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PROTON AND TRITON MOMENTUM DISTRIBUTIONS FROM ^{4}He FRAGMENTATION AT RELATIVISTIC ENERGIES

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The differential cross sections of the $^{12}C(^4He,p)$ and $^{12}C(^4He,t)$ reactions with a fragment emission angle, θ, of $< 0.4°$ were measured by the magnetic spectrometer "ALPHA" installed at the Dubna synchrophasotron. The momenta of a beam of α-particles were 4.52 and 2.69 GeV/c/neucleon for the $(^4He,p)$and $(^4He,t)$ reactions, respectively. Preliminary data were reported earlier /1/.

The experimental set-up did not, in the main, differ from the one used for studying deuteron fragmentation /2/. The one-arm spectrometer was placed after the bending magnet M used to separate secondary particles from the primary beam. Thus, the measurements with a beam intensity of up to 10^{10} α-particles per pulse were allowed. The statistics was collected within the momentum intervals $|(p-p_i)/p| < 0.05$. The momentum p_i was selected by setting the current of the magnet M. The proton spectrum was obtained at a maximum α-beam momentum. For this momentum the bending force of the magnet M is insufficient to turn a high momentum part of the triton spectrum to the spectrometer. Thus, the $(^4He,t)$ reaction was investigated at a lower beam momentum for which a maximum triton momentum in the ^4He rest frame was reached. In some regions of the momentum p_i it was difficult to identify protons among other particles (d, t, ^3He, ^4He). The protons were reliably registered when the yield of other particles was smaller than 1000 times of the proton one (which is not the case in the momentum regions $p_i \simeq 0.5 p_{^4He}$ and $p_i \simeq 0,75 p_{^4He}$). Threshold gas Čerenkov counters and scintillation counters were used for particle identification.

This experiment allowed a measurement of the relative cross sections. The absolute cross sections were obtained by normalizing the $(^4He,^3He)$ cross section in the region of a fragmentation peak, measured in this experiment, to the absolute data obtained in our previous experiment /3/. A main contribution to the systematic error ($\simeq$ 20%) of the absolute normalization results from uncertainties of the ^3He emission angle (± 1 mrad). The uncertainties are caused by the magnetic field induced by the accelerator near the magnet M. The statistical error of normalization is evaluated to be about 4%. The absolute cross sections in the region of the fragmentation

