Jet Reconstruction in the 4th Concept

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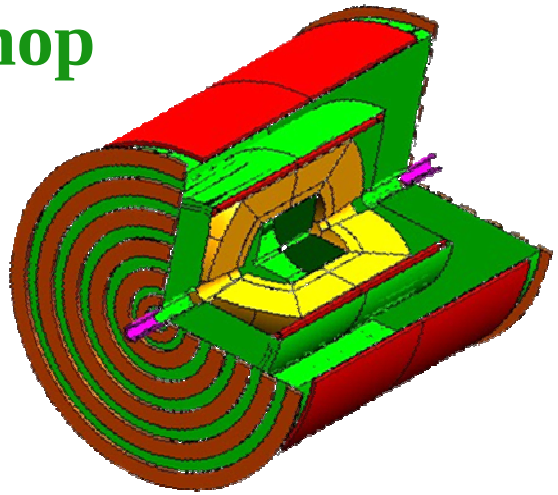
ILC Software Workshop

Orsay, 3rd May 2007



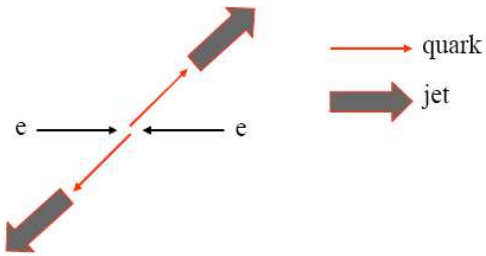
Outline

- Introduction
- Hadron Calorimeter of the 4th Concept
- Jet Finder Algorithm
- Preliminary Results

Jets: from parton to detector level

QCD partons ⇨ jets of hadrons ⇨ detector signals

Quarks and gluons decay because of color confinement: fragmentation



QCD ⇨ { Quark and gluon jets (identified to partons) can be compared to detector jets, if jet algorithms respect collinear and infrared safety (Sterman&Weinberg, 1977)

- **Infrared safeness: if we add a very soft parton to a generic configuration with n partons in the final state, the results of the jet algorithm don't change**

- **Collinear safeness: if we change a parton (massless) with a collinear couple of partons (massless) of equivalent energy and momentum, the results of the jet algorithm don't change**

Jet Definition

A "close" association of "particles" to each other

"particles"

- **partons (analytical calculations or parton showers MC)**
- **hadrons = final state particles**
  (MC particles or charged particles in trackers)
- **towers (or cells or preclusters or any localized energy deposit)**

"close" ⇨ distance

- ⇨ $\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$ **for Cone Algorithm (preferred by experimentalists)**
- ⇨ **relative p_t for k_T Algorithm (preferred by theorists)**

Jet Definition ⟺ Jet Algorithm

The Ideal Jet Algorithm

To compare jets at the parton, hadron and detector level

Jet algorithms should ensure:

General

- infrared and collinear safety
- invariance under longitudinal boosts
- fully specified and straightforward to implement
- same algorithm at the parton, hadron and detector level

Theory

- corrispndence between energy and direction of the final state parton and energy and direction of the jet

Experiment

- independence of detector detailed geometry and granularity
- minimal sensitivity to non-perturbative processes and multiple scatterings at high luminosity
- minimization of resolution smearing/angle bias
- maximal reconstruction efficiency (find all jets) vs minimal CPU time

Jet Reconstruction

- **Associate "close" to each other "particles"**
  ⇨ **Clustering**

- **Calculate jet 4momentum from "particles" 4momenta**
  ⇨ **Recombination**
  (used at the end of clustering process but also during clustering process)

- **Detectors involved**
  trackers ⊗ ECAL ⊗ HCAL
  - **Maximum energy resolution: low momenta particles with tracking, high momenta particles with CAL**
  - **Minimum granularity effects: only tracking**

Jet Reconstruction @ ILC

1. **Particle Flow Analysis (PFA)**

   Calorimeter information combined with measurements from tracking system

   (thought to be the best way to get the highest jet-energy resolution)

2. **Compensation (Dual-Readout Calorimeter) + simplified PFA**

   Two different signals from scintillation light and Ĉerenkov light in the same device to give the reconstructed hadron calorimeter energy (once Cal calibrated)

GLD

LDC

SiD

4th

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$

$$\eta_c = \left(\frac{e}{h}\right)_C$$

$$\eta_S = \left(\frac{e}{h}\right)_S$$

The PFA Calorimeters

Need very small granularity and segmentation along the radius.

Particles reconstruction in 3D.

Expected to be very precise, but huge number of channels.

The Dual Readout Calorimeters

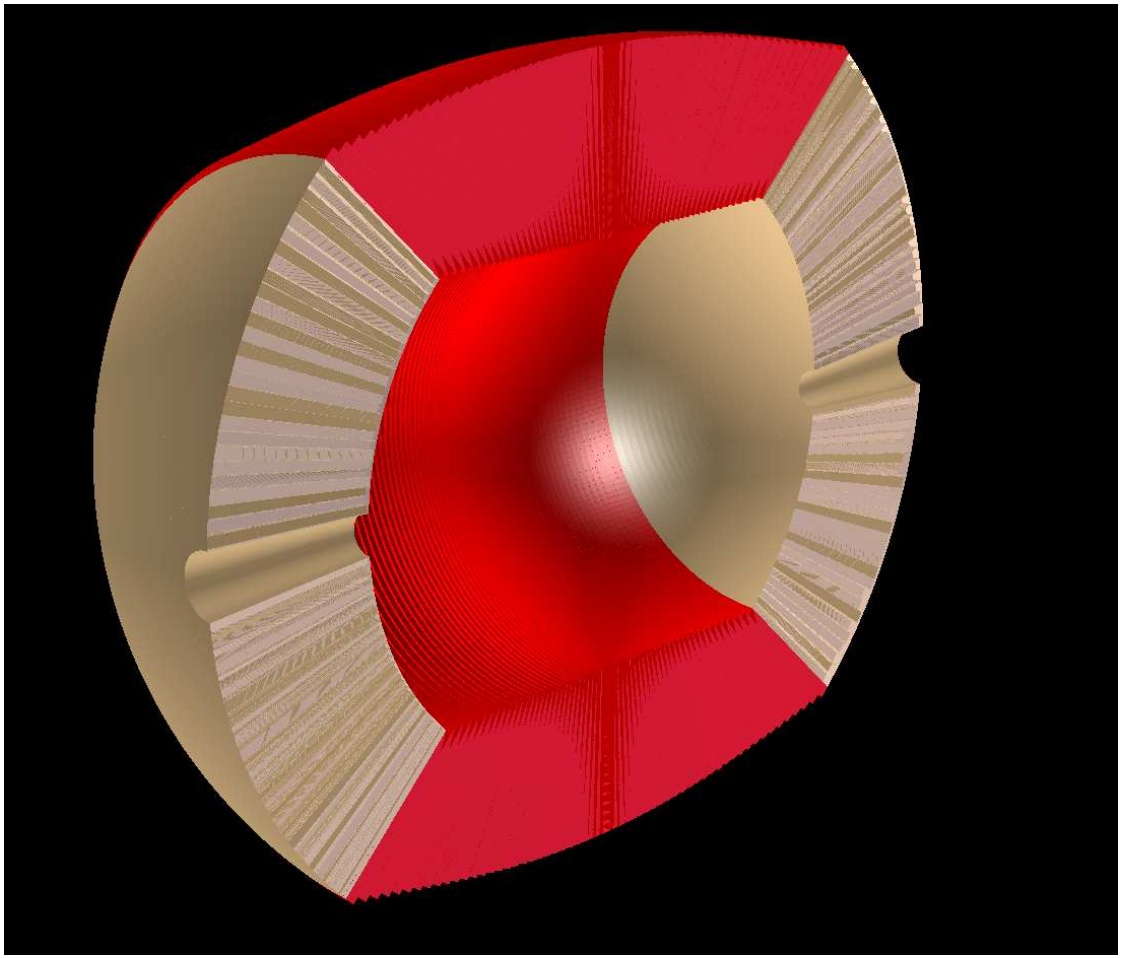
Very small granularity but NO segmentation along the radius.

Particles reconstruction in 2D.

Expected to be very precise (not to the extend PFA calorimeters).

Not huge number of channels.

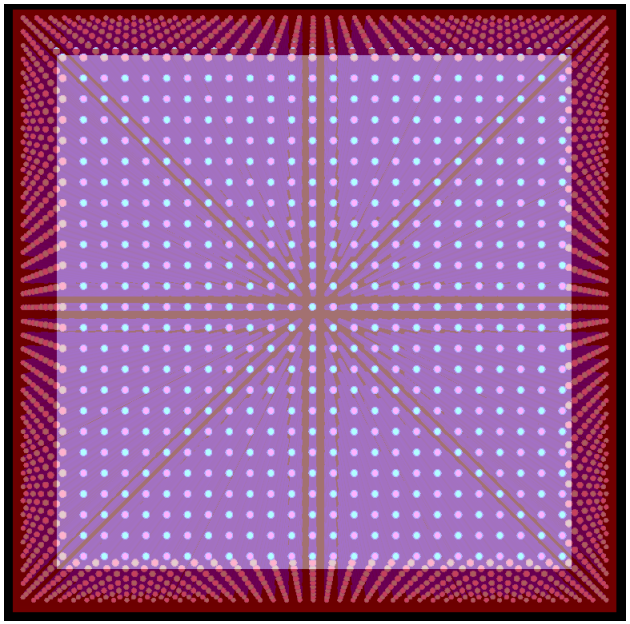
The 4th Concept Hadron Calorimeter



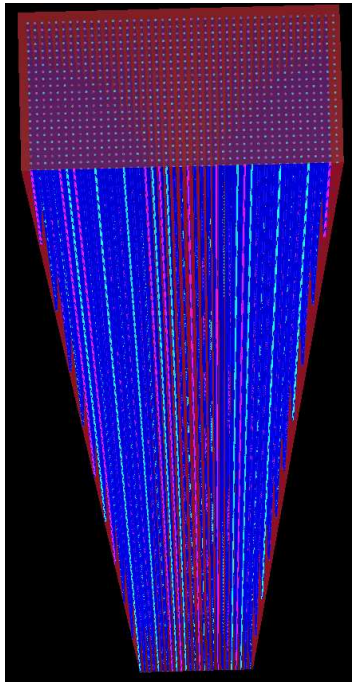
- Cu + scintillating fibers + Ĉerenkov fibers
- ~ 10 λ_{int} depth
- Fully projective geometry
- ~1.5° aperture angle
- Azimuth coverage down to 3.8°
- Barrel: 13924 cells
- Endcaps: 3164 cells

Hadronic Calorimeter Cell

Bottom view of single cell



Top cell size: ~ 4 cm



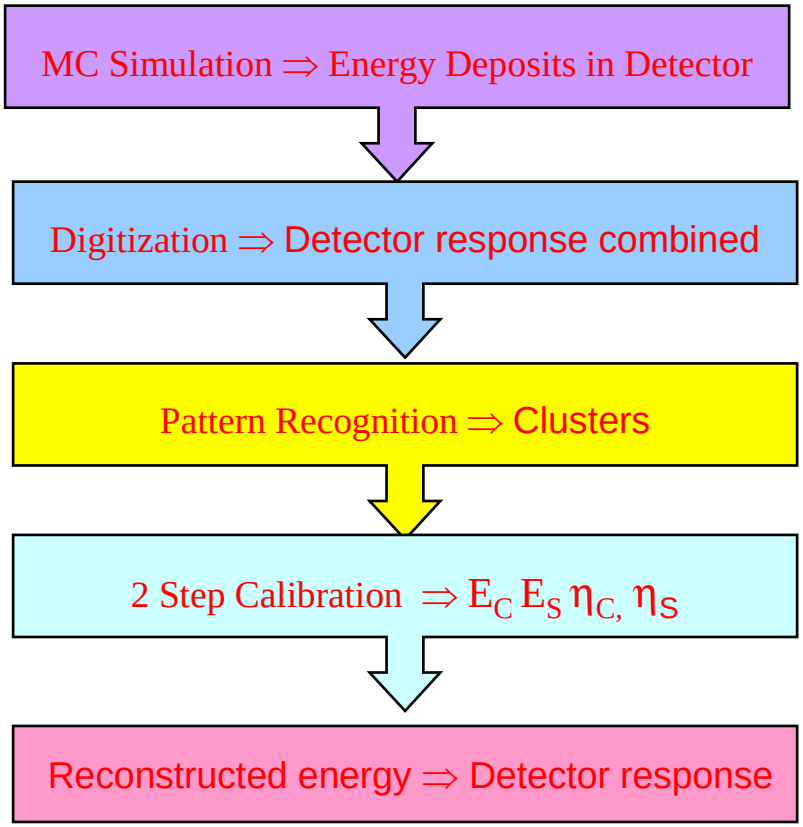
Prospective view of clipped cell

Cell length:
150 cm (but DoD has 100cm)

Number of fibers inside each cell: 1980 equally subdivided between Scintillating and Cerenkov
Fiber stepping ~2 mm

Bottom cell size: ~2 cm

Simulation/Reconstruction Steps



Simulation (1)

