

HLT Study

Search for Four top in Tau Final States

Anshul Kapoor Huiling Hua¹ Hongbo Liao¹

¹IHEP

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Outline

- 1 Introduction
- 2 Trigger efficiency
 - Baseline with ≥ 1 bjet
 - Remove double btag HLT
 - Baseline with no b jet requirement
 - HLT without PFJet450 trigger
- 3 What Signal Looks Like?

Section 1

Introduction



Trigger study strategy

- For trigger choice the primary goal is to have **very high signal efficiency**
- Define baseline selection so that trigger efficiency rest on turn on curve

Trigger choice

| year | MC | data |
|------|---|---|
| 2016 | HLT_PFJet450 | same as MC |
| | HLT_PFHT450_SixJet40_BTagCSV_p056 | same |
| | HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 | same |
| 2017 | HLT_PFJet500 | HLT_PFJet500 |
| | HLT_PFHT380_SixPFJet32_DoublePFBTagCSV_2p2 | HLT_PFHT430_SixJet40_BTagCSV_p080 or HLT_PFHT380_SixJet32_DoubleBTagCSV_p075 [297050, 299329] |
| | HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5 | HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5 or HLT_PFHT380_SixPFJet32_DoublePFBTagCSV_2p2 [299329, 306460] |
| 2018 | HLT_PFJet500 | HLT_PFJet500 |
| | HLT_PFHT450_SixPFJet36_PFBTagDeepCSV_1p59 | HLT_PFHT430_SixPFJet40_PFBTagCSV_1p5 or HLT_PFHT380_SixPFJet32_DoublePFBTagDeepCSV_2p2 ([315257, 315974]) |
| | HLT_PFHT400_SixPFJet32_DoublePFBTagDeepCSV_2p94 | HLT_PFHT430_SixPFJet40_PFBTagDeepCSV_1p5 or *HLT_PFHT380_SixPFJet32_DoublePFBTagDeepCSV_2p2 [315974, 317509] |
| | | HLT_PFHT450_SixPFJet36_PFBTagDeepCSV_1p59 or HLT_PFHT400_SixPFJet32_DoublePFBTagDeepCSV_2p94 [317509, 325173] |

Section 2

Trigger efficiency



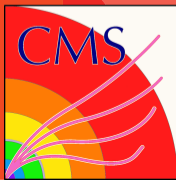
Trigger efficiency

- Reference trigger efficiency method
 - single Muon triggers `HLT_IsoMu24` (2016) or `HLT IsoMu27` (2017, 2018)
 - A unbiased reference trigger, to be able to measure efficiency in data
 - Measurement region: exactly one offline muon and pass the baseline selection,
 - derived per year as a function of HT, number of jets passing the medium b-tag working point (using the analysis tagger DeepJet2) and the pT of the 6th jet in the event.
- Pre-selection for trigger measurement
 - baseline: `HT>500GeV; jet multiplicity >= 6; leading 6 jet pt > 40GeV; b jet multiplicity>=1`
 - muon selection: muon number == 1 and muons pt >= 30
 - pre-selection = (`HLT_IsoMu24(2016)(HLT_IsoMu27(2017 and 2018))`)+ baseline + muon selection
 - Corrections for MC: pileup reweighting, pre-firing reweighting
- efficiency = $\frac{events_{HLT \& \textit{preselection}}}{events_{\textit{preselection}}}$

Section 2

Trigger efficiency

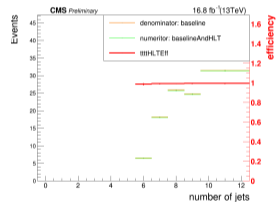
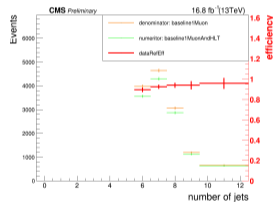
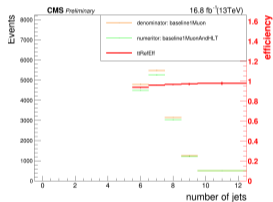
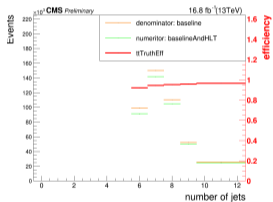
2.1 Baseline with ≥ 1 bjet



