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γ-PRODUCTION IN PERIPHERAL INTERACTIONS OF RELATIVISTIC CARBON NUCLEI IN PROPANE AND THE ANOMALON PROBLEM

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Introduction

A large amount of information on anomalons is accumulated nowadays. Some data have shown a significant decrease of the mean free path of multicharged fragments (MF) of projectile nuclei over the few first centimeters after emerging from a nuclear interaction. Details of experiments and theoretical approaches have been published, for instance, in papers/1,2/, in review/3/ and in the references therein.

An experimental study of the mean free path has been carried out, in particular, by means of a 2m propane bubble chamber exposed to a beam of carbon nuclei at 4.2 GeV/c per nucleon/2/. A total of 50.000 visually observed primary interactions of carbon in propane were treated. In order to reduce methodical errors in visual processing/2/, only low-multiplicity, peripheral interactions were selected. According to the charge conservation law, the fragment charges were limited to Z_f= 5 or 6 by the topologies of the primary interactions. In all the topologies one, and only one, MF emitted in the beam direction was required. This allowed one to pick out secondary ^{12}C, ^{11}C, ^{10}C, ^{12}B, ^{11}B and ^{10}B nuclei. A detailed analysis of the data obtained was made earlier by Gasparian and Grigalashvili/2/. We therefore summarize only a short description of the topologies which is relevant to this study.

1) Two-prong stars. One track is an MF, and a second one is a proton-recoil. Secondary ^{12}C nuclei, ^{11}C and ^{10}C isotopes can be produced, and 2168 events are selected in this topology.

2) Two-prong stars. One track is an MF. The second one could be a π^+ -meson, a proton with $P_p \gtrsim 0.7$ GeV/c, a deuteron with $P_d \gtrsim 1.5$ GeV/c or a triton with $P_t \gtrsim 2$ GeV/c. In this topology ^{11}C, ^{10}C, ^{11}B or ^{10}B can be secondary fragments. 1197 events are found in this case.

3) Three-prong stars. Except a multicharged fragment, there are one relativistic, singly-charged, positive particle and a proton-recoil. The ^{11}B and ^{10}B isotopes are preferentially formed in this topology, and 1580 stars were detected.

4) Three-prong stars. Except a multicharged fragment, there are one positive, singly-charged particle with any energy and one π^--meson. In this case the production of ^{11}C and ^{10}C isotopes is mainly expected in 170 primary interactions selected.

5) Four-prong stars. In addition to MF and π^--meson, there are two positive, singly-charged particles. In this topology ^{11}C, ^{10}C, ^{11}B and ^{10}B isotopes can be formed. As many as 616 events were found. A total of 5731 primary interactions were selected in all five topologies.

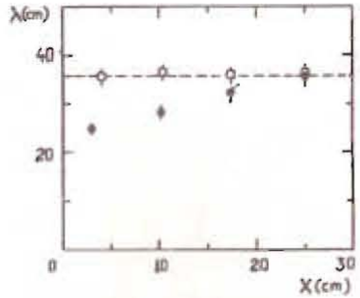

Fig.1. Dependence of the mean free path λ for secondary fragments of carbon nuclei with Z_f= 5 and 6 at the distance X from the primary interactions for the first topology (circles) and the other topologies combined.

Figure 1 shows the dependence of the mean free path for MFs on the distance X from the primary star for the first topology (circles) and the other topologies combined (squares). The anomalous λ decrease is observed only for such primary interactions of ^{12}C beam nuclei where carbon ^{12}C can be formed as a secondary fragment. The effect can be caused by an anomalous nuclear excitation which decays electromagnetically by the γ -emission. In this case an approximately isotropic source of low energy photons would be revealed over the background of γ -quanta from π^0-meson decays in the MF rest system.

On the other hand, an electronic experiment[4] has been undertaken to check the hypothesis of anomalon instability in ^{56}Fe interactions with an iron target at a kinetic energy of $T_0 = 940$ MeV. The expected γ-emission over an energy range of $100 < \varepsilon_\gamma < 2000$ MeV in the rest system of projectile fragments was not found.

The characteristics of γ-quanta, accompanying MF production in the peripheral collisions of carbon nuclei in propane at 4.2 GeV/c per nucleon, are studied in this paper. Some results have been published previously in paper[5]. The investigation has been performed on the sample of experimental data as for the search for anomalous carbon nuclei[2].

Data Obtaining and Background Generation

The electron-positron pairs of γ-conversion originated visually both in the range of the primary interaction and in the track of the MF were detected. Kinematical and geometrical parameters of MFs and e^+e^- pairs were measured.

