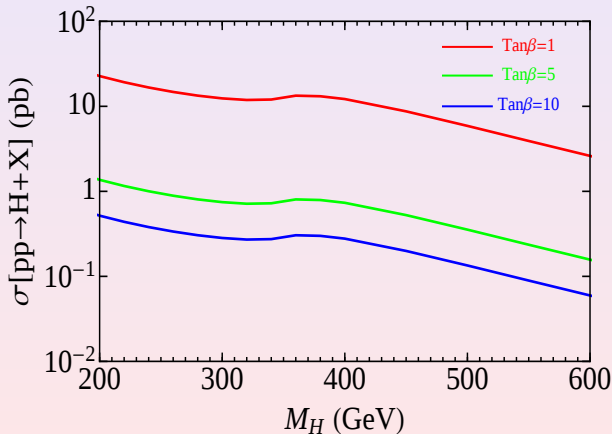
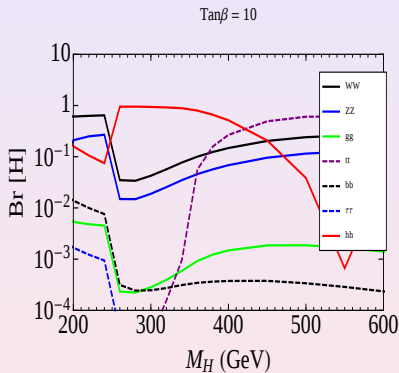
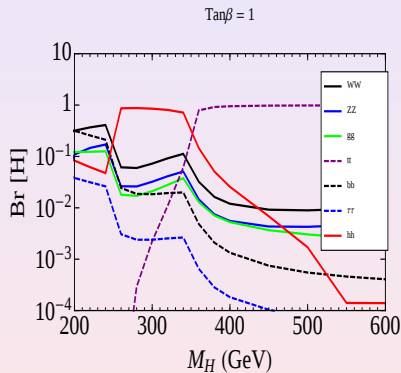


The 2HDM-I heavier CP-even Higgs production

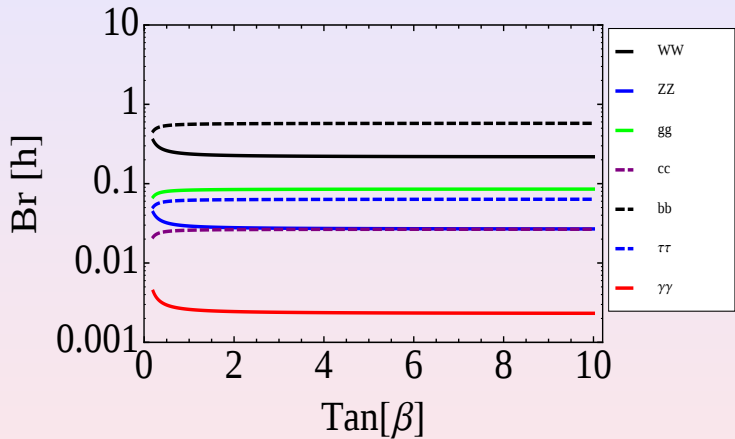
- $\sqrt{s} = 14$ TeV.
- Alinement limit: $\cos(\beta - \alpha) = -0.06$.



