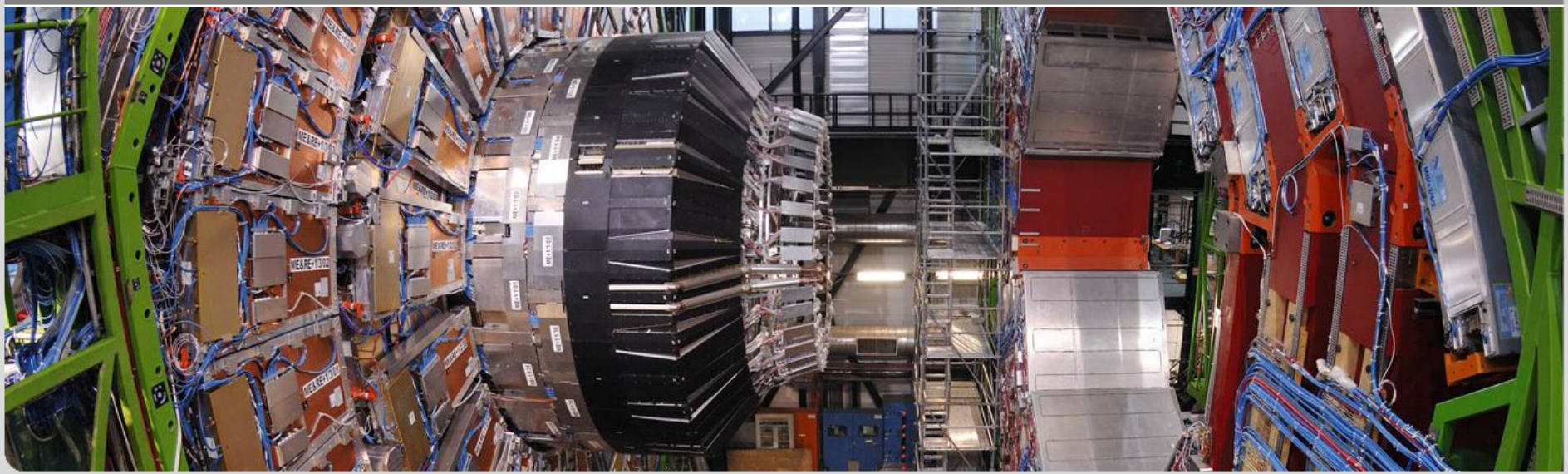
Karlsruhe Institute of Technology

14th EDS Blois Workshop

Underlying Event Measurements at the LHC

Michael Heinrich for the ATLAS and CMS collaborations

INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (EKP) · PHYSICS FACULTY

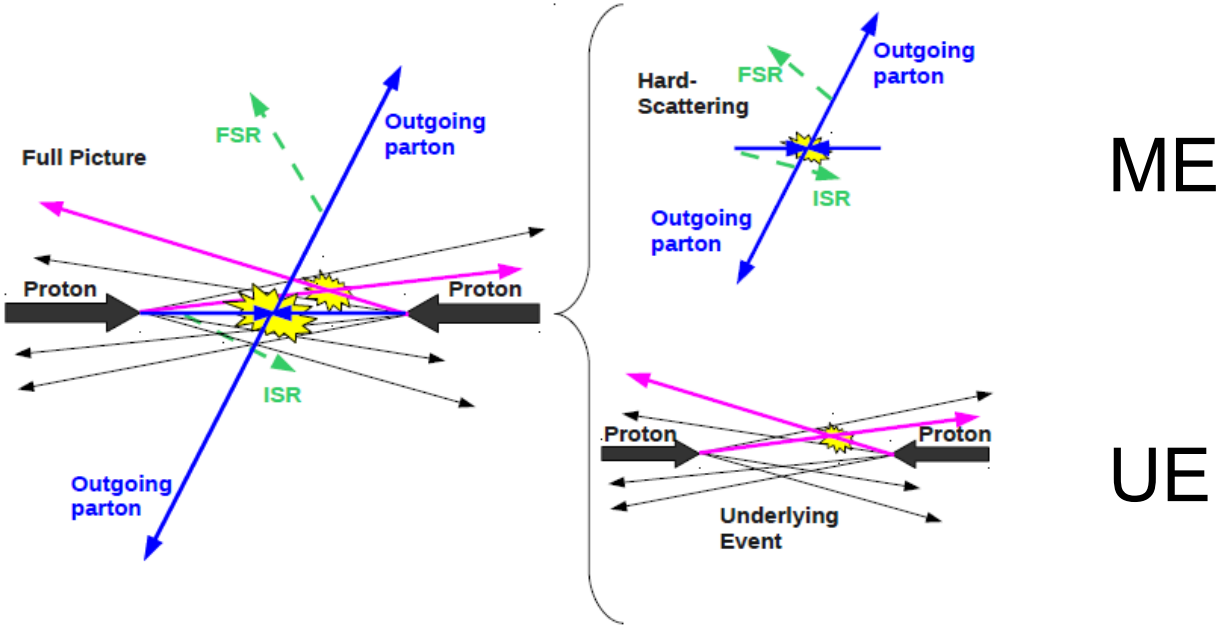


Outline

- Introduction
- Transverse Region Method
  - Track-Based Measurements
  - Calorimetric Measurements
- Other Methods

The Underlying Event

- Everything in hadron collisions apart from the hard parton interaction is called the Underlying Event (UE)
- Monte-Carlo generators have to deal with both hard and soft interactions

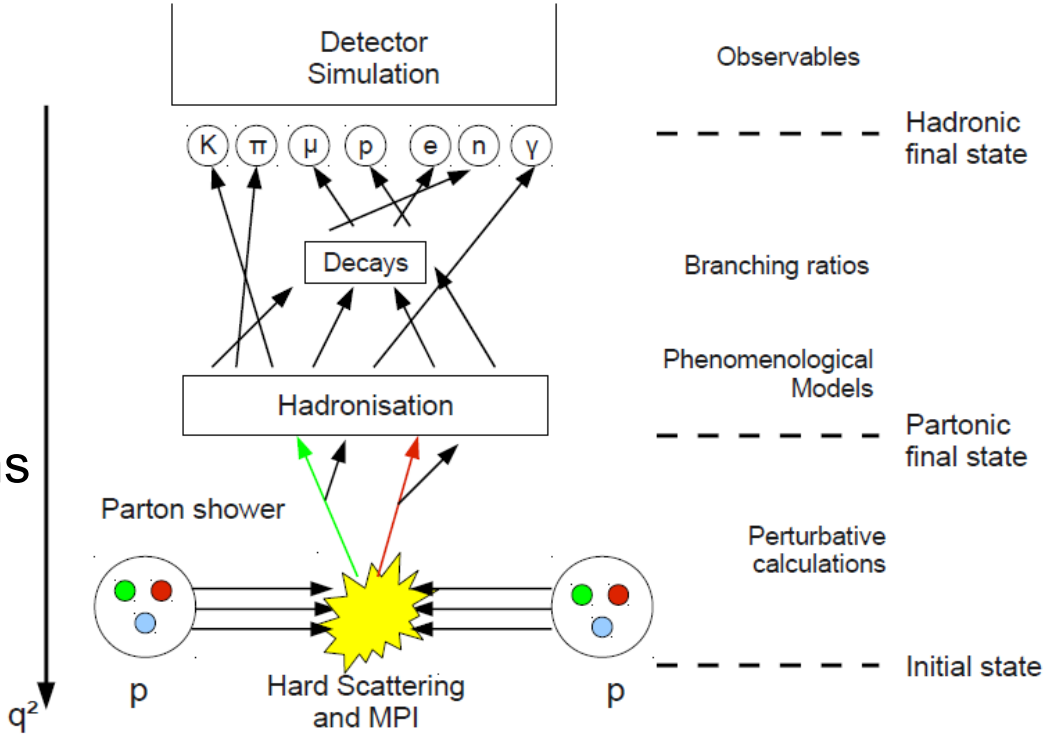


- Implications on all measurements using jets or isolation cones

Best possible description in MC is crucial

UE in Monte Carlo Event Generation

- At scales of low momentum transfers, perturbative QCD breaks down
- Particle level MC generators employ semi-phenomenological models to account for soft contributions
- Depending on the generator of choice, a large number of parameters are tunable

