Status of $WW\gamma\gamma \rightarrow l\nu qq\gamma\gamma$

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On behalf of the analysis team
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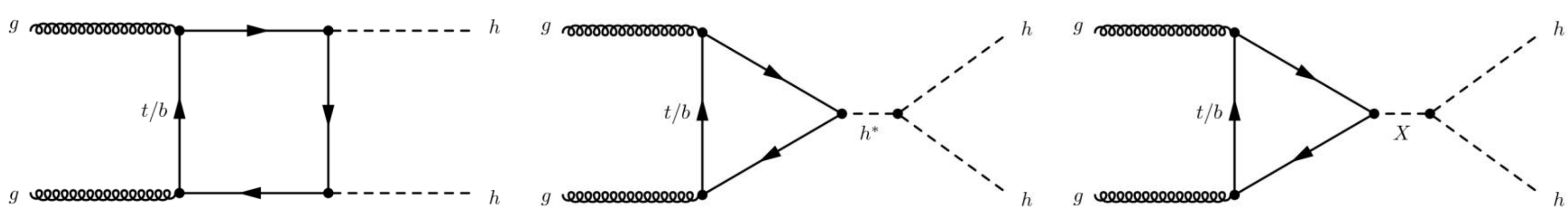
HGamma group meeting

Motivation

- Higgs pair production has a small XS in the SM (~33 fb @ 13 TeV)
- BSM can effectively enhance Higgs pair production.
  - non-resonance: altered tth coupling, Higgs self-coupling.
  - resonance: BSM resonance decay, such as heavy Higgs.



(a) (b) (c)

Introduction

- **Large BR from $h \to WW$ and clear signature from $h \to \gamma\gamma$**
- **Search for Higgs pair via $WW\gamma\gamma$**
  - **Explore non-resonance production**
  - **Explore resonance in low mass region**
    - **Mass of resonances: 260, 300, 400 and 500 GeV**

Background

- Continuum background
- SM h background
  - tth, Wh, Zh, ggh, VBF
- SM hh background for resonant searches

Object definitions

Photons:

PID: Tight; Iso: FixedCutLoose;

$|\eta| \in [0, 1.37] \cap [1.52, 2.37]$;

Rel. p_T cut:

$\frac{E_T(\gamma 1)}{m(\gamma\gamma)} \geq 0.35$, $\frac{E_T(\gamma 2)}{m(\gamma 1 \gamma 2)} \geq 0.25$

$m(\gamma 1 \gamma 2) \in [105, 160]$ **GeV**

Electrons:

$E_T > 10$ **GeV;**

$|\eta| \in [0, 1.37] \cap [1.52, 2.47]$;

$|d_0|$ significance < 5;

$|z_0| < 0.5$ **mm;**

PID: Medium; Iso: Loose

Jets:

AntiKt4EMTopoJets

$p_T > 25$ **GeV;** $|\eta| < 2.5$;

$JVT < 0.59$ ($p_T < 60$ **GeV** & $|\eta| < 2.4$)

Muons:

$E_T > 10$ **GeV;** $|\eta| \in [0, 2.7]$;

$|d_0|$ significance < 3; $|z_0| < 0.5$ **mm;**

PID: Medium; Iso: GradientLoose

Follow the setting in the tag for h015 but the central jets

$l\nu qq\gamma\gamma$: Selections

- Start with diphoton selections used in Hgam
  - Trigger: HLT_g35_loose_g25_loose
- At least two central jets, $|\eta| < 2.5$
- B-Veto, B-tagger: MV2c10, WP: 70%
- At least one lepton, $p_T > 10$ GeV
- $pT_{\gamma\gamma}$ cut for nonres, mh400 and mh500

- [SR] Signal Region (above)
- [CR] Control Region ($N(lep) = 0$ & $N(jets) \geq 2$)

