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Pion Interferometry of O+Au at 200 AGeV

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Pion Interferometry of O+Au at 200 AGeV[†]

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October 27, 1988

Abstract:

We analyse NA35 data on $O + Au \rightarrow \pi^- \pi^- + X$ at 200 AGeV including resonance decays and non-ideal dynamical and geometrical effects and find that a $\tau_f = R_{\perp f} = 4$ fm chaotic source is consistent with the data.

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* Supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil

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We analyse NA35 data on $O + Au \rightarrow \pi^- \pi^- + X$ at 200 AGeV including resonance decays and non-ideal dynamical and geometrical effects and find that a $\tau_f = R_{\perp f} = 4$ fm chaotic source is consistent with the data.

One of the provocative results emerging from the CERN O+Au runs is the indication of large transverse freeze-out radii and anomalous chaoticity parameters in the analysis of $\pi^- \pi^-$ correlations by NA35[1]. In this note we show that those conclusions are, however, model dependent and that rather different parameters can be deduced if additional dynamical and geometrical degrees of freedom are incorporated into the analysis. Conventionally (see review by Sinyukov these proceedings and Ref.[2]), the *two*-particle correlation function is analyzed in terms of $C(k_1, k_2) = P_2(k_1, k_2)/P_1(k_1)P_1(k_2) = 1 + \lambda |\rho(k_1 - k_2)|^2$, where P_2 denotes the *double*-pion inclusive distribution function, P_1 , the *single*-pion inclusive one, k_1 and k_2 are the four-momenta of the pions, $\rho(q) = \int d^4x e^{iqx} \rho(x)$ is the Fourier transform of the freeze-out space-time density, and λ is the incoherence or chaoticity parameter. The above simple relation is, however, only valid if space-time and momentum coordinates of pions in phase-space are uncorrelated. In the general case, the correlation function can be strongly influenced by phase-space correlations due to dynamical effects. For instance, in the Bjorken Inside-Outside Cascade picture there is a strong correlation between longitudinal coordinate z and longitudinal momentum component p_z [3,4,5,6], which drastically alters the form of the correlation function. In such cases the analysis of correlation functions necessarily becomes model dependent.

In the case of pion interferometry of nuclear collisions at 200 AGeV there are several dynamical effects which may be important to take into account, even if we restrict our attention to completely chaotic sources for which $\lambda = 1$. The rapidity distribution is clearly not uniform and has a width[1] $Y_c \approx 1.4$ for π^- . Also a large fraction of the final π^- could arise from the decay of long lived resonances such as $\omega, K^*, \eta, \dots$ [8]. In coordinate space, the finite nuclear thickness together with resonance effects can lead to a large spread ($\Delta\tau$) of freeze-out proper times and to a wide distribution of transverse decoupling radii. In phase-space, the imperfect correlation between the space-time and momentum rapidity variables, defined by $\eta = \frac{1}{2} \log((t+z)/(t-z))$ and $y = \frac{1}{2} \log((E+p_z)/(E-p_z))$, should be taken into account. Other correlations, e.g., between the transverse coordinate ($\mathbf{x}_\perp$) and the transverse momentum component ($\mathbf{p}_\perp$), may have to be considered if hydrodynamic flow occurs.

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To incorporate these many effects, we have developed a Monte Carlo program based on the covariant current ensemble formalism[4]. In this formalism an ensemble of pion source currents is specified as $\{j_a(x) = j_0(u_a^\mu(x - x_a)_\mu)\}$, where u_a^μ is the four-velocity, x_a is the space-time origin of current element a , and $j_0(x)$ specifies each current element in its rest frame. The Fourier transform of the total source current is then

$$j(k) = \sum_a j_0(u_a k) e^{ikx_a} e^{i\phi_a} , \quad (1)$$

where the factors $e^{i\phi_a}$ are random phases in the case of completely chaotic sources. The *double-pion* inclusive distribution function is then given by

$$P_2(k_1, k_2) = \langle |j(k_1)|^2 |j(k_2)|^2 \rangle , \quad (2)$$

which involves the ensemble average over all the space-time coordinates x_a , four velocities u_a , and random phases ϕ_a . In terms of the pion “freeze-out” distribution

$$D(x, p) = \langle \delta^4(x - x_a) \delta^4(p - p_a) \rangle , \quad (3)$$

where $p_a^\mu = mu_a^\mu$, the *single* and *double* pion inclusive distribution functions can be written as[4]

$$P_1(k) = G(k, k) , \quad P_2(k_1, k_2) = G(k_1, k_1)G(k_2, k_2) + |G(k_1, k_2)|^2 , \quad (4)$$

where the complex amplitude $G(k_1, k_2)$ is given by the convolution of the freeze-out distribution and two current elements that characterize the production dynamics,

$$G(k_1, k_2) = \int d^4p D(q, p) j_0^*(pk_1/m) j_0(pk_2/m) = \langle e^{iqx_a} j_0^*(p_a k_1/m) j_0(p_a k_2/m) \rangle , \quad (5)$$

with $q^\mu = k_1^\mu - k_2^\mu$.