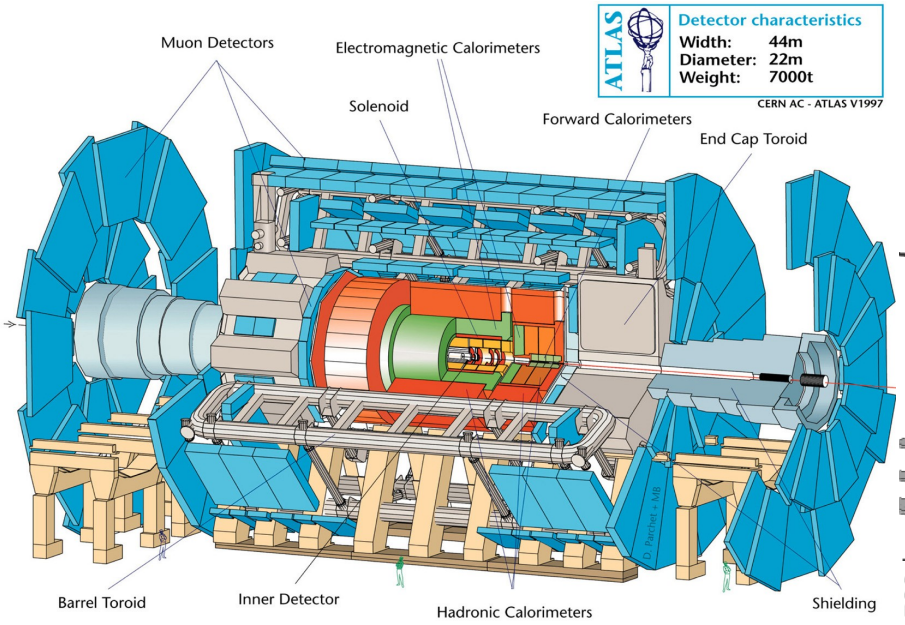


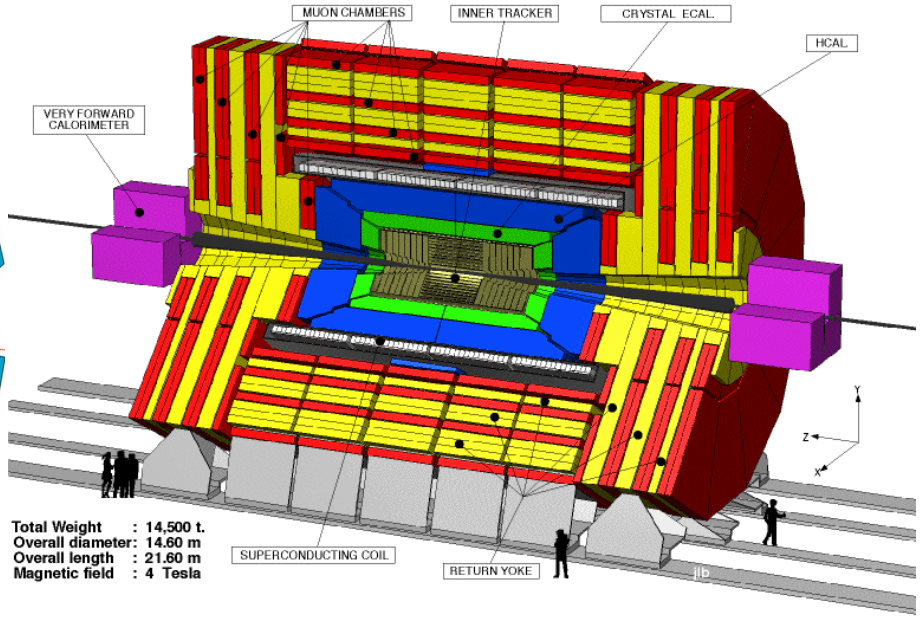
As some of the parameters are energy-dependent, improved tunes are derived at every newly accessed energy

The analyses to be presented contain pre-LHC and dedicated LHC tunes

The Detectors: ATLAS and CMS

- Two incredible machines...





...perfect to study all aspects of proton collisions

Challenges in UE measurements:

Hermetic coverage and lowest possible particle momenta

Underlying Event Measurements

- Measurements of the Underlying Event were early priorities in the LHC physics program
- Only small data samples are required for most analyses
- Pile-up would severely disturb measurements

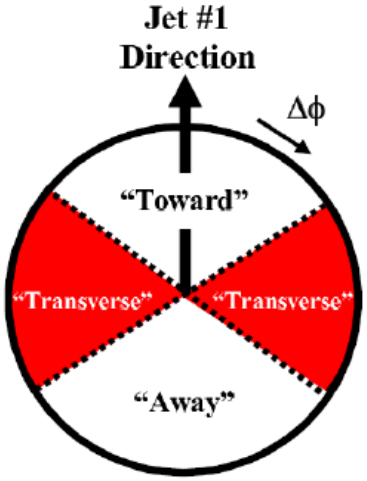
  → only low luminosity running periods are suitable
- Most analyses use minimum bias data, some extend into harder territory

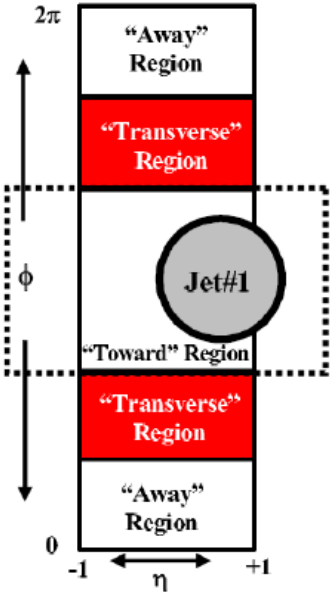
- However, isolating UE contributions in proton collisions is not trivial
- Origin of a given particle in the detector is inaccessible

Consistent separation of hard (ME) and soft (UE) contributions has to be applied to study the UE

Transverse Region Method

- Consistent separation of UE and ME contributions by geometrically slicing the event
- Transverse region approach:
  - Select suitable event topologies
    (e.g. di-jet events, Drell-Yan muons)
  - Identify leading object in event
  - Leading object defines event scale
  - Examine transverse region
  - Typical observables include
    $p_{T,\,sum}$ and $n_{Tracks}/n_{clusters}$
    in transverse region
  - Very well suited for MC tuning
- Vastly successful method



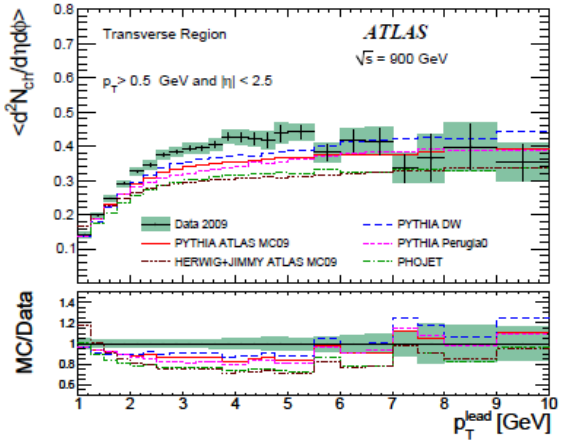


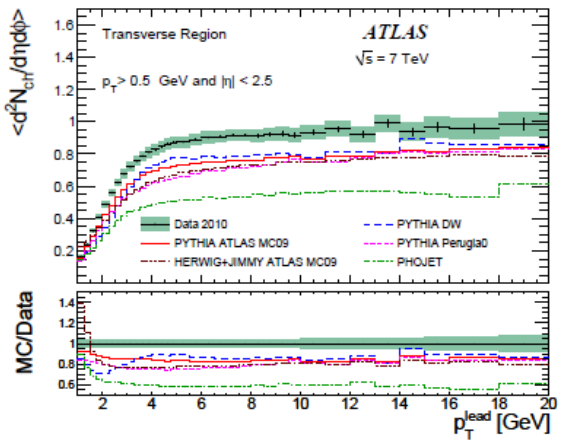
Applied at Tevatron, RHIC and LHC

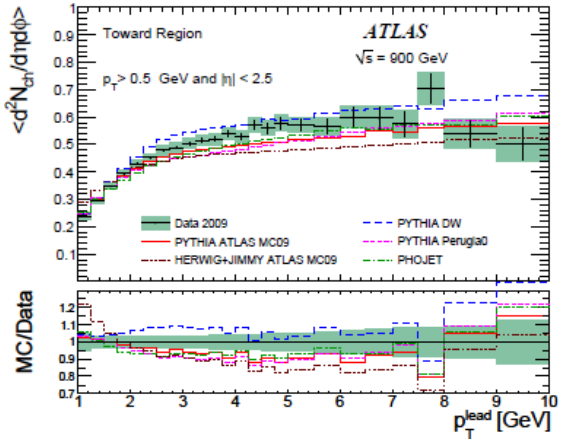
Measurement of underlying event characteristics using charged particles in pp collisions at √s = 900 GeV and 7 TeV with the ATLAS detector