CUTS
All Events
Duplicate
GRL
Pass Trigger
Detector Quality
Has PV
2 loose photons
Trigger Match
Tight ID
Isolation
Rel.Pt cuts
$105 < m_{\gamma\gamma} < 160$ GeV
At least two central jets
B-veto
At least 1 lepton
$pT_{\gamma\gamma} > 100$ GeV

Cut flow for signal

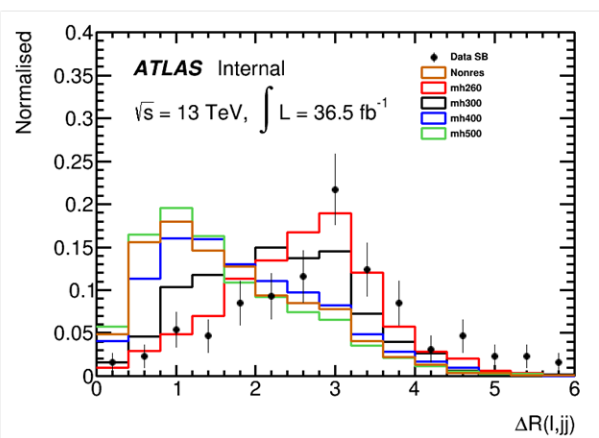
EFFICIENCY	SM Higgs pair	Mh260	Mh300	Mh400	Mh500
All Events	100%	100%	100%	100%	100%
Duplicate	100%	100%	100%	100%	100%
GRL	100%	100%	100%	100%	100%
Pass Trigger	73.7625%	68.4665%	69.3664%	71.7597%	74.4053%
Detector Quality	73.7625%	68.4665%	69.3664%	71.7597%	74.4053%
Has PV	73.7625%	68.4665%	69.3664%	71.7597%	74.4053%
2 loose photons	59.1395%	56.3914%	55.7954%	57.2582%	59.5911%
Trigger Match	58.8244%	56.0974%	55.5121%	56.9455%	59.2858%
Tight ID	48.7057%	45.3473%	44.7389%	46.8933%	49.5014%
Isolation	43.9575%	38.533%	38.5874%	41.982%	44.9905%
Rel.Pt cuts	40.4305%	36.1272%	35.0414%	38.2389%	41.7591%
$105 < m_{\gamma\gamma} < 160$ GeV	40.2725%	36.0309%	34.961%	38.0901%	41.5555%
At least two central jets	28.4887%	17.0745%	19.2584%	25.5078%	30.7726%
B-veto	26.669%	16.1243%	18.2133%	24.029%	28.8903%
At least 1 lepton	10.4724%	6.17819%	7.17794%	9.76825%	11.2784%
$pT_{\gamma\gamma} > 100$ GeV	8.69098%	-	-	7.89899%	10.4481%

