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Search for the QCD critical point at SPS energies

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Lattice QCD calculations locate the QCD critical point at energies accessible at the CERN Super Proton Synchrotron (SPS). We present average transverse momentum and multiplicity fluctuations, as well as baryon and anti-baryon transverse mass spectra which are expected to be sensitive to effects of the critical point. The future CP search strategy of the NA61/SHINE experiment at the SPS is also discussed.

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1. Introduction and motivation

Theoretical calculations suggest that the critical point (CP) of strongly interacting matter may be accessible in the SPS energy range [1]. We studied event-by-event average p_T and multiplicity fluctuations, as well as transverse mass spectra of baryons and anti-baryons which are suggested observables sensitive to effects of the CP in ultra-relativistic heavy ion collisions.

The effects are expected to be maximal when freeze-out happens near the critical point. The position of chemical freeze-out point in the $(T \quad \mu_B)$ diagram can be varied by changing the energy and the size of the colliding system (Fig. 1). Therefore we analyzed in NA49 [2] the energy dependence of the proposed CP sensitive observables for central Pb+Pb collisions (beam energies 20*A*-158*A* GeV), and their system size dependence (p+p, C+C, Si+Si, and Pb+Pb) at the highest SPS energy.

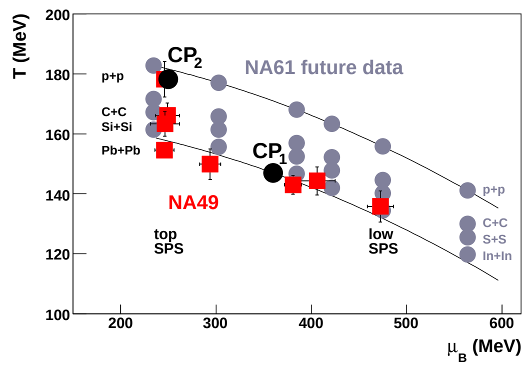

Figure 1: Chemical freeze-out points in NA49 (red) and those expected in NA61 (violet). CP_1 and CP_2 were considered in NA49 as possible locations of the critical point: $\mu_B(CP_1)$ from lattice QCD calculations [1] and CP_2 assuming that the chemical freeze-out point of p+p data at 158*A* GeV may be located on the phase transition line.

2. Event-by-event average p_T and multiplicity fluctuations

Enlarged event-by-event fluctuations of multiplicity N and mean p_T were suggested as a signature of the critical point [3]. The NA49 experiment used the Φ_{p_T} correlation measure [4, 5] and the scaled variance of the multiplicity distribution ω [6, 7] to study average p_T and N fluctuations, respectively. For ω, we selected very central collisions only (1% most central) due to its strong dependence on fluctuations of the number of participants N_{part}.

The energy (μ_B) dependence of Φ_{p_T} and ω together with predictions for CP_1 were presented at this conference (see also [8]). The NA49 data show no significant peak in the energy dependence of Φ_{p_T} and ω at SPS energies thus providing no indications of the critical point at CP_1 (see Fig. 1).

Figures 2 and 3 present the system size (T_{chem}[1]) dependence of Φ_{p_T} and ω. The lines correspond to predictions for CP_2 (see Fig. 1) with estimated magnitude of the effects [2] for Φ_{p_T} and ω at CP_2 taken from Ref.[3, 9] assuming correlation lengths ξ decreasing monotonically with decreasing system size: a) ξ(Pb+Pb) = 6 fm and ξ(p+p) = 2 fm (dashed lines) or b) ξ(Pb+Pb) = 3 fm and ξ(p+p) = 1 fm (solid lines). The width of the enhancement due to CP in the $(T;\mu_B)$ plane is based on Ref. [12] and taken as $\sigma(T)$ 10 MeV. A maximum of Φ_{p_T} and ω is observed for C+C and Si+Si interactions at the top SPS energy. It is two times higher for all charged than for negatively charged particles, as expected for the effect of the CP [3]. Results presented in Figs. 2 and 3 suggest that the NA49 data are consistent with CP_2 predictions.

