Status of Muon implementation in nanoAODplus

Nano meeting, 20.05.2020

(Excerpt from presentation to Muon POG meeting, 28.10.2019)

Achim Geiser, DESY Hamburg for the DPOA nanoAODplus team

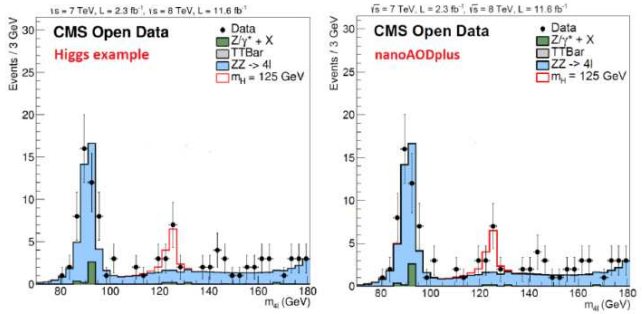
past and ongoing contributions (partially with EPR) by (contributed to muons)

Afiq Anuar, A.G., Nur Zulaiha Jomhari, Hannes Jung, Armando Martinez, Josry Metwally, Melanie Schmitz, Qun Wang, Stefan Wunsch (integral up to then: ~1 person-year)

and **Paula Martinez, Fabian Stäger, Lekhsmi Thulasidaran** (summer students 2018/19)

Matthew Snape, Vitus Magin (internship students 2018/19)

- current status
- plans
- summary and outlook



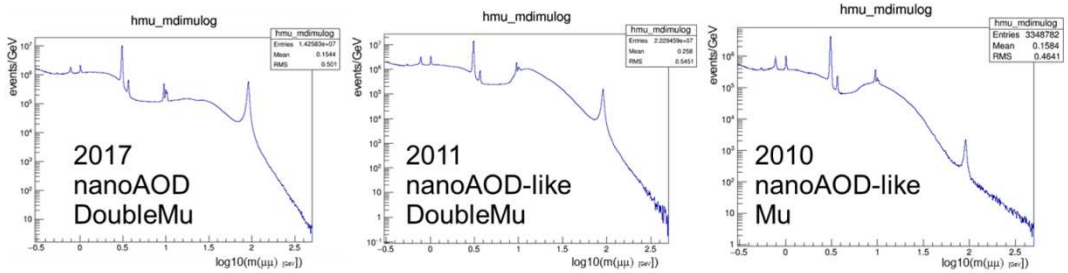
Twiki Documentation (under development) :

https://twiki.cern.ch/twiki/bin/viewauth/CMS/DPOANanoAODlike

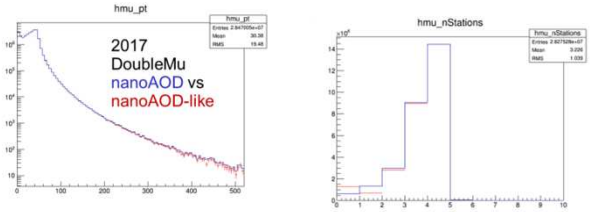
Updated!

Validation tools and strategy

- **Indirectly compare some physics distributions for different datasets:**



- **Directly compare technical distributions:** **(only possible for Run 2)**



- **Use BuildIndex and Friend functions of Root to compare nanoAOD and nanoAODplus variables event-by-event, even if input event sets only partially overlap and events occur in different order** **(only possible for Run 2)**

  -> can validate and debug exactly

  (currently ~75% of variables implemented, ~65% usefully filled, validation in progress)

- **Exactly reproduce some known/well-validated Run 1 distributions from nanoAODplus ntuple**

- **Use in actual Run 1 physics analyses**

Status of Muon variable implementation (w.r.t. nanoAODv3) part 1

Muon [back to top]

Object property	Type	Description
*$Muon_charge	Int_t	electric charge
-Muon_cleanmask	UChar_t	simple cleaning mask with priority to leptons
(*)($)Muon_dxy	Float_t	dxy (with sign) wrt first PV, in cm
(*)Muon_dxyErr	Float_t	dxy uncertainty, in cm
*Muon_dz	Float_t	dz (with sign) wrt first PV, in cm
(*)Muon_dzErr	Float_t	dz uncertainty, in cm
*$Muon_eta	Float_t	eta
-Muon_genPartFlav	UChar_t	Flavour of genParticle for MC matching to status==1 muons: 1 = prompt muon (including gamma*->mu mu), 15 = muon from prompt tau, 5 = muon from b, 4 = muon from c, 3 = muon from light or unknown, 0 = unmatched
+Muon_genPartIdx	Int_t(index to Genpart)	Index into genParticle list for MC matching to status==1 muons
-Muon_highPtId	UChar_t	high-pT cut-based ID (1 = tracker high pT, 2 = global high pT, which includes tracker high pT)
-Muon_ip3d	Float_t	3D impact parameter wrt first PV, in cm
*($)Muon_isGlobal	Bool_t	muon is global muon
*Muon_isPFcand	Bool_t	muon is PF candidate
*($)Muon_isTracker	Bool_t	muon is tracker muon
-Muon_jetIdx	Int_t(index to Jet)	index of the associated jet (-1 if none)
*$Muon_mass	Float_t	mass
*Muon_mediumId	Bool_t	cut-based ID, medium WP
-Muon_miniPFRelIso_all	Float_t	mini PF relative isolation, total (with scaled rho*EA PU corrections)
-Muon_miniPFRelIso_chg	Float_t	mini PF relative isolation, charged component
-Muon_mvaTTH	Float_t	TTH MVA lepton ID score
*Muon_nStations	Int_t	number of matched stations with default arbitration (segment & track)
*Muon_nTrackerLayers	Int_t	number of layers in the tracker
*Muon_pdgId	Int_t	PDG code assigned by the event reconstruction (not by MC truth)
(*)Muon_pfRelIso03_all	Float_t	PF relative isolation dR=0.3, total (deltaBeta corrections)
*Muon_pfRelIso03_chg	Float_t	PF relative isolation dR=0.3, charged component
(*)Muon_pfRelIso04_all	Float_t	PF relative isolation dR=0.4, total (deltaBeta corrections)
*$Muon_phi	Float_t	phi
*$Muon_pt	Float_t	pt
(*)Muon_ptErr	Float_t	ptError of the muon track

Documentation of nanoAODplus ntuple, version trigmu:
* filled and fully validated againts Run 2; use!
(*) filled with some known intentional or unknown not yet resolved differences w.r.t. Run 2, use with caution
+ filled, but not checked/validated yet; validate before use or do not use
- exists but is not or not properly filled yet; do not use
no prefix: does not (yet) exist on nanoAODlike ntuple
& nanoAODplus variable(s), not part of official nanoAOD, use for special purposes
# nanoAODplus variable(s), not part of official nanoAOD, not yet filled or checked (properly)
$ nanoAOD or nanoAODplus, validated against 2010 Open Data examples
($) nanoAOD or nanoAODplus, partially validated against 2010 Open Data examples

official Run 2 nanoAOD variables

filled for **all Run 1 AOD muons** from muon collection

Status of Muon variable implementation (w.r.t. nanoAODv3) part 2

*Muon_segmentComp	Float_t	muon segment compatibility
-Muon_sip3d	Float_t	3D impact parameter significance wrt first PV
*Muon_softId	Bool_t	soft cut-based ID
*Muon_tightCharge	Int_t	Tight charge criterion using pterr/pt of muonBestTrack (0:fail, 2:pass)
*Muon_tightId	Bool_t	cut-based ID, tight WP
#Muon_id	Int_t	Unique identifier of muon, to be used for cross-referencing
&$Muon_x	Float_t	x point of closest approach to beam line, in cm
&$Muon_y	Float_t	y point of closest approach to beam line, in cm
&$Muon_z	Float_t	z point of closest approach to beam line, in cm
&($)Muon_gpt	Float_t	global muon pt
&($)Muon_geta	Float_t	global muon eta
&($)Muon_gphi	Float_t	global muon phi
#Muon_dxyBest	Float_t	dxy (with sign) wrt best PV, in cm
#Muon_dzBest	Float_t	dz (with sign) wrt best PV, in cm
#Muon_ip3dBest	Float_t	3D impact parameter wrt best PV, in cm
#Muon_sip3dBest	Float_t	3D impact parameter significance wrt best PV
#Muon_looseId	Bool_t	loose cut-based ID
#Muon_softId4	Bool_t	soft cut-based ID, 2010 version
#Muon_softIdBest	Bool_t	soft cut-based ID, w.r.t. best PV
#Muon_isNano	Bool_t	can be found on NanoAOD
#Muon_isMini	Bool_t	can be found on MiniAOD
&$Muon_isGood	Bool_t	isGood(TMAnyStationTight)
&$Muon_isGoodLast	Bool_t	isGood(TMLastStationTight)
&$Muon_isGoodAng	Bool_t	isGood(TMLastStationAngTight)
&$Muon_isArbitrated	Bool_t	isGood(TrackerMuonArbitrated)
#Muon_isStandAlone	Bool_t	StandAlone Muon
#Muon_isRPCcand	Bool_t	RPC Muon
&$Muon_nValid	Int_t	number of valid tracker hits
&$Muon_nPix	Int_t	number of valid pixel hits
&($)Muon_gnValid	Int_t	number of valid tracker hits, global muon
&($)Muon_gnPix	Int_t	number of valid pixel hits, global muon
&($)Muon_gChi2	Float_t	global muon chi2/ndof
&($)Muon_nValidMu	Int_t	number of valid muon system hits
#Muon_trkIdx	Int_t(index to track)	index of the associated track (-1 if none)
#Muon_simIdx	Int_t(index to gen)	index of the associated gen object (-1 if none)
+$nMuon	UInt_t	all AOD Muons after basic nanoAODplus selection (may or may not correspond to b4_nMuon)
&$b4_nMuon	UInt_t	original number of AOD Muons without any selection
&Muon_nNano	UInt_t	number of slimmedMuons after basic nanoAOD selection (pt > 3 && track.isNonnull && isLooseMuon) = nMuon on nanoAOD

official Run 2 nanoAOD variables

additional variables for Run 1 analysis
(open for suggestions/criticism)

flags to indicate whether muon candidate would make it to miniAOD or nanoAOD if data would be Run 2

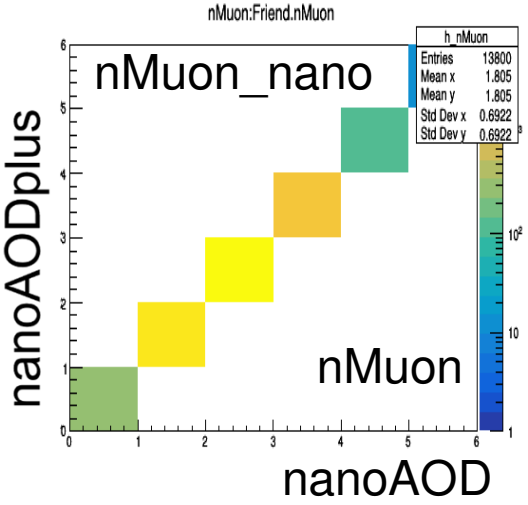
Additional variables added in latest nanoAOD, still missing:

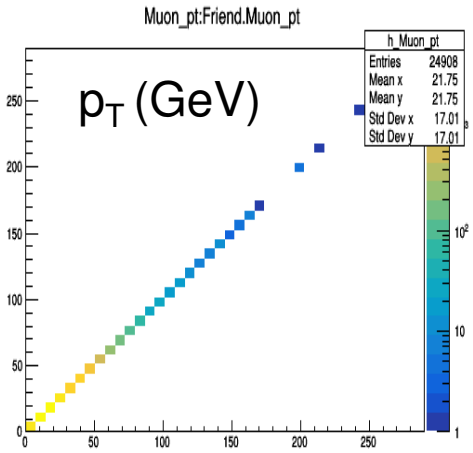
Muon_fsrPhotonIdx, Muon_multiIsoId, Muon_tightCharge
Muon_highPurity, Muon_mvaId, Muon_tkIsoId
Muon_inTimeMuon, Muon_mvaLowPt, Muon_tkRelIso
Muon_JetPtRelv2, Muon_mvaLowPtId,
Muon_JetRelIso, **Muon_pfIsoId,** Muon_triggerIdLoose
Muon_mediumPromptId, Muon_softMva, Muon_tunepRelpt
Muon_miniIsoId, Muon_softMvaId

