MET Significance Studies
(Results from the Retreat)

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Many thanks to Michael Peskin and Jay Wacker

SLAC ATLAS Forum
28-Mar-2007

Outline

Introduction to MET Significance.

New approach based on jet probability density functions.

Study of high METsig events in Multi-Jet samples.

- QCD heavy flavor.
- Jets in cracks.

Conclusions.

MET Significance Introduction

Ideal detector: non-zero value of MET indicates the presence of non-interacting particles. However, experimental effects can mimic a large MET in an event that has none.

Missing transverse energy resolution:

- *Energy resolution of physic objects*: jets, leptons, unclustered energy.
- *Instrumental effects*: hot cells, cracks, etc.

MET Significance:

Evaluate how likely the measured MET of an event is due to a resolution fluctuation, taking into account the particular topology and measured physics objects.

Technique developed in Dzero (Run1), by Bruce Knuteson and Mark Strovink (LBNL)

Missing ET Significance Formalism

New approach: Formulate p(met) in terms of jet probability density functions
(Transfer Functions used at Tevatron's top quark mass Matrix Element measurement)

$$p(met) = met - sum[W(p_T^{ptcl}; p_T^{jet}) \cos\Delta\Phi(met, jet)] - W(UE)$$

$W(p_T^{ptcl}; p_T^{jet})$ is the particle-jet probability density distribution, given that a jet with transverse momentum pT has been measured in the detector.

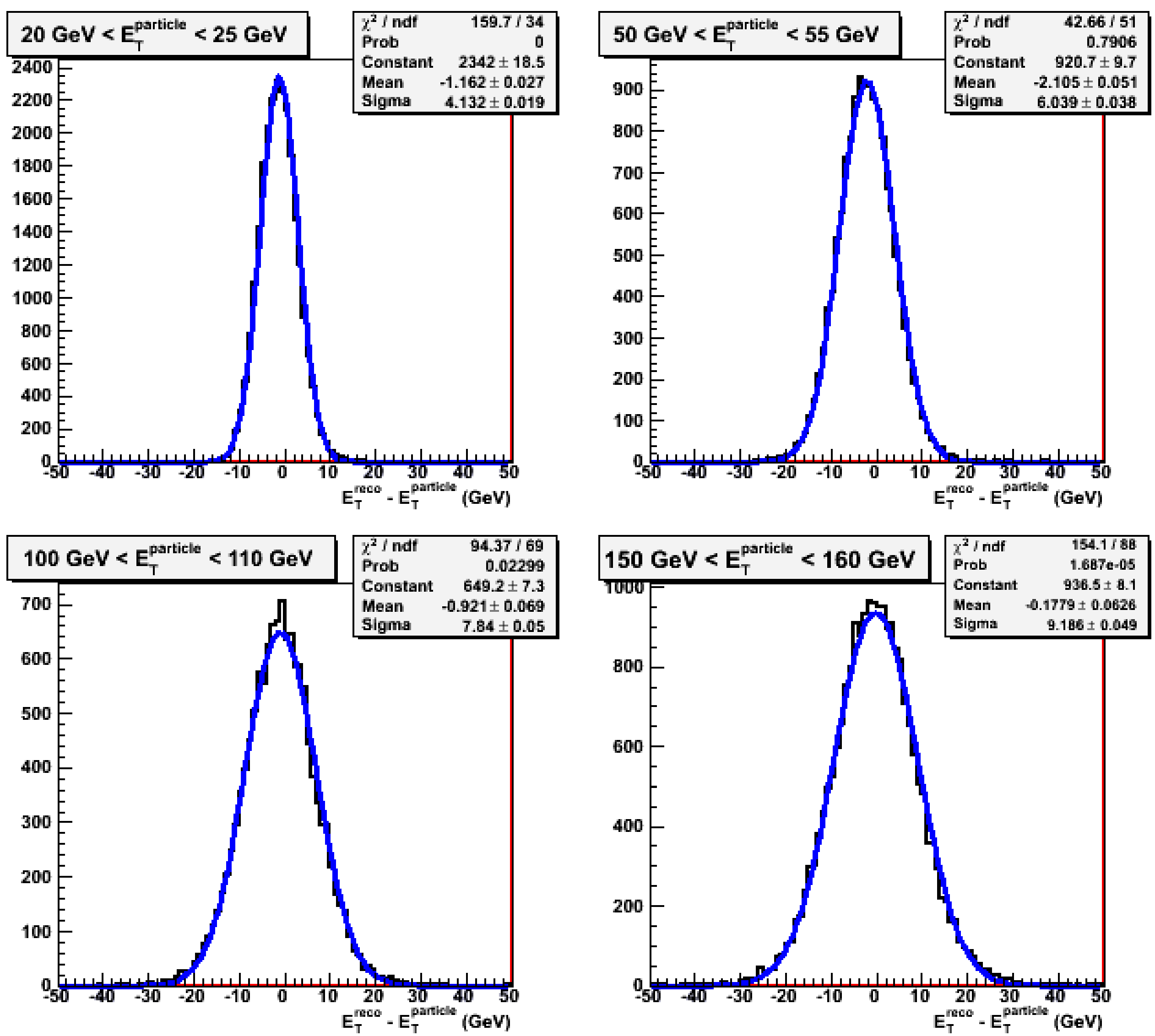
W contains more information than jet energy resolution:

- jet energy scale corrections.
- jet energy resolution (mean and *shape*)
- Non-Gaussian effects (explained in backup slides)
- Different for light/b quark jets.

W(UE) is the pdf for the unclustered energy in the event.

Define MET significance as a likelihood ratio: $L = \log \dfrac{p(met = met^{measured})}{p(met = 0)}$

Jet Probability Density Functions (II)

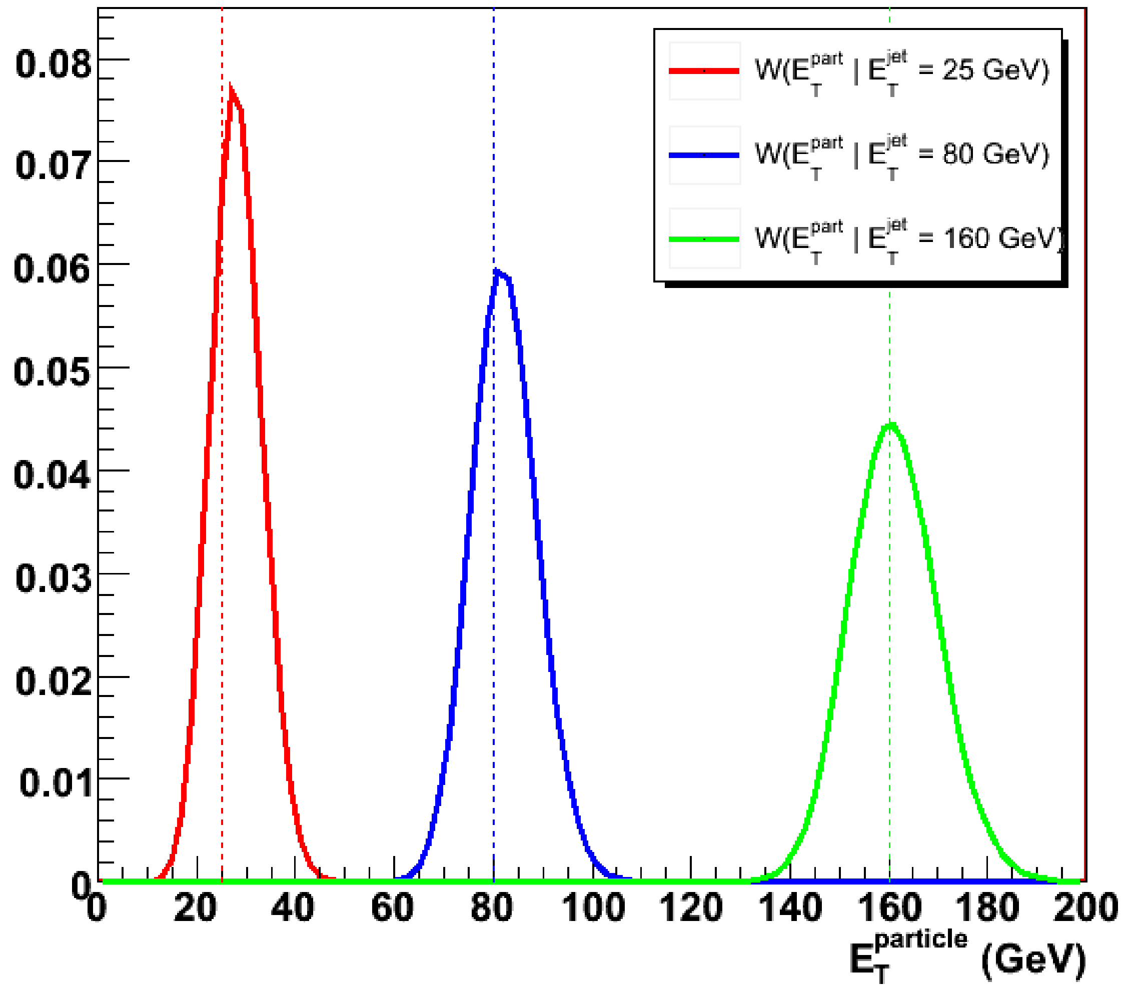


Jpdf derived using J1-J4 simulated events.

Jet Probability Density Functions (III)

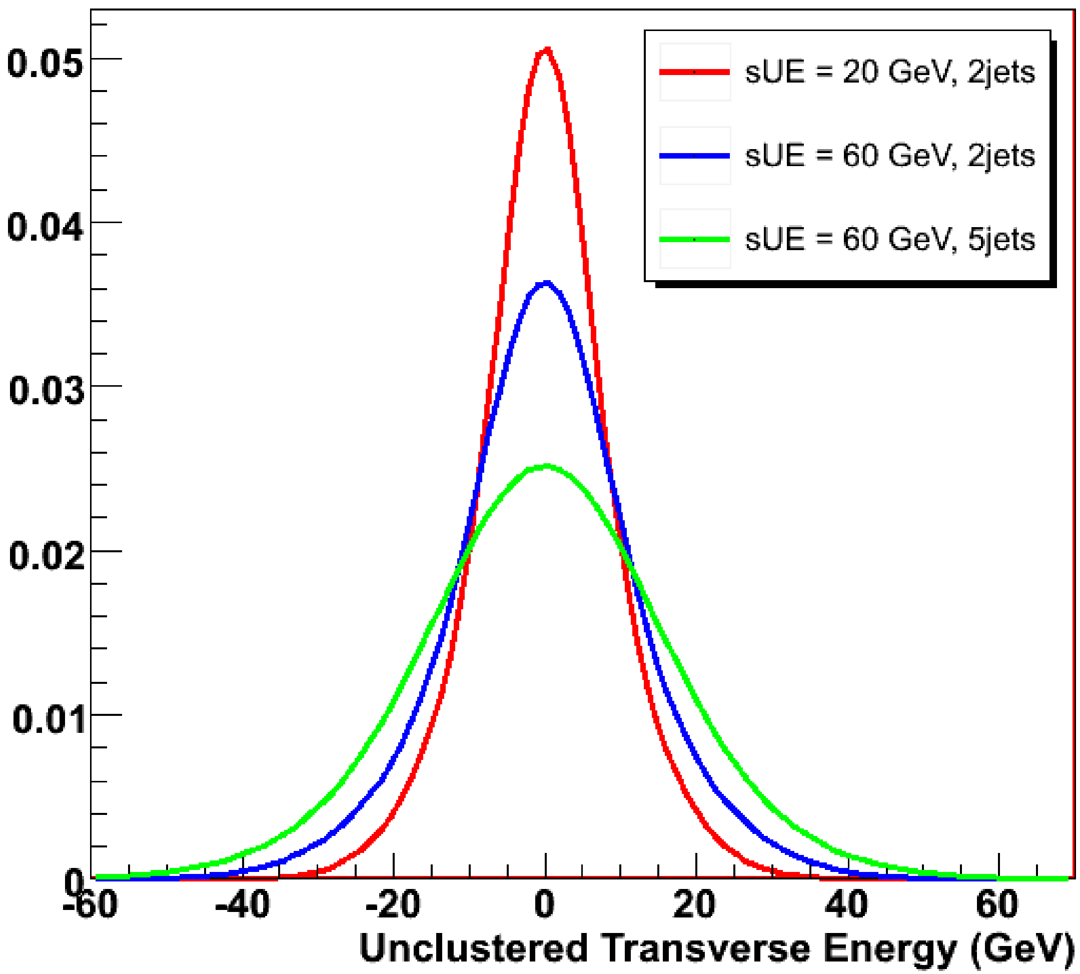
$$W(p_T^{ptcl}; p_T^{jet}) = p_0 \exp \frac{-[(p_T^{ptcl} - p_T^{jet}) - p_1]^2}{2\, p_2^{\,2}} \qquad p_{1,2} = a_{1,2} + b_{1,2}\, p_T^{ptcl}$$

p1 and p2 derived in 5 eta regions: 2x2x5 = 20 parameters

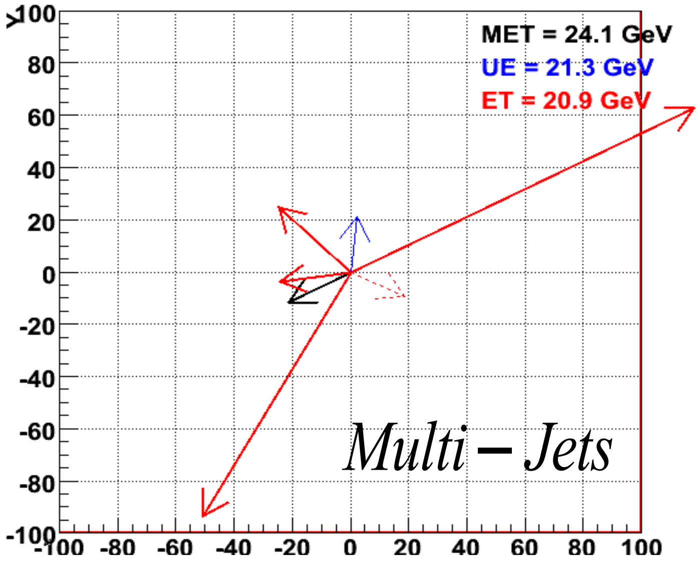


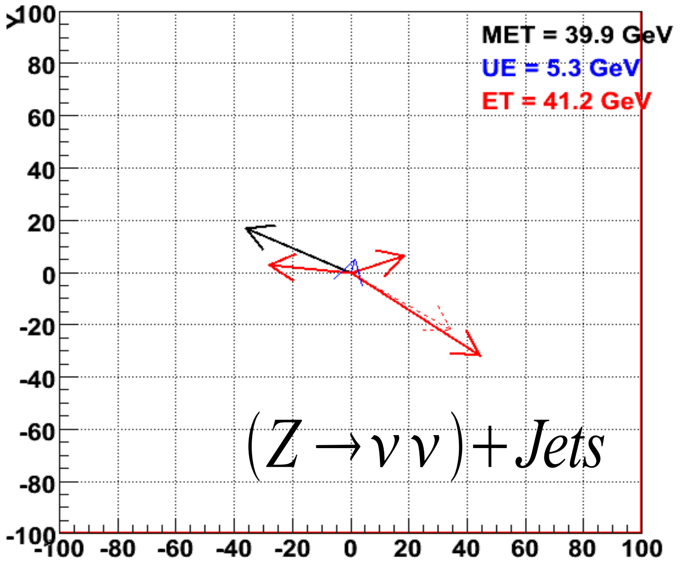
Unclustered Energy Probability Density Functions

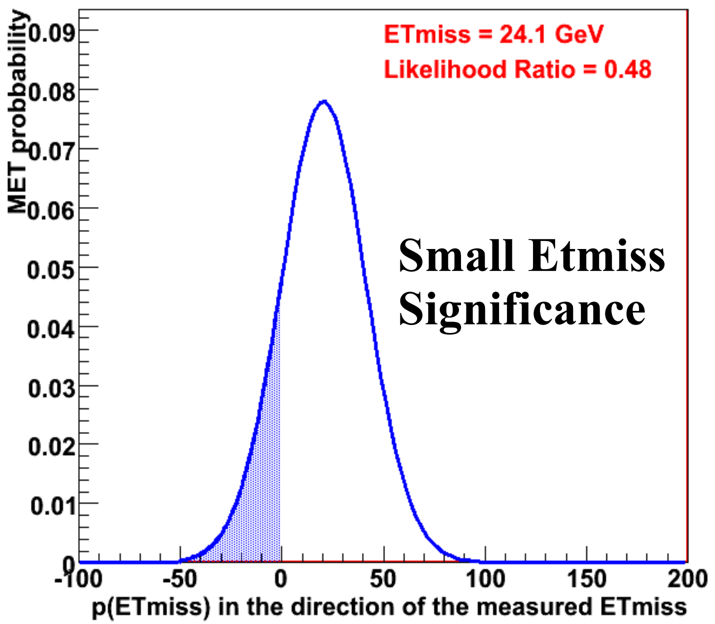
Derived as a function of the scalar unclustered energy and number of jets. More details in the backup slides.

