Particle production as a function of the underlying event in pp collisions simulated with PYTHIA 8

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In this work we present the production of charged particles associated with high-p_T trigger particles ($8 < p_T^{trig.} < 15$ GeV /c) at mid-pseudorapidity in proton-proton collisions at $\sqrt{s} = 5.02$ TeV simulated with the PYTHIA 8 Monte Carlo model. The study is performed as a function of the relative transverse activity classifier, R_T, which is the relative charged-particle multiplicity in the transverse region ($\pi/3 < |\Delta\phi| < 2\pi/3$) of the di-hadron correlations, and it is sensitive to the Multi-Parton Interactions. The evolution of the yield of associated particles on both the toward and the away regions with $3 \leq p_T^{assoc.} < 8$ GeV/c as a function of R_T is investigated. We propose a strategy which allows for the modelling and subtraction of the Underlying Event (UE) contribution from the toward and the away regions in challenging environments like those characterised by large R_T. We found that the signal in the away region becomes broader with increasing R_T. Contrarily, the yield increases with R_T in the toward region. This effect is reminiscent of that seen in heavy-ion collisions, where an enhancement of the yield in the toward region for $0 - 5\%$ central Pb–Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV was reported. To further understand the role of the UE and additional jet activity, the transverse region is divided into two one-sided sectors, "trans-max" and "trans-min" selected in each event according to which region has larger or smaller charged particle multiplicity. Based on this selection criterion, the observables are studied as a function of R_T^{max} and R_T^{min}, respectively. The presented results have been published in Refs. [1, 2].

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1. Introduction

One of the most important discoveries at the LHC is the presence of collectivity [3] in high-multiplicity proton-proton (pp) collisions which is originally present in heavy-ion collisions (AA) where the effect of jet quenching is observed [4]. To date no jet quenching is found in small collision systems, however several attempts have already been made to unveil it in high-multiplicity pp collisions, see e.g. Ref. [5]. To extract jet-quenching signal from pp data, one has to deal with the selection bias which is the main technical issue in the analysis. The high-activity event selection results a sample which is naturally biased toward hard processes (including jets). Following the definition by the CDF Collaboration, the direction of the trigger particle is used to define regions in the azimuthal plane that have different sensitivity to the underlying event (UE). The toward and the away regions are dominated by string fragments originating from the hardest partonic process of the event, and are expected to be nearly insensitive to the softer UE. In contrast, the trans. region is the most sensitive to UE, but it has contributions from initial- and final-state radiation (ISR and FSR) that accompanies the hard scattering. This UE region will be used to isolate events with exceptionally large or small activity with respect to the event-averaged mean.

In this work we explore a quantity called I_{pp} which is motivated by the I_{AA} [6–8] commonly used in AA collisions to study jet quenching effects. Also, we further investigate the UE-dominated trans. region considering a refinement to distinguish between the more and the less active sides of the trans. region on a per-event basis [9–11]. The purpose of using this geometrical selection criterion is to suppress hard ISR/FSR thus increasing the sensitivity of the trans. region to MPI component of the UE. Based on the CDF approach [12], the so-called trans-min and trans-max regions are introduced. The trans-min region is insensitive to wide angle emissions from the hard process, while the trans-max region receives contribution from hard ISR and/or FSR. We study the structures of the $\Delta\phi$ distribution for the trans-max and trans-min regions. The presented results are also discussed in the context of recent ALICE preliminary results [13, 14].

