Top quark mass reconstruction in the semi-leptonic channel using the Global χ^2 algorithm (I)

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Talk outline

Outline

- Introduction
- Data samples
- Reconstruction of physics objects (in the semi-leptonic channel)
  - Electron reconstruction performance
  - Muon reconstruction performance
  - Missing transverse energy
  - Jets reconstruction performance
- Event Selection

Introduction

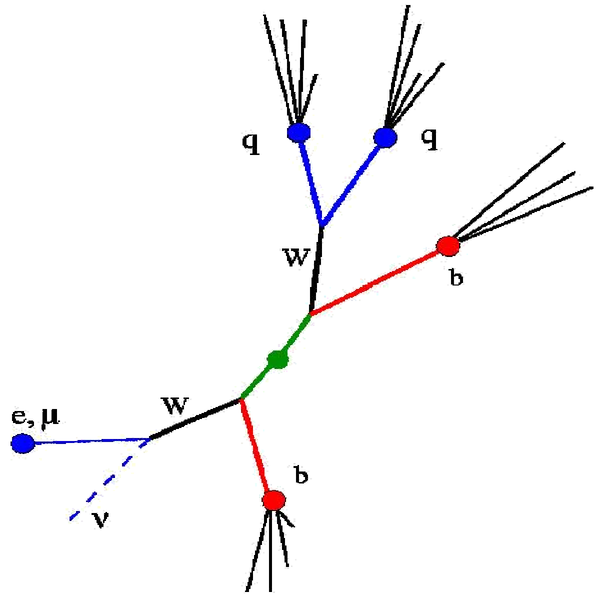
Goal:

- Contribute to the studies of the ATLAS potential to measure the top quark mass.
- To start, use CSC simulation.

How:

- Use the **semi-leptonic channel** (electron, muons or taus decaying leptonically + jets), σtt ~ 313 pb (golden channel).

  – Final state objects:
    - **1** (high pT) **isolated electron/muon**
    - 1 neutrino → **MET**
    - **2 light jets** (neglecting ISR and FSR)
    - **2 b jets**



Introduction

- From a kinematic fit using a χ^2 based on the entire final state:

$$\chi^2 = \sum_{\substack{4\,jets\\+lepton}} \left(\frac{E_i^{reco} - E_i^{fit}}{\sigma_{E_i}}\right)^2 + \left(\frac{M_{jj} - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{M_{l\nu} - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{M_{jjb_H} - M_{top_H}^{fit}}{\sigma_{top_H}}\right)^2 + \left(\frac{M_{l\nu b_L} - M_{top_L}^{fit}}{\sigma_{top_L}}\right)^2$$

(additional terms could be added in the future)

- Fit parameters: E_{fit} (for jets and lepton) and m_{top}.
- The $\chi 2$ minimization is done using a Global $\chi 2$ method (see next talk from Carlos)

→ Essential to determine first:
- E resolutions for jets and leptons
- For jets:

the jet calibration effects are removed by performing a jet calibration to the parton level using MC information. This allows jet calibration to be disentangled from other effects on the top mass measurement (selection, reconstruction,…).
- And in general to study the ATLAS performance for reconstructing electrons, muons, jets and missing Et.

All these aspects are studied in this talk.

Data samples

- Based on the official TopView ntuples (generated with v12.14.0.3)

  - Signal: semileptonic events (e, μ or τ decaying leptonically)
  - Main backgrounds: (Not yet considered!)
    - dileptonic and full-hadronic ttbar events,
    - W boson production: $W + jets, W + b\bar{b}, W + c\bar{c}$

Simulation for calibrations and alignment studies assuming as-built geometry (misaligments + magnetic field shifted)

↓

Calibration and alignment constants

→

Simulation for physics analysis: as-built geometry (misaligments+ magnetic field shifted + distorted material)

↓

Reconstruction: assuming nominal detector description + calibration, alignment constants

↓

AOD

↓

Top View ntuple

- NOTE: Calibration constants are derived from a simulation in which no extra material was added, while the physics simulation was done with additional material. Therefore the effect of material distorsion is in principle observable.

Reconstruction and selection of physics objects

- Physics objects studied: electrons, muons, jets and missing Et (MET).
- Efficiencies, purities, resolutions, linearities and uniformities have been studied for the signal ttbar semi-leptonic events.

$$\varepsilon(\Delta R) = \frac{\#\, matches\ of\ truth\ e/\mu/\ jets\ with\ reconstructed\ e/\mu/\ jets\ (\Delta R)}{\#\, truth\ e/\mu/\ jets};\quad \Delta R(truth, reco) < 0.2$$

$$P(\Delta R) = \frac{\#\, matches\ of\ reconstructed\ e/\mu/\ jets\ with\ truth\ e/\mu/\ jets\ (\Delta R)}{\#\, reconstructed\ e/\mu/\ jets};\quad \Delta R(truth, reco) < 0.2$$

$$Energy\ linearity = \frac{E_{reco} - E_{truth}}{E_{truth}}\ Vs.\ E_{reco}$$

$$Energy\ uniformity = \frac{E_{reco} - E_{truth}}{E_{truth}}\ Vs.\ \eta_{reco}\ or\ \phi_{reco}$$

$$Energy\ resolution = \sigma\left(\frac{E_{reco} - E_{truth}}{E_{truth}}\right)\ Vs.\ E_{reco}\ or\ \eta_{reco}$$

Electron reconstruction performance

Electron reconstruction and selection

- **Truth electrons**: electrons coming from the W leptonic decay.
- **Reconstructed electrons**:

  - Electron signature: energy deposits in the em calorimeter (but not in the hadronic one) and track pointing at the energy deposition and with momentum consistent with calo energy.

  - The standard algorithm for electron reconstruction (i.e. the calorimeter seeded one) has been used.

Seed em tower

(with ET> 3GeV)

+

Track in ID (not belonging to a photon conversion) required to:

- match the cluster within a $\Delta\eta\times\Delta\phi$ window of 0.05×0.10
- $E/p < 10$

↓

e-gamma (particle candidate)

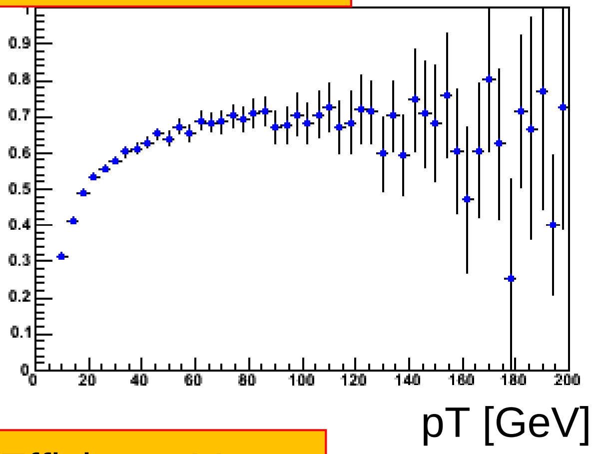
↓ **Optimized corrections & calibrations**

electrons

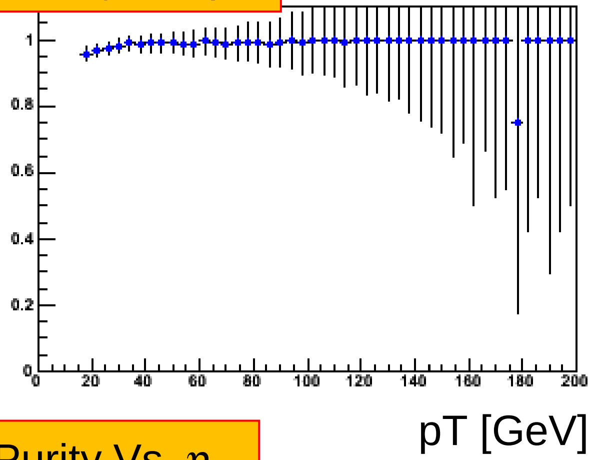
- The medium identification cuts have been used: based on information from EM calorimeters and tracking variables.
- $p_T > 25$ GeV
- $|\eta| < 2.5$ (and outside crack region: $1.37<|\eta|<1.52$)
- Isolation cut based on calorimeter energy: the additional Et in a cone with radius $\Delta R=0.2$ around the electron < 6 GeV.

