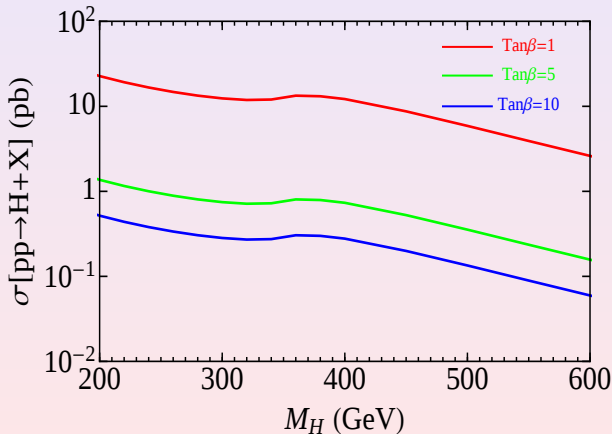
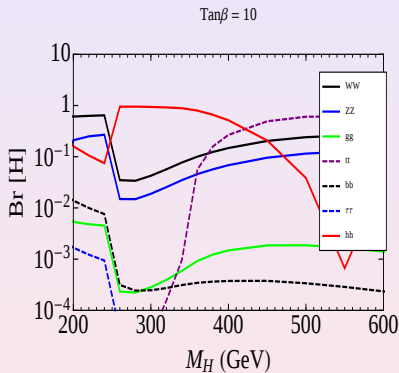
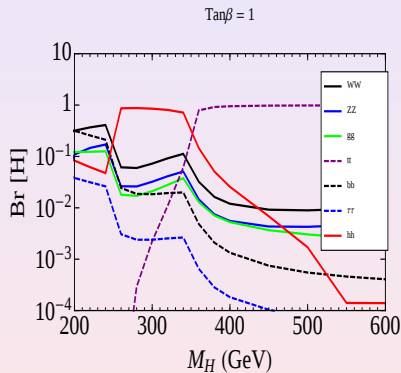


The 2HDM-I heavier CP-even Higgs production

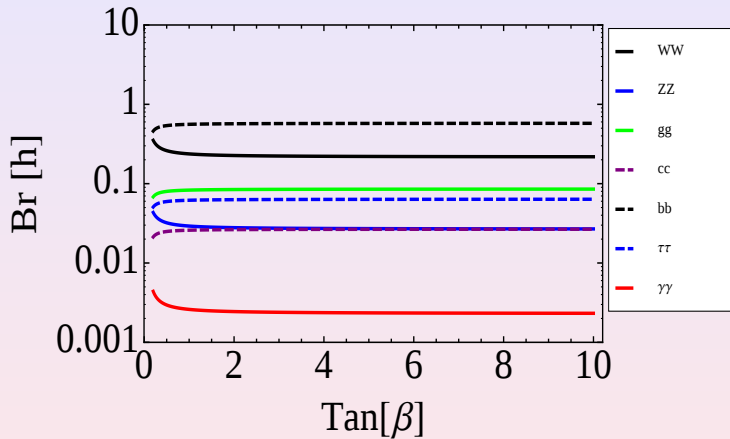
- $\sqrt{s} = 14$ TeV.
- Alinement limit: $\cos(\beta - \alpha) = -0.06$.



The 2HDM-I heavier CP-even Higgs Br

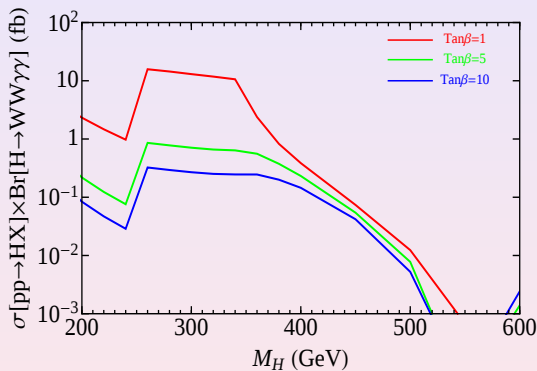


The 2HDM-I 125GeV Higgs Br



The 2HDM-I $pp \rightarrow H \rightarrow hh \rightarrow W^+ W^- \gamma\gamma$ channel

$$\sigma[pp \rightarrow HX] \times Br[H \rightarrow hh] \times Br[h \rightarrow W^+ W^-] \times Br[h \rightarrow \gamma\gamma] \times 2 :$$



We take Xsection= 1 fb for $M_H = 300\text{GeV}$ and Xsection= 10^{-1} fb for $M_H = 600\text{GeV}$ in the next analysis.

