ISSN 1512-1461

UDC 539.1

MECHANIZM OF CUMULATIVE PROTON PRODUC TION IN NUCLEUS-NUCLEUS IZM COLLISIONS

L. N. Abesalashvili[1], L. T. Akhobadze[1], V. R. Garsevanishvili[2], Yu. V. Tevzadze[1]

[1] Institute of High Energy Physics of I. Javakhishvili Tbilisi State University
[2] A. Razmadze Mathematical Institute of I. Javakhishvili Tbilisi State University

Abstract.
Average kinematic characteristics (akc) of cumulative protons – p^{cum} produced in pTa-(10GeV/c) and CC and CTa (4.2GeV/c) collisions are studied. Analysis has been performed on the basis of the so called "cold" and "hot" models, which are connected with appearance of fluctons (dense quark bags) in target nucleus.
The results obtain are compared with predictions of the quark–gluon string model (QGSM).

Key word *: nucleus, nucleon, fluctons, quark.*

Introduction

In lepton-lepton, lepton- nucleus, lepton- nucleon, nucleon- nucleon and nucleus- nucleus collisions for the selection of cumulative particles(hard and soft processes, jets of hadrons) the following variable is used:

$$n_k = (E - p_{||}) / m_N \qquad (1)$$

where E is the energy, $p_{||}$ is the longitudinal momentum in the Lab frame, m_N is the nucleon mass [1,2,3,13].

So defined variable is interpreted as the minimal mass of the target which is necessary for the creation of given particle [3]. Proton with $n_k > 1$ is called cumulative. This gives the information on the hard collision and on the influence of nuclear medium on the formation of particle characteristics.

Particles with different n_k are particles with different average kinematic characteristics(or,particles who creation on the different targets).

The study of cumulative particles and cumulative processes is performed during last 40 years, but the perfect theory still does not exist. The idea of the possible mechanism of realization of such processes has been put forward by A. Baldin in Ref. [4]. According to this idea for the formation of cumulative particle it is necessary the fusion of two or more nucleons into the nuclear droplet with space distribution less than 1 Fermi. This idea was essentially the development of the D. Blokhintsev hypothesis [5] which has been put forward for the explanation of the backward moving protons.

According to Ref. [4] creation of dense nuclear bags (fluctons) can occur by two mechanisms. As a result of fluctuation of density of the target in the usual nuclear matter
("cold model") and as a result of increase of the density of the target under the action of the incoming object ("hot model"). The difficulty of the choice between this two models remains nowdays [6,15].

ISSN 1512-1461

In the present paper average kinematic characteristics (akc) of cumulative protons - p^{cum} and surrounding particles protons - p^{ass} are studied; the dependence of average kinematic characteristics of p^{cum} - protons on the mass number A_i of the incoming nucleus, on the incident energy and on the number of cumulative protons n_p^{cum} (or, on the A_t-target mass).

Experimental data are obtained on the two metre propane bubble chamber PBC-500 of the Laboratory of High Energies of JINR (Dubna) . The chamber was bombarded by beams of light nuclei p, d, He, C, F, Mg in the momentum range (2-10)AGeV/c. Problems of data handling are considered in Refs [7-13].

Analysis of Characteristics of p^{cum} -Cumulative Protons and p^{ass} - Surrounding Protons

In Tables 1-9 and Figs. 1,2 average kinematics characteristics(akc) of cumulative protons- p^{cum} and surrounding protons- p^{ass} are given dependent on n_p^{cum} -number of cumulative protons in every event. According to the above ideas [4] cumulative protons ($n_p^{cum} > 1$) are produced in hard scattering on the multiquark system (flucton); therefore average kinematic characteristics of cumulative protons - p^{cum} and p^{ass} -surrounding protons should significantly differ. (see Table 1 and Fig.1,2).

Significantly differ the dependence $< p_L(n_p^{cum}) >$ and the dependence $< p_L^{ass}(n_p^{cum}) >$. Average momentum of p^{cum} -protons practically is constant as a function of the number of cumulative protons - n_p^{cum}. We wonder why $< p_L^{cum} >$ (or $< \theta_L^{cum} >$) does not depend on the number of cumulative protons n_p^{cum}. It seems that there is a mechanism of the emission of cumulative protons p^{cum}, which does not depend on the number of participating nucleons.