Efficiency and purity

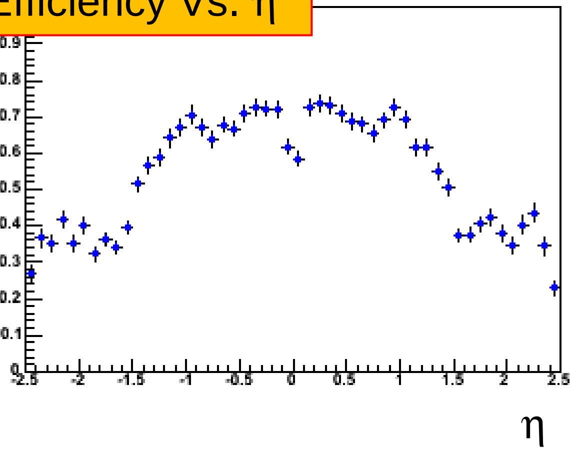
Efficiency Vs. pT



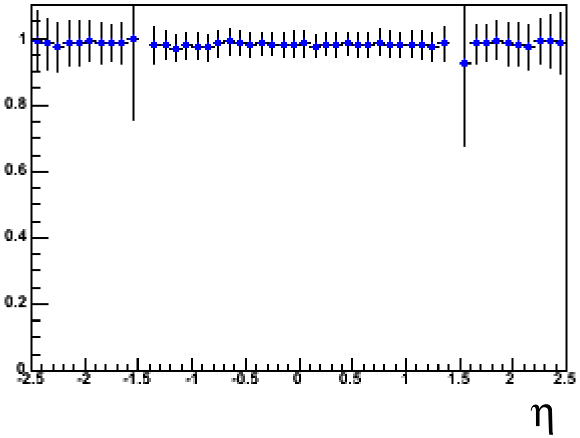
Purity Vs. pT



Efficiency Vs. η



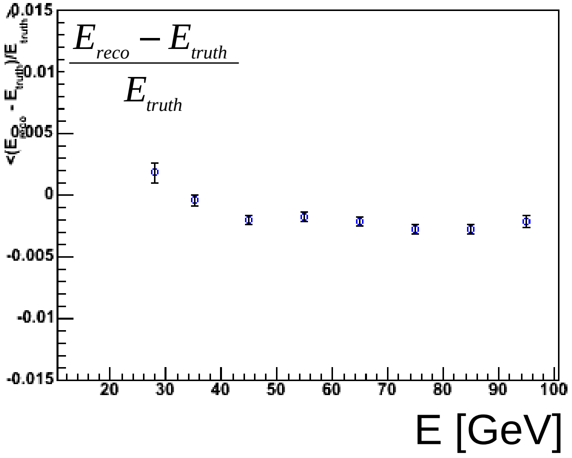
Purity Vs. η



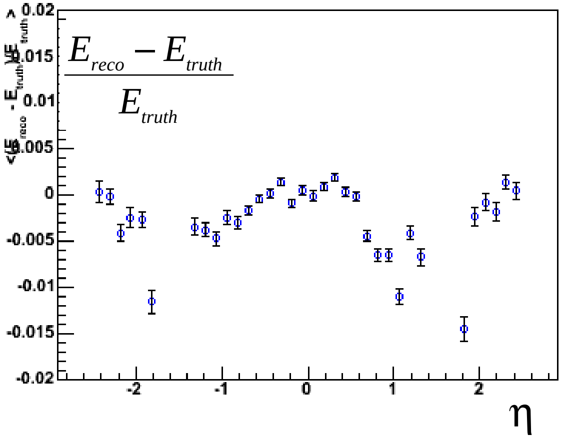
- Efficiency of electron reconstruction ~70%, except for:
  - low pT and large |η|,
  - the overlap region between barrel and endcap calorimeters (cracks): 1.37<|η|<1.52,
  - |η|>1.52 (calorimeter endcaps).
- The contamination is ~2% (purity: 98%).

Linearity, uniformity and resolution

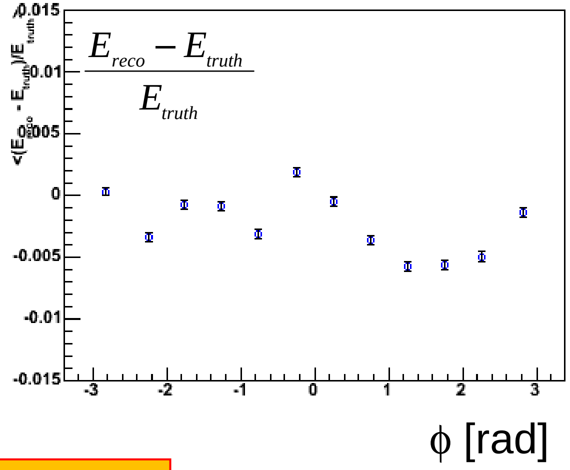
Energy linearity



Energy uniformity in η

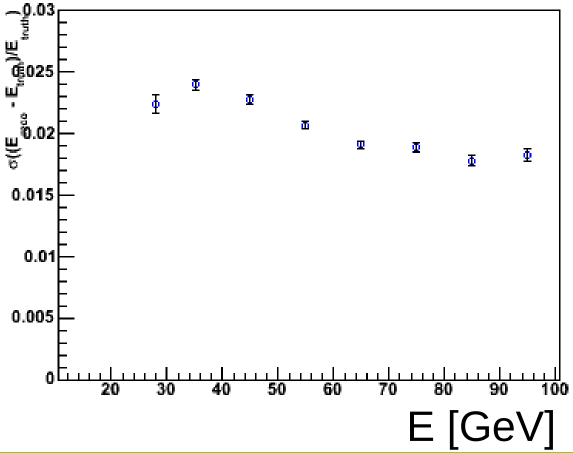


Energy uniformity in ϕ



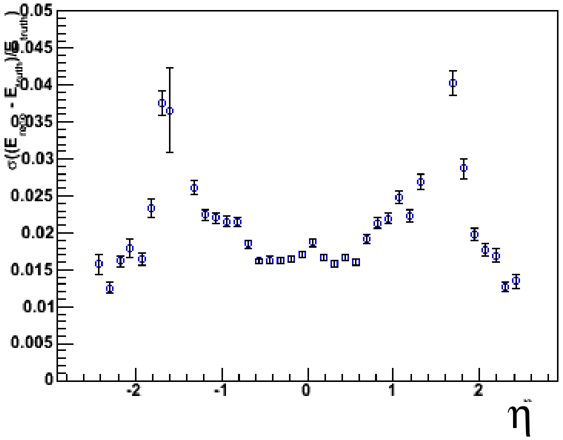
Energy resolution Vs E

$$\sigma\left(\frac{E_{reco} - E_{truth}}{E_{truth}}\right)$$



Energy resolution Vs η

$$\sigma\left(\frac{E_{reco} - E_{truth}}{E_{truth}}\right)$$



- A small departure from linearity and non-uniformities are observed. They are probably due to the additional material in front of the calorimeters. Remember: calibration constants were provided for the as-built geometry without material distorsions.
- Resolution is better for high energy and worse in the calorimeter cracks.

Muon reconstruction performance

Muon reconstruction and selection

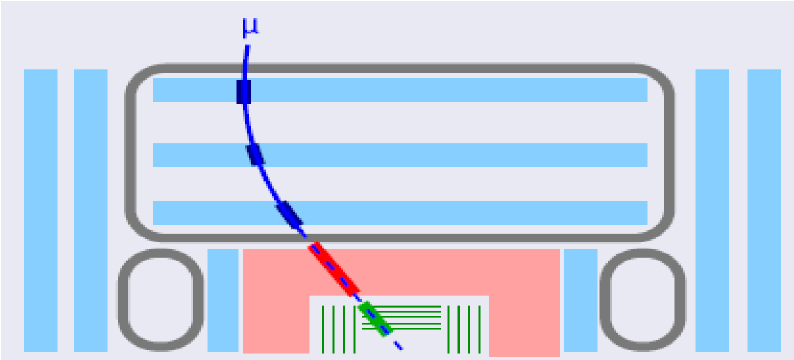
- **Truth muons**: muons coming from the W leptonic decay

- **Reconstructed muons**:

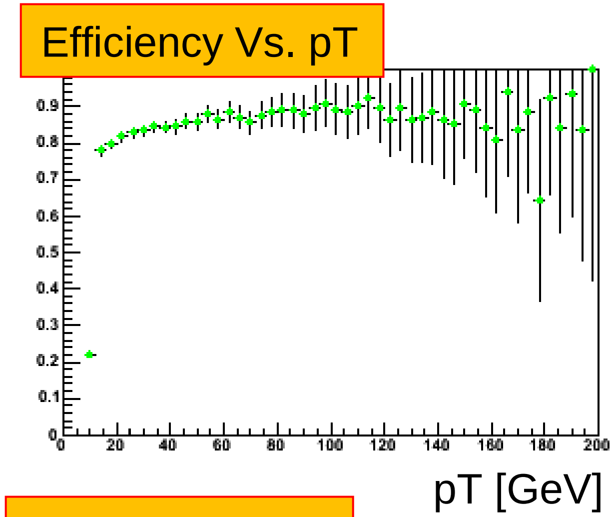
  - Muon signature: Muon track passes through the ID, the calorimeters material (minimum ionizing energy deposits) and the MS.

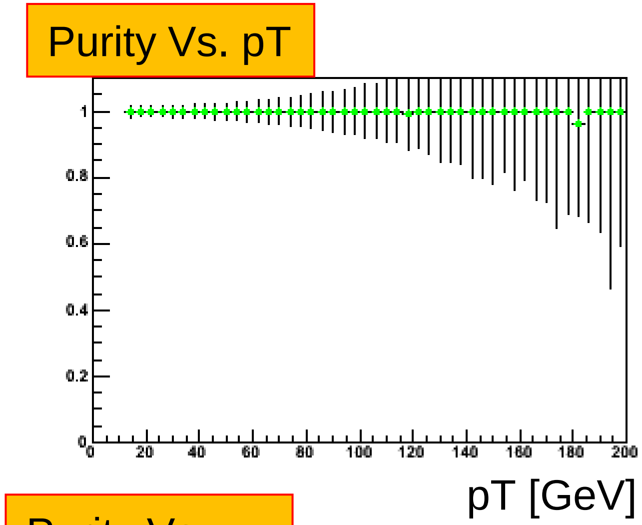
  - Muon reconstruction by STACO algorithm: ID + MS tracks→ $\chi 2$ match.

