

Recent results from the search for the critical point of strongly interacting matter at the CERN SPS

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Abstract

Recent searches at the CERN SPS for evidence of the critical point of strongly interacting matter are discussed. Experimental results on theoretically expected signatures, such as event-to-event fluctuations of the particle multiplicity and the average transverse momentum as well as intermittency in particle production are presented.

Keywords: heavy ion collisions, strongly interacting matter, critical point, fluctuations

1. Introduction

The exploration of the phase diagram of strongly interacting matter, particularly the search for a phase transition from hadronic to partonic degrees of freedom and possibly a critical endpoint, is one of the most challenging tasks in present heavy ion physics. NA49 data on inclusive hadron production indicate that the onset of deconfinement in central Pb+Pb collisions is located at about $\sqrt{s_{NN}}=30A$ GeV. It is mainly based on the observation of narrow structures in the energy dependence of hadron production in central Pb+Pb collisions which are not observed in elementary interactions [1, 2]. The NA61/SHINE experiment [3] continues the ion program of NA49 with the main aim of searching for the critical point and studying in details the onset of deconfinement by performing a two dimensional scan of the phase diagram in T and μ_B . This is achieved by varying collision energy (13A-158A GeV) and size of the colliding systems. The data sets recorded by both experiments and those planned to be recorded by NA61/SHINE for the scan of the phase diagram are presented in Fig. 1. Chemical freeze-out points in Fig. 1 are taken from [4]. The presence of the predicted critical point is expected to lead to an increase of event-by-event fluctuations of many observables [5, 6] provided that the freeze-out of the measured hadrons occurs close to its loca-

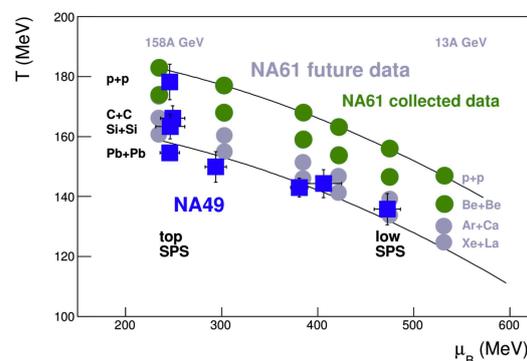


Figure 1: The planned scan of the phase diagram by varying collision energy (μ_B) and size of colliding nuclei (T). Chemical freeze-out points are taken from [4] and parametrizations therein.

tion in the phase diagram and the evolution of the final hadron phase does not erase the fluctuation signals. The NA61/SHINE experiment looks for a maximum of fluctuations as experimental signature for the critical point.

2. Event-by-event fluctuations

In the NA49 and NA61/SHINE experiments event-by-event fluctuations of the particle multiplicity are measured by the scaled variance ω which is an intensive measure (independent of interaction volume) and

defined as

$$\omega = \omega [N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle} \quad (1)$$

The transverse momentum fluctuations are measured by the Φ quantity proposed in [7] which was also successfully employed by the NA49 experiment to study charge and azimuthal angle fluctuations [8, 9]. Recently new strongly intensive fluctuation measures (independent of volume and volume fluctuations) Δ and Σ were proposed in [10]. Whereas $\Sigma[P_T, N]$ is closely related to Φ_{p_T} the quantity $\Delta[P_T, N]$ is sensitive to fluctuations of $\langle p_T \rangle$ and N in a different combination thus these two measures can be sensitive to various physics effects. All mentioned measures are defined below:

$$\Sigma[P_T, N] = \frac{1}{\langle N \rangle \omega [P_T]} \times [\langle N \rangle \omega [P_T] - \langle P_T \rangle \omega [N] - 2(\langle P_T, N \rangle - \langle P_T \rangle \langle N \rangle)]$$

$$\Phi_{p_T} = \sqrt{\bar{p}_T \omega [P_T]} \left[\sqrt{\Sigma[P_T, N]} - 1 \right] \quad (2)$$

$$\Delta[P_T, N] = \frac{1}{\langle N \rangle \omega [P_T]} [\langle N \rangle \omega [P_T] - \langle P_T \rangle \omega [N]]$$

where

$$P_T = \sum_{i=1}^N p_{T_i} \quad , \quad \omega [P_T] = \frac{\langle P_T^2 \rangle - \langle P_T \rangle^2}{\langle P_T \rangle}$$

Fig. 2 shows the dependence of multiplicity fluctuations quantified by scaled variance ω and fluctuations of the average transverse momentum measured by Φ_{p_T} as well as $\Delta[P_T, N]$ and $\Sigma[P_T, N]$ as a function of chemical freeze-out temperature T_{chem} (obtained from statistical model fits [4]) in p+p interactions and central C+C, Si+Si and Pb+Pb collisions. All quantities show a possible maximum of fluctuations at $T_{chem}=160-170$ MeV reached in collisions of medium-size nuclei. This agrees with expectations for the critical point represented by curves for ω and Φ_{p_T} [11].

