中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

ATLAS EXPERIMENT

HH → $\gamma\gamma + ML$ Unblinding approval request closure

Qiyu Sha

Institute of High Energy Physics CAS, Beijing

ON BEHALF OF THE MULTILEPTON ANALYSIS TEAM

General information

- Entry in glance
- Supporting note circulated Dec. 9
- 1st EB meetings
- 2nd EB meetings
- Unblinding approval
- Unblinding approval closure
- Action items on CDS

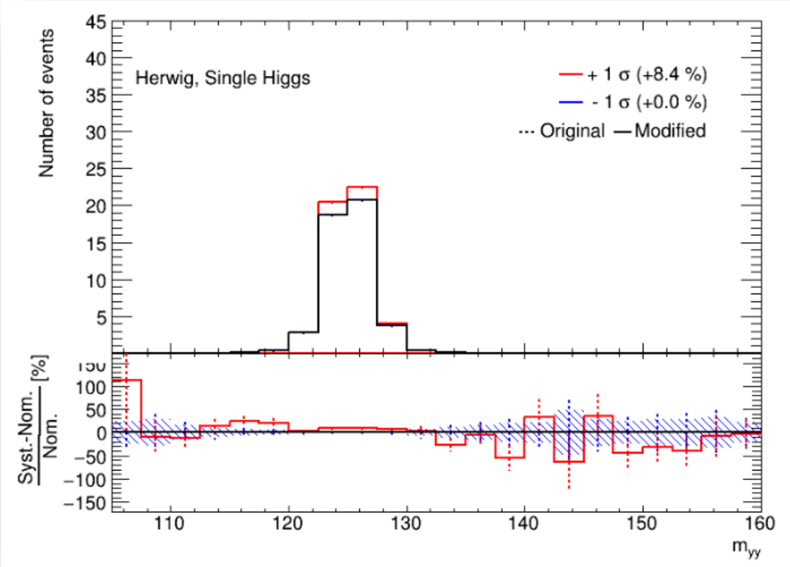
Action items from 31st Jan meeting

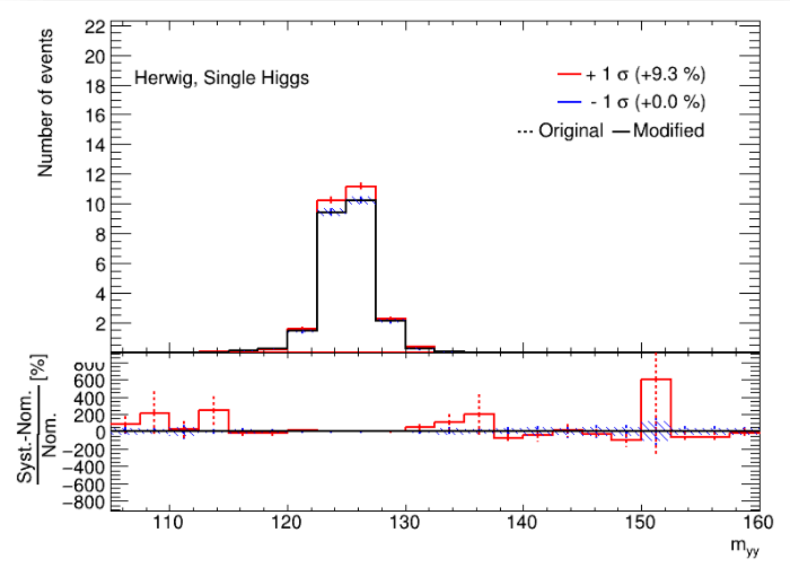
- 1) Add PS uncertainties on single-Higgs background.
- 2) Implement shape uncertainty on the continuum background, derived from MC-to-MC comparison.
- 3) Compare background model from fit to sideband in the SR to the postfit obtained from the baseline method with shape uncertainty.
- Change background modeling function to 1st exp-ploy and ensure the background shape is decreasing.

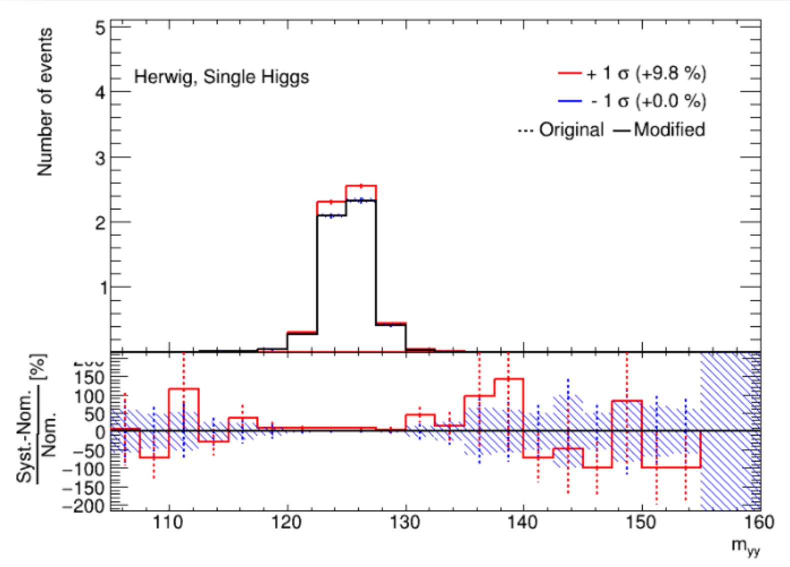
- Have updated the INT note (version 0.7)

Reply to action items

- Add PS uncertainties on single-Higgs background. Done, Table 61 in INT note







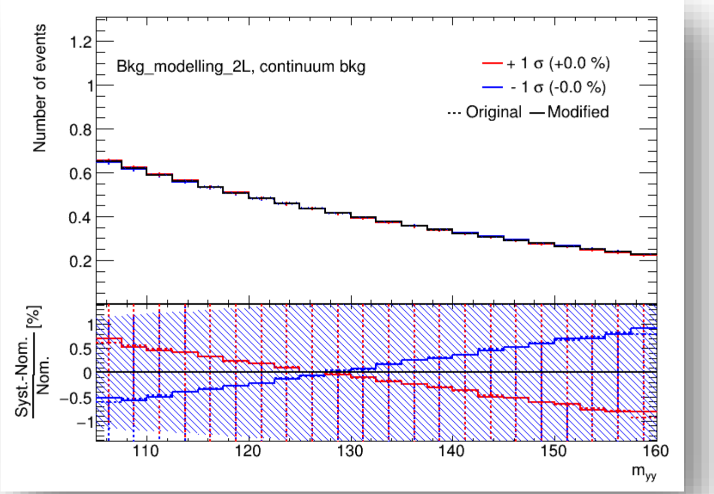
Channel	Process	Parton Shower (%)	PDF + α_s (%)	QCD Scale (%)
$\gamma\gamma+1\ell0\tau_{had}$	HH signal	2.51	4.46	$^{+13.03}_{-12.26}$
$\gamma\gamma+0\ell1\tau_{had}$	HH signal	1.18	4.53	$^{+13.15}_{-12.35}$
$\gamma\gamma$+2L	HH signal	2.85	4.47	$^{+13.03}_{-12.33}$
$\gamma\gamma+1\ell0\tau_{had}$	Single Higgs	8.45	5.86	$^{+3.73}_{-3.82}$
$\gamma\gamma+0\ell1\tau_{had}$	Single Higgs	9.34	5.98	$^{+10.49}_{-7.10}$
$\gamma\gamma$+2L	Single Higgs	9.78	5.35	$^{+9.09}_{-7.67}$

Table 61: Summary of theoretical uncertainties for the $\gamma\gamma + ML$channel.

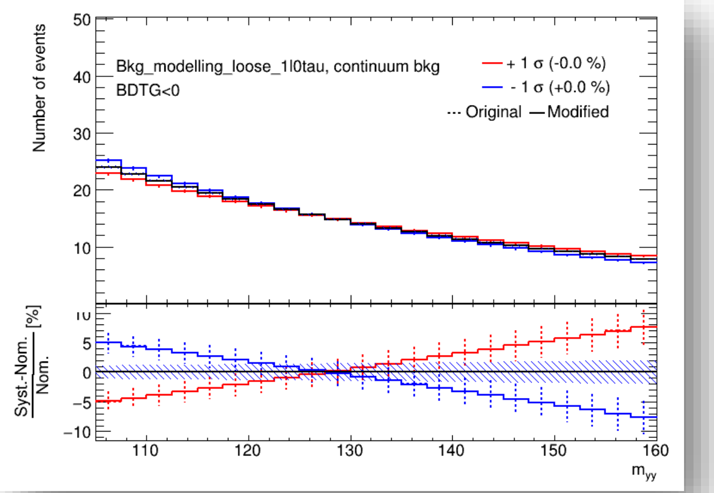
Reply to action items

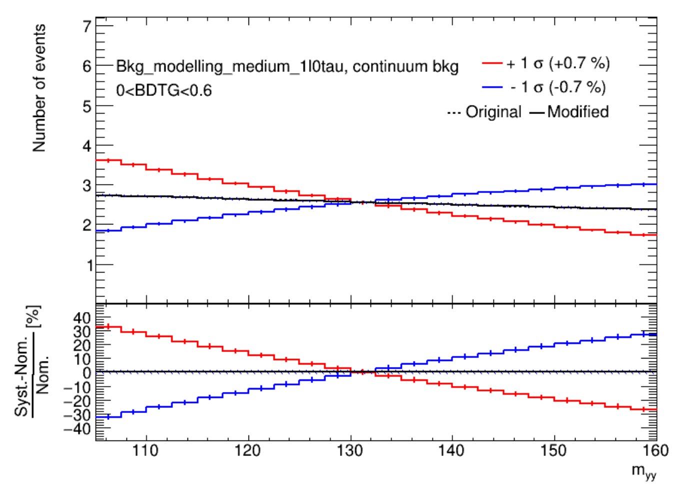
- Implement shape uncertainty on the continuum background, derived from MC-to-MC comparison. Done

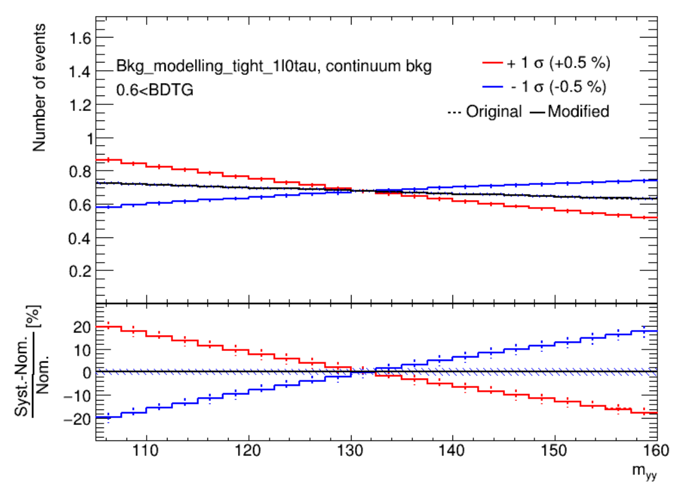
$\gamma\gamma + 2L$:



$\gamma\gamma + 1l0\tau_h$:





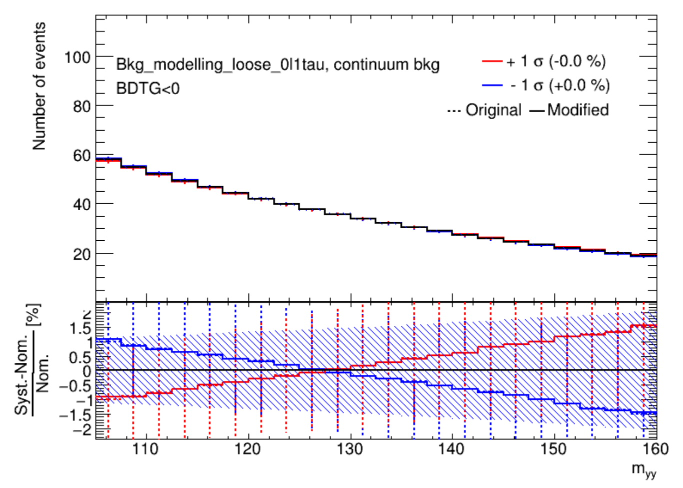


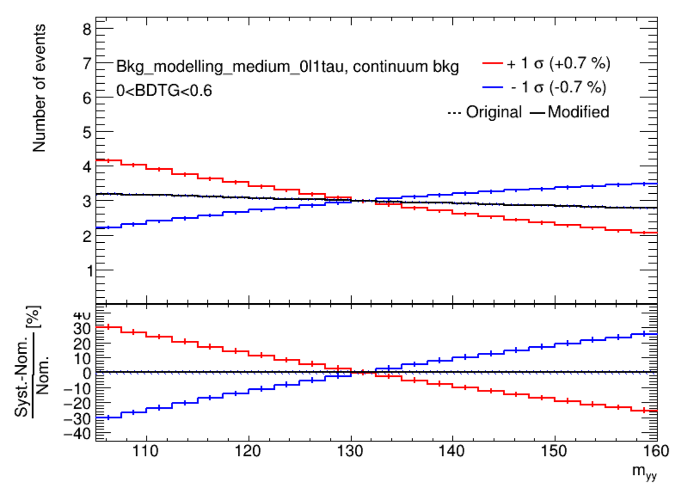
Reply to action items

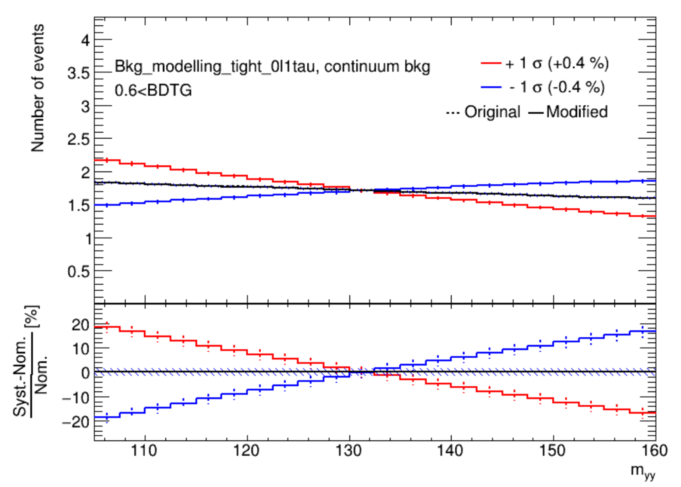
- Implement shape uncertainty on the continuum background, derived from MC-to-MC comparison.

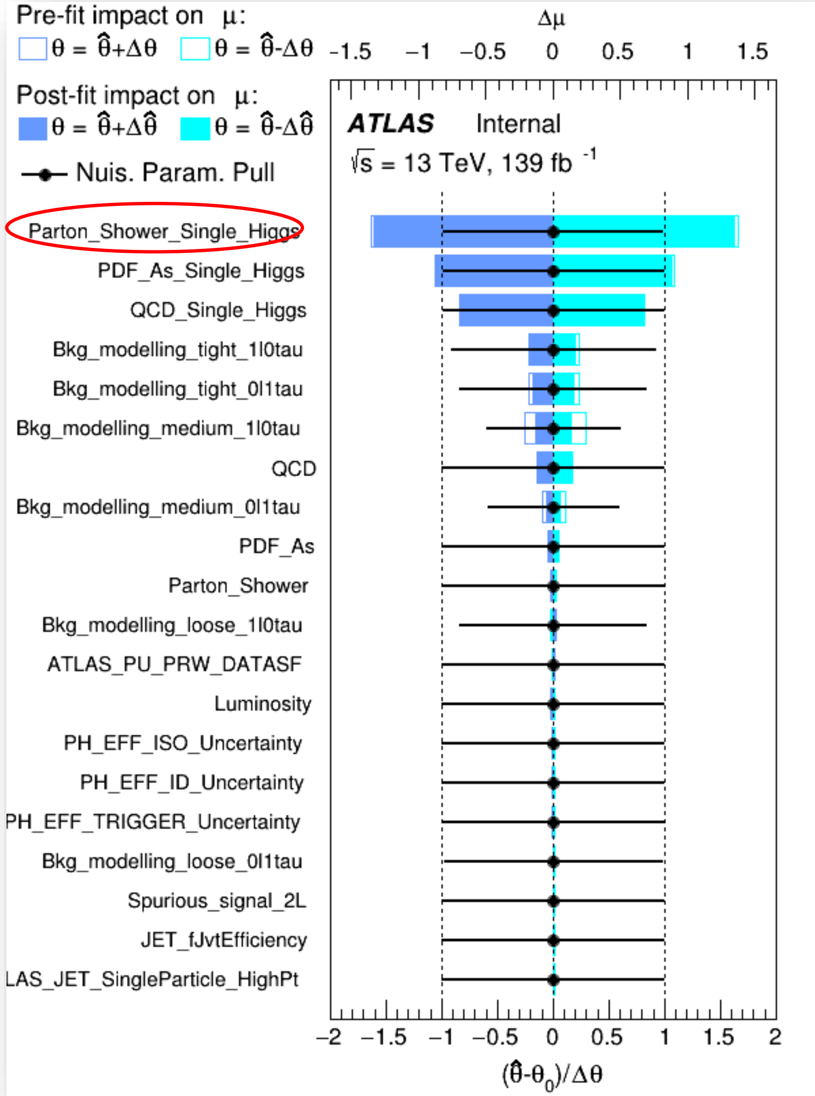
Done and update the ranking plots in INT note (such as Figure 111)

$\gamma\gamma + 0l1\tau_h$:









Reply to action items

After applying new background uncertainties and single-higgs parton shower uncertainty.

We can get new results following: (Table 72 in INT note)

Channels	Stats.Only	+ MC stats & Detector systematics	+ Bkg modelling&Theory systematics
$\gamma\gamma$+1ℓ0τ_{had}	$25.43^{36.95}_{18.32}$	$25.49^{37.05}_{18.32}$	$26.68^{39.53}_{19.23}$
$\gamma\gamma$+0ℓ1τ_{had}	$52.58^{76.54}_{37.89}$	$52.67^{76.74}_{37.95}$	$54.50^{80.98}_{39.27}$
$\gamma\gamma$+2L	$37.05^{54.86}_{26.70}$	$37.11^{55.00}_{26.74}$	$38.21^{57.76}_{27.53}$
$\gamma\gamma + ML$	$17.71^{25.50}_{12.76}$	$17.74^{25.57}_{12.78}$	$18.67^{27.48}_{13.46}$

Channels	Stats.Only (Asimov)	+MC stats.(Asimov)	+Systematics (Asimov)	With all uncertainties
$\gamma\gamma$+1ℓ0τ_{had}	$25.46^{36.99}_{18.35}$	-	$25.50^{37.09}_{18.37}$	$26.60^{39.43}_{19.17}$
$\gamma\gamma$+0ℓ1τ_{had}	$52.70^{76.71}_{37.98}$	-	$52.79^{76.91}_{38.04}$	$54.97^{81.64}_{39.61}$
$\gamma\gamma$+2L	$37.01^{54.79}_{26.67}$	-	$37.07^{54.94}_{26.71}$	$38.15^{57.66}_{27.49}$
$\gamma\gamma + ML$	$17.72^{25.52}_{12.77}$	-	$17.75^{25.59}_{12.79}$	$18.55^{27.32}_{13.37}$

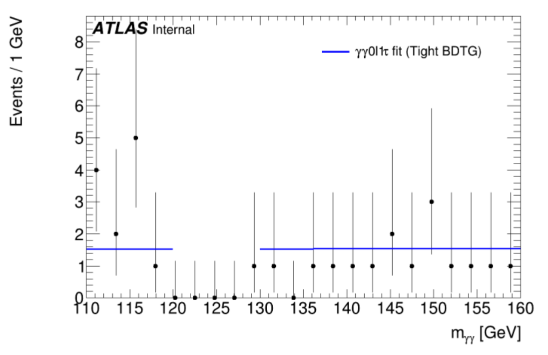
Reply to action items

◆Compare background model from fit to sideband in the SR to the postfit obtained from the baseline method with shape uncertainty. (have changed background modelling function to 1st exp-ploy)

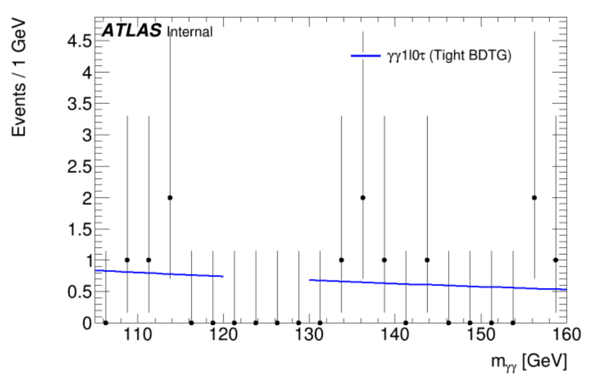
Can't fit the data sideband directly well. So some directly fit shape need to modify parameter:

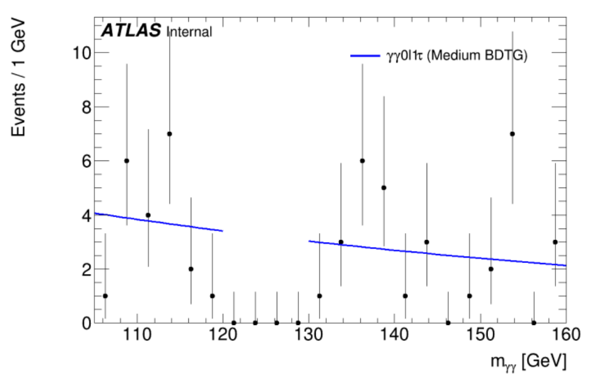
The way to modify parameter:

◆Ensure the shape is down (at least flat), like $\gamma\gamma + 0l1\tau_h$ Tight BDTG:



◆Considering the 0 or 1 event in the first bin around 105 just come from low statistic, fit the data sideband begin from ~110 and get the fitting parameter, like following:

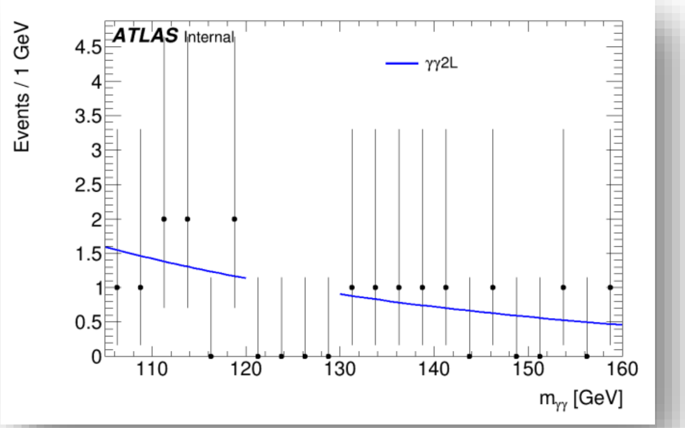




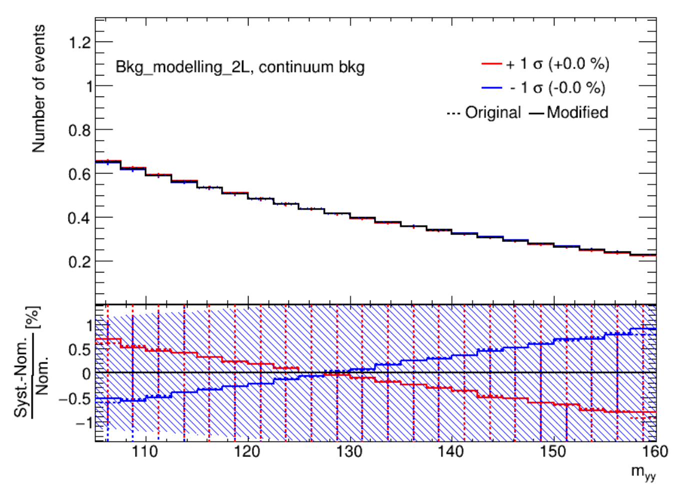
Reply to action items

$\gamma\gamma + 2L$:

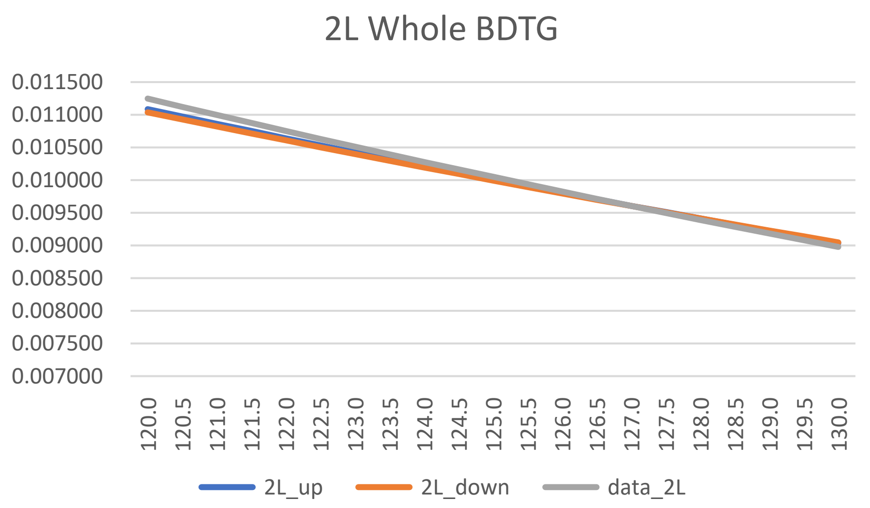
Background model from fit to data_2l sideband directly



Postfit obtained from the baseline method with shape uncertainty (Fit to data_0l0tau2j sideband and then apply MC shape uncertainty bin by bin):
The red shape is the bkg model with shape uncertainty.



