Excited pre-fragments

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It is shown that the residual nuclei or prefragments which decay into two detectable fragments and which are observed in inelastic interactions of neon-22 nuclei with emulsion nuclei at a momentum of 4.1*A* GeV/*c* are excited.

1. In the fragmentation of relativistic nuclei, the fragments observed experimentally may be decay products of residual nuclei, i.e., of prefragments.[1-3]

Essentially no experimental information is available on the properties of prefragments. An attempt was made in Ref. 4 to study their properties at a model level. The basic result reached there is that the transverse momenta of the fragments in the rest frame of the prefragment is smaller by a factor of 1.5 to 2.5 than the transverse momenta observed in the laboratory frame. This is a model-dependent conclusion. Experimental data were used in Ref. 5 to go over to a so-called symmetric system in the laboratory transverse frame, which is not the same as the transverse plane of the frame of the prefragment. The results found there agreed with those of Ref. 4. The reason for this agreement is that the transformations in Refs. 4 and 5 are inverses of each other. Specifically, in Ref. 4 a part of the random transverse momentum of the residual fragmenting nucleus—a part proportional to the mass of the fragment—was added vectorially to the transverse momenta of the fragments in the rest frame of this fragmenting nucleus. In Ref. 5, on the other hand, this part of the transverse random momentum was subtracted from the observed transverse momentum of each fragment in such a way that the resultant transverse momentum of all fragments in the event is zero. It was shown in Ref. 6 that the distributions of the quantity $X=P_{\perp\,\mathrm{expt}}/P_{\perp\,\mathrm{symm}}$ calculated by the procedure of Ref. 5 for the experimental data (neon-22, 4.1*A* GeV/*c* in the emulsion) and for a model of an independent emission of fragments are qualitatively the same (Fig. 1).

2. In this letter we propose a new method for estimating the transverse momenta of the fragments in the c.m. frame of the prefragment, on the basis of quantities observable experimentally, without the use of a symmetric system. We immediately state that this letter is restricted to prefragments which decay into only two fragments.

The transformation from observable quantities to the transverse momenta of the fragments in the proper frame of the two fragments is made through the transverse part of the invariant mass of the two particles:

$$M_{12\perp}^2=m_v^2(A_1+A_2)^2+4A_1A_2P_0\sin^2(\theta_{12}/2). \qquad (1)$$

Here A_1 and A_2 are the mass numbers of fragments 1 and 2, P_0 is the momentum per nucleon of the projectile particle, $m_v=0.931$ is the mass unit, and θ_{12} is the angle

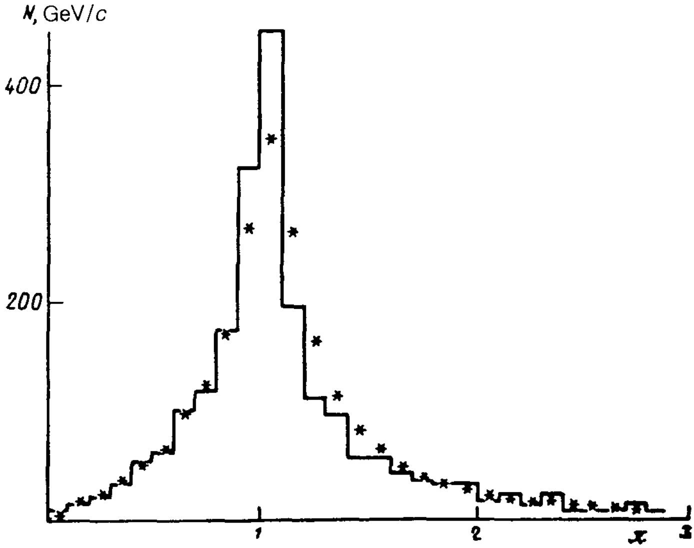

FIG. 1. Distribution of the quantity $X = P_{\perp\,\mathrm{expt}}/P_{\perp\,\mathrm{symm}}$ for protons. The historgram is experimental; the asterisks represent the independent-emission model.

between the tracks of fragments 1 and 2 in the emulsion. We are assuming the mass of the fragment to be $m_v A$, and its momentum $P_0 A$. The latter assertion means that the longitudinal components of the momenta are the same for all fragments. Accordingly, the fragments are in motion with respect to each other only in the direction perpendicular to the direction in which the c.m. frame is moving, or in the transverse plane of the c.m. frame, which is not the same as the transverse plane of the laboratory system. The total invariant mass of the two fragments consists of the sum of the rest masses of the fragments and the sum of their kinetic energies in the transverse plane of their c.m. frame; it is equal to (1). The transverse momentum in the c.m. frame of the two fragments is now

$$P_\perp^* = P_0 \sin(\theta_{12}/2)\left[A_1 A_2\left(1 - \frac{m_v^2(A_1 - A_2)^2}{M_{12\perp}^2}\right)\right]^{1/2}. \tag{2}$$

