Observation of narrow jets in hadron-carbon interactions at an average energy of 0.4 TeV

N. G. Dzhaoshvili, D. M. Kotlyarevskiĭ, and I. V. Paziashvili
Institute of Physics, Academy of Sciences of the Georgian SSR

(Submitted 5 February 1987)
Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 2, 264–267 (25 March 1987)

Narrow jets have been observed in interactions of cosmic-ray hadrons with a polyethylene (CH_2) target, in about half of the events. These jets are directed into the rear hemisphere in the c.m. frame of the incident hadron and the target nucleon. The average multiplicity of the particles in the jet is 4.0 ± 0.2; the average transverse momentum with respect to the jet axis is 0.16 ± 0.02; and the average transverse momentum of the jet with respect to the primary axis is 1.8 ± 0.4 GeV/c.

Narrow jets of hadrons have been observed in an examination of material obtained at the Tskhra-Tskaro-1 apparatus. The characteristics of the apparatus are described in detail in Refs. 1–3; methodological questions related to the data acquisition, the data processing, and the results are discussed in Refs. 2–6. This apparatus has been used to study multiple production in the interaction of cosmic-ray hadrons[1)] with energies of 0.1–2.0 TeV (the average energy is 0.4 TeV) with a polyethylene (CH_2) target. The events were detected in a large Wilson cloud chamber with dimensions of $2.0 \times 0.5 \times 1.0$ m positioned below the target (whose thickness is 0.1 radiation length). The cloud chamber is immersed in a uniform magnetic field of 7.5 kG. The energy is measured by a lead-iron calorimeter with a total thickness of 890 g/cm^2. The error of the energy measurements is no worse than 30% at 400 GeV, and the average error in the measurement of the momenta of the product particles is $\Delta p/p \sim 0.03p/\text{GeV}$. After the events were selected on the basis of the absence of an accompaniment, the absence of rescattering in the target, measurability of the momenta of the secondary particles, etc. (the details are given in Ref. 1–6), we found 50 events of incoherent multiple production in the CH_2 target. In the selected events, the admixture of unidentified δ-electrons, e^+e^- pairs, and products of the decay of neutral strange particles is estimated to be less than 5% of the tracks; a possible rescattering in the target is estimated to occur in no more than one event. Analysis shows that the loss of product particles (which we identify as pions, and whose multiplicity we denote by n_s) in the target is negligible, and most of the recoil nucleons remain in the target. To eliminate the remaining recoil nucleons from n_s, we took such a nucleon to be any particle with a positive charge with an energy $\leqslant 1.3$ GeV in the laboratory frame of reference if, upon a transformation to the c.m. frame of the impinging hadron and the target nucleon, the Feynman scaling variable satisfies $x_F \leqslant -0.4$, where $x_F = 2p_{\parallel}^*/\sqrt{s}$, $s \simeq 2m_pE_0$, E_0 is the energy of the initial particle, and $p_{\parallel}^*$ is the momentum component along it. Some characteristics of the events are listed in columns II–VI in Table I. Shown for comparison there are corresponding characteristics on proton-proton interactions[7] at 400 GeV. Column III gives the expected average number (NN) of hadron-nucleon interaction events per 50 interaction events with the CH_2 target, as estimated from the topological

TABLE I.

I	II number of events	III NN	IV $\langle n_s \rangle$	V $\langle E_0 \rangle$ GeV	VI $\langle p_\perp \rangle$ GeV/c	VII $n_{\rm jet}$	VIII $\langle x_j \rangle$	IX $\langle p_\perp \rangle_j$ GeV/c	X $\langle n_{sj} \rangle$
$n_s < 15$	34	9.4	9.6 ± 0.6	410 ± 50	0.39 ± 0.04	5+1+1	0.48 ± 0.13	0.16 ± 0.02	3.6 ± 0.3
$n_s \geqslant 15$	16	0.7	17.8 ± 0.6	390 ± 50	0.37 ± 0.04	7+5+1	0.43 ± 0.07	0.16 ± 0.02	4.2 ± 0.3
All	50	10.1	12.0 ± 0.5	400 ± 50	0.38 ± 0.03	12+6+2	0.45 ± 0.04	0.16 ± 0.02	4.0 ± 0.3
pp	–	–	9.1 ± 0.2	400	0.37 ± 0.01	–	–	–	–

cross sections and from the cross sections for the inelastic production of charged particles in hydrogen and carbon,[7] 30.0 ± 0.2 and 230 ± 10 mb. Table I is shown partly to demonstrate that the average characteristics of the selected events agree within the errors with those found in other experiments.[7,8]

