Search for T’→ top+H in Dilepton OS Final State

Status Report

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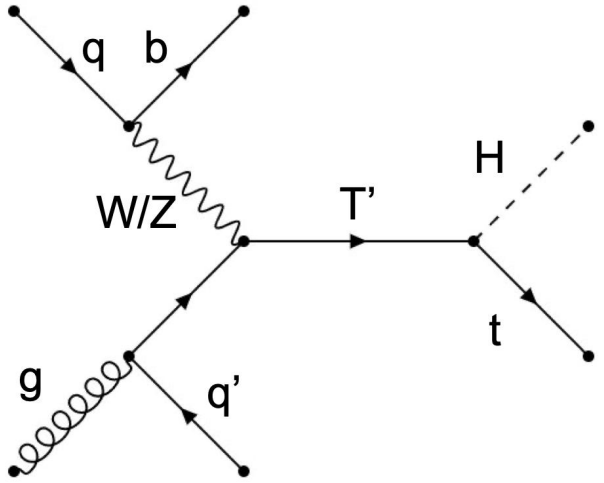
Group Meeting, Mar. 7th, 2023

Outline

- **General analysis strategy**
- **MC Samples**
- **Basic Selection**
- **Event selection**
- **Event reconstruction**
- **Summary**

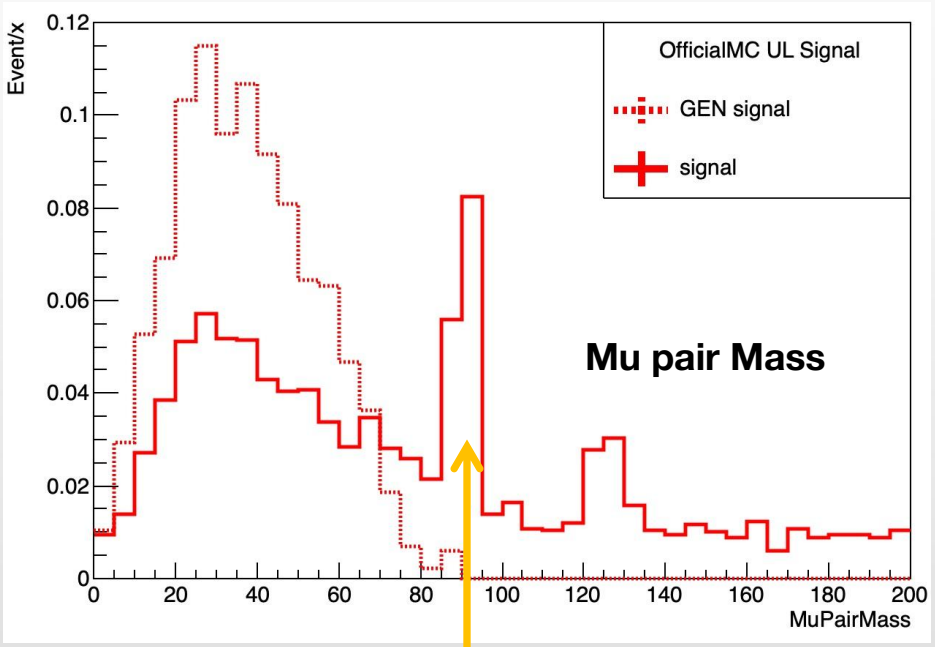
General Analysis Strategy

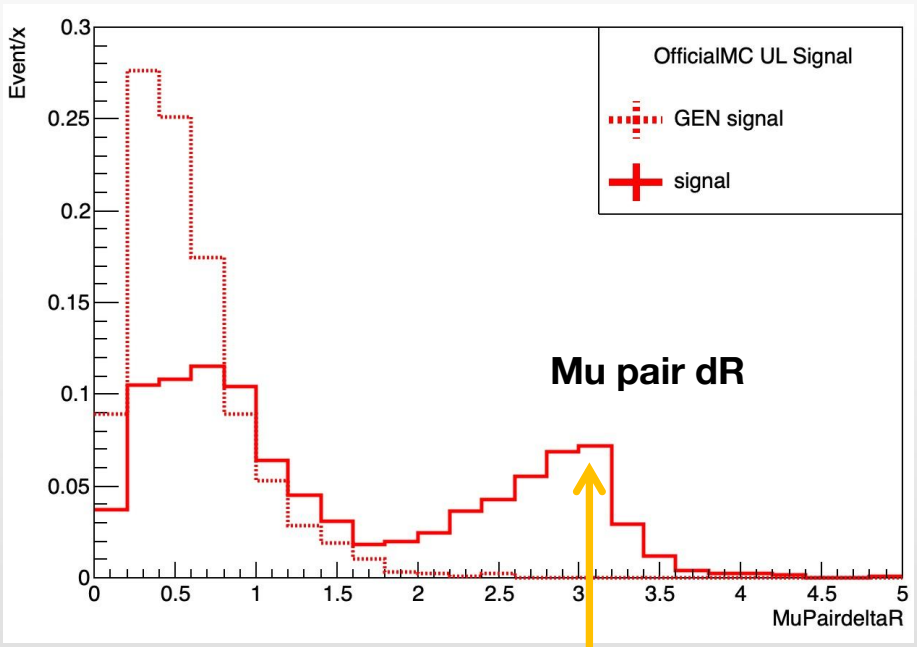
- **T'->tH**
  - **T' mass point is 700GeV**
    - **Decay products have high pT**
    - **Expected cross section(with NWA): 89fb**
- **VLQ lepton OS channel**
  - **Study case1 muon channel first**
    - **case1: T' -> tH; t->Wb->qqb; H->WW->l+l-vv**
      - **A full hadronic top can be directly reconstructed (page 12)**
        - **3 jets are selected by X^2 sorting algorithm**
        - **3 jets has High pT & small angular distance**
      - ***New method to reconstruct Higgs* (page 13)**
        - **Higgs has spin0: M(ll) is small**
      - **b jet and lepton are from different decays: a relatively big angular distance**
    - **case2: T' -> tH; t->Wb->blv; H->WW->qqlv**
      - **Both top and Higgs can not be directly reconstructed**
      - **b and one of the leptons are from different decays**
    - **case3: T' -> tH; t->Wb->qqb; H->ZZ->llqq**
      - **T' can be fully reconstruced!**
      - **Low expected signal events due to low BR of H->ZZ**



