Jet / Missing ET Studies

Ariel Schwartzman
SLAC, Stanford University

SLAC Physics Analysis Retreat, 05-Mar-2007

Outline

- Jet Energy Resolution Measurements:
  Data-driven techniques: di-jet and kT balance.
  Effect of gluon radiation.

- Improving Jet Energy Resolution Using Tracks:
  Jet energy response corrections using track variables.

- Missing ET Significance:
  Event-by-event likelihood ratio to estimate the probability that the measured Missing ET is due to instrumental (resolution) effects. Discriminate events with large fake Missing Et.

Jet Energy Resolution

Introduction

Jet energy resolution has three main contributions:

$$\frac{\sigma(E)}{E} \sim \frac{a}{\sqrt{(E)}} \oplus \frac{b}{E} \oplus c$$

Given a particle-jet energy, what is the distribution of the jet energy measured in the calorimeter. Does not include the contribution of particles outside the cone at particle-level.

- Stochastic response:
  Jet fragmentation
  Sampling fluctuations,
  EM fraction fluctuations per hadron.

- Electronic noise term

- Constant term:
  Dead material, magnetic field,
  calorimeter non-compensation.

- Absolute jet energy scale:
  denominator in sigma(E)/***E***.

Resolution must be ***measured*** in the data,
where there is no access to particle-jets: investigate data-driven techniques.

Jet resolution is crucial in many physics analysis and searches:
investigate ways to ***improve*** it.

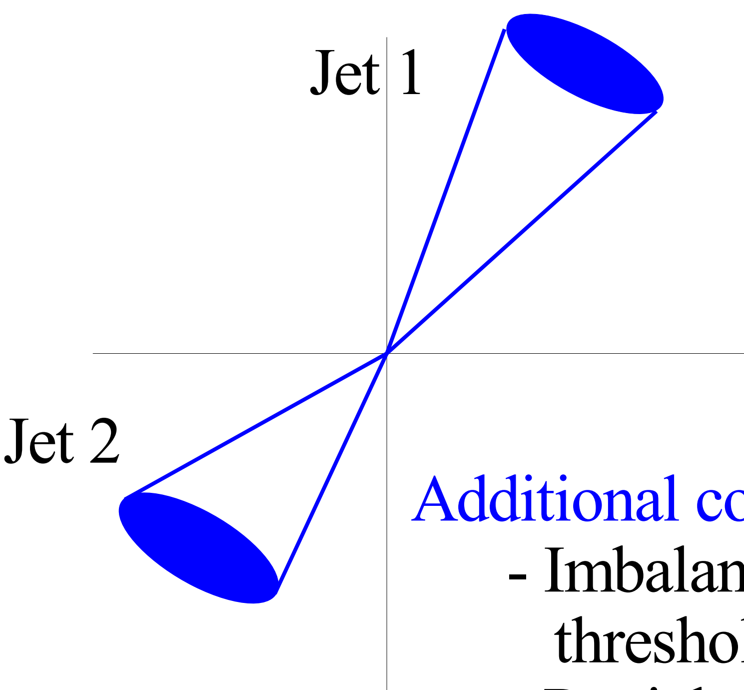
Jet Energy Resolution (Dijet balance)

Determination of the jet Et resolution based on energy conservation in the transverse plane.

- 1 primary vertex.
- 2 back-to-back leading jets (DeltaPhi<2.8)
- No other reconstructed jet with Et>10 GeV.
- Both jets in the *same* Eta region.

$$A = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$

$$\sigma_A^2 = \left| \frac{\partial A}{\partial E_{T,1}} \right|^2 \sigma_{E_{T,1}}^2 + \left| \frac{\partial A}{\partial E_{T,2}} \right|^2 \sigma_{E_{T,2}}^2$$

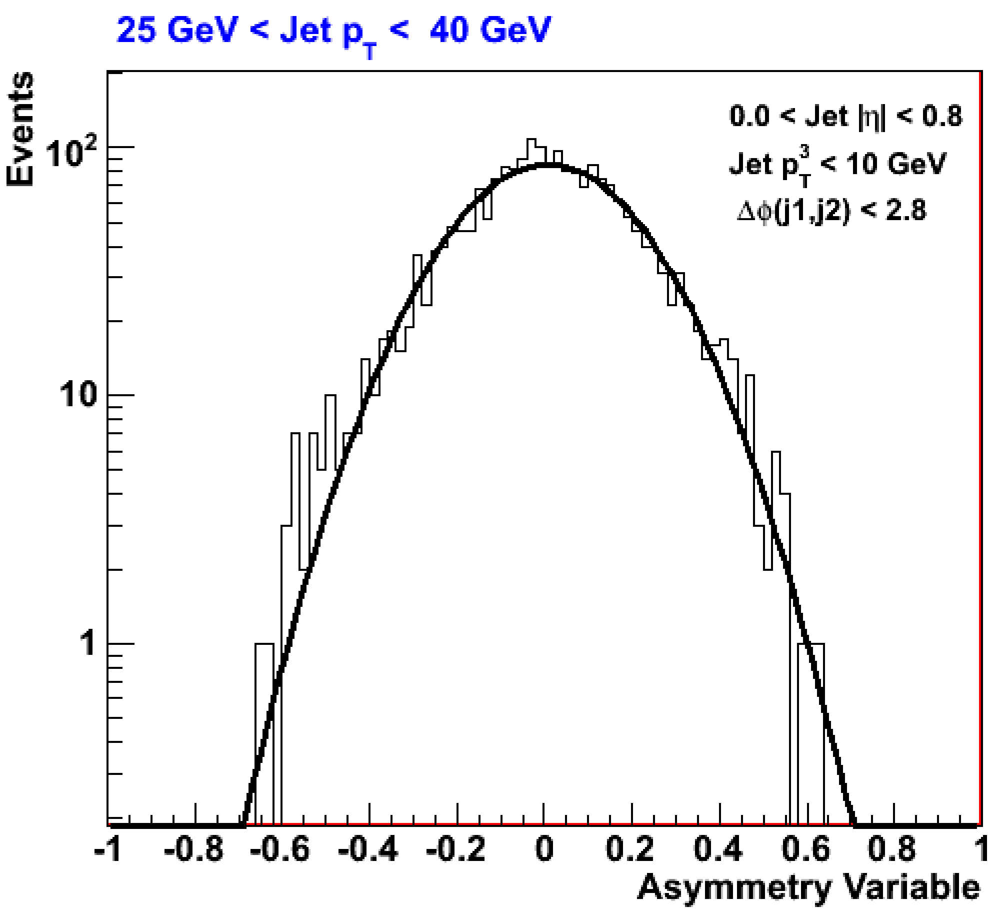


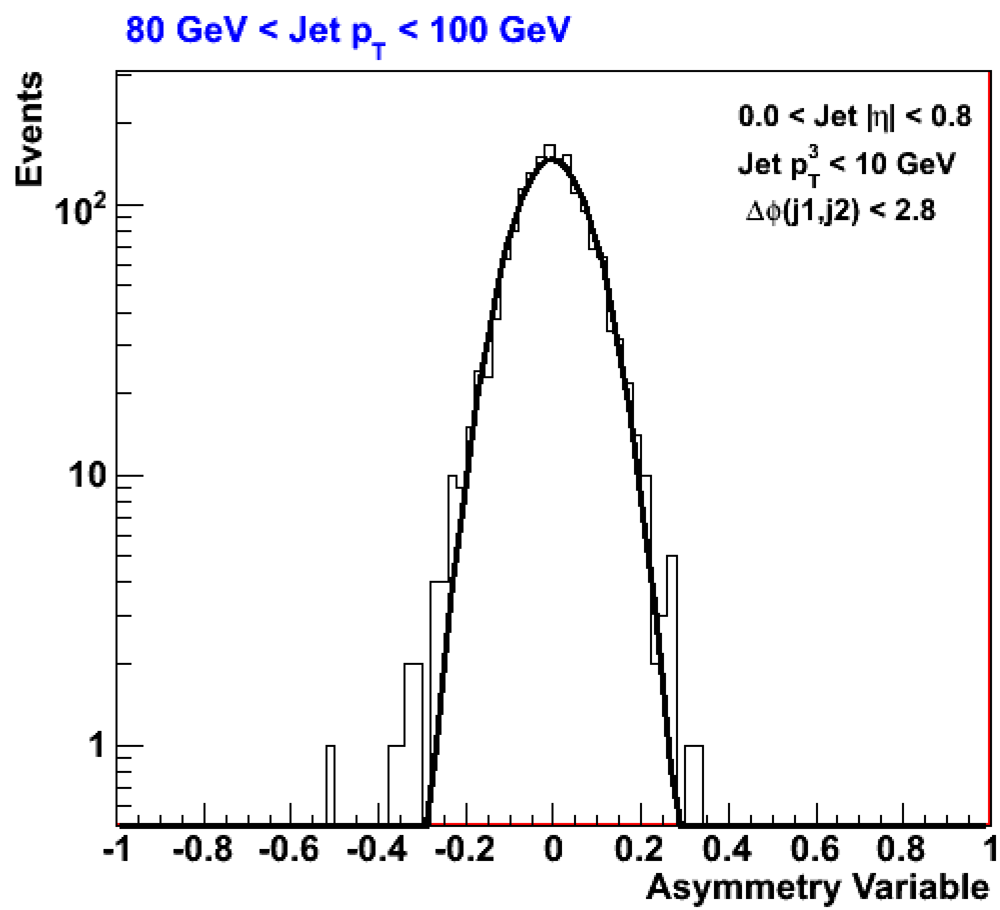
$$\left(\frac{\sigma_{E_T}}{E_T} \right) = \sqrt{2}\,\sigma_A$$

Additional corrections:

- Imbalance due to additional jets below the 10 GeV threshold and soft radiation in the event.
- Particle jet imbalance contribution.

Dijet balance: Asymmetry Distributions





Data sample divided in 4 p_T regions, and 4 eta regions.

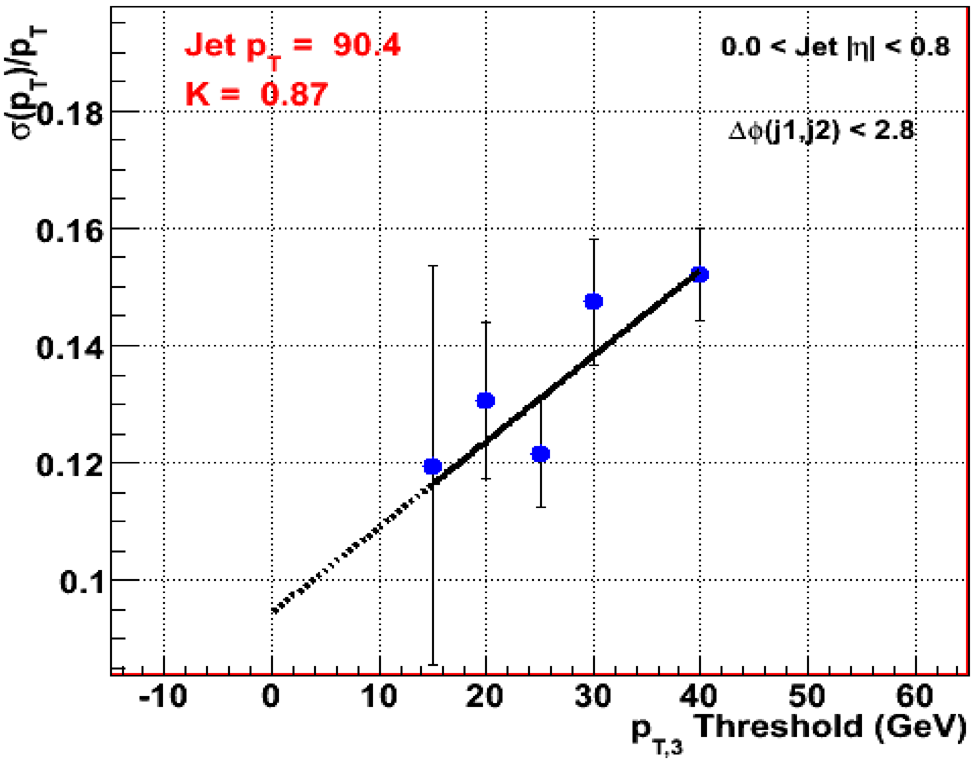
Asymmetry variables fitted with single Gaussians.

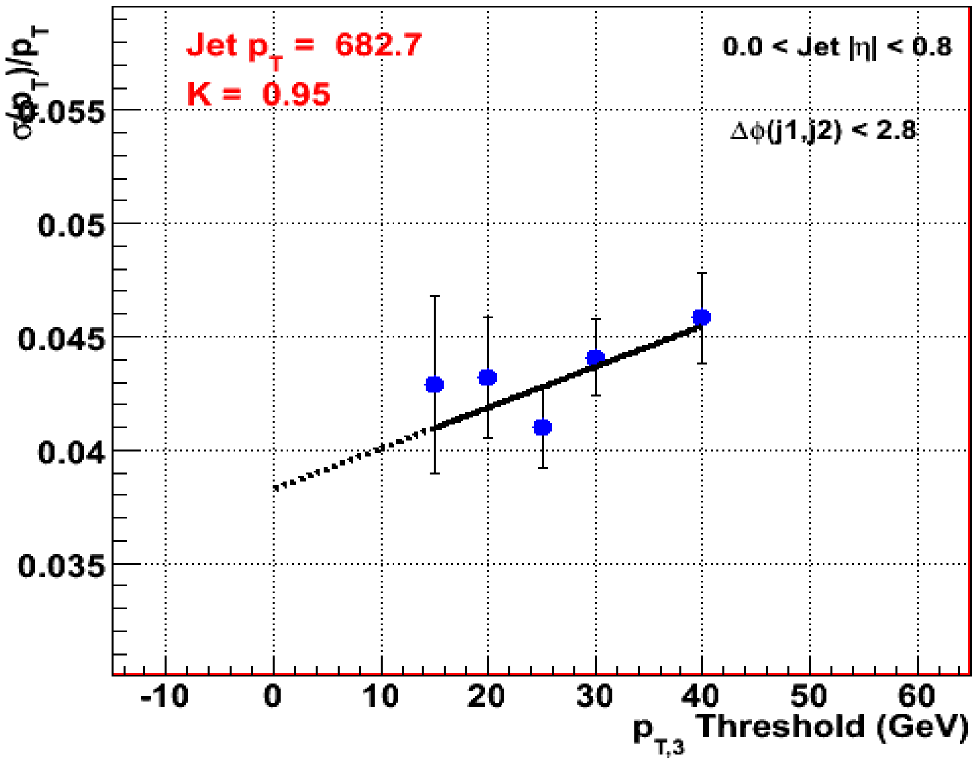
Soft Radiation Correction

Events with soft radiation prevent the two leading jets from balancing in the transverse plane.

