



# Interference Studies in the

# $H \rightarrow \gamma\gamma$ channel

*Livia Soffi*

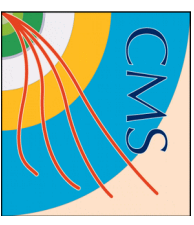
*on behalf of the*

*Off-shell and interference subgroup*



*Cornell University*

# 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 Beccot, et al.
  - Feasibility studies for HL-LHC [[ATL - PHYS - PUB - 2013 - 014](#)]
  - Studies at 8 TeV still under approval process

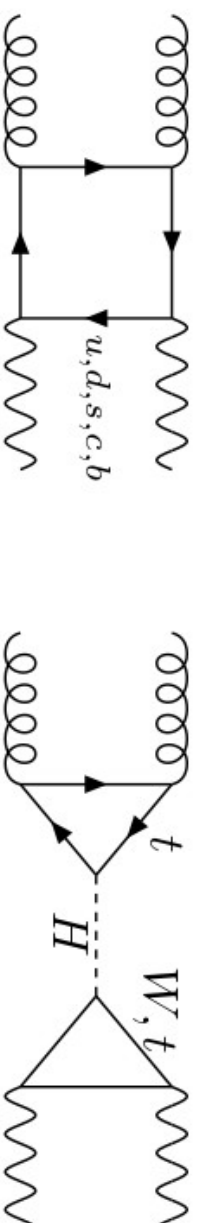
# Overview



- Study the coherent interference between the Higgs signal

$$ij \rightarrow X + H(\rightarrow \gamma\gamma) \quad \text{and the background } ij \rightarrow X + \gamma\gamma$$

$$gg \rightarrow \gamma\gamma:$$



- 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:**

$$\Delta m_H \text{ vs } \Gamma_H$$

- Two main issues related to Hgg Interference:

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

# Effects on size of total cross section



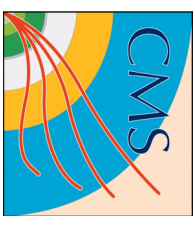
- Interference term to the total  $gg \rightarrow Y Y$  cross section

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

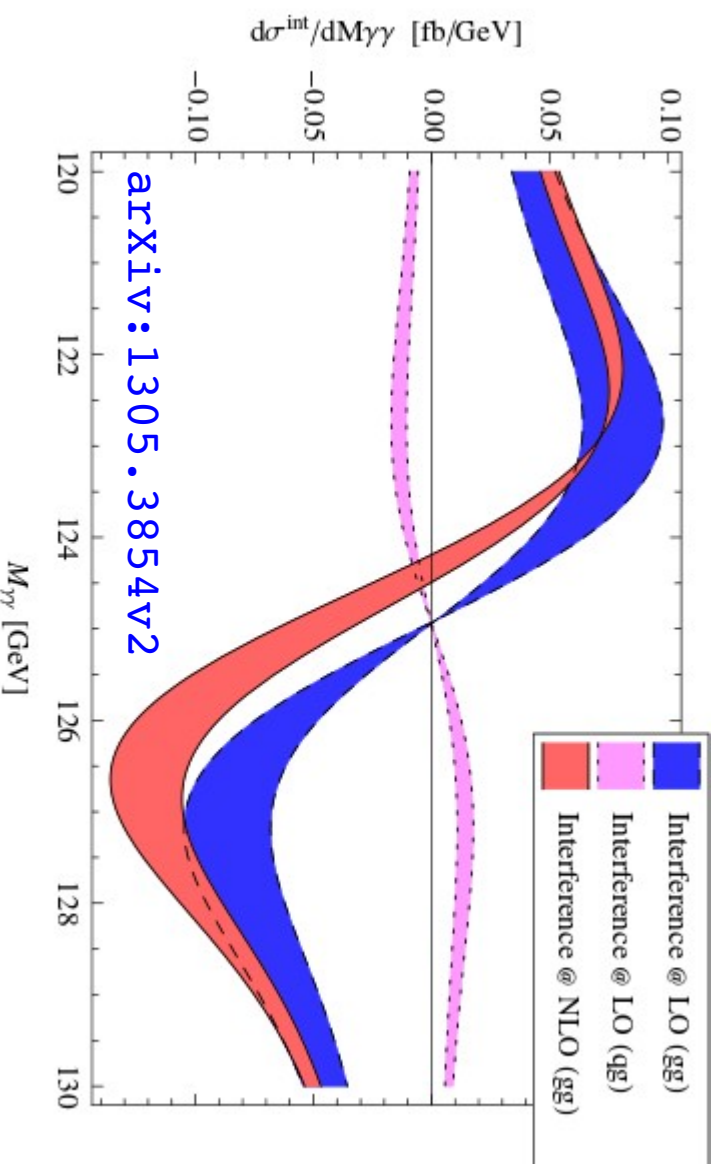
- Real term suppressed after integration under the narrow width hypothesis because odd in  $\hat{s}$
- Imaginary term small for quark mass suppression at LO
- Leading effect arises from the 2-loop order correction to the continuum amplitude.

