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

Status Report

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Group Meeting, Oct. 12th, 2022

Update from Last Meeting

- **Correct the transverse mass calculation**
  - $m_T^H = \sqrt{2 * p_T^{ll} * p_T^{MET} * [1 - \cos(\delta\phi(\overrightarrow{p_T^{ll}}, \overrightarrow{p_T^{MET}}))]}$ $m_T^{T'} = \sqrt{2 * p_T^{ll\&top} * p_T^{MET} * [1 - \cos(\delta\phi(\overrightarrow{p_T^{ll\&top}}, \overrightarrow{p_T^{MET}}))]}$
- **Refine cut strategy**
  - **Basic cuts: Remove jets number cuts**
  - **Cut0: Mu Pair Mass < 60**
  - **Cut1: ~~$\chi^2_W + \chi^2_{top} < 18$~~ -> Top reconstruction is valid**
  - **Cut2: ~~Higgs Transverse pT > 200~~ -> Mu pair Pt + top pt > 350 GeV**
  - **Cut3: Minimal delta R (mu, b jet from top) > 2**
  - **Cut4: delta R (b jet from top, W from top) < 2.5**
- **Main variables?**
  - **top mass & transverse Higgs mass**
- **Update Twiki page: All details here!**
  - **https://twiki.cern.ch/twiki/bin/view/CMS/VLQLepton**
- **Update analysis code**
  - **https://gitlab.cern.ch/fly/fly/-/tree/TPrimeLeptonOS/**

General Analysis Strategy

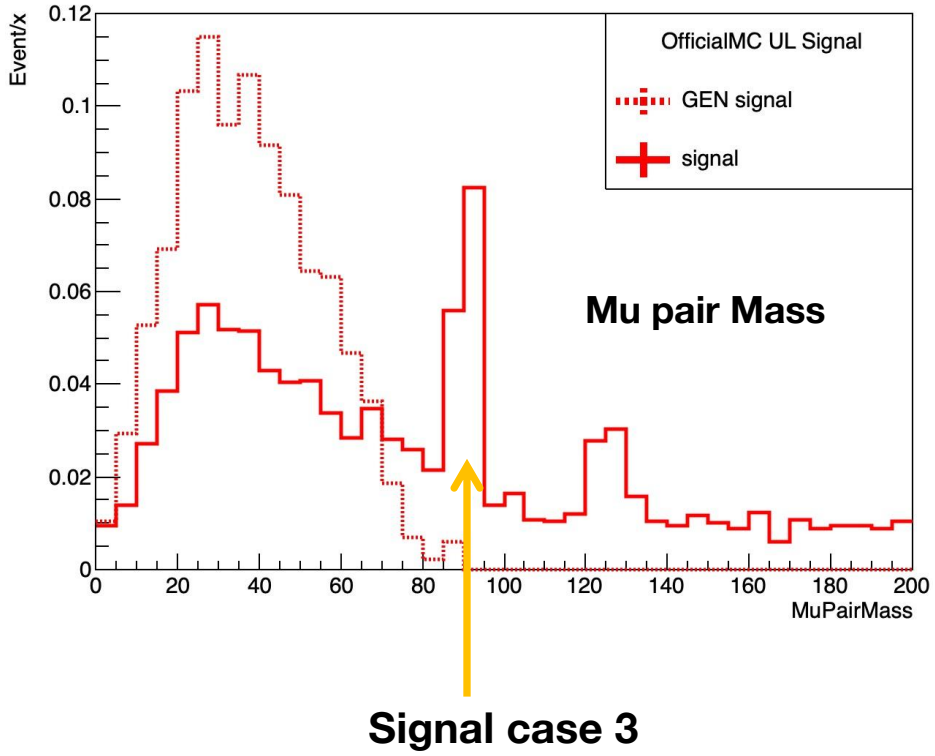
- **VLQ lepton OS channel**
  - Final states contains 2 OS leptons and 3 jets
    - case1: T' -> tH; t->Wb->qqb; H->WW->l+l-vv
      - T’ is heavy: High pt of decay products
      - A full hadronic top: can be reconstructed
      - 3 jets: High pT & small angular distance
      - Higgs are not be reconstructed due to 2 neutrinos: check transverse mass
      - Higgs has spin0: M(ll) is small & 2 leptons are close to each other
      - b jet and lepton are from different decays: a relatively big angular distance
    - case2: T' -> tH; t->Wb->blv; H->WW->qqlv
      - T’ is heavy: High pt of decay products
      - Both top and Higgs can not be reconstructed
      - b and one of the leptons are from different decays: Max(deltaR(bjet, lepton))
    - case3: T' -> tH; t->Wb->qqb; H->ZZ->llqq
      - T’ is heavy: High pt of decay products
      - T’ can be fully reconstruced!
      - Low expected signal events due to low BR of H->ZZ
  - Study case1 muon channel first

General Analysis Strategy

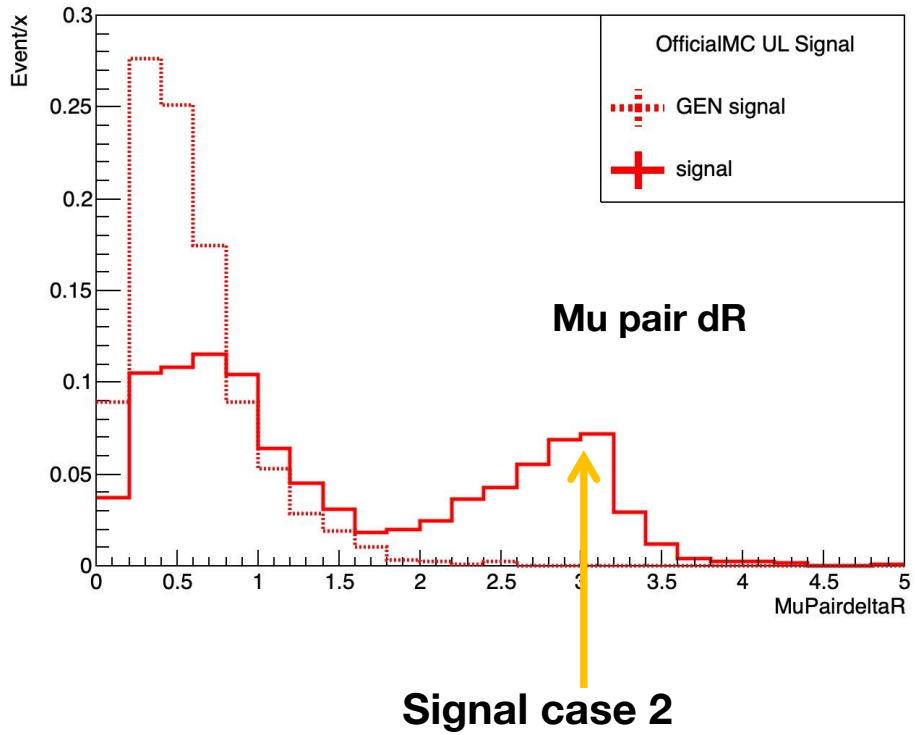
- **Background for VLQ OS lepton channel**
  - **Background from other processes**
    - **Main background: TTbar->WbWb->l+l-vv**
      - **Large cross section & has 2 OS leptons**
      - **TTbar are not from a heavy mother particle: low pt of decay products**
      - **For one top, a b jet and a lepton are from the same decay**
      - **2 leptons in final state: not supposed to see a top peak from jets**
    - **TTH, TTZ, TTW**
      - **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 can be killed by lepton mass cut**

General Analysis Strategy

- **Background for VLQ OS lepton channel**
  - **Other signal cases**
    - **signal case 2: T' -> tH; t->Wb->blv; H->WW->qqlv**
      - **leptons from different decays: High mu pair mass& big dR(l,l)**
    - **signal case 3: T' -> tH; t->Wb->qqb; H->ZZ->llqq**
      - **leptons from Z: Z peak on lepton mass plot**



Signal case 3



Signal case 2

MC Samples

- **Take all 3 year signal MC to increase statistics**
- **All samples are 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 Cuts

- **Basic cuts**
  - **Cuts for muons**
    - **Two opposite sign muons**
    - **Tight ID cut: Muon_tightId**
    - **Pt(mu) > 20GeV**
    - **|eta| < 2.4**
    - **Tight isolation cut: goodMuons_miniPFRelIso_all < 0.05**
    - **Impact parameter Significance cut: Muon_sip3d < 3**
  - **Cuts for jets**
    - **Tight jet ID cut: Jet_jetId: 6**
    - **Pt(jet) > 30GeV**
    - **|eta| < 2.5**
    - **Loose B tag: goodJets_btagDeepFlavB>0.049**

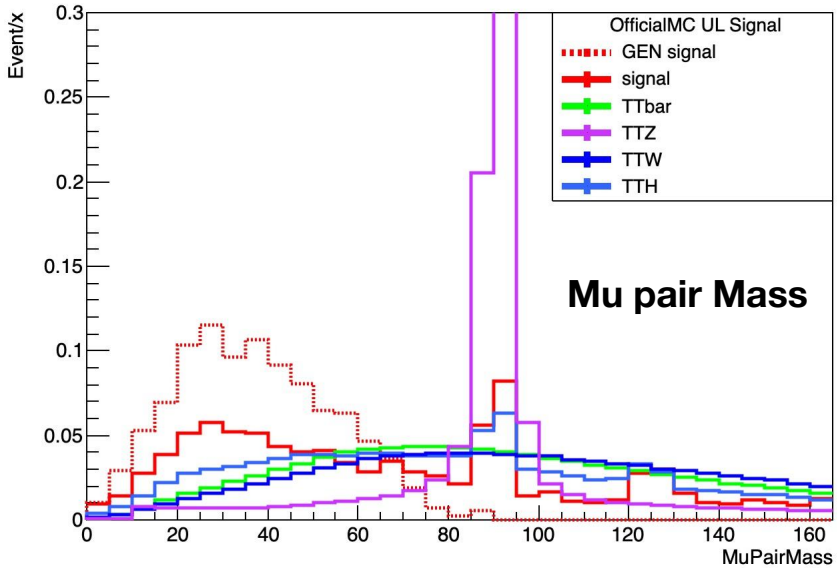
Should we also cut on MET_pt?