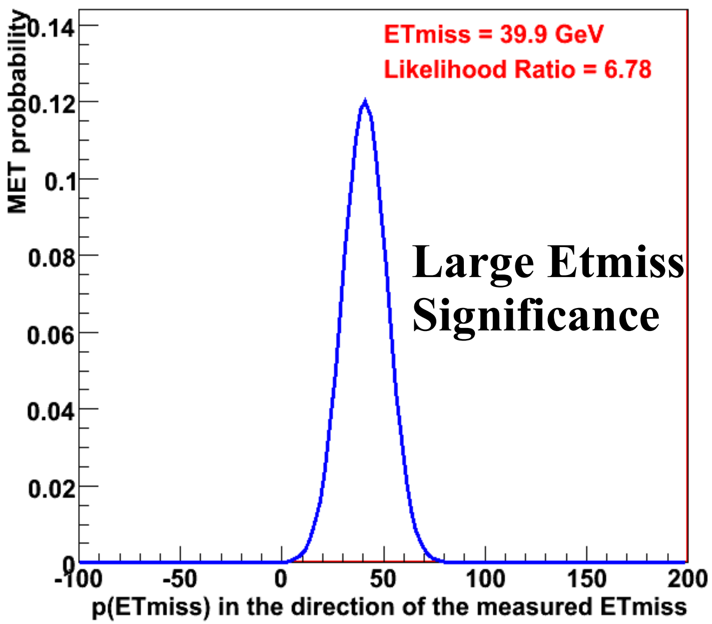


Missing ET Significance Examples

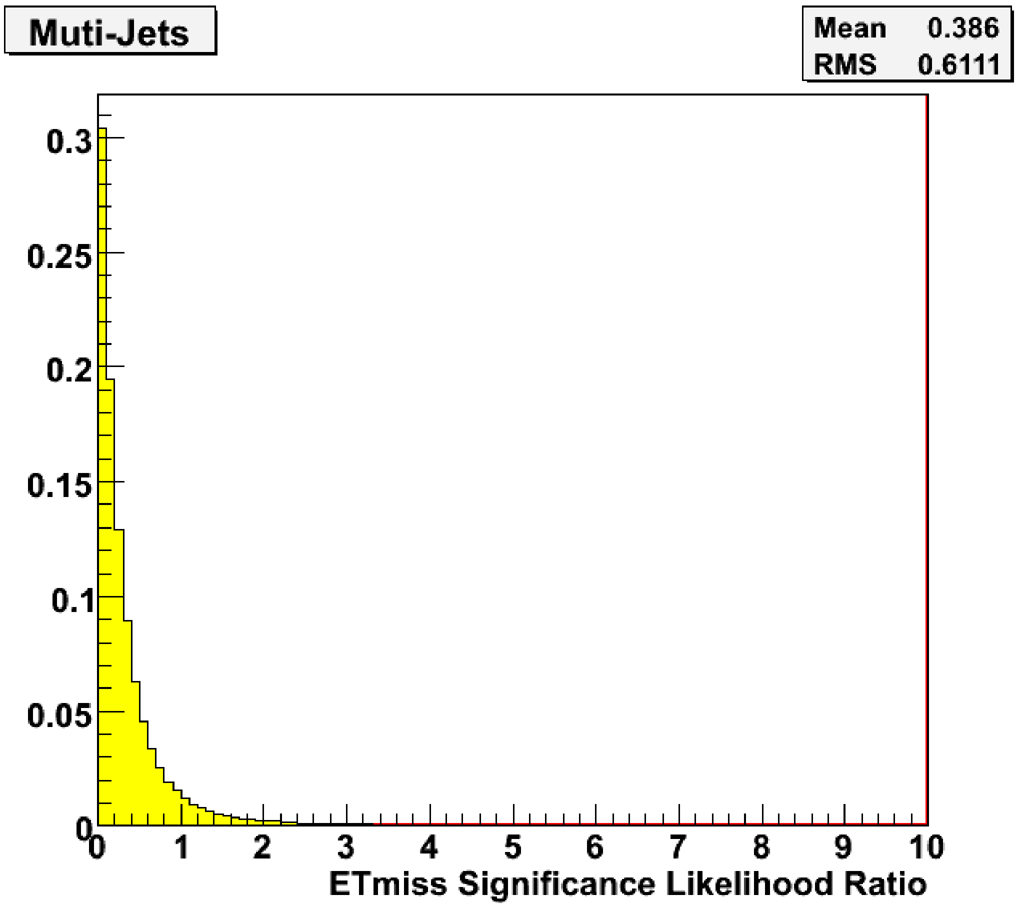


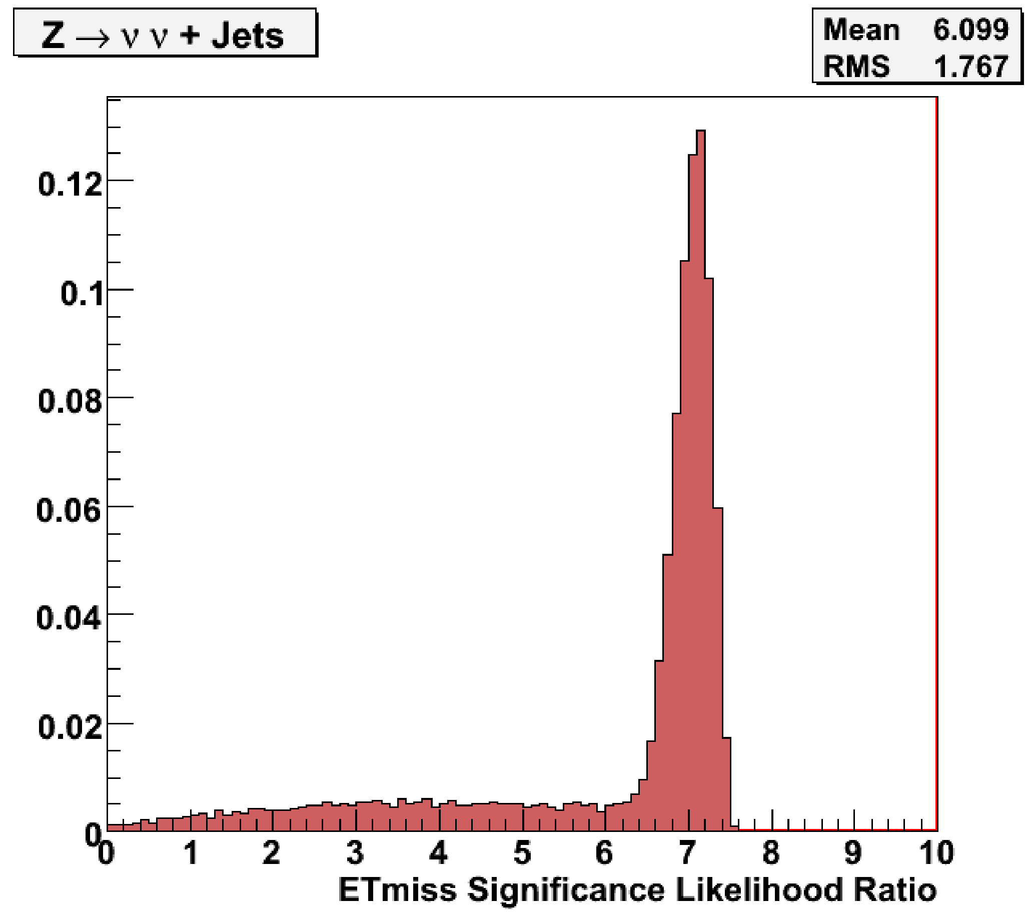






Missing ET Significance Performance



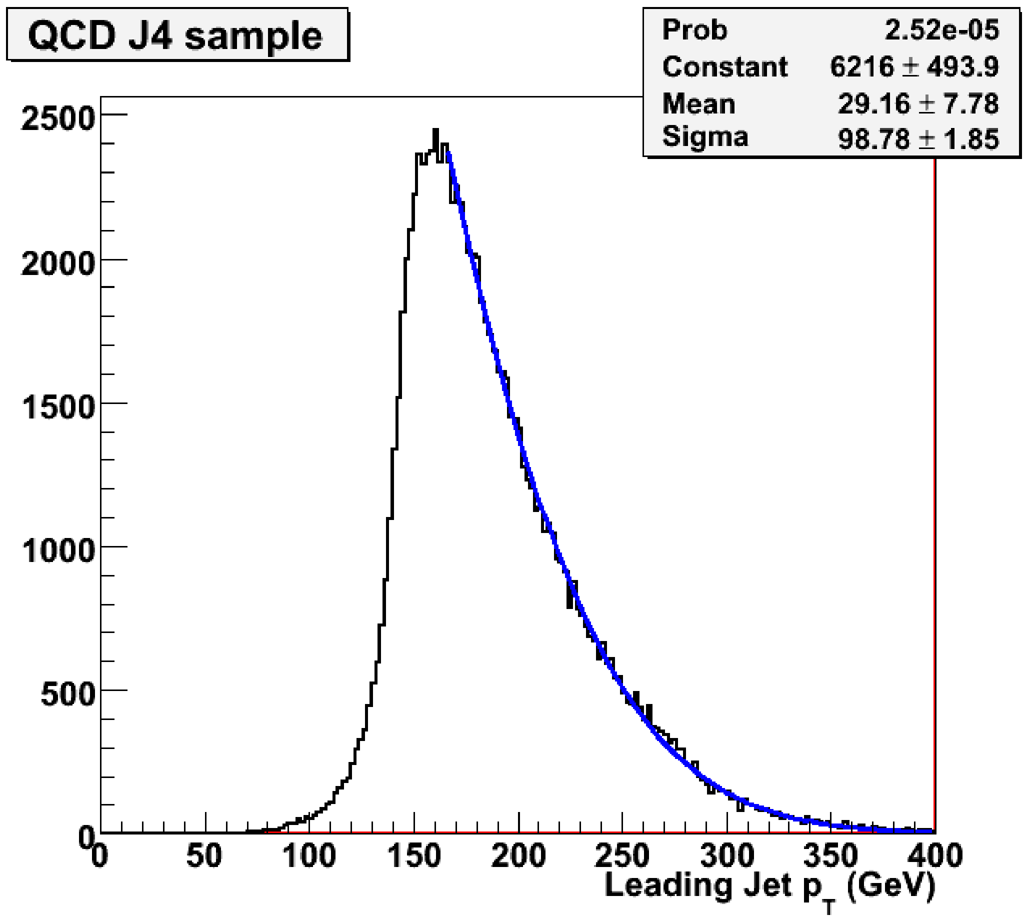


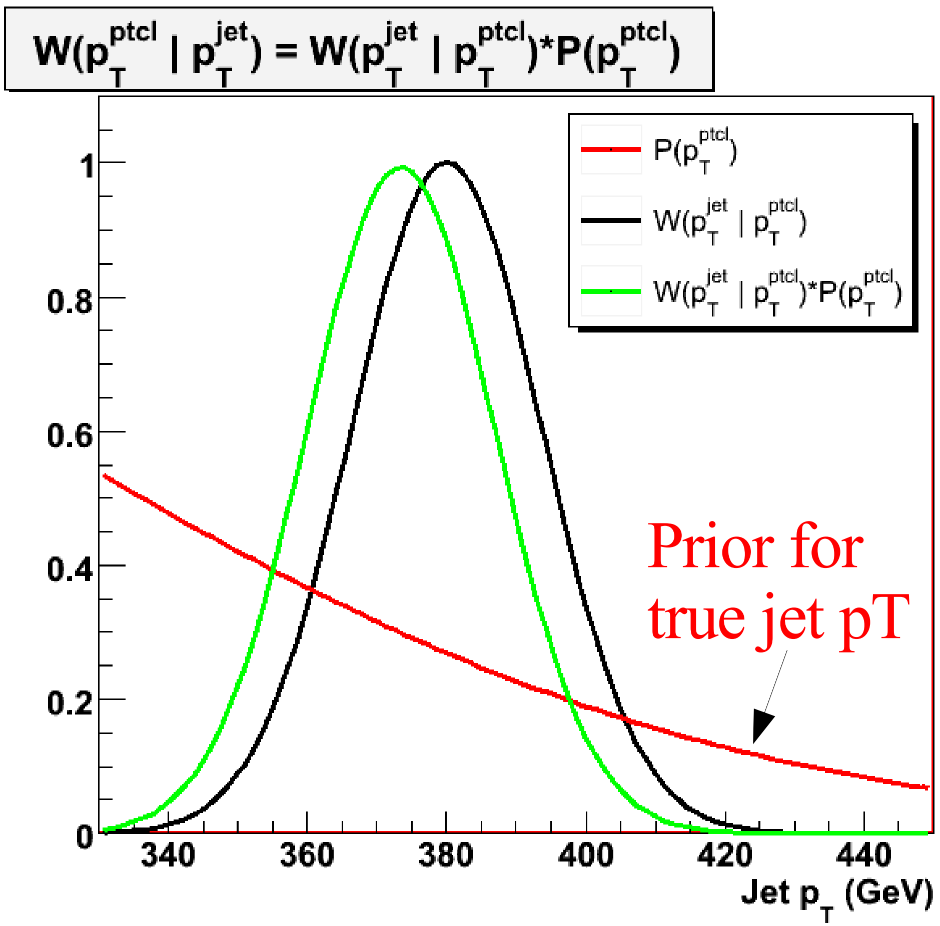
MET significance likelihood ratio (L) peaks at 0 for multi-jet (QCD) events and ~7 for events with real ETmiss.

Idea proposed and implemented during the retreat. (Michael, Richard, Reiner)

Missing ET Significance Improvements

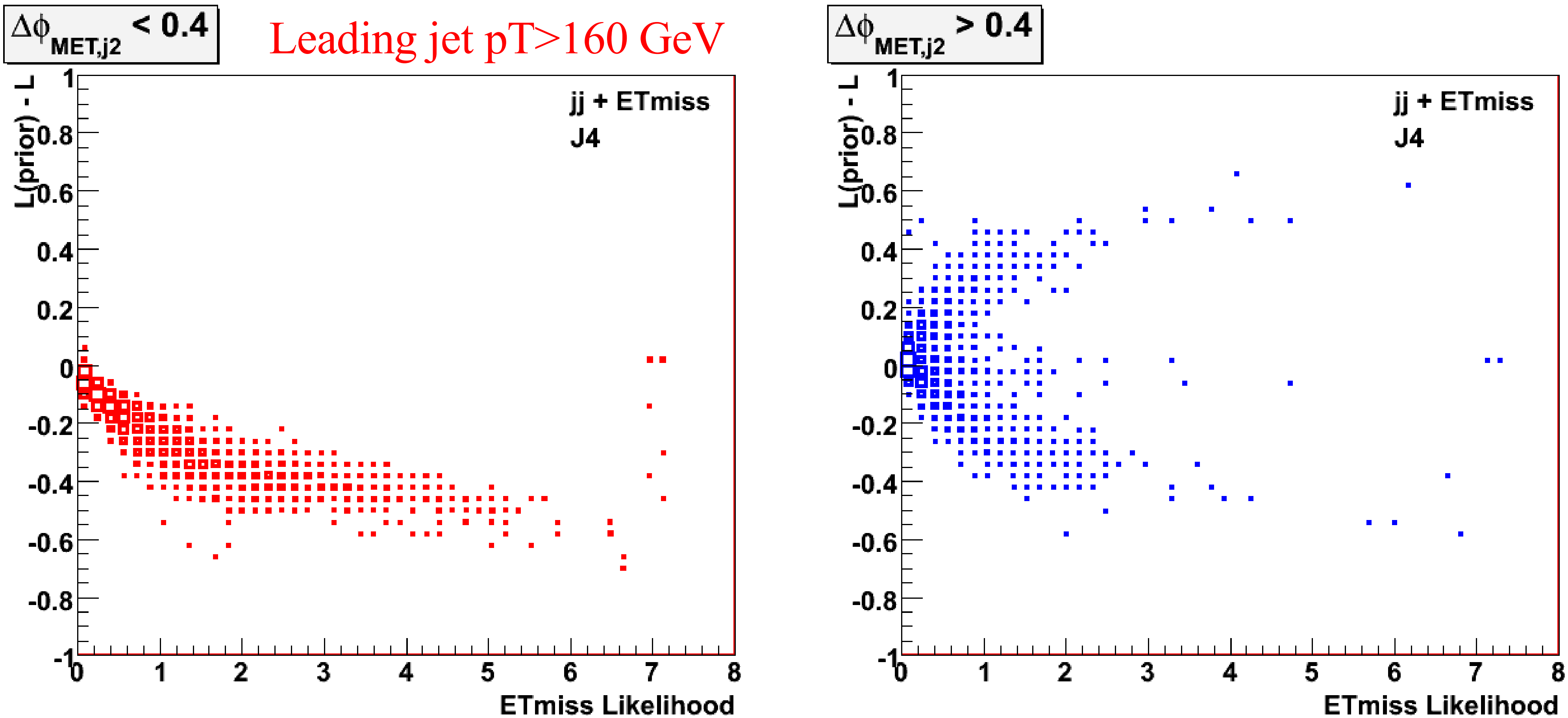
In a di-jet event with a hard jet back-to-back to a soft jet, it is more likely that the hard jet is a positive fluctuation, due to the fact that the pT of true jets follows a falling spectrum) -> Do not assume a flat prior for pT(true)





