Improving Calorimeter Jet Reconstruction Using Tracks and Vertices

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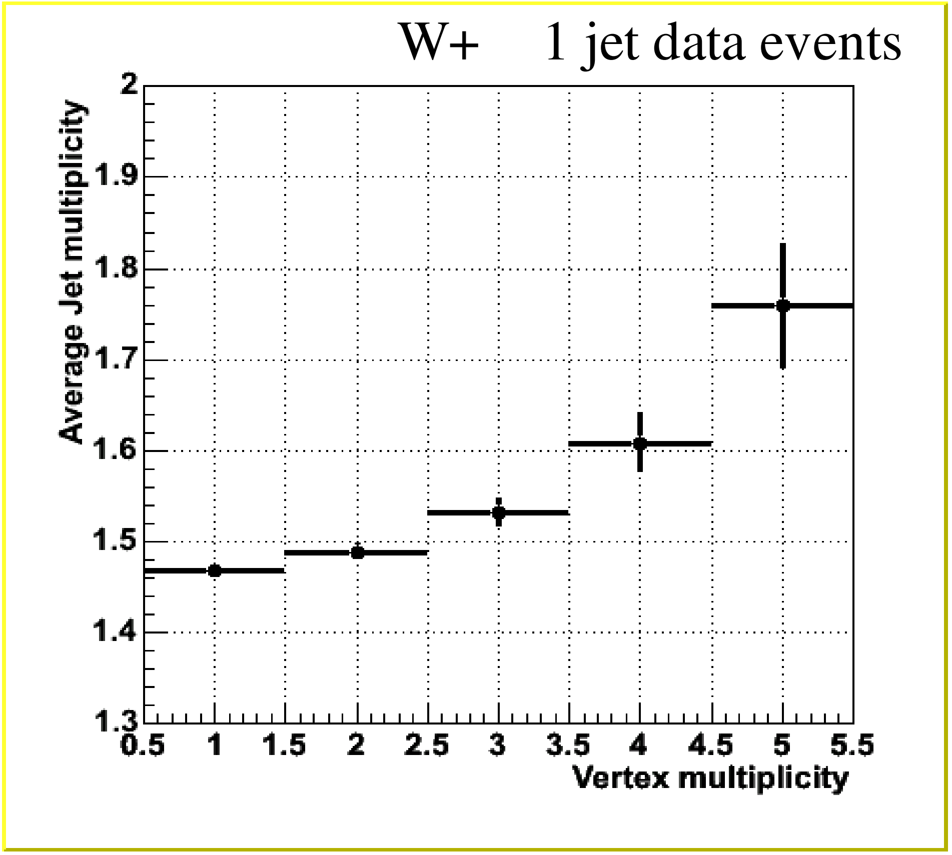
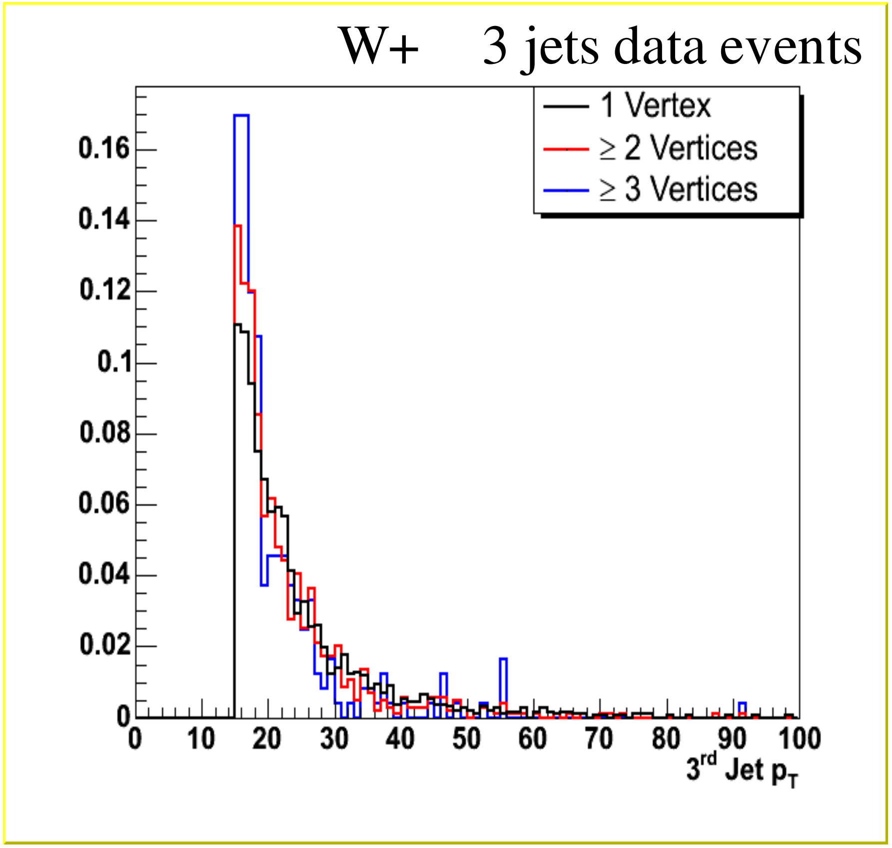
Outline

- Jet reconstruction at high luminosity:
    - Jet kinematics as a function of number of interactions.
    - Algorithm for calorimeter jet and vertex association.

- Improving jet energy resolution using tracks:
    - TrackCalJet algorithm overview.
    - Studies in simulated events:
        - Jet energy and mass resolution.
    - Studies in photon + jet data events:

Jet Multiplicity at High Luminosity



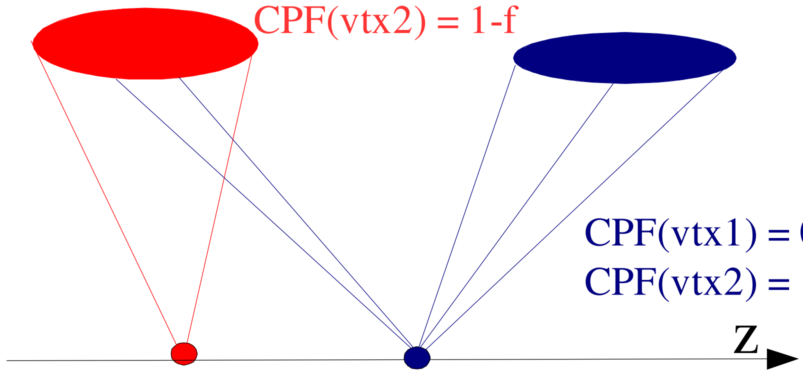


- Average jet multiplicity increases with number of primary vertices.
- Jet kinematics is distorted at low pT (extra low-pT jets)

→ Additional minimum bias interactions can give rise to extra jets.

Jet-Vertex Identification

Goal: Associate Cal-Jets to Vertices.



<u>Algorithm:</u>

- Select tracks matched to vertices and jets:

  $\Delta Z(trk_j, vtx_i) < 1.0cm$, $\Delta R(trk_j, jet_i) < 0.5$

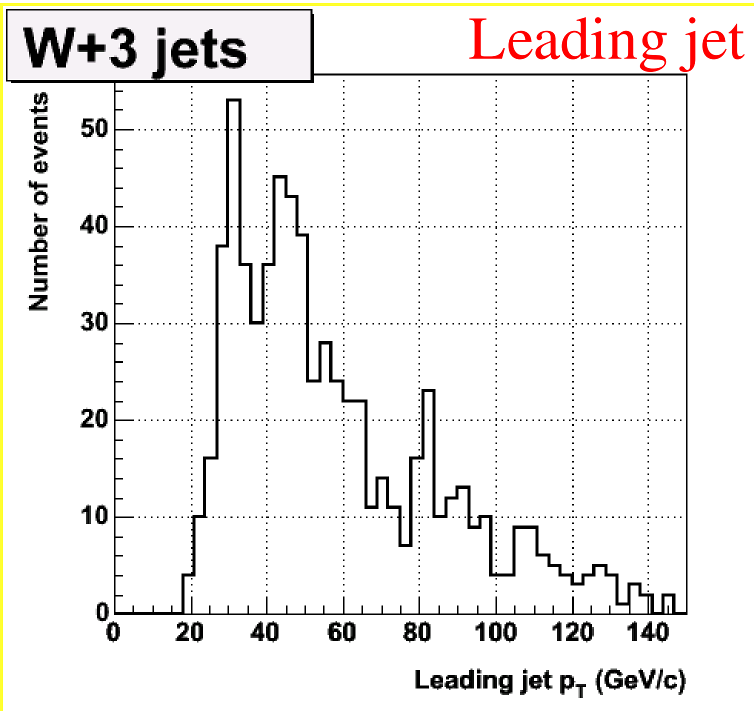
- For each jet, calculate the fraction of track energy associated to each vertex:

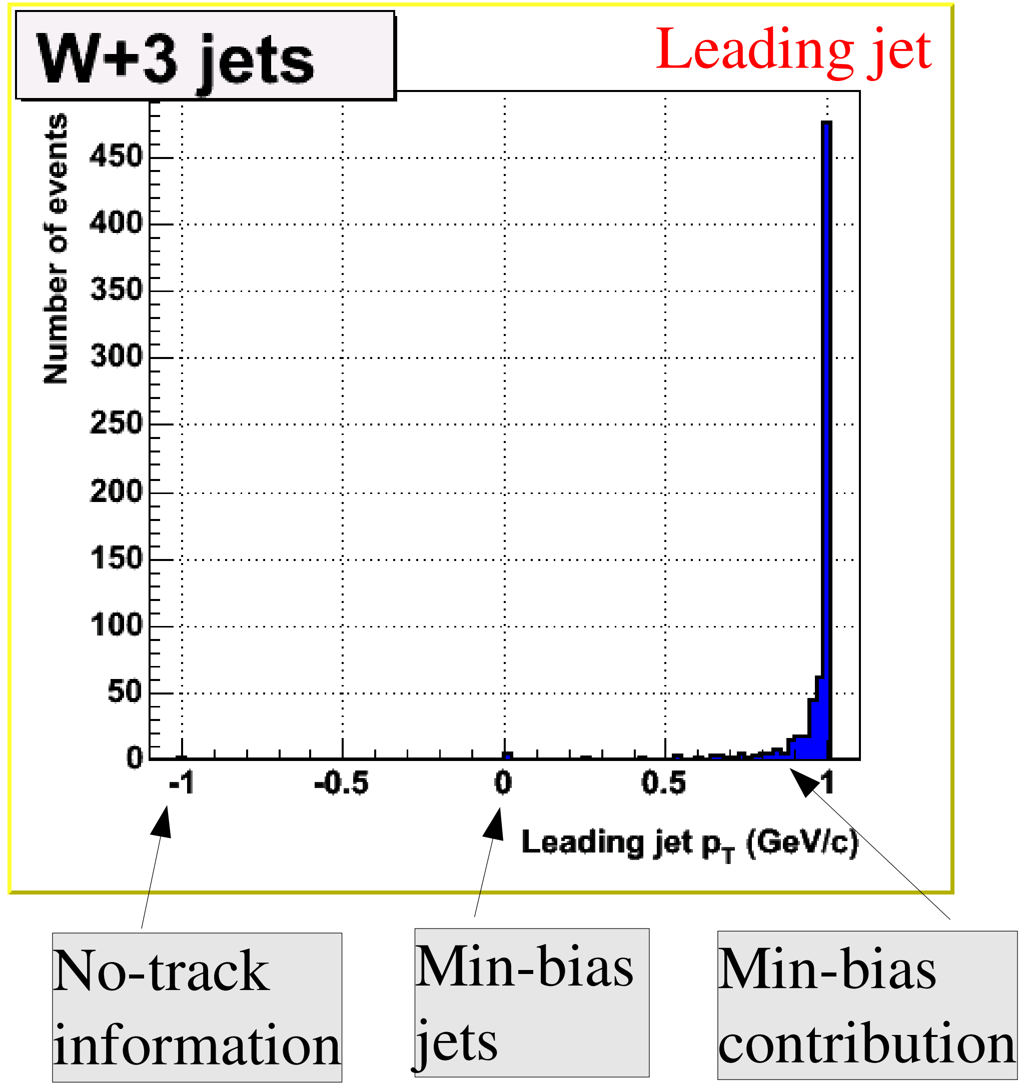
  $$CPF(jet_j, vtx_i) = \sum_{trk} p_T^{track}(jet_j, vtx_i) / \sum_i \sum_{trk} p_T^{track}(jet_j, vtx_i)$$

  associate *jet j* to the vertex *i* for which $CPF(jet_j, vtx_i)$ is maximum.

CPF is the charged particle energy fraction of jet *j* from vertex *i*.

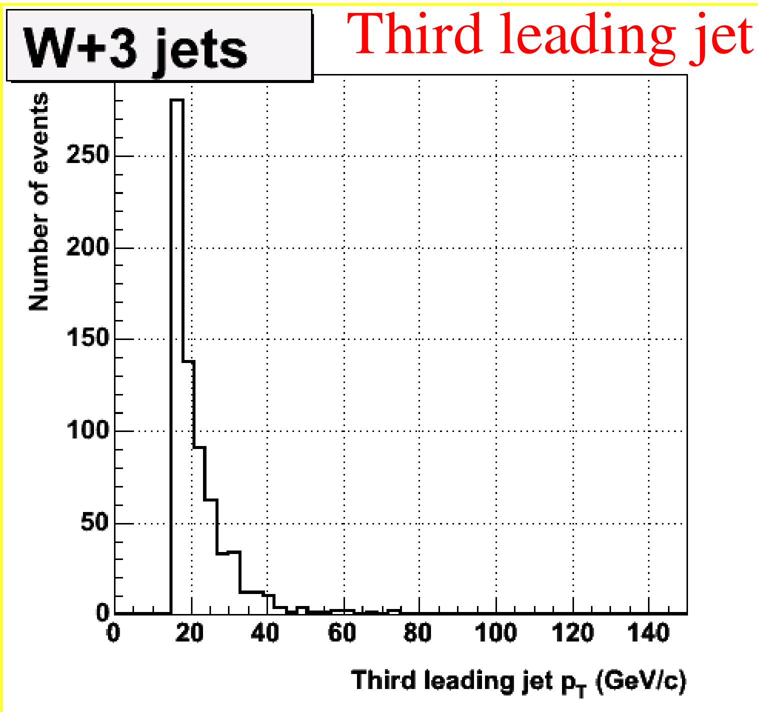
CPF (PV) in W+3 jet Events

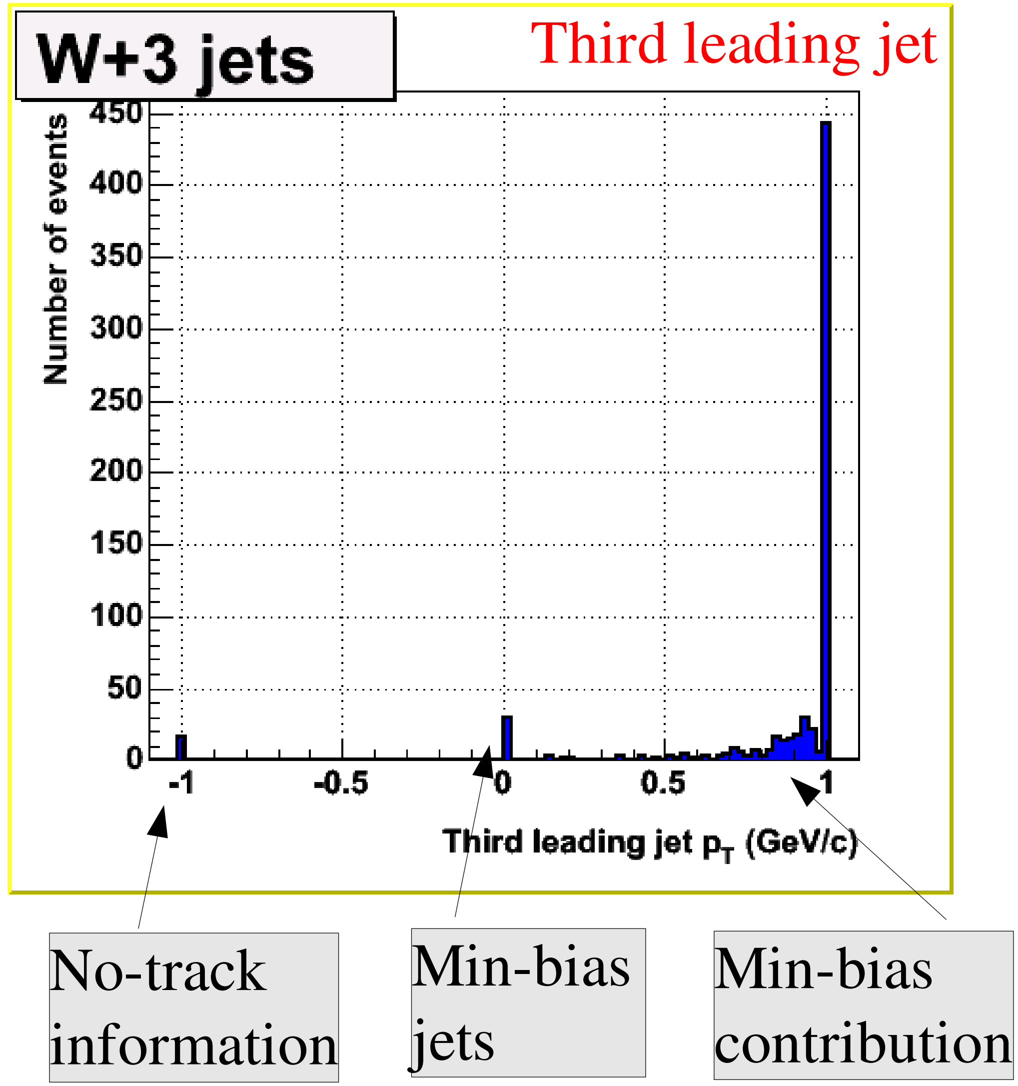




Hard Scatter Primary Vertex (PV) is identified by the high pT lepton from the W decay.
CPF is calculated with respect to the PV for each jet.

