

Search for $T' \rightarrow \text{top} + H$ in Dilepton Final State

Status Report

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DESY Meeting, Jun. 15th, 2022

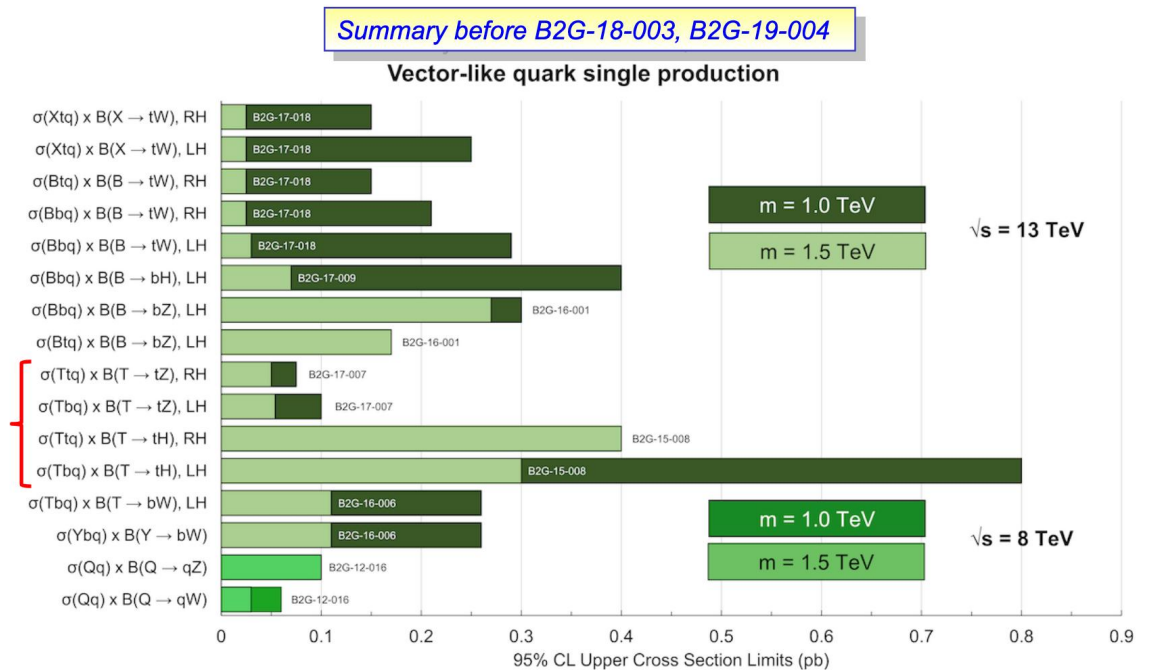
Motivation

- Our goal particle is vector-like top quark
 - Charge: $\pm 2/3$
 - Could be produced in pairs (Strong interaction processes) or singly (Electroweak processes)
 - Related to the stability of Higgs mass, offer a potential solution to the hierarchy problem
 - Related analyses are done with both CMS and ATLAS
 - No significant excess for lepton channel
 - Found significant signal in all-hadronic channel
- We are going to search $T' \rightarrow tH$ in dilepton channel
 - The leptons are OS
 - There are 3 cases in our signal
 - Case 1: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow WW \rightarrow l+l-\nu\nu$
 - Case 2: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow b\bar{l}\nu$; $H \rightarrow WW \rightarrow qq\bar{l}$
 - Case 3: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow ZZ \rightarrow l+l-qq$

Type	Decay channels
T	tZ, tH, bW
B	bZ, bH, tW
X	tW
Y	bW

Our channel

Summary on single production searches



From Search for vector-like quarks at CMS, Francesco Fabozzi, Pheno 2021

Estimating production rates

- $N_{events} = Lum\ inosity * Cross\ Section * BFs * \epsilon * Acc$
- Acc and eff can be obtained from MC study, for now we assume that the values are equal to 1
- Assume cross section for signal: 89fb
- Total luminosity for Run 2: 150fb-1
- Branching fraction values are got from pdg and CMS twiki
- $S_{total}/B_{total} = 0.015\%$

Process	Expected events number
Signal case 1: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow WW \rightarrow l+l-\nu\nu$	75.3
Signal case 2: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow bl\nu$; $H \rightarrow WW \rightarrow qq\bar{l}$	75.3
Signal case 3: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow ZZ \rightarrow l+l-qq$	5.5
TT bar background	518850.8
WW background	445988.4
WZ background	92105.4

MC Samples

- The Official MC samples we are using are
 - There are many mass point for the T'

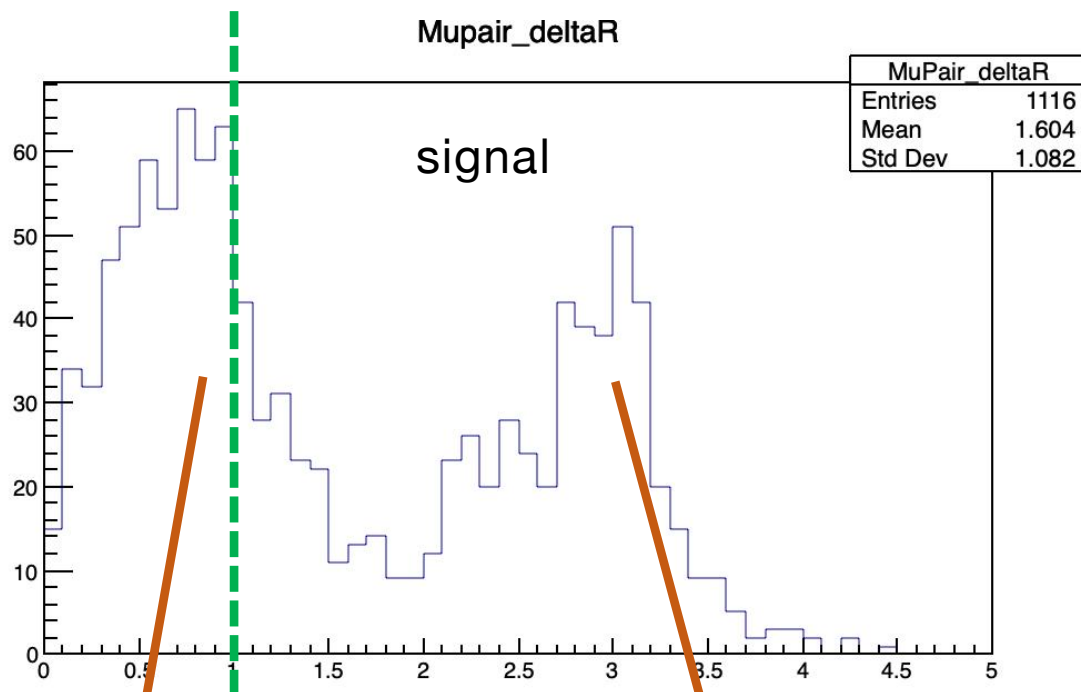
Process	Year	MC Sample
T' Signal	2018	/TprimeBToTH_M-700_LH_TuneCP5_PSweights_13TeV-madgraph_pythia8/RunIISummer19UL18NanoAODv2-106X_upgrade2018_realistic_v15_L1v1-v1/NANOAODSIM
TTbar background	2018	/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM
WW background	2018	/WW_TuneCP5_13TeV-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM
WZ background	2018	/WZ_TuneCP5_13TeV-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM

Cut Strategy

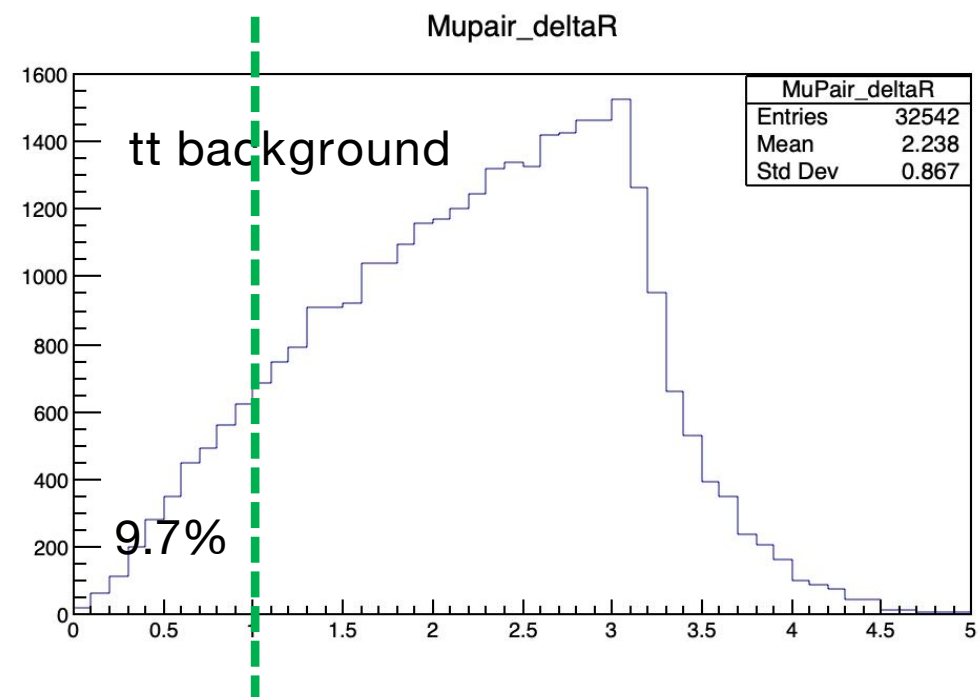
- We have 3 cases for signal
 - $T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow WW \rightarrow l+l-\nu\nu$ (1 lepton pair, 3 jets and at least 1 b jet)
 - $T' \rightarrow tH; t \rightarrow Wb \rightarrow b\bar{b}; H \rightarrow WW \rightarrow qq\bar{l}$ (1 lepton pair, 3 jets and at least 1 b jet)
 - $T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow ZZ \rightarrow l+l-\nu\nu$ (1 lepton pair, 3 jets and at least 1 b jet)
- Basic cuts:
 - Cuts for muons
 - Tight ID cut: Muon_tightId
 - $Pt(\mu) > 20\text{GeV}$
 - $|\eta| < 2.4$
 - Tight isolation cut: goodMuons_miniPFRelIso_all < 0.05
 - Cuts for jets
 - Tight jet ID cut: Jet_jetId: 6
 - $Pt(\text{jet}) > 30\text{GeV}$
 - $|\eta| < 2.5$
 - Cuts for events
 - 1 OS muon pair
 - At least 3 jets
 - At least 1 b jet
 - loose b-tag jet: goodJets_btagDeepFlavB > 0.049

MC Study

- $\Delta R(\mu^+, \mu^-)$ distribution for signal and $t\bar{t}$ background
 - All events in the plots passed the basic cuts
 - ΔR cut can be applied to separate the signal processes



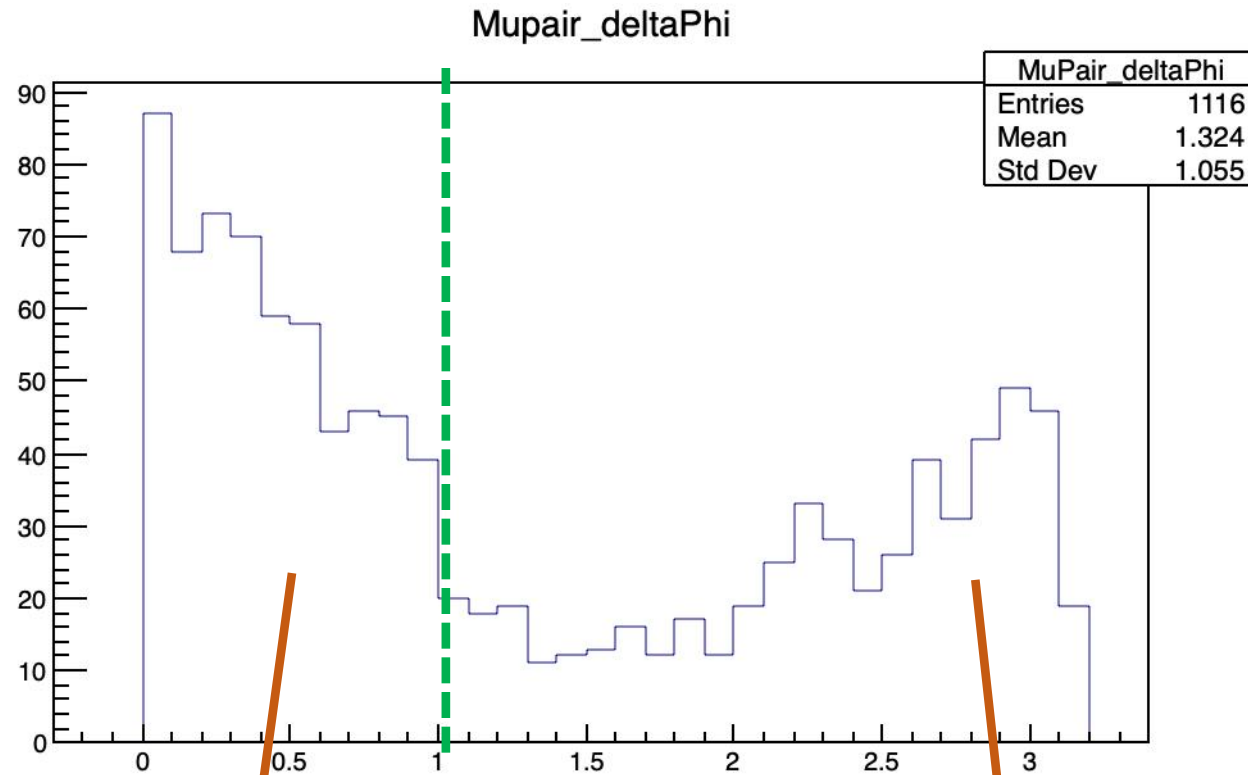
$T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow l+l-\nu\nu$
 $T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow ZZ \rightarrow l+l-qq$



$T' \rightarrow tH; t \rightarrow Wb \rightarrow bl\nu; H \rightarrow WW \rightarrow qq\bar{l}$

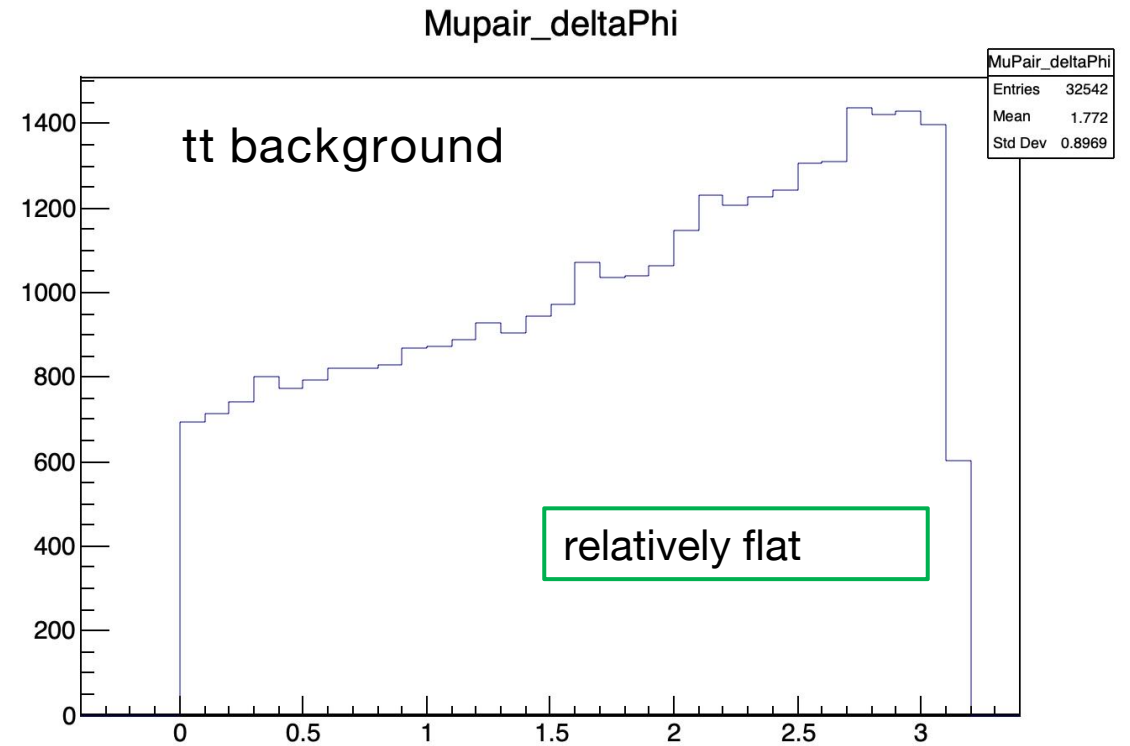
MC Study

- $|\Delta\Phi(\mu^+, \mu^-)|$ distribution for signal and $t\bar{t}$ background
 - All events in the plots passed the basic cuts
 - $\Delta\Phi$ cut can be applied to separate the signal processes
 - $\Delta\Phi$ is a variable related to ΔR , we won't cut on both of them



