Search for $T' \longrightarrow t + H^0$ in the trilepton channel

Status report #3 (week 6/12)

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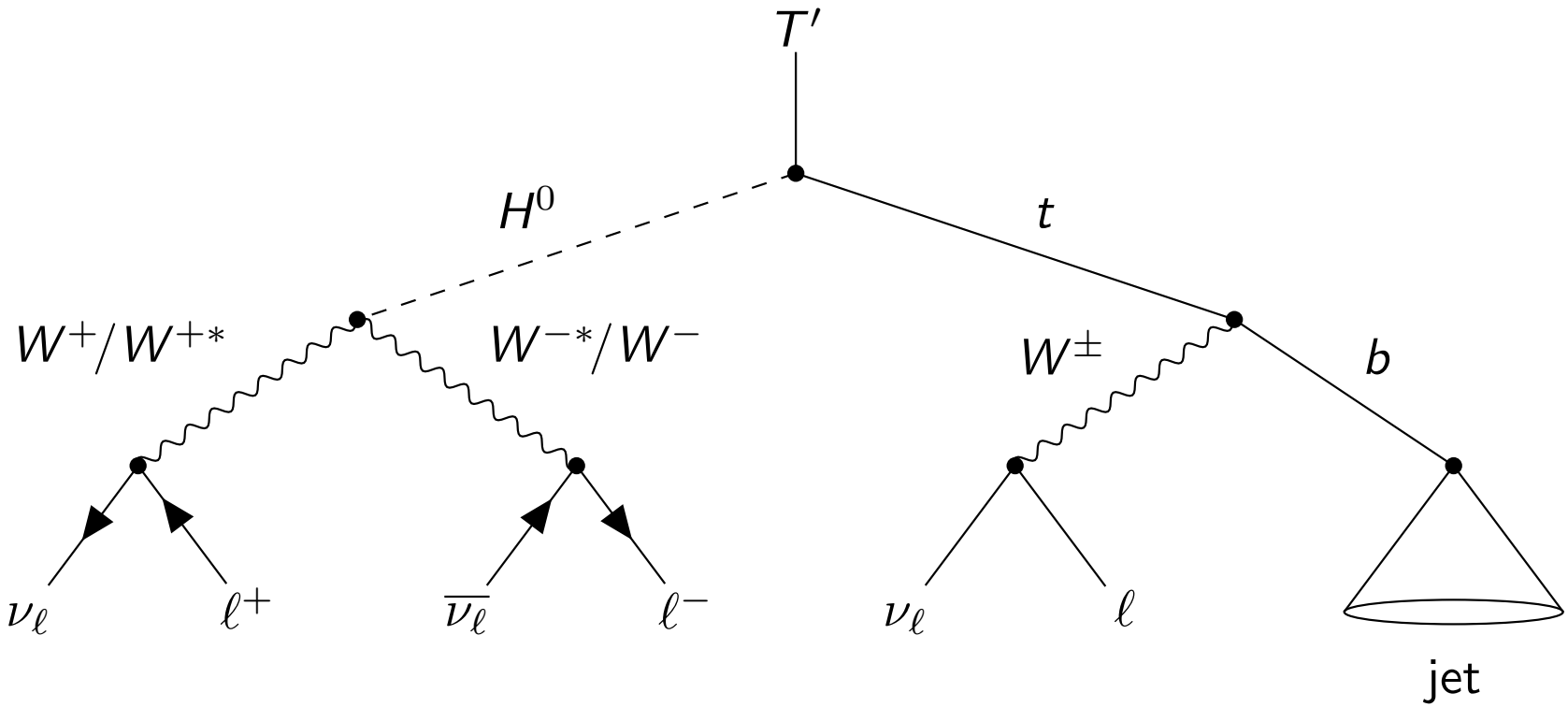
Signal

$\sigma\left(T' \longrightarrow t + H^0\right) = 89\,\text{fb}$

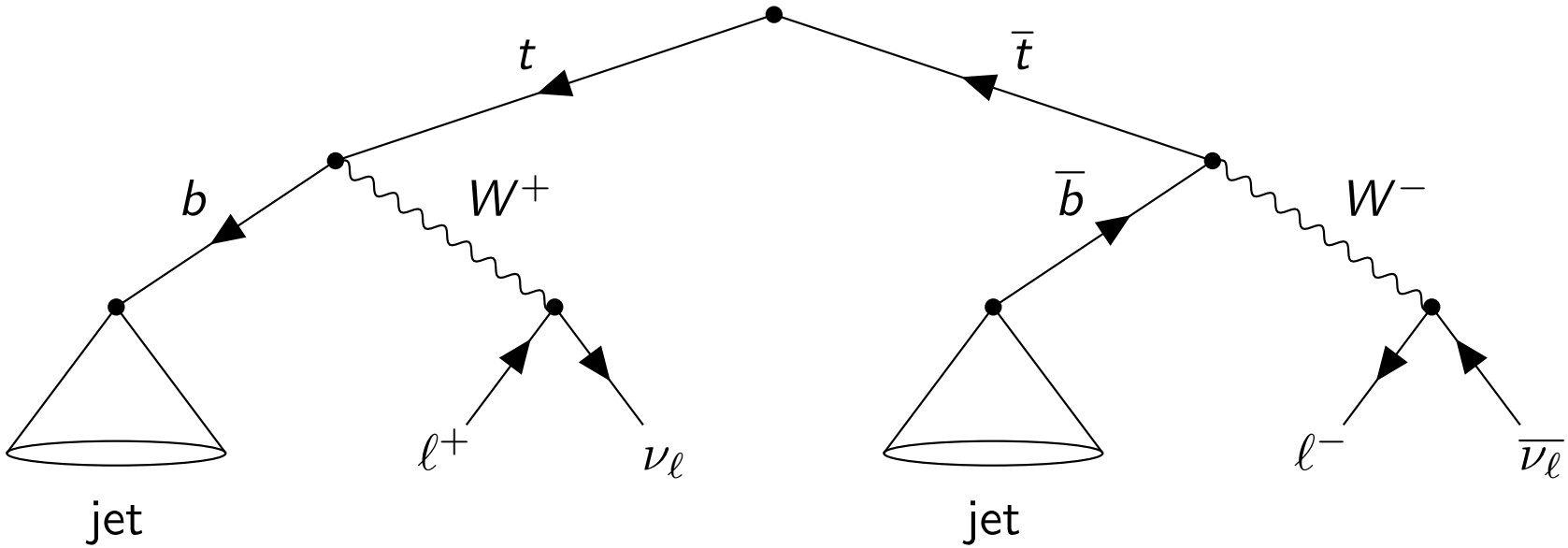


Final state: $\ell^+\ell^-\ell^\pm\nu\nu\nu + b$-tagged jet

Unless the Higgs boson is sufficiently boosted, one the two intermediate W bosons is off-shell ($m_{H^0} = 125\,\text{GeV}$, $m_{W^\pm} = 80.4\,\text{GeV}$)

