Studies of the underlying event with ATLAS

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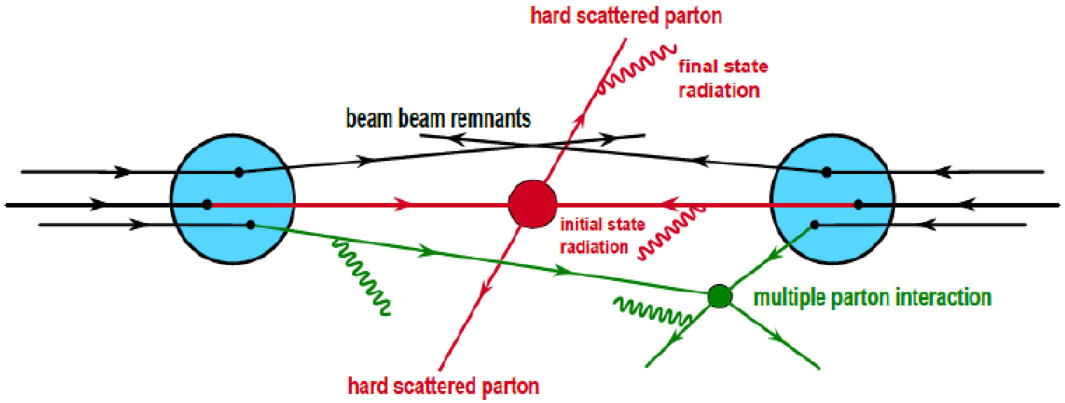
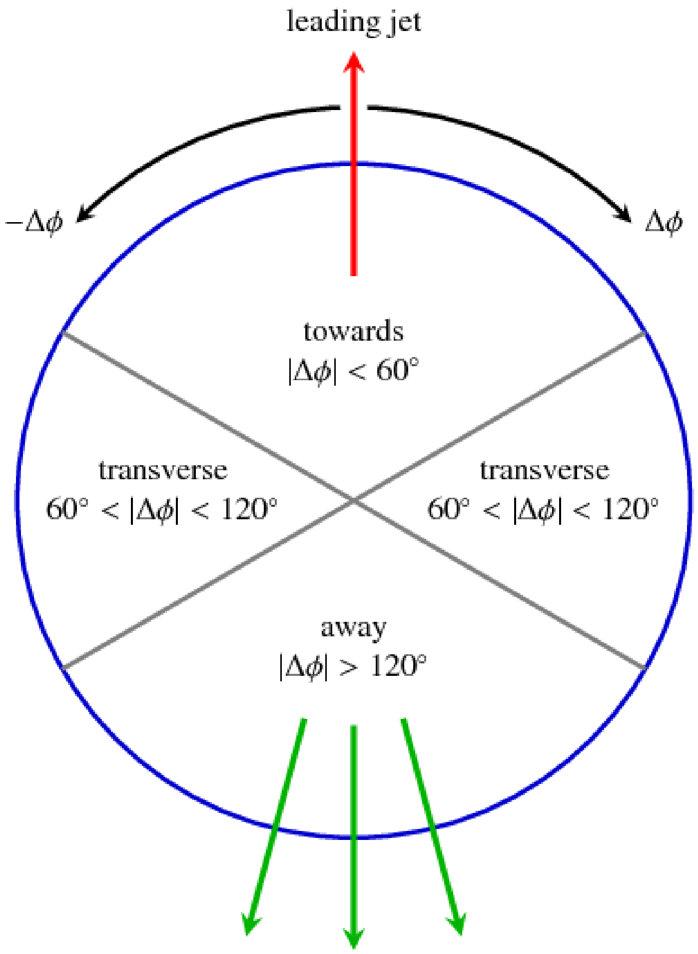
Underlying Event



- Underlying Event (UE) – everything except hard interaction objects with their ISR+FSR although the UE and the hard interaction can not be cleanly separated
- UE contains:
  - Products of soft hadronization of the colored proton remnants
  - Multiple parton interactions (MPI) with their ISR+FSR. MPI plays important role in soft particle production at the current LHC energy
- The low momentum QCD processes dominate the UE and they can not be reliably calculated with the perturbative QCD
- Phenomenological MC generators are used to model the UE and they contain a number of tuning parameters which should be fitted to the experimental data
- The correct modelling of the UE is important as it is a background to all hard QCD processes of interest

UE Analysis

- Hard process used in this analysis is a jet production. The results are preliminary, the final analysis is in preparation
- The UE objects are charged and neutral particles reconstructed on the base of tracks and calorimeter clusters
- Beam transverse plane is subdivided in 4 regions shown at the figure. Δφ is the azimuthal angle between the leading P_T jet and a particle
- Towards and away regions are dominated by the hard process, transverse regions are sensitive to the UE
- The transverse regions are distinguished on event-by-event base as having more or less activity and referenced as trans-max and trans-min correspondingly



