nanoAOD(plus) Validation from Comparison to 2010 Muon, MuOnia, and Electron Open Data Examples

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Fabian Stäger

28 August 2019

Supervisors: Achim Geiser, Josry Metwally

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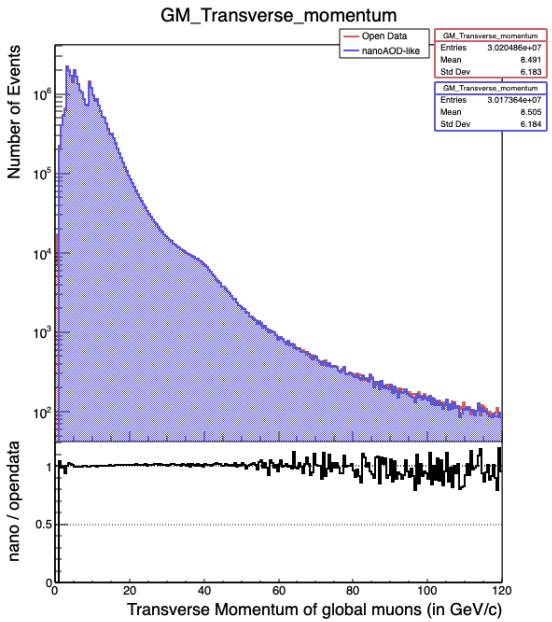
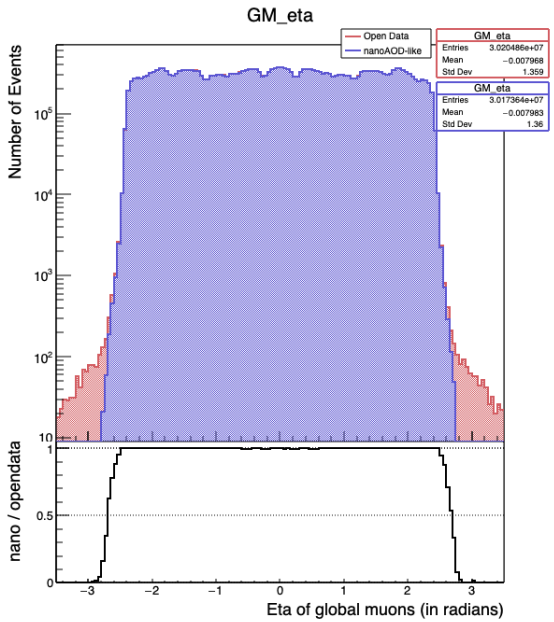
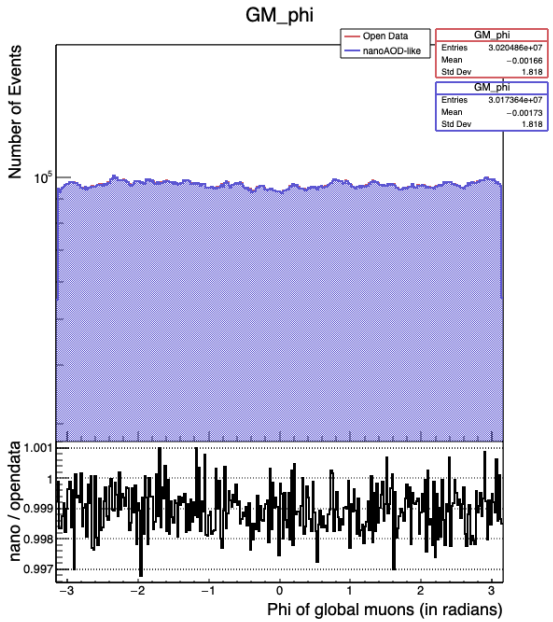
- Validation of nanoAOD-like variables in 2010 Muon, MuOnia, and Electron datasets
- Reproducing Open Data validation plots (`/afs/desy.de/user/g/geiser/public/CMS/opendata/MuOnia_2010_val/`) using nanoAOD-like ntuples
- 4 versions of nanoAOD-like ntuples for 2010 Muon and MuOnia dataset: `foroptmu`, `ZeroBias`, `ZeroBias2`, `ZeroBias3`
- 2 versions of nanoAOD-like ntuples for 2010 Electron dataset: `ele6`, `ZeroBias3`

Muon Variables

NanoAnalyzer.cc.foroptmu: global muon p_{T}, η, ϕ

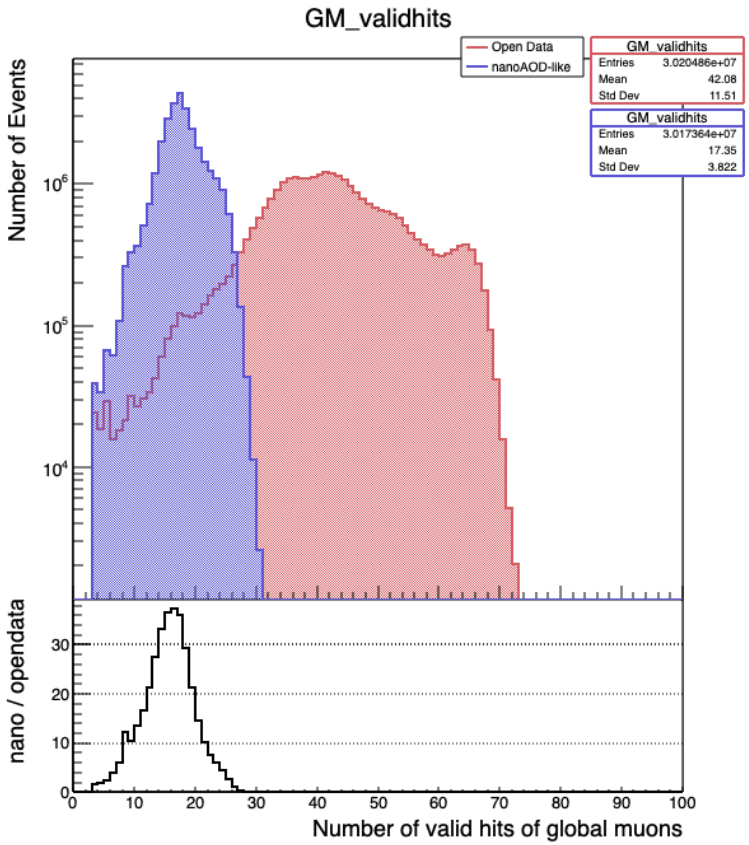


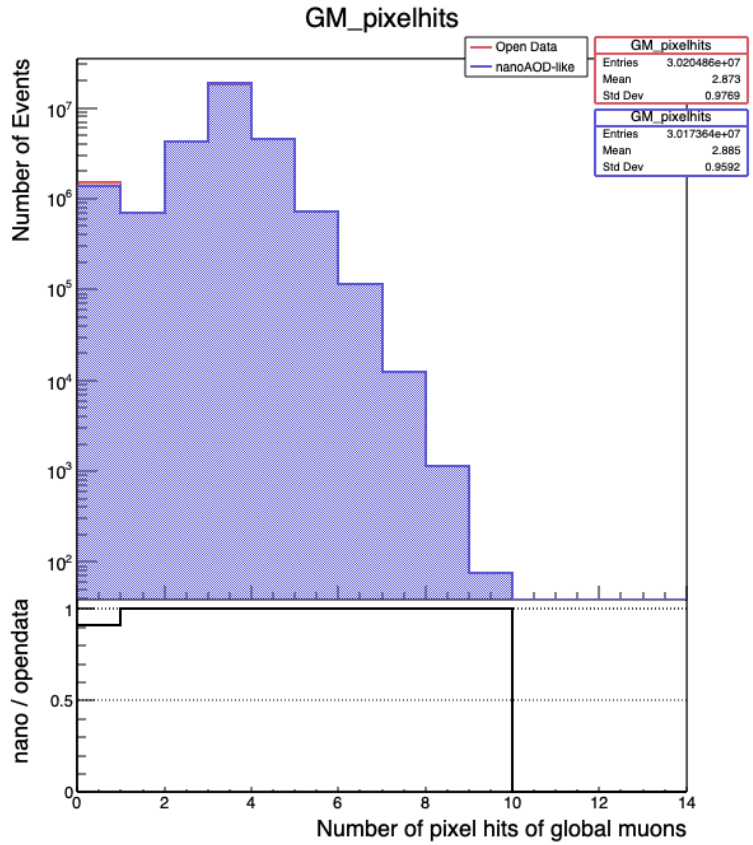




Open Data	nanoAOD-like
no p_{T} cut	$p_{\mathrm{T}} > 1\,\mathrm{GeV}$
no η cut	$\lvert\eta\rvert < 2.5$
global muon momenta	tracker muon momenta

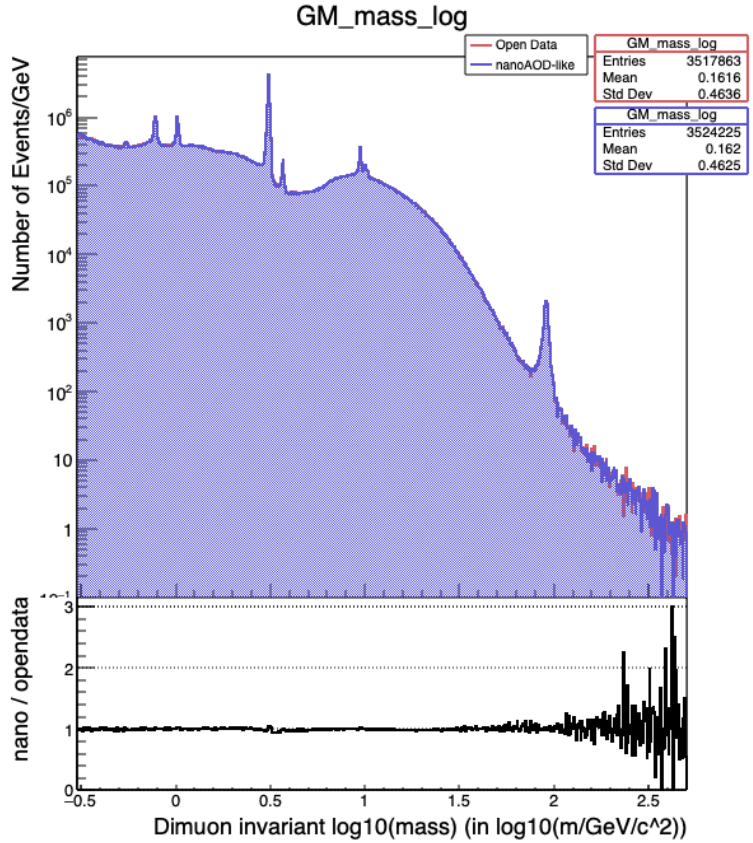
NanoAnalyzer.cc.foroptmu: valid hits and pixel hits





Open Data	nanoAOD-like
validhits: hits from pixel + strip detector + muon chambers	hits from strip detector only
global fit	tracker fit

NanoAnalyzer.cc.foroptmu: global dimuon inv. mass



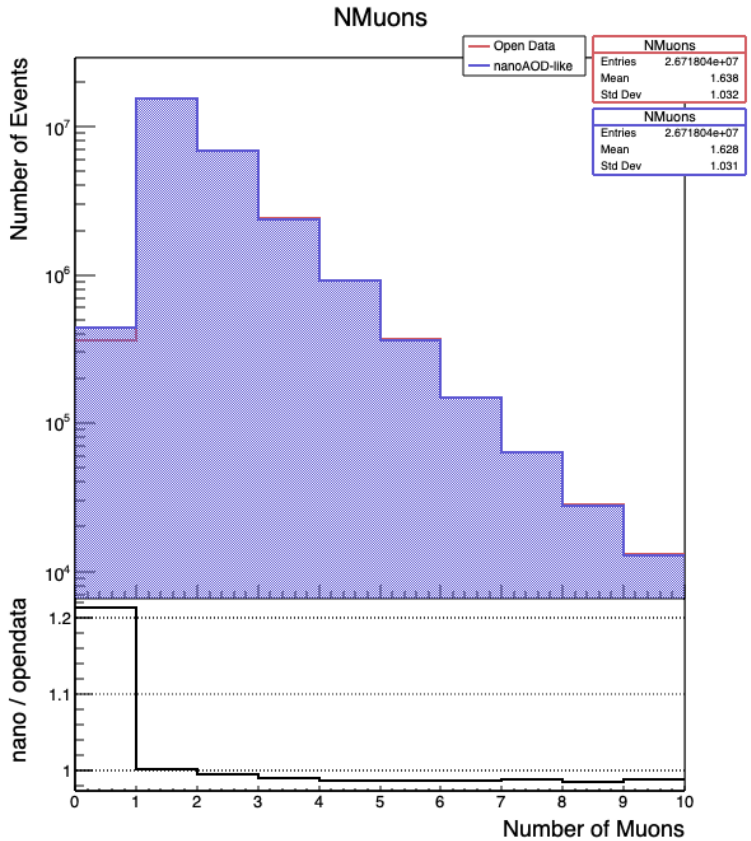
- number of valid hits ≥ 12 $(*)$
- number of pixel hits ≥ 2 $(*)$
- normalized $\chi^2 < 4$ $(*)$

NanoAnalyzer.cc.ZeroBias: Changes

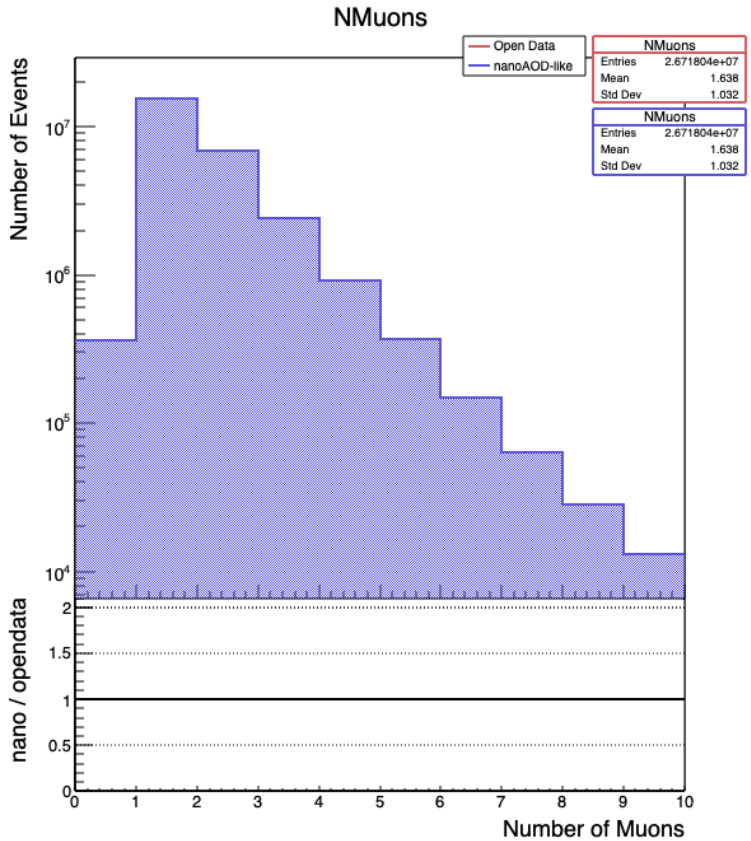
- p_{T} and η cuts removed
- New Variables:
  - `Muon_gChi2` (global muon chi2/ndof)
  - `Muon_nValidMu` (number of valid hits in muon chambers)
  - `Muon_gpt`, `geta`, `gphi` (global muon momenta)
  - `Muon_isGood` (`TMOneStationTight`)
  - `Muon_isGoodLast` (`TMLastStationTight`)

