Offshell and Interference

experimental review

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LHC Higgs cross-section working group meeting, 7-July-2016

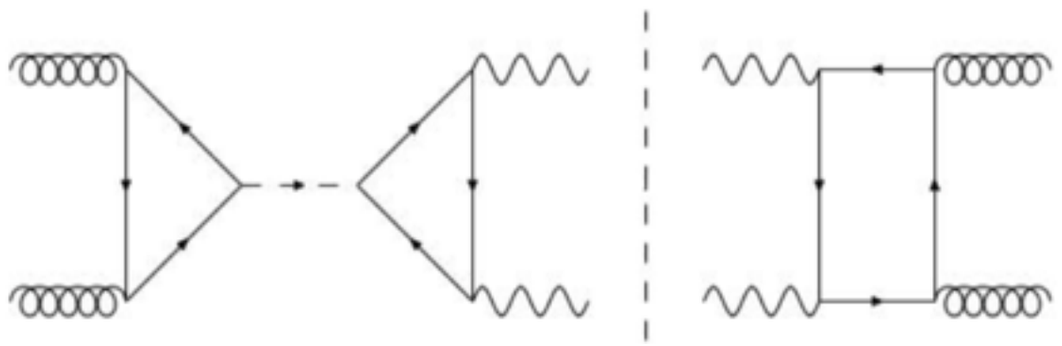
Overview

- Overall relatively lower activities within the experimental community
  - Run-1 results have been well established
  - Not an early Run-2 analysis experimentally
- Three new public results were produced
  - Estimate of mH shift due to interference ($gg \to \gamma\gamma$ and $gg \to H \to \gamma\gamma$) for $H \to \gamma\gamma$
    - ATL-PHYS-PUB-2016-009, https://cds.cern.ch/record/2146386
  - Studies of higher order corrections on the $gg \to H \to VV$
    - ATL-PHYS-PUB-2016-006: https://cds.cern.ch/record/2127515
  - CMS: "Search for Higgs boson off-shell production in proton-proton collisions at 7 and 8 TeV and derivation of constraints on its total decay width"
    - http://arxiv.org/abs/1605.02329

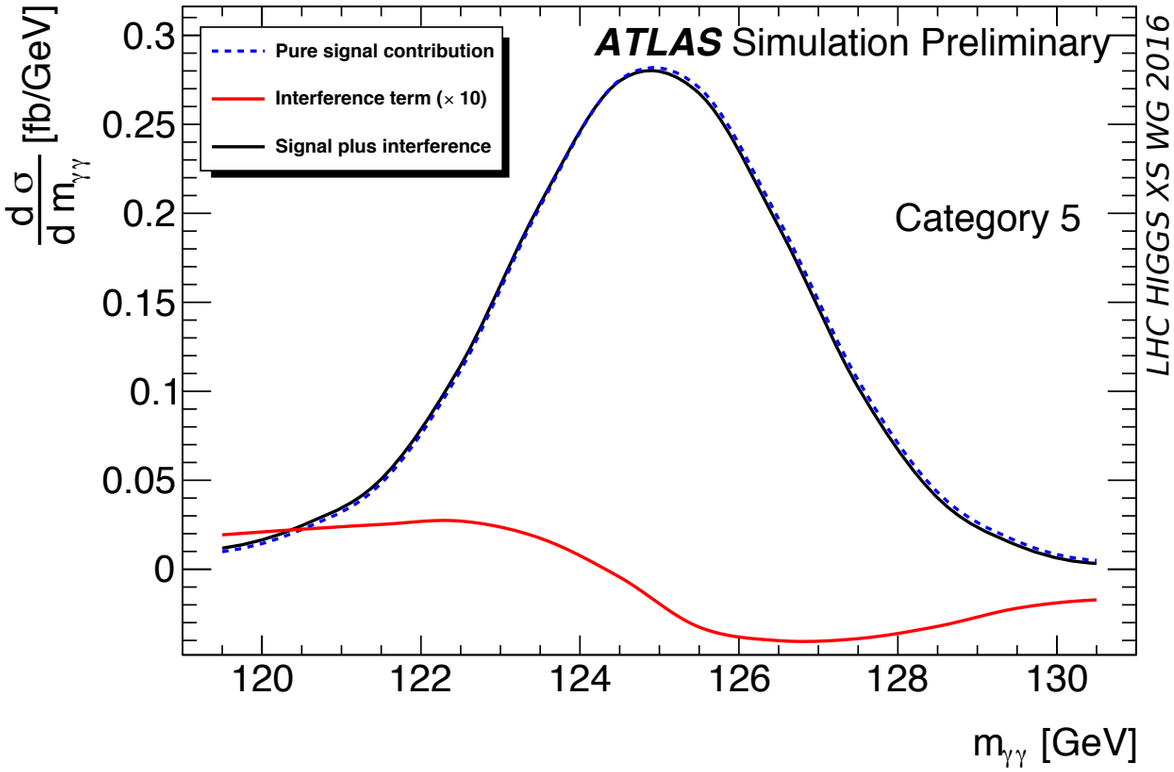
$H \to \gamma\gamma$ interference studies

Overview

- The imaginary part of the interference terms affect the overall yield by ~2%
  - Included in the H→γγ coupling analysis
- The real part of the interference terms change the line-shape of $m_{\gamma\gamma}$ → shift mH
  - Not included in the H→γγ coupling analysis
  - Quantify this shift using the correct detector description and event categorisation
    - Resolution, background shape and yield across different categories



	Conversion status	$\lvert\eta\rvert$ region	p_{T_t} cut
Category 1	Unconverted	Two γ in $\lvert\eta\rvert < 0.75$	$p_{T_t} < 70$ GeV
Category 2			$p_{T_t} > 70$ GeV
Category 3		Every other configurations	$p_{T_t} < 70$ GeV
Category 4			$p_{T_t} > 70$ GeV
Category 5		One γ in $1.3 < \lvert\eta\rvert < 1.8$	None
Category 6	Converted	Two γ in $\lvert\eta\rvert < 0.75$	$p_{T_t} < 70$ GeV
Category 7			$p_{T_t} > 70$ GeV
Category 8		Every other configurations	$p_{T_t} < 70$ GeV
Category 9			$p_{T_t} > 70$ GeV
Category 10		One γ in $1.3 < \lvert\eta\rvert < 1.8$	None