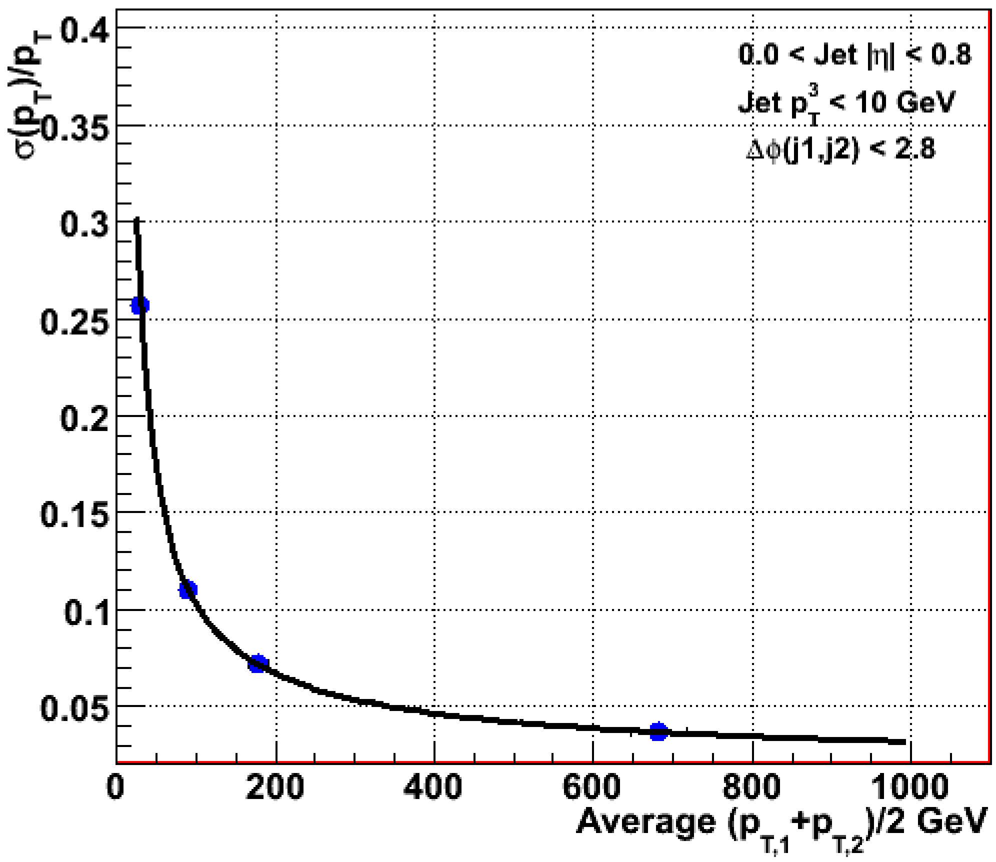
Compute resolutions in samples with different third jet cuts: 15,20,25,30,40 GeV

Extrapolate to p_T=0 (ideal Dijet sample)





Resolution after Soft Radiation Correction



$$\frac{\sigma\ p_T}{p_T} = \frac{0.79}{\sqrt{p_T}} \oplus \frac{6.41}{p_T} \oplus 0.019$$

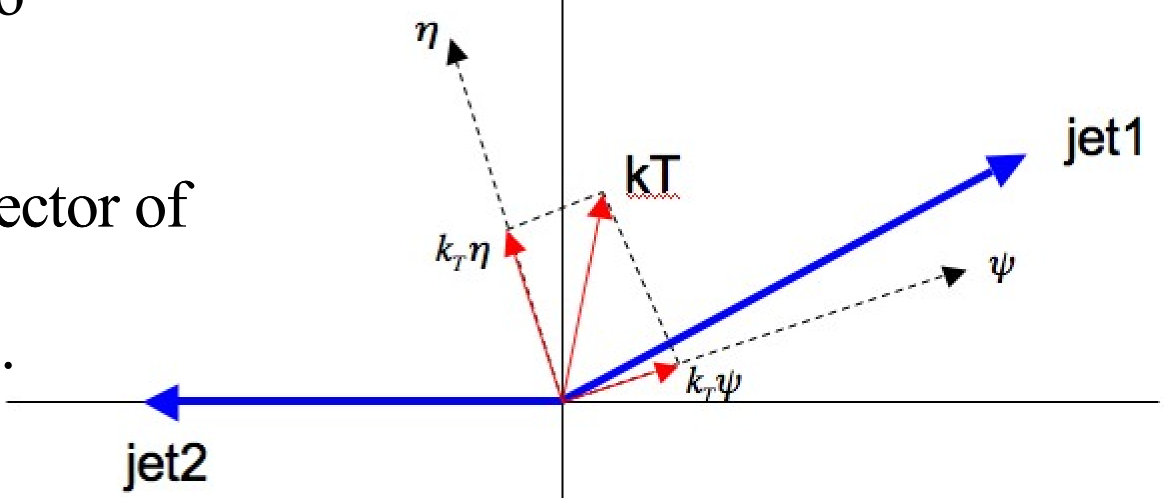
Kt Balance Technique

Method used in CDF, developed by UA2.

Reject events with a third jet to reduce hard gluon radiation effects

Project Imbalance vector kT onto 2 components (psi, eta)

- Eta axis: azimuthal angular bisector of the dijet system.
- Psi axis: orthogonal to Eta axis.

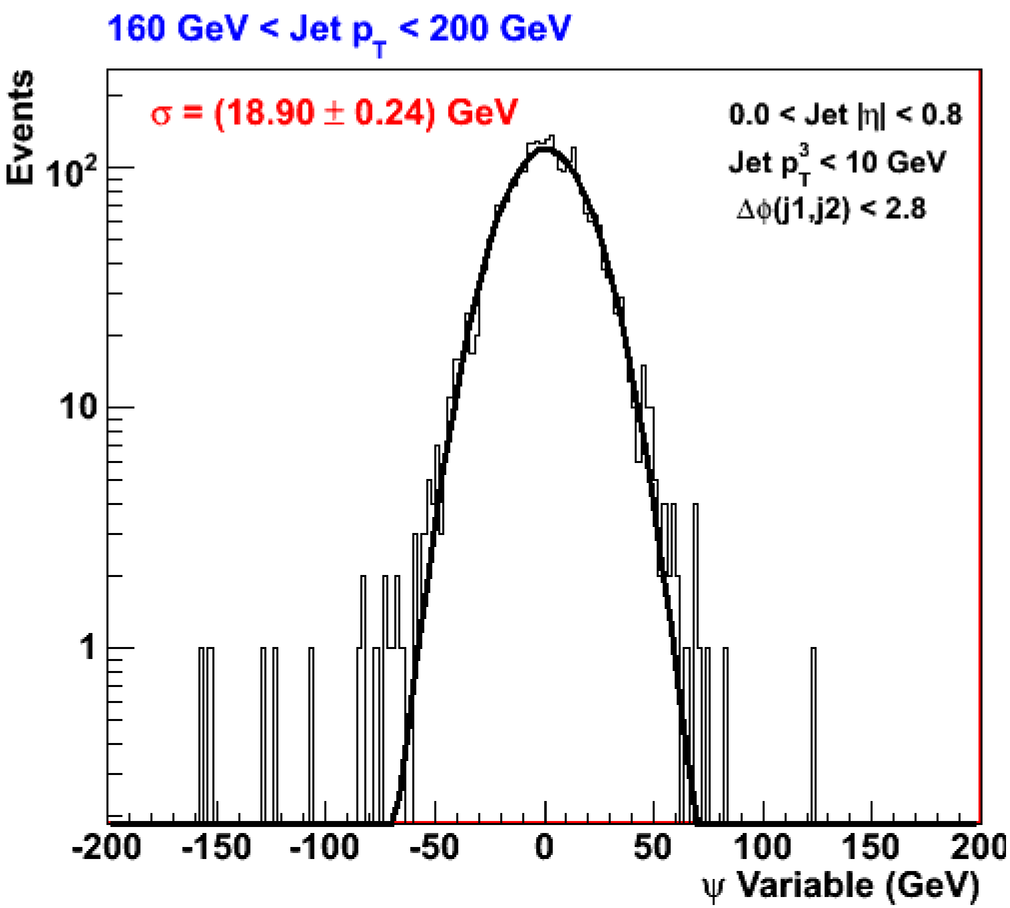


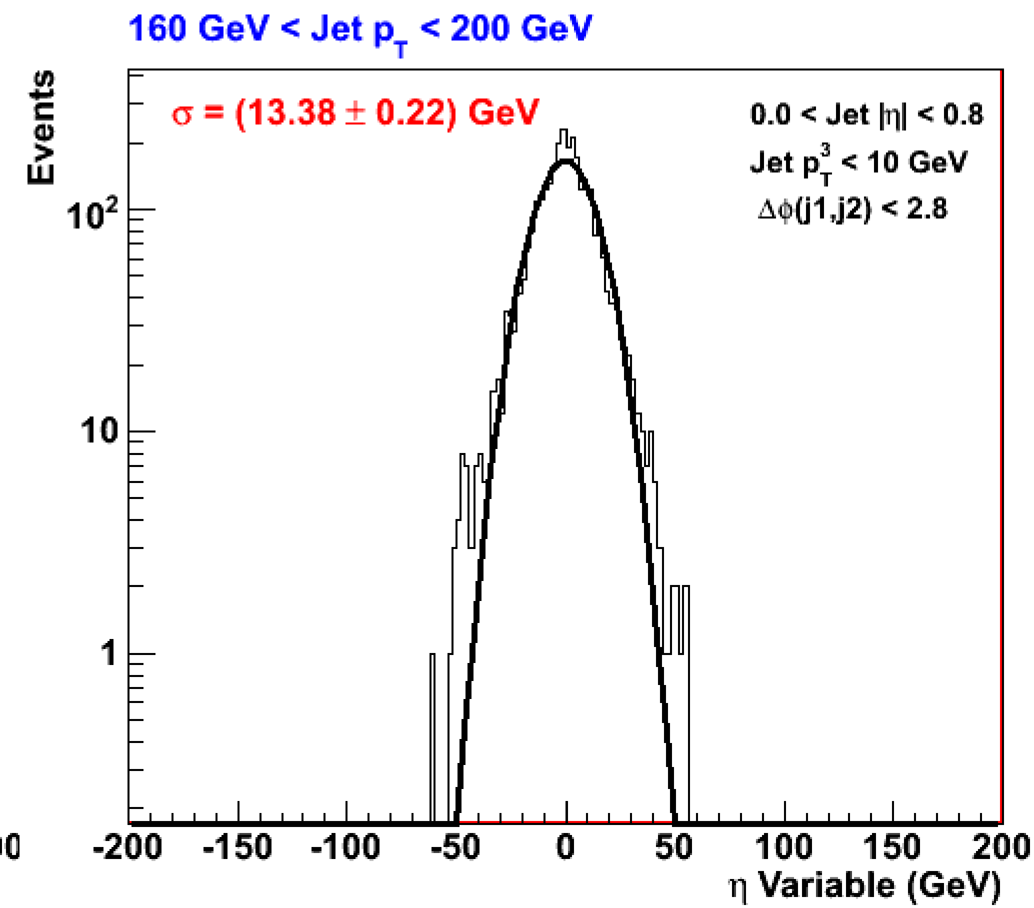
Psi, and Eta components are sensitive to different effects:

Psi distribution: jet energy resolution – gluon radiation.
Eta distribution: jet angular resolution – gluon radiation.

Remove soft radiation contribution by subtracting in quadrature sigma(Eta) from sigma(Psi)

Distributions of the 2 kT Components



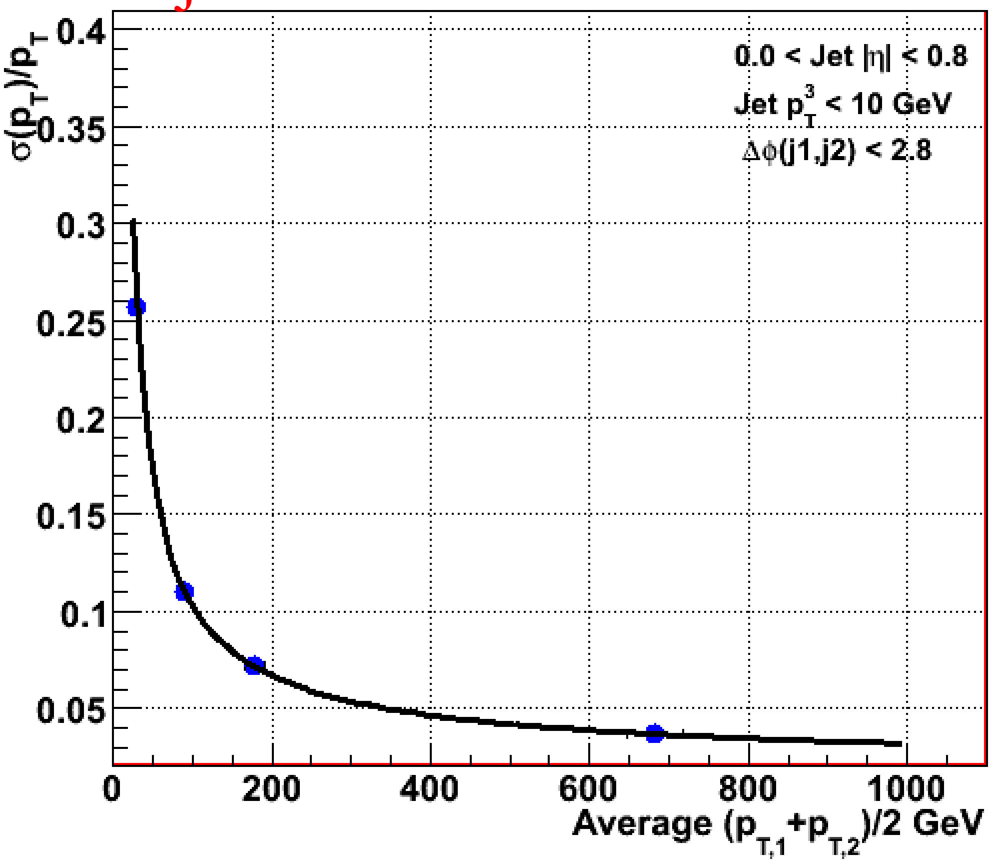


Data sample divided in 4 p_T regions, and 4 eta regions.

