Intermittency Analysis of Toy Monte Carlo Events

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Abstract

To learn about the mechanism of particle production and phase changes from quarks to hadrons, fluctuations of observables from experiments are studied. Scaling of the observables from these experiments can reveal the properties of the system created, as it expands from quark-gluon plasma phase to hadronic phase. One of such techniques is to study the scaling behaviour of the normalized factorial moments (F_q) of multiplicity fluctuations with the bin size resolution or the number of bins (M). A power law behaviour of F_q as function of number of bins (M), known as intermittency, is a signature of fluctuations of self-similar nature. Intermittency analysis of low energy data has been studied extensively as it promises to identify the quark-hadron phase transition and associated critical point. Event-by-event intermittency analysis of toy Monte Carlo events is carried in the scenario of high multiplicity events, where the charged particle bin multiplicity is large. Dependence of NFM on the detector efficiencies and on the presence of fluctuations have been studied. NFM are observed to be sensitive to any fluctuations of dynamical nature which appear as large local multiplicity fluctuations. With no physics in the toy Monte Carlo events the results presented here provide a baseline to the experimental results and clarity on application of detector efficiency corrections to the experimental data for analysis.

Objectives

- To check the efficiency correction methodology
- To check the dependence of normalized factorial moments (NFM) in case of
  - Uniform (Gaussian) efficiencies
  - Non-uniform efficiencies (deviation from Gaussian behaviour)
- To test the efficacy of NFM to gauge fluctuations present in the system.

Motivation

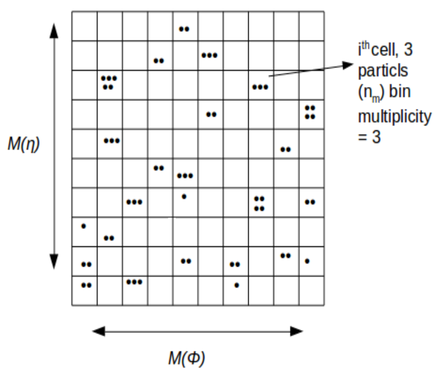
- Large density fluctuations in the initial stage of collisions transfer into final state collective behaviour as the strongly coupled quark gluon plasma expands.
- Near critical temperature there is tension between the collective interactions and thermal randomization leads to clusters of all sizes

Clustering → Fluctuations in the geometrical Configurations (Spatial patterns) → *Criticality And Quark-hadron phase transition*

- Fluctuations study of the observables is an important tool to understand the dynamics of the particle production and phase changes
- One of the proposed measure is to study *scaling properties of multiplicity fluctuations over wide range of bin sizes by* Normalized Factorial Moments referred to as ***Intermittency analysis.***

Formalism

- Phase space (η, Φ) is divided into a square lattice. Number of bins along eta and phi axis respt. M : 4 – 82
- Number of particles that go in each bin defines the bin multiplicity (n, that is used to determine the Normalized Factorial Moments, NFM)
- $F_q(M)$, calculated as a average over bins and events



$$F_q(M) = \frac{\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{i=1}^{M} f_q(n_{ie})}{\left(\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{i=1}^{M} f_1(n_{ie})\right)^q} \quad .....(1)$$

- **Intermittency** ***refers to power-law growth of the NFM with decrease of phase space bin (or increase in the number of bins).***

$$F_q(M) \;\alpha\; M^{\varphi_q} \quad .....(2)$$ ***where φ_q is known as intermittency index***

Observations

- **Toy Model :** Events are generated for a random multiplicity distribution such that
  - Two Phase space variables have---> Uniform random distribution
- **Uniform Efficiency Maps (x%)** Tracks are removed randomly from each event so as to maintain x% track efficiency.
- **Non-Uniform Efficiency Maps** Tracks are removed non uniformly from sample of events and tracking efficiency maps are obtained for all values of M.
- **Efficiency Corrections:** Efficiency maps in the two phase space variables are obtained for each "M".

$$\epsilon = \frac{\text{Number of tracks after removal of some tracks}}{\text{Number of tracks within acceptance}}$$

