Studies on Missing Transverse Momentum (MPT)

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Physics with non-detectable particles

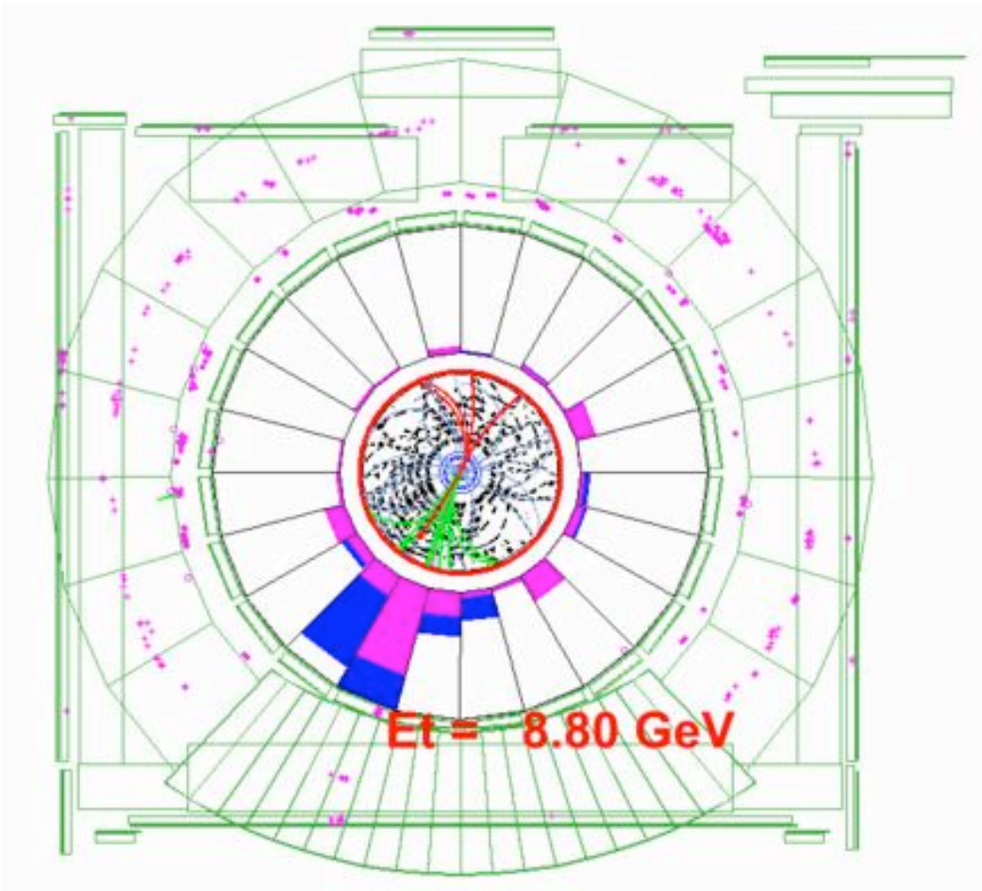
- Many physics topics (SM & BSM) have non-detectable particles in their final states, e.g., Higgs searches with neutrinos in the final states.
- Non-detectable particles appear in the calorimeter as an imbalance of transverse energy. We usually call it as the MET.

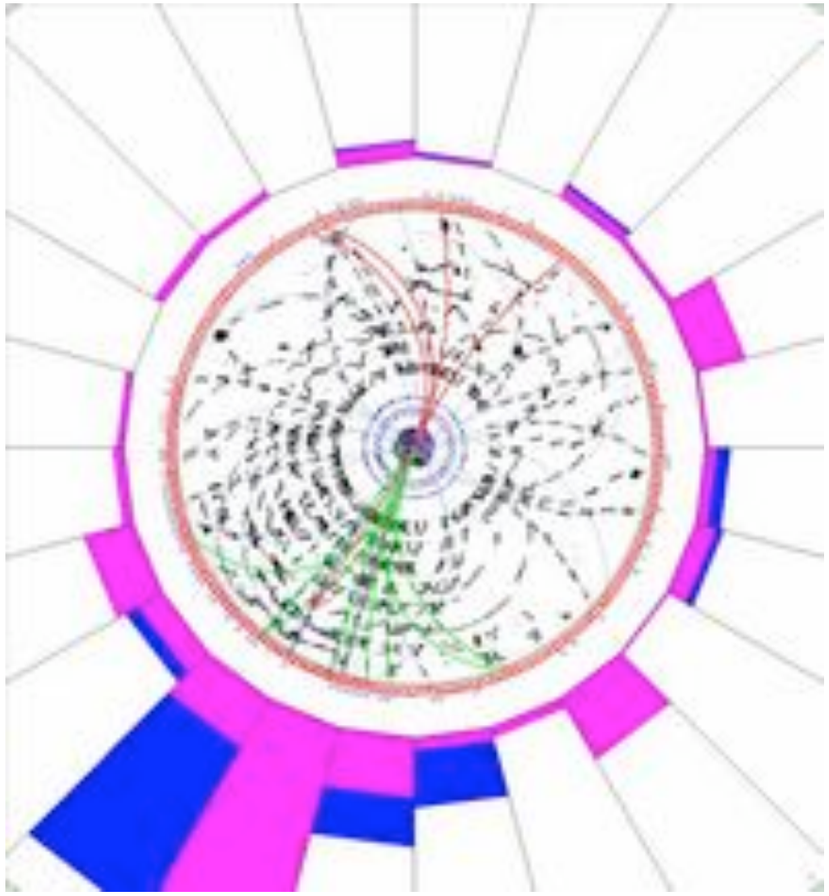
$$\boxed{\vec{\not{E}}_T = -\sum_{towers} \vec{E}_{T_i}}$$

- They could also be spotted as an imbalance of transverse momentum in the tracker. We call this as MPT (Missing p_T).

$$\boxed{\vec{\not{p}}_T = -\sum_{tracks} \vec{p}_{T_i}}$$

MET vs. MPT





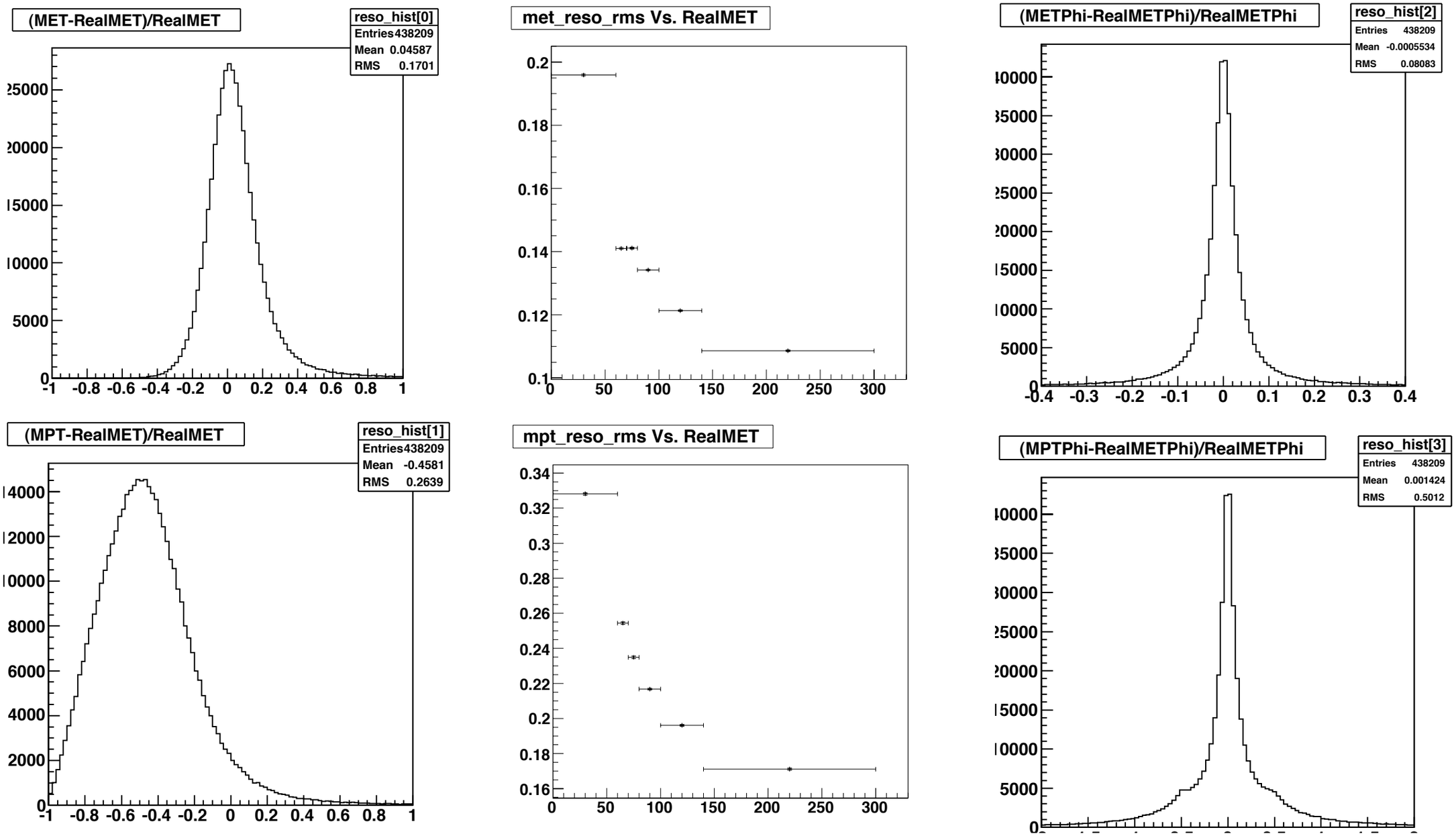
☑ MET measures non-detectable particles well, as long as the energy deposited in the calorimeter has been well reconstructed.

☑ MPT highly correlates to the non-detectable particles, because for each event a large portion of energy is carried by charged particles.

- In events with non-detectable particles, MET and MPT are highly correlated. However, they are acting quiet different in the QCD background, where the MET mainly comes from the detector effects.
- MPT has already been used for some analyses at CDF and D0. Mainly used to reduce QCD background or related.
- In our studies, we now understand the origin of MPT for QCD events and for the events with real non-detectable particles.
- We demonstrate that MPT is useful for MET+Jets channel with/without heavy flavor constrains, as well as for MET+Jets+Lepton channel.

MET/MPT relation in Higgs+W (METbb channel)

by comparing them to the HEPG MET



In events with real neutrino, the MET and MPT provide highly correlated information both on their magnitudes and their directions.