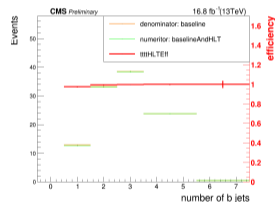
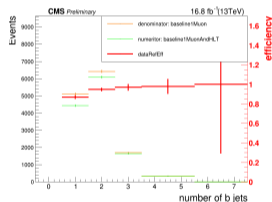
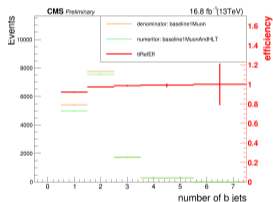
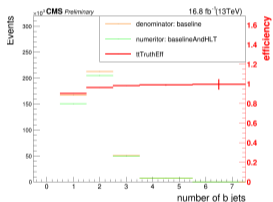
Selection for efficiency measurement

- Baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$: $b \text{ jet number} \geq 1$
- muon selection: muon number == 1 and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24(2016) + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450(2016)
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

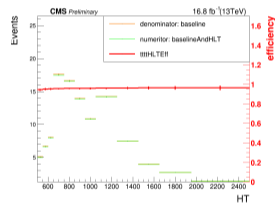
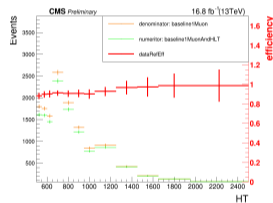
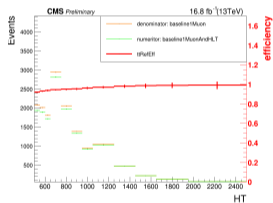
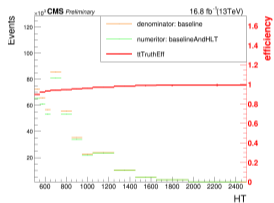
Trigger efficiency



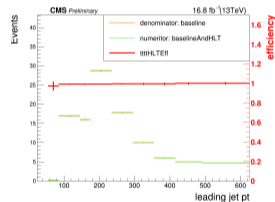
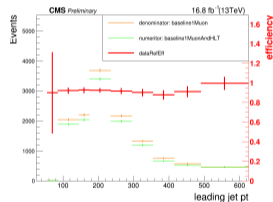
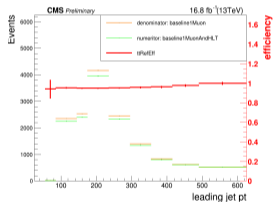
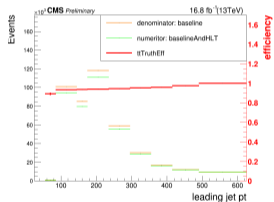
Trigger efficiency



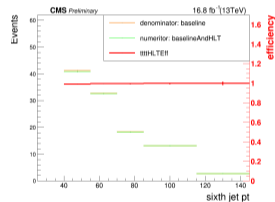
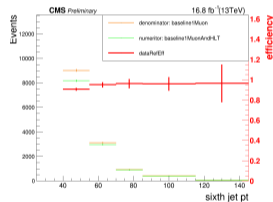
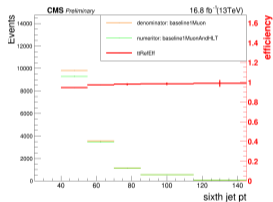
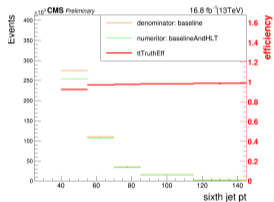
Trigger efficiency



Trigger efficiency



Trigger efficiency



Section 2

Trigger efficiency

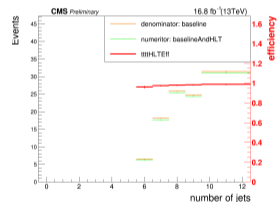
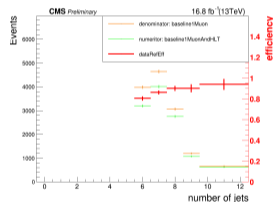
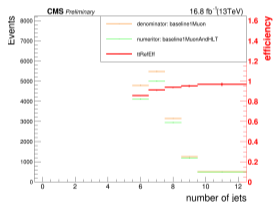
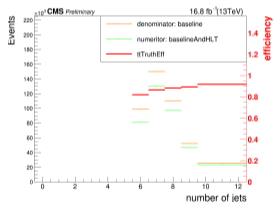
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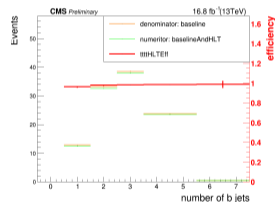
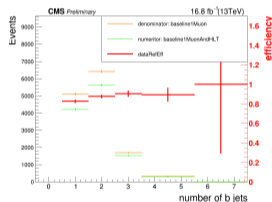
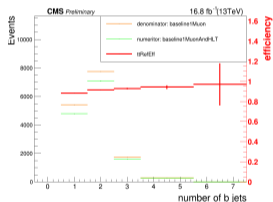
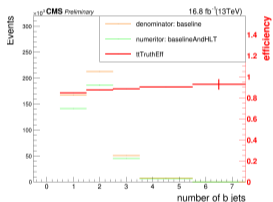
Selection for efficiency measurement

