Resonances in a sudden chemical freeze-out model

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Abstract. The prediction for p_T spectra of various resonances in equilibrium and non-equilibrium models is made. It includes the η, $\rho(770)$, $\Sigma(1385)$, $\Lambda(1520)$, and $\Xi(1530)$. The apparent differences may allow to distinguish between the models.

A chemical non-equilibrium model [1] with a single freeze-out appeared to be rather successful in describing the LHC ALICE data at 2.76 TeV for various particles [2, 3]. The p_T spectra of pions, kaons, protons, $K^*(892)^0$, and $\phi(1020)$ are described by the same hubble-like freeze-out hyper-surface that has only one parameter for the slope of the spectra – the ratio of the freeze-out time to the freeze-out radius [2, 3]. This is very surprising for the $K^*(892)^0$ and the $\phi(1020)$, because the first one is short living, while the second one is long living. The description of both of them may question the necessity of the long re-scattering phase, which is also successfully used to describe the ALICE data [4]. It may also indicate that the non-equilibrium, as implemented in [2, 3], may effectively include the re-scattering in the non-equilibrium chemical potentials. It is important to differentiate between the equilibrium with the re-scattering, and the single sudden freeze-out in the non-equilibrium, because the non-equilibrium also leads to pion condensation [5, 6].

A good test for the non-equilibrium single freeze-out scenario [2, 3] is the comparison to different resonances, especially strange resonances, because this scenario requires a special relation between the strange and the non-strange chemical potentials, depending on the quark content of a resonance. The heavy Λ, Ξ and Ω can be still described by the non-equilibrium very well, if one assumes a smaller slope for them [3]. This introduces the dependence on the mass of the resonance, but is also supported by smaller flow of heavy particles in other approaches, see e.g. [7]. The parameters obtained in the fit to the 2.76 TeV Pb+Pb LHC data in equilibrium (EQ), non-equilibrium (NEQ) [2, 3], and non-equilibrium with the possibility of pion Bose-Einstein condensation (BEC) on the ground state [5, 6] in hadron-resonance gas, using correspondingly modified SHARE [8] and THERMINATOR [9] codes, are shown in Fig. 1. One can see that the system is closer to the scenario with the condensate in central collisions. However, the uncertainty is rather large, which means that more mean multiplicities are needed to constrain the fit. At large chemical potentials finite size effects should be taken into account. The corresponding BEC fit of pion and kaon spectrum gives a good description of protons, while protons in EQ require a different freeze-out hypersurface. The amount and spectra of ρ^0 and η mesons are significantly different in EQ and BEC, see Fig. 2. Charged pions favor BEC[1], see Fig. 3, while the η/π^0 ratio favors EQ (data from A. Morreale [10]). However, the uncertainty, again, seems to be too large to judge. Both BEC and EQ explain K_S^0 and ϕ spectra similarly good, see

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[1] According to my best knowledge, there is no other model that explained this low p_T excess of pions together with proton spectra without giving pions and protons extra parameters since the data appearance in 2012.

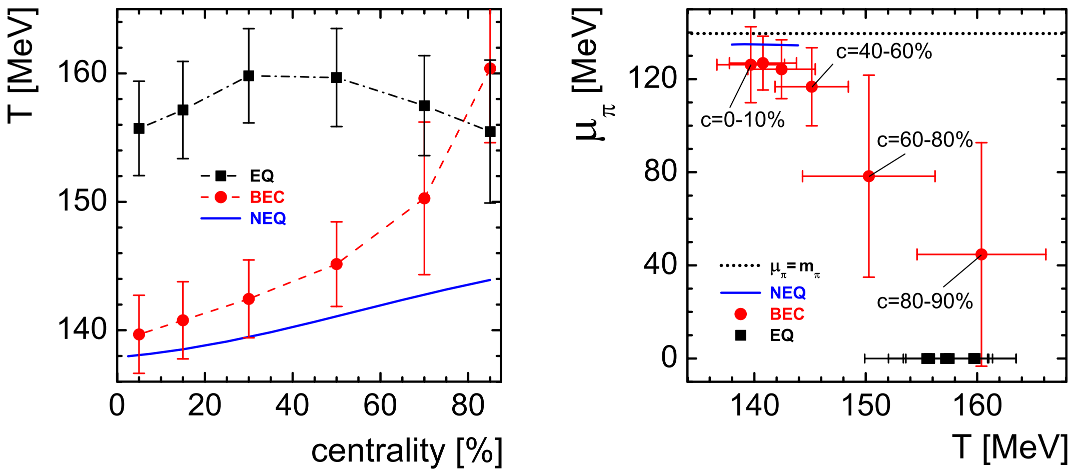

Figure 1. The temperature T and non-equilibrium chemical potential for pions μ_π for different centralities [5, 6].

