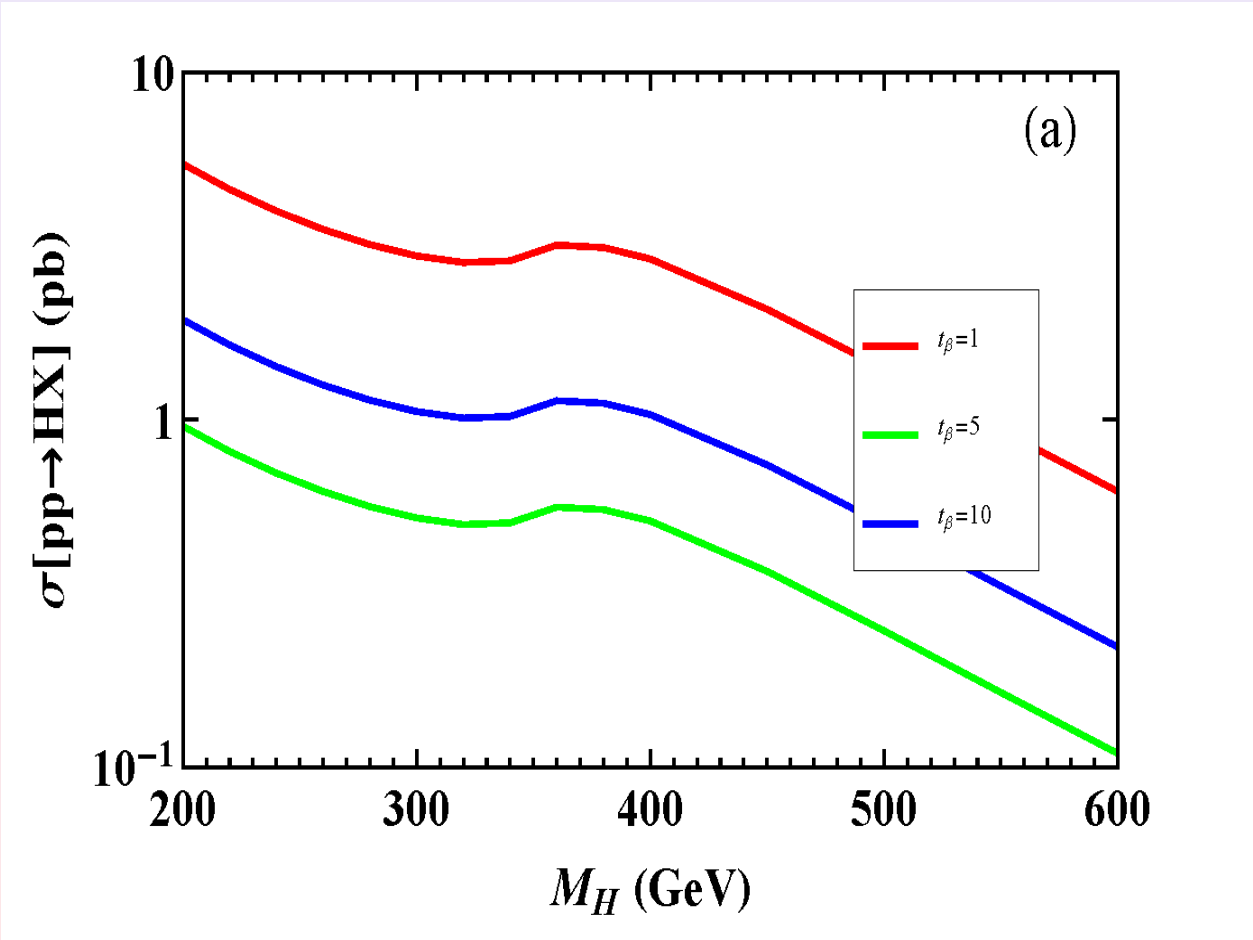
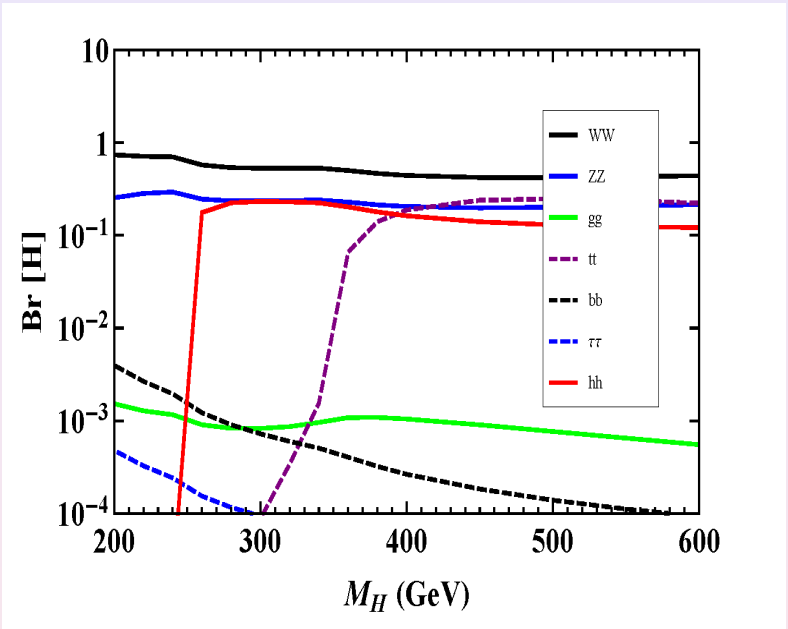
The 2HDM-I heavier CP-even Higgs production