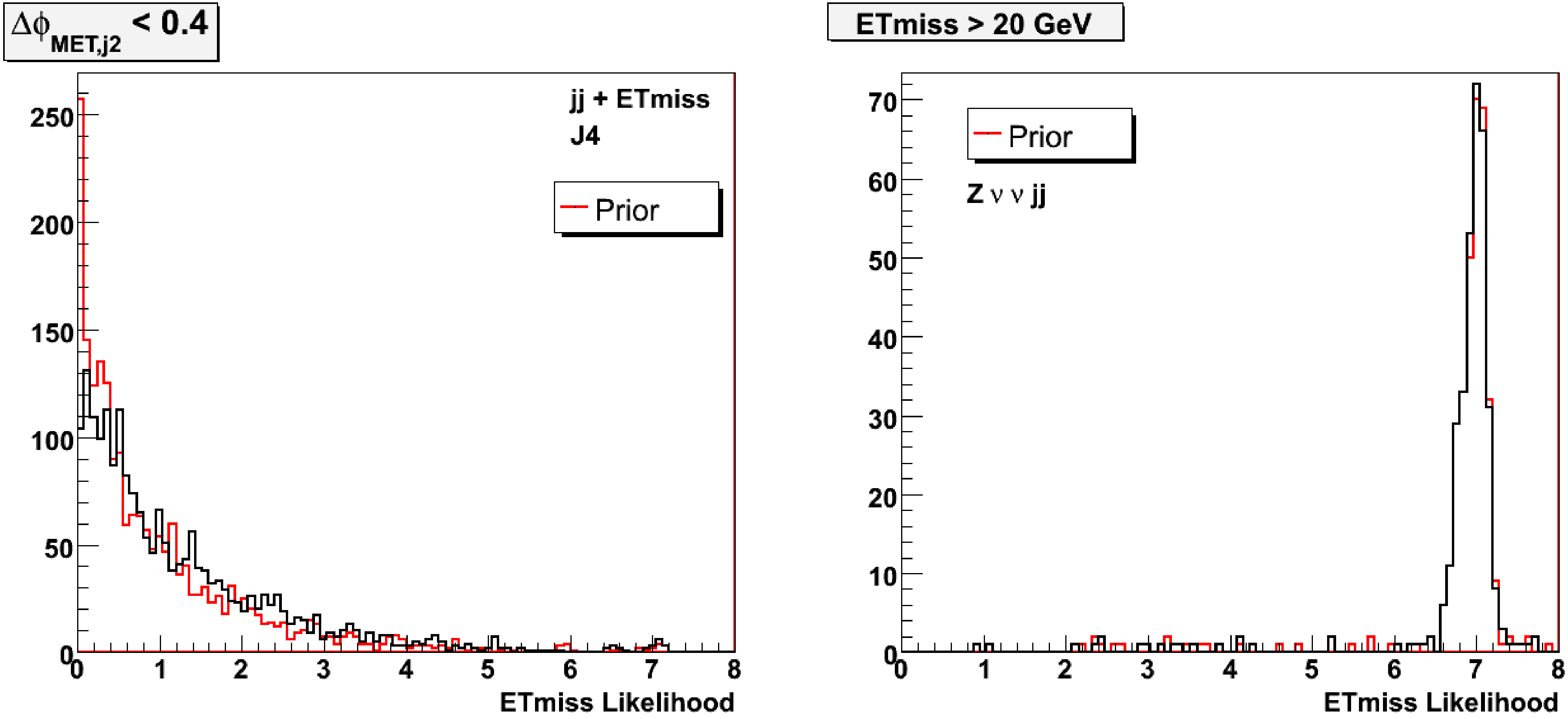
Use new jet probability density function including true jet pT prior probability

METsig Using Prior Probability (I)



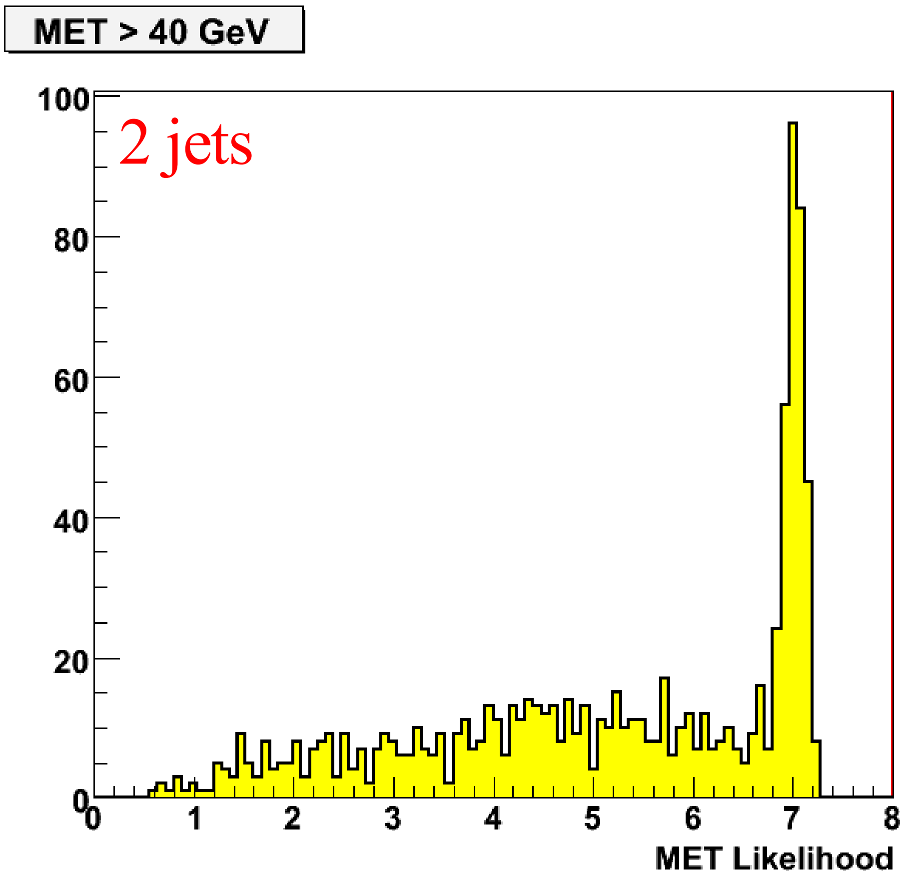
In back-to-back jj topologies with high ETmiss, the use of the prior probability correctly results in lower MET significance. Other topologies with low MET, are randomly affected.

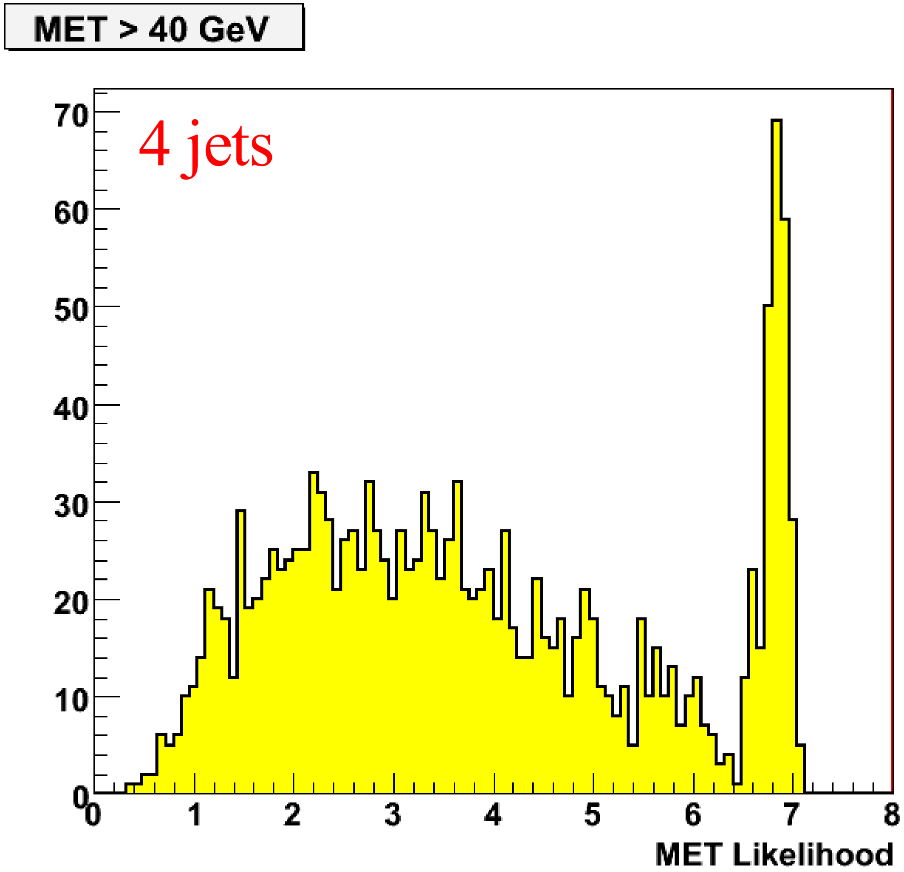
METsig Using Prior Probability (II)



Clear shift toward the left in MET significance distribution for QCD events. The use of a prior allows to reject 20% more QCD background (for a L>3 cut)

MET Significance in High MET Events

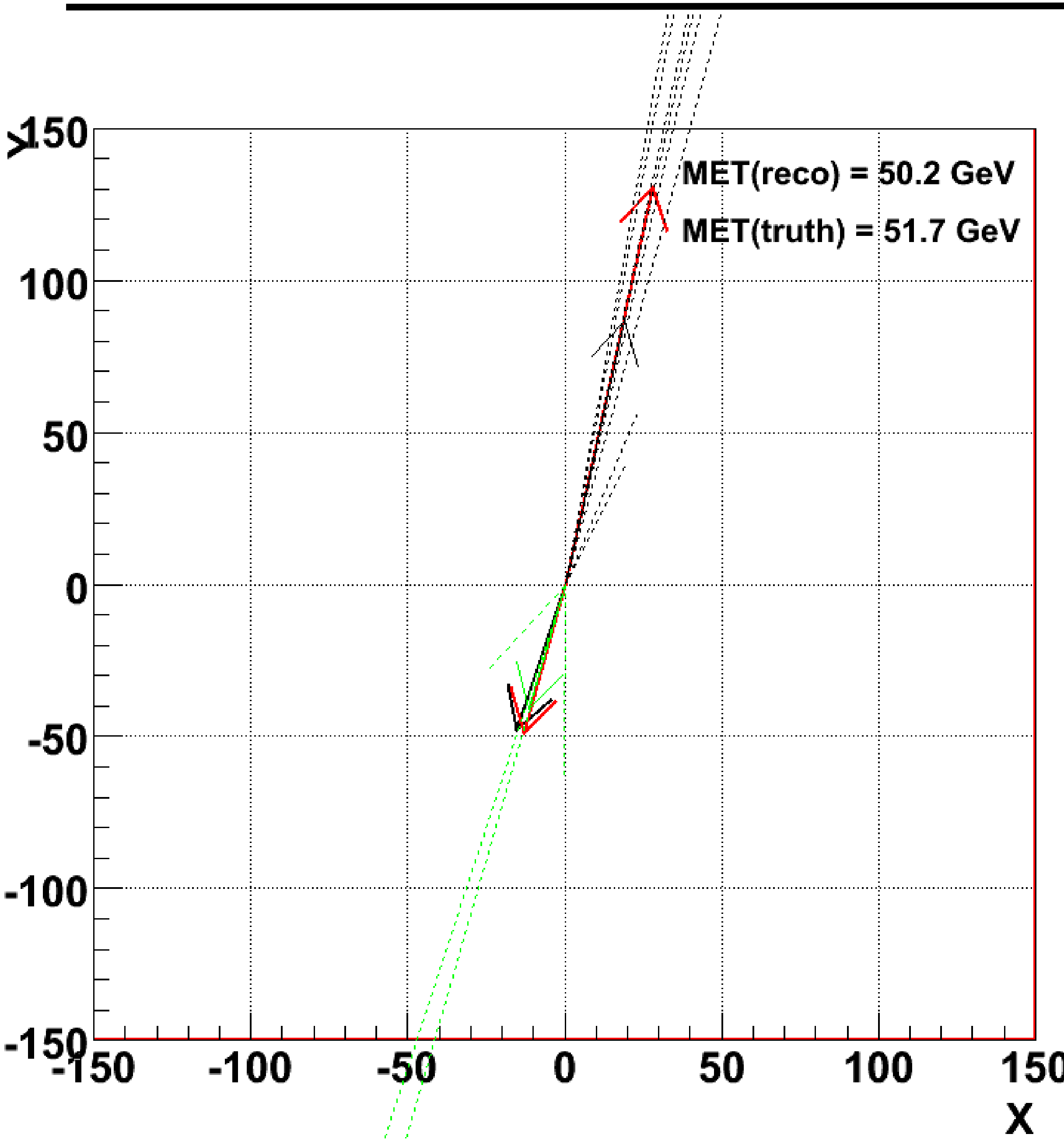




Most of QCD (J4) events with MET>40 GeV, also have high MET significance:
i.e.: The measured ETmiss is unlikely to come from jet-resolution fluctuations.

Algorithm problem (instrumental effect not yet accounted) or real MET?

High MET Significance Events (I)

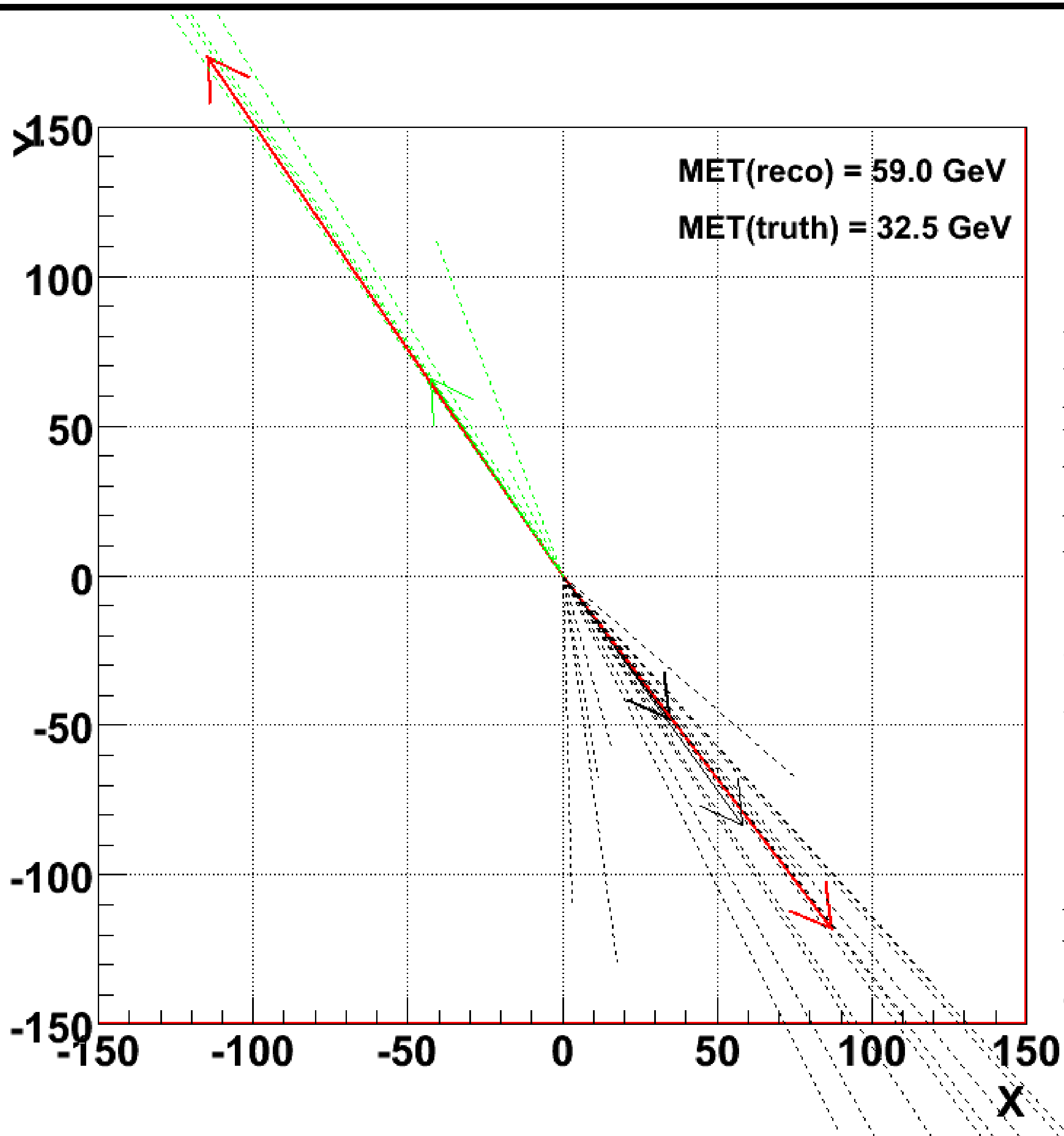


QCD Heavy Flavor event!

High pT neutrino from a semileptonic b/c decay in one of the jets.

Event displays:
- Red: 0.7 Cone Jets.
- Black: Etmiss.
- Dotted lines: 0.7 Cone Track-Jets.

