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ATLAS NOTE

November 12, 2014

Search for Higgs pair production with decays to WW and $\gamma\gamma$ in $20.3\,\text{fb}^{-1}$ proton-proton data at 8 TeV

ATLAS Collaboration

Abstract

A search is performed for resonant and non-resonant Higgs pair production with the one Higgs boson decaying to WW and the other one to $\gamma\gamma$. The final state with one W boson decaying hadronically and the other to an electron or muon plus a neutrino is considered. The search is performed using a sample of proton-proton collision data at 8 TeV centre-of-mass energy recorded with the ATLAS detector in 2012. The sample corresponds to $\mathbf{20.3\,fb^{-1}}$. For the non-resonant Higgs pair production, the observed (expected) upper limit $gg \to hh$ is xxx pb (xxx pb). For resonant Higgs pair production, the observed (expected) upper limits range from xxx pb (xxx pb) to xxx pb (xxx pb) as a function of resonant mass assuming that the narrow-width approximation holds.

Contents

1 Introduction

A Higgs boson was discovered by the ATLAS and CMS collaborations [1, 2] in 2012 and has been subsequently studied by spin and coupling measurements, which have established that its properties are very similar to the ones of the SM Higgs boson. These measurements are based on Higgs production via gluon-fusion, vector-boson-fusion and in association with a W or Z boson. Higgs pair production has not been measured and, if its value is similar to the SM predicted value, it is impossible to measure with the current data. However, Higgs pair production can be significantly enhanced either by altering the Higgs boson self-coupling λ_{HHH} or in extended Higgs sectors such as 2-Higgs-Doublet Model (2HDM). This note provides supporting material for the search of Higgs pair production with the decay of $hh \to WW\gamma\gamma$, where one W boson decays hadronically while the other one leptonically, leading to the final state of $jjl\nu\gamma\gamma$.

The ATLAS collaboration released the results on the same search by using a different final state $hh \to bb\gamma\gamma$ [3]. With the same level of sensitivity, these two searches can be combined.

2 Data and simulations

2.1 Data samples

The data samples used in this analysis correspond to the full dataset recorded by the ATLAS detector at 8 TeV center-of-mass energy proton–proton collisions produced by the LHC up to the technical stop of December 2012. The recorded integrated luminosity is 20.3 fb^{-1}.

2.2 Simulations

2.2.1 Simulated samples for signal

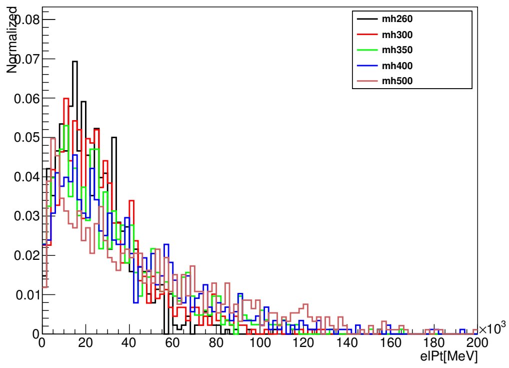
Signal samples are generated by MadGraph5+Pythia8, where MadGraph8 generates the hard scattering particles $gg \to H \to hh$ ($gg \to hh$) for resonant (non-resonant), and Pythia8 generates the decays of the light Higgs boson h and performs the event hadronization.

For non-resonant signal, the event generation is realized by a leading order SM Higgs pair model [4] in MadGraph5. This has been proved to better describe the kinematics than previous versions in internal note [5]. To require one of the SM Higgs bosons to decay into $\gamma\gamma$, ParentChildFilter is adopted.

For resonance signals, the event generation is realized by a leading order heavy resonant model [4] called HeavyScalar in MadGraph5. The heavy scalar, H, is assumed to have narrow width with respect to the experimental resolution. The decay width of the H boson in the simulation is set to 10 MeV, for the following masses: 260 GeV, 300 GeV, 350 GeV, 400 GeV and 500 GeV. The cards used in MadGraphs for signal event generations are attached in Appendix A. Subsequently, the H boson is required to decay into a pair of SM Higgs bosons, one of which decays into a pair of photons and the other one into anything except photons and b-quarks, since $bb\gamma\gamma$ analysis generated those samples already. The generator level filter `XtoVVDecayFilter` is used to realize the specific decay channels.

The kinematic distributions at parton level are shown for non-resonant and resonant Higgs pair production. In Figure **??**, the distributions of invariant mass from $jjl\nu\gamma\gamma$ are shown for H boson width of 10 MeV. mass distributions to-be-added In Figure 1, the transverse momentum distributions are shown for each object in the final state. For jets, the p_T distributions get harder from low mass H to high mass resonants once we have photon distributions, we could uncomment this discussion

maybe add MET, angles dPhi(l,MET) taking MET from neutrino pT



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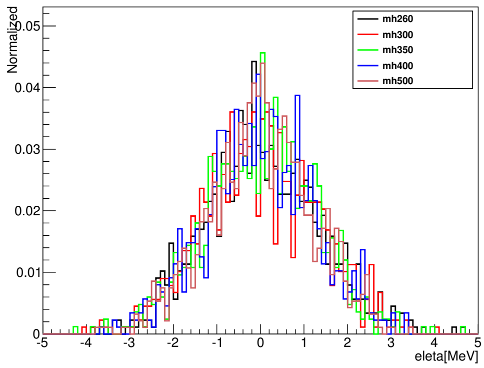

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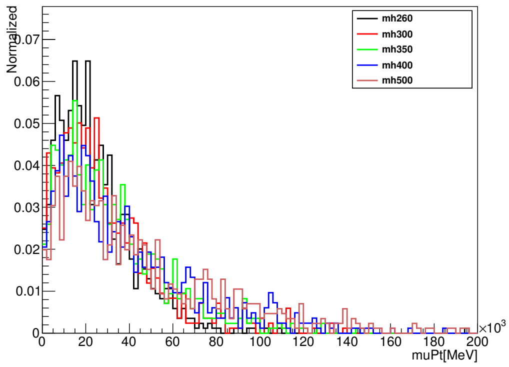

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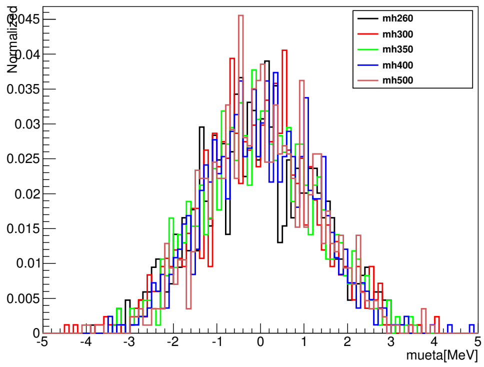

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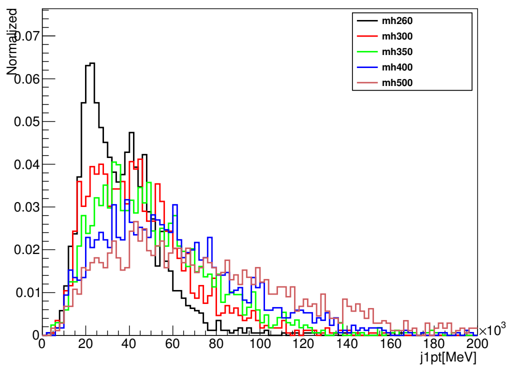

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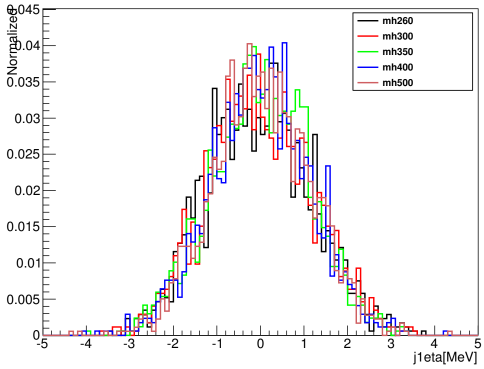

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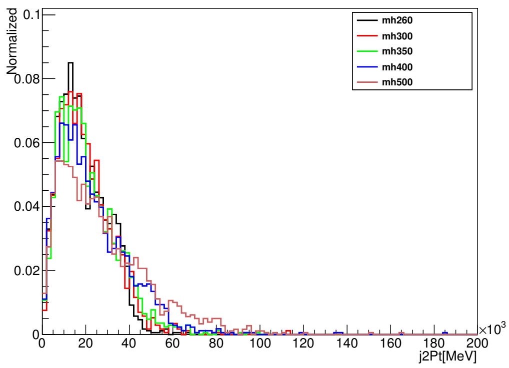

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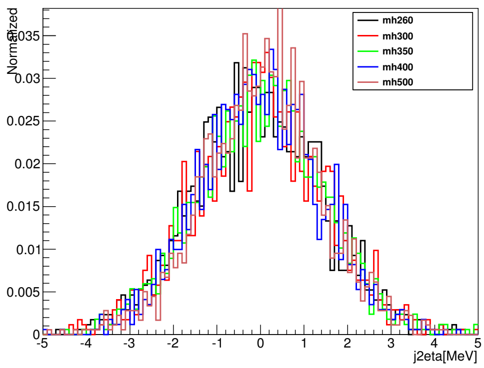


(h)

Figure 1: Kinematic distributions of the $jjl\nu\gamma\gamma$ final state for non-resonance and resonance at different mass points: (a) electron p_T, (b) electron η, (c) muon p_T, (d) muon η, (e) leading quark p_T, (f) leading quark η, (g) second leading quark p_T, and (h) second leading quark η.