General Analysis Strategy

- **Background for VLQ OS lepton case1**
  - **Case2 and case3 are considered as background**
    - **case1: T' -> tH; t->Wb->qqb; H->WW->l+l-vv**
    - **case2: T' -> tH; t->Wb->blv; H->WW->qqlv**
    - **case3: T' -> tH; t->Wb->qqb; H->ZZ->llqq**





Signal case 3

GEN signal: T'->H->W->l

Signal case 2

General Analysis Strategy

- **Background for VLQ OS lepton case1**
  - **Background from other processes**
    - **QCD background can be ignored**
    - **Main background: TTbar->WbWb->l+l-vv**
      - **Large cross section(87315 fb)**
      - **Final state has 2 OS leptons**
      - **TTbar are not from a heavy mother particle: low pt of decay products**
      - **For one top, a b jet and a lepton are from the same decay**
      - **2 leptons in final state: not supposed to see a top peak from jets**
    - **TTH(271fb), TTZ(770fb), TTW(610fb)**
      - **Cross sections are not very big**
      - **Have very similar final states to signal process**
      - **Not from a heavy mother particle: low pt of decay products**
      - **TTZ: Z peak in di-lepton mass spectrum**

MC Samples

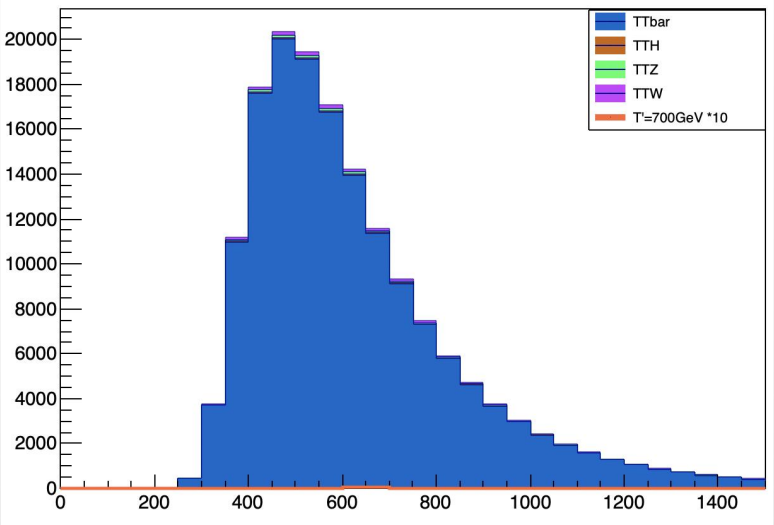
- **Take MC sample for analysis strategy study**
  - **Use all run2 MC samples for signal to reduce the statistical error**
- **All samples are lastest reconstructed (UL v9)**

Processes	Channel	MC Samples	Year (UL)	Cross-Section(fb)
Signal	T'ToTH	/TprimeBToTH_M-700_LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	2018	89
	T'ToTH	/TprimeBToTH_M-700_LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM	2017	89
	T'ToTH	/TprimeBToTH_M-700_LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM	2016	89
	T'ToTH	/TprimeBToTH_M-700_LH_TuneCP5_13TeV-madgraph_pythia8/RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM	2016APV	89
Background	TTTo2L2Nu	/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM	2018	87315
	TTW	/ttWJets_TuneCP5_13TeV_madgraphMLM_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	2018	610
	TTZ	/ttZJets_TuneCP5_13TeV_madgraphMLM_pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	2018	770
	TTH	/ttHToNonbb_M125_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM	2018	271

Basic Selection

➢ **Basic cuts**

- For Muons
  - Two opposite sign muons
  - Pt > 20GeV
  - |eta| < 2.4
  - Tight Muon ID: Muon_tightId
  - Tight isolation: goodMuons_miniPFRelIso_all < 0.05
  - Significance cut: Muon_sip3d < 3
- For jets
  - Tight jet ID: Jet_jetId= 6
  - Pt > 30GeV
  - |eta| < 2.5
  - At least 3 good jets
  - At least 1 Loose B jet(goodJets_btagDeepFlavB>0.049)
  - Remove overlap jets. Overlap jet: min(dR(jet, mu)) < 0.4