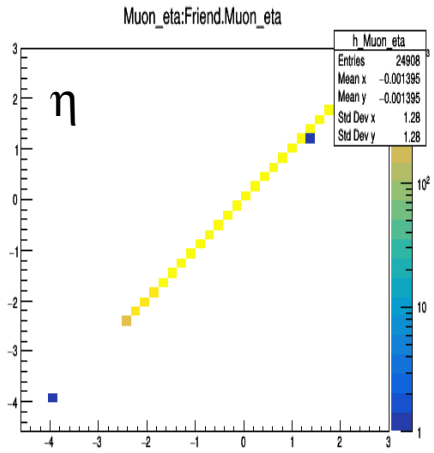
muon variables: comparison with official nanoAOD (for checking/validation only)

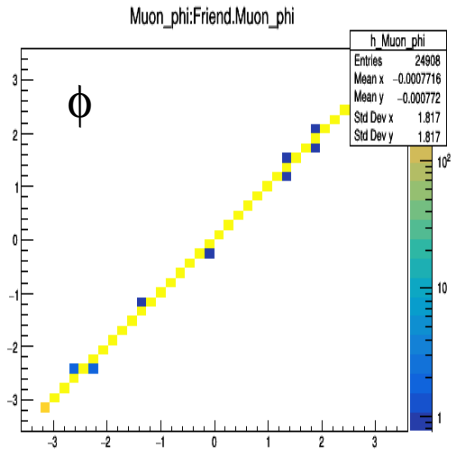
fraction of 2016 DoubleMu dataset: nanoAODplus from 8_X legacy AOD vs official 9_X nanoAOD
(reimplementation of variables from AOD according to workbook)

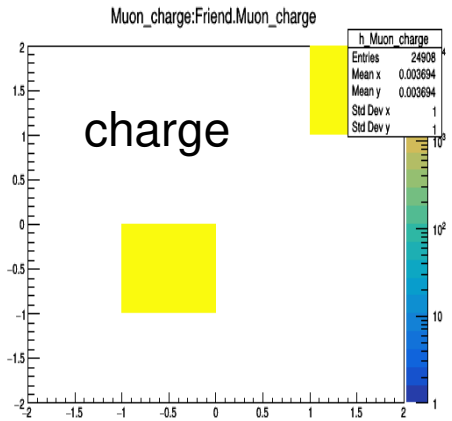
Use BuildIndex + Friend options of ROOT to compare ntuple contents

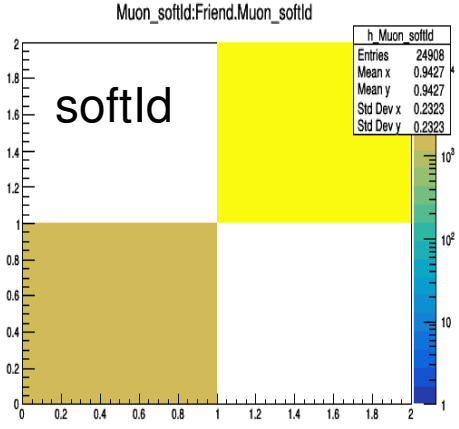


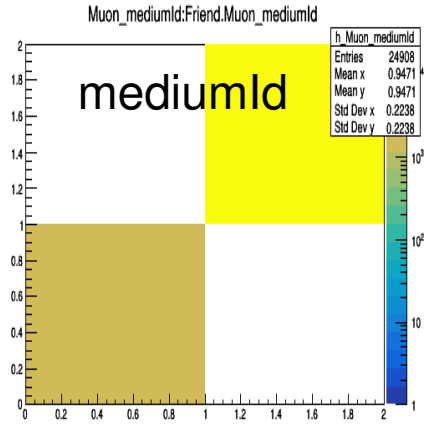


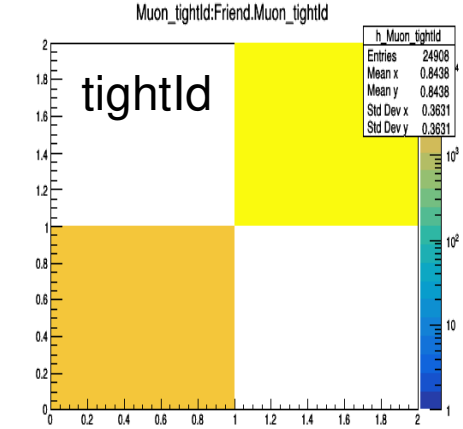












almost perfect agreement

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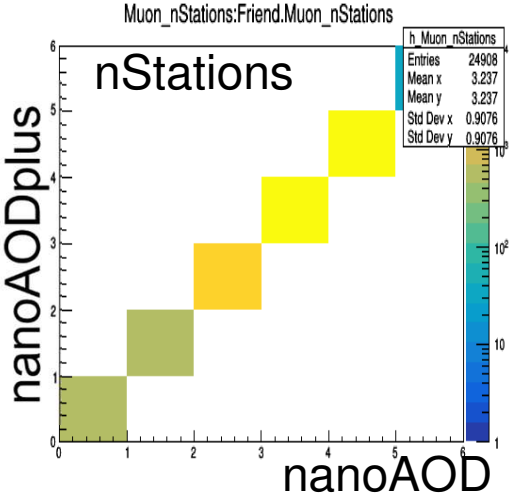

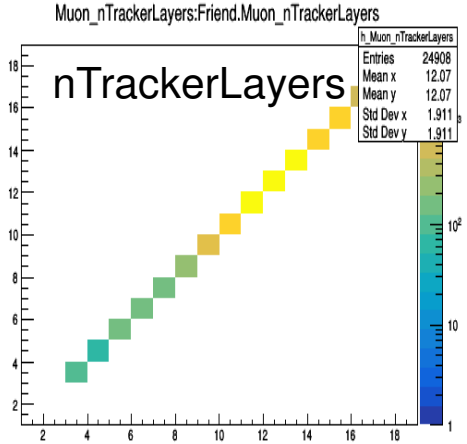

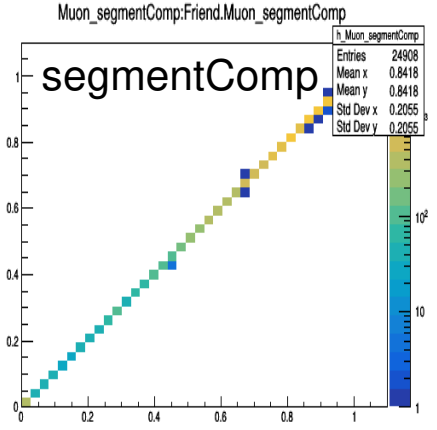

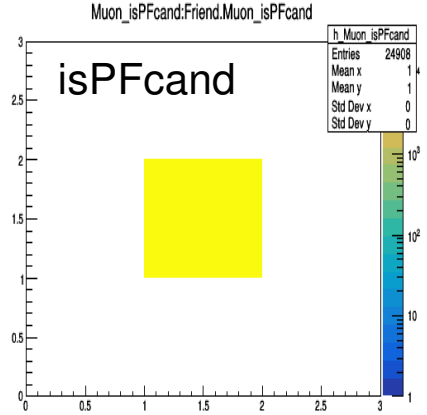

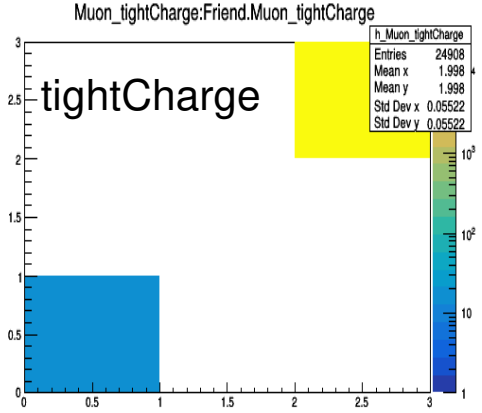

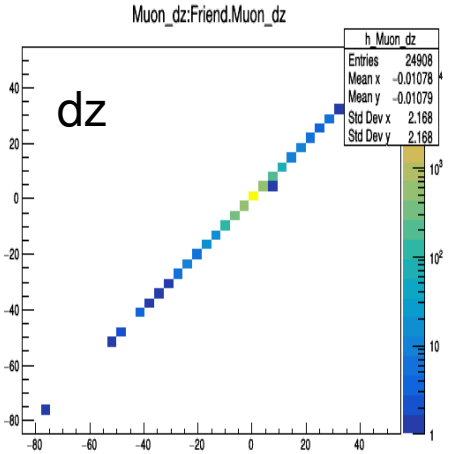

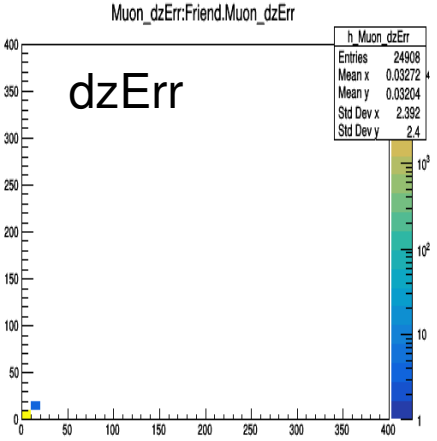

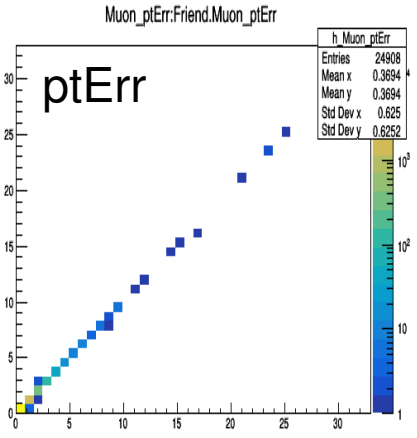

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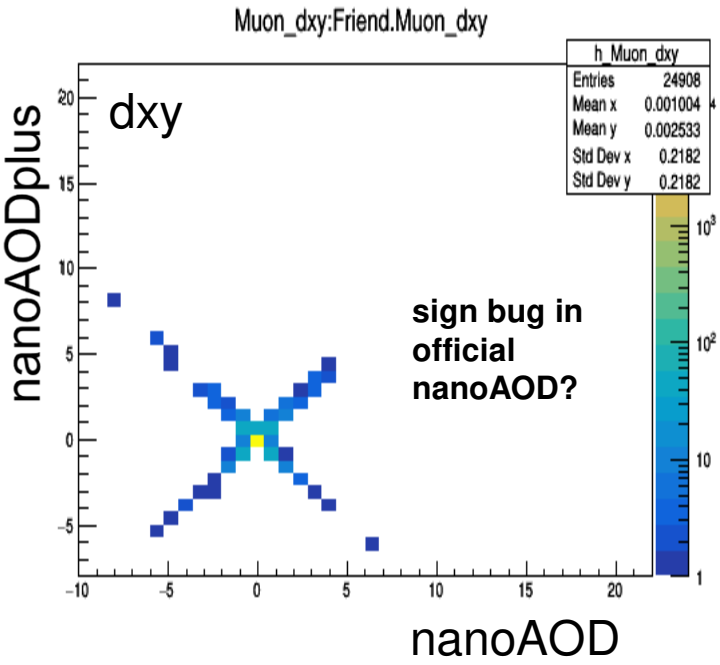
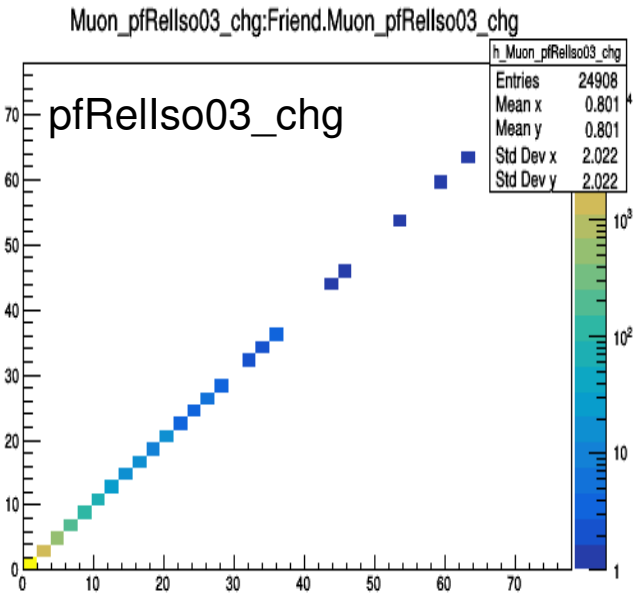
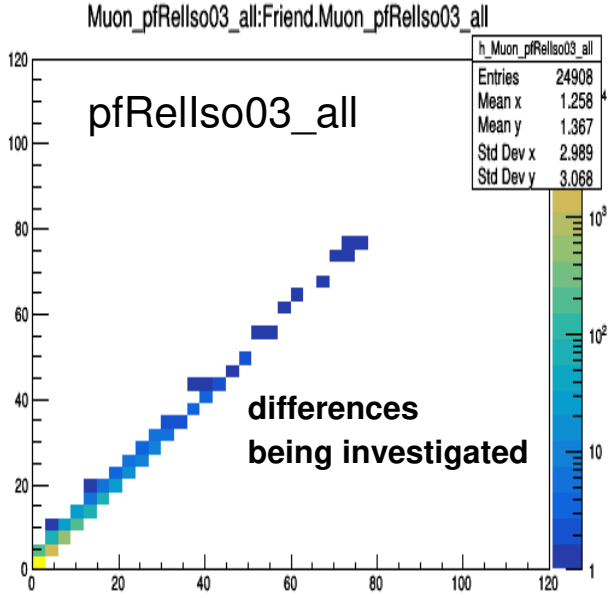






