Studying muon pair production based on open data from CMS

THE XV-th INTERNATIONAL SCHOOL-CONFERENCE «THE ACTUAL PROBLEMS OF MICROWORLD PHYSICS»

Minsk, Belarus, 27 August – 3 September, 2023

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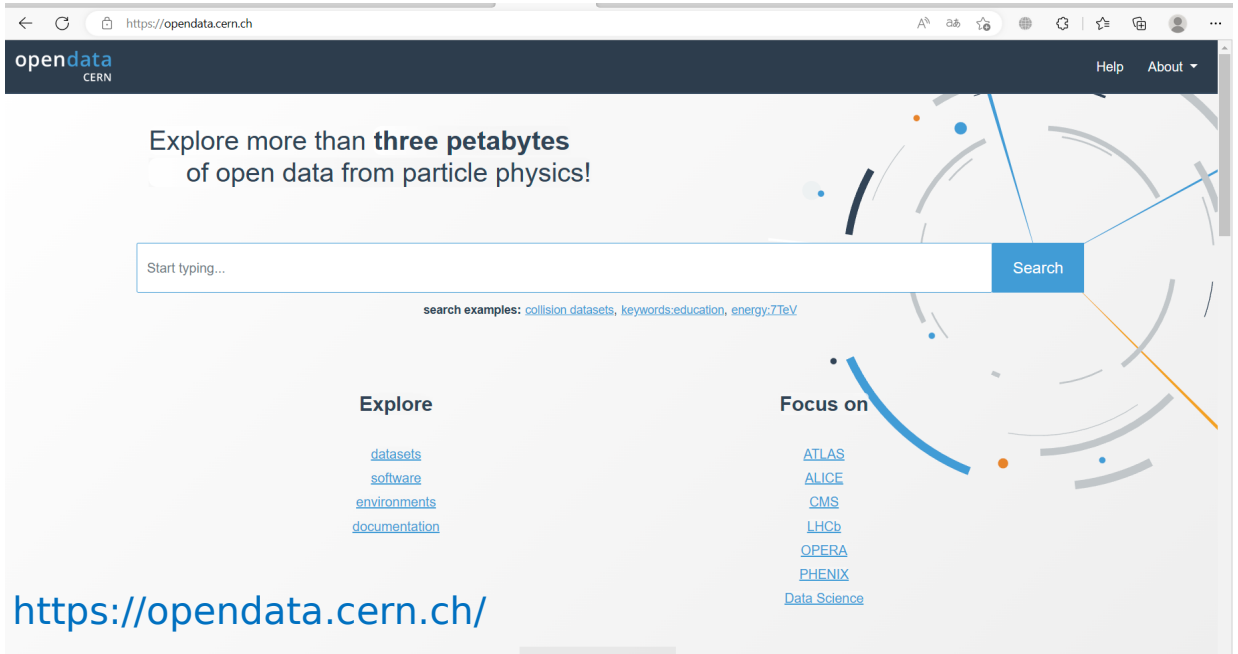
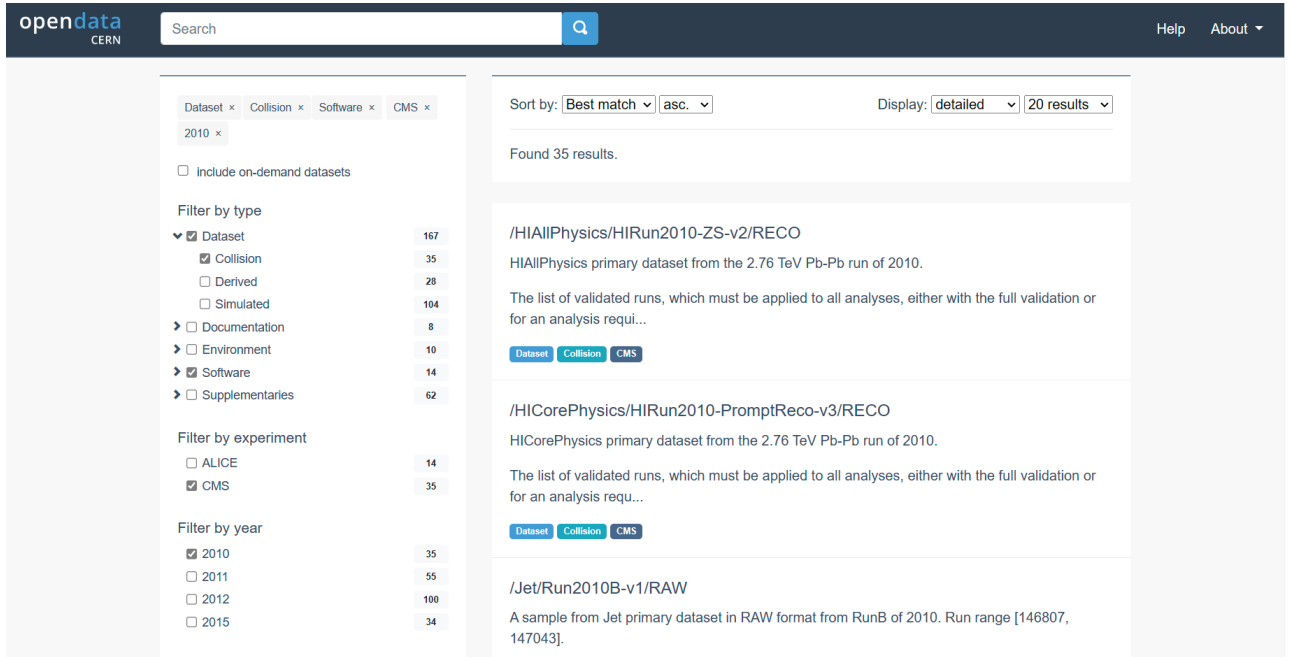
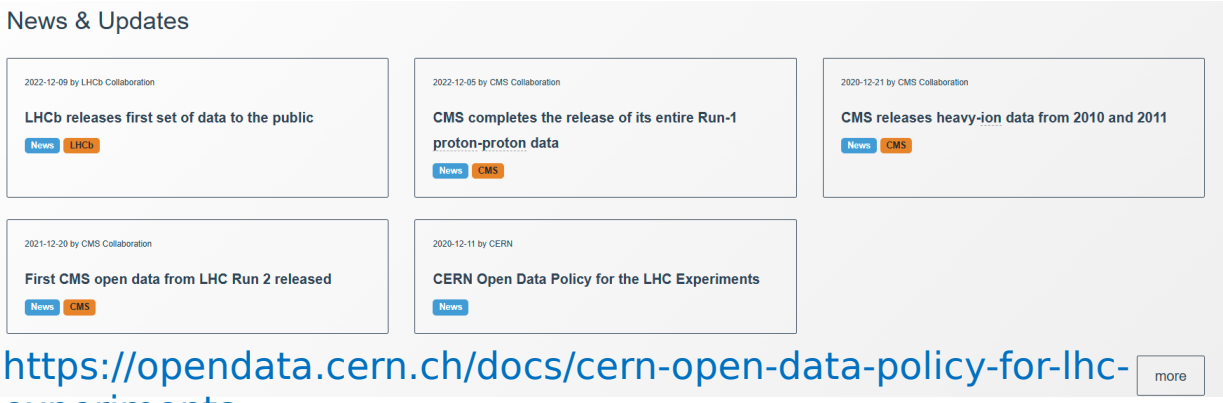
JINR, Dubna University

Open Data CMS



https://opendata.cern.ch/

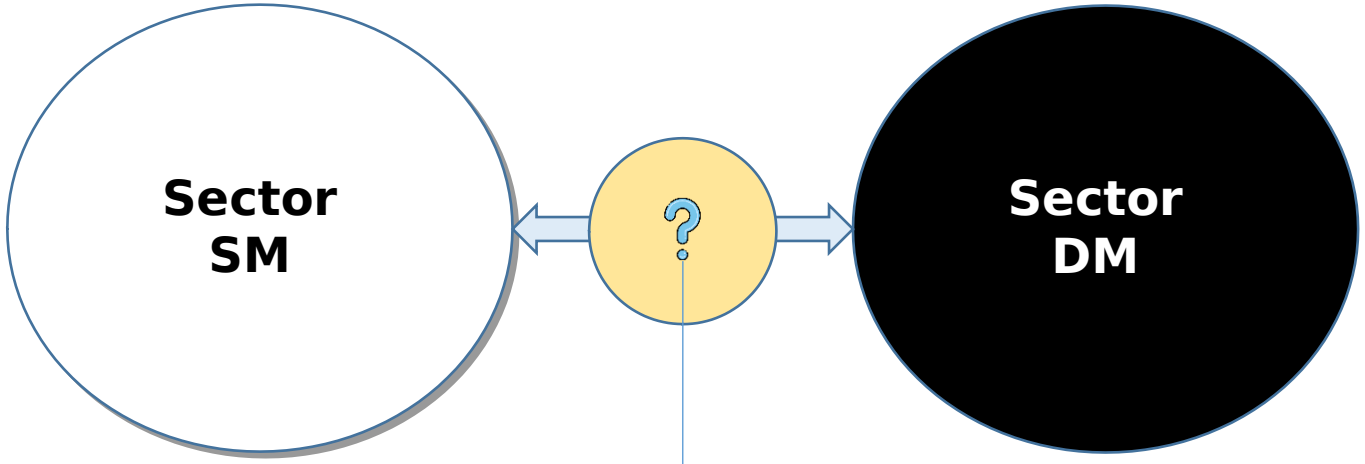


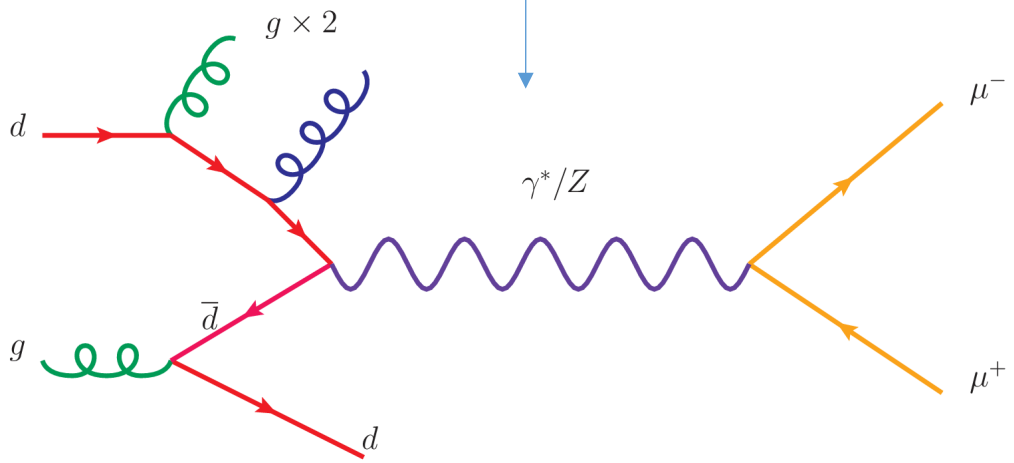


https://opendata.cern.ch/docs/cern-open-data-policy-for-lhc-experiments

Articles using CMS open data

1. Search for the production of dark matter candidates in association with heavy dimuon resonance using the CMS open data for pp collisions at √ s = 8 TeV arXiv:2109.11274v3
2. Disentangling Quarks and Gluons with CMS Open Data arXiv:2205.04459v2
3. Jet Substructure Studies with CMS Open Data arXiv:1704.05842v3