It is necessary to establish the criteria of γ-quantum belonging to the primary interaction or to the MF. A schematical view of the event selected is shown in fig.2 for the case when the point of γ-emission B is found beyond the range of primary interaction A. The direction of γ-quantum (shaded line) is determined by the e^+e^- pair parameters. Here $d = BC$ is a minimal distance between the γ-trajectory and the MF track, ℓ is the distance from the primary star A to the interaction point B. The restriction of the values of d and ℓ can be used as the criteria sought.

The direct γ-ray emission in the inelastic collisions of deuteron and carbon nuclei with carbon tantalum targets at 4.2 GeV/c per nucleon was investigated[6] to obtain these values. Approximately 95% of all detected electron-positron pairs satisfy the restrictions

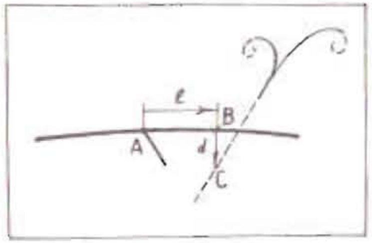

Fig.2. Outline of the event selected. Here A is the primary interaction point, $d = BC$ is a minimal distance between the γ-trajectory (dashed line) and the MF track and $\ell = AB$ is the distance from the primary interaction to the intersection point B of the γ-trajectory and the MF track.

$d \leq 1.5$ cm and $\ell \leq 2$ cm. As could be expected, the restrictions are close to experimental uncertainties of these values.

The γ-quanta with $d > 1.5$ cm were ruled out in the following analysis. The values of $\ell < 2$ cm correspond to γ-emission from the range of the primary interaction (for instance, from $\pi^0 \to 2\gamma$ decays). In the case of $\ell > 2$ cm the primary interaction is not a source of the γ-quantum, and its point of emission belongs to the MF.

If the γ-quantum is emitted, e.g., in interactions undetected visually (particle collisions in the walls of the chamber, neutral channels of neutron-neutron interactions and so on), a close intersection ($d < 1.5$ cm) can be accidentally obtained. To estimate the contribution of such "accidental" photons, the frames without visually observed interactions were scanned. The electron-positron pairs whose points of emission belong visually to the beam tracks were detected. The admixture of "accidental" photons was approximately 4% for γ-quanta emitted from the range of the primary interaction and about 15% for γ-quanta associated with the MF ($\ell > 2$ cm). The contributions to the range of small energies are close to those for the total interval of γ-energies.

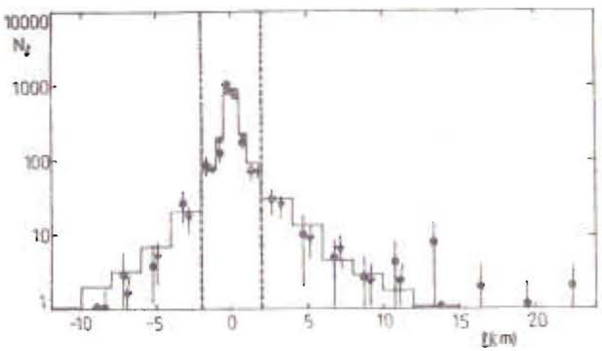

Fig.3. Distribution over the distance ℓ from the primary interaction to the intersection of the γ-trajectory and the MF track. The circles (●) show our data, the triangles (▼) are for direct γ-quanta in CC central collisions, and the histogram shows the background from π^0-meson decays (see text).

Figure 3 presents the distributions over the distance ℓ ($d < 1.5$ cm) both for the events selected (circles ●) and for the central collisions of carbon nuclei (triangles ▼) at 4.2 GeV/c[7] per nucleon without any multicharged projectile fragments. The background is shown as a histogram. It is generated by the Monte-Carlo method based on the characteristics of π^--mesons produced in the CC central collisions. The following procedure is used. Gamma-quanta are assumed to be produced only in $\pi^0 \to 2\gamma$ decays and the angular and momentum distributions of π^0 and π^- to be approximately identical[6]. The momentum and direction of π^0-mesons are generated in accordance with the corresponding experimental distributions of π^--mesons. Then the characteristics of γ-quanta are generated. The experimental resolutions and possible Compton scattering of γ-quanta are taken into account.

The background is also generated using the characteristics of π^--mesons emitted in the inelastic interactions of carbon in propane with the production of multicharged projectile fragments ($Z_f \geq 2$). No significant deviations for both variants are observed. As a larger number of π^--mesons are produced in the CC central collisions, they were explored later on for background generation. The experimental distribution is corrected for detection efficiency which depends on the energy and direction of γ-quantum.

