Argonne NATIONAL LABORATORY

Underlying event studies using calorimeter clusters

status report

S.Chekanov
(HEP division, ANL, USA)

October 8, 2010

ATLAS SM Meeting

Introduction

- **Thanks to all people participating in this analysis.**
- **Many elements have been taken from the tracking UE studies + calorimeter-performace studies**
- **https://twiki.cern.ch/twiki/bin/view/AtlasProtected/TopoClustersUE**

TopoClustersUE

- Studies of particle flow using calorimeter clusters in pp collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC
  - People
  - Paper outline
  - Introduction
  - Supporting material
    - Notes
    - Talks
    - Histograms and figures
  - Proposed final plots
  - Analysis Code
    - Topocluster energy scale

Studies of particle flow using calorimeter clusters in pp collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC

People

C. Bertella , A. Buckley, S. Chekanov , P. Giovaninni , N. Kanaya ,D. Kar, A. Moraes, S. Menke , J. Nielsen, G.A. Hare, J. Proudfoot , C. Roda , P.Starovoitov, I. Vivarelli , R. Yoshida , J. Zhang

Contains drafts, talks, paper outline, CONF draft

Introduction

- https://twiki.cern.ch/twiki/bin/view/AtlasProtected/TopoClustersUE

ATL-COM-PHYS-2010-210

ATLAS NOTE

May 14, 2010

Oct 18, 2010

Underlying event particle flow based on calorimeter clusters in *pp* collisions at 900 GeV with the ATLAS detector at the LHC

C. Bertella[a], S. Chekanov[b], P. Giovaninni[c], N. Kanaya[d], S. Menke[c], J. Proud
P. Starovoitov[e], I. Vivarelli[f], R. Yoshida[b], J. Zhang[b]

ATL-COM-PHYS-2010-293

Draft version 1.0

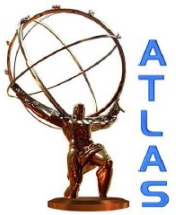
ATLAS NOTE

May 14, 2010

Oct 18, 2010

Underlying event particle flow based on calorimeter clusters in *pp* collisions at 7 TeV with the ATLAS detector at the LHC

C. Bertella[a], S. Chekanov[b], P. Giovaninni[c], N. Kanaya[d], S. Menke[c], J. Proudfoot[b], C. Roda[a], P. Starovoitov[e], I. Vivarelli[f], R. Yoshida[b], J. Zhang[b]



Draft version 1.0

ATLAS NOTE

May 14, 2010

Summary of results (conf note)
Now converted to ATLAS paper draft

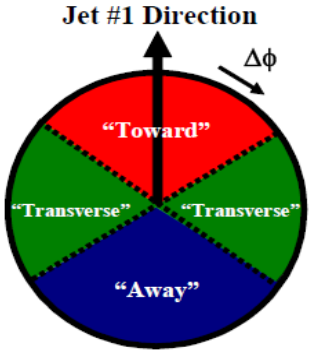
Each supporting document
~50 pages

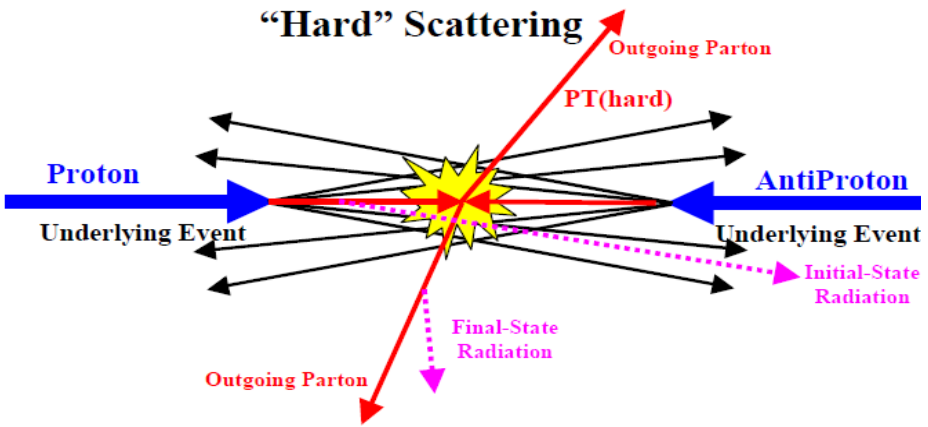
Studies of particle flow using calorimeter clusters in *pp* collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC

C. Bertella[a], A. Buckley[b], S. Chekanov[c], P. Giovaninni[d], G.A. Hare[e], N. Kanaya[f], D. Kar[d], S. Menke[g], J. Nielsen[e], J. Proudfoot[c], C. Roda[a], P. Starovoitov[g], I. Vivarelli[h], R. Yoshida[c], S. Wahrmund[d], J. Zhang[c]

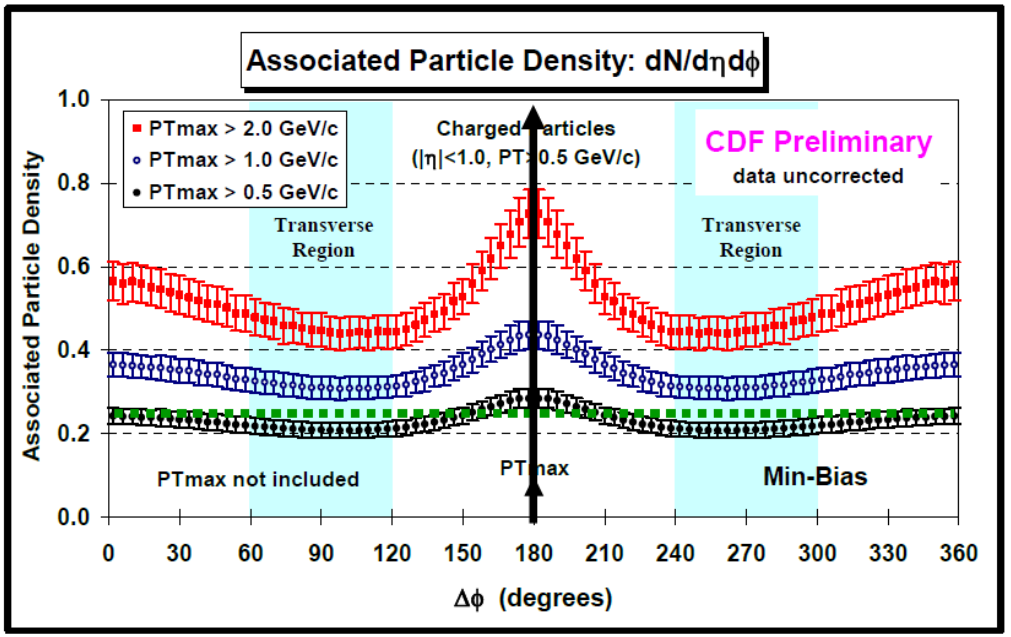
Introduction to UE studies

R.Field,
Acta Phys. Pol. B
36, No. 2 (2005) 167





A typical example of the UE studies



The "underlying event" consists of
- hard initial & final-state radiation
- beam-beam remnants
- possible multiple parton interactions

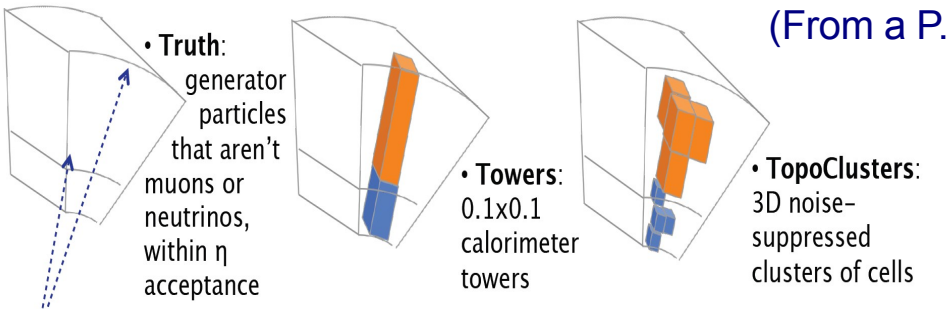
- **ATLAS UE studies based on tracks:**
  - ATL-COM-PHYS-2010-164
  - ATL-COM-PHYS-2010-165
  - ATL-COM-PHYS-2010-175
  - ATL-COM-PHYS-2010-237
  - ATL-COM-PHYS-2010-238 - **CONF note**

UE studies using topoclusters

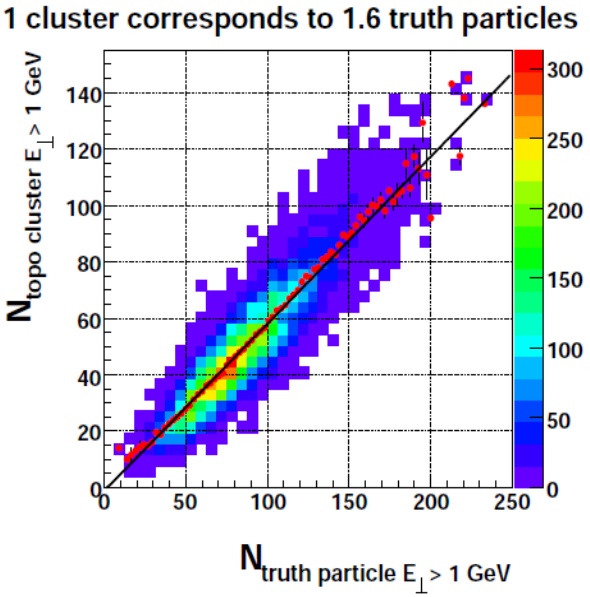
- **Use calorimeter measurements taking advantage a fine calorimeter granularity**
  - **Systematically completely independent of tracking**
    - Do we see the same discrepancies with MC as for the tracking analysis?
  - **Look at a complete final state (charged & neutral particles).**
    - + additional 40% of final state not seen by the tracking analysis
  - **More relevant for future jet-based studies**
    - Where the UE is the main issue for precision measurements

(S.Menke talk, 2008)

- **Topoclusters are the natural choice for such measurements:**
  - provide efficient noise and pile-up suppression
  - correspond to individual hadrons



(From a P.Loch's talk)



The UE measurement concentrates on
"density" measurement rather then "energy measurement"
- somewhat reduced energy scale systematics but new systematics for topocluster densities

Event & Topocluster selection: 900 GeV

- Good runs: 141565, 141707,141746,141748,141811,142166,142191,142193,142195,142383
- Monte Carlo sample: ATLAS-GEO-08-00-02 (r1051)
- L1_MBTS_1 trigger. Good primary vertex

TopoClusters:

