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PROPERTIES OF CENTRAL CC - INTERACTIONS AT A MOMENTUM OF 4.2 GEV/C PER NUCLEON

[1]Sultanov M. U, [2]Usarov A. A, [3]Yakhshiboyev Q. Kh ,[4]Suvanov A. I
Samarkand State Medical Institute[1],Jizzakh Politechnical Institute[2],Academic Lyceum under Samarkand State Architectural and Building Institute[3] , Samarkand branch of Tashkent State Agrarian University[4]
amattou@rambler.ru

ABSTRACT

In this paper the multiple of secondary hadrons($\pi^{\pm}$-mesons and protons)inCC-interactions, depending on the degree of collision centrality was studied. As the degree of centrality accepted number of protons participating formed in the event. The experimental values of the mean multiplicity $\pi^{\pm}$-mesons, protons, proton-participants identified for 4 methodically selected types of collisions. Estimate the yield of protons in different momentum intervals depending on the value of the impact parameter. The experimental data are compared with the results of theoretical calculations of the model FRITIOF. It is shown that the multiplicity of slow and evaporated protons model reproduced unsatisfactorily.

Key words: reaction, exit, participant proton, centrality, multiplicity, interval, model, distribution.

INTRODUCTION

The cascade-evaporation model (ECM) is based on the idea of a cascade of interactions inside the nucleus during a nuclear reaction. Thus, the formation of fast nucleons in hadron-nuclear and nucleus-nuclear collisions can be explained [1,2]. The great significance of the reaction yield in the regions of nuclear fragmentation in the EMC is due to a cascade of reggeon exchanges. According to [3], in hadron-nucleus interactions it is possible not only sequential knockout of nucleons, but also simultaneous knockout of nucleons, described by non-planar amplified diagrams. With simultaneous knocking out of nucleons, all of them are in a state characterized by the same physical characteristics, and therefore we can expect a weak dependence of the spectra of nucleons on the centrality of collisions.

Central and peripheral interactions differ primarily in the number of primary intranuclear collisions. In central interactions, the nucleon participants must be concentrated in the central rapidity region due to multiple scattering of nucleons inside the nucleus, i.e. we can expect a predominant nucleon production in nuclear fragmentation regions. With a decrease in the impact parameter, the number of primary collisions and the number of cascade interactions in residual nuclei increase, and therefore the yield of nucleons in the regions of nuclear fragmentation should be minimal. Therefore, according to the IMC, the shape of the nucleon spectra should change in the regions of nuclear fragmentation. The calculations presented in [4] confirm this reasoning. However, the opposite is observed in the experiment: with an increase in the centrality of collisions, the yield of protons in the central region increases rather than in the regions of nuclear fragmentation. Therefore, it is interesting to study the yields of nuclear reactions as a function of the degree of centrality and at different pulse intervals of secondary hadrons.

This paper is a continuation of the analysis of experimental data [5–8] on interactions of light nuclei with carbon nuclei at a pulse of 4.2 GeV/c per nucleon in the framework of the FRITIOF model, adapted to energies below 10 GeV/c [9].

RECEIVING AND PROCESSING TECHNIQUES OF EXPERIMENTAL MATERIAL

For processing, we used experimental material obtained on a 2 m propane bubble chamber placed in a magnetic field with a strength of 1.5 T and irradiated in a ^{12}C nuclear beam with a pulse of 4.2 AGeV/c at the

JINR Synchrophasotron (Dubna, RF). The selection of events of inelastic CC interaction from the complete ensemble of interactions of carbon nuclei with propane (more than 37,000 events), as well as the introduction of corrections for the number of secondary particles and their momentum and angular characteristics are described in detail in [10]. Of all $^{12}C(C_3H_8)$ interactions, according to the established criteria, 20527 inelastic CC events were identified.

