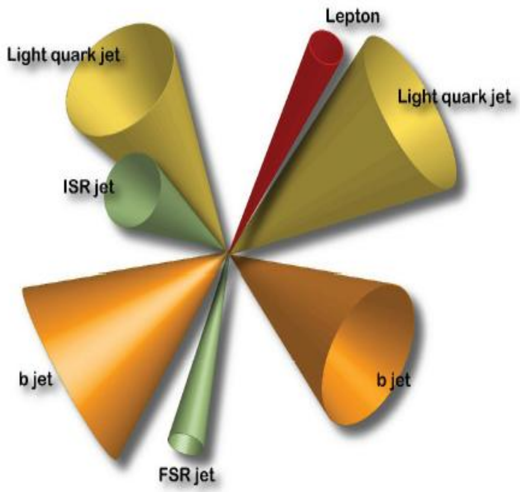
Top quark mass reconstruction in the semi-leptonic channel using the Global χ^2 algorithm

(MC08 @ 10 TeV)

TOP mass working group meeting



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30/06/2009

Talk outline

<ins>Outline</ins>

- Introduction
- Method
- Data samples and software
- Reconstruction of physics objects (in the semi-leptonic channel)
  - Electron reconstruction performance
  - Muon reconstruction performance
  - Missing transverse energy
  - Jet calibration studies
  - Jets reconstruction performance
- Event Selection (semi-leptonic channel)
- Top mass determination
  - Hadronic W mass reconstruction
  - Hadronic top mass reconstruction
  - Leptonic W mass reconstruction
  - Fitted top mass
- Conclusions

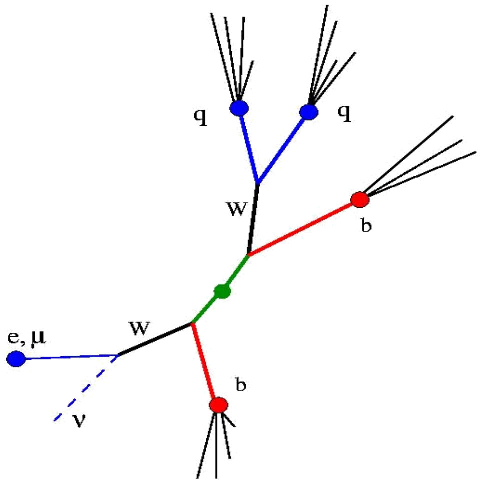
Introduction

Goal:

- Contribute to the studies of the ATLAS potential to measure the top quark mass using MC08 @ 10 TeV simulated data (**m_t = 172.5 GeV**).

How:

- Use the **semi-leptonic channel** (electron, muons or taus decaying leptonically + jets), σtt ~ 139 pb @ 10 TeV (golden channel).
  - Final state objects:
    - **1** (high pT) **isolated electron/muon**
    - 1 neutrino → **MET**
    - **2 light jets** (neglecting ISR and FSR)
    - **2 b jets**



- Following a strategy similar to the one described in T9 Top Mass note but using a global χ^2 technique to minimize the χ^2; see talk from Carlos Escobar in Jan. & May 09 Top Mass meetings:
  - http://indico.cern.ch/getFile.py/access?contribId=4&resId=0&materialId=slides&confId=47030
  - http://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=50899

Method

1. Physics objects selection and performance study and jet pre-calibration using MC
2. Event selection
3. Hadronic W mass fit using χ^2
4. Hadronic b-jet association
5. Compute p_z^ν from MET
6. Leptonic b-jet association
7. Kinematic fit using a global χ^2 based on the entire final state and selected candidates:

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

(additional terms could be added in the future)

- Fit parameters: E_{fit} (for jets and lepton) and m_{top}.

Data samples and software used

Simulation: **@ 10 TeV, m_t = 172.5 GeV**
ATLAS-GEO-02-01-00

↓

Hits G4

↓

Digitization & reconstruction (release 14.2.25.8):
- ATLAS-GEO-02-00-00 (same as ATLAS-GEO-02-01-00 but diff. conditions)
- OFLCOND-SIM-00-00-06

→ Misaligned ID
→ Beam spot displaced from (0, 0, 0) to (1.5, 2.5, -9) [mm]
→ Detector conditions as Sept. 08 (Pixel and LAr dead channels and modules)

↓

AOD
Dataset: mc08.**105200**.T1_**McAtNlo**_Jimmy.merge.AOD.e357_s462_r635_t53

↓

ARATopQuarkAnalysis (Our modifications are in tag 00-00-76)
- Running a private jobOptions on the Grid using Ganga.

↓

D3PD

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ROOT

Known problems:
There is a problem in the treatment of standalone muons in the MET computation.

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.

$$\varepsilon(\Delta R) = \frac{\#matches\ of\ truth\ e/\mu/\ jets\ with\ reconstructed\ e/\mu/\ jets\ (\Delta R)}{\#truth\ e/\mu/\ jets}$$

$$P(\Delta R) = \frac{\#matches\ of\ reconstructed\ e/\mu/\ jets\ with\ truth\ e/\mu/\ jets\ (\Delta R)}{\#reconstructed\ e/\mu/\ jets}$$

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

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

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

Electron reconstruction performance

Electron reconstruction and selection

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

- The medium identification cuts have been used: based on information from EM calorimeters and tracking variables (egamma isEM ElectronMedium)
- author=1 or author=3
- pT>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.

$$MATCHING \quad CRITERIA: \quad \Delta R = \sqrt{\left(\phi_{reco} - \phi_{truth}\right)^2 + \left(\eta_{reco} - \eta_{truth}\right)^2} < 0.05$$

How to calculate efficiencies?

MC@NLO samples have event weight, which is +1 or -1.

* How to deal with events with:
- 1 truth electron with EventWeight@NLO= -1
- no reconstructed electron

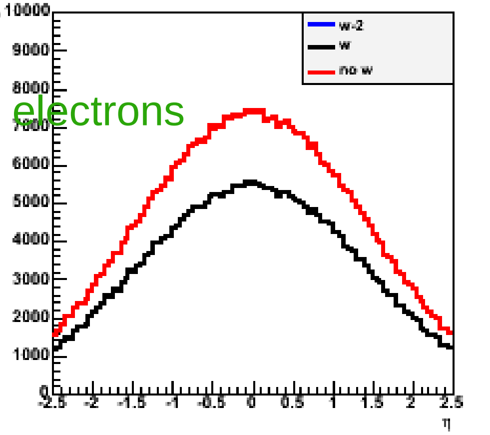
→Option A (w= -2):
Fill truth and matched reco. histograms using EventWeights and in case no electron is found and EventWeight = -1, fill reco histo with EventWeight= -2.

→Option B (use w):
Fill truth histograms with its EventWeight and if a reco electron is matched then fill reco histo with its weight.

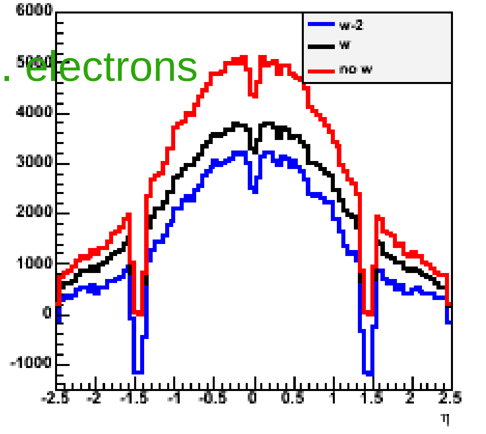
→ Option C (no w):
do not use EventWeights to calculate efficiencies or purities.

- About 12% of events have negative weight.
- Similar efficiencies obtain when using method B and C.
- Decide to use (in efficiency and purity plots) **method C**, (under discussion with the cross section note authors)

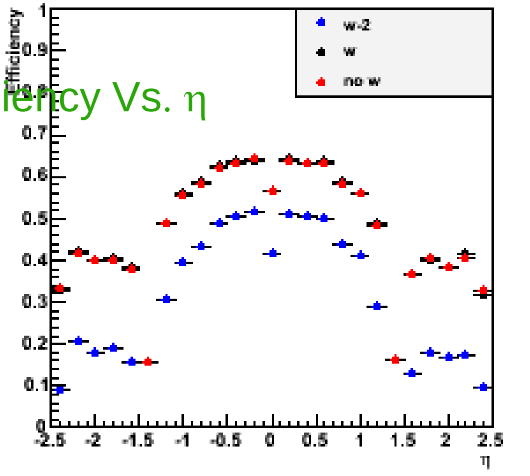
η of truth electrons



η of reco. electrons

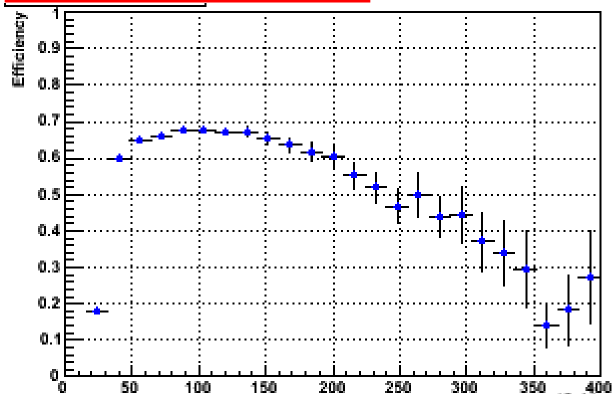


Efficiency Vs. η

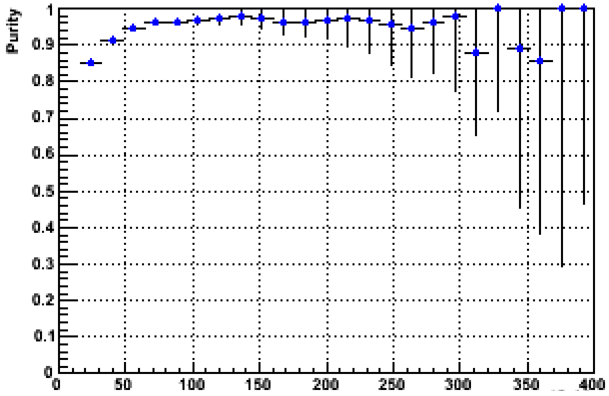


Efficiency and purity

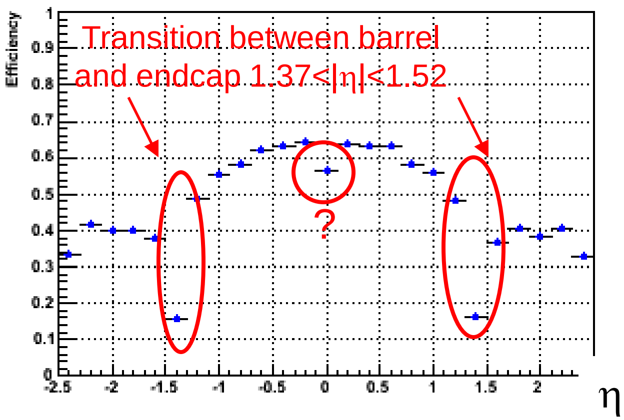
Efficiency Vs. pT



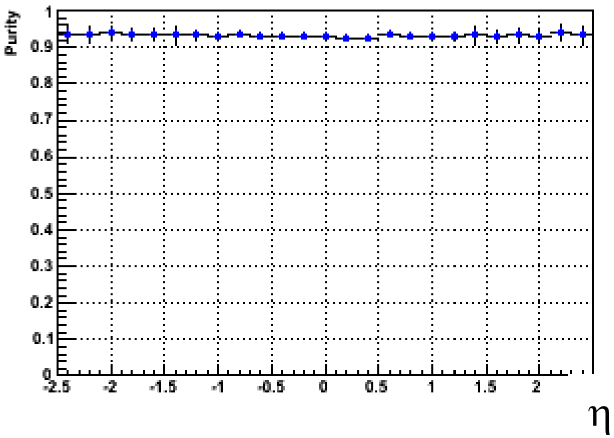
Purity Vs. pT



Efficiency Vs. η



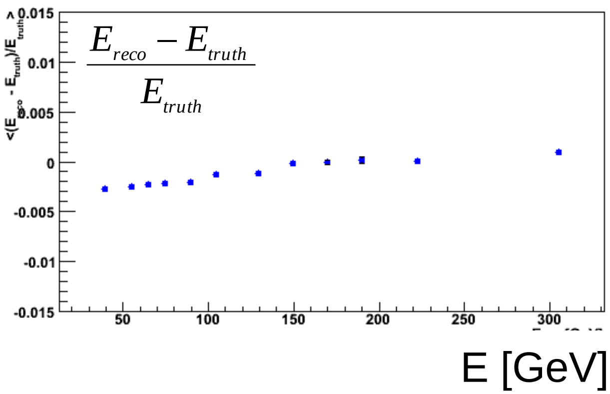
Purity Vs. η



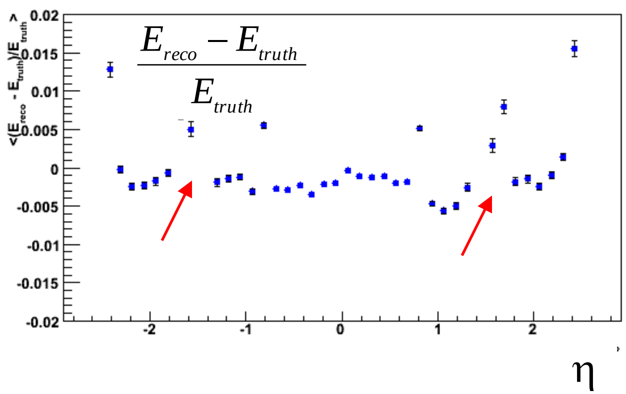
- Efficiency of electron reconstruction reaches 70% except for:
  - low pT and large |η|,
  - the overlap region between barrel and endcap calorimeters (cracks): 1.37<|η|<1.52,
  - |η|>1.52 (calorimeter endcaps).
- The contamination is ~5% (purity: ~95%, increases with pT).

