

Identified light-flavour particle production measured with ALICE at the LHC as a probe of soft QCD and hot hadronic matter

Barbara Guerzoni for the ALICE Collaboration

Dipartimento di Fisica dell'Università di Bologna and INFN sezione di Bologna, via Irnerio 46, Bologna, Italy

E-mail: barbara.guerzoni@bo.infn.it

Abstract. ALICE is a general-purpose heavy-ion experiment able to identify particles over a wide momentum range thanks to excellent vertexing and tracking performance, low material budget and different Particle IDentification (PID) techniques. In this paper the measurement of the production of identified light flavour particles in pp, p–Pb and Pb–Pb collisions is reported. It is of fundamental importance to study the particle production mechanisms playing a role in the different momentum ranges and probe the hot medium formed in heavy-ion collisions. Information on the effects of the medium produced in Pb–Pb collisions on particle production can be obtained comparing the particle ratios in pp and Pb–Pb events and studying the nuclear modification factor (R_{AA}). The transverse momentum (p_T) integrated yields and ratios are then discussed in terms of thermal models to extract the properties of the medium produced in Pb–Pb collisions at the chemical freeze-out.

1. Introduction

The ALICE Collaboration has shown that for peripheral Pb–Pb collisions the shapes of the invariant yields are similar to those observed in pp collisions [1]. Moving to central Pb–Pb events the spectra get flatter at low p_T (the heavier is the particle mass, the flatter is the spectrum) and are strongly suppressed at high p_T when compared to pp events scaled by the number of binary collisions. The spectra of identified particles provide hence a tool to study the dynamics of the quark-gluon plasma created in Pb–Pb collisions and the way it affects the particle production mechanisms in different momentum regions. Studying the low p_T spectra ($p_T \lesssim 2$ GeV/ c), information about the production of soft particles from the thermalized medium can be obtained. The high p_T region (p_T approximately > 8 GeV/ c) is important to study the hard production in perturbative regime and jet quenching phenomena. The intermediate p_T range provides possible explanation of the so-called baryon anomaly phenomena first observed at RHIC, that is the enhancement of the baryon over meson ratio as a function of p_T with increasing centrality of the collision. In the following, results on particle ratios and R_{AA} will be shown. Further information can be obtained comparing the integrated yields of identified particles produced in pp, p–Pb, Pb–Pb collisions. Finally, the comparison of the integrated yields of identified particles with predictions from thermal models, fundamental to characterize the medium at the chemical freeze-out, will be discussed.

2. Results

In Fig. 1 the p/π and K/π ratios (left panels) are shown as a function of p_T for pp and central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. It is remarkable the increase of the enhancement of the p/π ratio at $p_T \sim 3$ GeV/c from pp to Pb–Pb collisions, in line with a similar observation made at RHIC in central Au–Au collisions [2, 3]. At LHC energies a slight enhancement of the K/π ratio, not seen at RHIC, can also be observed. These observations can be understood in terms of a hydrodynamic expansion of the medium or parton recombination.

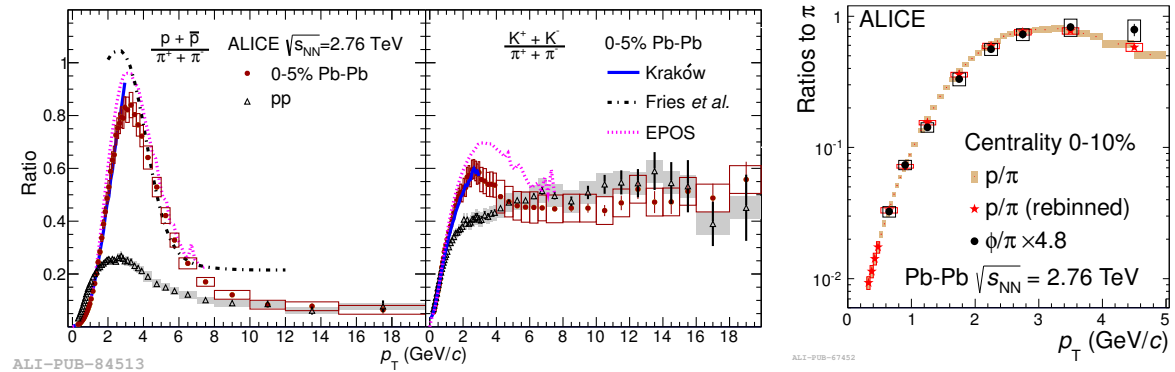
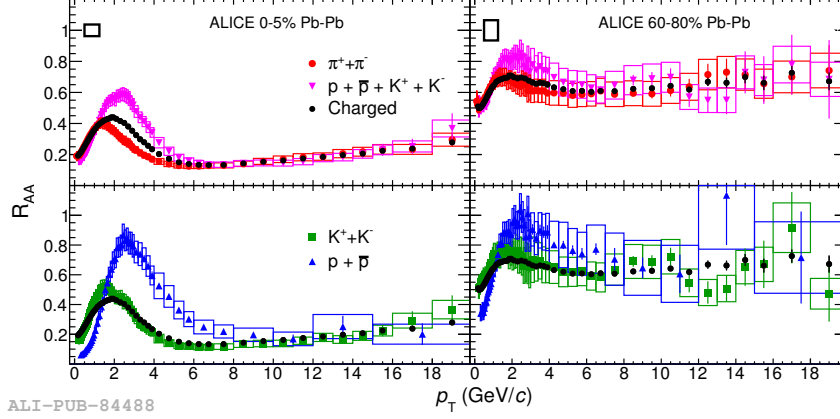


