Interference Studies in the $H \rightarrow \gamma\gamma$ channel

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on behalf of the
Off-shell and interference subgroup

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YR4: Interference in $H \rightarrow \gamma\gamma$ channel section

- Several inputs from theorists and CMS/ATLAS analyzers

- **Theory overview**: Ye Li, Nerina Fidanza

- **Monte Carlo interference implementations**: Stefan Hoeche

- **Exercise with Dire parton shower**: Livia Soffi

  → Studies at generator level: Compare results @13 TeV with parton shower w.r.t. theory results

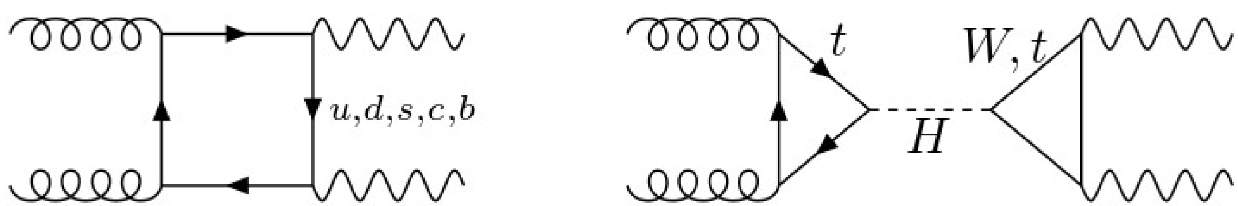
- **Studies from ATLAS**: Yanyan Gao, Florian Bernlochner, Cyril Becot, et al.

  → Feasibility studies for HL-LHC [ATL-PHYS-PUB-2013-014]
  → Studies at 8 TeV still under approval process

Overview

- Study the coherent interference between the Higgs signal $ij \to X + H(\to \gamma\gamma)$ and the background $ij \to X + \gamma\gamma$

$gg \to \gamma\gamma$:



1)Effects in diphoton observables
2)Use it to constrain Higgs properties

→ **Measure mass shift of the SM Higgs boson**
→ **Constrain the Higgs Width via Interferometry:**

Δm_H vs Γ_H

- Two main issues related to Hgg Interference:

Size of total xsec   **Shape** of mass distribution

Effects on size of total cross section

- Interference term to the total gg → γ γ cross section

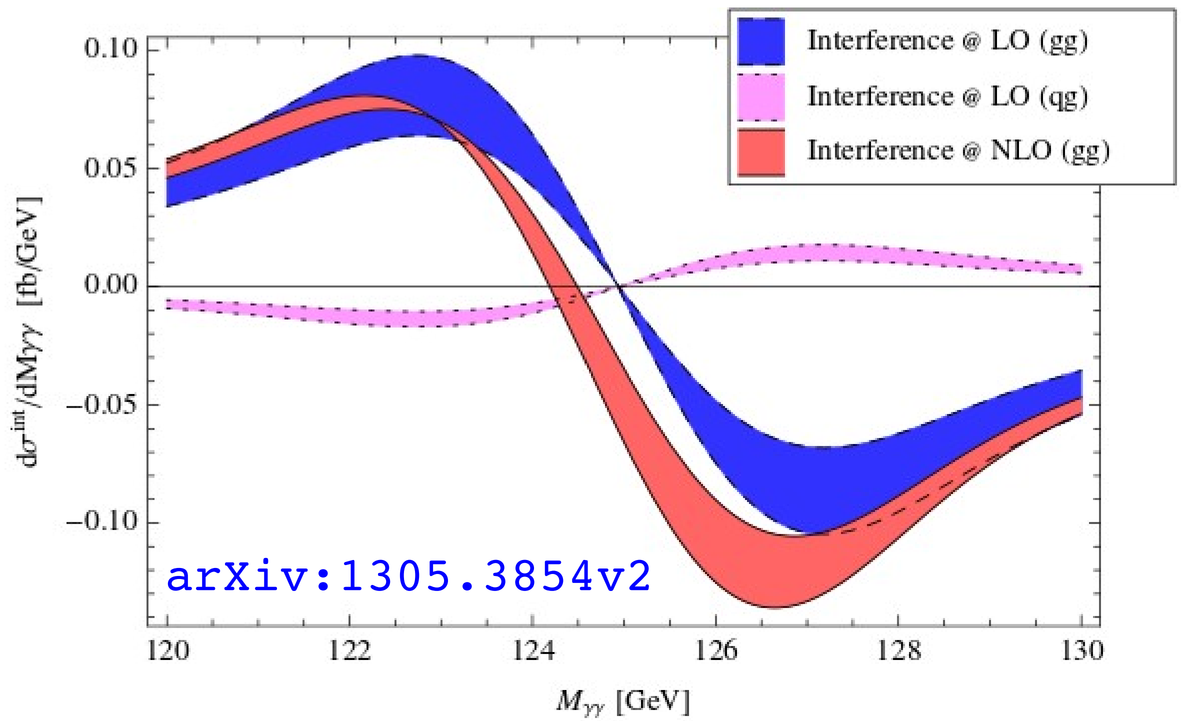
$$\delta\hat{\sigma}_{ij\to X+H\to\gamma\gamma} = -2(\hat{s}-m_H^2)\,\frac{\mathrm{Re}\left(\mathcal{A}_{ij\to X+H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\mathrm{cont}}\right)}{(\hat{s}-m_H^2)^2+m_H^2\Gamma_H^2} -2m_H\Gamma_H\,\frac{\mathrm{Im}\left(\mathcal{A}_{ij\to X+H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\mathrm{cont}}\right)}{(\hat{s}-m_H^2)^2+m_H^2\Gamma_H^2},$$

