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THE PRINCIPAL AXIS OF JETS - AN ATTEMPT TO ANALYSE HIGH-ENERGY COLLISIONS AS TWO-BODY PROCESSES

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In studies of high-energy collisions with strange-particle production 1)-7) we have established or confirmed the following general properties of these interactions :

1. Baryons are collimated around the line of flight of the colliding particles, i.e. for incident pions baryons are emitted strongly backwards in the c.m.s. of the collision, whereas the majority of mesons go forward.
2. The average values of the total and transverse c.m.s. momenta of secondaries show a marked dependence on the mass of these particles which can be approximately described by a linear function.

As already stated in a previous paper 6), both facts can be accounted for by the simple assumption that two intermediate bodies are formed in the interaction which break up afterwards into the particles actually observed.

The purpose of this letter is to discuss a method of analysis of high-energy interactions (jets) which tests the "intermediate bodies" model.

As it will be discussed later on, the analysis proposed may be useful even if the intermediate bodies model is not entirely valid, but the analysis methods are best visualized in considering this model.

Let us assume that the first effect of a high-energy collision (πp, for instance) is the production of two bodies, A and B. These two bodies will have equal and opposite momenta in the c.m.s. of the original πp system. The line of their momenta will most of the time not coincide with the line of flight of the πp system. It will make an angle with it which is small for peripheral events but which may be rather large for other types of events. The second

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step of the interaction is that A decays into particles (a_1, a_2...a_n) and B into particles (b_1, b_2...b_m). If the Q-values of both decays are not large, the particles a_i will travel more or less in the same direction as A, i.e. their momenta will make an angle less than 90° with the momentum of A. The same, of course, will be true for particles b_i vs. the momentum of B.

In analysing a jet we want to reconstruct A and B out of the particles of the jet. From the above, it must be clear that whenever we make a wrong assignment (considering for instance a particle b_i as a decay product of A), the result will be to find for A and B a momentum smaller than the true one. Even if the model is much too simple, it helps in understanding the method of analysis that we shall describe.

For every jet we define what we call the principal axis. The definition is as follows : given the momentum vectors of all secondaries in the c.m.s. of the collision, one puts any straight line through their common origin, projects all the momenta onto this line and sums up the absolute values of these projections. The line for which this sum is a maximum is defined as the principal axis of the jet (see Fig. 1). The "separation plane" (perpendicular to the principal axis) divides the vectors of secondaries into two groups. The vector sums of the momenta of all particles in each group coincide in direction with the principal axis and give the (equal and opposite) c.m.s. momenta of the two intermediate bodies that travel along the principal axis. This momentum $\overrightarrow{P^*}$ we call the "principal momentum". The principal momentum could also be found by associating all the particles into two groups, and making all possible combinations for these groups. That combination which gives the largest value for the resulting momentum of one group, defines the principal momentum.

These entities (principal axis, separation plane and principal momentum) have a purely mathematical definition and can be found for any jet. If the two intermediate bodies are really produced, their decay products will coincide in most of the cases with the two groups on both sides of the separation plane. Indeed, a study of the experimental momentum and angular distributions of the final particles of our events shows that a decay particle mixing (i.e. emission of one or several decay particles of an intermediate body onto the "wrong" side of the separation plane) should occur in only 10^{o}/o of the cases.

We present here some results obtained by applying this procedure to 95 events of the type $\pi^-+p\rightarrow K^0+\Lambda^0+\pi$'s, produced by incident π^- of 10 GeV/c5),6). The other channels of strange particle production4),5),6) by 10 GeV/c π^- on protons contained considerably fewer events, and are therefore not considered here.

Unfortunately, an experimental difficulty arises that makes the characterization of the $K\Lambda$ events by the c.m.s. momentum vectors of all secondaries impossible. This is because one has no information about the individual momenta of π^0's as soon as more than one neutral pion is created. To overcome this difficulty, a fictitious particle was introduced into all calculations : the energy and momentum of this particle is equal to the sum of energies and momenta of the unobserved π^0's, thus ensuring perfect energy and momentum conservation for the jet. The error introduced by this procedure is small, since both the average number and the average c.m.s. momentum of π^0's is small. Furthermore, it is clear that this procedure will tend to wash out the two-body structure of the jet, rather than to enhance it.