Light production in the fibers simulated through separate steps:

1. **Energy deposition (hits) in active materials calculated by the tracking algorithm of the MC**

1. Conversion of the energy into the number of S and C photons by specific algorithms taking account several factors: energy of the particle, angle between the particle and the fiber, etc. Poisson uncertaintity introduced in the number of photon produced

Simulation (2)

- **Response function of the electronics not yet simulated (digits)**

- **Random noise generated to test the ability of reconstruction algorithm to reject such spurious "hits"**

Reconstruction

- **Clusterization (⟹ pattern recognition)**

  cluster = collection of nearby "digits"

  - **Build Clusters from cells distant no more than two towers away**
  - **Unfold overlapping clusters through a Minuit fit to cluster shape**

- **Reconstructed energy E adding separately E_S and E_C of all the cells belonging to the reconstructed cluster**

4th Concept Jet Reconstruction

Hybrid jet algorithm implemented (compensation + simplified PFA)

- **Jet axis**
  - **Look for the jet axis using a Durham algorithm**
  - **Charged tracks**
  - **Calorimeter cells**
  - **Calorimeter Clusters**
- **Jet core**
  - **Open a cone increasingly bigger around the jet axis (< 60°)**
  - **Run a Durham j.f. on the cells of the calorimeter inside the cone**
- **Jet outliers**
  - **Check leftover/isolated calo clusters/cells for match with a track from TPC+VXD**
  - **Add calorimetric or track momentum (special care for V0's)**
  - **Add low P_t tracks not reaching the calorimeter**
- **Muons**
  - **Add tracks reconstructed in the Muon Detector**

Run a Durham j.f. on the cells/tracks/clusters

New Results

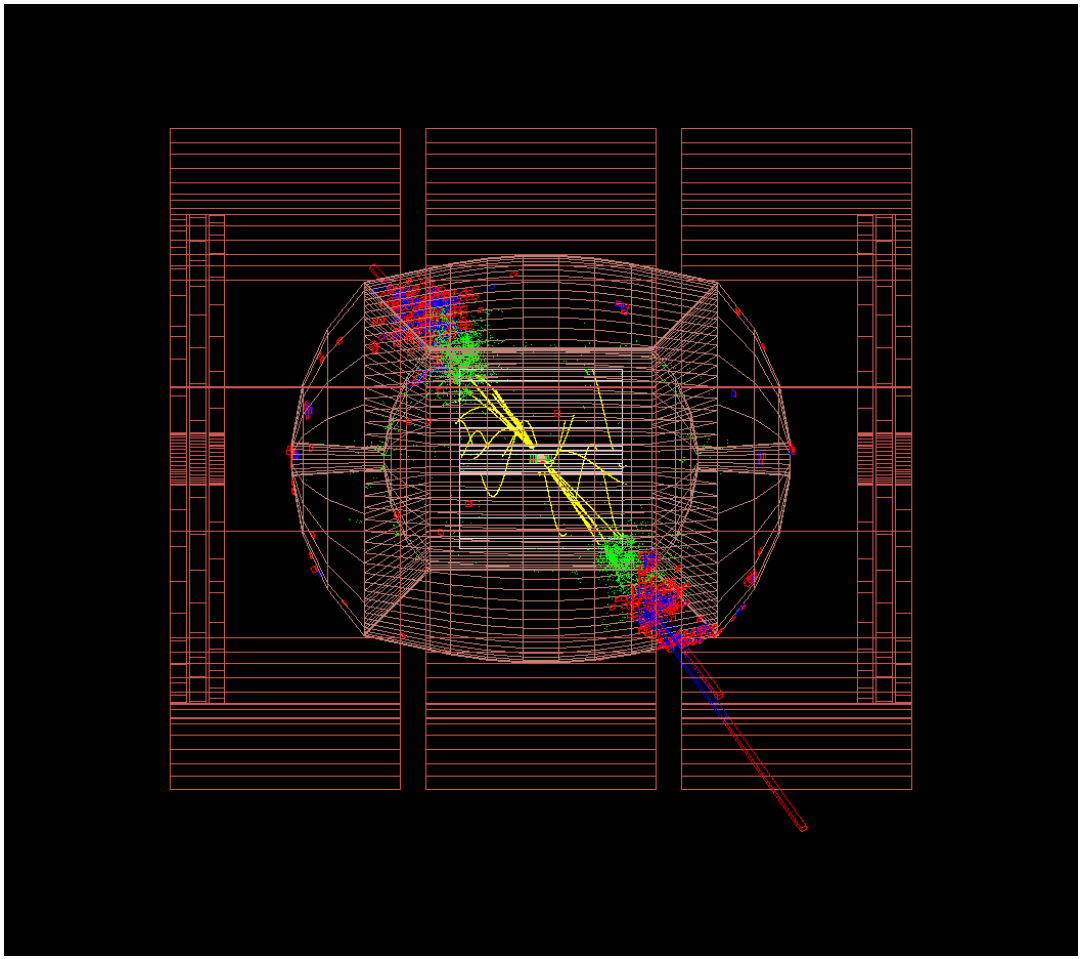
- **Generated (Pandora-Pythia)**

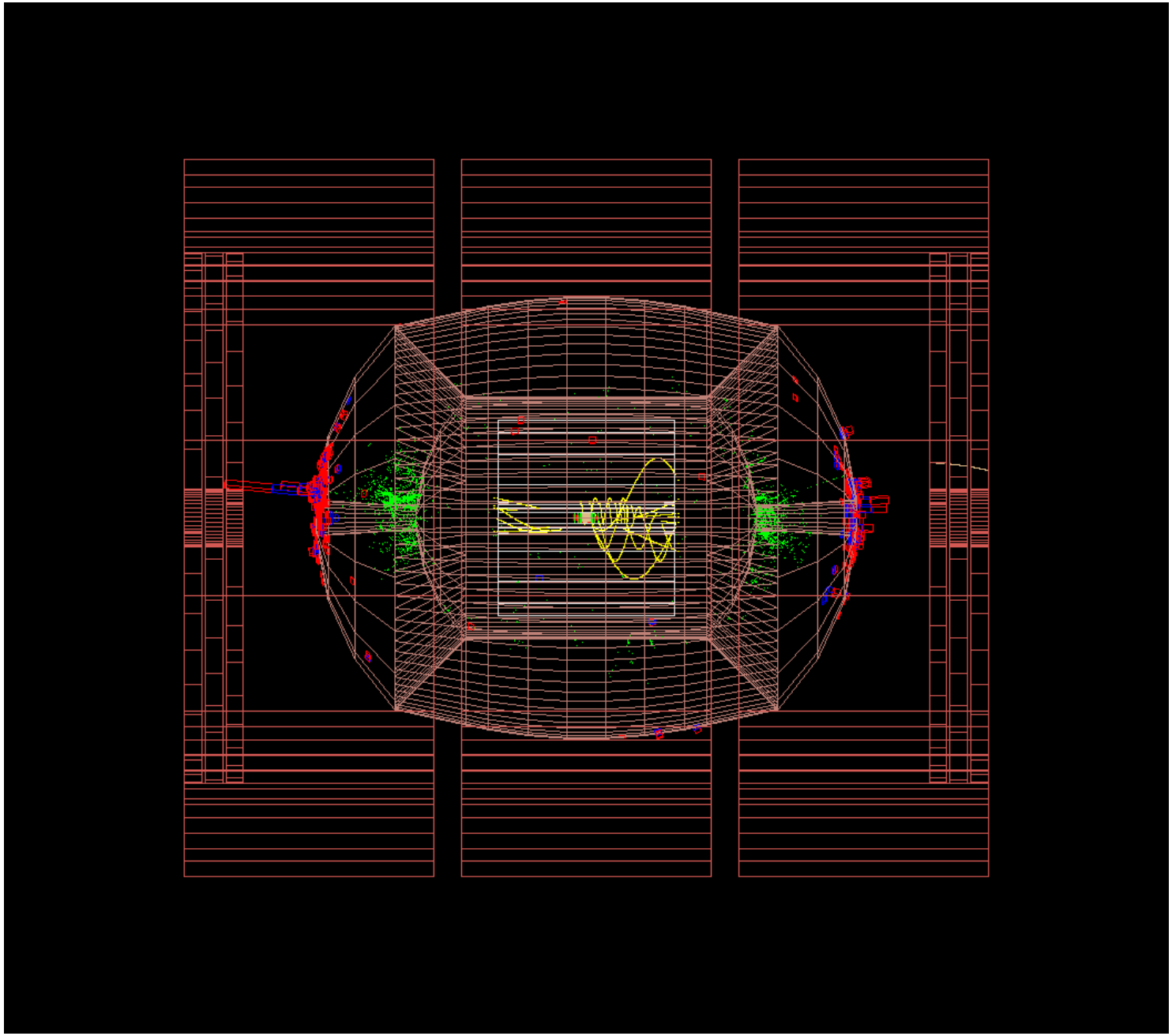
  $e^+ e^- \longrightarrow q\ qbar$ (q=uds)

  $e^+ e^- \longrightarrow z^0 h^0 \longrightarrow q\ qbar\ b\ bbar$
- **Simulated hits (Fluka)**
- **Reconstructed tracks and calo clusters**

