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SEARCH FOR AND STUDY OF THE EFFECTIVE MASS SPECTRA OF NUCLEON CLUSTERS PRODUCED IN RELATIVISTIC NUCLEON COLLISIONS

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§ I. INTRODUCTION

Great interest in the phisics of relativistic nuclear collisions in mainly motivated by hopes to obtain new states of nuclear matter in which quarqs and gluons are in the state of deconfinement. Howewver, investigations on nuclear matter properties in going from hadron matter to quarq-gluon plasma are no less important for modern theory as well. In particular, are the states of highly excited hadron matter realized under transition in terms of the observed values and (if we manage to observe) how are these states related to colour degrees of freedom?

Using the relativistic invariant method of analysis of nucleus-nucleus and hadron-nucleus reactions over an energy interval of 4-40 GeV, we have observed the existence of two types of nucleon clusters characterized by different values of temperature: type I with $\langle T_1 \rangle$ = 60-70 MeV and type II with $\langle T_2 \rangle$ = I20-I30 MeV. It has also been shown that clusters of type I have universal properties depending on neither the type of reaction in which they are produced nor collision energy from 4 to 40 GeV/c. Such properties of nucleon clusters characterize fundamental features of hadron matter, and the observation of nucleon clusters can be associated with the existence of highly exoited nuclear matter.

Assuming that nucleon clusters are decay products of some quasi-stationary states produced in relativistic nuclear collisions, the lifetime of excited nuclear matter can be estimated.

This paper presents the results of studying nucleon olusters as resonance states with the measurement of their widths and hence their lifetimes. Preminary results have published elsewere.[2]

§ 2. EXPERIMENT AND METHOD OF ANALYSIS

Experimental data are obtained using the 2m propane bubble chamber exposed to the beams of p, d, He and C particles with P = 4.2 A GeV/c at the Synchrophasotron at the Laboratory of High Energies, JINR. The methods of experiment and film information analysis are described in detail in papers /3-5/. The total statistics of interactions on propane is given in Table I. The separation criteria of p, d, He and C collisions with carbon nuclei from the events on propane are described in paper[5].

Table I

STATISTICS OF EVENTS

Type of interaction	Number of events
p (C_3H_8)	8884
d (C_3H_8)	II37I
He(C_3H_8)	9039
C (C_3H_8)	I4635

The efficiency of separation of collisions with carbon was no less than 96%.

Some peculiarities of secondary particle identification in the propane chamber should be noted. The chamber was located in the magnetic field, and so negative particles were identified by the curvature of their tracks. The lower limit of proton registration in the chamber, was P = I50 MeV/c. Protons could be distringuished from π^+ mesons up to P = 900 MeV/c by path and ionization. Positive singlecharged particles with momentum more than this value were classified as protons. The maximum mixture of π^+ mesons among positive particles in p, d, He and C collisions with carbon nuclei not exceed I2%.

Proton clusters were separated by the Lorentz invariant method in 4-velocity space.

Main variables are dimensionless relativistic - invariant quantities[6,7]

$$b_{ik} = -\left(\frac{P_i}{m_i} - \frac{P_k}{m_k}\right)^2 = -(u_i - u_k)^2 \qquad \text{(I)}$$

Here P_i and P_k are four - momenta; m_i and m_k the masses of the considered particles.

To separate clusters in the events with proton multiplicity $n_p \geqslant 4$, the quantity A_2 was minimized[I]:

$$A_2 = \min\left[-\sum_k \left(V_\alpha - u_k^\alpha\right)^2 - \sum_i \left(V_\beta - u_i^\beta\right)^2\right] \qquad (2)$$

were V_α and V_β are the centre of clusters α, β. They are unit 4-dimensional vectors.

$$V_{\alpha(\beta)} = \sum_i u_i^{\alpha(\beta)} \Big/ \sqrt{\left(\sum_i u_i^{\alpha(\beta)}\right)^2} \qquad (3)$$

$$u_k^\alpha = P_k^\alpha / m_k \quad ; \quad u_i^\beta = P_i^\beta / m_i$$

are 4-velocities of secondary protons relative to the centre of clusters α and β, respectively. Spectator ($P_{lab} \leq 250$ MeV/c) and stripping ($P_{lab} > 3,0$ GeV/c and $\theta_{lab} \leq 4^\circ$) protons were excluded from the analysis.

