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SECONDARY FRAGMENTS OF RELATIVISTIC ^{22}Ne AT 4.1 $A \cdot$ GeV/c NUCLEI IN NUCLEAR EMULSION

O. V. Levitskaya, F. G. Lepekhin

St. Petersburg Nuclear Physics Institute, Russian Academy of Sciences, Gatchina, Russia

By using emulsion detector irradiated by relativistic ^{22}Ne at 4.1 $A \cdot$ GeV/c as «production target» to produce projectile fragments (PFs), their properties have been investigated using the same detector as «break-up target» for these «primary» PFs. The transverse momentum distribution for «secondary» fragments originated from PFs was found to obey the Rayleigh distribution with the constant (113 ± 5) MeV/c. The Ψ_Q value, the secondary fragment azimuthal angle with respect to the reaction plane Q, was found to be uniformly distributed in $(0 - \pi)$ interval. The coefficient of azimuthal asymmetry is $A = -0.05 \pm 0.15$ and the second Fourier coefficient for $f(\Psi_Q)$, two-particle density function, is $\langle \cos 2\varepsilon_Q \rangle = (2.5 \pm 1.6) \cdot 10^{-3}$.

Свойства первичных фрагментов, полученных при фрагментации релятивистского ядра ^{22}Ne с импульсом 4,1 ГэВ/с на ядрах в фотоэмульсии, были изучены с использованием неупругих взаимодействий этих ядер-фрагментов с ядрами в той же самой фотоэмульсионной камере. Поперечные импульсы вторичных фрагментов, продуктов фрагментации первичных ядерных фрагментов, подчиняются распределению Рэлея с константой (113 ± 5) МэВ/с. Азимутальные углы вторичных фрагментов Ψ_Q с истинной плоскостью реакции Q распределены равномерно. Коэффициент азимутальной асимметрии — $A = -0,05 \pm 0,15$, а второй коэффициент разложения в ряд Фурье $f(\Psi_Q)$, экспериментальной двухчастичной функции плотности распределения, — $\langle \cos 2\varepsilon_Q \rangle = (2,5 \pm 1,6) \cdot 10^{-3}$.

INTRODUCTION

The transverse momenta of projectile fragments (PFs), $P_{\perp}$, as well as PF yields, are considered to be informative for understanding the projectile fragmentation mechanism [1, 2]. Being the Lorentz-invariant in the laboratory system and in the projectile rest frame, the observed PF transverse momenta represent the internal properties of this projectile nucleus, and their inclusive distributions are completely determined by nucleon Fermi momentum for this nucleus.

By using the rich experimental data it was concluded that the projectile disintegration can be described basically as a fast and cold process governed by the distribution of nucleon momenta in the projectile before collision [3], so the hypothesis of limiting fragmentation is a very good approximation for the energy region up to 160 $A \cdot$ GeV for nuclei from lithium to lead [4, 5].

Nevertheless, the properties of PFs nuclei are not investigated thoroughly. The suggestions and the first data about anomalously short interaction mean free path (MFP) for some PFs at the first few centimeters after their emission compared with interaction mean free path of primary ion beams with the same charges and masses have not been confirmed [6].

In experiments during last ten years the cluster structure of light neutron-rich nuclei has been observed by using the secondary relativistic ion beams [7]. In these experiments the time interval between the emission of such PFs after projectile interaction with «production target» and their subsequent interaction with «break-up» target is determined by the secondary beam track length and is equal approximately to $10^{-7} \div 10^{-8}$ s.

However, the emulsion chamber, being the «production target» as well as the «break-up target» at the same time, allows us to study the properties of primary projectile fragments in $\Delta t = 2 \cdot 10^{-12} \div 4 \cdot 10^{-10}$ s after their production.

Even if in high-energy heavy-ion collisions the dense and hot phase of nuclear matter can really be formed [8], as the system expands and cools down, it will hadronize and produce nuclear fragments again.