$t\bar{t}$ background

$\sigma(t\bar{t} \longrightarrow \text{dilepton}) = 87.315\,\text{pb}$



Final state: $\ell^+\ell^-\nu\nu + 2\,b$-tagged jets

The top quarks are heavy enough compared to the bottom quarks for the intermediate W bosons to be on-shell ($m_t = 173\,\text{GeV}$, $m_b = 4.2\,\text{GeV}$)

Generator-level signal selection

Define a flag: `IsSignal`
If `IsSignal == 1`, select signal events:

- H^0 from a T'
  - W^+W^- from a H^0 from a T'
    - $\ell^+\ell^-$ **from a** $\boldsymbol{W^+W^-}$ from a H^0 from a T'
- t from a T'
  - Wb from a t from a T'
    - ℓ **from a** $\boldsymbol{W^\pm}$ from a t from a T'
    - b-tagged jet from a b from a t from a T'

```
// In TopHiggsTrileptonAnalyser::selectSignal(bool isSignal)
.Define("IsSignal", isSignal ? "1" : "0")
.Define("GenMuons","abs(GenPart_pdgId) == 13")
.Define("MotherGenMuons","GenPart_genPartIdxMother[GenMuons]")
.Define("MotherPdgId", "ROOT::VecOps::Take(GenPart_pdgId, MotherGenMuons)")
.Define("IsFromW","abs(MotherPdgId) == 24")

// In TopHiggsTrileptonAnalyser::defineCuts()
addCuts("IsSignal == 0 || (IsSignal == 1 && Sum(IsFromW) >= 3)", "0");
```

Signal vs. $t\bar{t}$ comparison ($L_{\text{int}} = 300\,\text{fb}^{-1}$)

Summary/results

Cut 0: `IsSignal == 0 || (IsSignal == 1 && Sum(IsFromW) >= 3)`
Cut 1: `Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1`
Cut 2: `Selected_muon_sum_all_muons_pt >= 130.0`
Cut 3: `Selected_muon_deltaR_min_neutral <= 1`

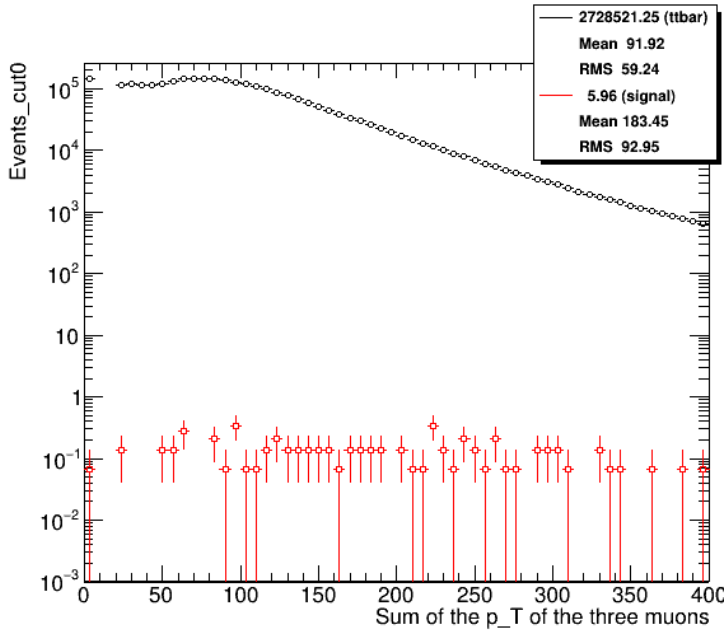
Without generator-level signal selection

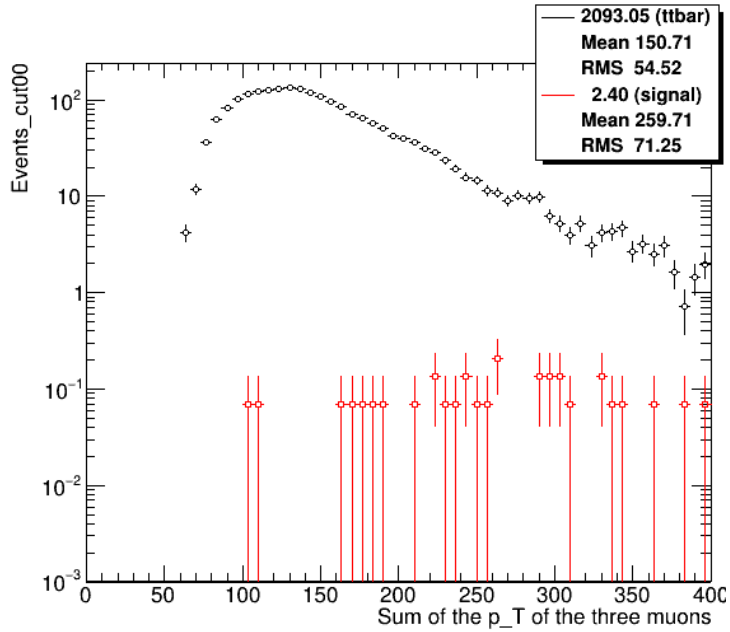
	Events (sig.)	Events ($t\bar{t}$ bkg.)	Cut (sig.)	Cut ($t\bar{t}$ bkg.)	S/B
Before	1184	2 728 521			0.0434 %
After Cut 1	7.47	2093	−99.4 %	−99.9 %	0.357 %
After Cut 2	6.72	1232	−10.0 %	−41.1 %	0.545 %
After Cut 3	5.28	280	−21.4 %	−77.3 %	**1.89 %**

