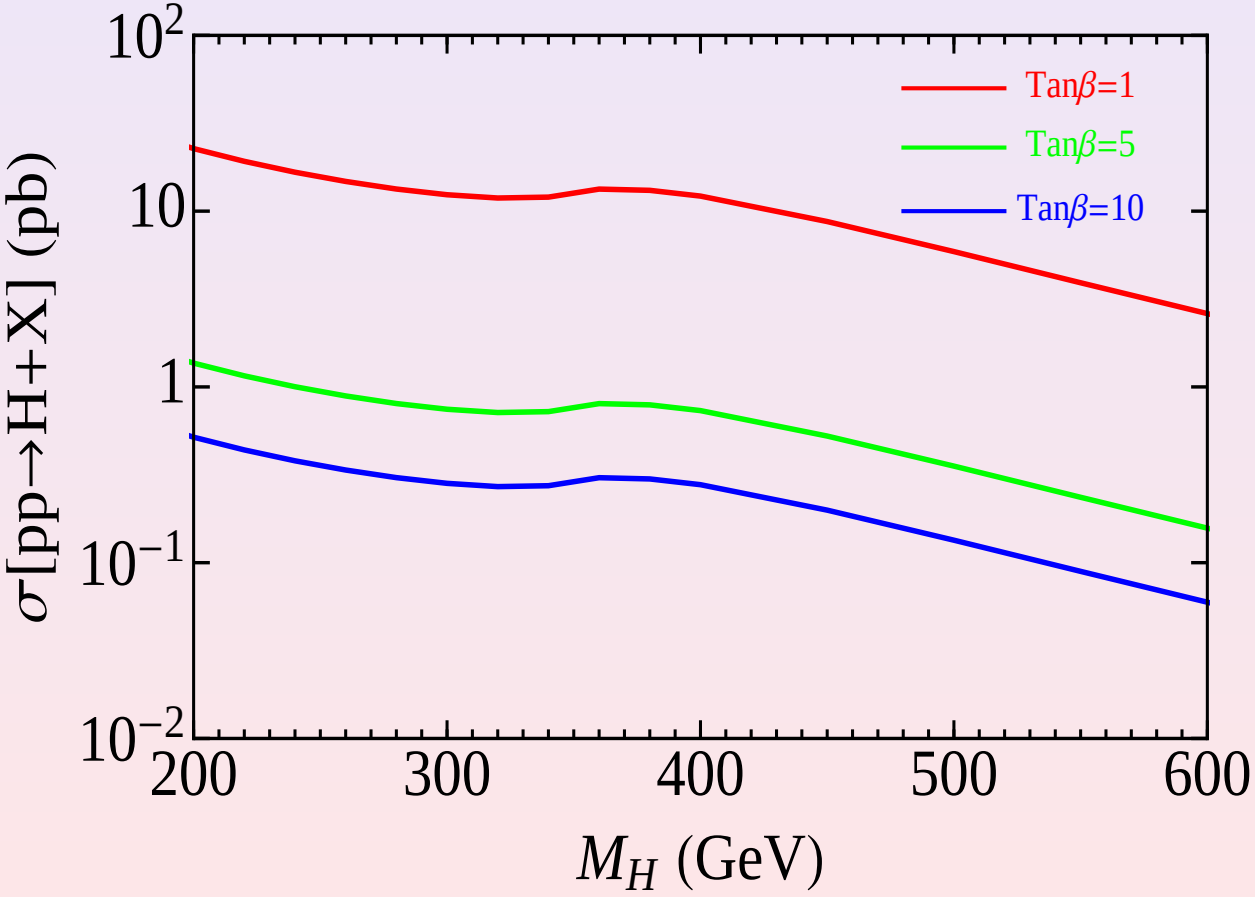
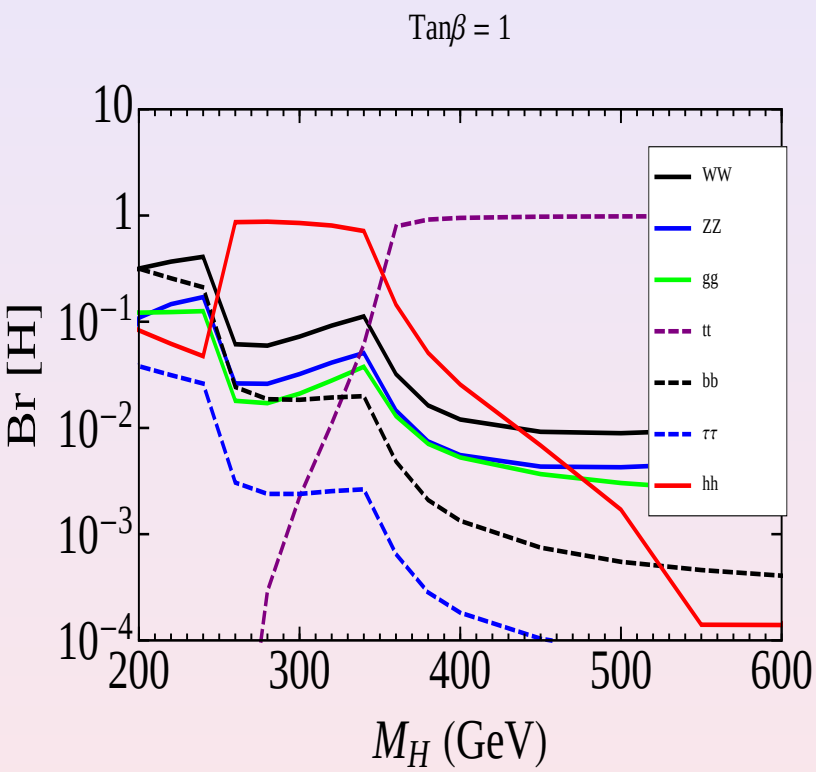
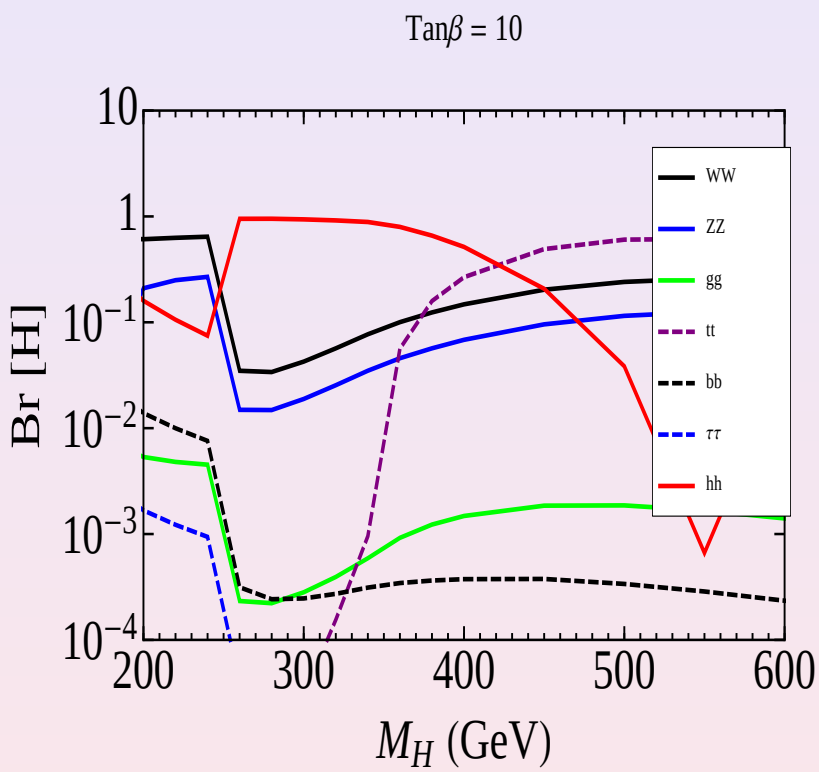
The 2HDM-I heavier CP-even Higgs production