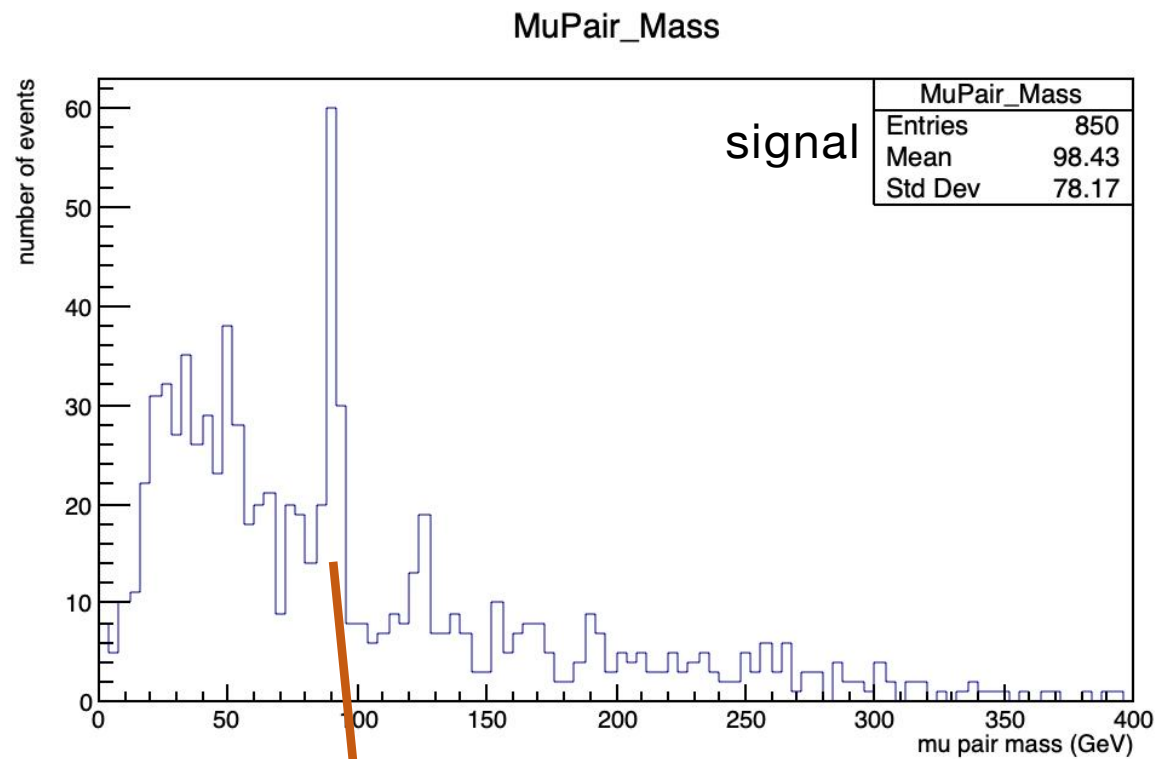
$T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow l+l-\nu\nu$
 $T' \rightarrow tH; t \rightarrow Wb \rightarrow qq\bar{b}; H \rightarrow ZZ \rightarrow l+l-qq$

$T' \rightarrow tH; t \rightarrow Wb \rightarrow bl\nu; H \rightarrow WW \rightarrow qq\bar{l}$

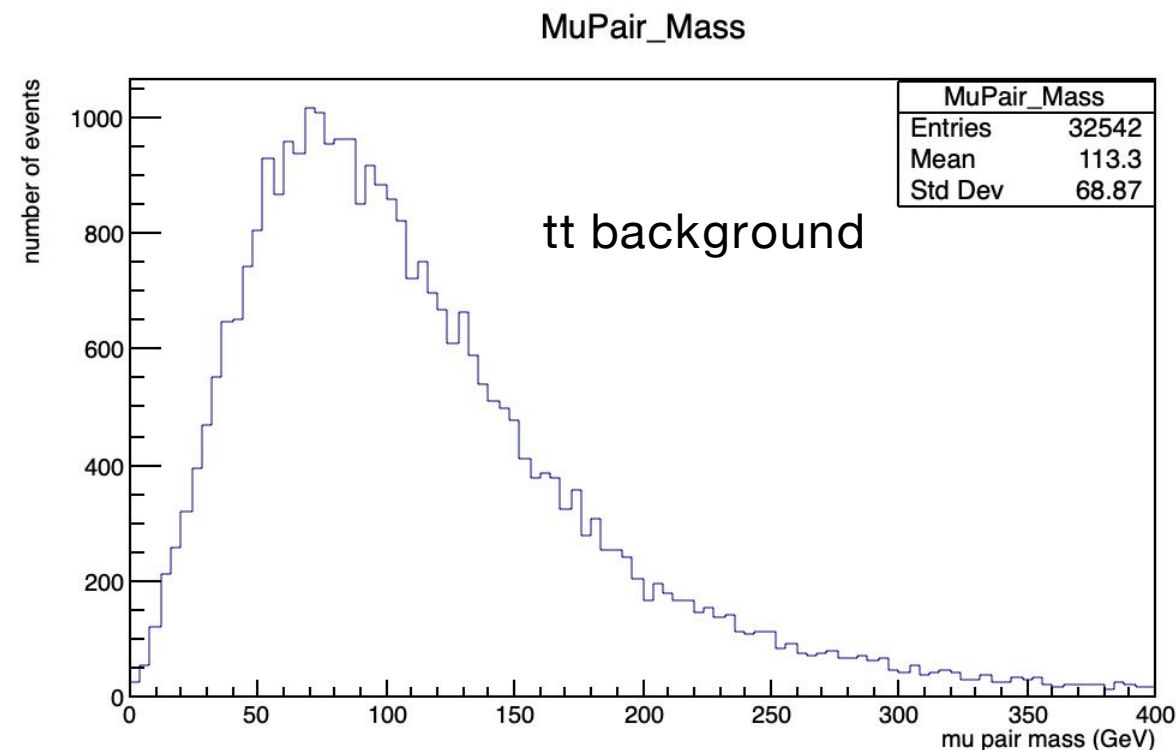


MC Study

- Muon mass(μ^+ , μ^-) distribution for signal and $t\bar{t}$ background
 - All events in the plots passed the basic cuts
 - Dimuon mass cut can be applied to select ZZ signal process

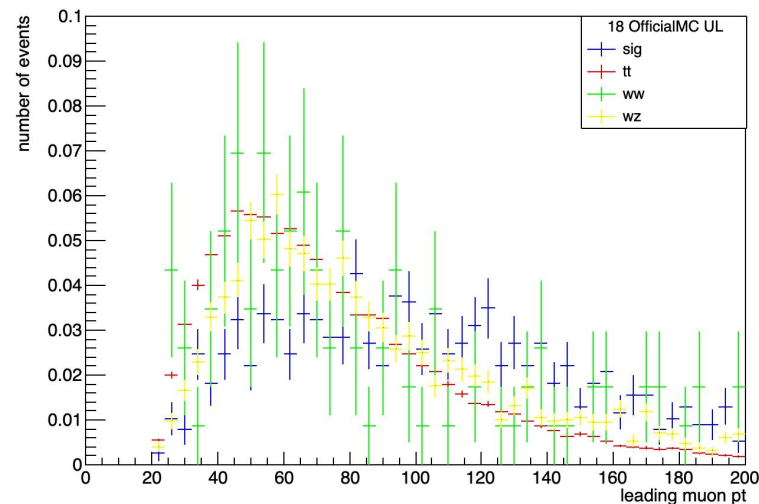
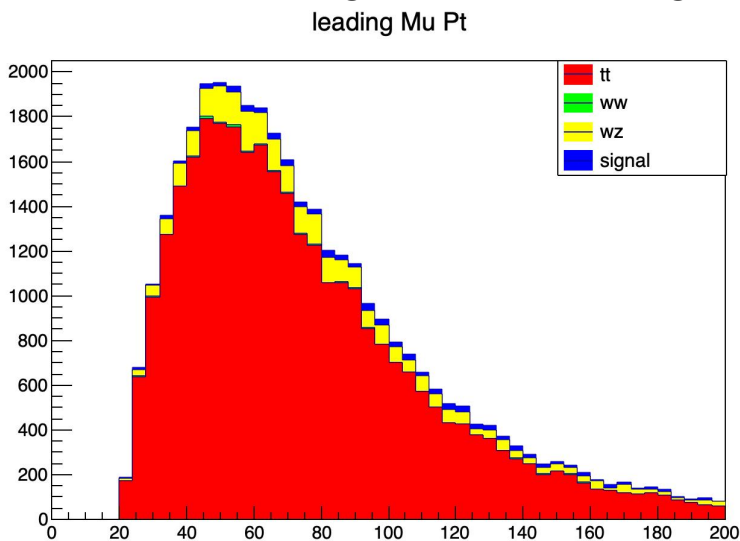


