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CORRELATIONS IN PHOTOPRODUCTION  
OF CUMULATIVE PROTONS

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ՀԱՄԱՀԱՐԱՔԵՐՈՒԹՅՈՒՆՆԵՐ ԿՈՒՄՈՒԼՅԱՏԻՎ ՊՐՈՏՈՆՆԵՐԻ  
ՓՈՏՈԾՆՄԱՆ ԴԵՊՐՈՒՄ

Բերված են համահարաբերությունների/կոոեկյացիաներ/ չափման արդյունքները կումուլյատիվ պրոտոնների, առաջնաթիռ պրոտոնների և  $\Xi$  -մեզոնների միջև, որոնք առաջանում են 4,5 ԳէՎ առավելագույն էներգիայով արգելակային  $\gamma$  -քվանտներով: Ցույց է տրված, կոոեկյացիաներ, որոնք ( $\bar{p} \bar{p}$ ) համընկնման դեպքում արտահայտվում են գործակցի անկյունից և իմպուլսից կախմամբ, այն ժամանակ, երբ ( $\bar{p} \bar{\pi}$ ) -համընկնումը կախված է միայն կումուլյատիվ պրոտոնների իմպուլսից: Հեռուլթյուն է արվում կումուլյատիվ պրոտոնների սպեկտրերի միամասնիկ ինկլյուզիվ ծնման և առաջնաթիռ պրոտոնների ծնման ժամանակի տարբերության մասին:

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CORRELATIONS IN PHOTOPRODUCTION OF CUMULATIVE PROTONS

The results of measurements of correlations between cumulative and forward protons and  $\pi$ -mesons produced by bremsstrahlung  $\gamma$ -quanta of maximum energy 4.5 GeV are presented. It is shown that such correlations exist. In  $(\bar{p} \bar{p})$  coincidence the correlation is expressed through the dependence of the correlation coefficient on the angle and momentum of cumulative protons, whereas in  $(\bar{p} \vec{\pi})$  coincidence it depends only on the momentum of cumulative protons. A conclusion is made, according to which the spectra of cumulative protons are different in single-particle inclusive production and in production with hadrons emitted in forward direction.

Yerevan Physics Institute

Yerevan 1986

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КОРРЕЛЯЦИИ В ФОТООБРАЗОВАНИИ КУМУЛЯТИВНЫХ  
ПРОТОНОВ

Приводятся результаты измерений корреляций между кумулятивными протонами и вперед летящими протонами и  $\pi$  - мезонами, образованными тормозными  $\chi$  - квантами с максимальной энергией 4,5 ГэВ. Показано, что такие корреляции имеются. В  $(\vec{p} \vec{p})$  совпадении наличие корреляции выражается через зависимость коэффициента корреляции от угла и импульса, тогда как в  $(\vec{p} \vec{\pi})$  - совпадении зависимость только от импульса кумулятивных протонов. Делается вывод о том, что спектры кумулятивных протонов при одночастичном инклюзивном рождении и при рождении с вперед летящими адронами разные.

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## 1. Introduction

In recent years the fragmentation of nuclei by different high-energy particles into products, the production of which is kinematically forbidden for collisions with nucleons at a rest, is intensively investigated. Such products, independent of their production mechanism, are at present called cumulative particles. Production of cumulative particles even in its simplest case of cumulative protons (CP) production, is not sufficiently understood. One of the reasons of this situation is, apparently, that such processes have been investigated only in inclusive production. Though such experiments allowed to find the main rules of the process, it turned out to be insufficient for the further understanding of the physical picture. There new, more informative experiments are needed. One of the new trends of investigations is the study of correlations between cumulative particles and other secondaries produced at one and the same interaction. Such experiments have already been carried out with primary hadrons [ 1-4 ] and are continued to be at present [5].

In this paper results of the first experiment on the study of correlations between cumulative photoprotons and forward (noncumulative)  $\pi^+$ -mesons and protons are presented. The reaction



has been studied in (pp) and (p $\pi$ ) coincidences where  $\bar{p}$  is the cumulative proton,  $\bar{p}$  is the forward proton ( $\pi^-$ -meson), X is the residual system.

## 2. Description of the Experiment

Yields of the reaction (1) have been measured by "Deuteron-2" (Fig.1) double armed setup laid out on the G-1 beam of Yerevan Electron Synchrotron. The setup was on line with computer.