Experimental methods

- This analysis follows closely the well established mass measurement in the H→γγ channel
- Fit (S+B+I) data in the standard H→γγ mass measurement analysis
  - Generate (S+I) asimov data using Sherpa2.0, normalised to expectations in 8 TeV
  - Merge the S+I asimov data with the Background shape from data as in H→γγ analysis
- Compare with the fit results using S+B data
- Expected shift is 10 times smaller than the experimental resolution (500 MeV)

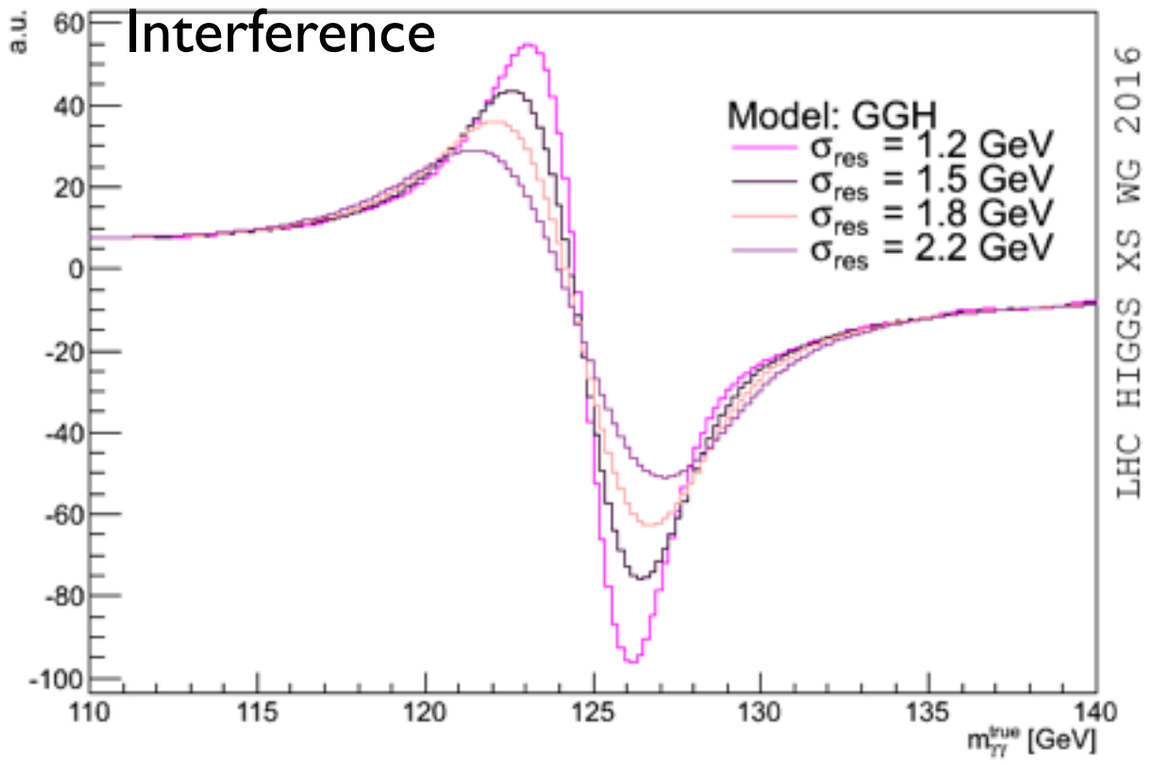
$$\Delta m_H = m_H^{S+I+B} - m_H^{S+B} = -35 \pm 0.3\,(\text{stat.})\,\text{MeV} \quad (1)$$

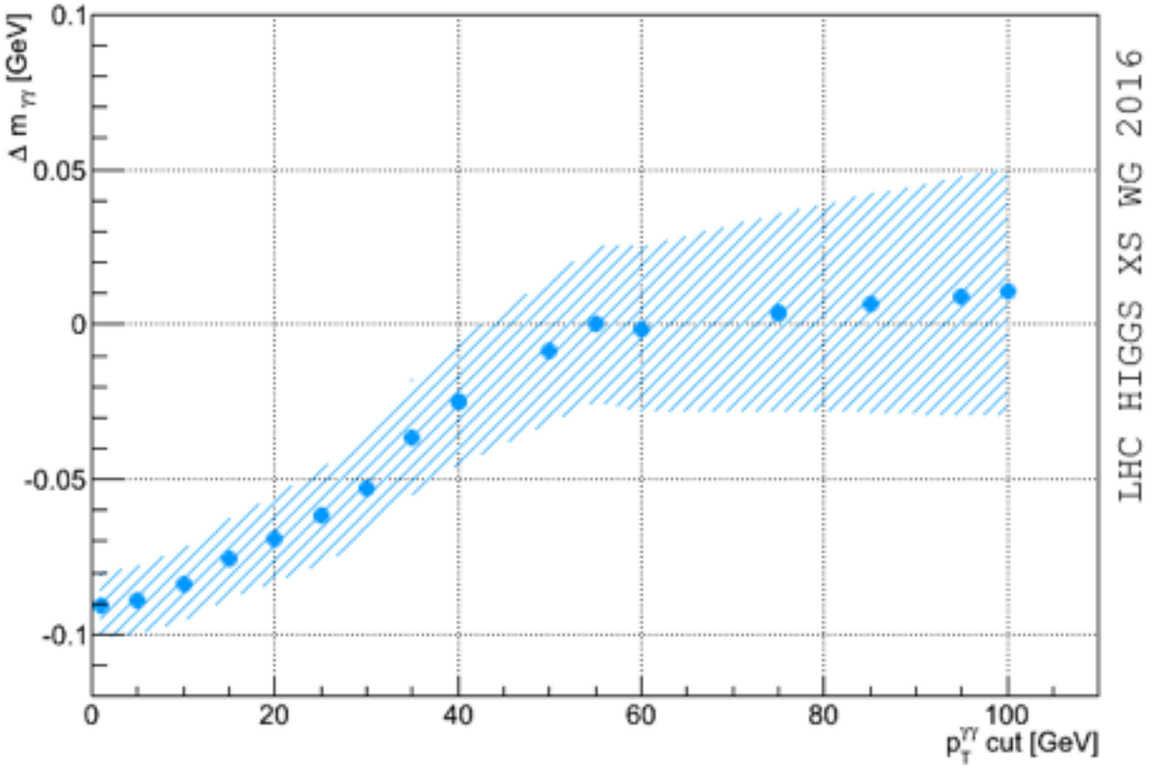
With/out interf.	Quantity	Sample 1	Sample 2	Sample 3	Sample 4	Mean	RMS
S+B	m_H	124.998	124.998	124.997	124.997		
	μ	0.995	0.995	0.995	0.994		
S+B+I	m_H	124.963	124.962	124.962	124.962		
	μ	0.988	0.988	0.988	0.988		
Δm_H [MeV]		-35	-35	-35	-35	-35	0.3

