Update on the $t\bar{t}HH$ data checking

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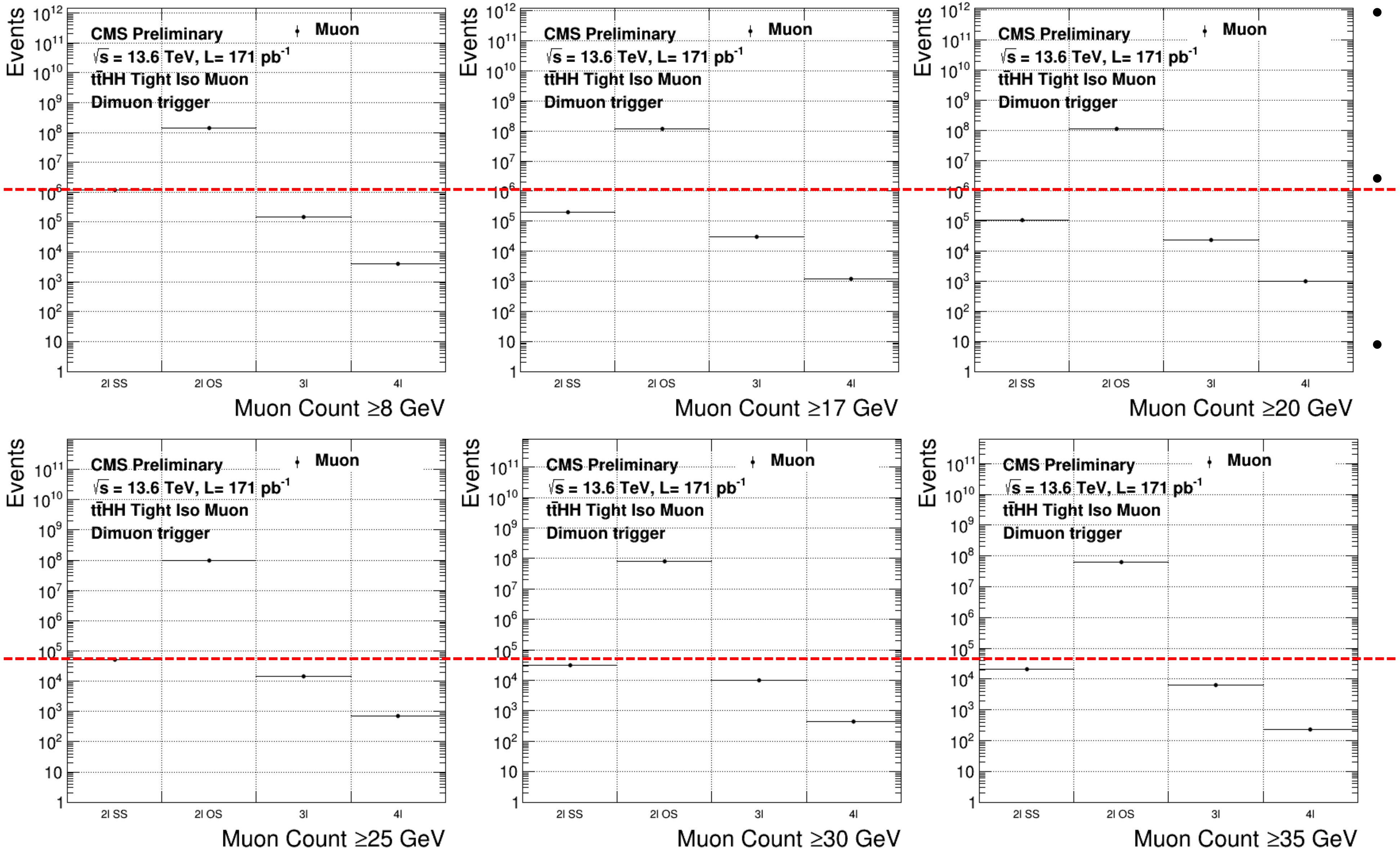
Full dataset

- Full Muon datasets downloaded already: /data2/common/NanoAOD/v12/data/
- Physical era with golden json:
  - 2022 C-G
  - 2023 C-D
  - 2024 C-I
- PDs used: 2022 Muon, 2023-2024 Muon0 + Muon1
- Total luminosity: $171\ \mathrm{fb}^{-1}$.

