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DETERMINATION OF THE ATOMIC NUMBER DEPENDENCE OF JET PRODUCTION FROM HIGH TRANSVERSE ENERGY (P)A COLLISIONS AT 400 GEV

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DETERMINATION OF THE ATOMIC NUMBER DEPENDENCE OF JET PRODUCTION FROM HIGH TRANSVERSE ENERGY pA COLLISIONS AT 400 GEV

by

SHAHEEN RAZAK TONSE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS

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ABSTRACT

DETERMINATION OF THE ATOMIC NUMBER DEPENDENCE OF JET PRODUCTION FROM HIGH TRANSVERSE ENERGY pA COLLISIONS AT 400 GEV

by

SHAHEEN RAZAK TONSE

High transverse energy events selected by an efficient jet trigger and using various nuclear targets form the data sample in this study. The targets cover a wide range of atomic weight. The A dependence of the cross sections does not obey $A^d$ scaling; we find that $d$ decreases with increasing $A$.

We find evidence for two-jet events formed as a result of hard single scattering of two partons. The A dependence of the fraction of these two-jet events over all triggered events is determined using three different methods. Details of the experiment and the procedures used to extract the jet signal are given.
ACKNOWLEDGEMENTS

I would like to express my gratitude to the following people for help they have given me in completing this thesis.

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Professor Marjorie D. Corcoran for improving my thesis and providing me with Monte Carlo results that I required.

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To my parents, who although they could not be here provided much needed moral support.
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CHAPTER 1
INTRODUCTION

It is widely believed that essentially all the features of large transverse momentum hadron-hadron collisions are at least qualitatively understood within the framework of perturbative QCD. However, a better understanding of the process by which partons turn into hadrons is required in order to get an accurate quantitative description. Hadron-nucleus collisions seem to provide a useful tool for studying both the space-time development of hadronization as well as the multiple interactions of quasi-free partons with nuclear matter.

It has been established experimentally that the $A$ dependence of hadron-nucleus invariant inclusive cross-sections can be parametrized as $^{1}$

$$\frac{E^3 d\sigma}{dp^3} \approx A^\alpha$$

$\alpha$ is a function of the four momenta of the particle. At high transverse momenta the value of $\alpha$ exceeds unity, a phenomenon known as anomalous nuclear enhancement. This
deviation from \( a = 1 \) could occur as a result of secondary interactions of partons inside the nucleus or from nuclear structure effects and has been observed in both a large acceptance high \( E_T \) experiment and in jet production.

In this work we study the production of large \( E_T \) events from 400 GeV/c protons incident on various nuclear targets viz. beryllium, carbon, aluminium, copper, tin, and lead. These data were collected during the run of experiment E-609 at Fermilab in 1983-84. The experiment employed a special trigger (the "two-high" trigger, described in Chapter 2) for selecting jet-like events, and in later chapters we show evidence for jet production from nuclei. Using three different methods we shall try to extract the A dependence of production of events that contain two coplanar jets which could have resulted from a single hard scatter of two partons. A naive expectation is that \( a = 1 \) in this case. We find that \( a \) is slightly larger than one for production of jet-like events, whereas it is significantly larger than one for production of most large \( E_T \) events. Relative merits of the three methods are discussed and suggestions for further work in this area are made.

\( \S1 \) (Transverse energy \( E_T \) of a particle is defined as \( E_T = E \sin \theta \) where \( \theta \) is the polar angle of the track.)
CHAPTER 2
EXPERIMENT AND APPARATUS

The layout of the E-609 apparatus is shown in Figure 1. The nuclear targets were mounted on a wheel arrangement in order that the systematic errors would not vary from target to target. A different target would be positioned in the beam line after each spill. This ensured that the response of the apparatus was identical for all targets. Nuclear target thicknesses were 1% to 3% of the hadronic interaction length. A proportional wire chamber was placed immediately downstream of the targets, followed by twelve drift chambers. A bending magnet was situated behind the first six drift chambers giving a 100 MeV/c transverse momentum kick to charged particles.

