

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

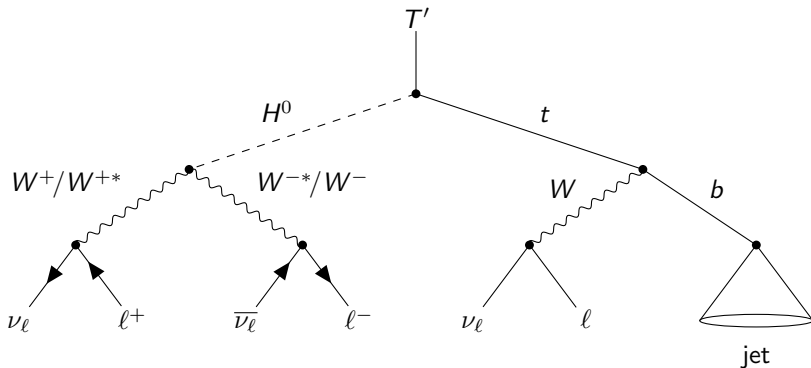
Status report #2 (weeks 4, 5)

Bastien Voirin

June 3, 2022

Signal

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

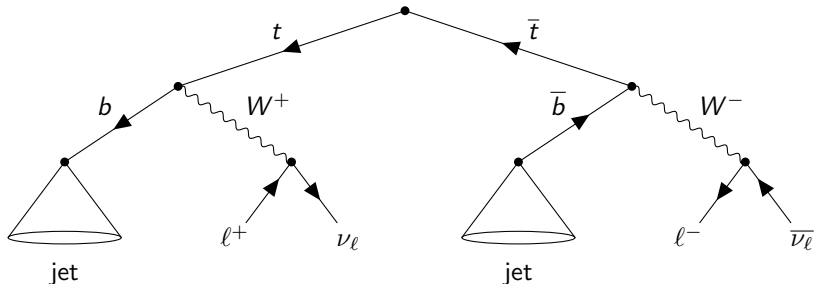


Final state: $\ell^+ \ell^- \ell^\pm \nu \nu \nu + b\text{-tagged jet}$

Unless the Higgs boson is sufficiently boosted, one of 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

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

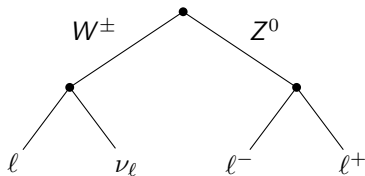


Final state: $\ell^+\ell^-\nu\nu + 2 \text{ b-tagged jets}$

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

WZ background

$\sigma(WZ) = 4.4297$ pb in Benjamin's dataset



Final state: $\ell^+ \ell^- \ell^\pm \nu$ (no b-tagged jet for $\ell \in \{\mu, e\}$)

Export of plots as individual images (Compare.cc)

- Simplified the legend
- Labeled the X and Y axes
- Removed an unnecessary plot

pyrootplots: ROOT files visualisation using Python

- Repository: <https://github.com/bastienvoirin/pyrootplots>
- Documentation: <https://pyrootplots.readthedocs.io/en/latest/>
- Classes:
 - Condition ($<$, $\leq$, $>$, $\geq$, $\in$, $\notin$)
 - Criterion (variable, condition, values/thresholds)
 - Cut (criterion, sig. before, sig. after, bkg. before, bkg. after...)
 - CutEffVsVal (#after/#before vs. cut value)
 - Histogram1D (TH1F, TH1D)
 - Histogram2D (TH2F, TH2D)
 - ROCCurve
 - ROOTDataLoader

Feel free to contribute!

pyrootplots: ROOT files visualisation using Python

Repository (<https://github.com/bastienvoirin/pyrootplots>)

The screenshot shows the GitHub repository page for `pyrootplots` by `bastienvoirin`. The repository is public and has 0 stars and 0 forks. The main branch is `main`. The repository description is "pyrootplots: ROOT files visualisation using Python".

Repository Details:

- Repository: `bastienvoirin / pyrootplots` (Public)
- Notifications: 0
- Fork: 0
- Star: 0

Repository Navigation:

- Code (selected)
- Issues
- Pull requests
- Actions
- Projects
- Wiki
- Security
- Insights

Repository Branches and Tags:

- main (selected)
- 1 branch
- 0 tags

Repository Files:

File	Description	Time
docs	Fix relative imports	5 hours ago
example	Develop CutEffVsVal.plot() and add example/example.py	23 hours ago
src/pyrootplots	Fix relative imports	5 hours ago
.gitignore	Make pyrootplots a package	yesterday
.readthedocs.yaml	Update docs	7 days ago
CHANGELOG.md	Develop ROCurve.plot() and add README/LICENSE/CHANGEL...	23 hours ago
LICENSE.md	Add LICENSE.md, update README.md environment.yml .gitign...	yesterday
README.md	Minor doc fixes	5 hours ago
environment.yml	Changed python version to 3.9.5 and added package <seabor...	2 hours ago
setup.py	Make pyrootplots a package	yesterday

Repository Commits:

- Christopher GREENBERG and bastienvoirin Changed python ver... 598d0a6 2 hours ago 28 commits

Repository About:

- pyrootplots.readthedocs.io/en/1...
- root-cern
- matplotlib-pyplot
- Readme
- MIT license
- 0 stars
- 1 watching
- 0 forks

Repository Releases:

- No releases published

Repository Packages:

- No packages published

Repository Languages:

- Python 100.0%

Repository README.md:

pyrootplots: ROOT files visualisation using Python

pyrootplots: ROOT files visualisation using Python

Documentation (<https://pyrootplots.readthedocs.io/en/latest/>)

pyrootplots
latest

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CONTENTS:

- Read me
- License
- Changelog
- Reference

» Welcome to pyrootplots' documentation! [Edit on GitHub](#)

Welcome to pyrootplots' documentation!

Contents:

- Read me
 - pyrootplots: ROOT files visualisation using Python
 - License
 - Documentation
 - Package installation
 - Usage
 - Development
- License
- Changelog
- Reference
 - Condition
 - Criterion
 - Cut
 - CutEffVsVal
 - Histogram1D
 - Histogram2D
 - ROC Curve

Next

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$\Delta R_{\min}$ between two muons of opposite charges

$$\Delta R_{\min} = \min(\Delta R_{01}, \Delta R_{02}) \quad \text{if } \text{charge}(1) = \text{charge}(2)$$

$$\Delta R_{\min} = \min(\Delta R_{02}, \Delta R_{12}) \quad \text{if } \text{charge}(0) = \text{charge}(1)$$

$$\Delta R_{\min} = \min(\Delta R_{12}, \Delta R_{01}) \quad \text{if } \text{charge}(0) = \text{charge}(2)$$

Let

$$v_{ab} \equiv \frac{\text{charge}(a) \text{charge}(b) + 1}{2} = \begin{cases} v_{ab} = 0 & \text{if } \text{charge}(a) \neq \text{charge}(b) \\ v_{ab} = 1 & \text{if } \text{charge}(a) = \text{charge}(b) \end{cases}$$

Then

$$\Delta R_{\min} = \min(\Delta R_{01}, \Delta R_{02}) \quad \text{if } v_{12} = 1, v_{01} = 0, v_{02} = 0$$

$$\Delta R_{\min} = \min(\Delta R_{02}, \Delta R_{12}) \quad \text{if } v_{01} = 1, v_{02} = 0, v_{12} = 0$$

$$\Delta R_{\min} = \min(\Delta R_{12}, \Delta R_{01}) \quad \text{if } v_{02} = 1, v_{12} = 0, v_{01} = 0$$

$$\Delta R_{\min} = \min(\Delta R_{01} v_{12} + \Delta R_{02} v_{01} + \Delta R_{12} v_{02}, \\ \Delta R_{02} v_{12} + \Delta R_{12} v_{01} + \Delta R_{01} v_{02})$$

$\Delta R_{\min}$ between two muons of opposite charges

$$v_{ab} \equiv \frac{\text{charge}(a) \text{charge}(b) + 1}{2} = \begin{cases} v_{ab} = 0 & \text{if } \text{charge}(a) \neq \text{charge}(b) \\ v_{ab} = 1 & \text{if } \text{charge}(a) = \text{charge}(b) \end{cases}$$

$$\Delta R_{\min} = \min(\Delta R_{01} v_{12} + \Delta R_{02} v_{01} + \Delta R_{12} v_{02}, \\ \Delta R_{02} v_{12} + \Delta R_{12} v_{01} + \Delta R_{01} v_{02})$$

```
("dR01", "ROOT::VecOps::DeltaR(Selected_muon_eta[0],  
→ Selected_muon_eta[1], Selected_muon_phi[0], Selected_muon_phi[1])")  
("dR02", "ROOT::VecOps::DeltaR(Selected_muon_eta[0],  
→ Selected_muon_eta[2], Selected_muon_phi[0], Selected_muon_phi[2])")  
("dR12", "ROOT::VecOps::DeltaR(Selected_muon_eta[1],  
→ Selected_muon_eta[2], Selected_muon_phi[1], Selected_muon_phi[2])")  
("Selected_muon_deltaR_min", "min(min(dR01, dR02), dR12)")  
("v01", "(1 + Selected_muon_charge[0]*Selected_muon_charge[1]) / 2")  
("v02", "(1 + Selected_muon_charge[0]*Selected_muon_charge[2]) / 2")  
("v12", "(1 + Selected_muon_charge[1]*Selected_muon_charge[2]) / 2")  
("Selected_muon_deltaR_min_neutral", "min(dR01*v12 + dR02*v01 +  
→ dR12*v02, dR02*v12 + dR12*v01 + dR01*v02)")
```