Linearity, uniformity and resolution

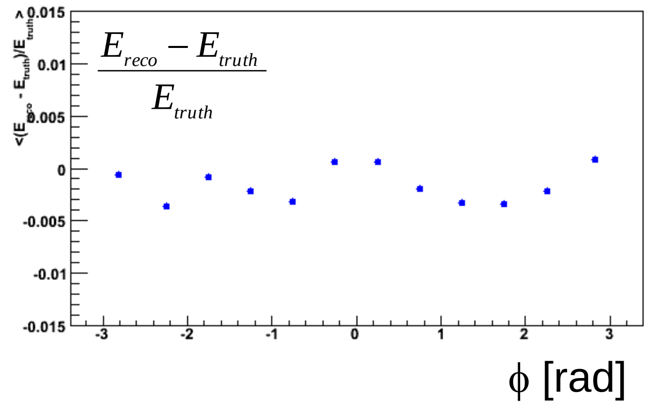
Energy linearity



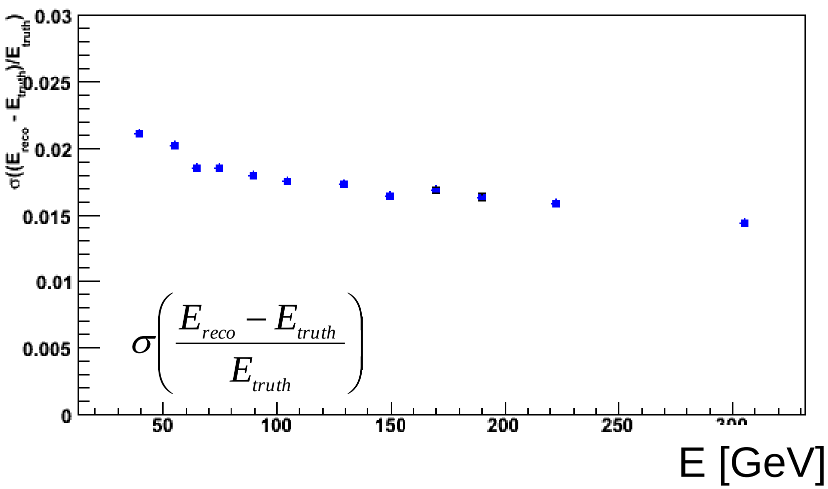
Energy uniformity in η



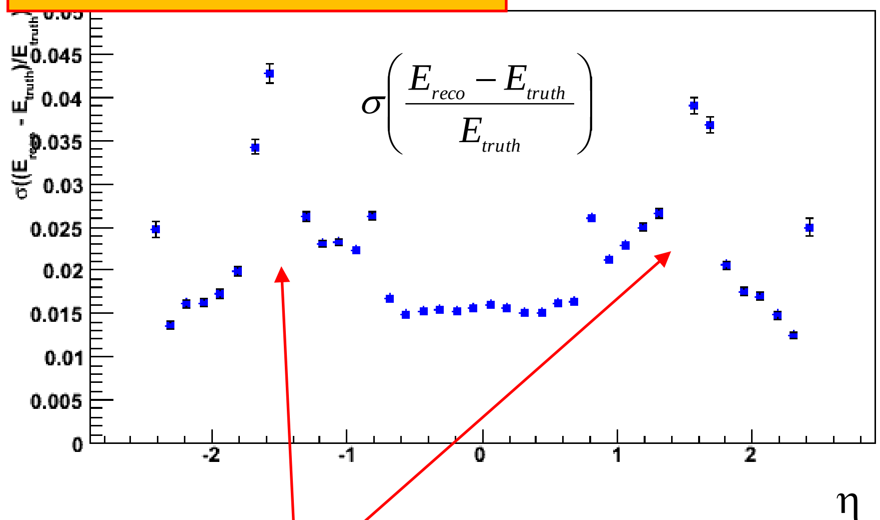
Energy uniformity in ϕ



Energy resolution Vs E



Energy resolution Vs η



- A small departure from linearity and non-uniformities are observed.
- Resolution is better for high energy and worse around the calorimeter cracks.

Muon reconstruction performance

Muon reconstruction and selection

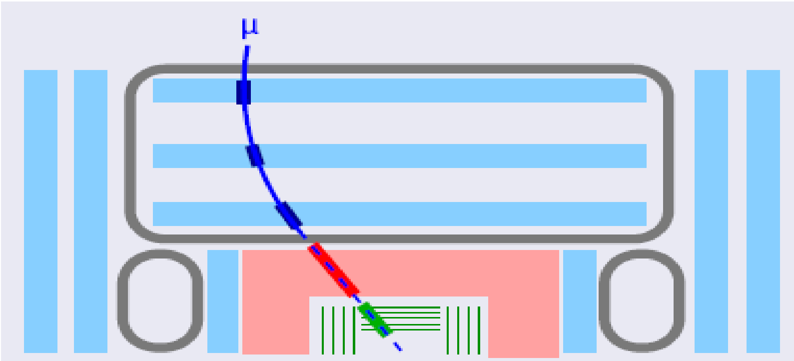
- **Truth muons**: muons coming from the W leptonic decay

- **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 → χ^2 match.

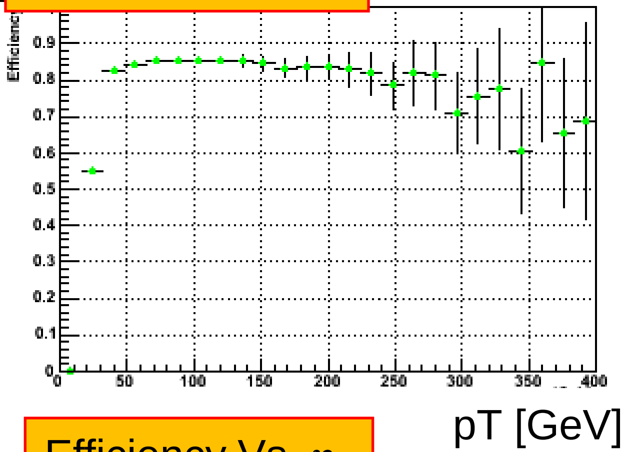
  - Cuts:
    - STACOmuons
    - isCombined=True
    - pT>20 GeV
    - $|\eta| < 2.5$
    - Isolation cut: the additional Et in a cone with radius ΔR=0.2 around the muon <6 GeV
    - remove muons if there is a good jet within $\Delta R < 0.3$.



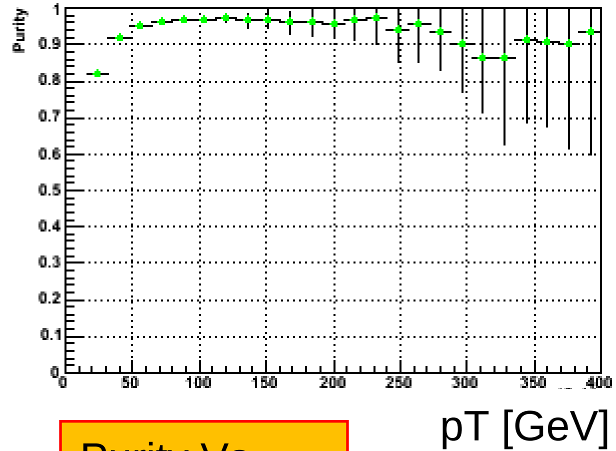
$$MATCHING \quad CRITERIA: \quad D_{ref} = \sqrt{\left(\frac{\phi_{reco} - \phi_{truth}}{0.005}\right)^2 + \left(\frac{\eta_{reco} - \eta_{truth}}{0.005}\right)^2 + \left(\frac{\Delta p_T / p_T}{0.03}\right)^2} < 100$$

Efficiency and purity

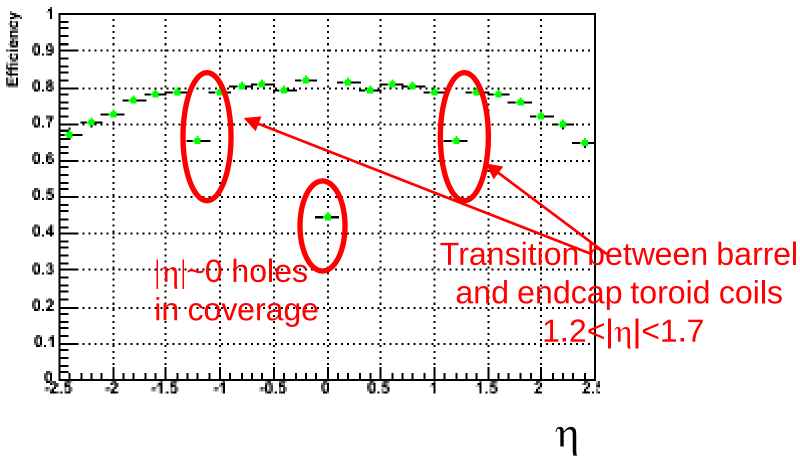
Efficiency Vs. pT



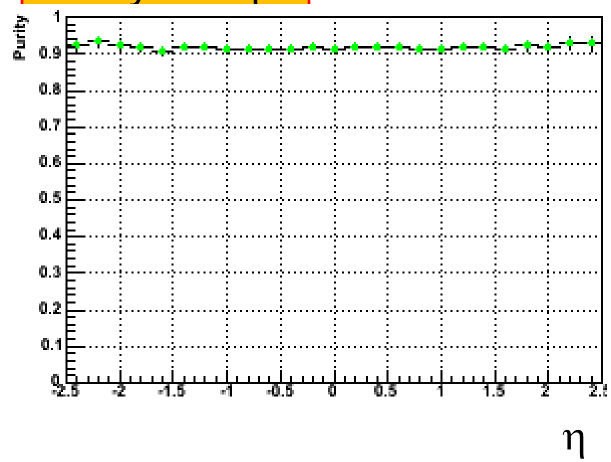
Purity Vs. pT



Efficiency Vs. η



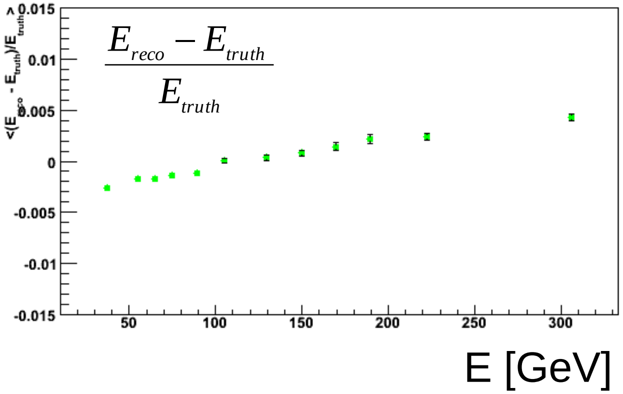
Purity Vs. η



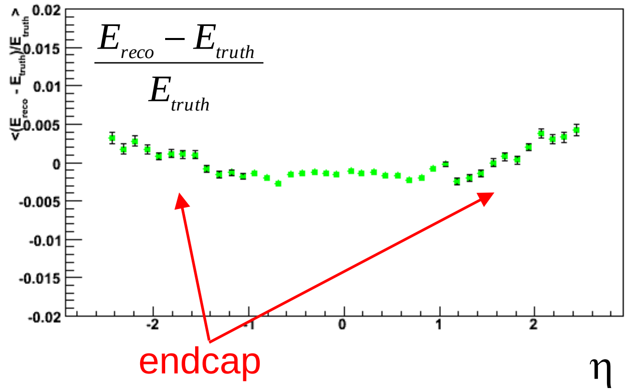
- Efficiency reaches 85% except for:
  - low pT region,
  - near $\eta \sim 0$ and intermediate region $1.2<|\eta|<1.7$.
- The purity is near 95%.

