FLUCTUATIONS AND CORRELATIONS STUDY AT NA61/SHINE*

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The strong interactions program of NA61/SHINE, a fixed-target experiment at the CERN SPS, focuses on the search for the critical point of strongly interacting matter. The strategy of the collaboration is to perform a comprehensive two-dimensional scan of the phase diagram μ_B–T by changing the collision energy and the system size. If in this scenario the system freeze-out occurs in the vicinity of the possible critical point, then a region of enhanced fluctuations is expected to be seen by properly sensitive fluctuation measures. The paper reviews the possible ways to study multiplicity fluctuations, *e.g.* in terms of pseudorapidity dependence of strongly intensive quantities or the study of the higher-order moments of multiplicity distributions. An important issue of the results corrections and possible systematic problems in the analysis is addressed.

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1. Introduction

The exact structure of the QCD phase diagram is an intriguing unresolved question [1]. Lattice calculations at zero baryon density, which is the LHC energies regime, provide us with a smooth cross-over from the hadron gas to the quark–gluon plasma region. Meanwhile, experimental evidence suggests that at lower energies the occurring phase transition is of the first order [2]. These circumstances encourage an active search for the possible Critical Point (CP) of strongly interacting matter from the point of view of both theory and experiment.

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2. Fluctuations oriented analysis

The vicinity of a possible critical point is considered to be quite remarkable from the experimental point of view since in this unstable region a system becomes scale-invariant and suffers fluctuations at all scales. Thus, one expects to be able to measure [3] some part of these critical fluctuations, which would survive after the system evolution and emerge in the final hadron yields. Therefore, for this purpose, it is mandatory to use very sensitive measures, which, however, must be robust to overwhelming trivial fluctuations.

NA61/SHINE [4] studies the fluctuations in terms of strongly intensive quantities (SIQs) that are manifested to be independent of both the volume and the event-by-event volume fluctuations in some simple reference models [5]. Being constructed from the first and second moments of the extensive event quantities distributions, SIQs are expected to reveal some strikingly non-monotonic behaviour if the system passed through the vicinity of the CP. The characteristic signatures might be seen in the fluctuations of the charged particles multiplicity.

The paper shows an example of the fluctuation probe — the strongly intensive quantity $\Sigma[N_{\rm F}, N_{\rm B}] = [\langle N_{\rm F}\rangle\omega[N_{\rm B}] + \langle N_{\rm B}\rangle\omega[N_{\rm F}] - 2(\langle N_{\rm F}N_{\rm B}\rangle - \langle N_{\rm F}\rangle\langle N_{\rm B}\rangle)]/[\langle N_{\rm F}\rangle + \langle N_{\rm B}\rangle]$ [6] as a function of the distance between the Forward and Backward pseudorapidity intervals, where the corresponding $N_{\rm F}$ and $N_{\rm B}$ multiplicities were evaluated (Fig. 1). The change of the pseudo-

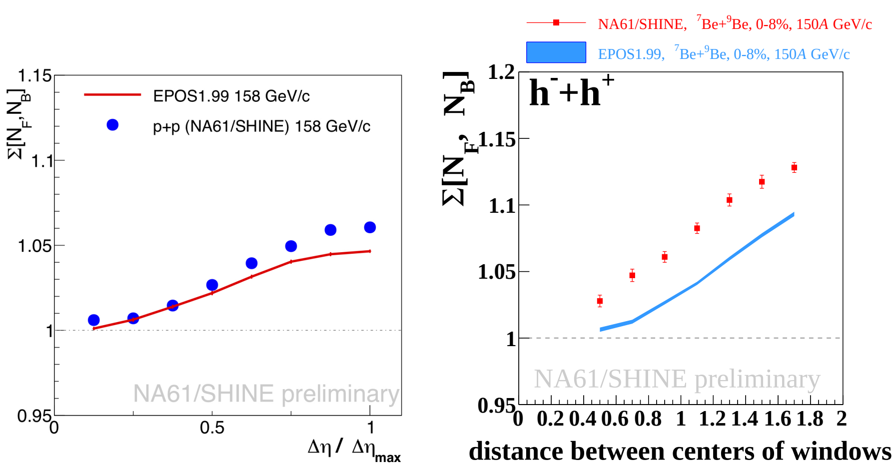

Fig. 1. $\Sigma[N_{\rm F}, N_{\rm B}]$ as a function of the distance between the Forward and Backward pseudorapidity intervals in inelastic $p+p$ reactions (left) and 8% most central Be+Be collisions (right) at beam momentum 158 GeV/c and 150A GeV/c, respectively. The dots represent the experimental data for all charged particles, lines show the EPOS1.99 results in the NA61/SHINE acceptance.

rapidity acceptance for $\Sigma[N_{\rm F}, N_{\rm B}]$ corresponds to the scan in the baryon chemical potential μ_B at the freeze-out stage [7]. The designed normalisation [8] determines that $\Sigma[N_{\rm F}, N_{\rm B}]$ should be exactly 1 for the Poisson distributions of $N_{\rm F}$ and $N_{\rm B}$ in the model of independent sources or for the ideal Boltzmann gas in GCE, and 0 for the absence of $N_{\rm F} - N_{\rm B}$ fluctuations.