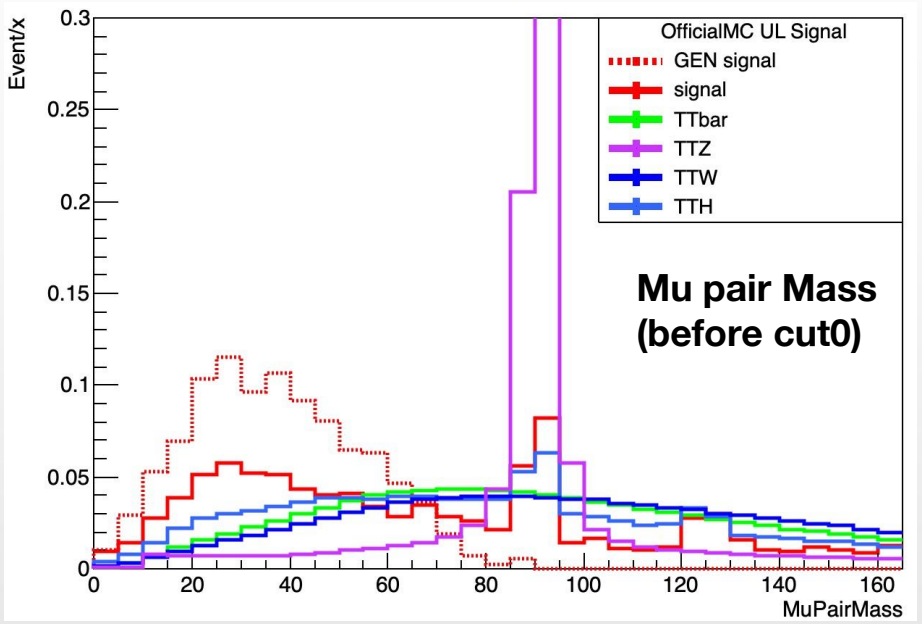


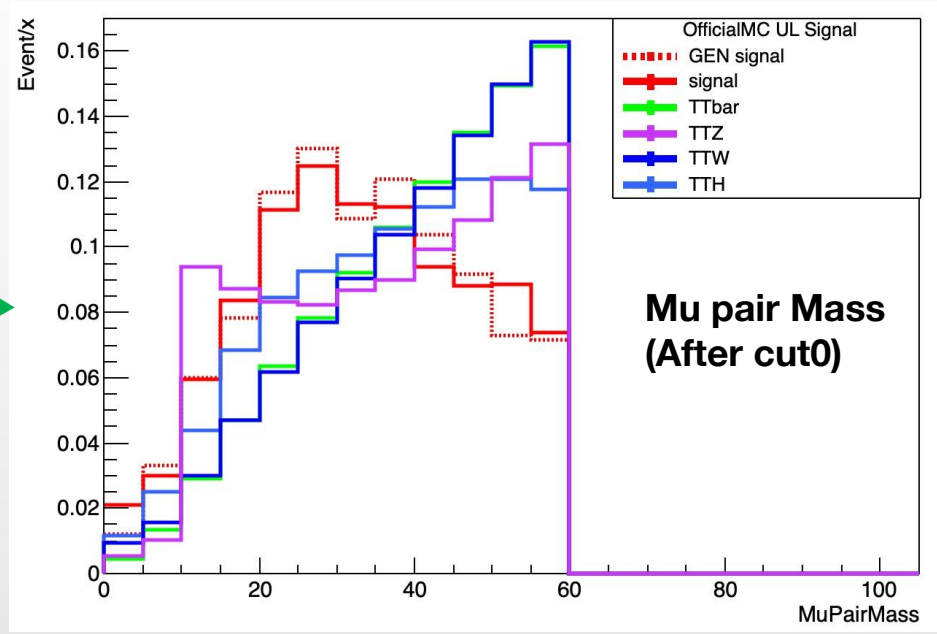
➢ **Enormous background after basic cuts, especially TTbar**

Cuts	N_Signal	N_GENSignal	signal efficiency	signal purity	N_TT	N_TTW	N_TTZ	N_TTH	S(GEN)/B
Basic cuts	33.35	9.48	100%	28%	296960	629	1846	455	0.003%

Cut0: Mu pair mass < 60GeV

- **Cut0: Mu pair mass < 60GeV**
  - **Remove TTbar& signal case2: leptons from different top decays have bigger mass**
  - **Remove TTZ& signal case3: remove the Z peak**





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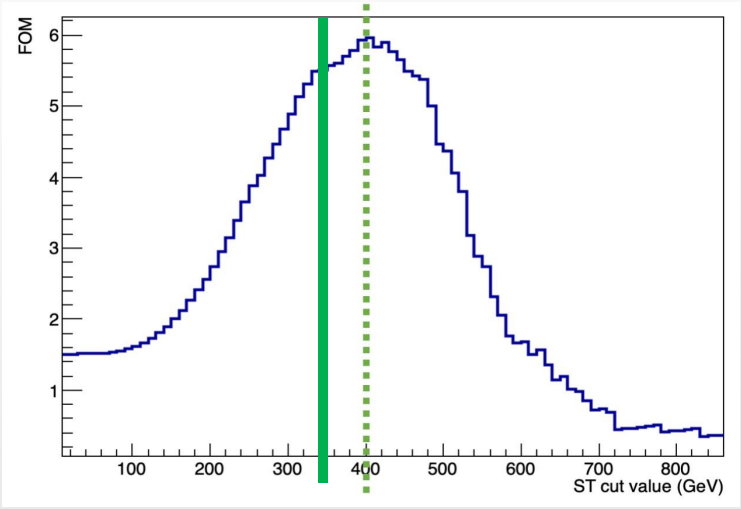
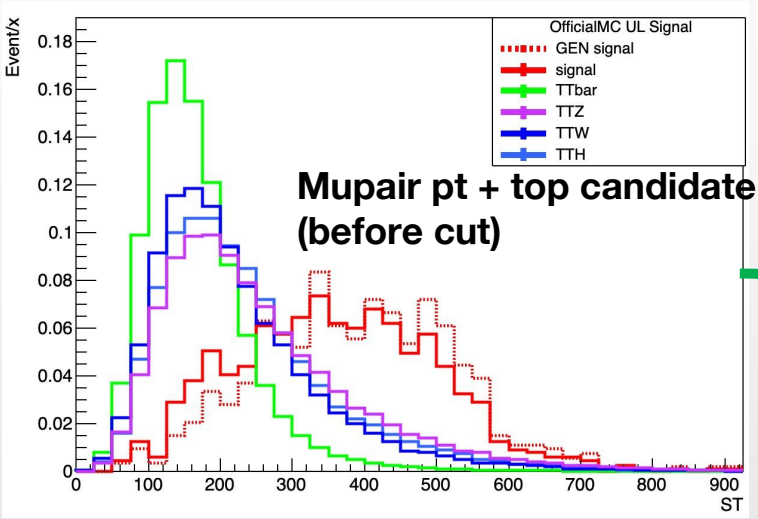
Basic cuts	33.35	9.48	100%	28%	296960	629	1846	455	0.003%
Basic cuts&& cut0	13.28	8.38	89%	63%	64179	102	145	132	0.013%