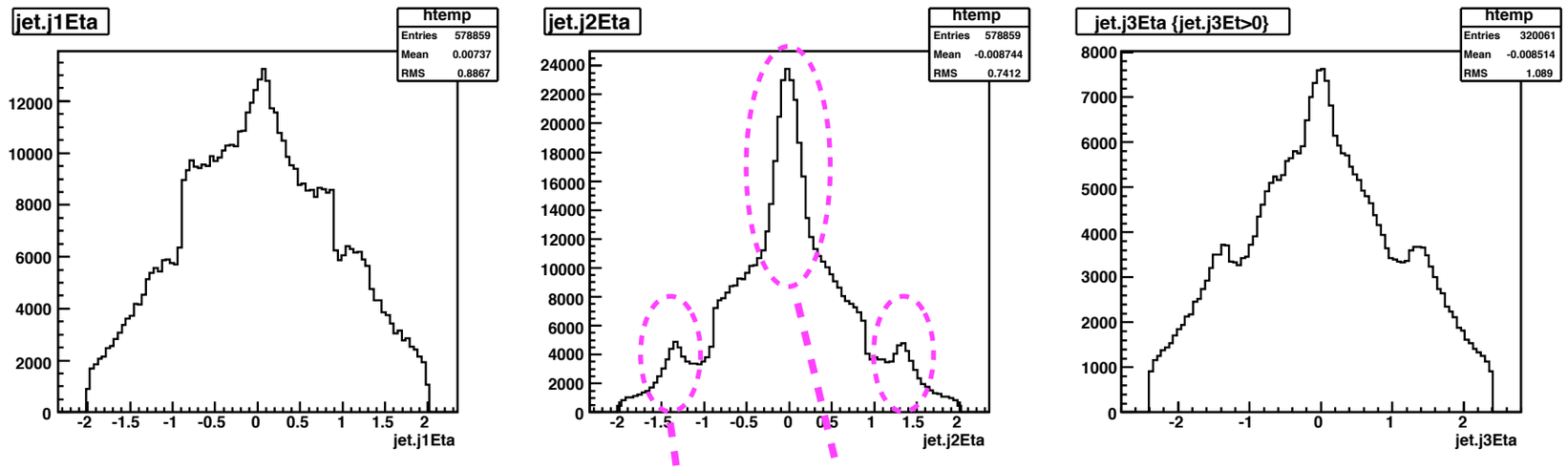
QCD Events with MET

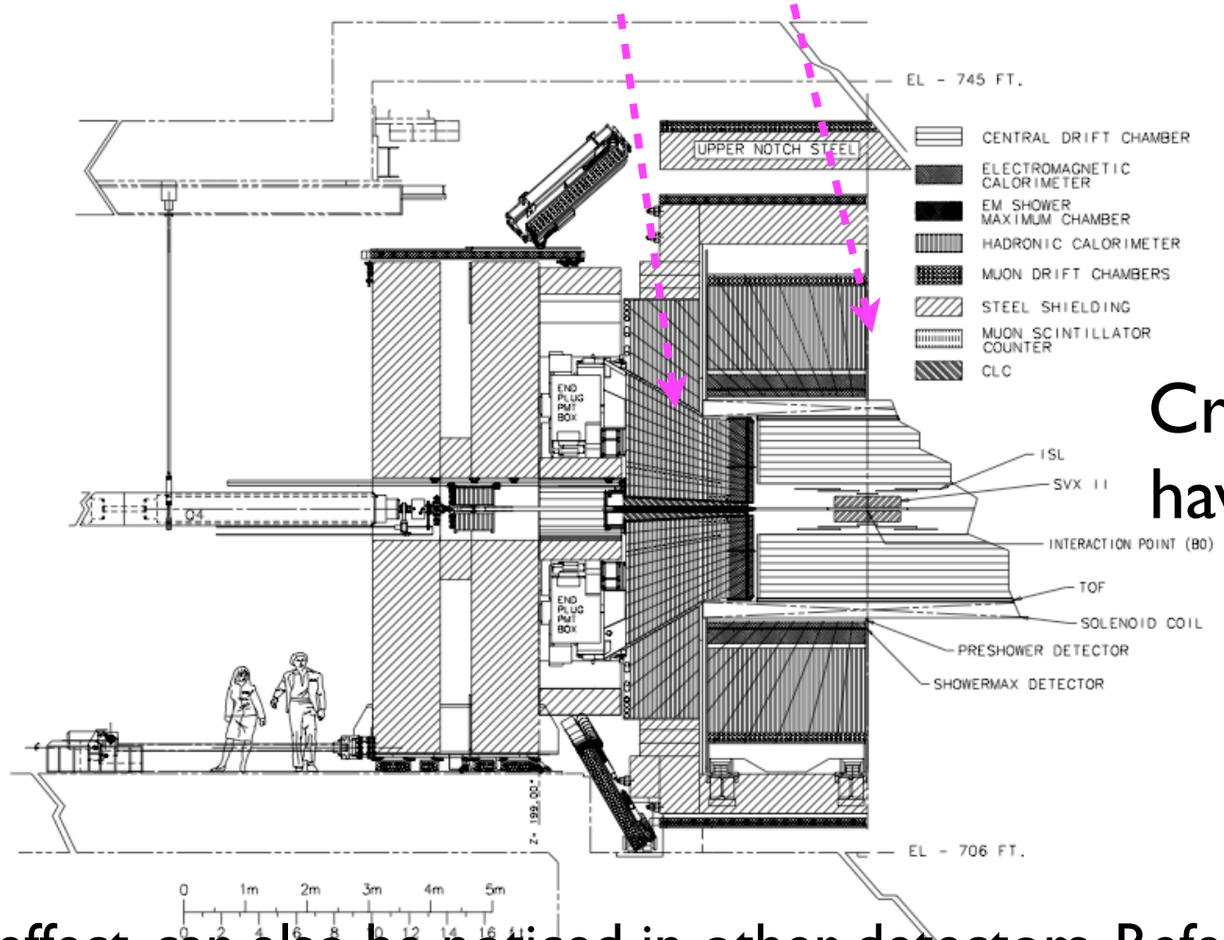
- The QCD background, however, is dominant in the MET +Jets analyses and noticeable in the MET+Jets+Lepton analyses, as a net result of its high production ratio and detector effects etc.

- An example: QCD in MET+Jets. MET in QCD can come from mismeasurement of jets, due to uninstrumented regions and resolution limits of the calorimeter (plots in next slide).

Jet η distribution for QCD MC

(Jet energy is corrected to L5 + H1)





Cracks pointing to the IP have a clear effect on the mis-measurements.

It is an universal effect, can also be noticed in other detectors. Refer to a ATLAS study at arXiv: 0909.4152

The relation between MET and MPT

what makes MPT to discriminate QCD

- Data: 2.1 fb^{-1}, triggered by MET+JET
- Monte Carlo: generated by Pythia.
  - QCD (MET comes from mis-measurement)
  - Higgs+W (m_H = 115GeV/c^2, H→bbbar, W→ ℓ ν; physics processes with neutrino.)
  - Higgs+Z (m_H = 115GeV/c^2, H→bbbar, Z→νν)
  - ttbar (m_t=175GeV/c^2)

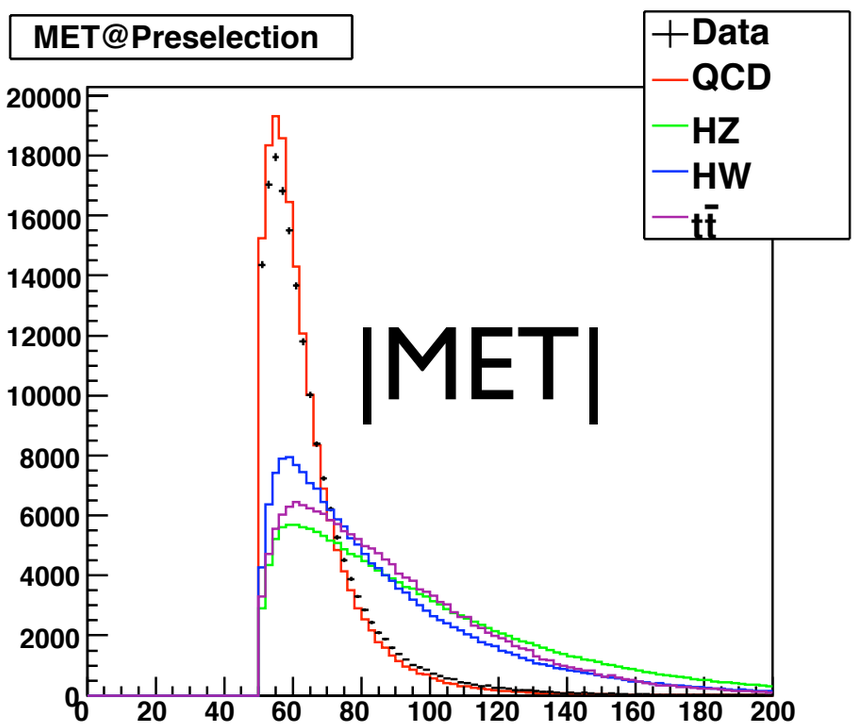
Preselections:

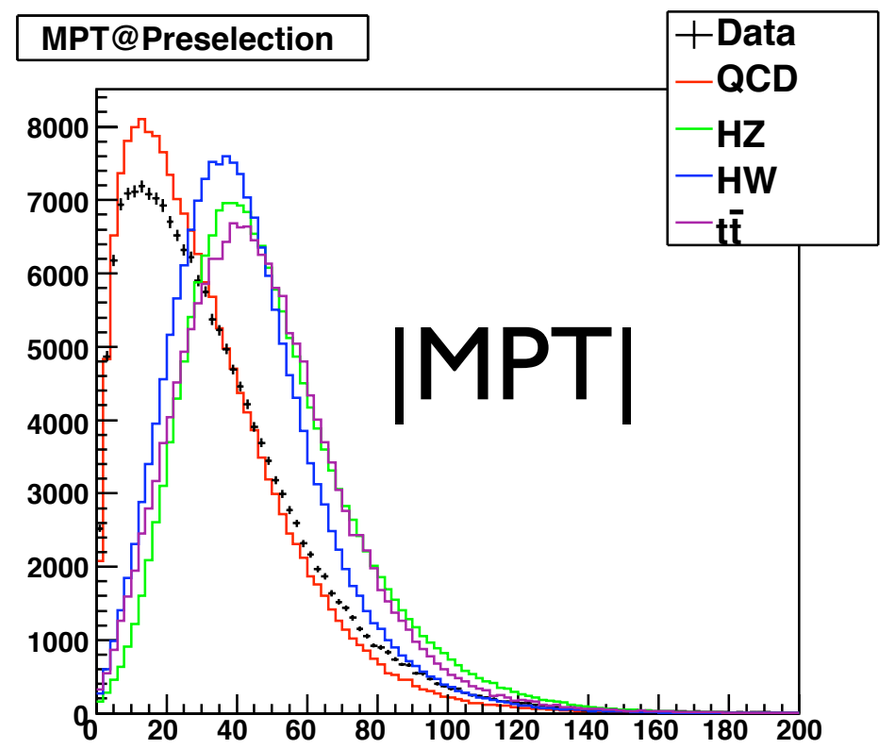
MET > 50, E_{tJ1}>35, E_{tJ2}>25, $|\eta_{Ji}|$<2, $|\eta_{J(1,2)}|$<0.9, $2 \leq N_{jets} < 4$, $\Delta R(J1,J2)>1$.

The relation between MET and MPT: magnitudes

MET+Jets channel

$$\vec{\not{E}}_T = -\sum_{towers} \vec{E}_{T_i} \qquad \vec{\not{p}}_T = -\sum_{tracks} \vec{p}_{T_i}$$



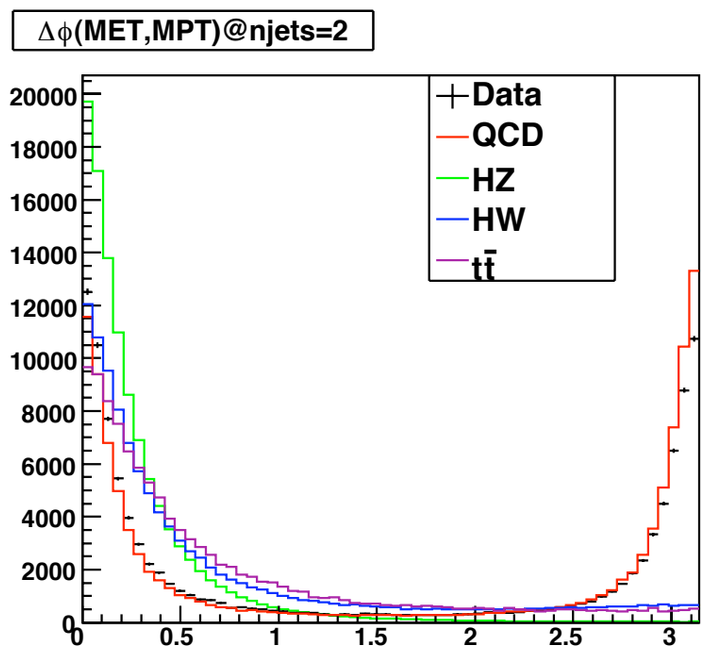


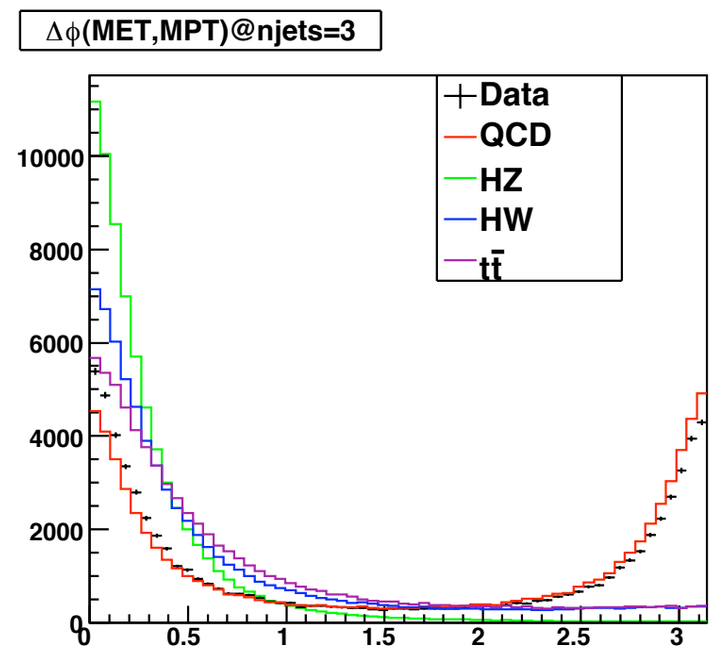
<u>Plots are normalized to data.</u>

In experiments with better tracker coverage, it is worth to investigate if we can put a cut on MPT at trigger level.

The relation between MET and MPT: directions

MET+Jets channel





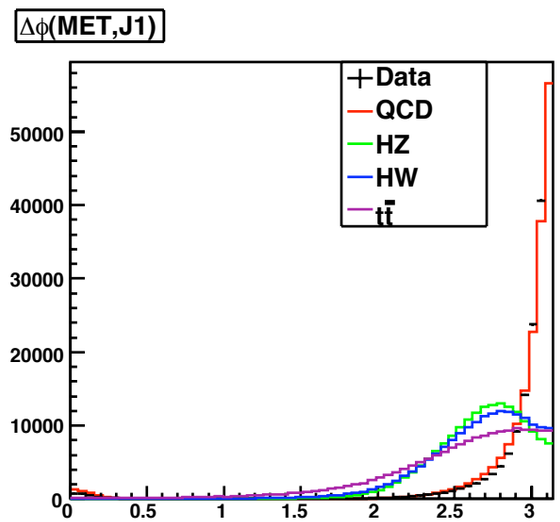
Δφ(MET,MPT)~π for QCD is what we most concerned about here.

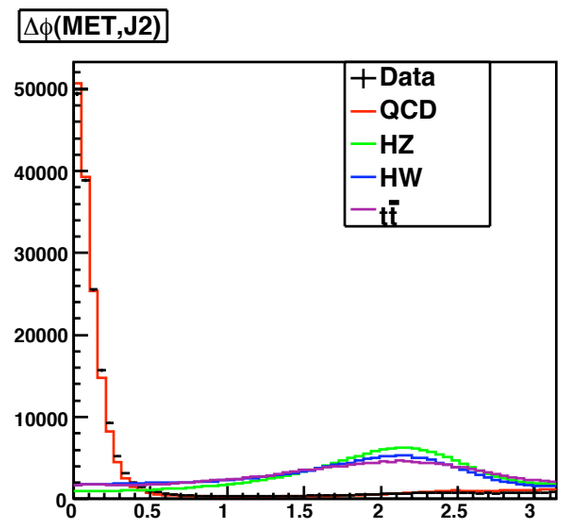
This feature has been applied to many analyses, for QCD rejecting or QCD modeling, etc. We'll explain this distribution in next slides.