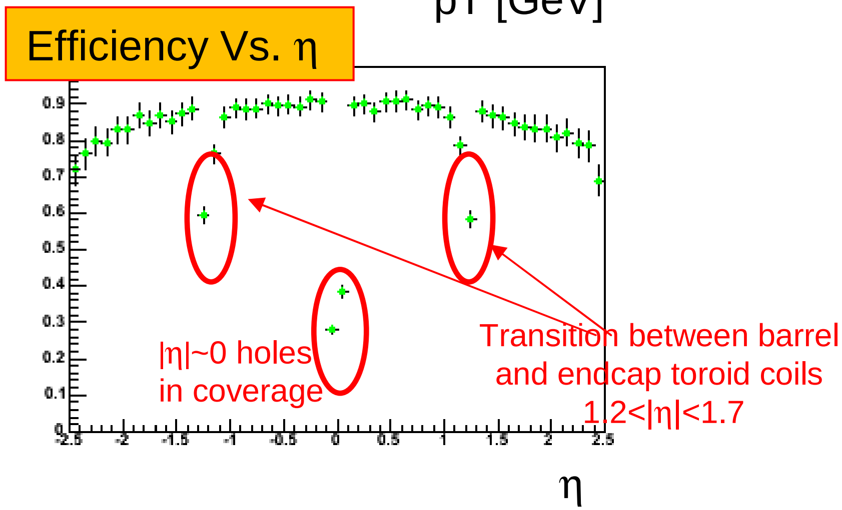
  - Cuts:
    - No $\chi 2$ cut
    - pT>20 GeV
    - $|\eta| < 2.5$
    - Isolation cut: the additional Et in a cone with radius ΔR=0.2 around the muon <6 GeV.

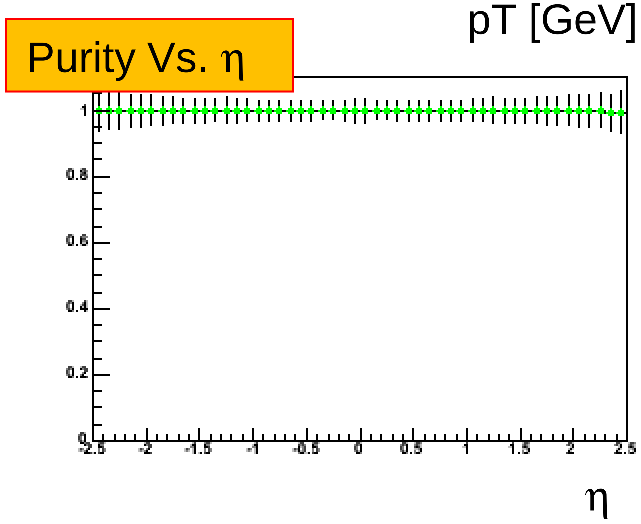


Efficiency and purity





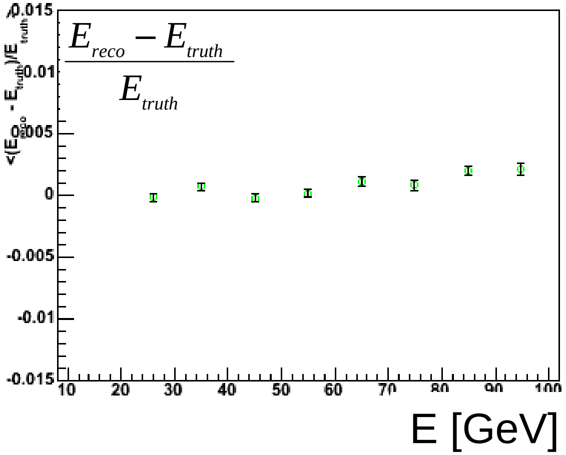




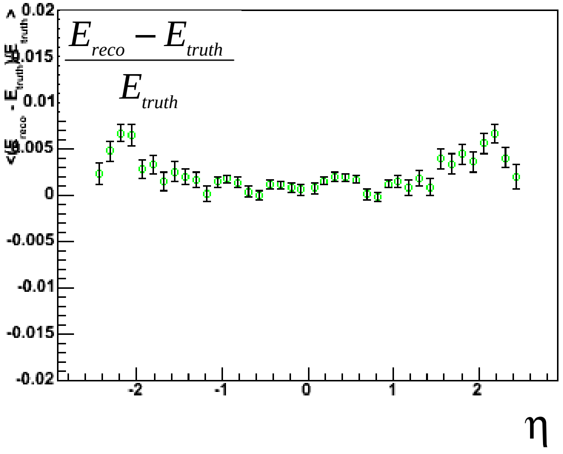
- About 85% of the truth muons are reconstructed.
- The efficiency is degraded at near $\eta \sim 0$ and intermediate region $1.2<|\eta|<1.7$.
- The purity is near 100%.

Linearity, uniformity and resolution

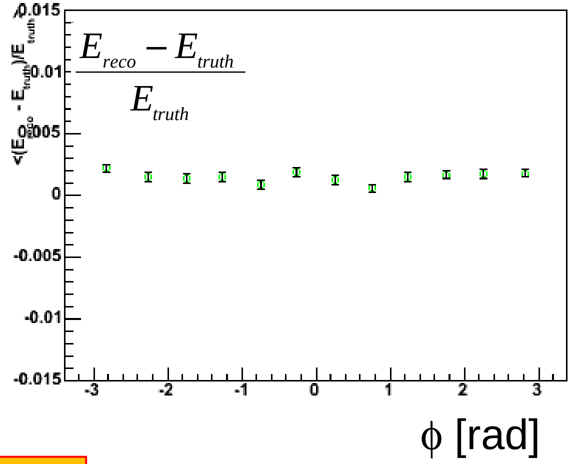
Energy linearity



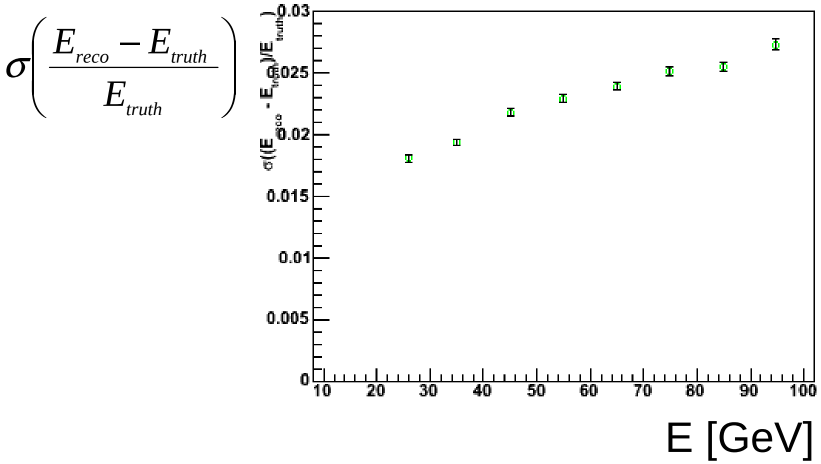
Energy uniformity in η



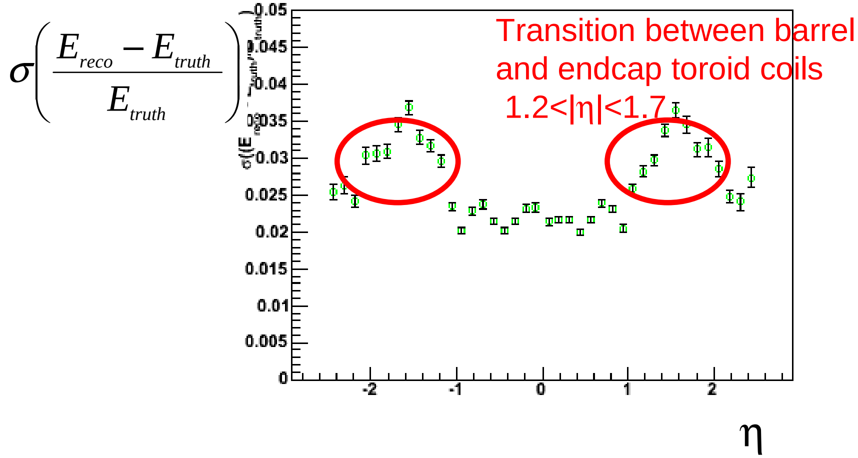
Energy uniformity in ϕ



Energy resolution Vs E



Energy resolution Vs η



- Great linearity and uniformity in ϕ. Small non-uniformities for large η regions are observed.
- Resolution is better for low energy muons and is worse in the transition region 1.2<|η|<1.7.

