Blast wave fits with resonances to p_t spectra from nuclear collisions at the LHC

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Abstract. We report our results for the freeze-out temperature and transverse flow profile obtained from fits to hadronic spectra measured by the ALICE collaboration. The influence of resonance decays is important and cannot be simply accounted for without the inclusion of their decays into the fits.

1. Introduction

Hadron spectra produced in ultrarelativistic nuclear collisions are shaped by the dynamical state of the fireball at the moment of its breakup. The azimuthally integrated spectra are particularly characterised by the temperature and the transverse expansion velocity.

We have analysed data by ALICE collaboration on transverse momentum spectra of π, K, p [1], K_0 and Λ [2], Ξ and Ω [3], K^* and Φ [4]. For a single species there is an ambiguity for the slope of the spectrum which goes like

$$T^* = T + m\langle v_t\rangle^2 \,. \tag{1}$$

This is resolved by common fitting of different species.

Many hadrons originate from decays of resonances. They crucially influence the shape of the spectrum. We will show below that this cannot be accounted for simply by shifting the extracted temperature. Also, it cannot be eliminated by choosing a fiducial p_t interval for data fitting.

The notorious problem of calculations with resonances is that they cannot be done reasonably analytically and one has to Monte-Carlo-simulate spectra which are then compared with real data. This is costly in terms of both CPU time and disk capacity. We have used the Monde Carlo event generator DRAGON [5] for the generation of theoretical spectra. It is a MC realisation of the blast wave model which was adapted to be identical to the one used by ALICE collaboration for data fiting [1].

2. The model

The blast wave model used in our fitting is characterised by the theoretical prescription

$$\frac{dN}{dy\,d^2p_t} = \int d\Sigma_\mu p^\mu\, f(p_\mu u^\mu, x) = \int d^4x\, S(x,p) \,, \tag{2}$$

Table 1. Selected fit results using the fiducial intervals as determined by the ALICE collaboration [1]. Compared are sets of results with and without inclusion of resonance decays.

centrality	no resonances			with resonances		
	T (MeV)	$\langle v_t \rangle$	n	T (MeV)	$\langle v_t \rangle$	n
0–5%	98	0.645	0.73	82	0.662	0.69
10–20%	102	0.637	0.73	90	0.649	0.71
30–40%	110	0.605	0.81	102	0.616	0.79
50–60%	122	0.527	1.15	126	0.541	1.03
70–80%	142	0.439	1.51	170	0.423	1.55

where $d\Sigma_\mu p^\mu$ indicate integration of the flux of particles through the three-dimensional freeze-out hypersurface and $f(p_\mu u^\mu, x)$ is the statistical distribution. The emission is conveniently expressed by the emission function

$$S(x,p)\, d^4x = g_i\, \delta(\tau - \tau_{fo})\, m_t \cosh(y - \eta_s)\Theta(R - r)\frac{1}{\exp\left(\frac{p_\mu u^\mu(x) - \mu(x)}{T}\right) \pm 1}\,\tau d\tau\, d\eta_s\, r\, dr\, d\varphi\,, \quad (3)$$

where we use $\tau = \sqrt{t^2 - z^2}$, $\eta_s = \frac{1}{2}\ln\frac{t+z}{t-z}$, polar coordinates r, φ, and g_i is spin degeneracy. The source is characterised by freeze-out Bjorken time τ_{fo} and transverse radius R. Statistical distributions are taken with the argument $p_\mu u^\mu$ which gives the energy in the local rest frame of the fluid. Here, u_μ is the local expansion four-velocity with longitudinal and transverse expansion $u^\mu = \gamma(1, \vec{v}) = (\gamma, \gamma v_t \cos\varphi, \gamma v_t \sin\varphi, \gamma v_l)$, where $v_l = \tanh\eta_s$ and the transverse velocity grows with r like $v_t(r) = \eta_f (r/R)^n$ with model parameters η_f and n. The mean transverse velocity is $\langle v_t \rangle = 2\eta_f/(1 + n)$.

