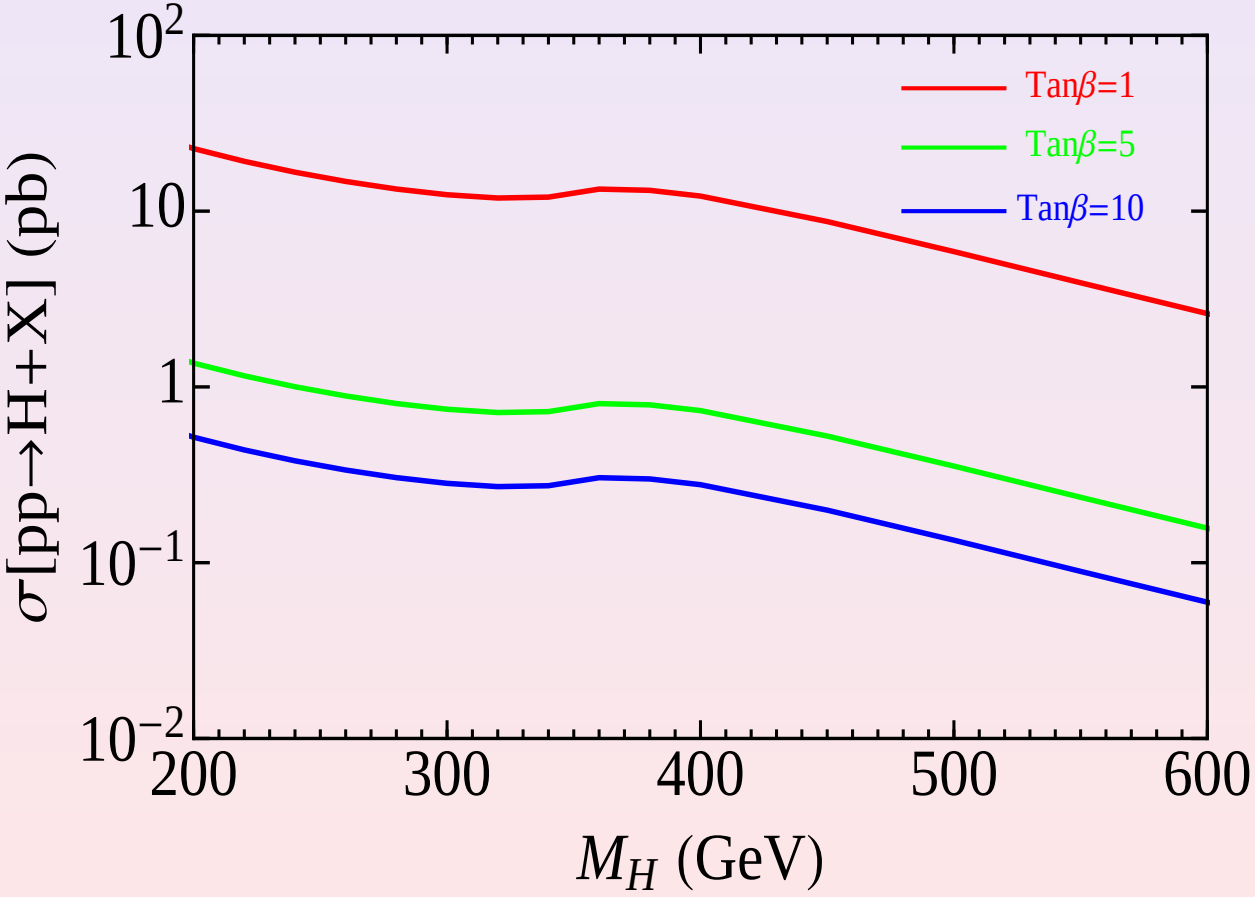
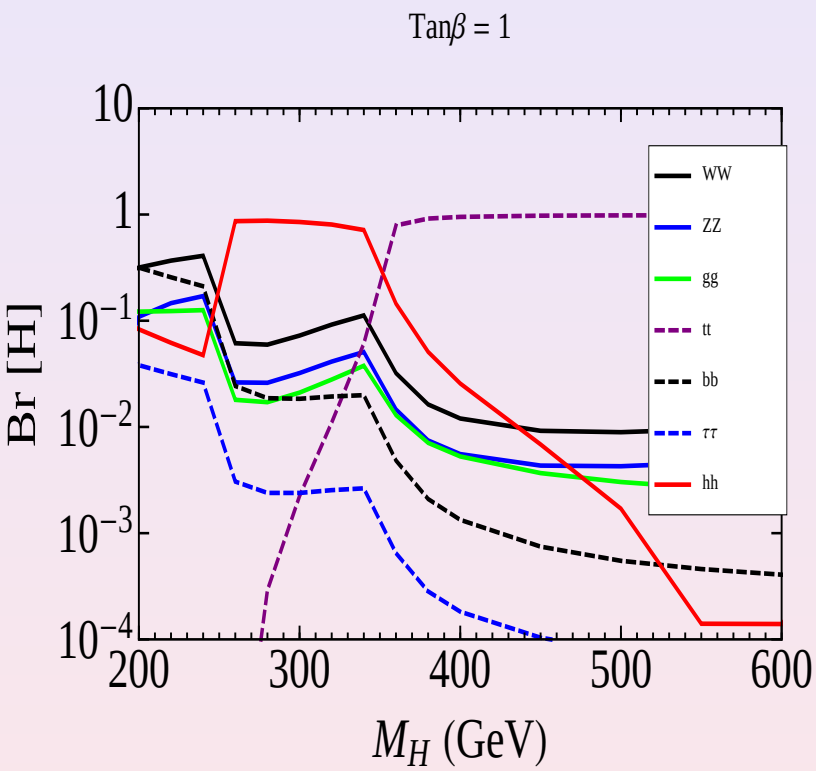
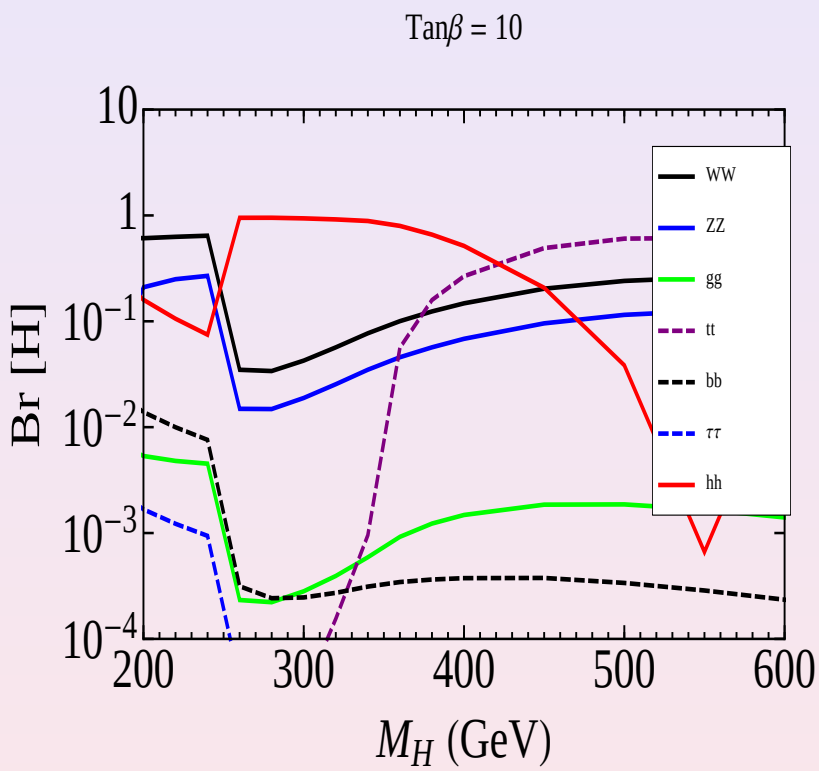
The 2HDM-I heavier CP-even Higgs production