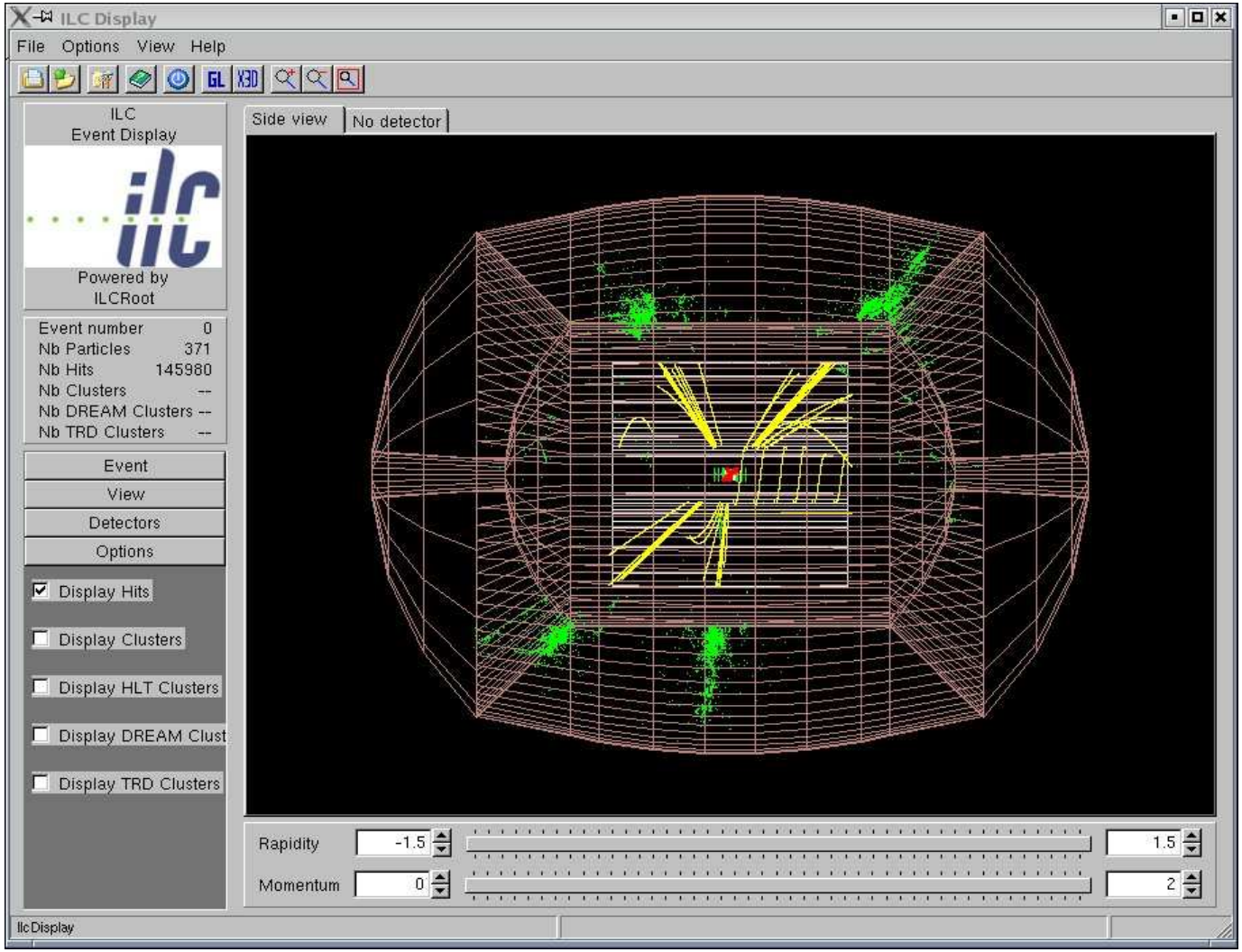
Same framework: IlcRoot

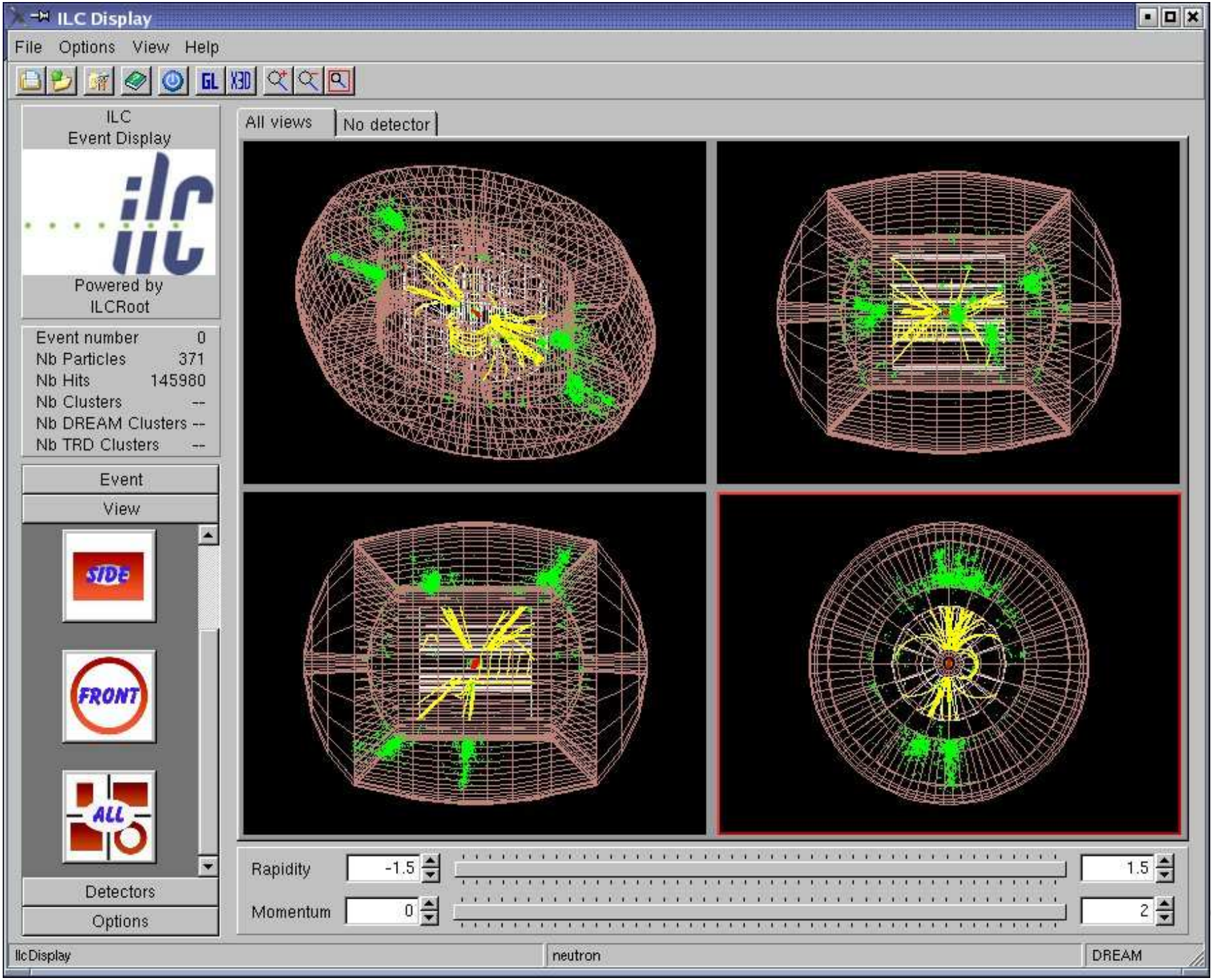
IlcRoot Event Display: dijets





IlcRoot Event Display: four jets




ILC Display
File Options View Help
ILC
Event Display
Powered by
ILCRoot
Event number 0
Nb Particles 371
Nb Hits 145980
Nb Clusters --
Nb DREAM Clusters --
Nb TRD Clusters --
Event
View
SIDE
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Detectors
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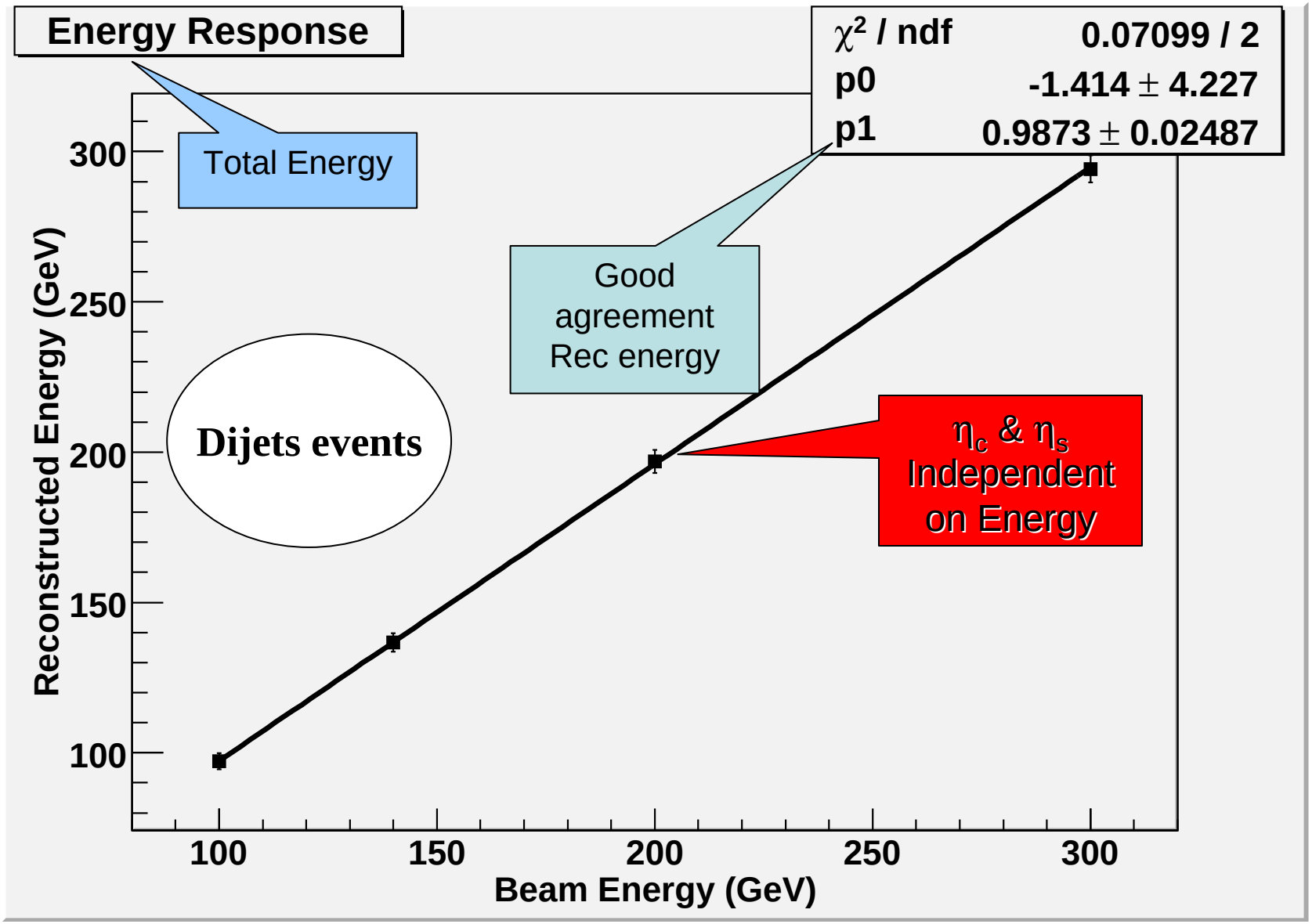
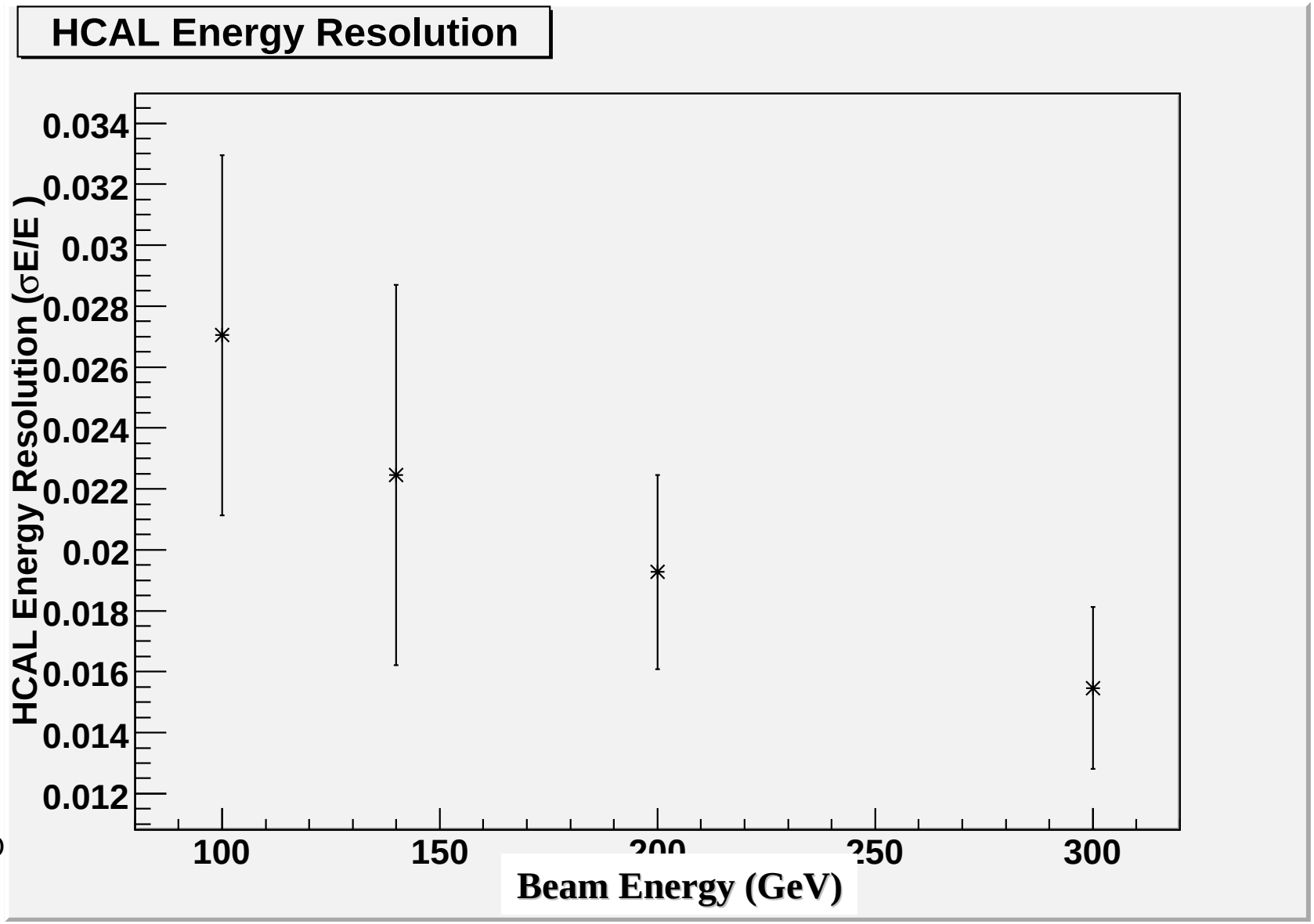
All views
No detector
Rapidity -1.5 1.5
Momentum 0 2
IlcDisplay
neutron
DREAM

Energy Response (visible)

