Preliminary results for Fake Rate measurements using 2018 & 2017 data

Marcello Maggi, INFN, Bari
Kalpanie Liyanage
University of Ruhuna
Sri Lanka

*Fake rate technique

- Objects falsely identified as prompt muons passing the entire Z' selection criteria could contribute the background in the di-muon invariant mass spectrum of the Z' analysis. These objects are referred as "fake" muons.

- The main sources :
  - Events with non-isolated muons in jets, mostly originated in secondary vertices and produced in the B-mesons (and D- mesons) decay
  - Real muons from decays of light-flavor bound states (pions and kaons)
  - Charged hadron "punching through" the calorimeter giving a signature of a muon with hits in the tracker and muon systems, so contributing to the rate of "fake muon" as hadrons mis-identified as muons

- The statistics of the simulated events is typically not enough to study and estimate this background, therefore a data-driven technique is used.

* With reference to AN_2018_011 and AN_2016_391

*Fake rate technique cont ..

- **Fake rate technique technique is based on the following conceptual steps:**

  - **Loosening some reconstruction and/or identification criteria for the muons in order to create a phase space enriched with “fake muons” candidates (hereafter referred to as fakeable object);**

  - **Defining a control region where to check and define the “fake muon” contribution;**

  - **Measuring the probability that a fakeable object passes the High p_T muon selection used for the current analysis, referred to as “fake rate” (FR);**

  - **Using that probability to evaluate the contribution of those “fake muon” in the signal region defined by the current selection analysis chain.**

* With reference to AN_2018_011 and AN_2016_391

Method used

- The selection criteria on muons were loosened as detailed in the Table 01; the cut on the error on the transverse momentum measurement is removed together with the isolation cut. No cut on the number of muon stations matched by the track is requested.
- Dimuon events passing the trigger selection used in the Z' baseline selection(using *HLT_Mu50* in conjunction with *HLT_OldMu100* and *HLT_TkMu*100) with muons fulfilling the cuts in Table 01 are used to study fake muons.

Variable	Cut value
Is GlobalMu and is TrackerMu	True
$\lvert d_z \rvert$	< 1.0
$\lvert d_{xy} \rvert$	< 0.2
Nb. of Tracker Layers with Measurement	> 5
Nb. of Valid Pixel Hits	> 0

Removed! This constraint is not included in Z' baseline selection criterion

Table 01

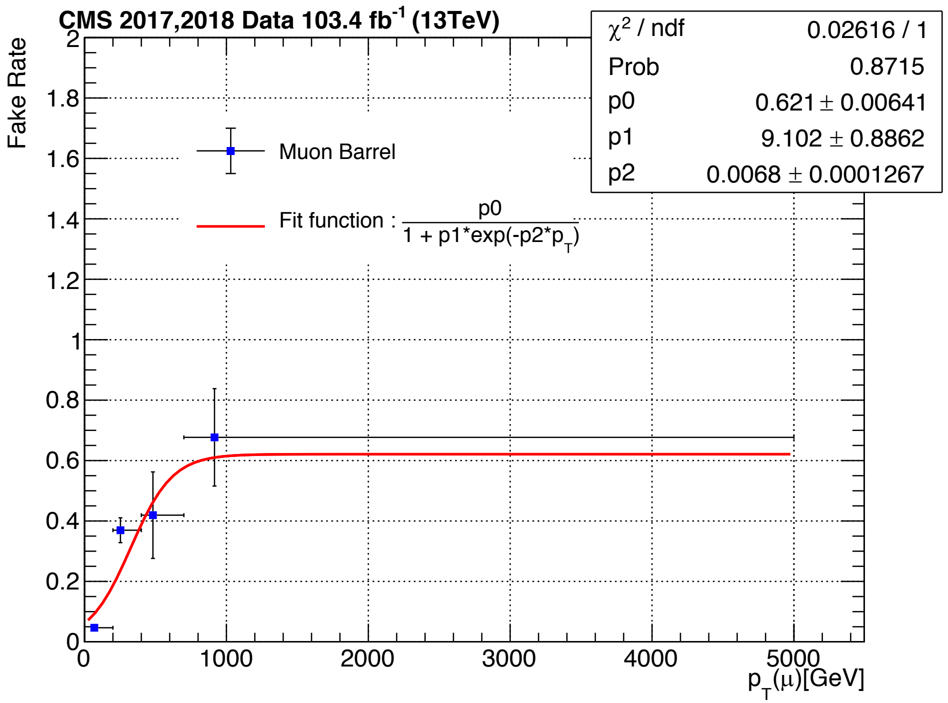
Definition of Fake Rate

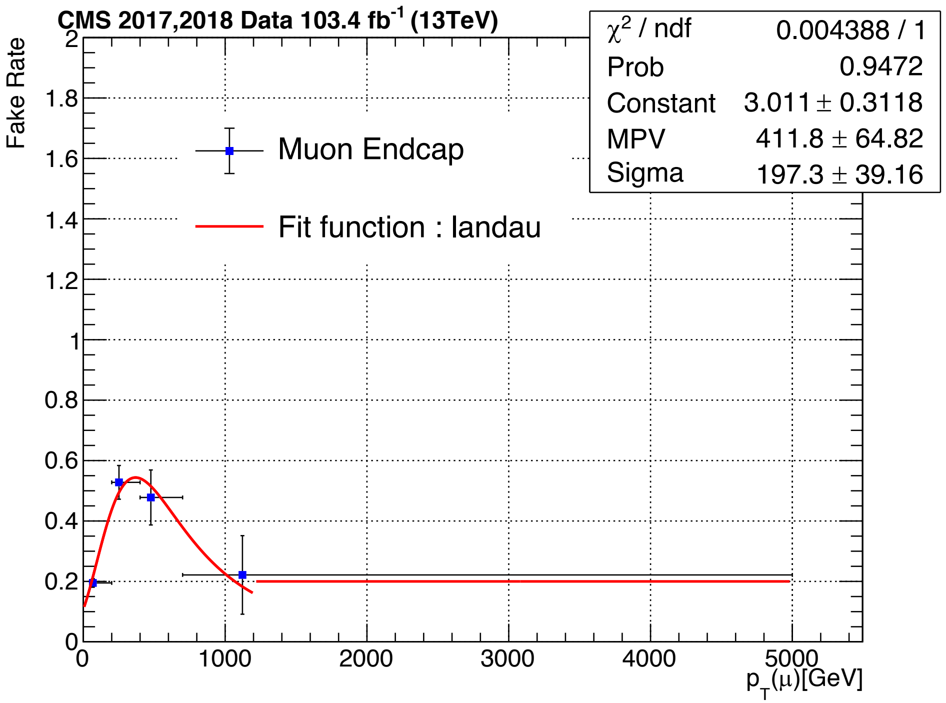
$$\mathrm{FR} = \frac{\text{Nb. Of muon objects passing the High } p_T \text{ muon ID selection \& hlt trigger}}{\text{Nb. Of muon objects passing the FR pre-selection}}$$

- The contamination of the electroweak processes, apart from QCD events, is evaluated from MC and the relative fraction of that contribution is subtracted from the data.

Combined FR measurement and parameterization for 2017 and 2018

- Binning has been changed in a way that the last p_T bin contain at least 100 events and FR parametrization is done as a function of muon p_T separately for Muon Barrel & Endcap.
- FR is taken as 0.2 above the p_T of 1200GeV in the Endcap region. But this made a negligible change on the final results.





- FR estimation done by Sherif in the past can be found here.
- Earlier version of p_T binning can be found here.

*Jet background estimation using FR measurements

- The fake rate is measured with respect to the muon candidates passing the fake rate pre-selection (Table 01) chosen from the dimuon events passing the trigger selection used in the main analysis (using *HLT_Mu50* in conjunction with *HLT_OldMu100* and *HLT_TkMu100*).

- The fake rate at a given p_T is therefore the probability of a misidentified jet to pass the High p_T muon selection.

- **Estimate of the dijet contribution**

    - The dijet contribution can be estimated by using events with two muons both failing to pass the High p_T muon ID requirements (as given in the backup), while passing the pre-selection given in Table 01, selected using the primary analysis trigger.

    - These events are weighted by a factor ***FR1/(1 - FR1) * FR2/(1 - FR2)***.

* With reference to AN_2018_011 and AN_2016_391

*Jet background estimation using FR measurements cont..

- **Estimate of the muon+jet contribution**

    - The muon+jet background is estimated by using muon pairs passing the primary analysis trigger with one muon passing and one muon failing the High p_T muon ID requirements, but both passing the pre-selection given in Table 01.

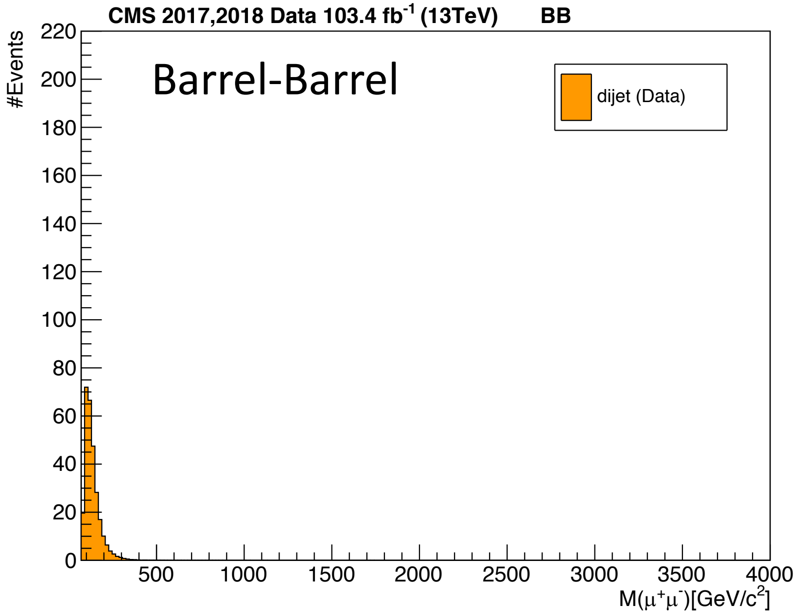
    - These events are weighted by a factor of ***FR/(1 - FR)***.

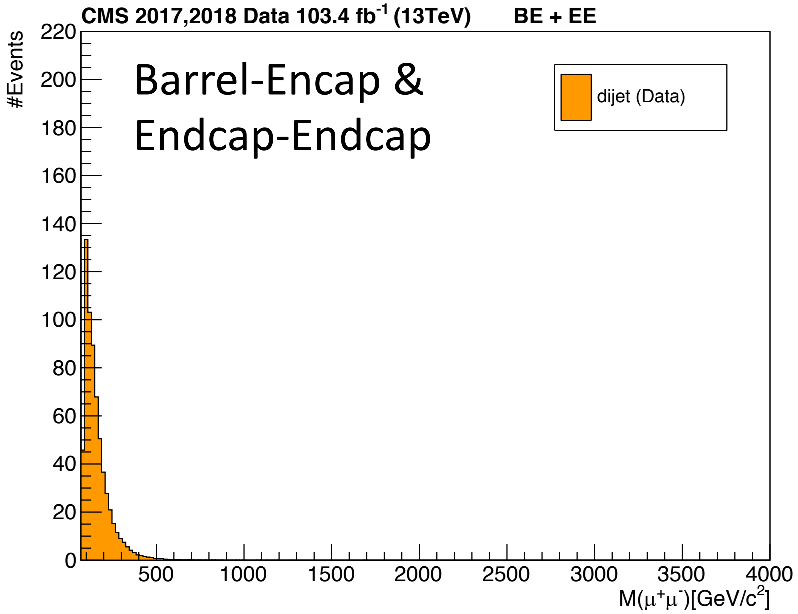
- The distribution of the dimuon invariant mass reweighted in this way provides the expected dimuon contribution from "fakes" ,once the contribution from all the electroweak processes, excluding those coming from QCD simulated events, is subtracted.

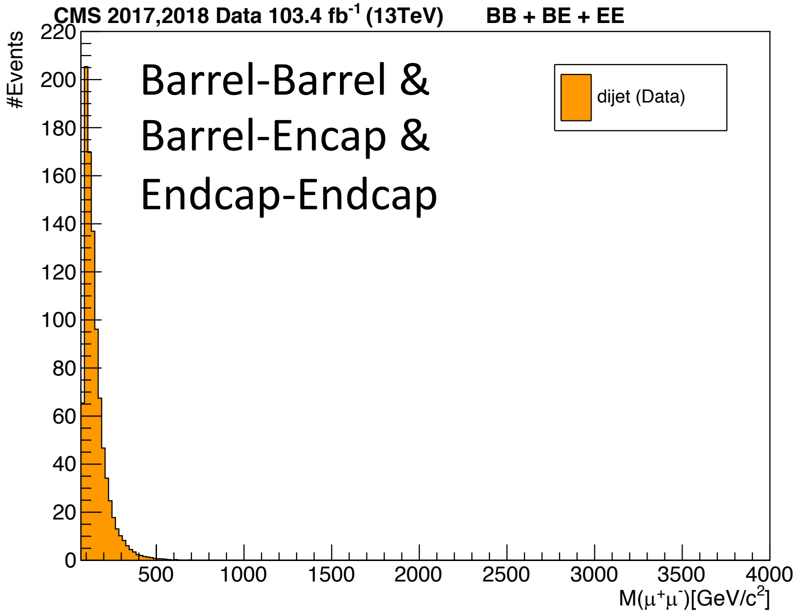
- The dijet estimate is subtracted from the muon+jet estimate to get the total jet background without double counting.