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

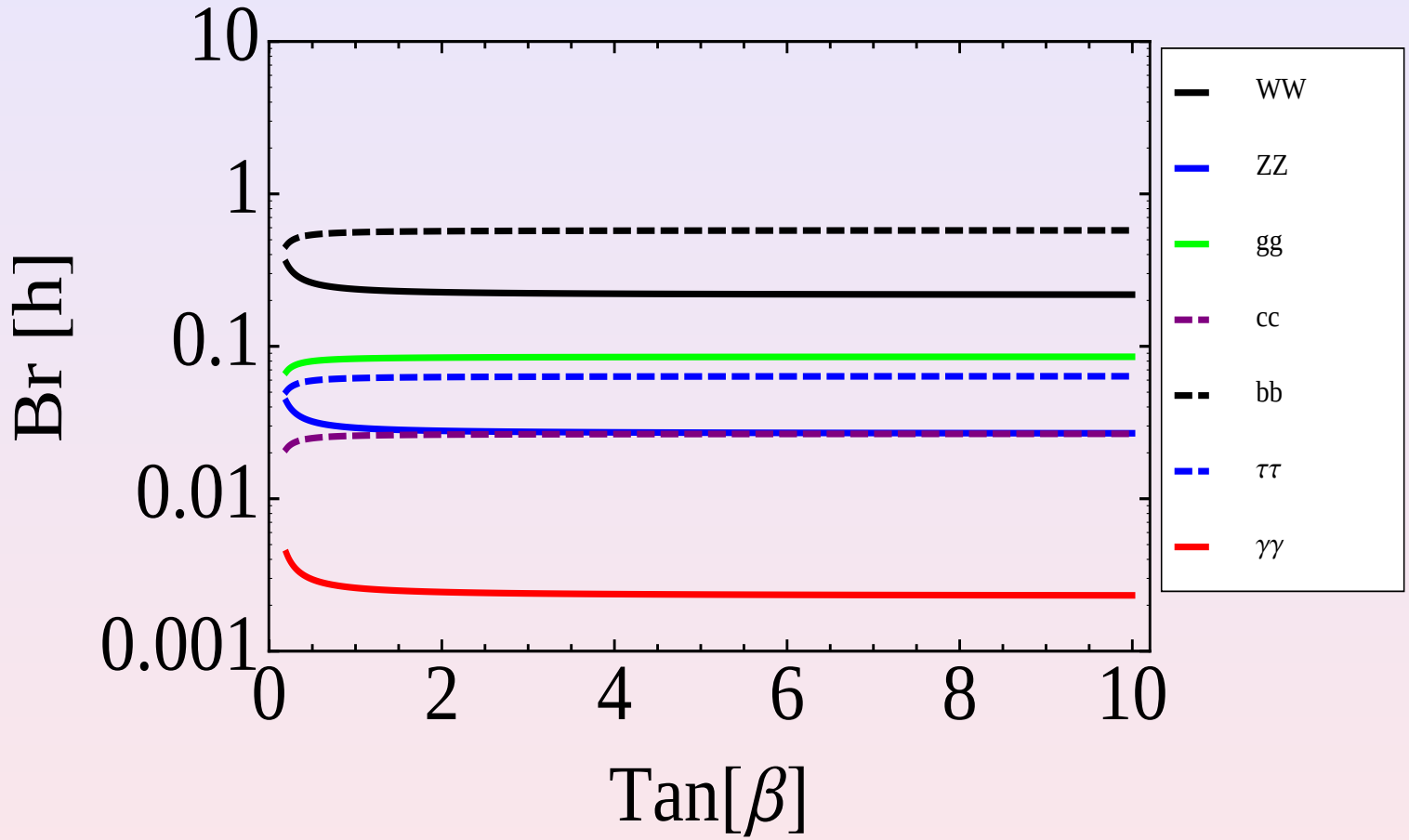


The 2HDM-I heavier CP-even Higgs Br



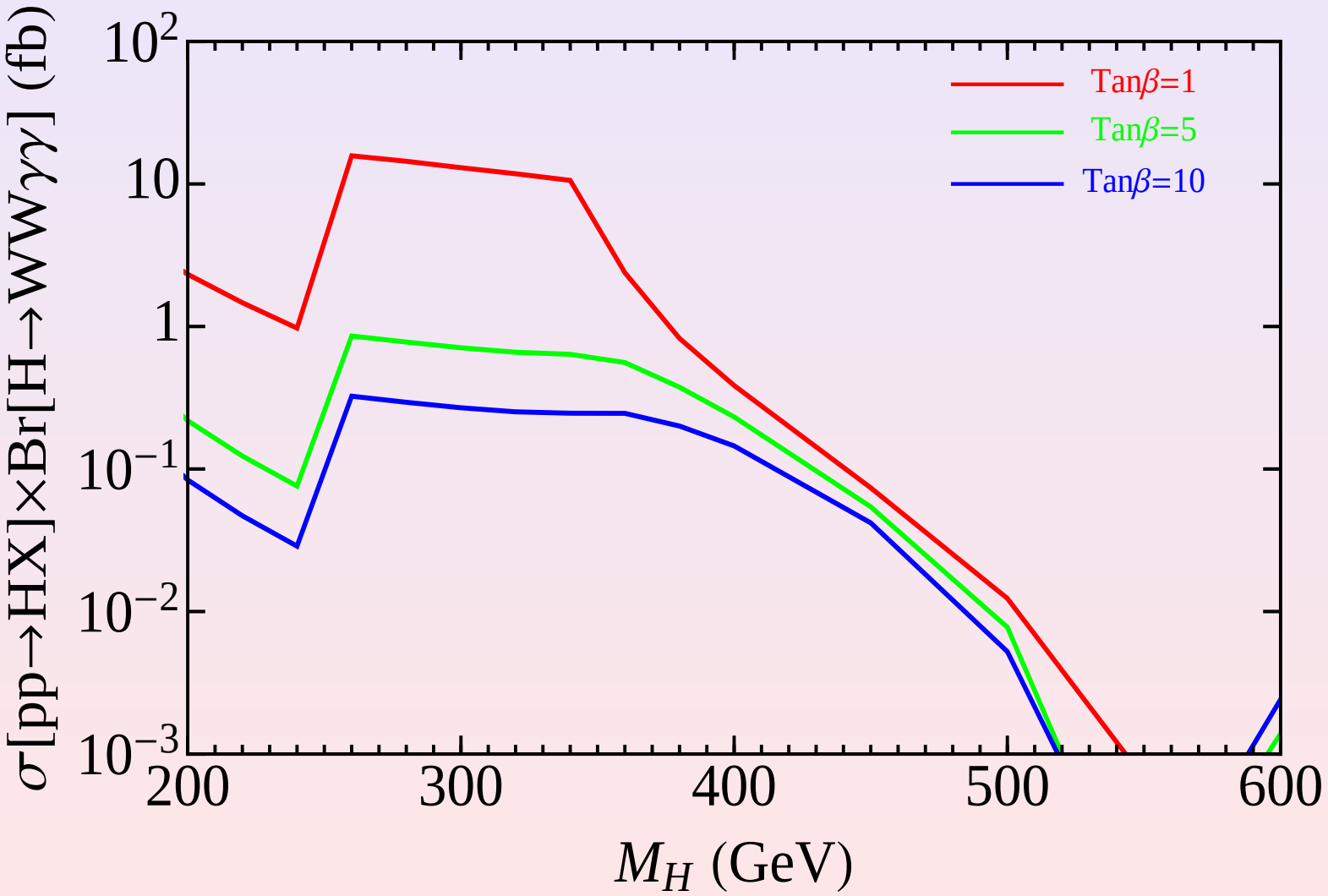


The 2HDM-I 125GeV Higgs Br



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: $0.38 \times 67.6\%^2 \times 2 \simeq 0.35$;

  leptonic decay: $0.38 \times (3 \times 10.8\%)^2 \times 2 \simeq 0.08$;

  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:

$$p\ p\ \to\ q\ q\ \ell\ \nu\ \gamma\ \gamma \text{ (domination).}$$