Table 2: Estimate of Δm_H using four different samples for signal and interference, and their averages

Additional generator level studies (L. Soffi)

- Generator level studies @ 13 TeV for signal and interference terms
  - Sherpa 2.2.0 + DIRE parton shower
- Gaussian smearing is used for photon energy resolution [1.2-2.2] GeV used
- Expected shift is calculated by compare the mass peak between S+I and S
  - ~ -90 MeV for the SM Higgs boson with realistic resolution of 1.7 GeV
  - Caveat not directly comparable to the ATLAS results



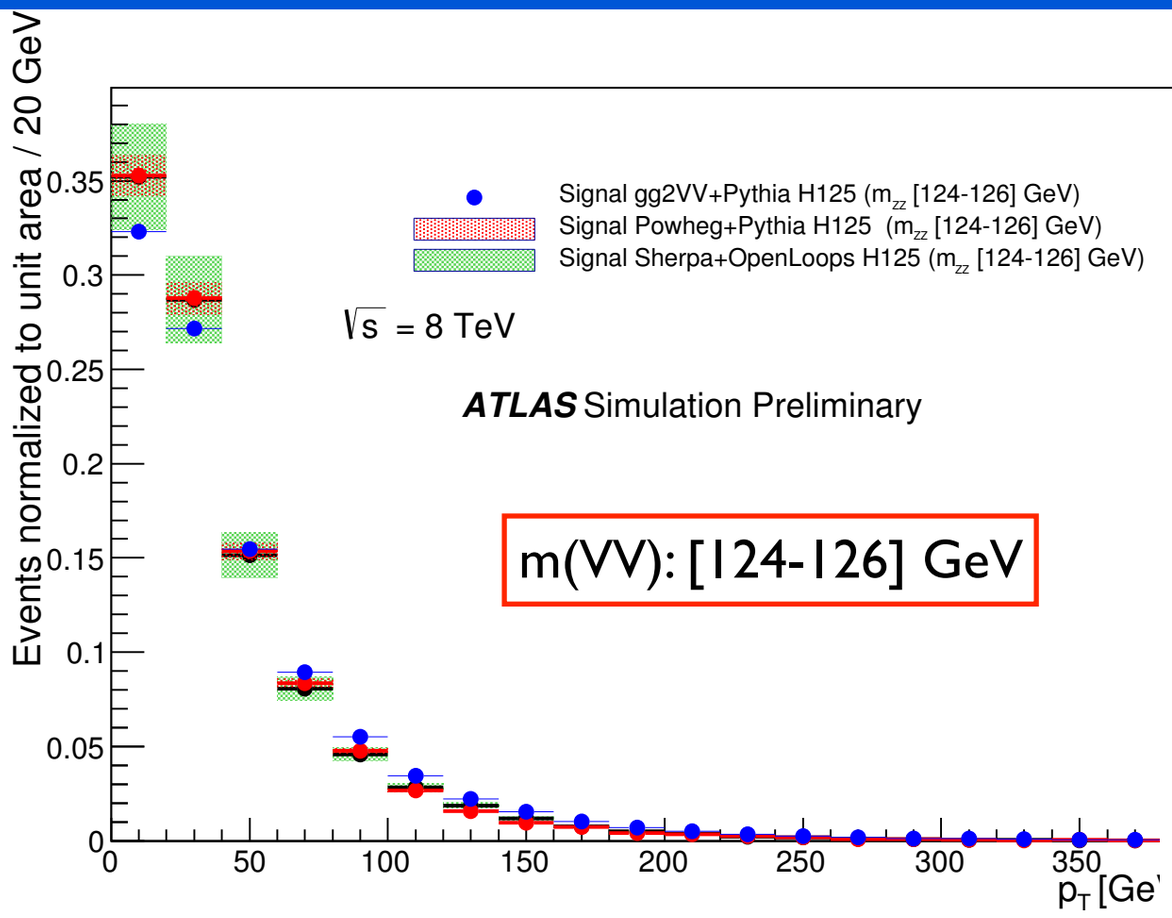


Higher order effect on $gg \rightarrow H \rightarrow VV$

Overview

- Offshell region relies on the LO MC: gg2VV and MCFM
  - Need to study the higher order impact, manifesting in the pT(VV), Y(VV)
    - Important for the analyses that depend on the pT(VV): ZZ→2l2ν and WW→lνlν
- Without the NLO@ ME, parton showering and scale uncertainties have been studied
  - gg2VV + pythia
  - Powheg + pythia
  - Sherpa2.0+OpenLoops
  - gg2VV+Herwig+Jimmy
- Different processes have been studied
  - Higgs (125) onpeak region
  - Higgs offshell region
  - Heavy Higgs signal in the H(125) offshell region