Event Selection

- 37 pb^{-1} of low pile-up pp interactions at 7 TeV taken in 2010 have been used
- Two different event topologies:
  - Events with at least one jet
  - Events with an exclusive dijet
- Jet/event selection
  - Triggered anti-kt calorimeter jets with R=0.4
  - jet P_T > 20 GeV, $|y|$ <2.8
  - Primary vertex with at least 5 charged tracks
  - Pile-up veto: no additional vertices with more than 2 tracks
- Additionally for dijets
  - Balance of the leading and sub-leading jets: $P_T(sub) / P_T(lead) > 0.5$
  - Back-to-back topology: $\Delta\varphi(lead,sub) > 2.5$
  - Events with additional jets are rejected
- The jets were fully corrected for detector effects

UE Objects Selection

- **Reconstructed charged tracks and topological 3D clusters of calorimeter cells are used to characterize UE**
- **Charged tracks reconstructed in the Inner Detector (ID):**
  - **P_T > 0.5 GeV, $|\eta| < 2.5$**
  - **Quality cuts on the ID hits and reconstruction χ^2**
  - **Transverse and longitudinal impact parameters with respect to the primary vertex < 1.5 mm**
- **Clusters of calorimeter cells with $|\eta| < 2.5$ as for the tracks or in the full range $|\eta| < 4.9$**
- **The following observables as a function of P_T^{lead} (transverse momentum of the leading jet) are used to study UE:**
  - **$d^2N_{ch}/d\eta d\varphi$ – mean charge particle density per unit η-φ**
  - **$d^2\Sigma P_T/d\eta d\varphi$ – mean scalar P_T sum of charged particles per unit η-φ**
  - **Mean P_T – scalar P_T of charged particles averaged in an event**
  - **$d^2\Sigma E_T/d\eta d\varphi$ – mean E_T sum of charged and neutral particles per unit η-φ**

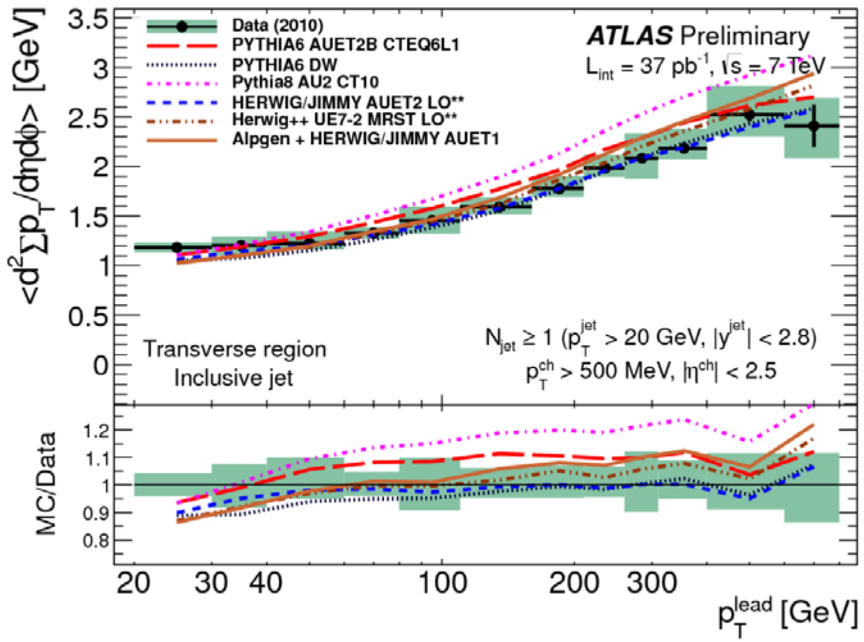
Corrections, Unfolding, Uncertainties

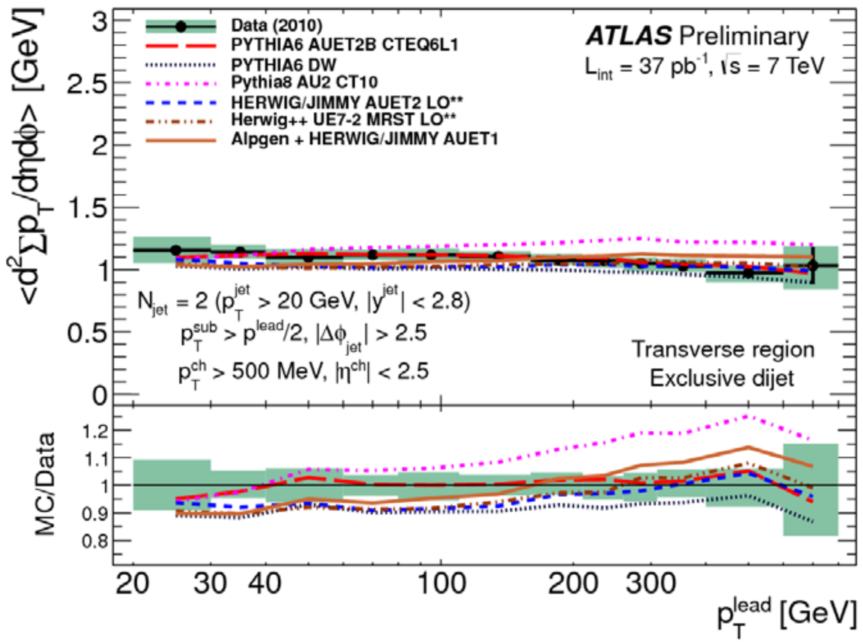
- To allow comparison of the results with theoretical predictions and other experimental studies, the UE distributions were corrected for selection efficiencies and detector resolution effects
- A two step correction procedure was used
  - The track efficiency corrections were applied to the track based observables
  - The cluster energy was corrected to the momentum of the charged or neutral hadron
  - The remaining detector effects were unfolded to produce observables at particle level
- Bayesian iterative unfolding method was used to correct for residual detector effects. The corresponding smearing matrix was calculated using MC samples
- The following main uncertainties were taken in to account
  - Jet/Cluster energy scales and track reconstruction efficiencies
  - Material uncertainty estimated using MC with different detector geometry
  - Unfolding uncertainty (using different MC inputs)
  - Merged vertex effects were studied comparing MC with/without pile-up

