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

We use several multi-muon signal triggers (Tab. 1) as described in Sec. ??. The typical tag-and-probe method cannot be used for the triple-muon triggers. The reference trigger method cannot be used either, since there is no shared single muon trigger leg. Instead, the overall efficiency is calculated at once on a control dataset with the orthogonal method.

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

2 Methodology

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 triggered by the substantial SingleMu 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 single muon triggers in the SingleMu dataset. SingleMu triggers with one or more muons in the selection are ignored. MC events are simulated for the processes WZ $\to 3l\nu$, ZZ $\to 4l$, and ttZ. The data and MC samples are 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 are made and the efficiency of the triple muon trigger is checked on the surviving events.

3 Datasets

We use the MiniAOD samples shown below in Tab. 2. 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_17SeptEarly-ReReco2018ABC_PromptEraD_Collisions18_JSON.txt. Events with more than 3 muons with $>$ 10 GeV are rejected. The pre-selection accepts 2% of the events in data as can be seen in Tab. 2. Additionally we use WZ $\rightarrow 3l\nu$, ZZ $\rightarrow 4l$, and ttZ Monte Carlo datasets shown in Tab. 3. The cross sections have been 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. Monte Carlo events are weighed with the integrated luminosity (59.7 fb^{-1}), the generator weight, and the pileup weight (the ratio of the pileup distributions in Fig. 1).

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

Dataset name	Total Events	Pre-selected Events
/SingleMuon/Run2018A-17Sep2018-v2/MINIAOD	24,160,8232	5,945,878
/SingleMuon/Run2018B-17Sep2018-v1/MINIAOD	11,991,8017	2,795,277
/SingleMuon/Run2018C-17Sep2018-v1/MINIAOD	11,003,2072	2,747,227
/SingleMuon/Run2018D-PromptReco-v2/MINIAOD	506,717,754	7,906,762
Total	978,276,075	19,395,144

Table 3: Monte Carlo samples for the trigger scale factor studies.

Abbreviation	Dataset name	Events	Cross Section [pb]
WZTo3LNu	WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8 /RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	10,749,269	5.114 ± 0.075
ZZTo4L	/ZZTo4L_13TeV_powheg_pythia8_TuneCP5 /RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	19,089,600	1.325 ± 0.002
TTZToLLNuNu	/TTZToLLNuNu_M-10_TuneCP5_13TeV-amcatnlo-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v2/MINIAODSIM	13,280,000	0.2432 ± 0.0003

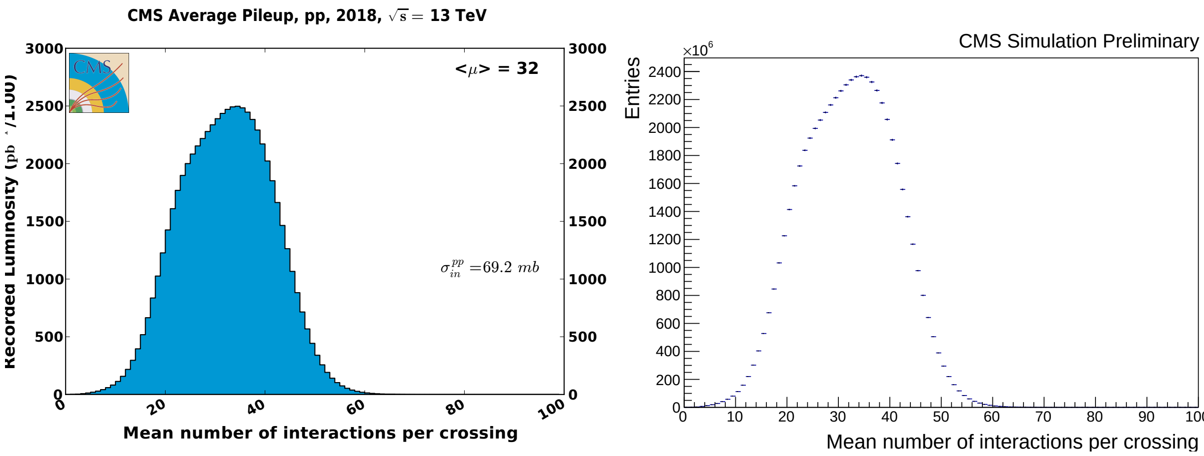

Figure 1: Left: Average pileup in 2018. Mean number of interactions per bunch crossing for the 2018 pp run at 13 TeV using the online luminosity values. The plot uses the CMS recommended value of 69.2 mb for the minimum bias cross section which is determined by finding the best agreement with data and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