Object selection

- Using the whole dimuon-triggered region: HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8.
- Muon requires the tight & iso condition:
  - TightID
  - $I_{\Delta R=0.4} > 0.15$
- Muon p_T threshold of different values are tested.

Muon threshold verification



- 2lSS, 3l, 4l signal regions would decrease rapidly with respect to increased Muon p_T threshold.
- 2lSS lose a lot before at cut $p_T \geq 17$ GeV, 3l at 25, 4l at 35.

- 2lOS control region seems not much affected by the p_T threshold.

Backgrounds considered

```
DYGto2LG-1Jets_MLL-50_PTG-10to100_TuneCP5_13p6TeV_amcatnloFXFX-pythia8
DYJetsToLL_M-50_TuneCP5_13p6TeV-madgraphMLM-pythia8
DYto2L-2Jets_MLL-10to50_TuneCP5_13p6TeV_amcatnloFXFX-pythia8
DYto2L-2Jets_MLL-50_TuneCP5_13p6TeV_amcatnloFXFX-pythia8
DYto2L-4Jets_MLL-50_TuneCP5_13p6TeV_madgraphMLM-pythia8
GluGluToContinto2Zto2E2Mu_TuneCP5_13p6TeV_mcfm701-pythia8
GluGluToContinto2Zto2E2Nu_TuneCP5_13p6TeV_mcfm701-pythia8
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GluGluToContinto2Zto2Mu2Tau_TuneCP5_13p6TeV_mcfm701-pythia8
GluGlutoContinto2Zto4E_TuneCP5_13p6TeV_mcfm-pythia8
GluGlutoContinto2Zto4Mu_TuneCP5_13p6TeV_mcfm-pythia8
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QCD_PT-120to170_MuEnrichedPt5_TuneCP5_13p6TeV_pythia8
QCD_PT-15to20_MuEnrichedPt5_TuneCP5_13p6TeV_pythia8
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QCD_PT-800to1000_MuEnrichedPt5_TuneCP5_13p6TeV_pythia8
QCD_PT-80to120_MuEnrichedPt5_TuneCP5_13p6TeV_pythia8
TbarBtoLminusNuB-s-channel-4FS_TuneCP5_13p6TeV_amcatnlo-pythia8
TbarWplusto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8
TbarWplustoLNu2Q_TuneCP5_13p6TeV_powheg-pythia8
TBbartoLplusNuBbar-s-channel-4FS_TuneCP5_13p6TeV_amcatnlo-pythia8
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THW_ctcvcp_HIncl_M-125_5FS_TuneCP5_13p6TeV_madgraph-pythia8
TTH_Hto2Z_4LFilter_M-125_TuneCP5_13p6TeV_powheg-jhugenv752-pythia8
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TTHtoNon2B_M-125_TuneCP5_13p6TeV_powheg-pythia8
ttHtoZG_ZtoAll_M-125_TuneCP5_13p6TeV_powheg-pythia8
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TTLL_MLL-50_TuneCP5_13p6TeV_amcatnlo-pythia8
TTLNu-1Jets_TuneCP5_13p6TeV_amcatnloFXFX-pythia8
TTto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8
TTto4Q_TuneCP5_13p6TeV_powheg-pythia8
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TTWH_TuneCP5_13p6TeV_madgraph-pythia8
TTWW_TuneCP5_13p6TeV_madgraph-madspin-pythia8
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TTZZ_TuneCP5_13p6TeV_madgraph-madspin-pythia8
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ZZto4L_TuneCP5_13p6TeV_powheg-pythia8
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Cross-section at LO

- Newly added full p_T range of the muon-enriched QCD backgrounds for studying the Muon p_T threshold.
- Cross-section for this not very reliable, but provide an order, showing the importance of the low-p_T contribution.

