Underlying Event with ATLAS

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on behalf of
The ATLAS collaboration

Contents

- What is underlying event and why should you care?
- Leading track measurement
- Event selection
- Track selection
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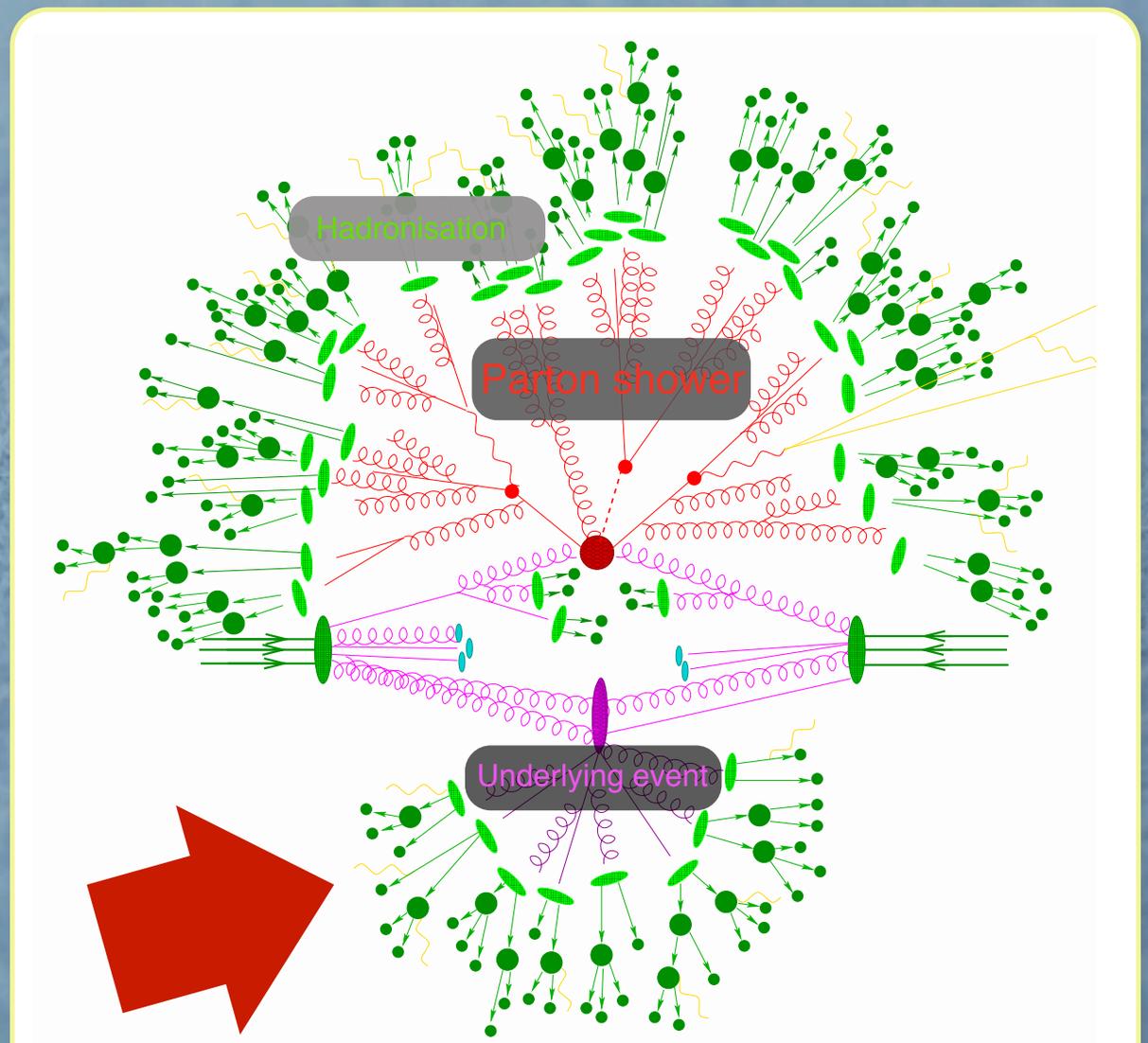
What do we mean by Underlying Event?

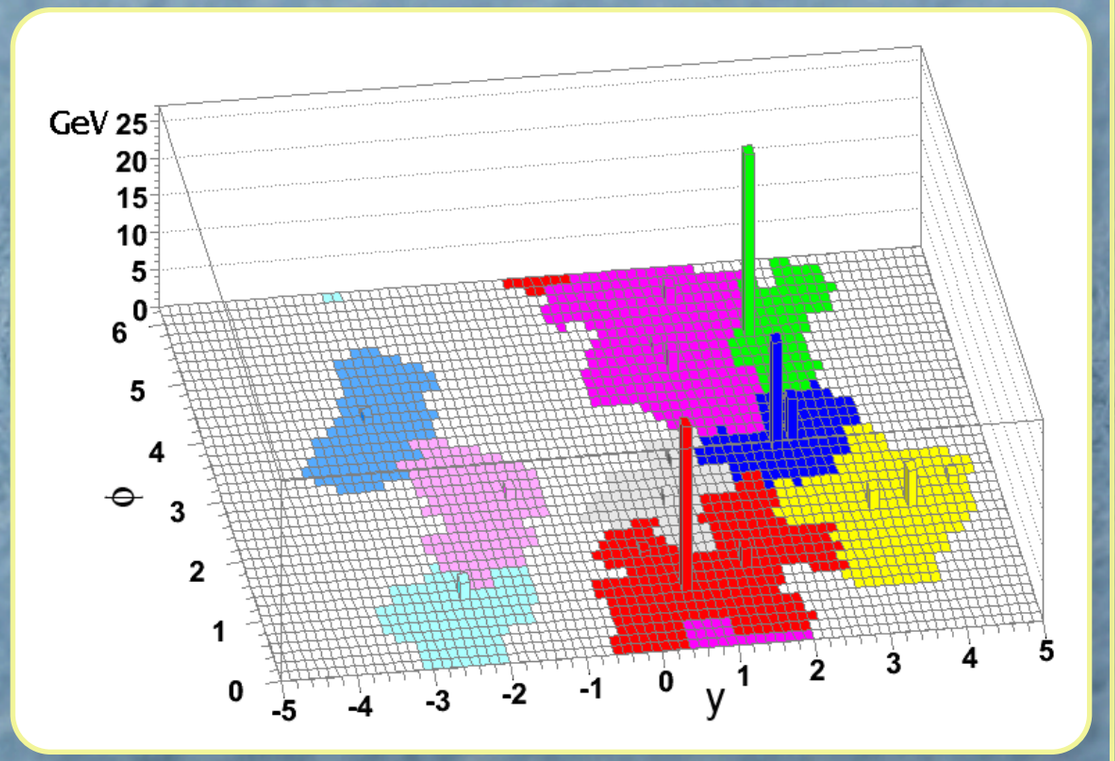
- There is no such thing as underlying event!
- Underlying event is a feature of the *model*
- Describes the softer secondary interactions between the proton remnants
- In the real world(™) it is not possible to separate the underlying event from the effects of showering and hadronisation



Want observables to which the UE model parameters are sensitive...

Why should you care about that?

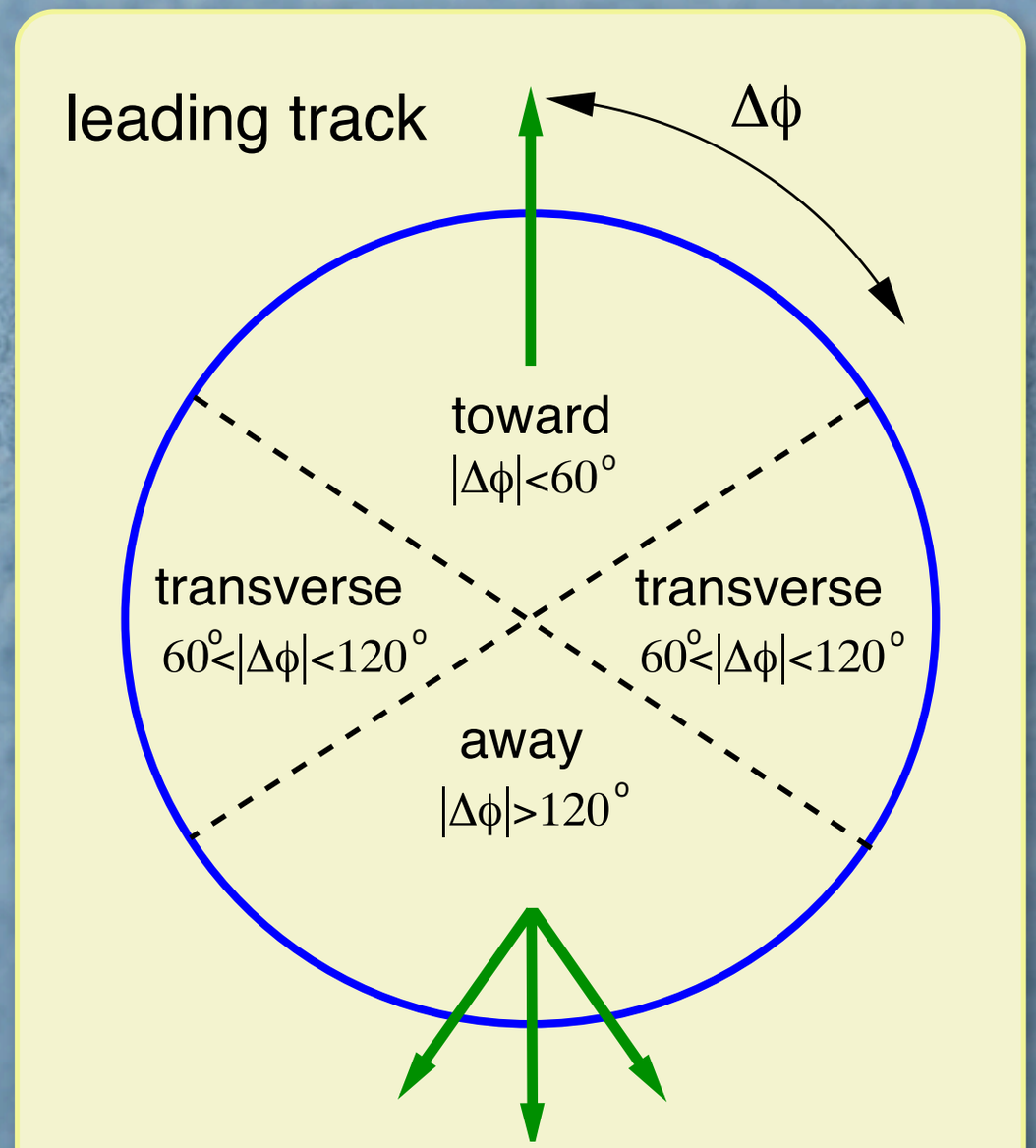
- The models for soft physics *are* our knowledge of non-perturbative QCD
- If the models do not describe features seen in data then *we have no knowledge*.
- It will not be easy to find new physics without knowledge of the bread-and-butter QCD processes that occur during every event.
- Affects jet energies, isolation cones, total cross section, Z pT...