Monte Carlo samples

- **Several MC samples produced with different generators and their tunes are used for comparison with data**
- **The following generators are used: Pythia6, Pythia8, Herwig+Jimmy, Herwig++, Alpgen+Herwig+Jimmy**
- **Jimmy is a MPI generator for Herwig**
- **Alpgen generator provides leading-order multi-leg matrix element events, i.e. gives more complex hard process topologies**
- **Tunes:**
  - **Pythia6 DW old Tevatron tune**
  - **Pythia6 AUET2B latest ATLAS Py6 tune using track jets, jet shapes**
  - **Pythia8 AU2 latest ATLAS Py8 tune (excellent UE with track jets description)**
  - **Herwig++ UE7-2 author tune with early LHC data**
  - **Herwig+Jimmy AUET2 latest ATLAS tune for standalone Herwig+Jimmy**
  - **Alpgen+Herwig+Jimmy AUET1 older ATLAS tune**

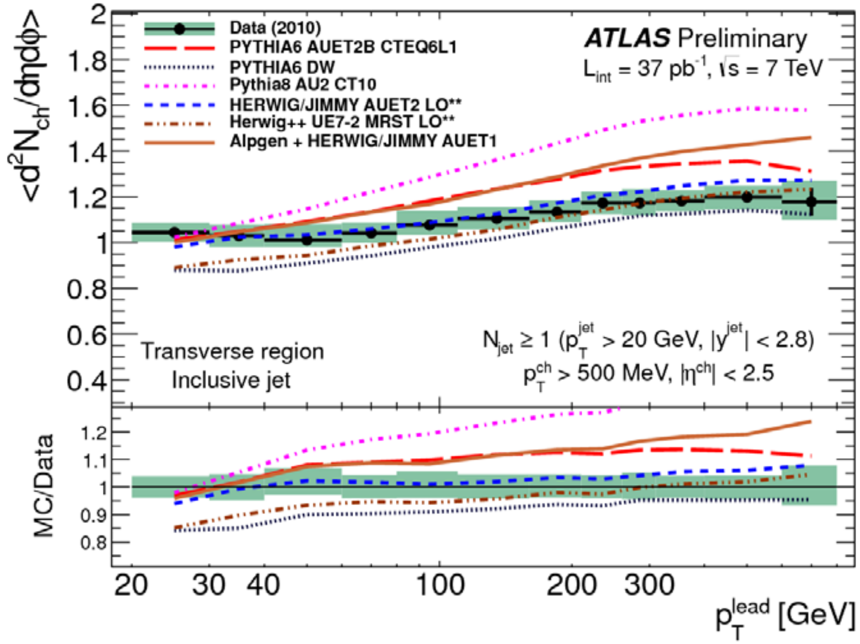
ΣP_T vs P_T^{lead} for charged particles, transverse region

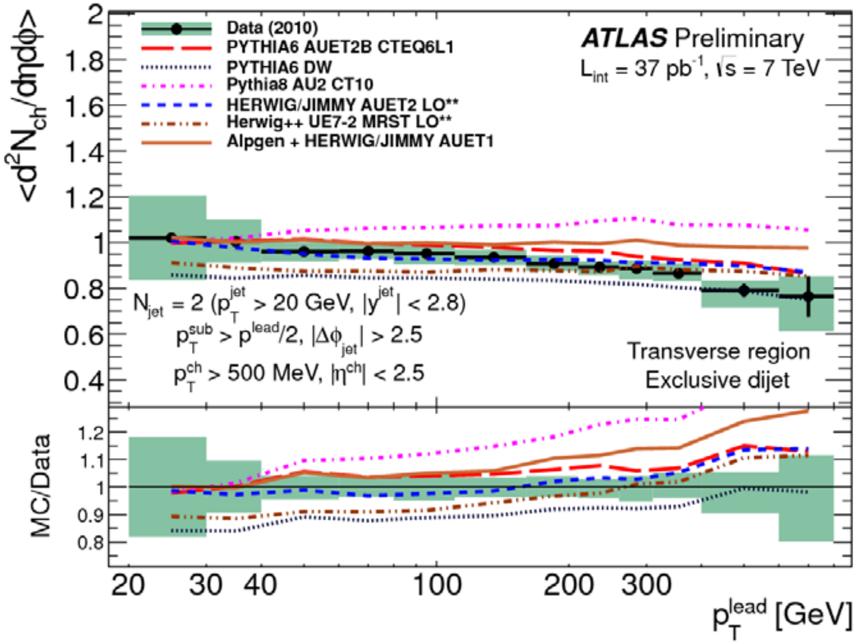




- **For inclusive jets (left) the total transverse ΣP_T increases with P_T^{lead} indicating the contributions of multijet topologies**
- **The exclusive dijet profile (right) decreases a bit as P_T^{lead} increases, although the dependence is much weaker than the rise for inclusive jets**
- **All MC qualitatively describe the trends but the decrease for dijets is noticeably smaller in all MC than in data**

