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Underlying event in jet events at 7 TeV with the ATLAS experiment

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The distributions sensitive to underlying event characteristics were measured in jet events in proton-proton collisions at a centre-of-mass energy of $\sqrt{s}$ = 7 TeV with the ATLAS detector at the LHC. The charged particle multiplicity, charged and inclusive sum p_{T} densities, in the regions azimuthally transverse to the hardest jet, are presented as a function of the hardest jet p_{T} from 20 GeV to 800 GeV. The measurements of inclusive sum p_{T} distributions of charged and neutral particles are extended up to forward pseudorapidity $|\eta| < 4.8$. Separate inclusive jet and exclusive dijet event selections, and event-by-event transverse min/max regions, are included in this work for all observables allowing for a detailed studies of the underlying event models implemented in Monte-Carlo generators.

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1. Introduction

The aim of the Large Hadron Collider (LHC) experiments is to study details of the electroweak symmetry breaking and search for new physics. Such processes typically involve high momentum transfer, contrary to the dominant part of the proton-proton cross section, which is driven by soft phenomena. Due to the composite nature of hadrons, multiple parton-parton interactions (MPI) can occur in the collisions, and it is likely that the additional interactions will be soft, i.e. dominated by low momentum transfer t-channel gluon exchanges. In order to make precise measurements at proton-proton colliders it is important to have a good understanding not only of the hard scattering interactions, but also of the accompanying interactions in the rest of the proton taking place in the collisions.

Collectively termed as Underlying Event (UE), the soft activity may receive contributions from initial and final state radiation (ISR, FSR), leftover partons in the collisions called beam remnants, and the MPI mentioned above. While they are kinematically interlinked and it is, even in principle, impossible to uniquely separate effects of the UE from the hard scattering, observables sensitive to UE may be formed and measured. Being dominated by low momentum exchanges, the perturbative theory fails to predict UE from first principles in Quantum Chromodynamics. It is therefore modelled in a phenomenological manner implemented in Monte-Carlo generators. Until now the UE has been observed to be largely independent of the hard processes. Thus, the model of UE when tuned to a range of experimental measurements can be applied to a simulation of a new process, and the larger the range of performed UE measurements the higher is the confidence that the extrapolation of the model is valid.

These proceedings report on the first LHC measurement of the underlying event activity in dijet events as a function of the leading calorimeter jet transverse momentum $p_{\mathrm{T}}^{\mathrm{lead}}$ up to 800 GeV [1] with ATLAS detector [2] and extends the previous ATLAS measurements of UE [4, 5]. To mitigate contributions of the hard process to the UE, the UE activity is measured in regions azimuthally transverse to the hardest jet, defined using $\Delta\phi = |\phi - \phi_{\mathrm{lead\ jet}}|$ as $60^\circ < |\Delta\phi| < 120^\circ$. Multi-jet events contribute to jet cross section (especially at large jet momenta) and are likely to affect the transverse energy flow. Therefore, the studies are performed in inclusive jet selection where multi-jet topologies contribute and in the subset of the exclusive dijet events where the dijet signature of the event is made explicit. The underlying observables are defined in terms of reconstructed charged particle tracks with $p_{\mathrm{T}} > 0.5$ GeV as well as using energy clusters. Tracks are reconstructed inside the ATLAS tracker $|\eta| < 2.5$, while the cluster measurement extends up $|\eta| < 4.8$, nearly to the limits of ATLAS calorimeter acceptance $|\eta| < 4.9$.

2. Underlying event observables

The measured observables are: the particle multiplicity of charged particles $\mathrm{d}^2N_{\mathrm{ch}}/\mathrm{d}\eta\,\mathrm{d}\phi$, the sum of transverse energy of charged $\mathrm{d}^2\sum p_{\mathrm{T}}/\mathrm{d}\eta\,\mathrm{d}\phi$ and charged plus neutral $\mathrm{d}^2\sum E_{\mathrm{T}}/\mathrm{d}\eta\,\mathrm{d}\phi$ particles normalized to the unit interval in pseudorapidity and transverse plane $\Delta\eta \times \Delta\phi$. In addition, the average transverse momentum $< p_{\mathrm{T}} >$ multiplicity dependence of charged particles is measured, but is not reported here.