$\gamma$ -quanta produced on the inner target pass through collimators (C)<sub>1</sub> and (C)<sub>2</sub> and sweeping magnet (SM) and hit the target (T). The beam is monitored by a Wilson quantometer (WQ). The forward secondary  $\pi^-$ -mesons and protons are identified by a magnetic spectrometer (MS) with a time-of-flight measuring system in a solid angle of 2.32msr and momentum range 0.5 - 1.5 GeV/c. The spread of momenta being  $(\frac{\Delta p}{p}) = \pm 12.5\%$ . A gas threshold Cerenkov counter  $\check{C}$  with a Freon radiator has been used to separate  $\pi^-$ -mesons from electrons. Protons produced at large angles are identified by a range spectrometer [6] in a solid angle of  $\sim 0.1$  sr and kinetic energy range of  $T = 80 + 300$  MeV at  $\frac{\Delta T}{T} \simeq 10\%$ . A typical time-of-flight distribution of particles with 1.1 GeV/c momentum is shown in Fig.2a. A typical dE/dx distribution at a fixed path length is shown in Fig.2c.

For (pp) and (p $\pi$ ) coincidences a similar information

has been stored at delayed (i.e. background) coincidences. The differences in the number of the true and "background" events are presented below as final yields.

### 3. The Experimental Results

The reaction (1) on  $^{12}\text{C}$ ,  $^{27}\text{Al}$ ,  $^{63}\text{Cu}$ , and  $^{118}\text{Sn}$  nuclei have been investigated at the maximum energy of bremsstrahlung  $\gamma$ -quanta of 4.5 GeV. Both, inclusive and two-particle invariant normalized yields are obtained

$$S_p = \frac{1}{\sigma_t^{\text{tot}}} \cdot \frac{E_{\vec{p}}}{P_{\vec{p}}^2} \cdot \frac{d\delta}{d\Omega_{\vec{p}} \cdot dP_{\vec{p}}} \quad (2)$$

$$S_{pp(\pi)} = \frac{1}{\sigma_t^{\text{tot}}} \cdot \frac{E_{\vec{p}}}{P_{\vec{p}}^2} \cdot \frac{E_{\vec{p}(\pi)}}{P_{\vec{p}(\pi)}^2} \cdot \frac{d\delta}{d\Omega_{\vec{p}} \cdot d\Omega_{\vec{p}(\pi)} \cdot dP_{\vec{p}} \cdot dP_{\vec{p}(\pi)}} \quad (3)$$

where  $\sigma_t^{\text{tot}}$  is the total photon-nucleus cross section,  $E_{\vec{p}}$ ,  $P_{\vec{p}}$  are the total energy and momentum of cumulative protons,  $E_{\vec{p}(\pi)}$ ,  $P_{\vec{p}(\pi)}$  are the total energy and momentum of forward protons ( $\pi$ -mesons).

For  $^{12}\text{C}$  nuclei the CP angular distributions have been obtained in the interval  $\theta_{\vec{p}} = 70^\circ - 155^\circ$  at  $P_{\vec{p}} = 0.4$  GeV/c, 0.57 GeV/c and at  $\theta_{\vec{p}(\pi)} = 16^\circ$ ,  $P_{\vec{p}(\pi)} = 1.1$  GeV/c. At a cumulative proton angle of  $\theta_{\vec{p}} = 155^\circ$  and momentum  $P_{\vec{p}} = 0.4$  GeV/c the dependence of yields  $S_{\vec{p}\vec{p}}$  and  $S_{\vec{p}\pi}$  on the mass number of target is also measured.

Due to small  $S_{\vec{p}\vec{p}}$  and  $S_{\vec{p}\pi}$  yields, the momentum resolution of the magnetic spectrometer has been improved up to  $\pm 45\%$ . This naturally leads to deterioration of  $P/\pi$  rejection in the spectrometer. In Fig.2b is shown the mass distribution.

obtained in such conditions, demonstrating a still satisfactory separation of protons from  $\pi^-$ -mesons. Using Fig.2b one can estimate the admixture of  $(p\pi^-)$  events in  $(pp)$  coincidences and vice versa. In the first case it can not exceed 8% and in the second case - 11%, which does not significantly distort the experimental results.

In Fig.3 the angular distributions of invariant yields  $f_{\bar{p}} = \sigma_{\pm} \rho_{\bar{p}}$  and  $f_{\bar{p}\bar{p}(\pi^-)} = \sigma_{\pm} \rho_{\bar{p}\bar{p}(\pi^-)}$  for  $^{12}\text{C}$  nucleus and two values of CP momenta are shown. Statistical errors are only shown. The comparison of the corresponding single-particle and two-particle distributions shows, that when the cumulative proton is registered with a forward one, then its angular distribution becomes less hard as compared with the single-particle one. While, the simultaneous production of CP and  $\pi^-$ -mesons does not noticeably affect the slope of the angular distribution of CP.