Resonances are also produced according to the emission function (3). Then they are let to decay with the assumption of constant matrix elements and uniform filling of the phase space.

3. The influence of resonances

Chemical composition of the fireball plays a crucial role as it determines which part of the final state hadrons is due to resonance decays. We apply here the scenario of two freeze-outs: chemical freeze-out at a higher temperature is followed by further cooling and expansion which ends up in the thermal freeze-out. The abundances of all species—including resonances—are determined by chemical equilibrium at chemical freeze-out temperature of 152 MeV and baryochemical potential of 1 MeV [6]. This assumption is rather extreme and actually means that the kinetic freeze-out follows the chemical so quickly that no resonances have enough time to decay.

Often, resonance contributions are left out in the fits to transverse momentum spectra. It is argued then that this simplification is justified if the fit is performed in a fiducial region where p_t is high enough so that resonance contributions are not important and still low enough so that hard processes play no role. Unfortunately, the common lore that resonance contribution is concentrated only at low p_t is wrong! We have checked this by performing fits to fiducial p_t-intervals used in [1].

Some of our results are summarised in Table 1. Our fit results with no resonances included agree with those by ALICE [1]. The inclusion of resonances, however, *does* change the results. Moreover, the change depends on centrality. While in central collisions the temperature *drops* by 10 MeV when resonances are included, in peripheral collisions it *rises* by 10 MeV.
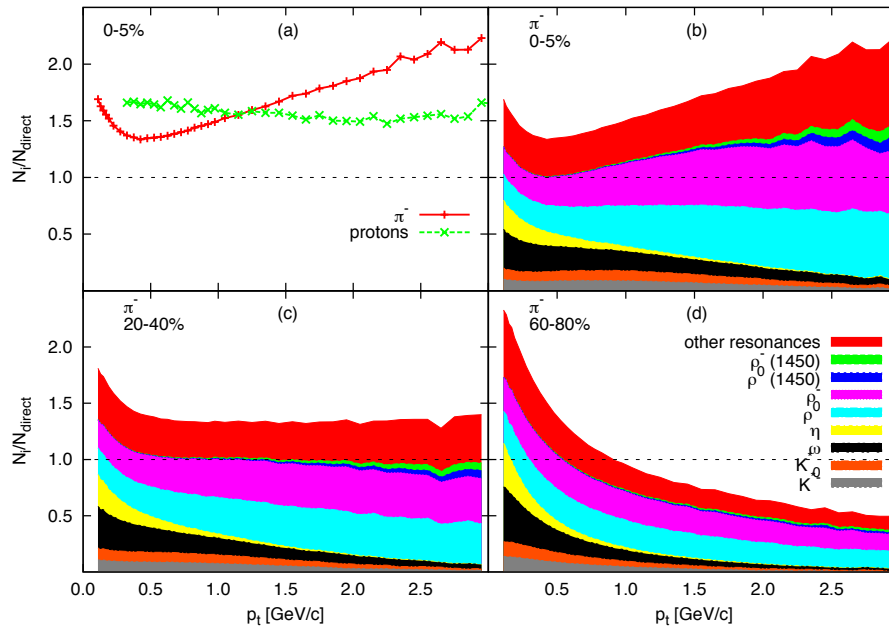
Figure 1. The ratio of hadrons from resonance decays to those produced directly as a function of p_t. (a) pions and protons in 0–5% central collisions; (b)-(d) the ratio is broken up into contributions from individual resonance species, different panels show different centralities. Simulations correspond to our best fits to the indicated centralities. The used values of T and $\langle v_t \rangle$ are indicated in Fig. 2.

To see the cause of such shifts, we show in Fig. 1 how the resulting spectra are build up from contributions of individual resonance species. This was calculated with our best fits to the given centrality classes, as reported below. In peripheral collisons we indeed observe that resonance production populates mainly the low p_t region. This feature still survives in the 20–40% centrality class. In the most central collisions, however, the relative contribution from resonance decays grows with increasing p_t.