* With reference to AN_2018_011 and AN_2016_391

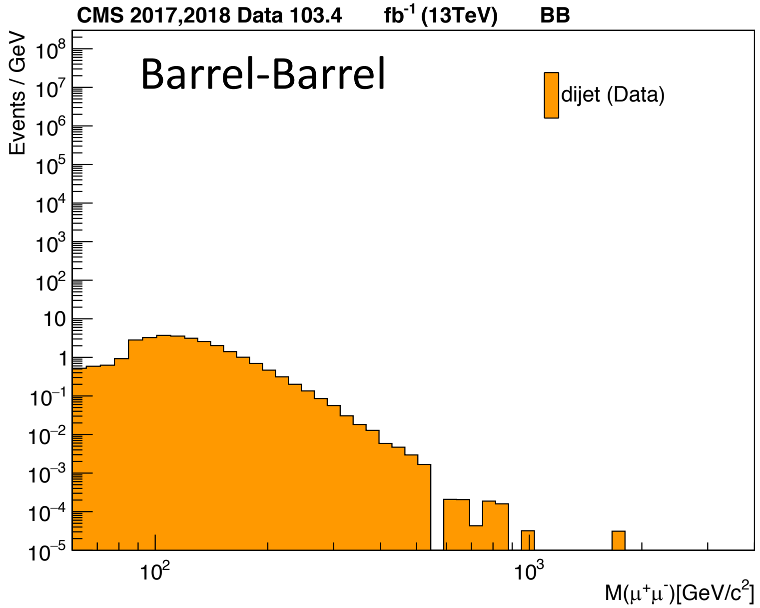
Dijet background estimation using FR measurements

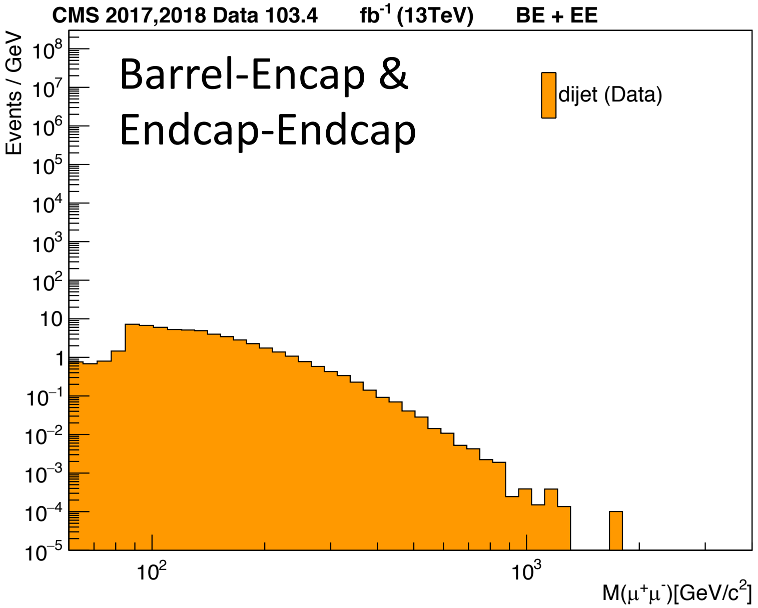


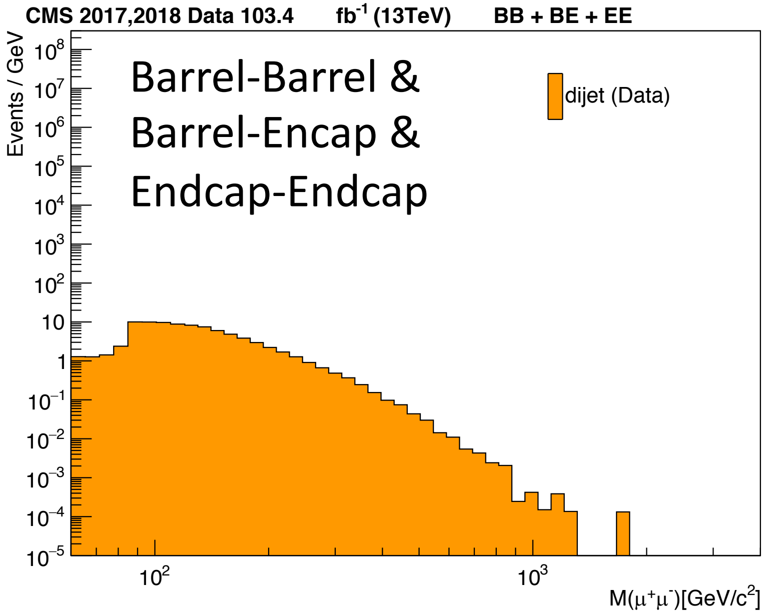




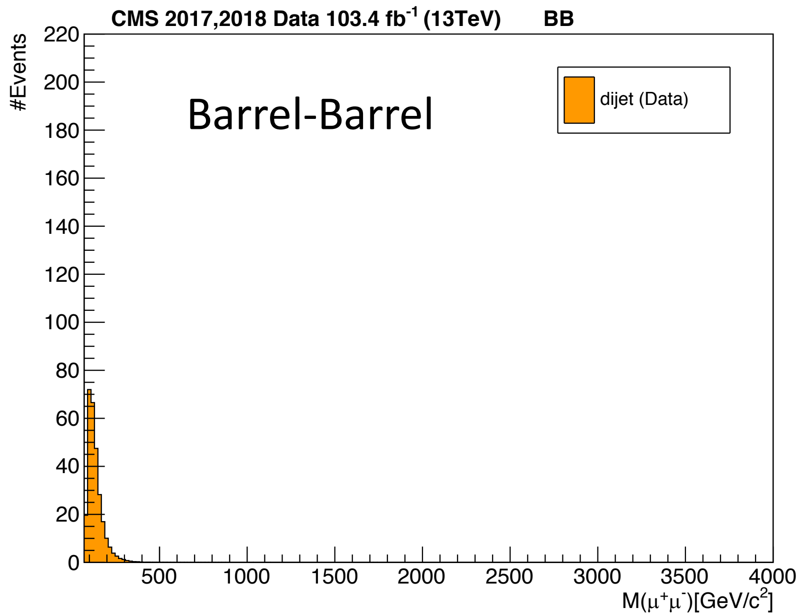
Dijet background estimation using FR measurements cont..