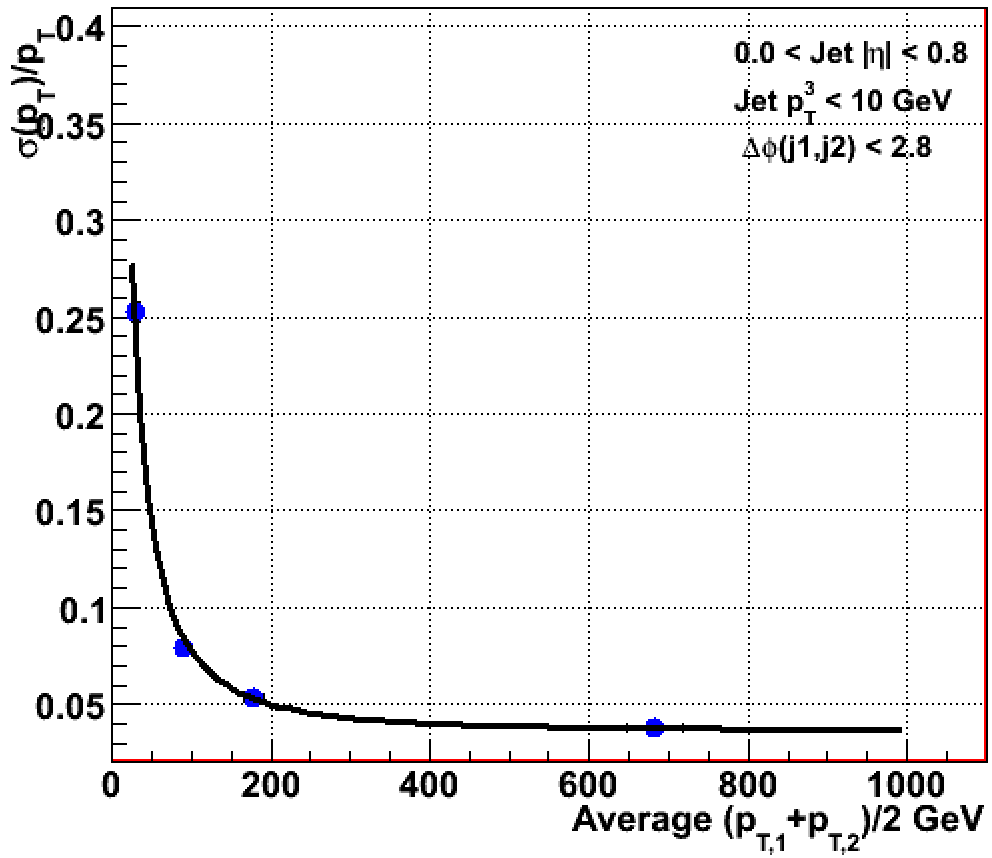
Psi and Eta variables fitted with single Gaussians.

Comparison of Dijet and Kt Balance Methods

Dijet balance



kT



Kt technique: smaller resolution at low pT.

Improving Jet Energy Resolution Using Tracks

Introduction

Tracking provides and independent measurement of energy that can be used to improve the energy resolution.

Match Cone 0.7 calorimeter jets with reconstructed tracks:

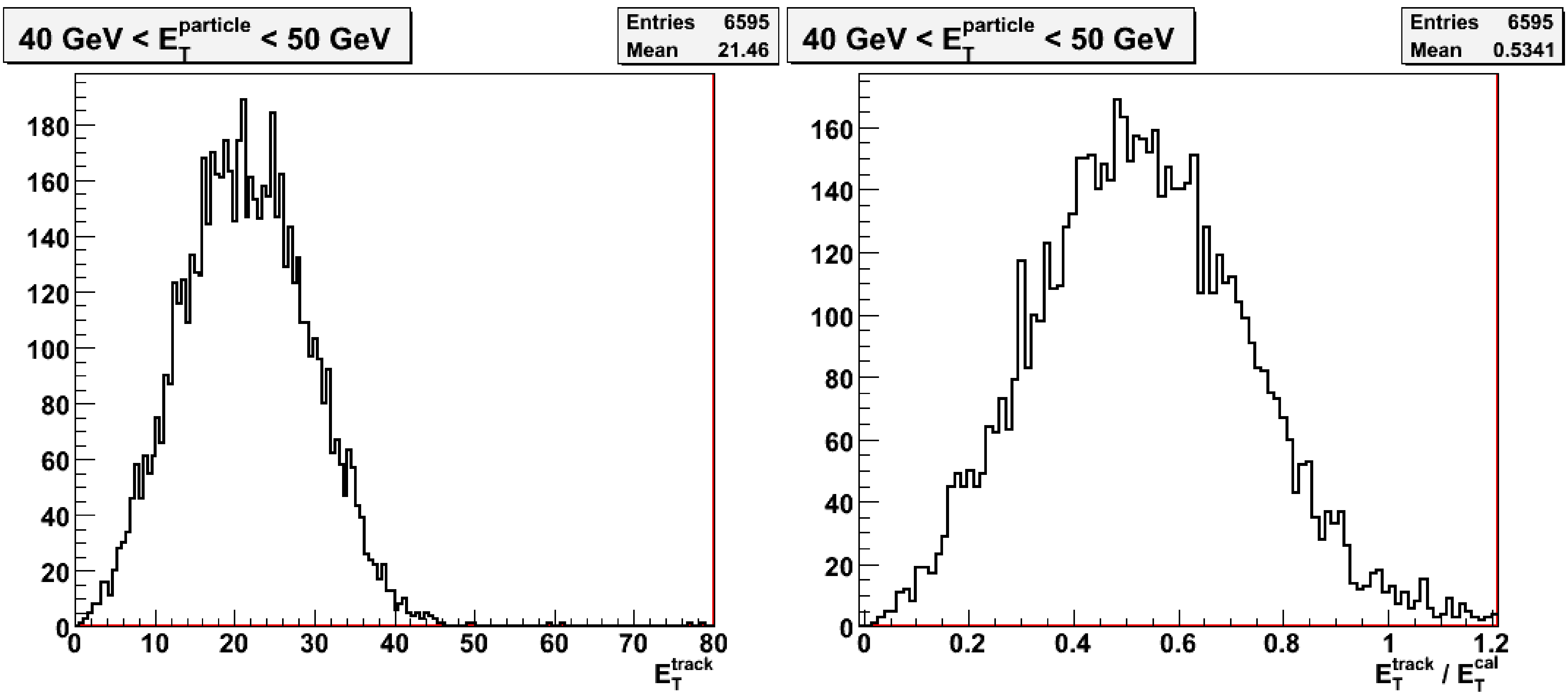
DeltaR(PV)<0.7
pT> 0.5 GeV

Consider the fraction of charged transverse momentum in jets:

$$f_{trk} = \frac{E_T^{trk}}{E_T^{cal}}$$

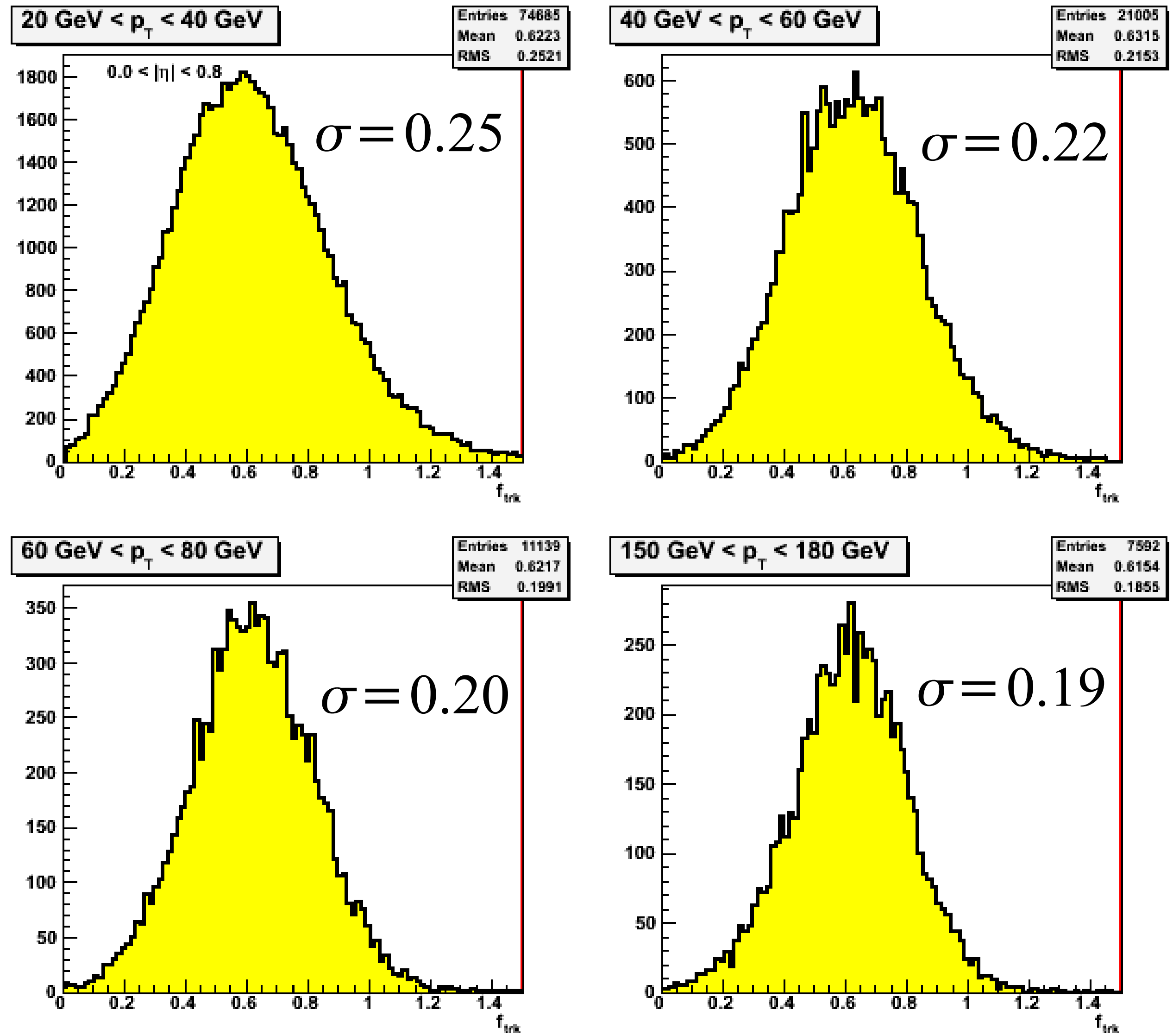
Look at the energy scale of cal-jets as a function of the charged particle composition, and *correct* for differences in scale.

