Measurement of underlying event characteristics using charged particles in pp collisions at $\sqrt{s} = 13$ TeV generated using PYTHIA 8

Gaurav Badre, Harshit Agarwal, Hemant, Mansi Bhanware, Nabeel Ahmed, Neeraj Ramavathu, Nikhil Vikas Khobragade, and Shruti Agrawal
Indian Institute of Technology Bombay, Mumbai, India
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Underlying events are those aspects of hadronic interaction which are attributed not to the hard scattering, but to the accompanying interactions of the rest of the proton. Every collision has an associated region of interest defined in terms of the azimuthal angle, which is sensitive to underlying events. Distributions of the charged particle multiplicity and transverse momentum density for this region of interest as well as other regions have been presented.

I. INTRODUCTION

The data provided has been generated using the PYTHIA 8 Monte Carlo Event Generator. The collision system is $p + p$ at centre-of-mass energy 13 TeV. There are a total of 2 million events.

We have presented data which corresponds to a subset of all the events. All observables presented are constructed from primary charged particles in the pseudorapidity range $|\eta| < 2.5$, whose transverse momentum component (p_T) is greater than 600 MeV/c. We have also narrowed our range to four multiplicity classes (i.e number of tracks per event): (0-20), (20-40), (40-60) and (60-80).

The direction of the track with the largest p_T in the event is referred to as *the leading track*. The axis given by the leading track is well-defined for all events and is highly correlated with the axis of the hard scattering in high p_T events. We define regions of the plane which have different sensitivities to the underlying events using the azimuthal angular difference between charged tracks and the leading track, as shown in Figure 1:

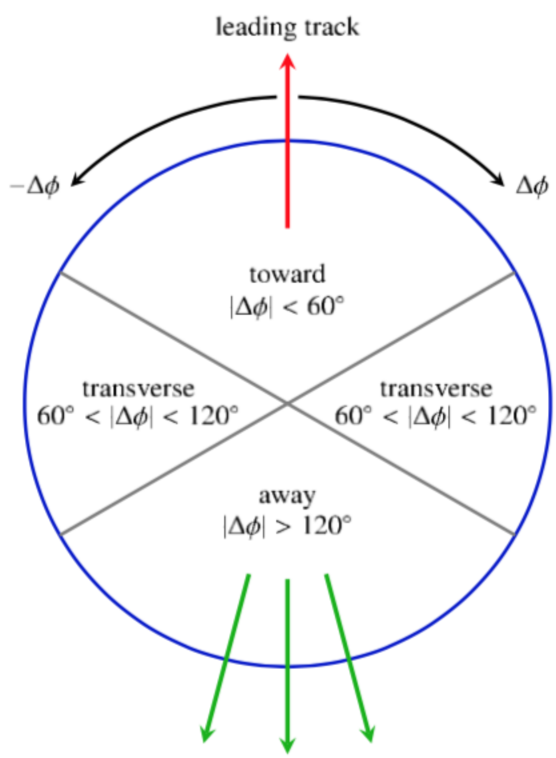

FIG. 1. (Color online) Definition of regions in the azimuthal angle with respect to the leading track[1]

For each track, we call $\phi - \phi_{lead} = \Delta\phi$ and define

1. $|\Delta\phi| < \pi/3$ as the *toward region*;
2. $\pi/3 < |\Delta\phi| < 2\pi/3$ as the *transverse region*; and
3. $2\pi/3 < |\Delta\phi| < \pi$ as the *away region.*

The transverse regions are most sensitive to the underlying event, since they are generally perpendicular to the axis of hardest scattering and hence have the lowest level of activity from this source.

We define certain physical quantities as given below:

Physical Quantity	Definition
p_T^{lead}	Transverse momentum of the leading track of an event
$\langle d^2N_{ch}/d\eta d\phi \rangle$	Mean number of stable charged particles per unit $\eta - \phi$
$\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$	Mean scalar p_T sum of stable charged particles per unit $\eta - \phi$

TABLE I. Physical quantities of interest

We shall be looking at $\langle d^2N_{ch}/d\eta d\phi \rangle$ and $\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$ in all three regions of interest, as a function of p_T^{lead}.