In the considered CC interactions, among the secondary particles, π+ and π^- -mesons, evaporative protons (protons with a momentum of p□0.3 GeV/c), stripping fragments from an incident carbon nucleus (p□3 GeV/c, and angles departures θ□3^0), and protons participants (p□0.3 GeV/c without stripping particles). Also, the “behavior” of protons with a pulse in the range of 0.3 □ p □ 0.75 GeV/c is studied - proton participants from the target and protons with a pulse of p□ 0.75 GeV/c - proton participants from the projectile nucleus. The whole ensemble of inelastic CC collisions was divided into three groups:

1.Peripheral interactions - the number of proton participants in which ≤4. The average value of the impact parameter □b□ for these events is greater than 4 fm and the average value of the participating protons is 4.41.

2.Events with the number of protons 4□n≤9. For these events, the average value of the impact parameter lies in the range from 2 to 4fm.

3.Central events, where the number of proton participants is greater than 9. For these events, □b□ is less than 2 fm.

In addition, a group of carbon-carbon events was identified in which the total charge of the stripping fragments Q_{str} of the projectile core is zero.

EXPERIMENTAL RESULTS AND COMPARISON WITH MODEL CALCULATIONS

The results obtained on the multiplicity of secondary particles for the considered groups of CC-collisions are shown in Table 1. The results of processing experimental material (20527 CC events) using the algorithmic program FORTRAN-77 showed that more than half of the CC-collisions are peripheral interactions and only a few percent of CC collisions satisfies the above conditions of centrality of events. From the analysis of the data given in Table 1 (Fig. 1), it is clearly seen that with an increase in the degree of centrality, the multiplicity of secondary charged particles increases. For example, when moving from peripheral collisions to deep central events, the π-meson fraction increases from 23% to 35%. The reasons for this is that as the measure of centrality increases, the number of nucleon-nucleon interactions with pion production will increase.

In the group with n_p≤4, the average multiplicity of π^+ -mesons is higher than the average multiplicity of π^-mesons. This is due to the fact that the group with np≤4 included more events with the charge exchange of protons into neutrons ($p \rightarrow n\pi^+$) than with the charge exchange of neutrons into protons ($n \rightarrow p\pi^-$). And in the group with np□9, the opposite is observed. Where charge exchange processes are equally likely, □$n_{\pi-}$□ = □$n_{\pi+}$□. This ratio was obtained for groups with 4□n_p≤9 and Q_{str} = 0.

During the transition from peripheral to central interactions, the shape of the event distribution by the number of π mesons changes significantly (see π for mesons fig.2). The number of events without the production of π-mesons sharply decreases, and the share of multi-meson events increases, as a result of this, an increase in the average multiplicities of π^+ and π^- mesons is observed (Table 1). In terms of the mean pion multiplicities per proton participant, it turned out that in the □n_π^-□ and □$n_{\pi+}$ events the □n_π-□ / □n_p^{par}□ relations coincide with the corresponding □n_π+□ / □n_p^{par}□ ratio for inelastic CC interactions equal to 0.325 ±

0.003. Different ratios between mean multiplicities of π + and π- -mesons in peripheral and central CC interactions leads to a different dependence of the mean values of negative and positive pions on the degree of centrality (Table 2).

