

# Underlying events and particle production in ATLAS

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Sebastian Wahrmund  
on behalf of the ATLAS Collaboration

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TECHNISCHE  
UNIVERSITÄT  
DRESDEN



Bundesministerium  
für Bildung  
und Forschung



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## 2 Measurement of the pseudorapidity dependence of the total transverse energy

- Introduction
- Results for mean sum of energy
- Results for 1D distributions

## 3 Double Parton Interaction

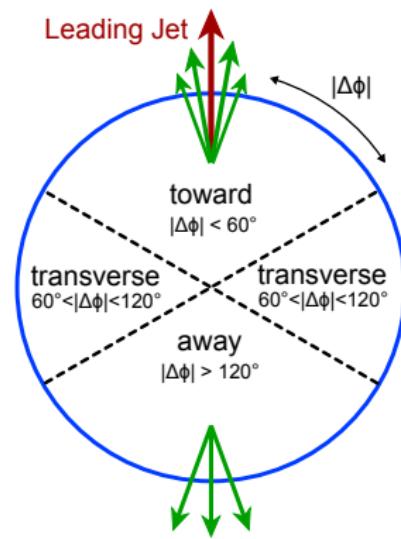
- Overview and Strategy
- Fit Results
- Results for  $\sigma_{\text{eff}}$

# Measurement of the underlying event in jet events

arXiv:1406.0392

# Underlying Event - Introduction

- Identify object corresponding to hard process  
⇒ anti- $k_T$  ( $\Delta R = 0.4$ ) jet with highest  $p_T$
- Use tracks or topoclusters to describe the underlying event
- Divide  $\phi$ -space into 3 regions according to  
 $\Delta\phi = \phi_{leading-jet} - \phi_{object}$ 
  - **toward**  $|\Delta\phi| < 60^\circ$
  - **transverse**  $60^\circ < |\Delta\phi| < 120^\circ$
  - **away**  $|\Delta\phi| > 120^\circ$
- Toward/away regions dominated by the hard process
- Transverse region sensitive to underlying event
- Define most/least active side of transverse region as trans-max/trans-min



# Observables

## Track based observables

- $p_T > 500 \text{ MeV}$ ,  $|\eta| < 2.5$
- Track quality criteria

$d^2 N_{\text{ch}} / d\eta d\phi$ : Mean number of stable charged particles per unit  $\eta - \phi$

$d^2 \sum p_T / d\eta d\phi$ : Mean scalar  $p_T$  sum of stable charged particles per unit  $\eta - \phi$

$\langle \text{mean } p_T \rangle$ : Average  $p_T$  of stable charged particles (Backup)

## Cluster based observables

- No  $E_T$  cut (except for noise thresholds)
- $|\eta^{\text{clus}}| < 2.5$  or  $|\eta^{\text{clus}}| < 4.8$

$d^2 \sum E_T / d\eta d\phi$ : Mean  $E_T$  sum of stable charged and neutral particles per unit  $\eta - \phi$

# Event Selection

## Inclusive Selection

- ▶ Event Cleaning
  - ▶ Trigger
  - ▶ Leading jet  $p_T > 20 \text{ GeV}$ ,  $|y| < 2.8$
  - ▶ Primary vertex with  $N_{\text{Trk}} \geq 5$
  - ▶ No additional vertex
- Stable beam, etc...
- 99% trigger efficiency
- Def. direction/scale of hard scattering
- Pileup veto

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## Exclusive Selection

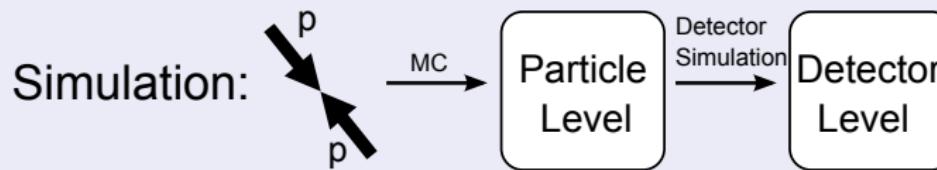
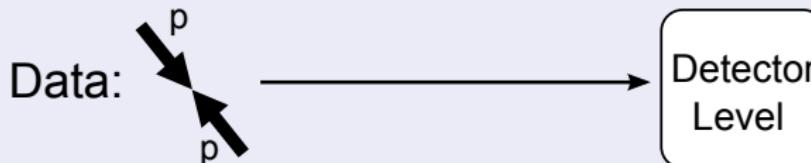
- ▶ Dijet selection
- ▶  $p_T^{\text{sub}} / p_T^{\text{lead}} > 0.5$
- ▶  $|\Delta\Phi_{\text{lead, sub}}| > 2.5$
- ▶ Reject events with 3rd jet

