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# Measurement of the Underlying Event Activity in the Drell-Yan process in proton-proton collisions at $\sqrt{s}$ = 7 TeV

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A measurement of the underlying event activity is performed in proton-proton collisions at a centre-of-mass energy $\sqrt{s}$ = 7 TeV using data collected with the CMS experiment at the LHC during 2010. The Drell-Yan process with muonic final state, $q\bar{q} \rightarrow \mu^+\mu^-$, provides an excellent way to study the underlying event activity by separating the hard interaction from the soft component. The observables which are sensitive to the underlying event, the average charged particle density and the average density of the scalar sum of the transverse momentum of the charged particles, have been studied in the directions opposite, along, and transverse to the resultant direction of the two muons, defined in the plane transverse to the beam direction. The underlying event activity is observed to be independent of the di-muon invariant mass in a region between 60 and 120 GeV/c$^2$ , implying a saturation of the multiple parton interactions at these energy scales. A slow growth of the underlying event activity is observed with increasing transverse momentum of the di-muon system. The data are corrected to the particle level and compared with the predictions of various non-perturbative models of soft interaction.

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## 1. Measurement of the Underlying Event Activity in the Drell-Yan Process

The *underlying event* (UE) in a hadron-hadron interaction consists of all the processes other than the hard component, which is characterized by the presence of a particle, or cluster of particles, with a large transverse momentum. The final state in an event is a superposition of various components: the hard interaction, initial and final state radiations (ISR, FSR), particles produced from the multiple parton interactions (MPI), and beam-beam-remnants (BBR) resulting from the hadronisation of the partonic constituents that did not participate in other scatterings. As a complementary approach to previous UE measurements at CMS [1] using jets [3], the di-muon final state of the Drell-Yan (DY) events ($q\bar{q} \rightarrow \mu\mu$) is used in this analysis [4]. It is one of the experimentally clean and theoretically well-understood processes [2]. The DY events with di-muon invariant mass ($M_{\mu\mu} = \sqrt{(E_1^{\mu} + E_2^{\mu})^2 - (\vec{p}_1^{\,\mu} + \vec{p}_2^{\,\mu})^2}$) around the Z-resonance, 60 GeV/$c^2 < M_{\mu\mu} <$ 120 GeV/$c^2$, are least contaminated from the background processes and hence, most suited for the measurement of the UE activity. The UE activity is measured with reference to the resultant direction of the di-muon system, whereby three distinct topological regions are defined in the plane transverse to the beam direction. The charged particles are categorized according to the azimuthal distance $\Delta\phi$ between the resultant direction of the di-muon system and that of the charged particle. The particle production in the *away* ($|\Delta\phi| > 120^o$) region is expected to be dominated by the component of the hard parton-parton interaction which balances the boost of the di-muon system. The *transverse* region ($60^o < |\Delta\phi| < 120^o$) still get some contribution from the recoiling activity whereas the *towards* region ($|\Delta\phi| < 60^o$) gets the least contamination from the hard interaction after excluding the muons coming from the DY events. The strength of the UE activity is measured in terms of the average charged particle multiplicity and the average scalar sum of $p_T$ of the charged particles, which are expressed as density obtained dividing by the area of the considered $\eta \times \phi$ space. The UE activity is studied as function of resultant transverse momentum ($p_T^{\mu\mu} = |\vec{p}_{T,1}^{\,\mu} + \vec{p}_{T,2}^{\,\mu}|$) and invariant mass ($M_{\mu\mu}$) for di-muon pair. While performing the study as function of $M_{\mu\mu}$, $p_T^{\mu\mu}$ is required to be less than 10 GeV/c to reduce the radiation contribution. DY event is reconstructed using the well reconstructed and isolated muons with transverse momentum greater than 20 GeV/c. Only the charged tracks, excluding the muons from DY process, with transverse momentum greater than 0.5 GeV/c and pseudorapidity less than 2.0 are considered for the measurement of the UE activity.

## 2. Results

The activity in the *transverse* region is found to be higher than the activity in the *towards* region due to the spill-over contribution from the hadronic recoil activity in the *away* region. The UE activity shows a small growth with the increasing $p_T^{\mu\mu}$ as shown in Figures 1(a)-1(d). This growth is mainly due to the increase of radiations, combined with a saturated MPI contribution due to the high $M_{\mu\mu}$ requirement. The saturation hypothesis is confirmed by the flat dependence of the average densities on the $M_{\mu\mu}$ as shown in Figure 1(e) and 1(f).