All calculations were done by a program called AJAX (a jet axis), written entirely in FORTRAN for the IBM 7090 computer. A description of the program and of further details and results of the analysis will be published as a CERN report.

From the different results obtained, the following seem to be the most interesting :

1. The angular distributions of secondaries in the rest systems of the intermediate states show a clear isotropy for all particles. This is especially interesting for Λ-hyperons which are strongly anisotropic in the c.m.s. of collision. In Fig. 2 we present the $p_\perp - p_L^*$ plots and the angular distributions for Λ^0's in the c.m.s. of collision and in the Λ-containing intermediate body which we call the "baryonic body".
2. Table I gives the values $\overline{p_\perp}$ (average of the momentum transverse to the line of flight of the incident π^-) and $\overline{{}^{\Lambda}p_\perp^*}$ (average of the component of the c.m.s. momentum perpendicular to the principal axis) for Λ-hyperons, kaons and pions. The columns entitled Γ^- and Γ^+ give a measure of the width of the distributions. The Γ-values are defined

such that the two intervals $\overline{p_{\perp}} - \Gamma^{-} < p_{\perp} < \overline{p_{\perp}}$ and $\overline{p_{\perp}} < p_{\perp} < \overline{p_{\perp}} + \Gamma^{+}$ contain each 1/3 of the events (the corresponding definition is true for the Γ-values relevant to the ${}^{\Lambda}p_{\perp}^{*}$ distribution).

TABLE I

	$p_{\perp}$			${}^{\Lambda}p_{\perp}^{*}$		
	$\overline{p_{\perp}}$ GeV/c	Γ^{-} GeV/c	Γ^{+} GeV/c	$\overline{{}^{\Lambda}p_{\perp}^{*}}$ GeV/c	Γ^{-} GeV/c	Γ^{+} GeV/c
Λ	0.47	0.25	0.23	0.31*	0.19	0.19
K	0.37	0.16	0.23	0.29	0.15	0.21
π	0.31	0.14	0.24	0.26	0.12	0.19

The errors on all values of $\overline{p_{\perp}}$ and $\overline{{}^{\Lambda}p_{\perp}^{*}}$ are of the order of ± 0.02 GeV/c.

* This value is originally 0.27 GeV/c. Omitting, however, 13 events in which the Λ forms the baryonic body by itself and therefore has ${}^{\Lambda}p_{\perp}^{*} = 0$, we arrive at the above value.

One observes that the strong dependence of $\overline{p_{\perp}}$ on the mass of the particles 3),8),6),5) almost vanishes for the quantity ${}^{\Lambda}p_{\perp}^{*}$. This is exactly what is expected : the mathematical definition of the principal axis ensures automatically exact balance of the components of momenta perpendicular to the principal axis for each group of particles on both sides of the separation plane independent of the mass of the decay particles. Should the groups consist always of two particles only, any correlation between mass and ${}^{\Lambda}p_{\perp}^{*}$ would disappear identically. If the groups consist of more than two particles, it is likely that such a correlation will be weaker than it is between mass and $p_{\perp}$. How strong it is depends on the mechanism of the intermediate body decay.

