Submitted to XXI High Energy Conference, Paris July, 1982

July 1982

CONF-820718--10

CONF-820718--10

DE83 001336

EVIDENCE FOR JETS FROM A TRANSVERSE-ENERGY-TRIGGERED CALORIMETER EXPERIMENT AT FERMILAB

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AS05-76ER 05096

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ABSTRACT

We have recently completed the first part of running for experiment E-609 at Fermilab. The E-609 hadron jet experiment uses a 132-segment 8-steradian full azimuth calorimeter with tower structure. Additional parts of the apparatus are described in the paper. A novel triggering system allowed us to take data with many different kinds of triggers simultaneously. We give a preliminary report on data obtained in 400 GeV pp collisions, concentrating on data from two triggers, both of which have no special geometrical requirement for the form of the transverse energy deposition. One of these was a global total E-transverse trigger; the other was a "2-high" trigger, which required that 2 or more calorimeter segments (any 2) each give a signal larger than about 1.0 GeV/c. This report further concentrates on the data sample with total transverse energy above 11 GeV. We will present results concerning planarity distributions as well as theta-phi energy flow, for these events.

For the globally triggered events in this kinematic region, only a few percent show clear di-jet structure, with clustering, co-planarity, and concentration of high-p_T fragments near the jet axes. For the 2-high events however, at this E-transverse, approximately 30 percent of the events show di-jet structure. The 2-high events constitute only about 15 percent of the global events, but contain virtually all the events which show this clear di-jet structure.

Details of the analysis are presented, including studies of whether the features of the di-jet events can be explained by simple random fluctuations.

I. INTRODUCTION

We have recently completed the first part of running for experiment E-609 at Fermilab. The E-609 hadron jet search experiment uses a full azimuth calorimeter with unique well-proven design features. The flexibility of the E-609 detector system allowed us to take data with simultaneous use of approximately two hundred different trigger conditions. In this note, we give a preliminary report on data which we obtained using transverse energy triggers and related triggers which have no special geometrical requirement for the transverse energy deposit.

Interest in understanding the effects of using such triggers has increased since the NA5 experiment at CERN reported an absence of clear jet structure in 300 GeV hadron collision events having large transverse energy.(1) This absence, as observed by NA5 in the first hadron calorimeter experiment with full coverage in azimuthal angle, has stimulated several calculations and models(2) concerning the origins of large E_T events and has also raised questions concerning hadron jet phenomena which had been previously observed at Fermilab and the ISR.(3)

II. EXPERIMENTAL SETUP

Our detector system,(4) shown in Fig. 1, is located in the M6E beam line at Fermilab. The results described in this note were obtained using a 400 GeV proton beam. The heart of the detector system is a segmented sampling scintillation calorimeter, consisting of 132 towers of four longitudinal sections each. These towers point at the liquid hydrogen target, so that the cascade shower crosstalk between adjacent towers is minimized. The front face of the calorimeter is shown in Fig. 2. The calorimeter has several special features which prevent spurious responses such as high pulse height tails and hot spots.(5) Transverse momentum in each calorimeter segment is the product of sin theta-lab and the deposited energy. Calorimeter module signals were balanced against each other by steering a muon beam through each module and adjusting the high voltage to achieve the required pulse height. The calorimeter response was then determined using hadron beams of various momenta. The analysis of the calibration data is still in progress, and the p_T scale of the data reported here is uncertain to 10-15 percent.

The detector system also incorporates a magnetic spectrometer using 12 planes of drift chambers, 3 PWC planes, and a magnet with a small transverse momentum kick of $\sim$ 0.1 GeV/c. This small value was used to avoid large systematic shifts in trigger thresholds, which are determined by the geometry of the calorimeter and based on straight line trajectories. Another special feature of our detector system is the imaging Cerenkov counter[6] for secondary particle identification.

Data were taken using many types of triggers concurrently. Most of these triggers summed the transverse energy in the calorimeter in particular geometric regions (e.g., "two-arm" triggers or "one-arm" triggers). However, the results presented in this note are based only upon triggers for which no special geometric requirements were imposed, as described in the next section.

III. PLANARITY ANALYSIS

Our analysis effort to date has focussed on the question of whether events observed using as a trigger the total transverse energy (called the "global" trigger) show evidence for clustering of the secondary hadrons, i.e., "jet", behavior. We have studied "planarity" distributions, as used in the CERN NA5 analysis,[1] as well as azimuthal distributions, which have been used in the E-557 Fermilab preliminary analysis.[7]

The experimental planarity distribution which we obtained for global trigger events with $E_T > 11$ GeV into the angular region 17 < theta-lab < 122 mrad (i.e., 30 degrees < theta c.m. < 120 degrees) is given in Fig. 3. Note that the side "wings" of our calorimeter array as shown in Fig. 2 were not used in our planarity analysis. The planarity distribution in Fig. 3 is similar to those reported by the NA5 and E-557 experiments. (The agreement concerning the absolute cross-section for E_T (global) triggers among the three experiments has not yet been studied thoroughly.)

A central physics question concerning Fig. 3 is whether the rather non-planar average character of the events is due to all events having little or no jet structure, or whether, to the contrary, Fig. 3 contains a substantial number of jet-like events (e.g., with planarity $> \sim 0.8$) which are not merely statistical fluctuations of the average (non-planar) events. To answer this question requires knowledge of the planarity distribution to be expected in the absence of jet behavior. We have estimated this uncorrelated particle planarity distribution using two different methods. In the first, we took real events and randomized the azimuthal angles of calorimeter energy clusters ($\approx$ individual hadrons) while maintaining the observed degree of transverse momentum unbalance for each event. Using conservative choices of clustering algorithms, which would be expected to over-estimate the planarity of the randomized event sample, we obtained the dashed histogram in Fig. 3. In the second method, we used a simple Monte Carlo program to generate artificial events whose single hadron distributions in p_T and multiplicity agree with experiment and which are constrained to satisfy transverse momentum conservation. The details of both of these methods are rather lengthy to describe, but the essential results are that neither method can completely account for the observed frequency of events with planarity > 0.8. This has led us to the conclusion that some of the global trigger events with planarity > 0.8 contain correlated structure.

Additional insight into these issues can be achieved by considering only events in which any two or more calorimeter segments each detected a p_T of greater than, say, 1 GeV/c. This minimum value is high enough to be improbable in the low p_T (e^{-6p_T}) single particle distribution, and yet low enough to be very probable in the fragmentation of partons having a few GeV/c of transverse momentum. Our "two-high" trigger had the sole requirement that any two calorimeter segments each have E_T

$>$ 1 GeV, and produced events whose planarity distribution is shown in Fig. 4. For direct comparison with Fig. 3, this figure shows only events having global $E_T > 11$ GeV. It is evident that these events are substantially more planar than those in Fig. 3. The possibility that statistical fluctuations of non-correlated particles led to the observed planarity distribution of Fig. 4 was estimated using the same two methods described above. Our preliminary conclusion is that the event sample with planarity > 0.8 from the "two-high" trigger contains a significant fraction of events (probably > 50 percent) having dynamical momentum clustering (rather than being statistical fluctuations of events having no real jet structure).