Drell-Yan process

The Drell-Yan process is the main background in the search for signals of new physics beyond the Standard Model (SM), particularly in the search for candidate particles for the role of the Dark Matter

CMS NOTE AN-11-013

Measurement of the Drell-Yan Cross Section in pp Collisions at √s = 7 TeV

arXiv:1108.0566

Datasets and selection criteria for muons

Reconstructed datasets :
Mu Run2010A Apr21ReReco-v1 AOD
Mu Run2010B Apr21ReReco-v1 AOD

- The energy in the center-of-mass frame is 7 TeV
- Luminosity: $10^{27} cm^{-2} c$

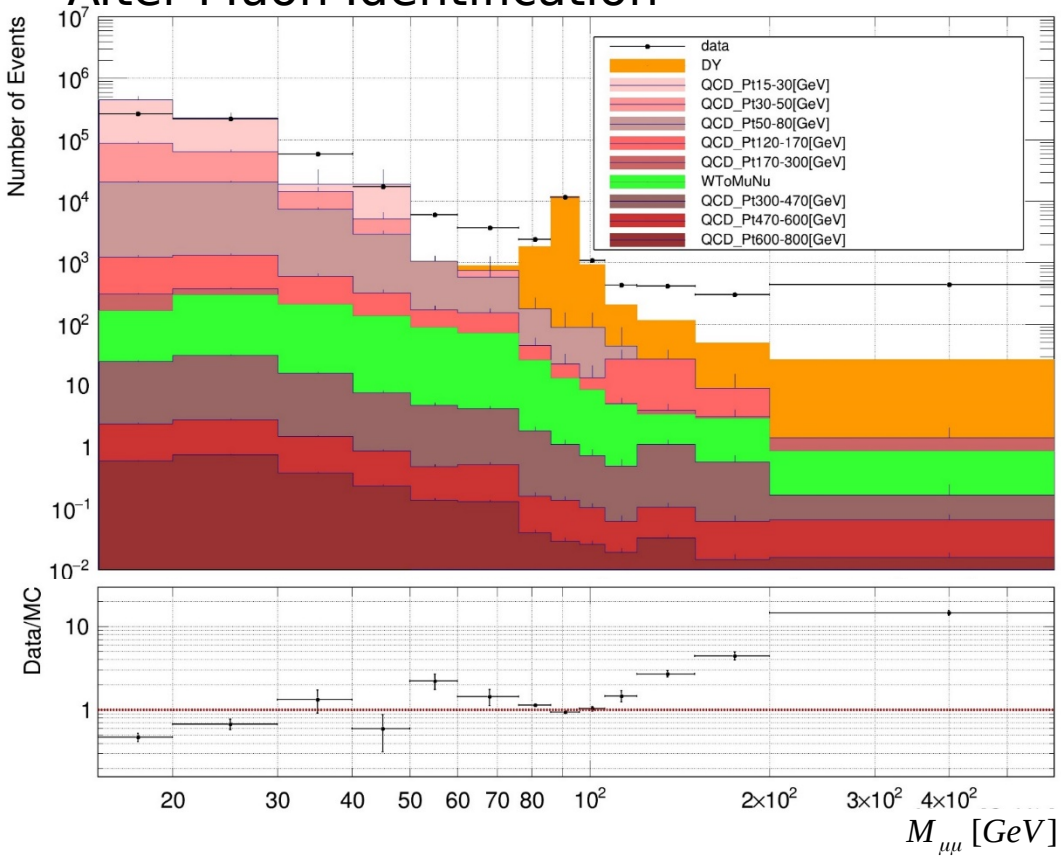
Monte-Carlo datasets:
DYToMuMu M-20 TuneZ2Star, 1300.0 pb
WToMuNu TuneZ2star, 9181.0 pb
QCD_Pt_15to30_TuneZ2star, 815,912,800.0 pb
QCD_Pt_30to50_TuneZ2star, 53122370.0 pb
QCD_Pt_50to80_TuneZ2star, 6359119.0 pb
QCD_Pt_120to170_Tune4C, 128761.3 pb
QCD_Pt_170to300_TuneZ2star, 24262.83 pb
QCD_Pt_300to470_TuneZ2star, 1168.494 pb
QCD_Pt470to600_Tune23, 77.03948 pb
QCD_Pt600to800_Tune23, 15.55374 pb

- PYTHIA6 with CTEQ6 PDF function
- $\alpha_S = 0.12978$

Name	Selection cut
Kinematic	
Muon identification	$p_T > 7\ GeV/c$, $\lvert\eta\rvert < 2.1$ Each muon should be Global and Tracker Muon $\chi^2 / ndof > 10\%$ $N_{trk} > 10$ $N_{muon} > 0$ $N_{pixel} > 0$
Impact parameter	$N_{segmentmachted} > 1$
Isolation	$\lvert d_{xy} \rvert < 2\ mm$
Angel between muon tracks	$\sum_i (I_{trk} + I_{HACL}) / p_T^{\mu} < 0.15$ $\alpha_{3D} = ((p_1^{track}, p_2^{track}) / p_1^{track} / p_2^{track}) < 5\ mrad$
Vertex Probability	$VP > 0.02$

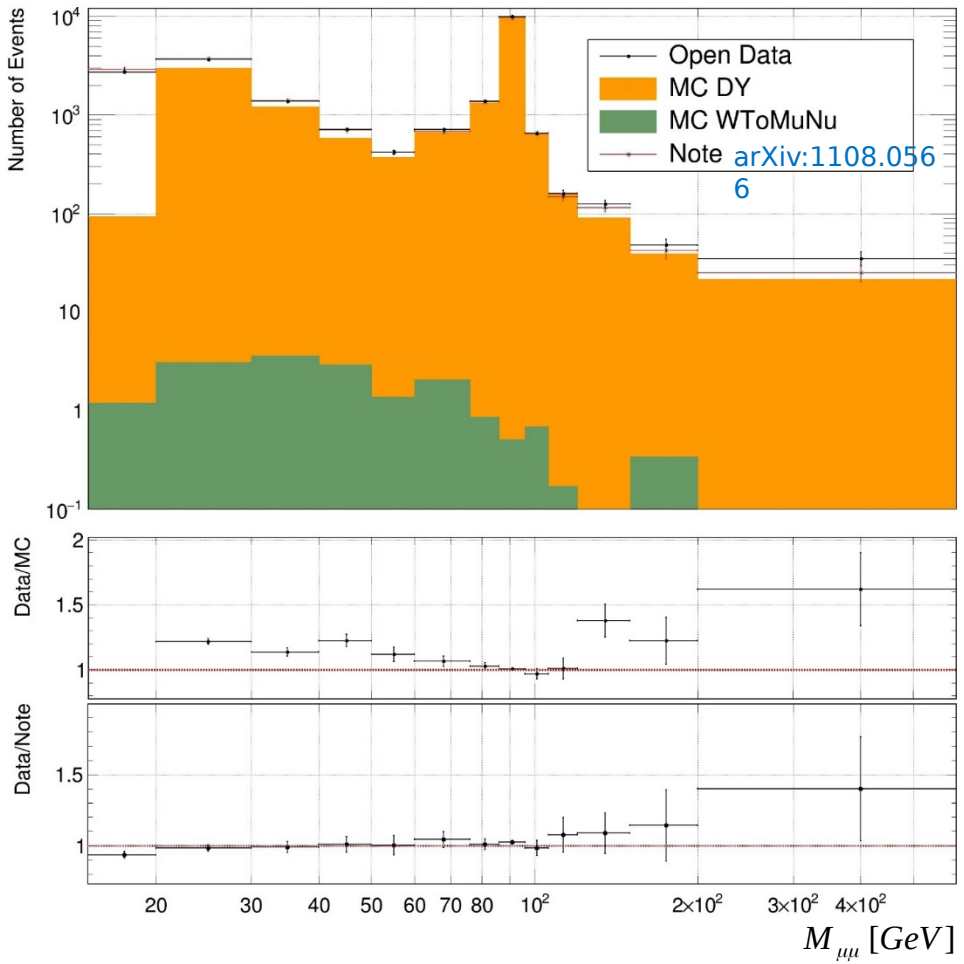
Invariant mass of muon pair

After Muon Identification



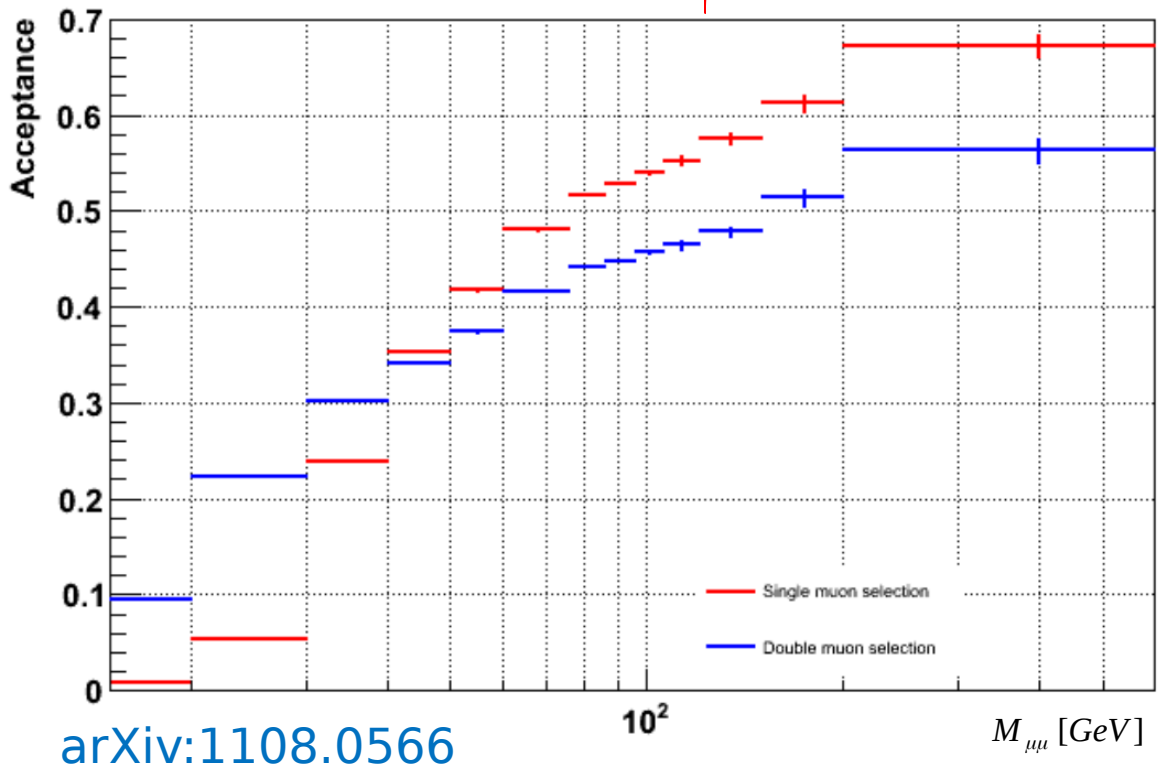
$k = \frac{\sigma_{MC} L_{ing}}{N_{MC}}$ normalization coefficient