As both these processes together take time $\sim \hbar/mc^2$, the abnormal phase does not differ from the quantum fluctuations of strong interactions and cannot really be observed. That is why the value of transition time from dense and hot phase to the normal one is of great significance.

To study the properties of PFs in the shortest time intervals after their originating from initial projectile is the main goal of this experiment.

As is shown in [9], the transverse momenta of PFs of ^{32}S nuclei at 4.1 GeV/c/nucleon momentum are correlated with respect to the reaction plane Q. But the real reaction plane was unknown and was determined for every particle in event. In our experiment the reaction plane, containing the initial ^{22}Ne projectile momentum and projectile fragment transverse momentum, is really known. The azimuthal angles of secondary fragments with respect to this plane can really be determined.

EXPERIMENT

Stacks of NIKFI BR-2 nuclear photoemulsion have been irradiated horizontally by ^{22}Ne at 4.1 $A \cdot$GeV/c momentum at the Dubna Synchrophasotron. We dealt with a part of the emulsion chamber (4 stacks) 20×10 cm and 600 micron thickness. The search of inelastic interactions of ^{22}Ne nuclei with nuclei in emulsion was carried out along the beam. The projectile fragments with charges $Z \geq 3$ were traced downstream the first event vertex within $\theta = 3^\circ$ interval up to their subsequent inelastic interaction with nucleus in emulsion, and the distances between two vertexes have been measured.

In 163 secondary inelastic interactions of PFs with nuclei in emulsion 255 secondary fragments with charges $Z \geq 2$ have been observed. For every event the charge of primary PF, Z_1, and the charges of secondary fragments, Z_2, were determined by measuring the δ-electron density. The angles φ_1 of primary PFs momentum projection onto emulsion plane with respect to the momentum direction of ^{22}Ne nucleus and their dip-component angles α_1 have also been measured, as well as the corresponding angles φ_2 and α_2 for secondary fragments with respect to primary PF momentum direction.

Assuming the mass of fragment to be $A = 2Z$ and its longitudinal momentum $P_x = AP_0$, the experimental distribution of values $P_y = \mathrm{tg}\,\varphi_2\, K$ for secondary fragments has to obey the Gaussian distribution with zero average and dispersion σ^2_{exp} [10, 11]. Here, P_0 is the momentum per nucleon for ^{22}Ne projectile,

$$K = P_0 \sqrt{\frac{Z_2(2Z_1 - 1)}{(Z_1 - Z_2)}}.$$

The dispersion $\sigma^2_{\rm exp}$ is close to σ^2_0, the dispersion of the projection of nucleon momentum for the primary projectile fragment nucleus onto any direction in its rest frame. This dispersion value is determined by the Fermi momentum for these projectile fragment nuclei as $\sigma^2_0 = P^2_F/5$ and is approximately the same for all these light nuclei [12]. That is why all the secondary fragments can be combined to obtain the single distribution of P_y value.

The distribution of the value

$$P_\perp = K\sqrt{\mathrm{tg}^2\,\varphi_2 + \mathrm{tg}^2\,\alpha_2}$$

for secondary fragments has to obey the Rayleigh distribution (or χ_2 distribution):

$$f(P_\perp) = \frac{P_\perp}{\sigma^2_{\rm exp}} \exp\left(-\frac{P^2_\perp}{2\sigma^2_{\rm exp}}\right),$$

with the constant $\sigma^2_{\rm exp}$ equal to the dispersion of the normal distribution for P_y values.

The statistical tests (ω^2, Kolmogorov) confirm the hypotheses of the normal distribution for the value P_y with the constant $\sigma_{\rm exp} = (105 \pm 7)$ MeV/c and of Rayleigh distribution for the value $P_\perp$ with the constant $\sigma_{\rm exp} = (113 \pm 7)$ MeV/c (see Fig. 1).