Track Distributions in Jets

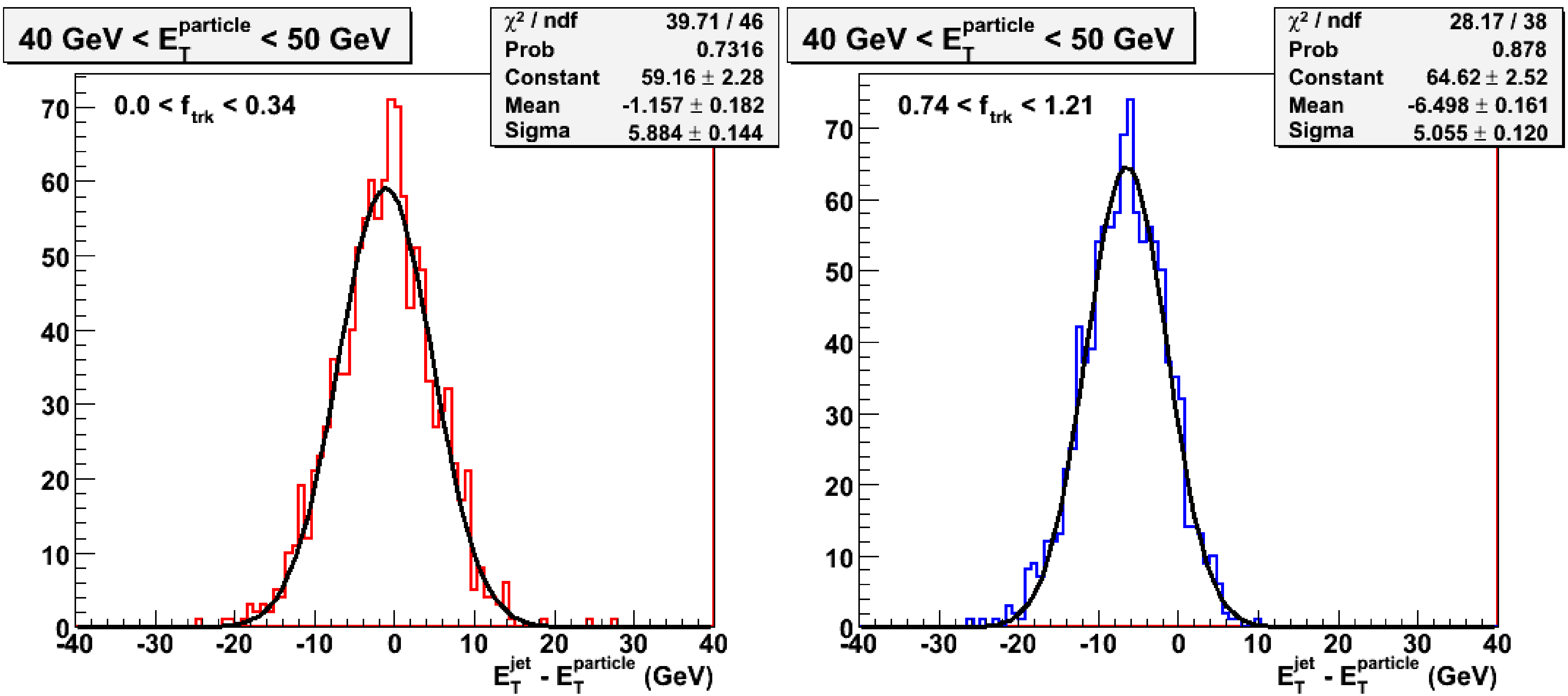


Track selection studies in progress: remove poorly measured and high E tracks

Charged Momentum Fraction in Jets

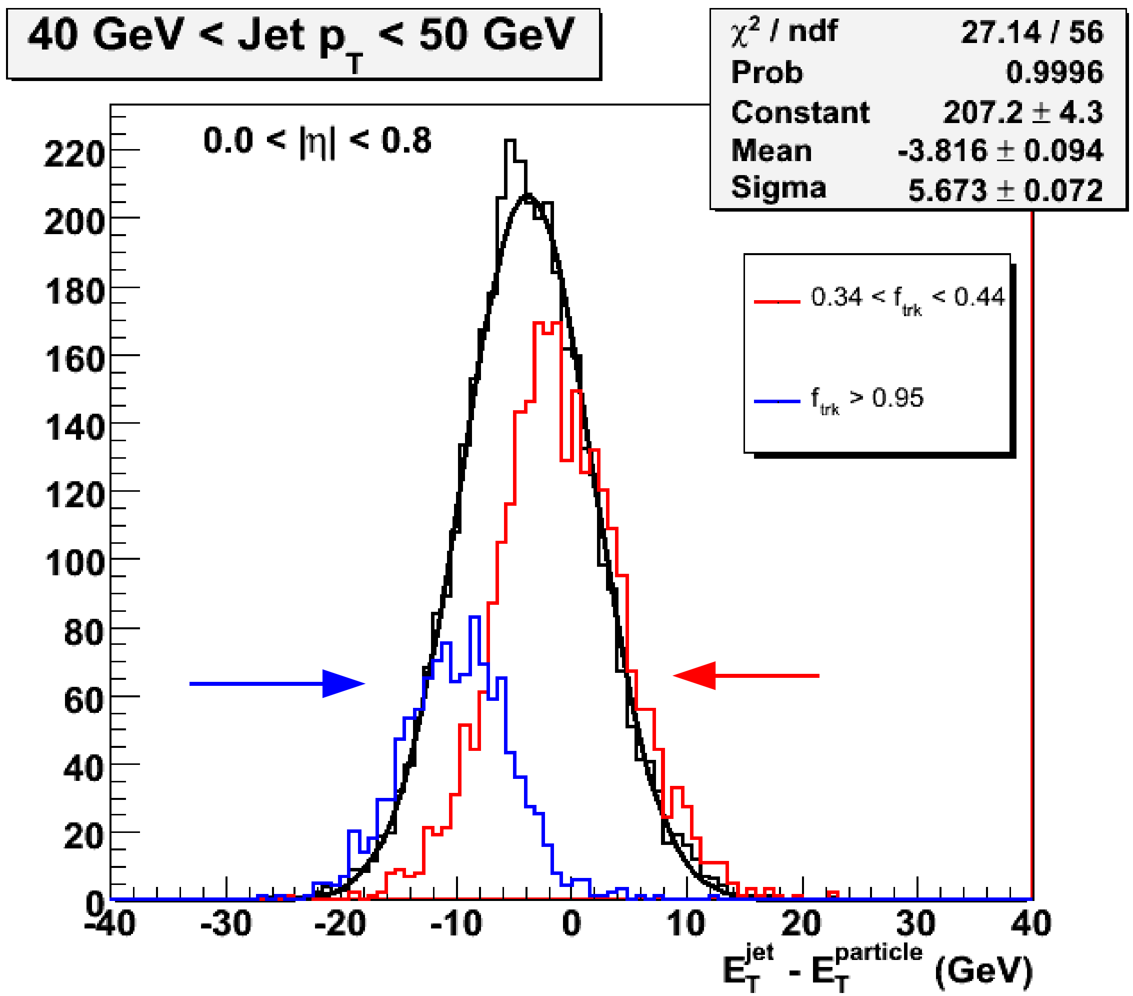


Jet Resolution vs Charged ET fraction



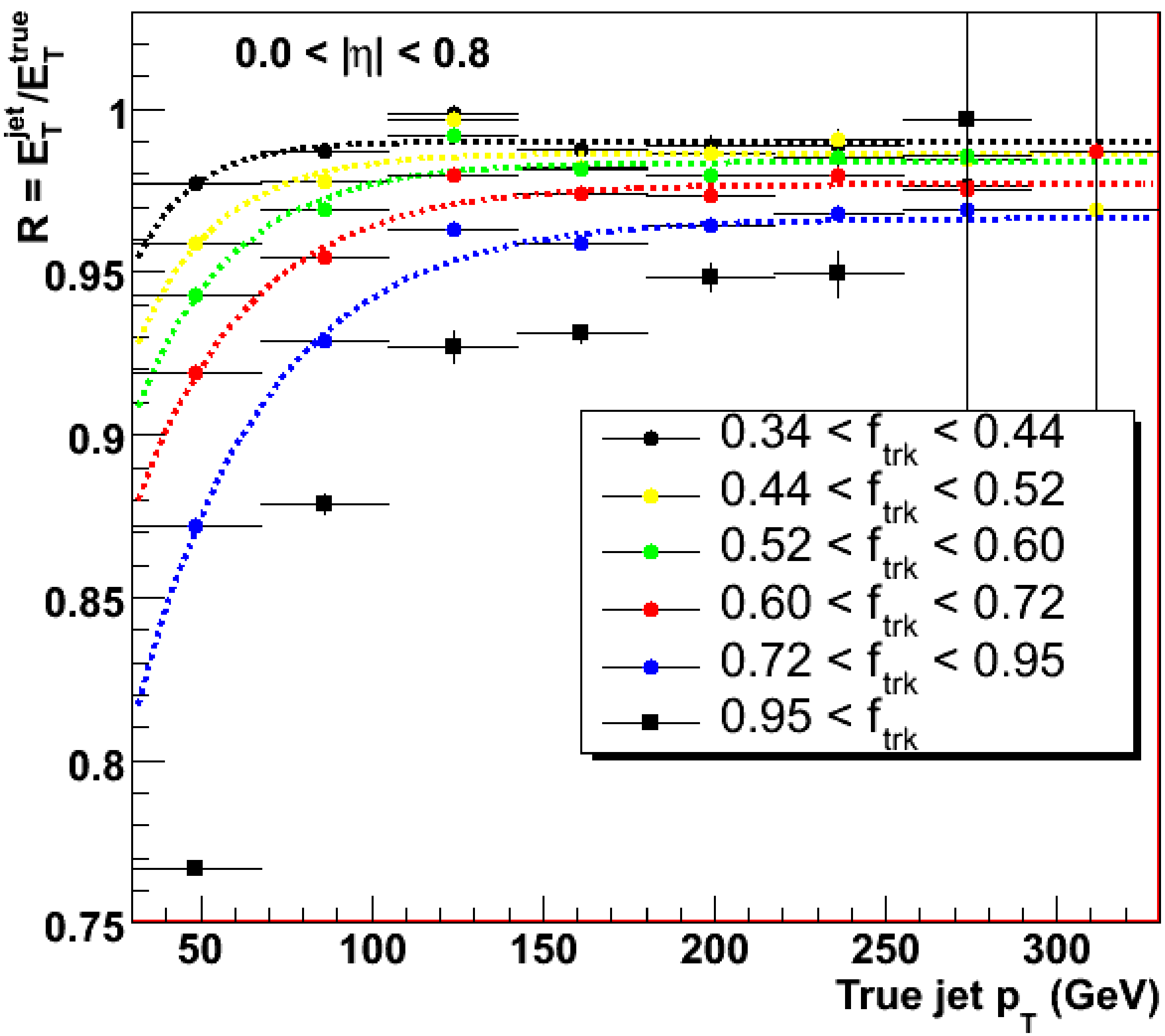
Significant Cal-Jet ***energy scale*** differences as a function of ET fraction.

Jet Resolution vs Charged ET fraction



The Cal Jet resolution width can be improved if jets with different f_trk are calibrated such that they have the same energy scale.

Jet Response vs. Charged ET fraction

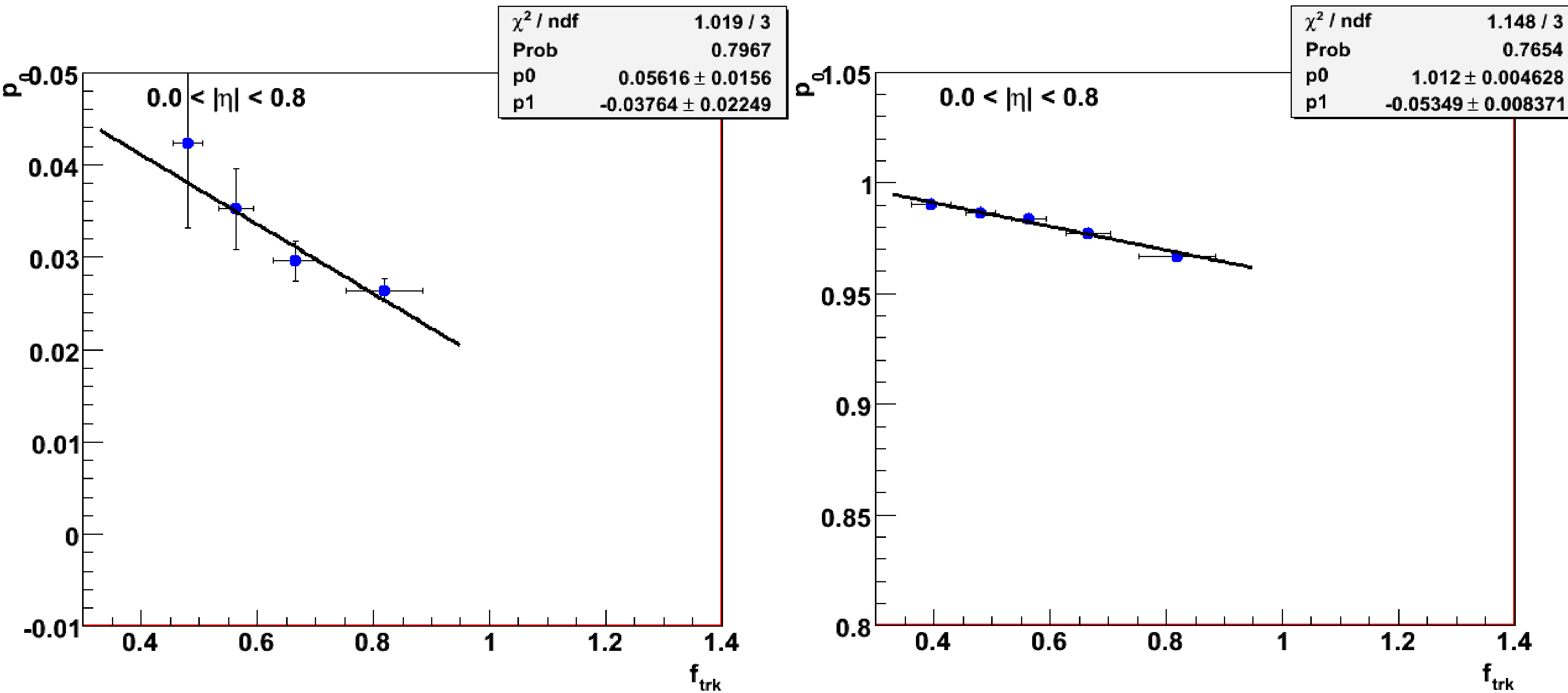


Significant energy scale dependence at low ET (<150 GeV)
Most of the energy shift comes from f_trk>0.5

Jet Energy Scale Correction using Tracks

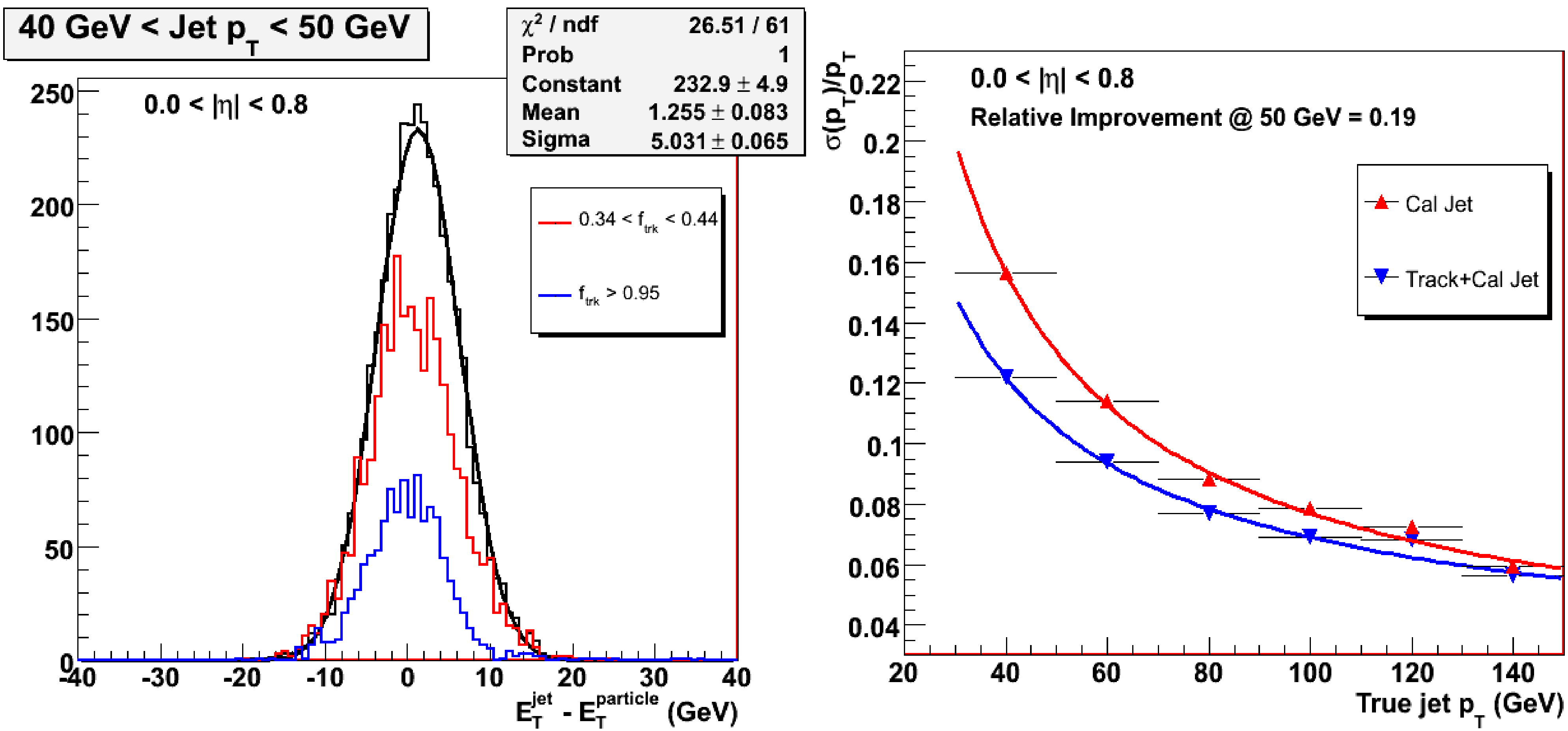
$$R(Ecal, Etrk) = p0(ftrk)(1 - exp[p1(ftrk) + p2(ftrk)Et])$$

$$p_i(ftrk) = a_i + b_i ftrk$$



Fit Jet Energy Response for each f_trk, and derive a track-based response correction: R(Ecal,Etrk)

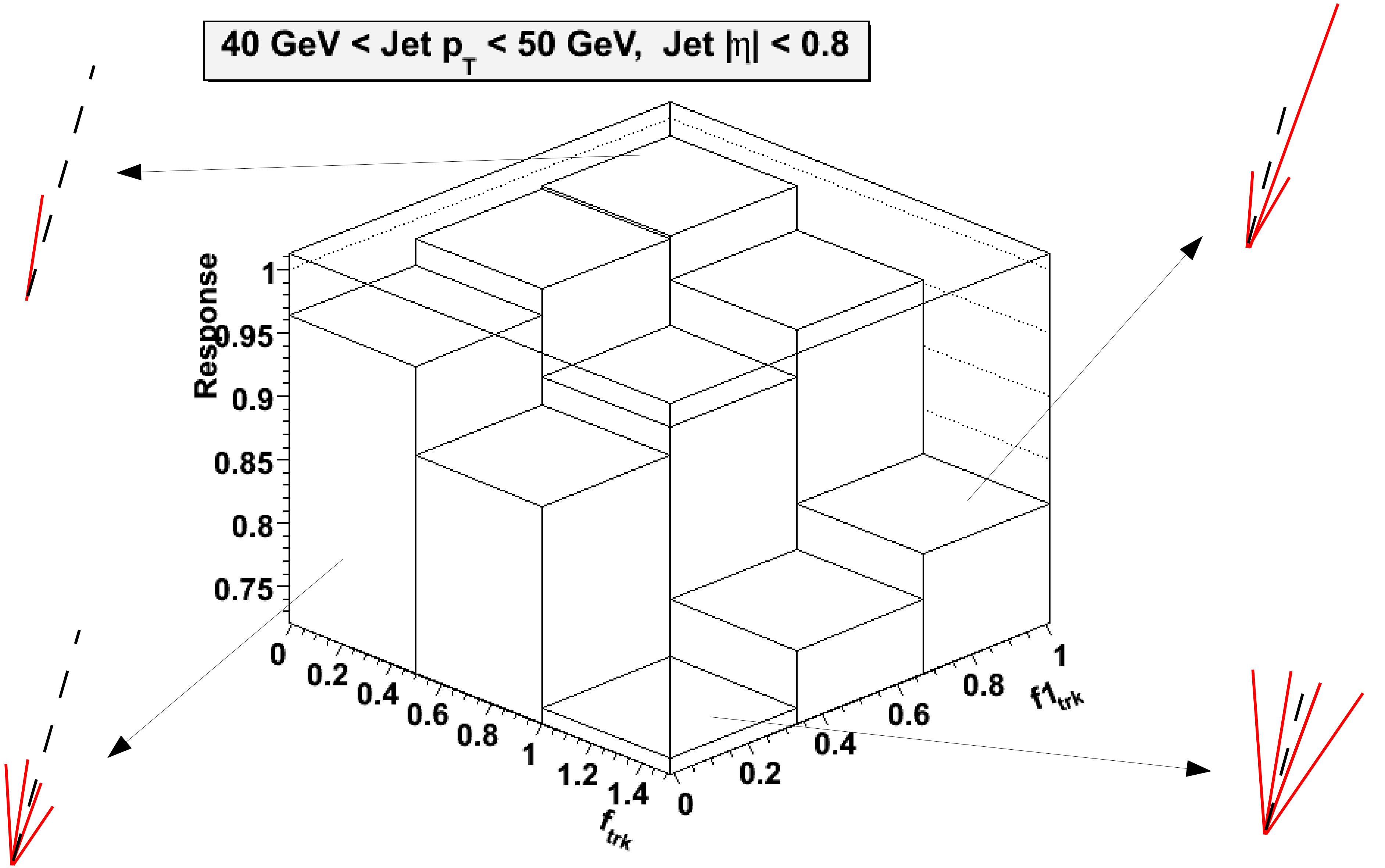
Track+Jet Energy Resolution Improvement



Jet Resolution is improved because jets with with different charged fraction are corrected to the same energy scale, reducing the overall width.