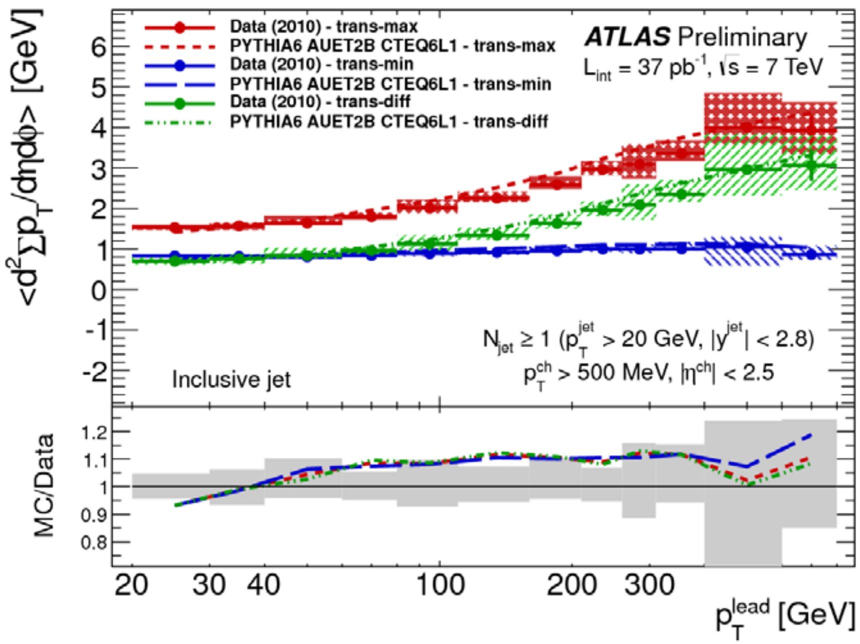
N_{ch} vs P_T^{lead} for charged particles, transverse region

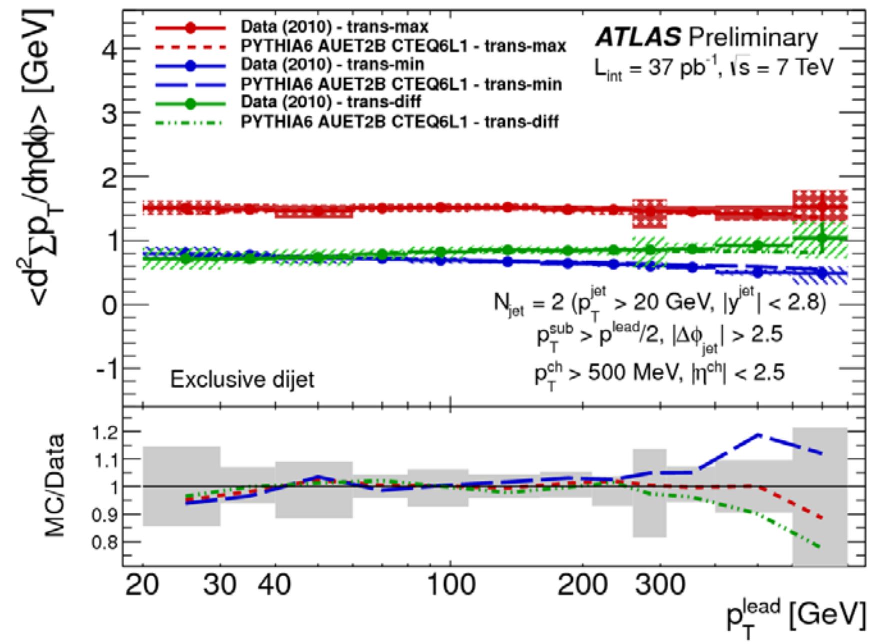




- **The particle densities demonstrate the same trends for both the distributions but the decrease for dijets and its discrepancy with MC are even somewhat larger**
- **Pythia8 AU2 (latest ATLAS tune) gives the worst description as well as at the previous slide**
- **In general MC deviations for these plots are larger than in the previous slide**