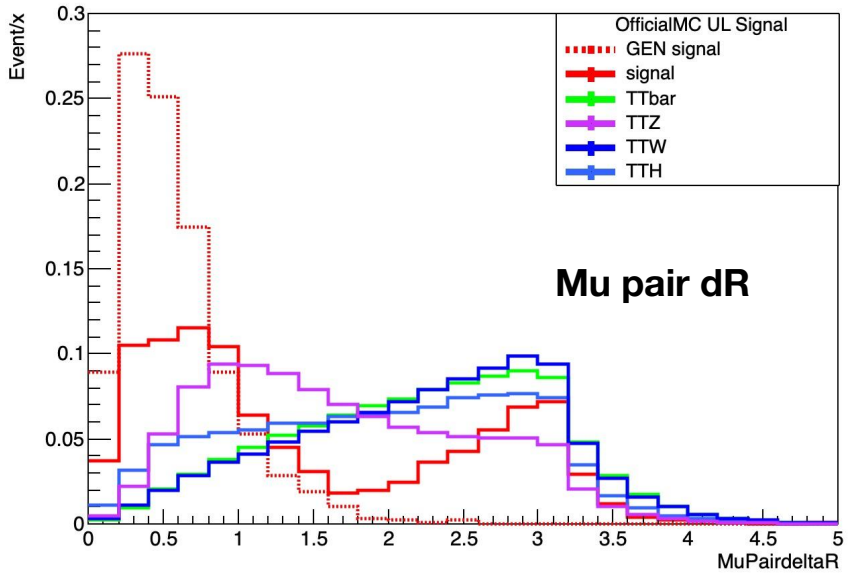
$$\epsilon = \frac{N(GENselection \cap Cuts)}{N(GENselsction)} \qquad Purity = \frac{N(GENselection \cap Cuts)}{N(Cuts)}$$

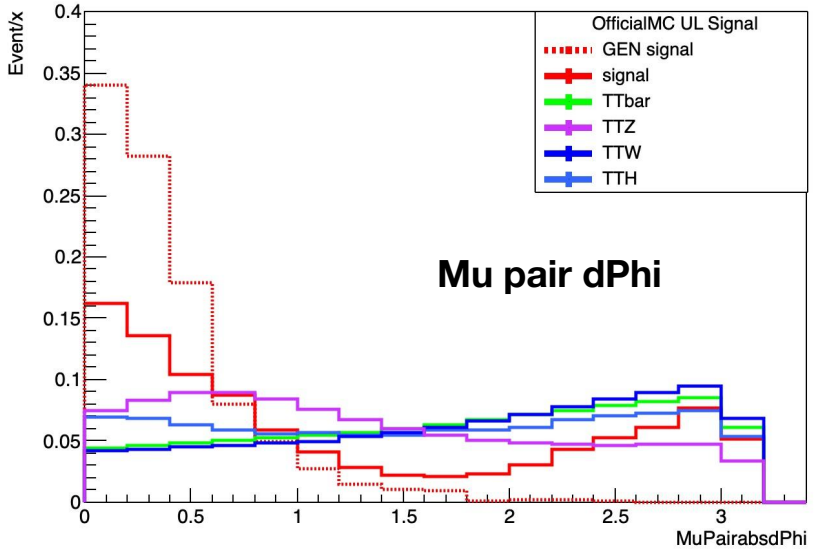
Cuts	N_Signal	N_GENSignal	signal efficiency	signal purity	N_TT	N_TTW	N_TTZ	N_TTH	S(GEN)/B
Basic cuts	33.35	9.48	100%	28%	296960	629	1846	455	0.003%

After Basic Cuts

- **Higgs has spin0:**
  - **M(ll) is small**
  - **2 leptons are close to each other**
  - **M(ll), dR(l, l), dPhi(l,l) are related variables**

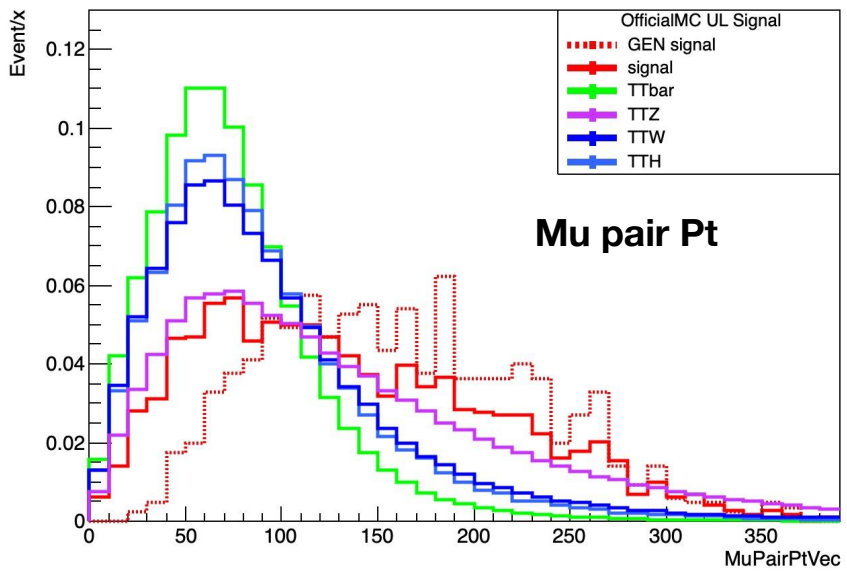


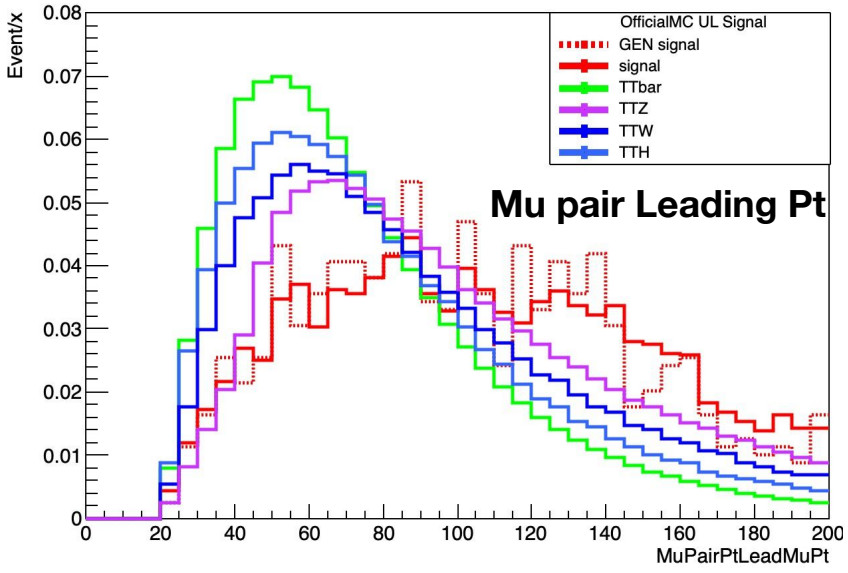


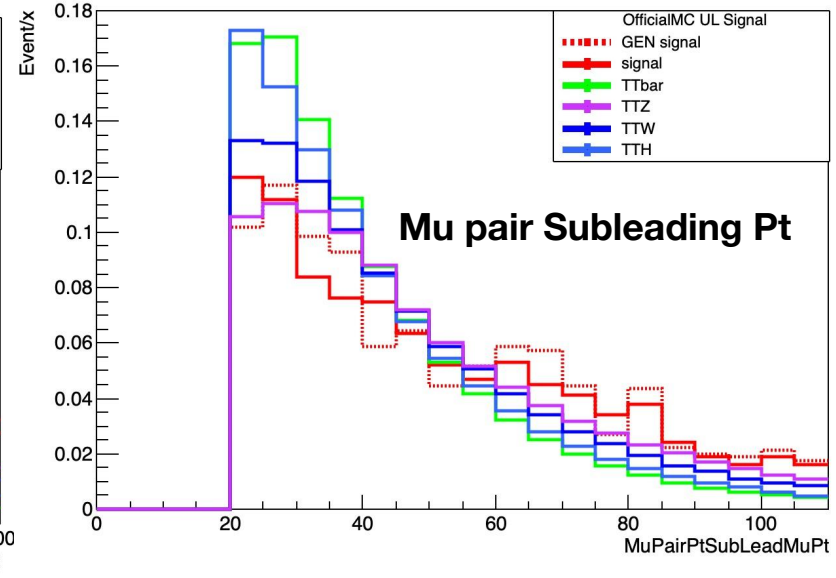


After Basic Cuts

- **T' is heavy:**
  - **High pt decay products**
  - **leptons are close to each other**
    - **Make vector sum of Mu pair pt a good variable**