NanoAnalyzer.cc.ZeroBias: number of muons

NanoAnalyzer.cc.foroptmu



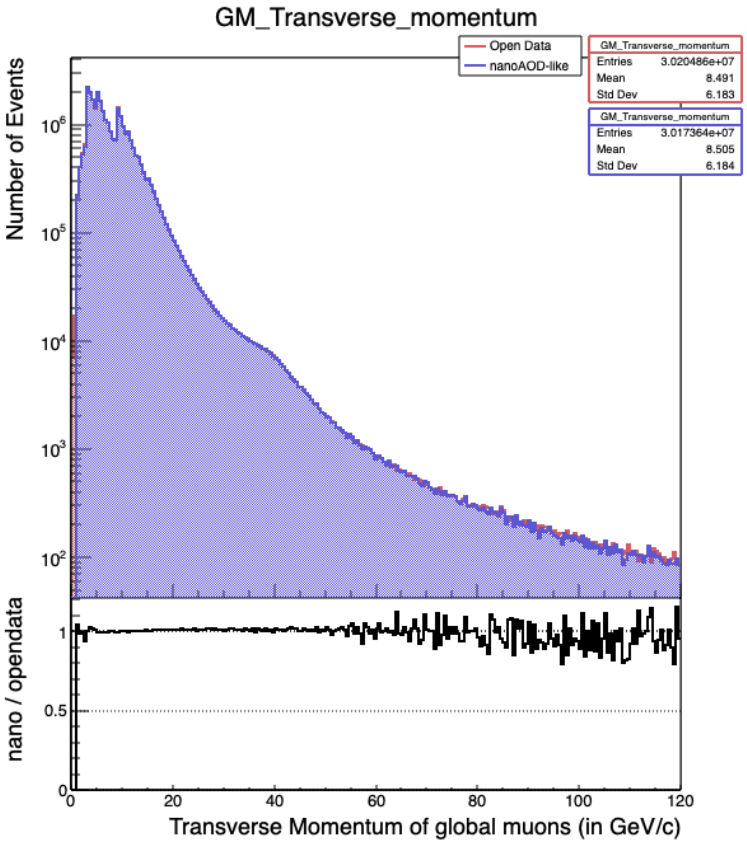
NanoAnalyzer.cc.ZeroBias



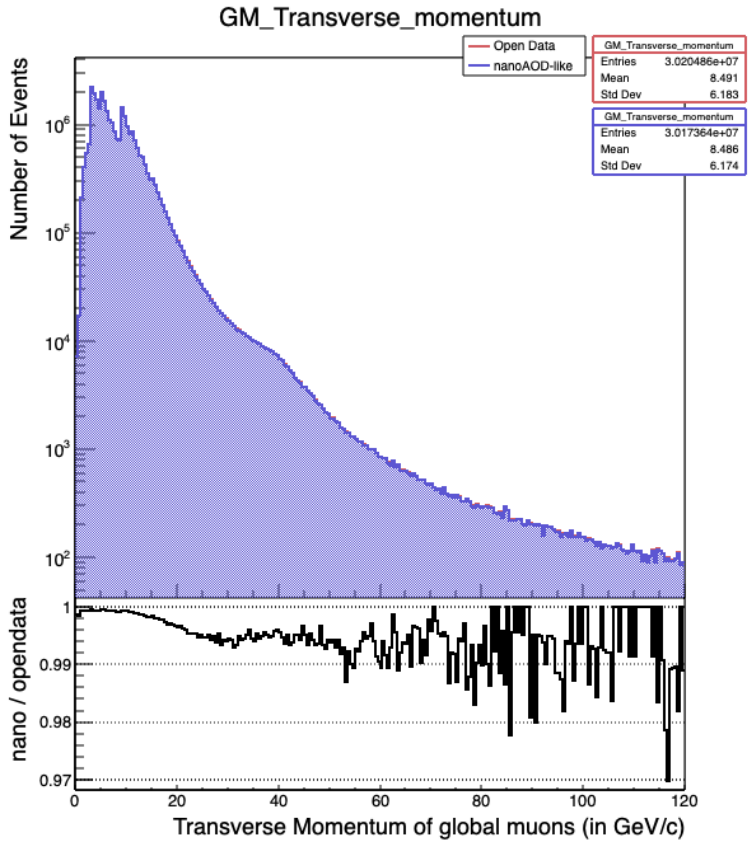
- removed p_{T} and η cuts
- `nMuons` validated

NanoAnalyzer.cc.ZeroBias: p_{T}

NanoAnalyzer.cc.foroptmu



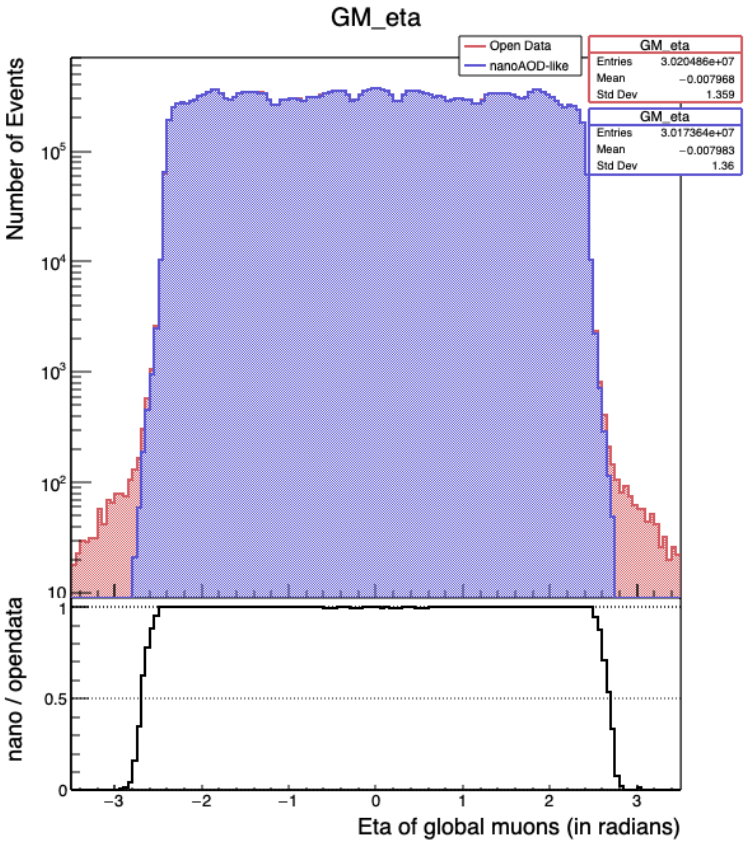
NanoAnalyzer.cc.ZeroBias



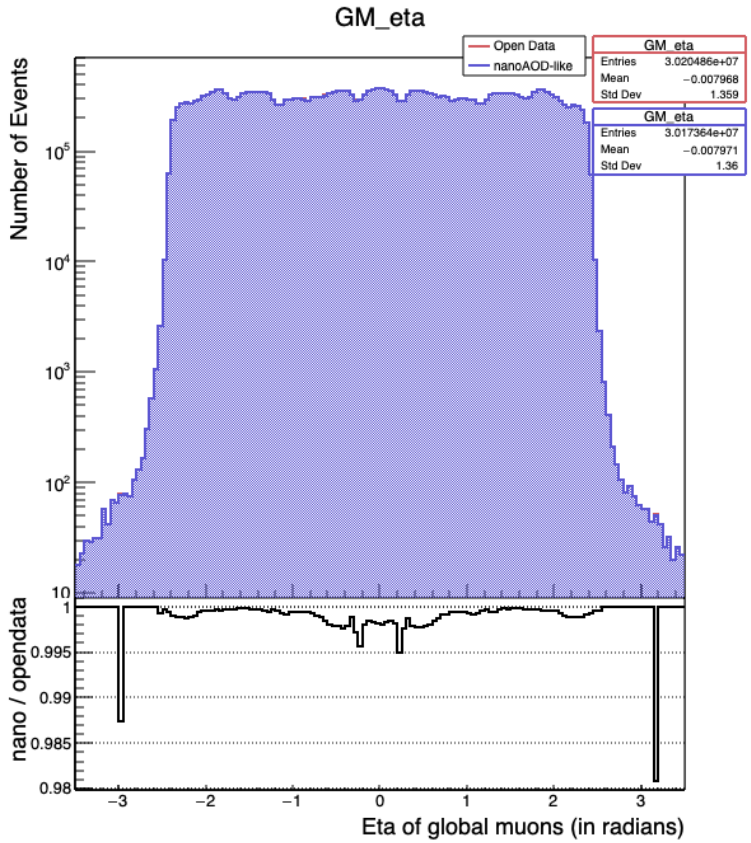
- removed p_{T} and η cuts
- changed `Muon_pt` to `Muon_gpt`
- `Muon_gpt` validated

NanoAnalyzer.cc.ZeroBias: η

NanoAnalyzer.cc.foroptmu



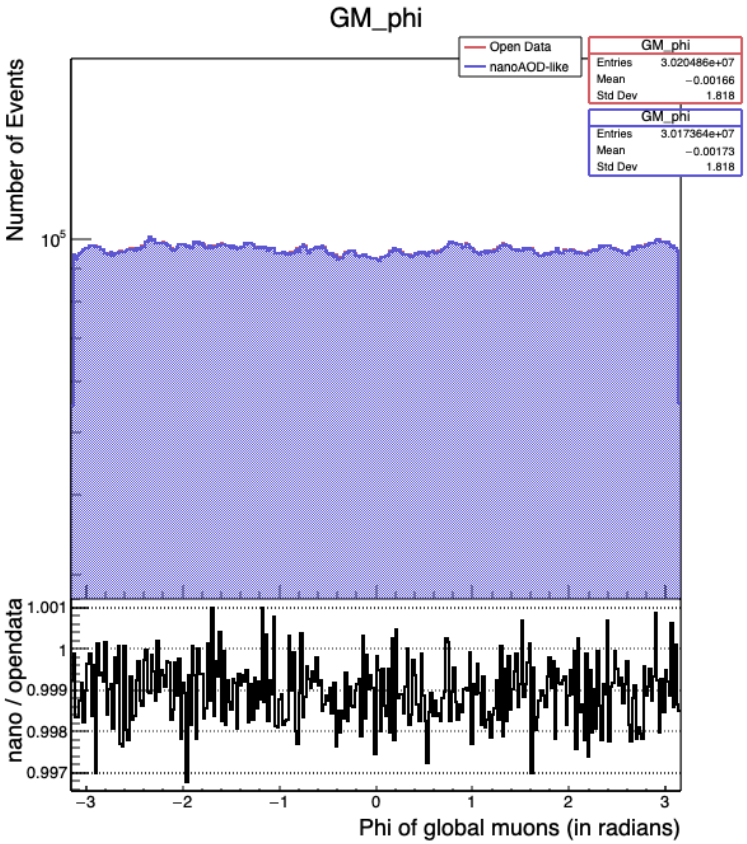
NanoAnalyzer.cc.ZeroBias



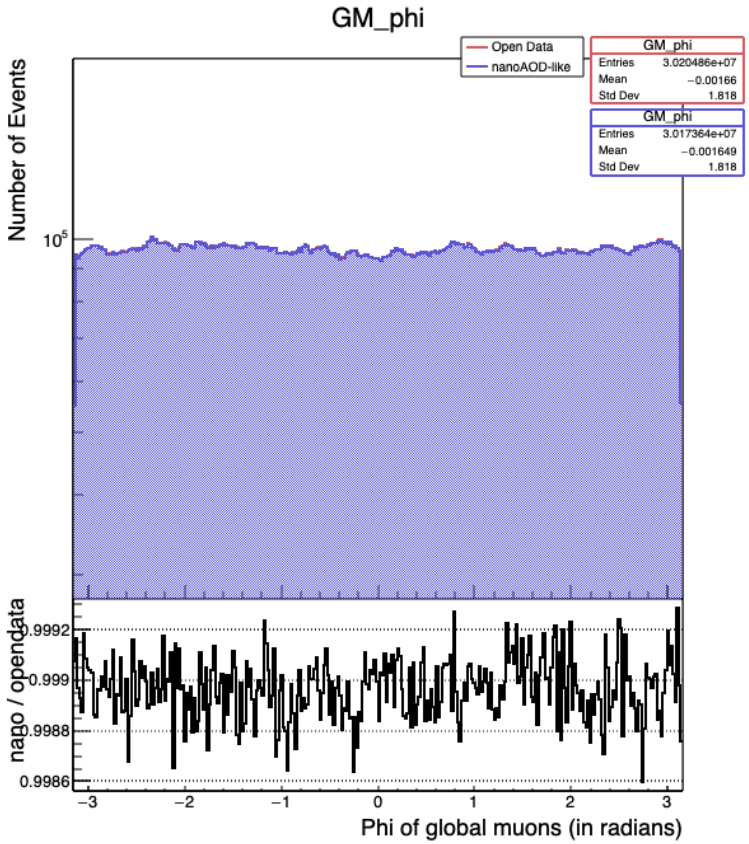
- removed p_{T} and η cuts
- changed `Muon_eta` to `Muon_geta`
- `Muon_geta` validated

NanoAnalyzer.cc.ZeroBias: ϕ

NanoAnalyzer.cc.foroptmu



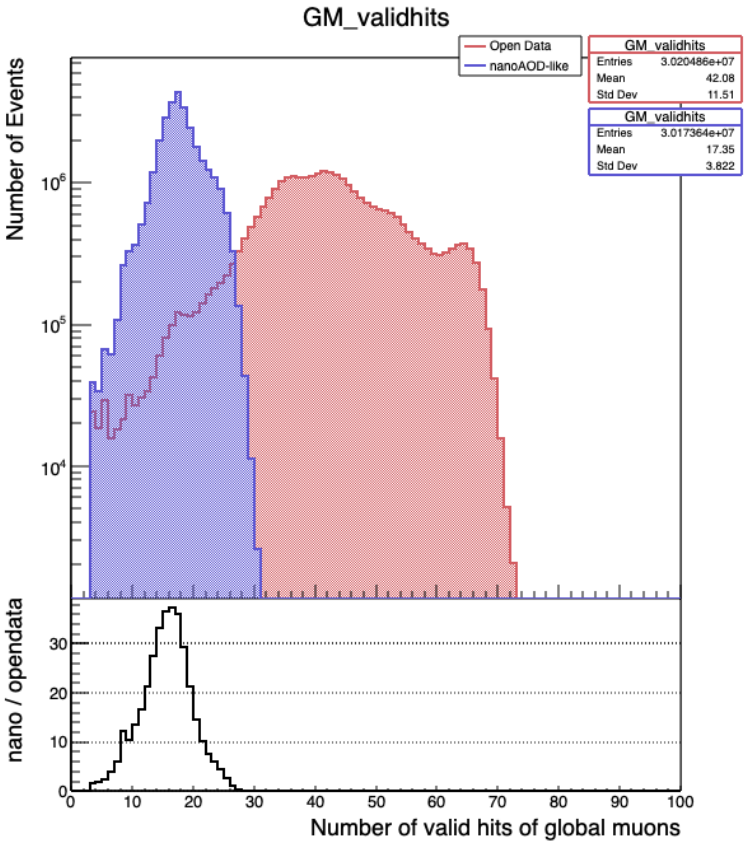
NanoAnalyzer.cc.ZeroBias



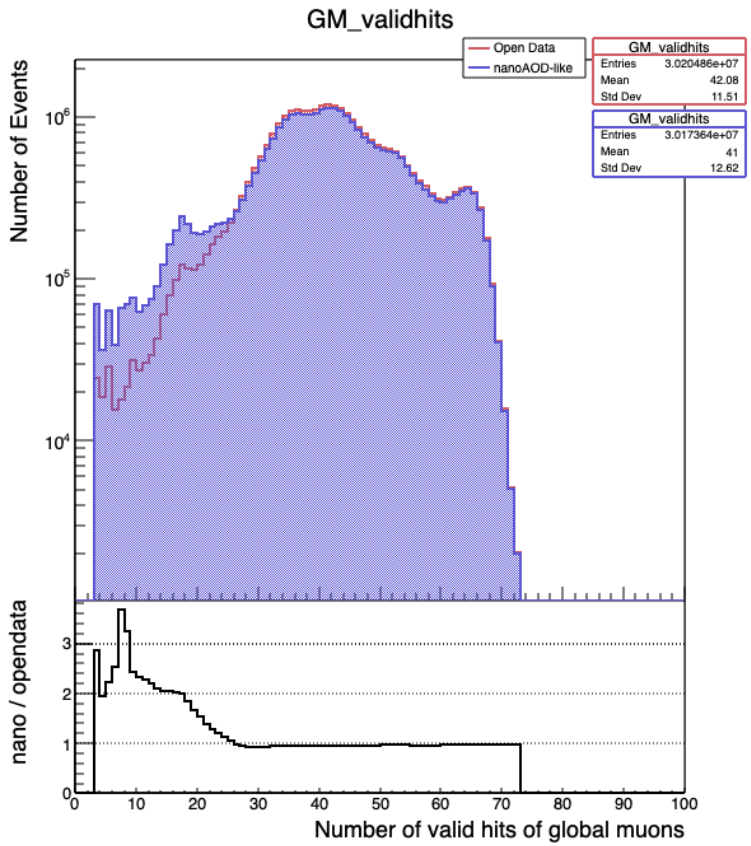
- removed p_{T} and η cuts
- changed `Muon_phi` to `Muon_gphi`
- `Muon_gphi` validated