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

# Effects on the shape



- Contribution of interference to  $H \rightarrow \gamma\gamma$  mass distribution.



- surplus of events for  $\hat{s} < M_H^2$  and a deficit for  $\hat{s} > M_H^2$   
→ **shifting the  $\gamma\gamma$  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](mailto: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

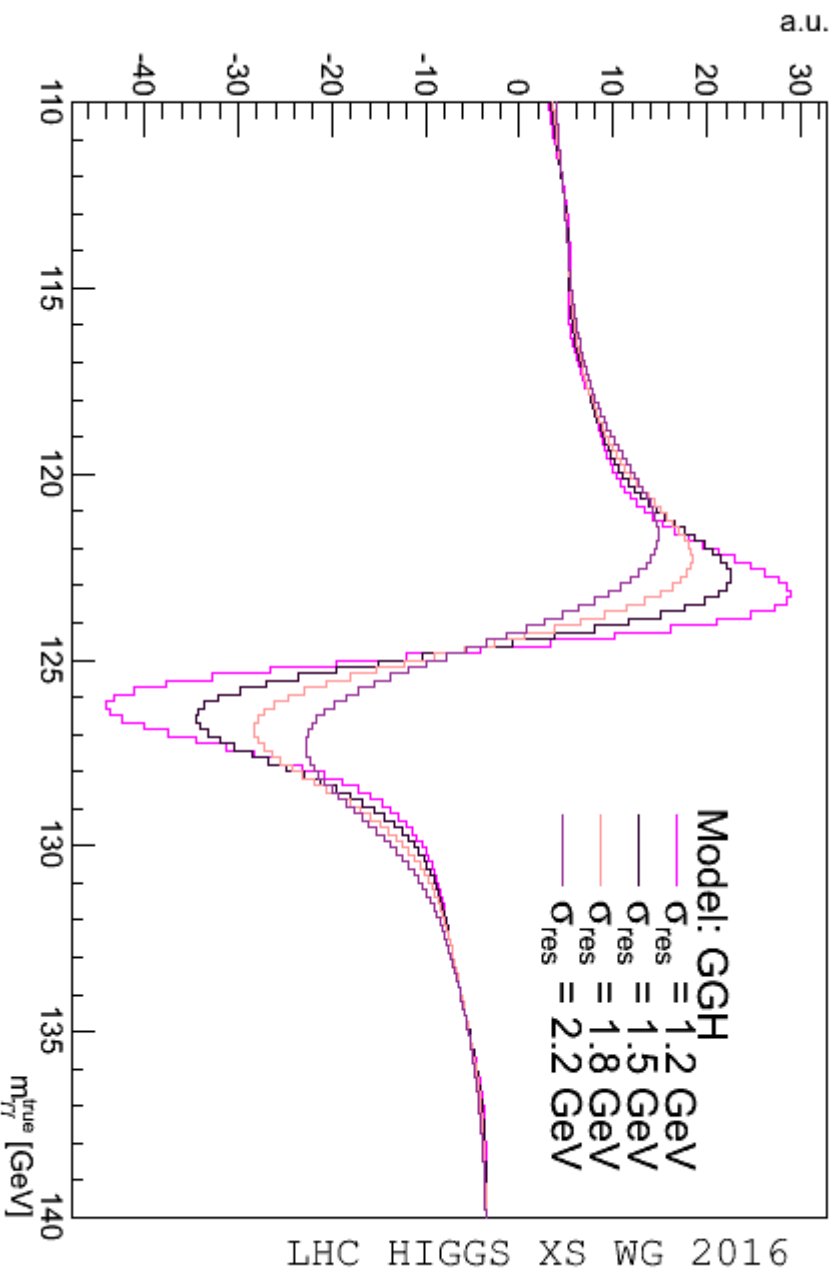


- So far considering only gluon fusion (GGH) process @ 13 TeV
- Assuming SM Higgs width of 4 MeV
- Applying basic “Higgs Finder” requirements:
  - $P_{T1} > 40 \text{ GeV}$
  - $P_{T2} > 30 \text{ GeV}$
  - $|\eta| < 2.5$
  - $M_{\gamma\gamma}$  in (100-150) GeV
  - Frizione Isolation in  $R = 0.4$
- 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**