Linearity, uniformity and resolution

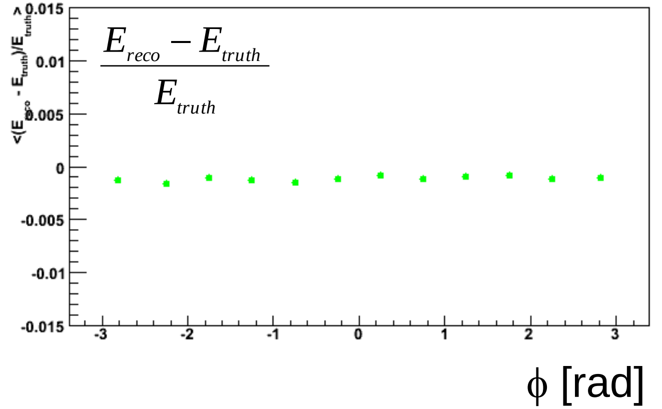
Energy linearity



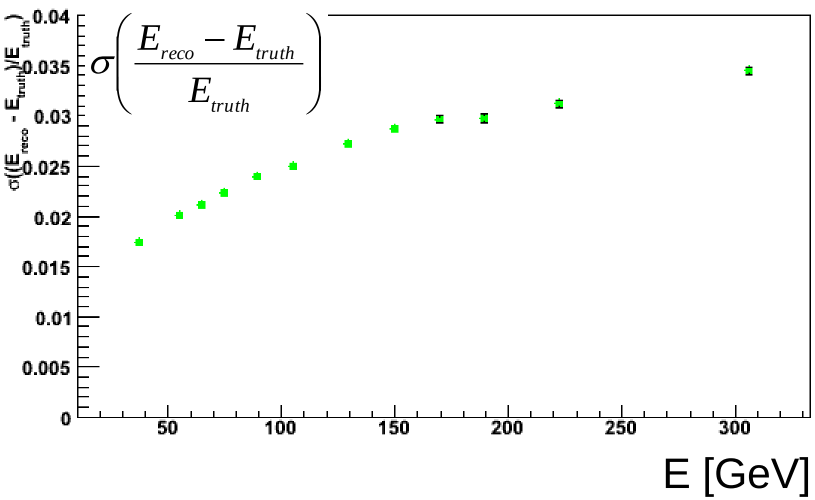
Energy uniformity in η



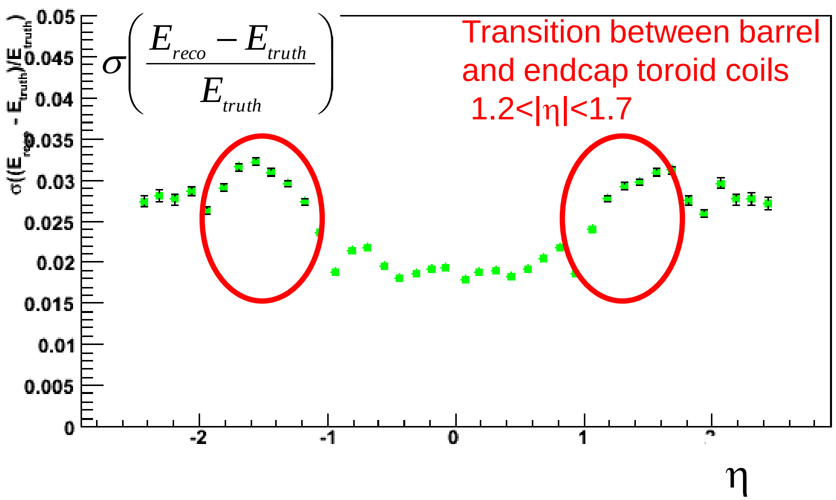
Energy uniformity in ϕ



Energy resolution Vs E



Energy resolution Vs η



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

MET reconstruction performance

MET reconstruction

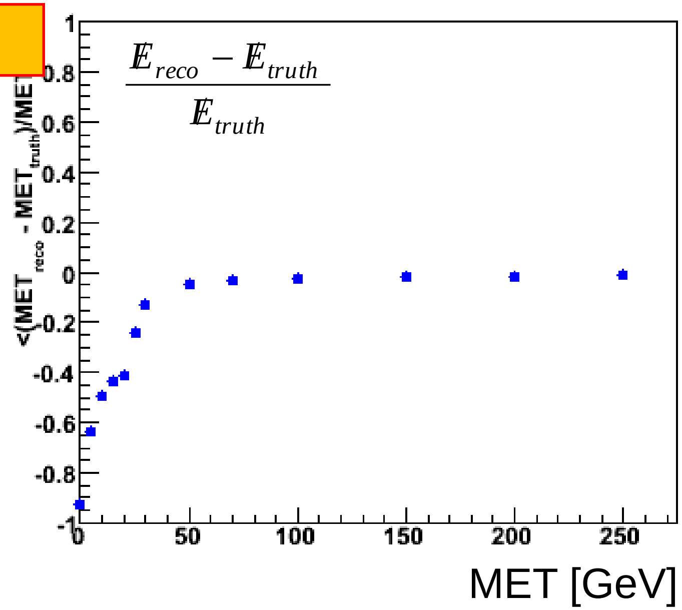
- The MET is used as an estimate of the neutrino transverse momentum.
- **Truth MET**: contribution from all stable and non-interacting particles in the final state.
- **Reconstructed MET**:
    - Reconstructed by the RefMET algorithm (cell based):

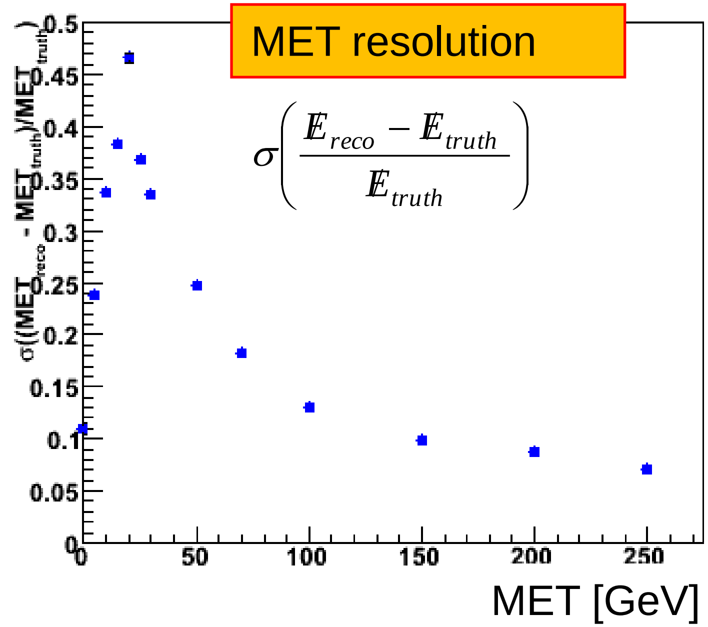
$$\not{E}_{x,y}^{Final} = MET_{x,y}^{Final} = MET_{x,y}^{Calo} + MET_{x,y}^{Cryo} + MET_{x,y}^{Muon}$$

There is a problem in the treatment of standalone muons in the MET computation.

MET performance

MET linearity





- Departure from linearity.
- The resolution is better for higher MET.
- A resolution of about 12 GeV is obtained, in agreement with what is expected.

Jet pre-calibration

- The jet calibration effects are removed by performing a jet pre-calibration to the parton level using MC information. This is done by:
  - matching jets to partons (requiring ΔR(quark-reco jet)<0.3)
  - deriving the correction factor: $C=E_{quark}/E_{jet}$ Vs. η_{jet} and E_{jet}.

This is performed separately for light jets and b-quark jets with and without muons.

Jet reconstruction and selection

- The ATLAS implementation of the fixed cone jet finder algorithm (Cone4TowerJets) with R_{cone} = 0.4 was used to build jets.
- Jets are defined at 3 levels:

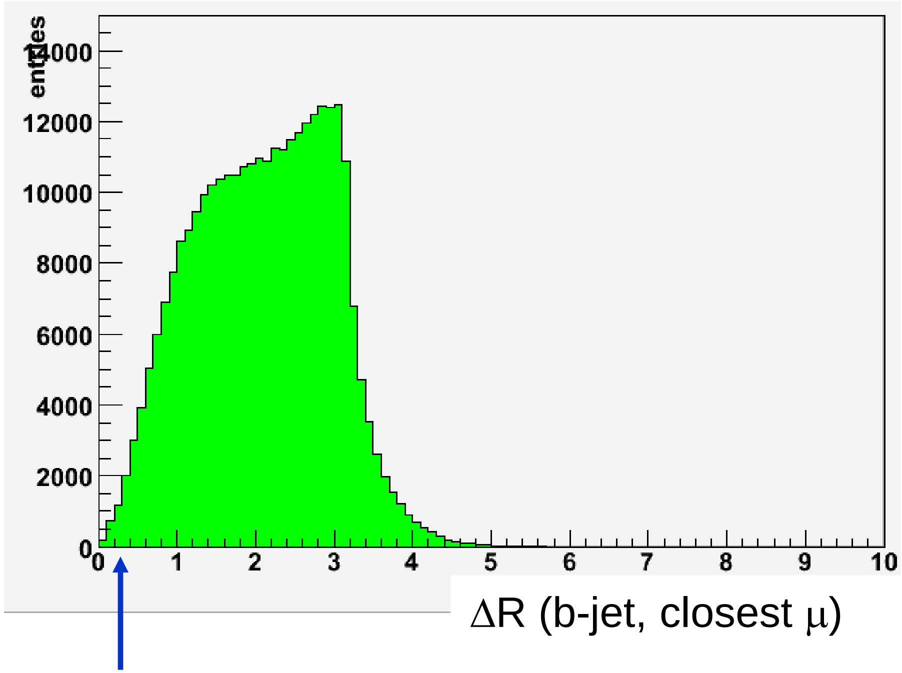
- **Quark level**: each quark is taken as a different jet
- **Truth Particle jets**: built from stable particles (neutrinos and muons generated in the collisions are excluded)
- **Reconstructed jets**: built from calorimeter towers defined as massless pseudo-particles (corrected by detector effects)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

$$\Delta R = \sqrt{(\phi_{reco} - \phi_{truth})^2 + (\eta_{reco} - \eta_{truth})^2} < 0.3$$

Jet clasification

- 3 types of jets have been considered separately:
  - light jets
  - b-jets not close to a reconstructed muon
  - b-jets close to a reconstructed muon (i.e. $\Delta R(\text{jet,muon})<0.2$)



* Muon selection here is:
- STACO
- is High pT
- pT>10 GeV
- $|\eta| < 4$
- Etcone20< 6 GeV

→ Selection not optimized for the selection of soft muons within jets.

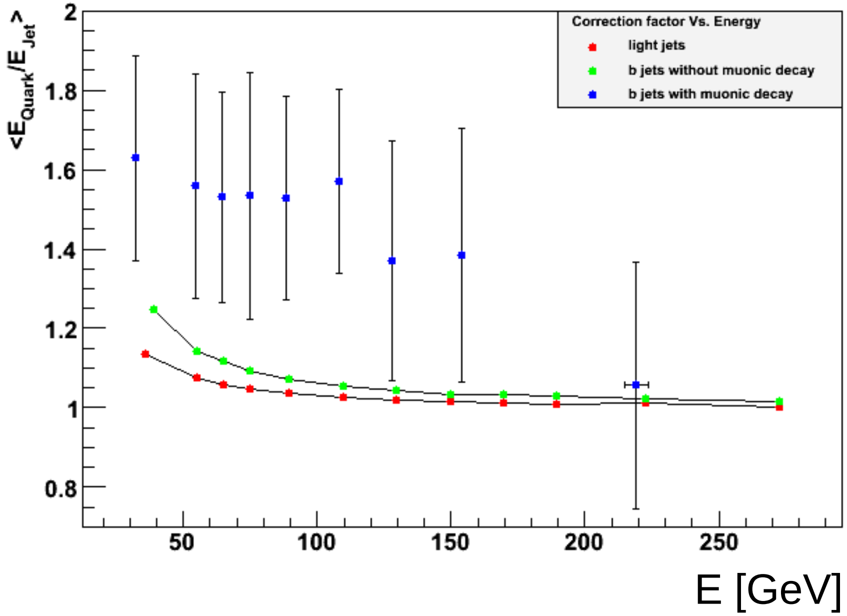
- at reconstruction level the IP3D + SV1 b-tagging algorithm was used to tag b-jets (weight > 6)

Correction factors and resolutions

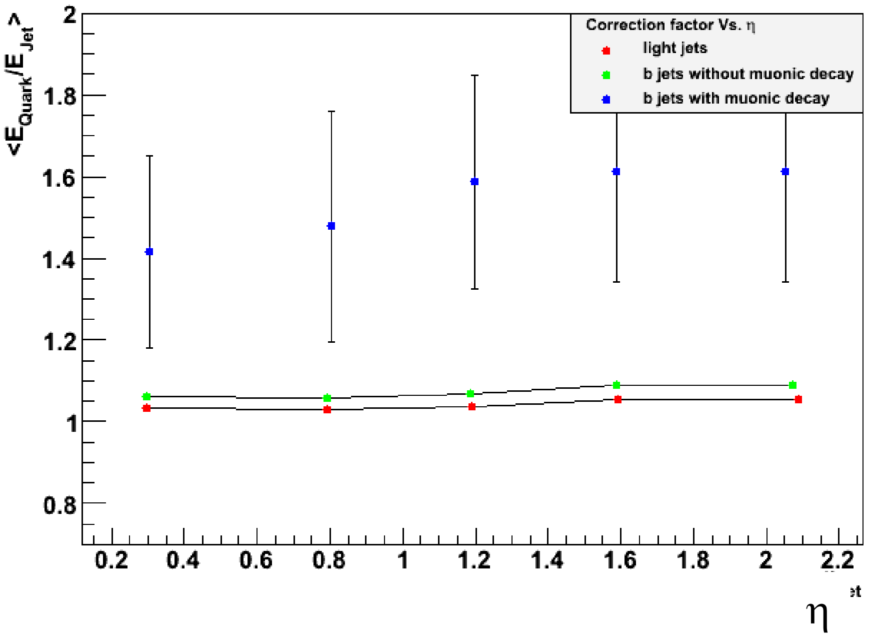
- Correction factors (E_{quark}/E_{jet}) and energy resolutions ($\sigma(E_{quark}-E_{jet})$) depend on the jet energy and η.