It is interesting the influence of the target mass A_t on the production of p^{cum} - cumulative protons. It is seem from the Table 1 that the number of cumulative protons n_p^{cum} in CTa-collisions reaches 11. Thus there appear 11 fluctons in the Ta nucleus. In CC- collisions the number of cumulative protons n_p^{cum} reaches 4. (see Table 2). It is seen from the Table 2 that in CC- collisions average kinematic characteristics of p^{cum} and p^{ass} protons do not depend on n_p^{cum}, in contrast to CTa— interactions, where the dependence $< p_L(n_p^{cum}) >$ is good pronounced (Table 1, Fig. 1). Average numbers of cumulative protons $< n_p^{cum} >$ in CC and CTa- collisions significantly differ (See Table 3).

$< n_p^{cum}(CTa) >= 1.66 \pm 0.10$, $< n_p^{com}(CC) >= 0.35 \pm 0.01$. Thus the probability of the creation of fluctons in the heavy nucleus Ta is higher than in the light nucleus C. The same is the reason that the percentage of hard processes in CTa- collisions is (54±2)% but in CC- collisions is (30.0±0.5)%. The percentage of cumuletive protons :
$R_p^{cum}(CC) = (7.55 \pm 0.12)\%$, $R_p^{cum}(CTa) = (18.35 \pm 0.31)\%$ (Table 3).

ISSN 1512-1461

Average kinematic characteristics are well described by theQGSM- quark – gluon string model (Table 4).

Average cumulative numbers for all protons $< n_p^{cum}(t) >$, for cumulative protons $< n_k^p(cum) >$, for cumulative protons emitted backward $< n_p^{cum}(b) >$ and forward $< n_p^{cum}(f) >$ in the Lab. frame are given in the Table 5.

It is seen that average experimental and model values of n_k protons are close to each other in both CC and CTa-collisions; But average values of the cumulative number for all protons $< n_p^{cum}(t) >$ in CC and CTa- collisions differ

$$< n_k^p(t)(CTa) > \approx 1.50 < n_k^p(t)(CC) > \qquad (2)$$

Average values of cumulative protons $< n_k^p(cum) >$ practically coincide:

$$\begin{aligned} &< n_k^p(cum)(CC) > \approx 1.20 \pm 0.02 \\ &< n_k^p(cum)(CTa) > \approx 1.25 \pm 0.02 \end{aligned} \qquad (3)$$

Situation for the p^{ass}-surrounding protons is the following:

$$\begin{aligned} &< n_k^p(ass)(CC) > \approx 0.443 \pm 0.003 \\ &< n_k^p(ass)(CTa) > \approx 0.600 \pm 0.010 \end{aligned} \qquad (4)$$

They are significant different.

From the data analysis (see Table 5) it is seen that average kinematic characteristics of cumulative protons p^{cum} produced in CC and CTa-interactions should practically the same , they are produced on the similar targets (similar fluctons); but average kinematic characteristics of surrounding protons - p^{ass} should significantly differ. Experimental data confirm our suggestion (see Tables 1,6).

Thus, experimental data and comparative analysis of protons confirm the “cold” model in the formation of fluctons.

It is interesting what is the role of incoming particle and his energy in the formation of fluctons(or , p^{cum} - cumulative protons).

Average values of cumulative number for all protons (in pTa-collisions at 10GeV/c) is equal to:

$$< n_k^p(t) > (PTa) >= (0.73 \pm 0.01) \qquad (5)$$

Thus, $< n_k^p(t) >$ for CTa-collisions at 4.2AGeV/c and pTa- collisions at 10GeV/c practically coincide (see Table 5). This means that collisions occur mainly on the similar targets (similar fluctons). Thus average momentum and angular characteristics for all protons should by similar. Experiment confirm this suggestion (see Table 8). Average values of n_k variable cumulative protons $< n_k^p(cum) >$ in CC, CTa and pTa- collisions are close to each other. Thus, average kinematic characteristics ot p^{cum} - protons should be close to each other (see Table 1,2 5,7,9).

Maximal number of fluctons in to event in every pTa- collisions at 10GeV/c reaches 7, but in CTa -collisions at 4.2AGeV/c reaches 11 (see Tables 1,9). This means that in the formation of cumulative particles certain role is played by the incident particle A_i and his energy.

ISSN 1512-1461

Analyzng characteristics of cumulative p^{cum} and surrounding - p^{ass} protons, we may say: target nucleus are not a volume with consist with free nucleons. Incoming nucleons interact not only free nucleons and nucleons clusters (fluctons) inside target nucleus but incoming nucleons interact also with two (or, three) nucleons (see Fig. 3).