} Leading and balancing jet are located in the toward and away region

Remove add. contribution from hard scattering

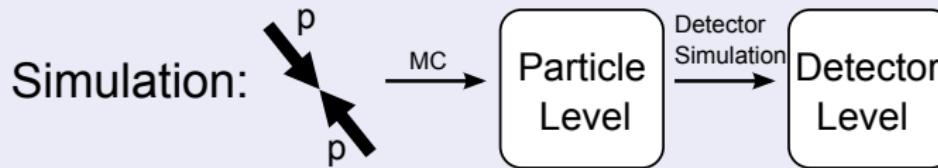
# Correction back to particle level

## Corrections



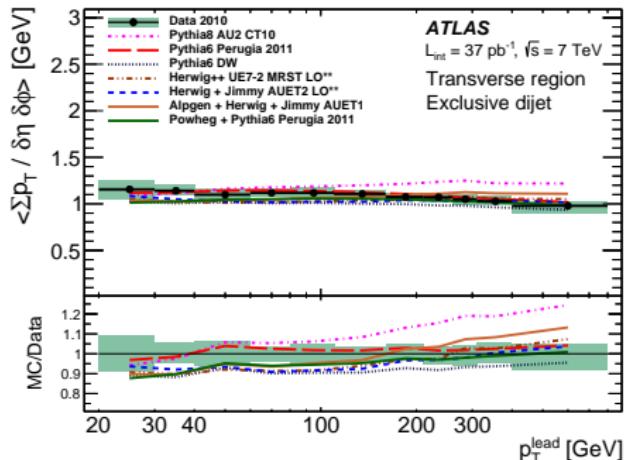
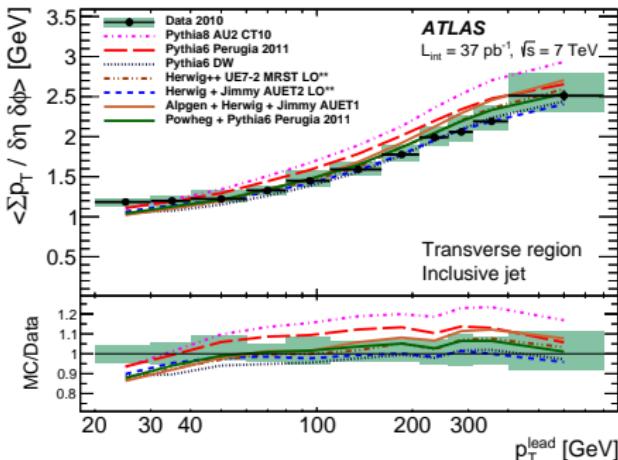
# Correction back to particle level

## Corrections



- Corrections of track/trigger effects using independent studies
- Additional correction for secondary particles
- Iterative Bayesian unfolding including all systematics

# $\sum p_T$ vs $p_T^{\text{lead}}$

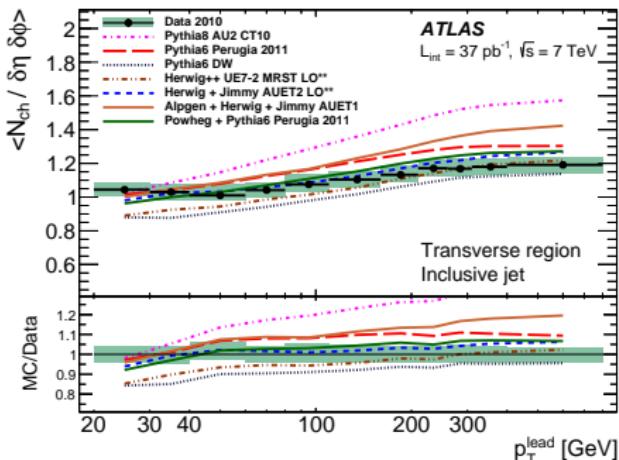


Inclusive

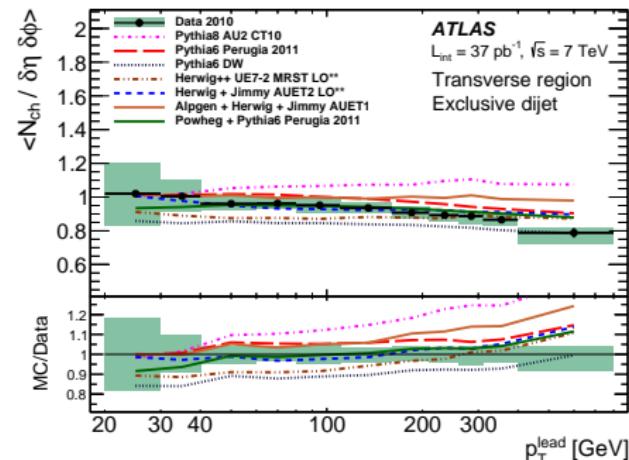
Exclusive

- Continues increase of activity for inclusive jet selection
- Flat activity for exclusive dijet region with small decrease of activity at larger values of  $p_T^{\text{lead}}$

# $N_{\text{ch}}$ vs $p_{\text{T}}^{\text{lead}}$



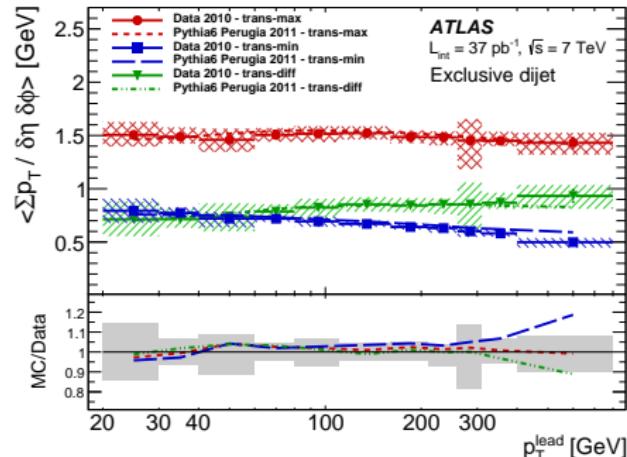
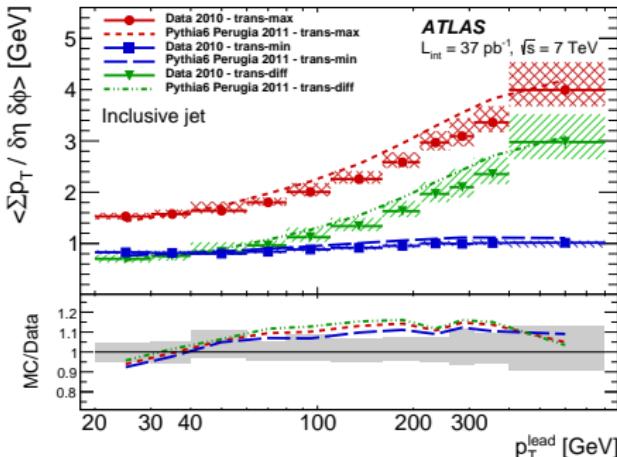
Inclusive