3. In Fig. 3 we present the $P_{\perp} - P_L^*$ plot for the baryonic bodies together with their angular distribution in the c.m.s. of the $\pi^- p$ collision, the P_L^* axis being the πp line of flight. The average values of the transverse and longitudinal momenta are $\langle P_{\perp} \rangle = 0.65$ GeV/c and $\langle P_L^* \rangle = -0.79$ GeV/c for the baryonic body. Three groups of events can be distinguished. There is a cloud at high negative values of P_L^*. These events we call strongly peripheral and we believe that at least for them our model is most likely true. Then there is a belt of points around the point $P^* = 0$. Finally, we observe a small excess of points at high positive values of P_L^* (which is in fact more clearly visible in the angular distribution). For comparison, artificial events of the type 10 GeV/c $\pi^- + p \longrightarrow \Lambda^o + K^o + 4\pi$ created according to phase space predictions <u>without</u> any 2-centres-structure were submitted to the same procedure. A plot like that of Fig. 3 for these events gave only the belt around the point $P^* = 0$ which corresponds (obviously) to an isotropic angular distribution of the principal axis. It is not yet quite sure that the forward cluster in Fig. 3 represents a true effect and not just a statistical fluctuation of a background formed by an isotropic distribution of the principal axis. However, the possible existence of such a cluster constitutes a strong incentive to continue the analysis we are proposing in this letter. Indeed, in the $p_{\perp} - p_L^*$ plots for Λ, K and π, separately, there is no apparent clustering of events for high values of P_L^* or $\cos \theta^*$. Furthermore, if the effect really existed, this would demonstrate that our analysis could be applied to events that are not at all peripheral. On the contrary, the events with forward-going baryonic bodies kinematically resemble backward elastic scattering, whereas peripheral events resemble diffraction scattering.

4. If one studies the mass distributions of the intermediate bodies, no identification of the bodies with known or unknown isobars with definite quantum numbers can be done within our limited statistics. The distributions show rather a broad maximum around 2.05 GeV/c^2 or 1.3 GeV/c^2 for the baryonic and mesonic body, respectively.

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Summarizing, we can say that a simple mathematical procedure enables us to make a quantitative analysis of jets in terms of a two intermediate bodies model. Results of this application to events of the type $\pi^- + p \longrightarrow \Lambda^0 + K^0 +$ pions at 10 GeV/c make the assumption of such a model plausible.

Of course, the two intermediate states model is not a new idea and has been discussed in many variations, especially for interactions at cosmic ray energies (see for instance 9). To our knowledge, no applications similar to ours have been tried to individual events and at accelerator energies.

Before concluding, we want to emphasize that the interest of our analysis does not depend entirely on the validity of the two-body model of high-energy interactions in its simplest form. Indeed, it is sure from the existence of peripheral events that the statistical model does not apply for a large number of jets and may be it does not apply to any. The two-body model is then the most natural and simplest approximation for the description of real jets. The principal axis analysis allows the characterization of any jet by simple parameters : the principal momentum, the angle of the principal axis with the line of flight of the incident particle and the invariant masses of the two bodies. One can then define a 4-momentum transfer Δ^2 (e.g. between the baryon before the collision and the baryonic body) and this Δ^2 distribution can be compared to the one obtained for other two-body interactions like elastic scattering or two-body production of isobars (Fig. 4 shows this Δ^2 distribution for our jets). Our analysis therefore does not depend at all on further assumptions on the nature of the intermediate bodies. (Are they true isobars or not ? Is the decay purely statistical or not ?) Therefore, this analysis may remain useful even if the two-body model were not entirely correct.

Another interest of the proposed method lies in the following fact. The search for the production of resonant states becomes very complicated for high-energy interactions with high multiplicities. The principal axis analysis provides a first "sorting out" of particles by accepting from all possible combinations of secondaries that might form a given resonance only those where all the particles in the combination come from the same intermediate body. Reducing the background in this way might make the search for resonances more easy and more fruitful. Conversely, if this method turns out to be successful in the search for resonances, this will constitute a justification of the intermediate bodies model.

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In the study of antiproton-proton annihilations in flight, French and co-workers[10) have successfully employed, independently of us, a method very similar to ours to do this first "sorting out" of secondary particles.

We wish to thank Dr. B.R. French for stimulating discussions. Two of us (S.B. and Ch.P.) would like to thank Professor M. Danysz for his invitation to visit his institute in Warsaw, and the Warsaw High Energy Group for the kind hospitality extended to them. It is on one of these occasions that the idea for the analysis appeared. They are also indebted to Professors M. Miesowicz and J. Gierula for very interesting discussions in Krakow about two centre models in general.

FIGURE CAPTIONS

Fig. 1 Definition of principal axis and separation plane

Fig. 2 $p_\perp - p_L^*$ plot (B) and corresponding angular distribution (A) for Λ-hyperons ($p_\perp$ = transverse and p_L^* = longitudinal momentum in the c.m.s. of $\pi^- p$ collision). $p_\perp^{**} - p_L^{**}$ plot (D) and corresponding angular distribution (C) for Λ-hyperons ($p_\perp^{**}$ and p_L^{**} are the momentum components transverse and longitudinal to the line of flight of the baryonic body in the rest system of this body).