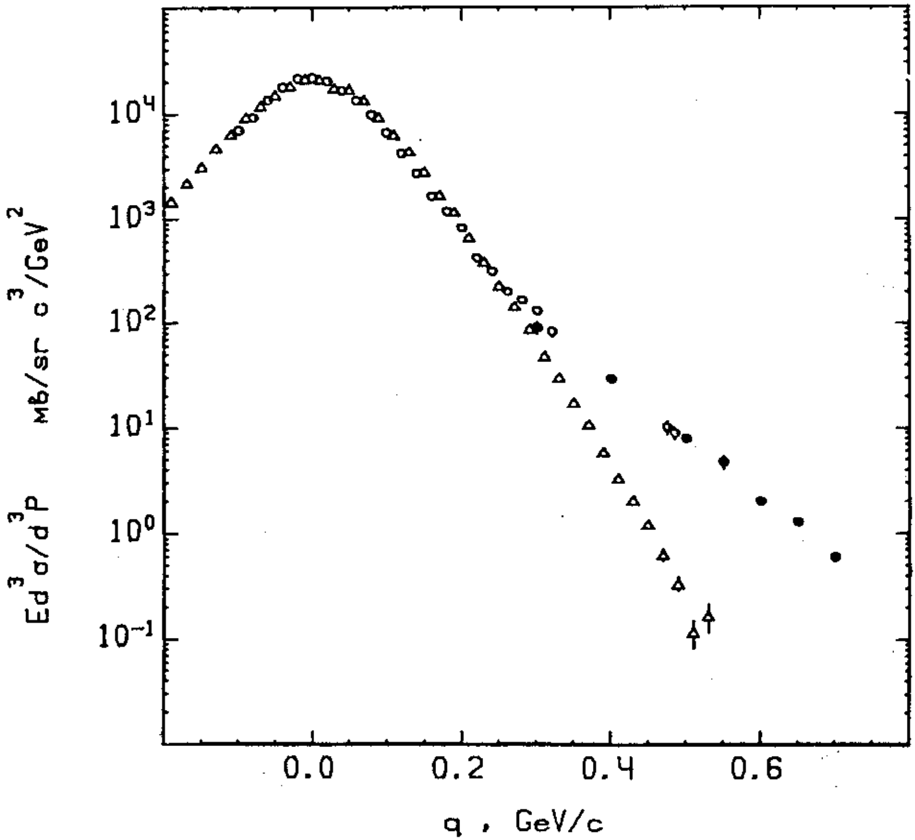

Fig.1. Invariant differential cross sections vs fragment momentum q in the ^{4}He rest frame for the $^{12}C(^4He,t)$ reaction (Δ - our data); the $^{12}C(^4He,p)$ reaction (o - our data) and the $^4He(p,p(180°))$ data[5] *(●) multiplied by factor 3. The error bars indicate statistical uncertainties only.*

peak for the $^{12}C(^4He,p)$ and $^{12}C(^4He,t)$ reactions are in good agreement with the data[4] obtained at an α-particle beam momentum of 1.75 GeV/c/nucleon for the corresponding reactions.

Figure 1 presents the invariant cross sections for the $^{12}C(^4He,p)$ and $^{12}C(^4He,t)$ reactions versus the fragment momentum q in the projectile rest frame along with the high momentum proton data[5] for the $^4He(p,p(180°))$ reaction (in the laboratory frame) at 8.6 GeV/c multiplied by factor 3.

This factor was estimated in the overlap region of both sets of data. This procedure is correct if the ^{4}He fragmentation cross sections on carbon and hydrogen are similar*.

A relativistic impulse approximation in the framework of the so-called light-cone dynamics will be used to analyse our data. Such an approximation was used in our previous paper /7/ in the case of ^{3}He fragmentation as well. The reason for such an approximation has been discussed elsewhere by us /8/ and other authors /9/.

By analogy with /10/, where the (^{3}He,d) cross section was obtained in the relativistic impulse approximation, the ^{4}He fragmentation cross section in the forward direction is connected with the momentum distribution $n_s(k)$ of the fragment s in ^{4}He as follows:

$$E\,\frac{d^3\sigma}{d^3q} = F\,C_f\,\frac{\epsilon_s\,\epsilon_f}{(1-\alpha_s)M_{sf}}\,n_s(k)\,. \tag{1}$$

In this approach $n_s(k)$ depends on the so-called "internal" momentum k: the momentum of the spectator s and the fragment-participant f in the (s+f) rest frame inside ^{4}He. This momentum differs (in the relativistic case) from the momentum q of the spectator s in the ^{4}He rest frame and is related to it by:

$$k^2 = \frac{\lambda(M_{sf}^2, m_s^2, m_f^2)}{4M_{sf}^2}, \quad M_{sf}^2 = \frac{m_s^2}{\alpha_s} + \frac{m_f^2}{1-\alpha_s}, \quad \alpha_s = \frac{E + q_{\parallel}}{m_{^4He}}, \tag{2}$$

$$\lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 3ac - 2bc\,.$$

Here M_{sf} is the effective mass of the (s+f) system and α_s is the part of the momentum carried away by the spectator in the longitudinal direction in the infinite-momentum frame. The quantites E and $q_{\parallel}$ are the energy and longitudinal momentum of the spectator in the ^{4}He rest frame, m_s is the spectator

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We have shown /6/ that such similarity takes place for A(d,p) reactions at q >100 MeV/c. The ratio of the cross sections for this reaction on carbon and hydrogen is 2.7 ± 0.3 which is close to the above factor. Using the same ratio /6/, a better description of ^{3}He fragmentation on carbon was achieved /7/. This allows one to conclude that the ratio is the same for the fragmentation of all the lightest nuclei.