IV. ANGULAR DISTRIBUTION OF p_T DEPOSITION ININDIVIDUAL EVENTS

In hadron collisions, jets from a single pair of hard (i.e., high p_T) partons can be obscured, or made almost invisible, by particles arising from sources other than those hard partons. The difficulty of cleanly identifying jet pairs is made even greater, with a calorimeter type detector, by the fact that in general it is deposition of p_T in segments that is measured directly, and these p_T values give a distorted representation of the individual hadron momenta.

Nevertheless, if jet pairs are to be clearly seen, they must show several distinguishing characteristics:

1) Each jet will in general appear as a cluster of high-p_T segment signals, rather than as an isolated single high-p_T signal.
2) Jet pairs should be roughly co-planar in phi, the azimuthal angle around the beam.
3) The total p_T of a cluster must be largely contained within a small enough solid angle to enable the "jet" to be seen clearly above the "background" p_T distribution.
4) The jet p_T values for the two jets in a pair should roughly balance.

As is well-known from studies of jets in e^+e^- collisions, these characteristics should be expected to become rapidly more clear as the jet momentum increases. 3-GeV jets are probably in general almost unrecognizable, 8 GeV jets can be expected to be easily recognizable if the background is not too large. The present report deals with jets which appear to be of order 4.5 to 5.5 GeV/c each.

In the following we shall show the degree to which the events found in E-609 with the 2 triggers described above do or do not exhibit these characteristics. Apart from quantities like planarity, which has been discussed above, it is difficult to give simple quantitative measures of event characteristics, since the events are of a number of different types. (E.g., a considerable number of events show one jet-like cluster but not two--the limited (though large) solid angle of the detector can readily account for a second jet missing the calorimeter and thus producing such events.) We therefore give, in this report, a sample of events, chosen with very broad cuts, to try to illustrate the extent to which the jet-pair characteristics listed above are present.

V. TYPICAL GLOBAL AND 2-HIGH EVENTS

Fig. 5 shows a "3-dimensional" representation of a quite typical 2-high event of large E_T. The "plane" corresponds to the front view of the calorimeter array (shown in Fig. 2), but with no beam hole shown--and the "height" of the bumps corresponds linearly to the p_T deposited in each individual segment (tower) of the calorimeter. The degree to which the segment p_T's (a) cluster together, (b) show grouping of several segments with individually high p_T's, is seen most readily by noting that apart from the two groups seen, which are at roughly opposite phi values, the calorimeter is quite empty of signals. The individual highest peaks correspond to p_T's of 1.0 to 2.0 GeV/c in a single segment. p_T's as small as 0.025 GeV/c are shown on this plot.

Fig. 6 shows similarly a quite typical event obtained with the global trigger. It is clear that in this event the E_T deposition is much more uniformly spread around the calorimeter, and that no pronounced clustering or co-planar character is evident.

VI. CLUSTERING AND CO-PLANARITY, IN PHI: p_T(SEGMENT) DISPLAY

A sample of about 150 2-high events with E_T above 11 GeV was studied in some detail. Approximately one-third of these events show clear clustering, co-planarity, relatively low background, and rough momentum balance--all the properties expected of di-jet events.

Fig. 7 shows 2 sample events which display these characteristics. The ordinate is the p_T of an individual segment; the abscissa is the azimuth of the center of that segment. The calorimeter has about 24 segments in each roughly circular ring, and thus has about 15 degree resolution in phi. (At the inner and outer borders the number is somewhat different.) In plotting this Figure, a p_T threshold of 0.1 GeV/c per segment has been imposed.

A word about how these events were selected. Since not all 2-high events above 11 GeV E_T show clear di-jet characteristics, we made one additional cut, which left about 40 percent of the events. This cut required that the number of "unusually high p_T" segments, specifically the number with 0.5 GeV/c or more, be at least 5. With these combined cuts--1) at least 2 segments above 1.0 GeV/c ("2-high trigger"), 2) total E_T above 11 GeV, and 3) "multiplicity above 0.5 GeV/c" equal to 5 or more, more than half the final events had clear 2-jet character. The multiplicity cut left about 40 percent of the events which had triggered and which had E_T above 11.

Of these surviving events, Fig. 7 shows 2 of the first 3 events on the data tape. These 2 events appeared roughly di-jet like, the third did not.

A larger number of events will be shown below. Many other events satisfying the broad cuts described above look even more highly clustered than the 2 in Fig. 7.

VII. FURTHER PLOTS OF p_T VS. PHI AND THETA: IDEOGRAM DISPLAY

The individual segments range from about 20 degrees by 20 degrees in theta-c.m. and phi to approximately 10 by 10 degrees at the largest theta values. In order to see the degree of the clustering in both theta and phi, and the degree of co-planarity, we have made ideograms of the events. We show these ideogram distributions, for six events in phi and for three sample events in theta as well. The ideograms used 10 degree by 10 degree bins; a segment p_T threshold of 0.05 GeV/c was used.

Fig. 8 shows the first six 2-high events which satisfied the E_T and multiplicity (of 0.5 GeV/c segments) conditions. No other selection criteria have been used. From these plots, 4 of the 6 events (events 2, 3, 4 and 6) appear to have a simple di-jet character, to a greater or lesser degree; the other two (1 and 5) do not. (The second and third events are the same two events shown in Fig. 7--where the actual segment p_T's are shown.) A crude algorithm has been used to determine the central phi of each peak--the average is calculated for the 120-degree interval which includes the peak and which maximizes the included E_T. The phi difference between the two clusters in each event, using these crudely determined cluster centers, has the value, for events 2, 3, 4, and 6 respectively, of 182, 183, 188, and 192 degrees. These values differ from 180 degrees, on the average, by a little over 0.1 radian. That degree of non-coplanarity corresponds to a non-coplanar "P-out" momentum of somewhat over 0.5 GeV/c, and is roughly in agreement with the effect expected from parton "initial" transverse momentum. Note that momentum balance requirements alone do not require the two peaks to be exactly coplanar, even if there were zero momentum in the calorimeter outside of the two peaks. Coplanarity would not be forced, even in this case, because substantial transverse momentum can escape the calorimeter, particularly from the many fragments which in general go down the beam hole without depositing any energy in the calorimeter.