MET reconstruction performance

MET reconstruction

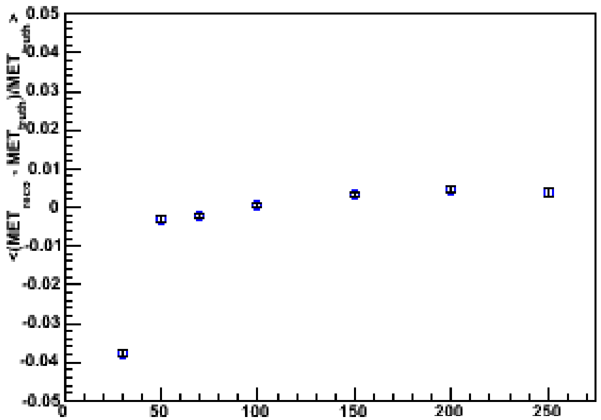
- The MET is used as an estimate of the neutrino transverse momentum.
- **Truth MET**: contribution from all stable and non-interacting particles in the final state.
- **Recontructed MET**:
  - Reconstructed by the RefMET algorithm (cell based):

$$\not{E}_{x,y}^{Final} = MET_{x,y}^{Final} = MET_{x,y}^{Calo} + MET_{x,y}^{Cryo} + MET_{x,y}^{Muon}$$

MET performance

MET linearity

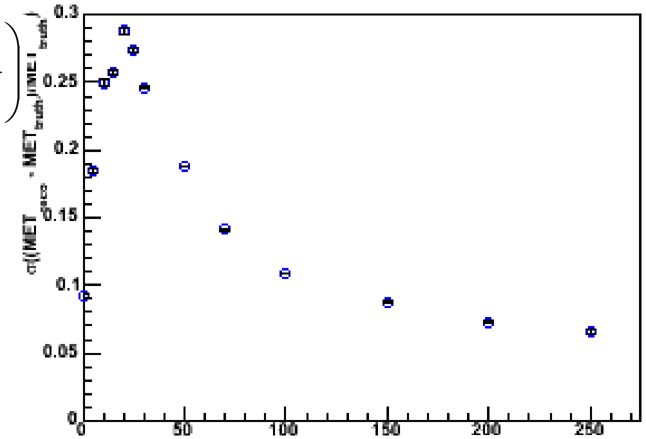
$$\frac{E_{reco} - E_{truth}}{E_{truth}}$$



MET [GeV]

MET resolution

$$\sigma\left(\frac{E_{reco} - E_{truth}}{E_{truth}}\right)$$



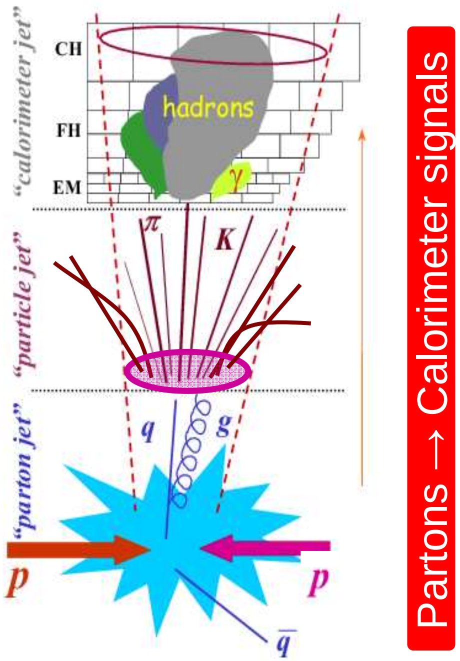
MET [GeV]

- The resolution is better for higher MET.
- A resolution of about 10 GeV is obtained, in agreement with what is expected.

Jet reconstruction performance

Jet calibration to quark level

The signals in the detector produced by the calorimeters must be reconstructed and calibrated back to parton level in order to study the physics of the event.



Calo cells

↓ pre-clustering or tower building

Protojets

↓ Jet finding algorithm

Uncalibrated jets

↓ Calibration (detector effects)

Calibrated jets → In-situ calibration (physics effects) → Parton level

TopView jets

Calorimeter domain
Jet reconstruction domain
Physics analysis domain

Parton level calibration is performed by physics groups.

- **Goal:**
  - compute correction factors to go from reconstructed jets calibrated by detector effects to quark level
  - compute jet energy resolutions

Jet reconstruction and selection

- The ATLAS implementation of the fixed cone jet finder algorithm with Rcone = 0.4 was used to build jets.
- Jets are defined at 3 levels:

- **Quark level**: each quark is taken as a different jet
- **Truth Particle jets**: built from stable particles (neutrinos and muons generated in the collisions are excluded)
- **Reconstructed jets**: built from calorimeter towers defined as massless pseudo-particles (corrected by detector effects)

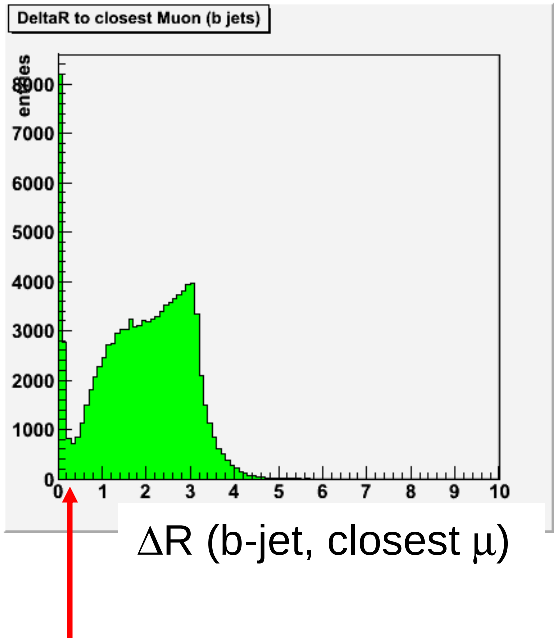
  - Cuts applied:

  - pT > 40 GeV (for top mass measurement) and pT>20 GeV (for jet calibration)
  - $|\eta|< 2.5$
  - Jets coinciding within $\Delta R<0.2$ with reconstructed electrons are removed.

- Matching criteria:
  - Jets at different levels are associated based on the minimum ΔR and requiring $\Delta R < 0.3$.

Jet clasification

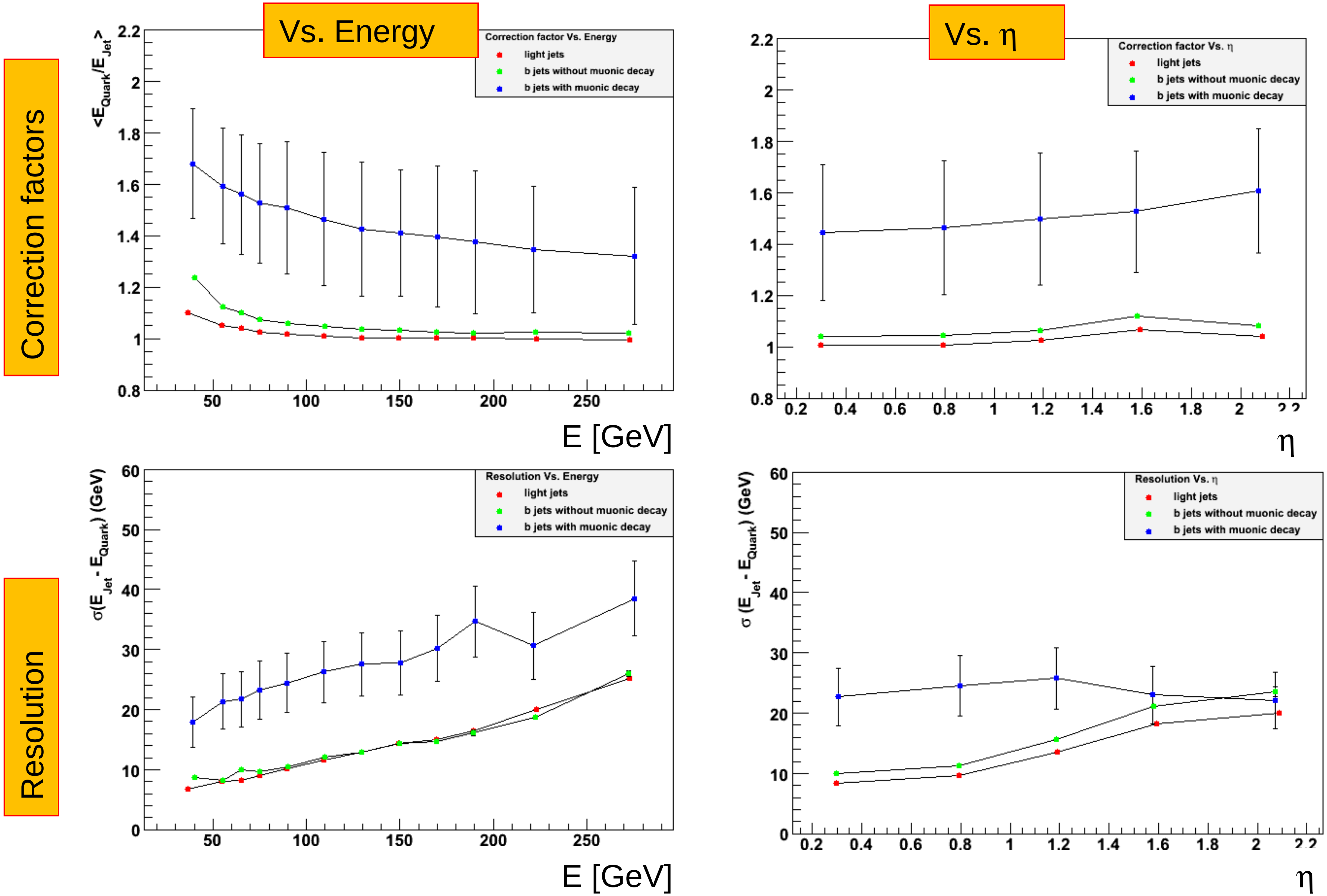
- 3 types of jets have been considered separately:
  - **light jets**
  - **b-jets close to a reconstructed muon** (i.e. ΔR(jet,muon)<0.2)
  - **b-jets not close to a reconstructed muon**