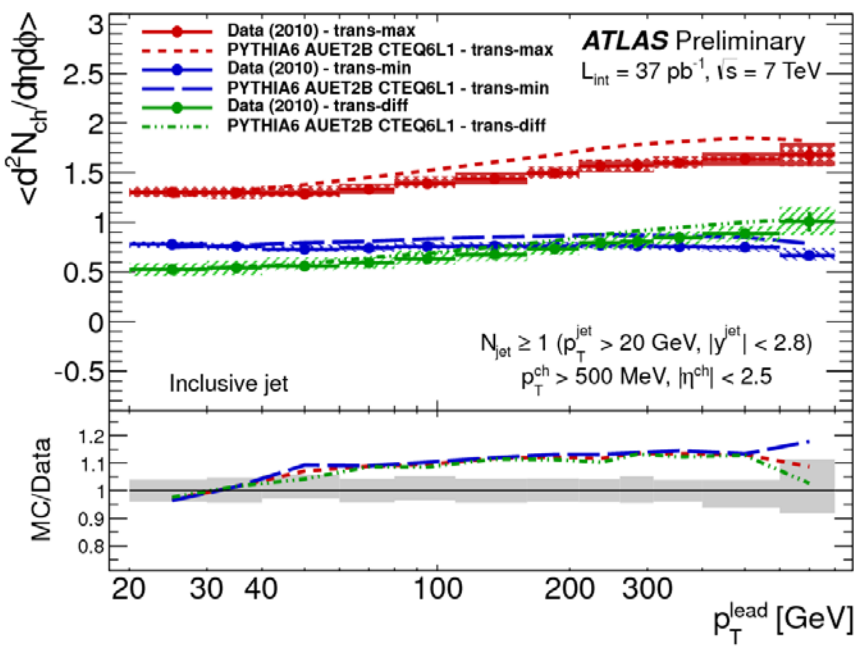
ΣP_T vs P_T^{lead} for charged particles TransMaxMin

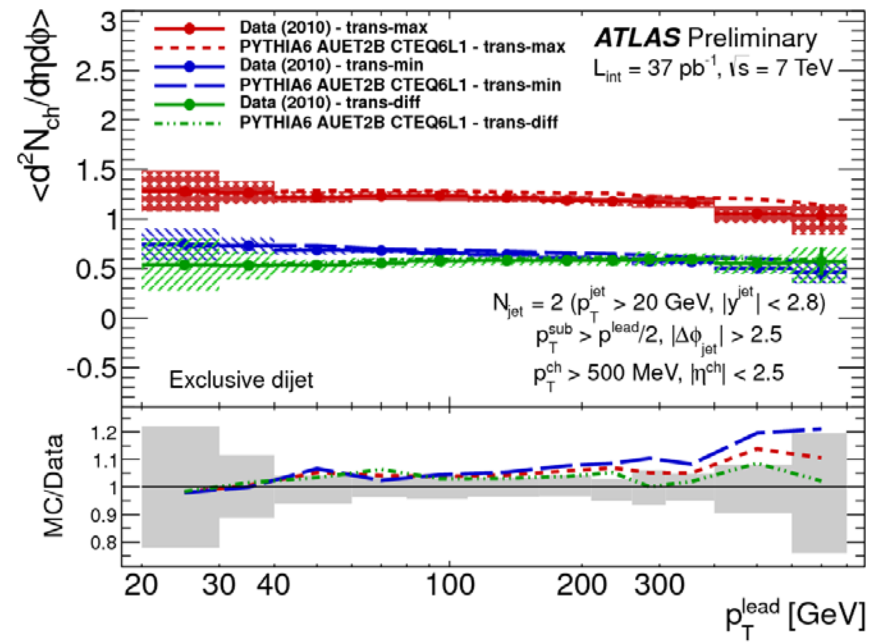




- **In the inclusive jet events the trans-max activity (ΣP_T and N_{ch} at the next slide) grows with P_T^{lead}, similarly to the total transverse region trend, but its trans-min component is almost constant**
- **Trans-min region is obviously being less affected by the hard part of the UE**
- **PYTHIA6 AUET2B describes the data within the experimental uncertainties**

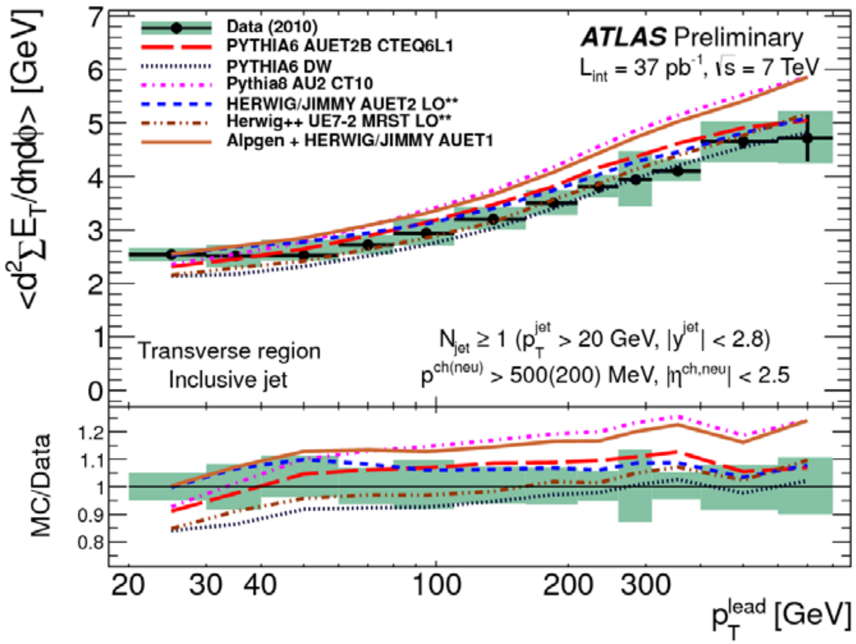
N_{ch} vs P_T^{lead} for charged particles TransMaxMin