To show the phi-shape of an average cluster for events 2, 3, 4 and 6 in Fig. 8, we have taken the 8 clusters in these 4 events and plotted their average distribution in $dp_T/d(\text{phi})$. The result is shown in

Fig. 9. As we shall now explain, the theta-distribution in the vicinity of each cluster is similar to this phi-distribution.

For the theta distribution, we show, in Fig. 10, these 4 events in ideogram plots in the theta/phi plane (20 degree bins), and in projection for the theta distribution (10 degree bins). A p_T threshold of 0.1 GeV/c has been applied to each 20 degree by 20 degree bin. In Fig. 10 one sees that the clustering occurs in theta as well as in phi, as is expected on a jet model. Any possible fine differences in the widths of the theta and phi distributions would not be seen in the present simplified analysis.

VIII. SUMMARY AND CONCLUSIONS

From the very recent data obtained in E-609, we report here on 2 of the triggers we used. We find that while only a few percent of the "global trigger" events show di-jet characteristics at large E_T, approximately 30 percent of the "2-high" triggered events show the clustering, co-planarity, and concentration of high-p_T fragments near the cluster axes, expected for jet pairs. For the half of these 2-high events which have higher multiplicity of 0.5 GeV/c segments, the fraction which are di-jet like increases to about 50 percent.

The "background" p_T level between the 2 clusters in each event is less than about 0.5 GeV/c per steradian, while the 5 GeV/c or so in each jet is typically 60 percent to 80 percent contained in little over 1.0 steradian.

One may ask whether the "2-high" trigger has a trigger bias which strongly selects events with fluctuations which make them look like di-jet events. The various Monte Carlo and scrambling studies we have carried out, described above, lead us to believe that this is not so, although surely this question can stand further attention. We remark, however, that the trigger requirement, of 2 segments with at least 1.0

GeV/c each, calls only for a very small fraction of the total center-of-mass energy (27.4 GeV) to be deposited in <u>any</u> 2 segments of the 132-segment array. There is no requirement visible in this trigger which would force, with such high probability, the co-planar character of the events, or the clustering of high-p_T fragments (i.e., of high-p_T segments), or the very low background at azimuths perpendicular to the major axis of the typical event producing this trigger.

The ability to observe the clustering is substantially assisted by the 2-dimensional segmenting, and the tower structure, of the E-609 calorimeter.

Finally, we note that the "2-high" events observed are also present in the "global trigger" sample. But the global trigger evidently responds also, with about an order of magnitude greater cross-section, to events which do not have this clear di-jet structure.

IX. ACKNOWLEDGMENTS

This work could not have been carried out without the strong support of Fermilab. We thank Dr. L. Lederman, Dr. T. Yamanouchi, and their many associates, for that support, particularly through the severely trying period of putting a new superconducting beam line into operation. Our thanks also to Dr. H. Hagerty and his group for their unstinting efforts with the beam line.

This work was supported in part by the U.S. Dept. of Energy.

REFERENCES

(1) C. DeMarzo et al., Phys. Lett. 112B, 173 (1982).

(2) Some examples are described in:

R. Singer et al., Phys. Rev. D25, 2451 (1982);
G. C. Fox and R. L. Kelly, LBL-13985 (1982);
F. W. Bopp and P. Aurenche, Z. Phys. C 13, 205 (1982).

(3) For a recent review, see P. Darriulat, Ann. Rev. Nucl. Sci. 30, 159 (1981)

(4) The E-609 detector system is described in a separate instrumentation paper submitted to the poster session of this conference.

(5) L. Cormell et al., Performance of a Segmented Hadron Calorimeter, IEEE Trans. Nucl. Sci. NS29, 307 (1982).

(6) B. Robinson, to be published.

(7) B. Brown et al., Fermilab Conf.-82/34-EXP.

FIGURE CAPTIONS

Fig. 1. Top view of apparatus.

Fig. 2. Front face of calorimeter array, showing CM angles at 400 GeV.

Fig. 3. Planarity distribution for globally-triggered events with $E_T > 11$ GeV. Solid line: original data. Dashed line: result after randomizing the azimuthal distribution of calorimeter energy clusters.

Fig. 4. Planarity distribution for "2-high"-triggered events with $E_T > 11$ GeV. Solid line: original data. Dashed line: result after randomizing the azimuthal distribution of calorimeter energy clusters.

Fig. 5. Display of segment p_T's (height) vs. position in the calorimeter (shown as the "plane"), for a typical 2-high-triggered event. The highest peaks correspond to 1.0 to 2.0 GeV/c in a segment.

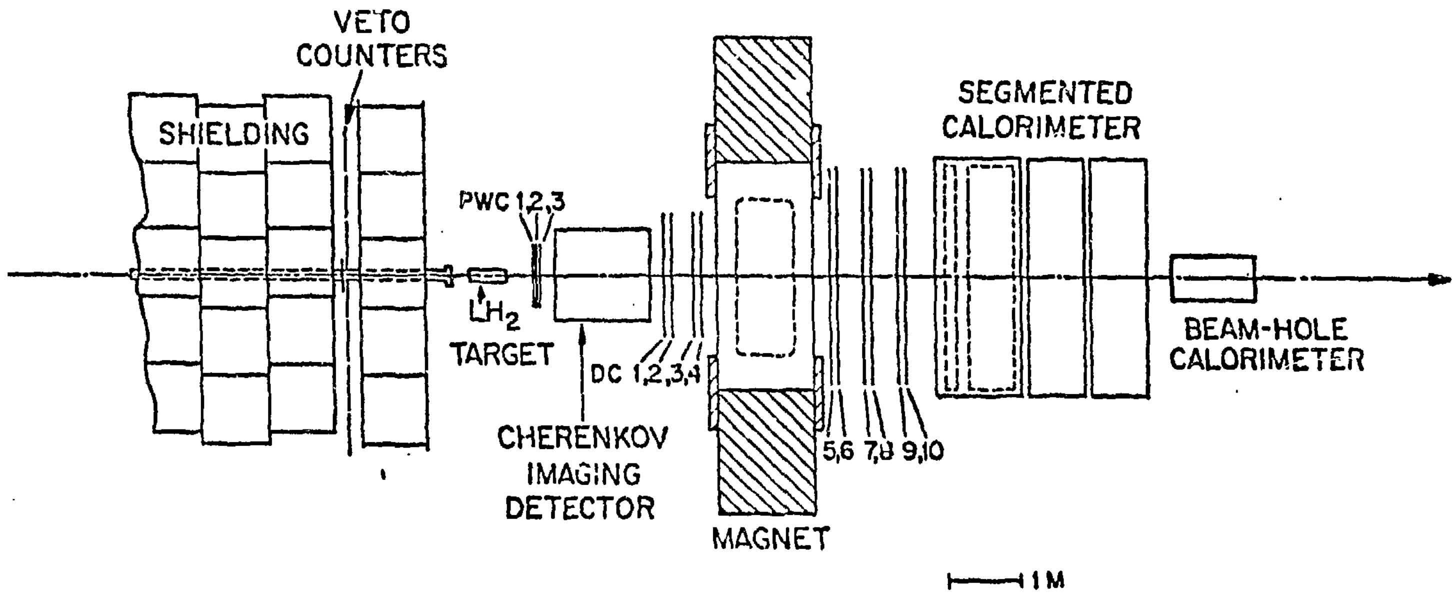
Fig. 6. Display of segment p_T's for a typical globally-triggered event. See previous caption for further remarks.