NanoAnalyzer.cc.ZeroBias: valid hits

NanoAnalyzer.cc.foroptmu
nValid

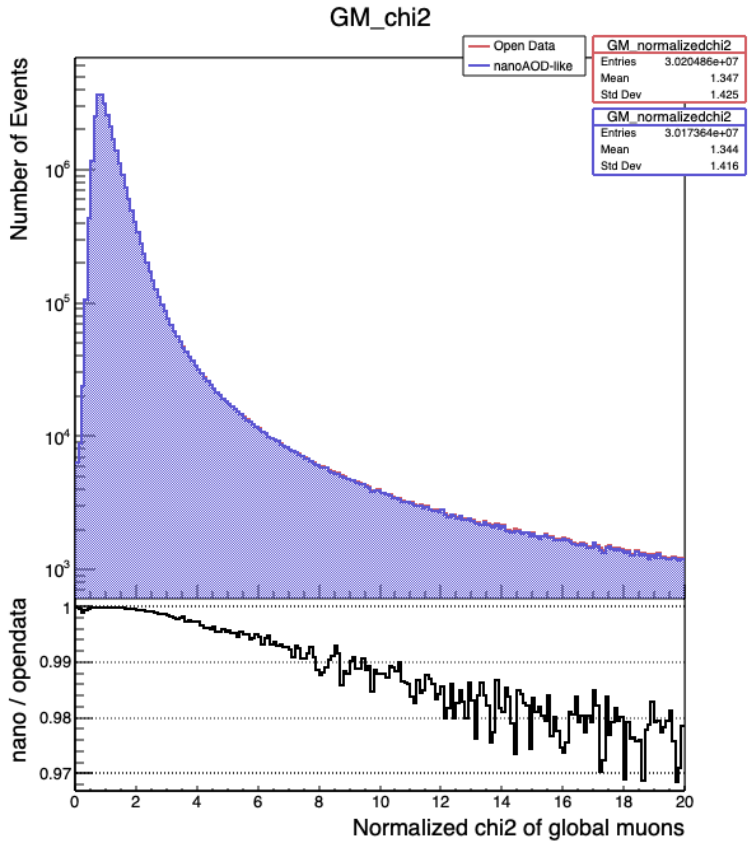


NanoAnalyzer.cc.ZeroBias
nValid + nValidMu



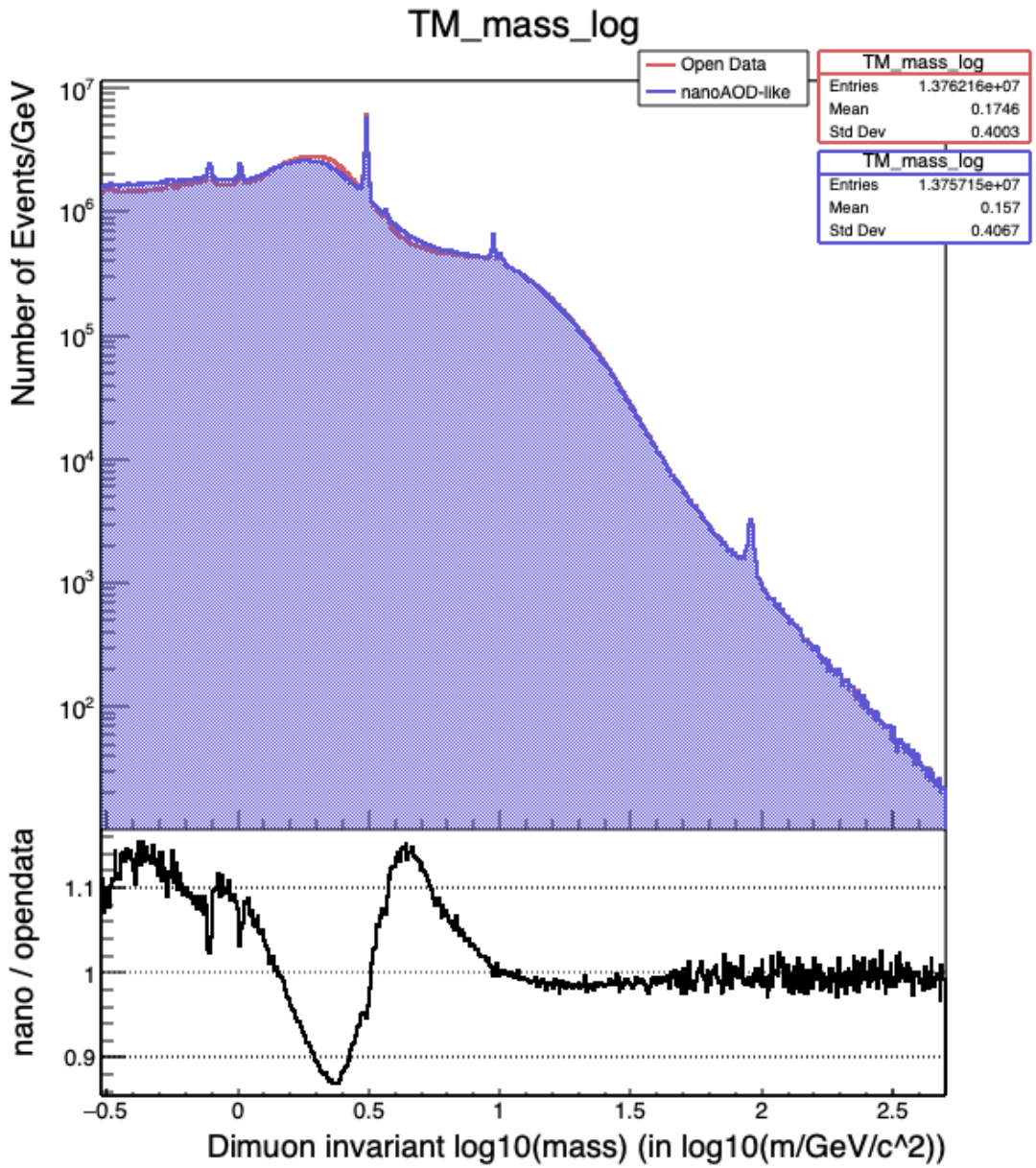
- added valid muon chamber hits (Muon_nValidMu)

NanoAnalyzer.cc.ZeroBias: normalized χ^2



- added normalized χ^2 of global fit (`Muon_gChi2`)
- `Muon_gChi2` validated

NanoAnalyzer.cc.ZeroBias: tracker dimuon inv. mass

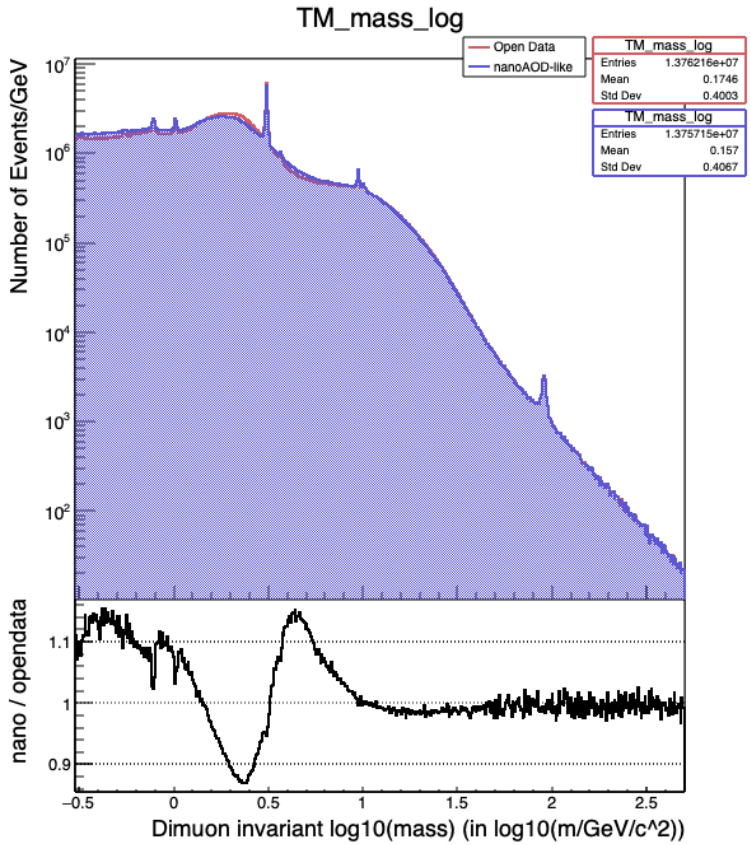


NanoAnalyzer.cc.ZeroBias2: Changes

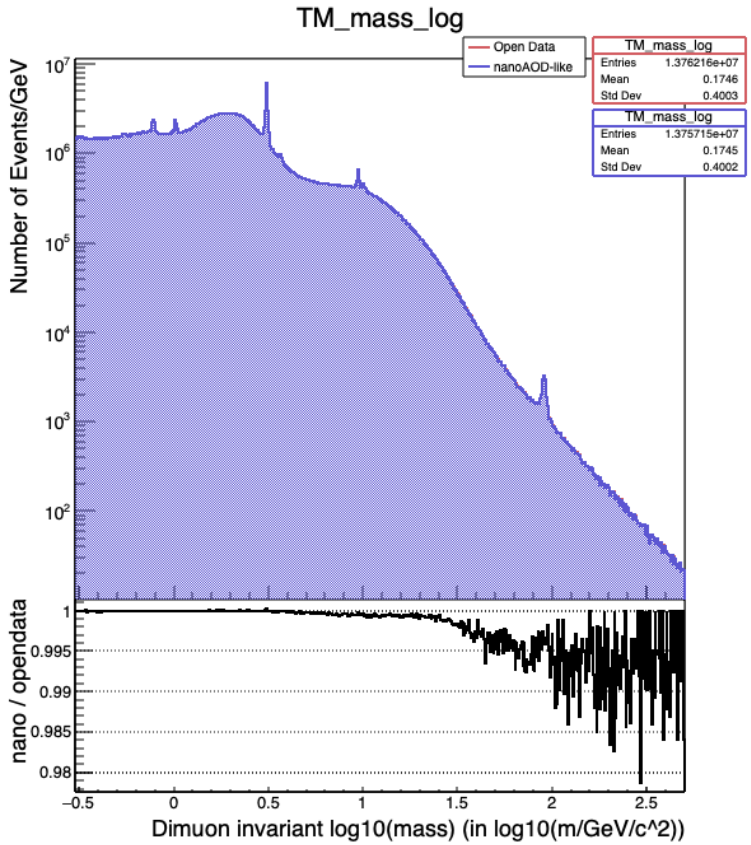
- bug fix to `Muon_phi`
- New Variables:
  - `Muon_gnValid` (valid strip detector hits of global track fit)
  - `Muon_gnPix` (valid pixel detector hits of global track fit)

NanoAnalyzer.cc.ZeroBias2: tracker dimuon inv. mass

NanoAnalyzer.cc.ZeroBias

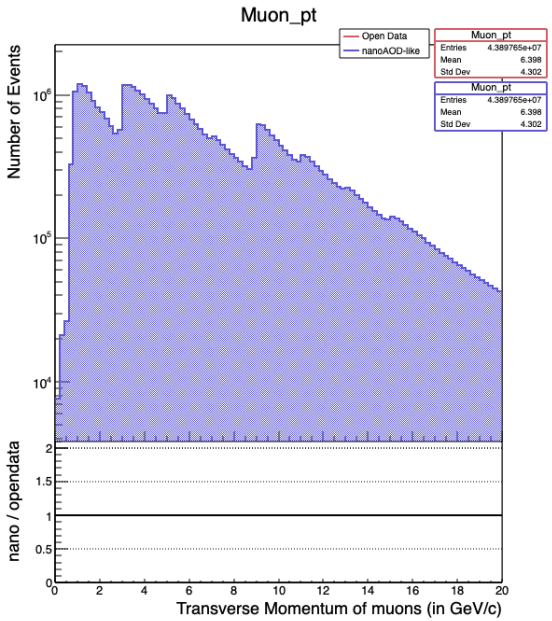


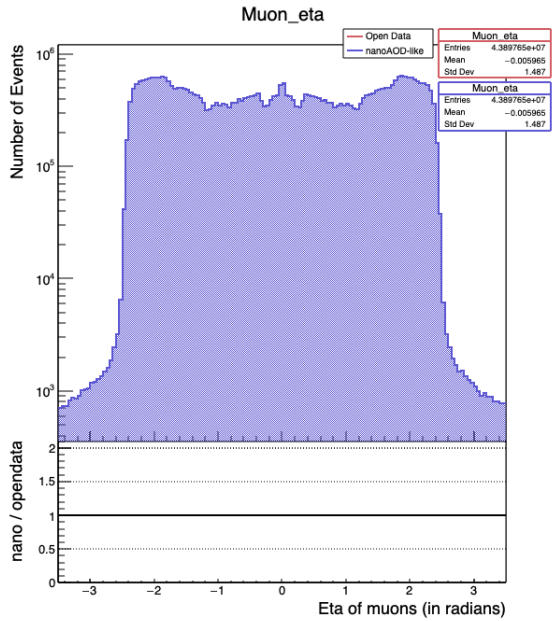
NanoAnalyzer.cc.ZeroBias2

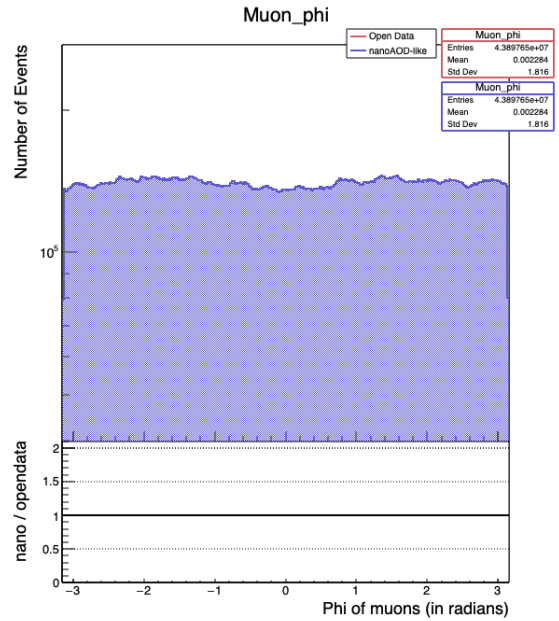


- fixed bug in `Muon_phi`
- `Muon_charge`, `Muon_mass`, `Muon_pt`, `Muon_eta`, `Muon_phi` validated

NanoAnalyzer.cc.ZeroBias2: tracker muon p_{T}, η, ϕ



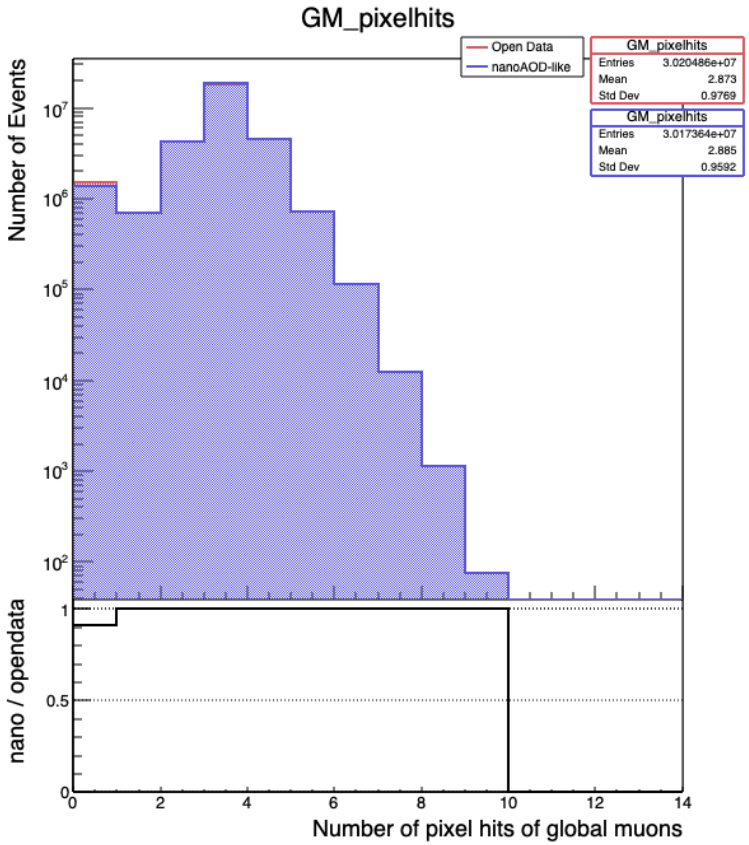




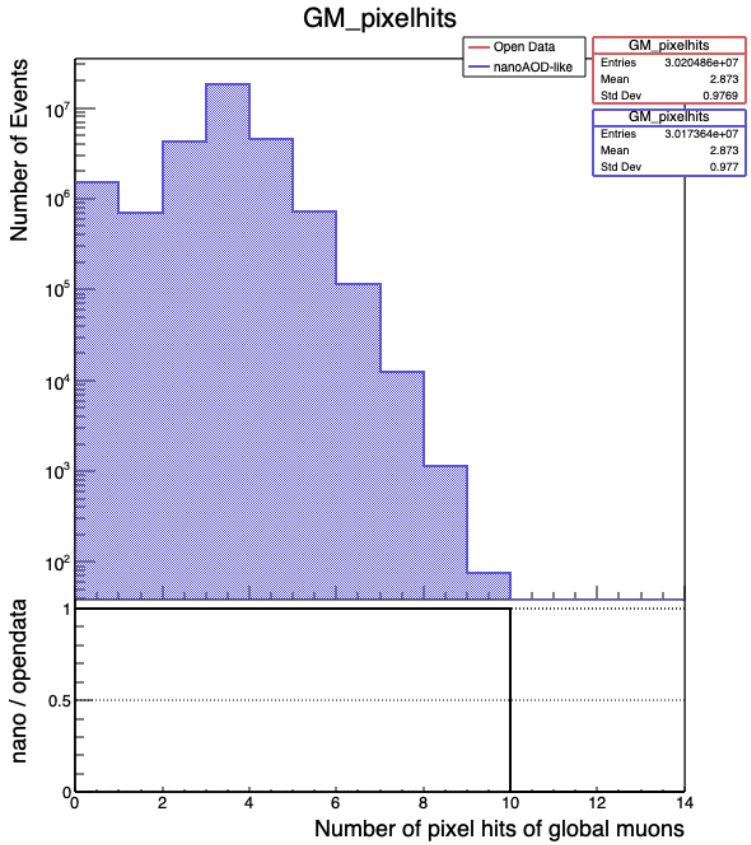
- `Muon_pt`, `Muon_eta`, `Muon_phi` validated