- Topoclusters after local **hadronic calibration** (EM-scale as systematics checks)
- Concentrate on the central region |eta|<2.5 (easy cross check with tracks)
- pT>500 MeV and above (as for the tracking analysis)

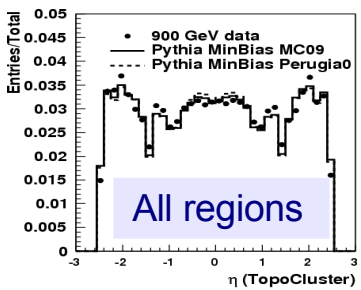
Event & Topocluster selection: 7 TeV

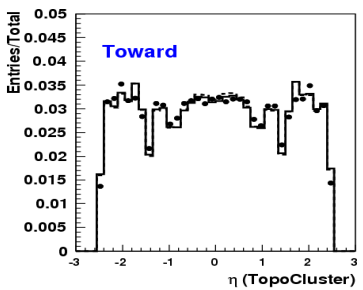
- Good run & lumi blocks for 152166- 152844. Lumi ~ 238 μb^{-1}
- Same event cuts as for 900 GeV + pile-up removal
- Same cuts on topoclusters

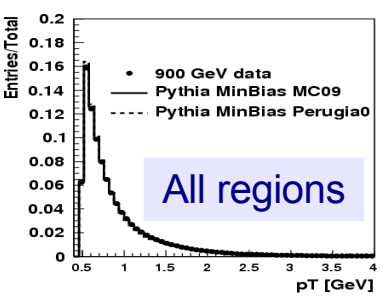
QCD predictions

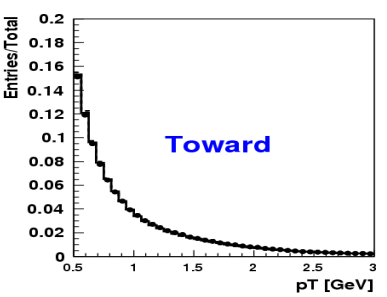
PYTHIA MC09	- pT ordered shower, tuned to pp(bar) data.	- **Main MC for unfolding**
PYTHIA Perujia0	- tuned using only MinBias data from pp(bar)	- (used for systematics studies)
PYTHIA DW	- virtuality-ordered parton shower + max ISR	- (only for truth comparison)
PHOJET	- better description of hard diffraction	- (used for systematics studies)

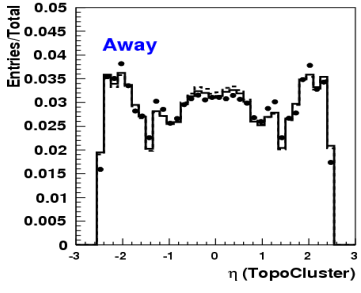
TopoCluster properties at 900 and 7 TeV GeV

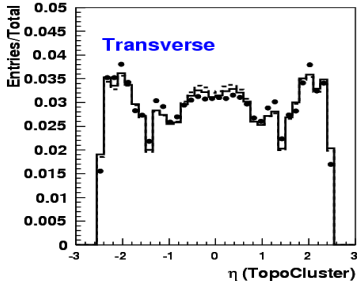


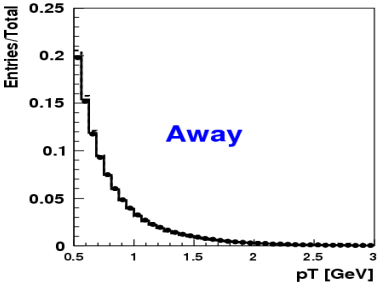


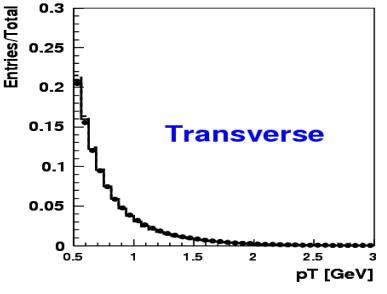




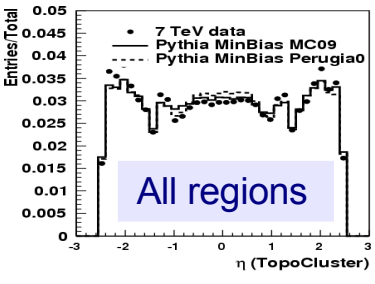


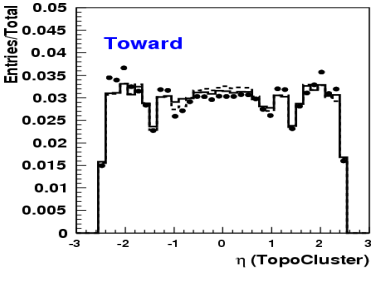


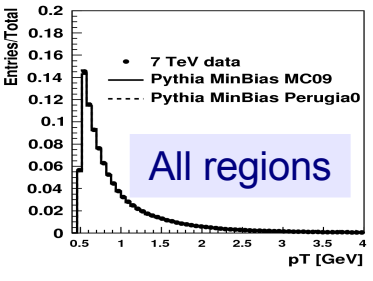


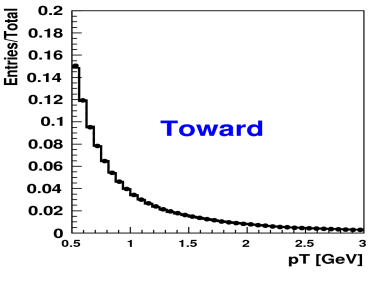


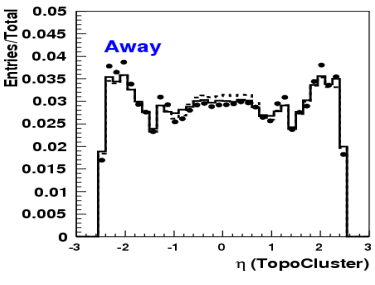
900 GeV

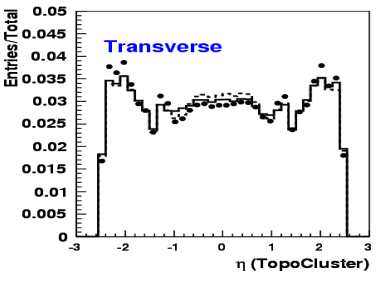


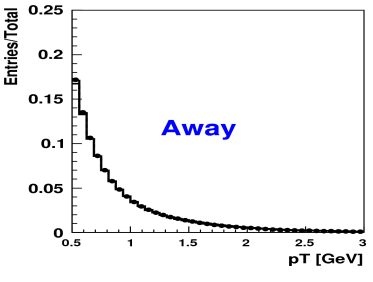


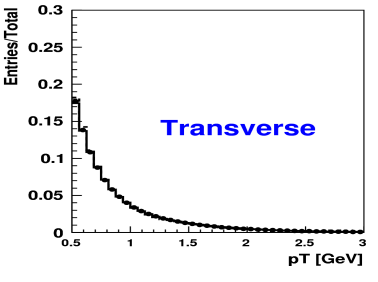












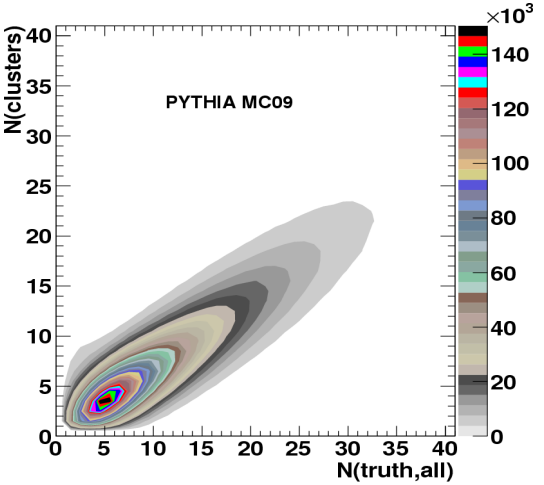
7 TeV

- **Reasonable agreement with MC09 & Perugia0 tunes**

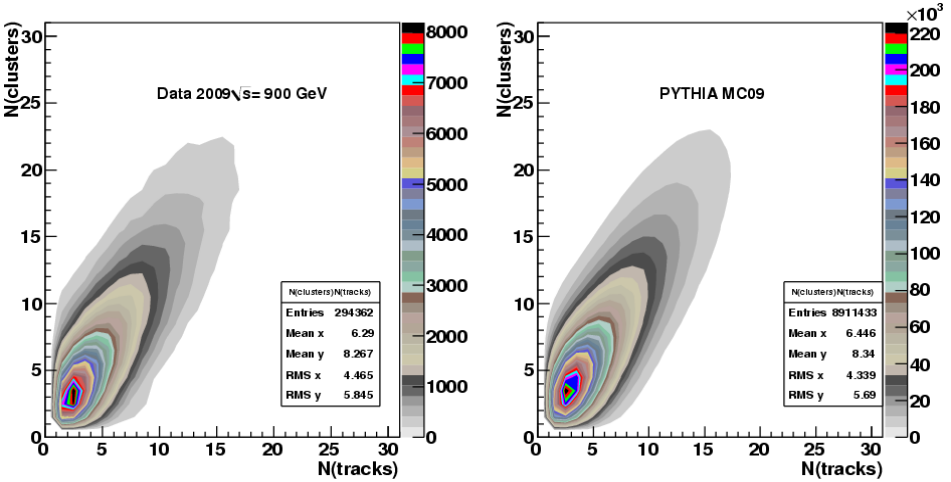
Topocluster properties for the UE studies

- **Good association with the number of truth hadrons**
- **Reasonable description of data using MC**

Clusters vs truth particles



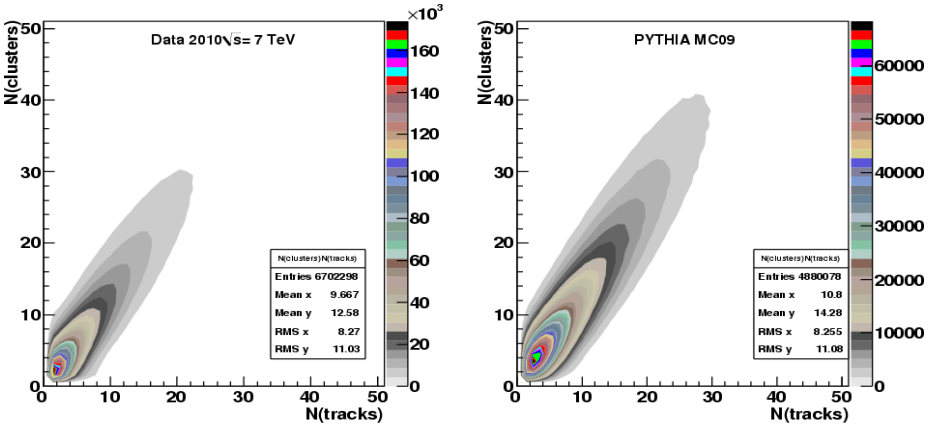
Clusters vs Tracks: 900 GeV



Although visually identical, and Kolmogorov–Smirnov gives ~1, data and MC still have discrepancies:

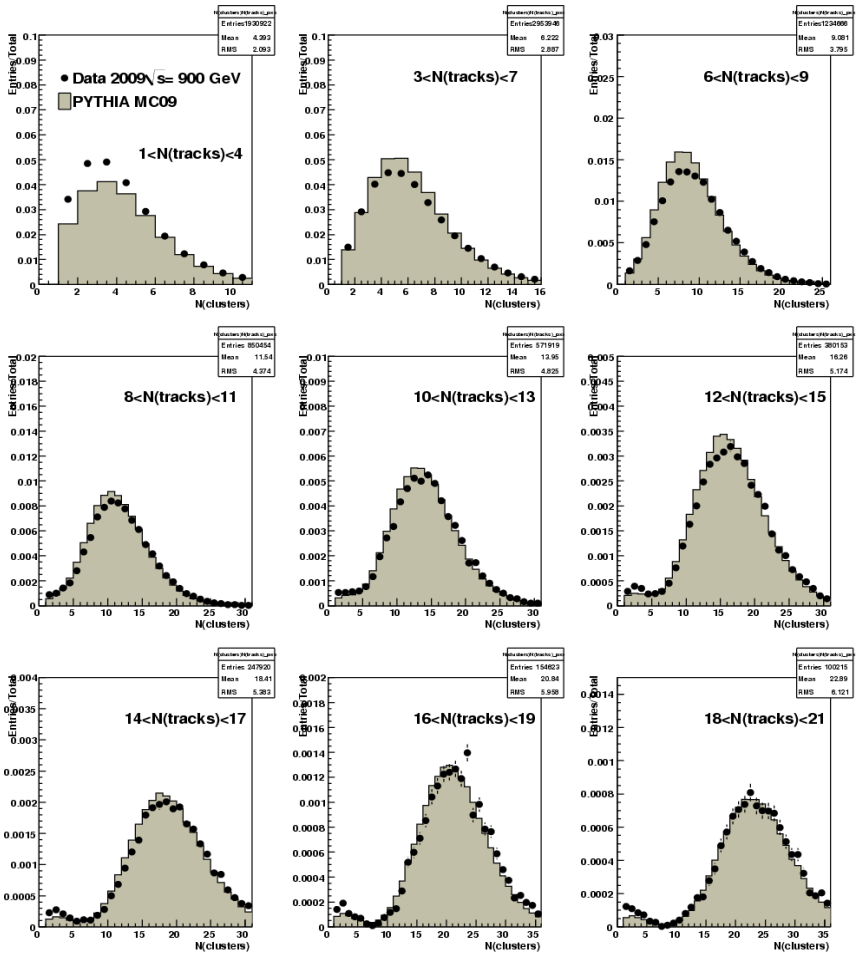
Normalize 2D histograms to 1 and project using N(tracks)

Clusters vs Tracks: 7 TeV



Topoclusters vs Tracks

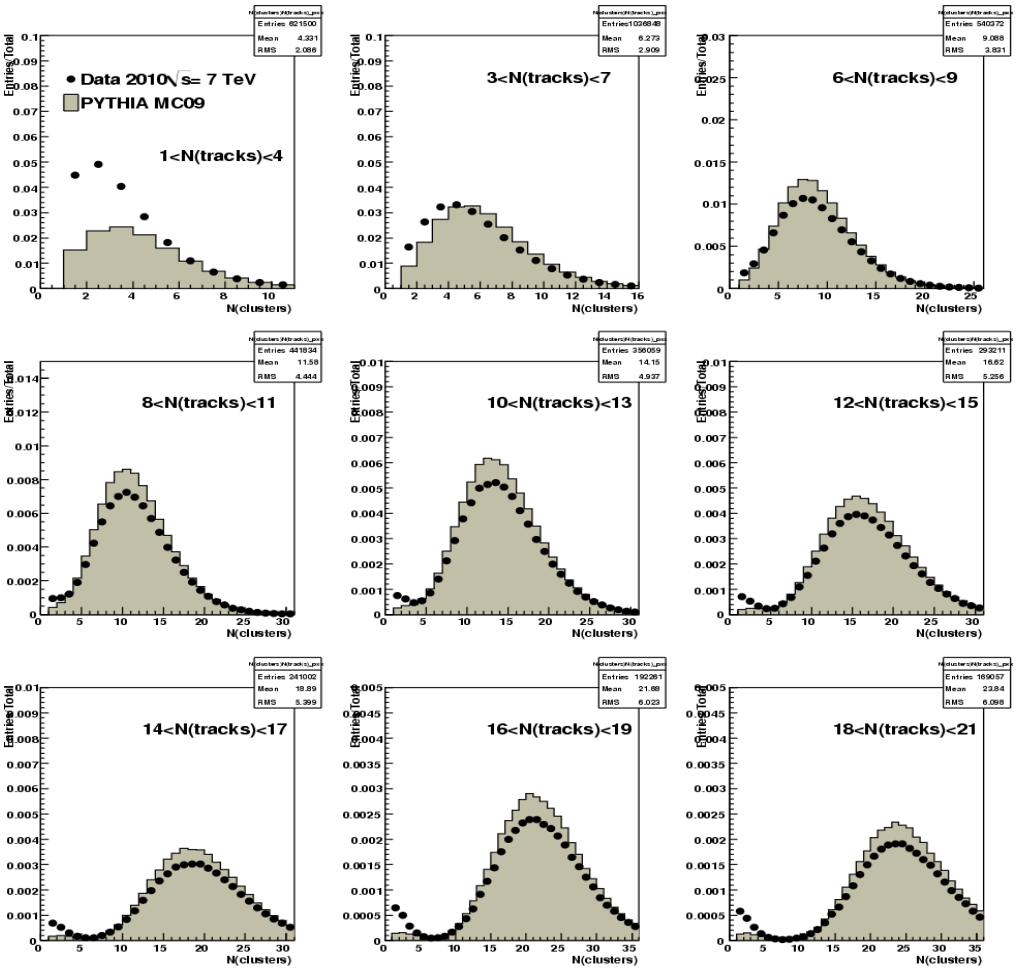
900 GeV



- discrepancies will be taken into account reweighing events

- Discrepancies for low multiplicities
- Diffraction? Performance problems?

7 TeV

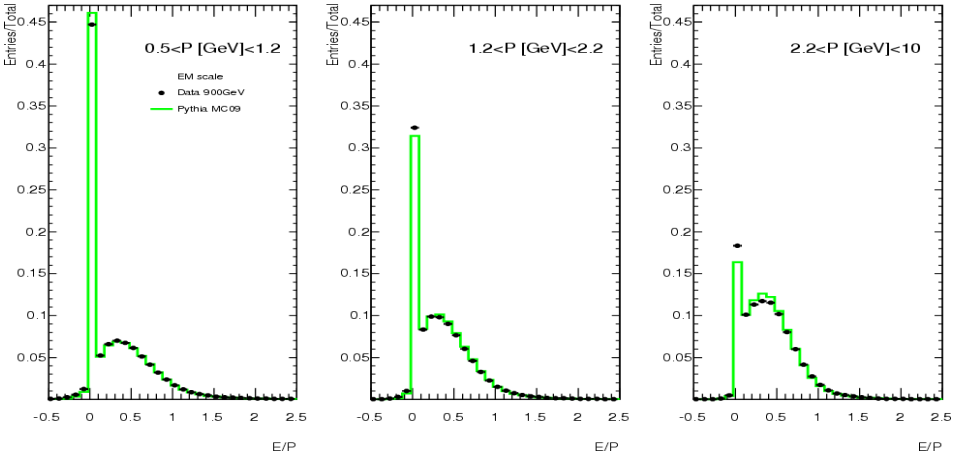


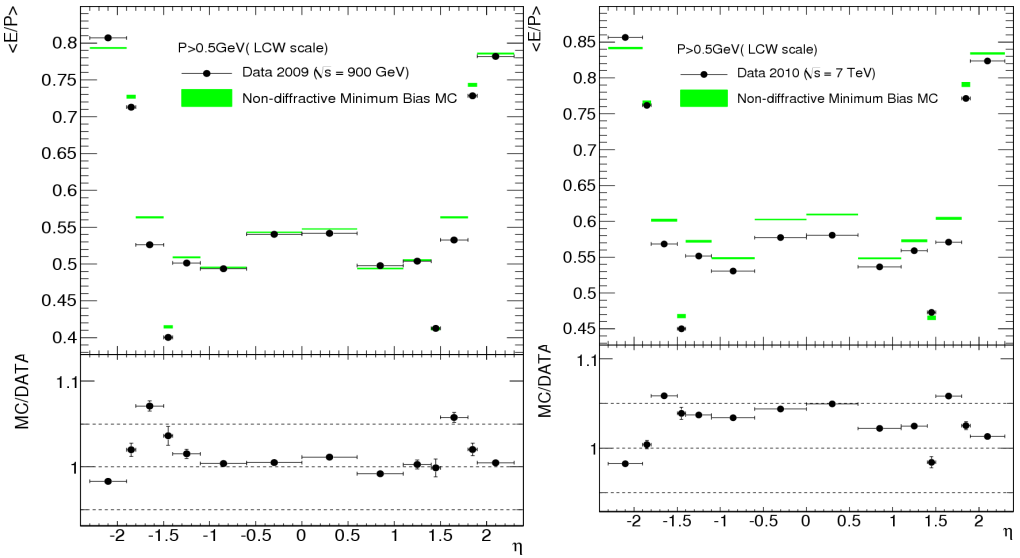
Energy-scale measurements

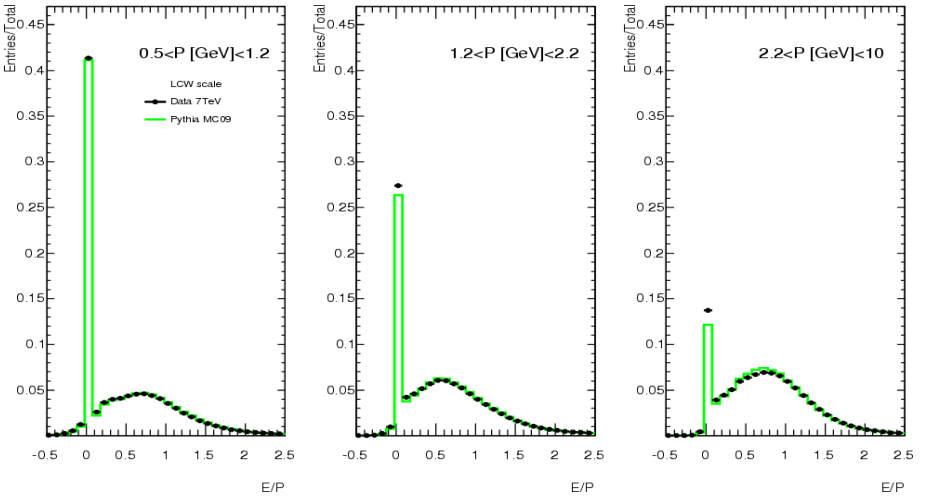
http://indico.cern.ch/getFile.py/access?contribId=3&resId=0&materialId=paper&confId=87760

From P.Starovoitov

- Compare <E/p> for data and MC
- Many studies by several groups
- Agreement within 3% in most regions, and ~10% in the transition region
- Use data/MC ratios in a grid in η-P for systematics studies (not what shown here!)