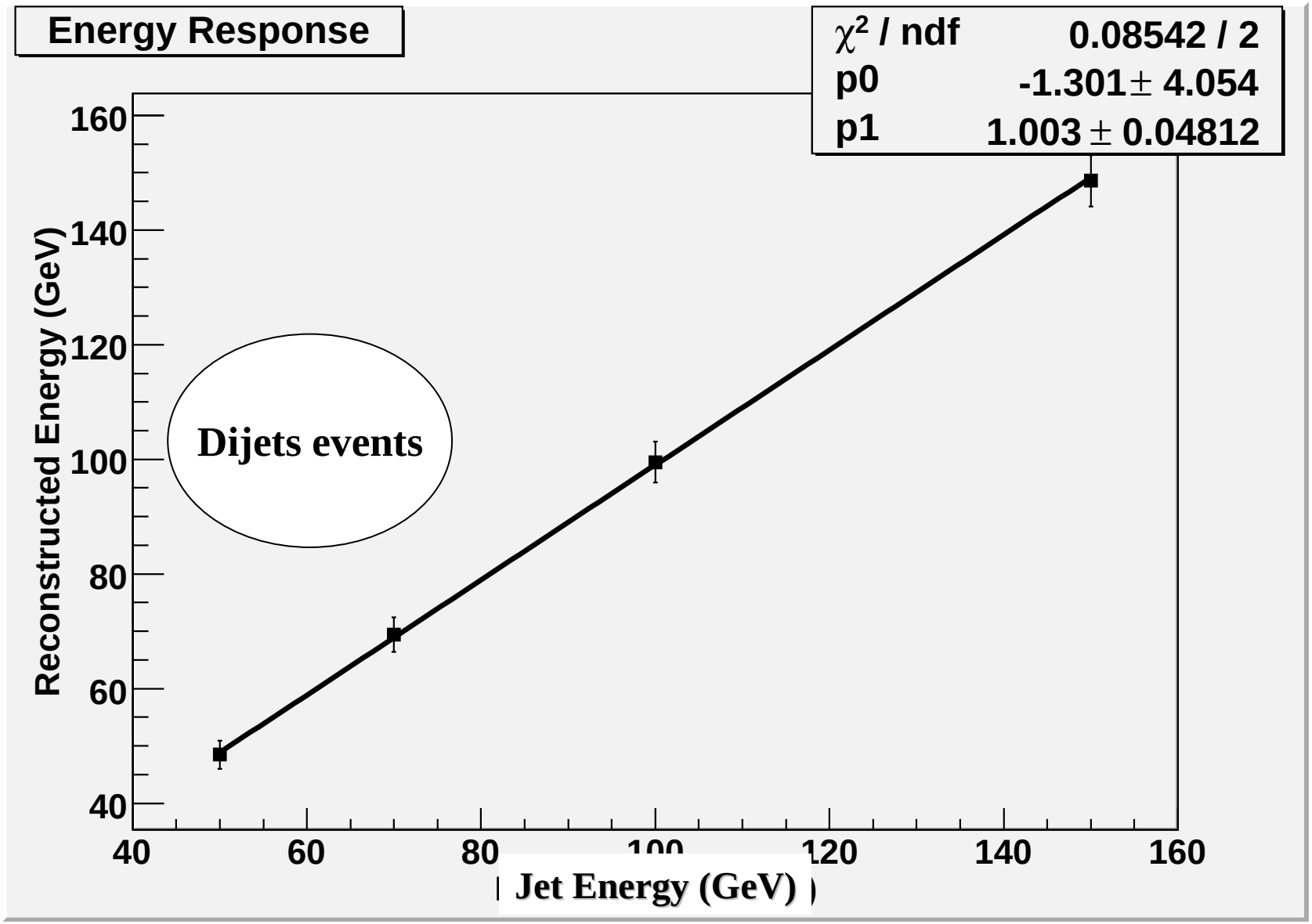


Energy Resolution (visible)

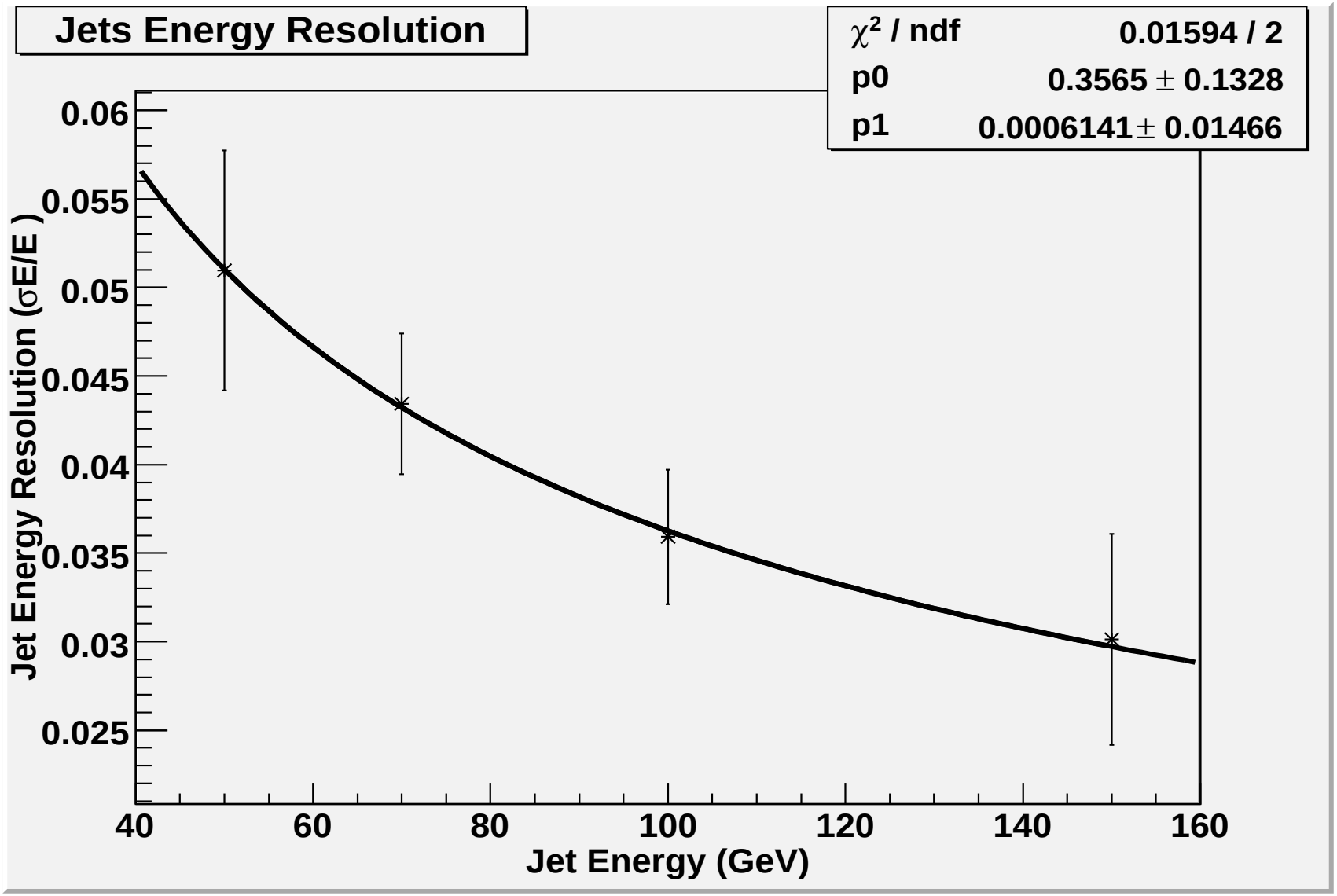


O

Energy Response (single jets)

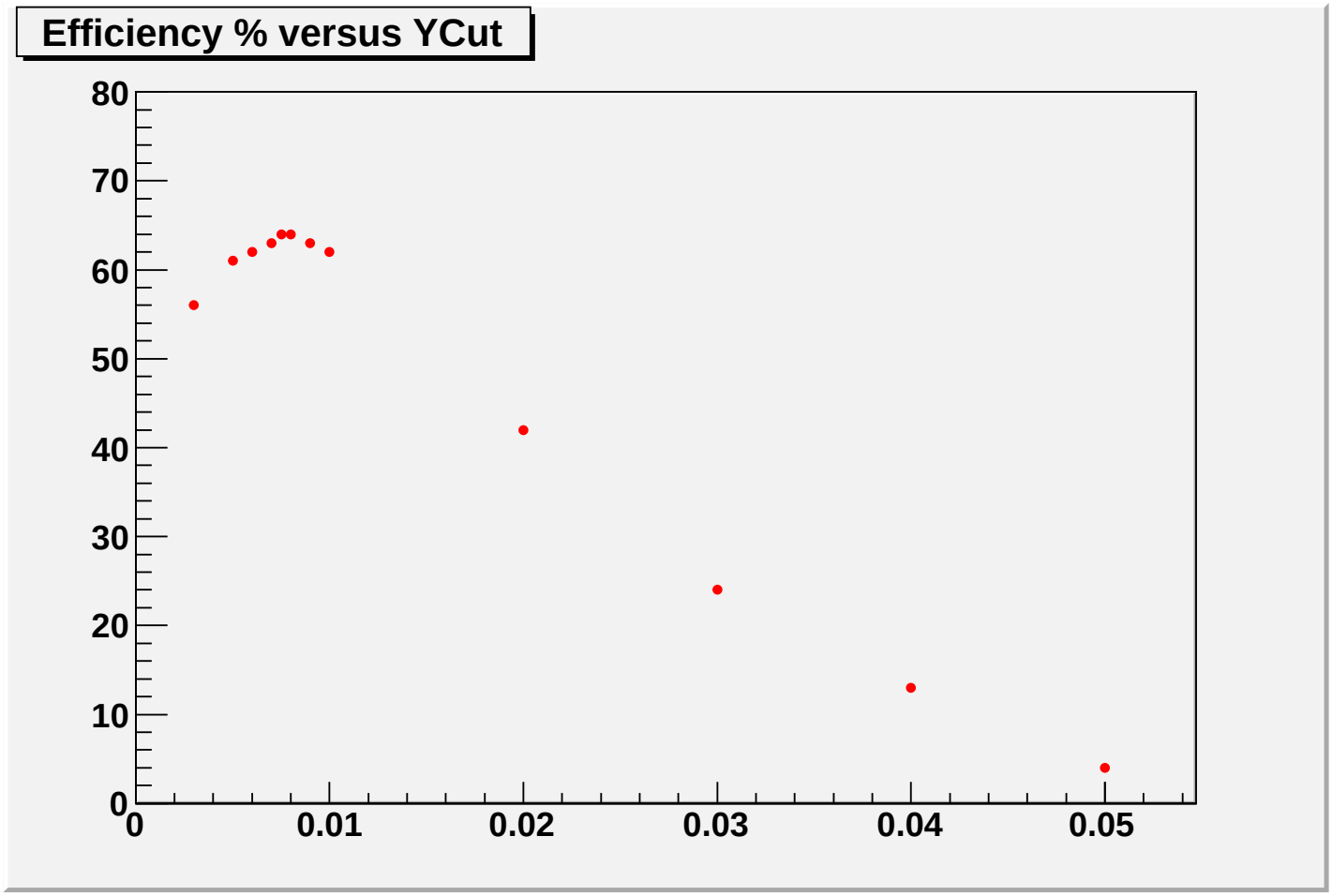


Energy Resolution (single jets)