Fig. 7. Azimuthal distribution of segment p_T values for two typical 2-high-triggered events of jet-like character. See text for cuts. These events correspond to the events numbered 2 and 3 in Fig. 8.

Fig. 8. Azimuthal p_T distribution for 6 events, using ideogram calculation. These are the first 6 events on the data tape which 1) give a 2-high trigger, 2) have total $E_T > 11$ GeV, 3) have at least 5 segments with 0.5 GeV/c or more.

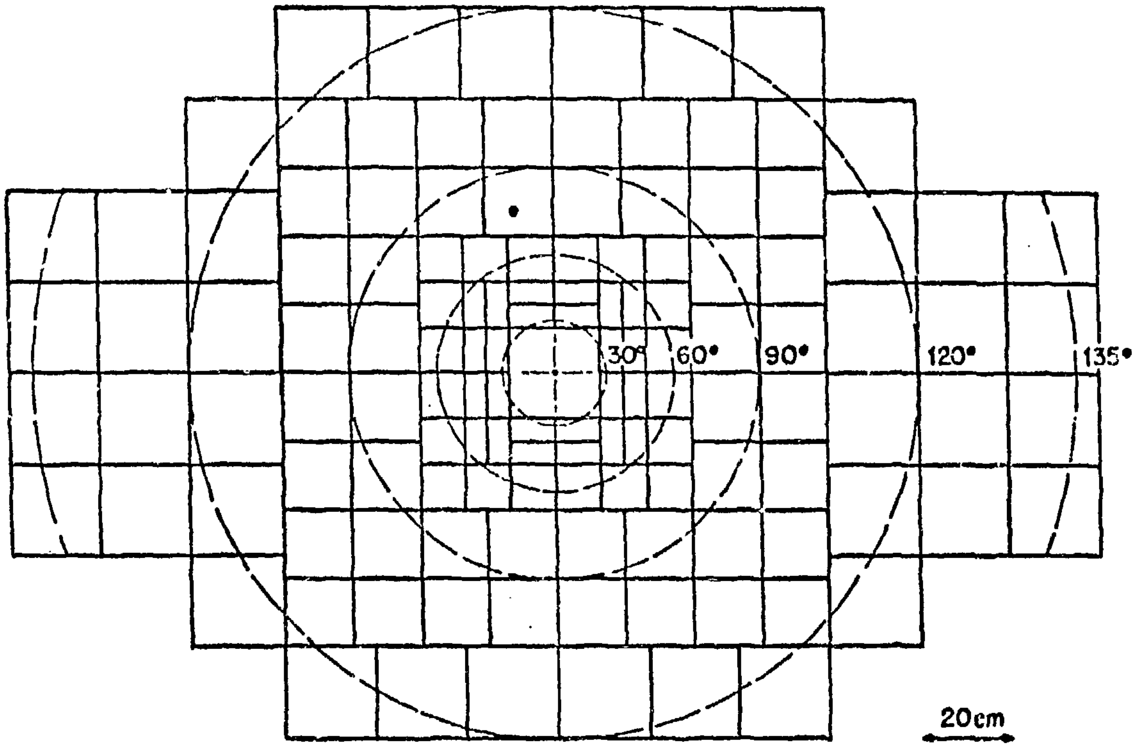
Fig. 9. Composite shape of the 8 clusters in events 2, 3, 4 and 6 of Fig. 8.

Fig. 10. Two-dimensional ideograms in theta-c.m. vs. phi, for events 2, 3, 4 and 6 of Fig. 8. At the right is the projected theta distribution for each cluster, in 10-degree bins.