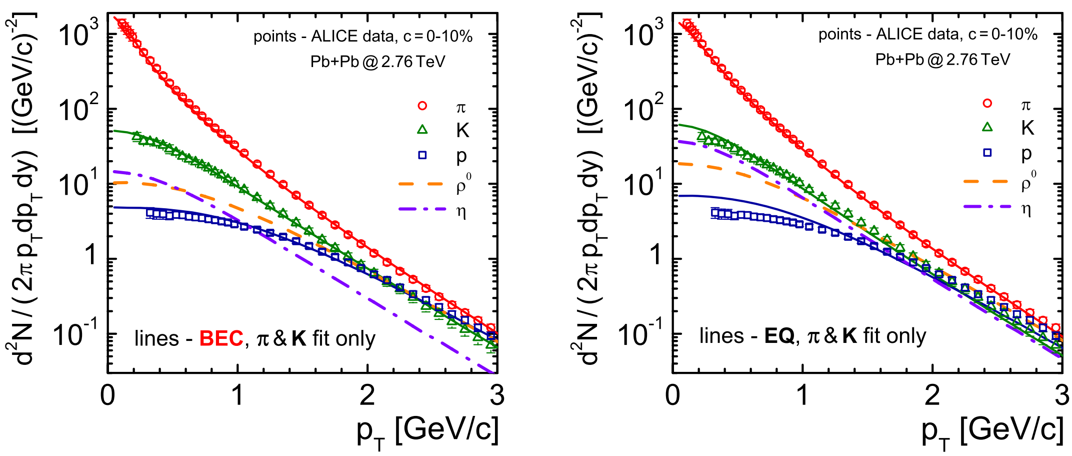

Figure 2. The fit of pions and kaons, and the prediction for protons, ρ and η in 0-10% centrality window.

Fig. 4. The $K^*(892)^0$ is closer to BEC prediction. Note, that $K^*(892)^0$ was not included neither in the fit of mean multiplicities, nor in the fit of spectra (data from [11]). It means that BEC can be treated as an effective parameterizations of the freeze-out. Strange baryons require different freeze-out hypersurface compared to that one for π, K, p, K_S^0, K^*, and ϕ, see Fig. 5, and also [7, 12]. There is the mass dependence in BEC - the heavier the baryon, the smaller is the slope, i.e. the flow, or, equivalently, smaller radius of the hypersurface. BEC predicts similar multiplicities and spectra of $\Lambda(1520)$ and $\Xi(1530)$, see Fig. 6. EQ predicts larger multiplicity difference between $\Lambda(1520)$ and $\Xi(1530)$ than BEC. There is a significant dependence of the spectra on the freeze-out hypersurface for heavy strange baryons in BEC, while in EQ only $\Sigma(1385)$ is sensitive to the hypersurface, see Figs. 5, 6.

Therefore, one may conclude that π, K, K_S^0 and ϕ particles may have a common freeze-out hypersurface in both BEC and EQ models. The BEC additionally allows to explain protons, low p_T

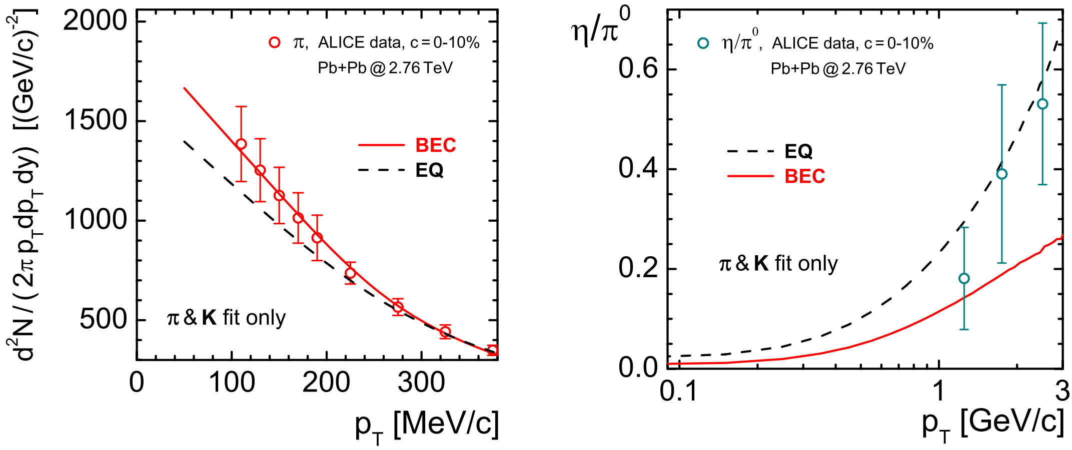

Figure 3. Low p_T charged pions and η/π^0 in EQ and BEC.

