right

Determination of the Trigger Scale Factors for a search for new light bosons decaying to muon pairs with 2018 Data (AN-19-153).

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1 Introduction

Our $aa \to$ analysis is progressing well and we're at the point where we want to estimate the trigger scale factor. In our analysis we use a number of multi-muon triggers both dimuon and trimuon. In the previous iteration where we used a trimuon trigger we employed the orthogonal method. In the current analysis we use a combination of triggers shown in Tab. 1.

Table 1: Signal Triggers used in the Analysis

Trigger Path
HLT_DoubleL2Mu23NoVtx_2Cha
HLT_Mu18_Mu9_SameSign
HLT_TripleMu_12_10_5
HLT_TrkMu12_DoubleTrkMu5NoFiltersNoVtxv

For the double muon triggers we could try using the tag-and-probe method if the single muon legs were included in the menu. For the two triple-muon triggers we were considering the orthogonal method where we use data sets other than the DoubleMuon (e.g. MET SingleElectron...). Do you know if there are other options for trimuon triggers? Also what would be the best procedure is to estimate the overall trigger scale factor?

In your case it looks too complicated to derive the overall trigger scale factor out of individual scale factors. It might be more realistic to measure the overall efficiency at once instead of breaking it down into individual trigger efficiencies. The reference trigger method [1] is popularly used to measure the efficiency of a mixture of multi-muon triggers but it seems not applicable to your analysis as there are no shared legs (and also no corresponding control triggers I guess) of the same muon type among your triggers. For now I couldn't think of anything other than just measuring the overall trigger efficiency using the orthogonal method.

2 Methodology

We use several muon signal triggers as described in Sec. **??**. The scale factor of the signal triggers will be estimated with the orthogonal method using three-muon events emulating WZ events as done in the previous iteration of this analysis [**?**]. The orthogonal method assumes that such events are mainly triggered by the substantial MET in the event topology and therefore independent of muons selection criteria. The efficiency of the triple-muon trigger is determined on events passing a set of selection criteria optimized to select WZ events. This will be done both on data and on MC simulated events. The data are selected using a set of pure MET triggers in the MET dataset. MET triggers with one or more muons in the selection are ignored. MC events are simulated for the processes (1) $pp \to WZ$ and (2) $pp \to t\bar{t}Z$. The data and MC samples will be cleaned by selecting high-quality muons to obtain a set of well-reconstructed WZ-like events. The selection criteria are being derived from Ref. [**?**]. Data vs MC plots in the control region and plot of the efficiency of control region events to pass the signal trigger will be added soon.

3 Datasets

We use the MiniAOD samples shown below in Tab. 2. Additionally we use WZ Monte Carlo and ttZ Monte Carlo datasets shown in Tab. 3. The cross sections were calculated with the GenXSecAnalyzer [1]. The mean number of interactions per bunch crossing for the 2018 pp run at 13 TeV and in simulation is shown in Fig. 1.

Table 2: SingleMuon data samples for the trigger scale factor studies.

Dataset name	Number of events
/SingleMuon/Run2018A-17Sep2018-v2/MINIAOD	241608232
/SingleMuon/Run2018B-17Sep2018-v1/MINIAOD	119918017
/SingleMuon/Run2018C-17Sep2018-v1/MINIAOD	110032072
/MET/Run2018D-PromptReco-v2/MINIAOD	506717754
Total	978276075

Table 3: Monte Carlo samples for the trigger scale factor studies: $WZ \to 3l\nu$ process and $ttZ \to ll\nu\nu$ process.

Abbreviation	Dataset name	Events	Cross Section [pb]
WZTo3LNu1	WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8 /RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	10749269	5.114 ± 0.075
TTZToLLNuNu	/TTZToLLNuNu_M-10_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v2/MINIAODSIM	13280000	0.2432 ± 0.0003

[1] https://twiki.cern.ch/twiki/bin/view/CMS/HowToGenXSecAnalyzer

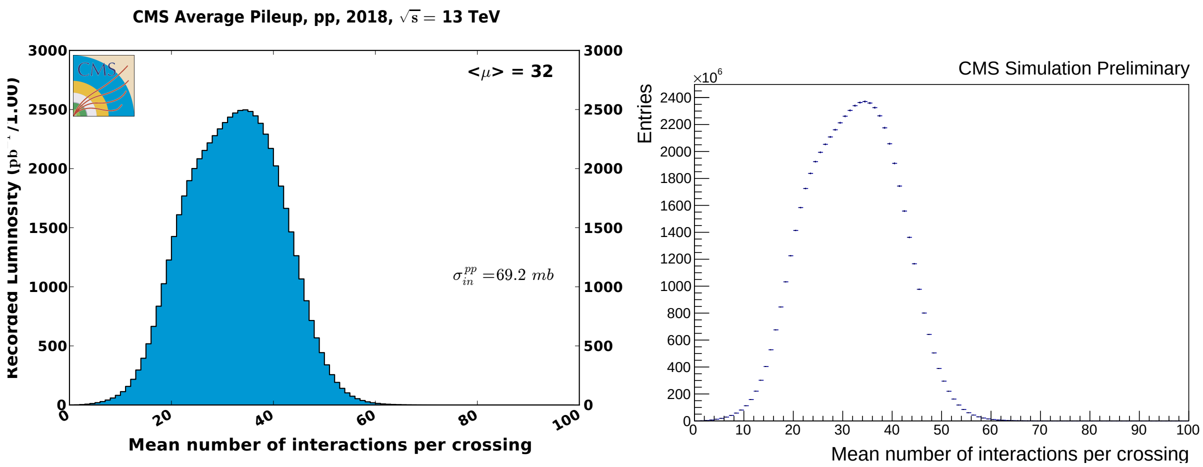


Figure 1: Left: Average pileup in 2018. Mean number of interactions per bunch crossing for the 2018 pp run at 13 TeV using the online luminosity values. The plot uses the CMS recommended value of 69.2 mb for the minimum bias cross section which is determined by finding the best agreement with data and is recommended for CMS analyses. Right: Simulated average pileup in 2018 with the `mix_2018_25ns_JuneProjectionFull18_PoissonOOTPU_cfi` configuration.