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

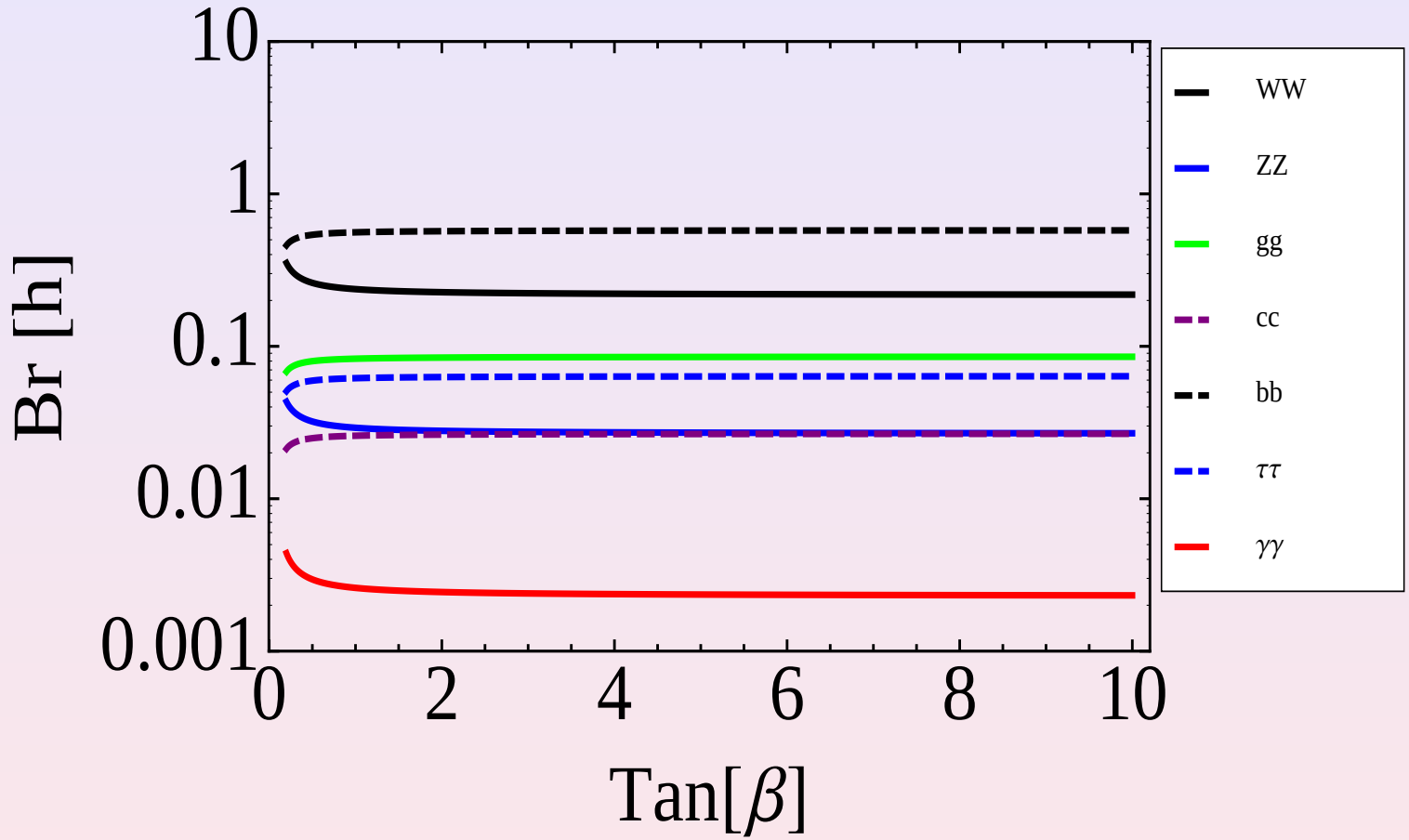


The 2HDM-I heavier CP-even Higgs Br



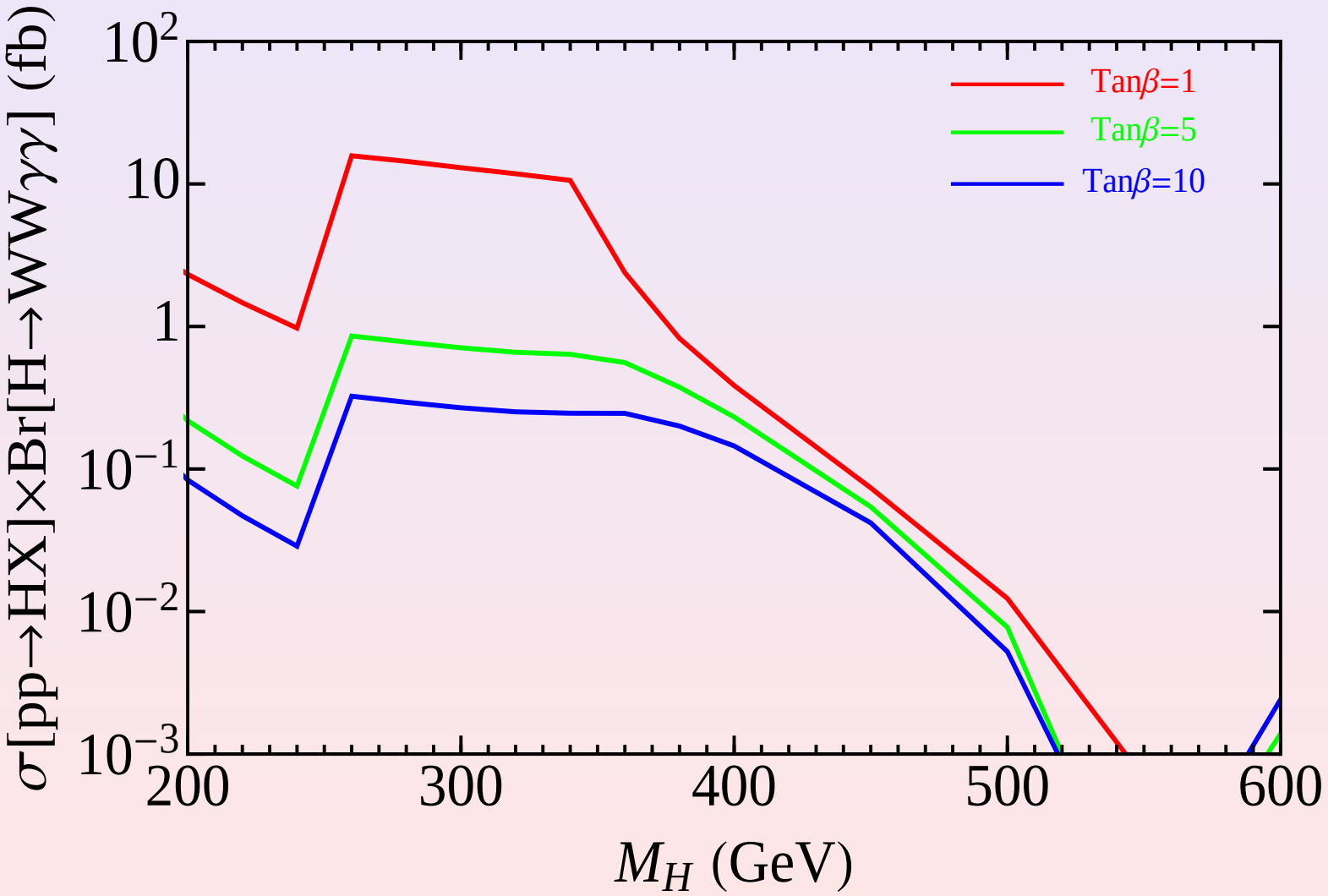


The 2HDM-I 125GeV Higgs Br



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

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



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

- $Br\,[\, h \to W^+ W^- \,]\,/\,Br\,[\, h \to b\ b \,] \simeq 0.38$;
- $Br\,[\, W \to \ell\ \nu \,] \simeq 10.8\% \quad (\ell : e \text{ or } \mu \text{ or } \tau)$;
- $Br\,[\, W \to \text{hadrons} \,] \simeq 67.6\%$.
- 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:

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

- SM reducible background:

$$\begin{aligned}
p\ p \ &\to \ q\ q\ \ell\ \nu\ g\ g \ &\sim \ \ &\text{o}(10^{-4})[\text{fb}],\\
p\ p \ &\to \ q\ q\ \ell\ \nu\ g\ q \ &\sim \ \ &\text{o}(10^{-4})[\text{fb}],\\
p\ p \ &\to \ q\ q\ \ell\ \nu\ q\ q \ &\sim \ \ &\text{o}(10^{-4})[\text{fb}],\\
p\ p \ &\to \ q\ q\ \ell\ \nu\ q\ \gamma \ &\sim \ \ &\text{o}(10^{-1})[\text{fb}],\\
p\ p \ &\to \ q\ q\ \ell\ \nu\ g\ \gamma \ &\sim \ \ &\text{o}(10^{-1})[\text{fb}].
\end{aligned}$$

with photon identification efficiencies:

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

Semi-leptonic decay channel

- SM Higgstrahlung:

$$\text{Radiate Higgs: } p\ p\ \rightarrow\ h\ \rightarrow\ W^+\,W^-\ \rightarrow\ W^+\,W^-\,h.$$

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

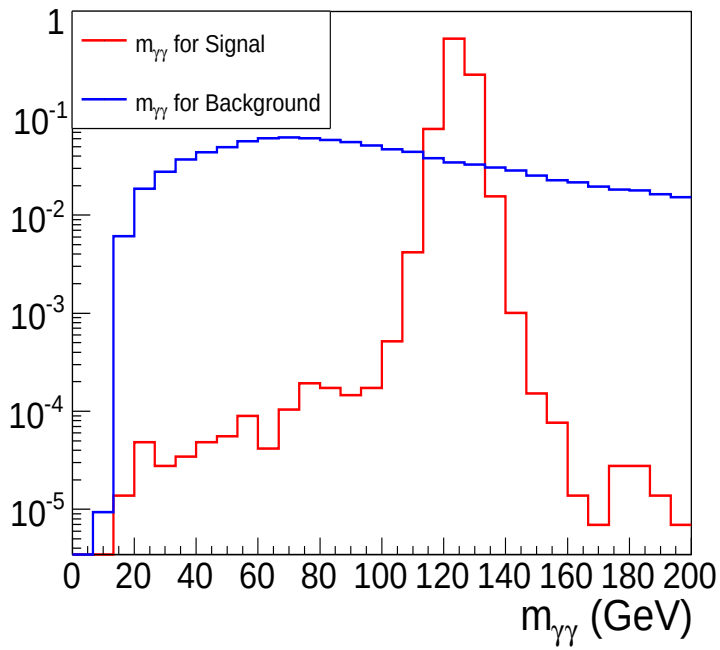
- SM reducible background:

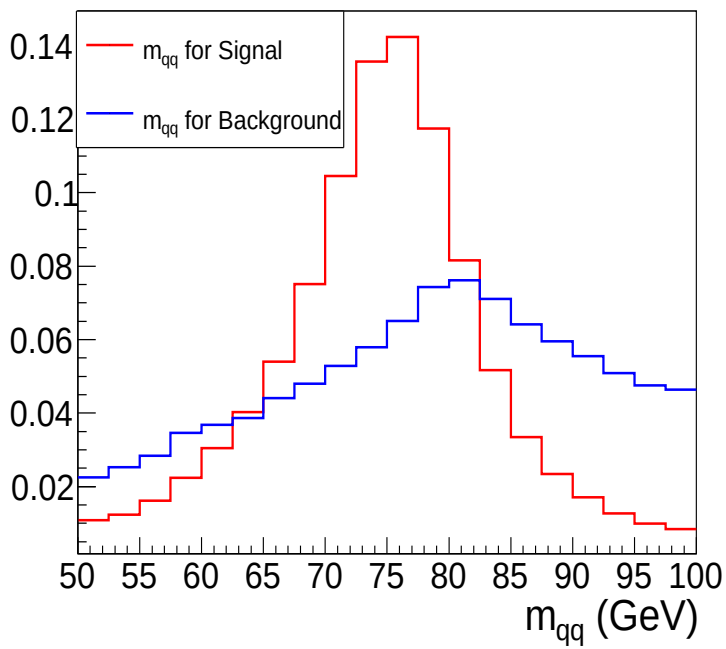
$$p\ p\ \rightarrow\ \ell\ \nu\ \gamma\ \gamma\ \sim\ 143.3[\mathrm{fb}].$$

Events selection

- Overlab 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, m_{qq} of qjet pair closest to m_W;
  - ▶ Number of photon ≥ 2, $m_{\gamma\gamma}$ of photon pair closest to m_h;
  - ▶ Number of electron or muon $= 1$.
- Basic cuts: $|\eta_{\gamma,q,\ell}| < 2.5$, $P_{T_{\gamma,q}} > 25$ GeV, $P_{T_\ell} > 15$ GeV.