Almost 20% relative improvement at 50 GeV.

Energy Scale Corrections using Track Correlations: fraction of leading track pT



Missing ET Significance

MET Significance Introduction (I)

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:

- *Mis-identification of the primary vertex*.
- *Energy resolution of physic objects*: jets, leptons, unclustered energy.
- *Instrumental effects*: hot cells, calorimeter noise.

MET Significance Introduction (2)

Given a particular event with some measured MET:

How likely it could be due to a resolution fluctuation, taking into account the particular topology and measured physics objects in the event?

Which is the ***significance*** of the measured MET for that ***particular event***?

Missing ET Significance Formalism

New approach for ATLAS: Formulate p(ETmiss) in terms of jet probability density functions (Transfer functions)

$$p(ETmiss) = \vec{ETmiss} - sum\,\vec{W}(p_T^{ptcl};\, p_T^{jet}) - W(UE)$$

$W(p_T^{ptcl};\, p_T^{jet})$ 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 next slide)
- Different for light/b quark jets.

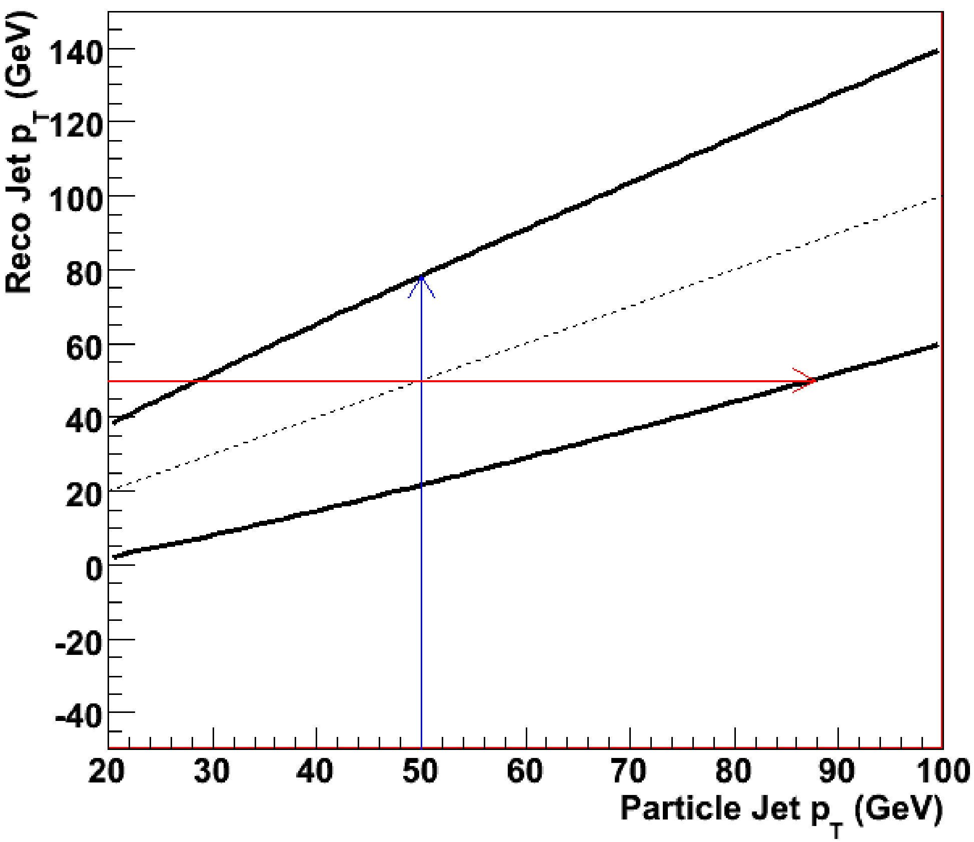
W(UE) is the pdf for the unclustered energy in the event.

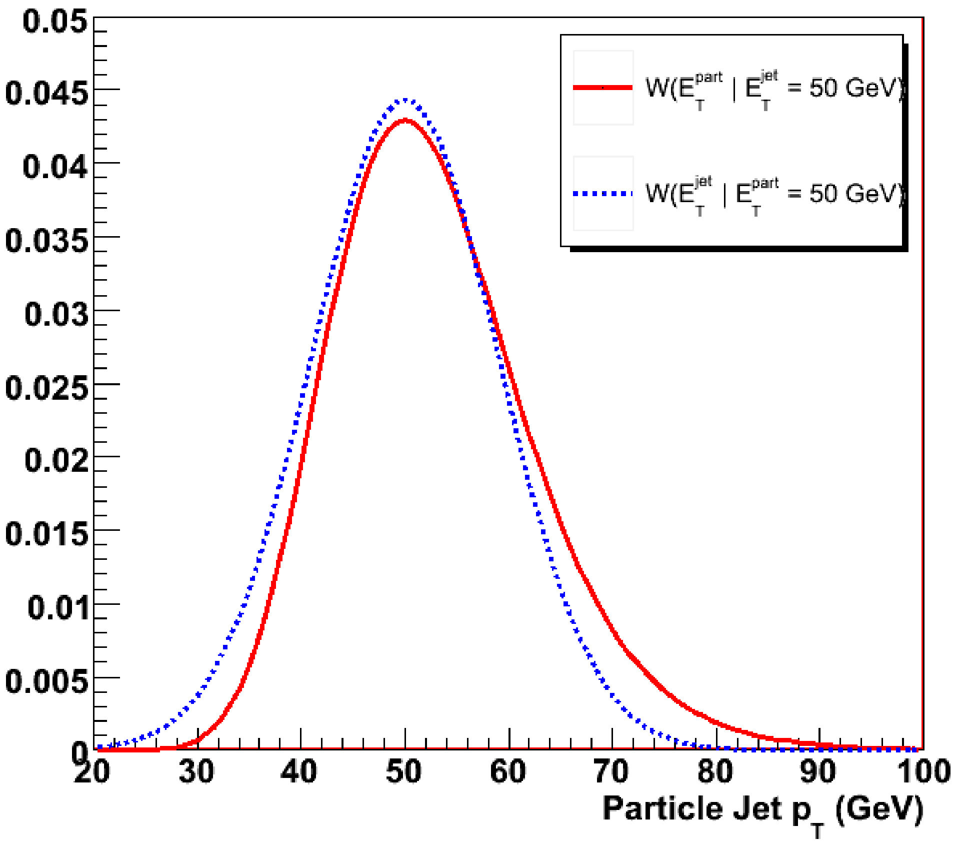
Define MET significance as a likelihood ratio:

$$L = \log \frac{p(ETmiss = ETmiss^{measured})}{p(ETmiss = 0)}$$

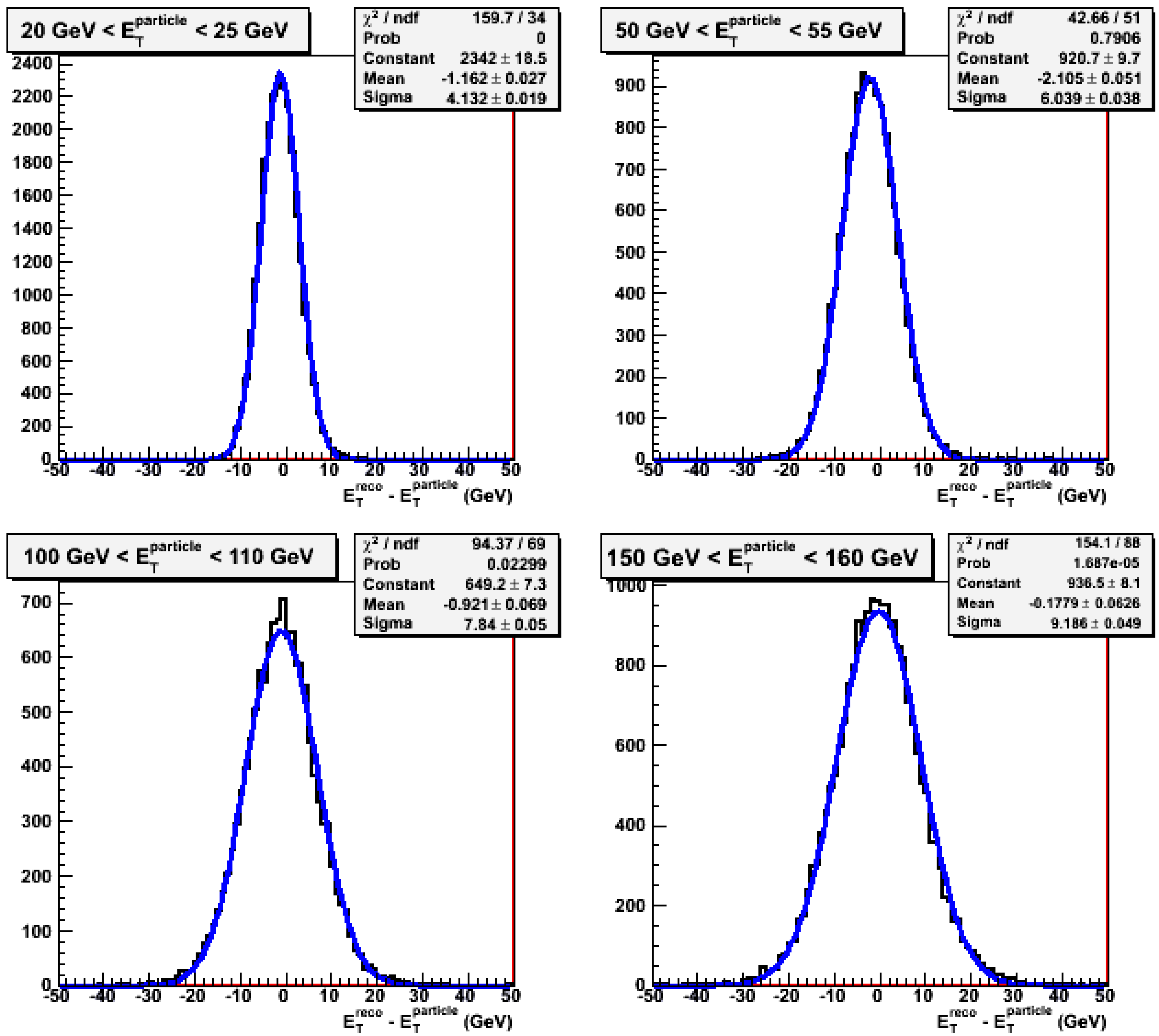
Jet Probability Density Functions (I)

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





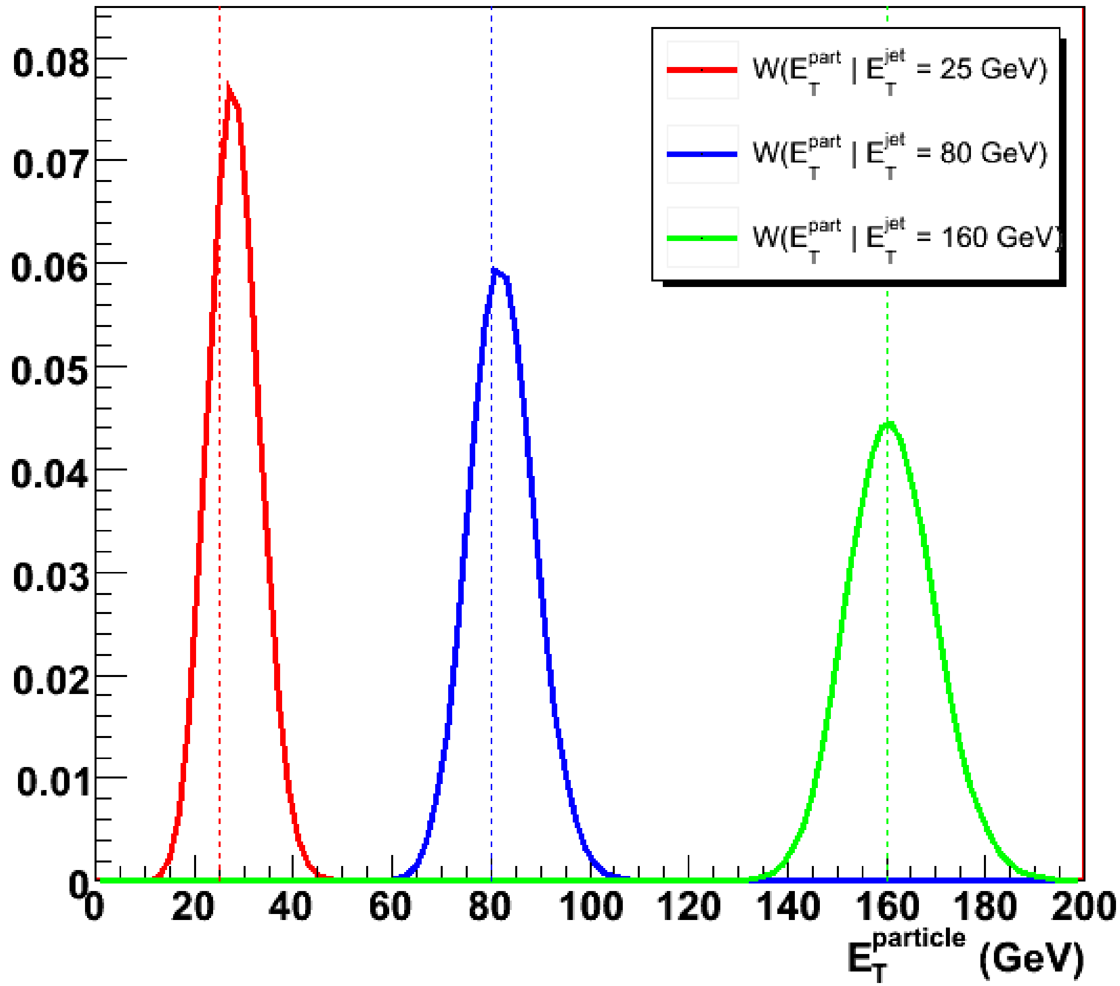
Jet Probability Density Functions (II)



