Underlying event studies in inelastic *pp* events with the ATLAS detector

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on behalf of the ATLAS Collaboration

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Results from ATLAS-CONF-2010-029 and ATLAS-CONF-2010-031

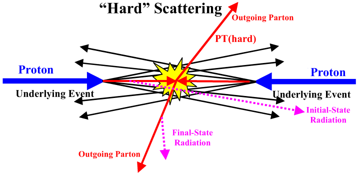
BMBF-Forschungsschwerpunkt
ATLAS Experiment
Physics on the TeV-scale at the Large Hadron Collider
FSP 101 ATLAS

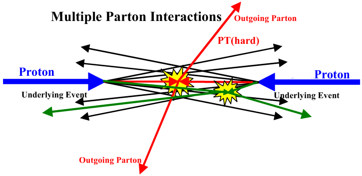
PHYSICS AT THE TERA SCALE
Helmholtz Alliance

UNI FREIBURG

Underlying Event (UE)

- Everything except the hard scattering process
- Model-dependent contributions:
  - Multi-parton-interactions (MPI)
  - ISR, FSR, ...
- Modelling in MC generators important for description of high p_T processes, i.e. understanding of jet energy scale
- Huge step in centre-of-mass energy ⇒ important to measure UE properties in LHC experiments





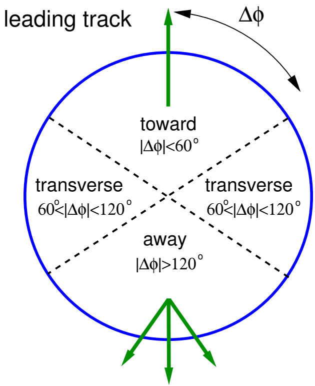
(taken from R. Field)

How to measure the UE?

- Separate off hard scattering region
- Assume Di-jet structure
- Region transverse in ϕ to Jets is filled mostly by UE

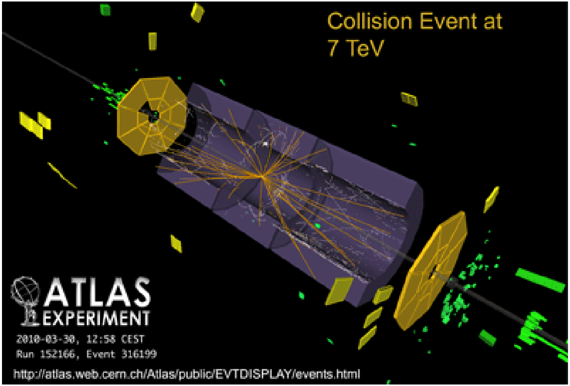
Leading Track Method

- Use leading track to define directions
- Usually contained in leading jet
- Low p_T: Leading track-jet often has leading track as only constituent
- Can already be used with small statistics ⇒ early data



Event and Track Selection

- Minimum bias trigger
- Cosmic ($< 10^{-6}$) and beam induced ($< 10^{-4}$) background negligible
- Primary vertex (≥ 2 tracks, $p_T > 100$ MeV)
- Removal of pileup-events
- ≥ 1 track with $p_T > 1$ GeV, $|\eta| < 2.5$
- Tracks: $p_T > 500$ MeV, $|\eta| < 2.5$

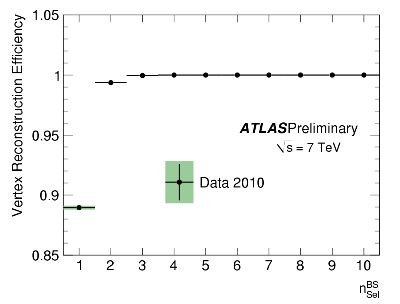


Datasets

$\sqrt{s}$ [GeV]	selected events	selected tracks	L_{int} [μb^{-1}]
900	202 285	1 540 373	9
7000	265 622	3 474 551	6.8

Event-level Corrections

- Trigger: from data (orthogonal trigger, small correction)
- Vertexing: from data
  - Dependent on tracks selected wrt. beam-spot
  - Three or less tracks: dependent on η (see also ATLAS-CONF-2010-024 and Phys. Lett. B **688** (2010) 21)