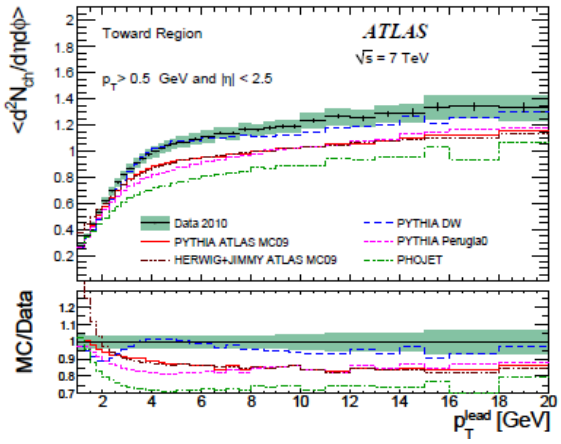
- Track-based ATLAS analysis

  → investigating charged particle production
- Comparison of corrected detector data and several MC generators
- Two center-of-mass energies, minimum bias event selection





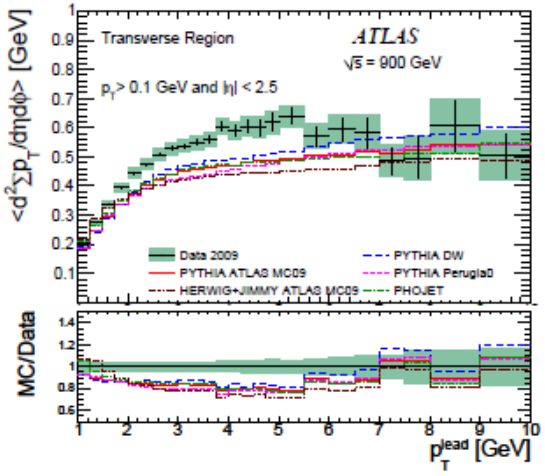


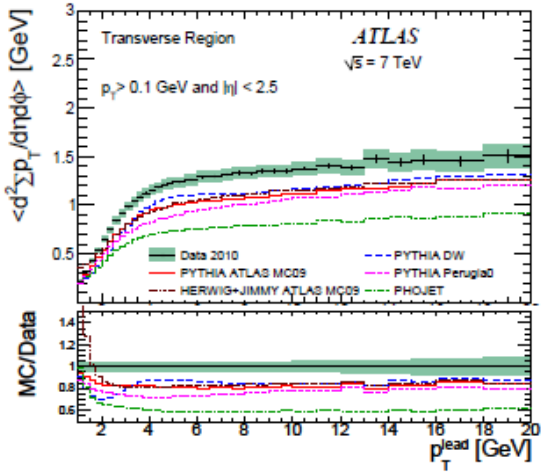


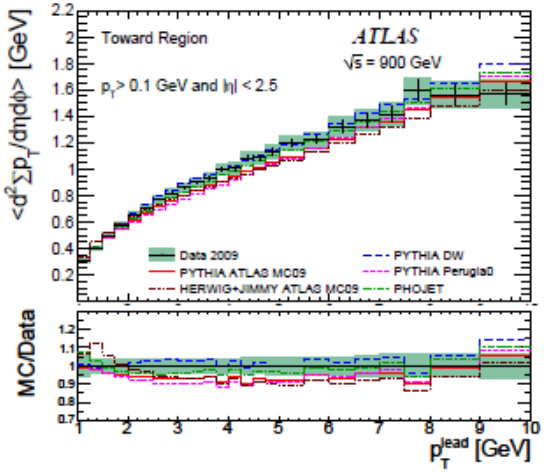
- Unique feature:

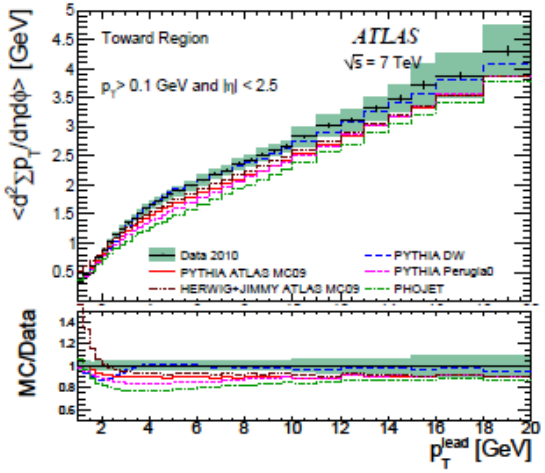
  Two different minimum p_T cuts providing very good phase-space coverage

All available tunes tend to underestimate the Underlying Event activity





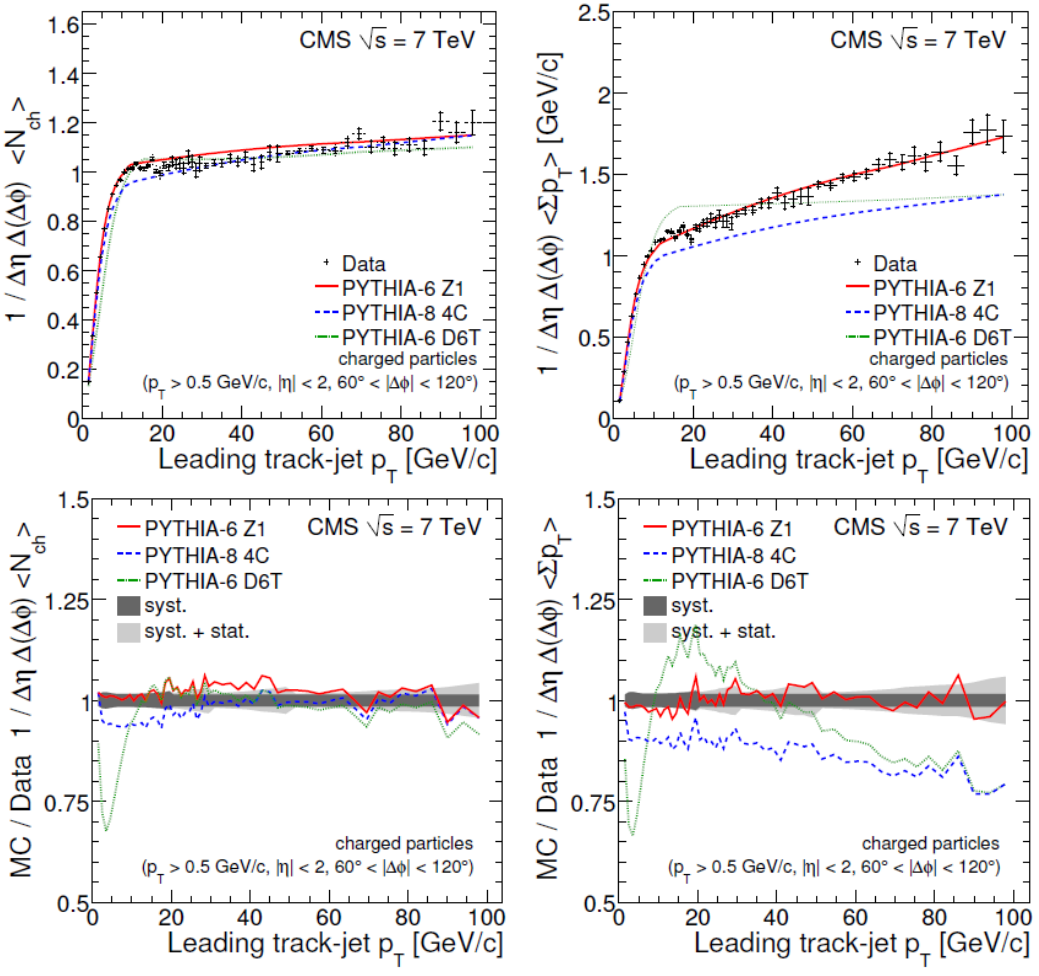




https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2010-04/

Measurement of the Underlying Event Activity at the LHC with √s = 7 TeV and Comparison with √s = 0.9 TeV (CMS)