The 2HDM-I $pp \rightarrow H \rightarrow hh \rightarrow W^+ W^- \gamma\gamma$ channel

- $Br [W \rightarrow \ell \nu] \simeq 10.8\%$ ($\ell : e \text{ or } \mu \text{ or } \tau$);
- $Br [W \rightarrow \text{hadrons}] \simeq 67.6\%$.
- Signal cross section with W decay:

- hadronnic decay:

$$67.6\%^2 \times \text{Xsection} \simeq 0.457 \times \text{Xsection};$$

- leptonic decay:

$$(3 \times 10.8\%)^2 \times \text{Xsection} \simeq 0.105 \times \text{Xsection};$$

- semi-leptonic decay:

$$67.6\% \times 3 \times 10.8\% \times 2 \times \text{Xsection} \simeq 0.438 \times \text{Xsection}.$$

Semi-leptonic decay channel

- Fast-simulation project:

MG5 + pythia + delphes 3.0.10.

- 2HDM Signal: $M_H = 300$ GeV and $M_H = 600$ GeV.
- SM irreducible background:

$$p p \rightarrow q q \ell \nu \gamma \gamma \sim 31.13[\text{fb}].$$

- SM reducible background:

$$p p \rightarrow q q \ell \nu g g \sim \text{o}(10^{-4})[\text{fb}],$$

$$p p \rightarrow q q \ell \nu g q \sim \text{o}(10^{-4})[\text{fb}],$$

$$p p \rightarrow q q \ell \nu q q \sim \text{o}(10^{-4})[\text{fb}],$$

$$p p \rightarrow q q \ell \nu q \gamma \sim \text{o}(10^{-1})[\text{fb}],$$

$$p p \rightarrow q q \ell \nu g \gamma \sim \text{o}(10^{-1})[\text{fb}].$$

with photon identification efficiencies:

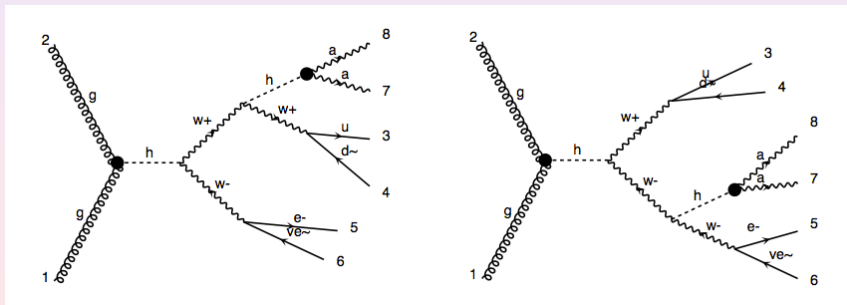
$$\epsilon_{q \rightarrow \gamma} \approx 3.6 \times 10^{-4}, \quad \epsilon_{g \rightarrow \gamma} \approx 3.6 \times 10^{-5}.$$

Semi-leptonic decay channel

- SM Higgstrahlung:

Radiate Higgs: $p p \rightarrow h \rightarrow W^+ W^- \rightarrow W^+ W^- h$.

$p p \rightarrow W^+ W^- h \rightarrow q q \ell \nu \gamma \gamma \sim 2.3 \times 10^{-3} [\text{fb}]$.



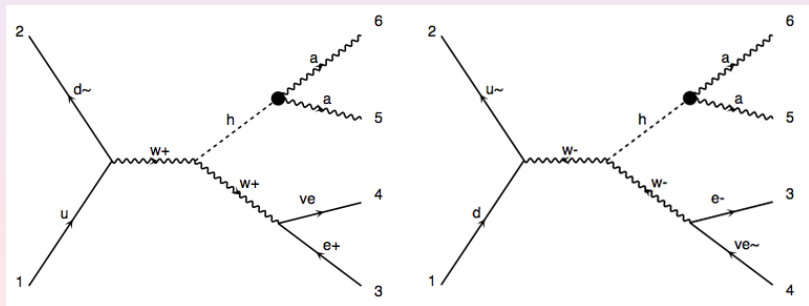
Semi-leptonic decay channel

- SM reducible background:

$$p p \rightarrow \ell \nu \gamma \gamma \sim 143.3[\text{fb}].$$

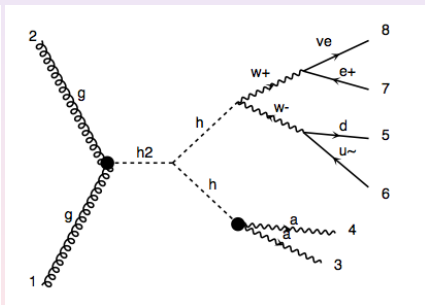
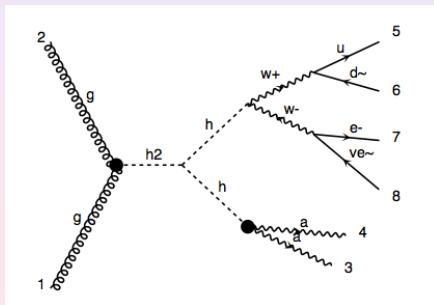
- SM Higgs reducible background:

$$p p \rightarrow W h \rightarrow \ell \nu \gamma \gamma \sim 0.42[\text{fb}].$$



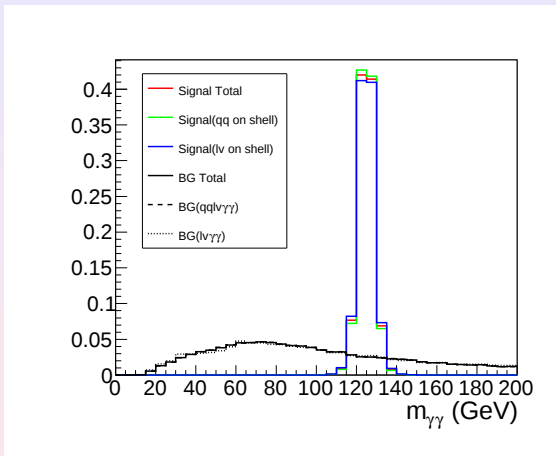
Signal generated by MG5

- Generating $q q$ on shell ($\ell \nu$ off shell) and $q q$ off shell ($\ell \nu$ on shell) separately



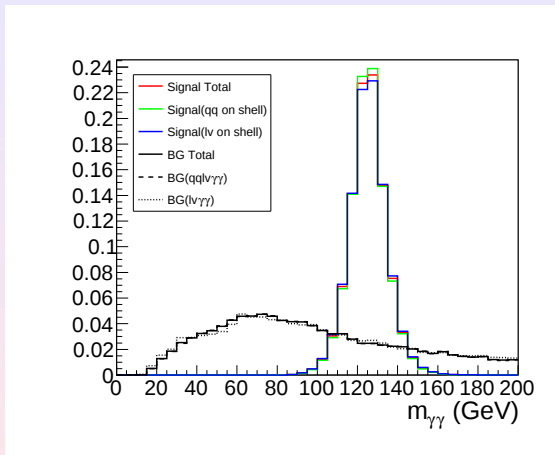
- Overlap remove:
 - Electrons with $\Delta R(e, \gamma) < 0.4$ are removed;
 - Jets(BTag, TauTag = 0) with $\Delta R(\text{jet}, e) < 0.2$ or $\Delta R(\text{jet}, \gamma) < 0.4$ are removed;
 - Muons with $\Delta R(\mu, \text{jet}) < 0.4$ or $\Delta R(\mu, \gamma) < 0.4$ are removed.
- Final state($q\ q\ \ell\ \nu\ \gamma\ \gamma$) selection:
 - Number of qjet ≥ 2 , choosing leading and subleading qjet pair;
 - Number of photon ≥ 2 , $m_{\gamma\gamma}$ of photon pair closest to m_h ;
 - Number of electron or muon = 1.
- Basic cuts: $|\eta_{\gamma, q, \ell}| < 2.5$, $P_{T_{\gamma, q}} > 25\text{ GeV}$, $P_{T_\ell} > 15\text{ GeV}$.

Distribution of photon($M_H = 300\text{GeV}$)



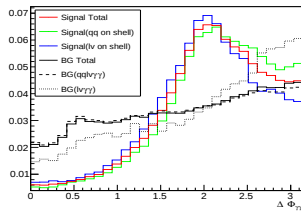
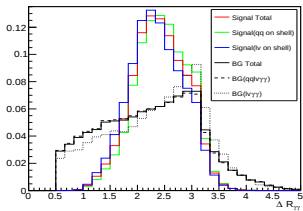
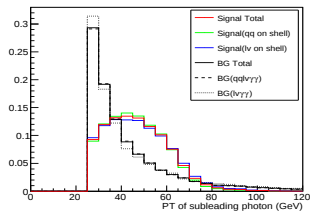
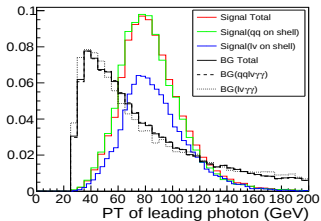
- Cut based: $120 \text{ GeV} < m_{\gamma\gamma} < 130 \text{ GeV}$.