The figure also demostrates the reason for such a behaviour. In central collisons temperature is low and transverse flow strong. Low p_t region is populated by decays of η and ω. The former is light and the latter decays into three pions. Hence, there is not much energy left for the momentum of the pions. The higher-p_t tail is mainly populated by decays of ρ and heavier resonances. When they decay, much energy is available for the kinetic energy of the pions. Pions get a kick from decays of such resonances. Also, due to low temperature not many direct pions have high p_t and so the share of pions from heavy resonance decays grows. Strong transverse flow boosts also the heavy resonances and helps to pronounce the kick to high p_t. This changes when the temperature grows and the transverse expansion is weaker (peripheral collisions). There, directly produced pions can better populate also higher p_t and the share of resonance production at high p_t does not grow anymore.

Qualitatively similar results for resonance production, although not so much pronounced as for pions, are obtained for protons, as well. (Shown in the supplementary online material.)

Thus there is i) no fiducial interval where resonance decay contribution can be ignored; ii) no simple recipe stating that the inclusion of resonances will just shift the fit results by any fixed value, since even qualitatively the influence of resonance decays depends on the state of the fireball.
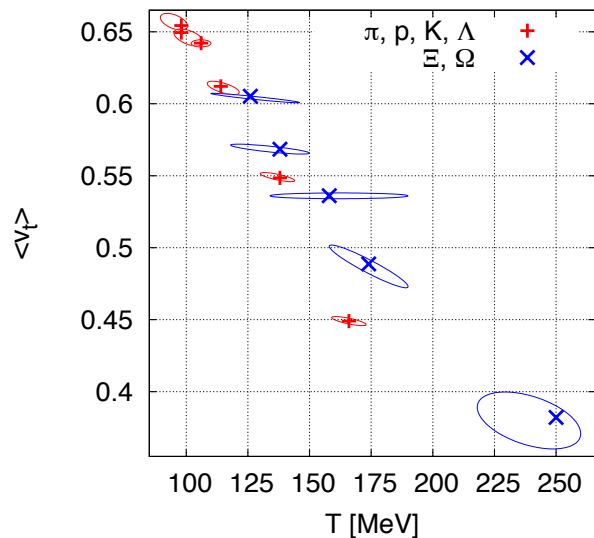
Figure 2. Summary of the fitted temperatures and transverse flows. Different values show results for different centralities with top left being the most central and bottom right the most peripheral. The centralities for common fits to π, K, p, and Λ spectra (symbol +) are: 0–5%, 5–10%, 10–20%, 20–40%, 40–60%, 60–80%. Centralities for Ξ and Ω spectra (symbol ×) are: 0–10%, 10–20%, 20–40%, 40–60%, 60–80%. Elipses indicate our estimates of 99% confidence levels (for π, K, p, and Λ) and 1σ intervals (for Ξ and Ω).

4. Fit results

The obtained freeze-out temperatures grow and the transverse expansion velocity decreases as we move from central collisions to more peripheral. The overview of results can be found in Figure 2. With the model fitted to pions, kaons, nucleons, and Λ's we were able to reproduce also the K^* and ϕ spectra. However, the spectra of multistrange hadrons, Ξ and Ω did not fall into this systematics. When we fitted them separately, the obtained temperatures were generally higher and transverse flows generally weaker than those of more abundant species.

　　More detailed description of the procedure and results can be found in [7].

5. Conclusions

Our results indicate that between the chemical and thermal freeze-out the temperature drops considerably in central collisions. It opens the question whether assuming abundances of all resonances given by chemical freeze-out temperature is justified. We shall reconsider it soon.

　　It should also be noted that a successful fit on p_t spectra including resonances and assuming common chemical and thermal freeze-out was recently reported in [8].

References

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