The transverse, toward, and away regions each have an area of $\Delta\eta\Delta\phi = 10\pi/3$ in the $\eta - \phi$ space, so $\langle d^2N_{ch}/d\eta d\phi \rangle$ and $\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$ are constructed by dividing the mean values by the corresponding area.

II. EXPERIMENTAL OBSERVATIONS

1. Distributions of $\langle d^2N_{ch}/d\eta d\phi \rangle$ for four different multiplicity classes (0-20), (20-40), (40-60) and (60-80) are given in Figure 2.

2. Distributions of $\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$ for four different multiplicity classes (0-20), (20-40), (40-60) and (60-80) are given in Figure 3.

It is to be noted that each multiplicity class has a different number of events. The number of events corresponding to each class is given in Table 2:

Multiplicity Class	Number of Events
(0-20)	2380640
(20-40)	873322
(40-60)	445805
(60-80)	207990

TABLE II. Number of events in each multiplicity class

3. Distributions of $\langle d^2N_{ch}/d\eta d\phi \rangle$ across all multiplicity classes, i.e for one single multiplicity class (0-80) are given in Figure 4.

4. Distributions of $\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$ across all multiplicity classes, i.e for one single multiplicity class (0-80) are given in Figure 5.

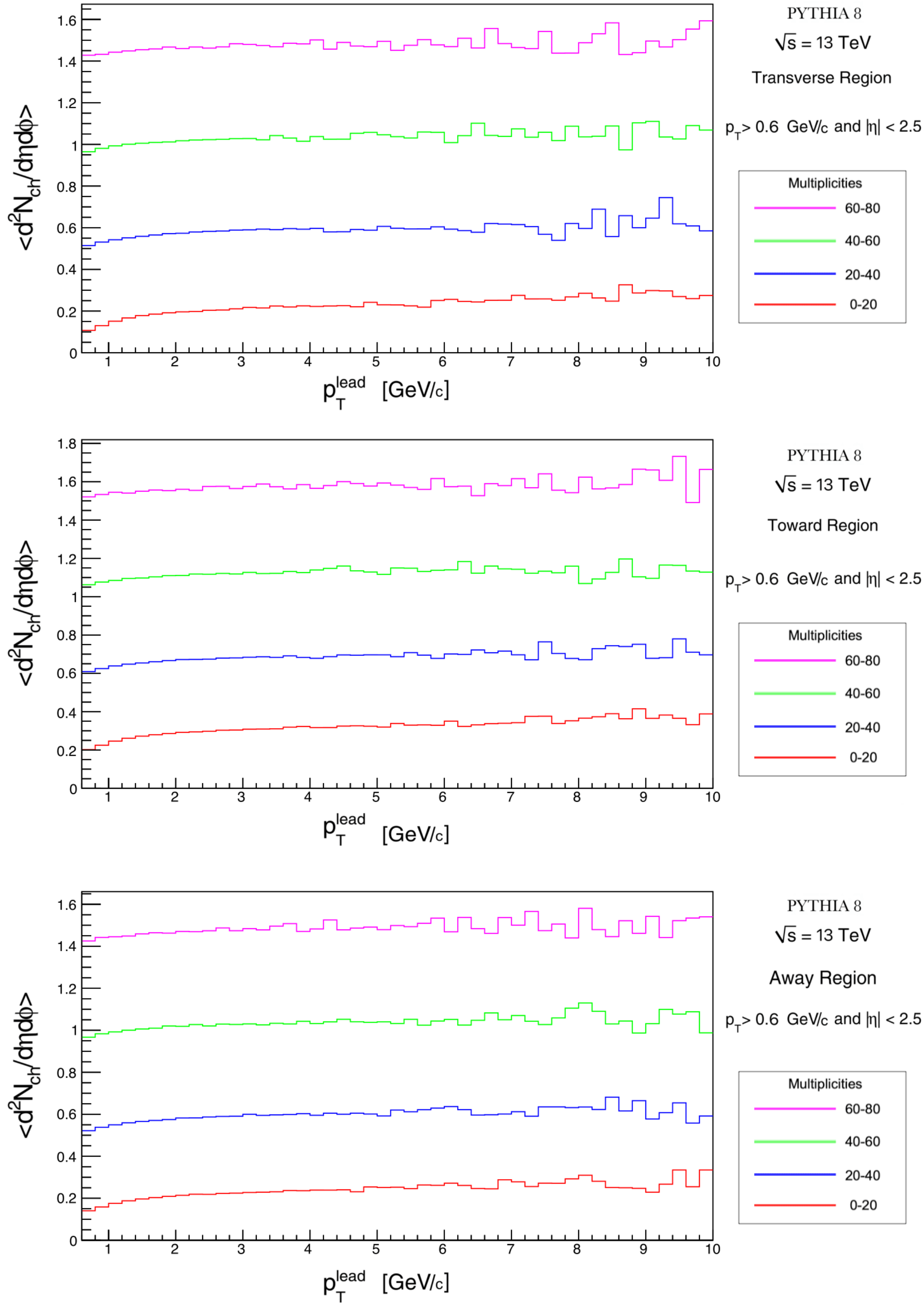

FIG. 2. (Color online) PYTHIA 8 data showing the density of charged particles $\langle d^2N_{ch}/d\eta d\phi \rangle$ with $p_T > 0.6$ GeV/c and $|\eta| < 2.5$, as a function of p_T^{lead}, for the multiplicity classes (0-20), (20-40), (40-60) and (60-80). The top, middle and the bottom rows, respectively, show the transverse, toward and away regions defined by the leading charged particle.