Underlying event and pile-up subtraction based on jet areas (hep-ph: 0802.1188)

Leading Track UE Measurement

- Identify leading track in each event
- Define 3 regions relative to this track:
  - Toward: $|\Delta\phi| < 60^{\circ}$
  - Away: $|\Delta\phi| > 120^{\circ}$
  - Transverse: $60^{\circ} < |\Delta\phi| < 120^{\circ}$
- Determine pT sum, multiplicity, av. pT of tracks and other observables in each region



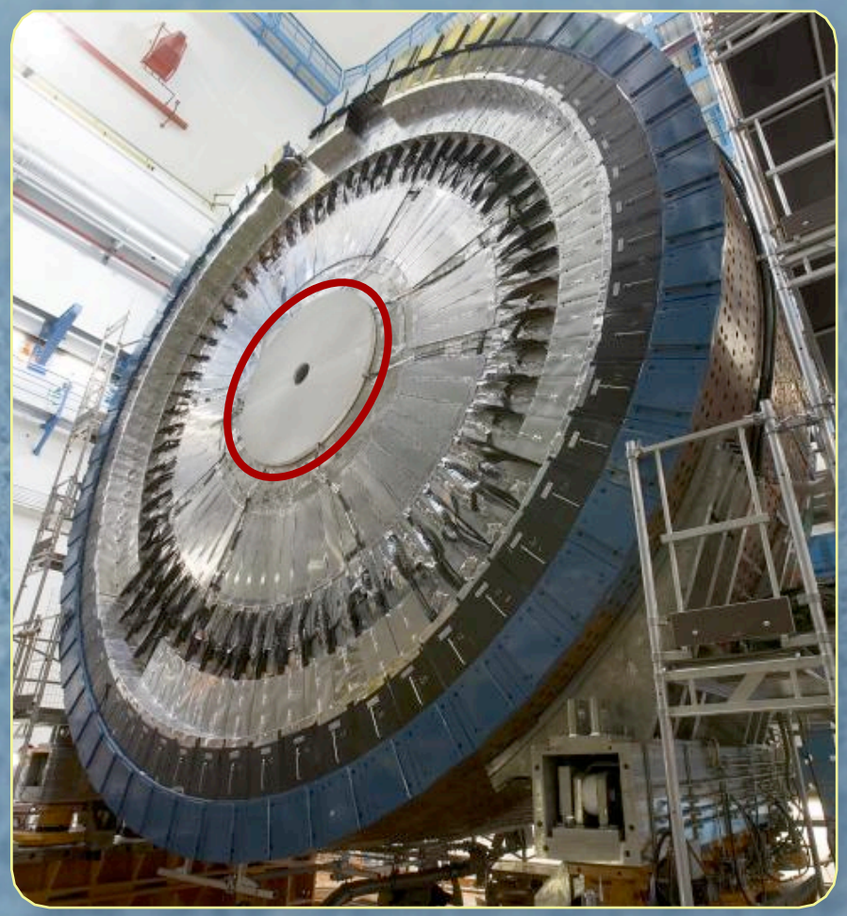
Why leading track analysis?

- The leading track acts as a proxy for the leading jet, and is/was more easily understood in early data
- The hard scatter contributes most to the towards and away regions
- The transverse region is sensitive to the soft non-perturbative effects - underlying event.

Event Selection

- Trigger by requiring that at least one side of the Minimum Bias Trigger Scintillator (MBTS) was active
- Single sided trigger takes more of the total cross section than a two-arm trigger
- A single vertex with >2 tracks (veto pile-up vertices with > 4 tracks)
- Same dataset as the Min Bias analysis

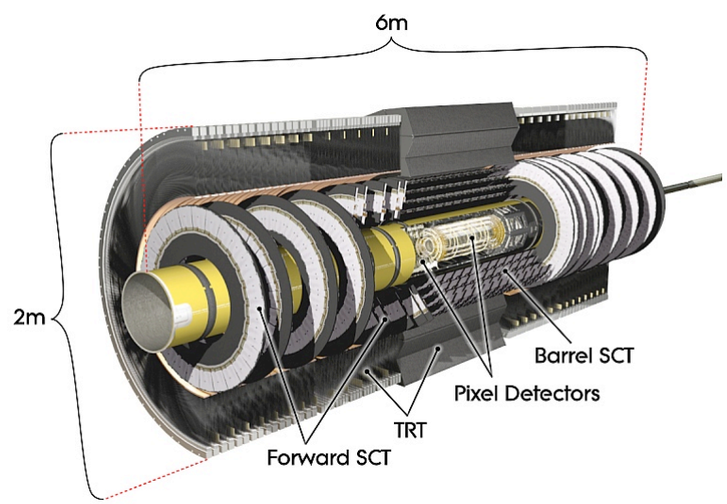
Collision energy	Date	# Events	Luminosity
900 GeV	Dec. 2009	189164	$7\mu b^{-1}$
7 TeV	Mar-Apr.2010	6927129	$168\mu b^{-1}$



MBTS scintillator (highlighted in red) attached to the inside of the endcap calorimeter. Covers $2.1 < \eta < 3.8$

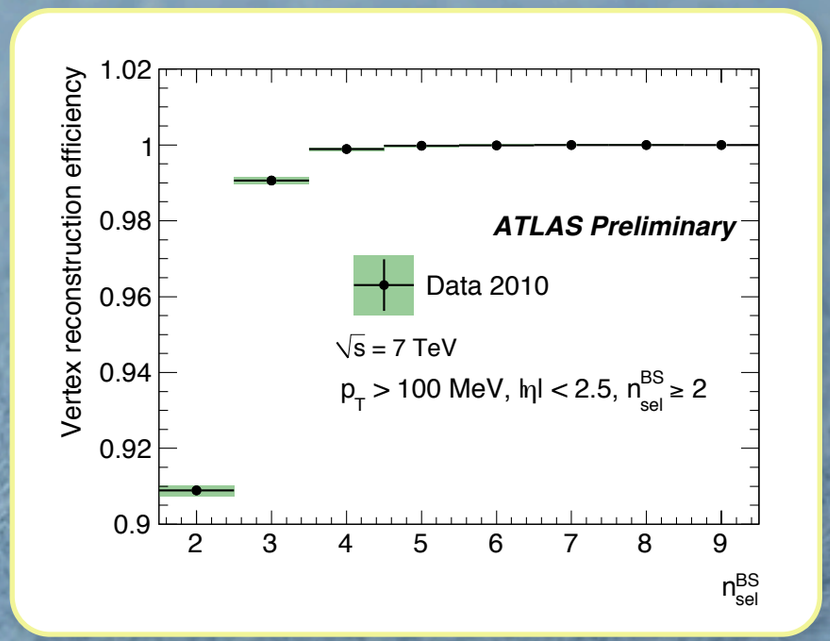
Track Selection

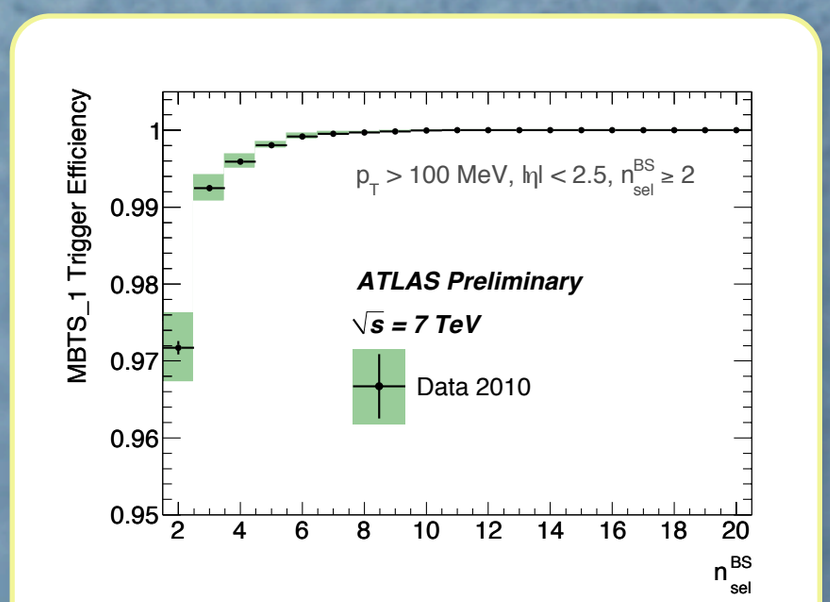
- Charged tracks within $|\eta|<2.5$
- pT > 500 MeV
- At least 1 hit in the pixel detector
- At least 6 hits in the SemiConductor Tracker (SCT)
- Track fit probability > 0.01 for tracks with pT > 10 GeV (eliminate high pT fakes)
- Distance of closest approach in the x-y plane (d0) no greater than 1.5 mm
- Distance of closest approach along beam pipe (z0 $\sin\{\theta\}$) no greater than 1.5 mm
- Lead track pT > 1 GeV