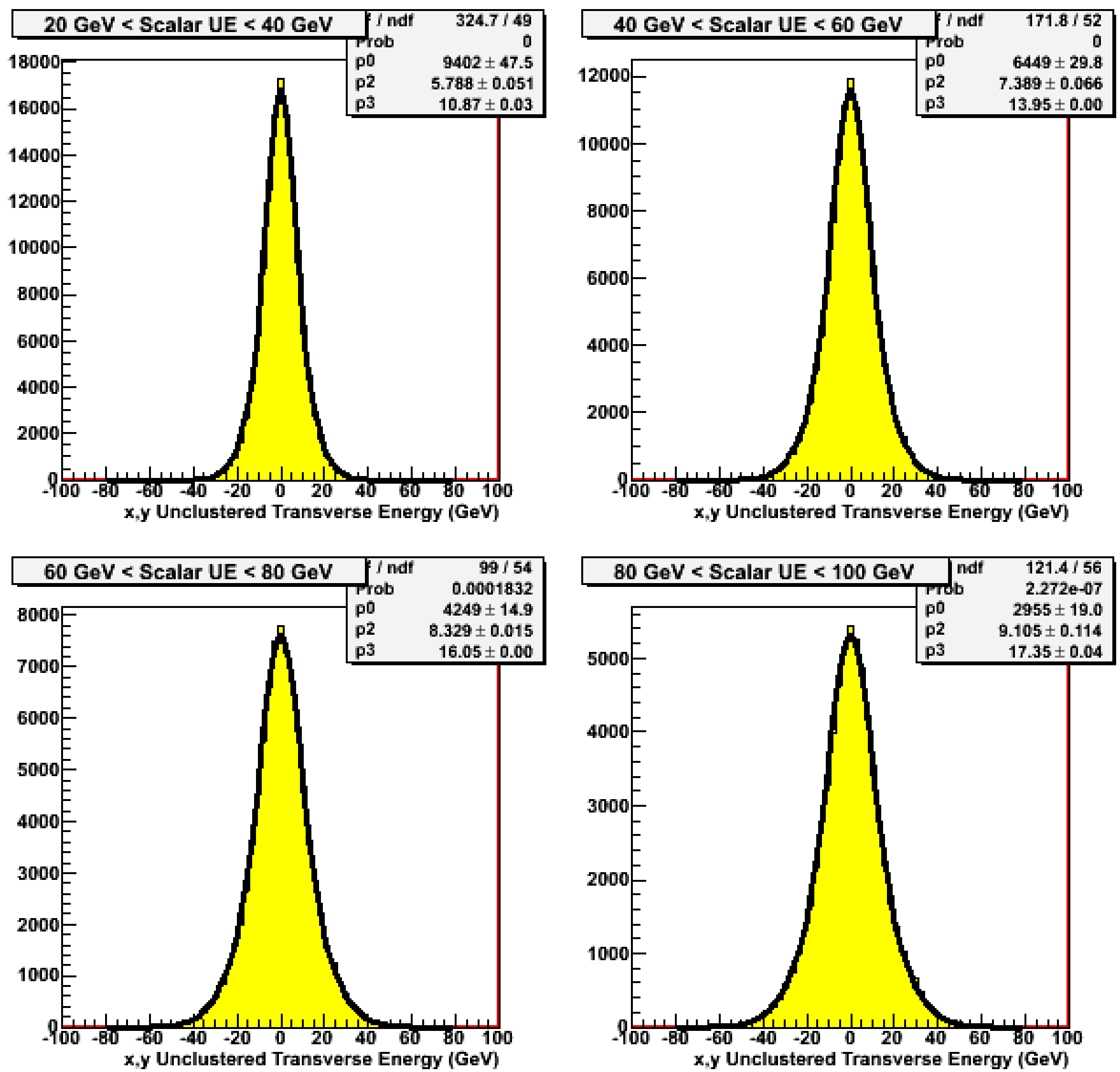
Jet Probability Density Functions (III)

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

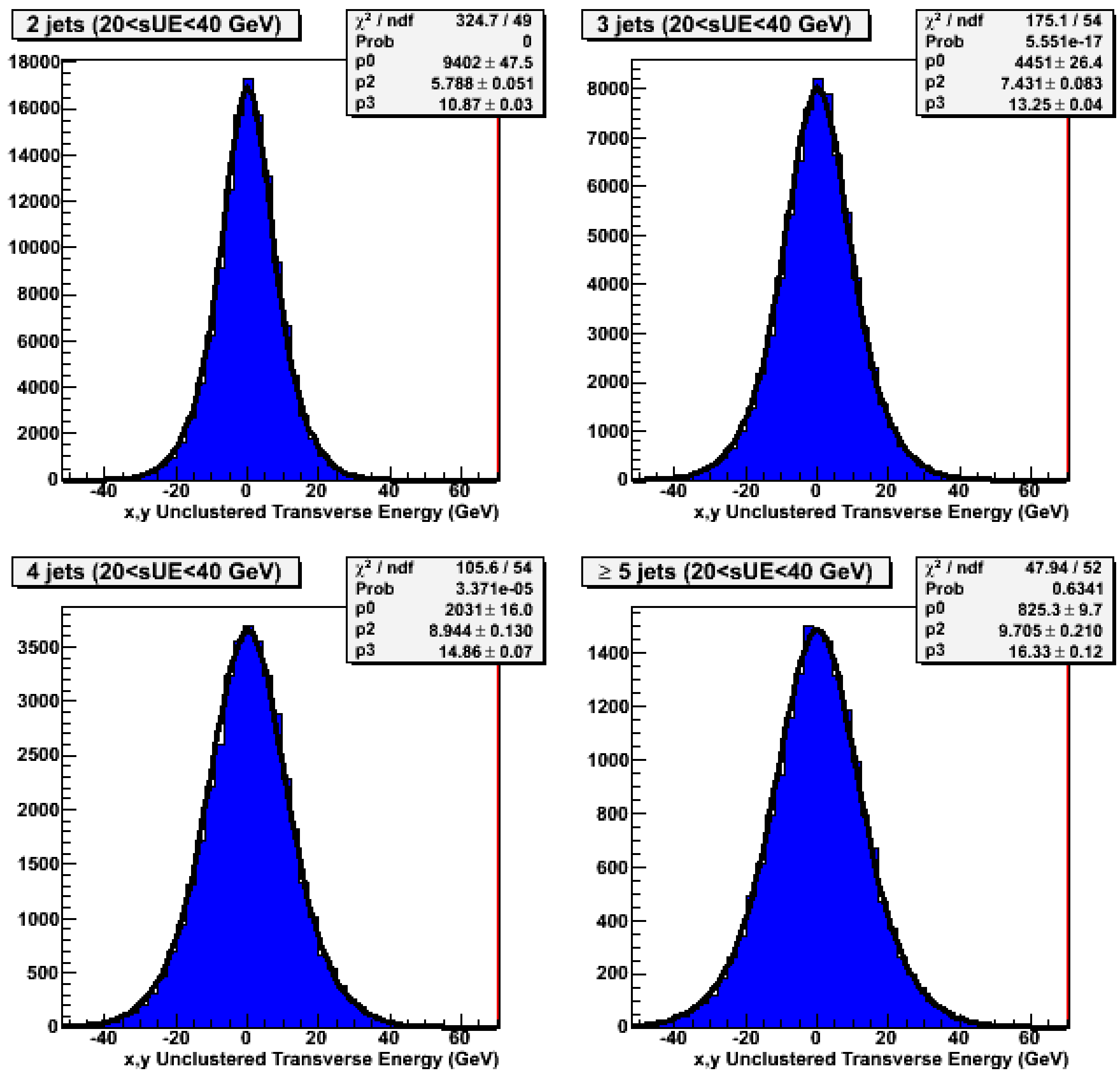
$$p_{1,2} = a_{1,2} + b_{1,2}\,p_T^{ptcl}$$



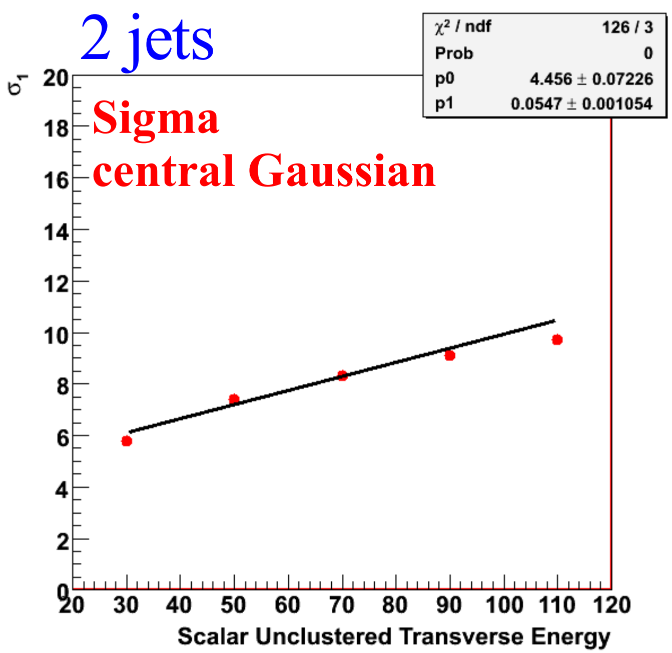
Unclustered Energy Probability Density Functions (I)

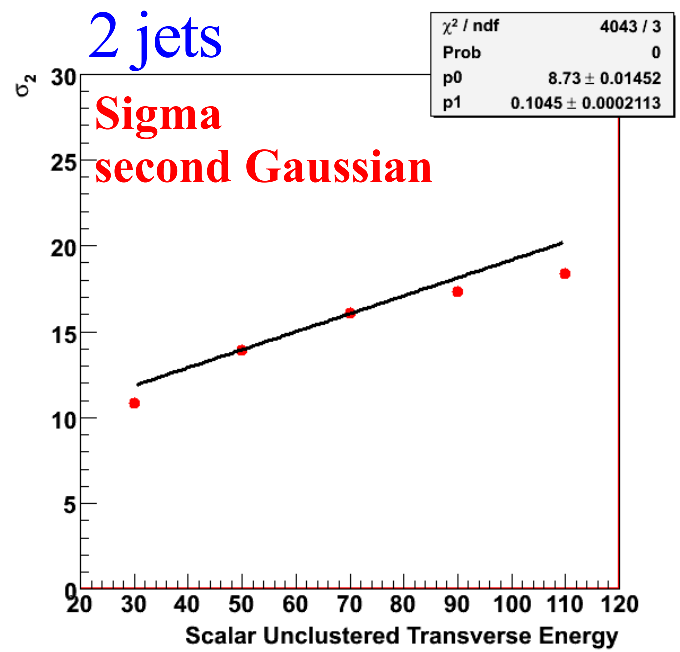


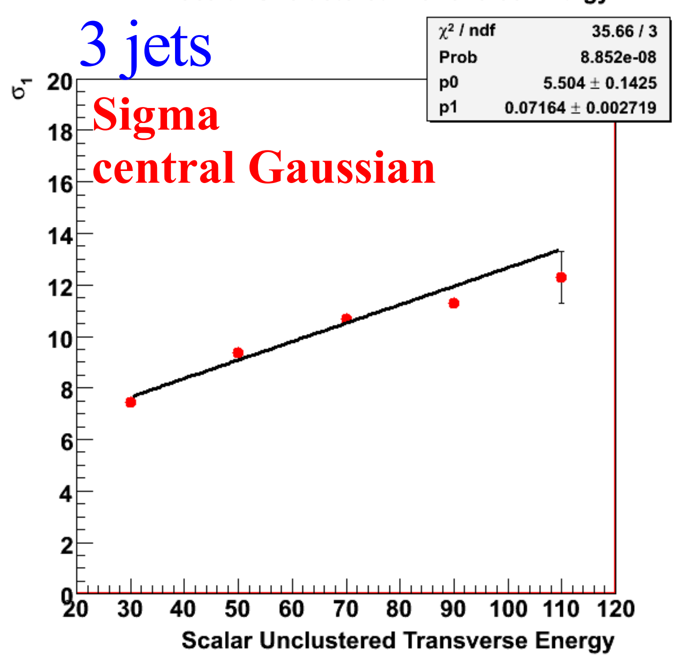
Unclustered Energy Probability Density Functions (II)

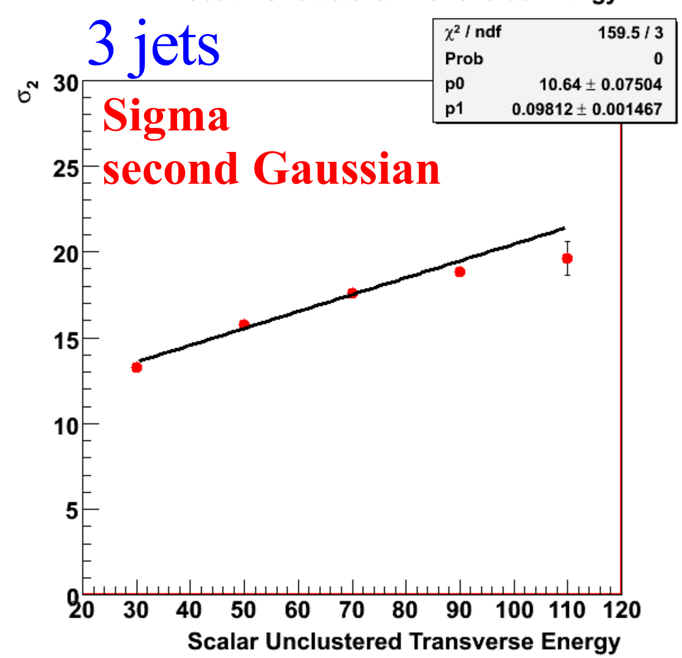


Unclustered Energy Probability Density Functions (III)

