Event Texture Search for Critical Fluctuations in Pb+Pb Collisions

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NA44 uses a 512 channel Si pad array covering $1.5 < \eta < 3.3$ to study charged hadron production in 158 A GeV Pb+Pb collisions at the CERN SPS. We apply a multiresolution analysis, based on a Discrete Wavelet Transformation, to probe the texture of particle distributions event-by-event, by simultaneous localization of features in space and scale. Scanning a broad range of multiplicities, we look for possible critical behaviour in the power spectra of local density fluctuations. The data are compared with detailed simulations of detector response, using heavy ion event generators, and with a reference sample created via event mixing. An upper limit is set on the probability and magnitude of dynamical fluctuations.

1. Introduction

The deconfinement/chiral symmetry restoration phase transition in ultrarelativistic heavy ion collisions is inherently a multiparticle phenomenon. Therefore, event-by-event analysis of multiparticle hadronic observables is of paramount interest. We carry out a texture, or local fluctuation, analysis to determine the correlation/fluctuation content of single events, and analyze the scale composition of the correlations.

The idea to look at particle distributions in rapidity y to search for critical behaviour was proposed [1,2] based upon a Ginzburg-Landau type of multihadron production theory [1], where a random hadronic field plays the role of an order parameter in a hadronization transition. Enhanced large scale correlations of hadrons in y at the phase transition would signal critical fluctuations in the order parameter. Stephanov and coworkers [3]

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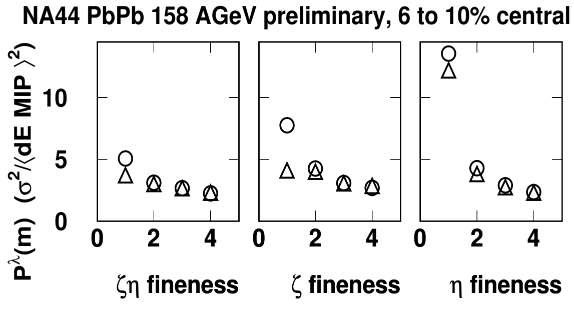


Figure 1. Power spectra : ○ – true events, △ – mixed events.

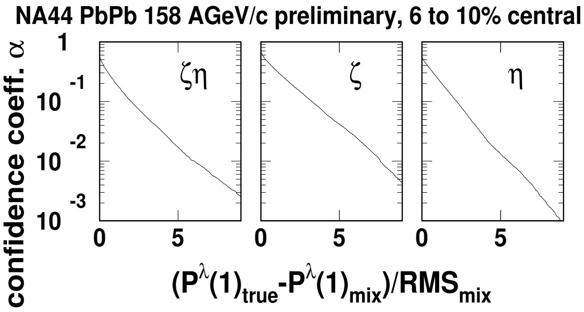


Figure 2. Confidence coefficient as a function of the fluctuation strength.

indicated a second order QCD phase transition point which should exist under certain initial conditions, within the reach of today's experiments.

In our work, a power spectrum analysis of event texture in pseudorapidity η and azimuthal angle ζ, based on a Discrete Wavelet Transformation (DWT)[4], is performed on a number of large event ensembles sampled according to their multiplicity, thereby studying the impact parameter dependence of the observables. DWT quantifies contributions of different ζ and η scales into the event's overall texture, thus testing the possible large scale enhancement.