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

4 Event Selection

Events are required to pass at least one SingleMuon trigger (see Tab. 4). Furthermore, events must have exactly three muons $|\eta| < 2.4$ and with transverse momenta thresholds $p_{\mathrm{T},1} > 20$ GeV, $p_{\mathrm{T},2} > 20$ GeV, $p_{\mathrm{T},3} > 10$ GeV. The events are further cleaned by requiring that each muon passes the medium muon ID. To suppress muons from hadrons decaying in-flight (non-prompt muons), selections on the muon impact parameter and distance to the interaction point (IP) are applied. The impact parameter must be $|d_{xy,i}| < 0.005$ cm and the distance to the IP $|d_{z,i}| < 0.01$ cm for each muon. Non-isolated muons are rejected. A relative isolation cut of $relIso < 0.1$ is applied on each muon. Two muons with opposite charge and with an invariant mass compatible with the Z mass ($|m_{\mu\mu} - m_Z| < 10$ GeV) are paired. At least one pair is required in each event.

Table. 5 shows the event selection in data and Monte Carlo. The data are found to be consistent with the Monte Carlo prediction. Figures 4-4 shows the agreement between data and Monte Carlo for several event variables.

Table 4: 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

Table 5: Table with event selection for the three-muon control region.

Selection	WZTo3LNu	ZZTo4Mu	Data
No selection	301245.23	70517.5327254	18051620
Passes at least one orthogonal trigger	118895.46	22794.2715612	18014171
Exactly three muons	22819.88	4019.38	3405670
$\lvert\eta_i\rvert < 2.4$	22819.88	4019.38	3405670
$p_{\mathrm{T},1} > 20$ GeV, $p_{\mathrm{T},2} > 20$ GeV, $p_{\mathrm{T},3} > 10$ GeV	1007.26	116.17	373507
Medium muon ID	883.84	90.35	25518
$\lvert d_{xy,i}\rvert < 0.005$ cm	830.48	79.92	8069
$\lvert d_{z,i}\rvert < 0.01$ cm	709.53	65.70	4652
$\mathrm{RelIso}_i < 0.1$	466.64	39.49	591
Two muons with opposite charge	466.64	39.49	591
$\lvert m_{\mu\mu} - m_Z\rvert < 10$ GeV	389.29	23.46	402
Passes at least one signal trigger	385.37	23.21	396

5 Results

The trigger efficiency on Monte Carlo is evaluated as $\varepsilon_{\mathrm{WZTo3LNu}} = 385.37/389.29 = 0.99$, $\varepsilon_{\mathrm{ZZTo4L}} = 23.21/23.46 = 0.99$. Efficiency in data is observed to be $\varepsilon_{\mathrm{Data}} = 396/402 = 0.985$. This results in a trigger scale factor of $SF = 0.985/0.99 = 0.995$. A statistical uncertainty of 5% on the selected data events is quoted in the control region. The overall trigger scale factor is estimated to be $99.5\% \pm 5\%$ (stat.).