Distribution of photon($M_H = 600\text{GeV}$)



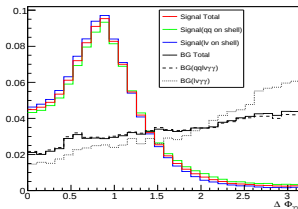
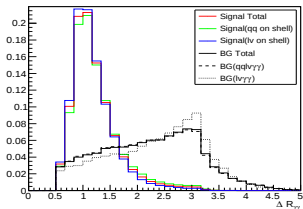
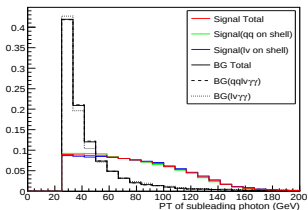
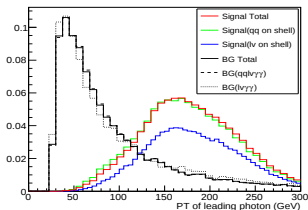
- Cut based: $115 \text{ GeV} < m_{\gamma\gamma} < 135 \text{ GeV}$.

Distribution of photon($M_H = 300\text{GeV}$)



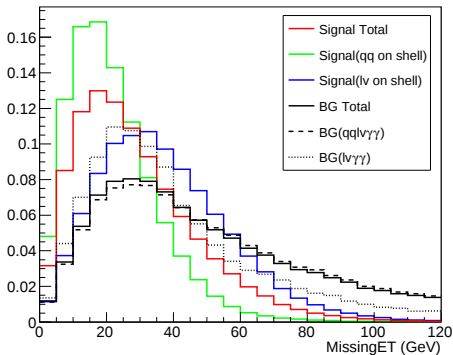
- Cut based: $60 \text{ GeV} < P_{T\gamma\text{-leading}} < 120 \text{ GeV}$.

Distribution of photon($M_H = 600\text{GeV}$)



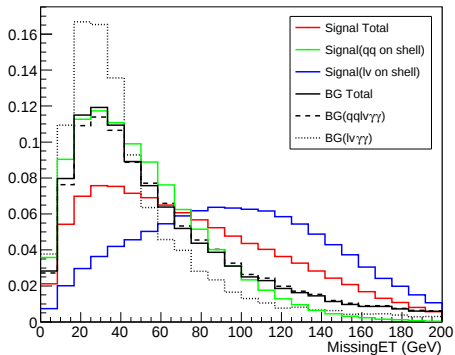
- Cut based: $P_{T\gamma\text{-leading}} > 120 \text{ GeV}$, $\Delta R_{\gamma\gamma} < 1.7$, $\Delta\Phi_{\gamma\gamma} < 1.4$.

Missing ET distribution($M_H = 300\text{GeV}$)

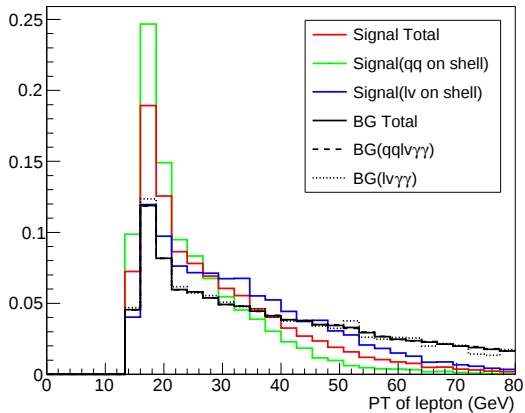


- Cut based: $\text{MET} < 40\text{ GeV}$.

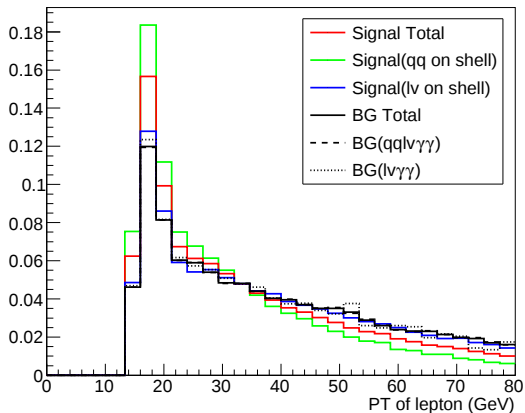
Missing ET distribution($M_H = 600\text{GeV}$)



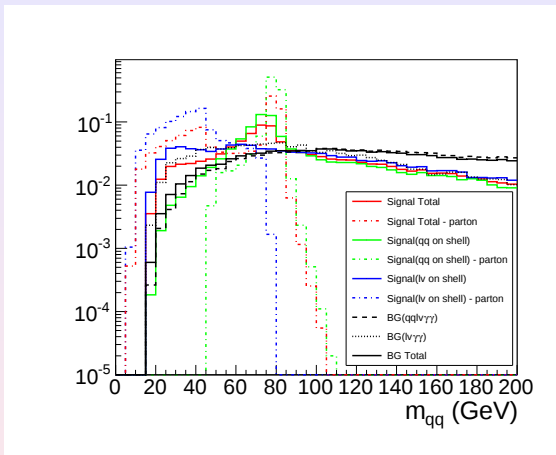
Distribution of lepton($M_H = 300\text{GeV}$)