Correction factors

Vs. Energy



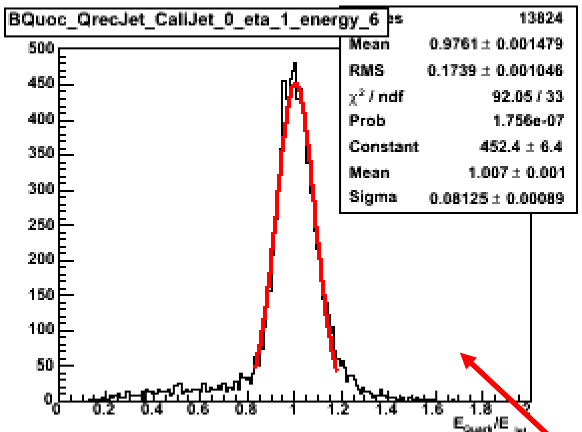
Vs. η



- Energy scale depends on the type of jets
- Correction factors are higher for b-jets with muonic decay (since the energy of the muon is not reconstructed in the jet).

Correction factors and resolutions

- Correction factors (E_{quark}/E_{jet}) and energy resolutions ($\sigma(E_{quark}-E_{jet})$) are computed for different energy and η regions.

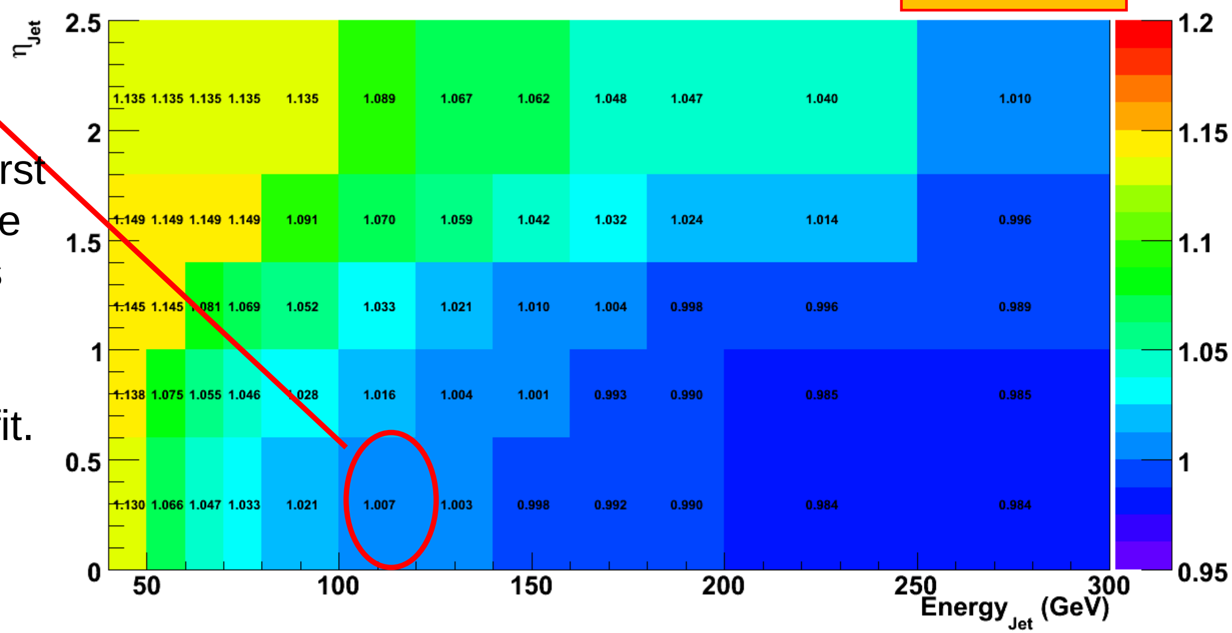


To make the fit more stable, a first Gaussian was fitted between the mean of the histogram ±2 times the RMS. A second fit is then perform in the same way using the mean and width of the first fit.

$100<|E_{jet}| \leq 120$

$0\leq|\eta_{jet}| <0.6$

Light jets

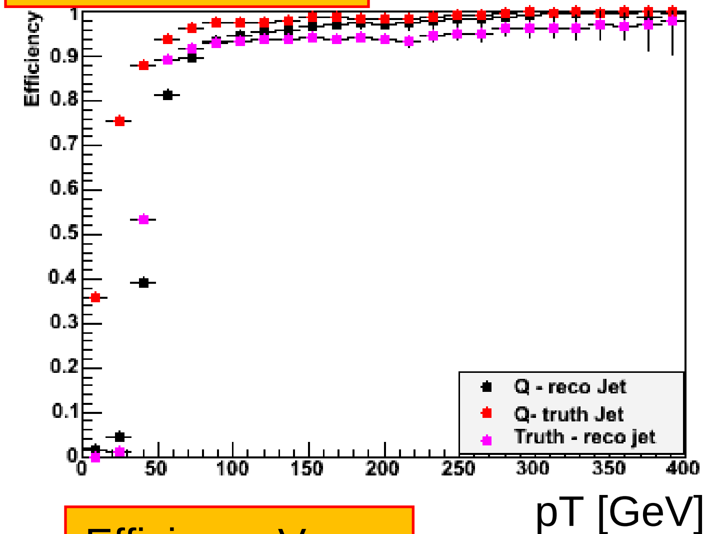


Jets reconstruction performance

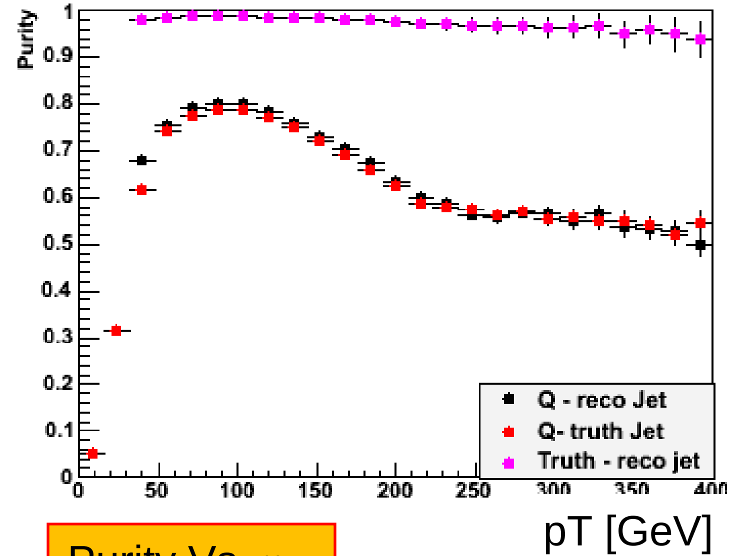
Once jets are pre-calibrated, …

Efficiency and purity

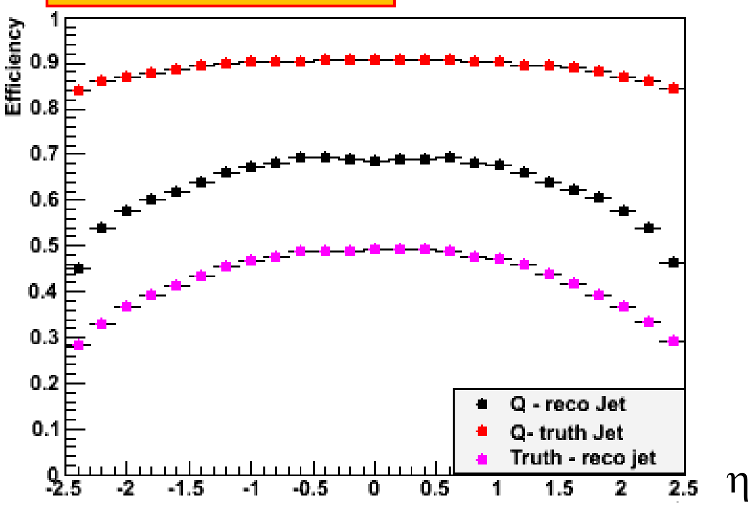
Efficiency Vs. pT



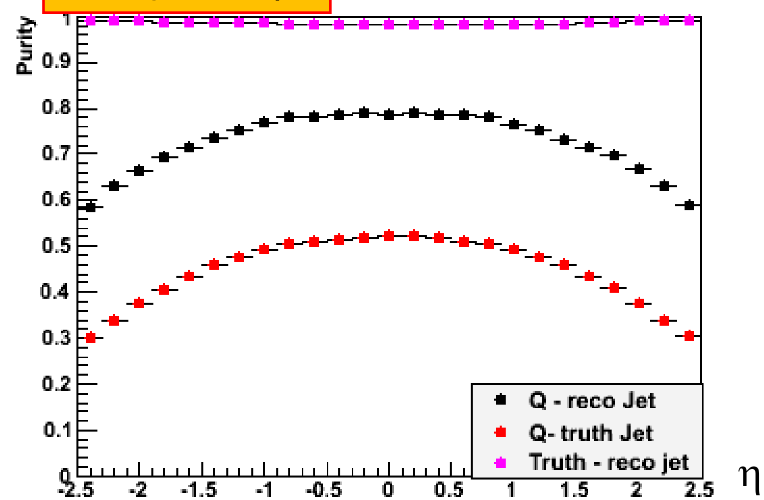
Purity Vs. pT



Efficiency Vs. η



Purity Vs. η

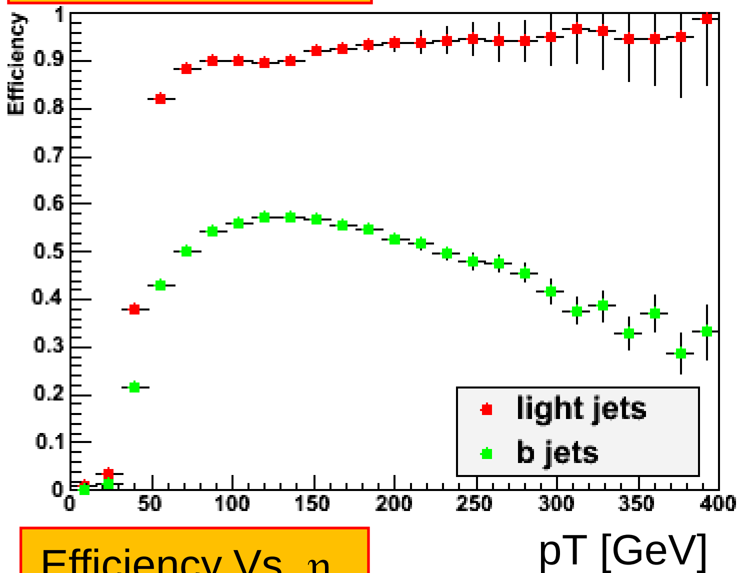


- Efficiencies are higher when comparing quarks-truth jets.
- Purity is near 1 when comparing truth and reco jets; while the others are lower due to effects of the hadronization.