For hadronic TopoClusters, data and MC agree for calibrated and uncalibrated clusters within ~4%

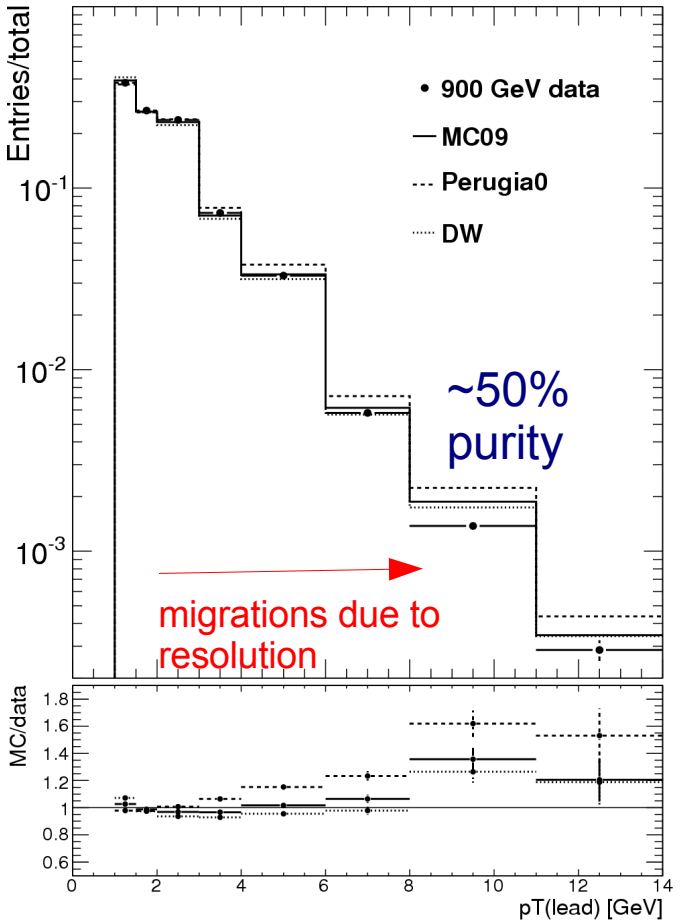
- For trackless clusters, see J.Zhang's talk :

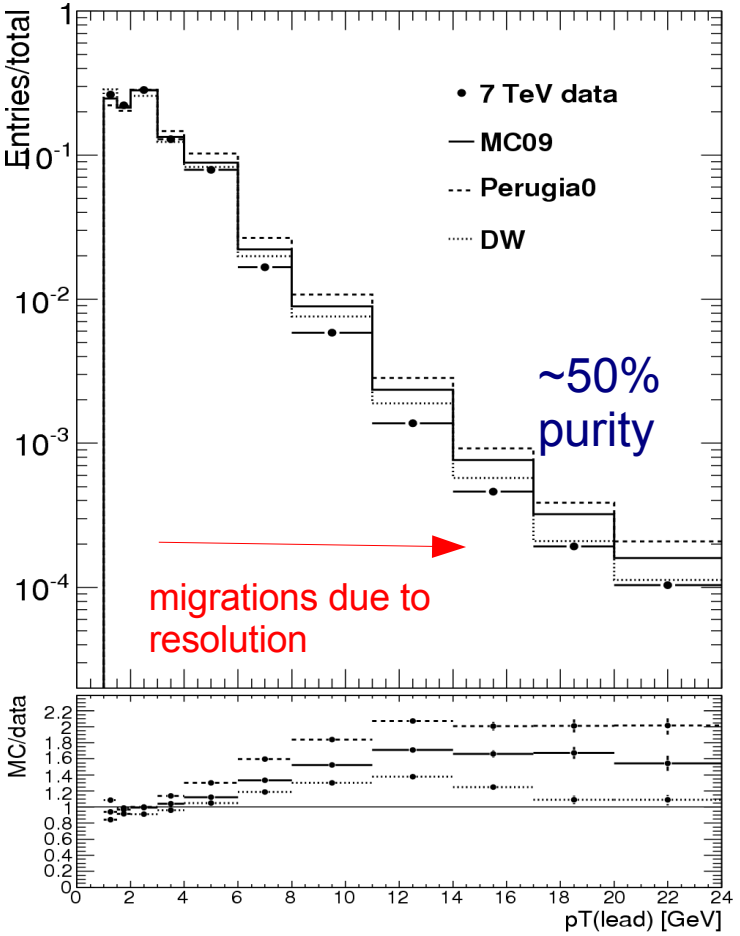
http://indico.cern.ch/getFile.py/accesscontribId=49&sessionId=6&resId=0&materialId=slides&confId=88935

Resolution tails

- **Must be sure that resolution tails for leading clusters are well described**
  - **Previous slides shows that resolution is well described for all clusters**
  - **Since we take leading clusters at large pT we probe the detector performance in greater details (see the Pisa workshop material, "Using leading topoclusters to probe detector performance")**
    - Resolution tails drop slower with pT than jet cross section
    - Leads to large rate of fake topoclustes & low purity

Difference between different MC tunes

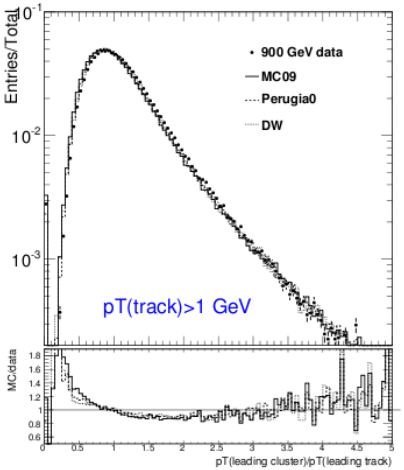


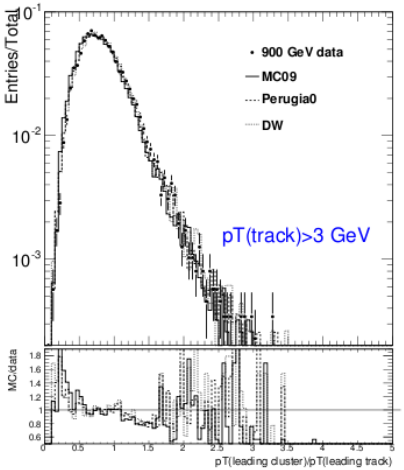


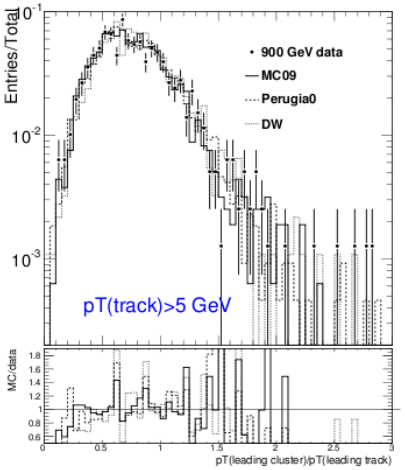
Resolution tails for leading topoclusters

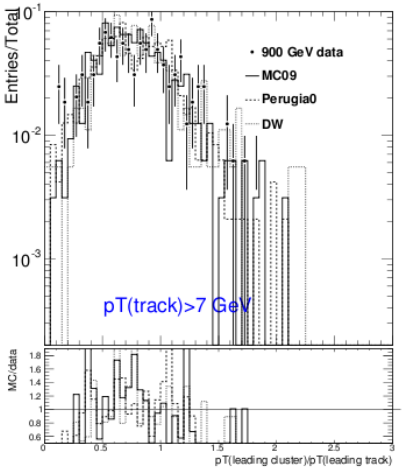
For a given leading track, identify a leading cluster and look at **pT(cluster,lead)/pT(track,lead)**
Should be relatively independent of MC tune. How well we understand the resolution tails?

