ATLAS Fiducial and Differential Cross Sections

Laurelle Veloce on behalf of DiffXS

Introduction

- H4l recently published fiducial & differential cross section results with 139 fb^{-1}
- Hγγ and other channel results are in progress
- We are interested in an ATLAS-CMS combination with 4l, γγ, possibly with additional channels if available
- Possibility to also plan for a 4l-4l (and γγ-γγ) combination with ATLAS and CMS
- Today we will be discussing:
    1. Binning for differential variables
    2. Signal extraction and unfolding
    3. Modelling uncertainties
    4. Additional details about fiducial selection and truth object definitions for 4l

Set of differential XS variables

Common variables are highlighted.

H4l variable set is published, Hγγ variables are planned.

$H4\ell$	$H\gamma\gamma$
Higgs-related variables	
$p_T^{4\ell}$, $\|y_{4\ell}\|$	$p_T^{\gamma\gamma}$, $\|y^{\gamma\gamma}\|$
m_{12}, m_{34}	$p_T^{\gamma 1}/m_{\gamma\gamma}$, $p_T^{\gamma 2}/m_{\gamma\gamma}$
$\|\cos\theta *\|, \cos\theta_1, \cos\theta_2$	
ϕ, ϕ_1	
Jet-related variables	
$N_{\mathbf{jets}}$, $N_{b-\mathbf{jets}}$	$N_{\mathbf{jets}}$, $N_{b-\mathbf{jets}}$
$p_T^{\mathbf{lead.\ jet}}$ $p_T^{\mathrm{sublead.\ jet}}$	$p_T^{\mathbf{lead.\ jet}}$, τ, τ_1
m_{jj}, $\|\Delta\eta_{jj}\|$, $\Delta\phi_{jj}$	m_{jj}, $\Delta\phi_{jj}$, H_T
$p_T^{4\ell j}$, $p_T^{4\ell jj}$	$p_T^{\gamma\gamma j}$, $p_T^{4\gamma\gamma jj}$
$m_{4\ell j}$, $m_{4\ell jj}$	$m_{\gamma\gamma j}$ $\Delta\phi_{\gamma\gamma jj}$