Conclusion

Analisis of characteristics of cumulative protons - p^{cum} allows one to say:

1. The main role in the formation of fluctons(of cumulative protons) is played by the heavy target nucleus (cold model). But the certain role is played also by the incident particle and his energy;
2. Incoming (incident) nucleons, interact not only with free nucleons of the target and nucleons clusters (fluctons), but also with parts of nucleons (quarks);
3. In some sense fluctons can be considered as a droplet qg-quark-gluon plasma inside volume target nucleus.

Table #1

CTa(4.2AGeV/c) –interactions

Dependence of average kinematic characteristics (akc) p^{cum}-cumulative protons and p^{ass}-surrounding protons on the number n_p^{cum} - cumulative protons.

p^{cum}-protons

N	$< P_L^{cum} > GeV/c$	$< P_\perp^{cum} > GeV/c$	$< \theta_L^{cum} > \deg r$	$< Y_L^{cum} >$	n_p^{cum}
1	0.524±0.041	0.446±0.037	109.4±5.15	-0.101±0.015	1
2	0.550±0.039	0.475±0.035	108.3±4.50	-0.097±0.014	2
3	0.569±0.040	0.499±0.036	105.0±4.47	-0.069±0.011	3
4	0.559±0.042	0.493±0.038	107.0±0.76	-0.084±0.012	4
5	0.573±0.041	0.496±0.040	106.1±4.77	-0.081±0.013	5
6	0.621±0.047	0.555±0.044	101.2±4.76	-0.041±0.010	6
7	0.631±0.053	0.519±0.045	103.1±5.48	-0.054±0.011	7
8	0.595±0.061	0.526±0.055	104.0±6.50	-0.059±0.013	8
9	0.610±0.071	0.519±0.066	102.3±7.10	-0.051±0.016	9
10	0.517±0.085	0.450±0.070	109.1±8.00	-0.080±0.031	10
11	0.594±0.092	0.533±0.080	101.3±8.50	-0.049±0.033	11

p^{ass} - protons

N	$< P_L^{ass} > GeV/c$	$< P_\perp^{ass} > GeV/c$	$< \theta_L^{ass} > \deg r$	$< Y_L^{ass} >$	n_p^{cum}
1	1.674±0.037	0.448±0.014	25.88±0.46	1.010±0.020	0
2	1.306±0.032	0.446±0.015	30.90±0.58	0.804±0.022	1
3	1.178±0.030	0.464±0.017	34.02±0.68	0.723±0.021	2
4	1.091±0.031	0.464±0.017	35.34±0.89	0.669±0.024	3
5	1.049±0.034	0.468±0.019	36.08±0.86	0.650±0.023	4
6	1.011±0.035	0.471±0.021	36.79±0.93	0.628±0.025	5
7	0.972±0.038	0.467±0.023	37.88±1.05	0.598±0.026	6
8	0.939±0.041	0.458±0.026	37.33±1.00	0.591±0.037	7
9	0.996±0.034	0.497±0.034	39.44±1.80	0.601±0.033	8
10	0.993±0.064	0.445±0.038	37.03±1.65	0.592±0.077	9

ISSN 1512-1461

11	0.848±0.080	0.448±0.055	39.24±2.10	0.541±0.063	10
12	0.935±0.085	0.462±0.047	36.74±2.47	0.598±0.071	11

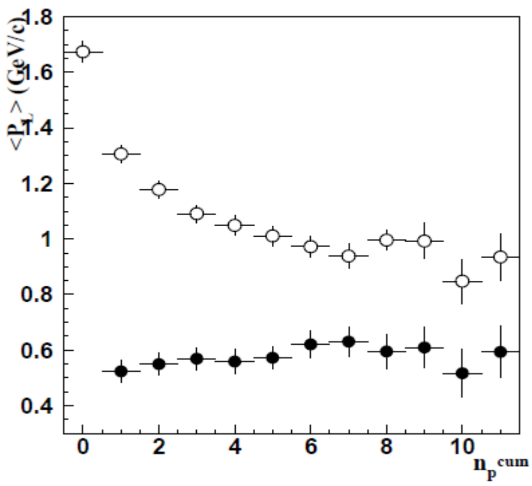

Fig.1 CTa-carbon- tantalum interactions at 4.2AGeV/c. Dependence of $< p_L(n_p^{cum}) >$ average momenta of protons on n_p^{cum}; p^{cum} -●, p^{ass} -o;

