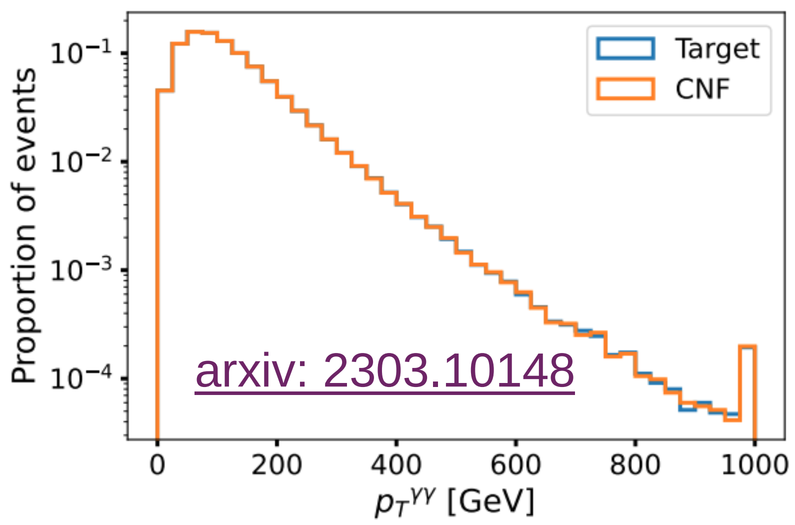
Quite computer time-consuming for the detector simulation → NF model is developed to mimic the detector responses and solve the generation problem.

NF model can well describe the detector response. It is quite easy and fast to produce MC samples with higher statistic for more data analysis in future.

NF is used to produce a large statistic background MC sample for spurious signal study



Di-photon information



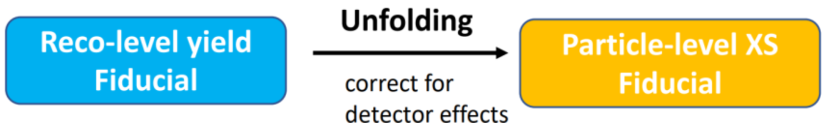
Agreements between NF and full sim. MC

Background modeling

- **Background templates of the diphoton invariant mass are built as the sum of the γγ and the γj + jj components.**
  - The γj + jj template is reweighted γγ sample
- **The spurious signal yields are defined as the measured signal obtained in signal-plus-background fits to the background-only.**
  - Several functions which can describe the template shape well are tested. The exponential function (ExpPoly2) is selected.
- **The condition of a background function to be accepted is that either**
  - S is less than 20% of the background uncertainty
  - S is less than 10% of the number of expected signal events (S_{ref}).

Measurement Results

Correction factor are derived to account for detector effects. For diphoton fiducial measurement, the strategy to unfold reco-level yield to truth-level cross-section is:



- $N_r = L \cdot \left(\sigma_t^{inc} \cdot Acc \cdot B_{\gamma\gamma}\right) \cdot \frac{v_{reco}}{v_{truth}} \cdot f_{datitz}$

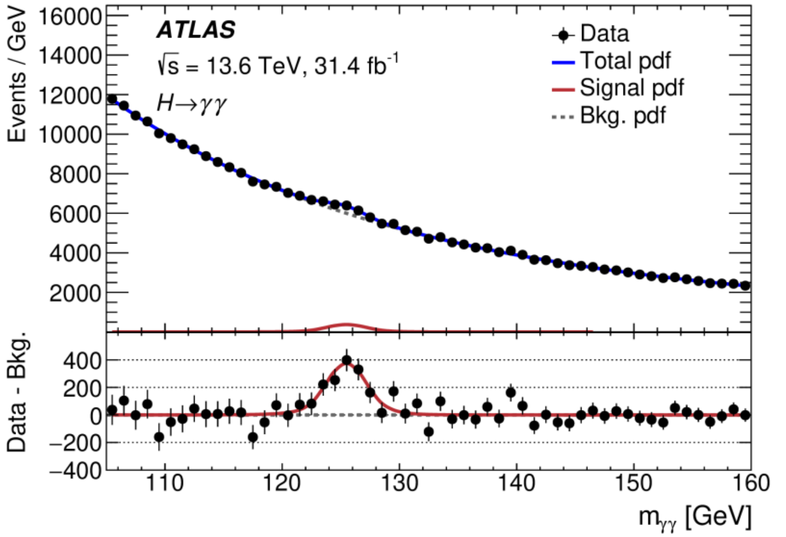
Measured fiducial XS

- Fiducial XS:$\sigma_{fid}(pp \to H \to \gamma\gamma) = 76^{+14}_{-13}\, fb\ [\pm 11(stat.)^{+9}_{-7}(syst.)]$
- Standard Model prediction: $\sigma_{SM} = 67.5 \pm 3.4\ fb$

Extrapolating this result to the full phase space and correcting for the branching ratio, the total XS is