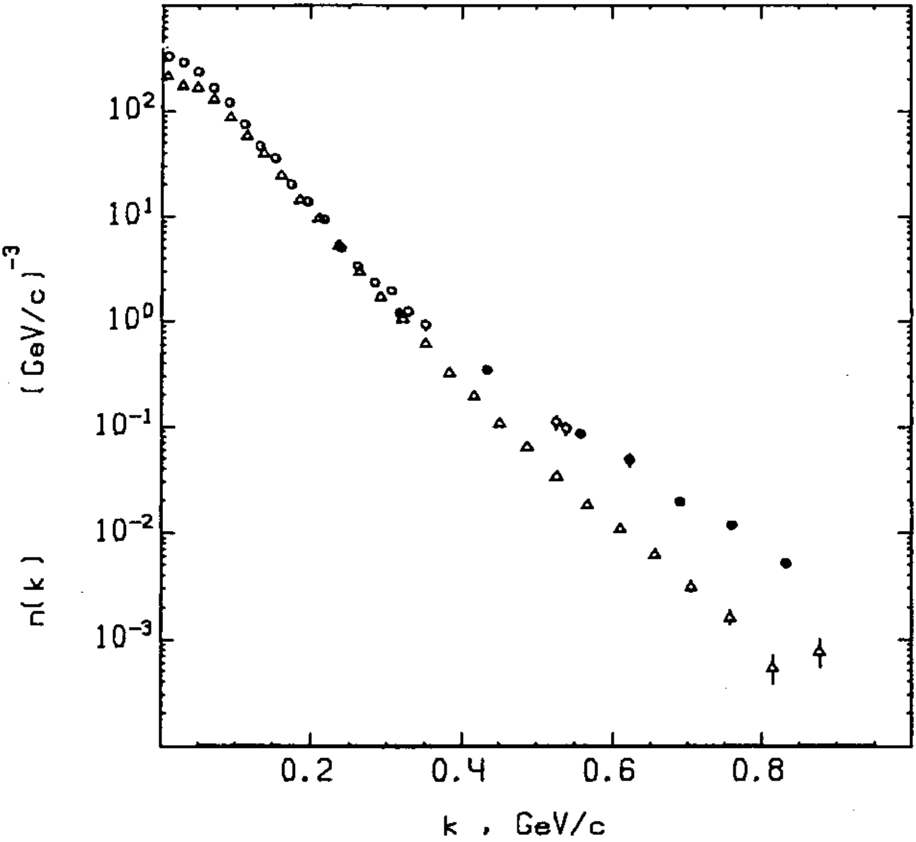

Fig.2. Momentum distributions in ^{4}He for protons (o and ●) and tritons (Δ) vs internal momentum k obtained from the cross sections in fig.1 using eq.(1).

mass (m_p or m_t, respectively) and m_f is the effective mass of the fragment-participant which is equal to m_p for the (^{4}He,t) reaction and supposed to be m_t for the (^{4}He,p) reaction.

In eq.(1) F is a kinematic factor, $\epsilon_{s(f)} = \sqrt{m^2_{s(f)} + k^2}$. The constant C_f is proportional to the total cross section of the participant f on the target nucleus σ^{tot}_{fC}. We have extracted the momentum distributions $n_s(k)$ using eq.(1). These distributions are normalized to:

$$\int n_s(k)\, d^3k = N_s\ , \quad N_p = 2, \quad N_t = 1.6\ . \qquad (3)$$

The effective number of tritons, $N_t = 1.6$, has been theoretically estimated in ref.[11]. Using the effective numbers N_p and N_t, one obtains from eq.(1) the ratio $C_t/C_p = 2.04$, which is close to the ratio of the total tC and pC cross sections (estimated as 1.93[12]).

The momentum distributions of protons (n_p) and tritons (n_t) are shown in fig.2. From theoretical considerations[11] it follows that in the low-momentum region the (p+t)-configuration predominates over the other (p+(nnp))-ones and governs the total momentum distribution $n_p(k)$ of ^{4}He. An approximate coincidence of the distributions $n_p(k)$ and $n_t(k)$ up to $k \simeq 350$ MeV/c agrees with such a conclusion. At higher values of k the ratio $n_p(k)/n_t(k)$ becomes larger and reaches one order of magnitude at $k \simeq 800$ MeV/c hence indicating an increasing role of the configuration other than the (p+t)-one.

As is seen from fig.3a, the proton momentum distribution $n_p(k)$ extracted from the ^{4}He fragmentation experiments is in agreement with the one derived in ref.[13] from the electrodisintegration data of ^{4}He(e,e′) measured at SLAC. The results of some theoretical calculations[14,15,16] for $n_p(k)$ are also shown in fig.3a. The theoretical curve of ref.[11], calculated for the interval $0 < k < 350$ MeV/c using the Urbana potential, is very similar to the curve of ref.[14]. We note a distinctive deviation of the data points from the calculations with realistic NN-potentials at values of $k \simeq 400$ MeV/c. Recently this conclusion has been confirmed[17] by analysing the proton momentum distribution in ^{4}He extracted from the Kharkov data for the ^{4}He(e,e′) reaction.