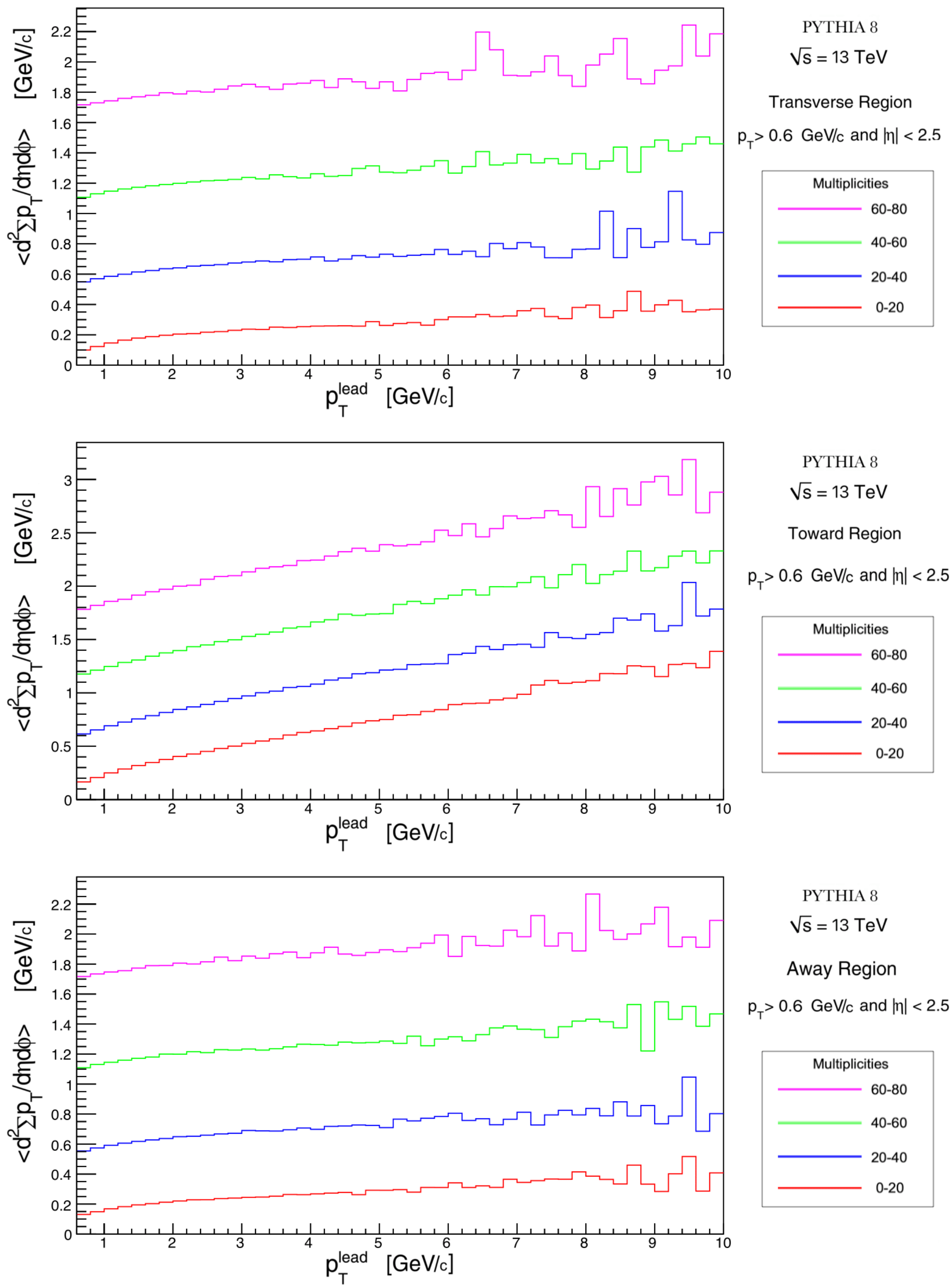

FIG. 3. (Color online) PYTHIA 8 data showing the scalar Σp_T density of the charged particles $\langle d^2(\Sigma p_T)/d\eta d\phi \rangle$ with $p_T > 0.6$ GeV/c and $|\eta| < 2.5$, as a function of p_T^{lead}, for the multiplicity classes (0-20), (20-40), (40-60) and (60-80). The top, middle and the bottom rows, respectively, show the transverse, toward and away regions defined by the leading charged particle.

