УДК 539.123.6

HADRON JETS IN DEEP-INELASTIC $\tilde{\nu}$N INTERACTIONS AND UNIVERSALITY OF THE JET PROPERTIES IN RELATIVE FOUR-VELOCITY SPACE

A.M.Baldin, L.A.Didenko, V.G.Grishin, A.A.Kuznetsov, G.M.Maneva, Z.V.Metreveli*, P.P.Temnikov

A new definition of the jets as clusters in the four-velocity space has been used to make an invariant analysis of the jet production processes in $\tilde{\nu}$N collisions for the three energy intervals of the hadron system: <W> = 3.5; 4.9; 8.0 GeV. The obtained results are compared with the characteristics of the four-dimensional jets in various types of interactions: pp, $\bar{p}$p, π^-p, π^-C, pC and pTa at energies from 6 to 205 GeV. The characteristics of the four-dimensional jets in soft and hard interactions are shown to be universal, i.e., independent of neither the type of the fragmenting system (p, $\bar{p}$, π^-, C, q), nor the collision energy for $P_{lab} \geq$ 22 GeV/c ($\sqrt{S}$ = W > 6 GeV). The obtained result means that the hadronization of the colour charges is determined by the dynamics of their interaction with vacuum.

The investigation has been performed at the Laboratory of High Energies, JINR.

Струи адронов в глубоконеупругих $\tilde{\nu}$N-взаимодействиях и универсальность их характеристик в пространстве 4-мерных относительных скоростей

А.М.Балдин и др.

На основе нового определения струй как кластеров в четырехмерном пространстве относительных скоростей проводится инвариантный анализ струйного рождения адронов в $\tilde{\nu}$N-столкновениях для трех интервалов энергии W адронной системы: <W>= 3,5; 4,9; 8,0 ГэВ. Полученные результаты сравниваются с характеристиками четырехмерных струй в различных типах взаимодействий: pp, $\bar{p}$p, π^-p, π^-C, pTa, pC в области энергий от 6 до 205 ГэВ. Показано, что характеристики четырехмерных струй в мягких и жестких взаимодействиях универсальны, т.е. не зависят ни от типа фрагментирующей системы

*High Energy Institute of Tbilisi State University.

(p, $\bar{p}$, π^-, C, q), ни от первичной энергии для $P_{лаб} > 22$ ГэВ/с ($\sqrt{S} = W > 6$ ГэВ). Полученный результат означает, что адронизация цветных зарядов определяется динамикой их взаимодействия с вакуумом.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

A new relativistic invariant method was suggested in refs. [1,2,3] to obtain the characteristics of the hadron jets in soft hadron-hadron ($\pi^- p$, pp, $\bar{p}p$) and hadron-nucleus ($\pi^- C$, pC, pTa) interactions in an energy range of 6 ÷ 205 GeV.

In this method the multiple particle production processes

$$I + II \to 1 + 2 + 3 \ldots. \qquad (1)$$

are considered in the space the points of which are the four-velocities $u_i = P_i/m_i$, where P_i are the four-momenta of the particles divided by their masses m_i. The positive invariant quantities having the meaning of the squared distances in this space,

$$b_{ik} = -(u_i - u_k)^2 = 2[(u_i u_k) - 1], \qquad (2)$$

where i,k = I, II, 1,2,3..., are basic variables describing the relative particle motion.

The idea of introducing the b_{ik} variables consists in that the cross section of processes (1) have the following properties: in definite domains of these variables the b_{ik} distributions decrease monotonously and rather rapidly with increasing b_{ik}. These properties are formulated [1] as the correlation depletion principle (CDP), which results in the fact that the distributions describing multiple particle processes are factorized in the four-velocity space b_{ik}, i.e. decay into factors assigned to different clusters in this space.

In the present paper CDP has just been used to formulate a new approach to hadron jets: the jet is considered as a cluster with relatively small b_{ik} values in the relative velocity space. The jet axis is determined as a single four-vector V that is extracted from the condition of minimum of the quantity:

$$\sum_k b_k = -\sum_k (V - u_k)^2 . \qquad (3)$$

Summation is performed over the particles belonging to a separated group of particles. Quantity (3) is minimal for

$$V = \sum_k u_k / \sqrt{(\sum_k u_k)^2} \,. \qquad (4)$$

In the pp , $\bar{p}$p , π^-p, π^-C, pC and pTa interactions the hadron jets produced in the beam and target fragmentation regions were selected using the relativistic invariant method, and the b_k distributions of different particles in the jets were studied.

