Argonne NATIONAL LABORATORY

Measurements of Underlying Event at ATLAS

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for the ATLAS collaboration

ATLAS EXPERIMENT

4th Meeting of the LHC WG on MB&UE

U.S. DEPARTMENT OF ENERGY

Introduction

- Underlying event (UE) consists of
  - Beam-beam remnants
  - Possible multiple parton interactions
  - … …
- Measurements of UE
  - Better tunes of models
  - Important input for hard process measurements (jet, etc)
- ATLAS results in this talk
  - with Charged tracks with low P_T cut (100MeV)

    Accepted by Phys. Rev. D, http://arxiv.org/abs/1012.0791

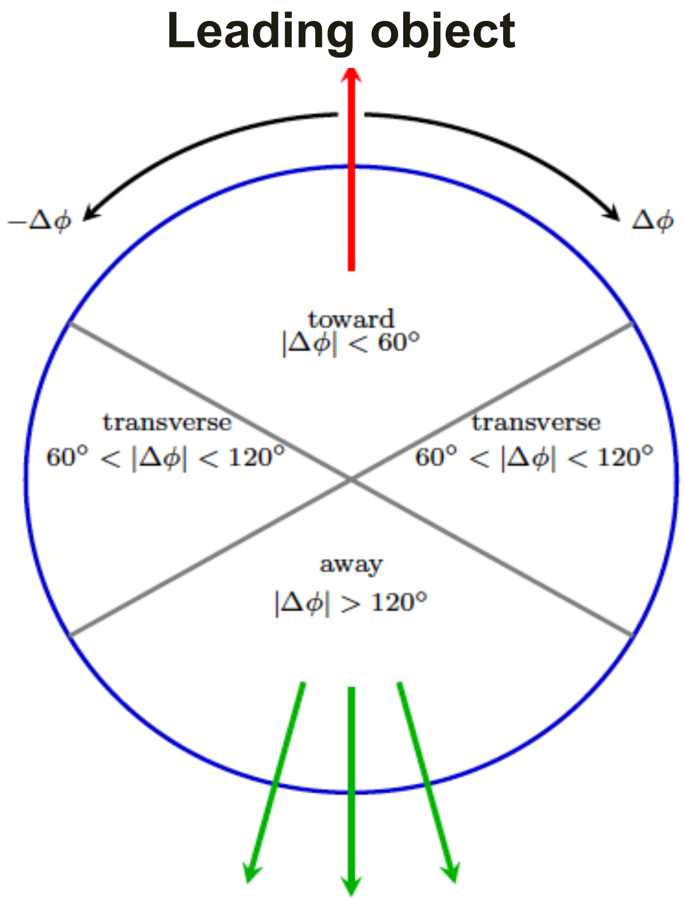
    HEPDATA: http://hepdata.cedar.ac.uk/view/p7919
  - with Calorimeter clusters

    Publication soon

Data Samples

- **Data**
  - 900 GeV stable beam data in 2009; ~7 μb^{-1}
  - 7 TeV stable beam data in 2010;
    - ~ 168 μb^{-1} for track based analysis
    - ~ 238 μb^{-1} for cluster based analysis
- **MC samples with different tunes**
  - PYTHIA ATLAS MC 09
  - PYTHIA Perugia0
  - PYTHIA DW
  - PHOJET
  - HERWIG+JIMMY ATLAS MC 09

UE Observables



Using leading object (track, cluster, jet, etc) to define regions: toward, away and transverse

- <N> vs. $\Delta\phi$
- <N> vs. P_T^{lead}
- <N> vs. η^{lead}
- ΣP_T vs. P_T^{lead}
- … …

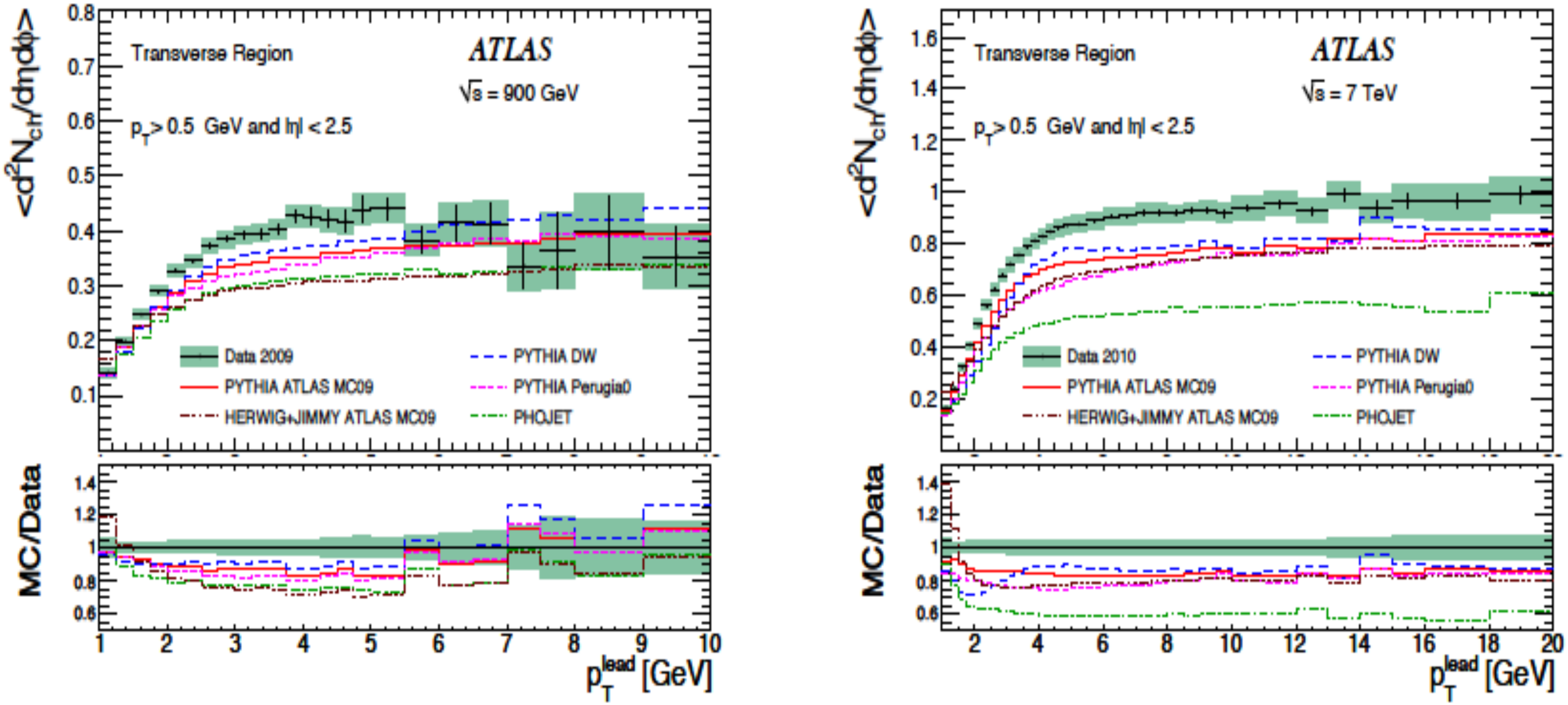
Selection for Track Based Analysis

- **L1_MBTS_1 trigger**
- **Reconstructed primary vertex**
- **No second vertex with more than 3 tracks**
- **At least 2 selected tracks**
- **Track quality**
  - $P_T > 500$ MeV or 100 MeV
  - $|\eta| < 2.5$
  - $|d_0| < 1.5$ mm, $|z_0 \sin\theta| < 1.5$ mm
  - Silicon hit requirement according to P_T

Correction Procedure

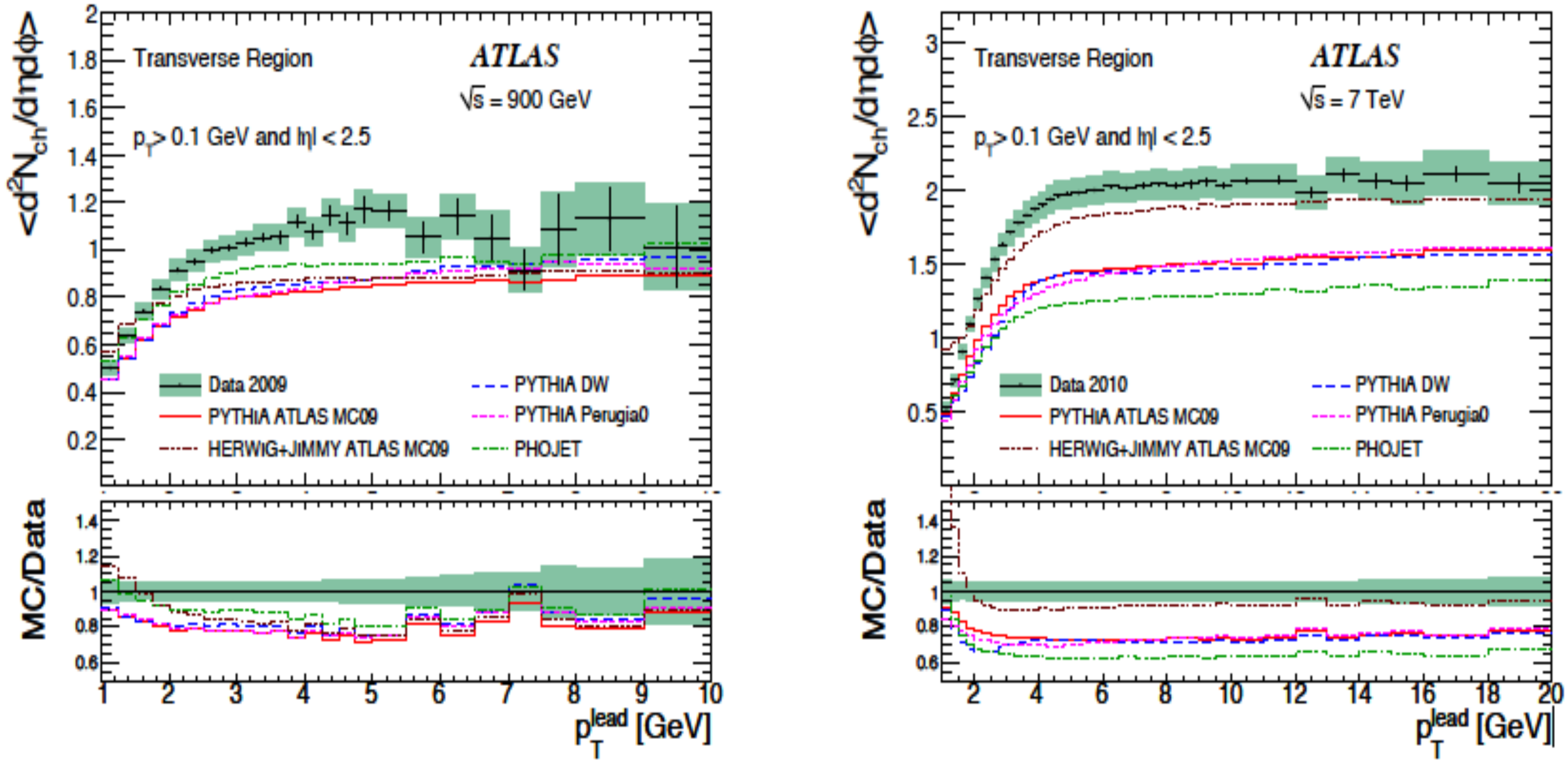
- The distributions are corrected back to the hadron level and compared with MC generators
- Event level corrections
  - Trigger inefficiency
  - Vertex inefficiency
  - No particle with P_T > 1.0 GeV reconstructed
- Track level corrections
  - Tracking efficiency
  - Non-primaries
  - Outside kinematic range
- Unfolding factor
  - Bin migrations

Particle Density vs. P_T^{lead} (P_T>500 MeV)



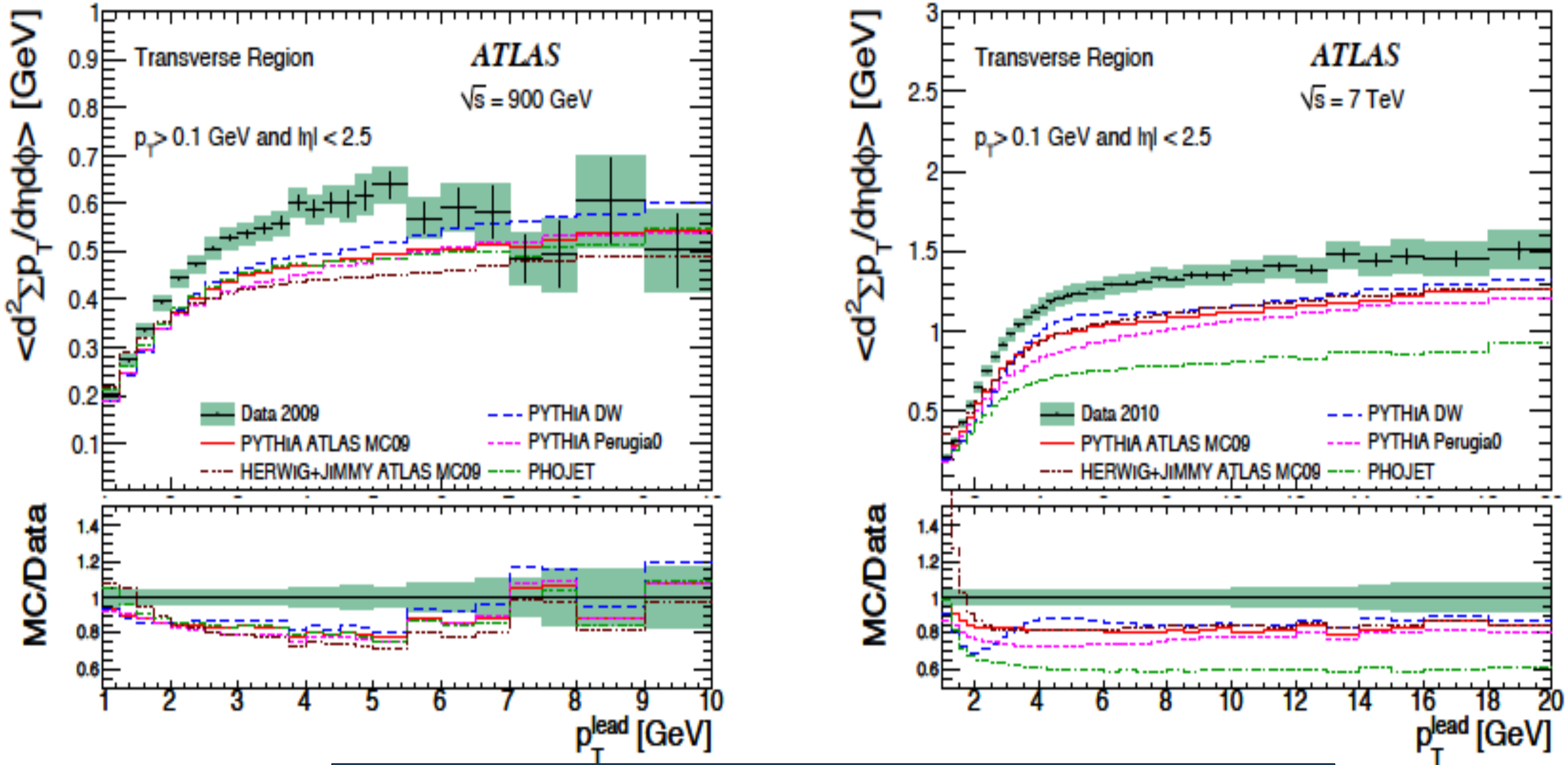
Lower particle density in MC tunes
Larger discrepancies at 7 TeV (PHOJET worst)

Particle Density vs. P_T^{lead}



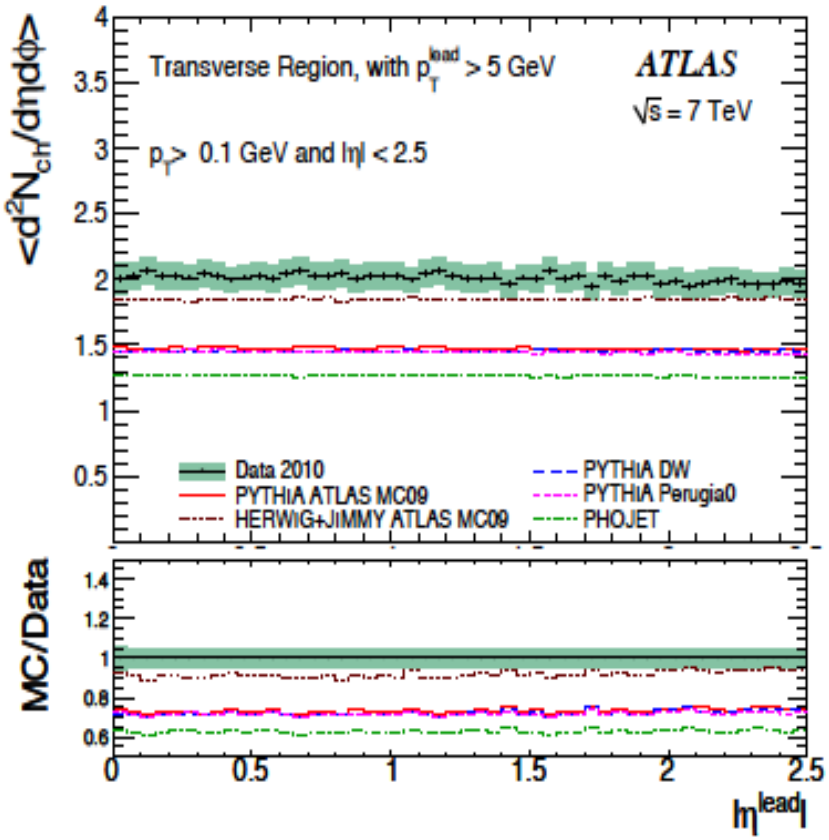
Particle density increases by a factor of ~2 but
The conclusion is the same

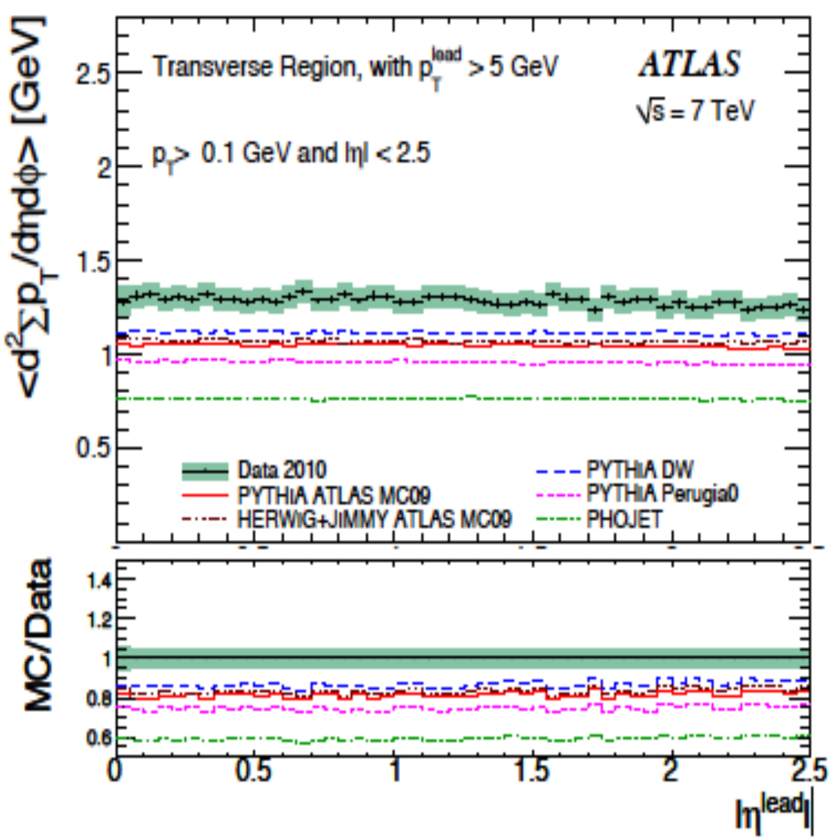
Scalar ΣP_T vs. P_T^{lead}



Lower particle ΣP_T in MC tunes
Larger discrepancies at 7 TeV (PHOJET worst)

Particle Density, Scalar ΣP_T vs. η^{lead}





Lower particle activities in MC tunes
Particle density & scalar ΣP_T independent of η^{lead}

UE with Calorimeter Clusters

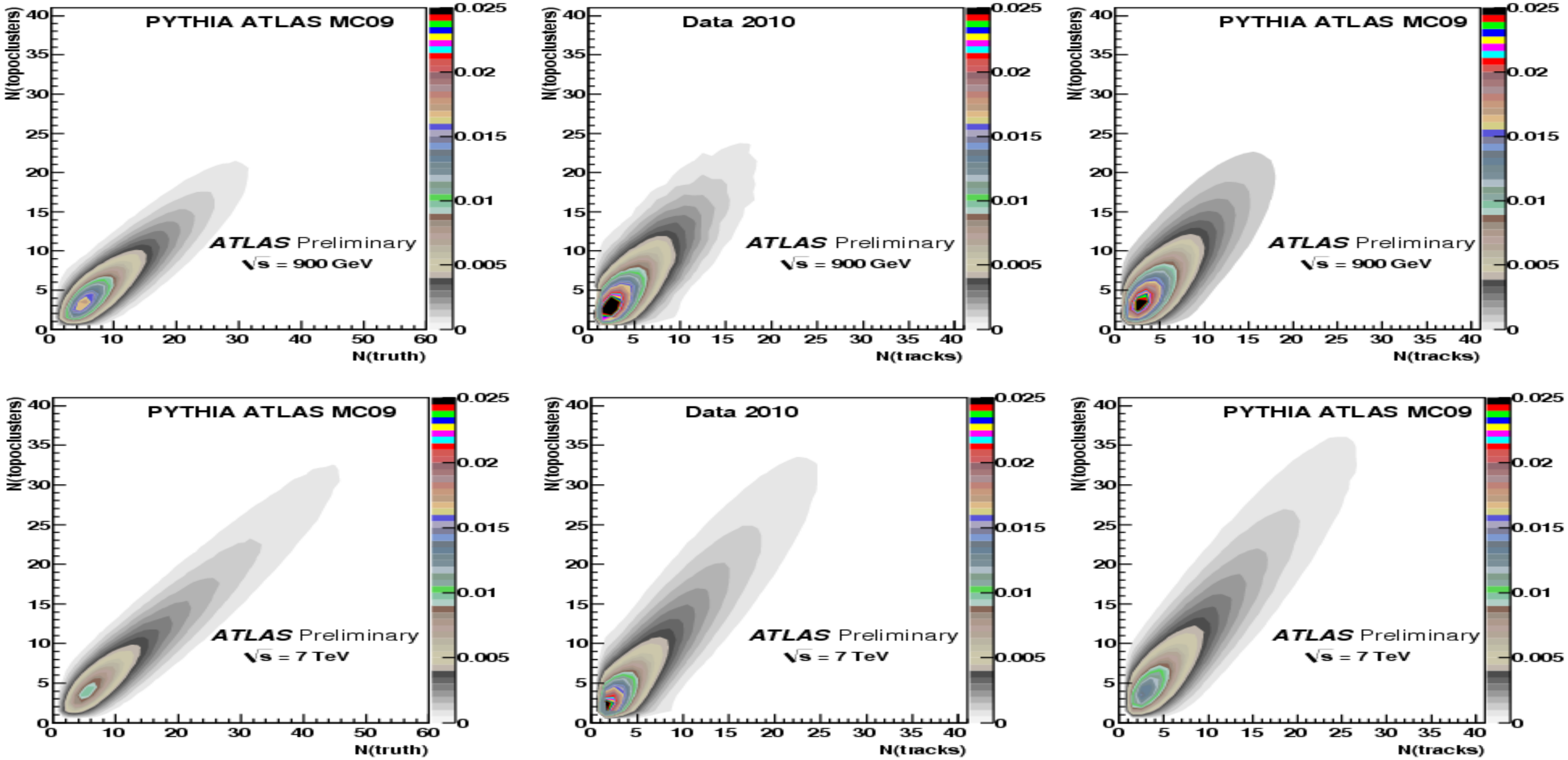
- Measurements using calorimeters
  - Sensitive to a complete final state including neutrals (extra ~40%)
  - Useful for many high precision jet measurements based on energy deposition
- Taking advantage of the ATLAS calorimeters
  - 175k channels for electromagnetic, 20k channels for hadronic calorimeter
  - Excellent transverse sampling and longitudinal sampling allowing the reconstruction of topological clusters (Topocluster) in 3D closely related to single particles
    - Built from calorimeter cells
    - Follow shower development
    - Reduce noise and pileup effects
    - Used for jet reconstruction

Selection for Cluster Based Analysis

- Same trigger requirement as track based
- Same vertex requirement as track based
- Topocluster quality
  - Clustering method (4-2-0)
    - Seeded by cells with |E| > 4 x (noise level)
    - Neighboring cells with |E| > 2 x (noise level) iteratively added (in 3D)
    - All neighbors around cluster with |E| > 0 added
  - Hadronic calibration
  - Energy scale measured with E/p and π^0 mass
  - $|\eta| < 2.5$
  - $P_T > 500$ MeV
  - Cluster cleaning
    - Leading cell energy < 90%
    - Energy sampling max not in region without good calibration
    - Fraction of energy associated with problematic cells < 50%

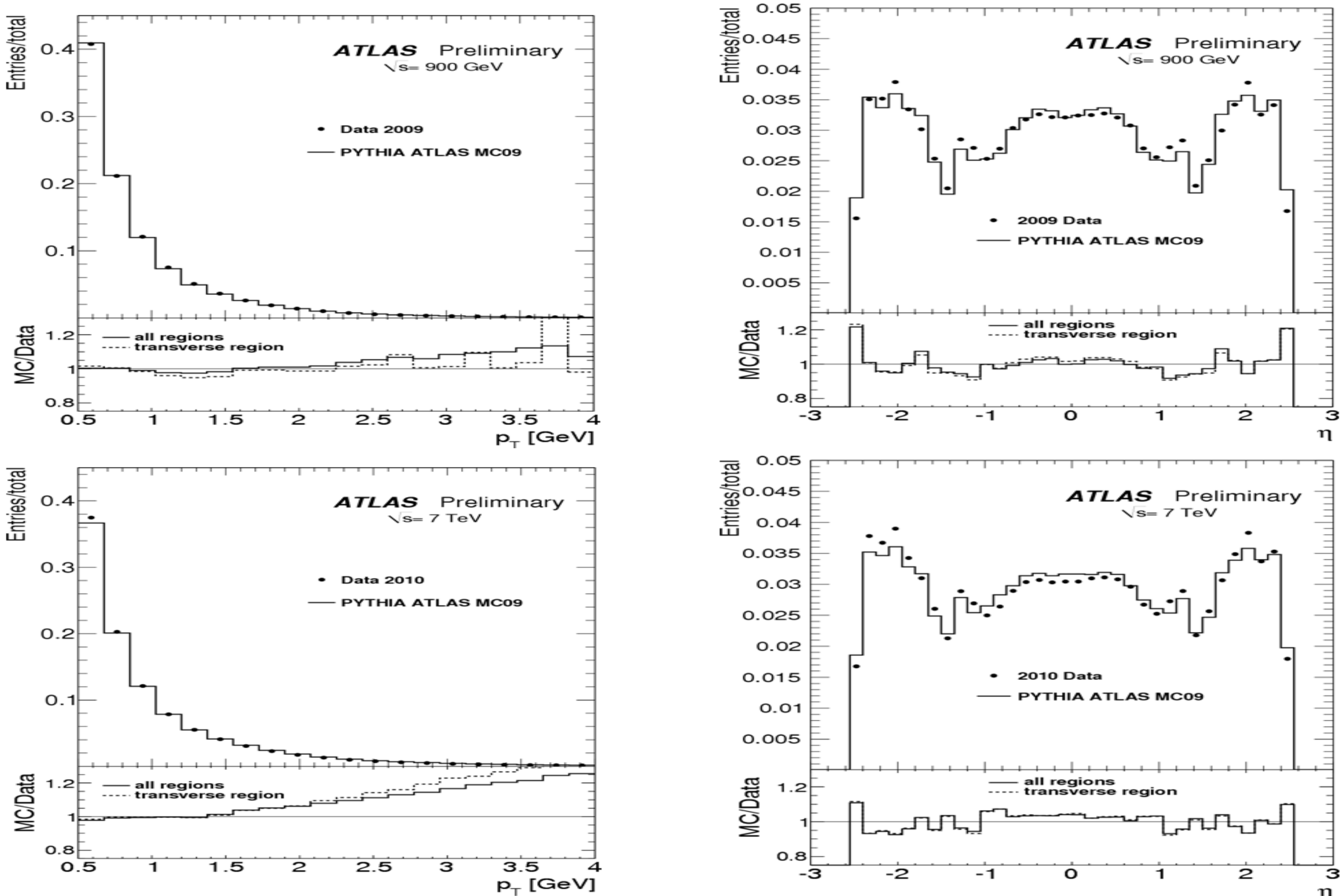
Topocluster Properties

- Good association with the truth hadrons
- Reasonable description by MC



Systematic introduced for the discrepancy in the low multiplicity region by reweighting

Topocluster Properties

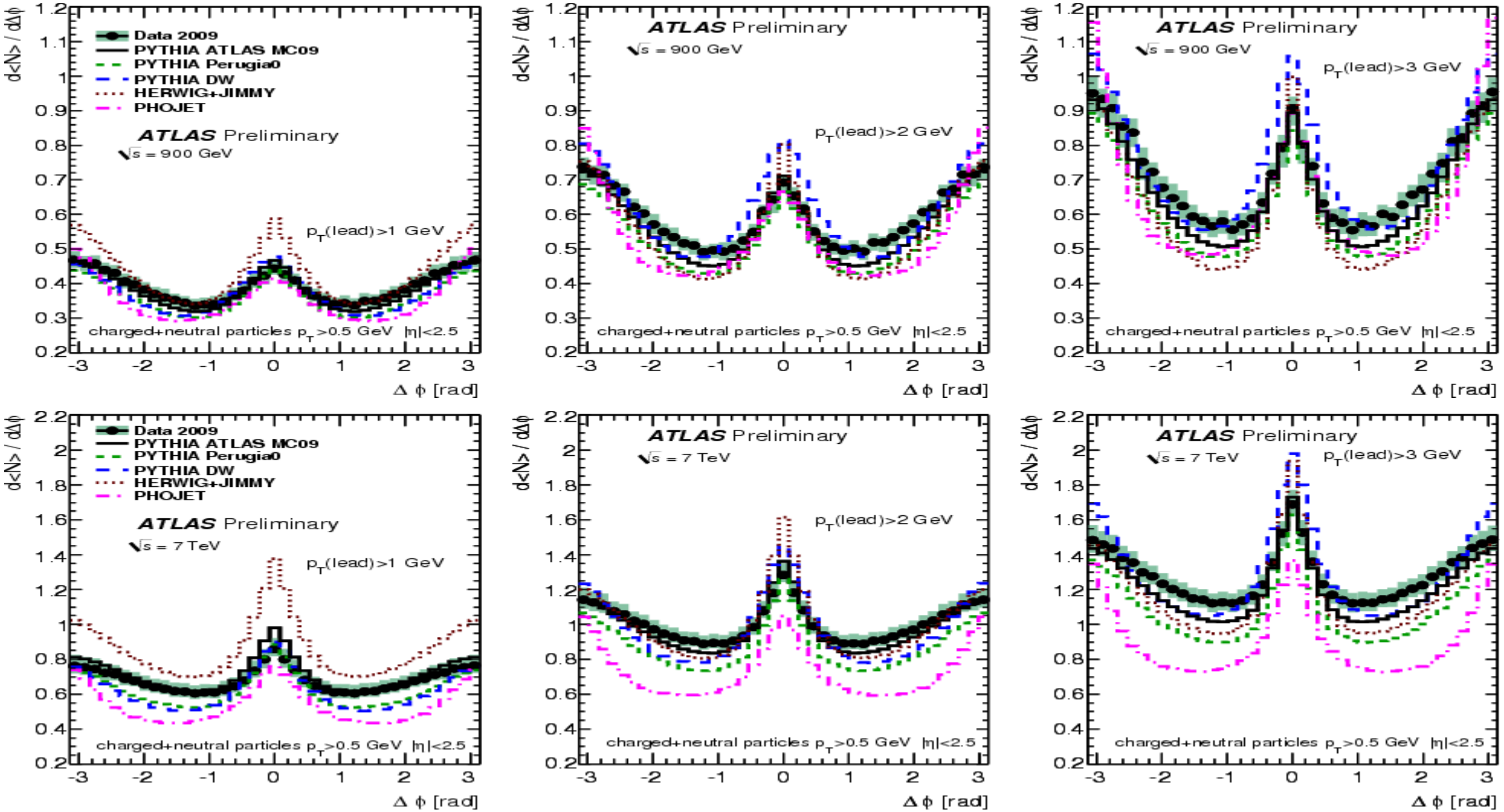


Systematic introduced for the discrepancy in the high P_T tail by reweighting

Correction Procedure

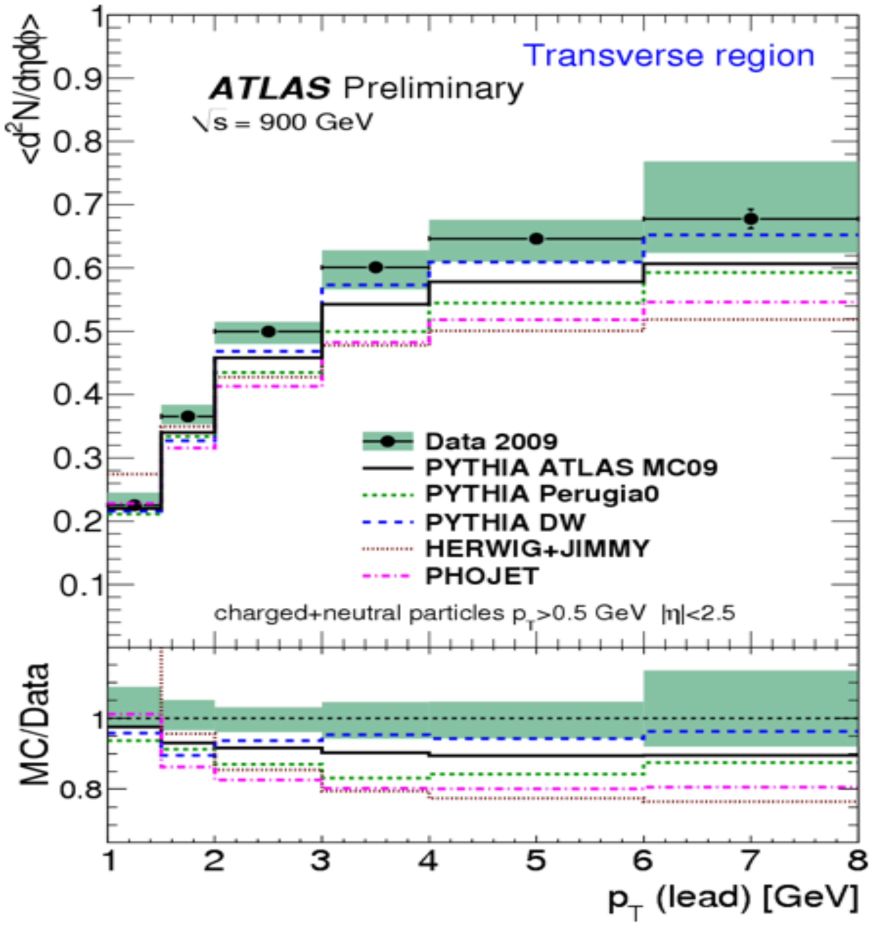
- Unfold the observable distributions by bin-by-bin correction from detector level to hadron level **(charged and neutral)**
- Take into account
  - Event selection
  - Cluster selection
  - Bin by bin migration
  - Smearing
  - …
- Minimize the resolution smearing by choosing bin sizes larger than resolutions in each bin
- Control model dependence using alternative MCs
- Not apply correction for diffraction
- Reweight the low multiplicity region with track multiplicity, reweight the resolution tail of P_T(Lead) with leading track P_T distribution

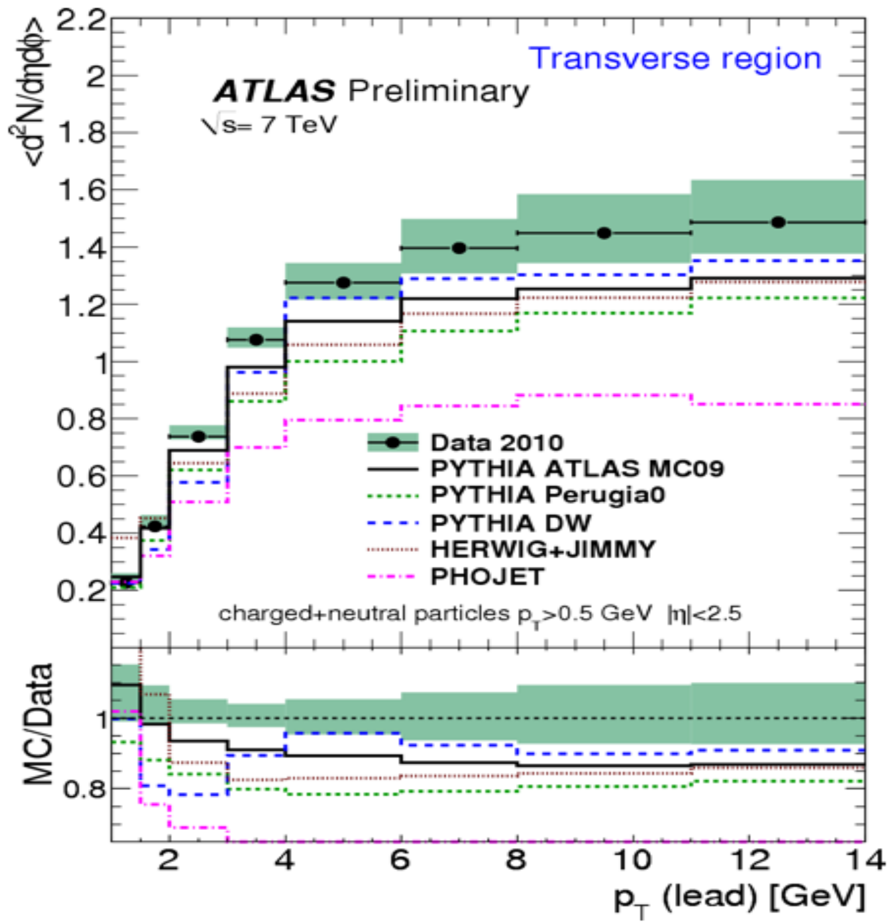
Particle Density vs. Δϕ



MC tunes don't describe data well
~40% increase in particle density due to neutrals

Particle Density vs. P_T(lead)





Lower particle density in MC tunes
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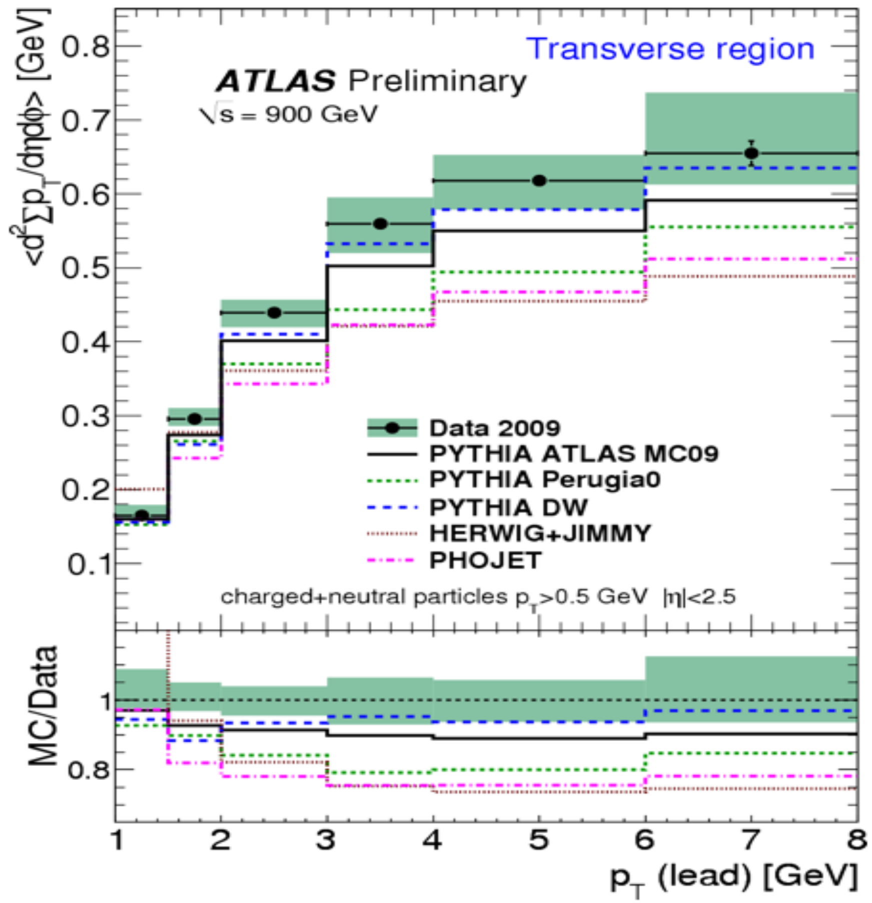
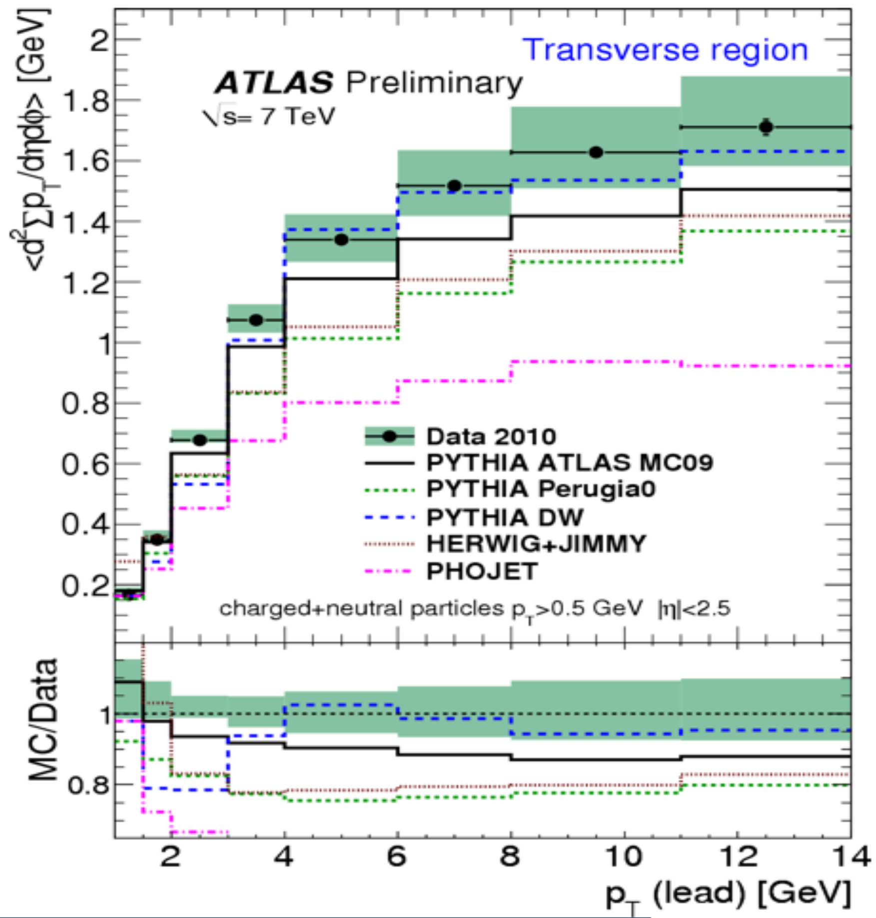
Scalar ΣP_T vs. P_T(lead)





Lower particle ΣP_T in MC tunes
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Systematics

Check	$d < N > /d\Delta\phi$	$< d^2N/d\eta d\phi >$	$< d^2\sum p_T/d\eta d\phi >$
$N < 3$ rejection	$+0.2\%$	$+10\%$	$+10\%$
Energy scale	$\pm 4.3\%$	$\pm 4\%$	$\pm 5.6\%$
ϕ position	$\pm 1.3\%$	$\pm 0.2\%$	$\pm 0.2\%$
η position	$\pm 0.2\%$	$\pm 0.2\%$	$\pm 0.2\%$
Additional material	$+3.5\%$	$+3\%$	$+3.6\%$
Model dependence	$\pm 3.5\%$	$\pm 5\%$	$\pm 4.5\%$
Multiplicity reweighting	$\pm 4.5\%$	$\pm 10\%$	$\pm 11\%$
Resolution reweighting	$\pm 0.4\%$	$\pm 6\%$	$\pm 6\%$

Showing maximum uncertainties (not the average over bins)

Summary

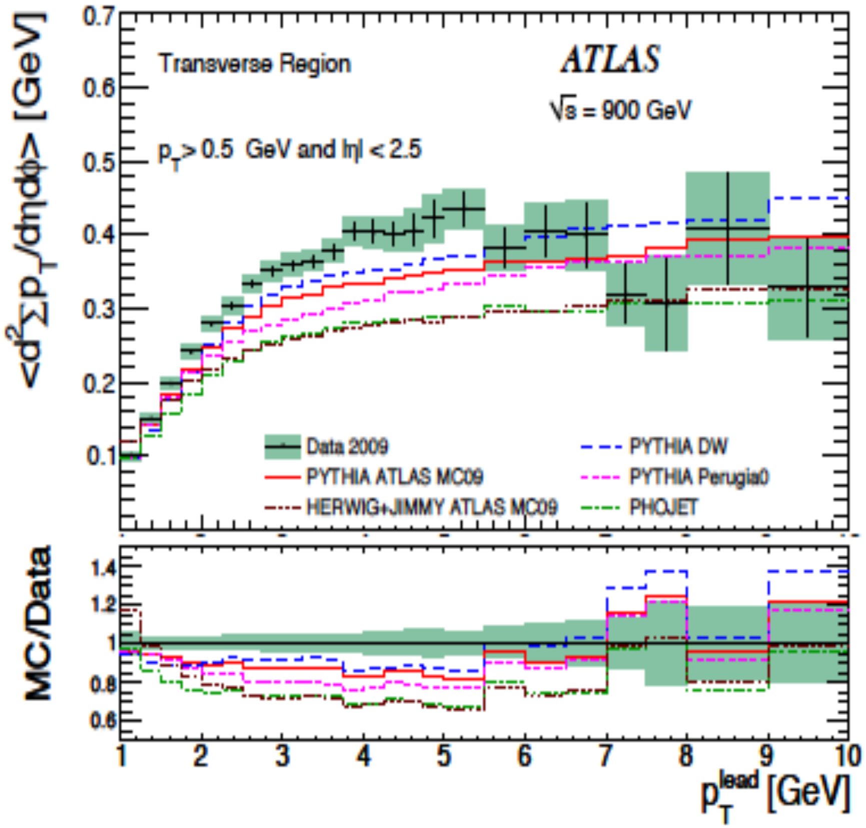
- New UE measurements using charged tracks with low P_T cut
- First UE measurements using calorimeter clusters
- Excellent comparison between these measurements and consistent conclusions
  - No MC tunes have good description of all observables
  - MC tunes have smaller particle activity in the transverse regions

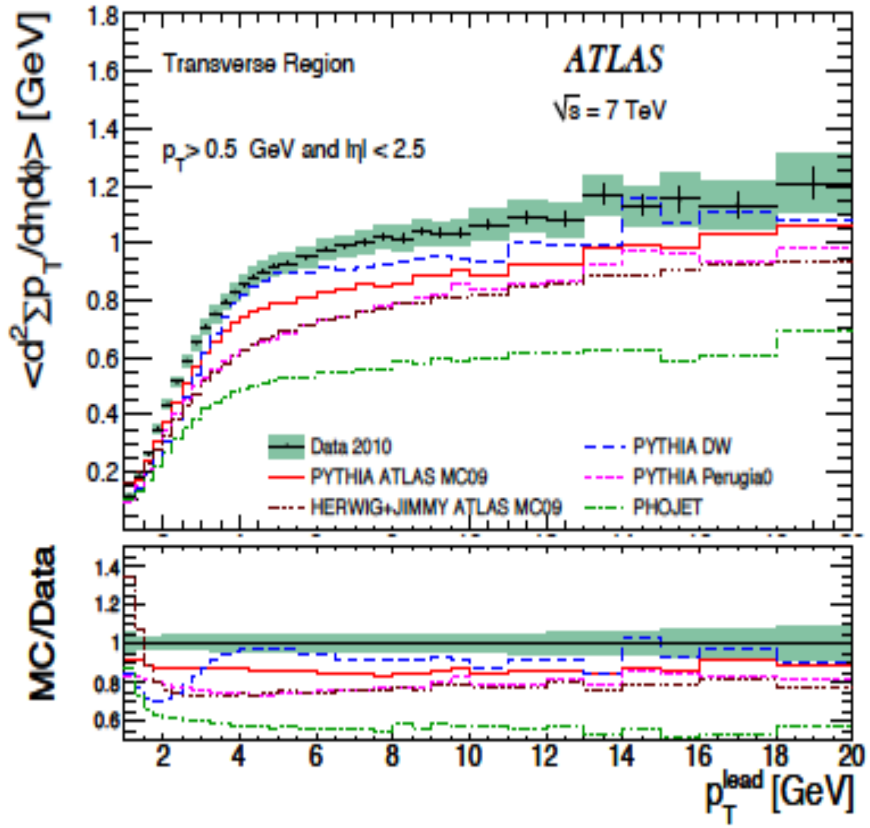
Systematics

	Lowest-p_T bin	Intermediate-p_T bin	Highest-p_T bin
Systematic uncertainty on unfolding			
PYTHIA/PHOJET difference	4%	2%	2%
PYTHIA unfolding stat. uncertainty	< 0.1%	1% (2%)	4% (5%)
Systematic uncertainties from efficiency corrections			
Track reconstruction	3%	4%	4%
Leading track requirement	1%	< 0.1%	< 0.1%
Trigger and vertex efficiency	——	< 0.1% (everywhere)	——
Total from efficiency corrections	2.5%	4%	4%
Systematic uncertainty for bin migration			
Bin migration due to mismeasured p_T	-	2.5% (0%)	5% (0%)
Total systematic uncertainty	4.5%	4.5% (5%)	8% (6.5%)

Showing the uncertainties for ΣP_T in the transverse region; comparable or smaller for other distributions

Scalar ΣP_T vs. P_T^{lead} (PT>500MeV)