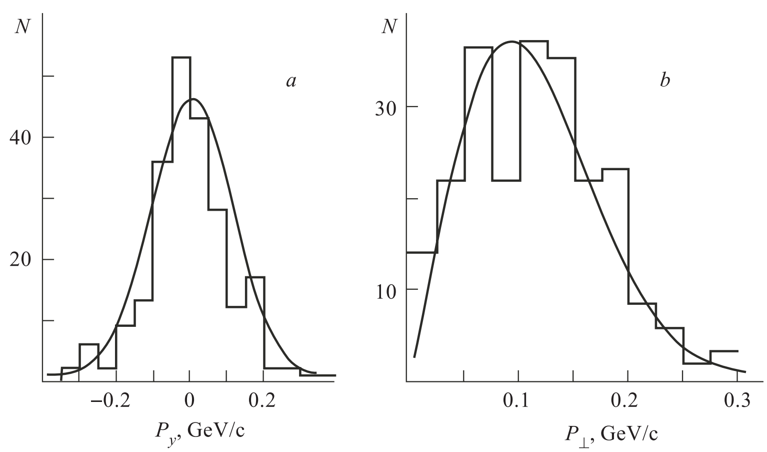

Fig. 1. Experimental distribution of the values P_y (*a*) and $P_\perp$ (*b*) for the secondary fragments (histograms). The smooth curves correspond to the Gaussian distribution with the constant $\sigma_{\rm exp} = 105$ MeV/c (*a*) and to the expected Rayleigh distribution with the constant $\sigma_{\rm exp} = 113$ MeV/c (*b*)

The particle correlations in the transverse plane are described by two Fourier coefficients for the two-particle density function [13–15]:

$$f(\Psi_Q) = 1/\pi(1 + A\cos\Psi_Q + \nu_2\cos 2\Psi_Q).$$

The estimates of both these values for secondary fragments agree with the zero values: $A = -0.05 \pm 0.065$, $\nu_2 = (-2.5 \pm 1.6) \cdot 10^{-3}$.

The distribution of Ψ_Q, the azimuthal angles for secondary fragments with respect to reaction plane Q, coincides with the uniform one (see Fig. 2).

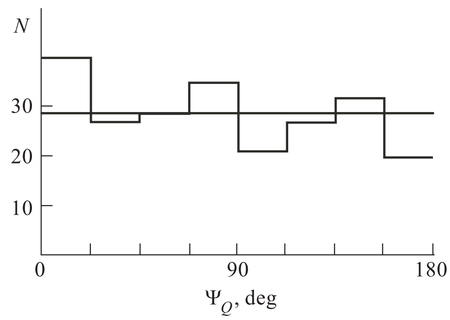

Fig. 2. Experimental distribution of Ψ_Q, the azimuthal angles of secondary fragments with respect to the reaction plane Q containing initial ^{22}Ne projectile momentum and transverse momentum of its primary fragment (histogram). The straight line corresponds to the uniform distribution

The time intervals between production of such projectile fragment nuclei and their subsequent interaction with nuclei in emulsion were found to be $2 \cdot 10^{-12} \div 4 \cdot 10^{-10}$ s.

CONCLUSIONS

It is concluded that the properties of PFs originated from ^{22}Ne at 4.1 $A \cdot$GeV/c (which basically represent the nuclei with charges $5 \div 9$) do not differ from the properties of the stable isotopes.

The constant $\sigma_{\rm exp} = (105 \pm 7)$ MeV/c obtained from the distribution of P_y transverse momentum projection for secondary fragments, emitted from such PFs, coincides with the value obtained from Fermi momentum for ^{22}Ne nucleus.

As is determined, the transition time of nuclear matter (if it ever had been compressed) to the normal phase is less than $2 \cdot 10^{-12} \div 4 \cdot 10^{-10}$ s.

The azimuthal angles of secondary fragments with respect to the reaction plane Q, as well as the pair azimuthal angles, are distributed uniformly in the interval $[0, \pi]$. The coefficient of azimuthal asymmetry is $A = -0.05 \pm 0.15$.

Disintegration of projectile fragments may also be treated as a fast and cold process governed by the distribution of nucleon momenta in such nuclei before collision.

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