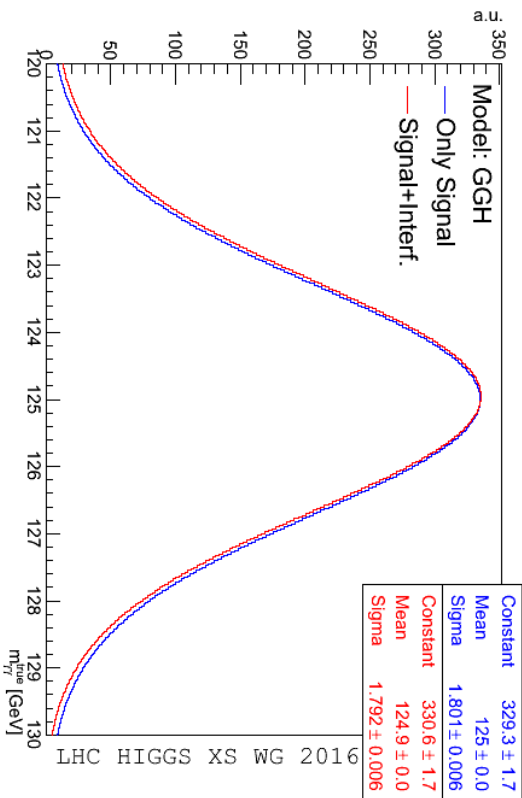




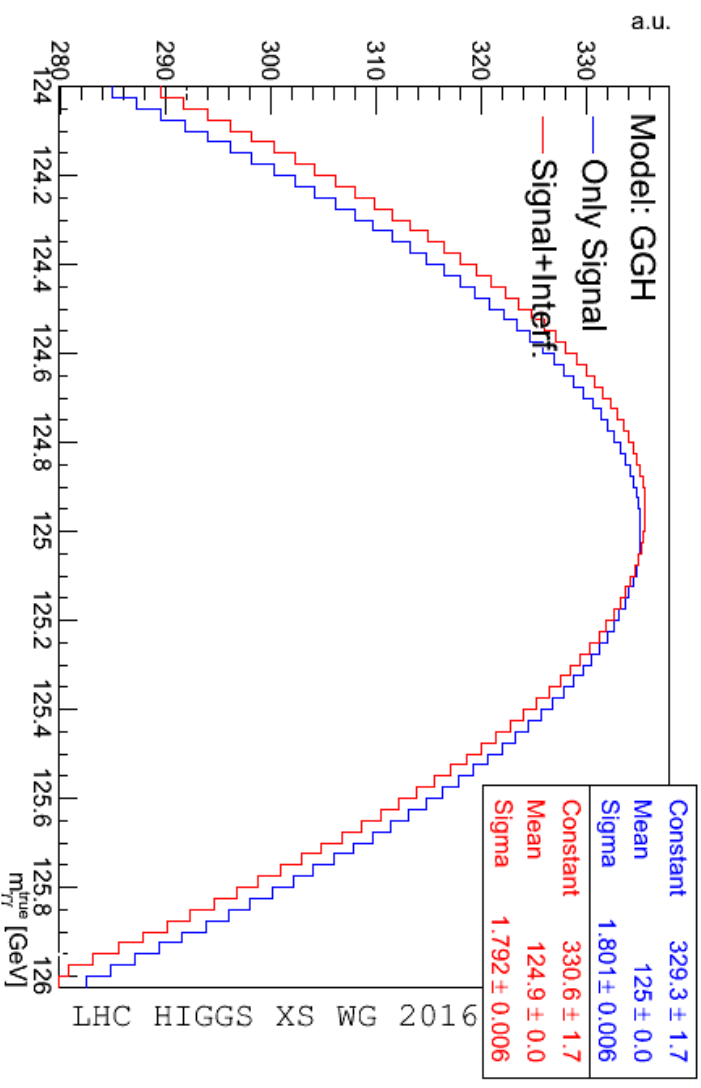
# Evaluate Mass Shift



- Compare signal **with** and **without** interference (for  $\sigma = 1.7\text{GeV}$ ):