4 Event Pre-Selection

Events are pre-selected which have at least three muons with pT $>$ 10 GeV and at least one muon with $p\_T > 20$ GeV and are required to be in the run range specified in this JSON file Cert_314472-325175_13TeV_17SeptEarlyReReco2018ABC_PromptEraD_Collisions18_JSON.txt. Events with more than 3 muons with $>$ 10 GeV are rejected. The pre-selection accepts 3.4% of the events in data as can be seen in Tab. 4. Events in Monte Carlo are not pre-selected.

Table 4: 2018 MET Data pre-selection numbers

Sample	Total Events	Pre-selected Events
2018A	52744621	1810214
2018B	29714277	921467
2018C	31237456	1146290
2018D	162272551	5403483
2018	275968905	9281454

5 Event Selection

Events are required to pass at least one SingleMuon trigger (see Tab. 5). Each of these trigger applies a cut of at least $100 GeV$ on the missing transverse energy in the trigger. In addition events must have exactly three muons with $|\eta| < 2.4$ and with transverse momenta thresholds $40 : 40 : 10\ GeV$. The thresholds have been chosen to reduce the nonprompt contribution. Two muons must have the same charge and one muon have the oppositely charge. Two event categories can thus be identified: $\mu^+\mu^+\mu^-$ and $\mu^+\mu^-\mu^-$. The muons must be prompt i.e. $dxy < 0.01$ cm and $dz < 0.1$ cm and must pass the tight ID and tight PF isolation requirement. These selections significantly reduce decays-in-flight. Two muons with opposite charge and with an invariant mass compatible with the Z mass ($|m_{2mu} - m_Z| < 10\ GeV$) are paired. At least one pair is required in each event. Finally events with at least one b jet with $p_T > 20 GeV$ are vetoed.

Events in Monte Carlo are weighted according to. The luminosity is 59.7 fb^{-1}

$$cross\ section \times luminosity \times relative\ generator\ weight \times pileupweight \qquad (1)$$

Table 5: SingleMu Triggers used in the Analysis

Trigger Path
HLT_IsoMu20_eta2p1_LooseChargedIsoPFTauHPS27_eta2p1_CrossL1
HLT_IsoMu20_eta2p1_LooseChargedIsoPFTauHPS27_eta2p1_TightID_CrossL1
HLT_IsoMu20_eta2p1_MediumChargedIsoPFTauHPS27_eta2p1_CrossL1
HLT_IsoMu20_eta2p1_MediumChargedIsoPFTauHPS27_eta2p1_TightID_CrossL1
HLT_IsoMu20_eta2p1_TightChargedIsoPFTauHPS27_eta2p1_CrossL1
HLT_IsoMu20_eta2p1_TightChargedIsoPFTauHPS27_eta2p1_TightID_CrossL1
HLT_IsoMu20
HLT_IsoMu24_TwoProngs35
HLT_IsoMu24_eta2p1
HLT_IsoMu24
HLT_IsoMu27
HLT_IsoMu30
HLT_L1SingleMu18
HLT_L1SingleMu25
HLT_L2Mu10
HLT_L2Mu50
HLT_Mu10_TrkIsoVVL_DiPFJet40_DEta3p5_MJJ750_HTT350_PFMETNoMu60
HLT_Mu12
HLT_Mu15_IsoVVVL_PFHT450_CaloBTagDeepCSV_4p5
HLT_Mu15_IsoVVVL_PFHT450_PFMET50
HLT_Mu15_IsoVVVL_PFHT450
HLT_Mu15_IsoVVVL_PFHT600
HLT_Mu15
HLT_Mu20
HLT_Mu27
HLT_Mu3_PFJet40
HLT_Mu3er1p5_PFJet100er2p5_PFMET100_PFMHT100_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMET70_PFMHT70_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMET80_PFMHT80_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMET90_PFMHT90_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMETNoMu100_PFMHTNoMu100_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMETNoMu70_PFMHTNoMu70_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMETNoMu80_PFMHTNoMu80_IDTight
HLT_Mu3er1p5_PFJet100er2p5_PFMETNoMu90_PFMHTNoMu90_IDTight
HLT_Mu4_TrkIsoVVL_DiPFJet90_40_DEta3p5_MJJ750_HTT300_PFMETNoMu60
HLT_Mu50_IsoVVVL_PFHT450
HLT_Mu50
HLT_Mu55
HLT_Mu8_TrkIsoVVL_DiPFJet40_DEta3p5_MJJ750_HTT300_PFMETNoMu60
HLT_OldMu100
HLT_TkMu100

6 Results

Add plots and tables here

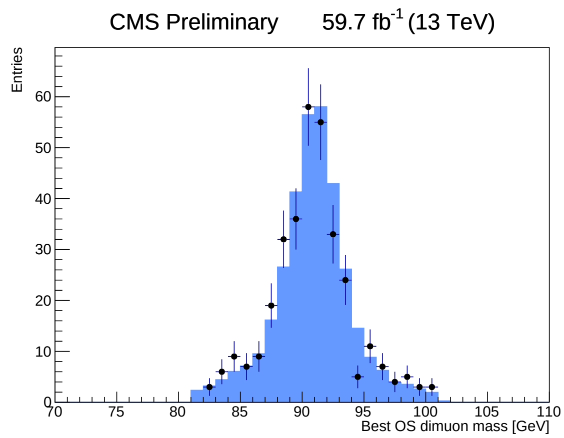
Table 6: Cutflow table for the WZ control region

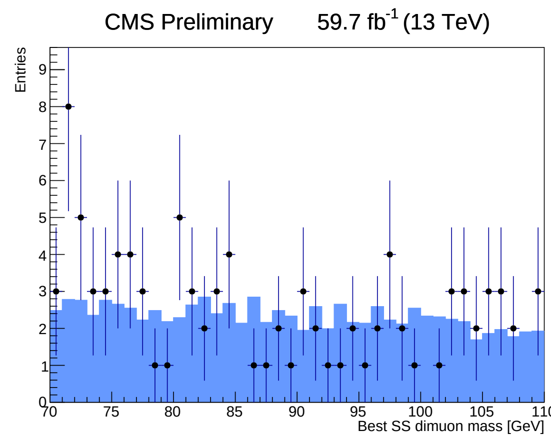
Selection	WZTo3LNu1	WZTo3LNu3	WZTo3LNu3	WZTo3LNu4	ttZ	Data
No selection						

Figures of data vs monte carlo comparisons efficiencies in data efficiencies in monte carlo.