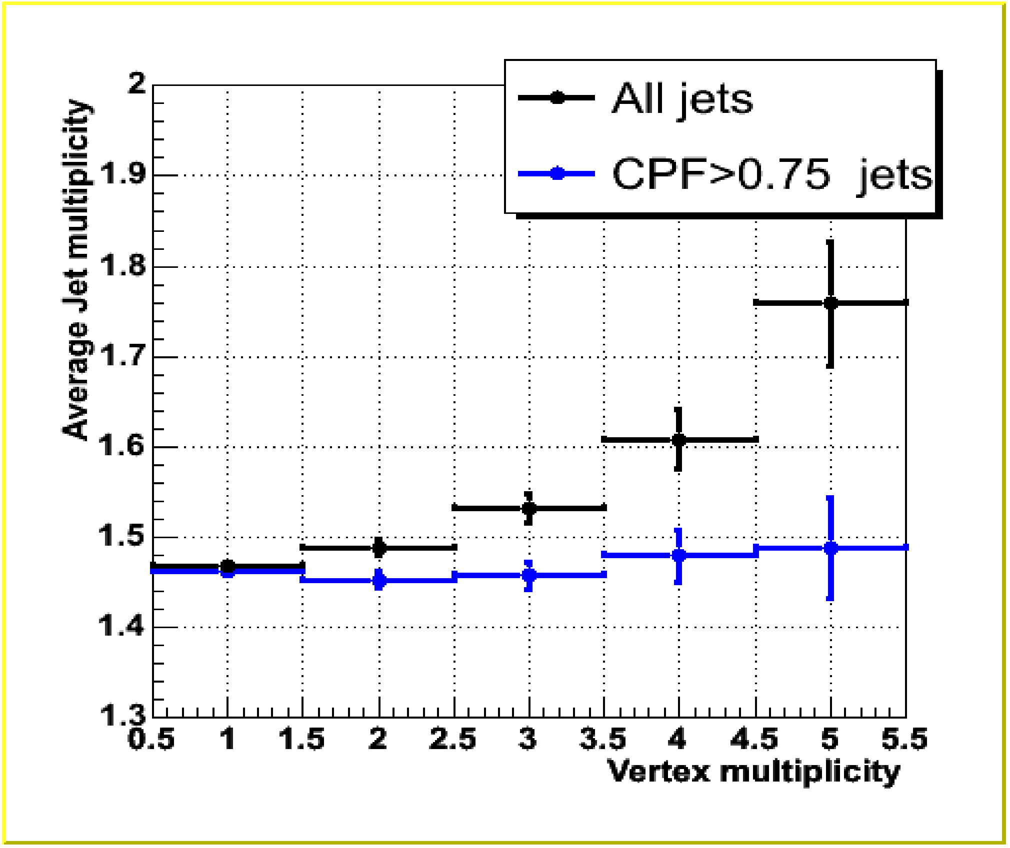
CPF (PV) in W+3 jet Events



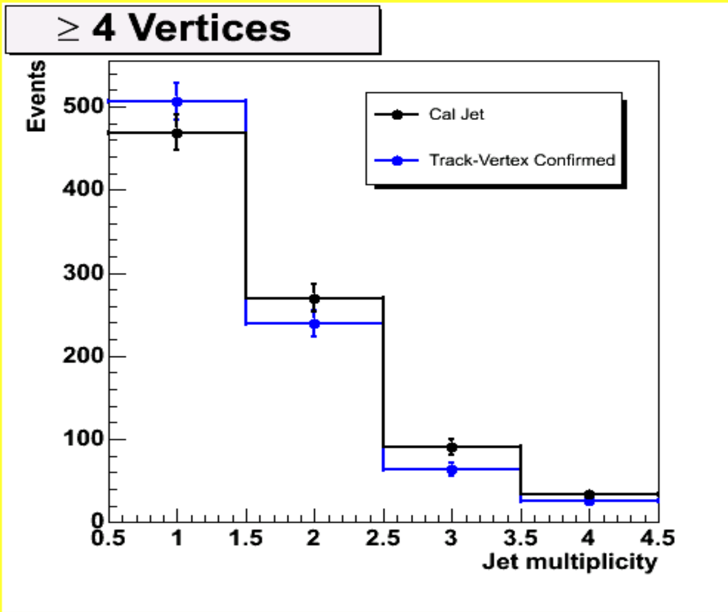


The 3rd leading jet is more likely to be associated to a min-bias interaction.

Jet Multiplicity vs. Number of Vertices



The dependence of jet multiplicity on the number of interactions is significantly reduced for jets with more than 75% of its energy coming from the hard scatter vertex.



Jet-Vertex algorithm allows to identify (remove) soft jets arising from min-bias interactions.

Improving Jet Energy Resolution Using Tracks

Jet energy resolution has two main contributions:

- Intrinsic calorimeter resolution:

  Noise.

  Different responses of electrons/photons and hadrons.

  Magnetic field.

- Jet composition: ← Tracks in jets

  Fragmentation.

Technique: for every charged hadron (track) matched to a jet:

- *subtract* the expected energy deposited in the calorimeter.
- *add* the track momentum.

- *Add* the energy of out-of-cone tracks.

Based on Jet Plus Track CMS Algorithm technique

TrackCalJet Algorithm Overview

Propagate tracks to the calorimeter surface.

dca(xy) < 0.5cm, dca(z) < 1.0 cm.

Classify tracks:

R(vtx)<0.5, R(cal)<0.5 : IN jet

R(vtx)<0.5, R(cal)>0.5 : Out-of-cone

For each IN-jet track:

If $E^{cal}(3x3) / E^{trk} > 0.5$

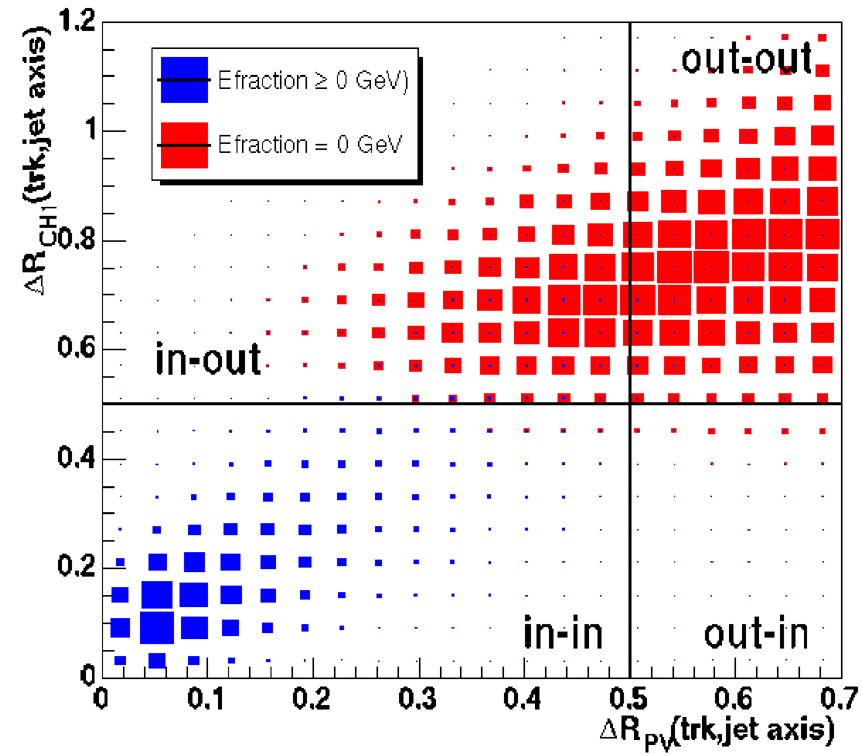
$$E_{jet} = E_{jet} + \left(1 - R^{cal}(E_{track})\right) E_{track}$$