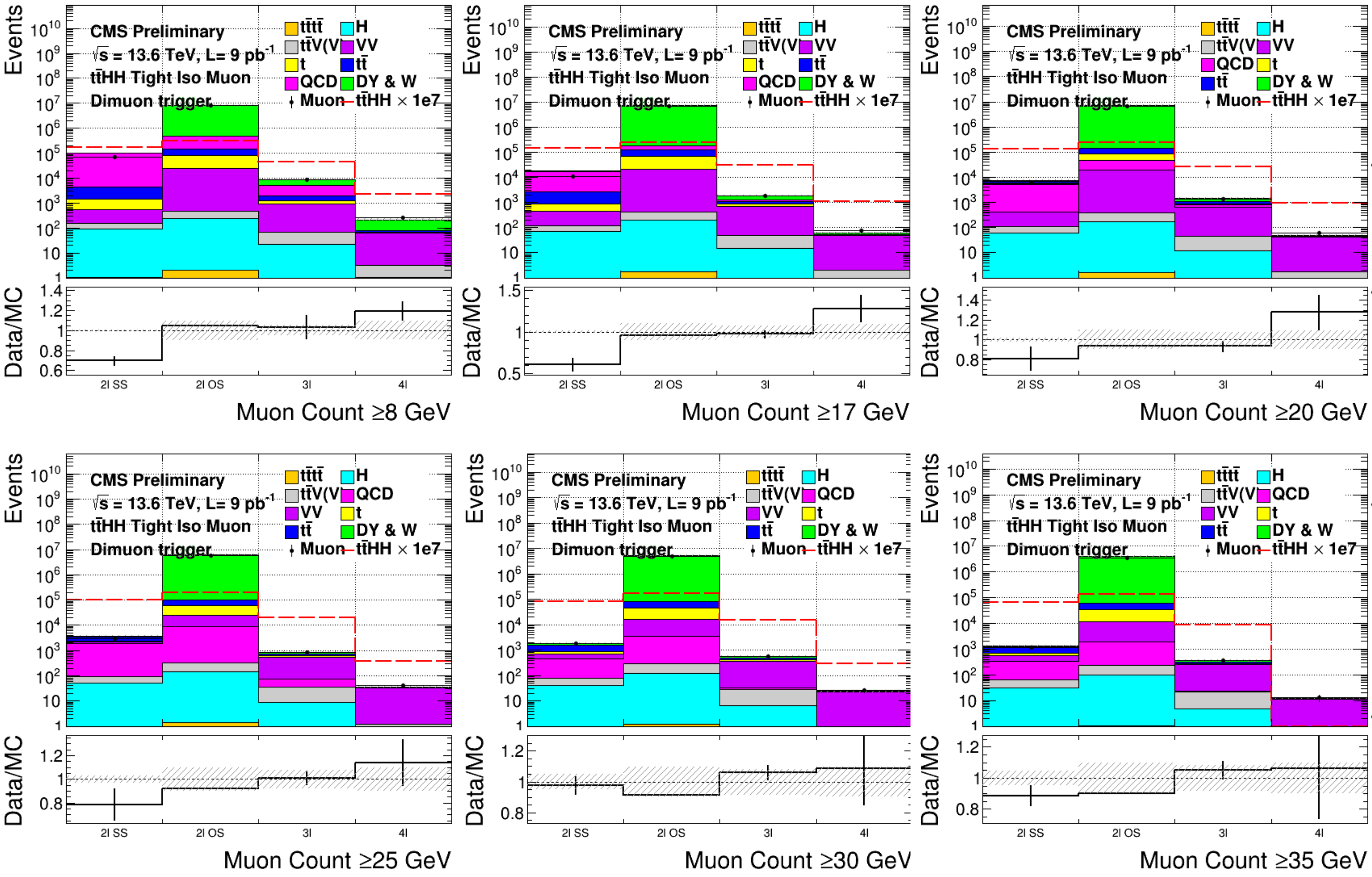
MC cross-section uncertainties

- From AN2024_226:

  - **Theoretical cross section**. Uncertainties on the SM cross sections of background processes are applied, based on available theory uncertainties computed at NLO accuracy. Uncertainties of: 7%, 11%, 10%, 10%, and 10% are applied to $t\bar{t}Z$ [37], tZq [38], two and tri-boson processes [39, 40], and processes in association with a photon [41, 42], respectively. A 5% uncertainty is applied to the $t\bar{t}$ [43] process while a 10% uncertainty is applied to the DY process [44] and the remaining processes in which a $t\bar{t}$ pair plus addittionally particles is produced. Finally, an uncertainty of 20% is assigned to the WZ+b-jets background, to account for an increased uncertainty in the processes where b-jets are present (derived from the differential $t\bar{t}Z$ measurement [45]).

