The energy density representation of the strangeness enhancement from $p+p$ to $Pb+Pb$

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Abstract

The energy density is the prime parameter to define the deconfinement of quarks and gluons occurring in collisions of heavy ions. Recently, there is mounting evidence that many observables in proton-proton collisions behave in a manner very similar to the one observed in heavy ions. We present as an additional piece of evidence, a scaling of the strange particle yields as a function of the energy density of the three collision systems: $p+p$, $Pb+Pb$, using the latest results of the ALICE collaboration.

1 Introduction

Since the very beginning of the searches for quark gluon plasma, the production of strange and multi-strange baryons has been in the focus of the experimental community, the reason being that one expected to observe an enhancement of the strangeness production in heavy ion collisions compared with the production in collisions of protons or lighter systems\[1, 2, 3\]. On the other hand, it is generally accepted that strange particle densities and their ratios can be, for heavy ion collisions at full AGS energy and higher, well described by the thermal model\[4, 5\] in a grand-canonical ensemble while in small colliding systems the canonical description is needed\[6\]. Recently the ALICE Collaboration has published\[7, 8\] two interesting articles where the production of strangeness with respect to the pion production is reported for several strange and multi-strange particles for three colliding systems: $p+p$, $Pb+Pb$. They report the relative enhancements in function of the multiplicity. The papers give an important message that the integrated yields of strange and multi-strange particles relative to pions increase significantly with multiplicity and the results cannot be reproduced by any of the models commonly used.

The present situation as well as the mounting evidence for collective effect has prompted us to examine the possibility of a scaling of the strangeness production with the energy densities achieved in the various colliding systems. Observing such scaling, would raise many interesting questions about the underlying processes. It might be noted that the scaling idea was presented\[9\], using a variable which is related to initial energy to describe the kaon to pion ratio from different colliding systems and different energies. Recently, a similar approach was shown\[10\] for minimum bias values, where they conclude that the degree of strangeness suppression in hadronic and nuclear collisions is fully determined by the initial energy density. In Ref.\[11\], we have already presented the results for the ratio of cascades to pion production.

In the present work we study the relative enhancements of strangeness production for each multiplicity bin, using the Bjorken energy density approach\[12\] i. e. the energy density reached in colliding systems, assuming that a thermal equilibrium is achieved.

The work is organized as follows. In the first part we explain the way we calculate the energy density of the systems in collision. In the second part we apply the scaling to the ALICE results for $p+p$, $Pb+Pb$ and finally $Pb+Pb$ collisions for the strange and multi strange baryons. In the third part we present the results and the discussion. Finally some conclusions are drawn.
2 Energy density

The initial Bjorken energy density approach provides a relation of the transverse energy and the covering area of the thermalized system produced in hadron/nucleus collisions:

\[ \epsilon \sim \frac{dE_T/dy}{\pi R^2 \tau} \]

where the transverse energy function of the rapidity can be expressed in terms of the pseudo-rapidity and the average transverse momentum distribution,

\[ dE_T/dy \sim < p_T > \frac{dN/d\eta}{A^k} \]

where the hadronization time, \( \tau \), is essentially a rather unknown factor so that we actually compute the value

\[ \epsilon \tau = \frac{3}{2} < p_k^+ > \frac{dN^k/d\eta}{A^k} \]

where \( k \) represents the colliding systems \( p+p \), \( p+Pb \) or \( Pb+Pb \). In this way \( \epsilon \tau \) is computed for each multiplicity bin where ratios strangeness to pions are measured, \( A^k \) is the area of the thermalized system mentioned above, and \( dN^k/d\eta \) is the charged particle density.

Our calculation was done using each multiplicity bin where strangeness to pions were measured, \( A^k \) and \( dN^k/d\eta \) are obtained from ALICE measurements[^16], which correspond to the same energy as data of the multi-strange ratios, but in pseudorapidity range of \( |\eta| < 0.3 \).

Up to here, one of the main questions are the values of the radii used to calculate the thermalized systems created. This area can be calculated by several approaches, the Glauber model for instance, which allow the to study possible fluctuations of this area, however, we decide to use experimental values of the invariant radii[^17] obtained from momentum correlations in the experiment[^17]. This reference shows radii for the pions source from two and three cumulant methods, with small differences between the results for \( p+p \) and \( p+Pb \) (of the order of 10-15%), so that we decided to use the same radii extracted for \( p+p \) for the two systems using the functional form given in Eq.3[^17] for \( p+p \) and \( p+Pb \), and Eq.4[^17] for \( Pb+Pb \):

\[ R_{p+p} = 0.405 \frac{dN_i^{1/3}}{d\eta} + 0.332 \]
\[ R_{Pb+Pb} = 0.772 \frac{dN_i^{1/3}}{d\eta} + 0.049 \]

where the index \( i \) refers to multiplicity bins. We would like to add that we have tried several other methods to calculate the energy density and the functional form does not substantially influence the conclusions presented here.

3 Results

In order to estimate the ratios: \((\Xi^- + \Xi^+)/(\pi^- + \pi^+), 2\Lambda/(\pi^- + \pi^+) \) and \((\Omega^- + \Omega^+)/(/\pi^- + \pi^+) \) versus initial energy density, we use the Eqs.2 and the radii extracted from results of \( p+p \), Eq.3[^17] for the results from \( p+p \) and \( p+Pb \), while for those from \( Pb+Pb \) the Eq.2 and Eq.4[^17] are used. The Figs.4 5 and 6 show these ratios for the systems studied. We can observe in the three cases the same trend of the enhancements, a nearly perfect scaling among the three different systems. The \((\Omega^- + \Omega^+)/(/\pi^- + \pi^+) \) ratio seems to indicate more production of strangeness in \( Pb+Pb \) systems, but it is not completely conclusive due to the large errors.

[^1]: We are aware that the radii used here refer to the kinetic freezeout and are therefore somewhat larger than the proper thermalization ones. However we believe that a coherent approach for all systems does not affect the result as long as one would not seek to determine the real energy density value.
Figure 1: (Color online) $(\Xi^- + \Xi^+)/ (\pi^- + \pi^+)$ ratios at 7 (p+p), 5.02 (p+Pb) and 2.76 (Pb+Pb) TeV as function of energy density.

Figure 2: (Color online) $2\Lambda/ (\pi^- + \pi^+)$ ratios at 7 (p+p), 5.02 (p+Pb) and 2.76 (Pb+Pb) TeV as function of energy density.
4 Conclusion

The energy density plotted using the Bjorken formula show that at the same energy $\epsilon$, one obtains the same enhancement regardless of the system measured. The scaling of the relative production of strange and multi strange baryons looks reasonably successful for all the baryons presented except for the case of the Omega baryons where the large errors prevent to draw a final judgement. However it seems that the production in Pb+Pb collisions is more copious.

In our opinion this has important consequences, for instance, it is comforting the idea that, even in small systems, the thermalized energy density may be a relevant parameter to describe the production of strangeness. The results are in agreement with those from the holographic duality studies that demonstrate the applicability of hydrodynamics to small systems at sufficiently high initial temperatures[18]. On the other hand, the results presented do not indicate a clear tendency towards a limiting temperature as predicted by the thermal models.

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