2. Experiment and Results

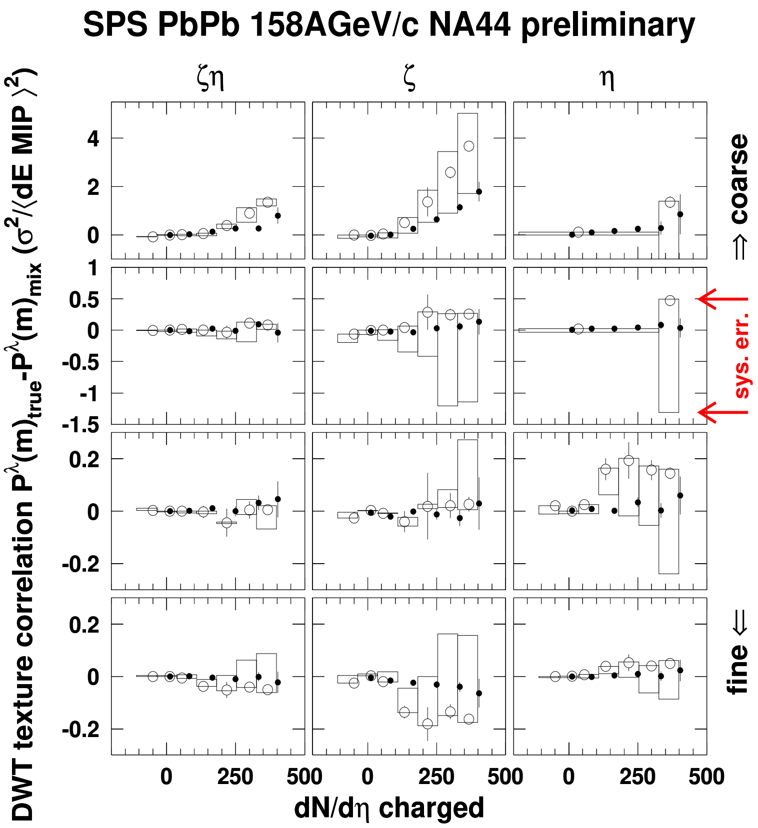
Ionization energy loss of charged particles was measured in 512 silicon pads, with radial granularity of 16 and azimuthal granularity of 32. The pads were read out by AMPLEX [5] chips, one chip per sector. δ-electrons, produced by the *Pb* beam traversing the target, were swept away to one side by a dipole magnetic field (≤ 1.6 T). Only the δ-electron-free side was used in the analysis. Empty target runs were used to measure the background. Cross-talk in the detector was evaluated off-line.

Track density in an individual event $\rho(\zeta,\eta)$ is represented by a 2D array of the calibrated digitized amplitudes of the channels (an *amplitude array*). This is expanded into a basis of *Haar wavelet*[4] functions $\Psi^{\lambda}_{m,i,j}(\zeta,\eta)$, orthogonal with respect to scale fineness m and location (i,j), with the λ index numbering three modes of texture direction sensitivity – ζ, η, and $\zeta\eta$ – for azimuthal, pseudorapidity and diagonal [2]. With our binned detector, the act of data taking is the first stage of the Haar wavelet transformation (not true for any other wavelet).

From the squared expansion coefficients a *power spectrum* is formed:

$$P^{\lambda}(m) = \frac{1}{2^{2m}} \sum_{i,j} \langle \rho, \Psi^{\lambda}_{m,i,j} \rangle^2. \tag{1}$$

[2]Technically, the 2D basis $\Psi^{\lambda}_{m,i,j}(\zeta,\eta) = 2^m \Psi^{\lambda}(2^m\zeta - i, 2^m\eta - j)$ is constructed from 1D functions in the following way: $\Psi^{\zeta} = \psi(\zeta)\phi(\eta), \Psi^{\eta} = \phi(\zeta)\psi(\eta), \Psi^{\zeta\eta} = \psi(\zeta)\psi(\eta)$, where for any variable x, the wavelet function $\psi(x) = \{+1 \text{ for } 0 \leq x < \frac{1}{2}; -1 \text{ for } \frac{1}{2} \leq x < 1; 0 \text{ otherwise}\}$, and the scaling function $\phi(x) = 1$ for $0 \leq x < 1$ and 0 otherwise.



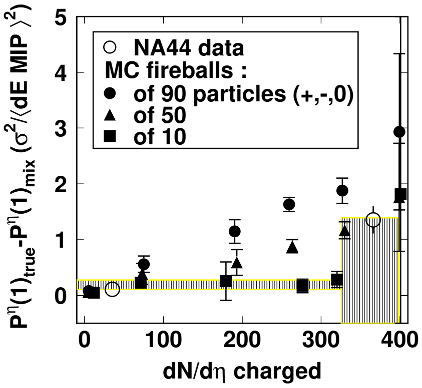


Figure 4. Coarse scale η texture correlation in the NA44 data, shown by ◯ (from the top right plot of Figure 3), is compared with that from the multifireball event generator for three different fireball sizes. Detector response is simulated.

Figure 3. Multiplicity dependence of the texture correlation. ◯ – the NA44 data, • – RQMD. The boxes show the systematic errors vertically and the boundaries of the multiplicity bins horizontally; the statistical errors are indicated by the vertical bars on the points. The rows correspond to the scale fineness m, the columns – to the directional mode λ (discussed in the text).