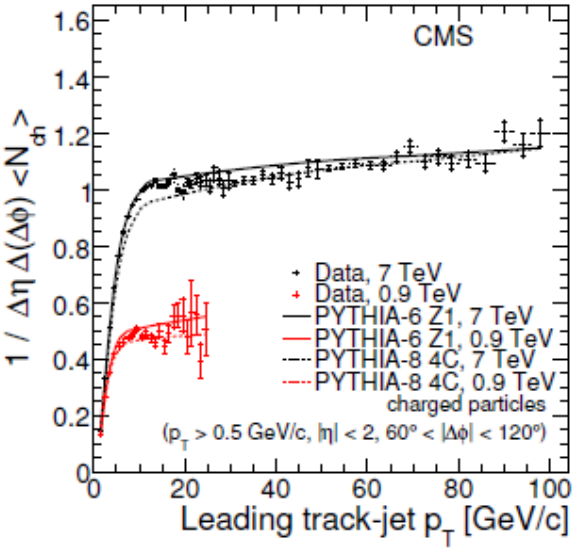
- Track-based CMS analysis
  → investigating charged particle production
- Corrected data and three tunes of Pythia MC
- Two center-of-mass energies, minimum bias as well as jet stream data

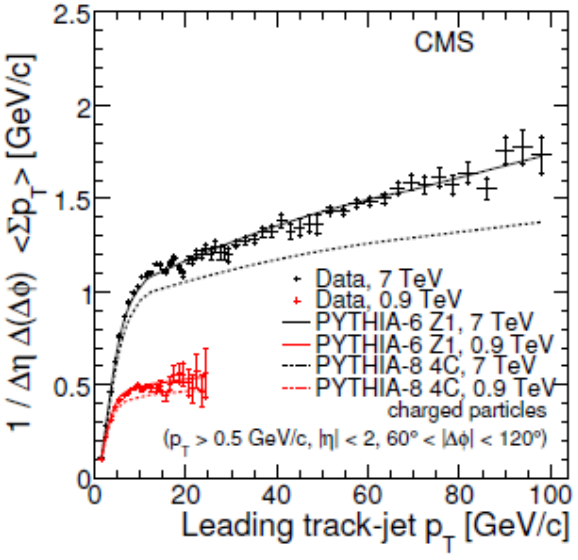


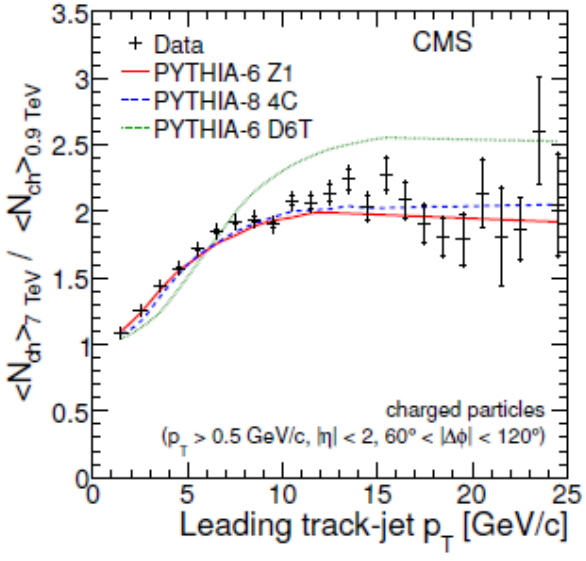
- Unique feature:

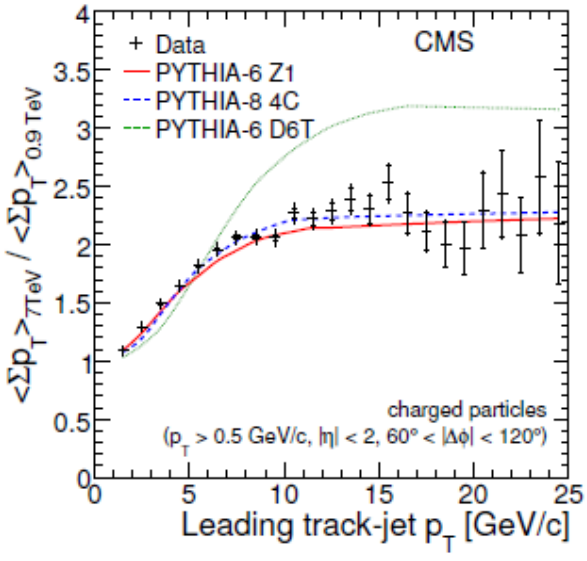
  Extending event scale far into plateau region

Dedicated tunes Z1 and 4C perform very well for both 0.9 and 7 TeV









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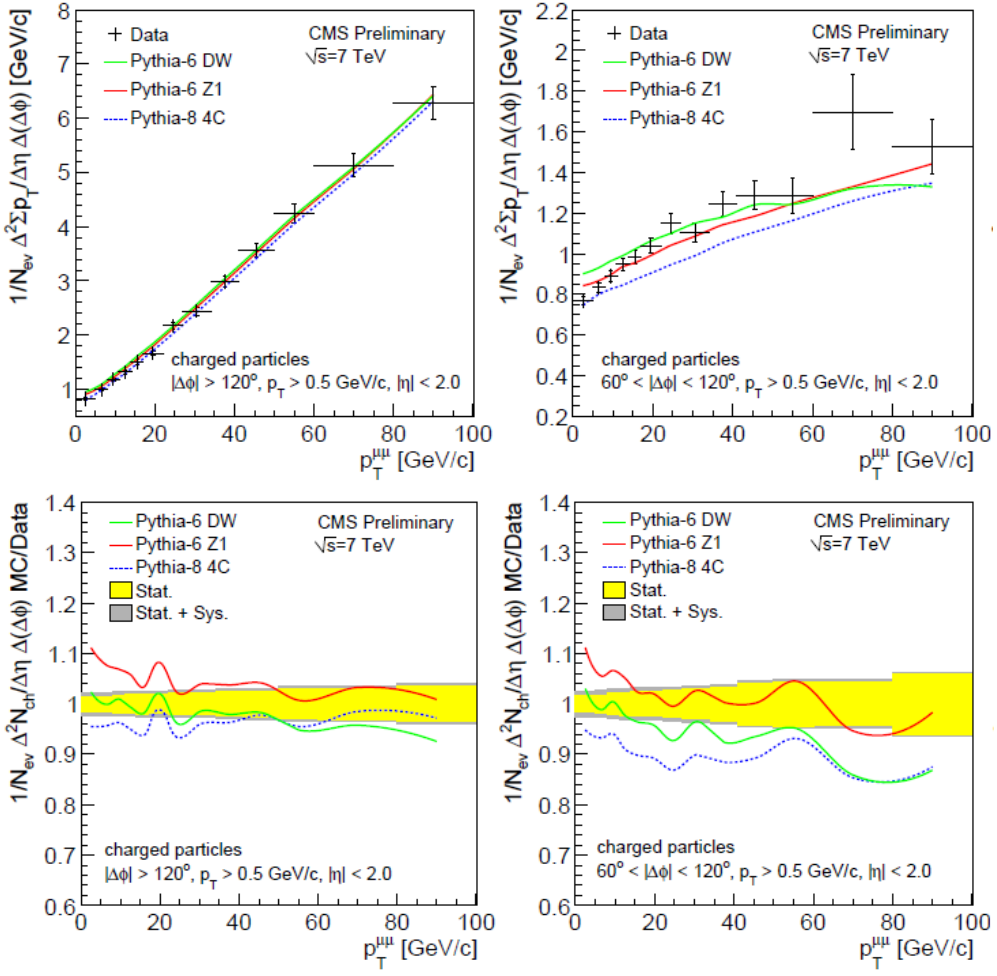
Measurement of the Underlying Event Activity in the Drell-Yan process in proton-proton collisions at $\sqrt{s}$ = 7 TeV (CMS)