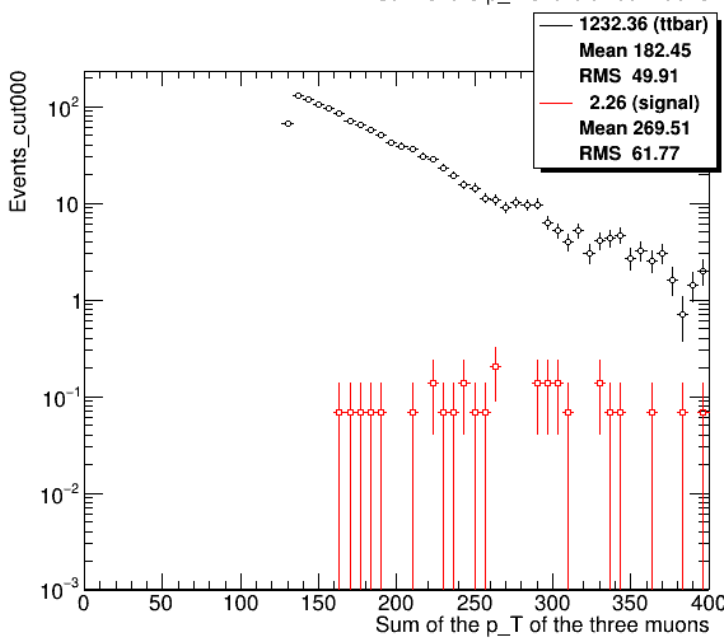
With generator-level signal selection

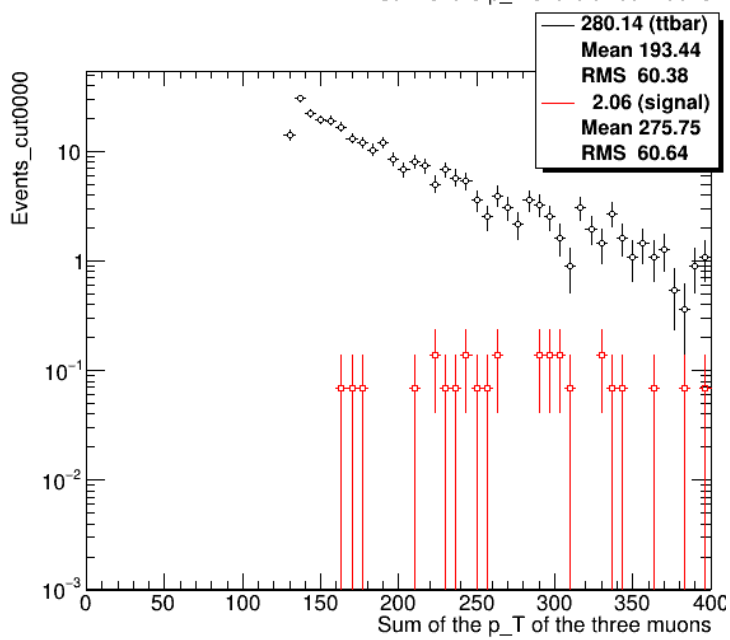
	Events (sig.)	Events ($t\bar{t}$ bkg.)	Cut (sig.)	Cut ($t\bar{t}$ bkg.)	S/B
Before	1184	2 728 521			0.0434 %
After Cut 0	5.96	2 728 521	−99.5 %	−0 %	0.0002 %
After Cut 1	2.40	2093	−59.7 %	−99.9 %	0.115 %
After Cut 2	2.26	1232	−5.83 %	−41.1 %	0.183 %
After Cut 3	2.06	280	−8.85 %	−77.3 %	**0.736 %**