Figure 1. (left) p/π and K/π ratios as a function of p_T for pp and central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [1]. Kraków, Fries and EPOS predictions are superimposed to the data. (right) p/π and ϕ/π ratios as a function of p_T measured in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [4].

The model proposed by Fries et al. [5], that introduces the recombination for soft thermal radially flowing partons, is able to describe qualitatively the data. The rise of the ratios up to $p_T \sim 3$ GeV/c can be also described by the predictions of the Kraków hydrodynamic model [6]. The EPOS generator [7], that combines a hydrodynamic description of the medium with high p_T physics and jet quenching, can also describe the data although it overestimates the peak. In the right panel of Fig. 1 it is evident that, in central Pb–Pb collisions, the shape of the ϕ/π and p/π ratios as a function of p_T [4] are consistent. This could suggest that the peak is the results of the hydrodynamic radial flow whose effect depends on the particle mass, in contrast to other hadronization processes that would only increase the baryon production. For $p_T > 10$ GeV/c, the p/π and K/π ratios obtained in pp and Pb–Pb collisions are in agreement suggesting that the parton fragmentation (jet chemistry) is not modified by the medium produced in Pb–Pb collisions. This hypothesis is supported by Fig. 2 where the nuclear modification factor R_{AA} for pions, kaons, protons and all charged particles in central (left) and peripheral (right) Pb–Pb collisions are reported [1]. The R_{AA} is defined as the ratio between the Pb–Pb spectra normalized to the number of binary collisions and the pp spectra. While at low momentum ($p_T < 8$ GeV/c) there is a mass hierarchy in particle suppression, namely protons are less suppressed than kaons and pions, at high momenta ($p_T > 10$ GeV/c) the suppression is the same for all the particle species. This is an indication that particle composition and ratios at high momenta are the same in medium and in vacuum disfavouring models where large energy loss is associated with mass ordering or large fragmentation differences between baryons and mesons.

In the left panel of Fig. 3, momentum-integrated particle ratios measured in pp, high multiplicity p–Pb and central Pb–Pb collisions are compared to study the system-size dependence of particle production. Looking at the K/π , Ξ/π and Ω/π ratios, one observes that the production of strange hadrons increases with the system size even if the Ξ/π ratio seems to decrease moving from p–Pb to Pb–Pb collisions. This behavior still needs to be



ALI-PUB-84488

Figure 2. Nuclear modification factor R_{AA} as a function of p_T in central (left) and peripheral (right) Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for all charged (black), pions (red), kaons (green) protons (blue) and protons + kaons (purple) [1].

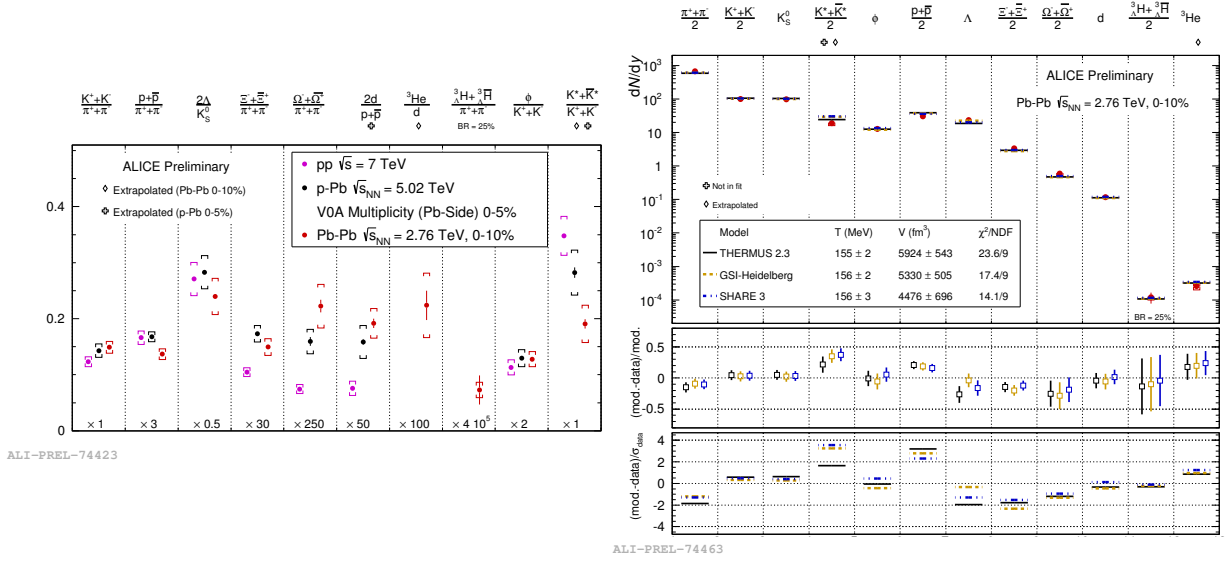


Figure 3. (left) Particle ratio in pp, high multiplicity p–Pb and central Pb–Pb collisions at $\sqrt{s_{NN}} = 7, 5.02$ and 2.76 TeV respectively. (right) Particle yields measured in central Pb–Pb collisions compared to results of fit with THERMUS, GSI and SHARE thermal models.