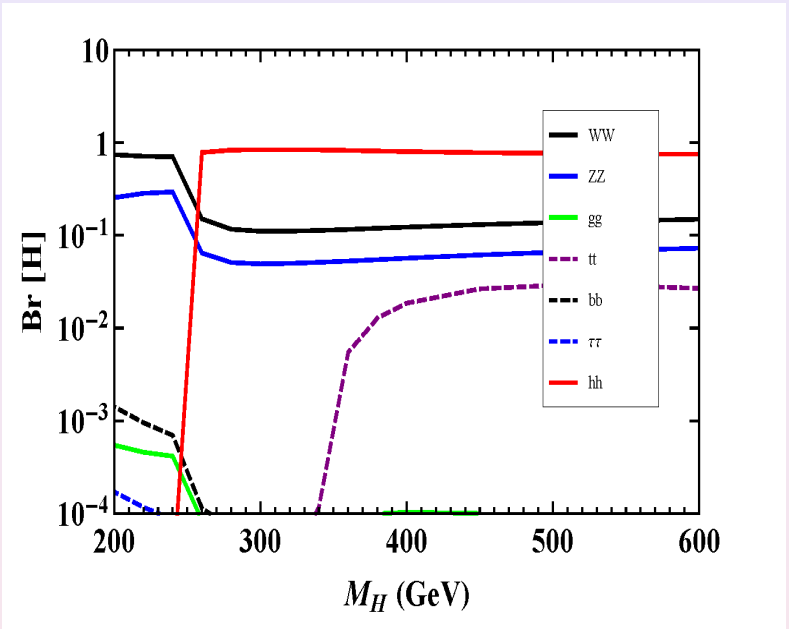
- $\sqrt{s} = 14$ TeV.
- Alinement limit: $\cos(\beta - \alpha) = 0.4$.



The 2HDM-I heavier CP-even Higgs Br



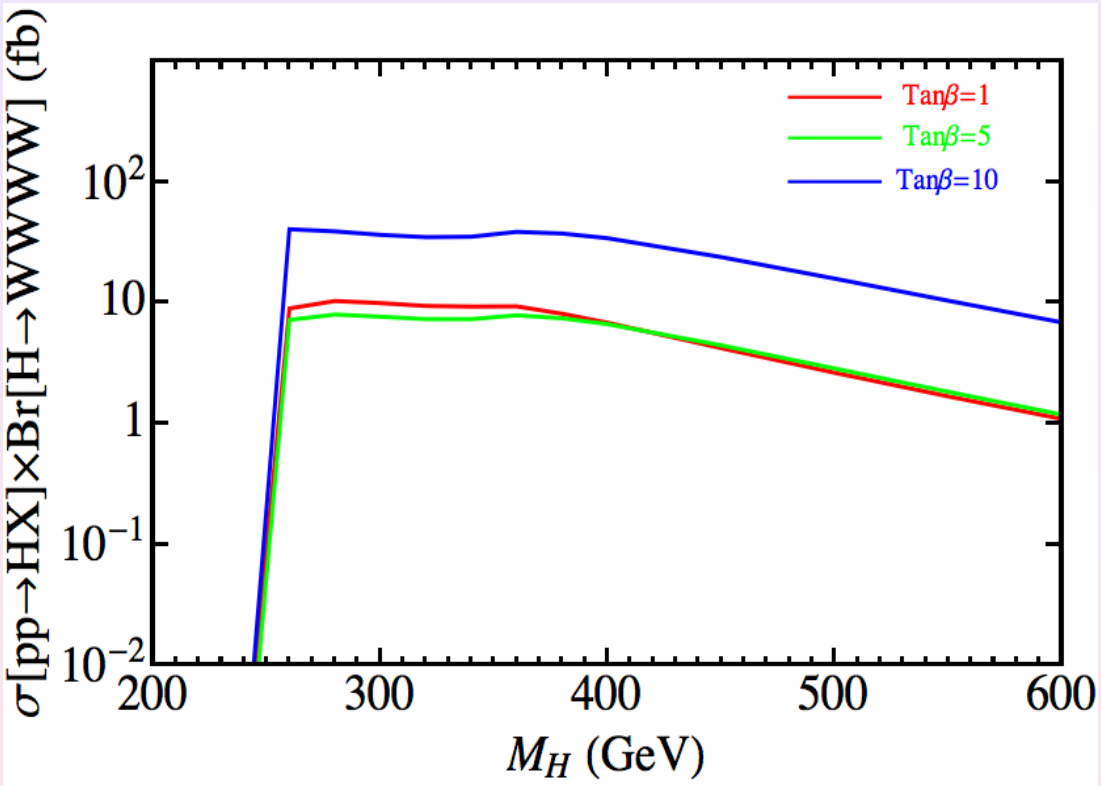
$\tan\beta = 1$



$\tan\beta = 10$

The 2HDM-I $pp \to H \to hh \to 4\,W$ channel

$$\sigma[\ pp \to HX\ ] \times Br\ [\ H \to hh\ ] \times \left(Br\ [\ h \to\ W^+\,W^-\ ]\right)^2 :$$



We take Xsection= 50 fb for $M_H = 300$GeV.

The 2HDM-I $pp \to H \to hh \to 4\,W$ channel

- $Br\,[\ W \to \ell\ \nu\ ] \simeq 10.8\%$ $\quad$ (ℓ : e or μ or τ);
- $Br\,[\ W \to$ hadrons $\ ] \simeq 67.6\%$.
- Signal cross section with W decay:
  - 1 hadronnic decay:

$67.6\% \times (3 \times 10.8\%)^3 \times 4 \times \text{Xsection} \simeq 0.092 \times \text{Xsection}$;

  - all leptonic decay:

$(3 \times 10.8\%)^4 \times \text{Xsection} \simeq 0.011 \times \text{Xsection}$.