- at reconstruction level the IP3D + SV1 b-tagging algorithm was used to tag b-jets (weight > 6)

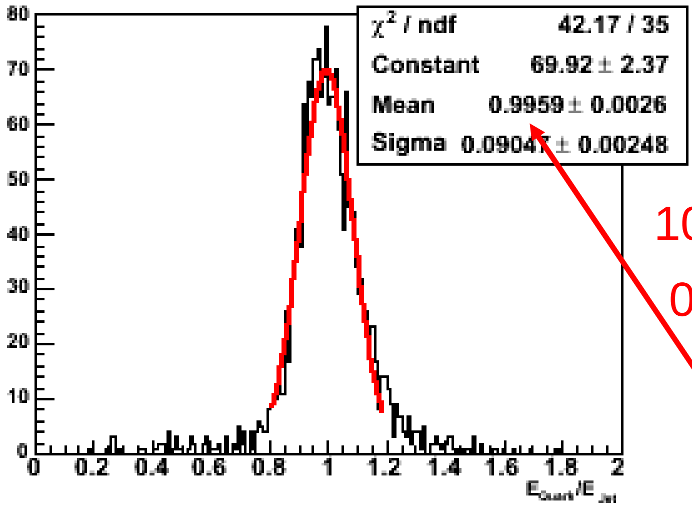
Correction factors and resolutions

- Correction factors and resolutions depend on the jet energy and η.



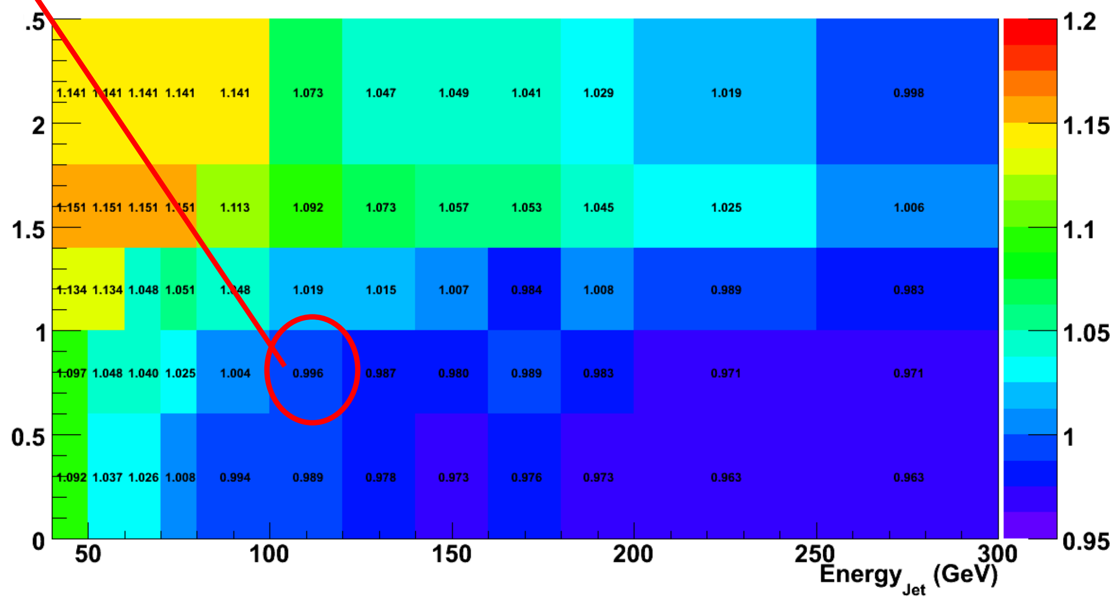
Correction factors and resolutions

- Correction factors and energy resolutions are then computed for each energy and η region.



100<|Ejet| ≤ 120

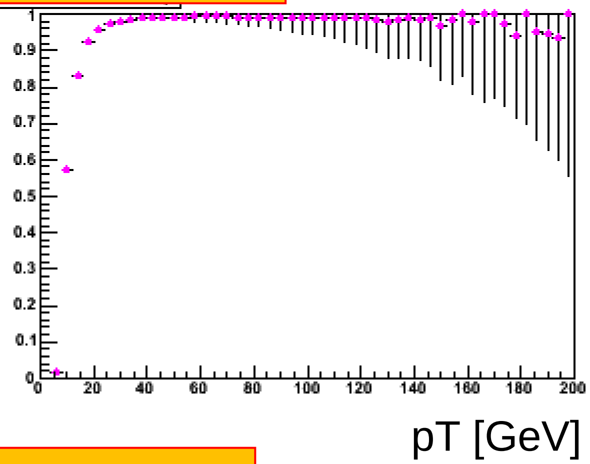
0.6≤|ηjet| <1.0



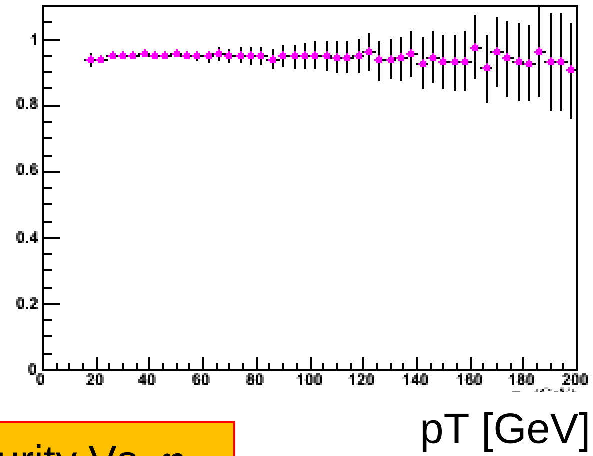
Already applied in the top mass determination (see Carlos talk).

Efficiency and purity

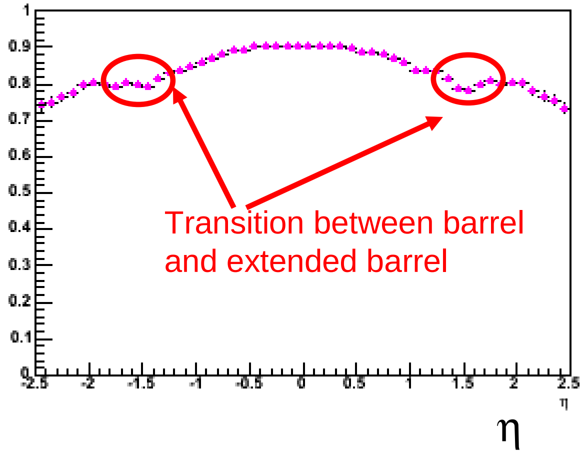
Efficiency Vs. pT



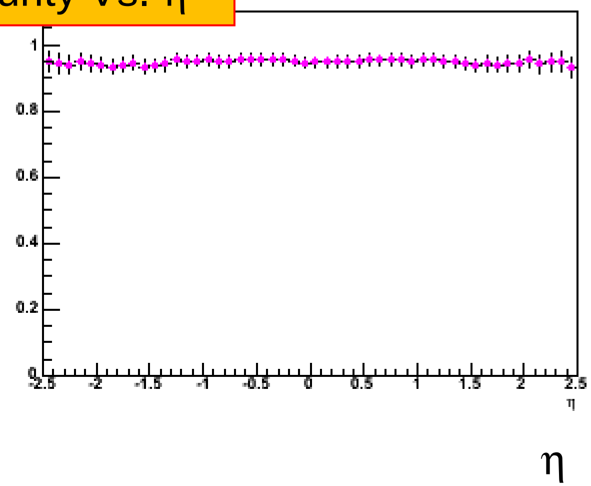
Purity Vs. pT



Efficiency Vs. η



Purity Vs. η



- About 85% of the truth jets are reconstructed. The efficiency decreases for higher η and in the transition region between barrel-extended barrel (|η|~1.5).
- The purity of the jets is about 95%.