reducible background:

$$p\ p\ \to\ q\ q\ \ell\ \nu\ g\ g$$
$$p\ p\ \to\ q\ q\ \ell\ \nu\ g\ q$$
$$p\ p\ \to\ q\ q\ \ell\ \nu\ q\ q$$
$$p\ p\ \to\ q\ q\ \ell\ \nu\ q\ \gamma$$
$$p\ p\ \to\ q\ q\ \ell\ \nu\ g\ \gamma$$

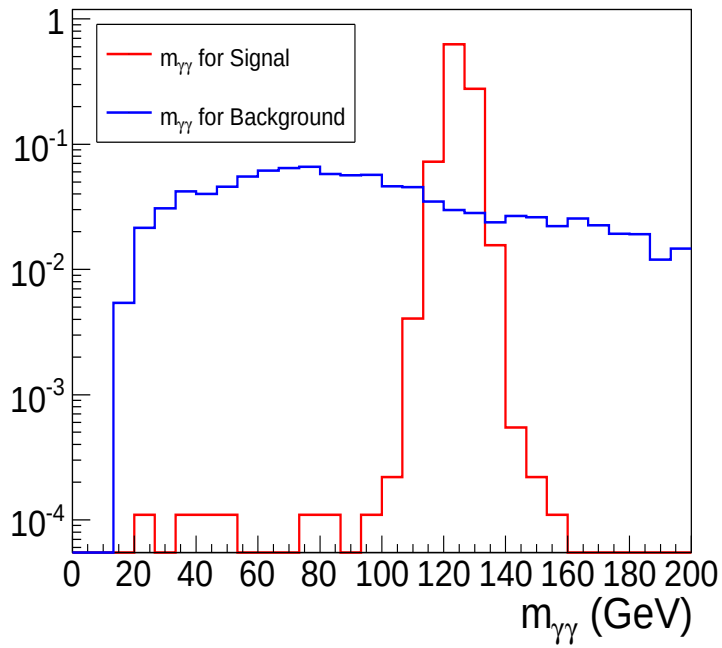
with photon identification efficiencies:

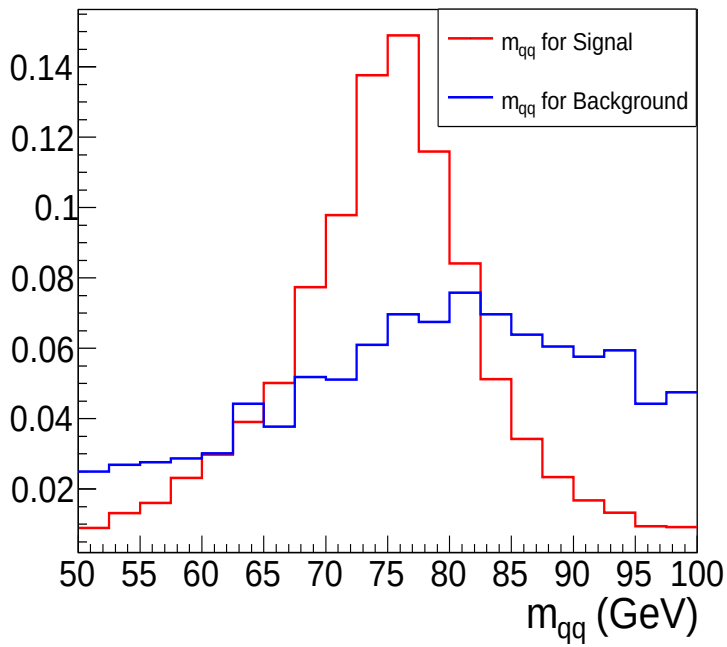
$$\epsilon_{q\to\gamma} \approx 3.6 \times 10^{-4}\,, \quad \epsilon_{g\to\gamma} \approx 3.6 \times 10^{-5}\,.$$

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.