7 Summary

The overall trigger scale factor is estimated to be XX% +/- XX%(stat.).


CMS Preliminary
59.7 fb^{-1} (13 TeV)
Entries
Best OS dimuon mass [GeV]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Entries
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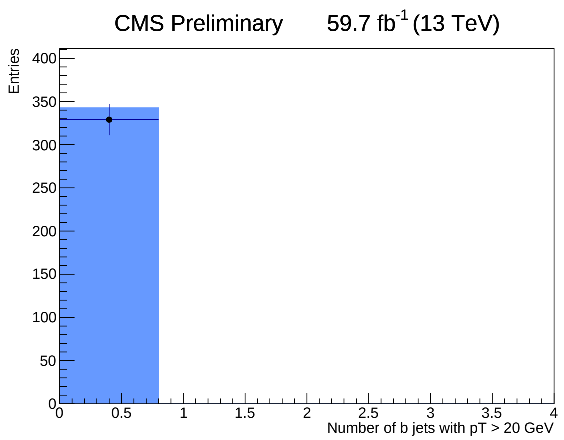
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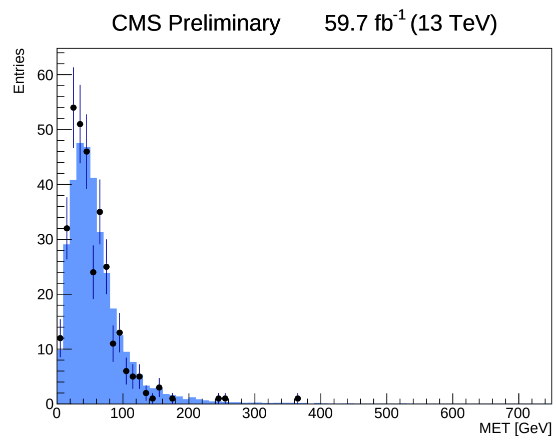
Entries
Number of b jets with pT > 20 GeV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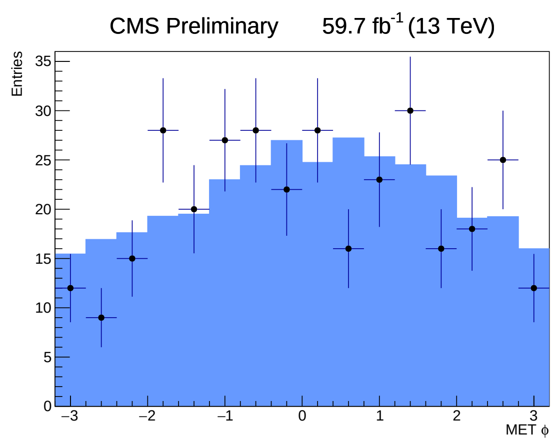
Entries
MET [GeV]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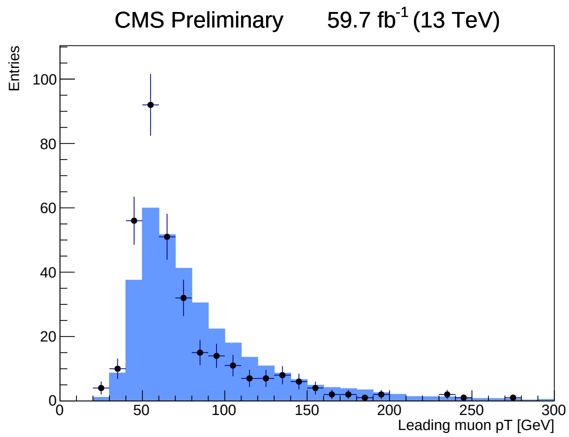
Entries
MET ϕ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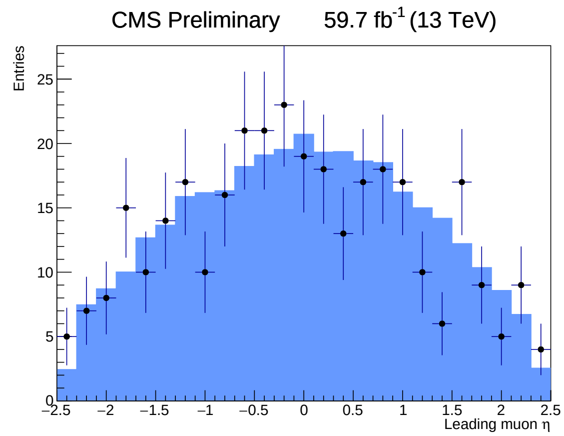