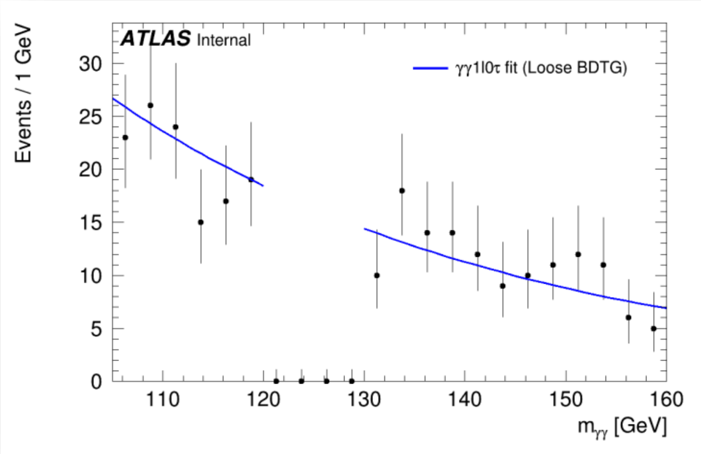
Compare: The uncertainty almost cover the difference. (The difference less than 0.03%)



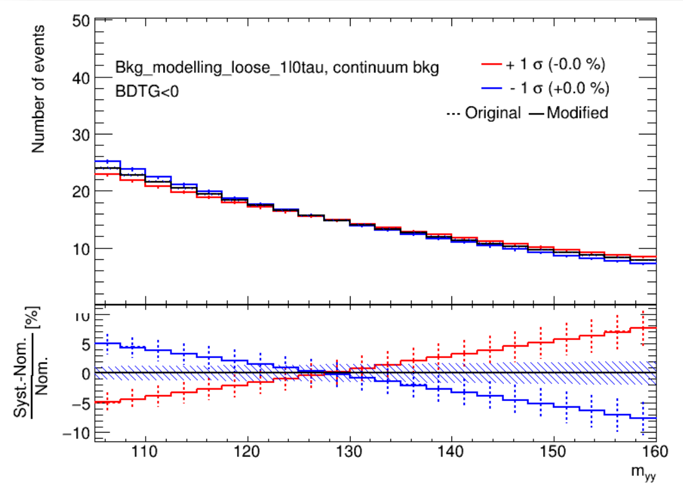
Reply to action items

$\gamma\gamma + 1l0\tau_h$ loose BDTG:

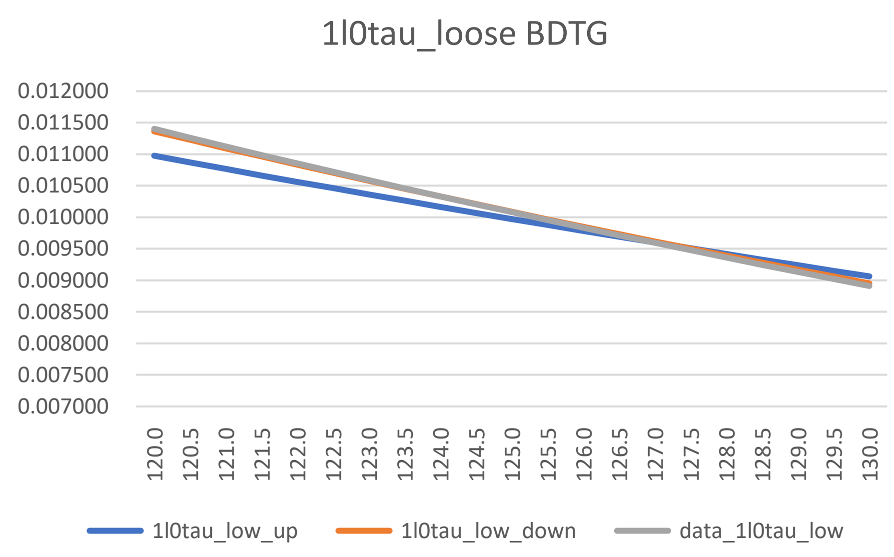
Background model from fit to data_1l0tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



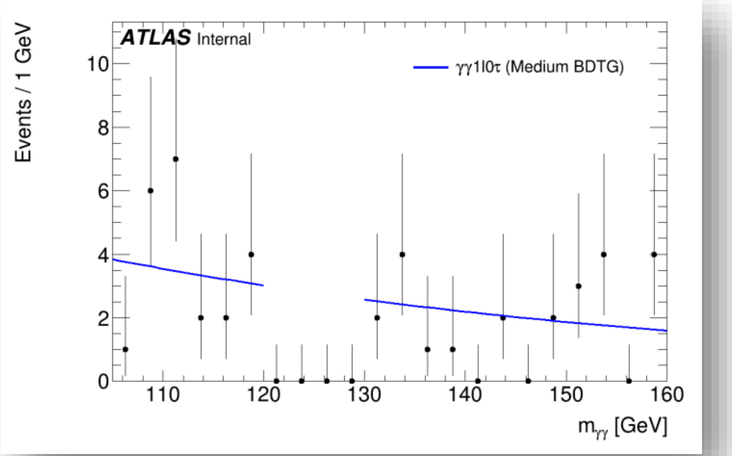
Compare: The uncertainty cover the difference



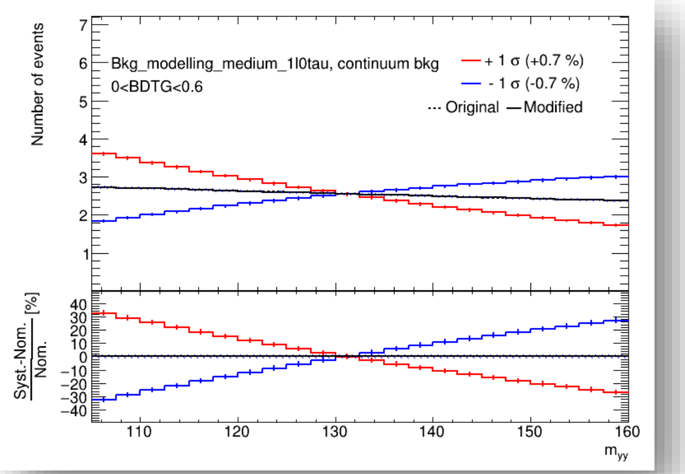
Reply to action items

$\gamma\gamma + 1l0\tau_h$ medium BDTG:

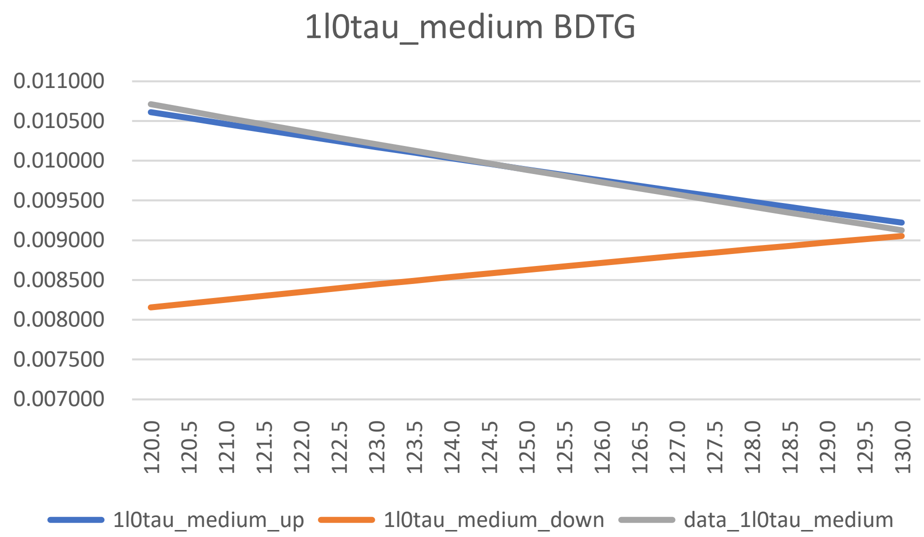
Background model from fit to data_1l0tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



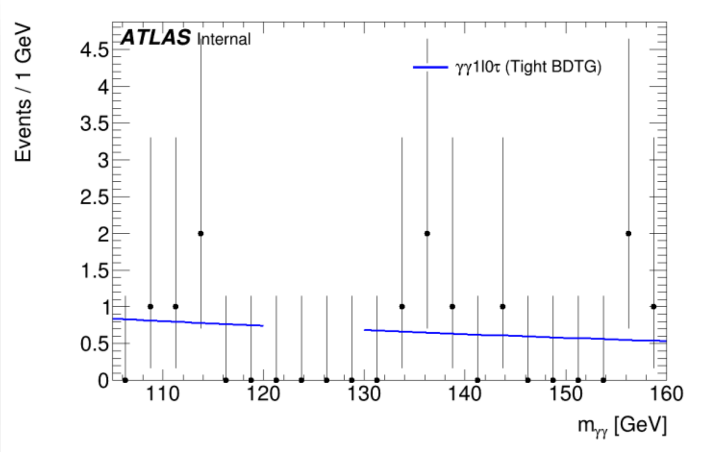
Compare: The uncertainty cover the difference



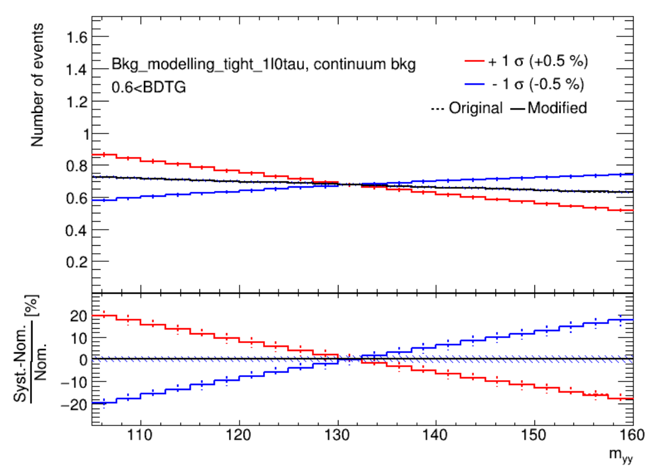
Reply to action items

$\gamma\gamma + 1l0\tau_h$ tight BDTG:

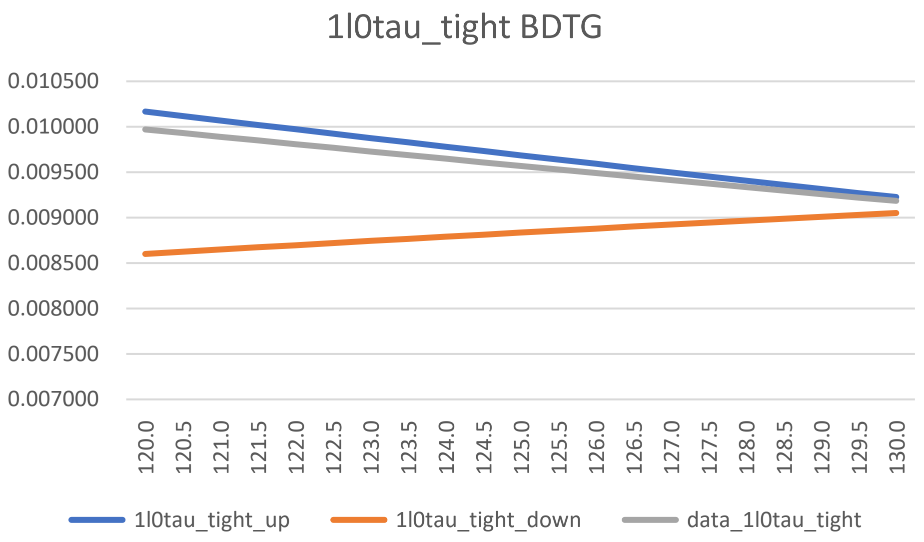
Background model from fit to data_1l0tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



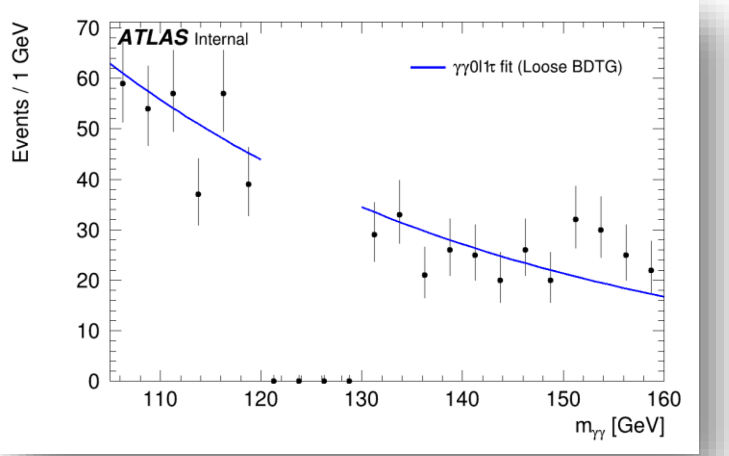
Compare: The uncertainty cover the difference



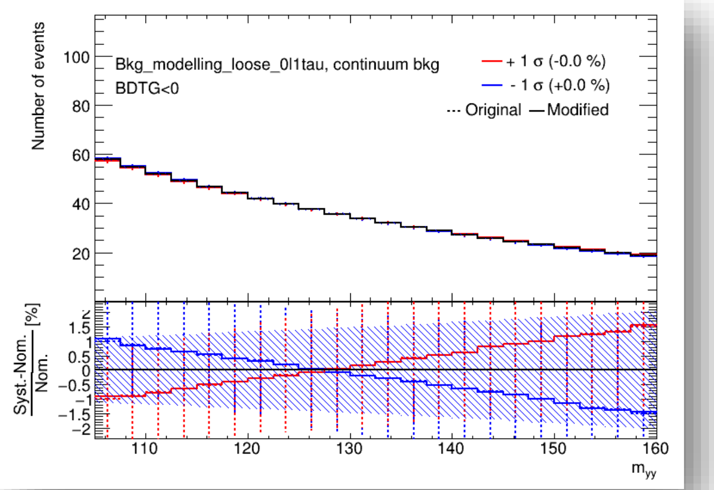
Reply to action items

$\gamma\gamma + 0l1\tau_h$ loose BDTG:

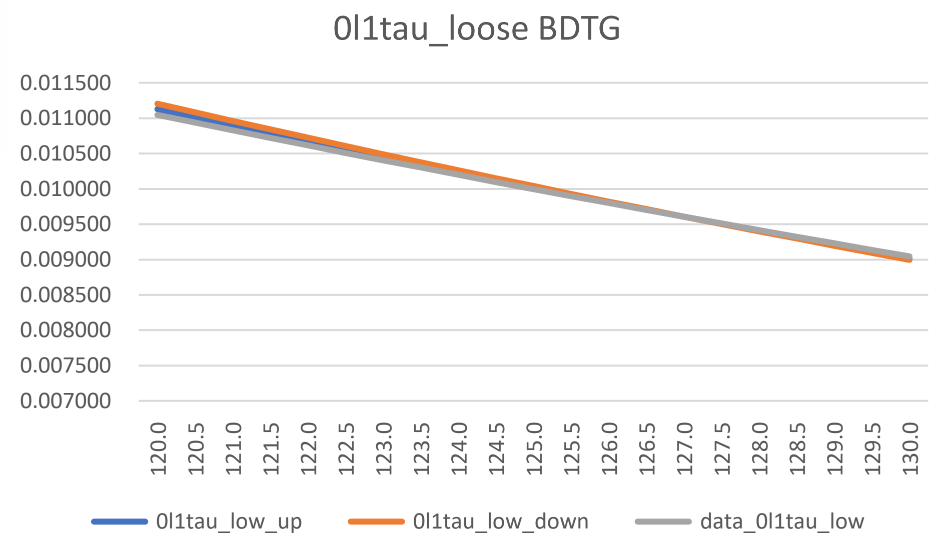
Background model from fit to data_0l1tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



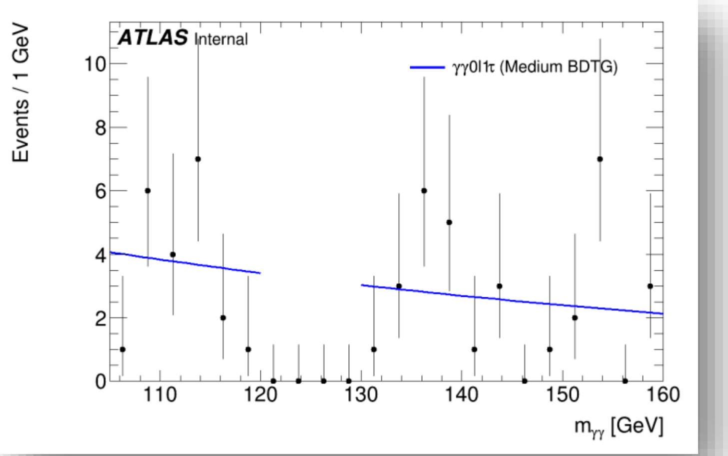
Compare: The uncertainty almost cover the difference



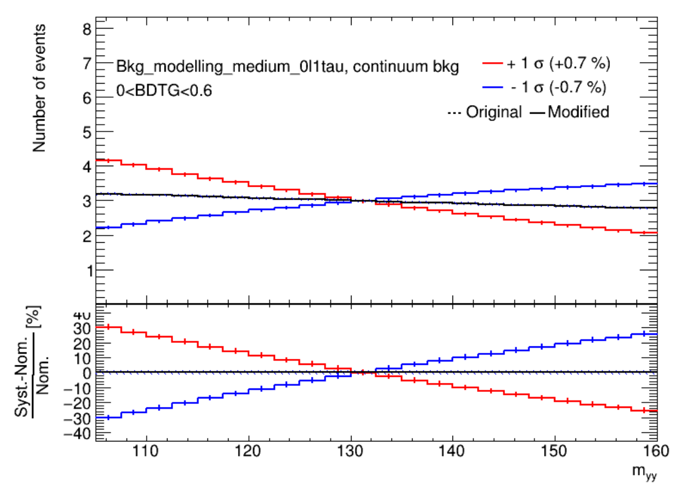
Reply to action items

$\gamma\gamma + 0l1\tau_h$ Medium BDTG:

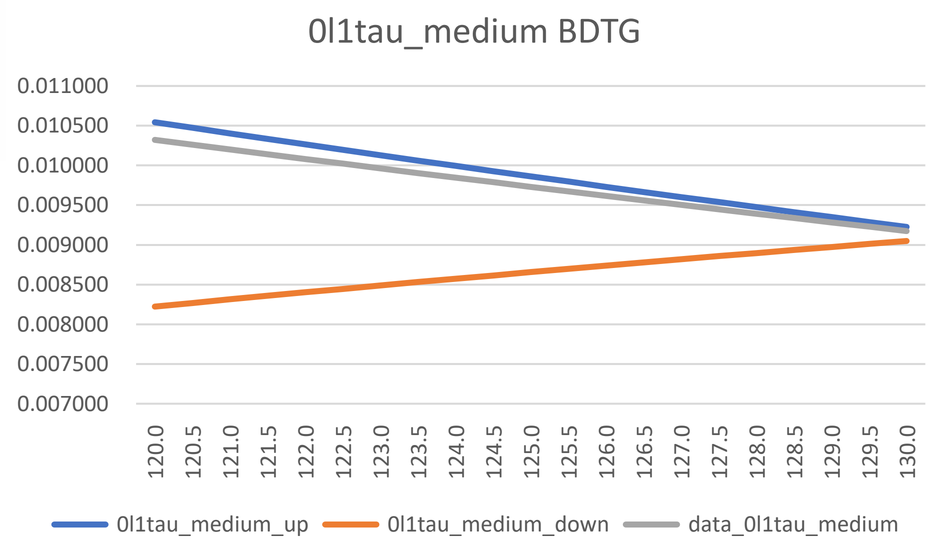
Background model from fit to data_0l1tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



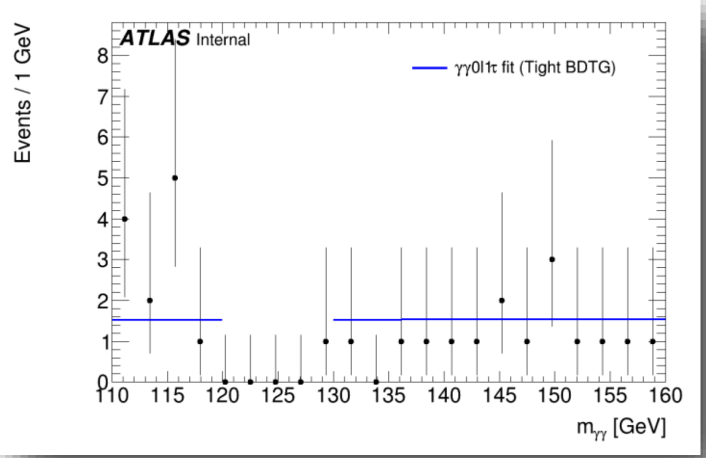
Compare: The uncertainty cover the difference



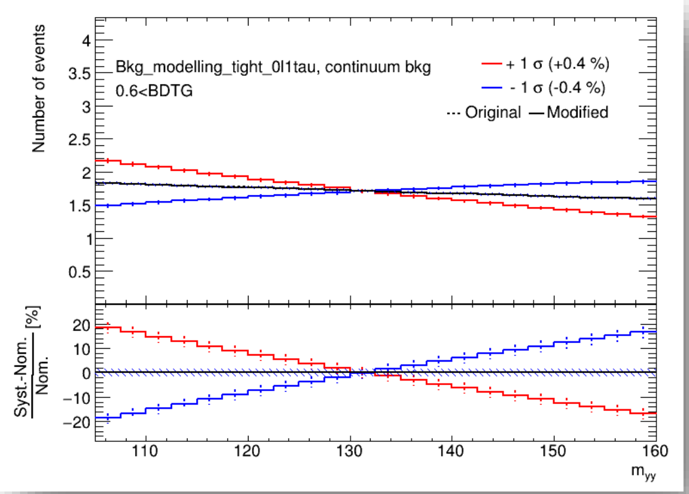
Reply to action items

$\gamma\gamma + 0l1\tau_h$ Tight BDTG:

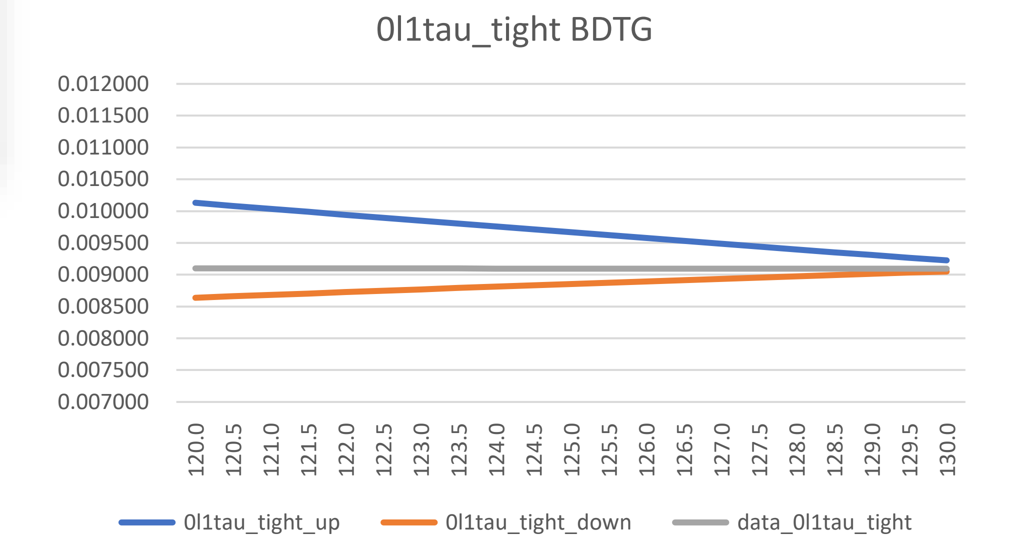
Background model from fit to data_0l1tau sideband directly:



Postfit obtained from the baseline method with shape uncertainty(Fit to data_0l0tau1j sideband and then apply MC shape uncertainty bin by bin): The red shape is the bkg model with shape uncertainty.



Compare: The uncertainty cover the difference



Backup (last action items)

Action items

- Reply to all comments on CDS
- Clarify in the note how the BDT boundaries are chosen
- Add labels making clear what is shown in the data/MC BDT plots in the sidebands.
- Include spurious signal uncertainty in the fit
- Include single higgs uncertainties in the fit and in the INT note.
- Add plots of the shape uncertainty for the continuum background modeling
- Split the background modelling NPs per channel.
- Add plots showing the pulls for all NPs included in the fit in the INT note.
- yy+2L: Combine the two high BDT regions or all regions in a single one with enough data statistics
- Make the final myy plots for all regions entering the fit including all background systematics.

    - Have updated the INT note.

Reply to action items

- Reply to all comments on CDS

Done, some of them are about ML channel. Google doc.

- Clarify in the note how the BDT boundaries are chosen

Done, we add more details in the section 10.3 in updated version: Also show in backup

We use 10 bins in BDTG shape and then calculate the significance with different regions for the Tight BDTG region using the Equation 3, the results are shown in Table 50. Although the best value is $0.8 < \text{BDTG}$, considering the low statistic in this region. Finally, we choose the $0.6 < \text{BDTG}$. After choosing the tight region, we do the another scan on the remaining BDTG regions, the results are shown in Table 51, and the best region here is the $0 < \text{BDTG} \leq 0.6$ in both $\gamma\gamma+0\ell 1\tau_{\text{had}}$ and $\gamma\gamma+1\ell 0\tau_{\text{had}}$ channel, so we choose this region as the Medium BDTG region, and the remaining region is the Loose BDTG region.

Tight Region	$\gamma\gamma+0\ell 1\tau_{\text{had}}$ channel		$\gamma\gamma+1\ell 0\tau_{\text{had}}$ channel	
	Z-value	data sideband yield	Z-value	data sideband yield
[0.8, 1]	0.0268	16	0.0486	6
[0.6, 1]	0.0221	31	0.0464	12
[0.4, 1]	0.0190	47	0.0430	27
[0.2, 1]	0.0167	57	0.0406	44
[0, 1]	0.0150	84	0.0381	57

Table 50: The significance value used to choose the Tight BDTG region in $\gamma\gamma+0\ell 1\tau_{\text{had}}$ and $\gamma\gamma+1\ell 0\tau_{\text{had}}$ channel.

Medium Region	$\gamma\gamma+0\ell 1\tau_{\text{had}}$ channel		$\gamma\gamma+1\ell 0\tau_{\text{had}}$ channel	
	Z-value	data sideband yield	Z-value	data sideband yield
[0.4, 0.6]	0.0026	16	0.0109	15
[0.2, 0.6]	0.0030	26	0.0128	32
[0.0, 0.6]	0.0032	53	0.0134	45
[−0.2, 0.6]	0.0031	78	0.0131	61
[−0.4, 0.6]	0.0029	119	0.0126	80

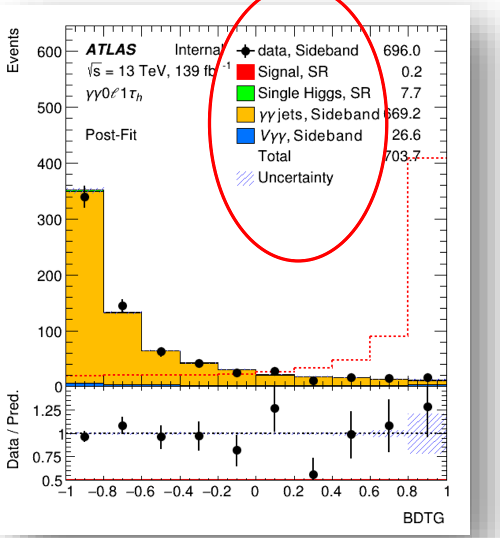
Table 51: The significance value used to choose the Medium BDTG region in $\gamma\gamma+0\ell 1\tau_{\text{had}}$ and $\gamma\gamma+1\ell 0\tau_{\text{had}}$ channel.

Reply to action items

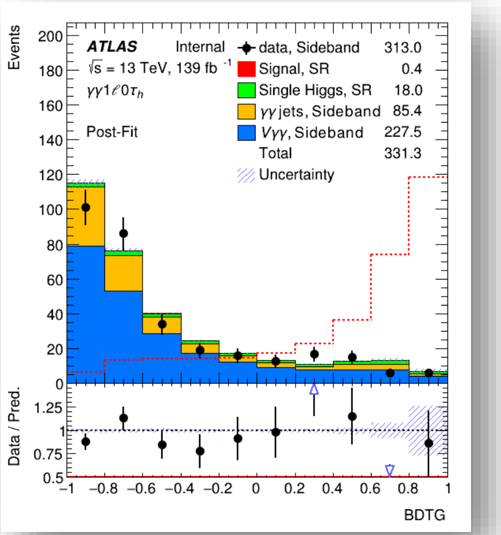
◆ Add labels making clear what is shown in the data/MC BDT plots in the sidebands.

Done, Figure 81 in INT note:

$\gamma\gamma + 0l1\tau_h$:



$\gamma\gamma + 1l0\tau_h$:



$\gamma\gamma + 2L$:

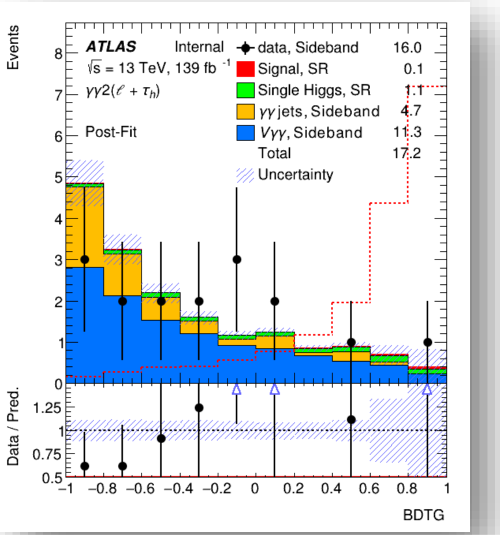


Figure 81: The BDTG distribution in different sub-channels (The MC continuum background sample which is composed of $V\gamma\gamma$ and $\gamma\gamma$+jets is in the sideband region and already apply the background scaling; The MC Signal and Single Higgs are in the signal region): (a) $\gamma\gamma+1\ell0\tau_{\text{had}}$ sub-channel; (b) $\gamma\gamma+0\ell1\tau_{\text{had}}$ sub-channel; (c) $\gamma\gamma$+2L (include $\gamma\gamma+1\ell1\tau_{\text{had}}$, $\gamma\gamma+2\ell0\tau_{\text{had}}$ and $\gamma\gamma+0\ell2\tau_{\text{had}}$) sub-channel. The HH signal distribution is scaled to the total background events and the expected HH yield is quoted in the legend.

Reply to action items

◆Include spurious signal uncertainty in the fit

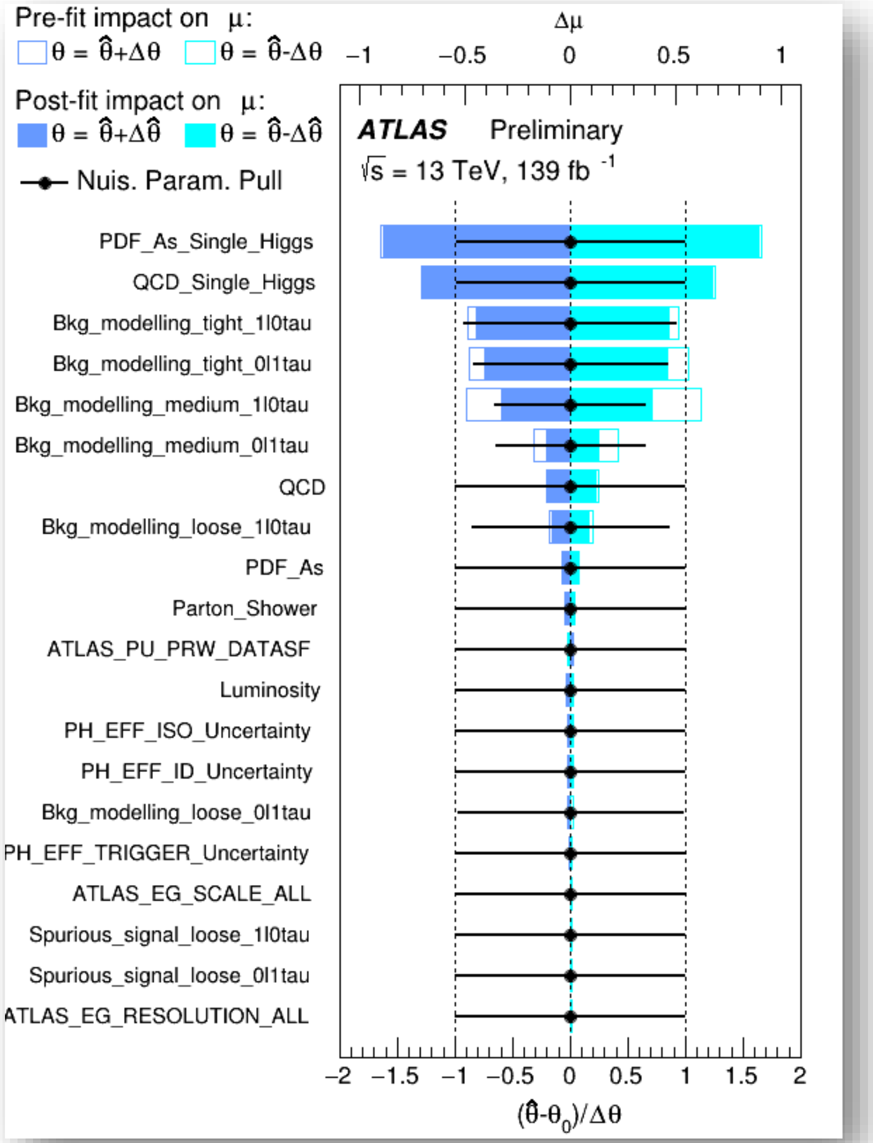
Done, can see the ranking plot Figure 111 in INT note (with 20 NPs)

The ranking plot is combined results.

