

Distinguishing Hadronic Cascades from Hydrodynamic Models in Pb(160 AGeV)+Pb Reactions by Impact Parameter Variation

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Abstract

We propose to study the impact parameter dependence of the $\bar{\Lambda}/\bar{p}$ ratio in Pb(160AGeV)+Pb reactions. The $\bar{\Lambda}/\bar{p}$ ratio is a sensible tool to distinguish between hadronic cascade models and hydrodynamical models, which incorporate a QGP phase transition.

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Hadron abundances and ratios have been suggested as possible signatures for exotic states and phase transitions in hot and dense nuclear matter. Bulk properties like temperatures, entropies and chemical potentials of highly excited hadronic matter have been extracted from high energy heavy ion data assuming thermal and chemical equilibrium [1–4]. However, unambiguous signals of a phase transition into an equilibrated deconfined quark gluon plasma (QGP) state are still missing: the predicted change in observables, e.g. strangeness enhancement [4], may also be understood in hadronic non-equilibrium transport models [5].

In this letter, the variation of the $\bar{\Lambda}/\bar{p}$ ratio¹ as a function of the impact parameter b in Pb(160 AGeV)+Pb reactions is proposed as a method to distinguish equilibrium from non-equilibrium scenarios. In models based on the assumption of local thermal equilibrium (e.g. in thermal models or hydrodynamical models) the $\bar{\Lambda}/\bar{p}$ ratio is sensitive only to the temperature and chemical potentials achieved in the reaction. Microscopic transport theory, however, is not constrained by equilibrium assumptions. Thus, this ratio provides a sensible tool to probe the creation of a chemically equilibrated phase in nucleus-nucleus collisions as a function of centrality. A comparison to upcoming data by the NA49 and the CERES collaborations may therefore provide an estimate of the degree of local chemical equilibration. The differences in the predicted centrality dependence among the discussed models can help to determine the applicability of these theories.

In the 3-fluid hydrodynamical model [6] [7] an equation of state with a first order phase transition to a QGP is used. We employ that model to calculate entropy production during the initial stage of the reaction as described in detail in [7]. To show the behaviour of the $\bar{\Lambda}/\bar{p}$ ratio for the chemical equilibrium case, the creation of a fireball, composed of all hadrons up to mass $m = 2$ GeV, with a uniform S/A ratio (entropy S per net participating baryon A) and net baryon density ρ is assumed. The 3-fluid model is used to calculate S/A as a function of impact parameter b . The hadron ratios are calculated assuming chemical

¹Note that the $\bar{\Lambda}$'s contain the decayed $\bar{\Sigma}^0$'s, while \bar{p} do not contain decays from $\bar{\Lambda}(\bar{\Sigma}^0)$'s.

isochronous freeze-out at a net baryon density $\rho = \rho_0/2$.

For $S/A > 25$, which is the relevant S/A range for SPS energies, the $\bar{\Lambda}/\bar{p}$ ratio is practically unchanged if a chemical freeze-out temperature of $T = 160$ MeV (as suggested in [2]) is employed instead of the freeze-out density $\rho = \rho_0/2$ (cf. Fig. 1).

Within the UrQMD model [8], the non-equilibrium dynamics is treated in a microscopic hadronic scenario. Baryon-baryon, meson-baryon and meson-meson collisions lead to the formation and decay of resonances and color flux tubes. The produced, as well as the incoming particles, rescatter in the further evolution of the system.

Fig. 1 shows the $\bar{\Lambda}/\bar{p}$ ratio for different impact parameters from 0 fm to 13 fm (UrQMD) and 0 fm to 9 fm (3-fluid Hydro+Fireball; for larger impact parameters, the assumption of a chemically equilibrated fireball may not be justified). The hydrodynamical calculation with phase transition is depicted by the black line (using a freeze-out density $\rho = \rho_0/2$) and the dotted line (using a freeze-out temperature $T = 160$ MeV), the full squares denote the - microscopic non-equilibrium - UrQMD [8] calculation.

In the 3-fluid approach the $\bar{\Lambda}/\bar{p}$ ratio stays constant with b .

In contrast, the hadronic UrQMD model yields a strong dependence of this ratio on impact parameter b . The $\bar{\Lambda}/\bar{p}$ ratio drops rapidly with increasing b from 1.3 to 0.5.

The behaviour of the 3-fluid hydrodynamical model can be understood in terms of the local equilibration of the hot and dense medium. The temperature and specific entropy of the fluid elements are only slightly affected by b (at least for not too large impact parameters). As long as the assumption of local chemical equilibrium is justified, the particle number densities are independent of the volume (in the grand canonical formulation) - thus their ratios remain constant.

In the case of the microscopic UrQMD model, there is an interplay between particle production and subsequent annihilation: In peripheral (large b) collisions the $\bar{\Lambda}$ production is basically the same as in proton+proton reactions. $\bar{\Lambda}$'s and \bar{p} 's are produced via the fragmentation of color flux tubes (strings). The production of (anti-)strange quarks in the color field is suppressed due to the mass difference between strange and up/down quarks.