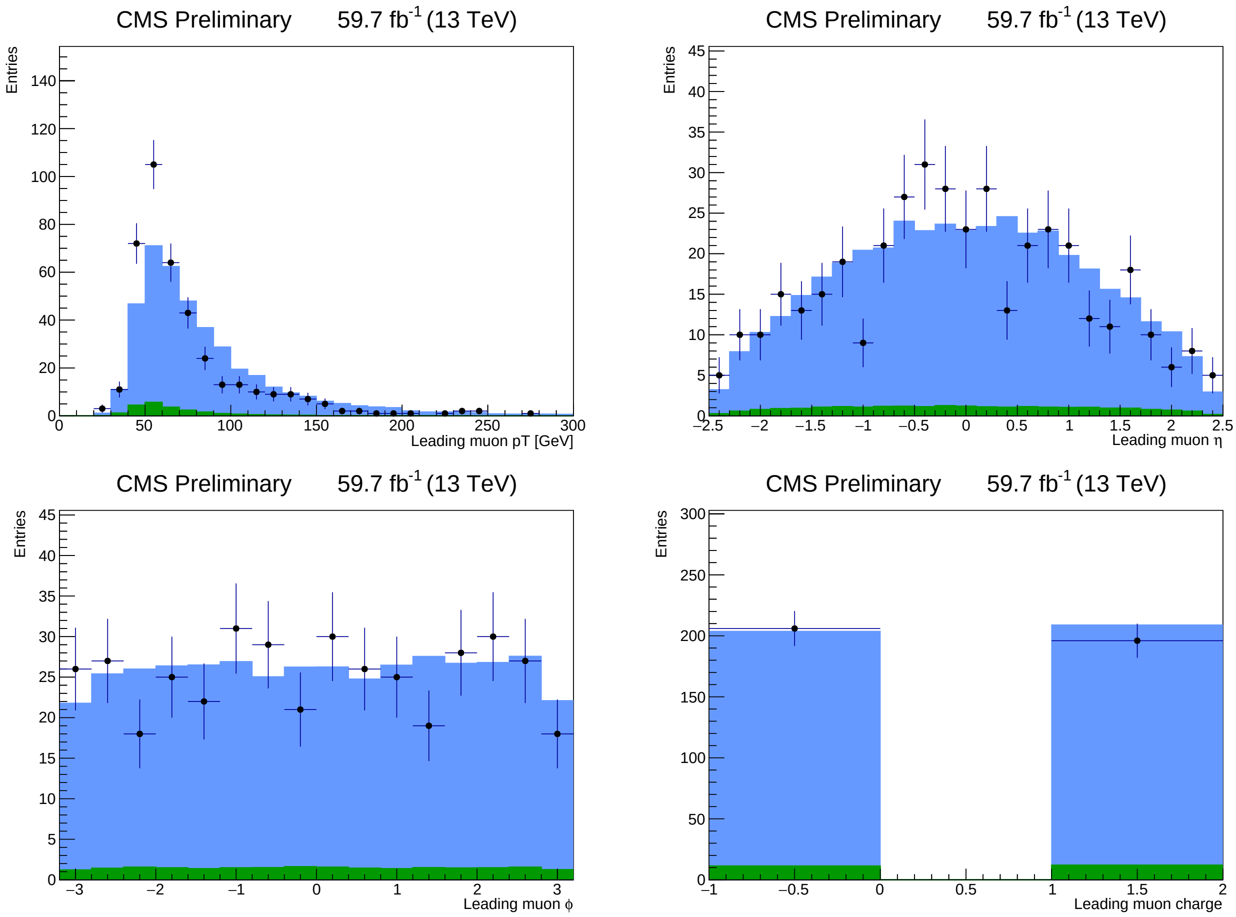

Figure 2: Data vs Monte Carlo comparisons in the control region.