After all of cuts

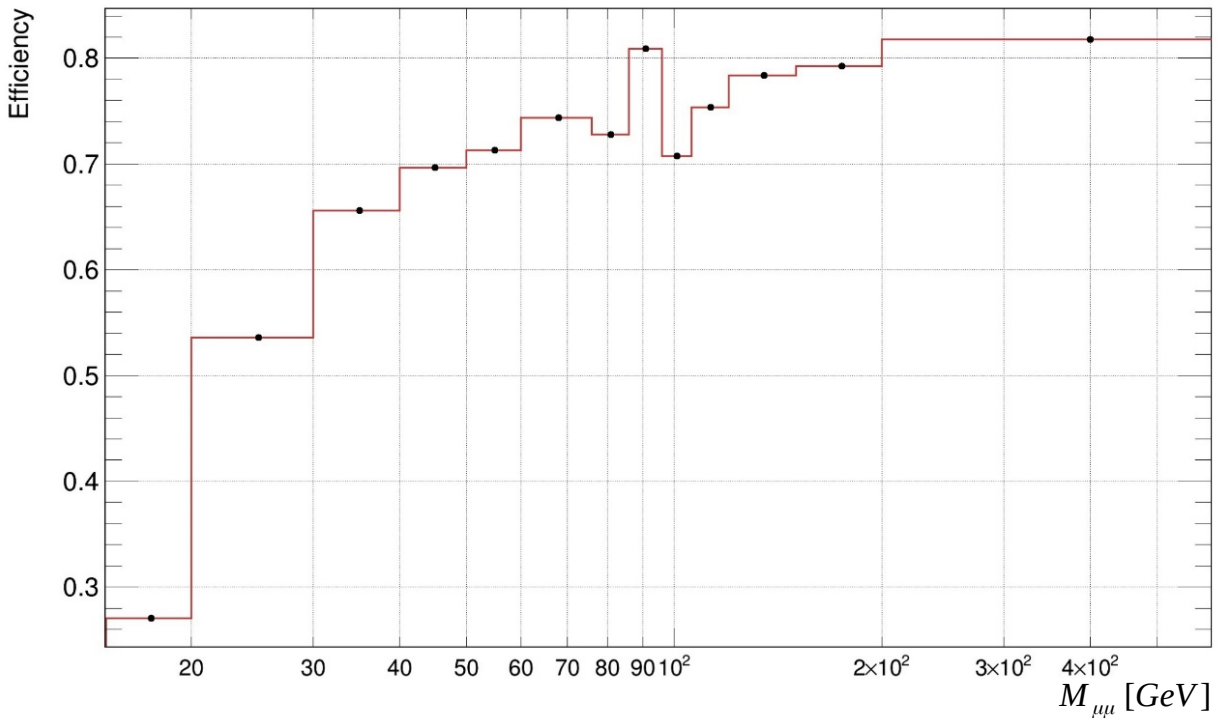


Efficiency

$$E(Full\ Eff.) = A(Eff.Acc.) \cdot \varepsilon, \quad \varepsilon(Eff.\ selection\ \ and\ reco.) = \varepsilon_{reco} \cdot \varepsilon_{trigger} \cdot \varepsilon_{identficaton} \cdot \varepsilon_{iso} \ldots$$

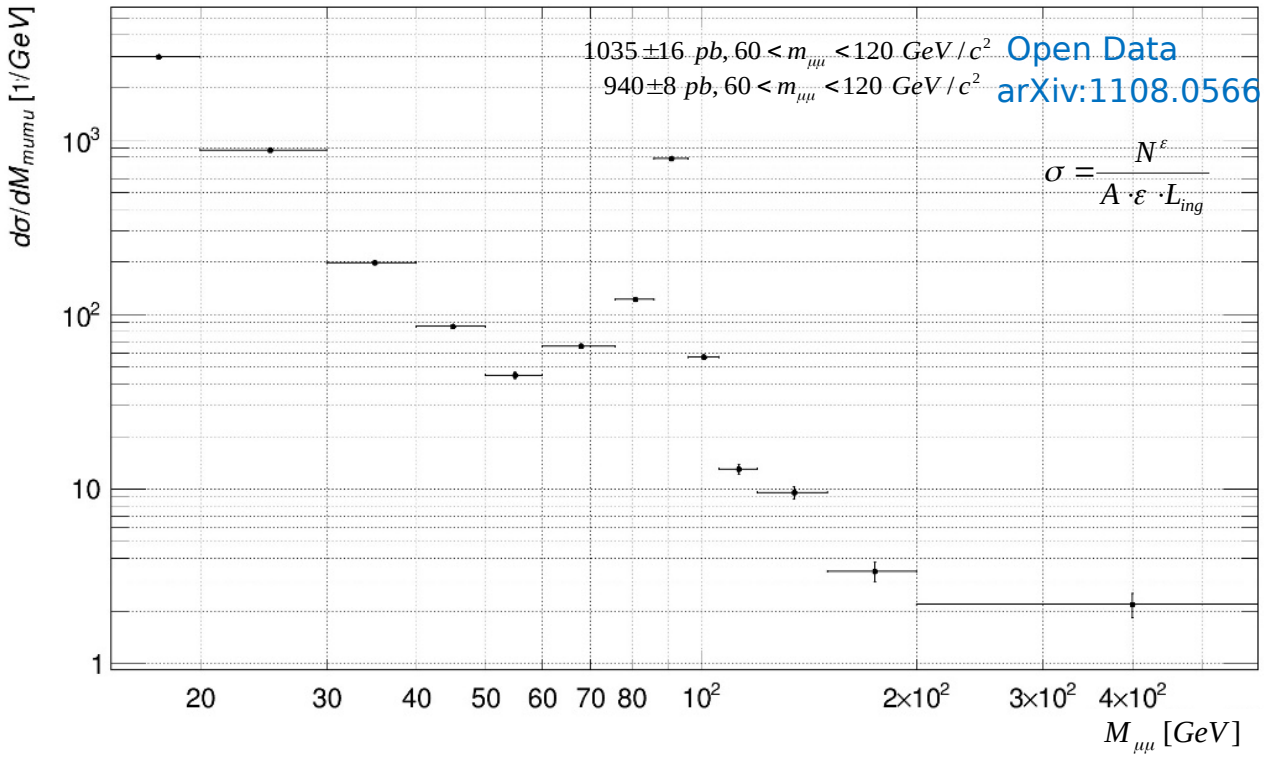


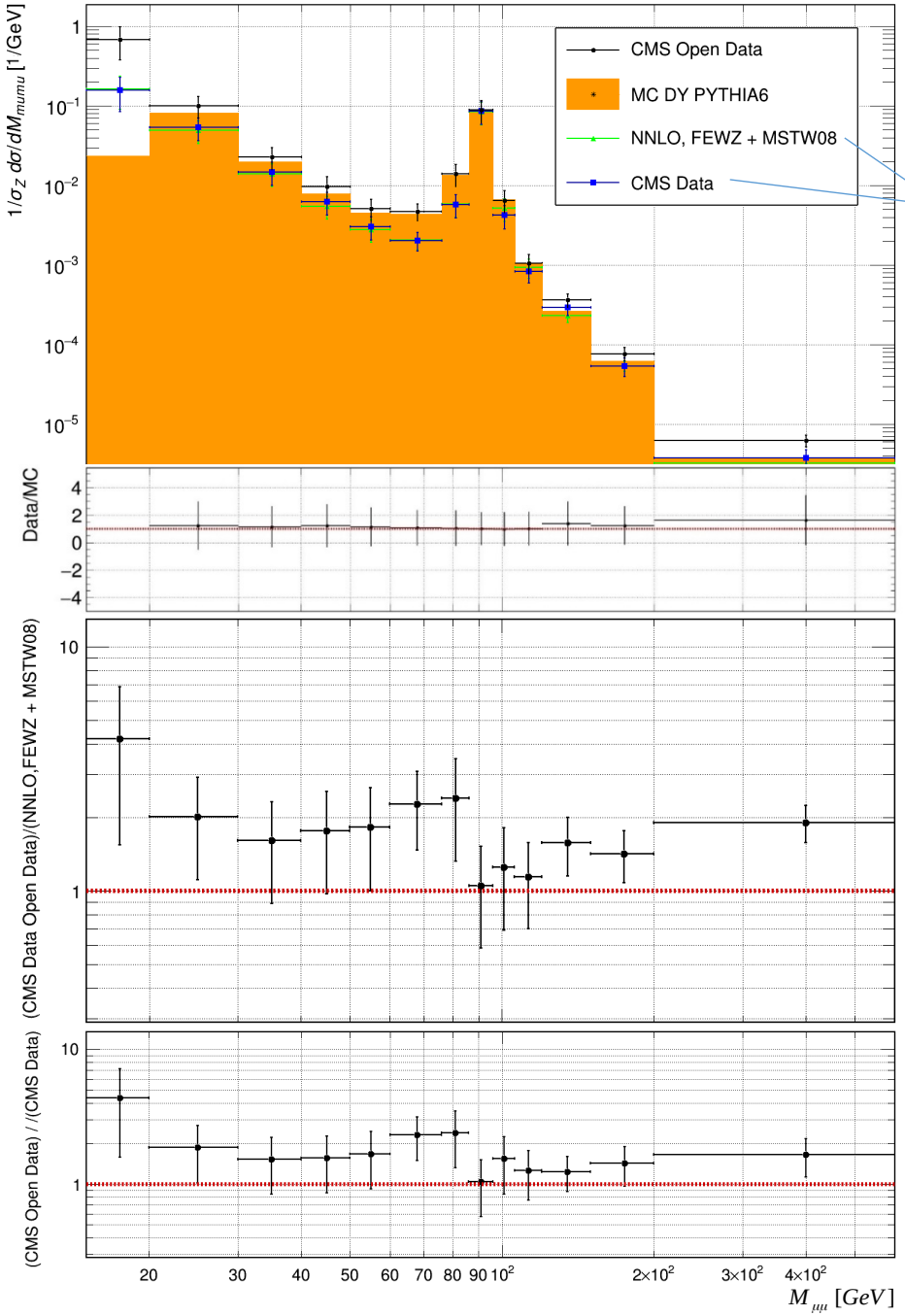
arXiv:1108.0566



Cross Section

$$R_i = \frac{\dfrac{N^{\varepsilon}}{A \cdot \varepsilon}}{\dfrac{N^{\varepsilon}_{norm}}{A_{norm} \cdot \varepsilon_{norm}}}, \quad r_i = \frac{R_i}{\Delta M_i}$$