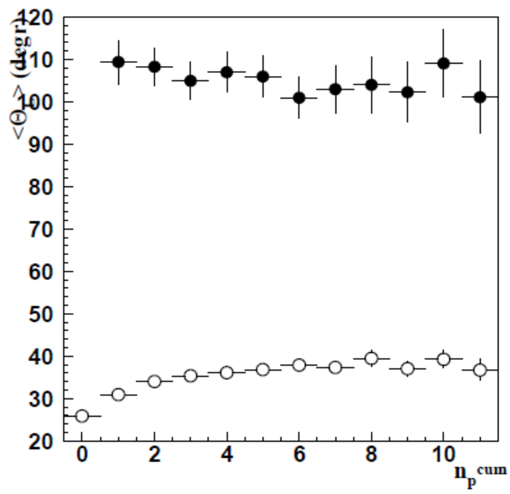

Fig.2 CTa-carbon- tantalum interactions at 4.2AGeV/c.Dependence of $< \theta_L(n_p^{cum}) >$ - average scattering angles protons on n_p^{cum}; p^{cum} -●, p^{ass} -o;

Table 2

CC-carbon-carbon interactions at 4.2AGeV/c
Dependence of average kinematic characteristics of p^{cum} and surrounding p^{ass} - protons on the number of cumulative protons - n_p^{cum}

P^{cum} - protons

N	$< P_L^{cum} > GeV/c$	$< p_\perp^{cum} > GeV/c$	$< \theta_L^{cum} > \deg r$	$< Y_L^{cum} >$	n_p^{cum}
1	0.617±0.015	0.498±0.013	96.41±1.50	-0.009±0.001	1
2	0.642±0.030	0.496±0.025	93.35±2.65	0.019±0.004	2
3	0.598±0.018	0.480±0.059	94.41±5.11	-0.003±0.002	3
4	0.718±0.200	0.581±0.172	89.82±8.11	0.006±0.021	4

P^{ass} - protons

N	$< p_L^{ass} > GeV/c$	$< p_\perp^{ass} > GeV/c$	$< \theta_L^{ass} > \deg r$	$< Y_L^{ass} >$	n_p^{cum}
1	1.873±0.017	0.463±0.006	22.52±0.020	1.122±0.011	1
2	1.874±0.047	0.467±0.015	22.38±0.043	1.124±0.029	2
3	1.979±0.140	0.440±0.046	20.92±1.230	1.179±0.123	3
4	2.132±0.301	0.449±0.120	17.09±10.100	1.132±0.254	4

Table 3

The percentage of cumulative protons - $R(p^{cum})$, cumulative (hard) processes - R_{ev}^H; n_p^{cum} - average value of cumulative protons in CTa and CC(4.2AGeV/c) and pTa(10GeV/c) interactions

A_iA_t-collisions	$< n_p^{cum} >$	R_{ev}^H(%)	$R(P^{cum})$%
CTa	1.66± 0.04	54±2.0	18.35±0.31
CC	0.35±0.01	30±0.5	7.55±0.12
PTa	0.76±0.02	42±2.0	19.74±0.50

ISSN 1512-1461

Table 4

Average kinematic characteristics of protons in CC and CTa-collisions 4.2AGeV/c. (Experimental and model- QGSM)

	$< P_L > GeV/c$	$< P_\perp > GeV/c$	$< \theta_L > \deg r$	$< Y_L >$	$< \cos\theta^*_{NN} >$
CTa- collisions					
EXP	1.144±0.010	0.457±0.050	46.32+0.30	0.624±0.007	-0.500±0.007
MOD	1.172±0.002	0.524±0.002	46.30±0.40	0.619±0.003	-0.513±0.004
CC- collisions					
EXP	1.891±0.009	0.467±0.023	28.24±0.02	1.042±0.005	-0.046±0.005
MOD	1. 925±0.005	0.584±0.002	28.95±0.06	1.071±0.003	-0.040±0.001

Table 5

Average values of cumulative number n_k of protons in CC and CTa- collisions at 4.2AGeV/c and pTa-collisions at 10GeV/c.(Experimental and Model data).