TOP VIEW OF E-609 APPARATUS

Fig. 1



FRONT VIEW OF CALORIMETER ARRAY AT 400 GeV/c

Fig. 2

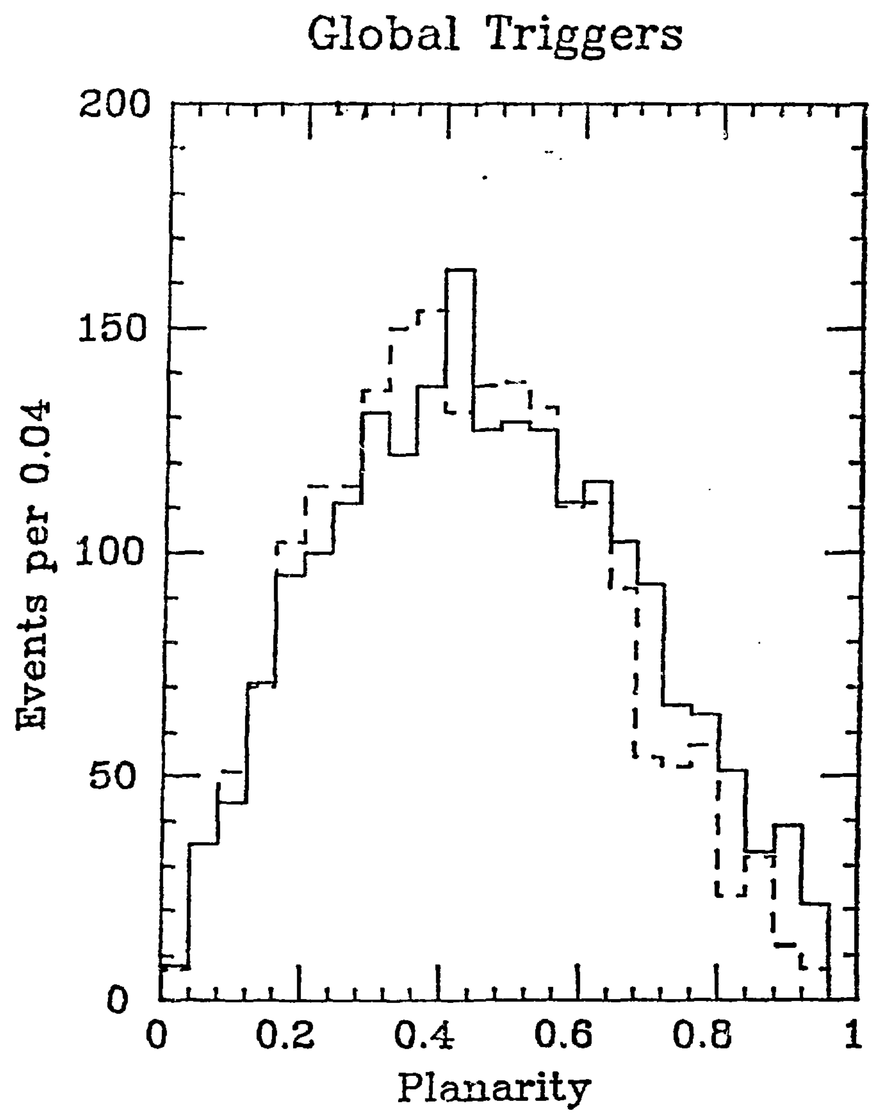

Global Triggers
200
150
100
50
0
Events per 0.04
0
0.2
0.4
0.6
0.8
1
Planarity

Fig. 3

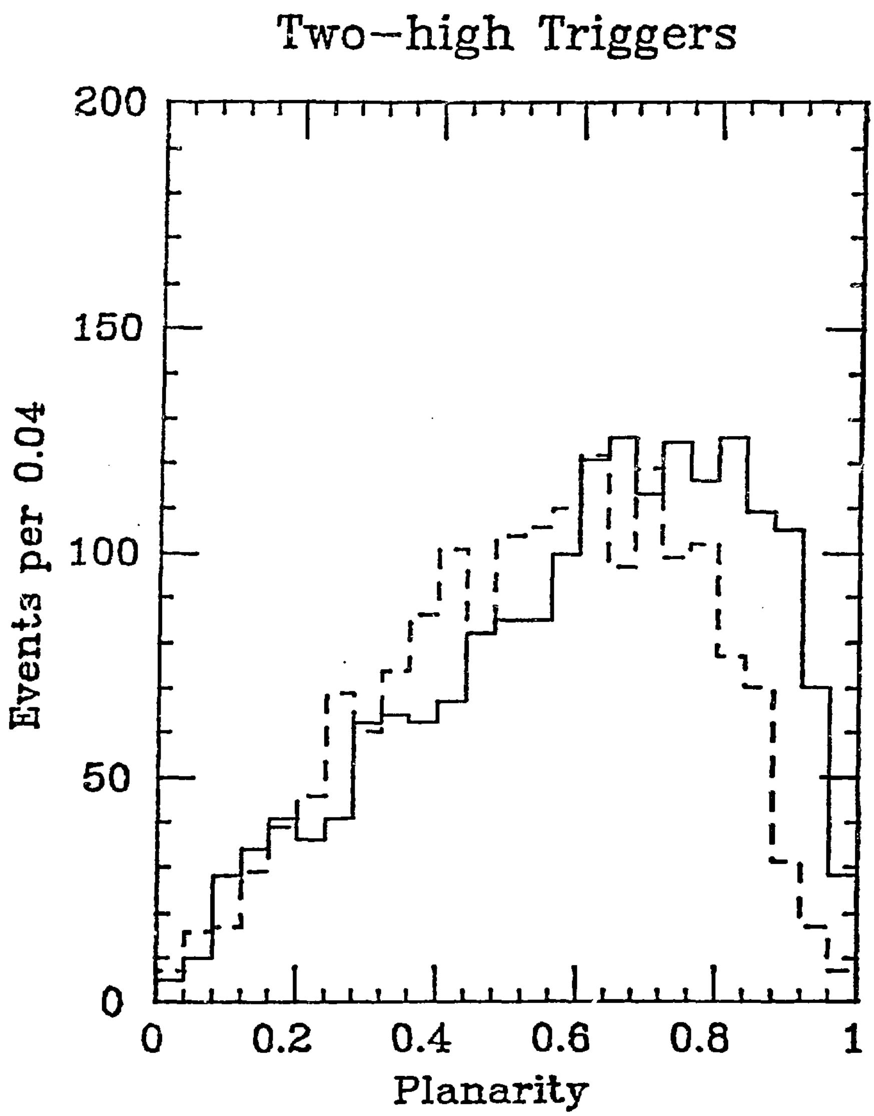
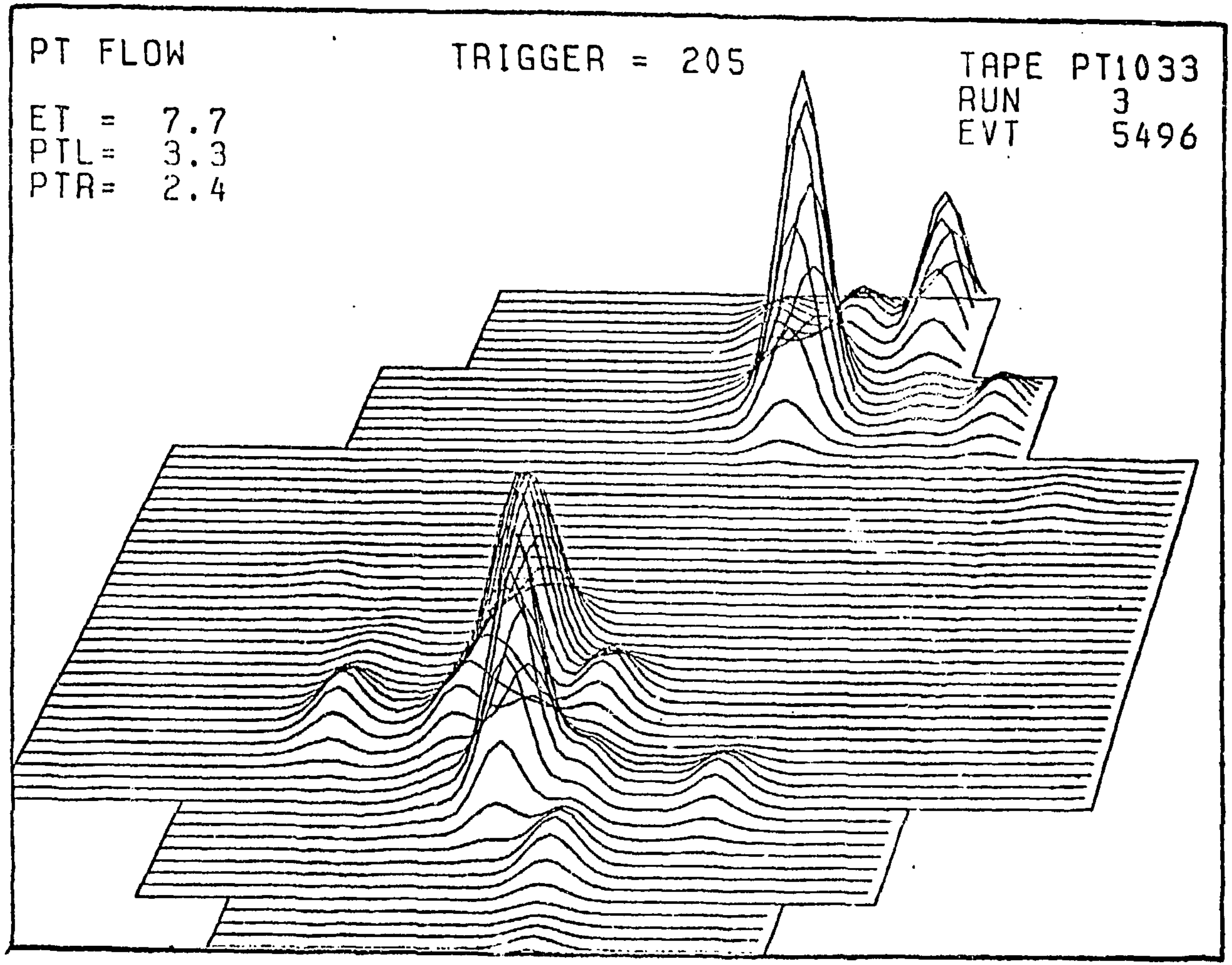

