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ENERGY DIVISION AND HADRON TRANSVERSE MOMENTA IN THE QUARK-GLUON STRINGS MODEL

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Деление энергии и поперечные импульсы адронов в модели кварк-глюонных струн

Корреляция среднего поперечного импульса адронов $\langle P_\perp \rangle$ и их множественности анализируется в рамках модели кварк-глюонных струн (МКГС). Показано, что последовательное деление поперечного импульса $P_\perp$ между n померонными ливнями приводит к более сильной зависимости $\langle P_\perp \rangle$ от числа померонов n и, следовательно, от множественности N. Результаты расчетов сравниваются с подобными, полученными методом равномерного деления $P_\perp$.

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Energy Division and Hadron Transverse Momenta in the Quark-Gluon Strings Model

The correlation of the average transverse momentum $\langle p_T \rangle$ and the hadron multiplicity in the framework of the quark-gluon strings model (QGSM) is analyzed. It is shown that the successive division of the transverse momentum p_T between n-Pomeron showers results in the stronger dependence of $\langle p_T \rangle$ on the Pomeron number n and, consequently, on the multiplicity. The calculation results are compared with those obtained by the regular p_T division method.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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1. Introduction

The significant progress in the quantitative description of different hadron characteristics has been reached in the last years in the frame of the quark-gluon strings model (QGSM) [1-6], based on the 1/N-expansion in QCD [7-9]. The QGSM reproduces a large amount of existing experimental data on production of hadrons at high energies [4,6,10,11]. The strong violation of KNO scaling at $s \to \infty$ for multiplicity distribution was predicted [12] by the model just of the form observed by the UA5 group at the SPS collider [13]. In particular, the QGSM allows one to establish the connection between hadron yields in soft and hard processes [14].

So one of the interesting characteristics of the strong interactions at high energies is the dependence of the average transverse momentum $\langle p_T \rangle$ of hadrons produced in hadron-hadron collisions on their multiplicity N. As known, this quantity $\langle p_T \rangle$ increases if the number of produced chared particles N_{ch} rises at the initial energies $\sqrt{s} \geq 20$ GeV [15]. This increase of $\langle p_T \rangle$ comes from large p_T effects in the central region. But this problem is not studied very well.

Explanations have been proposed in terms of possible evidence for hadronic phase transition [16], small impact parameter scattering in the geometrical model [17], production of (mini-)jets from semi-hard scattering [18], or the combination of the two latter effects [19]. The experimental data about $\langle p_T \rangle(N_{ch})$ are compared with the calculations of two currently used low p_T models. These are a two-chain version of the Dual Parton Model [20] and a two-chain FRITIOF Model [21]. The FRITIOF 2.0 version of the Lund model gives the theoretical results which exceed the experimental data, but come close to the data, in particular at large p_T. On the other hand, the DPM cannot reproduce the behavior at large p_T, which it successfully does at low p_T [22,23].

The dependence of $\langle p_T \rangle$ on N_{ch} is analysed in this paper in frame of the QGSM, but with allowance for the dependence of the quark structure functions and the fragmentation functions on the internal quark transverse momentum [24,25]. It was shown in our ref.[25], that the successive division of the transverse momentum p_T between n-Pomeron showers or 2n quark-antiquark chains gives strong dependence of $\langle p_T\rangle$ on n, $\langle p_T\rangle \sim \sqrt{n}$, but the regular division of p_T gives sufficiently weak dependence $\langle p_T\rangle \sim \sqrt{2-1/n}$ [24]. Therefore, it is very interesting to analyse the dependence of $\langle p_T\rangle$ on N_{ch} in the frame of these two models.