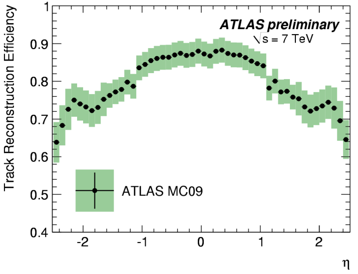


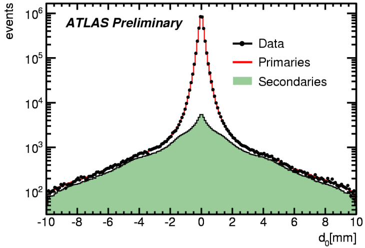
- 1 GeV track requirement:
  - Estimated from probability to fail to reconstruct all of the found tracks with $p_{\mathrm{T}} > 1$ GeV
  - 98% for low p_T, close to 100% for high p_T

Track-level Corrections

Obtained from MC (PYTHIA6, ATLAS MC09 tune)

$$w_{\text{trk}} = \underbrace{1/\epsilon_{\text{trk}}(p_T,\eta)}_{\text{Tracking efficiency}} \cdot \underbrace{(1 - f_{\text{sec}}(p_T))}_{\text{secondary fraction}} \cdot \underbrace{(1 - f_{\text{okr}}(p_T,\eta))}_{\text{truth particle outside acceptance}}$$

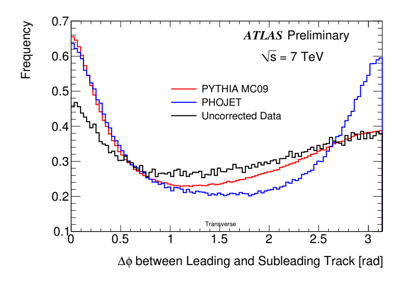




ATLAS-CONF-2010-024

Final Bin-by-Bin Unfolding

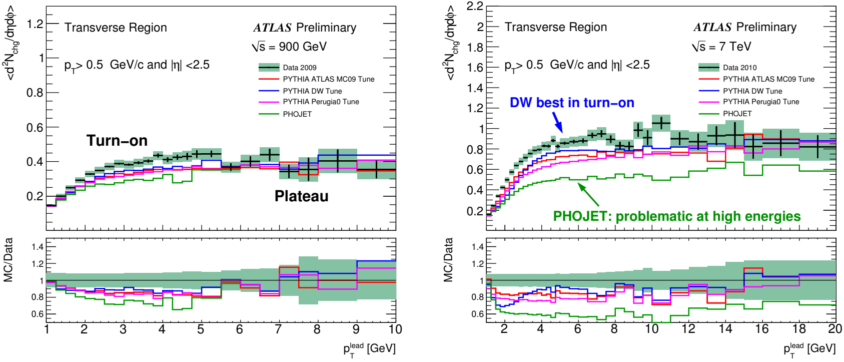
- $\mathrm{U_{bin}} = \dfrac{\text{generated in bin}}{\text{reconstructed and corrected in bin}}$
- Based on PYTHIA ATLAS MC09 tune
- About 5% in lowest p_T bins, smaller for high p_T
- PHOJET as alternative model: 2% absolute differences (tracking efficiency: $\approx$ 5% syst. uncertainty)



- Leading track missed $\Rightarrow$ reorientation to sub-leading track direction
- Reorientation into transverse region $\Rightarrow$ strong bias
- Data/PYTHIA $\approx$ PYTHIA/PHOJET $\Rightarrow$ covered by model variation

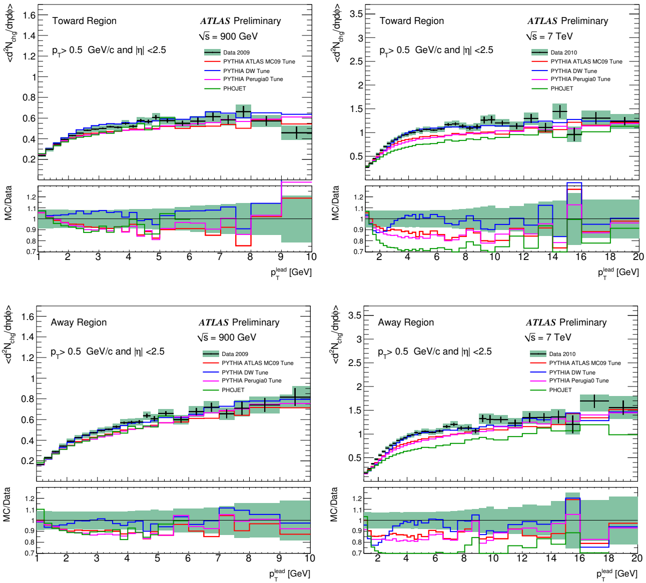
Mean charged multiplicity vs. p_T^{lead}