1 hadronnic decay channel

- Fast-simulation project:

  MG5 + pythia + delphes 3.0.10.

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

- SM irreducible background:

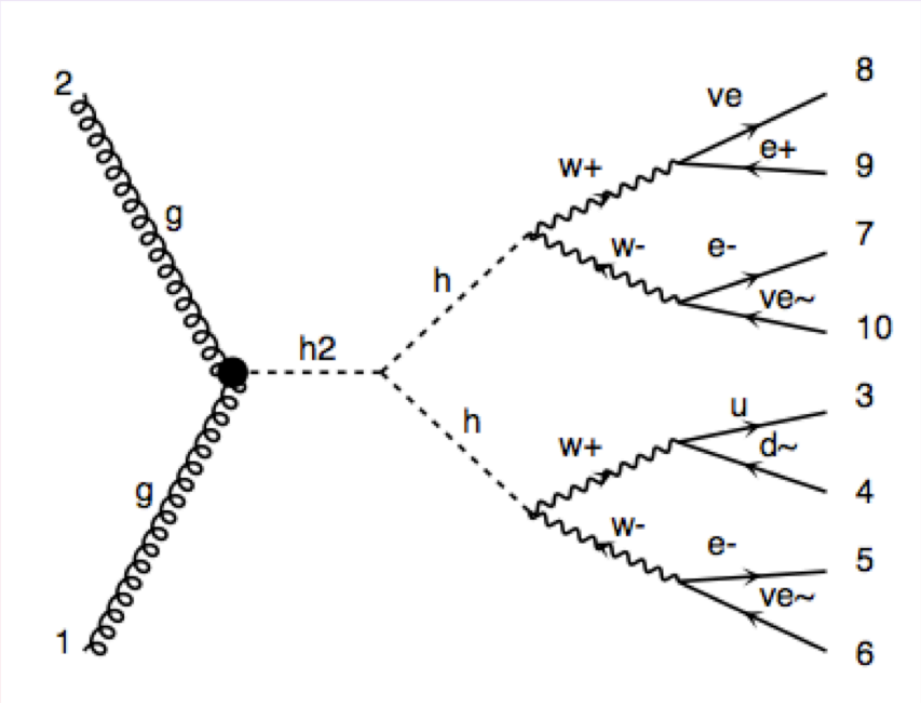
  $p\ p \ \to\ \ell\ \nu\ W\ W\ W \ \to\ q\ q\ \ell\ \nu\ \ell\ \nu\ \ell\ \nu \ \sim\ 0.03837$[fb].

- SM reducible background:

  - $p\ p \ \to\ \ell\ \nu\ \ell\ \nu\ \ell\ \nu \ \sim\ 3.811$[fb].
  - $p\ p \ \to\ \ell\ \nu\ \ell\ \ell\ W \to\ \ell\ \nu\ \ell\ \ell\ q\ q \ \sim\ 2.197$[fb].
  - $p\ p \ \to\ \ell\ \nu\ \ell\ \ell \ \sim\ 468.2$[fb].

Signal generated by MG5

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



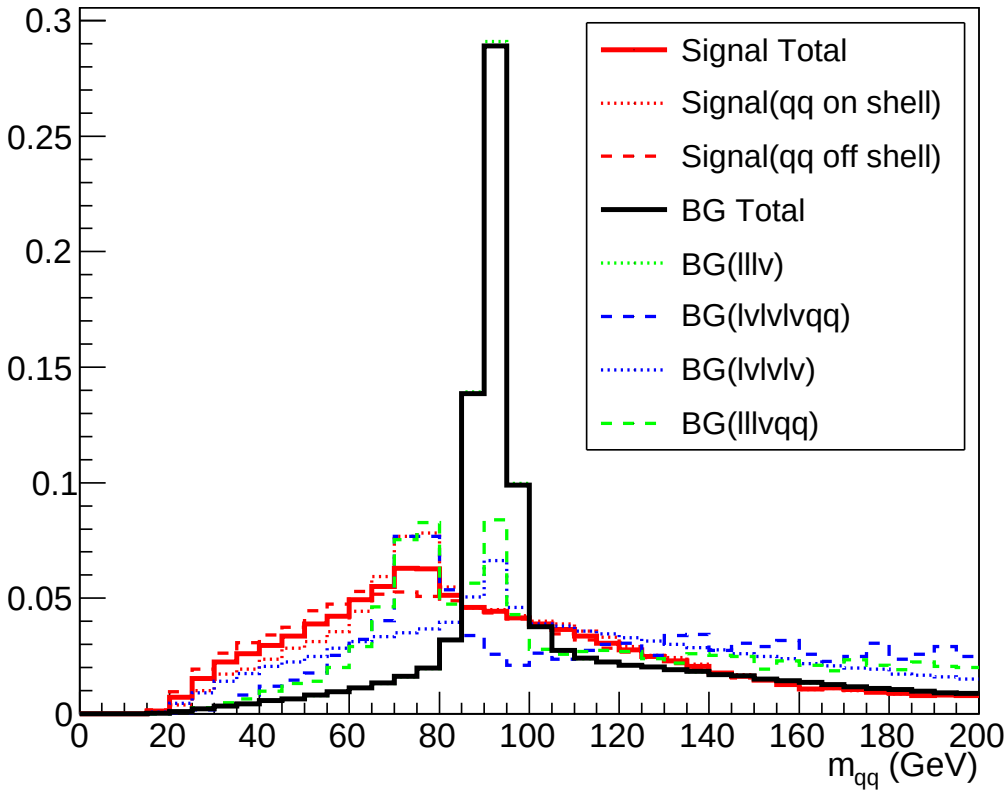
Events selection

- 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($q\ q\ \ell\ \nu\ \ell\ \nu\ \ell\ \nu$) selection:
  - Number of qjet ≥ 2, choosing leading and subleading qjet pair;
  - Number of electron + Number of muon $= 3$.