CC-collisions (4.2AGeV/c)					
*	$< n^p_k(t) >$	$< n^p_k(cum) >$	$< n^p_k(ass) >$	$< n^p_k(b) >$	$< n^p_k(f) >$
MOD(QGSM)	0.494±0.002	1.182±0.012	0.441±0.002	1.291±0.007	1.127±0.014
EXP	0.496±0.003	1.200±0.021	0.443±0.003	1.280±0.00	1.110±0.030
CTa- collisions(4.2AGeV/c)					
MOD(QGSM)	0.720±0.003	1.222±0.010	0.591±0.007	1.33±0.01	1.097±0.011
EXP	0.721±0.011	1.250±0.021	0.601±0.011	1.32±0.03	1.130±0.040
PTa- collisions (10GeV/c)					
EXP	0.730±0.011	1.27±0.04	0.641±0.040	1.32±0.05	1.130±0.06

Table 6

CC and CTa- collisions at (4.2AGeV/c). Average kinematic characteristics of P^{cum} - protons and P^{ass} -surrounding protons

CC- collisions (4.2AGeV/c)

$< P^{cum}_L > GeV/c$	0.623±0.013	$< P^{ass}_L > GeV/c$	1.891±0.009
$< P^{cum}_\perp > GeV/c$	0.504±0.011	$< p^{ass}_\perp > GeV/c$	0.464±0.003
$< \theta^{cum}_L > \deg r$	95.61±3.34	$< \theta^{ass}_L > \deg r$	22.400±0.009
$< Y^{cum}_L >$	-0.002±0.006	$< Y^{ass}_L >$	1.132±0.006

CTa- collisions

ISSN 1512-1461

$<P_L^{cum}> GeV/c$	0.578±0.015	$<P_L^{ass}> GeV/c$	1.202±0.012
$<P_\perp^{cum}> GeV/c$	0.502±0.014	$<p_\perp^{ass}> GeV/c$	0.459±0.006
$<\theta_L^{cum}> \deg r$	105.31±4.73	$<\theta_L^{ass}> \deg r$	33.46±0.025
$<Y_L^{cum}>$	-0.073±0.004	$<Y_L^{ass}>$	0.737±0.008

Table N7

CC- collisions. QGSM- Quark Gluon String Model. Dependance of average kinematic characteristics of p^{cum} и p^{ass} -protons on the number n_p^{cum}.

P^{cum} (QGSM)					
N	$< p_L^{cum}(M) > GeV/c$	$< p_\perp^{cum}(M) > GeV/c$	$< \theta_\perp^{cum}(M) > GeV/c$	$< Y_L^{cum} >$	n_p^{cum}
1	0.689±0.002	0. 649±0.009	87.28±0.78	0.059±0.002	1
2	0.684±0.016	0.617±0.016	86.56±1.35	0.062±0.004	2
3	0.667±0.046	0.37±0.041	87.05±3.21	0.055±0.011	3
4	0.716±0.201	0.680±0.99	85.24±9.11	0.078±0.040	4
P^{ass} (QGSM)					
N	$< p_L^{ass}(M) > GeV/c$	$< p_\perp^{ass}(M) > GeV/c$	$< \theta_\perp^{ass}(M) > GeV/c$	$< Y_L^{ass} >$	n_p^{ass}
1	2.007±0.011	0.573±0.004	24.30±0.012	1.145±0.007	1
2	1.997±0.025	0.566±0.009	24.22±0.24	1.142±0.016	2
3	1.998±0.028	0.554±0.033	23.28±0.86	1.156±0.007	3
4	2.012±0.035	0.513±0.156	22.18±4.06	1.166±0.243	4

Table N8

Average values of momenta and angles in pTa (10GeV/c) и CTa (4.2AGeV/c) –collisions .

	$< P_L > GeV/c$	$< P_\perp > GeV/c$	$< \theta_L > \deg r$	$< \cos\theta_{NN}^* >$
pTa	1.071±0.015	0.432±0.081	47.86±0.900	-0.560±0.008
CTa	1.144±0.010	0.457±0.050	46.32±0300	-0.530±0.007

Table N9

PTa(10GeV/c)-collisions. Dependence of characteristics of p^{cum} on n_p^{cum}.