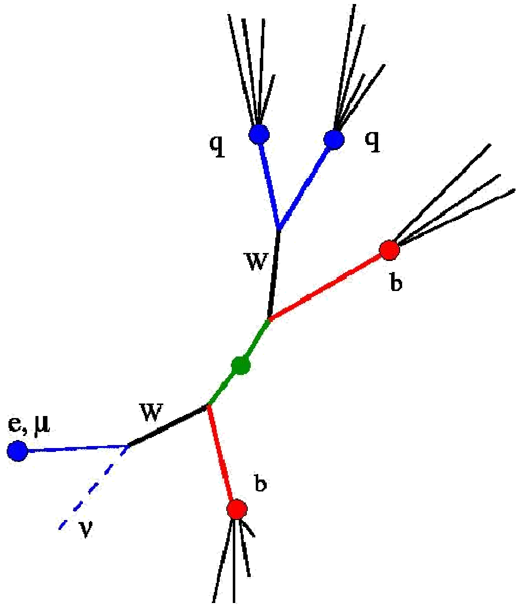
Event selection

- Semi-leptonic channel:

- 1 lepton (e or μ) isolated, P_T > 25 (20) GeV , |η| < 2.5
- MET> 20 GeV
- Jet energy calibration
- Jets selection

→ ≥ 4 jets, P_T > 40 GeV, |η| < 2.5

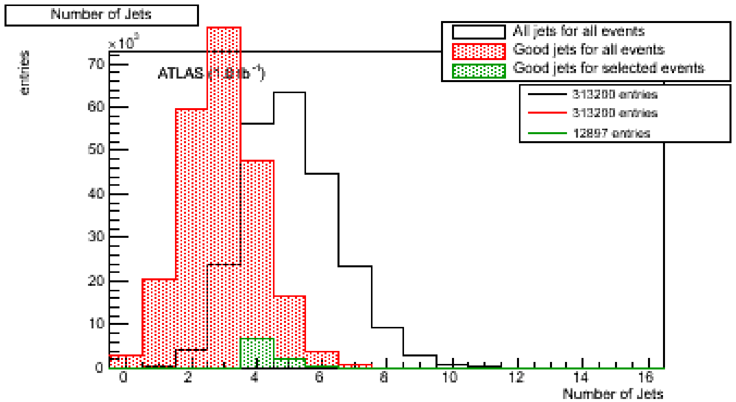
→ 2 of the jets tagged as b-jets



L=1fb^{-1}

Cut	Efficiencies of each cut	Accumulated effciency
Number of events	313200	313200
1 isolated lepton pT>20(25) GeV	155042 (50%)	155042 (50%)
MET>20 GeV	286502 (91%)	139526 (45%)
>= 4 jets pT>40 GeV	94282 (30%)	39390 (13%)
= 2b-jets pT>40 GeV	63138 (20)	12889 (4%)

- About 4 % of the events pass all cuts!



Conclusions

• Several studies have been investigated in order to perform an accurate top quark mass measurement in the ttbar semi-leptonic channel.

• The performance of the reconstruction of final state objets of the semi-leptonic channel: electron, muons, jets and missing Et has been studied.
The results obtained are in good agreement to those published in the ATLAS paper (*Expected performance of the ATLAS Experiment, Detector, Trigger and Physics*, ATLAS collaboration, CERN-OPEN-2008-020, Dec. 2008).

• Energy resolutions have been provided for leptons and jets, in order to use them in the χ^2 function used to determine the top mass (see next talk from Carlos).
• For jets, a calibration to correct reconstructed jets energy to parton level has been provided.
energy and η.

• <u>Future plans:</u>

- move to more recent simulated samples (MC08 and top mixing exercise).
- migrate to new data formats (D3PD) and integrate analysis code in Athena to run over AOD/DPDs and produce our own D3PD to be analyzed in ROOT.

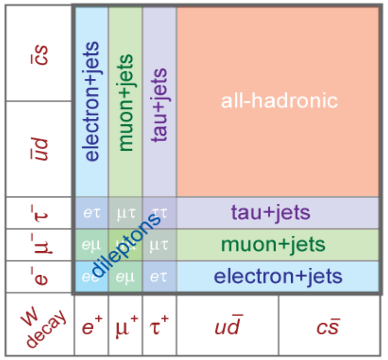
BACK-UP SLIDES

TOP decays

- **Production**: σtt(LHC) ~ (833 ± 100) pb
- **Final states:** depending on the W decay channel
  1) Fully-leptonic (1/9): 2l + 2ν + 2 jets
  2) Fully-hadronic (4/9) 6 jets
  3) Semi-leptonic (4/9): 1l + 1ν + 4 jets → *Golden channel*: 2.5 million ev/year

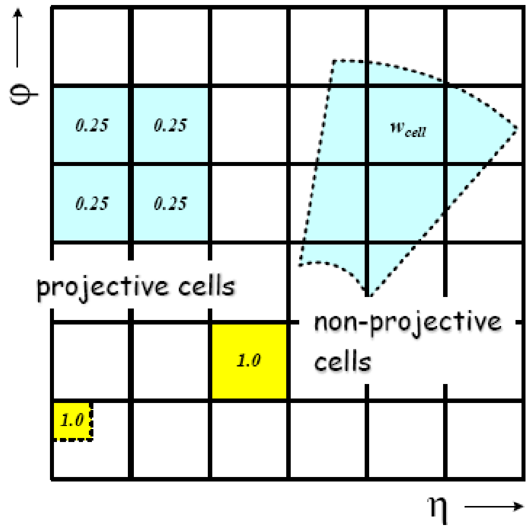
Category	Decay Mode	BR	
Dilepton	tt-bar →eνb eνb	1/81	4/81 (5%)
	tt-bar →μνb μνb	1/81	
	tt-bar →eνb μνb	2/81	
τ-Dilepton	tt-bar →eνb τνb	2/81	5/81 (5%)
	tt-bar →μνb τνb	2/81	
	tt-bar →τνb τνb	1/81	
Lepton+jets	tt-bar →eνb qqb	12/81	24/81 (30%)
	tt-bar →μνb qqb	12/81	
	tt-bar →τνb qqb	12/81	
All-hadronic	tt-bar →qqb qqb	36/81	36/81(44%)

Top Pair Decay Channels



Reconstruction of jets

- **Truth light jets**: light quarks coming from the W hadronic decay.
- **Truth b jets**: b quarks coming from the top quark decay.
- **Reconstructed jets**:
  - Jets are reconstructed with the ATLAS cone algorithm in $\eta-\phi$ space for $|\eta| < 2.5$ and a cone of radius 0.4, operating on energy depositions in calorimeter towers:
  - Jets are circles when projected in $\eta-\phi$ space
  - the cells are projected onto a fixed grid in η and ϕ (tower bin size is $\Delta\eta x \Delta\phi = 0.1\times0.1$)
  - start with a "seed" tower above a threshold energy
  - draw a circle in $\eta-\phi$ space (cone size: 0.4)
  - include all towers with above a threshold energy
  - calculate transverse energy centroid
  - iterate list of towers until stable



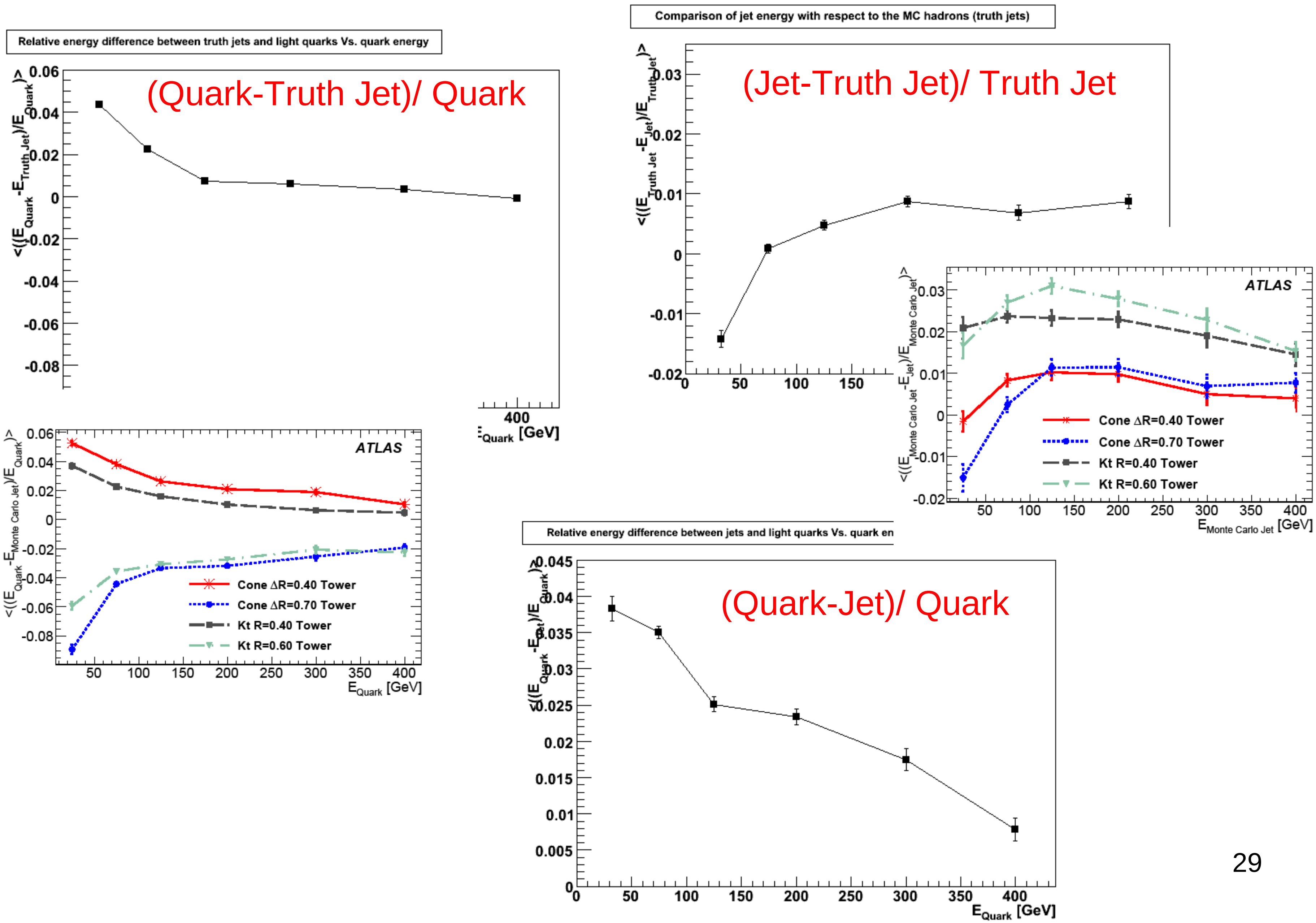
- Jets in TopView are calibrated by <u>H1 calibration</u>