NanoAnalyzer.cc.ZeroBias2: global pixel hits

NanoAnalyzer.cc.ZeroBias



NanoAnalyzer.cc.ZeroBias2

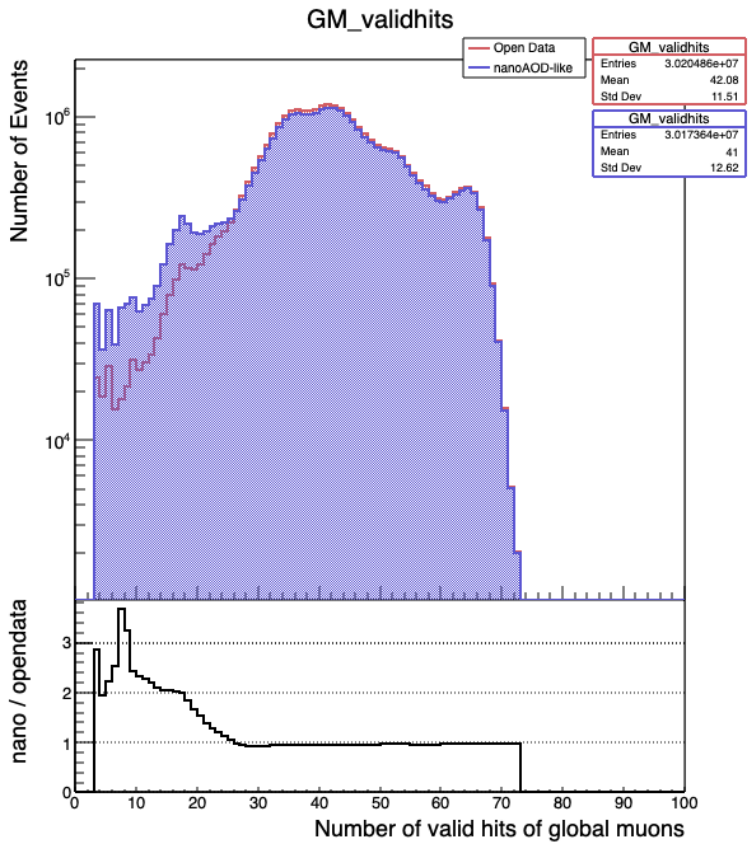


- changed `Muon_nPix` to `Muon_gnPix`
- `Muon_gnPix` validated

NanoAnalyzer.cc.ZeroBias2: global valid hits

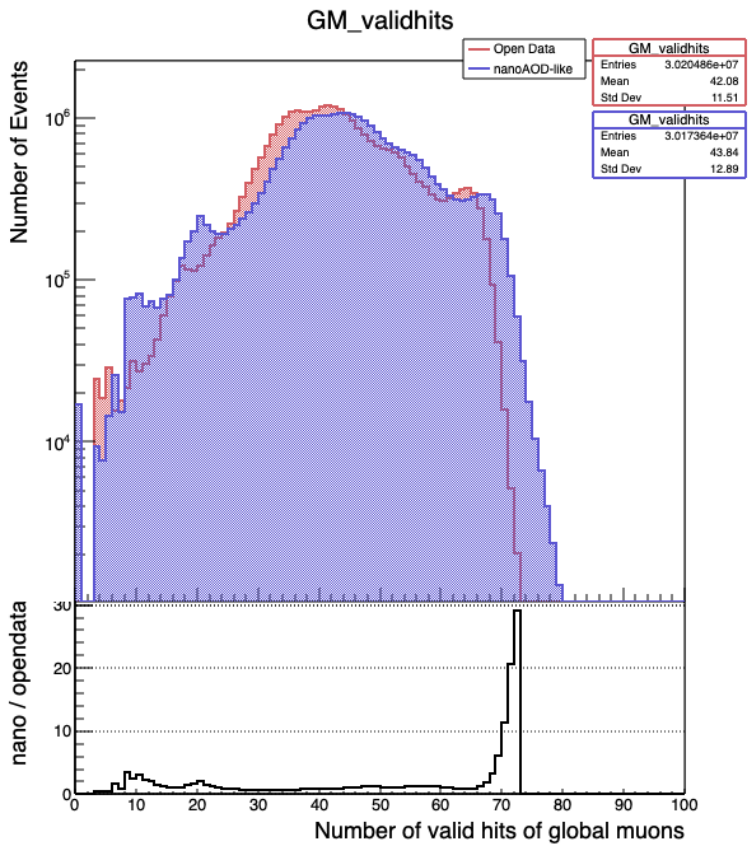
NanoAnalyzer.cc.ZeroBias

Muon_nValid + Muon_nValidMu



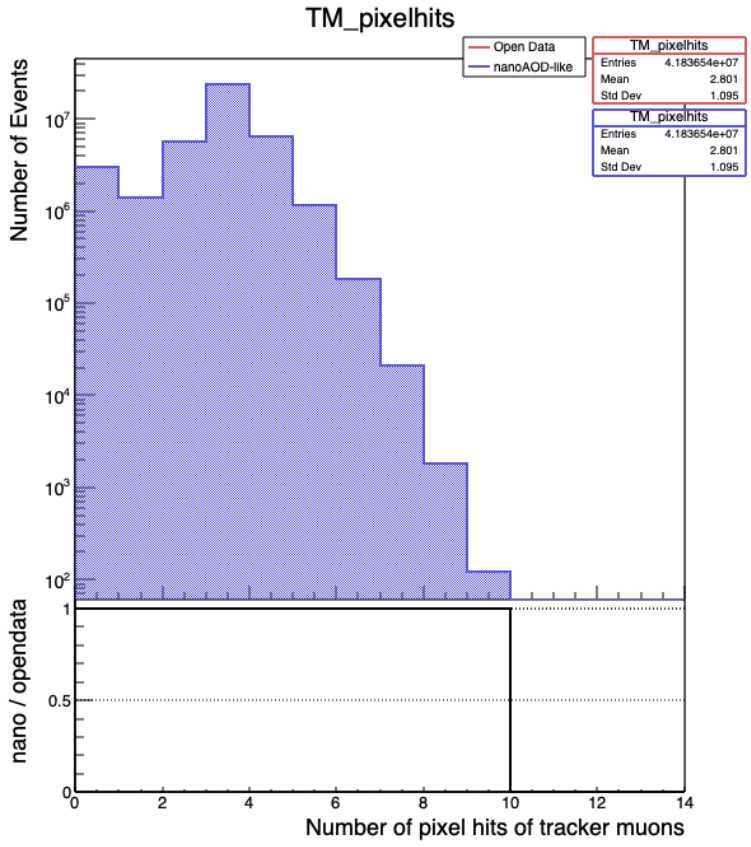
NanoAnalyzer.cc.ZeroBias2

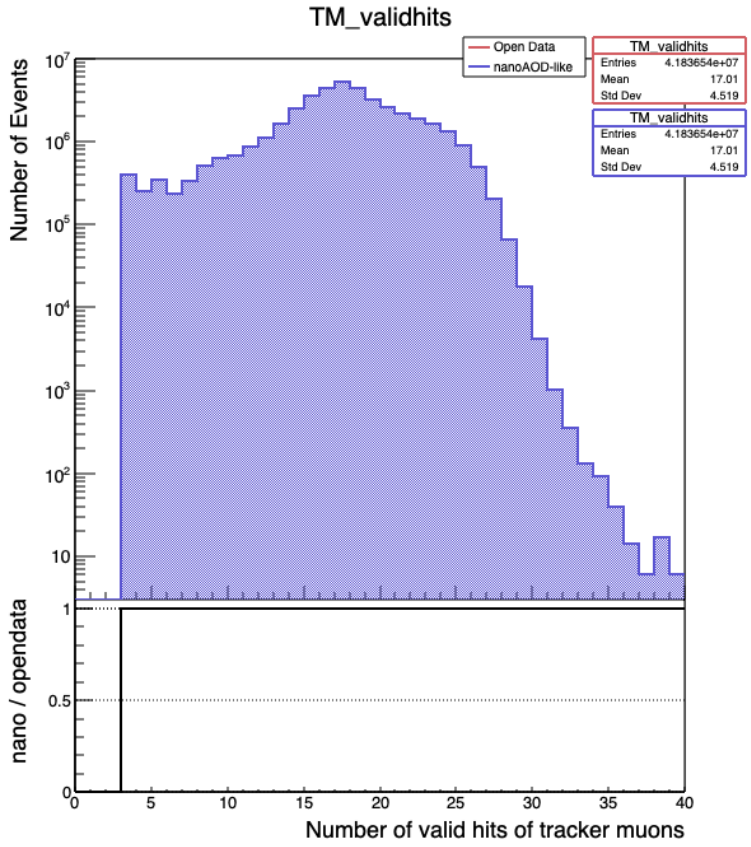
Muon_gnValid + Muon_gnPix + Muon_nValidMu



- changed Muon_nValid to Muon_gnValid

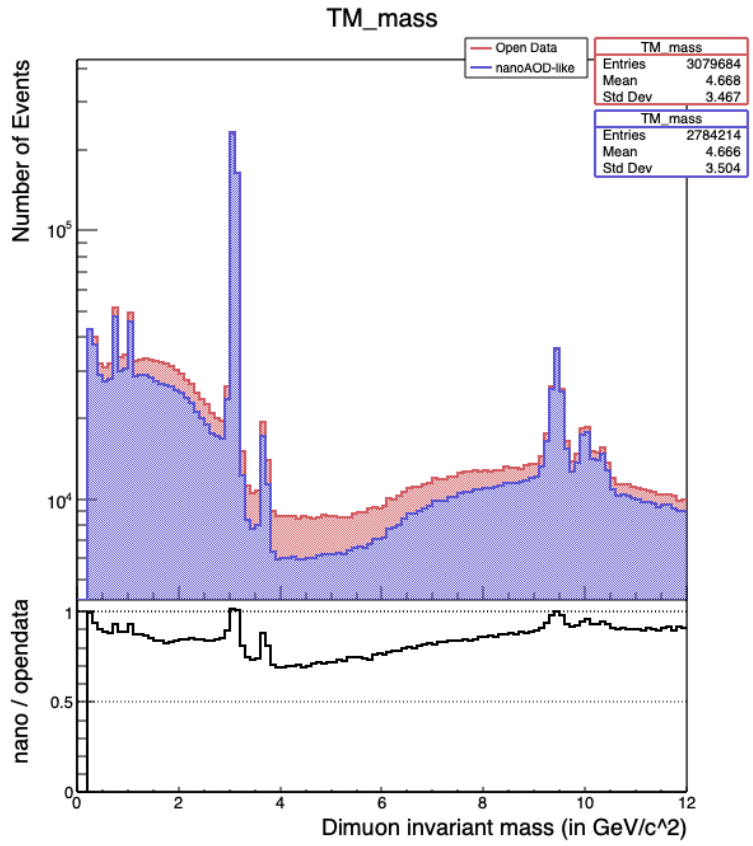
NanoAnalyzer.cc.ZeroBias2: tracker valid hits





- `Muon_nPix` validated
- `Muon_nValid` validated

NanoAnalyzer.cc.ZeroBias2: tracker dimuon inv. mass

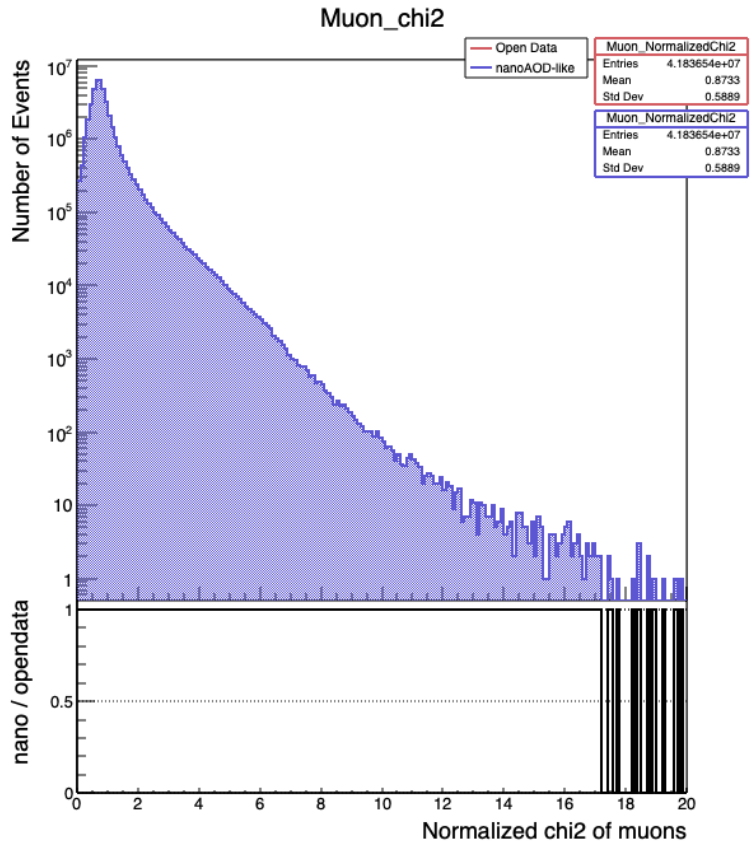


- number of valid hits ≥ 12
- number of pixel hits ≥ 2
- normalized $\chi^2 < 4$ $(*)$
- cuts on p_{T} and η
- $v_{x,y}(\mu_1) - v_{x,y}(\mu_2) < 0.1$
- $v_z(\mu_1) - v_z(\mu_2) < 0.3$
- `TMLastStationAngTight` $(*)$
- `TrackerMuonArbitrated` $(*)$

NanoAnalyzer.cc.ZeroBias3: Changes

- New Variables:
  - `Muon_Chi2` (normalized χ^2 of tracker fit)
  - `Muon_isGoodAng` (`TMLastStationAngTight`)
  - `Muon_isArbitrated` (`TrackerMuonArbitrated`)

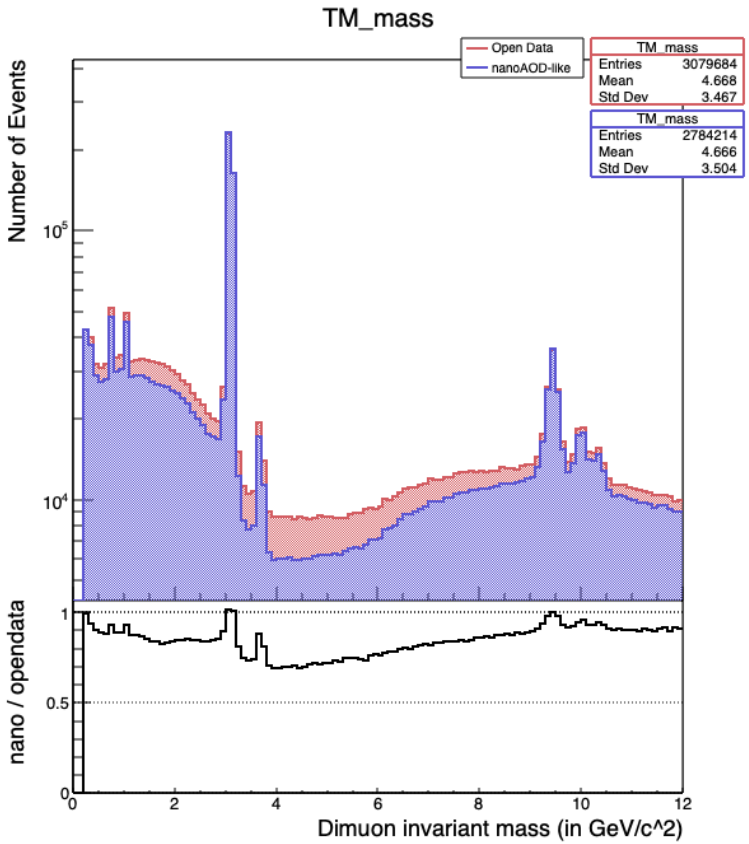
NanoAnalyzer.cc.ZeroBias3: normalized χ^2