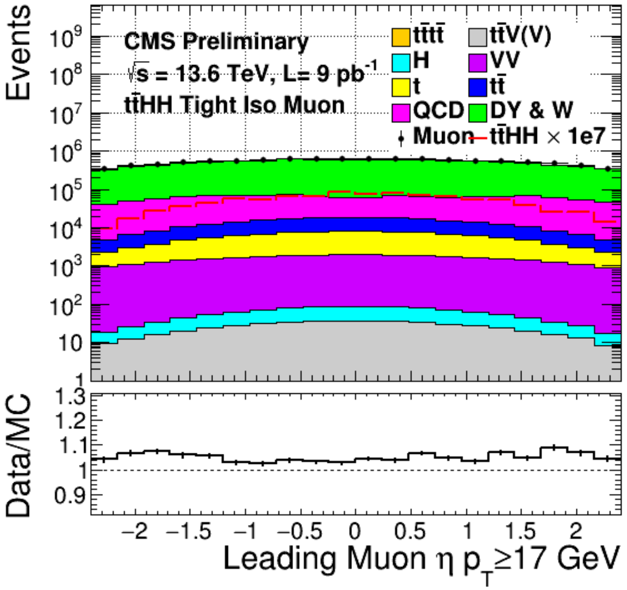
- The dominant contribution in the inclusive region should be the Drell-Yan cross-section ~10%.
- The QCD uncertainties are not directly given by a percentage value but requires data-driven estimation.

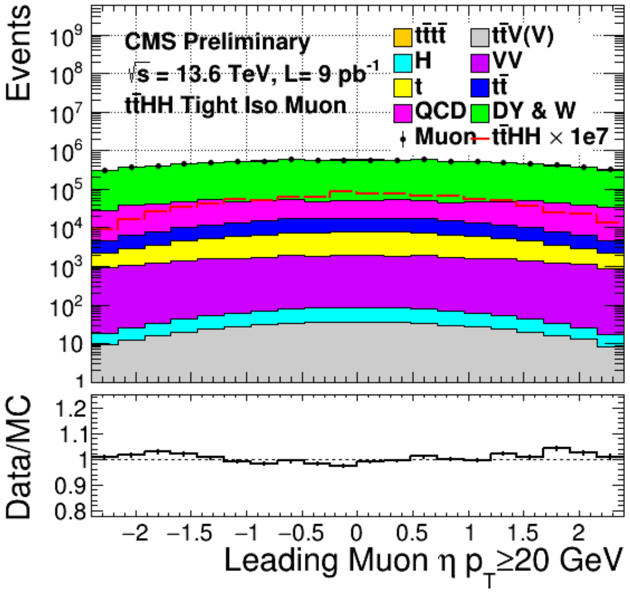
Data-MC comparison



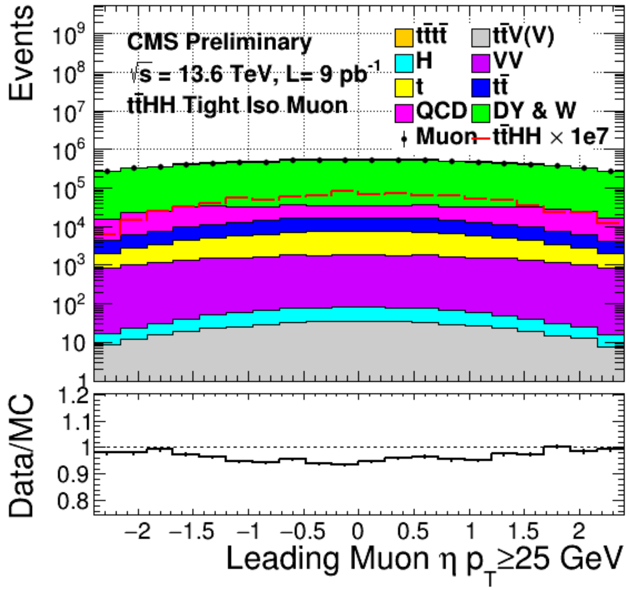
- The matching is good in 2lOS and 3l region.