2.2.2 Simulated sameples for SM Higgs background

The SM Higgs background considered here is taken from five production modes: ggh, VBF, Wh, Zh and tth. These samples are simulated using the full ATLAS simulation and reconstruction chain. The mass of the SM Higgs is set to 125 GeV. The samples are dumped into NTUP_PHOTON format with tag p1344. More details on generator, parton shower and simulation tags are listed in Table 1.

The cross sections under $\sqrt{s} = 8$ TeV correponding to each production mode are listed in Table 2. In the analysis, these cross sections will be multiplied by the $h \to \gamma\gamma$ branching ratio of 0.00228, since all simulated samples are produced with SM Higgs decaying into photon pairs.

DSID	sample	generator+parton shower	tags
160009	ggh	Powheg+Pythia8	$e1189\_s1771\_s1741\_r4829\_r4540\_p1344$
160019	vbf	Powheg+Pythia8	$e1195\_s1771\_s1741\_r4829\_r4540\_p1344$
160039	Wh	Pythia8	$e1189\_s1771\_s1741\_r4829\_r4540\_p1344$
160054	Zh	Pythia8	$e1189\_s1771\_s1741\_r4829\_r4540\_p1344$
181702	tth	Powheg+Pythia8	$e2412\_s1831\_s1741\_r4829\_r4540\_p1344$

Table 1: SM Higgs background full simulation samples

production	cross sections (pb)
ggh	19.27
VBF	1.578
Wh	0.7046
Zh	0.4153
tth	0.1293

Table 2: Cross sections for SM Higgs processes under $\sqrt{s} = 8$ GeV with $m_h = 125$ GeV

3 Object definition

HSG1 2012 8 TeV object definitions and selections [6] are applied in this analysis.

3.1 Photons

Photons are reconstructed based on the clusters of energy deposits in electromagnetic calorimeter. Clusters without any matching tracks or conversion vertices extrapolated from inner detector to the second layer of the calorimeter are considered as unconverted photons. The average reconstruction efficiency is 96.5%. The photon identification is realized in two steps: loose and tight. Loose requirements utilizes the information from the second layer of the electromagnetic calorimeter and from the energy deposits in hadronic calorimeter. Tight photon identification (PID) additionally introduces the information from the strip layer of the electromagnetic calorimeter. In average, 85% efficiency is reached by PID. The isolation requirements can further purify photons. The calorimetric isolation requires that the sum of transverse energy from electromagnetic clusters and hadroinc calorimeter within a cone of $\Delta R = 0.4$ around the photon candidate should be less than 6 GeV. Additionally a track-based isolation is asked to maintain good rejection rates by requiring the transverse momentum of the well-defined tracks [1] within $\Delta R = 0.2$ around the photon candidate to be less that 2.6 GeV. The corresponding efficiencies due to photon identification and isolation on signal are shown in the events selection part in Table 4.

3.2 Jets

Jets are defined as groups of topologically-related energy deposits in the calorimeters which are used in anti-k_t jet-finding algorithm [7] to group and merge topoclusters into jets and finally reconstruct the jets to be used in analyses. The distance parameter $R = 0.4$ is adopted in anti-k_t algorithm. In general, the transverse momentum is asked to be larger than 25 GeV for $|\eta_{det}| < 2.4$ and 30 GeV for $|\eta_{det}| > 2.4$ within the η_{det} range of 4.5. To suppress pileup jets from additional interactions, the jet vertex fraction is required to be higher than 0.5 within $p_T < 50$ GeV and $|\eta| < 2.4$, which is defined as the sum of track p_T of the tracks produced in the primary, diphoton vertex, over the sum of track p_T from all primary vertices. To avoid doubling counting to photons that leave enery clusters in calorimeters, the jets around photons within $\Delta R < 0.4$ are removed. Similarly, against electrons, jets close to electrons within $\Delta R < 0.2$ are removed. Table 3 show the selection efficiencies for jets.

!!! need to change to lephad table !!!

	SM	Resonant				
	Higgs pair	260 GeV	300 GeV	350 GeV	400 GeV	500 GeV
Total	100%	100%	100%	100%	100%	100%
Jet p_T	58.06%	52.73%	54.09%	55.50%	56.22%	57.72%
Jet η	58.05%	52.71%	54.08%	55.49%	56.20%	57.71%
Jet vertex fraction	56.69%	50.87%	52.34%	53.85%	54.65%	56.33%
Jet revmoval (electron)	36.48%	24.52%	26.66%	28.27%	30.09%	32.26%

Table 3: Efficiencies for jet selections at object level.

3.3 Electrons

Electron candidates consist of clusters of energy deposited in the electromagnetic calorimeter that are associated with ID tracks. All tracks associated with electromagnetic clusters are re-fitted using a Gaussian Sum Filter, which accounts for bremsstrahlung energy losses. The clusters are required to satisfy a set of identification criteria that require the longitudinal and transverse shower profiles to be consistent with those expected for electromagnetic showers. The electron transverse momentum is computed from the cluster energy and the track direction at the interaction point. Electron candidates are required to pass $|\eta| < 2.47$ and $E_T > 15$ GeV, after correcting for the electronon E_T using similar energy correction factors as for photons. E_T is computed using the cluster energy and the track direction. Electrons candidates are required to pass the *mediumPP* identification.

The electron candidates must pass both a track and a calorimetric isolation. The calorimetric transverse isolation energy of the electron in a $\Delta R = 0.4$ cone, divided by the corrected electron candidate's E_T, is required to be below 0.2, whereas the sum of the tracks' transverse impulsion in a cone of $\Delta R = 0.2$ around the electron candidate's track, divided by its corrected E_T, has to be below 0.15.

cut flow on electron obj

[1] Well-defined tracks need to have transverse momentum larger than 1 GeV, a transverse impact parameter (d_0) less than 1.5 mm as well as a longitudinal impact parameter (z_0) less than 15 mm.

3.4 Muons

Muons are required to pass $\eta < 2.7$ and $p_T > 10$ GeV. The MC-simulated energy for muons is smeared to match the resolution observed in data. The muon vertex is required to have a transverse impact parameter $|d_0| < 1$ mm and a longitudinal impact parameter $|z_0| < 10$ mm. Combined muons are those for which the tracks reconstruction is performed independently in the tracker and the muon spectrometer and a track is formed from the successful combination of the two tracks. A muon is segment-tagged if a track in the inner tracker is extrapolated to the muon spectrometer and is associated with straight track segments in the precision muon chambers. In this analysis, both combined and segment-tagged muons are considered. Pixel, SCT and TRT hits are required. Muon candidates are required to have a calorimetric isolation energy in a cone of $\Delta R = 0.4$, divided by the muon candidates' p_T, less than 0.2 and a sum of the tracks' transverse impulsion in a cone of $\Delta R = 0.2$, divided by the muon candidates' p_T, less than 0.15.

3.5 Missing transverse energy

Missing transverse energy is calculated as the complement to the visible transverse energy in an event, assuming conservation of momentum, consistent with the previous definition used in the $H \to \gamma\gamma$ analysis so far. The variable used is $MET\_PhotonTight\_Calib\_OR\_stdvert\_RefFinal\_et$, which was adapted from the standard refFinal for the analysis by giving the photons precedence over electrons for object calibration, selecting them according to the 2012 tight photon menu (same used in the analysis), and by calibrating these objects to the best photon calibration.

3.6 Overlap removal

An overlap removal procedure is applied, in the following order:

- The two leading photons are always kept
- Electrons with $\Delta R(e, u) < 0.4$ are removed
- Jets such as $\Delta R(jet, e) < 0.2$ or $\Delta R(jet, mu) < 0.4$ are removed
- Muons with $\Delta R(u, jet) < 0.4$ or $\Delta R(u, y) < 0.4$ are removed

4 Event selection

The basic idea to select candidate events starts from finding two photons and then applies requrements on jet-lepton side in order to collect as many as possible signal events other than background events with $jjl\nu\gamma\gamma$ signature. The event selection follows the $h \to \gamma\gamma$ Moriond analysis [6], with some additional requirements on jet multiplicity. The cuts follow:

- **trigger**: diphoton trigger `EF_g35_loose_g25loose` is used to trigger events collected by the detector.
- **preselection**: events are removed once the corresponding region in LAr or Tile has error. Events are also required to have at least one reconstructed primary vertex and at least two loose photon.
- **photon** p_T: the leading (second) photon is required to have $p_T > 40$ GeV ($p_T > 30$ GeV).
- **photon ID**: the primary vertex is calibrated with neural network algorithm and all photon's four-momentum are corrected according to this calibration. In the same time, photon quality flag isEM is required with tight quality for the two photon candidates.

- **photon isolation**: both photon candidates are required to pass a calorimeter-based isolation cut of < 6 GeV as well as a track-isolation cut of < 2.6 GeV is applied.
- **jet multiplicity**: at least two jets in the final states are required.
- **lepton**: at least one muon or electron.
- **B-veto**: reject event if it has a jet with $MV1 > 0.81$.
- **Missing ET**: require $MET > 10$ GeV.

why $MET > 10GeV$?

The event selection efficiencies after each step are listed in Table 4. These efficiencies are derived from simulated signal samples. After the selection on the photon side, the signal efficiencies are approximately 30% – 40%, while after the additional selection on jets, leptons and missing transverse energy, the signal efficiencies range from 5% to 9%.