Entries
Leading muon pT [GeV]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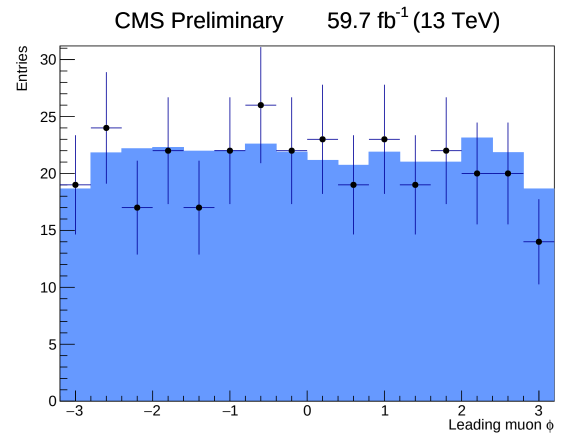
Entries
Leading muon η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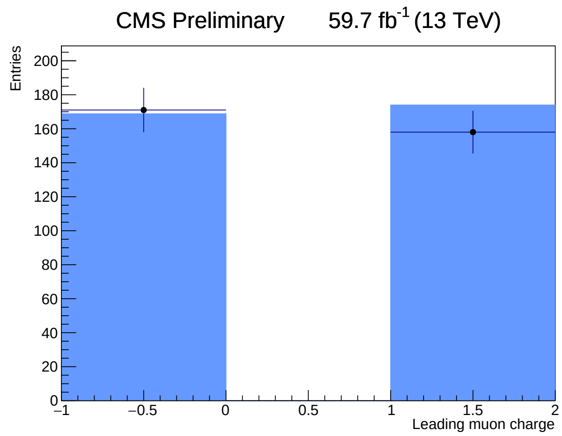
Entries
Leading muon ϕ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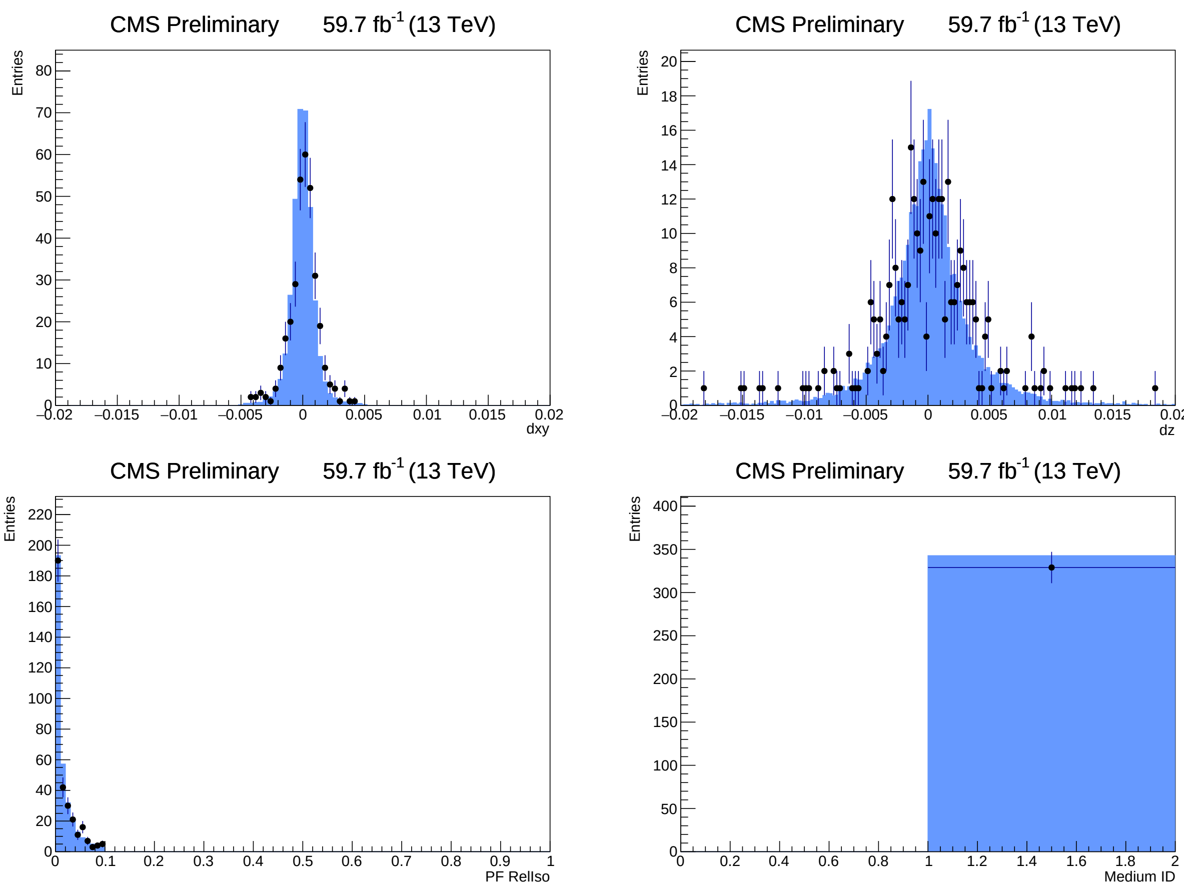
Entries
Leading muon charge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Entries
dxy
CMS Preliminary
59.7 fb-1 (13 TeV)
Entries
dz
CMS Preliminary
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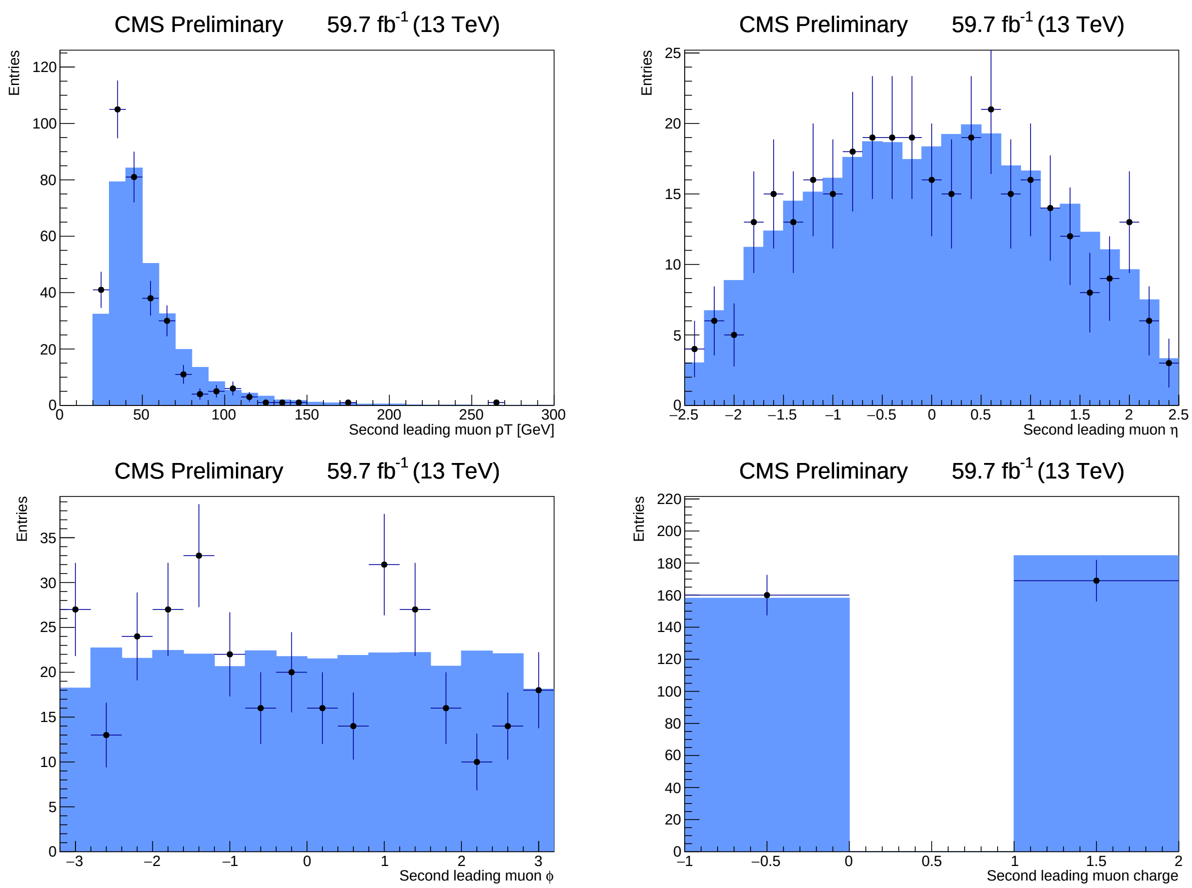
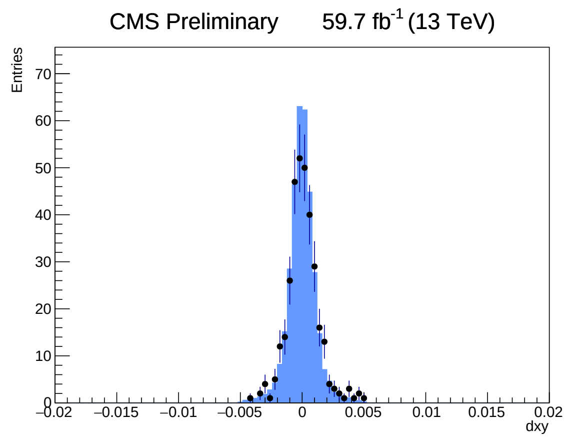
Entries
PF RelIso
CMS Preliminary
59.7 fb-1 (13 TeV)
Entries
Medium ID