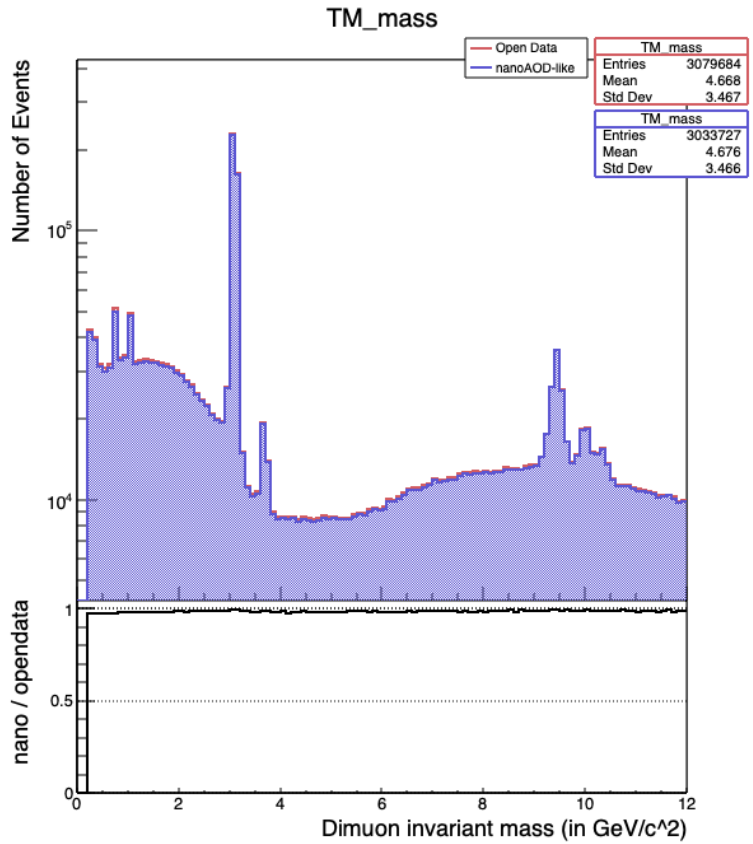
- added normalized χ^2 of tracker fit (`Muon_Chi2`)
- `Muon_Chi2` validated

NanoAnalyzer.cc.ZeroBias3: tracker dimuon inv. mass

NanoAnalyzer.cc.ZeroBias2

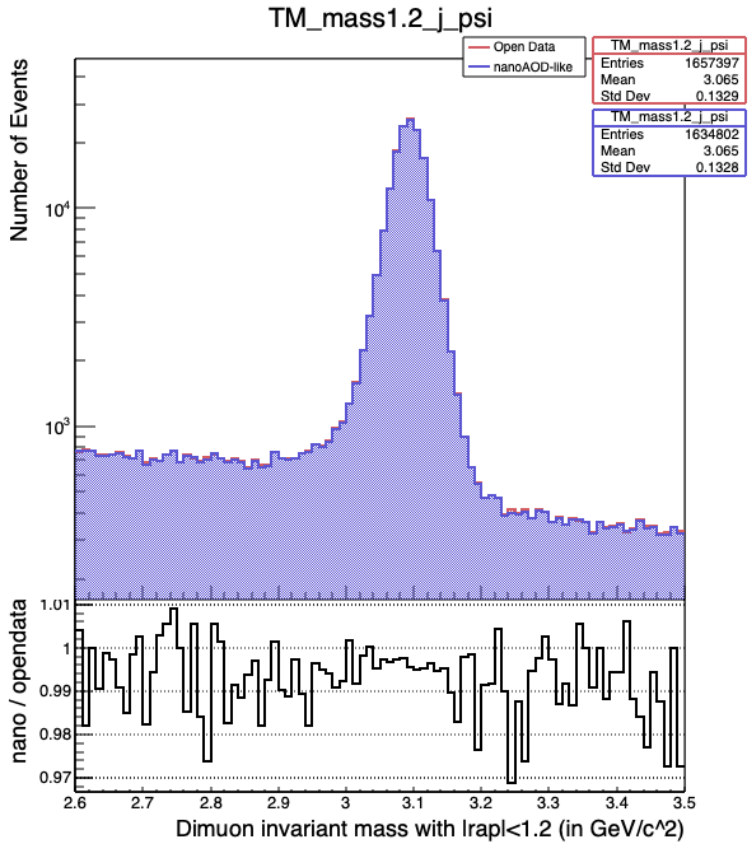


NanoAnalyzer.cc.ZeroBias3



- added cut normalized $\chi^2 < 4$ (`Muon_Chi2`)
- changed `Muon_isGoodLast` to (`Muon_isGoodAng` and `Muon_isArbitrated`)

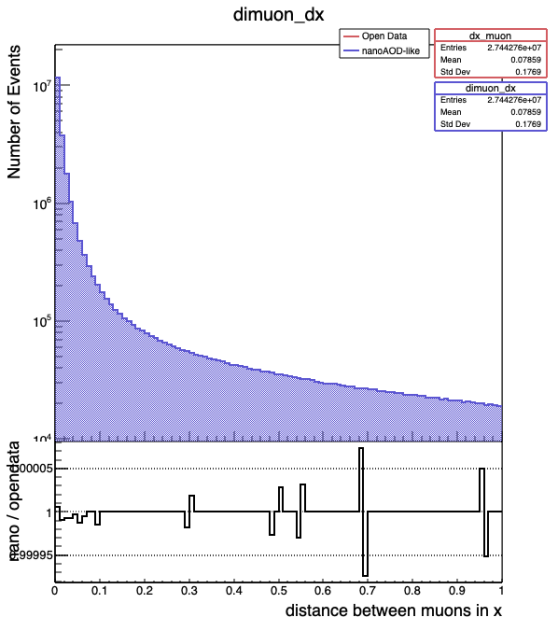
NanoAnalyzer.cc.ZeroBias3: $J/\psi \to \mu\mu$ (tracker μ)

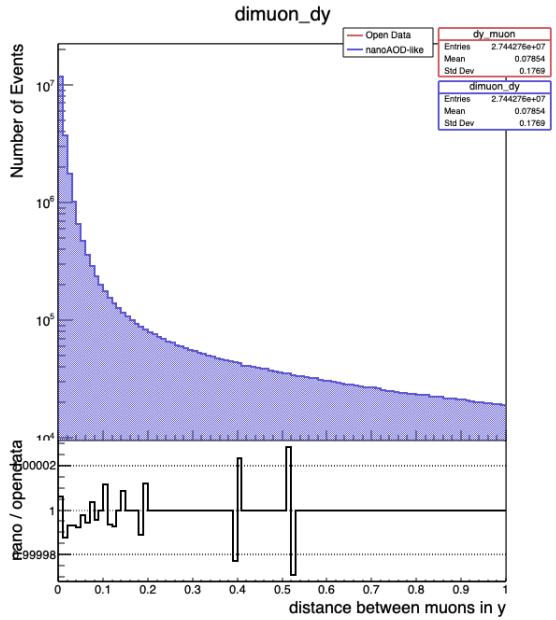


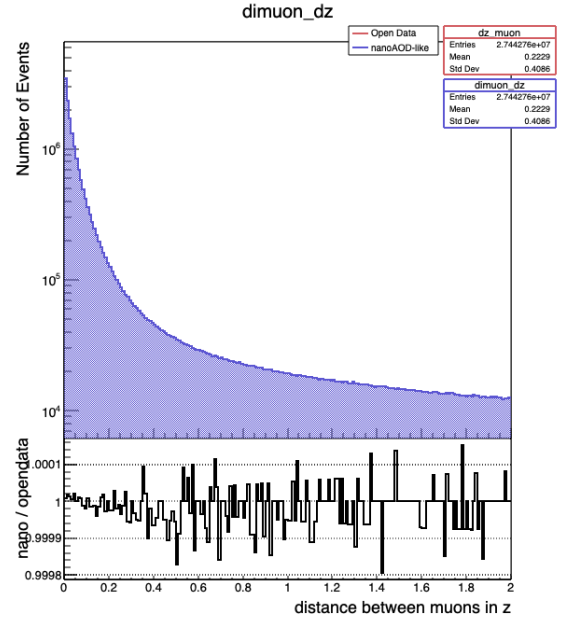
- $\sim 2\%$ difference in number of entries
- possible reason 1: cuts on muon quality flags (`Muon_isGoodLast` and `Muon_isArbitrated`)
- possible reason 2: cuts on vertex distances $v_{x,y,z}(\mu_1) - v_{x,y,z}(\mu_2)$ (calculated using `Muon_x/y/z`)

NanoAnalyzer.cc.ZeroBias3: vertex distances x, y, z

$|v_x(\mu_1) - v_x(\mu_2)|$ $|v_y(\mu_1) - v_y(\mu_2)|$ $|v_z(\mu_1) - v_z(\mu_2)|$





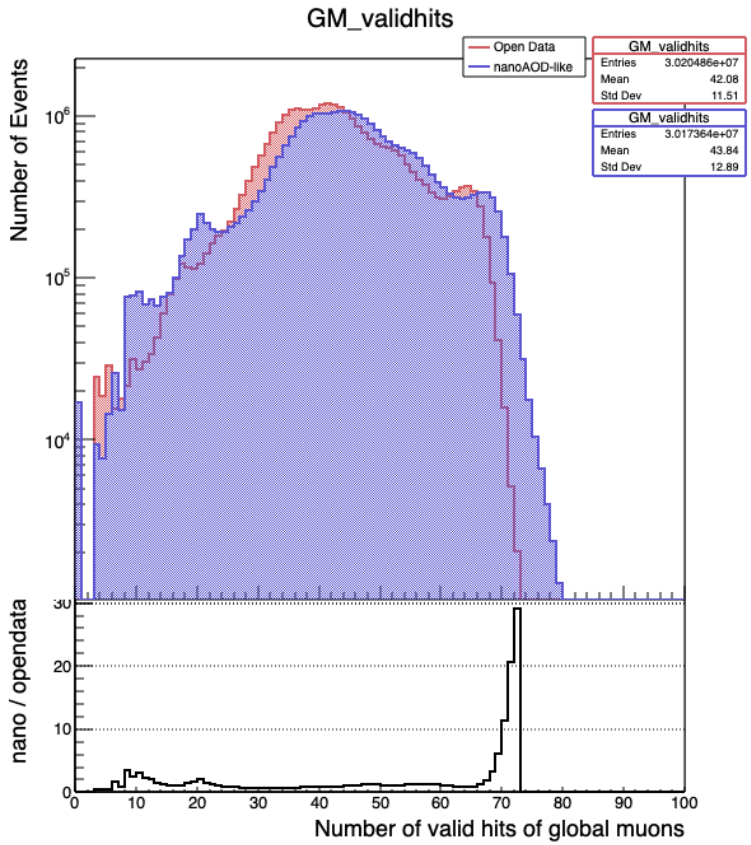


- Distributions look good
- However: bug in `DemoAnalyzer.cc` (absolute value not taken) that might not be reproduced exactly

NanoAnalyzer.cc.ZeroBias3: global valid hits

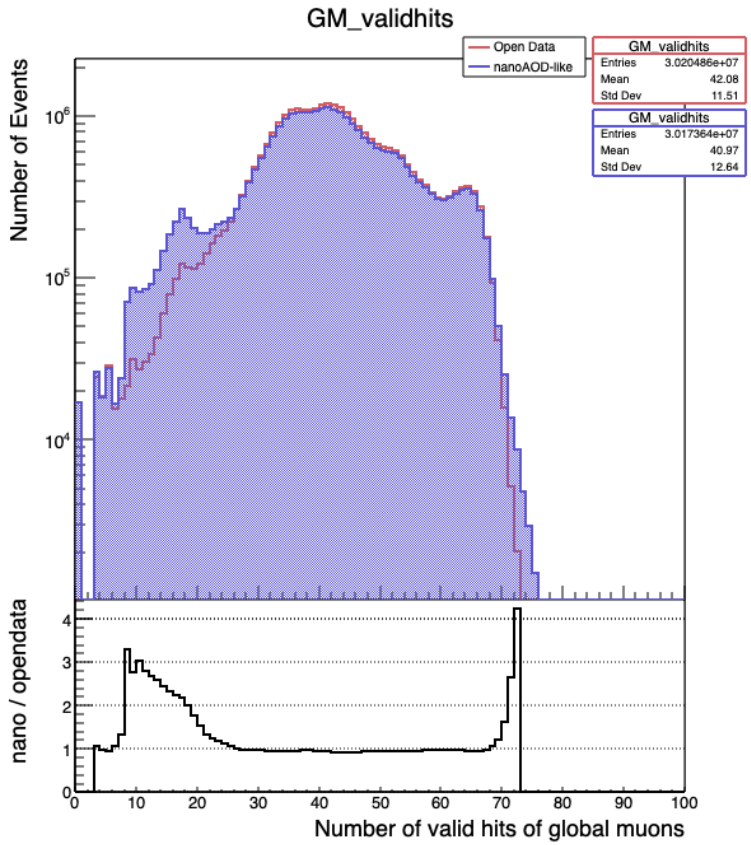
NanoAnalyzer.cc.ZeroBias2

Muon_gnValid + Muon_gnPix + Muon_nValidMu



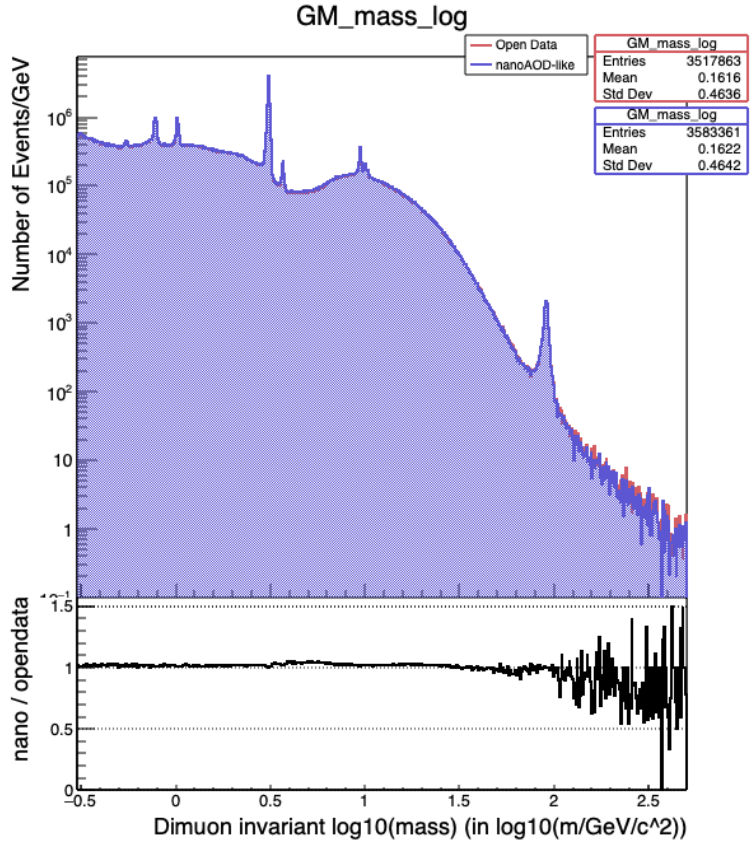
NanoAnalyzer.cc.ZeroBias3

Muon_gnValid + Muon_nValidMu



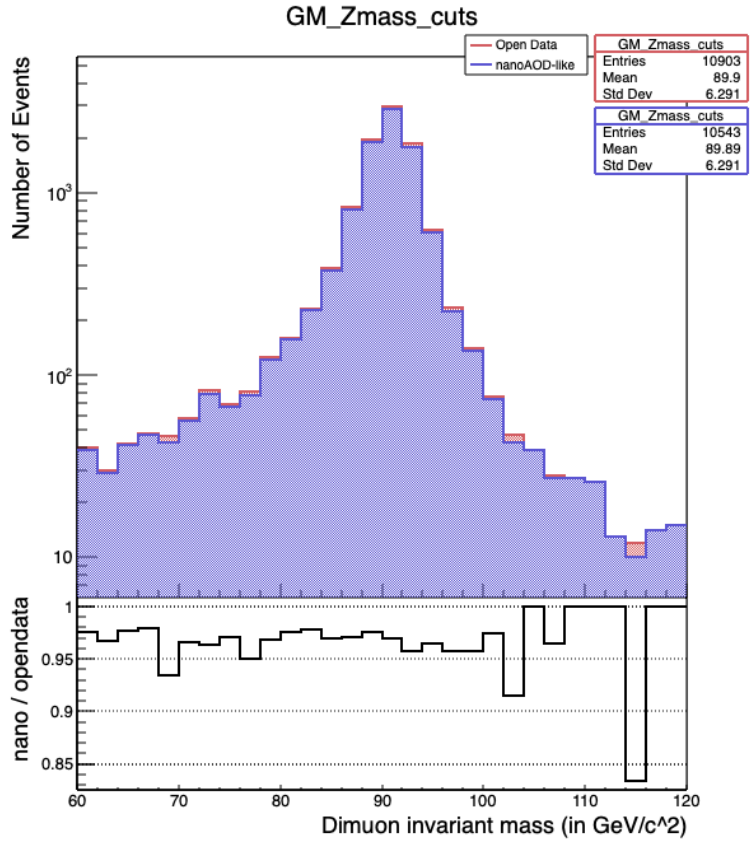
- removed + Muon_gnPix

NanoAnalyzer.cc.ZeroBias3: global dimuon inv. mass



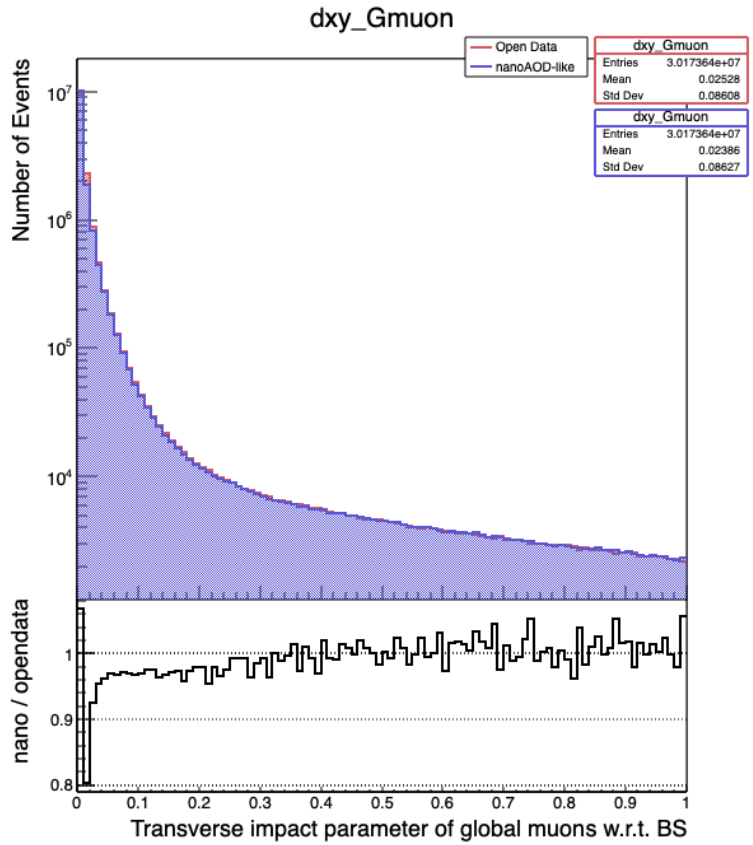
- $\sim 2\%$ difference in number of entries
- possible reason: cut on number of valid hits (`Muon_gnValid` and `Muon_nValidMu`)