This results in a suppression of $\bar{\Lambda}$ over \bar{p} by a factor of 2 ($\bar{\Lambda}/\bar{p} \approx 0.3 - 0.5$ in pp).

In central Pb+Pb encounters meson-baryon and meson-meson reactions work as additional sources for the anti-hyperon and anti-proton production. The absolute $\bar{\Lambda}$, \bar{p} yield increases far above the naive p+p extrapolation. Then, additional rescattering effects have to be taken into account in the hot and dense medium. Anti-baryons are strongly affected by the comoving baryon density. The additive quark model yields smaller annihilation cross section of anti-lambdas than the annihilation cross sections of anti-protons at the same momentum: Thus the annihilation probability for $\bar{\Lambda}$'s is smaller than for \bar{p} 's, leading to an increase of the $\bar{\Lambda}/\bar{p}$ ratio above 1 in very central reactions.

In conclusion, it has been demonstrated that a study of the impact parameter dependence of the $\bar{\Lambda}/\bar{p}$ ratio can be used as a powerful tool to distinguish local equilibrium from off-equilibrium models for heavy ion collisions.

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FIGURES
Pb(160AGeV)+Pb

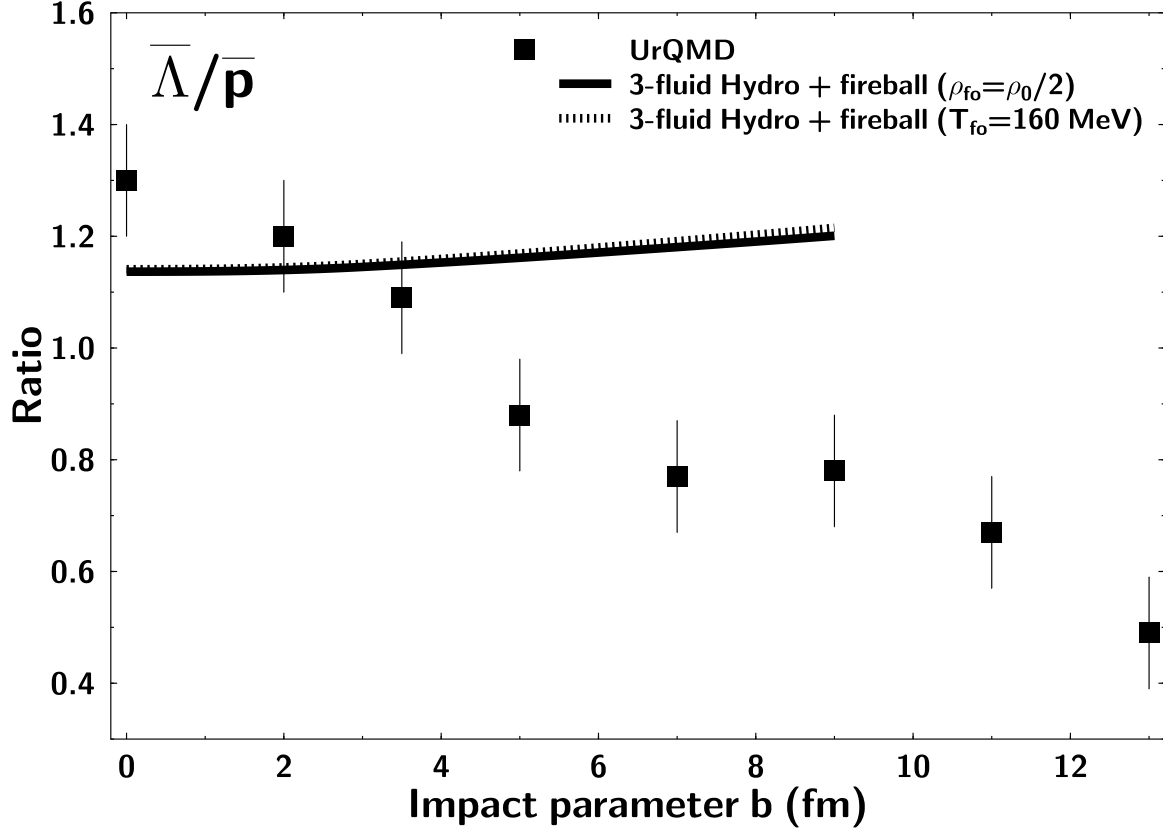


FIG. 1. Impact parameter dependence of the $\bar{\Lambda}/\bar{p}$ ratio in Pb(160 AGeV)+Pb reactions. The full squares denote hadronic cascade (UrQMD) calculations, the lines show the 3-Fluid Hydro + Fireball calculation including a first order phase transition (full line: freeze-out at $\rho = \rho_0/2$, dashed line: freeze-out at $T = 160\text{MeV}$).