900 GeV

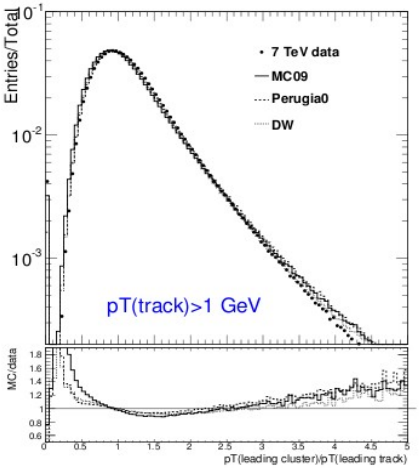


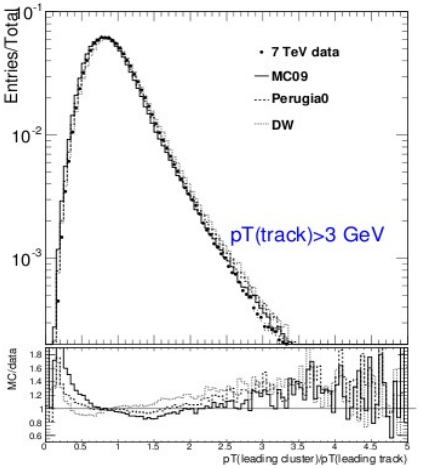


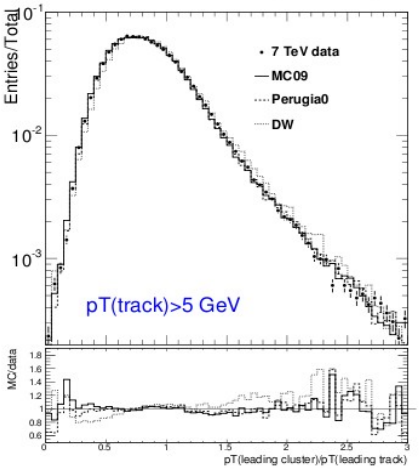


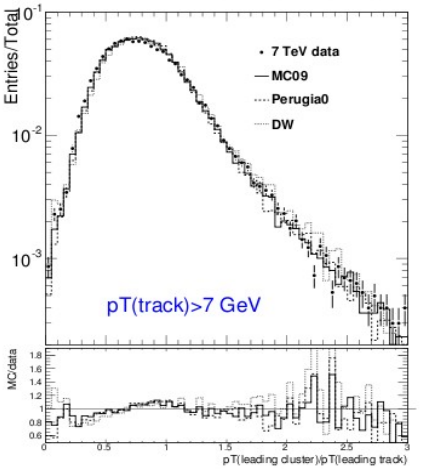


7 TeV





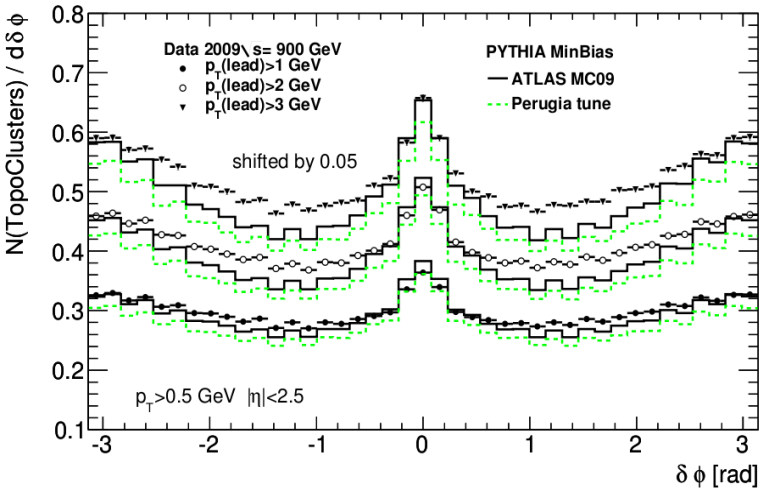


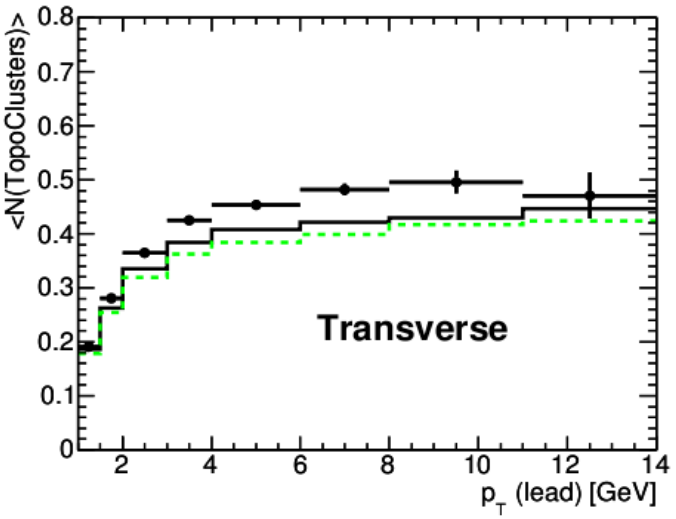


Discrepancies between data and MC should be taken into account
Due to some MC-tune dependence, correction to the resolution tails will be used for systematics (rather than for the central values)

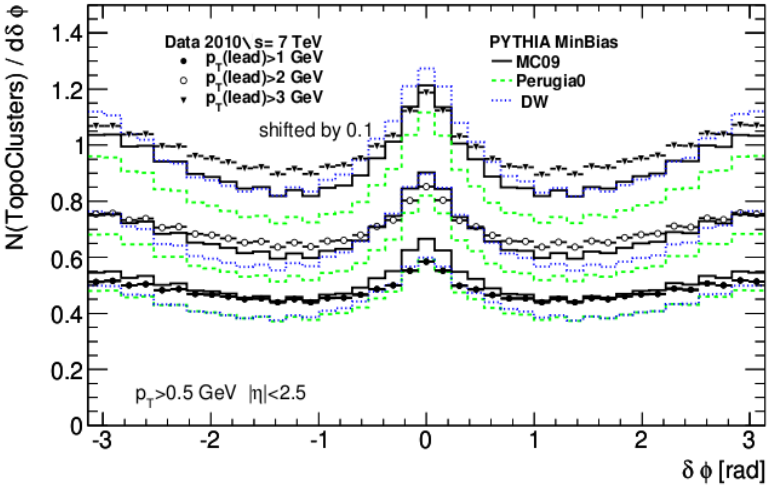
Detector-level distributions

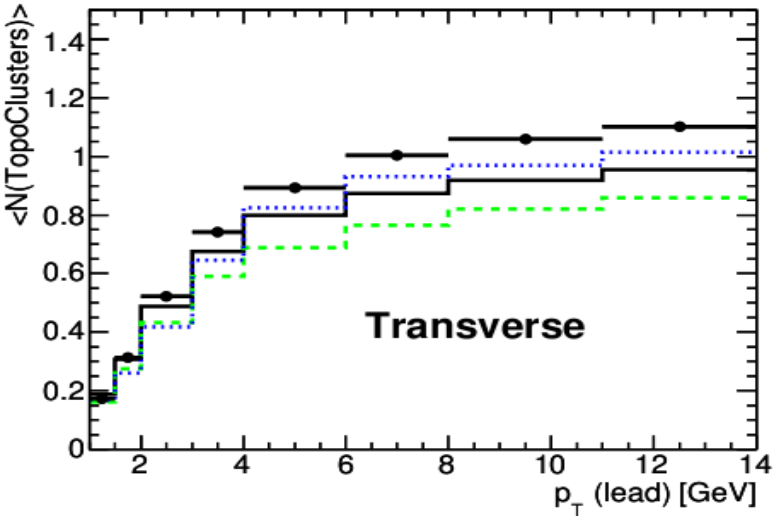
900 GeV





7 TeV





Sensitivity to MC tunes. Can be used for MC tuning

- unfold the distributions to the truth level to simplify the task

No single MC tune with a good description of all distributions.

- Data 2010 $\sqrt{s}$= 7 TeV
- PYTHIA MC09
- PYTHIA Perugia0
- PYTHIA DW

Correction procedure

- **All distributions are measured with respect to "reference" particles**
- **Mismeasured particle introduces smearing (lower purity in bins)**
- **Can be taken into account using a bin-by-bin correction:**

C= N(gen)/N(reco) = purity / efficiency

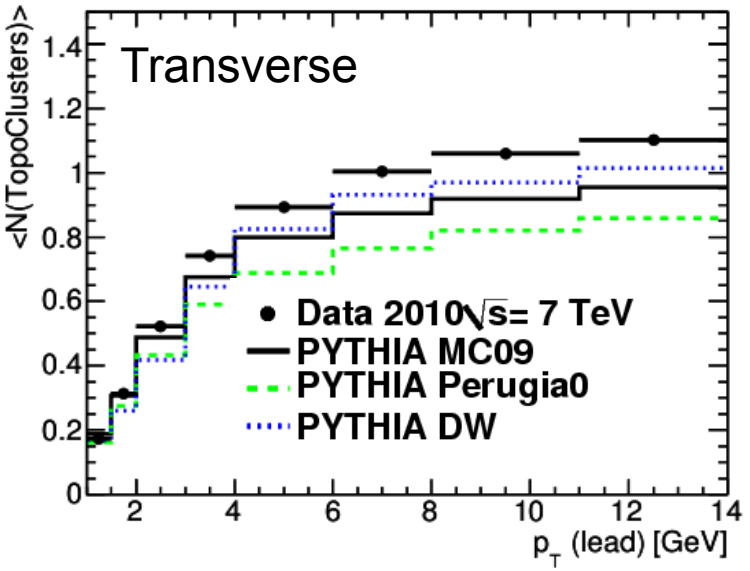
Corrects for:

- event selection
- clusters selection (inefficiencies due to threshold cut effect, losses, merging/splitting etc.)
- resolution smearing (leading cluster is lost), other impurity effects
- decays of long-lived resonances (truth level is defined by $\tau < 3\ 10^{-10}$ sec)

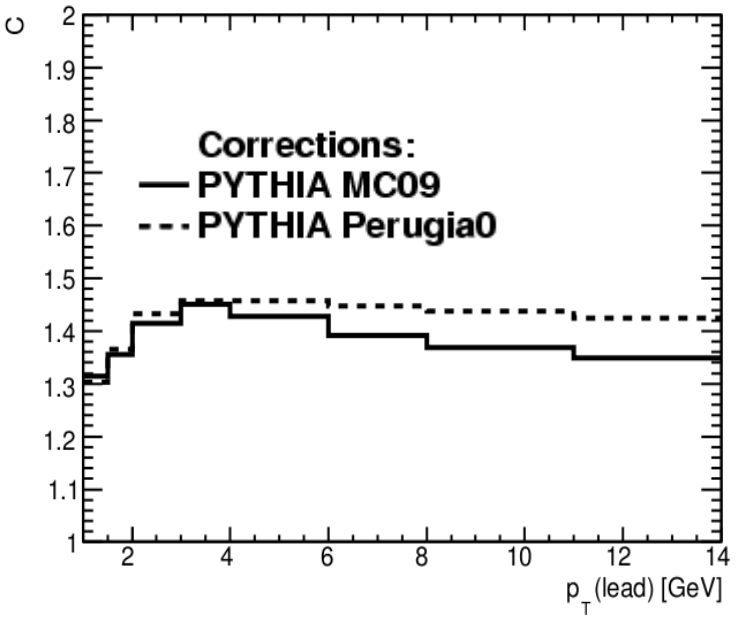
- **Resolution smearing is minimized choosing bin sizes larger than resolutions in each bin**
- **Model dependence is controlled using alternative MCs**
- **Tested using track-based MinBias studies (fully agrees with the track-weighting approach)**
  - ATL-COM-PHYS-2010-165 and ATL-COM-PHYS-2010-237
- **No correction for diffraction was applied:**
  - Single and Double diffraction is expected at the level of:
    - <1% for PYTHIA (SD/DD) when pT>1 GeV
    - ~1% for PHOJET (SD/DD) – more diffractive events at pT>1 GeV (hard diffraction), but SD/DD are similar in shape and show a small contribution to the final densities
- **Only measurements are presented where the correction factor are understood and <50%**

