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Intermittency in pseudorapidity space of *pp* collisions at $\sqrt{s}$ = 7 TeV

*Z.*Ong[1,*], *E.* Yuen[1], *H.W.* Ang[1], *A.H.* Chan[1], and *C.H.* Oh[1]

[1]Department of Physics, National University of Singapore. 2 Science Drive 3, Singapore 117551.

Abstract. The intermittency-type fluctuations in the pseudorapidity space of *pp* collisions at $\sqrt{s} = 7$ TeV done at the LHC is investigated, by analysing the scaling properties (exponents) of the factorial moments of the event multiplicity distributions in decreasing pseudorapidity bin size. It is found that the scaling behaviour persists in the $\sqrt{s} = 7$ TeV regime, indicating intermittent behaviour as observed previously in analyses done at lower energies [1,2]. Comparison is also made with the theoretical predictions of the Generalised Multiplicity Distribution (GMD) [3,4,6].

Introduction

The study of intermittency seeks to find large fluctuations in the (pseudo)rapidity distributions of hadron production in high energy collisions. In 1986, A. Bialas and R. Peschanski proposed a method to investigate intermittent phenomena by studying the scaling properties of the factorial moments of the multiplicity distribution in decreasing phase space domains [1]. Theoretical and experimental studies of intermittency will shed light on the hadronization process of quarks and gluons, which is still not fully understood in QCD [2].

In this work, we are interested in intermittent phenomena in multiplicity over *pseudorapidity space*, and hence we consider the bin-averaged moments:

$$F_p(\delta\eta) = \frac{1}{M}\sum_{m=1}^{M}\frac{< n_m(n_m-1)...(n_m-p+1) >}{< n_m >^p} \tag{1}$$

where F_p is the p^{th} bin-averaged moment; $\delta\eta$ is the pseudorapidity bin size; M is the number of equal-width bins which span the pseudorapidity space; n_m is the number of particles (multiplicity) in bin m in a single event; and $< \cdots >$ is an average performed over all events for that particular bin m.

F_p can be computed for varying bin sizes $\delta\eta$, and it is thought that a power law relation $F_p \sim (\delta\eta)^{-\nu_p}$ would be indicative of intermittent phenomena. Hence, we make plots of $\ln F_p$ vs. $\ln\delta\eta$ and observe for a straight line with non-zero slope.

Main Objectives

1. Produce plots of $\ln F_p$ vs. $\ln\delta\eta$ from LHC 7 TeV data

2. Compare results with GMD (Generalised Multiplicity Distribution) calculations

*e-mail: ongzongjin@u.nus.edu

About the Data

The experimental data used in this work is obtained from the MinimumBias primary dataset from RunA of 2011, which describes proton-proton collisions at $\sqrt{s}$ = 7 TeV. The raw data published on the CERN opendata portal [5] is then skimmed for offline analysis to include only:

- validated runs, as listed in [5]
- events with one primary vertex (to avoid looking at events with pileup)

The analysis was then performed over 1,024,005 events.

Generalised Multiplicity Distribution

The Generalised Multiplicity Distribution [3,4,6] describes multiparticle production, given by

$$P_n(\overline{n}, k, k') = \frac{\Gamma(n+k)}{\Gamma(n-k'+1)\Gamma(k'+k)} \times \left(\frac{\overline{n}-k'}{\overline{n}+k}\right)^{n-k'} \left(\frac{k'+k}{\overline{n}+k}\right)^{k'+k} \tag{2}$$

where P_n is the normalised probability that n final state particles are produced (a full derivation of eq. (2) can be found in [6]). The distribution is parametrised by:

- $\overline{n}$ = mean multiplicity of experimental data
- $k \propto$ mean number of quarks in collisions
- k' = mean number of gluons in collisions

With $\overline{n}$ fixed from experimental data, k and k' are adjusted to fit the experimental multiplicity distribution by reducing the least squares error. With these 3 parameters, the normalised factorial moments F_p (p = 2, 3, 4, 5) based on the GMD can be obtained using the following:

$$< n >^2 F_2 = k(k+1)\beta^2 - 2k'(1+k)\alpha\beta + k'(k'-1)\alpha^2 \tag{3}$$

$$\begin{aligned} < n >^3 F_3 = &- k(k+1)(k+2)\beta^3 + 3k'(1+k)(2+k)\alpha\beta^2 \\ &- 3k'(k'-1)(k+2)\alpha^2\beta + k'(k'-1)(k'-2)\alpha^3 \end{aligned} \tag{4}$$

$$\begin{aligned} < n >^4 F_4 = &k(k+1)(k+2)(k+3)\beta^4 - 4k'(1+k)(2+k)(3+k)\alpha\beta^3 \\ &- 6k'(k'-1)(k+2)(k+3)\alpha^2\beta^2 - 4k'(k'-1)(k'-2)(k+3)\alpha^3\beta \\ &+ k'(k'-1)(k'-2)(k'-3)\alpha^4 \end{aligned} \tag{5}$$

$$\begin{aligned} < n >^5 F_5 = &- k(k+1)(k+2)(k+3)(k+4)\beta^5 \\ &+ 5k'(k+1)(k+2)(k+3)(k+4)\alpha\beta^4 \\ &- 10k'(k-1)(k+2)(k+3)(k+4)\alpha^2\beta^3 \\ &+ 10k'(k-1)(k'-2)(k+3)(k+4)\alpha^3\beta^2 \\ &- 5k'(k'-1)(k'-2)(k'-3)(k+4)\alpha^4\beta \\ &+ k'(k'-1)(k'-2)(k'-3)(k'-4)\alpha^5 \end{aligned} \tag{6}$$

where

$$\alpha = \frac{< n > +k}{k' + k}, \quad \beta = \frac{k' - < n >}{k' + k} \tag{7}$$