Z peak from
 $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow ZZ \rightarrow l+l-q\bar{q}$



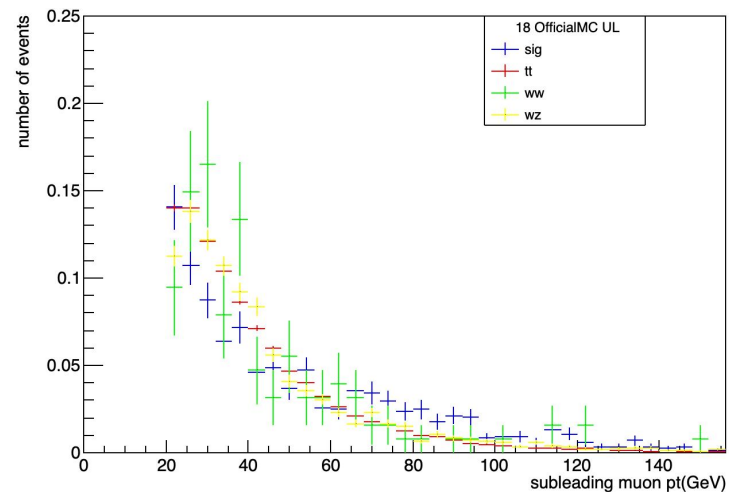
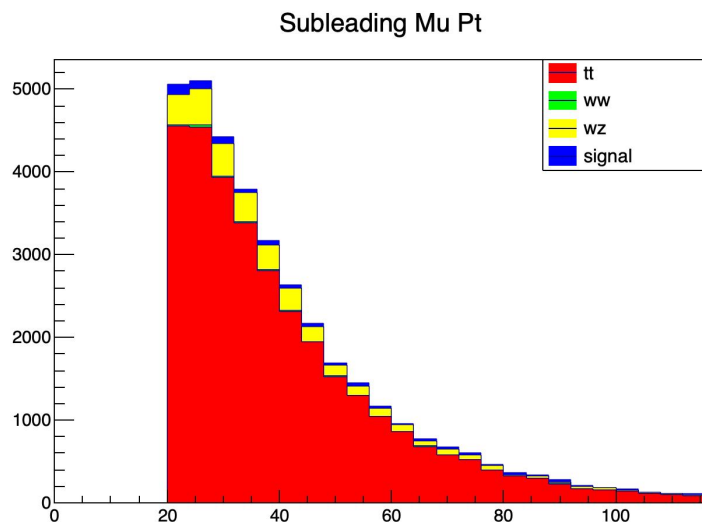
MC Study

- Leading muon pt distribution
 - Signal has a stronger leading mu pt distribution than all background



All events in the plots passed the basic cuts

- Distribution of sub-leading muon pt

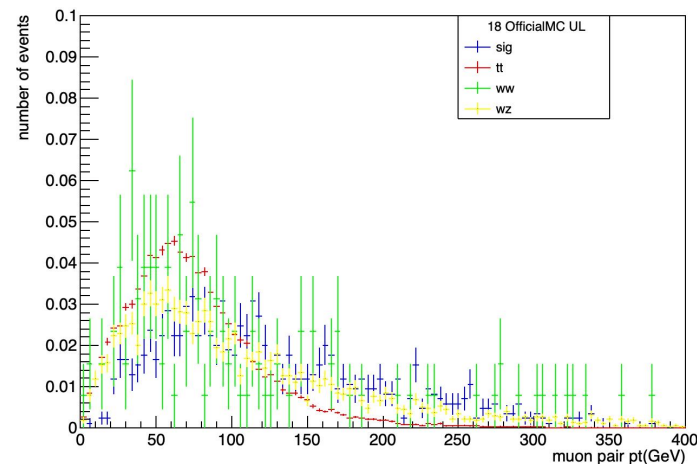
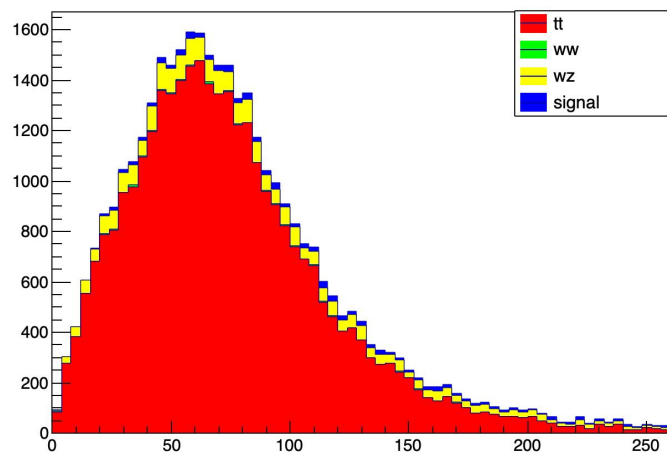


MC Study

➤ Muon pair pt ($\vec{P}t(\mu^+) + \vec{P}t(\mu^-)$) distribution

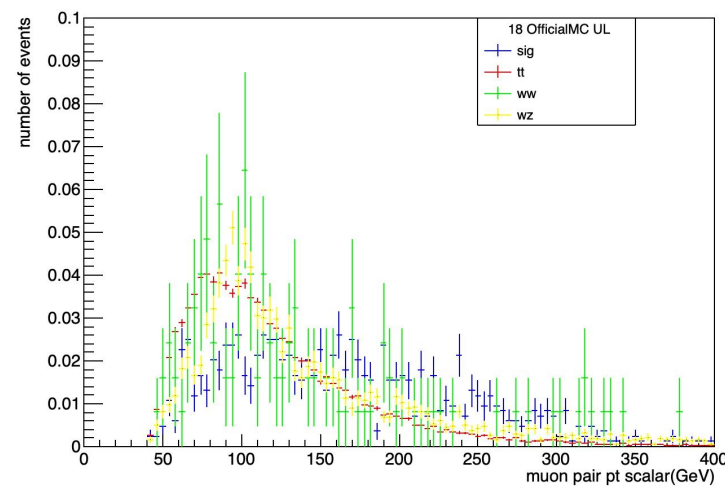
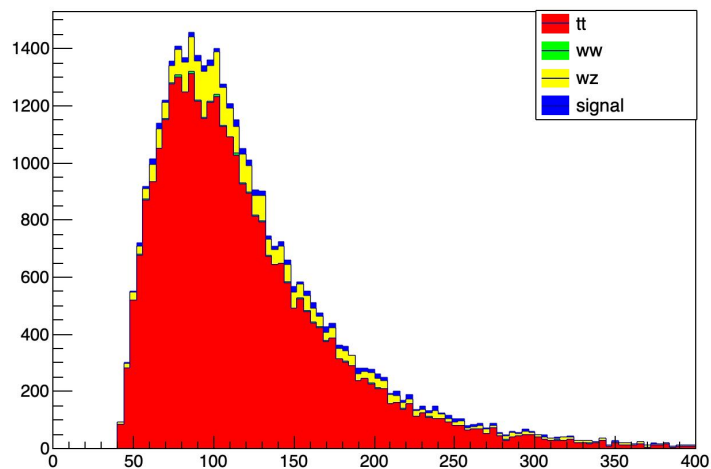
■ Related to delta R