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

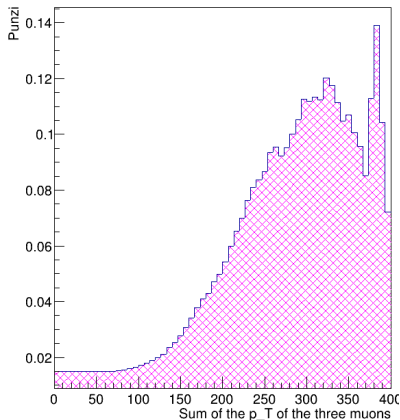
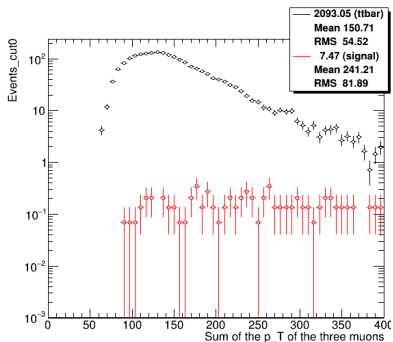
Selected_muon_sum_all_muons_pt

Cut 1: Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1

Cut 2: Selected_bjet_number >= 1 (relevant for some backgrounds but not $t\bar{t}$)

Cut 2: Selected_muon_sum_all_muons_pt >= 130.0

Cut 3: Selected_muon_deltaR_min_neutral <= 1



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

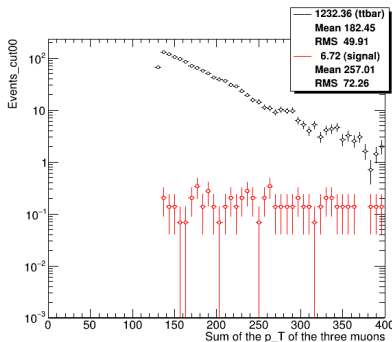
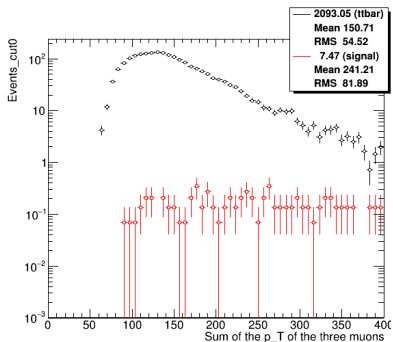
Selected_muon_sum_all_muons_pt

Cut 1: Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1

~~Cut 2:~~ Selected_bjet_number >= 1 (relevant for some backgrounds but not $t\bar{t}$)

Cut 2: Selected_muon_sum_all_muons_pt >= 130.0

Cut 3: Selected_muon_deltaR_min_neutral <= 1



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

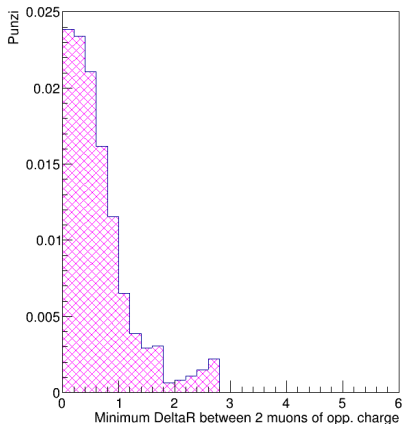
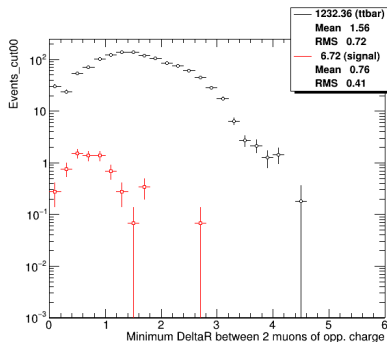
Selected_muon_deltaR_min_neutral

Cut 1: Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1

Cut 2: Selected_bjet_number >= 1 (relevant for some backgrounds but not $t\bar{t}$)