➢ Spurious signal test results:

Channel	Region	$\mu_{sp,tight}$ [%]	$Z_{sp,tight}$ [%]	$P(\chi^2)$ [%]	Selected
$\gamma\gamma$+1ℓ0τ_{had}	loose	1.20	1.66	92.70	Yes
$\gamma\gamma$+1ℓ0τ_{had}	medium	0.29	0.43	32.27	Yes
$\gamma\gamma$+1ℓ0τ_{had}	tight	0.07	0.18	45.88	Yes
$\gamma\gamma$+0ℓ1τ_{had}	loose	5.58	6.42	83.43	Yes
$\gamma\gamma$+0ℓ1τ_{had}	medium	0.29	0.34	26.40	Yes
$\gamma\gamma$+0ℓ1τ_{had}	tight	0.03	0.09	73.97	Yes
$\gamma\gamma$+2L	whole	0.15	0.35	99.29	Yes

Table 55: The spurious signal test results for all channels with the 2^{nd} order exponential polynomial function.



Use μ_{sp}S+B function to fit B-only, we can get the fake signal μ_{sp}.

Then use the μ_{sp} as the spurious signal uncertainty like the theory uncertainties and apply this number to the signal sample.

Reply to action items

◆Include single higgs uncertainties in the fit and in the INT note.

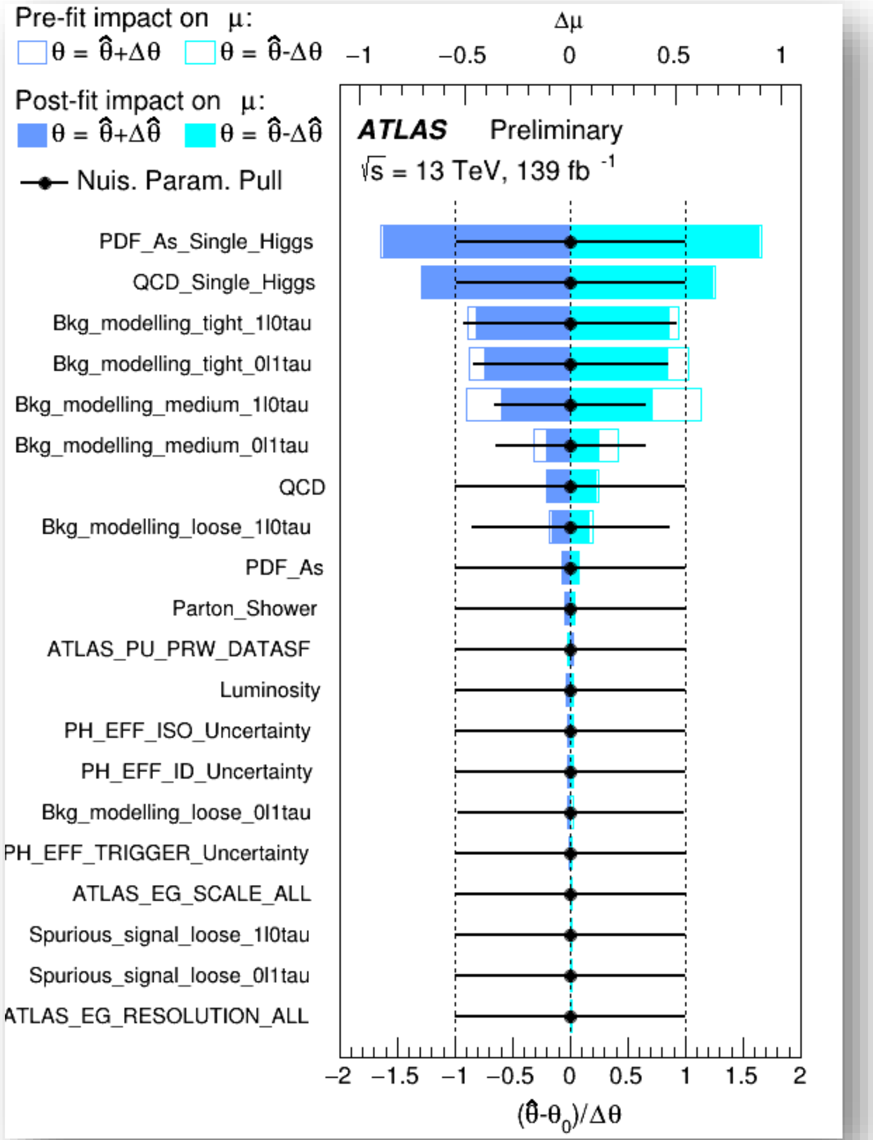
Done, in Section 11.2 and 12.4.6, only miss Single Higgs Parton Shower

➢ Theory uncertainties:

Channel	Process	Parton Shower (%)	PDF + α_s (%)	QCD Scale (%)
$\gamma\gamma+1\ell0\tau_{had}$	HH signal	2.51	4.46	$^{+13.03}_{-12.26}$
$\gamma\gamma+0\ell1\tau_{had}$	HH signal	1.18	4.53	$^{+13.15}_{-12.35}$
$\gamma\gamma$+2L	HH signal	2.85	4.47	$^{+13.03}_{-12.33}$
$\gamma\gamma+1\ell0\tau_{had}$	Single Higgs	-	5.86	$^{+3.73}_{-3.82}$
$\gamma\gamma+0\ell1\tau_{had}$	Single Higgs	-	5.98	$^{+10.49}_{-7.10}$
$\gamma\gamma$+2L	Single Higgs	-	5.35	$^{+9.09}_{-7.67}$

Table 60: Summary of theoretical uncertainties for the $\gamma\gamma + ML$channel.

We don't finish Single Higgs Parton Shower uncertainties yet and will finish it around Feb 14th .

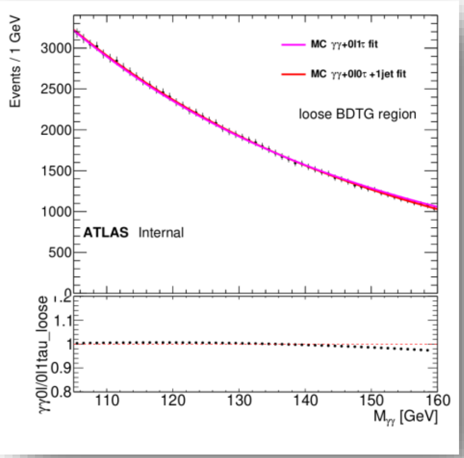


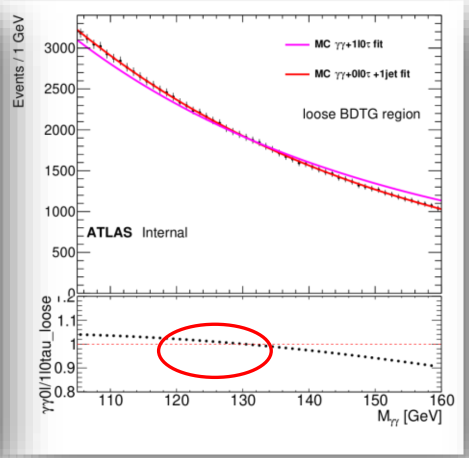
Reply to action items

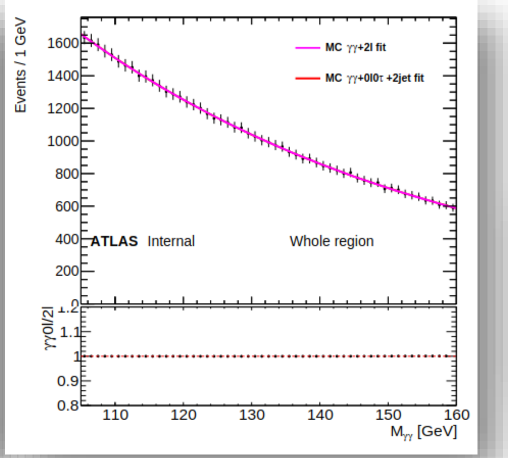
◆ Add plots of the shape uncertainty for the continuum background modeling

The plots we show before are the shape uncertainty for the continuum background modeling.

We just apply an average value of shape variation to all bins because this value can cover the variation in the signal region which has the most impact on the fit results in all channels. This is a simplified and reasonable method.







Channel	Loose BDTG region	Medium BDTG region	Tight BDTG region
$\gamma\gamma$+$1\ell0\tau_{\mathrm{had}}$	±3.37%	±15.73%	±11.22%
$\gamma\gamma$+$0\ell1\tau_{\mathrm{had}}$	±0.75%	±14.67%	±10.67%
$\gamma\gamma$+2L	Whole BDTG region : ±0.03%		

➢ The most variation in the signal region:

Channel	Loose BDTG region	Medium BDTG region	Tight BDTG region
$\gamma\gamma$+$1\ell0\tau_{\mathrm{had}}$	+2.20% / +0.16%	+0.88% / −10.53%	+2.36% / −7.18%
$\gamma\gamma$+$0\ell1\tau_{\mathrm{had}}$	+0.61% / +0.34%	+4.55% / −8.22%	+1.83% / −7.07%
$\gamma\gamma$+2L	Whole BDTG region : −0.023% / −0.030%		

Table 57: The most deviation of the background modeling in the signal region which is described in Section 10.4.2 for different categories in the $\gamma\gamma + ML$ analysis.

Reply to action items

◆Split the background modelling NPs per channel.

Done, see the ranking plot in the page 5. Figure 111 in INT note.

◆Add plots showing the pulls for all NPs included in the fit in the INT note.

Done, in section 12.4.6. Figure 112 in INT note (with all NPs).

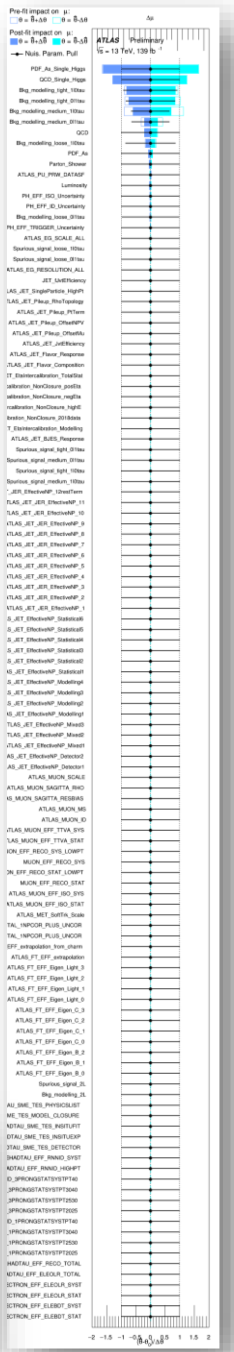
◆yy+2L: Combine the two high BDT regions or all regions in a single one with enough data statistics

Combine all regions and redo all analysis about yy+2L. (Two high BDT have 4 data sideband yield)

Also, modify the INT note and provide a new version of unblinding approval request slide following backup.

The final upper limit is changed:

- 2L with detector sys: $25.16 \rightarrow 37.07$
- Combined results with detector sys: $14.87 \rightarrow 17.75$



- With three BDT regions in yy+2L channel:

Channels	Stats.Only (Asimov)	+MC stats.(Asimov)	+Systematics (Asimov)	+Bkg estimation uncertainties
$\gamma\gamma$+$1\ell0\tau_{\text{had}}$	$25.46^{36.99}_{18.35}$	-	$25.50^{37.09}_{18.37}$	$25.64^{37.29}_{18.22}$
$\gamma\gamma$+$0\ell1\tau_{\text{had}}$	$52.70^{76.71}_{37.98}$	-	$52.79^{76.91}_{38.04}$	$53.30^{77.60}_{38.40}$
$\gamma\gamma$+2L	$25.13^{38.23}_{18.11}$	-	$25.16^{38.32}_{18.13}$	$25.18^{38.34}_{18.15}$
$\gamma\gamma + ML$	$14.85^{21.65}_{10.70}$	-	$14.87^{21.70}_{10.71}$	$14.98^{21.86}_{10.80}$

- With whole BDT region in yy+2L channel :

Channels	Stats.Only (Asimov)	+MC stats.(Asimov)	+Systematics (Asimov)	With all uncertainties
$\gamma\gamma$+$1\ell0\tau_{\text{had}}$	$25.46^{36.99}_{18.35}$	-	$25.50^{37.09}_{18.37}$	$26.60^{39.43}_{19.17}$
$\gamma\gamma$+$0\ell1\tau_{\text{had}}$	$52.70^{76.71}_{37.98}$	-	$52.79^{76.91}_{38.04}$	$54.97^{81.64}_{39.61}$
$\gamma\gamma$+2L	$37.01^{54.79}_{26.67}$	-	$37.07^{54.94}_{26.71}$	$38.15^{57.66}_{27.49}$
$\gamma\gamma + ML$	$17.72^{25.52}_{12.77}$	-	$17.75^{25.59}_{12.79}$	$18.55^{27.32}_{13.37}$

Reply to action items

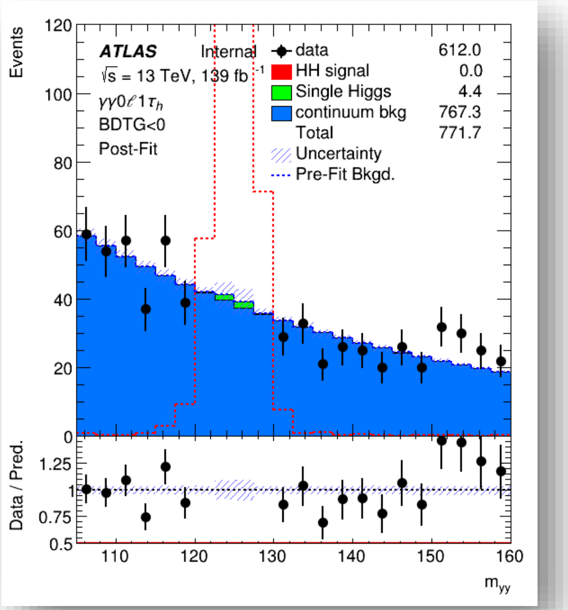
◆Make the final myy plots for all regions entering the fit including all background systematics.

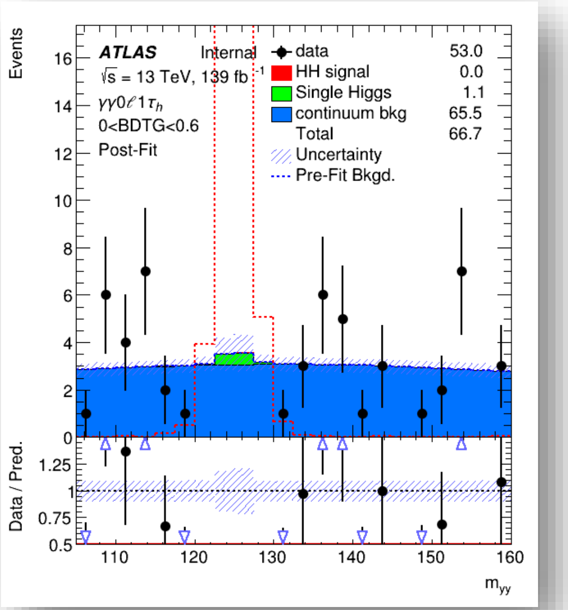
Done, Figure 89 in INT note, like following:

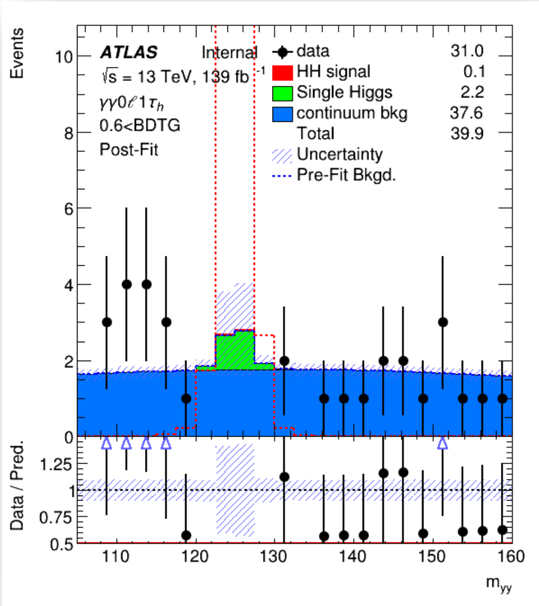
Uncertainty in these plots including detector uncertainties, theory uncertainties, spurious signal uncertainties and background modeling uncertainties:

$\gamma\gamma + 0l1\tau_h$: $m_{\gamma\gamma}$ distribution in different BDTG regions

◆Small events lead to these fluctuations which not be covered by background uncertainties.



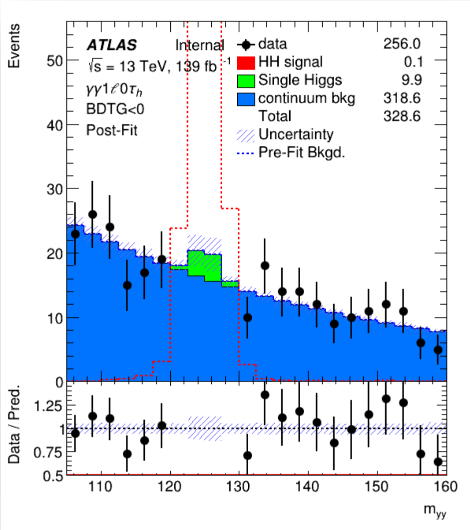


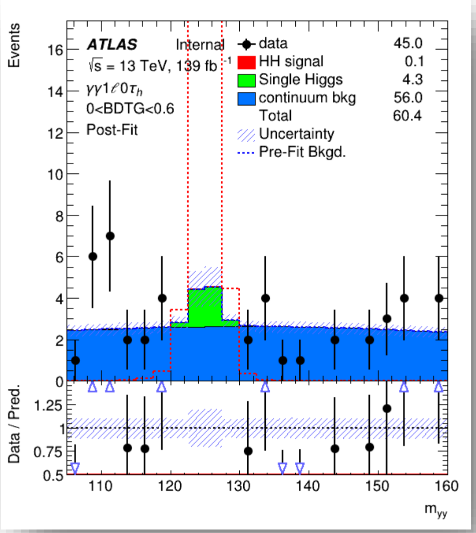


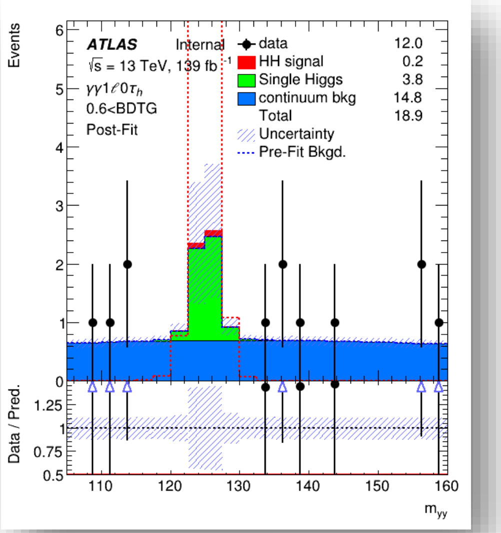
Reply to action items

- Make the final myy plots for all regions entering the fit including all background systematics.

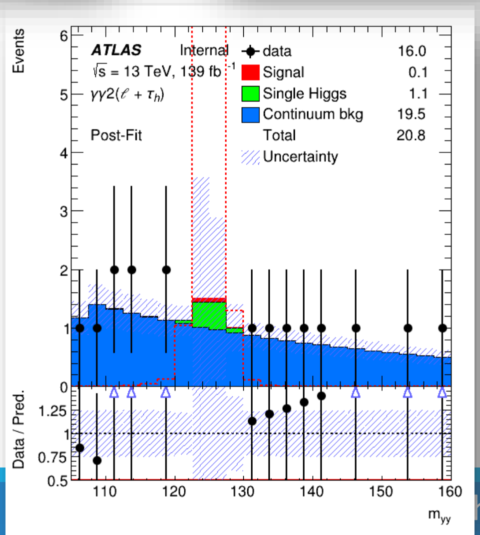
$\gamma\gamma + 1l0\tau_h$: $m_{\gamma\gamma}$ distribution in different BDTG regions







$\gamma\gamma + 2l$: $m_{\gamma\gamma}$ distribution in whole BDTG regions



Comments

- Given that many people were confused about the fit strategy, could you please add one slide where you explain how the fit is performed? E.g. explain how you derive the continuum background function and how you then use this function to determine the background template in your binned fit.

We use the second-order exponential to fit the $\gamma\gamma + 0l0\tau_h 1/2j$ sideband data in all BDTG regions.

Then use this fit function with fixed parameters to generate fake sample with 1000k random number and reweight to the expect yields. (Yield in sideband region in these fake samples are reweighted to the corresponding data-sideband yield)

Finally, use this fake sample as the background template sample and apply it in the fit.

Comments

Slide 5:

◆Could you explain a bit better how the spurious signal uncertainty is derived and then included in your binned fit?

Use the μ_{sp} as the spurious signal uncertainty and apply this number to the signal.

◆Please add the PS uncertainty for single-Higgs (in the table and in the fits).

We don't finish yet. Will finish around Feb 14th.

Slide 7:

◆Did you try also the other suggested configuration merging only the 2 high BDT regions (obtaining a region with 4 events)?

No. To avoid the same argument as before, we don't try this suggestion with merging 2 high BDT regions.

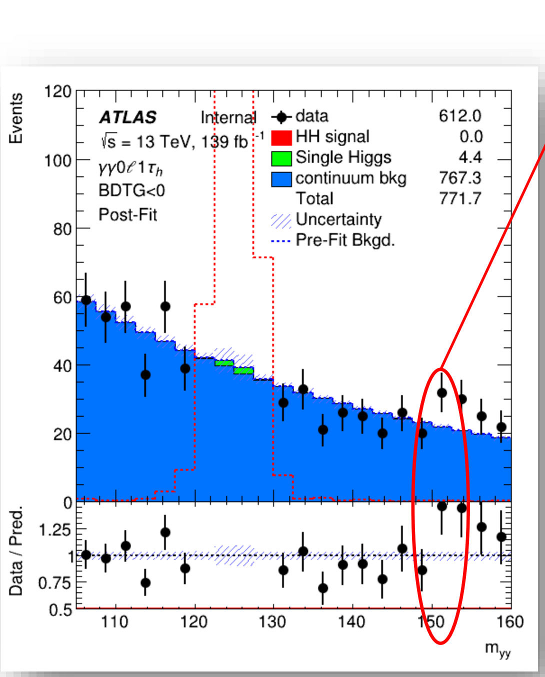
Comments

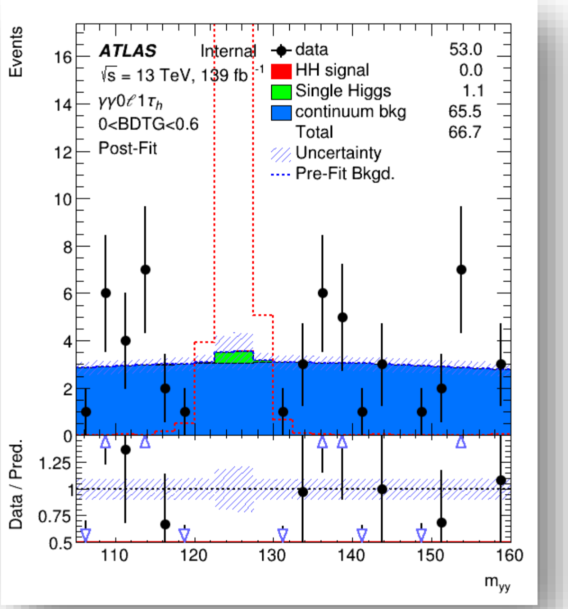
Slide 8:

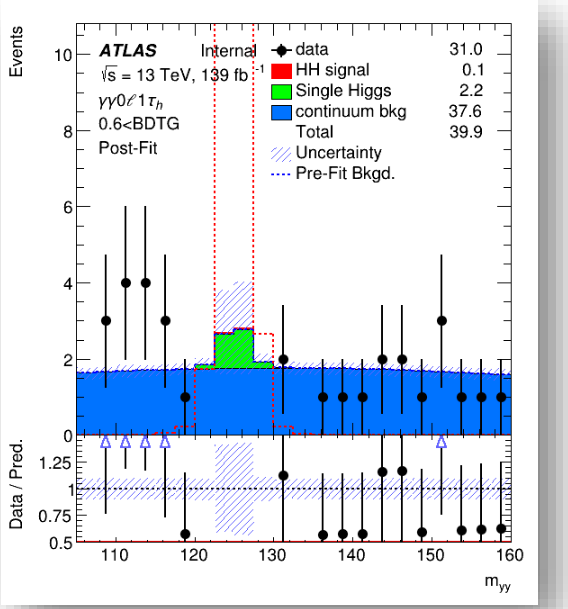
◆Background uncertainties are small compared to the fluctuations you see in data in some of the regions, how do we justify these large fluctuations?

Small events lead to these fluctuations which not be covered by background uncertainties.

Fluctuations statistically not significant + disagreement in myy around 150 GeV studied and documented in Appendix F.4







Backup

HH → $\gamma\gamma + ML$ Unblinding approval request updated version

Qiyu Sha

Institute of High Energy Physics CAS, Beijing

ON BEHALF OF THE MULTILEPTON ANALYSIS TEAM

Updated

- Updated all plots and tables about yy+2L channel.
- Clarify how the BDT boundaries are chosen
- Add labels making clear what is shown in the data/MC BDT plots in the sidebands.
- Update the theory uncertainties.
- Include all uncertainties in the fit and update the ranking plots/pull plots.
- Updated the final myy plots for all regions entering the fit including all background systematics.
- Updated the final results with all uncertainties and the results of yy+2L channel are changed.

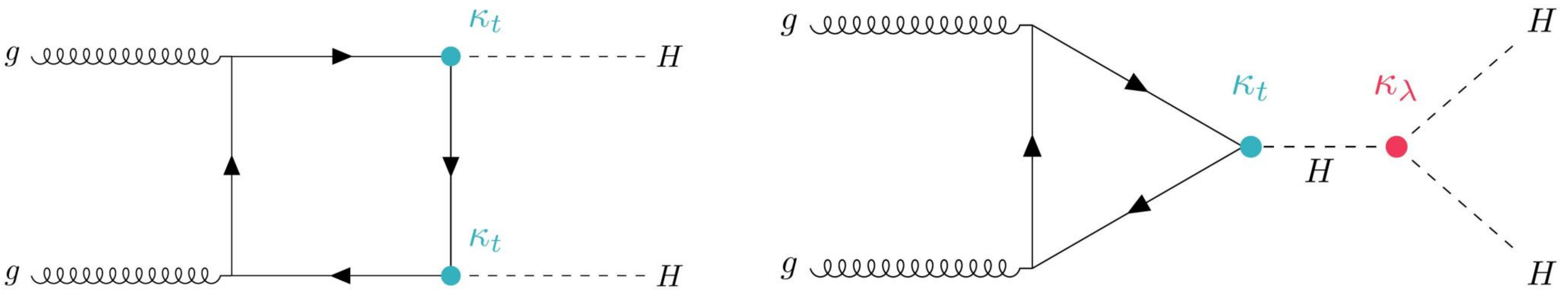
General information

- Entry in glance
- Supporting note circulated Dec. 9
- 1st EB meetings
- 2nd EB meetings
- Editorial Board:
  - ARNAEZ, Olivier (Annecy LAPP)
  - DUCU, Otilia Anamaria (Bucharest IFIN-HH) (Chair)
  - VEATCH, Jason Robert (Cal State)

Introduction

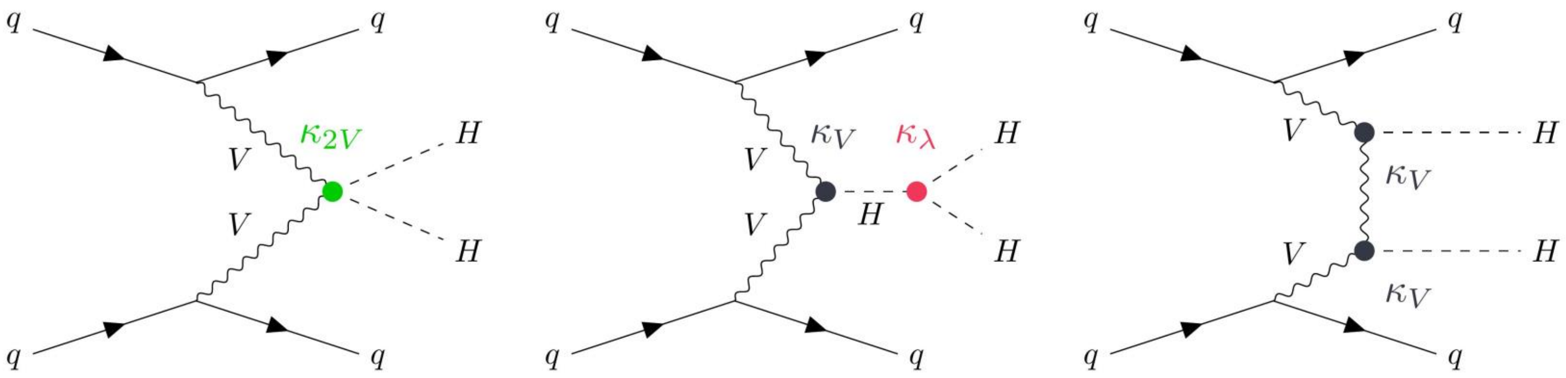
The Run2 HH → multilepton analysis searches the Standard Model(SM) di-Higgs production via two deacy modes:

- Gluon-gluon Fusion (ggF): Dominant production mode, sensitive to K_t, K_λ



$\sigma \approx 31.05\ fb$

- Vector Boson Fusion (VBF): Used as additional yields to the ggF signal , sensitive to K_{2V}, K_V, K_λ



$\sigma \approx 1.726\ fb$

Introduction

$\gamma\gamma + ML$ final states: 0.14% of HH decays ($HH \rightarrow yy + WW / ZZ / \tau\tau$)

Analysis strategy:

Categorize final states by number of e, μ, τ_h:

- $\gamma\gamma + ML$: 2 photons with light leptons and τ_h, include three sub channels:
  - $\gamma\gamma + 1l0\tau_h$: Events with only one light lepton (e, μ) and zero hadronic τ (τ_h).
  - $\gamma\gamma + 0l1\tau_h$: Events with only zero light lepton and one hadronic τ.
  - $\gamma\gamma + 2L$: Events with only two opposite-sign leptons (The capital "L" represents light lepton or hadronic τ).