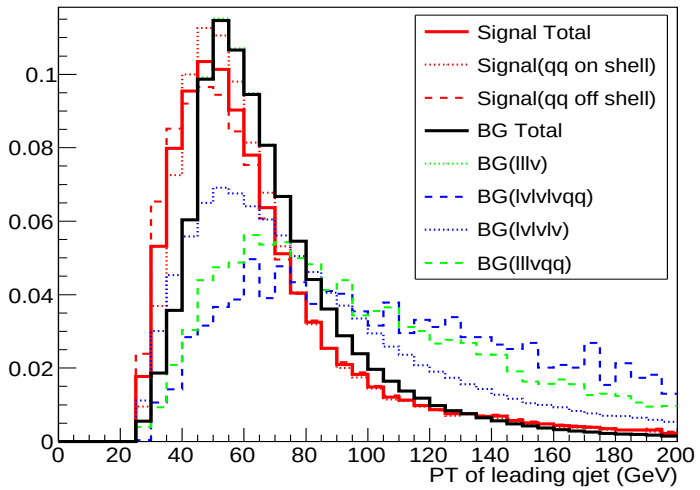
- Basic cuts: $|\eta_{q,\ell}| < 2.5$, $P_{T_q} > 25$ GeV, $P_{T_\ell} > 15$ GeV.

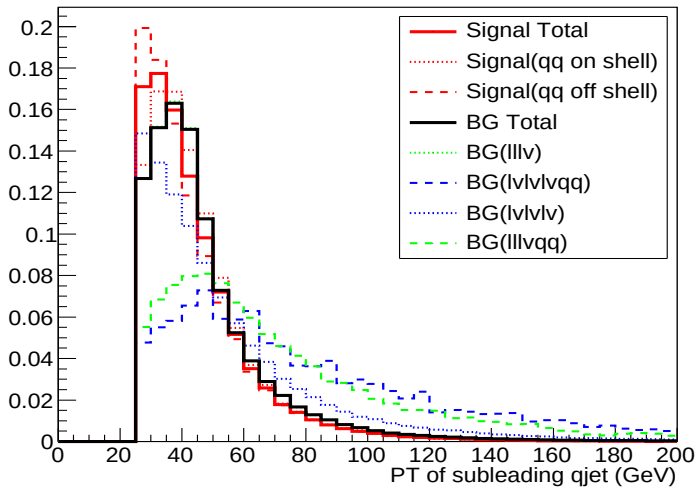
Distribution of qjet($M_H = 300$GeV)

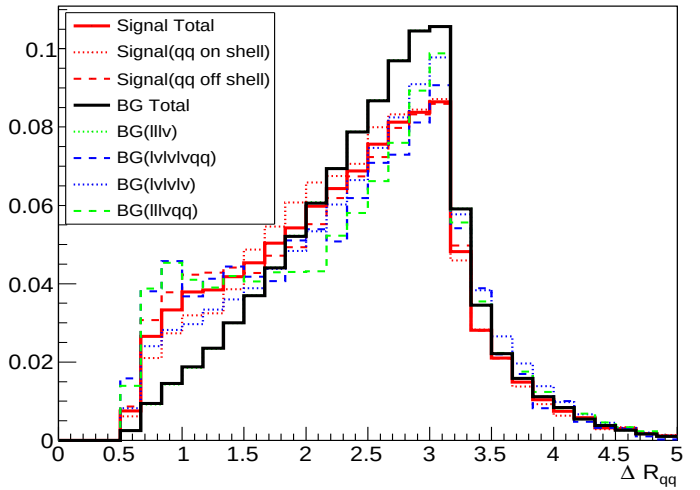


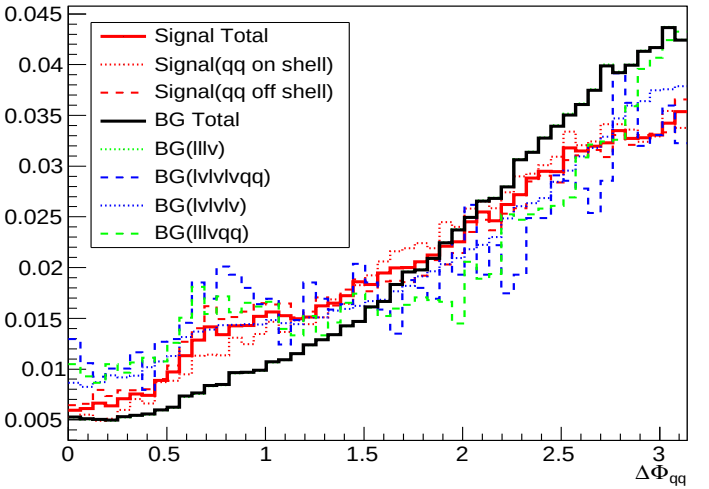
- Cut based: $m_{qq} < 85$ GeV.