2. Energy division between Pomeron showers

Usually, the characteristics integrated over the transverse momentum p_T or at the average $\langle p_T\rangle$ are considered in the frame of the QGSM. In the QGSM the inclusive cross section of the hadron production of type h is given in the following simple form [1]:

$$\frac{d\sigma^h}{dy} = x_R \frac{d\sigma^h}{dx} = \int E\frac{d\sigma}{d^3\vec{p}} d^2p_T = \sum_n \sigma_n(s)\Phi_n^h(s,y) \cdot \qquad (1)$$

where y is the rapidity, $x=2p_L/\sqrt{s}$ is the Feynman variable, p_L is the longitudinal momentum of the produced hadron, $\sqrt{s}$ is the total energy of two colliding hadrons in their c.m.s., σ_n is the cross section of the n-Pomeron shower production (or 2n quark-gluon strings decaying into hadrons) [26], $\Phi_n(s,y)$ is the hadron distribution produced in n-Pomeron shower; $x_R = (x_\perp^2 + x^2)^{1/2}$, $x_\perp = 2[(\langle p_T^2\rangle + m_h^2)/s]^{1/2}$, m_h, $\langle p_T\rangle$ are the mass and the average transverse hadron momentum respectively.

The distribution $\Phi_n(s,y)$ depends on the method of the initial energy division between n Pomeron showers [1]. We consider two simple versions of this division. In the first of them the energy is divided evenly and the role of the Feynman variable in the n-Pomeron shower is played by the value $x_n = nx$. The distribution $\Phi_n(s,n)$ in this case is:

$\Phi_n(\xi,x) = n\Phi_1(\xi_n,x)$, $\xi_n = \xi - 2*\ln(n)$, $\xi = \ln(s/s_0)$, $s_0 = 1$ GeV^2.

The second version is based on the sequence emission of showers by the leading hadron states. That is why here the functions $\Phi_n(s,x)$ have the form [1]:

$$\Phi_n(\xi,x) = \sum_{k=1}^{n} \Phi_1(\xi_k,x_k), \qquad x_k = \frac{x}{(1-x_0)^{k-1}}, \qquad (2)$$

$$\xi_k = \xi - 2(k-1)\ln(1-x_0)^{-1},$$

where x_0 is the energy lost parameter; $x_0 \simeq 0.15$ at the SPS energies.

To derive the dependence of the observed values on p_T it is necessary to know the p_T-dependence of the distribution functions of quarks(diquarks) and their fragmentation into hadrons. The analysis of the processes in the frame of QGSM taking into account the quark and diquark transverse momenta was performed in ref.[24] by the method that is analogical to the regular division of the energy (see above). That is why the weak dependence of the average transverse hadron momentum on the number of $q\bar{q}$-chains n and, consequently, on the Feynman variable x was derived in ref.[24].

Another method of the division of the internal transverse momentum between the quarks (valence and sea) and the diquarks in proton was proposed in our ref.[25], the method is similar to the sequence energy division between n Pomeron showers in hp-interactions.

3. Hadron transverse momenta in Pomeron shower

Let us consider the process $pp \to hx$ at high energy in the frame of the QGSM, taking into account the quark and diquark transverse momenta. As is known, the main contribution to this process give the cylinder type graphs, cut in s-channel (see fig.1). Then we can write the invariant hadron spectrum corresponding to these graphs in the following form [1,2]:

$$E\frac{d\sigma}{d^3\vec{p}} = \sum_n \sigma_n(s)\phi_n(x,p_T), \qquad (3)$$

where $\phi_n(x,p_T)$ is the hadron distribution over Feynman variable x and transverse momentum p_T produced in the decay of the 2n quark-gluon strings. The hadron distribution over rapidity y as a function of transverse momentum p_T and the number of charged particles N_{ch} in the frame of QGSM can be written in the following form [1]:

$$\frac{d\sigma_N}{dy} = \sum_n \sigma_n W_n(N,\bar{N}_n)\Phi_n(y) = \sum_n \sigma_n W_n(N,\bar{N}_n)\int \phi_n(x,p_T)dp_T\ , \qquad (4)$$

$$\bar{N}_n = \int_{-y_{max}}^{y_{max}} \Phi_n(y)dy \qquad (5)$$

is the average multiplicity. The hadron distribution as function of the number of particles N in n-Pomeron shower can be chosen in the Poisson form:

$$W_n(N,\bar{N}_n) \simeq P(N,\bar{N}_n) = \frac{\bar{N}_n^N}{N!}\exp(-\bar{N}_n), \qquad (6)$$