The main detector, a segmented calorimeter, was located downstream of the chambers. The front face was divided into 132 segments. Segment sizes in the lab frame varied in such a way as to subtend approximately the same solid angle (0.6 steradian) to the target when boosted to the proton-proton centre of mass frame. Every segment was
FRONT VIEW OF CALORIMETER ARRAY AT 400 GeV/c

TOP VIEW OF E-609 APPARATUS
divided longitudinally into 4 modules each of which was 6 to 8 nuclear interaction lengths. The foremost module was comprised of alternate layers of lead and scintillator. It was here that we expected the electromagnetically interacting photons from \( \pi^0 \) decay and electrons to deposit their energy. The three modules behind this used iron instead of lead for detection of hadrons since the ratio of radiation length to hadronic interaction length is larger for iron than it is for lead. Light produced in the scintillators was optically guided to photo-multipliers, converted to a voltage pulse and then digitized. Modules towards the rear were wider than those at the front so as to contain a shower in one segment as much as possible. In the proton-proton centre of mass frame the acceptance of the calorimeter ranged from 30° to 130° in polar angle and covered 360° in azimuthal angle. Calibration runs before the actual data acquisition involved steering electrons, muons and hadrons (separately) into individual segments and recording the response of the calorimeter. The energy resolution was determined to be approximately 0.70/\( \sqrt{E} \) for hadrons and 0.30/\( \sqrt{E} \) for electrons.\textsuperscript{4}
The rapidly falling cross-section made it necessary to trigger the apparatus only on those high $E_T$ events of interest. The two main triggers were as follows. (a) A global trigger which required that the total $E_T$ summed over all the segments in the calorimeter exceed a given threshold. Actual values were 8 GeV in one setting and 14 GeV in another. (b) A "two-high" trigger which fired if at least 1.0 GeV of $E_T$ was deposited in two separate segments with no constraint on the relative positions of these segments. Later during software analysis the trigger was altered so as to require 1.3 GeV in the highest segment. Previous studies with this trigger\(^5\) show it to be an efficient jet trigger.
CHAPTER 3
DATA ANALYSIS

The raw data as recorded online at the experiment consisted of digitized pulse heights from the 528 calorimeter modules (as well as wire chamber information which we have not used in the present analysis.) The details of the process by which it was converted to its final form will not be described here but essentially entailed (a) rejecting events that were clearly spurious, but had managed to pass the triggers (eg. two incident particles in one event, or an event that was recorded although it did not have enough $E_T$ to satisfy the triggers) and (b) reconstructing particle momenta from the pattern of energy deposition in the calorimeter. The reconstruction algorithm incorporated the longitudinal and lateral shower development as observed in the calibration runs.

Various sets of targets were used in the nuclear target wheel. These consisted of wheels that had (a) all targets (b) only the lighter targets: Be, C, Al, Cu and
(c) only the heavier targets: Al, Cu, Sn, Pb. The actual real time acquisition of data for these different sets was done in intervals separated by a week. This meant that systematic differences could occur between runs, necessitating a run by run scrutiny of the shapes and means of various distributions. The quantities histogrammed included total $E_T$, total energy, multiplicity$^2$, planarity, $P_T$ imbalance and $\phi$ dependence of $P_T$ imbalance.

Information on individual calorimeter segments such as mean $P_T$ per event for each segment and the number of times a segment was the highest or second highest firing segment in the event was also examined. In this way several abnormal segments were detected and corrected for, either by cutting the event out completely or scaling down the response of the segment by comparing it to other segments in azimuthally symmetric positions. The histogramming was done (a) for all events (b) for events in the range $12 \text{GeV} < E_T < 15 \text{GeV}$ and (c) for events with $E_T > 15 \text{GeV}$ as an added precaution and to aid in understanding the results. The results of this monitoring showed that all runs were in fairly good agreement. The $E_T$ scale of the light target wheel was shifted up by 200 MeV. This was done in

$^2$(Multiplicity unless otherwise stated is determined from the pattern of energy deposition in the calorimeter and includes both neutral and charged particles.)
order to bring the mean $E_T$ for targets common to all three wheels (viz. Al and Cu) into agreement. Other discrepancies that occurred did not appear to have any consistent pattern (such as the increase of mean $E_T$ with time) and in any case were fairly small.