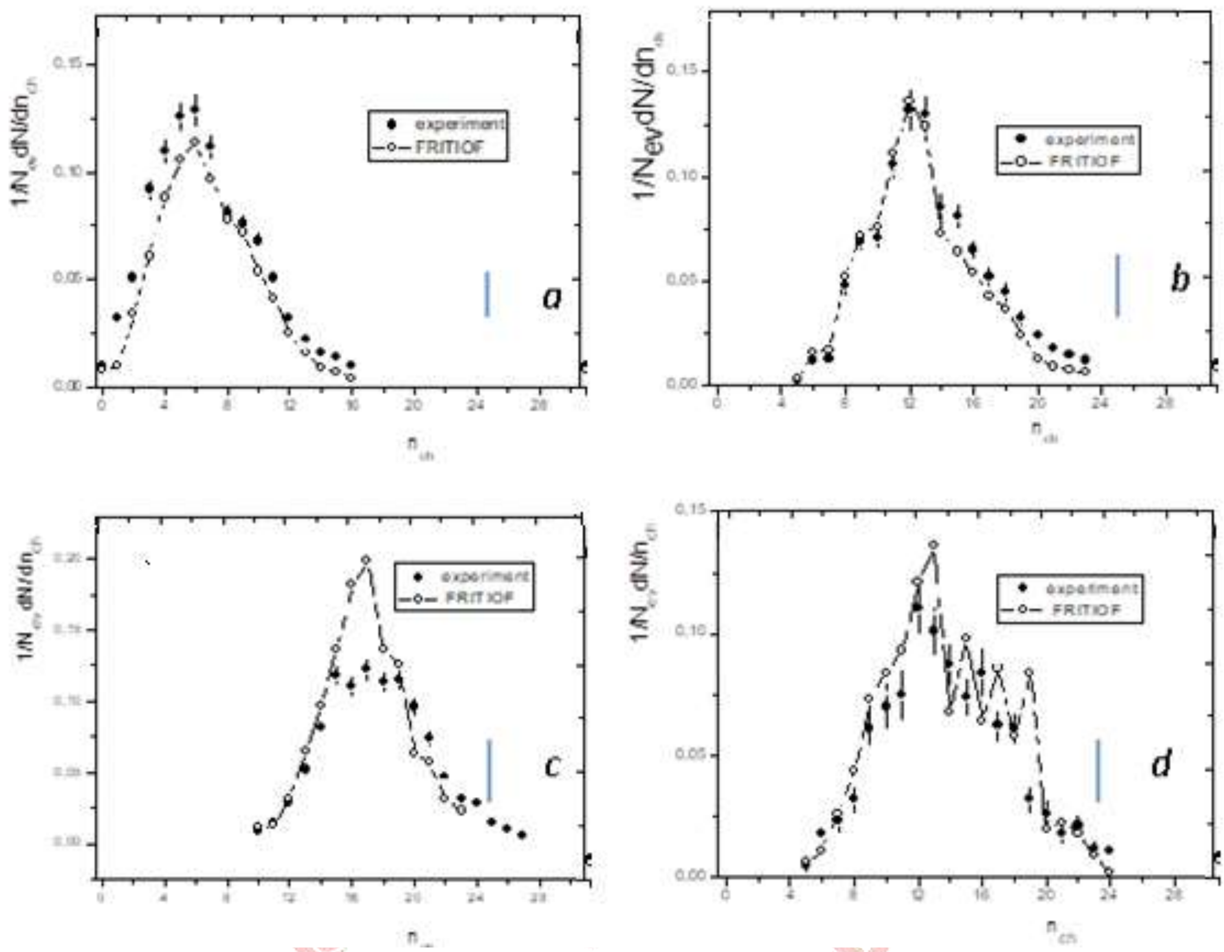

Fig.1. Multiple distribution of charged particles in CC interactions.

a) $n_p^{par} \leq 4$, **b)** 4 □ $n_p^{par} \leq 9$, **c)** n_p^{par} □9, **d)** $Q_{str} = 0$.

Table 1. The average multiplicities of charged hadrons in CC interactions with a different number of proton participants (the upper line is the experimental results, the lower line is calculations using the FRITIOF model).

Event type	$n_p^{par} \leq 4$	4□ $n_p^{par} \leq 9$	n_p^{par} □9	$Q_{str}=0$
N_{ev}	12010 24501	7101 21351	1416 4150	672 2313
$<n_{\pm}>$	6.82±0.02 6.61±0.02	13.77±0.04 12.38±0.02	19.34±0.09 17.12±0.07	17.48±0.16 15.22±0.08
$<n_{\pi}^{-}>$	0.714±0.005 0.698±0.005	2.158±0.016 1.633±0.008	4.05±0.04 3.46±0.02	3.25±0.07 2.58±0.003
$<n_{\pi}^{+}>$	0.892±0.006	2.152±0.018	2.96±0.04	3.35±0.07

