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MULTI-PION PRODUCTION

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Abstract

Preliminary analysis of pion production in 1.2 GeV/nucleon Kr-RbBr collisions is presented. The negative pion multiplicity is consistent with a convolution of Poisson distributions and a freeze-out density between 1/3 and 1/2 normal nuclear density is extracted. Global negative pion kinematic variables are used to search for possible structure in the multi-pion emission. No evidence for structured emission or conservation constraints is found. Pion interferometry analysis gives a source radius of 5.4±1.2 Fermi and a freeze-out density of .3±.2 times normal nuclear density.

An unresolved problem for phenomenological models is the lack of an adequate description of the observed pion production in relativistic heavy ion collisions. Recent interpretation[1] of the difference between data and the models[2] has led to some interesting and controversial conclusions. In addition, the differences between various models suggest more refinement is required before physical conclusions can be drawn from such comparisons. The measurement of pion production in heavier nuclear systems will provide the necessary information to develop a more adequate description of the

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pion production mechanism. We present preliminary data for multi-negative pion production for the mass symmetric collisions of 1.2 GeV/nucleon Kr on RbBr. The preliminary nature of the data and statistics (approx. 40% of data sample) precludes any detailed comparisons with models at present. Instead, we will address two features of the multi-negative pion production:

1) The negative pion multiplicity and the extraction of a freeze-out density,
2) the types of pion correlations present in the data.

The data were obtained using the LBL streamer chamber at the Bevalac[3]. The 1.2 GeV/nucleon Kr beam was focused on a 0.65 g/cm^2 RbBr target located in the fiducial volume of the streamer chamber. The chamber was triggered to accept all but the most peripheral interactions, selecting 85% of the reaction cross section. Geometrically, this would correspond to accepting all interactions with an impact parameter of 9.8 Fermi or less. The average observed charged particle multiplicity is 37. The charged particle multiplicity distribution is shown in Fig. 1. The extension of the distribution beyond the total nuclear disintegration limit of 71 is due to the charged pion production. The suppression of the low multiplicity events by the trigger is clearly evident.

The average observed negative pion multiplicity is 2.9. The negative pion multiplicity distribution is shown in Fig. 2. The distribution decreases monotonically with an approximately exponential behavior at large N_{π^-}. The flattening at small negative pion multiplicities is a result of the trigger bias. The overall shape of the distribution is the result of the averaging over impact parameters.

In thermal models the pion multiplicity distribution is sensitive to the freeze-out density. To discuss this sensitivity, we will use the effective one-pion fireball model of M. Gyulassy and S. K. Kauffmann[4], which assumes both thermal and chemical equilibrium. The pion production ceases when the system expands to a critical freeze-out density. The results derived from a critical freeze-out density of 1/3 ρ_0 (solid curve) and 1/2 ρ_0 (dashed curve) where ρ_0 is the normal nuclear density, are shown in Fig. 2. The trigger selection has been imposed and the estimated negative pion detection efficiency of 90% has been included in the calculations. The observed pion multiplicity distribution can be well described by a freezeout density between 1/3 and 1/2 ρ_0, giving an optimum value of $\rho_c = (.38\pm.04)\ \rho_0$. The results demonstrate that the slope of the N_{π^-} distribution at large N_{π^-} is sensitive to the freezeout density. The freezeout density can be extracted by using the average of the N_{π^-} distribution; however, the average is more sensitive to the details of the trigger selection process than the slope of the N_{π^-} distribution at large N_{π^-}.

The results demonstrate that the observed distribution is consistent with being a convolution of Poisson distributions. This expectation is based on very general principles and the assumption that emission of sequential pions is independent and occurs under identical conditions.[4] Additional parameters such as the percentage of center of mass energy availiable for thermalization can be introduced. The analysis of the N_{π^-} distribution can then be augmented with fitting the observed temperature to determine the additional parameters. More detailed models allowing for separate determination of chemical and thermal freezeout densities can be applied as recently done by J. W. Harris et al.[5] The negative pion distribution provides a statistically sensitive measure of the freezeout densities within the framework of the various models.

We also test whether there are multi-pion correlations in the data. The negative pions have been measured in a sample of 2500 events with $N_{\pi^-} \geq 1$. In looking for multi-negative pion correlations, we restrict ourselves to the subsample of 2000 events with $N_{\pi^-} \geq 2$. For this subsample, the average negative pion multiplicity is 4.4 and the average charged particle multiplicity is 49. This subsample is weighted more to central collisions than the overall data sample.

We will first investigate if there are detectable correlations in global pion variables. Possible correlations between the orientation of the event plane and structure in the pion emission could result from the absorption of pions by spectator nucleon matter or collective flow. The sensitivity to possible correlations will depend on the variables chosen. In this analysis we use the transverse pion source velocity

$$\beta_\perp = \sum_{i=1}^{N_{\pi^-}} \vec{P}_{\perp i} \Big/ \sum_{i=1}^{N_{\pi^-}} E_i$$

and the longitudinal pion source velocity

$$\beta_\parallel = \sum_{i=1}^{N_{\pi^-}} \vec{P}_{\parallel i} \Big/ \sum_{i=1}^{N_{\pi^-}} E_i \quad .$$

The two velocity distributions are shown in Fig. 3a, b. To determine if this distribution is the result of structured pion emission, it is necessary to compare with background events which have no inherent correlations present.