High MET Significance Events (II)

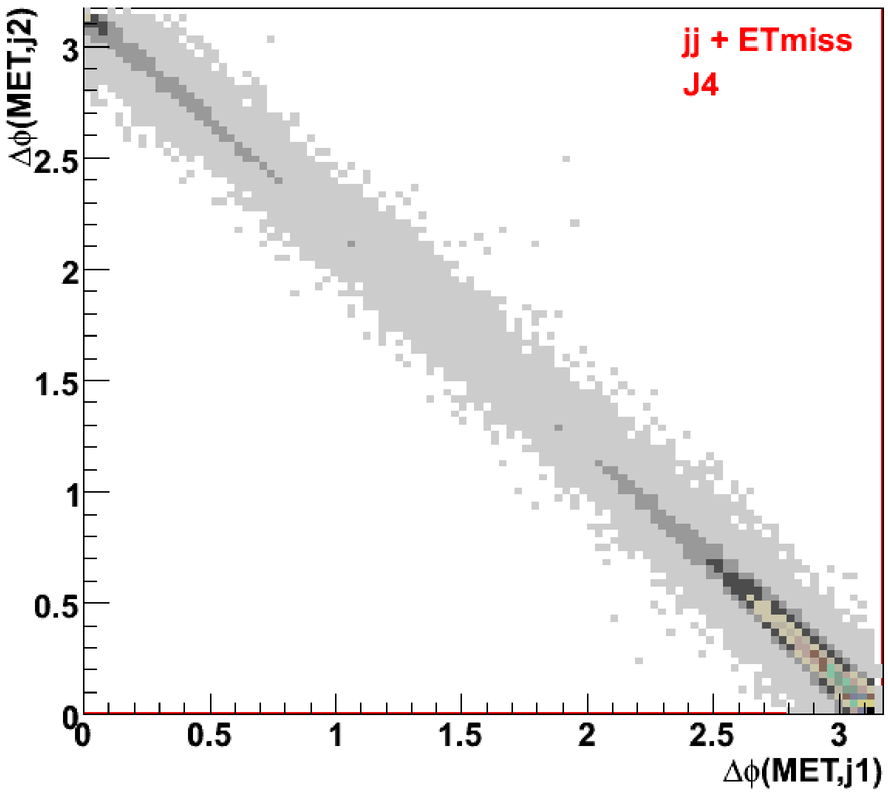


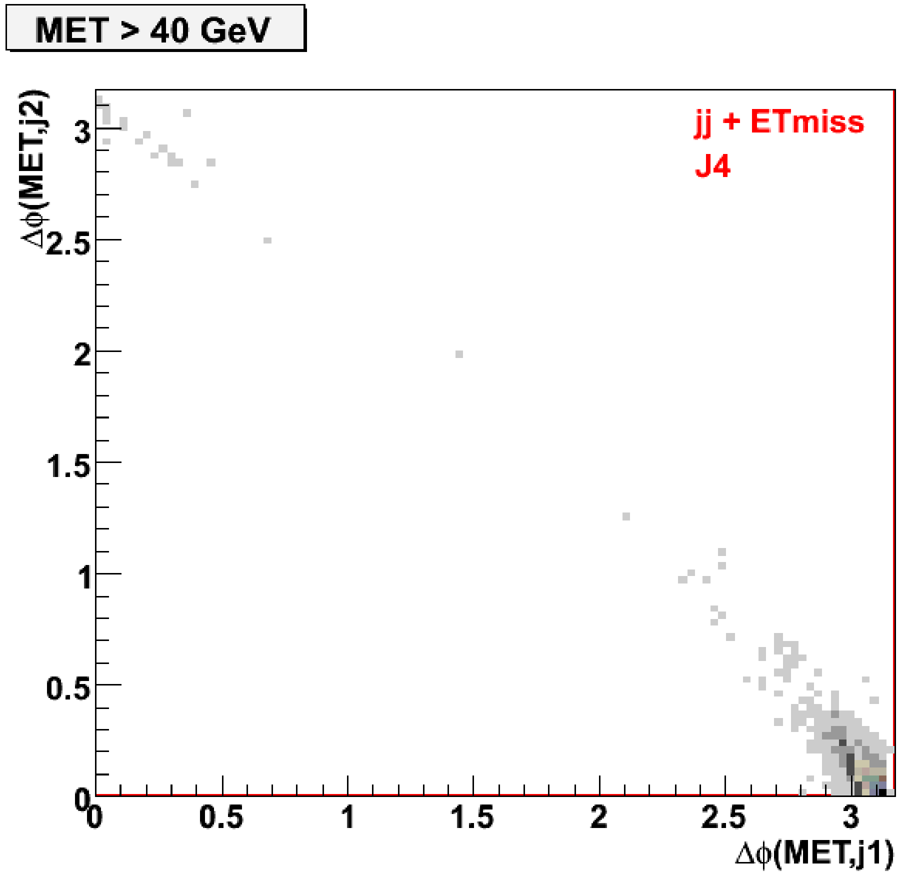
QCD Heavy Flavor event.

I found that the majority of the events with high MET and significance in QCD Monte Carlo is due to heavy flavor.

Another result from the work at the retreat (with Michael and Jay)

Angular Correlations in QCD Events (I)



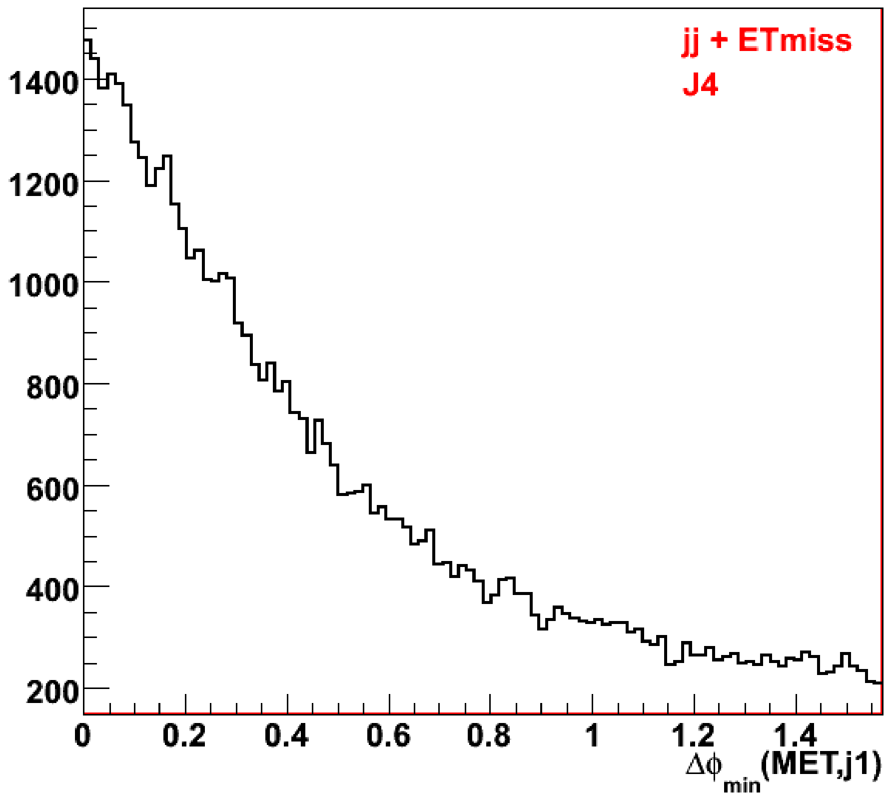


In di-jet events, High ETmiss is in the direction of the second leading jet:

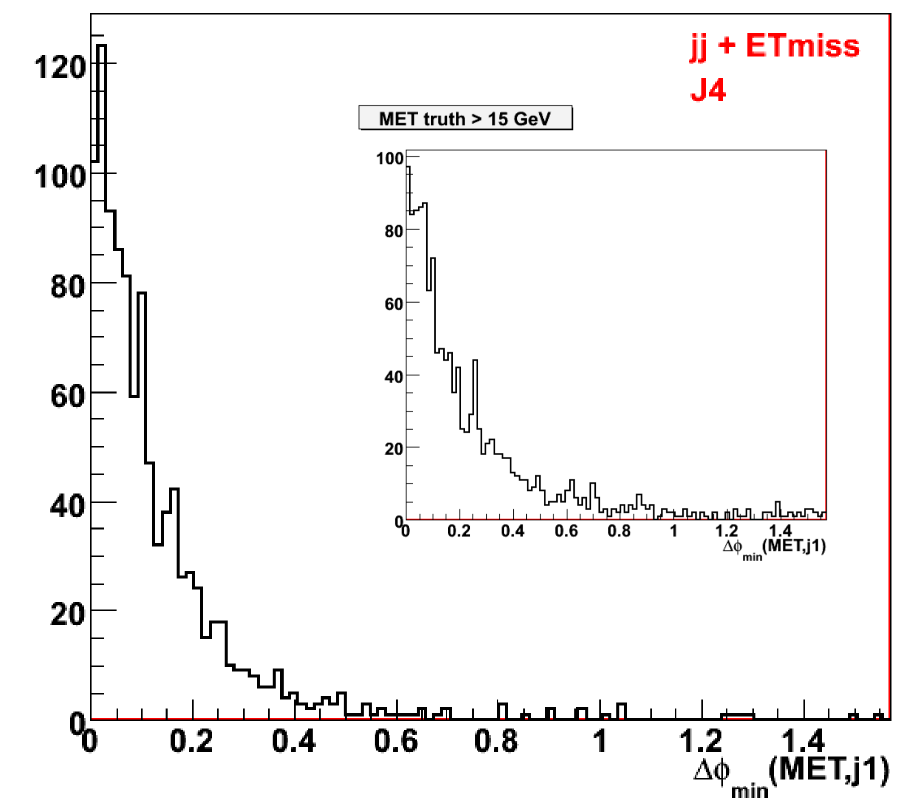
- Jet resolution fluctuations (leading jet fluctuating high)
- Heavy flavor with real neutrino aligned with a jet.

Angular Correlations in QCD Events (II)

Minimum angle between MET vector and any jet

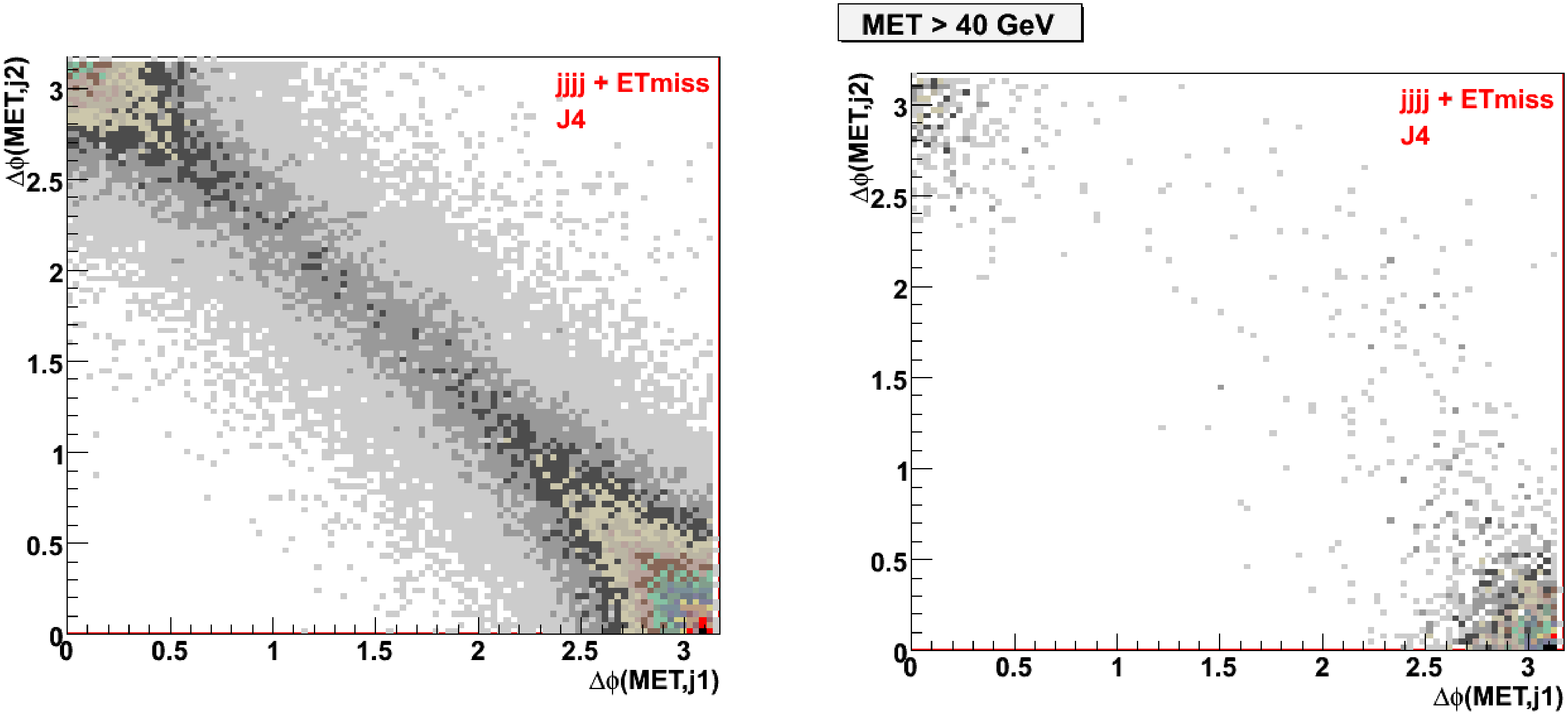


L > 3



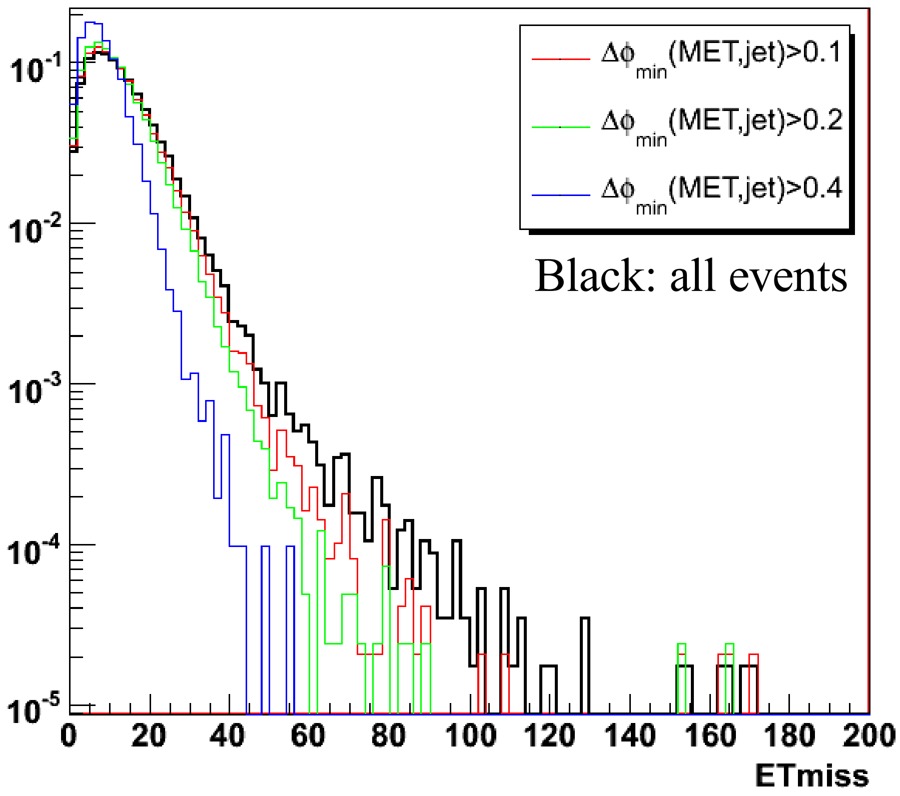
A requirement of L>3 rejects events in which MET is consistent with (average) jet resolution fluctuations: Expect large contribution of high ETmiss events from QCD heavy flavor.

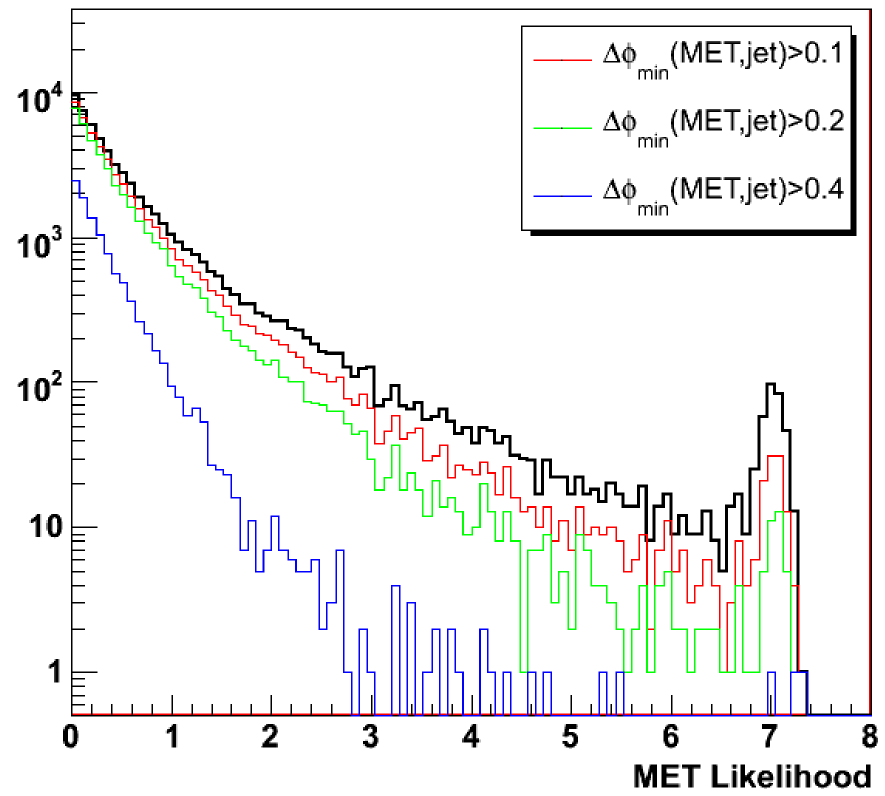
Angular Correlations in QCD Events (III)



In events with higher jet multiplicity the ETmiss from the neutrino of a b/c decay is "smeared" by larger jet resolution fluctuations.