Exclusive

- Very similar behavior like for  $\sum p_{\text{T}}$

# TransMax/Min/Diff

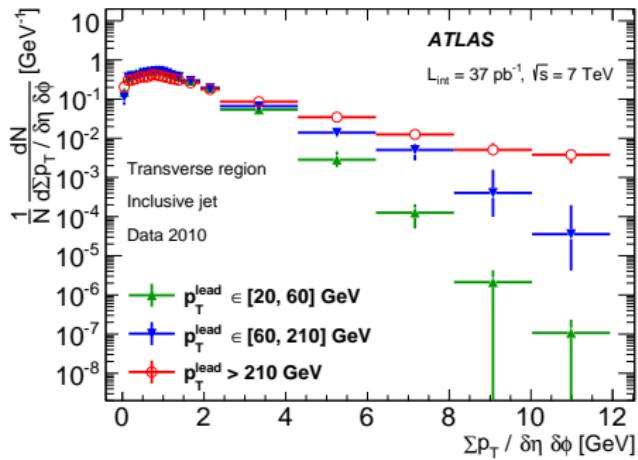
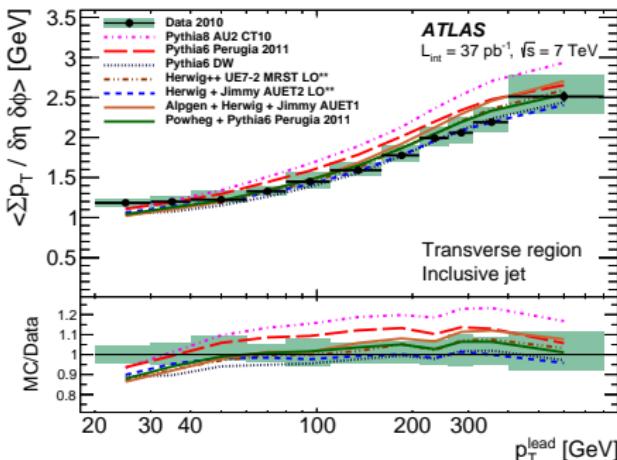


## Inclusive

## Exclusive

- Increase of activity in inclusive region comes mainly from trans-max region
- Decrease of activity in exclusive region comes mainly from trans-min region

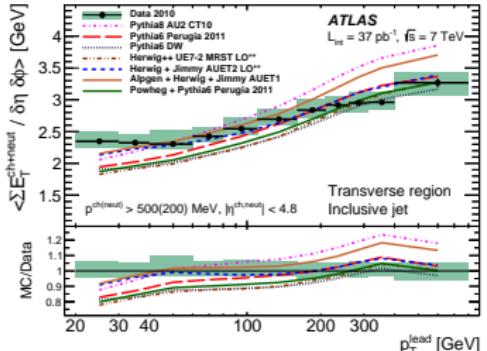
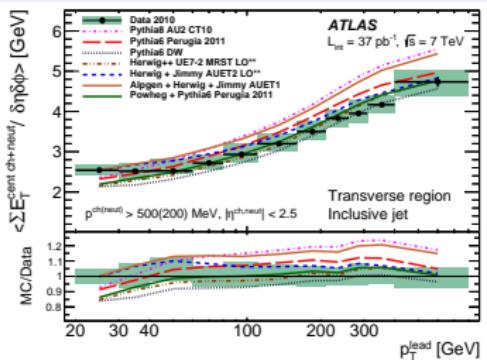
# 1D Slices for $\sum p_T$



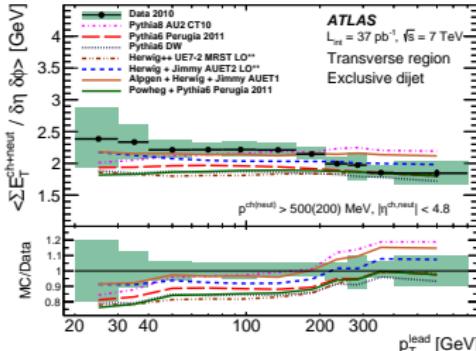
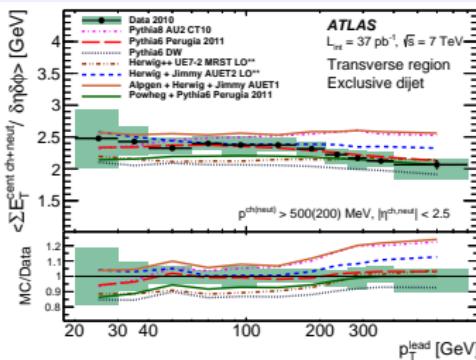
- 1D distribution of  $\sum p_T$  slices for different  $p_T^{\text{lead}}$
- The increase of the mean  $\sum p_T$  value is triggered by the increase in the high  $\sum p_T$  tail