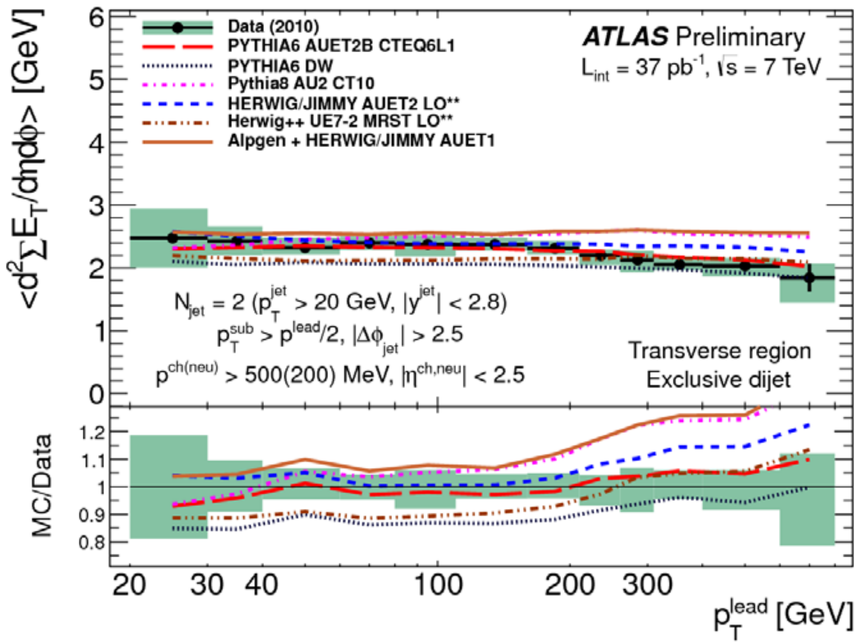




- **N_{ch} density shows the same behavior as ΣP_T at the previous slide**
- **But PYTHIA6 AUET2B description is noticeably worse**
- **The insensitivity of the trans-min region to changes in P_T^{lead} indicates that UE activity can indeed be modelled as approaching a constant as a function of a hard process scale**

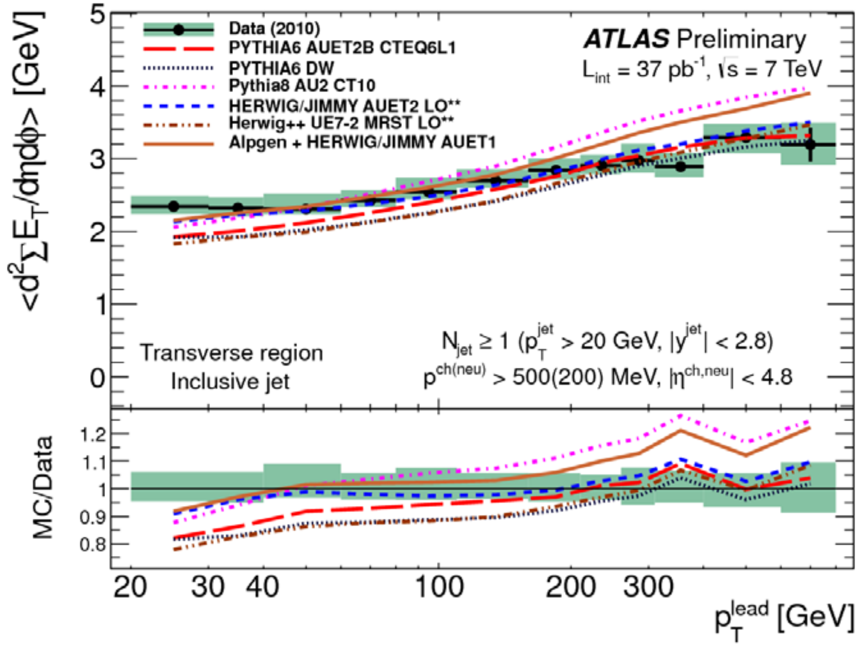
ΣE_T vs P_T^{lead} for charged and neutral particles $|\eta| < 2.5$

