

Higgs Pair Production at HL-LHC.

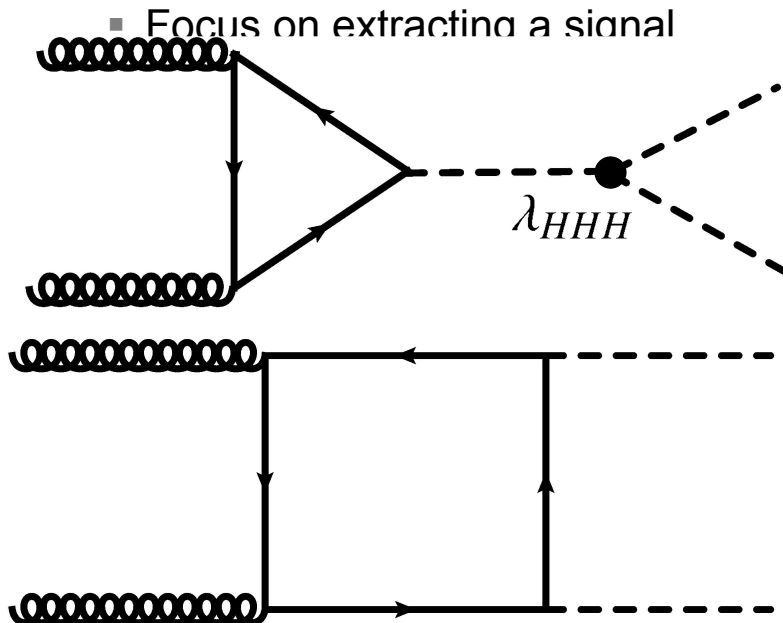
Prospects for Higgs pair production in the channel $HH \rightarrow b\bar{b}\gamma\gamma$



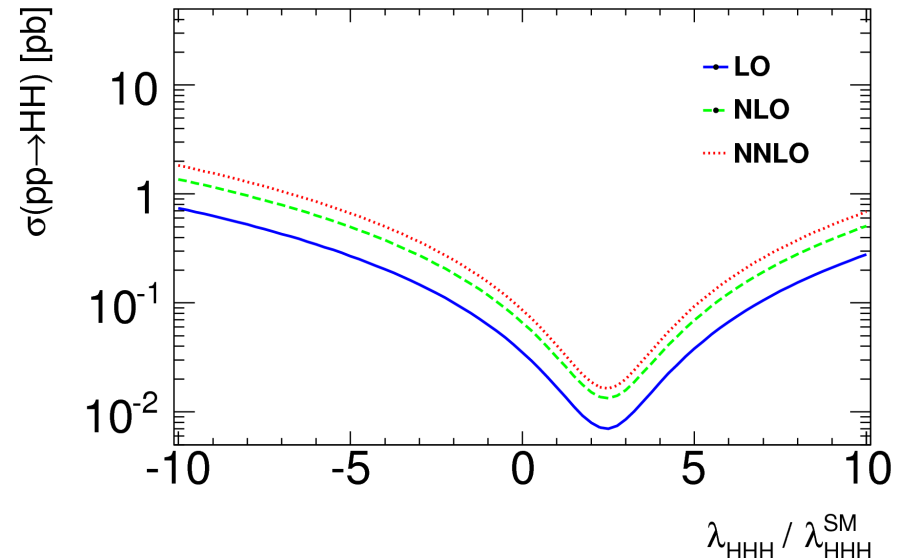
N. Styles, presenting work from the ATLAS Higgs Prospects group
HH Subgroup Meeting
08/12/14

Introduction

- > Self coupling is a fundamental property of the SM Higgs field
 - To understand if observed Higgs boson is really SM, must measure this coupling as well as its coupling to other particles
- > Self-coupling strength can be determined by measuring Higgs pair production cross-section
 - Destructive interference between diagrams with and without self-interaction
- > NB Analysis is not currently optimised specifically for sensitivity to λ_{HHH}



N.