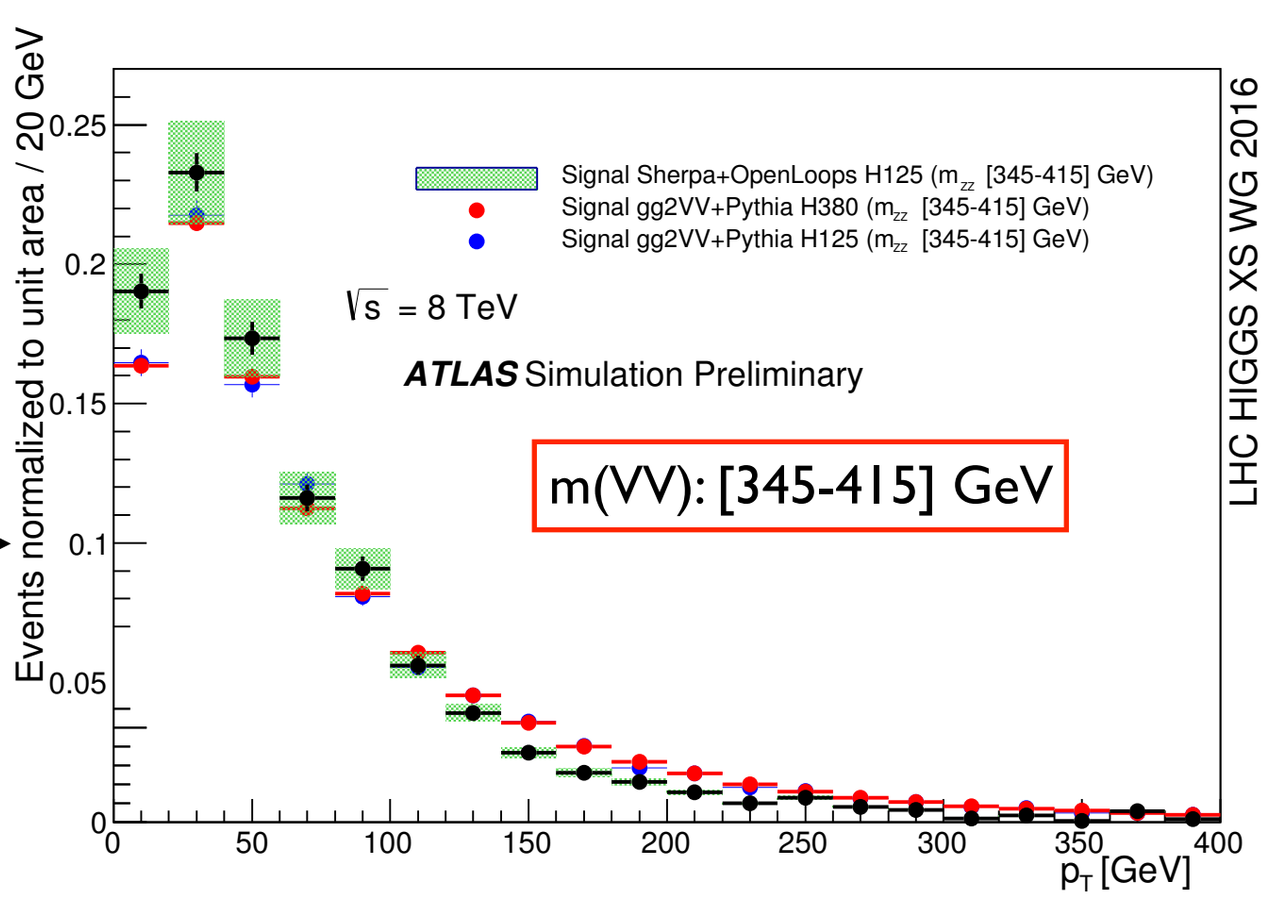
Compare different generators



Good agreement in the on-peak region
Sherpa+OpenLoops, gg2VV+Pythia, Powheg+Pythia

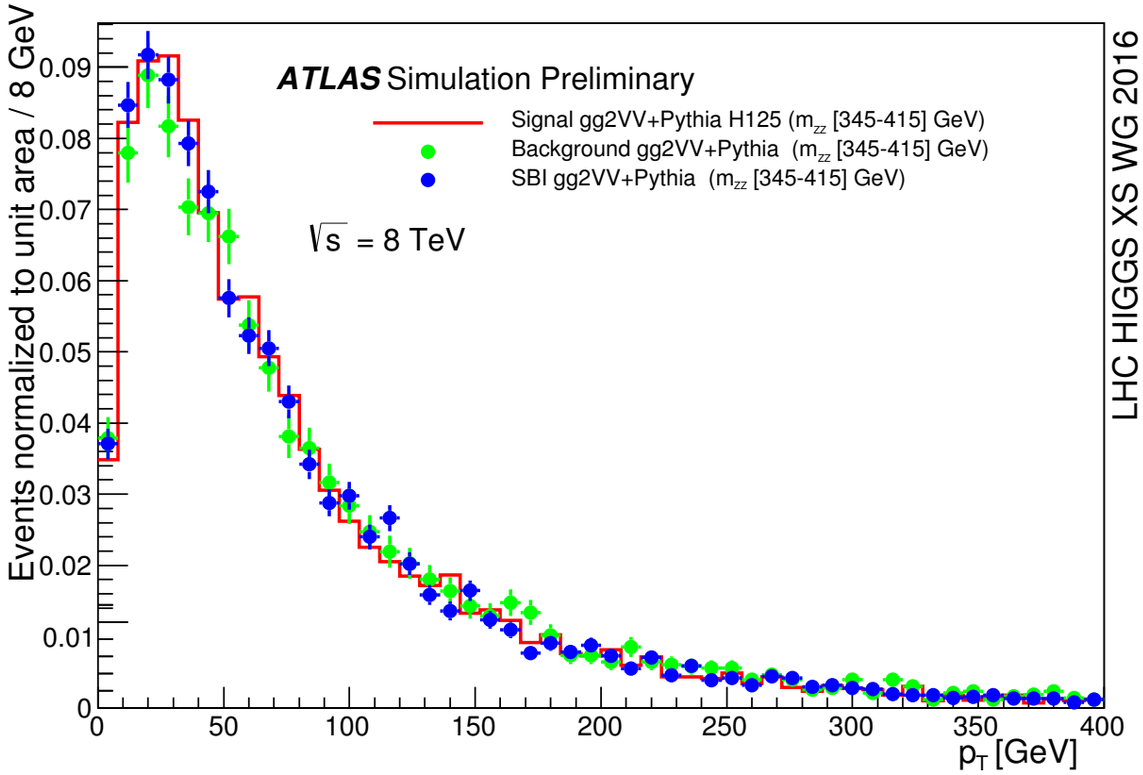
Reasonable agreement in the off-peak region