All possible permutations of n_p protons into two groups were concidered in order to separate out two clusters.

Two clusters or one cluster and a positively charged particle were assumed to be produced in the event if the distance between separated groups of protons in the four-velocity space satisfied the condition

$$b_{\alpha\beta} = -\left(V_\alpha - V_\beta\right)^2 \geqslant 1 \qquad (4)$$

If this condition is fulfilled the event is treatad as undivided. The fraction of undivided events is 32% in pC collisions and decreases up to I4% with increasing projectile mass in CC collisions.

Further, as in previous papers, clusters produced in the target fragmentation region, i.e. the carbon nucleus, have been studied because positively charged particles are identified better in this region. The separation of clusters by variables x_{Ic} and x_{IIc} is discribed in detail in papers [I,8]. Under this condition (4) $\sim$ 8% of protons fall within the overlap region of two clusters in 4-velocity space.

Table 2 gives the number of separated clusters with n_p = 2÷6 in pC, dC, HeC and CC collisions.

Table 2

Number of clusters with proton multiplicity n_p = 2÷6 in p, d , He and CC collisions

n_p	N
2	2090
3	I8I3
4	I020
5	549
6	253

§ 3. **ANALISIS OF EFFECTIVE MASS SPECTRA OF NUCLEON CLUSTERS**

It has been shown[2] that the largest contribution to the production of clusters with T_1 = 60÷70 MeV is made by clusters with small proton multiplicity n_p = 2;3.

Figures I and 2 show the effective mass spectra of clusters with a step of I0 MeV and 25 MeV for this multiplicity, respectively. As seen from the figures, maxima pointing to the possibility of production of nucleon resonance states are observed for some values of masses.

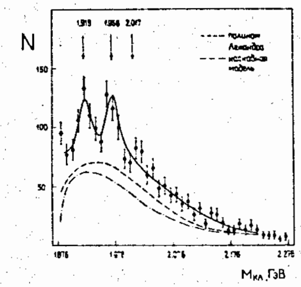

Fig. I

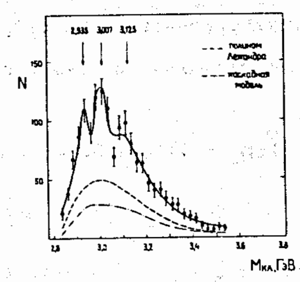

Fig. 2

To analyse the obtained spectra, the resolution function has been defined over different mass M_{cl} intervals. This was realized as follows: for each couple (or three) tracks of particles from the cluster two or three random numbers K_i, distributed according to the normal law were simulated by the Monte Carlo method. These numbers were then multiplied by the value of experimental errors in measuring particle momenta ΔP_i. Later on the cluster mass M'_{cl} was determined taking into account new particle momenta $P_i + K_i \Delta P_i$. The $(M_{cl} - M'_{cl})$ distribution was obtained for diffrent M_{cl} intervals. Such a procedure was repeated more than once for each combination of particle tracks in the cluster. The errors in measuring the emission angles of particles in our experiment are negligibly small in comparison with the momentum ones, and so they were not taken into account.

The obtained $(M_{cl}-M'_{cl})$ distributions in different M_{cl} intervals are satisfactorily described by the Gaussian function.

Dispersions σ of these distributions were derived by approximation with the Gaussian function. The σ dependences on the clusters mass M_{cl} with n_p = 2 and 3 are shown in figs 3 and 4. The errors in determining M_{cl} are small and equal to 2.5÷ 4 MeV within the first two mass M_{cl} intervals at the phase space boundary at n_p = 2 and 3.

A small error is due to that all proton momenta in this region determined by path with a precision of 2÷3%. Further the value of σ rises linearly with increasing the cluster mass. At n_p = 2 the dependence can be described by the function:

$$\sigma(n_p = 2) = -0.245 + 0.131 \cdot M_{cl} \qquad (5)$$

at n_p = 3

$$\sigma(n_p = 3) = -0.366 + 0.127 \cdot M_{cl} \qquad (6)$$

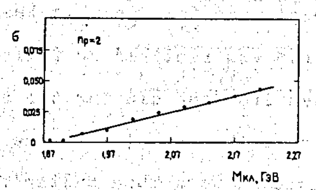

Fig. 3

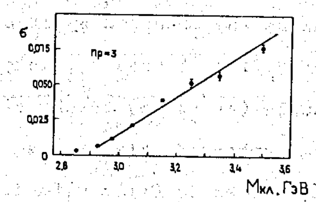

Fig. 4

The obtained dependences have been used to determine the masses and widths of presumable nucleon resonances. For this the experimental dN/dM_{cl} spectra were approximated by an analitical expression containing the sum of the B.W. functions corresponding to 3 resonance states and a background term

