Proceedings of the DAE Symp. on Nucl. Phys. 65 (2021)

Angular Dependence of Multiplicity Classes and Transverse-momentum Spectra within Non-extensive Statistical Approach in pp Collisions at $\sqrt{s} = 13$ TeV

Aditya Nath Mishra[1], Gergely Gábor Barnaföldi[1], and Guy Paić[2]
[1] *Wigner Research Centre for Physics, 29-33 Konkoly-Thege Miklós str., 1121 Budapest, Hungary and*
[2] *Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México,*
Apartado Postal 70-543, México City 04510, México
(Dated: September 19, 2021)

Transverse momentum spectra of produced primary charged-particles and their evolution have been studied in function of the position of the azimuthal of the particles associated to the leading particle. for proton-proton collisions at $\sqrt{s} = 13$ TeV using PYTHIA8 Monte Carlo event generator. Additionally, the behavior of the spherocity distribution in the same azimuthal bins is reported. The Multiplicity and midrapidity transverse momentum spectra of charged hadrons in azimuthal bins have been analyzed in the non-extensive statistical framework. The results on the findings corresponding to the Underlying Event are cross-checked with the Tsallis-parameter derivatives and spherocity-classified events.

I. INTRODUCTION

In this work, the aim is to qualitatively and quantitatively classify high-energy events in comparison to the well known event shape observable. The method here is to generate hadron spectra in ultra-relativistic proton-proton collisions, extract the Tsallis-parameters in given multiplicity classes, which provide an entropy-based event classification. This led us to understand the strongly correlated, non-perturbative regime and to determine the absolute and quantitative properties of the Underlying Event (UE). The results reported in this paper are obtained from 1 billion non-diffractive events for pp collisions at $\sqrt{s} = 13$ TeV simulated using PYTHIA version 8.240 with the default Monash 2013 tune [1]. The events and particles are selected for this analysis according to the following criteria. The events having at least three primary charged particle with transverse momentum $p_T > 0.15$ GeV/c within the pseudorapidity $|\eta| < 0.8$ are analyzed, which selection is required by the later-defined event-shape variable calculations.

II. ANALYSIS METHOD AND DEFINITIONS

To understand the particle production mechanism, by exploring the contributions of UE activity, in the azimuthal space we consider two Cases to divide azimuthal space, $\Delta\phi$, in 18 different sections, where $\Delta\phi$ is the angle between the leading charged particle and associated charged particles of the event.

Case I: : We open $\Delta\phi$ angle in steps of 20°, named "opening angle". The binning starts from -10 - $10°$ and the last bin covers full azimuthal space i.e. -180 - $180°$. It is easy to recognize, that the last bin is the Minimum Bias (MB) and, therefore the ratio of the largest $\Delta\phi$ bin to the MB found exactly one. Case I is useful to investigate the evolution of the thermodynamical observables of the system.

Case II: : We make slices of the $\Delta\phi$ of size 20°, named "sliding angle". In this case, the results for the first bin 0 - 20° are reported in two ways: including and excluding the leading particle in the result. Case II is a tool for exploring the geometrical structure of the Underlying Event.

Note, Case I and Case II can be cross-checked within the 1st bin with and without including the leading particle. This first bin is important, since this is the perturbative region, therefore well-described by theoretical models. Moreover one has to take into account, that angle opening for Case I and Case II is treated differently, which will present as different structures in the $\Delta\phi$ plots. Case I definition includes both sides of the leading particles, while Case II has mirror symmetry for $\Delta\phi = \pi$.

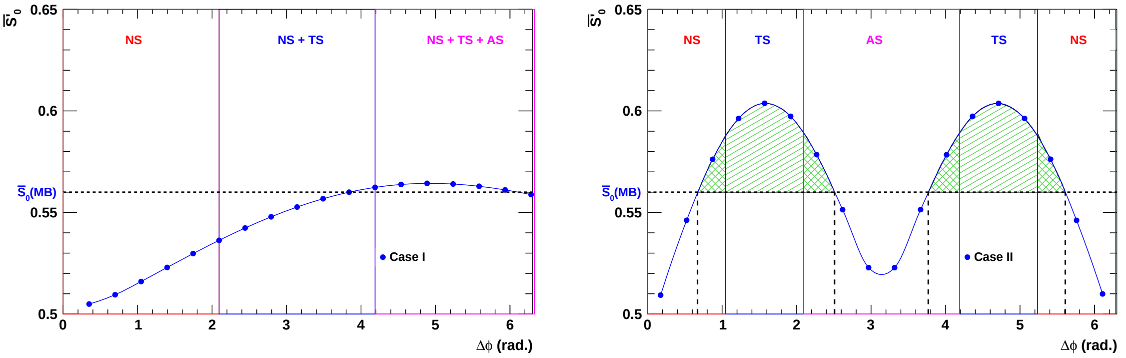
III. TRANSVERSE MOMENTUM SPECTRA WITH NON-EXTENSIVE TSALLIS STATISTICS

In the present study, we use one particular form of Tsallis distribution, named Tsallis − Pareto distributions [2, 3], which satisfy the thermodynamic consistency relations and given by:

$$f(m_T) = A \cdot \left[1 + \frac{q-1}{T_s}(m_T - m)\right]^{-\frac{1}{q-1}} \quad , \qquad (1)$$

where A is scale parameter, q is the non-extensive parameter, T_s is a temperature-like parameter, called Tsallis temperature and $m_T = \sqrt{p_T^2 + m^2}$ is the transverse mass of the given (identified) hadron species.

Since our aim here is to characterise the events by analysing different the UE contributions in the azimuthal space therefore, we fit p_T-spectra of charged particle with Tsallis − Pareto fitting function and explored the evolution of the Tsallis − Pareto parameters A, T_s and q in different $\Delta\phi$ bins for both cases. We found that the standard definition of the Underlying Event can be extended with about 66% in geometry within the



(a) Case I

(b) Case II

FIG. 1. Average spherocity ($\bar{S}'_0$) in $\Delta\phi$ bins are shown for Case I (left) and Case II (right). The horizontal dashed line corresponds to the minimum bias (MB) average spherocity for both cases.

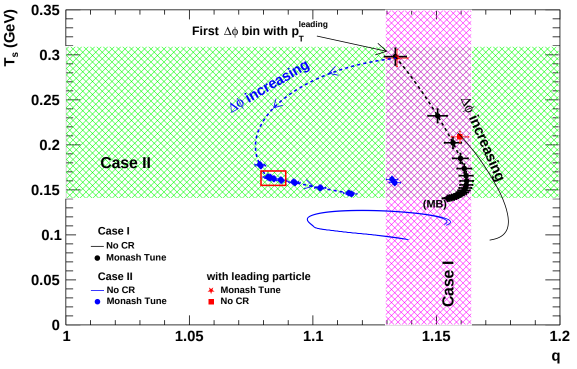


FIG. 2. The Tsallis-thermometer, which presents the relation between Tsallis temperature T_s and non-extensivity parameter (q) for both Case I and Case II. Red box represents the region obtained for new UE definition for Case II as defined in Fig. 1(b).

range, [±40°, ±140°] in comparison to the widely-used CDF-definition, [±60°, ±120°]. Indeed we found an upper transverse-momentum threshold, $p_T \lesssim$ 3-4 GeV/c for hadrons with Underlying Event origin. Location of the Underlying Event on the Tsallis-thermometer has been also presented at $T_s = 160 \pm 10$ MeV and at $q = 1.085 \pm 0.05$. Non-extensivity value was found to be the closest to the Boltzmann – Gibbs limit ($q = 1.0$) of the Tsallis – Pareto distribution's in isotropic events.

These findings were cross-checked with the parameter derivatives and spherocity-classified events. The obtained, nearly-zero angular variation of the spectral parameters in the Transverse Side region can support the identification and better localization of the Underlying Event by the Tsallis – Pareto parameters. Finally our quantified values correlated well with the spherocity-classified parameter trends.

Plotting the corresponding T_s and q values one can identify a compact locations at $T_s = 160 \pm 10$ MeV and at $q = 1.085 \pm 0.05$ marked as red box in Fig. 2. Interestingly this region is the lowest in non-extensivity, thus as the most isotrope Transverse Side bins seem to be the closest to the special case of the Tsallis – Pareto distribution, the $q = 1$ Boltzmann – Gibbs description. Following the obtained geometrical structure from Fig. 1, the Underlying Event can be associated with the [±40°, ±140°] ([$\pm 2\pi/9, \pm 7\pi/9$]), region in Case II, indeed the more strict CDF-definition in [±60°, ±120°] ([$\pm\pi/3, \pm 2\pi/3$]).

ACKNOWLEDGEMENTS

Authors would like to thank the Hungarian National Research, Development and Innovation Office (NKFIH) under the contract numbers OTKA K135515, K123815 and NKFIH 2019-2.1.11-TET-2019-00078, 2019-2.1.11-TET-2019-00050, Wigner GPU Laboratory, Mexican Conacyt project CF2042 and the support of the Coordinacion de la Investigacion Cientifica, Mexico. Discussion on the fit procedure with G. Bíró and T.S. Biró is highly appreciated.

[1] P. Z. Skands, S. Carrazza and J. Rojo, Eur. Phys. J. C **74** 3024 (2014) .

[2] T. S. Biró, G. G. Barnaföldi and P. Ván, Physica A **417** (2015) 215.

[3] T. S. Biró, G. G. Barnaföldi and P. Ván, Eur. Phys. J. A **49** (2013) 110.