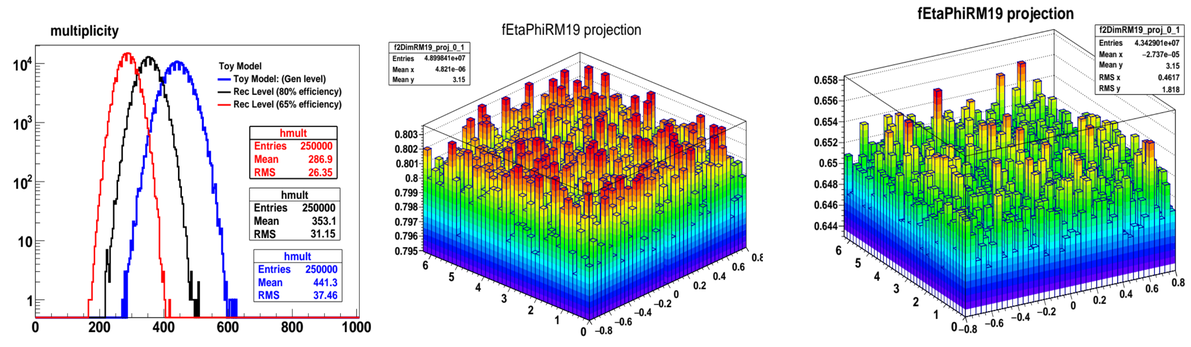


Fig.1. Uniform case : Multiplicity and efficiency maps (With 80% and 65% efficiency)

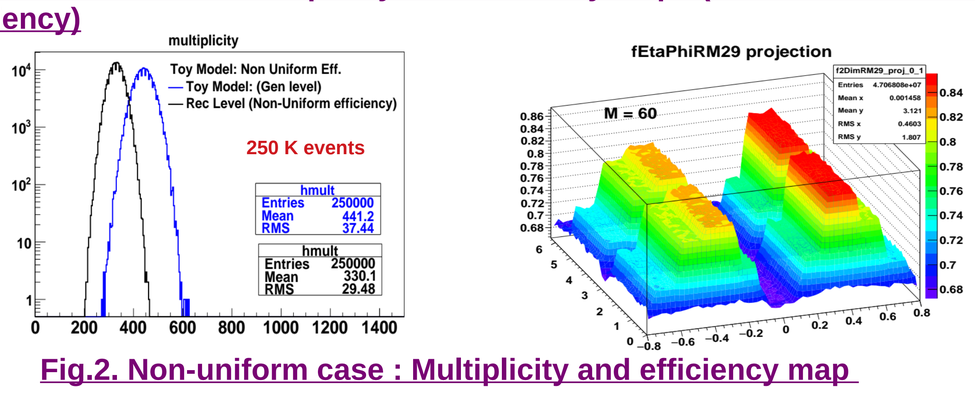


Fig.2. Non-uniform case : Multiplicity and efficiency map

Observations and Results

M-dependence of F_q (M)