	SM	Resonant				
	Higgs pair	260 GeV	300 GeV	350 GeV	400 GeV	500 GeV
Generated	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Trigger	72.2%	71.8%	71.3%	71.2%	71.7%	73.7%
Preseletion	57.1%	56.0%	55.8%	55.9%	56.5%	58.3%
Photon p_T	52.3%	52.2%	50.4%	49.8%	51.2%	54.0%
Photon identification	45.3%	44.6%	42.9%	42.7%	44.4%	47.1%
Isolation	39.0%	31.3%	33.2%	35.6%	38.4%	41.4%
$105 < m_{\gamma\gamma} < 160$ GeV	39.0%	31.2%	33.1%	35.6%	38.3%	41.3%
$120 < m_{\gamma\gamma} < 130$ GeV	38.3%	33.0%	34.0%	35.9%	37.7%	40.3%
At least two jets	28.8%	18.0%	20.8%	24.6%	27.5%	31.9%
At least 1 lepton	9.7%	6.2%	7.4%	8.7%	9.7%	10.9%
B veto	8.6%	5.6%	6.7%	7.8%	8.7%	9.5%
MET > 10 GeV	8.3%	5.3%	6.3%	7.4%	8.3%	9.2%

Table 4: Efficiencies for event selection

	ggH	VBF	WH	ZH	ttH
$105 < m_{\gamma\gamma} < 160$ GeV	NG	NG	34.1%	34.7%	31.5%

Table 5: Efficiencies for event selection

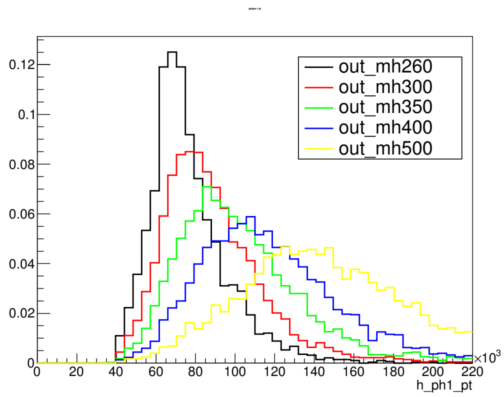
5 Search for resonant Higgs boson pair production

5.1 Signal shapes in lephad channel

The strategy is simply doing a cut-and-count experiment to search for the signal with the cuts all described in the previous section. Kinematic distributions are shown in Figure 2.

add lepton, eta for all add jetN leptonN before cutting on them (logY)

suggest to put acc curve for signal in the end of this subsection suggest to put signal yield assuming 1pb for xsec



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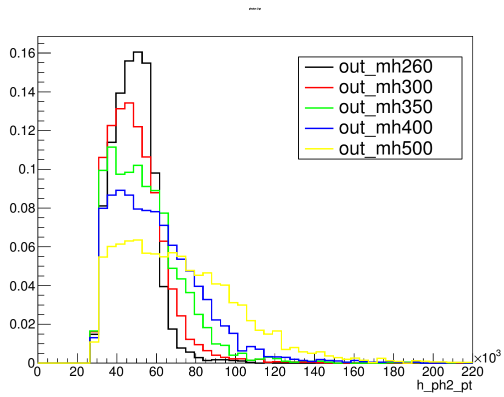

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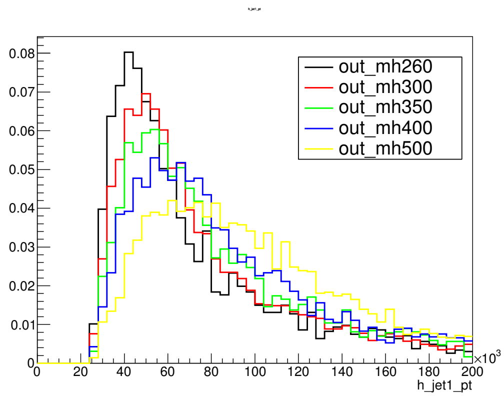

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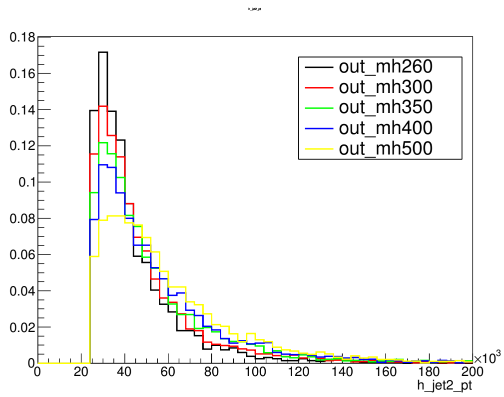

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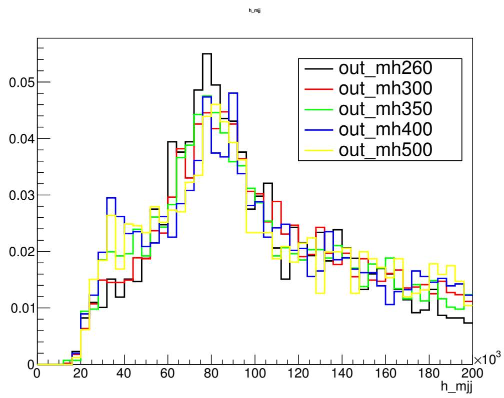

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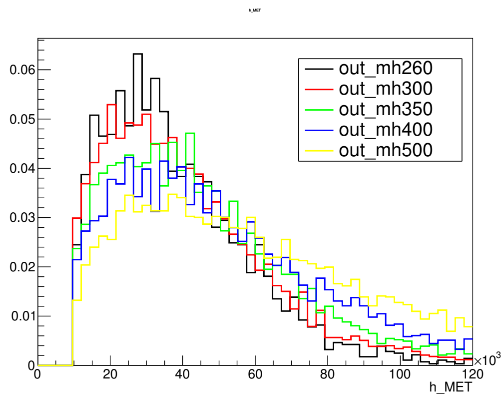


(f)

Figure 2: Kinematic distributions of the $jjl\nu\gamma\gamma$ final state for resonance at different mass points: (a) leading photon p_T, (b) second leading photon p_T, (c) leading jet p_T, (d) second leading jet p_T, (e) invariant mass of jets, and (f) missing transverse energy.

5.2 Background shape in lephad channel

not understand why this sentence is here The cut efficiency increases for large H mass. This is due to the higher p_T of the Higgs boson decay products for higher Higgs bosons masses. Backgrounds with similar final states are mainly composed of SM Higgs boson production and continuous backgrounds. SM Higgs production is estimated from HSG1 MC samples in Table 6.

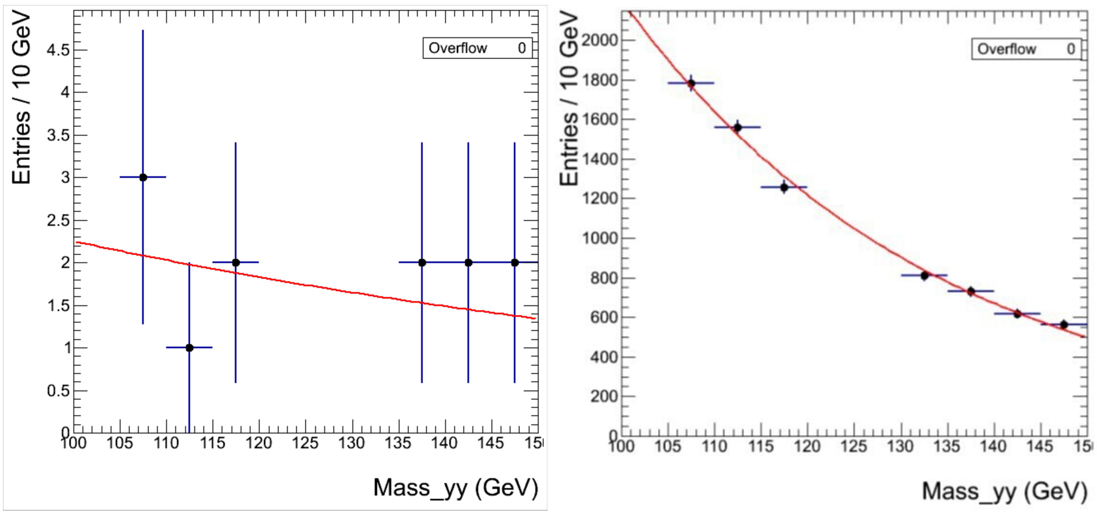
Channel	TTH	WH	ZH	VBF	ggF
Events	0.14	0.24	0.005	negligible	negligible

Table 6: Event yield for SM Higgs productions

The continuous background is estimated from mass sideband in data, which uses the data after object selection and then exclude events with $m_{\gamma\gamma}$ from $|m_h - \Delta m_h - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$, where m_h stands for the true value of Higgs mass, Δm_h = 150 MeV introduces the shift of the mean value when the crystal ball function was fit to data in HSG1, and $\sigma_{\gamma\gamma}$ = 1.6 GeV is the mass resolution.