Detector Corrections

- Events are weighted according to the trigger and vertex reconstruction efficiency.
- Individual tracks are given a weight according to the track reconstruction efficiency
- Track reconstruction efficiency also used to estimate the probability that the event was rejected due to missing the lead track > 1 GeV cut



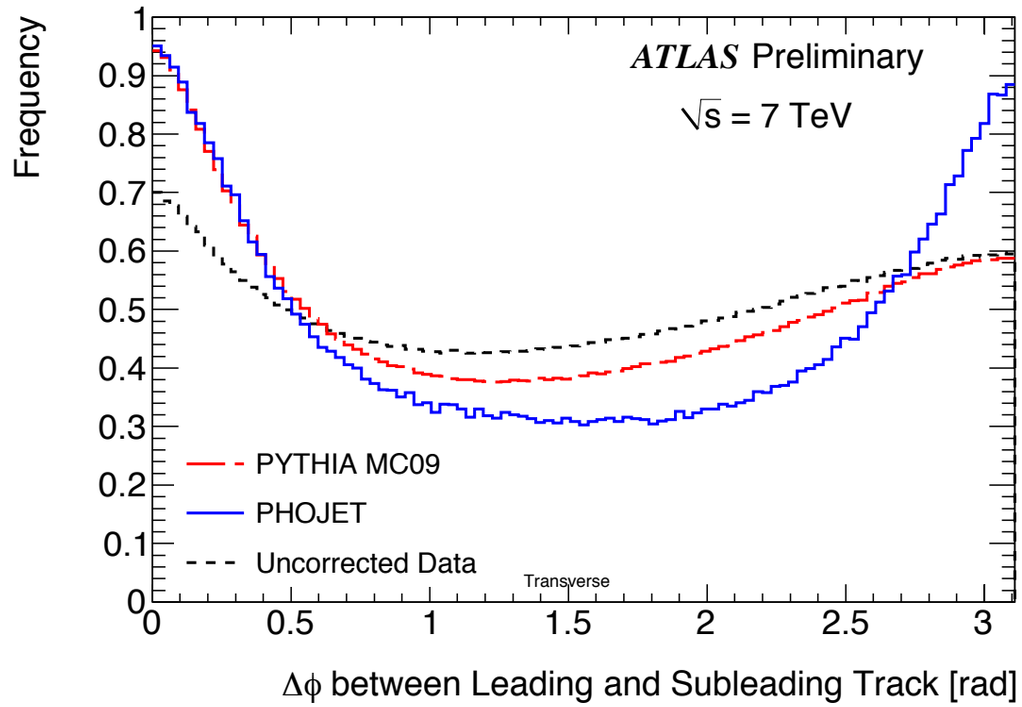


Reorientation and bin-by-bin Correction

- If the lead track is mis-reconstructed then the next-to-leading track defines the towards direction

- Complete reorientation of the event!

- This effect, as well as additional possible migrations between neighbouring bins in the final observable, is corrected for bin-by-bin



Correction factor for the ith bin:

$$C_i = T_i / D_i$$

where

T_i = truth level

D_i = detector full simulation

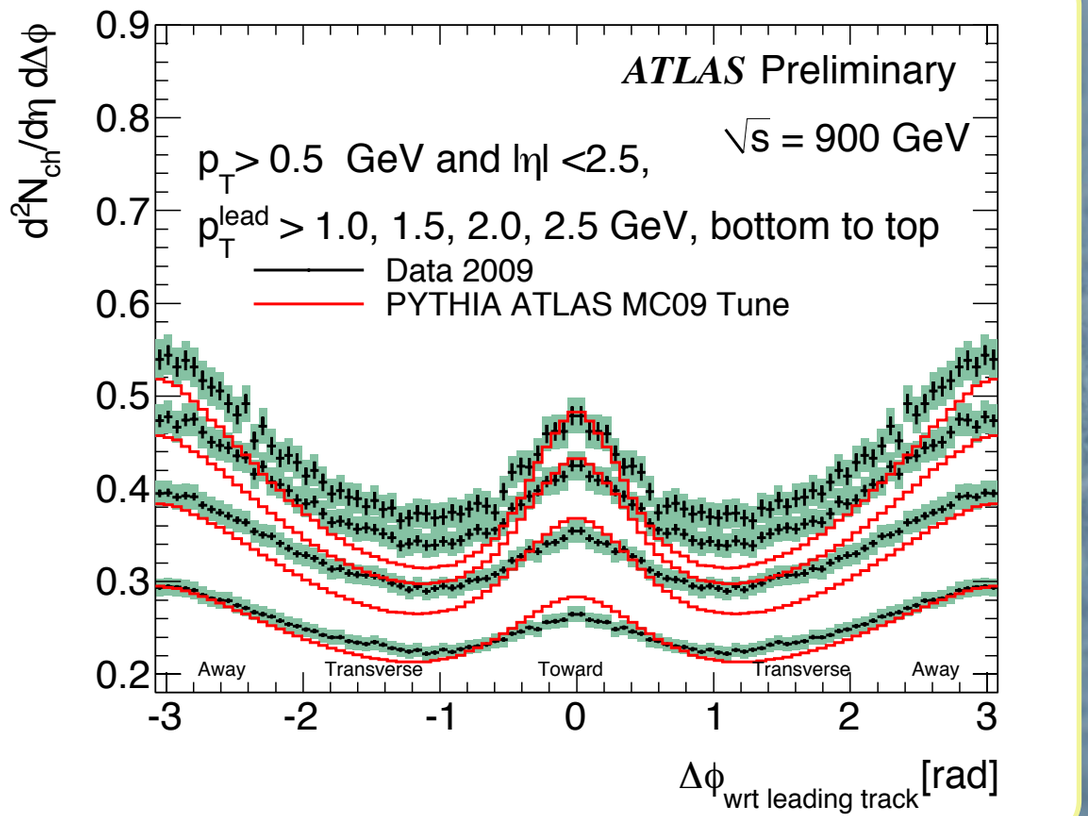
Pre-LHC Monte Carlo Models

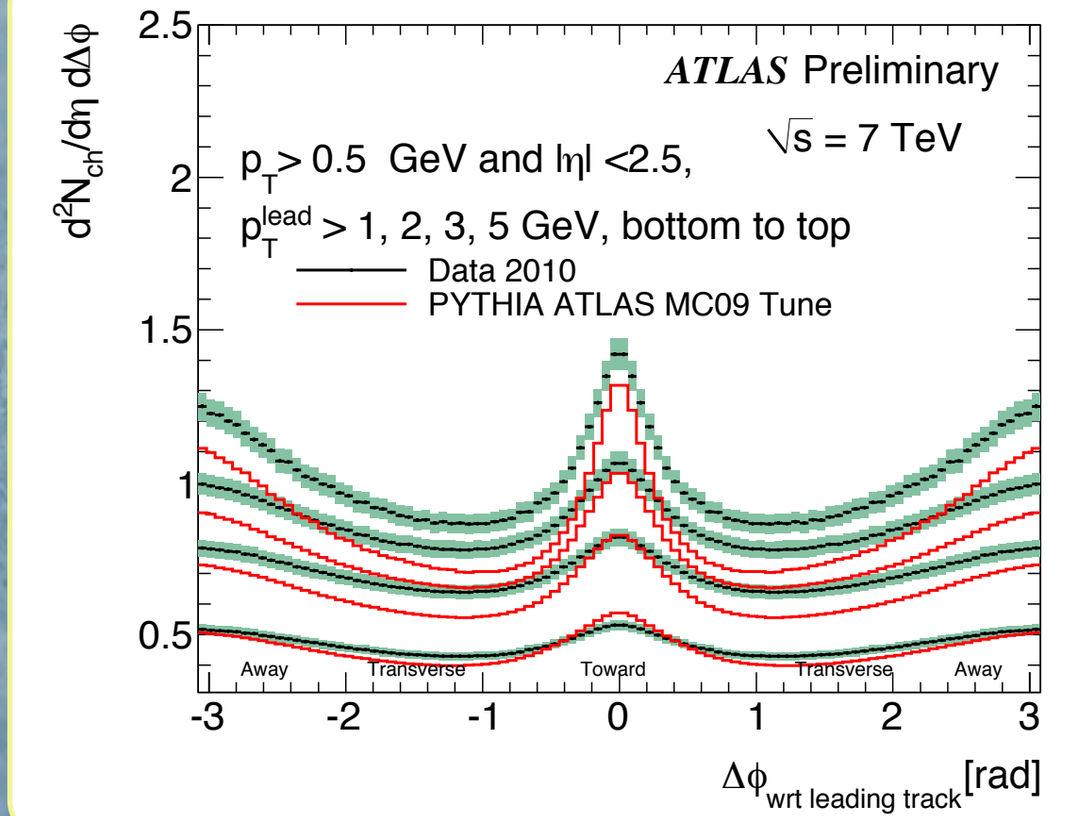
- Pythia MC09: ATLAS tune of fortran Pythia using the newer pT ordered shower and interleaved ISR+MPI with MRST LO* PDF
- Pythia Perugia0: Peter Skands' tune of fortran Pythia. Also uses the newer shower + MPI model. Tuned to Tevatron and SPS min bias data using CTEQ 5L PDF.
- Pythia DW: Quite old tune of fortran Pythia by Rick Field. Uses the old virtuality ordered shower in which the MPI is independent of ISR. Tuned to Tevatron UE and Drell-Yan data. Also uses CTEQ 5L.
- Herwig + Jimmy: Jimmy provides an underlying event model to the fortran version of Herwig. ATLAS uses MRST LO* PDF.
- Phojet: Provides a min bias model using colour singlet exchange for non-perturbative interactions. Double diffractive, single diffractive and non-diffractive processes.