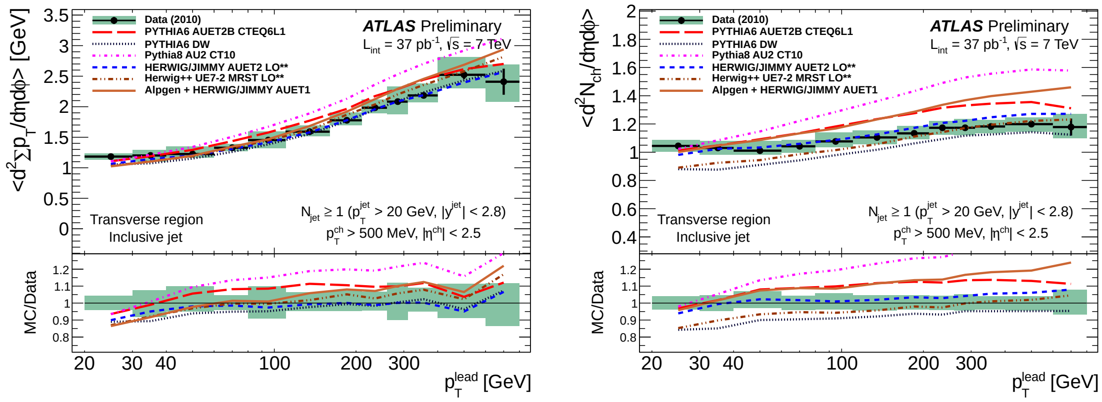

Figure 1: Charged particle energy (left) and multiplicity (right) densities at central region $|\eta| < 2.5$ as a function of the leading jet transverse momentum $p_{\mathrm{T}}^{\mathrm{lead}}$ compared with Monte-Carlo predictions [1].

UE observables are corrected back to particle level with fiducial region defined in terms of primary particles, i.e. particles with a mean proper lifetime $\tau > 0.3 \times 10^{-30}$ either directly produced in primary pp interaction or in the decay of particles with a shorter lifetime. The selected tracks correspond to charged particles with $p_{\mathrm{T}} > 0.5\,\mathrm{GeV}$ and $|\eta| < 2.5$. The summed energy in calorimeters correspond to charged particles with momentum $p > 0.5\,\mathrm{GeV}$ or primary neutral particles with $p > 0.2\,\mathrm{GeV}$. Particles with lower momentum are not considers as they are unlikely to deposit energy in the ATLAS calorimeters due to interactions with upstream material and due to bending in magnetic field.

3. Event selection

The analysis uses the entire 2010 ATLAS data of jet events in proton-proton collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ corresponding to an integrated luminosity of 37 pb^{-1}, with jets of $p_{\mathrm{T}}^{\mathrm{lead}} > 20\,\mathrm{GeV}$ and $|y| < 2.8$ found using anti-k$_t$ algorithm with radius-like parameter $R = 0.4$. Jets with transverse momenta in the range $20-60$, below the full efficiency of the calorimeter triggers were selected using minimum bias trigger. For higher transverse jet momenta several jet triggers with various thresholds were used. For each p_{T}-bin a single trigger chain has been used, chosen as the fully efficient trigger (>99%) with the smallest prescale [3].

The inclusive jet topology requires no other selection for the jets. For the exclusive dijet selection an additional requirement of one and only one sub-leading jet was made, with $p_{\mathrm{T}}^{\mathrm{sub}}/p_{\mathrm{T}}^{\mathrm{lead}} > 0.5$ and $|\Delta\phi| > 2.5$. The jets were fully corrected to account for the response of the energy deposited in the calorimeter. Contributions from cosmic ray muons and other non-collision background was removed by requiring at least one primary vertex to be reconstructed compatible with the beam-spot position with at least five associated tracks. To remove the impact of multiple proton-proton interactions, events with more then one reconstructed vertex with at least two associated tracks were removed. The selection efficiency of this vertex requirement for events passing all other event and jet selections was over 99%.