Due to the low statistics, it is difficult to make a fit in data sideband after the requirement on lepton multiplicity. To solve this problem, inclusive electron samples without any requirements on lepton multiplicity are used for the estimation of the continuous background. The ratio of $N_{in\,mass\,window}/N_{NOT\,in\,mass\,window}$ is calculated in invlusive lepton samples and is extrapolated in our sideband regoin.

please update these plot with eps

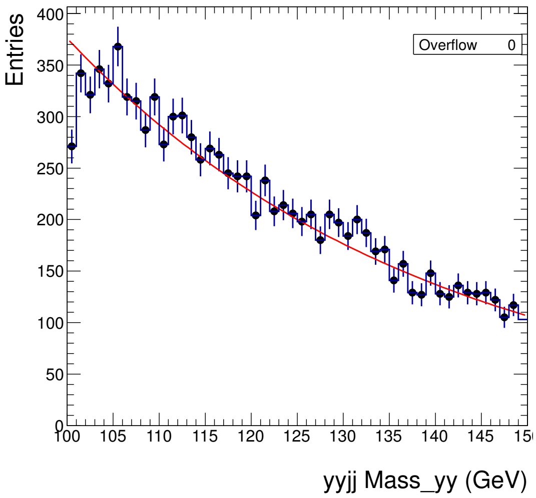


(a) (b)

This method is validated with SM $l\nu\gamma\gamma$ and $jj\gamma\gamma$ MC samples as shown in figure 3. The idea is to prove that the ratio $N_{in\,mass\,window}/N_{NOT\,in\,mass\,window}$ is constantly independent of the existence of an electron or not in the event. This validation procedure gives a difference of 1-2%. this difference is on what? could you give the numeric table derived from different MC samples?

6 Search for non-resonant Higgs boson pair production

For the non-resonant Higgs boson pair production search, the object definitions and event selections are the same as described in Section 4. Assuming the cross section at 1 pb, one can get xxx events for



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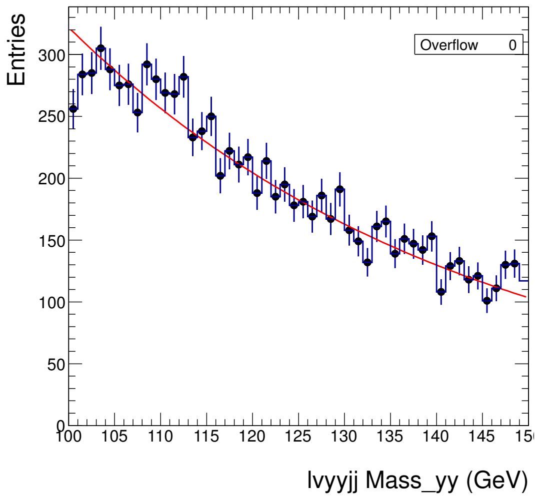

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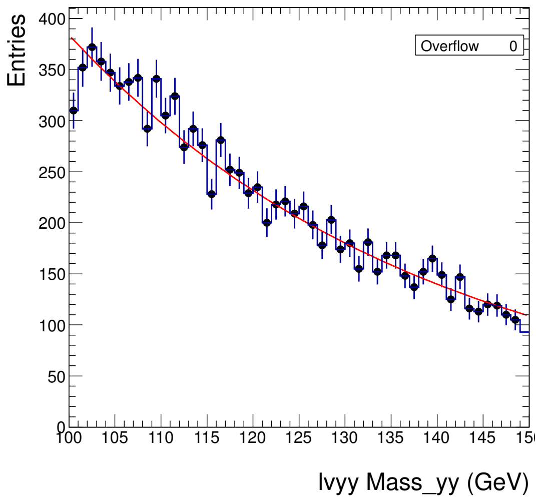


(e)

Figure 3: The invariant mass distributions in SM $l\nu\gamma\gamma$ and $jj\gamma\gamma$ MC samples.

non-resonance production. Due to the exactly same cuts used for resonance and non-resonance search, the background estimation is totally share in between, as described in Section 5.2.

please add photon eta, MET, jet eta, and second leading jet jetN leptonN,be consistent with resonance

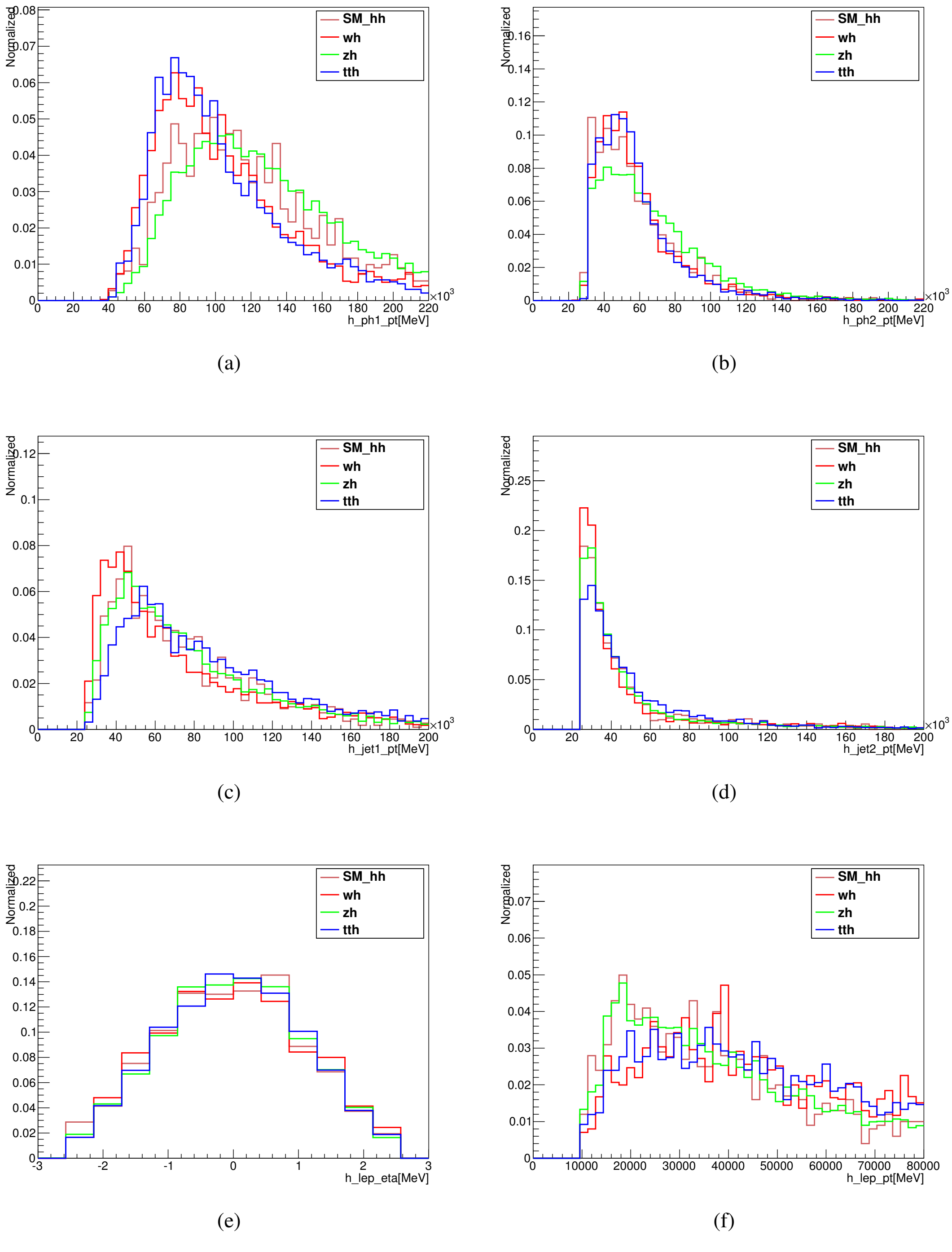


Figure 4: Kinematic distributions of the $jjl\nu\gamma\gamma$ final state for non-resonance: (a) leading photon p_T, (b) second leading photon p_T, (c) leading jet p_T, (d) second leading jet p_T, (e) lepton η, (f) lepton p_T.

7 Systematic uncertainties

7.1 Hadhad channel

7.1.1 Uncertainties on $m_{\gamma\gamma}$ cut

For the continuous background the uncertainty on the efficiency $\epsilon^{B}_{\gamma\gamma}$ is derived from the differnces among validation samples **??** and **??**. and correspondingly a relative uncertainty of 1% on $\frac{\epsilon^{B}_{\gamma\gamma}}{1-\epsilon^{B}_{\gamma\gamma}}$.

Additionally, efficiencies are extracted with 2nd order exponential e^{ax+bx^2} in order to check the uncertainties due to the choice of the fitting model, as shown in Figure 5, 6(a), and 6(b). The results are the same as the ones obtained with the linear model.

Figure 5: The efficiency $\epsilon^{B}_{\gamma\gamma}$ with 2nd order exponential e^{ax+bx^2} for continuous background extracted with 4-jet inclusive events.

For H boson signal, the uncertainties are estimated by varying up and down one sigma the mass resolution of two photons as implemented in `EnergyRescalerUpgrade` in `egammaAnalysisUtils`. The efficiencies after these variations are shown in Table 7 for each mass point. The relative differences are taken as uncertainties. These range from 3% to 6% as a function of the Higgs boson mass.

7.1.2 Uncertainties related to jets, leptons and missing transverse energy

Since jets are required in the analysis, uncertainties on jet energy scale (JES), jet energy resolution (JER), jet vertex fraction (JVF) and pileup effects are considered. More detailed information on these uncertainties are shown in Appendix B. Summarized tables are shown in Table 8 for signal, and 9 for SM Higgs production.

The systematic uncertainties for the standard model Higgs samples are listed here. There are no numbers on ggF and vbf processes as the events yields for these are negligible.