CMS Preliminary 59.7 fb^{-1} (13 TeV)
Entries
Second leading muon pT [GeV]
CMS Preliminary 59.7 fb^{-1} (13 TeV)
Entries
Second leading muon η
CMS Preliminary 59.7 fb^{-1} (13 TeV)
Entries
Second leading muon ϕ
CMS Preliminary 59.7 fb^{-1} (13 TeV)
Entries
Second leading muon charge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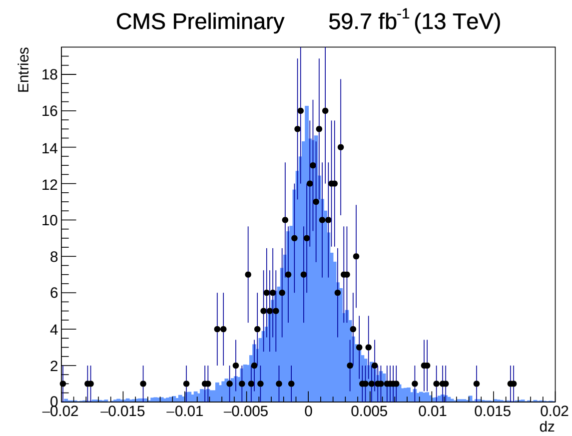
Entries
dxy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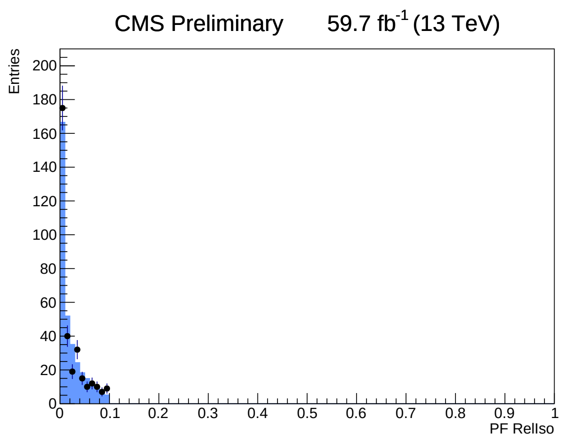
Entries
dz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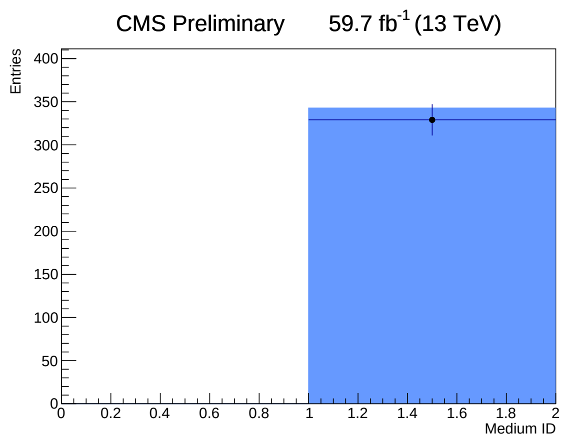
Entries
PF RelIso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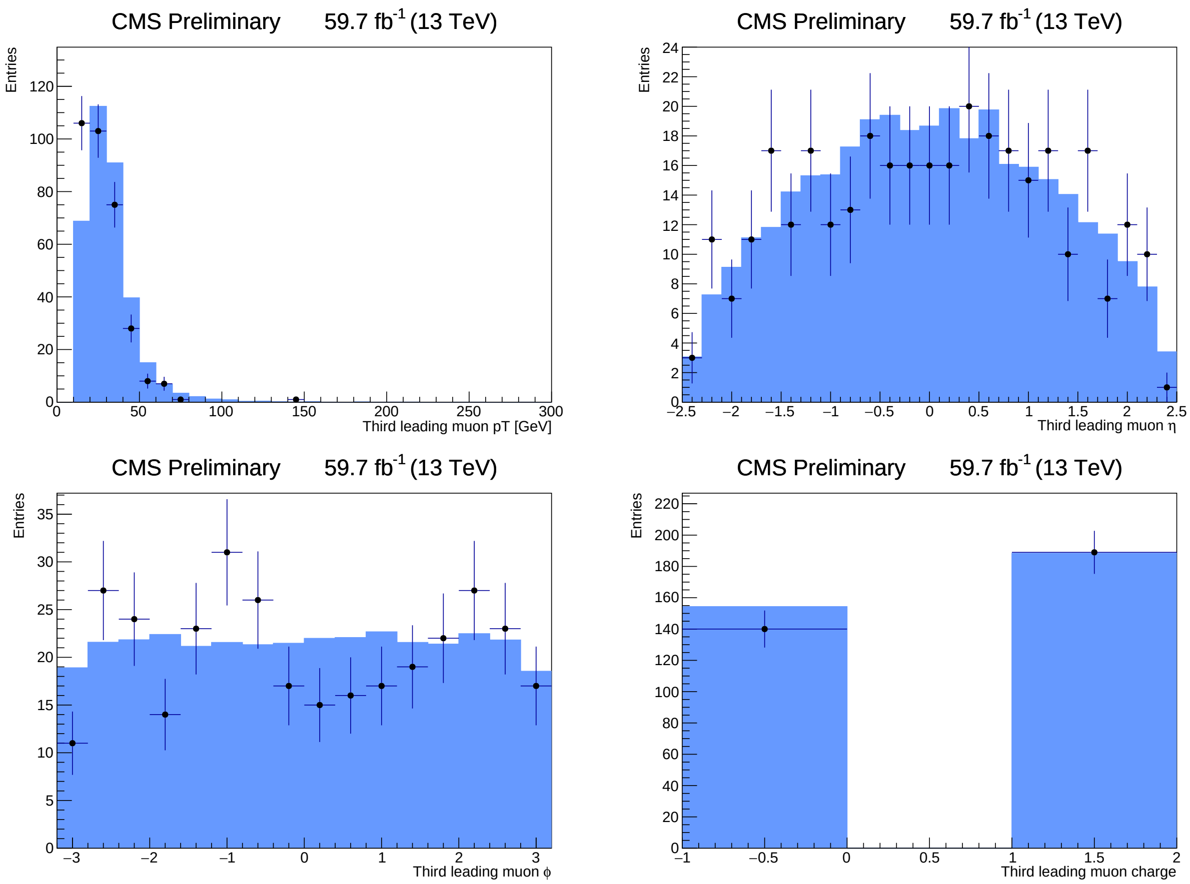