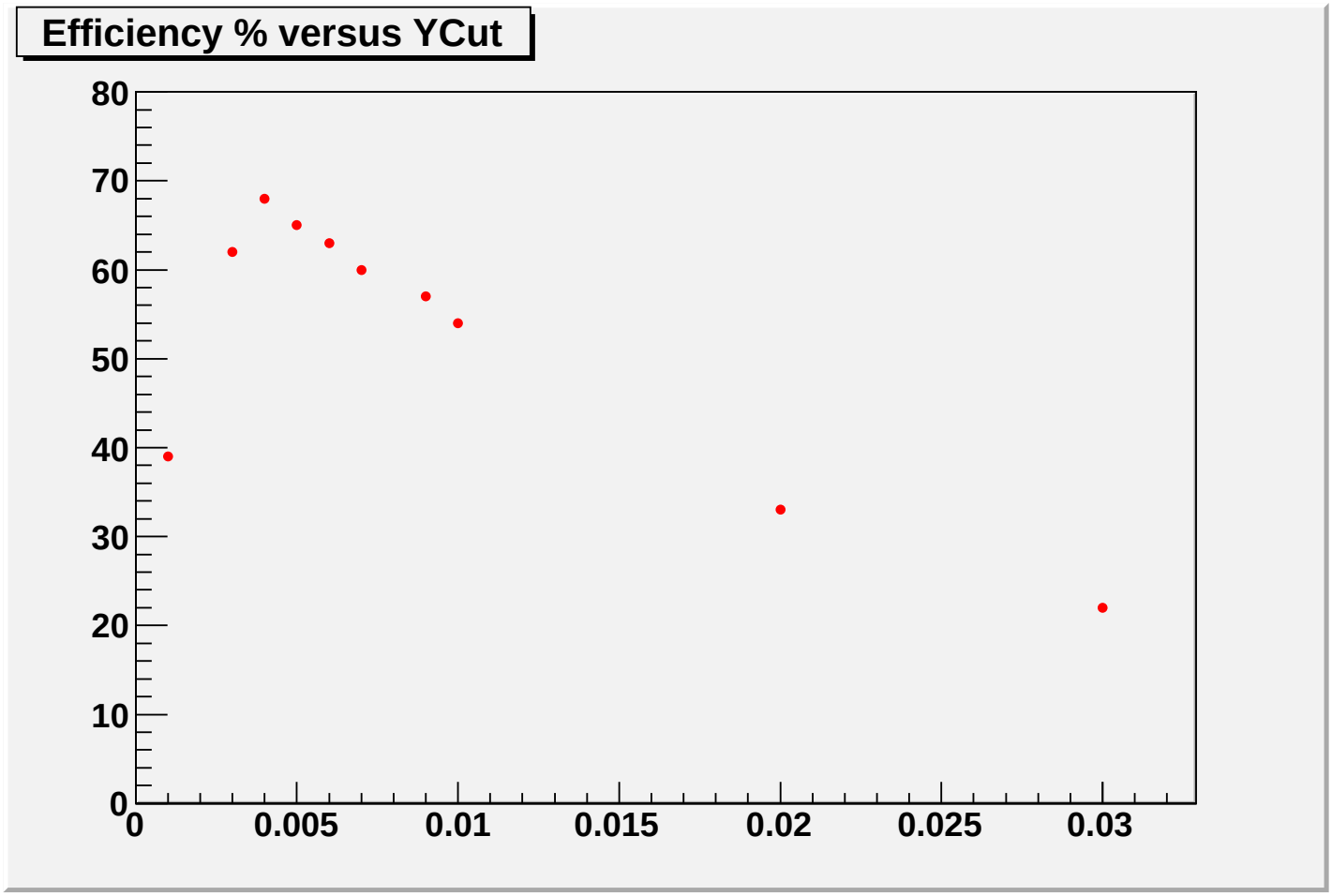


ZH → qqbb Preliminary Studies

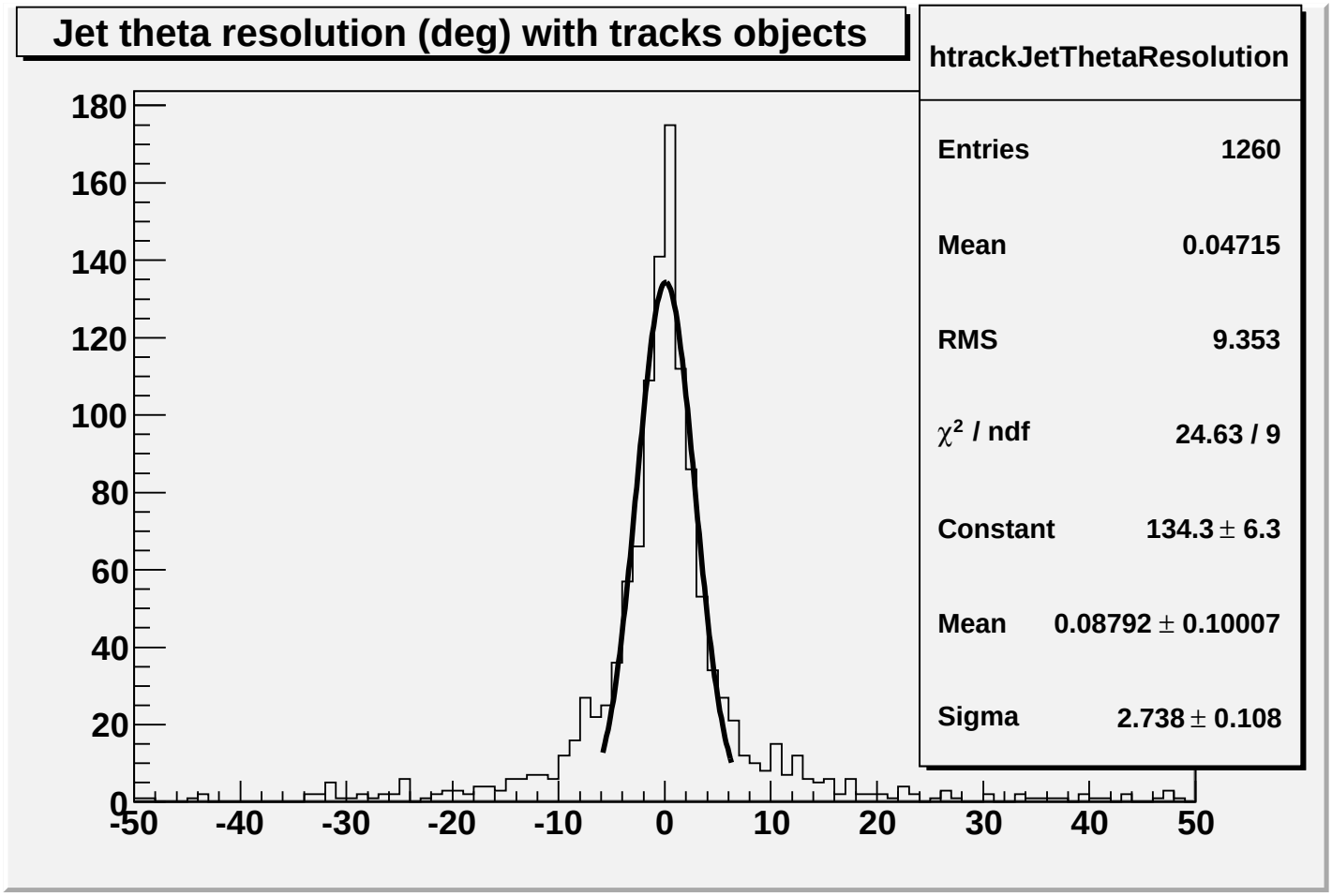
Jet Finder Efficiency with track objects



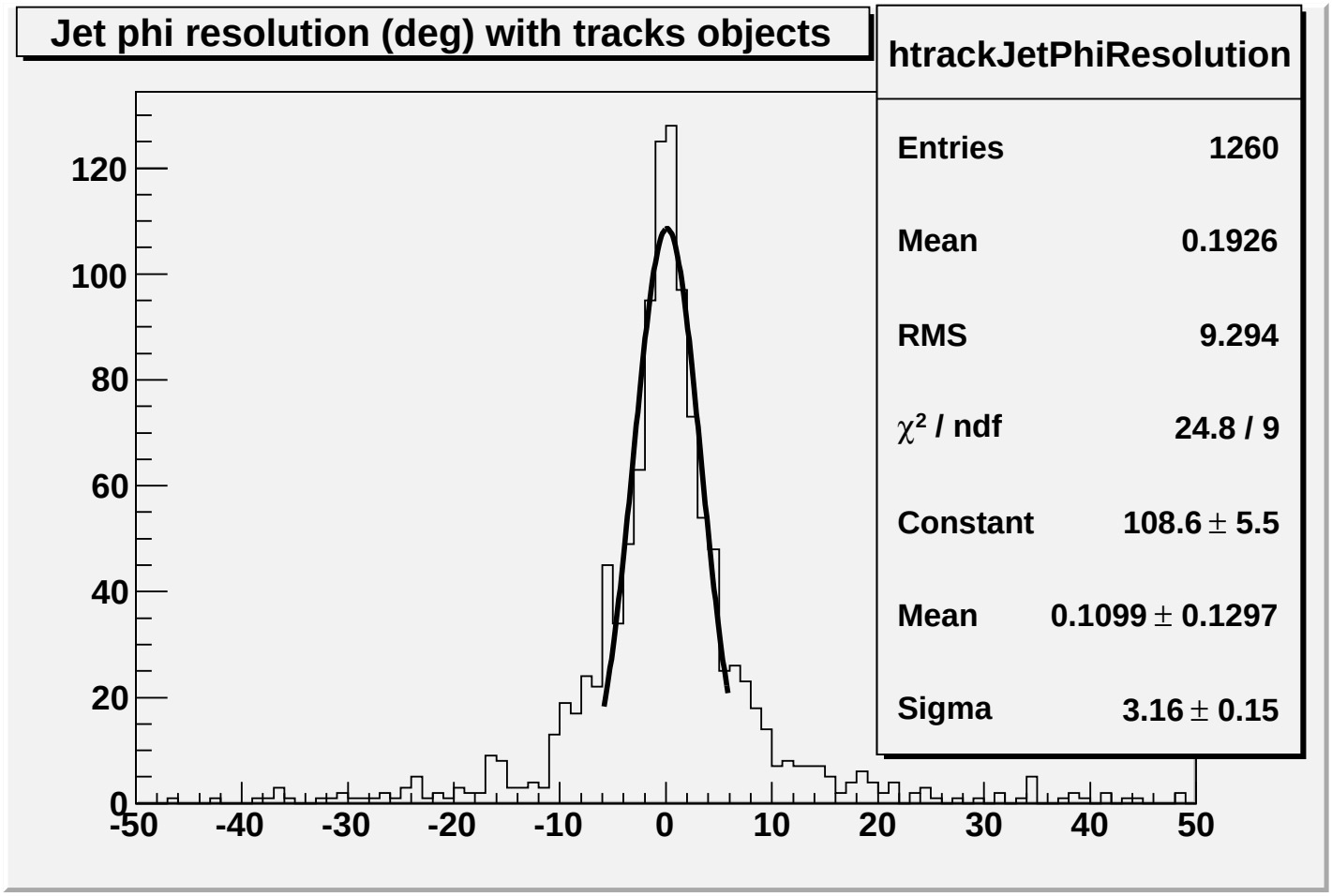
Jet Finder Efficiency with cluster/cell objects



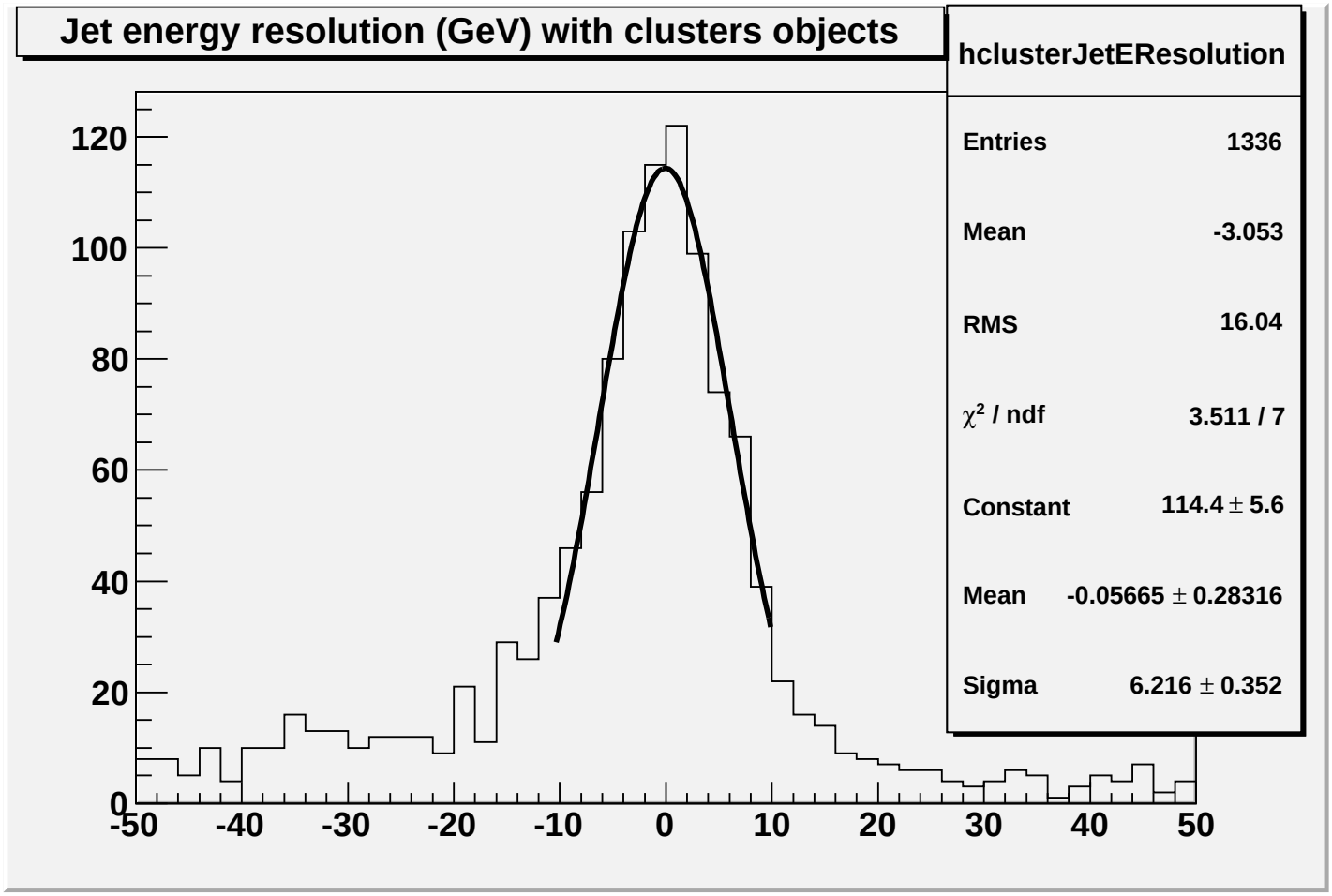
Resolutions with track objects(θ)