The background events are generated by randomly choosing m negative pions from m different events to create a "statistical" event of negative pion multiplicity m. Background events have been generated to produce the same multiplicity distribution as the data. Generation of the background in this manner has the advantages of producing the correct inclusive distributions convoluted with the detection efficiency, and is model independent. In addition to removing possible correlations, any effects of momentum and energy constraints on these global distributions is also removed. The solid curve in Fig. 3a,b is the distribution of the source velocity obtained from the background events. The data and the "statistical" events are in good agreement. We conclude that the momentum and energy conservation constraints do not effect the N_{π^-} phase space. We also conclude that there are no strong correlations, or structure, in the pion emission. We have subdivided the data sample into multiplicity subgroups $2 \leq N_{\pi^-} \leq 5$ and $6 \leq N_{\pi^-} \leq 10$ and find the conclusions unchanged.

The symmetrization of the like-boson wavefunction causes an enhancement in the multipion cross section. For two radiated negative pions, this enhancement can be measured and the pion source dimensions, lifetime and degree of coherence can be extracted using the technique of pion interferometry. For a Gaussian space-time source, this enhancement can be represented as[6]

$$C(q,q_0) = K[1 + \lambda \exp(-\vec{q}^{\,2}R^2/2 - q_0^2\tau^2/2)] \quad ,$$

where R is the source radius, τ the lifetime, q and q_0 are the relative momentum and energy in the center of mass, λ is a measure of the degree of coherence (or intercept parameter) and K is a normalization parameter. The function $C(q,q_0)$ is the ratio of correlated two π^- cross section to the two π^- cross section containing all phase space constraints and correlations except those caused by the Bose-Einstein symmetrization. As already discussed, there is no evidence of any strong dynamical correlations or phase space constraints and therefore $C(q,q_0)$ is the ratio of the two π^- cross section to the square of the single π^- cross section.

The analysis is performed on the 2000 events with $N_{\pi^-}>2$. A momentum cut of $P_{LAB}>75$ MeV/c is imposed to reduce electron contamination and multiple scattering. There are a total of 15000 correlated pion pairs using all possible pairs within an event. The combinatorics of generating these pairs causes the interferometry analysis to be heavily weighted towards high multiplicity events , i.e., central collisions. The average negative pion multiplicity is 7.4 and the average charged particle multiplicity is 66 when weighted by the number of pion pairs.

The sensitivity of the analysis is controlled by the pair density $d^2n/(dqdq_0)$ and is discussed in the literature.[7,8] Our data analysis is most sensitive to the radius and less sensitive to the lifetime. The correlation function $C(q,q_0)$ and the fit have been integrated over the relative energy and displayed in Fig. 4. The fitted source parameters are

$$R = (5.4\pm1.2)\text{fm},$$

$$\tau = (3.+7-3)\text{fm/c},$$

and $$\lambda = .8\pm.3.$$

The intercept parameter is consistent with the value $\lambda=1$ expected for a totally chaotic source. The intercept parameter is the only parameter which is sensitive to the correction for the π^--π^- Coulomb repulsion by a

Gamow factor. A value of $\lambda = .6$ is obtained without the Gamow correction.

The pion source radius can be used to extract a measure of the pion freeze-out density. The Gaussian radius of 5.4 Fermi can be converted to a sphere of uniform density with a radius of 8.4 Fermi. We estimate the mean number of participant nucleons weighted by the pion pairs to be 110. A pion freezeout density of $(.3\pm.2)\rho_0$ is obtained. Figure 5 shows the freeze-out densities for four data samples as a function of the mean number of participant nucleons. The data are consistent with a constant value of the freeze-out density of $(.3)\rho_0$ and therefore a scaling of the source radius with the cube root of the number of nucleons.[8] This value of the freeze-out density is also consistent with the value H. A. Gustafsson et al. have reported[9] for proton- proton correlations. We note that the sensitivity to freezeout densities is approximately five times better when extracted from the negative pion multiplicity distribution then when inferred through π^- interferometry. It might be expected that the negative pion distribution is determined by the density when chemical equilibrium[5] occurs, while the pion interferometry measures the density when both inelastic and elastic scattering processes cease. It does appear that the data is consistent with this hypothesis but any conclusive interpretation must await more statistics and a more complete analysis.

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Figure Captions

1. The number of events/bin as a function of the charged particle multiplicity.

2. The number of events/bin as a function of the negative pion multiplicity.

3. The events/bin as a function of the a) transverse pion source velocity and b) the longitudinal pion source velocity. The data points (error bars) and the results of the background events (solid curve) are shown.

4. The correlation function $C(q,q_o)$ and the fit are summed over the relative energy and displayed as a function of the relative momentum, q.