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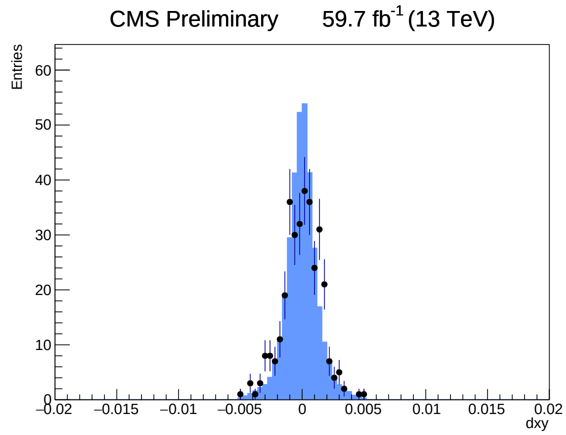
Entries
Third leading muon pT [GeV]
Third leading muon η
Third leading muon ϕ
Third leading muon charge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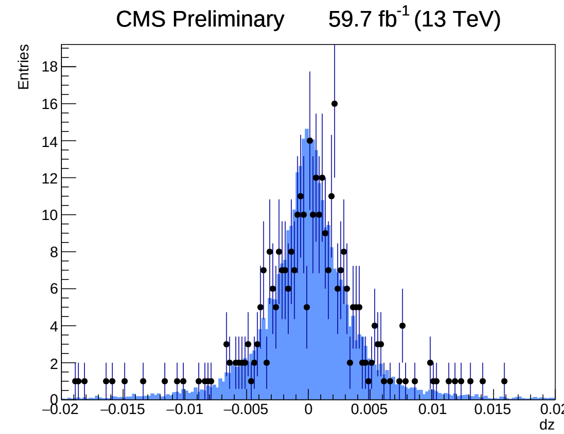
Entries
dxy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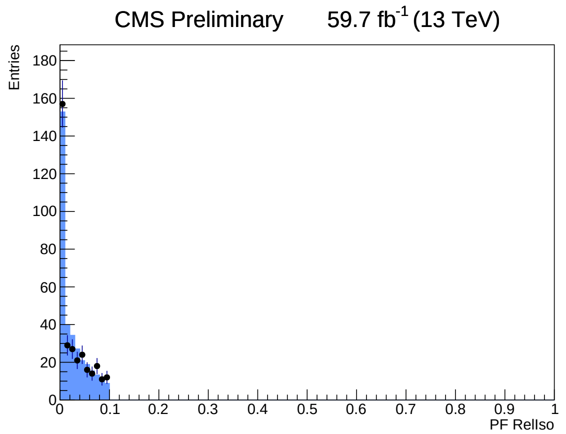
Entries
dz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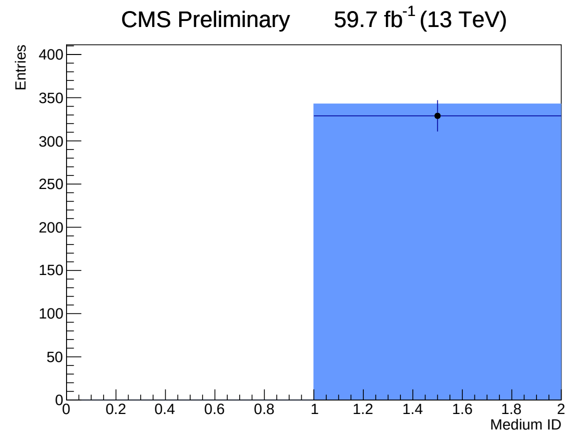
Entries
PF RelIso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Entries
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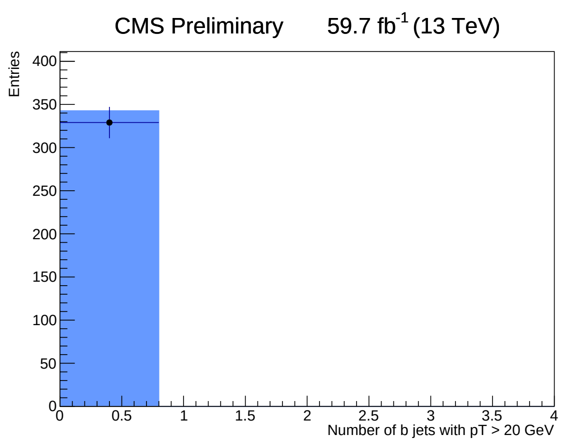