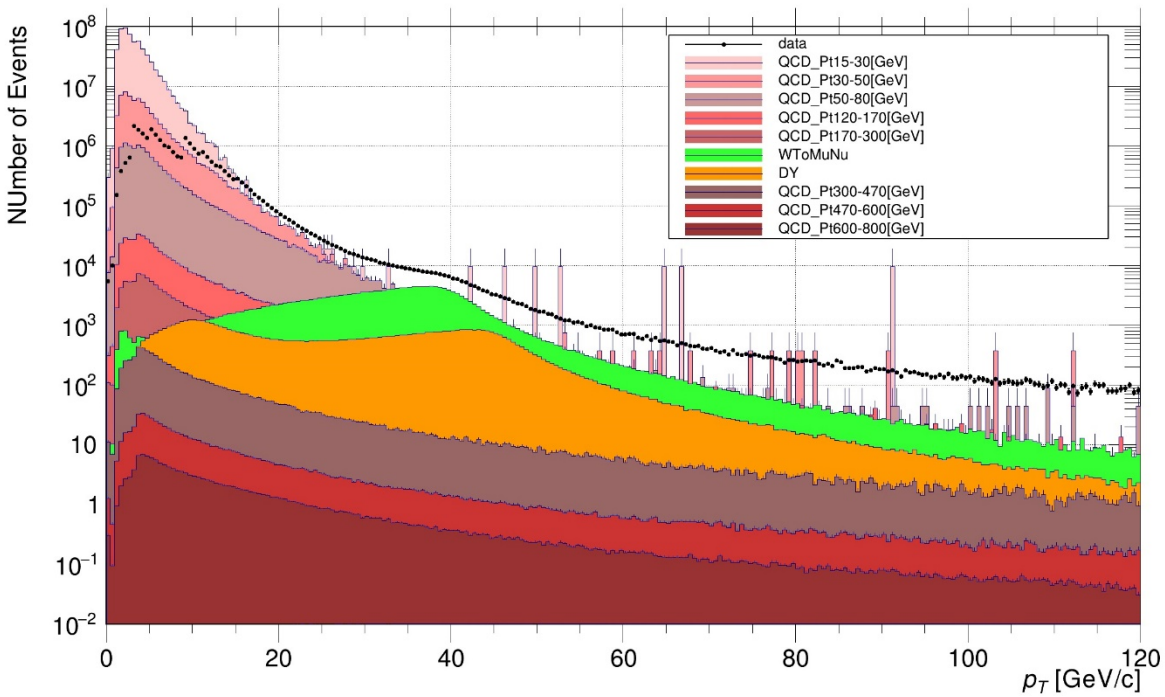
Conclusions

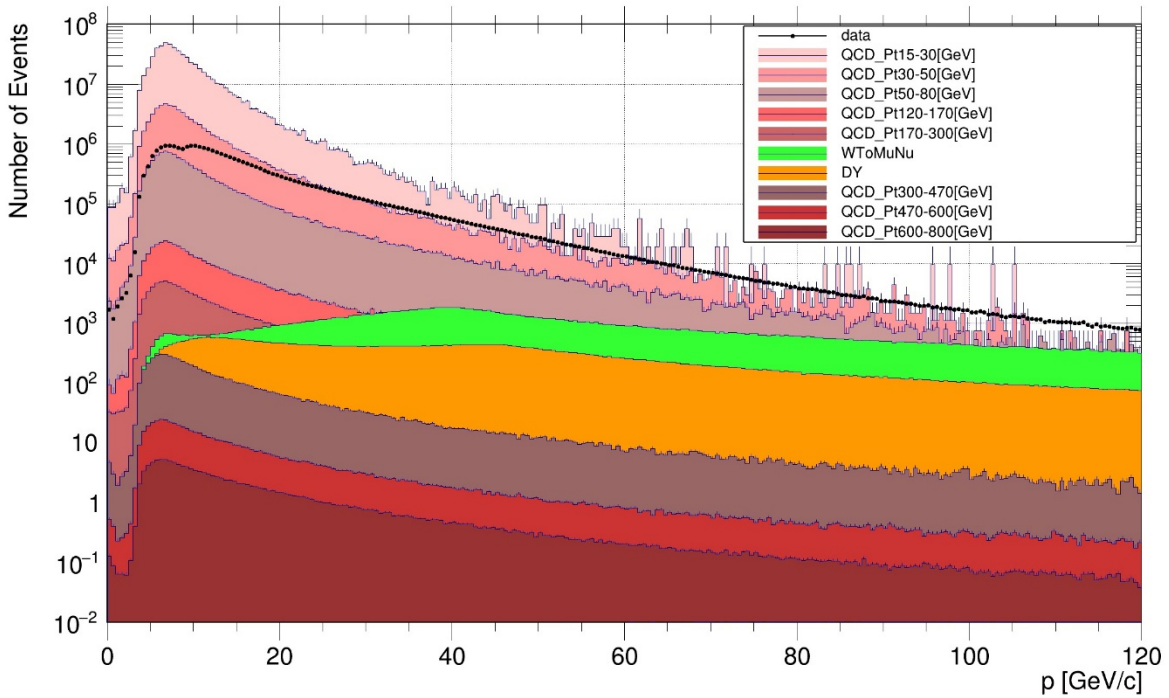
- All statistics from RUN2010 have been analyzed
  - ✓ Kinematic characteristics of events with muon pairs have been obtained
  - ✓ The Differential cross-section of the Drell-Yan process has been calculated based on the invariant mass of muon pairs $1035 \pm 16\ pb,\ 60 < m_{\mu\mu} < 120\ GeV/c^2$
  - ✓ A comparison is made between the results of the analysis of the CMS open data and predictions of the Standard Model, as well as previously published results from the collaboration.
  - ✓ The agreement between the measurement results and calculations at the leading-order of the electroweak theory and the next-to-leading order of QCD is demonstrated

- The results of this work can be used in further searches for physics beyond the Standard Model, particularly in the search for candidate particles for dark matter

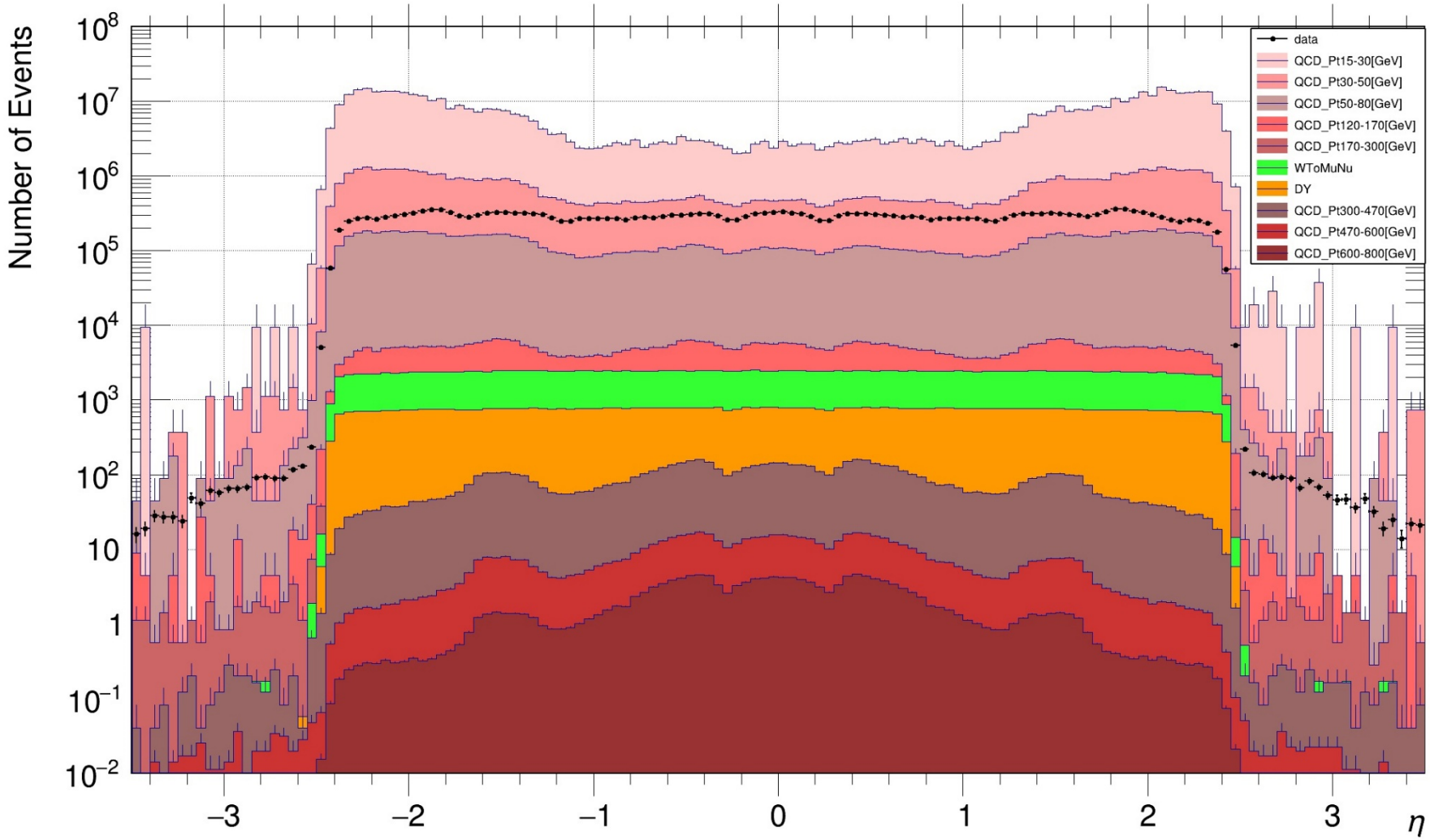
Thanks for your attention!