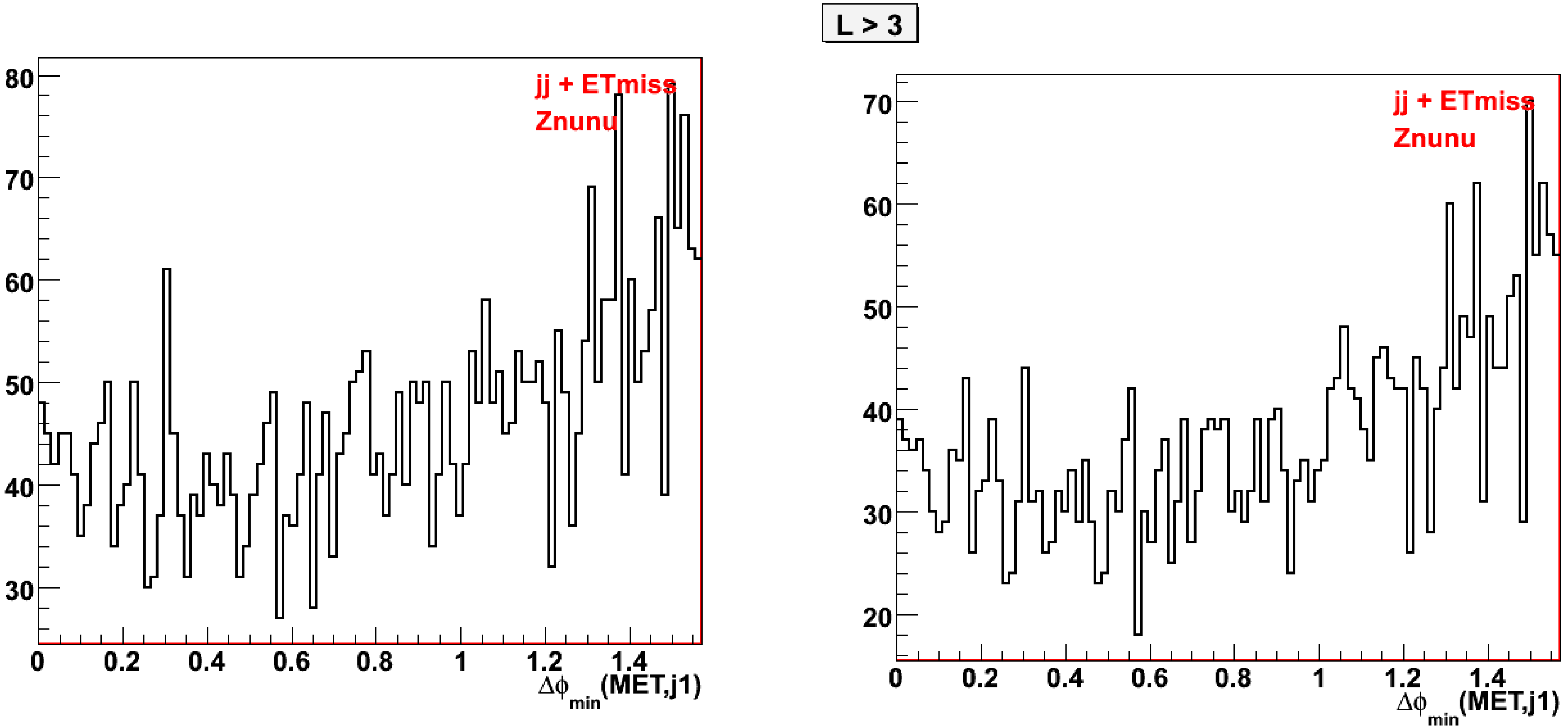
Angular Correlations in QCD Events (IV)





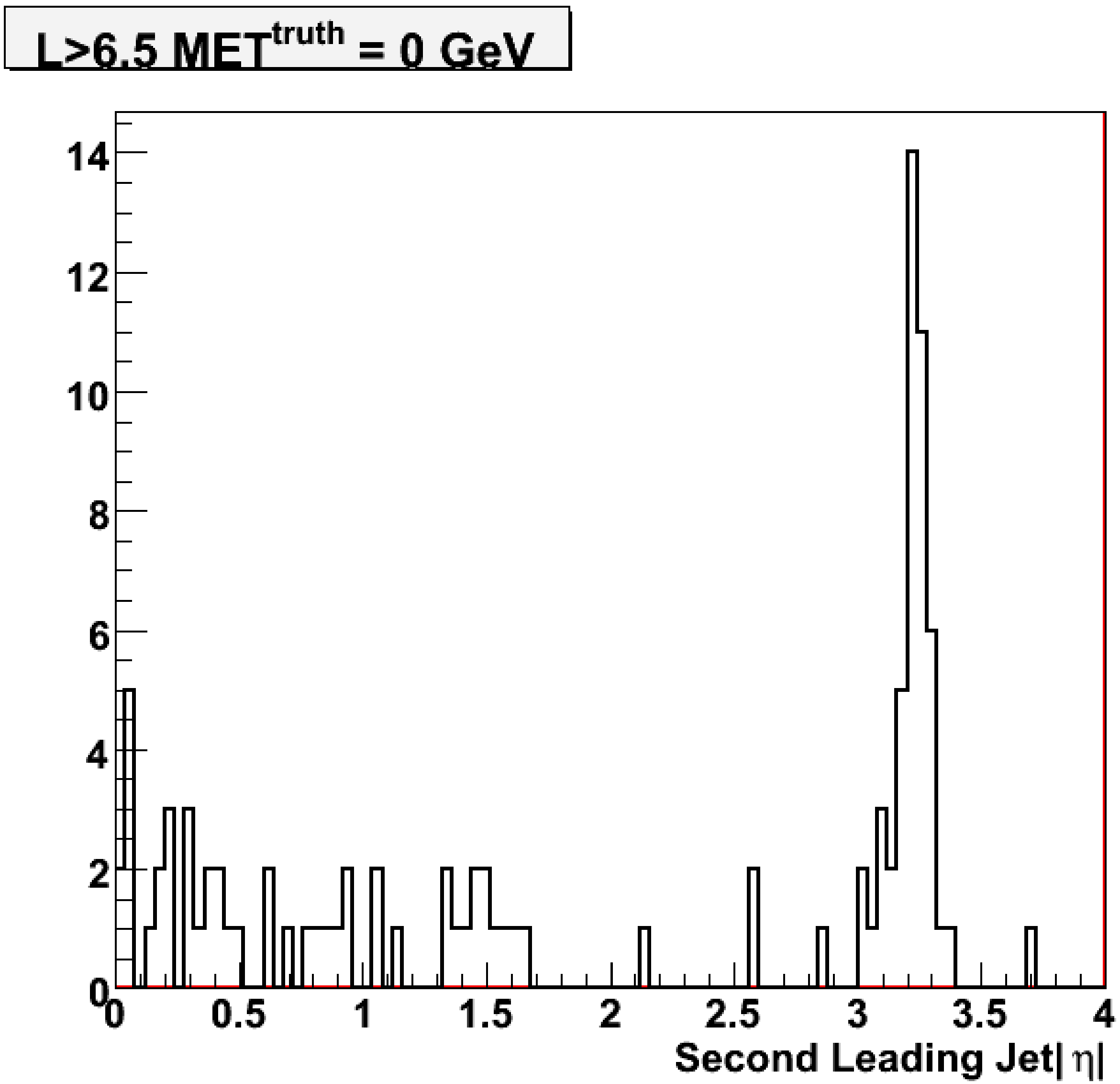
Requiring large $\Delta\Phi_{min}(MET, jet)$ removes semileptonic b-decays with energetic neutrinos. MET significance algorithm (correctly) tag these events as having significant Etmiss.

Angular Correlations in Znunu Events



ETmiss in signal events (containing isolated neutrinos) is not strongly correlated with $\Delta\Phi_{min}(MET, jet)$

High METsig Events from non-HF Events

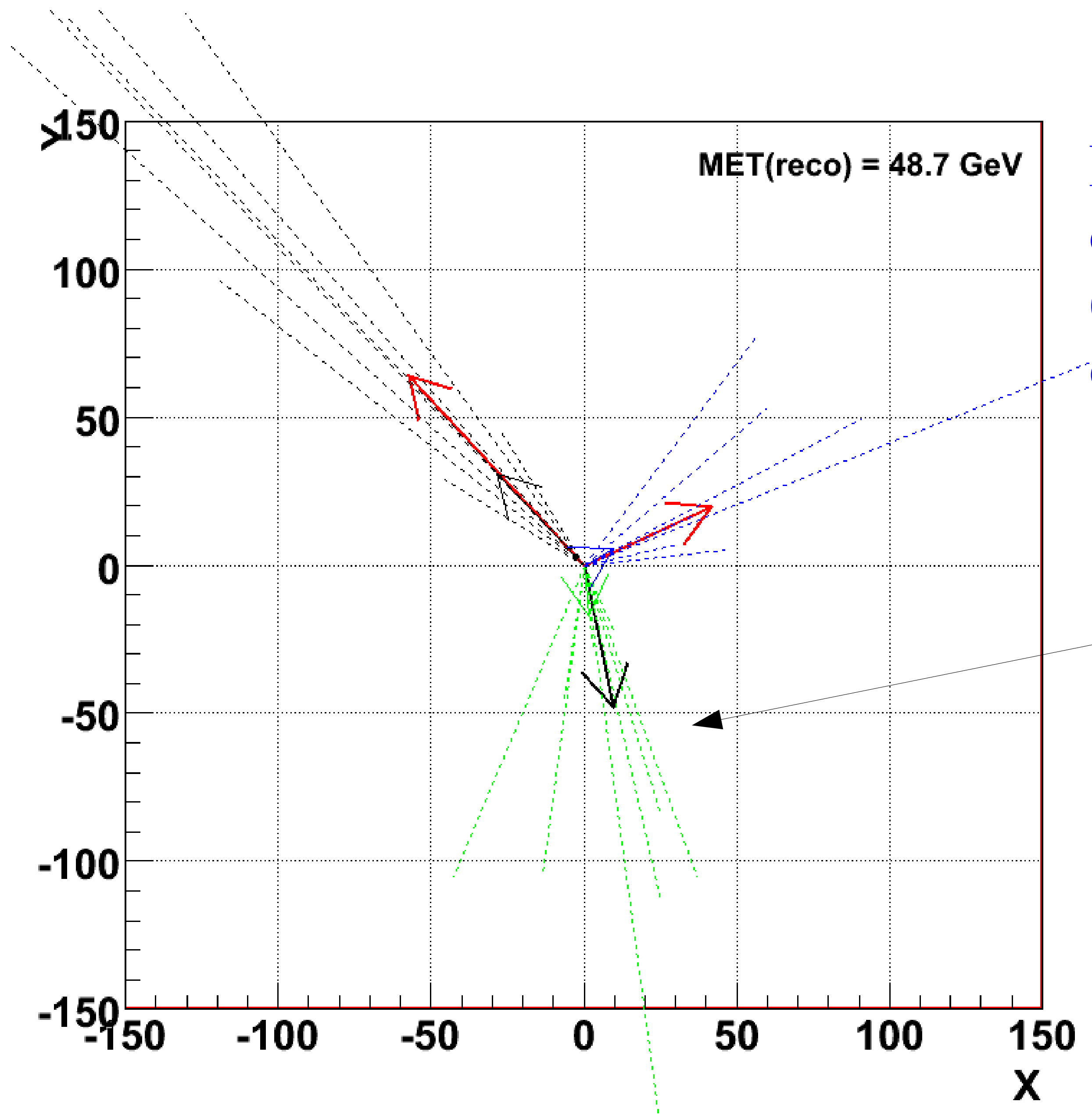


Miscalibration of jet energies at high eta!

METsig can be used to understand the calorimeter performance (commissioning) and validate JES.

Require MET(truth)=0 to explicitly remove events with neutrinos from semileptonic decays.

Another Source of High MET Significance Events: Detector Geometry (I)

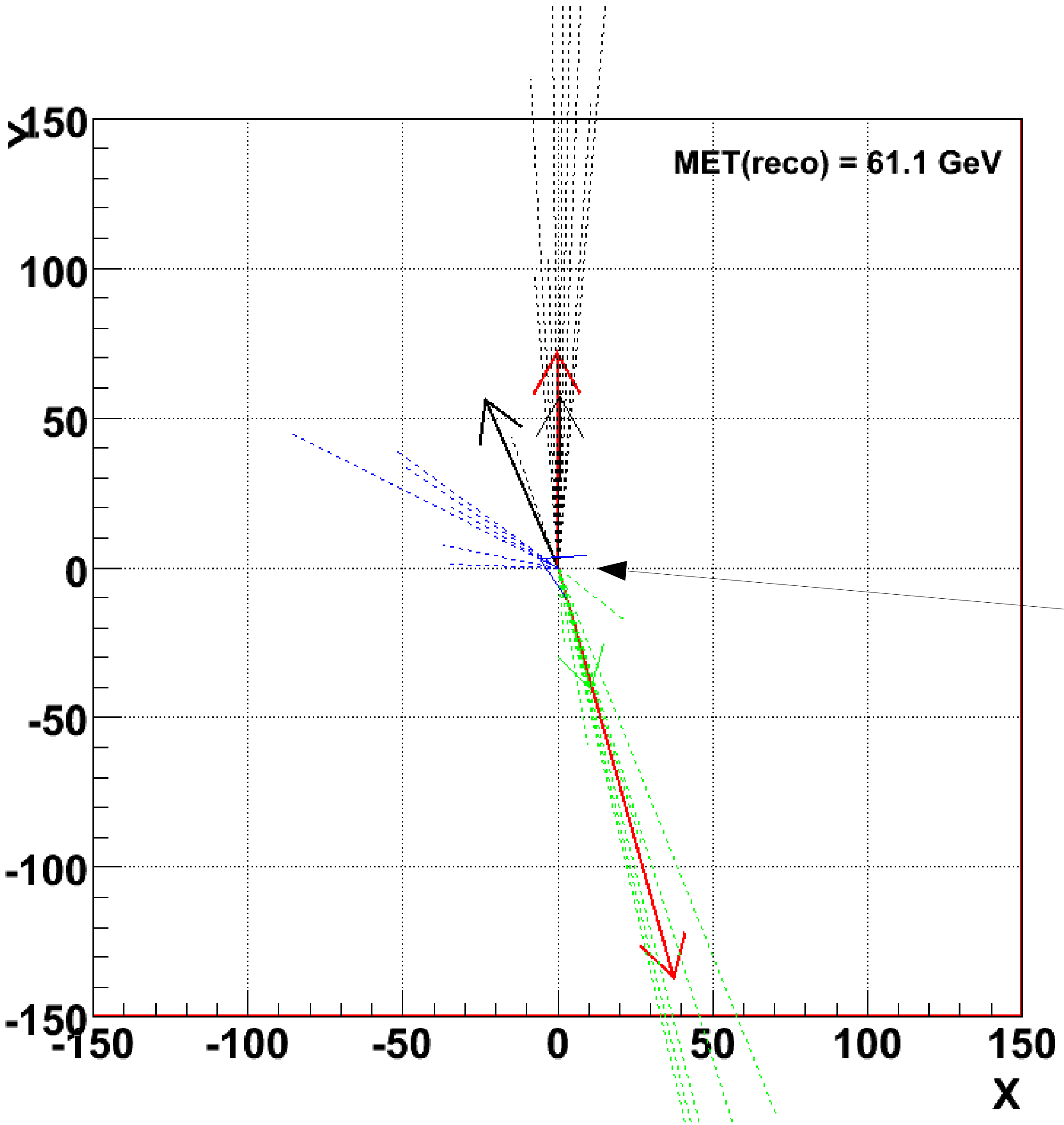


MET pointing in the direction of a track-jet: (missing calorimeter energy)

Track Jet:

$$\eta = -0.71$$
$$p_T = 17.14\, GeV$$
$$ntrk = 7$$

Another Source of High MET Significance Events: Detector Geometry (II)



