FREEZE-OUT PARAMETERS IN CENTRAL 158·A GeV ^{208}Pb+^{208}Pb COLLISIONS

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The measured neutral pion cross section from central Pb+Pb reactions as a function of $m_T - m_0$ is shown in Fig. 1. It is compared to a fit with a hydrodynamical model [1] including transverse flow and resonance decays. This computer program calculates the direct production of π^0 and the contributions from the most important resonances having two- or three-body decays including pions (ρ, K^0_S, $\mathrm{K}^\star$, Δ, Σ^+, Λ, η, ω, η'). The code, originally intended for charged pions, has been adapted to predict neutral pion production. The model uses a gaussian transverse spatial profile. The transverse flow rapidity is assumed to be a linear function of the radius.

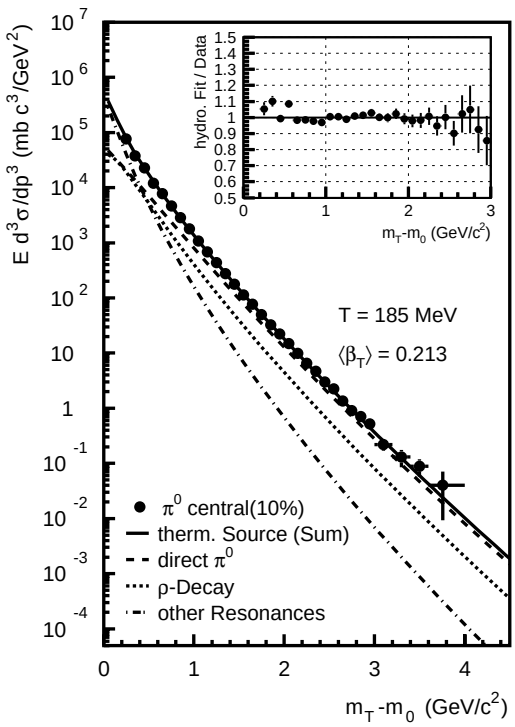

Figure 1: Transverse mass spectra of neutral pions in central collisions (10% of min. bias cross section) of 158 A·GeV Pb+Pb. The invariant cross section of neutral pions is compared to a fit using a hydrodynamical model [1] including transverse flow and resonance decays, with the direct production and the contribution of ρ decays and all other resonances shown separately. The ratio of the fit to the data is shown in the inset. m_0 is the π^0 mass.

This model provides an excellent description of the neutral pion spectra with a temperature $T = 185\,\mathrm{MeV}$ and an average flow velocity of $\langle\beta_T\rangle = 0.213$. These values are very similar to the parameters obtained with similar fits to neutral pion spectra in central reactions of ^{32}S+Au [2]. The 2σ lower limit on the temperature is $T^{low} = 171\mathrm{MeV}$, and the corresponding upper limit on the flow velocity is $\langle\beta_T^{upp}\rangle = 0.253$.

The observed curvature at low m_T is largely a result of resonance decay contributions. Performing a fit with only the direct contribution leads to $T = 142\,\mathrm{MeV}$ and $\langle\beta_T\rangle = 0.301$, with corresponding 2σ limits of $T^{low} = 135\,\mathrm{MeV}$ and $\langle\beta_T^{upp}\rangle = 0.318$, similar to other analyses which have neglected decay contributions [3, 4]. The larger average velocity which results in this case is due to the fact that all of the observed curvature must now be accounted for by transverse flow.

The high statistical accuracy and large transverse mass coverage of the present π^0 measurement reveals the concave curvature of the π^0 spectrum over a large m_T range, which constrains the parameters significantly. This is further demonstrated by studying the local slope at each m_T. The local (inverse) slope is defined as

$$T_{local}^{-1} = -\left(E\frac{d^3\sigma}{dp^3}\right)^{-1} \frac{d}{dm_T}\left(E\frac{d^3\sigma}{dp^3}\right). \tag{1}$$

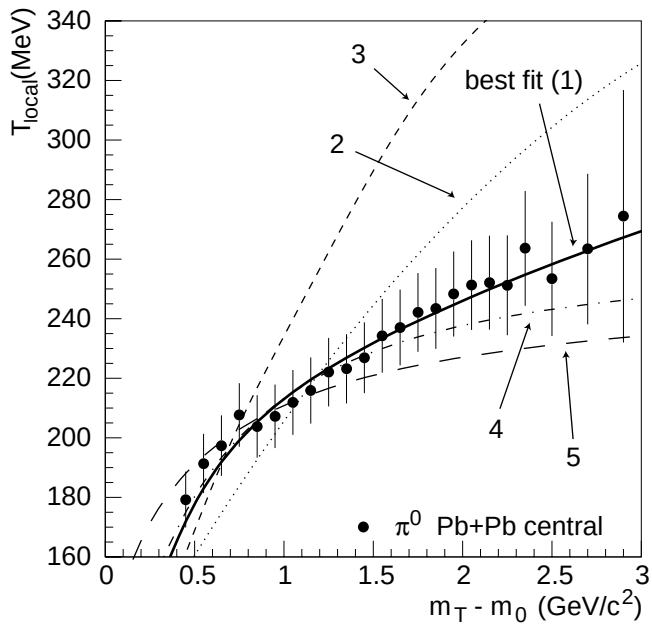

Figure 2: The local inverse slope of the transverse mass spectrum of neutral pions in central collisions of 158 AGeV Pb+Pb. The measured results (solid points) are compared to the hydrodynamical model best fit result (solid line; $T = 185\,\mathrm{MeV}$ $\langle\beta_T\rangle = 0.213$, also shown in Fig. 1) and to the other results given in Table 1.