- Total XS: $\sigma(pp \to H) = 67^{+13}_{-12}\ pb$
- Standard Model prediction: $\sigma_{SM} = 59.8 \pm 2.6\ pb$

$$\sigma_{fid} = \sigma_{tot} \times Br(H \to \gamma\gamma) \times Acceptance$$



Statistical analysis and systematic uncertainties

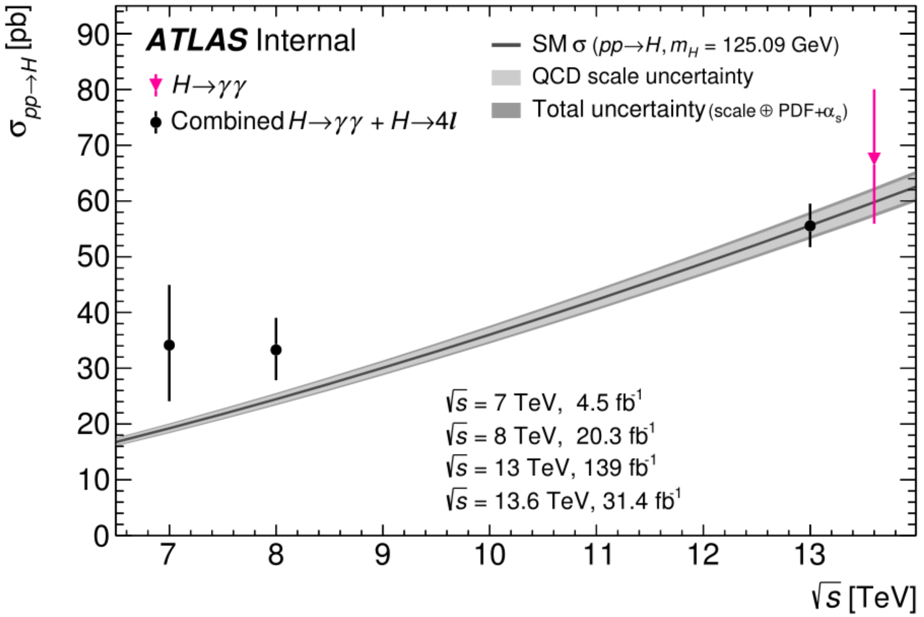
- **We consider the following grouping of uncertainties**
  - The statistical uncertainty is dominant uncertainty followed by selection efficiency and background modeling uncertainty

Source	Uncertainty [%]
Statistical uncertainty	14.0
Systematic uncertainty	10.9
Photon trigger and selection efficiency	6.7
Background modeling (spurious signal)	6.0
Photon energy scale & resolution	5.5
Luminosity	2.2
Pile-up modeling	1.1
Higgs boson mass	0.1
Theoretical (signal) modeling	< 0.1
Total	17.7

Summary & Conclusions

- **We used 31.4 /fb of pp collision data collected with the ATLAS detector at $\sqrt{s} = 13.6$ TeV in 2022 to measure the Higgs fiducial cross-section in the di-photon decay.**

- **The fiducial measurement is extrapolated to the full phase space, yielding a total cross-section has a good agreement with the Standard Model predictions.**



Thanks!

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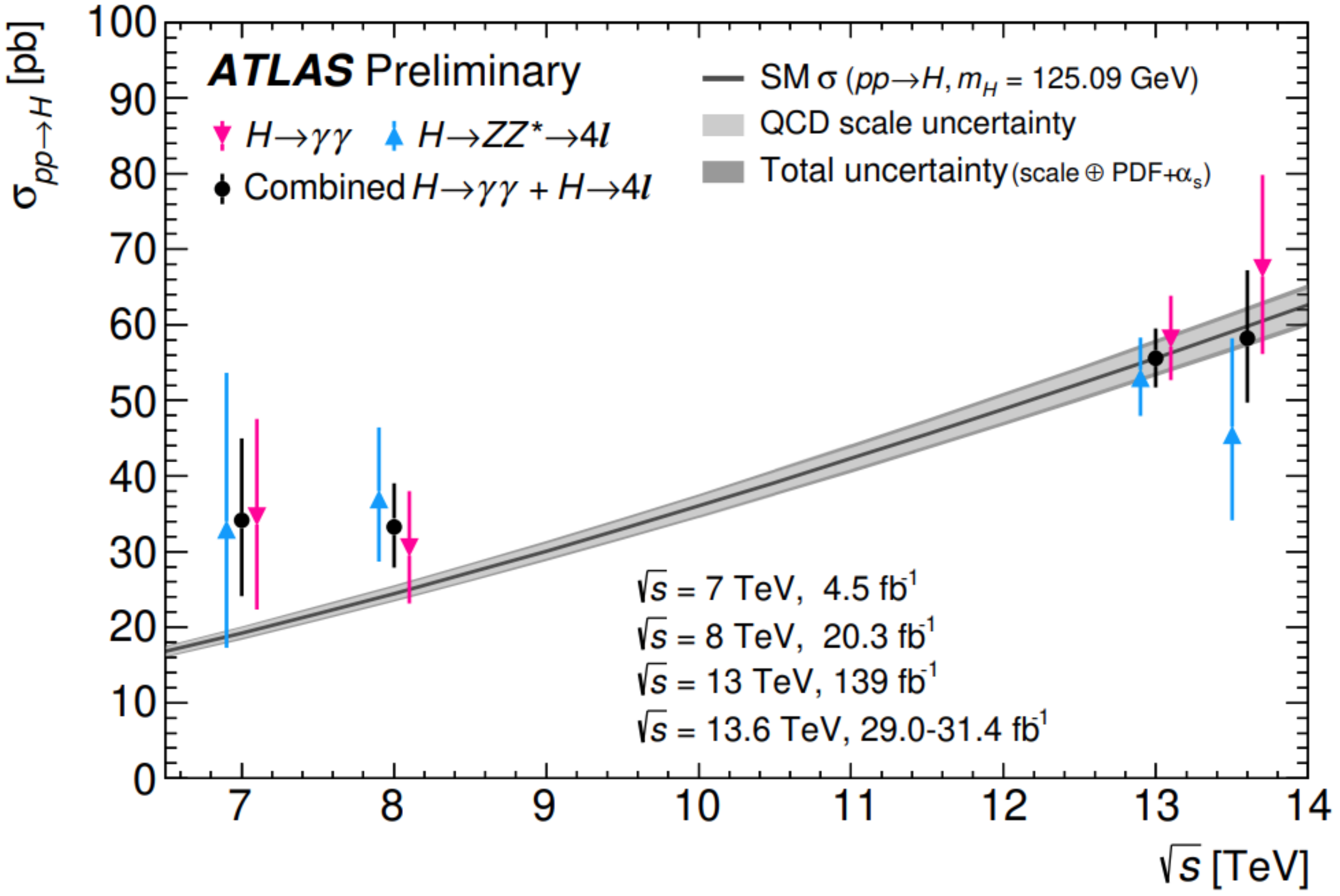
Combination with $H \to ZZ^* \to 4l$



