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EXAMPLES OF SOFT PHYSICS OBSERVABLES IN THE ALICE EXPERIMENT*

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The forthcoming ALICE experiment at LHC will have the unique capability of identifying particles with a high separation power and it is expected to give new insights into dynamics of relativistic heavy ion collisions, *e.g.* the interplay between soft and hard processes in the hadron production as discussed here. The results obtained from the heavy ion experiments at the Relativistic Heavy Ion Collider (RHIC) and the expectations at the unprecedented LHC energies will be also shown. Particle ratios from equilibrium and non equilibrium scenarios are presented. Furthermore, hadron momentum spectra and the production of some resonances as will be measured by ALICE are discussed.

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1. Introduction

According to the QCD theory, in the interactions between heavy nuclei at relativistic energies a new state of matter, named Quark Gluon Plasma (QGP) is expected to be formed. In such a state the degrees of freedom of the system are only quarks and gluons no more confined in the nucleons. After the plasma formation, while the system expands and cools, the partons rearrange themselves into hadrons that undergo multiple interactions before being detected. During the hadronic interactions two freeze out conditions come into play: the chemical freeze out and the kinetic freeze out. The former fixes the particle yields at the hadronization stage, the latter affects particle momenta. The latest data collected by the experiments at RHIC show that the effects of soft processes, dominating the low momentum region,

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are well interpreted by hydrodynamical models, whereas in the intermediate momentum region ($p_{\rm T} \sim 2$–$5\,{\rm GeV}/c$) the role of soft and hard processes is still under investigation. At LHC energies the interaction volume, the energy density, the initial temperature and the time duration of the QGP phase will increase with respect to RHIC. The increasing importance of hard processes might affect the bulk properties providing new physical conditions that will affect the low and intermediate momentum region [1]. Whether the theoretical assumptions valid for RHIC in the soft physics regime will be still able to describe the same observables at LHC is, then, an open question. In the following sections, the physical interests of some observables of the soft physics sector in ALICE such as particle abundances, momentum spectra and resonance production will be discussed.

2. Particle abundances

The particle abundances are a tool to investigate the degree of chemical equilibration of the fireball. Both statistical equilibrium and non equilibrium scenarios have been studied to reproduce the measured particle ratios in heavy ion collisions. If the system is chemically equilibrated it is governed by the chemical freeze out temperature $T_{\rm ch}$ and the baryochemical potential $\mu_{\rm B}$. At RHIC the comparison of the data with the statistical model has revealed a high degree of chemical equilibration. This model has been demonstrated successful in describing particle ratios also for AGS and SPS energies. It provides an unified picture for the hadron production in heavy ion collisions showing that the $(T,\ \mu_{\rm B})$ extracted from data lay on a curve characterized by an average energy per particle of about $1\,{\rm GeV}$ [2,4]. Moreover, the chemical freeze out temperature, $T_{\rm ch}$, extracted from RHIC data is very close to the critical temperature of the phase transition between the hadronic matter and the QGP, calculated in lattice QCD simulations [3]. This suggests that the observed hadrons have been produced from a deconfined phase as the quark gluon plasma state [2]. Nevertheless, the statistical equilibrium model is not able to reproduce the horn of the K^+/π^+ ratio at $\sqrt{s_{NN}} > 10\,{\rm GeV}$ (see [5]). The strange quark production with respect to light quark production is not well described in a chemically equilibrated system at these energies. Further studies about the strangeness production lead to introduce two new parameters, named γ_s and $\gamma_q (q = u, d)$ [7] that make the statistical description deviate from the equilibrium hypothesis. In particular the chemical equilibrium is valid only if $\gamma_s = \gamma_q = 1$, whereas higher values mean an over-saturation of u, d and s quark phase space (the opposite for lower values). The horn structure around $\sqrt{s_{NN}} = 8\,{\rm GeV}$ is well reproduced if the phase space occupancy parameters are fitted independently resulting in values different from one [6]. Latest predictions for soft hadron ratios at the LHC energies were provided within a non equilibrium scenario. The results are given in Fig. 1 as a function of γ_s. Extrapolating from RHIC data, the expected γ_s at LHC is about 5 [8], that is twice higher than the one extracted from RHIC. The strangeness production may be the result of new processes and the equilibrium hypothesis may be too weak. It should also be noticed that these predictions differ markedly from the equilibrium if γ_s is higher than 4, lower values are ambiguous because the particle ratios from $\gamma_s \sim 2$ are similar to the equilibrium scenario. The comparison of the forthcoming ALICE data with the predictions based on equilibrium and non equilibrium scenarios will provide new insights in the chemical properties of the plasma.