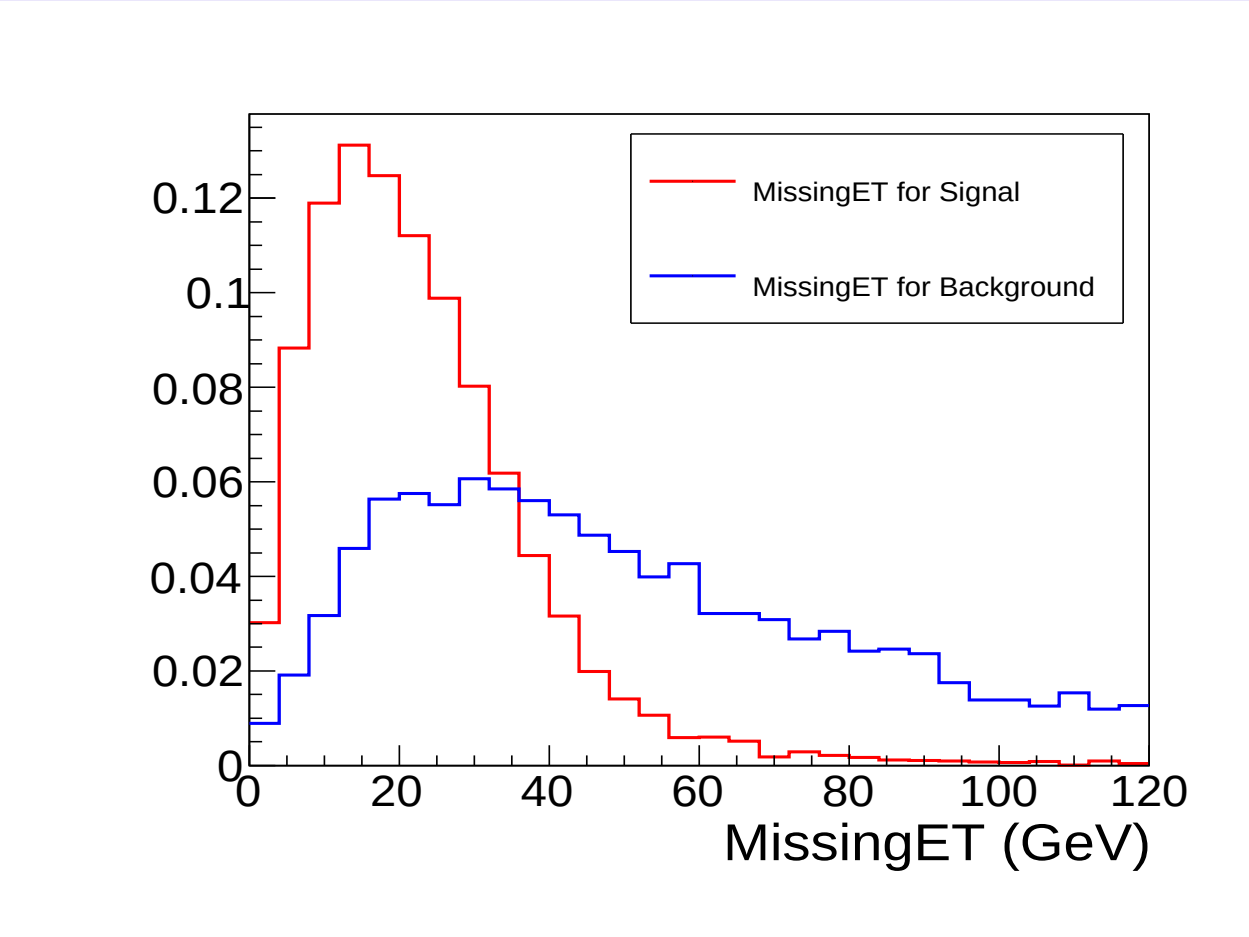
Invariant mass distribution





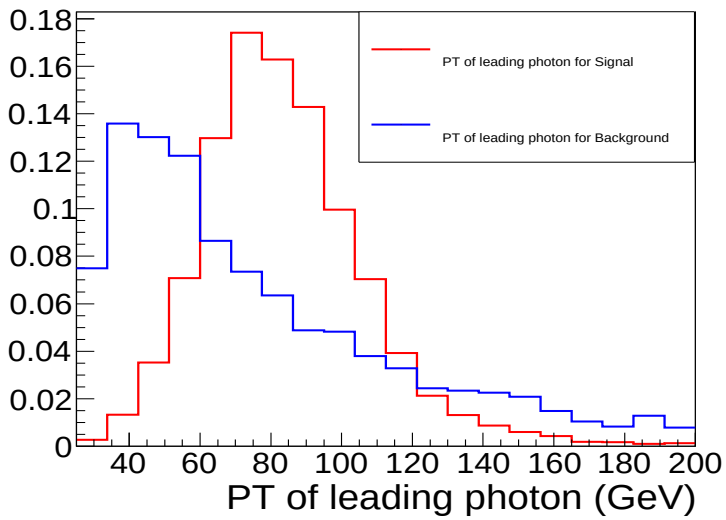
- Invariant mass cuts: $120\text{GeV} < m_{\gamma\gamma} < 130\text{GeV}$ and $70\text{GeV} < m_{qq} < 82\text{GeV}$ to be used.

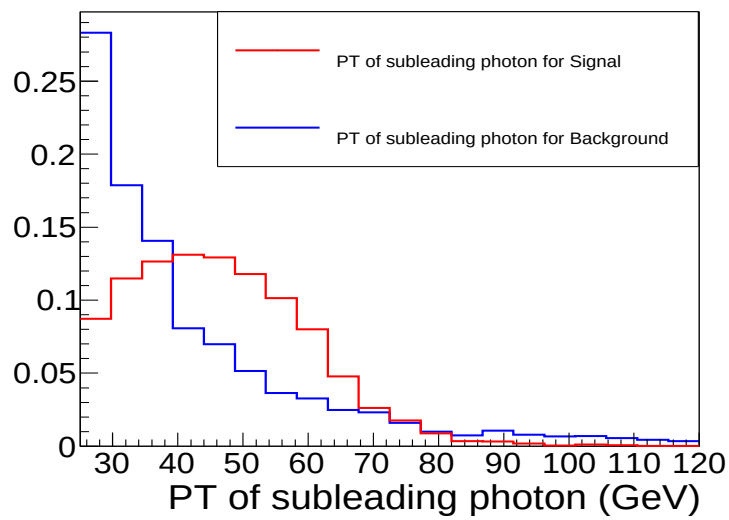
Missing ET distribution

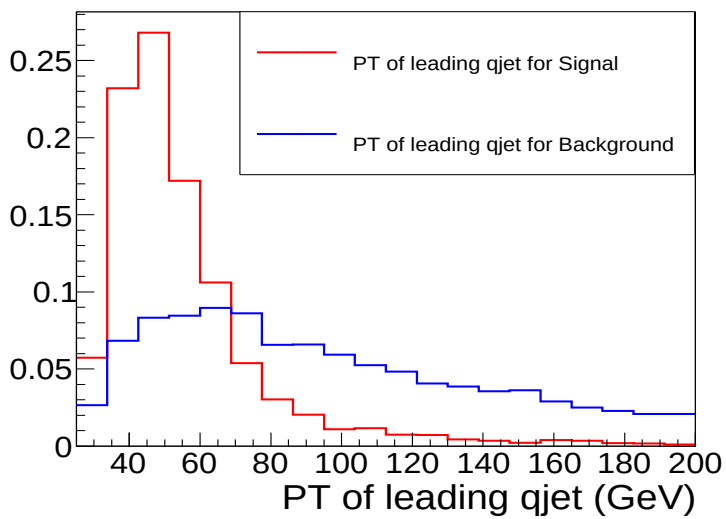


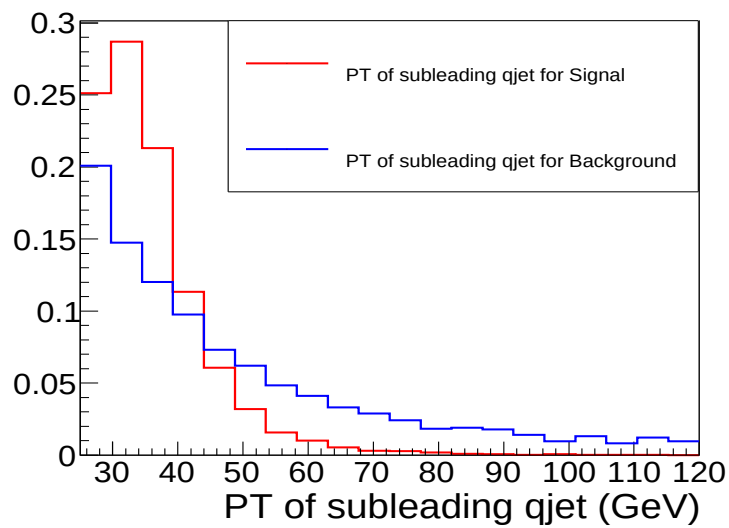
- Missing ET cut: MET < 35GeV to be used.