A total of 515 γ-quanta are included in the experimental distribution (circles) presented in fig.3 (the corrected number is 2768 γ). They were emitted in 501 peripheral interactions. The values of $\ell < -2$ cm were obtained for 31 (141) γ-quanta; 424(2361) γ-quanta were in the range of the primary interaction (-2 cm $< \ell < 2$ cm), and the emission points of 60(266) photons belonged to the MF ($\ell > 2$ cm).

All the distributions were normalized to the number of γ-quanta in the experimental one in the range of the primary interaction. The experiment agrees with the background from π^0-decays at $\ell < 2$ cm. Some excess over the background is observed at $\ell > 2$ cm.

Experimental Data Analysis

As mentioned above, a total of 515 photons were selected in the peripheral collisions of relativistic carbon nuclei in propane. Among them 81 (452 with respect to detection efficiency) γ-quanta were emitted in the first topology and 434(2316) in the other topologies combined.

The purpose of this paper is to study the characteristics of all selected photons accompanying the MF production and, in particular, the properties of γ-quanta produced in the topology 1), in which the anomalous decrease of the MF mean free path has been earlier detected[2]. It is convenient to study the experimental characteristic of γ -quanta in the rest system of the fragments, that is in the antilaboratory system (ALS). Both in the laboratory system (LS) and in the ALS the photon energy spectrum has a typical shape with a maximum at $\varepsilon_\gamma \sim 70$ MeV.

The experimental spectra will be compared with the background ones from π^0-decays. An excess over the background would testify to the existence of an additional source of photons.

The spectrum of all γ -quanta selected is shown in fig.4 by circles (●) in the LS (a) and in the ALS (b). The data are corrected for detection efficiency. The background distribution shown here and below as a histogram is normalized to the number of photons in the experimental spectrum. The background is in good agreement with the corresponding spectrum in CC central collisions (triangles ▼). Some excess of small energy background γ -quanta over the experiment is associated with their low detection efficiency at $\varepsilon_\gamma < 30$ MeV in the propane bubble chamber. On the other hand, a significant excess over the background is observed in the ALS (fig.4b) in the first two bins at $\varepsilon_\gamma < 80$ MeV.

The open circles in fig.4 a), b) show the γ -quantum spectrum in topology 1). The energy distribution of γ -quanta in the remaining topologies is presented in fig.4c. It is obvious that the excess of low-energy γ -quanta over the background from $\pi^0 \to 2\gamma$ decays is caused, to a great extent, by the γ -quanta produced in topology 1).

Let us consider the known mechanism of low-energy γ -quanta generation in order to estimate their contribution to the experimental spectrum.

Bremsstrahlung. Low-energy γ -quanta from bremsstrahlung in the ALS have been observed in the 2m propane bubble chamber experi-

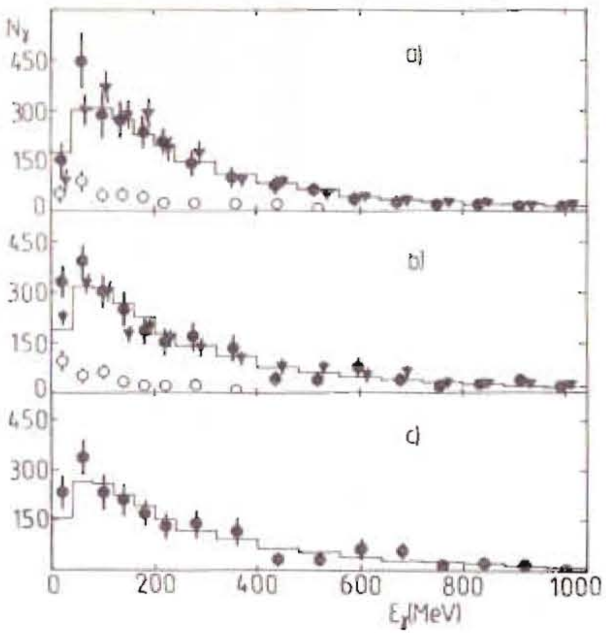

Fig.4. Spectra of γ -quanta (circles ●) accompanying the MF production in the LS (a), in the ALS (b) and in the ALS for the topologies 2-5 combined (c). The open circles correspond to the data for the topology 1) and the triangles (▼) for CC central collisions.