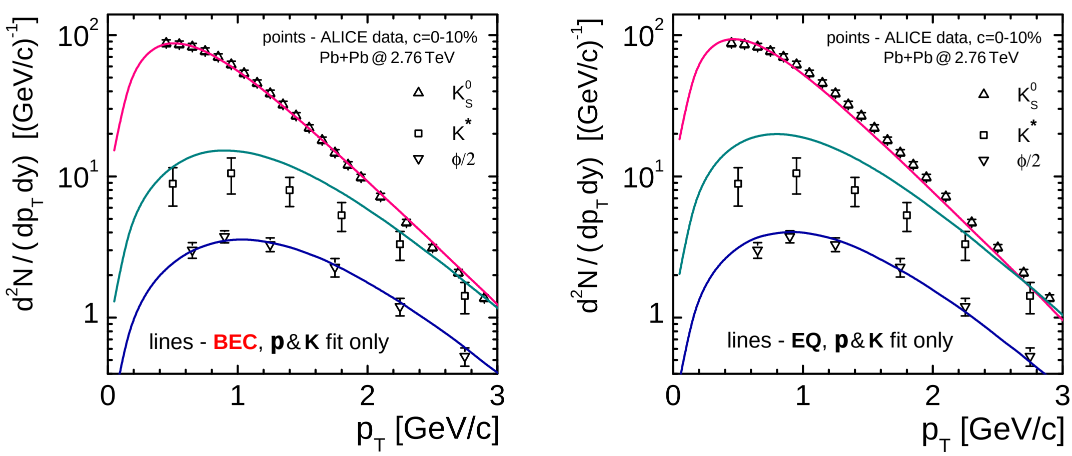

Figure 4. Strange mesons obtained for the hypersurface, which was fitted to pions and kaons only.

pions, and $K^*(892)^0$. Strange baryons require different freeze-out in both models. The predictions for ρ^0, η, $\Sigma(1385)$, $\Lambda(1520)$, and $\Xi(1530)$ are significantly different in BEC and EQ.

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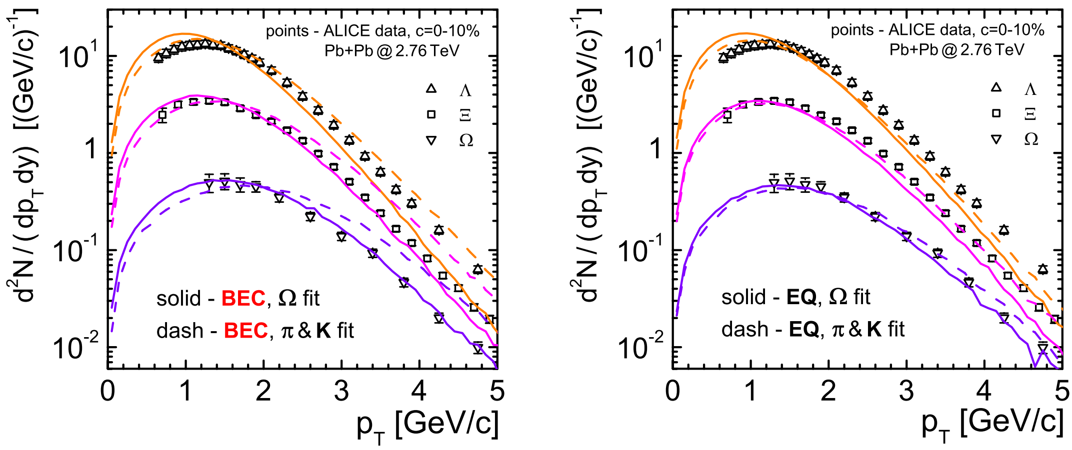

Figure 5. Strange baryons obtained for the hypersurface that was fitted either to pions and kaons, or to Ω baryons.

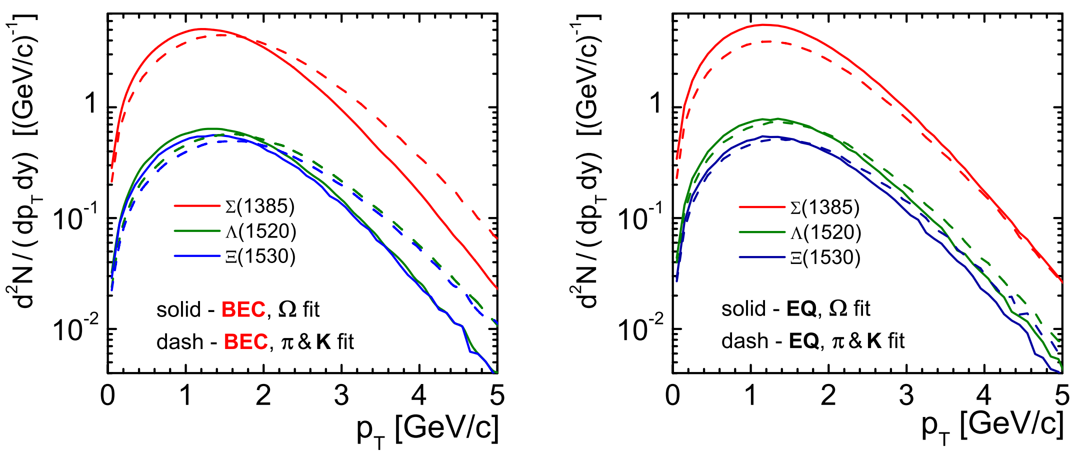

Figure 6. Prediction for strange baryon resonances.

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