Backup (1)

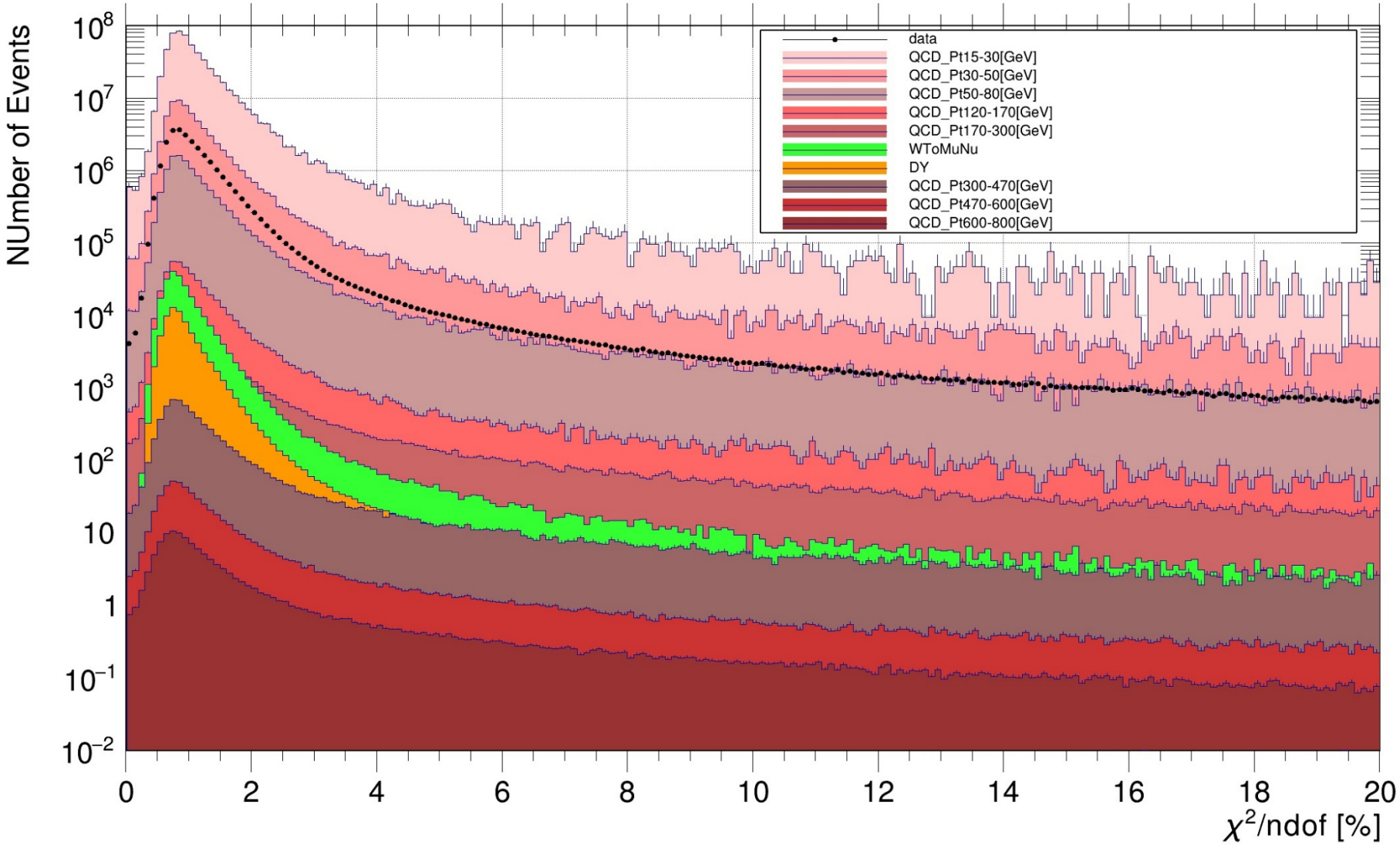

NUmber of Events
p_T [GeV/c]
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]


Number of Events
p [GeV/c]
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

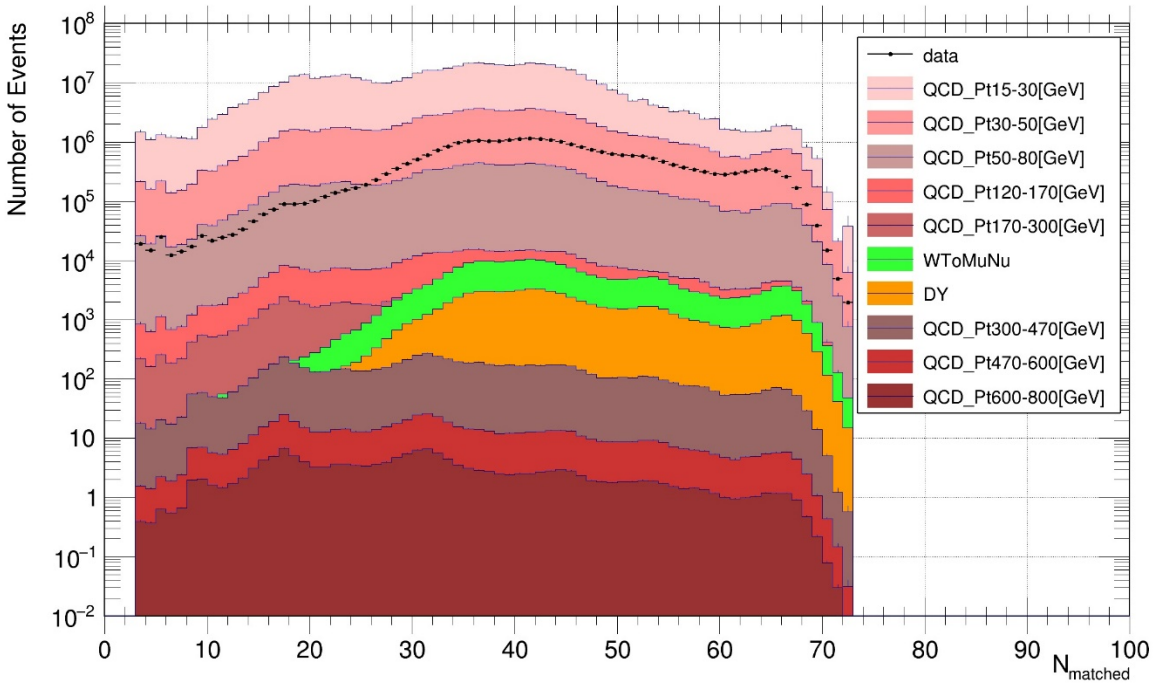
Backup (2)

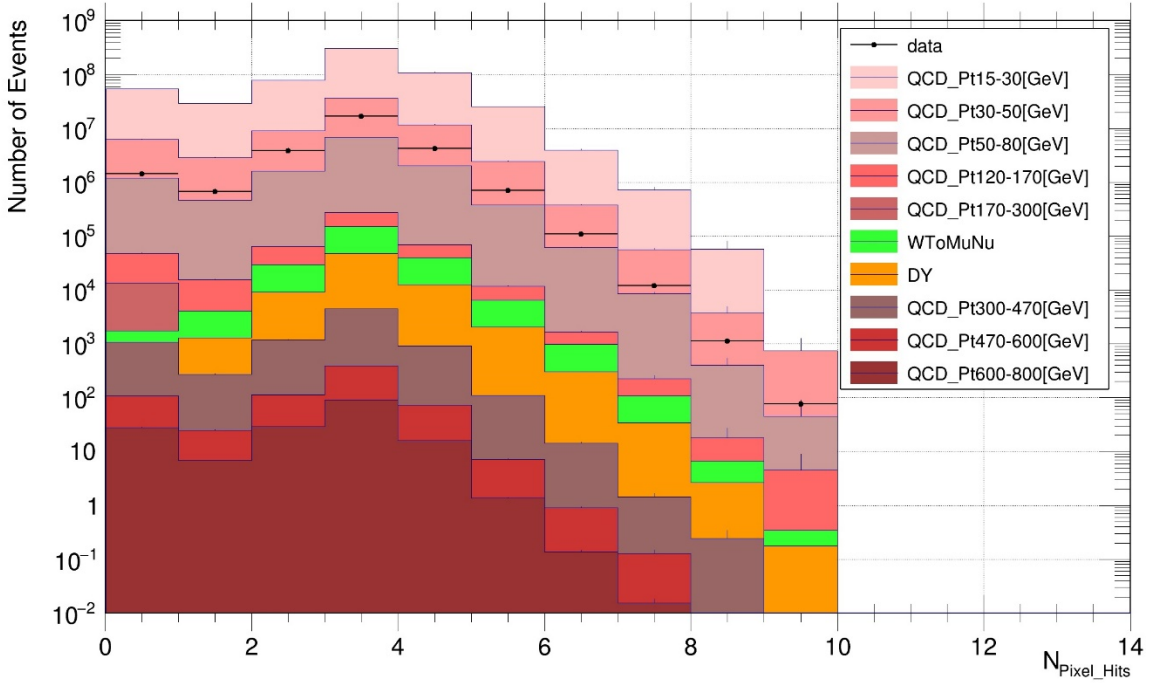

Number of Events
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
−3
−2
−1
0
1
2
3
η
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

Backup (3)