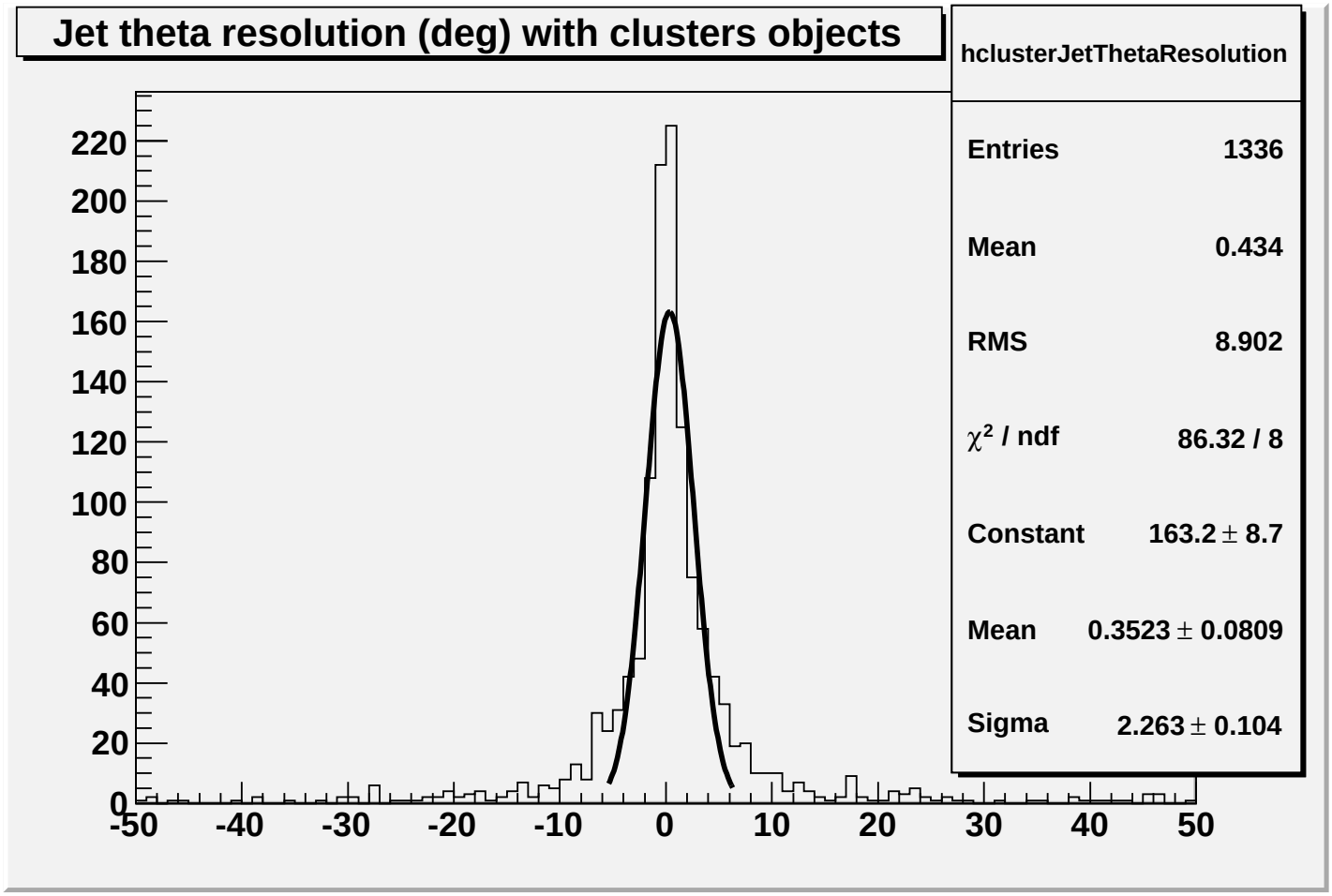
Resolutions with track objects(Φ)



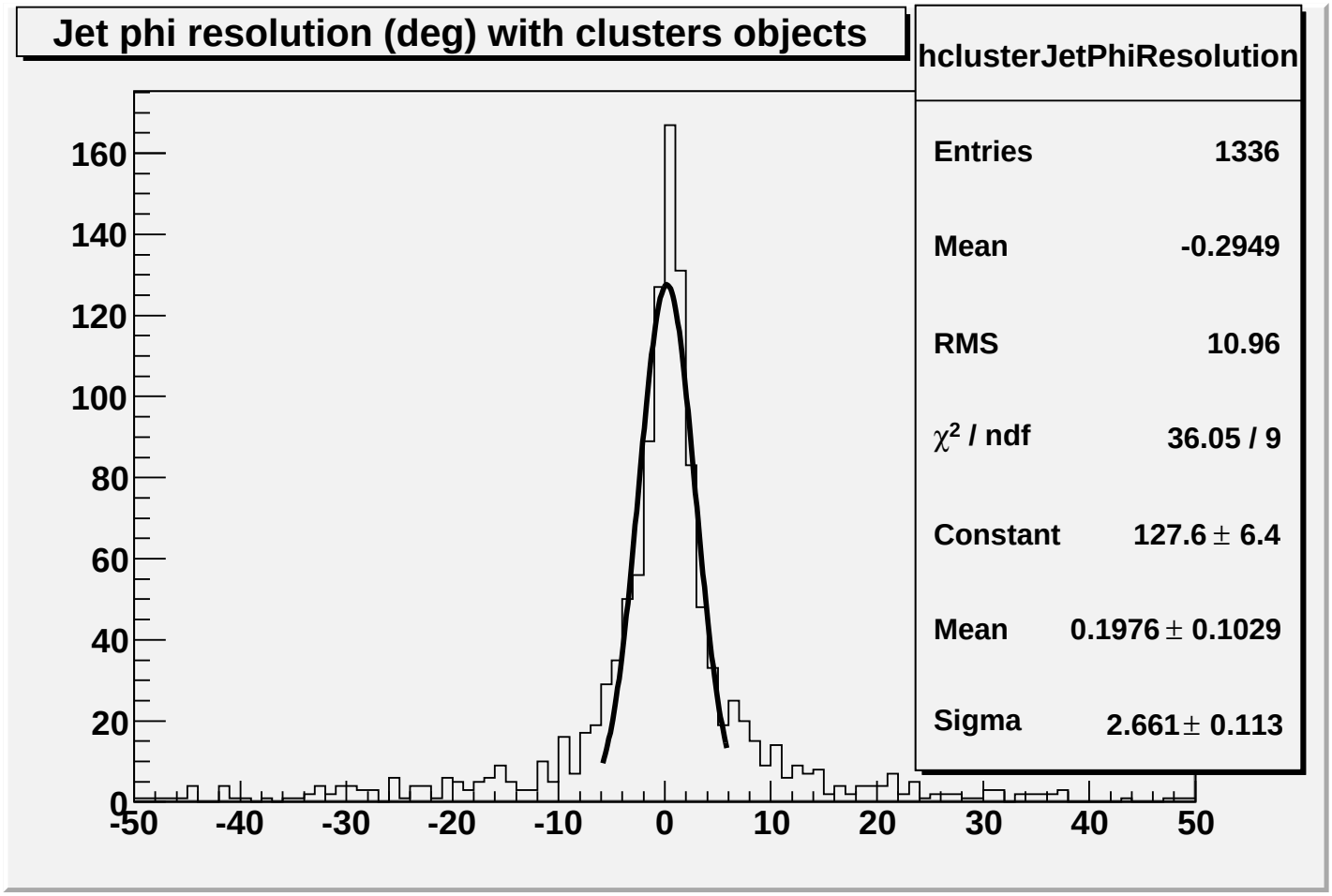
Resolutions with cluster objects(E)



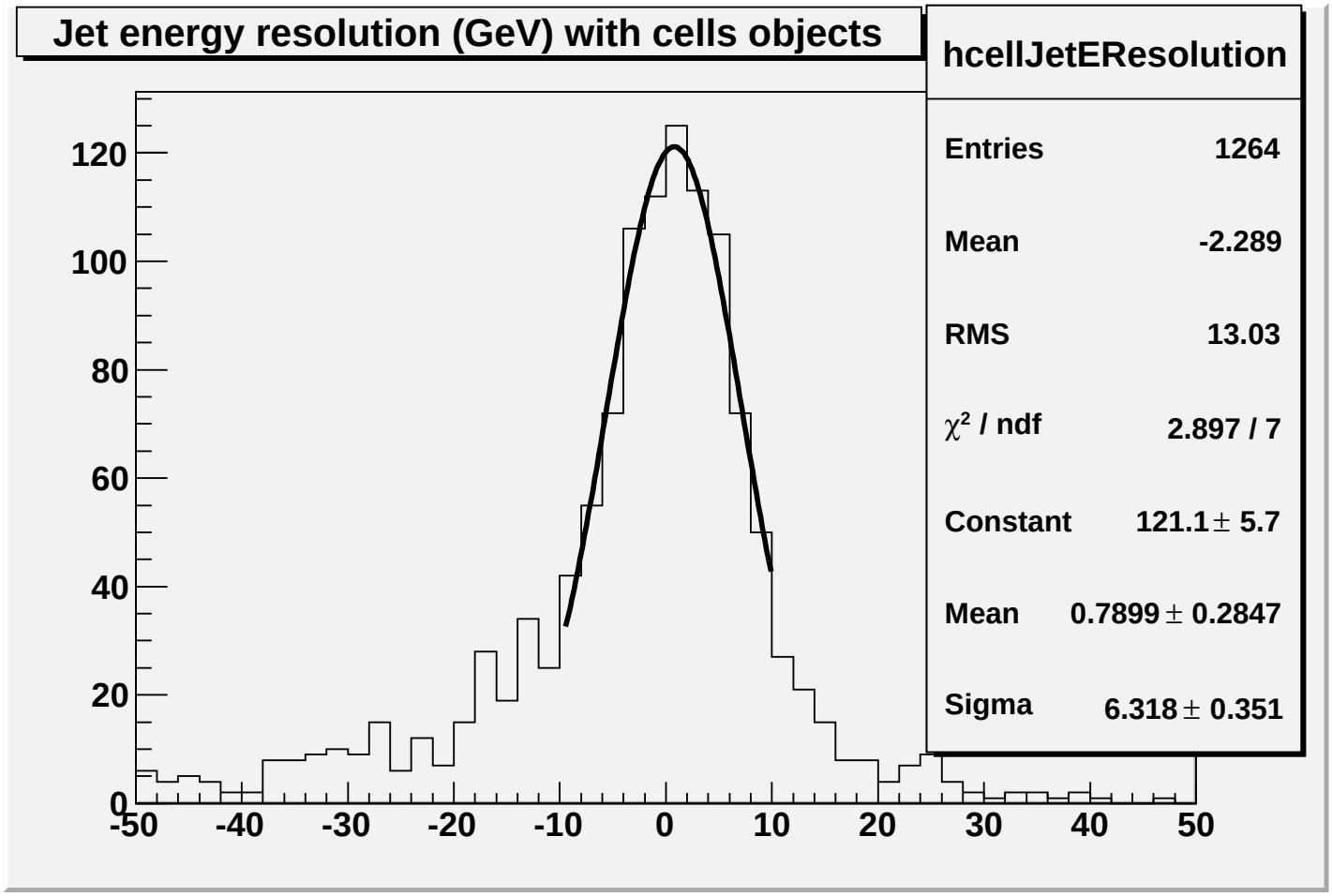
Resolutions with cluster objects(θ)



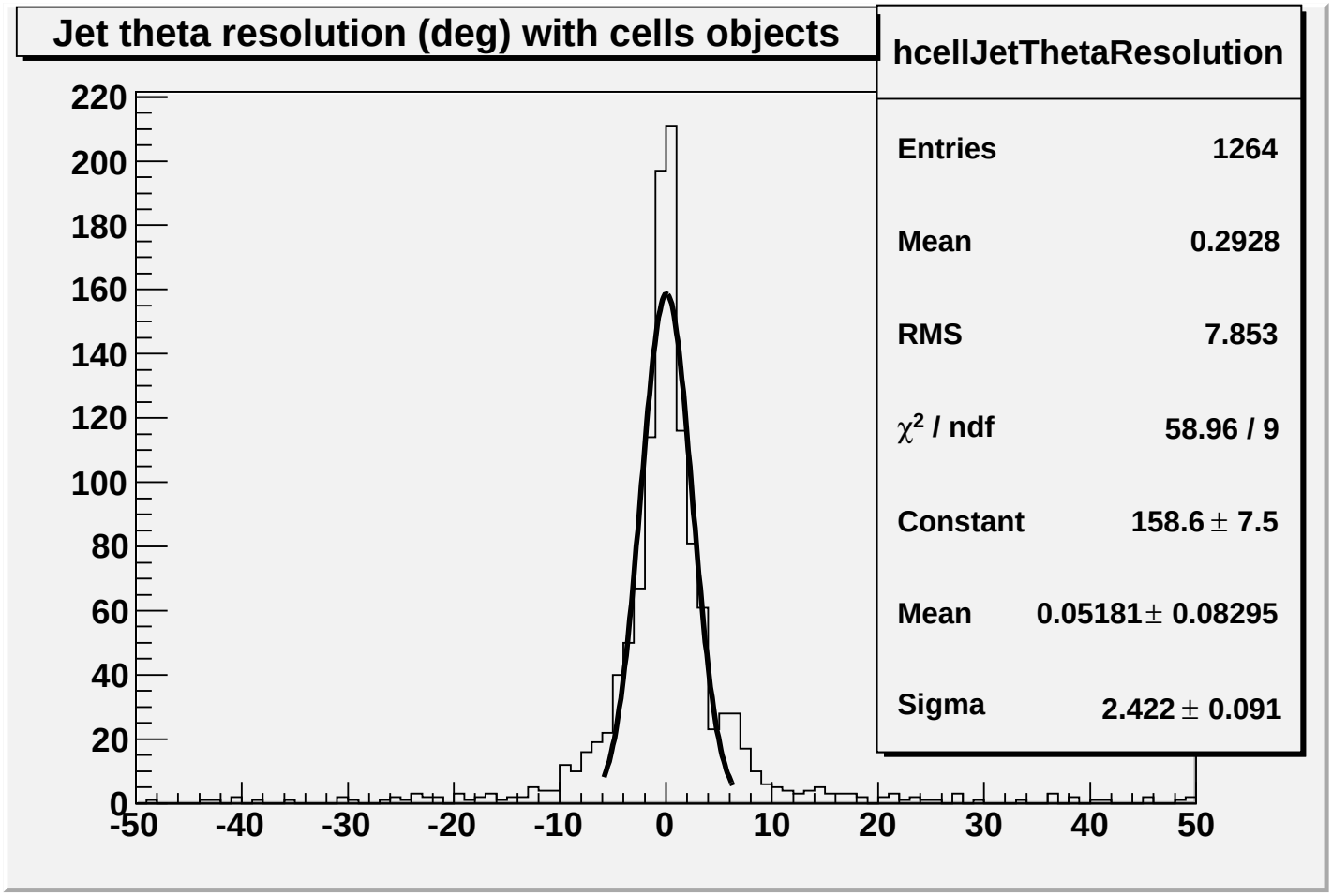
Resolutions with cluster objects(Φ)