(a)

(b)

Figure 6: The efficiencies $\epsilon^{B}_{\gamma\gamma}$ with 2nd order exponential e^{ax+bx^2} for continuous background extracted with (a) 2-jet exclusive events, (b) 3-jet exclusive events.

	$\epsilon_{\gamma\gamma}$ for various Higgs boson mass assumptions			
	nominal	variation up	variation down	relative differences
260 GeV	83.9%	80.0%	86.9%	-4.6/+3.6%
300 GeV	84.2%	79.9%	87.6%	-5.1/+4.0%
350 GeV	85.3%	80.9%	88.9%	-5.2/+4.2%
400 GeV	86.8%	82.1%	90.6%	-5.4/+4.4%
500 GeV	87.8%	82.6%	91.8%	-5.9/+4.6%

Table 7: Efficiencies and uncertainties due to mass resolution variations for $m_{\gamma\gamma}$ window on signal.

	260 GeV	300 GeV	350 GeV	400 GeV	500 GeV	Higgs pair
JES	0.2373	0.1183	0.0503	0.0346	0.0311	0.0350
JER	0.0106	0.0028	0.0050	0.0007	0.0022	0.0052
JVF	0.0027	0.0015	0.0008	0.0002	0.0044	0.0018
Pileup	0.0030	0.0010	0.0010	0.0000	0.0016	0.0007
MET	0.0014	0.0017	0.0017	0.0050	0.0016	0.0033
LEP	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050

Table 8: Rate uncertainties for signals

8 Statistical interpretation

A likelihood ratio based test statistic is used that is defined as follows:

	WH	ZH	ttH
JES	0.1028	0.0902	0.0105
JER	0.0069	0.0070	0.0034
JVF	0.0116	0.0267	0.0034
Pileup	0.0053	0.0089	0.0001
MET	0.0027	0.0109	0.0026
LEP	0.0050	0.0050	0.0050

Table 9: Rate uncertainties for SM Higgs components

	260 GeV	300 GeV	350 GeV	400 GeV	500 GeV
+2σ					
+1σ					
-1σ					
-2σ					
Expected					
Observed					

Table 10: Combined exclusion limits at the 95% CL for the production cross section of a gluon fusion produced H boson times its branching ratio to hh.

$$\tilde{q}_\mu = \begin{cases} -2\ln\frac{\mathcal{L}(\mu,\hat{\hat{\theta}}(\mu))}{\mathcal{L}(0,\hat{\hat{\theta}}(0))} & \text{if } \hat{\mu} < 0 \\ -2\ln\frac{\mathcal{L}(\mu,\hat{\hat{\theta}}(\mu))}{\mathcal{L}(\hat{\mu},\hat{\theta})} & \text{if } 0 \le \hat{\mu} \le \mu \\ 0 & \text{if } \hat{\mu} > \mu \end{cases}$$

where single hat stands for unconditional fit and double hat for conditional fit (i.e., μ is fixed to a certain value). With this test statistic, one can derive the upper limits of the cross section production times the branching ratio for each scanned mass point by using the CL$_s$ method [8] under the asymptotic approximation [9].

8.1 Resonant searches

A 95% CL upper limit on the cross section times branching ratio of $H \to hh$ as a function of m_H is extracted from only hadhad channel as shown in Figure **??**, and is also extracted from only the lep-had channel as shown in Figure 7. The upper limits extracted from the combined results are shown in Figure **??**. As shown in the combined limits, lephad channel dominates the sensitivity.

!!! maybe limits setting on xsecXbrs,since only one channel exists !!!

!!! pull distributions are neede !!!

Checks on pull of nuisance parameters are shown in Figure **??**, **??**, **??**,**??** and **??** for lephad chanel,

Using the 95% CL upper limits, one can make exclusions in 2HDM phase space if considering the heavy resonance that we look for as the CP-even heavy Higgs, as shown in Figure 8 for type I, II, III and IV.

please fill numeric value of limits in this table

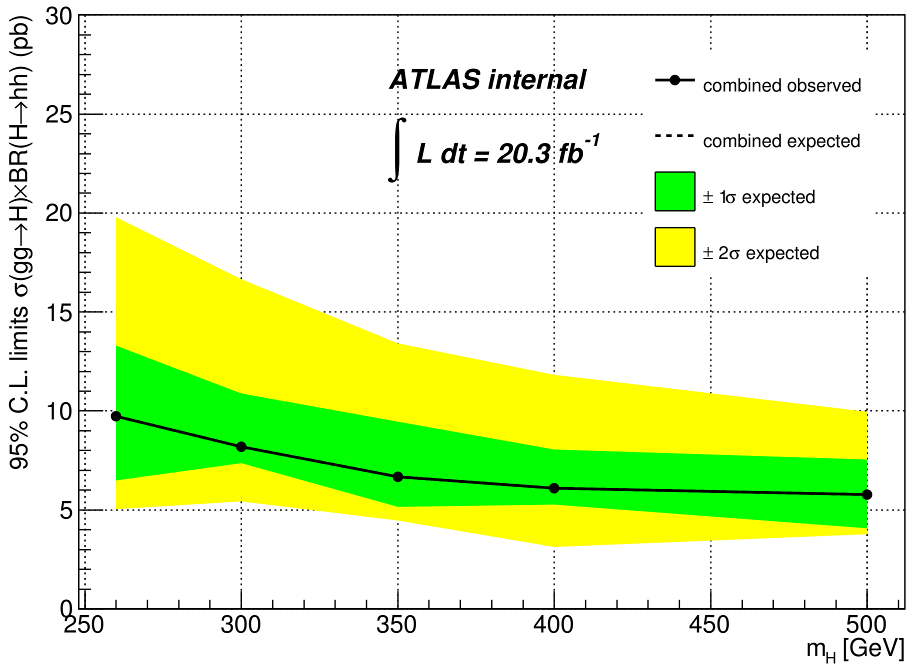


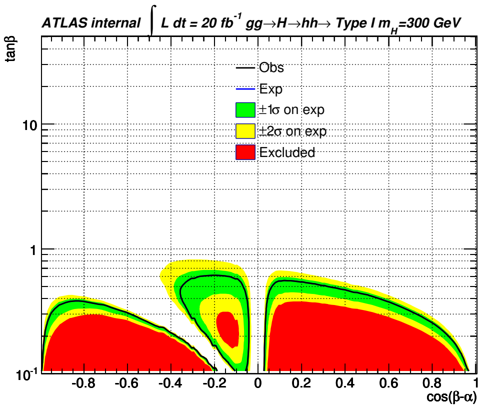
Figure 7: 95% CL upper limit on the cross section times branching ratio of $H \to hh$ as a function of m_H. These limits are extracted from only lephad channel. Observed limits are equal to expected limits before unblinding.

8.2 Non-resonant searches

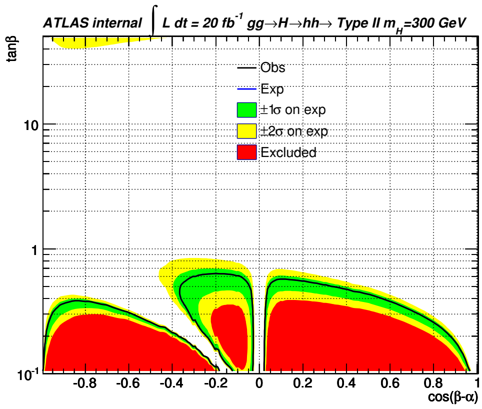
95% CL upper limits on the cross section times branching ratio of $H \to hh$ are extracted from individual and combined channels. From hadhad channel alone the expected 95% CL upper limit is, from lephad channel alone, and from combined channels.

9 Results

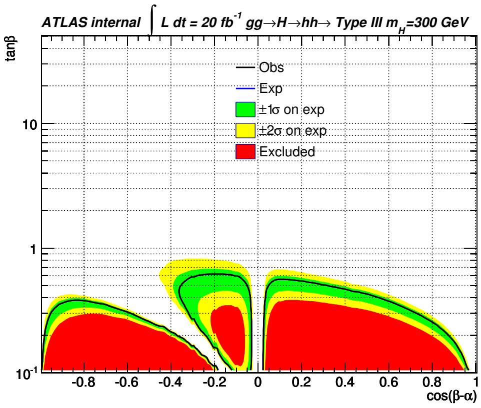
In this note, a search is performed for resonant and non-resonant Higgs pair production with the one Higgs boson decaying to WW and the other one to $\gamma\gamma$. For the non-resonant Higgs pair production, the observed (expected) upper limit $gg \to hh$ is xxx pb ($xxxx$ pb). For resonant Higgs pair production, the observed (expected) upper limits range from xxx pb ($xxxx$ pb) to xxx pb ($xxxx$ pb) as a function of resonant mass with the assumption of the narrow-width approximation. The results are interpreted in 2HDM phase space.



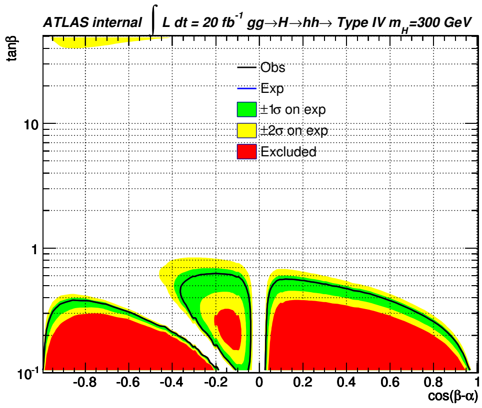
(a)



(b)



(c)



(d)

Figure 8: 2HDM interpretation plots: (a) for type I, (b) for type II, (c) for type III, (d) for type IV.