- Baseline: HT>500GeV; jet multiplicity ≥ 6 ; leading 6 jet pt > 40GeV: **b jet number** ≥ 1
- muon selection: muon number == 1 and muons pt ≥ 30
- pre-selection = HLT_IsoMu24(2016) + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFJet450(2016)
- efficiency = $\frac{events_{HLT \& \text{preselection}}}{events_{\text{preselection}}}$

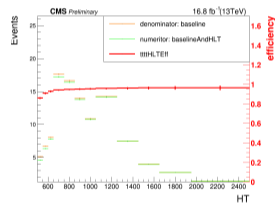
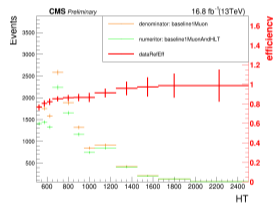
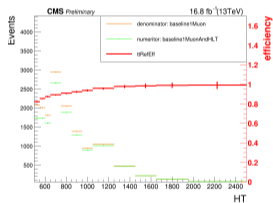
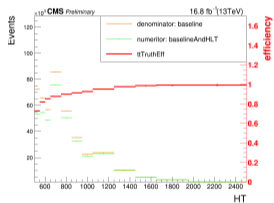
Trigger efficiency



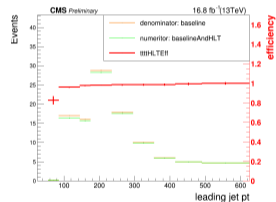
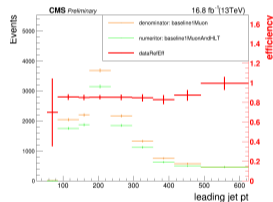
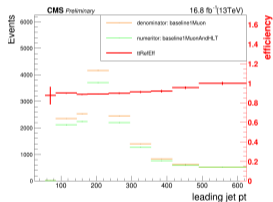
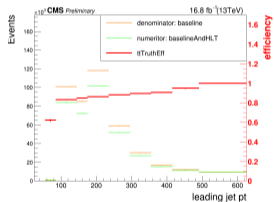
Trigger efficiency



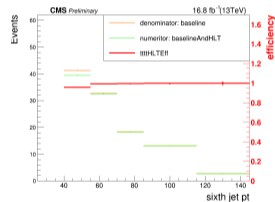
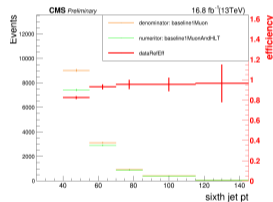
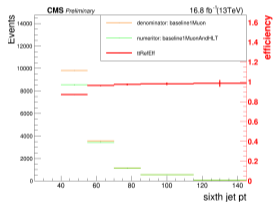
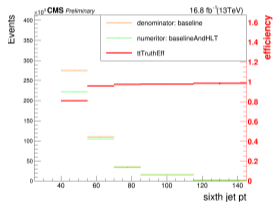
Trigger efficiency



Trigger efficiency



Trigger efficiency



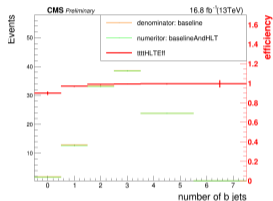
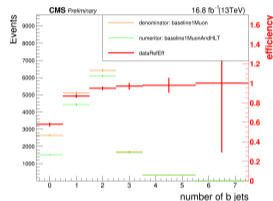
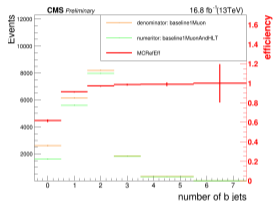
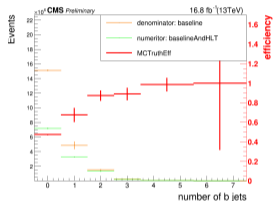
Section 2