- Large p_T^{lead}: flat plateau
- Clear differences between data and MC prediction
- PHOJET off especially at 7 TeV
- PYTHIA DW seems to be closest



toward region

away region

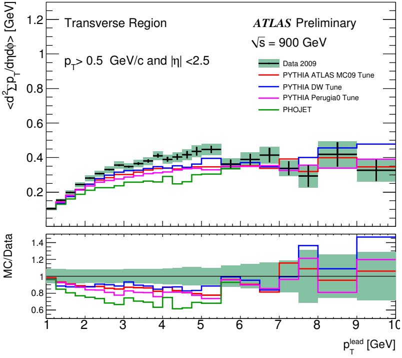


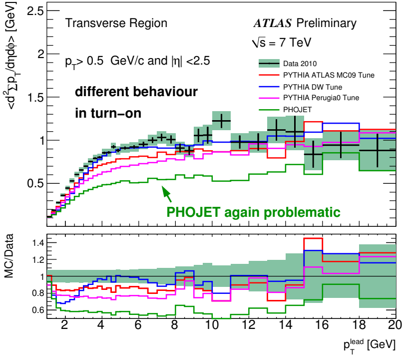
N_{chg} density

- DW better in toward and away regions than other tunes
- PHOJET has problem to describe overall activity at $\sqrt{s} = 7$ TeV

Mean charged transverse momentum sum vs. p_T^{lead}

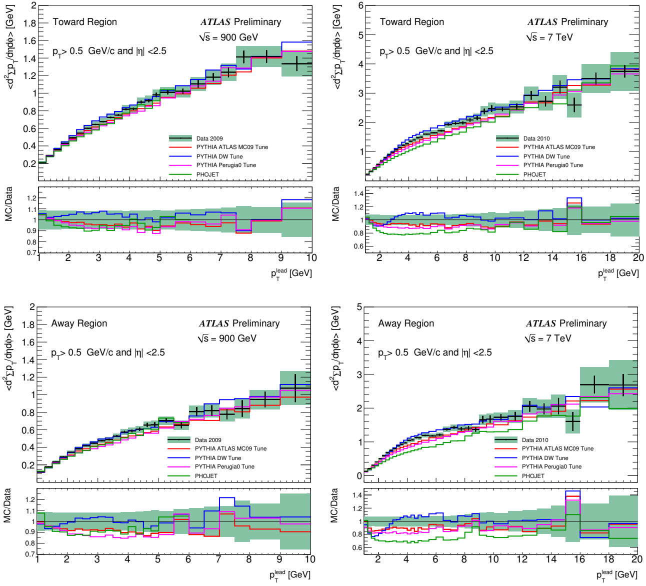
- Clear differences between data and MC prediction
- PHOJET off especially at 7 TeV
- PYTHIA DW seems to be closest, even better than for multiplicity





toward region

away region

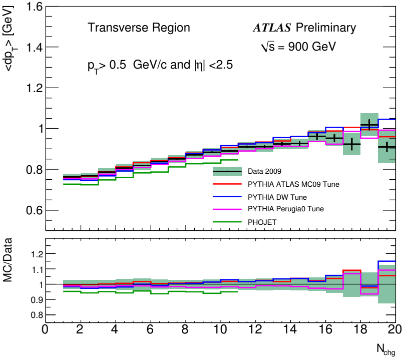


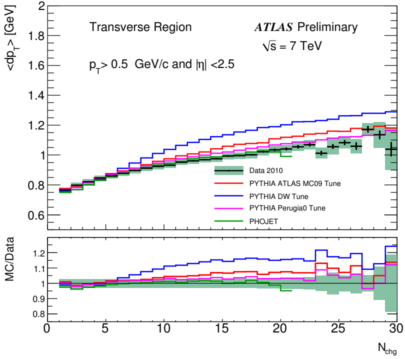
p_T^{sum} density

- no plateau because of jet activity
- DW again slightly better
- PHOJET has problem to describe overall activity at $\sqrt{s} = 7$ TeV

