A look into the "hedgehog" events in pp collisions

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The UA1 and CDF collaborations have reported the presence of events with a very extended structure of low momentum tracks filling in a uniform way the $\eta - \varphi$ phase space. However, these events have not caused interest with respect to the details of the interaction that provoke them. We have undertaken to study whether such events are predicted by present event generators like PYTHIA 8. We report the existence of events without any discernible jetty structure in high-multiplicity pp collisions. In the simulations those events originate from several parton-parton scatterings within the same pp collision. We introduce the event shape ρ ($flatenicity$) as a tool to tag those events in experiments.

1 Introduction

The proton-proton (pp) collisions at ultra relativistic energies have shown very important similarities with heavy-ion collisions [1] like collectivity [2], and strangeness enhancement [3]. The origin of these effects in small systems like pp collisions is still a matter of debate [4]. The pp collisions offer a very important laboratory to study high-energy density features of quantum chromodynamics (QCD). The present work illustrates the possibility to observe very rare pp collisions, and study their properties. These collisions would not, because of their rarity, give a noticeable contribution to the traditional measurements performed as a function of the average charged particle multiplicity [5].

It is interesting that before the LHC era in the long history of investigation of pp collisions there were, to our knowledge, only two mentions of "strange" pp collisions in the literature, one by the UA1 collaboration and the other by the CDF experiment. The rarity of these events lays in the fact that the tracks of charged particles are not obviously connected to jets resulting from hard parton-parton scatterings, instead, they present an almost isotropic distribution of low transverse momentum particles over a large pseudorapidity (η) range. Regarding the CDF document, C. Quigg has named them as "hedgehog" events [6]. Some attempts to characterize these events involved the development of tools like event shapes [7,8]. Early LHC measurements of transverse sphericity as a function of the charged particle multiplicity unveiled features which suggested that a very active underlying event was needed by the event generators in order to explain the properties of pp collisions with $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta > 30$ [9, 10]. In other words, high multiplicity pp collisions seemed to be more isotropic (headhehog-like structure) than predicted by MC generators. Recently, the average transverse momentum as a function of charged particle multiplicity in isotropic events was found to be smaller than that measured in jet-like events [11]. The preliminary ALICE results on identified particle p_{T} spectra show a clear event shape dependence which hints to a larger strangeness enhancement in isotropic events relative to jet-like events [12]. Other results as a function of the event classifier R_{T} [13, 14] point to the same direction. However, given the limited acceptance ($|\eta| < 0.8$) used to measure the event multiplicity and event shape the sample can be biased towards pp collisions with large activity from hard radiation which would go to the transverse region of the di-hadron correlations [15]. This background has to be taken into consideration for the interpretation of the results. However, in view of the plans of a new detector for heavy-ion physics at CERN, ALICE 3 [16], it is pertinent to explore the hedgehog-event tagging in the proposed detector which would have excellent tracking capabilities at low momenta ($p_{\mathrm{T}} > 0.1\,\mathrm{GeV}/c$) within a wide acceptance ($|\eta| < 4$).

In the present paper we show that the PYTHIA 8 [17] Monte Carlo event generator predicts the existence of "hedgehog" events. In the model, this event topology originate from a large number of semi-hard parton-parton scatterings, termed as multiparton interactions (MPI), occurring within the same pp collision [18]. Together with the fragments from the beam-beam remnants, particles from MPI define the underlying event [19]. The existence of such events in the event generator has opened the possibility to present a study of their properties and propose a potential way to tag them. Derived from these studies, we present a novel event structure parameter ρ-$flatenicity$ that permits identifying/triggering very easily the events and study their characteristics in future experiments like ALICE 3.

2 Flatenicity, ρ

Hedgehog events are expected to have a uniform distribution of transverse momentum over the whole $\eta - \varphi$ range. In order to determine how uniform the particle's transverse momentum (p_{T}) is distributed in a given event, event-by-event a grid in $\eta - \varphi$ (10×10) is be built. Given the tracking capabilities of the new detectors which are planned for the Run 5 at the Large Hadron Collider, charged particles within $|\eta| < 4$ and $p_{\rm T} > 0.15\,{\rm GeV}/c$ are considered in the calculation of $flatenicity$. In each cell, the average transverse momentum is calculated ($p_{\rm T}^{\rm cell}$). Event-by-event, the distribution of $p_{\rm T}^{\rm cell}$ (see e.g. Fig. 1) is used to get the $flatenicity$ as follows:

$$\rho = \frac{\sigma_{p_{\rm T}^{\rm cell}}}{\langle p_{\rm T}^{\rm cell}\rangle}, \quad (1)$$

which is the relative standard deviation of the $p_{\rm T}^{\rm cell}$ distribution. Events with jet signals on top of the underlying event are expected to have a large spread, the opposite is expected in the case in which particles would be isotropically distributed. Although, only results considering the average transverse momentum are presented, it is worth mentioning that average charged particle multiplicity can be used instead. Moreover, the method was also tested considering smaller acceptances ($|\eta| < 1$) which are accessible to experiments like ALICE [20].