- Missing VVV contribution, which should contribute to the gap in 4l.
- The 2lSS region has overshoot before $p_T \geq 30$ GeV.
- In the other region, the Drell-Yan and di-boson contributions are important, which have known cross-section uncertainties.
- The dominant background in the whole 2lSS region is QCD, which lacks the modeling.
- The 2lSS signal seems not decrease much with p_T threshold, but multi-Muon lose a lot.

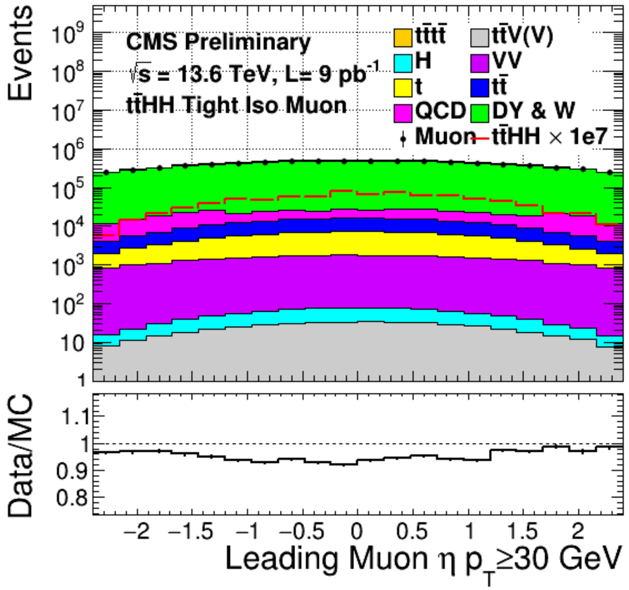
Data-MC comparison

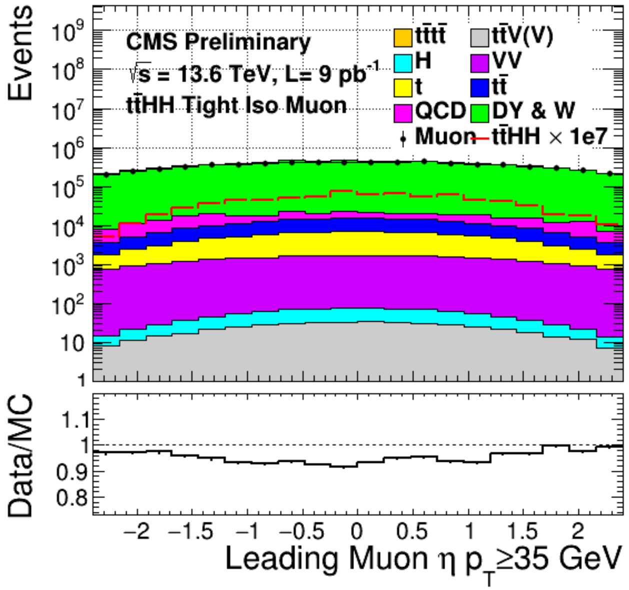




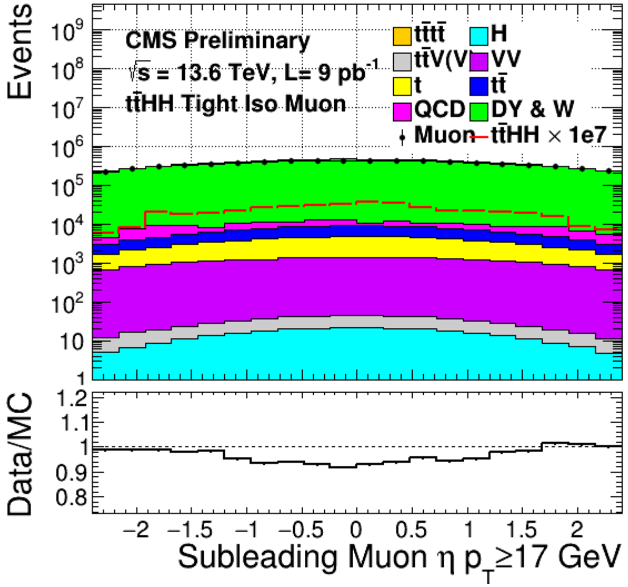
- In the inclusive dimuon-triggered region, the data-MC matching is changing as the leading Muon p_T threshold.