Several lead targets were made with double the thickness to check the possibility of multiple interactions within the target. The only significant change seen was an increase in average charged multiplicity (recorded by the proportional wire chamber) from 28.7 to 31.5 for the double thickness targets, but no shift in the $E_T$ spectrum was detected.
CHAPTER 4

CHARACTERISTICS OF DATA FROM THE TWO-HIGH TRIGGER

In this chapter we present some of the general features of the data obtained with the two-high trigger and make a few comparisons to global trigger data. The $E_T$ distributions, (Figure 2) normalised to the same number of entries for each target, show that the average $E_T$ shifts upward with A. We note that the rise is slow unlike that of the global trigger which has a relatively sharp threshold by definition. The reasons for the precise shape and its A dependence are not fully understood at the moment and a careful Monte Carlo study is needed to understand shapes of the spectra and the role of the trigger bias. The $E_T$ and multiplicity are strongly inter-dependent and increase together almost linearly. The multiplicity distributions for beryllium, aluminum and lead are shown in Figure 3. This distribution is seen to shift upward with A, a result also seen in a large acceptance detector minimum bias trigger experiment. The planarity distribution peaks at a higher value for the two-high
trigger than for the global trigger. (0.52 versus 0.35 in the case of lead) It shifts upward with decreasing A.

The A dependence of relative cross sections is displayed in Figure 4. We have plotted $\sigma_{pA}/A$ versus A for $E_T > 12$ GeV. The overall normalisation is essentially arbitrary and for convenience we have set $\sigma_{pA}/A = 4$ for aluminum. The errors indicated in the plot are purely statistical and we have essentially no varying systematic error between points due to our use of the target wheel. The anomalous nuclear enhancement can be clearly seen. An exact $A^\alpha$ dependence of the cross section would result in a straight line in this plot; $\alpha = 1$ would give a horizontal line. We see that $\alpha$ decreases as we go to heavier targets and that an $A^\alpha$ fit is not necessarily the correct one. There is no obvious reason for adopting the $A^\alpha$ parametrization; it was originally chosen as it fitted earlier data. Table 1 below shows the summarised results from the two-high trigger events.
$E_T$ Distributions normalized to equal numbers of entries for two-high trigger events.
FIGURE 3

Multiplicity distributions normalized to equal numbers of entries for two-high trigger events
FIGURE 4

Relative cross sections for two-high trigger events of $E_T > 12$ GeV. The points have been shifted on this plot so that aluminum has a value equal to 4.
### TABLE 1

**Data from the two-high trigger**

<table>
<thead>
<tr>
<th>TARGET</th>
<th>Empty</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_p$ in GeV</td>
<td>10.4</td>
<td>10.5</td>
<td>10.6</td>
<td>11.2</td>
<td>11.5</td>
<td>11.9</td>
<td>12.1</td>
</tr>
<tr>
<td>Total Energy in GeV</td>
<td>222</td>
<td>224</td>
<td>225</td>
<td>235</td>
<td>239</td>
<td>241</td>
<td>242</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>24.8</td>
<td>24.7</td>
<td>25.0</td>
<td>27.1</td>
<td>27.5</td>
<td>28.9</td>
<td>29.4</td>
</tr>
<tr>
<td>Planarity</td>
<td>0.58</td>
<td>0.59</td>
<td>0.58</td>
<td>0.55</td>
<td>0.55</td>
<td>0.53</td>
<td>0.52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TARGET</th>
<th>Empty</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy in GeV</td>
<td>282</td>
<td>282</td>
<td>274</td>
<td>277</td>
<td>272</td>
<td>268</td>
<td>265</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>32.2</td>
<td>32.8</td>
<td>32.6</td>
<td>33.9</td>
<td>33.0</td>
<td>33.5</td>
<td>33.4</td>
</tr>
<tr>
<td>Planarity</td>
<td>0.52</td>
<td>0.55</td>
<td>0.53</td>
<td>0.51</td>
<td>0.51</td>
<td>0.50</td>
<td>0.49</td>
</tr>
</tbody>
</table>
CHAPTER 5
EVIDENCE OF JET PRODUCTION

Before indirect arguments in favour of the existence of jets are presented, such as shapes of planarity distributions etc., more direct visual proof in the form of individual jet-like event plots should be shown. It may later be argued that they are fluctuations or are not the result of an interaction within the target, but without them a claim to have seen jets cannot be made. Figures 5 and 6 show such events from beryllium and lead targets respectively. Quantities on the axes are rapidity in the proton-proton centre of mass frame and $\phi$, the azimuthal angle around the beam axis. The limits of the plot are slightly larger than the acceptance of the calorimeter which ranges from rapidity of $-0.75$ to $+1.3$. Each tower represents a single particle, with a height proportional to the $P_T$ of the particle.