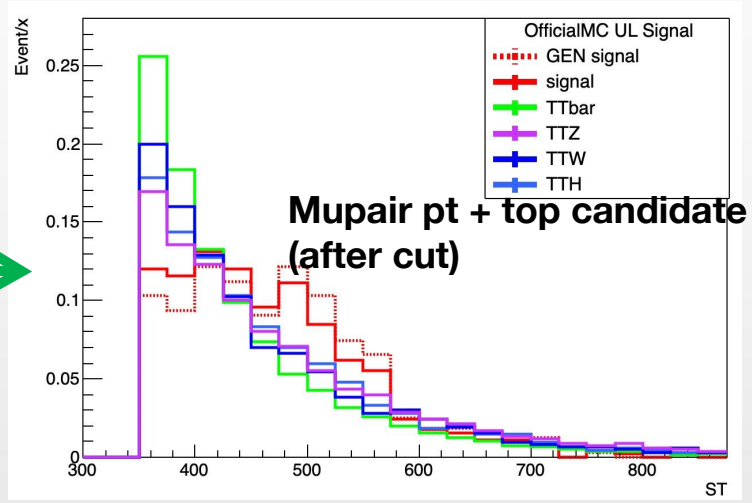
Cut1: Mu pair Pt + top pt > 350 GeV

- **Mu pair and top candidate from T' have high pt**
  - **Punzi optimized point is 400GeV**
  - **Take 350 GeV to save more signal**

$$FOM = \frac{N_{signal}}{\sqrt{N_{background} + 3/2}}$$







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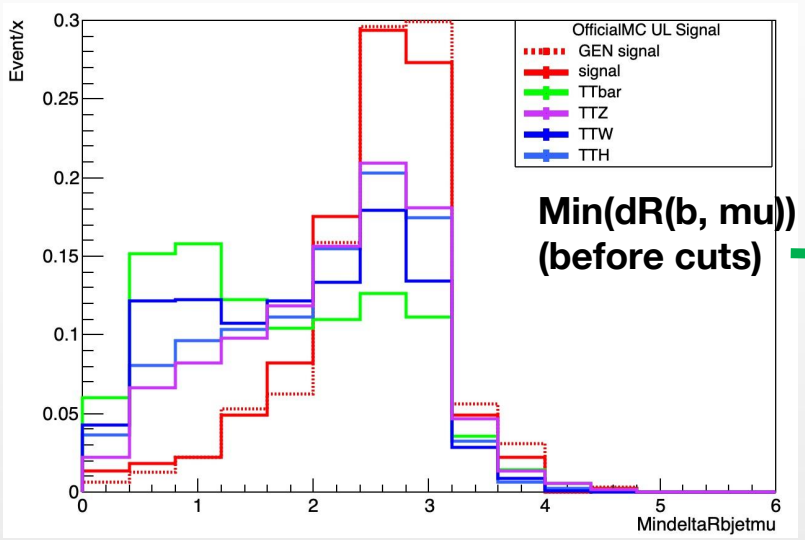
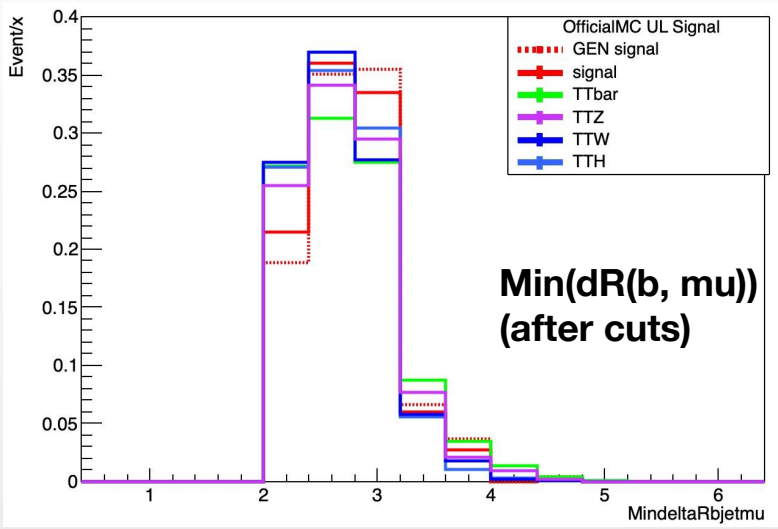
Basic cuts&& cut0&& cut1	5.01	3.57	38%	71%	1163	10	23	16	0.29%

Cut2: Minimal delta R (mu, b jet from top) > 2

- **Signal case1: T' -> tH; t->Wb->qqb; H->WW->l+l-vv**
  - **Mu and b jet are from different decays**
- **TTbar: top->Wb->l+b; top->Wb->l-b**
  - **Mu and b jet are from same decays**



Min(dR(b, mu))
(before cuts)