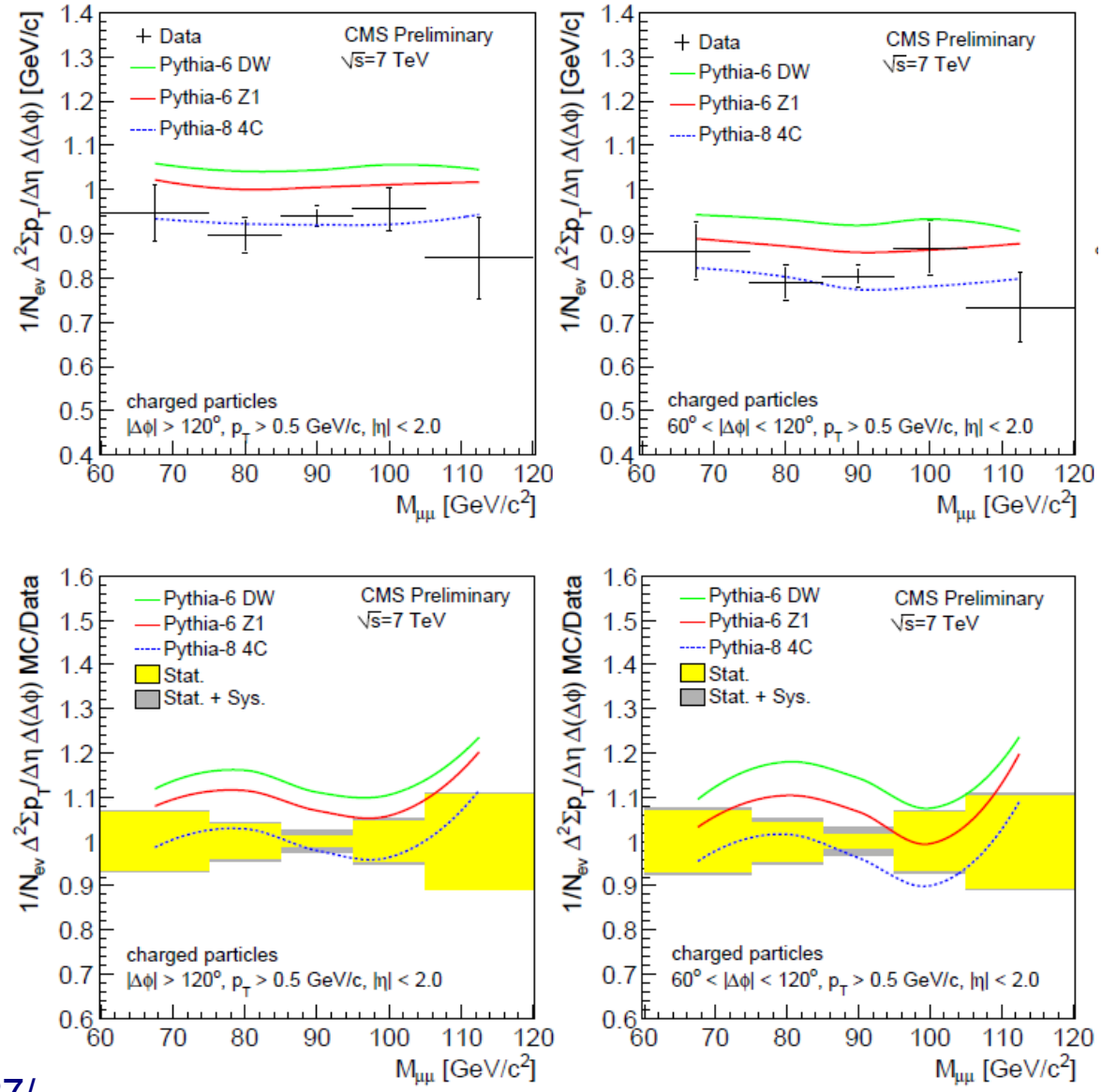
- Track-based CMS analysis on DY muon data
- Event scale defined by transverse momentum of the di-moun system
- Due to lower cross-section only at 7TeV
- Corrected data and three different Pythia tunes



- Unique feature:

  No hadronic activity from hard interaction, no interplay of production mechanisms expected

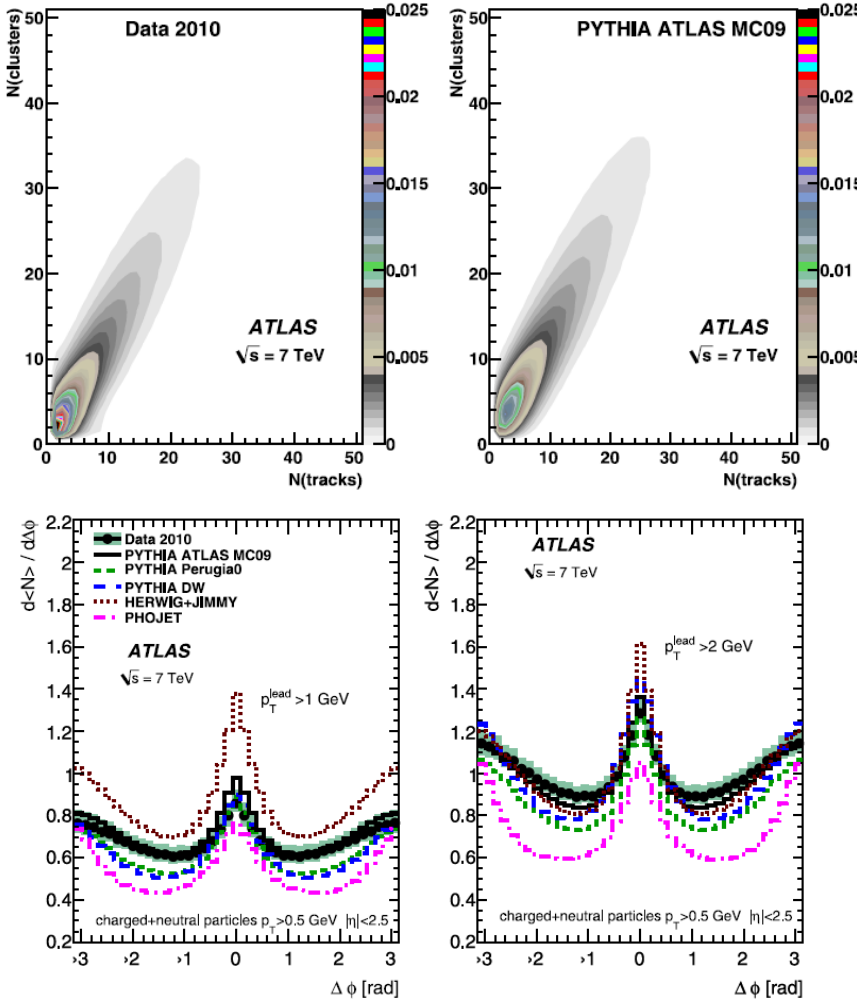
Plateau region less pronounced than in QCD events, performance of MC is comparable



http://cdsweb.cern.ch/record/1369227/

Measurements of underlying-event properties using neutral and charged particles in pp collisions at √s = 900 GeV and √s = 7 TeV with the ATLAS detector at the LHC