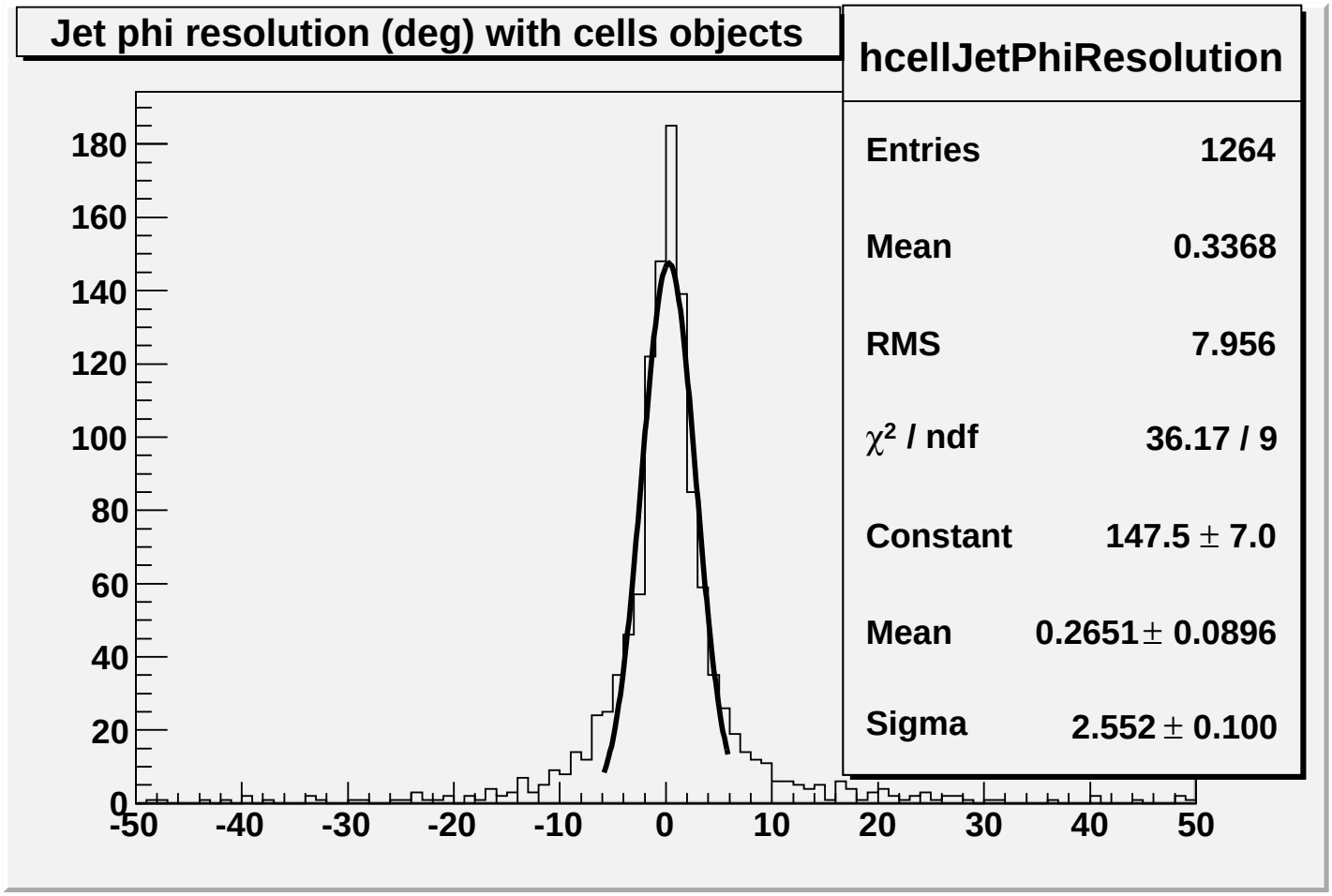
Resolutions with cell objects(E)



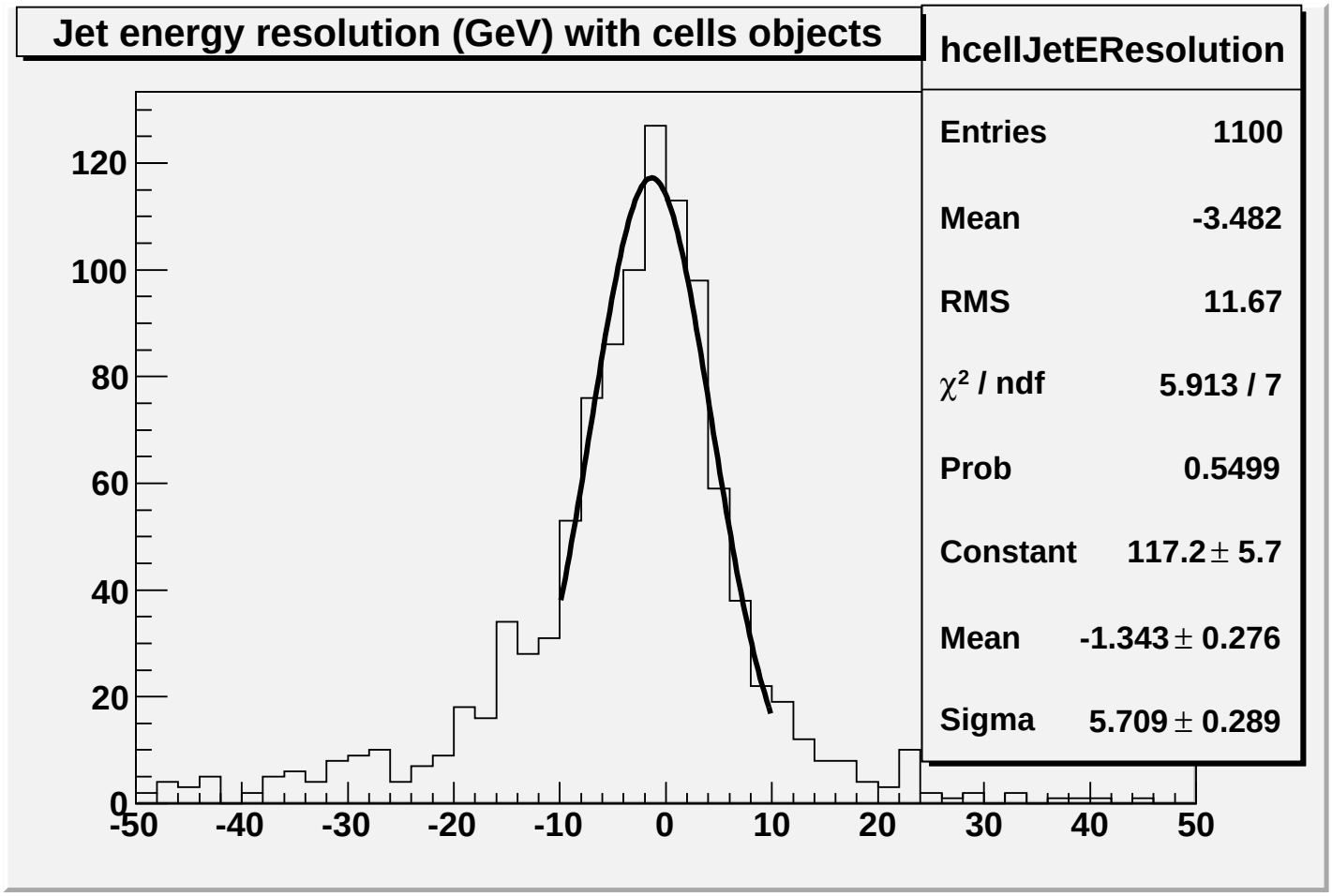
Resolutions with cell objects(θ)



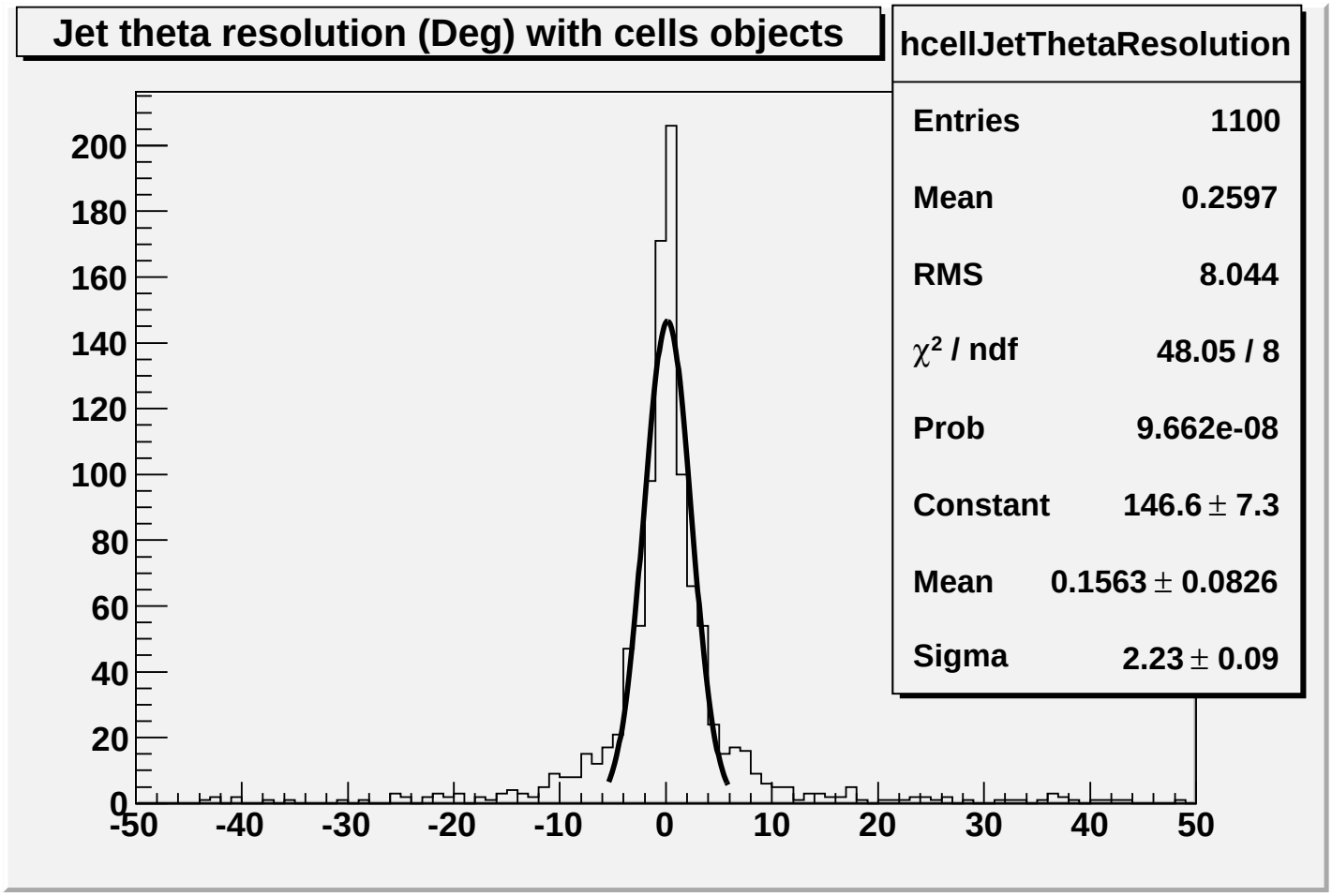
Resolutions with cell objects(Φ)