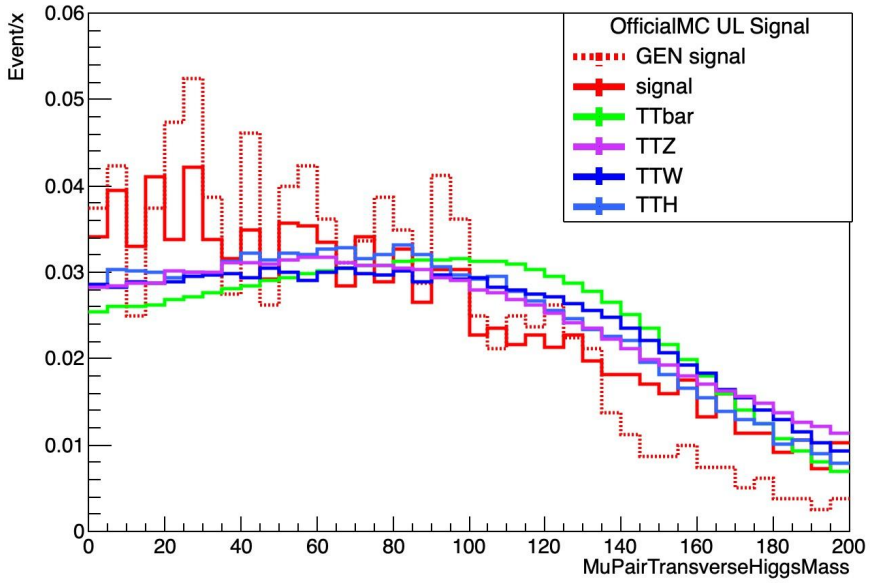


After Basic Cuts

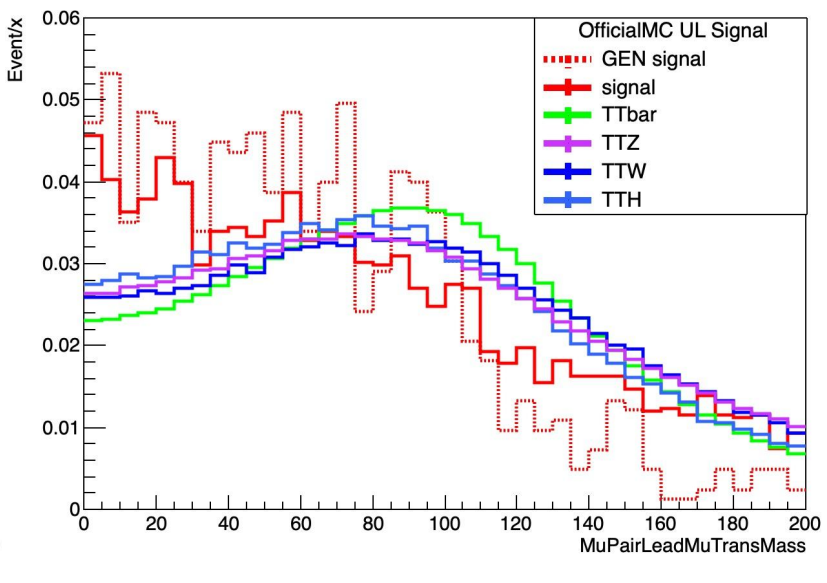
- **Higgs can not be reconstructed: Check transverse mass**

$$m_T^H = \sqrt{2 * p_T^{ll} * p_T^{MET} * [1 - \cos(\delta\phi(\overrightarrow{p_T^{ll}}, \overrightarrow{p_T^{MET}}))]}$$

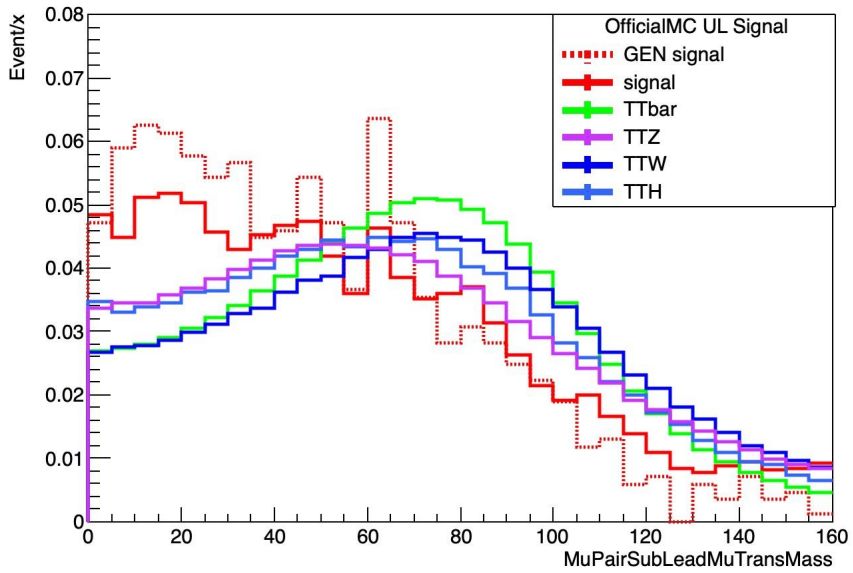
$$m_T^l = \sqrt{2 * p_T^{l} * p_T^{MET} * [1 - \cos(\delta\phi(\overrightarrow{p_T^{l}}, \overrightarrow{p_T^{MET}}))]}$$



Higgs transverse mass



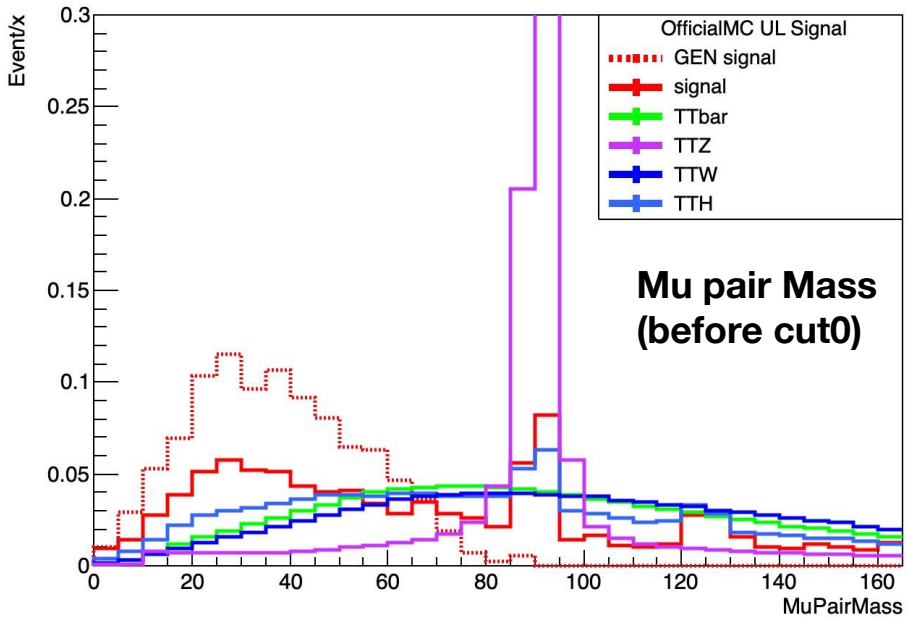
Lead Mu transverse mass (mu with higher pt)

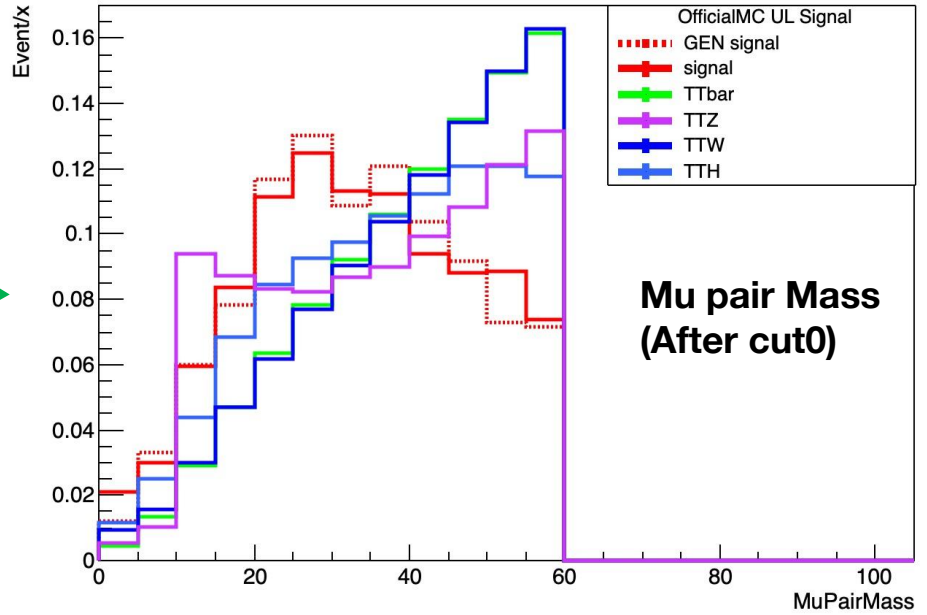


Sublead Mu transverse mass (mu with higher pt)