NanoAnalyzer.cc.ZeroBias3: $Z \to \mu\mu$ (global muons)



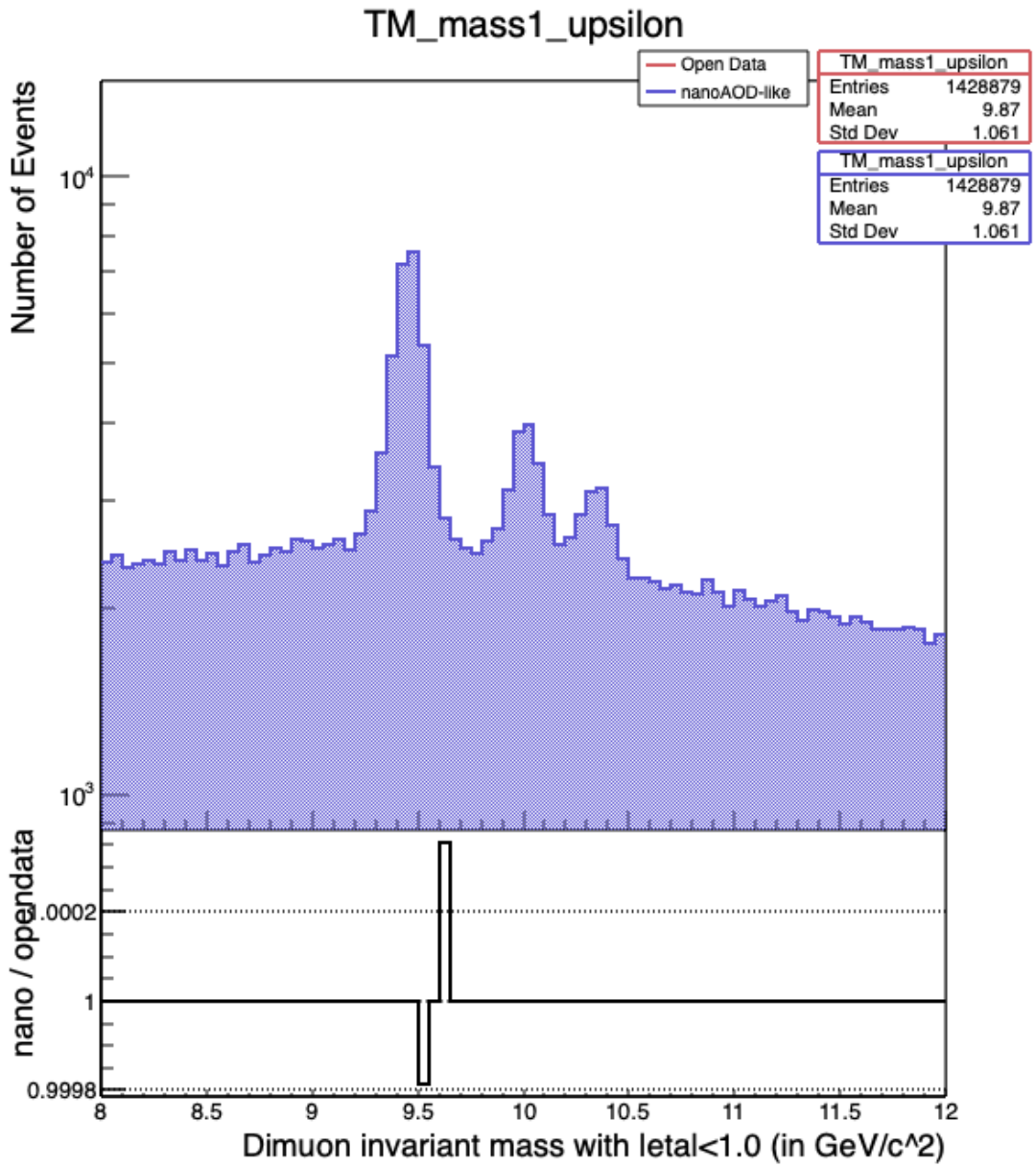
- $\sim 4\%$ difference in number of entries
- possible reason 1: cut on number of valid hits (`Muon_gnValid` and `Muon_nValidMu`)
- possible reason 2: cuts on muon quality flag `Muon_isGoodLast` and on `Muon_pfRelIso03_all`
- possible reason 3: cut on d_{xy} (`Muon_dxy`)

NanoAnalyzer.cc.ZeroBias3: d_{xy}

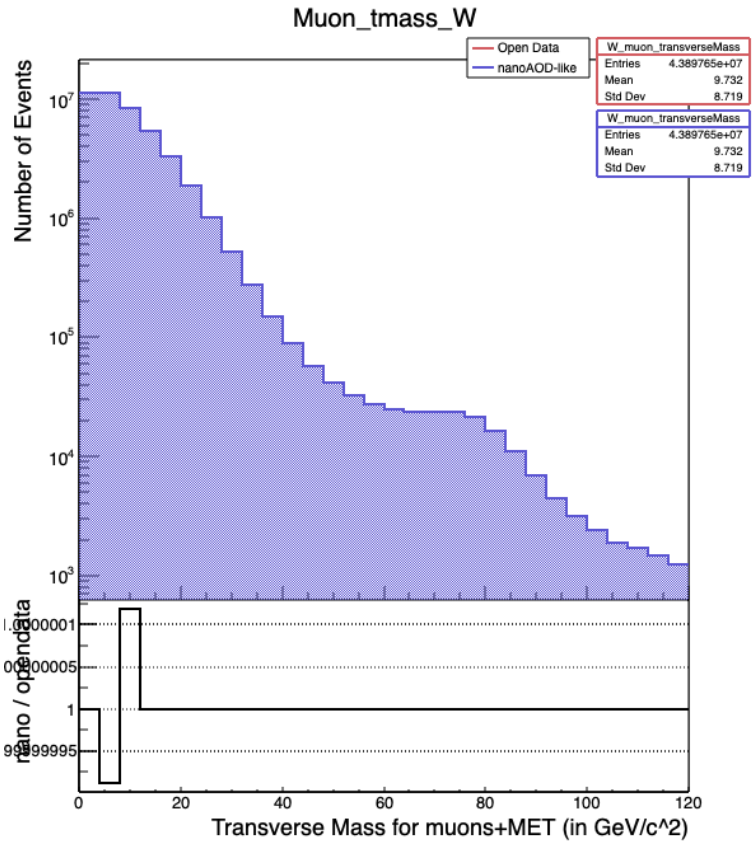


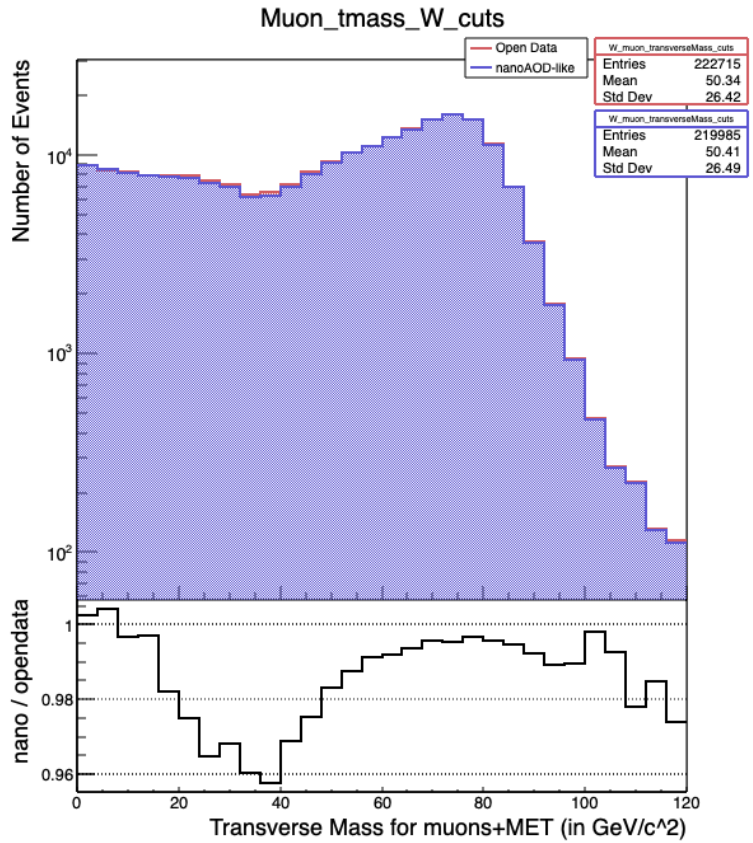
Open Data	nanoAOD-like
d_{xy}: global fit	tracker fit

NanoAnalyzer.cc.ZeroBias3: $\Upsilon \to \mu\mu$ (tracker muons)



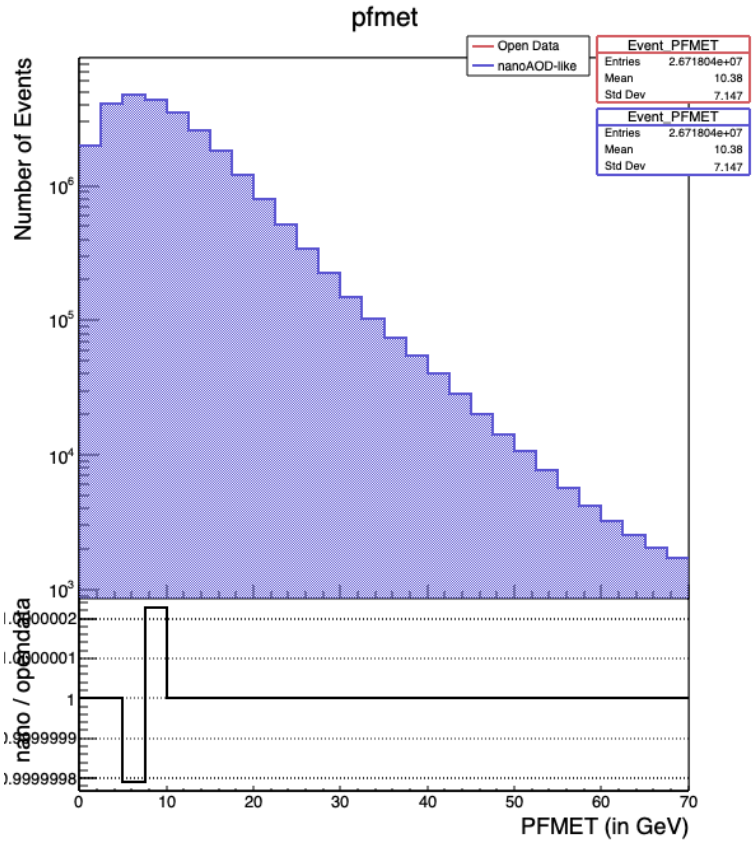
NanoAnalyzer.cc.ZeroBias3: $W \to \mu\nu_\mu$ (global muons)

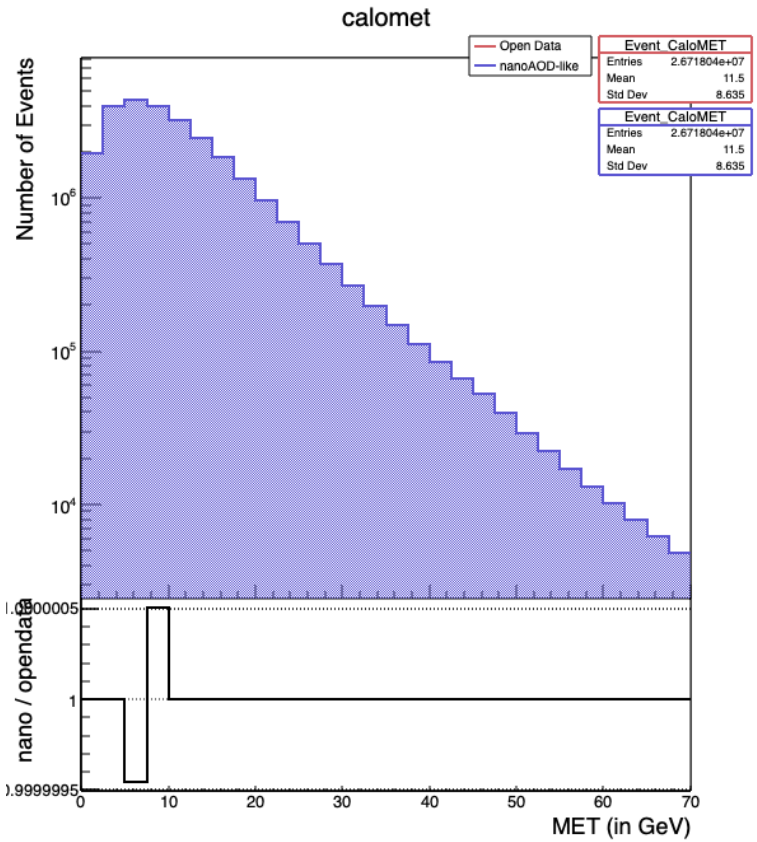




- $\sim 1\%$ difference in number of entries
- same possible reasons as in $Z \to \mu\mu$
- plus a bug in `DemoAnalyzer.cc` that can not be reproduced exactly
- `MET_pt`, `MET_phi`, and `Muon_isGlobal` validated

NanoAnalyzer.cc.ZeroBias3: Missing E_{T}





- `MET_pt`, `CaloMET_pt` validated

Muon Variables: nanoAOD-like

nanoAOD-like variable	AOD variable	validated
nMuon	size()	yes
Muon_charge	muon->charge()	yes
Muon_dxy	muon->track->dxy()	$\sim$
Muon_eta	muon->eta()	yes
Muon_phi	muon->phi()	yes
Muon_pt	muon->pt()	yes
Muon_isGlobal	muon->isGlobalMuon()	yes
Muon_isTracker	muon->isTrackerMuon()	$\sim$
Muon_mass	0.105658 GeV	yes
Muon_pfRelIso03_all	(muon->isolationR03().sumPt() +muon->isolationR03().hadEt() +muon->isolationR03().emEt()) /muon->pt()	$\sim$
MET_pt	pfmet->begin()->pt()	yes
MET_phi	pfmet->begin()->phi()	yes
CaloMET_pt	calomet->begin()->pt()	yes

Muon Variables: nanoAOD-like

nanoAOD-like variable	validated
Muon_cleanmask	no
Muon_dxyErr	no
Muon_dzErr	no
Muon_genPartFlav	no
Muon_genPartIdx	no
Muon_highPtId	no
Muon_ip3d	no
Muon_isPFcand	no
Muon_jetIdx	no
Muon_mediumId	no
Muon_miniPFRelIso_all	no
Muon_miniPFRelIso_chg	no
Muon_mvaTTH	no
Muon_nStations	no
Muon_nTrackerLayers	no
Muon_pdgId	no
Muon_pfRelIso03_chg	no
Muon_pfRelIso04_all	no
Muon_ptErr	no
Muon_segmentComp	no
Muon_sip3d	no
Muon_softId	no
Muon_tightCharge	no
Muon_tighId	no