Mu pair Pt



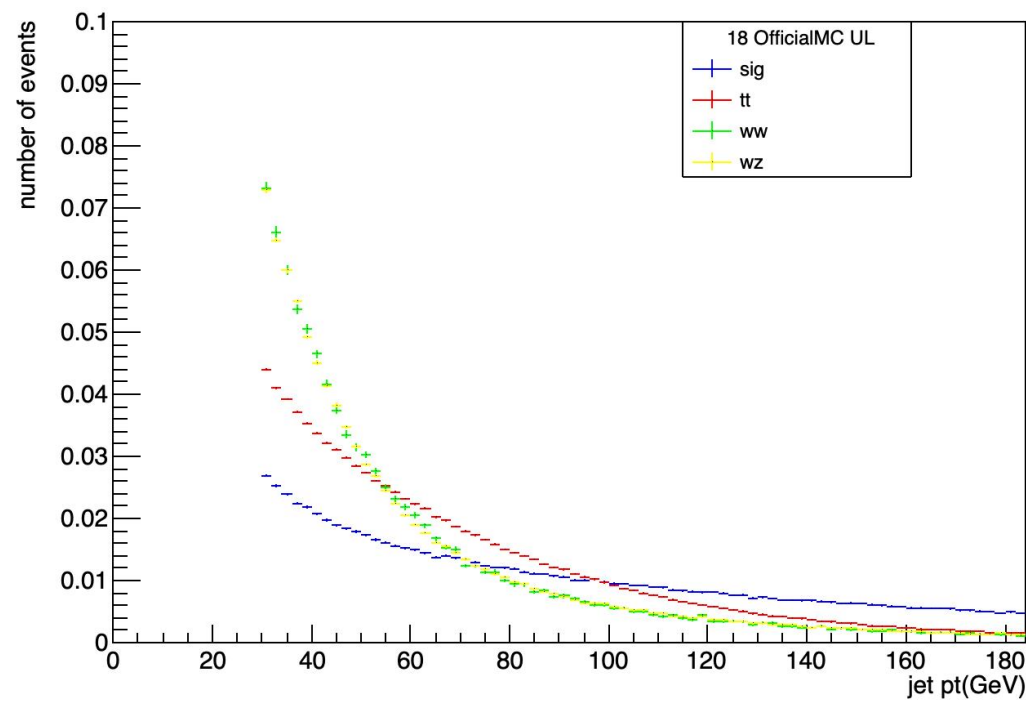
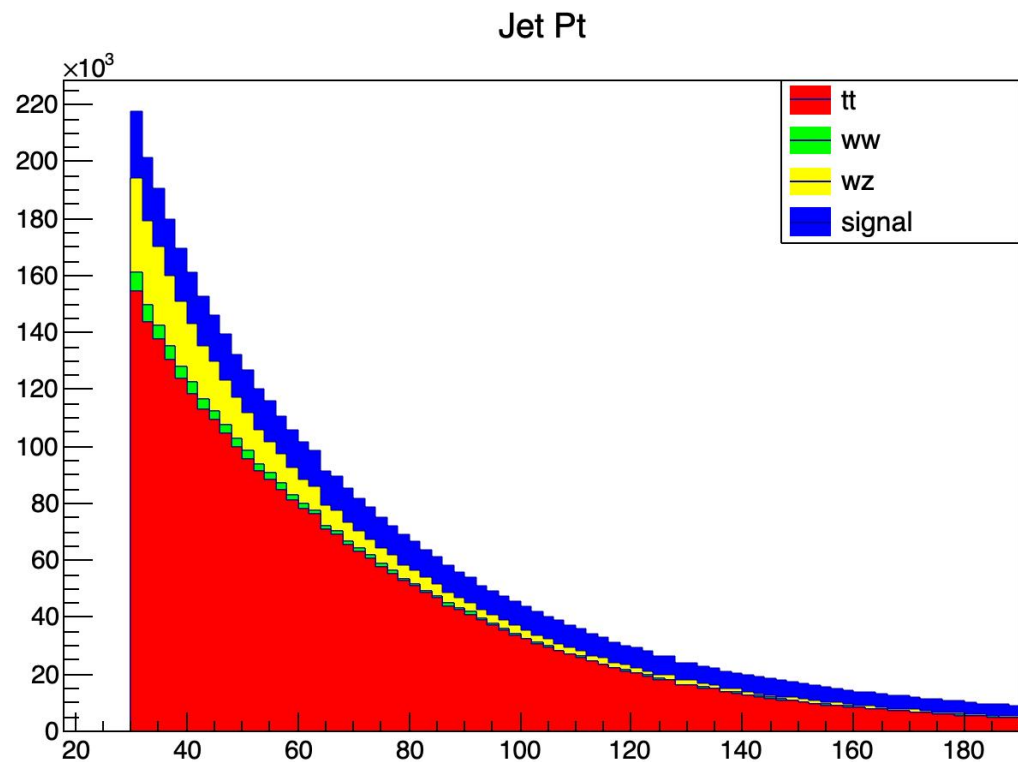
➤ Distribution of muon pair pt (pT(mu+) + pT(mu-))

Mu pair Pt scalar



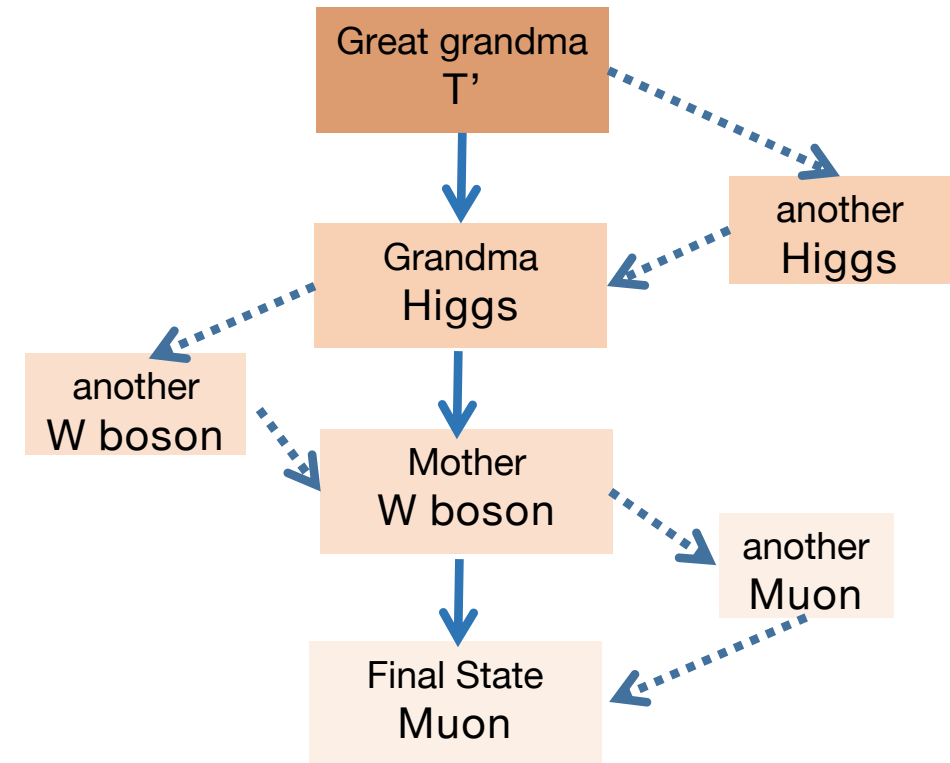
MC Study

- All jet pt distribution of
 - Signal has a stronger pt distribution than background