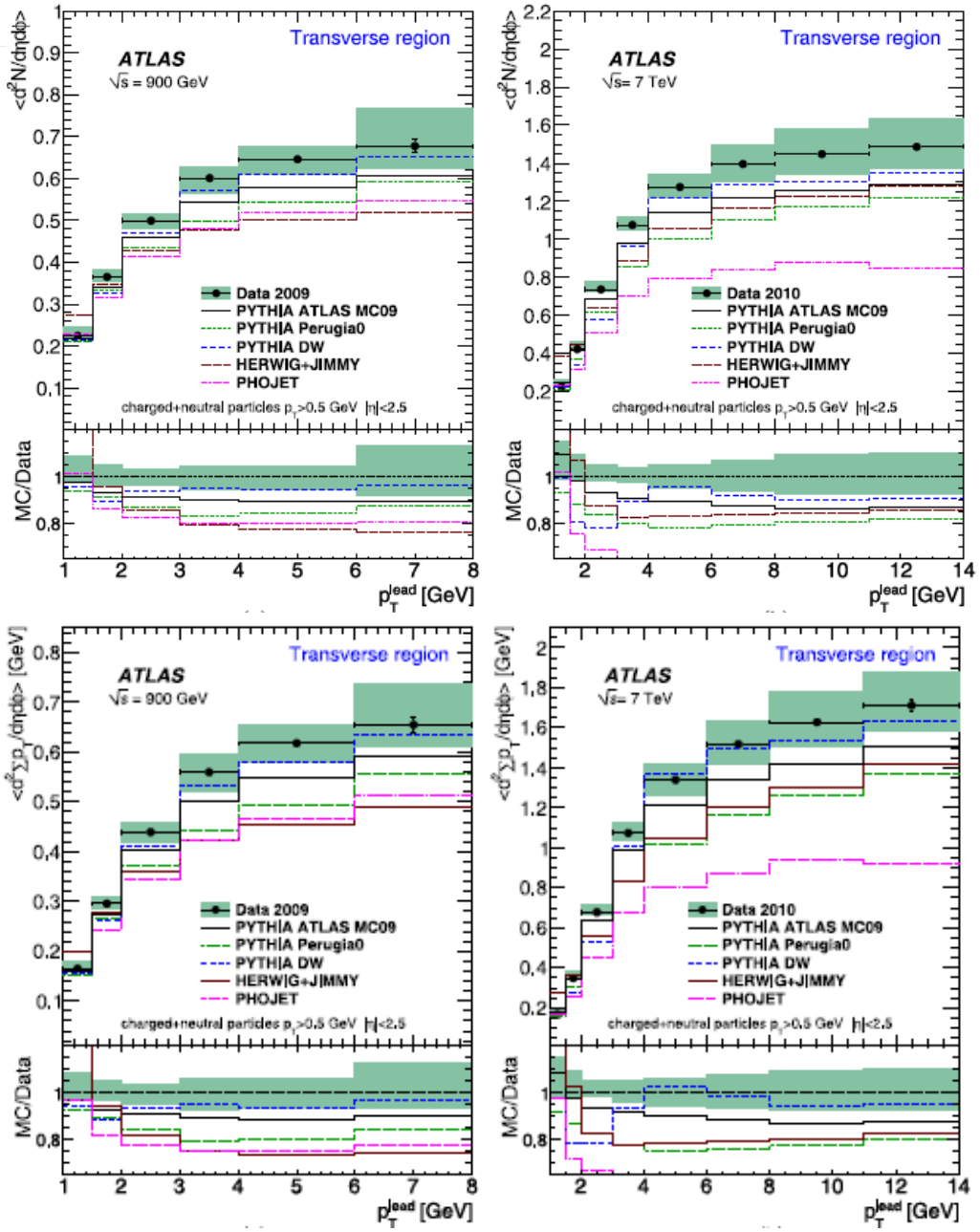
- Calorimeter-based ATLAS measurement
- Includes both neutral and charged particles without discrimination
- Minimum bias data at both center-of-mass energies
- Corrected data and several tunes/generators



- Unique feature:

  Not limited to the charged component

Results are consistent with track-based analysis, extend them to neutral component



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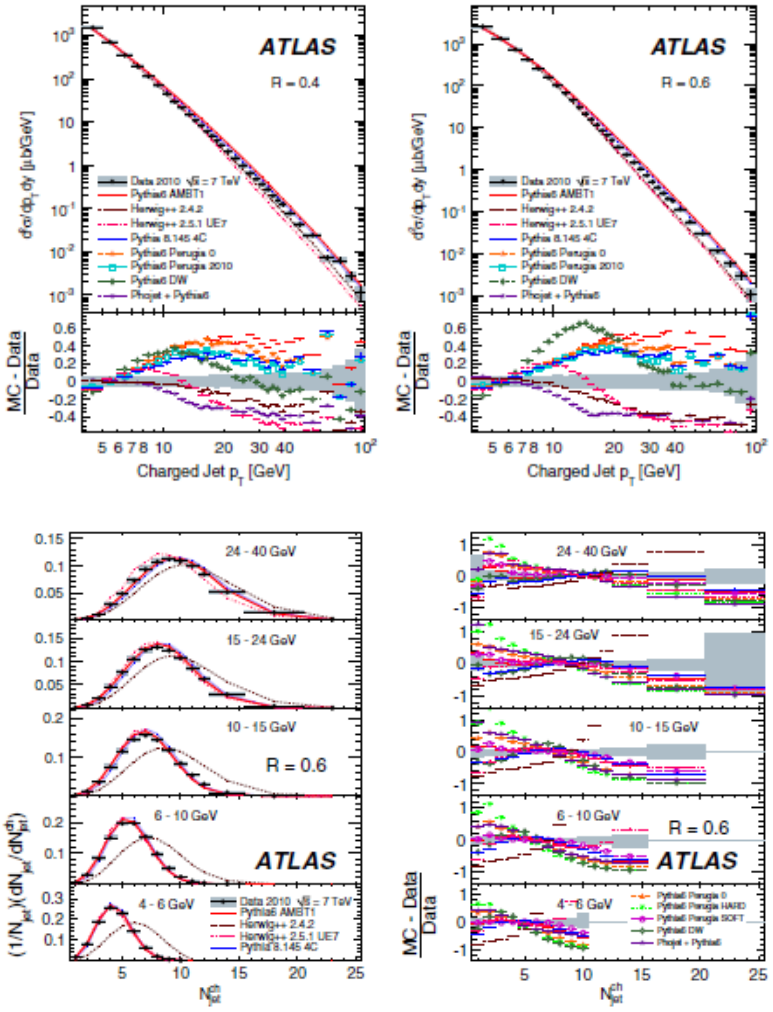
Other Approaches

- Several additional measurements are closely connected to the Underlying Event
- Range goes from jet substructure to forward activity
- A number of these analyses has dealt with comparing MC predictions to data

Properties of jets measured from tracks in proton-proton collisions at center-of-mass energy s√ = 7 TeV with the ATLAS detector

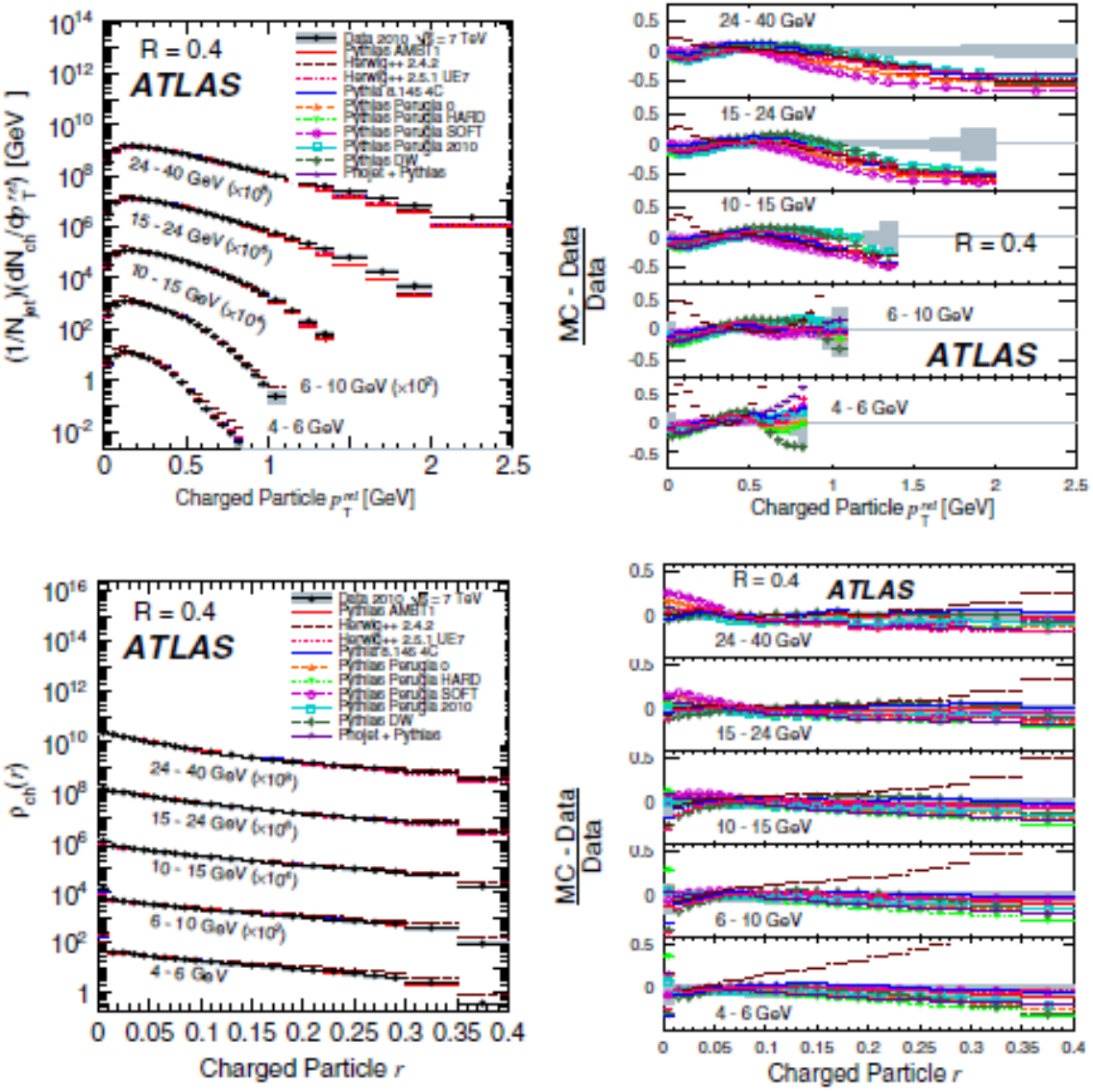
- Measurement of track-jet properties allows look into fragmentation also inside hard jets
- Different resolution parameters of the anti-k_T jet algorithm and lots of tunes/generators
- Minimum bias and jet stream data at 7TeV