$\cos \Theta^* = p_L^* / |p^*|$, $\cos \Theta^{**} = p_L^{**} / |p^{**}|$.

The circle in (B) is the kinematic limit for the reaction $\pi^- + p \rightarrow K^0 + \Lambda^0$. In (D) the circle gives the kinematic limit if the mass of the baryonic body is equal to half of the available energy in the $\pi^- p$ c.m.s. and the body would decay into Λ and π only.

Fig. 3 $P_\perp - P_L^*$ plot (B) and corresponding angular distribution (A) of the baryonic bodies - i.e. hyperon containing intermediate states - ($P_\perp$, P_L^* and P^* are transverse longitudinal and total (principal) momentum in the c.m.s. of $\pi^- p$ collision, $\cos \Theta^* = P_L^* / |P^*|$).

13 events in which the Λ formed the baryonic body by itself were not included in the diagram.

The circle in (B) represents the kinematic limits for the reaction $\pi^- + p \rightarrow K^0 + \Lambda^0$.

Fig. 4 Distribution of the 4-momentum transfer Δ^2 between the proton before the collision and the baryonic body.

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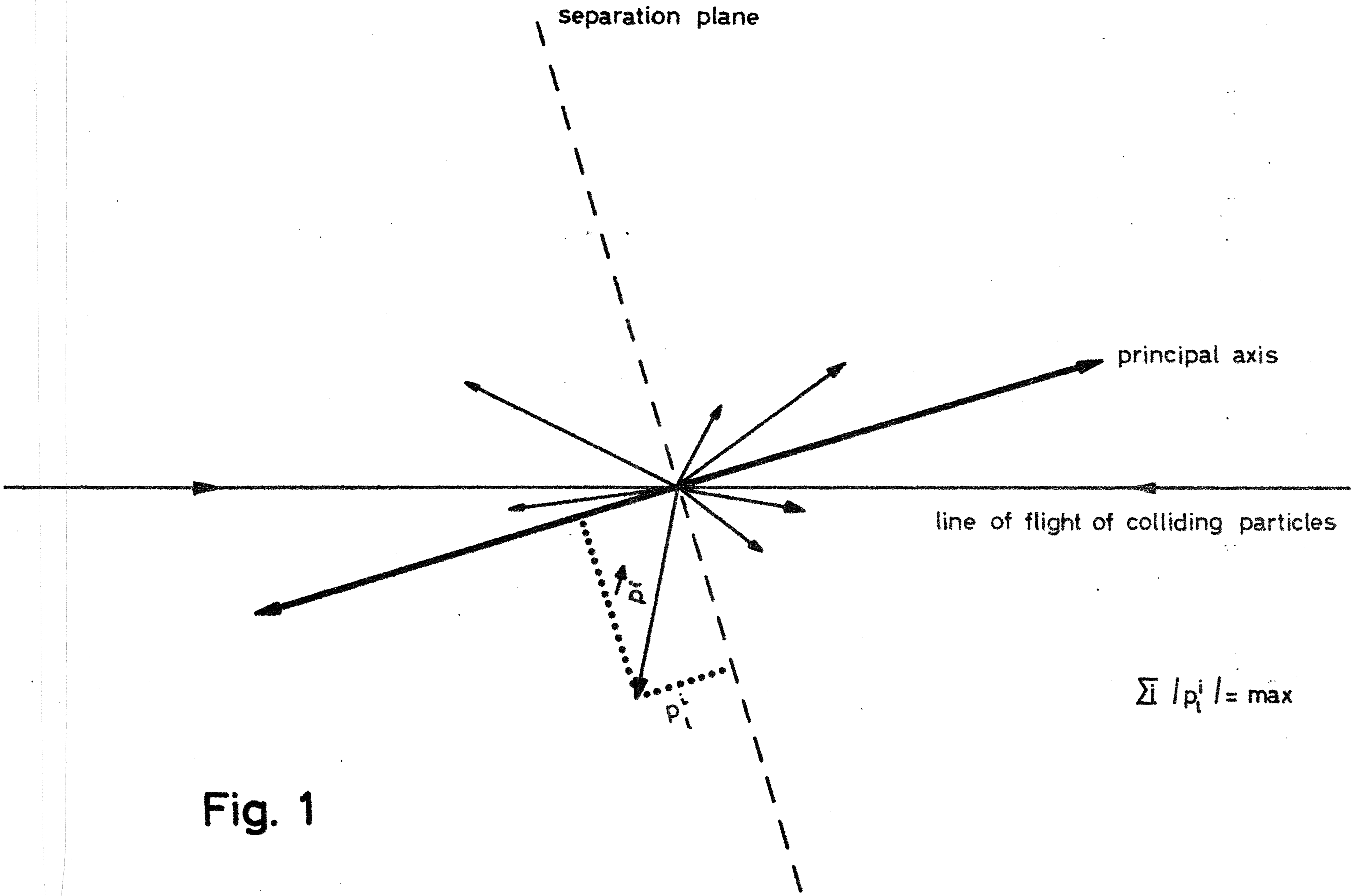