The Results

Full set of plots at http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-081/

Track densities Vs. ϕ





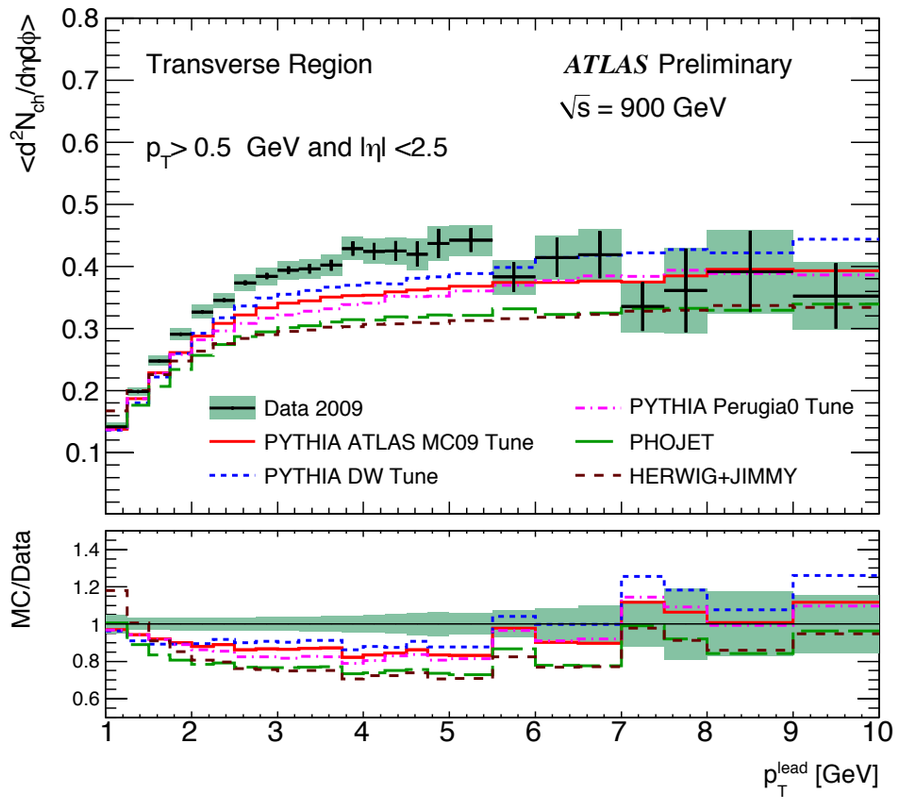
Shows position of all tracks w.r.t leading track in the event

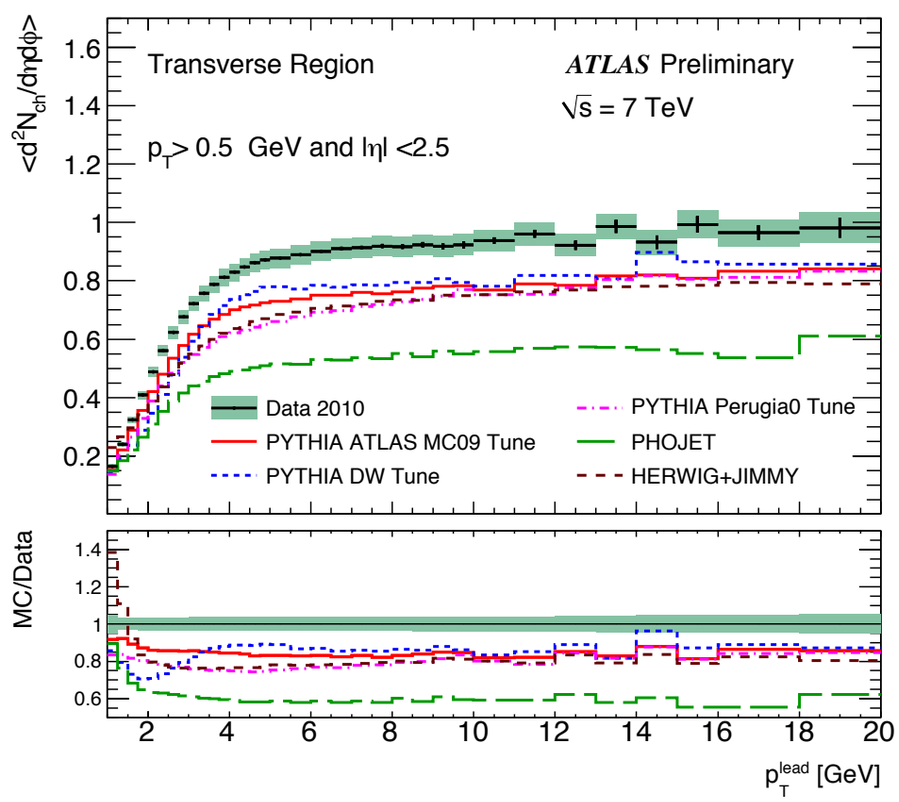
Leading track left out in order to avoid large peak at 0

As pT of lead track is increased see increased activity in toward and away region