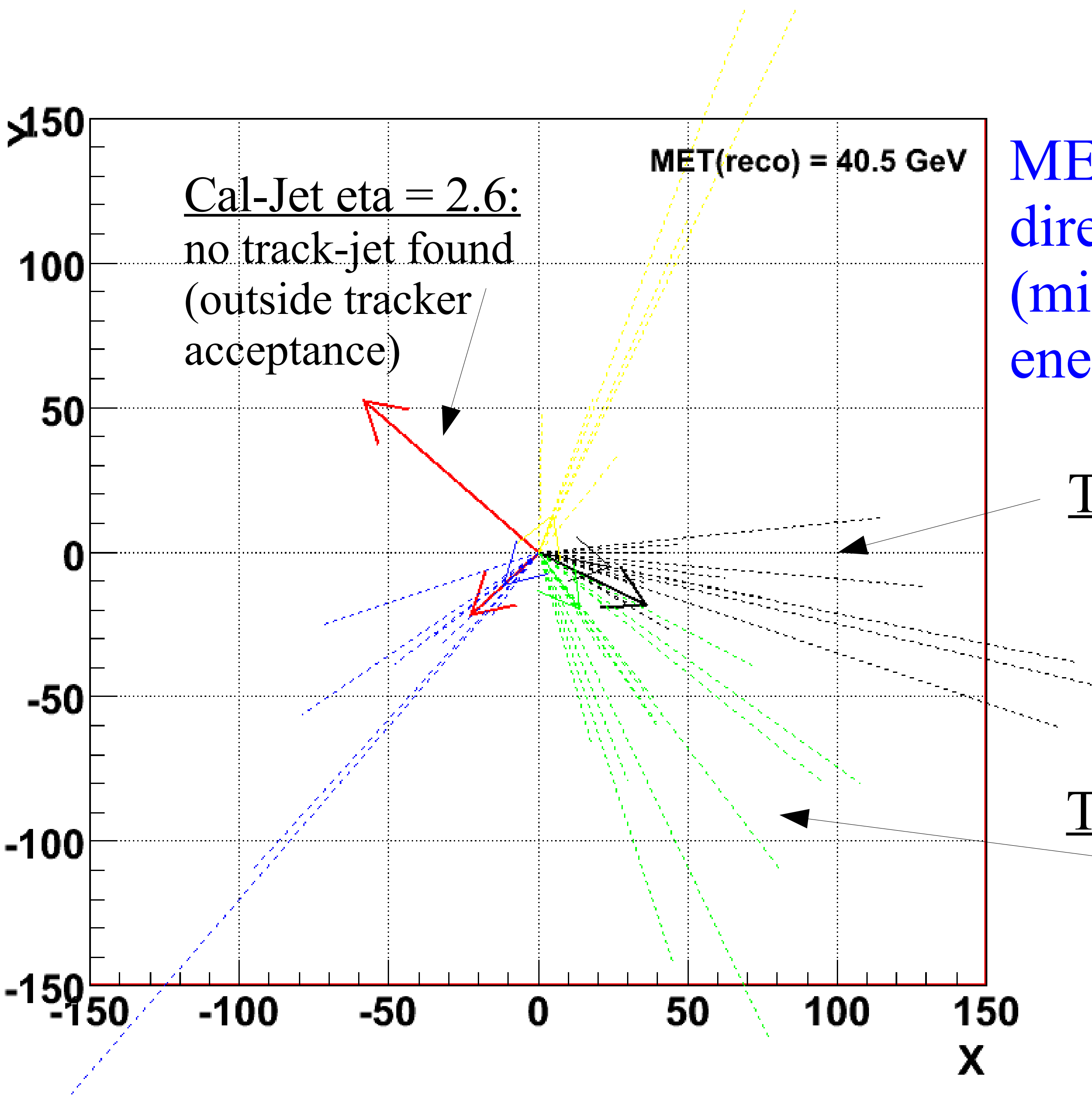
MET pointing in the direction of a track-jet: (missing calorimeter energy)

Track Jet:

$$\eta = -0.94$$
$$p_T = 6.5\, GeV$$
$$ntrk = 6$$

More event displays in backup slides

Another Source of High MET Significance Events: Detector Geometry (III)



MET pointing in the direction of two track-jets: (missing calorimeter energy)

Track Jet:

$\eta = -0.45$

$p_T = 25.0\ GeV$

$ntrk = 14$

Track Jet:

$\eta = +1.21$

$p_T = 24.1\ GeV$

$ntrk = 13$

Summary and Conclusions

New approach to MET significance using Jet Probability Density Functions and Prior Probability for jet pT:

- Accounts for events with fake MET due to jets fluctuating high.
- Improves background rejection (in di-jet events) by 20%

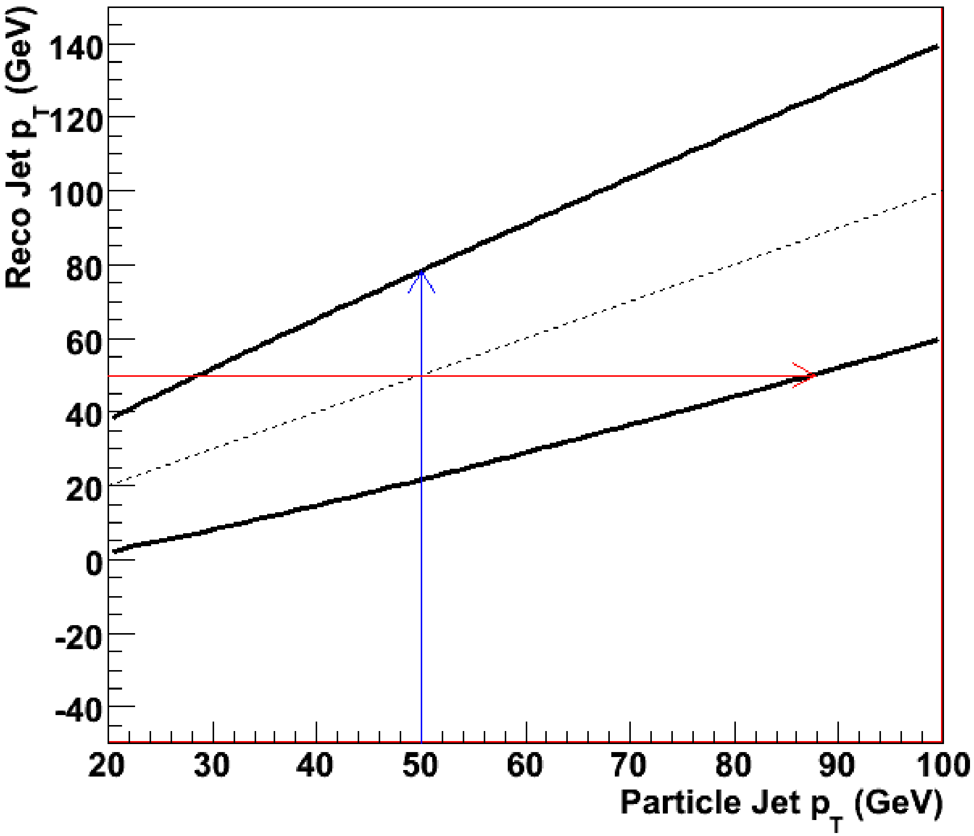
High MET significance events:

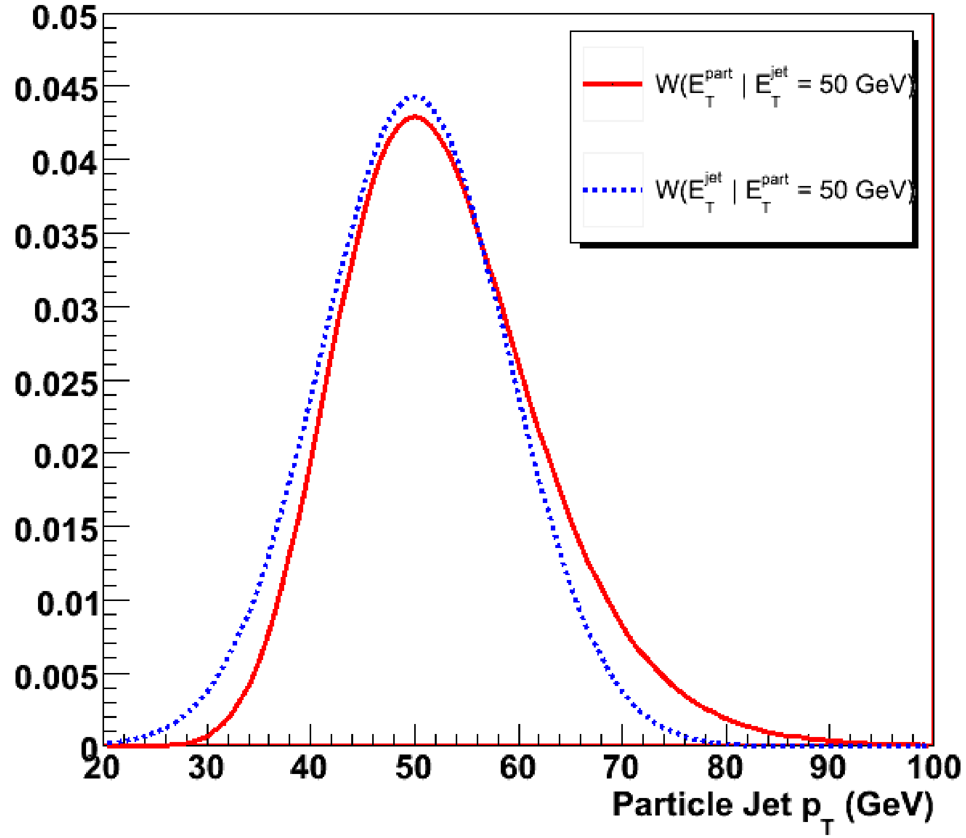
- QCD heavy flavor (semileptonic decays):
  - Dphi(met,jet) cut.
  - b-tagging with loose cuts.
- Detector geometry (cracks):
  - Track jets.
- Poorly calibrated jets:
  - Explore the use of tracks, and other cal-based variables.

Backup Slides

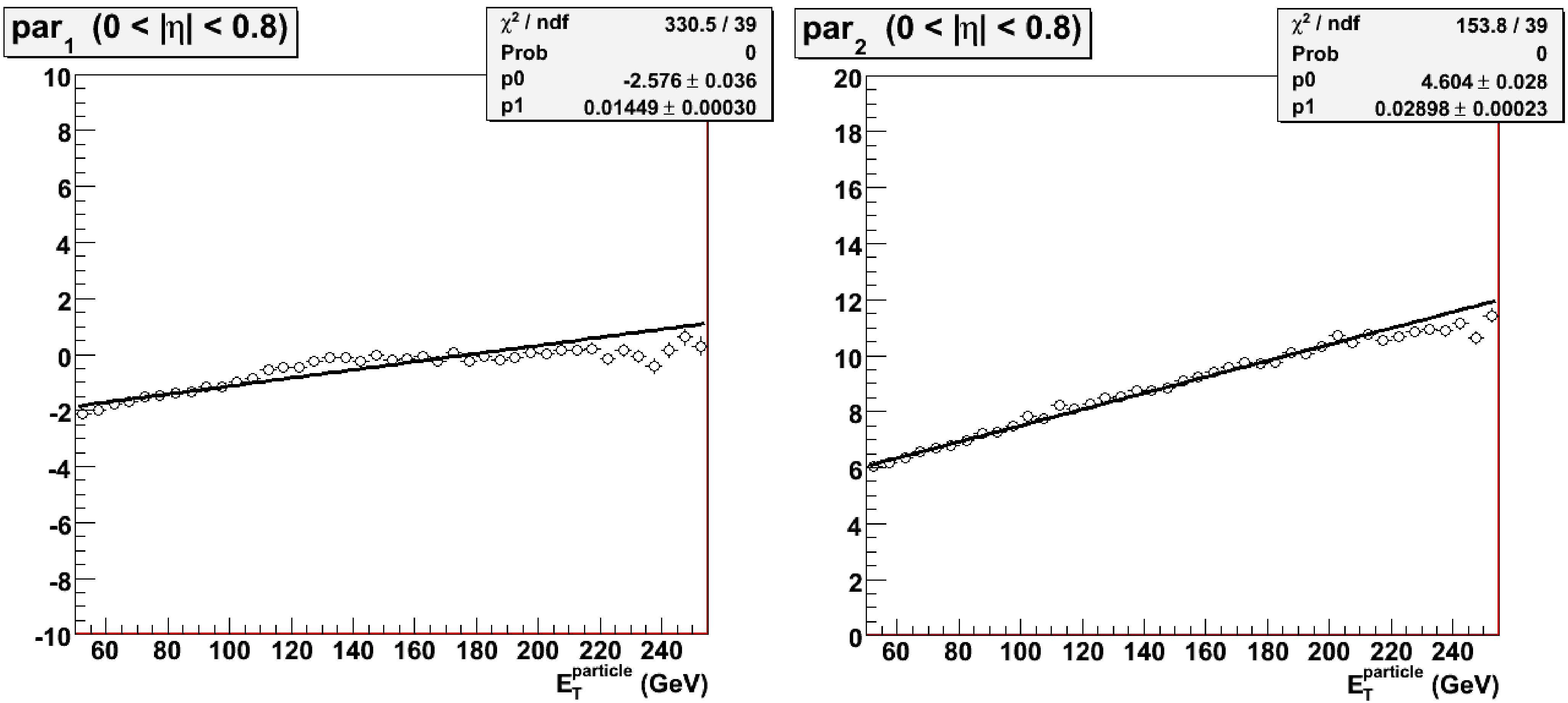
Jet Probability Density Functions (I)

Assuming Gaussian jet energy resolution, the probability distribution for particle jets is non-Gaussian since jet energy resolution depends on energy.





Jet Probability Density Functions (II)



$$W(p_T^{ptcl}; p_T^{jet}) = p_0 \exp \frac{-[(p_T^{ptcl} - p_T^{jet}) - p_1]^2}{2\, p_2{}^2}$$

$$p_{1,2} = a_{1,2} + b_{1,2}\, p_T^{ptcl}$$

p1 and p2 derived in 5 eta regions: 2x2x5 = 20 parameters.

Jet Probability Density Functions (III)

Jpdf described the combined effect of jet energy scale, resolution, and non-linearities due to the energy dependence of the jet resolution.

$$W(p_T^{ptcl};p_T^{jet}) = p_0 \exp\frac{-[(p_T^{ptcl}-p_T^{jet})-p_1]^2}{2(a_2+b_2\,p_T^{ptcl})^2}$$

Responsible for non-Gaussian and assymetric tails

Under approximations, Jpdf are equal to the standard jet energy resolution:

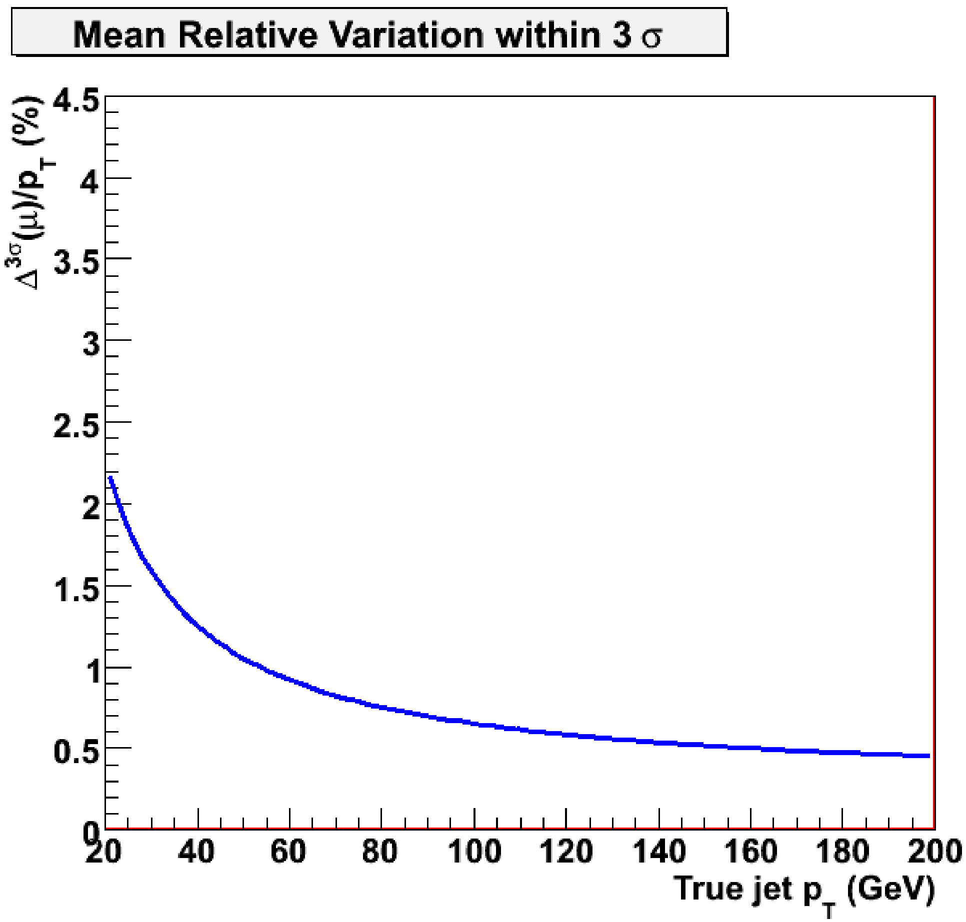
1- Most probable value for W: $[p_T^{ptcl}] = \frac{p_T^{jet}-a_1}{1+b_1}$