arXiv:2306.11379

Event Selection & Fiducial Regions

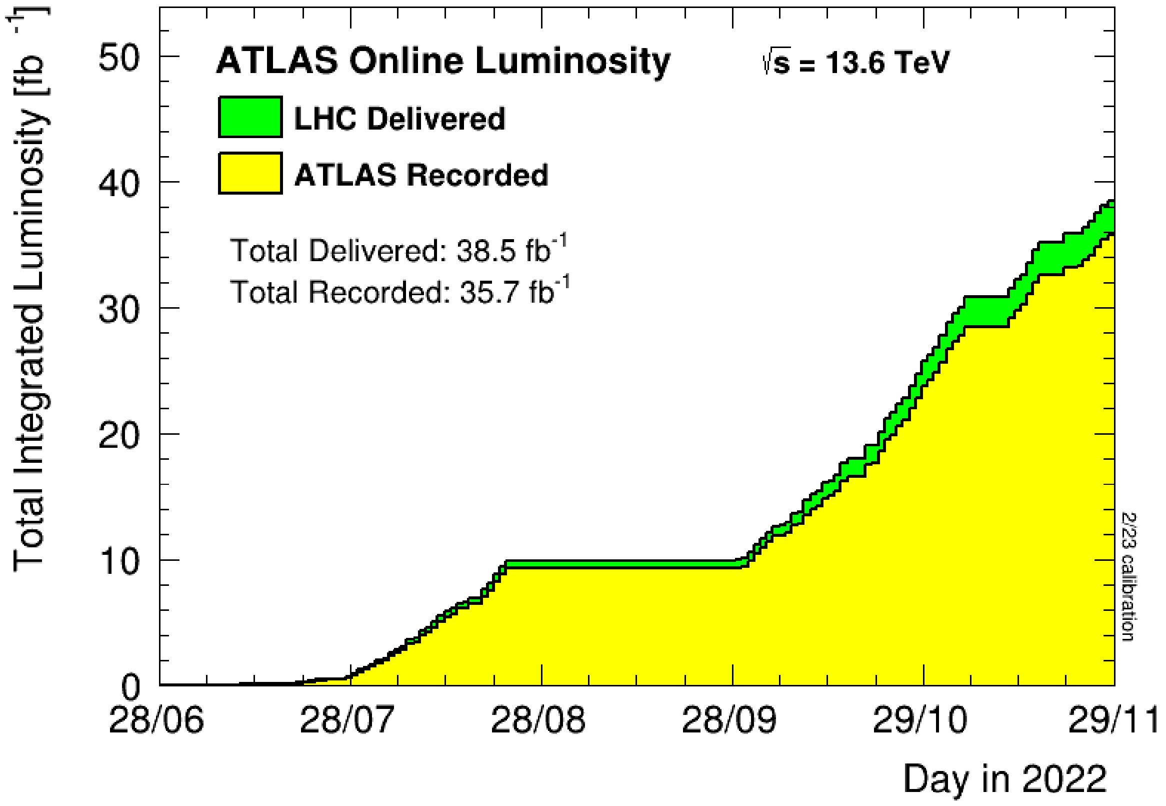
- **Diphoton trigger requires pT thresholds of 35 and 25 GeV**
- **Single-photon trigger also considered (only contributes 1% to the selected events)**
- **Photon candidates with the highest transverse momentum have to be matched to photon trigger objects**

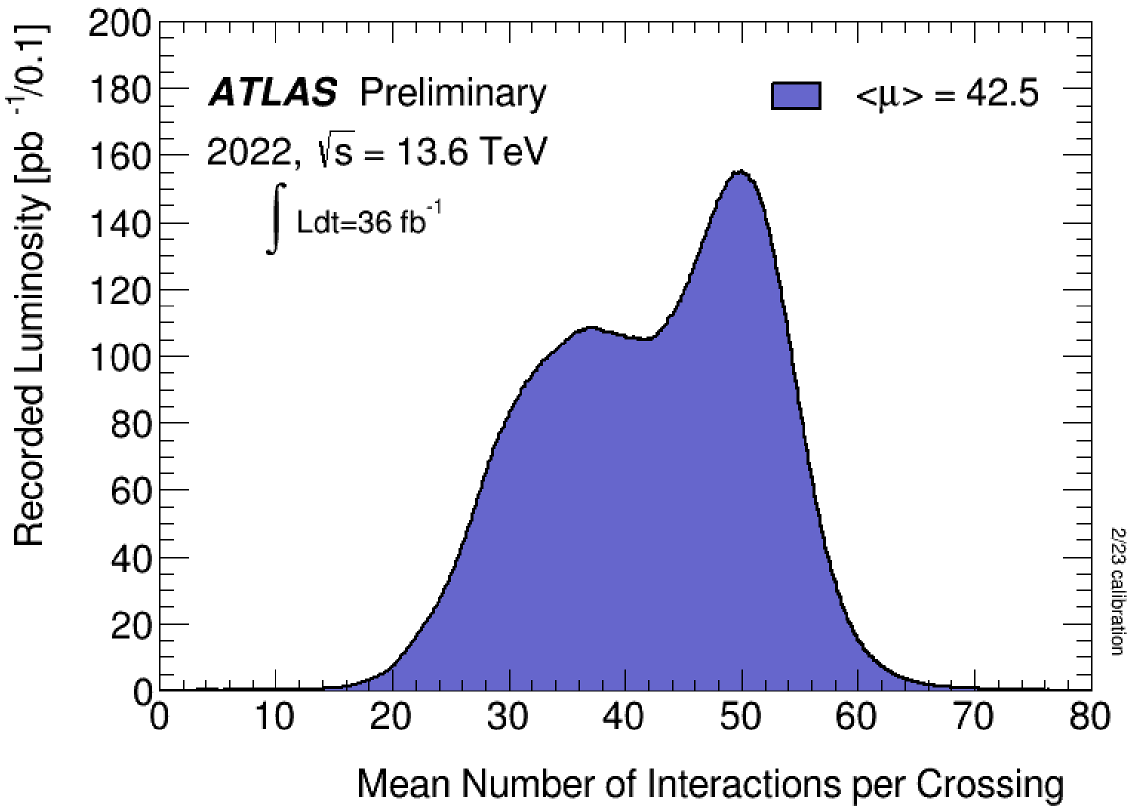
Used to reconstruct Higgs boson candidate