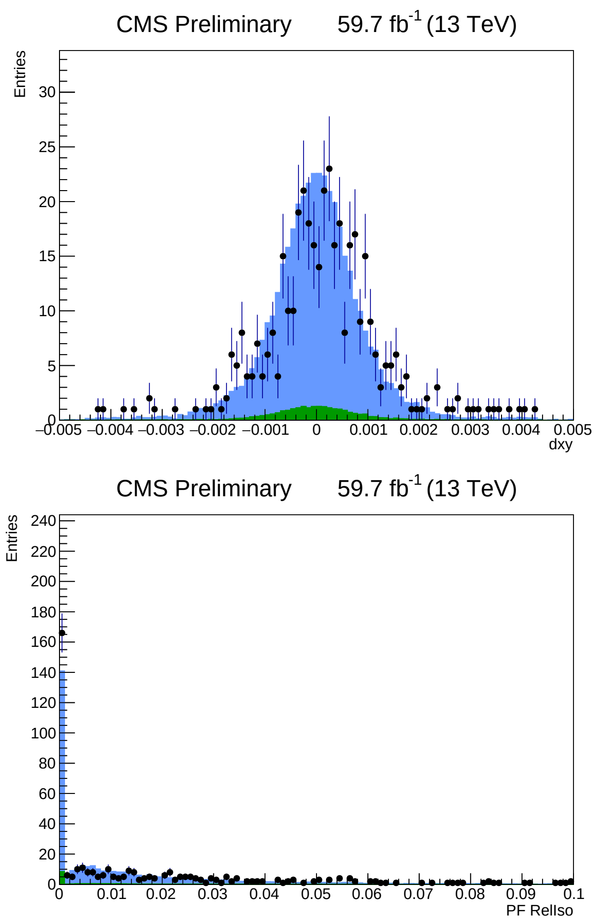

Figure 3: Data vs Monte Carlo comparisons in the control region (continued).