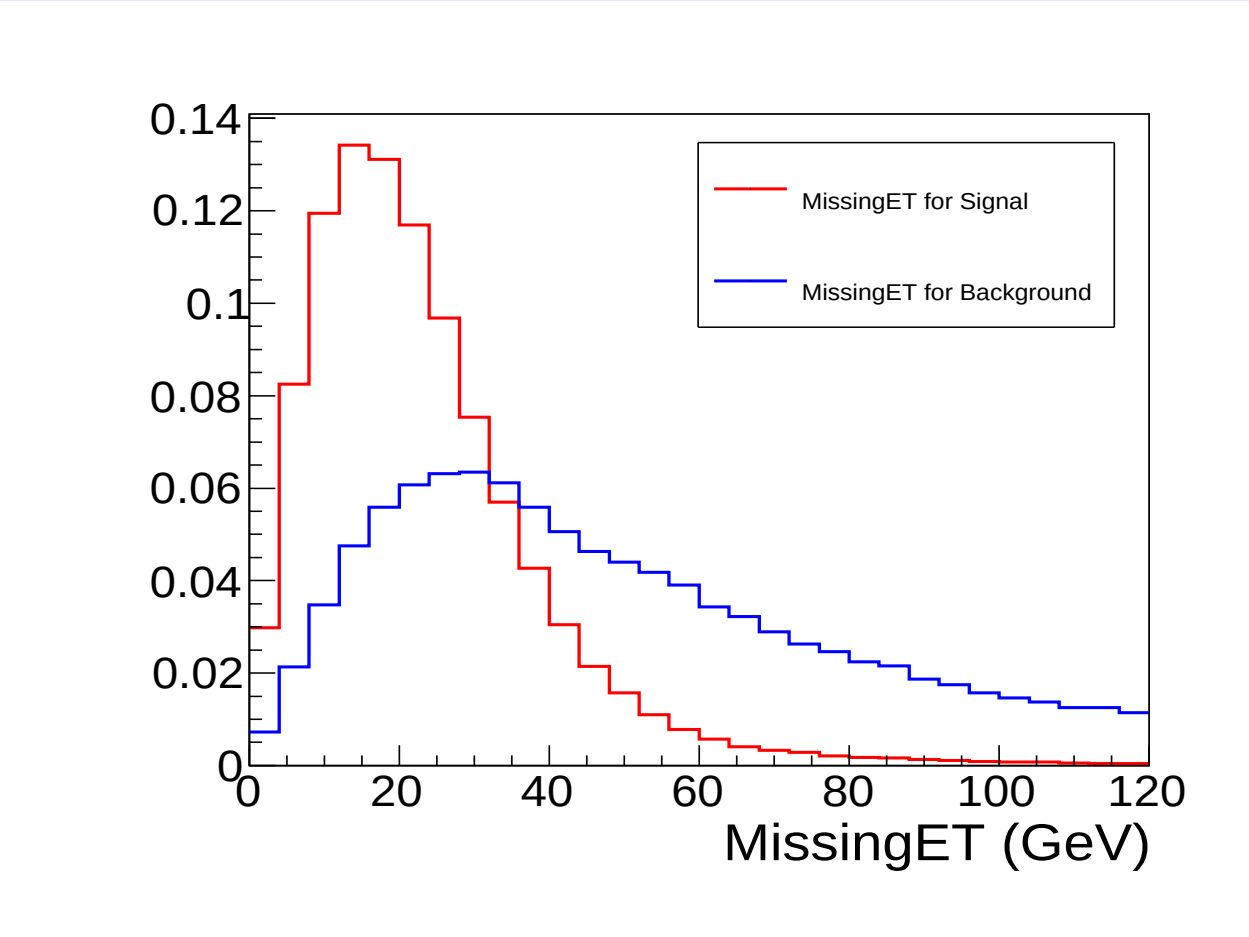
Invariant mass distribution





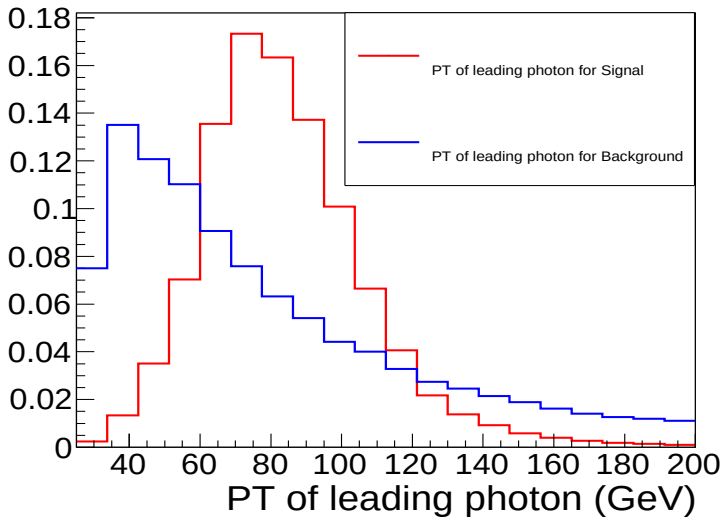
- Invariant mass cuts: $120\text{GeV} < m_{\gamma\gamma} < 130\text{GeV}$ and $65\text{GeV} < m_{qq} < 82\text{GeV}$ to be used.

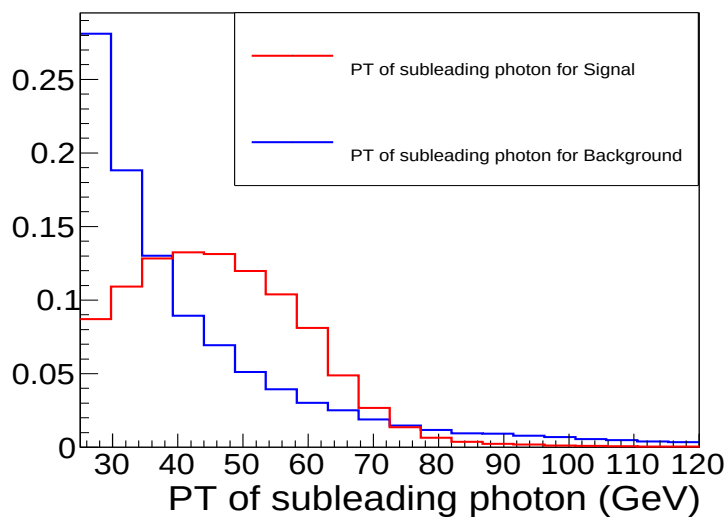
Missing ET distribution

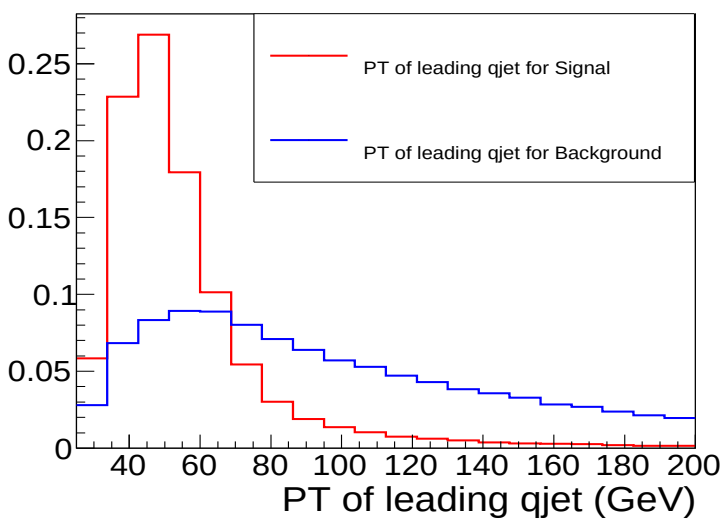


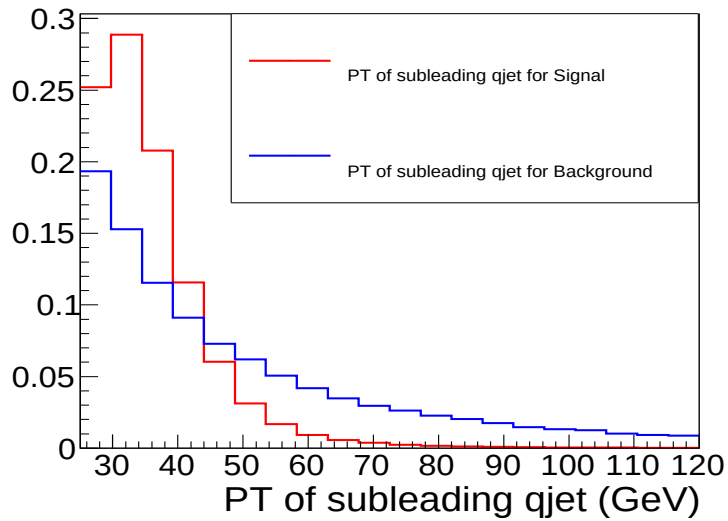
- Missing ET cut: MET < 35GeV to be used.