Table of "b" parameters of  $f \sim \exp(-b \cos \theta_{\bar{p}})$  for inclusive and exclusive yields

$f_{\bar{p}}$  and  $f_{\bar{p}\bar{p}(\pi^-)}$

process	$\gamma^{12}\text{C} \rightarrow \bar{p}X$		$\gamma^{12}\text{C} \rightarrow \bar{p}\bar{p}X$		$\gamma^{12}\text{C} \rightarrow \bar{p}\pi^-X$	
momentum						
GeV/c	0.40	0.57	0.40	0.57	0.40	0.57
$b \pm \Delta b$	$0.98 \pm 0.006$	$2.04 \pm 0.06$	$0.36 \pm 0.077$	$1.19 \pm 0.091$	$1.00 \pm 0.14$	$1.86 \pm 0.059$

A-dependences of inclusive cumulative protons and of the same ones accompanied by forward protons and  $\pi^-$ -mesons at  $P_{\bar{p}} =$

$=0.4$  GeV/c and  $\Theta_{\bar{p}}=155^\circ$  are shown in Fig.4 . In case of (pp)-coincidences no noticeable changes relative to the inclusive production are observed. In case of (p $\bar{\pi}$ )-coincidences the A-dependence is changed: at large A the yield of (p $\bar{\pi}$ )-events is considerably suppressed.

#### 4. Correlations in CP Photoproduction

The available data allow us to investigate possible correlations in the production of cumulative protons with forward  $\bar{\pi}$ -mesons and protons.

Let us consider, as usual [7] , the following relation

$$K_{1,2} = \frac{S_{1,2}}{S_1 \cdot S_2} \quad (4)$$

as correlation function. Apparently, at independent production of 1 and 2 particles  $K_{1,2} = 1$ , and with correlations -  $K_{1,2} > 1$ .

In Fig.5 dependences of  $K_p$ ,  $p(\bar{\pi})$  on  $\cos \Theta_{\bar{p}}$  for (pp)- and (p $\bar{\pi}$ )-correlations are shown. The presented data show that:

1. the absolute values of correlation functions in some cases are less than unity. This may be due to the circumstance, that in the present work a continuous spectrum bremsstrahlung

$\gamma$ -quanta beam has been used. The measured number of events in this case, as known, is normalized to the so-called one equivalent and not to one real  $\gamma$ -quantum of fixed energy. If at the investigation of any one process such normalization does not essentially distort this or that dependence, say angular distribution, then at the investigation of different processes (in the given case inclusive and exclusive production) it can change the ratio of absolute values of their yields. Besides,

in the Eq.(4) is used the mean value of  $\sigma_t^{SM}$  obtained by integrating over the whole spectrum of  $\gamma$ -quanta [8] and not over the interval which really contributes to the process under investigation. The taking of this effect into account can somewhat change the value of  $K$ . That is why it is impossible to determine the absolute value of  $K$  in this paper.

2. the correlation functions  $K$  differently depend on the registration angle and momentum of CP in (pp)- and (p $\pi$ )-correlations. In the first case  $K_{pp}$  is obviously growing with the angle  $\theta_p$ , while for (p $\pi$ )-events  $K_{p\pi}$  remains the same within the limits of errors. The correlation functions in both cases grow with the momentum of CP. On the basis of these results two important conclusions can be made:

a) though our data do not allow to determine the absolute values of correlation functions, nevertheless the change of  $K_{p,p(\pi)}$  with the kinematic parameters of CP (the angle, the momentum) testifies to the fact that there exist correlations between CP and forward  $\pi$ -mesons and protons. In the first case it is expressed by the change of  $K_{pp}$  with both, momentum and angle, but in the second case - with the CP momentum only;

b) the second conclusion is that the spectra of CP are different for the inclusive production and forward-backward correlations. The mentioned difference in (pp)-correlations increases with the cumulativeness (registration angle) of protons, while in (p $\pi$ )-correlations it remains the same in the whole range of measurements.

Note, that in Ref. [4] with incident hadrons, the CP spectra have been observed to be independent of forward particles re-

gistered in coincidence.