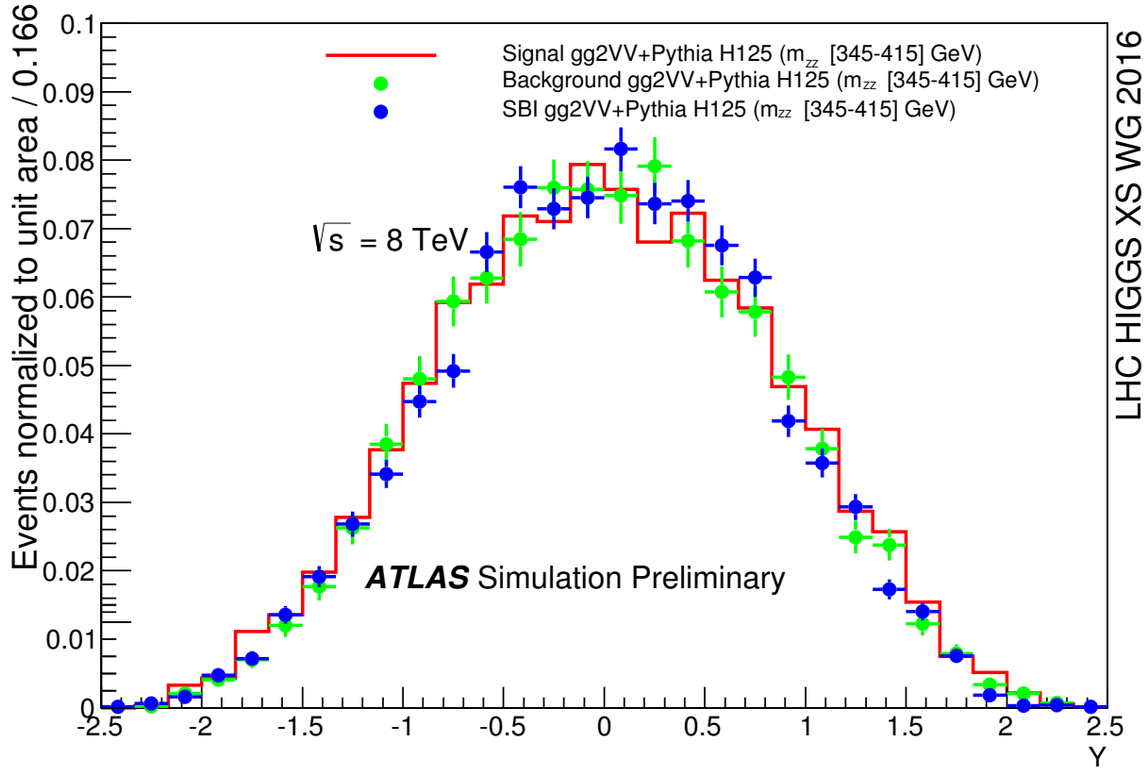
Sherpa+OpenLoops H125
gg2VV+Pythia H125
gg2VV+Pythia H380



Compare different processes in offshell region (gg2VV)

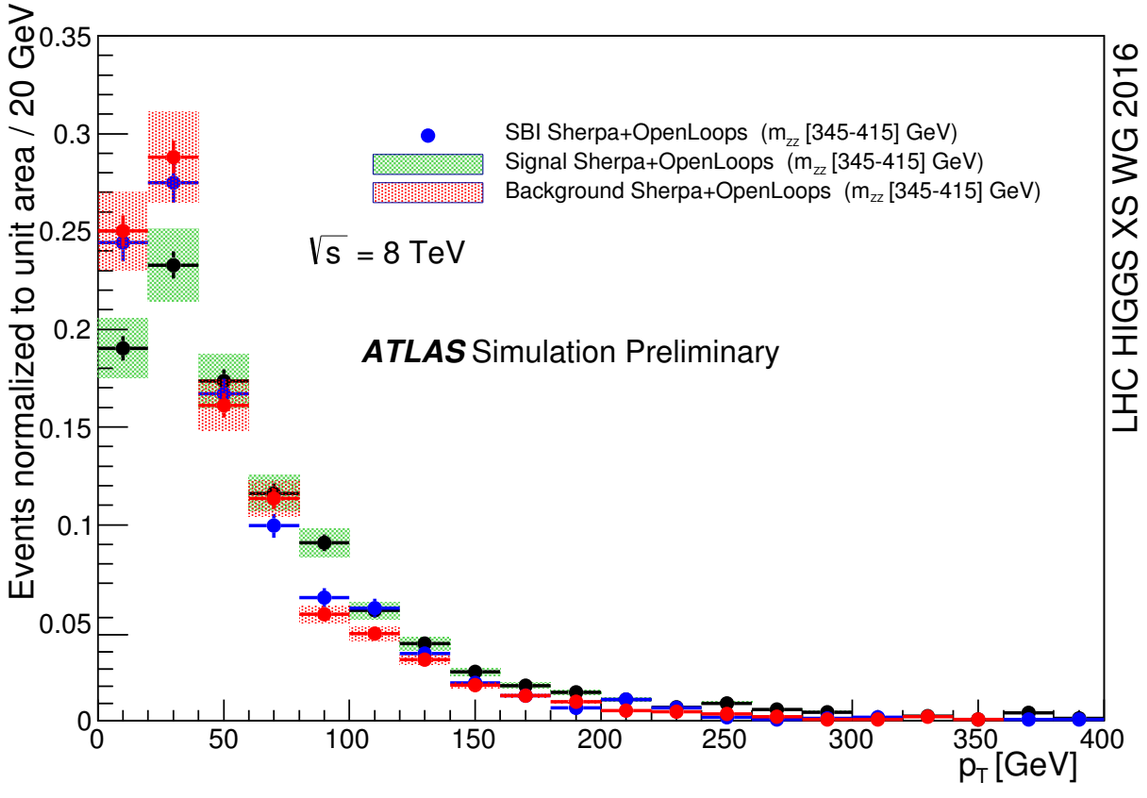
- Compare three processes in the H(125) offshell region mVV [345-415] GeV
  - All are simulated with LO gg2VV + pythia
  - Higgs signal, gg→VV background, and gg→VV (signal+interference+background)
  - Good agreement in both pT and rapidity of the VV system

