Universal Pion Freeze-out Phase-Space Density

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G. Bertsch has indicated [1] a possibility to measure the pion freeze-out phase-space density and thereby test the local thermal equilibrium in a pion source. In case of thermal equilibrium at temperature T, identical pions of energy E would follow the Bose-Einstein distribution

$$f = \frac{1}{e^{\frac{E}{T}} - 1}. \tag{1}$$

An average of this function over different phase-space regions is the quantity to be measured. When the p_T-spectrum is parameterized by an exponential with $T_{\rm eff}(y)$ being the inverse slope parameter, averaging over the spatial coordinates yields

$$\langle f \rangle(p_T, y) = \frac{\frac{\sqrt{\pi}}{2}\,\frac{\sqrt{\lambda_{\rm dir}(p_T,y)}}{E_p\,T^2_{\rm eff}(y)}\,\exp\left(-\frac{p_T}{T_{\rm eff}(y)}\right)\,\frac{dn^-}{dy}(y)}{R_s(p_T,y)\sqrt{R_o^2(p_T,y)R_l^2(p_T,y) - R_{ol}^4(p_T,y)}}. \tag{2}$$

This equation comprises information from essentially two different classes of experimental results: the single particle momentum spectra $(dn^-/dy, T_{eff})$, and the two pion Bose-Einstein correlations $(R_s, R_o, R_l, R_{ol}, \lambda_{dir})$. We have calculated $\langle f \rangle(p_T, y)$ for the S-S, S-Cu, S-Ag, S-Au, S-Pb and Pb-Pb data from the experiments NA35 [2], NA49 [3], NA44 [4], and for the π-p data from the NA22 experiment [5] at CERN-SPS. From the results for $\langle f \rangle$ as a function of p_T, presented in Fig. 1, one may conclude:

1. universal phase-space density
All the nuclear collision data from the SPS in Fig. 1 are indistinguishably similar, in spite of a factor of ~ 10 difference in multiplicity density.

2. agreement with Bose-Einstein distribution
Using simultaneously pion spectra and pion correlations NA49 has disentangled thermal motion from collective expansion [3]. Taking the NA49 result for the local freeze-out temperature $T = 120$ MeV as the **only** parameter in Eq. (1) one indeed finds good agreement with the data. This is consistent with the thermal nature of the pion source, and inconsistent with the presence of a hypothetic pion condensate.

3. radial flow
Looking in more detail, one finds that the data indicate a somewhat slower decrease with increasing p_T than the Bose-Einstein curve. This is most likely due to radial collective expansion which adds extra transverse momentum to particles, i.e. the local $\langle f \rangle$ values appear in the measurement at a p_T that is higher than the local $\langle p_T \rangle$ in the source reference frame. A detailed study is under way.

4. rapidity dependence
A certain departure from the universal scaling is seen for the data at rapidities close to the projectile rapidity, both at AGS and SPS; moreover, the two results are consistent.

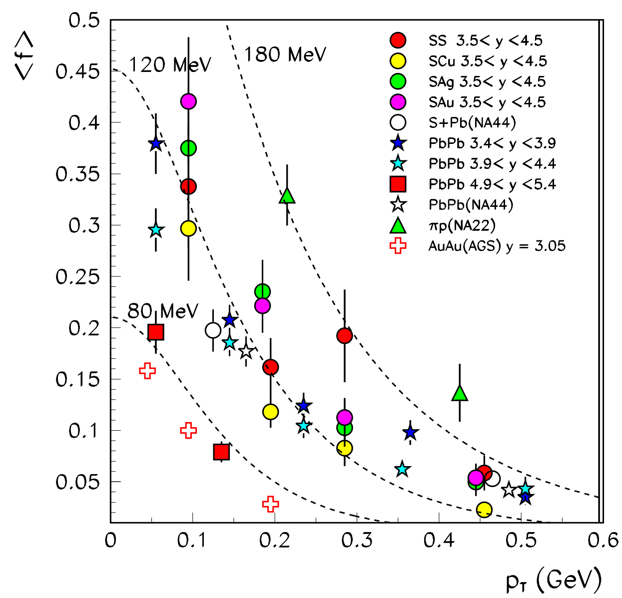

Figure 1: Phase-space density as a function of p_T for different data sets. Heavy-ion data from SPS are indistinguishably similar, although they span over an order of magnitude range in multiplicity. A Bose-Einstein function (Eq. (1)) is superimposed with the three choices of the local freeze-out temperature: 80 MeV, 120 MeV and 180 MeV.

5. high temperature decoupling in $\pi - p$ collisions
In contrast to freeze-out in nuclear collisions which takes place in two steps (chemical at $T \simeq$ 170-180 MeV and thermal at $T \simeq 120$ MeV), pion production in π-p collisions [5] is essentially immediate, without the second evolution stage, and therefore freeze-out temperatures of around 180 MeV should be expected. The data [5] are indeed consistent with this expectation, as seen in Fig. 1.

References

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