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**

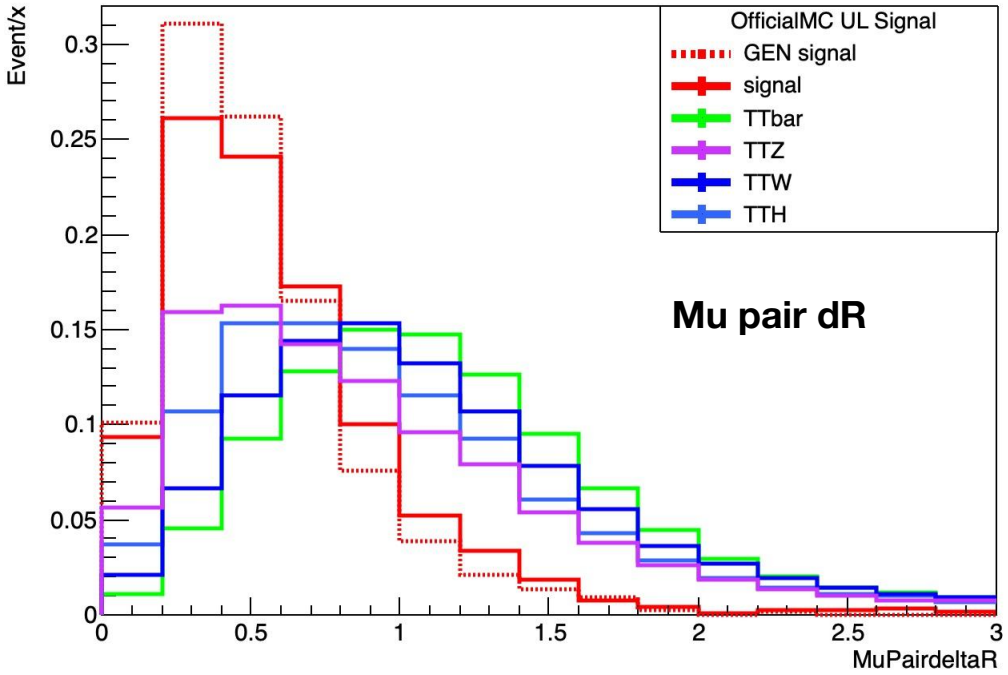


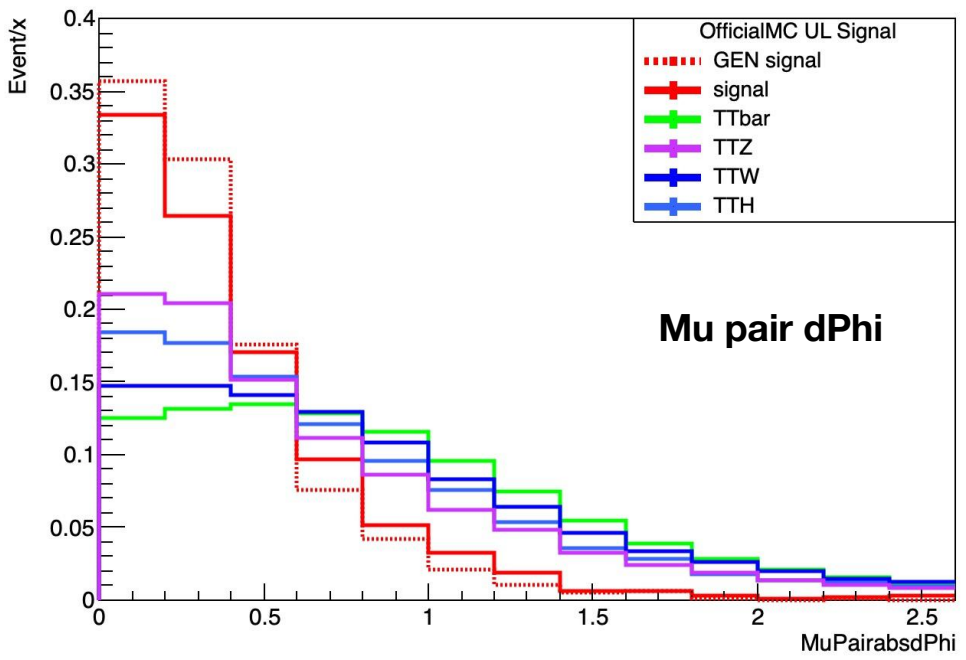


Cuts	N_Signal	N_GENSignal	signal efficiency	signal purity	N_TT	N_TTW	N_TTZ	N_TTH	S(GEN)/B
Basic cuts	33.35	9.48	100%	28%	296960	629	1846	455	0.003%
Basic cuts&& cut0	13.28	8.38	89%	63%	64179	102	145	132	0.013%

After Cut0

- **Mu pair dR and dPhi from signal looks similar to background after cut0**
  - **Cause Mu pair mass, dR and dPhi are related to each other**





Cut1: Top reconstruction is valid

- **Cut1 is the preparation of the following jet-related cuts**
  - **No cut on Chi2 values**
  - **imply jet number requirement: At least 3 jets, includes 1 b jet**
- **Find 3 jets and make a top candidate**
  - **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)**

$$\chi^2_W = \frac{(M_W - M_{jj})^2}{\sigma^2_W} \qquad \chi^2_{top} = \frac{(M_t - M_{bjj})^2}{\sigma^2_t}$$

Sigma & mass are fixed values from observation

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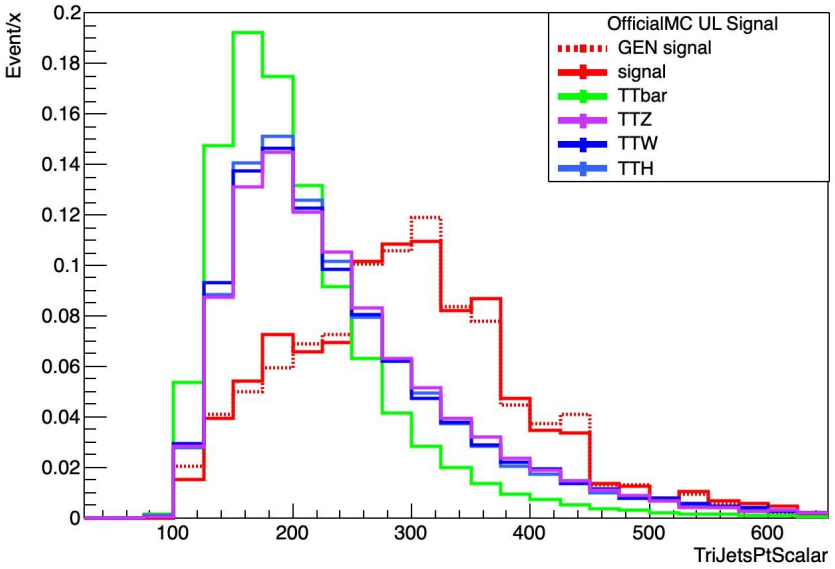
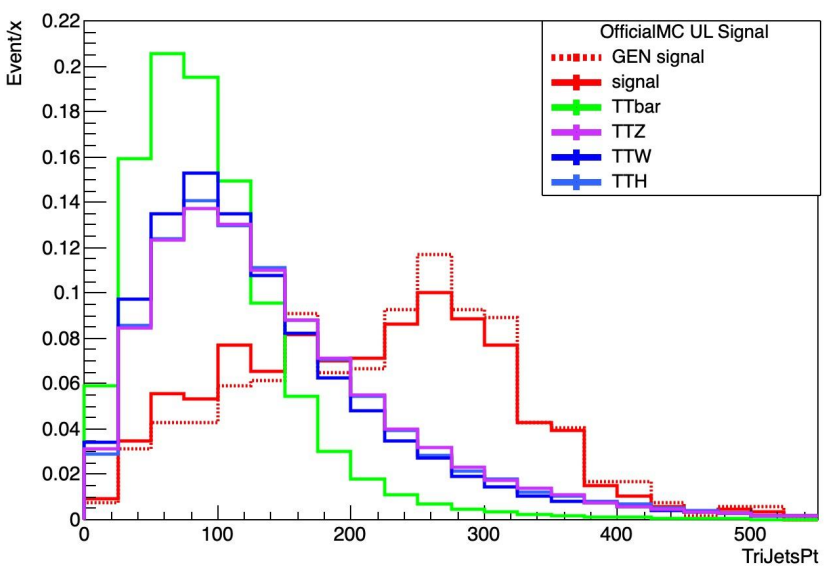
Basic cuts&& cut0	13.28	8.38	89%	63%	64179	102	145	132	0.013%
Basic cuts&& cut0&& cut1	9.66	6.01	62%	64%	44925	79	120	110	0.013%

After Cut1

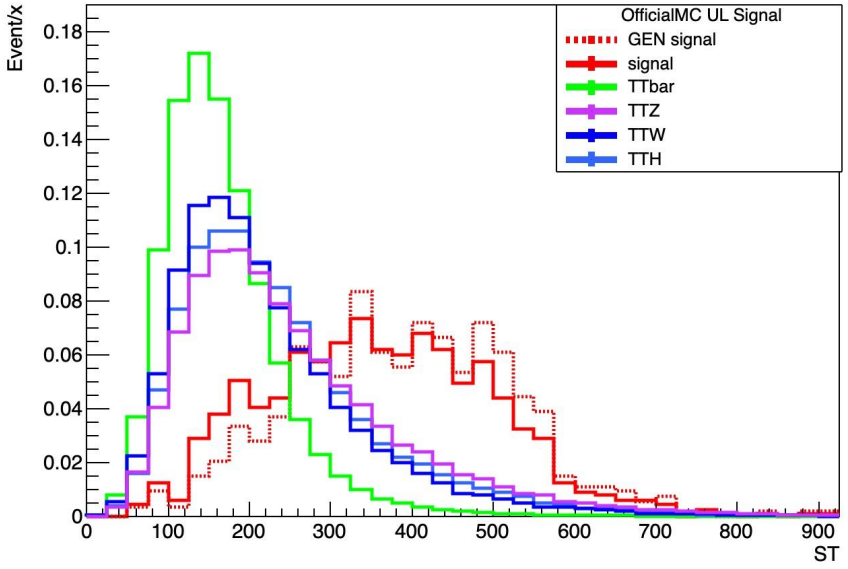
- **Top candidate pt is high**
  - **Decay from heavy T'**
  - **3 jets are close to each other cause they are from the same top**
- **Top candidate pt + Mu pair pt is even higher**
  - **Both of them are from T'**