Otherwise,

$$E_{jet} = E_{jet} + E_{track}$$

For each Out-of-cone track:

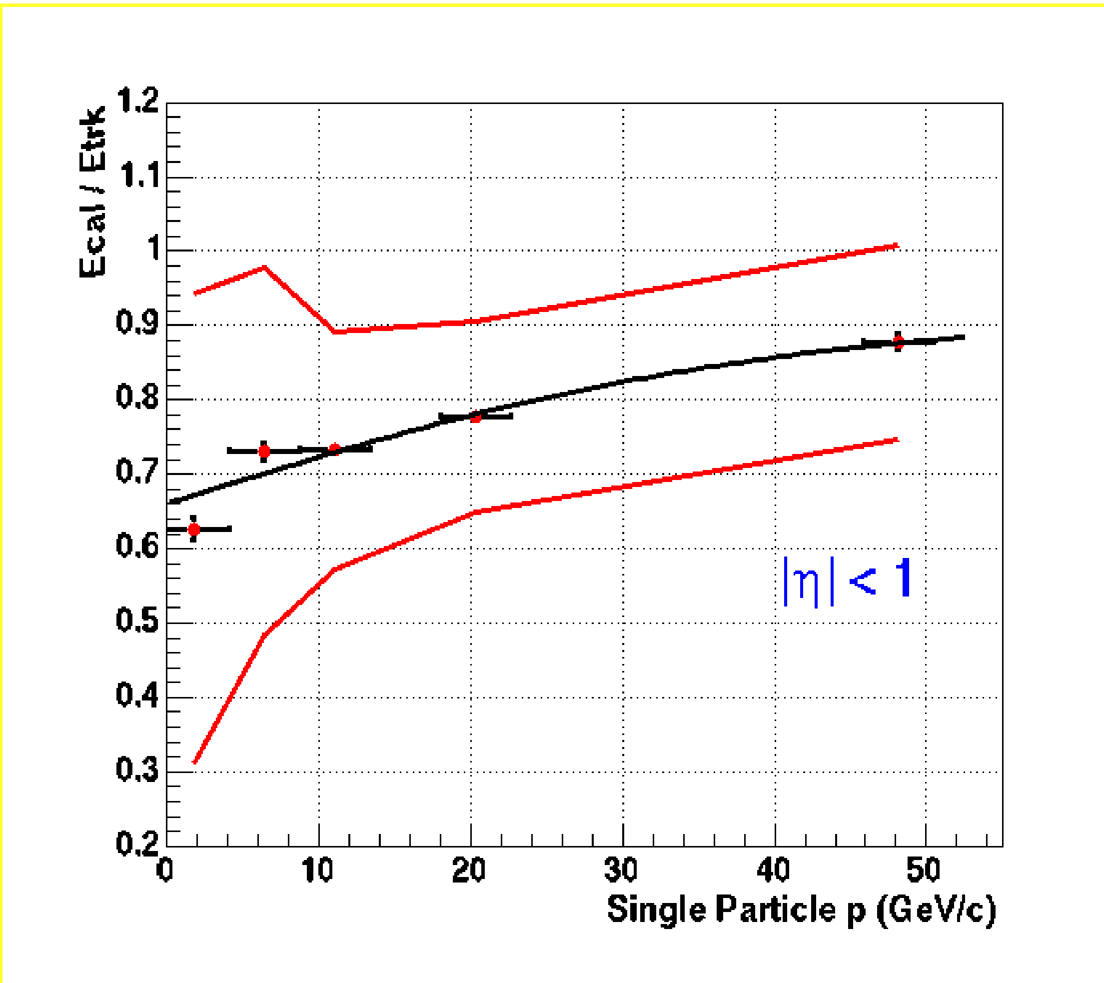
$$E_{jet} = E_{jet} + E_{track}$$



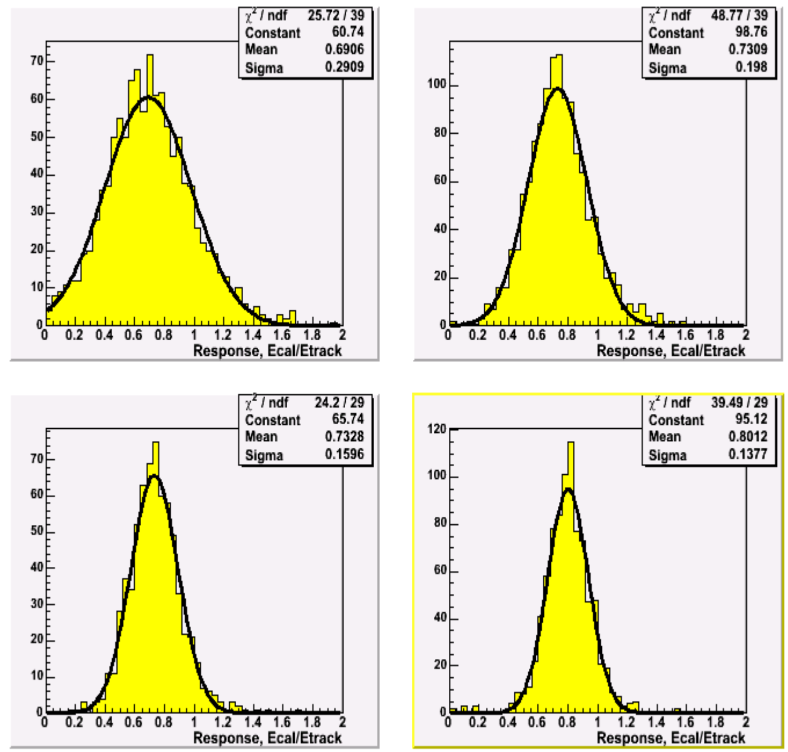
$$R^{cal}(E_{track}) = E^{cal} / E^{track}$$

is the single pion calorimeter response.

Single Pion Response in the Simulation

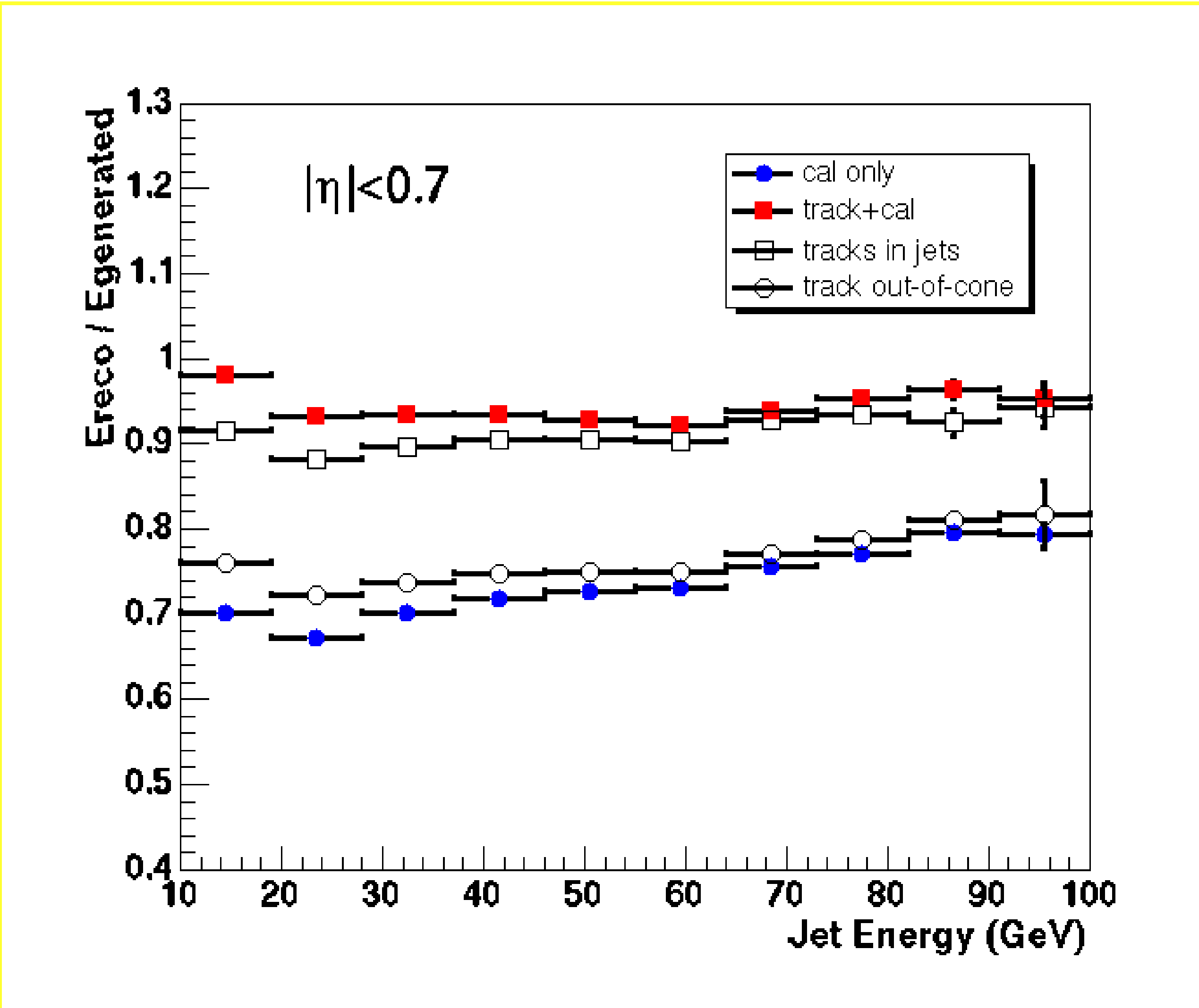


Hadronic response in the Central Calorimeter as a function of track momentum.