P_T distribution

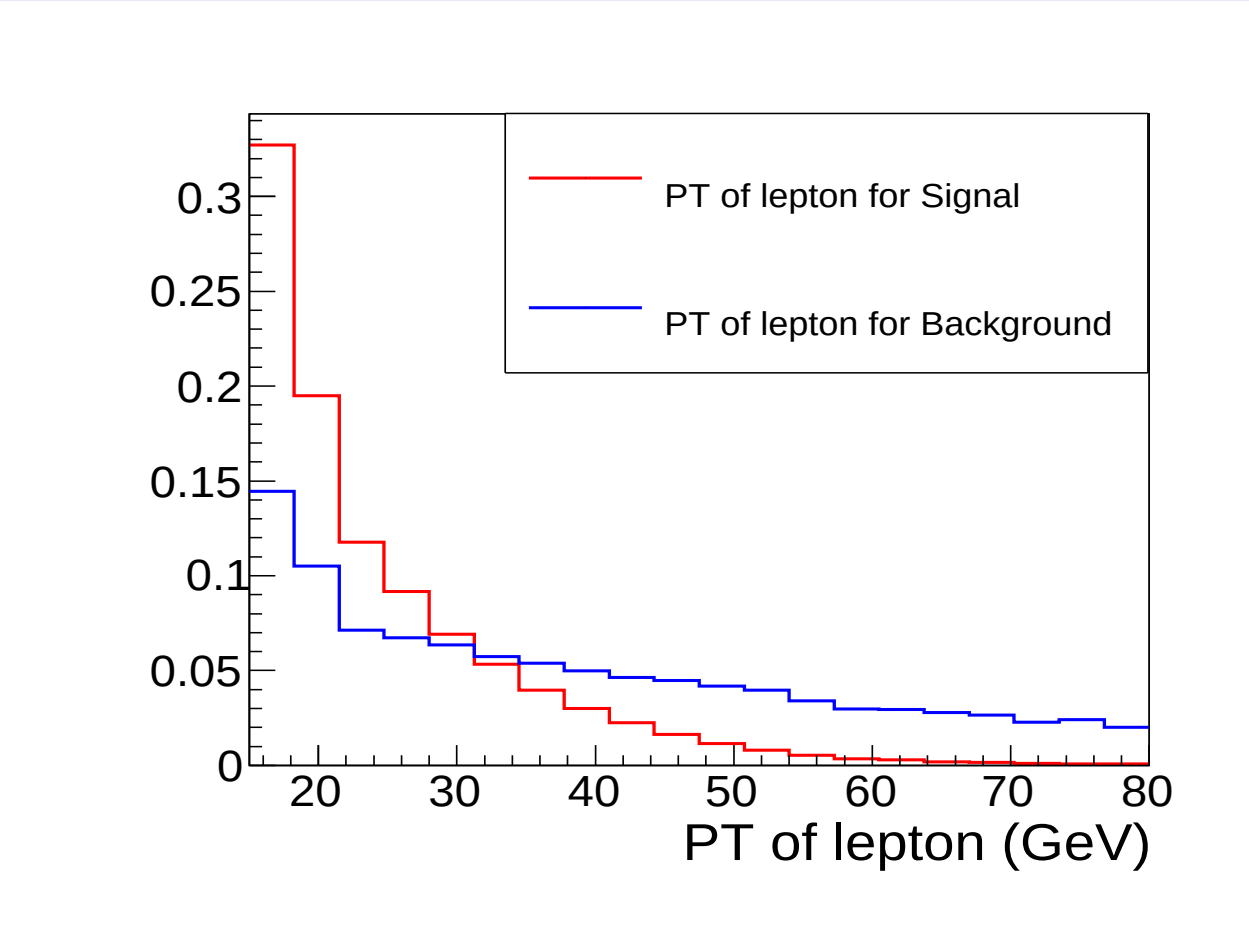




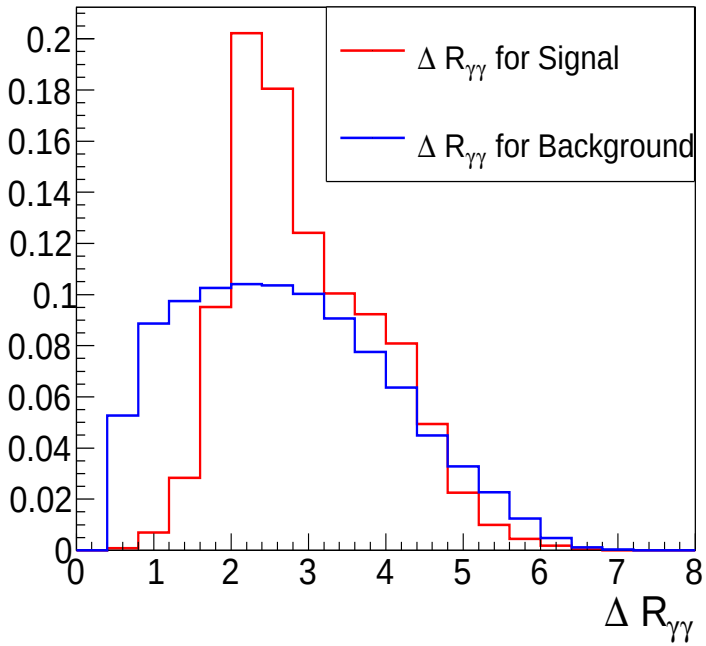


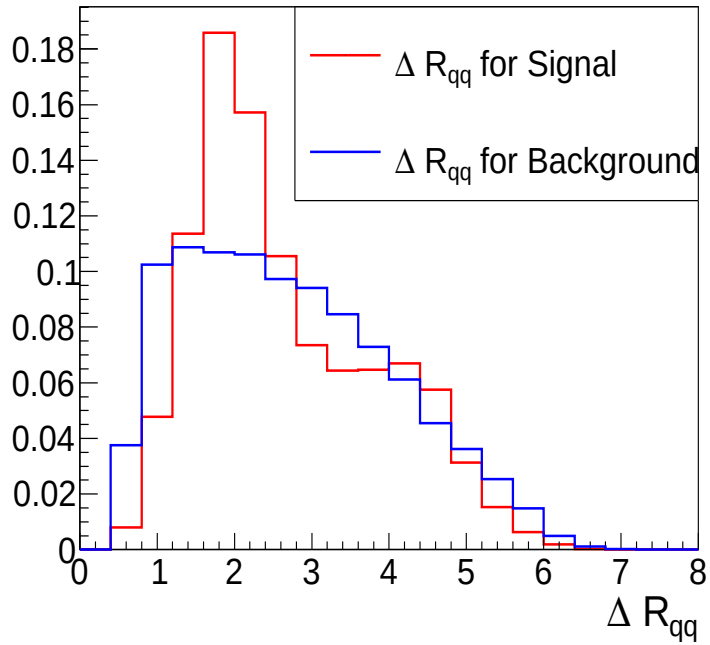


P_T distribution

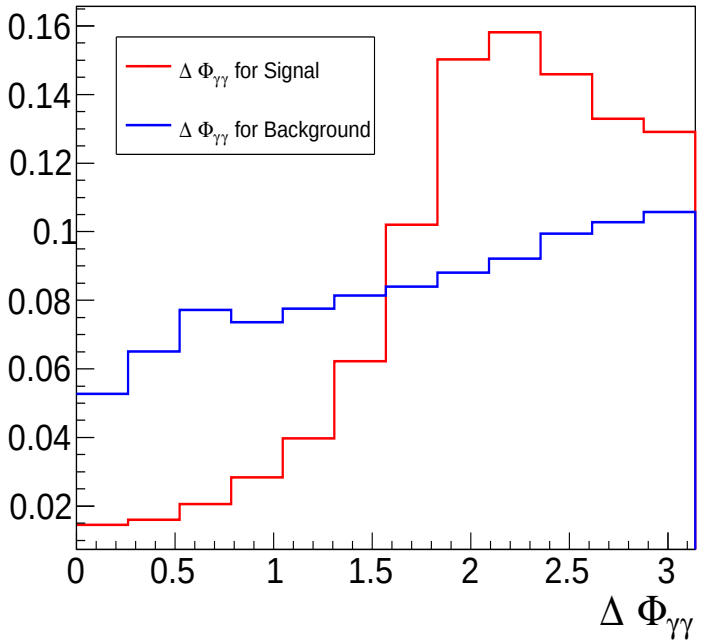


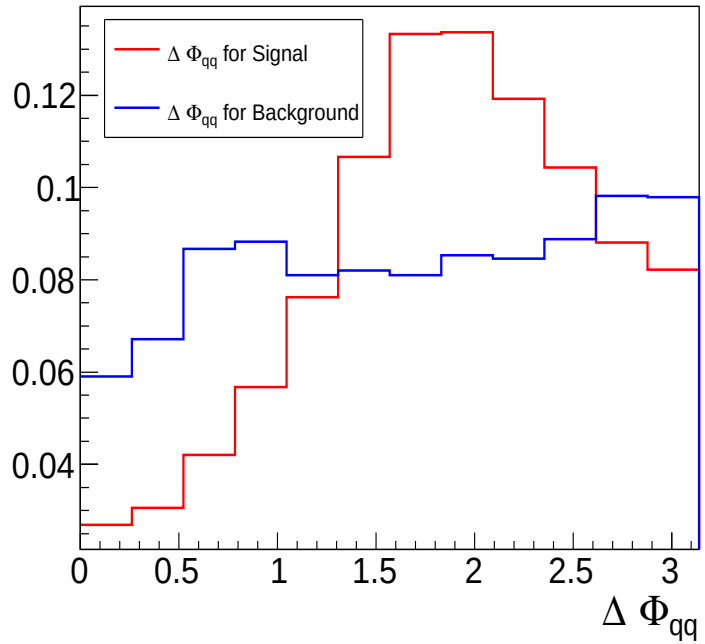
ΔR distribution





$\Delta\Phi$ distribution





- $\Delta\Phi$ cuts: $\Delta\Phi_{\gamma\gamma} > 1.6$ and $1.3 < \Delta\Phi_{qq} < 2.6$ to be used.