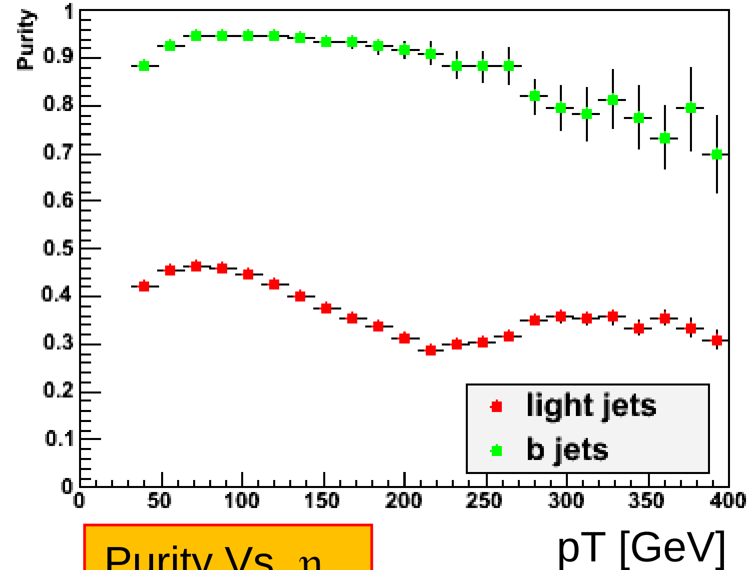
Efficiency and purity

Q-reco jet

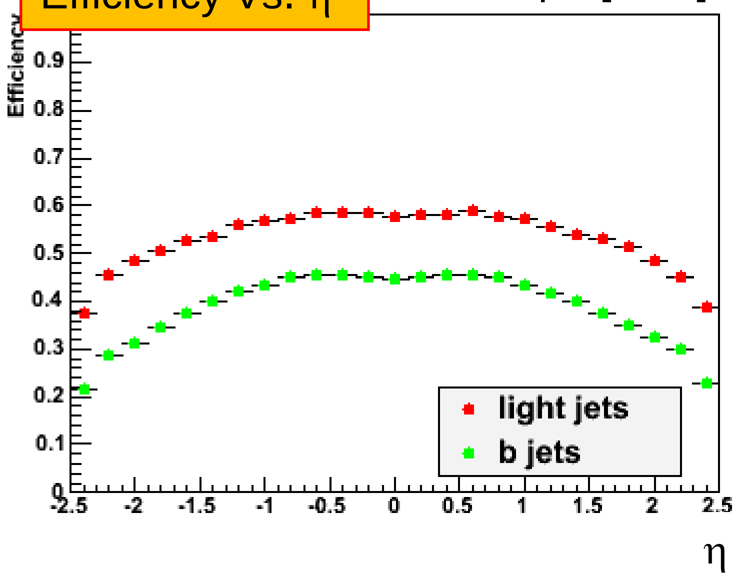
Efficiency Vs. pT



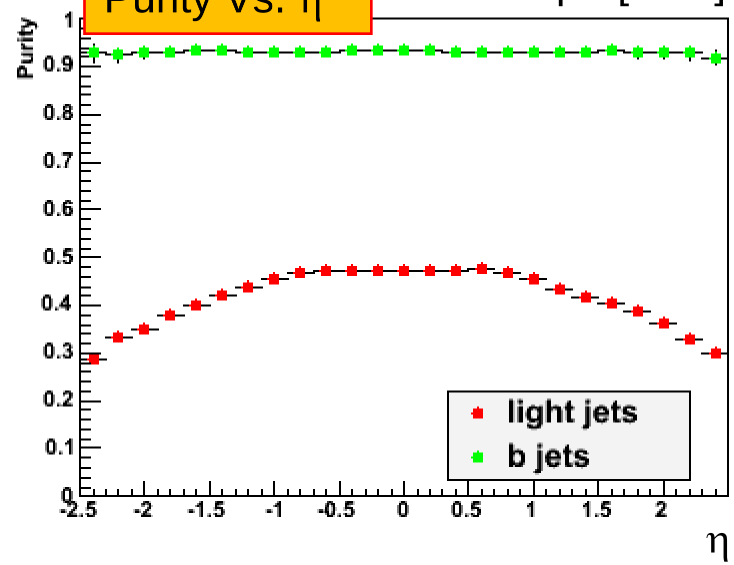
Purity Vs. pT



Efficiency Vs. η



Purity Vs. η

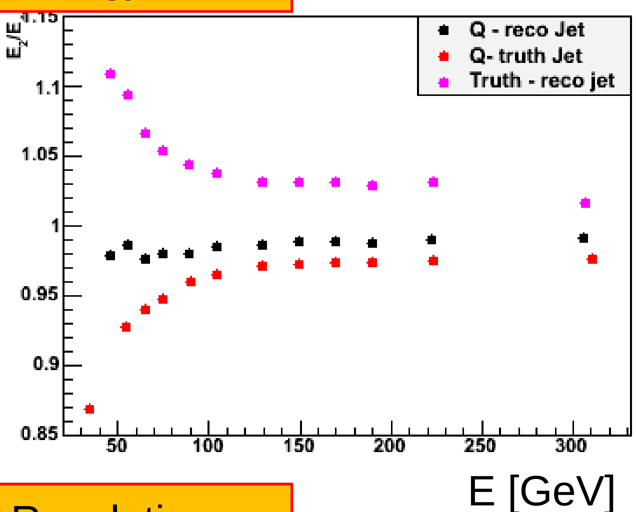


- Efficiency is higher for light jets than for b-jets while the purity is lower.

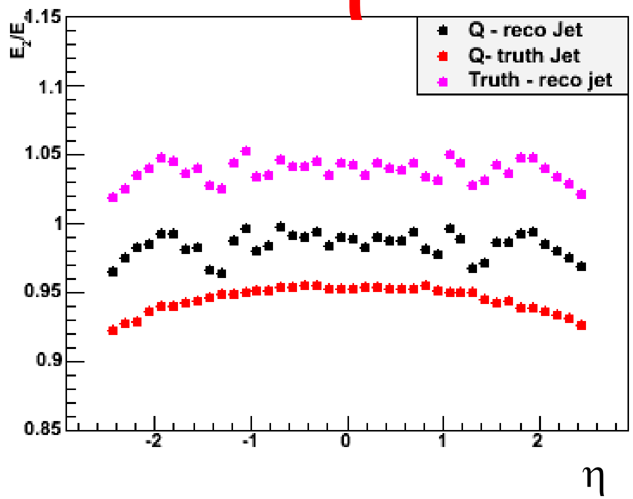
Linearity, uniformity and resolution

Energy scale

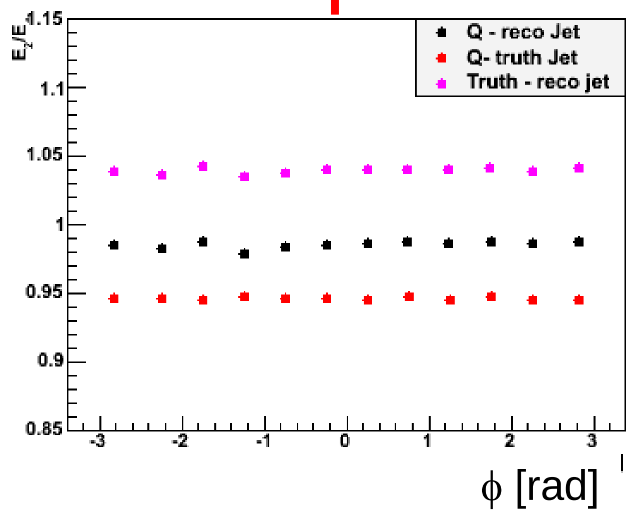
Vs E



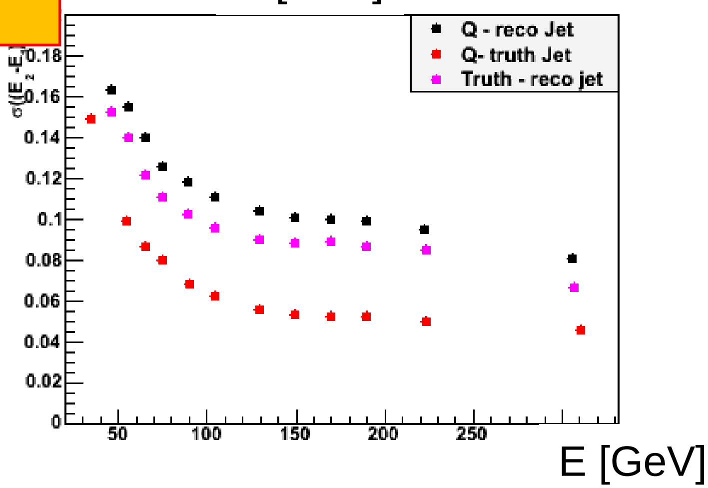
Vs η

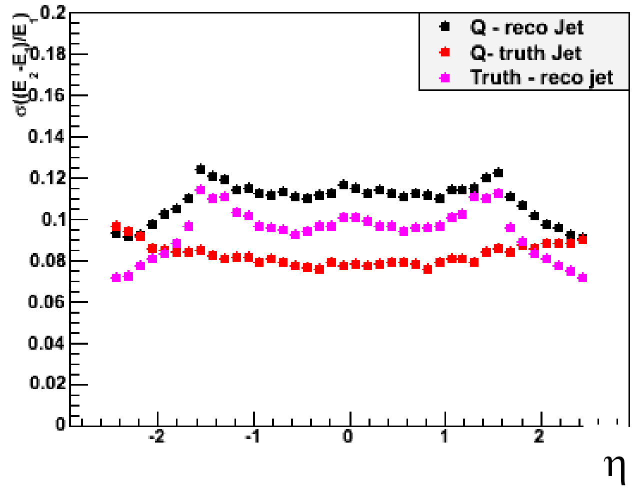


Vs ϕ



Resolution

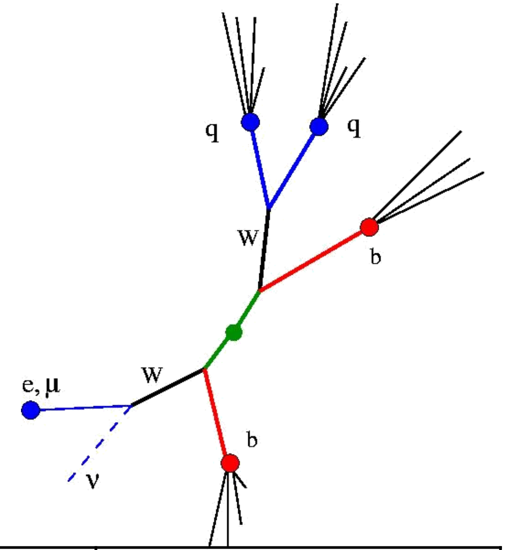




- Departures from linearity when comparing Q-truth jets or truth – reco jets.
- After jet calibration (from reco jets to quarks) the linearity is near 1; although there is still room for improving calibration.
- Resolution increases for higher energies and is worse when comparing Q-reco jets.

Event selection

- **Semi-leptonic channel** (electron, muons or taus decaying leptonically + jets), :



- **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=200 pb^{-1} @ 10 TeV

Process	Number of events	1 isolated lepton pT>20(25) GeV	MET>20 GeV	>= 4 jets pT>40 GeV	= 2b-jets pT>40 GeV
Signal	**27832**	**14685 (53%)**	**13139 (47%)**	**4986 (18%)**	**1207 (4%)**
Di-leptonic	8882	4317 (49%)	4062 (46%)	645 (7%)	174 (2%)
τ (hadronic decay)+jets	7698	43 (0.6%)	40 (0.5%)	10 (0.14%)	2 (0.02%)

- About 4 % of the signal events pass all cuts
(similar to the result obtained with TopView ntuples @ 14 TeV).
- Acumultaive efficiencies after each cut are shown.

Top mass determination

- Hadronic W mass reconstruction
- Hadronic b-jet association
- Leptonic W mass reconstruction
- Leptonic b-jet association
- Kinematic fit (global χ^2) using selected candidates

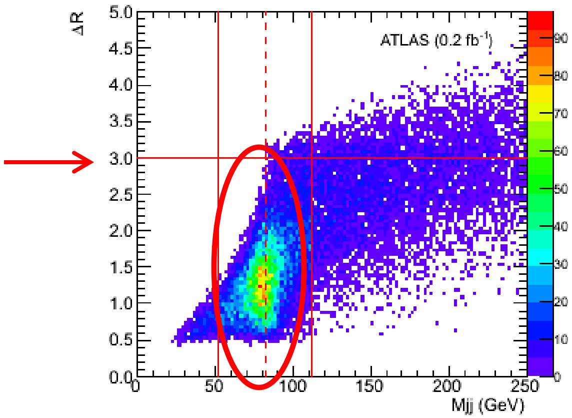
Hadronic W mass reconstruction

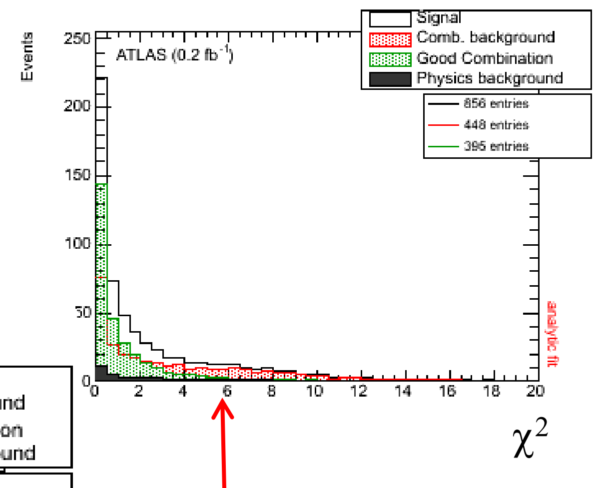
Reconstruct the hadronic W boson using a χ^2:

$$\chi^2 = \left(\frac{M_{jj}(\alpha_{E_{j1}},\alpha_{E2}) - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{E_{j1}(1-\alpha_{E_{j1}})}{\sigma_1}\right)^2 + \left(\frac{E_{j2}(1-\alpha_{E_{j2}})}{\sigma_2}\right)^2$$

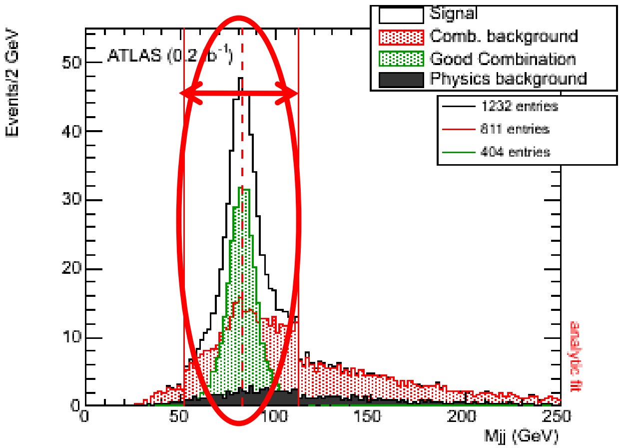
- If N_{jets} >2→pair with χ_{min}^2 is kept
- $\Delta R(j_1,j_2)<3$ (purity increases ~5%)
- $|M_{jj}-82| < 30$ GeV
- Fit parameters: $\mathbf{M_{jj}, \alpha_{Ej1}, \alpha_{Ej2}}$
- After χ^2 minization, only events with $\chi^2<6$ are kept **[MyC0 cut]**

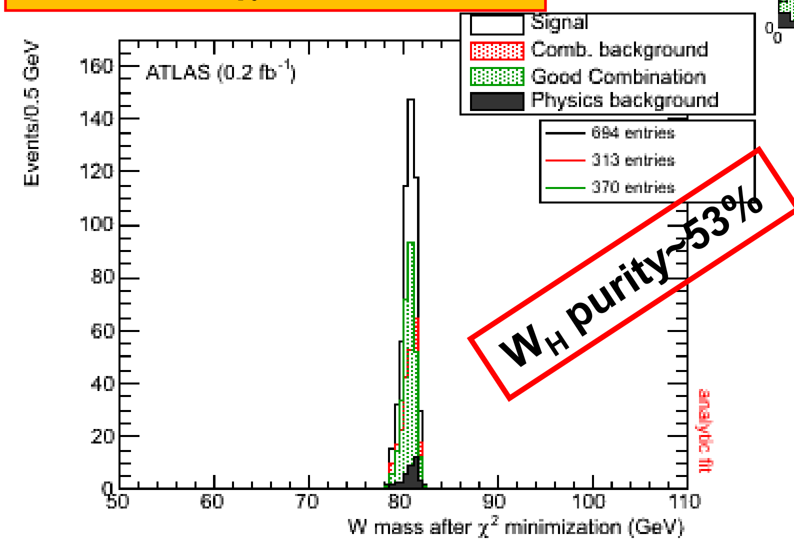
** The resolutions σ_1 and σ_2 ($\sigma(E_{jet} - E_{quark})$) are extracted from MC (see back-up slides).