For particles of equal mass, e.g., in the dissociation of ^{6}Li into ^{3}H and ^{3}He, we have

$$P_\perp^* = P_0 \sin(\theta_{12}/2). \tag{3}$$

Since the transverse momentum observed in the lab frame for the fragment is $P_\perp = AP_0 \sin\theta$ (θ is the polar angle at which the fragment is emitted; it has a Rayleigh distribution[6]), we find the following estimate of the constant of this distribution by the maximum-likelihood method:

$$S = [(A^2 P_0^2/2)\overline{\sin^2\theta}]^{1/2}, \tag{4}$$

where we have

$$\sin^2\theta=\left(\sum_{i=1}^{N}\sin\theta_i\right)/N$$

for all N fragments observed in the experiment. The quantity in (4) is proportional to the average observed transverse momentum of the fragments, $\langle P_\perp\rangle$, only within a relative error half that for the $\langle P_\perp\rangle$ calculated directly. If we assume that $P_\perp^*$ also has a Rayleigh distribution, we find

$$\langle P_\perp\rangle/\langle P_\perp^*\rangle=[\overline{\sin^2\theta}/\overline{\sin^2(\theta_{12}/2)}]^{1/2}. \quad (5)$$

For independent emission of the particles in the lab frame we find, within the approximations $1+\cos\theta\simeq 2$, $\sin\theta\simeq\theta$ (small angles),

$$\langle P_\perp\rangle/\langle P_\perp^*\rangle\simeq 2^{1/2}. \quad (6)$$

3. To test relation (6), we selected 1004 events containing only two fragments from an experimental set of inelastic interactions of neon-22 nuclei with emulsion nuclei at a momentum of 4.1 GeV/c. In the experiment, the angles θ and ψ (ψ is the azimuthal emission angle of the fragment) and the charge of the fragment, Z,were measured. For particles with $Z=1$, the momentum was determined on the basis of multiple scattering. It thus became possible to separate the hydrogen isotopes. The mass numbers of the fragments with $Z\geqslant 2$ were taken to be $A=2Z$. This information was sufficient to find the ratio $\langle P_\perp\rangle/\langle P_\perp^*\rangle$ in the experiment.

For each observed event we immediately worked from the values of A_1 and A_2 to generate the event by the Monte Carlo method. The constant of the Rayleigh distribution for the fragment with mass number A was calculated from the parabolic law

$$S=S_0\{[A(22-A)]/21\}^{1/2} \quad (7)$$

with a constant $S_0=105$ MeV/c (Ref. 6). The projections of the transverse momentum of the fragment onto two mutually perpendicular and otherwise arbitrary directions Y and Z in the transverse plane are

$$P_{\perp\,Y}=AP_{0\,\sin}\varphi,\quad P_{\perp\,Z}=AP_0\sin\alpha, \quad (8)$$

where φ and α are the angles between the X axis, along which the vector P_0 is directed, and the projection of the total momentum of the fragment onto the XY and XZ planes. Both quantities in (8) had normal distributions with a zero mean and a variance S^2. A random number R from this distribution thus determines a random value: $\sin\varphi=R/(AP_0)$ and $\sin\alpha=R/(AP_0)$. From the angles φ and α we find an estimate of $\langle P_\perp\rangle/\langle P_\perp^*\rangle$ for a random and independent emission of the fragments in the laboratory frame.

4. This Monte Carlo calculation yielded a value of 1.461 ± 0.003 for the ratio $\langle P_\perp\rangle/\langle P_\perp^*\rangle$. If the difference between this value and that in (6) is assumed to be significant, it must be attributed to the approximate estimate of the expected value itself. Experimentally, this ratio is 1.32 ± 0.01, much smaller than both the prediction and the Monte Carlo estimate. Consequently, the experimental value $\langle P_\perp^*\rangle = 0.197\pm 0.006$ GeV/c is larger than for the expected value of this quantity for an independent dispersion of fragments (0.150 ± 0.003 GeV/c), and the experimental transverse part of the invariant mass of the two fragments is larger than for an

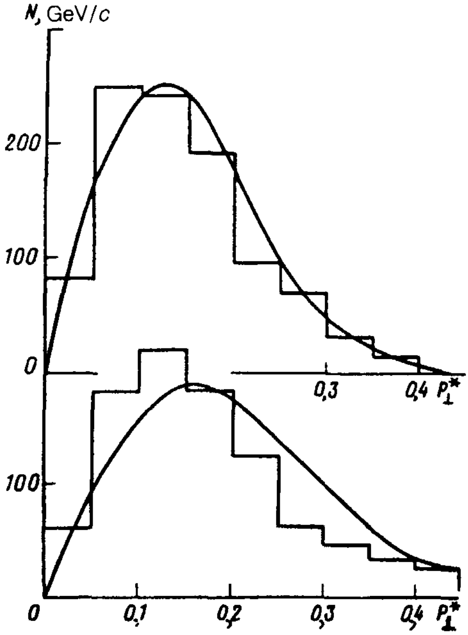

FIG. 2. Transverse momentum distribution in the c.m. frame of the two fragments. The lower histogram is experimental, the upper one a Monte Carlo calculation. The smooth curves are the expected Rayleigh distribution.

independent emission of fragments. This circumstance might be viewed as an indication that the prefragments which decay into two fragments in our experiment were excited.

Figure 2 shows separately distributions of $P_\perp^*$ for the experiment and for the Monte Carlo calculation. We see the qualitative agreement with a Rayleigh distribution (the smooth curve) which was expected.

The accuracy of the estimate of $P_\perp^*$ is determined primarily by the accuracy of the measurement of θ_{12}, the angle between the particles. In the present study this angle was calculated from the angles θ and ψ, but it could also be measured directly in an experiment. We will carry out such measurements in a study of the fragmentation of relativistic ^{6}Li nuclei.

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