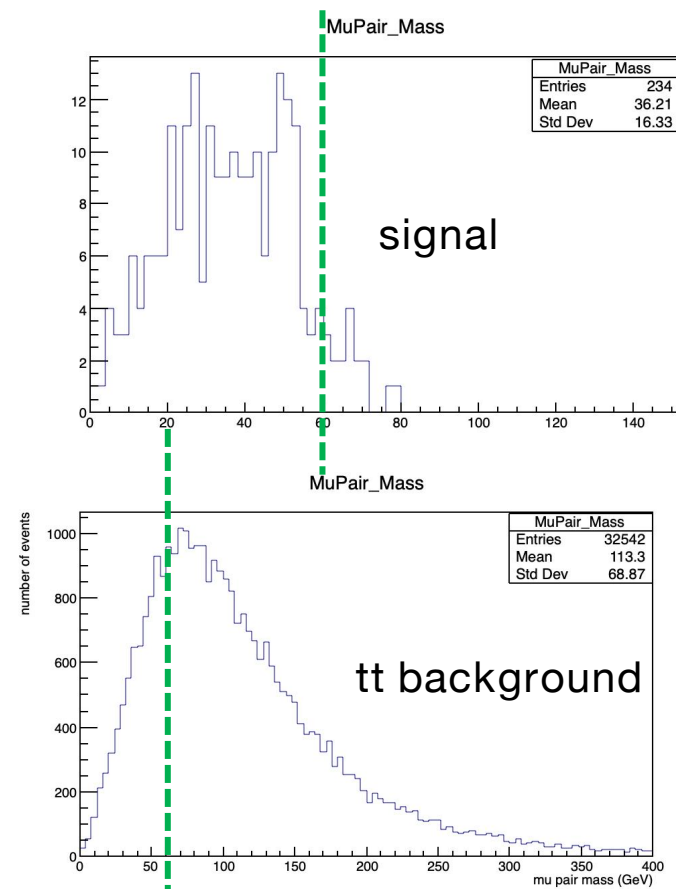
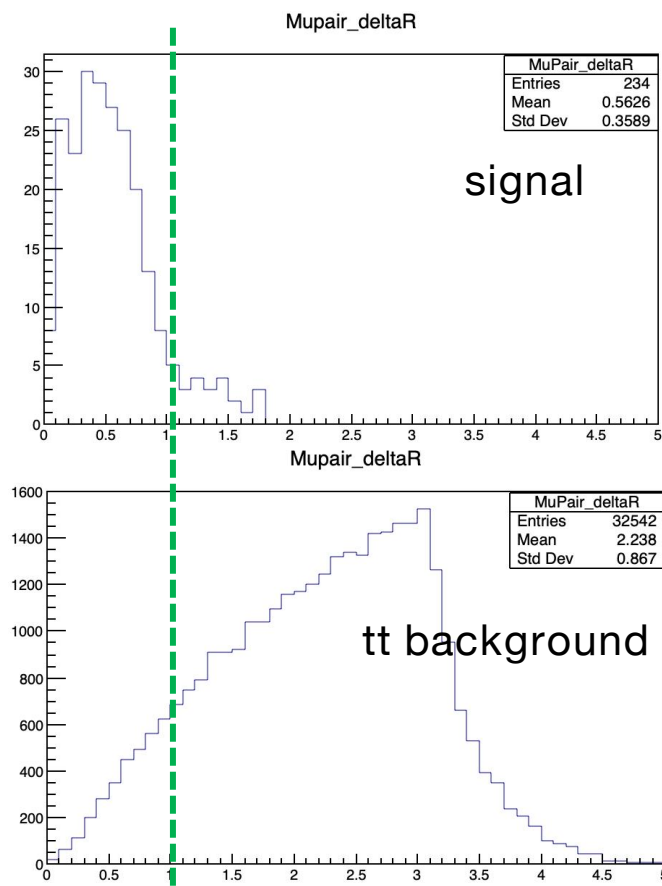
MC Study

- Study 3 signal processes separately
 - case 1: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow WW \rightarrow l+l-\nu\nu$
 - case 2: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow b\bar{l}\nu$; $H \rightarrow WW \rightarrow q\bar{q}l$
 - case 3: $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow ZZ \rightarrow l+l-q\bar{q}$
- Study $T' \rightarrow tH$; $t \rightarrow Wb \rightarrow qq\bar{b}$; $H \rightarrow WW \rightarrow l+l-\nu\nu$ first
 - Apply DeltaR cut or dimuon mass cut to select signal case 1
 - GEN selection study
 - Find final state particles and their mothers/ancestors to follow through the full decay chain at gen level
 - Consider multi muons/ W bosons/ Higgs: Mother of Mu/ W/ H could be another Mu/ W/ H
 - Find 8 events after scaling (signal cross section is 89fb^{-1})
- Pt cut optimization
 - Use Punzi parameter
 - Apply cut on muon pair Pt (scalar), muon pair Pt (vector) or delta R
 - Focus on $T\bar{T}$ background first



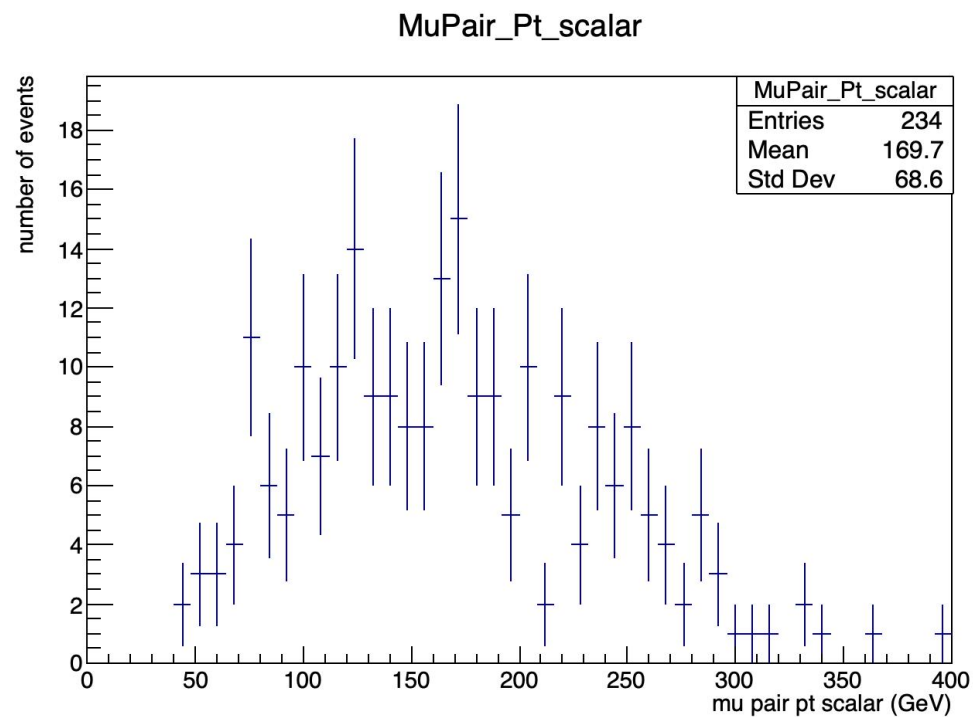
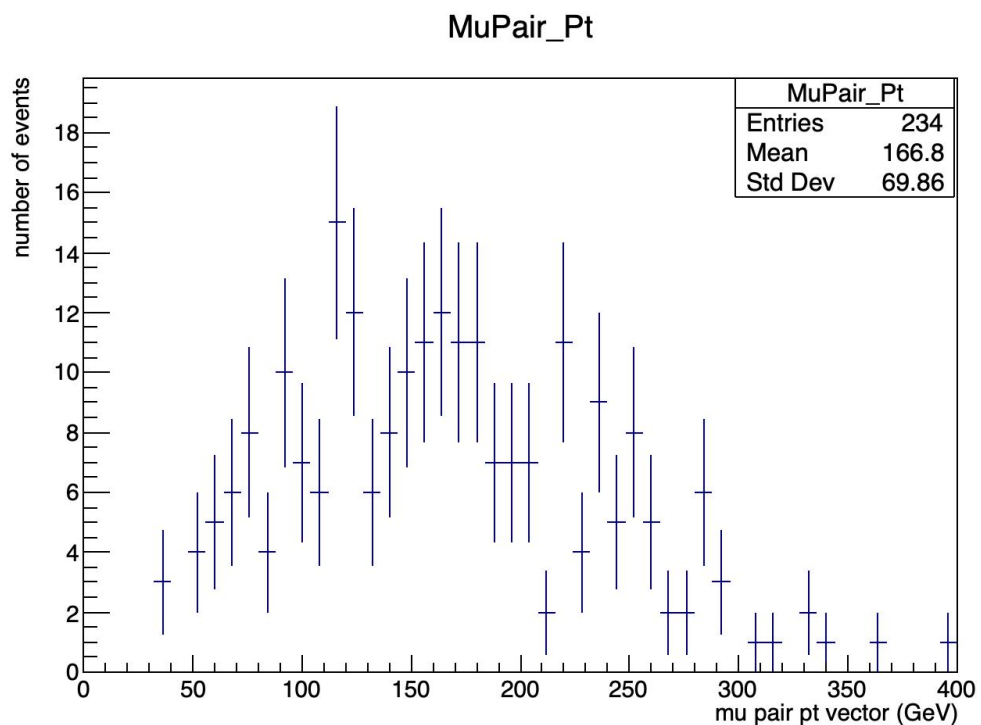
GEN Selection Study (Signal MC)

- DeltaR and MuonPair mass distribution at Gen Level
 - After applying Basic cuts
 - Check the DR distribution for both Signal and $t\bar{t}$ background
 - $\Delta R(\mu^+, \mu^-) < 1$
 - Check Dimuon mass distribution for both signal and $t\bar{t}$ background
 - $M(\mu \text{ pair}) < 60 \text{ GeV}$