	0.898±0.006	1.666±0.010	2.08±0.02	2.81±0.03
$< n_p>$ p□0.15	4.223±0.04 4.366±0.03	1.822±0.024 2.012±0.014	0.42±0.10 0.55±0.09	1.18±0.08 1.44±0.06
$<n_p >$ 0.15≤p□0.3	0.682±0.007 0.367±0.005	0.865±0.012 0.674±0.006	0.54±0.02 0.40±0.01	0.86±0.04 0.62±0.02
$<n_p >$ 0.3<p≤0.75	0.728±0.005 0.626±0.005	1.744±0.015 1.726±0.009	2.66±0.04 2.52±0.02	1.86±0.06 1.52±0.03
$<n_p >$ p□0.75	1.611±0.007 1.718±0.007	4.936±0.019 4.961±0.012	8.44±0.05 8.51±0.05	8.44±0.09 8.12±0.04
$< n_p^{par})>$ p□0,15	2.282±0.007 2.344±0.008	6.605±0.016 6.676±0.009	12.04±0.03 11.23±0.02	11.12±0.09 9.14±0.05

From Table 2 it can be seen that during the transition from CC events from n_p □4 to events from n_p□9, there is a slight decrease (~ 10%) of the yield of charged pions per proton-participant. With a decrease in the impact parameter, the average number of proton participants both from the projectile nucleus and from the target nucleus naturally increases and, accordingly, the multiplicity of stripping fragments of the projectile nucleus and evaporative protons of the target nucleus decreases, and to a greater extent due to protons with impulse less than 0.15 GeV/c (Fig.3-4). The average number of protons with p□0.15 GeV/c was estimated by the missing charge in the event (Table 1). It should be noted that the average multiplicity of proton participants in a subgroup with momenta from 0.3 to 0.75 GeV/c grows more slowly than in a subgroup with p□0.75 GeV/c. Analysis of the experimental data showed that part of the proton participants from the target nucleus (40-50%), when colliding with the nucleons of the projectile nucleus, receives large momentum transfers and transfers to the group of proton participants with a momentum of p□0.75 GeV/c. Hence a significant increase in the average number of proton participants with an impulse greater than 0.75 GeV/c in central interactions.