- Unique feature:

  Transition from soft to hard event scales, new observables

Provides new observables that none of the available tunes is able to describe correctly



PHYSICAL REVIEW D 84, 054001 (2011)

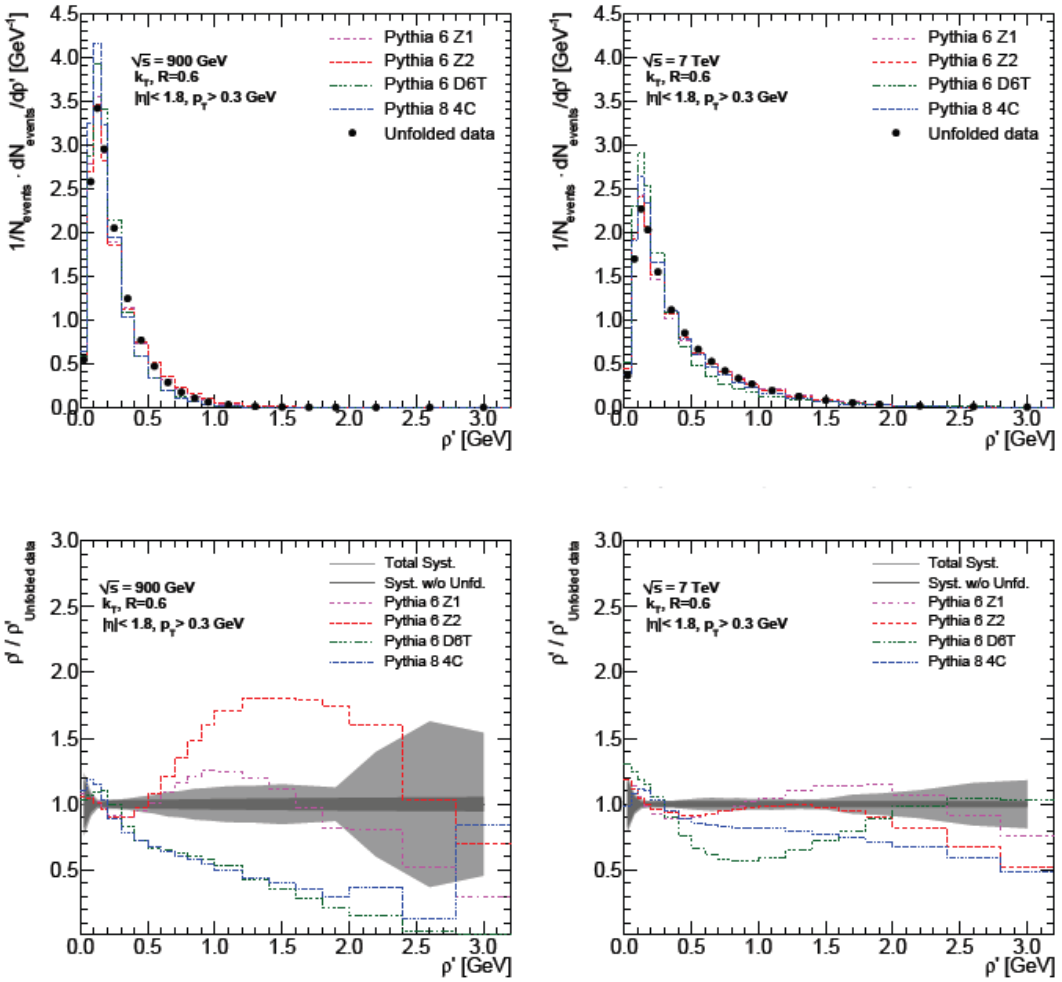
Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 7 TeV and comparison to 0.9 TeV

- Track-jet based analysis of new observable

$$\rho' = \underset{j \in physical\ jets}{\text{median}} \left[\left\{ \frac{p_{T,j}}{A_j} \right\} \right] * C$$

$$C = \frac{\Sigma_j A_j}{A_{tot}}$$

- Makes use of active area clustering in k_T algorithm
- Corrected minimum bias data at both center-of-mass energies and multiple tunes of Pythia

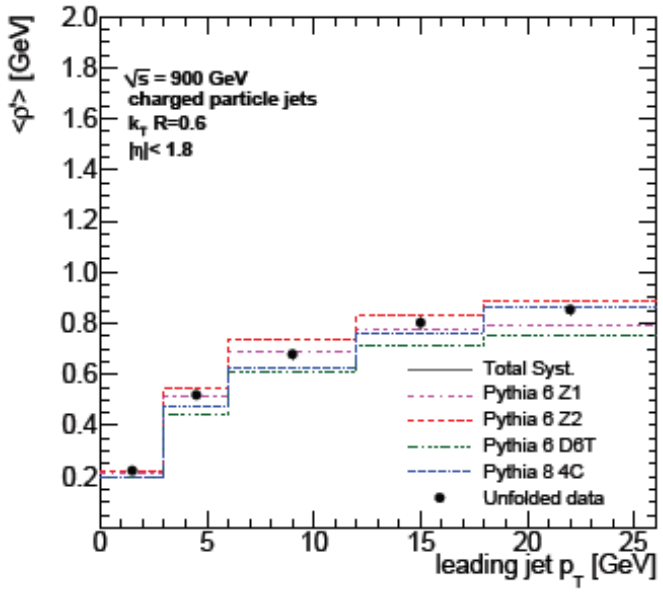


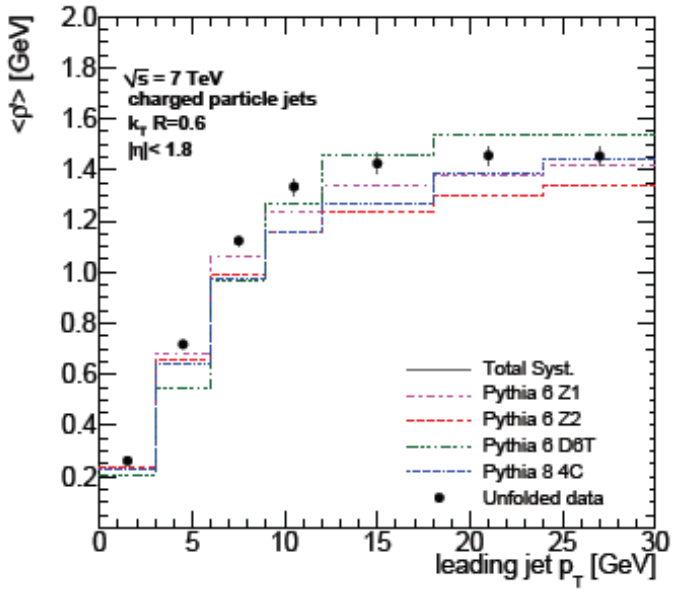
- Unique feature:

  Event based observable, taking into account event geometry to quantify soft charged activity