Emergence of di-jets

Multiplicities in the Transverse Region

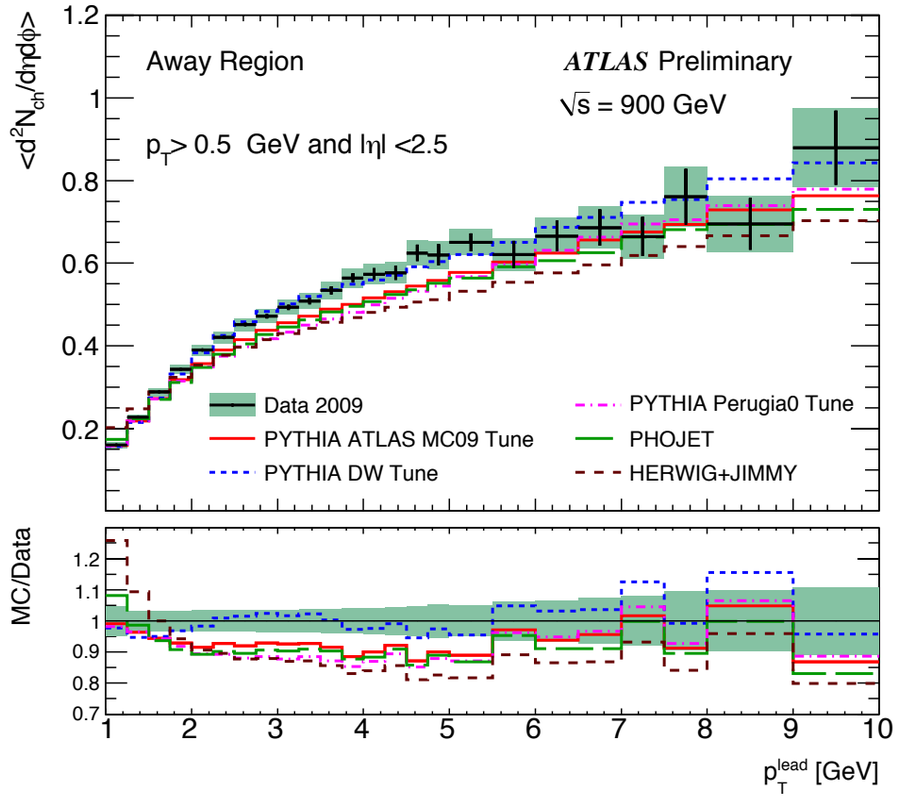


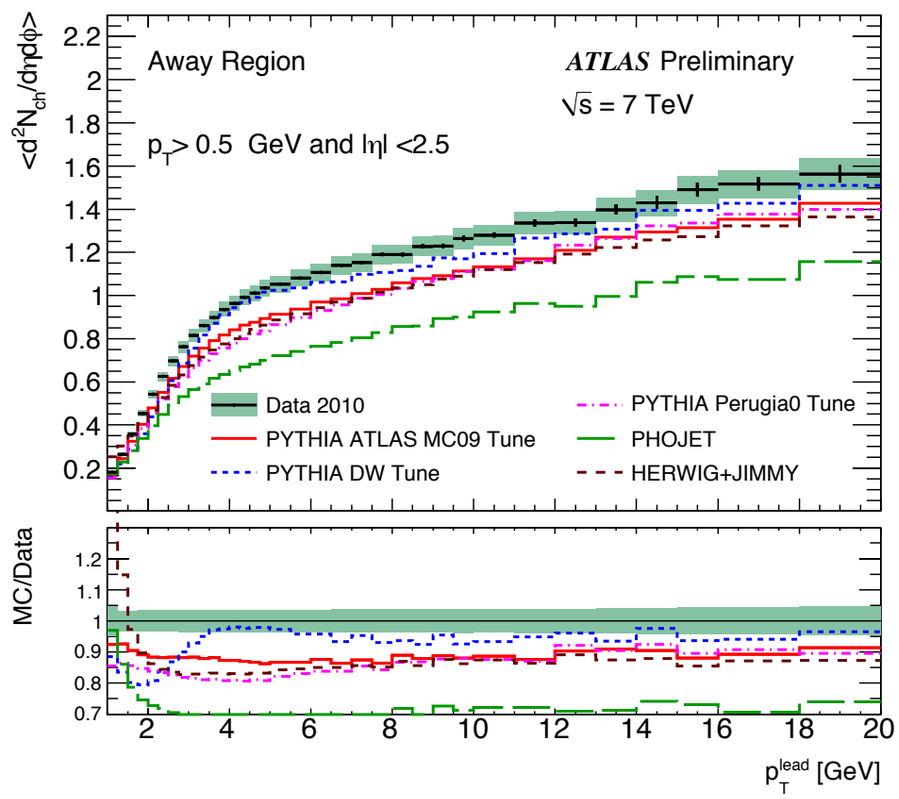


Approx. 10% more particles than Monte Carlo

Underlying event more active than in pre-LHC prediction

Multiplicities in the Away Region

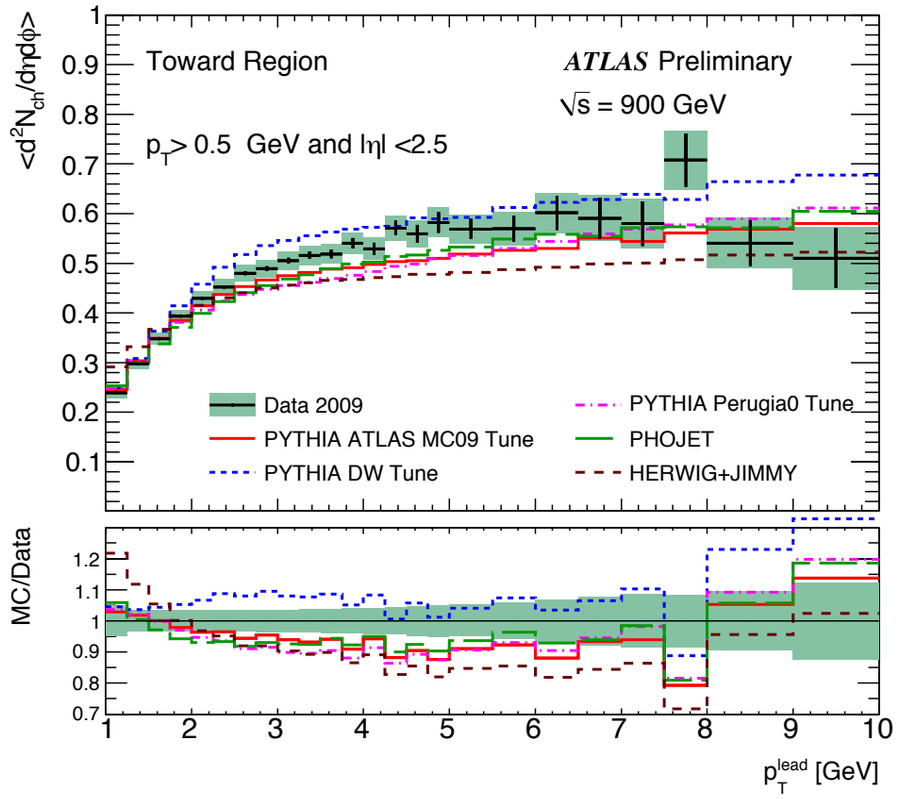


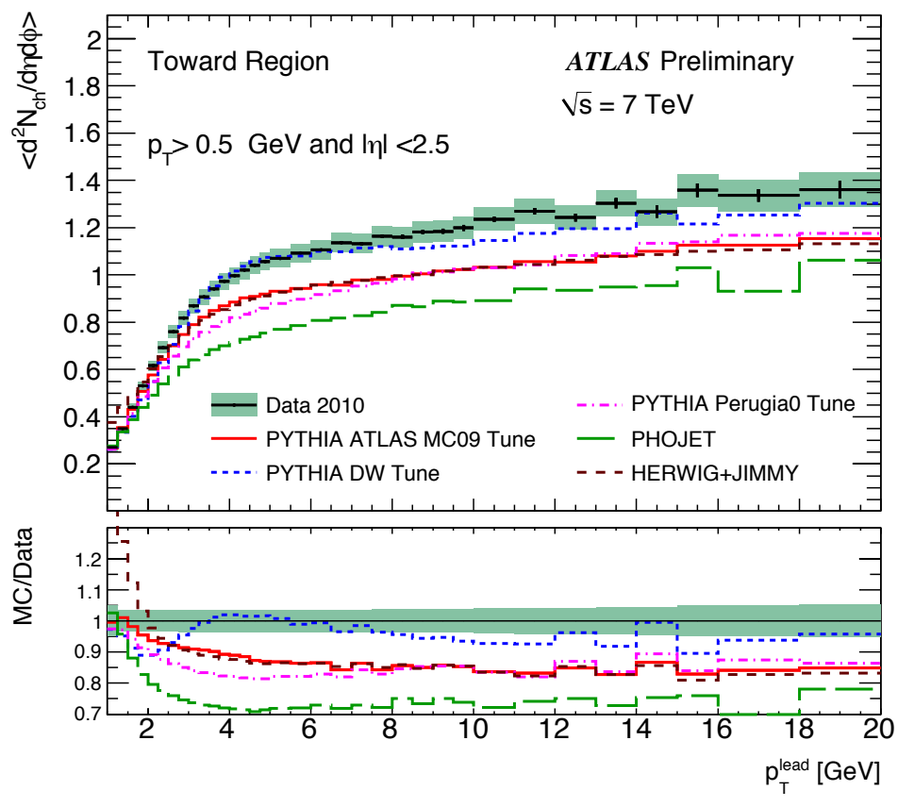


Agreement between MC and data is better than the transverse region

Prediction of emergence of jets better than UE prediction

Multiplicities in the Toward Region





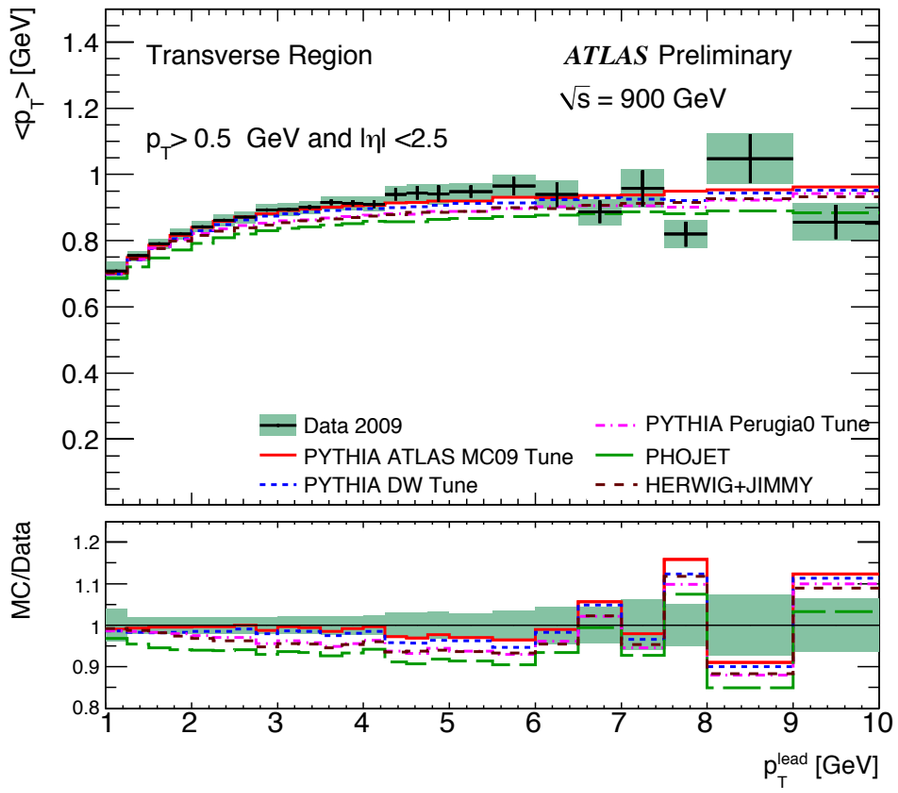
Agreement between MC and data is better than the transverse region

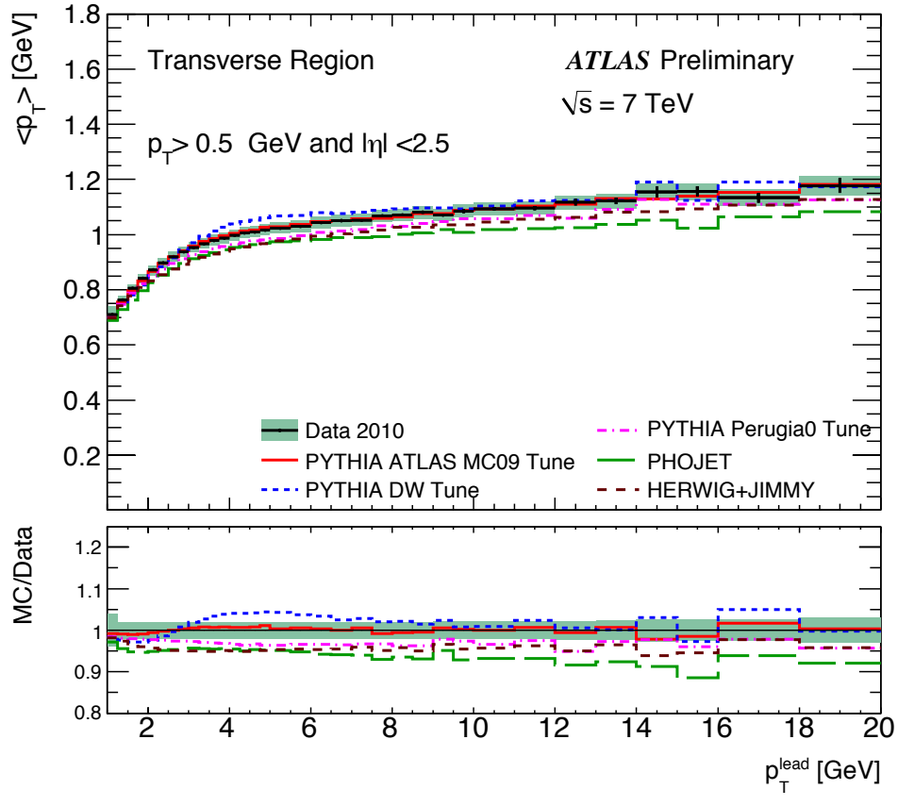
Prediction of emergence of jets better than UE prediction

Comments on Multiplicities

- In all three regions the multiplicity saturates as the lead pT is increased - do not get *more* particles, but *more energetic* particles.
- Tune DW produces the most activity and is closest to data in all three regions.
- None of the models produces enough transverse activity; UE description not perfect.
- Phojet's model does not produce enough jet-like (towards/away) or UE activity (transverse).