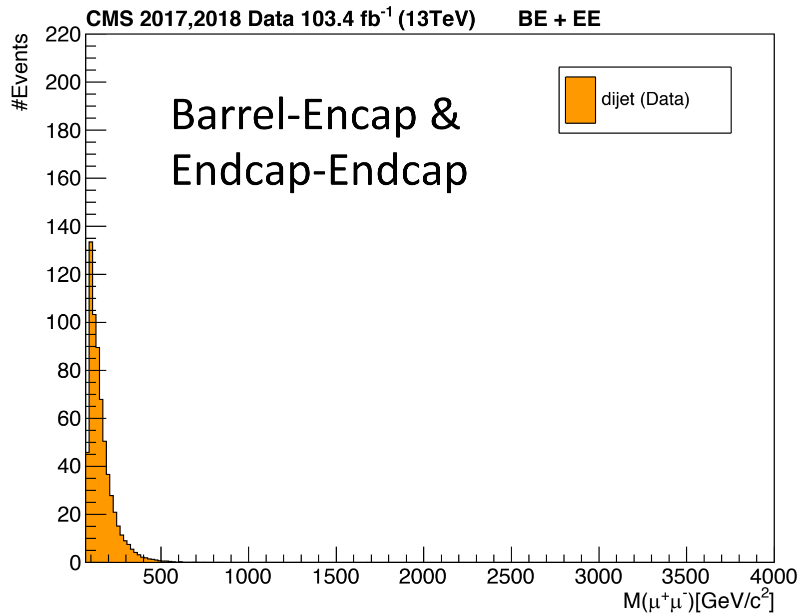


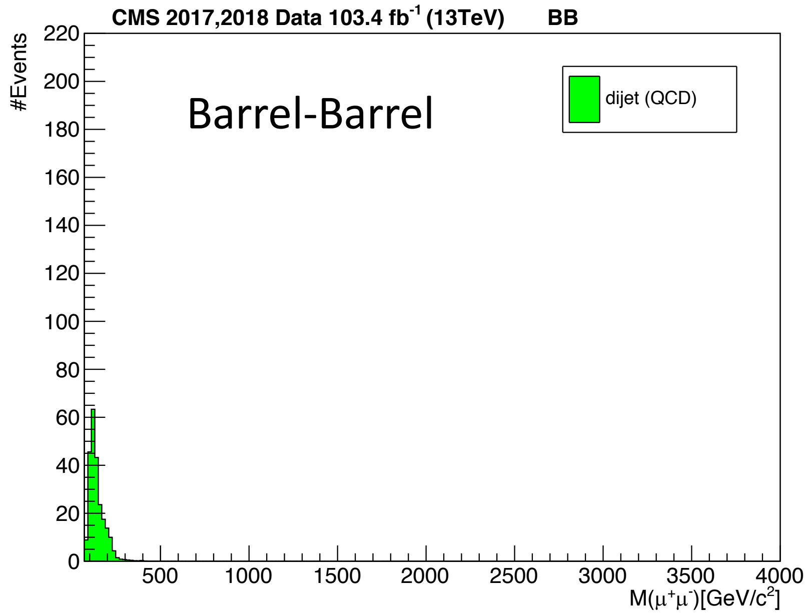


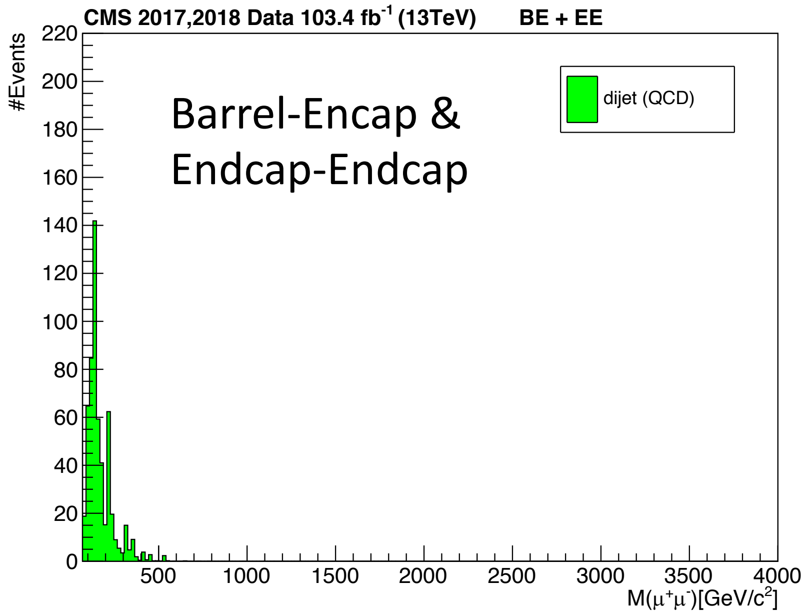


Dijet background estimation using FR measurements – Comparison with QCD

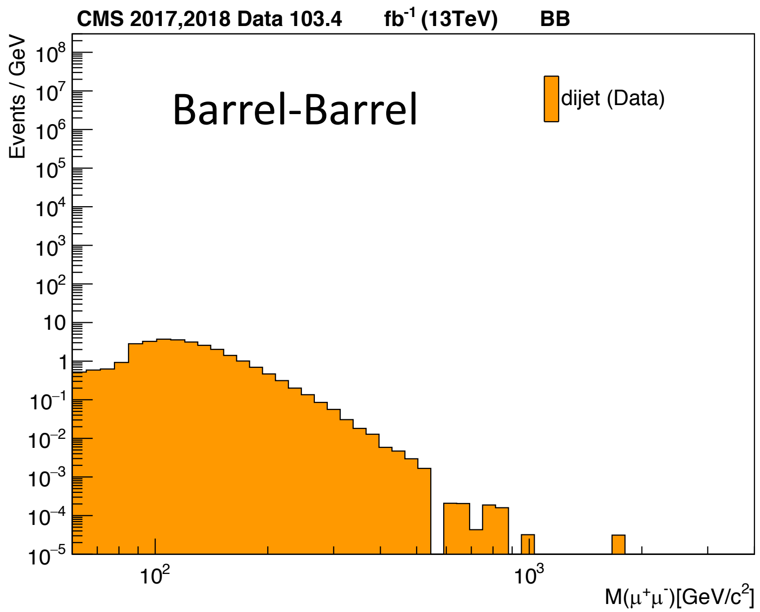


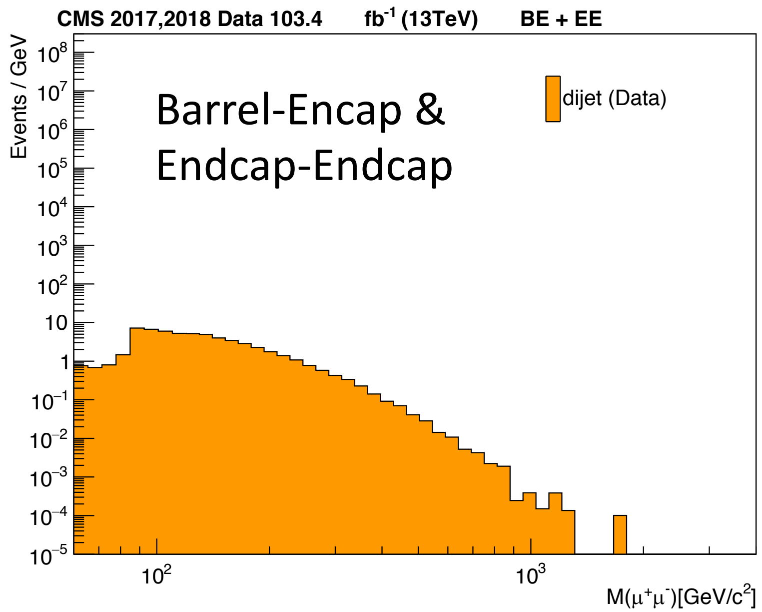


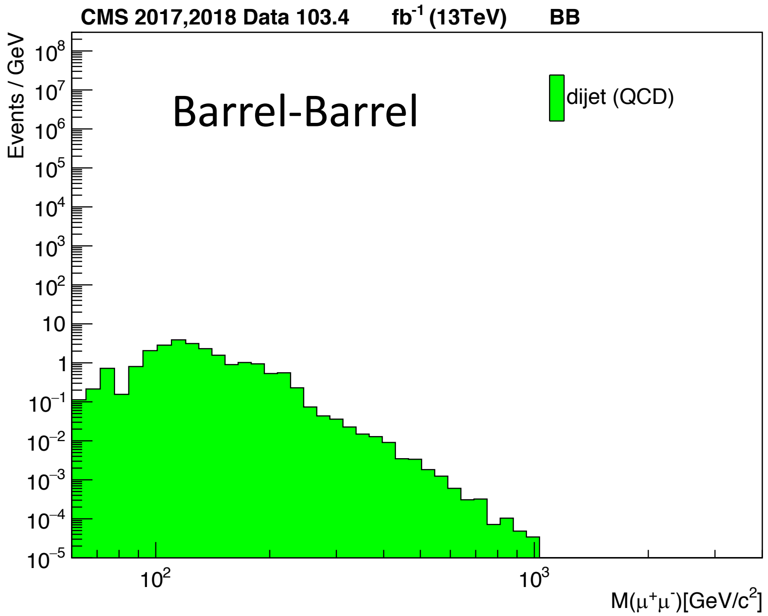


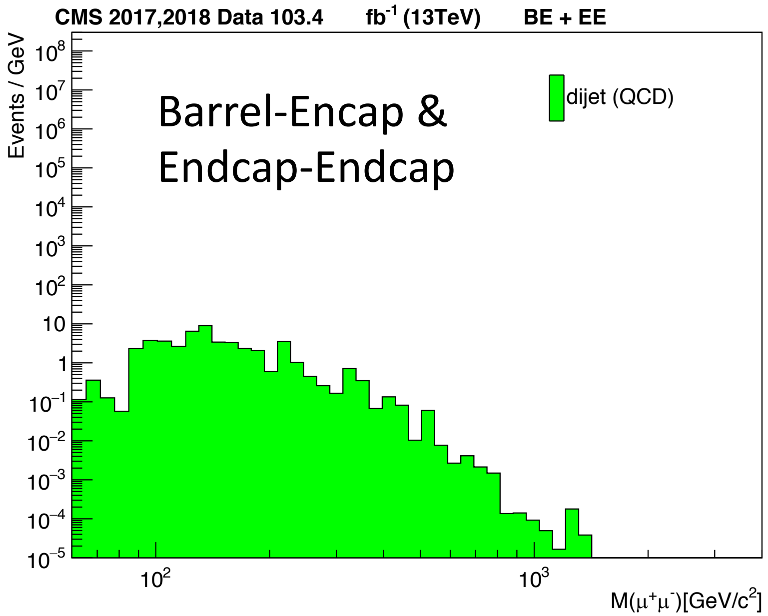


Dijet background estimation using FR measurements – Comparison with QCD

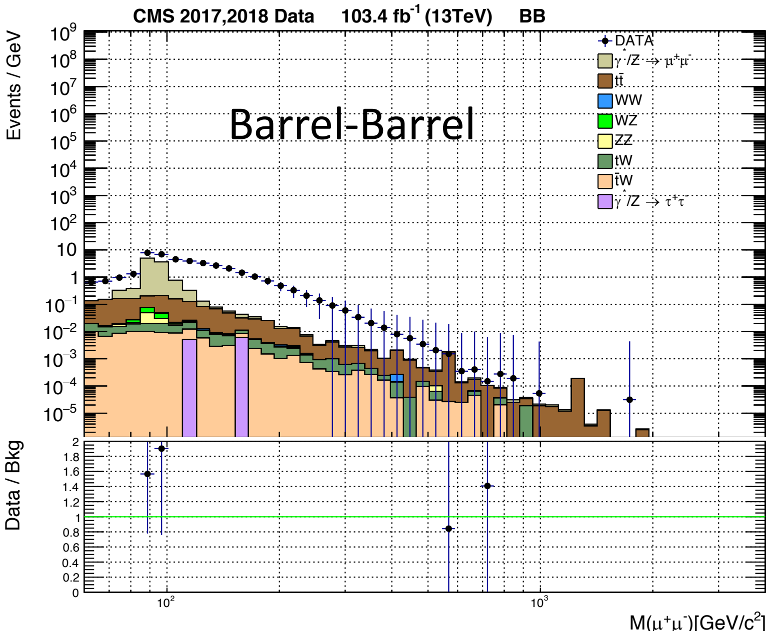




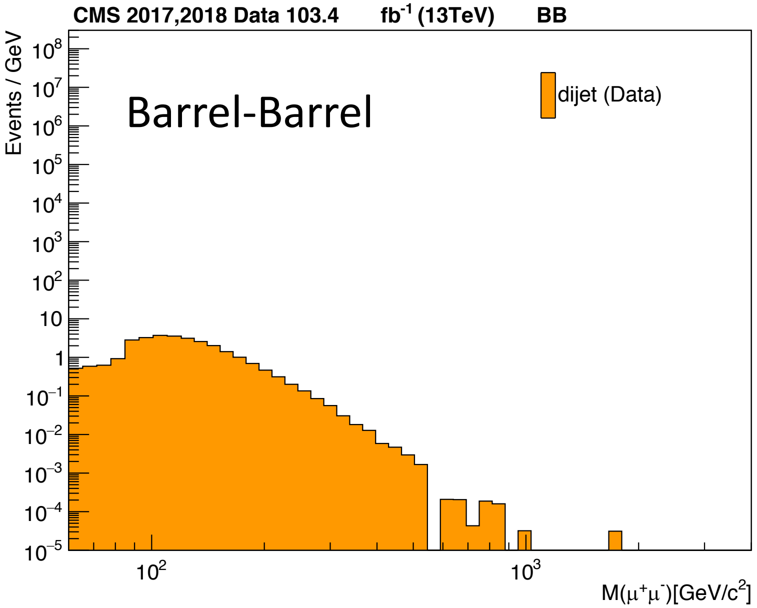


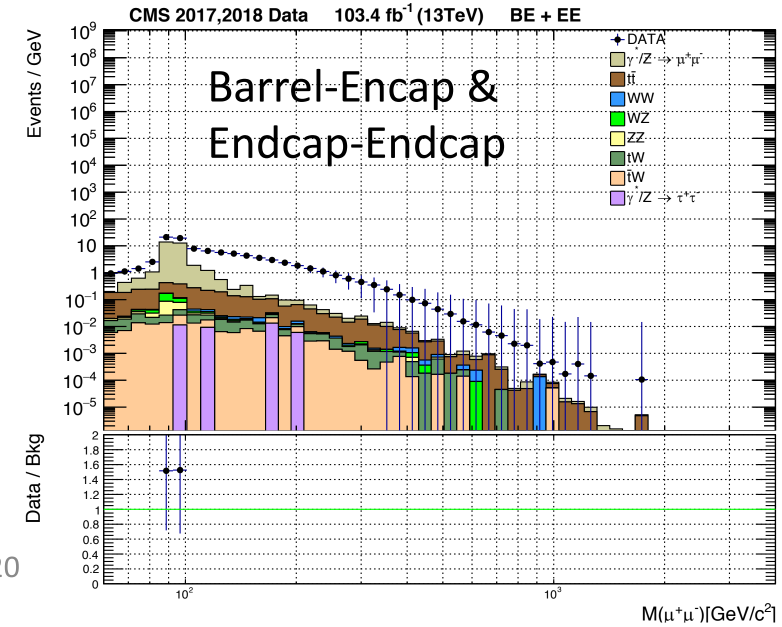


Dijet background estimation using FR measurements

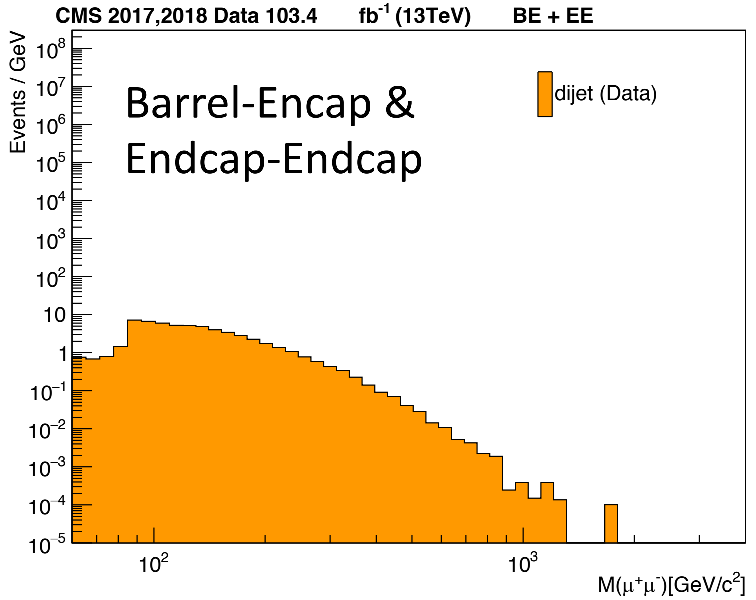


Data - MC

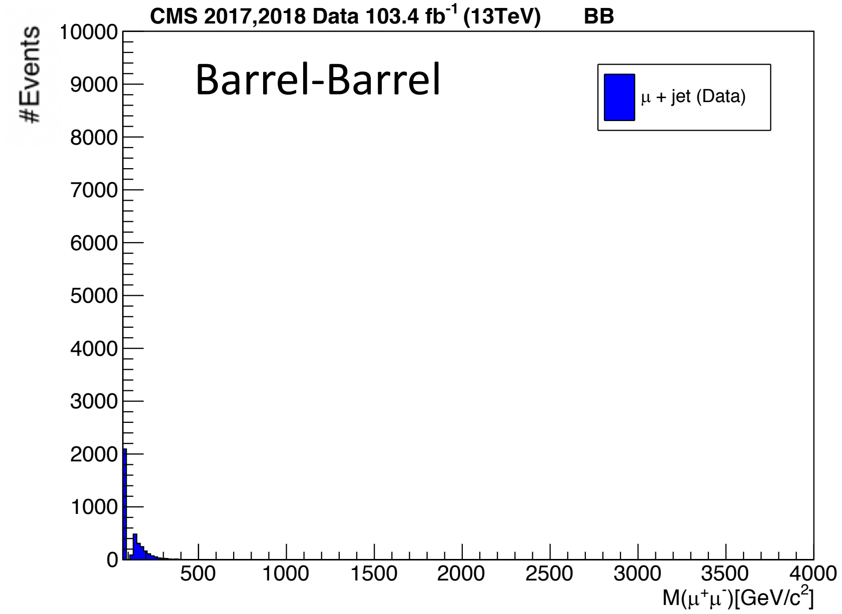


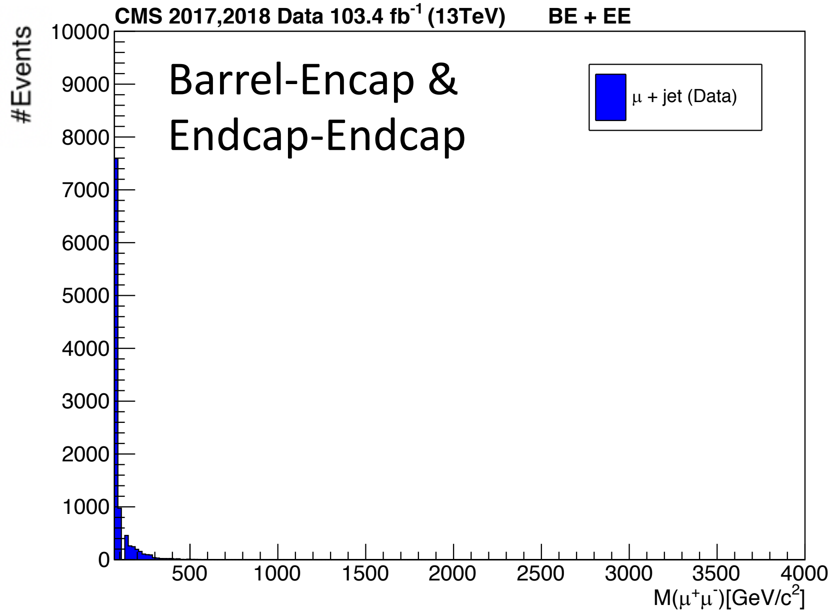


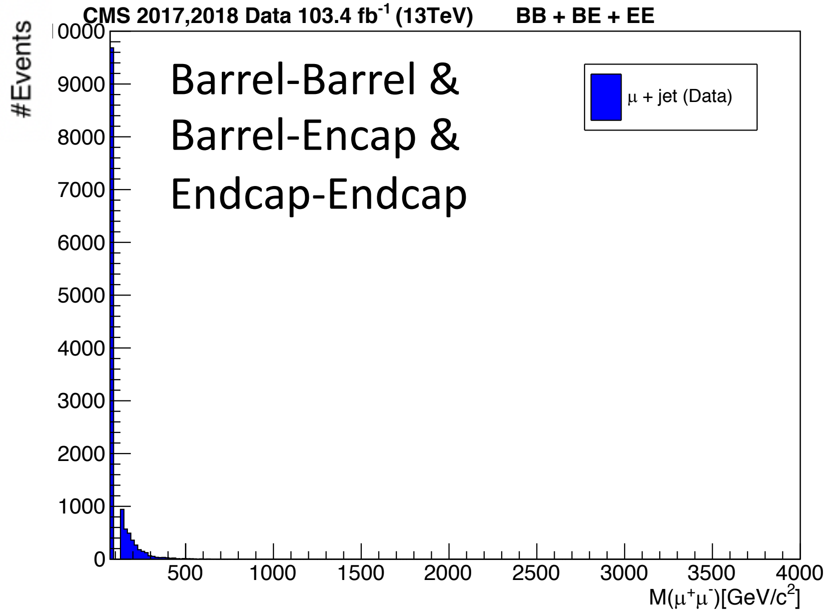
Data - MC



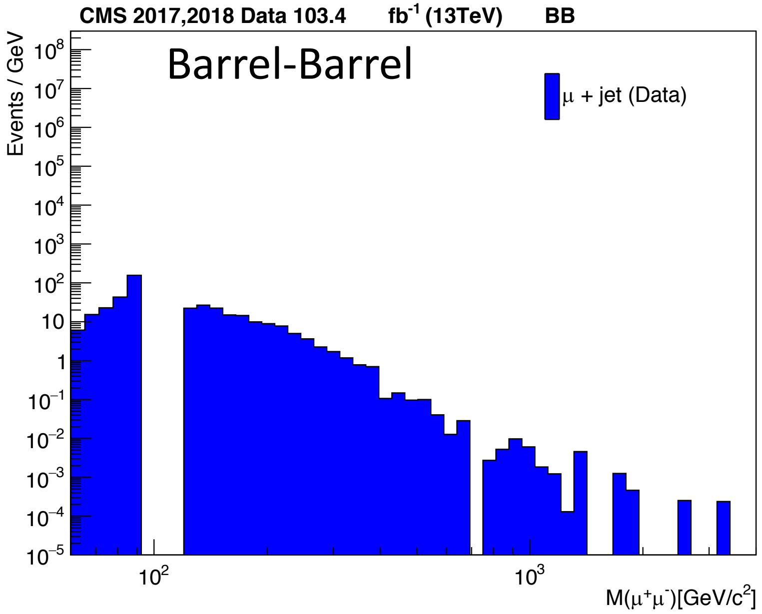
Muon + jet background estimation using FR measurements