Distribution of lepton($M_H = 600\text{GeV}$)

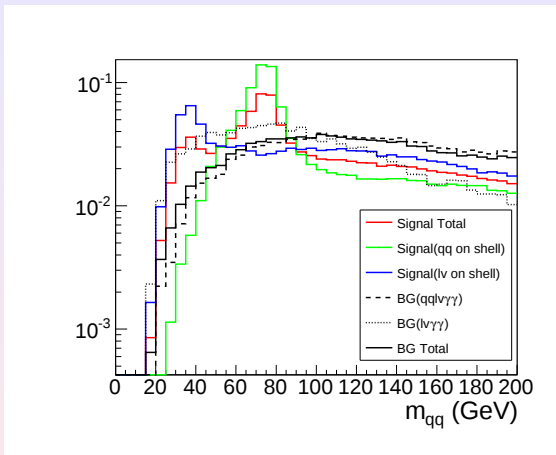


Distribution of $q_{\text{jet}}(M_H = 300\text{GeV})$



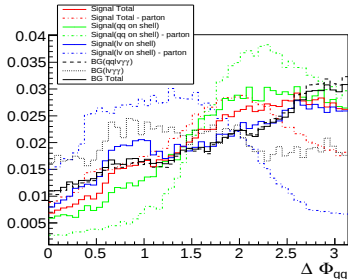
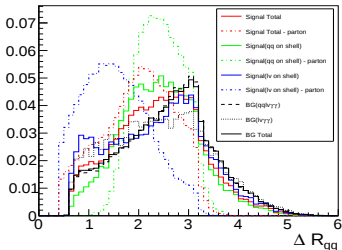
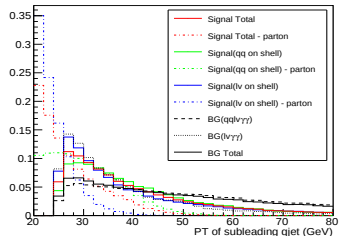
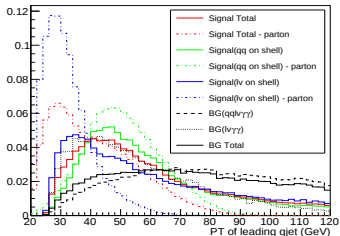
- Cut based: $m_{qq} < 90\text{ GeV}$.

Distribution of $q_{\text{jet}}(M_H = 600\text{GeV})$

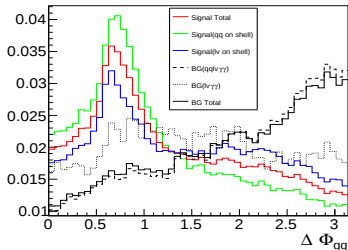
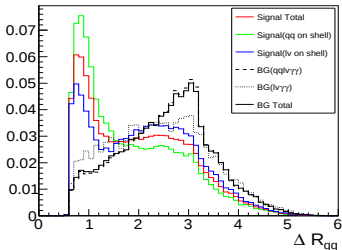
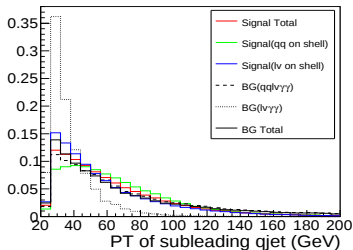
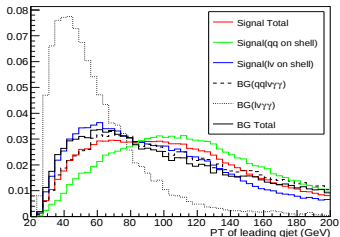


- Cut based: $m_{qq} < 90\text{ GeV}$.

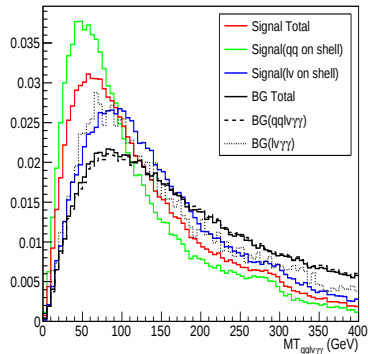
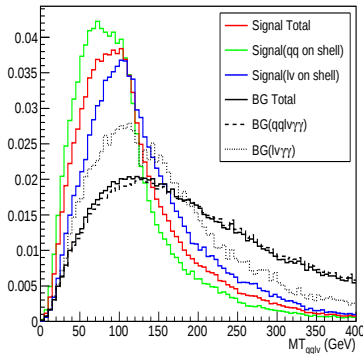
Distribution of $q_{\text{jet}}(M_H = 300\text{GeV})$