Two-high Triggers
200
150
100
50
0
Events per 0.04
0
0.2
0.4
0.6
0.8
1
Planarity

Fig. 4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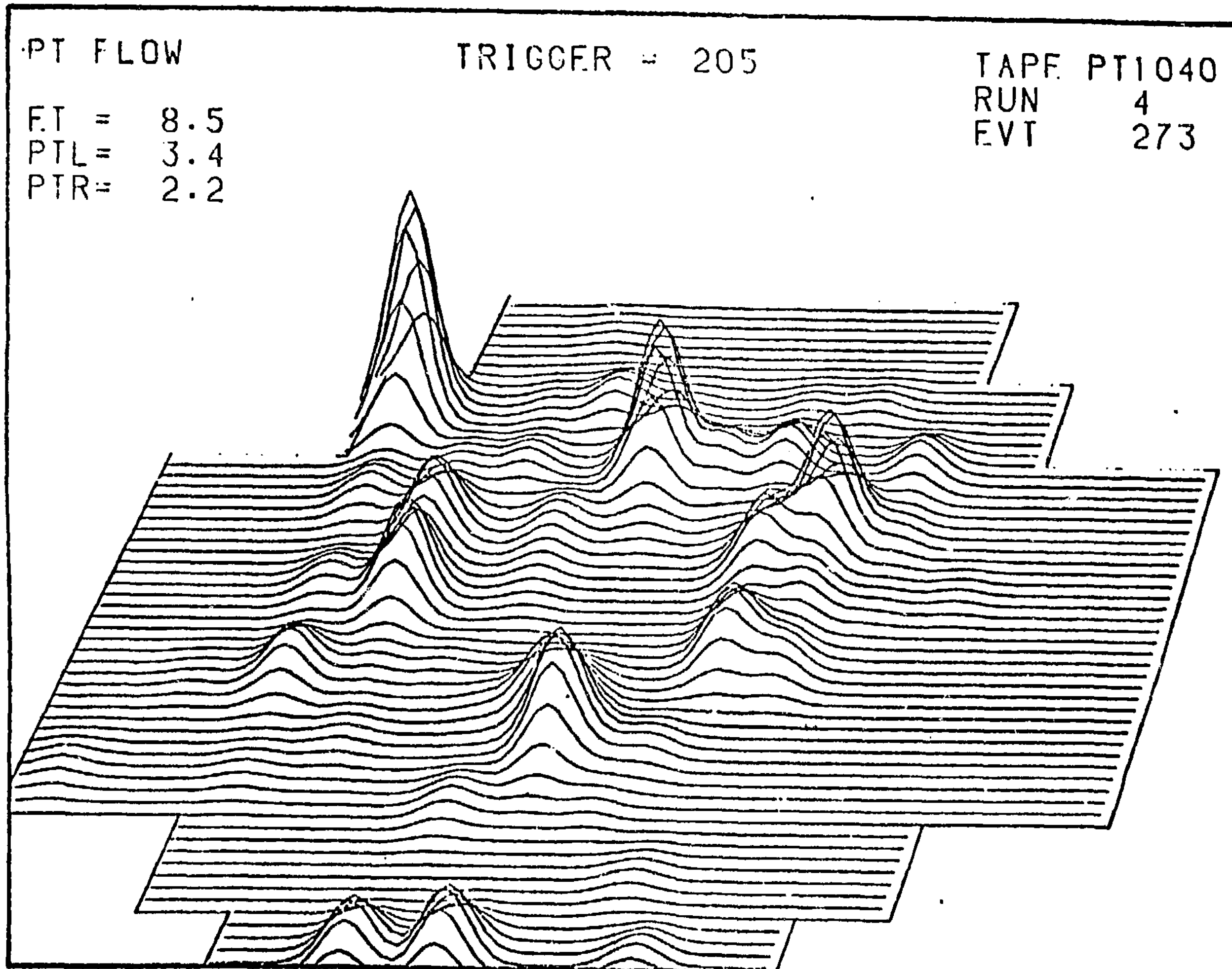
TRIGGER = 205
TAPE PT1033
RUN 3
EVT 5496
ET = 7.7
PTL= 3.3
PTR= 2.4

Fig. 5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TRIGGER = 205
TAPE PT1040
RUN 4
EVT 273
FT = 8.5
PTL = 3.4
PTR = 2.2