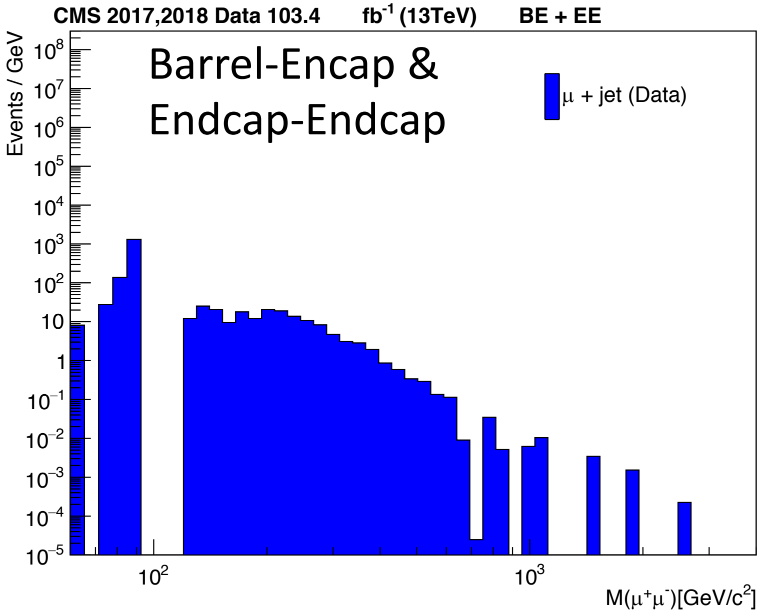


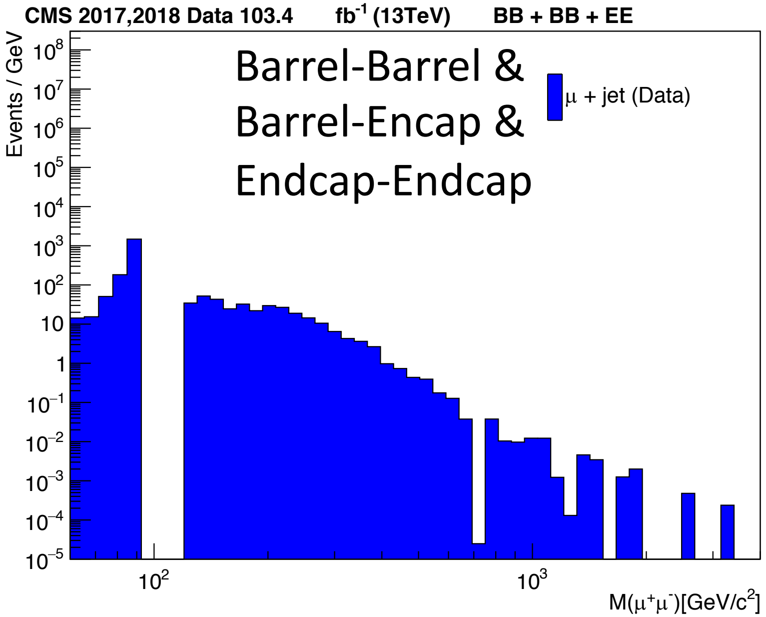




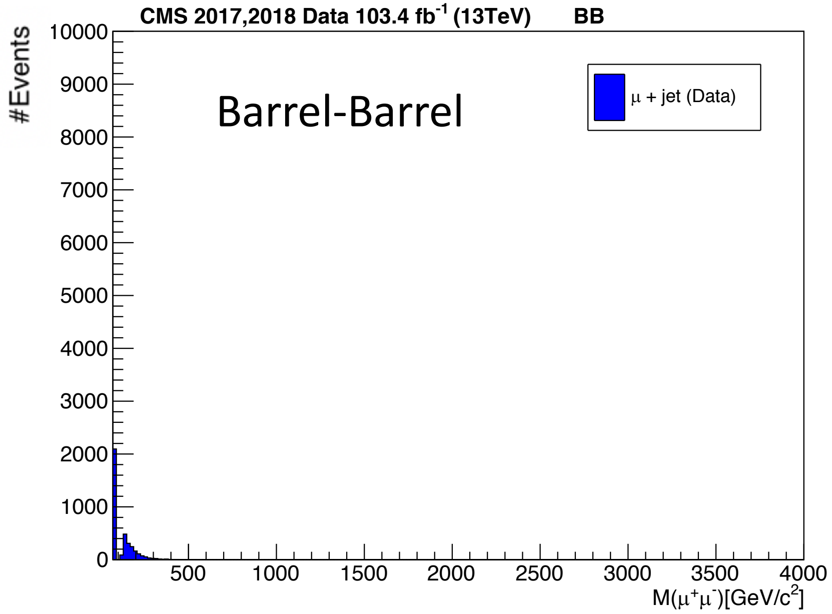
Muon + jet background estimation using FR measurements cont..