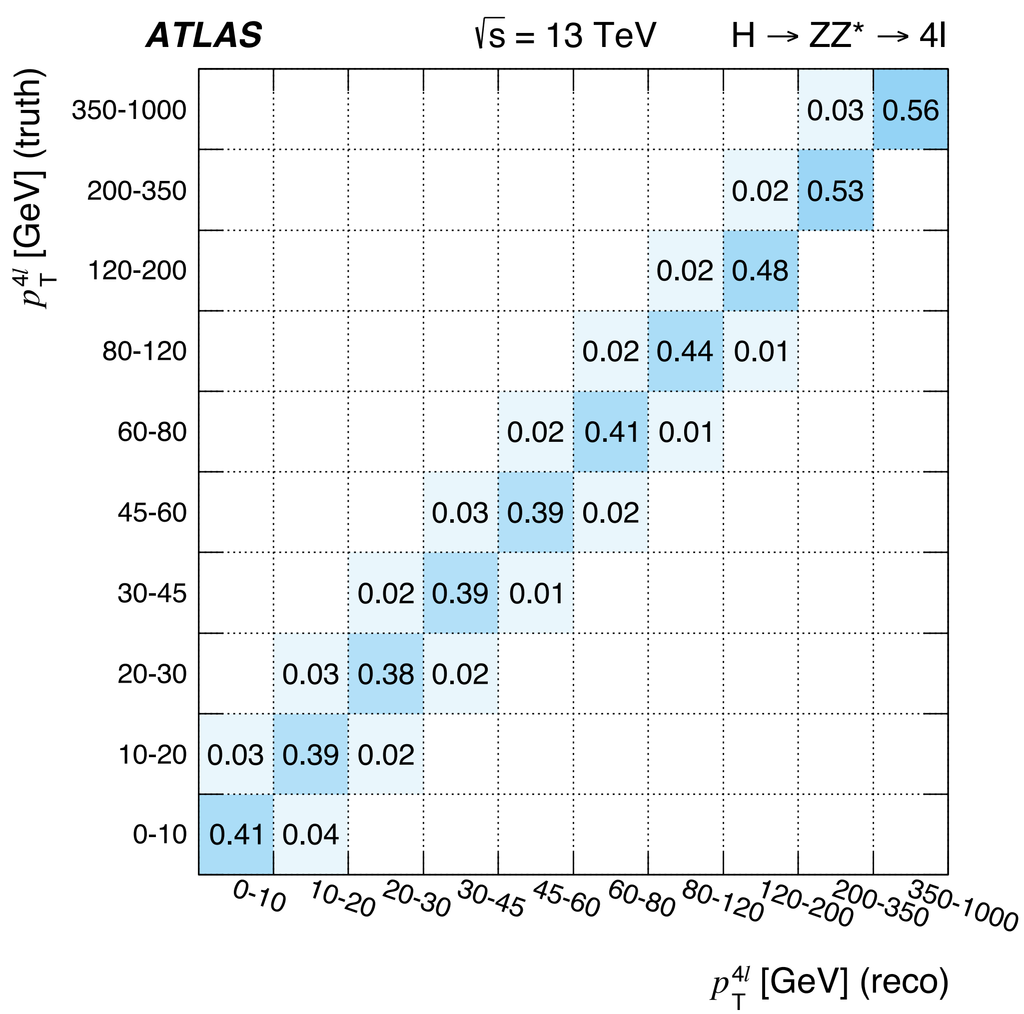
+ Double Differential

m_{12} vs. m_{34}, p_T^{4l} vs. N_{jets}, p_T^{4l} vs. $p_T^{lead.jet}$, p_T^{4l} vs p_T^{4lj}, p_T^{4l} vs $|y_{4l}|$, p_T^{4lj} vs. m_{4lj}, $p_T^{lead.jet}$ vs. $p_T^{sublead.jet}$, and $p_T^{lead.jet}$ vs. $|y^{lead.jet}|$

$|y^{\gamma\gamma}|$ vs. $p_T^{\gamma\gamma}$, $(p_T^{\gamma 1}+p_T^{\gamma 2})/m_{\gamma\gamma}$ vs. $(p_T^{\gamma 1} - p_T^{\gamma 2})/m_{\gamma\gamma}$, $p_T^{\gamma\gamma j}$ vs. $p_T^{\gamma\gamma}$

Binning schemes for common variables

- H4l binning schemes are shown
- All bin edges agree between H4l and Hγγ, though in some cases Hγγ has finer binning



p_T^H [GeV]
0-10
10-20
20-30
30-45
45-60
60-80
80-120
120-200
200-350
350-1000

Different from 36 fb^{-1} CMS: 0, 15, 30 GeV - our goal is to be sensitive to light quark couplings

Binning schemes for common variables

- H4l binning schemes are shown
- All bin edges agree between H4l and Hγγ, though in some cases Hγγ has finer binning

$\lvert y^H \rvert$
0.0-0.15
0.15-0.30
0.30-0.45
0.45-0.60
0.60-0.75
0.75-0.90
0.90-1.2
1.2-1.6
1.6-2.0
2.0-2.5

No changes to bin edges for this variable.

Binning schemes for common variables

- H4l binning schemes are shown
- All bin edges agree between H4l and Hγγ, though in some cases Hγγ has finer binning
- note: full jet phase space uses STXS jets
    - all stable particles clustered using anti-kt algorithm with R=0.4; particles from Higgs and leptonic vector boson decays are excluded

N_{jets}
0 jets
1 jet
2 jets
3 or more jets

Changed from last round to remove bin 4 (four or more jets) due to low stats, high migrations, no accurate predictions

Binning schemes for common variables

$p_T^{lead. jet}$ [GeV]
0 jets
30-60
60-120
120-350

Different from 36 fb^{-1} CMS (30, 55, 95, 120, 200, 200+ GeV). Updated bin edge from 55 to 60 due to large bin migrations.

m_{jj} [GeV]
Events with less than two jets
0-120
120-450
450-3000

Changed from last round to match STXS bin definitions.