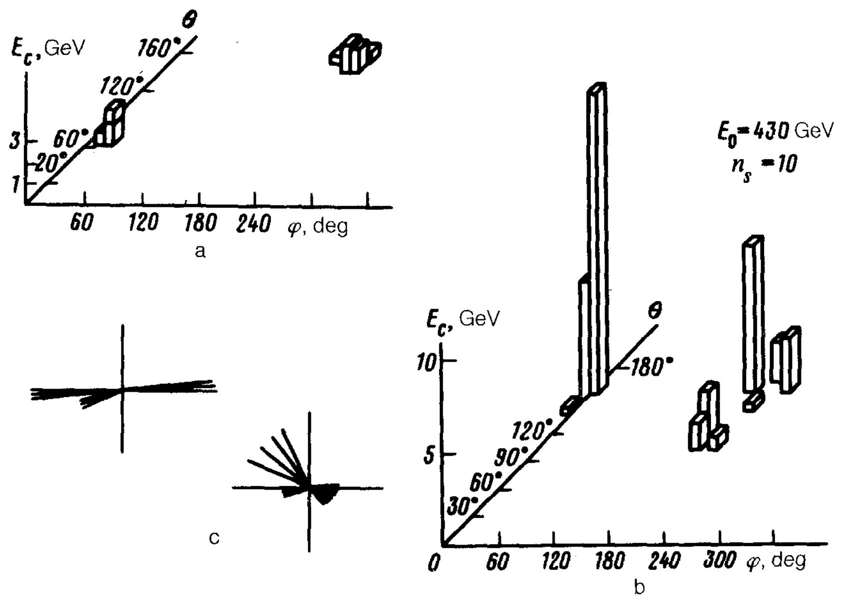

FIG. 1. Examples of the angular distribution of the energy flux for (a) a two-jet event and (b) a three-jet event; examples of the azimuthal-angle distribution of tracks for two-jet (three-jet) events.

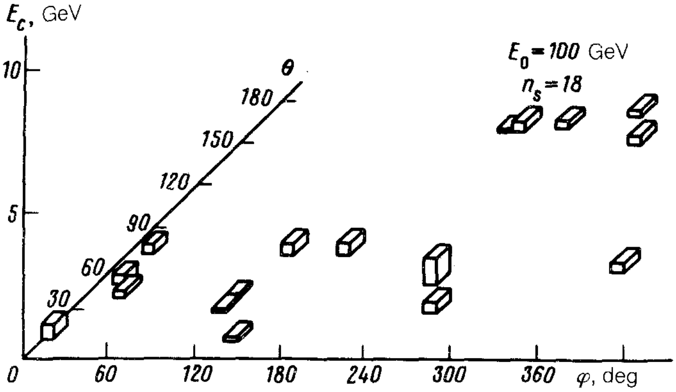

FIG. 2. Example of the angular distribution of the energy flux for a nonjet event.

To search for structural features in the momentum distribution, we plotted a picture of the energy-flux distributions in the (θ, φ) plane—the polar and azimuthal angles of the tracks of the product particles with respect to the direction of the primary particle—for each event in the c.m. frame of the impinging hadron and the target nucleon. Some of these distributions are shown in Figs. 1 and 2. We will be concerned below primarily with polar angles $\theta > 90°$ (the rear hemisphere), where the uncertainties regarding the measurement of the momenta and the angles are minimal. We take a "jet" to be a group of three or more tracks which fall within a cone with a vertex angle $\Delta\theta < 36°$ and which satisfy the following conditions: a) $x_j \equiv |\Sigma_i x_i| \geqslant 0.20$, where

$$x_i = 2|\mathbf{p}_i^*| / \sqrt{s}, \tag{1}$$

b) the squares of the differences between the 4-momenta p_i and p_j of the jet particles

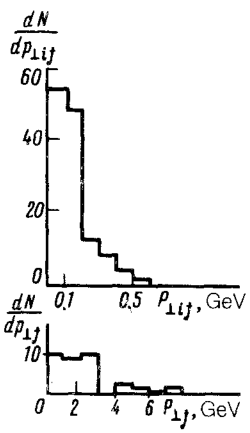

FIG. 3. Distributions of the transverse momenta of the particles with respect to the jet axis and of the transverse momenta of the jet with respect to the direction of the primary axis; $\langle p_{\perp j} \rangle = 1.8 \pm 0.4$ GeV/c.

satisfy the modified condition of Baldin, Didenko, *et al.*,[9,10]

$$t_{ij} \equiv -(p_i - p_j)^2 < 5m_\pi^2 \ , \tag{2}$$

and c) if there are particles near the jet which satisfy conditions (1) and (2) with some of the jet particles, they are also included in the jet.