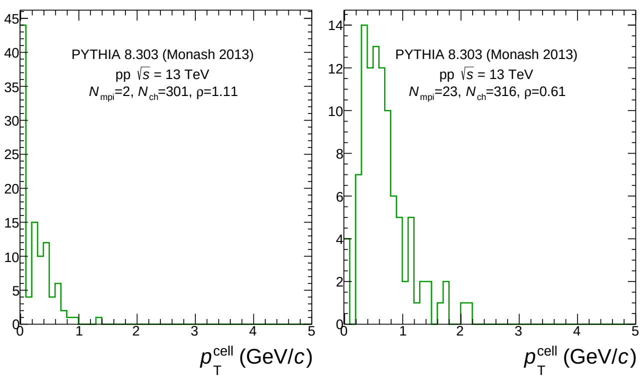

FIGURE 1. Average transverse momentum in each cell for two high multiplicity pp collisions at $\sqrt{s} = 13\,{\rm TeV}$. Examples for events with low (left) and high (right) $N_{\rm mpi}$ are displayed.

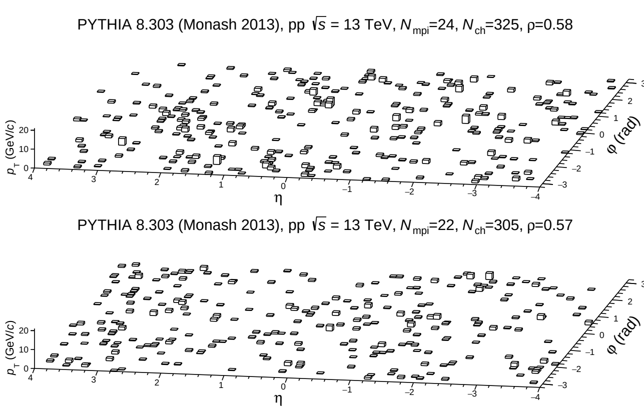

FIGURE 2. Two event displays of hedgehog events generated with PYTHIA 8.244 tune Monash. More than 300 primary charged particles and more than 20 multiparton interactions were required within the same pp collision. The probability of this type of events is around 10^{-4}%.

In order to illustrate how $flatenicity$ works for hedgehog tagging, pp collisions at $\sqrt{s} = 13\,{\rm TeV}$ were simulated using PYTHIA 8.244 (tune Monash). In this generator, hedgehog events originate from pp collisions where several semi-hard scatterings ocur within the same pp collision. 50 million events were generated, out of them only 87 events have more than 20 multiparton interactions fragmenting in more than 300 primary charged particles within $|\eta| < 4$. Figure 2 shows the characteristic transverse momentum as a function of η and φ for hedgehog events. The $flatenicity$ values for this type of events is below one. Generally, few events with a clear jet signal accompanied by the fragmentation of several multiparton interactions are also produced, and their $flatenicity$ is found to be above 1.

Events with similar multiplicity but originated from the fragmentation of less than five semi-hard scatterings more likely have $flatenicity$ larger than one, their characteristic event structure is shown in Fig. 3. In this case, we clearly see a jet- signal which is accompanied by the recoil jet fragmenting into several charged particles, and also particles from a few additional multiparton interactions. The probability of this type of rare events is 2 orders of magnitude smaller than in the case of hedgehog events.

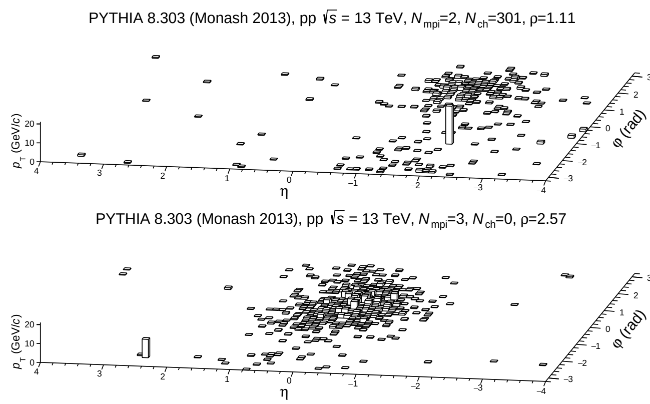

FIGURE 3. Two event displays of events generated with PYTHIA 8.244 tune Monash. More than 300 primary charged particles and less than 5 multiparton interactions were required within the same pp collision. The probability of this type of events is around 10^{-6}%.

In order to illustrate the scenario without MPI, very high multiplicity pp collisions where generated in PYTHIA with the option PartonLevel:MPI=off. This type of events have a very small probability, for example, for charged particle multiplicities larger than 200 the probability is 10^{-7}%. The event displays clearly shown in Fig. 4 clearly exhibit multi-jet structures, which originate $flatenicity$ values larger than 1. Even in this case, the event classifier $flatenicity$ seems to be robust to discriminate hedgehog events from multi-jet topologies.