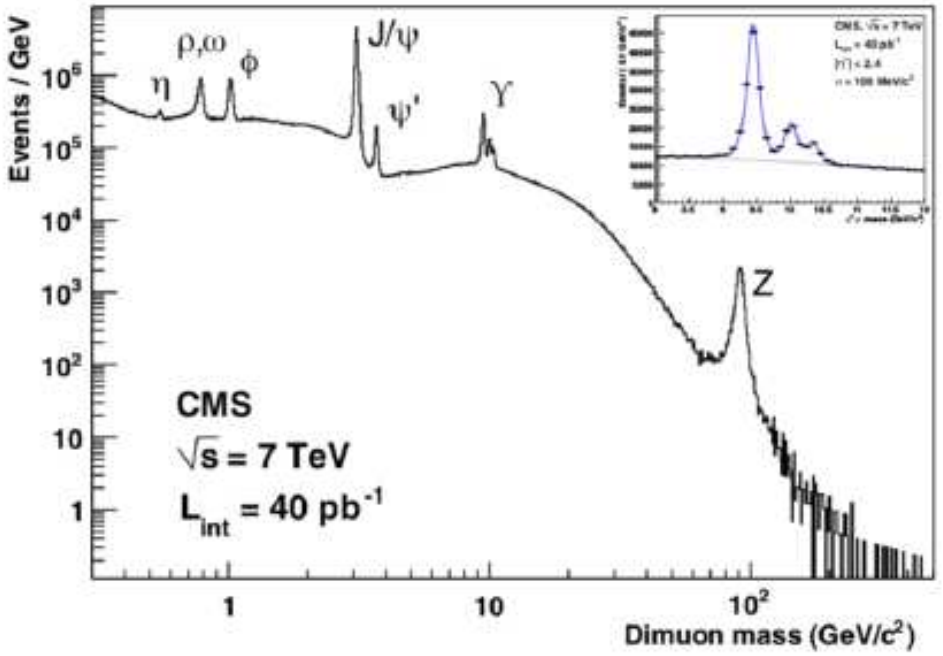
can be used, but more work needed

many more, which are not yet usefully implemented

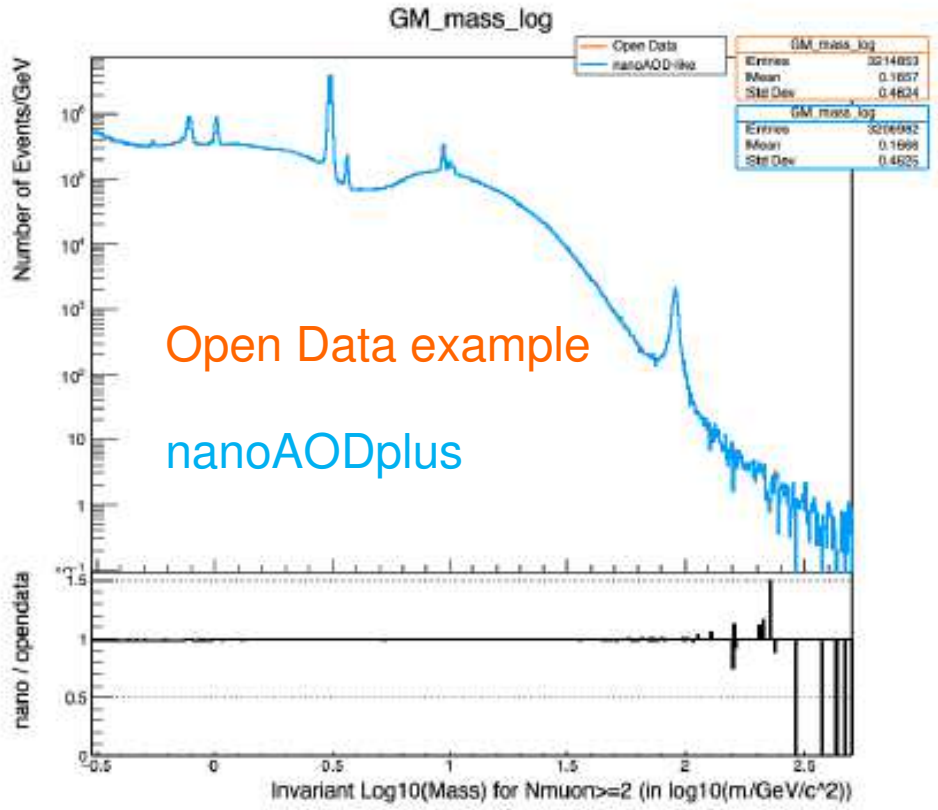
2010 Dimuon validation example

slide Fabian Stäger

public plot: CMS-MUO-10-004



2010 Mu dataset



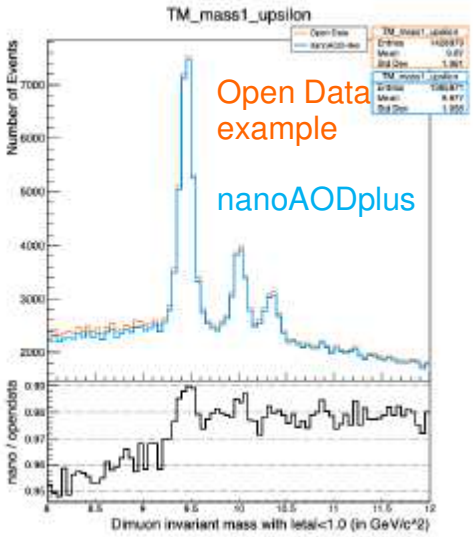
2010
CMSSW_4_2_8

- ~ 2‰ difference remaining

(global muon directly vs. from muon collection)

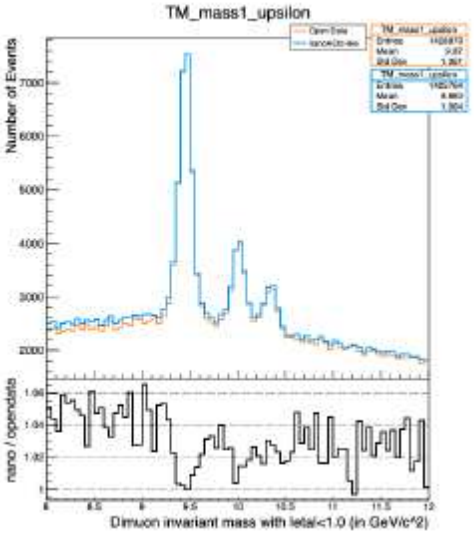
Validation procedure using Open Data examples

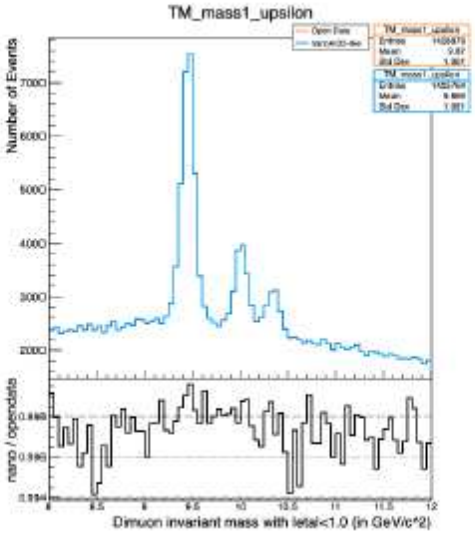
slide Fabian Stäger

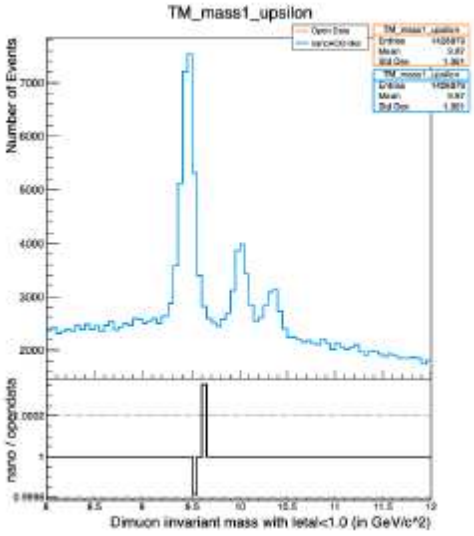


1) pick histogram from Open Data example (e.g. $\Upsilon \to \mu^+\mu^-$ in 2010 Muon dataset)
2) read the code to see which cuts were made
3) make same cuts on nanoAOD(plus) variables
4) think about why there is still a difference 🤔
5) make some changes on the ntuple and repeat steps 2) to 4)