Distribution of $q_{\text{jet}}(M_H = 600\text{GeV})$

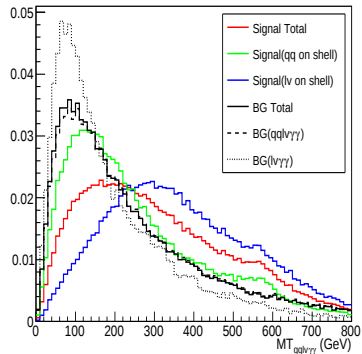
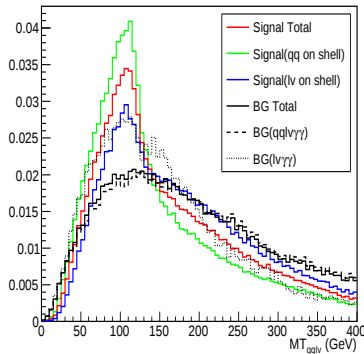


Transverse mass distribution($M_H = 300\text{GeV}$)



- Cut based: $M_{T_{q\ell\nu}} < 150\text{ GeV}$.

Transverse mass distribution($M_H = 600\text{GeV}$)



- Cut based: $M_{T_{q\ell\nu}} < 150\text{ GeV}$.

Cut efficiency(Semi-leptonic decay, $M_H = 300\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} MET	$P_{T\gamma}, M_{T_{q\ell\nu}}$
Signal [fb]	0.44	0.025	0.0083	0.0067
$q\ell\nu\gamma\gamma$ [fb]	31.59	0.58	0.0017	0.00069
$\ell\nu\gamma\gamma$ [fb]	143.3	0.064	0.00078	0.00036
Wh [fb]	0.42	0.0051	0.00026	0.00015
WW_h [fb]	0.0023	0.00021	0.00002	0.00001
S/B	0.0025	0.038	3.05	5.61
$S/\sqrt{B}$	1.05	0.97	5.04	6.14
Signif-P	1.05	0.97	3.78	4.06

Signif-P: $\sqrt{2 \times \left\{ (S+B) \times \ln[(S+B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 1000 \text{ fb}^{-1}$.

Cut efficiency(Semi-leptonic decay, $M_H = 600\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} $P_{T\gamma}$	$M_{T_{qq\ell\nu}}$ $\Delta R_{\gamma\gamma}$ $\Delta\Phi_{\gamma\gamma}$
Signal [fb]	0.044	0.0026	0.00063	0.00048
$qq\ell\nu\gamma\gamma$ [fb]	31.59	0.58	0.0010	0.000069
$\ell\nu\gamma\gamma$ [fb]	143.3	0.064	0.00033	0.000013
Wh [fb]	0.42	0.0051	0.00029	0.000065
WW [fb]	0.0023	0.00021	0.000026	0.000005
S/B	0.00025	0.0040	0.38	3.17
$S/\sqrt{B}$	0.11	0.10	0.49	1.23
Signif-P	0.11	0.10	0.46	0.92

Signif-P: $\sqrt{2 \times \left\{ (S + B) \times \ln[(S + B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 1000 \text{ fb}^{-1}$.

Cut efficiency(Semi-leptonic decay, $M_H = 600\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} $P_{T\gamma}$	$M_{T_{qq\ell\nu}}$ $\Delta R_{\gamma\gamma}$ $\Delta\Phi_{\gamma\gamma}$
Signal [fb]	0.044	0.0026	0.00063	0.00048
$qq\ell\nu\gamma\gamma$ [fb]	31.59	0.58	0.0010	0.000069
$\ell\nu\gamma\gamma$ [fb]	143.3	0.064	0.00033	0.000013
Wh [fb]	0.42	0.0051	0.00029	0.000065
WW [fb]	0.0023	0.00021	0.000026	0.000005
S/B	0.00025	0.0040	0.38	3.17
$S/\sqrt{B}$	0.23	0.23	1.09	2.76
Signif-P	0.23	0.23	1.03	2.05

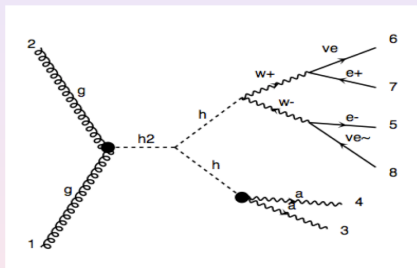
Signif-P: $\sqrt{2 \times \left\{ (S + B) \times \ln[(S + B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 5000 \text{ fb}^{-1}$.

Leptonic decay channel

- Fast-simulation project:

MG5 + pythia + delphes 3.0.10.

- 2HDM Signal: $M_H = 300$ GeV and $M_H = 600$ GeV.