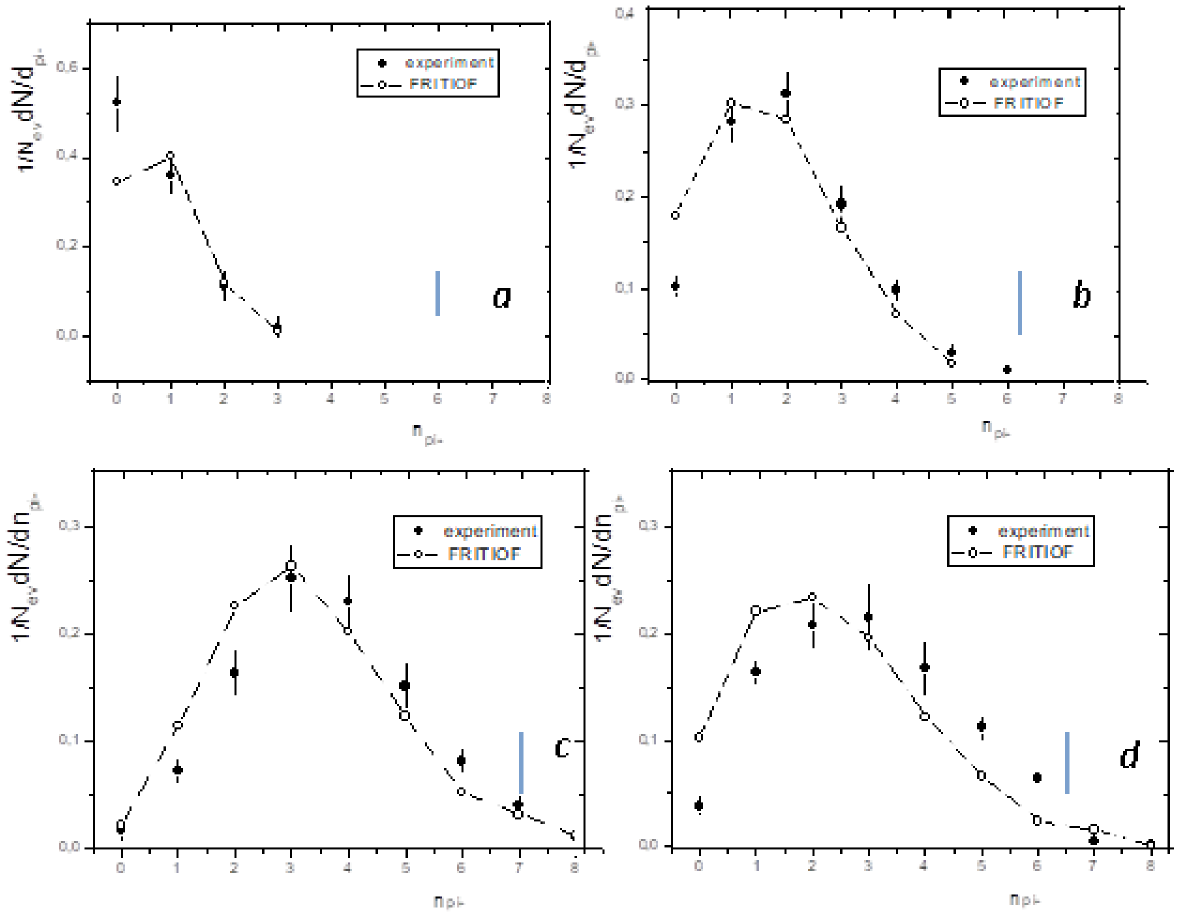

Fig.2. Multiple π-mesons distribution in CC interactions.

a) $n_p^{par} \leq 4$, b) 4 □ $n_p^{par} \leq 9$, c) n_p^{par} □9, d) Qstr = 0.

Table 2 Relative multiplicities of π^- and π^+ -mesons in CC interactions with different number of proton participants (top line – experimental results, bottom line - calculations using the FRITIOF model).

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Event type	$n_p^{par} \leq 4$	4□$n_p^{par} \leq 9$	n_p^{par}□9	$Q_{str}=0$
$\langle n_\pi^- \rangle / \langle n_p^{par} \rangle$	0.312±0.003	0.326±0.003	0.363±0.004	0.314±0.007
	0.296±0.002	0.249±0.002	0.290±0.003	0.239±0.004
$\langle n_\pi^+ \rangle / \langle n_p^{par} \rangle$	0.385±0.003	0.321±0.003	0.263±0.004	0.329±0.008
	0.384±0.003	0.245±0.002	0.179±0.003	0.267±0.006
$(\langle n_\pi- \rangle + \langle n_\pi^+ \rangle)/$	0.697±0.004	0.647±0.004	0.626±0.006	0.643±0.010
$\langle n_p^{par} \rangle$	0.680±0.004	0.494±0.003	0.469±0.004	0.506±0.007