2010
CMSSW_4_2_8





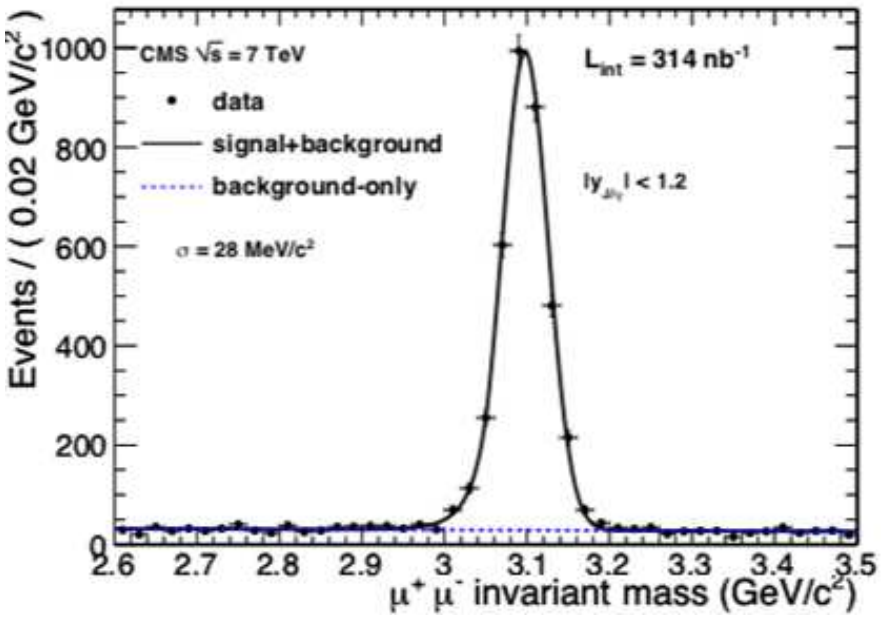


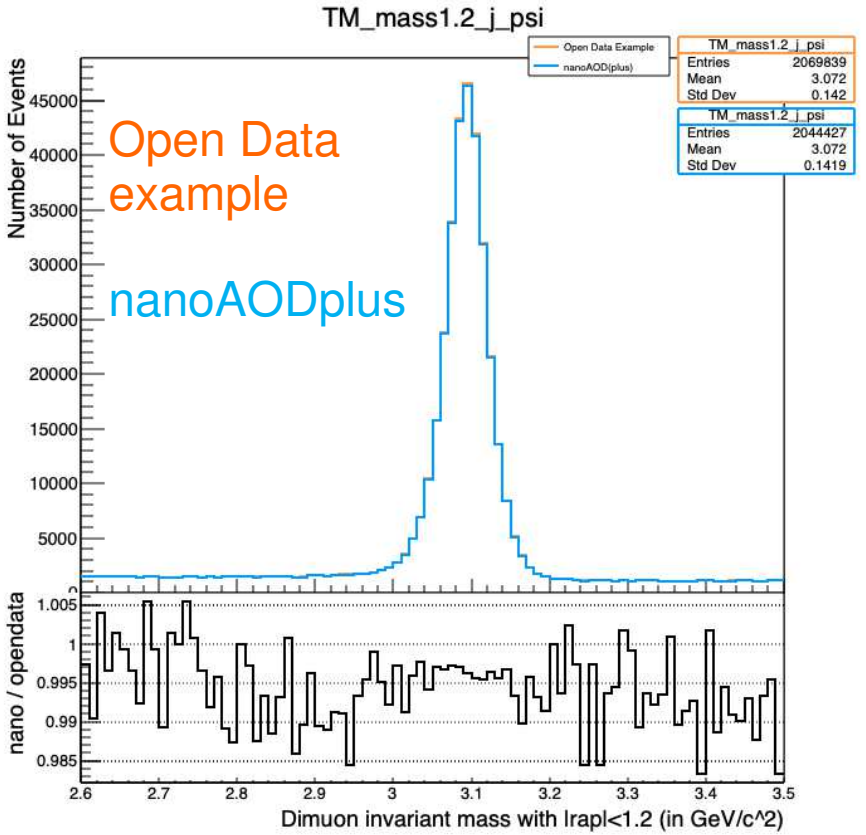
2010 MuOnia validation example, J/ψ ->μμ

2010
CMSSW_4_2_8

Fabian Stäger, A.G., Josry Metwally, Nuha Jomhari

2010B MuOnia dataset

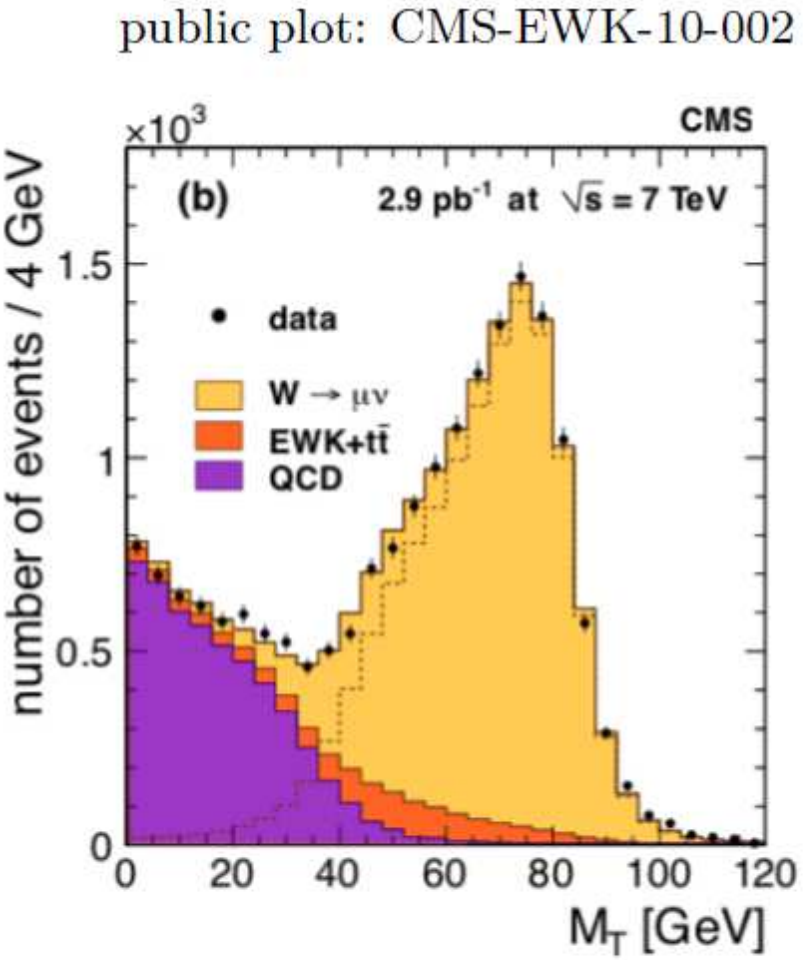


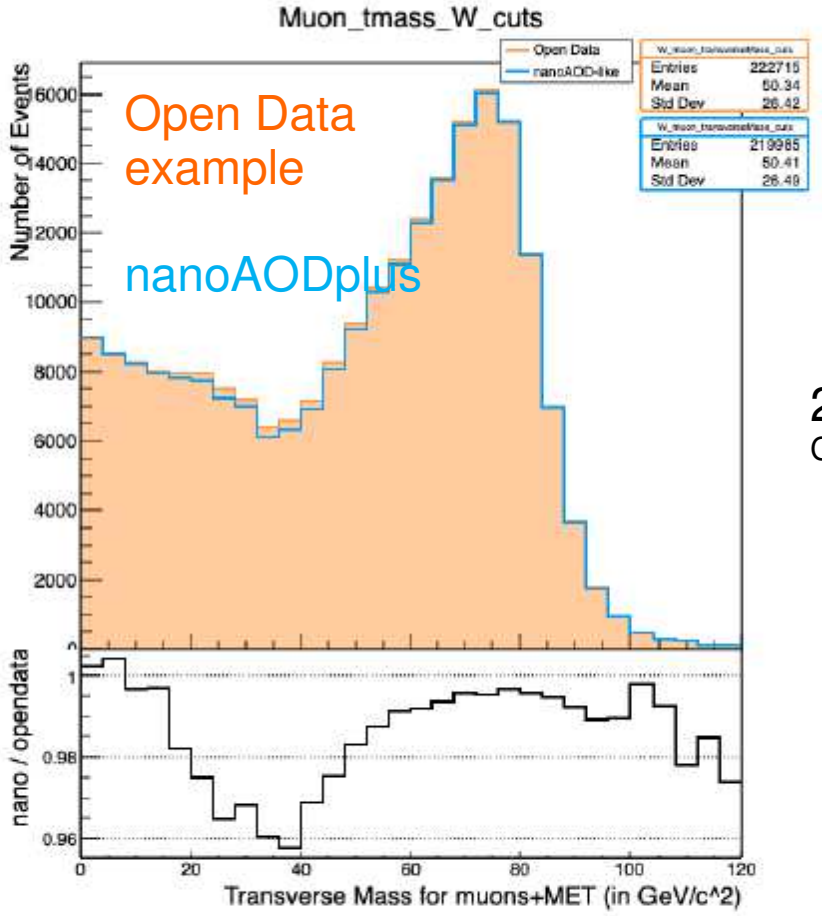


Would have needed one more iteration

2010 W->μν validation example

2010B Mu dataset slide Fabian Stäger





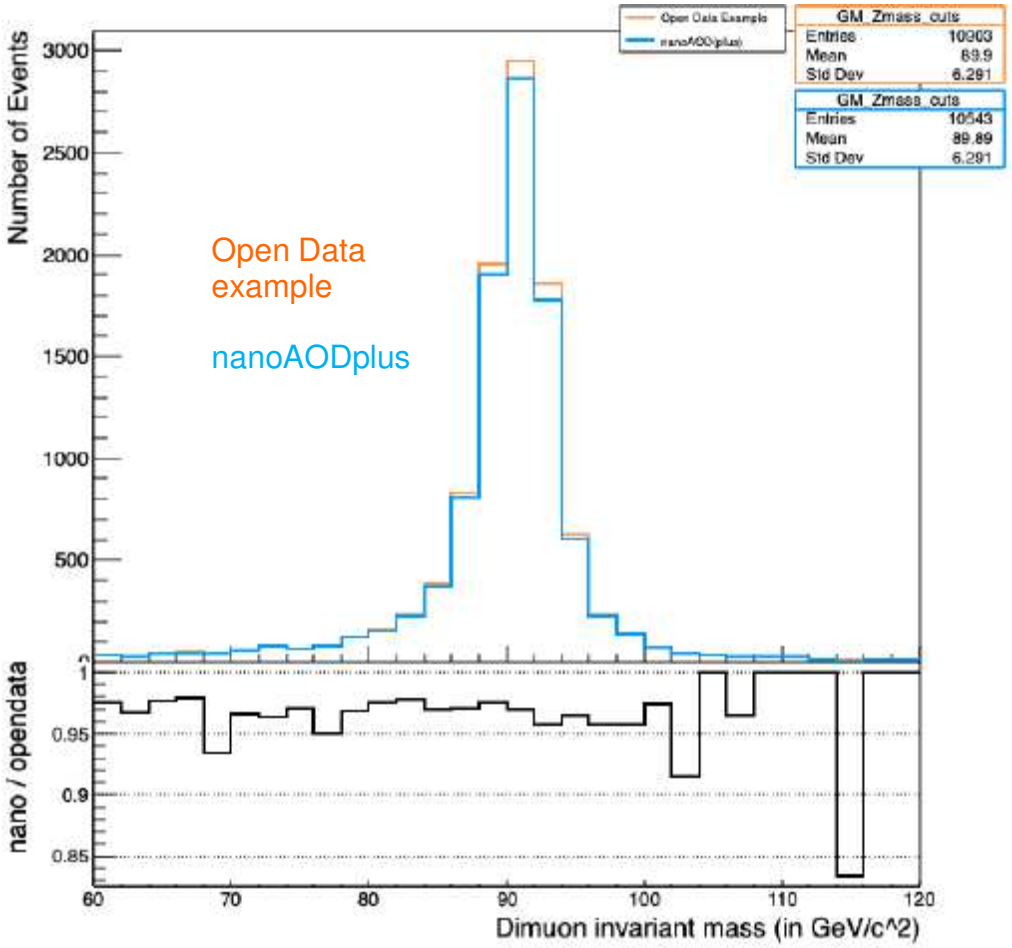
2010
CMSSW_4_2_8

- ~ 1% difference remaining (MET not yet fully the same)

Validation using Open Data examples

2010
CMSSW_4_2_8

Fabian Stäger



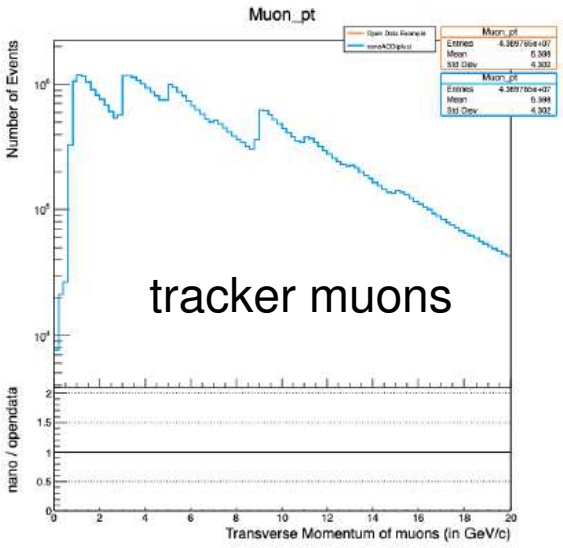
(c) $Z \to \mu^+\mu^-$ resonance [8], MuOnia example, Muon dataset

lose global muons
not in muon collection
(still in Run 2?)