The dependence of all fluctuation measures on μ_B (obtained from statistical model fits [4]) in p+p interactions (NA61) and central Pb+Pb collisions (NA49) is shown in Fig. 3. Here the data don't indicate a maximum as might be expected for the critical point (curves for ω and Φ_{p_T} [11]).

A new identification procedure called identity method [12, 13] allowed to measure the energy dependence of fluctuations of identified proton, kaon and pion multiplicities in p+p and Pb+Pb collisions. As in the case of charged particle multiplicities no indication of the critical point was found.

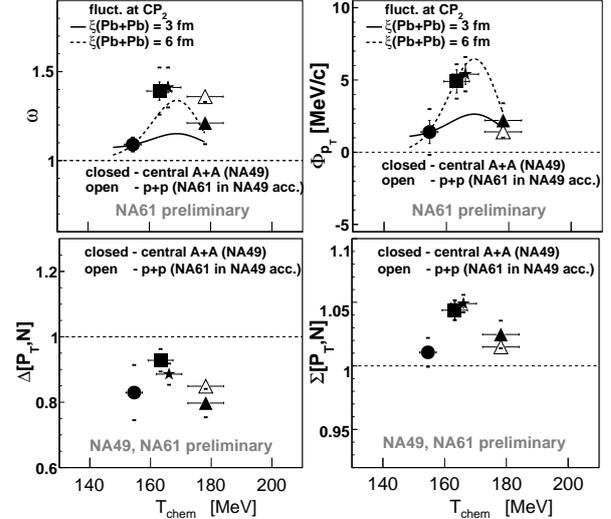


Figure 2: The dependence of the Φ_{p_T} , $\Sigma[P_T, N]$ and $\Delta[P_T, N]$ measures and the scaled variance of multiplicity fluctuations ω on T_{chem} (system size) for charged hadrons in central A+A collisions and p+p interactions. Curves indicate the estimated effects of the critical point ($T=178$ MeV, $\mu_B=250$ MeV) for two values of the correlation length ξ .

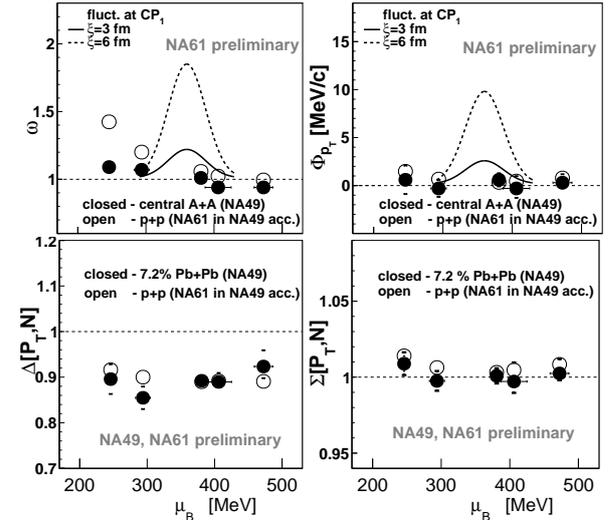


Figure 3: The dependence of the Φ_{p_T} , $\Sigma[P_T, N]$ and $\Delta[P_T, N]$ measures and the scaled variance of multiplicity fluctuations ω on μ_B (collision energy) for charged hadrons in central Pb+Pb collisions and p+p interactions. Curves indicate the estimated effects of the critical point ($T=147$ MeV, $\mu_B=360$ MeV) for two values of the correlation length ξ .

Chemical (particle type) fluctuations for two different particle types A and B were analysed using the Φ_{AB} measure (see [14, Eq.6.7]).

Fig. 4 shows two particle chemical fluctuations as a function of interaction energy. The fluctuations cannot be corrected for the limited acceptance thus the results are presented both for the NA49, NA61 acceptance and a common NA49/NA61 phase space region. The left panel of Fig. 4 shows combinations of

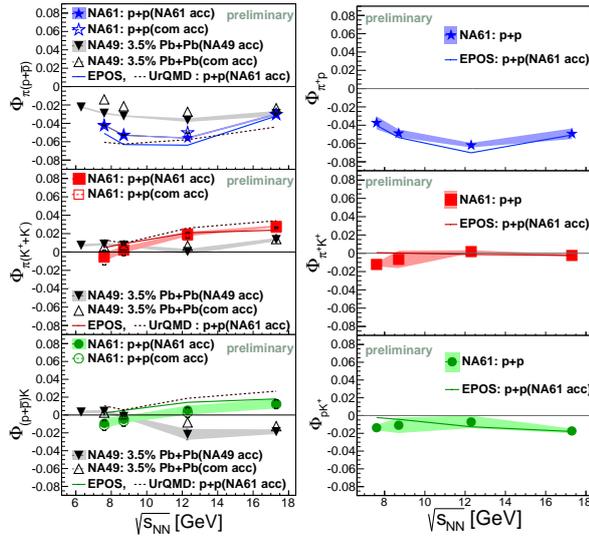


Figure 4: Chemical (particle type) fluctuations in inelastic p+p interactions at 30, 40, 80, and 158 GeV/c. NA61 p+p data are compared to those obtained by NA49 in Pb+Pb collisions [15]. See [16] for NA49, NA61 acceptance and common phase space region.

both charges while the right one shows only positively charged particles. The values of $\Phi_{\pi(p+\bar{p})}$ are negative for all studied energies. This is most probably due to charge conservation and resonance decays. In p+p collisions $\Phi_{\pi(K^++K^-)}$ is higher than zero probably due to strangeness conservation. It slightly increases with energy for p+p interactions which is not observed for Pb+Pb collisions. For both systems $\Phi_{(p+\bar{p})K}$ crosses zero at medium SPS energies. Finally, we observe no significant energy dependence of Φ_{pK^+} in the NA61 data. The EPOS and UrQMD model predictions reproduce p+p data reasonably well.