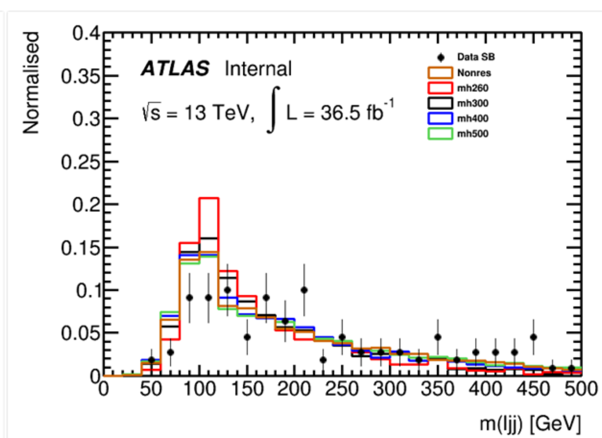
Cut flow for background

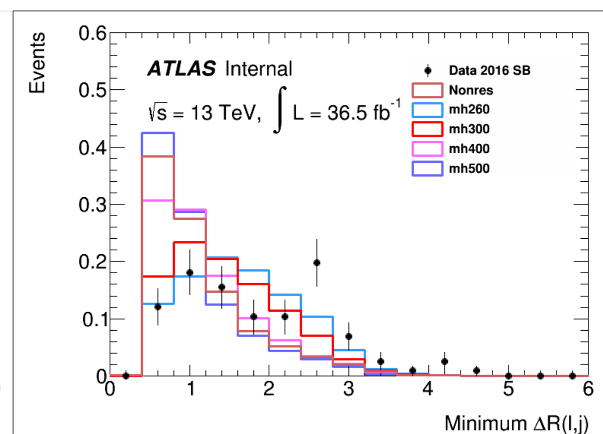
EFFICIENCY	ggh	VBF	Wh	Zh	tth
All Events	100%	100%	100%	100%	100%
Duplicate	100%	100%	100%	100%	100%
GRL	100%	100%	100%	100%	100%
Pass Trigger	59.582%	61.3022%	56.6327%	56.0975%	72.6999%
Detector Quality	59.582%	61.3022%	56.6327%	56.0975%	72.6999%
Has PV	59.582%	61.3022%	56.6327%	56.0975%	72.6999%
2 loose photons	49.7509%	51.158%	44.4874%	45.1516%	58.3089%
Trigger Match	49.6578%	51.0287%	44.3349%	45.0261%	57.8913%
Tight ID	43.1065%	44.1216%	38.0513%	38.6808%	48.2156%
Isolation	38.5746%	39.8454%	33.5347%	34.0292%	39.7781%
Rel.Pt cuts	35.8048%	36.1992%	30.7218%	31.0854%	36.3467%
$105 < m_{\gamma\gamma} < 160$ GeV	35.7962%	36.1585%	30.4956%	30.8919%	35.8595%
At least two central jets	5.46598%	10.0621%	14.5093%	15.4831%	34.0003%
B-veto	5.20212%	9.50073%	13.7451%	12.5776%	5.95848%
At least 1 lepton	0.00381033%	0.0103539%	0.511647%	0.346517%	1.77117%
$pT_{\gamma\gamma} > 100$ GeV	0.00196536%	0.00568231%	0.274052%	0.165589%	1.04159%

Optimization

- Optimize on the significance = $\sqrt{2 \times [(S+B) \times ln\left(\frac{S+B}{B}\right) - S]}$ as well as limits.
- A bit improvements on $\Delta R(l, jj)$
- A bit improvements on $m(ljj)$
- minimum $\Delta R(l, j)$, not promising
- No cut on the $\Delta R(l, jj), m(ljj)$ and minimum $\Delta R(l, j)$







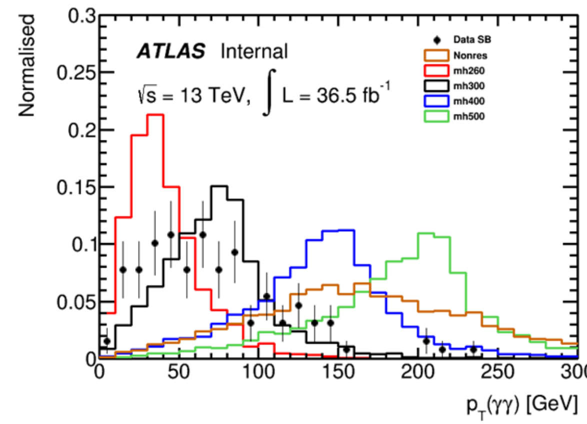
$pT_{\gamma\gamma}$ cut

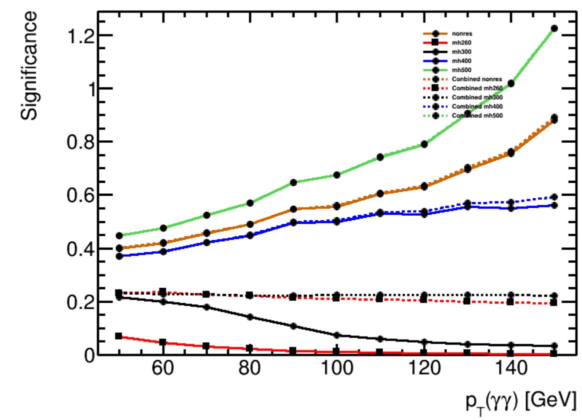
Applying cut on $pT_{\gamma\gamma}$ for mh400, mh500 and nonres