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Appendices

A MadGraphs5 cards used for signals

Here, the cards used for generating heavy scalar resonant at the mass point of 300 GeV are given. The cards for other mass points are basically the same except the mass setting.

```
#************************************************************
#*                        MadGraph 5                        *
#*                                                          *
#*                *                       *                 *
#*                  *        * *        *                   *
#*                    * * * * 5 * * * *                     *
#*                  *        * *        *                   *
#*                *                       *                 *
#*                                                          *
#*                                                          *
#*         VERSION 1.5.12                2013-08-21         *
#*                                                          *
#*    The MadGraph Development Team - Please visit us at    *
#*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
#*                                                          *
#************************************************************
#*                                                          *
#*               Command File for MadGraph 5                *
#*                                                          *
#*     run as ./bin/mg5  filename                           *
#*                                                          *
#************************************************************

set group_subprocesses Auto
set ignore_six_quark_processes False
set gauge unitary
set complex_mass_scheme False
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~
define l+ = e+ mu+
define l- = e- mu-
define vl = ve vm vt
define vl~ = ve~ vm~ vt~
import model HeavyHiggsTHDM
generate p p > h h
output HeavyScalar

######################################################################
## PARAM_CARD AUTOMATICALY GENERATED BY MG5 FOLLOWING UFO MODEL   ####
######################################################################
```

```
##                                                                    ##
##  Width set on Auto will be computed following the information    ##
##        present in the decay.py files of the model. By default,   ##
##        this is only 1->2 decay modes.                            ##
##                                                                    ##
######################################################################

###################################
## INFORMATION FOR BSM
###################################
Block bsm
  188 0.000000e+00 # ctr
  189 0.000000e+00 # cy
  190 1.000000e+00 # ctrH
  191 1.000000e+00 # cyH
  1560 300 # MHH
  1561 1.000000e-02 # WHH

###################################
## INFORMATION FOR MASS
###################################
Block mass
    5 4.700000e+00 # MB
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
## Dependent parameters, given by model restrictions.
## Those values should be edited following the
## analytical expression. MG5 ignores those values
## but they are important for interfacing the output of MG5
## to external program such as Pythia.
  1 0.000000 # d : 0.0
  2 0.000000 # u : 0.0
  3 0.000000 # s : 0.0
  4 0.000000 # c : 0.0
  11 0.000000 # e- : 0.0
  12 0.000000 # ve : 0.0
  13 0.000000 # mu- : 0.0
  14 0.000000 # vm : 0.0
  16 0.000000 # vt : 0.0
  21 0.000000 # g : 0.0
  22 0.000000 # a : 0.0
  24 79.824360 # w+ : cmath.sqrt(MZ__exp__2/2. + cmath.sqrt(MZ__exp__4/4. - (aEW*cmath.pi*MZ

###################################
## INFORMATION FOR SMINPUTS
###################################
```

```
Block sminputs
    1 1.279000e+02 # aEWM1
    2 1.166370e-05 # Gf
    3 1.184000e-01 # aS

###################################
## INFORMATION FOR YUKAWA
###################################
Block yukawa
    5 4.700000e+00 # ymb
    6 1.720000e+02 # ymt
   15 1.777000e+00 # ymtau

###################################
## INFORMATION FOR DECAY
###################################
DECAY   6 1.508336e+00 # WT
DECAY  23 2.495200e+00 # WZ
DECAY  24 2.085000e+00 # WW
DECAY  25 5.753088e-03 # WH
## Dependent parameters, given by model restrictions.
## Those values should be edited following the
## analytical expression. MG5 ignores those values
## but they are important for interfacing the output of MG5
## to external program such as Pythia.
DECAY  1 0.000000 # d : 0.0
DECAY  2 0.000000 # u : 0.0
DECAY  3 0.000000 # s : 0.0
DECAY  4 0.000000 # c : 0.0
DECAY  5 0.000000 # b : 0.0
DECAY  11 0.000000 # e- : 0.0
DECAY  12 0.000000 # ve : 0.0
DECAY  13 0.000000 # mu- : 0.0
DECAY  14 0.000000 # vm : 0.0
DECAY  15 0.000000 # ta- : 0.0
DECAY  16 0.000000 # vt : 0.0
DECAY  21 0.000000 # g : 0.0
DECAY  22 0.000000 # a : 0.0
#===========================================================
# QUANTUM NUMBERS OF NEW STATE(S) (NON SM PDG CODE)
#===========================================================

Block QNUMBERS 1560  # hh
        1 0  # 3 times electric charge
        2 1  # number of spin states (2S+1)
        3 1  # colour rep (1: singlet, 3: triplet, 8: octet)
        4 0  # Particle/Antiparticle distinction (0=own anti)
```

```

#*********************************************************************
#                       MadGraph/MadEvent                             *
#                  http://madgraph.hep.uiuc.edu                       *
#                                                                     *
#                        run_card.dat                                 *
#                                                                     *
#  This file is used to set the parameters of the run.                *
#                                                                     *
#  Some notation/conventions:                                         *
#                                                                     *
#   Lines starting with a '# ' are info or comments                   *
#                                                                     *
#   mind the format:   value    = variable     ! comment              *
#*********************************************************************
#
#*******************
# Running parameters
#*******************
#
#*********************************************************************
# Tag name for the run (one word)                                     *
#*********************************************************************
  tag_1     = run_tag ! name of the run
#*********************************************************************
# Run to generate the grid pack                                       *
#*********************************************************************
  .false.     = gridpack  !True = setting up the grid pack
#*********************************************************************
# Number of events and rnd seed                                       *
# Warning: Do not generate more than 1M events in a single run        *
# If you want to run Pythia, avoid more than 50k events in a run.     *
#*********************************************************************
  12000 = nevents ! Number of unweighted events requested
      0 = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                            *
# lpp: 0=No PDF, 1=proton, -1=antiproton, 2=photon from proton,       *
#                                         3=photon from electron      *
#*********************************************************************
        1     = lpp1    ! beam 1 type
        1     = lpp2    ! beam 2 type
     4000     = ebeam1  ! beam 1 total energy in GeV
     4000     = ebeam2  ! beam 2 total energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-handed)     *
#*********************************************************************
        0     = polbeam1 ! beam polarization for beam 1
```

```
        0     = polbeam2 ! beam polarization for beam 2
#*********************************************************************
# PDF CHOICE: this automatically fixes also alpha_s and its evol.    *
#*********************************************************************
 'cteq6l1'    = pdlabel     ! PDF set
#*********************************************************************
# Renormalization and factorization scales                           *
#*********************************************************************
 F        = fixed_ren_scale  ! if .true. use fixed ren scale
 F        = fixed_fac_scale  ! if .true. use fixed fac scale
 91.1880  = scale            ! fixed ren scale
 91.1880  = dsqrt_q2fact1    ! fixed fact scale for pdf1
 91.1880  = dsqrt_q2fact2    ! fixed fact scale for pdf2
 1        = scalefact        ! scale factor for event-by-event scales
#*********************************************************************
# Matching - Warning! ickkw > 1 is still beta
#*********************************************************************
 0        = ickkw            ! 0 no matching, 1 MLM, 2 CKKW matching
 1        = highestmult      ! for ickkw=2, highest mult group
 1        = ktscheme         ! for ickkw=1, 1 Durham kT, 2 Pythia pTE
 1        = alpsfact         ! scale factor for QCD emission vx
 F        = chcluster        ! cluster only according to channel diag
 T        = pdfwgt           ! for ickkw=1, perform pdf reweighting
 5        = asrwgtflavor     ! highest quark flavor for a_s reweight
#*********************************************************************
# Automatic ptj and mjj cuts if xqcut > 0
# (turn off for VBF and single top processes)
#**********************************************************
   T  = auto_ptj_mjj  ! Automatic setting of ptj and mjj
#**********************************************************
#
#**********************************
# BW cutoff (M+/-bwcutoff*Gamma)
#**********************************
  15  = bwcutoff      ! (M+/-bwcutoff*Gamma)
#**********************************************************
# Apply pt/E/eta/dr/mij cuts on decay products or not
# (note that etmiss/ptll/ptheavy/ht/sorted cuts always apply)
#**********************************************************
   T  = cut_decays    ! Cut decay products
#*************************************************************
# Number of helicities to sum per event (0 = all helicities)
# 0 gives more stable result, but longer run time (needed for
# long decay chains e.g.).
# Use >=2 if most helicities contribute, e.g. pure QCD.
#*************************************************************
   0  = nhel          ! Number of helicities used per event
#*******************
```

```
# Standard Cuts
#*******************
#
#*********************************************************************
# Minimum and maximum pt's (for max, -1 means no cut)                *
#*********************************************************************
  0  = ptj       ! minimum pt for the jets
  0  = ptb       ! minimum pt for the b
  0  = pta       ! minimum pt for the photons
  0  = ptl       ! minimum pt for the charged leptons
  0  = misset    ! minimum missing Et (sum of neutrino's momenta)
  0  = ptheavy   ! minimum pt for one heavy final state
  0  = ptonium   ! minimum pt for the quarkonium states
 -1  = ptjmax    ! maximum pt for the jets
 -1  = ptbmax    ! maximum pt for the b
 -1  = ptamax    ! maximum pt for the photons
 -1  = ptlmax    ! maximum pt for the charged leptons
 -1  = missetmax ! maximum missing Et (sum of neutrino's momenta)
#*********************************************************************
# Minimum and maximum E's (in the lab frame)                         *
#*********************************************************************
  0  = ej     ! minimum E for the jets
  0  = eb     ! minimum E for the b
  0  = ea     ! minimum E for the photons
  0  = el     ! minimum E for the charged leptons
 -1   = ejmax ! maximum E for the jets
 -1   = ebmax ! maximum E for the b
 -1   = eamax ! maximum E for the photons
 -1   = elmax ! maximum E for the charged leptons
#*********************************************************************
# Maximum and minimum absolute rapidity (for max, -1 means no cut)   *
#*********************************************************************
  -1  = etaj    ! max rap for the jets
  -1  = etab    ! max rap for the b
  -1  = etaa    ! max rap for the photons
  -1  = etal    ! max rap for the charged leptons
  -1  = etaonium ! max rap for the quarkonium states
   0  = etajmin ! min rap for the jets
   0  = etabmin ! min rap for the b
   0  = etaamin ! min rap for the photons
   0  = etalmin ! main rap for the charged leptons
#*********************************************************************
# Minimum and maximum DeltaR distance                                *
#*********************************************************************
 0   = drjj    ! min distance between jets
 0   = drbb    ! min distance between b's
 0   = drll    ! min distance between leptons
 0   = draa    ! min distance between gammas
```

```
 0   = drbj    ! min distance between b and jet
 0   = draj    ! min distance between gamma and jet
 0   = drjl    ! min distance between jet and lepton
 0   = drab    ! min distance between gamma and b
 0   = drbl    ! min distance between b and lepton
 0   = dral    ! min distance between gamma and lepton
 -1  = drjjmax ! max distance between jets
 -1  = drbbmax ! max distance between b's
 -1  = drllmax ! max distance between leptons
 -1  = draamax ! max distance between gammas
 -1  = drbjmax ! max distance between b and jet
 -1  = drajmax ! max distance between gamma and jet
 -1  = drjlmax ! max distance between jet and lepton
 -1  = drabmax ! max distance between gamma and b
 -1  = drblmax ! max distance between b and lepton
 -1  = dralmax ! maxdistance between gamma and lepton
#*********************************************************************
# Minimum and maximum invariant mass for pairs                      *
#*********************************************************************
 0   = mmjj    ! min invariant mass of a jet pair
 0   = mmbb    ! min invariant mass of a b pair
 0   = mmaa    ! min invariant mass of gamma gamma pair
 0   = mmll    ! min invariant mass of l+l- (same flavour) lepton pair
 -1  = mmjjmax ! max invariant mass of a jet pair
 -1  = mmbbmax ! max invariant mass of a b pair
 -1  = mmaamax ! max invariant mass of gamma gamma pair
 -1  = mmllmax ! max invariant mass of l+l- (same flavour) lepton pair
#*********************************************************************
# Minimum and maximum invariant mass for all letpons                *
#*********************************************************************
 0   = mmnl    ! min invariant mass for all letpons (l+- and vl)
 -1  = mmnlmax ! max invariant mass for all letpons (l+- and vl)
#*********************************************************************
# Minimum and maximum pt for 4-momenta sum of leptons               *
#*********************************************************************
 0   = ptllmin  ! Minimum pt for 4-momenta sum of leptons(l and vl)
 -1  = ptllmax  ! Maximum pt for 4-momenta sum of leptons(l and vl)
#*********************************************************************
# Inclusive cuts                                                    *
#*********************************************************************
 0  = xptj ! minimum pt for at least one jet
 0  = xptb ! minimum pt for at least one b
 0  = xpta ! minimum pt for at least one photon
 0  = xptl ! minimum pt for at least one charged lepton
#*********************************************************************
# Control the pt's of the jets sorted by pt                         *
#*********************************************************************
 0   = ptj1min ! minimum pt for the leading jet in pt
```

```
 0   = ptj2min ! minimum pt for the second jet in pt
 0   = ptj3min ! minimum pt for the third jet in pt
 0   = ptj4min ! minimum pt for the fourth jet in pt
 -1  = ptj1max ! maximum pt for the leading jet in pt
 -1  = ptj2max ! maximum pt for the second jet in pt
 -1  = ptj3max ! maximum pt for the third jet in pt
 -1  = ptj4max ! maximum pt for the fourth jet in pt
 0   = cutuse  ! reject event if fails any (0) / all (1) jet pt cuts
#*********************************************************************
# Control the pt's of leptons sorted by pt                           *
#*********************************************************************
 0   = ptl1min ! minimum pt for the leading lepton in pt
 0   = ptl2min ! minimum pt for the second lepton in pt
 0   = ptl3min ! minimum pt for the third lepton in pt
 0   = ptl4min ! minimum pt for the fourth lepton in pt
 -1  = ptl1max ! maximum pt for the leading lepton in pt
 -1  = ptl2max ! maximum pt for the second lepton in pt
 -1  = ptl3max ! maximum pt for the third lepton in pt
 -1  = ptl4max ! maximum pt for the fourth lepton in pt
#*********************************************************************
# Control the Ht(k)=Sum of k leading jets                            *
#*********************************************************************
 0   = htjmin ! minimum jet HT=Sum(jet pt)
 -1  = htjmax ! maximum jet HT=Sum(jet pt)
 0   = ihtmin  !inclusive Ht for all partons (including b)
 -1  = ihtmax  !inclusive Ht for all partons (including b)
 0   = ht2min ! minimum Ht for the two leading jets
 0   = ht3min ! minimum Ht for the three leading jets
 0   = ht4min ! minimum Ht for the four leading jets
 -1  = ht2max ! maximum Ht for the two leading jets
 -1  = ht3max ! maximum Ht for the three leading jets
 -1  = ht4max ! maximum Ht for the four leading jets
#*********************************************************************
# WBF cuts                                                           *
#*********************************************************************
 0   = xetamin ! minimum rapidity for two jets in the WBF case
 0   = deltaeta ! minimum rapidity for two jets in the WBF case
#*********************************************************************
# maximal pdg code for quark to be considered as a light jet         *
# (otherwise b cuts are applied)                                     *
#*********************************************************************
 4 = maxjetflavor    ! Maximum jet pdg code
#*********************************************************************
# Jet measure cuts                                                   *
#*********************************************************************
 0   = xqcut   ! minimum kt jet measure between partons
#*********************************************************************
```