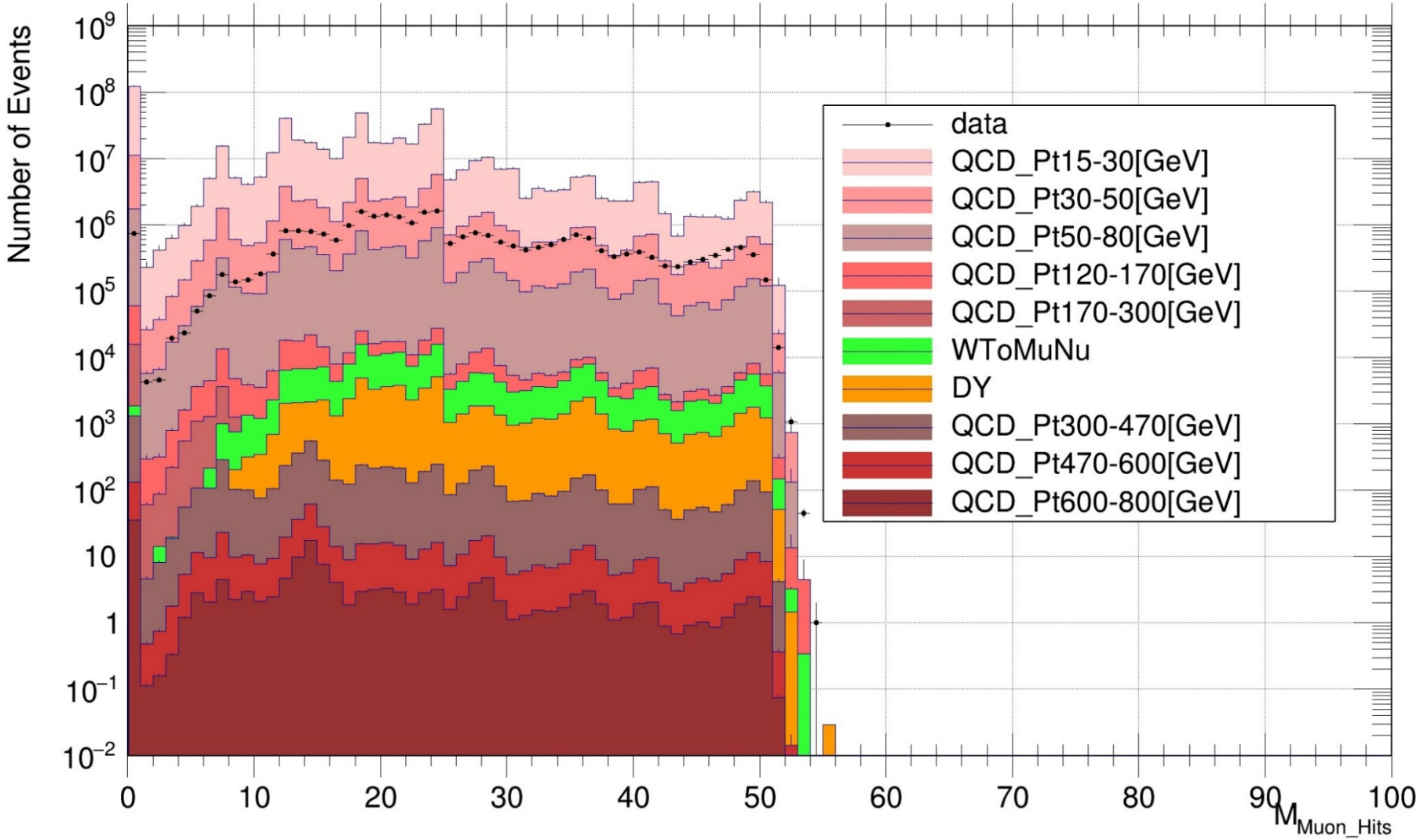

NUmber of Events
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
2
4
6
8
10
12
14
16
18
20
χ^2/ndof [%]
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

Backup (4)

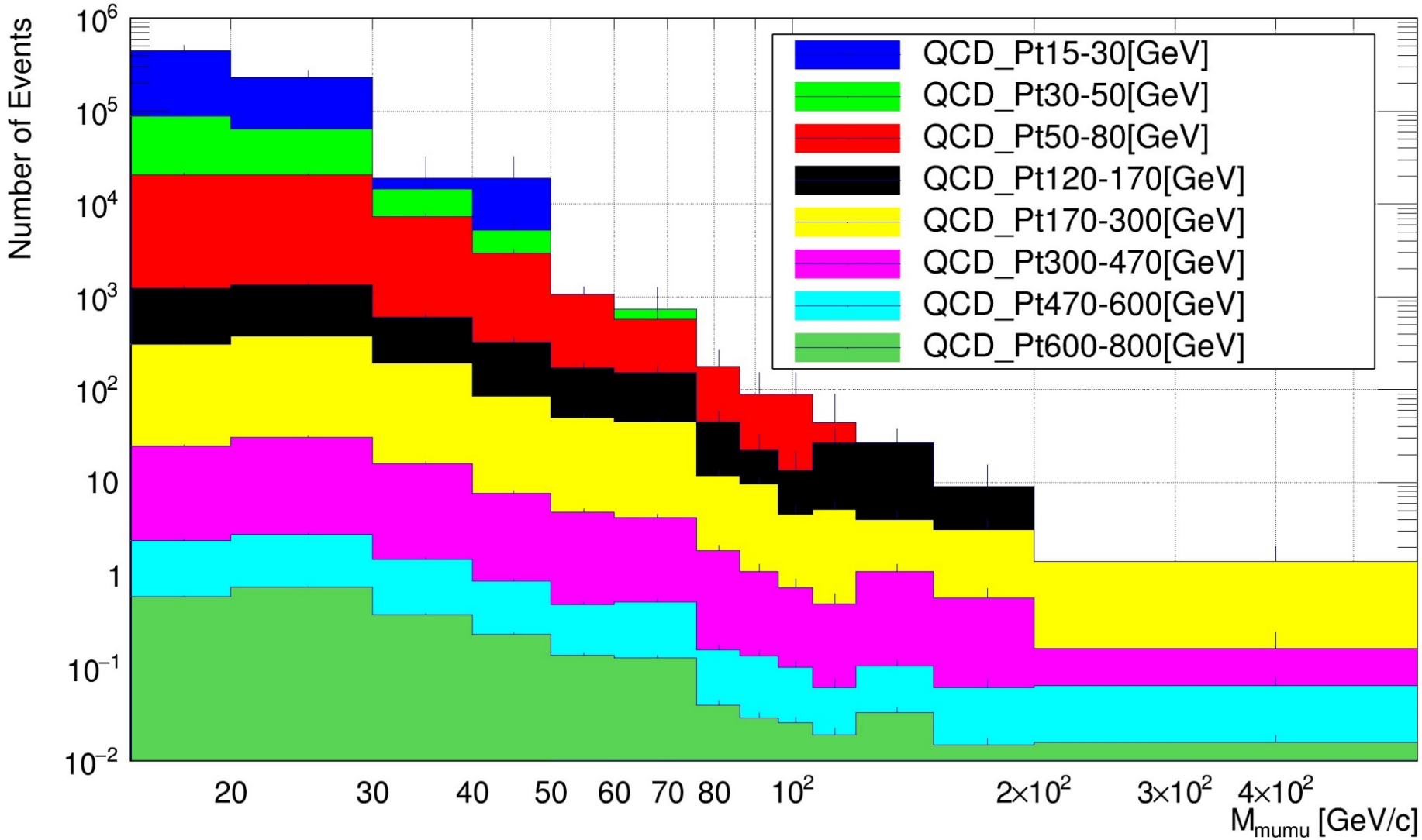

Number of Events
$N_{matched}$
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]


Number of Events
N_{Pixel_Hits}
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

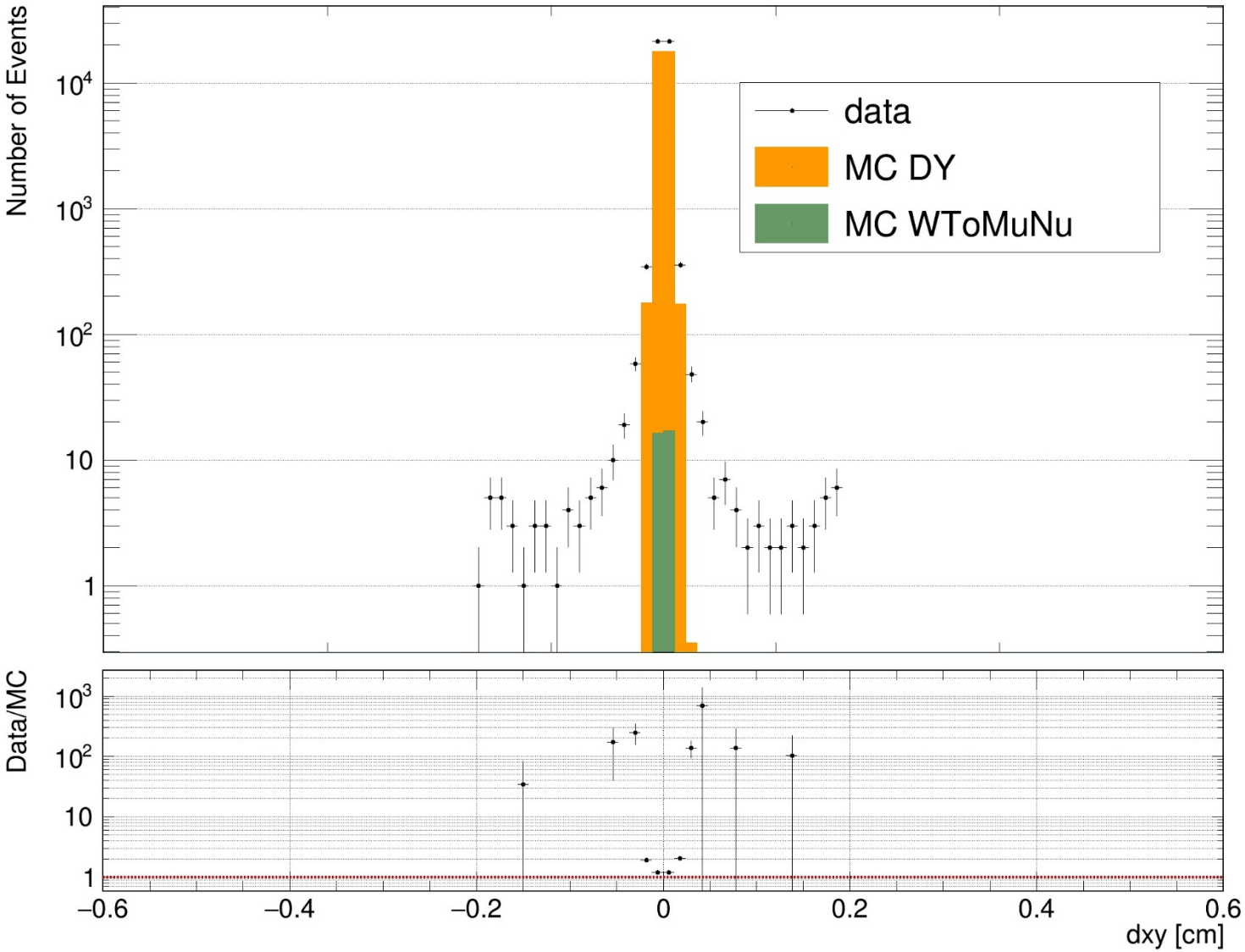
Backup (5)


Number of Events
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
10
20
30
40
50
60
70
80
90
100
M_{Muon_Hits}
data
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
WToMuNu
DY
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