The distributions $\phi_n(x,p_T)$ were represented in the following manner [25]:

$$\Phi_n(x,p_T) = \int_{x_+}^{1} \Psi_n(x,p_T;x_1)dx_1\ , \qquad (7)$$

$$\Psi_n(x,p_T;x_1) = a_h\{F_{qq}^{(n)}(x_+,p_T;x_1) + F_{q_v}^{(n)}(x_+,p_T;x_1) +$$

$$+ 2(n-1)F_{q_{sea}}^{(n)}(x_+,p_T;x_1)\}\ .$$

Here in (7), $x_+=[(x^2+x_\perp^2)^{1/2}+x]/2$, $x_\perp=2[(p_T^2+m_h^2)/s]^{1/2}$. In the case of the π-meson production $a_\pi=0.4$; $a_k=0.05$ -for K-mesons. [1,2];

$$F_\tau^{(n)}(x_+,p_T;x_1) = \int d^2k_T f_\tau^{(n)}(x_1,k_T)\tilde{G}_{\tau\to h}(z;p_T-zk_T), \qquad (8)$$

$$z=x_+/x_1,$$

where the symbol τ means the flavour of (anti-)quarks (valence q, $\bar{q}$ or sea q, $\bar{q}$) and diquarks qq, respectively, $f_\tau(x,k_T)$ is the distribution function of the (anti-,di-)quark τ after n-Pomeron exchange over its longitudinal momentum fraction x and the transverse momentum k_T ; $\tilde{G}_\tau(z,k_T)=zD_{\tau\to h}(z,k_T)$; $D_{\tau\to h}$ - is the fragmentation function of the (anti-,di-)quark into the hadron h.

The distributions of (anti-,di-)quarks, as in ref.[24], were represented in the factorized form: $\tilde{f}_\tau(x,k_T)=f_\tau(x)g_\tau(k_T)$. Functions $g_\tau(k_T)$ are chosen in the form of the Gauss distribution normalized to 1, i.e. $g_\tau(k_T)=(\gamma/\pi)\exp(-\gamma k_T^2)$, so it will also be factorized in the n-chain: $\tilde{f}_\tau^{(n)}(x,k_T)=f_\tau^{(n)}(x)g_\tau^{(n)}(k_T)$. Let us consider the graph of the "cut cylinder" type, fig.1a, corresponding to the production of one Pomeron shower or the decay of two quark-gluon strings [1-3]. The hadron production can be represented in the following manner: each of two colliding protons is divided into quark and a diquark with the opposite transverse momenta; after the colour interection between them and the diquark and the quark respectively of another proton two quark-gluon strings are produced in the chromostatic constant field; then they decay into hadrons. This process of the division of three quarks into a diquark and a quark is repeated n times during production of n Pomeron showers (or 2n $q\bar{q}$-chains) and therefore the diquark or the quark at the ends of every string (see fig.1b) acquires the nonzero transverse momentum. The more division stages are the greater is the momentum. The calculation procedure of the (di-, anti-)quark distribution after the n division can mathematically be represented in the following manner:

$$g_{\tau}^{(n)}(k_T) = \int \prod_{i=1}^{n} g_{\tau}(k_{iT})\,\delta^{(2)}\Big(k_T - \sum_{i=1}^{n} k_{iT}\Big)\,d^2k_{iT}. \qquad (9)$$

If $g_{\tau}(k_T)$ is the Gauss distribution then we have from (9):

$$g_{\tau}^{(n)}(k_T) = (\gamma_n/\pi)\exp(-\gamma_n k_T^2), \qquad (10)$$

where $\gamma_n = \gamma/n$. But in the case of ref.[25] $\gamma_n = \gamma/(2-1/n)$; here γ is the parameter.