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005 %

Signal production strategy:

- ggF: 600859-600861 ($\gamma\gamma 0l, \gamma\gamma 1l, \gamma\gamma 2l$)
- VBF: 508676-508678 ($\gamma\gamma 0l, \gamma\gamma 1l, \gamma\gamma 2l$)
- Joboptions for ggF and VBF: (Details are shown in the backup)
  - $H \rightarrow yy\ and\ H \rightarrow WW / ZZ / \tau\tau$
  - $P_T(\mathrm{L}) > 7\ GeV$
  - Use lepton filters:
    - $\gamma\gamma 0l$: hyyFilter and hXXFilter and not LepOneFilter
    - $\gamma\gamma 1l$: hyyFilter and hXXFilter and LepOneFilter and not LepTwoFilter
    - $\gamma\gamma 2l$: hyyFilter and hXXFilter and LepTwoFilter

Data and MC samples

Data: Full Run 2 data ($139 fb^{-1}$)

MC samples:

- *signals*:
  - *ggF HH signal*:
    - Powheg + Pythia8 as nominal samples.(SM case $K_\lambda = 1$)
  - *VBF HH signal*:
    - MadGraph5 + Pythia8 as nominal samples.

- *Backgrounds*:
  - *Single Higgs*:

    Powheg/MG5_aMC@NLO +Pythia8 including all production modes.
  - *MC* continuum background: (Is expected to be a smoothly falling down shape that can be modeled with an analytical function.)
    - $\gamma\gamma + jets$: Sherpa 2.2.4 (ME@NLO+PS)
    - $V\gamma\gamma$: Including $V + \gamma\gamma$ and $t\bar{t} + \gamma\gamma$.
      - $t\bar{t} + \gamma\gamma$: MG5_aMC@NLO +Pythia8
      - $V + \gamma\gamma$: Sherpa 2.2.4 (ME@LO+PS)

- *MC* continuum background will be replaced by the background modeling which is driven by $\gamma\gamma 0l0\tau_h + 1/2\ jet$ sideband data.

- The $\gamma\gamma 0l0\tau_h + 1/2\ jet\ MC$ continuum background are used for the background modeling uncertainty. (X->SH->yy+1/2 leptons analysis which will be reported by Kaili next uses different samples)

DSID	Prod. Mode	Generator + Parton shower	PDF	Tune
		Single Higgs		
343981	ggH	Powheg + Pythia8	PDF4LHC15NNLO	AZNLO
346214	VBF	Powheg + Pythia8	PDF4LHC15NLO	AZNLO
345318	W^+H	Powheg + Pythia8	PDF4LHC15NLO	AZNLO
345317	W^-H	Powheg + Pythia8	PDF4LHC15NLO	AZNLO
345319	$qq \to ZH$	Powheg + Pythia8	PDF4LHC15NLO	AZNLO
345061	$gg \to ZH$	Powheg + Pythia8	PDF4LHC15NLO	AZNLO
346525	$t\bar{t}H$	Powheg + Pythia8	NNPDF3.0NLO	A14
345315	$b\bar{b}H$	Powheg + Pythia8	NNPDF3.0NLO	A14
346188	tHbj four flavour	MadGraph5_aMC@NLO + Pythia8	NNPDF3.0NLO	A14
346486	tHW	MadGraph5_aMC@NLO + Pythia8	NNPDF3.0NLO	A14
		$\gamma\gamma + jets$, with 0,1 additional jets at NLO and 2,3 jets at LO precision.		
364352	$\gamma\gamma + jets$ ($m_{\gamma\gamma}$ range: 90-175 GeV)	Sherpa 2.2.4 (MEPS@NLO)	NNPDF3.0NNLO	
		$V + \gamma\gamma$		
364862	$ee\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364865	$\mu\mu\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364868	$\tau\tau\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364871	$\nu\nu\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364874	$e\nu\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364877	$\mu\nu\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
364880	$\tau\nu\gamma\gamma$	Sherpa 2.2.4 (MEPS@LO)	NNPDF3.0NNLO	
		$t\bar{t}\gamma\gamma$		
345868	$t\bar{t}\gamma\gamma$ (non-all-hadronic)	MadGraph5_aMC@NLO + Pythia8	NNPDF2.3LO	A14
345869	$t\bar{t}\gamma\gamma$ (all-hadronic)	MadGraph5_aMC@NLO + Pythia8	NNPDF2.3LO	A14

Object definition

Di-photon triggers: (The trigger matching is applied)

- HLT_g35_loose_g25_loose (2015/2016).
- HLT_g35_loose_g25_medium_L12EM20VH (2017/2018).

- share the same object definition with kaili's SH analysis except τ_{had}.)

Object definition: (Default setting in HGam framework)

- $Electrons$:
  - $P_T > 10\ GeV$, $|\eta| < 2.37$, crack region excluded ($1.37 < |\eta| < 1.52$), Medium LH ID, $|d_0|/\sigma_{d_0} < 5$, $|\Delta Z_0 \times \sin\theta| < 0.5\ mm$.
  - Isolation requirements: topoEtCone20 < 0.02 × P_T and ptcone20 < 0.15 × P_T.
- $Muons$:
  - $P_T > 10\ GeV$, $|\eta| < 2.7$, Medium ID , $|d_0|/\sigma_{d_0} < 3$, $|\Delta Z_0 \times \sin\theta| < 0.5\ mm$.
  - Isolation requirements: Loose_FixedRad.
- τ_{had}:
  - $P_T > 20\ GeV$, $|\eta| < 2.5$, crack region excluded, Charge = ± 1.
  - JetID RNN Loose, N_{track}= 1 or 3 (Have a efficiency of 60%(45%) for one-(three-) prong τ_{had} decays).
  - Electron veto: passEleBDT; Muon overlap removal: passMuonOLR
- $Jets$:
  - AntiK4EMPFlow
  - $P_T > 20\ GeV$, $|\eta| < 2.5$
  - JVT WP tight, Jet cleaning WP: LooseBad
  - B-tagging with DL1r@77% fixed-cut WP

Event selection

Channel definitions:

➢share the same event selections with SH analysis except the purple part.

Channel	Light lepton selection	$\sum \ell$ charge	$n\tau_{\rm had}$	$\sum \tau_{\rm had}$ charge	Photons	$N_{\rm jets}$	$N_{b-\rm jets}$
$\gamma\gamma$+$1\ell 0\tau_{\rm had}$	1	±1	0	0	2	-	0
$\gamma\gamma$+$0\ell 1\tau_{\rm had}$	0	0	1	±1	2	-	0
$\gamma\gamma$+2L	$n_\ell + n_{\tau h} = 2$	0, ±1	$n_\ell + n_{\tau h} = 2$	0, ±1	2	-	0

Event selection:

- Mass window: $105\ \mathrm{GeV} < m_{\gamma\gamma} < 160\ \mathrm{GeV}$.
- 2 tight isolated photons with $E_T^\gamma > 35\ (25)\ GeV$ and $P_T^\gamma / m_{\gamma\gamma} > 0.35\ (0.25)$ for the leading (subleading) photon.
- B-veto: $N_{b-jets} = 0$. (At 77% WP and to be orthogonal to HH->bb$\gamma\gamma$)
- $E_T^{miss} > 35\ GeV$ except $1\mu 0\tau$ channel.
- $P_{T\_yy} > 50\ GeV$.
- $m_{ll} > 12\ GeV$ in $2l0\tau$ channel. (We use this selection just for harmonizing with ML channel.)

MVA used to further separate signal and background.

Signal and control region:

- ➢Signal region: $120\ \mathrm{GeV} < m_{\gamma\gamma} < 130\ \mathrm{GeV}$.
- ➢Control region: Sideband region (Whole region except $120\ \mathrm{GeV} < m_{\gamma\gamma} < 130\ \mathrm{GeV}$)

Cut-flow checks

Cut-flow checks in whole mass region($105\ \text{GeV} < m_{\gamma\gamma} < 160\ \text{GeV}$):

- Total of signal means initial number of events: $L * \sigma(HH) * Br(HH \rightarrow yy + WW/\ ZZ\ /\tau\tau)$

Selection Criteria	Signal	Single Higgs	$V\gamma\gamma$	$\gamma\gamma$+jets
Total	6.38	8609.49	7920.16	2877250.00
Two tight photons	2.57	6254.33	1485.34	942950.00
b-jet veto	2.25	6045.58	1278.27	912626.00
$p_T^{\gamma\gamma} > 50$ GeV	2.13	1855.20	641.85	230422.00
$E_T^{miss} > 35$ GeV except $\gamma\gamma+1\mu0\tau_{had}$ channel	1.38	494.88	457.10	49882.10
$\gamma\gamma+1\ell0\tau_{had}$	0.39	18.04	167.54	62.89
$\gamma\gamma+0\ell1\tau_{had}$	0.18	7.70	32.22	810.01
$\gamma\gamma$+2L (Include $m_{\ell\ell} > 12$ GeV in $\gamma\gamma+2\ell0\tau_{had}$ channel)	0.14	1.07	9.65	3.82

Cut-flow checks in sideband region:

Selection Criteria	$V\gamma\gamma$ and $\gamma\gamma$+jets from MC	Sideband data
Total	2544027.47	5585600
Two tight photons	754340.44	937470
b-jet veto	729958.81	911352
$p_T^{\gamma\gamma} > 50$ GeV	184570.23	198921
$E_T^{miss} > 35$ GeV except $\gamma\gamma+1\mu0\tau_{had}$ channel	40217.28	51505
$\gamma\gamma+1\ell0\tau_{had}$	185.34	313
$\gamma\gamma+0\ell1\tau_{had}$	673.61	696
$\gamma\gamma$+2L (Include $m_{\ell\ell} > 12$ GeV in $\gamma\gamma+2\ell0\tau_{had}$ channel)	10.86	16

MVA method

MVA: Boosted Decision Tree with the GradientBoost algorithm(BDTG)

- Use 4-folds cross-validation training which gives a better and smoother ROC curve.
- Training sample and test sample are separated by the event number which is reproducible for each simulation events.
- For each fold, the training method stays the same.
- For BDTG, the training parameters are listed as the following:
  - Number of trees: 1000
  - Maximal depth of trees: 2
  - Boost type: Gradient
  - Bagged Boost is used. (Bagged sample fraction: 0.5)
  - nCuts: 20

MVA method

Variables used for BDTG training:

- The "H" represents the SM Higgs which decays to di-photon
- The capital “L” represents light lepton or hadronic τ

- $p_{\mathrm{T}}(H)$: transverse momentum of H.
- $\phi(H)$: ϕ of H.
- $\phi_0(L_1)$: polar angle difference between the leading lepton and H.
- $p_{\mathrm{T}}(L_1)$: transverse momentum of the leading lepton.
- $p_{\mathrm{T}}(L_2)$: transverse momentum of the subleading lepton.
- E_T^{miss}: missing transverse momentum.
- $\phi(E_T^{\mathrm{miss}})$: ϕ of missing transverse momentum.
- $\phi_0(\gamma_1)$: polar angle difference between the leading γ and H.
- $\eta(\gamma_1)$: η of the leading γ.
- N_{jcen}: number of central jets.
- $\min\Delta\Phi(E_T^{\mathrm{miss}}, j, L)$: minimum polar angle difference between E_T^{miss}, jets and the lepton.
- $\Delta\Phi(E_T^{\mathrm{miss}}, \gamma\gamma)$: polar angle difference between E_T^{miss} and di-photon system.
- $\Delta\Phi(E_T^{\mathrm{miss}}, LL)$: polar angle difference between E_T^{miss} and di-lepton system.
- $\Delta R(L\nu)$: angle difference between ℓ and E_T^{miss} system.
- $\Delta R(\gamma\gamma, W)$: angle difference between $\gamma\gamma$ and W system.
- $\eta(W)$: η of W.
- $\Delta m(L, L)$: mass of di-lepton system.
- $\Delta R(L, L)$: angular difference between two leptons.
- $\Delta\phi(L, L)$: polar angle difference between two leptons.
- $\Delta R(LL, \gamma\gamma)$: angular difference between di-lepton system and di-photon system.
- $pt(j_1)$: transverse momentum of leading jet.

Variable	$\gamma\gamma$+$1\ell 0\tau_{\mathrm{had}}$	$\gamma\gamma$+$0\ell 1\tau_{\mathrm{had}}$	$\gamma\gamma$+2L
$p_{\mathrm{T}}(H)$	✓	✓	✓
$\phi(H)$			✓
$\phi_0(L_1)$	✓	✓	✓
$p_{\mathrm{T}}(L_1)$	✓	✓	✓
$p_{\mathrm{T}}(L_2)$			✓
E_T^{miss}	✓	✓	✓
$\phi(E_T^{\mathrm{miss}})$			✓
$\phi_0(\gamma_1)$	✓	✓	
$\eta(\gamma_1)$		✓	
N_{jcen}	✓	✓	✓
$\min\Delta\Phi(E_T^{\mathrm{miss}}, j, L)$	✓		✓
$\Delta\Phi(E_T^{\mathrm{miss}}, \gamma\gamma)$	✓	✓	✓
$\Delta\Phi(E_T^{\mathrm{miss}}, LL)$			✓
$\Delta R(L\nu)$	✓		✓
$\Delta R(\gamma\gamma, W)$	✓		
$\eta(W)$	✓		
$\Delta m(L,)$			✓
$\Delta R(L, L)$			✓
$\Delta\phi(L, L)$			✓
$\Delta R(LL, \gamma\gamma)$			✓
$pt(j_1)$			✓

MVA method

The method of choosing BDTG variables in different channels:

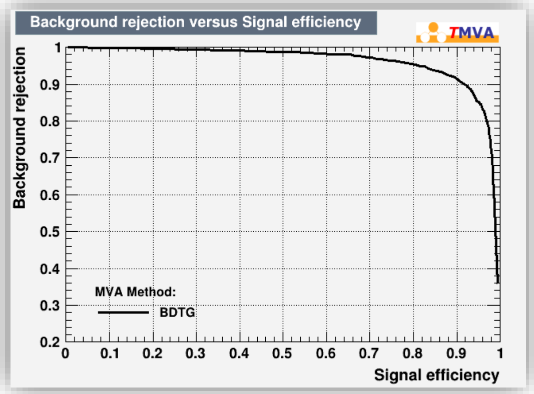
- We select ~ten best variables with the best separation power from a pool of ~30 candidate variables.
- We check the correlations of these variables and ensure that they are all small. (And ensure these variables have little correlation with $m_{\gamma\gamma}$)

$\gamma\gamma + 0l1\tau_h$: (other channels are shown in the backup)

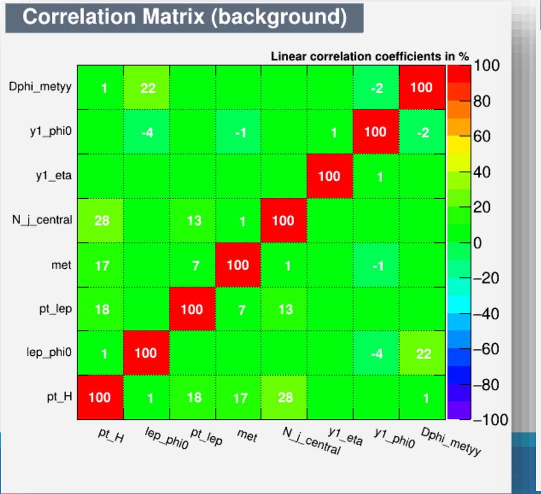
Separation power:

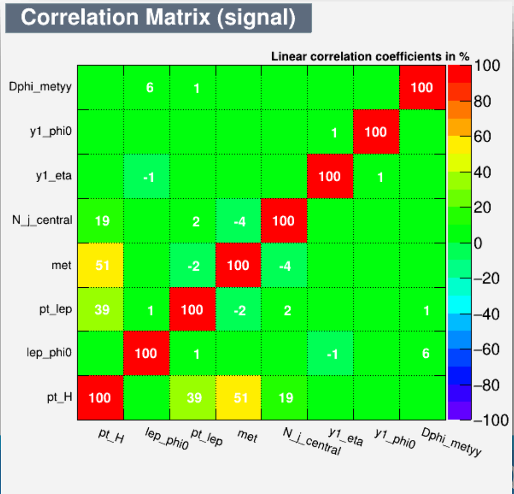
Variable	Rank	Separation power
$p_{\mathrm{T}}(H)$	1	45.52%
E_T^{miss}	2	29.89%
$p_{\mathrm{T}}(L_1)$	3	18.51%
$\phi_0(L_1)$	4	10.97%
$\Delta\Phi(E_T^{\mathrm{miss}}, \gamma\gamma)$	5	10.70%
$\phi_0(\gamma_1)$	6	4.76%
N_{jcen}	7	2.81%
$\eta(\gamma_1)$	8	2.72%

ROC-value: 0.941

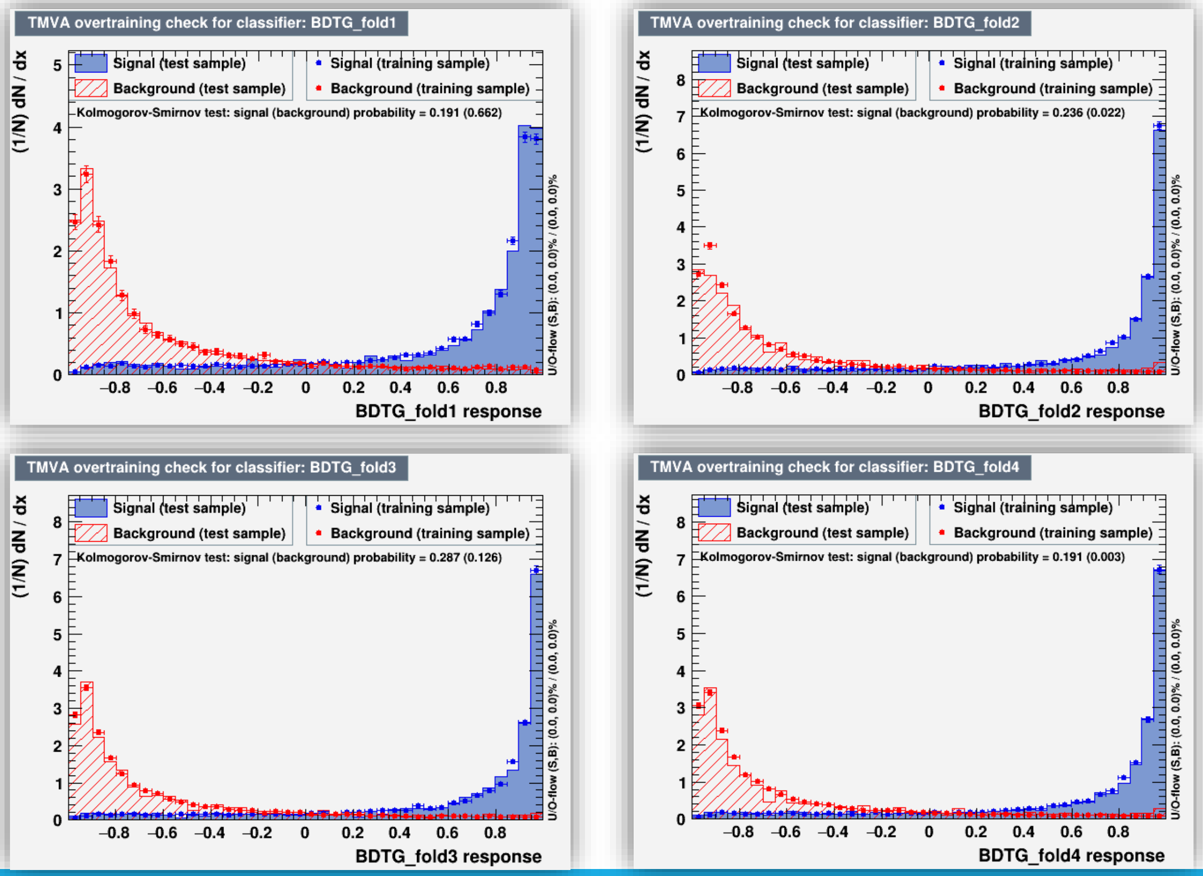


Correlation Matrix:





Overtraining plots with ks test values for 4 folds:

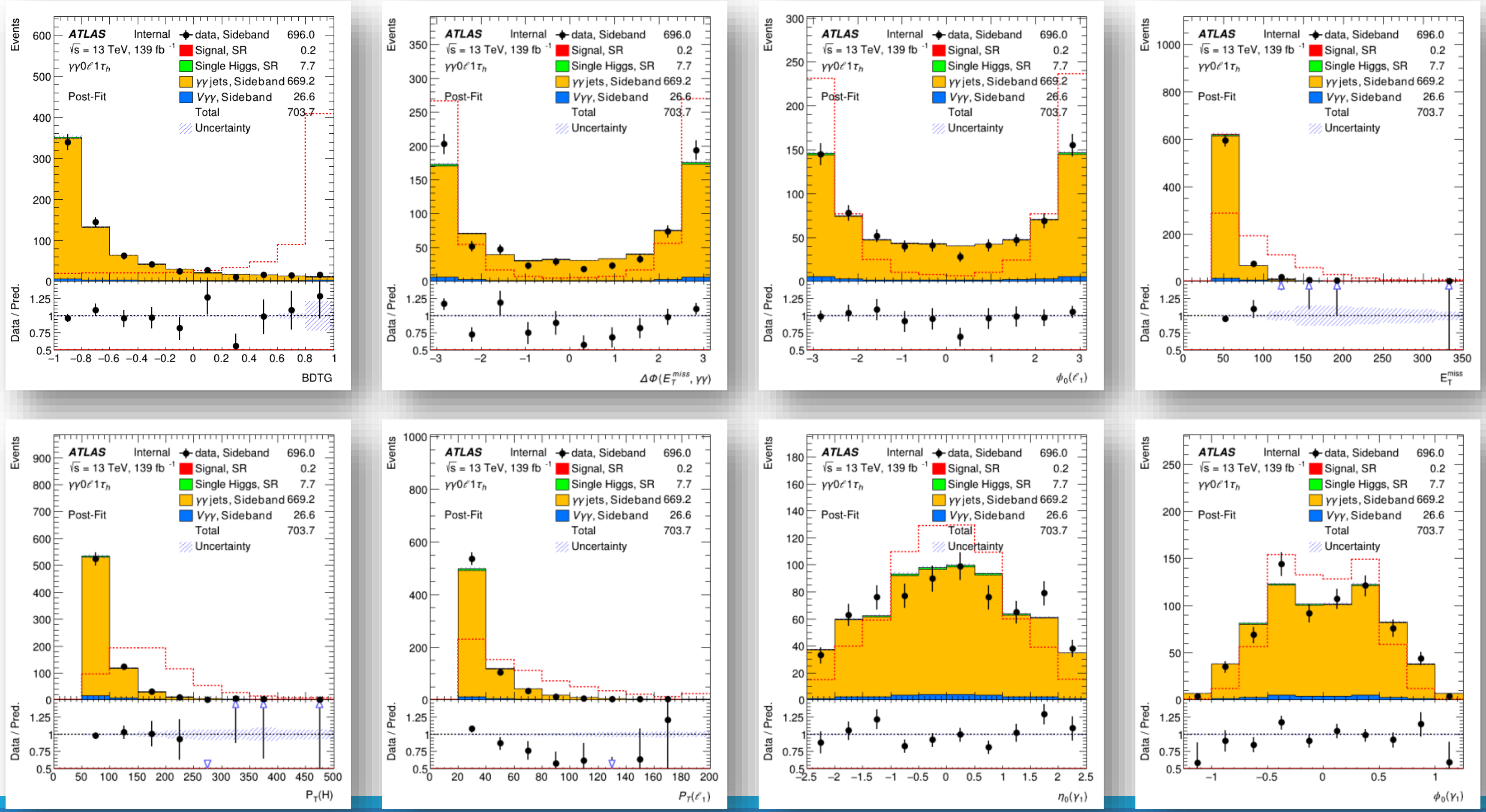


MVA method

$\gamma\gamma + 0l1\tau_h$: (other channels are shown in the backup)

- Consider a rough background scaling:
  - Apply a scale factor on MC continuum background ($\gamma\gamma$+$jets$ and $V\gamma\gamma$) which corresponds to the ratio between MC continuum background sideband yields and the data sideband yields:
- After background scaling, the BDTG and most of input variables distribution show here:

Channel	Scale factor
$\gamma\gamma$+$1\ell0\tau_{\text{had}}$	1.68
$\gamma\gamma$+$0\ell1\tau_{\text{had}}$	1.03
$\gamma\gamma$+2L	1.47



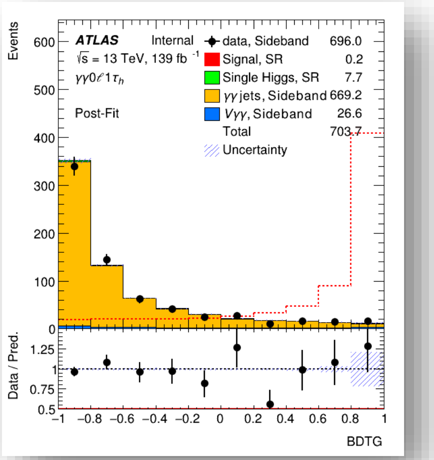
Variable	Rank	Separation power
$p_T(H)$	1	45.52%
E_T^{miss}	2	29.89%
$p_T(L_1)$	3	18.51%
$\phi_0(L_1)$	4	10.97%
$\Delta\Phi(E_T^{\text{miss}}, \gamma\gamma)$	5	10.70%
$\phi_0(\gamma_1)$	6	4.76%
N_{jcen}	7	2.81%
$\eta(\gamma_1)$	8	2.72%

BDTG regions

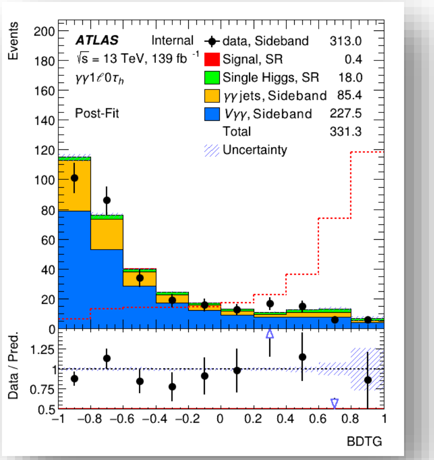
BDTG distribution in different channels:

- The signal distribution is scaled to the total background events and the expected HH yield is quoted in the legend.
- The MC continuum background ($\gamma\gamma$+$jets$ and $V\gamma\gamma$) is in the $m_{\gamma\gamma}$ sideband region and after background scaling:

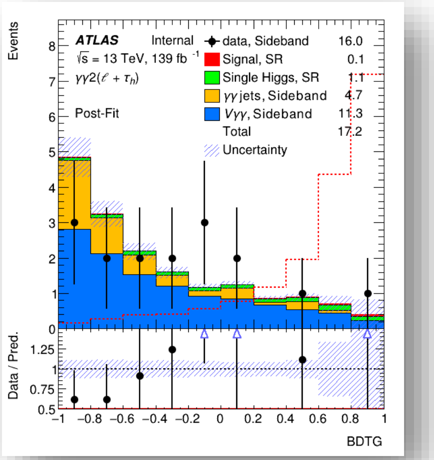
$\gamma\gamma + 0l1\tau_h$:



$\gamma\gamma + 1l0\tau_h$:



$\gamma\gamma + 2L$:



Three regions are defined in $\gamma\gamma + 0l1\tau_h$ and $\gamma\gamma + 1l0\tau_h$ channel by splitting the BDTG output distribution:

- The optimal value of the BDTG cuts is obtained by maximizing the expected significance, using the equation:
- To ensure there are enough sideband data events in each BDTG regions: (The details are shown in the next page.)

Loose BDTG region:	$BDTG \leq 0$
Medium BDTG region:	$0 < BDTG \leq 0.6$
Tight BDTG region:	$0.6 < BDTG$

$$Z = \sqrt{2 \times \left[(B+S) \times \left(ln\frac{S+B}{B} - S \right) \right]}$$

BDTG regions

Three regions are defined in $\gamma\gamma + 0l1\tau_h$ and $\gamma\gamma + 1l0\tau_h$ channel by splitting the BDTG output distribution:

- Consider $\gamma\gamma + 2L$ channel have too low data statistics, just use the whole BDTG region in this channel.