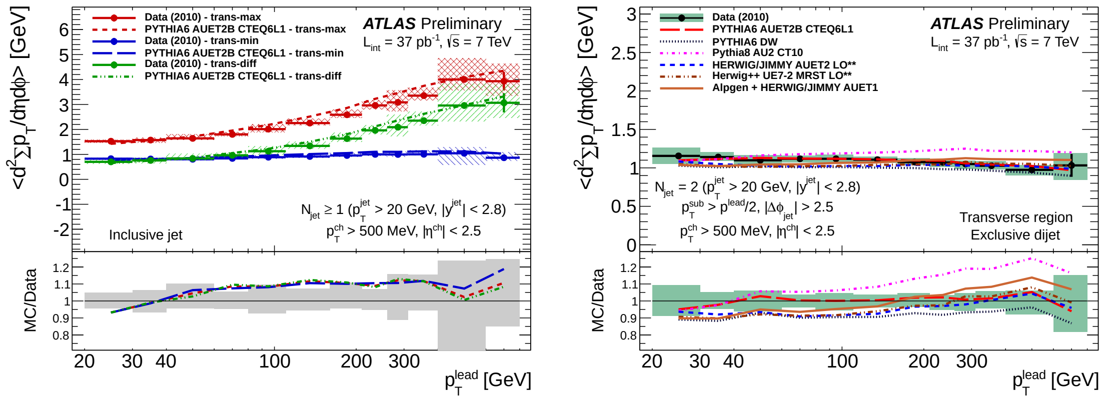

Figure 2: Charged particle energy density measured in trans-min and trans-max regions and their difference trans-diff as defined in the text (left) and the charged particle energy density for exclusive dijet selection (right) [1].

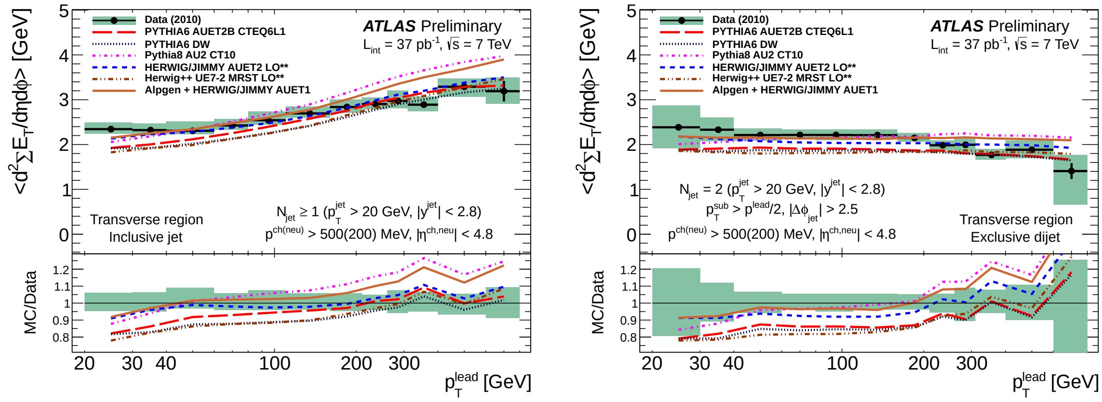

Figure 3: Charged and neutral particle energy density measured inside the full ATLAS calorimeter acceptance $|\eta| < 4.8$ for inclusive jet selection (left) and for a subset of exclusive events (right) [1].