Trigger efficiency

2.3 Baseline with no b jet requirement

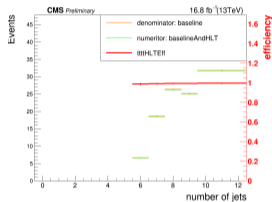
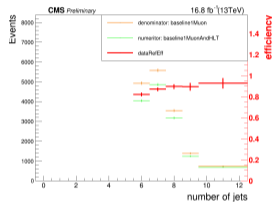
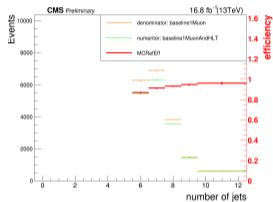
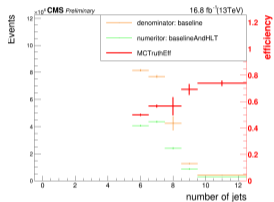


Trigger efficiency



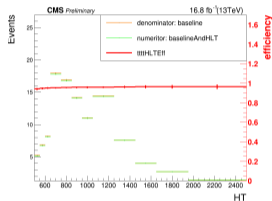
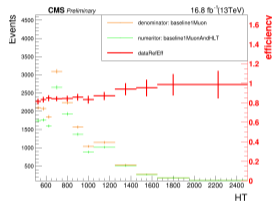
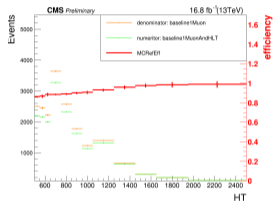
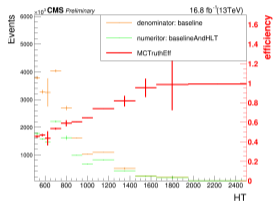
- baseline: HT>500GeV; jet multiplicity >= 6; leading 6 jet pt > 40GeV
- muon selection: muon number == 1 and muons pt >= 30
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- efficiency = $\frac{events_{HLT \& \text{preselection}}}{events_{\text{preselection}}}$

Trigger efficiency



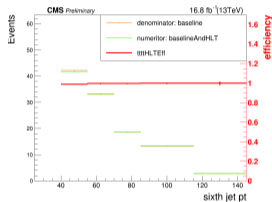
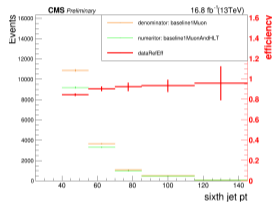
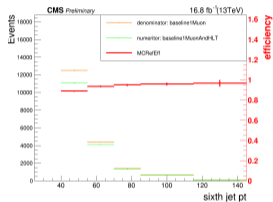
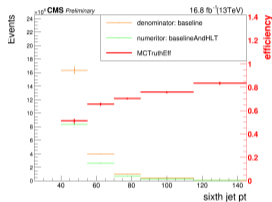
- baseline: HT>500GeV; jet multiplicity >= 6; leading 6 jet pt > 40GeV
- muon selection: muon number == 1 and muons pt >= 30
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- $$\text{efficiency} = \frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$$

Trigger efficiency



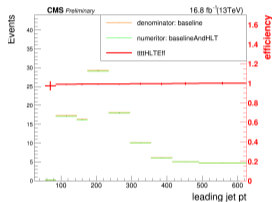
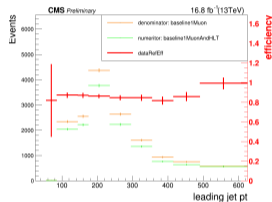
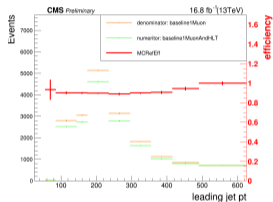
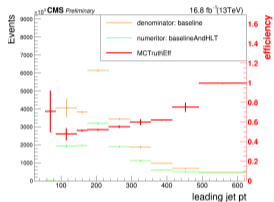
- baseline: HT>500GeV; jet multiplicity >= 6; leading 6 jet pt > 40GeV
- muon selection: muon number == 1 and muons pt >= 30
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- efficiency = $\frac{events_{HLT \& \text{preselection}}}{events_{\text{preselection}}}$

Trigger efficiency



- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- $$\text{efficiency} = \frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$$

Trigger efficiency



- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

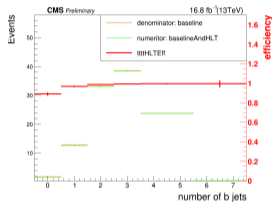
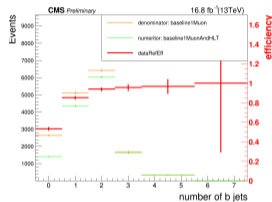
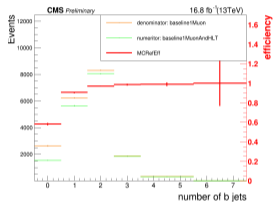
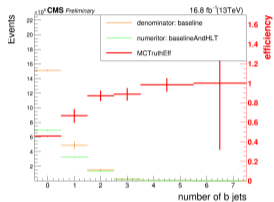
Section 2