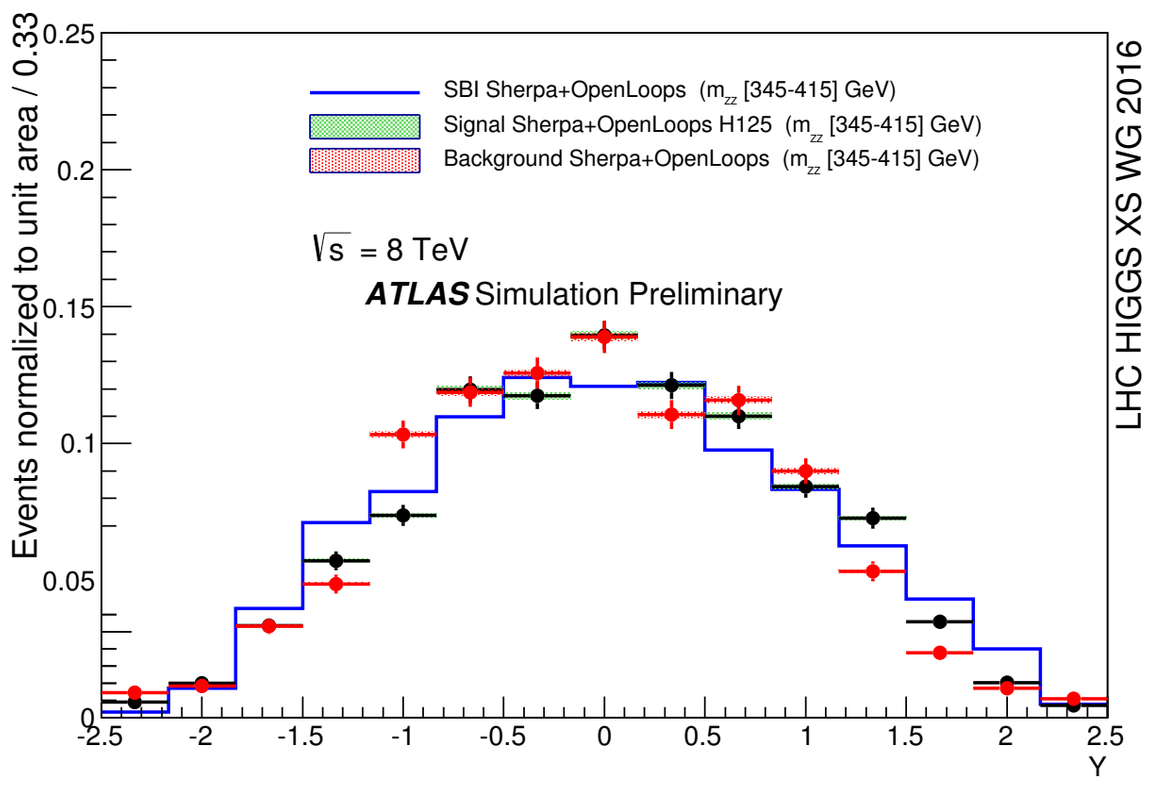




Compare different processes in offshell region (Sherpa+OpenLoops)

- Compare three processes in the H(125) offshell region mVV [345-415] GeV
  - All are simulated with Sherpa+OpenLoops
  - Higgs signal, gg→VV background, and gg→VV (signal+interference+background)
  - ~20% impact on the pT(VV)
  - Smaller difference in the rapidity