Self Coupling at HL-LHC

Decay Channel	Branching Ratio	Total Yield (3000 fb ⁻¹)
$b\bar{b} + b\bar{b}$	33%	40,000
$b\bar{b} + W^+W^-$	25%	31,000
$b\bar{b} + \tau^+\tau^-$	7.3%	8,900
$ZZ + b\bar{b}$	3.1%	3,800
$W^+W^- + \tau^+\tau^-$	2.7%	3,300
$ZZ + W^+W^-$	1.1%	1,300
$\gamma\gamma + b\bar{b}$	0.26%	320
$\gamma\gamma + \gamma\gamma$	0.0010%	1.2

> Total (SM) NNLO cross-section 40.8 fb⁻¹

- Need large HL-LHC data sample to have a good chance of measuring this process

> A wide variety of final states available

- High branching fraction modes are largely swamped by backgrounds
- $b\bar{b}\gamma\gamma$ chosen as promising mode for study due to clean $\gamma\gamma$ signature

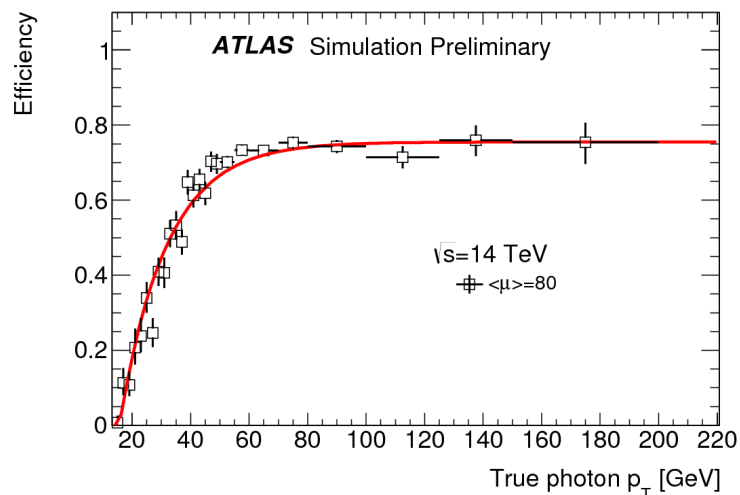
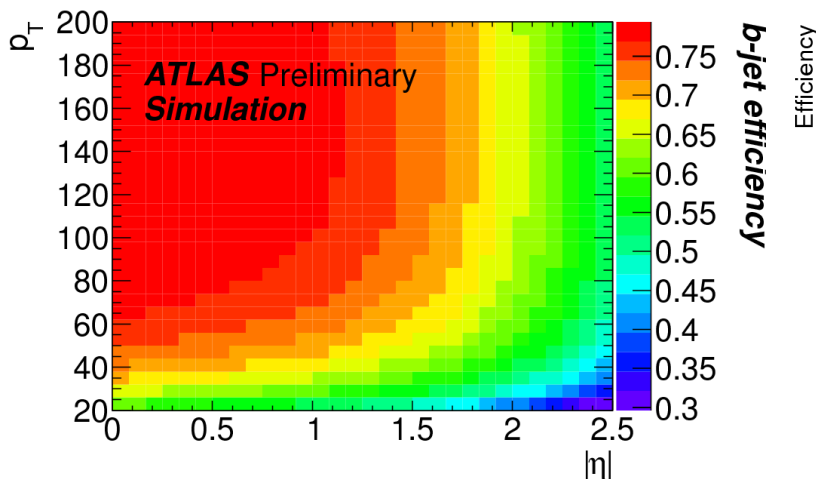
> Final measurement will use combination of final states