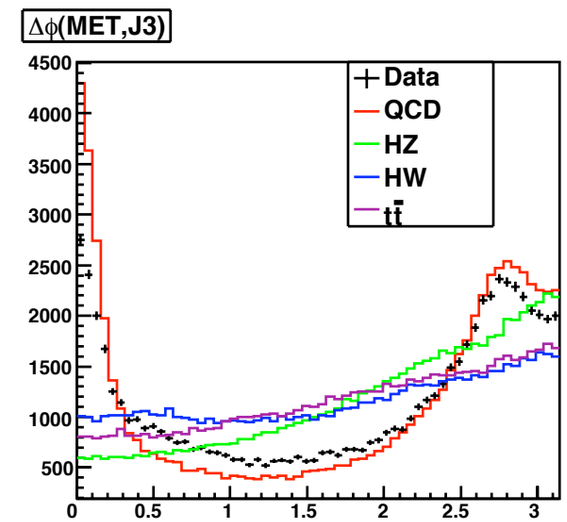
Setting a cut at π/2 would reject 52% QCD, while keep 86%HW, 98%HZ and 85%ttbar.

The relation between MET and MPT: directions (cont.)

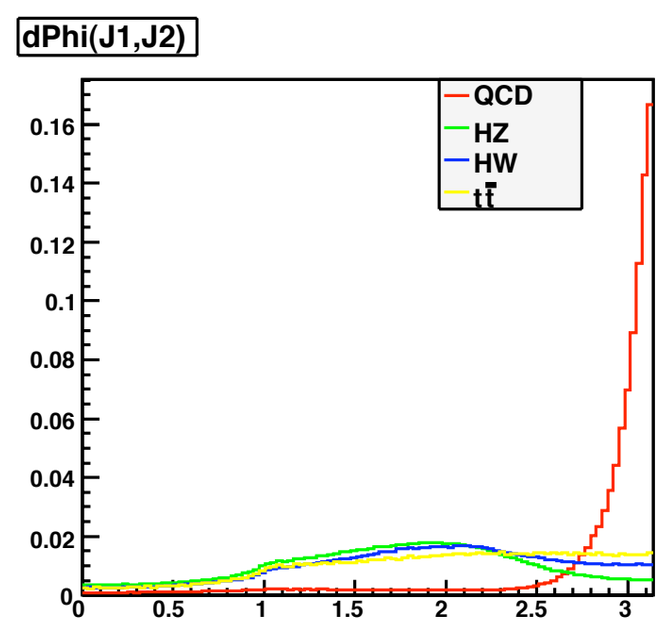
MET+Jets channel







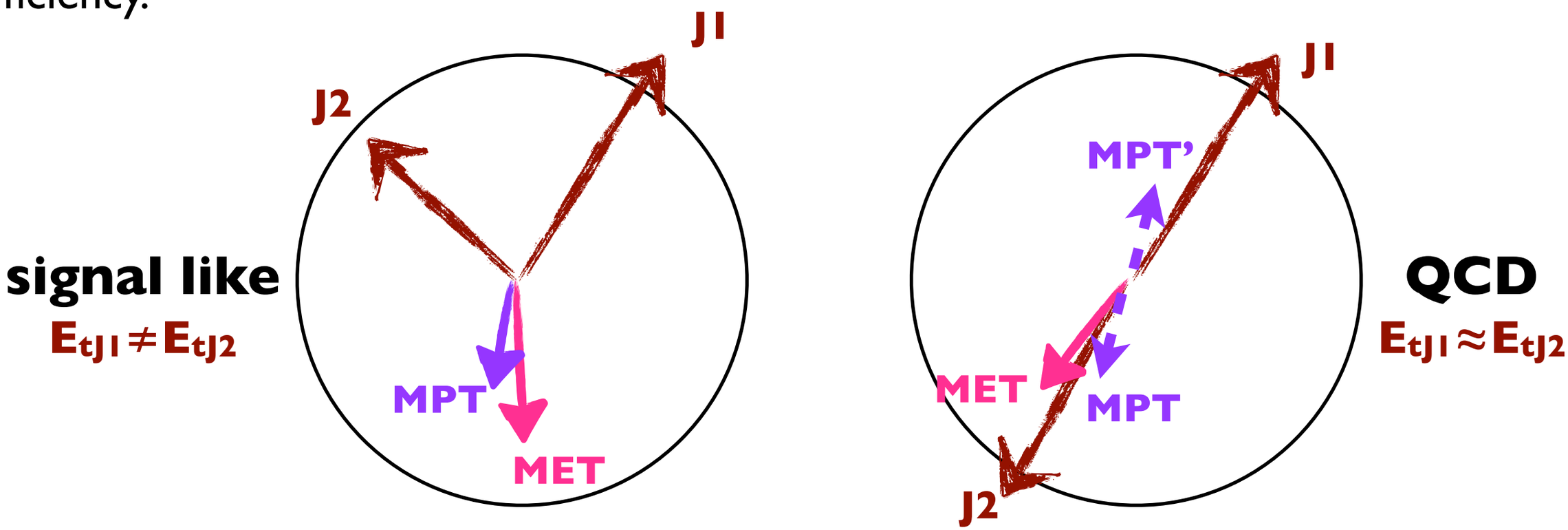
The MET for most QCD events aligns to the 2nd jet, the under-measured one.



Unlike signals, most QCD events have **back-to-back** jets.

Case I:

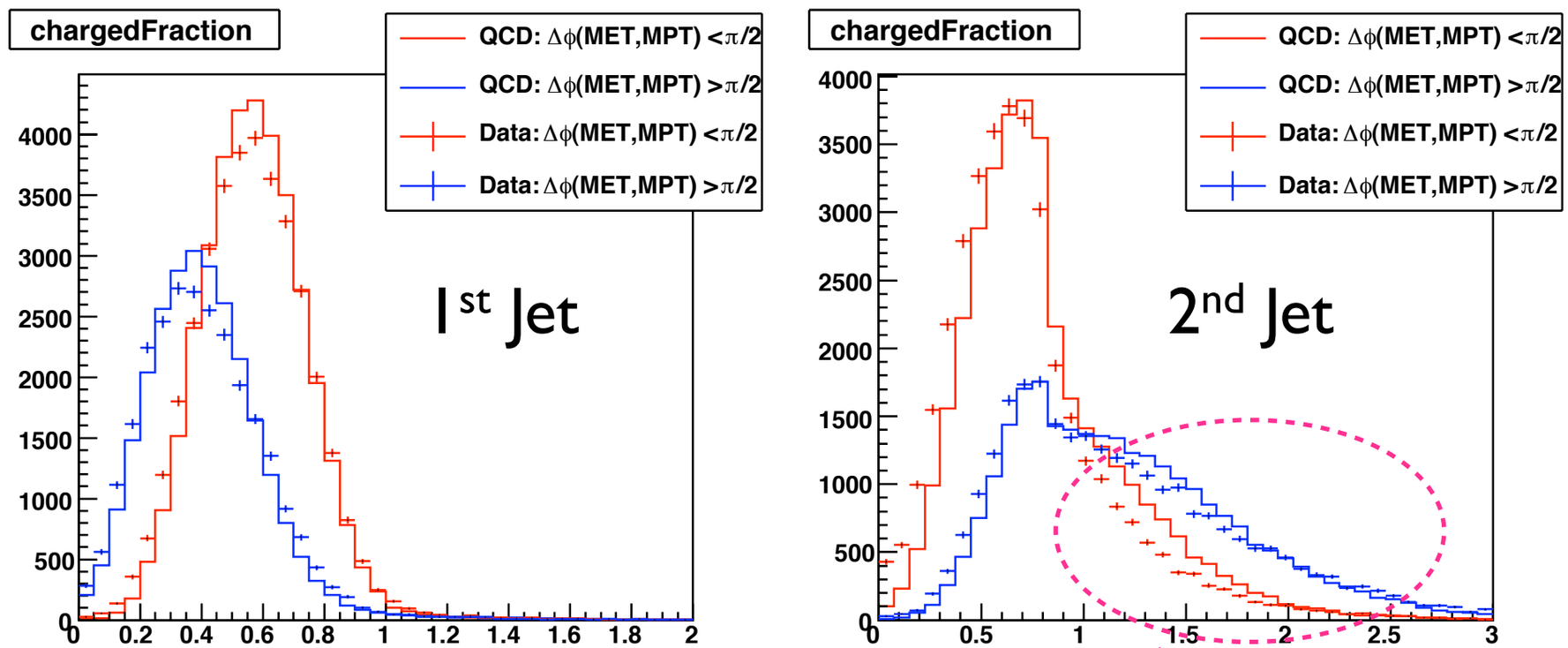
For simplicity, we concentrate on 2 jets events.
First, we have both jets in the central region with $|\eta_{ji}|<1$ to retain high tracking efficiency.

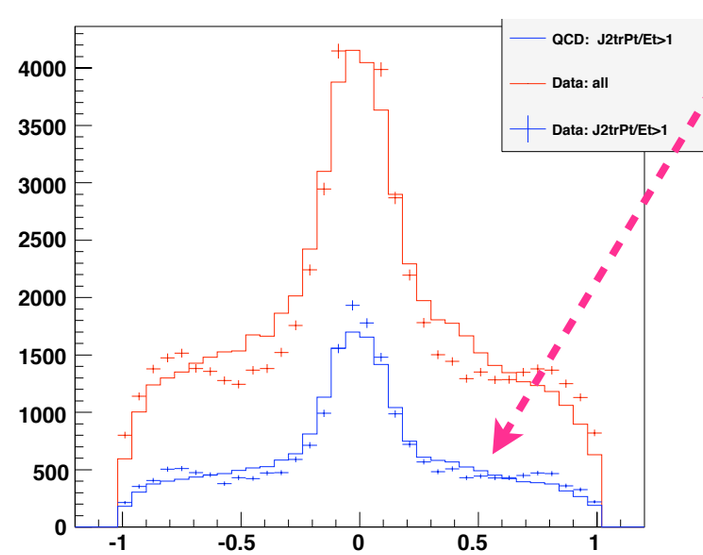


For QCD events, MET aligns to the under-measured jet, while MPT aligns to the one with less energy carried by charged particles. i.e., the fluctuation of charged fraction in jets decides MPT to be align or anti-align to MET. The magnitude of MPT for QCD also mainly comes from these fluctuations.

To verify this explanation, we define the charged fraction of jet as:

$$p_T^{chgd} = \frac{\left|\sum_{Jet_{track_i}} \vec{p}_{T_i}\right|}{p_T^{jet}}$$

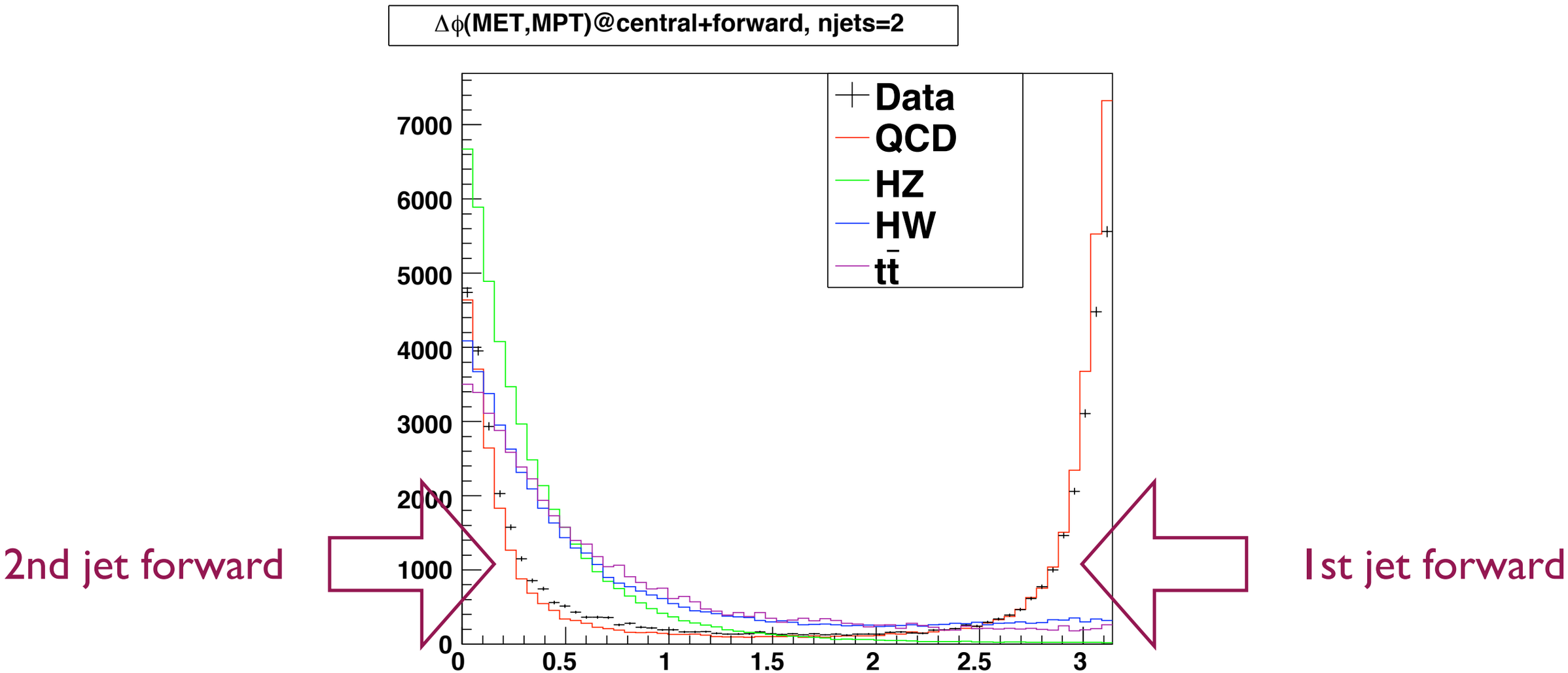




Many QCD events have their 2nd jet under-measured.