Loose BDTG region:	$BDTG \leq 0$
Medium BDTG region:	$0 < BDTG \leq 0.6$
Tight BDTG region:	$0.6 < BDTG$

The method of choosing regions:

- Use 10 bins in BDTG distribution and then calculate the significance with different regions which are shown in the left table.(Table 50)
- Although the best value is $0.8 < BDTG$, considering the low statistic in this region, we choose the second one as the Tight BDTG region which is $0.6 < BDTG$.
- Then we do another scan on the remaining BDTG region and the results are shown in the right table.(Table 51)
- We can find the best region is the $0 < BDTG \leq 0.6$ both in two channels. So this is the Medium BDTG region.
- The remaining region is the Loose BDTG region.

Tight Region	$\gamma\gamma$+0ℓ1τ_{had} channel		$\gamma\gamma$+1ℓ0τ_{had} channel	
	Z-value	data sideband yield	Z-value	data sideband yield
[0.8, 1]	0.0268	16	0.0486	6
[0.6, 1]	0.0221	31	0.0464	12
[0.4, 1]	0.0190	47	0.0430	27
[0.2, 1]	0.0167	57	0.0406	44
[0, 1]	0.0150	84	0.0381	57

Table 50: The significance value used to choose the Tight BDTG region in $\gamma\gamma$+0ℓ1τ_{had} and $\gamma\gamma$+1ℓ0τ_{had} channel.

Medium Region	$\gamma\gamma$+0ℓ1τ_{had} channel		$\gamma\gamma$+1ℓ0τ_{had} channel	
	Z-value	data sideband yield	Z-value	data sideband yield
[0.4, 0.6]	0.0026	16	0.0109	15
[0.2, 0.6]	0.0030	26	0.0128	32
[0.0, 0.6]	0.0032	53	0.0134	45
[−0.2, 0.6]	0.0031	78	0.0131	61
[−0.4, 0.6]	0.0029	119	0.0126	80

Table 51: The significance value used to choose the Medium BDTG region in $\gamma\gamma$+0ℓ1τ_{had} and $\gamma\gamma$+1ℓ0τ_{had} channel.

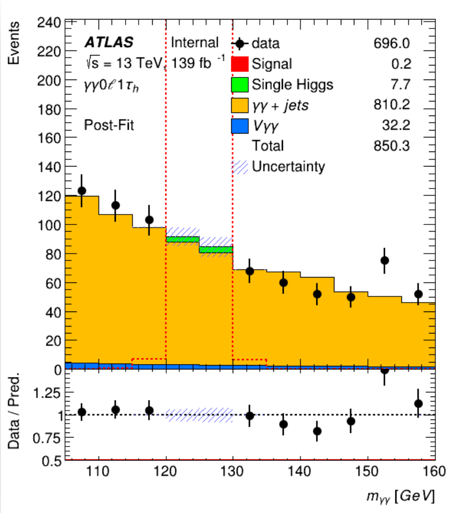
Background estimation

MC Backgrounds:

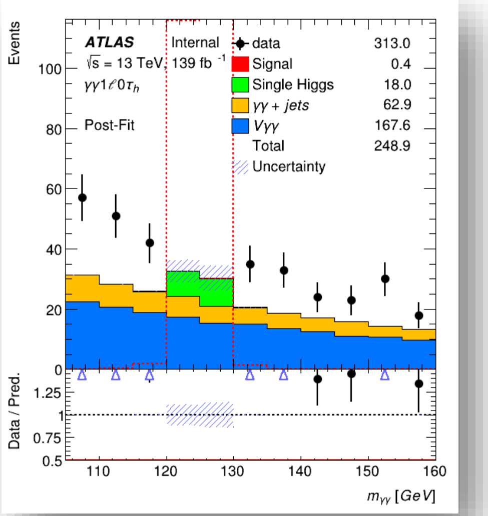
- *Single Higgs*
- *MC continuum background:* (Is expected to be a smoothly falling down shape that can be modeled with an analytical function.)
  - $\gamma\gamma + jets$
  - $V\gamma\gamma$: Including $V + \gamma\gamma$ and $t\bar{t} + \gamma\gamma.$

Consider MC Continuum background sample and data in sideband disagree:

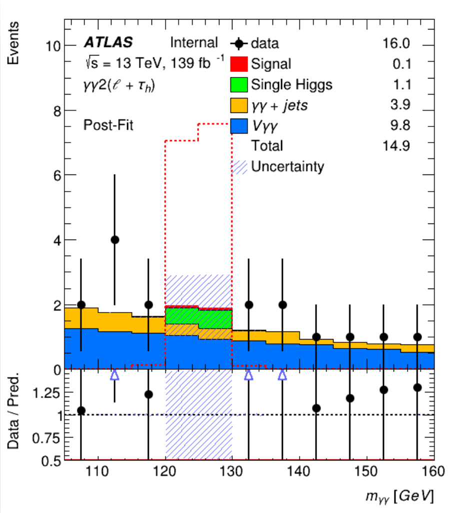
$\gamma\gamma + 0l1\tau_h$:



$\gamma\gamma + 1l0\tau_h$:



$\gamma\gamma + 2L$:



➢ Need to perform the background modeling.

Background estimation

Backgrounds modeling by using sideband data:

- The $m_{\gamma\gamma}$ shape is evaluated in $\gamma\gamma + 0l0\tau_h$ sideband data instead of three sub-channels, due to limited statistics.
- Use $\gamma\gamma 0l0\tau_h + 1/2\ jets$ to mimic the kinematic performance of $\gamma\gamma + 1L$ (Include $\gamma\gamma + 0l1\tau_h$ and $\gamma\gamma + 1l0\tau_h$) and $\gamma\gamma + 2L$.
- Several functional forms are evaluated by fitting di-photon mass spectrum in the $\gamma\gamma 0l0\tau_h + 1/2\ jets$ sideband data.

- Consider the different $m_{\gamma\gamma}$ shape in different BDTG region(loose, medium and tight), need to use different functions to fit them.
- Because the tight BDTG region has too low statistics to fit (less than 80 in $\gamma\gamma 0l0\tau_h + 1\ jets$ data sideband).
  - Medium and tight BDTG regions are merged to high BDTG region. ($BDTG \geq 0$)
  - Correspondingly, rename loose BDTG region to low BDTG region. ($BDTG < 0$)
- Then use different functions to fit the $m_{\gamma\gamma}$ shape in different regions and use the chi-square value to evaluate them.
  - Dof means degree of freedom.
  - Use 45 bins in sideband

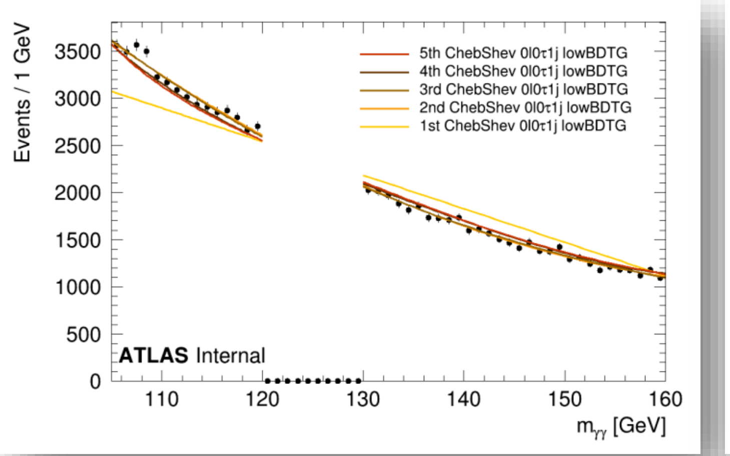
$$\frac{\chi^2}{n_{\text{dof}}} = \frac{\sum_1^{45} \frac{\left(x_{MC} - x_{\text{data},SB}\right)^2}{x_{\text{data},SB}}}{45 - \text{dof}}$$

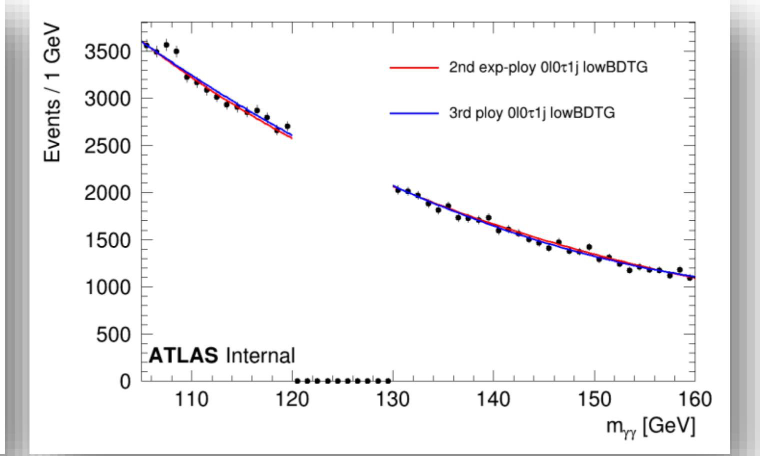
Background estimation

Fit results

$\gamma\gamma + 0l0\tau_h 1j$ in low BDTG region ($BDTG < 0$):

$$\frac{\chi^2}{n_{\text{dof}}} = \frac{\sum_1^{45} \frac{\left(x_{MC} - x_{\text{data},SB}\right)^2}{x_{\text{data},SB}}}{45 - \text{dof}}$$



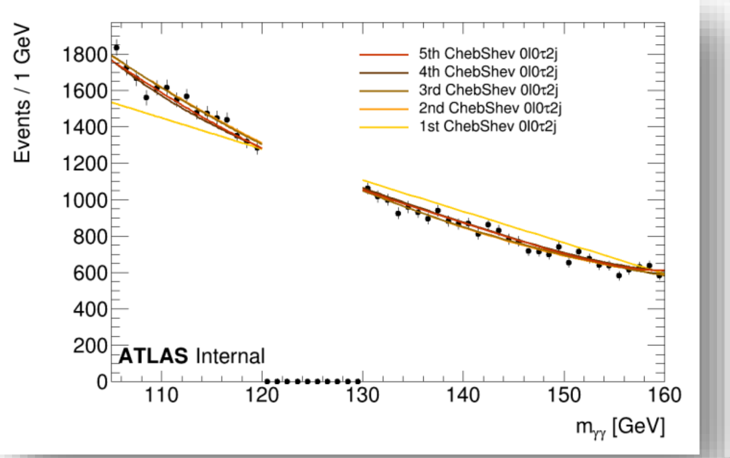


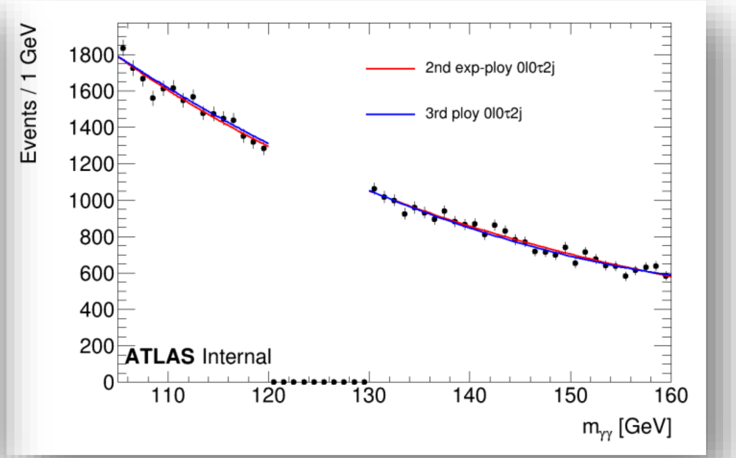
Function	dof	$\frac{\chi^2}{n_{dof}}$ in $\gamma\gamma 0\ell 0\tau_{\text{had}}$+1jet	$\frac{\chi^2}{n_{dof}}$ in $\gamma\gamma 0\ell 0\tau_{\text{had}}$+2jet
3^{rd} polynomial	3	556.11	281.60
2^{nd} exponential	2	538.74	272.83
1^{st} Chebyshev-polynomial	1	563.50	281.79
2^{nd} Chebyshev-polynomial	2	543.18	275.11
3^{rd} Chebyshev-polynomial	3	553.06	280.46
4^{th} Chebyshev-polynomial	4	567.53	287.22
5^{th} Chebyshev-polynomial	5	585.92	292.19

- In low BDTG region, the best function is second-order exponential:

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

$\gamma\gamma + 0l0\tau_h 2j$ in whole BDTG region:

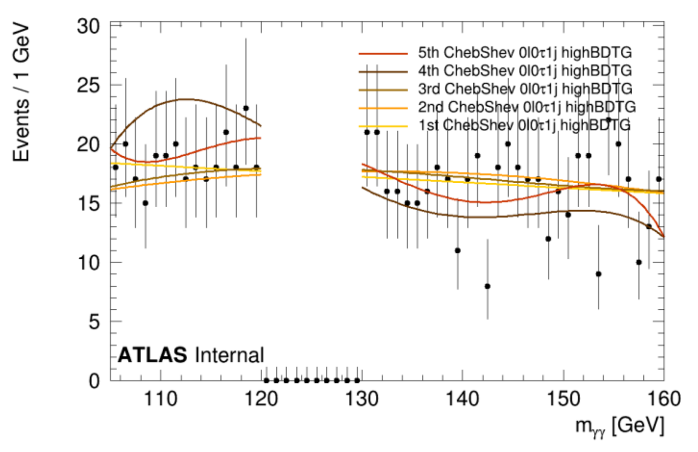


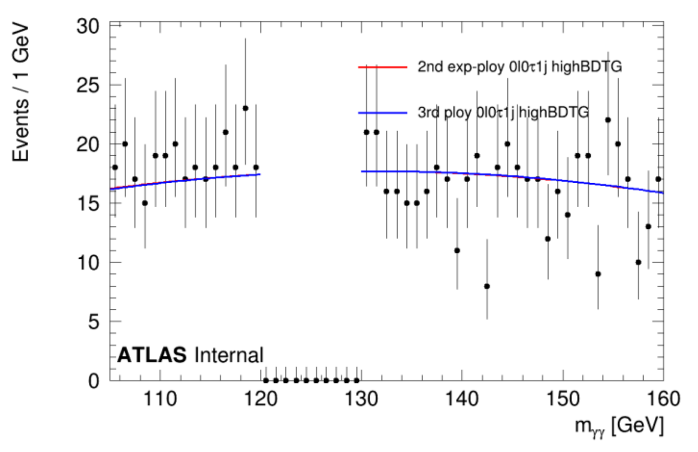


Background estimation

Fit results

$\gamma\gamma + 0l0\tau_h 1j$ in high BDTG region ($BDTG \geq 0$):





$$\frac{\chi^2}{n_{\text{dof}}} = \frac{\sum_1^{45} \frac{(x_{MC} - x_{\text{data},SB})^2}{x_{\text{data},SB}}}{45 - \text{dof}}$$

Function	dof	$\frac{\chi^2}{n_{dof}}$ in $\gamma\gamma 0\ell 0\tau_{\text{had}}$+1jet
3^{rd} polynomial	3	5.00
2^{nd} exponential	2	4.88
1^{st} Chebyshev-polynomial	1	4.67
2^{nd} Chebyshev-polynomial	2	4.88
3^{rd} Chebyshev-polynomial	3	5.03
4^{th} Chebyshev-polynomial	4	6.03
5^{th} Chebyshev-polynomial	5	5.72

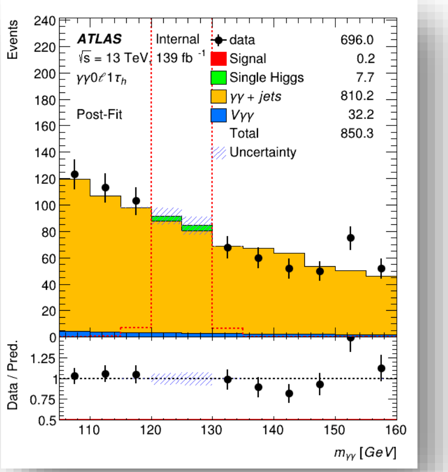
- In low BDTG region, the best function is first-order Chebyshev-polynomial.
- Consider none of these fit functions works well in this region due to the low statistic, for harmonize, we also use second-order exponential in the high BDTG region.

- We use second-order exponential to fit the $\gamma\gamma + 0l0\tau_h 1/2j$ sideband data in all BDTG regions.

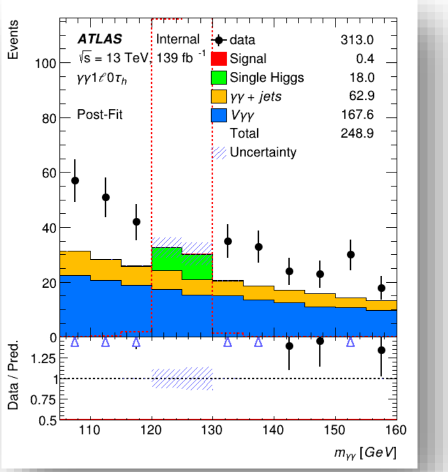
Background estimation

Before background modeling:

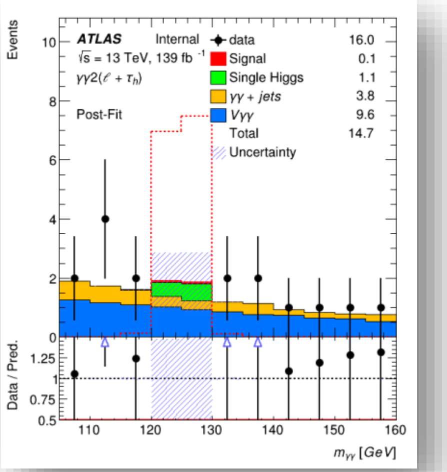
$\gamma\gamma + 0l1\tau_h$:



$\gamma\gamma + 1l0\tau_h$:

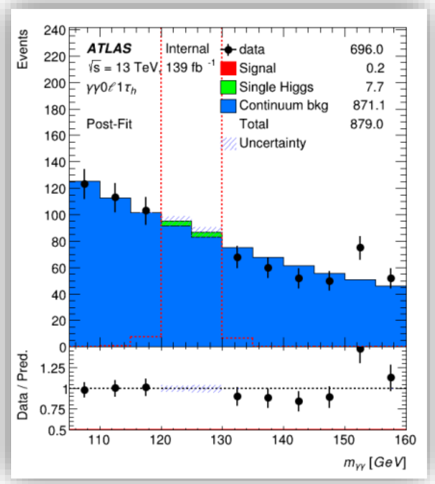


$\gamma\gamma + 2L$:

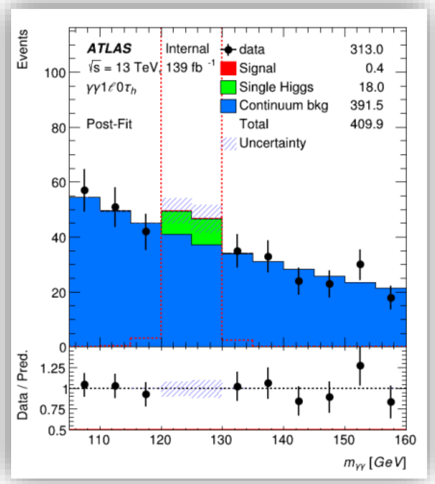


After background modeling: (Continuum background modeling agree with sideband data)

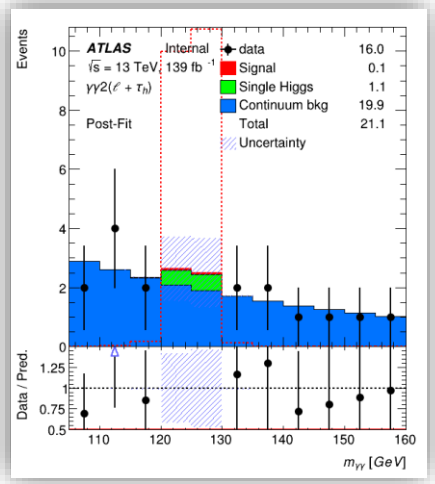
$\gamma\gamma + 0l1\tau_h$:



$\gamma\gamma + 1l0\tau_h$:



$\gamma\gamma + 2L$:



Spurious signal test

The potential bias due to the mis-modeling of background in estimated via the spurious signal test:

- Calculations of different BDTG categories in each sub-channel are treat independently.
- The conditions of the test:

Fitted signal yield

$S_{spur} < 10\% N_{s,exp}$ where $N_{s,exp}$ is the expected number of signal yields in that category ($\mu_{sp} = S_{spur}/N_{s,exp}$),

$S_{spur} < 20\% \sigma_{sig}$, where σ_{sig} is the statistical uncertainty on the fitted number of signal yields when fitting the signal+background model to a background-only Asimov dataset ($Z_{sp} = S_{spur}/\sigma_{sig}$).

$$P(\chi^2) > 5\,\%\,, \chi^2 = \sum^{45} \frac{(x_{MC} - x_{data,SB})^2}{x_{data,SB}}$$

➢ Spurious signal test results:

Channel	Region	$\mu_{sp,tight}$ [%]	$Z_{sp,tight}$ [%]	$P(\chi^2)$ [%]	Selected
$\gamma\gamma+1\ell 0\tau_{had}$	loose	1.20	1.66	92.70	Yes
$\gamma\gamma+1\ell 0\tau_{had}$	medium	0.29	0.43	32.27	Yes
$\gamma\gamma+1\ell 0\tau_{had}$	tight	0.07	0.18	45.88	Yes
$\gamma\gamma+0\ell 1\tau_{had}$	loose	5.58	6.42	83.43	Yes
$\gamma\gamma+0\ell 1\tau_{had}$	medium	0.29	0.34	26.40	Yes
$\gamma\gamma+0\ell 1\tau_{had}$	tight	0.03	0.09	73.97	Yes
$\gamma\gamma$+2L	whole	0.15	0.35	99.29	Yes

Table 55: The spurious signal test results for all channels with the 2^{nd} order exponential polynomial function.

Systematic uncertainties

Background modeling uncertainties:

- The shape differences between the $\gamma\gamma 0l0\tau_h + 1/2\ jets$ and three sub-channels ($\gamma\gamma + 0l1\tau_h$, $\gamma\gamma + 1l0\tau_h$ and $\gamma\gamma + 2L$) lead to additional uncertainties in the estimations of background yields for individual categories.
- This uncertainty can be only evaluated by the continuum background MC samples, due to the low statistics in data sideband.

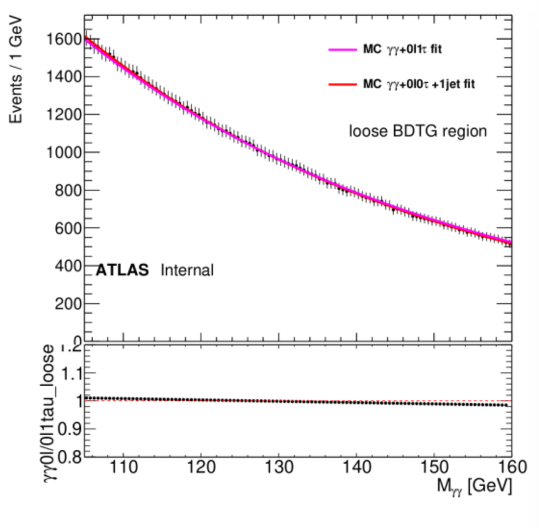
➢The average of the relative deviation for all bins is chosen as the background modeling uncertainties:

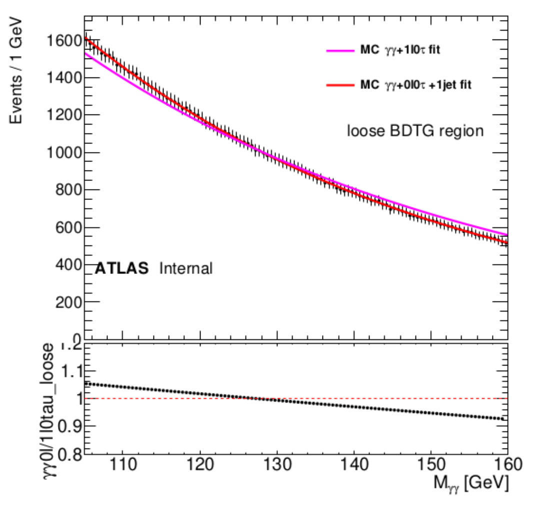
$$\pm\sigma = \pm\sum_{1}^{n}\frac{|MC_{0l0\tau 2j} - MC_{2L}|}{MC_{2L} * n}$$

Channel	Loose BDTG region	Medium BDTG region	Tight BDTG region
$\gamma\gamma$+1ℓ0τ_{had}	±3.37%	±15.73%	±11.22%
$\gamma\gamma$+0ℓ1τ_{had}	±0.75%	±14.67%	±10.67%
$\gamma\gamma$+2L	Whole BDTG region : ±0.03%		

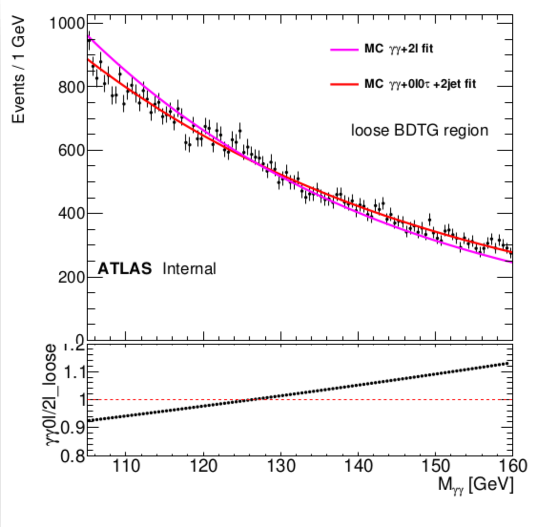
➢$\gamma\gamma + 0l1\tau_h$ and $\gamma\gamma + 1l0\tau_h$ In loose BDTG region:(BDTG<0)

Other regions are shown in backup





➢$\gamma\gamma + 2L$ In Whole BDTG region:



Systematic uncertainties

Experimental uncertainties:

- Luminosity: 1.7 %
- Pile-up reweighting
- Photon: efficiency, energy scale, resolution, trigger uncertainties provided by Egamma CP group.
- Muon: efficiency, energy scale, resolution, object reconstruction, identification and isolation
- Electron: efficiency, energy scale, resolution
- Tau: trigger, identification, reconstruction, energy scale
- Jet : JER(Jet energy resolution), JES(Jet energy scale), vertex tagging
- Flavour tagging: b-jets, c-jets, light-jets and extrapolations
- MET: scale, resolution

➢ The detail list of experimental uncertainties is shown in backup.

Systematic uncertainties

Theory systematic uncertainties:

Signal:

- QCD
- PDF+α_s
- Parton Shower uncertainty

Background (only single Higgs, the background modeling is driven by data sideband)

- QCD
- PDF+α_s
- Parton Shower uncertainty (not finished yet, need to find the Herwig sample of Single Higgs.)

Channel	Process	Parton Shower (%)	PDF + α_s (%)	QCD Scale (%)
$\gamma\gamma$+1ℓ0τ_{had}	HH signal	2.51	4.46	$^{+13.03}_{-12.26}$
$\gamma\gamma$+0ℓ1τ_{had}	HH signal	1.18	4.53	$^{+13.15}_{-12.35}$
$\gamma\gamma$+2L	HH signal	2.85	4.47	$^{+13.03}_{-12.33}$
$\gamma\gamma$+1ℓ0τ_{had}	Single Higgs	-	5.86	$^{+3.73}_{-3.82}$
$\gamma\gamma$+0ℓ1τ_{had}	Single Higgs	-	5.98	$^{+10.49}_{-7.10}$
$\gamma\gamma$+2L	Single Higgs	-	5.35	$^{+9.09}_{-7.67}$

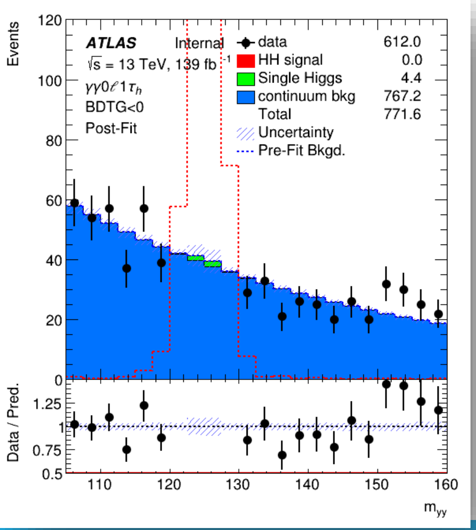
Table 60: Summary of theoretical uncertainties for the $\gamma\gamma + ML$channel.