B Systematic uncertainties in details

Please add captions

sys	up	dowm
JES_BJES	0%	-10.0364%
JES_FlavComp	4.39387%	-4.36226%
JES_FlavResp	2.29177%	-2.29177%
JES_MU	0.347716%	-0.158053%
JES_NPV	0.758653%	-0.458353%
JES_Nuisance_10	0.0790264%	-0.0790264%
JES_Nuisance_11	0.0158053%	-0.0316106%
JES_Nuisance_12	0.26869%	-0.158053%
JES_Nuisance_13	1.43828%	-1.24862%
JES_Nuisance_14	0.648016%	-0.56899%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.3003%	-0.142248%
JES_Nuisance_1	0.252884%	-0.142248%
JES_Nuisance_2	-0.252884%	0.347716%
JES_Nuisance_3	0.3003%	-0.189663%
JES_Nuisance_4	1.89663%	-1.83341%
JES_Nuisance_5	-0.316106%	0.395132%
JES_Nuisance_6	0.237079%	-0.158053%
JES_Nuisance_7	0.205469%	-0.142248%
JES_Nuisance_8	0.537379%	-0.489964%
JES_Nuisance_9	0.0316106%	-0.0474158%
JES_PileupPt	-0.126442%	0.173858%
JES_PileupTopo	2.21274%	-2.24435%
JVF	-0.142248%	0%
JER_Nom	0.205469 %	-0.205469 %
Pileuprand	-0.126442 %	0.126442 %

sys	up	dowm
JES_BJES	0%	0%
JES_FlavComp	4.76369%	-4.68867%
JES_FlavResp	2.4006%	-2.4006%
JES_MU	0.337584%	0.0375094%
JES_NPV	0.187547%	-0.337584%
JES_Nuisance_10	0.112528%	0%
JES_Nuisance_11	0%	0%
JES_Nuisance_12	0.187547%	-0.0375094%
JES_Nuisance_13	1.68792%	-1.42536%
JES_Nuisance_14	0.450113%	-0.375094%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.225056%	-0.187547%
JES_Nuisance_1	0.187547%	-0.0375094%
JES_Nuisance_2	-0.187547%	0.300075%
JES_Nuisance_3	0.300075%	-0.112528%
JES_Nuisance_4	1.95049%	-1.95049%
JES_Nuisance_5	-0.262566%	0.262566%
JES_Nuisance_6	0.187547%	-0.0375094%
JES_Nuisance_7	0.187547%	-0.0375094%
JES_Nuisance_8	0.375094%	-0.300075%
JES_Nuisance_9	0%	0%
JES_PileupPt	-0.112528%	0.262566%
JES_PileupTopo	2.4006%	-2.28807%
JVF	-0.225056%	0%
JER_Nom	-1.31283 %	1.31283 %
Pileuprand	-0.300075 %	0.300075 %