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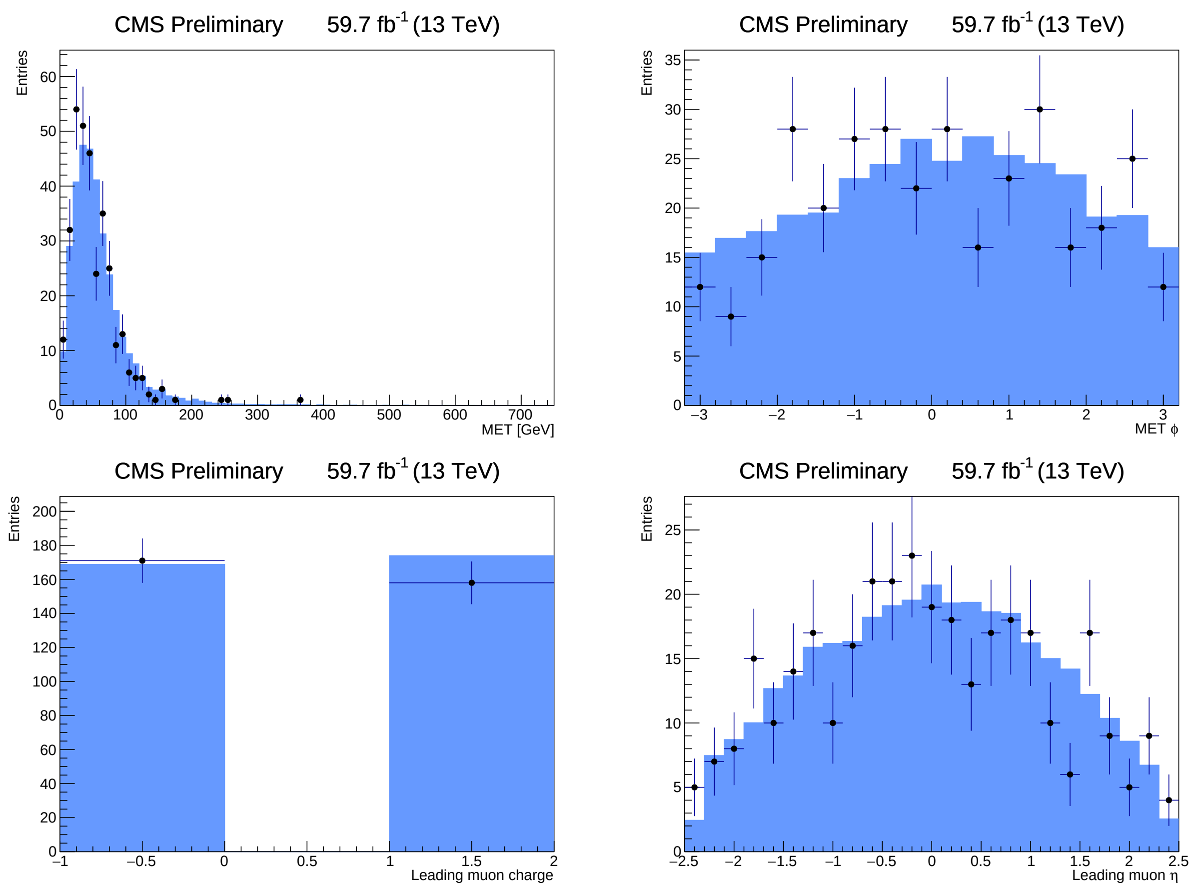
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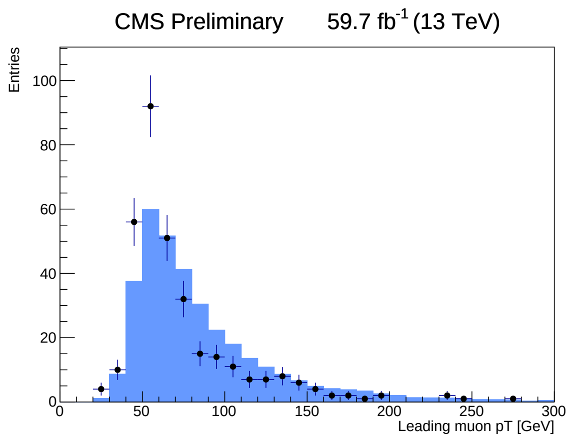
Entries
MET [GeV]
MET ϕ
Leading muon charge
Leading muon η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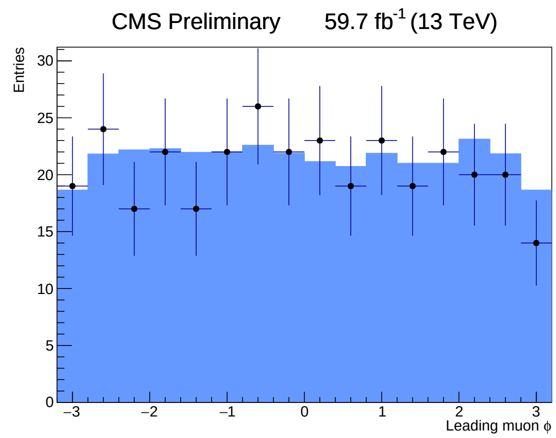
Entries
Leading muon pT [GeV]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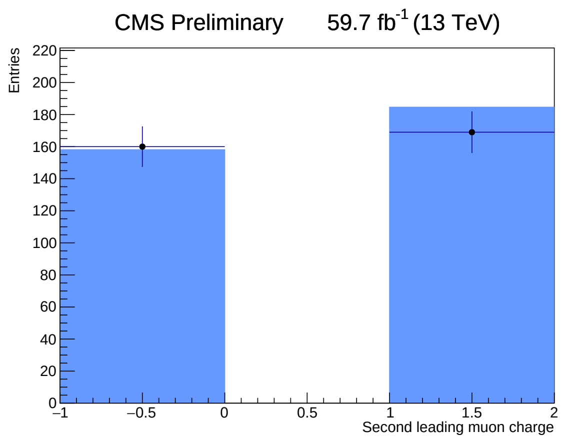
Entries
Leading muon ϕ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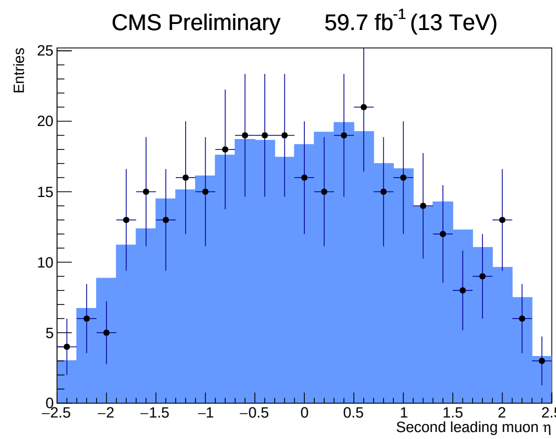
Entries
Second leading muon charge