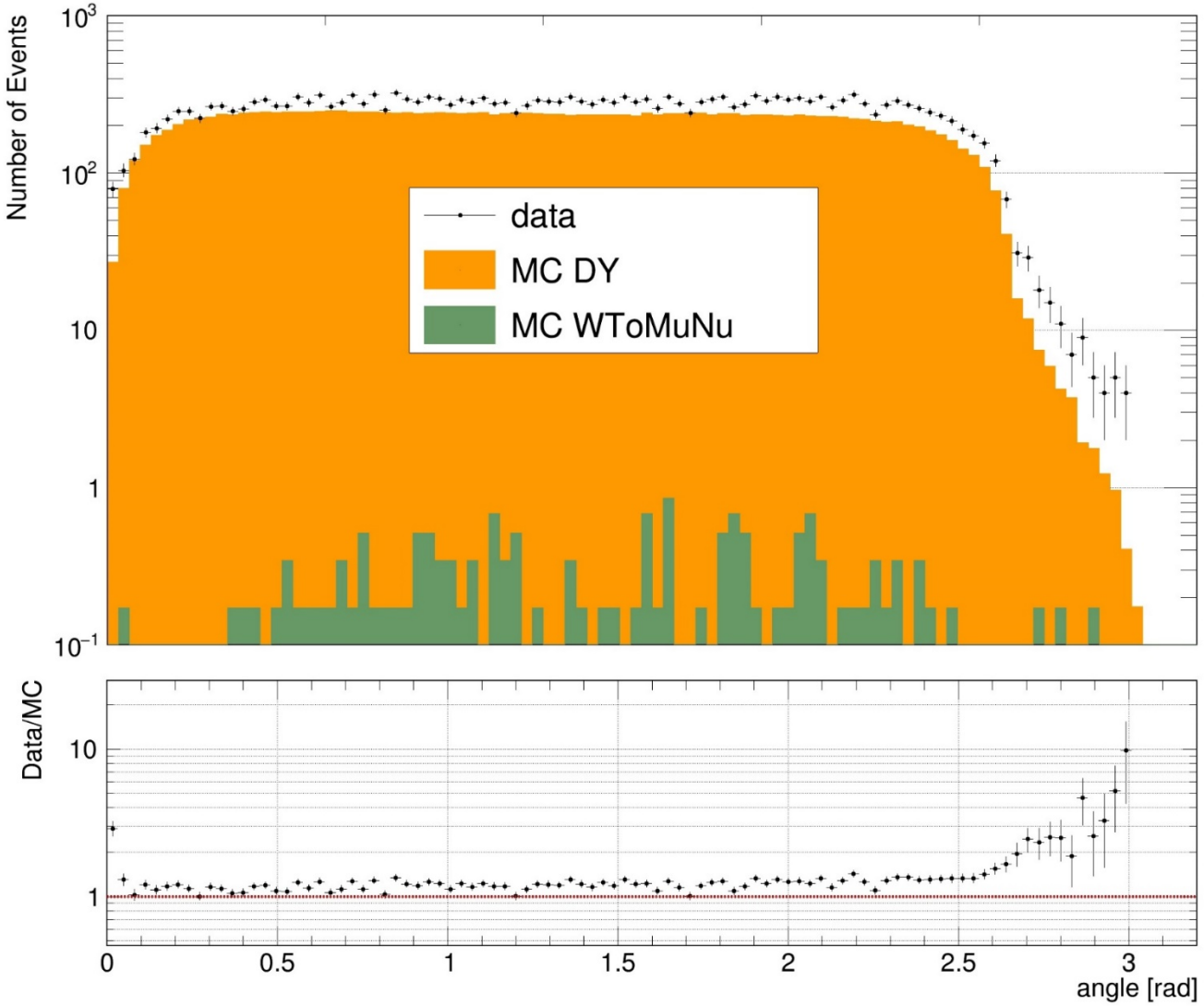
Backup (6)


Number of Events
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
20
30
40
50
60
70
80
10^2
2×10^2
3×10^2
4×10^2
M_{mumu} [GeV/c]
QCD_Pt15-30[GeV]
QCD_Pt30-50[GeV]
QCD_Pt50-80[GeV]
QCD_Pt120-170[GeV]
QCD_Pt170-300[GeV]
QCD_Pt300-470[GeV]
QCD_Pt470-600[GeV]
QCD_Pt600-800[GeV]

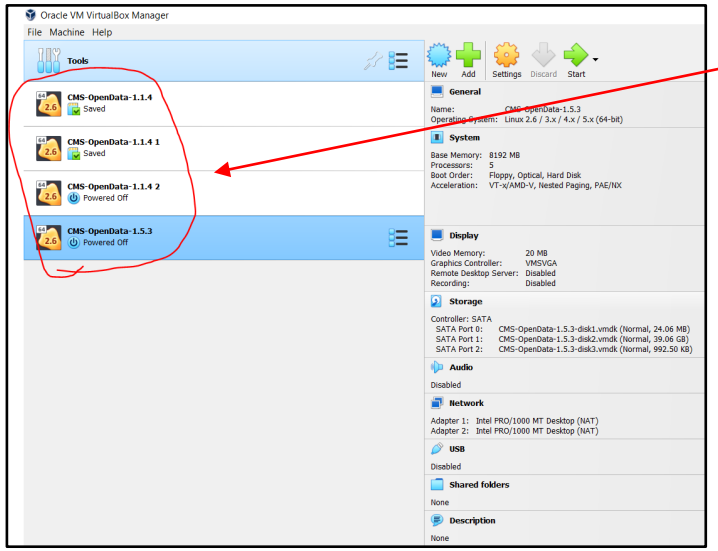
Backup (7)


Number of Events
10^4
10^3
10^2
10
1
data
MC DY
MC WToMuNu
Data/MC
10^3
10^2
10
1
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
dxy [cm]

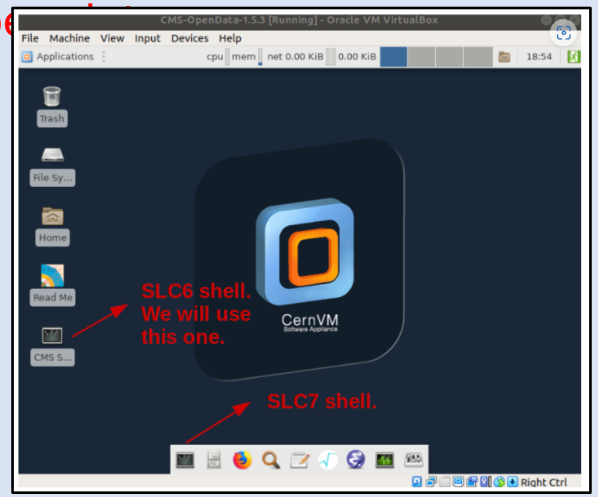
Backup (8)


Number of Events
10^3
10^2
10
1
10^{-1}
data
MC DY
MC WToMuNu
Data/MC
10
1
0
0.5
1
1.5
2
2.5
3
angle [rad]

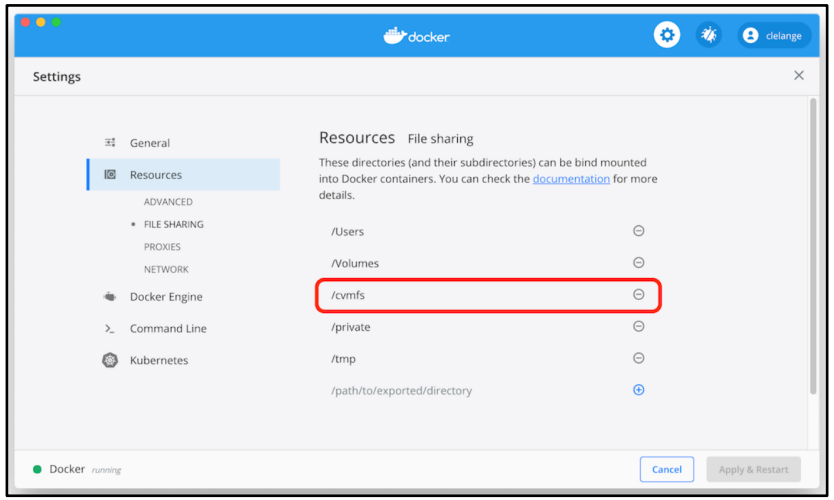
Backup (9)

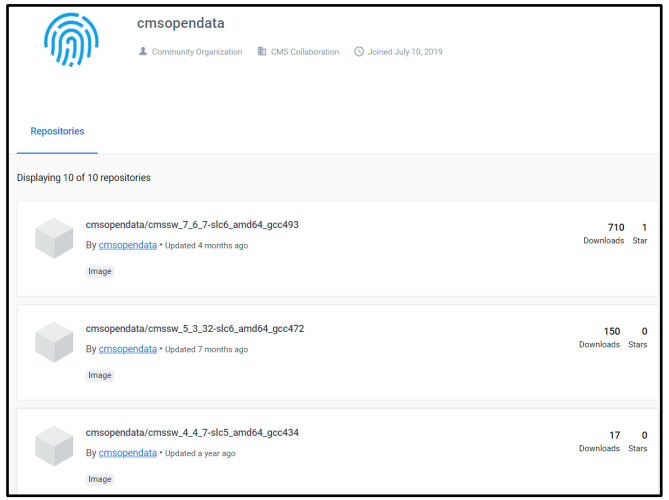


CMS VM Image, for 2010 CMS ope



1. VirtualBox





2. Docker

Backup (10)

CMS AN-15-324
arXiv:1812.10529

Стат
ья

Dataset	Run range
/SingleMuon/Run2015C_25ns-16Dec2015-v1/MINIAOD	253888-254914
/SingleMuon/Run2015D-16Dec2015-v1/MINIAOD	256629-260627
/SingleElectron/Run2015C_25ns-16Dec2015-v1/MINIAOD	254227-254914
/SingleElectron/Run2015D-16Dec2015-v1/MINIAOD	256630-260627

Table 1: Details of the 2015 datasets.

Channel	Dataset	Proc.	Lum.(fb^{-1})
Muon	Cert_13TeV_16Dec2015ReReco_Collisions15_25ns_JSON_MuonPhys.txt	Rereco	2.76
Muon	Cert_13TeV_16Dec2015ReReco_Collisions15_25ns_JSON_Silver.txt	Rereco	2.62
Electron	Cert_246908-260627_13TeV_PromptReco_Collisions15_25ns_JSON_v2.txt	Rereco	2.26

Table 2: Details of the JSON files used in the analysis.