No cut on the $pT_{\gamma\gamma}$ for mh260 and mh300

Mh500	$pT_{\gamma\gamma} > 100$ GeV	$pT_{\gamma\gamma} > 80$ GeV	$pT_{\gamma\gamma} > 50$ GeV
Limits	4.22396	4.64051	5.42144

Applying $pT_{\gamma\gamma} > 100$ gives the best limit for mh500



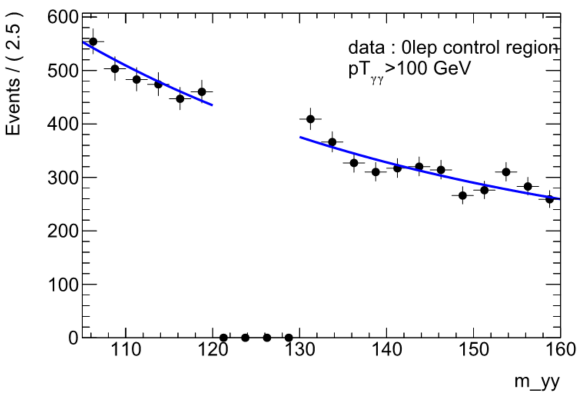


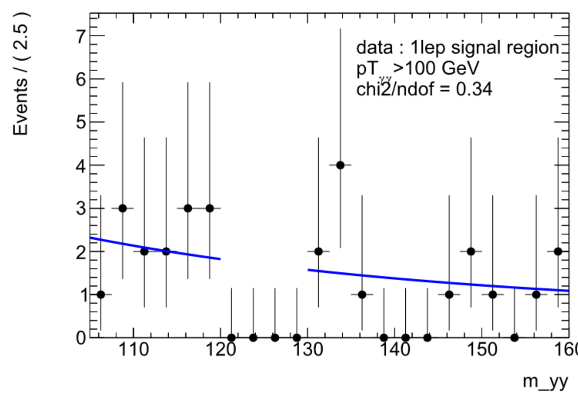
A scan on the $pT_{\gamma\gamma}$ greater than X

Shape consistency - $\chi^2/ndof$

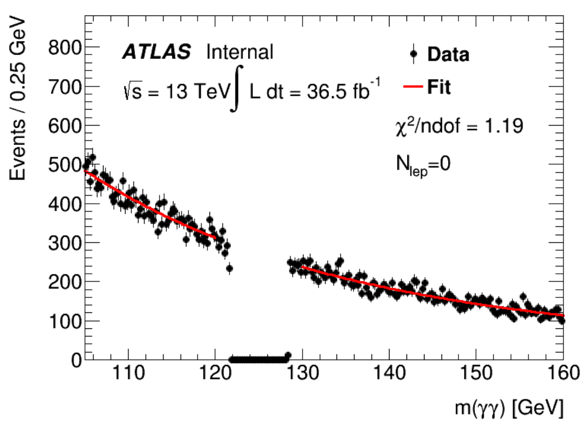
Model: $e^{c_1 m_{\gamma\gamma} + c_2 {m_{\gamma\gamma}}^2}$

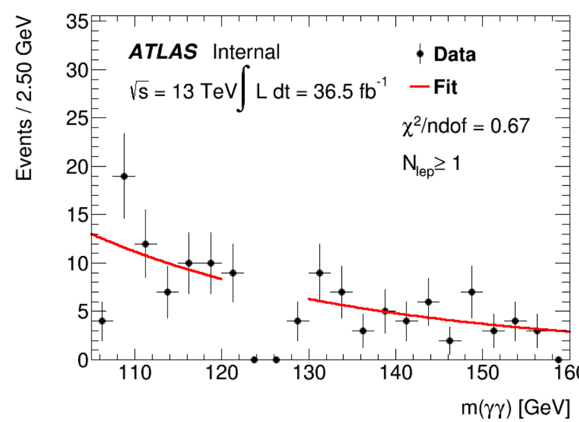
Fit to the high statistical region (0Lep) with c1 and c2 floating, obtain the values of c1 and c2. Fix c1 and c2 in the model and fit to the 1Lep region to check the chi2/ndof in both of the regions.