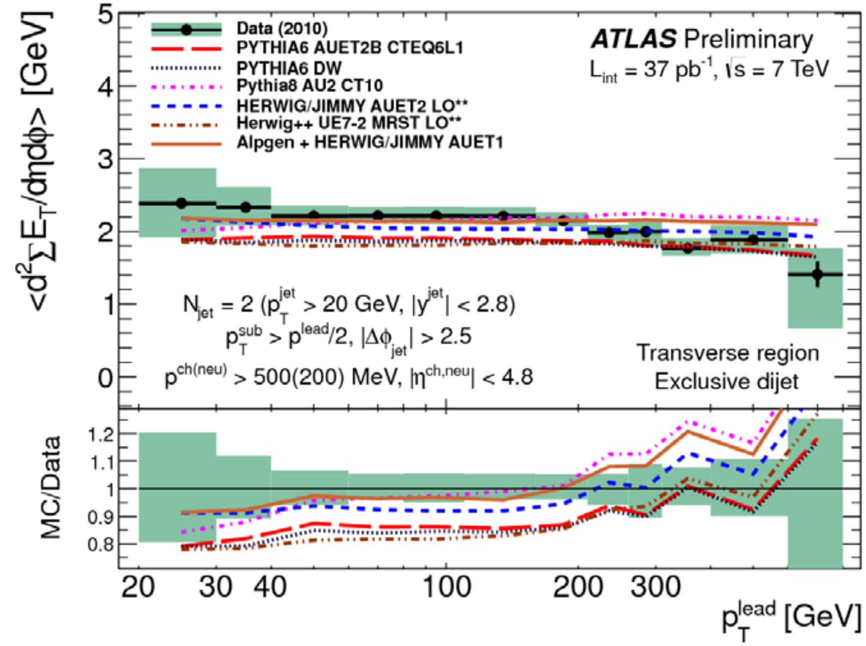




- **Mean sum of E_T density is twice larger than for charged particles only for the central region $|\eta| < 2.5$**
- **The trends are broadly similar to those for the track-based observables including the profile decrease with increasing P_T^{lead} for exclusive dijet topology**
- **MC gives also comparable quality of description as for the charged tracks**
- **PYTHIA8 AU2 and Alpgen+HERWIG/JIMMY AUET1 predicts too high activity**

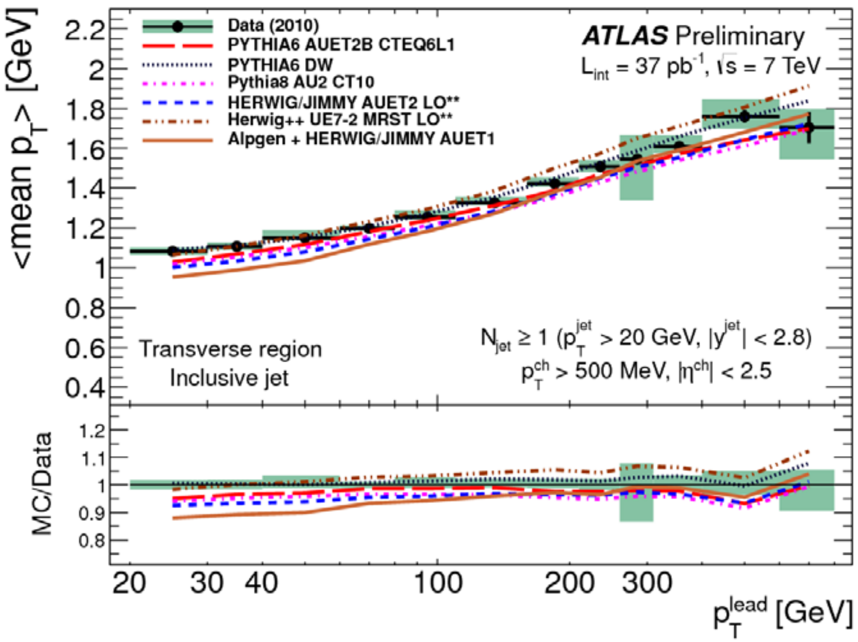
ΣE_T vs P_T^{lead} for charged and neutral particles $|\eta| < 4.9$

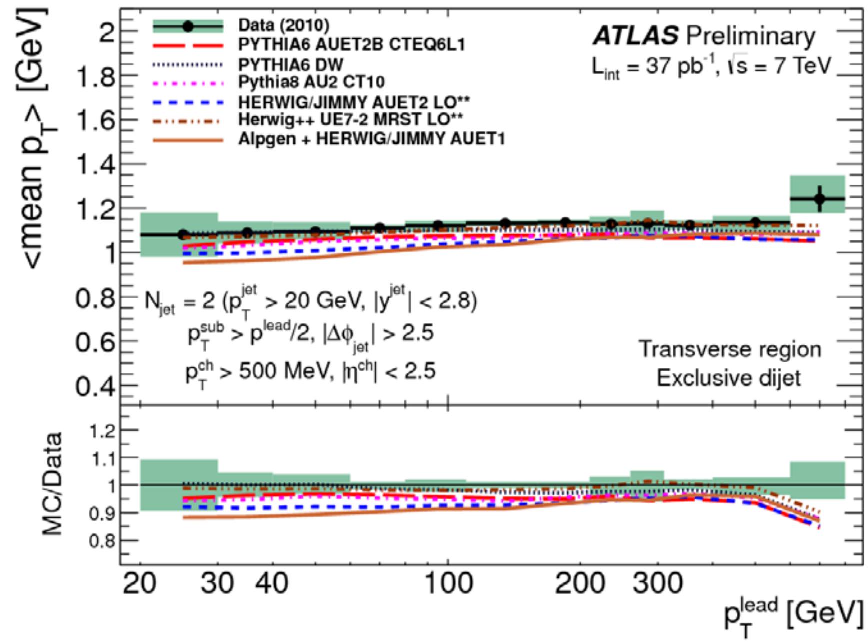




- **The full η acceptance plots show increased disagreement between the MC and data: the MC models undershoot the observed level of activity at low P_T^{lead} values in both the inclusive and exclusive event selection**
- **This discrepancy is notable as all MPI models have to date been tuned to observables measured solely for the central region**
- **All models except HERWIG/JIMMY predict a faster rise of ΣE_T as a function of P_T^{lead} than seen in the data**