The 2HDM-I heavier CP-even Higgs Br

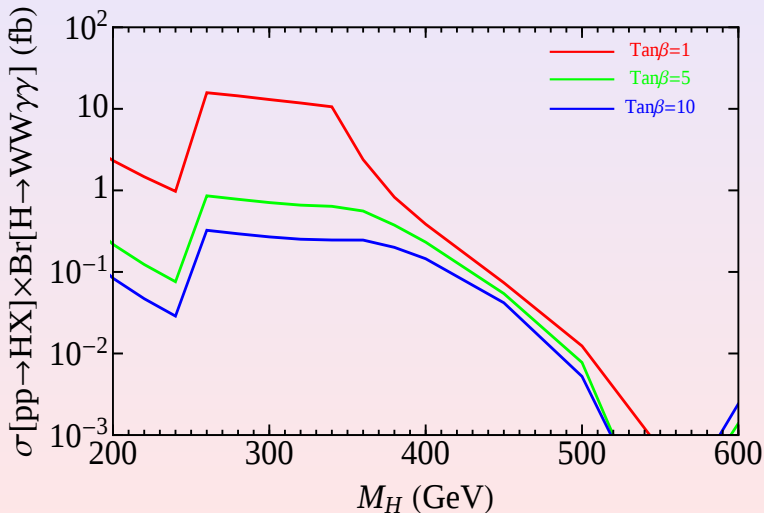


The 2HDM-I 125GeV Higgs Br



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

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



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

- $Br [h \rightarrow W^+ W^-] / Br [h \rightarrow b b] \simeq 0.38;$
- $Br [W \rightarrow \ell \nu] \simeq 10.8\% \quad (\ell : e \text{ or } \mu \text{ or } \tau);$
- $Br [W \rightarrow \text{hadrons}] \simeq 67.6\%.$
- Signal cross section ratio $\sigma[W^+ W^- \gamma \gamma] / \sigma[b b \gamma \gamma]:$
 - hadronnic decay: $0.38 \times 67.6\%^2 \simeq 0.18;$
 - leptonic decay: $0.38 \times (3 \times 10.8\%)^2 \simeq 0.04;$
 - semi-leptonic decay: $0.38 \times 67.6\% \times 3 \times 10.8\% \times 2 \simeq 0.17.$

Semi-leptonic decay channel

- Fast-simulation project:

MG5 + pythia + delphes 3.0.10.

- 2HDM Signal: $M_H = 300$ 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:

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

- SM Higgstrahlung:

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

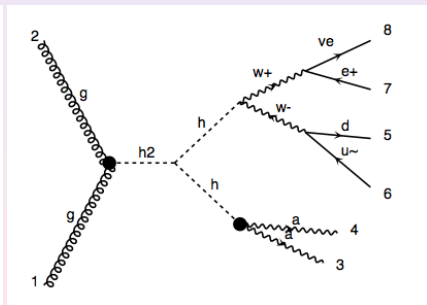
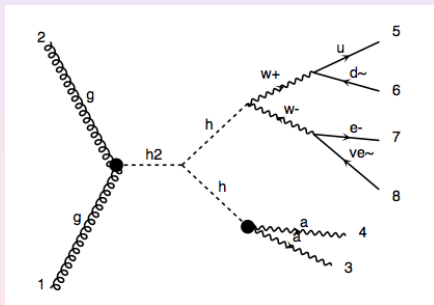
$$p p \rightarrow W^+ W^- h \rightarrow q q \ell \nu \gamma \gamma \sim \mathcal{O}(10^{-3})[\text{fb}].$$

- SM reducible background:

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

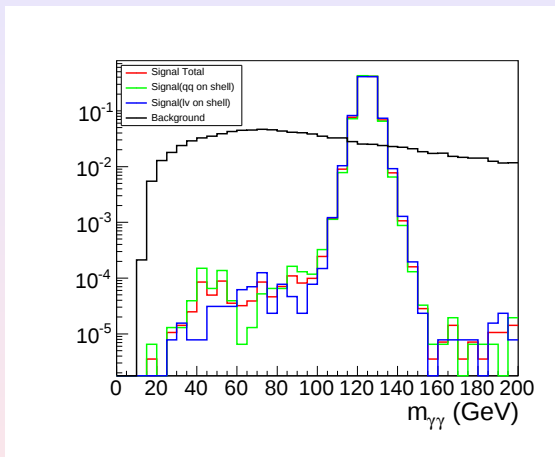
Signal generated by MG5

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



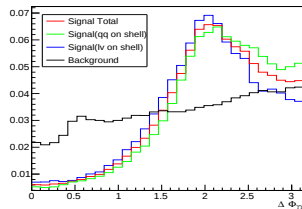
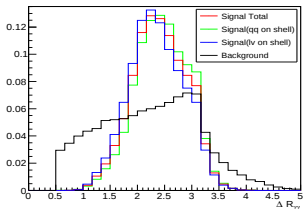
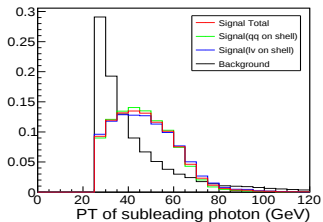
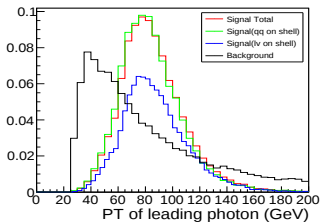
- Overlap remove:
 - Electrons with $\Delta R(e, \gamma) < 0.4$ are removed;
 - Jets(BTag, TauTag = 0) with $\Delta R(\text{jet}, e) < 0.2$ or $\Delta R(\text{jet}, \gamma) < 0.4$ are removed;
 - Muons with $\Delta R(\mu, \text{jet}) < 0.4$ or $\Delta R(\mu, \gamma) < 0.4$ are removed.
- Final state($q\ q\ \ell\ \nu\ \gamma\ \gamma$) 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