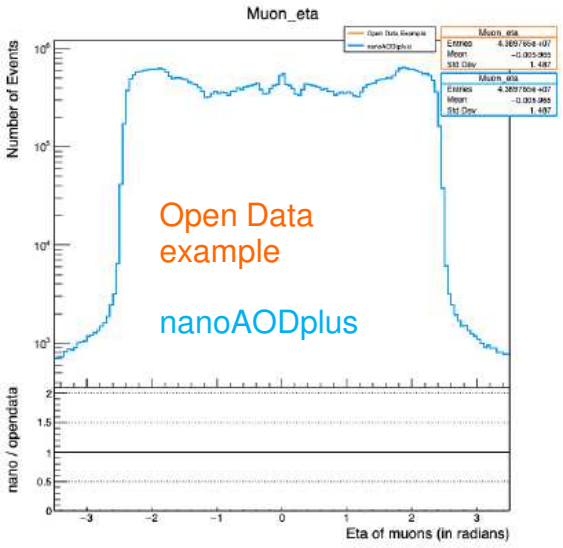
to be checked further

Variable validation using Open Data examples

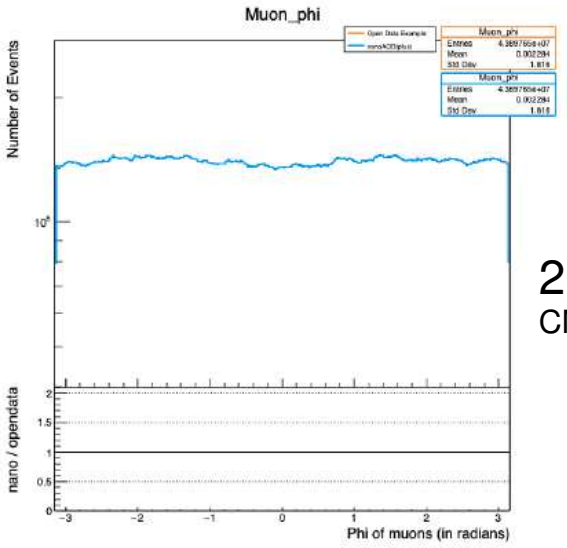
Fabian Stäger



(a) Muon_pt

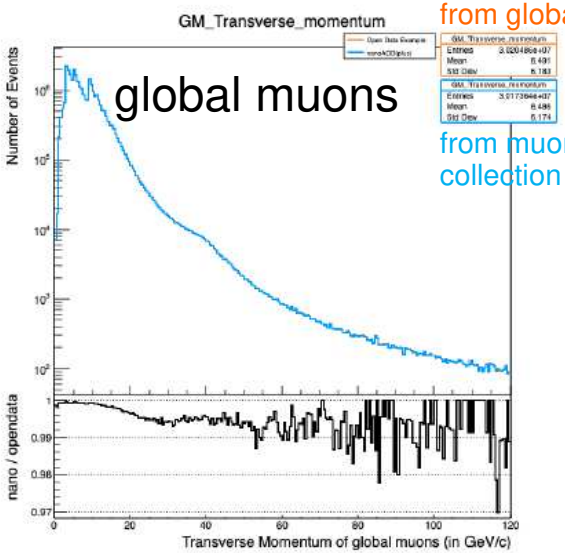


(b) Muon_eta

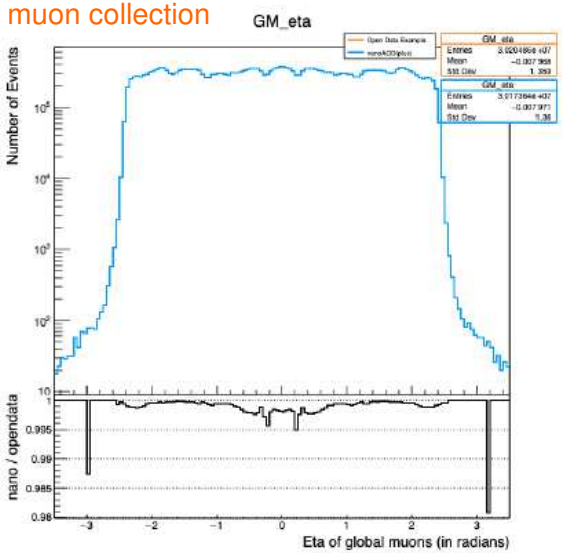


(c) Muon_phi

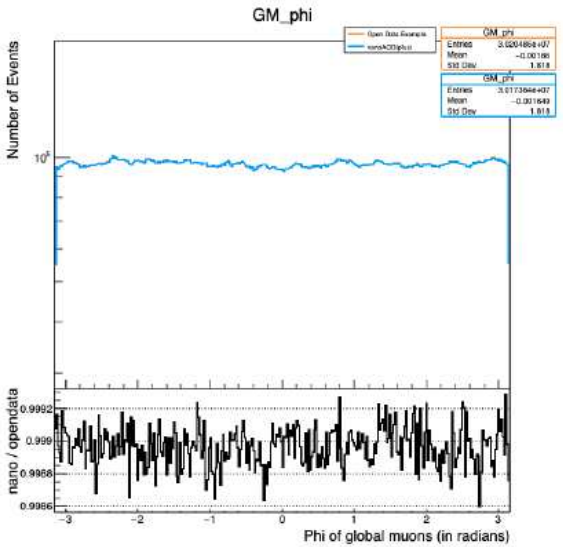
2010
CMSSW_4_2_8



(d) Muon_gpt



(e) Muon_geta



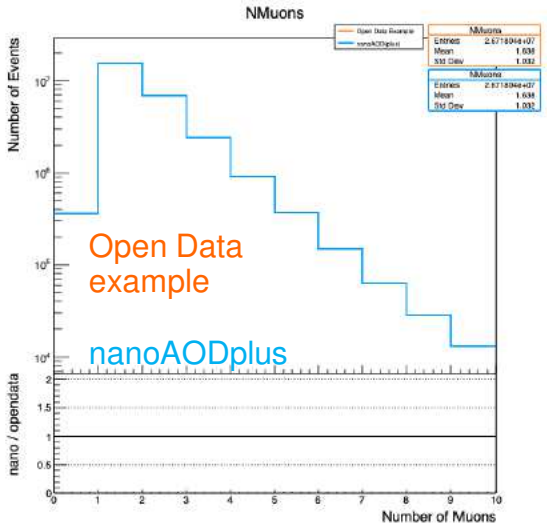
(f) Muon_gphi

some global muons are not in (tracker) muon collection

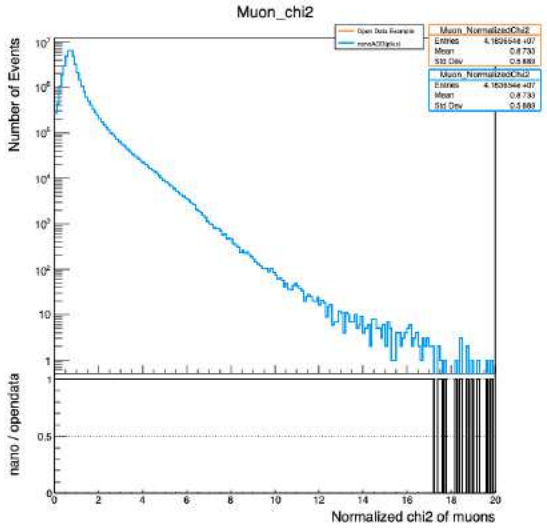
Variable validation using Open Data examples

Fabian Stäger

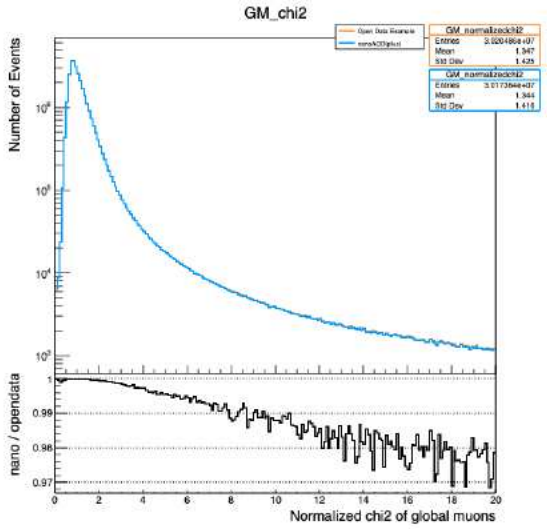
2010
CMSSW_4_2_8



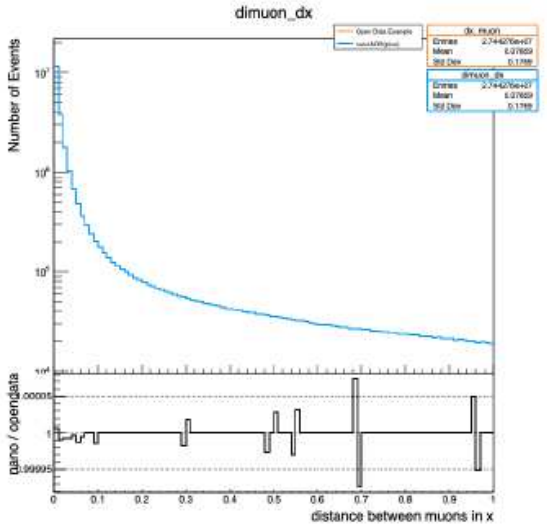
(a) nMuon



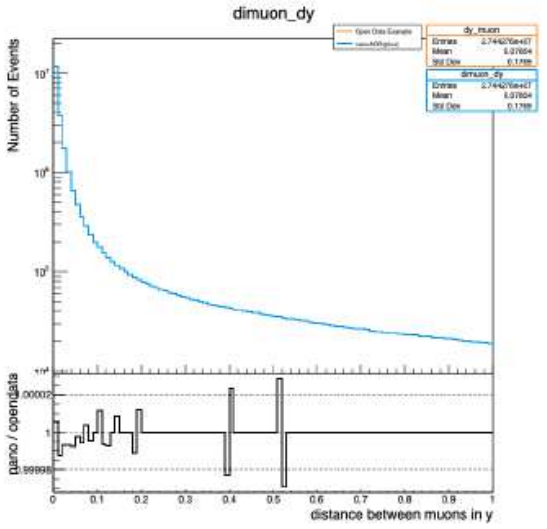
(b) Muon_Chi2



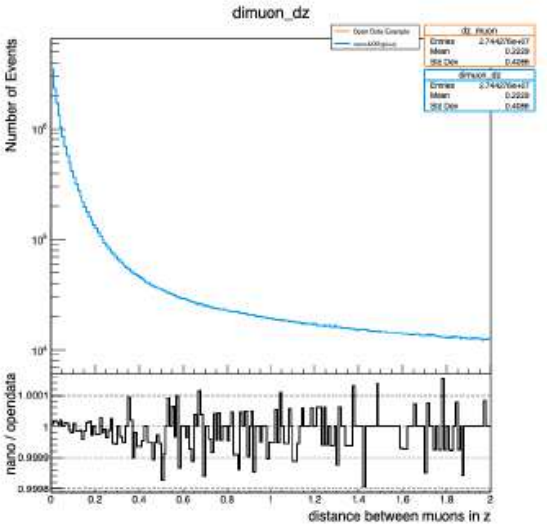
(c) Muon_gChi2



(a) abs(Muon_dx(1) - Muon_dx(2))



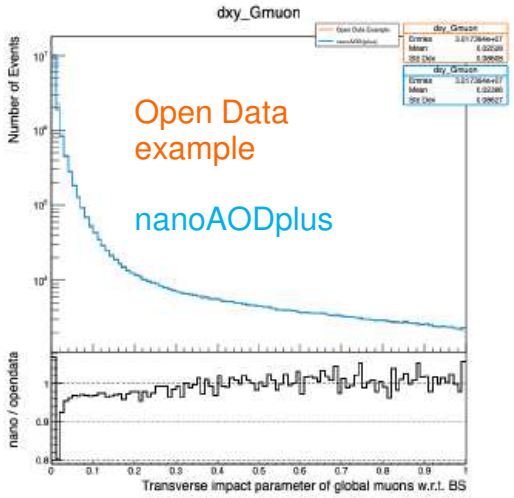
(b) abs(Muon_dy(1) - Muon_dy(2))