$pT_{\gamma\gamma} > 100$ **GeV**





No $pT_{\gamma\gamma}$ **cut**

Systematics

<u>All the sys have been put into the WS</u>

- Photons
  - 5 NPs, scale, resolution, ID, Iso
- Jets
  - 22 NPs
- Flavor tagging
  - 14 NPs
- PU reweighting
  - 1 NPs
- Electrons
  - 3 NPs, ID, ISO, Reco
- Muons
  - 11 NPs
- Theory
  - SCALE, PDF, α_S, EFT, BR($h \to \gamma\gamma$), BR($h \to WW$)
- Luminosity
  - 1 NP, 3.2%
- Trigger
  - 1 NP, 0.4%
- Spurious signal
  - 1 NP
- Uncertainty on the transfer factor
  - 1 NP
- Wh generator
  - 1 NP, special uncertainty caused by that the jets in the Pythia is derived from parton shower for Wh process, 37.5%

Limits by shape fitting

Limits	Non-res	mh260	mh300	mh400	mh500
Fitting	5.0243	11.7322	9.96703	5.69469	4.22559
Counting	7.77684	13.5264	11.6477	8.4209	7.08669

- Limits are on $pp \to X \to hh$ / $pp \to hh$. Unit is pb. All the sys have been included.
- Continuum background model: expPoly2; SM h background models: DSCB; SM hh background (for resonance) model: DSCB; Signal models: DSCB
- Fit the SR and CR simultaneously. Fit to the OneLep and ZeroLep regions with nConBkg (continuum BKG in OneLep) constrained by nConBkgCR (continuum BKG in ZeroLep, high statistics), nConBkg = Transfer factor * nCongBkgCR , a uncertainty is introduced on the Transfer factor.

Summary

- **All the results are updated to V.h015**
- **Cuts frozen at the stage: on the page 5.**
- **Apply $pT_{\gamma\gamma}$ cut for nonres, mh400 and mh500. Other cuts were tested but not used, like tight ID leptons, $\Delta R(l, jj)$, $\Delta R(l,j)$ and minimum $\Delta R(l, j)$ (since the improvements on sensitivities are too small)**
- **Statistical strategy (fixed): simultaneous shape fitting in 1lep and 0lep regions**
- **Work ongoing: quick checks on lepton purity, photon purity and SS**
- **Updating the supporting note to the shape fitting from counting, supporting note: ATL-COM-PHYS-2016-1406**
- **$WW\gamma\gamma \rightarrow qqqq\gamma\gamma$ is not going to the publication since the sensitivities in this channel are not so good (shown in the backup).**