The results of this analysis have shown that the properties of the four-dimensional jets are independent of neither the type of the fragmentating system (π^-, p, $\bar{p}$, C) nor the collision energy for $E \geq 22$ GeV. These experimental facts have pointed out that the hadronization of quarks, diquarks and multiquark systems at high energies is identical in these variables and determined by the interaction dynamics of colour charges with vacuum. In this connection it is particularly important to apply the suggested method to the processes in which, as is generally agreed, the jets are produced due to the hadronization of colour objects in vacuum. It is interesting to analyse the properties of the hadron jets in deep inelastic lepton-nucleon collisions in which, according to the presently existing ideas, an "isolated" (knocked-out) quark and a diquark the hadronization of which is similar to the soft hadronization of quarks and diquarks in hadron collisions (fig. 1) are produced.

To this end, we have analysed the hadron jet properties using the experimental material on $\tilde{\nu}$N interactions obtained by the IHEP, ITEP, FNAL and Michigan State Uniservity Collaboration.

The data on $\tilde{\nu}$N interactions were obtained with the aid of a 15-foot bubble chamber filled with a neon-hydrogen mixture (64% of Ne atoms) at the FNAL accelerator. The chamber was exposed to a beam of muon antineutrinos with

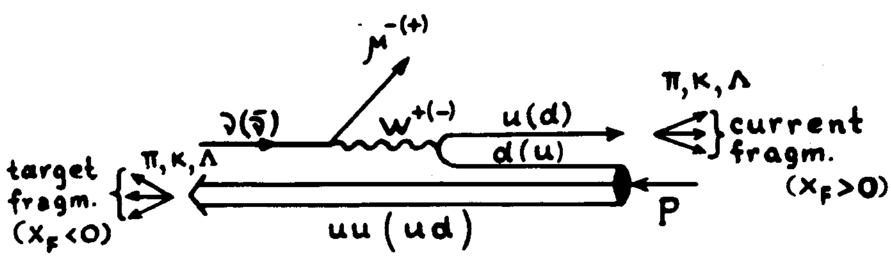

Fig.1. The diagrams of $\bar{\nu}$p *interaction.*

a broad energy spectrum. A total of about 8000 interactions of the type

$$\tilde{\nu} + N \to \mu^+ + \sum_i h_i$$

in which $E_\mu \geq 4$ GeV and $E_{\tilde{\nu}} \geq 10$ GeV, in this case $\langle E_{\tilde{\nu}} \rangle = 35$ GeV $^{/4/}$, were measured. The events with $Q^2 = -q^2 \geq 1$ $(GeV/c)^2$ and

$$x_B = Q^2/2M\nu \geq 0.1, \qquad (5)$$

where q is the four-momentum transfer; M, the nucleon mass; and $\nu = E_{\tilde{\nu}} - E_{\mu+}$, the energy of hadrons in the laboratory system, were selected to separate deep inelastic $\tilde{\nu}N$ collisions with valent u-quarks. To separate the multiple particle production region W was required to be $W^2 \geq 9$ GeV^2 (W is the total hadron energy in the c.m.s.). According to these criteria, 2383 interactions were selected. The conditions $\sum_i e_i = 0$ or -1 and $n_N \leq 1$ (e_i is the charge of secondary particles and n_N the number of secondary nucleons in the interaction) were used to exclude nuclear effects which are due to cascade nucleon reproduction in the nucleus. As a result, we had selected about 1000 events of deep inelastic $\tilde{\nu}$ collisions with valent u-quarks and $W^2 \geq 9$ GeV^2.

It is generally accepted that in the $\tilde{\nu}N$ collisions the particles with $y_i^* > 0$, where y_i^* is the hadron rapidity in the c.m.s., are attributed to the knocked-out quark jet and the particles with $y_i^* < 0$ to the jet of the diquark spectrator. For the pion jets selected in such a way (protons were not considered in this analysis)the jet axis was found by formula (4) and the b_k distribution (3) of π^--mesons was obtained by analogy with the hadron-hadron and hadron-nucleus collisions considered earlier. In order to clear up the energy dependence of the pion b_k distributions in the $\tilde{\nu}N$ collisions, the latter were divided into three energy intervals: 1) $W = 3 \div 4$ GeV, 2) $W = 4 \div 6$ GeV and 3) $W \geq 6$ GeV. Figure 2 shows the b_k distributions of $\pi^\pm$ mesons (the π^+ and π^- b_k distributions are the same) in the jets produced in the fragmentation of the knocked-out quark and the diquark spectator for the three energy intervals of the hadron system. In the $b_k \geq 2$ region all the distributions have an exponential character.