2. Classification of event activity using the underlying event

We simulated inelastic pp collisions at $\sqrt{s} = 5.02$ TeV and only primary charged particles [15] with $p_T > 0.5$ GeV/c and pseudorapidity $|\eta| < 0.8$ are considered in the analysis. We use the Relative Transverse Activity Classifier, R_T, which has been recently introduced [16, 17] and used on LHC data [18, 19]. R_T uses the conventional definition of the transverse region, which was adopted in the UE analysis originally introduced by the CDF collaboration [20, 21]. We classify events with a trigger particle in the range $8 \leq p_T^{\text{trig.}} < 15$ GeV/c based on their per-event activity in the trans. region with respect to the mean: $R_T = N_{\text{ch}}^{\text{trans.}}/\langle N_{\text{ch}}^{\text{trans.}}\rangle$. Also, we define two regions that are characterized in terms of their relative charged-particle multiplicities, $N_{\text{ch}}^{\text{trans. max}}$ and $N_{\text{ch}}^{\text{trans. min}}$, termed trans-max and trans-min. Trans-max (trans-min) refers to the trans, region containing the largest (smallest) number of charged particles. Using $N_{\text{ch}}^{\text{trans. min}}$ and $N_{\text{ch}}^{\text{trans. max}}$, instead of $N_{\text{ch}}^{\text{trans.}}$, we also can define the quantities R_T^{min} and R_T^{max}, respectively. For R_T, $R_T^{\text{max}} \approx 8$ and $R_T^{\text{min}} \approx 8$, the inclusive multiplicity reach is about six- and four times the mean multiplicity. The average N_{mpi} increases with R_T^{min} as opposed to what is observed for R_T^{max}. Results of the correlation between
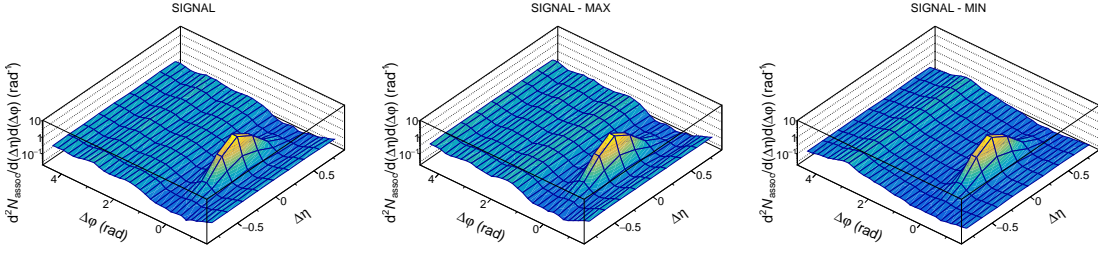
Figure 1: Charged particle yield as a function of $\Delta\eta - \Delta\phi$ for $R_T \geq 3.5$ and $4 \leq p_T^{assoc.} < 6\,\mathrm{GeV}/c$ simulated with PYTHIA 8 in pp collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$. Second and third columns represent the cases of trans-max and trans-min corresponding to high and low activities in the transverse region.

the average N_{mpi} and R_T showed that events selected with $R_T > 2$ but with similar N_{mpi} include additional jets to enhance the activity in the trans. region which in turn causes a selection bias.

3. Extraction of jet-like signals

Figure 1 shows the charged particle yield as a function of $\Delta\eta - \Delta\phi$ for $R_T \geq 3.5$. A structure elongated in $\Delta\eta$ is present in the trans. region which is a consequence of the event selection. Therefore, its contribution to the toward and the away regions has to be removed. For this purpose mixed events are used to model the uncorrelated contribution as well as the acceptance effect. The signal is extracted after removing the mixed event distribution from the same event distribution. The $\Delta\eta$-$\Delta\phi$ distributions are flat in $\Delta\eta$, therefore, the underlying event contribution to the toward and away regions is subtracted with the zero yield at minimum assumption [22].

4. Results

We calculated the I_{pp} quantity, which is the ratio of yields from different R_T classes to the R_T-integrated one. In the absence of either selection bias or jet quenching, I_{pp} is expected to be consistent with unity. The influence on the jet-like signals of the remaining structures are reduced by integrating the $\Delta\phi$ distribution within the interval $|\Delta\phi| < 0.8$ ($|\Delta\phi - \pi| < 0.8$) for the toward (away) region. Figure 2 shows the I_{pp} as a function of $p_T^{assoc.}$ for both the toward and the away region. Three $p_T^{assoc.}$ intervals are considered: $3 \leq p_T^{assoc.} < 4\,\mathrm{GeV}/c$, $4 \leq p_T^{assoc.} < 6\,\mathrm{GeV}/c$, and $6 \leq p_T^{assoc.} < 8\,\mathrm{GeV}/c$. Results with and without underlying event subtraction are also presented. We observe that the I_{pp} quantity is independent of R_T in simulations which do not include ISR and FSR. With physical settings (including ISR/FSR) the yield in the toward region increases with R_T; this effect is reminiscent of the Pb–Pb data from the ALICE and CMS experiments, although in the PYTHIA 8 model it is driven by a bias, and has to be taken into account in any analysis which use R_T as an event classifier. The bias originates from hard Bremsstrahlung gluons that can produce an apparent modification of the jet-like yield in events with extremely large underlying event. In contrast, the I_{pp} in the away region is consistent with unity, and independent of R_T and $p_T^{assoc.}$. This suggests that PYTHIA 8 can partially mimic jet-quenching effects.