# Adding neutral components

$$\sum E_T \quad (|\eta| < 2.5)$$

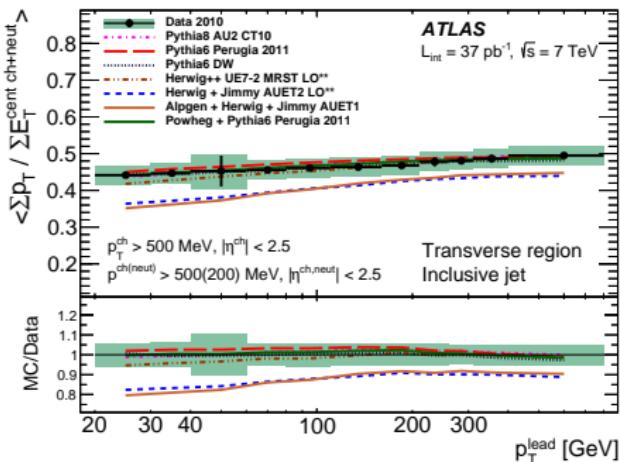


Inclusive



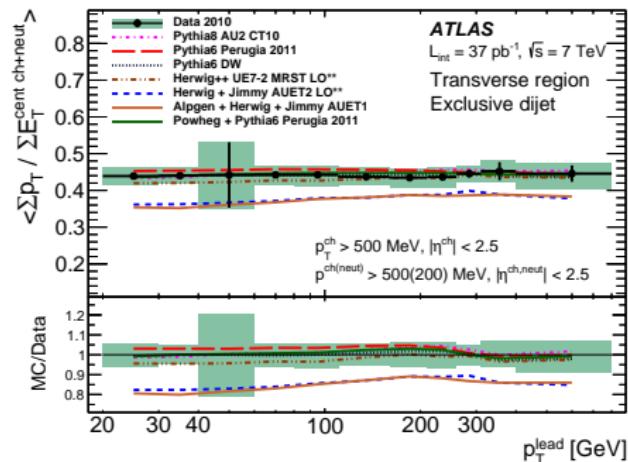
Exclusive

# Ratio between charge/neutral components



Inclusive

- Slight dependence on  $p_T^{\text{lead}}$  for inclusive region
- Flat distribution for exclusive region



Exclusive

# Measurement of the pseudorapidity dependence of the total transverse energy

JHEP11(2012)033

# Introduction

- Measurement of the sum of transverse energy depending on  $\eta$
- Use full range covered by ATLAS calorimeter
- Two selection regions:
  - ① Minimum bias(MB):
    - Most inclusive selection
    - Minimal event selection to ensure an inelastic collision
  - ② Dijet selection:
    - Requirement of 2 jets
    - Only consider cluster/particles in azimuthal transverse region to hard scatter plane
    - Bias to less peripheral collisions
- Early 2010 ATLAS data is used to reduce contamination of pileup

# Event Selection & Unfolding

## Minimum Bias Selection

- One sided MBTS trigger
- One primary vertex with at least 2 tracks
- No add. vertices with  $N_{\text{trk}} > 5$  (pileup veto)

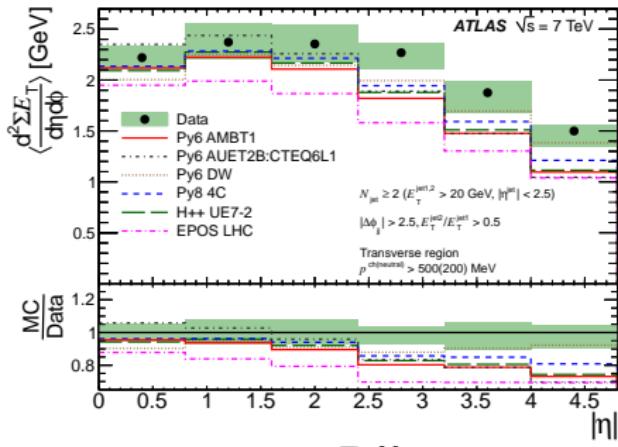
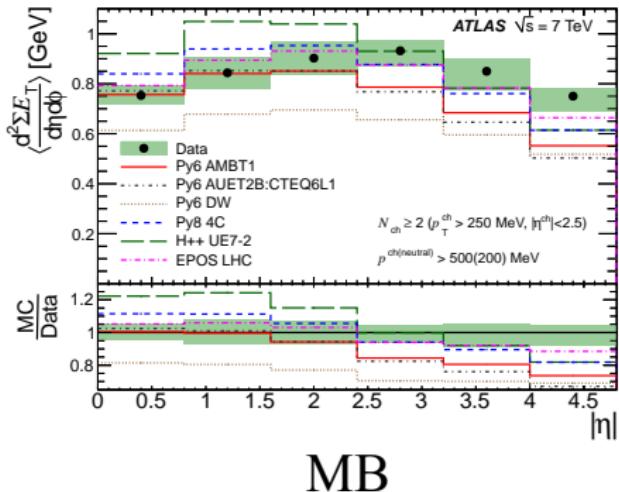
## Dijet Selection

- Performed on top of MB selection
- 2 jets with  $E_T > 20\text{GeV}$  and  $|\eta| < 2.5$
- Balance requirements:  $|\phi_{jj}| > 2.5$  and  $\frac{E_T^{\text{jet}2}}{E_T^{\text{jet}1}}$

## Unfolding

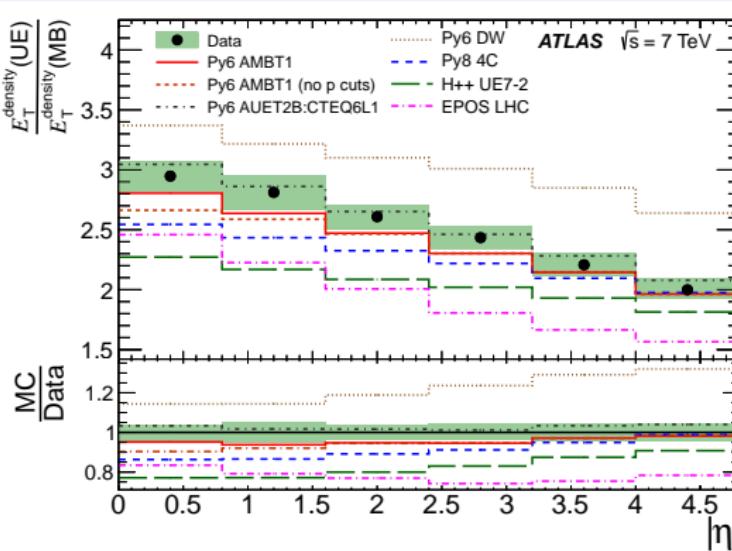
- Iterative Bayesian unfolding procedure is used for each  $\eta$  region