Case II:

one jet being forward and the other being central.



In this case, the explanation is different: the MPT for QCD will more likely align to the jet with lower tracking efficiency; the MPT for signal like events, however, is still highly correlated to the MET.

Be aware of this while using related information in QCD modeling.

MPT for Jet+MET+Lepton

- The QCD background also plays a role in Jet+MET+Lepton channel.
- Fake W leptons can come from conversions (electrons) or mis-identified pions/kaons (muons), and additional real leptons from off-shell Ws can come from semi-leptonic heavy flavor decays.

Lepton selection

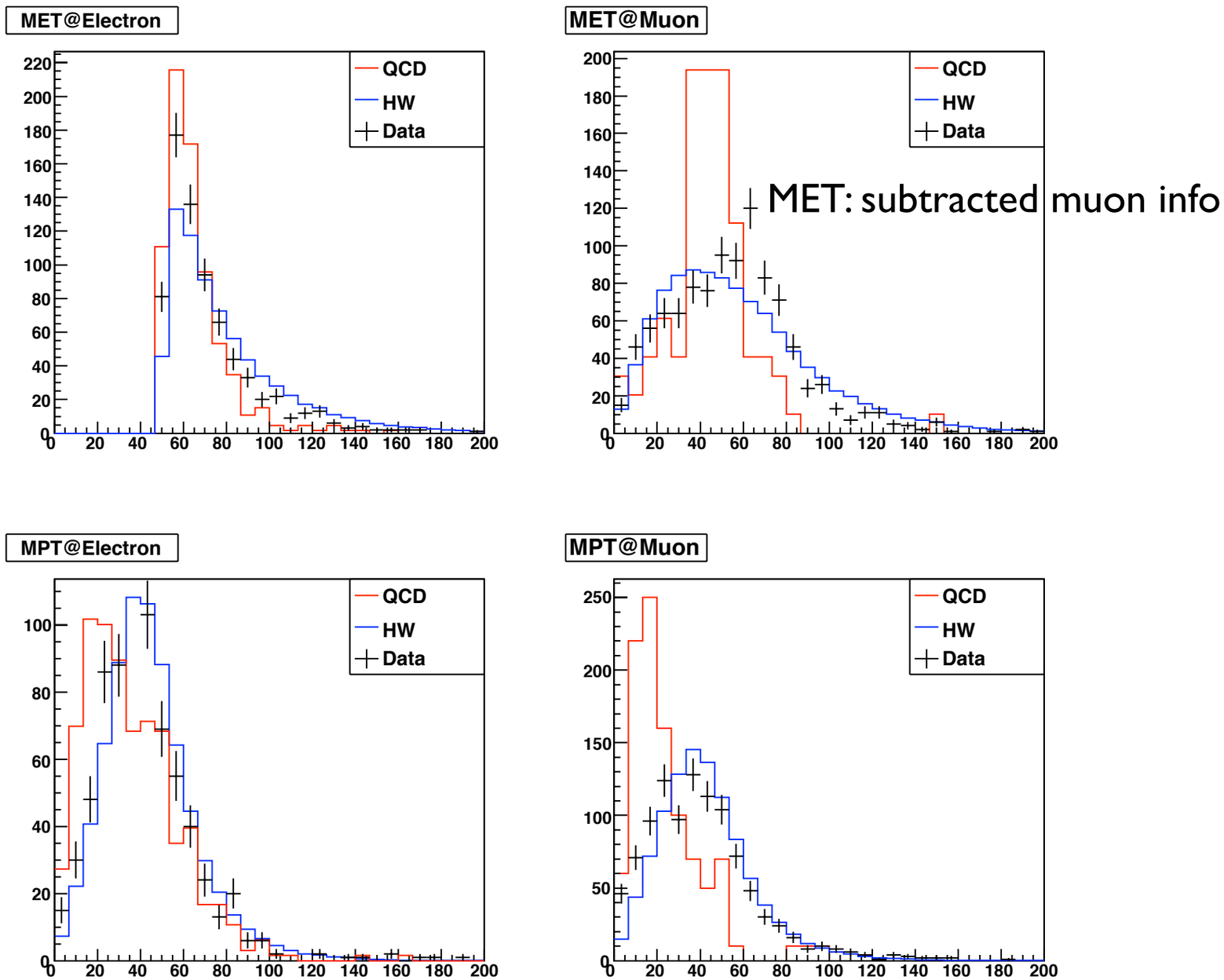
Electron	**CEM**	elEt≥20, elEP<4, elHadEm<0.125, elLshr<0.2, elDX<3, elDZ<5, elIso4<0.2, elchi2<10
	Plug	elEtPlug≥20, elHadEmPlug<0.125, elchi2Plug<10
Muon	**High P_t**	trPt≥20, trEm>0, trEm<2, trHad>1, trHad<6, trZ0<60, trIso<0.02, trCotAx≥3, trCotSt≥2
	Low P_t	trPt≥10, trPt<20, trEm>0, trEm<2, trHad>1, trHad<(3.5+trPt/8), trZ0<60, trIso<2, trCotAx≥3, trCotSt≥2.

Table 2: Lepton selections (tight).

Using the same data sets as in the MET+Jets (data, QCD and Higgs+W MC), but requiring the presence of a muon or electron. We require all the jets and lepton in the central region and $\Delta\varphi(\ell, J_i) > 0.3$.

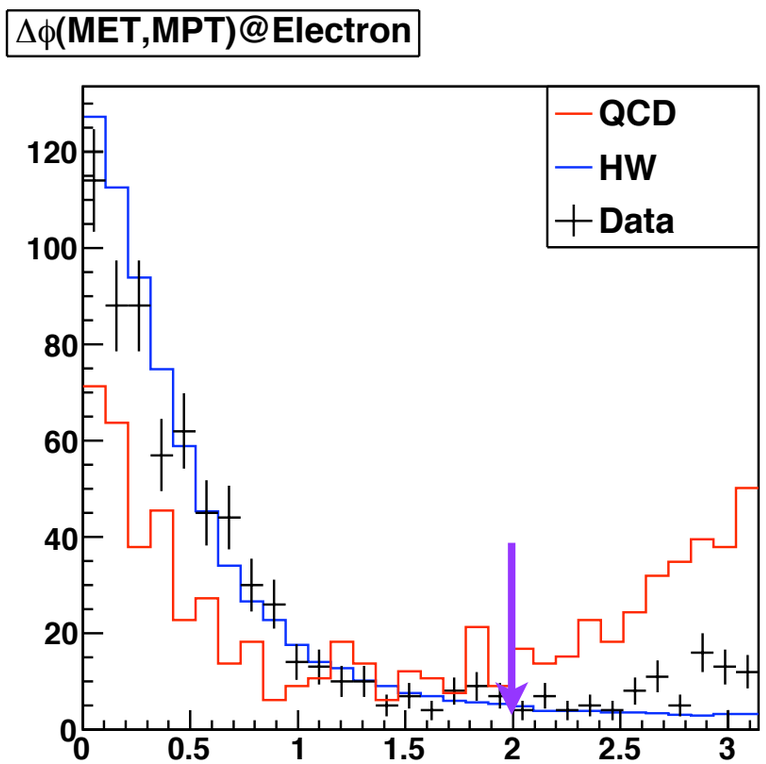
The relation between MET and MPT: magnitudes

MET+Jets+Lepton channel

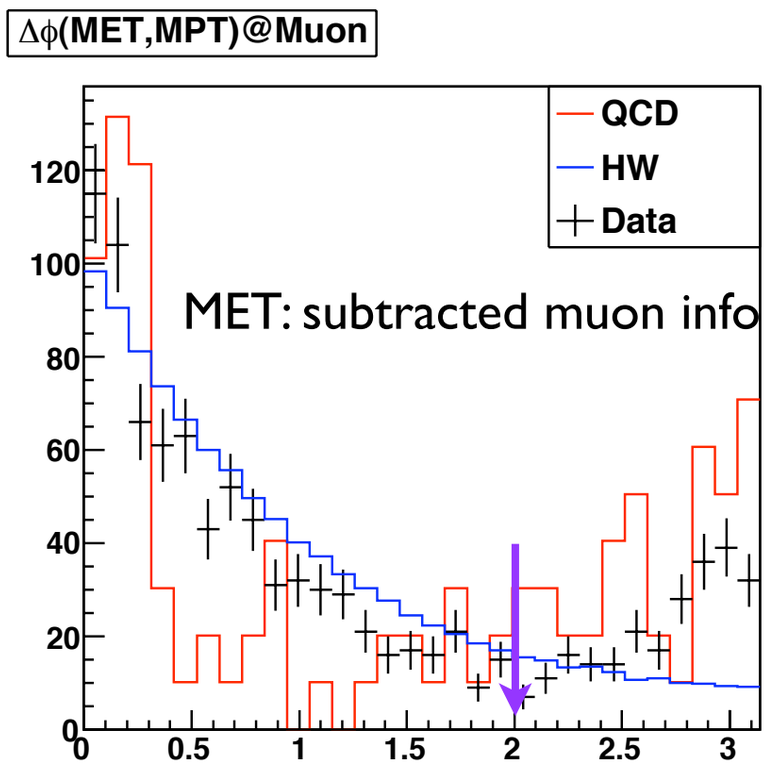


The relation between MET and MPT: directions

MET+Jets+Lepton channel



cut at 2 rejects 42% QCD,
keeps 95% Higgs+W



cut at 2 rejects 40% QCD,
keeps 87% Higgs+W

Δφ(MET,MPT) still shows the peculiar feature for QCD.

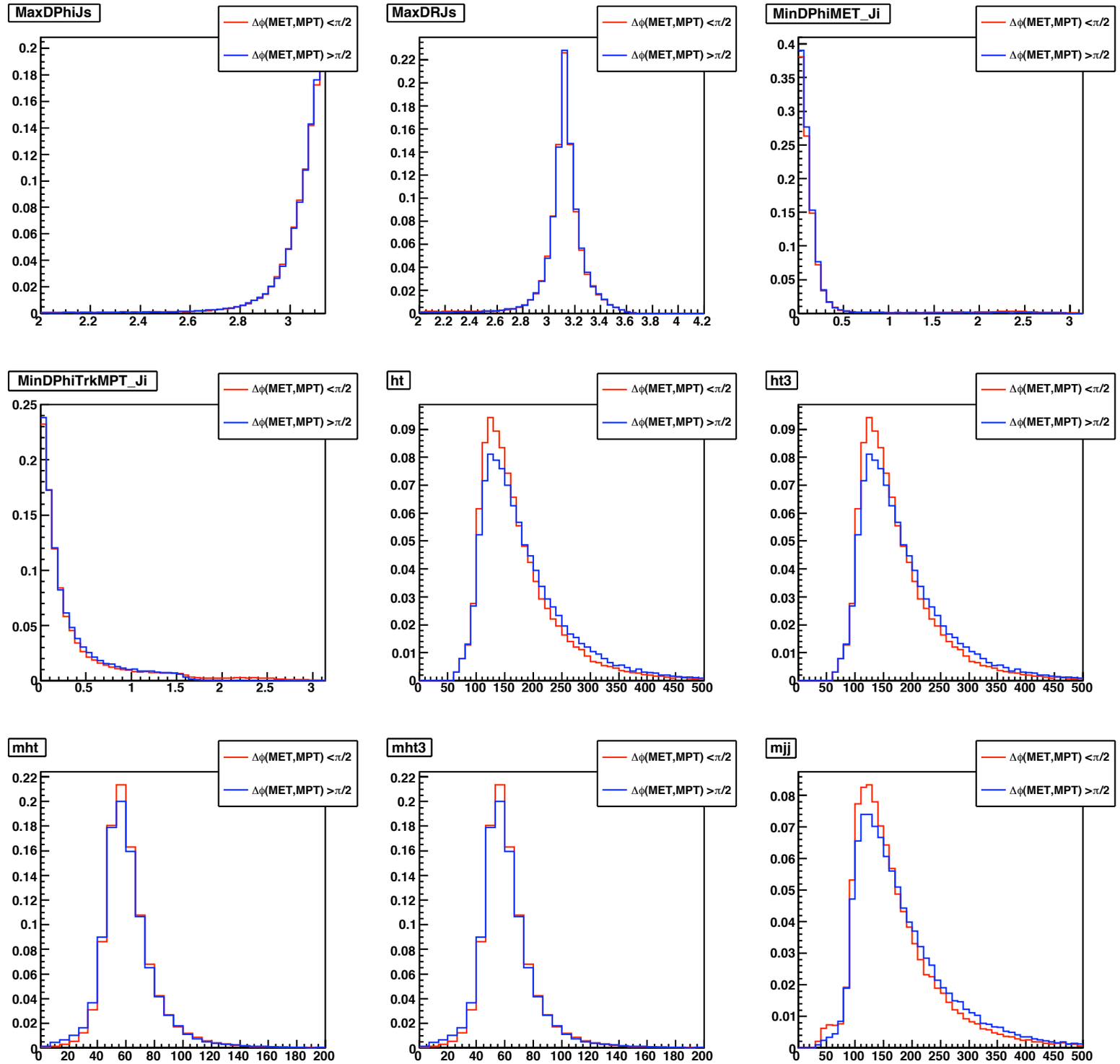
More investigation in data sets used in Jet+MET+Lepton channel would be valuable. Note that we have different selections, and the MPT-related information might be correlated to the ones used in MET+Jets+Lepton channel.