Scalar sum of 3 jets from top



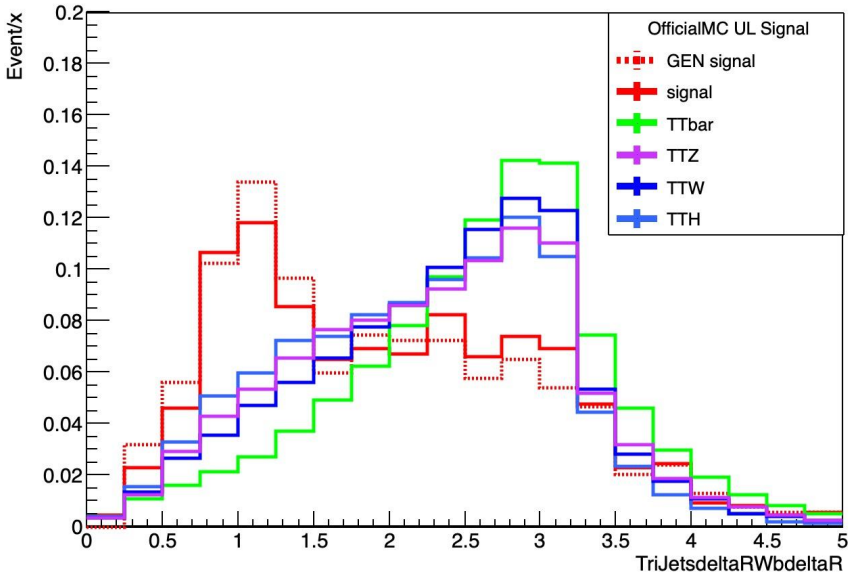
Vector sum of 3 jets from top (pt of top candidate)



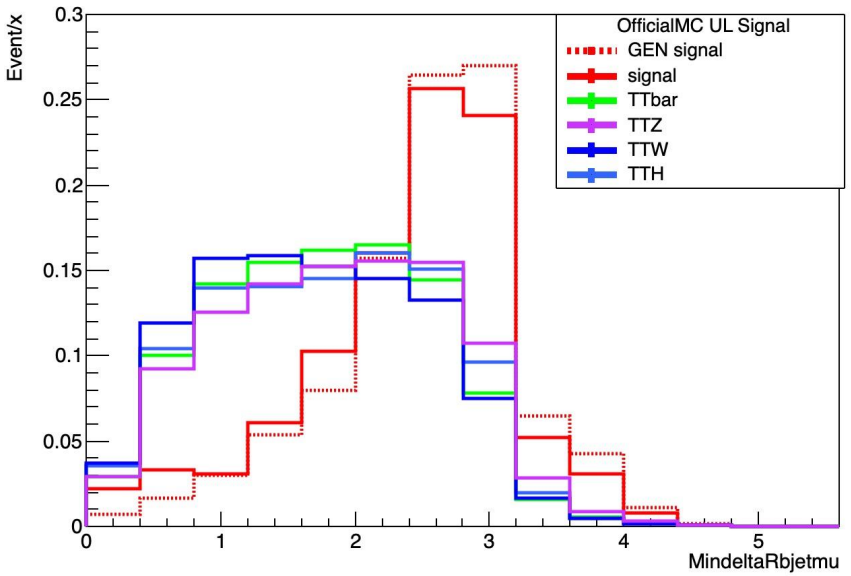
Mupair pt + top candidate pt

After Cut1

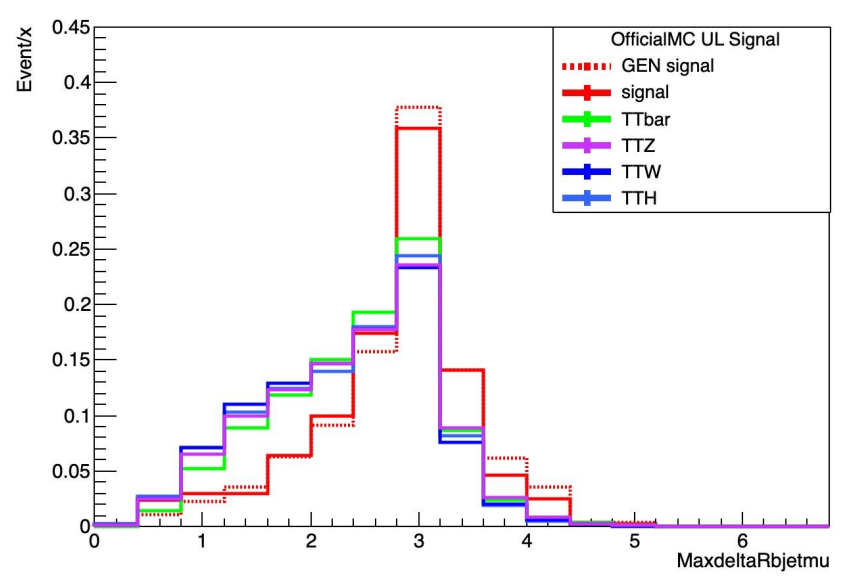
- **Angular variables describe substructure of T' decay**
  - **b and W are from a same top: small dR**
  - **b and mu are from different decays**
    - **Min(dR(b, mu)): In TTbar b and mu are from the same top decay**
    - **Max(dR(b, mu)): In both TTbar and signal, b and mu are from different decays**



dR(b, W)



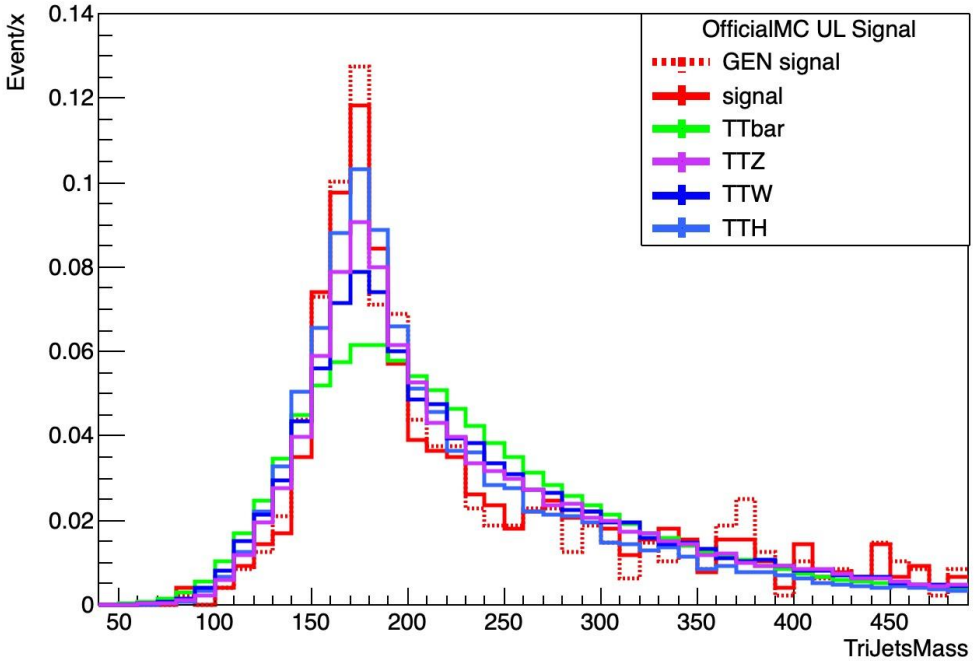
Min(dR(b, mu))



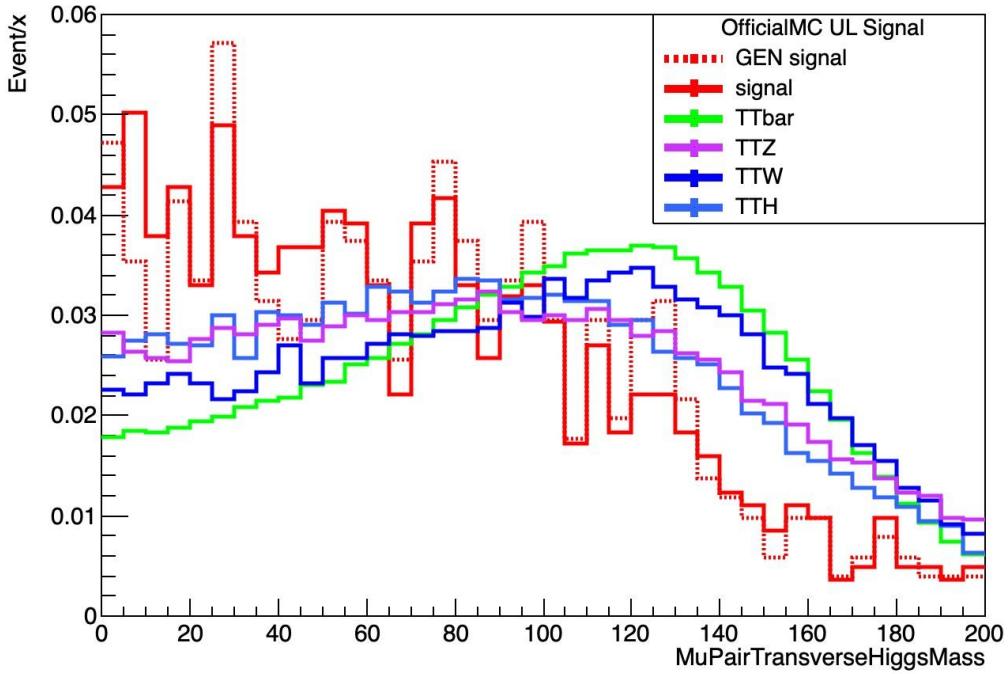
Max(dR(b, mu))