GEN Selection Study (Signal MC)

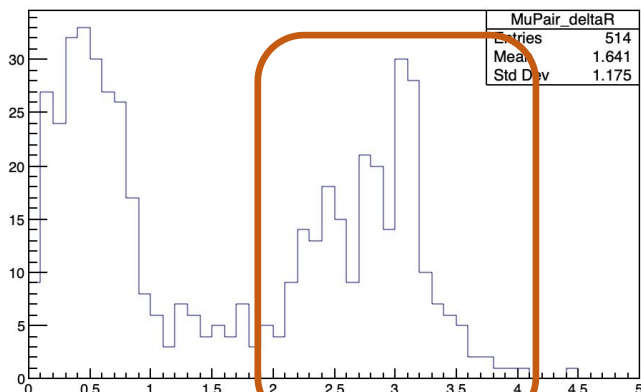
➤ Muon pair p_T distribution at Gen Level



GEN Selection Study (Signal MC)

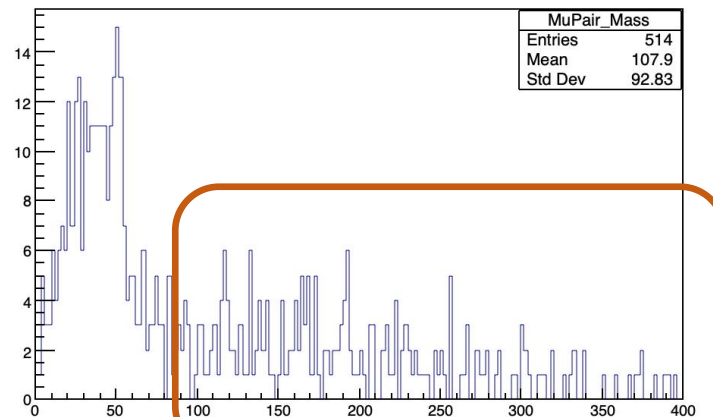
- Half decay chain GEN selection for cross check
 - Basic cuts for muons and jets are applied
 - Perform GEN selection for $W \rightarrow \text{Mu}$
 - Consider multi muons: Mother of Mu could be another Mu
 - Find 17 events after scaling (signal cross section is 89fb)

Mupair_deltaR



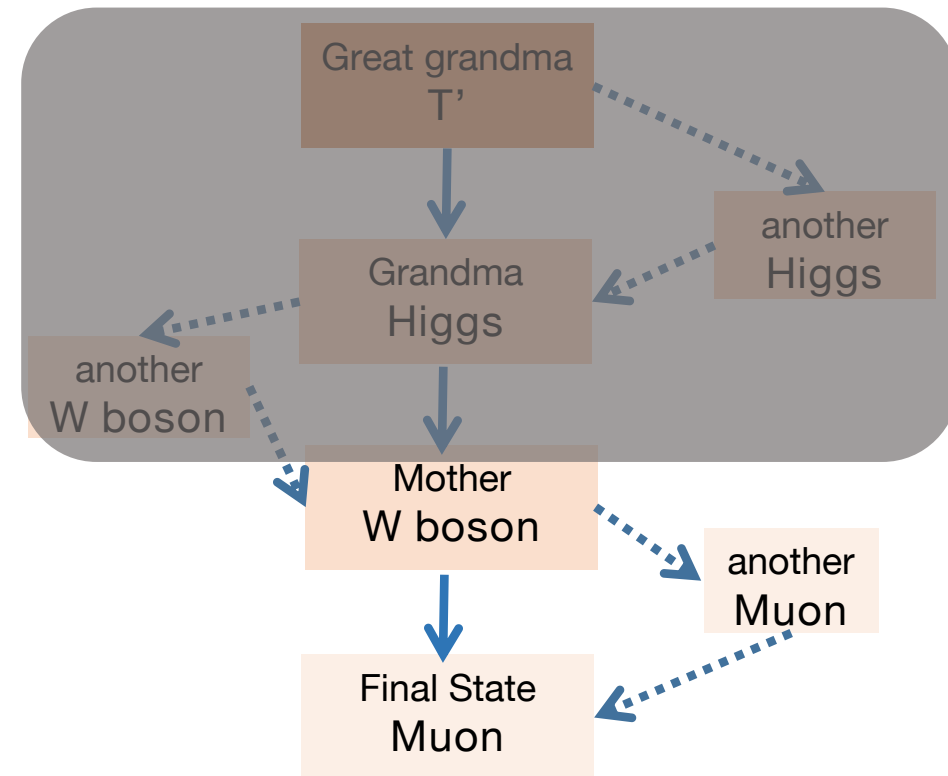
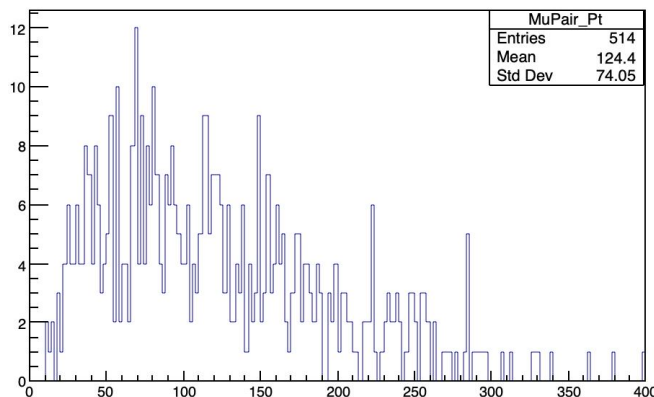
Background