To make specific calculations, we adopt for convenience the covariant pseudo-thermal parametrization for the current elements[4], $j_0(pk/m) = \exp(-p^\mu k_\mu / (2mT))$, characterized by a effective “temperature” T . In this case the amplitude assumes the particularly simple form $G(k_1, k_2) = \langle \exp(iq_\mu x_a^\mu - K_\mu p_a^\mu / (mT)) \rangle$, where $K^\mu = \frac{1}{2}(k_1^\mu + k_2^\mu)$.

To include effects of long lived resonances in the semiclassical approximation, we note that the pion freeze-out coordinates, $(t_a, \mathbf{x}_a)$, are related to the resonance production coordinates, $(t_r, \mathbf{x}_r)$, by $\mathbf{x}_a = \mathbf{x}_r + \mathbf{v}_r(t_d - t_r)$, $t_a = t_d$, where $\mathbf{v}_r$ is the resonance velocity and t_d is the time of its decay. Averaging over the proper decay time of the resonance, of width Γ_r , leads to

$$G(k_1, k_2) \approx \langle \sum_r f_r \left(1 - \frac{iqp_r}{m_r \Gamma_r}\right)^{-1} \exp(iqx_r - Kp_r / (m_r T_r)) \rangle , \quad (6)$$

where f_r is the fraction of the final π^- ’s arising from the decay of a resonance of type r , and T_r is an effective temperature that characterizes the decay distribution of that resonance.

The ensemble average in (6) is evaluated by Monte Carlo sampling from the following non-ideal freeze-out distribution:

$$D(x, p) \propto \tau e^{-\tau^2/\tau_f^2} e^{-(\eta-y)^2/2\Delta\eta^2} e^{-(y-y^*)^2/2Y_c^2} e^{-r_\perp^2/R_\perp^2} . \quad (7)$$

A similar form was considered in Ref.[7], with $Y_c = \infty$ and with other parameters estimated using a hydrodynamic model assuming an initial quark-gluon plasma state. In that calculation resonances were not considered. In this work, we estimate the parameters of the freeze-out distribution and resonance fractions using the ATILA version[9] of the LUND Fritiof multi-string model and a string tension, $\kappa = 1$ GeV/fm, to map momentum space into coordinate space. For O+Au at 200 AGeV, we find that $Y_c \approx 1.4$, $y^* = 2.5$, $\Delta\eta \approx 0.7$, $\tau_f \approx 3$ fm/c and $R_\perp \approx 3$ fm. The fraction of π^- coming from various resonance species is found to be $f_\pi = 0.19$, $f_\rho = 0.40$, $f_\omega = 0.16$, and $f_{K^*} = 0.09$. The contribution from longer lived resonances is set to zero. The above estimates for the dynamical and geometrical parameters are, of course, highly model dependent. Our aim is only to test one of the conventional hadronic model that at least reproduces many of the global features of nuclear reactions at this energy range[9].

To compare with data on the transverse projected correlation function[1], $\langle C(q_\perp) \rangle$, we calculate the six dimensional integrals over external momenta (k_1, k_2) in both numerator and denominator by importance sampling. A good test of the method is provided by reproducing the calculated curves in Ref.[1] obtained with the ideal inside-outside cascade distribution, $D \propto \delta(\tau - \tau_f) \delta(\eta - y) \exp(-r_\perp^2/R_\perp^2)$. In Fig 1a and 1c, we show that our calculations employing the reported parameters[1], $\tau_f = 6.4$ fm/c, $R_\perp = 7.3$ fm and $\lambda = 0.84$ for π^- in the rapidity interval $2 < y < 3$ and $\tau_f = 2.5$ fm/c, $R_\perp = 4.0$ fm and $\lambda = 0.30$ in the interval $1 < y < 2$, do in fact provide a good fit to the data (which have been corrected for the Coulomb Gamov factor). In both cases we adopted the temperature $T = 0.13$ GeV, as in the experimental analysis.