Trigger efficiency

2.4 HLT without PFJet450 trigger

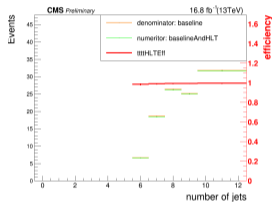
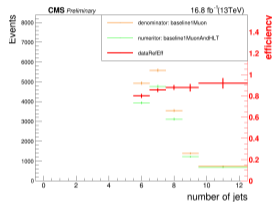
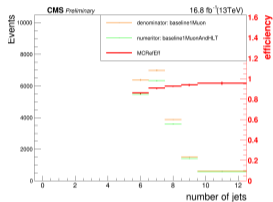
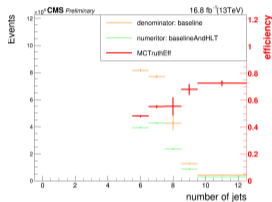


Trigger efficiency



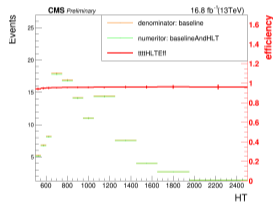
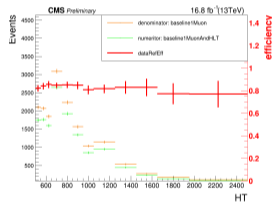
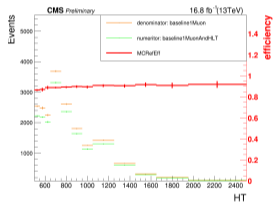
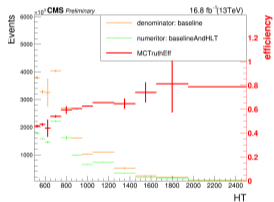
- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

Trigger efficiency

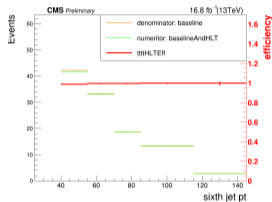
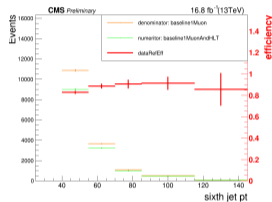
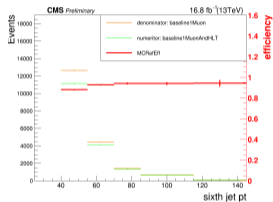
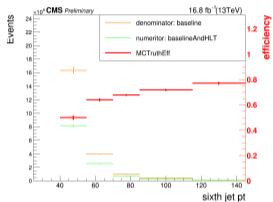


- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

Trigger efficiency

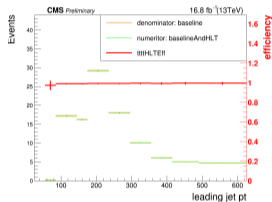
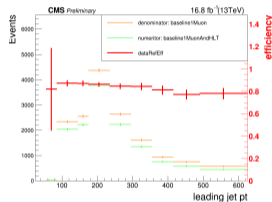
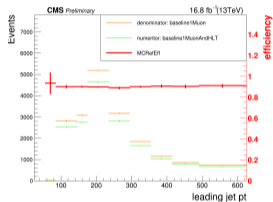
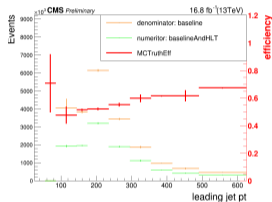


Trigger efficiency



- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40 \text{ GeV}$
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