Red contour indicates ±1 sigma of Ecal/Etrk resolution.

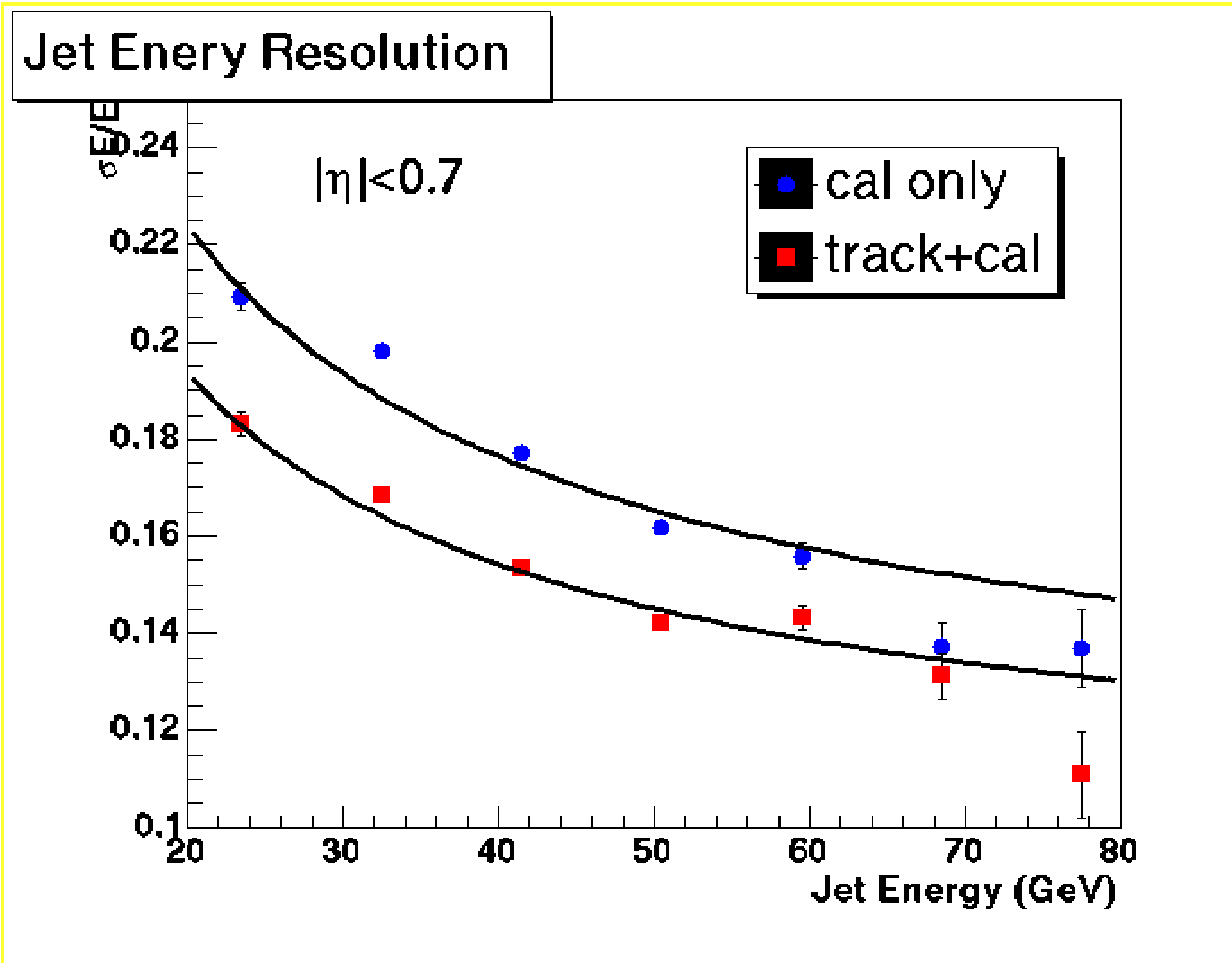
Algorithm Performance in Zqq Events



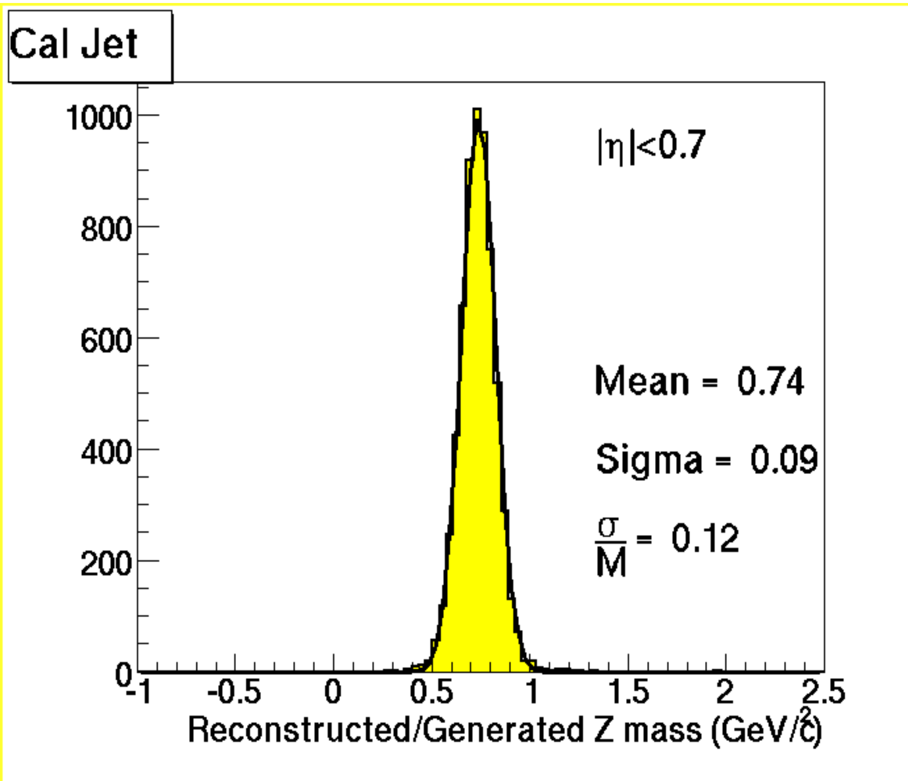
Jet energy scale is significantly improved with the use of tracks.

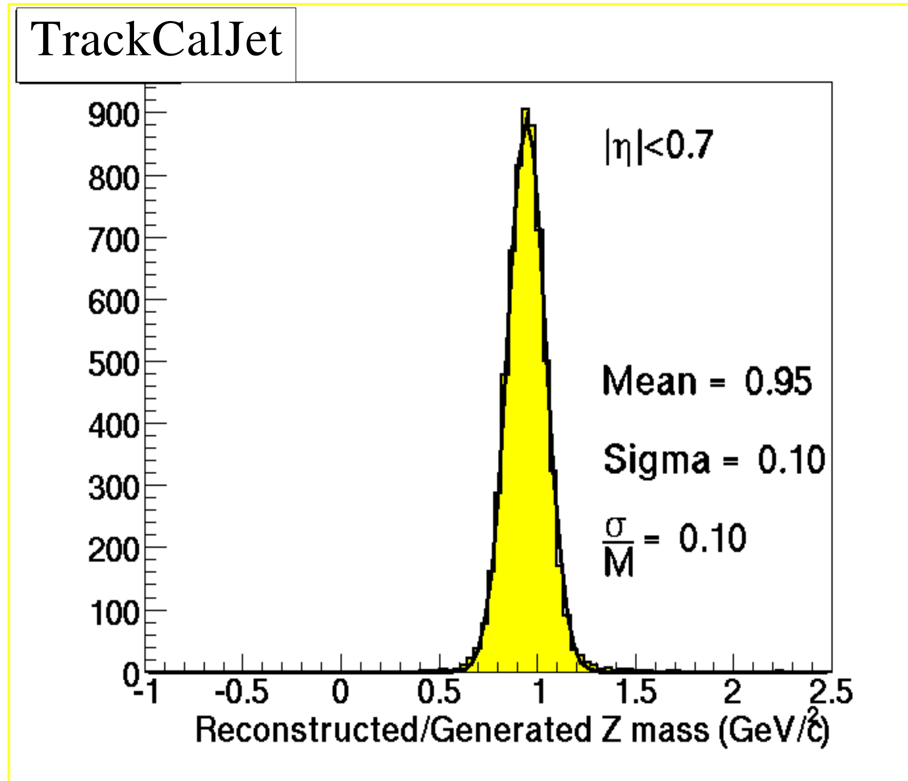
The largest improvement comes from tracks inside the jet cone.