Fig. 1

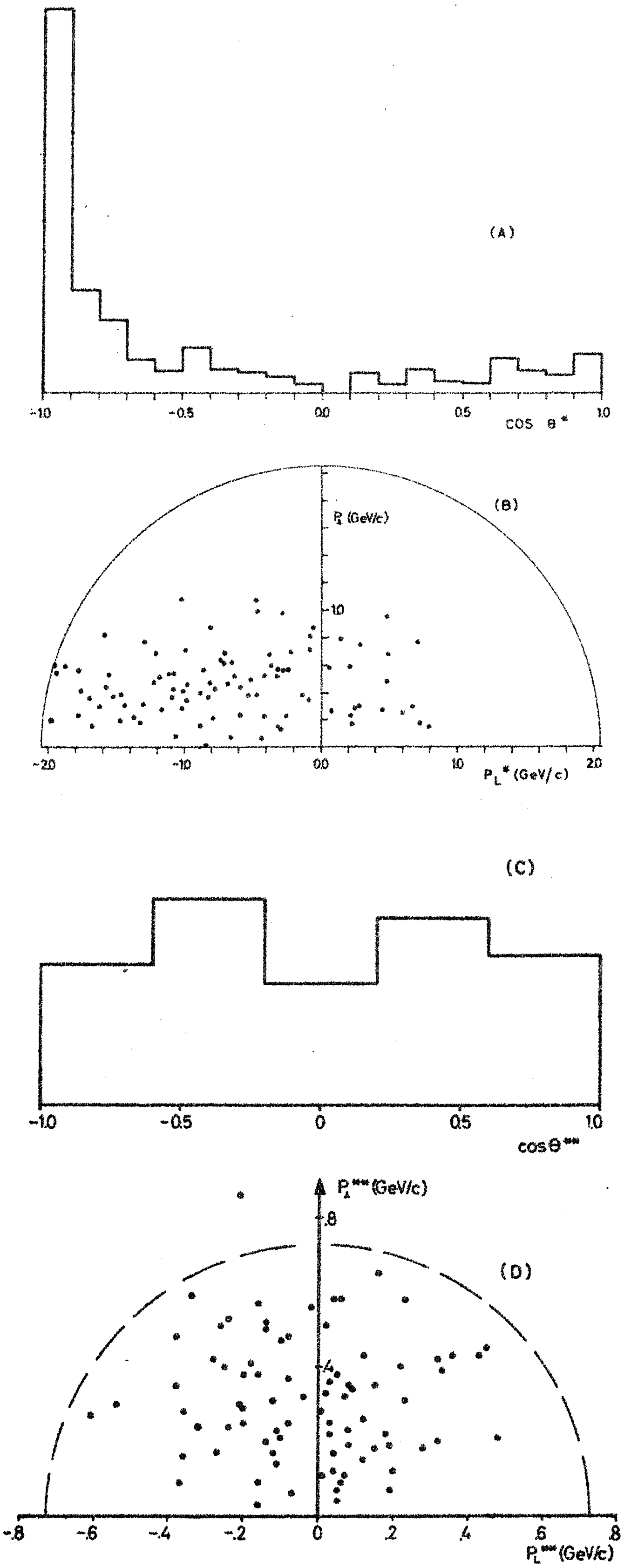

Fig. 2