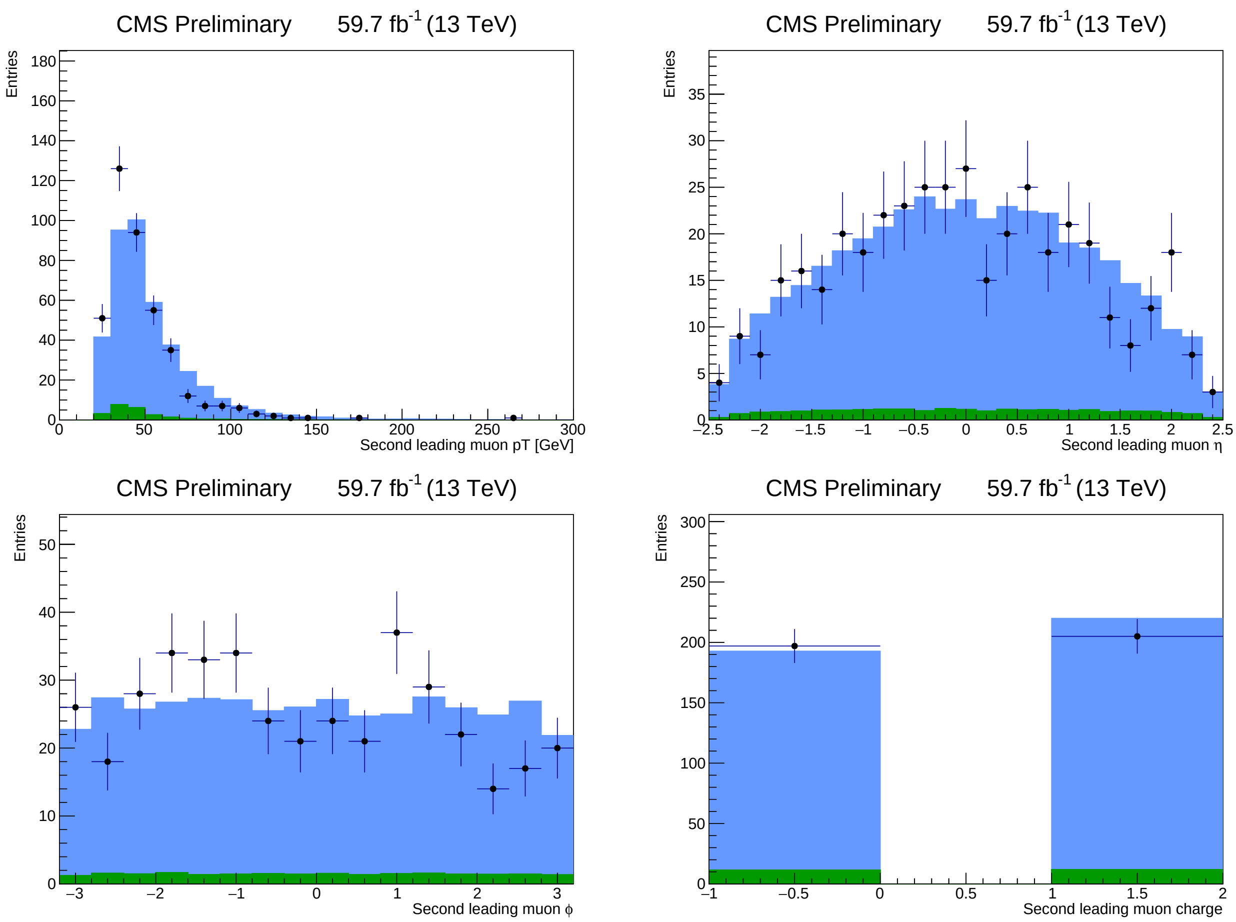

Figure 4: Data vs Monte Carlo comparisons in the control region (continued).

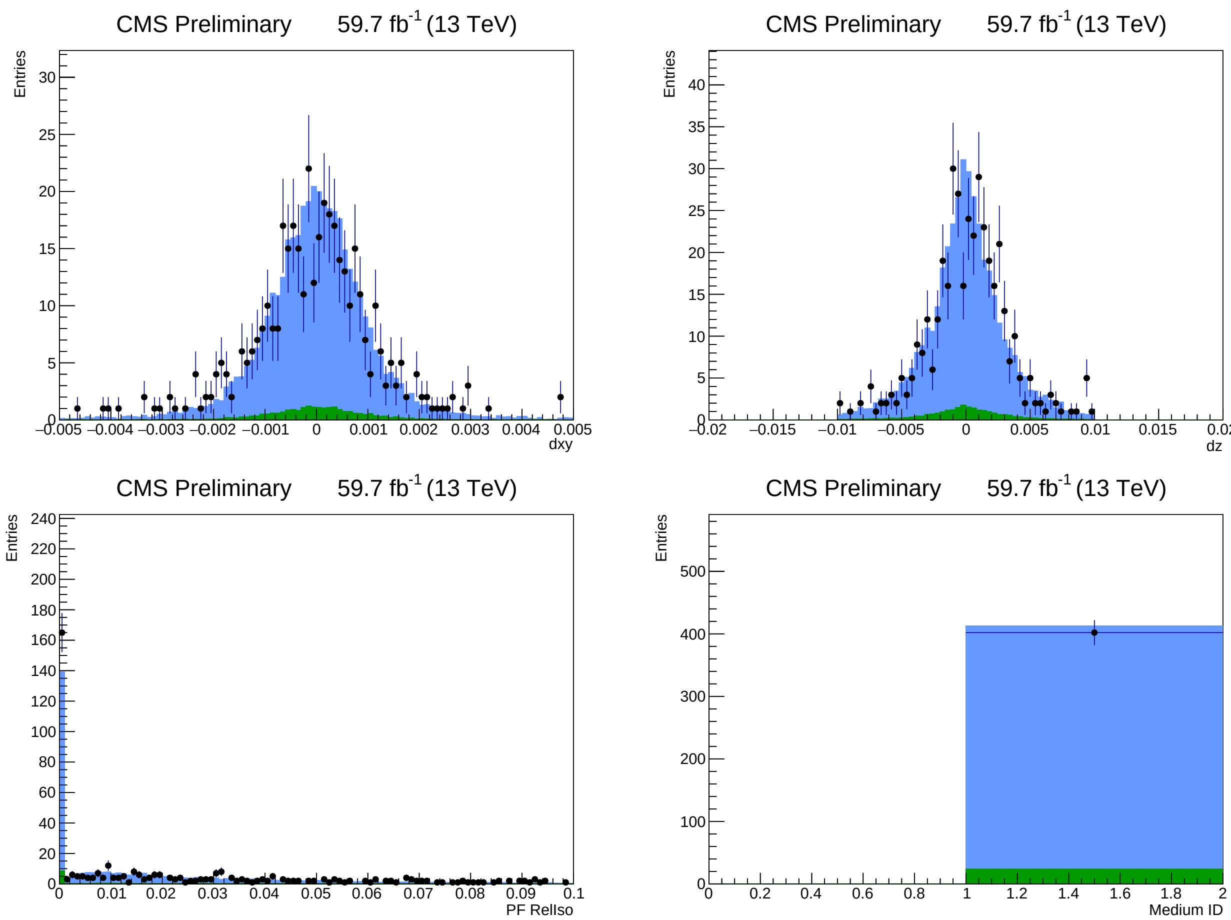

Figure 5: Data vs Monte Carlo comparisons in the control region (continued).