p^{cum} - protons

N	$< p_L^{cum}(M) > GeV/c$	$< p_\perp^{cum}(M) > GeV/c$	$< \theta_\perp^{cum}(M) > GeV/c$	$< Y_L^{cum} >$	n_p^{cum}
1	0.575±0.037	0.489±0.041	106. ±0.41	-0.084±0.013	1
2	0.579±0.042	0.478±0.037	107.9±4.85	-0.087±0.012	2
3	0.571±0.047	0.476±0.041	107.7±5.41	-0.095±0.025	3
4	0.547±0.068	0.468±0.050	109.0±6.50	-0.106±0.025	4
5	0.566±0.076	0.464±0.065	108.7±7.50	-0.106±0.026	5
6	0.450±0.090	0.377±0.070	111.0±8.50	-0.131±0.040	6
7	0.553±0.130	0.477±0.110	110.0±11.00	-0.121±0.080	7

p^{ass} - protons

ISSN 1512-1461

N	$< p_L^{ass}(M) > GeV/c$	$< p_\perp^{ass}(M) > GeV/c$	$< \theta_\perp^{ass}(M) > GeV/c$	$< Y_L^{ass} >$	n_p^{ass}
1	1.582±0.037	0.425±0.014	26.95±0.50	0.943±0.032	0
2	1.080±0.033	0.424±0.017	34.32±0.80	0.674±0.024	1
3	0.850±0.036	0.403±0.022	37.95±1.12	0.543±0.026	2
4	0.804±0.044	0.419±0.280	38.30±1.50	0.505+0.041	3
5	0.746±0.072	0.378±0.044	39.65±2.68	0.499±0.061	4
6	0.674±0.080	0.380±0.053	43.04±3.22	0.433±0.058	5

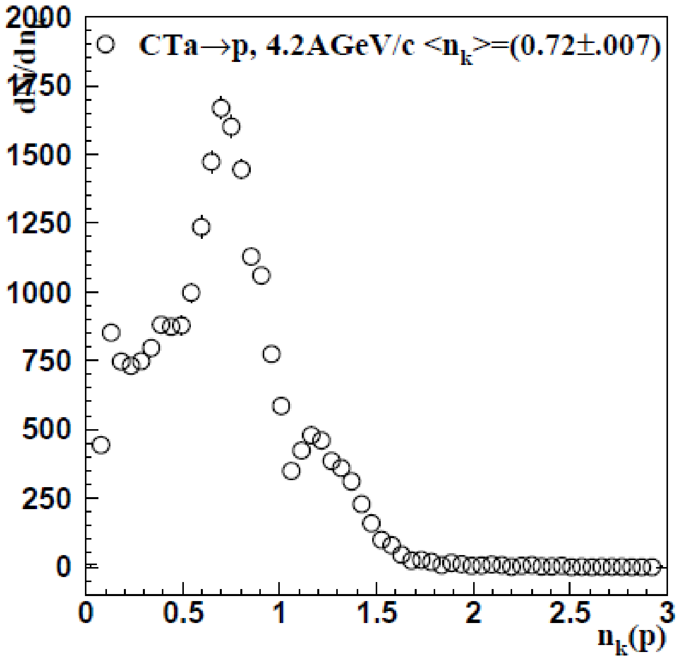

Fig.3 .Distribution of n_k -cumulative number(variable) for protons (CTa- collisions 4.2AGeV/c)

References

1. A.M.Baldin. JINR, E-80-545, Dubna, 1980;
2. A.I.Anoshin et all. YaF, 1982, 36, 409;
3. Ts.I.Baatar et all , YaF, 1982, 36, 431;
4. A.M.Baldin, ECHAYA,1977, 8, 429;
5. D.I.Blokhintsev,JETP, 1957, 33, 1295;
6. A.V.Efremov, ECHAYA, 1982, 13, 613;
7. G.N.Agakishiev et all . JINR , P1-86-370, Dubna, 1986. P1-89-488, Dubna,1989:
8. G.N. Agakishiev et al. JINR, E1-84-448, Dubna, 1984;
9. G.N.Agakishiev et all, YaF, 1987, 45, 1373;
10. Gazdicki M. and Rohrlich D., Z .Phys., 1995, C65, 215;
11. Lu J.J. et al. Phys Rev. Lett., 1981, 46, 898;
12. L.V. Chkhaidze et al. Phys Particles and Fields, 1988, 54, 179;
13. V.S.Stavinski ., ECHAYA, 1979, 10, 949;
14. K.Olimov et all YaF, 2009, 72, N3, 604;
15. V.I.Kukulin, YaF 2011, 74, 1594.

Article received: 2013-11-12