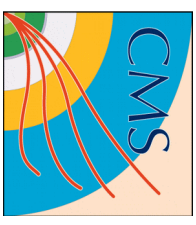


## Inclusive $\Delta m_H \sim -89 \text{ MeV}$



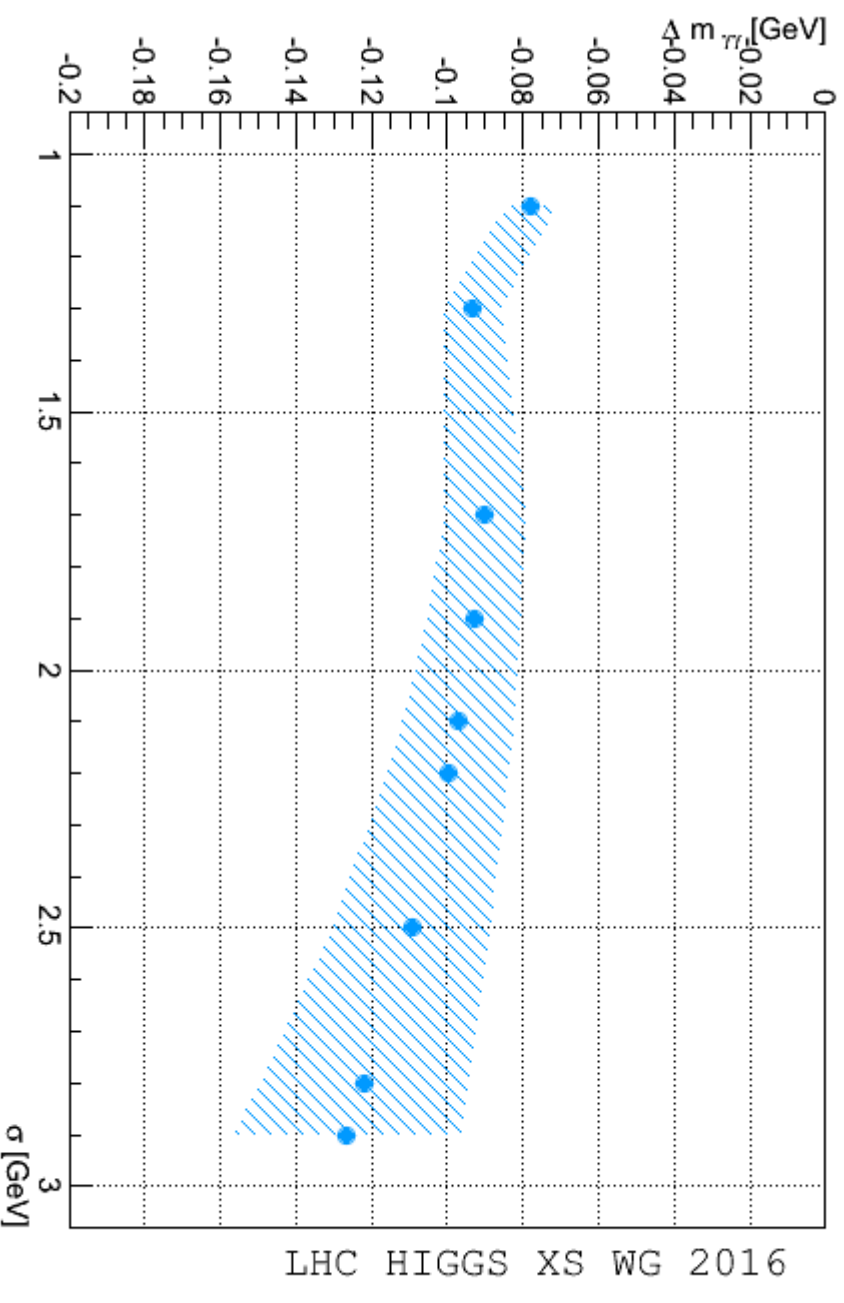
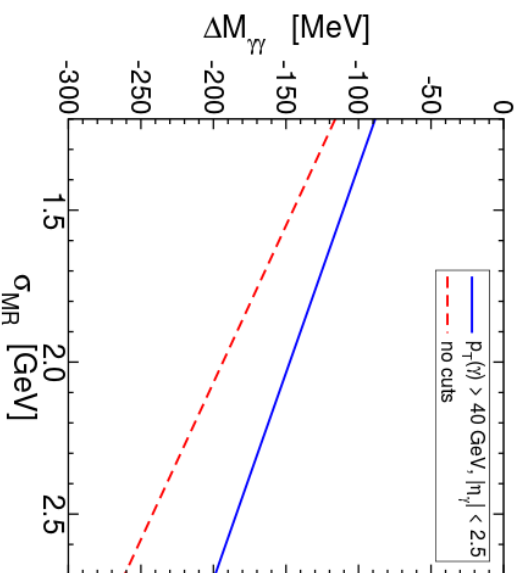
- @8 TeV  $\Delta m_H \sim -85 \text{ MeV}$  to be compared with  $-70 \text{ MeV}$  in [arxiv:1305.3854v2](https://arxiv.org/abs/1305.3854v2)