Sum of the p_T of the 3 muons

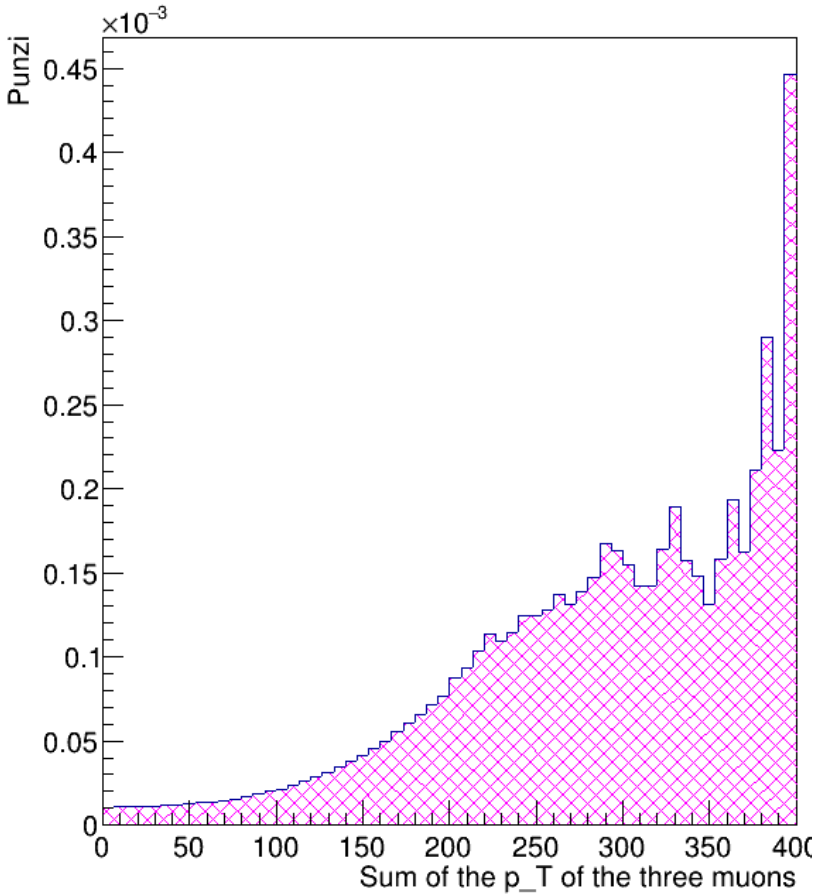


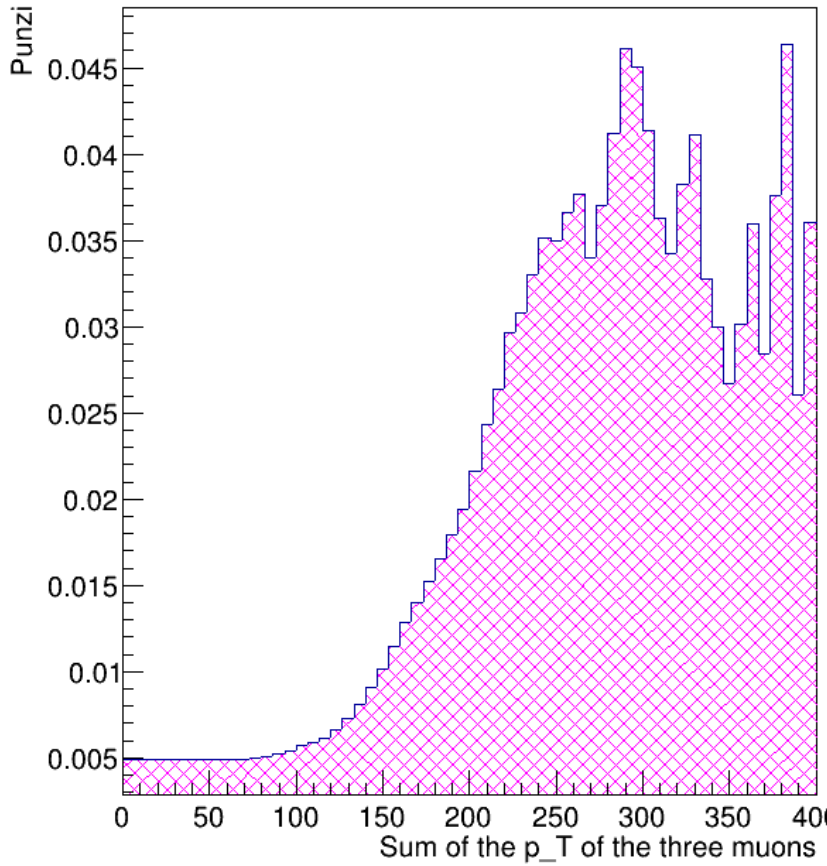




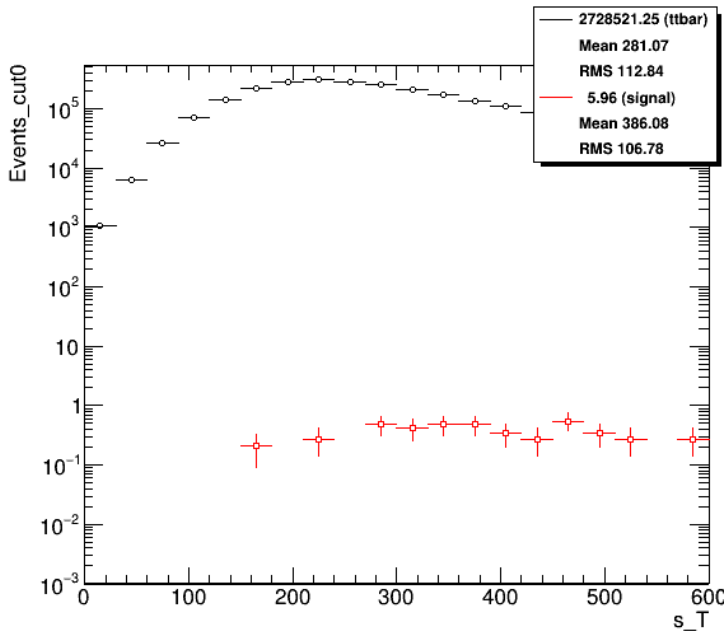


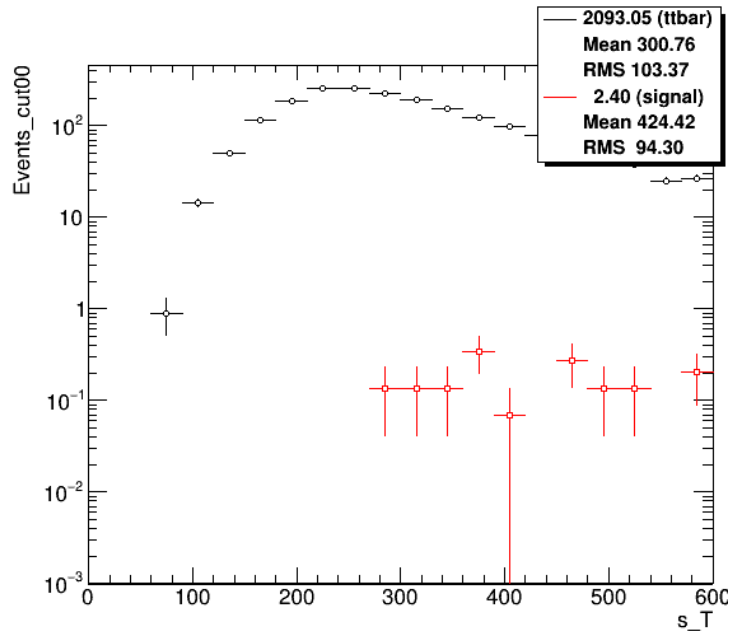
Sum of the p_T of the 3 muons

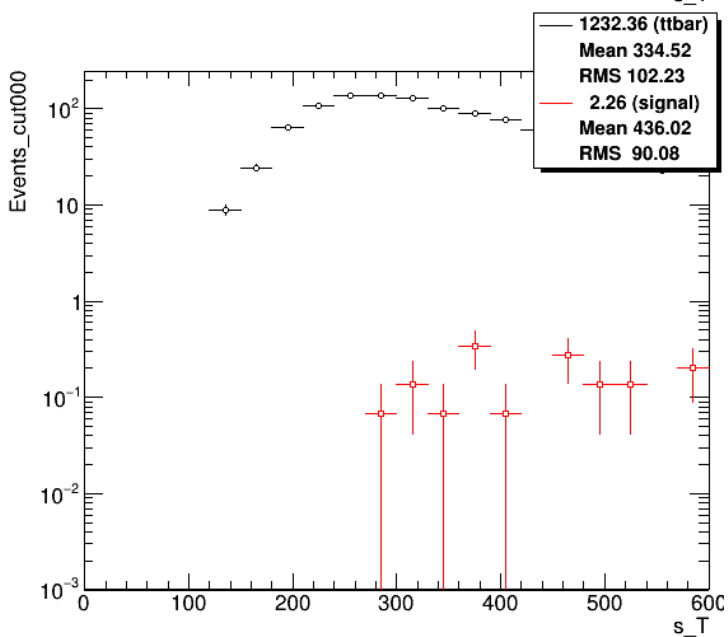


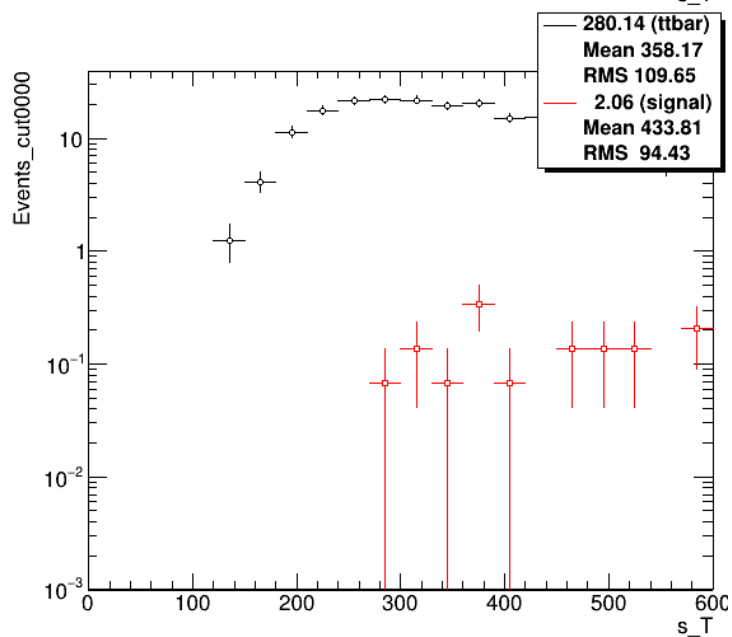