- Deviation within the Drell-Yan cross-section uncertainty.
- If the change in the data-MC comparison with increasing threshold an issue?

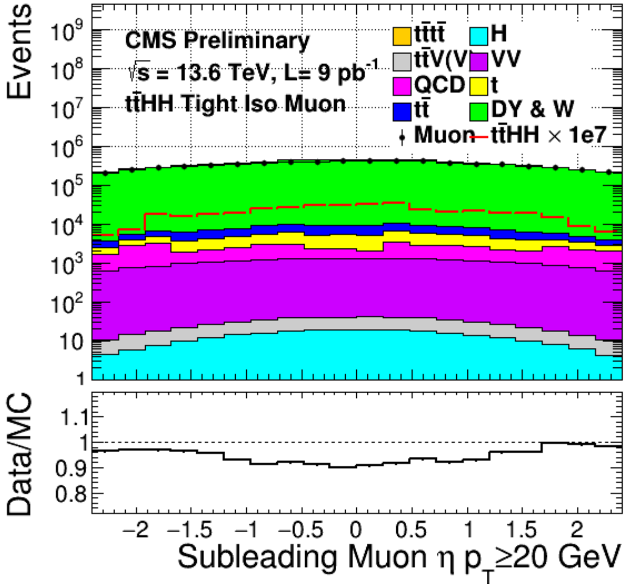


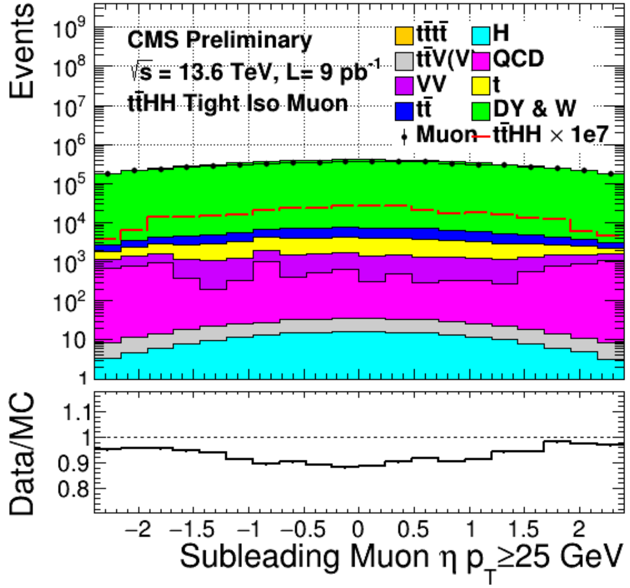