Fig. 6

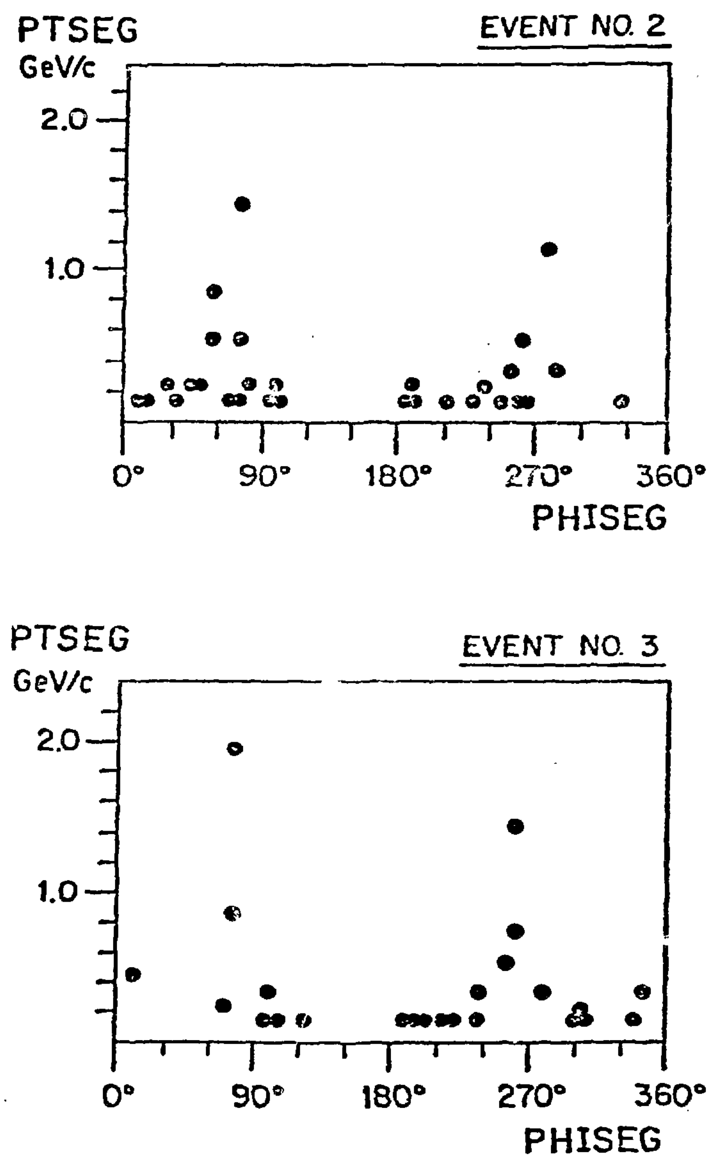
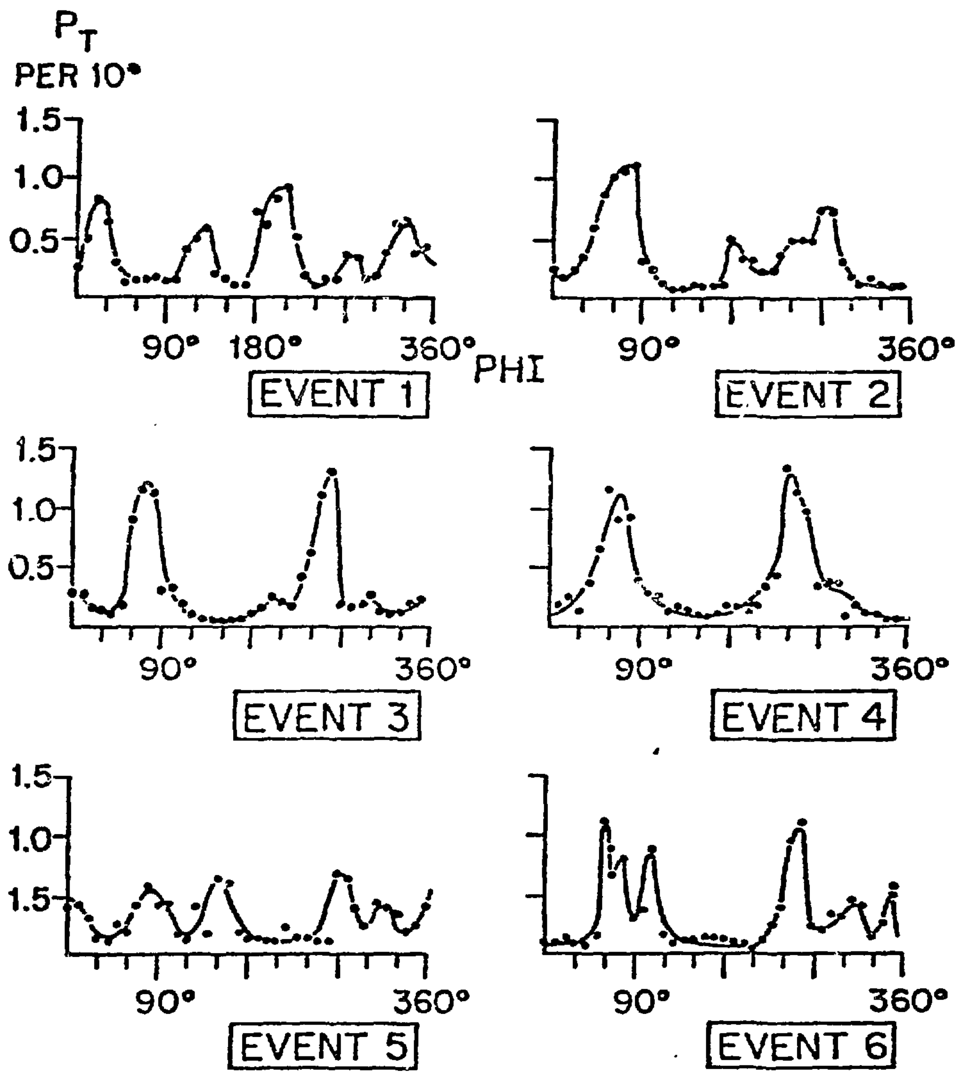

PTSEG
GeV/c
EVENT NO. 2
2.0
1.0
0°
90°
180°
270°
360°
PHISEG
PTSEG
GeV/c
EVENT NO. 3
2.0
1.0
0°
90°
180°
270°
360°
PHISEG

Fig. 7



P
T
PER 10°
1.5
1.0
0.5
90° 180° 360°
PHI
EVENT 1
90° 360°
EVENT 2
1.5
1.0
0.5
90° 360°
EVENT 3
90° 360°
EVENT 4
1.5
1.0
1.5
90° 360°
EVENT 5
90° 360°
EVENT 6