Av. pT / track in the Transverse Region

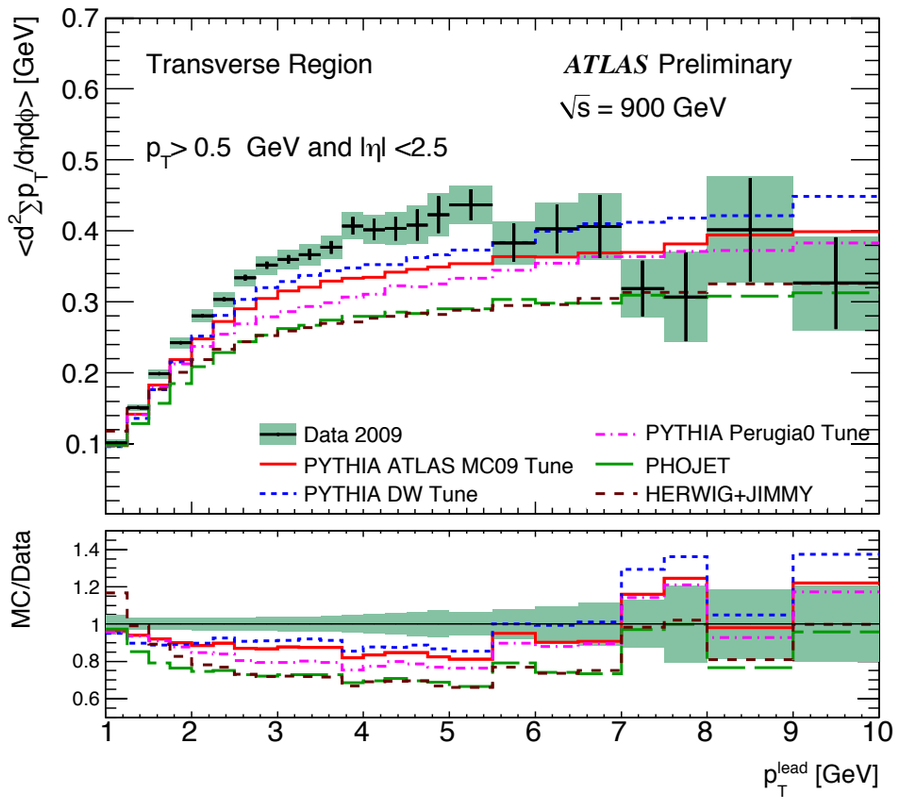


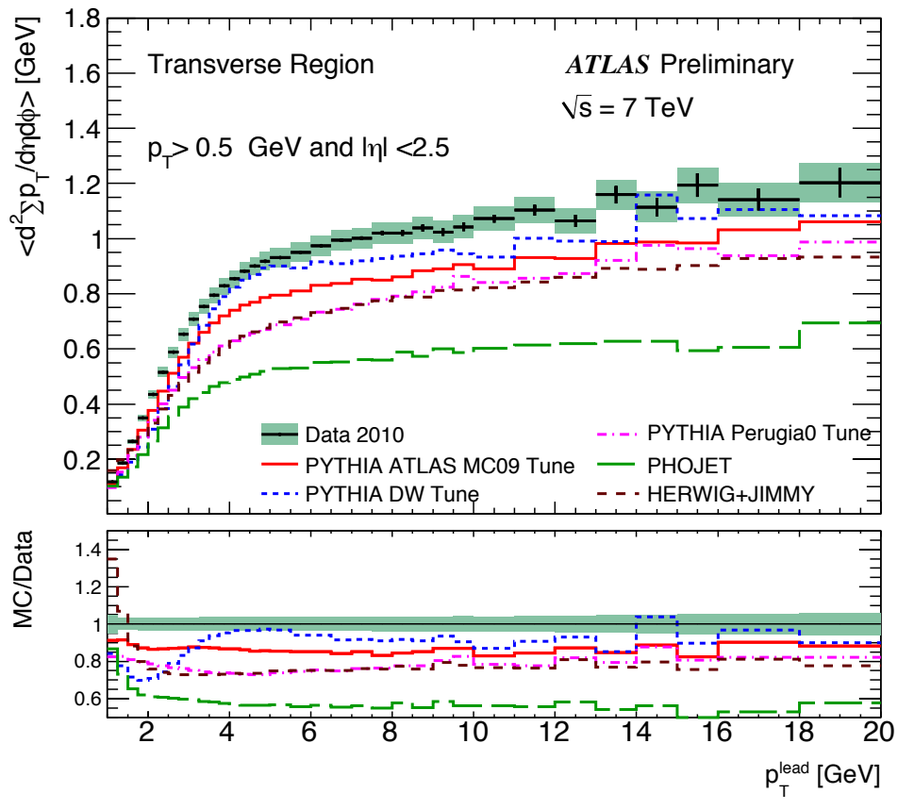


MC in better agreement with data this time

Prediction is underestimating *number* of particles, not so much their pT

PT sum in the Transverse Region

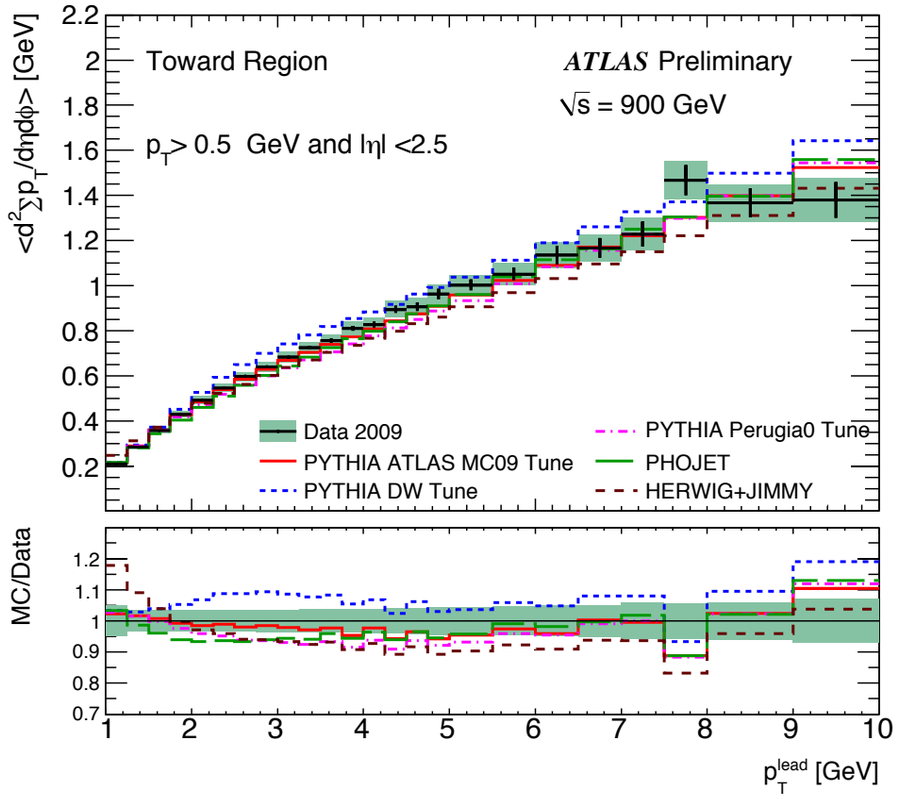


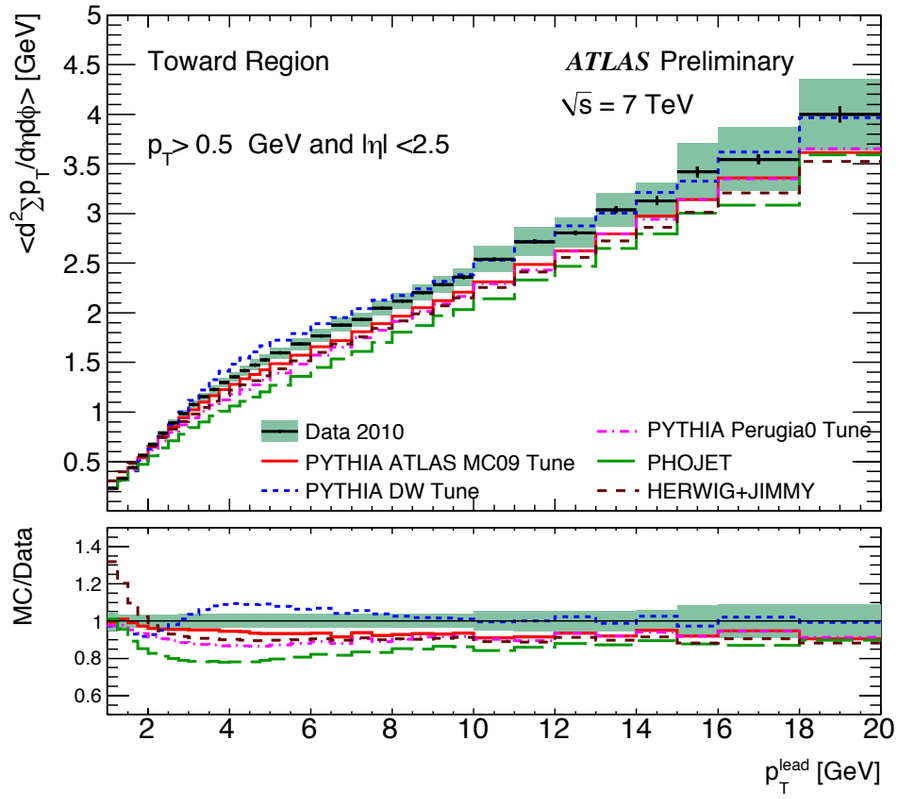


MC still undershoots data

We already saw that the predictions didn't have enough activity in the transverse region