P_T distribution

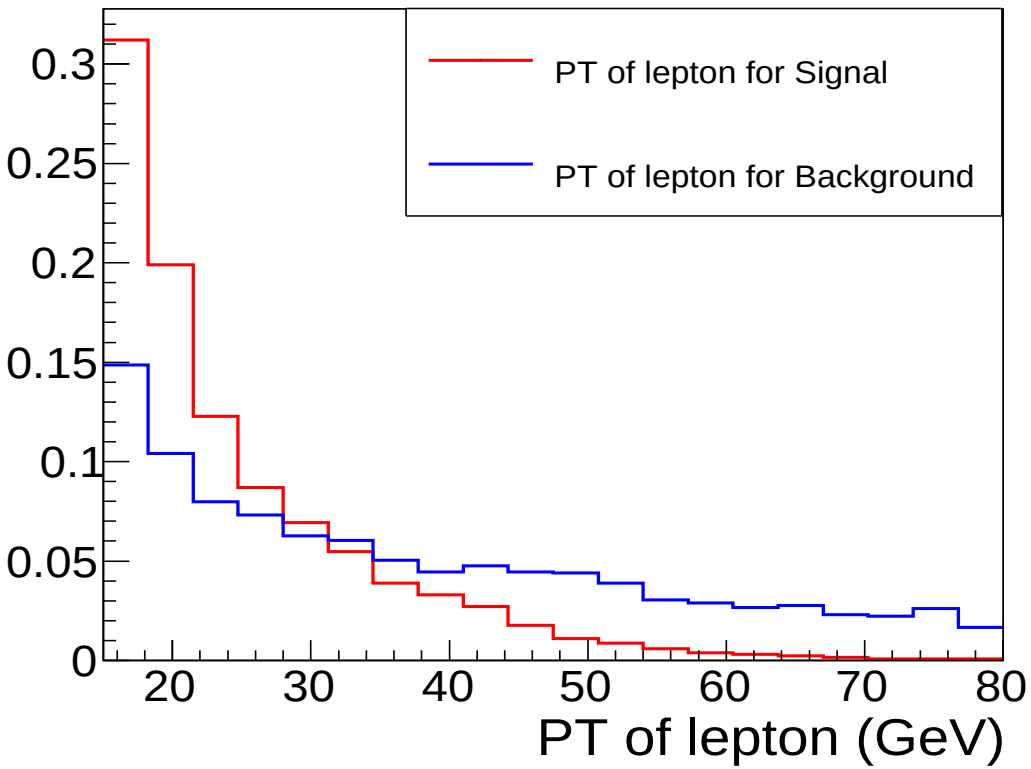




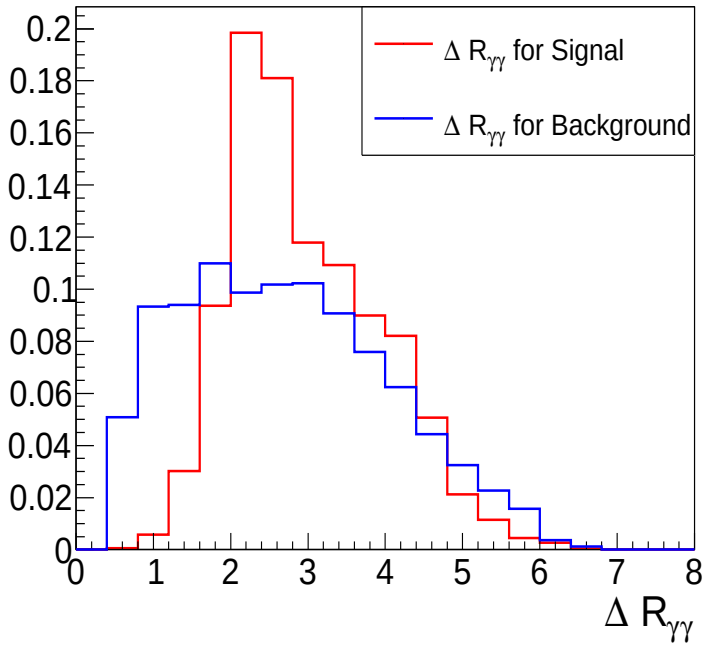


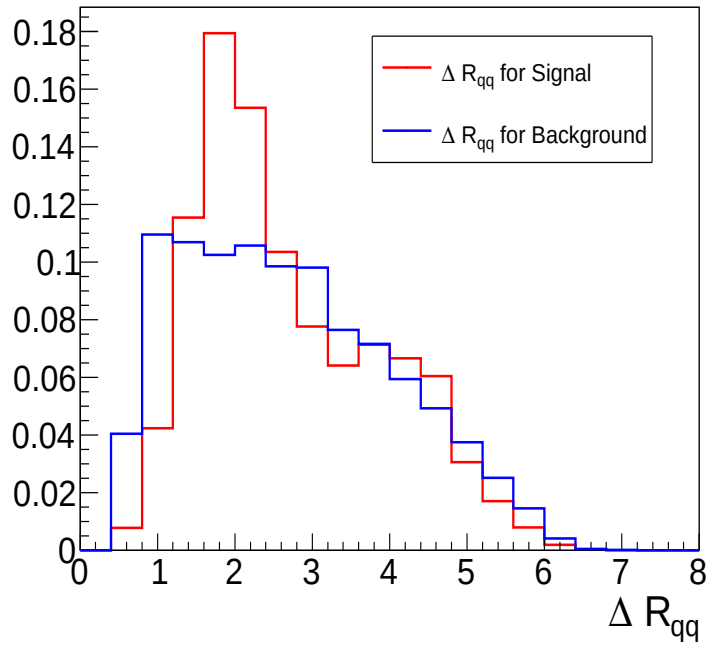


P_T distribution

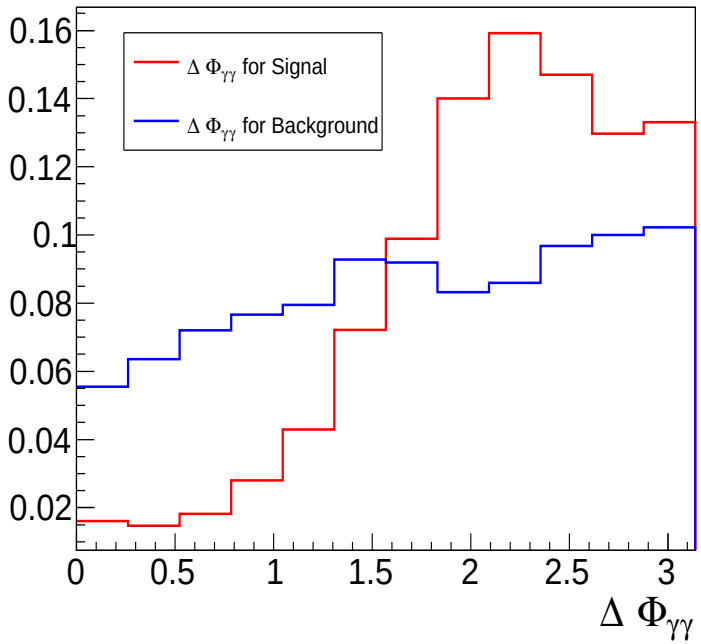


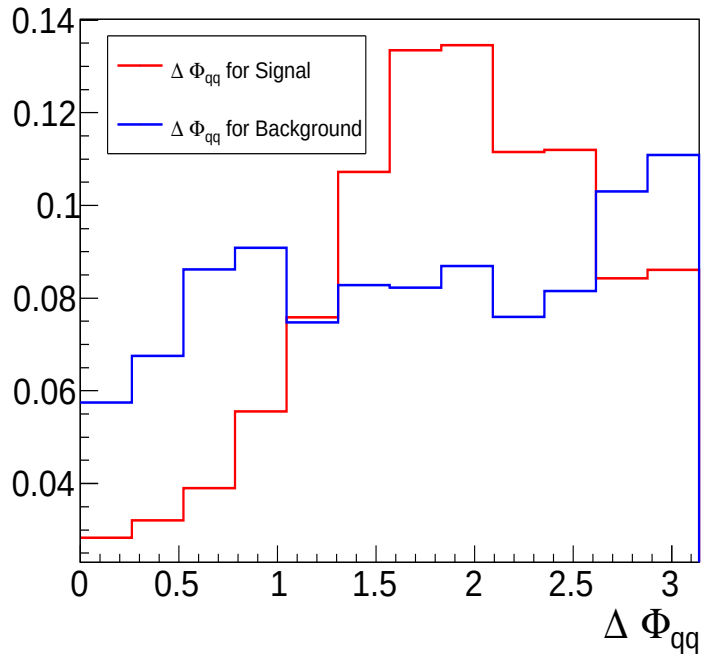
ΔR distribution





$\Delta\Phi$ distribution