Fragmentation functions are represented in the factorized form too: $\tilde{G}_{\tau\to h}(z,p_T,k_T) = G_{\tau\to h}(z,\tilde{k}_T)g_{\tau\to h}(\tilde{k}_T)$, where $\tilde{k}_T = p_T - zk_T$. Functions $g_{\tau\to h}$ are taken in the form: $g_{\tau\to h}(k_T) = (\tilde{\gamma}/\pi)\exp(-\tilde{\gamma}\tilde{k}_T^2)$. The functions $G_{\tau\to h}(z,\tilde{k}_T)$ were represented in the following manner:

$$G_{\tau\to h}(z,\tilde{k}_T) = \bar{G}_{\tau\to h}(z)\exp(-\beta_z \tilde{k}_T^2), \quad \beta_z = 2\alpha_R' \ln(1-z)^{-1},$$

where $\alpha_R' = 1\ (\mathrm{GeV}/c)^{-2}$ is the slope of the Regge-trajectory at $t=0$. (Note that in the case of ref.[24] fragmentation functions $G_{\tau\to h}$ depend on the variables z and p_T). Therefore, after integration over d^2k_T we obtain the following expression for the hadron distribution over x and p_T in the decay of 2n-quark-gluon strings [25]:

$$\phi_n(x,p_T) = \int_{x_+}^{1} dx_1\, \Psi_n(x,p_T;x_1) = \qquad (11)$$

$$\int_{x_+}^{1} dx_1 \Big[f_{qq}^{(n)}(x_1)\bar{G}_{qq\to h}(z)\tilde{I}_n(z,p_T) + f_{q_v}^{(n)}(x_1)\bar{G}_{q_v\to h}(z)\tilde{I}_n(z,p_T) +$$

$$f_{\bar{q}_{sea}}^{(n)}(x_1)\bar{G}_{\bar{q}_{sea}\to h}(z)\sum_{k=1}^{n-1}\tilde{I}_k(z,p_T) + f_{q_{sea}}^{(n)}(x_1)\bar{G}_{q_{sea}\to h}(z)\sum_{k=2}^{n}\tilde{I}_k(z,p_T)\Big],$$

where

$$\tilde{I}_n(z,p_T) = \frac{\gamma_z^{(n)}}{\pi}\exp(-\gamma_z^{(n)}p_T^2), \qquad (12)$$

$$\gamma_z^{(n)} = \tilde{\gamma}/[1+n\rho z^2(1+\tilde{\gamma}^{-1}\beta_z)], \quad \rho = \tilde{\gamma}/\gamma. \qquad (13)$$

As known, the cross section $d\sigma/dp_T^2$ of hadron production at high energy in the region $p_T \le 0.5$ GeV/c is a good approximation by the Gauss distribution. However, in the region $p_T \ge 5$ GeV/c the data of the p_T-distributions are better approximated by the function $\exp(-Bp_T)$. Therefore, as in ref.[24] instead of (12) for p_T-dependence of charged produced hadrons we used the following expression:

$$I_n(z,p_T) = \{B_z/2\pi(1+B_z m_h)\}\exp[-B_z(m_T-m_h)], \qquad (14)$$

where $B_z = B_0/[1+n\rho z^2(1+\tilde{\gamma}^{-1}\beta_z)]$, $B_0 = 2m_h\tilde{\gamma}$.