[1] T_{chem} values were taken from fits of the hadron gas model [11] to particle yields.

[2] Predicted magnitudes include corrections by NA49 due to the limited rapidity range (forward-rapidity) and azimuthal angle acceptance of the detector.

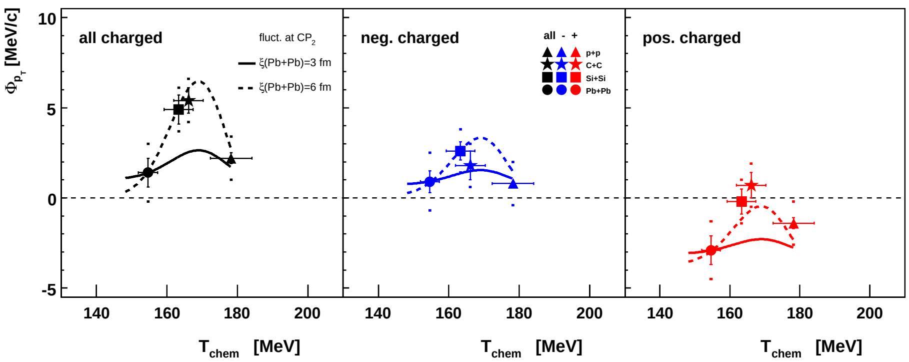

Figure 2: System size dependence of Φ_{p_T} at 158*A* GeV (forward rapidity, NA49 azimuthal angle acceptance) showing results from p+p, semi-central C+C (15.3%) and Si+Si (12.2%), and 5% most central Pb+Pb collisions [4]. Lines correspond to CP_2 predictions (see text) shifted to reproduce the Φ_{p_T} value for central Pb+Pb collisions.

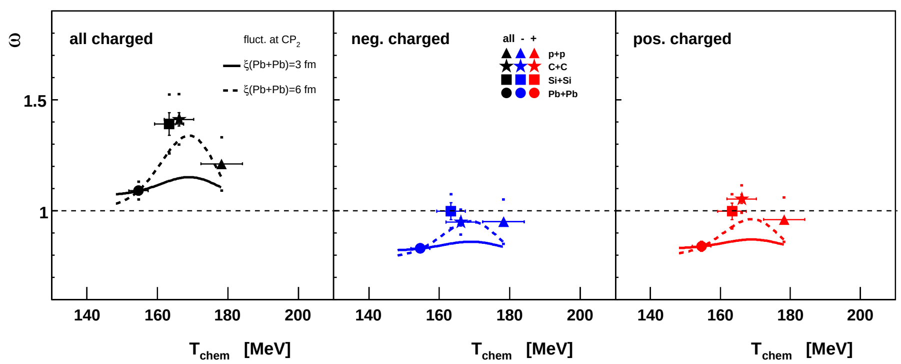

Figure 3: System size dependence of ω at 158*A* GeV (forward rapidity, NA49 azimuthal angle acceptance) for the 1% most central p+p [6], C+C and Si+Si [10], and Pb+Pb collisions [7]. Lines correspond to CP_2 predictions (see text) shifted to reproduce the ω value for central Pb+Pb collisions.

It is expected that fluctuations due to the CP originate mainly from low p_T pions [3]. Therefore the NA49 analysis of Φ_{p_T} was performed also for two separate p_T regions (Figs. 4 and 5). Indeed, the high p_T region shows fluctuations consistent with zero (Fig. 4) and correlations are observed predominantly at low p_T (Fig. 5). However, in low p_T region, data do not show a maximum of Φ_{p_T}, but a continuous rise towards Pb+Pb collisions. The origin of this behavior is currently being analyzed (short range correlations are considered).