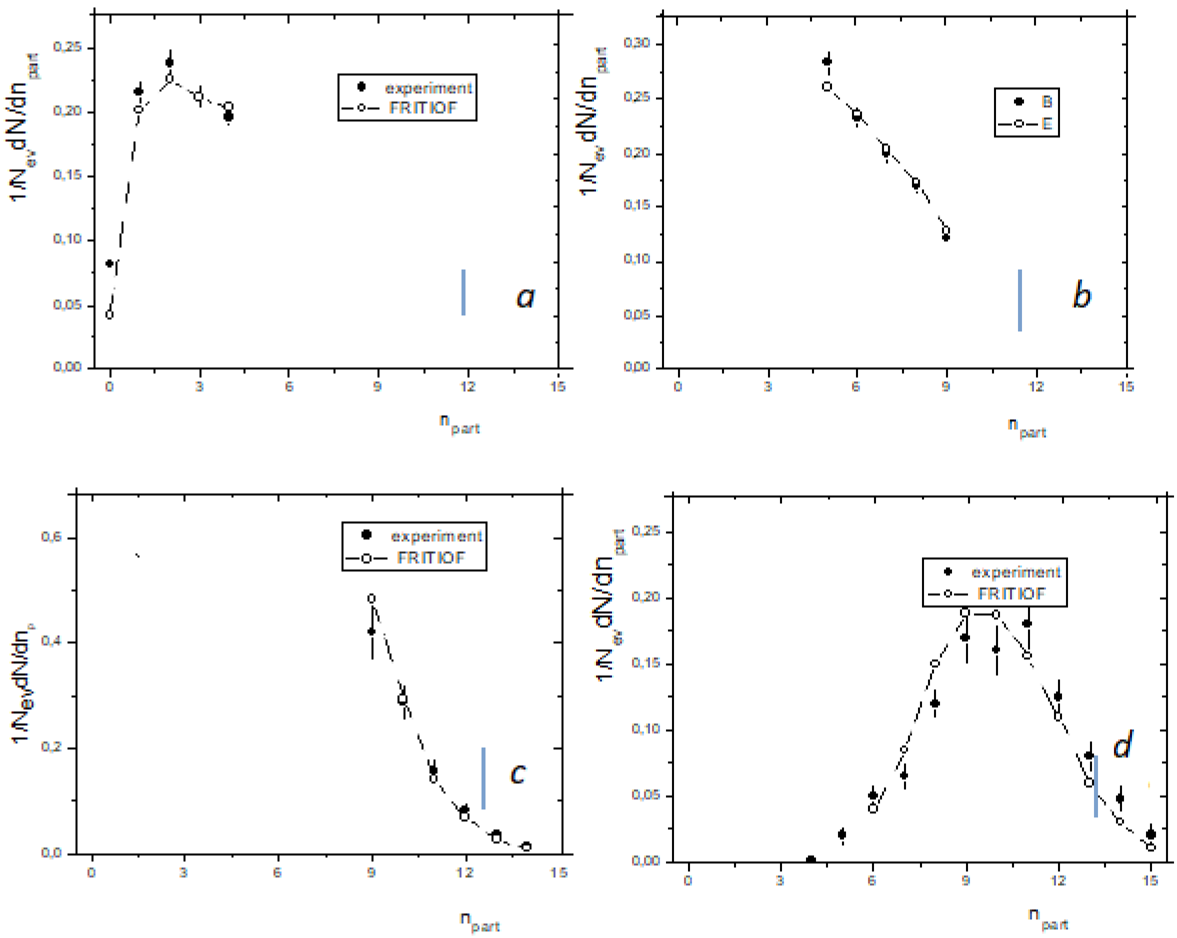

Fig.3. Multiple distribution of proton-participants in inelasticCC interactions. a) $n_p^{par} \leq 4$, b) 4 □ $n_p^{par} \leq 9$, c) n_p^{par}□9, d) $Q_{str} = 0$.

A comparison of the mean multiplicities of particles in CC groups of events with n_p^{par}□9 and Qstr = 0 shows that events with n_p^{par}□9 are distinguished by a higher average multiplicity of secondary charged particles, a significantly smaller average multiplicity of evaporation protons and the presence of stripping fragments of the projectile nucleus (Table 1).

In events with $Q_{str} = 0$, by definition, all six protons of the carbon nucleus interact with the target. Of the target nucleus, on average, 4.2 protons take part in the interaction. In events n_p^{par}□9, these numbers are respectively 7.78 and 5.13. They

obtained using the average multiplicities of stripping particles and evaporative protons from Table 1. A visual representation of the features of the two types of central CC interactions (n_p^{par} □9 and $Q_{str} = 0$) can be obtained from Fig. 3 c, d.