The expression for the dependence of average hadron transverse momentum $\langle p_T\rangle$ on N_{ch} can be written in the following form:

$$\langle p_T\rangle(N) = \int_{|y|\le y_{max}} p_T \frac{d\sigma_N}{dy}dy \Big/ \int_{|y|\le y_{max}} \frac{d\sigma_N}{dy}dy. \qquad (15)$$

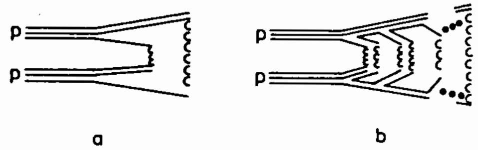

Fig. 1. a -The graph of the "cut cylinder" type in the s -channel of the pp-scattering, corresponding to production of two $q\bar{q}$-chains; b - the graph corresponding to production of n-Pomeron showers or 2n $q\bar{q}$-chains in the reaction pp → hx.

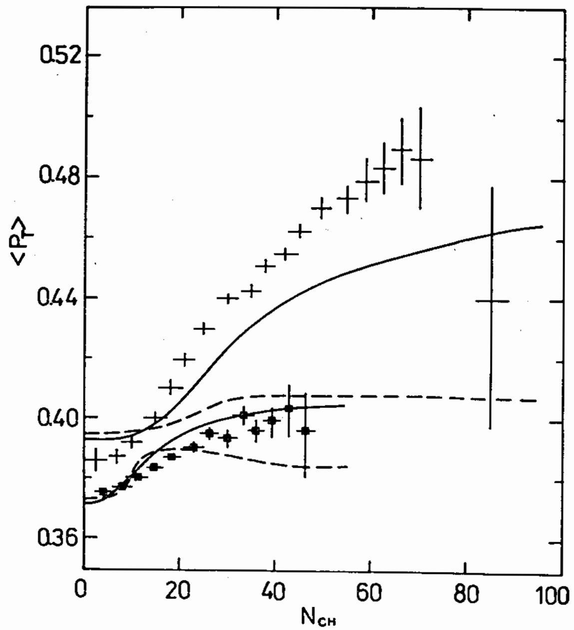

Fig. 2. The dependence of $\langle p_T \rangle$ on the number of charge produced particles N_{ch}. The solid curves correspond to our calculation: upper curve - $\sqrt{s}$ =540 GeV (parameters: B_0=6.19 $(GeV/c)^{-1}$, ρ=4.85), lower one - $\sqrt{s}$ = 63 GeV (parameters: B_0=7.62 $(GeV/c)^{-1}$, ρ=3.17). The dashed curves correspond to the model of ref.[24] with the same parameters B_0 and ρ as in our case: upper curve -$\sqrt{s}$ = 540 GeV, lower one $\sqrt{s}$=63 GeV. Exp. data: ┼ - $\sqrt{s}$=540 GeV, $|\eta|\leq 2.5$ [15,15b], ■ - $\sqrt{s}$ = 63 GeV. $|y|\leq 2.0$ [15,15b].

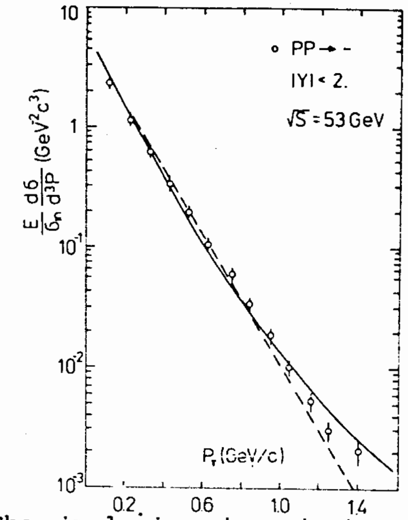

Fig. 3a. The inclusive invariant spectrum of negative charged particles produced in pp -collisions as the function of p_T when $|y|\leq 2$; O - experimental data at $\sqrt{s}$=53 GeV [15d]. The solid curve corresponds to our calculation, the dashed one corresponds to the model of ref. [24] ; parameters: B_0= 7.73 $(GeV/c)^{-1}$, ρ=3.12.