Jet Energy Resolution in Zqq events



Dijet Mass Resolution in Zqq events

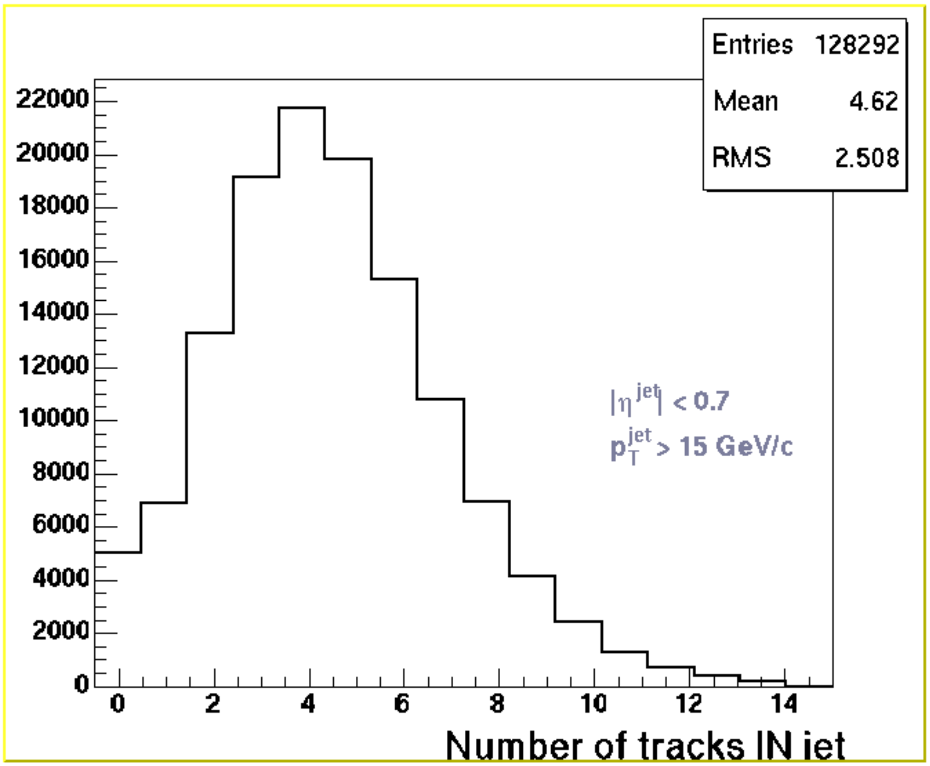


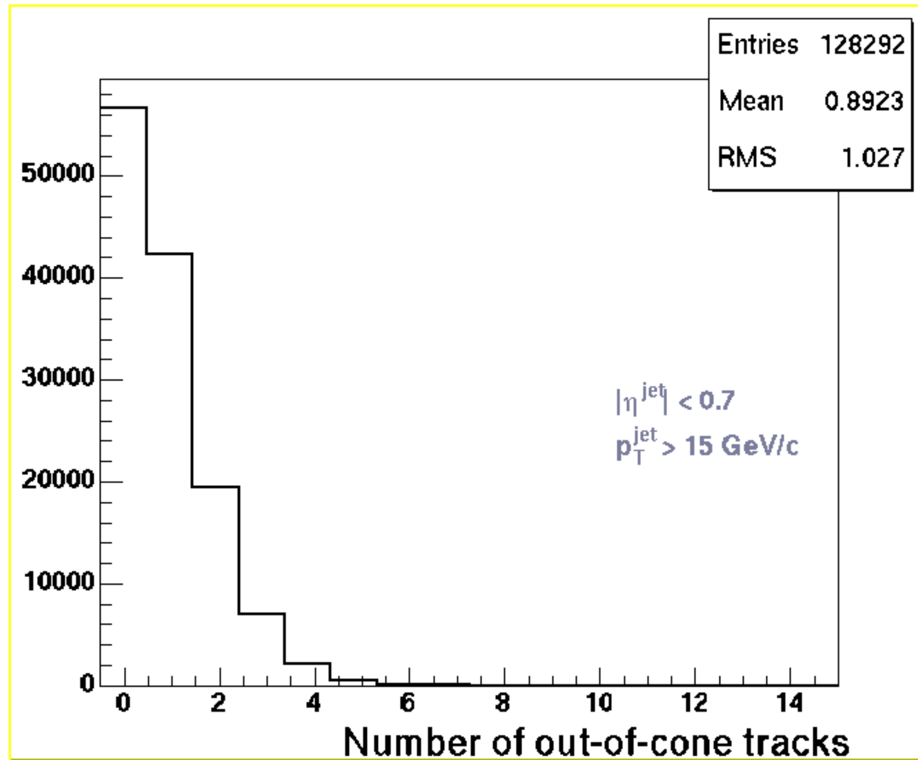


15% mass resolution improvement.

Algorithm Performance in photon +jet Data

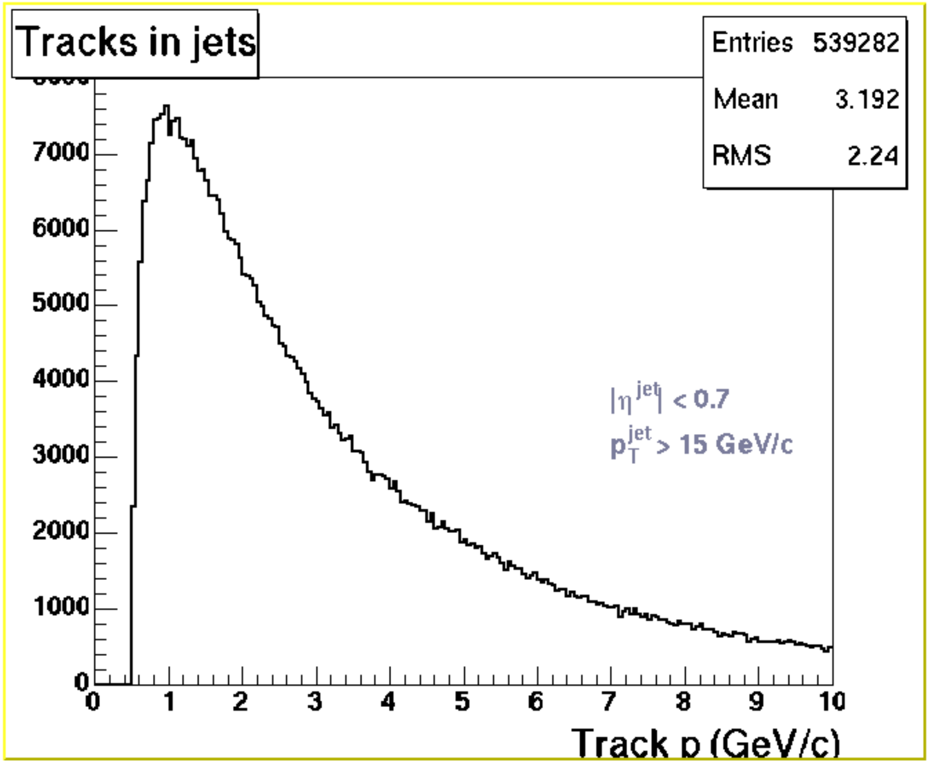
Photon Energy is very well measured: Jet Energy resolution >> photon energy resolution.