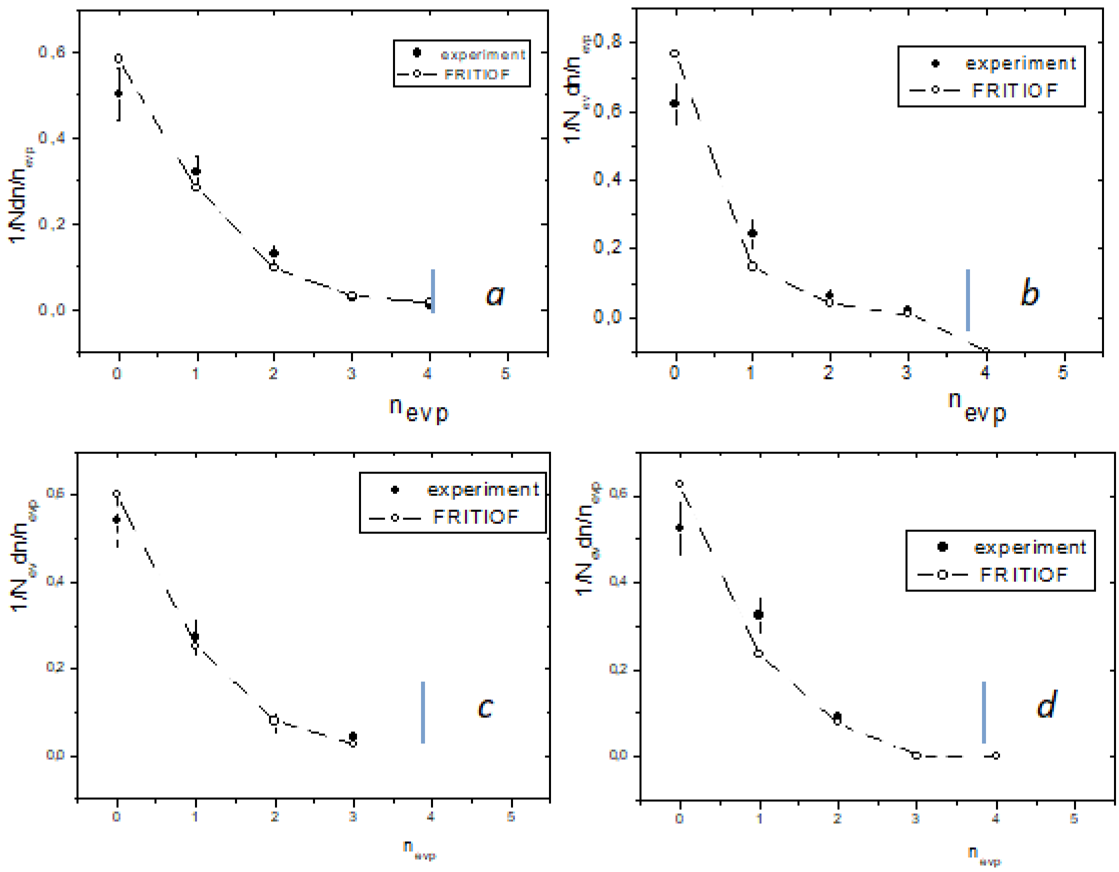

Fig.4. Multiple distribution of evaporative protons in CC interactions. a) $n_p^{par} \leq 4$, b) 4 □ $n_p^{par} \leq 9$, c) n_p^{par}□9, d) $Q_{str} = 0$.

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CONCLUSION

The result of the analysis of the obtained experimental data and their comparison with the calculations of the FRITIOF model allows us to draw the following conclusions:

- With close values of the average multiplicities of the protons involved (difference of about 10%), the SS-events have completely different distributions by hand. By virtue of the selection criterion, events n_p^{par}□9 are concentrated in a narrow interval of n_p^{par}, while for events with $Q_{str} = 0$, the distribution of nrubs is quite wide (Fig. 3d). Apparently, in events with $Q_{str} = 0$, proton-neutron interactions ($pn \rightarrow pnX$) and interactions with proton charge exchange ($pn \rightarrow nn\pi^+$) play a significant role. This may explain the occurrence of events with n_p^{par}□9 at the interaction of six protons from the incident carbon nucleus with a carbon target.

- As a result of the comparison, we can conclude that the degree of centrality of CC-interactions with nruv □9 and Qstr = 0 is approximately the same.

- Comparison of experimental data on the multiplicity of secondary particles with calculations using the FRITIOF model shows that the model satisfactorily reproduces the average multiplicities of all charged particles, proton participants and evaporative protons in all analyzed groups of events (Table 1 and Figure 1,3). The greatest discrepancy between the experiment and the model is observed when comparing the multiplicities of π-mesons and evaporative protons in subgroups with momenta of p□0.15 GeV/c and 0.15≤p□0.3 GeV/c.

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