- **At least 2 photons with $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$**
- **At least one primary vertex candidate (based on NN selection)**
- **Tight ID and loose isolation of two photon candidates**
- **Relative pT cuts: $p_T/m_{\gamma\gamma} > 0.35(0.25)$ for leading (subleading) photon**
- **Diphoton invariant mass in the range: $m_{\gamma\gamma} \in [105\text{-}160]$ GeV**

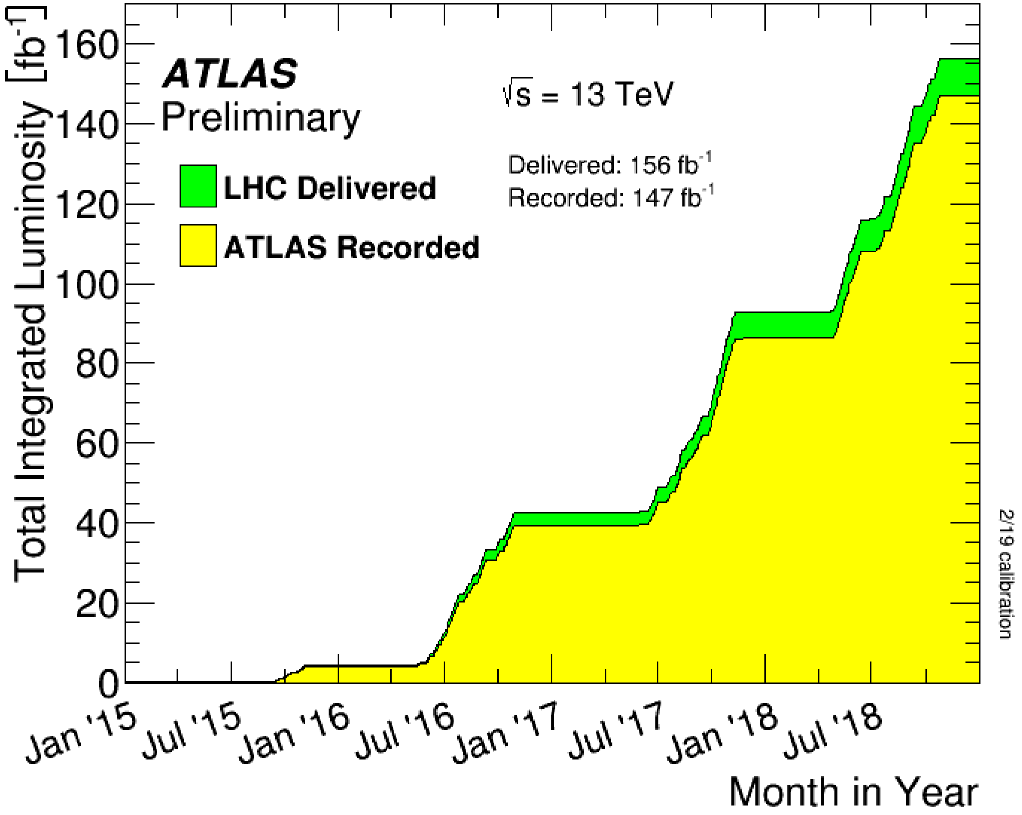
Selections are unchanged with respect to Run 2 analysis.