- Real term suppressed after integration under the narrow width hypothesis because odd in ŝ
- Imaginary term small for quark mass suppression at LO
- Leading effect arises from the 2-loop order correction to the continuum amplitude.

→ **Net effect is to decrease total cross section by few per cent.**

Effects on the shape

- Contribution of interference to H→γγ mass distribution.



- surplus of events for $\hat{s} < M_H^2$ and a deficit for $\hat{s} > M_H^2$
  → shifting the γγ mass distribution lower from Real Term

- After experimental resolution effects, there remains a small but (eventually) measurable effect

Dire shower tool in Sherpa 2.1.0

Stefan Hoeche from Sherpa authors provided a pre-release which include parton shower simulation at both fixed-order and MC@NLO, using the new Dire shower in Sherpa.

- Sherpa MC generator: https://sherpa.hepforge.org
- svn co http://sherpa.hepforge.org/svn/branches/hintmcnlo
- Exercise:
  - → Produce 1M events in HepMC format
  - → Convert HepMC format in EDM root
  - → Run CMS Diphoton analyzer to store gen particles infos: photon kinematics, Higgs kinematics

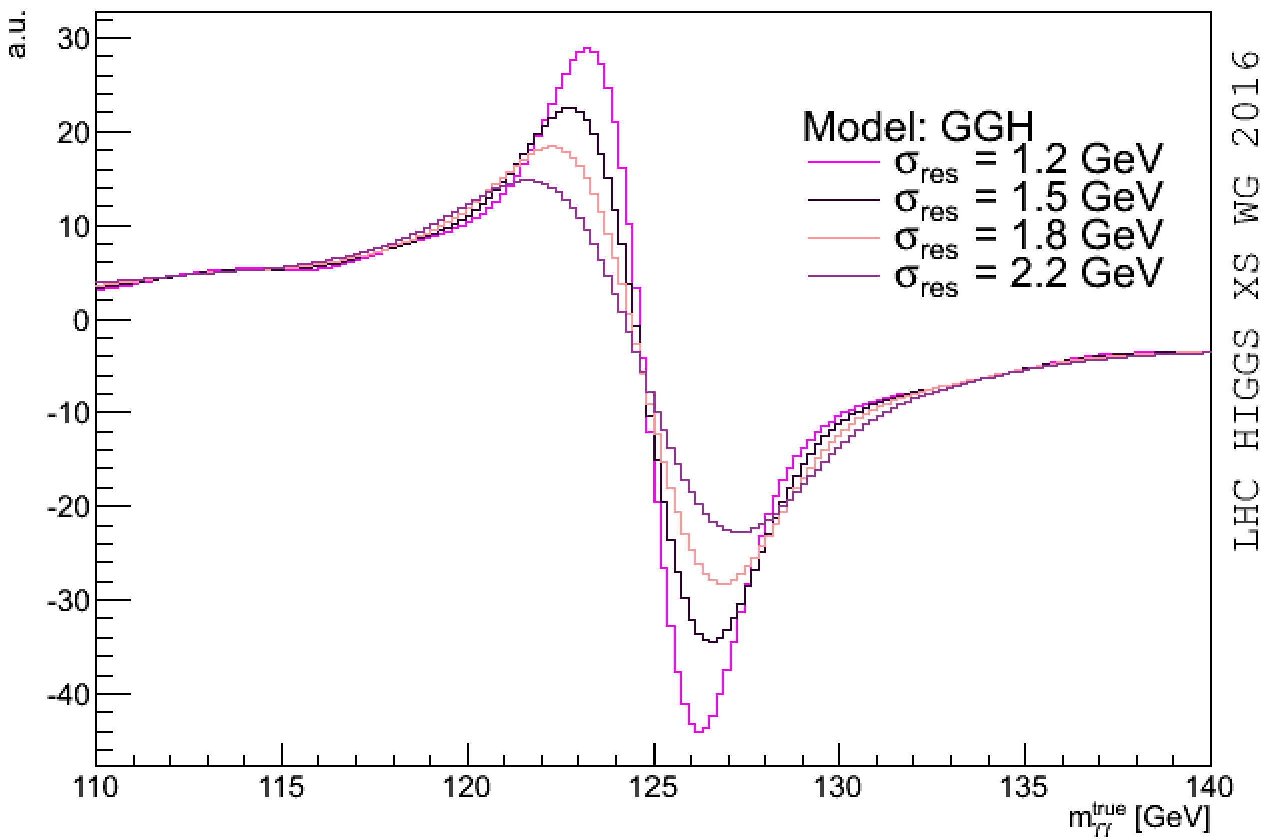
https://github.com/lsoffi/SherpaHggInterference

Technicalities

- So far considering only gluon fusion (GGH) process @13 TeV
- Assuming SM Higgs width of 4 MeV
- Applying basic "Higgs Finder" requirements:
  - P_{T1}>40 GeV
  - P_{T2} > 30 GeV
  - |eta|<2.5
  - $M_{\gamma\gamma}$ in (100-150) GeV
  - Frixione Isolation in R = 0.4
- Interference only: $|S+B|^2 - |S|^2 - |B|^2$
- Signal + Interference : $|S+B|^2 - |B|^2$
- Signal + Interference + Background: $|S+B|^2$

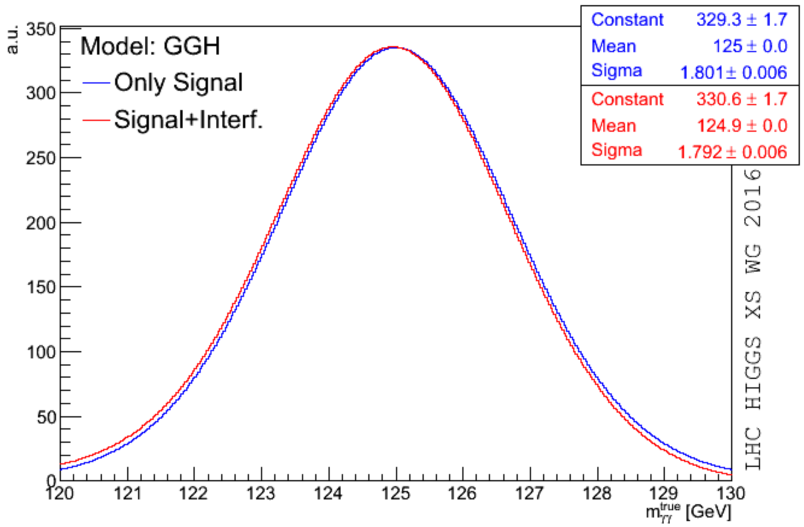
Interference effects including detector smearing

- Look at qualitatively results simulating detector resolution smearing mass distributions with a **gaussian term**