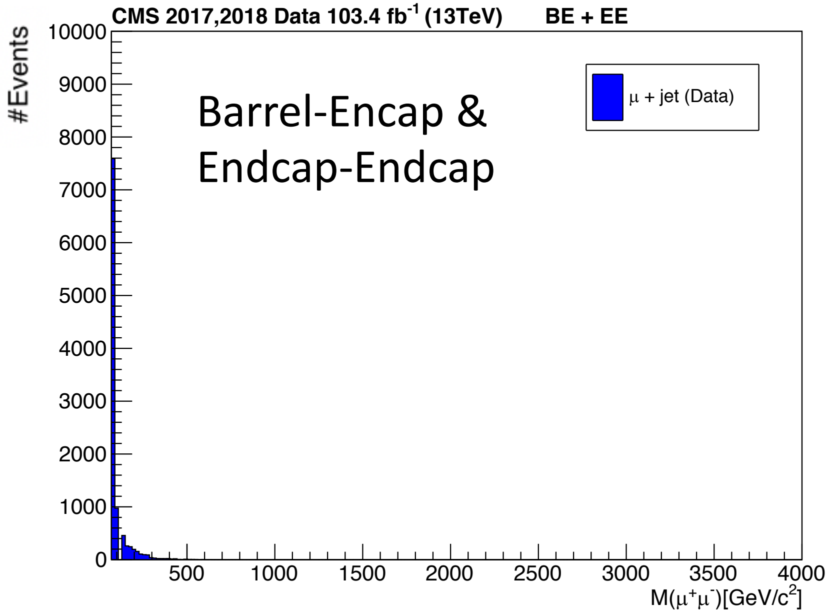


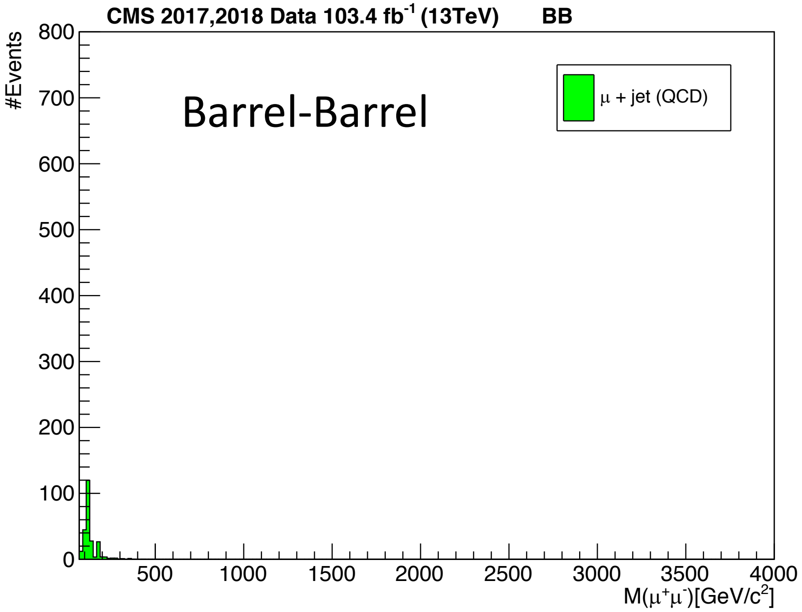


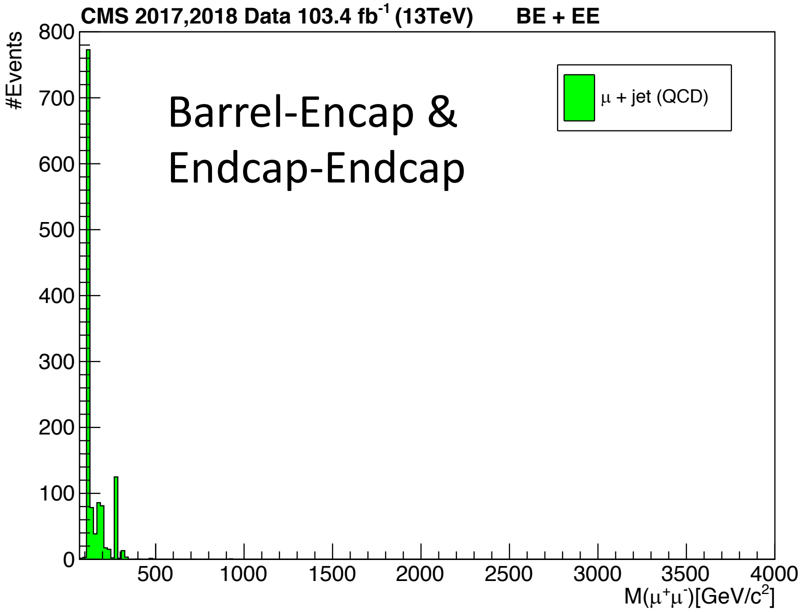


Muon + jet background estimation using FR measurements – Comparison with QCD









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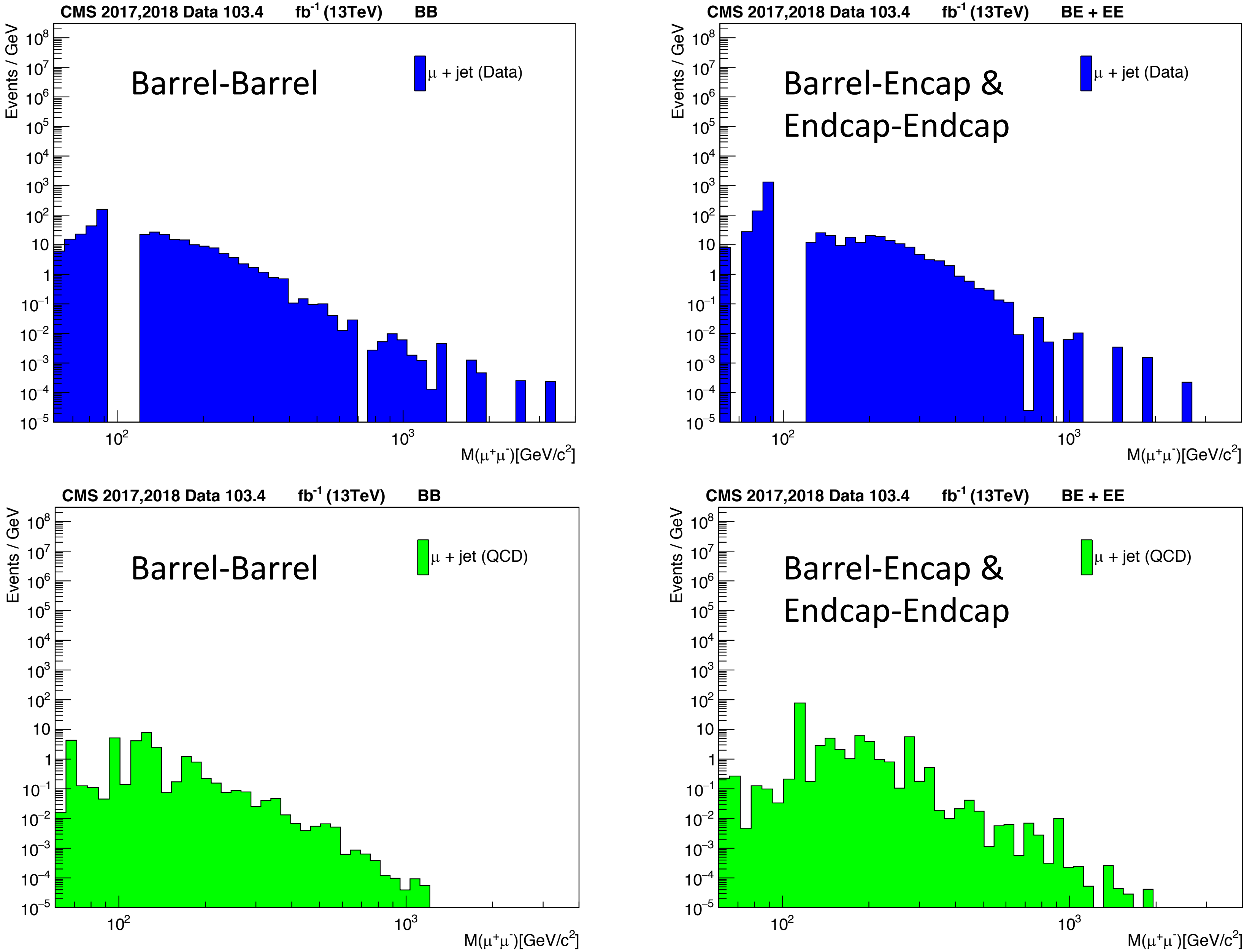
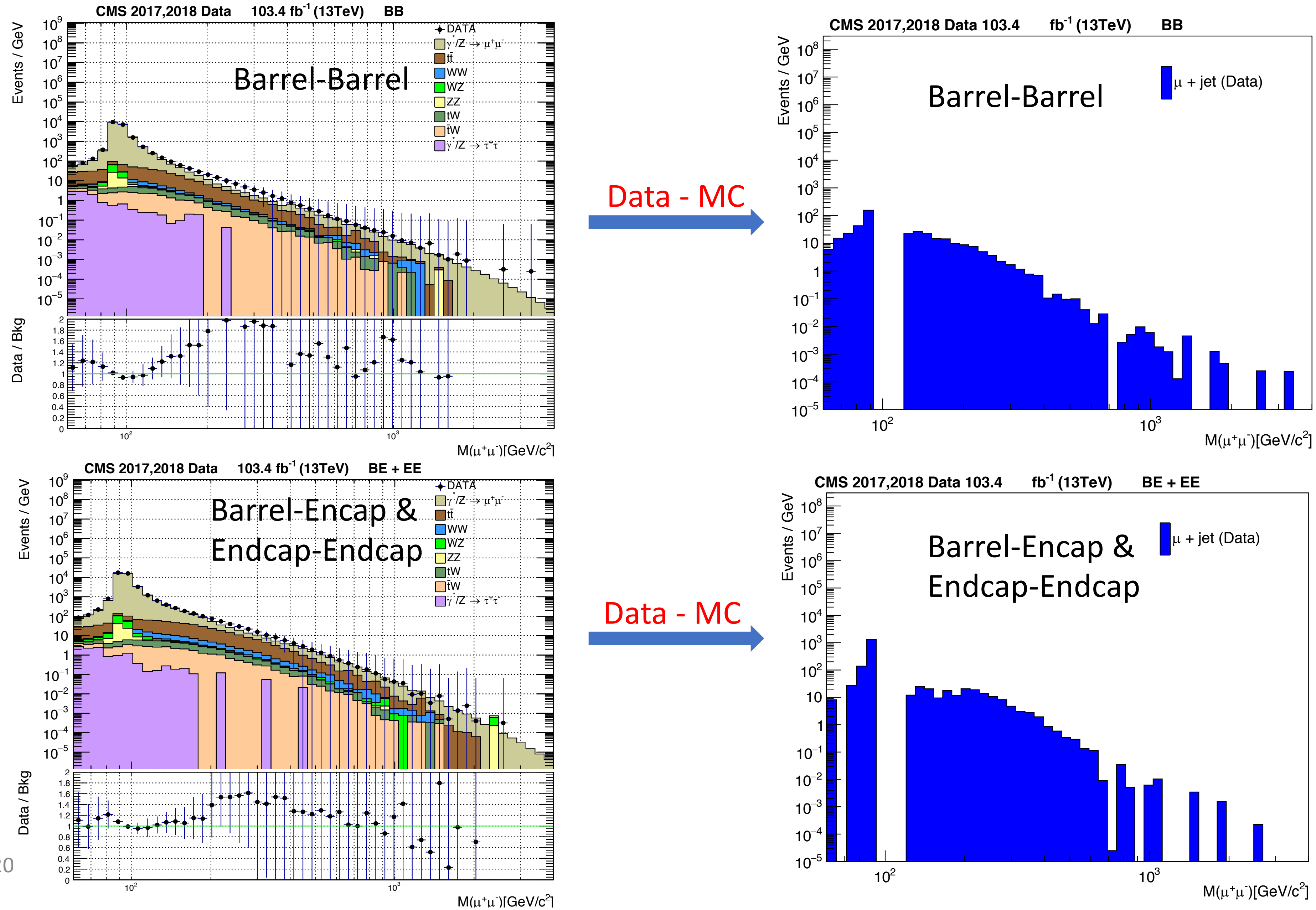
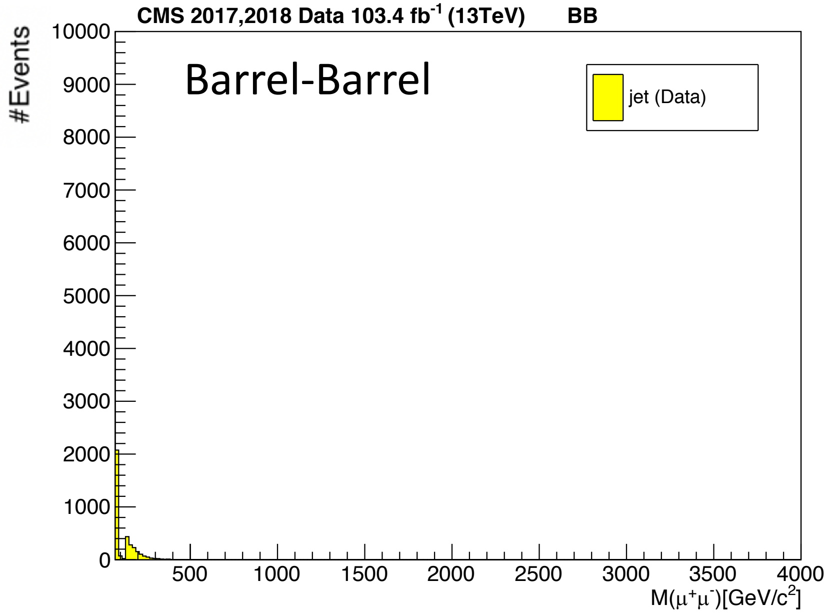
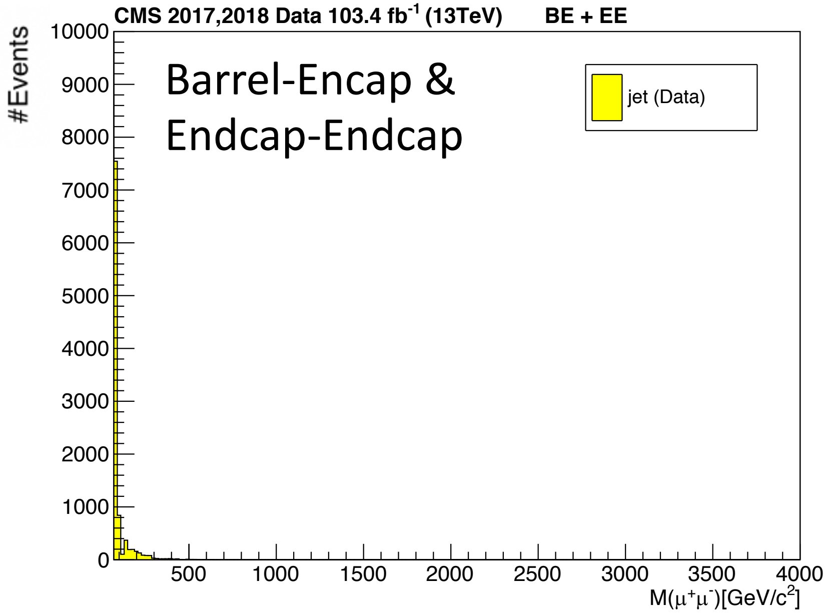


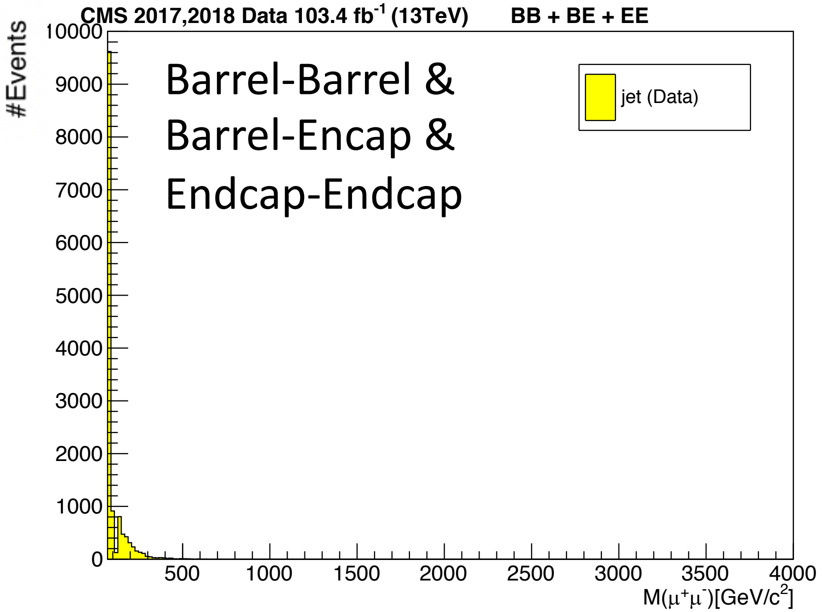
Muon + jet background estimation using FR measurements



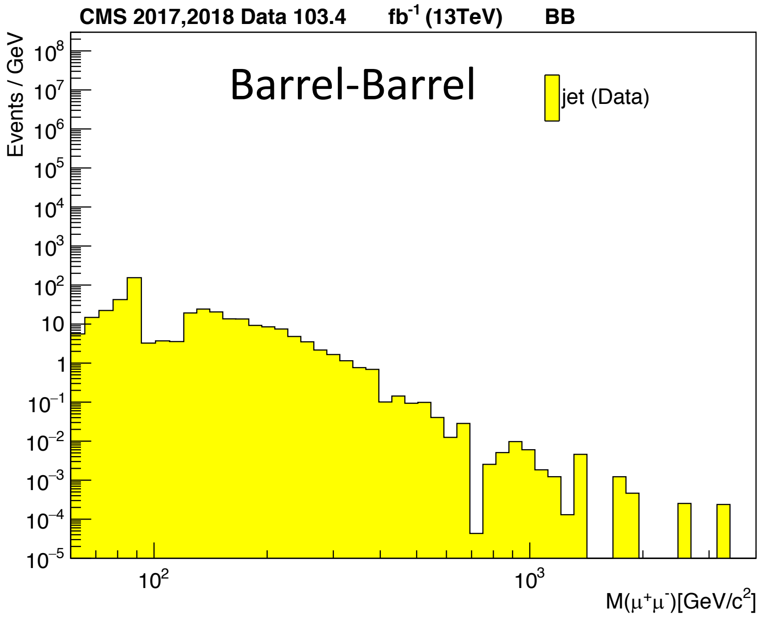
Jet background estimation using FR measurements

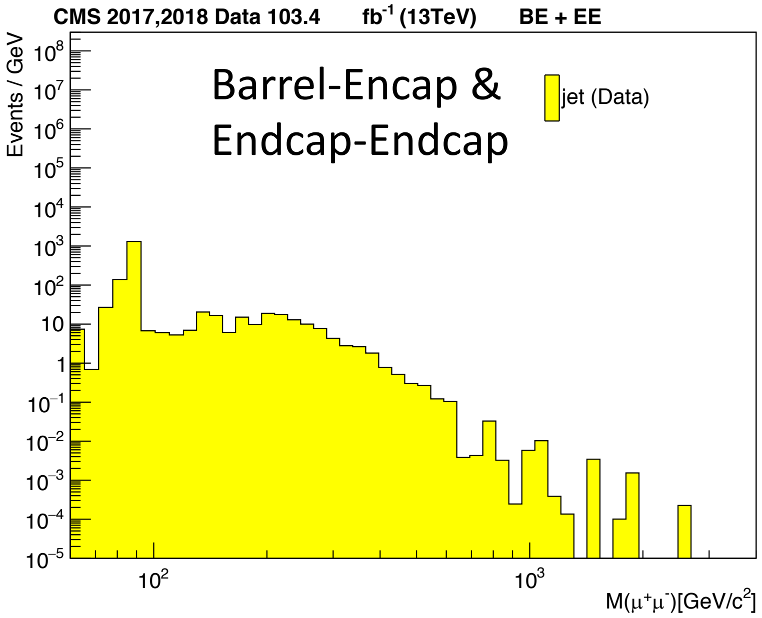


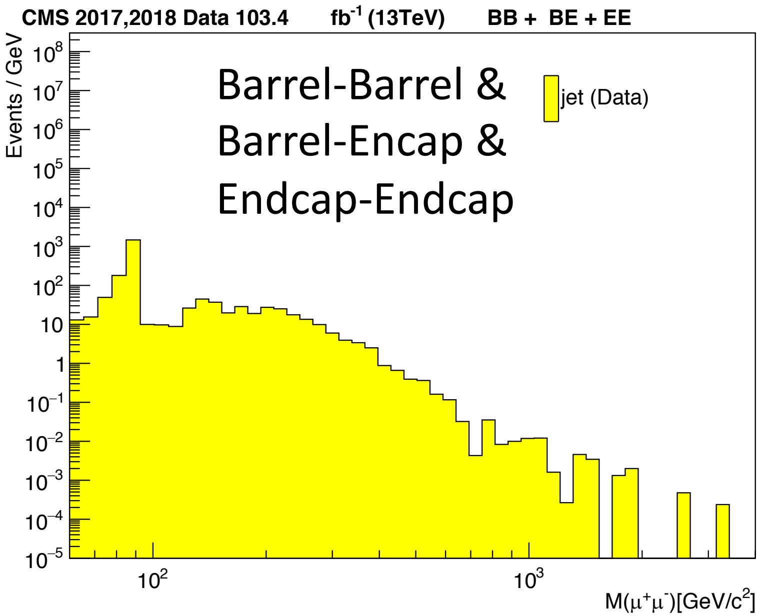




Jet background estimation using FR measurements







Summary

- A data-driven technique is used to estimate the background to the invariant mass spectrum of Z’ coming from “fake” muons.

- The dijet contribution is estimated by using events with two muons both failing to pass the High p_T muon ID requirements (given in the backup), while passing the pre-selection, selected using the primary analysis trigger.

- The muon+jet background is estimated by using muon pairs passing the primary analysis trigger with one muon passing and one muon failing the High p_T muon ID requirements, but both passing the pre-selection.

- The total background from non-prompt muons(jets) is estimated using both dijet and muon+jet background estimations.