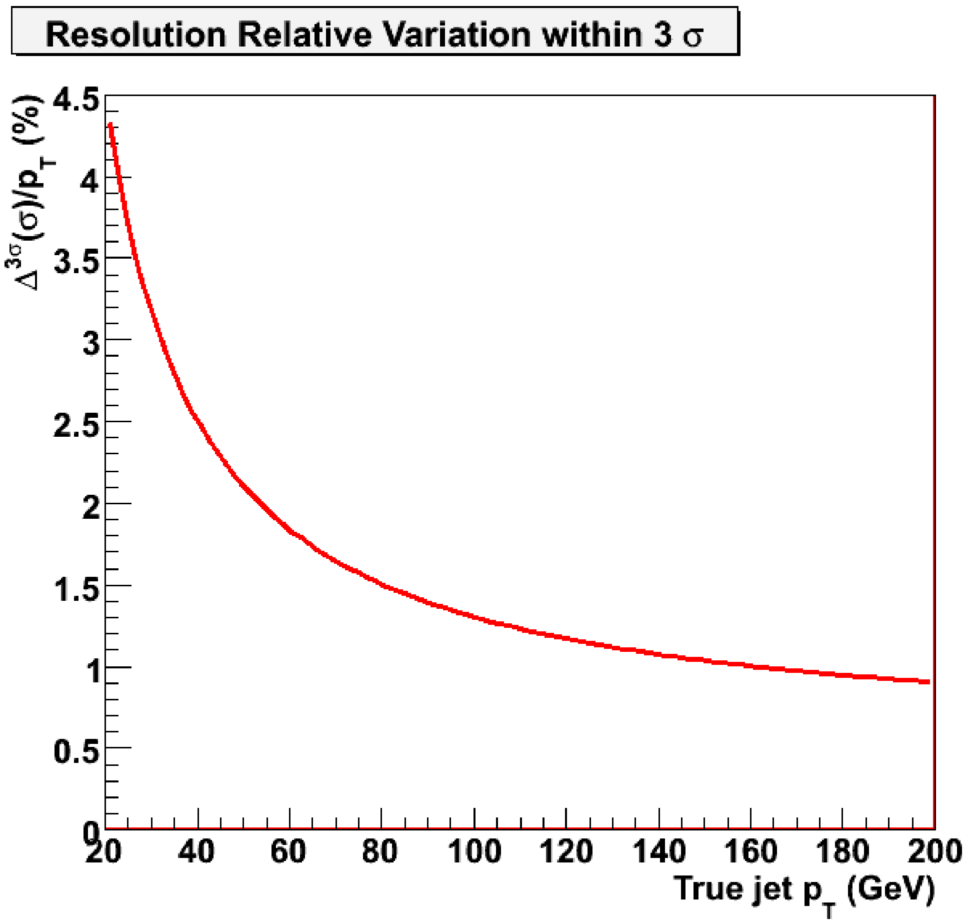
2- Gaussian approximation:

If the change in resolution within 3 sigmas around the most probable value of W is small, we can approximate the denominator by:

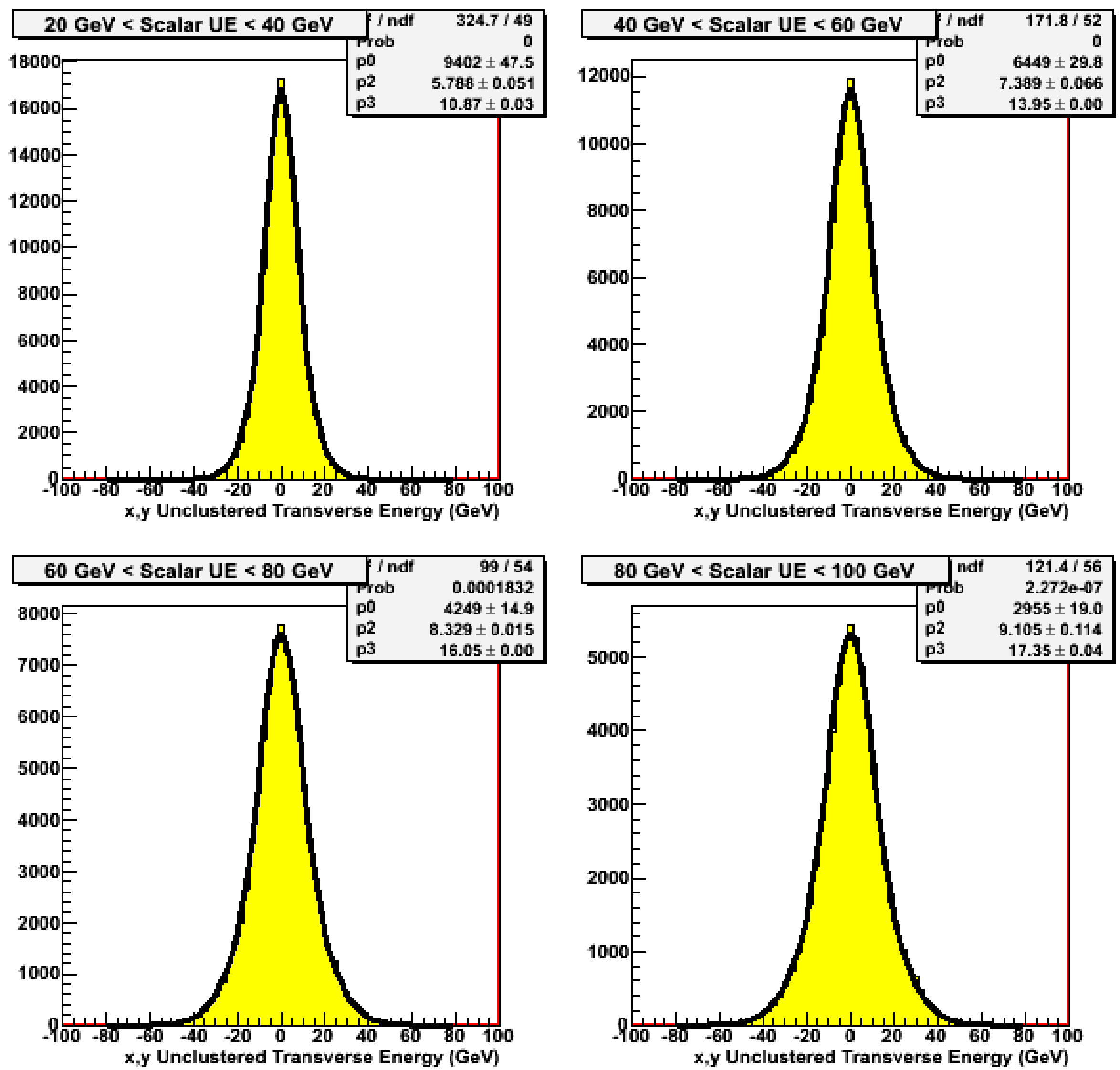
$$p_T^{ptcl} = [p_T^{ptcl}] = p_T^{jet} \Rightarrow \sigma(W) = \sigma(p_T)$$

Jet Probability Density Functions (IV)

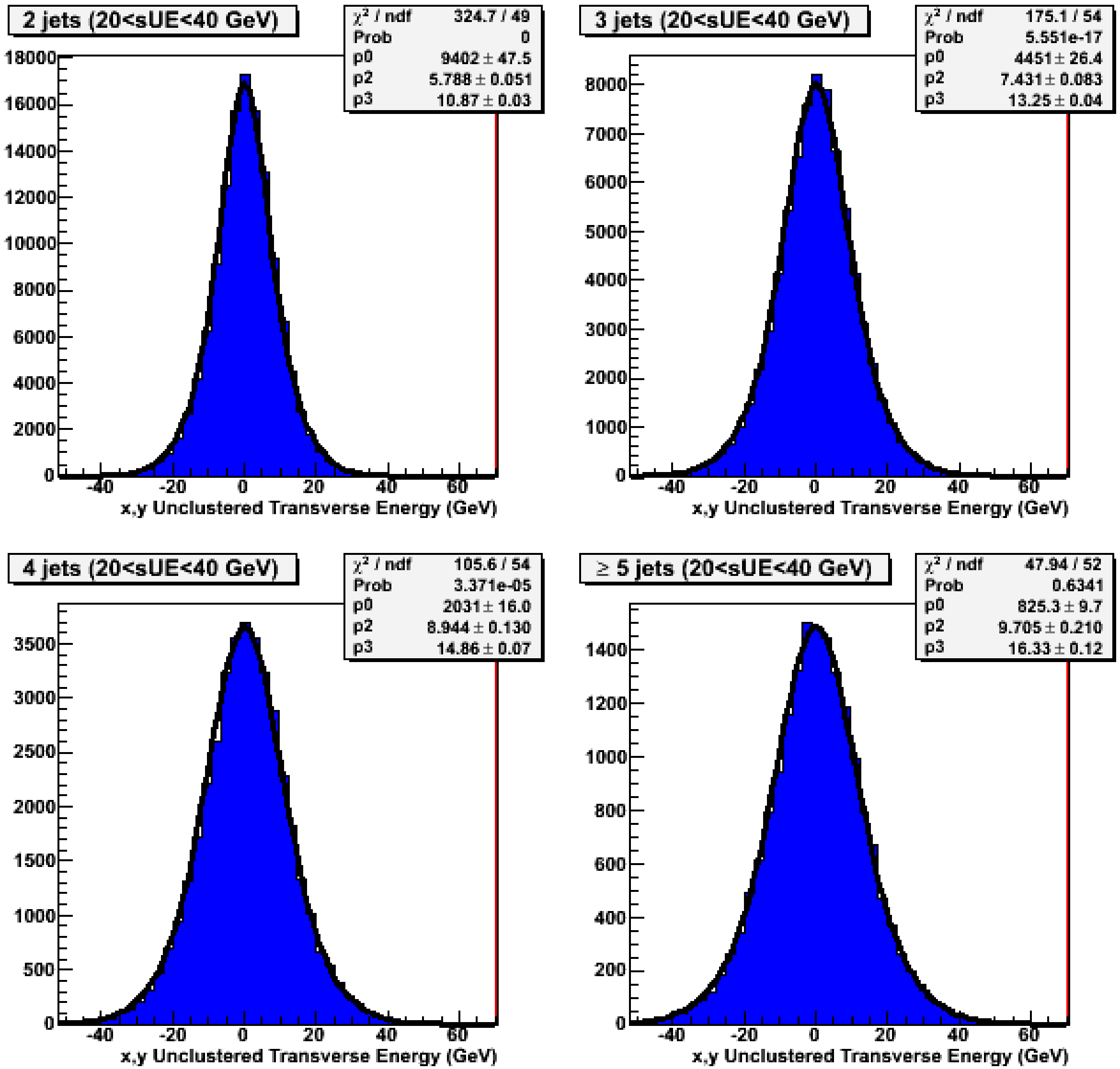




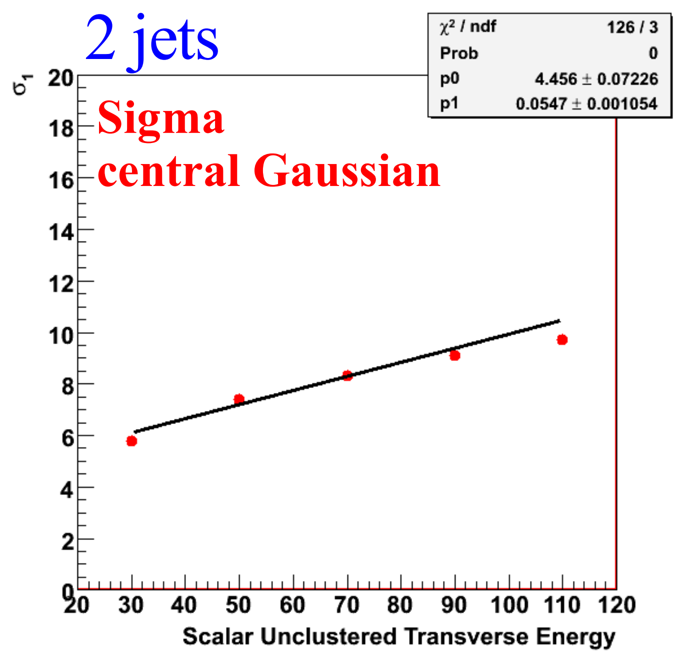
Unclustered Energy Probability Density Functions (I)

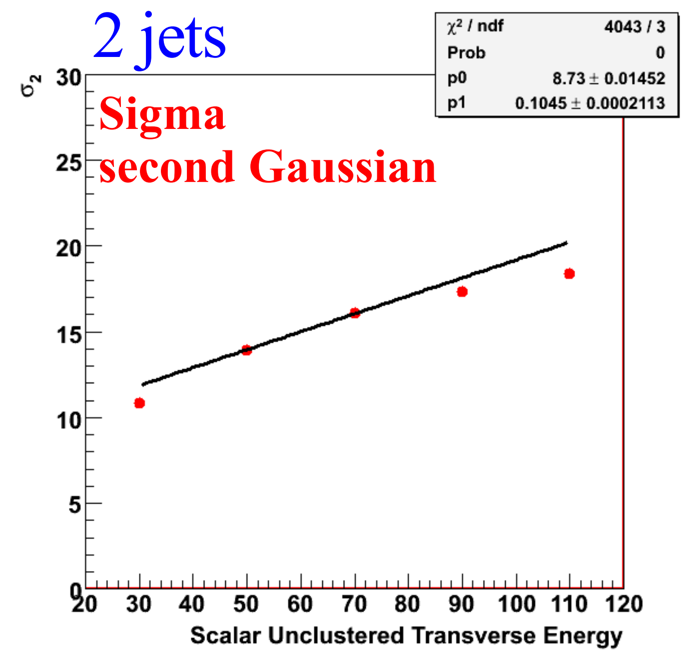


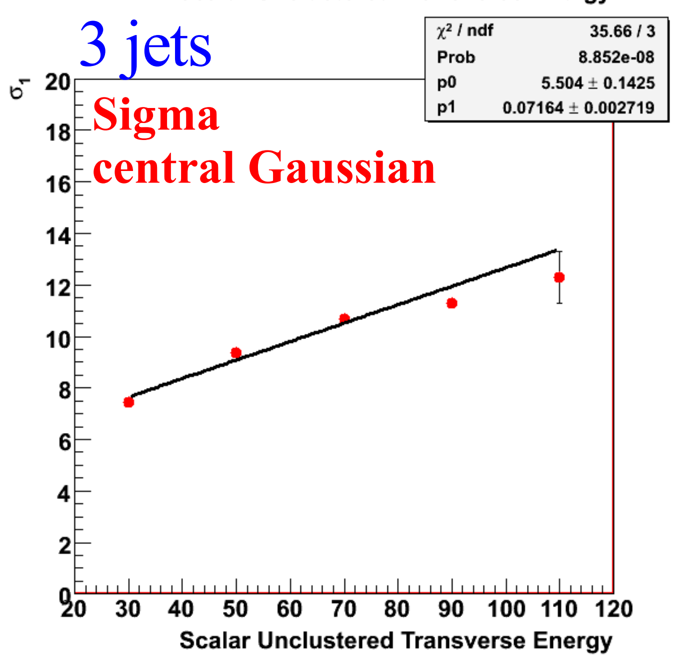
Unclustered Energy Probability Density Functions (II)

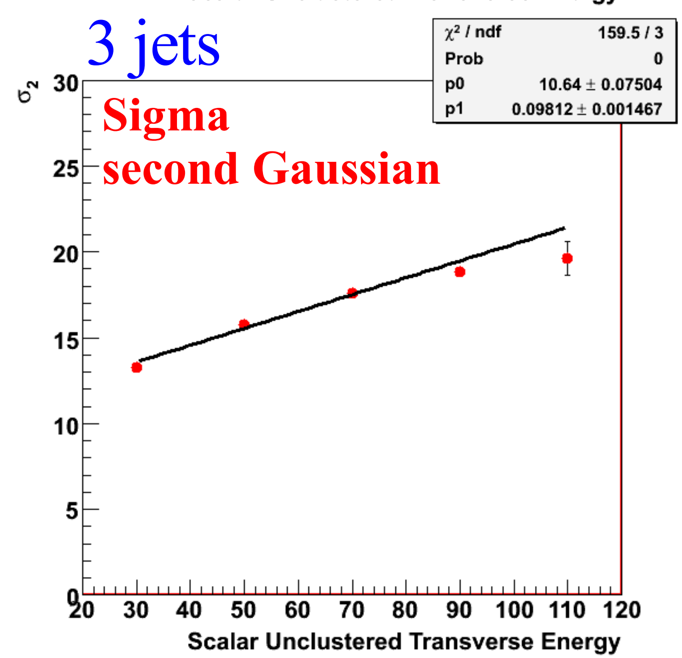


Unclustered Energy Probability Density Functions (III)