New variable: $s_T \equiv \sum_{\text{leptons}} p_T + \sum_{\text{jets}} p_T$



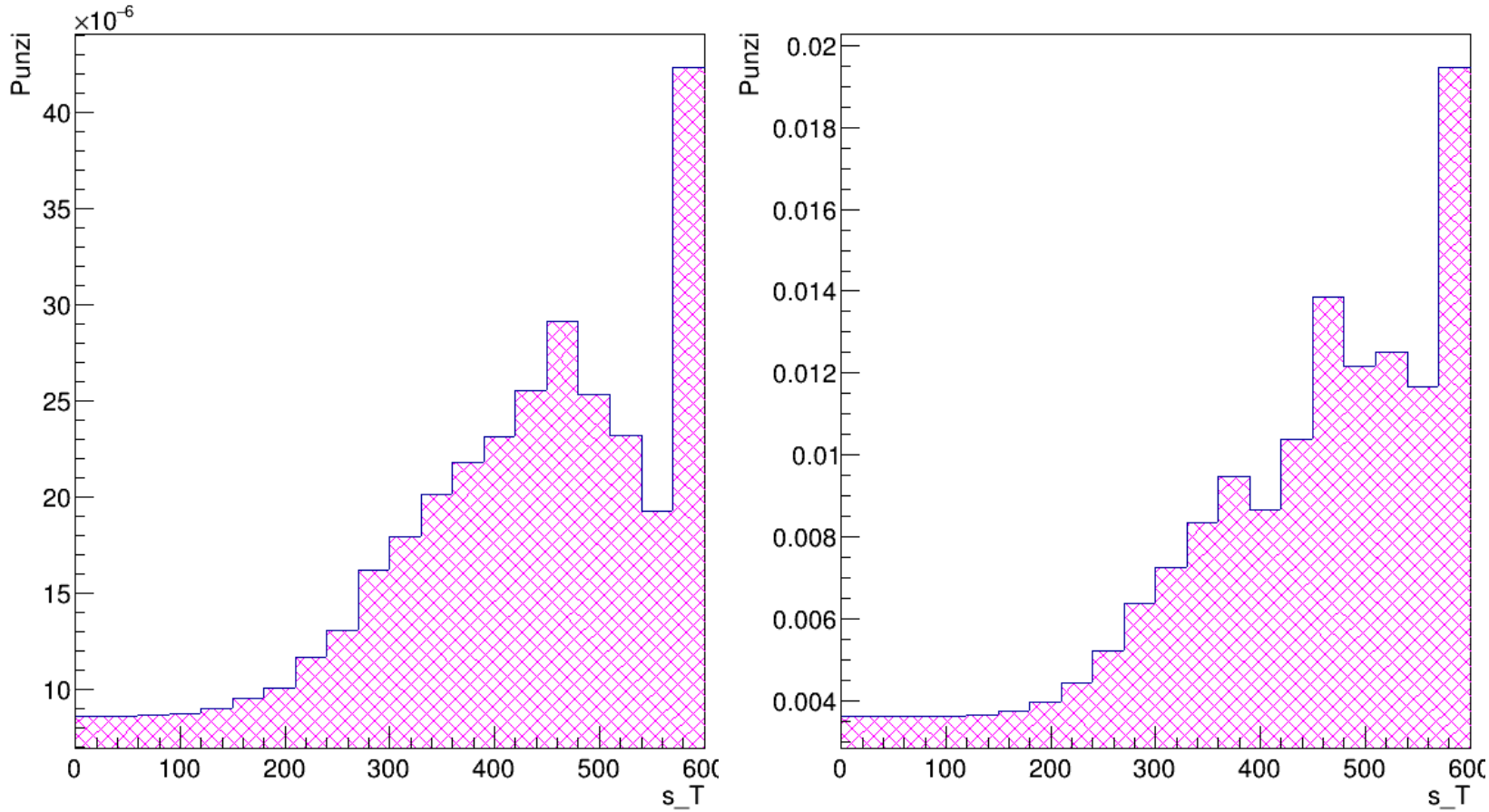






New variable: $s_T \equiv \sum_{\text{leptons}} p_T + \sum_{\text{jets}} p_T$

```
addVar({"St", "Sum(Selected_electron_pt) + Sum(Selected_muon_pt) + Sum(Selected_jet_pt)"});
```