# Mean Sum of Energy



- Decrease of transverse energy density in forward region compared to central region
- MB data is lower in central region than dijet selection due to relative fraction of low momentum particles
- All MCs underestimate the energy density in forward region

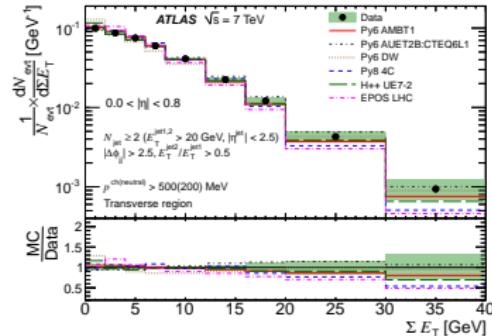
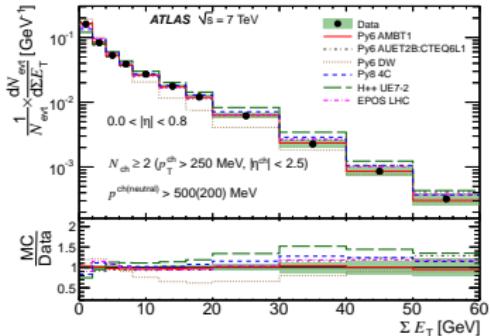
# Ratio between MB and Dijet Selection



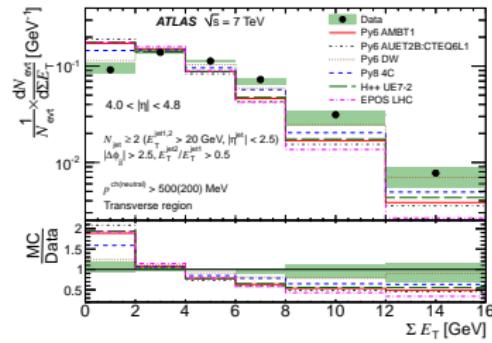
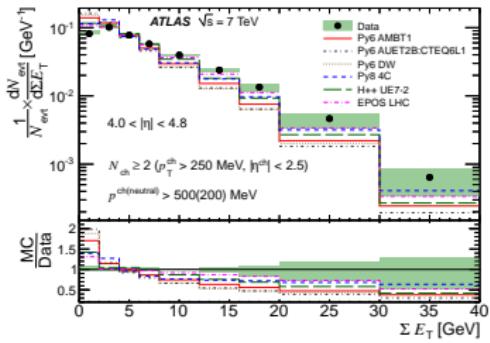
- $E_T^{\text{density}}$  is larger in dijet selection compared to MB selection
- Dijet requirement biases the selection towards small impact parameter

# EtSum distributions for several $\eta$ ranges

$0.0 < |\eta| < 0.8$



$4.0 < |\eta| < 4.8$



MB

Dijet

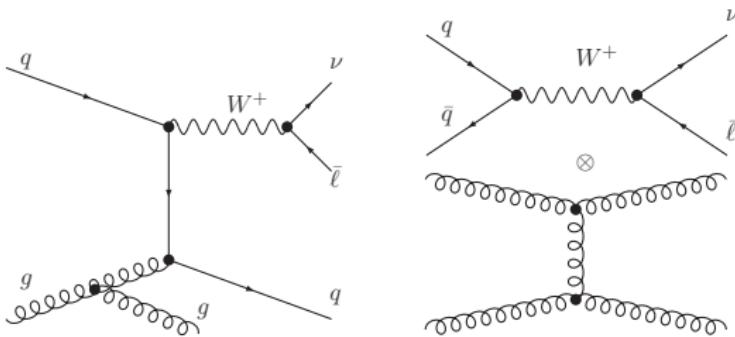
Underlying events and particle production in ATLAS

# Double parton interaction measurements in $W \rightarrow l\nu + 2\text{jet}$ events

New J. Phys. 15 (2013) 033038

# Introduction

- Measurement of double parton interactions using  $W \rightarrow l\nu + 2\text{jet}$  events



- Obtain the fraction of events with  $W + \text{additional 2 jet system}$
- Calculate the effective cross-section for double parton scattering

# Measurement Strategy

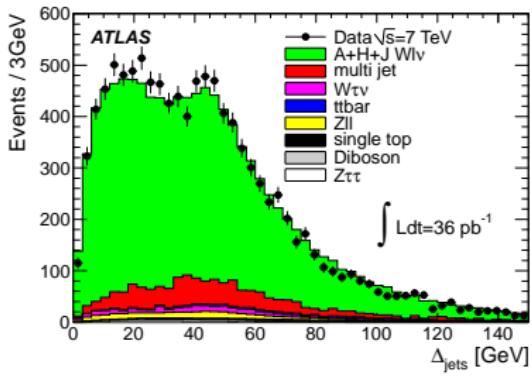
## Analysis

- $f_{\text{DP}}^{(\text{D})}$ : Fraction of  $W + 2\text{jet}$  events, where both jets originate from hard DPI

$$f_{\text{DP}}^{(\text{D})} = \frac{N_{W_0j+2j_{\text{DPI}}}}{N_{W_2j} + N_{W_0j+2j_{\text{DPI}}}}$$