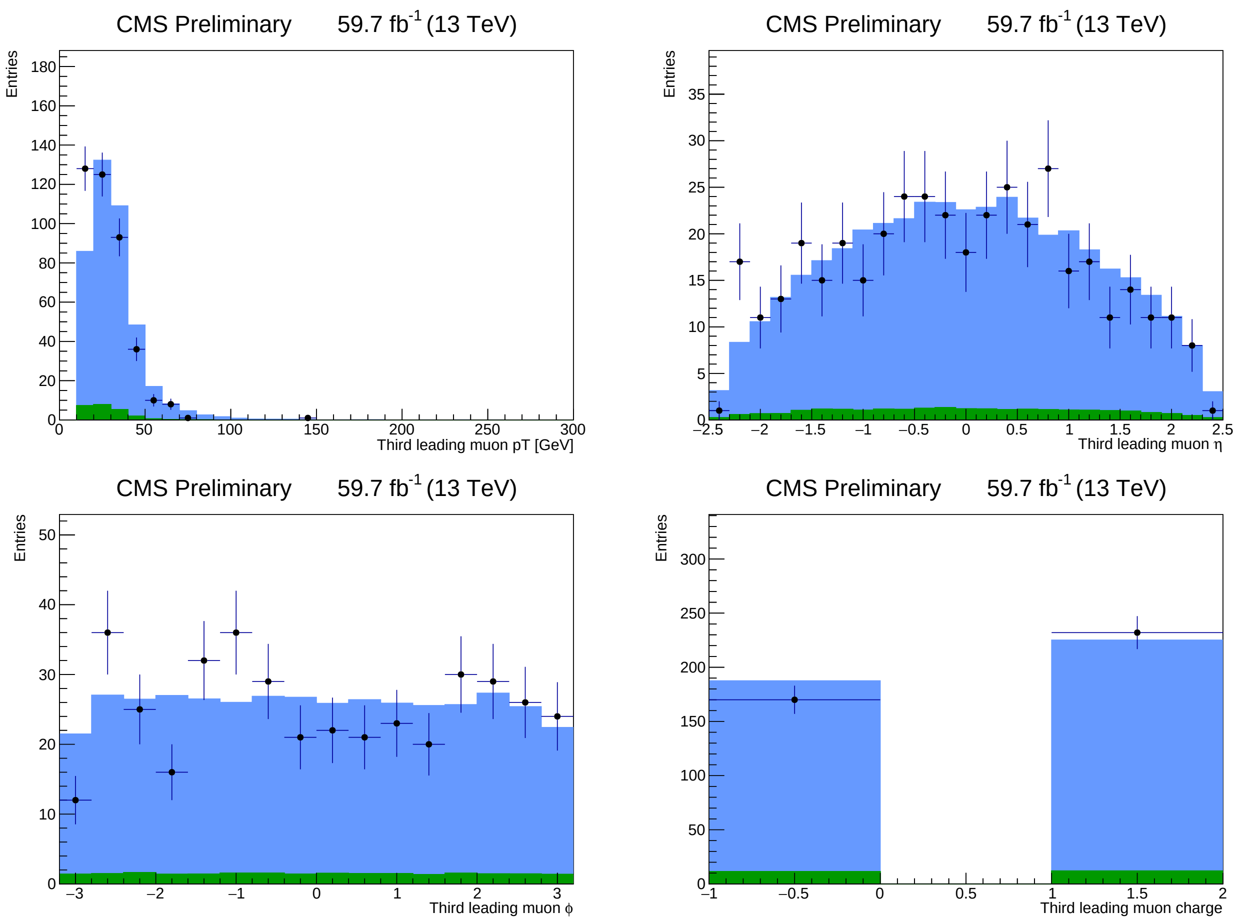

Figure 6: Data vs Monte Carlo comparisons in the control region (continued).