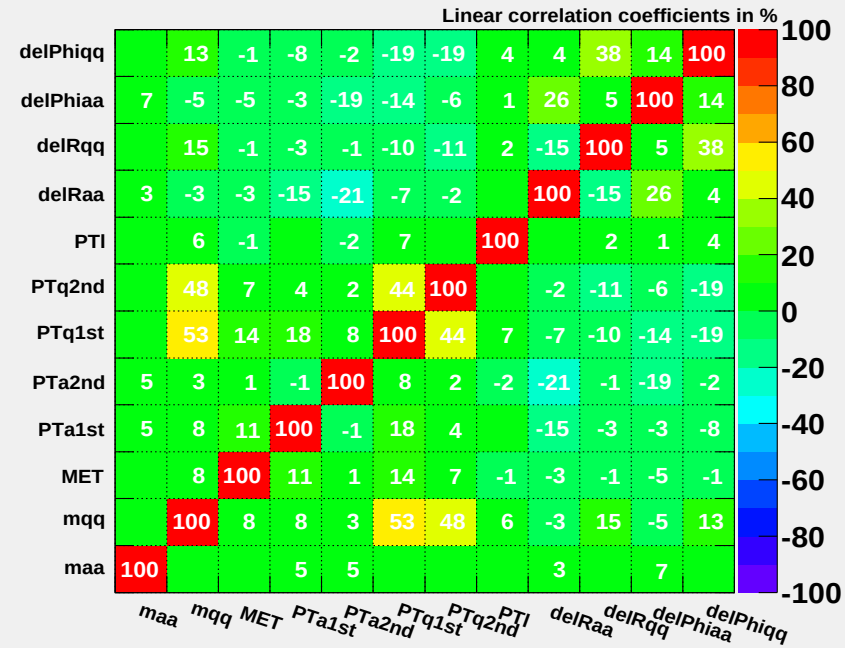
Cut efficiency

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} MET	$\Delta\Phi$
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

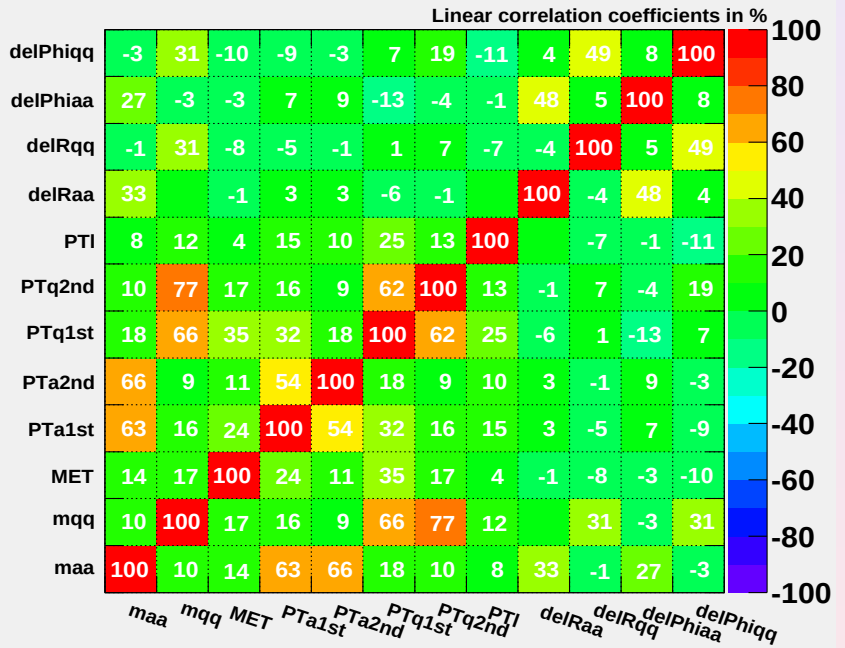
Signif-P: $\sqrt{2\times\Big\{(S+B)\times\ln[(S+B)/B\,]-S\Big\}}$. Integrate luminosity is assumed to be [1] $\int\mathcal{L}dt = 1000$ fb^{-1} and [2] $\int\mathcal{L}dt = 5000$ fb^{-1}.

- BDT method

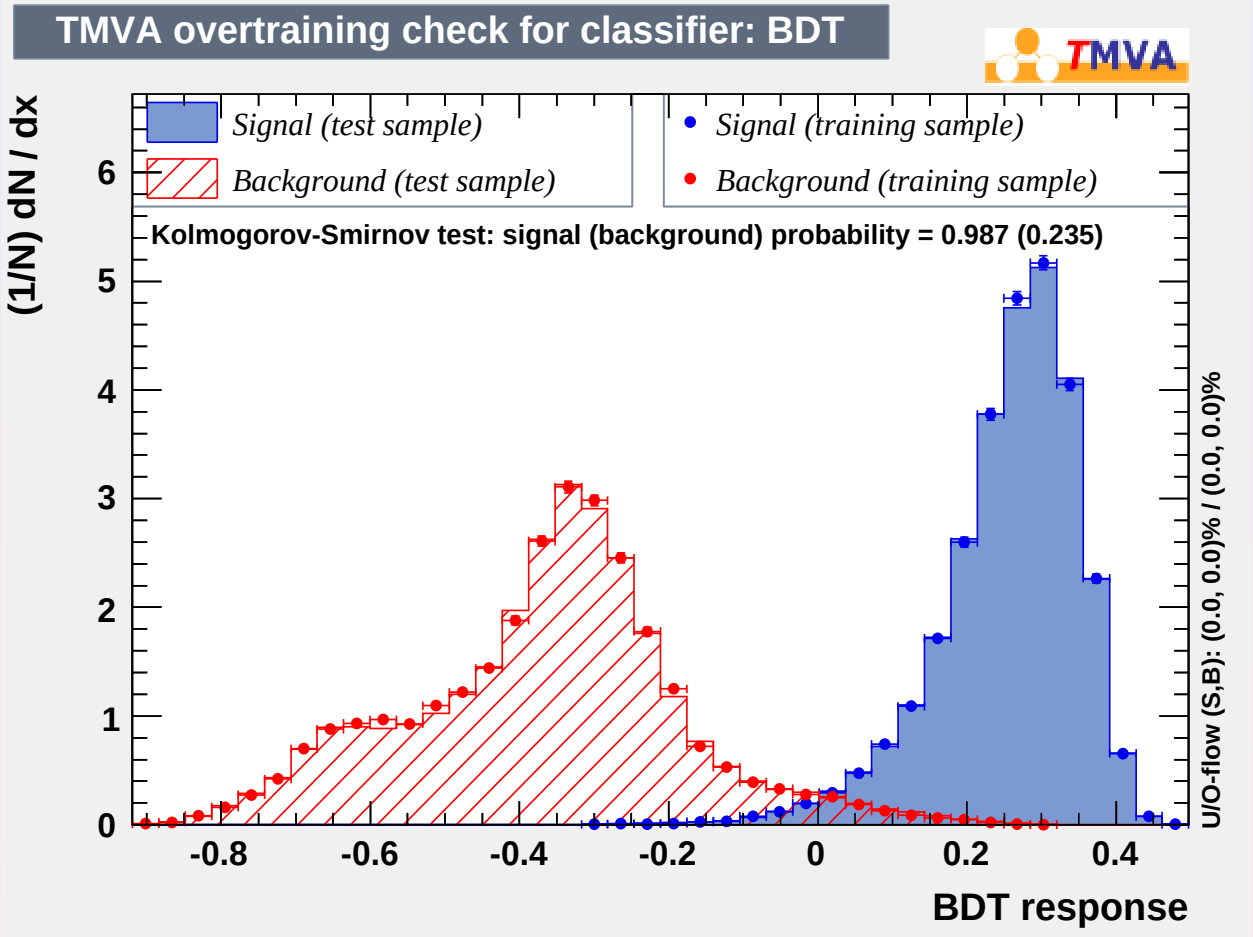
Correlation Matrix (signal)