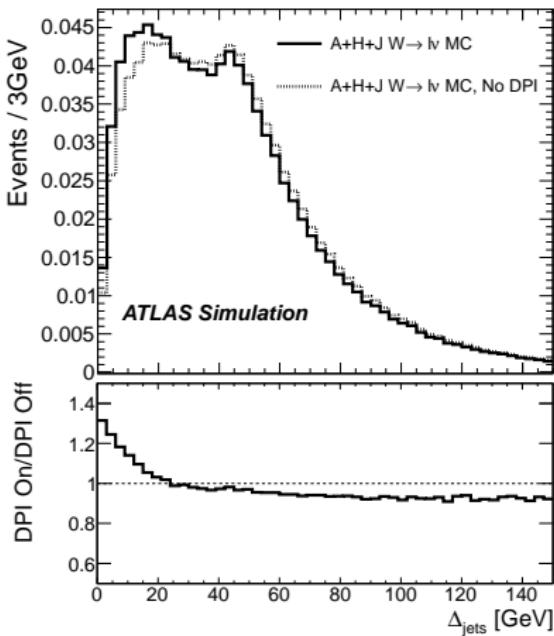
- Select  $W \rightarrow e\nu/\mu\nu + 2\text{jets}$  events from data
  - Subtraction of the main backgrounds
  - Template fit to estimate  $f_{\text{DP}}^{(\text{D})}$
  - Discrimination variable: Balance of jet momenta
- ⇒ Dijet system is decorrelated to the  $W$  system (for DPI)

# Balance of $p_T$

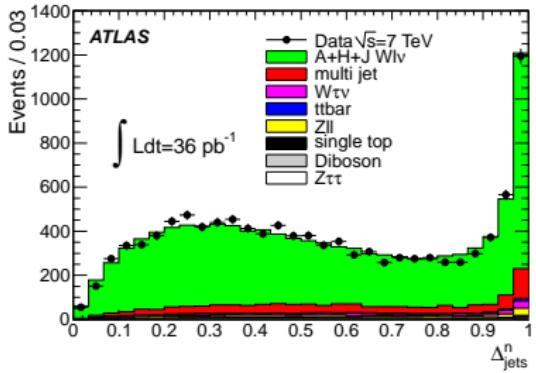


$$\Delta_{\text{jets}} = \left| \vec{p}_{\text{T}}^{\text{j1}} + \vec{p}_{\text{T}}^{\text{j2}} \right|$$

- Signal: Alpgen interfaced with Herwig/Jimmy

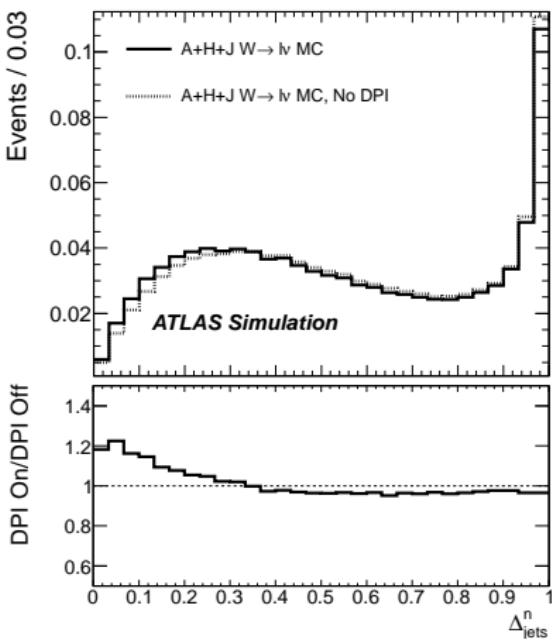


# Balance of $p_T$ - normalised

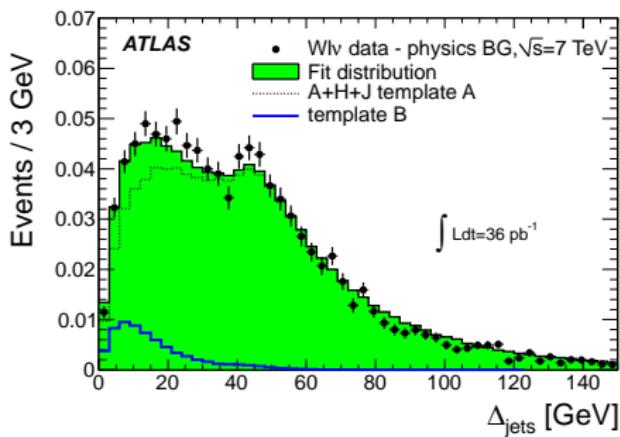
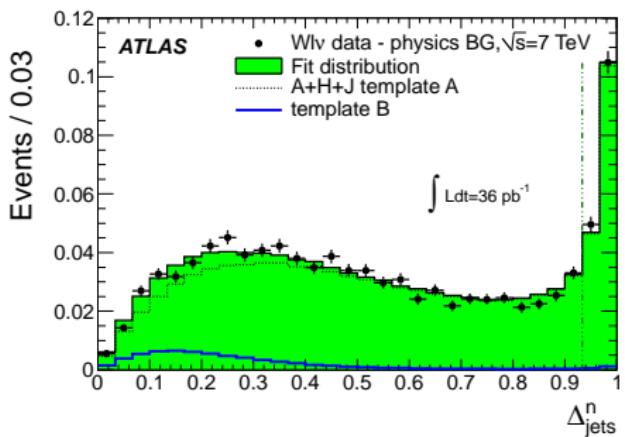


$$\Delta_{\text{jets}}^n = \frac{\left| \vec{p}_T^{\text{J1}} + \vec{p}_T^{\text{J2}} \right|}{\left| \vec{p}_T^{\text{J1}} \right| + \left| \vec{p}_T^{\text{J2}} \right|}$$