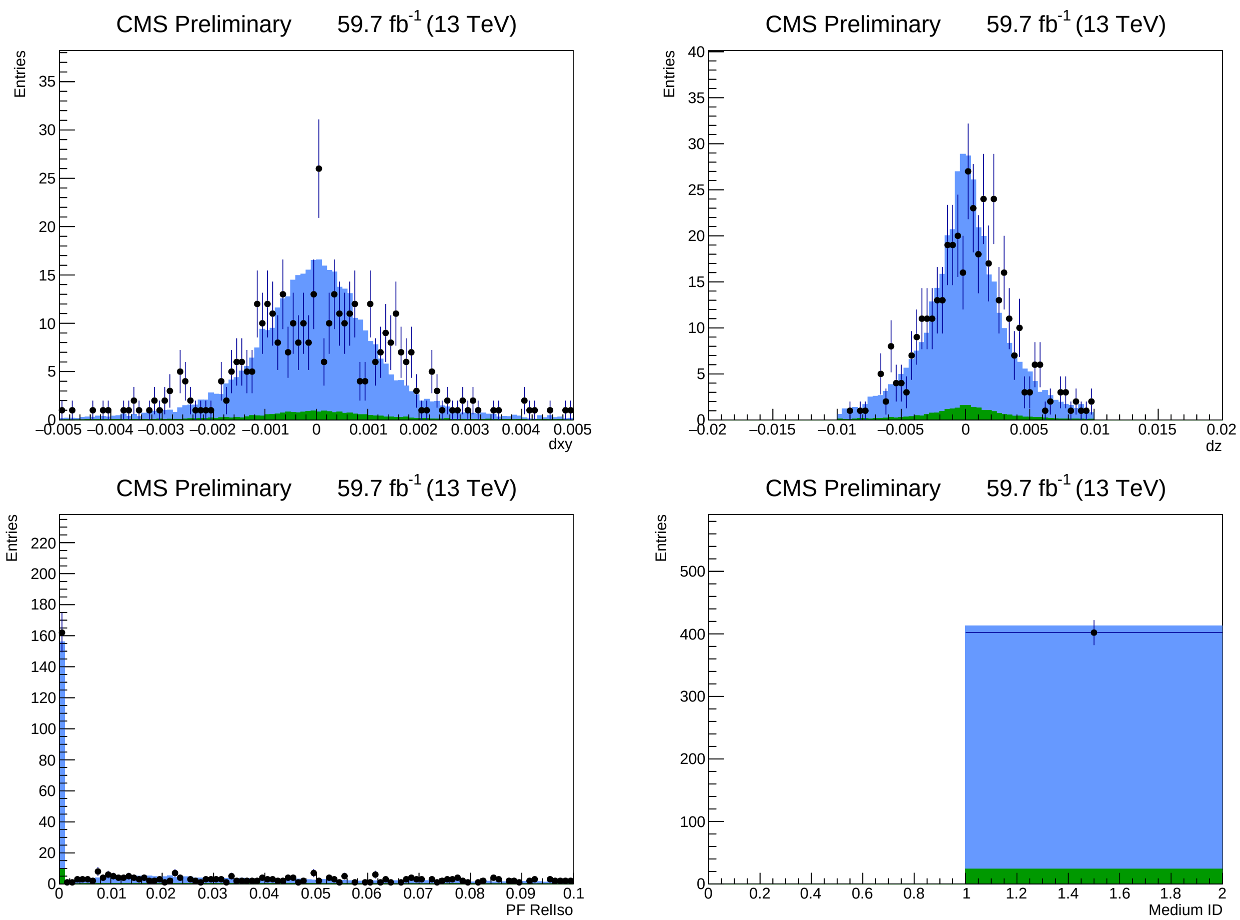

Figure 7: Data vs Monte Carlo comparisons in the control region (continued).