3. Density fluctuations of protons and low-mass $\pi^+\pi^-$ pairs

Theoretical investigation [17] predicts near the critical point the appearance of local density fluctuation for protons [18] and low-mass $\pi^+\pi^-$ pairs of power-law nature with known critical exponents [19]. This can be studied by the intermittency analysis method in transverse momentum space using second factorial moments $F_2(M)$, where M is the number of subdivisions in each p_T direction. After combinatorial background subtraction the exponents ϕ_2 are obtained from a power-law fit to the corrected moments $\Delta F_2(M) \approx M^{2\phi_2}$. The resulting values of ϕ_2 obtained for central C+C, Si+Si and Pb+Pb collisions at 158 GeV are plotted in Fig. 5. Remarkably, ϕ_2 seems to reach a maximum for Si+ Si collisions which is consistent with the theoretical expectations for the critical point.

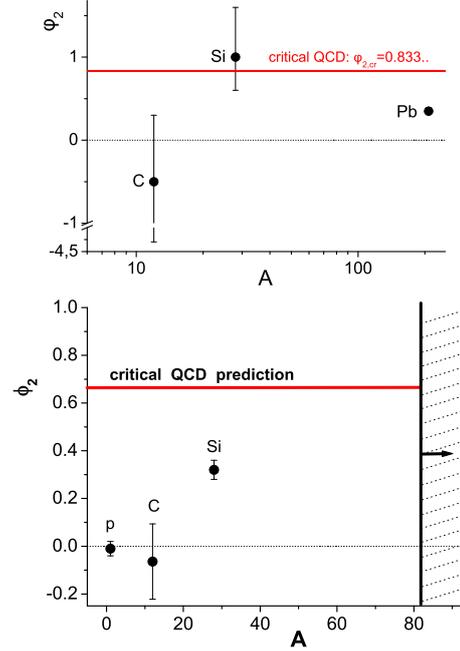


Figure 5: Exponent ϕ_2 obtained from power-law fits to corrected second scaled factorial moments of protons (upper) and low-mass $\pi^+\pi^-$ pairs (bottom) for several collision systems at 158 AGeV.

4. Acknowledgments

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References

- [1] C. Alt *et al.* [NA49 Coll.], Phys. Rev. **C77**, 024903 (2008).
- [2] M. Gazdzicki *et al.* [NA49 Coll.], J. Phys. **G30**, S701 (2004).
- [3] The NA61/SHINE homepage - <https://na61.web.cern.ch/na61/>.
- [4] F. Becattini, J. Manninen, M. Gazdzicki, Phys. Rev. **C73**, 044905 (2006).
- [5] M. Stephanov, K. Rajagopal, E. Shuryak, Phys. Rev. **D60**, 114028 (1999).
- [6] B. Berdnikov, K. Rajagopal, Phys. Rev. **D61**, 105017 (2000).
- [7] M. Gazdzicki and S. Mrowczynski, Z. Phys. **C54**, 127 (1992).
- [8] C. Alt *et al.* [NA49 Coll.], Phys. Rev. **C70**, 064903 (2004).
- [9] T. Cetner, K. Grebieszko [NA49 Coll.], J.Phys.Conf.Ser. **270**, 012023 (2011).
- [10] M. Gazdzicki, M.I. Gorenstein, M. Mackowiak-Pawlowska Phys. Rev. **C88**, 2, 024907 (2013).
- [11] K. Grebieszko [NA49 Coll.], Nucl. Phys. **A830**, 547C (2009).
- [12] M. Gazdzicki, K. Grebieszko, M. Mackowiak-Pawlowska, S. Mrowczynski, Phys. Rev. **C83**, 054907 (2011).
- [13] M.I. Gorenstein, Phys. Rev. **C84**, 024902 (2011).
- [14] M.I. Gorenstein, M. Gazdzicki, Phys. Rev. **C84**, 014904 (2011).
- [15] A. Rustamov, POS. **CPOD2013**, 005 (2013).
- [16] <https://edms.cern.ch/document/1237791/1>.
- [17] N.G. Antoniou *et al.*, Nucl. Phys. **A693**, 799 (2001); N.G. Antoniou *et al.*, Nucl. Phys. **A761**, 149 (2005).
- [18] Y. Hatta, M.S. Stephanov, Phys. Rev. Lett. **91**, 102003 (2003).
- [19] N.G. Antoniou *et al.*, Phys. Rev. Lett. **97**, 032002 (2006).