Average p_T vs. multiplicity in transverse region

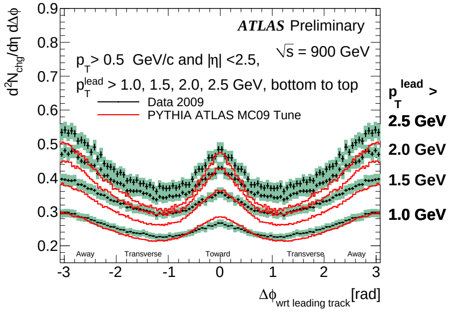
- Well described by Perugia0
- MC09 and DW have problems at high $\sqrt{s}$
- PHOJET problematic at low $\sqrt{s}$
- Similar behaviour in toward and away regions

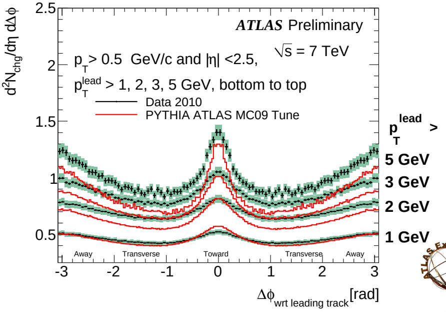




$\Delta\phi$ wrt. leading track for different leading particle p_T

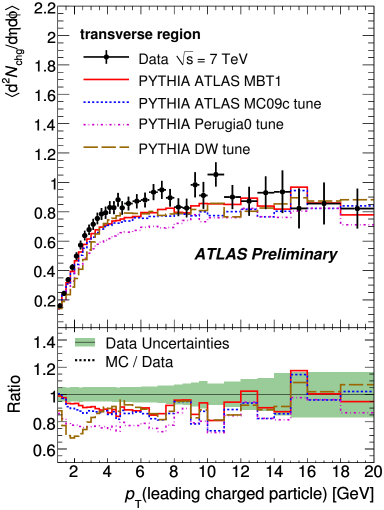
- Clear emergence of jet-like structure with increasing p_T^{lead}
- Not described by MC (corresponding to earlier shown descrepancy)
- Different shapes, different level of saturation





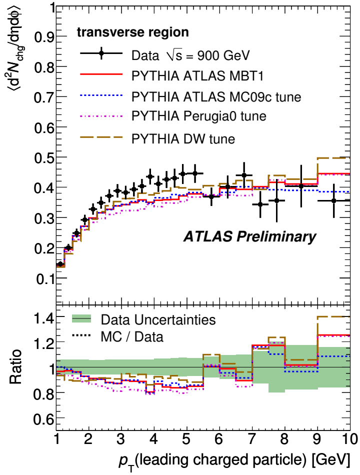
New PYTHIA tune

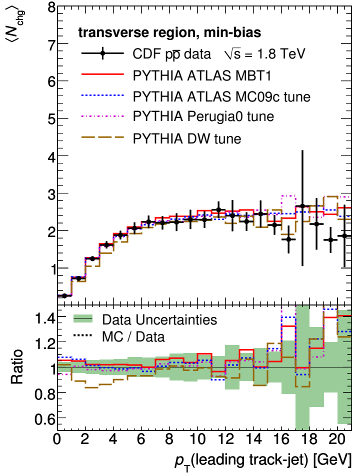
- New PYTHIA tune AMBT1
- Based on model switches as in ATLAS MC09 tune (ATL-PHYS-PUB-2010-002)
- Tuned mostly to ATLAS minimum bias data (see talk by G. Brandt and ATLAS-CONF-2010-031)
- Improves description of inclusive charged particle spectra in diffraction-reduced phase-space
- Slight improvement in UE



Comparison with CDF data

- Tunes describe CDF UE data correctly, apparent tension





CDF data from Phys. Rev. D **65** (2002) 092002

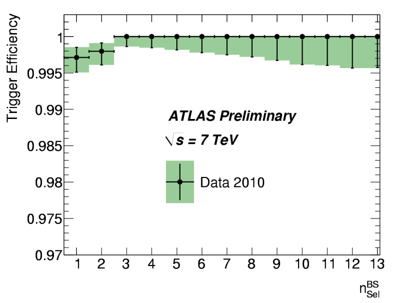
Summary

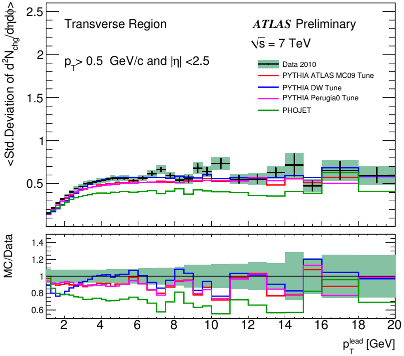
- Presented analysis of underlying event activity in *pp* collisions at $\sqrt{s} = 900\ \mathrm{GeV}$ and $7\ \mathrm{TeV}$
  - Regions classified wrt. leading charged particle
  - Fully corrected to particle level
- Current MC models/tunes have difficulty describing all measurements, but many basic characteristics are predicted correctly by the models
- Two energy points $\Rightarrow$ important for MC tuning
- Outlook:
  - Adding more statistics
  - Jet based topologies
  - Drell-Yan events
  - Additions to analysis methods