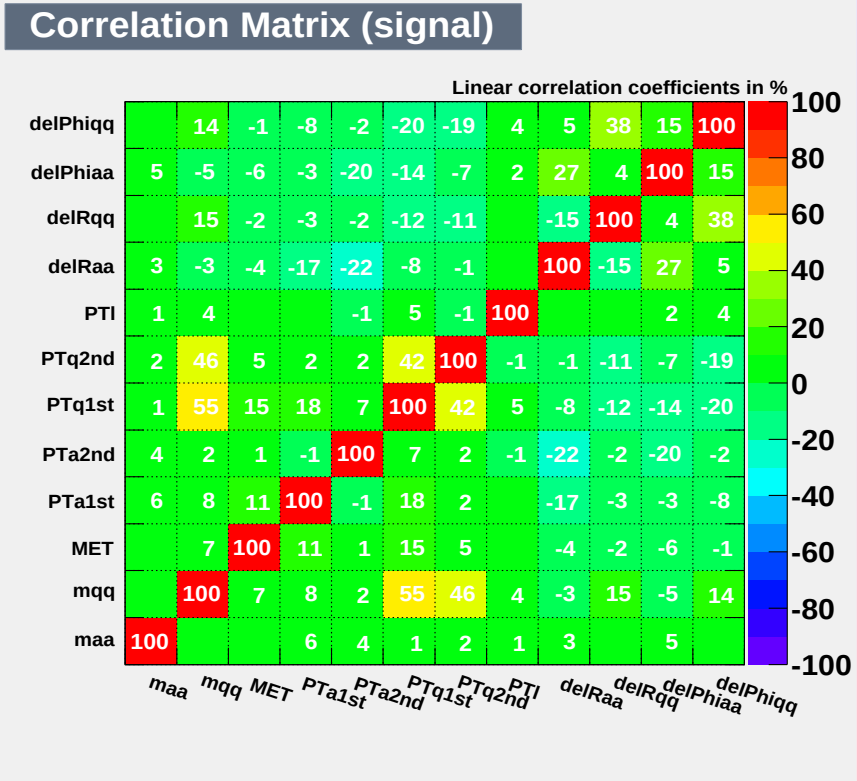


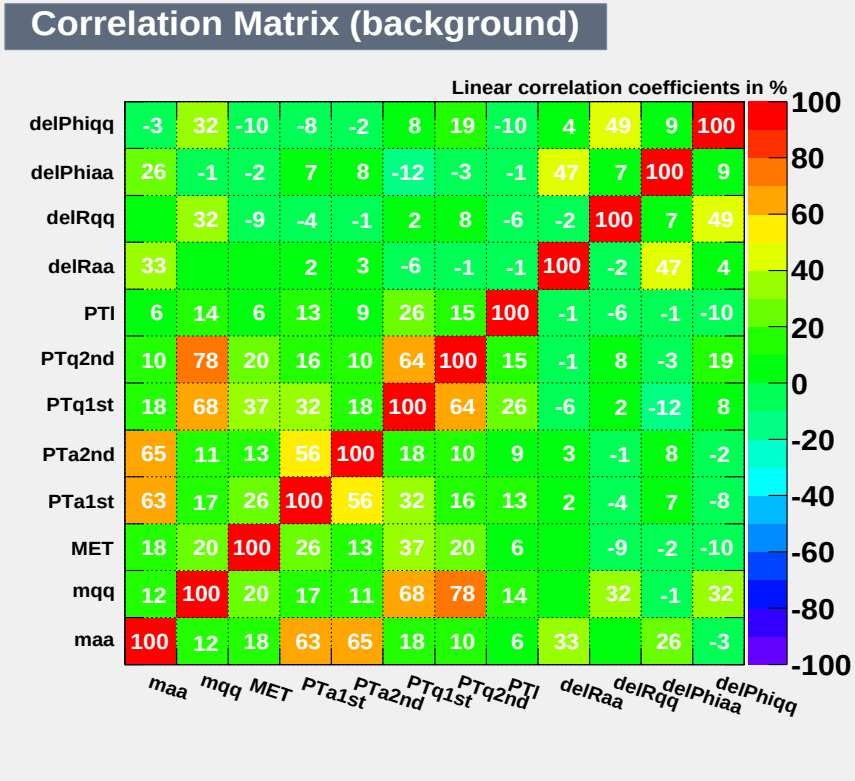
Cut efficiency

Cuts	σ_{total}	Events selection	$m_{\gamma\gamma}$ m_{qq} MET	BDT
Signal [fb]	0.17	0.011	0.0042	
$qq\ell\nu\gamma\gamma$[fb]	31.59	0.512	0.0008	
S/B	0.005	0.022	5.6	
$S/\sqrt{B}$	0.96	0.50	4.9	