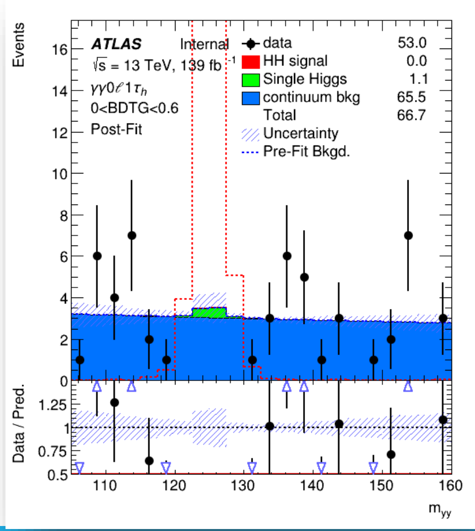
Fit procedure

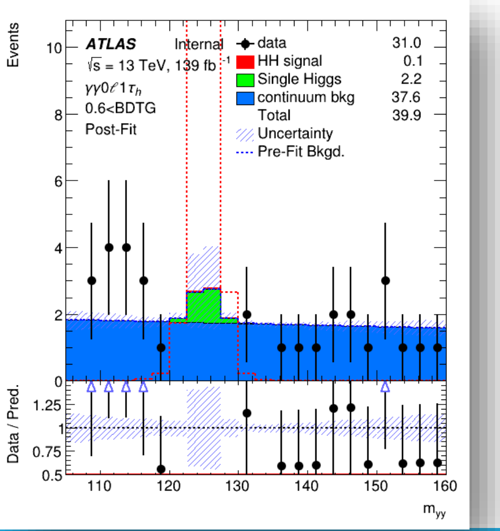
- Framework: TRexFitter, limit cross checked by quickStats
- Binned likelihood fit to the $m_{\gamma\gamma}$ distributions, the binning of $m_{\gamma\gamma}$ is chosen to be 2.5GeV.
  - Signal modeling: number counting.
  - Single Higgs background modeling: number counting.
  - Continuum background modeling (sideband data driven) instead of the MC $\gamma\gamma$+$jets$ and $V\gamma\gamma$ samples.
- Consider experimental uncertainties and background modeling uncertainties in the fit.
- Number of bins in SR for three sub-channels: 4. (4 bins in $120 < m_{\gamma\gamma} < 130$ region)

$\gamma\gamma + 0l1\tau_h$: (other channels are shown in the backup)

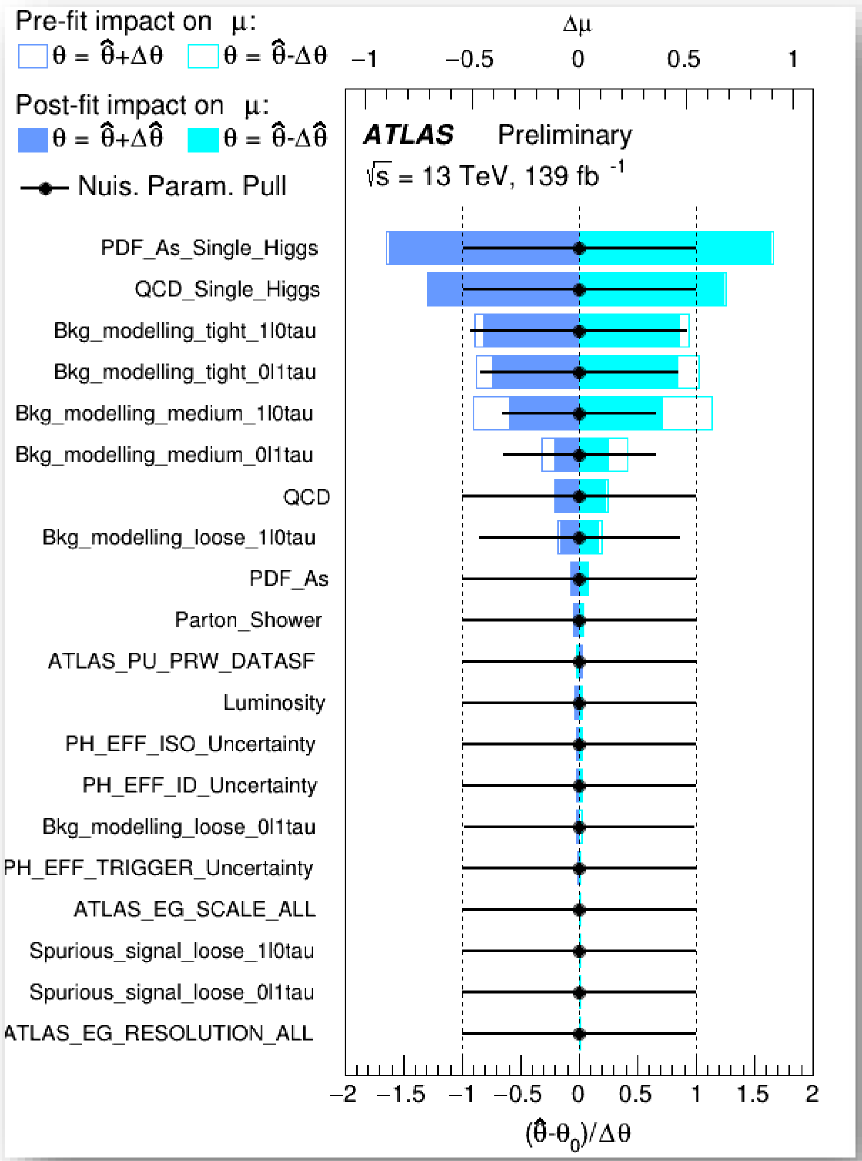
$m_{\gamma\gamma}$ distribution in different BDTG regions:

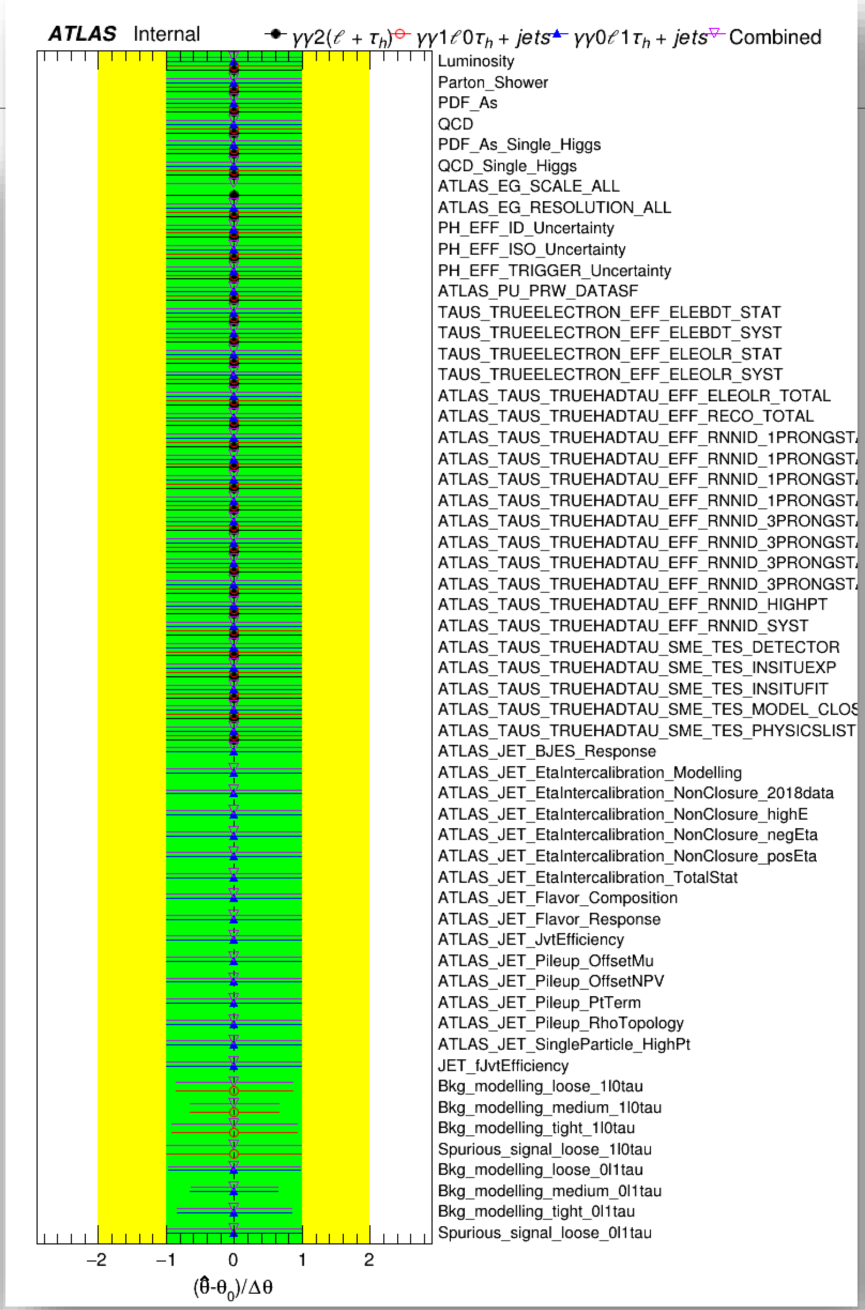






Pulls and Rankings





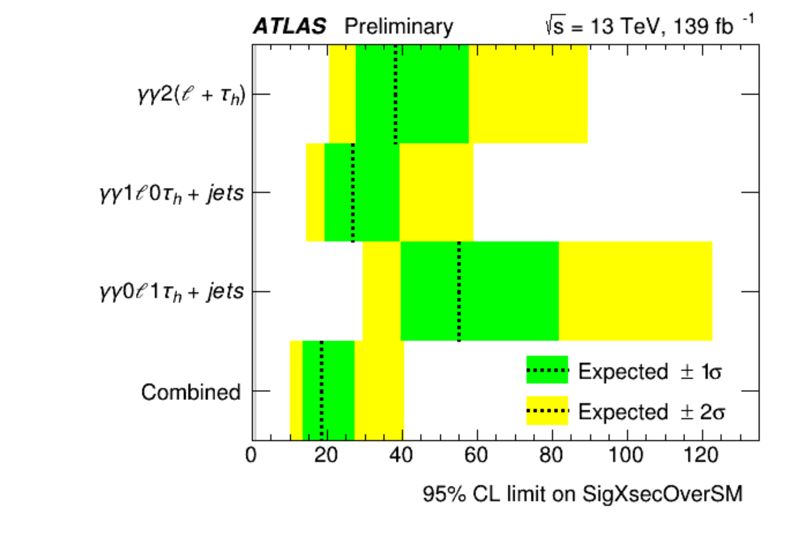
- Most of the NPs don't pass the threshold:
  - 1% on shape and 0.5% on normalization
- Including Experimental uncertainties, theory uncertainties, spurious signal and background modeling uncertainties.

Fit results

- Performed a signal + background fit with part of systematic MC.
- Asimov dataset are assumed in all signal regions for the upper limit setting.

Channels	Stats.Only (Asimov)	+MC stats.(Asimov)	+Systematics (Asimov)	+Bkg estimation uncertainties
$\gamma\gamma$+1ℓ0τ_{had}	$25.46^{36.99}_{18.35}$	-	$25.50^{37.09}_{18.37}$	$25.64^{37.29}_{18.22}$
$\gamma\gamma$+0ℓ1τ_{had}	$52.70^{76.71}_{37.98}$	-	$52.79^{76.91}_{38.04}$	$53.30^{77.60}_{38.40}$
$\gamma\gamma$+2L	$25.13^{38.23}_{18.11}$	-	$25.16^{38.32}_{18.13}$	$25.18^{38.34}_{18.15}$
$\gamma\gamma + ML$	$14.85^{21.65}_{10.70}$	-	$14.87^{21.70}_{10.71}$	$14.98^{21.86}_{10.80}$

Channels	Stats.Only (Asimov)	+MC stats.(Asimov)	+Systematics (Asimov)	With all uncertainties
$\gamma\gamma$+1ℓ0τ_{had}	$25.46^{36.99}_{18.35}$	-	$25.50^{37.09}_{18.37}$	$26.60^{39.43}_{19.17}$
$\gamma\gamma$+0ℓ1τ_{had}	$52.70^{76.71}_{37.98}$	-	$52.79^{76.91}_{38.04}$	$54.97^{81.64}_{39.61}$
$\gamma\gamma$+2L	$37.01^{54.79}_{26.67}$	-	$37.07^{54.94}_{26.71}$	$38.15^{57.66}_{27.49}$
$\gamma\gamma + ML$	$17.72^{25.52}_{12.77}$	-	$17.75^{25.59}_{12.79}$	$18.55^{27.32}_{13.37}$



- Have similar limit to preliminary ML channel result. For comparison:

- Multilepton channel (in progress).

Channels	Stats. Only (Asimov)	+ MC stats.(Asimov)	+ Systematics (Asimov)
2ℓSS	$32.34^{51.69}_{26.25}$	$33.55^{47.38}_{24.17}$	$35.85^{50.77}_{28.85}$
3ℓ	$26.11^{37.12}_{18.82}$	$28.34^{40.77}_{20.43}$	$29.29^{42.2}_{15.7}$
$b\bar{b}4\ell$	$27.77^{41.59}_{20.02}$	$28.85^{44.01}_{20.79}$	$28.97^{44.28}_{20.87}$
1ℓ+2τ_{had}	$32.97^{47.30}_{23.74}$	$36.34^{51.76}_{26.18}$	$37.56^{53.65}_{27.06}$
2ℓ+2τ_{had}	$33.10^{48.77}_{23.88}$	$33.73^{49.55}_{24.30}$	$34.10^{50.20}_{24.55}$
2ℓSS+1τ_{had}	$42.60^{61.10}_{30.70}$		$44.70^{64.50}_{32.2}$
Multilepton	$11.18^{15.89}_{8.05}$	$11.76^{16.76}_{8.47}$	$12.18^{17.40}_{8.78}$

Summary

Analysis status:

- The analysis strategy is established and well defined
- Expected upper limit on the signal strength in $\gamma\gamma$+ML channel: 18.41 times its SM value.
- The limit is comparable with preliminary results from ML channels, the combined limit is around 10xSM.

Documentation status

- Supporting note circulated 12.9, comments are being implemented.
- New supporting note under preparation:
  - Updated final results: Include background modeling and background modeling uncertainties.
  - Working on CDS comments received during circulation.
- Paper can be prepared quickly.

From our side: ready for unblinding.

- ML channels will follow as soon as the new ML sample production is ready.

Thank you!

Backup

JobOption

$\gamma\gamma + 0l\ ggF$: (600859)

```
#--------------------------------------------------------------
# Pythia8 showering setup
#--------------------------------------------------------------
# initialize Pythia8 generator configuration for showering

runArgs.inputGeneratorFile=runArgs.inputGeneratorFile

include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")

#--------------------------------------------------------------
# Edit merged LHE file to remove problematic lines
#--------------------------------------------------------------
include("Pythia8_i/Pythia8_Powheg.py")

fname = "merged_lhef._0.events"

f = open(fname, "r")
lines = f.readlines()
f.close()

f = open(fname, 'w')
for line in lines:
  if not "#pdf" in line:
    f.write(line)
f.close()

include("Pythia8_i/Pythia8_Powheg_Main31.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",   # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",   # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",   # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",   # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale

#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]
```

```
#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

#--------------------------------------------------------------------------------------------------
# EVGEN Configuration
#--------------------------------------------------------------------------------------------------
evgenConfig.generators    += ["Powheg", "Pythia8"]
evgenConfig.description    = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords       = ["hh", "SM", "SMHiggs", "nonResonant", "ggF", "multlepton"]
evgenConfig.contact        = ['Shuiting Xin <Shuiting.Xin@cern.ch>']
evgenConfig.nEventsPerJob  = 10000
evgenConfig.maxeventsfactor = 1.0
evgenConfig.inputFilesPerJob = 10

# #--------------------------------------------------------------------------------------------------
# # Generator Filters
# #--------------------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepOneFilter")
filtSeq.LepOneFilter.IncludeHadTaus = True
filtSeq.LepOneFilter.NLeptons = 1
filtSeq.LepOneFilter.MinPt = 7000
filtSeq.LepOneFilter.MinVisPtHadTau = 15000
filtSeq.LepOneFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and not LepOneFilter"
```

JobOption

$\gamma\gamma + 1l\ ggF$: (600860)

```
#--------------------------------------------------------------
# Pythia8 showering setup
#--------------------------------------------------------------
# initialize Pythia8 generator configuration for showering

runArgs.inputGeneratorFile=runArgs.inputGeneratorFile

include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")

#--------------------------------------------------------------
# Edit merged LHE file to remove problematic lines
#--------------------------------------------------------------
include("Pythia8_i/Pythia8_Powheg.py")

fname = "merged_lhef._0.events"

f = open(fname, "r")
lines = f.readlines()
f.close()

f = open(fname, 'w')
for line in lines:
  if not "#pdf" in line:
    f.write(line)
f.close()

include("Pythia8_i/Pythia8_Powheg_Main31.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",    # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",    # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",    # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",    # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale

#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]
```

```
#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

#--------------------------------------------------------------------------------------------------
# EVGEN Configuration
#--------------------------------------------------------------------------------------------------
evgenConfig.generators    += ["Powheg", "Pythia8"]
evgenConfig.description    = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords       = ["hh", "SM", "SMHiggs", "nonResonant", "ggF", "multlepton"]
evgenConfig.contact        = ['Shuiting Xin <Shuiting.Xin@cern.ch>']
evgenConfig.nEventsPerJob  = 10000
evgenConfig.maxeventsfactor = 1.0
evgenConfig.inputFilesPerJob = 12

# #-------------------------------------------------------------------------------------------------
# # Generator Filters
# #-------------------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepOneFilter")
filtSeq.LepOneFilter.IncludeHadTaus = True
filtSeq.LepOneFilter.NLeptons = 1
filtSeq.LepOneFilter.MinPt = 7000
filtSeq.LepOneFilter.MinVisPtHadTau = 15000
filtSeq.LepOneFilter.MaxEta = 3

filtSeq += MultiElecMuTauFilter("LepTwoFilter")
filtSeq.LepTwoFilter.IncludeHadTaus = True
filtSeq.LepTwoFilter.NLeptons = 2
filtSeq.LepTwoFilter.MinPt = 7000
filtSeq.LepTwoFilter.MinVisPtHadTau = 15000
filtSeq.LepTwoFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and LepOneFilter and not LepTwoFilter"
```

JobOption

$\gamma\gamma + 2l\ ggF$: (600861)

```
#--------------------------------------------------------------
# Pythia8 showering setup
#--------------------------------------------------------------
# initialize Pythia8 generator configuration for showering

runArgs.inputGeneratorFile=runArgs.inputGeneratorFile

include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")

#--------------------------------------------------------------
# Edit merged LHE file to remove problematic lines
#--------------------------------------------------------------
include("Pythia8_i/Pythia8_Powheg.py")

fname = "merged_lhef._0.events"

f = open(fname, "r")
lines = f.readlines()
f.close()

f = open(fname, 'w')
for line in lines:
  if not "#pdf" in line:
    f.write(line)
f.close()

include("Pythia8_i/Pythia8_Powheg_Main31.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",    # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",    # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",    # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",    # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale

#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]
```

```
#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

#---------------------------------------------------------------------------------------------------
# EVGEN Configuration
#---------------------------------------------------------------------------------------------------
evgenConfig.generators    += ["Powheg", "Pythia8"]
evgenConfig.description    = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords       = ["hh", "SM", "SMHiggs", "nonResonant", "ggF", "multlepton"]
evgenConfig.contact        = ['Shuiting Xin <Shuiting.Xin@cern.ch>']
evgenConfig.nEventsPerJob  = 10000
evgenConfig.maxeventsfactor = 1.0
evgenConfig.inputFilesPerJob = 12

# #---------------------------------------------------------------------------------------------------
# # Generator Filters
# #---------------------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepOneFilter")
filtSeq.LepOneFilter.IncludeHadTaus = True
filtSeq.LepOneFilter.NLeptons = 1
filtSeq.LepOneFilter.MinPt = 7000
filtSeq.LepOneFilter.MinVisPtHadTau = 15000
filtSeq.LepOneFilter.MaxEta = 3

filtSeq += MultiElecMuTauFilter("LepTwoFilter")
filtSeq.LepTwoFilter.IncludeHadTaus = True
filtSeq.LepTwoFilter.NLeptons = 2
filtSeq.LepTwoFilter.MinPt = 7000
filtSeq.LepTwoFilter.MinVisPtHadTau = 15000
filtSeq.LepTwoFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and LepOneFilter and not LepTwoFilter"
```

JobOption

$\gamma\gamma + 0l\ VBF$: (508676)

```python
import MadGraphControl.MadGraph_NNPDF30NLO_Base_Fragment
from MadGraphControl.MadGraphUtils import *

beamEnergy=-999
if hasattr(runArgs,'ecmEnergy'):
    beamEnergy = runArgs.ecmEnergy / 2.
else:
    raise RuntimeError("No center of mass energy found.")

#---------------------------------------------------------------------------------------------------
# Due to the low filter efficiency, the number of generated events are set to safefactor times maxEvents,
# to avoid crashing due to not having enough events
# Also putting protection to avoid from crashing when maxEvents=-1
#---------------------------------------------------------------------------------------------------
safefactor=30
nevents=5000*safefactor
if runArgs.maxEvents > 0:
    nevents=runArgs.maxEvents*safefactor

mode=0

#---------------------------------------------------------------------------------------------------
# Setting parameters for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters = {}
parameters['NEW'] = {'CV':  '1.0000000',  # CV
                     'C2V': '1.0000000',  # C2V
                     'C3':  '1.0000000'}  # C3

#---------------------------------------------------------------------------------------------------
# Setting higgs mass to 125 GeV for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters['MASS']={'25':'1.250000e+02'} #MH

#---------------------------------------------------------------------------------------------------
# Setting some parameters for run_card.dat
#---------------------------------------------------------------------------------------------------
extras = { 'lhe_version':'2.0',
           'cut_decays':'F',
           'scale':'125',
           'dsqrt_q2fact1':'125',
           'dsqrt_q2fact2':'125',
           'nevents':int(nevents)}
```


```python
#---------------------------------------------------------------------------------------------------
# Setting higgs mass to 125 GeV for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters['MASS']={'25':'1.250000e+02'} #MH

#---------------------------------------------------------------------------------------------------
# Setting some parameters for run_card.dat
#---------------------------------------------------------------------------------------------------
extras = { 'lhe_version':'2.0',
           'cut_decays':'F',
           'scale':'125',
           'dsqrt_q2fact1':'125',
           'dsqrt_q2fact2':'125',
           'nevents':int(nevents)}
```


```python
#---------------------------------------------------------------------------------------------------
# Generating non-resonant VBF-Only HH process with MadGraph
# Parameters are set above
#---------------------------------------------------------------------------------------------------
process="""
import model sm
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
import model /cvmfs/atlas.cern.ch/repo/sw/Generators/madgraph/models/latest/HHVBF_UFO
generate p p > h h j j $$ z w+ w- / a j QED=4
output -f"""

process_dir = new_process(process)

#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the run_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new run_card.dat from an existing one
# Using the values given in "extras" above for the selected parameters when setting up the run_card
# If not set in "extras", default values are used
#---------------------------------------------------------------------------------------------------
modify_run_card(process_dir=process_dir,runArgs=runArgs,settings=extras)
```

```python
#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the param_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new param_card.dat from an existing one
# Used values given in "parameters" for CV, C2V, C3
# Higgs mass is set to 125 GeV by "higgsMass"
#---------------------------------------------------------------------------------------------------
modify_param_card(process_dir=process_dir,params=parameters)

#---------------------------------------------------------------------------------------------------
# Printing cards
#---------------------------------------------------------------------------------------------------
print_cards()

#---------------------------------------------------------------------------------------------------
# Generate events
#---------------------------------------------------------------------------------------------------
generate(process_dir=process_dir,runArgs=runArgs)

#---------------------------------------------------------------------------------------------------
# Move output files into the appropriate place, with the appropriate name
#---------------------------------------------------------------------------------------------------
arrange_output(process_dir=process_dir,runArgs=runArgs,lhe_version=2,saveProcDir=True)

#---------------------------------------------------------------------------------------------------
# EVGEN Configuration
#---------------------------------------------------------------------------------------------------
evgenConfig.generators = ["MadGraph", "Pythia8"]
evgenConfig.description = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords = ["hh","SM", "SMHiggs", "nonResonant", "VBF", "multilepton"]
evgenConfig.contact = ['Varsha Senthilkumar <varsha.senthilkumar@cern.ch>']

evgenConfig.nEventsPerJob = 10000
#evgenConfig.tune = "MMHT2014"
```

```python
#---------------------------------------------------------------------------------------------------
# Pythia8 showering
#---------------------------------------------------------------------------------------------------
include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")
include("Pythia8_i/Pythia8_MadGraph.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",   # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",   # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",   # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",   # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass                 "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale


#---------------------------------------------------------------------------------------------------
# Dipole option Pythia8
#---------------------------------------------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

# #---------------------------------------------------------------------------------------------------
# # Generator Filters
# #---------------------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepOneFilter")
filtSeq.LepOneFilter.IncludeHadTaus = True
filtSeq.LepOneFilter.NLeptons = 1
filtSeq.LepOneFilter.MinPt = 7000
filtSeq.LepOneFilter.MinVisPtHadTau = 15000
filtSeq.LepOneFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and not LepOneFilter"
```

JobOption

$\gamma\gamma + 0l\ VBF$: (508677)

```python
import MadGraphControl.MadGraph_NNPDF30NLO_Base_Fragment
from MadGraphControl.MadGraphUtils import *

beamEnergy=-999
if hasattr(runArgs,'ecmEnergy'):
    beamEnergy = runArgs.ecmEnergy / 2.
else:
    raise RuntimeError("No center of mass energy found.")

#---------------------------------------------------------------------------------------------------
# Due to the low filter efficiency, the number of generated events are set to safefactor times maxEvents,
# to avoid crashing due to not having enough events
# Also putting protection to avoid from crashing when maxEvents=-1
#---------------------------------------------------------------------------------------------------
safefactor=30
nevents=5000*safefactor
if runArgs.maxEvents > 0:
    nevents=runArgs.maxEvents*safefactor

mode=0

#---------------------------------------------------------------------------------------------------
# Setting parameters for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters = {}
parameters['NEW'] = {'CV':  '1.0000000',  # CV
                     'C2V': '1.0000000',  # C2V
                     'C3':  '1.0000000'}  # C3

#---------------------------------------------------------------------------------------------------
# Setting higgs mass to 125 GeV for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters['MASS']={'25':'1.250000e+02'} #MH

#---------------------------------------------------------------------------------------------------
# Setting some parameters for run_card.dat
#---------------------------------------------------------------------------------------------------
extras = { 'lhe_version':'2.0',
           'cut_decays':'F',
           'scale':'125',
           'dsqrt_q2fact1':'125',
           'dsqrt_q2fact2':'125',
           'nevents':int(nevents)}
```

```python
#---------------------------------------------------------------------------------------------------
# Generating non-resonant VBF-Only HH process with MadGraph
# Parameters are set above
#---------------------------------------------------------------------------------------------------
process="""
import model sm
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
import model /cvmfs/atlas.cern.ch/repo/sw/Generators/madgraph/models/latest/HHVBF_UFO
generate p p > h h j j $$ z w+ w- / a j QED=4
output -f"""

process_dir = new_process(process)

#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the run_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new run_card.dat from an existing one
# Using the values given in "extras" above for the selected parameters when setting up the run_card
# If not set in "extras", default values are used
#---------------------------------------------------------------------------------------------------
modify_run_card(process_dir=process_dir,runArgs=runArgs,settings=extras)

#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the param_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new param_card.dat from an existing one
# Used values given in "parameters" for CV, C2V, C3
# Higgs mass is set to 125 GeV by "higgsMass"
#---------------------------------------------------------------------------------------------------
modify_param_card(process_dir=process_dir,params=parameters)
```


```python
#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the param_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new param_card.dat from an existing one
# Used values given in "parameters" for CV, C2V, C3
# Higgs mass is set to 125 GeV by "higgsMass"
#---------------------------------------------------------------------------------------------------
modify_param_card(process_dir=process_dir,params=parameters)
```


```python
#---------------------------------------------------------------------------------------------------
# Printing cards
#---------------------------------------------------------------------------------------------------
print_cards()

#---------------------------------------------------------------------------------------------------
# Generate events
#---------------------------------------------------------------------------------------------------
generate(process_dir=process_dir,runArgs=runArgs)

#---------------------------------------------------------------------------------------------------
# Move output files into the appropriate place, with the appropriate name
#---------------------------------------------------------------------------------------------------
arrange_output(process_dir=process_dir,runArgs=runArgs,lhe_version=2,saveProcDir=True)

#---------------------------------------------------------------------------------------------------
# EVGEN Configuration
#---------------------------------------------------------------------------------------------------
evgenConfig.generators = ["MadGraph", "Pythia8"]
evgenConfig.description = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords = ["hh","SM", "SMHiggs", "nonResonant", "VBF", "multilepton"]
evgenConfig.contact = ['Varsha Senthilkumar <varsha.senthilkumar@cern.ch>']

evgenConfig.nEventsPerJob = 10000
#evgenConfig.tune = "MMHT2014"
```

```python
#------------------------------------------------------------------
# Pythia8 showering
#------------------------------------------------------------------
include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")
include("Pythia8_i/Pythia8_MadGraph.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",   # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",   # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",   # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",   # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass                  "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale


#------------------------------------------------------------------
# Dipole option Pythia8
#------------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

# #---------------------------------------------------------------------------------------
# # Generator Filters
# #---------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepOneFilter")
filtSeq.LepOneFilter.IncludeHadTaus = True
filtSeq.LepOneFilter.NLeptons = 1
filtSeq.LepOneFilter.MinPt = 7000
filtSeq.LepOneFilter.MinVisPtHadTau = 15000
filtSeq.LepOneFilter.MaxEta = 3

filtSeq += MultiElecMuTauFilter("LepTwoFilter")
filtSeq.LepTwoFilter.IncludeHadTaus = True
filtSeq.LepTwoFilter.NLeptons = 2
filtSeq.LepTwoFilter.MinPt = 7000
filtSeq.LepTwoFilter.MinVisPtHadTau = 15000
filtSeq.LepTwoFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and LepOneFilter and not LepTwoFilter"
```