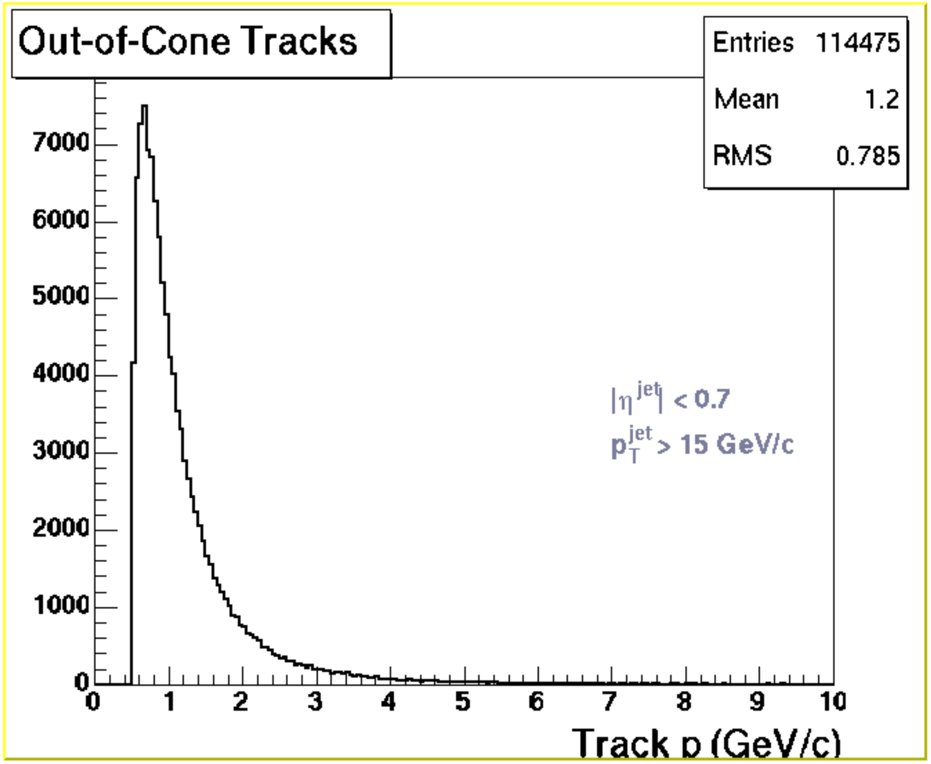




Distribution of number of tracks classified as *IN-jet*, and *Out-of-cone*.

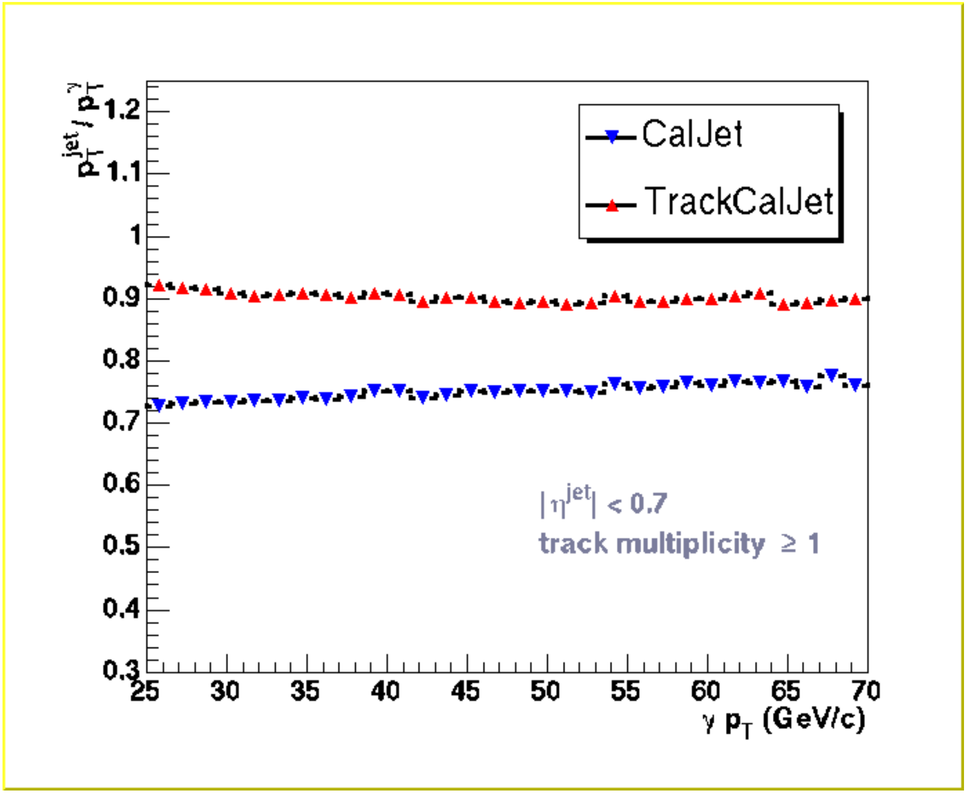
TrackCalJet Kinematics

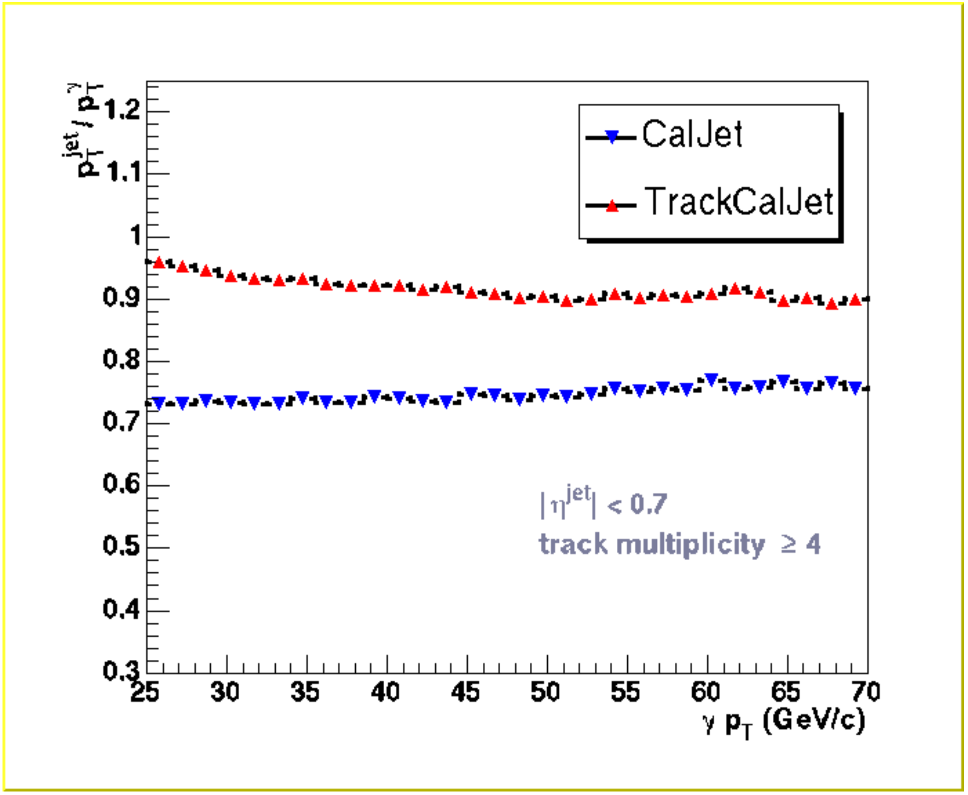




Momentum distribution of tracks classified as *IN-jet*, and *Out-of-cone*.