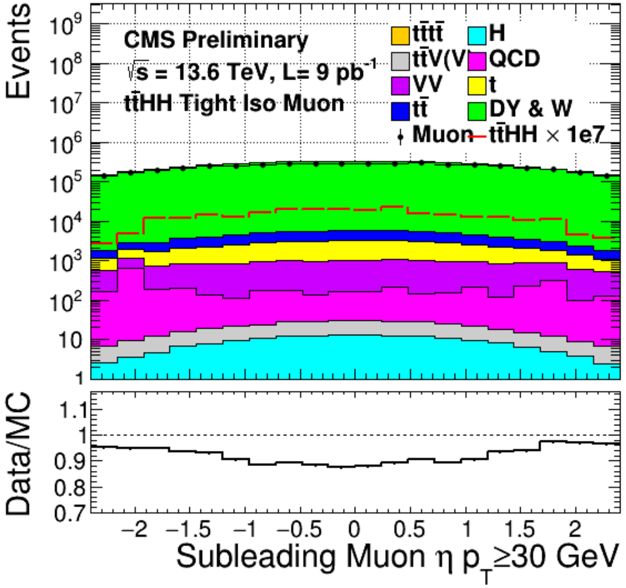


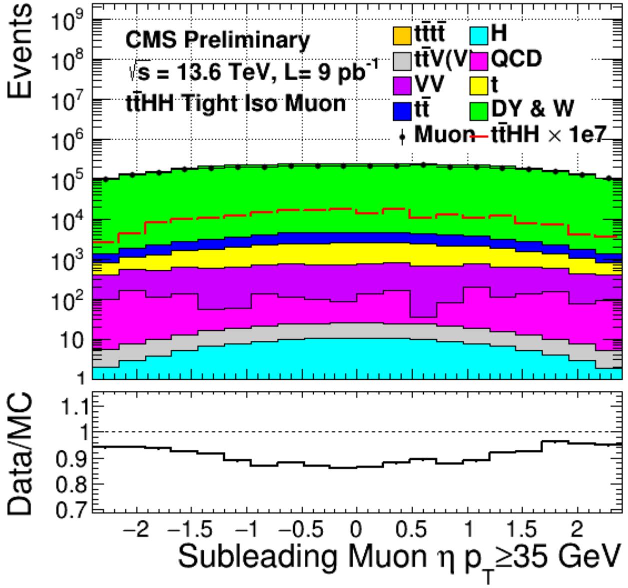
Data-MC comparison





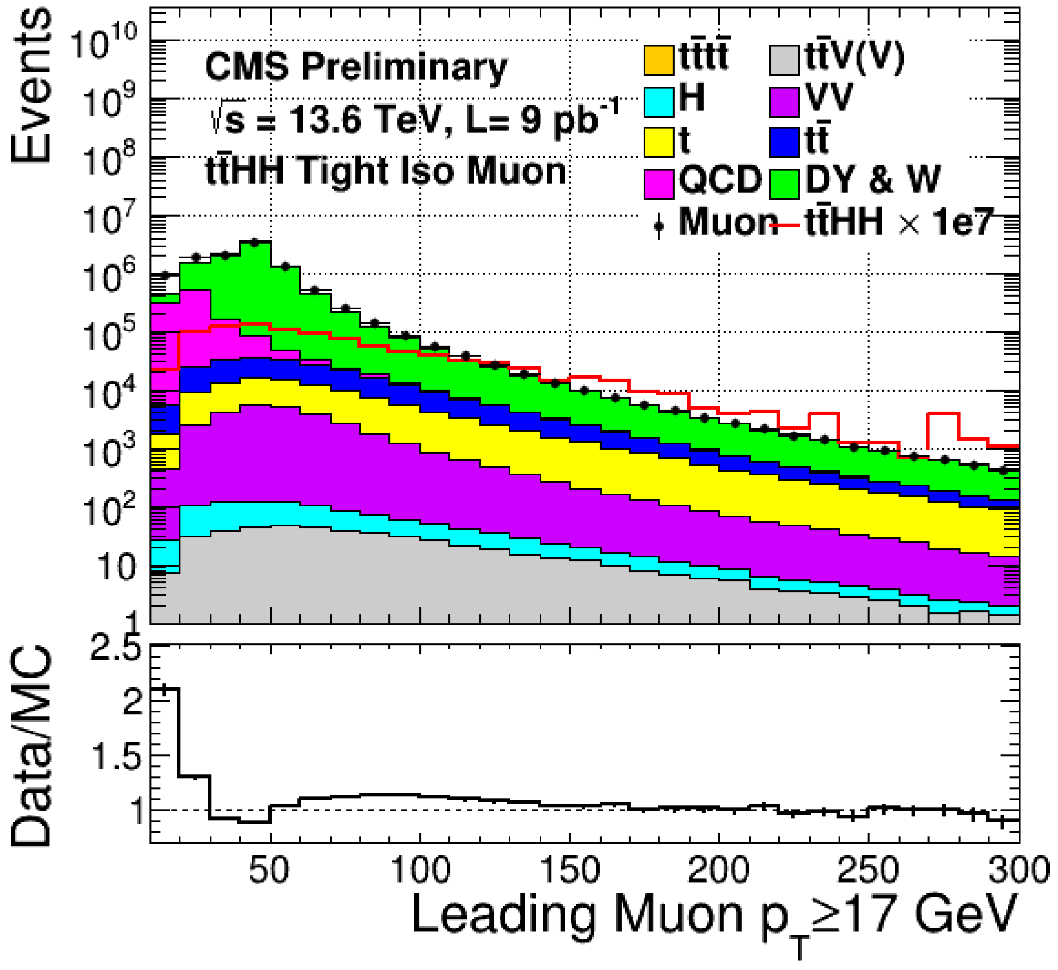






- In the inclusive dimuon-triggered region, the data-MC matching is changing as the p_T threshold.