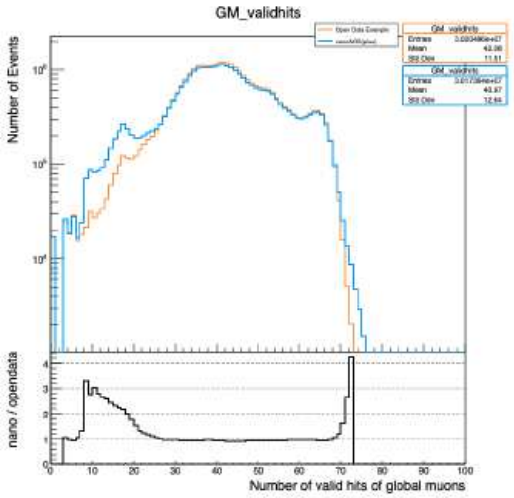
(c) abs(Muon_dz(1) - Muon_dz(2))

Variable validation using Open Data examples

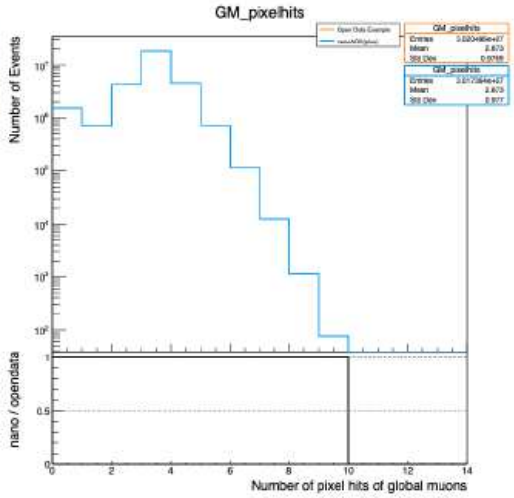
Fabian Stäger



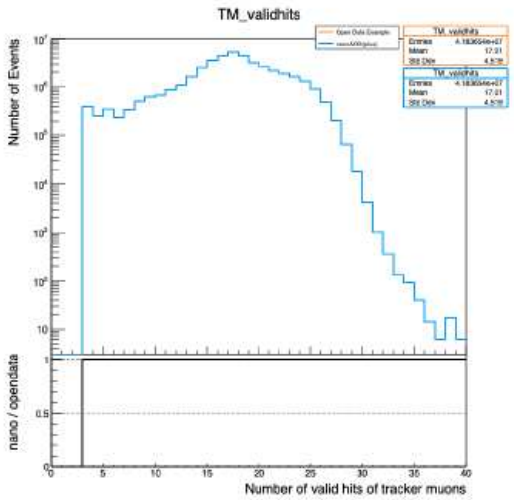
(d) `Muon_dxy` (`Muon_isGlobal`)



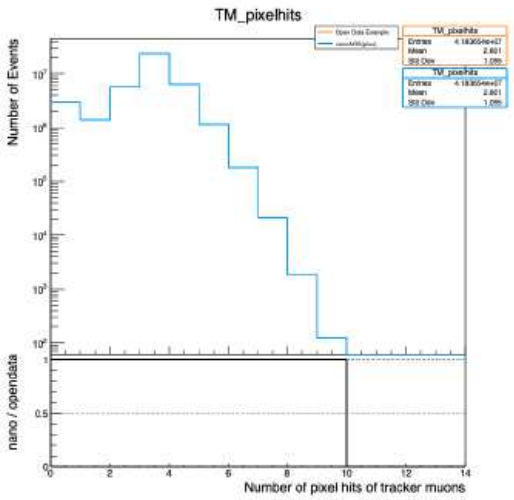
(e) `Muon_nValid + _nValidMu` (`Muon_isGlobal`)



(f) `Muon_gnPix` (`Muon_isGlobal`)



(g) `Muon_nValid` (`Muon_trkIdx != -1`)



(h) `Muon_nPix` (`Muon_trkIdx != -1`)

2010
CMSSW_4_2_8

Variables validated using Open Data examples

Fabian Stäger

2010
CMSSW_4_2_8

nMuon	size()	yes	figure A.3a
Muon_charge	muon->charge()	yes	figure 3.4
Muon_dxy	muon->track->dxy()	partially	figure A.6d
Muon_eta	muon->eta()	yes	figure A.4b
Muon_phi	muon->phi()	yes	figure A.4c
Muon_pt	muon->pt()	yes	figure A.4a
Muon_isGlobal	muon->isGlobalMuon()	partially	figure 3.5a
Muon_isTracker	muon->isTrackerMuon()	partially	figure 3.5b
Muon_mass	0.105658 GeV	yes	figure 3.4
Muon_pfRelIso03_all	(muon->isolationR03().sumPt() + muon->isolationR03().hadEt() + muon->isolationR03().emEt()) / muon->pt()	partially	figure 3.5c
Muon_x	muon->vx()	yes	figure A.6a
Muon_y	muon->vy()	yes	figure A.6b
Muon_z	muon->vz()	yes	figure A.6c

Variables validated using Open Data examples

Fabian Stäger

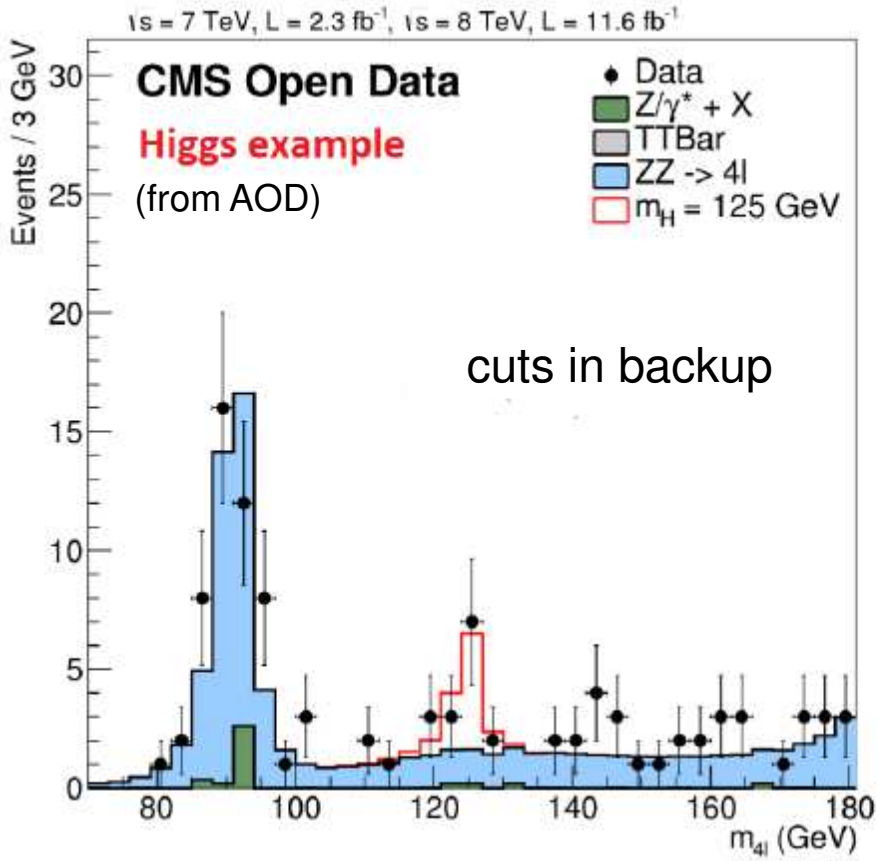
2010
CMSSW_4_2_8

Muon_nValid	muon->innerTrack()-> hitPattern(). numberOfValidTrackerHits()	yes	figure A.6g
Muon_nPix	muon->innerTrack()-> hitPattern(). numberOfValidPixelHits()	yes	figure A.6h
Muon_trkIdx	Muon Track Index	yes	figure A.6g
Muon_gChi2	muon->globalTrack()-> normalizedChi2()	partially	figure A.3c
Muon_geta	muon->globalTrack()->eta()	partially	figure A.4e
Muon_gphi	muon->globalTrack()->phi()	partially	figure A.4f
Muon_gpt	muon->globalTrack()->pt()	partially	figure A.4d
Muon_nValidMu	muon->globalTrack()-> hitPattern(). numberOfValidMuonHits()	partially	figure A.6e
Muon_isGood	TMOneStationTight	partially	figure A.6i
Muon_isGoodLast	TMLastStationTight	partially	figure 3.5c
Muon_gnValid	muon->globalTrack()-> hitPattern(). numberOfValidTrackerHits()	partially	figure A.6e
Muon_gnPix	muon->globalTrack()-> hitPattern(). numberOfValidPixelHits()	yes	figure A.6f
Muon_Chi2	muon->innerTrack()-> normalizedChi2()	yes	figure A.3b
Muon_isGoodAng	TMLastStationAngTight	partially	figure 3.5b
Muon_isArbitrated	TrackerMuonArbitrated	partially	figure 3.5b

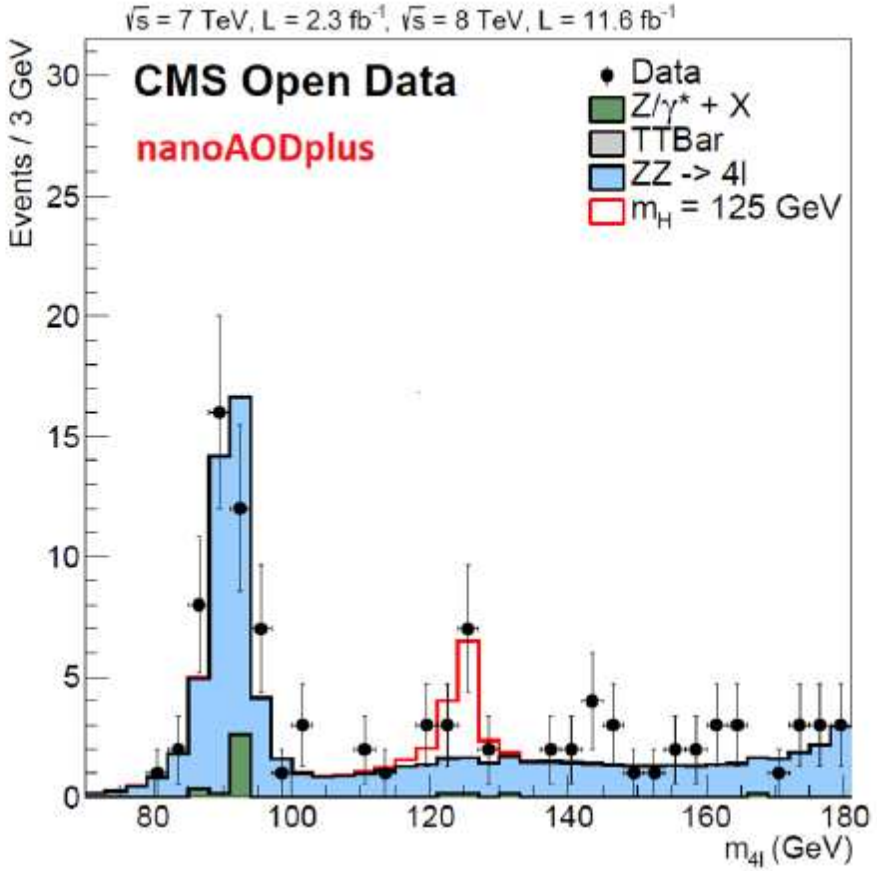
Higgs -> 4 lepton Open Data example

2011+2012 DoubleMuon+DoubleElectron data + MC

Paula Martinez,
Nuha Jomhari



cuts in backup



very close -> all contributing 2011/12 variables (CMSSW_5_3_32) validated

left plot takes ~few CPU-months (from AOD), right ~CPU-minutes (from nanoAODplus)