The triton momentum distribution $n_t(k)$ not only deviates from the theoretical calculations[11,15] but also does not confirm the existence of a dip at $k \simeq 400$ MeV/c predicted theoretically (fig.3b). The preliminary data[18] from the exclusive ^{4}He(e,e′p)t reaction also show no minimum in this region.

The following analysis could throw some light on the nature of the observed deviation between the momentum distributions extracted in the relativistic impulse approximation and the theory. The theoretical proton distribution can be presented[13] as $n_p = n_t + n_{exc}$, where n_{exc} is the proton momentum distribution when the participant (nnp) differs from the triton. To describe the data, additional terms can be introduced for the proton and triton momentum distribution:

$$n_p^{exp} = n_t + n_{exc} + n_p^{add}, \quad n_t^{exp} = n_t + n_t^{add}. \qquad (4)$$

We obtain the additional terms n_p^{add} and n_t^{add} subtracting the

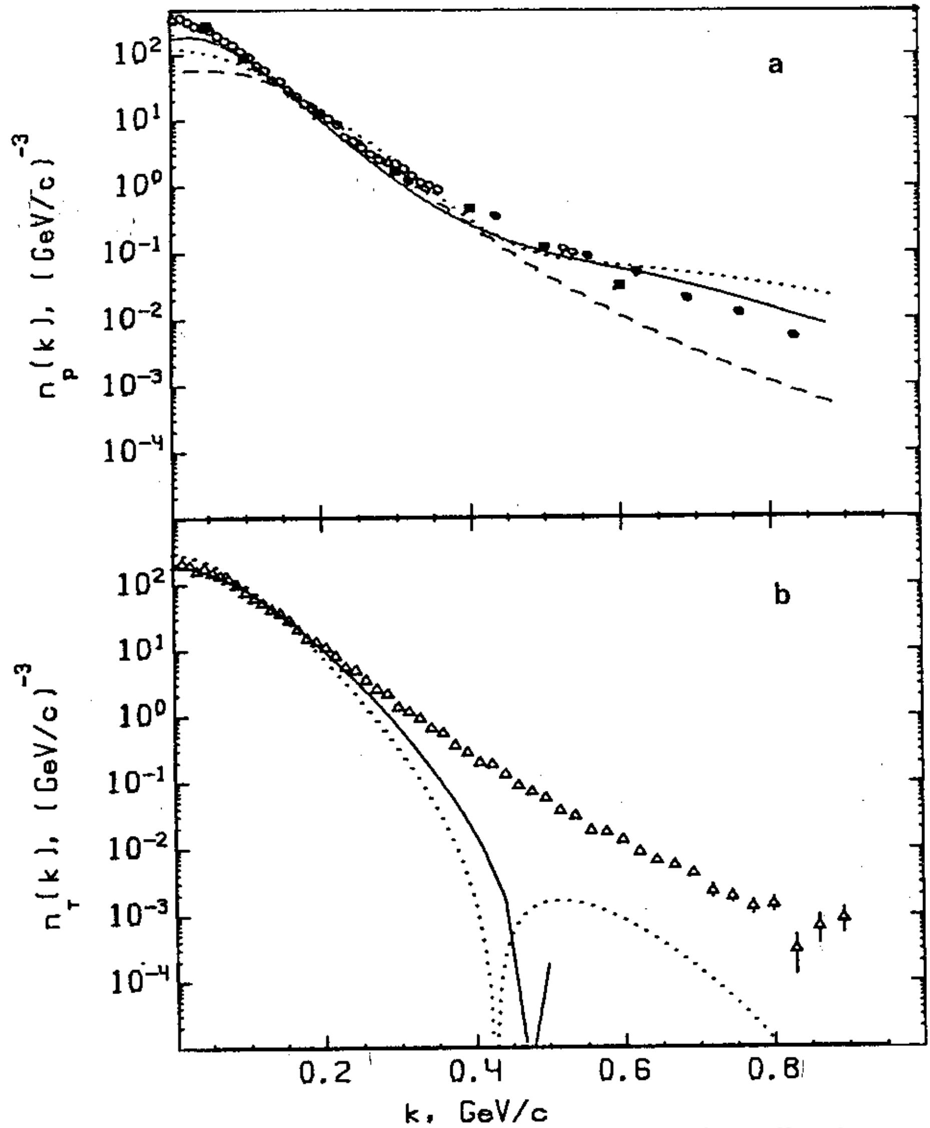

Fig.3. a) Comparison of the proton momentum distribution in ^{4}He from fig.2(o and ●) with the data/13/ *(■), extracted from the* ^{4}*He(e,e′) reaction, with the theoretical calculations*/14/ *(solid line) and* /15/ *(dotted line) using the RSC potential and with the flucton model calculations*/16/ *(dashed line). b) Comparison of the triton momentum distribution in* ^{4}*He from fig.2 (Δ) with the theoretical calculations (solid line) using the Urbana potential and*/15/ *(dotted line) using the RSC potential.*