PT sum in the Towards Region

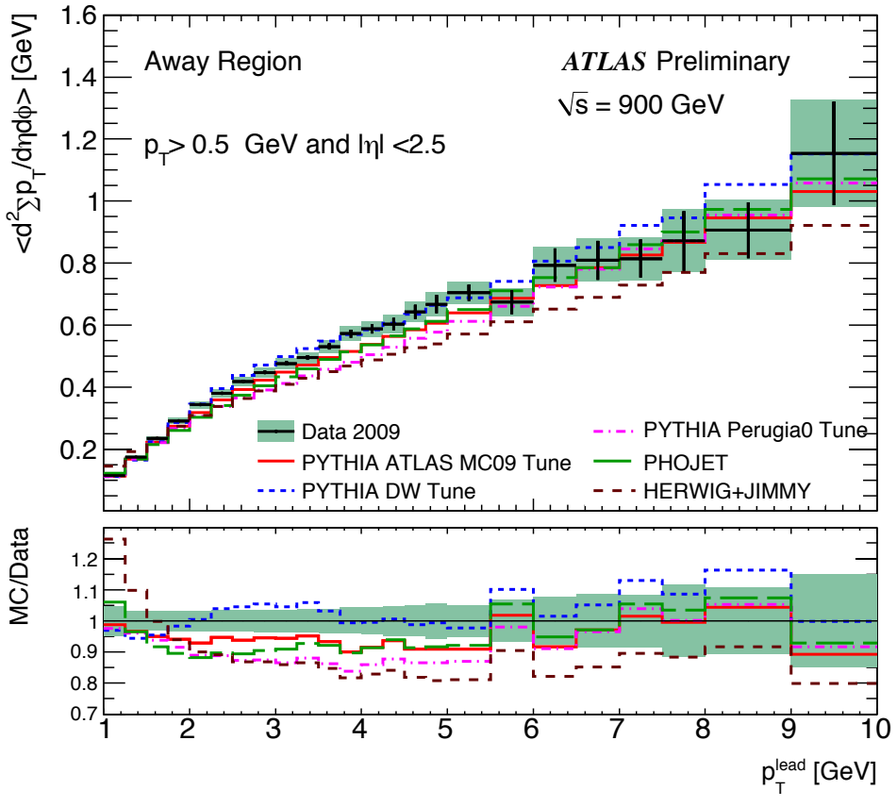


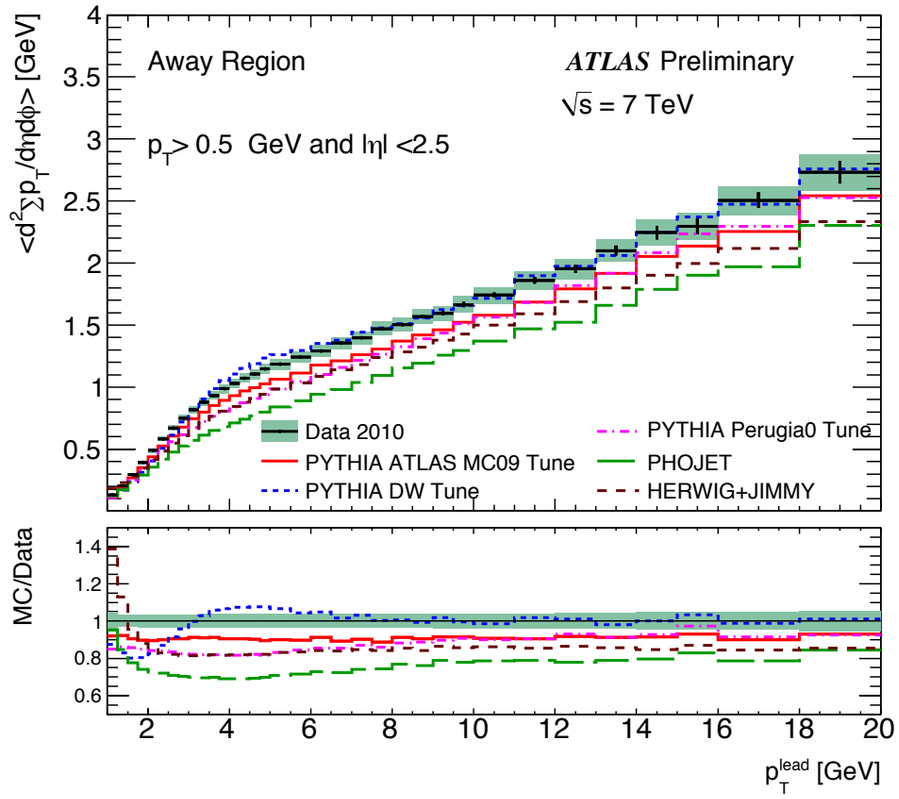


MC in better agreement with data than in transverse region

DW is the only model to (slightly) overestimate the data

PT sum in the Away Region





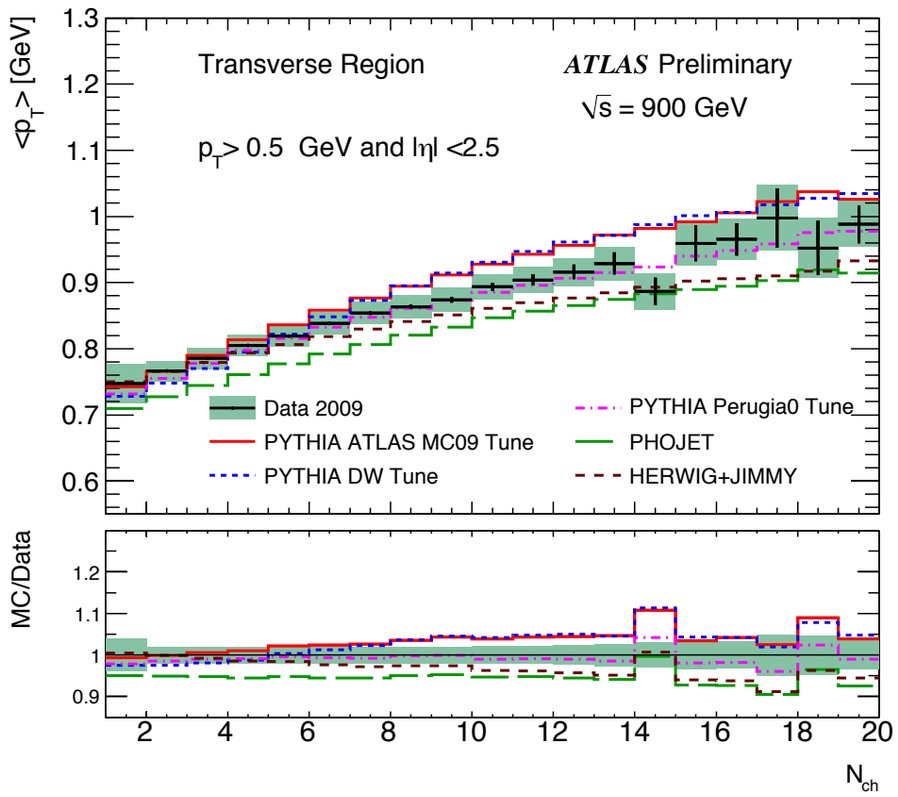
MC in better agreement with data than in transverse region

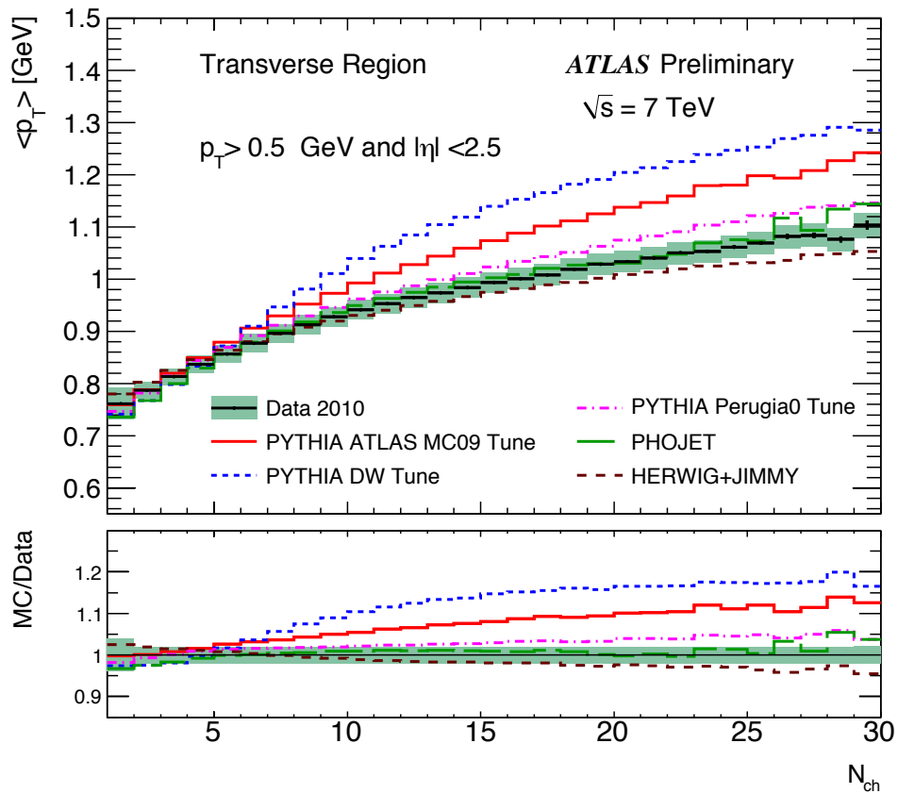
DW is the only model to (slightly) overestimate the data

Comments on pT Sums

- MC predictions of pT sum in the transverse region an underestimate because of too-low particle production.
- Av. pT/particle is not so bad.
- Description of activity in the towards region is better than the other regions - leading jet.