- $b\bar{b}\tau\tau$, $WW\tau\tau$ and others are also under study



HL-LHC performance & object definitions

- Full simulation not available for signal plus all backgrounds under HL-LHC conditions
 - Performance parameterisations extracted from benchmark samples, and applied to generator-level particle 4-vectors
 - ATL-PHYS-PUB-2013-009, ATL-PHYS-PUB-2013-004
 - Momentum smearings, efficiency functions, fake rates, etc...
- Probabilities for $e \rightarrow \gamma$ fakes not described in notes
 - After discussion, took assumption that performance will be ~similar to today
 - Apply 2/5 % for barrel/endcap



Monte Carlo Samples

Samples	Generated/ Showered With	$\sigma \cdot BR$ (fb)	Order pQCD	Generated Events	Equivalent Lum. (fb ⁻¹)
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 1)$	MadGraph5/Pythia8	0.11	NNLO	3×10^5	2.8×10^6
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 0)$	MadGraph5/Pythia8	0.23	NNLO	3×10^5	1.3×10^6
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 2)$	MadGraph5/Pythia8	0.05	NNLO	3×10^5	6.1×10^6
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 10)$	MadGraph5/Pythia8	1.81	NNLO	3×10^5	0.2×10^6
$b\bar{b}\gamma\gamma$	MadGraph5/Pythia8	338	LO	4.0×10^6	1.2×10^4
$c\bar{c}\gamma\gamma$	MadGraph5/Pythia8	1.6×10^3	LO	1.8×10^7	1.2×10^4
$b\bar{b}\gamma j$	MadGraph5/Pythia8	2.6×10^5	LO	1.9×10^7	72
$b\bar{b}jj$	MadGraph5/Pythia8	9.4×10^7	LO	4.9×10^5	5.2×10^3
$jj\gamma\gamma$	MadGraph5/Pythia8	2.2×10^4	LO	4.6×10^7	2×10^3
$t\bar{t}(\geq 1 \text{ lepton})$	MC@NLO/Herwig	5.3×10^5	NNLO	1.5×10^7	280
$t\bar{t}\gamma$	MadGraph5/Pythia8	3.3×10^3	LO	6.2×10^6	1.9×10^3
$t\bar{t}H(\gamma\gamma)$	POWHEG/Pythia8	1.39	NLO	1.2×10^5	8.4×10^4
$Z(b\bar{b})H(\gamma\gamma)$	Pythia8	0.304	NLO	1.0×10^6	3.3×10^6
$b\bar{b}H(\gamma\gamma)$	MadGraph5/Pythia8	1.32	NLO	7.5×10^5	5.6×10^5