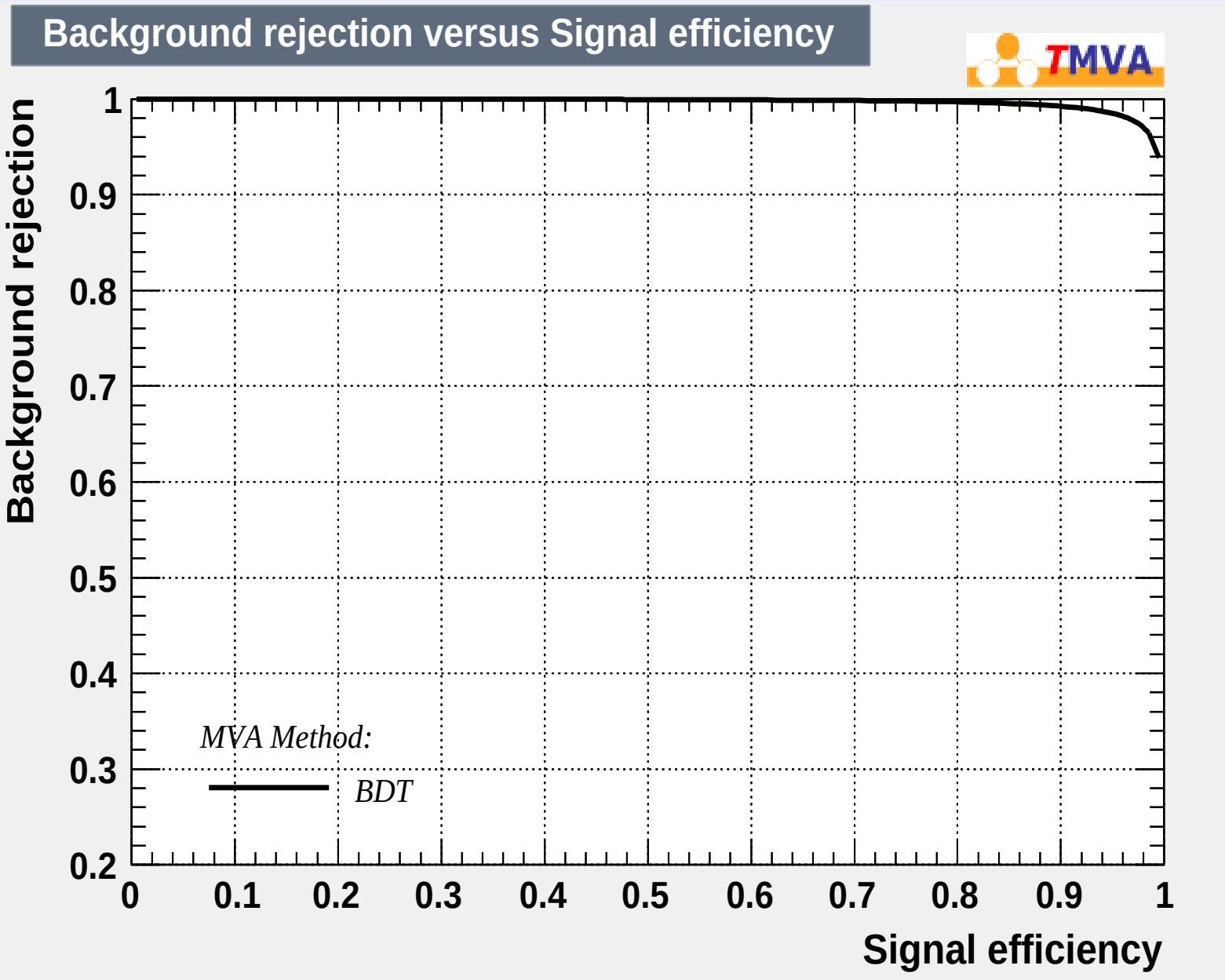


Correlation Matrix (background)