CMS Preliminary
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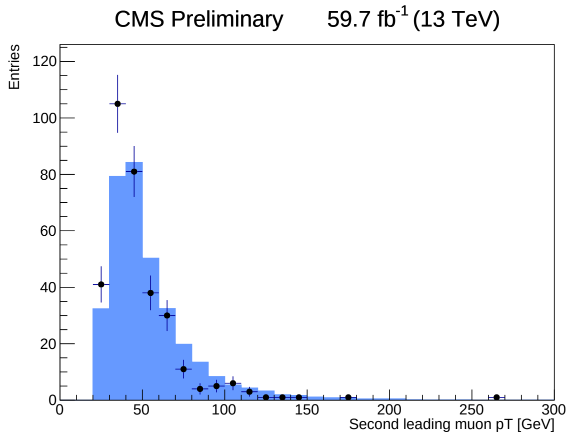
Entries
Second leading muon η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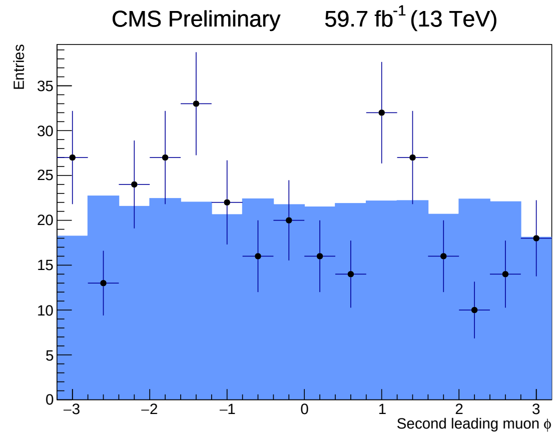
Entries
Second leading muon pT [GeV]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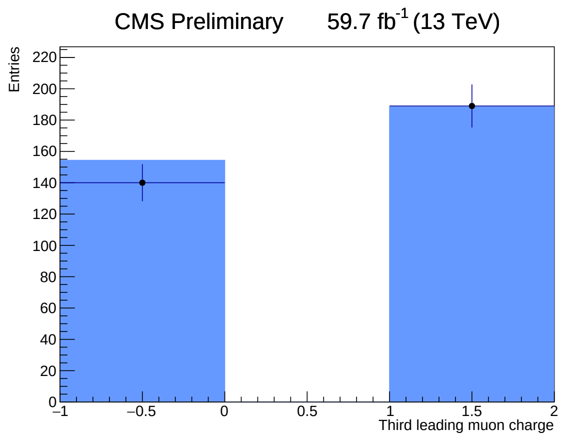
Entries
Second leading muon ϕ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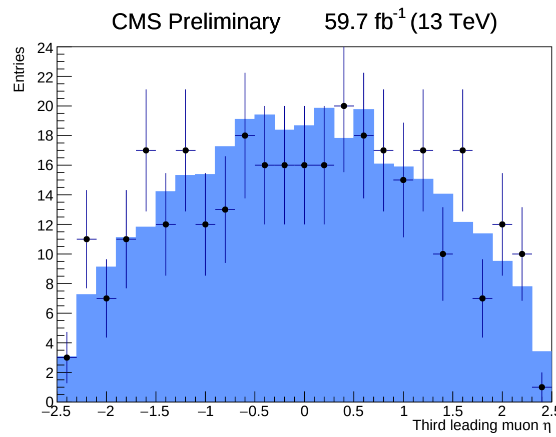
Entries
Third leading muon charge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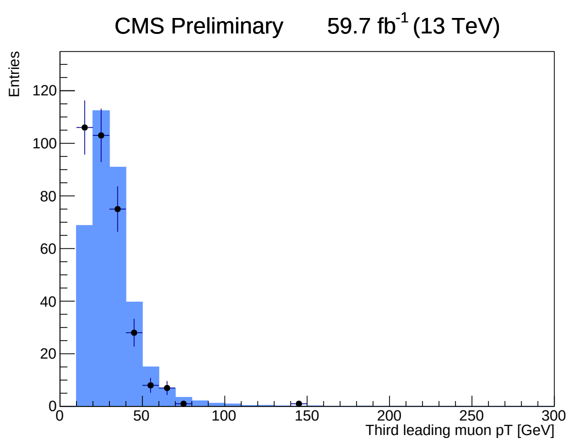
Entries
Third leading muon η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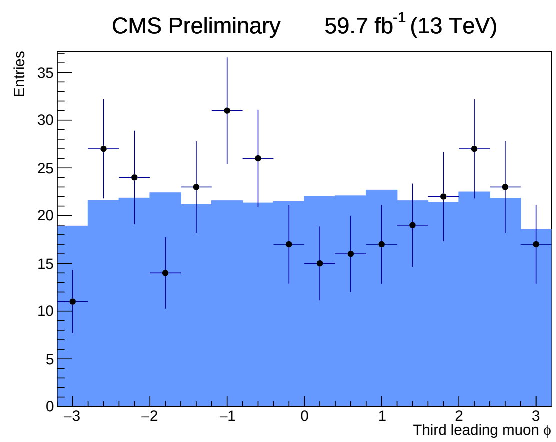
Entries
Third leading muon pT [GeV]


CMS Preliminary
59.7 fb^{-1} (13 TeV)
Entries
Third leading muon ϕ