The average $\langle b_k \rangle$ values and B slope distributions obtained by approximation

$$dN/db_k = A\exp(-b_k/B) \qquad (6)$$

are given in Table 1.

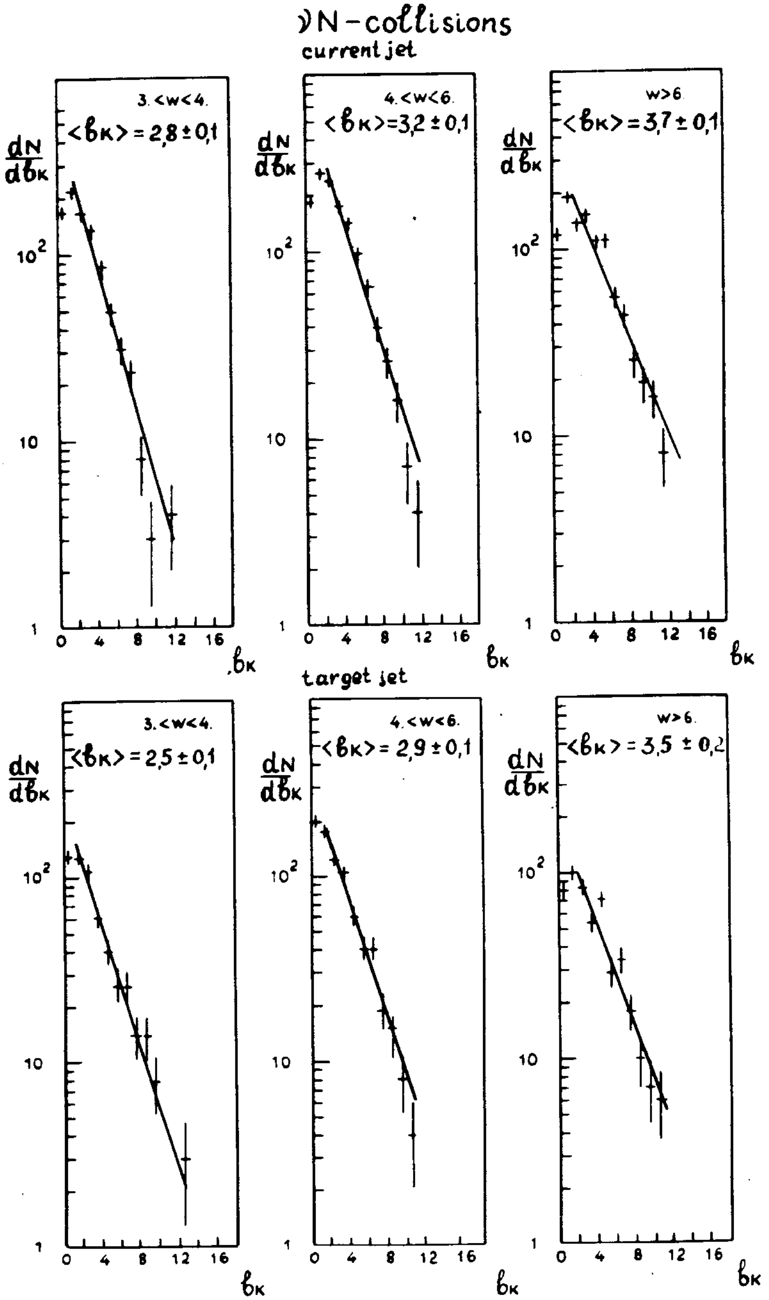

Fig. 2. The b_k *distributions of* $\pi^{\pm}$ *mesons in* $\tilde{\nu}N$ *collisions in the fragmentation region of current and target in different* W *energy intervals. The solid lines shows the results of approximating data by the exponential dependence.*

Table 1

The average $\langle b_k \rangle$ values and B slope for π^-mesons in $\tilde{\nu}N$ collisions