All of the above events have been isolated with the aid of a jet finding algorithm, using a specific set of thresholds and cuts. For these same thresholds we find
FIGURE 5a

Individual events that show a jet-like structure. (Beryllium target)
FIGURE 6a

Individual events that show a jet-like structure. (Lead target)
that the fraction of such events out of all two-high events is the same for the empty target as it is for lead. Since the empty target rate\(^3\) for lead is fairly low only a small fraction of the "jets" we see are spurious although on an individual event basis we are unable to tell.

In the near future a tracking program will use wire chamber hit information in conjunction with the calorimeter signals, making it possible to reject events that are not the result of genuine interactions in the target. However, even lacking this information, on the basis of the empty target rate we can conclude that the majority of the jet-like events observed originate in the target.

\(^3\)\textit{(Empty target rate} is defined as the fraction of observed events that are the result of interactions outside the target. It is calculated using the rate at which events occur in the absence of a target.)
CHAPTER 6

THE A DEPENDENCE OF JET PRODUCTION

To extract the A dependence of jet production we have used 3 different techniques. (a) High planarity method, (b) a scrambling method and (c) the use of a jet finding algorithm.

(a) **High planarity method**: This is the simplest of the three. We merely make a cut at planarity equals 0.7 and claim that all events with a planarity greater than this are jet events. The fraction of these events is shown in Table 2, done both for events of all $E_T$ and for those with $E_T > 12$ GeV. The planarity cut was decided upon by examining the relative orientation of $P_T$ vectors for many individual events and picking a value at which events started to appear reasonably jet-like. This method is admittedly crude as it does not take into account the possibility that some or all of these events could be fluctuations. We do however get a rough idea of how the incidence of jets will behave with A. Figure 7 shows
\( \sigma_{pA/A} \text{ vs } A \text{ for all two-high events with } E_T > 12 \text{ GeV and for those with planarity } > 0.7 \text{ and } E_T > 12 \text{ GeV.} \)

**TABLE 2**

*Fraction of events with planarity \( > 0.7 \).*

<table>
<thead>
<tr>
<th>Events of all ( E_T )</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.37</td>
<td>0.35</td>
<td>0.30</td>
<td>0.27</td>
<td>0.25</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>±.008</td>
<td>±.008</td>
<td>±.007</td>
<td>±.007</td>
<td>±.008</td>
<td>±.005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Events with ( E_T &gt; 12 \text{ GeV} )</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.22</td>
<td>0.19</td>
<td>0.17</td>
<td>0.16</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>±.010</td>
<td>±.009</td>
<td>±.007</td>
<td>±.007</td>
<td>±.007</td>
<td>±.004</td>
</tr>
</tbody>
</table>

(b) **Scrambling:** Instead of claiming that all high planarity events are jets, we assume that there are contributions from both jet-producing processes and a non-jet background. The background could contain high planarity events which are just fluctuations but resemble jet events. The motivation behind scrambling is to extract the jet signal by subtracting a randomized distribution (which approximates the background) from the observed planarity distribution i.e.
FIGURE 7

\( \sigma / A \) vs \( A \) for the two-high trigger in the range \( E_T > 12 \ \text{GeV} \) (i) for all events and (ii) for events with planarity > 0.7. The points have been shifted so that the point corresponding to aluminum equals 4 for the solid circles. The planarity > 0.7 data set has been shifted so that the beryllium points overlap.
Jet signal = \frac{dn}{dp} \text{obs.} - \frac{dn}{dp} \text{random}.