> Signal under several self-coupling scenarios

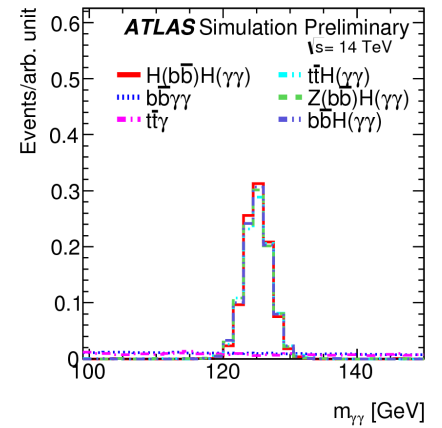
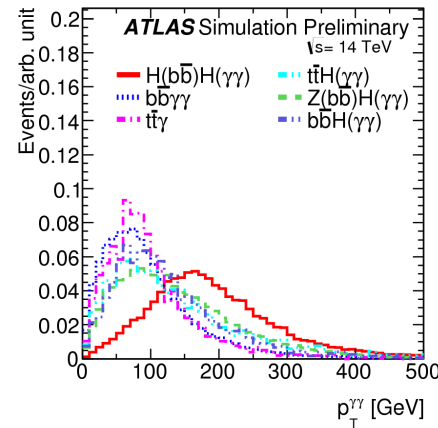
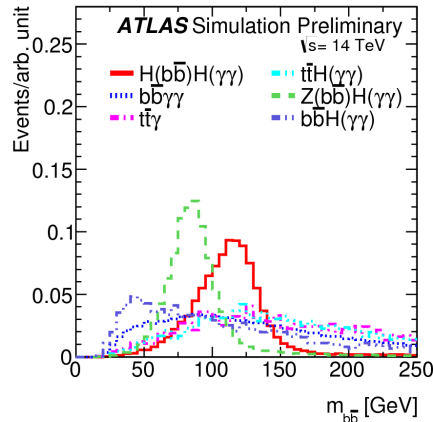
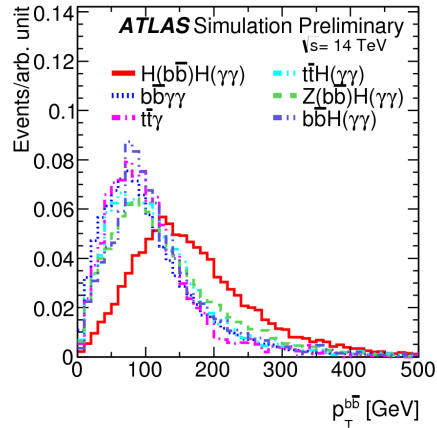
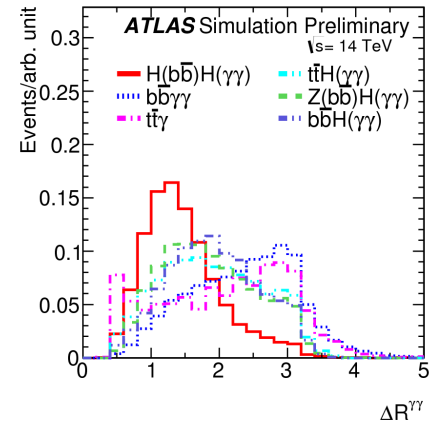
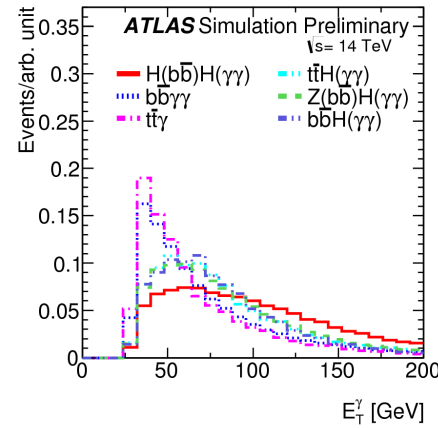
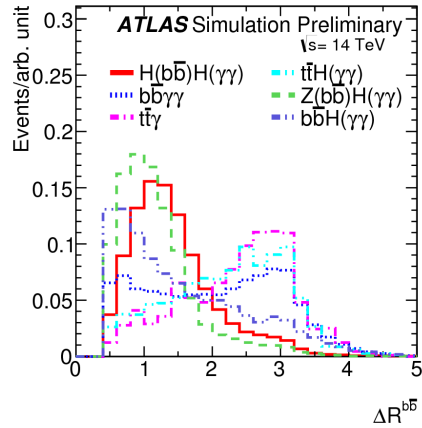
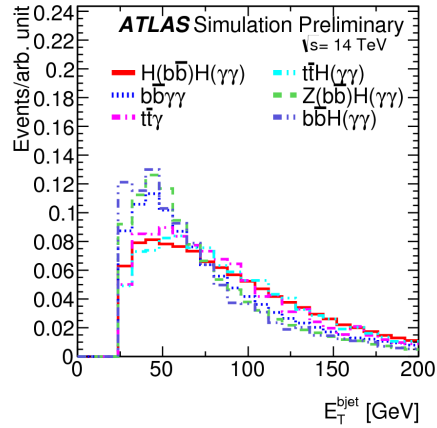
- Unless otherwise stated, talking about SM scenario