Av. pT in Multiplicity Bins - Transverse Region





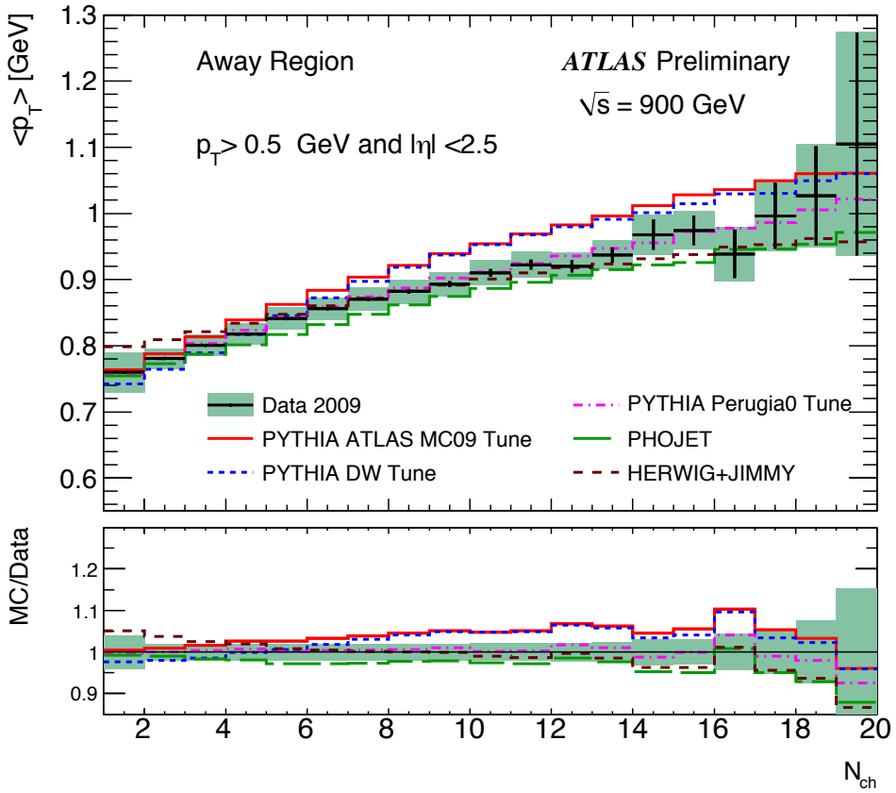
MC brackets data

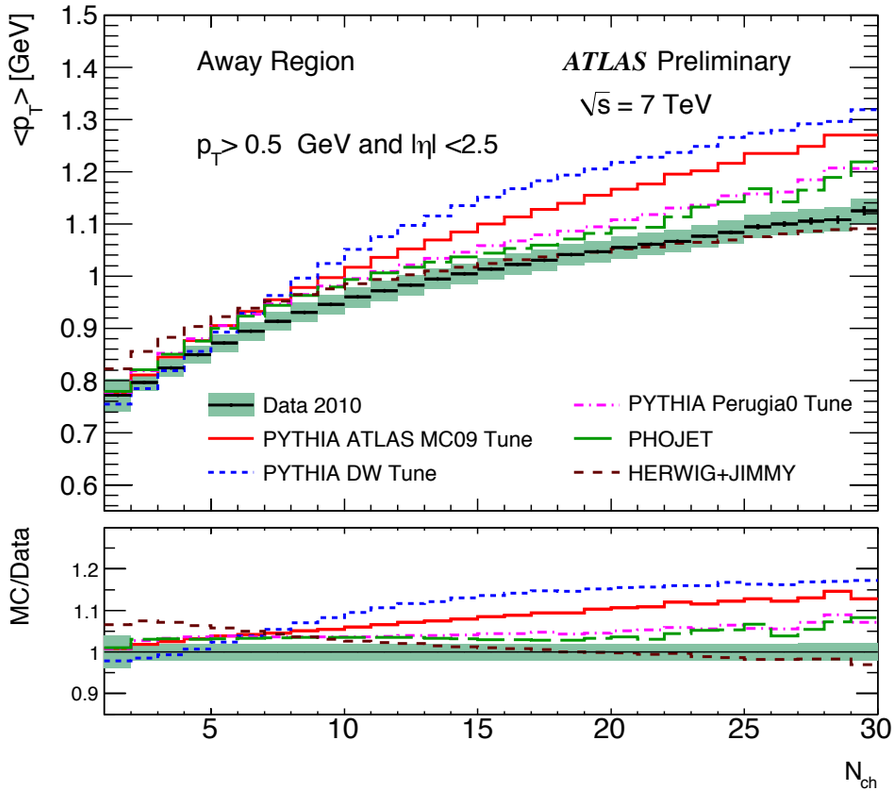
Pythia overshoots, Herwig undershoots

Different hadronisation models.

DW the worst (but provided the best transverse and away pT sum)

Av. pT in Multiplicity Bins - Away Region



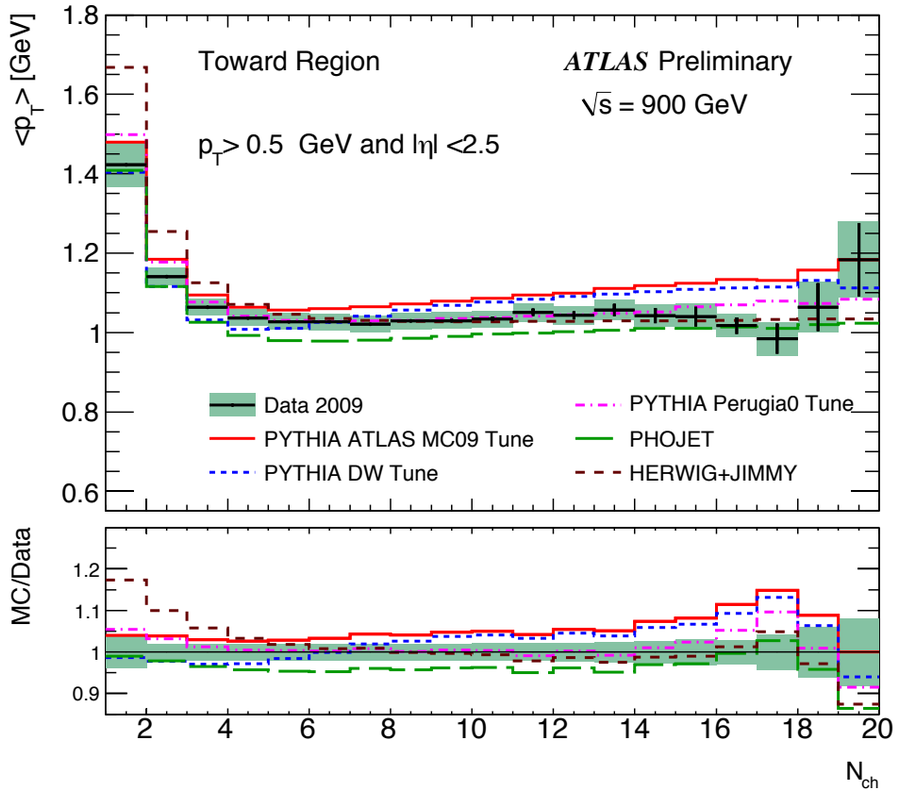


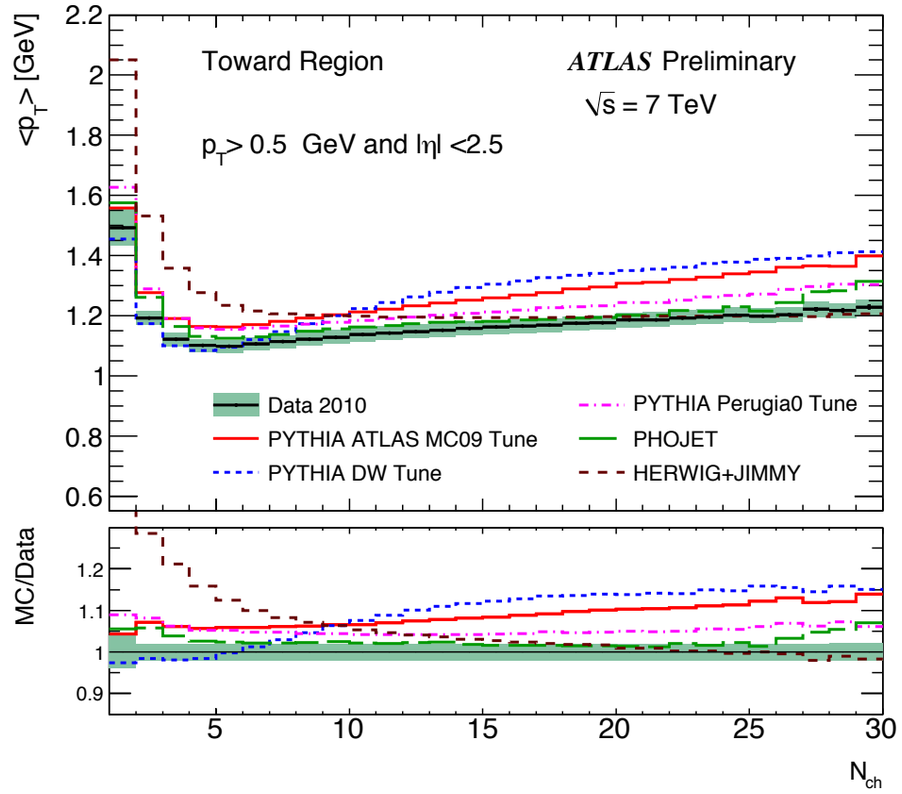
MC tends to overshoot data. Pythia generally more so than Herwig

Different hadronisation models.

Similar to transverse region

Av. pT in Multiplicity Bins - Towards Region





Even Herwig overshoots data over a lot of the range

Spike at Nch=1 because leading track is *included* (more energetic lead track if there are no splittings and Nch=1)

Summary

- Underlying event is important for our understanding of QCD and ultimately for our ability to make measurements at hadron colliders.
- Underlying event analysis in the towards/away/transverse region was performed using charged tracks in both 900 GeV and 7 TeV proton collisions.
- None of the pre-LHC tunes are a good fit to the data. They generally produce too little UE activity
- On the other hand, at a given particle multiplicity tend to produce too much pT per particle.
- These results provide an important input to future improvements in our descriptions of QCD.