Another possibility to spot the CP is to look more carefully at the event distributions by studying their higher-order moments. For example, the calculation of intensive skewness and kurtosis (Fig. 2, [9]) can shed some light on the possible criticality of multiplicity distributions, because $S\sigma$ and $\kappa\sigma^2$ are proportional to the higher powers of the system correlation length and, therefore, are more sensitive to the CP-induced divergence of it. The reference non-critical value for h^- distribution is the Poisson. For the $h^+ - h^-$ distribution, the simplest baseline is the Skellam, which is valid if h^+ and h^- are distributed according to independent Poissons.

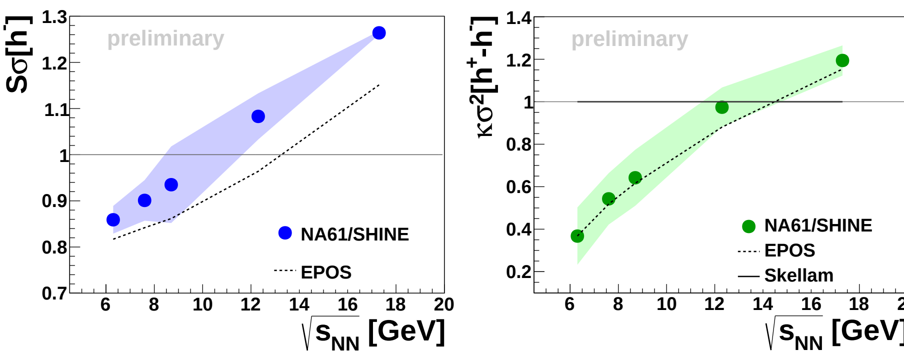

Fig. 2. $S\sigma[h^-]$ (left) and $\kappa\sigma^2[h^+ - h^-]$ (right) as functions of the collision centre-of-mass energy in inelastic $p + p$ reactions. Dots represent data, dashed lines are EPOS1.99 predictions, solid lines are Skellam baselines for the net-charge and Poisson for the negatively charged.

3. Corrections for the detector inefficiencies

When all is said and done, another important issue is a proper correction procedure for the experimental results to be comparable to the models and other data. The main illness of data is an undesirable detector influence, which can result in trigger biases or losses/gains of tracks. The former cause event losses and the latter generate the event migration in the space of the *e.g.* event multiplicity. The solution is unfolding, *i.e.* deconvolution or unsmearing, of the measured distributions. After being unfolded, they are assumed to reflect the pure nature without any detector bias.

The different methods of the distributions unfolding for the study of fluctuations were verified on the toy-models with extreme conditions and on some MC generators output. The most convenient method is RooUnfold-Bayes from the RooUnfold package [10], since it can be applied for both 1D and 2D distributions. The key object in the unfolding procedure is a response matrix (Fig. 3), whose elements are probabilities to measure $N_{\rm rec}$ charged particles in the event with originally $N_{\rm sim}$, filled simultaneously event by event. This matrix contains all the information of detector biases and must cover as wide phase space as possible in order to account for all possible "data" issues. In the case of a perfect detector, RM would be diagonal and the simplest correction of bin-by-bin weighting could be applied.

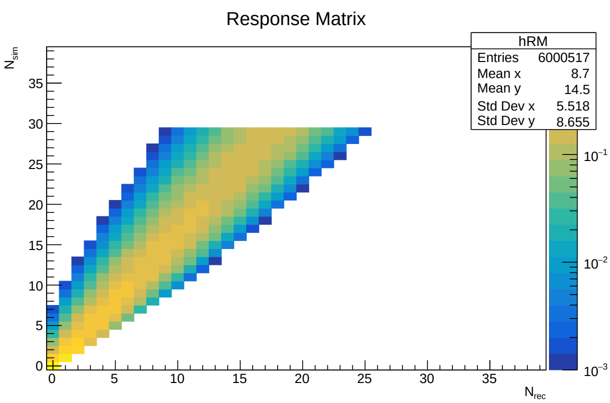

Fig. 3. Example of a non-normalized response matrix calculated in a toy-model with $N_{\rm sim}$ — pure simulated event multiplicity and $N_{\rm rec}$ — detector-biased one.

4. Conclusions

NA61/SHINE conducts the search for the critical point of strongly interacting matter by means of fluctuations. The paper presents examples of the fluctuation probes of interest. The results of strongly intensive quantity $\Sigma[N_{\rm F}, N_{\rm B}]$ in $p + p$ and Be+Be data do not show any non-monotonic behaviour. The study of the higher-order intensive cumulants in terms of skewness $S\sigma$ and kurtosis $\kappa\sigma^2$ of negatively charged particles and net-charge in $p + p$ interactions also does not reveal any significant discontinuity that one would expect if the system approaches the Critical Point. Several methods of data corrections for detector inefficiencies were tested. The analysis of the accumulated data is ongoing by NA61/SHINE.

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