The local slope results are plotted in Fig. 2. Each individual value of T_{local} has been extracted from 3 adjacent data points of Fig. 1. The data are compared to the hydrodynamical model best fit results of Fig. 1, as well as fits in which the transverse flow velocities have been fixed to larger values comparable to those obtained by Refs. [5] and NA49 [3] (sets 2 and 3). The corresponding fit parameters are given in Table 1. The comparison demonstrates that while the large transverse flow velocity fits can provide a reasonable description of the data up to transverse masses of about 1 GeV, they significantly overpredict the local slopes at large transverse mass. While application of the hydrodynamical

model at large transverse mass is questionable, the model certainly cannot overpredict the measured yield! The observed overprediction, therefore, rules out the assumption of large transverse flow velocities, or points to a deficiency in the model assumptions.

Table 1: Parameters for different hydrodynamical model fits to the neutral pion spectrum shown in Figs. 2 and 3. The temperature T, average and RMS transverse flow velocity $\langle\beta_T\rangle$ and β_{RMS} are given together with the effective temperature $T_{eff} = T/\sqrt{(1-\langle\beta_T\rangle)/(1+\langle\beta_T\rangle)}$.

Set	Spatial profile	T (MeV)	$\langle\beta_T\rangle$	β_{RMS}	T_{eff} (MeV)
1	Gauss	185 $\pm$ 4	0.213 $\pm$ 0.020	0.107	230
2	Gauss	75 $\pm$ 1	0.469	0.199	125
3	Gauss	49 $\pm$ 1	0.527	0.213	88
4	Uniform	178 $\pm$ 13	0.274 $\pm$ 0.046	0.093	235
5	Uniform	100	0.540 $\pm$ 0.018	0.164	183

The large curvature at large transverse mass results from the combined assumption of a transverse rapidity profile which grows linearly with radius and a gaussian density profile, which together produce a high velocity tail [6]. Figure 3 shows the transverse velocity profiles for different parameter sets. The curves labeled 1-3 correspond to the calculations in Fig. 2 using a gaussian spatial profile. In addition, velocity profiles are shown for a uniform density profile for a free fit to the neutral pion spectrum (set 4) and a fit using a fixed temperature of $T = 100\,\mathrm{MeV}$ (set 5). These are included in figures 2 and 3. It is seen that the uniform density assumption truncates the high velocity tail resulting in less curvature in the pion spectrum. While the gaussian and uniform density assumptions have very different velocity profiles, it is interesting that both can provide acceptable fits to the pion spectrum with parameters which give similar effective temperatures and velocity widths, β_{RMS}, given in Table 1.

Compared to the gaussian profile result, the best fit result using the uniform profile gives a lower temperature of 178 MeV and would lead to weaker limits (2σ for $m_T - m_0 \leq 2\,\mathrm{GeV/c}$) of $\langle\beta_T^{upp}\rangle = 0.42$ and $T^{low} = 134\,\mathrm{MeV}$.

In summary, we have demonstrated that high accuracy neutral pion spectra with a large transverse mass coverage can constrain the thermal freeze-out parameters of relativistic heavy-ion collisions. Since the pions most directly reflect the thermal evironment in the late stage of the collision, it is mandatory that hydrodynamical models provide an accurate description of the pion spectra. In particular, models, or parameter sets, which overpredict the observed pion yields, even at large transverse mass, can immediately be ruled out. Within the context of the hydrodynamical model of Ref. [1] an excellent description of the neutral pion spectra is obtained with a temperature $T = 185\,\mathrm{MeV}$ and an average flow velocity of $\langle\beta_T\rangle = 0.213$, with a 2σ lower limit on the temperature of $T^{low} = 171\,\mathrm{MeV}$. These thermal freeze-out temperatures are consistent with temperatures extracted for chemical freeze-out for the same system [7]. However, they are inconsistent with those extracted

from recent analyses including HBT results which have indicated lower temperatures and larger transverse flow velocities.

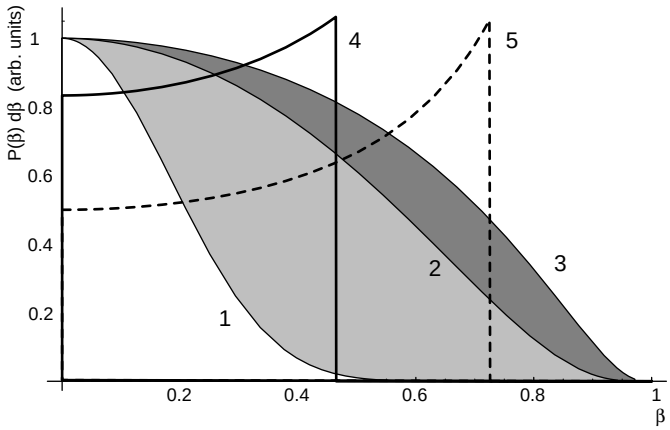

Figure 3: Unnormalized transverse velocity probability distributions for the parameter sets given in table 1.

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