Distribution of qjet($M_H = 300$GeV)

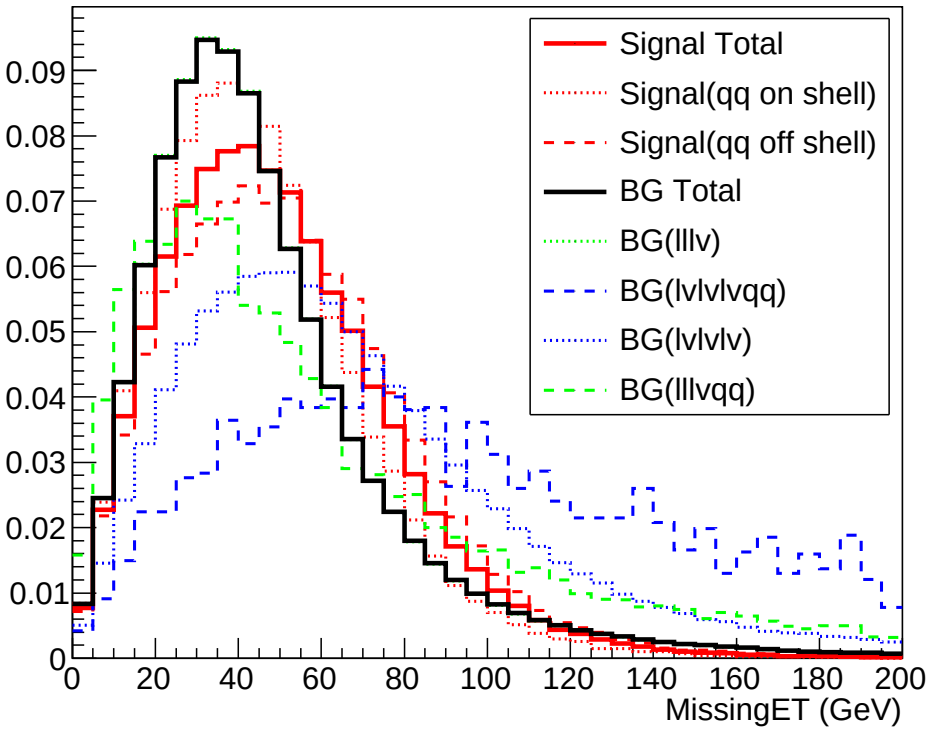




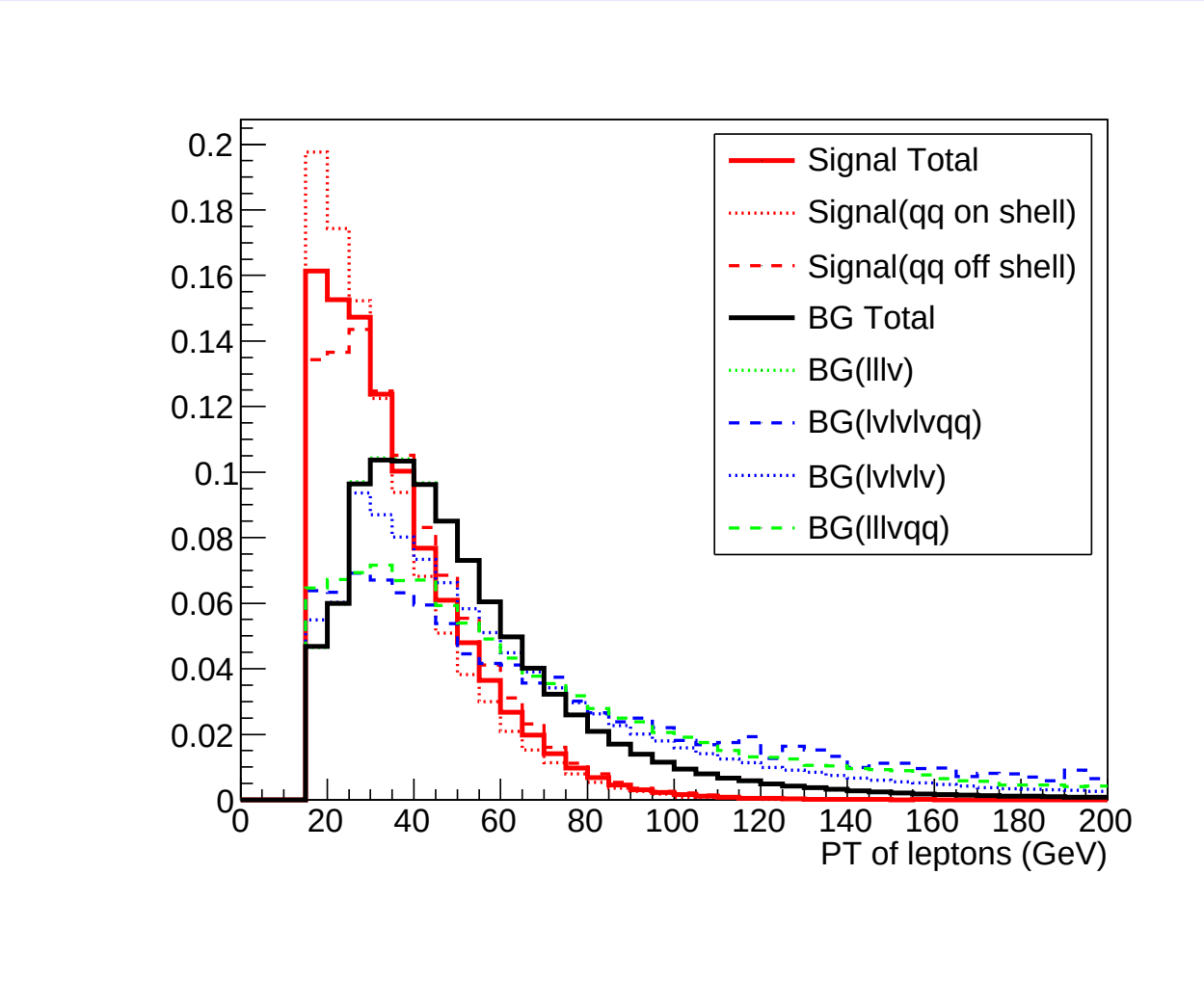




Missing ET distribution($M_H = 300\text{GeV}$)

