Search for $HH \rightarrow WW\gamma\gamma$ in semi-leptonic channel with ATLAS detector

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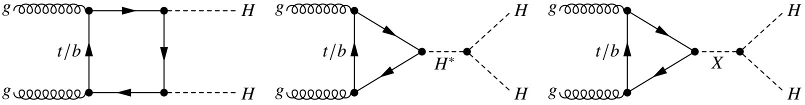
Outline

- Motivation
- Event Selection
- Signal and background estimation.
- Systematics
- Results

Motivation —Why HH

- Di-higgs search is important to
  - Measurement of Higgs self-coupling.
  - Search of Heavy Higgs, X particle in the diagram, in 2HDM and etc.
  - Anomolous coupling could enhance HH production.
- This study is searching for non-resonant and resonant HH production.



Motivation —Why $WW\gamma\gamma \to l\nu jj\gamma\gamma$

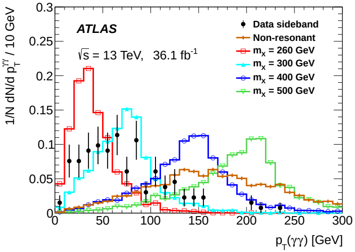
- Public result

channel	Branching ratio	ATLAS result	CMS result
4b	33.6%	36.1 fb^{-1}	35.9 fb^{-1}
WWbb	24.8%	36.1 fb^{-1}	35.9 fb^{-1}
4W	4.6%	36.1 fb^{-1}	-
$bb\tau\tau$	7.3%	36.1 fb^{-1}	35.9 fb^{-1}
$bb\gamma\gamma$	0.26%	36.1 fb^{-1}	35.9 fb^{-1}
$WW\gamma\gamma$	0.098%	36.1 fb^{-1}	-

- The advantage is :
  - Good mass resolution from diphoton and nice sideband to extract background in signal region.
  - Large branching ratio from WW
  - Good background rejection from semi-leptonic decay.

Event Selection

- Diphoton selection
  - Diphoton trigger
  - Two tight-ID, isolated photons
  - $p_{T\gamma1(2)}/m_{\gamma\gamma} > 0.35(0.25), 105 < m_{\gamma\gamma} < 160\ GeV$
- $WW \rightarrow l\nu jj$
  - B-veto and at least two jets
  - At least one lepton with $p_T > 10\ GeV$
- Further optimization
  - $p_{T\gamma\gamma} > 100\ GeV$ for $m_X = 400\ GeV$, $m_X = 500\ GeV$ and non-resonant.



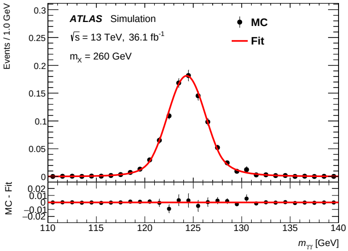
- Data sideband is used to model continuum background.
- SM Higgs is more boosted in $m_X = 400,\ 500\ GeV$ and non-resonant.

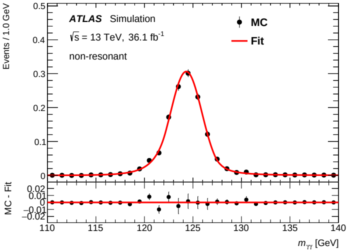
Signal estimation

- Signal efficiency : signal with higher m_X has higher efficiency.

	No $p_T^{\gamma\gamma}$ selection			$p_T^{\gamma\gamma} > 100$ GeV		
m_X [GeV]	260	300	400	400	500	Non-resonant
Acceptance × efficiency [%]	6.1	7.1	9.7	7.8	10	8.5

- Signal shape : Double-Sided Crystal Ball (DSCB)





Background estimation

- Background shape : 2nd-order exponential which has best χ^2passes spurious signal test.
  - Spurious signal is the fitted signal when perform a S+B fit to background-only sample. This is used to estimate the modeling uncertainty.
- Background yield in Higgs mass region is extracted from a fit to data sideband.

Process	Number of events	
	No $p_T^{\gamma\gamma}$ selection	$p_T^{\gamma\gamma} > 100$ GeV
Continuum background	22 ± 5	5.1 ± 2.3
SM single-Higgs	1.92 ± 0.15	1.0 ± 0.9
SM di-Higgs	0.046 ± 0.004	0.038 ± 0.004
Sum of expected background	24 ± 5	6.1 ± 2.5
Data	33	7

Systematics

- Spurious signal
  - 0.46 (0.26) with (without) $p_{T\gamma\gamma}$ cut
- The dominant systematics are
  - Spurious signal, e/γ energy scale and resolution