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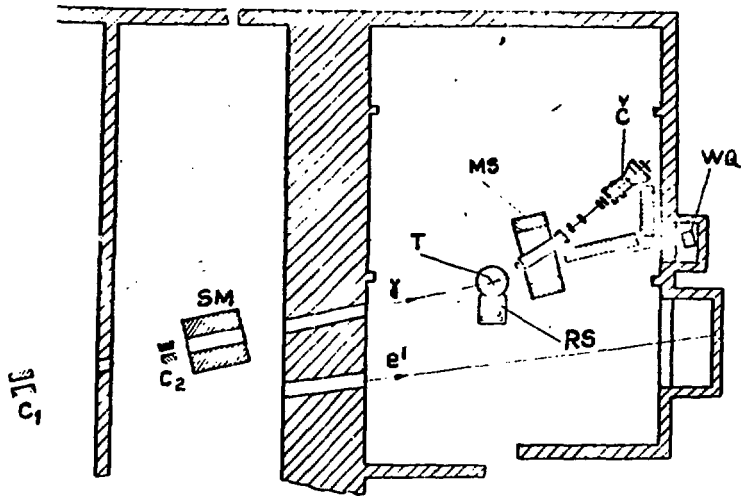


Fig.1 The setup "Deuteron-2".  $C_1$  and  $C_2$  are the collimators, SM is the sweeping magnet, T is the target, WQ is the Wilson quantometer, MS is the magnetic spectrometer,  $\check{C}$  is the Cerenkov counter, RS is the range spectrometer.

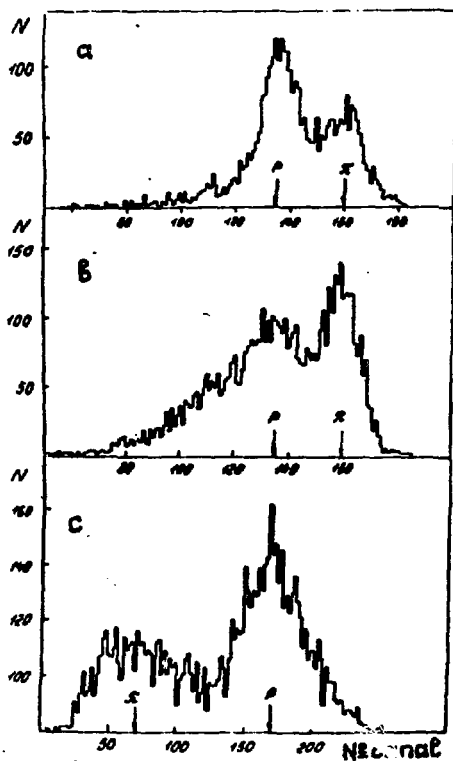


Fig.2 The time-of-flight distribution of particles of momentum 1.1 GeV/c (a and b), and  $dE/dX$  distribution (c) at  $T=80$  MeV; in case when: a) the spectrometer resolution  $\frac{\Delta P}{P} = \pm 12.5\%$ , b)  $\frac{\Delta P}{P} = \pm 45\%$ . The arrows show the expected maxima of  $dE/dx$  distributions of protons and  $\pi$ -mesons.

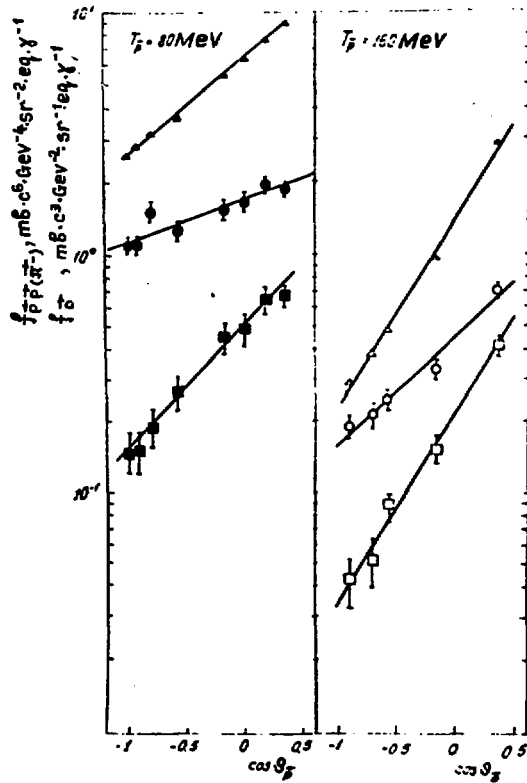


Fig.3 The angular distributions of invariant yields of reactions  $\gamma^{12}\text{C} \rightarrow \bar{p}x (\blacktriangle, \triangle)$ ;  $\gamma^{12}\text{C} \rightarrow \bar{p}\bar{p}x (\bullet, \circ)$  and  $\gamma^{12}\text{C} \rightarrow \bar{p}\pi x (\blacksquare, \square)$  at CP momenta  $P_{\bar{p}} = 0.04 \text{ GeV}/c$  (Dark symbols) and at  $P_{\bar{p}} = 0.57 \text{ GeV}/c$  (open symbols). The lines are drawn by the method of least squares according to  $f \sim \exp(\delta \cos \theta_{\bar{p}})$

Figure captions of Fig.4 and Fig.5 to be interchanged.