(to correct from detector effects)

- Jet selection for semi-leptonic events:
  - Cone 0.4, tower jets
  - pT>40 GeV
  - |h| < 2.5
  - Isolation cut

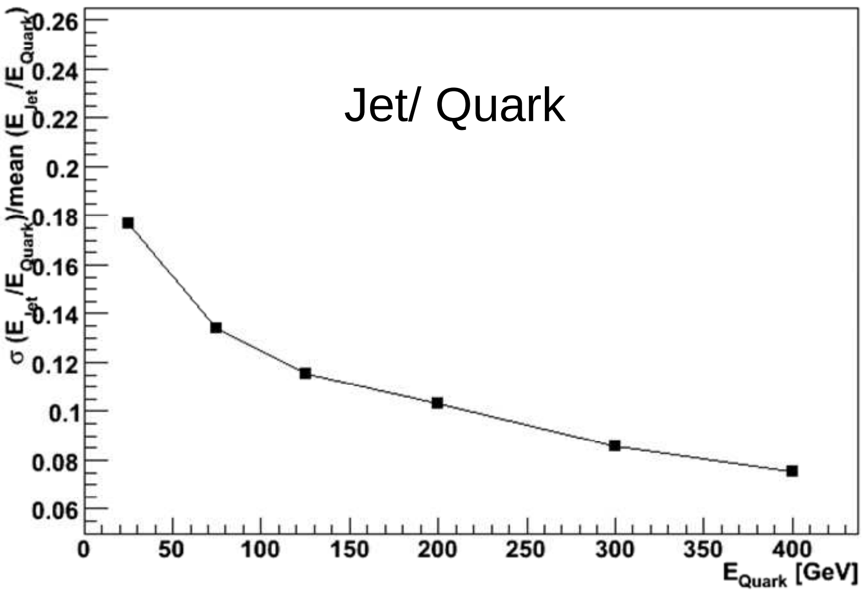
Linearity

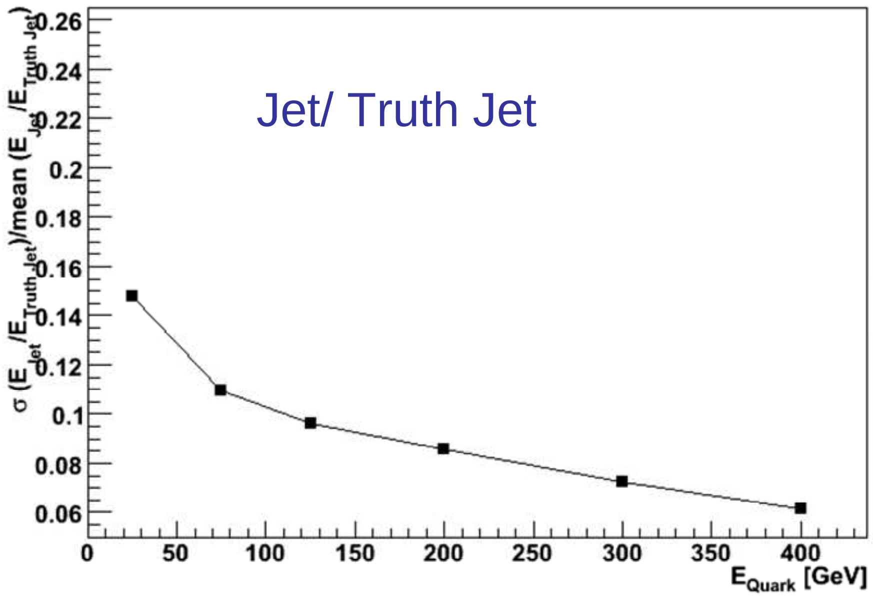
Light jets

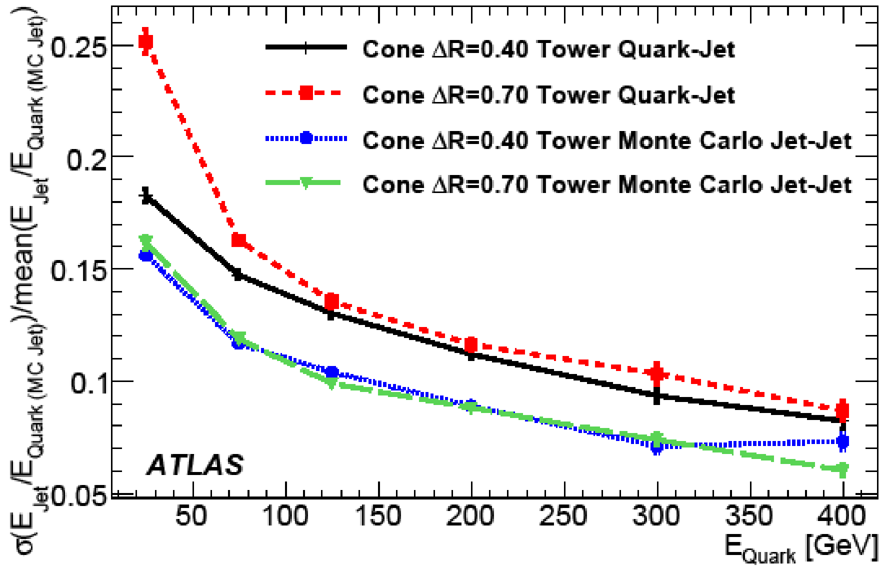


Energy scale resolution

Light jets



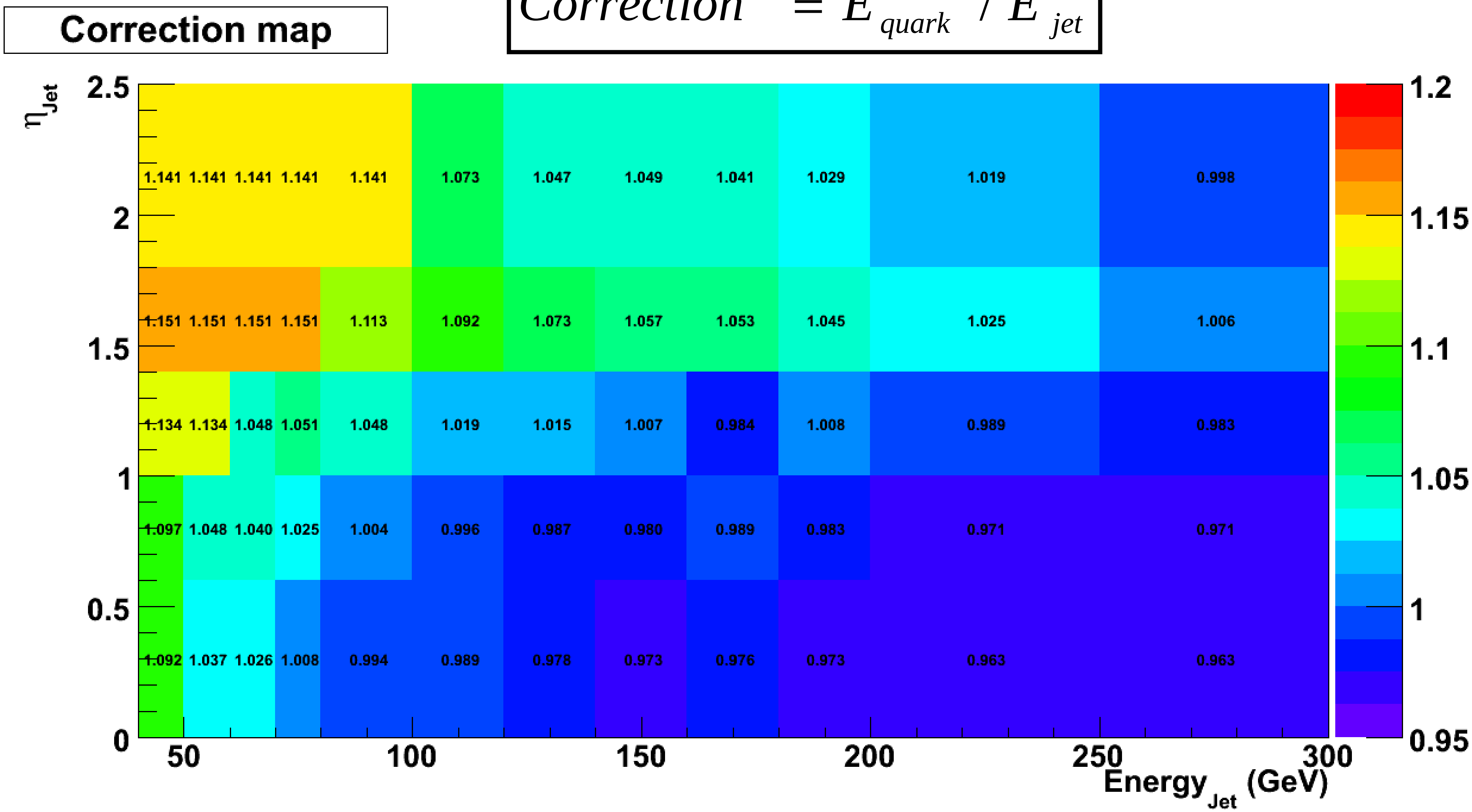




Energy scale

Correction map for light jets

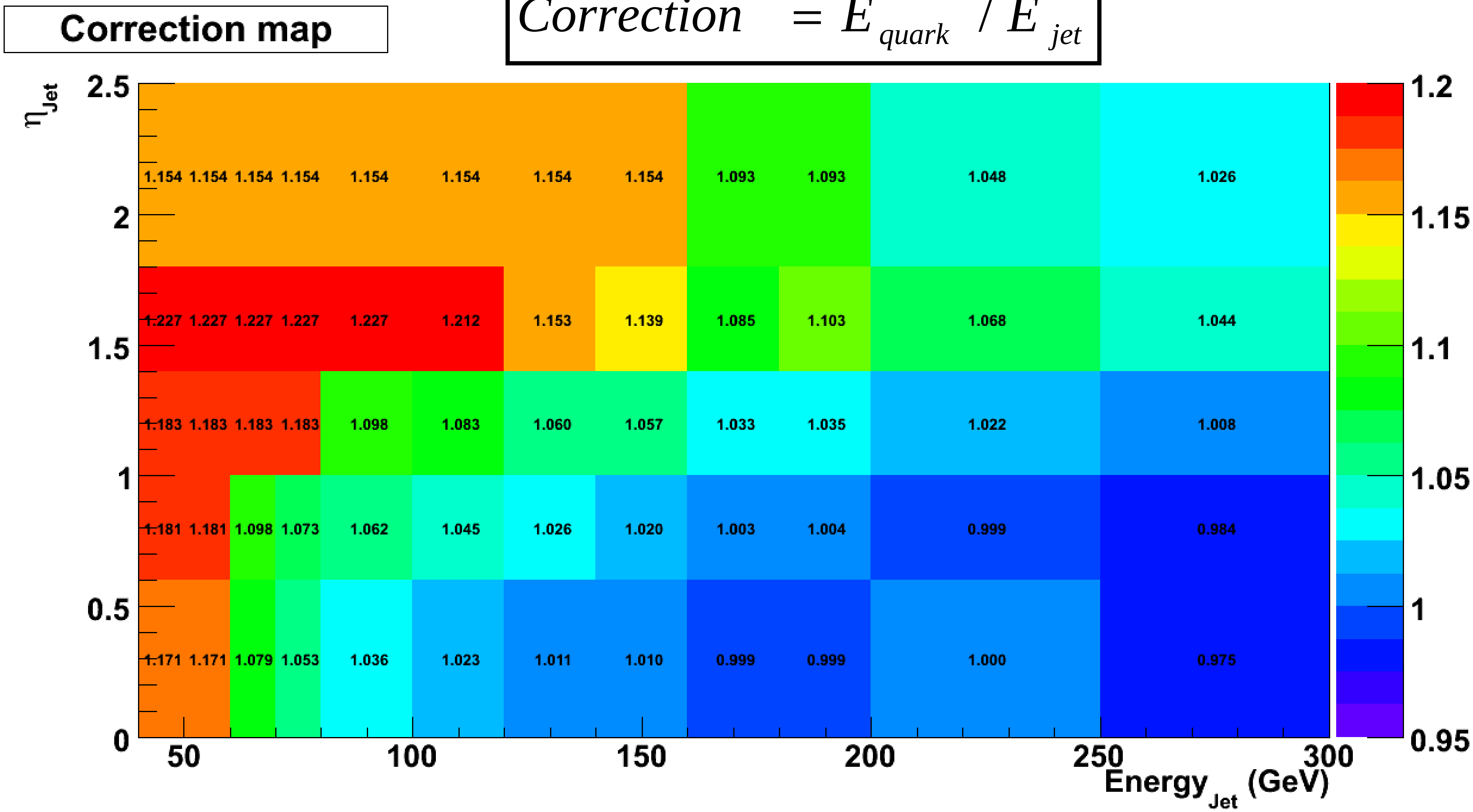