Trigger efficiency



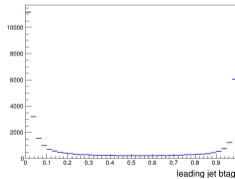
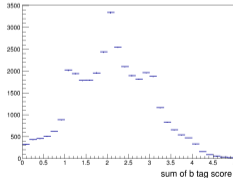
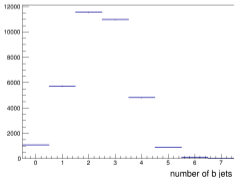
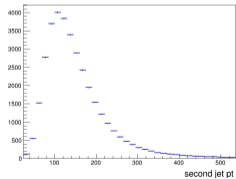
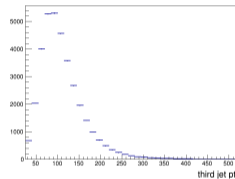
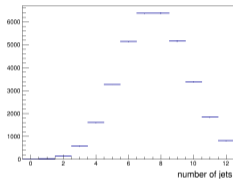
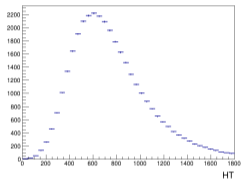
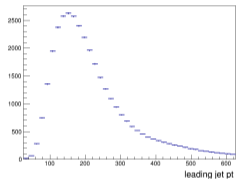
- baseline: HT>500GeV; jet multiplicity >= 6; leading 6 jet pt > 40GeV
- muon selection: muon number == 1 and muons pt >= 30
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056
- efficiency = $\frac{events_{HLT \& \text{preselection}}}{events_{\text{preselection}}}$

Section 3

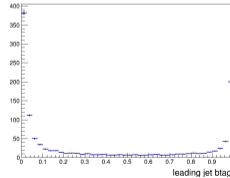
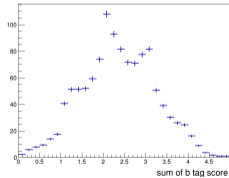
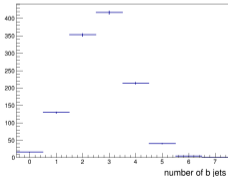
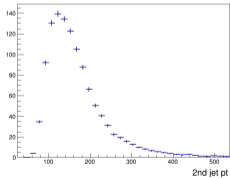
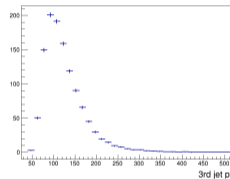
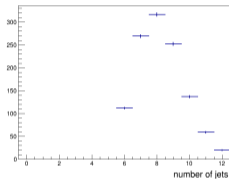
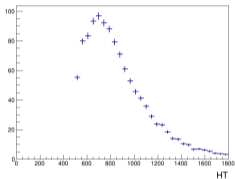
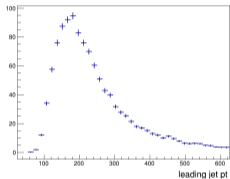
What Signal Looks Like?



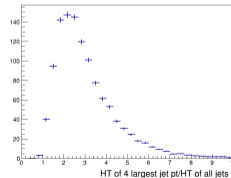
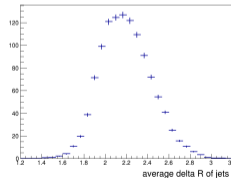
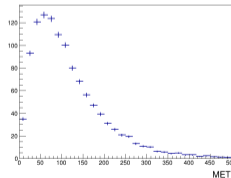
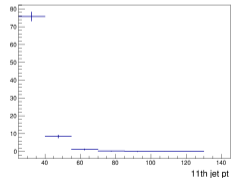
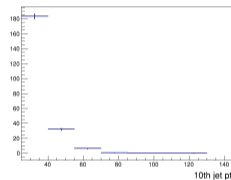
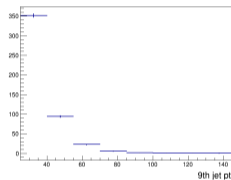
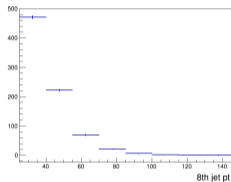
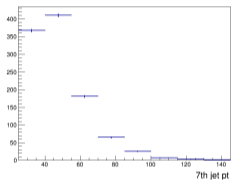
What does signal look like?(no selection)



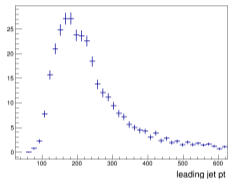
What does signal look like?(1 tau)



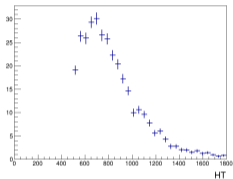
What does signal look like?(1 tau)



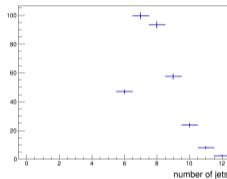
What does signal look like?(1tau1l)