> 4 main background categories

- irreducible continuum, reducible continuum, top, and single Higgs



Kinematics

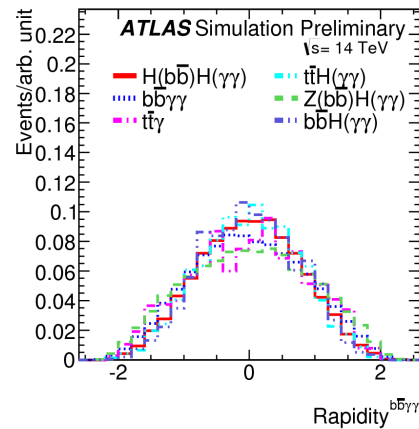
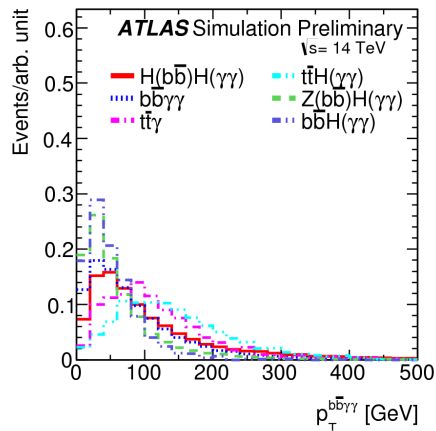
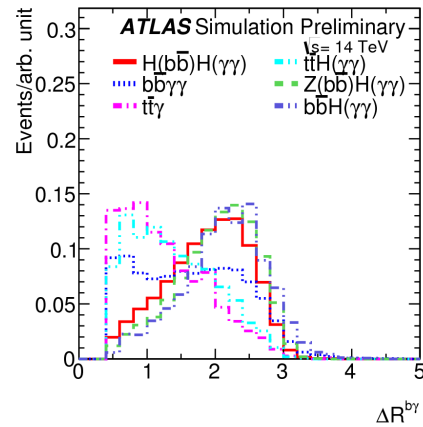
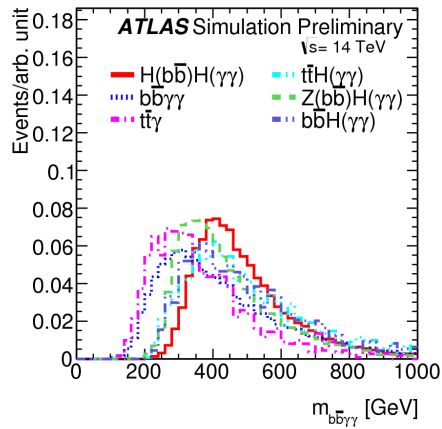