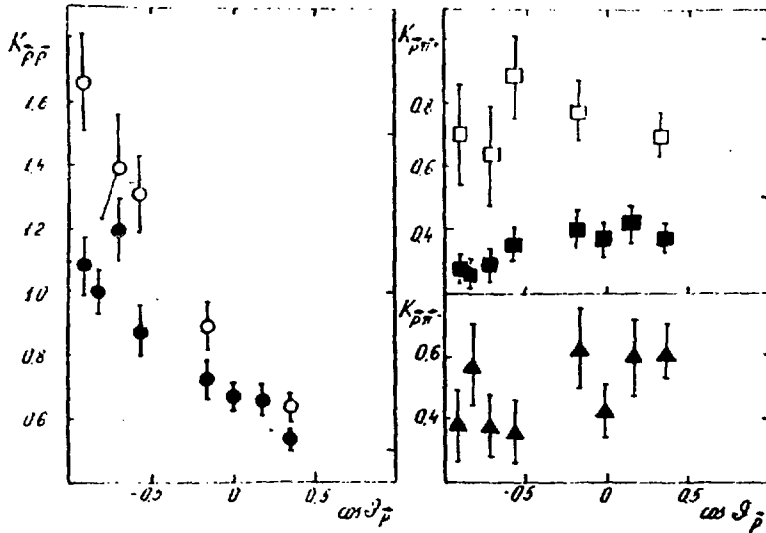


Fig.4 A-dependence of invariant yields of reactions  $\gamma A \rightarrow \bar{p} X$  ( $\blacktriangle$ );  $\gamma A \rightarrow \bar{p} \bar{p} X$  ( $\bullet$ ) and  $\gamma A \rightarrow \bar{p} \pi X$  ( $\blacksquare$ ) at the momentum of CP  $P_{\bar{p}} = 0.4$  GeV/c and the angle  $\theta_{\bar{p}} = 155^\circ$ . The lines are drawn by the method of least squares according to  $f_{P(P)} \sim A^{n_{P(P)}}$ ;  $n_p = 1.15 \pm 0.022$ ,  $n_{pp} = 1.08 \pm 0.06$ .

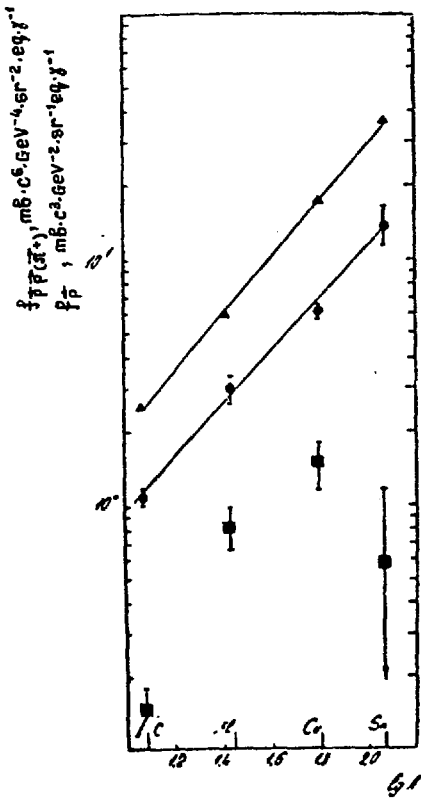


Fig.5 The dependences of the correlation functions  $K_{pp}$  (a),  $K_{p\pi^+}$  (b) and  $K_{p\pi^-}$  (c) on the angle of CP ( $\bullet$ ,  $\blacksquare$ ,  $\blacktriangle$ ) indicate the momentum of CP  $P_p = 0.4$  GeV/c; ( $\circ$ ,  $\Delta$ ,  $\square$ ) -  $P_p = 0.57$  GeV/c.

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КОРРЕЛЯЦИИ В ФОТООБРАЗОВАНИИ КУМУЛЯТИВНЫХ ПРОТОНОВ

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