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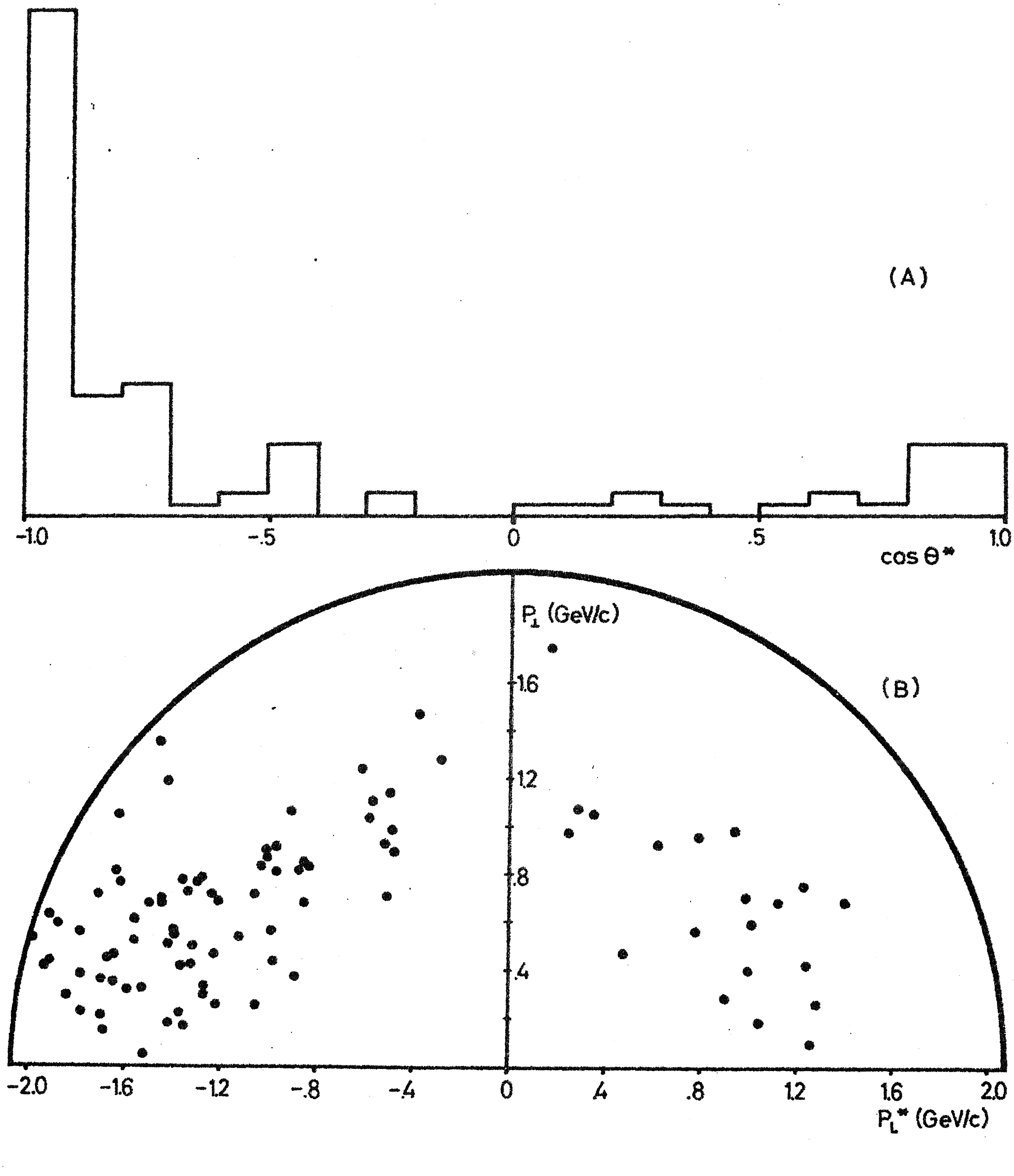