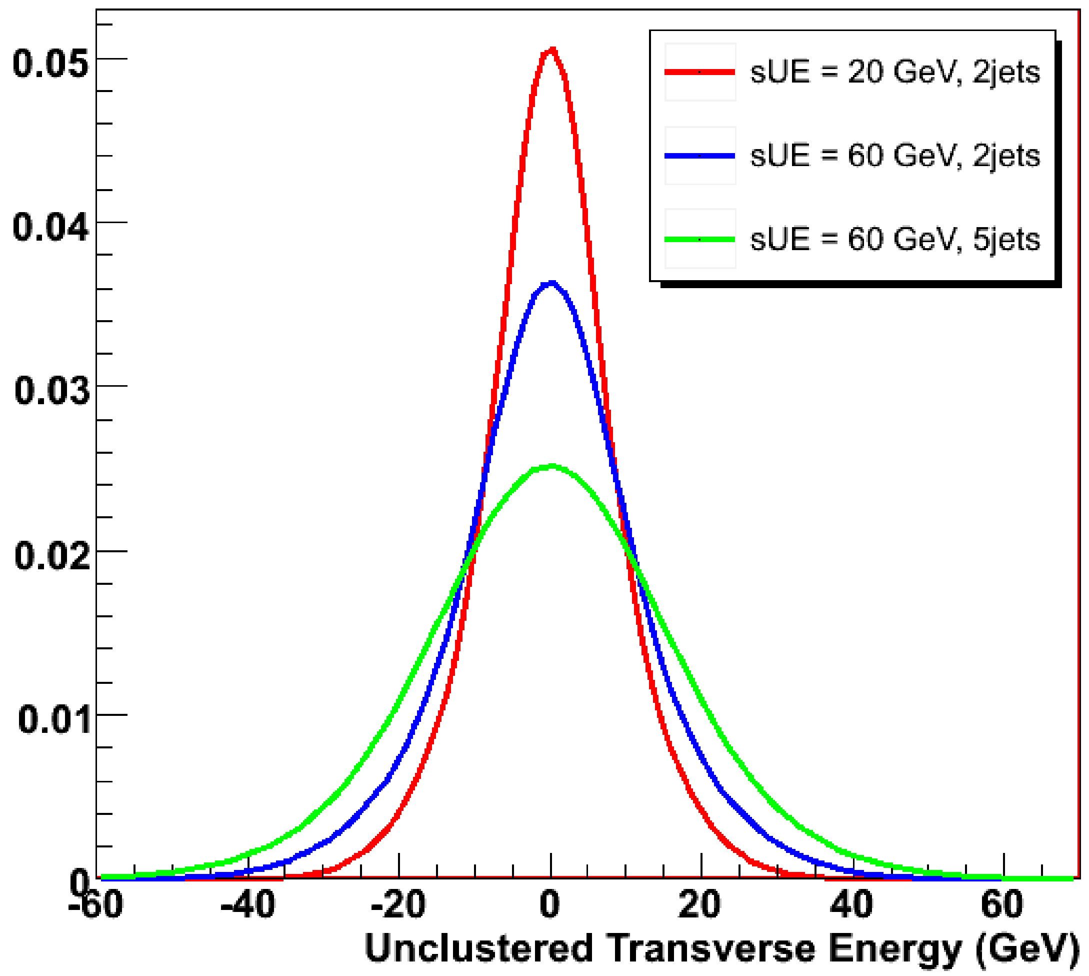




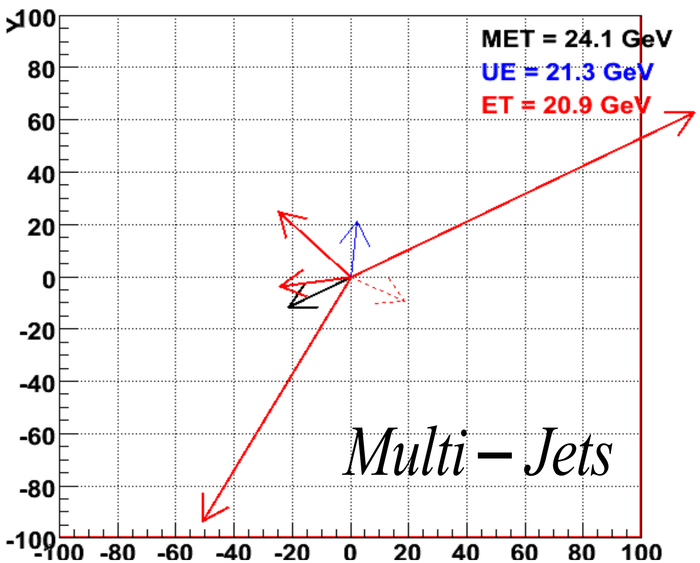


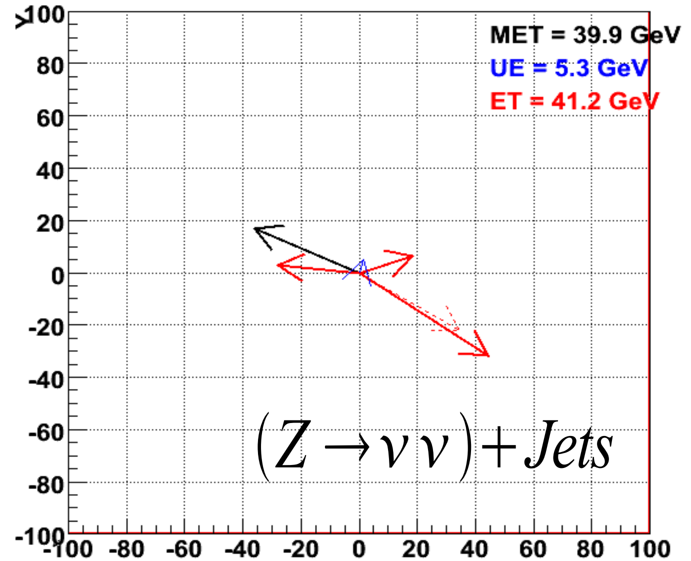


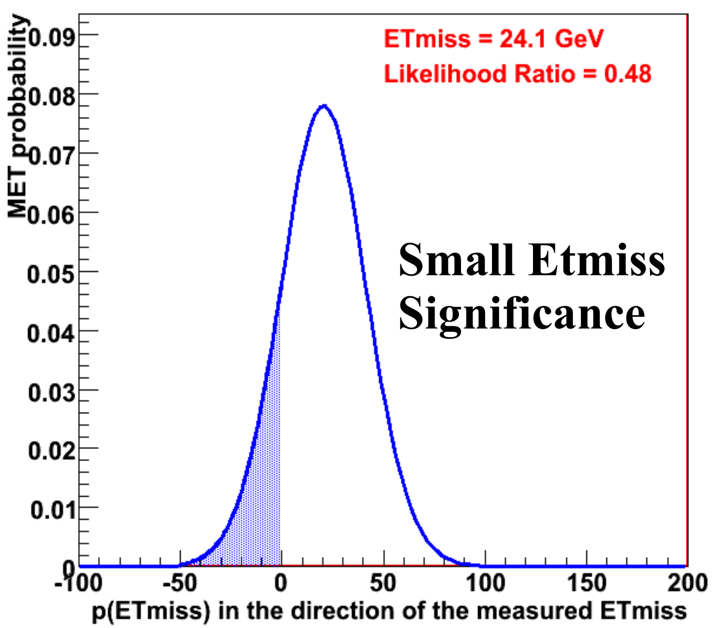
Unclustered Energy Probability Density Functions (IV)