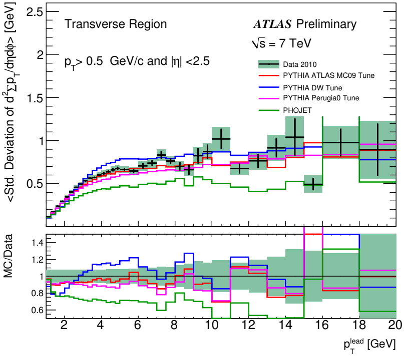
Event-level Corrections: Trigger

$$w_{ev} = \boxed{\frac{1}{\epsilon_{trig}}} \cdot \frac{1}{\epsilon_{vtx}} \cdot \frac{1}{\epsilon_{ld\ trk}}$$

- Determined in data from orthogonal trigger
- Dependent on tracks selected wrt. beam-spot
- As in ATLAS-CONF-2010-024 and Phys. Lett. B **688** (2010) 21
- Small correction for selected events



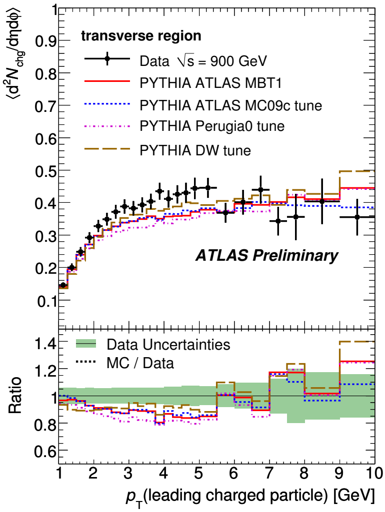


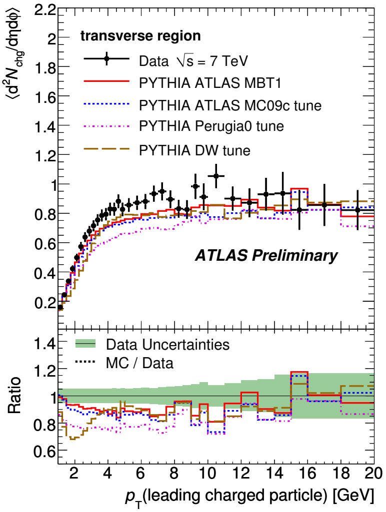


Higher moments: Standard deviations of N_{ch} and $\sum p_T$

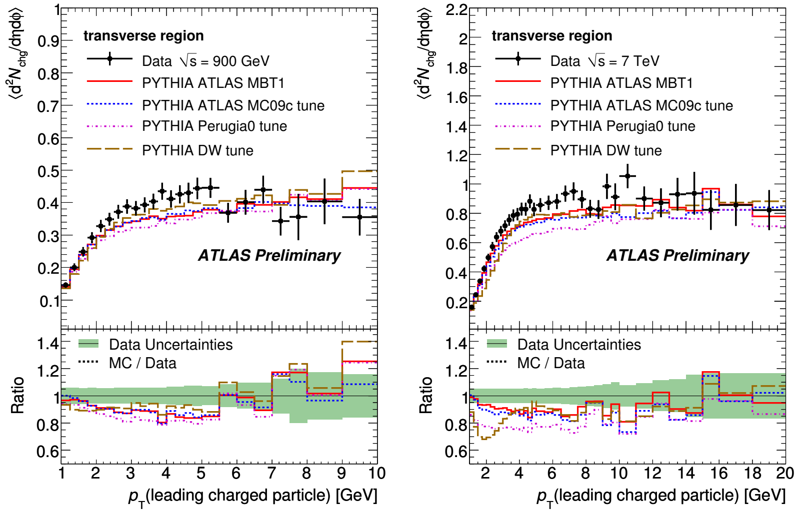
- Seem to be better described by MC models than mean values