Muon Variables: nanoAOD(plus)

nanoAOD(plus) variable	AOD variable	validated
Muon_x	muon->vx()	∼
Muon_y	muon->vy()	∼
Muon_z	muon->vz()	∼
Muon_nValid	muon->innerTrack()->hitPattern(). numberOfValidTrackerHits()	yes
Muon_nPix	muon->innerTrack()->hitPattern(). numberOfValidPixelHits()	yes
Muon_trkIdx	Track Index	yes
Muon_gChi2	muon->globalTrack()->normalizedChi2()	yes
Muon_geta	muon->globalTrack()->eta()	yes
Muon_gphi	muon->globalTrack()->phi()	yes
Muon_gpt	muon->globalTrack()->pt()	yes
Muon_nValidMu	muon->globalTrack()->hitPattern(). numberOfValidMuonHits()	∼
Muon_isGood	TMOneStationTight	∼
Muon_isGoodLast	TMLastStationTight	∼
Muon_gnValid	muon->globalTrack()->hitPattern(). numberOfValidTrackerHits()	∼
Muon_gnPix	muon->globalTrack()->hitPattern(). numberOfValidPixelHits()	yes
Muon_Chi2	muon->innerTrack()->normalizedChi2()	yes
Muon_isGoodAng	TMLastStationAngTight	∼
Muon_isArbitrated	TrackerMuonArbitrated	∼

Muon Variables: nanoAOD(plus)

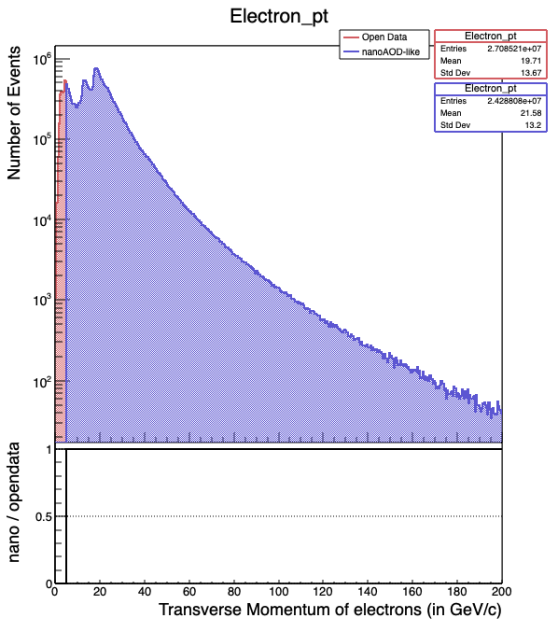
nanoAOD(plus) variable	validated
Muon_Id	no
Muon_looseId	no
Muon_softId4	no
Muon_isNano	no
Muon_isMini	no
Muon_isStandAlone	no
Muon_vtxIdx	no
Muon_simIdx	no

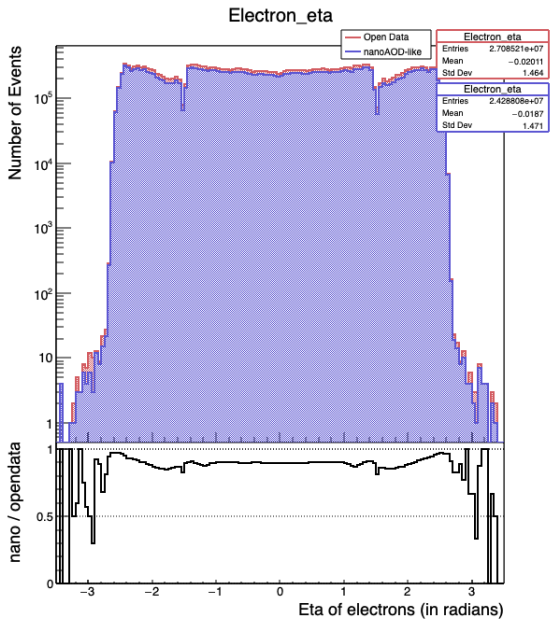
Muon Variables: What to do next

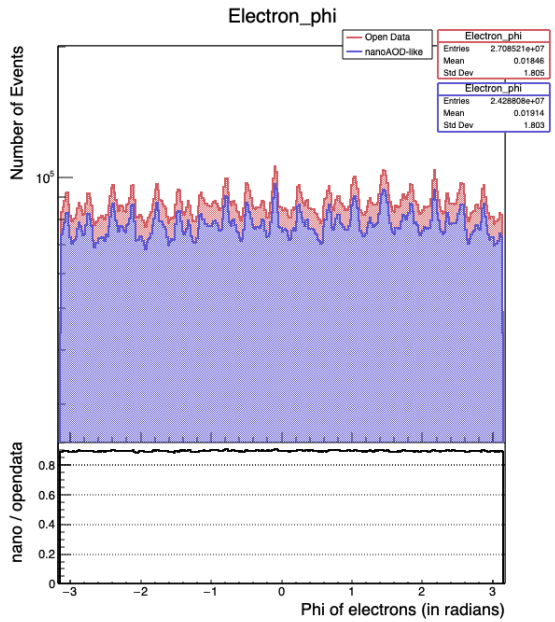
- Find the reasons for remaining differences in $J/\psi \to \mu\mu$, $Z \to \mu\mu$, $W \to \mu\nu_\mu$, and global dimuon invariant spectrum
- Fix bugs in `DemoAnalyzer.cc` and redo Open Data validation plots
- Reproduce Open Data validation plots using only official nanoAOD variables to check which of the introduced nanoAOD(plus) variables are really needed

Electron Variables

NanoAnalyzer.cc.ele6: p_{T}, η, ϕ

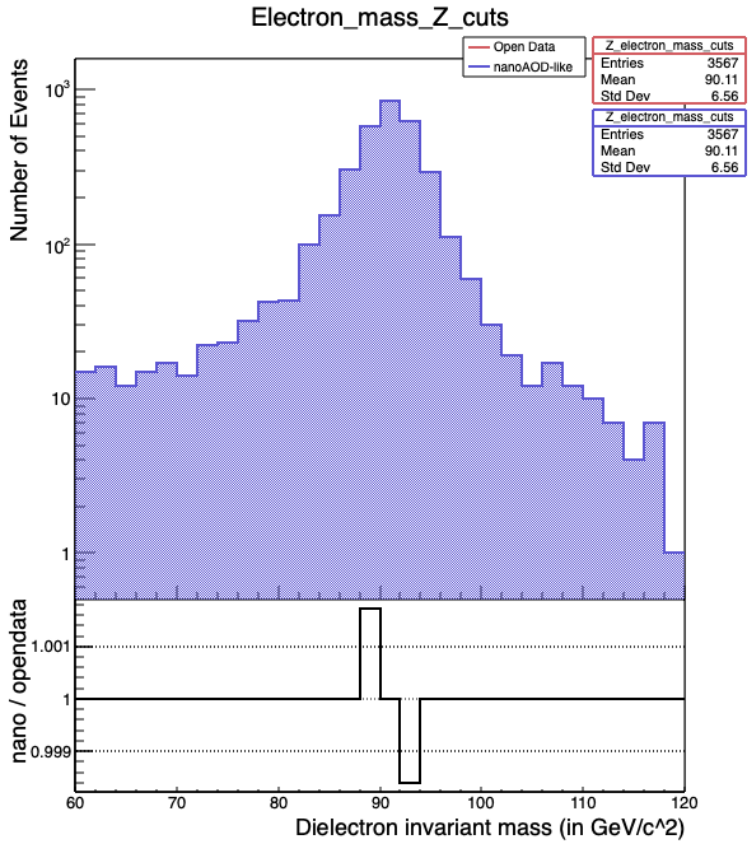






Open Data	nanoAOD-like
no p_{T} cut	$p_{\mathrm{T}} > 5\,\mathrm{GeV}$

NanoAnalyzer.cc.ele6: $Z \to ee$



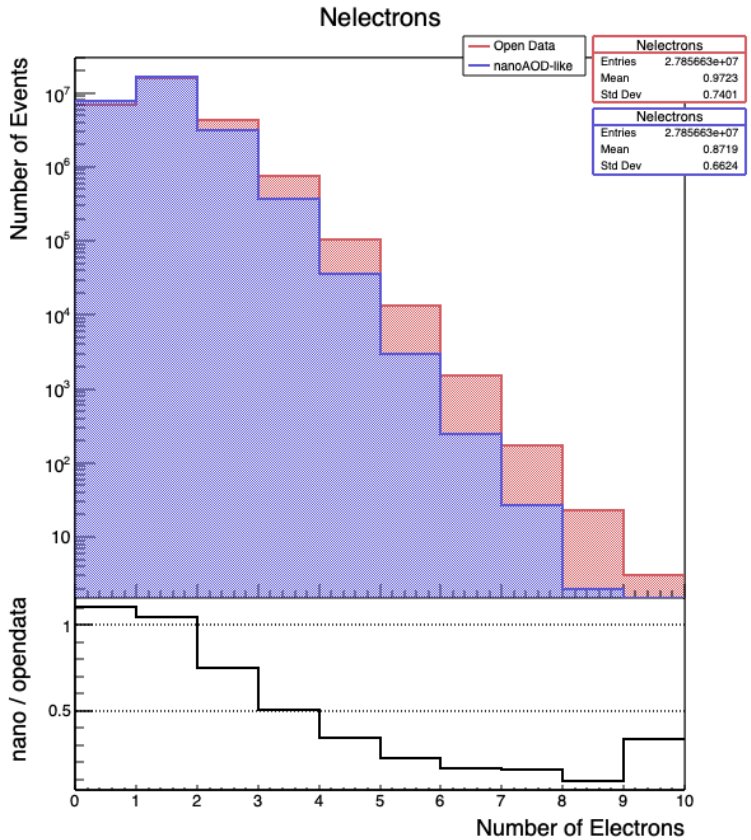
- $E_{\mathrm{T}} > 20\,\mathrm{GeV}$
- `Electron_lostHits` ≤ 1
- additional cuts on: `Electron_SCeta`, `Electron_isEB`, `Electron_isEE`, `Electron_dr03TKSumPt`, `Electron_dr03EcalRecHitSumEt`, `Electron_dr03HcalTowerSumEt`, `Electron_convDist`, `Electron_convDcot`, `Electron_sieie`, `Electron_hoe`, `Electron_deltaPhiSC`, `Electron_deltaEtaSC`

`NanoAnalyzer.cc.ZeroBias3`: Changes

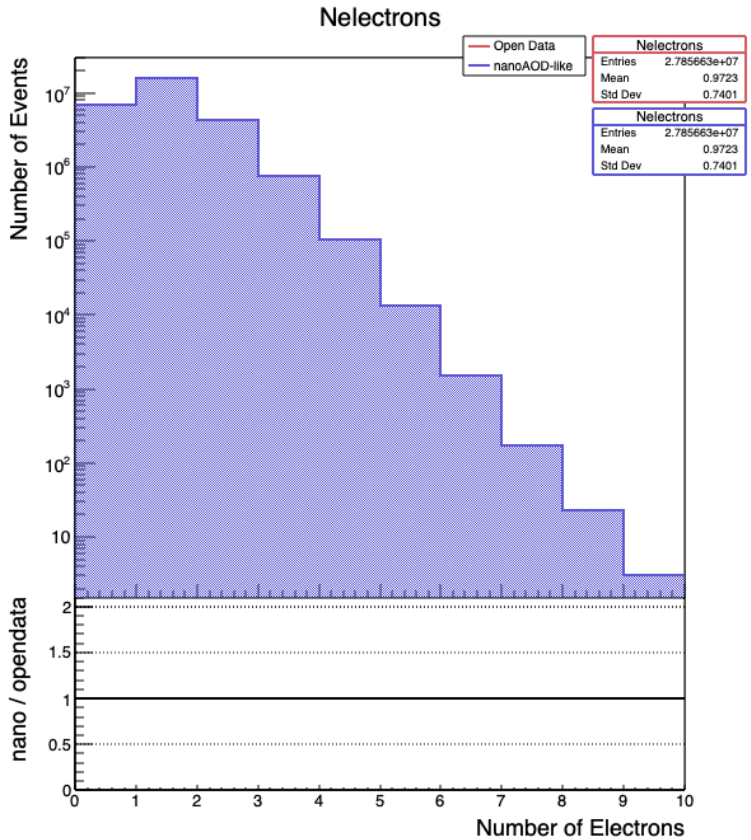
- New Variables:
  - remove p_{T} cut on electrons
  - definition of `Electron_deltaEtaSC` changed

NanoAnalyzer.cc.ZeroBias3: number of muons

NanoAnalyzer.cc.ele6

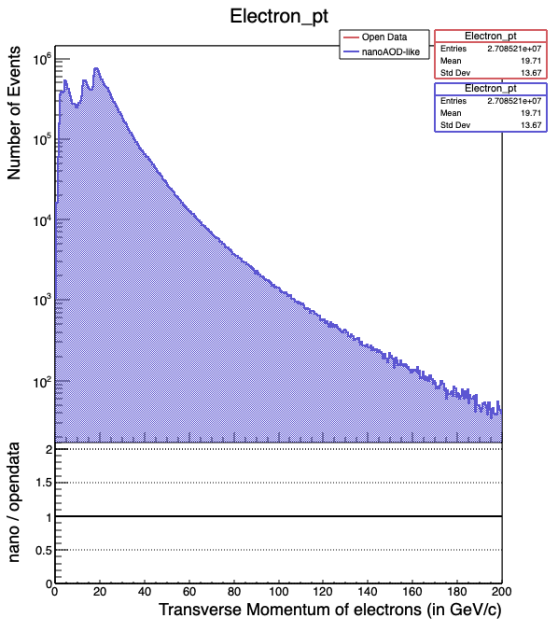


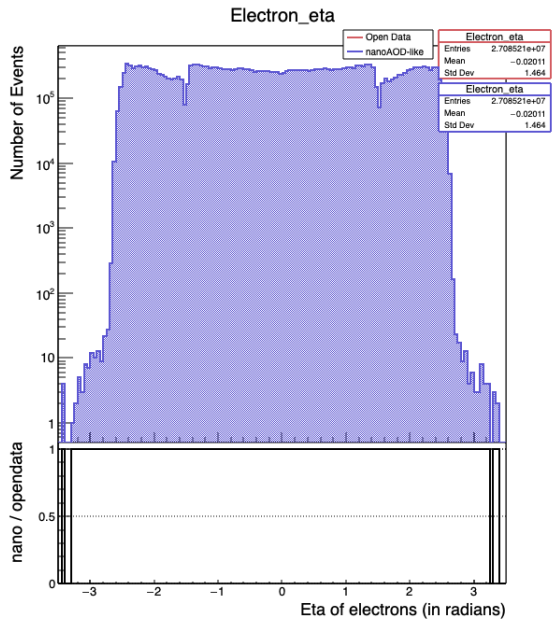
NanoAnalyzer.cc.ZeroBias3

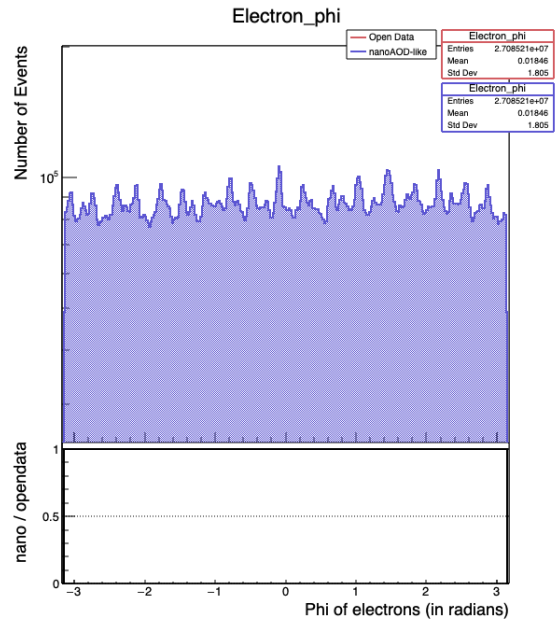


- removed p_{T} cuts
- `nElectrons` validated

NanoAnalyzer.cc.ZeroBias3: p_{T}, η, ϕ

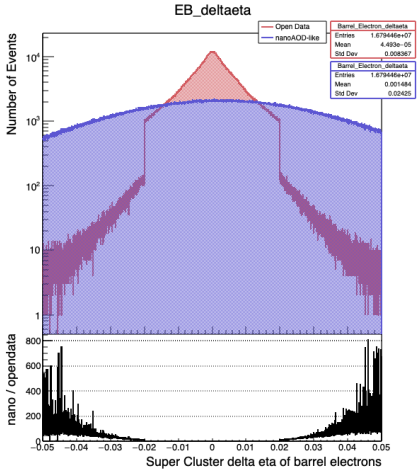


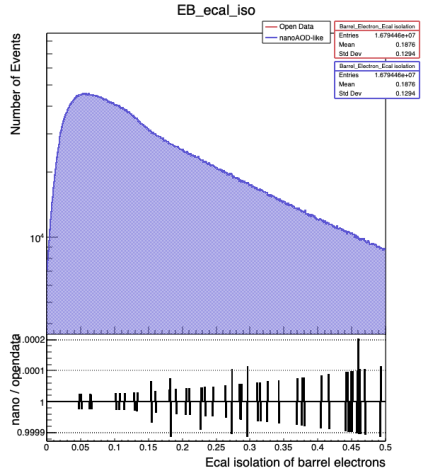


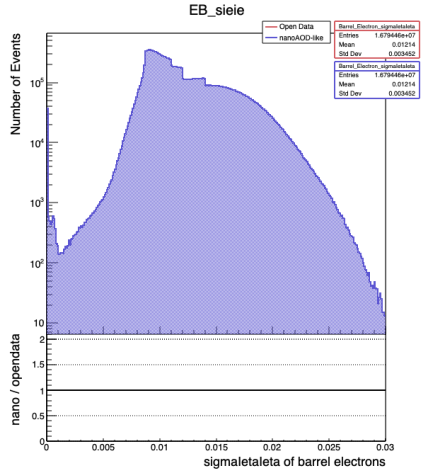


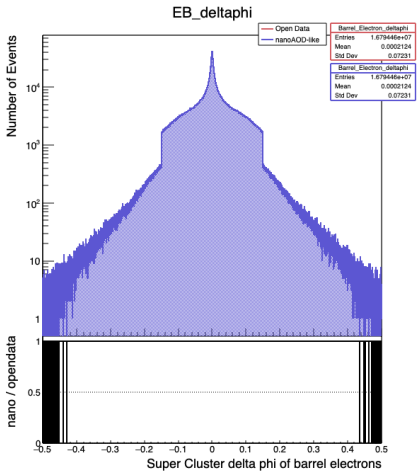
- removed p_{T} cuts
- `Electron_pt`, `Electron_eta`, `Electron_phi` validated