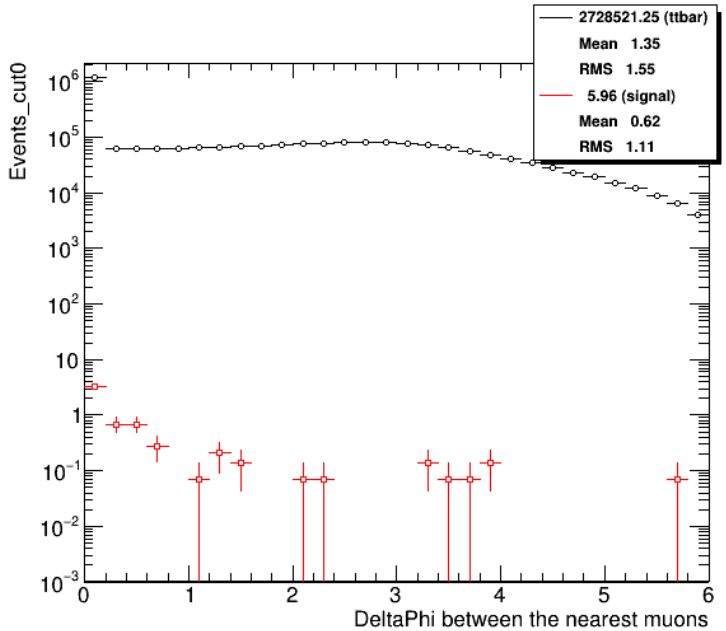


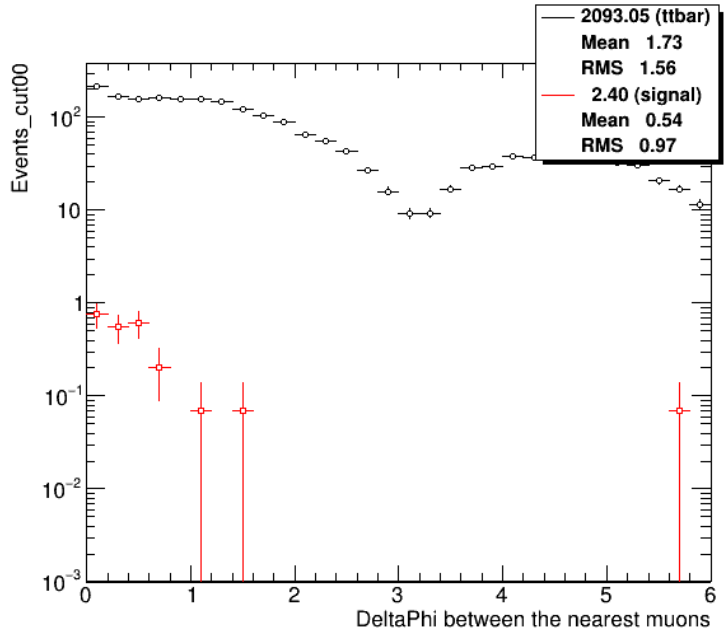
New variable: invariant mass of the nearest muons

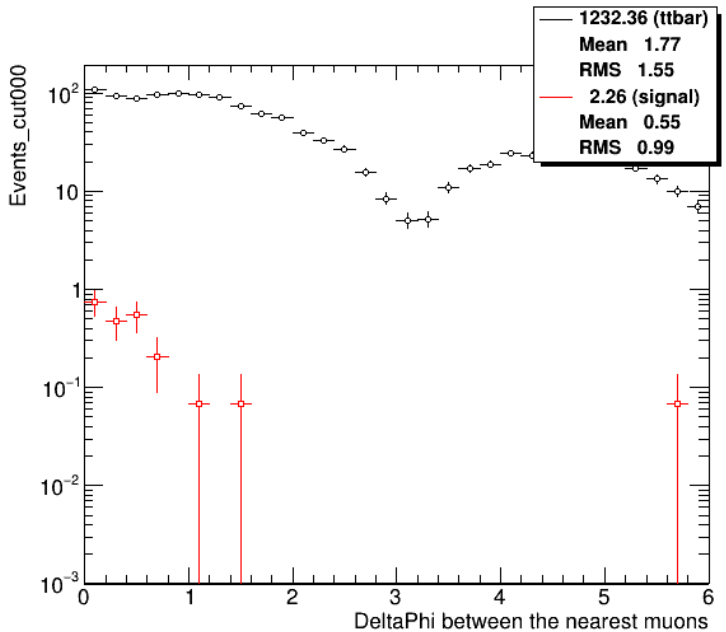
```
ints nearest(floats &eta1, floats &eta2, floats &phi1, floats &phi2, ints charge1, ints charge2)
{
  ints out = {-1, -1};
  float mindr = FLT_MAX;
  for (unsigned int i = 0; i < eta1.size(); i++)
  {
    for (unsigned int j = i+1; j < eta2.size(); j++)
    {
      auto dr = ROOT::VecOps::DeltaR(eta1[i], eta2[j], phi1[i], phi2[j]);
      if (dr < mindr and charge1[i] != charge2[j])
      {
        out = {i, j};
        mindr = dr;
      }
    }
  }
  return out;
}
```

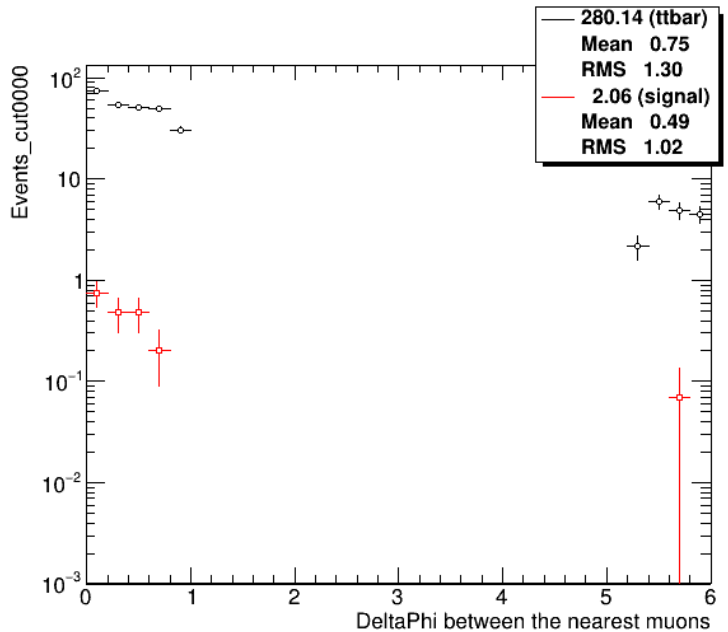
```
.Define("dimuon", ::nearest, {"Selected_muon_eta", "Selected_muon_eta", "Selected_muon_phi",
↪  "Selected_muon_phi", "Selected_muon_charge", "Selected_muon_charge"})
.Define("dimuon_deltaR", "ROOT::VecOps::DeltaR(Selected_muon_eta[dimuon[0]],
↪  Selected_muon_eta[dimuon[1]], Selected_muon_phi[dimuon[0]], Selected_muon_phi[dimuon[1]])");
```