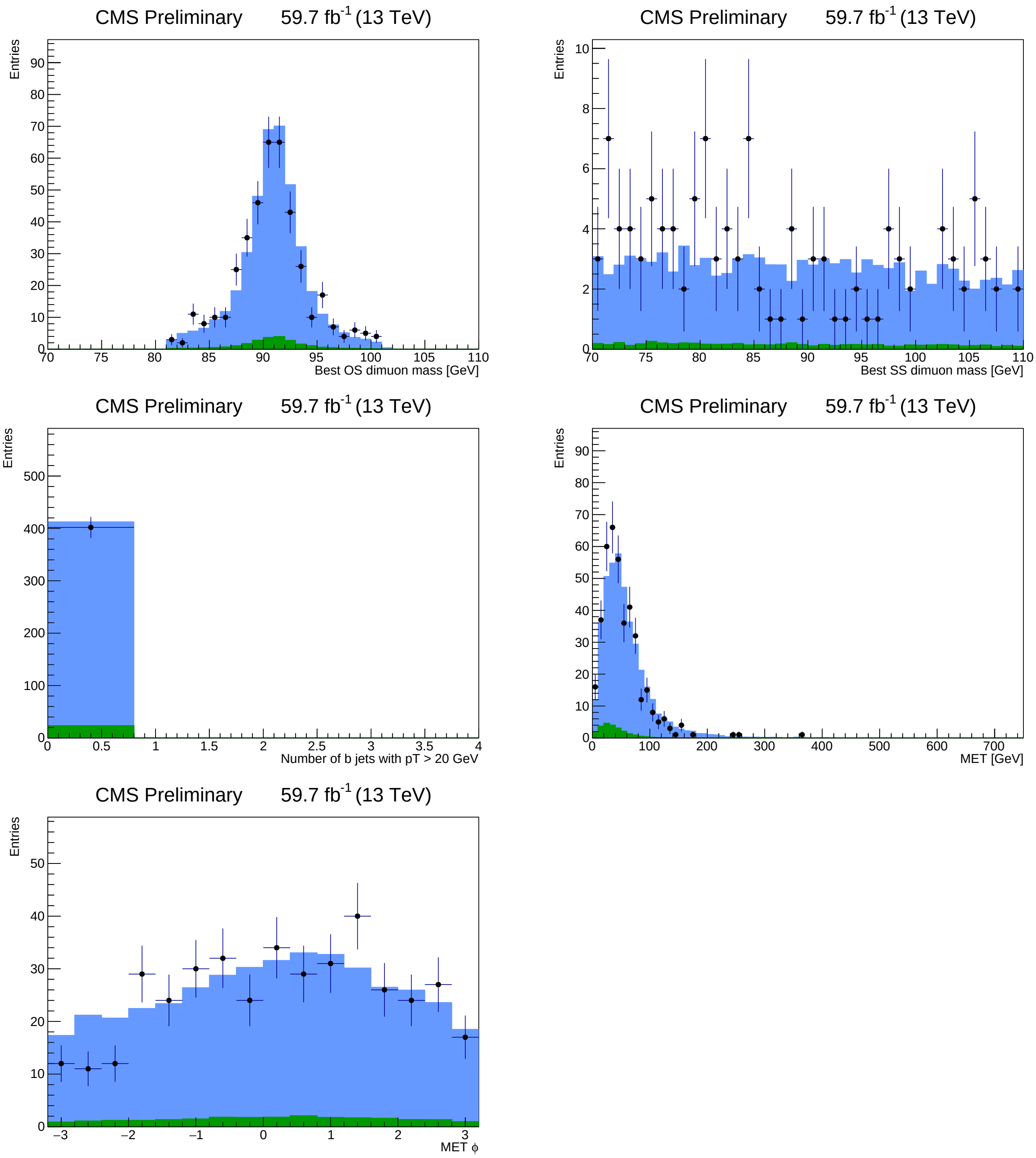

Figure 8: Data vs Monte Carlo comparisons in the control region (continued).