bb system

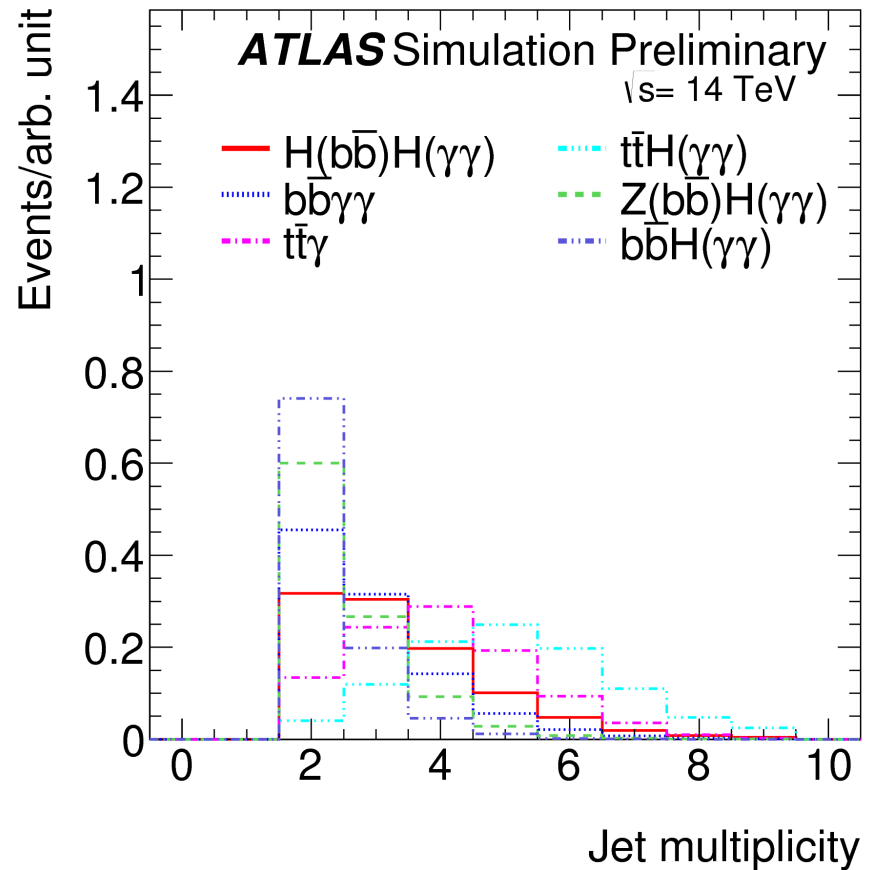
$\gamma\gamma$ system



Kinematics



$b\bar{b}\gamma\gamma$ system



Selection Criteria

- The following event selection was arrived at following an optimisation
 - Mostly optimised S/\sqrt{B} , but tried to avoid overly tight cuts on parameters where it could reduce sensitivity to self-coupling through restricting the phase space

Event Selection Criteria
≥ 2 isolated photons, with $p_T > 30$ GeV, $ \eta < 1.37$ or $1.52 < \eta < 2.37$
≥ 2 jets identified as b -jets with leading/subleading $p_T > 40/25$ GeV, $ \eta < 2.5$
No isolated leptons with $p_T > 25$ GeV, $ \eta < 2.5$
< 6 jets with $p_T > 25$ GeV, $ \eta < 2.5$
$0.4 < \Delta R^{b\bar{b}} < 2.0$, $0.4 < \Delta R^{\gamma\gamma} < 2.0$, $\Delta R^{\gamma b} > 0.4$
$100 < m_{b\bar{b}} < 150$ GeV, $123 < m_{\gamma\gamma} < 128$ GeV
$p_T^{\gamma\gamma}, p_T^{b\bar{b}} > 110$ GeV