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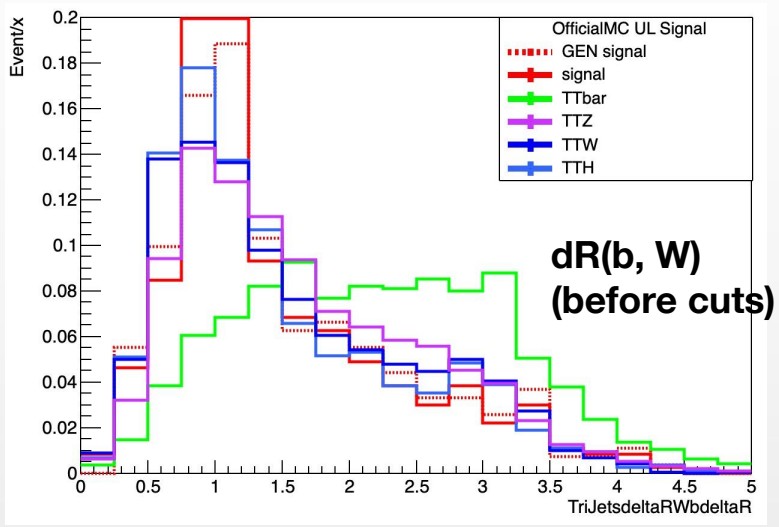
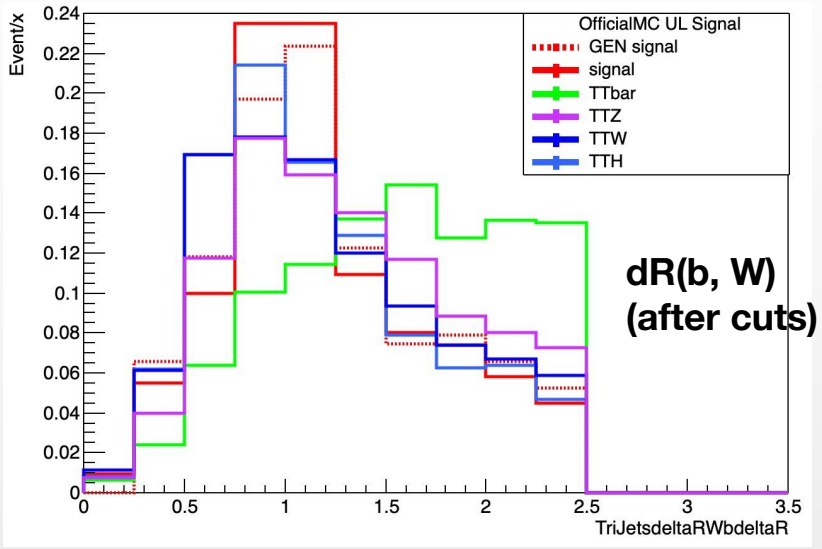
Basic cuts&& cut0&& cut1&& cut2	4.08	3.01	32%	74%	470	5	14	9	0.605%

Cut3: delta R (b jet from top, W from top) < 2.5

- **b jet and W are close to each other in signal**
  - **from the same top decay**
  - **from a heavy mother particle**





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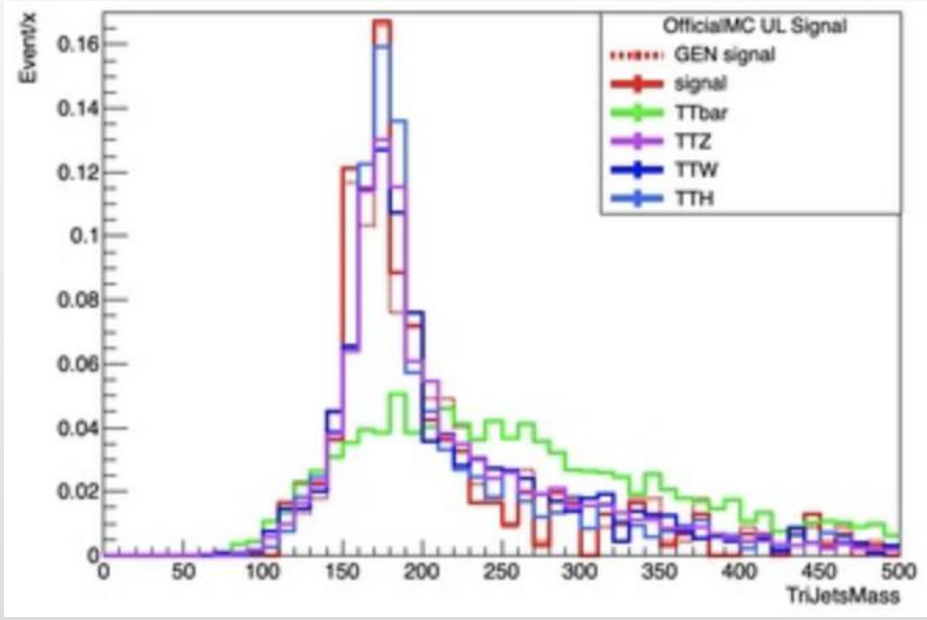
Basic cuts&& cut0&& cut1&& cut2&& cut3	3.46	2.54	27%	73%	281	4	11	8	0.834%

Event Reconstruction

- **Obtain four momentum of each decay products**
  - **Select 3 jets (including 1 b jet) with X^2 sorting algorithm to build top**
    - **1st loop for W reconstruction: select 2 jets with minimal χ^2_W**
    - **Remove 2 jets from W**
    - **2nd loop for top reconstruction: select 1 b jet with minimal χ^2_{top} (loose b tag)**