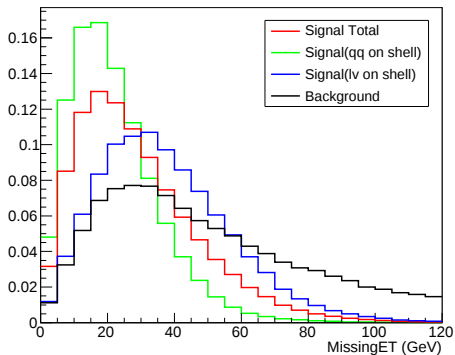
- Cut based: $120 \text{ GeV} < m_{\gamma\gamma} < 130 \text{ GeV}$.

Distribution of photon



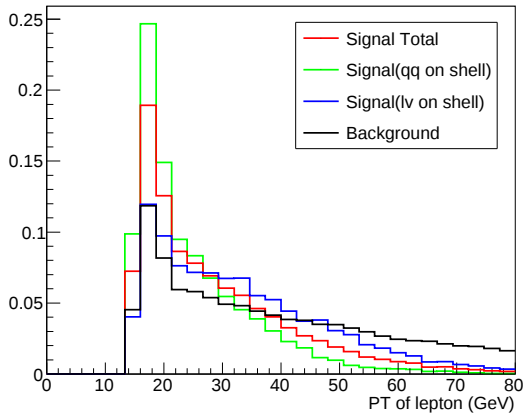
- Cut based: $1.7 < \Delta R_{\gamma\gamma} < 3.2$ and $\Delta\Phi_{\gamma\gamma} > 1.5$.

Missing ET distribution

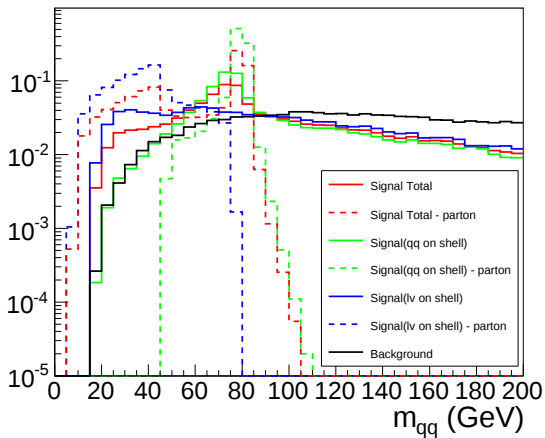


- Cut based: $\text{MET} < 40 \text{ GeV}$.

Distribution of lepton

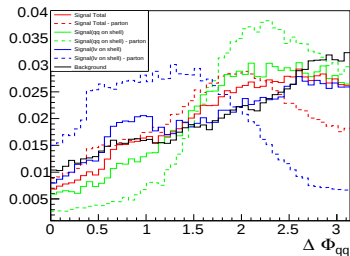
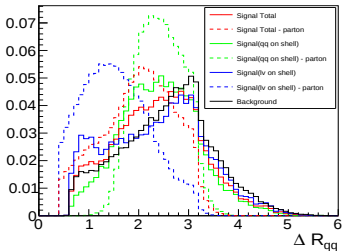
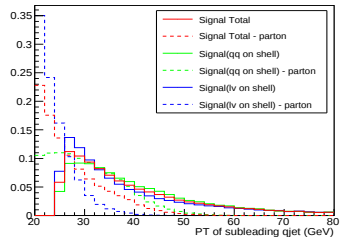
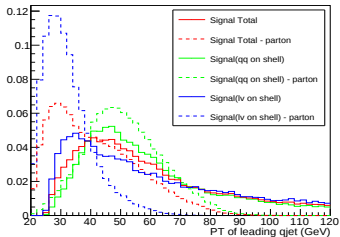