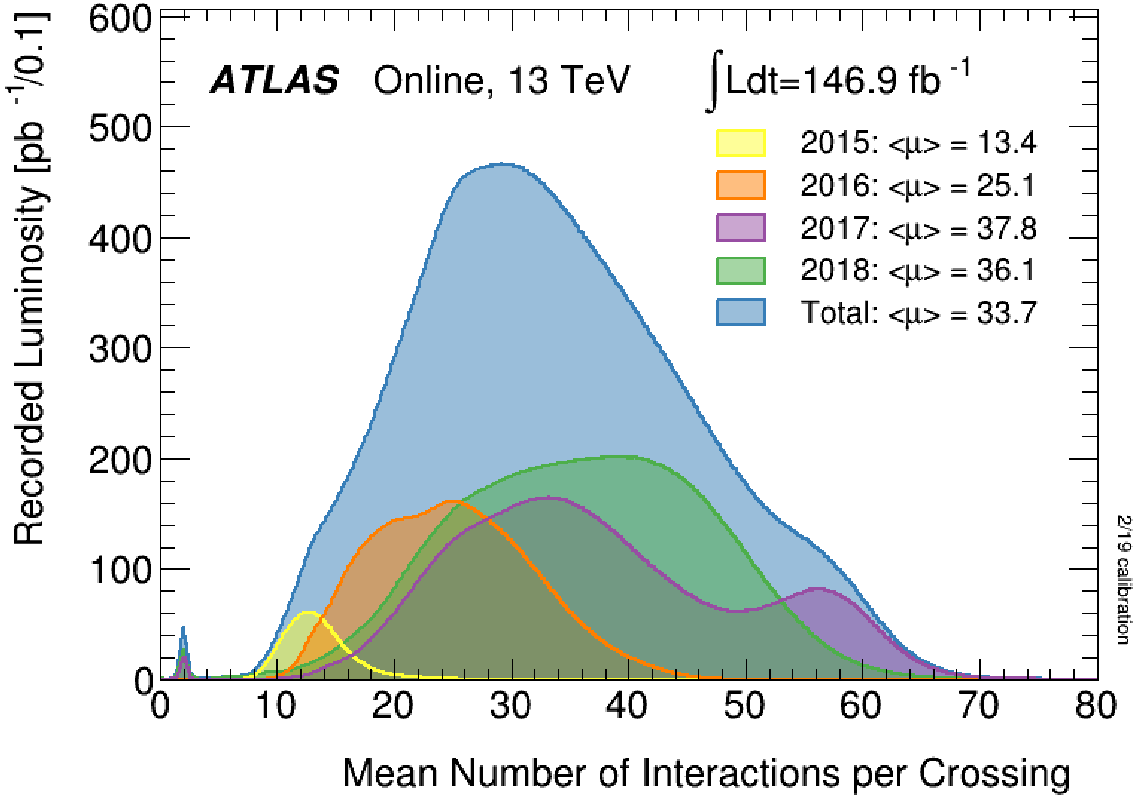
ATLAS Luminosity Results for Run-3 of the LHC