$$F(M) = \sum_{i=1}^{3} \alpha_i \, B.W._i(M) + \beta \cdot Ph(M) \qquad (7)$$

Here and are the coefficients defining the contributions of the B.W. functions and the background term. When analysing the spectra of cluster masses, we have to take into account the distortion of the B.W. functions because of changing the experimental mass errors.

So the B.W. functions are given as follows

$$B.W._i(M) = \frac{1}{\sqrt{2\pi}} \int_{n_p; m_p} B.W._i(m) \frac{1}{\sigma(m)} \exp\left[-\frac{(M-m)^2}{2\sigma^2(m)}\right] dm \qquad (8)$$

The σ(m) dependence is taken according to formulae (5) and (6). The B.W. (m) functions are written as

$$B.W._i(m) = \frac{1}{(M_i - m)^2 + \Gamma_i^2/4} \qquad (9)$$

Intergration in formula (8) was performed over the whole mass interval observed in the experiment. The intergral value of the $B.W._i$ functions smeared by the resolution function was normalized to unity.

Two variants have been considered as a background term.

I. Background term was taken as a linear combination of Legendre orthogonal polinomials of the 4th degree

$$\Phi_{n+1} = a_0 P_0 + a_1 P_1 + \ldots + a_n P_n \qquad (10)$$

The coefficients a_n were derived approximating the dN/dM_{cl} experimental spectra by function (10).

2. The effective mass distributions obtained in pC, dC, ^{4}HeC and ^{12}CC collisions simulated by the cascade model were regarded as background ones /9,10/. These distributions were obtained with the aid of the algorithm used for the analysis of experimental data.

Simulated events of different types were summed up in the same proportions as in the experiment.

In both cases background and experimental distributions were previously normalized to the same square. Then the value of the coefficient β was derived approximating by formula (8).

The results of approximation of the experimental spectra by the function (8) are shown in figs. 2 and 3 by the solid lines. The contribution of background distribution is denoted by the dashed lines.

Tables 3 and 4 give both the values of masses M_i, widths Γ_i, and also coefficients determing the contribution of background distributions.

Table 3

The values of masses M_i and widths Γ_i of proton resonances with multiplicity $n_p = 2$

i	M_i, GeV	Γ_i, GeV	χ^2/n	M_i, GeV	Γ_i, GeV	χ^2/n
	Background is taken as the sum of Jegendre polinomials (β = 0.66)			Background is taken as "cluster" mass distributions in events simulated by the cascade model (β = 0.36)		
I	I.919±0.003	0.023±0.0I2	I.05	I.920±0.002	0.022±0.0II	I.04
2	I.967±0.004	0.0I0±0.0I5		I.966±0.004	0.0I0±0.0I4	
3	2.0I4±0.042	0.I68±0.084		2.009±0.007	0.I95±0.023	

Table 4

The values of masses Mi and widths Γi of proton resonances with multiplicity n_p= 3

i	Mi , GeV	Γi, GeV	χ^2/n	Mi, GeV	Γi, GeV	χ^2/n
	Background is taken as the sum of Jegendre polynomials (β= 0.46)			Background is taken as "cluster" mass distributions in events simulated by the cascade model (β = 0.27)		
I	2.935±0.0II	0.07I±0.020	0.94	2.933±0.007	0.09I±0.0I8	0.86
2	3.007±0.005	0.0I6±0.0I5		3.006±0.005	0.022±0.0I8	
3	3.I25±0.029	0.249±0.045		3.I22±0.0I2	0.225±0.032	

As seen from the tables, in two - and three - proton clusters the first two states with M_1 and M_2 are characterized by widths from a few MeV to a few tens MeV, i.e. they are rather narrow. The masses M_1 at n_p = 2 concide within the experimental errors with the masses of narrow dibaryon resonances observed in paper /II/ as well as in a number other works.