AMBT1 tune, transverse region, charged multiplicity

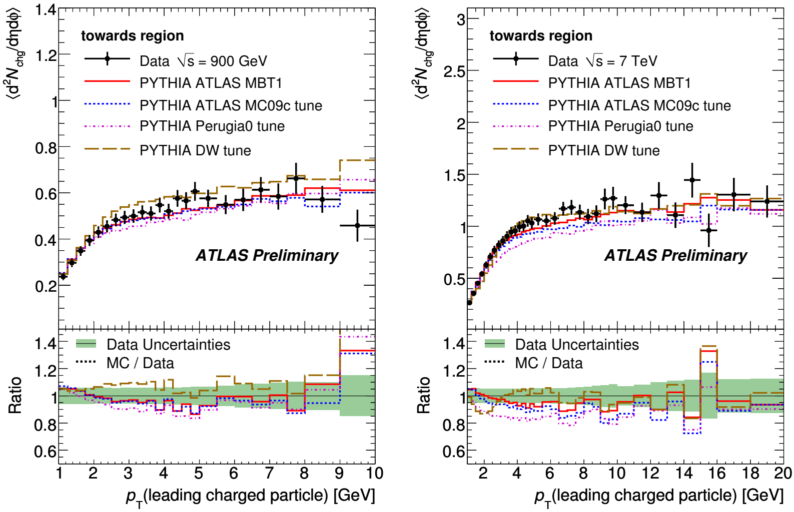




AMBT1 tune, transverse region, charged momentum sum



AMBT1 tune, toward region, charged multiplicity



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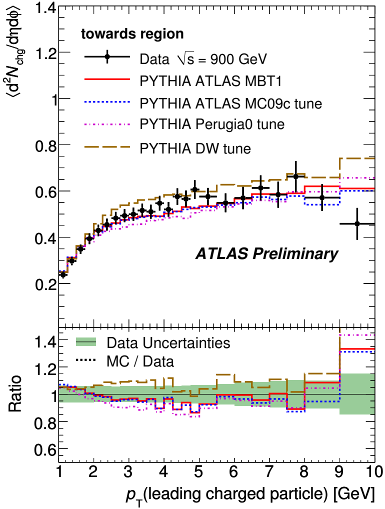
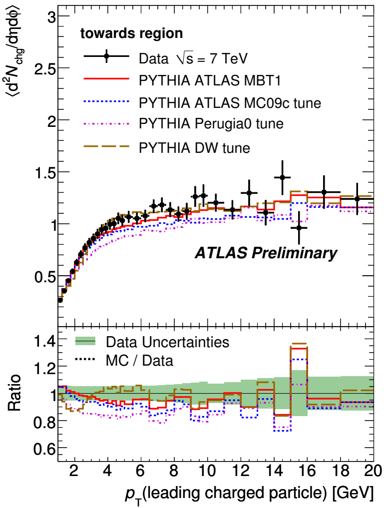
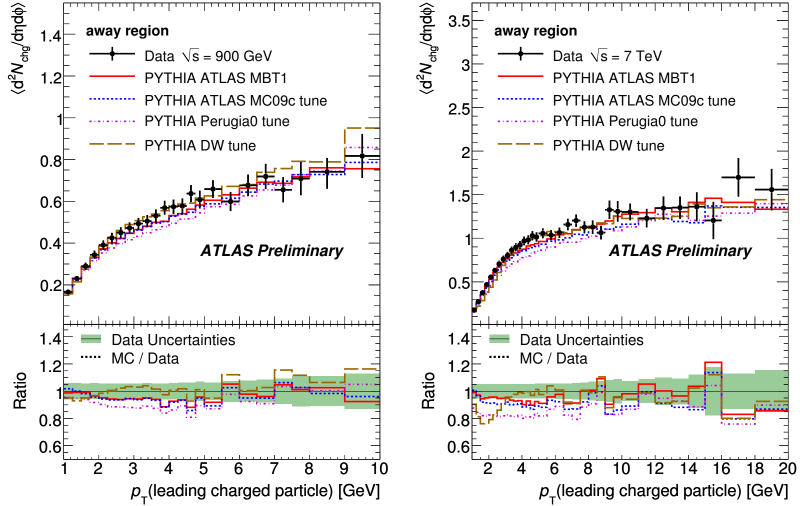