MPT for QCD model

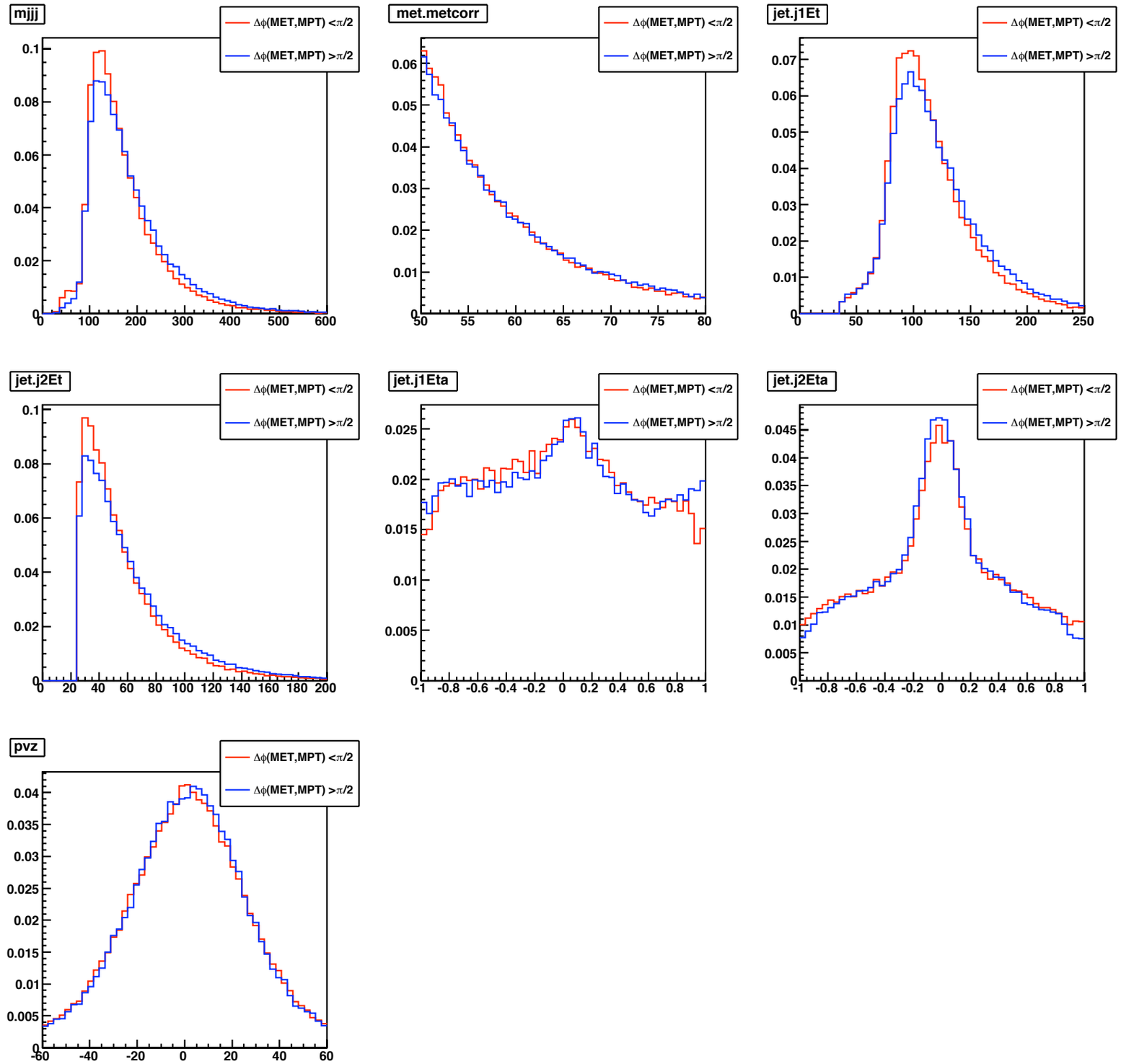
- At this stage, we confirmed MPT is strongly correlated to MET in signal events, while it could be correlated or anti-correlated to MET in QCD.
- We concluded that in the central region the correlation between MPT and MET in QCD only depends on the fluctuation of charged fraction of jets, but is independent of the other kinematic of jets (next slides).
- When one jet is in the forward region, the MPT would align to this jet for QCD events. For signal like events, MPT still aligns to MET quiet well.
- The question now is if we can use events with $\Delta\varphi(\mathrm{MET},\mathrm{MPT})>\pi/2$, the QCD dominant region, to model the whole QCD background? (Already adopted by some analyses.)

$\Delta\varphi(MET,MPT)<\pi/2$
$\Delta\varphi(MET,MPT)>\pi/2$

For events with 2 jets, and both jets in the central region



We randomly checked a series of variables when $\Delta\varphi(MET,MPT)$ is in $(0,\pi/2)$ or $(\pi/2,\pi)$.

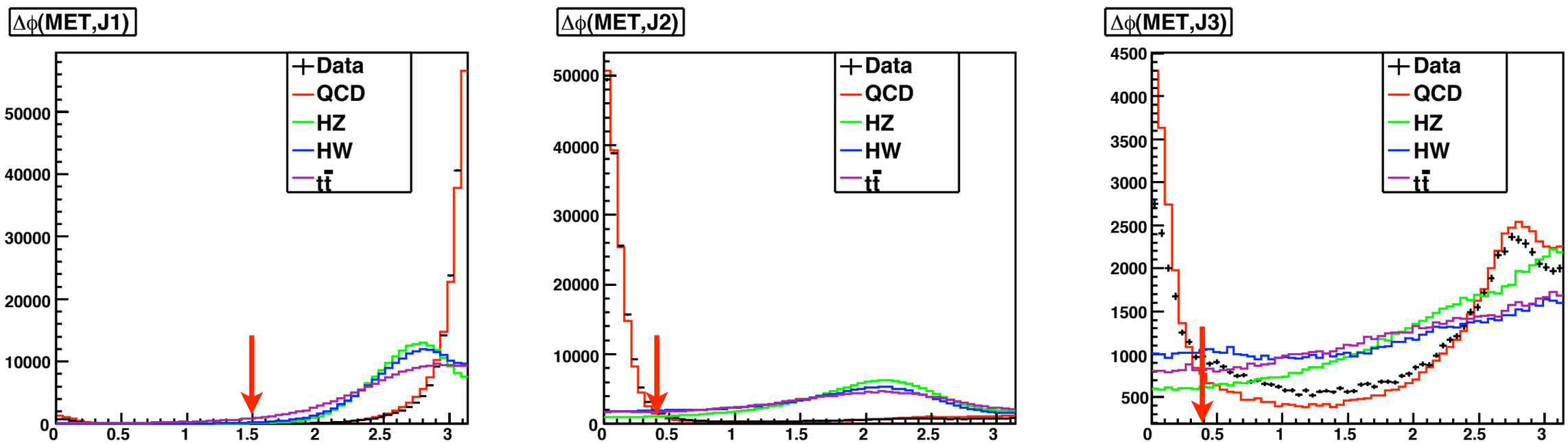


Δφ(MET,MPT)<π/2
Δφ(MET,MPT)>π/2

For events with 2 jets, and both jets in the central region

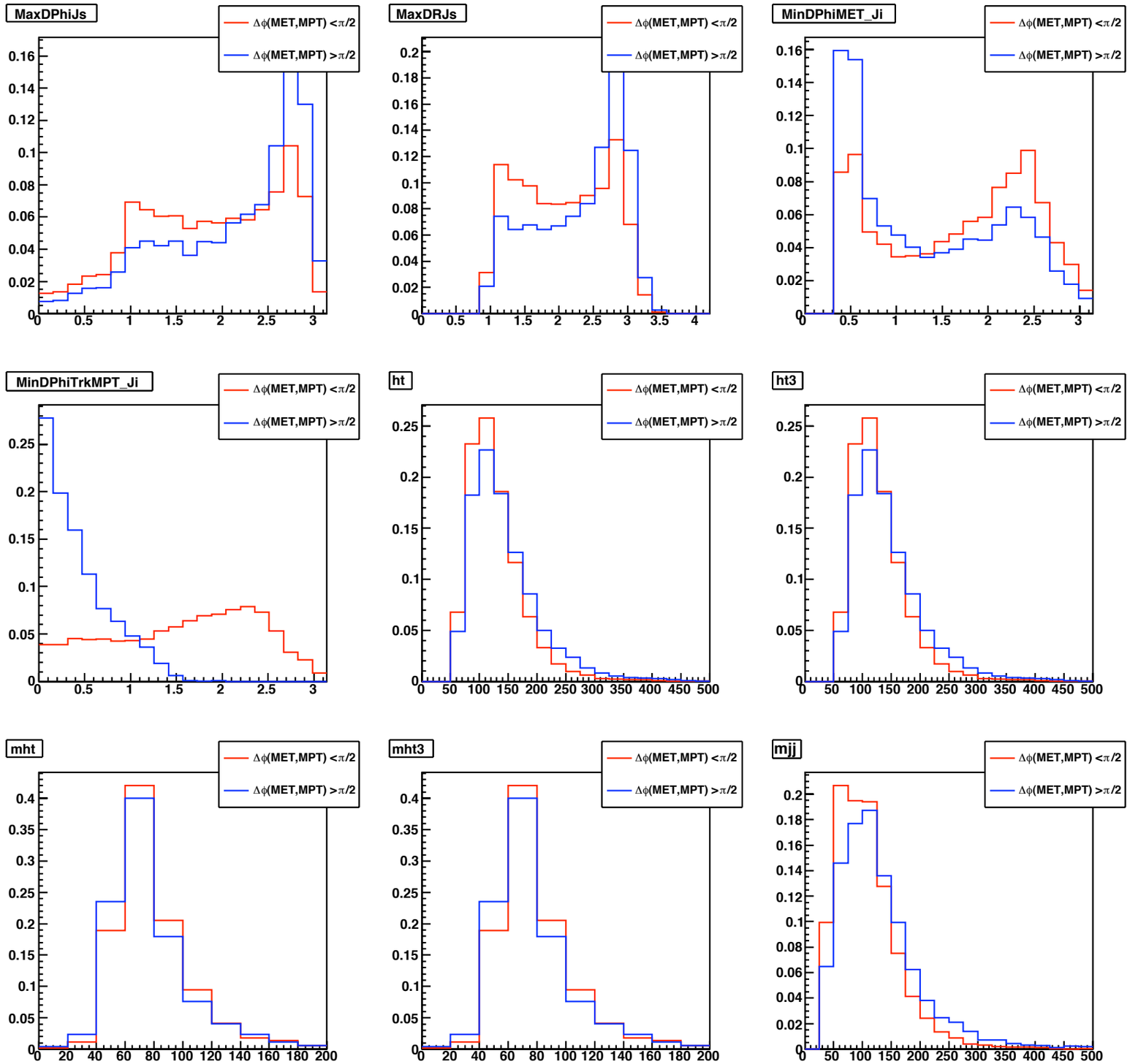
Their shapes agree with each other well.

Furthermore, we usually apply some other selections to reject QCD backgrounds.



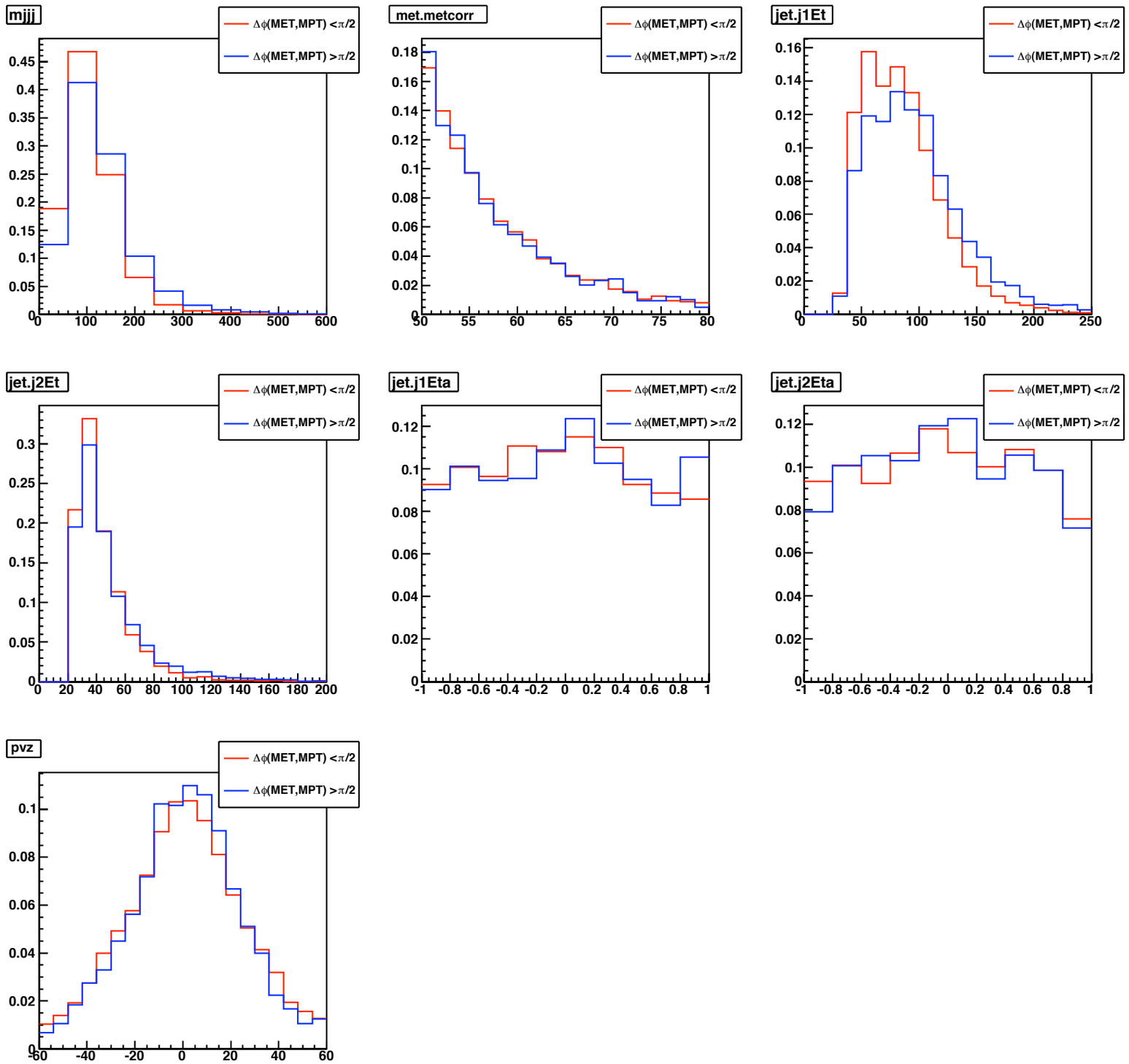
A common selection in the Higgs and Single top analyses is to use the Δφ(MET, Ji) to define control/signal regions.