sys	up	dowm
JES_BJES	0%	-0.05%
JES_FlavComp	4.39387%	-4.36226%
JES_FlavResp	2.29177%	-2.29177%
JES_MU	0.347716%	-0.158053%
JES_NPV	0.758653%	-0.458353%
JES_Nuisance_10	0.0790264%	-0.0790264%
JES_Nuisance_11	0.0158053%	-0.0316106%
JES_Nuisance_12	0.26869%	-0.158053%
JES_Nuisance_13	1.43828%	-1.24862%
JES_Nuisance_14	0.648016%	-0.56899%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.3003%	-0.142248%
JES_Nuisance_1	0.252884%	-0.142248%
JES_Nuisance_2	-0.252884%	0.347716%
JES_Nuisance_3	0.3003%	-0.189663%
JES_Nuisance_4	1.89663%	-1.83341%
JES_Nuisance_5	-0.316106%	0.395132%
JES_Nuisance_6	0.237079%	-0.158053%
JES_Nuisance_7	0.205469%	-0.142248%
JES_Nuisance_8	0.537379%	-0.489964%
JES_Nuisance_9	0.0316106%	-0.0474158%
JES_PileupPt	-0.126442%	0.173858%
JES_PileupTopo	2.21274%	-2.24435%
JVF	-0.142248%	0%
JER_Nom	0.205469 %	-0.205469 %
Pileuprand	-0.126442 %	0.126442 %

sys	up	dowm
JES_BJES	-0.0269107%	0%
JES_FlavComp	3.09473%	-3.63294%
JES_FlavResp	1.61464%	-1.91066%
JES_MU	0.0538213%	-0.0538213%
JES_NPV	-0.107643%	-0.322928%
JES_Nuisance_10	0.0538213%	-0.080732%
JES_Nuisance_11	0.0269107%	-0.0269107%
JES_Nuisance_12	0.107643%	-0.134553%
JES_Nuisance_13	1.21098%	-1.07643%
JES_Nuisance_14	0.296017%	-0.484392%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.161464%	-0.349839%
JES_Nuisance_1	0.107643%	-0.080732%
JES_Nuisance_2	-0.296017%	0.161464%
JES_Nuisance_3	0.134553%	-0.215285%
JES_Nuisance_4	1.2648%	-1.61464%
JES_Nuisance_5	-0.296017%	0.242196%
JES_Nuisance_6	0.107643%	-0.080732%
JES_Nuisance_7	0.107643%	-0.080732%
JES_Nuisance_8	0.269107%	-0.376749%
JES_Nuisance_9	0.0538213%	-0.0269107%
JES_PileupPt	-0.0269107%	-0.134553%
JES_PileupTopo	1.56082%	-1.88375%
JVF	0.107643%	0%
JER_Nom	-0.538213 %	0.538213 %
Pileuprand	0.080732 %	-0.080732 %

sys	up	dowm
JES_BJES	0.0237869%	0%
JES_FlavComp	2.45005%	-2.64034%
JES_FlavResp	1.30828%	-1.28449%
JES_MU	0.214082%	-0.214082%
JES_NPV	0.333016%	-0.333016%
JES_Nuisance_10	0.0713606%	-0.0237869%
JES_Nuisance_11	0.0475737%	0%
JES_Nuisance_12	0.166508%	-0.0237869%
JES_Nuisance_13	0.737393%	-0.784967%
JES_Nuisance_14	0.428164%	-0.285442%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.0951475%	-0.214082%
JES_Nuisance_1	0.142721%	-0.0237869%
JES_Nuisance_2	-0.118934%	0.237869%
JES_Nuisance_3	0.214082%	-0.0951475%
JES_Nuisance_4	1.0942%	-0.999049%
JES_Nuisance_5	-0.142721%	0.261656%
JES_Nuisance_6	0.118934%	-0.0237869%
JES_Nuisance_7	0.118934%	-0.0237869%
JES_Nuisance_8	0.333016%	-0.190295%
JES_Nuisance_9	0.0475737%	-0.0237869%
JES_PileupPt	0.0475737%	0.0951475%
JES_PileupTopo	1.40343%	-1.07041%
JVF	-0.0237869%	0%
JER_Nom	-0.0951475 %	0.0951475 %
Pileuprand	-0.0237869 %	0.0237869 %

sys	up	dowm
JES_BJES	0%	0.0212495%
JES_FlavComp	2.1037%	-2.16745%
JES_FlavResp	1.12622%	-1.16872%
JES_MU	0.106247%	-0.361241%
JES_NPV	0.40374%	-0.467488%
JES_Nuisance_10	0.0212495%	-0.0424989%
JES_Nuisance_11	0%	-0.0212495%
JES_Nuisance_12	0.0849979%	-0.148746%
JES_Nuisance_13	0.828729%	-0.764981%
JES_Nuisance_14	0.212495%	-0.38249%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.106247%	-36.3366%
JES_Nuisance_1	0.0637484%	-0.148746%
JES_Nuisance_2	-0.191245%	0.169996%
JES_Nuisance_3	0.127497%	-0.148746%
JES_Nuisance_4	0.849979%	-0.913727%
JES_Nuisance_5	-0.254994%	0.127497%
JES_Nuisance_6	0.0424989%	-0.148746%
JES_Nuisance_7	0.0424989%	-0.127497%
JES_Nuisance_8	0.169996%	-0.318742%
JES_Nuisance_9	0%	-0.0212495%
JES_PileupPt	-0.0849979%	0.0849979%
JES_PileupTopo	1.04122%	-1.01997%
JVF	0.467488%	0%
JER_Nom	0.318742 %	-0.318742 %
Pileuprand	0.169996 %	-0.169996 %

sys	up	dowm
JES_BJES	-0.805519%	0.797366%
JES_FlavComp	0.102097%	-0.515014%
JES_FlavResp	0.0641827%	-0.282999%
JES_MU	0.0003722%	-0.186078%
JES_NPV	-0.298139%	0.133153%
JES_Nuisance_10	0.00007224%	-0.0762169%
JES_Nuisance_11	0%	0%
JES_Nuisance_12	-0.0361028%	-0.090451%
JES_Nuisance_13	-0.170032%	0.173138%
JES_Nuisance_14	-0.0192807%	-0.0549953%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.0579715%	0.0002801%
JES_Nuisance_1	-0.0258801%	-0.0993797%
JES_Nuisance_2	-0.0678059%	-0.0287269%
JES_Nuisance_3	-0.0361028%	-0.090451%
JES_Nuisance_4	-0.458854%	0.279893%
JES_Nuisance_5	-0.0398554%	-0.043608%
JES_Nuisance_6	-0.0258801%	-0.0993797%
JES_Nuisance_7	-0.0258801%	-0.0762169%
JES_Nuisance_8	-0.043608%	-0.0549953%
JES_Nuisance_9	0%	0%
JES_PileupPt	0.0605595%	-0.15554%
JES_PileupTopo	-0.6109%	0.515661%
JVF	0.234344%	0%
JER_Nom	0.196042 %	-0.196042 %
Pileuprand	-0.152304 %	0.152304 %

sys	up	dowm
JES_BJES	0.0452495%	0%
JES_FlavComp	7.28221%	-6.013%
JES_FlavResp	3.42116%	-2.9746%
JES_MU	0.828586%	-0.479942%
JES_NPV	1.31001%	-0.756632%
JES_Nuisance_10	0.19435%	-0.13649%
JES_Nuisance_11	0%	0%
JES_Nuisance_12	0.601596%	-0.13649%
JES_Nuisance_13	2.67788%	-2.44941%
JES_Nuisance_14	0.979912%	-0.422082%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.313038%	-0.332324%
JES_Nuisance_1	0.482167%	-0.13649%
JES_Nuisance_2	-0.259629%	0.67726%
JES_Nuisance_3	0.691354%	-0.258887%
JES_Nuisance_4	3.0421%	-2.51246%
JES_Nuisance_5	-0.25592%	0.770726%
JES_Nuisance_6	0.385734%	-0.13649%
JES_Nuisance_7	0.333808%	-0.13649%
JES_Nuisance_8	0.828586%	-0.349386%
JES_Nuisance_9	0%	0%
JES_PileupPt	0.0215121%	0.634235%
JES_PileupTopo	3.62961%	-2.69346%
JVF	-1.00884%	0%
JER_Nom	0.814492 %	-0.814492 %
Pileuprand	-0.454721 %	0.454721 %

sys	up	dowm
JES_BJES	0%	-0.130731%
JES_FlavComp	3.72526%	-6.9215%
JES_FlavResp	2.24644%	-4.08429%
JES_MU	0.563706%	-0.689482%
JES_NPV	0.533977%	-1.76048%
JES_Nuisance_10	0%	0%
JES_Nuisance_11	0%	0%
JES_Nuisance_12	0.347981%	-0.0712731%
JES_Nuisance_13	1.37896%	-2.56507%
JES_Nuisance_14	0.875478%	-0.921596%
JES_Nuisance_15	0%	0%
JES_Nuisance_16	0.495482%	-0.843843%
JES_Nuisance_1	0.172275%	-0.0712731%
JES_Nuisance_2	-0.227922%	0.466134%
JES_Nuisance_3	0.405914%	-0.0712731%
JES_Nuisance_4	2.18241%	-2.83568%
JES_Nuisance_5	-0.548079%	0.67881%
JES_Nuisance_6	0.172275%	-0.0712731%
JES_Nuisance_7	0.172275%	-0.0712731%
JES_Nuisance_8	0.67881%	-0.548079%
JES_Nuisance_9	0%	0%
JES_PileupPt	-0.365132%	0.55837%
JES_PileupTopo	2.24644%	-3.74089%
JVF	-3.72755%	0%
JER_Nom	0.87281 %	-0.87281 %
Pileuprand	-1.0569 %	1.0569 %