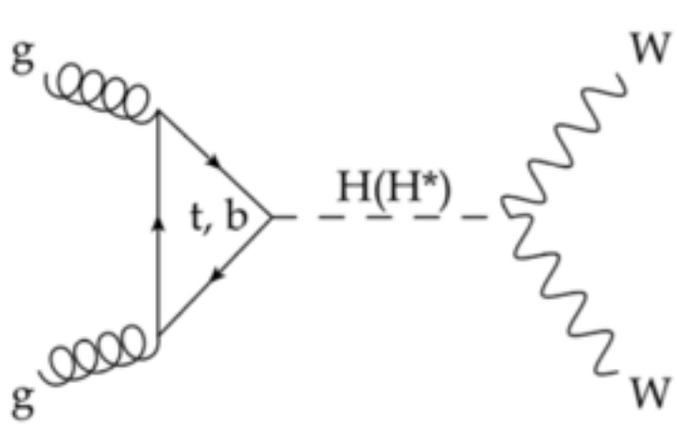


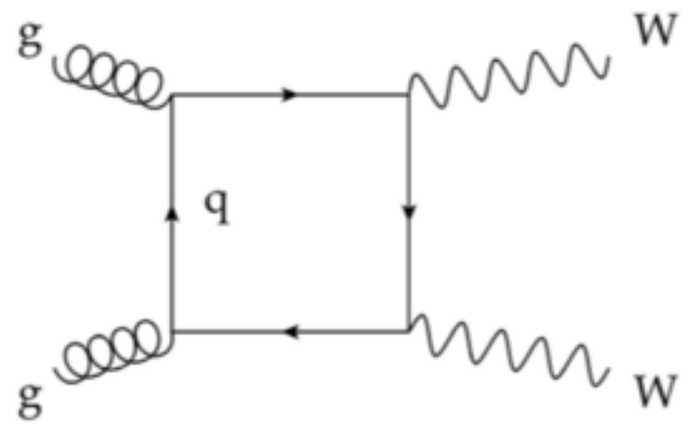


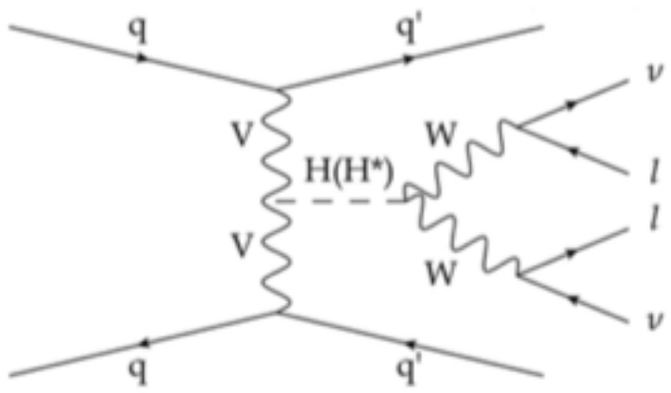
Offshell constraints from CMS

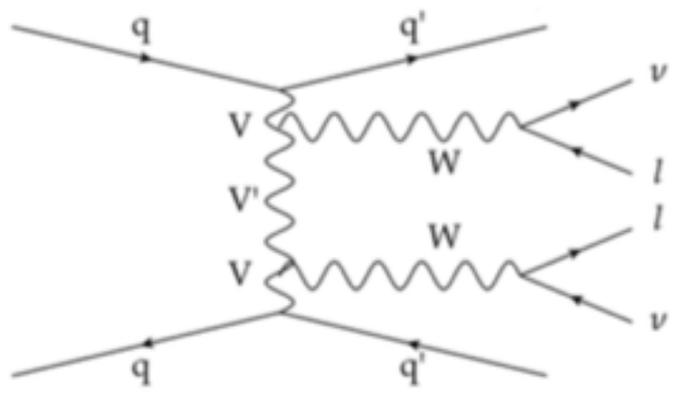
Overview

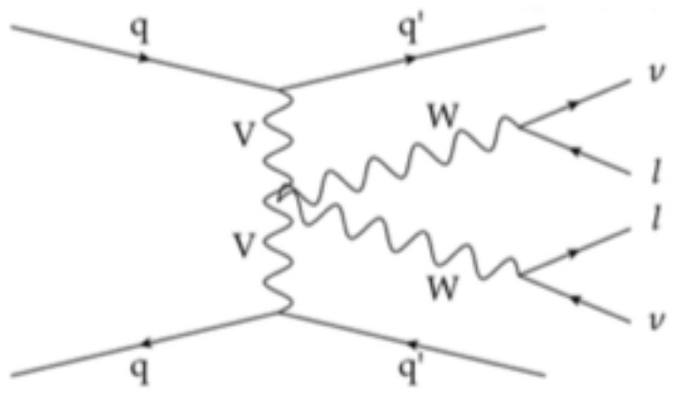
- Adding the WW channel
  - Based on well established HWW analysis for background estimations etc
- Perform a combined fit including ZZ(4l) and WW











Analysis overview

- Offshell Higgs coupling signal strength $\mu_{offshell}$

$$\begin{aligned}\mathcal{P}_{\text{tot}}(m_{\ell\ell}, m_{\text{T}}^{\text{H}}(\text{MVA})|\mu\text{s}) = & \mu_{\text{GF}}^{\text{off-shell}}\,\mathcal{P}_{\text{H, off-shell}}^{\text{gg}} + \sqrt{\mu_{\text{GF}}^{\text{off-shell}}}\,\mathcal{P}_{\text{int}}^{\text{gg}} + \mathcal{P}_{\text{bkg}}^{\text{gg}} \\ & + \mu_{\text{VBF}}^{\text{off-shell}}\,\mathcal{P}_{\text{H, off-shell}}^{\text{VBF}} + \sqrt{\mu_{\text{VBF}}^{\text{off-shell}}}\,\mathcal{P}_{\text{int}}^{\text{VBF}} + \mathcal{P}_{\text{bkg}}^{\text{VBF}} \\ & + \mu_{\text{GF}}\,\mathcal{P}_{\text{H, on-shell}}^{\text{gg}} + \mu_{\text{VBF}}\,\mathcal{P}_{\text{H, on-shell}}^{\text{VBF}} + \mathcal{P}_{\text{bkg}}^{\text{q}\bar{\text{q}}} + \mathcal{P}_{\text{other bkg}}.\end{aligned}$$

- A combination with $\mu_{onshell}$ gives the interpretation of Higgs width

- Additional kinematic variables are used to separate off-shell Higgs signal from the other background, in addition to dilepton mass