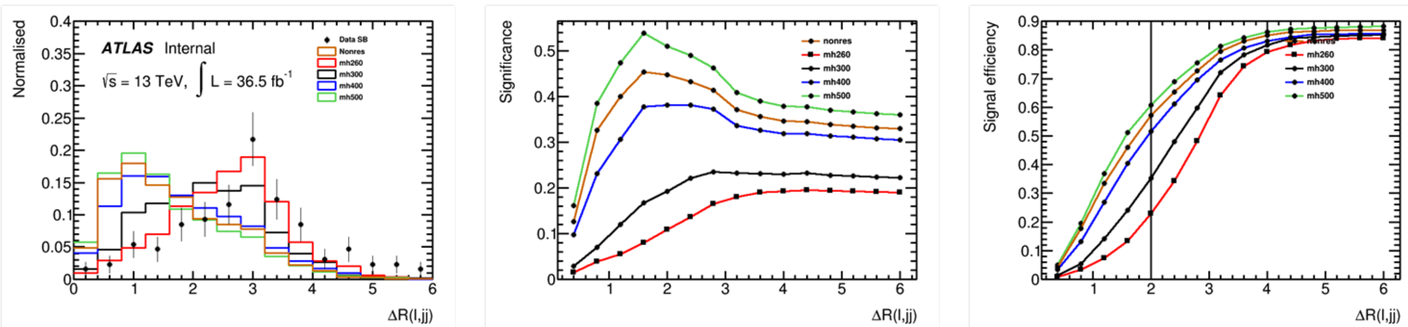
Backup

Limits in $qqqq\gamma\gamma$

Limits (pb)	Nonres	Mh260	Mh300	Mh400	Mh500
4jet	25.17	61.73	58.75	26.71	16.22
1lep	6.5	11.6	9.9	7.0	6.1

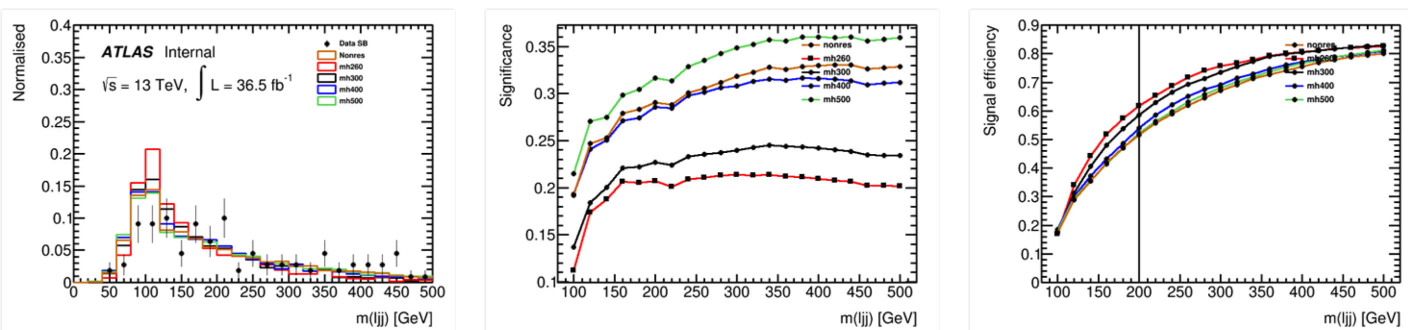
Sensitivities in 4jets are not so good compared to the 1lep analysis.

Optimization



A bit improvements by applying cut on $\Delta R(l, jj)$,

No cut



A bit improvements by applying cut on $m(ljj)$

No cut

Tight ID leptons: a bit improvements, ~3%

Choose medium ID leptons

Fitting	MediumID	TightID
Limits	6.31239	6.12344

Shape fitting strategy

Expected	Non-res	mh260	mh300	mh400	mh500
Case1	7.77684	13.5264	11.6477	8.4209	7.08669
Case2	6.73591	12.1821	10.4071	7.35074	6.41912
Case3	6.76732	12.2245	10.4445	7.38623	6.44435
Case4	6.37882	11.5519	9.87742	6.94376	6.0937
Case5	6.68888	12.2188	10.4403	7.30223	6.42284

Case 1: counting

Case 2: fit to the OneLep region with parameters c1 and c2 fixed in $e^{c_1 m_{\gamma\gamma} + c_2 {m_{\gamma\gamma}}^2}$