New variable: $\Delta\phi_{\min} \equiv \Delta\phi(\text{dimuon})$









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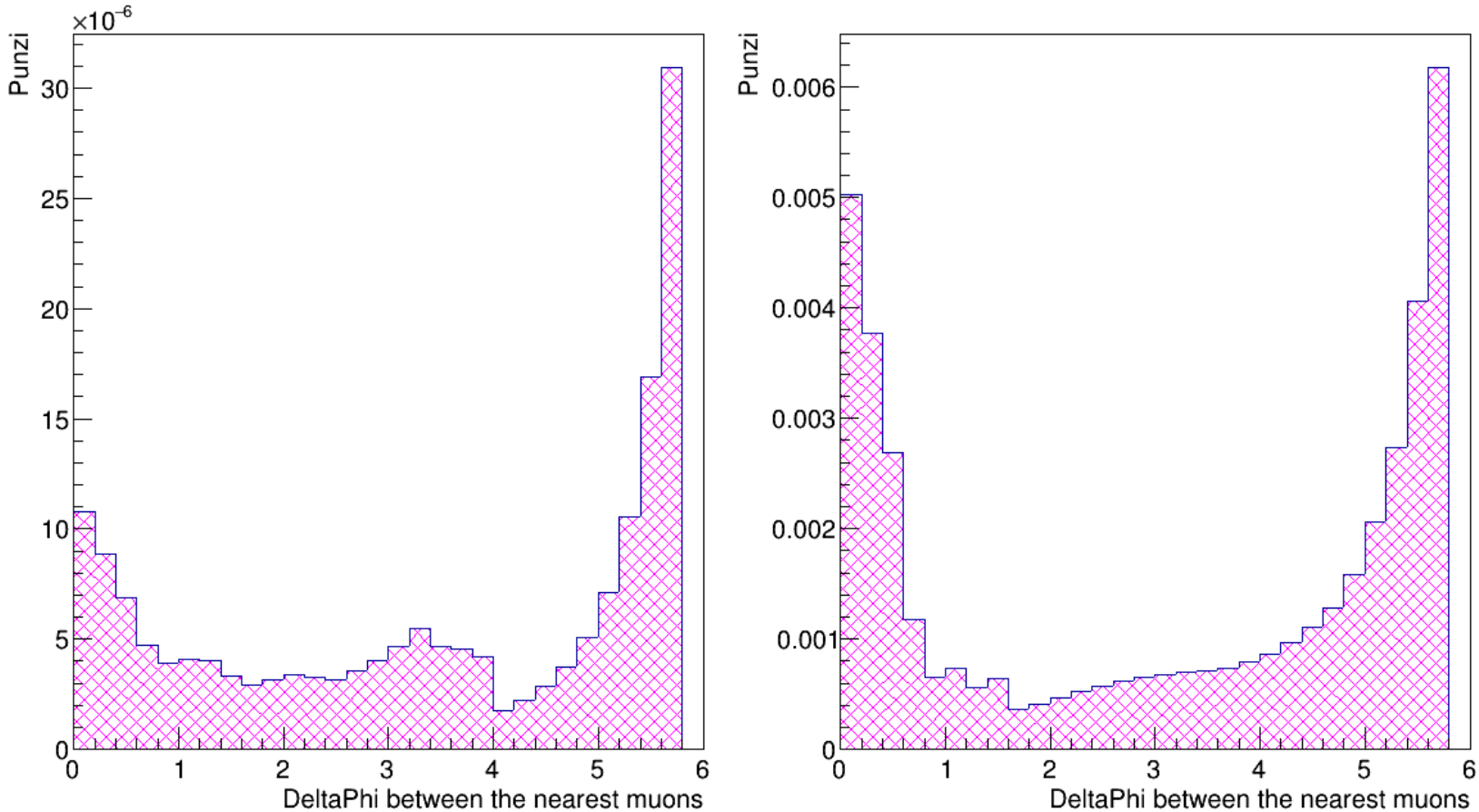
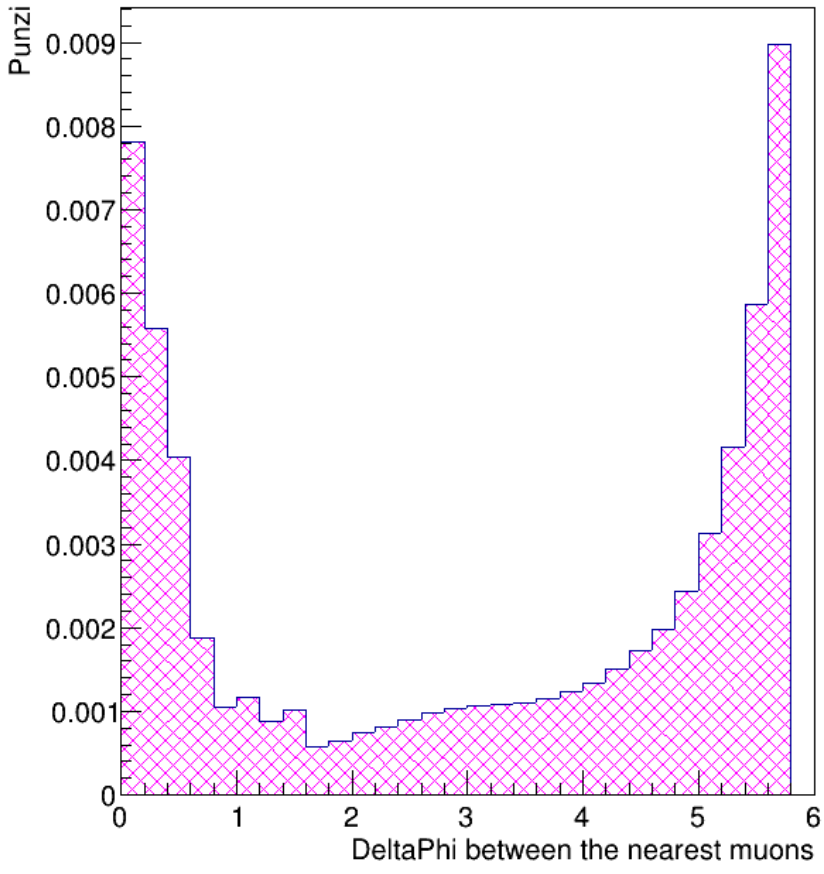
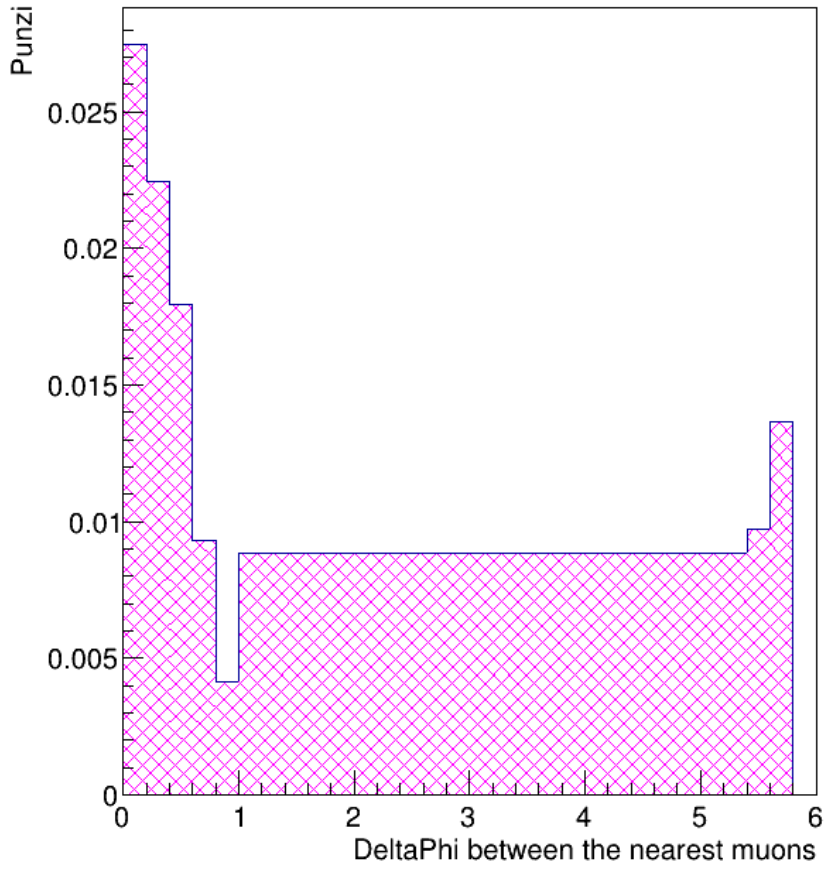