The predictions of various PYTHIA tunes have been compared to the measurements in data. Specifically, the PYTHIA-6 Z1, DW tunes, and the PYTHIA-8 4C tune, have been used for the comparisons. These models differ in the PDF description, in the implementation of radiation, fragmentation, and the MPI. The average density of the scalar sum $p_T$ is described well by the



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PYTHIA-6 Z1 tune with a maximum discrepancy of 10% at small values of $p_T^{\mu\mu}$ whereas the average charged particle density is described well by the prediction of PYTHIA-6 Z1 and DW. PYTHIA-8 4C predictions show good agreement with the data only at small $p_T^{\mu\mu}$. The average density of the scalar sum $p_T$, as function of $M_{\mu\mu}$, is well described by PYTHIA-8 4C, whereas PYTHIA-6 Z1 shows agreement within 10-15%. The average charged particle density, as function of $M_{\mu\mu}$, is described well by the prediction of PYTHIA-8 4C and PYTHIA-6 DW tunes.

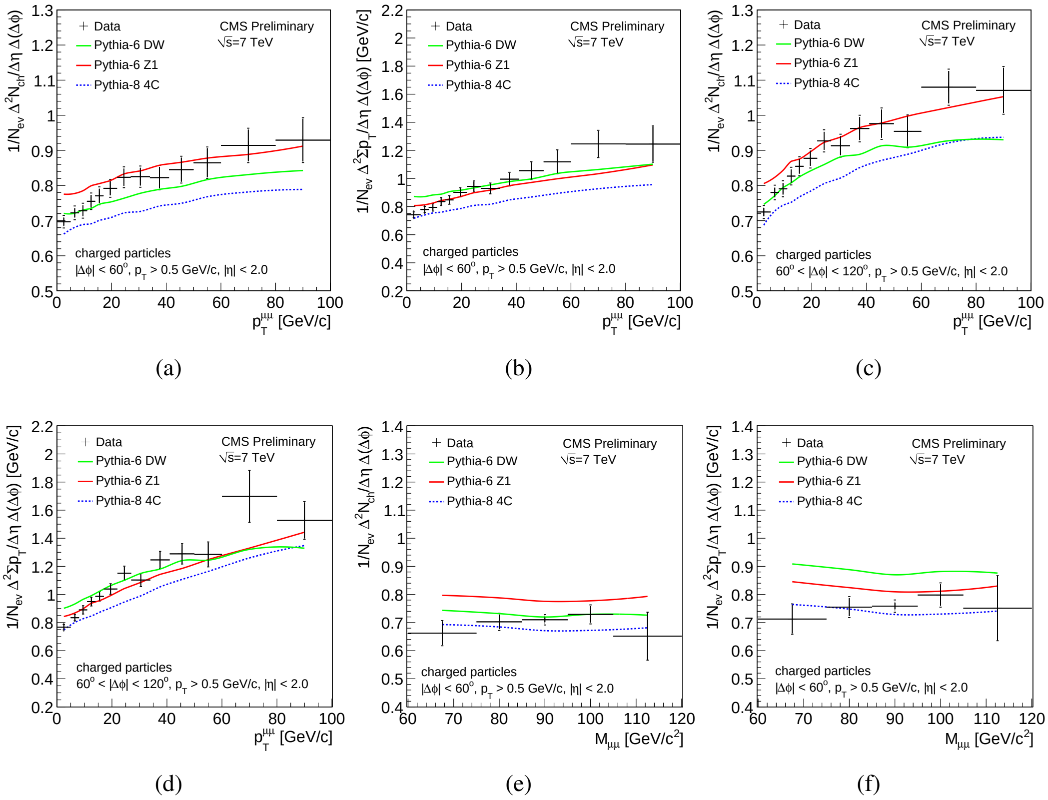


**Figure 1:** Figure (a) and (c) shows the average charged particle density, for charged particles with $p_T$ >0.5 GeV/$c$ and $|\eta|$ <2.0, as function $p_T^{\mu\mu}$ in the *towards* and *transverse* region respectively whereas the average density of the scalar sum of the transverse momenta of the charged particles for the *towards* and *transverse* region are reported in Figure (b) and (d). Figure (e) and (f) shows the average charged particle density and average density of the scalar sum of the transverse momenta in *towards* region as function $M_{\mu\mu}$.

## 3. Conclusion

We have presented the measurement of the underlying event using Drell-Yan events in proton-proton collision at $\sqrt{s}$ = 7 TeV at the LHC with the CMS detector. The DY process provides a complementary approach for the UE measurement where a clean separation of the hard interaction from the soft component is possible. The DY process provides a good handle to study the dependence of the UE activity on the hard interaction scale, related to the invariant mass of the dimuon pair. The influence of the hard and soft ISR is probed by the dependence on the transverse momentum of the muon pair.

The UE activity is observed to be independent of the dimuon mass in the range 60-120 GeV/$c^2$, after limiting the recoil activity, which confirms the MPI saturation at this scale. The UE activity in the towards and transverse regions shows a slow growth with the transverse momentum of the muon pair and provides an important probe for the ISR. The average density of the scalar sum $p_T$ is described well by the PYTHIA-6 Z1 tune with a maximum discrepancy of 10% at small values of $p_T^{\mu\mu}$ whereas the average charged particle density is described well by the prediction of PYTHIA-6 Z1 and DW.

## References

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