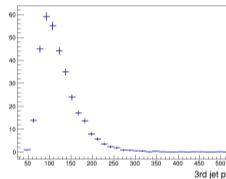
leading jet pt



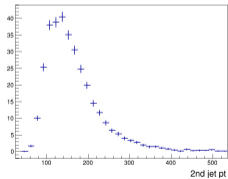
HT



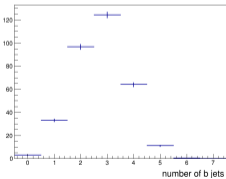
number of jets



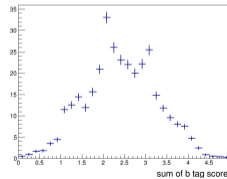
3rd jet pt



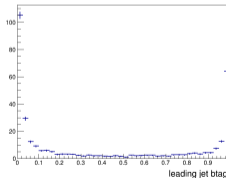
2nd jet pt



number of b jets

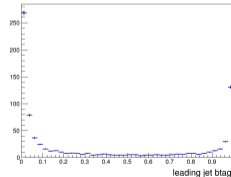
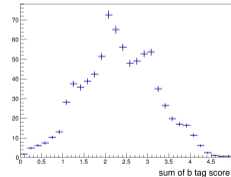
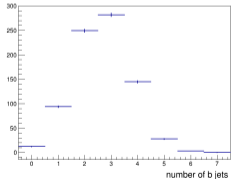
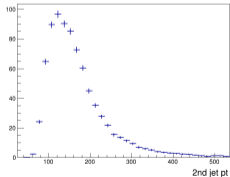
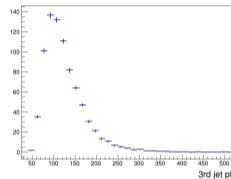
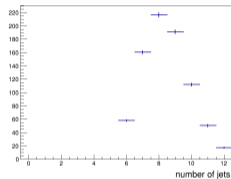
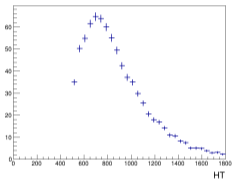
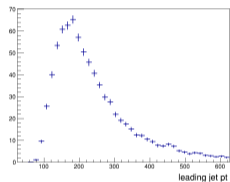


sum of b tag score



leading jet btag

What does signal look like?(1tau0l)



Correlation between variables(no selection)

Section 4

Back up



Questions

- Why do we require 1 muon to ensure reference trigger fires?
- Why do we have to require just one bg not all of them?

Background composition in baseline region

| regions | tttt | uncert | tt | uncert | qcd | uncert | ttX | uncert | VV | uncert | singleTop | uncert | WJets | uncert | total bg | sensitivity | data | data/MC |
|---------------------|---------|--------|------------|---------|--------------|------------|----------|--------|--------|--------|-----------|--------|----------|--------|--------------|-------------|------------|---------|
| baseline1Muon | 16.920 | 0.069 | 16191.183 | 27823 | 141.117 | 47130 | 485.149 | 10.076 | 0.948 | 0.089 | 220.765 | 7.726 | 2098.575 | 22.240 | 19137.737 | 0.122 | 16213.000 | 0.920 |
| baseline1MuonAndHLT | 16.790 | 0.069 | 15265.837 | 27050 | 60.826 | 22.508 | 466.394 | 9.839 | 0.615 | 0.072 | 201.096 | 7.378 | 1340.848 | 16.879 | 17335.616 | 0.127 | 14035.000 | 0.940 |
| baseline | 111.029 | 0.176 | 473547.448 | 174.911 | 21283958.601 | 522195.139 | 9694.891 | 51.662 | 88.703 | 0.905 | 8597.749 | 48.541 | 15327193 | 64.370 | 21791214.583 | 0.024 | 308000.000 | 0.810 |
| baselineAndHLT | 110.162 | 0.175 | 438665.666 | 168.362 | 11560124.102 | 102357282 | 9151.274 | 49974 | 54.463 | 0.721 | 7725.497 | 46.039 | 9471.085 | 48.004 | 12025192.086 | 0.032 | 230868.000 | 1.170 |

- Data is singleMu

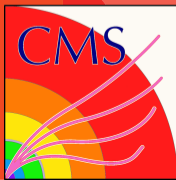
Possible challenges for HT+6jet+htag trigger

- Trigger re- tuned in 2017 and 2018 data
- HLT offline b tag and online b tag algorithm
 - DeepJet is used offline while CSVv2 (2016, 2017) or DeepCSV (2018) are used online
 - differences in online and offline b-tagging can lead to shifts in turn-ons
 - o validate the performance of the trigger strategy, the efficiencies are additionally measured using the **same b-tagging algorithm** on analysis level (offline) and trigger level (online)
- Drop in data efficiency in high HT
 - last run period of the LHC in 2016 (Run H) which had very high instantaneous luminosity.
 - L1 HT triggers suffered a problem in which saturated (high pT) jets were excluded from the HT calculation
 - A partial mitigation strategy of including an OR of a single jet trigger HLT PFJet450 v* has been implemented, which recovers most of the lost efficiency at high HT.
- 2017
 - HLT_PFHT300PT30_QuadPFJet_75_60_45_40_TriplePFBTagCSV_3p0: BTagCSV