We used WAILI [7] software to obtain the wavelet expansions. More experimental and algebraic details can be found in [8] and the references therein.

Figure 1 shows that the power spectra in central Pb+Pb collisions are indeed enhanced on the coarse scale. It is necessary to eliminate "trivial" and detector related contributions to this enhancement. Event mixing is done by taking different channels from different events. In order to reproduce electronic cross-talk effects in the mixed event sample, mixing is done sector-wise, i.e. the sectors constitute the subevents subjected to the event number scrambling. The mixed events preserve the texture associated with detector position offsets, the inherent $dN/d\eta$ shape, cross-talk and dead channels. This is *static* texture as it reproduces its pattern event after event; we are interested in *dynamic* texture. We reduce sources of static texture in the power spectra by empty target subtraction and by subtraction of the mixed event power spectra, thus obtaining the *texture correlation*

$P^\lambda(m)_{true} - P^\lambda(m)_{mix}$. This quantity, normalized to the RMS fluctuation of $P^\lambda(m)_{mix}$, is used to characterize the relative strength of local fluctuations in an event. Its distribution for different λ is plotted in Figure 2 in an integral way, i.e. as an $\alpha(x)$ graph where for every x, α is the fraction of the distribution above x. The *confidence level* with which local fluctuations of a strength x can be excluded is then $1-\alpha$. Fluctuations greater than $3 \times RMS_{mix}$ are excluded in the azimuthal and pseudorapidity modes with 90% and 95% confidence, respectively. The monotonic fall of the curve is consistent with absence of abnormal subsamples in the data.

Figure 3 summarizes texture correlation data for different multiplicity events. The systematic errors were evaluated by removing the Pb target and switching magnetic field polarity to expose the analyzed side of the detector to δ-electrons, while minimizing nuclear interactions. Correlations (i.e. deviations of $P^\lambda(m)_{true}$ from $P^\lambda(m)_{mix}$) in such events measure the remaining systematic uncertainties. Thus, this component of the systematic error is *signed*, and the systematic errors are asymmetric. The other component (significant only on the coarsest scale) is the uncertainty of our knowledge of the beam's geometrical cross-section.

3. Discussion and Conclusions

A Monte Carlo simulation was performed, including known background texture effects and the subtraction of mixed simulated events. The finite beam size effect, irreducible by the subtraction methods, is thereby taken into account.

The finite beam size effect explains the rise of RQMD points with $dN/d\eta$ in Fig. 3. Finally, the sensitivity of the method is evaluated (see Figure 4) in MC by generating multiple fireball events with given mean number of particles (charged and neutral), N_p, per fireball. The total p_T of each fireball is 0; its total p_Z is chosen to simulate longitudinal flow by Lorentz-boosting the fireballs along the Z direction, keeping the total $\vec{p}$ of an event at 0. By varying N_p per fireball, one varies "grain coarseness" of the event texture in η. The data are consistent with clustering of N_p per fireball below 50.

This novel method of event-by-event analysis, applied to the SPS $PbPb$ data, does not reveal any evidence of critical phenomena. The authors thank N.Antoniou, I.Dremin, E.Shuryak, M.Stephanov, and T.Trainor for illuminating discussions.

REFERENCES

1. D.J.Scalapino, R.L.Sugar, Phys. Rev. **D8**, No 7, 2284-2294 (1973)
2. P.Carruthers, I.Sarcevic, Phys. Lett. **B189**, No 4, 442-448 (1987)
3. M.Stephanov, K.Rajagopal, E.Shuryak, Phys. Rev. Lett. **81** 4816 (1998)
4. I.Daubechies, Ten Lectures on Wavelets, SIAM, 1992
5. E. Beuville *et al.*, NIM **A288**, 157-167 (1990)
6. J.Pando, L-Z.Fang, Phys. Rev. **E57**, 3593-3601 (1998); L-Z.Fang, astro-ph/9701228.
7. G. Uytterhoeven *et al.*, WAILI: Wavelets with Integer Lifting. TW Report 262, Department of Computer Science, Katholieke Universiteit Leuven, Belgium, July 1997.
8. M.Kopytine for the NA44 Collaboration, in: Proceedings of the XXXth International Symposium on the Multiparticle Dynamics; nucl-ex/0101006.