Results

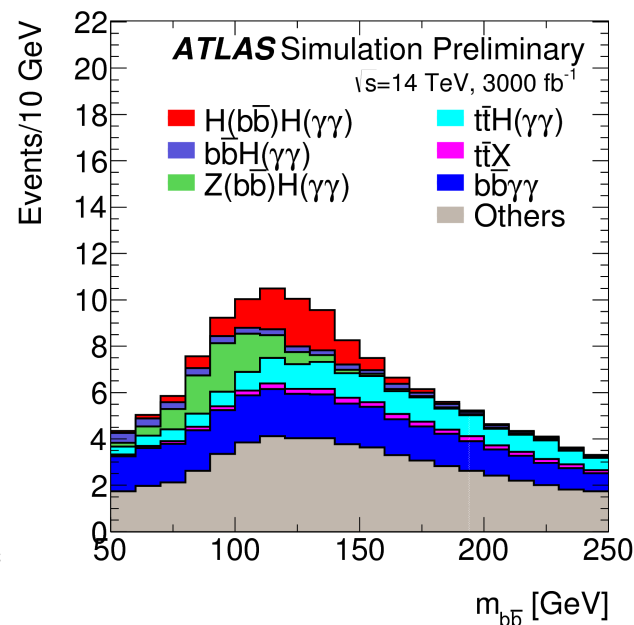
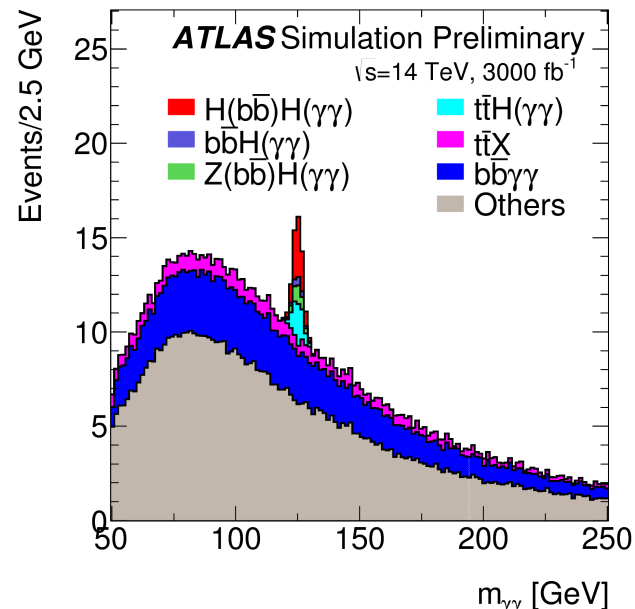
Expected yields (3000 fb ⁻¹) Samples	Total	Barrel	End-cap
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 1)$	8.4 ± 0.1	6.7 ± 0.1	1.8 ± 0.1
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 0)$	13.7 ± 0.2	10.7 ± 0.2	3.1 ± 0.1
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 2)$	4.6 ± 0.1	3.7 ± 0.1	0.9 ± 0.1
$H(b\bar{b})H(\gamma\gamma)(\lambda/\lambda_{SM} = 10)$	36.2 ± 0.8	27.9 ± 0.7	8.2 ± 0.4
$b\bar{b}\gamma\gamma$	9.7 ± 1.5	5.2 ± 1.1	4.5 ± 1.0
$c\bar{c}\gamma\gamma$	7.0 ± 1.2	4.1 ± 0.9	2.9 ± 0.8
$b\bar{b}\gamma j$	8.4 ± 0.4	4.3 ± 0.2	4.1 ± 0.2
$b\bar{b}jj$	1.3 ± 0.2	0.9 ± 0.1	0.4 ± 0.1
$jj\gamma\gamma$	7.4 ± 1.8	5.2 ± 1.5	2.2 ± 1.0
$t\bar{t}(\geq 1 \text{ lepton})$	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
$t\bar{t}\gamma$	3.2 ± 2.2	1.6 ± 1.6	1.6 ± 1.6
$t\bar{t}H(\gamma\gamma)$	6.1 ± 0.5	4.9 ± 0.4	1.2 ± 0.2
$Z(b\bar{b})H(\gamma\gamma)$	2.7 ± 0.1	1.9 ± 0.1	0.8 ± 0.1
$b\bar{b}H(\gamma\gamma)$	1.2 ± 0.1	1.0 ± 0.1	0.3 ± 0.1
Total Background	47.1 ± 3.5	29.1 ± 2.7	18.0 ± 2.3
$S/\sqrt{B}(\lambda/\lambda_{SM} = 1)$	1.2	1.2	0.4