After Cut1

- **A top peak in 3 jets mass plot**
  - **No clear top peak in TTbar: both two tops decay to leptons**
  - **Top peaks exists in TTH, TTZ, and TTW: similar final states to signal**
- **Higgs transverse mass**
  - **Most signl values are lower than 125GeV cause they came from Higgs**



top candidate mass

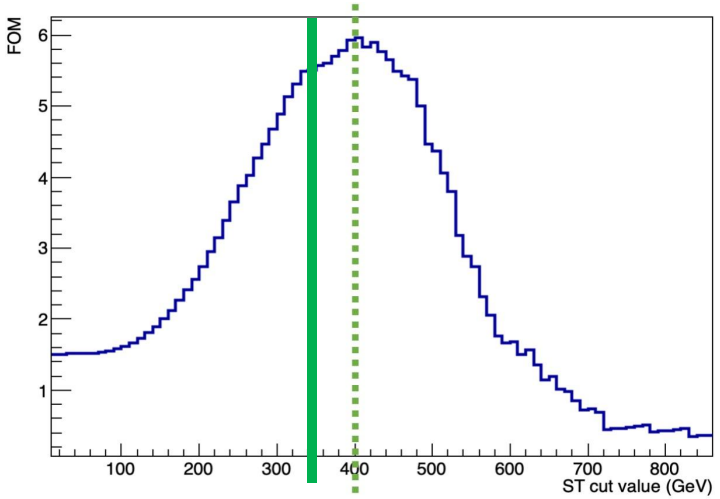


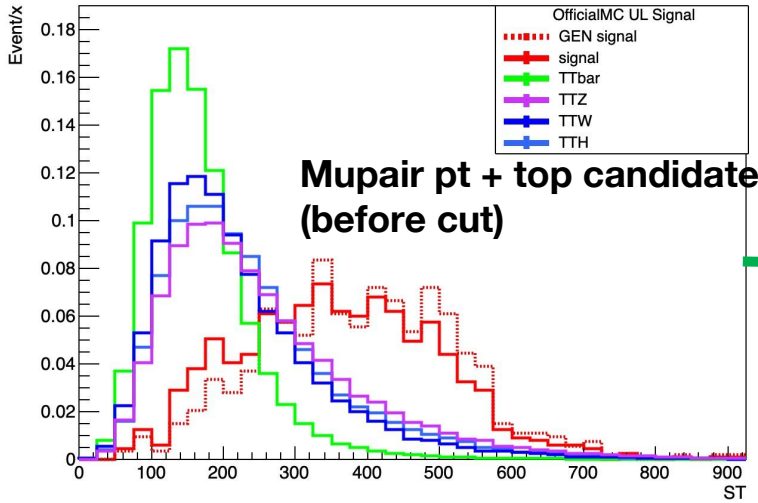
Higgs transverse mass

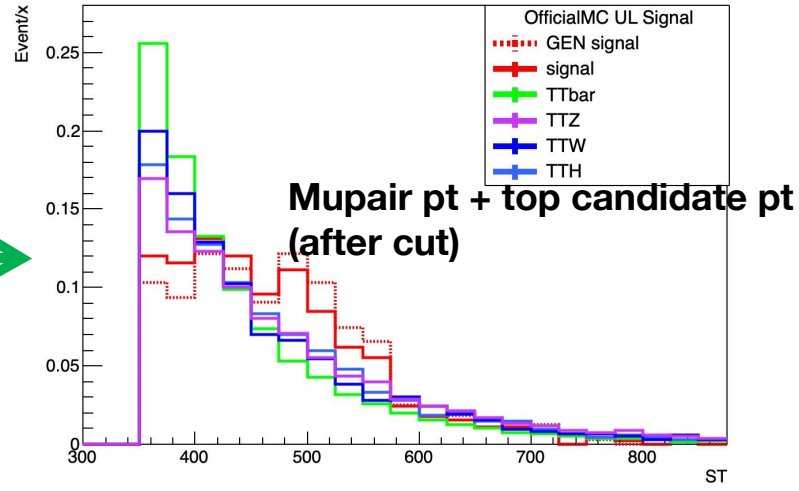
Cut2: Mu pair Pt + top pt > 350 GeV

- **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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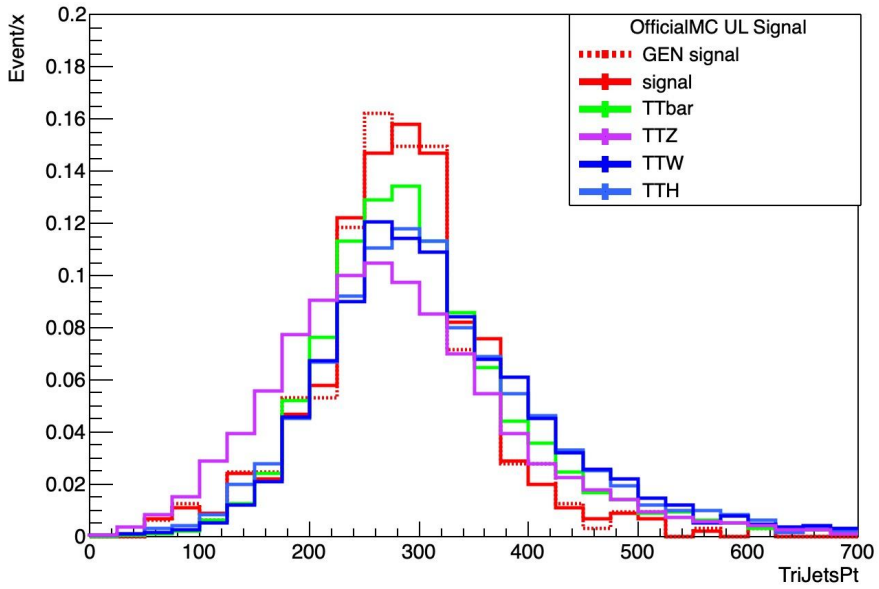
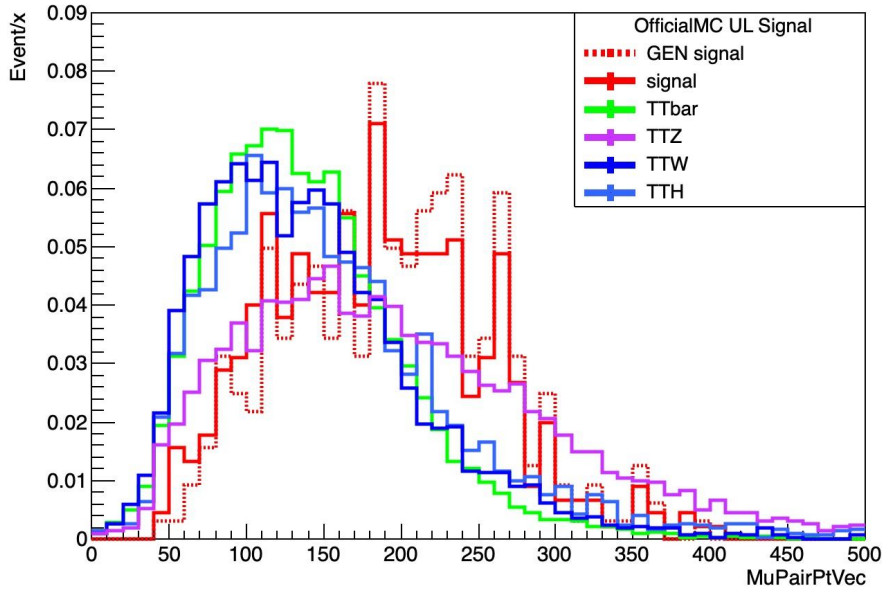
Basic cuts&& cut0&& cut1& cut2	5.01	3.57	38%	71%	1163	10	23	16	0.29%

After Cut2

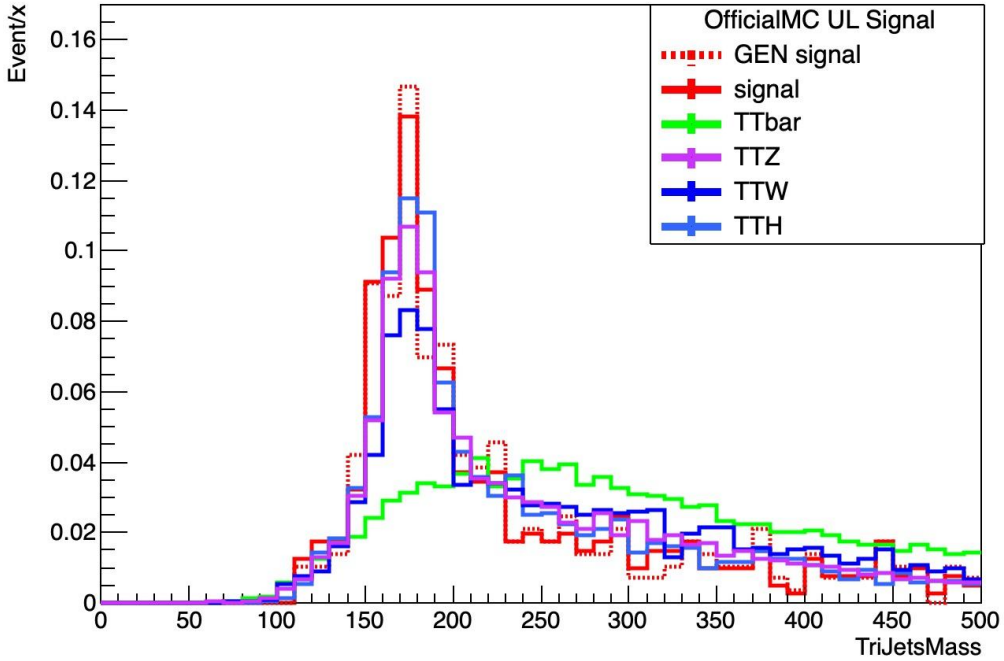
- **Top candiadte pt and dimuon pt from signal looks similar to background after cut2**