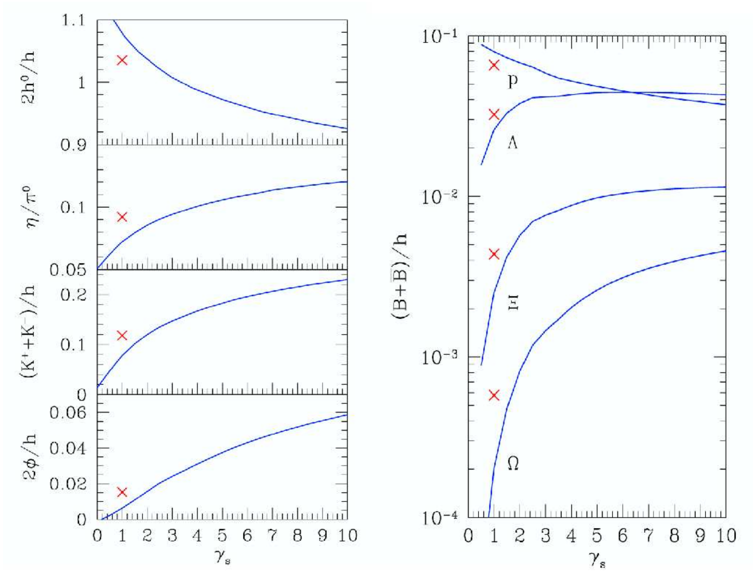

Fig. 1. Soft hadron ratios expected at LHC in a non equilibrium scenario. The crosses are the results for the chemical equilibrium [8].

3. Momentum spectra and flow

One important feature of relativistic heavy ion collisions is that hadrons show a collective behavior. If it is assumed that after the hadronization the particles can still interact before their free streaming (kinetic freeze out), the shape of the spectra follows the exponential law $dN/dy\, m_{\rm T}\, dm_{\rm T} \sim e^{-m_{\rm T}/T_{\rm slope}}$ [9], where the $T_{\rm slope}$ parameter is an apparent temperature. The particles are emitted from a source and the parameter contains the kinetic freeze out temperature ($T_{\rm fo}$) and the kinetic term of the flowing source (β_T). An hydrodynamical approach to the evolution of the fireball has also been developed. The model assumes that in the colliding system the mean free path of the particles is much smaller than the interaction volume and that the system is an ensemble of non-viscous cells of fluid in thermal equilibrium [10]. The hydrodynamics approach needs assumptions on the equation of state of the thermalized matter and the initial conditions of the expanding system (*e.g.* the equilibration time, the initial entropy density, the initial temperature). The comparison of hydro predictions with the data may shed light on these parameters. The hydrodynamics describe successfully hadron momentum spectra, but its applicability is not valid for fast particles because they can escape the medium too quickly without thermalizing. At RHIC hydrodynamical calculations work just up to $p_{\mathrm{T}} \leq 2\,\mathrm{GeV}/c$ [11], whereas for LHC this limit is unclear. At LHC the increase of the hard processes contribution in the fireball will affect the hydrodynamical calculations valid for RHIC energies. Fig. 2 shows the shape of the momentum spectra in a wide p_{T} range, making a comparison between the hydrodynamical predictions up to $6\,\mathrm{GeV}/c$ and the spectrum predicted by the pQCD (+ energy loss effects) above $2\,\mathrm{GeV}/c$. An open question is what will be the relative contribution