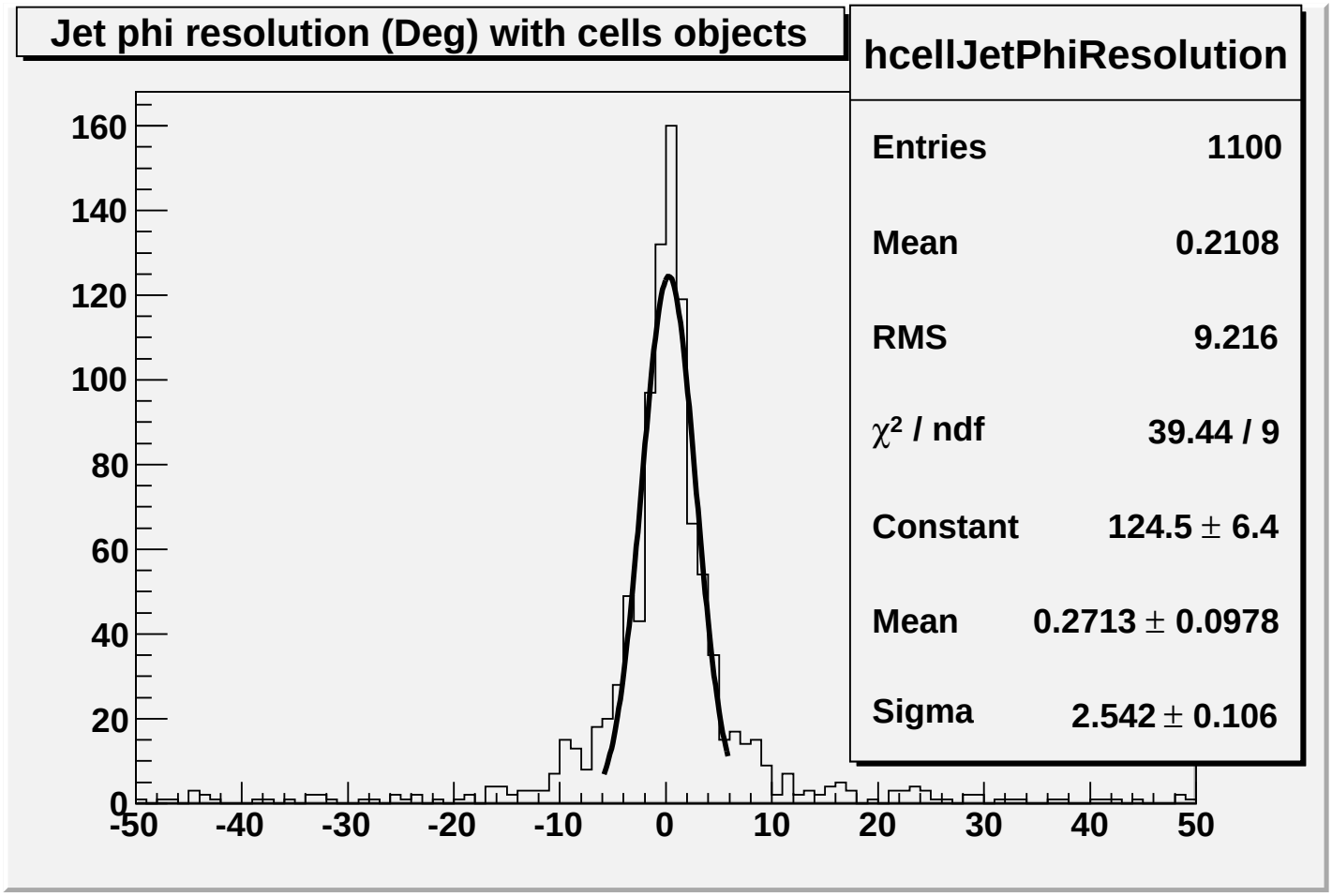
Resolutions with cell/track/cluster objects(E)



Resolutions with cell/track/cluster objects(θ)



Resolutions with cell/track/cluster objects(Φ)



Conclusions

- Performance of Calorimeter is good:

  $\sigma_E/E \sim 30\%/\sqrt{E}$ (visible energy)

  $\sigma_E/E \sim 36\%/\sqrt{E}$ (jet energy) ⇨

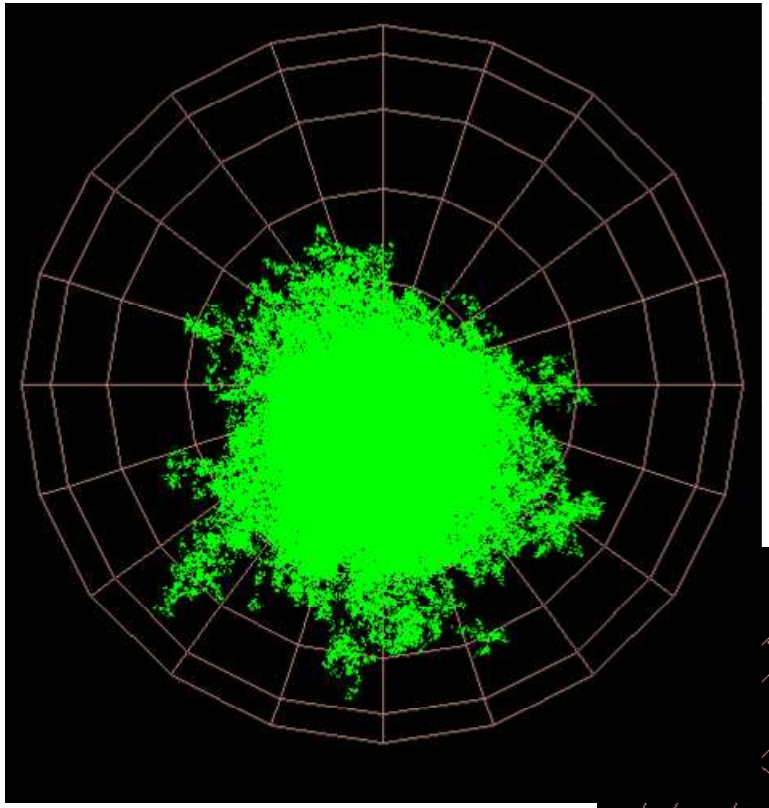
- Need to improve/tune jet finder algorithm

- Results presented here are very preliminary (too low statistics)

- Work is in progress, results will be presented at LCWS07

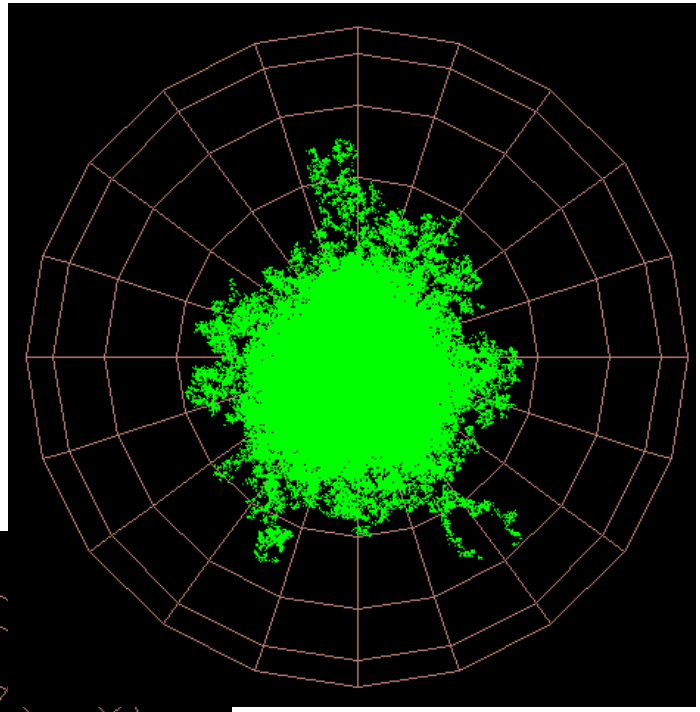
Backup Slides

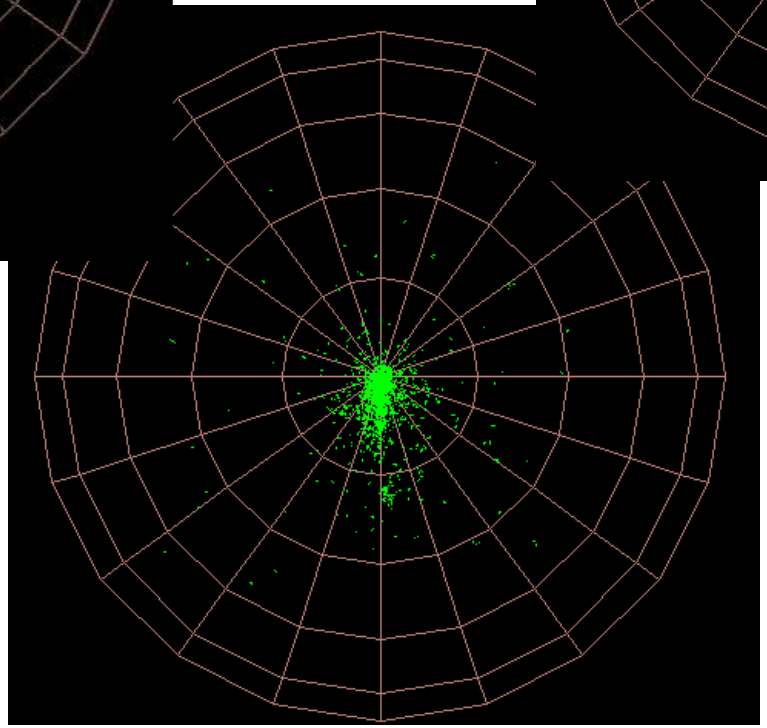
Fluka vs G3/G4



Fluka

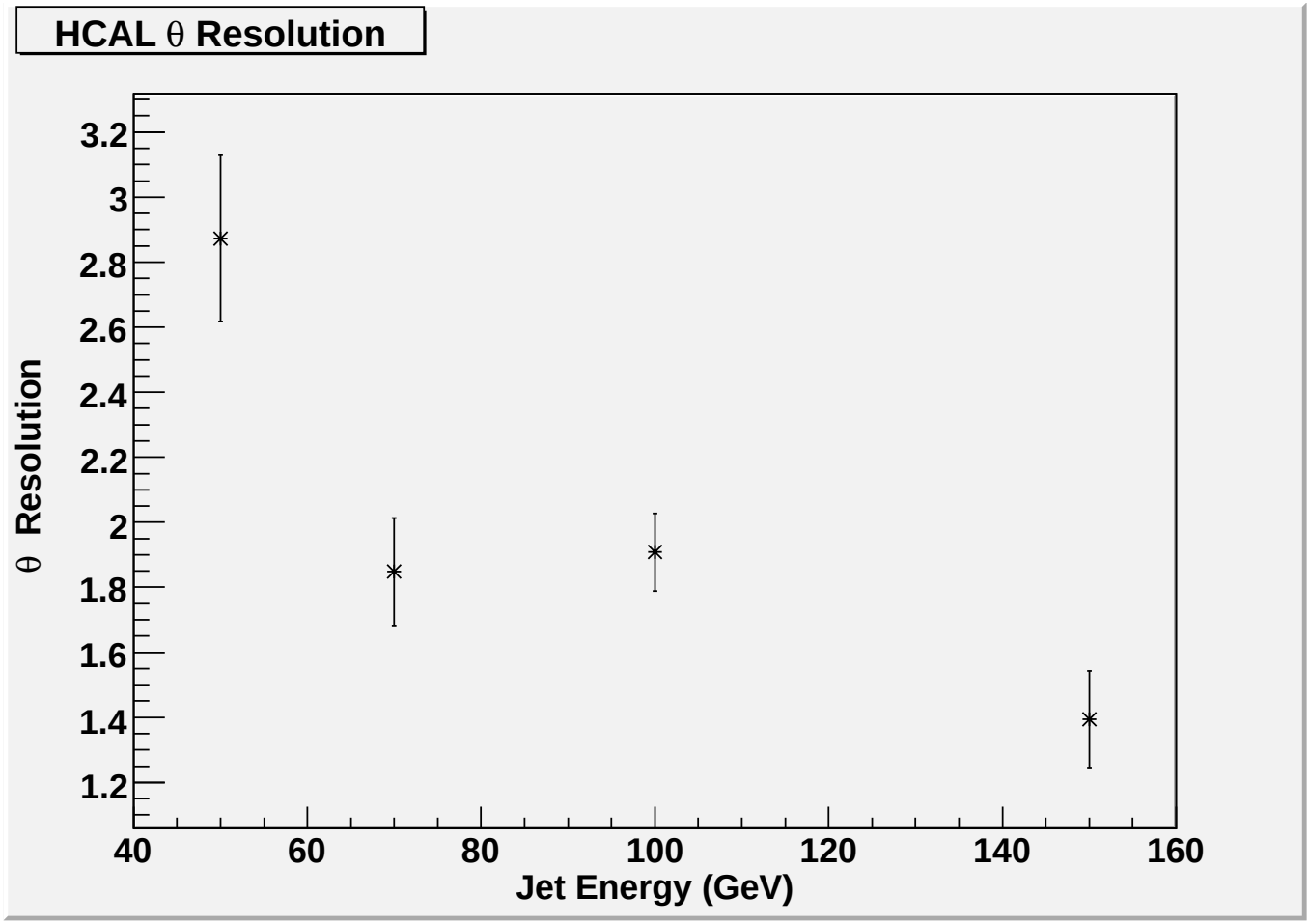
Geant3





Geant4

θ Resolution vs single Jet Energy



Φ Resolution vs single Jet Energy