Closure Test

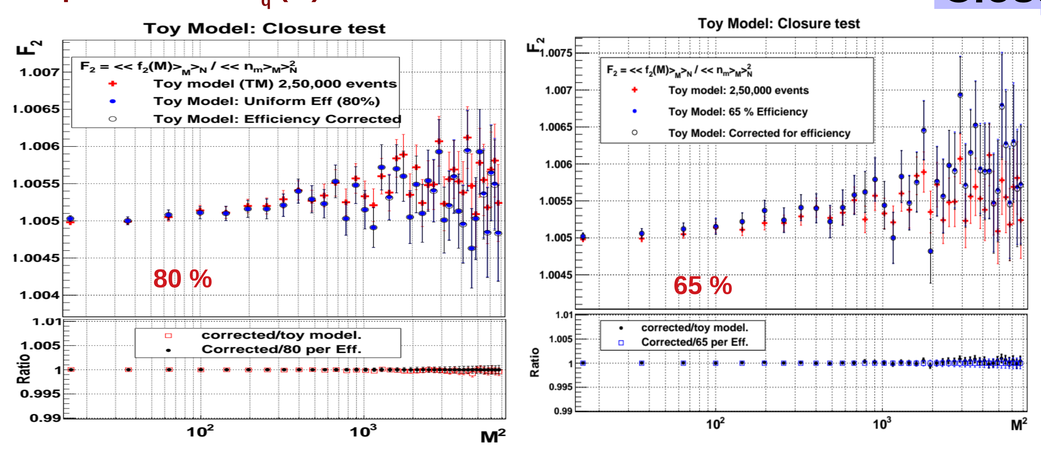


Fig. 3. Uniform case : Closure Test with a) 80% and b) 65% uniform efficiency

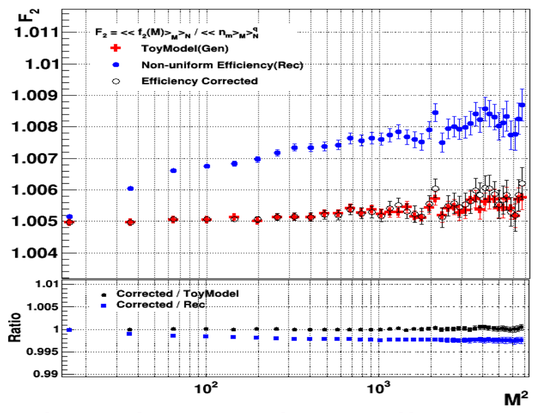


Fig. 4 Closure Test in non-uniform case

- *Closure is achieved both in case of uniform and non-uniform efficiencies.*
- *Uniform efficiency corrections get cancelled out in F_q immaterial of the percentage.*
- *In case of non-uniform inefficiencies*
  - *Ratio Corrected/Uncorrected ≠ 1*
  - *Visible closure.*
  - *Efficiency correction method works.*

With Intermittency Signal

Intermittency Signal --------> By Increasing Particle density in certain bins

Method 1: Added tracks in certain selected bins (~5%) replacing equal number of tracks

Method 2: Added tracks in certain selected bins (~5%) without replacing any track

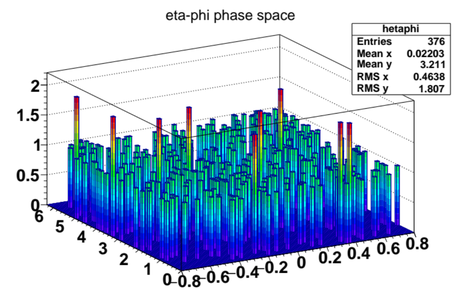


Fig 5. Spatial distributions of particles of an event in eta-phi space

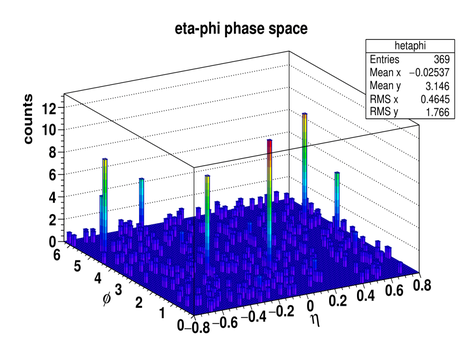


Fig 6. Spatial distributions of particles of an event with 5% tracks added in selected bins while removing equal number of tracks from rest of the region

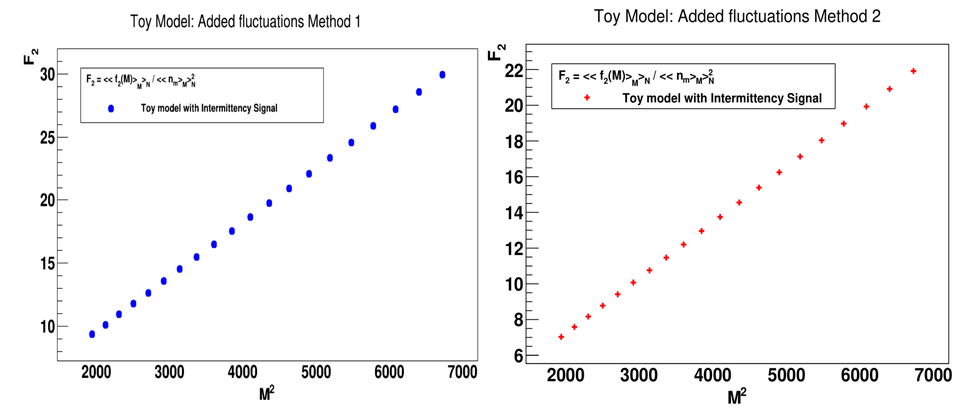


Fig 7. Intermittency observed at higher M that is in small size bins when 5% tracks are added in certain bins (Method 1 and Method 2) so as to increase particle density in certain bins.

Summary

- ✔ Intermittency analysis of the Toy Monte Carlo events is performed in two dimensional phase space.
- ✔ It is observed to be an efficient technique to look for fluctuations in the system that is indicated by power law behaviour of normalized factorial moments with the decrease in bin size.
- ✔ It is also established that the normalized factorial moments are robust against measurement inefficiencies of Gaussian nature.
- ✔ However, in event the measurement efficiencies have large departure from the Gaussian nature then NFM should be corrected to extract the true nature of the system.
- ✔ Intermittency analysis is a good candidate to probe the nature of multiparticle production in heavy ion collisions.

References

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