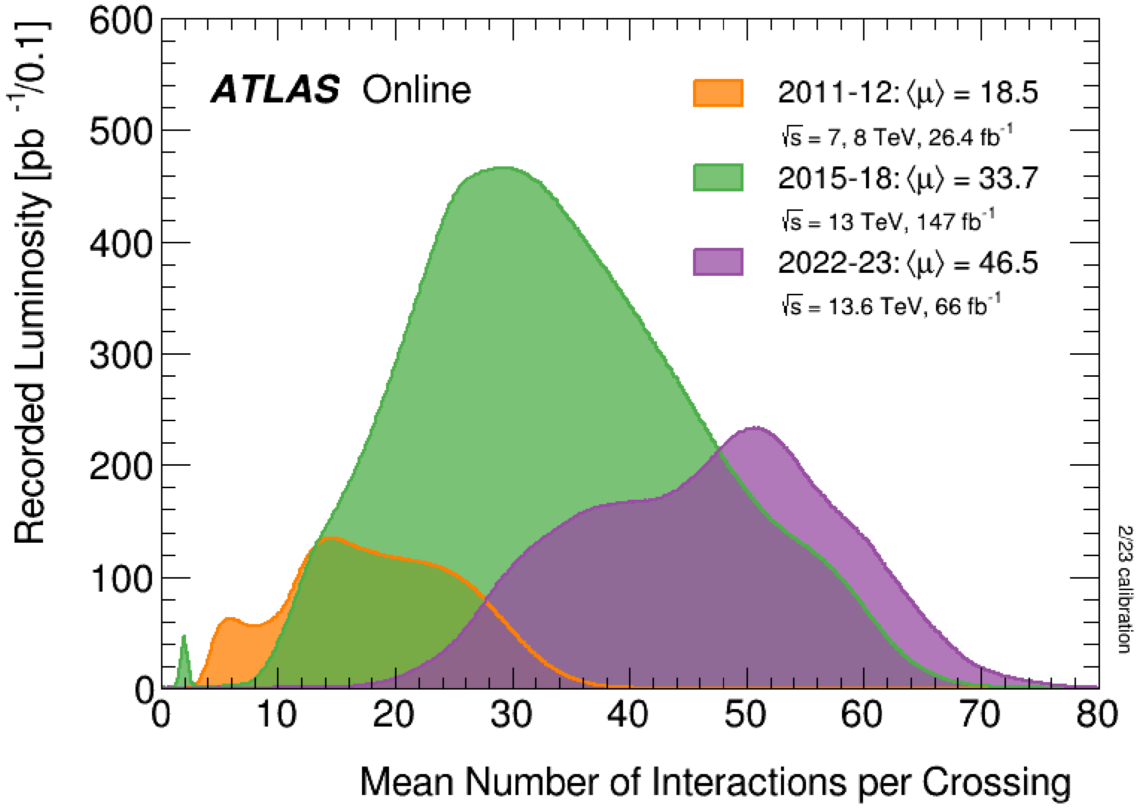


ATLAS Luminosity Results for Run-2 of the LHC

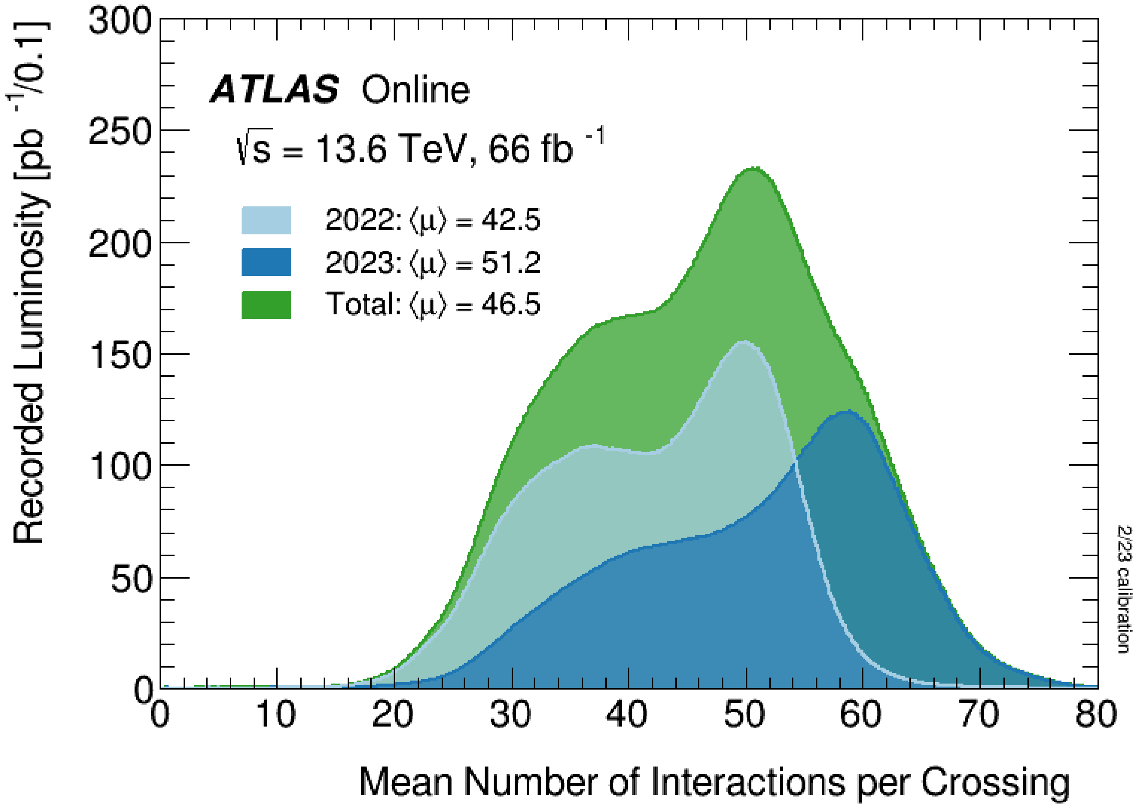




Comparison



ATLAS Online
2011-12: ⟨μ⟩ = 18.5
√s = 7, 8 TeV, 26.4 fb⁻¹
2015-18: ⟨μ⟩ = 33.7
√s = 13 TeV, 147 fb⁻¹
2022-23: ⟨μ⟩ = 46.5
√s = 13.6 TeV, 66 fb⁻¹
2/23 calibration
Recorded Luminosity [pb⁻¹/0.1]
Mean Number of Interactions per Crossing



ATLAS Online
√s = 13.6 TeV, 66 fb⁻¹
2022: ⟨μ⟩ = 42.5
2023: ⟨μ⟩ = 51.2
Total: ⟨μ⟩ = 46.5
2/23 calibration
Recorded Luminosity [pb⁻¹/0.1]
Mean Number of Interactions per Crossing

NN method

Define ΔZ to perform the diphoton vertex selection

- $\Delta Z = Z_{PV}^{selected} - Z_{PV}^{truth}$
- Z_{PV}^{truth}: for ggH MC , it's truth photon's vertex;
- $Z_{PV}^{selected}$: hardest primary vertex/NN-selected vertex, chosen by the NN/pointing method.

Diphoton vertex selection efficicency:

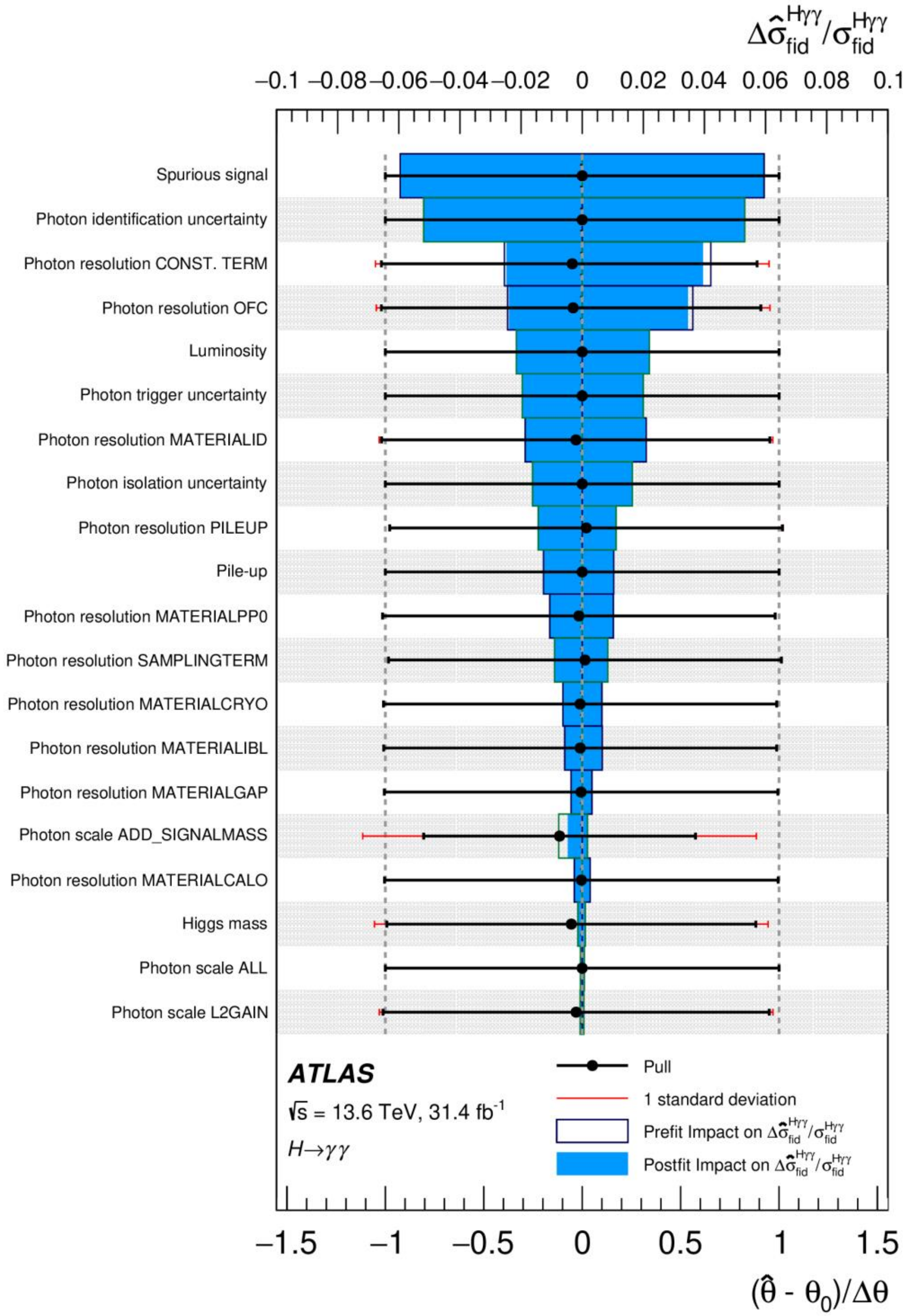
- $\epsilon = \frac{vertex\ matched\ events}{total\ events}$
- Macth definition: $\Delta Z < 0.3\text{mm}$

Variables used in NN selection:

- $(Z_{common} - Z_{vertex})/\sigma_Z$, where Z_{vertex} is the position of the primary vertex; σ_Z is the associated error.
- $\Delta\phi(\gamma\gamma, vertex)$, the azimuthal angle between the diphoton system and system defined by the vector sum of the tracks associated to the vertex.
- $\log(\Sigma p_T)$, the scalar sum of transverse momenta of the tracks associated to the vertex.
- $\log(\Sigma p_T^2)$, idem with p_T^2 instead of p_T

Ranking plot

Figure 7: Impact of systematic uncertainties on the fitted Higgs boson cross-section. Only the 25 most relevant systematic uncertainties are shown in decreasing order of their impact on the cross-section. The filled boxes show the relative impact on the cross-section, referring to the top x-axis, when fixing the corresponding individual nuisance parameter to its fitted value modified upwards or downwards by its fitted uncertainty, and performing the fit again, with all the other parameters allowed to vary, so as to take correlations between systematic uncertainties properly into account. The dots, referring to the bottom x-axis, show the deviations of the fitted nuisance parameters from their nominal values, normalised to their nominal uncertainties. The associated error bars show the fitted uncertainties of the nuisance parameters, relative to their nominal uncertainties. The nuisance parameter Photon scale ADD_SIGNALMASS refers to the 0.4% additional uncertainty on the photon energy scale and it is constrained by the data due to their sensitivity to the Higgs boson mass value.



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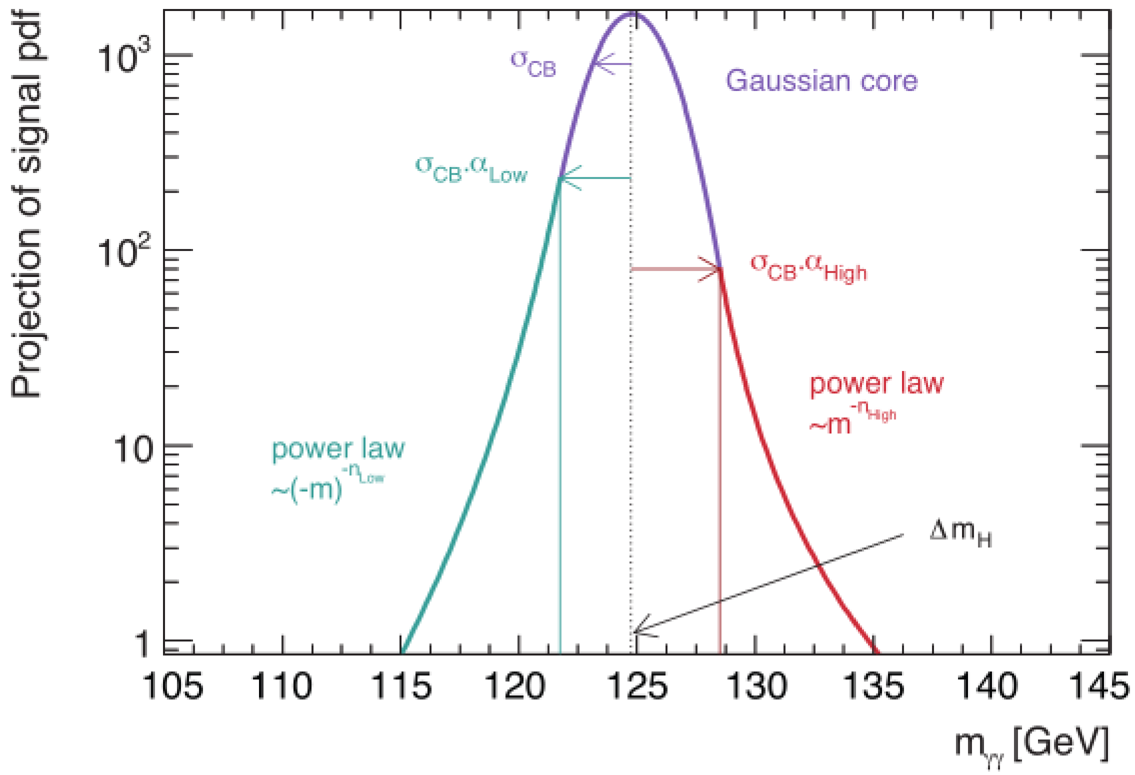
Signal modeling