Backup

Data sets and run selection

Data set	Run range
2017	
/SingleMuon/Run2017B-31Mar2018-v1	297050 – 299329
/SingleMuon/Run2017C-31Mar2018-v1	299368 – 302029
/SingleMuon/Run2017D-31Mar2018-v1	302031 – 302663
/SingleMuon/Run2017E-31Mar2018-v1	303824 – 304797
/SingleMuon/Run2017F-31Mar2018-v1	305045 – 306460
2018	
/SingleMuon/Run2018A-17Sep2018-v2	315257 – 316995
/SingleMuon/Run2018B-17Sep2018-v1	317080 – 319077
/SingleMuon/Run2018C-17Sep2018-v1	319337 – 320065
/SingleMuon/Run2018D-22Jan2019-v2	320673 – 325172

Table 01

- Integrated luminosity up to 42.1 fb^{-1} and 61.3 fb^{-1} for 2017 and 2018 runs, respectively calculated with the normtags using the corresponding Collisions17/13TeV/Final/Cert 294927-306462 13TeV PromptReco Collisions17 JSON MuonPhys.txt and Collisions18/13TeV/ReReco/Cert 314472-325175_13TeV_17SeptEarlyReReco2018ABC_PromptEraD_Collisions18_JSON_MuonPhys.txt

- The HLT path used: OR between three paths: HLT_Mu50, HLT TkMu100 and HLT OldMu100

2018 MC samples

QCD Sample	*Cross-section[pb]
/QCD_Pt_15to30_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v2/MINIAODSIM	1246000000.0
/QCD_Pt_30to50_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	106900000.0
/QCD_Pt_50to80_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	15710000.0
/QCD_Pt_80to120_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	2336000.0
/QCD_Pt_120to170_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	407300.0
/QCD_Pt_170to300_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	103500.0
/QCD_Pt_300to470_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	6830.0
/QCD_Pt_470to600_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	552.1
/QCD_Pt_600to800_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	156.5
/QCD_Pt_800to1000_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v2/MINIAODSIM	26.28
/QCD_Pt_1000to1400_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	7.47
/QCD_Pt_1400to1800_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	0.6484
/QCD_Pt_1800to2400_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	0.08743
/QCD_Pt_2400to3200_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	0.005236
/QCD_Pt_3200toInf_TuneCP5_13TeV_pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	0.0001357

Table 02

* Xsec values are from XSDB, also manually calculated using GenXSecAnalyzer tool

2018 MC samples

Other background samples	*Cross-section[pb]
/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	61526.7
/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	6077.22
/ZZ_TuneCP5_13TeV-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	16.523
/WZ_TuneCP5_13TeV-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v3/MINIAODSIM	50.2
/WW_TuneCP5_13TeV-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	118.7
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v1/MINIAODSIM	35.6
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext1-v1/MINIAODSIM	35.6
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	88.29

Table 03

*Xsec values were cross checked and validated. Values in blue have been changed after the discussion with Alexander

2018 MC samples

Drell-Yan samples	*Cross-section[pb]
/ZToMuMu_NNPDF31_13TeV-powheg_M_50_120/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	2112.904
/ZToMuMu_NNPDF31_13TeV-powheg_M_120_200/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	20.553
/ZToMuMu_NNPDF31_13TeV-powheg_M_200_400/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	2.866
/ZToMuMu_NNPDF31_13TeV-powheg_M_400_800/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	0.2517
/ZToMuMu_NNPDF31_13TeV-powheg_M_800_1400/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v1/MINIAODSIM	0.01707
/ZToMuMu_NNPDF31_13TeV-powheg_M_1400_2300/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	0.001366
/ZToMuMu_NNPDF31_13TeV-powheg_M_2300_3500/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	0.00008178
/ZToMuMu_NNPDF31_13TeV-powheg_M_3500_4500/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	3.19E-06
/ZToMuMu_NNPDF31_13TeV-powheg_M_4500_6000/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	2.79E-07
/ZToMuMu_NNPDF31_13TeV-powheg_M_6000_Inf/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15-v2/MINIAODSIM	9.57E-09

Table 04

- Moved to “RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1” data set from “RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v2”.

*Xsec values were cross checked and validated. Values in blue have been changed after the discussion with Alexander

2017 MC samples

QCD Sample	*Cross-section[pb]
/QCD_Pt_15to30_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	1246000000.0
/QCD_Pt_30to50_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	106900000.0
/QCD_Pt_50to80_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	15710000.0
/QCD_Pt_80to120_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	2336000.0
/QCD_Pt_120to170_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	407300.0
/QCD_Pt_170to300_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	103500.0
/QCD_Pt_300to470_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	6830.0
/QCD_Pt_470to600_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	552.1
/QCD_Pt_600to800_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	156.5
/QCD_Pt_800to1000_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	26.28
/QCD_Pt_1000to1400_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	7.47
/QCD_Pt_1400to1800_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	0.6484
/QCD_Pt_1800to2400_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	0.08743
/QCD_Pt_2400to3200_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	0.005236
/QCD_Pt_3200toInf_TuneCP5_13TeV_pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	0.0001357

Table 05

* Xsec values are from XSDB, also manually calculated using GenXSecAnalyzer tool

2017 MC samples

Other background samples	***Cross-section[pb]**
/WJetsToLNu_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v3/MINIAODSIM	61526.7
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v2/MINIAODSIM	88.29
/WW_TuneCP5_13TeV-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v2/MINIAODSIM	118.7
/WZ_TuneCP5_13TeV-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	50.2
/ZZ_TuneCP5_13TeV-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	16.523
/ST_tW_top_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	35.6
/ST_tW_antitop_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v2/MINIAODSIM	35.6
/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/RunIIFall17MiniAODv2-PU2017RECOSIMstep_12Apr2018_94X_mc2017_realistic_v14-v1/MINIAODSIM	6077.22

Table 06

*Xsec values were cross checked and validated. Values in blue have been changed after the discussion with Alexander

2017 MC samples

Drell-Yan samples (MUOTrackFix)	*Cross-section[pb]
/ZToMuMu_NNPDF31_13TeV-powheg_M_50_120/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	2112.904
/ZToMuMu_NNPDF31_13TeV-powheg_M_120_200/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	20.553
/ZToMuMu_NNPDF31_13TeV-powheg_M_200_400/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	2.866
/ZToMuMu_NNPDF31_13TeV-powheg_M_400_800/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	0.2517
/ZToMuMu_NNPDF31_13TeV-powheg_M_800_1400/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	0.01707
/ZToMuMu_NNPDF31_13TeV-powheg_M_1400_2300/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	0.001366
/ZToMuMu_NNPDF31_13TeV-powheg_M_2300_3500/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	0.00008178
/ZToMuMu_NNPDF31_13TeV-powheg_M_3500_4500/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	3.19E-06
/ZToMuMu_NNPDF31_13TeV-powheg_M_4500_6000/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	2.79E-07
/ZToMuMu_NNPDF31_13TeV-powheg_M_6000_Inf/RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1/MINIAODSIM	9.57E-09

Table 07

- Moved to "RunIIFall17MiniAODv2-MUOTrackFix_12Apr2018_94X_mc2017_realistic_v14_ext1-v1" data set from "RunIIFall17MiniAODv2-PU2017_12Apr2018_94X_mc2017_realistic_v14-v2".

*Xsec values were cross checked and validated. Values in blue have been changed after the discussion with Alexander

High p_T muon ID selection

- fabs(lep_eta[n])<2.4 &&
- lep_pt[n]>=53. &&
- lep_isTrackerMuon[n]==1 &&
- lep_isGlobalMuon[n]==1 &&
- (lep_numberOfMatchedStations[n] > 1 || (lep_numberOfMatchedStations[n] == 1 &&
  (lep_expectedNnumberOfMatchedStations[n] < 2 || !(lep_stationMask[n] == 1 || lep_stationMask[n] == 16) ||
  lep_numberOfMatchedRPCLayers[n] > 2))) &&
- (lep_glb_numberOfValidMuonHits[n]>0 || lep_TuneP_numberOfValidMuonHits[n]>0) &&
- lep_glb_numberOfValidPixelHits[n]>0 &&
- lep_glb_numberOfValidTrackerLayers[n]>5 &&
- lep_sumPt[n]/lep_tk_pt[n]<0.10 &&
- lep_pt_err[n]/lep_pt[n]<0.3 &&
- lep_triggerMatchPt[n]>50

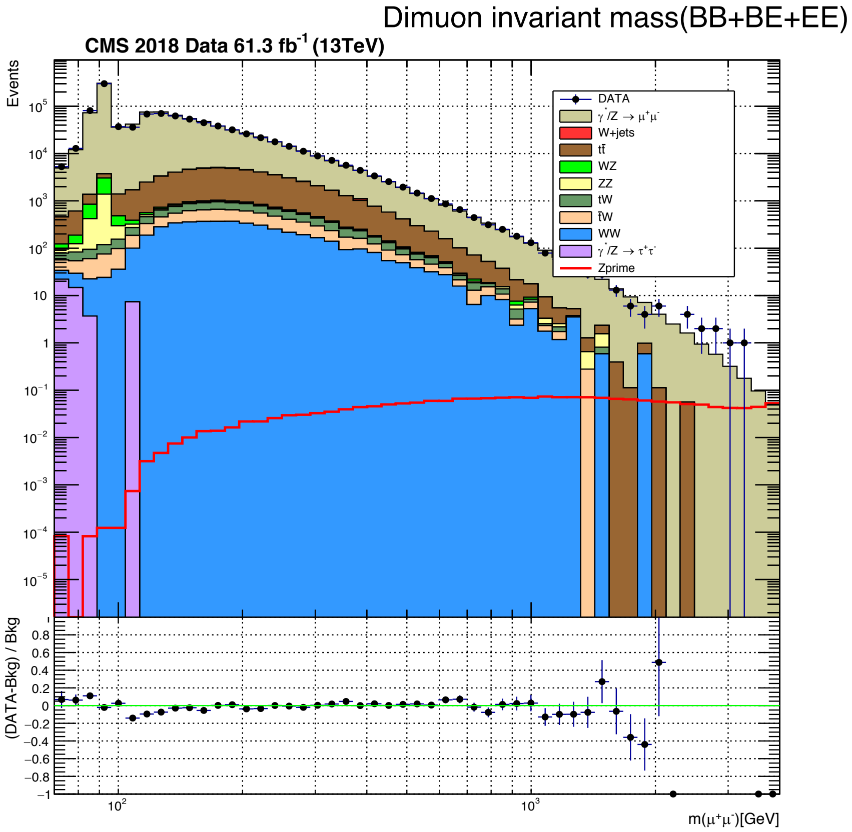
Z’ baseline event selection cuts

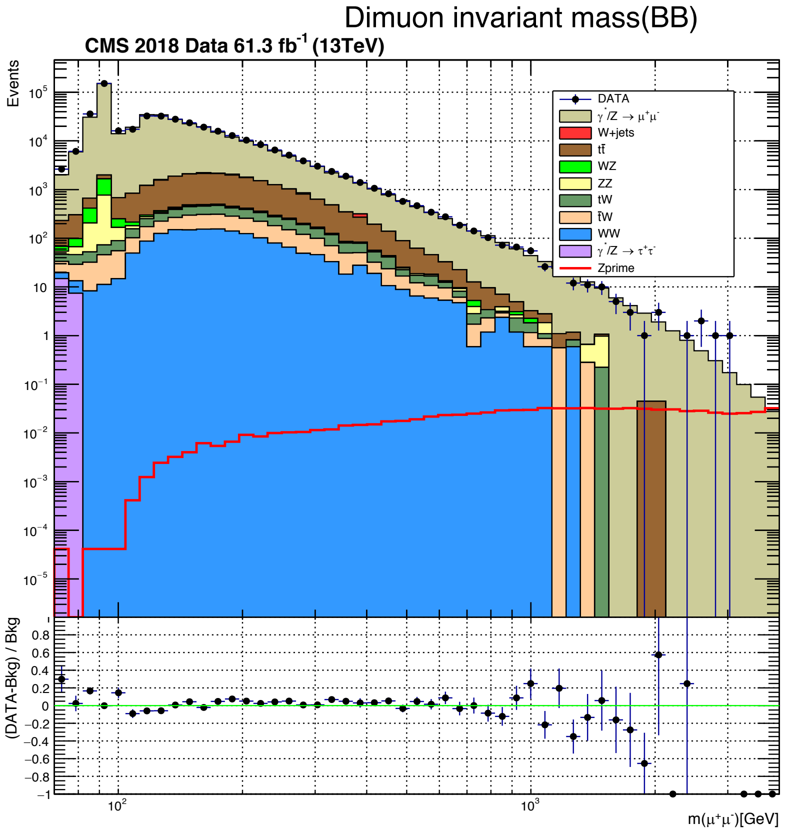
- GoodVtx // A “good” offline-reconstructed primary vertex
- fabs(lep_eta[0])<2.4 && fabs(lep_eta[1])<2.4 // Detector acceptance
- lep_pt[0]>53. && lep_pt[1]>53.0 // Offline muon reconstruction p_T threshold
- lep_isTrackerMuon[0]==1 && lep_isTrackerMuon[1]==1 // Both muons in the dimuon event should be “tracker”
- lep_isGlobalMuon[0]==1 && lep_isGlobalMuon[1]==1 // Both muons in the dimuon event should be “global”
- fabs(lep_dB[0]) < 0.2 && fabs(lep_dB[1]) < 0.2
- (lep_numberOfMatchedStations[0] > 1 || (lep_numberOfMatchedStations[0] == 1 && (lep_expectedNnumberOfMatchedStations[0] < 2 || !(lep_stationMask[0] == 1 || lep_stationMask[0] == 16) || lep_numberOfMatchedRPCLayers[0] > 2)))
- (lep_numberOfMatchedStations[1] > 1 || (lep_numberOfMatchedStations[1] == 1 && (lep_expectedNnumberOfMatchedStations[1] < 2 || !(lep_stationMask[1] == 1 || lep_stationMask[1] == 16) || lep_numberOfMatchedRPCLayers[1] > 2)))
- (lep_glb_numberOfValidMuonHits[0]>0 || lep_TuneP_numberOfValidMuonHits[0]>0) && (lep_glb_numberOfValidMuonHits[1]>0 || lep_TuneP_numberOfValidMuonHits[1]>0)
- lep_glb_numberOfValidPixelHits[0]>=1 && lep_glb_numberOfValidPixelHits[1]>=1
- lep_glb_numberOfValidTrackerLayers[0]>5 && lep_glb_numberOfValidTrackerLayers[1]>5
- lep_sumPt[0]/lep_tk_pt[0]<0.10 && lep_sumPt[1]/lep_tk_pt[1]<0.10 // Relative tracker-only isolation cut
- lep_pt_err[0]/lep_pt[0]<0.3 && lep_pt_err[1]/lep_pt[1]<0.3 // Relative p_T error
- cos_angle>-0.9998 // 3-D angle between the two muons’ momenta should be less than (π - 0.02) rad
- lep_id[0]*lep_id[1]<0
- (lep_triggerMatchPt[0]>50 || lep_triggerMatchPt[1]>50) //Trigger p_T threshold
- vertex_chi2 < 20

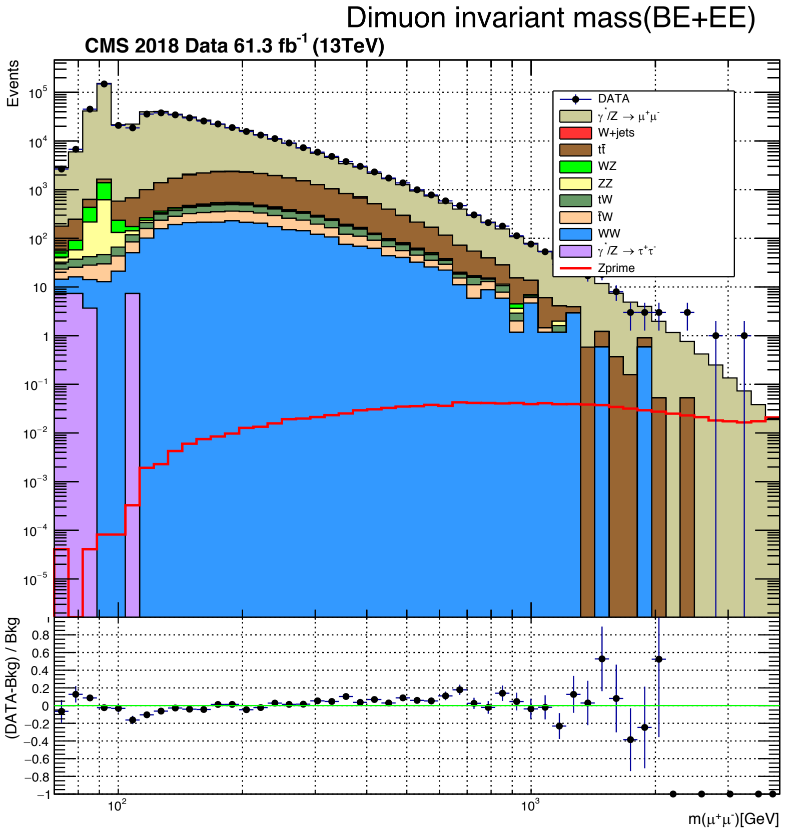
➢ If there are more than one opposite-sign dimuon pair passing all the above requirements, first select a pair with invariant mass closest to the Z boson mass if the mass is within ±20 GeV of Z boson mass, and then the two muons with highest p_T are selected.