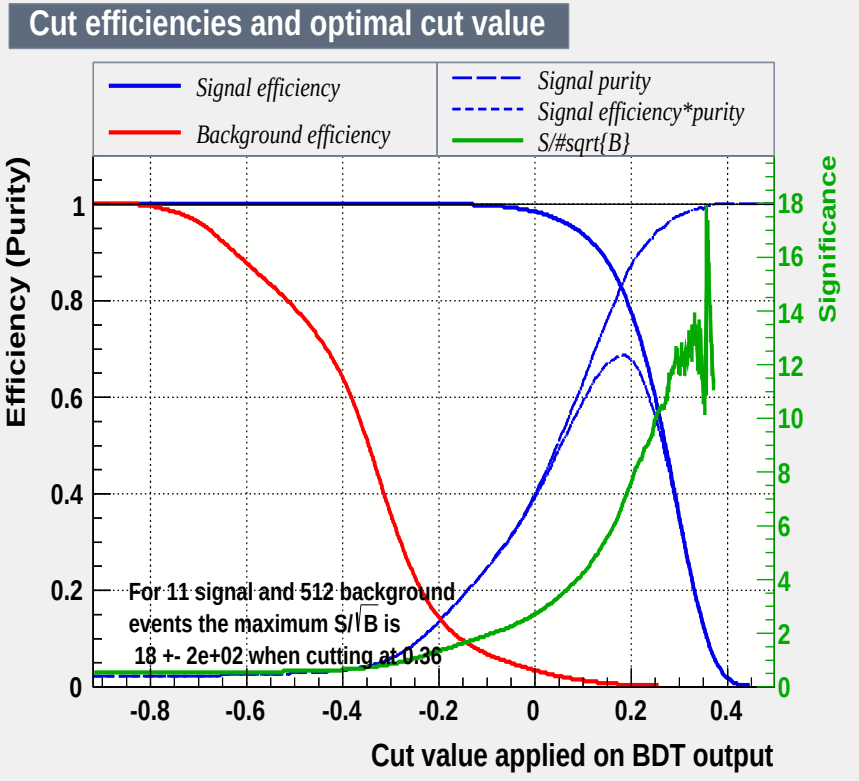


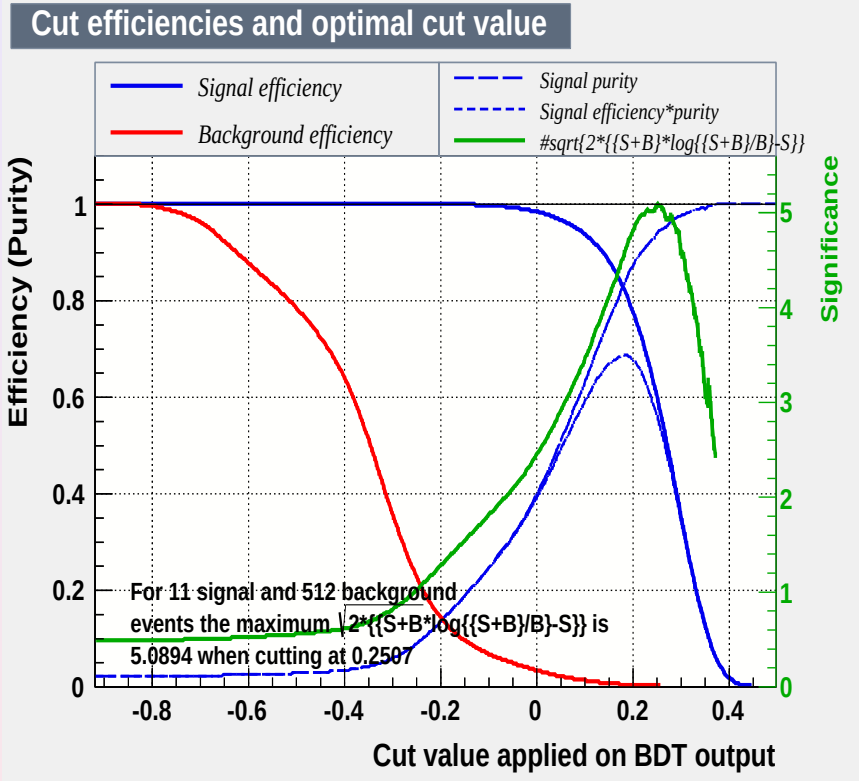
- Overtraining check



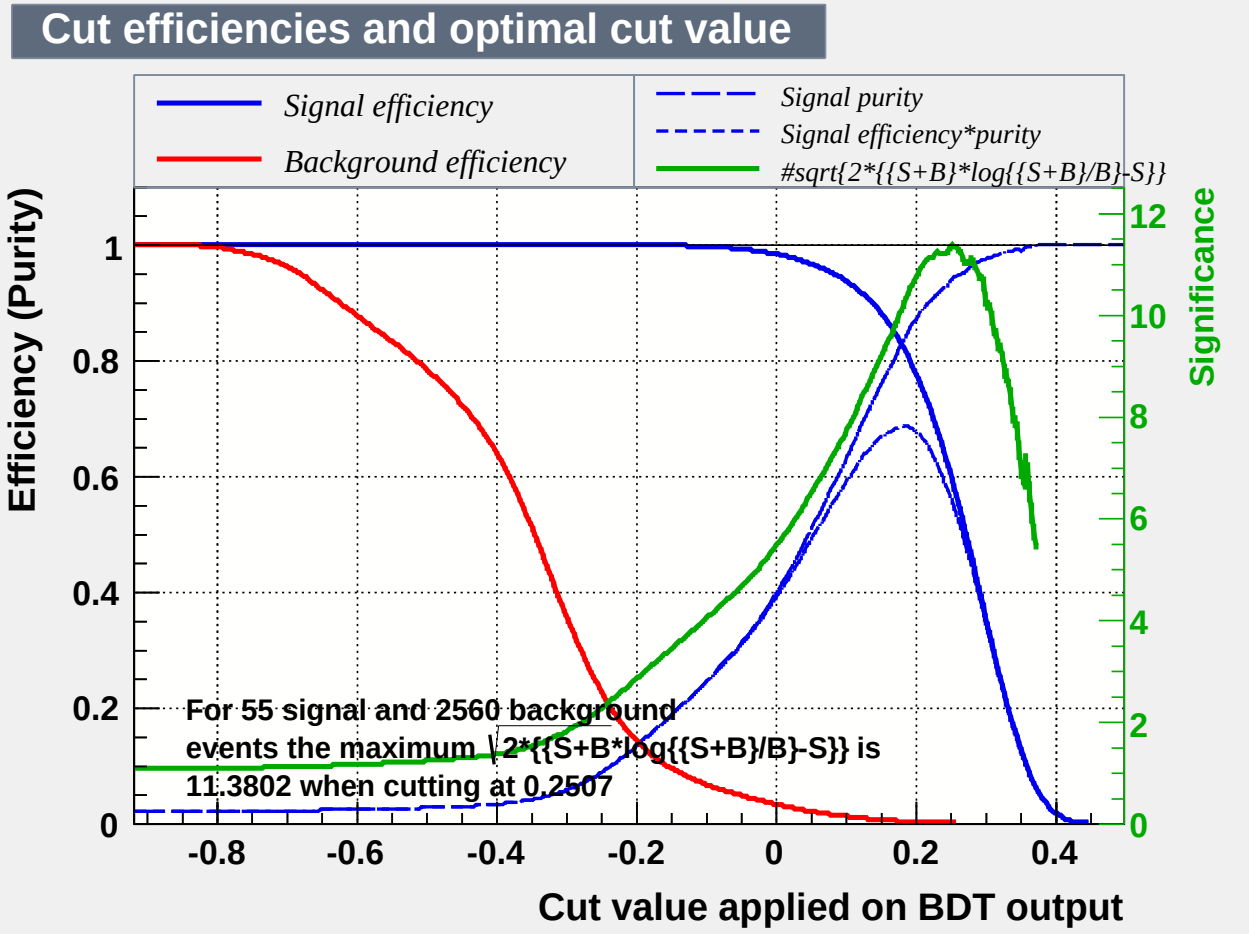

Background rejection versus Signal efficiency
TMVA
Background rejection
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Signal efficiency
MVA Method:
BDT

MVA analysis



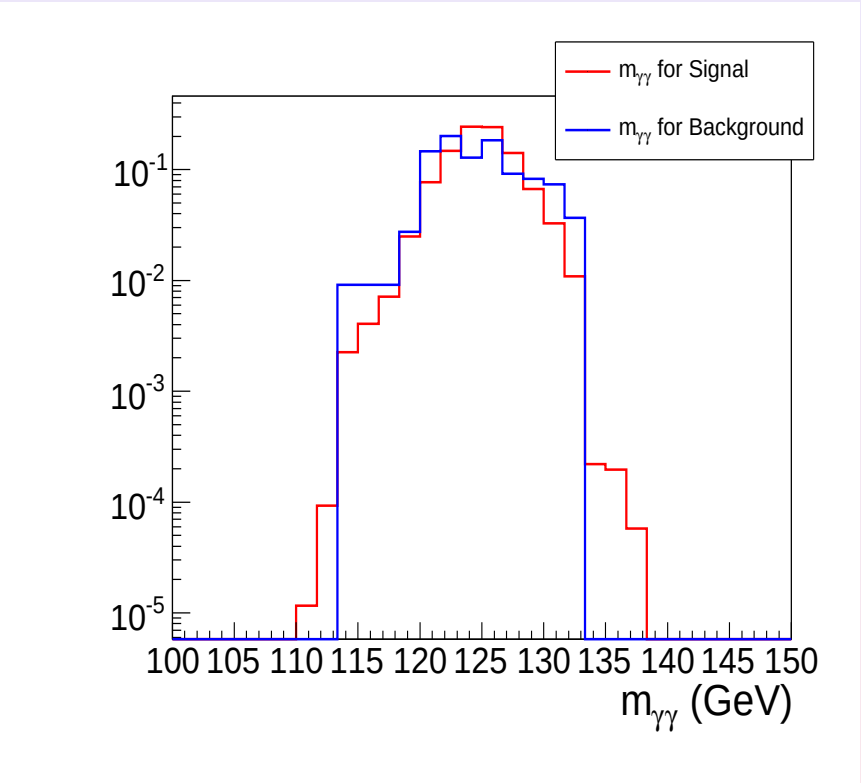


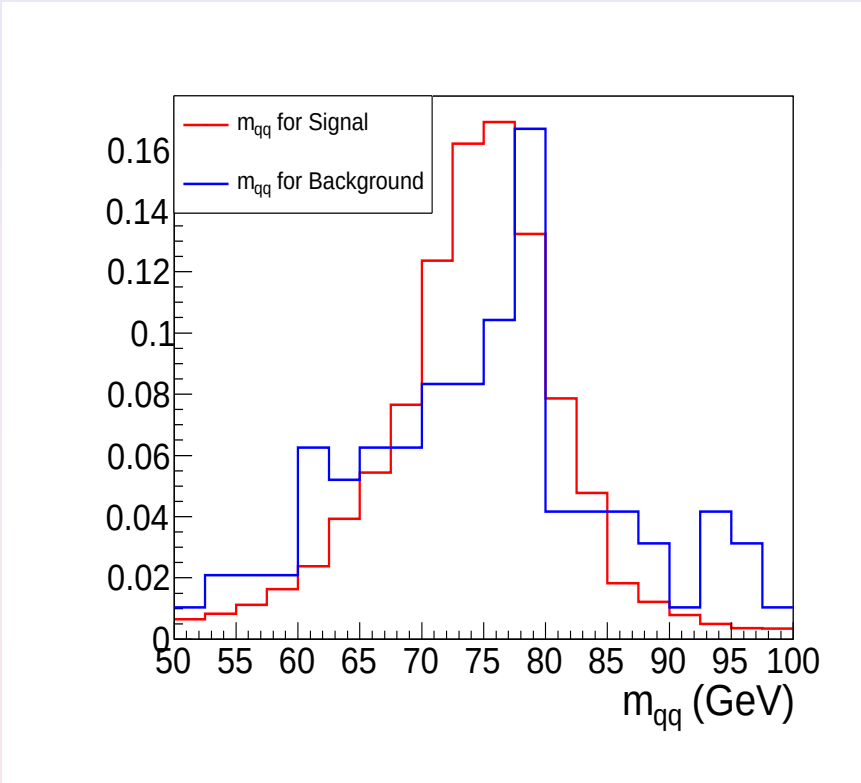
$\int \mathcal{L} dt = 1000\ \text{fb}^{-1}$. BDT cut: BDT ≥ 0.2507.



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

Invariant mass distribution after BDT





$$\text{BDT} \geq 0.2507.$$