From the multiplicity distribution of each reduced pseudorapidity window (e.g. $\delta\eta = 1.2$, 0.6, 0.3, etc.), we can derive values of $\overline{n}$, k and k' which are then substituted into eq. (3) to (6) to obtain data points for $\ln F_p$ vs. $\ln \delta\eta$, which are then plotted in Fig. 1.

Results and Plots

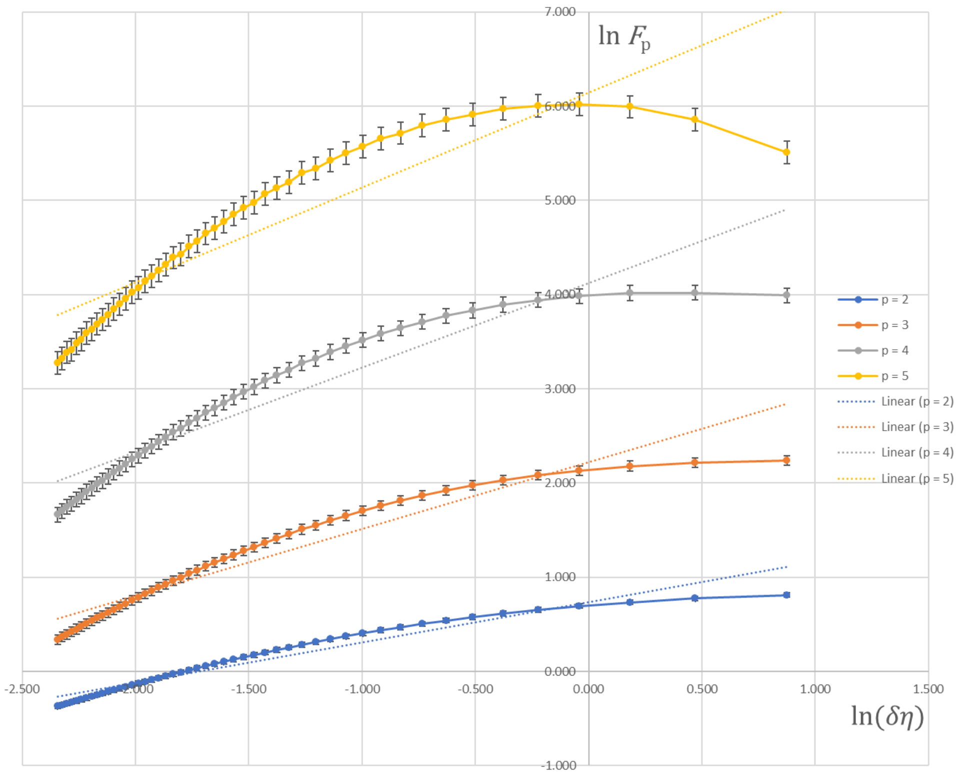

Figure 1: Plots of $\ln F_p$ vs. $\ln(\delta\eta)$ (experimental values)

Table 1: Comparison of gradient parameters ν_p

p	ν_p **(data)**	ν_p **(GMD)**
2	0.43 ± 0.01	0.42 ± 0.01
3	0.71 ± 0.03	0.85 ± 0.02
4	0.90 ± 0.05	1.40 ± 0.03
5	1.01 ± 0.07	-0.12 ± 0.05

Conclusions

- Intermittent phenomena persists in the TeV range, as clearly seen by the non-zero and well-defined gradient parameters from the 7 TeV collision data (Fig. 1 and Table 1)
- The GMD does not describe the gradient parameters well (except $p = 2$), and may need to be further modified to better describe intermittency in the TeV scale (Table 1)

Future Extensions

This work can be further expanded in the following domains:

1. **More events:** this analysis covers approximately one third of the available dataset due to limited computational resources at the time of this work. The analysis can be extended to cover the complete 7 TeV dataset, which will include more events and reduced statistical error.
2. **Unfolding and error analysis:** the current work represents a preliminary analysis with minimal treatment of the raw data. Data unfolding and systematic error analysis can be done to further add to the reliability of the conclusion.
3. **Fitting with theoretical distributions:** the experimental results can be compared to more distributions used to describe multiparticle production, such as the Negative Binomial Distribution, the Furry-Yule Distribution, etc. to look for a better theoretical description of intermittent phenomena.
4. **Higher collision energy:** with the upgraded LHC beginning its second run at $\sqrt{s} = 13$ TeV in 2015, we also look forward to extending this analysis to a higher energy regime when the collision data is released by the CMS collaboration.

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