$$\chi^2_W = \frac{(M_W - M_{jj})^2}{\sigma_W^2}$$

$$\chi^2_{top} = \frac{(M_t - M_{bjj})^2}{\sigma_t^2}$$

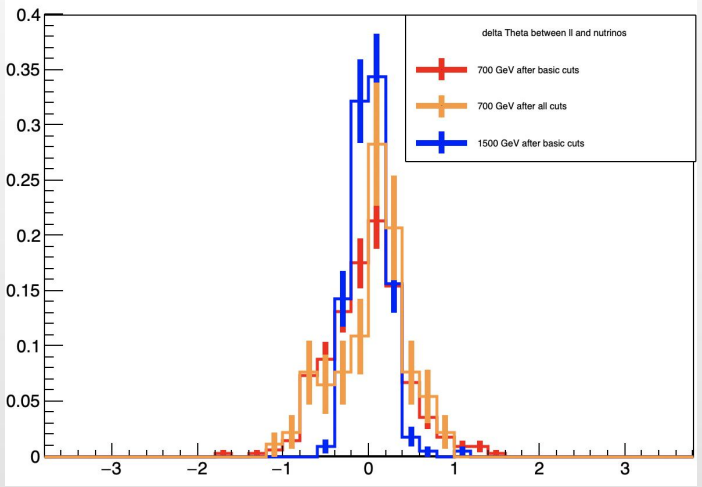


Event Reconstruction

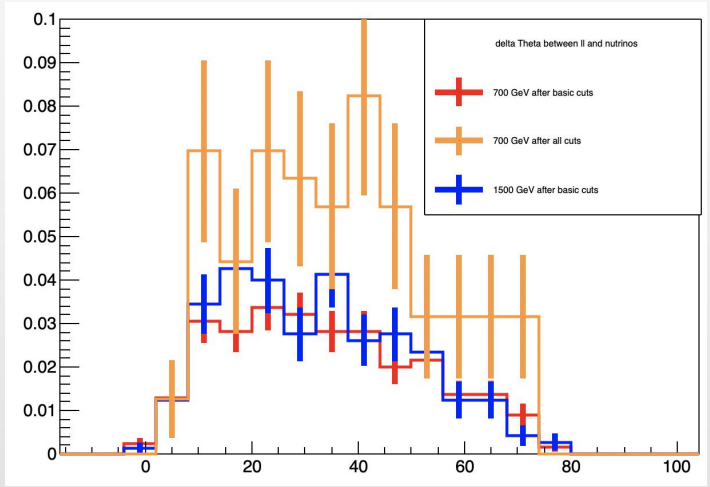
- **Obtain four momentum of each decay products**
  - **Obtain 4 momentum of Higgs by an unique method (reference CMS-B2G-20-007)**
    - **Decay products of boosted H decay are collimated: assume that θinv=θll**

$$Px_{inv} = MET\_pt * cos(MET\_\phi)$$
$$Py_{inv} = MET\_pt * sin(MET\_\phi)$$
$$Pz_{inv} = MET\_pt/tan(\theta_{inv}) = MET\_pt/tan(\theta_{ll})$$

    - **Invariant mass due to the neutrinos is obtained from GEN neutrino**
      - m_{inv} **from GEN information: Higgs->W->mu: 33GeV**



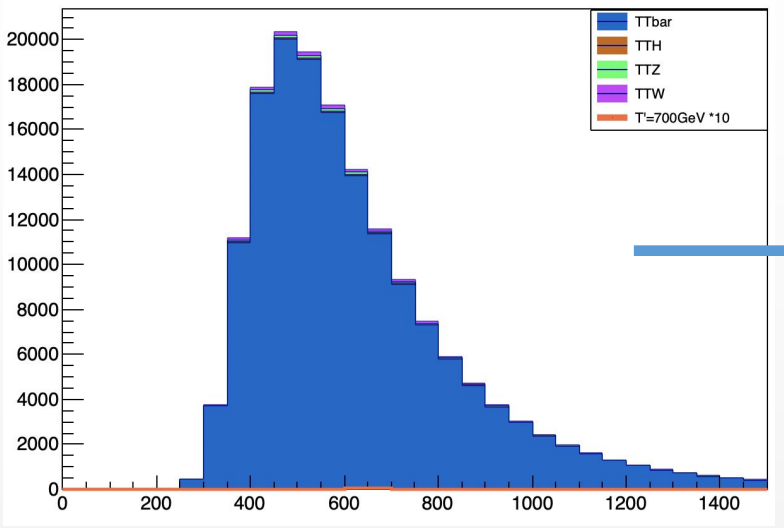
$\theta_{inv} - \theta_{.ll}$



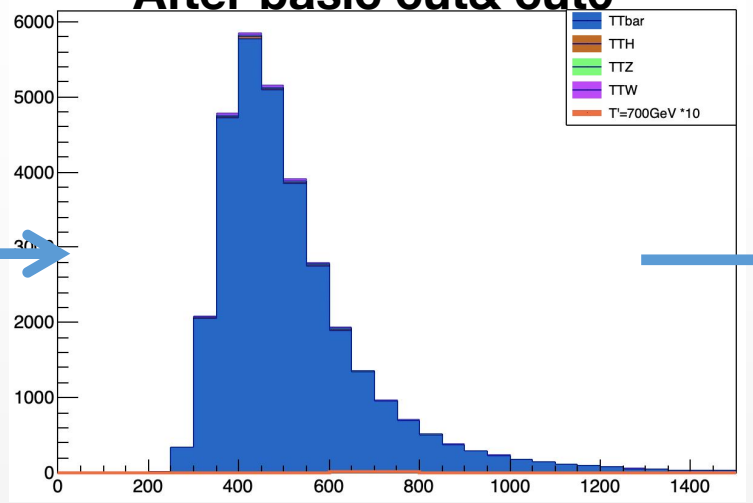
m_{inv} is not sensitive to T' mass value (page19 backup)