AMBT1 tune, away region, charged multiplicity



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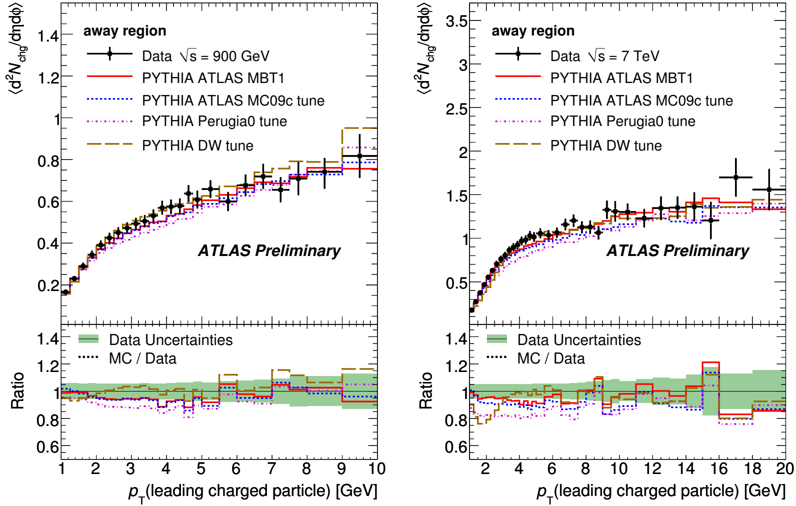
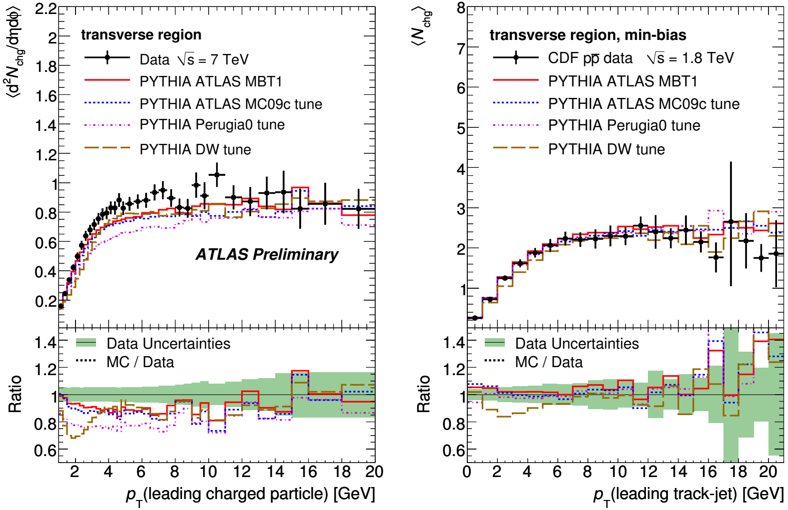
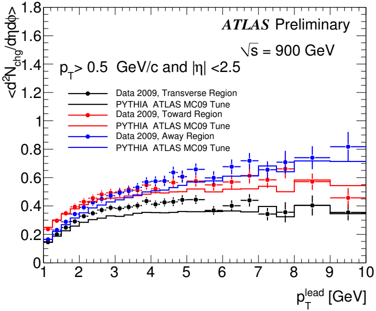
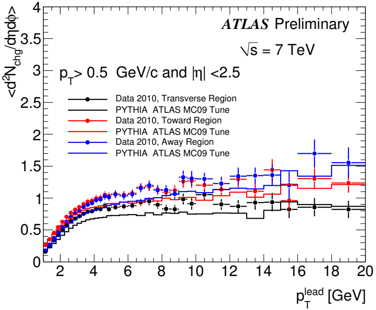


Tension with Tevatron UE data



Apparent tension between data!