MyC0 cut: χ^2<6

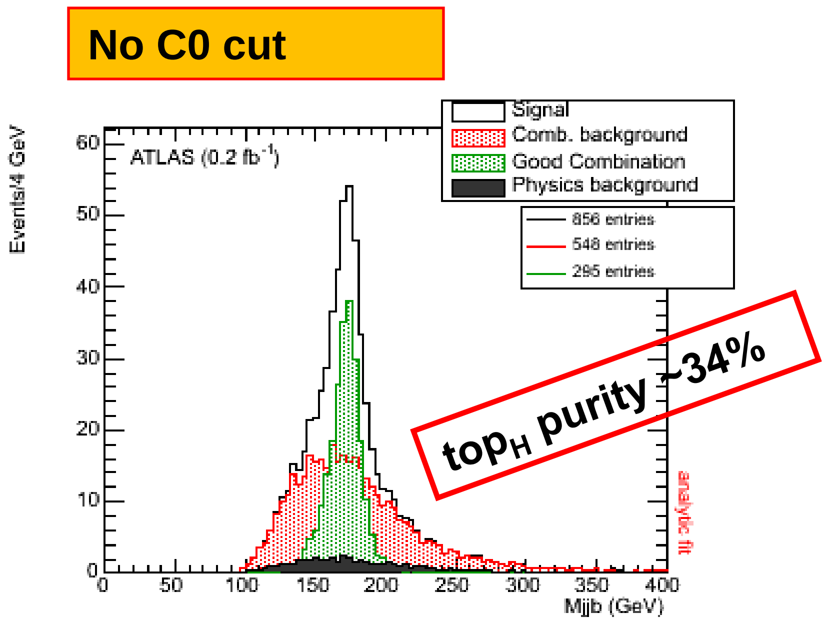


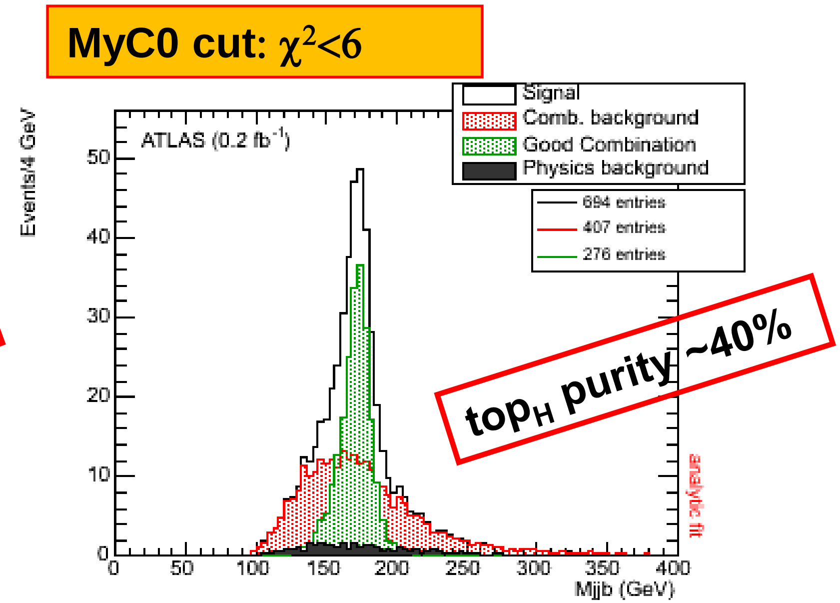


<u>Note:</u> With MyC0 cut W purity increases ~6% with respect to T9 C0 cut.

Hadronic top mass reconstruction

- Once the hadronic boson is reco, it is associated to the closest b-jet and the hadronic top is then reconstructed. (The remaining b-jet and the leptonic W boson then define the leptonic top quark).





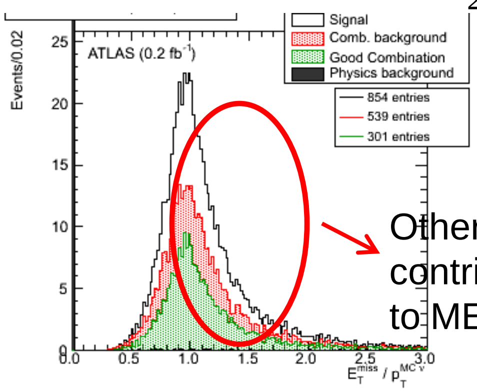
Leptonic W mass reconstruction

- The difficulty comes from the kinematics of the neutrino
- MET measurement is used as an estimate of the neutrino $\mathbf{p_T}^\nu$ (assuming Et in CM is zero)
- The $\mathbf{p_z}^\nu$ is obtained using the known W mass and four-momentum conservation:

$$p_z^\nu = \frac{1}{2\cdot(E_l^2 - p_z^{l\,2})}\left\langle p_z^l\left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right] \pm \sqrt{E_l^2\left[(2p_x^l \not{E}_t \cos\phi + 2p_y^l \not{E}_t \sin\phi - m_l^2 + M_W^2)^2 - 4\not{E}_t^2(E_l^2 - p_z^{l\,2})\right]}\right\rangle$$

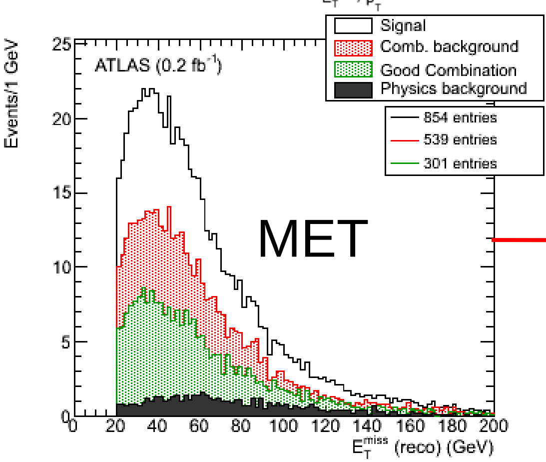
- If discriminant Δ is <0, the MET is re-calculated by finding which MET value makes $\Delta \geq 0$:

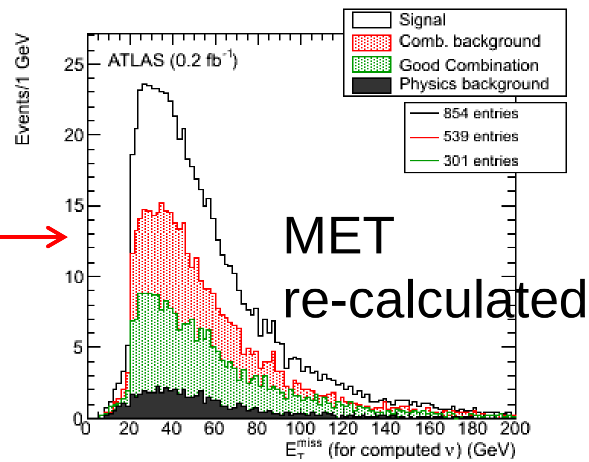
$$\Delta \geq 0 -> \not{E}_t = \frac{1}{2\left[E_l^2 - p_z^{l\,2} - (p_x^l\cos\phi + p_y^l\sin\phi)^2\right]}\left\langle -(p_x^l\cos\phi + p_y^l\sin\phi)\cdot(m_l^2 - M_W^2) \pm \sqrt{(m_l^2 - M_W^2)^2\cdot(E_l^2 - p_z^{l\,2})}\right\rangle$$

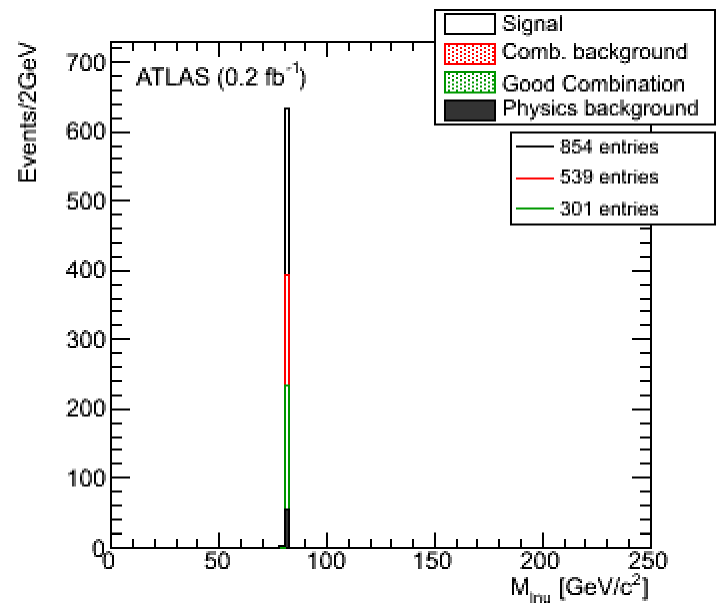


Other contributions to MET!

-The b-jet association is re-done:
the option leading to smaller $|M_{jjb}-M_{l\nu b}|$ is taken.





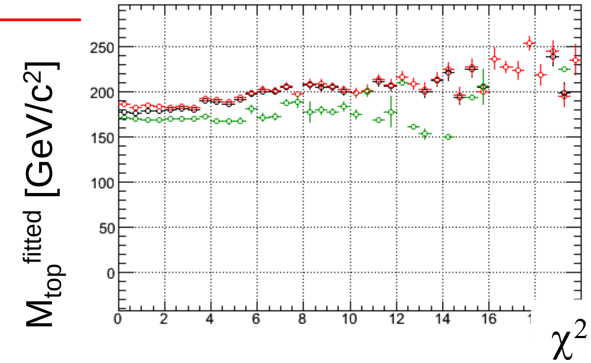


Fitted top mass

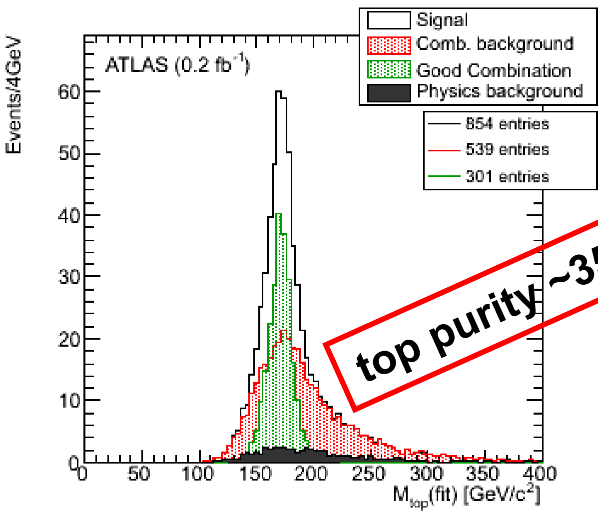
MyC0 or T9C0 cut
not yet applied

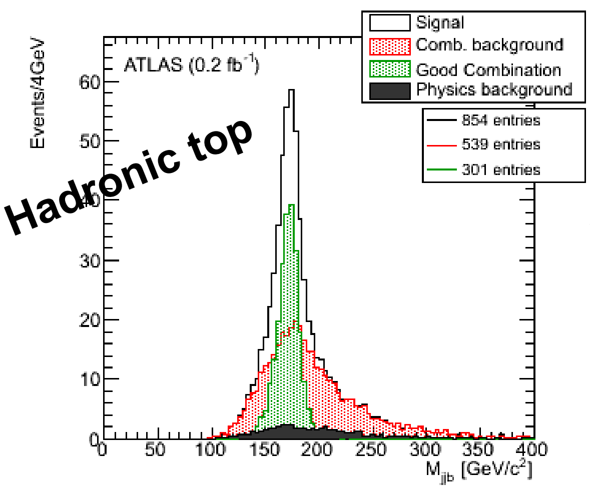
- From a kinematic fit using a χ^2 based on the entire final state:

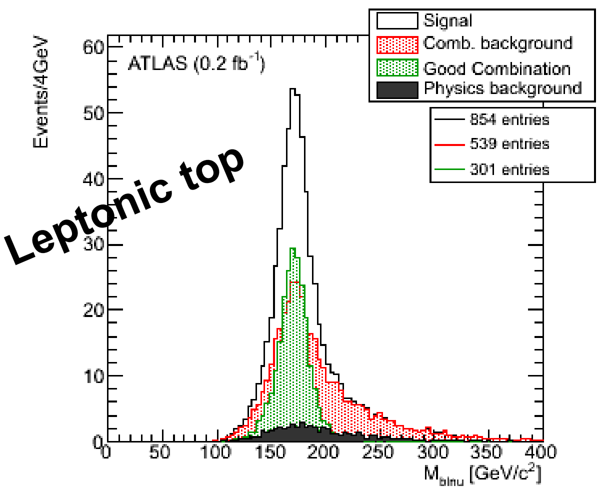
$$\chi^2 = \sum_{\substack{4\,jets\\+lepton}} \left(\frac{E_i^{reco} - E_i^{fit}}{\sigma_{E_i}}\right)^2 + \left(\frac{M_{jj} - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{M_{l\nu} - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{M_{jjb_H} - M_{top}^{fit}}{\sigma_{top_H}}\right)^2 + \left(\frac{M_{l\nu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



No C0 cut







* The resolutions functions are extracted from MC by fitting the distributions E_{reco}-E_{truth} or E_{jet} –E_{quark} as a function of E_{reco} or E_{jet} with a polynomial (3rd degree) for 5 η regions (back-up slides).
* σ_{topH} and σ_{topL} are the widhts of mass distributions, fixed to 10 and 15 GeV respectively (like in ATL-PHYS-INT-2008-021 note).