Δφ(MET,MPT)<π/2
Δφ(MET,MPT)>π/2
For events with 2 jets, and both jets in the central region



Shape comparison plots while requiring Δφ(MET,J1)>1.5, Δφ(MET,J2)>0.4.

These selections will bias our QCD model a lot!!



Δφ(MET,MPT)<π/2
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For events with 2 jets, and both jets in the central region

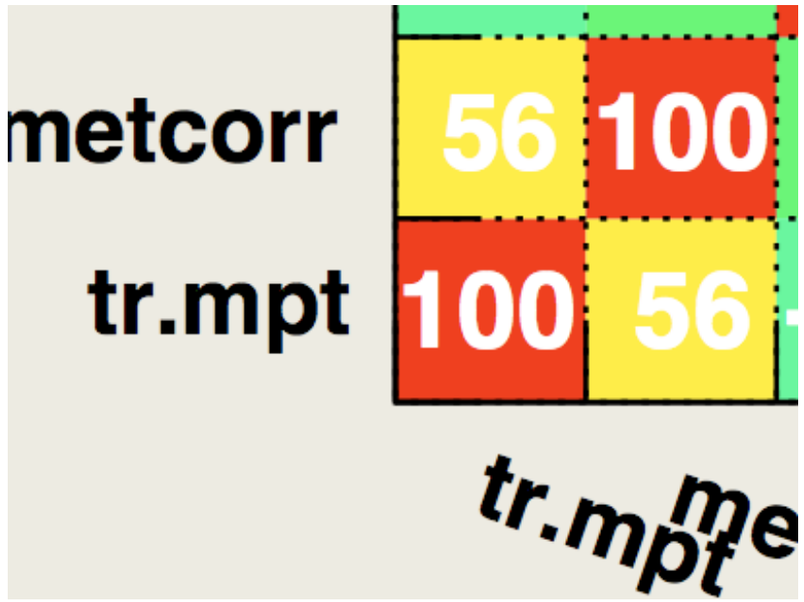
Shape comparison plots while requiring Δφ(MET,J1)>1.5, Δφ(MET,J2)>0.4.

These selections will bias our QCD model a lot!!

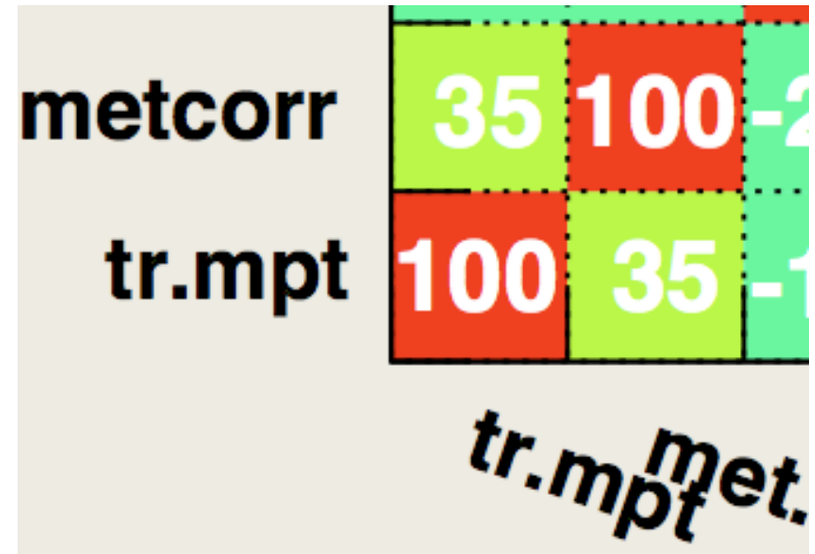
Summary

- We studied the origin/behavior of the MPT and its relation to MET in different physics processes.
- It is advantage to use MPT in MET+Jets channel to reduce the dominant QCD background. That could also be done in MET+Jets +Lepton channel.
- We encourage to investigate MPT in analyses where the QCD bkg with MET is important.
- Details can be found at cdf note 9843.