W, GeV	Current Fragmnetation		Target Fragmentation	
	$\langle b_k \rangle$	B	$\langle b_k \rangle$	B
3÷4	2.8 ±0.1	2.5 ±0.3	2.54±0.12	2.22±0.26
4÷6	3.22±0.09	2.71±0.20	2.91±0.13	2.58±0.26
≤ 6	3.71±0.12	3.52±0.26	3.47±0.17	3.95±0.66

As is seen from the table, the average $\langle b_k \rangle$ and B values are identical within the experimental errors for the quark and diquark fragmentation at the same W energy and grow with increasing W. In this case the average size of the jet is equal to $\langle b_k \rangle = 3 \div 4$. In order to make a more exact comparison with the data on hadron-hadron and hadron-nucleus collisions, the jets in the $\tilde{\nu}N$ collisions were selected by a cut off with respect to the variable x in just the same way as this was done in soft hadron-hadron and hadron-nucleus collisions. We denote the jet production process in the $\tilde{\nu}N$ collisions as follows:

$$\tilde{\nu} + N \rightarrow J_q + J_{qq}, \qquad (7)$$

where J_q is the knocked-out quark jet and J_{qq} the diquark spectrator jet. The particles belonging to one or another jet were selected with the aid of the invariant variables:

$$x_q^k = (P_{qq} \cdot P_k)/(P_q \cdot P_{qq}) \geq 0.1, \qquad (8)$$

$$x_{qq}^k = (P_q \cdot P_k)/(P_q \cdot P_{qq}) \geq 0.1, \qquad (9)$$

where $P_q = xP_N + q$, $P_{qq} = (1-x)P_N$. Here P_N, P_k are the four-momenta of a nucleon and a k-th particle, the indices q(qq) show that the particle belongs to the jet of either the knocked-out quark or diquark spectrator. In addition, in order to separate the hadrons in the jet overlap region, an auxiliary condition was used: $y_k^* \geq 0$ for the quark fragmentation and $y_k^* < 0$ for the diquark fragmentation. The b_k values for π^-mesons thus obtained for the three energy intervals are presented in Table 2. The $\langle b_k(\pi^-) \rangle$ values for the $\tilde{\nu}N$ interactions are seen to coincide, within one standard deviation, with the $\langle b_k(\pi^-) \rangle$

Table 2

Type of collision	P_{lab}, (GeV/c) W, GeV	Fragmentation region	$\langle b_k(\pi^-)\rangle$ *
pp	205($\sqrt{S}$ =19.7)	target fragment.	4.5 ±0.1
π^-p	40($\sqrt{S}$ = 8.7)	beam fragment.	4.21±0.03
π^-C	40	beam fragment.	4.19±0.04
$\tilde{\nu}$N	<W> = 8	current fragment.	4.12±0.17
π^-p	40($\sqrt{S}$ = 8.7)	target fragment.	4.06±0.04
π^-C	40	target fragment.	4.36±0.04
$\tilde{\nu}$N	<W> = 8	target fragment.	4.16±0.30
$\bar{p}$p	22.4($\sqrt{S}$ = 6.6)	target fragment.	3.95±0.03
$\tilde{\nu}$N	<W>= 4.9	current fragment.	3.68±0.11
$\tilde{\nu}$N	<W>= 3.5	current fragment.	3.17±0.11
$\tilde{\nu}$N	<W> = 4.9	target fragment.	3.45±0.19
p(C_3H_8)+pTa	10	target fragment.	2.13±0.04
$\bar{p}$p	12($\sqrt{S}$ = 4.9)	target fragment.	3.53±0.01
$\bar{p}$p	5.7($\sqrt{S}$ = 3.6)	target fragment.	3.21±0.01
$\tilde{\nu}$N	<W>= 3.5	target fragment.	2.75±0.15

* Statistical errors are presented in the Table. The systematic errors that are due to the incorrect identification of positive particles are 5÷10%.

values for the soft jets in hadron-hadron and hadron-nucleus collisions at equal energies $\sqrt{S}$ = W in the c.m.s.

Figure 3 shows the main results of this analysis: the average $\langle b_k\rangle$ values $\bar{p}$p, π^-p, π^-C, pp, pC, pTa and $\tilde{\nu}$N processes are plotted against the energy $\sqrt{S}$ = W in the c.m.s. The figure also presents the $\langle b_k\rangle$ calculations obtained by the LUND model[5] for π^- mesons in the beam target fragmentation for 40 and 360 GeV/c ($\sqrt{S}$ = 8.7,26 GeV) π^-p collisions which satisfactorily describe one-particle distributions in the experimental π^-p data[6]. The average $\langle b_k\rangle$ values are seen to grow with increasing $\sqrt{S}$ = W, and for $\sqrt{S}$ > 6 GeV ($b_{J_1J_2} = -(V_{J_1} - V_{J_2})^2 \geq 10$) they reach the asymptotic regime. The average size of the pion jet is $\langle b_k\rangle \simeq 4$.