# Shift vs Detector smearing



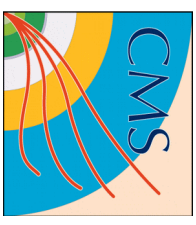
- Compare mass shift for difference detector resolutions

[arXiv:1303.3342](https://arxiv.org/abs/1303.3342)

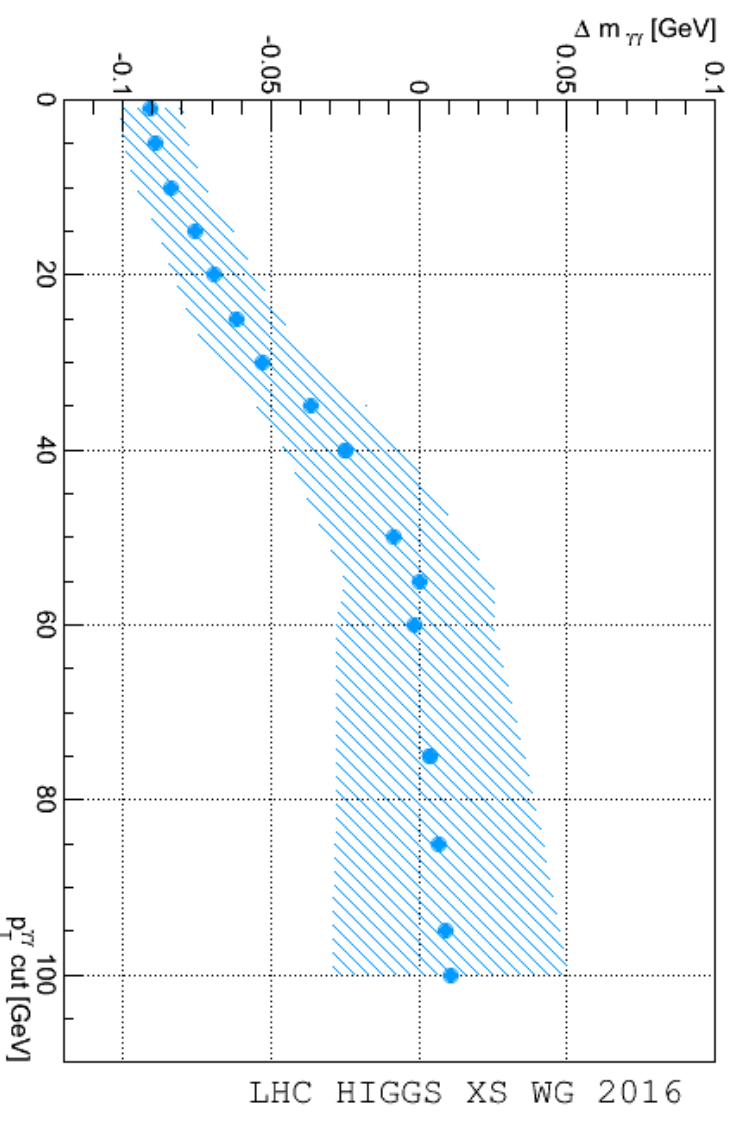
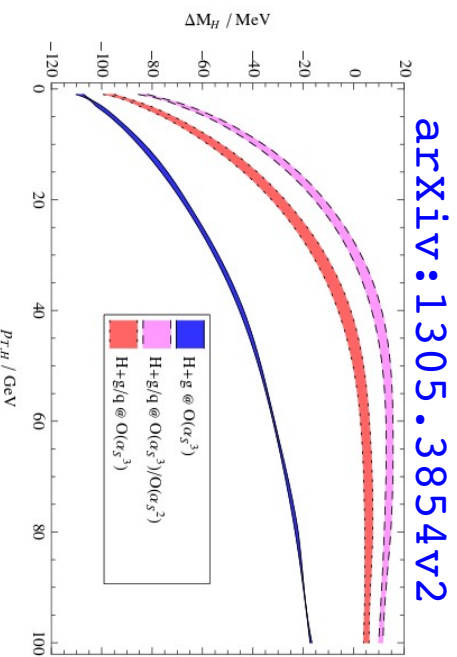


- Shift increases with mass resolution

# Mass Shift vs $P_T$ cut



Mass shift dependence on a lower cut on the Higgs transverse  $p_T$   
 → Observed experimentally, completely within the  $\gamma\gamma$  channel

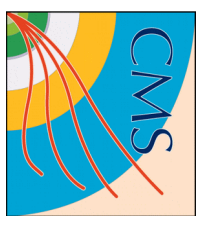


- Key Idea: Categorize events in two  $p_T$  bins and measure  $\Delta m_H$   
 → Limited by statistics

# 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
- Possible 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

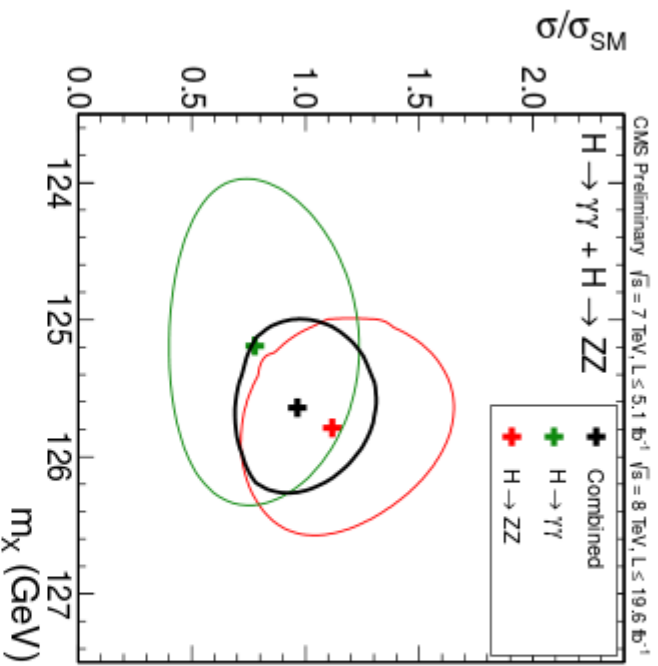
# DIRE Details



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

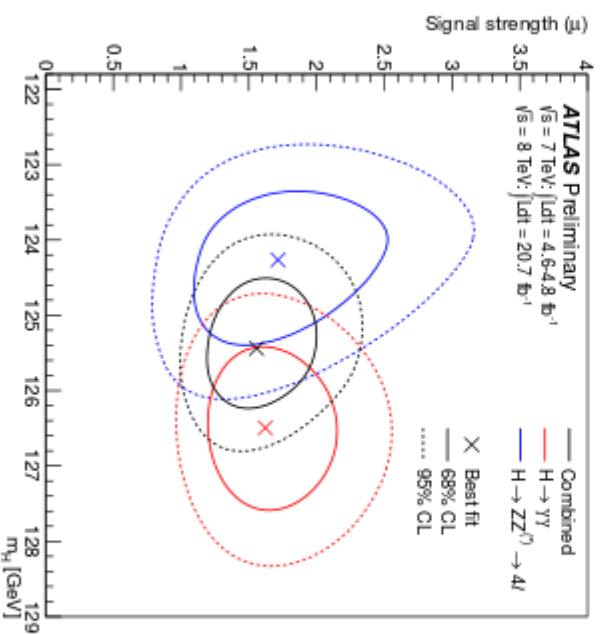


CMS  $M_H$ , stat, syst:

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

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

$$125.7 \pm 0.3 \pm 0.3 \quad (\text{combined})$$



ATLAS  $M_H$ , stat, syst:

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

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

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

# Mass Shift Formulas



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

$$m_H^{\gamma\gamma} - m_H^{ZZ} = +2.3_{-0.7}^{+0.6} \pm 0.6 \text{ GeV (ATLAS)}$$

$$= -0.4 \pm 0.7 \pm 0.6 \text{ GeV (CMS),}$$