Dimuon Mass - 2018

Using Z' baseline selection

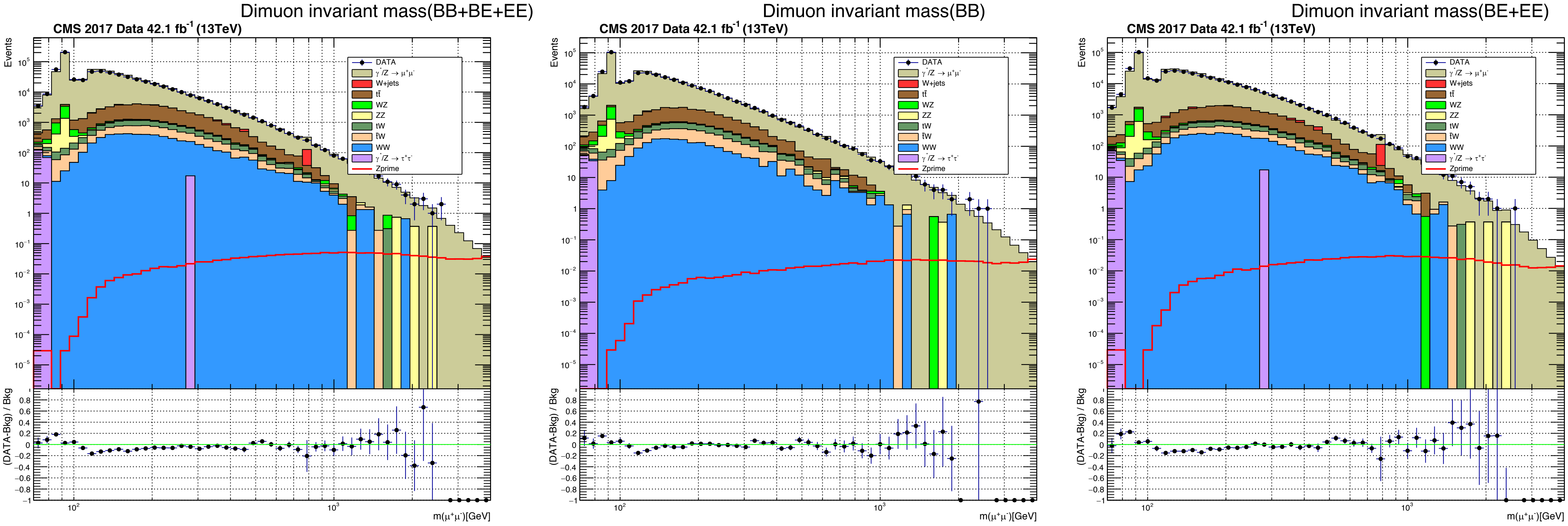






Dimuon Mass - 2017

Using Z' baseline selection

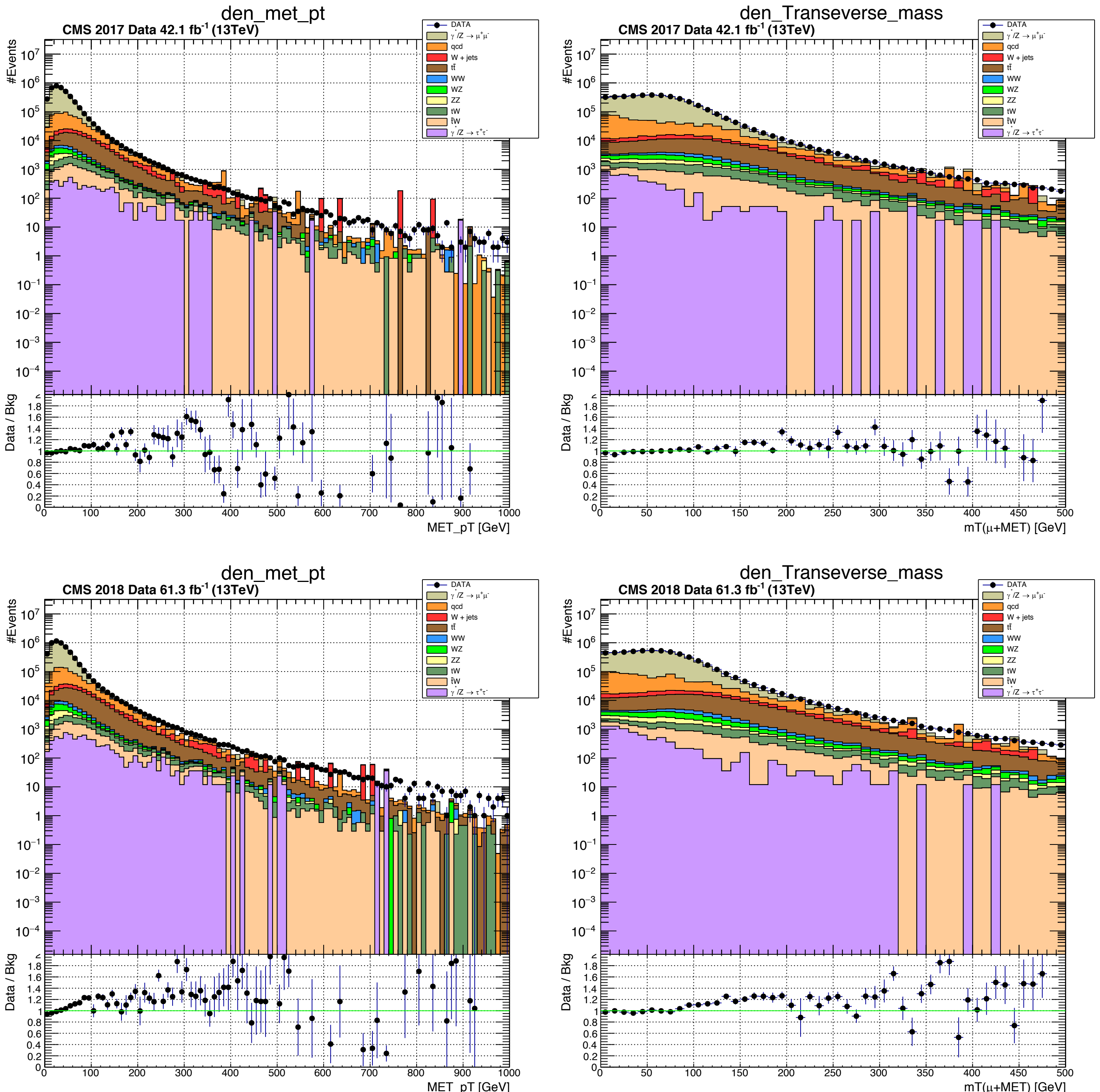


Transverse mass(m_T) and Missing Trannsverse Energy distridutions

- The traverse mass(m_T) of the leading-p_T muon passing the high p_T muopn ID selection and the reconstructed missing transverse energy (MET), where Δϕ is the difference in ϕ between the muon and the MET vector is calculated as follows;

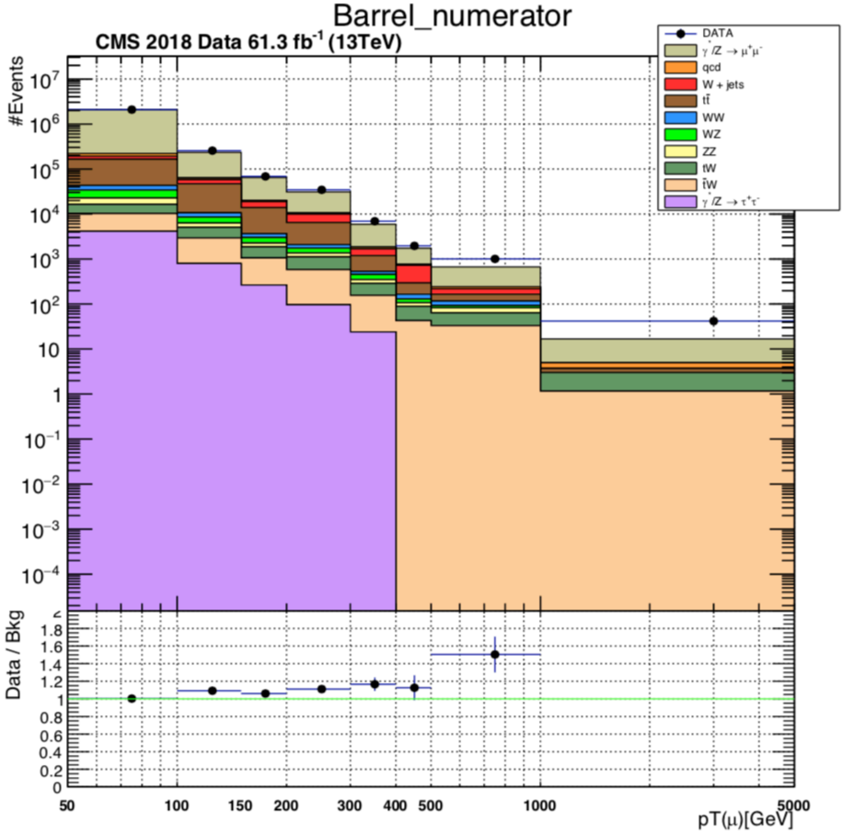
- **m_T =sqrt[2p_T * MET (1 − cos(Δϕ)]**

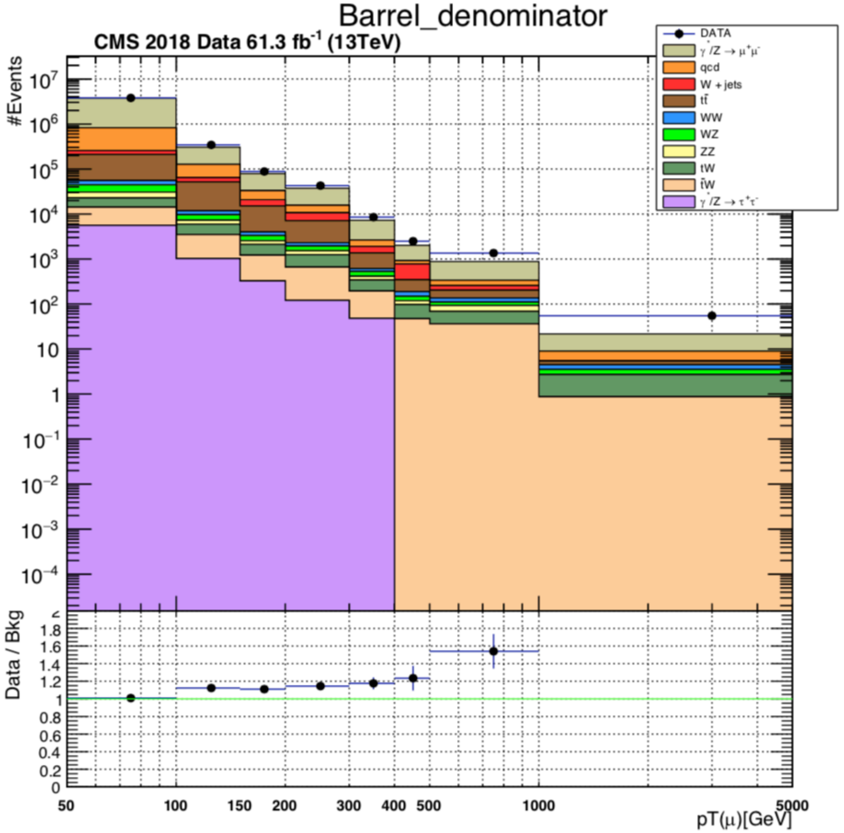
- According to AN_2018_011 and AN_2016_391, to reduce the contribution of W+jets events to the control region, a m_T cut (m_T < 35GeV) has been imposed on the leading-p_T muon passing the high p_T muon ID selection. I have studied this cut and I saw that this largely reduces the statistics of the control region. So, this cut is not applied for the moment.