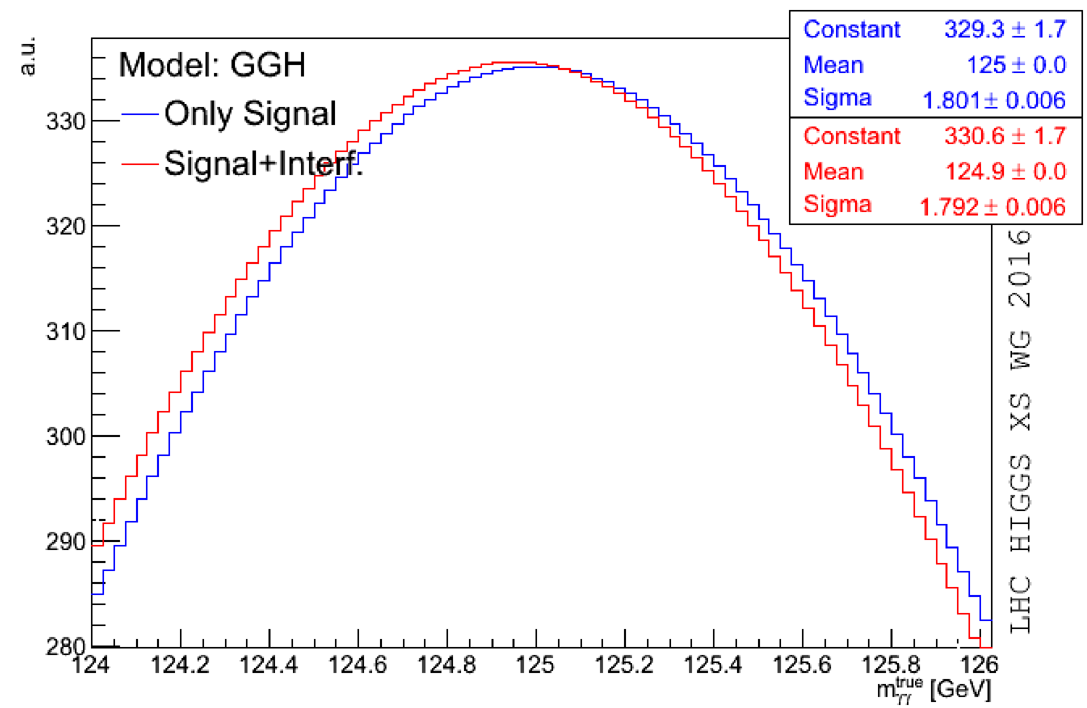


Evaluate Mass Shift

- Compare signal **with** and **without** interference (for σ = 1.7GeV):