4. Results and conclusion

The typical signature of UE is the emergence of the so called pedestal effect, the plateau in both particle and energy densities, when transverse momentum of the hard probe increases. This has been observed in previous ATLAS UE measurements with leading track and leading track jet as the hard probes. In this case of dijets with $p_{\mathrm{T}}^{\mathrm{lead}} > 20\,\mathrm{GeV}$ the activity has already reached the plateau. The $\sum p_{\mathrm{T}}$ and multiplicity distributions of charged particles are shown in Figure 1. The average contribution of UE to the energy density at $p_{\mathrm{T}}^{\mathrm{lead}} \sim 20\,\mathrm{GeV}$ for the unit of $\mathrm{d}\eta\mathrm{d}\phi$ is $\sim$1 GeV, and is typically deposited by one particle. This observation is compatible with ATLAS previous measurements of UE [4, 5]. Both the energy and multiplicity show a rise in the activity as the $p_{\mathrm{T}}^{\mathrm{lead}}$ increases. It is due to multi-jet events whose rate increases with hardness of the collision, and originates in the initial and final state radiation off the partons involved in the hard scattering. To see that it is convenient to split the transverse region in two equal sub-regions in azimuth and depending on the energy measured in these regions denote, on event-by-event basis, trans-min and trans-max the regions with smaller and higher activity, respectively. By construction the trans-max region is more likely to receive contribution from the extra radiation. The $\sum p_{\mathrm{T}}$ distribution in trans-min/trans-max regions is shown in Figure 2 (left), together with an energy difference in these regions trans-diff. While the activity increases for trans-max and trans-diff with $p_{\mathrm{T}}^{\mathrm{lead}}$, the activity is constant in trans-min region suggesting that that the trans-min distribution is predominantly sensitive to soft effects of UE and less to ISR/FSR. The slow rise of the trans-min profile with $p_{\mathrm{T}}^{\mathrm{lead}}$ may either indicate the residual contributions of multijet topologies or an increase in the MPI activity as the hard process scale rises. The insensitivity of the trans-min region to changes in $p_{\mathrm{T}}^{\mathrm{lead}}$ indicates that pure MPI activity can indeed be modelled as plateauing as a function of hard process scale once the scale is hard enough that the proton impact parameters are effectively zero and all collisions are central.

The energy density of exclusive dijet topology, where multijet events are explicitly excluded, provides another window to study the UE. It is shown in Figure 2 (right). The distribution in exclusive dijets is generally constant, again suggesting that depositions from multi-jet events have been removed, but decreasing slightly towards the highest $p_{\mathrm{T}}^{\mathrm{lead}}$. This is probably due to the fact that the veto on third jet suppresses contributions of additional multiple interactions, creating a bias towards less central collisions with softer activity.

By including neutral particles down to $p > 200\,\mathrm{MeV}$ the energy density is augmented approximately by a factor of 2. A similar observation between inclusive and exclusive jet samples can be made also when the measurement is extended further in pseudorapidity $|\eta| < 4.8$ as shown in Figure 3. The UE activity is generally flat across the full spectrum, slightly decreasing for the hardest leading jet topologies in the event. The reduction of the activity for the highest values of leading jet transverse momenta is however more pronounced than for the central activity.

The results of the measurements are compared to six different Monte-Carlo generators whose detailed description can be found in the ATLAS conference note [1]. It is observed that all generators model reasonably well the gross features of the activity increase with $p_{\mathrm{T}}^{\mathrm{lead}}$ in inclusive sample and constant trend for exclusive selection. Nevertheless, none of the generators is able to describe all distributions perfectly. The observed deviations are within 10-20% level, significantly above the systematic uncertainties, which are typically between 1-5%. It seems that HERWIG/JIMMY generator [6] with AUET2LO** tune [7] describe the overall data best. While some of the generators are able to predict the decrease of the activity in exclusive jet sample for high $p_{\mathrm{T}}^{\mathrm{lead}}$ in the central region $|\eta| < 2.5$ significant discrepancies are seen for the more forward measurement $|\eta| < 4.8$. This is not surprising. While the models were extensively tuned to data from central tracking detectors, various LHC measurements dedicated to forward energy flow are yet to be taken into account in the future developments of the generators, and the presented UE measurement in dijet events will significantly contribute to that effort.

References

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