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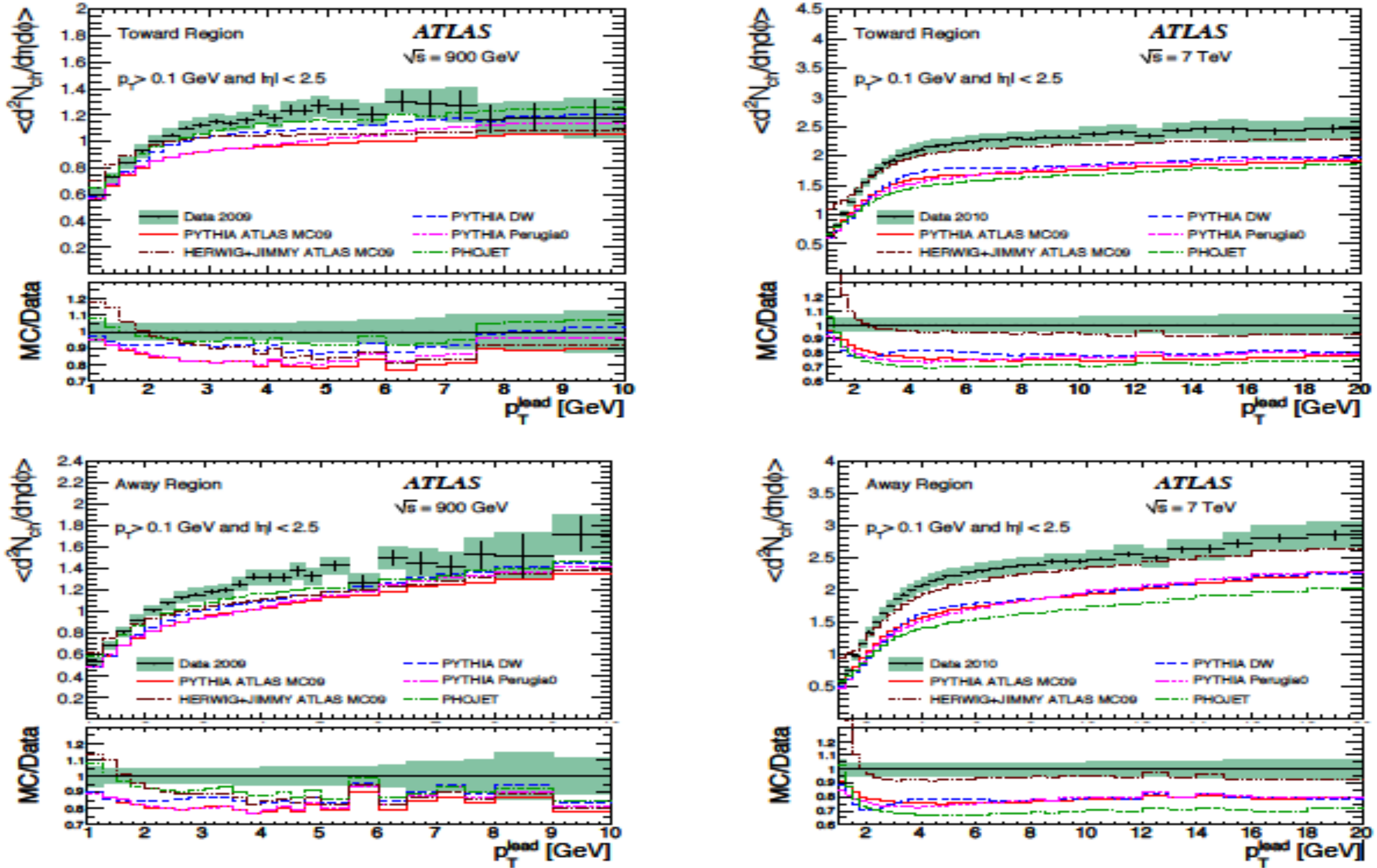
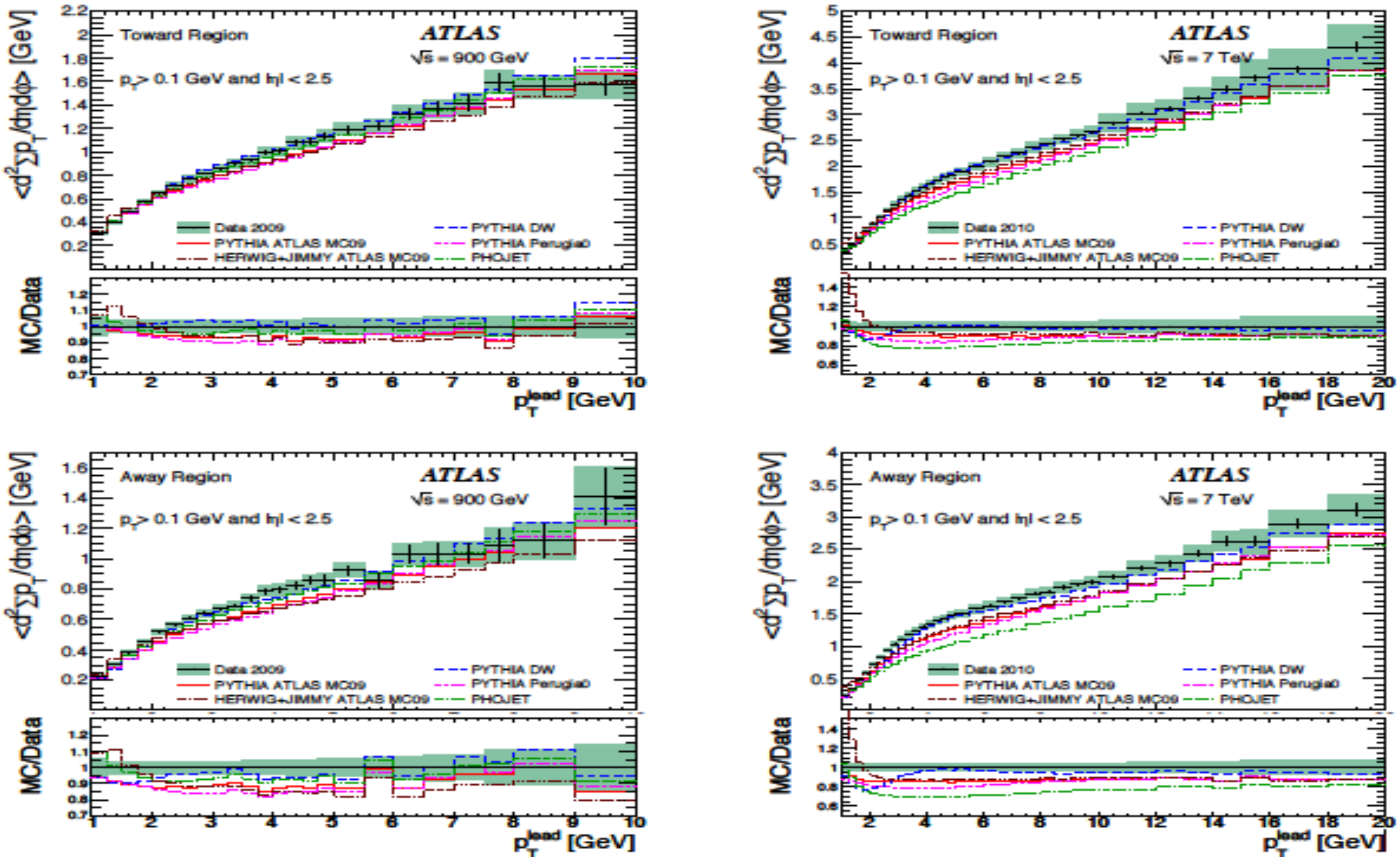
Particle Density vs. P_T^{lead}



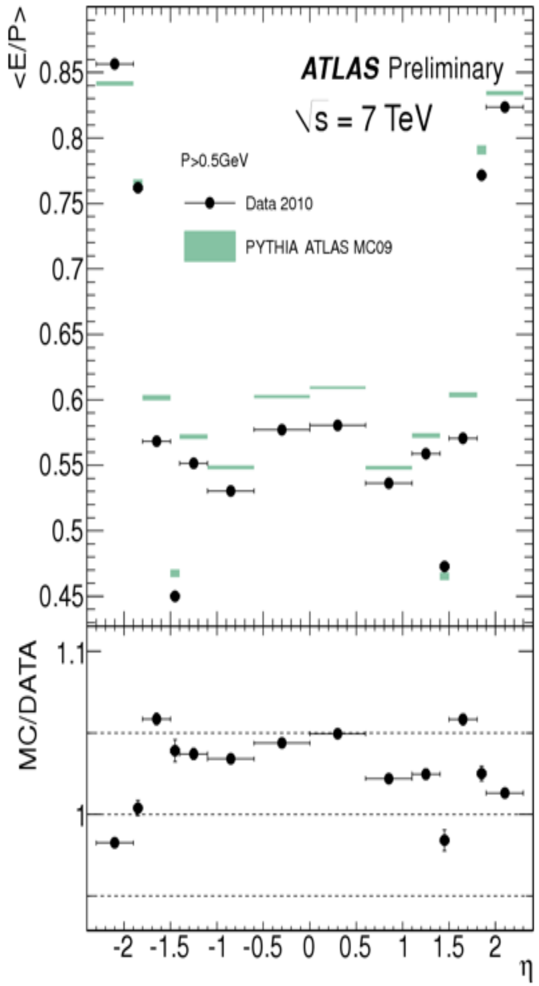
Data and MC agree reasonably in toward and away regions

Scalar ΣP_T vs. P_T^{lead}



Data and MC agree reasonably in toward and away regions

Energy Scale Measurements



<E/p> distribution showing the discrepancy between Data and MC < 5% but P_T and η dependent.