Fig. 3

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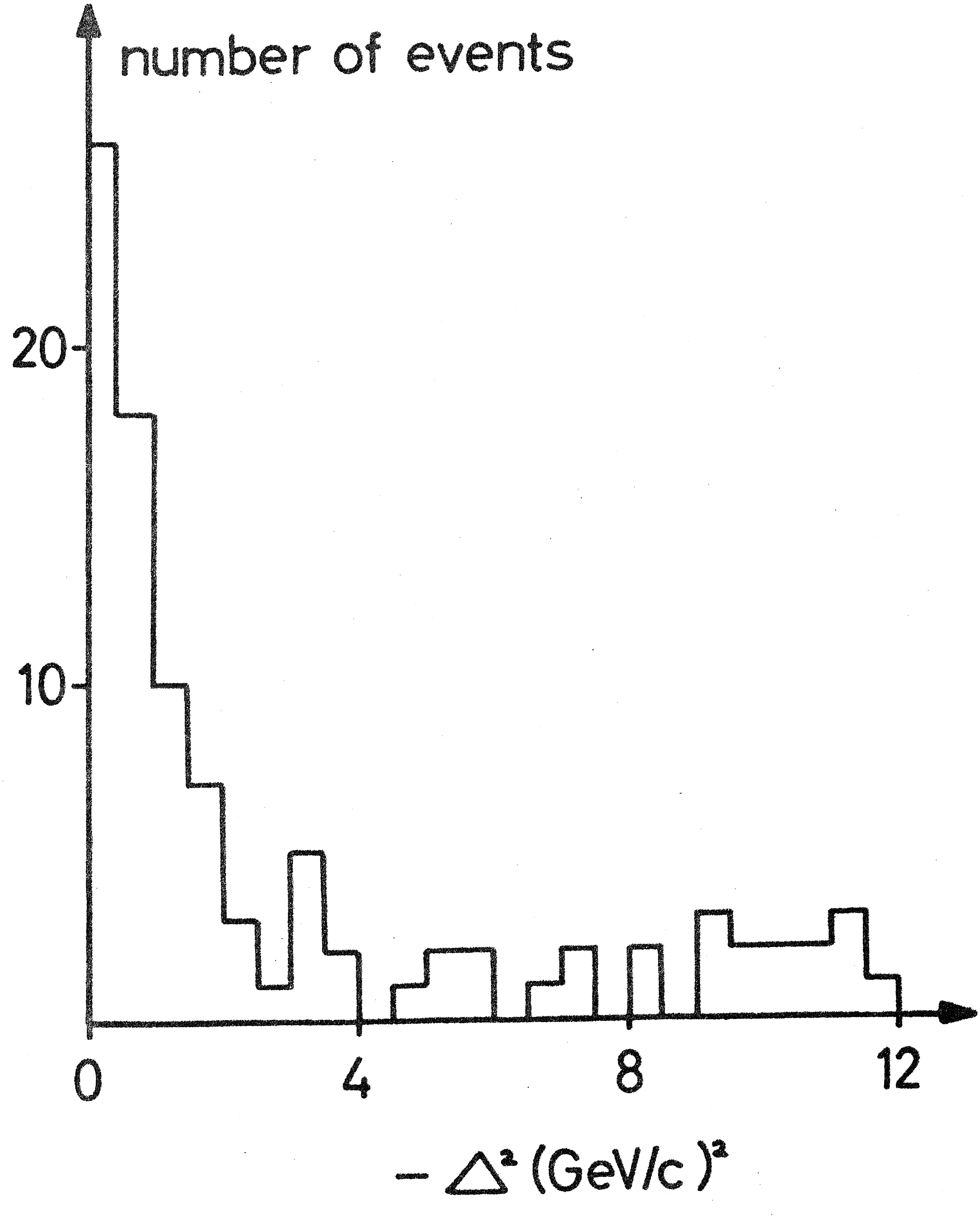

Fig. 4

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