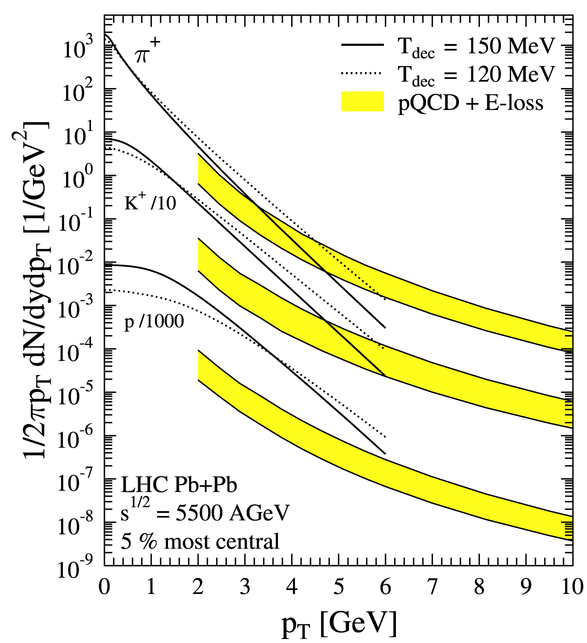

Fig. 2. Comparison between the predictions of the momentum spectra calculated at LHC energies [12]. The hydrodynamical calculations are given for two different decoupling temperatures and the band for the pQCD+Eloss is due to the uncertainties of the extrapolations at the LHC energies.

of hydrodynamics (dominated by soft interactions) and the pQCD contributions at intermediate p_{T}. The ALICE experiment, through the identification of pions and kaons up to $3\,\mathrm{GeV}/c$ and protons up to $5\,\mathrm{GeV}/c$ will provide new insights in the interplay between soft and hard processes in the hadron formation.

4. Resonances

One of the consequences of the QGP formation is the modification of the mass value and the width of the $\rho(770)$ meson. The $\phi(1020)$ or the $\omega(782)$ can also exhibit such changes [13, 14]. The detection of the features of short lived mesons as their mass and width are good probes of the deconfined state, however the subsequent hadronic phase might mask their direct observation. A quantitative understanding of the hadronic phase is crucial to disentangle the two phases. At RHIC recent studies show that short lived particles (lifetimes compatible with the duration of the collision (~ 15 fm/c)) can give insights in the hadronization process and they can also probe the evolution of the hot system between the chemical freeze out and the kinetic freeze out of the fireball. For the last topic good candidates are the $K^*(892)$, the $\phi(1020)$, the $\Delta^{++}(1232)$ and the $\Lambda(1520)$ (see Table I).

TABLE I

Brief summary of some short lived particles.

	$K^*(892)$	$\phi(1020)$	$\Delta^{++}(1232)$	$\Lambda(1520)$
lifetime (fm/c)	3.9	44	1.3	13

These resonances either may travel undisturbed before decaying or two competing processes can come into play: the rescattering and the recombination. The former consists in the interaction of at least one of the decay products, so the information about the particle is missed in the invariant mass calculation. The latter consists in a further production of the particle due to the formation of the same resonant state in the expanding system (*e.g.* a kaon and a pion in the fireball can form the $K^*(892)$ that decays after the hadron decoupling). These two effects are competitive so either an enhancement or a suppression of the resonance should be present if their contributions are not the same. Recent results from RHIC about the ratios between the resonances and the non resonant particles, normalized to the yield of K^*/K in pp collisions are shown as a function of the centrality in Fig. 3. Clearly the $K^*(892)$ and the $\Lambda(1520)$ are suppressed with respect to the relative pp yield whereas the ϕ and the Δ^{++} are not. The ϕ has a low cross section for scattering with non-strange hadrons [16] (*i.e.* the numerous pions).

