Strangeness Saturation: Dependence on System-Size, Centrality and Energy

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Abstract. The dependence of the strangeness saturation factor on the system size, centrality and energy is studied in relativistic heavy-ion collisions.

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1. Introduction

Statistical-thermal models (see [1] for a review) aim at reproducing hadron multiplicities in relativistic heavy-ion collisions in certain phase space regions by a small number of parameters. As these parameters evolve smoothly with external conditions, thermal models have predictive power. Moreover, the thermal parameters, taken literally, allow for a quantification of the conditions reached in the transient stage of compressed and heated strongly interacting matter. While there is exhaustive literature on the successful use of the thermal models, the foundation of the applicability is far from settled. One should also keep in mind that thermal models address only a subset of the wealth of observables.

The present contribution summarizes our recent work [2–4] investigating the dependence of strangeness saturation on system size, centrality and energy, both in full phase space (4π) and at mid-rapidity (y ≈ 0).

2. Thermal Model

Our model is based on the grand canonical ensemble expression for the abundance of hadron species \( i \) (Fermions \([+1]\) or Bosons \([-1]\)) with degeneracy \( g_i \)

\[
N_i^{\text{prim}} = V g_i \int \frac{d^3 p}{(2\pi)^3} \, dm_i \left[ \gamma \left[ \gamma_i \exp \left\{ \frac{-E_i - \bar{\mu}_i \tilde{q}_i}{T} \right\} \pm 1 \right] \right]^{-1} \text{BW}(m_i, \Gamma_i), \quad (1)
\]
where $T$ is the temperature, $\mu$ a set of chemical potentials corresponding to the conserved charges $Q_i$, $E_i = [p_i^2 + m^2_i]^{-1/2}$ with vacuum mass $m_i$.

For small particle numbers one has to turn to a canonical ensemble, e.g. by the projection method [5]. It is important to include resonances (we include meson (baryon) states composed of the three lightest quarks and anti-quarks up to 2.3 (2.6) GeV); their widths are included via the Breit–Wigner parameterization $BW(m_i, \Gamma_i)$, which collapses to a $\delta$-function for the respective ground states. Due to feeding and resonance decays, the final hadron multiplicities become $N_i = N_i^{\text{prim}} + \sum_j \{N_j^{\text{prim}} Br(j \rightarrow i) - N_i^{\text{prim}} Br(i \rightarrow j)\}$, where $Br$ denotes the corresponding branching ratio.

Our focus here is the phenomenological strangeness saturation factor $\gamma_s$ in Eq. (1). It is thought [6] to parameterize possible deviations from chemical equilibrium in the strange sector. Whether one common factor $\gamma_s$ is sufficient, with powers $|S_i|$ determined by the total strangeness content of hadron $i$, needs still to be tested by analyzing data. Also in the non-strange sector such an off-equilibrium parameter should be introduced [7]. Due to the small data samples at our disposal, such an additional parameter cannot be unambiguously fixed; therefore, we are forced here to assume full equilibration in the non-strange sector.

The parameters $T$ and $\mu$ appear exponentially in Eq. (1), while the sensitivity on variations of $\gamma_s$ is weaker. For this reason, we study the mentioned parameter dependencies based on analyses of data sets comprised of the same hadron species. Otherwise variations of $\gamma_s$ can be absorbed in small changes of $T$ and $\mu$. Unfortunately, this shrinks the wealth of available data to quite poor subsets.

Within the Cooper–Frye formalism, dynamical effects factor out of fully-integrated hadron yields [8], provided that freeze-out occurs on a hyper-surface with constant $T$ and $\mu$. In this respect, Eq. (1) covers also dynamical situations. Instead of considering hadron ratios, we consider multiplicities $N_i^{\text{prim}}$ with a fiducial normalization volume $V$ in Eq. (1).

3. Data Analysis

3.1. CERN-SPS energies

3.1.1. Centrality and system size dependence at $E_{\text{beam}} = 158$ AGeV

$4\pi$ multiplicities of $\pi^\pm$, $K^\pm$, $\phi$ and $N_{\text{part}}$ are at our disposal for i) central collisions of $C + C$ and $Si + Si$, and ii) centrality binned collisions $Pb + Pb$. More baryon information is desirable, but only $p$'s are available additionally for $Pb + Pb$. The left panel of Fig. 1 summarizes our findings [3]. We observe,

- $Pb + Pb$: $\gamma_s$ increases with centrality, but stays below unity, irrespective of whether $p$'s are included or not; inclusion of $\bar{p}$'s reduces $\gamma_s$ somewhat; minimizing $\chi^2$ or the quadratic deviation of data and the model multiplicities, $q^2$, yields slightly different results.