Cut Flow Stacked Plot

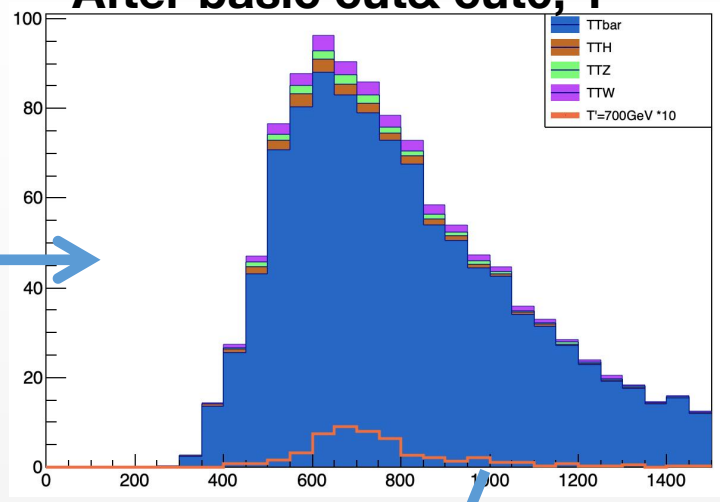
After basic cuts

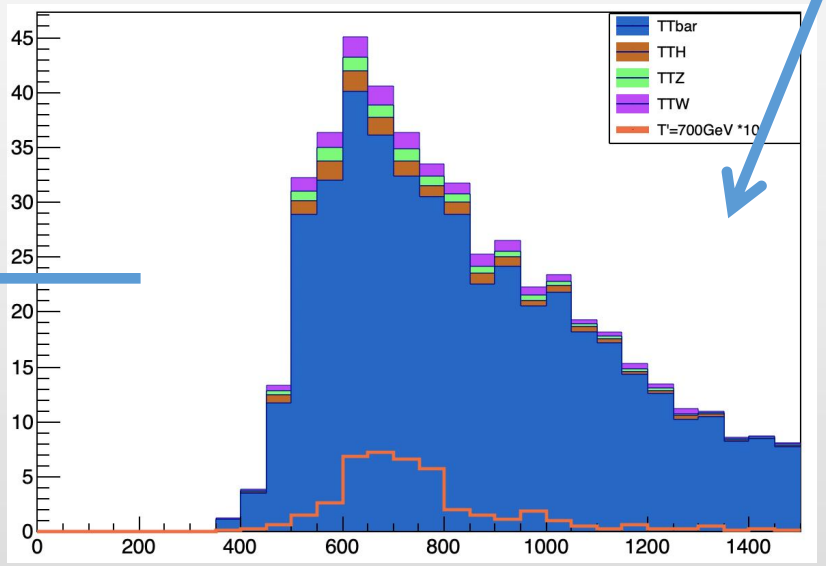


After basic cut& cut0

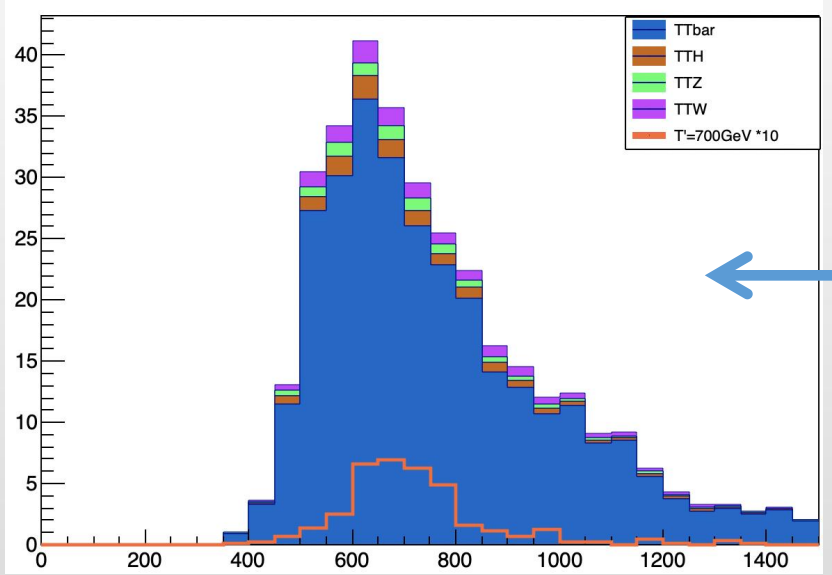


After basic cut& cut0, 1





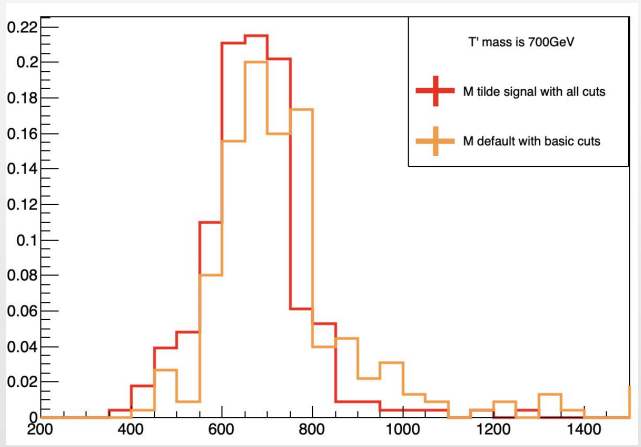
After basic cut& cut0, 1, 2

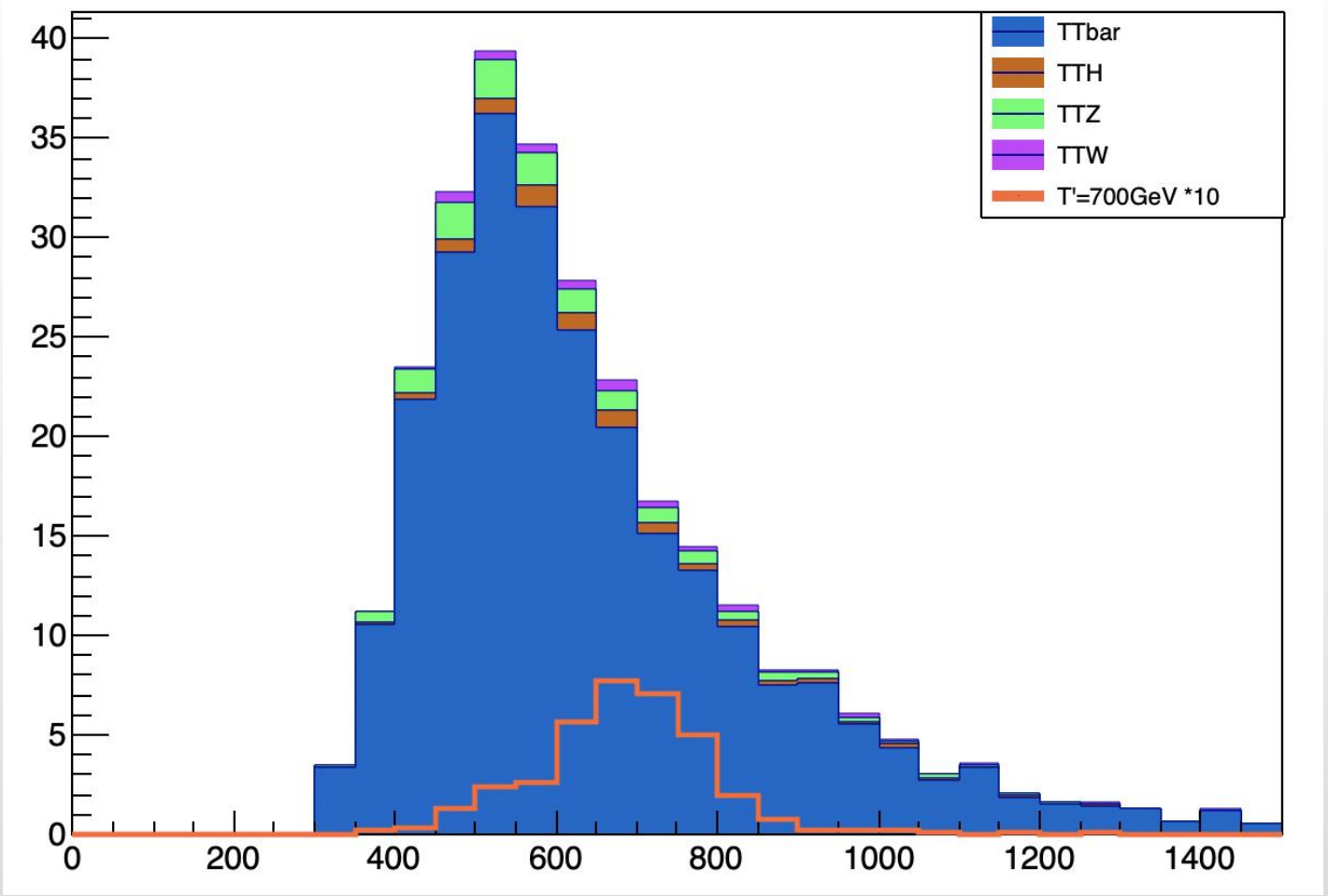


After basic cut& cut0, 1, 2

T’ Mass Tilde

- $\tilde{M_T}$ will be the main vairable: Signal peak on falling background spectrum
- Apply T’ mass constraint
  - $\tilde{M_T} = M_T - \sqrt{E_H^2 - \vec{p}_H^2} - \sqrt{E_{top}^2 - \vec{p}_{top}^2} + m_H^{pole} + m_{top}^{pole}$





Summary

- Develop cut based selection strategy using MC samples
  - Basic cuts
  - Cut0: Mu pair mass < 60GeV
  - Cut1: Mu pair Pt + top pt > 350 GeV
  - Cut2: Minimal delta R (mu, b jet from top) > 2
  - Cut3: delta R (b jet from top, W from top) < 2.5
- Apply an unique reconstruction method
  - Top is made from 3 jets selected by X^2 sorting algorithm
  - Higgs is reconstructed by approximating ν four-momentum
  - T' mass distribution is refined by T' mass tilde method
- More plots and details on my twiki: https://twiki.cern.ch/twiki/bin/view/CMS/VLQLepton

- To-do list