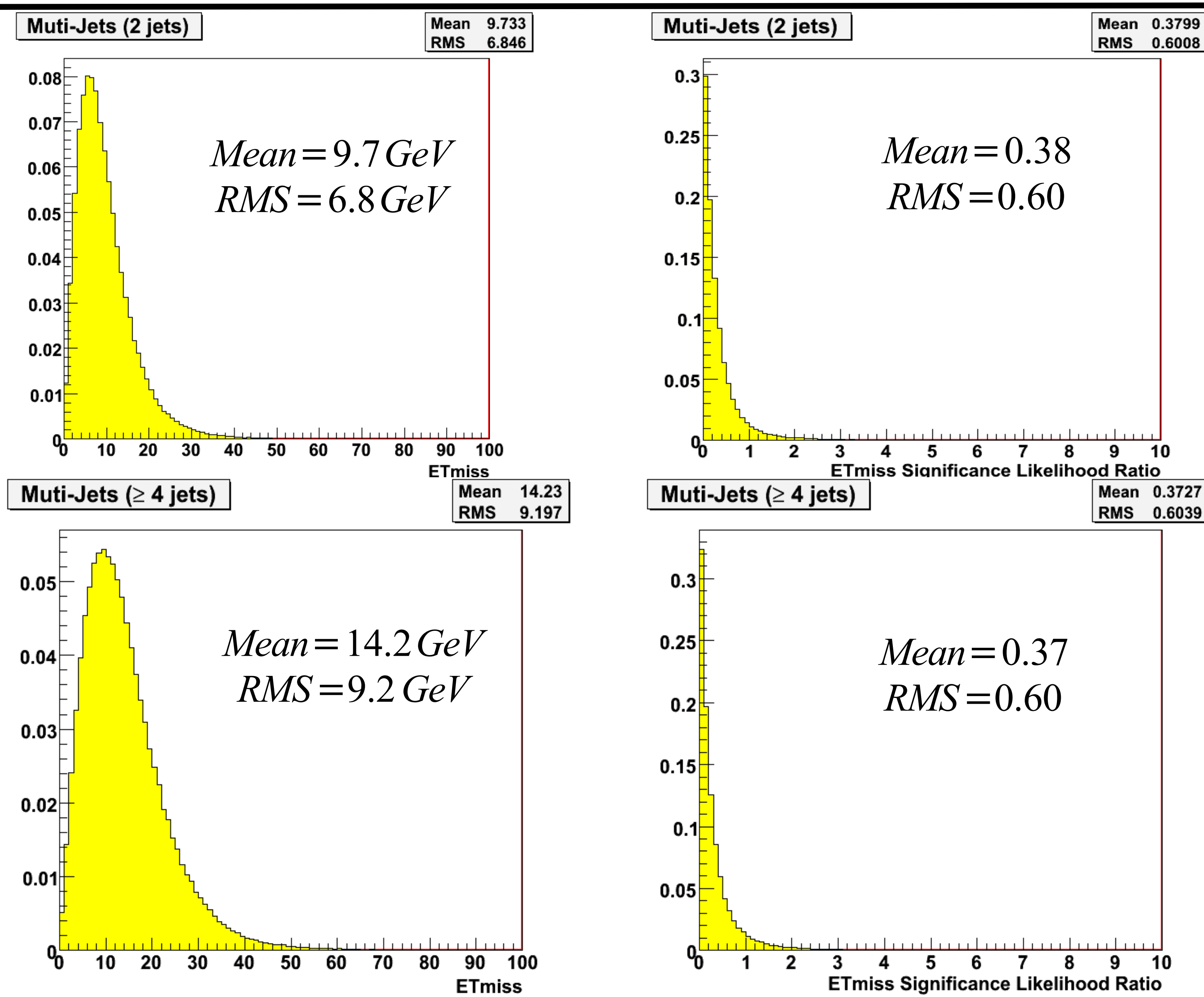




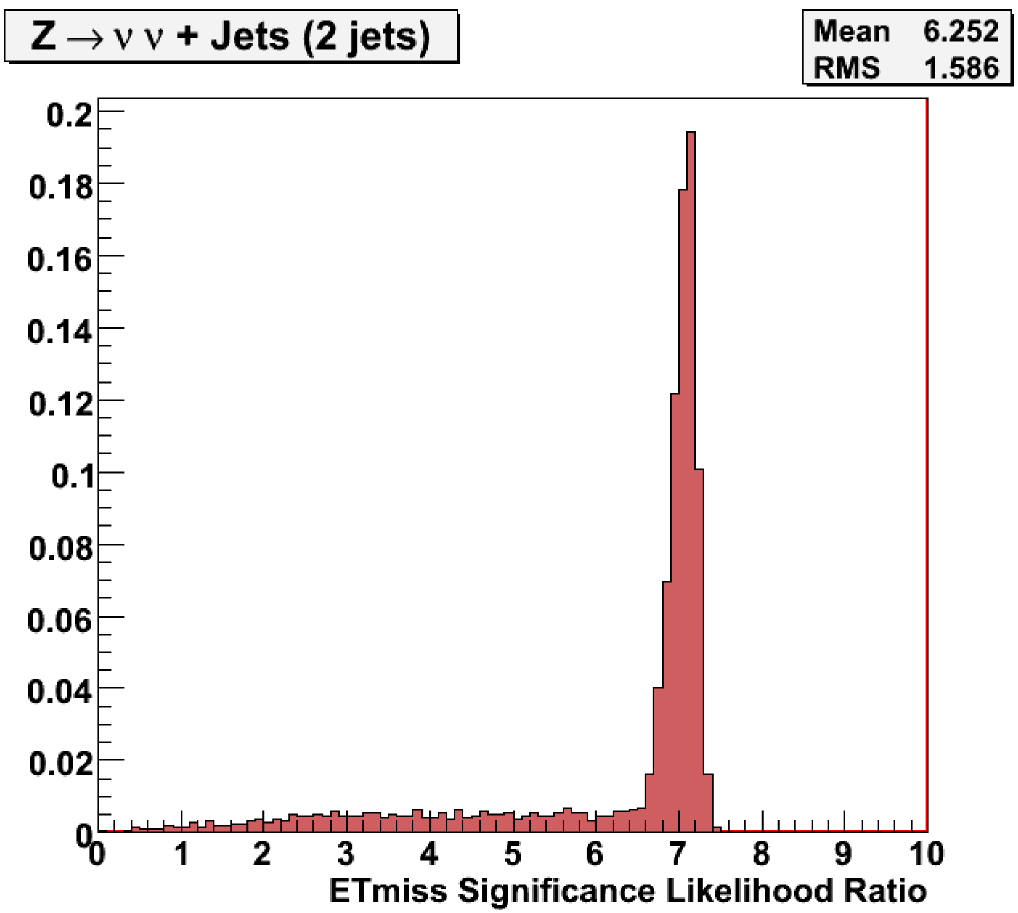


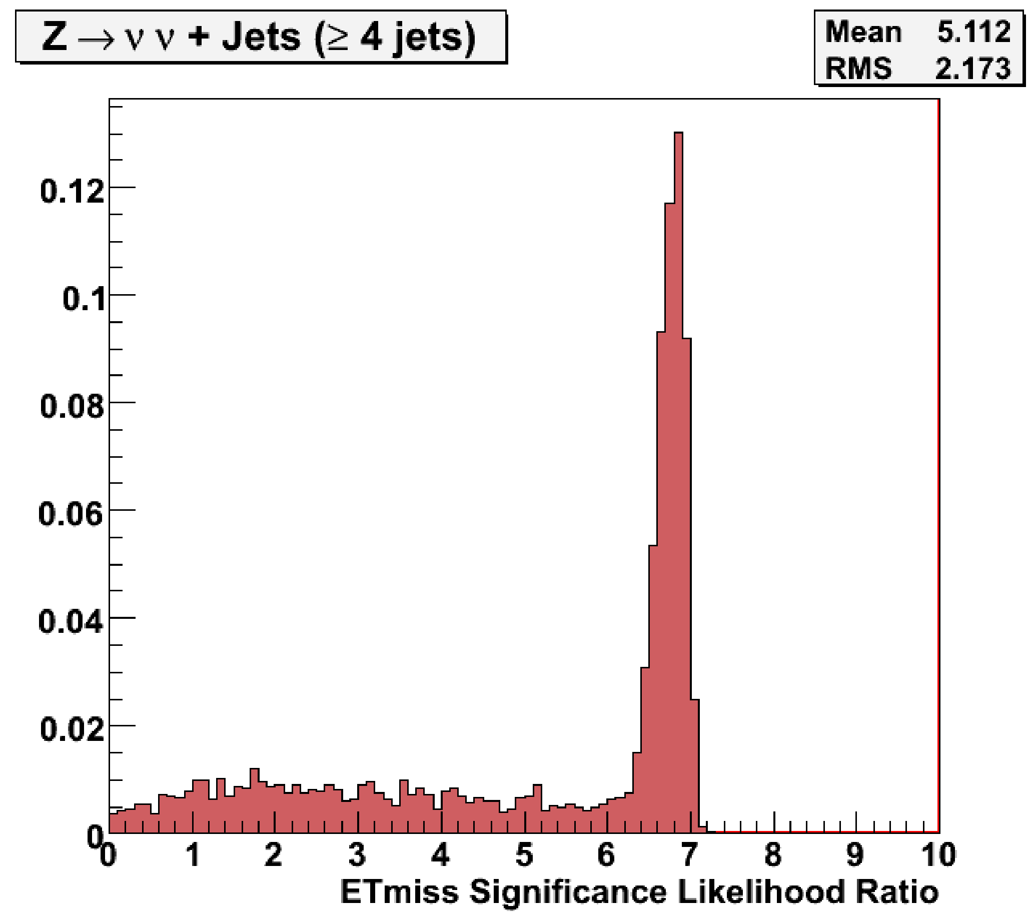


Missing ET Significance Performance (II)



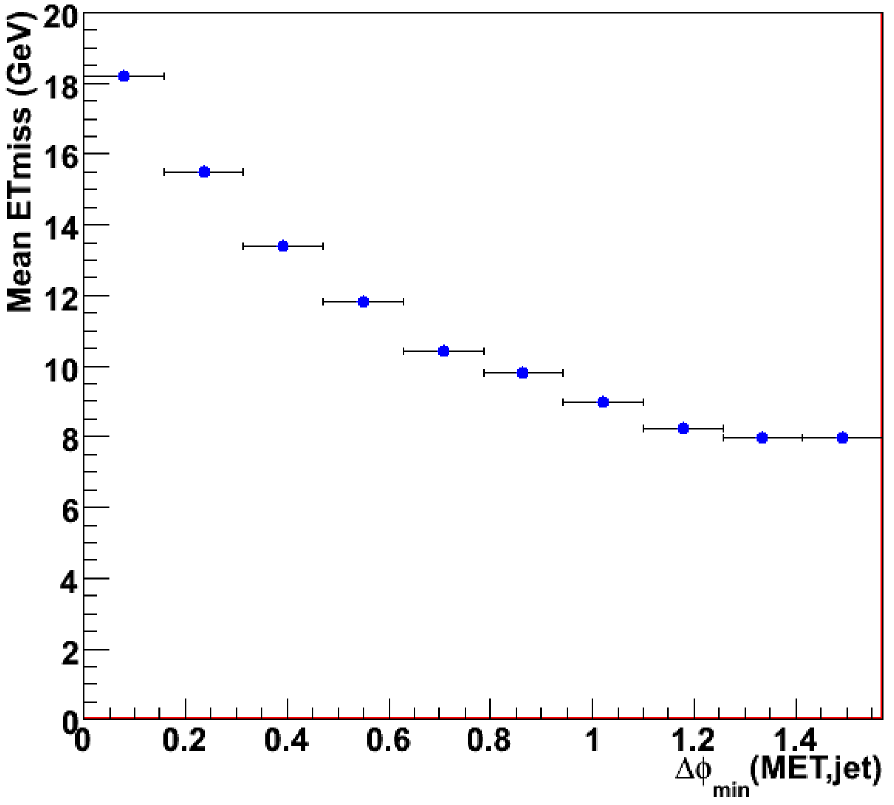
Missing ET Significance Performance (III)

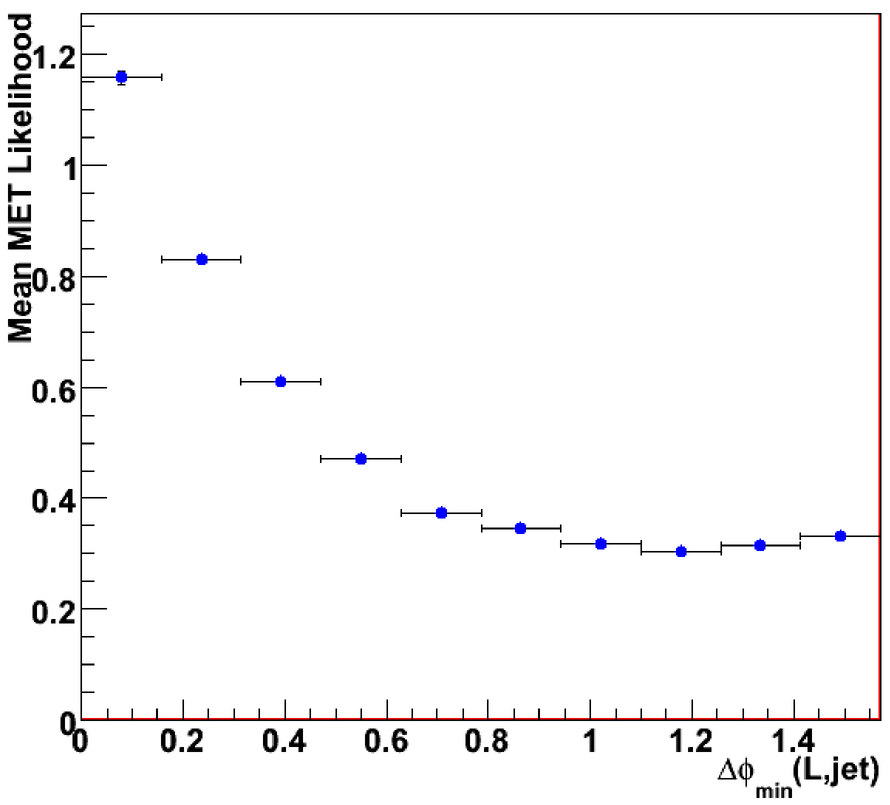




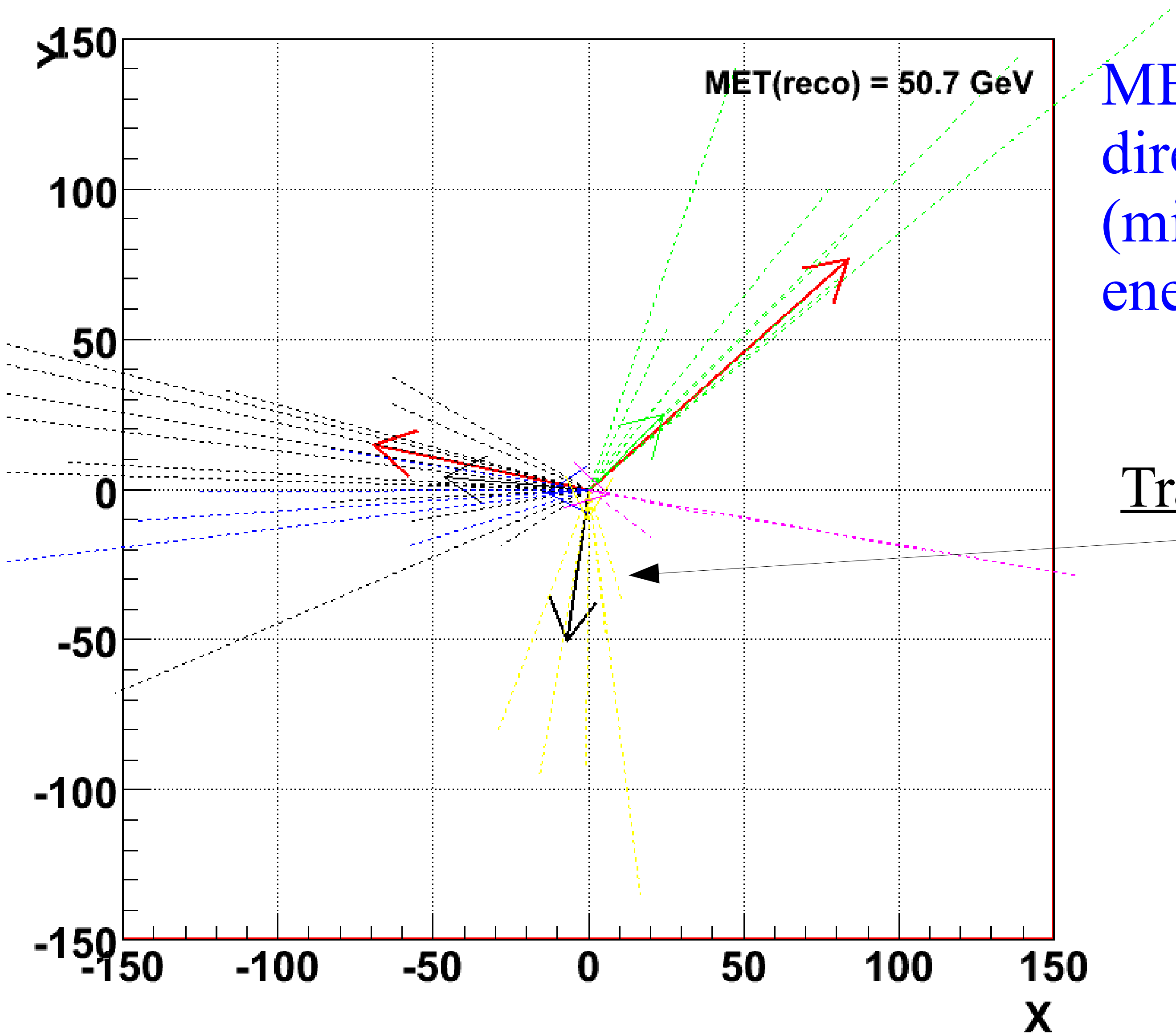
Larger Jet multiplicity increases the fraction of real ETmiss events with low MET significance.

MET and METsig vs DPhi(MET,jet)





MET due to Cracks



MET pointing in the direction of a track-jet: (missing calorimeter energy)

<u>Track Jet:</u>

$$\eta = +1.1$$

$$p_T = 5.9\, GeV$$

$$ntrk = 4$$

METsig Improvement using Prior Probability