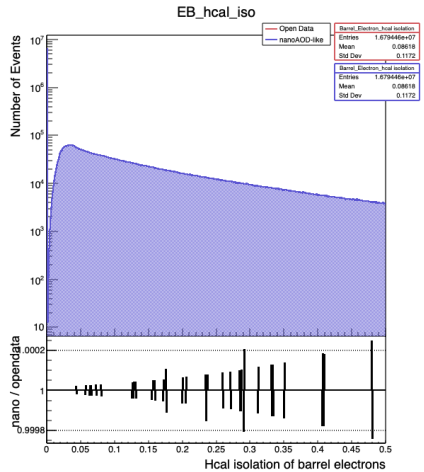
NanoAnalyzer.cc.ZeroBias3: barrel electrons

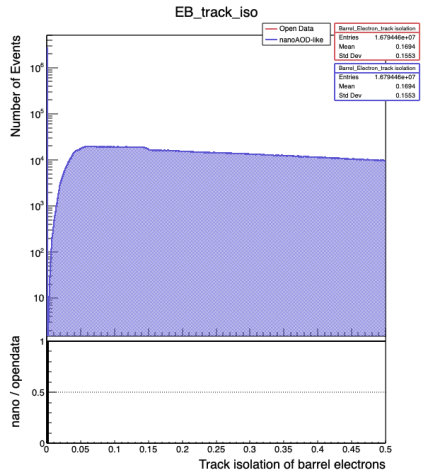






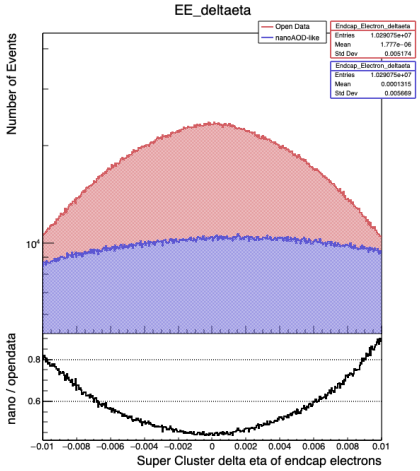


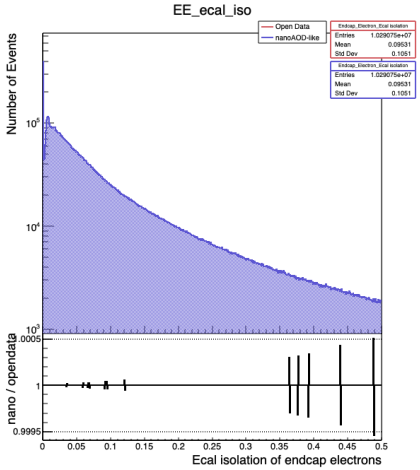


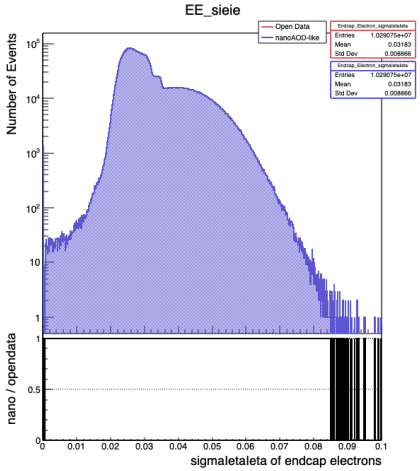


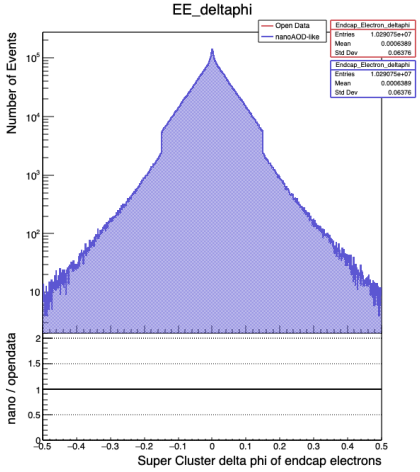
- something went wrong with `Electron_deltaEtaSC`
- `Electron_isEB`, `Electron_dr03TKSumPt`, `Electron_dr03EcalRecHitSumEt`, `Electron_dr03HcalTowerSumEt`, `Electron_sieie`, `Electron_deltaPhiSC` validated

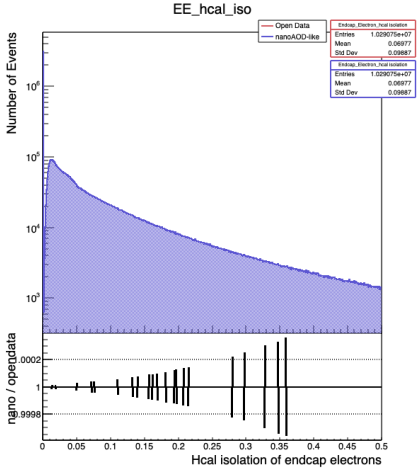
NanoAnalyzer.cc.ZeroBias3: endcap electrons

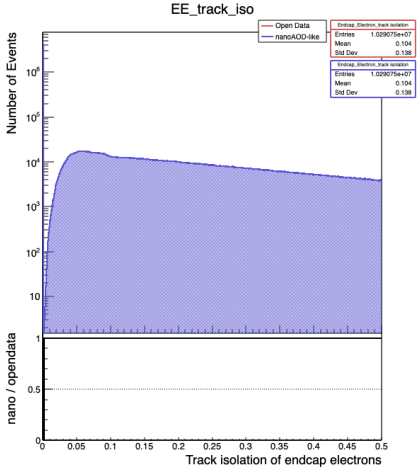






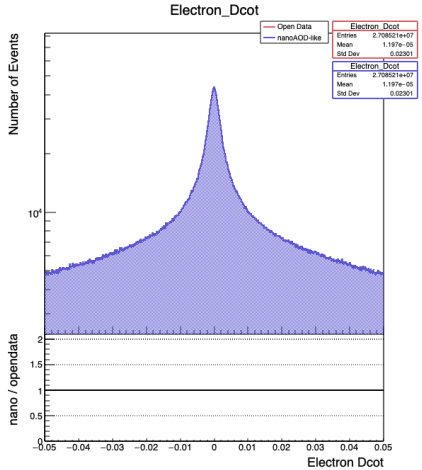


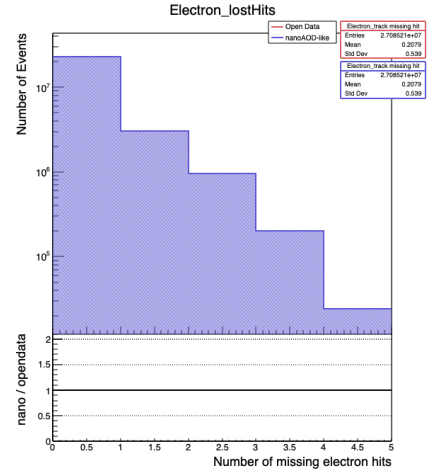


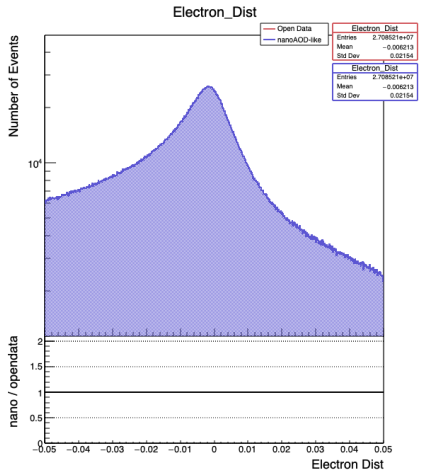


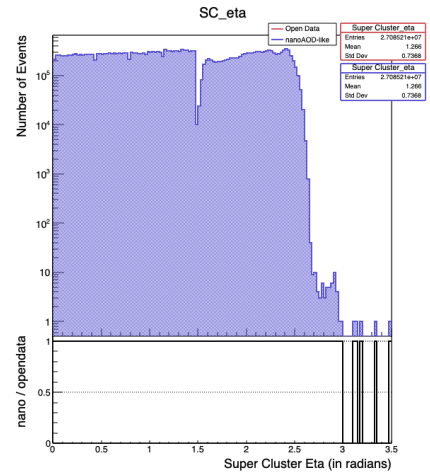
- `Electron_isEE` validated

NanoAnalyzer.cc.ZeroBias3: more electron variables





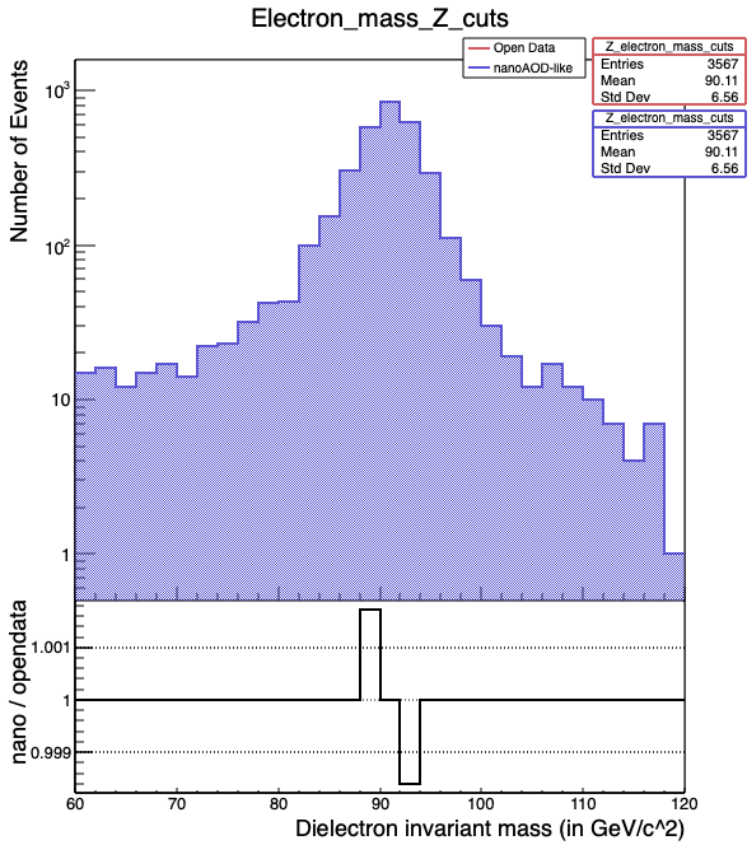




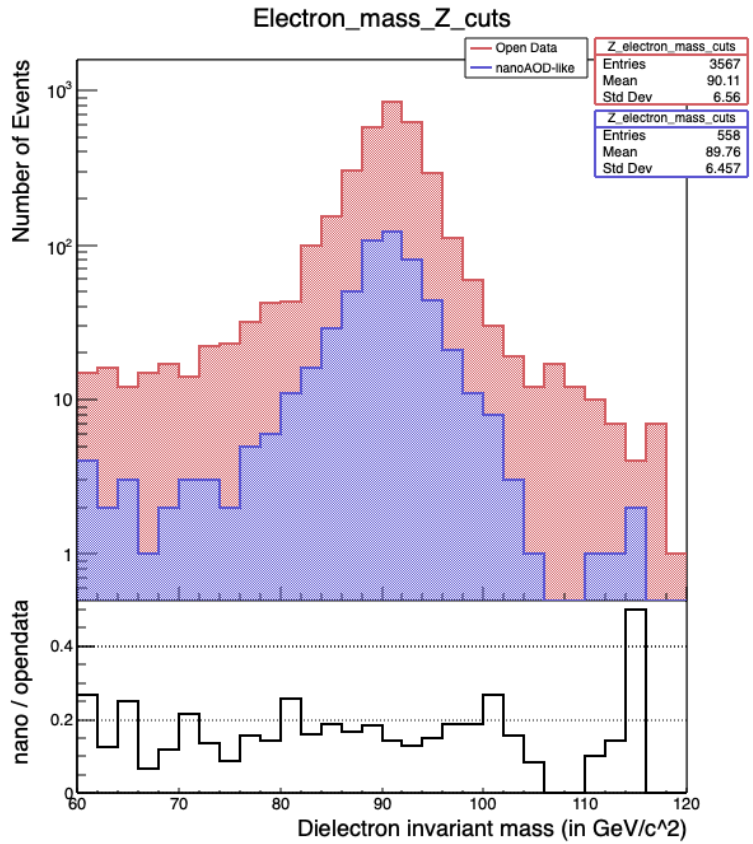
- `Electron_convDcot`, `Electron_convDist`, `Electron_lostHits`, `Electron_SCeta` validated

NanoAnalyzer.cc.ZeroBias3: $Z \to ee$

NanoAnalyzer.cc.ele6



NanoAnalyzer.cc.ZeroBias3



- does not work anymore because definition of `Electron_deltaEtaSC` changed
- change might have to be reversed

Electron Variables: nanoAOD-like

nanoAOD-like variable	AOD variable	validated
nElectron	`size()`	yes
`Electron_charge`	`electron->charge()`	yes
`Electron_deltaEtaSC`	`electron->deltaEtaSuperClusterTrackAtVtx()`	$\sim$
`Electron_dr03EcalRecHitSumEt`	`electron->dr03EcalRecHitSumEt()`	yes
`Electron_dr03TKSumPt`	`electron->dr03TkSumPt()`	yes
`Electron_eta`	`electron->eta()`	yes
`Electron_phi`	`electron->phi()`	yes
`Electron_pt`	`electron->pt()`	yes
`Electron_hoe`	`electron->hcalOverEcal()`	yes
`Electron_lostHits`	`electron->gsfTrack()->trackerExpectedHitsInner().numberOfHits()`	yes
`Electron_mass`	`electron->mass()`	no
`Electron_sieie`	`electron->sigmaIetaIeta()`	yes

Electron Variables: nanoAOD-like

nanoAOD-like variable	val.
Electron_cleanmask	no
Electron_convVeto	no
Electron_cutBased	no
Electron_cutBased_HEEP	no
Electron_dr03HcalDepth1TowerSumEt	no
Electron_dxy	no
Electron_dxyErr	no
Electron_dz	no
Electron_dzErr	no
Electron_eCorr	no
Electron_eInvMinusPInv	no
Electron_energyErr	no
Electron_genPartFlav	no
Electron_genPartIdx	no
Electron_ip3d	no
Electron_isPFcand	no
Electron_jetIdx	no

nanoAOD-like variable	val.
Electron_miniPFRelIso_all	no
Electron_miniPFRelIso_chg	no
Electron_mvaFall17Iso	no
Electron_mvaFall17Iso_WP80	no
Electron_mvaFall17Iso_WP90	no
Electron_mvaFall17Iso_WPL	no
Electron_mvaFall17noIso	no
Electron_mvaFall17noIso_WP80	no
Electron_mvaFall17noIso_WP90	no
Electron_mvaFall17noIso_WPL	no
Electron_mvaTTH	no
Electron_pdgId	no
Electron_pfRelIso03_all	no
Electron_pfRelIso03_chg	no
Electron_photonIdx	no
Electron_r9	no
Electron_sip3d	no
Electron_tightCharge	no
Electron_vidNestedWPBitmap	no

Electron Variables: nanoAOD(plus)

nanoAOD(plus) variable	AOD variable	validated
`Electron_convDist`	`electron->convDist()`	yes
`Electron_convDcot`	`electron->convDcot`	yes
`Electron_deltaPhiSC`	`electron->deltaPhiSuperClusterTrackAtVtx()`	yes
`Electron_dr03HcalTowerSumEt`	`electron->dr03HcalTowerSumEt()`	yes
`Electron_isEB`	`electron->isEB()`	yes
`Electron_isEE`	`electron->isEE()`	yes
`Electron_SCeta`	`electron->superCluster->eta()`	yes

Electron Variables: What to do next

- Produce a new version of 2010 Electron nanoAOD-like ntuple where change in definition of `Electron_deltaEtaSC` is reversed