Интегральная светимость для D набора

L_{ing} = 2.648702895 fb^{-1}

L_{ing} = 2.255382597 fb^{-1}

Открытые данные

SingleMuon primary dataset in AOD format from RunD of 2015 (/SingleMuon/Run2015D-16Dec2015-v1/AOD)

/SingleMuon/Run2015D-16Dec2015-v1/AOD, CMS collaboration

Cite as: CMS collaboration (2021). SingleMuon primary dataset in AOD format from RunD of 2015 (/SingleMuon/Run2015D-16Dec2015-v1/AOD). CERN Open Data Portal. DOI:10.7483/OPENDATA.CMS.VO9I.66P1

Dataset Collision CMS 13TeV CERN-LHC

DoubleMuon primary dataset in MINIAOD format from RunD of 2015 (/DoubleMuon/Run2015D-16Dec2015-v1/MINIAOD)

/DoubleMuon/Run2015D-16Dec2015-v1/MINIAOD, CMS collaboration

Cite as: CMS collaboration (2021). DoubleMuon primary dataset in MINIAOD format from RunD of 2015 (/DoubleMuon/Run2015D-16Dec2015-v1/MINIAOD). CERN Open Data Portal. DOI:10.7483/OPENDATA.CMS.H3TX.ZJZX

Dataset Collision CMS 13TeV CERN-LHC

Отсутствует набор «C»

CMS list of validated runs for primary datasets of 2015 data taking, only valid muons

CMS list of validated runs Cert_13TeV_16Dec2015ReReco_Collisions15_25ns_JSON_MuonPhys.txt, CMS Collaboration

Environment Validation CMS CERN-LHC

http://opendata.cern.ch/record/14211

CMS list of validated runs for primary datasets of 2015 data taking

CMS list of validated runs Cert_13TeV_16Dec2015ReReco_Collisions15_25ns_JSON_v2.txt, CMS Collaboration

Environment Validation CMS CERN-LHC

http://opendata.cern.ch/record/14210

Backup (11)

Открытые данные

CMS AN-15-324
arXiv:1812.10529

Статья

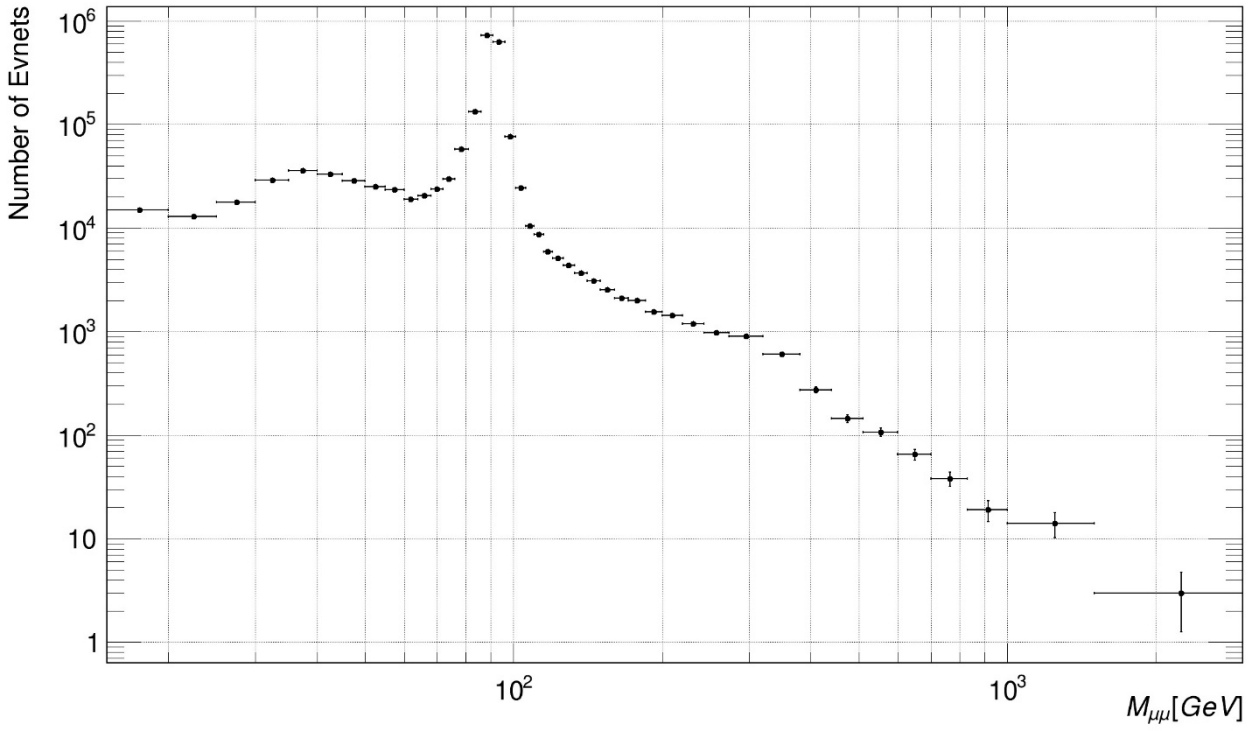
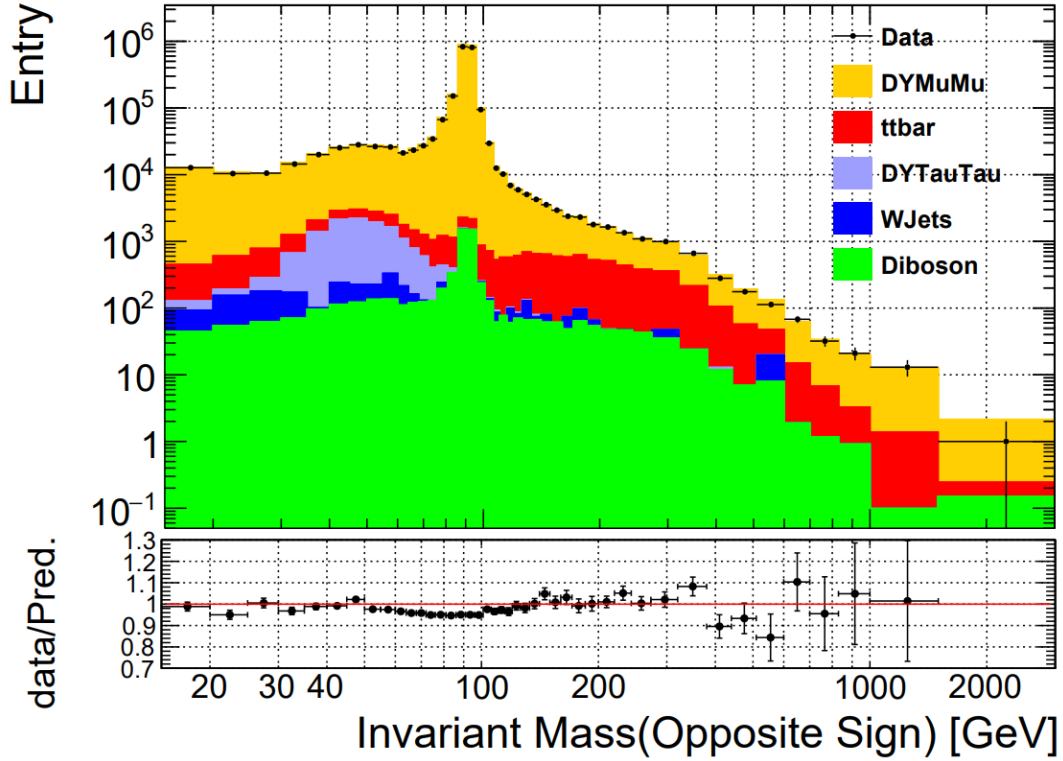
Dataset path	X-section*Eff(pb)
/DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	18610
/DYJetsToLL_M-50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	6025.2
/DYJetsToLL_M-100to200_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	226
/DYJetsToLL_M-200to400_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	7.67
/DYJetsToLL_M-400to500_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.423
/DYJetsToLL_M-500to700_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.24
/DYJetsToLL_M-700to800_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.035
/DYJetsToLL_M-800to1000_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.03
/DYJetsToLL_M-1000to1500_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.016
/DYJetsToLL_M-1500to2000_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.002
/DYJetsToLL_M-2000to3000_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext1-v1/MINIAODSIM	0.00054
/TT_TuneCUETP8M1_13TeV-powheg-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext3-v1/MINIAODSIM	831.76
/ST_tW_top_5f_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	38.09
/ST_tW_antitop_5f_inclusiveDecays_13TeV-powheg-pythia8_TuneCUETP8M1/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	38.09
/WJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	61526
/WW_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	118.7
/WZ_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	47.13
/ZZ_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	16.523
/QCD_Pt-20to30_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	558528000*0.0053
/QCD_Pt-30to50_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	139803000.0*0.01182
/QCD_Pt-50to80_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	19222500.0*0.02276
/QCD_Pt-80to120_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	2758420.0*0.03844
/QCD_Pt-120to170_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	469797.0*0.05362
/QCD_Pt-170to300_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	117989.0*0.07335
/QCD_Pt-300to470_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	7820.25*0.10196
/QCD_Pt-470to600_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	645.528*0.12242
/QCD_Pt-600to800_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v3/MINIAODSIM	187.109*0.13412
/QCD_Pt-800to1000_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM	32.3486*0.14552
/QCD_Pt-1000toInf_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v3/MINIAODSIM	10.4305*0.15544

Datasets path	X-section (pb)	
DYJetsToLL_M-5to50 (http://opendata.cern.ch/record/16478)	73036	
DYJetsToLL_M-50 (http://opendata.cern.ch/record/16465)	5416	
DYJetsToLL_M-100to200 (http://opendata.cern.ch/record/16426)	169	
DYJetsToLL_M-200to400 (http://opendata.cern.ch/record/16438)	6	
DYJetsToLL_M-400to500 (http://opendata.cern.ch/record/16440)	0.3584	
DYJetsToLL_M-500to700 (http://opendata.cern.ch/record/16441)	0.1589	
DYJetsToLL_M-700to800 (http://opendata.cern.ch/record/16479)	0.02218	
DYJetsToLL_M-800to1000 (http://opendata.cern.ch/record/16482)	0.02138	
DYJetsToLL_M-1000to1500 (http://opendata.cern.ch/record/16425)		
DYJetsToLL_M-1000to1500 (http://opendata.cern.ch/record/16424)		

Datasets path	X-section (pb)	Number of Events
TT_TuneCUETP8M1 (http://opendata.cern.ch/record/19991)		
ttWJets (http://opendata.cern.ch/record/22310)		
WWTo2L2Nu (http://opendata.cern.ch/record/20661)		
WZTo1L3Nu (http://opendata.cern.ch/record/20684)		
W2JetsToLNu (http://opendata.cern.ch/record/20512)		
ZZTo4L (http://opendata.cern.ch/record/21597)		
ZZTo2L2Nu (http://opendata.cern.ch/record/21593)		
QCD_Pt-15to20 (http://opendata.cern.ch/record/18326)		
QCD_Pt-20to30 (http://opendata.cern.ch/record/18333)		
QCD_Pt-30to50 (http://opendata.cern.ch/record/18340)		
QCD_Pt-50to80 (http://opendata.cern.ch/record/18350)		
QCD_Pt-80to120 (http://opendata.cern.ch/record/18354)		
QCD_Pt-120to170 (http://opendata.cern.ch/record/18323)		
QCD_Pt-170to300 (http://opendata.cern.ch/record/18331)		
QCD_Pt-300to470 (http://opendata.cern.ch/record/18335)		
QCD_Pt-470to600 (http://opendata.cern.ch/record/18348)		
QCD_Pt-600to800 (http://opendata.cern.ch/record/18351)		
QCD_Pt-800to1000 (http://opendata.cern.ch/record/18352)		
Pt-1000toInf (http://opendata.cern.ch/record/18316)		

Backup (13)

Open Data, Single Muon RUN2015



arXiv:1812.10529 CMS AN-15-324