Muon p_T - 2018

Using FR denominator and numerator definition for Barrel

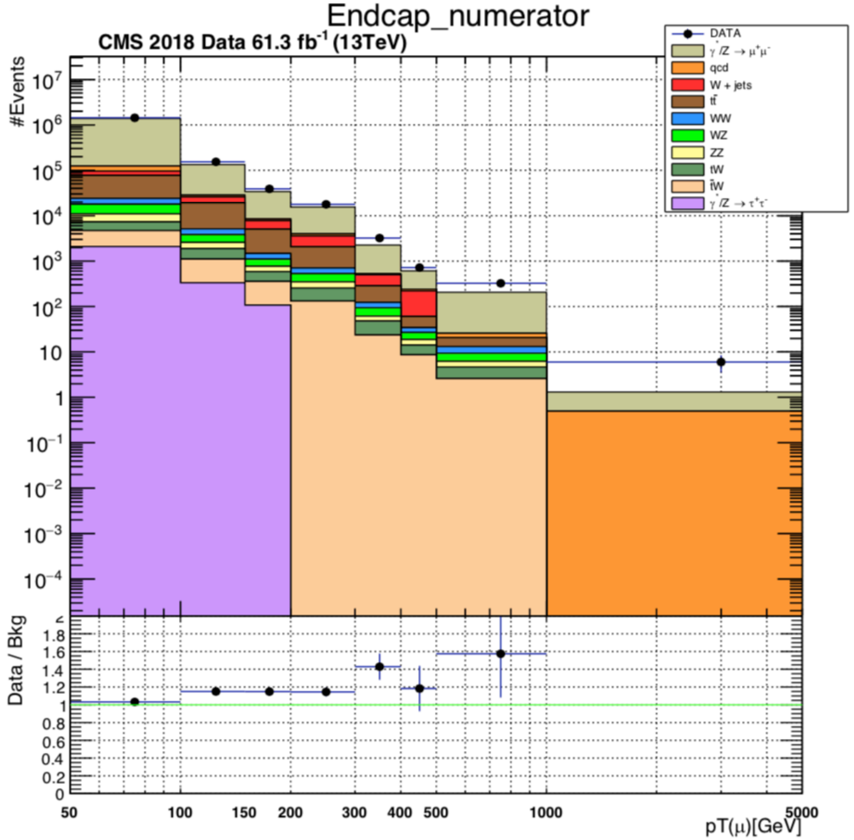


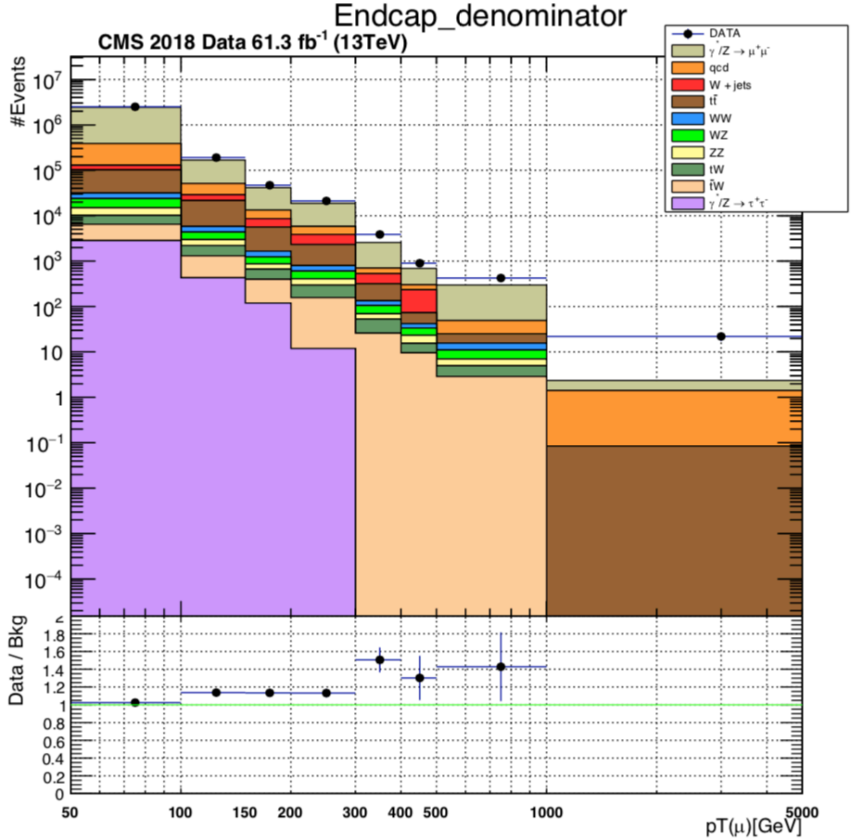


- Comparatively better Data/MC ratio is seen in low p_T bins after applyling latest SFs
- The large contribution of QCD events in the distribution of the denominator is clearly visible and provides us with confidence that the control region defined above is enriched in fakeable objects.

Muon p_T - 2018

Using FR denominator and numerator definition for Endcap

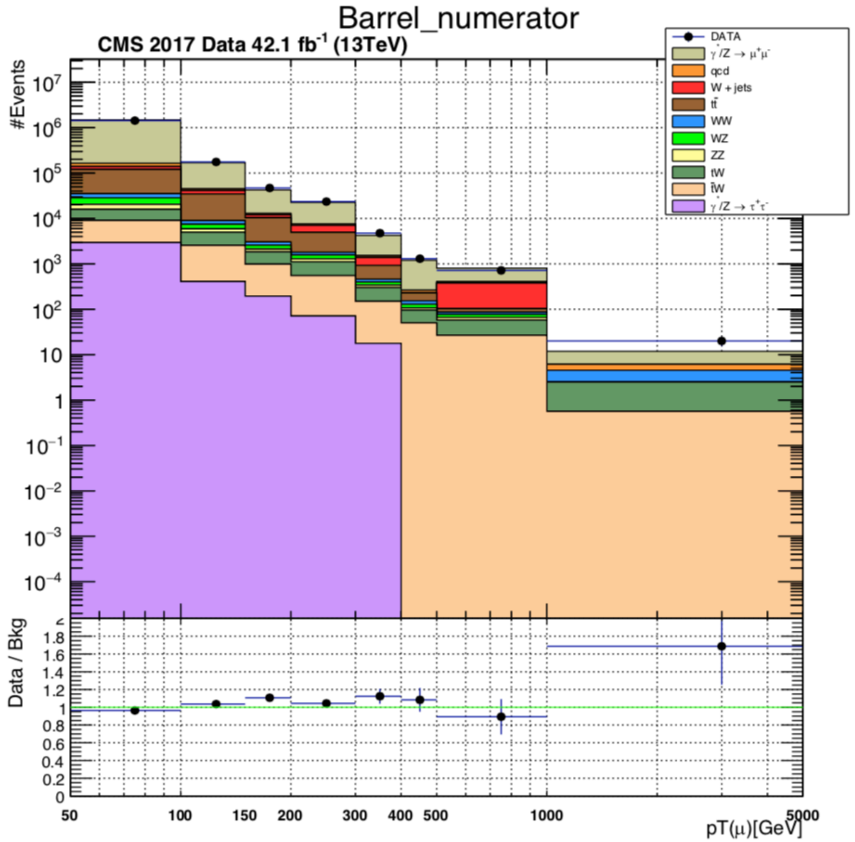


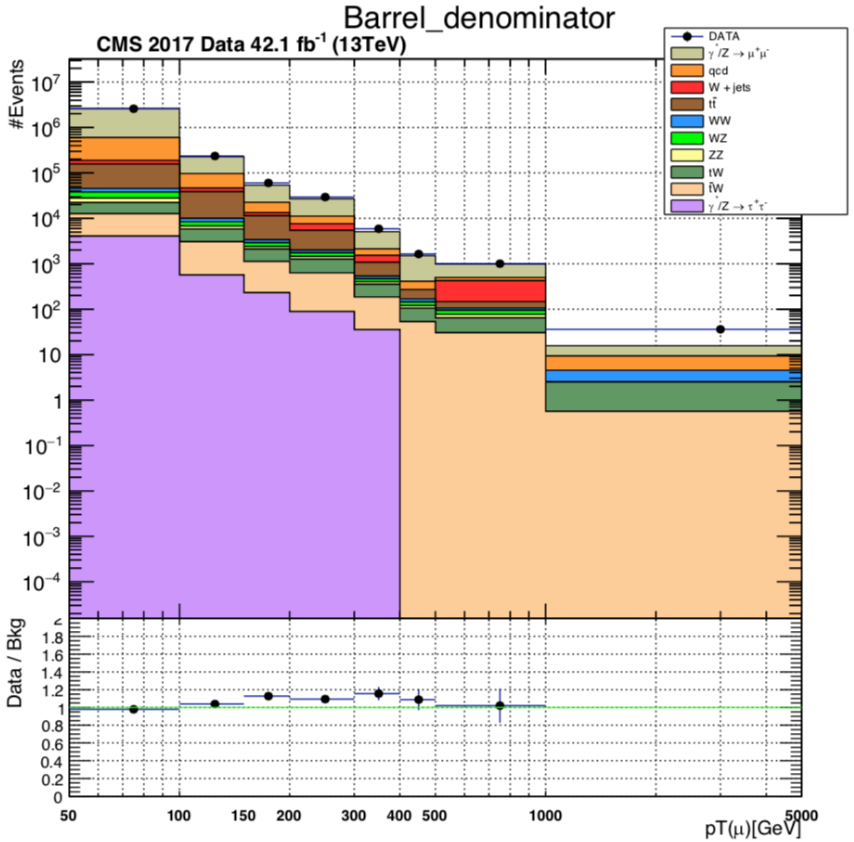


- Comparatively better Data/MC ratio is seen in low p_T bins after applyling latest SFs
- The large contribution of QCD events in the distribution of the denominator is clearly visible and provides us with confidence that the control region defined above is enriched in fakeable objects.

Muon p_T - 2017

Using FR denominator and numerator definition for Barrel

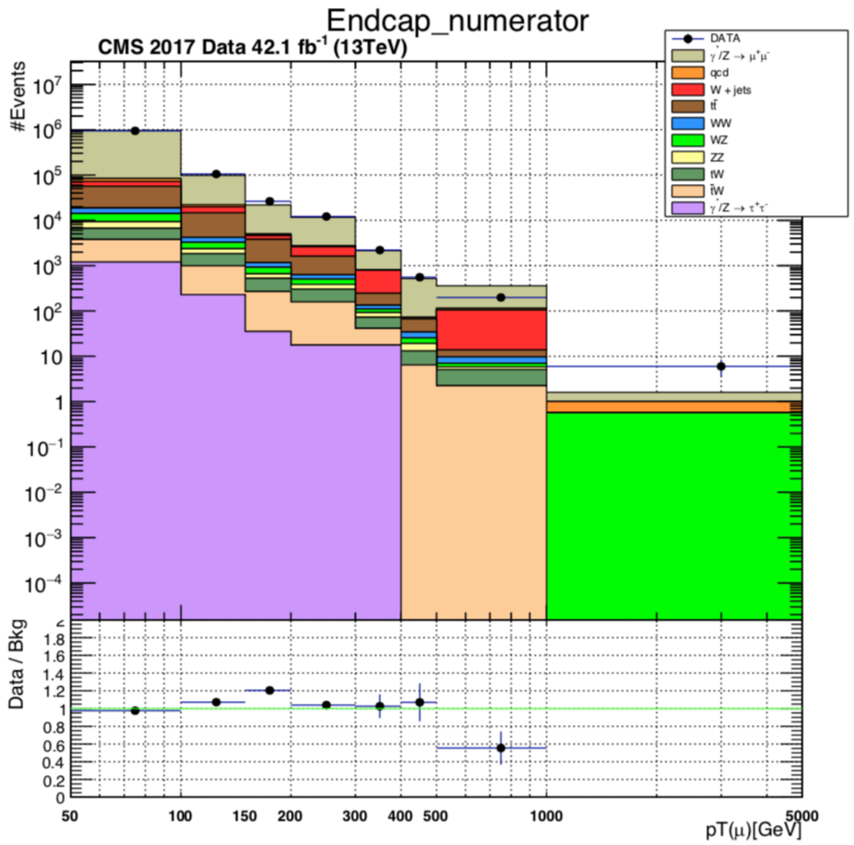


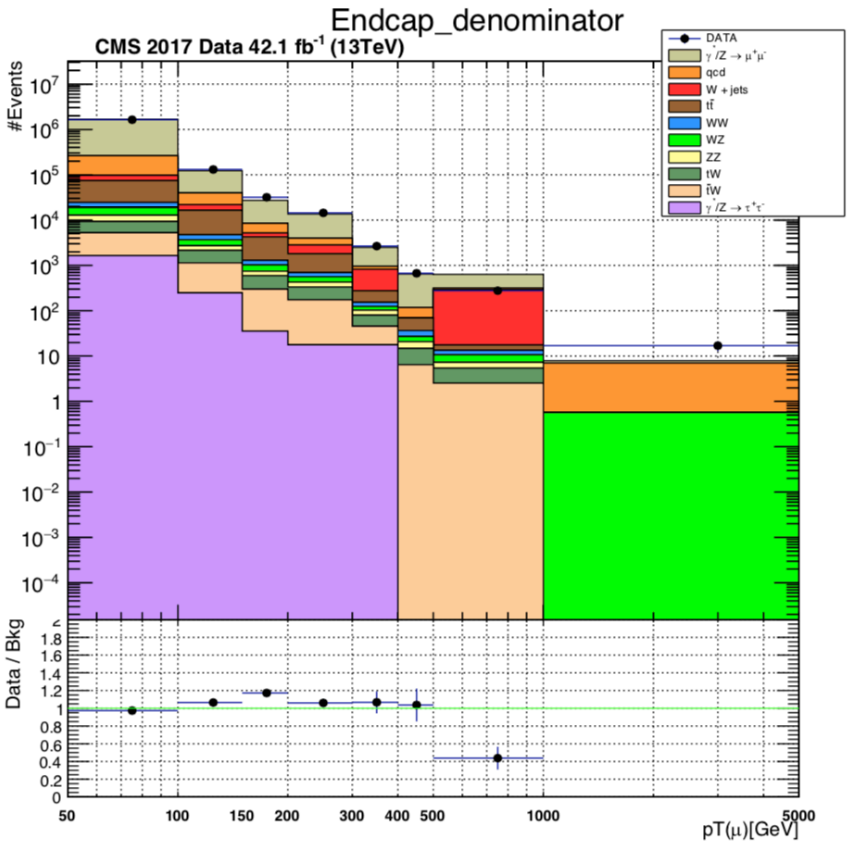


- Comparatively better Data/MC ratio is seen in all p_T bins after applyling latest SFs
- The large contribution of QCD events in the distribution of the denominator is clearly visible and provides us with confidence that the control region defined above is enriched in fakeable objects.

Muon p_T - 2017

Using FR denominator and numerator definition for Endcap





- Comparatively better Data/MC ratio is seen in all p_T bins after applyling latest SFs
- The large contribution of QCD events in the distribution of the denominator is clearly visible and provides us with confidence that the control region defined above is enriched in fakeable objects.