5. The freeze-out density from the interferometry analysis for 1.2 (circle) and 1.5 (square) GeV/nucleon Ar-KCl (ref. 7), 1.8 (triangle) GeV/nucleon Ar-Pb (ref. 10), and 1.2 (diamond) GeV/nucleon Kr-RbBr. The densities are shown as a function of the mean number of participant nucleons, where the multiplicities have been weighted in proportion to the number of pion pairs in the interferometry analysis.

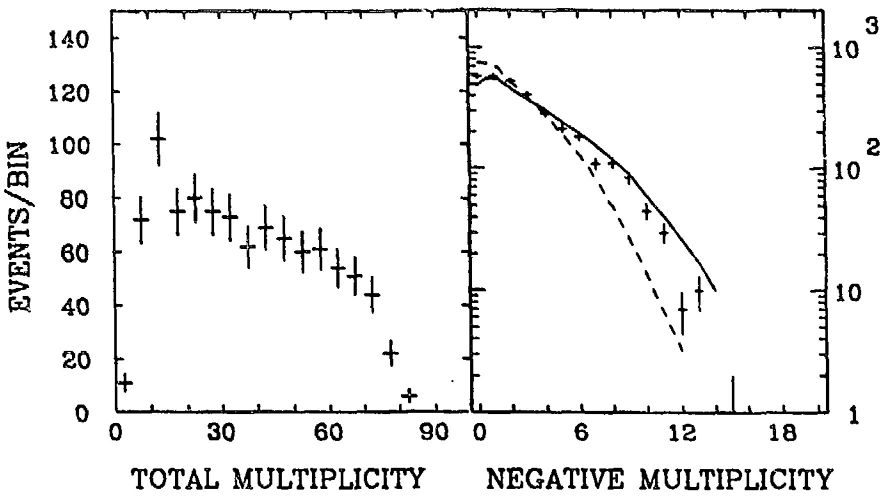

FIG. 1

FIG. 2

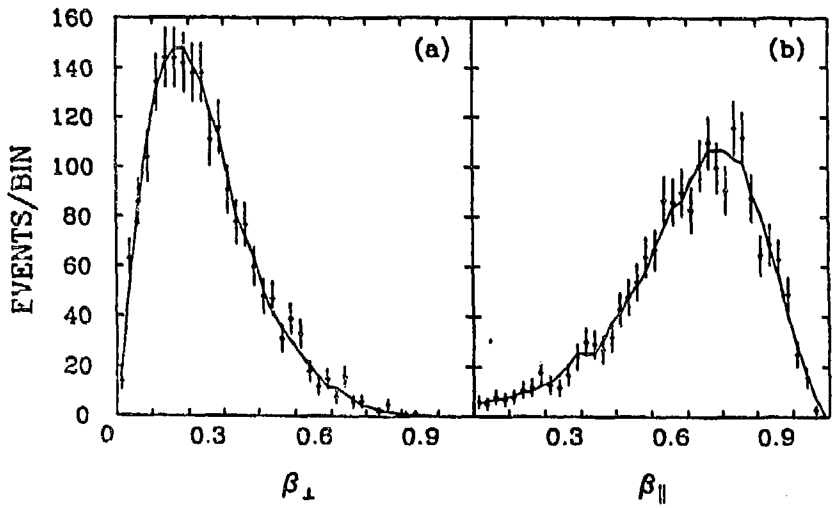

FIG. 3

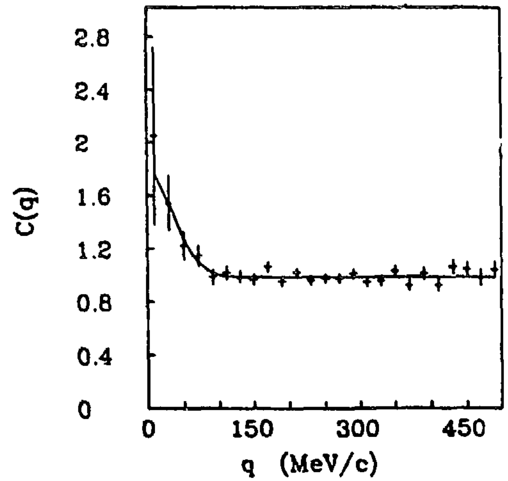

FIG. 4

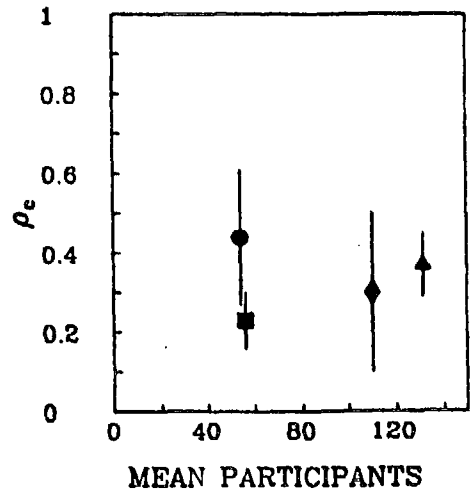

FIG. 5