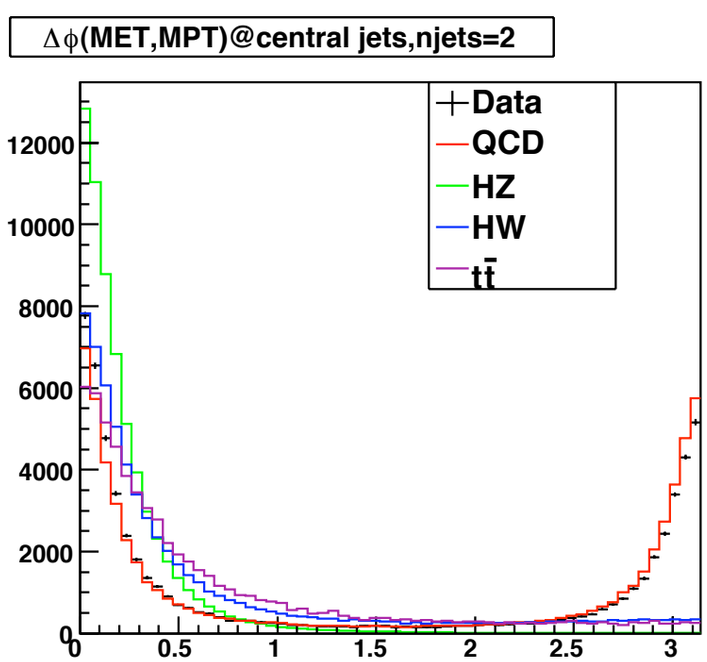
backup

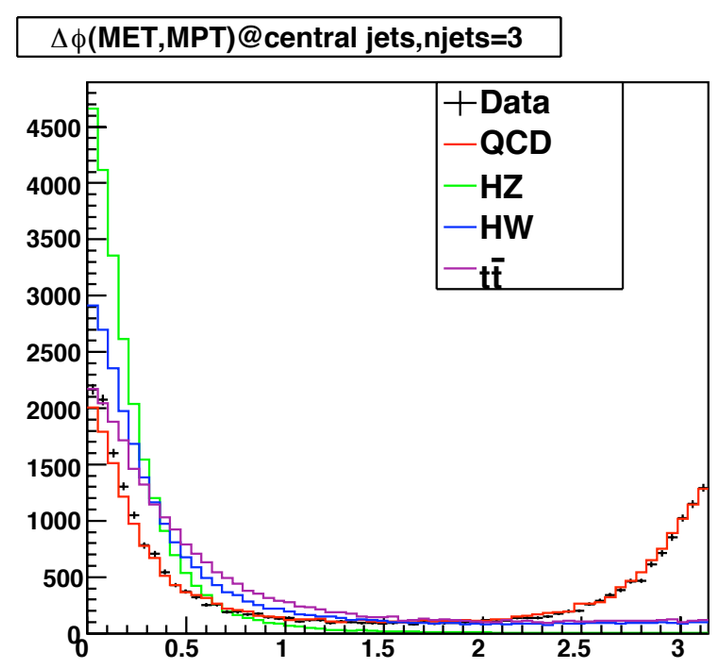


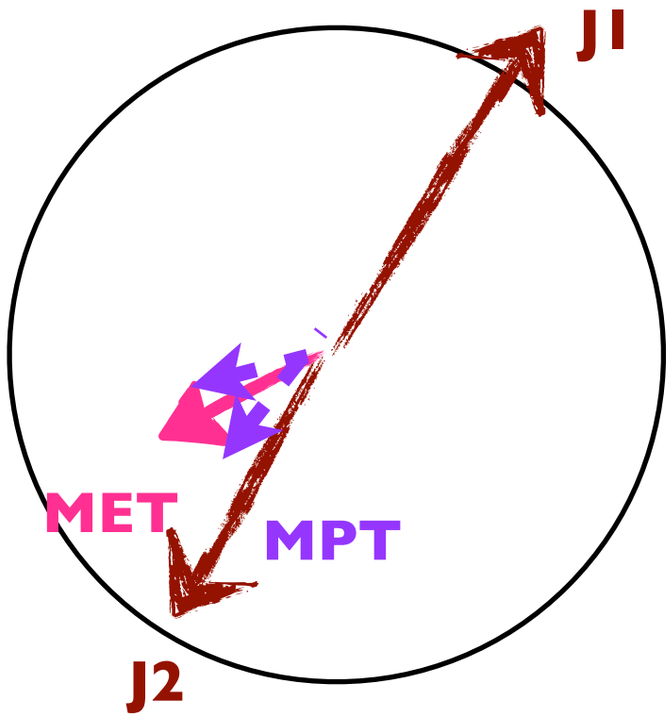
Diboson

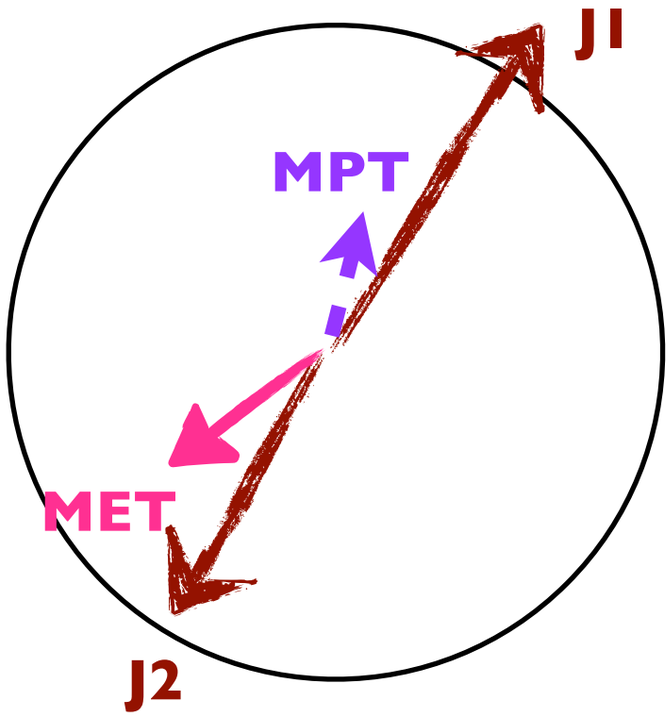


Pretag-data

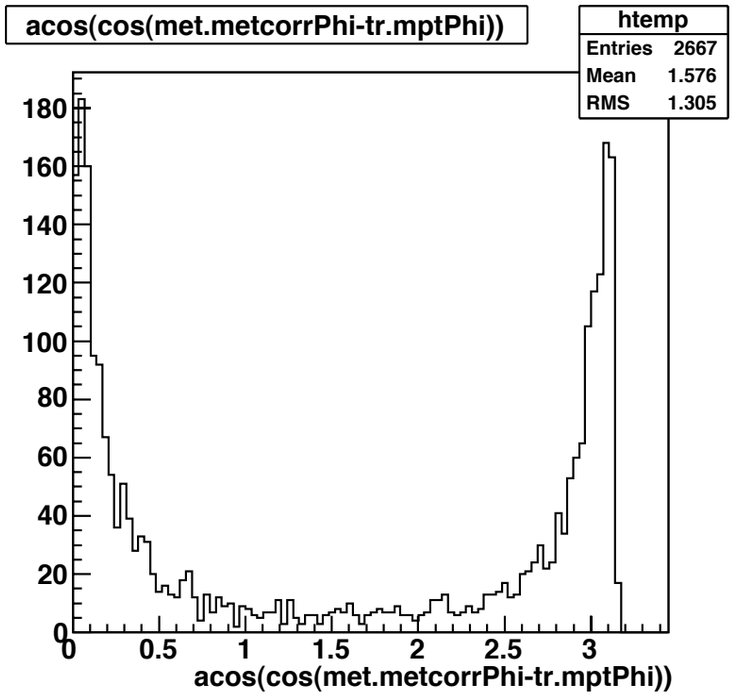




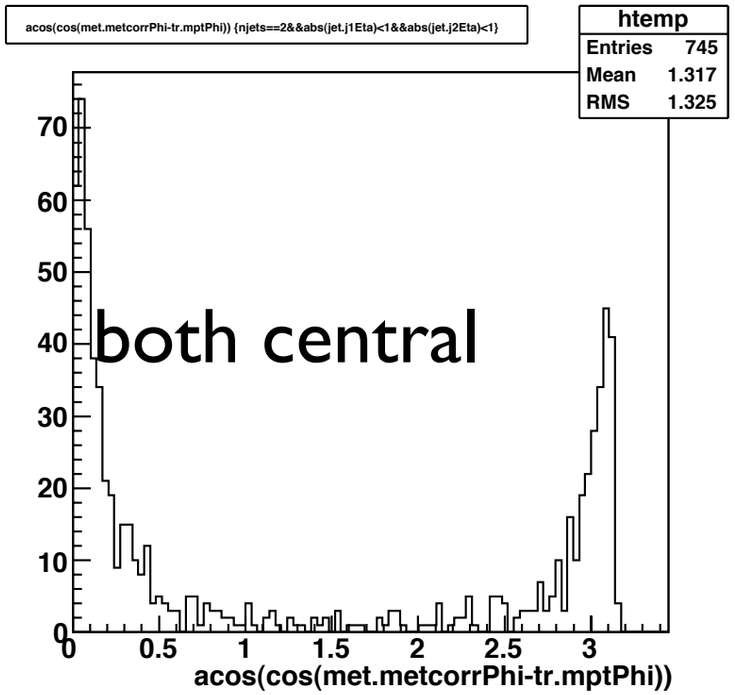


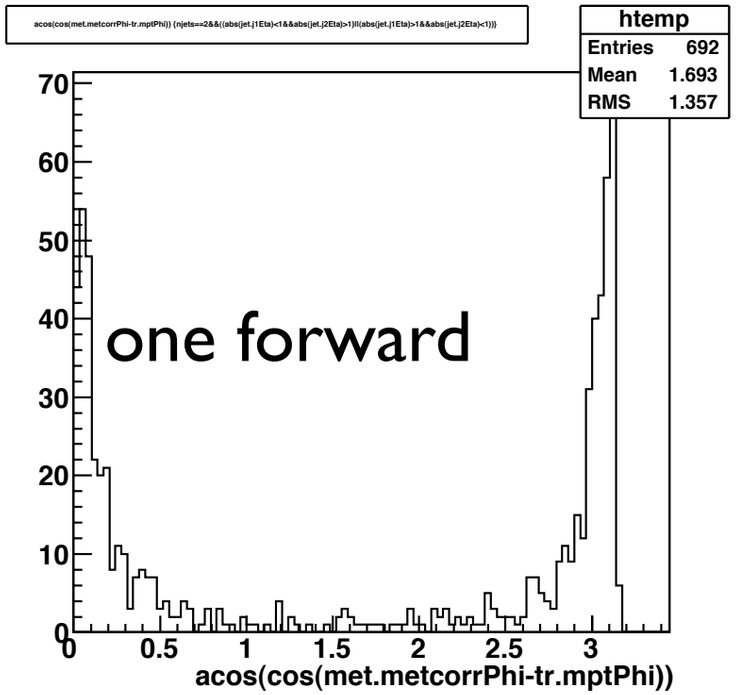


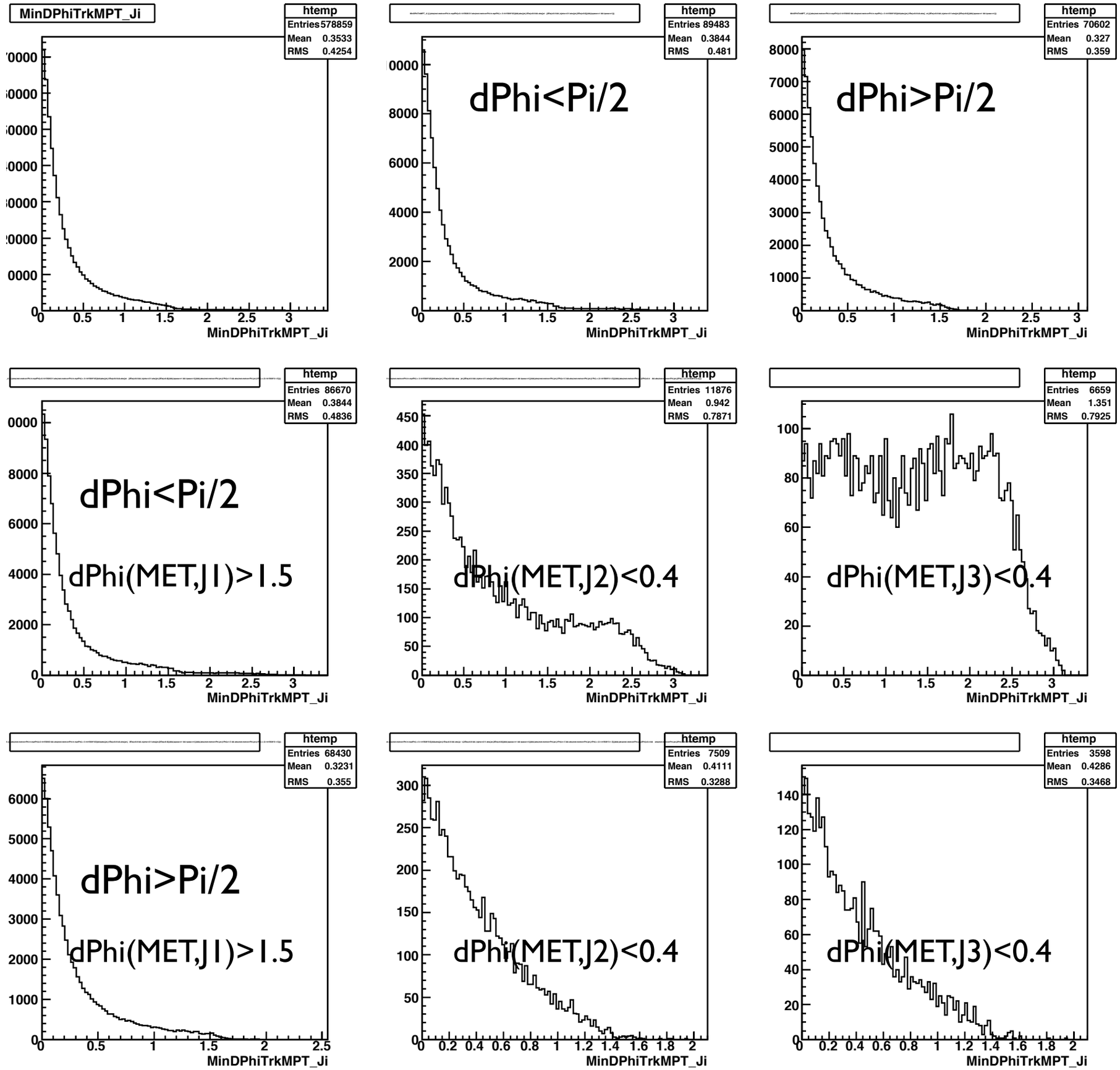
Shape comparison in signal region, the MindPhiMPT_Ji distribution.

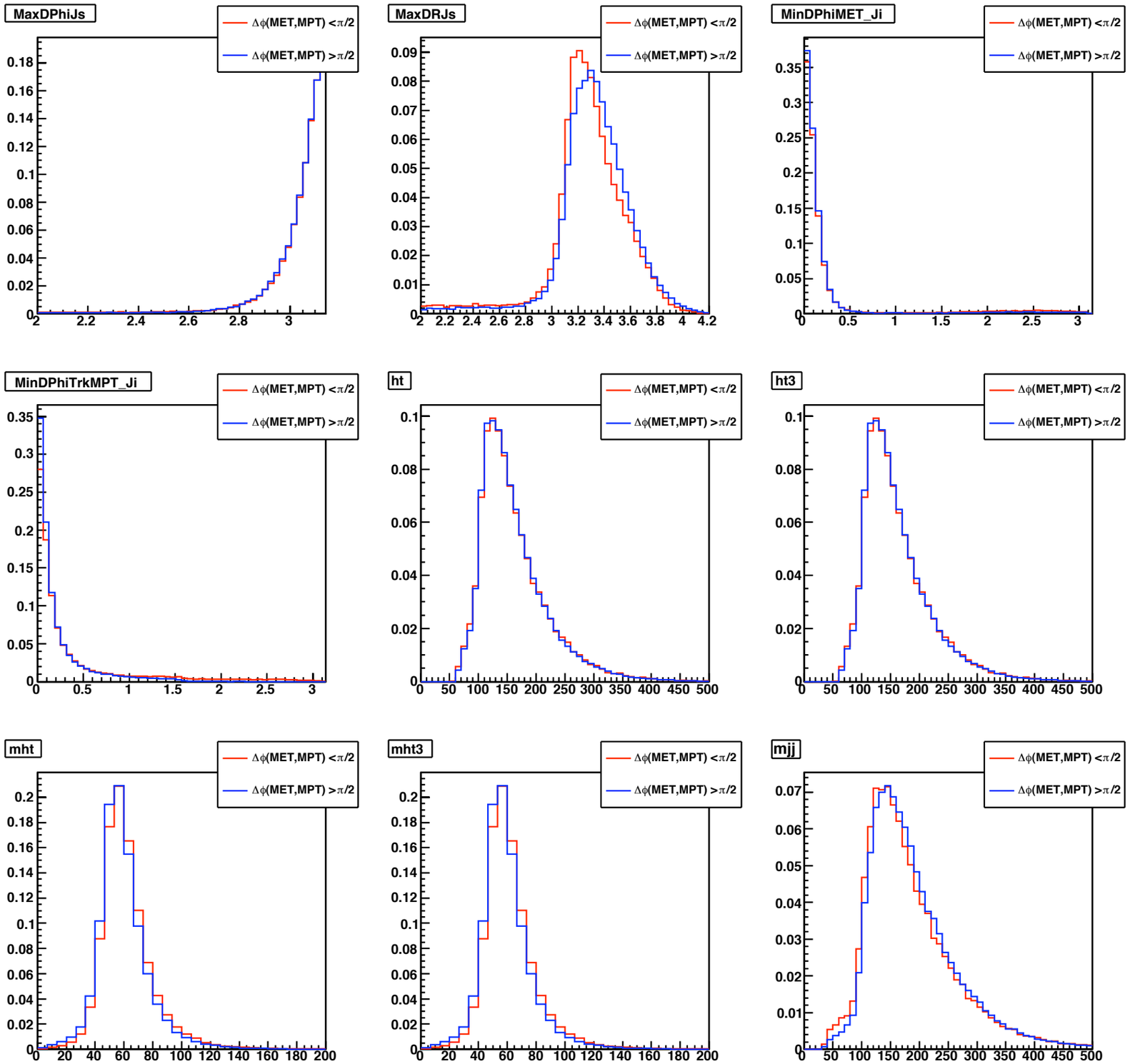


QCD without b-filter restriction, and no central requirement.

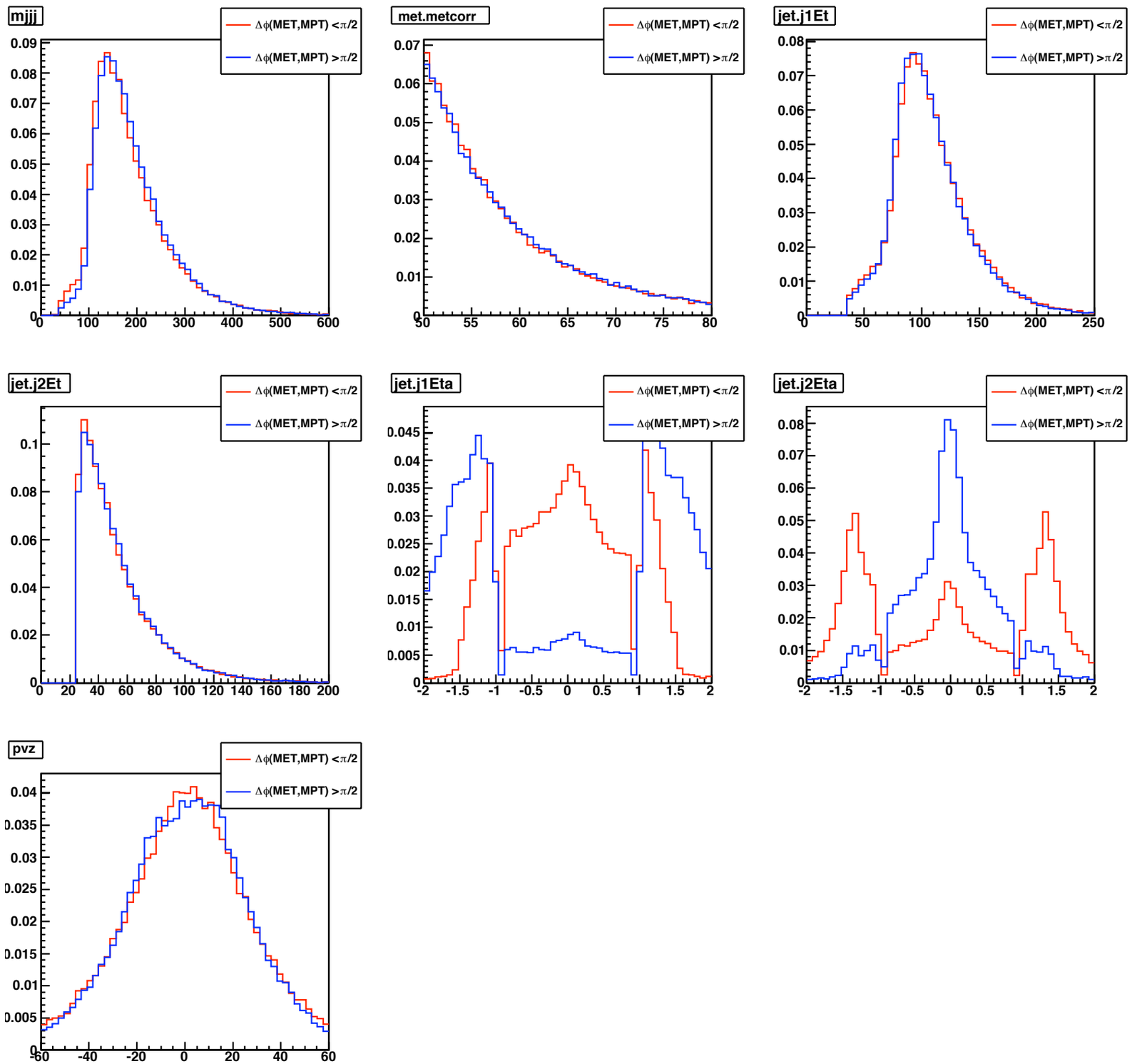





MinDPhiTrkMPT_Ji
htemp
Entries 578859
Mean 0.3533
RMS 0.4254
dPhi<Pi/2
htemp
Entries 89483
Mean 0.3844
RMS 0.481
dPhi>Pi/2
htemp
Entries 70602
Mean 0.327
RMS 0.359
dPhi<Pi/2
dPhi(MET,J1)>1.5
htemp
Entries 86670
Mean 0.3844
RMS 0.4836
dPhi(MET,J2)<0.4
htemp
Entries 11876
Mean 0.942
RMS 0.7871
dPhi(MET,J3)<0.4
htemp
Entries 6659
Mean 1.351
RMS 0.7925
dPhi>Pi/2
dPhi(MET,J1)>1.5
htemp
Entries 68430
Mean 0.3231
RMS 0.355
dPhi(MET,J2)<0.4
htemp
Entries 7509
Mean 0.4111
RMS 0.3288
dPhi(MET,J3)<0.4
htemp
Entries 3598
Mean 0.4286
RMS 0.3468
MinDPhiTrkMPT_Ji