We take the jet axis to be the vector $p = \vec{\Sigma} p_i$, where p_i are the momenta of the jet particles.

Some characteristics of the jets are shown in Table I (columns VII–X). The successive terms in column VII are the numbers of events with 1, 2, and 3 jets;c$\langle p_\perp \rangle_j$ in column IX is the average transverse momentum with respect to the jet axis; and $\langle n_{sj} \rangle$ is the multiplicity of tracks in the jet.

Jets with $x_j \geqslant 0.75$ ("cumulative jets") constitute 17% of the total number of jets or 22% of the number of jets oriented backward. For them, $\langle x_j \rangle$ is 1.1 ± 0.2, while for the other backward jets, it is $\langle x_j \rangle = 0.36 \pm 0.02$.

Calculations carried out to randomly generate events with a flat distribution in the angle φ and with the experimental distribution in θ showed that, on the average, no more than three single-jet events with $\geqslant 3$ particles in the jet could occur per 16 events of the type selected with $n_s \geqslant 15$. An event with two jets, each consisting of four particles, is expected less frequently than in one event out of a thousand.

Finally, we note that (a) the average transverse momentum of the particles with respect to the jet axis is small and (b) a substantial part of the hadron-nucleus avalanche takes the form of events of the jet type.

The observed phenomenon apparently requires further study in experiments with a larger statistical base. If this phenomenon proves to be general in nature, it should be seen more obviously in experiments with heavier targets and also in the nuclear fragmentation region in deep inelastic lepton-nucleus scattering with a high energy transfer, on the order of that reached in the EMC experiment.

We are particularly indebted to N. N. Roinishvili, T. T. Barnaveli, S. D. Kananov, G. Z. Shtemanetyan, A. A. Tyapkin, Yu. G. Verbetskiĭ, E. G. Gurvich, É. V. Gedalin, O. V. Kancheli, I. I. Roĭzen, and M. G. Ryskin for extensive and extremely useful discussions of experimental and theoretical aspects of this phenomenon.

[1)]At the height of this apparatus, 2500 m above sea level, the composition of the particle flux in the energy range studied is estimated to be ~40% protons, ~35% neutrons, and ~25% pions.

[1]É. L. Andronikashvili *et al.*, Yadernye vzaimodeĭstviya pri vysokikh energiyakh (High-Energy Nuclear Interactions) Izd. Metsniereba, Tbilisi, 1969, p. 88.
[2]N. N. Roinishvili, Protsessy mnozhestvennoĭ generatsii pri energii vyshe 200 GeV. Doktorskaya dissertatsiya (Multiple-Production Processes Above 200 GeV. Doctoral Dissertation), Tbilisi, 1971.
[3]D. M. Kotlyarevskiĭ, Issledovanie vzaimodeĭstviĭ adronov s yadrami v intervale energiĭ 0.05–5 TeV. Doktorskaya dissertatsiya (Study of Hadron-Nucleus Interactions in the Energy Range 0.05–5 TeV. Doctoral Dissertation) Tbilisi, 1981.
[4]O. L. Berdzenishvili *et al.*, Izv. Akad. Nauk SSSR, Ser. Fiz. **34**, 1907 (1970).
[5]O. L. Berdzenishvili *et al.*, Yad. Fiz. **13**, 779 (1971) [Sov. J. Nucl. Phys. **13**, 443 (1971)].
[6]M. I. Atanelishvili *et al.*, Izv. Akad. Nauk SSSR, Ser. Fiz. **36**, 1649 (1972).

[7]V. S. Murzin and L. I. Sarycheva, Vzaimodeĭstviya adronov vysokikh energiĭ (High-Energy Interactions of Hadrons) Nauka, Moscow, 1983.
[8]De Marzo *et al.*, Phys. Rev. D **26**, 1019 (1982).
[9]A. M. Baldin and L. A. Didenko, Kratkie soobshcheniya OIYaI No. 3-84, 5 (1984); No. 8-85, 5 (1985).
[10]A. M. Baldin *et al.*, JINR Preprint E-1-85-415, 1985; Yad. Fiz. **44**, 1209 (1986) [Sov. J. Nucl. Phys. **44**, 785 (1986)].

Translated by Dave Parsons