clarified. The K^*/K ratio decreases with increasing the system size, a phenomenon that can be understood as due to the rescattering of the K^* decay products in the hadronic medium. The d/p ratio increases with the system size, providing further constraints on the proposed deuteron production mechanisms, based on thermal and coalescence models. Looking at the p/π and Λ/K_s^0 ratios, it is also possible to notice a hint of momentum-integrated baryon suppression moving from p–Pb to Pb–Pb collisions.

In the right panel of Fig. 3, the integrated yields (dN/dy) of identified particles measured in central Pb–Pb collisions are reported. They are interpreted in terms of thermal models that describe the properties of the system at chemical freeze-out. These models are based on six main parameters: the chemical freeze-out temperature T_{ch} , the baryochemical potential μ_B that

at the LHC energies is fixed to zero, the volume V and the parameters that take into account deviation from equilibrium production for strange, charm or light quarks, $\gamma_{s,c,q}$. Equilibrium thermal models ($\gamma_s = \gamma_c = \gamma_q = 1$) were able to reproduce the yields measured at RHIC but, once their parameters were extrapolated to LHC energies, they were found to overestimate the proton production by a factor 1.5. In Fig. 3 the results of the fit to the data of three different models implementing full equilibrium, Thermus 2.3 [8], GSI-Heidelberg [9] and SHARE [10], are reported. The disagreement of the protons with respect to the equilibrium model expectations persists. Note that the K^* resonances are not included in the fit. It can be also noticed that the value of the temperature parameter obtained from the fit by the three models are compatible (~ 156 MeV) and lower than the value predicted from the extrapolation of RHIC data (~ 164 MeV).

To explain the deviations from the thermal models many hypotheses have been formulated. At lower energies particle abundances were described by thermal models assuming thermal and chemical equilibrium, assuming the modification of particle ratios in the hadronic phase negligible. These deviations from thermal predictions can be explained assuming that final state interactions in the hadronic phase are not negligible and affecting in different way baryons and mesons [11, 12]. One process that might be important is baryon annihilation, in line with the observation of the lower value of the protons compared to the model predictions. A non-equilibrium configuration and a quark-gluon plasma undergoing a sudden hadronization without rescattering can be represented by the SHARE model [10] with the γ_q parameter not fixed to 1. This gives to the hadrons the possibility to be produced out of equilibrium. In such a configuration it is possible to fit all hadrons except nuclei with $\chi^2/ndf \approx 1$. Another possible explanation invokes a flavour-dependent transition temperature [13] hence a single freeze-out temperature could not be able to describe the data.

3. Conclusions

Light flavour measurements performed by the ALICE Collaboration allow to study the effect of the medium produced in Pb–Pb collisions on particle production. p/π , K/π and ϕ/π ratios provide information to understand the baryon anomaly and suggest that spectra are characterised by hadron masses rather than their (valence) quark content. The R_{AA} at high p_T suggests that the parton fragmentation is not modified by the medium. Finally, equilibrium thermal models successfully describe the integrated yields of the measured particle species, though overestimating proton and K^* production in central Pb–Pb collisions.

References

- [1] Abelev B et al. (ALICE Collaboration) 2014 *Phys. Lett. B* **736** 196.
- [2] Abelev B et al. (STAR Collaboration), 2006 *Phys. Rev. Lett.* **97** 152301.
- [3] Adare A et al. (PHENIX Collaboration), 2013 *Phys. Rev. C* **88** 024906.
- [4] Abelev B et al. (ALICE Collaboration), arXiv:1404.0495.
- [5] Fries RJ, Muller B, Nonaka C and Bass SA 2003 *Phys. Rev. C* **68** 044902.
- [6] Bozek P and Wyslkiel-Piekarska 2012 *Phys. Rev. C* **85** 064915.
- [7] Werner K et al. 2012 *Phys. Rev. C* **85** 064907.
- [8] Wheaton S et al., 2009 *Comp. Phys. Commun.* **180** 84.
- [9] Andronic A et al., 2009 *Phys. Lett B* **673** 142.
- [10] Petran M et al., arXiv:1310.5108v2.
- [11] Becattini F et al., arXiv:1405.0710.
- [12] Becattini F et al., 2013 *Phys. Rev. Lett* **111** 082302.
- [13] Bellwied R et al., 2013 *Phys. Rev. Lett* **111** 202302.