Case 3: fit to the OneLep region with floating parameters c1 and c2

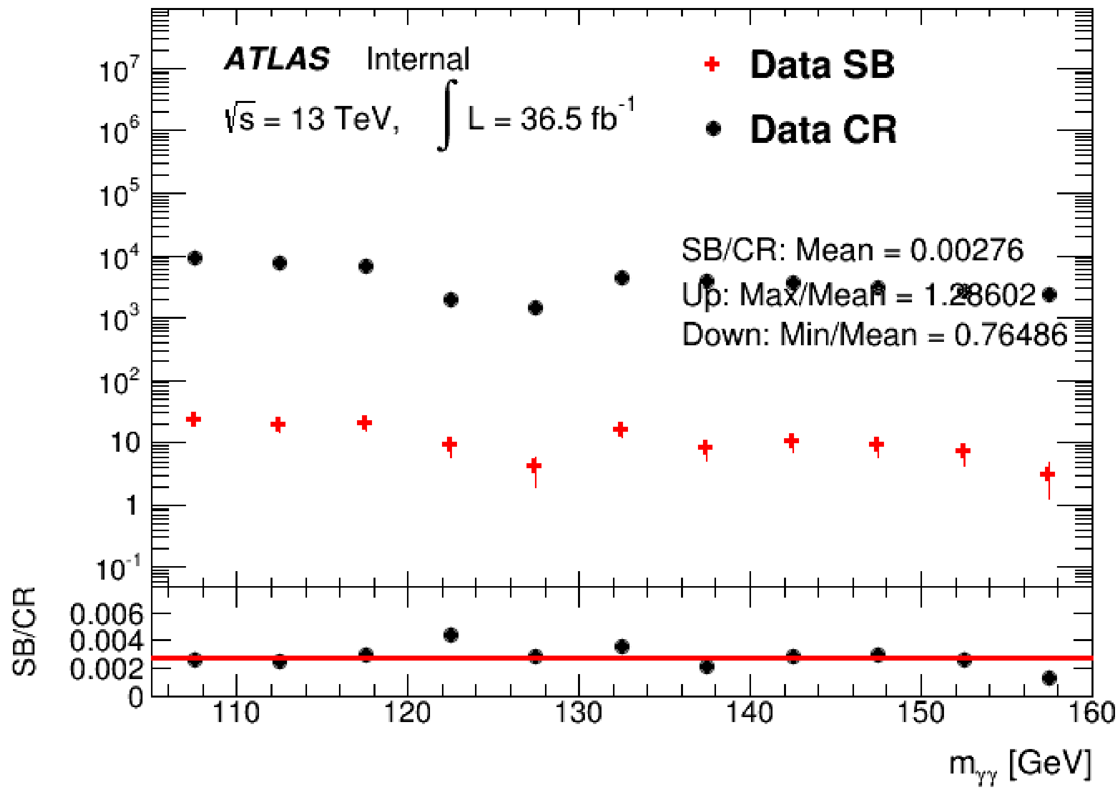
Case 4: fit to the OneLep and ZeroLep regions with nConBkg (continuum BKG in 1Lep) constrained with nConBkgCR (continuum BKG in 0Lep), nConBkg = Transfer factor * nCongBkgCR

Case 5: fit to the OneLep and ZeroLep regions with floating nConBkg and nConBkgCR

THE CASE4 HAS THE BEST LIMITS, CHOOSE THE METHOD IN CASE 4

Uncertainty on transfer factor

Up: 1.28602
Down: 0.76486



Signal and background yields

36.47 fb^{-1}	ggh	VBF	Wh	Zh	tth	smhh
Yields (no $pT_{\gamma\gamma}$ cut)	0.153054	0.0323924	0.579876	0.253135	0.742679	0.0546108
Yields ($pT_{\gamma\gamma} >$ 100 GeV)	0.078945	0.0177772	0.310598	0.120965	0.436755	0.0453211

36.47 fb^{-1}	nonres	Mh260	Mh300	Mh400	Mh500
Yields (no $pT_{\gamma\gamma}$ cut)	-	0.96431	1.12035	-	-
Yields ($pT_{\gamma\gamma} >$ 100 GeV)	1.35651	-	-	1.2329	1.63077