We modified of the original R_T definition: split the transverse region into the trans-min and trans-max regions in order to control the sensitivity to hard processes. Using R_T^{min} instead of R_T or
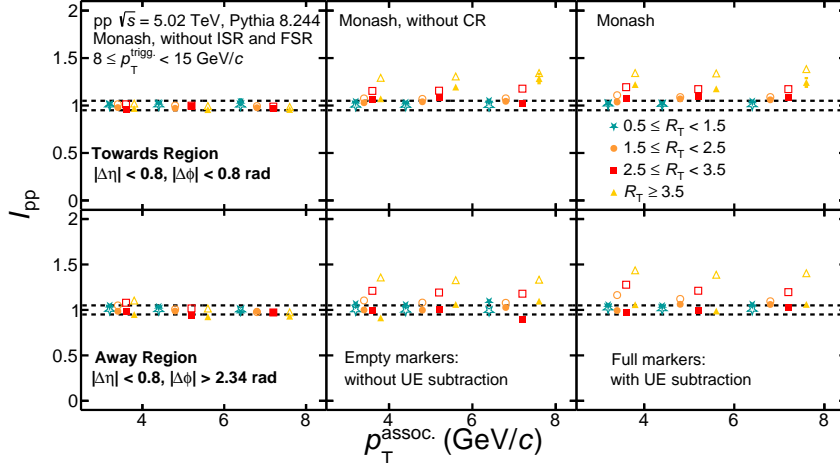
Figure 2: I_{pp}, the ratio of yield from different R_T classes and from the R_T-integrated class as a function of R_T for the toward (top) and away region (bottom). Dashed lines indicate $\pm 5\%$ deviation from unity.
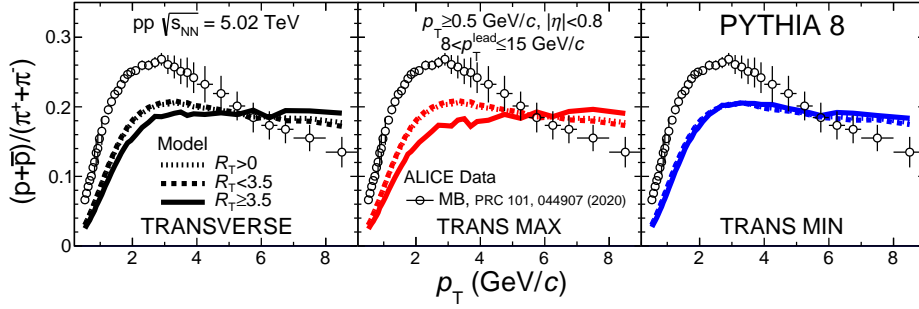

Figure 3: Proton-to-pion ratio as a function of p_T for the transverse (left panel), trans-max (middle panel), and trans-min (right panel) regions for pp collisions at $\sqrt{s} = 5.02$ TeV.

R_T^{max}, we do not observe a remarkable evolution of both the toward and away regions with increasing R_T^{min}, moreover, the remaining signal in the transverse region is much smaller and roughly R_T^{min} independent. The p_T dependent p/π ratios shown in Fig. 3 for various R_T event classes exhibit a depletion at $p_T \approx 2-3$ GeV/c with increasing R_T which is consistent with the presence of jets in the trans. region. As reported earlier both in MC [23] and data [24], the ratio is smaller in the jet region than in the UE region. The R_T^{max}-dependent ratios receive a large amount of particles from hard Bremsstrahlung gluons produced in ISR/FSR radiation.

The middle panel of Fig. 3 reports the high-activity trans. region which receives a large amount of particles from hard gluon-radiated processes, i.e. from ISR/FSR. In effect, the bump structure is smeared out; a similar effect is seen as for particle ratios inside jets [24]. In contrast, the R_T^{min}-dependent ratios shown in the right panel of Fig. 3 exhibit an opposite behaviour: only a weak dependence on the R_T^{min} event classes is seen. However, the position of its maximum is slightly shifted to higher p_T values in events with large R_T^{min}, which is expected in PYTHIA 8 events with large N_{mpi} and color reconnection [25–27].

Acknowledgments

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