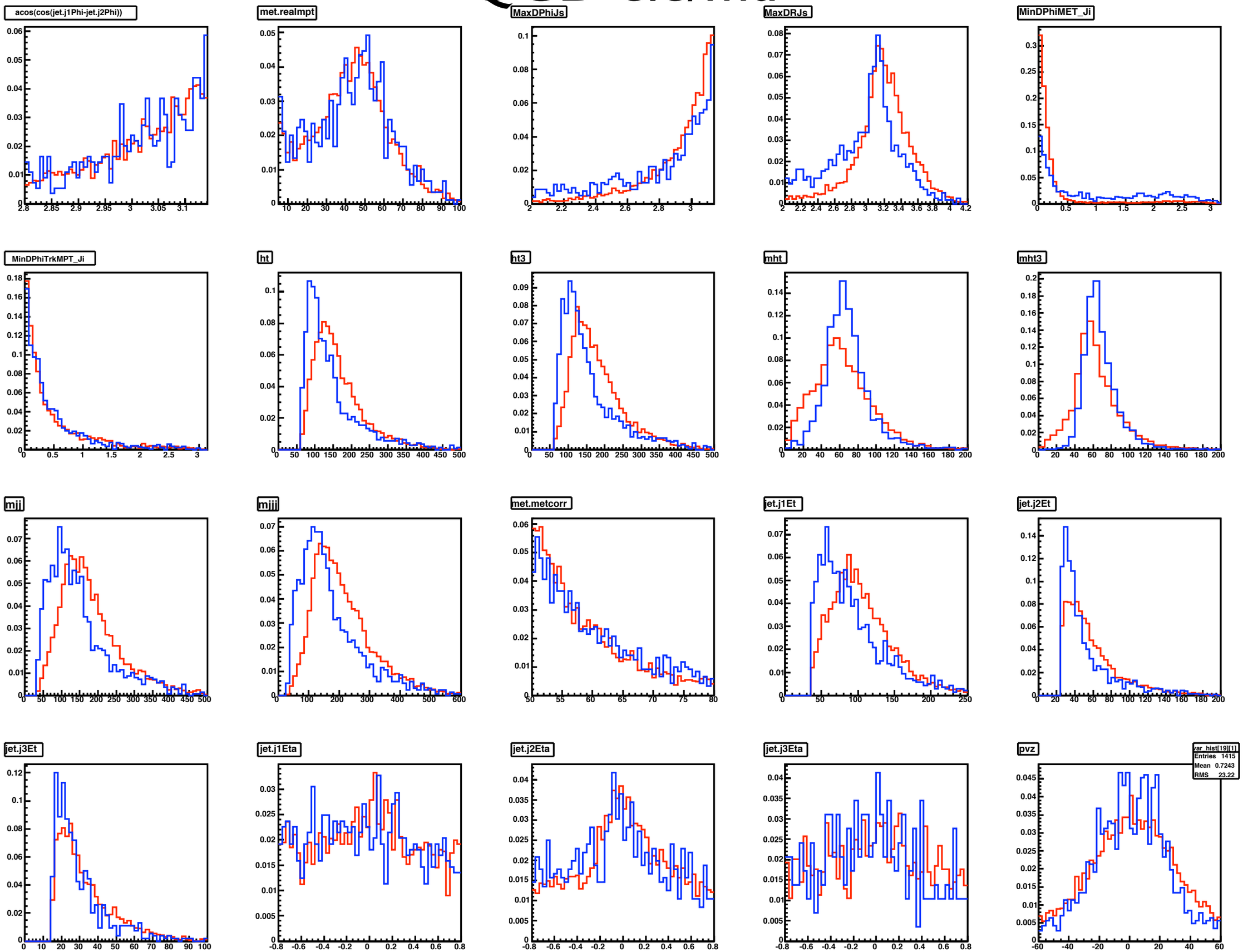


Shape comparison for one jet forward.

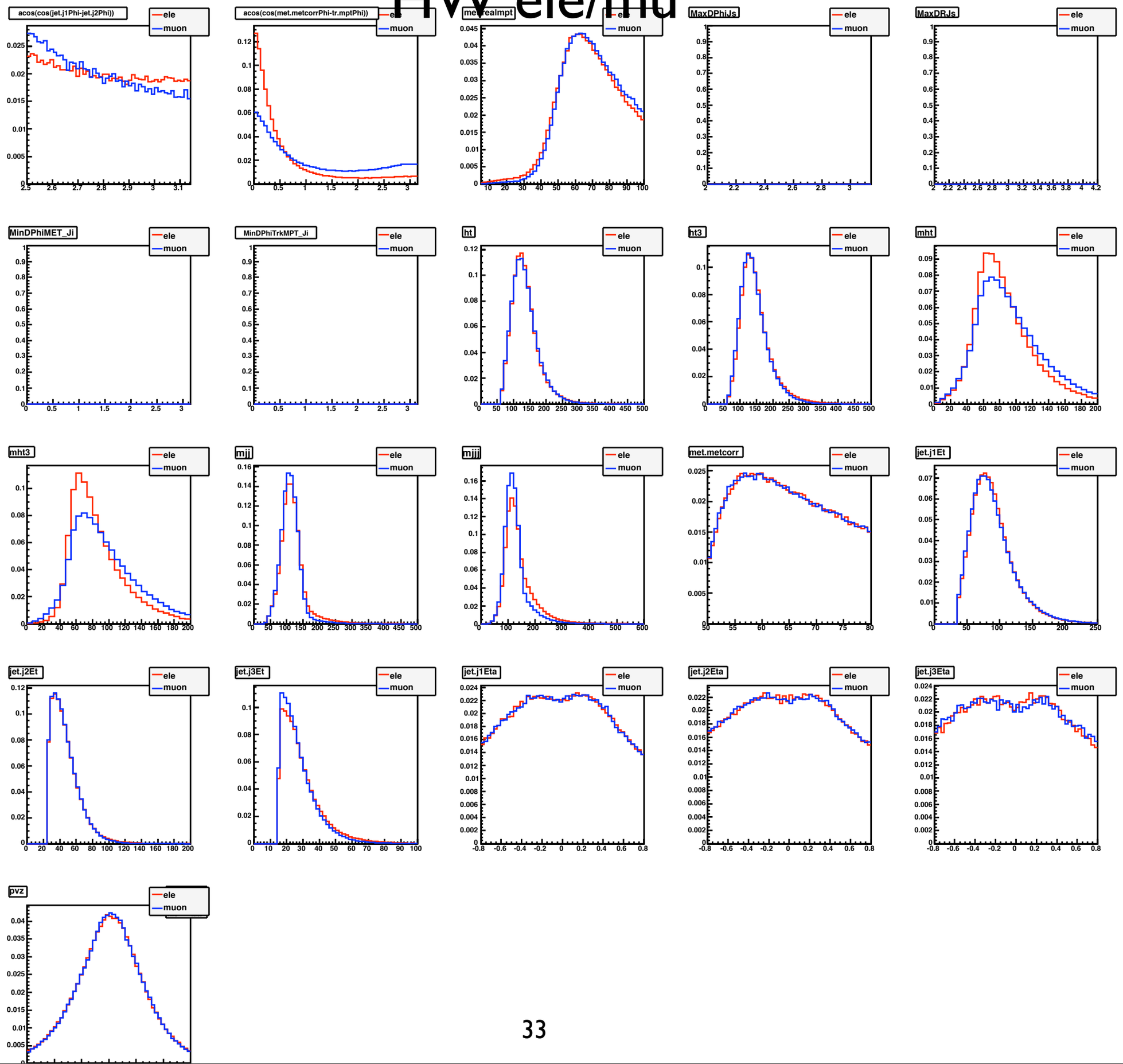


Shape comparison for one jet forward.

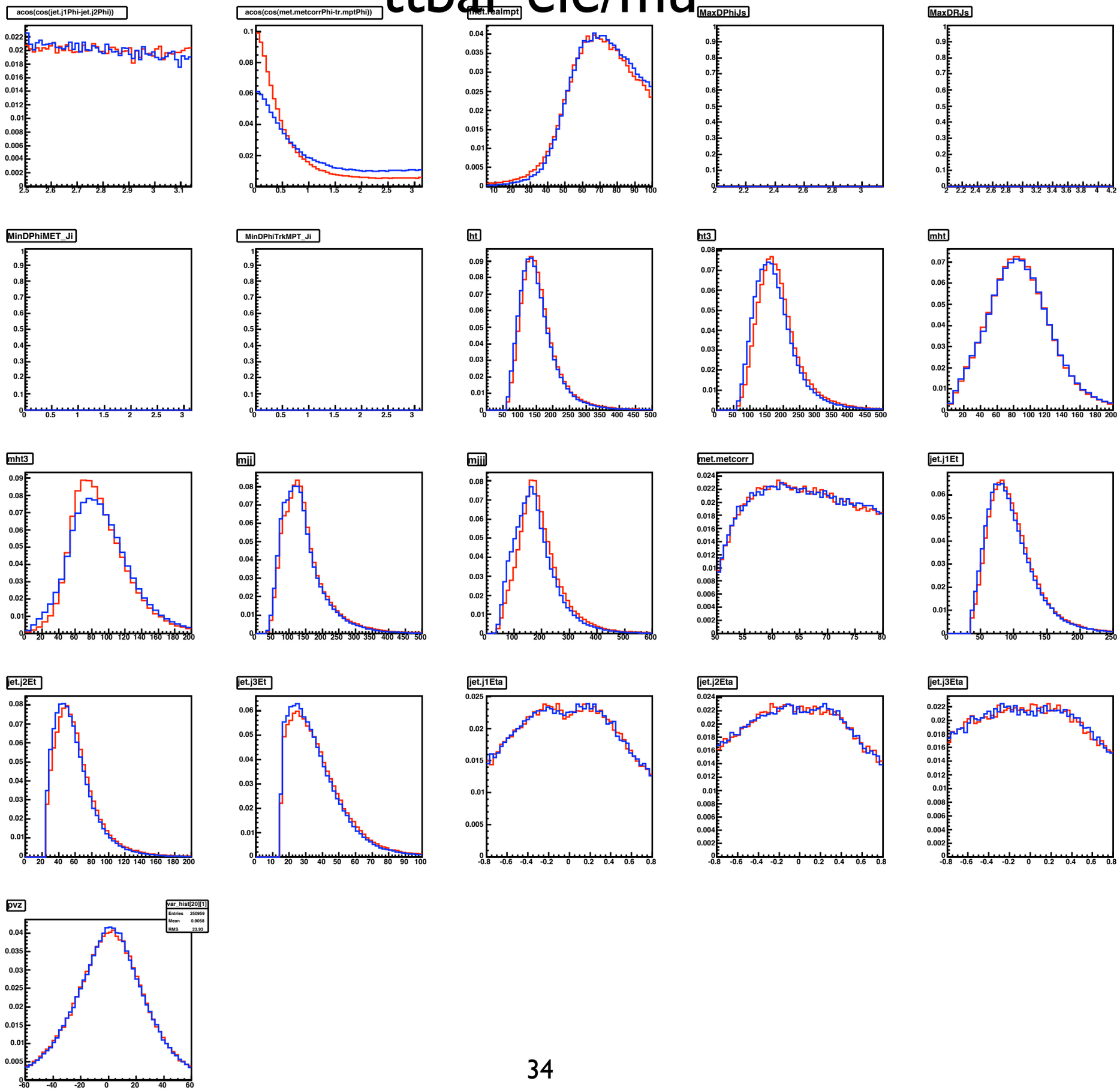
QCD ele/mu


acos(cos(jet.j1Phi-jet.j2Phi))
met.realmpt
MaxDPhiJs
MaxDRJs
MinDPhiMET_Ji
MinDPhiTrkMPT_Ji
ht
ht3
mht
mht3
mjj
mjjj
met.metcorr
jet.j1Et
jet.j2Et
jet.j3Et
jet.j1Eta
jet.j2Eta
jet.j3Eta
pvz
var_hist[19][1]
Entries 1415
Mean 0.7243
RMS 23.22

HW ele/mu


acos(cos(jet.j1Phi-jet.j2Phi))
acos(cos(met.metcorrPhi-tr.mptPhi))
metrealmpt
MaxDPhiJs
MaxDRJs
MinDPhiMET_Ji
MinDPhiTrkMPT_Ji
ht
ht3
mht
mht3
mjj
mjjj
met.metcorr
jet.j1Et
jet.j2Et
jet.j3Et
jet.j1Eta
jet.j2Eta
jet.j3Eta
pvz
ele
muon

ttbar ele/mu


acos(cos(jet.j1Phi-jet.j2Phi))
acos(cos(met.metcorrPhi-tr.mptPhi))
met.realmpt
MaxDPhiJs
MaxDRJs
MinDPhiMET_Ji
MinDPhiTrkMPT_Ji
ht
ht3
mht
mht3
mjj
mjjj
met.metcorr
jet.j1Et
jet.j2Et
jet.j3Et
jet.j1Eta
jet.j2Eta
jet.j3Eta
pvz
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