Results are consistent with other analyses in CMS

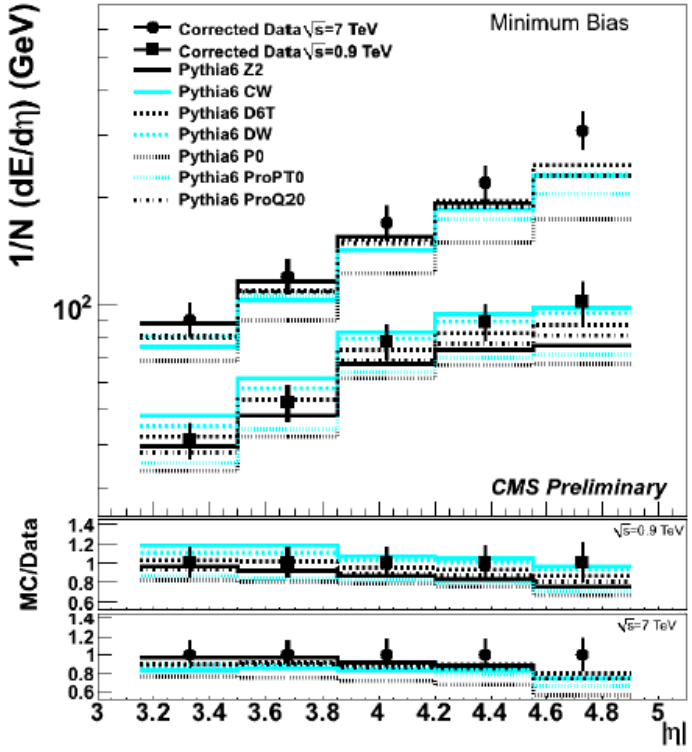
Important study in the light of area based pile-up subtraction

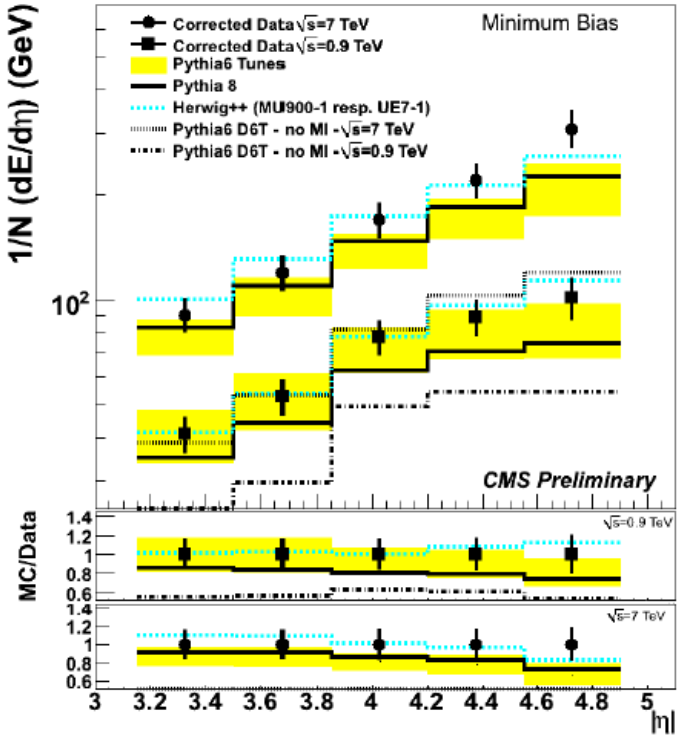




Forward energy flow in the CMS detector

- Energy measurement with forward hadronic calorimeter
- Minimum bias and di-jet events at both center of mass energies
- Corrected data and lots of tunes

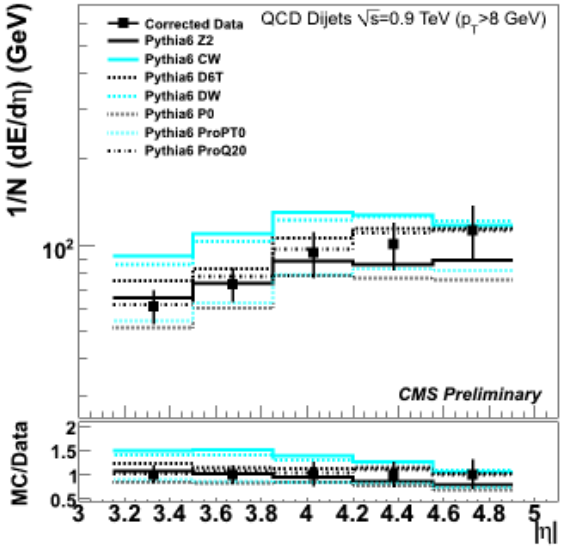


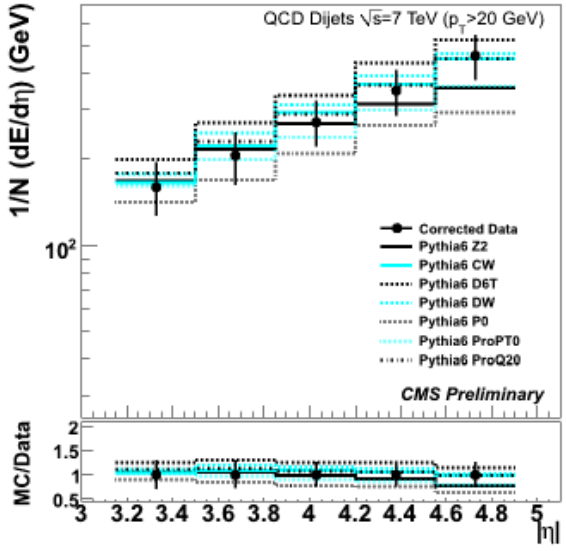


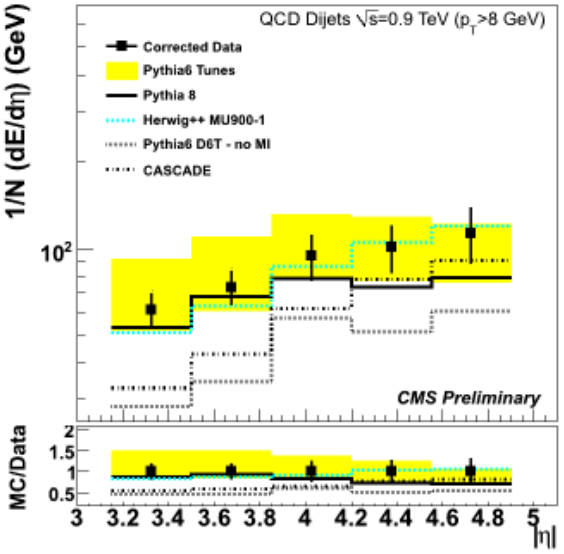
- Unique feature:

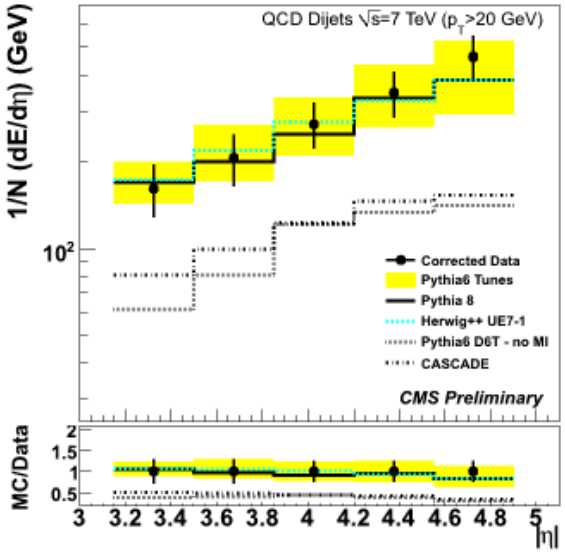
  Investigates geometrical space inaccessible to tracking based analyses

Demonstrates and quantifies scale dependence on forward energy flow









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Summary and Conclusion

- A number of ATLAS and CMS studies investigating the Underlying Event have been presented
- Different approaches, physical objects and detector components have been used to produce a complete picture of UE contributions at the LHC
- New tunes have been produced by both experiments based on these analyses (AMBT and Z1,Z2) that are already widely in use
- The transition from extrapolations to LHC tunes has been made
- Further tuning will be necessary as not all observables are perfectly described yet

Thank you for your attention!

Backup

Underlying Event MC Tuning

- Tuning Monte Carlo generators in an art form
- Dedicated tools such as PROFESSOR and RIVET help with the brute force minimization problems and tests of new tune
- Important parameters include
  - Choice of parton distribution function (PDF)
  - Multi-parton interaction (MPI) model and proton matter distribution
  - Regularization scale for MPI and extrapolation
  - Fragmentation function
  - ….
- A plethora of tunes is available for the different MC generators