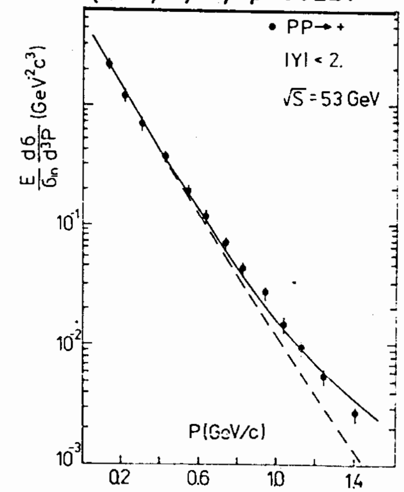

Fig. 3b . The inclusive invariant spectrum of positive charged hadrons produced in pp- collision as the function of p_T, when $|y| \leq 2$, ● —experimental data at $\sqrt{s}$=53 GeV [15d]. The solid curve corresponds to our calculation, the dashed one corresponds to the model of ref.[24]; the parameters are: B_0=7.73$(Gev/c)^{-1}$, ρ=3.12.

Two methods of the division of the hadron transverse momentum between 2n quark-antiquark chains (the successive [24] and the regular [25]) were used in the calculation of expressions (15). Note that in the successive division of p_T the variable x was divided successively too, according to ref.[1].

4. Discussion of results

The calculation results of $\langle p_T\rangle(N_{ch})$ for the pp-collisions are represented in fig.2. Note firstly that the different dependence of $\langle p_T\rangle$ on the number of Pomeron showers n in these two versions of QGSM, as mentioned above, gives the different behaviour of $\langle p_T\rangle(N_{ch})$, as seen from fig.2. This difference is seen more clearly at large initial energies, in particular at $\sqrt{s} \geq 540$ GeV. Note that the experimental data of $\langle p_T\rangle(N_{ch})$ at $\sqrt{s} \approx 540$ GeV are presented for pp-collisiins, but the calculations were performed for pp-collisions. However, the difference between these two processes is small at so high energies and this interval rapidity $|y| \leq 2$, because the main contribution to these interactions is made by cylinder graphs, considered in this paper. The discrepancy of the calculation results in the frame of QGSM and the experimental data on $\langle p_T\rangle(N_{ch})$ at $\sqrt{s} \approx 540$ GeV can be caused by the following. In our version of QGSM the so-called Regge-graphs of the "enhanced" type can give a noticeable contribution at $x \sim 0$ where a lot of hadrons is produced. Besides the above mentioned the semi-hard parton scattering is not taken into account.

Consider now the distributions of hadrons produced in pp-collisions at high energies. The calculation results of the invariant spectrum $E(d\sigma/d^3\vec{p})$ and the corresponding experimental data are presented in fig.3. It is seen from these figures that our version of QGSM and the one of [24] give different results at $p_T \geq 0.5$ GeV/c. In our case there is a long tail of the spectrum at $p_T \geq 1$ GeV/c. It is caused basicaly by the different methods of the division of the transverse momentum between $q\bar{q}$ -chains.

Therefore, the correlation $\langle p_T\rangle(N_{ch})$ and the invariant hadron spectrum $E(d\sigma/d^3\vec{p})$ at $p_T \geq 0.5$ GeV/c are very sensitive to different methods of the division of the energy and the transverse momentum between $q\bar{q}$-chains. The successive division of x and p_T between n-Pomeron showers results in more stronger correlation of $\langle p_T\rangle(N_{ch})$ than the regular division of x and p_T.