Here \frac{dn}{dp} \text{random} is ideally a distribution that the two-high trigger would select if dynamical jets did not exist in large \( E_T \) events. We therefore require that the randomized events closely fit the \( E_T \), multiplicity, and rapidity distributions of the observed data, obey kinematic restrictions and also satisfy the two-high trigger. The actual scrambling procedure consists of the following steps:

(i) The \( p_T \) vector of each particle is rotated by a random azimuthal angle about the beam axis. This generally leaves a \( p_T \) imbalance (ii) A "ghost" track is now created so as to exactly balance the \( p_T \). For this ghost track we make the approximation \( p_T = E_T \) and leave its longitudinal momentum undefined as it is unnecessary. The new event now has an increased total \( E_T \); accordingly when (iii) the planarity of the new events is calculated the histogram entry is weighted down by \( e^{-\Delta E_T} \) where "a" is the constant obtained from the parametrisation of the differential cross section as

\[
\frac{d\sigma}{dE_T} = \text{constant} \times e^{-aE_T}
\]

The value of "a" for different targets varies from 0.51 for beryllium to 0.37 for lead. Using this method a
planarity distribution for the scrambled data is obtained. We then assume that any jet signal will not have a component below planarity of 0.35, therefore any events in this region would have to be background. The data and scrambled background are normalised to the same number of entries below planarity of 0.35 and the difference between the two distributions is interpreted as the jet signal. Both distributions and the jet signal are shown in Figure 8. The final number we seek is the fraction of jet events (see Table 3) and we get this by dividing the number of entries in the jet signal by the total number of events in the actual data. All scrambled events were restricted to $E_T > 12$ GeV. The $A$ dependence of $\sigma_{pA}$ for the events in the jet signal is shown in Figure 9.

**TABLE 3**

<table>
<thead>
<tr>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.2</td>
<td>23.2</td>
<td>16.2</td>
<td>15.9</td>
<td>11.4</td>
<td>10.9</td>
</tr>
<tr>
<td>$\pm 2.7$</td>
<td>$\pm 2.1$</td>
<td>$\pm 1.9$</td>
<td>$\pm 1.5$</td>
<td>$\pm 1.9$</td>
<td>$\pm 1.2$</td>
</tr>
<tr>
<td>$\pm 1.1$</td>
<td>$\pm 1.0$</td>
<td>$\pm 0.7$</td>
<td>$\pm 0.7$</td>
<td>$\pm 0.6$</td>
<td>$\pm 0.3$</td>
</tr>
</tbody>
</table>

% of the number of entries in the jet signal to total number of events as determined by the scrambling method. Expressed as a percentage $\pm$ systematic error $\pm$ statistical error.
Several different scrambling methods were tried before choosing the one described above. A major point in its favour is that at low planarities (less than 0.35) its shape matches well with the distribution from the data indicating that there is little difference between the actual events and the scrambled events at low planarities.

(c) Using a jet finding algorithm: The scrambling method of the last section, while indicating the presence of a high planarity class of events that are not background, does not provide any characteristics of these events apart from the planarity distribution. To obtain this we search on an event by event basis using an algorithm to pick out the jet-like events, i.e. concentrations of high $E_T$ in small solid angles. We have chosen to use the Gaussian smearing method. A brief description follows:

The solid angle presented by the calorimeter face is represented as a flat plane in the rapidity-#phi space. The input event consists of $N$ particles in the rapidity-#phi plane and a $P_T$ associated with each particle. A two-dimensional Gaussian is formed at the position of each particle with a height equal to the $P_T$ of the particle and
**FIGURE 8**

Planarity distributions of the actual events, scrambled events and the jet signal that results when the difference is taken. (Copper target)
FIGURE 9

$\sigma_{/A}$ vs $A$ for the two-high trigger in the range $E_{T} > 12$ GeV (i) for the data and (ii) for the jet signal. The points have been shifted so that the point corresponding to aluminum equals 4 for the data. The scrambled data set has been shifted so that the beryllium points overlap.
with fixed widths $\sigma_Y$ and $\sigma_\phi$. The Gaussians are summed to form the smooth two-dimensional function

$$G(Y,\phi) = \sum P^i_T \exp \left[ -\frac{(Y-Y_i)^2}{2\sigma_Y^2} - \frac{(\phi-\phi_i)^2}{2\sigma_\phi^2} \right]$$