Inclusive Δm_H ~ -89 MeV

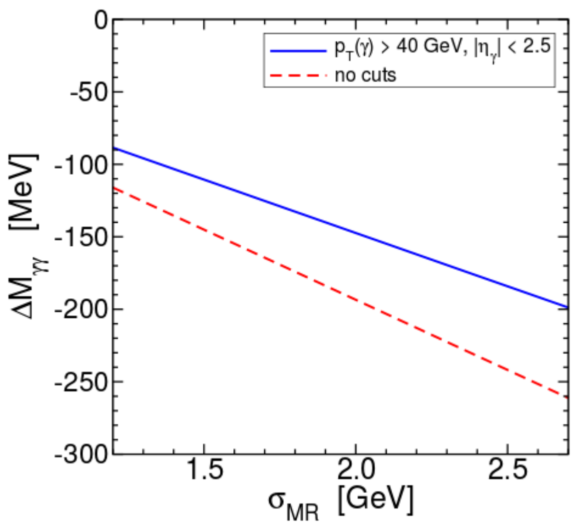


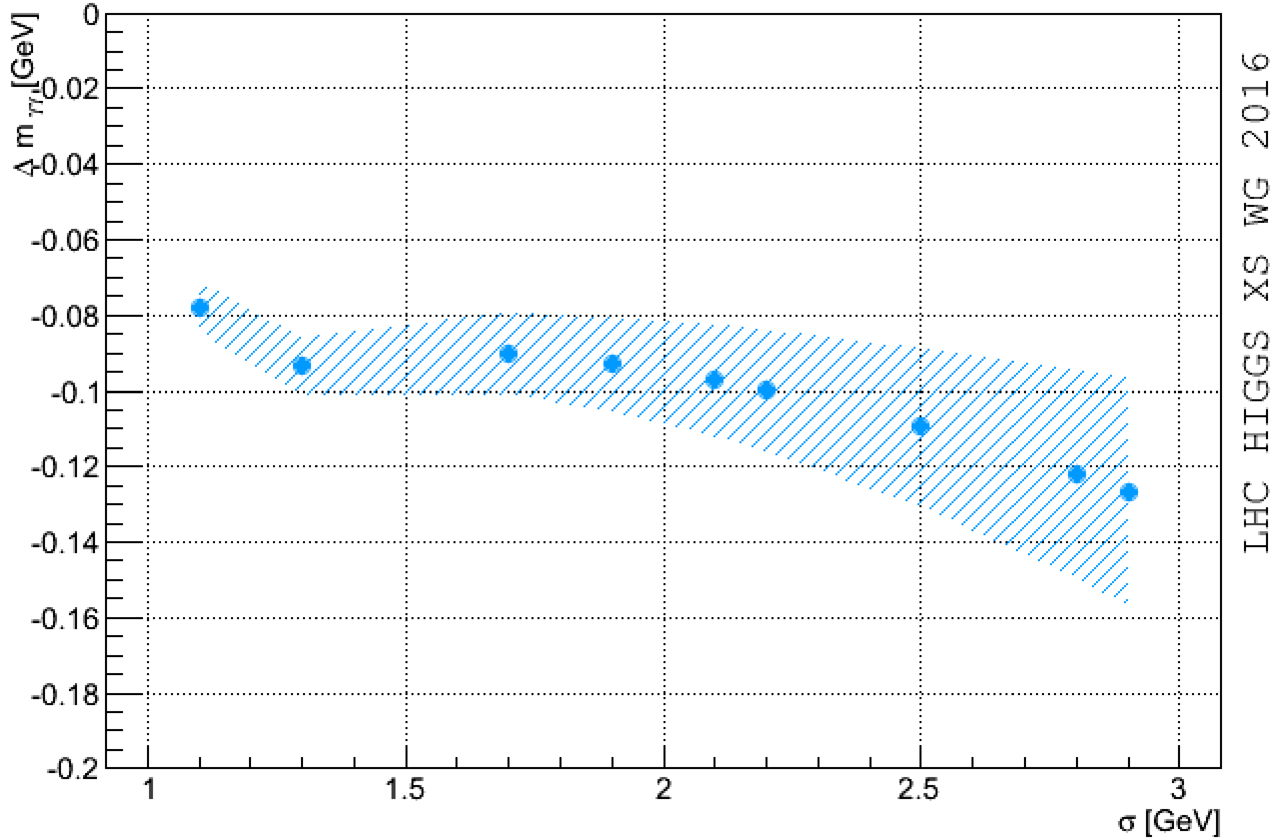
- @8 TeV **Δm_H ~ -85 MeV** to be compared with -70 MeV in arXiv:1305.3854v2