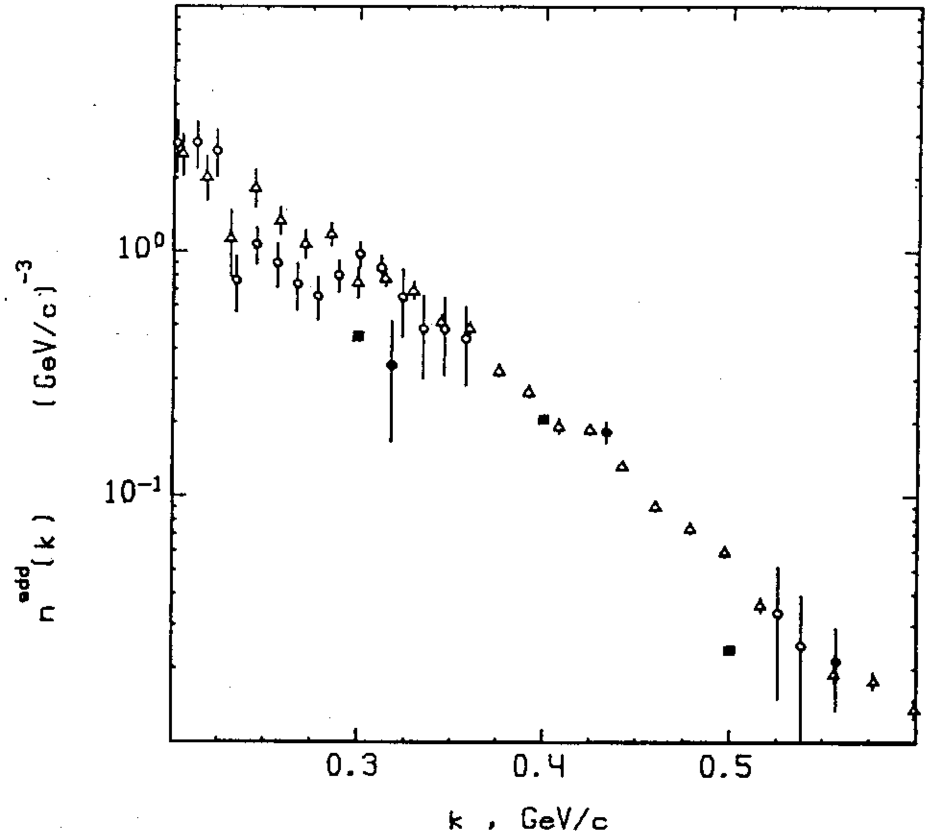

Fig.4. $n_p^{add}(k)$ *(o, ● and ■) and* $n_t^{add}(k)$ *(Δ) (see eq.(4) for definition) obtained from the data in fig.3 for protons (o, ● and ■) and tritons (Δ). Errors for the* $^4He(e,e\ )$ *data* [13] *(■) are not given.*

theoretically estimated momentum distributions from the experimental ones. To this end, we use the estimations for the proton [14] and triton [11] momentum distributions. Figure 4, where the result of this procedure is shown, indicates similarity of the additional terms, $n_p^{add} \simeq n_t^{add}$, for a rather broad momentum region of $200 < k < 600$ MeV/c. Furthermore, n_p^{add} is approximately the same for two different types of reaction, fragmentation and electrodisintegration. It is difficult to explain such an independence in the excess from the type of the spectator and from the type of the reaction by the interaction in the final state. At the same time this fact does not contradict the hypothesis of the existence of degrees of freedom other than nucleon ones in the ^{4}He structure which affect the (p+t)-configuration in ^{4}He.

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