ments in inelastic collisions of hadrons and nuclei with nuclei[5]. As in our experiment only low multiplicity interactions are selected and the charge of the MF does not differ visibly from the charge of the projectile carbon, the formula for the energy losses dE of charged particles in the frequency interval $d\omega$ caused by scattering is applicable[8]

$$dE = \frac{2e^2 z^2}{3\pi c} \langle \theta^2 \rangle \gamma^2 d\omega \ .$$

Here z is the charge of the MP and $\langle\theta^2\rangle$ is the average value of the MP scattering angle squared in primary interactions. In our case $Z = Z_f = 5.6$, $\langle\theta^2\rangle = 3 \cdot 10^{-4}$ rad^2 and Lorentz factor $\gamma^2 = 21.1$. Taking into account the average detection efficiency of γ-quanta, the energy losses of all selected MPs due to bremsstrahlung do not exceed 900 MeV. Let us assume for simplicity that because of bremsstrahlung all the γ-quanta have a small energy of $\varepsilon_\gamma < 80$ MeV. The total energy of the γ-quanta selected over this range is approximately 31530 MeV. Thus, the upper limit of the bremsstrahlung contribution to the range $\varepsilon_\gamma < 80$ MeV is about 3%.

Amusia et al.[9] have considered γ-generation due to the giant resonances produced in relativistic collisions of hadrons and nuclei with nuclei. The cross sections of γ-generation by the giant resonances are six or seven times larger than those for bremsstrahlung. This is the reason why the contribution of the giant resonances and bremsstrahlung combined to the range $\varepsilon_\gamma < 80$ MeV in the ALS does not exceed 20 %.

Nuclear Excitation. The γ-quanta spectrum due to ordinary nuclear excitation in the rest system of the nucleus is concentrated in the range $\varepsilon_\gamma < 8$ MeV[10]. Moreover, the lifetime of the excited nucleus is greater in comparison with the MP time flight inside the chamber. Therefore we can observe γ-quanta from the excitation of predominantly target nuclei. The total energy of the selected γ-quanta emitted from the range of the primary interaction at $\varepsilon_\gamma < 8$ MeV in the LS is about 110 MeV and does not exceed 1% as compared to the total energy at $\varepsilon_\gamma < 80$ MeV.

Thus, the total contribution of bremsstrahlung, giant resonances and excited nuclei radiation to the range $\varepsilon_\gamma < 80$ MeV in the ALS is no larger than 25%. That is enough to explain the excess of the γ-quantum spectrum over the background at $\varepsilon_\gamma < 80$ MeV for topologies (2 – 5) combined (fig.4c), but not for low-energy γ-quanta of topology 1).

A number of theoretical models suggests the emission of photons as the decay of anomalous MPs. If the excitation of MPs is relieved by means of small energy (a few MeV) γ-quanta produced isotropically in the rest system of the MP, then photons, which are produced in a narrow ($\sim 1/\gamma$) forward cone with respect to the direction of the MP, must be observed. The energy of the photons will not be larger than a few scores of MeV.

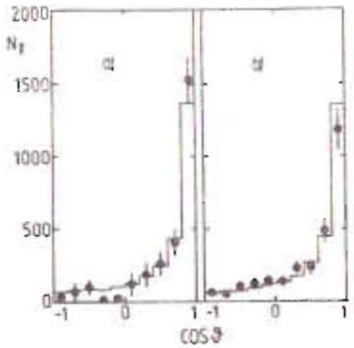

Fig.5. Angular distribution of all selected γ-quanta (circles ●) in the LS (a) and ALS (b). The histogram shows the background from π^0-meson decays.

The angular distributions of all selected γ-quanta are presented in fig.5 both in the LS (a) and in the ALS (b). The distributions do not demonstrate any visible features. In order to separate γ-quanta produced by anomalous MPs, we exclude those ejected at angles of $\theta_{LS} > 20°$. The obtained spectrum in the ALS (circles) is shown in fig.6a. In comparison with the initial energy distribution of all selected γ-quanta a relative excess over the background at $\varepsilon_\gamma < 40$ MeV becomes greater. The latter agrees qualitatively with the expected picture of γ-radiation by the anomalous MP.

The corresponding spectrum in the topologies (2 – 5) is presented in fig.6b. The excess over the background at low energies becomes smaller, and it can be explained by the bremsstrahlung contribution (see above).

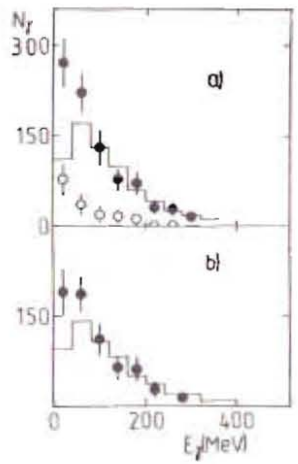

Fig.6. Energy spectrum of γ-quanta (circles ●) ejected at angles $Q_{LS} > 20°$ in all selected topologies combined (a) (open circles are for the topology 1))and in the topologies(2 - 5)combined (b).