- Use for  $f_{\text{DP}}^{(\text{D})}$  fit



# Fit Results



- Background subtraction based on MC/data-driven estimations
- Dijet data sample as template for DPI only
- Correction for pile-up applied

$$f_{DP}^{(D)} = 0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{sys.})$$

$\sigma_{\text{eff}}$ 

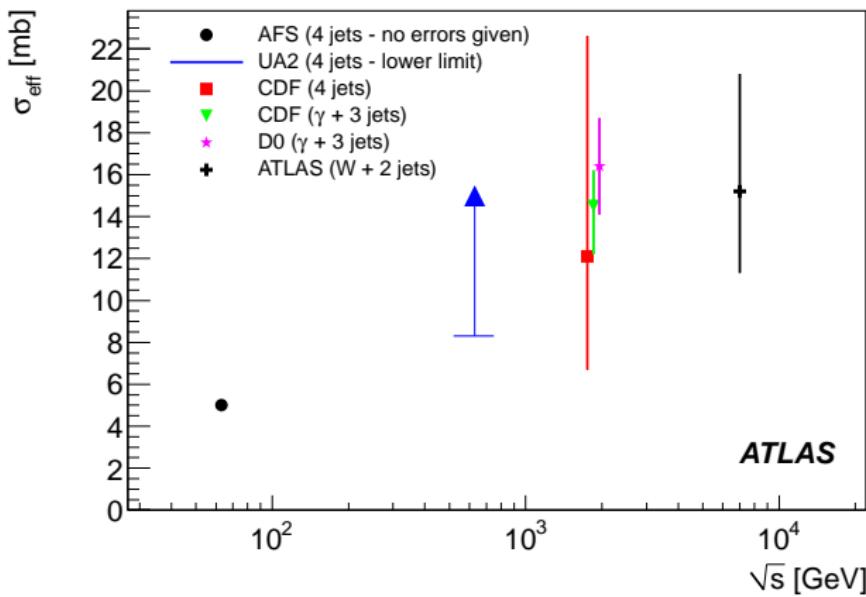
- Use  $f_{\text{DP}}^{(\text{D})}$  to estimate  $\sigma_{\text{eff}}$

$$\sigma(A + B) \underset{A \neq B}{=} \frac{\sigma(A) \cdot \sigma(B)}{\sigma_{\text{eff}}} \Rightarrow \sigma_{\text{eff}} = \frac{\sigma_{W_{0j}} \cdot \sigma_{2j}}{\sigma_{W_{0j}+2j_{\text{DPI}}}}$$

- Assumptions:
  - No influence of W systems to the dijet system
  - Kinematics of of DPI can be modeled using single-scattered dijet events

$$\sigma_{\text{eff}} = \frac{N_{W_{0j}} N_{2j}}{L_{2j} \cdot f_{\text{DP}}^{(\text{D})} \cdot N_{W+2j}}$$

# Final result for $\sigma_{\text{eff}}$



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

# Summary

- Wide program of soft QCD physic within ATLAS
- Presented a snapshot today:
  - Underlying event measurements using jets up to 800 GeV
  - Energy flow measurements
  - Double parton interaction
- Furthermore:
  - $\phi$  meson production
  - Event shapes
  - ...

Thank for your attention!

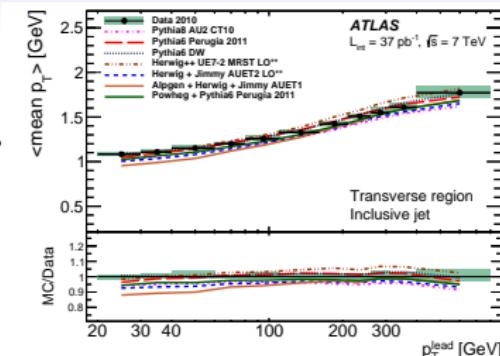
# Backup

# UE Analysis - Object Selection Details

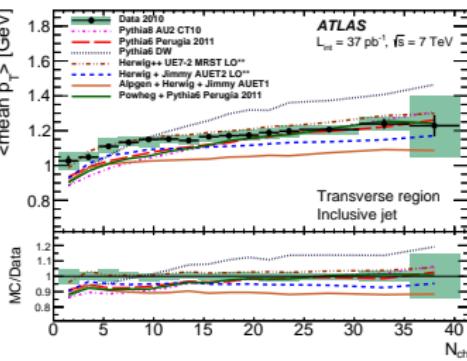
|         | Detector Level (Data)  | Particle Level (MC)  |
|---------|--|--|
| Jets    | anti- $k_T$ ( $R=0.4$ ) based on calorimeter cluster<br>$p_T > 20 \text{ GeV}$ , $ y  < 2.8$   | anti- $k_T$ ( $R=0.4$ ) based on stable particles<br>$p_T > 20 \text{ GeV}$ , $ y  < 2.8$  |
| Tracks  | Inner detector tracks<br>$p_T > 500 \text{ MeV}$ , $ \eta  < 2.5$<br>Quality cuts on hits in ID<br>$ d_0  < 1.5 \text{ mm}$ ,<br>$ z_0 * \sin(\theta)  < 1.5 \text{ mm}$ | Charged and stable particles<br>$p_T > 500 \text{ MeV}$ , $ \eta  < 2.5$                   |
| Cluster | Topological clusters of calorimeter cells<br>$ \eta^{\text{clus}}  < 2.5$ or<br>$ \eta^{\text{clus}}  < 4.8$<br>Quality cuts   | Stable particles<br>$p > 200(500) \text{ MeV}$ for neutral(charged)<br>$ \eta  < 2.5(4.8)$ |