Example of the correction procedure

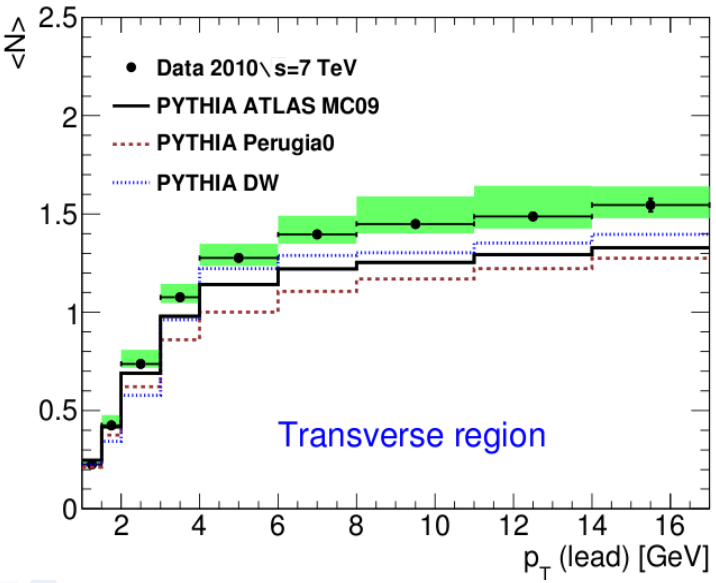
detector-level



Bin-by-bin correction



Corrected (+ systematics)



Bin-by-bin correction

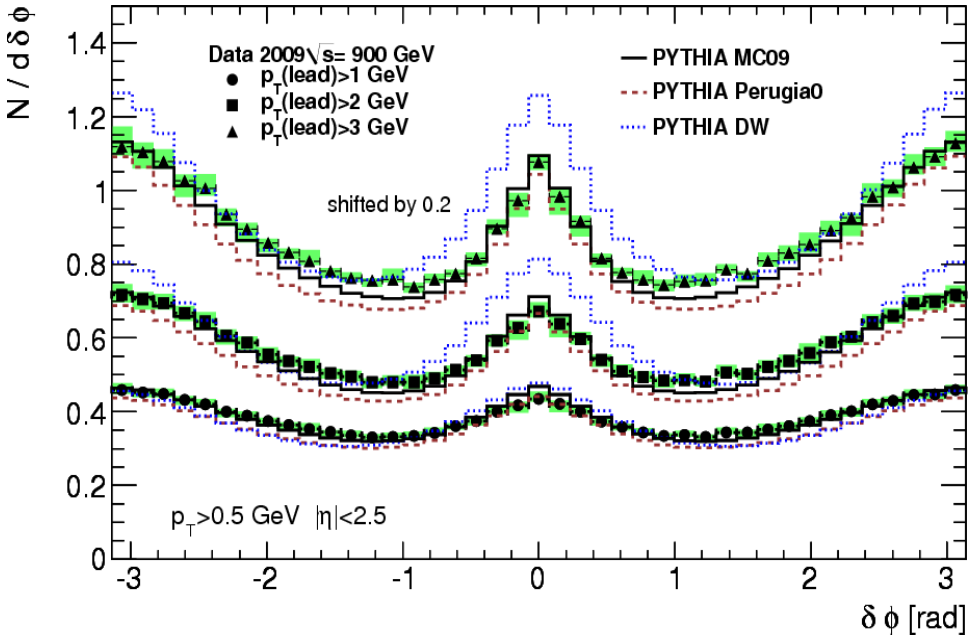
C= N(truth)/N(reco) = purity / efficiency

- **Validated using track-based UE/MinBias studies**
  - ATL-COM-PHYS-2010-165 and ATL-COM-PHYS-2010-237

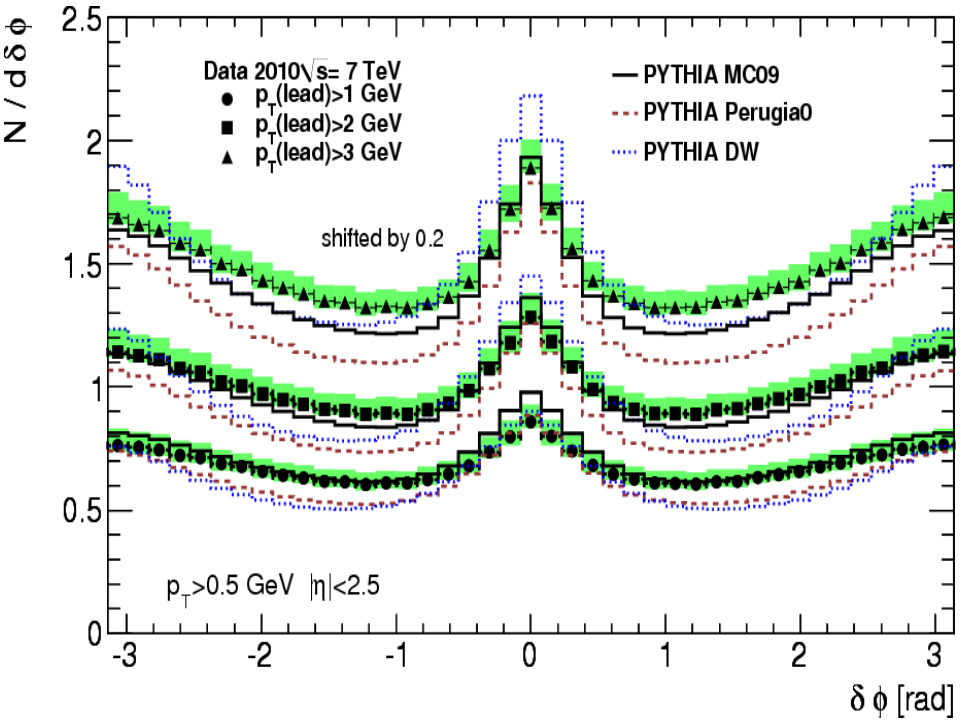
- **Example of worst-case correction (50%)**
- **Other distributions have smaller corrections**

Final results: azimuthal correlations

900 GeV

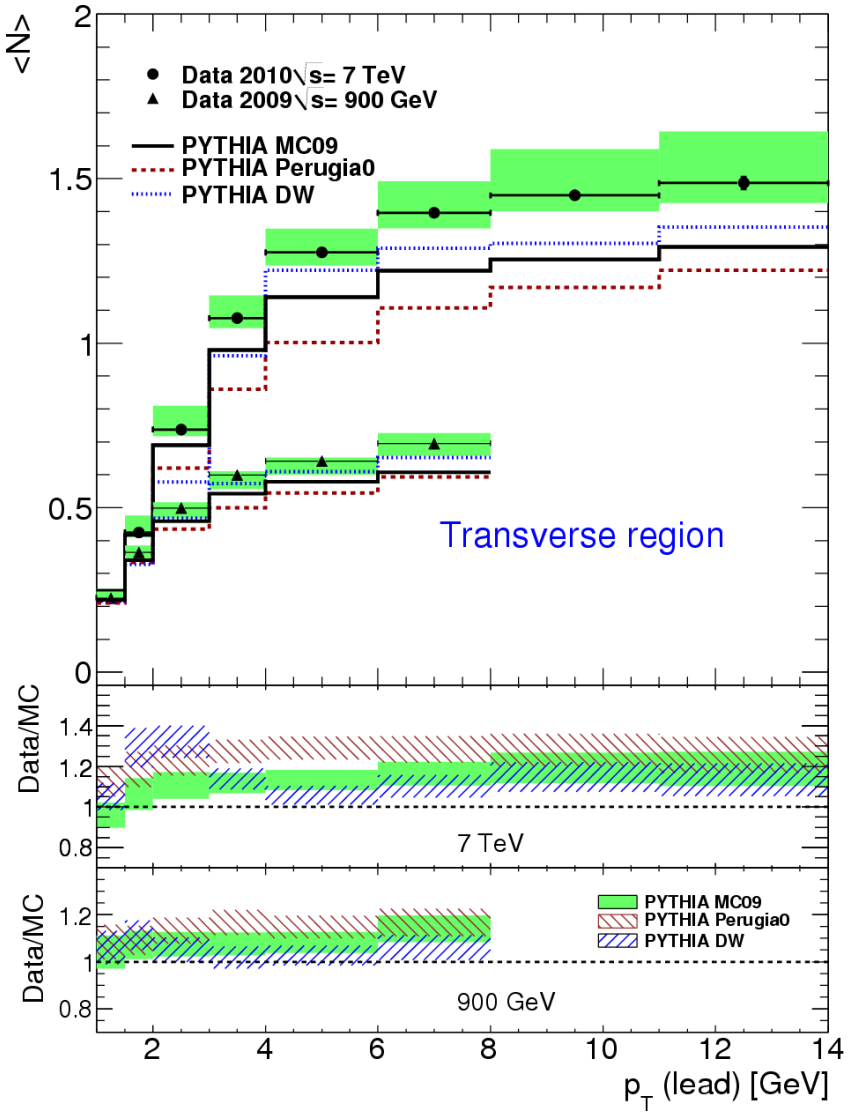


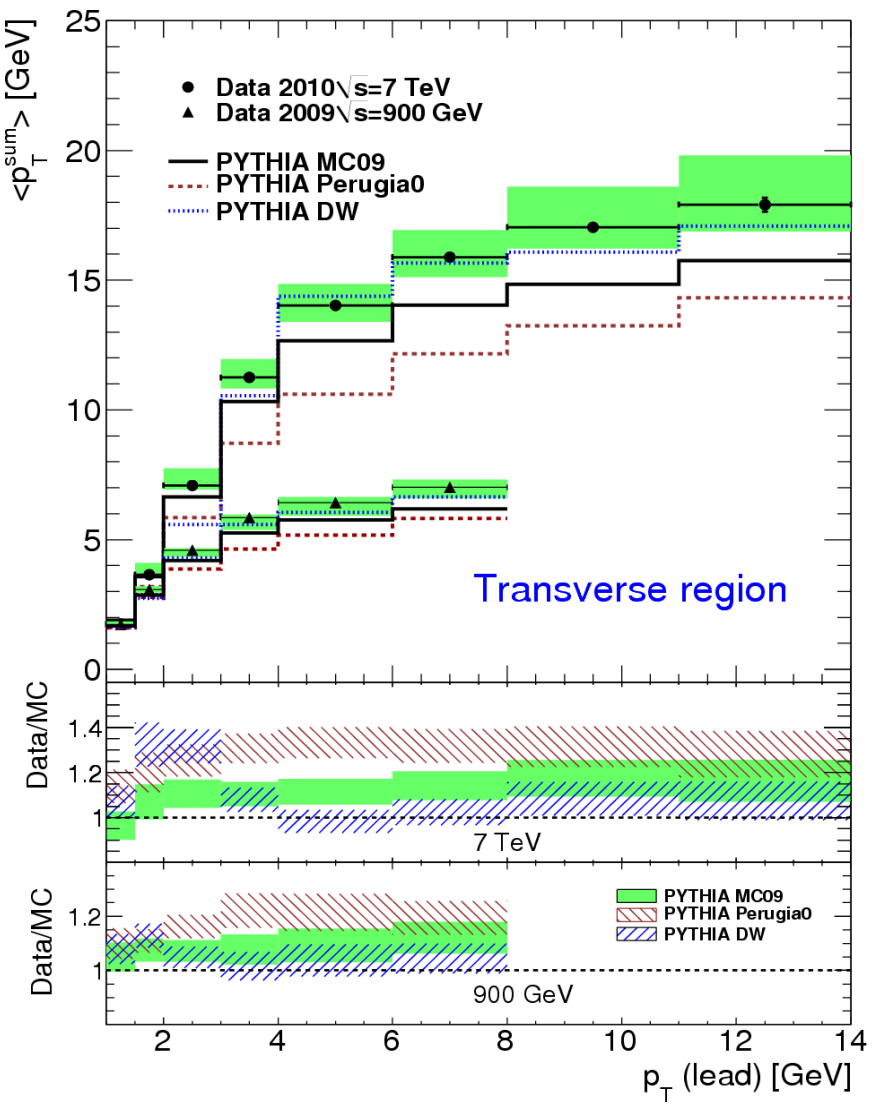
7 TeV



Perugia0 and DW are disfavored. Some (smaller) problems with MC09

Final results: densities as a function of pT(lead)





All MC fail. DW and MC09 are closest to data.