> Split events into barrel/endcap categories

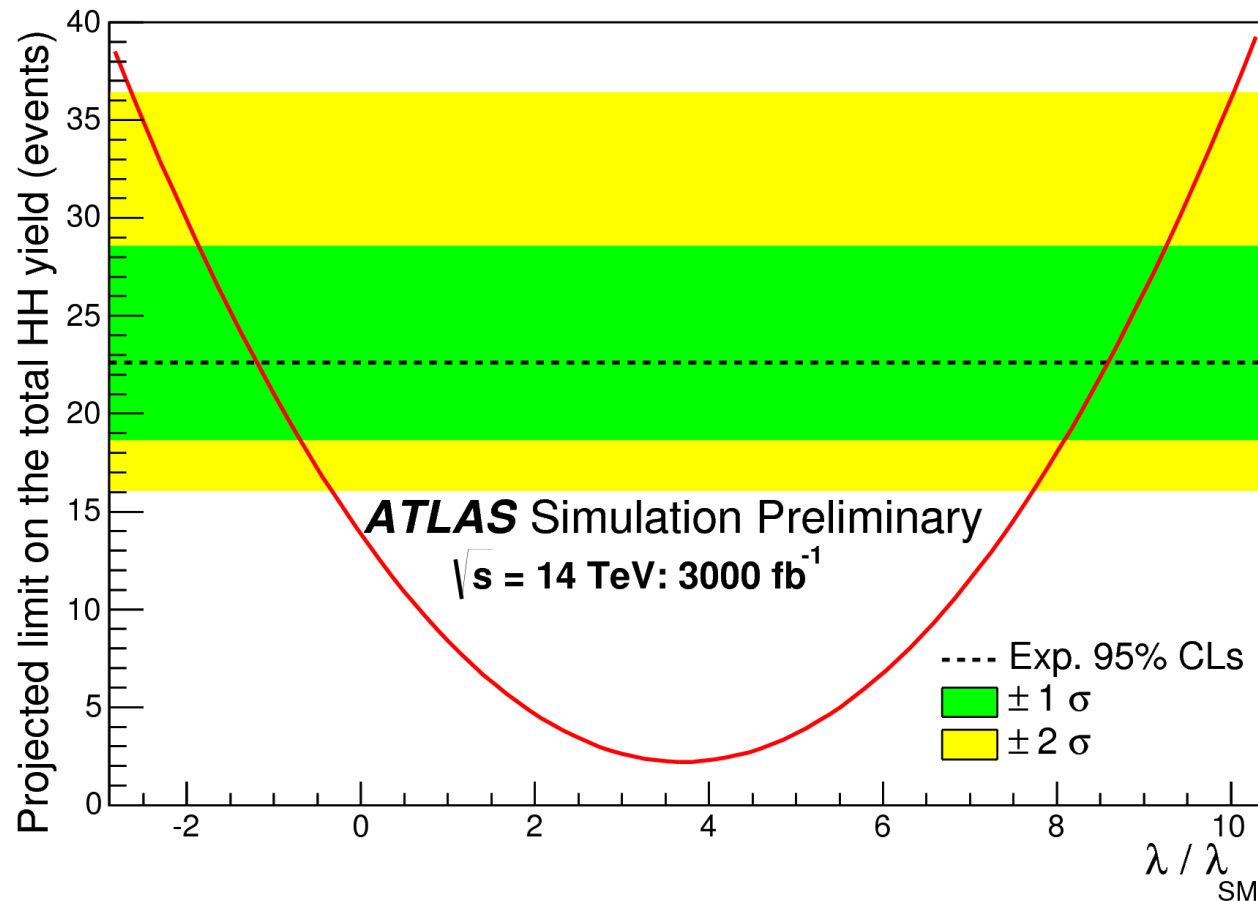
- If one photon has $1.37 < |\eta| < 2.37$, endcap

> Overall significance 1.3 σ

- ('total' column means 'only one category')



Limit Setting



- Based on these results, we should be able to exclude values of the self-coupling strength larger than $8.7 \times \text{SM}$, and smaller than $-1.3 \times \text{SM}$

Summary

- > Projected signal significance $\sim 1.3 \sigma$ in this channel, for 3000 fb^{-1} of 14 TeV p-p data
 - Significantly more realistic analysis than was previously available
 - Not very inspiring on its own, but can form a component of a measurement that uses multiple channels (perhaps combining results across ATLAS and CMS)
 - Work is ongoing on these other channels
- > Number of places where we can improve matters
 - Different b-tagging working points (including specialization for c-jet rejection)
 - Look at Multi-Variate Analysis techniques; very preliminary look suggests $\sim 30\%$ improvement
- > Full documentation was recently approved as a PUB note for ECFA workshop
 - ATL-PHYS-PUB-2014-019