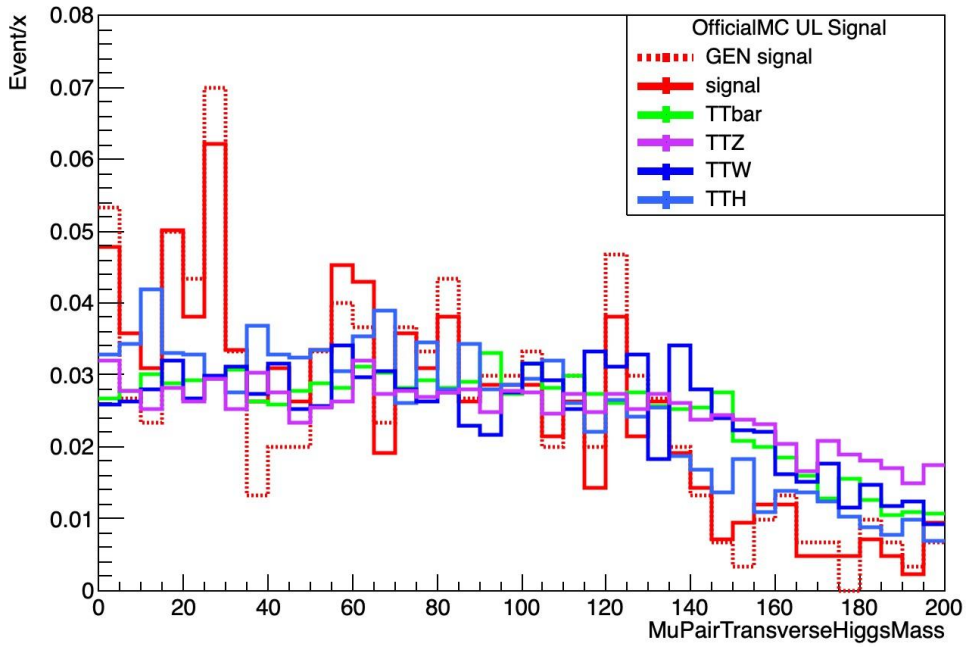


After Cut2

- **Top peak is more clear after cut2**
  - **Top bump from TTbar is almost gone**
  - **Top peak from TTW, TTZ, and TTH are still there(hard to remove)**
- **Small Higgs transverse mass values from signal**
  - **Background is almost flat**
  - **Big fluctuation in signal distribution (need more MC events)**



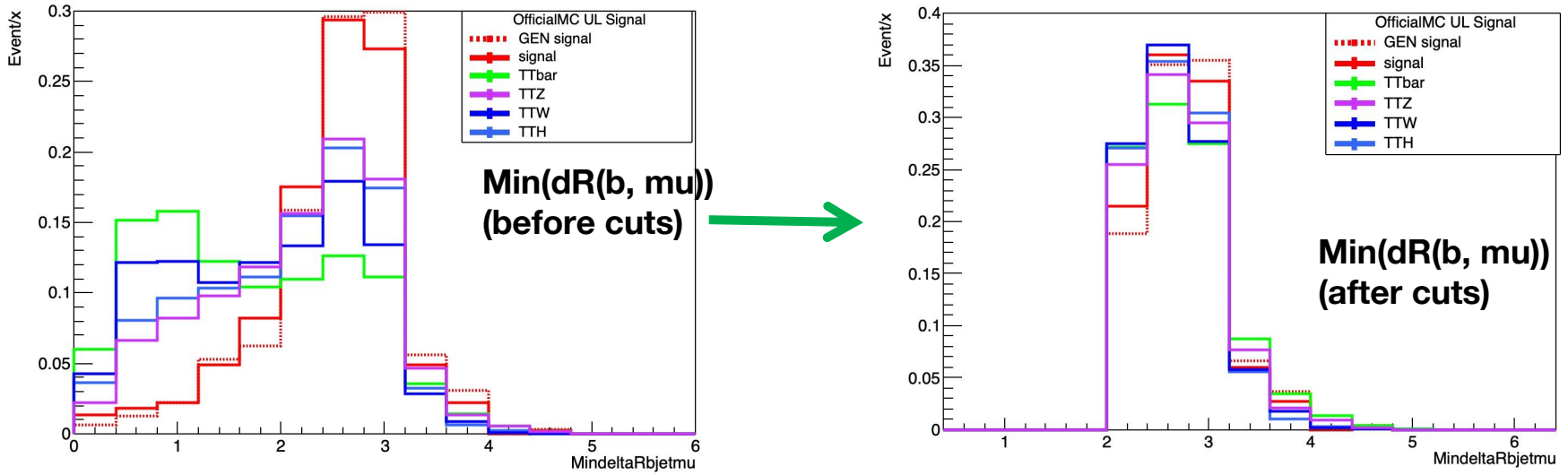
top candidate mass



Higgs transverse mass

Cut3: 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**



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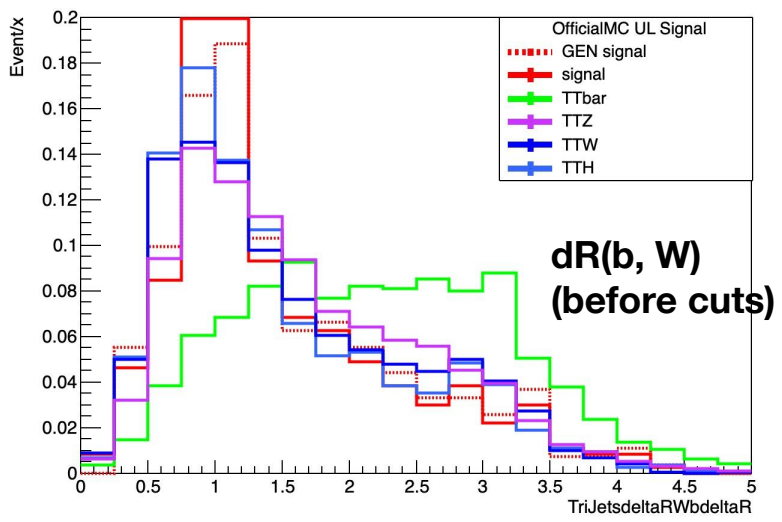
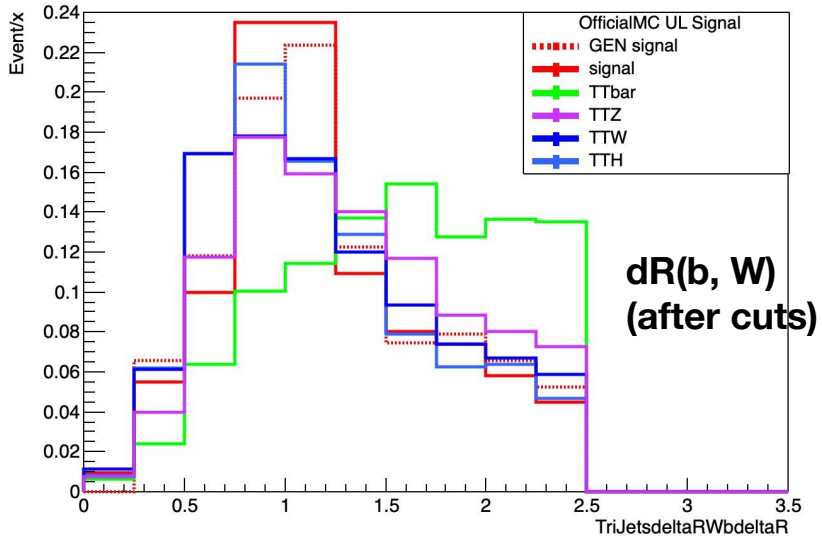
Basic cuts&& cut0&& cut1& cut2	5.01	3.57	38%	71%	1163	10	23	16	0.29%
Basic cuts&& cut0&& cut1& cut2&& cut3	4.08	3.01	32%	74%	470	5	14	9	0.605%