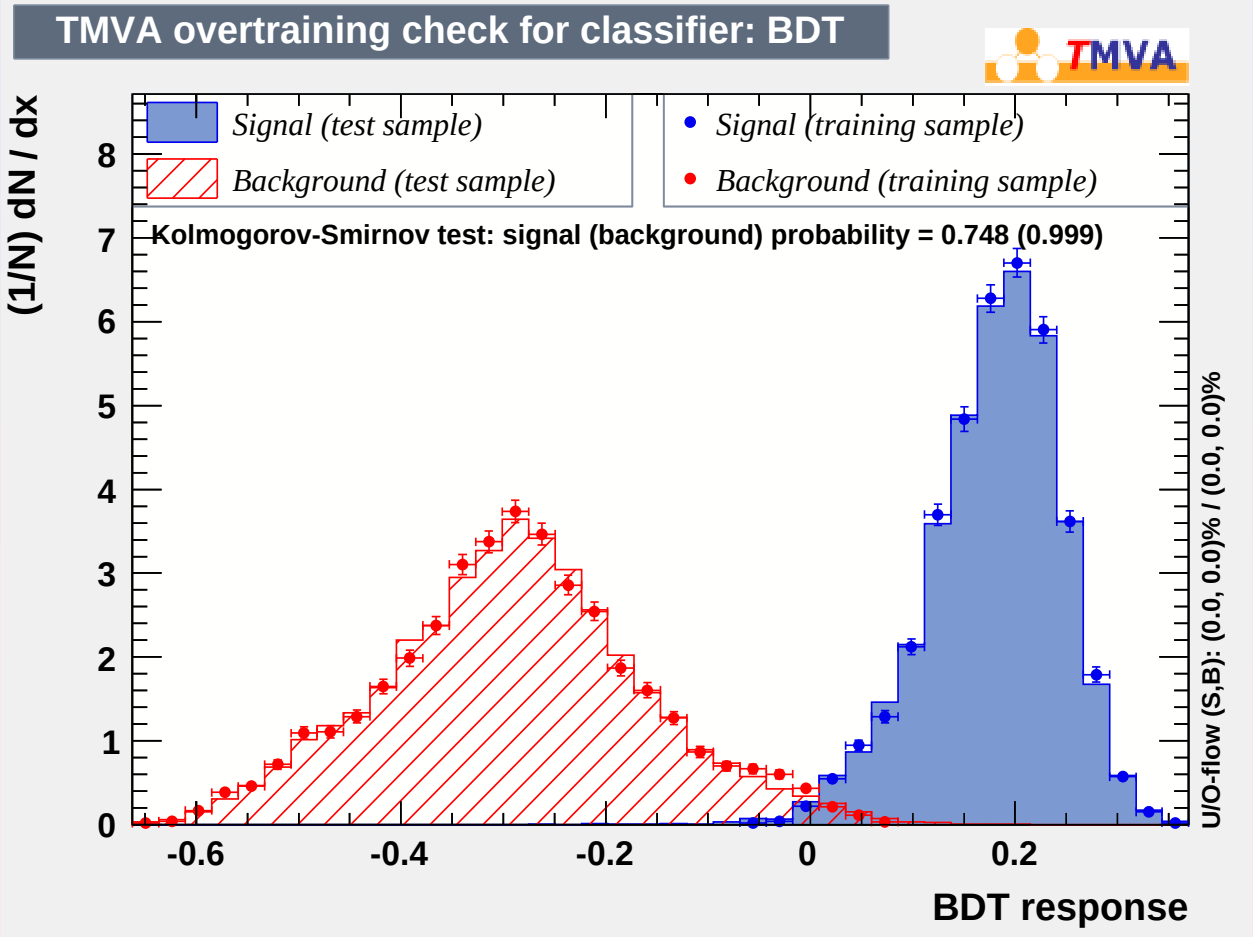
The event cut efficiency for LHC 14 TeV run of the signal($p\ p \to H \to h\ h \to\ W\ W\ \gamma\ \gamma \to q\ q\ \ell\ \nu\ \gamma\ \gamma$) and background processes. Integrate luminosity is assumed to be $\int \mathcal{L} dt = 5000\ \text{fb}^{-1}$.