Conclusions

• The analysis code has been modified to read both TopView ntuples (to compare with CSC results) and D3PDs.
• D3PDs are produced from AODs in Athena (ARATopQuarkAnalysis) using the Grid (Ganga).

• Only dataset 105200 has been studied so far which includes signal events and ttbar di-leptonic and tttbar τ (hadronic decay)+jets backgrounds. Need to look to others backgrounds.

• The performance of the reconstruction of final state objets of the semi-leptonic channel: electrons, muons, jets and missing Et has been studied using MC08.

• 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.
For jets, a calibration to correct reconstructed jets energy to parton level has been provided.

• First look at kinematic fit results leads to reasonable results.

• **ToDo:**
  - take into account trigger information
  - tune jet calibration
  - improve the fits M_W and M_{top}
  - apply others cuts to increase top purity
  - study contribution from others backgrounds
  - estimate systematic uncertainties

BACK-UP SLIDES

Leptonic W mass reconstruction

- Reconstruct the leptonic W boson using MET measurement as an estimate of the neutrino pT.

$$M_W^2 = m_l^2 + 2E_l\sqrt{(p_x^\nu)^2 + (p_y^\nu)^2 + (p_z^\nu)^2} - 2(p_x^l p_x^\nu + p_y^l p_y^\nu + p_z^l p_z^\nu) = m_l^2 + 2E_l\sqrt{\not{E}_t^2 + (p_z^\nu)^2} - 2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi + p_z^l p_z^\nu)$$

$$M_W^2 = m_l^2 + 2E_l\sqrt{(p_x^\nu)^2 + (p_y^\nu)^2 + (p_z^\nu)^2} - 2(p_x^l p_x^\nu + p_y^l p_y^\nu + p_z^l p_z^\nu) = m_l^2 + 2E_l\sqrt{\not{E}_t^2 + (p_z^\nu)^2} - 2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi + p_z^l p_z^\nu)$$

$$-> 2E_l\sqrt{\not{E}_t^2 + (p_z^\nu)^2} = 2p_z^l p_z^\nu + 2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2$$

$$-> 4E_l^2\left[\not{E}_t^2 + (p_z^\nu)^2\right] = \left[2p_z^l p_z^\nu + 2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]^2$$

$$-> (4E_l^2 - 4p_z^{l\,2})(p_z^\nu)^2 - 4p_z^l\left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]p_z^\nu - \left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]^2 + 4E_l^2\not{E}_t^2 = 0$$

$$-> (E_l^2 - p_z^{l\,2})(p_z^\nu)^2 - p_z^l\left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]p_z^\nu - \left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]^2/4 + E_l^2\not{E}_t^2 = 0$$

$$-> p_z^\nu = \frac{1}{2\cdot(E_l^2 - p_z^{l\,2})}\left\langle p_z^l\left[2(p_x^l \not{E}_t \cos\phi + p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right] \pm \sqrt{E_l^2\left[(2p_x^l \not{E}_t \cos\phi + 2p_y^l \not{E}_t \sin\phi - m_l^2 + M_W^2)^2 - 4\not{E}_t^2(E_l^2 - p_z^{l\,2})\right]}\right\rangle$$

- If discriminant is <0,

the MET is re-calculated by finding which MET value makes the discriminant >=0
And that new value is taken as estimate of pnux and pnuy.

$$\left[(2p_x^l \not{E}_t \cos\phi + 2p_y^l \not{E}_t \sin\phi) - m_l^2 + M_W^2\right]^2 - 4\not{E}_t^2(E_l^2 - p_z^{l\,2}) = 0$$

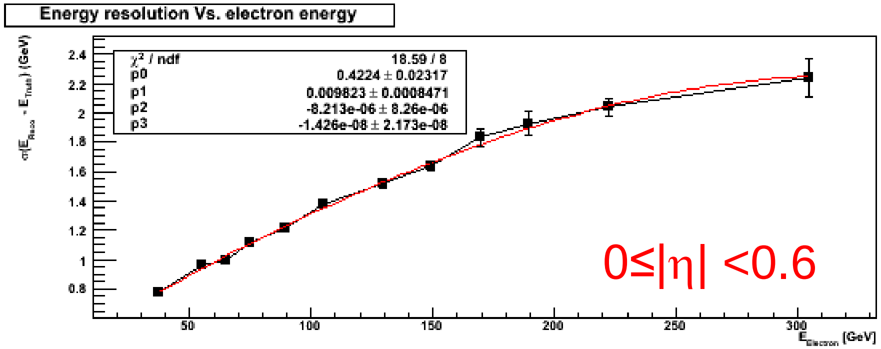
$$-> \not{E}_t^2\cdot\left[(2p_x^l\cos\phi + 2p_y^l\sin\phi)^2 - 4(E_l^2 - p_z^{l\,2})\right] + \not{E}_t\left[2(2p_x^l\cos\phi + 2p_y^l\sin\phi)\cdot(-m_l^2 + M_W^2)\right] + (-m_l^2 + M_W^2)^2 = 0$$

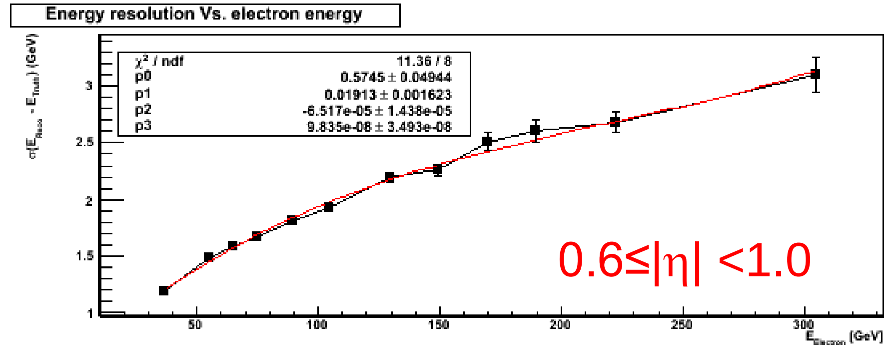
$$-> \not{E}_t^2\cdot\left[-(p_x^l\cos\phi + p_y^l\sin\phi)^2 + E_l^2 - p_z^{l\,2}\right] + \not{E}_t\left[(p_x^l\cos\phi + p_y^l\sin\phi)\cdot(m_l^2 - M_W^2)\right] + (m_l^2 - M_W^2)^2/4 = 0$$

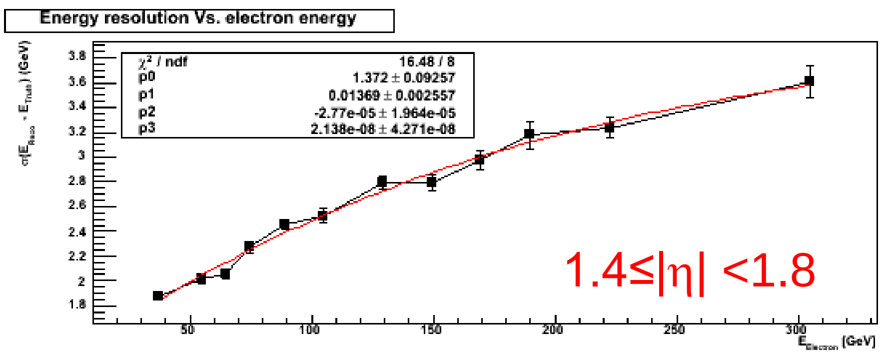
$$\not{E}_t = \frac{1}{2\cdot\left[E_l^2 - p_z^{l\,2} - (p_x^l\cos\phi + p_y^l\sin\phi)^2\right]}\left\langle -(p_x^l\cos\phi + p_y^l\sin\phi)\cdot(m_l^2 - M_W^2) \pm \sqrt{(m_l^2 - M_W^2)^2\cdot(E_l^2 - p_z^{l\,2})}\right\rangle$$

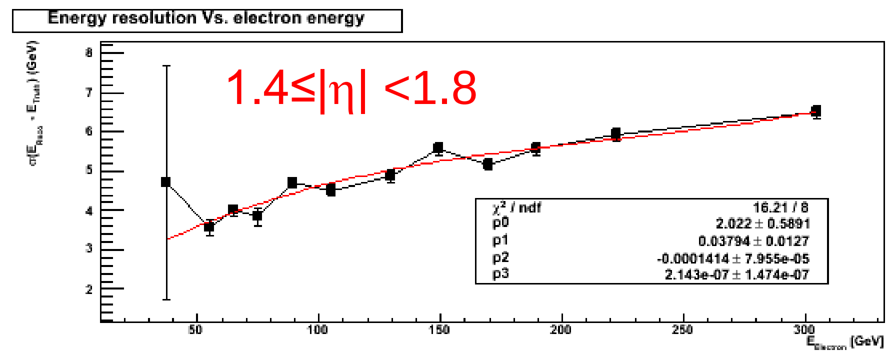
Resolution $\sigma(E_{reco} - E_{truth}) = p0 + p1 \cdot E_{reco} + p2 \cdot E_{reco}^2 + p3 \cdot E_{reco}^3$