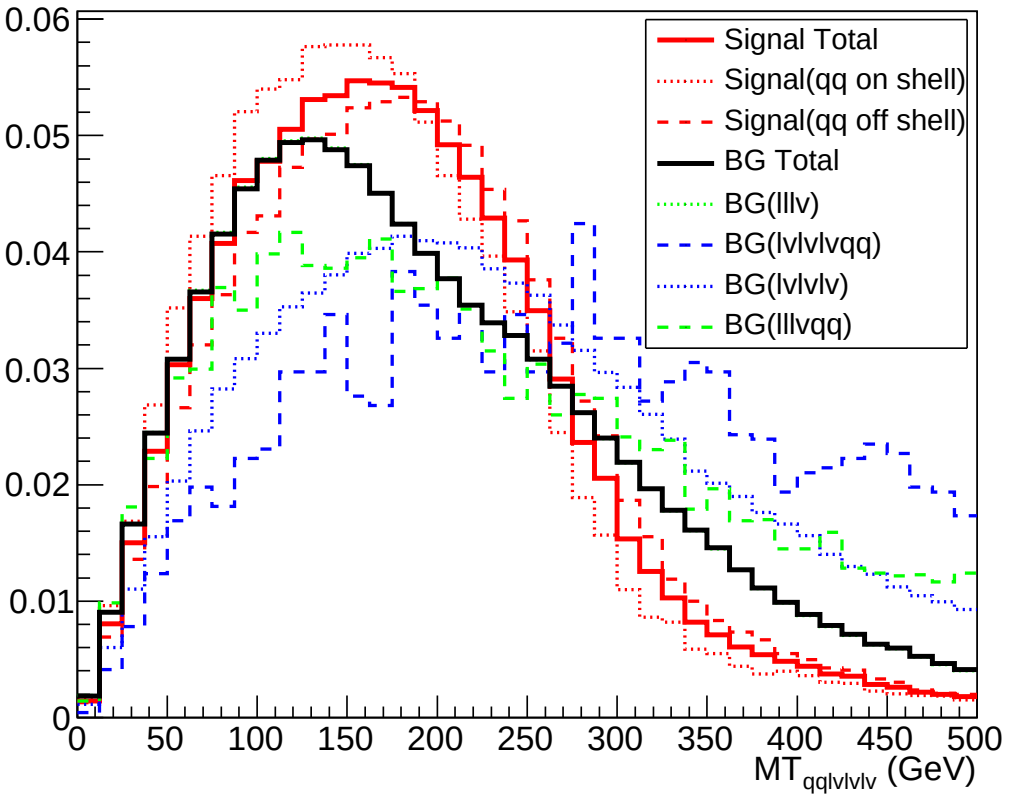


Distribution of leptons($M_H = 300$GeV)



- Cut based: $P_{T_\ell} < 40$ GeV to be used.

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



- Cut based: $M_{T_{qq\ell\nu\ell\nu\ell\nu}} < 280$ GeV.

Cut efficiency(1 hadronnic decay, $M_H = 300\text{GeV}$)

Cuts	σ_{total}	Events selection	m_{qq}	$P_{T\ell}$, $M_{T_{qq\ell\nu\ell\nu\ell\nu}}$
Signal [fb]	4.6	0.22	0.097	0.037
$\ell\ell\ell\nu$[fb]	468.2	47.56	5.46	0.78
$qq\ell\nu\ell\nu\ell\nu$[fb]	0.03837	0.0048	0.00087	0.00006
$\ell\nu\ell\nu\ell\nu$[fb]	3.811	0.301	0.072	0.0012
$qq\ell\ell\ell\nu$[fb]	2.197	0.30	0.065	0.0037
S/B	0.0097	0.0046	0.017	0.047
$S/\sqrt{B}^{[1]}$	6.68	1.02	1.29	1.31
$S/\sqrt{B}^{[2]}$	14.94	2.28	2.89	2.94
Signif-P$^{[1]}$	6.67	1.02	1.29	1.30
Signif-P$^{[2]}$	14.91	2.28	2.88	2.92

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

all leptonic decay channel

- Fast-simulation project:

  MG5 + pythia + delphes 3.0.10.

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

- SM reducible background:

  - $p\ p \rightarrow \ell\ \ell\ \ell\ \nu\ \ell\ \nu \sim 0.808$[fb].
  - $p\ p \rightarrow \ell\ \ell\ \ell\ \ell \sim 62.48$[fb].