MuPair_Mass



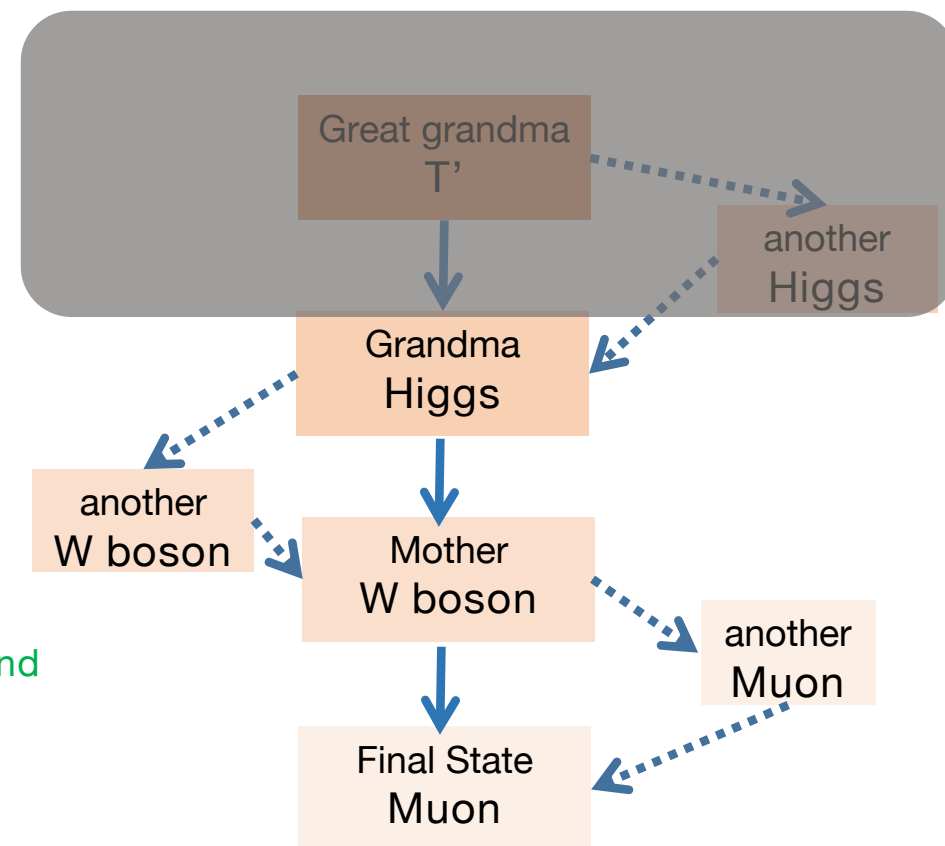
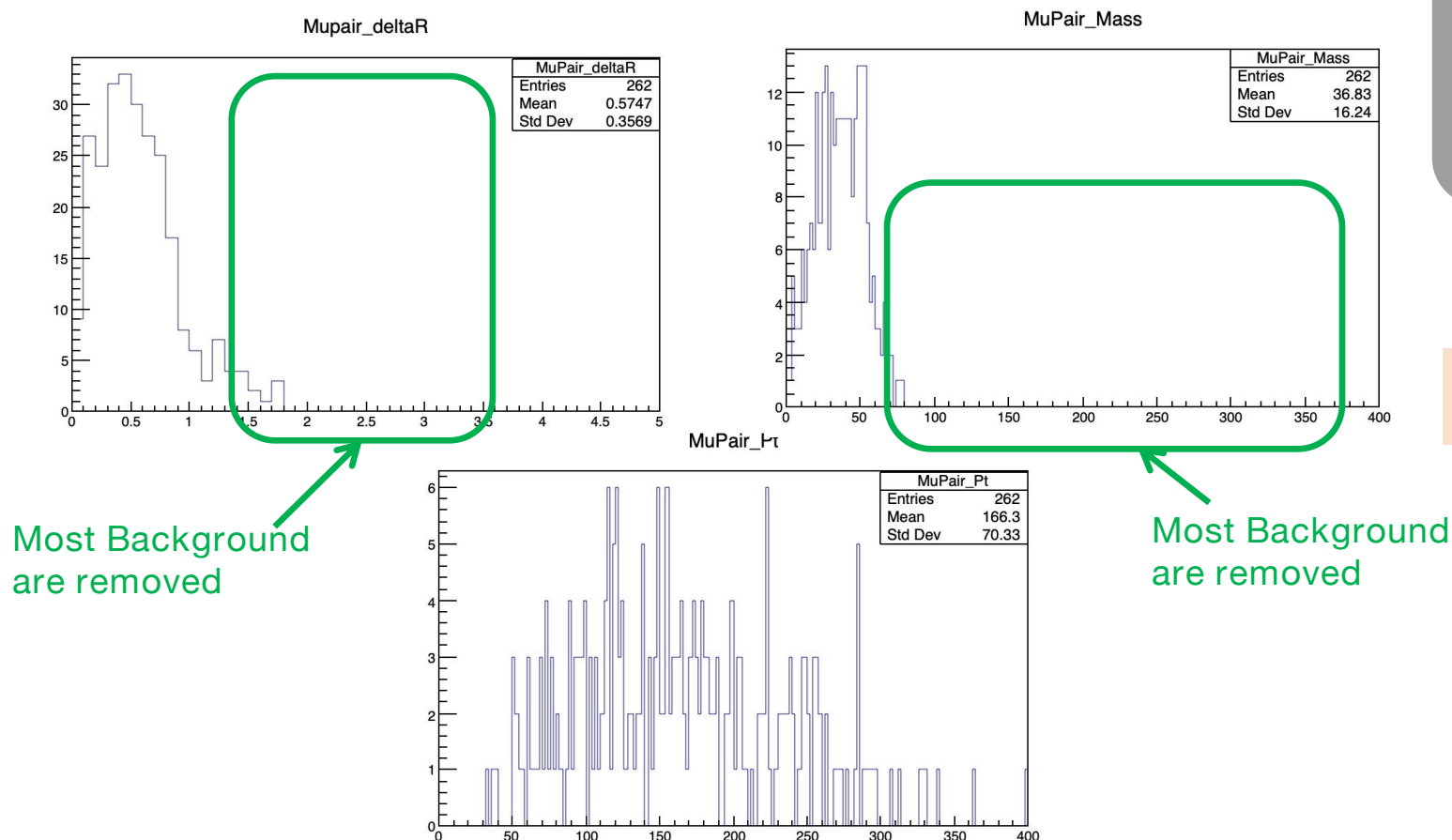
Background

MuPair_Pt



GEN Selection Study (Signal MC)

- Half decay chain GEN selection for cross check
 - Basic cuts for muons and jets are applied
 - Perform GEN selection for $H \rightarrow W \rightarrow \mu$
 - Consider multi muons: Mother of Mu could be another Mu
 - Find 8.95 events after scaling (signal cross section is 89fb)



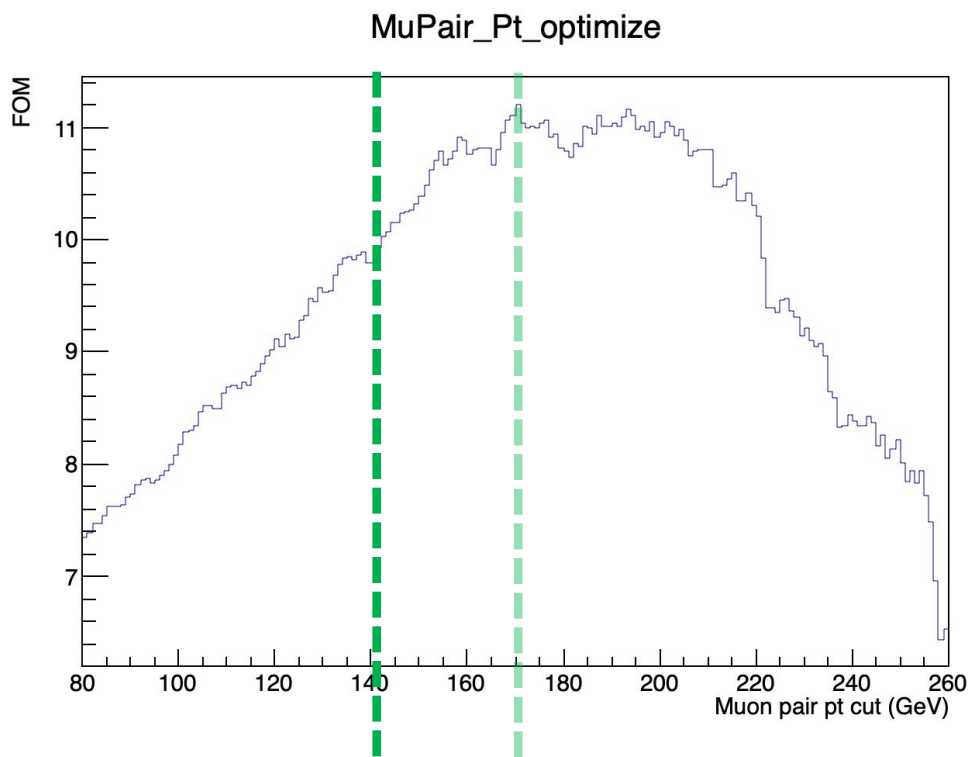
MC Study with New Cuts

- **Remove GEN selection** and apply the following cuts to signal MC and TTbar MC
 - Basic cuts
 - Basic cuts && $\Delta R(\mu^+, \mu^-) < 1$ (This cut will be applied to select signal case1!)
 - Basic cuts && $m(\mu \text{ pair}) < 60 \text{ GeV}$
- Many TT background events are removed after 2 new cuts
 - We still have lots of TT background (It's natural to observe them in OS channel)
- Study more variables to reject the background, especially for the b jets & muon

	Number of TT events (after scaling)	Number of WW events (after scaling)	Number of WZ events (after scaling)	Number of Signal events (after scaling)	S/B ratio
Basic cuts	181137.6	5261.7	7726.4	28.0 (lots of fake signal)	0.0144%
Basic cuts && $\Delta R(\mu^+, \mu^-) < 1$	17621.0	1107.7	1461.4	12.6	0.0624%
Basic cuts && $m(\mu \text{ pair}) < 60 \text{ GeV}$	39227.7	1384.7	700.7	11.7	0.028%

Preliminary Cuts Optimization

- Optimize Pt cuts separately using Punzi parameter
 - $\text{FOM} = N_{\text{signal}} / (\sqrt{N_{\text{background}} + 3/2})$
 - Take TT bar as background
 - Take signal case 1 as signal
- Preliminary optimized result: $\text{Pt}(\mu^+\mu^-) > 140 \text{ GeV}$
 - Didn't take 170 GeV because we don't want to remove too many signal



	Number of TT events (after scaling)	Number of Signal events (after scaling)	Ratio S/B_tt
Basic cuts&& $\Delta R(\mu^+, \mu^-) < 1$	17621.0	12.6	0.0715%
Basic cuts&& $\Delta R(\mu^+, \mu^-) < 1$ && μ pair pt > 140	2681.3	7.4	0.276%

Summary & To do list

- Summary
 - Study MC samples and cut strategy
 - GEN selection study
 - Preliminary cut optimization
- To do list
 - Study more variables to reject background
 - Study b jet related variables
 - Final cut optimization
 -

Thanks!