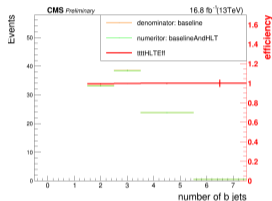
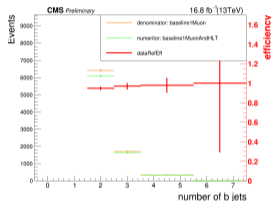
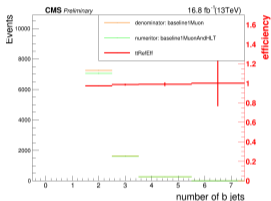
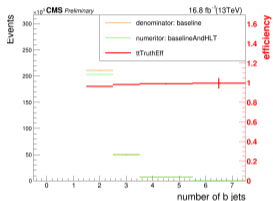
Section 4

Back up

4.1 Add ≥ 2 b jets in baseline

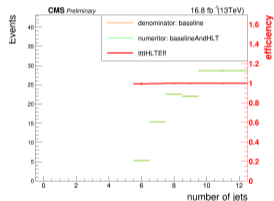
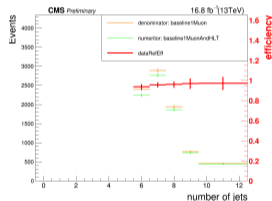
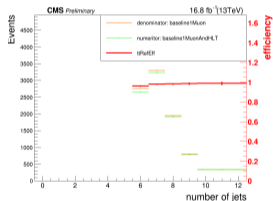
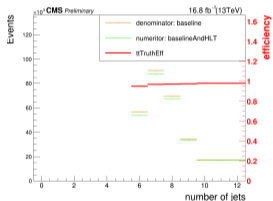


Trigger efficiency

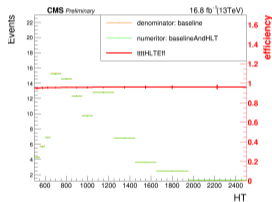
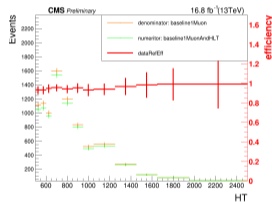
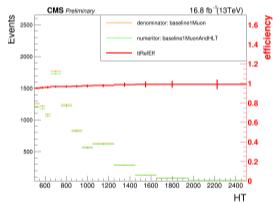
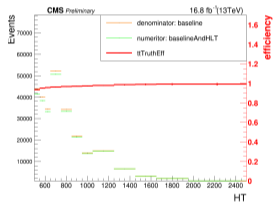


- baseline: $HT > 500 \text{ GeV}$; jet multiplicity ≥ 6 ; leading 6 jet $pt > 40$; **b jets number ≥ 2**
- muon selection: muon number $= 1$ and muons $pt \geq 30$
- pre-selection = HLT_IsoMu24 + muon selection + baseline
- HLT : HLT_PFHT450_SixJet40_BTagCSV_p056 or HLT_PFHT400_SixJet30_DoubleBTagCSV_p056 or HLT_PFJet450
- efficiency = $\frac{\text{events}_{\text{HLT \& preselection}}}{\text{events}_{\text{preselection}}}$

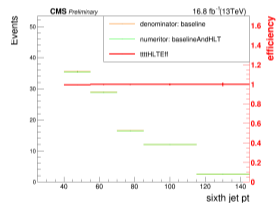
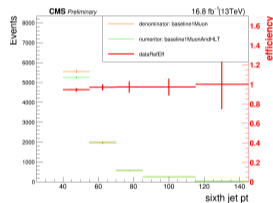
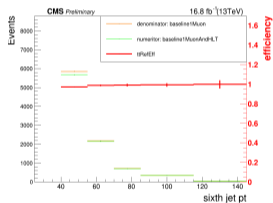
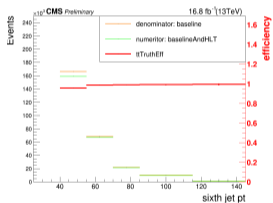
Trigger efficiency



Trigger efficiency



Trigger efficiency



Trigger efficiency