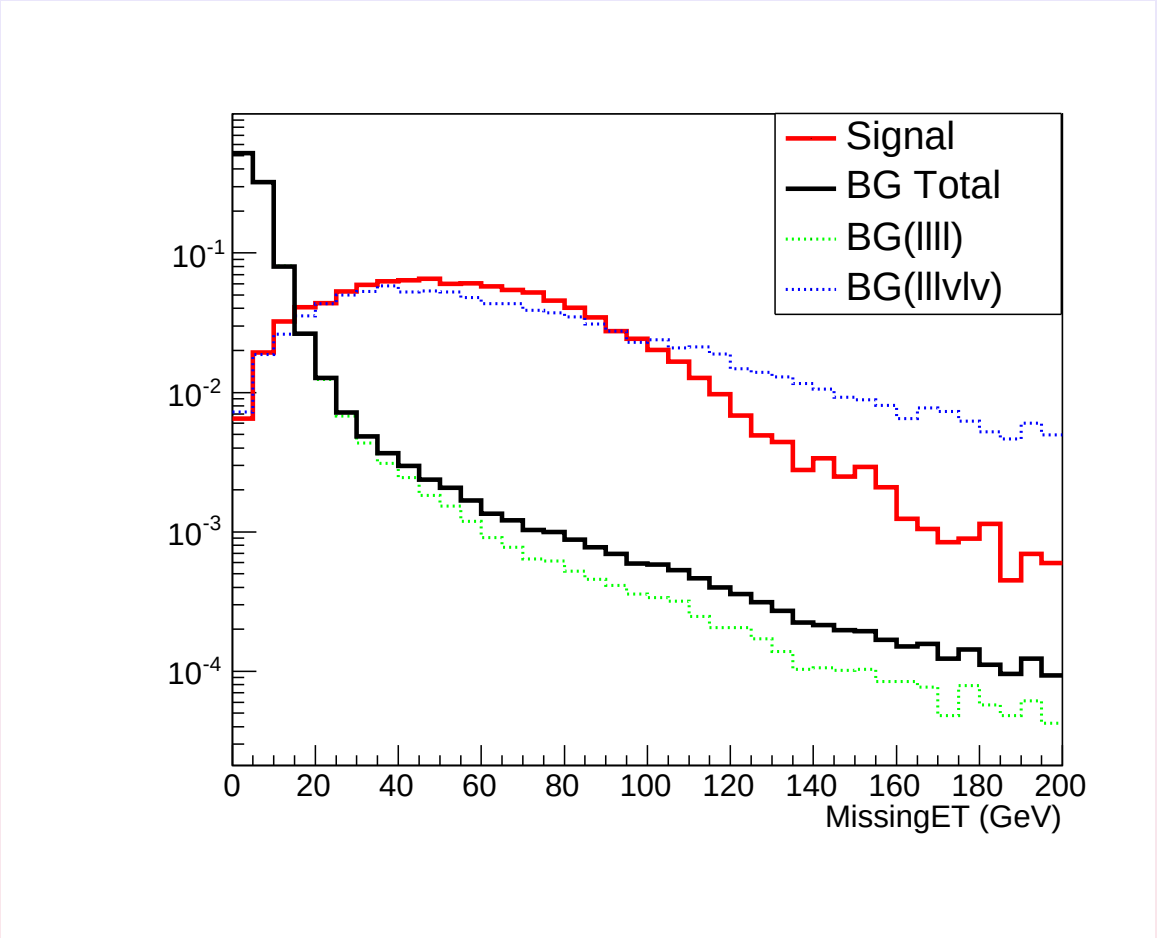
Events selection

- 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($\ell\ \nu\ \ell\ \nu\ \ell\ \nu\ \ell\ \nu$) selection:
  - Number of electron + Number of muon $= 4$.

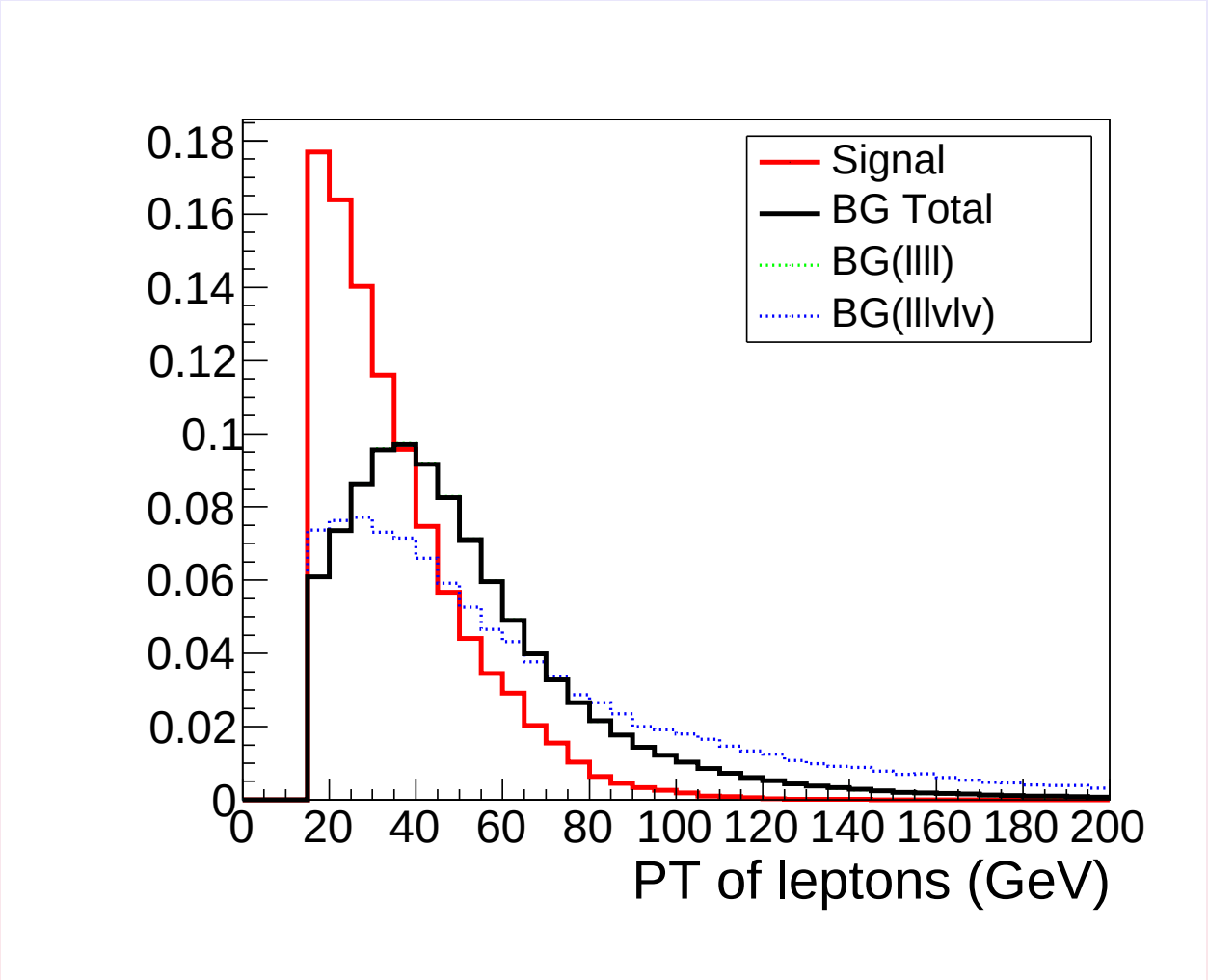
- Basic cuts: $|\eta_\ell| < 2.5$, $P_{T_\ell} > 15$ GeV.