Systematic uncertainties

- Reject events with N(clusters)<3 (diffraction)
- Energy scale using the grid in η-P (to take into account 10% uncertainty in the transition region)
  - Includes +3 MeV shift to account for the difference between data and MC for pi0 peak
- ± 0.025 rad for cluster centers φ and η (shift by 1 Ecell)
- (a) PYTHIA with 10% extra material; (b) with improved PP0 geometry
  - http://cdsweb.cern.ch/record/1243587
- Using Peruji0 for unfolding (model dependence)
  - A typical difference between bin-by-bin corrections ~2-3%
- Multiplicity of clusters vs MC tracks was re-weighted
- Resolution tails were re-weighted
- Entire analysis repeated using EM-scale clusters

Check	$N/d\delta\phi$	$< p_T >$ vs N	$< N >$ vs $p_T(lead)$
Event selection	±0.5%	±0.5%	1.5%
Energy scale	±5.1%	±1.5%	±5%
ϕ positions	±1.3%	±0.2%	±0.2%
η positions	±0.2%	±0.2%	±0.2%
Additional material	±0.5%	±0.8%	±1.8%
Model dependence	±2%	±1.0%	±3%
Multiplicity reweighting	±2%	±3%	±3%
Resolution reweighting	±3%	±5%	±5%

Summary

- **First UE measurements using calorimeter objects**
  - Directly relevant for future calorimeter-based measurements
  - Studies are sensitive to the entire hadronic final state (+40% compare to the tracking analysis)
- **Provide systematically independent check of track-based UE measurements**
  - Additional constraint on the understanding of UE & model tunings
- **TopoClusters measurements confirm the conclusions for charged-particle UE studies.**
  - No MC tunes with good description of all observables
  - MC tunes have smaller particle activity in the transverse regions
    - systematically below the data in the transverse region
    - but the discrepancies are not too large given the significant systematic uncertainties

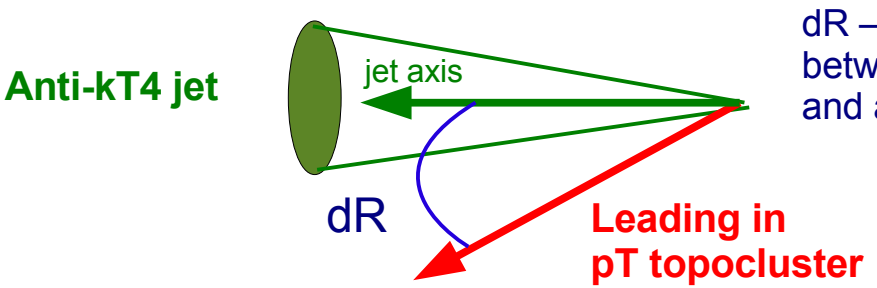
Two COM notes with technical details are ready. CONF note is available

Backup slides

Topocluster properties for the UE studies

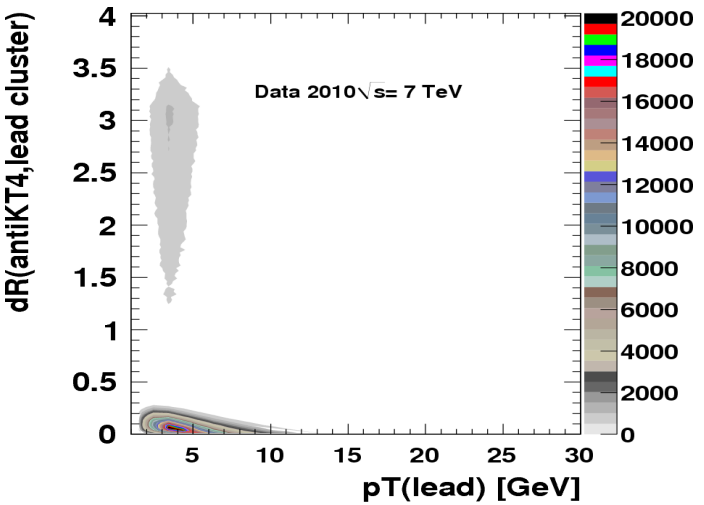
- Good position measurements. Agreement with MC
  - See April's workshop on jet reconstruction (J.Proudfoot etc..)

- Good match between the jet axis and a leading topocluster

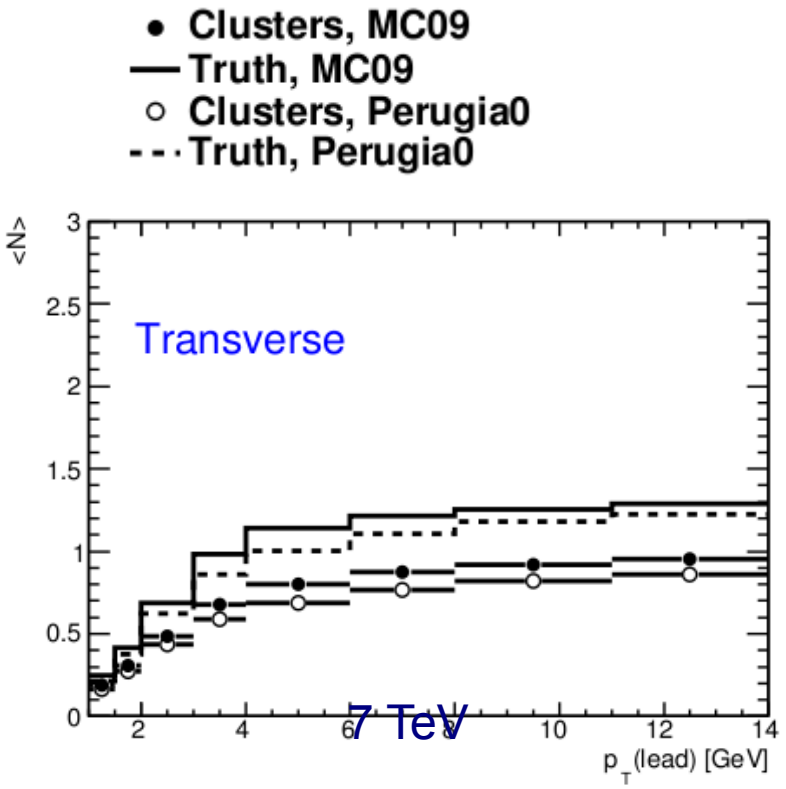


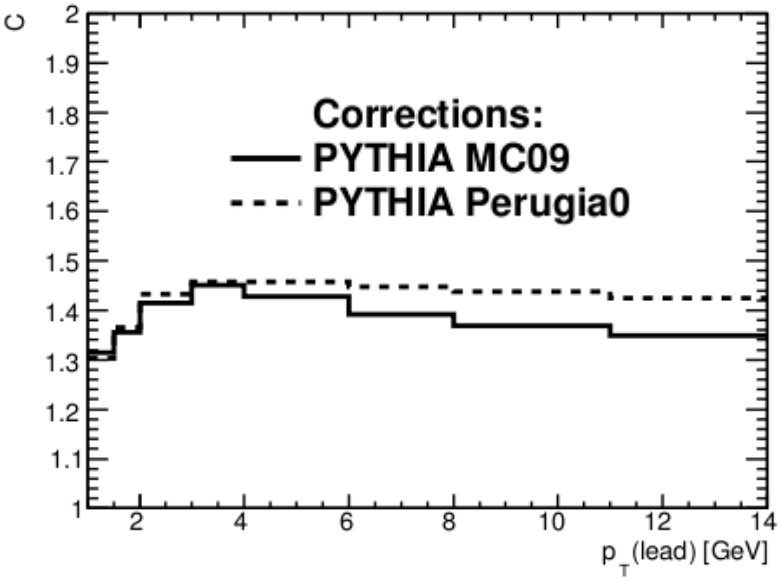
dR – a distance (in η and φ) between a leading topocluster and anti-KT jet

38.4% (data)
39.3% (MC09)