Distribution of $q\bar{q}j$

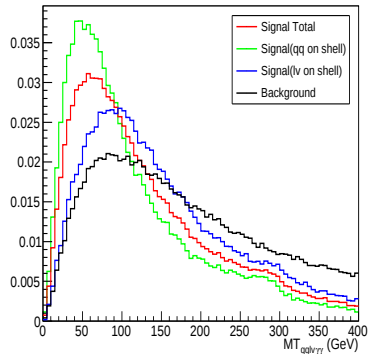
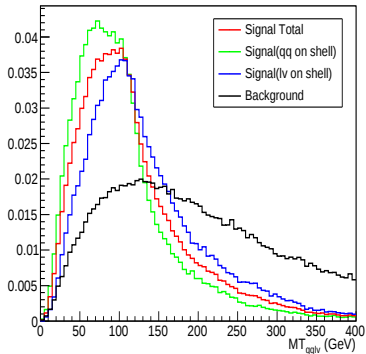


- Cut based: $m_{qq} < 90$ GeV.

Distribution of $q_{\text{j}et}$



Transverse mass distribution



Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} MET	$\Delta R_{\gamma\gamma}, \Delta\Phi_{\gamma\gamma}$
Signal [fb]	0.17	0.011	0.0051	0.0028
$qq\ell\nu\gamma\gamma$ [fb]	31.59	0.514	0.0011	0.0004
$\ell\nu\gamma\gamma$ [fb]	143.3	0.06	0	0
S/B	0.001	0.020	4.5	6.6
$S/\sqrt{B}^{[1]}$	0.41	0.47	4.8	4.3
$S/\sqrt{B}^{[2]}$	0.91	1.06	10.7	9.6
Signif-P ^[1]	0.41	0.47	3.3	2.7
Signif-P ^[2]	0.91	1.06	7.5	6.1

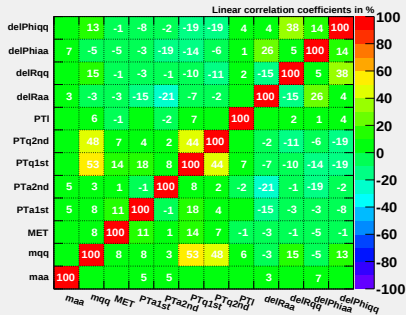
Signif-P: $\sqrt{2 \times \left\{ (S+B) \times \ln[(S+B)/B] - S \right\}}$. Integrate

luminosity is assumed to be ^[1] $\int \mathcal{L} dt = 1000 \text{ fb}^{-1}$ and
^[2] $\int \mathcal{L} dt = 5000 \text{ fb}^{-1}$.

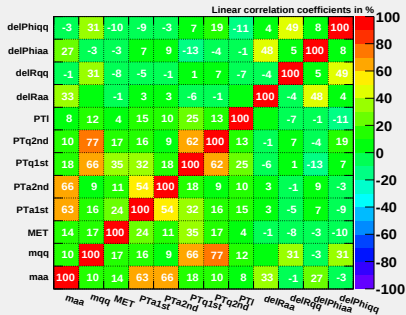
MVA analysis

- BDT method

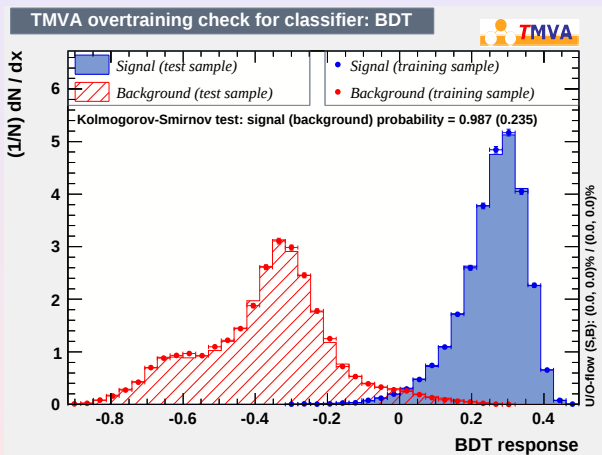
Correlation Matrix (signal)