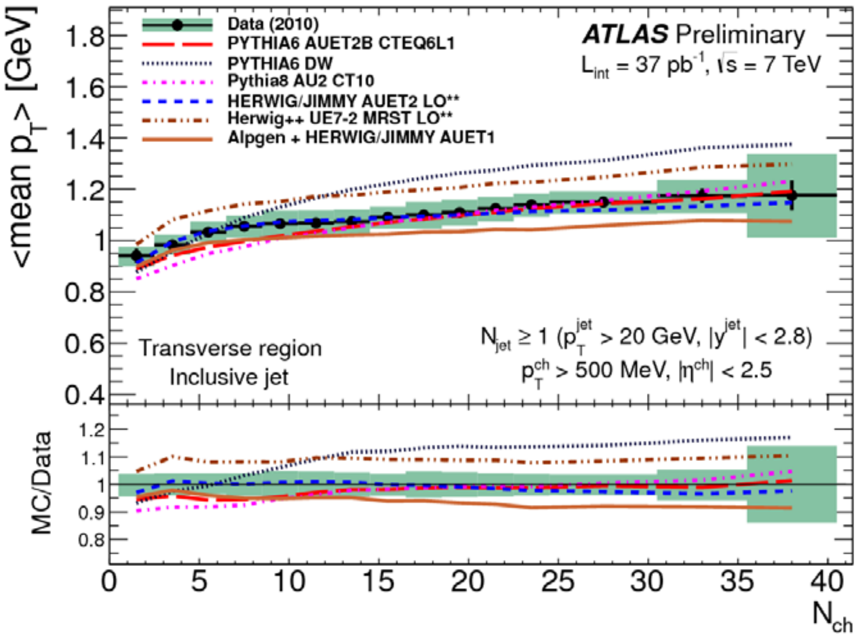
<mean P_T> of charged particles vs P_T^{lead}

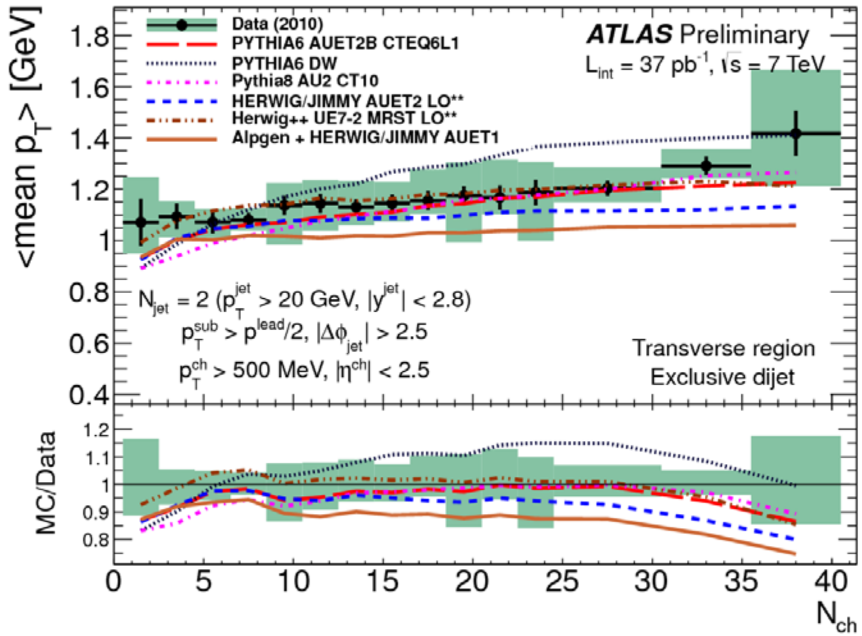




- **The profile displays a very different behavior between the inclusive jet and exclusive dijet event selections: it rises strongly for inclusive jet case but is flat within uncertainties for dijet case. The high P_T tails of UE particle production are effectively removed by the dijet selection**
- **Both the profiles is well described by the MC models – within 10% of the data**

<mean P_T> of charged particles vs N_{ch}





- **Mean P_T of charged particles is increasing function of the number of charged particles for both the selections**
- **PYTHIA6 DW overshoots and Alpgen+HERWIG/JIMMY AUET1 undershoots both the profiles**
- **HERWIG++ significantly overshoots the inclusive data but gives one of the best descriptions for dijets**

Summary

- **The ATLAS preliminary results on the UE analysis using inclusive jet and exclusive dijet topologies up to P_T = 800 GeV are presented**
- **The results are shown for both the charged particles in the central region $|\eta| < 2.5$ and charged+neutral particles in the central region and in the full interval $|\eta| < 4.9$**
- **Rising levels of transverse activity as a function of P_T^{lead} are observed in the inclusive jet selection**
- **Selection of the trans-min region as well as application of the exclusive dijet event selection removes this feature, producing instead constant or weakly decreasing dependence on jet P_T^{lead}**
- **This can be interpreted as UE activity is nearly independent of the hard scattering scale**
- **MC models in general provide qualitative description of the data behavior, but there are some noticeable discrepancies, especially in the full η acceptance.**
- **The data give more input for further MC generators tuning**
- **Based on ATLAS public results: ATLAS-CONF-2012-164**