New variable: $\Delta\phi_{\min} \equiv \Delta\phi(\text{dimuon})$





What's next

- Two days off (Mon/Tue)
- New variable: invariant mass of $b\ell$
- Define and compare many variables to determine relevant cuts
- WZ background which should be filtered out by `Selected_bjet_number >= 1`
- Study $\mu\mu e$, μee, eee final states

Appendix

$$N_{\text{data set}}(\text{sig.}) = 389\,500 \tag{1}$$

$$N_{\text{data set}}(t\bar{t}) = 145\,962\,000 \tag{2}$$

$$N_{\text{expected}}(\text{sig.}) = \underbrace{L_{\text{int}} \times \sigma(\text{sig.})}_{26\,700} \times \underbrace{\text{BR}\left(H^0 \longrightarrow WW\right)}_{21\ \%} \times \underbrace{\text{BR}\left(t \longrightarrow Wb\right)}_{\approx 100\ \%} \times \text{BR}\left(W \longrightarrow \ell\nu\right)^3 \tag{3}$$

$$= 7.46\ (\ell = \mu) \tag{4}$$

$$= 12.32\ (\ell = \mu)\ \text{(intermediate } \tau \text{ leptons allowed)} \tag{5}$$

$$= 59.70\ (\ell = e, \mu) \tag{6}$$

$$= 98.55\ (\ell = e, \mu)\ \text{(intermediate } \tau \text{ leptons allowed)} \tag{7}$$

$$N_{\text{expected}}(t\bar{t}) = \underbrace{L_{\text{int}} \times \sigma(t\bar{t})}_{26\,194\,500} \times \underbrace{\text{BR}\left(t \longrightarrow Wb\right)}_{\approx 100\ \%} \times \text{BR}\left(W \longrightarrow \ell\nu\right)^2 \tag{8}$$

$$= 316\,953\ (\ell = \mu) \tag{9}$$

$$= 442\,687\ (\ell = \mu)\ \text{(intermediate } \tau \text{ leptons allowed)} \tag{10}$$

$$= 1\,267\,814\ (\ell = e, \mu) \tag{11}$$

$$= 1\,770\,748\ (\ell = e, \mu)\ \text{(intermediate } \tau \text{ leptons allowed)} \tag{12}$$

$$N_{\text{scaled}}(\text{sig.}) = N_{\text{unscaled}} \times \frac{\sigma(\text{sig.}) \times L_{\text{int}}}{N_{\text{data set}}} = N_{\text{unscaled}} \times \frac{26\,700}{389\,500} = N_{\text{unscaled}} \times 0.068\,55 \tag{13}$$

$$N_{\text{scaled}}(t\bar{t}) = N_{\text{unscaled}} \times \frac{\sigma(t\bar{t}) \times L_{\text{int}}}{N_{\text{data set}}} = N_{\text{unscaled}} \times \frac{26\,194\,500}{145\,962\,000} = N_{\text{unscaled}} \times 0.179\,46 \tag{14}$$