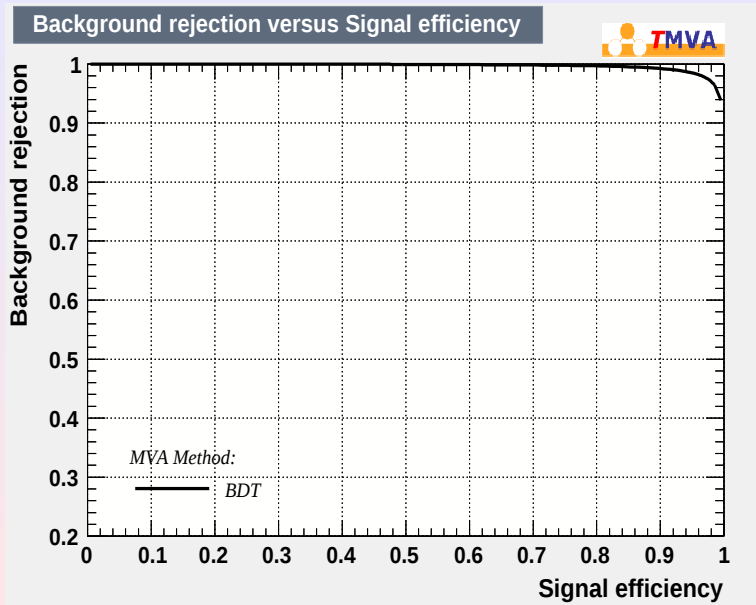


Correlation Matrix (background)



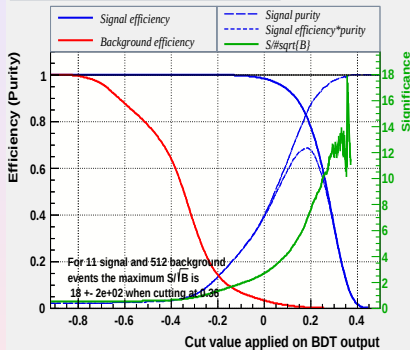
- Overtraining check



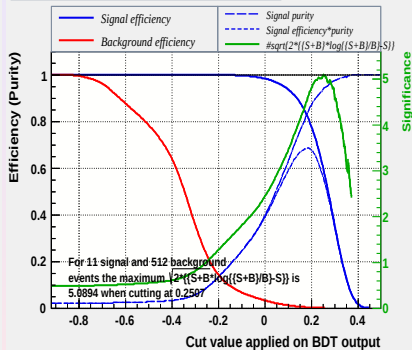


MVA analysis

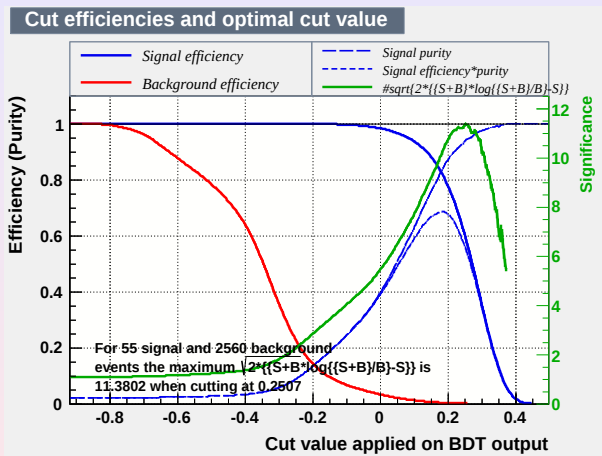
Cut efficiencies and optimal cut value



Cut efficiencies and optimal cut value

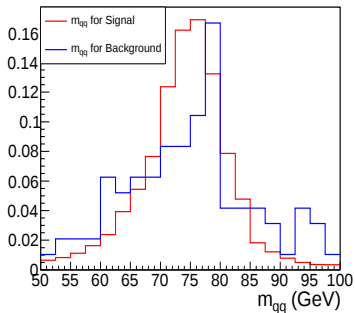
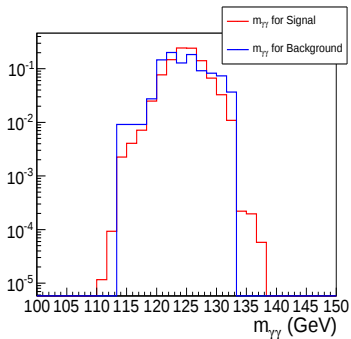


$$\int \mathcal{L} dt = 1000 \text{ fb}^{-1}. \text{ BDT cut: } \text{BDT} \geq 0.2507.$$



$$\int \mathcal{L} dt = 5000 \text{ fb}^{-1}. \text{ BDT cut: } \text{BDT} \geq 0.2507.$$

Invariant mass distribution after BDT



$\text{BDT} \geq 0.2507$.