Signal extraction and unfolding

- H4l method shown here, but Hγγ is very similar
  - Data are unfolded using the detector response matrix
  - Higgs mass is set to 125 GeV
  - (for H4l only) XS fit is performed in $105 < m_{4l} < 160$ mass window to obtain ZZ background normalization from data

$$N_i(m_{4\ell}) = \sum_j r_{ij} \cdot (1 + f_i^{\text{nonfid}}) \cdot \sigma_j^{\text{fid}} \cdot \mathcal{P}_i(m_{4\ell}) \cdot \mathcal{L} + N_i^{\text{bkg}}(m_{4\ell})$$

- r_{ij}: detector response matrix

$$\frac{\text{number of events in bin i truth matched to an event in bin j}}{\text{truth events in bin j}}$$

- f_i^{nonfid}: Events outside the fiducial region reconstructed in bin i
- σ_j^{fid}: fiducial XS

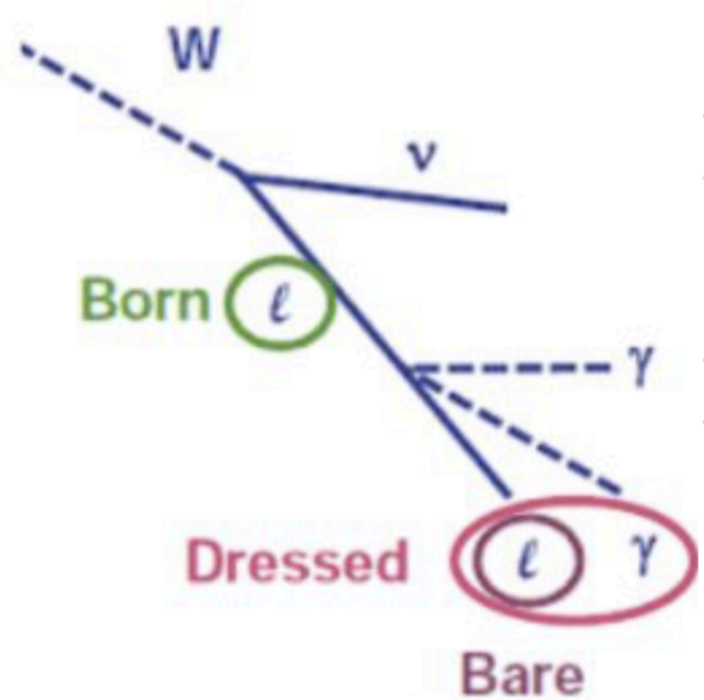
$$\sigma_j^{\text{fid}} = \sigma_j \cdot A_j \cdot \mathcal{B}$$

- $\mathcal{P}_i(m_{4\ell})$: signal shape containing the fraction of events as a function of m4l expected in each reconstruction bin (taken from MC simulation)
- $N_i^{\text{bkg}}(m_{4\ell})$: background contribution

Model uncertainties propagated through response matrix and acceptance factors

- **QCD scale systematics**
  - ggF, VBF - LHCXSWG recommendations (STXS scheme), all other production modes use envelope of μR/μF variations
- **PDF systematics**
  - individual eigenvector variations from PDF4LHC_30
- **Shower systematics**
  - internal Pythia8 weights, comparison with Herwig samples
- **Signal composition**
  - vary production mode XS individually by experimental uncertainties

Additional information about 4l: Truth Objects and Fiducial Selection



Leptons and jets	
Leptons	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Jets	$p_T > 30$ GeV, $\|y\| < 4.4$
Lepton selection and pairing	
Lepton kinematics	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12})	SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34})	remaining SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one quadruplet per event)	
Mass requirements	50 GeV$< m_{12} <$ 106 GeV and 12 GeV$< m_{34} <$ 115 GeV
Lepton separation	$\Delta R(\ell_i, \ell_j) > 0.1$
Lepton/Jet separation	$\Delta R(\ell_i, \text{jet}) > 0.1$
J/ψ veto	$m(\ell_i, \ell_j) > 5$ GeV for all SFOC lepton pairs
Mass window	105 GeV$< m_{4\ell} <$ 160 GeV
If extra lepton with $p_T > 12$ GeV	Quadruplet with largest matrix element value