JobOption

$\gamma\gamma + 0l\ VBF$: (508678)

```
import MadGraphControl.MadGraph_NNPDF30NLO_Base_Fragment
from MadGraphControl.MadGraphUtils import *

beamEnergy=-999
if hasattr(runArgs,'ecmEnergy'):
    beamEnergy = runArgs.ecmEnergy / 2.
else:
    raise RuntimeError("No center of mass energy found.")

#---------------------------------------------------------------------------------------------------
# Due to the low filter efficiency, the number of generated events are set to safefactor times maxEvents,
# to avoid crashing due to not having enough events
# Also putting protection to avoid from crashing when maxEvents=-1
#---------------------------------------------------------------------------------------------------
safefactor=30
nevents=5000*safefactor
if runArgs.maxEvents > 0:
    nevents=runArgs.maxEvents*safefactor

mode=0

#---------------------------------------------------------------------------------------------------
# Setting parameters for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters = {}
parameters['NEW'] = {'CV':  '1.0000000',  # CV
                     'C2V': '1.0000000',  # C2V
                     'C3':  '1.0000000'}  # C3

#---------------------------------------------------------------------------------------------------
# Setting higgs mass to 125 GeV for param_card.dat
#---------------------------------------------------------------------------------------------------
parameters['MASS']={'25':'1.250000e+02'} #MH

#---------------------------------------------------------------------------------------------------
# Setting some parameters for run_card.dat
#---------------------------------------------------------------------------------------------------
extras = { 'lhe_version':'2.0',
           'cut_decays':'F',
           'scale':'125',
           'dsqrt_q2fact1':'125',
           'dsqrt_q2fact2':'125',
           'nevents':int(nevents)}
```

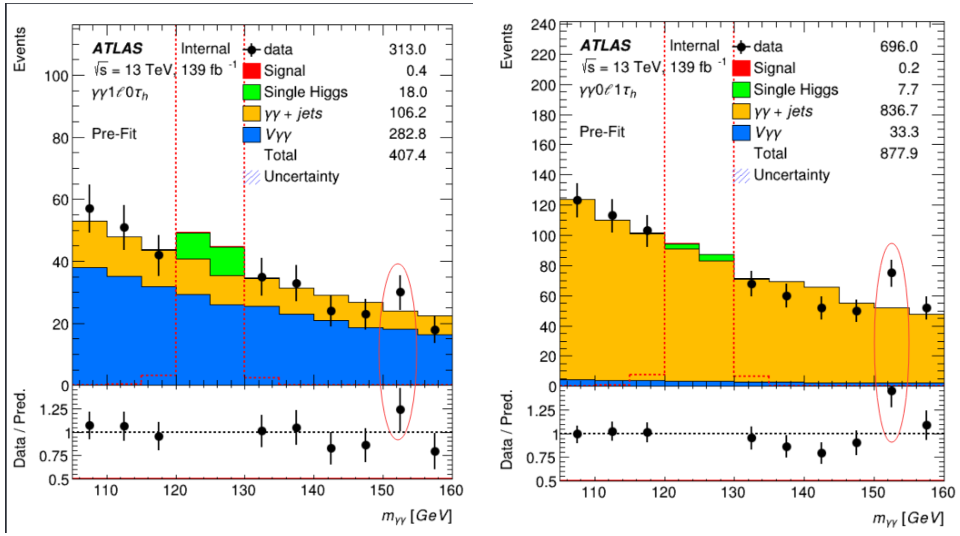
```
#---------------------------------------------------------------------------------------------------
# Generating non-resonant VBF-Only HH process with MadGraph
# Parameters are set above
#---------------------------------------------------------------------------------------------------
process="""
import model sm
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
import model /cvmfs/atlas.cern.ch/repo/sw/Generators/madgraph/models/latest/HHVBF_UFO
generate p p > h h j j $$ z w+ w- / a j QED=4
output -f"""

process_dir = new_process(process)

#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the run_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new run_card.dat from an existing one
# Using the values given in "extras" above for the selected parameters when setting up the run_card
# If not set in "extras", default values are used
#---------------------------------------------------------------------------------------------------
modify_run_card(process_dir=process_dir,runArgs=runArgs,settings=extras)

#---------------------------------------------------------------------------------------------------
# Using the helper function from MadGraphControl for setting up the param_card
# https://gitlab.cern.ch/atlas/athena/-/tree/master/Generators/MadGraphControl
# Build a new param_card.dat from an existing one
# Used values given in "parameters" for CV, C2V, C3
# Higgs mass is set to 125 GeV by "higgsMass"
#---------------------------------------------------------------------------------------------------
modify_param_card(process_dir=process_dir,params=parameters)
```

```
#---------------------------------------------------------------------------------------------------
# Generate events
#---------------------------------------------------------------------------------------------------
generate(process_dir=process_dir,runArgs=runArgs)

#---------------------------------------------------------------------------------------------------
# Move output files into the appropriate place, with the appropriate name
#---------------------------------------------------------------------------------------------------
arrange_output(process_dir=process_dir,runArgs=runArgs,lhe_version=2,saveProcDir=True)

#---------------------------------------------------------------------------------------------------
# EVGEN Configuration
#---------------------------------------------------------------------------------------------------
evgenConfig.generators = ["MadGraph", "Pythia8"]
evgenConfig.description = "SM diHiggs production, decay to multi-lepton, with Powheg-Box-V2, at NLO + full top mass."
evgenConfig.keywords = ["hh","SM", "SMHiggs", "nonResonant", "VBF", "multilepton"]
evgenConfig.contact = ['Varsha Senthilkumar <varsha.senthilkumar@cern.ch>']

evgenConfig.nEventsPerJob = 10000
#evgenConfig.tune = "MMHT2014"

#--------------------------------------------------------------
# Pythia8 showering
#--------------------------------------------------------------
include("Pythia8_i/Pythia8_A14_NNPDF23LO_EvtGen_Common.py")
include("Pythia8_i/Pythia8_MadGraph.py")

# configure Pythia8
genSeq.Pythia8.Commands += [ "25:oneChannel = on 0.353 100 24 -24 ",   # WW decay
                             "25:addChannel = on 0.043 100 23 23  ",   # ZZ decay
                             "25:addChannel = on 0.104 100 15 -15 ",   # tautau decay
                             "25:addChannel = on 0.5   100 22 22  ",   # yy decay
                             "24:mMin = 0", # W minimum mass
                             "24:mMax = 99999", # W maximum mass
                             "23:mMin = 0", # Z minimum mass
                             "23:mMax = 99999", # Z maximum mass                    "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale
                             "TimeShower:mMaxGamma = 0" ] # Z/gamma* combination scale
```

```
#--------------------------------------------------------------
# Dipole option Pythia8
#--------------------------------------------------------------
genSeq.Pythia8.Commands += [ "SpaceShower:dipoleRecoil = on" ]

# #---------------------------------------------------------------------------------------------------
# # Generator Filters
# #---------------------------------------------------------------------------------------------------
from GeneratorFilters.GeneratorFiltersConf import ParentChildFilter
filtSeq += ParentChildFilter("hyyFilter", PDGParent = [25], PDGChild = [22])
filtSeq += ParentChildFilter("hXXFilter", PDGParent = [25], PDGChild = [15,23,24])

from GeneratorFilters.GeneratorFiltersConf import MultiElecMuTauFilter
filtSeq += MultiElecMuTauFilter("LepTwoFilter")
filtSeq.LepTwoFilter.IncludeHadTaus = True
filtSeq.LepTwoFilter.NLeptons = 2
filtSeq.LepTwoFilter.MinPt = 7000
filtSeq.LepTwoFilter.MinVisPtHadTau = 15000
filtSeq.LepTwoFilter.MaxEta = 3

filtSeq.Expression = "hyyFilter and hXXFilter and LepTwoFilter"
```

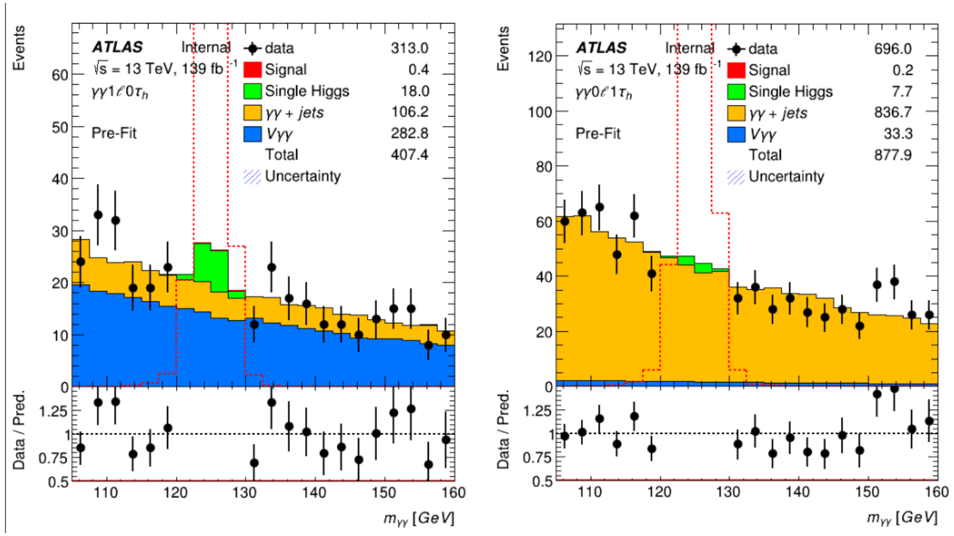
Investigation on $m_{\gamma\gamma}$ disagreement (Appendix F.4)

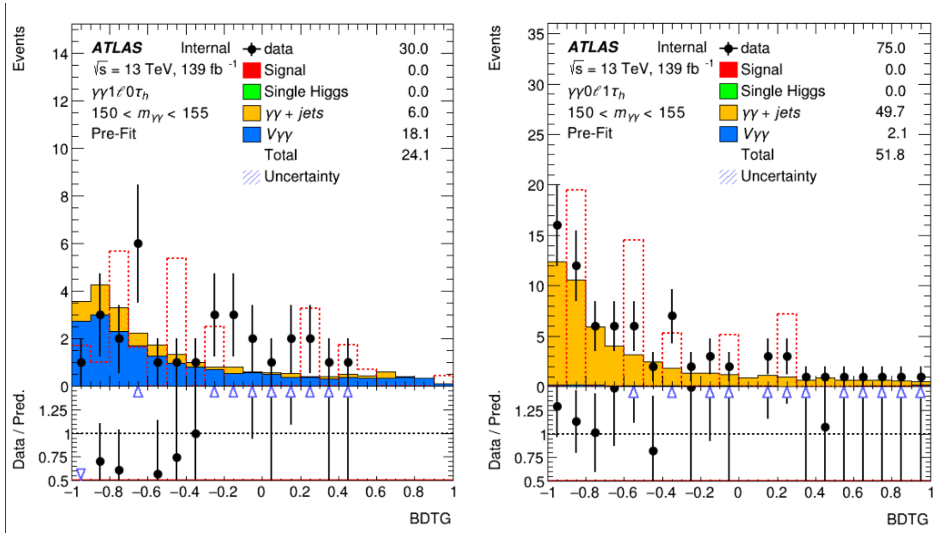
What happens in the **m_gammagamma >150 GeV <155 GeV** bin? (that peak)



The disagreement is below 2 sigma, we do some check:

- This peak goes down with smaller bins(in the left plots)
- When we check the BDTG shape in (150,155)GeV.(Right one)
- the most events are in the low BDTG ⇒ not HH signal like.





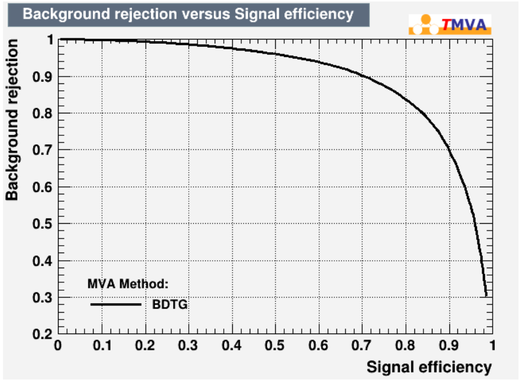
MVA method

$\gamma\gamma + 1l0\tau_h$:

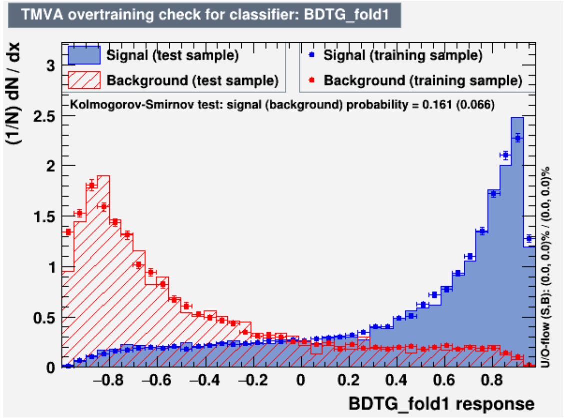
Separation power:

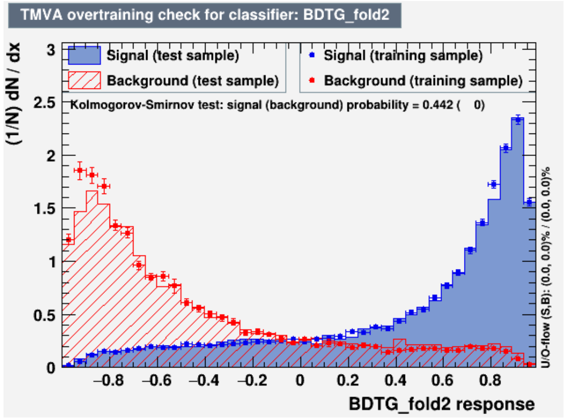
Variable	Rank	Separation power
$p_T(H)$	1	31.15%
$\Delta R(\gamma\gamma, W)$	2	11.75%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	3	8.34%
E_T^{miss}	4	7.04%
$\phi_0(L_1)$	5	6.51%
$\min\Delta\Phi(E_T^{miss}, j, L)$	6	5.03%
$\Delta R(L\nu)$	7	4.68%
N_{jcen}	8	3.31%
$\eta(W)$	9	3.20%
$\phi_0(\gamma_1)$	10	3.12%
$p_T(L_1)$	11	1.81%

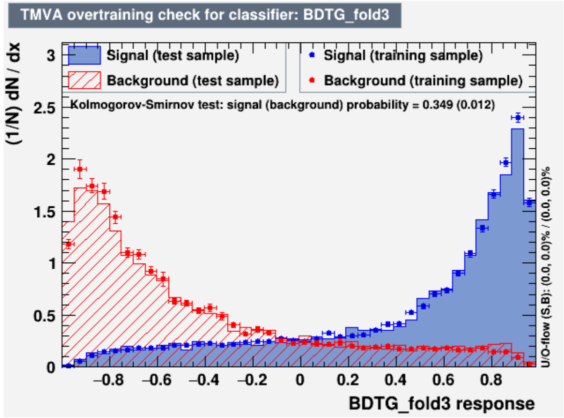
ROC-value: 0.896

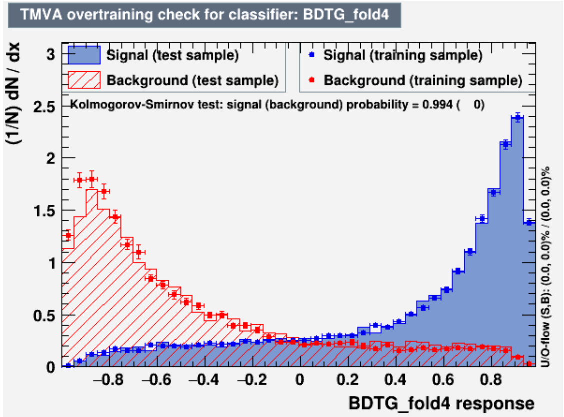


Overtraining plots with ks test values for 4 folds:

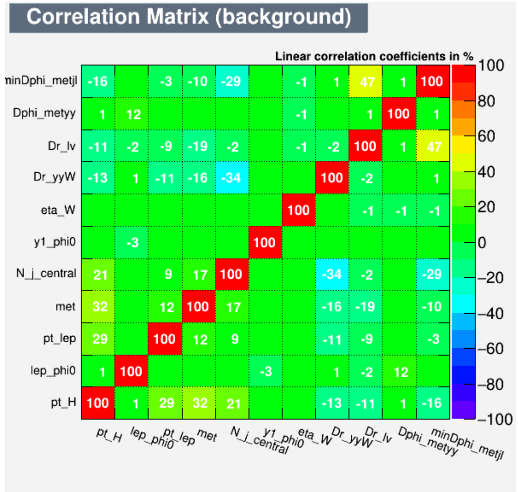


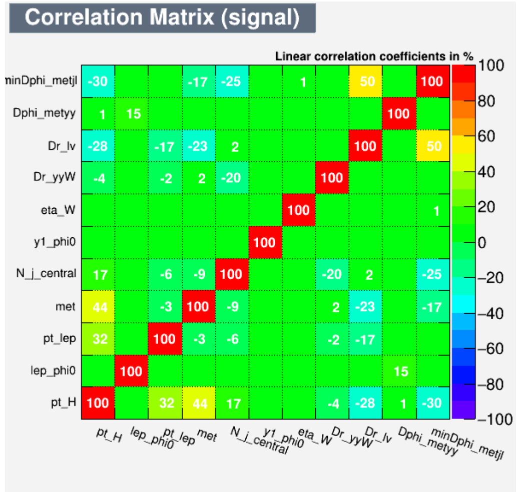






Correlation Matrix:





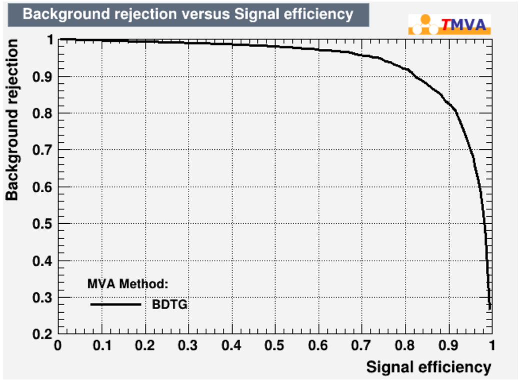
MVA method

$\gamma\gamma + 1l1\tau_h : (\gamma\gamma + 2L \text{ include } 1l1\tau_h, 2l0\tau_h, 0l2\tau_h)$

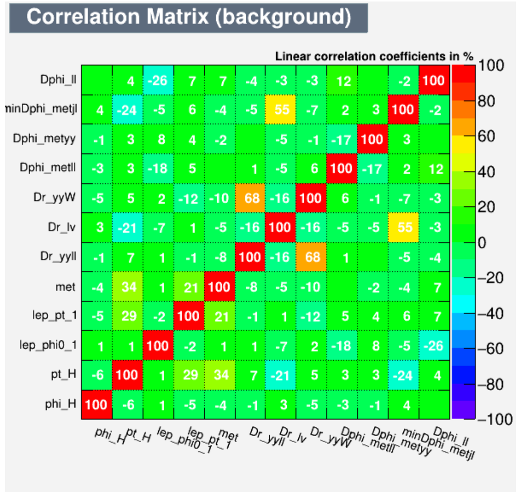
Separation power:

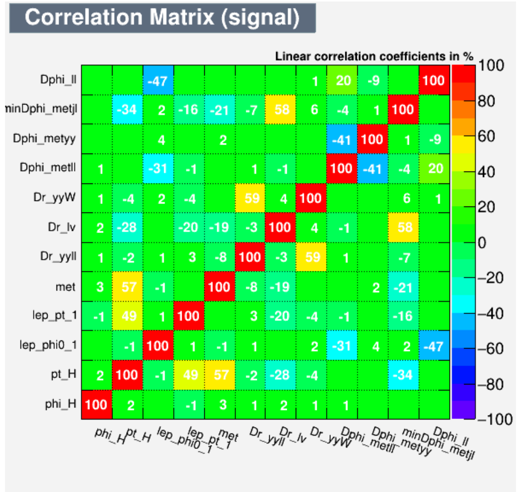
Variable	Rank	Separation power
$p_T(H)$	1	33.92%
$\Delta\Phi(E_T^{miss}, LL)$	2	17.63%
$\Delta\phi(\ell, \ell)$	3	16.60%
$\Delta R(L\nu)$	4	15.80%
$\Delta R(LL, \gamma\gamma)$	5	14.67%
$\phi_0(L_1)$	6	13.40%
$\Delta R(\gamma\gamma, W)$	7	13.16%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	8	11.54%
E_T^{miss}	9	8.51%
$\min\Delta\Phi(E_T^{miss}, j, L)$	9	8.26%
$p_T(L_1)$	11	4.80%
$\phi(H)$	12	2.15%

ROC-value: 0.937

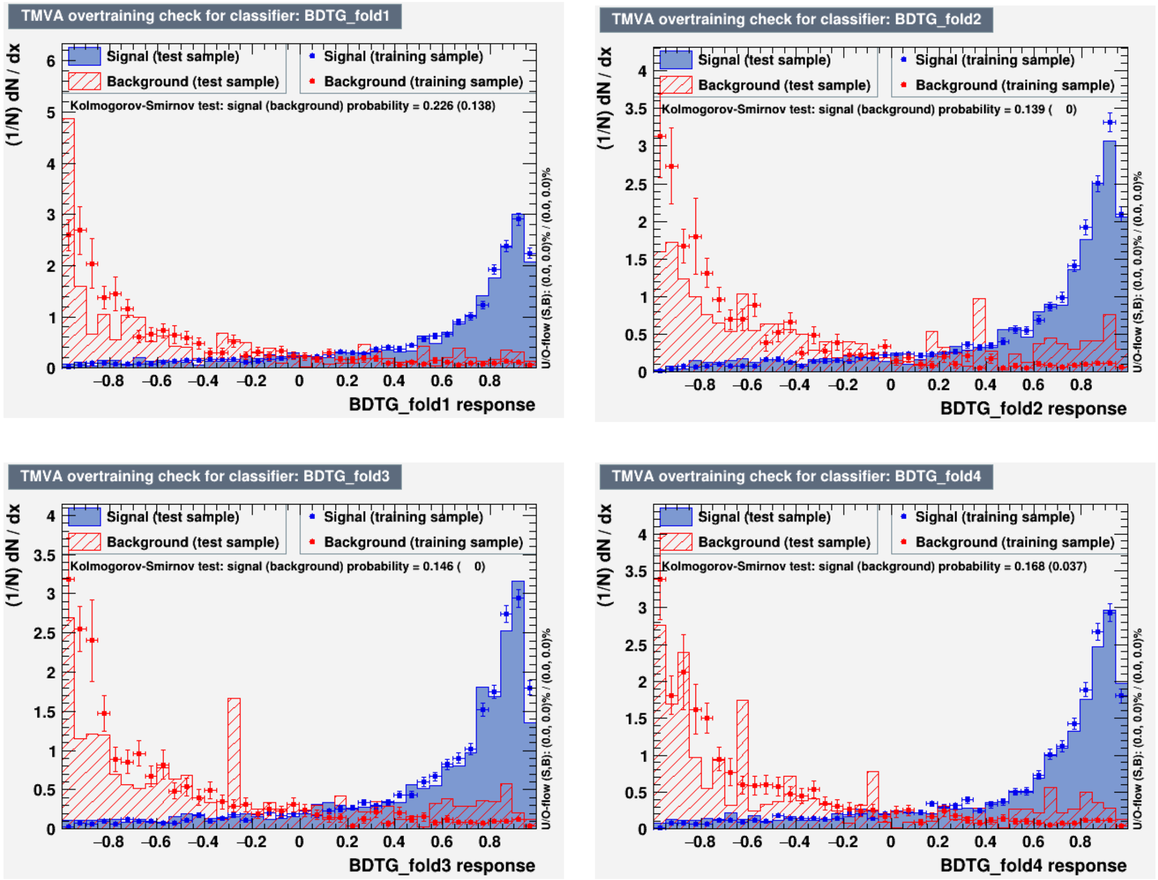


Correlation Matrix:





Overtraining plots with ks test values for 4 folds:



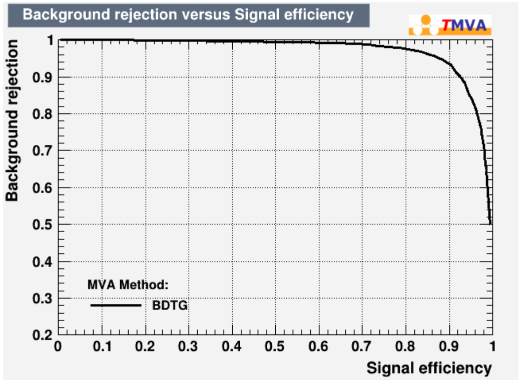
MVA method

$\gamma\gamma + 2l0\tau_h$: ($\gamma\gamma + 2L$ include $1l1\tau_h$, $2l0\tau_h$, $0l2\tau_h$)

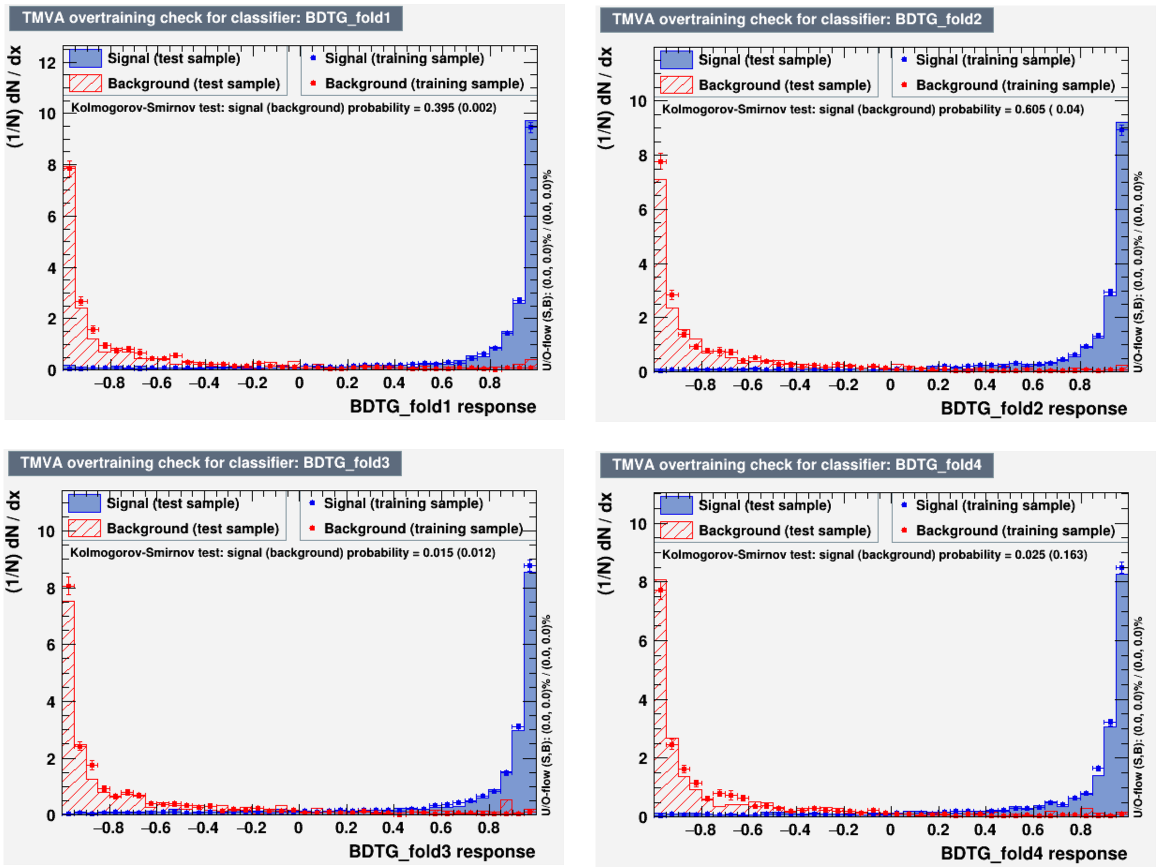
Separation power:

Variable	Rank	Separation power
$\Delta m(LL)$	1	31.78%
E_T^{miss}	2	29.40%
$p_T(H)$	3	29.35%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	4	25.37%
$\Delta\Phi(E_T^{miss}, LL)$	5	24.88%
$\Delta R(L\nu)$	6	22.14%
$\Delta R(LL)$	7	20.43%
$\Delta\phi(LL)$	8	16.06%
$\phi_0(L_1)$	9	9.86%
N_{jcen}	10	4.04%
$\min\Delta\Phi(E_T^{miss}, j, L)$	11	2.42%

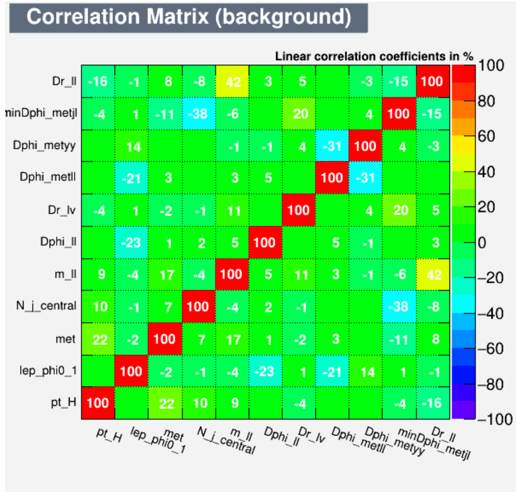
ROC-value: 0.971

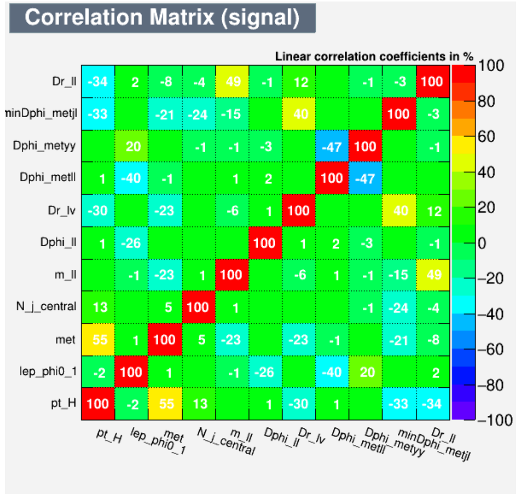


Overtraining plots with ks test values for 4 folds:



Correlation Matrix:





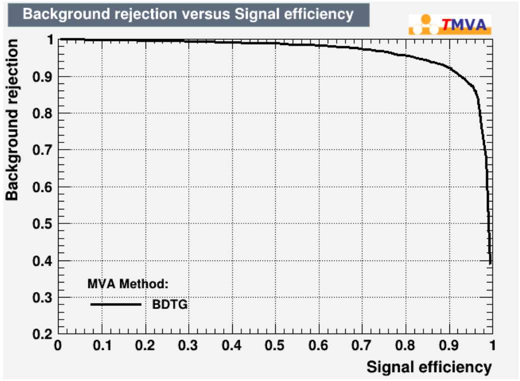
MVA method

$\gamma\gamma + 0l2\tau_h : (\gamma\gamma + 2L \text{ include } 1l1\tau_h, 2l0\tau_h, 0l2\tau_h)$

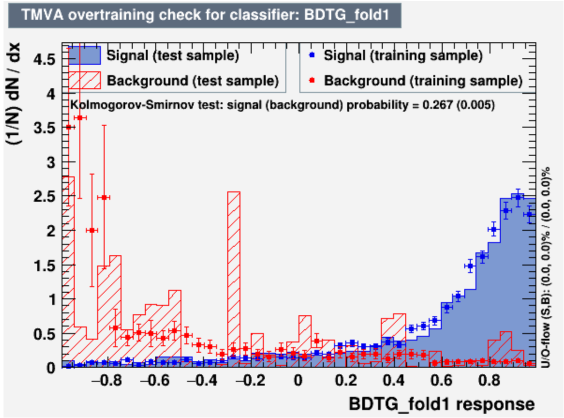
Separation power:

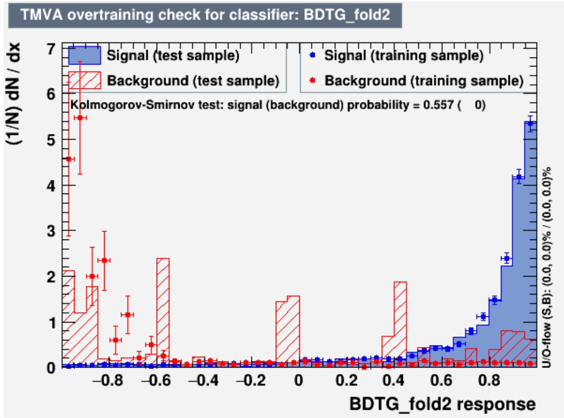
Variable	Rank	Separation power
$p_T(H)$	1	44.16%
$\Delta\Phi(E_T^{miss}, LL)$	2	28.34%
$p_T(L_1)$	3	25.49%
$p_T(L_2)$	4	18.84%
E_T^{miss}	5	17.64%
$\phi_0(L_1)$	6	14.40%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	7	12.54%
$\phi(E_T^{miss})$	8	11.15%
N_{jcen}	9	9.90%

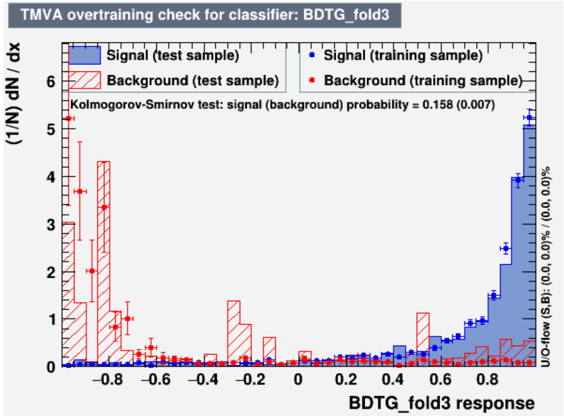
ROC-value: 0.965

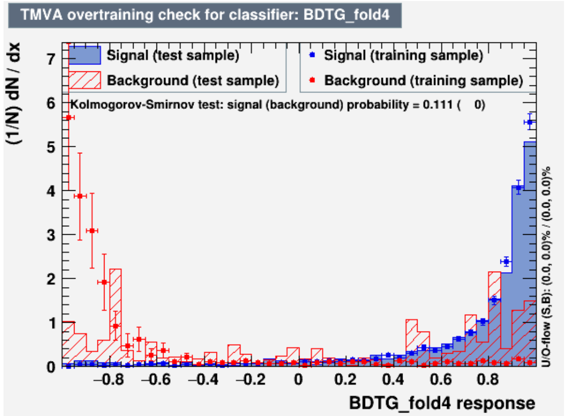


Overtraining plots with ks test values for 4 folds:

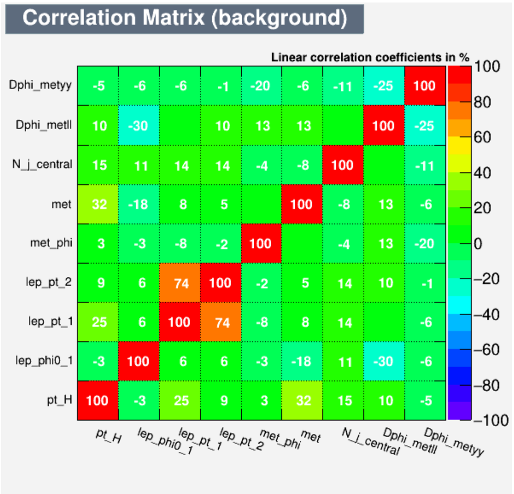


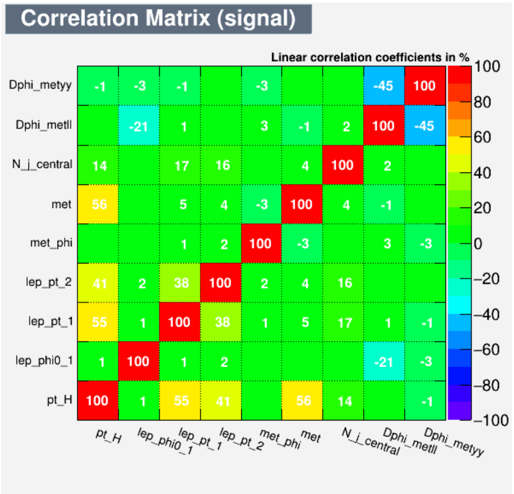






Correlation Matrix:





MVA method

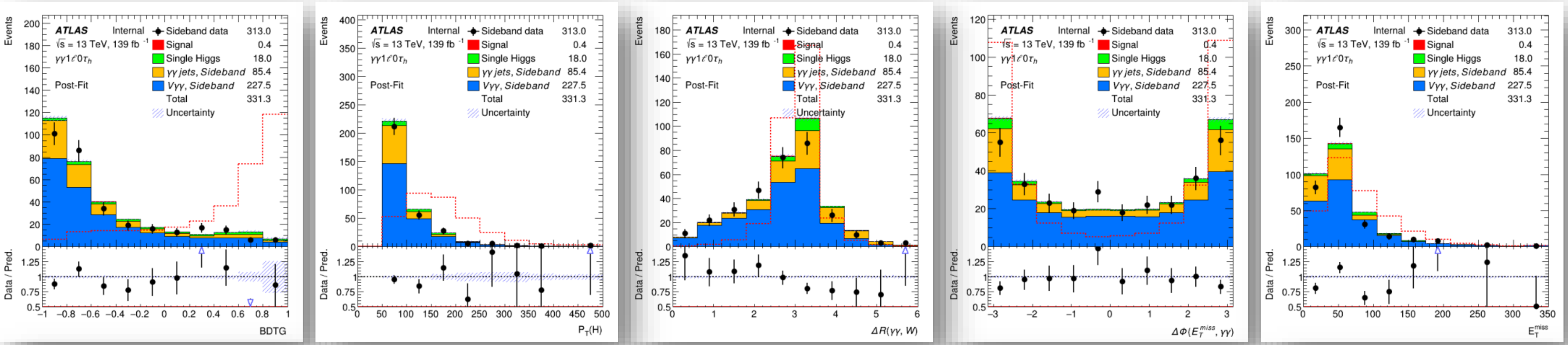
$\gamma\gamma + 1l0\tau_h$:

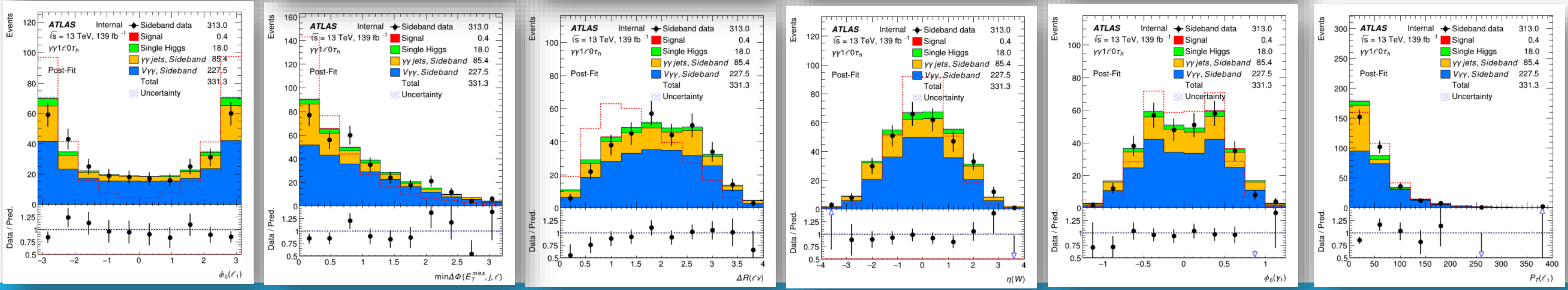
Consider a tough background scaling:

- Apply a scale factor on MC continuum background ($\gamma\gamma$+$jets$ and $V\gamma\gamma$) which corresponds to the ratio between MC continuum background sideband yields and the data sideband yields:

- After background scaling, the BDTG and most of input variables distribution show here:

Variable	Rank	Separation power
$p_T(H)$	1	31.15%
$\Delta R(\gamma\gamma, W)$	2	11.75%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	3	8.34%
E_T^{miss}	4	7.04%
$\phi_0(L_1)$	5	6.51%
$\min\Delta\Phi(E_T^{miss}, j, L)$	6	5.03%
$\Delta R(L\nu)$	7	4.68%
N_{jcen}	8	3.31%
$\eta(W)$	9	3.20%
$\phi_0(\gamma_1)$	10	3.12%
$p_T(L_1)$	11	1.81%



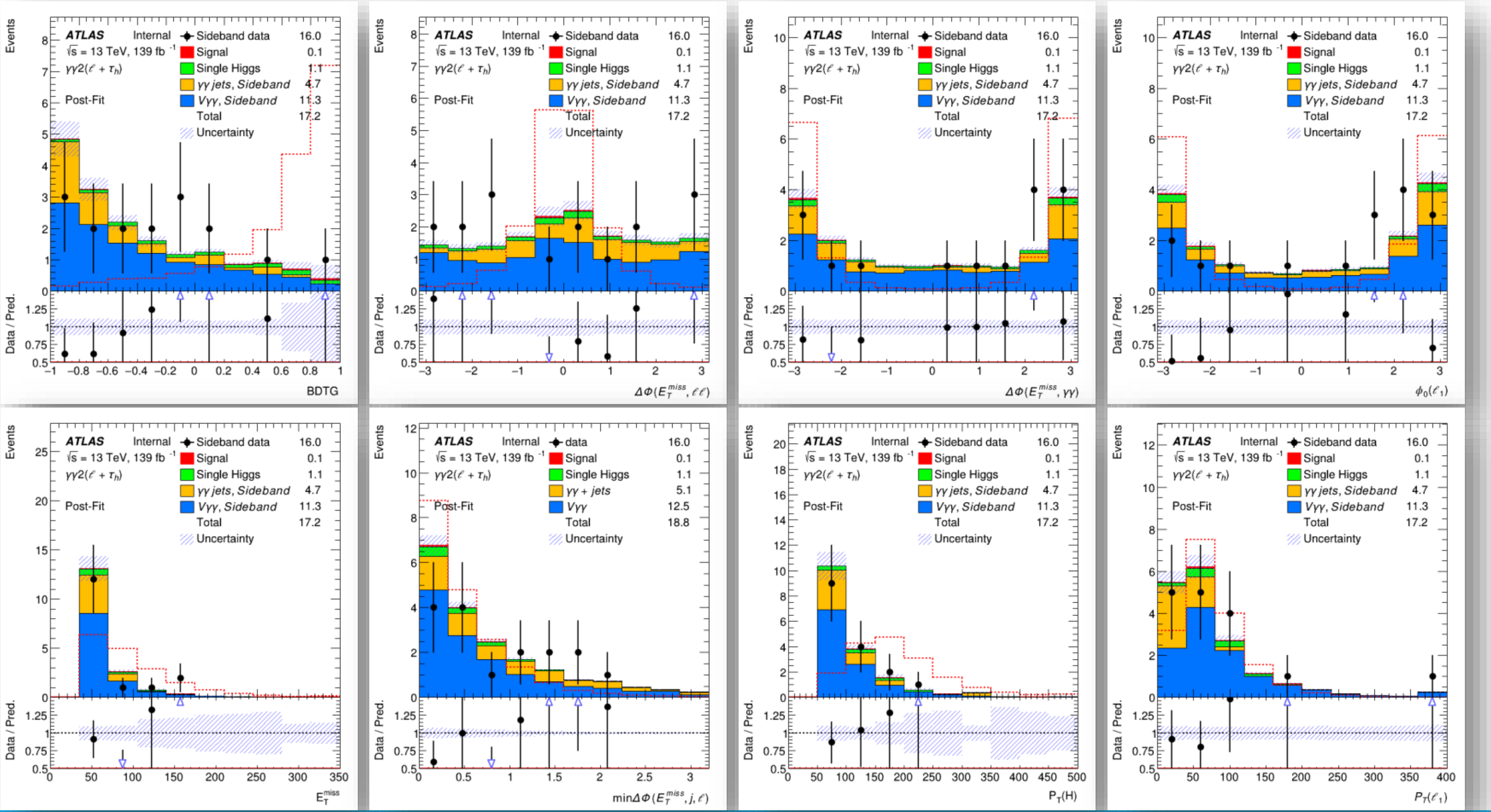


MVA method

$\gamma\gamma + 2L$:

Consider a tough background scaling:

- Apply a scale factor on MC continuum background ($\gamma\gamma$+$jets$ and $V\gamma\gamma$) which corresponds to the ratio between MC continuum background sideband yields and the data sideband yields:
- After background scaling, the BDTG and most of input variables distribution show here:



$\gamma\gamma + 1l1\tau_h$

Variable	Rank	Separation power
$p_T(H)$	1	33.92%
$\Delta\Phi(E_T^{miss}, LL)$	2	17.63%
$\Delta\phi(\ell,\ell)$	3	16.60%
$\Delta R(L\nu)$	4	15.80%
$\Delta R(LL,\gamma\gamma)$	5	14.67%
$\phi_0(L_1)$	6	13.40%
$\Delta R(\gamma\gamma, W)$	7	13.16%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	8	11.54%
E_T^{miss}	9	8.51%
$\min\Delta\Phi(E_T^{miss}, j, L)$	9	8.26%
$p_T(L_1)$	11	4.80%
$\phi(H)$	12	2.15%

$\gamma\gamma + 2l0\tau_h$

Variable	Rank	Separation power
$\Delta m(LL)$	1	31.78%
E_T^{miss}	2	29.40%
$p_T(H)$	3	29.35%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	4	25.37%
$\Delta\Phi(E_T^{miss}, LL)$	5	24.88%
$\Delta R(L\nu)$	6	22.14%
$\Delta R(LL)$	7	20.43%
$\Delta\phi(LL)$	8	16.06%
$\phi_0(L_1)$	9	9.86%
N_{jcen}	10	4.04%
$\min\Delta\Phi(E_T^{miss}, j, L)$	11	2.42%

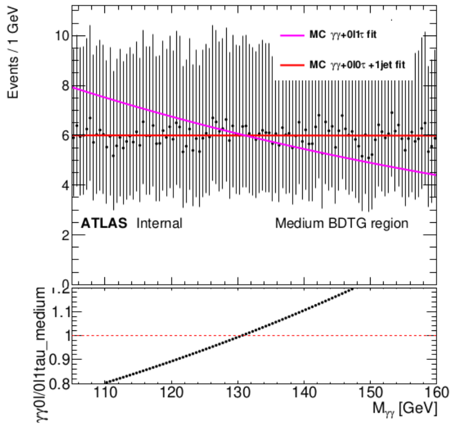
$\gamma\gamma + 0l2\tau_h$

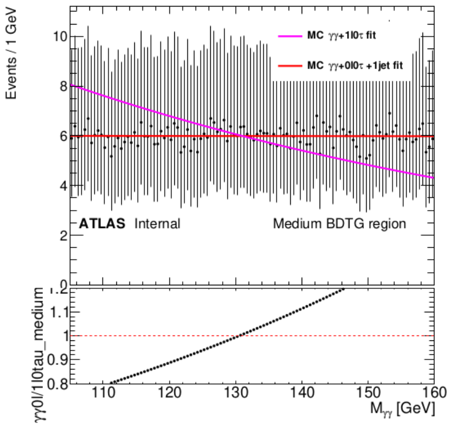
Variable	Rank	Separation power
$p_T(H)$	1	44.16%
$\Delta\Phi(E_T^{miss}, LL)$	2	28.34%
$p_T(L_1)$	3	25.49%
$p_T(L_2)$	4	18.84%
E_T^{miss}	5	17.64%
$\phi_0(L_1)$	6	14.40%
$\Delta\Phi(E_T^{miss}, \gamma\gamma)$	7	12.54%
$\phi(E_T^{miss})$	8	11.15%
N_{jcen}	9	9.90%

Systematic uncertainties

- In Medium BDTG region:

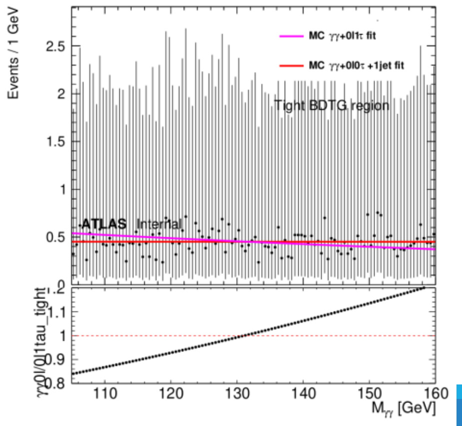
(0<BDTG<0.6)

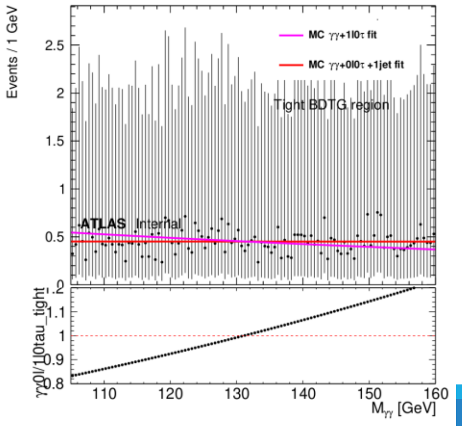




- In Tight BDTG region:

(0.6<BDTG)





Systematic uncertainties list

- Luminosity: 1.7 %
- Pile-up reweighting
- Muon
- Electron
- Tau

NP Name	Description
Event	
ATLAS_LUMI_Run2	Uncertainty on the total integrated luminosity (1.7%)
ATLAS_PU_PRW_DATASF	Pile-up reweighting
electrons	
EL_EFF_TRIG_TOTAL_1NPCOR_PLUS_UNCOR	electron-trigger
EL_EFF_RECO_TOTAL_1NPCOR_PLUS_UNCOR	electron-reconstruction
EL_EFF_ID_TOTAL_1NPCOR_PLUS_UNCOR	electron-identification
EL_EFF_ISO_TOTAL_1NPCOR_PLUS_UNCOR	electron-isolation
muons	
MUON_EFF_TrigStatUncertainty	mun-trigger
MUON_EFF_TrigSystUncertainty	
MUON_EFF_RECO_STAT	muon-reconstruction
MUON_EFF_RECO_SYS	
MUON_EFF_RECO_STAT_LOWPT	
MUON_EFF_RECO_SYS_LOWPT	
MUON_EFF_ISO_STAT	muon-isolation
MUON_EFF_ISO_SYS	
MUON_EFF_TTVA_STAT	muon-TTVA
MUON_EFF_TTVA_SYS	
MUON_ID	muon-momentum calibration
MUON_MS	
MUON_SCALE	
MUON_SAGITTA_RHO	
MUON_SAGITTA_RESBIAS	

τ-leptons	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATDATA161718	τ-trigger
TAUS_TRUEHADTAU_EFF_TRIGGER_STATDATA1718	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATDATA2016	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATDATA2018	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATDATA2018AFTTS1	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATMC161718	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATMC1718	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATMC2016	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATMC2018	
TAUS_TRUEHADTAU_EFF_TRIGGER_STATMC2018AFTTS1	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYST161718	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYST1718	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYST2016	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYST2018	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYST2018AFTTS1	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYSTMU161718	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYSTMU1718	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYSTMU2016	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYSTMU2018	
TAUS_TRUEHADTAU_EFF_TRIGGER_SYSTMU2018AFTTS1	
TAUS_TRUEHADTAU_EFF_RECO_HIGHPT	τ-reconstruction
TAUS_TRUEHADTAU_EFF_RECO_TOTAL	
TAUS_TRUEHADTAU_EFF_RNNID_1PRONGSTATSYSTPT2025	τ-identification
TAUS_TRUEHADTAU_EFF_RNNID_1PRONGSTATSYSTPT2530	
TAUS_TRUEHADTAU_EFF_RNNID_1PRONGSTATSYSTPT3040	
TAUS_TRUEHADTAU_EFF_RNNID_1PRONGSTATSYSTPTGE40	
TAUS_TRUEHADTAU_EFF_RNNID_3PRONGSTATSYSTPT2025	
TAUS_TRUEHADTAU_EFF_RNNID_3PRONGSTATSYSTPT2530	
TAUS_TRUEHADTAU_EFF_RNNID_3PRONGSTATSYSTPT3040	
TAUS_TRUEHADTAU_EFF_RNNID_3PRONGSTATSYSTPTGE40	
TAUS_TRUEHADTAU_EFF_RNNID_HIGHPT	
TAUS_TRUEHADTAU_EFF_RNNID_SYST	
TAUS_TRUEHADTAU_SME_TES_INSITUEXP	τ-energy scale
TAUS_TRUEHADTAU_SME_TES_INSITUFIT	
TAUS_TRUEHADTAU_SME_TES_MODEL_CLOSURE	
TAUS_TRUEHADTAU_SME_TES_PHYSICSLIST	
TAUS_TRUEELECTRON_EFF_ELEBDT_STAT	τ-electron veto
TAUS_TRUEELECTRON_EFF_ELEBDT_SYST	
TAUS_TRUEHADTAU_EFF_ELEOLR_TOTAL	

Systematic uncertainties

- Photon
- MET
- Flavour tagging

- Jet

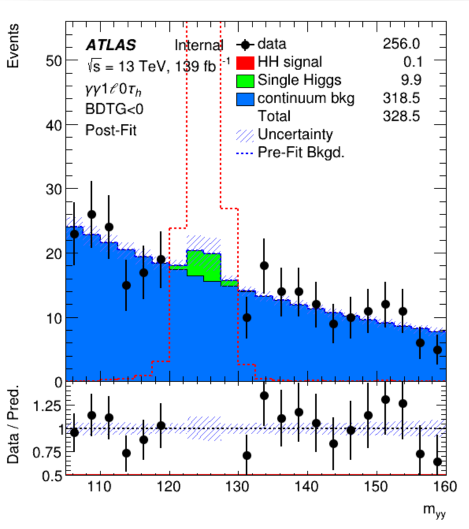
egamma	
EG_RESOLUTION_ALL EG_SCALE_ALL EG_SCALE_AF2	egamma resolution egamma scale
photon	
PH_EFF_TRIGGER PH_EFF_ID PH_EFF_ISO	Photon trigger Photon identification Photon isolation
E_T^{miss}	
MET_SoftTrk_ResoPara MET_SoftTrk_ResoPerp MET_SoftTrk_ScaleDown MET_SoftTrk_ScaleUp	

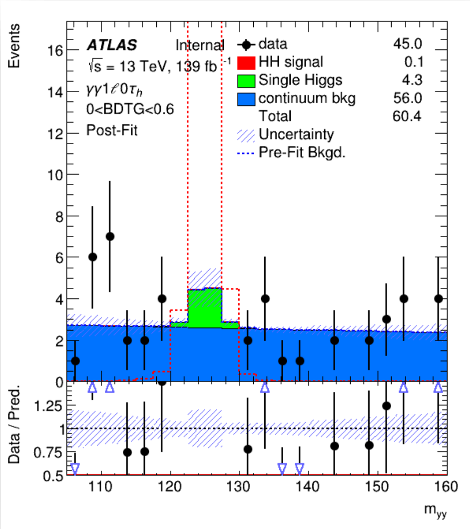
b-tagging	
FT_EFF_Eigen_B_0 FT_EFF_Eigen_B_1 FT_EFF_Eigen_B_2 FT_EFF_Eigen_C_0 FT_EFF_Eigen_C_1 FT_EFF_Eigen_C_2 FT_EFF_Eigen_C_3 FT_EFF_Eigen_Light_0 FT_EFF_Eigen_Light_1 FT_EFF_Eigen_Light_2 FT_EFF_Eigen_Light_3 FT_EFF_extrapolation FT_EFF_extrapolation_from_charm	

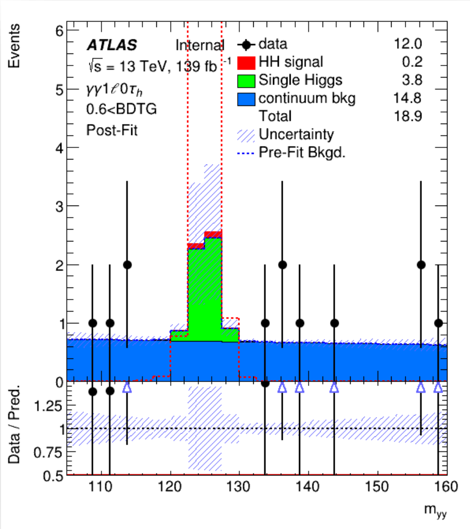
NP Name	Description
Jets	
JET_EtaIntercalibration_Modelling	Jet energy scale (CategoryReduction)
JET_EtaIntercalibration_TotalStat	
JET_EtaIntercalibration_NonClosure_highE	
JET_EtaIntercalibration_NonClosure_negEta	
JET_EtaIntercalibration_NonClosure_posEta	
JET_Pileup_OffsetMu	
JET_Pileup_OffsetNPV	
JET_Pileup_PtTerm	
JET_Pileup_RhoTopology	
JET_Flavor_Composition	
JET_Flavor_Response	
JET_PunchThrough_MC16	
JET_PunchThrough_AFII	
JET_EffectiveNP_Detector1	
JET_EffectiveNP_Detector2	
JET_EffectiveNP_Mixed1	
JET_EffectiveNP_Mixed2	
JET_EffectiveNP_Mixed3	
JET_EffectiveNP_Modelling1	
JET_EffectiveNP_Modelling2	
JET_EffectiveNP_Modelling3	
JET_EffectiveNP_Modelling4	
JET_EffectiveNP_Statistical1	
JET_EffectiveNP_Statistical2	
JET_EffectiveNP_Statistical3	
JET_EffectiveNP_Statistical4	
JET_EffectiveNP_Statistical5	
JET_EffectiveNP_Statistical6	
JET_SingleParticle_HighPt	
JET_RelativeNonClosure_AFII	
JET_BJES_Response	
JET_EtaIntercalibration_NonClosure_2018data	
JET_JER_DataVsMC_MC16	Jet energy resolution (FullJer)
JET_JER_DataVsMC_AFI	
I JET_JER_EffectiveNP_1	
JET_JER_EffectiveNP_2	
JET_JER_EffectiveNP_3	
JET_JER_EffectiveNP_4	
JET_JER_EffectiveNP_5	
JET_JER_EffectiveNP_6	
JET_JER_EffectiveNP_7	
JET_JER_EffectiveNP_8	
JET_JER_EffectiveNP_9	
JET_JER_EffectiveNP_10	
JET_JER_EffectiveNP_11	
JET_JER_EffectiveNP_12restTerm	
JET_JVT_EFF	Jet vertex tagging
JET_FJVT_EFF	Forward jet vertex tagging

Fit procedure

$\gamma\gamma + 1l0\tau_h$: $m_{\gamma\gamma}$ distribution in different BDTG regions:







$\gamma\gamma + 2L$: $m_{\gamma\gamma}$ distribution in only one BDTG regions: