

# Recent results on UE and double parton scattering with the ATLAS detector

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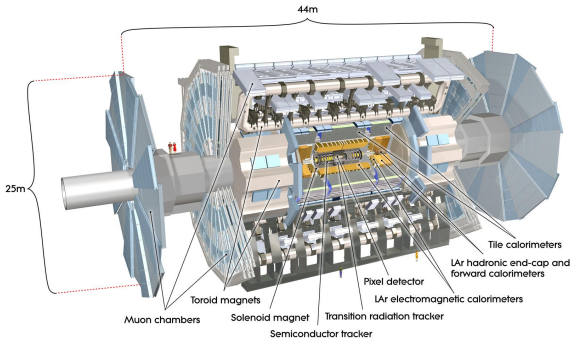


# Introduction

Presenting two ATLAS analyses:

- The underlying event in jet production
- Measuring DPI in W-boson events with 2 jets

## ATLAS



Different subdetectors relevant for identification of particular objects:

- Tracking detectors  $|\eta| < 2.5$  — charged particles
- Calorimeters  $|\eta| < 4.8$  — charged and neutral particles, jet and electron identification
- Muon tracker  $|\eta| < 2.7$

# Dataset

Using data collected in 2010:

- $\sqrt{s} = 7 \text{ TeV}$
- Integrated luminosity  $36 \text{ pb}^{-1}$
- Low pileup (increasing over the run to  $\sim 2$  interactions per bunch-crossing)

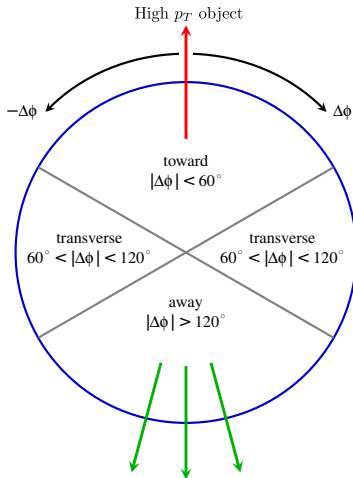


## Underlying Event



# Underlying Event in Jet Production

- Classic definition of event topology, oriented by the highest  $p_T$  jet in the event
- Anti- $k_T$  jets with  $R = 0.4$ ,  $p_T > 20$  GeV,  $|y| < 2.8$
- Inclusive selection requires one or more jets
- Exclusive selection requires exactly two jets with  $p_T$  balance
- Most and least active sides of the transverse region dubbed trans max/min



## Leading Jet UE - MC Models

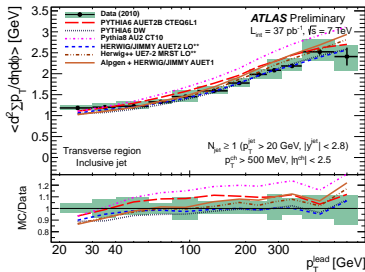
All data distributions corrected to the particle level, then compared with the following MC models:

- Pythia 6 AUET2B
- Pythia 6 DW
- Pythia 8 AU2
- Herwig + Jimmy AUET2
- Herwig++ UE7-2
- Alpgen + Herwig + Jimmy AUET1

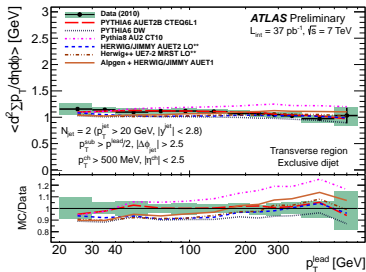


# Leading Jet UE - Charged Particle $\Sigma p_T$

## Inclusive



## Exclusive

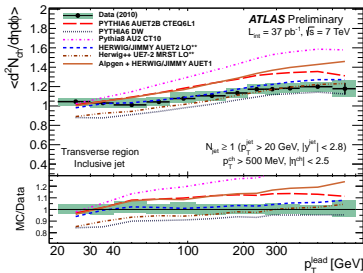


Inclusive selection shows rising activity with lead jet  $p_T$ , but the exclusive selection gives flat behaviour

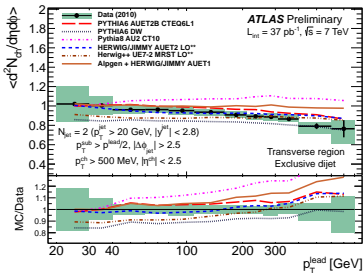


# Leading Jet UE - Charged Particle Multiplicity

## Inclusive



## Exclusive

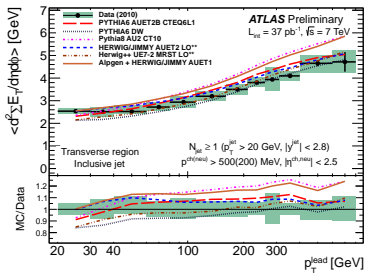


Similar behaviour to  $\Sigma p_T$  — note the exclusive profile shows falling activity with lead jet  $p_T$

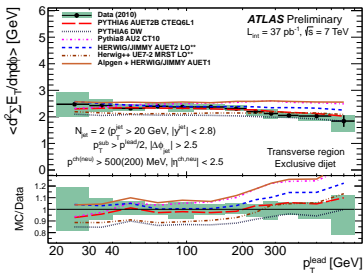
The exclusive di-jet requirement may veto jets from MPI

# Leading Jet UE - Charged and Neutral Particle $\Sigma E_T$

## Inclusive



## Exclusive

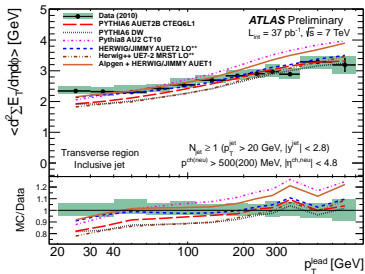


Using the ATLAS calorimeters allows the inclusion of neutral particles

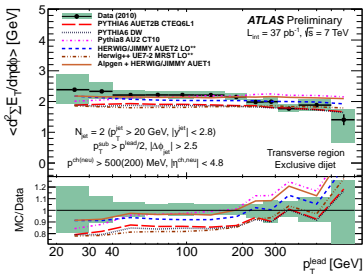
Similar UE behaviour as charged particle  $\Sigma p_T$

# Leading Jet UE - Charged and Neutral Particle $\Sigma E_T$

## Inclusive



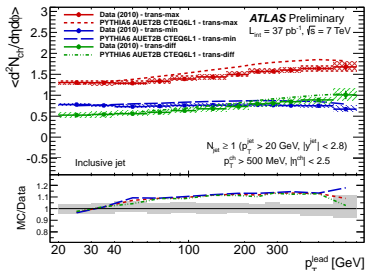
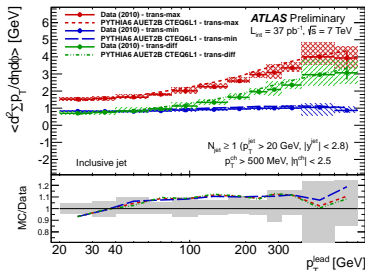
## Exclusive



The calorimeters also give greater acceptance, with  $|\eta| < 4.8$

Including these regions does not dramatically change the data behaviour, but MC performance is less good

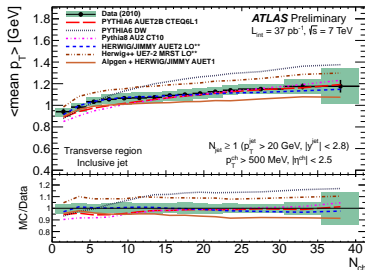
# Leading Jet UE - Trans Max/Min

 $\Sigma p_T$  $N_{ch}$ 

Inclusive trans min results similar to exclusive selection, suggesting the pure MPI activity is independent of the hard process scale (when collisions are central)

# Leading Jet UE - Mean $p_T$ vs Multiplicity

## Inclusive

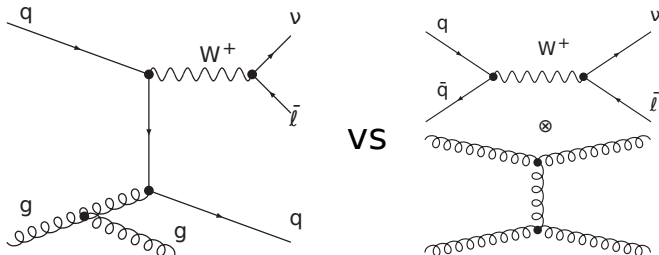


The behaviour of this distribution has been well established in past experiments, but note that even recent MC tunes can still get it wrong

## Double Parton Interactions



# DPI in $W \rightarrow l\nu + 2 \text{ jets}$



Compare the rate of production of  $W + 2$  associated jets (left) with rate of double parton interactions producing a  $W$ -boson in one case and a dijet in the other (right)

## Observables

In DPI events the dijet system should conserve momentum independently of the W-boson decay, so examine the total transverse momentum of the two jets:

$$\Delta_{\text{jets}} = |\vec{p}_T^1 + \vec{p}_T^2|$$

To remove dependence on the jet energy scale, this observable is normalised:

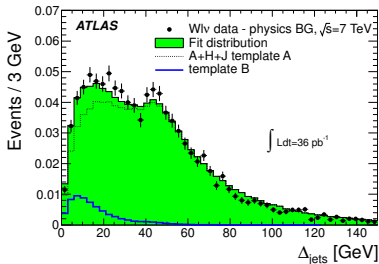
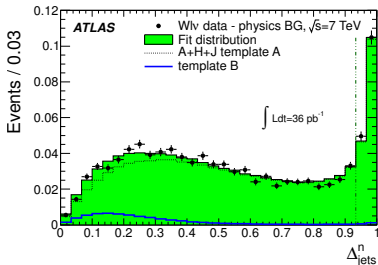
$$\Delta_{\text{jets}}^n = \frac{|\vec{p}_T^1 + \vec{p}_T^2|}{|\vec{p}_T^1| + |\vec{p}_T^2|}$$

$\Delta_{\text{jets}}^n$  is the observable used for fitting, but  $\Delta_{\text{jets}}$  distributions are retained for cross-checks





# Templates



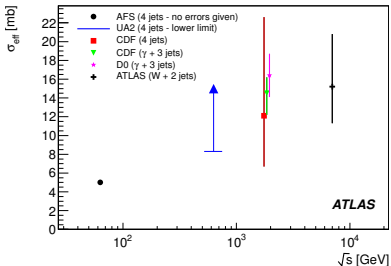
Fit the distributions of these two observables using two templates:

- Template A: W + 2 jets, using Alpgen + Herwig + Jimmy
- Template B: Data sample of di-jet events

Extract the fraction of DPI events:  $f_{DP}^{(D)} = 0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{sys.})$



## Effective cross-section



The extracted value for the effective DPI cross-section is

$$\sigma_{\text{eff}}(7 \text{ TeV}) = 15 \pm 3(\text{stat.})_{-3}^{+5}(\text{sys.}) \text{ mb}$$

This is comparable to values measured at other centre-of-mass energies at other experiments



# Summary

Analysis of low-pileup 2010 data still yielding interesting results:

- The underlying event in leading jet events has been measured
  - Exclusive di-jet selection showing flat/falling UE activity
  - High  $|\eta|$  acceptance (potential for MC improvement)
  - Results up to 800 GeV leading jet  $p_T$
- The effective cross-section for DPI has been measured in events containing both a W-boson decay and 2 jets
  - $\sigma_{\text{eff}}(7 \text{ TeV}) = 15 \pm 3(\text{stat.})_{-3}^{+5}(\text{sys.}) \text{ mb}$
  - Comparable to previous results at lower  $\sqrt{s}$



## For Further Reading I



The underlying event in jet events at 7 TeV with the ATLAS experiment

<https://cds.cern.ch/record/1497185>



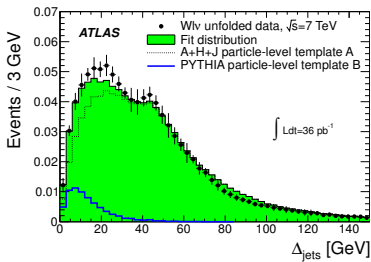
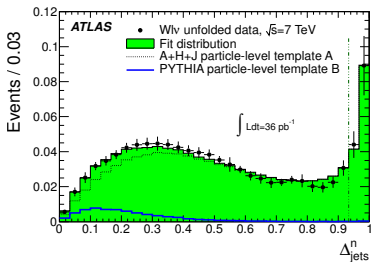
Measurement of hard double-parton interactions in  $W$  ( $\rightarrow l\nu$ ) + 2 jet events at  $\sqrt{s} = 7$  TeV with the ATLAS detector

New J. Phys. 15 (2013) 033038

<https://cds.cern.ch/record/1510534>

# Backup

# W + 2 jets unfolded



Unfolded data and MC templates at particle level