also comparisons of many technical distributions + Z mass plots

Comparison of Data and Simulation — 2011 Drell-Yan

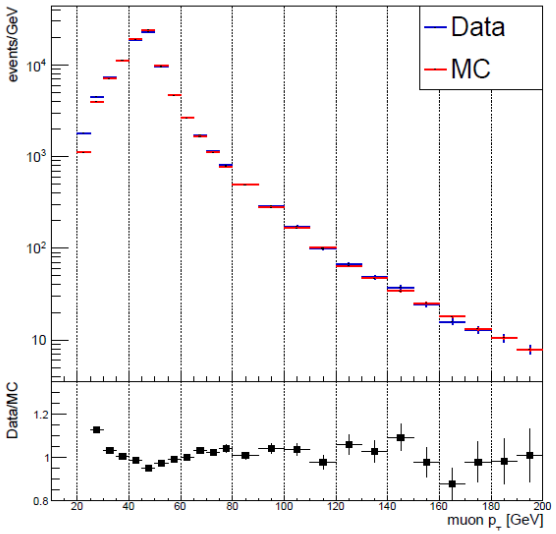
Melanie Schmitz

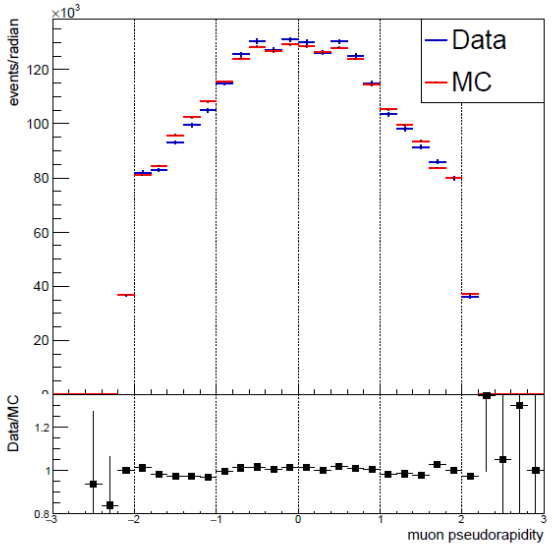
First real application of nanoAODplus, for **master thesis**
(more in backup)

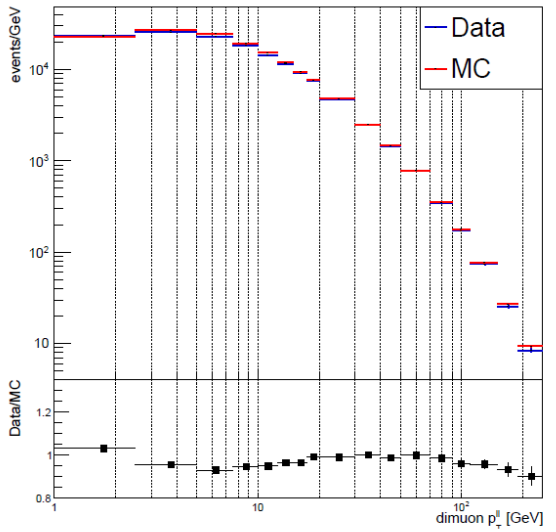
MC events are Pileup Reweighted & scaled with

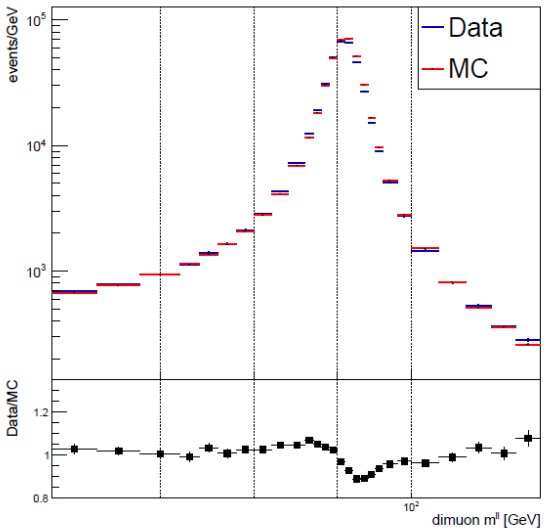
$$\omega_{\text{norm}} = \frac{\sigma L}{N_{\text{MC}}}$$

→ a general good agreement is observed









plans

nanoAOD-like data format for Run 1 making progress,
need to further strengthen interaction with XPOG, POGs/PAGs, and PPD

first actual applications starting **some of you are participating!**

-> hope to complete for Run 1 by end of 2020,
in parallel to Run 2 ultra-legacy processings
-> all legacy data should be analysable in nanoAOD(plus) format

current situation:

Table:	0.9	2.76	5	7	8	13 TeV
ep	(ZEUS*)					
pp	2010/17	2010/13	2015/17	2010/11 (also ALICE, ATLAS*)	2012	2015 2016/17/18
pPb			2012/13/15		2016	
PbPb		2010/11	2015			

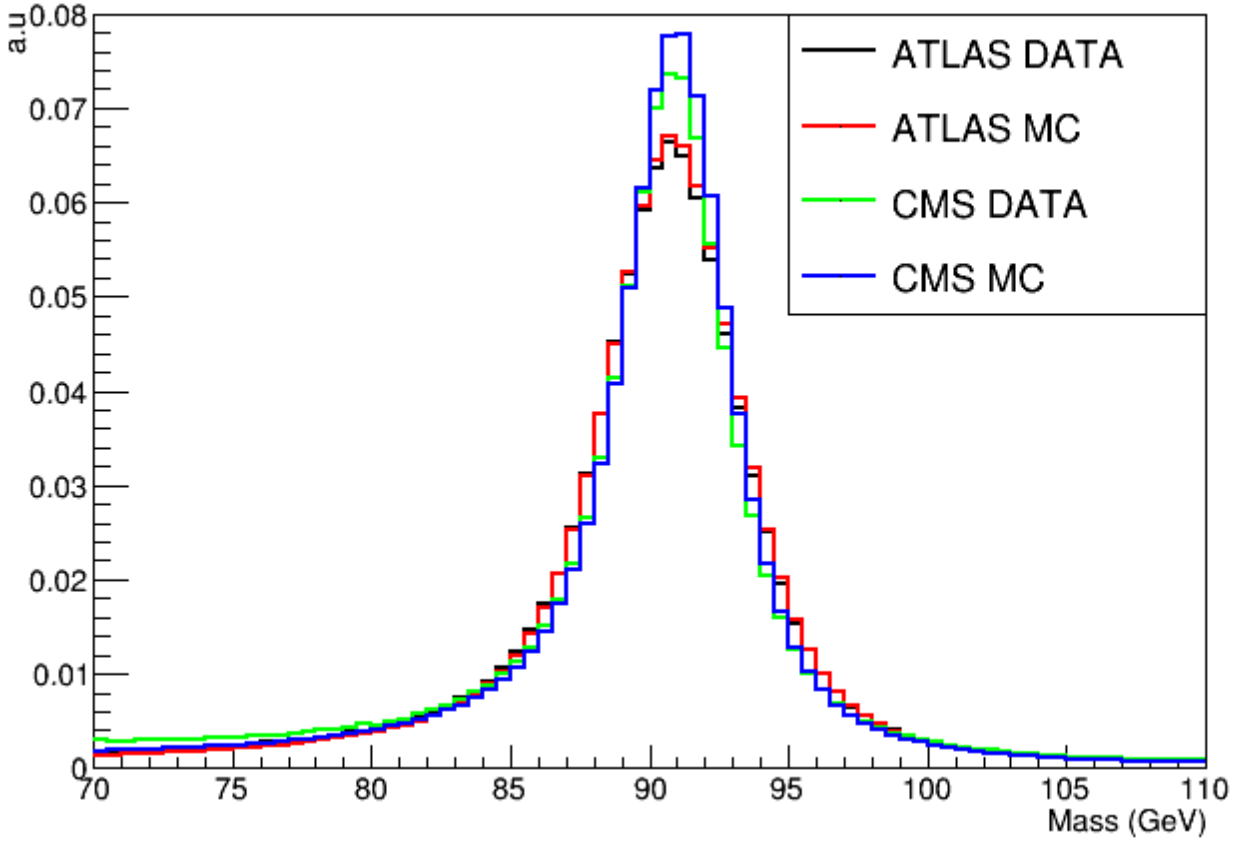
AOD
nanoAOD available
miniAOD available
RECO only

*external projects

Backup

Data from other experiments -> nanoAODplus?

e.g. 2011 Drell-Yan Dimuon data, ATLAS vs. CMS (not an official project)



Lekshmi Thulasidaran
Matthew Snape

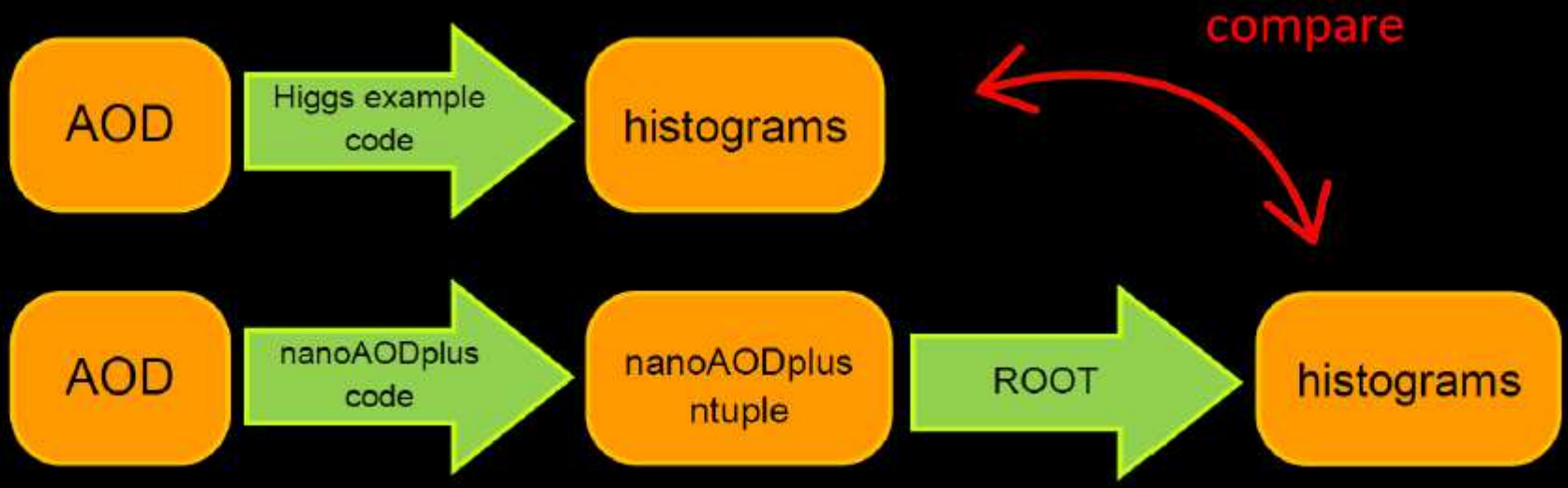
Allows comparison of physics distributions using same Root script ☺

Validation through Open Data examples

slide from Paula Martinez

The steps that we need to follow are:

- Matching the variables from AOD and nanoAODplus format.
- Verify that they are correctly defined and identify internal cuts in the nanoAODplus.
- Find the cuts in the Open Data example and apply them to our nanoAODplus ntuple.
- Produce the same histograms and compare the final results.