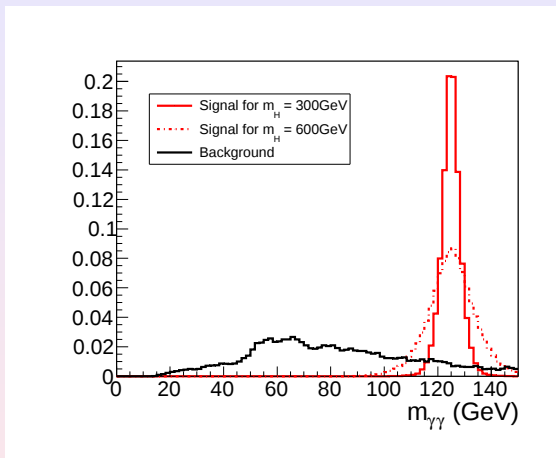


- SM irreducible background:

$$\begin{aligned} p p &\rightarrow \ell \nu \ell \nu \gamma \gamma \\ + p p &\rightarrow \ell^+ \ell^- \gamma \gamma \sim 153.3[\text{fb}]. \end{aligned}$$

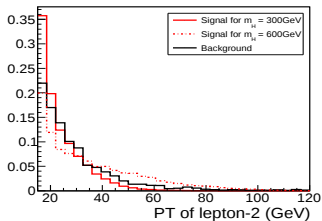
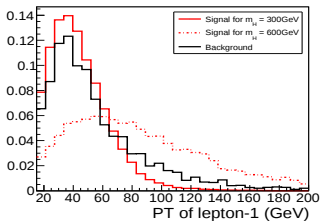
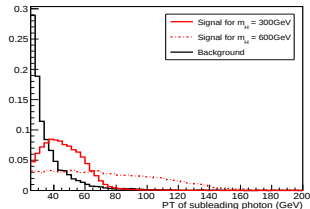
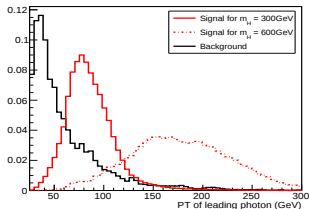
- Overlap remove:
 - Electrons with $\Delta R(e, \gamma) < 0.4$ are removed;
 - Jets(BTag, TauTag = 0) with $\Delta R(\text{jet}, e) < 0.2$ or $\Delta R(\text{jet}, \gamma) < 0.4$ are removed;
 - Muons with $\Delta R(\mu, \text{jet}) < 0.4$ or $\Delta R(\mu, \gamma) < 0.4$ are removed.
- Final state($\ell \nu \ell \nu \gamma \gamma$) selection:
 - Number of photon ≥ 2 , $m_{\gamma\gamma}$ of photon pair closest to m_h ;
 - Number of electron + muon = 2.
- Basic cuts: $|\eta_{\gamma, \ell}| < 2.5$, $P_{T\gamma} > 25$ GeV, $P_{T\ell} > 15$ GeV.

Distribution of photon



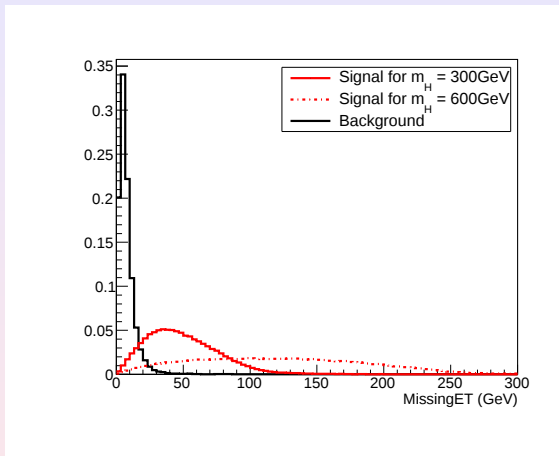
- Cut based: $120\text{ GeV} < m_{\gamma\gamma} < 130\text{ GeV}$ ($m_H = 300\text{GeV}$).
- Cut based: $115\text{ GeV} < m_{\gamma\gamma} < 135\text{ GeV}$ ($m_H = 600\text{GeV}$).

Distribution of PT



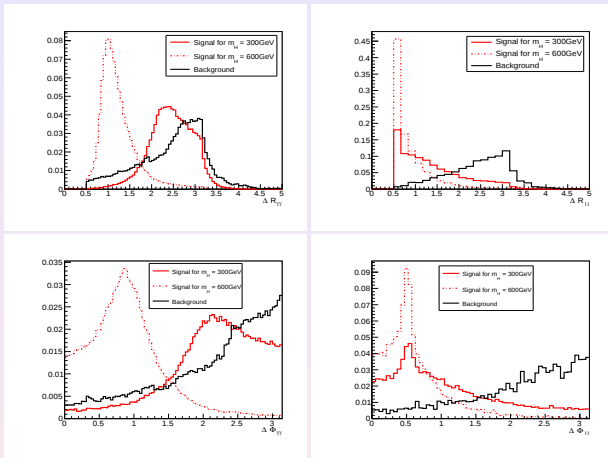
- Cut based: $P_{T\gamma\text{-leading}} > 100\text{ GeV}$,
 $P_{T\gamma\text{-subleading}} > 50\text{ GeV} (m_H = 600\text{GeV})$.