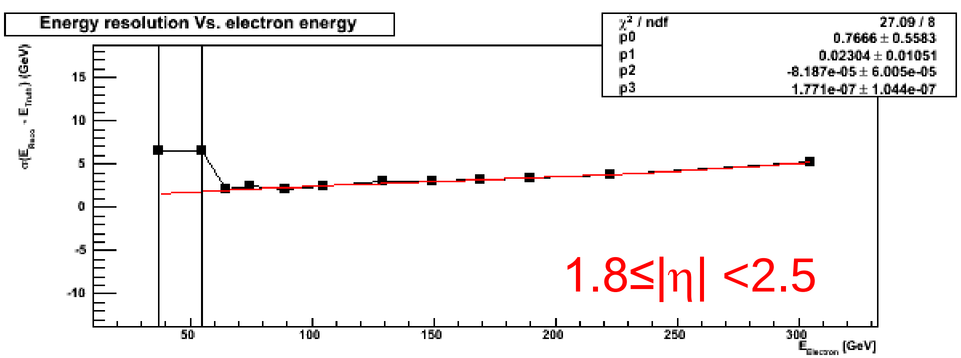
Electrons





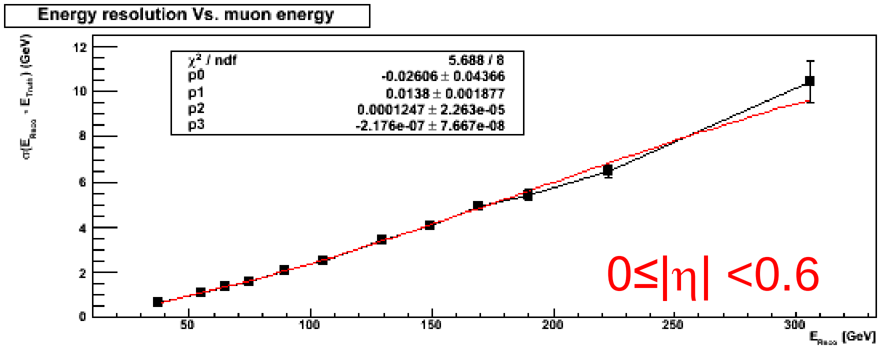


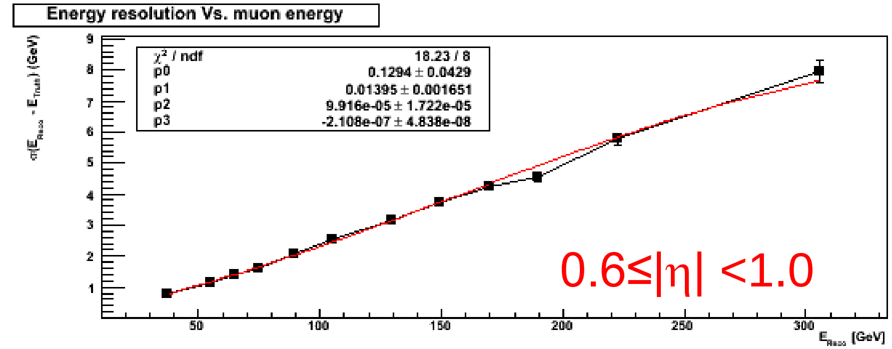


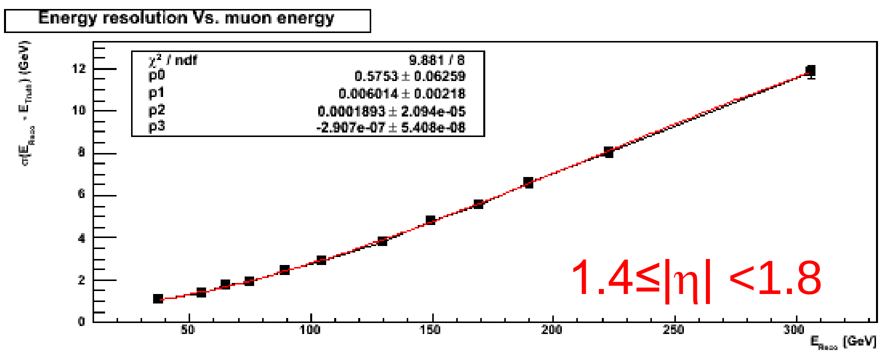


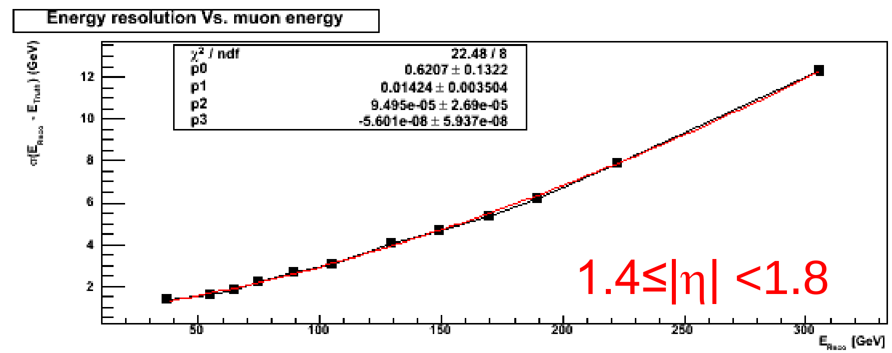
Resolution $\sigma(E_{reco} - E_{truth}) = p0 + p1 \cdot E_{reco} + p2 \cdot E_{reco}^2 + p3 \cdot E_{reco}^3$

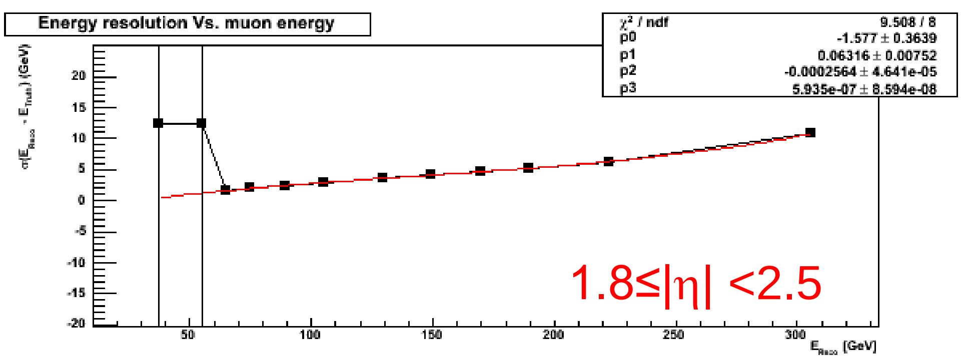
Muons







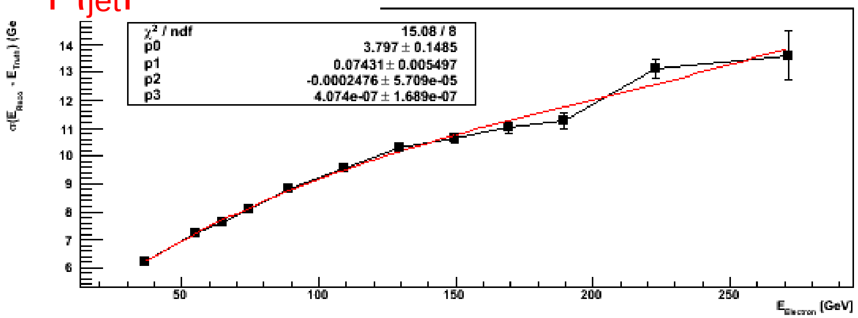




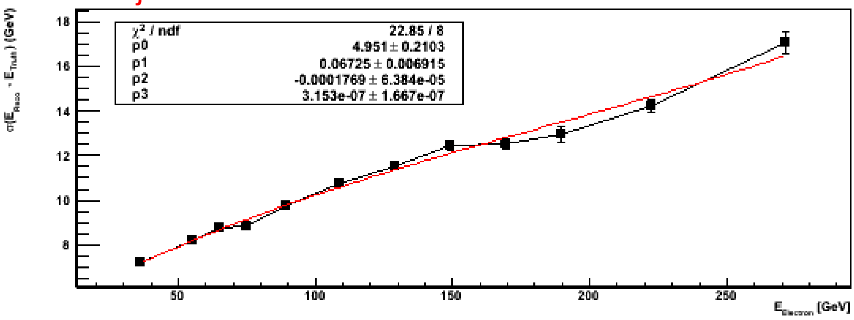
Resolution $\sigma(E_{reco} - E_{truth}) = p0 + p1 \cdot E_{reco} + p2 \cdot E_{reco}^2 + p3 \cdot E_{reco}^3$

Light jets

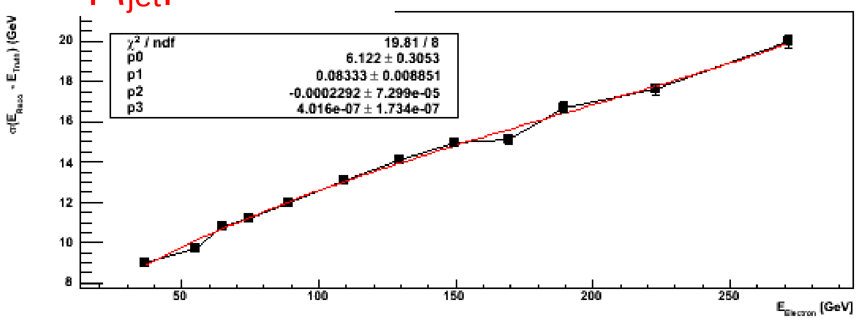
$0 \leq |\eta_{jet}| < 0.6$



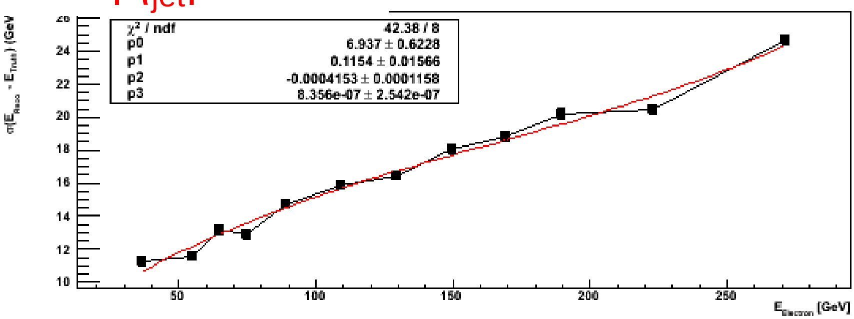
$0.6 \leq |\eta_{jet}| < 1.0$



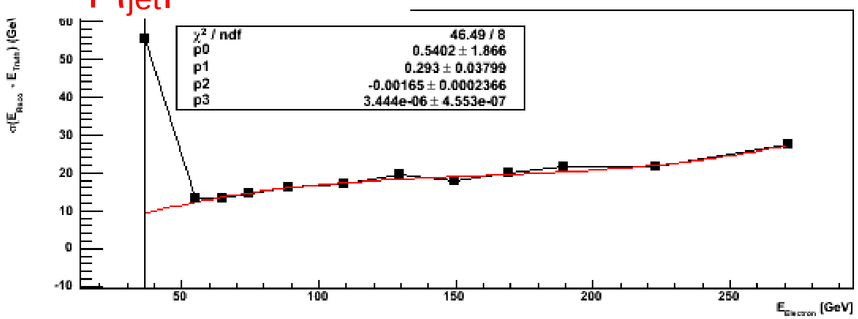
$1.4 \leq |\eta_{jet}| < 1.8$



$1.4 \leq |\eta_{jet}| < 1.8$



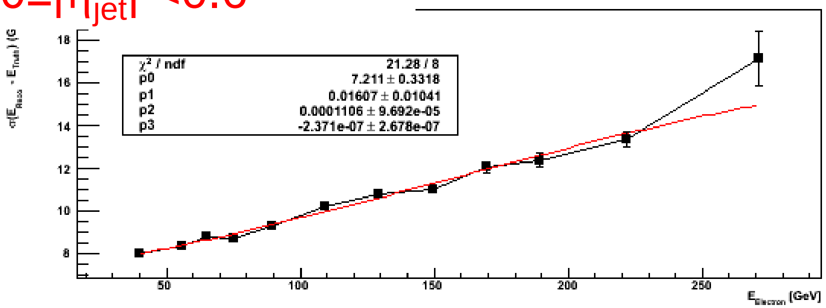
$1.8 \leq |\eta_{jet}| < 2.5$



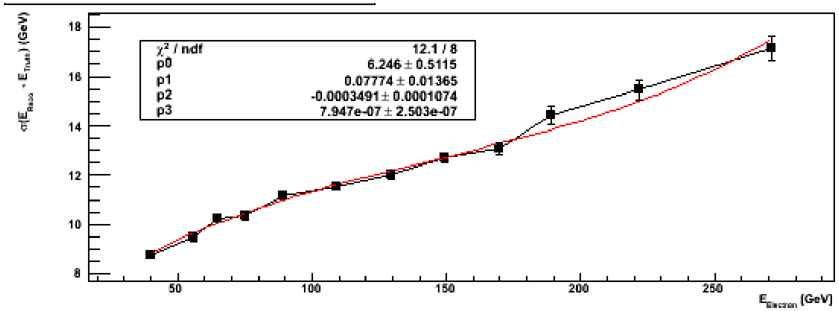
Resolution $\sigma(E_{reco} - E_{truth}) = p0 + p1 \cdot E_{reco} + p2 \cdot E_{reco}^2 + p3 \cdot E_{reco}^3$

b jets (non muonic decay)

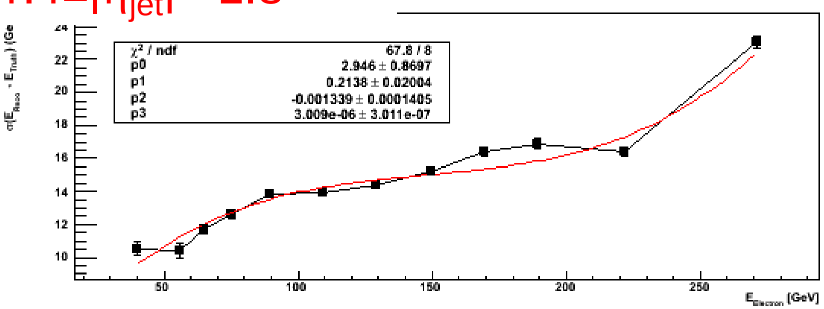
$0 \leq |\eta_{jet}| < 0.6$



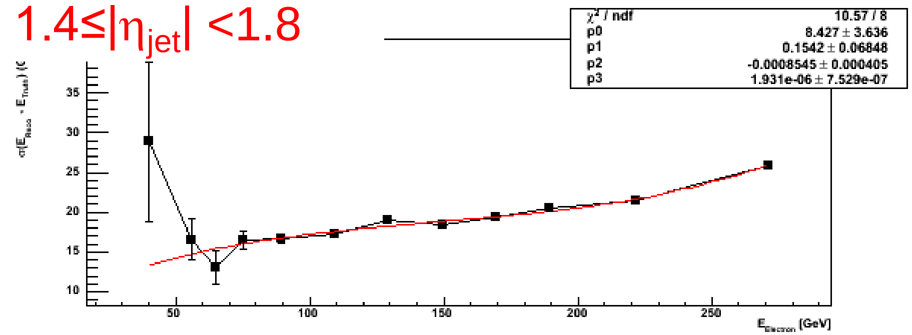
$0.6 \leq |\eta_{jet}| < 1.0$



$1.4 \leq |\eta_{jet}| < 1.8$



$1.4 \leq |\eta_{jet}| < 1.8$



$1.8 \leq |\eta_{jet}| < 2.5$