# UE Analysis - $\langle \text{mean } p_T \rangle$ vs $p_T^{\text{lead}}$ and $N_{\text{ch}}$

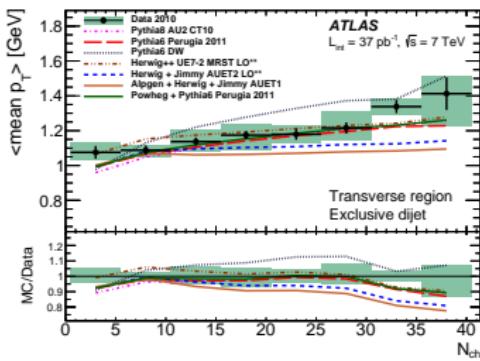
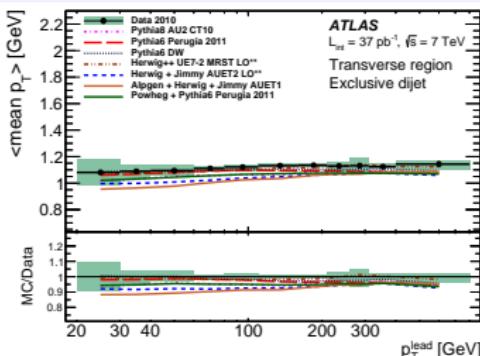
$\langle \text{mean } p_T \rangle$   
vs  $p_T^{\text{lead}}$



$\langle \text{mean } p_T \rangle$   
vs  $N_{\text{ch}}$



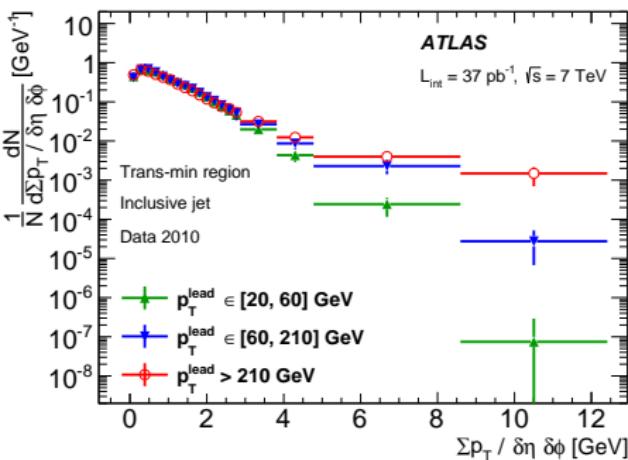
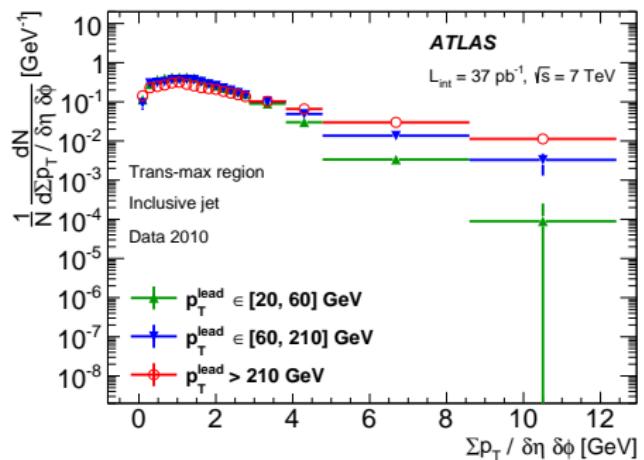
Inclusive



Exclusive

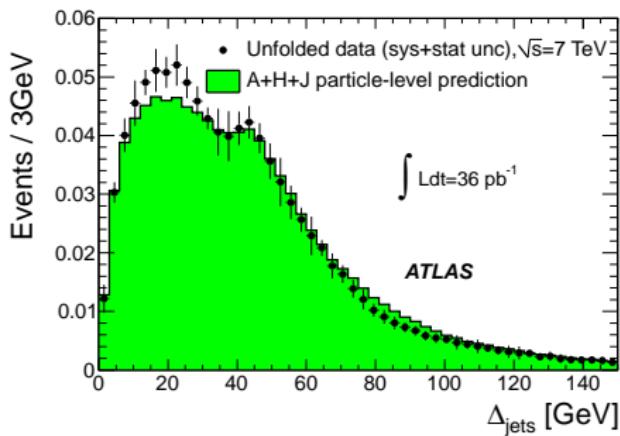
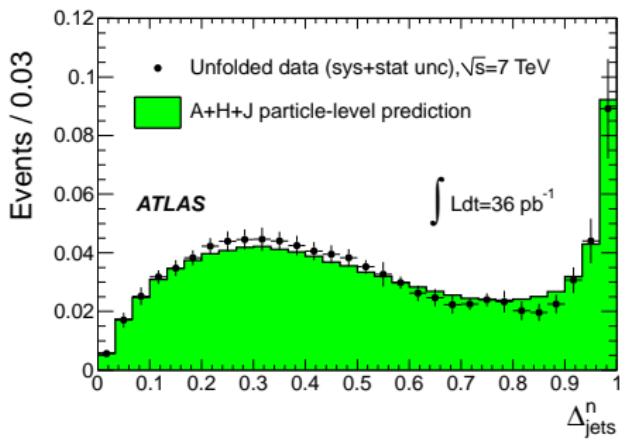
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# UE Analysis - 1D Slices for $\sum p_T$ in trans-max/min



- Increased dependence of 1D distribution from  $p_T^{\text{lead}}$  in trans-max compared to trans-min

# DPI - Results for Unfolded Data



- Iterative Bayesian unfolding procedure was used for data (after background subtraction)
- Response matrix based on Alpgen+Herwig/Jimmy predictions