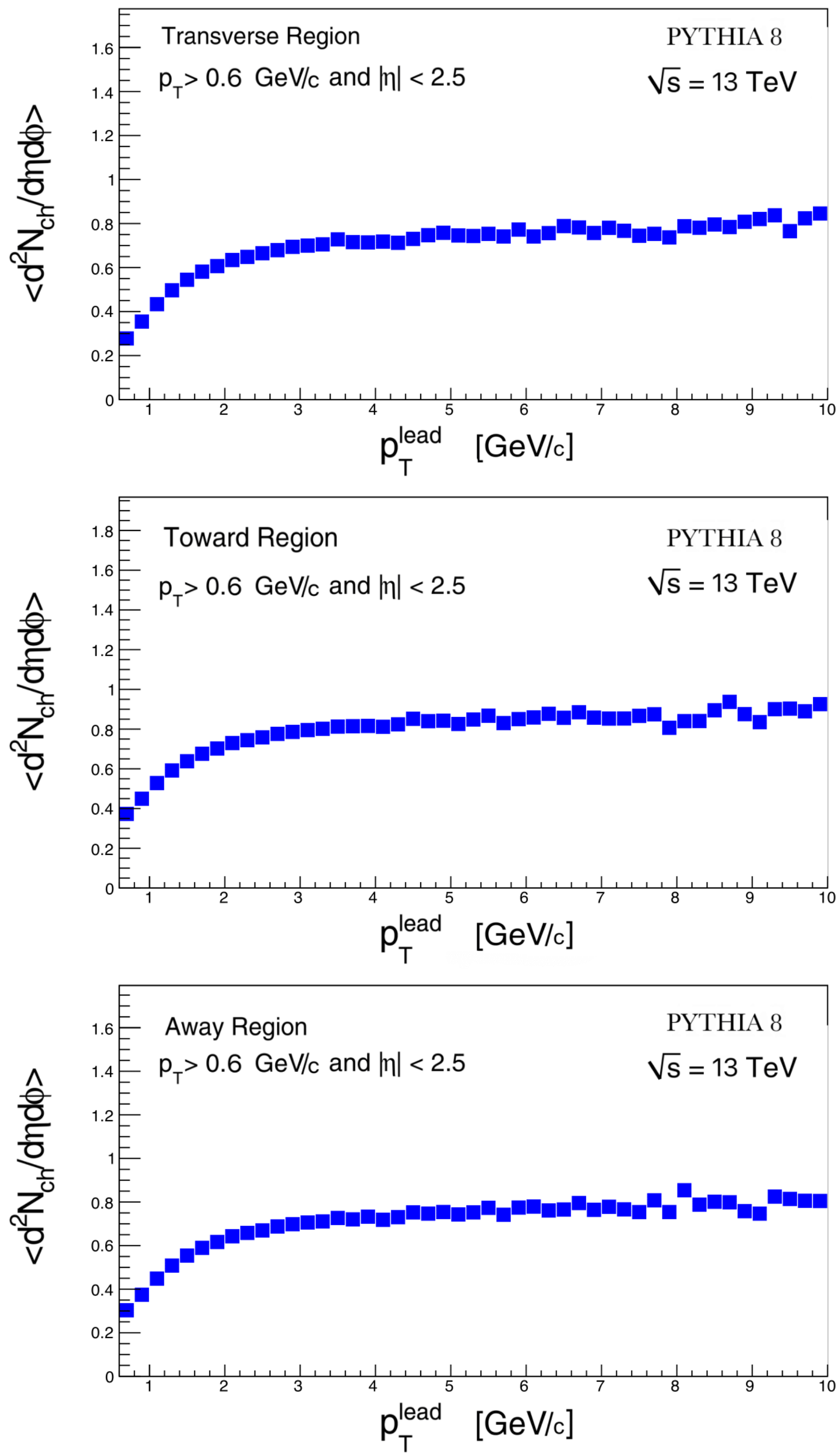

FIG. 4. (Color online) PYTHIA 8 data showing the density of charged particles $< d^2N_{ch}/d\eta d\phi >$ with $p_T > 0.6$ GeV/c and $|\eta| < 2.5$, as a function of p_T^{lead}. The top, middle and the bottom rows, respectively, show the transverse, toward and away regions defined by the leading charged particle.