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



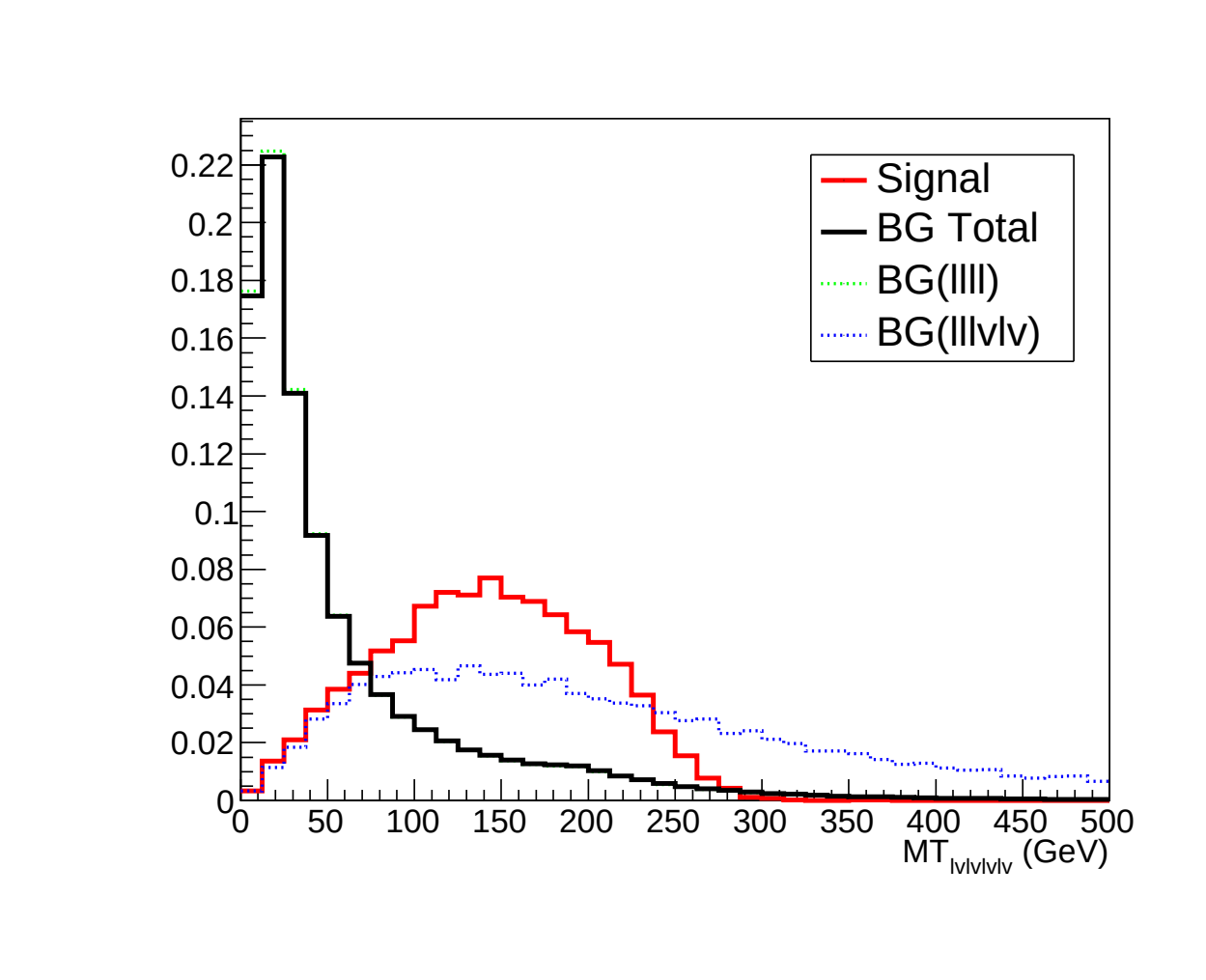
- Cut based: MET > 20 GeV.

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



- Cut based: $P_{T_\ell} < 40$ GeV to be used.

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



- Cut based: 70 GeV $< M_{T_{\ell\nu\ell\nu\ell\nu\ell\nu}} <$ 270 GeV.

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

Cuts	σ_{total}	Events selection	MET, $P_{T\ell}$	$M_{T_{\ell\nu\ell\nu\ell\nu\ell\nu}}$
Signal [fb]	0.55	0.022	0.0048	0.0043
$\ell\ell\ell\ell$[fb]	62.48	8.147	0.0075	0.0043
$\ell\ell\ell\nu\ell\nu$[fb]	0.808	0.091	0.0015	0.0013
S/B	0.0087	0.0027	0.54	0.76
$S/\sqrt{B}^{[1]}$	2.19	0.24	1.61	1.81
$S/\sqrt{B}^{[2]}$	4.89	0.55	3.60	4.04
Signif-P$^{[1]}$	2.18	0.24	1.49	1.63
Signif-P$^{[2]}$	4.88	0.55	3.34	3.64

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