$$Correction = E_{quark} / E_{jet}$$



Energy scale

Correction map for b-jets (non muonic decay)

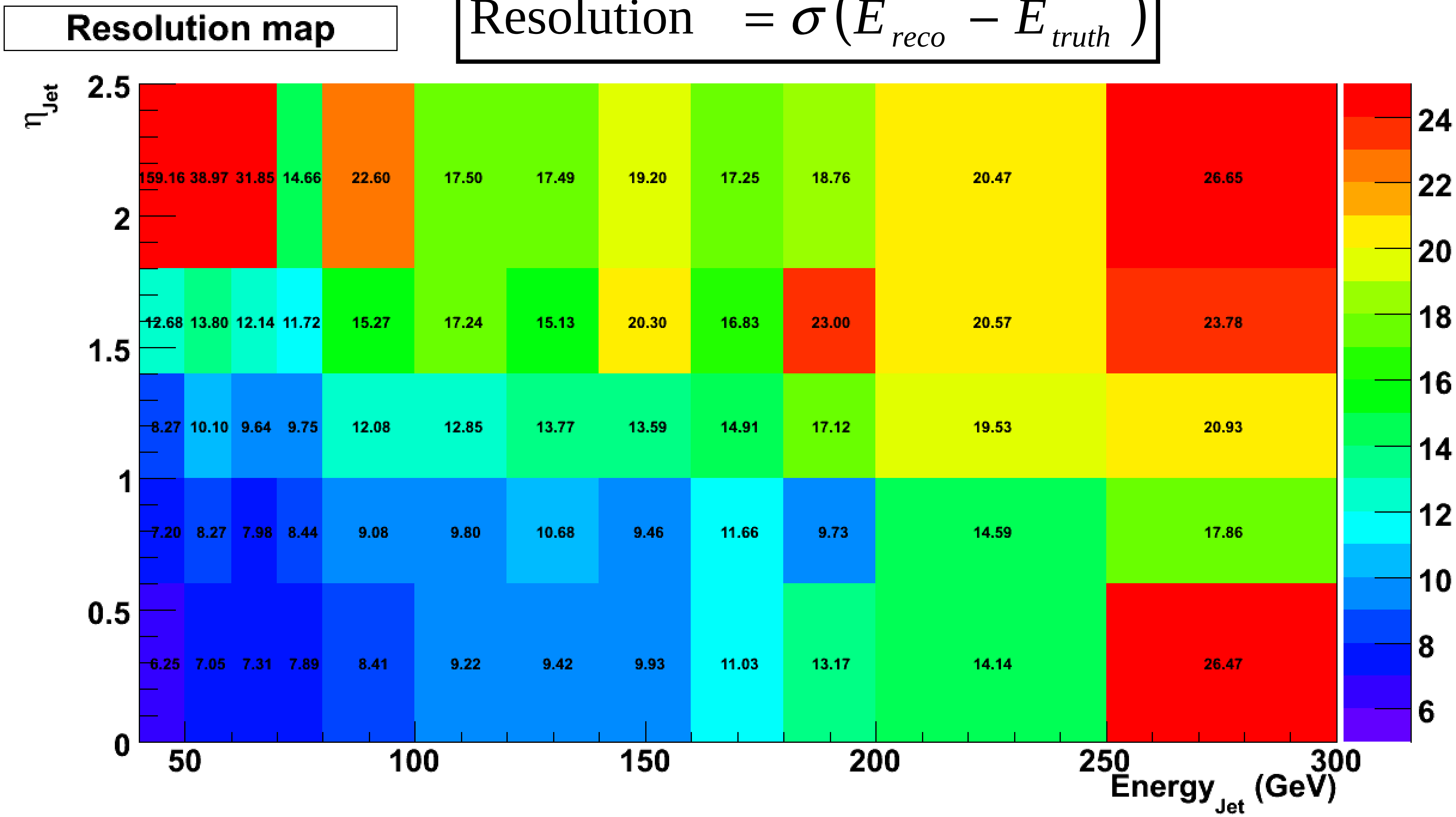
$$Correction = E_{quark} / E_{jet}$$



Energy resolution

Resolution map for light jets

$$\text{Resolution} = \sigma\left(E_{reco} - E_{truth}\right)$$



Energy resolution

Resolution map for b jet with non muonic decay

$$\text{Resolution} = \sigma\left(E_{reco} - E_{truth}\right)$$