Machine learning background

- **The generative models of machine learning have been used to generate large MC sample, without the detector simulation step.**
  - A normalizing flow (NF) method to generate high-statistics truth level continuum diphoton sample and then apply the smearing for realistic detector effects.
  - This approach will be important with full Run3 data and a higher luminosity.
- **The NF training with mc16a Sherpa MC $\gamma\gamma$ shows very good agreements between MC detector simulation and the NF prediction.**
- **We have generated 500M Madgraph $\gamma\gamma$ sample at TRUTH level (more than 100M at RECO level) , which allows us to validate the NF method of the background modeling**

Spurious signal test

- Fit background MC with signal+background parametrisation, with different background functions tested:
  - Exponentials of different order polynomials (Exp, ExpPoly2, ExpPoly3):

$$\mathcal{B}\left(m_{\gamma\gamma}, \vec{\alpha}^{bkg}\right) = N(\vec{\alpha}^{bkg}) \cdot \exp\left(-\frac{m_{\gamma\gamma}}{\vec{\alpha}_1^{bkg}} - \frac{{m_{\gamma\gamma}}^2}{\vec{\alpha}_2^{bkg}} - \cdots - \frac{{m_{\gamma\gamma}}^n}{\vec{\alpha}_n^{bkg}}\right)$$

  - Bernstein polynomials of different orders (Bern3, Bern4, Bern5):

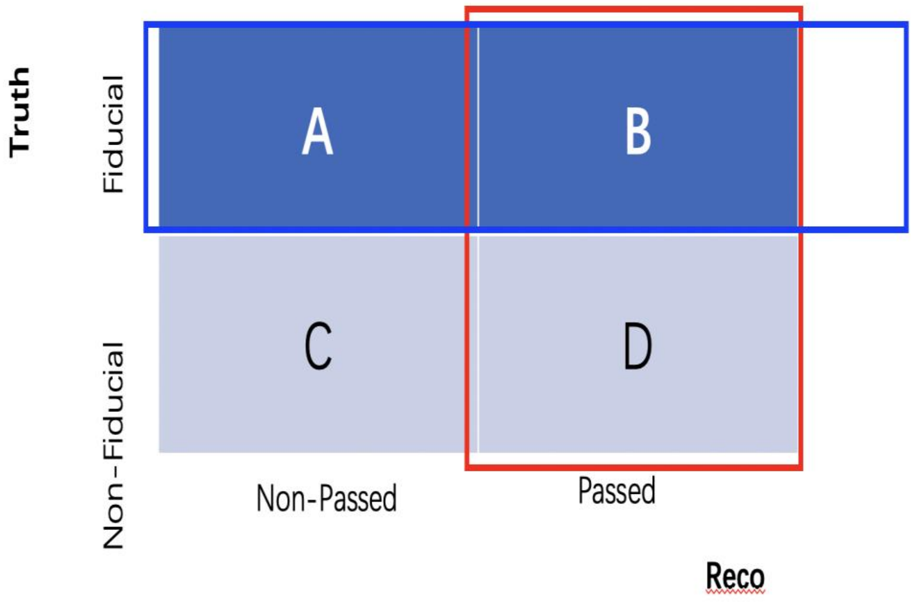
$$\mathcal{B}\left(m_{\gamma\gamma}, \vec{\alpha}^{bkg}\right) = N(\vec{\alpha}^{bkg}) \cdot \sum_{i=0}^{n} \alpha_i^{bkg} x^i \cdot (1-x)^{n-i} \cdot \frac{n!}{i! \cdot (n-i)!}$$

  - Power law function (Pow): $\mathcal{B}\left(m_{\gamma\gamma}, \vec{\alpha}^{bkg}\right) = N(\vec{\alpha}^{bkg}) \cdot m_{\gamma\gamma}^{\alpha_0}$

- Previously, ExpPoly2 was usually found to model the distribution best

Unfolding factors

- **For diphoton fiducial measurement, the strategy to unfold reco-level yield to truth-level cross-section is:**
  - $N_r = L \cdot \left(\sigma_t^{inc} \cdot Acc \cdot B_{\gamma\gamma}\right) \cdot \frac{v_{reco}}{v_{truth}} \cdot f_{datitz}$
  - Where $\frac{v_{reco}}{v_{truth}}$ is ratio of reco. yield in acceptance region over truth yield in fiducial volume.
  - f_{datitz} corrects for the contributions from Dalitz events $(H \rightarrow f\bar{f}\gamma)$
- **These two factors ($\frac{v_{reco}}{v_{truth}}$ and f_{datitz}) computed from simulation samples.**



correction = (B+D)/(A+B)