~50 2010 nanoAOD(plus) variables validated

A.2. Validated nanoAOD(plus) variables

nanoAOD variable	corresponding AOD variable	validated	reference
nElectron	size()	yes	figure A.1d
Electron_charge	electron->charge()	yes	figure 3.6
Electron_ deltaEtaSCtr	electron->deltaEtaSuper ClusterTrackAtVtx()	yes	figure A.2a
Electron_ dr03EcalRecHitSumEt	electron-> dr03EcalRecHitSumEt()	yes	figure A.2d
Electron_ dr03TKSumPt	electron->dr03TkSumPt()	yes	figure A.2f
Electron_eta	electron->eta()	yes	figure A.1b
Electron_phi	electron->phi()	yes	figure A.1c
Electron_pt	electron->pt()	yes	figure A.1a
Electron_hoe	electron->hcalOverEcal()	yes	figure 3.6
Electron_lostHits	electron->gsfTrack()-> trackerExpectedHitsInner(). numberOfHits()	yes	figure A.1e
Electron_mass	electron->mass()	no	
Electron_sieie	electron->sigmaIetaIeta()	yes	figure A.2c
Electron_convDist	electron->convDist()	yes	figure A.1h
Electron_convDcot	electron->convDcot	yes	figure A.1g
Electron_ deltaPhiSCtr	electron->deltaPhiSuper ClusterTrackAtVtx()	yes	figure A.2b
Electron_ dr03HcalTowerSumEt	electron->dr03HcalTowerSumEt()	yes	figure A.2e
Electron_isEB	electron->isEB()	yes	figure A.2b
Electron_isEE	electron->isEE()	yes	figure A.2d
Electron_SCeta	electron->superCluster->eta()	yes	figure A.1f
nMuon	size()	yes	figure A.3a
Muon_charge	muon->charge()	yes	figure 3.4
Muon_dxy	muon->track->dxy()	partially	figure A.6d
Muon_eta	muon->eta()	yes	figure A.4b
Muon_phi	muon->phi()	yes	figure A.4c
Muon_pt	muon->pt()	yes	figure A.4a
Muon_isGlobal	muon->isGlobalMuon()	partially	figure 3.5a
Muon_isTracker	muon->isTrackerMuon()	partially	figure 3.5b
Muon_mass	0.105658 GeV	yes	figure 3.4
Muon_pfRelIso03_all	(muon->isolationR03().sumPt() + muon->isolationR03().hadEt() + muon->isolationR03().emEt()) / muon->pt()	partially	figure 3.5c
Muon_x	muon->vx()	yes	figure A.6a
Muon_y	muon->vy()	yes	figure A.6b
Muon_z	muon->vz()	yes	figure A.6c

Muon_nValid	muon->innerTrack()-> hitPattern(). numberOfValidTrackerHits()	yes	figure A.6g
Muon_nPix	muon->innerTrack()-> hitPattern(). numberOfValidPixelHits()	yes	figure A.6h
Muon_trkIdx	Muon Track Index	yes	figure A.6g
Muon_gChi2	muon->globalTrack()-> normalizedChi2()	partially	figure A.3c
Muon_geta	muon->globalTrack()->eta()	partially	figure A.4e
Muon_gphi	muon->globalTrack()->phi()	partially	figure A.4f
Muon_gpt	muon->globalTrack()->pt()	partially	figure A.4d
Muon_nValidMu	muon->globalTrack()-> hitPattern(). numberOfValidMuonHits()	partially	figure A.6e
Muon_isGood	TMOneStationTight	partially	figure A.6i
Muon_isGoodLast	TMLastStationTight	partially	figure 3.5c
Muon_gnValid	muon->globalTrack()-> hitPattern(). numberOfValidTrackerHits()	partially	figure A.6e
Muon_gnPix	muon->globalTrack()-> hitPattern(). numberOfValidPixelHits()	yes	figure A.6f
Muon_Chi2	muon->innerTrack()-> normalizedChi2()	yes	figure A.3b
Muon_isGoodAng	TMLastStationAngTight	partially	figure 3.5b
Muon_isArbitrated	TrackerMuonArbitrated	partially	figure 3.5b
MET_pt	pfmet->begin()->pt()	yes	figure A.5a
MET_phi	pfmet->begin()->phi()	partially	figure 3.5d
CaloMET_pt	calomet->begin()->pt()	yes	figure A.5b

Table A.2: List of validated or partially validated nanoAOD(plus) variables with reference plots and corresponding AOD variables.

Higgs to 4 lepton example, cuts

slide from Paula Martinez

Quality cuts

~20 nanoAODplus variables validated for 2011/12 data + MC sets

Global muons
Particle flow muons and electrons

Kinematic cuts → to save only the good muons/electrons

Main cuts
$p_T > 5$ GeV for muons, $p_T > 7$ GeV for electrons
$|\eta| < 2.4$ for muons, supercluster $|\eta| < 2.5$ for electrons

For both muons and electrons
|Impact parameter significance| < 4
|Distance in xy to the vertex| < 0.5
|Distance in z to the vertex| < 1
Relative isolation < 1

Only for electrons
Misshits ≤ 1
Within barrel or endcap acceptance

Further cuts

If we want to keep only $H \to ZZ \to 4\ell$ we need:

4 good ℓ
Total charge = 0
Charge of each pair (that comes from a Z boson) = 0

Drell-Yan analysis using the nanoAODplus format

Melanie Schmitz, Hannes Jung

A Drell-Yan analysis is performed that makes use of a dataset and a Monte Carlo simulation that are available in the **nanoAODplus** format

→ transverse momentum spectrum of Z boson is measured

→ results can be used as a validation of the nanoAODplus ntuples

- **Data & Monte Carlo samples:**
  - Data: Single muon dataset at $\sqrt{s} = 7$ TeV from RunA in 2011
  - Monte Carlo: Z+jets ($m_{ll} > 50$ GeV) generated by MADGRAPH
- **Trigger:**

Run Range	Trigger Path	Luminosity $[\text{pb}^{-1}]$
160431 - 173692	HLT_IsoMu17	1614.4939

→ in this analysis the trigger efficiency is assumed to be ~ 1 in the data and MC simulation (for p_T>20 GeV)

Muon selection

Melanie Schmitz

- Selection cuts on muons:

Variable	Cut
PF candidate	true
p_T	> 20 GeV
$\lvert\eta\rvert$	< 2.1
$\lvert d_{xy}\rvert$ w.r.t. primary vertex	< 2 mm
$\lvert d_z\rvert$ w.r.t. primary vertex	< 2 mm
relative isolation	< 0.1
ΔR	< 0.4

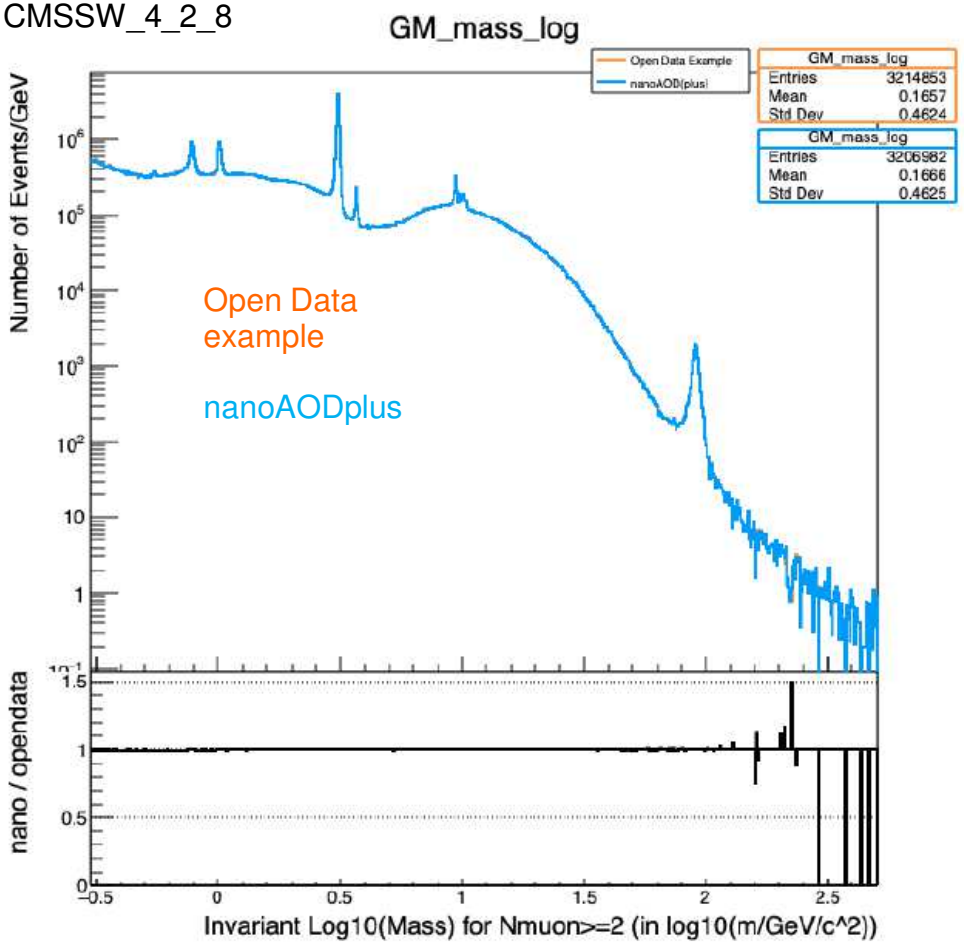
Both muons are required to originate from the same primary vertex (using `Muon_vtxIdx`) and to be tight muons (using `Muon_nTrackerLayers`, `Muon_nValid`, `Muon_Chi2`, `Muon_nPix`, `Muon_nStations`).

- The two highest p_T muons with opposite charge are selected to identify the Z boson

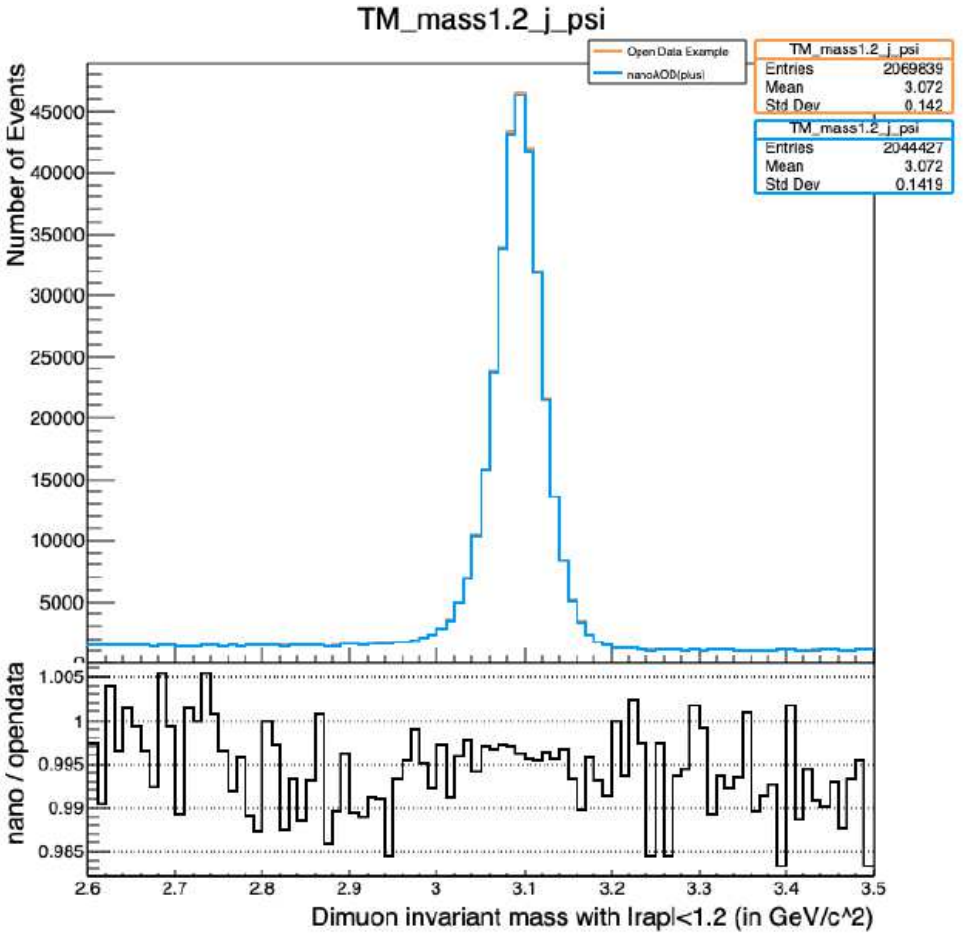
Validation using Open Data examples

2010
CMSSW_4_2_8

Fabian Stäger



(a) dimuon invariant mass spectrum [6], MuMonitor example, Muon dataset



(b) $J/\psi \to \mu^+\mu^-$ resonance [8], MuOnia example, MuOnia dataset