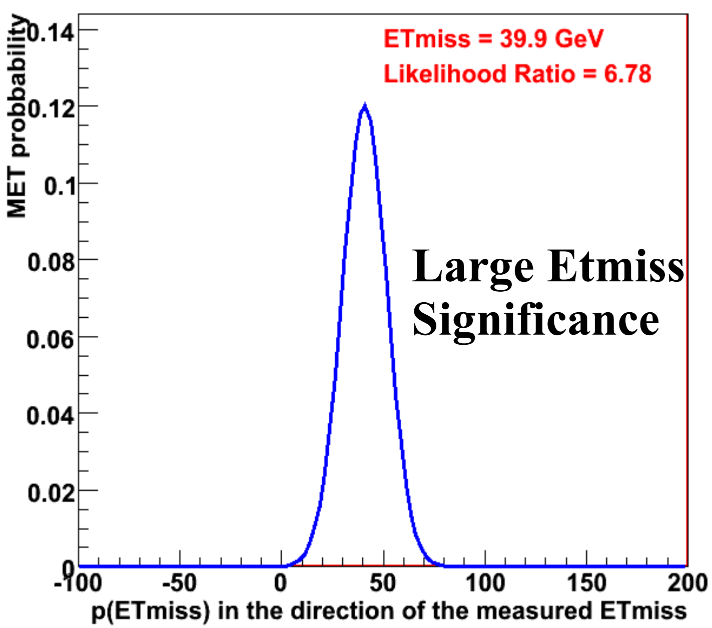


Missing ET Significance Examples

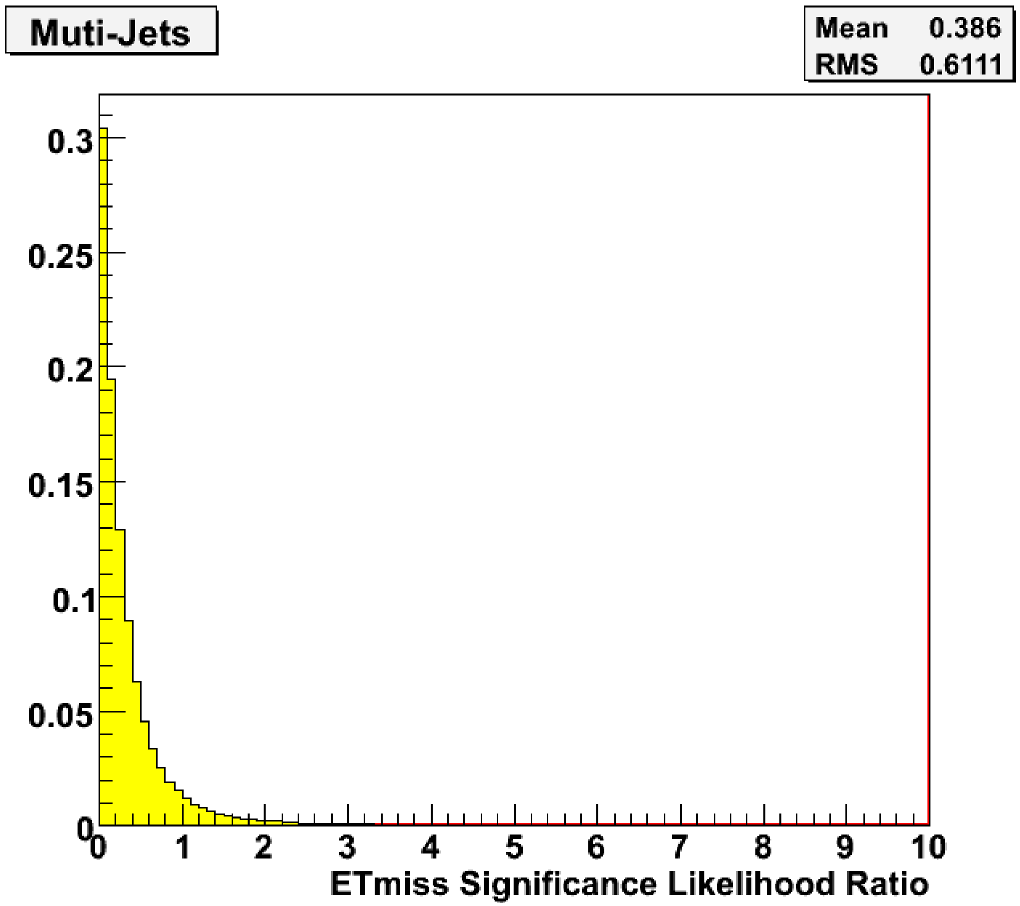


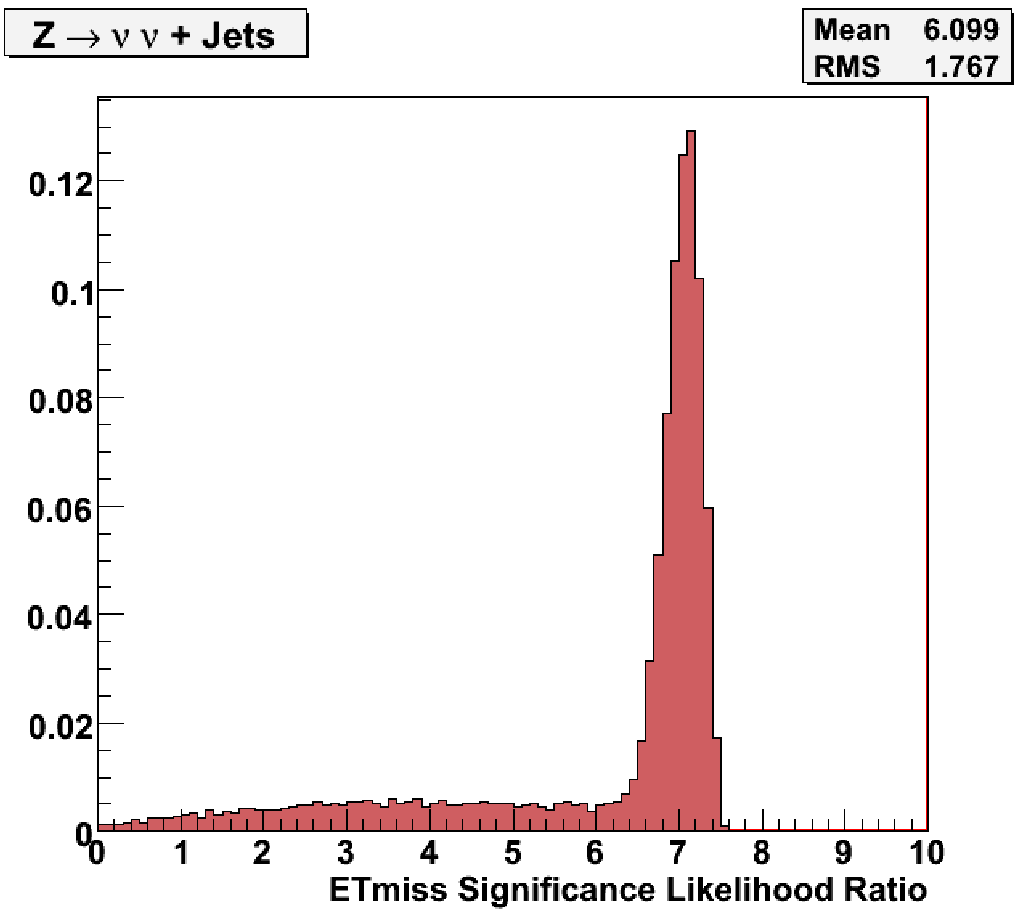






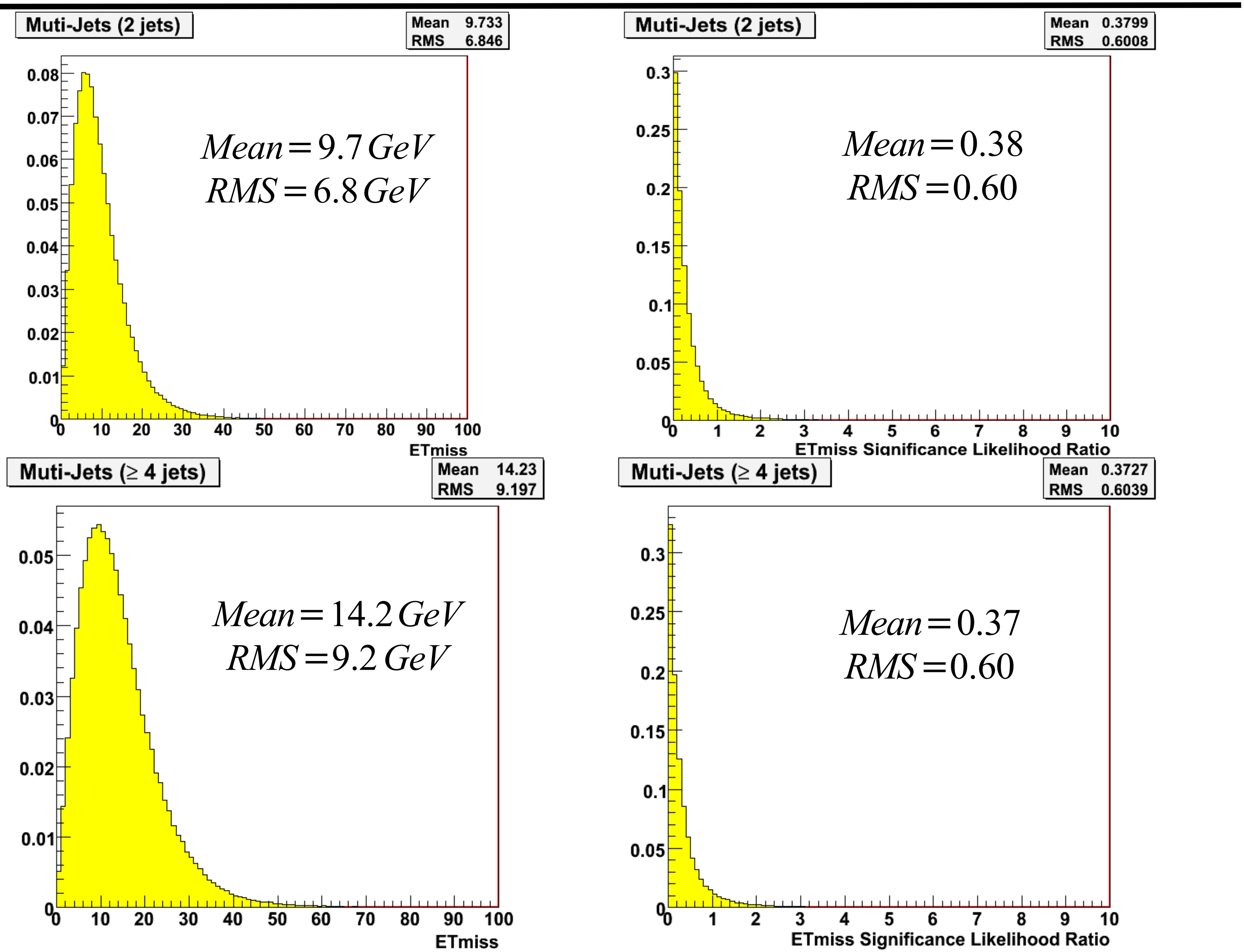
Missing ET Significance Performance (I)



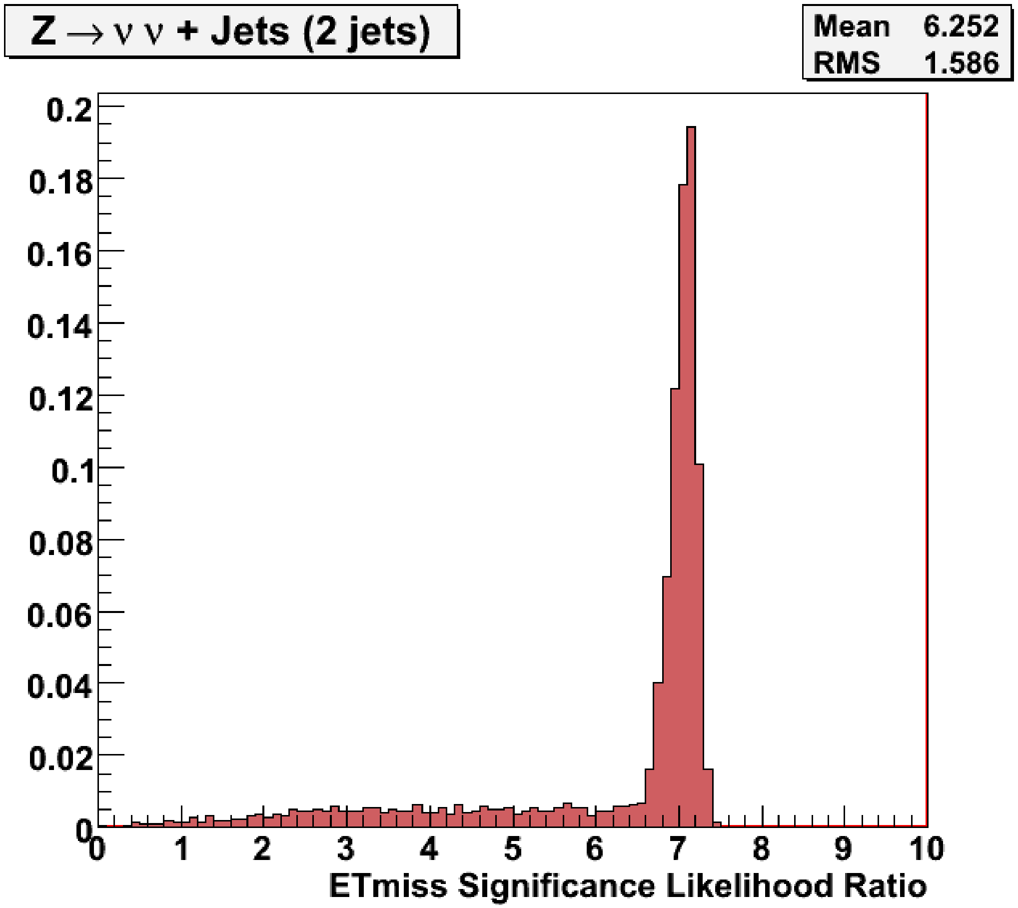


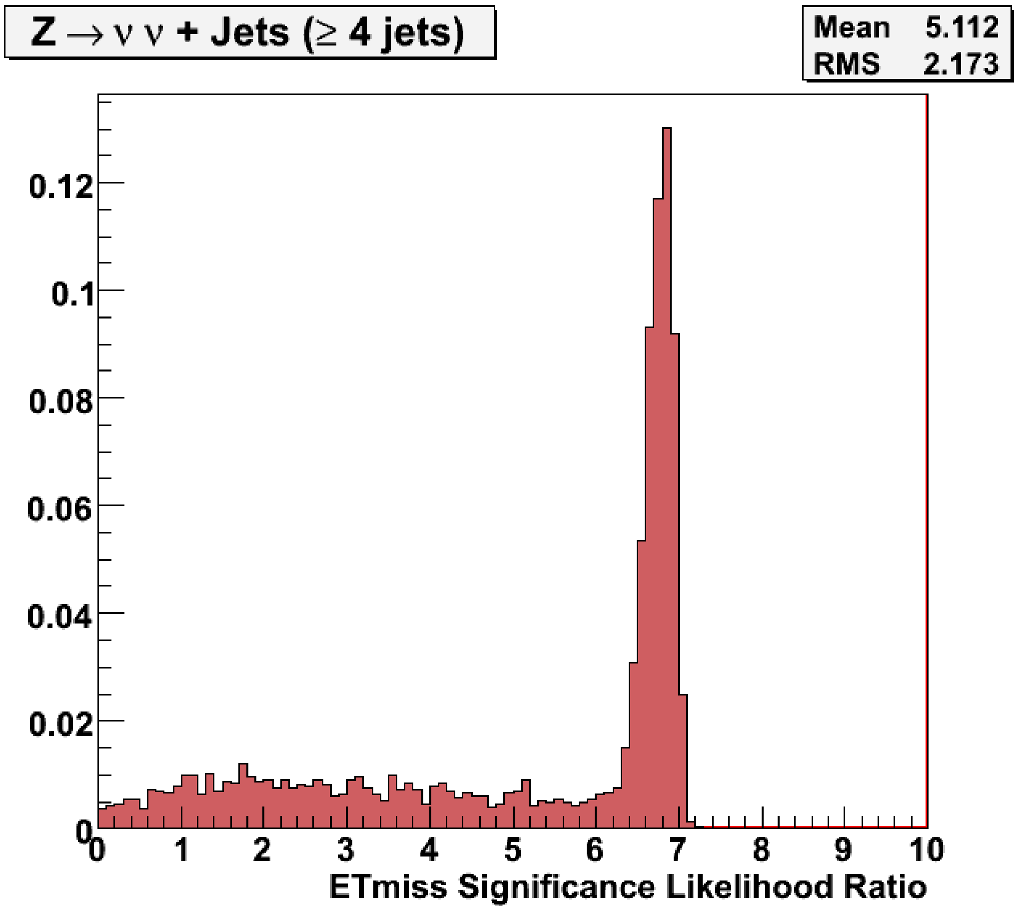
Et-significance likelihood ratio (L) peaks at 0 for multi-jet events. Tail at low L for Znunu when the neutrino is in the direction of any jet.

Missing ET Significance Performance (II)



Missing ET Significance Performance (III)





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

Summary

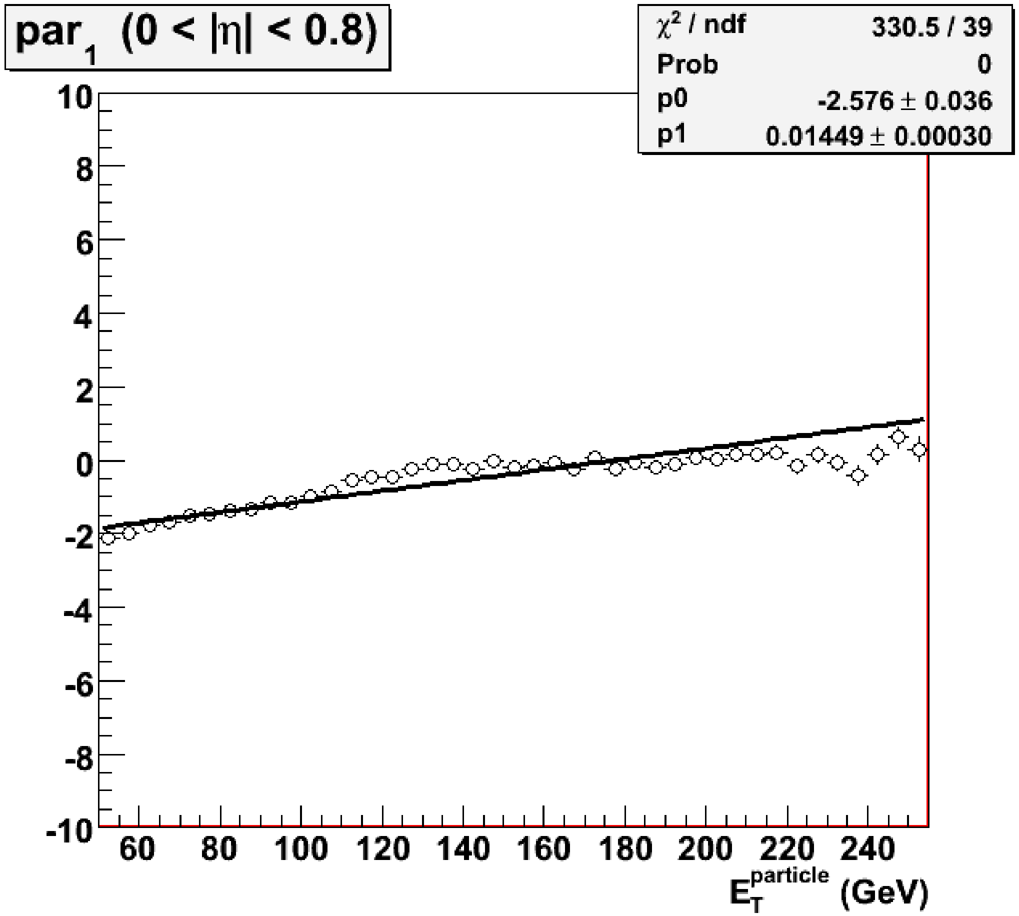
- Data-driven techniques to measure jet energy resolution resolutions: Dijet balance, kT.
  Differences between both methods at low transverse energy.

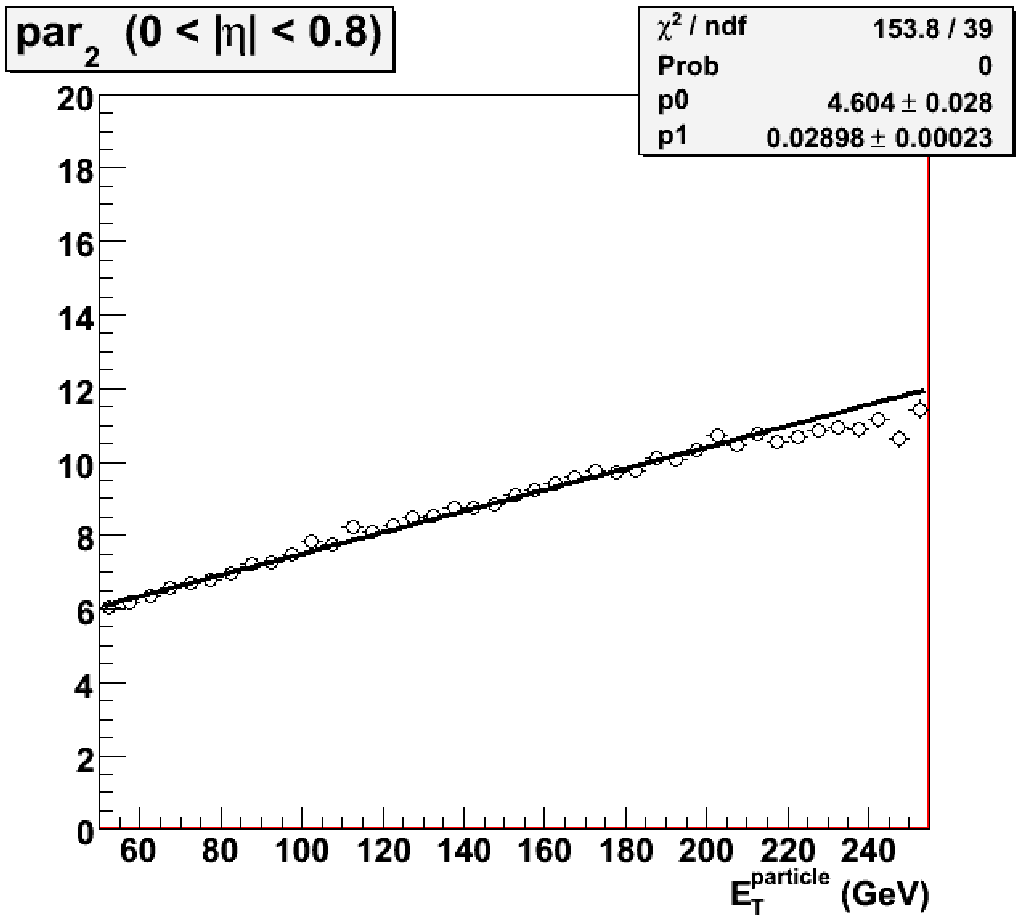
- Use of tracks to improve the jet energy resolution:
  Track-based jet response corrections.
  The gain is due to the proper calibration of jets as a function of its charged particle energy content, measured with the tracker (19% @ 50 GeV)

- Missing ET Significance:
  New approach based on jet probability density functions.
  Take into account jet energy scale, resolution, and non-linearities at the same time.
  Discriminate large fake MET events from events with real ETmiss.

Backup Slides

Jet Probability Density Functions (I)





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

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

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

Jet Probability Density Functions (II)

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: $[p_T^{ptcl}] = \dfrac{p_T^{jet} - a_1}{1 + b_1}$

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 (III)