Next, we show in Figs 1b,1d, the calculated curves for the case of non-ideal dynamics including resonances. For these calculations we chose $\Delta\eta = 0.8$ and $\tau_f = R_\perp = 4$ fm to take into account possible final state cascading. In both Fig. 1b and 1d the chaoticity parameter is fixed to $\lambda = 1$, as appropriate for completely chaotic sources. It is clear that the calculated curves reproduce qualitatively the apparent intercept at $q_\perp = 0$ as well as the scale of fall-off. Given the present statistics, it would be difficult to exclude either set of parameters at this time. The “exotic” parameters obtained by fitting the ideal K-G formula[4] to the data in Figs 1a and 1c are less compelling, however, since it would be truly remarkable if the degree of coherence in such violent nuclear collisions were not negligible. Note that in Fig 1c the ideal Bjorken dynamics with $\lambda = 1$ in fact fails to reproduce the data.

A final calculation that we report is one taking the freeze-out distribution parameters from the quark-gluon plasma evolution model of Ref.[7], for which $\tau_f = 9.0$ fm/c, $R_\perp = 3.3$ fm, $Y_c = \infty$ but with no resonances. We found the remarkable result (in contrast to the results of Ref.[7]) that correlation function with these parameters also fits the data! The curves differ by less than 10% from those in Fig.1b,1d.

Therefore, we have shown that at least three very different sets of dynamical and geometrical parameters are consistent with the present transverse projected correlation

function of NA35. We emphasize, however, that the “conservative” set suggested by the LUND string fragmentation model is also consistent. The most important new elements in our calculation were the inclusion of long lived resonances and non-ideal dynamical effects through $Y_c, \Delta\eta, \Delta\tau$. As the data become more precise it will be useful to perform a multi-parameter search of higher dimensional projected correlations to narrow the range of acceptable parameters. Further details of these calculation will be published elsewhere[10] and comparison of this formalism to the Wigner one[3] is discussed in [11].

As a final note we accept G. Bertsch’s challenge (these proceedings) to find an alternate explanation for the different transverse radii reported by T. Humanic for “outward” and “sideward” directions. As suggested by S. Pratt[3] a substantially larger transverse radius outwards could be a signature of a long lived mixed phase. However, we find[10] that with the inclusion of long lived resonances, $\omega, \eta, \dots$, the “outward” and “sideward” transverse projected correlation functions are again very similar with both our hadronic transport set and the quark-gluon plasma set of Ref.[7].

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References

- [1] A. Bamberger, et al. (NA35 collab.) Phys. Lett. B203 (1988) 320.
- [2] W. A. Zajc, Nevis Preprint R1384 (1987), to appear in Hadronic Multiparticle Production, World Scientific Press, P. Carruthers, ed. (1988).
- [3] S. Pratt, Phys. Rev. D33 (1986) 1314.
- [4] K. Kolehmainen, M. Gyulassy, Phys. Lett. 180B (1986) 203; M. Gyulassy, et al., Phys. Rev. C20 (1979) 2267.
- [5] Y. Hama, S. S. Padula, Phys. Rev. D37 (1988) 3237.
- [6] A. N. Makhlin, Yu. M. Sinyukov, Z. Phys. C39 (1988) 69.
- [7] G. Bertsch, M. Gong, M. Tohyama, Phys. Rev. C37 (1988) 1896.
- [8] P. Grassberger, Nucl. Phys. B120 (1977) 231.
- [9] M. Gyulassy, CERN-TH.4794 (1987) preprint; B. Andersson, et al., Nucl. Phys. B281 (1987) 289.
- [10] M. Gyulassy, S. S. Padula, LBL-26077 (1988) preprint.
- [11] S. S. Padula, M. Gyulassy, S. Gavin, LBL-24674 (1988) preprint.

Figure 1:
Comparison of the transverse projected $\pi^-\pi^-$ correlation data of NA35[1] with calculations employing the current ensemble formalism with eqs.(4,6). The histograms in parts (a) and (c) are calculated assuming the ideal Bjorken scaling model[4] for the freeze-out distribution and neglecting resonances. Those curves reproduce the fits reported in Ref.[1]. The histograms in (b) and (d) are calculated, on the other hand, using the non-ideal distribution,(7), with parameters suggested by the ATTILA version of the LUND Fritiof model[9]. Parts (a) and (b) refer to the central rapidity region, $2 < y_\pi < 3$, and parts (c) and (d) refer to the region $1 < y_\pi < 2$.

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