3. Transverse mass spectra of baryons and anti-baryons

It was suggested [13] that the critical point serves as an attractor of hydrodynamical trajectories in the (T, μ_B) phase diagram. This was conjectured to lead to a decrease of the anti-baryon to baryon ($\bar{B}/B$) ratio with increasing transverse momentum. The $\bar{p}/p$, $\bar{\Lambda}/\Lambda$, and $\bar{\Xi}^+/\Xi^-$ ratios versus reduced transverse mass $m_T - m_0$ were studied by the NA49 experiment [8] and presented at this conference. The slopes of all three $\bar{B}/B$ ratios show no significant energy dependence, thus implying that transverse mass spectra of B and $\bar{B}$ do not provide evidence for the critical point in the SPS energy range.

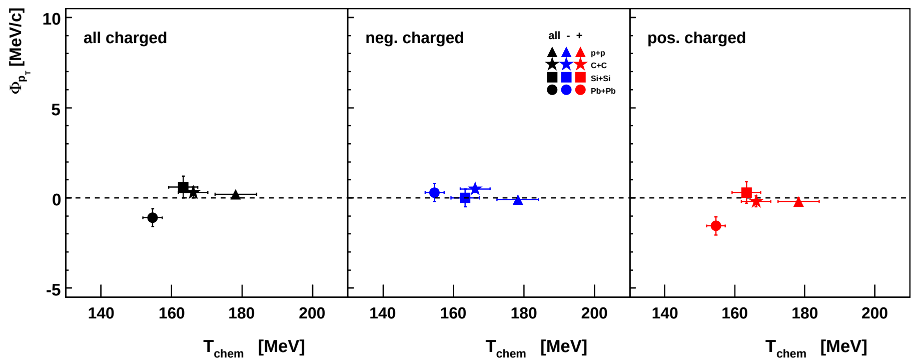

Figure 4: The same as Fig. 2 but high p_T region shown ($0.5 < p_T < 1.5$ GeV/c).

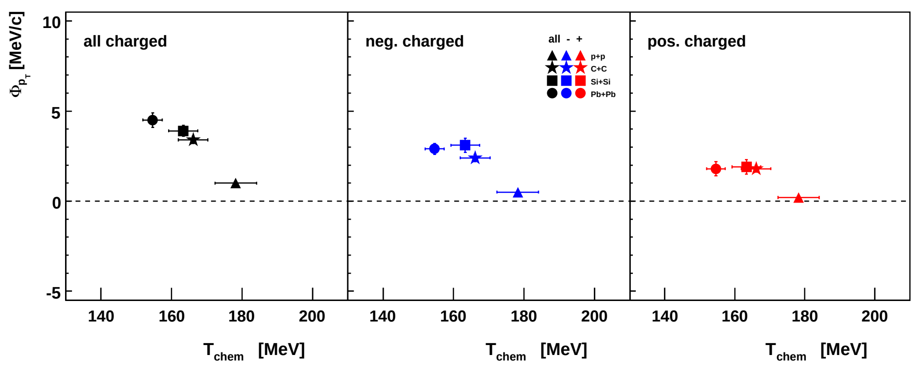

Figure 5: The same as Fig. 2 but low p_T region shown ($0.005 < p_T < 0.5$ GeV/c).

4. Summary of NA49 results and strategy of NA61/SHINE

The energy dependence of average p_T and multiplicity fluctuations, and ratios of the anti-baryon/baryon transverse mass spectra in central Pb+Pb collisions provide no indications of the critical point. The system size dependence at 158*A* GeV exhibits a maximum of mean p_T and multiplicity fluctuations in the complete p_T range (consistent with CP_2 predictions) and an increase (from p+p up to Pb+Pb) of mean p_T fluctuations in the low p_T region. The low p_T region will be carefully analyzed for the effects of short range correlations on Φ_{p_T} and ω.

A detailed energy and system-size scan is necessary to establish the existence of the critical point. Therefore the CP search will be continued by the NA61/SHINE [14] experiment which is based on the upgraded NA49 detector. We plan to perform a two-dimensional scan with lighter ions (p+p, C+C, S+S, In+In) in a broad beam energy range (10*A* - 158*A* GeV). The hypothetical chemical freeze-out points in the NA61 experiment are presented in Fig. 1.Together with existing NA49 data the scan may help to locate the QCD critical point in the (T, μ_B) phase diagram.

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