  - Most sensitive channels 0/1-Jet: MVA

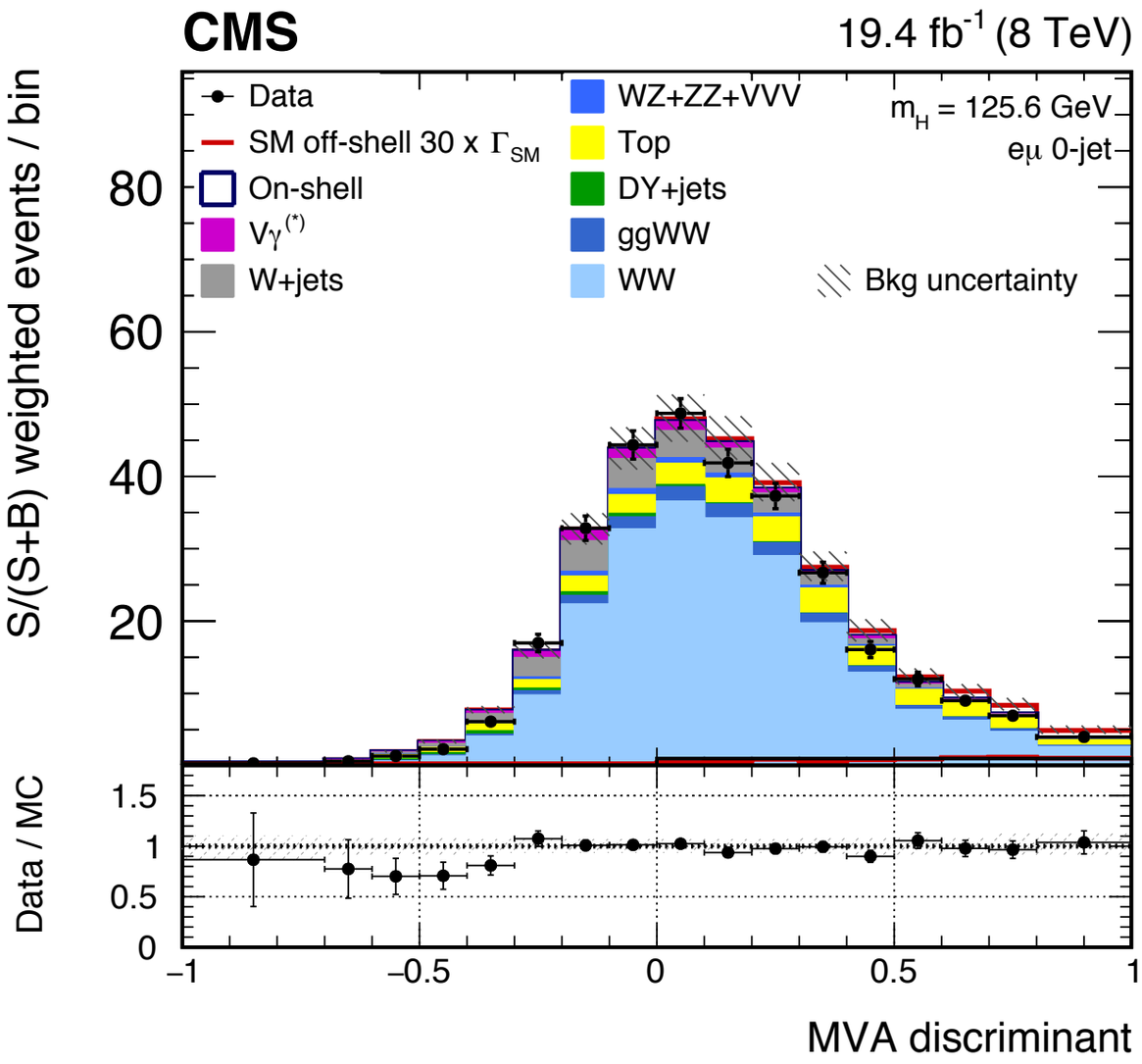
  - VBF 2-jet: transverse Higgs mass

Table 1: Analysis region definitions for on- and off-shell selections.

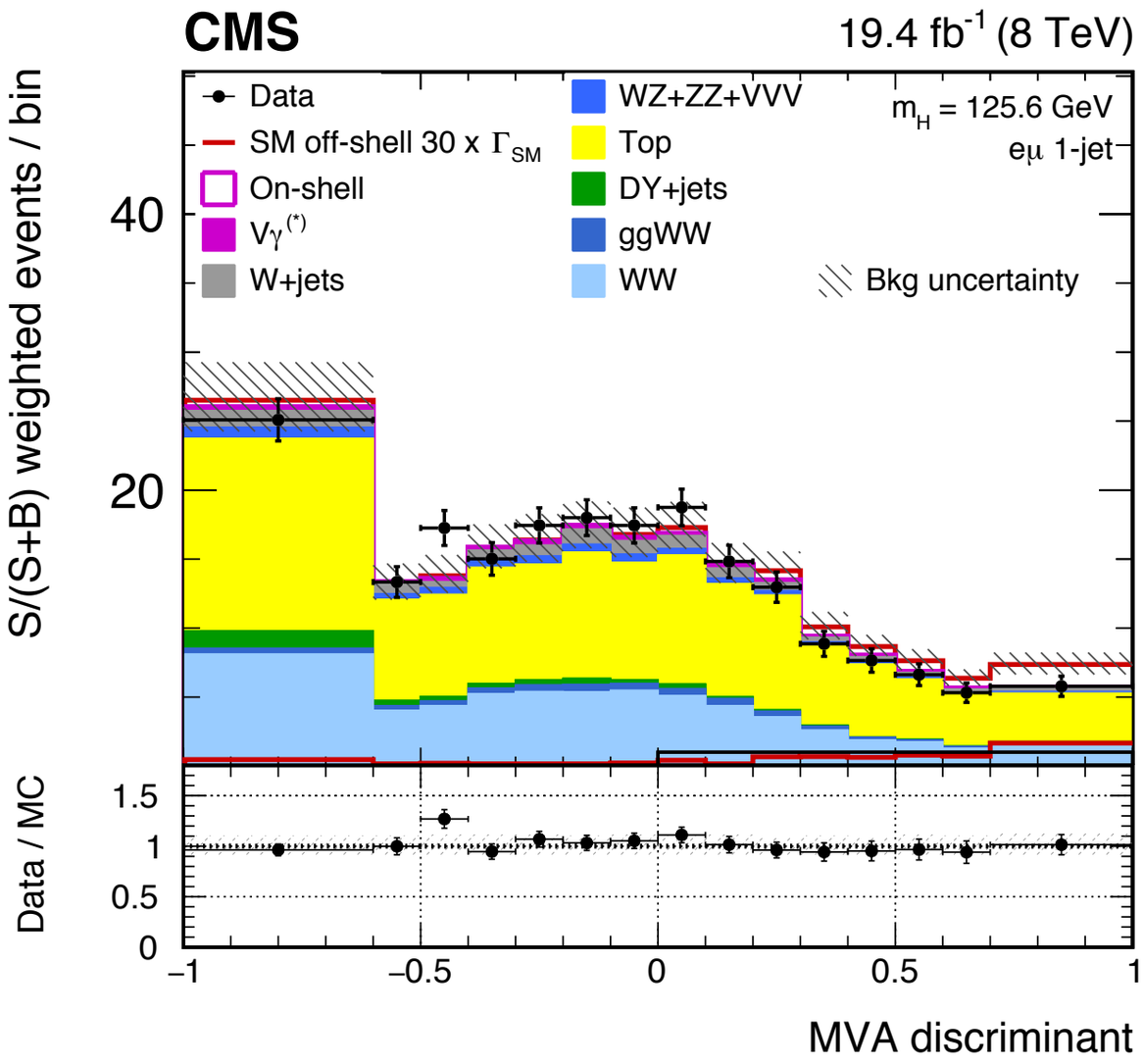
	On-shell (7, 8 TeV: all-jet)	Off-shell (8 TeV: 0,1-jet)	Off-shell (7 TeV: all-jet, 8 TeV: 2-jet)
$m_{\ell\ell}$	< 70 GeV	> 70 GeV	> 70 GeV
$p_{\text{T}}^{\ell\ell}$	> 30 GeV	> 45 GeV	> 45 GeV
$p_{\text{T}}{}^{\ell_2}$	> 10 GeV	> 20 GeV	> 20 GeV
fit Var.	$m_{\ell\ell}$, m_{T}^{H}	$m_{\ell\ell}$, MVA	$m_{\ell\ell}$, m_{T}^{H}

Offshell kinematic discriminant

MVA in 0-jet



MVA in 1-jet



No excess seen in the offshell region

Highlight of main results

- Deficit in the signal region leads to much stronger observed $\mu_{offshell}$ in WW channel
  - 95% C.L. limit on $\mu_{offshell}$ s 3.5(16.0) for observed (expected)
- Interpretations on the Higgs boson total width constraints are 13 MeV combining WW/ZZ
  - Expectation is 26 MeV