Measurements of the underlying event with ATLAS

Stefano Camarda

On behalf of the ATLAS Collaboration

MPI at LHC
Kraków, Poland
3-7 November 2014

Underlying event measurements with ATLAS

- Motivation
- Underlying event observables
- Underlying event in Drell-Yan and Jets production
  - Event selection
  - Results
- Conclusions

arXiv:1409.3433

Eur.Phys.J.C74 (2014) 2965

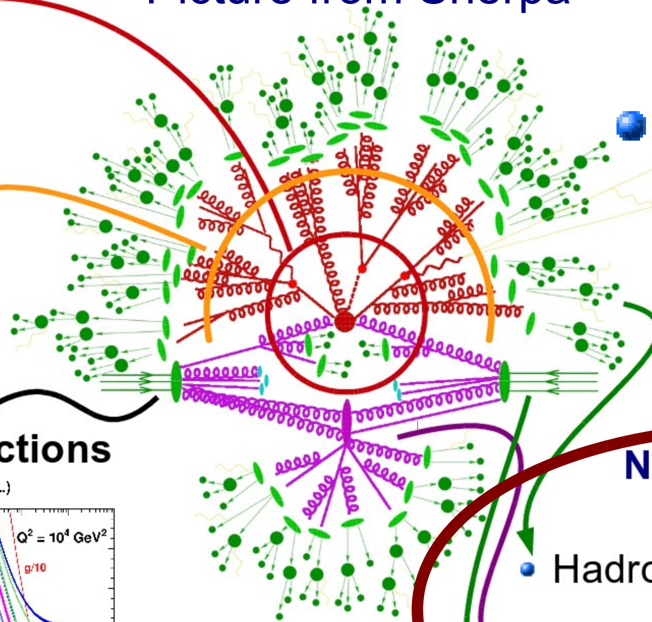
Motivation

- Measurements at hadron colliders always require modelling of QCD effects
- Almost every observable is influenced by non perturbative QCD effects, including PDF, multi parton interactions, and hadronisation

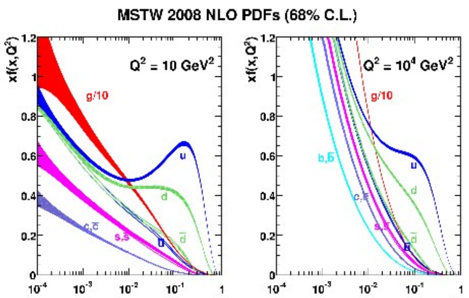
Perturbative QCD

- **Hard scattering**
  - Fixed Order
  - Resummation
- **Fragmentation**
  - Parton Shower
    - Initial state
    - Final state

Picture from Sherpa



Parton Distribution Functions (PDF)



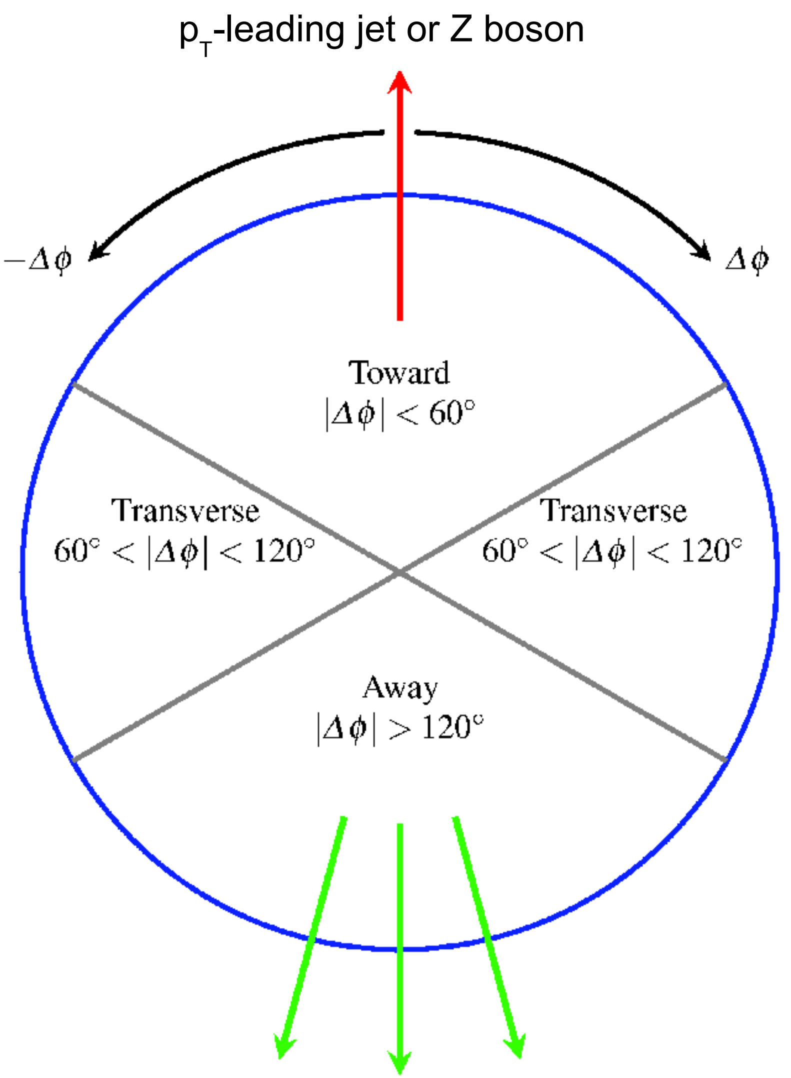
- A good non perturbative QCD modelling is a prerequisite for precision physics and searches
- Measurements of underlying event associated to QCD and EW signatures help to constrain the parameters of soft QCD models

Non perturbative QCD

- Hadronization
- Multi-parton interactions
- Primordial k_T

Underlying event observables

- Underlying event refers to event activity in hadron collisions, not associated to the hard process
- Includes soft ISR and FSR, MPI, and color reconnection with beam remnants
- Observables are charged particles multiplicity N_{ch} and transverse energy or momentum flow Σp_T, ΣE_T
- Transverse, toward and away regions are defined with respect to the p_T-leading jet or Z boson
- Toward and transverse regions are sensitive to the UE, away region has larger contributions from high p_T recoil, which is modelled by perturbative QCD
- Transverse regions are further distinguished in trans-max and trans-min, depending on the amount of N_{ch}, Σp_T, ΣE_T



Underlying event observables

- Densities and averages
  - Charged particles average p_T $< p_T >$
  - Charged particles density $N_{\mathrm{ch}}/\delta\eta\delta\phi$
  - Charged particles p_T density $\sum p_T/\delta\eta\delta\phi$
  - Particles E_T density $\sum E_T/\delta\eta\delta\phi$
- Particles spectra
  - Charged particle p_T spectrum
  - Charged particle multiplicity spectrum

Event selection

- p_T-leading object
  - Z boson: $66 < m_{ll} < 116$, $p_T^l > 20$, $|\eta^l| < 2.4$
  - Jet: anti-kt R=0.4, $p_T > 20$ GeV, $|\eta| < 2.8$
  - Inclusive jet selection, and dijet exclusive selections in order to suppress QCD radiation
- Luminosity
  - Jet: 37 pb^{-1}
  - Z boson: 4.6 fb^{-1}

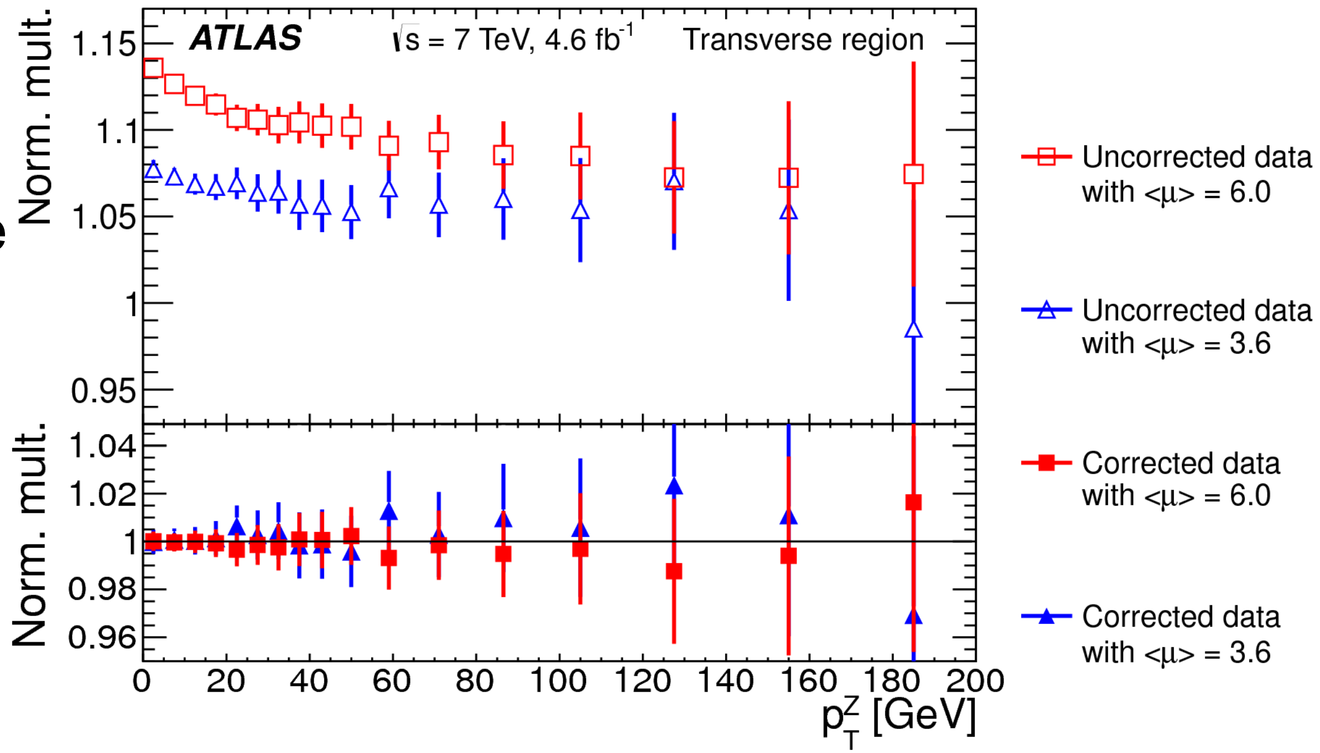
- Charged particles are identified by tracks with
  - $p_T > 0.5$ GeV
  - $|\eta| < 2.5$
- Charged and neutral particles measured with calorimeter clusters (only in the jet measurement)
  - Charged particles $p > 0.5$ GeV
  - Neutral particles $p > 0.2$ GeV
  - $|\eta| < 4.8$

Subtraction of pile-up of multiple pp interactions

- In the Z-boson underlying event measurement with 4.6 fb^{-1}, Pile-up contribution to the underlying event observables needs to be accounted
- To reduce pile-up, tracks are required to be associated to the primary vertex (PV) in $|d_0|$ < 1.5 mm and $|z_0| \sin\theta$ < 1.5 mm

arXiv:1409.3433

- Residual contribution is estimated and subtracted with a data driven technique
- Tracks associated to points at distance larger than 2 cm from the PV are selected, and used to estimate the pile-up contribution



- Pile-up correction is checked in subsamples with different average number of pile-up interactions

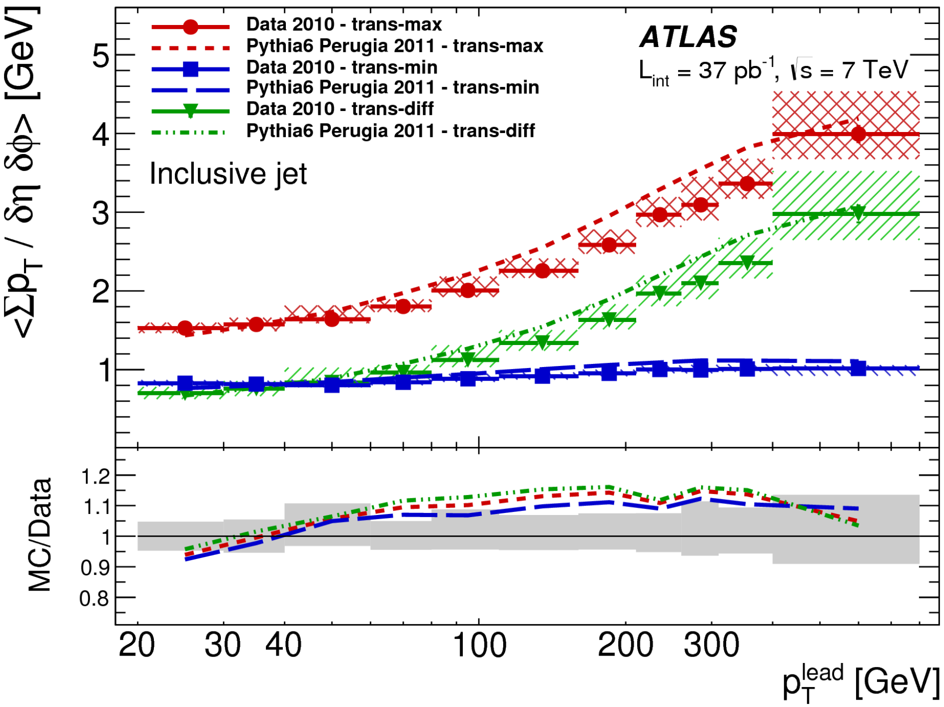
Measurement methodology

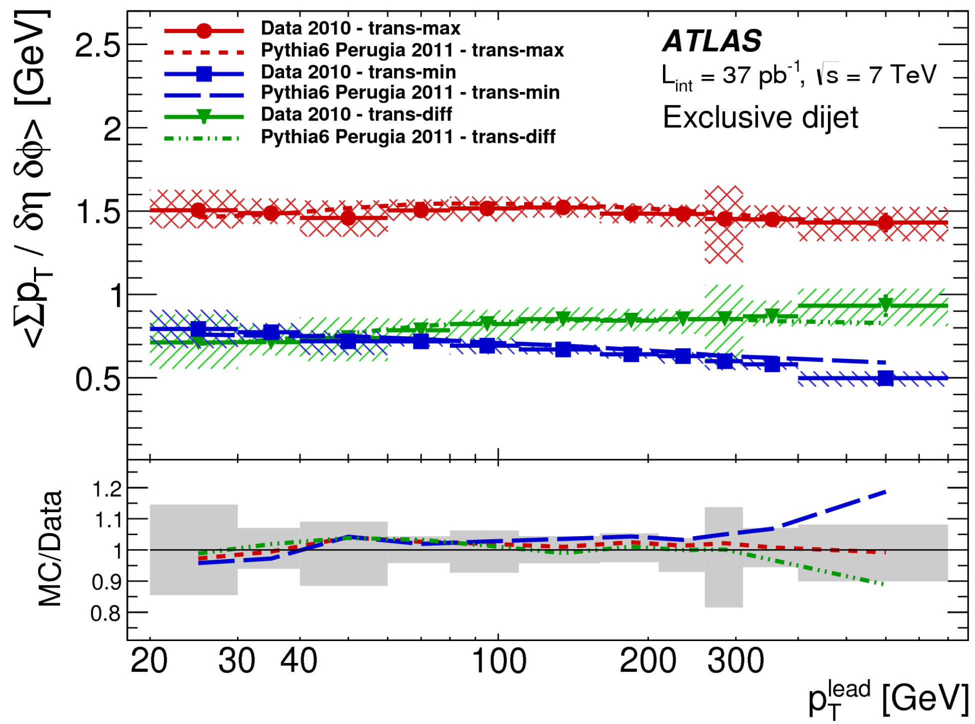
- Measurements are unfolded to the particle level with an iterative bayesian unfolding
- Systematic uncertainties from
  - Jets and leptons reconstruction
  - Tracks, calorimeter clusters reconstruction
  - Pile-up, Background, Unfolding, etc...
- Jet UE analysis already in Rivet as ATLAS_2014_I1298811, Z will be available soon

Results for Underlying event in jets production

- Jets inclusive and dijet exclusive selections

Eur.Phys.J.C74 (2014) 2965





- In the inclusive jet sample, Trans-max region shows increase as a function of jet p_T, trans-min region is flat
- Trans-max has a large contribution from pQCD

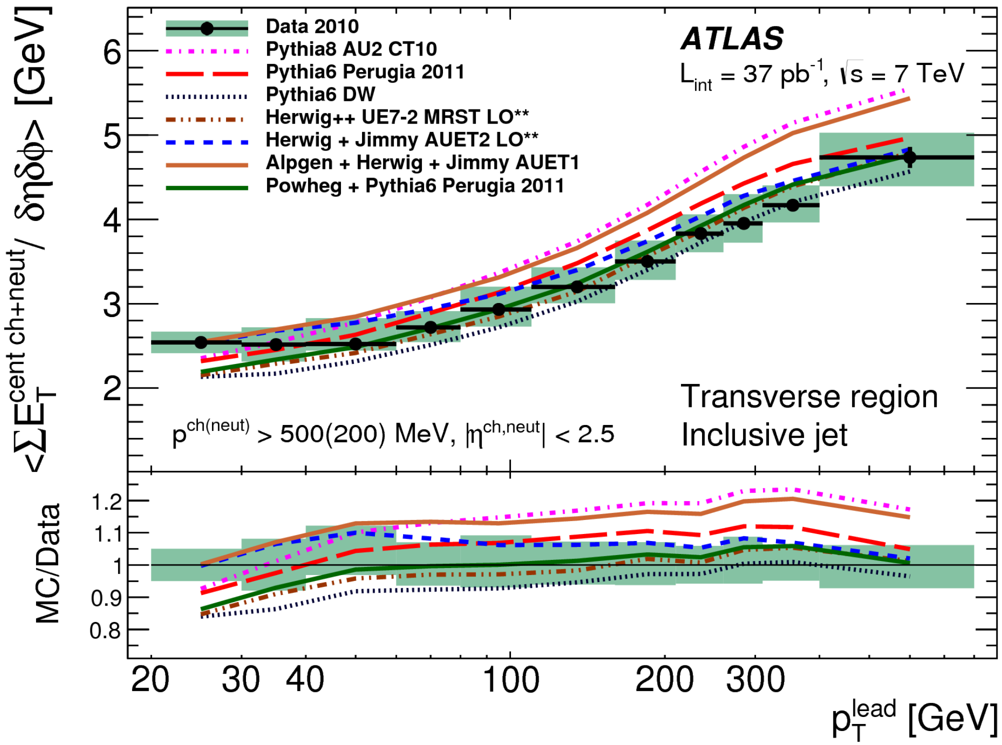
- In the exclusive dijet sample also the trans-max region is flat

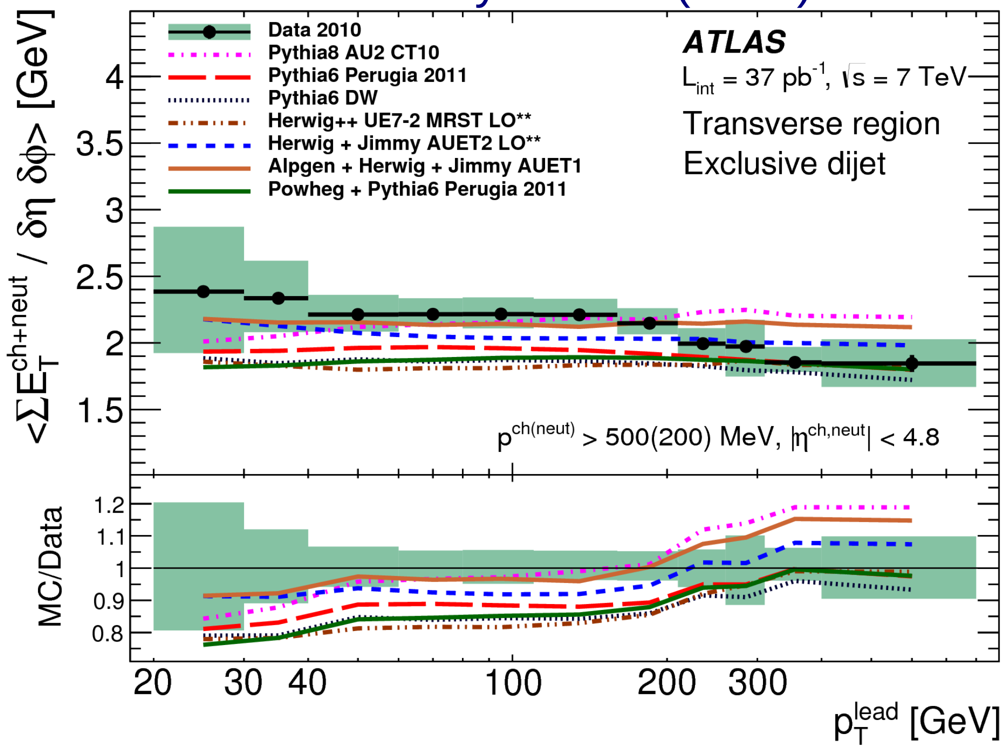
  → Less sensitive to perturbative QCD effects

Results for Underlying event in jets production

- Jets inclusive and dijet exclusive selections

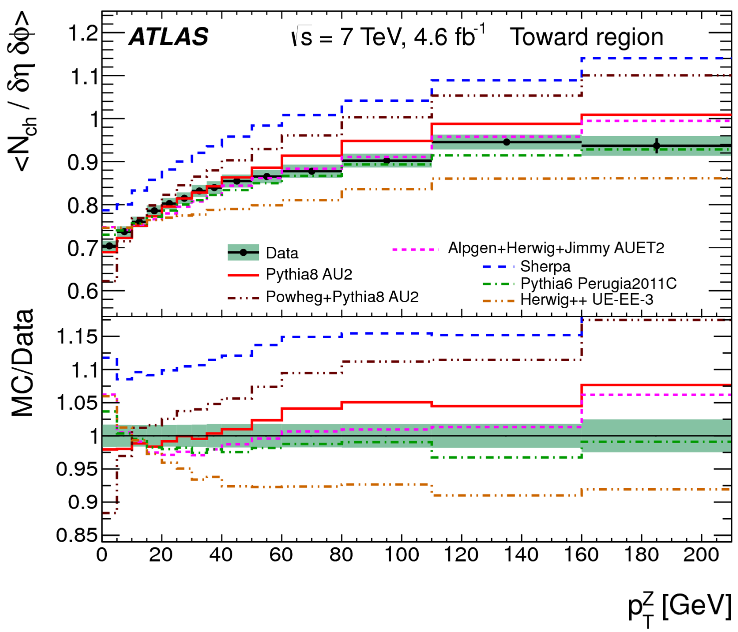
Eur.Phys.J.C74 (2014) 2965

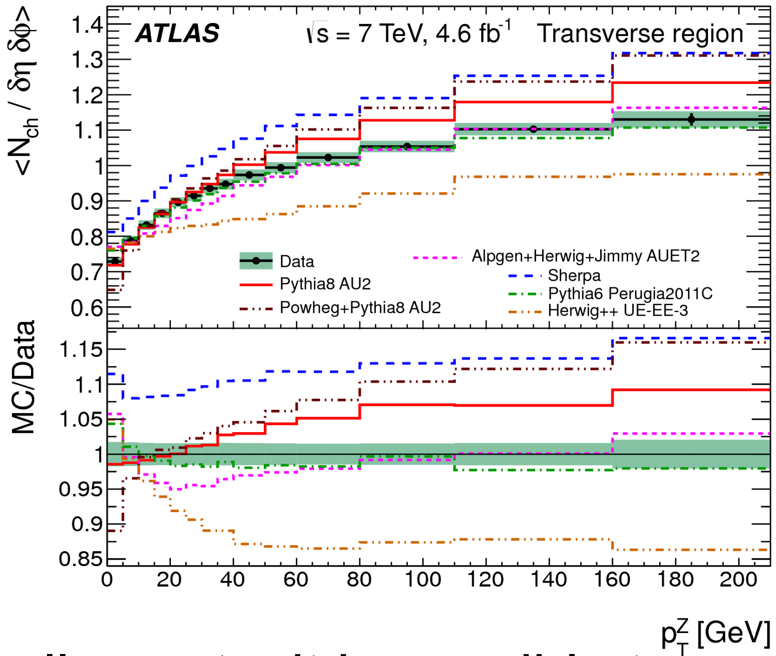


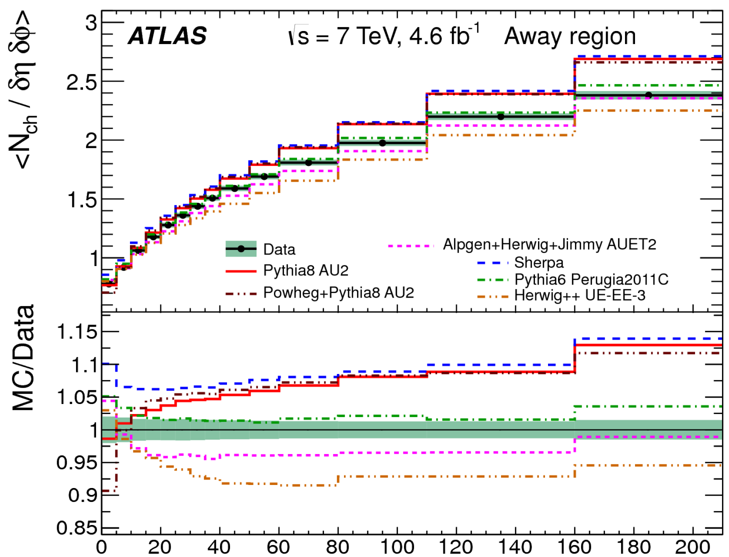


- Similar distributions also for ΣE_T measured with calorimeter clusters

Results for Underlying event associated to Z boson







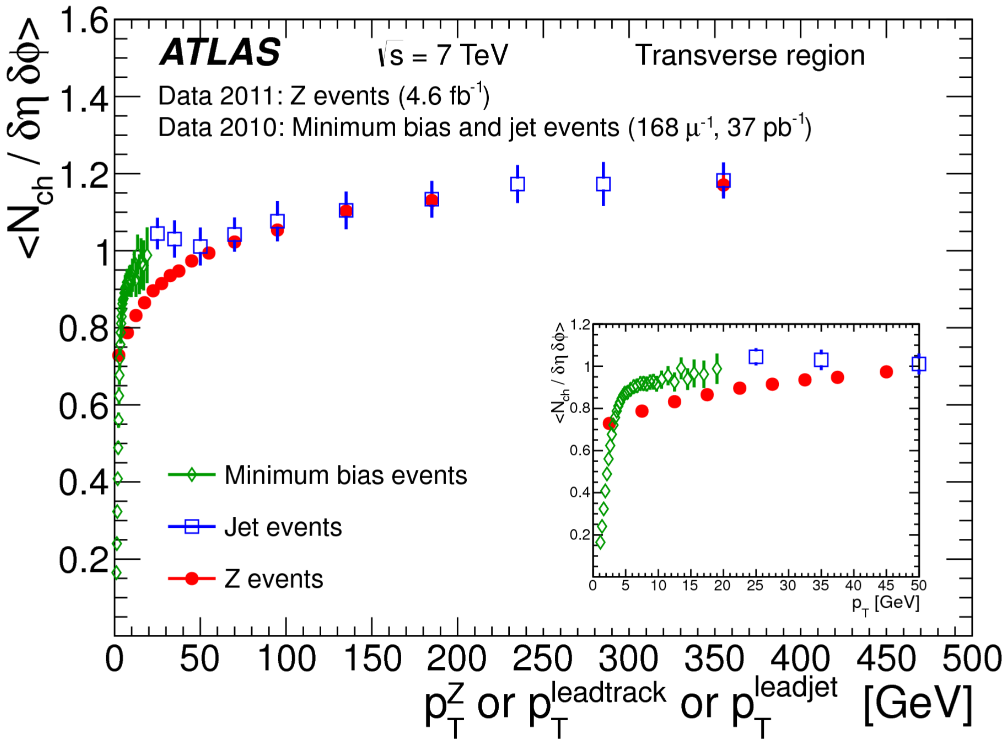
arXiv:1409.3433

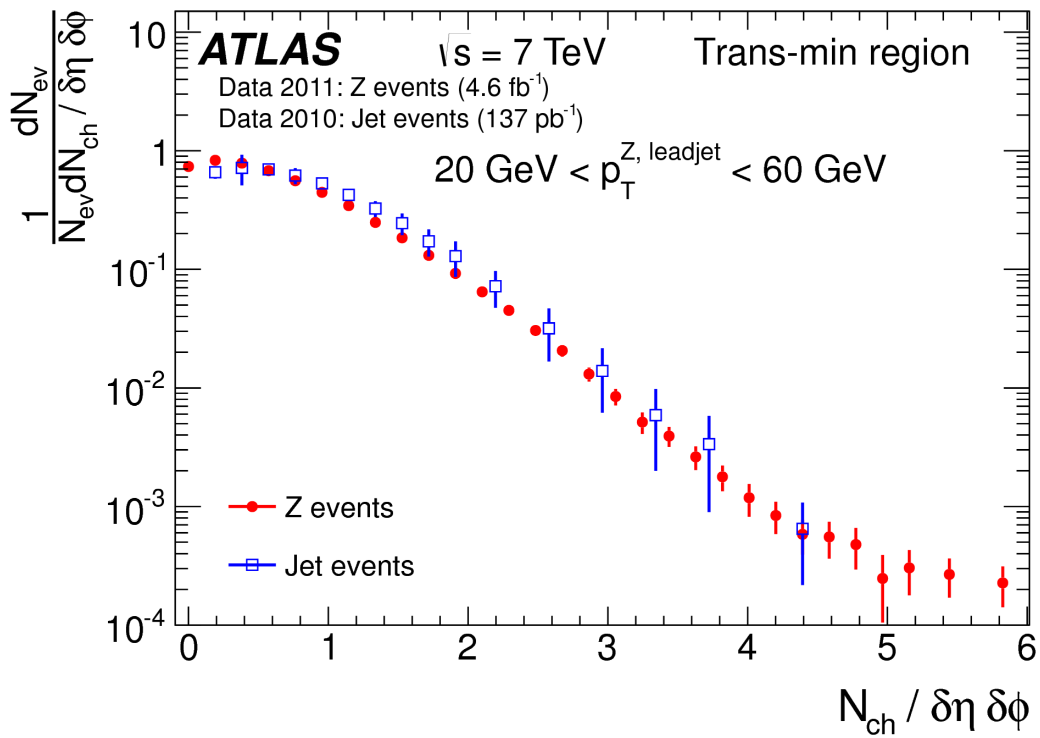
p_T^Z [GeV]

- In $Z \rightarrow ll$ events, it is possible to measure the UE in the toward, transverse and away regions
- In the high p_T region, the contribution from pQCD ME starts at different jets multiplicity for the away (Z+≥1jet), toward (Z+≥2jets), trans (Z+≥3 jets)
- Low p_T region is less sensitive to perturbative QCD, and can be used for tuning the non-pQCD parameters

Comparison between UE and Minimum bias

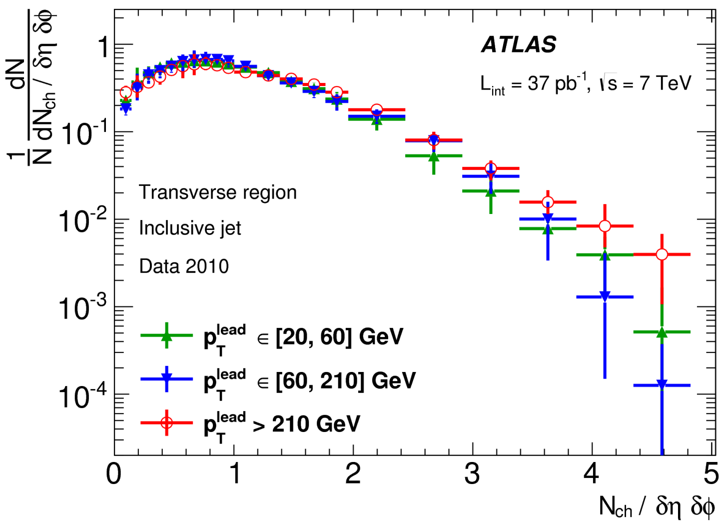
arXiv:1409.3433

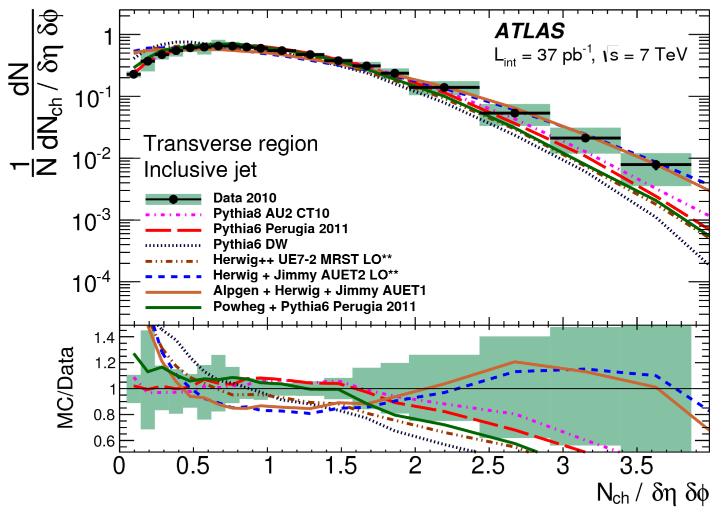




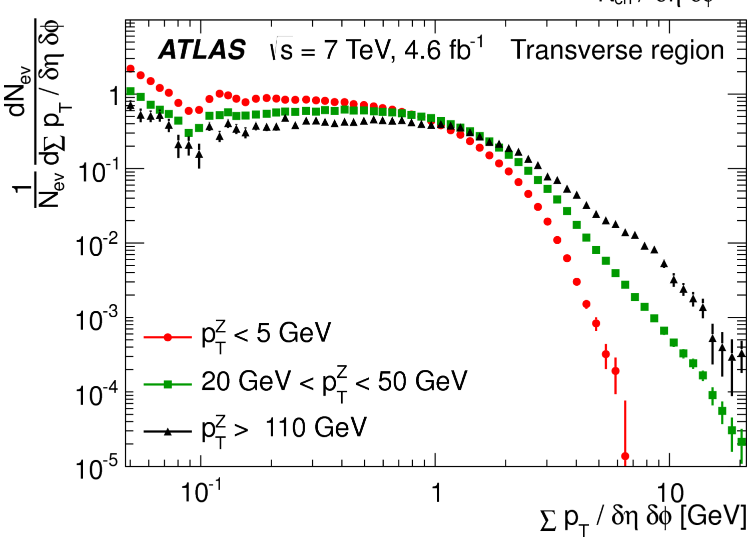
- Underlying event observables can be compared between jets and Z boson production, and also to minimum bias measurements
- Similar behaviour between jets and Z boson, especially in the trans-min region, which is most sensitive to the MPI
- Qualitative check of the universality of the MPI model in different hard processes

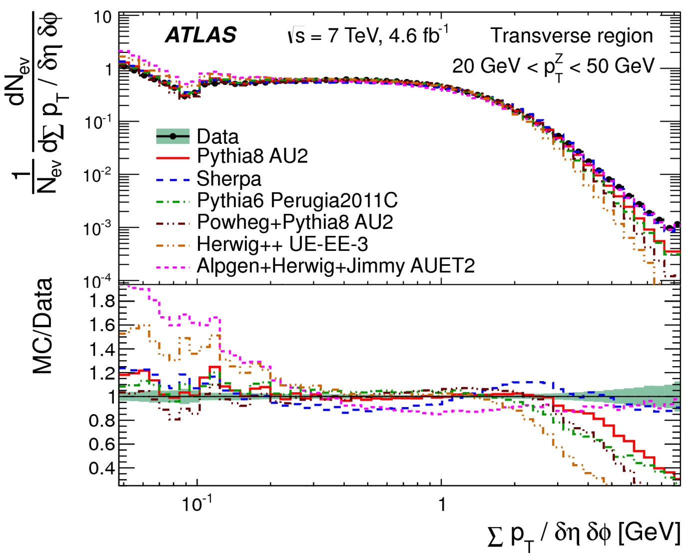
Charged particle p_T and multiplicity spectra





Eur.Phys.J.C74 (2014) 2965





arXiv:1409.3433

- Differential and double differential particles multiplicity and Σp_T spectra provide further discrimination between MC models
- Very challenging for the soft QCD models to describe these observables, see also the new ATLAS tune A14 in A. Buckley's talk in the next session

Summary and conclusions

- New ATLAS measurements of underlying event observables in Jets and Z boson production
- Large variety of multiplicity and energy density distributions, as well as multiplicity and p_T particles spectra
- Compared underlying event measurements and minimum bias measurements
- Measurements are sensitive to non-perturbative QCD parameters and models, and can be used to tune the MC generators
- Underlying event are expected to be sensitive to the MPI parameters like IR cut-off, $\alpha_s^{MPI}(m_Z)$, and to the various color reconnection models
- Underlying event measurements in Run 2 will provide further insight into the center-of-mass energy dependence of the parameters

BACKUP

Systematic uncertainties

- Jet reconstruction / lepton identication and scale
- Track reconsttruction efficiency
- Calorimeter reconstruction
- Pile-up
- Background
- Unfolding

Quantity	Inclusive jets			Exclusive dijets		
All observables	Pile-up and merged vertices 1–3%			Pile-up and merged vertices 1–5%		
Charged tracks	Unfolding	Efficiency		Unfolding	Efficiency	
$\sum p_{\mathrm{T}}$	3%	1–7%		3–13%	2–7%	
N_{ch}	1–2%	3–4%		3–22%	3–7%	
mean p_{T}	1%	0–4%		1–9%	1%	
Calo clusters	Unfolding	Efficiency		Unfolding	Efficiency	
$\sum E_{\mathrm{T}}, \lvert\eta\rvert < 4.8$	2–3%	4–6%		5–21%	4–9%	
$\sum E_{\mathrm{T}}, \lvert\eta\rvert < 2.5$	3–5%	4–6%		1–21%	4–7%	
Jets	Energy resolution	JES	Efficiency	Energy resolution	JES	Efficiency
$p_{\mathrm{T}}^{\mathrm{lead}}$	0.3–1%	0.3–4%	0.1–2%	0.4–3%	1–3%	0.3–3%

Observable	Correlation	N_{ch} vs $p_{\mathrm{T}}^{\mathrm{Z}}$	$\sum p_{\mathrm{T}}$ vs $p_{\mathrm{T}}^{\mathrm{Z}}$	Mean p_{T} vs $p_{\mathrm{T}}^{\mathrm{Z}}$	Mean p_{T} vs N_{ch}
Lepton selection	No	$0.5-1.0$	$0.1-1.0$	< 0.5	$0.1-2.5$
Track reconstruction	Yes	$1.0-2.0$	$0.5-2.0$	< 0.5	< 0.5
Impact parameter requirement	Yes	$0.5-1.0$	$1.0-2.0$	$0.1-2.0$	< 0.5
Pile-up removal	Yes	$0.5-2.0$	$0.5-2.0$	< 0.2	$0.2-0.5$
Background correction	No	$0.5-2.0$	$0.5-2.0$	< 0.5	< 0.5
Unfolding	No	$0.5-3.0$	$0.5-3.0$	< 0.5	$0.2-2.0$
Electron isolation	No	$0.1-1.0$	$0.5-2.0$	$0.1-1.5$	< 1.0
Combined systematic uncertainty		$1.0-3.0$	$1.0-4.0$	< 1.0	$1.0-3.5$