Shift vs Detector smearing

- Compare mass shift for difference detector resolutions

arXiv:1303.3342





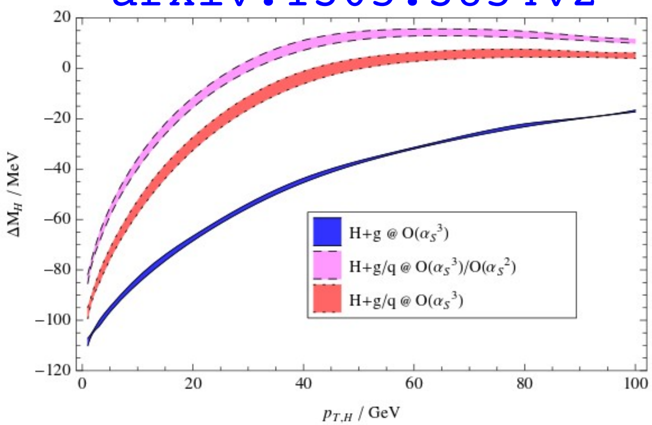
- Shift increases with mass resolution

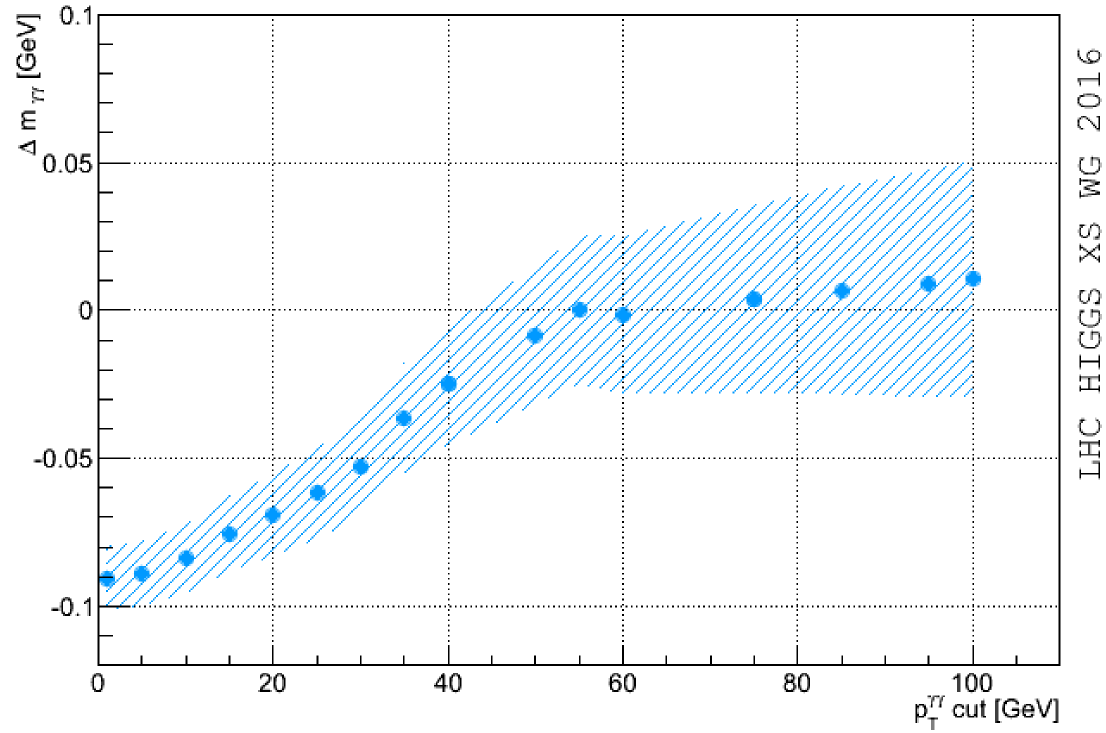
Mass Shift vs P_T cut

Mass shift dependence on a lower cut on the Higgs transverse p_T

→ Observed experimentally, completely within the γγ channel

arXiv:1305.3854v2





- Key Idea: Categorize events in two p_T bins and measure $\mathbf{\Delta m_H}$

  → Limited by statistics

Summary

- YR4 write-up will be finished by end of January

- A lot of work done on Hgg interference section already in a good shape

  → Additional studies to be added from ATLAS after internal approval

- Possibile improvements:

  1 → Study interference effects and mass shift varying the width of the Higgs

  2 → Look at VBF production (to discuss with Sherpa Authors)

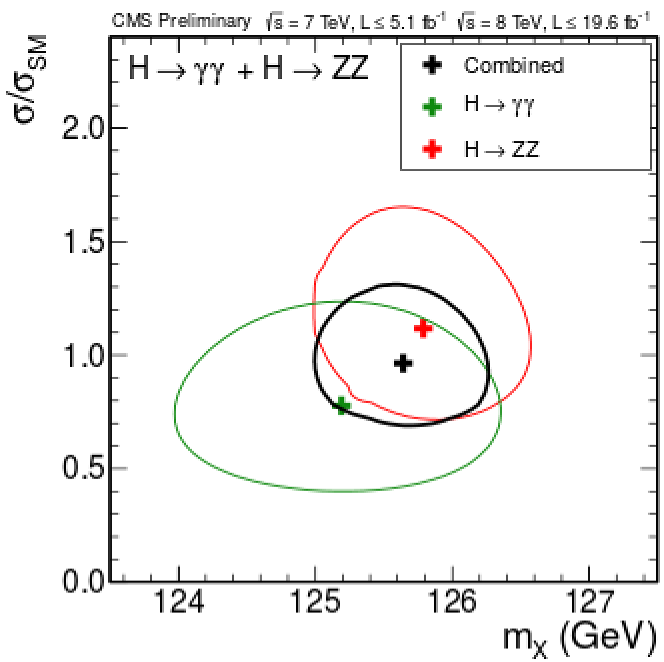
- Comments/inputs/suggestions are more than welcome