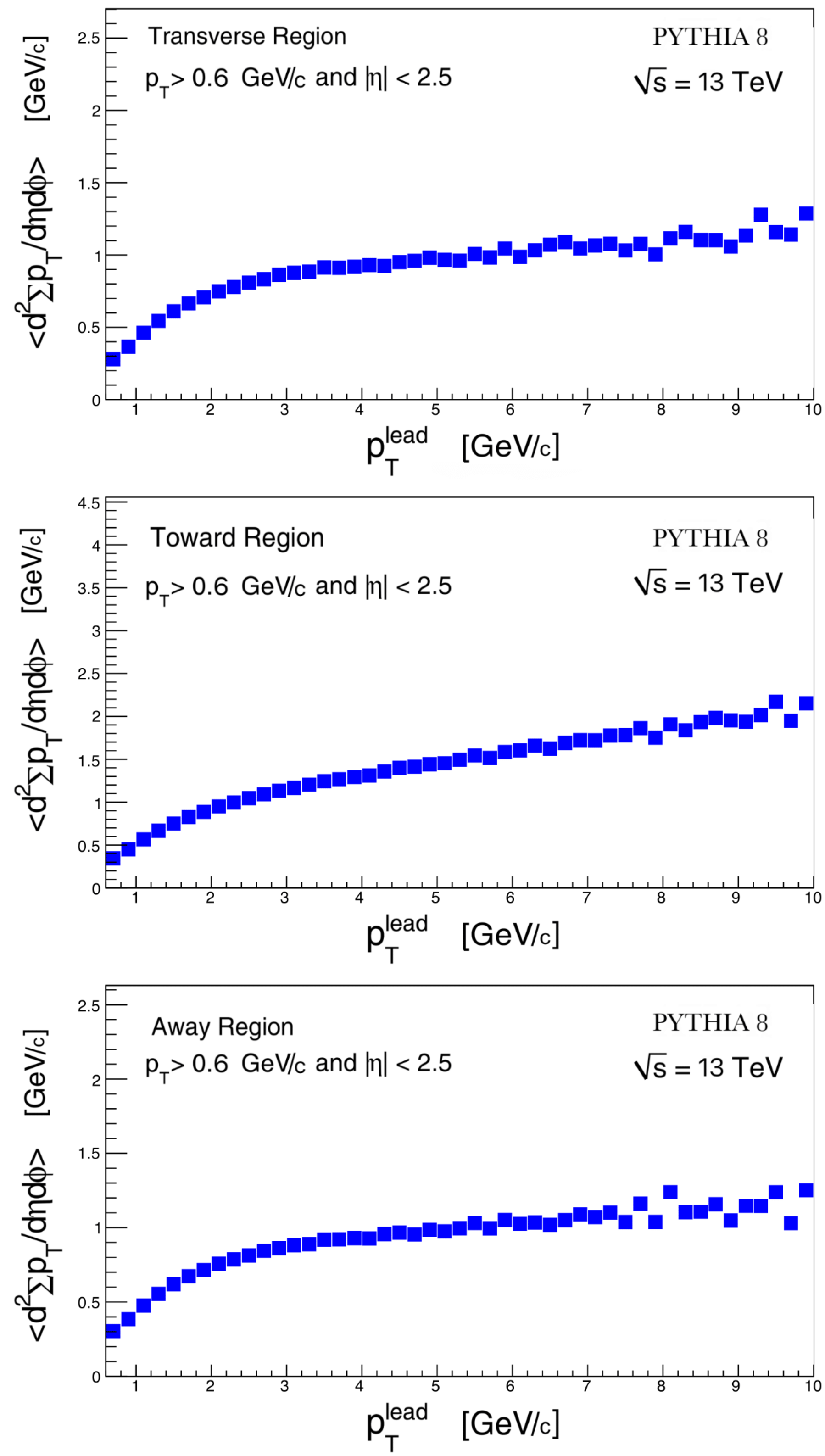

FIG. 5. (Color online) PYTHIA 8 data showing the scalar Σp_T density of the charged particles $\langle d^2(\Sigma p_T)/d\eta d\phi\rangle$ with $p_T > 0.6$ GeV/c and $|\eta| < 2.5$, as a function of p_T^{lead}. The top, middle and the bottom rows, respectively, show the transverse, toward and away regions defined by the leading charged particle.

III. SUMMARY

1. Figure 2 shows the distribution of $\langle d^2N_{ch}/d\eta d\phi\rangle$ for different multiplicity classes. The histograms for higher multiplicity classes are higher than those of the lower multiplicity classes. However, this does not imply that there is any correlation between the underlying events and the number of tracks per event. The reason for this is that the number of events for the higher multiplicity classes are less than the lower multiplicity classes. (Table 2).

2. Figure 3 shows the distribution of $\langle d^2(\Sigma p_T)/d\eta d\phi\rangle$ for different multiplicity classes. As with Figure 2, we can not conclude any correlation between the underlying events and the number of tracks per event, due to the difference in the number of events per multiplicity class.

3. Figure 4 shows the overall distribution of $\langle d^2N_{ch}/d\eta d\phi\rangle$ in the three regions of interest. The density of particles is similar for the transverse, toward, and away regions.

4. Figure 5 shows the overall distribution of $\langle d^2(\Sigma p_T)/d\eta d\phi\rangle$ in the three regions of interest. As p_T^{lead} increases, the scalar Σp_T density is significantly higher in the toward region as compared to the transverse and away regions.

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[1] G. Aad *et al.*, (ATLAS Collaboration), Physical Review D **83**, 112001 (2011)