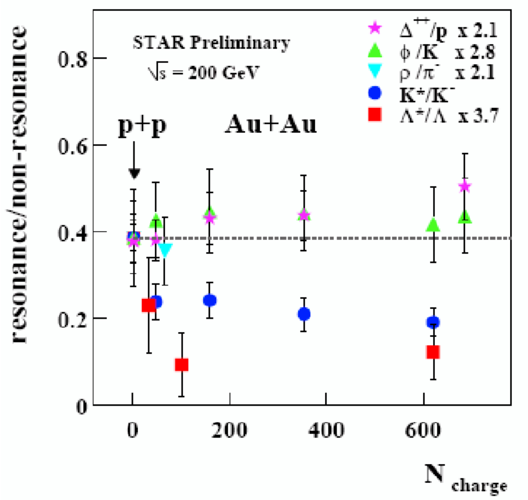

Fig. 3. Resonance over non resonant hadron ratios *versus* centrality in AuAu and *pp* collisions at RHIC [15].

Therefore, it should decay outside the fireball almost undisturbed, whereas the $\Delta^{++}(1232)$ has a very short lifetime so either there is no rescattering or both rescattering and regeneration provide the same contribution. The suppression of the K^* and the $\Lambda(1520)$ indicates that the rescattering play a relevant role after their formation. The time interval between the chemical freeze out and the kinetic freeze out that emerges from RHIC data seems to be finite and of the order of a few fm/c. In ALICE, many preliminary studies of the resonance identification have been performed. The $K^*(892)$, the $\rho(770)$ and the $\phi(1020)$ are identified in their hadronic decay channels [17, 18]) and in general ALICE can identify them up to 15 GeV/c, 8 GeV/c and 15 GeV/c [19], respectively. Now additional studies about the $\Lambda(1520)$ identification are also ongoing.

Furthermore, the similarity of the $\phi(1020)$ mass to the proton mass makes the meson a good tool to disentangle the predominant effect between quark content or mass dependence in the hadronization process. One of the puzzles coming out from the RHIC data is the enhancement of the baryon yield with respect to mesons in the intermediate $p_{\rm T}$ region ($2\,{\rm GeV}/c < p_{\rm T} < 5\,{\rm GeV}/c$) [20]. Recent results of the ϕ identification up to 3 GeV/c at RHIC show that its momentum distribution is well described if the parameters ($T_{\rm fo}$, β_T) from proton $p_{\rm T}$ spectrum are used. On the contrary, in the nuclear modification factor $R_{\rm CP}$ (Fig. 4), the $\phi(1020)$ scales like the pions and, therefore, its yield depends on the quark content [21]. The resonances identified by ALICE will probe the deconfined phase of hadronic matter, furthermore, they will help to clarify the new topic about the evolution of

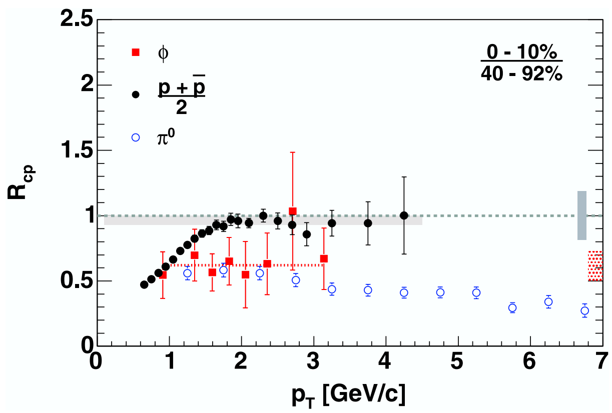

Fig. 4. The nuclear modification factor shows a ϕ suppression similar to that of pions [21].

the hot hadronic matter from its formation to the free streaming stage. In particular the detection of the ϕ meson, compared to protons, will also help to understand the underlying mechanisms of the hadronization process.

5. Final remarks

An overview of some issues in the soft physics sector in ALICE like the degree of the chemical equilibrium of the colliding system, the range of validity of hydrodynamics predictions and the importance of the resonance studies has been provided. In the LHC regime the hard processes will contribute much more than at RHIC. How this will affect the soft physics observables is a crucial question.

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