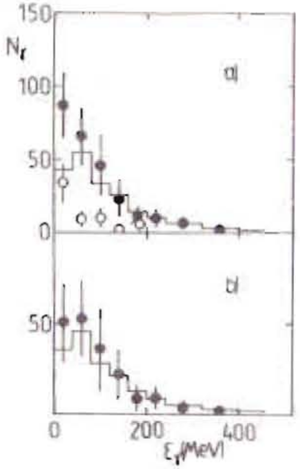

Fig.7. γ-quantum spectrum at $\ell > 2$ cm in the ALS (circles ●) in all selected topologies combined (a) (open circles are for the topology 1))and in the topologies(2 - 5)combined (b).

Interest has been aroused in the characteristics of γ -quanta accompanying the MF in the range $\ell > 2$ cm where some excess over the background from direct photons ($\pi^0 \to 2\gamma$) was observed (fig.2). The energy spectrum of all selected γ -quanta is presented in fig.7a (circles ●) in the ALS in the range $\ell > 2$ cm. Figure 7b shows the corresponding spectrum for topologies (2 - 5). It is evident that the excess over the background at $\varepsilon_\gamma < 40$ MeV is stipulated by photons of the topology 1). The γ -quantum angular distributions in the LS (a) and ALS are presented in fig.8. The distribution in the ALS is close to the isotropical one.

Thus, the hypothesis of γ -quantum production by anomalous MFs

does not contradict the totality of experimental data. The function of anomalous MFs producing photons at $\varepsilon_\gamma < 40$ MeV can be estimated using the number of secondary ^{12}C nuclei in the events selected, the number of anomalous fragments and the associated γ -quantum excess over the background. Within the statistical errors, the portion is (19 ± 5)%. This is the lower limit since a significant part of low-energy γ -quanta is not observed in the propane bubble chamber.

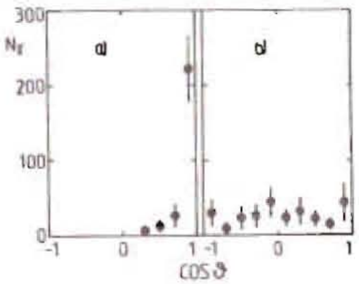

Fig.8. γ -quantum angular distributions at $\ell > 2$ cm in the LS (a) and ALS (b).

Conclusion

The peripheral interactions of carbon nuclei in propane at 4.2 GeV/c per nucleon have been investigated. An anomalous decrease of the mean free path of secondary ^{12}C nuclei was observed there before.

The analysis of the γ -quanta characteristics accompanying the production of multicharged fragments has been performed using the same experimental data. An excess of γ -quanta at $\varepsilon_\gamma < 40$ MeV over the background from known sources has been detected. The effect is observed especially in the events with secondary ^{12}C nuclei.

The totality of our experimental data does not contradict the hypothesis of the existence of a low-energy isotropical source of γ -quanta in the rest system of nuclear fragments. This is probably associated with the γ-radiation of anomalous multicharged fragments.

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Образование γ-квантов в периферических взаимодействиях релятивистских ядер углерода в пропане и проблема аномалонов

На дубненском синхрофазотроне с помощью 2-метровой пропановой камеры исследовались периферические взаимодействия релятивистских ядер углерода ^{12}C с протонами и ядрами углерода при импульсе 4,2 ГэВ/с на нуклон. Просмотрено около 50000 фотоснимков. Проанализированы угловые и энергетические характеристики γ-квантов, сопровождающих образование многозарядных фрагментов с зарядом $Z_f = 5$ и 6. Показано, что в системе покоя фрагмента имеется избыток γ-квантов с энергией $E_\gamma < 40$ МэВ над фоном от известных источников /распады $\pi^0 \to 2\gamma$, тормозное излучение и т.д./.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Cheplakov A.P. et al. E1-85-861

γ-Production in Peripheral Interactions of Relativistic Carbon Nuclei in Propane and the Anomalon Problem

Peripheral interactions of ^{12}C nuclei with protons and carbon nuclei have been investigated in a 2m propane bubble chamber at 4.2 GeV/c per nucleon. Energetic and angular characteristics of γ-quanta accompanying the production of multicharged fragments with $Z_f = 5$ and 6 have been analyzed. It is shown that in the fragment rest system there is an excess of γ-quanta with $E_\gamma < 40$ MeV over the background from known sources ($\pi^0 \to 2\gamma$ decays, bremsstrahlung and so on).

The investigation has been performed at the Laboratory of High Energy, JINR.

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