Cut 2: Selected_muon_sum_all_muons_pt >= 130.0

Cut 3: Selected_muon_deltaR_min_neutral <= 1



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

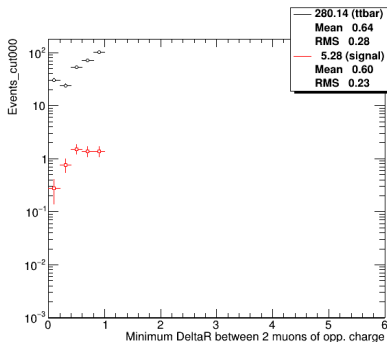
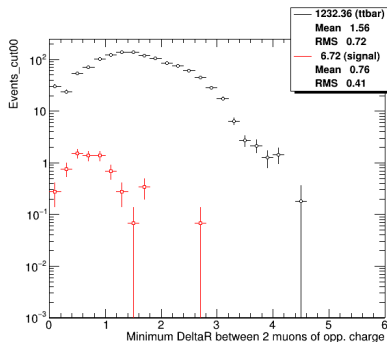
Selected_muon_deltaR_min_neutral

Cut 1: Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1

Cut 2: Selected_bjet_number >= 1 (relevant for some backgrounds but not $t\bar{t}$)

Cut 2: Selected_muon_sum_all_muons_pt >= 130.0

Cut 3: Selected_muon_deltaR_min_neutral <= 1



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

Summary/results

Cut 1: `Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1`

~~Cut 2: `Selected_bjet_number >= 1` (relevant for some backgrounds but not $t\bar{t}$)~~

Cut 2: `Selected_muon_sum_all_muons_pt >= 130.0`

Cut 3: `Selected_muon_deltaR_min_neutral <= 1`

	Events (sig.)	Events ($t\bar{t}$ bkg.)	Cut (sig.)	Cut ($t\bar{t}$ bkg.)	S/B
Before	1184	2728521			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 %

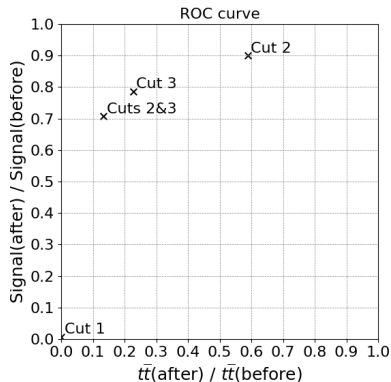
ROC curve

Cut 1: `Selected_muon_number == 3 && abs(Selected_muon_charge_sum) == 1`

~~Cut 2:~~ `Selected_bjet_number >= 1` (relevant for some backgrounds but not $t\bar{t}$)

Cut 2: `Selected_muon_sum_all_muons_pt >= 130.0`

Cut 3: `Selected_muon_deltaR_min_neutral <= 1`



- Cut 2 and Cut 3 are quite interesting but I should be able to find better ones
- To be compared with *actual* signal events: are these cuts still relevant?

Selecting actual signal events from generator particles

- Define a flag: `Is_signal`
- If `Is_signal == 1`, select signal events:
 - H^0 from a T'
 - W^+W^- from a H^0 from a T'
 - $\ell^+\ell^-$ from a W^+W^- from a H^0 from a T'
 - t from a T'
 - Wb from a t from a T'
 - ℓ from a $W^\pm$ from a t from a T'
 - b -tagged jet from a b from a t from a T'

```
addCuts("Is_signal == 0 || (Is_signal == 1 && ... && ... && ...) ", "0");
```

What's next

- **Select actual signal events from generator particles (WIP)**
- Study $\mu\mu e$, μee , eee final states
- WZ background which should be filtered out by `Selected_bjet_number >= 1`
- Invariant mass of the nearest muons (corresponding to $\Delta R_{\min}$)
- Invariant mass $m(b\ell)$ of the $b\ell$ from the t , where ℓ is the most distant lepton from the two others (corresponding to $\Delta R_{\min}$) or the closest to the b : we should find 1 m_t for the signal and 2 for the $t\bar{t}$ background
- Plot $s_T \equiv \sum_{\text{leptons}} p_T + \sum_{\text{jets}} p_T$ for signal and $t\bar{t}$ to compare the distributions
- $\Delta\phi_{\min}$ should be more stable for H^0 than $\Delta R_{\min}$ (which includes η /the boost)
- Define and compare many variables to determine relevant cuts

Appendix

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

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

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

$$= 7.46 \quad (\ell = \mu) \quad (4)$$

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

$$= 59.70 \quad (\ell = e, \mu) \quad (6)$$

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

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

$$= 316\,953 \quad (\ell = \mu) \quad (9)$$

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

$$= 1\,267\,814 \quad (\ell = e, \mu) \quad (11)$$

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

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

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