ATLAS Preliminary
√s = 900 GeV
pT> 0.5 GeV/c and |η| <2.5
Data 2009, Transverse Region
PYTHIA ATLAS MC09 Tune
Data 2009, Toward Region
PYTHIA ATLAS MC09 Tune
Data 2009, Away Region
PYTHIA ATLAS MC09 Tune
<d²Nchg/dηdφ>
pTlead [GeV]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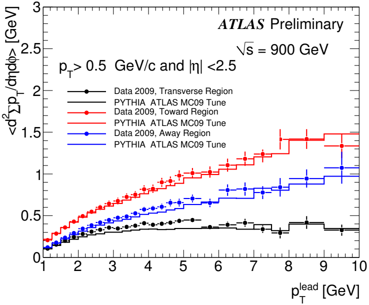
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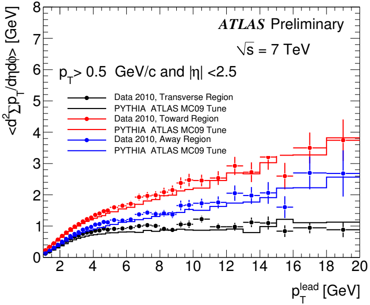
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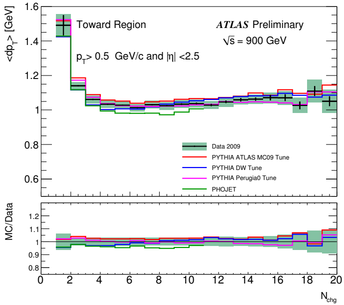
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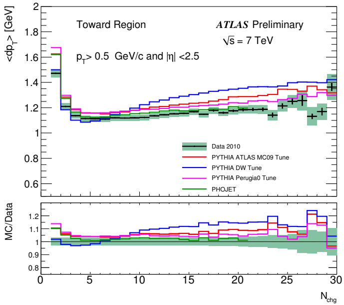
PYTHIA DW Tune
PYTHIA Perugia0 Tune
PHOJET
<dp_T> [GeV]
MC/Data
N_{chg}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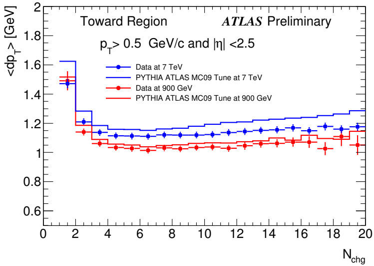
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PYTHIA ATLAS MC09 Tune at 7 TeV
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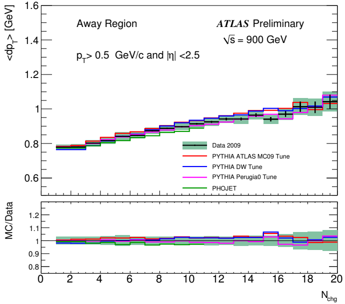
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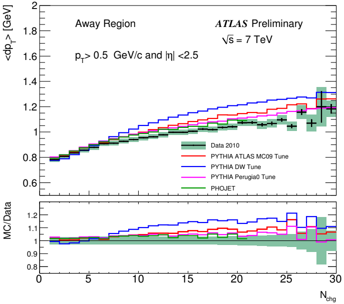
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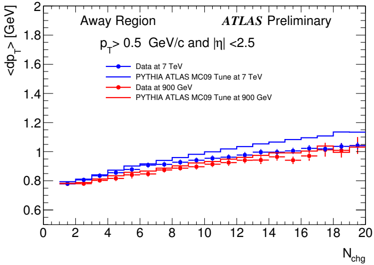
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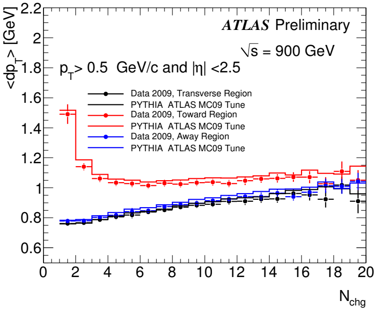
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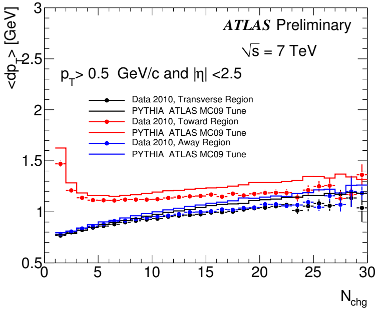
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Nchg

Systematic Uncertainties

	p_T bin		
	Lowest	Intermediate	Highest
Systematic uncertainty on unfolding			
Difference PYTHIA– PHOJET	——	2% (everywhere)	——
Stat. unc. on PYTHIA unfolding	0.1%	4.0% (7%)	10% (15%)
Systematic uncertainties from efficiency corrections			
Track reconstruction	5.5%	5%	5%
Leading track requirement	1.0%	0.1%	$< 0.1\%$
Trigger and vertex efficiency	——	$< 0.1\%$ (everywhere)	——
Total from efficiency corrections	4.5%	5%	5%
Total systematic uncertainty	5.5%	7.5% (9%)	12% (16%)