Source of uncertainties		Non-resonant HH	$X \to HH$	Single-H bkg $p_T^{\gamma\gamma} > 100$ GeV	Single-H bkg No $p_T^{\gamma\gamma}$ selection
Luminosity 2015+2016		2.1	2.1	2.1	2.1
Trigger		0.4	0.4	0.4	0.4
Event sample size		1.7	2.2	1.6	1.3
Pile-up reweighting		0.5	0.9	0.7	0.6
Photon	identification	1.7	1.4	0.8	0.8
	isolation	0.8	0.7	0.4	0.4
	energy resolution	0.1	0.1	0.2	<0.1
	energy scale	0.2	<0.1	0.2	<0.1
Jet	energy scale	4.0	9.9	2.4	2.6
	energy resolution	0.1	1.6	0.5	1.0
b-tagging	b-hadron jets	<0.1	<0.1	3.8	3.6
	c-hadron jets	1.5	1.0	0.7	0.6
	light-flavour jets	0.3	0.3	0.1	0.1
	extrapolation	<0.1	<0.1	0.1	<0.1
Lepton	electron	0.5	0.7	0.2	0.2
	muon	0.5	0.7	0.3	0.5
Theory	PDF on σ	2.1	-	3.4	3.4
	α_S on σ	2.3	-	1.3	1.3
	scale on σ	6.0	-	0.9	0.9
	HEFT on σ	5.0	-	-	-
	scale on $\epsilon \times A$	2.8	2.5	-	-
	PDF on $\epsilon \times A$	3.0	2.4	-	-
	parton shower on $\epsilon \times A$	7.8	29.6	-	-
	$B(H \to \gamma\gamma)$	2.1	2.1	2.1	2.1
	$B(H \to WW^*)$	1.5	1.5	1.5	1.5
Total		13.6	31.8	7.1	6.8

Results

- Observed 36.1 fb^{-1} data and fit

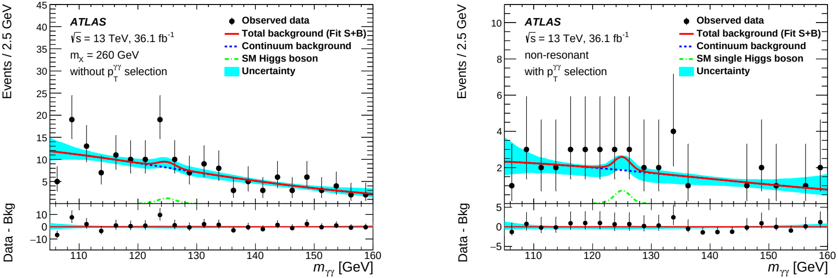
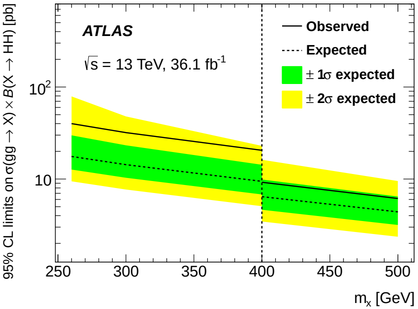


Figure 1: Left plot is without $p_{T\gamma\gamma}$ cut and right plot is with $p_{T\gamma\gamma}$ cut. The fit includes all the components and systematic uncertainties.

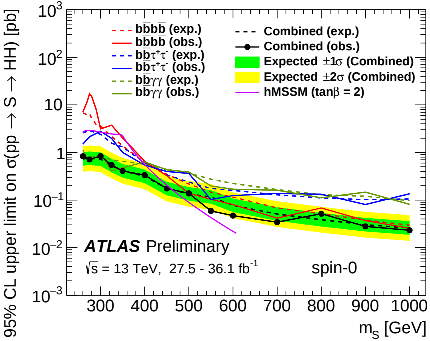
Upper limit

- Expected upper limit on $pp \rightarrow HH$ is 7.7pb for non-resonant and varies from 17.6pb ($m_X = 260\ GeV$) to 4.4pb ($m_X = 500\ GeV$) for resonant.
- The jump at $m_X = 400\ GeV$ is due to $p_{T\gamma\gamma}$ cut.



Discussion on the results

- Compare with other HH channel
  - $WW\gamma\gamma$ is not the best!
- Next step : We need improvements!
  - Re-optimize semi-leptonic channel
  - Include full-leptonic channel
  - Investigate other model like $pp \to\to X \to S(\to WW)H(\to \gamma\gamma)$.



Summary

- Review the 36.1 fb^{-1} $WW\gamma\gamma$ analysis
  - Upper limit is set and the study has been published at Eur. Phys. J. C 78 (2018) 1007
- Discuss the plan
  - Re-optimize semi-leptonic channel
  - Include full-leptonic channel
  - Investigate other model like $pp \to X \to S(\to WW)H(\to \gamma\gamma)$.