Fig. 8

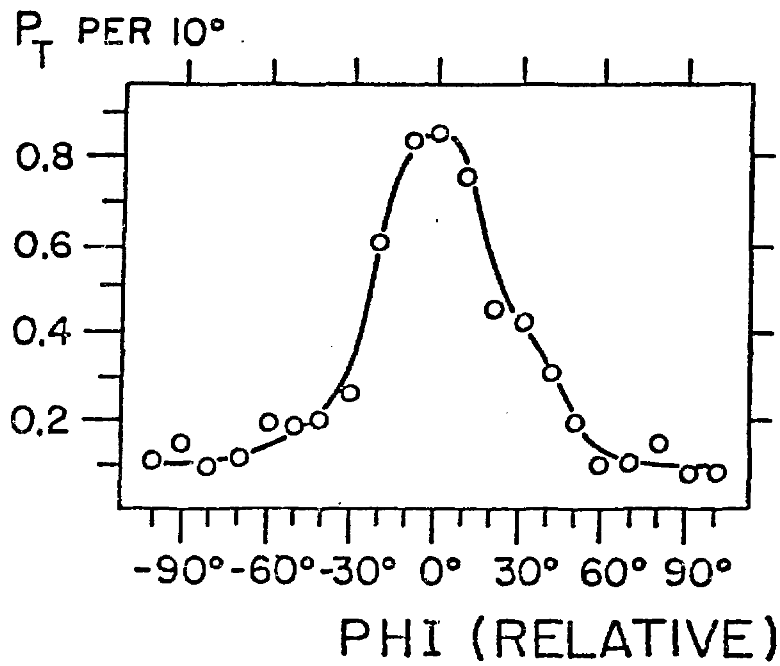


Fig. 9

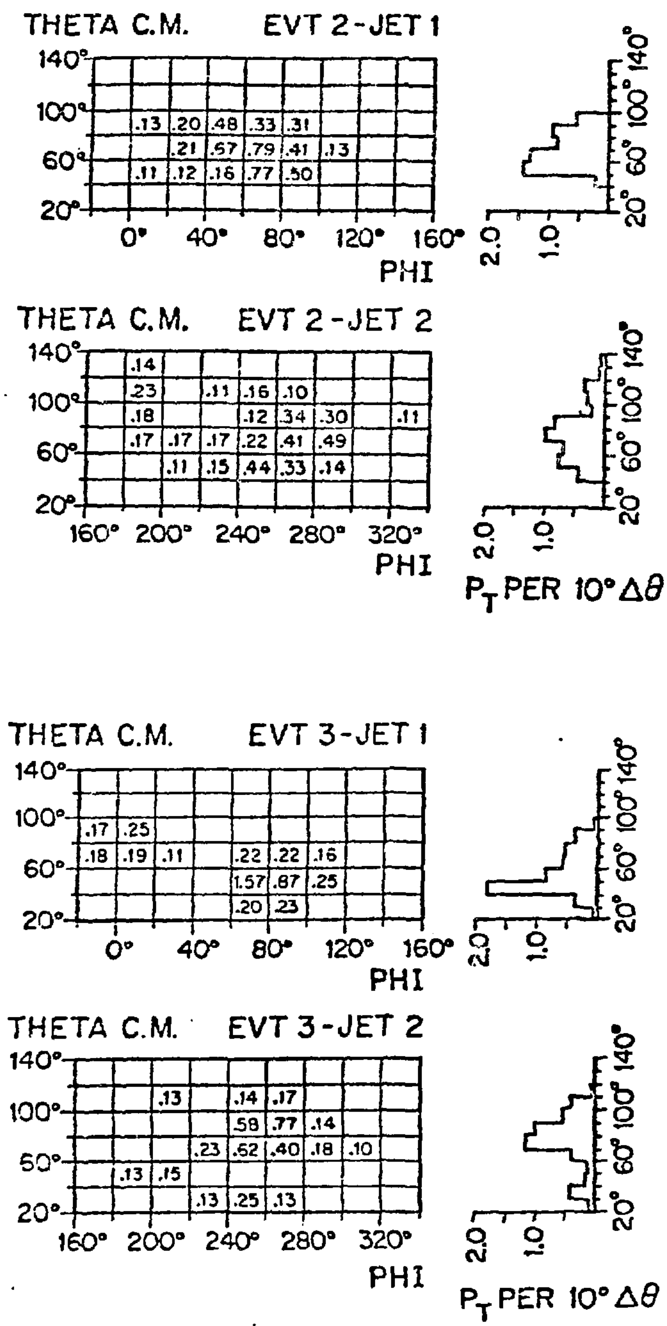

THETA C.M.
EVT 2-JET 1
EVT 2-JET 2
EVT 3-JET 1
EVT 3-JET 2
PHI
P_T PER 10° Δθ

Fig. 10 a

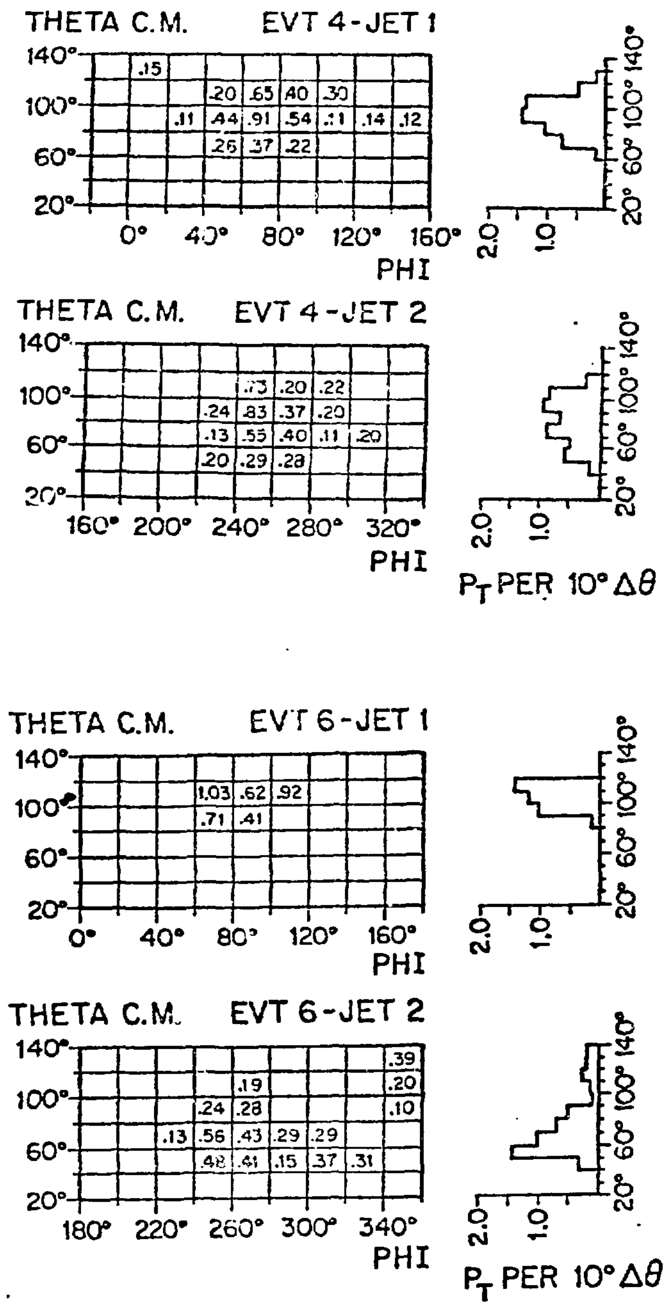

THETA C.M.
EVT 4-JET 1
EVT 4-JET 2
EVT 6-JET 1
EVT 6-JET 2
PHI
P_T PER 10° Δθ

Fig. 10 b