  - Finding good control region and validation region for TTbar
    - Find a good cut and reverse it
  - Check electron channel

Thanks!

Backup

Invariant mass from the neutrinos

- **The general cross section formula:**
  - **C1, C2: T' produce and decay coupling parameters**
  - **Gamma: total decay width of T'**

$$\sigma(C_1, C_2, m_{\mathrm{B}}, \Gamma_B) = C_1^2\ C_2^2\ \tilde{\sigma}_{FW}(m_{\mathrm{B}}, \Gamma_B)$$

- **When $\frac{\Gamma_{T'}}{m_{T'}} \to 0$ (NWA) the formula can be simplified:**
  - **C1: coupling corresponding to T' production interaction**
  - **$\hat{\sigma}$(NWA): Check the github tables**
  - **BR(T'->tH): 0.25**

T' mass	Cross section(pb)
600.000000	11.173525
650.000000	8.843881
700.000000	0.088588
800.000000	0.045870
900.000000	0.025097
1000.000000	0.014484
1100.000000	0.008675
1200.000000	0.005356
1300.000000	0.003388
1400.000000	0.002195
1500.000000	0.001440
1500.000000	0.001446
1600.000000	0.000971
1600.000000	0.000974
1700.000000	0.000657
1700.000000	0.000663
1800.000000	0.000458
1900.000000	0.000319
2000.000000	0.000224

Invariant mass from the neutrinos

- **Compare M_T and $\tilde{M_T}$ distribution with $m_{inv} = 55/30\ GeV$**
  - **<10GeV difference**