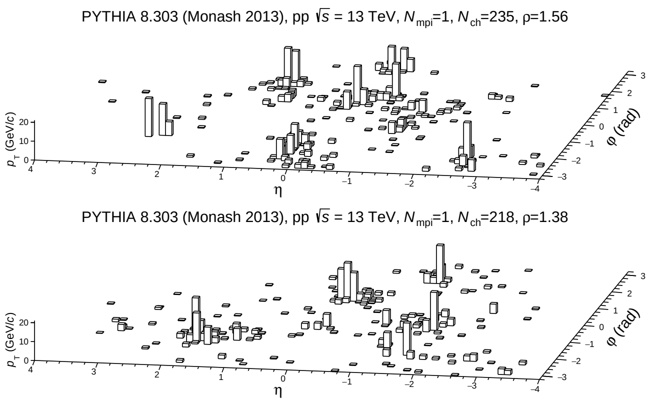

FIGURE 4. Two event displays of events generated with PYTHIA 8.244 tune Monash. More than 200 primary charged particles from pp collision simulated without MPI are displayed. The probability of this type of events is around 10^{-7}%.

3 Flatenicity distributions

The correlation between $flatenicity$ and the number of multiparton intactions is presented in Fig. 5. At low $N_{\rm mpi}$ the *flatenicity* distribution is very wide, it gets narrow with increasing $N_{\rm mpi}$. The average *flatenicity* is significantly above unity for low $N_{\rm mpi}$, and goes below one for $N_{\rm mpi} > 12$. For $N_{\rm mpi} > 25$ the average *flatenicity* approaches to 0.5. By construction this behaviour is expected, the pp collisions with extremely large underlying event ($N_{\rm mpi} > 25$) must have a uniform distribution of particles in the $\eta - \varphi$ space. Since in the experiment, the charged particle multiplicity is expected to be sensitive to $N_{\rm mpi}$, the correlation between $flatenicity$ and the charged particle multiplicity is shown in Fig. 6. The behavior is qualitatively similar to that from the analysis as a function of $N_{\rm mpi}$, suggesting that the isolation of hedgehog events would requires both ρ and multiplicity.

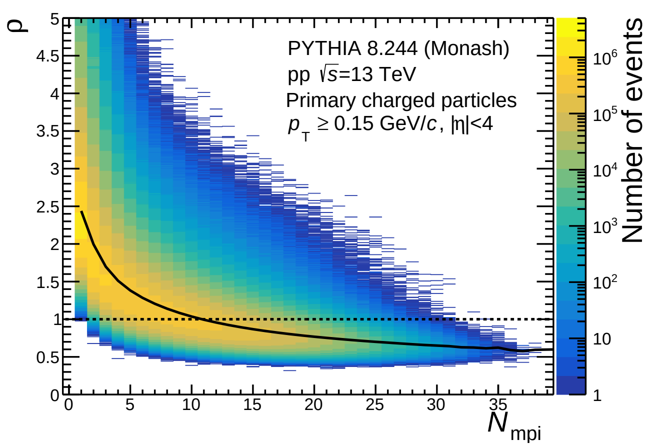

FIGURE 5. Flatenicity as a function of the number of multiparton interactions, the number of events in each bin is depicted in different colors. The results were produced using PYTHIA 8.244 simulations of pp collisions at $\sqrt{s}$ =13 TeV. Only primary charged particles within $|\eta| < 4$ and $p_{\rm T} \geq 0.15$ GeV/c were considered.

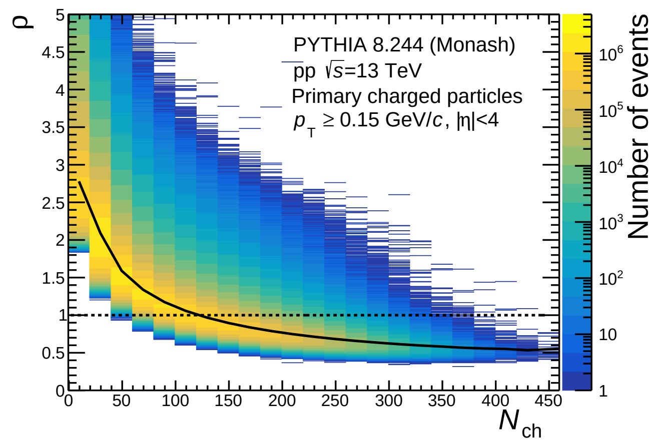

FIGURE 6. Flatenicity as a function of the charged particle multiplicity, the number of events in each bin is depicted in different colors. The results were produced using PYTHIA 8.244 simulations of pp collisions at $\sqrt{s}$ =13 TeV. Only primary charged particles within $|\eta| < 4$ and $p_{\rm T} \geq 0.15$ GeV/c were considered.

4 Conclusions

In this work we have shown that PYTHIA 8.244 predicts the existence of hedgehog events in pp collisions. These type of events were observed at TEVATRON energies, but they properties were never studied. Hedgehog events are produced when several semi-hard (> 20) scatterings occur within the same pp collision. In this contribution we have also introduced a tool which can be used by experiments in order to tag this type of rare pp collisions. We have introduced *flatenicity*, we argue that this new event shape together with the event multiplicity would allow to characterize the hedgehog events. This would requires an aparatus like ALICE 3 which is expected to have excellent particle identification capabilities at midrapidity, as well as tracking over a wide pseudorapidity.

5 Acknowledgement

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