Missing ET distribution



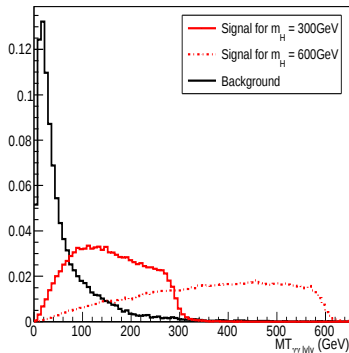
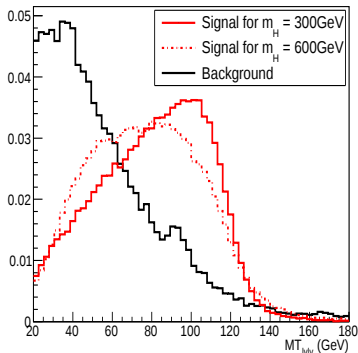
- Cut based: $\text{MET} > 20 \text{ GeV}$ ($m_H = 300\text{GeV}$).
- Cut based: $\text{MET} > 30 \text{ GeV}$ ($m_H = 600\text{GeV}$).

Distribution of ΔR and $\Delta\Phi$



- Cut based: $\Delta R_{\ell\ell} < 1.8$ and $\Delta\Phi_{\ell\ell} < 1.5$ ($m_H = 300\text{ GeV}$).
- Cut based: $\Delta R_{\gamma\gamma} < 1.8$, $\Delta\Phi_{\gamma\gamma} < 1.6$, $\Delta R_{\ell\ell} < 1.5$, $\Delta\Phi_{\ell\ell} < 1.2$ ($m_H = 600\text{ GeV}$).

Transverse mass distribution



- Cut based: $70\text{ GeV} < M_{T_{\ell\nu\ell\nu\gamma\gamma}} < 300\text{ GeV}$ ($m_H = 300\text{GeV}$).
- Cut based: $75\text{ GeV} < M_{T_{\ell\nu\ell\nu\gamma\gamma}} < 600\text{ GeV}$ ($m_H = 600\text{GeV}$).

Cut efficiency(Leptonic decay, $M_H = 300\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}, \text{ MET}$	$M_{T_{\ell\nu\ell\nu\gamma\gamma}}$ $\Delta R_{\ell\ell}$ $\Delta\Phi_{\ell\ell}$
Signal [fb]	0.105	0.0051	0.0038	0.0023
BG[fb]	153.3	0.94	0.0013	0.00009
S/B	0.0007	0.005	2.99	25.3
$S/\sqrt{B}$	0.27	0.17	3.37	7.69
Signif-P	0.27	0.17	2.54	3.34

Signif-P: $\sqrt{2 \times \left\{ (S + B) \times \ln[(S + B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 1000 \text{ fb}^{-1}$.

Cut efficiency(Leptonic decay, $M_H = 600\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ MET $P_{T\gamma}$	$M_{T_{\ell\nu\ell\nu\gamma\gamma}}$ $\Delta R_{\ell\ell,\gamma\gamma}$ $\Delta\Phi_{\ell\ell,\gamma\gamma}$
Signal [fb]	0.0105	0.00057	0.00026	0.00023
BG[fb]	153.3	0.94	0.000031	0.000015
S/B	0.00007	0.0006	8.58	14.70
$S/\sqrt{B}$	0.027	0.019	1.50	1.82
Signif-P	0.027	0.019	0.90	0.94

Signif-P: $\sqrt{2 \times \left\{ (S + B) \times \ln[(S + B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 1000 \text{ fb}^{-1}$.

Cut efficiency(Leptonic decay, $M_H = 600\text{GeV}$)

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ MET $P_{T\gamma}$	$M_{T_{\ell\nu\ell\nu\gamma\gamma}}$ $\Delta R_{\ell\ell,\gamma\gamma}$ $\Delta\Phi_{\ell\ell,\gamma\gamma}$
Signal [fb]	0.0105	0.00057	0.00026	0.00023
BG[fb]	153.3	0.94	0.000031	0.000015
S/B	0.00007	0.0006	8.58	14.70
$S/\sqrt{B}$	0.060	0.042	3.36	4.07
Signif-P	0.060	0.042	2.00	2.09

Signif-P: $\sqrt{2 \times \left\{ (S + B) \times \ln[(S + B)/B] - S \right\}}$. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 5000 \text{ fb}^{-1}$.