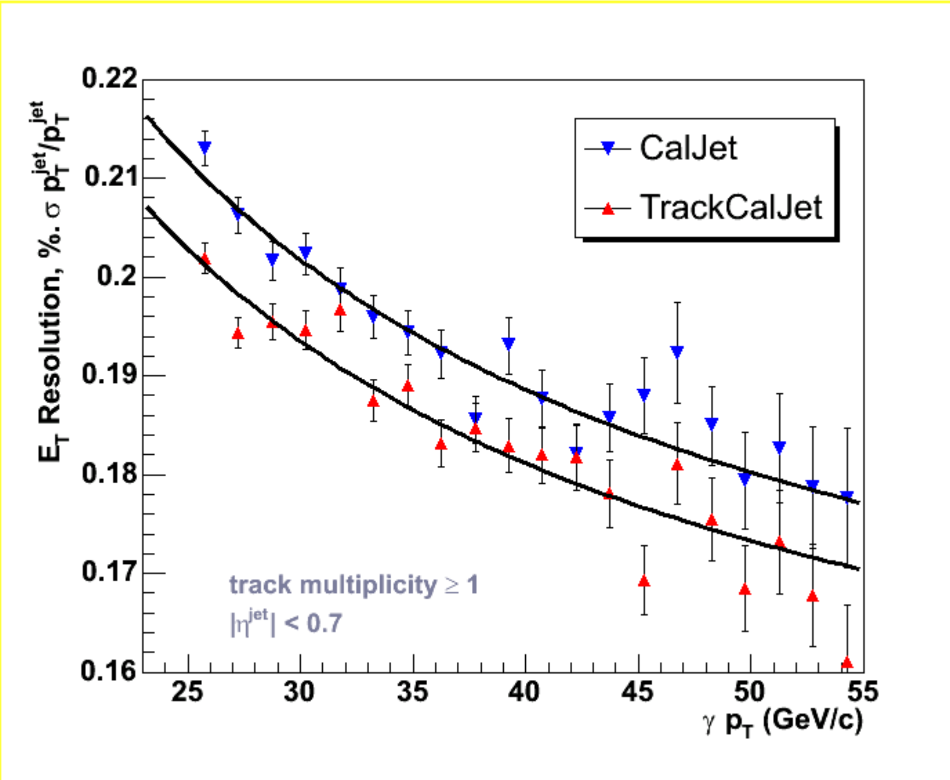
Jet Energy Scale in photon+jet Data

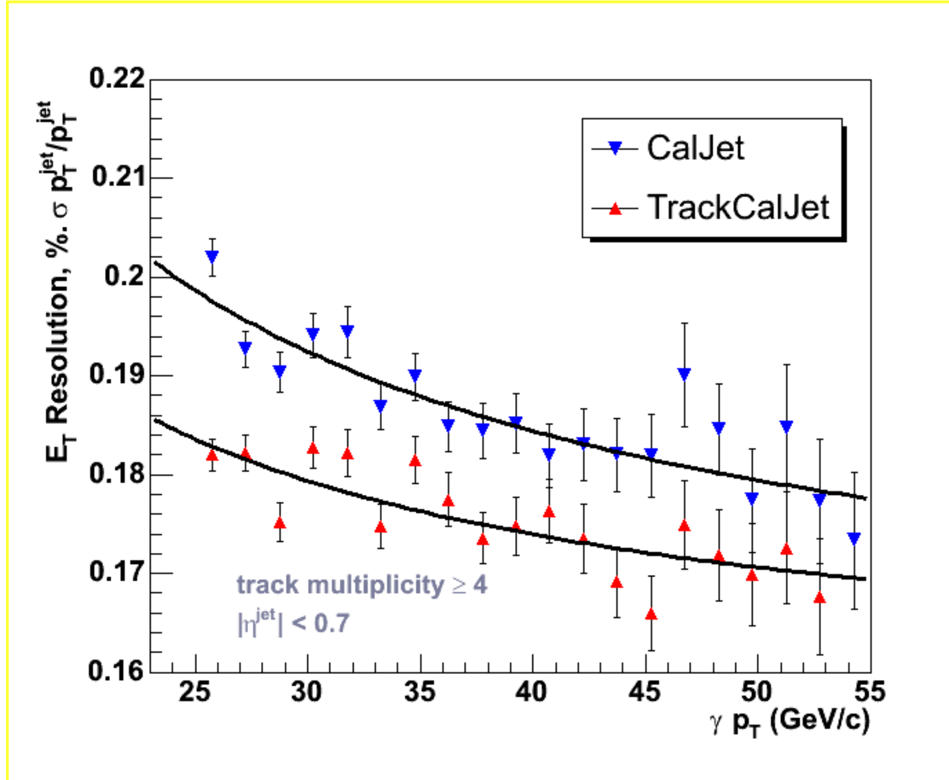




Jet energy offset is significantly improved with the use of tracks.

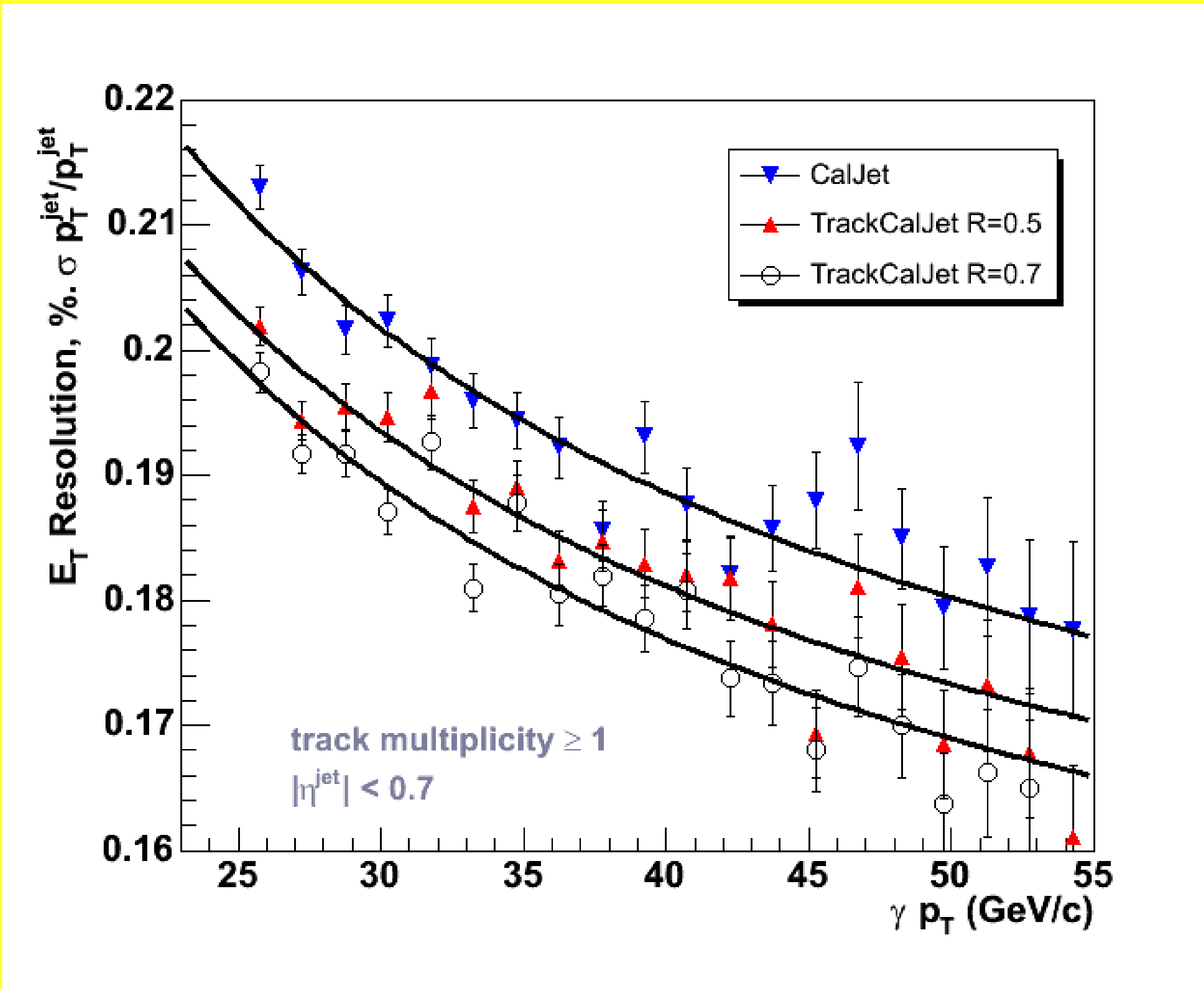
Jet Energy Resolution in photon+jet Data





Jet energy resolution dependence on Jet p_T for low and high track-multiplicity jets. ~10% Improvement.

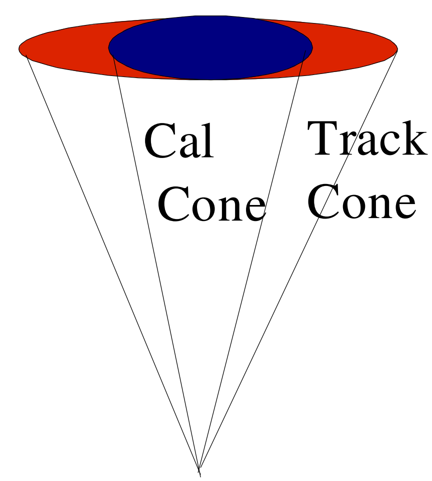
Track Cone Size



Jet Energy Resolution is further improved by using a larger track-cone size.

Rcal = 0.5

Rtrack = 0.7



Summary and Conclusions

Jet reconstruction at high luminosity:

- Additional min-bias interactions produce extra soft jets.
- Event selections based on number of jets are biased towards high luminosity events.
- Jet-Vertex association algorithm allows to discriminate between jets arising from the hard scatter vertex and additional minimum bias interactions.

Improving jet energy resolution using tracks:

- CMS technique for combining tracks and vertices has been implemented.
- 10-15% jet resolution improvement in photon+jet data.
- Largest improvement comes from considering tracks in-jets.
- Increasing the track-cone size further improves the jet resolution.