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REFERENCES

1. Kaidalov A.B., Ter-Martirosyan K.A. //Phys. Lett., 1982, V.117B, P.247; //Yad. Fiz., 1984, V39, P.1545; V.40, P.211.
2. Kaidalov A.B. //Yad. Fiz., 1981, V.33, P.1369; //Phys. Lett. 1982, V.116, P.459; "Elementary particles", Moscow, Energoatomizdat, 1983, V.2, P.3.
3. Capella A. et al. //Z. Phys. 1980,V.C3, P.329.
4. Capell A., Tran Thanh Van J. //Z. Phys. 1981, V.C10, P.249;
//Phys. Lett., 1982, V.114B, P.450.
5. Aurenche P., Boop F.W., Ranft J. Preprint LAPP-TH-83, 1983.
6. Aurenche P., Boop F.W., Ranft J. //Phys. Lett., 1982, V. 114B, P.363; Z. Phys., 1982, V.C13, P.205.
7. t' Hooft G. //Nucl. Phys., 1974, V.B72, P.461.
8. Veneziano G. //Phys. Lett.,1974, V.52B, P.220; //Nulc. Phys., 1976, V.B117, P.519.
9. Ciafaloni M., Marchesini G., Veneziano G. //Nucl. Phys., 1975, V.B98, P.472.
10. Shabelsky Yu.M. //Yad. Fiz., 1986, V.44, P.186.
11. Kaidalov A.B., Ter-Martirosyan K.A., Shabelsky Yu.M. //Yad. Fiz., 1986, V.43, P.1282.

12. Kaidalov A.B., Ter-Martirosyn K.A. Preprint ITEP-61, Moskow, 1983.
13. Alpgard K. et al.(UA5) Preprint CERN/EP 81-179.
14. Kaidalov A.B. Pis'ma v JETP, 1980, V.32, P.494; //Z. Phys., 1982, V.C12, P.63.
15. Kittel W. //Proc. XXIV Int. Conf. on HEP. Munich, 1988 eds. R.Kotthaus and J.H.Kuhn. P.625. a)Arnison G. et al. Phys. Lett. 1982. V. 118B. P.167. b) BurnettT.H. et al. Phys. Rev. Lett. 1986. V. 57. P. 3249. c)Alexopoulos T. et al. Phys.Rev.Lett. 1988. V.60. P.1622. d)Breakstone A. et al. //Z. Phys. 1987. V.C33. P.333; //Phys. Lett. 1987, V.183B. P. 227; //Phys. Lett. 1983. V. 132B. P. 463.
16. Van Hove L. //Phys. Lett. 1982, V.118B, P.138.
17. Barshay S. //Phys. Lett. 1983, V.127B, P.129.
18. Jacob M. Preprint CERN TH-3515, 1983; G.Pancheri, C.Rubbia //Nucl. Phys. 1984, V.A418, P.117.
19. Wang X.-N. and Hwa R.C. Oregon preprint OITS-387, 1988.
20. Capella A. et al. Phys.Lett. 1979. V.81B. P.68; Z. Phys. 1980. V. C3. P. 329; Adamus M. et al.(NA22) Z. Phys. 1988, V. C39. P. 311.
21. Andersson B., Gustafson G., Nilsson-Almqvist B. Nucl. Phys.1987. V. B281. P. 289; Lundpreprint LU TP 87-6.
22. Capella A.,Tran Thanh Van J. Z.Phys. 1981. V. C10. P.249; Phys. Lett. 1982. V. 114B. P. 450.
23. Aurenche P., Boop F.W. Phys. Lett. 1982. V. 114B. P.363. Z. Phys. 1982. V. C13. P 205.
24. Veselov A.I., Piskounova O.I., Ter-Martirosyn K.A. Preprint ITEP-176, Moscow, 1984; Phys. Lett. V.158B, P.175.
25. Lykasov G.I., Slavin N.V. Yad. Fiz. 1989. V.49. P.1446. JINR Preprint, E2-88-418, Dubna, 1988.
Lykasov G.I., Sergeenko M.N. JINR Preprint, E2-90-363, Dubna, 1990.
26. Ter-Martirosyan K.A. Phys. Lett. 1983. V. 44B. P. 377.

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