- Leptons are dressed i.e.: photons within $\Delta R < 0.1$ are added to lepton to mimic QED FSR recovery
- No isolation, d0sig, or vertex selection
- m4l mass window 105 < m4l < 160 GeV

Additional information about 4l: Truth particle definitions

- **Leptons**: required to originate from Z and W decays (not from hadron decays)
- **Jets**
  - **Full Phase Space**: all stable particles clustered using anti-kt algorithm with R=0.4; particles from Higgs and leptonic vector boson decays are excluded (***STXS jets***)
  - **Fiducial Phase Space**: clustered using anti-kt algorithm with R=0.4; muons and electrons from W/Z/H/tau are not included, nor are photons from Higgs decays or those used in dressing
  - **b-jets**: b-hadron within a cone around the jet axis of radius DeltaR = 0.3 with pT > 5 GeV
- **Photons** (*for FSR recovery*): stable, do not come from hadrons, and are within ΔR of 0.1 from a lepton that itself comes from a W/Z boson
  - For $H\gamma\gamma$ - two highest pT photons not originating from a hadron

Backup

Summary of H4l variables and binning choices

Binning schemes for Higgs-related variables:

Variable	Bin Edges	N_{bins}	ZZ Sidebands Bin Edges	$N_{ZZ\ \text{bins}}$
p_T	0, 10, 20, 30, 45, 60, 80, 120, 200, 350, 1000 GeV	11	0, 10, 20, 30, 60, 1000	5
m_{12}	50, 73, 64, 85, 106 GeV	4	50, 73, 85, 106	3
m_{34}	12, 20, 24, 28, 32, 40, 55, 65 GeV	7	12, 24, 32, 65	3
$\|y\|$	0.0, 0.15, 0.3, 0.45, 0.6, 0.75, 0.9, 1.2, 1.6, 2.0, 2.5	10	0.0, 0.15, 0.3, 0.45, 0.6, 0.75, 1.2, 2.5	7
$\|cos(\theta^*)\|$	0, 0.125, 0.25, 0.375, 0.5, 0.625, 0.75, 0.875, 1.0	8	0, 0.25, 0.5, 0.75, 1.0	4
$cos(\theta_1)$	-1.0, -0.75, -0.50, -0.25, 0.0, 0.25, 0.50, 0.75, 1.0	8	-1.0, -0.5, 0.0, 0.5, 1.0	
$cos(\theta_2)$	-1.0, -0.75, -0.50, -0.25, 0.0, 0.25, 0.50, 0.75, 1.0	8	-1.0, -0.5, 0.0, 0.5, 1.0	
ϕ	$-\pi, -\frac{3\pi}{4}, -\frac{2\pi}{4}, -\frac{\pi}{4}, 0, \frac{\pi}{4}, \frac{2\pi}{4}, \frac{3\pi}{4}, \pi$	8	$-\pi, -\frac{2\pi}{4}, 0, \frac{2\pi}{4}, \pi$	4
ϕ_1	$-\pi, -\frac{3\pi}{4}, -\frac{2\pi}{4}, -\frac{\pi}{4}, 0, \frac{\pi}{4}, \frac{2\pi}{4}, \frac{3\pi}{4}, \pi$	8	$-\pi, -\frac{2\pi}{4}, 0, \frac{2\pi}{4}, \pi$	4

Summary of H4l variables and binning choices

Binning schemes for jet-related variables:

Variable	Bin Edges	N_{bins}	ZZ Sidebands Bin Edges	$N_{ZZ\text{ bins}}$
N_{jets}	0, 1, 2, ≥3	5	0, 1, ≥2	3
$N_{b-\text{jets}}$	0 jets, 0 b-jets, ≥1 b-jets	2	0 jets, ≥ 0 b-jets	1
$p_T^{\text{lead. jet}}$	N_{jets}=0, 30, 60, 120, 350 GeV	4	N_{jets}=0, 30, 60, 120, 350	4
$p_T^{\text{sublead. jet}}$	N_{jets}=0, 30, 60, 120, 350 GeV	4	$N_{\text{jets}} < 2$, 30, 60, 350	4
m_{jj}	$N_{\text{jets}} < 2$, 0, 120, 450, 3000 GeV	4	$N_{\text{jets}} < 2$, 0, 120, 3000	3
$\Delta\eta_{jj}$	$N_{\text{jets}} < 2$, 0, 1, 2.5, 9	4	$N_{\text{jets}} < 2$, 0, 1, 9	3
$\Delta\phi_{jj}$	$N_{\text{jets}} < 2$, 0, $\frac{1}{2}\pi$, π, $\frac{3}{2}\pi$, 2π	5	$N_{\text{jets}} < 2$, 0, π, 2π	3

Summary of H4l variables and binning choices

Binning schemes for Higgs+jet-related variables:

Variable	Bin Edges	N_{bins}	ZZ Sidebands Bin Edges	$N_{ZZ\ \text{bins}}$
$m_{4\ell j}$	N_{jets}=0, 120, 180, 220, 300, 400, 600, 2000 GeV	7	N_{jets}=0,120, 220, 2000	3
$m_{4\ell jj}$	N_{jets}<2, 180, 320, 450, 600, 1000, 2500 GeV	6	N_{jets}<2, 180, 450, 2500	3
$p_{T,4\ell j}$	N_{jets}=0, 0, 60, 120, 350 GeV	4	N_{jets}=0, 0, 350	2
$p_{T,4\ell jj}$	N_{jets}<2, 0, 60, 120, 350 GeV	4	N_{jets} < 2, 0, 350	2

Summary of H4l variables and binning choices

Binning schemes for double-differential variables:

Variable	Bin Edges		N_{bins}
$p_{T,4\ell}$ vs. N_{jets}	$N_{\text{jets}} = 0$	$p_{T,4\ell}$ $\{0, 15, 30, 120, 350\}$	
	$N_{\text{jets}} = 1$	$p_{T,4\ell}$ $\{0, 60, 80, 120, 350\}$	12
	$N_{\text{jets}} = 2$	$p_{T,4\ell}$ $\{0, 120, 350\}$	
	$N_{\text{jets}} \geq 3$	$p_{T,4\ell}$ $\{0, 120, 350\}$	
m_{12} vs. m_{34}	$m_{12} < 82$	$m_{34} < 32$	
	$m_{12} < 74$	$m_{34} > 32$	
	$m_{12} > 74$	$m_{34} > 32$	5
	$m_{12} > 82$	$24 < m_{34} < 32$	
	$m_{12} > 82$	$m_{34} < 24$	
$p_{T,4\ell}$ vs. $\|y\|$	$0.0 < \|y\| < 0.5$	$p_{T,4\ell}$ $\{0, 45, 120, 350\}$	
	$0.5 < \|y\| < 1.0$	$p_{T,4\ell}$ $\{0, 45, 120, 350\}$	12
	$1.0 < \|y\| < 1.5$	$p_{T,4\ell}$ $\{0, 45, 120, 350\}$	
	$1.5 < \|y\| < 2.5$	$p_{T,4\ell}$ $\{0, 45, 120, 350\}$	
$p_{T,4\ell}$ vs. $p_{T,\text{lead.jet}}$	$N_{\text{jets}} = 0$		
	$30 < p_{T,\text{lead.jet}} < 60$	$p_{T,4\ell}$ $\{0, 80, 350\}$	7
	$60 < p_{T,\text{lead.jet}} < 120$	$p_{T,4\ell}$ $\{0, 120, 350\}$	
	$120 < p_{T,\text{lead.jet}} < 350$	$p_{T,4\ell}$ $\{0, 120, 350\}$	
$p_{T,4\ell}$ vs. $p_{T,4\ell,j}$	$N_{\text{jets}} = 0$		
	$0 < p_{T,4\ell,j} < 60$	$p_{T,4\ell}$ $\{0, 120, 350\}$	5
	$60 < p_{T,4\ell,j} < 350$	$p_{T,4\ell}$ $\{0, 120, 350\}$	
$p_{T,4\ell,j}$ vs. $m_{4\ell,j}$		$N_{\text{jets}} = 0$	
	$120 < m_{4\ell,j} < 220$	$0 < p_{T,4\ell,j} < 350$	
	$220 < m_{4\ell,j} < 350$	$p_{T,4\ell,j}$ $\{0, 60, 350\}$	4
	$350 < m_{4\ell,j} < 2000$	$0 < p_{T,4\ell,j} < 350$	
$p_T^{\text{lead. jet}}$ vs. $p_T^{\text{sublead. jet}}$	$N_{\text{jets}} = 0$		
	$p_T^{\text{lead. jet}}$ $\{30, 60, 350\}$	$N_{\text{jets}} = 1$	
	$30 < p_T^{\text{lead. jet}} < 60$	$30 < p_T^{\text{sublead. jet}} < 60$	6
	$60 < p_T^{\text{lead. jet}} < 350$	$30 < p_T^{\text{sublead. jet}} < 60$	
	$60 < p_T^{\text{lead. jet}} < 350$	$60 < p_T^{\text{sublead. jet}} < 350$	
$p_T^{\text{lead. jet}}$ vs. $\|y^{\text{lead. jet}}\|$	$N_{\text{jets}} = 0$		
	$30 < p_T^{\text{lead. jet}} < 120$	$0.0 < \|y^{\text{lead. jet}}\| < 0.8$	
	$30 < p_T^{\text{lead. jet}} < 120$	$0.8 < \|y^{\text{lead. jet}}\| < 1.7$	
	$30 < p_T^{\text{lead. jet}} < 120$	$\|y^{\text{lead. jet}}\| > 1.7$	6
	$120 < p_T^{\text{lead. jet}} < 350$	$0 < \|y^{\text{lead. jet}}\| > 1.7$	
	$120 < p_T^{\text{lead. jet}} < 350$	$\|y^{\text{lead. jet}}\| > 1.7$	

Summary of Hγγ variables and binning choices

Binning schemes for Higgs-related variables:

Variable	Bin Edges	N_{bins}
$p_{\text{T}}^{\gamma\gamma}$	0, 5, 10, 15, 20, 25, 30, 35, 45, 60, 80, 100, 120, 140, 170, 200, 250, 350, 450, 1000	19
$\lvert y_{\gamma\gamma} \rvert$	0, 0.15, 0.3, 0.45, 0.6, 0.75, 0.9, 1.2, 1.6, 2.0, 2.5	11
$p_{\text{T}}^{\gamma 1}/m_{\gamma\gamma}$	0.35, 0.45, 0.5, 0.55, 0.6, 0.65, 0.75, 0.85, 0.95, 4	9
$p_{\text{T}}^{\gamma 2}/m_{\gamma\gamma}$	0.25, 0.35, 0.4, 0.45, 0.5, 0.55, 0.65, 0.75, 0.85, 4	9

Summary of Hγγ variables and binning choices

Binning schemes for jet-related variables:

Variable	Bin Edges	N_{bins}
$N_{\text{jets}}^{\geq 30\text{GeV}}$	0, 1, 2, ≥3	4
$N_{\text{b-jets}}^{\geq 30\text{GeV}}$	TODO	
$p_{\text{T}}^{j_1}$	$N_{\text{jets}} = 0, 30, 60, 90, 120, 350, 999$	6
$p_{\text{T}}^{\gamma\gamma j}$	$N_{\text{jets}} = 0, 0, 30, 60, 120, 350$	5
H_{T}	$N_{\text{jets}} = 0, 30, 70, 140, 200, 500, 999$	6
$\tau_{C,j1}$	$N_{\text{jets}} = 0, 0, 5, 15, 25, 40, 400$	6
$\sum \tau_{C,j}$	$N_{\text{jets}} = 0, 5, 15, 25, 40, 80, 200$	6
$m_{\gamma\gamma j}$	$N_{\text{jets}} = 0, 120, 180, 220, 300, 400, 600, 900, 2000$	8
m_{jj}	$N_{\text{jets}} < 2, 0, 120, 450, 3000, 9999$	5
$\Delta\phi_{jj,\text{signed}}$	$N_{\text{jets}} < 2, -\pi, -\frac{\pi}{2}, 0, \frac{\pi}{2}, \pi$	5
$p_{\text{T},\gamma\gamma jj}$	$N_{\text{jets}} < 2, 0, 30, 60, 120, 350$	5
$\Delta\phi_{\gamma\gamma,jj}$	$N_{\text{jets}} < 2, 0, 2.5, 3.0, 3.15$	4

Summary of Hγγ variables and binning choices

Binning schemes for double-differential variables:

Variable	Bin Edges		N_{bins}
$p_T^{\gamma\gamma}$ vs $\|y_{\gamma\gamma}\|$	$0.0 < \|y_{\gamma\gamma}\| < 0.5$	$p_T^{\gamma\gamma}$: 0, 45, 120, 350	
	$0.5 < \|y_{\gamma\gamma}\| < 1.0$	$p_T^{\gamma\gamma}$: 0, 45, 120, 350	12
	$1.0 < \|y_{\gamma\gamma}\| < 1.5$	$p_T^{\gamma\gamma}$: 0, 45, 120, 350	
	$1.5 < \|y_{\gamma\gamma}\| < 2.5$	$p_T^{\gamma\gamma}$: 0, 45, 120, 350	
$(p_T^{\gamma 1} + p_T^{\gamma 2})/m_{\gamma\gamma}$ vs $(p_T^{\gamma 1} - p_T^{\gamma 2})/m_{\gamma\gamma}$	$0.6 < (p_T^{\gamma 1} + p_T^{\gamma 2})/m_{\gamma\gamma} < 0.8$	$(p_T^{\gamma 1} - p_T^{\gamma 2})/m_{\gamma\gamma}$: 0, 0.3	
	$0.8 < (p_T^{\gamma 1} + p_T^{\gamma 2})/m_{\gamma\gamma} < 1.1$	$(p_T^{\gamma 1} - p_T^{\gamma 2})/m_{\gamma\gamma}$: 0,0.05,0.1,0.2,0.8	8
	$1.1 < (p_T^{\gamma 1} + p_T^{\gamma 2})/m_{\gamma\gamma} < 4$	$(p_T^{\gamma 1} - p_T^{\gamma 2})/m_{\gamma\gamma}$: 0,0.3,0.6,4	
$p_T^{\gamma\gamma}$ vs $p_T^{\gamma\gamma j}$	$N_{\text{jets}} = 0$		
	$0 < p_T^{\gamma\gamma j} < 30$	$p_T^{\gamma\gamma}$: 0,45,120,350	10
	$30 < p_T^{\gamma\gamma j} < 60$	$p_T^{\gamma\gamma}$: 0,45,120,350	
	$60 < p_T^{\gamma\gamma j} < 350$	$p_T^{\gamma\gamma}$: 0,45,120,350	
$p_T^{\gamma\gamma}$ vs $\tau_{C,j1}$	$N_{\text{jets}} = 0$		
	$0 < \tau_{C,j1} < 15$	$p_T^{\gamma\gamma}$: 0,45,120,350	
	$15 < \tau_{C,j1} < 25$	$p_T^{\gamma\gamma}$: 0,120,350	10
	$25 < \tau_{C,j1} < 40$	$p_T^{\gamma\gamma}$: 0,120,350	
	$40 < \tau_{C,j1} < 200$	$p_T^{\gamma\gamma}$: 0,200,350	