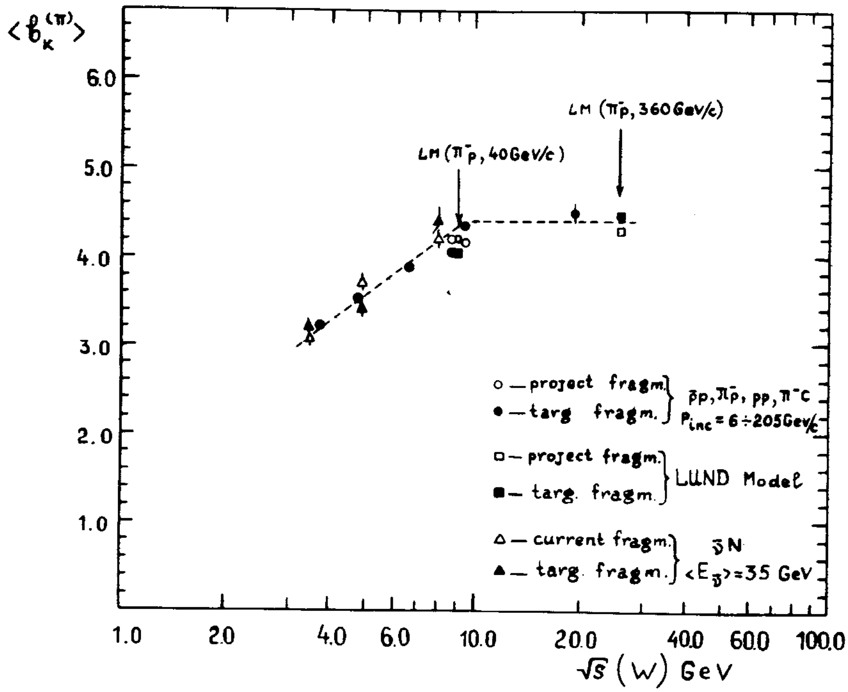

Fig. 3. The dependence of the average $\langle b_k \rangle$ *values of* π^- *mesons in jets of various processes on* $\sqrt{S}=W$ *in the c.m.s.*

This analysis has shown that the b_k distributions of hadrons in the jets have a universal character in both soft and hard particle collisions which is independent of neither the type of a fragmenting system (N, π^-, $\bar{p}$, C, q), nor the collision energy for $P_{lab} \geq 22$ GeV/c ($\sqrt{S} = W >$ > 6 GeV).

Thus, we can conclude that the hadronization of the quarks and diquarks in soft and hard particle interactions in the 4-velocity space is universal, that is independent of neither the origin, nor the properties of the colour quark system. It seems to us that this universality is due to the interaction properties of colour charges with vacuum and means that the colour charge hadronization in vacuum is independent of the production process. The asymptotic regime sets in at $E_q\,(E_{qq}) \geq 3$ GeV.

The QCD calculation of these distributions as universal parameters of strong interaction physics is of particular interest.

We are pleased to thank the IHEP, ITEP, FNAL and Michigan State University Collaboration for giving us the permission to use DST on $\bar{\nu}N$ collisions.

References

1. Baldin A.M., Didenko L.A. In: JINR Rapid Communications, № 3-84, Dubna, 1984, p.5; № 8-85, Dubna, 1985, p.5.
2. Baldin A.M. et al. JINR, P1-85-820, Dubna, 1985.
3. Baldin A.M. et al. In: JINR Rapid Communications, № 16-86, Dubna, 1986, p.24.
4. Berge J.P. et al. Nucl.Phys., 1981, B184, p.13. Ammosov V.V. et al. Nucl. Phys., 1982, B203, p.1; 1982, B203, p.16.
5. Sjostrand T. LUPT 82-3, March, 1982.
6. Higgins P.D. et al. Phys.Rev.D., 1979, v.19, p.65; Phys.Rev.D., 1979, v.19, p.731; Biswas N.N. et al. Nucl.Phys., 1980, B167, p.41.

Received on January 21, 1987.