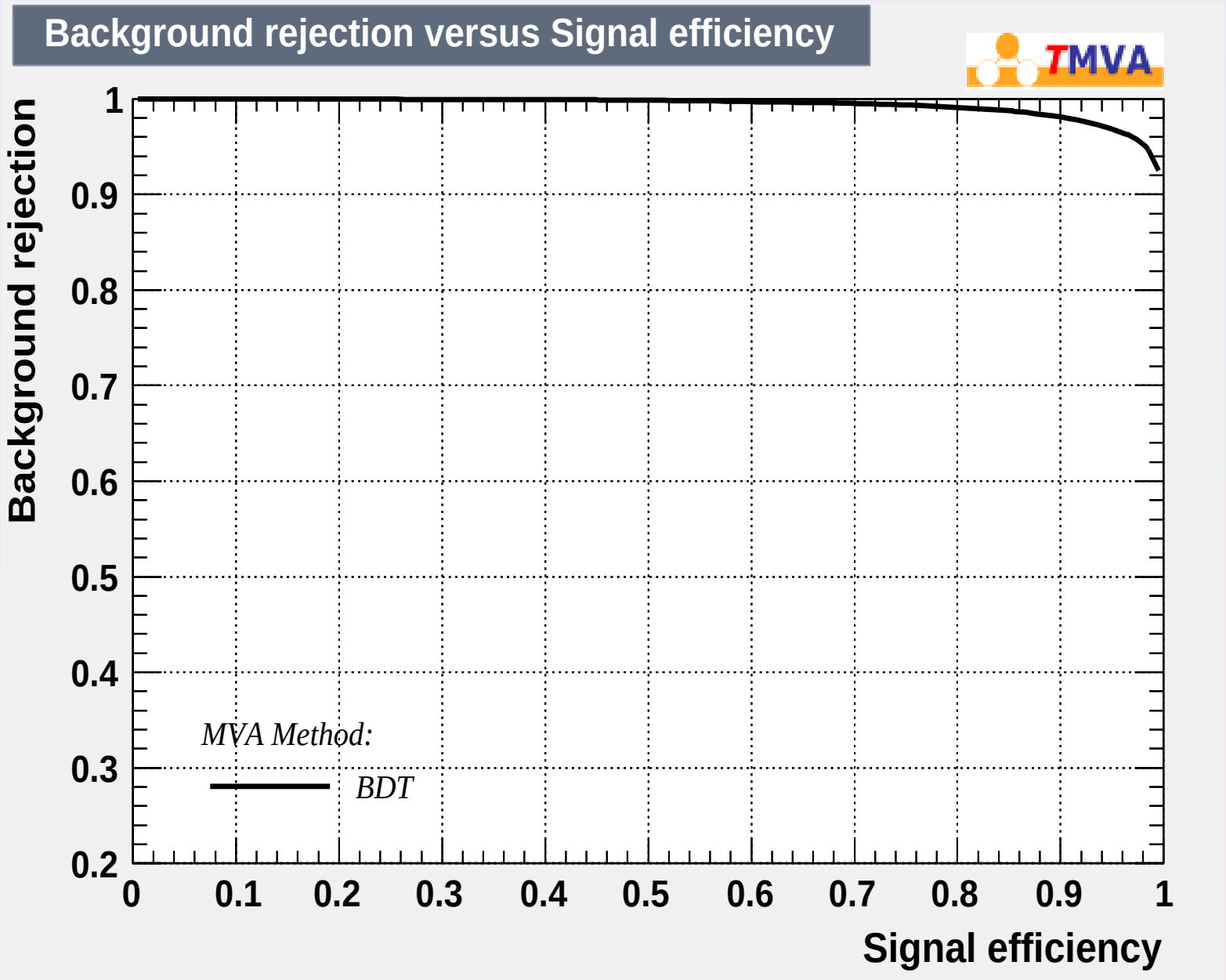
- BDT method

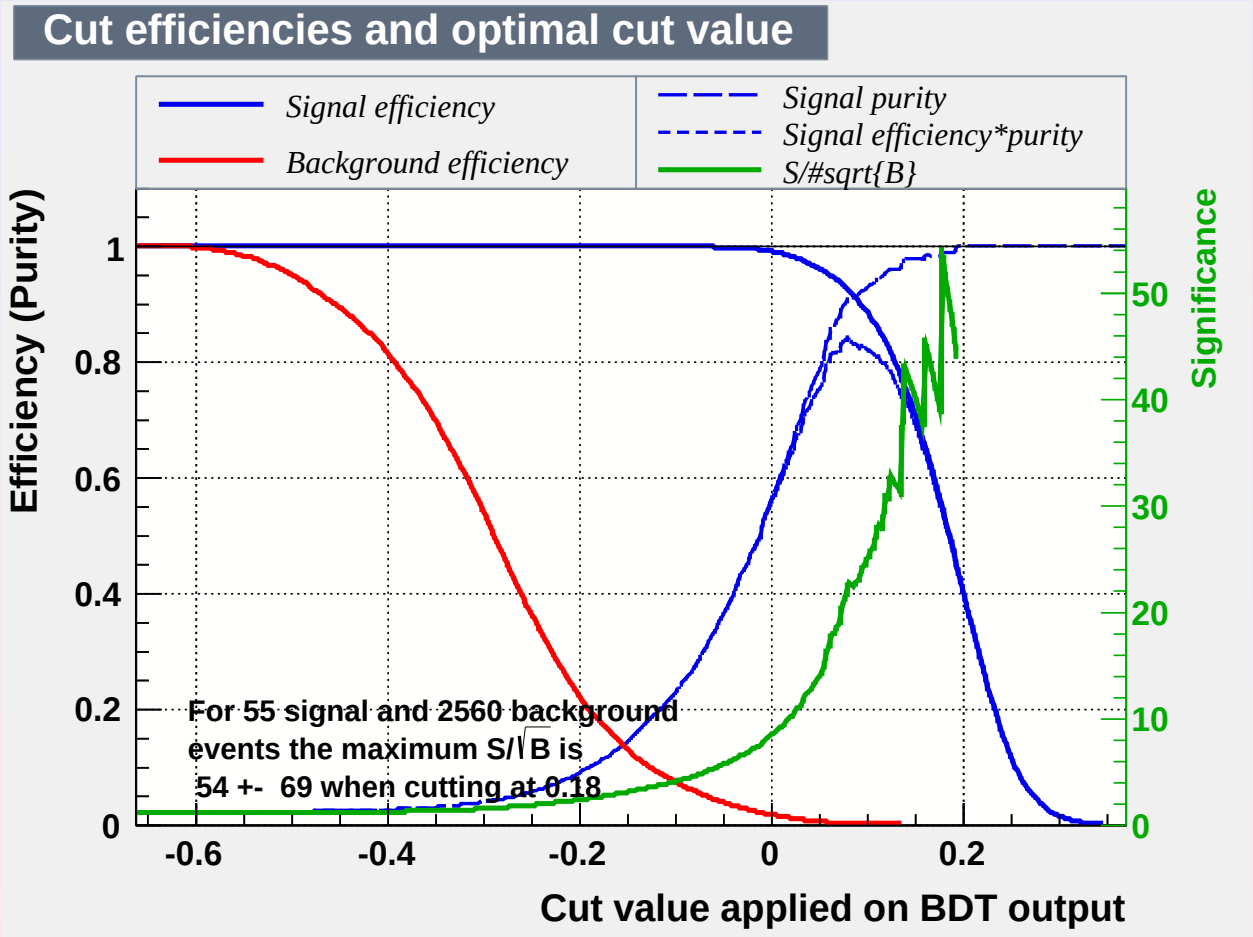

Correlation Matrix (signal)
Linear correlation coefficients in %
delPhiqq 14 -1 -8 -2 -20 -19 4 5 38 15 100
delPhiaa 5 -5 -6 -3 -20 -14 -7 2 27 4 100 15
delRqq 15 -2 -3 -2 -12 -11 -15 100 4 38
delRaa 3 -3 -4 -17 -22 -8 -1 100 -15 27 5
PTl 1 4 -1 5 -1 100 2 4
PTq2nd 2 46 5 2 2 42 100 -1 -1 -11 -7 -19
PTq1st 1 55 15 18 7 100 42 5 -8 -12 -14 -20
PTa2nd 4 2 1 -1 100 7 2 -1 -22 -2 -20 -2
PTa1st 6 8 11 100 -1 18 2 -17 -3 -3 -8
MET 7 100 11 1 15 5 -4 -2 -6 -1
mqq 100 7 8 2 55 46 4 -3 15 -5 14
maa 100 6 4 1 2 1 3 5
maa mqq MET PTa1st PTa2nd PTq1st PTq2nd PTl delRaa delRqq delPhiaa delPhiqq
100 80 60 40 20 0 -20 -40 -60 -80 -100


Correlation Matrix (background)
Linear correlation coefficients in %
delPhiqq -3 32 -10 -8 -2 8 19 -10 4 49 9 100
delPhiaa 26 -1 -2 7 8 -12 -3 -1 47 7 100 9
delRqq 32 -9 -4 -1 2 8 -6 -2 100 7 49
delRaa 33 2 3 -6 -1 -1 100 -2 47 4
PTl 6 14 6 13 9 26 15 100 -1 -6 -1 -10
PTq2nd 10 78 20 16 10 64 100 15 -1 8 -3 19
PTq1st 18 68 37 32 18 100 64 26 -6 2 -12 8
PTa2nd 65 11 13 56 100 18 10 9 3 -1 8 -2
PTa1st 63 17 26 100 56 32 16 13 2 -4 7 -8
MET 18 20 100 26 13 37 20 6 -9 -2 -10
mqq 12 100 20 17 11 68 78 14 32 -1 32
maa 100 12 18 63 65 18 10 6 33 26 -3
maa mqq MET PTa1st PTa2nd PTq1st PTq2nd PTl delRaa delRqq delPhiaa delPhiqq
100 80 60 40 20 0 -20 -40 -60 -80 -100

- 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


Cut efficiencies and optimal cut value
Signal efficiency
Background efficiency
Signal purity
Signal efficiency*purity
S/#sqrt{B}
Efficiency (Purity)
Significance
1
0.8
0.6
0.4
0.2
0
50
40
30
20
10
0
-0.6
-0.4
-0.2
0
0.2
For 55 signal and 2560 background
events the maximum S/√B is
54 +- 69 when cutting at 0.18
Cut value applied on BDT output