Backup

DIRE Details

Parton showers have been used for more than three decades to predict the dynamics of multi-
particle final states in collider experiments (17, 18). Recently, a new model was proposed (19),
which combines the careful treatment of collinear configurations in parton showers with the correct
resummation of soft logarithms in color dipole cascades (20–23). Following the basic ideas of the
dipole formalism, the ordering variable is chosen as the transverse momentum in the soft limit.
The evolution equations are based on the parton picture. Color-coherence is implemented by
partial fractioning the soft eikonal following the approach in (24), and matching each term to the
double logarithmically enhanced part of the DGLAP splitting functions. Enforcing the correct
collinear anomalous dimensions then determines all splitting kernels to leading order. Two entirely
independent implementations of this model have been provided, which can be used with the two
different event generation frameworks Pythia (25) and Sherpa (26, 27).

Higgs Mass Measurements

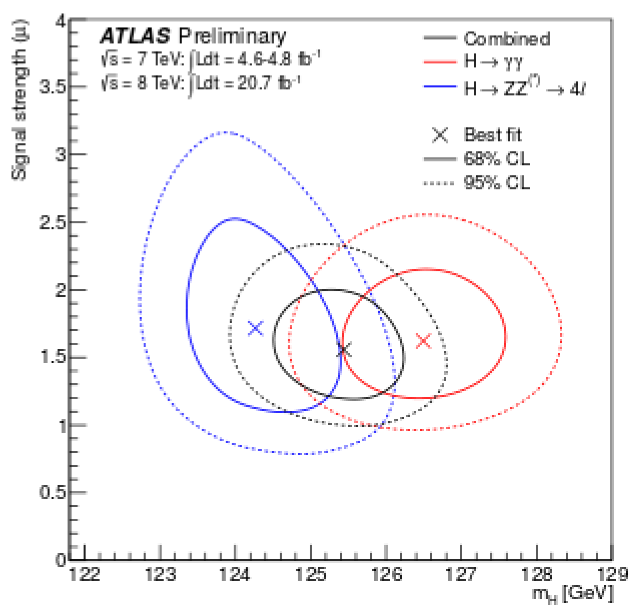


CMS M_H, stat, syst:

$125.4 \pm 0.5 \pm 0.6 \quad (H \to \gamma\gamma)$

$125.8 \pm 0.5 \pm 0.2 \quad (H \to ZZ^*)$

$125.7 \pm 0.3 \pm 0.3$ (combined)



ATLAS M_H, stat, syst:

$126.8 \pm 0.2 \pm 0.7 \quad (H \to \gamma\gamma)$

$124.3 \, ^{+0.6}_{-0.5} \, ^{+0.5}_{-0.3} \quad (H \to ZZ^*)$

$125.5 \pm 0.2 \, ^{+0.5}_{-0.6}$ (combined)

Mass Shift Formulas

$$\frac{c_{g\gamma}^2 S}{m_H \Gamma_H} + c_{g\gamma} I = \left(\frac{S}{m_H \Gamma_H^{\mathrm{SM}}} + I \right) \mu_{\gamma\gamma} \qquad c_{g\gamma} = \sqrt{\mu_{\gamma\gamma} \Gamma_H / \Gamma_H^{\mathrm{SM}}}$$

$$\begin{aligned} m_H^{\gamma\gamma} - m_H^{ZZ} &= +2.3^{+0.6}_{-0.7} \pm 0.6 \text{ GeV (ATLAS)} \\ &= -0.4 \pm 0.7 \pm 0.6 \text{ GeV (CMS)}, \end{aligned}$$