Cut4: 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**

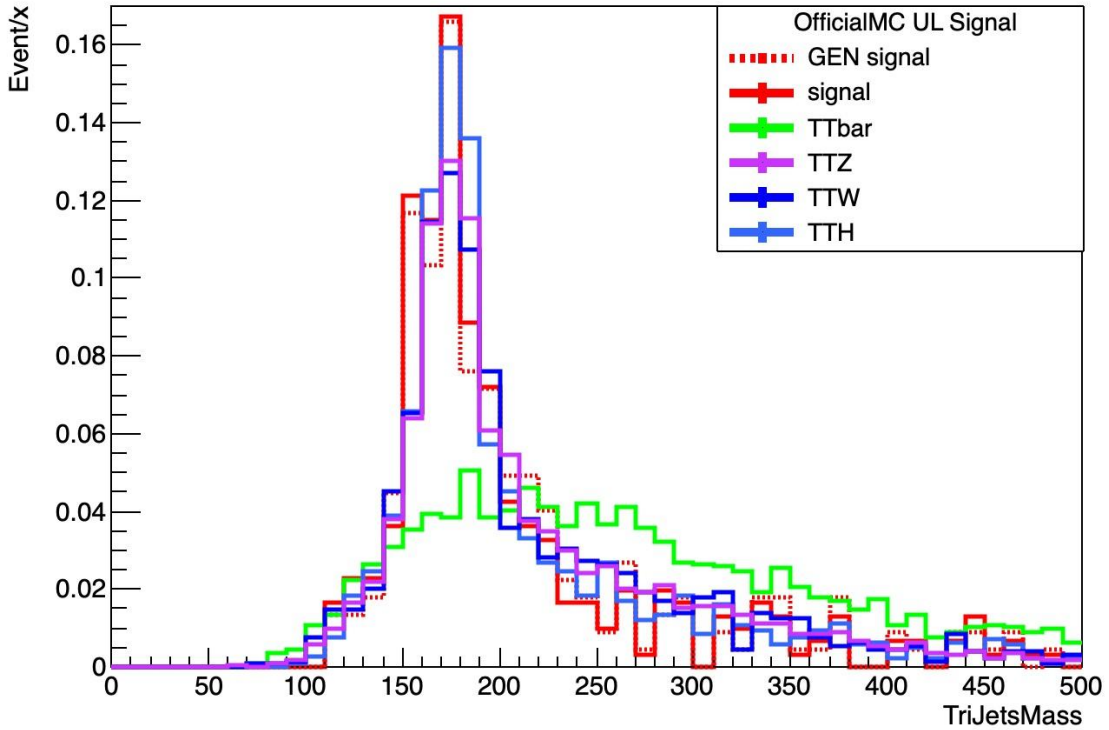


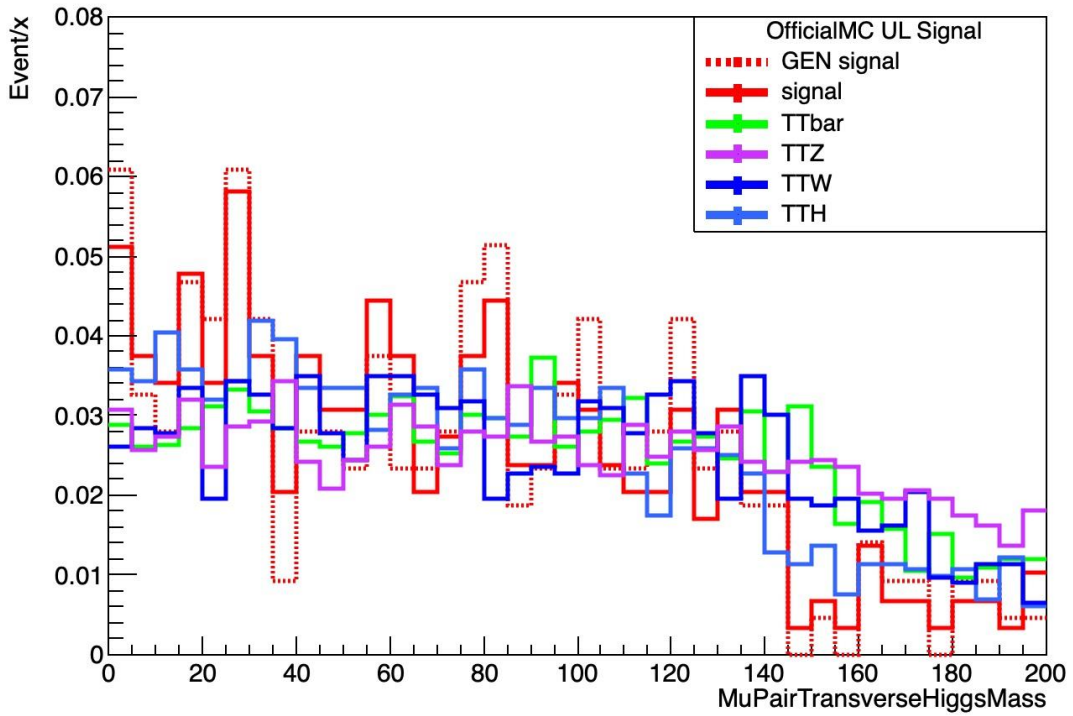


Cuts	N_Signal	N_GENSignal	signal efficiency	signal purity	N_TT	N_TTW	N_TTZ	N_TTH	S(GEN)/B
Basic cuts	33.35	9.48	100%	28%	296960	629	1846	455	0.003%
Basic cuts&& cut0	13.28	8.38	89%	63%	64179	102	145	132	0.013%
Basic cuts&& cut0&& cut1	9.66	6.01	62%	64%	44925	79	120	110	0.013%
Basic cuts&& cut0&& cut1& cut2	5.01	3.57	38%	71%	1163	10	23	16	0.29%
Basic cuts&& cut0&& cut1& cut2&& cut3	4.08	3.01	32%	74%	470	5	14	9	0.605%
Basic cuts&& cut0&& cut1& cut2&& cut3&& cut4	3.46	2.54	27%	73%	281	4	11	8	0.834%

Main Variable Candidates

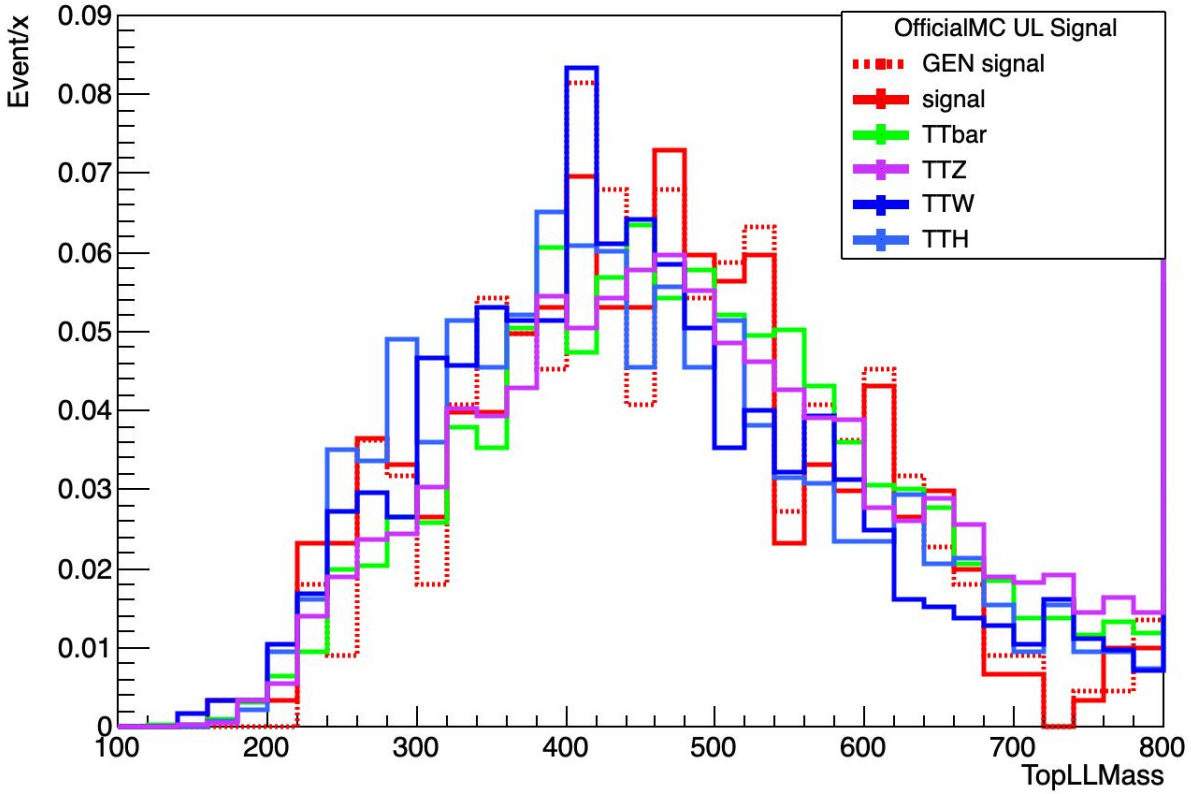
- **Take top candidate mass and transverse Higgs mass as main variables?**
  - **Can not remove top peak in TTZ, TTH and TTW**
  - **Not sure if Higgs transverse mass is a good one(need more signal events)**

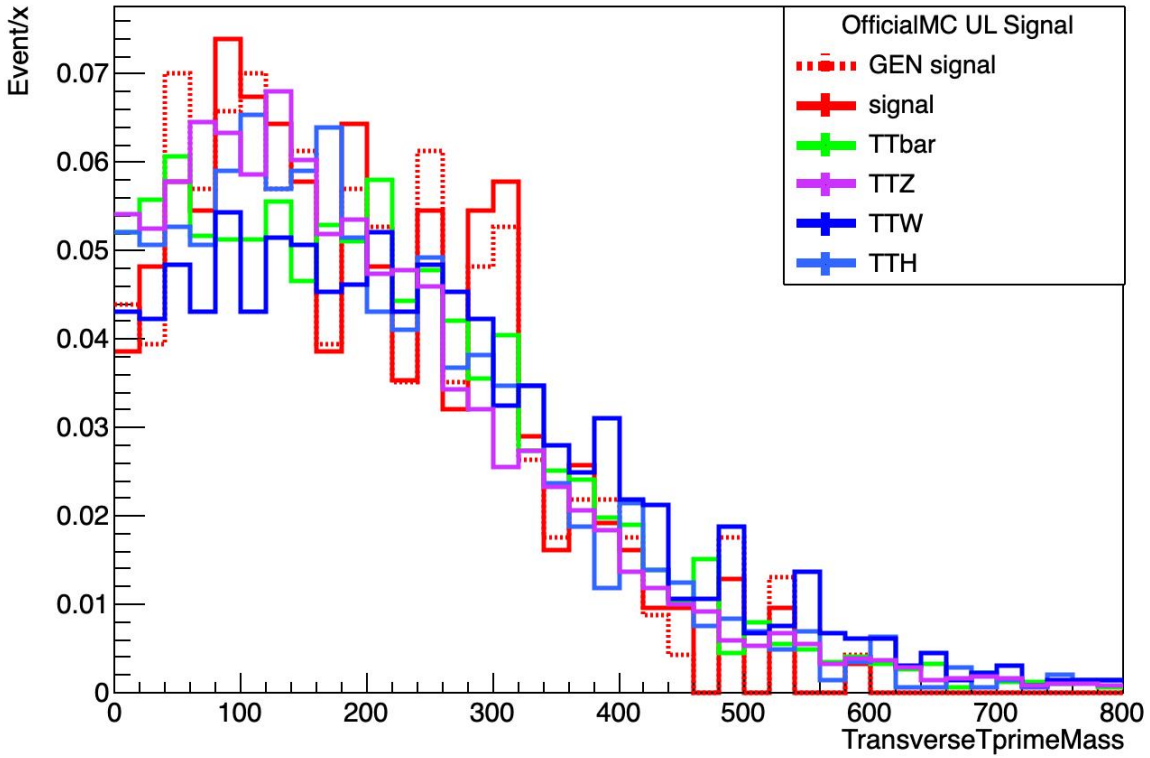




Main Variable Candidates

- **Take top+ll mass or transverse T' mass as main variables?**
  - **Transverse T' mass is a traditional choice**
  - **No obvious bump from signal**
    - **Still need to double check the calculation**
    - **Maybe loose the cuts a little bit?**





Main Variable Candidates

- **Take relative HT as main variables?**
  - $$relativeHT = \frac{\sum PTof topcandidatejet}{\sum goodjet}$$
  - **A very unusual choice (I don't think it's a smart one)**
  - **Obvious bump from signal**