The states with masses M_3 are characterized by widths of I00÷200 MeV. However, the mass resolution does not allow one to register resonance states with widths of tens MeV in the region of large M_{cl}.

That is why the observed states with masses M_3 can be realy the superposition of such states, and this lead to increasing the measured width Γ_3.

We failed to find a resonance structure in effective mass distributions of clusters with multiplicity $n_p \geqslant 4$ using the available statistical data.

§ 4. ANGULAR DISTRIBUTIONS OF PROTONS PRODUCED IN RESONANCE DECAY

The angular distributions of protons in the rest frame of clusters produced in the mass region close to resonance values have been studied in order to have a notion about spin states of presumable resonances. The folliwing mass regions were chosen: at n_p = 2: $M_{cl} = M_1 \pm$ I2 MeV and $M_{cl} = M_2 \pm$ I0 MeV; at n_p = 3: $M_{cl} = M_1 \pm 50$ MeV and $M_{cl} = M_2 \pm 30$ MeV.

Figures 5 and 6 show the proton $|\cos\theta_s|$ distributions in the cluster rest frame, were θ_s is the emission angle of protons relative to the momentum direction of the cluster in the lab. system. Similar distributions are presented for comparison in the region of large masses were no resonance structures are observed within the experimental errors. As seen from the figures, the angular distributions of protons in the cluster rest frame differ from the isotropic ones except the mass region

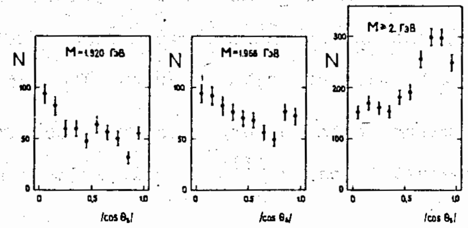

Fig. 5

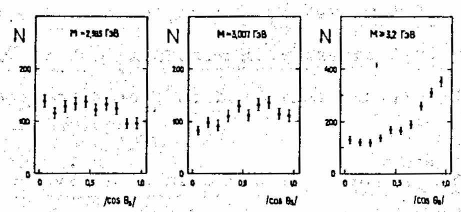

Fig. 6

near M_1 = 2.935 GeV. This shows that presumable nucleon resonances could have a spin different from zero. However, our statictics should be increased significantly on order determine spin states of nucleon resonances.

§ 5. CONCLUSIONS

The study of the nucleon cluster properties with T_1 = 60÷70 MeV produced in hadron-nucleus and nucleus-nucleus collisions at T = 4.2 A GeV allows the following main conclusions to be drawn.

I. Previously discovered universal properties of nucleon clusters, i.e. their independence of the type of reaction and projectile energy indicate that the process of nucleon cluster production is closely related to the degree of excited nuclear matter in relativistic nuclear collisions.

2. The analysis of the effective mass spectra of nucleon clusters with n_p = 2;3 allows one to assume that they are a decay products of

nucleon resonance states with widths from a few MeV up to a few tens MeV which corresponds to the lifetime of such states $\tau = \hbar/\Gamma \sim 10^{-22}$ sec.

3. The angular distribution character of protons in the cluster rest frame relative to the direction of cluster momentum in the lab. system shows that presumable resonance states could have spins different from zero.

4. A sizeable increase of statistics is reguired for completion of this analysis.

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REFERENCES

I. Baldin A.M. et al. - Yad. Fiz., I989, v. 49, p.I034
2. Baldin A.M. et al. - Yad.Fiz., I990, v.52, p.I427
3. Akhababian N. et. al. - JINR, I-I2II4, Dubna, I979
4. Angelov N. et.al. - JINR, I-I2424, Dubna, I979
5. Armutlijski D. et. al. - JINR, PI-86-263, Dubna, I986
6. Baldin A.M. - DAN SSSR, I975, v.222, p.I064
7. Baldin A.M. and Didenko L.A. - JINR Rapid Comm., №3-84, Dubna, I984, p.5
8. Armutlijski D. et. al. - JINR Rapid Comm., № 4(24)-87, Dubna, I987, p.5
9. Gudima K.K. and Toneev V.D., Yad. Fiz.,I978, v.27, p.669
I0.Gudima K.K. and Toneev V.D., Nucl.Phis.A, I983, v. 400, p.I73
II.Troyan Yu.A. et.al. JINR, PI-90-78, Dubna, I990

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