- Deviation becomes larger at higher p_T threshold.

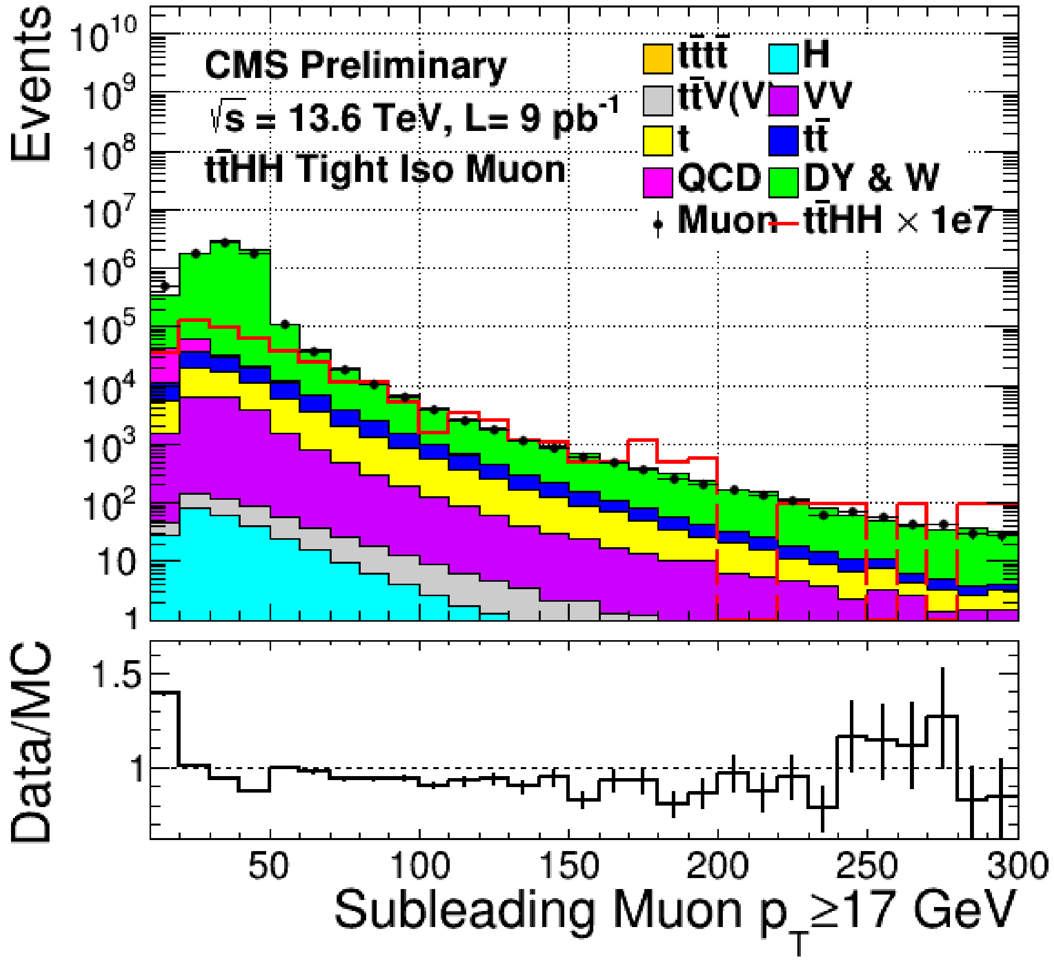
Data-MC comparison



- The mis-modeling in the low-p_T region is noticed. **What is the source of it? This is the most important thing to investigate now.**

- The low-p_T region has fewer well-modeled Drell-Yan background, but this does not look like QCD modeling uncertainty shall cover the 2 times data.

Data-MC comparison



- Subleading Muon similarly has a low-p_T region modeling issue.
- Clearly the missing is already larger than the Drell-Yan cross-section uncertainty.
- We need to understand the source of the low-p_T Muon modeling to make good data-MC comparison.