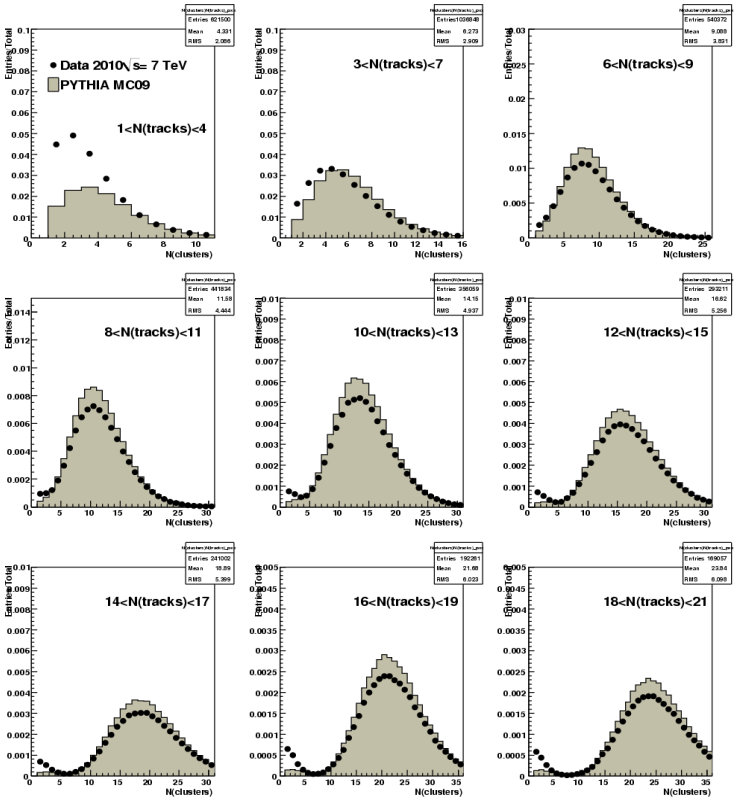


MC dependence

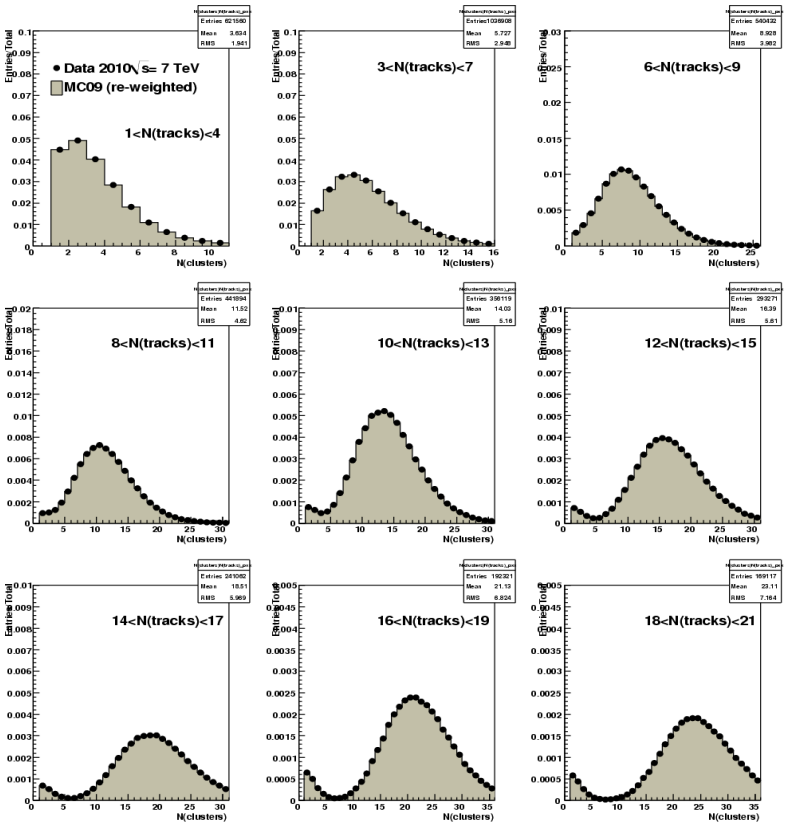


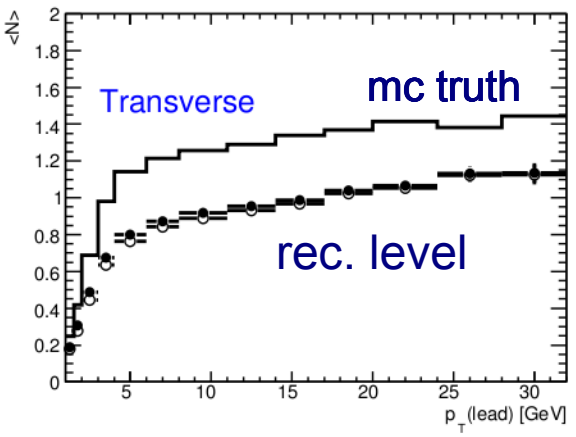


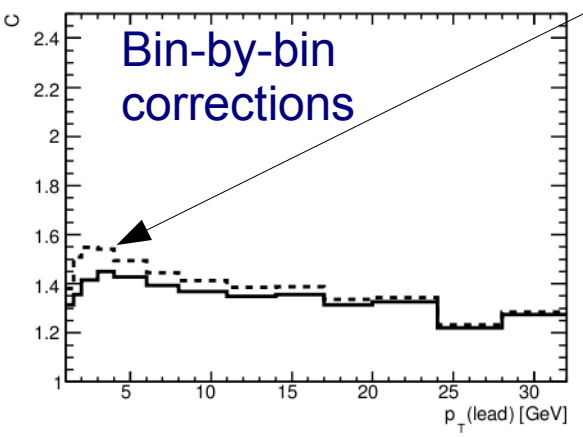
Multiplicity re-weighting. 7 TeV



re-weight





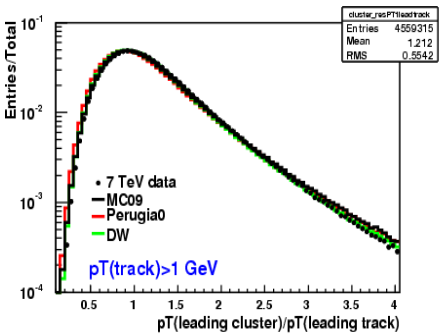


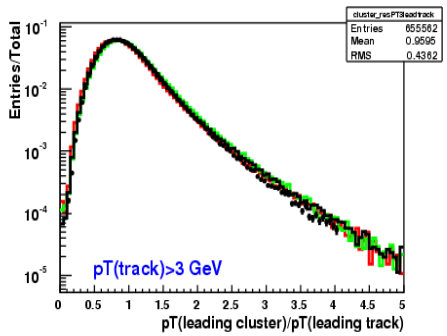
Solid line: before re-weighting

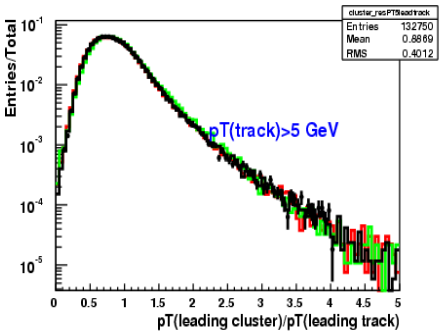
Dashed: after re-weighting

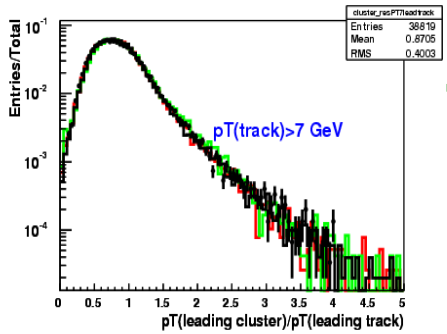
Note: effect from re-weighting for 900 GeV is smaller

Resolution tails for leading clusters re-weighting

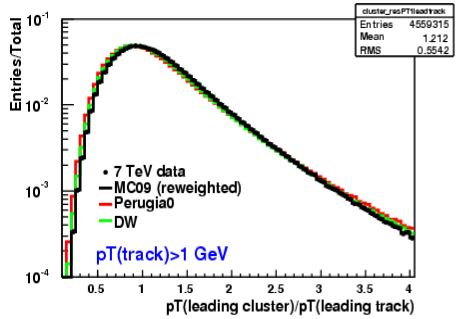


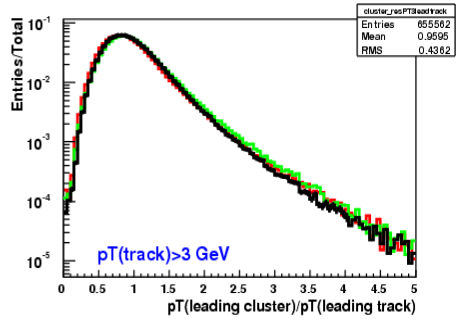


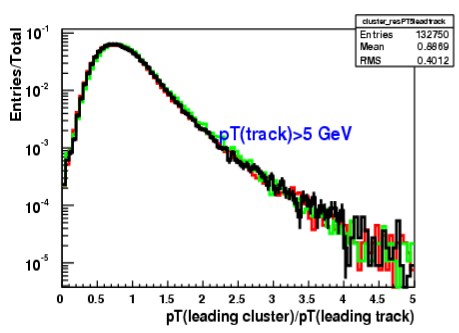


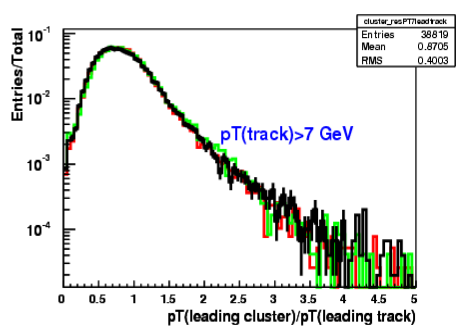


re-weight

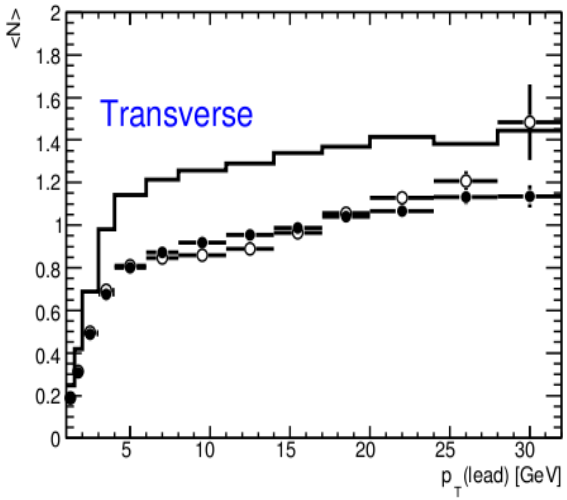


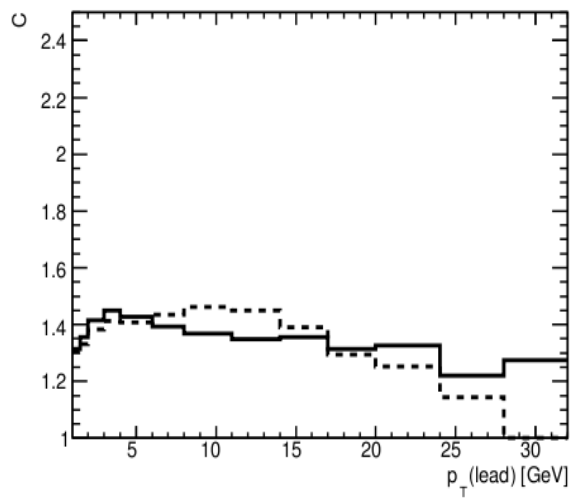






7 TeV





Solid line: before re-weighting

Dashed: after re-weighting