(See Figure 10) The algorithm (referred to as the jet-finder from now on) then begins a search for peaks in the function $G(Y,\phi)$. A peak is a candidate for a jet if it passes several requirements which include (i) that $G(Y,\phi)$ be greater than some threshold and (ii) it is no closer to another peak than $35^\circ$ in $\phi$ and 0.5 units of rapidity. Once all the peaks are found the individual particles are assigned to jets. Any particle with $P_T$ in the range 0.5 $G(Y,\phi) < P_T < G(Y,\phi)$ is considered as a member of the jet provided it is within $90^\circ$ in $\phi$ from the peak. A final requisite is that $G(Y,\phi)$ must increase monotonically as we go from $(Y,\phi)$_particle to $(Y,\phi)$_peak in 5 equal steps. The position of the jet axis is defined as the position $(Y,\phi)_\text{peak}$, and $P_T$ of the jet as the height of the peak. The positions are in good agreement with those obtained by doing a vector sum of the constituent particles of the jet, with the angle between the two jet vectors averaging to $4.6^\circ$ with a $\sigma$ of $4.2^\circ$. The relation between the height of the peak and $P_T$ of the the vector sum shows that the
FIGURE 10

The function $G(Y,\phi)$ mapped over the entire acceptance of the calorimeter for a two-jet event.
vector sum is typically 0.86 GeV higher with a $\sigma$ of 0.6 GeV. Since this is seen in all targets and our final result is a measure of the relative abundance of two-jet events as a function of A, either quantity is an acceptable choice as a measure of jet $P_T$.

This method has been used with success in analyzing jet data acquired at the ISR\textsuperscript{10}. The parameters used in the ISR jetfinder, namely the Gaussian widths, were optimized by applying the jetfinder to Monte Carlo jet events superimposed on a non-jet background. We have left these values unchanged at $\sigma_Y = 0.5$ and $\sigma_\phi = 0.5$.

The progressive increase of transverse energy for higher A nuclear targets makes it more probable that the jetfinder labels isotropic, high $E_T$ events jet events. To prevent this it was necessary to raise the jet $P_T$ threshold above the value that was used in the ISR experiment mentioned earlier. Individual event plots (similar to Figures 5 and 6) were examined at different thresholds and a value of 3 GeV per jet was finally chosen. Individual event plots show that the high $E_T$ (high multiplicity) events still present a slight problem. The mean multiplicity of two-jet events from lead is 35, as opposed to 29 for all two-high events from lead. In an effort to
channel more $E_T$ into jets and reduce non-jet background we require that jet events satisfy the condition that the sum of the $P_T$ of both jets must be greater than $0.5 E_T$. This results in a decrease of $E_T$, multiplicity and jet multiplicity. The events also become more planar. We also require that $\Delta \phi$ of the jets is greater than $150^\circ$ because we expect jets from single scattering to be at opposite azimuthal angles, with a little variation due to intrinsic transverse momentum of the partons and soft deflections of the scattered partons. This cut does not help in selecting events with less background but it is necessary to ensure that we are looking at single hard scattering.

The results of applying the jetfinder with both the $\Delta \phi > 150^\circ$ and $E_T$ ratio cut are in Table 4. The fractions of two-jet events over all two-high events are for events of all multiplicities. However this fraction is dependent on multiplicity. (See Table 5). Probable reasons for this are (i) The jetfinder picks out high multiplicity non-jet events and calls them jets. The incidence of this has been reduced by the cut restricting the ratio of $P_T$ of the jets to $E_T$ of the event. (ii) The efficiency of the two-high trigger is known to increase with jet $P_T$. (iii) The possibility that the jet fraction does in fact
TABLE 4

Results of applying the jetfinder to actual data.

<table>
<thead>
<tr>
<th>TARGET</th>
<th>Empty</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1413</td>
<td>5558</td>
<td>6029</td>
<td>9651</td>
<td>8688</td>
<td>3749</td>
<td>10845</td>
</tr>
<tr>
<td># events</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># 2-jet events</td>
<td>107</td>
<td>412</td>
<td>478</td>
<td>773</td>
<td>708</td>
<td>302</td>
<td>903</td>
</tr>
<tr>
<td>Percentage of jets</td>
<td>7.6</td>
<td>7.4</td>
<td>7.9</td>
<td>8.0</td>
<td>8.1</td>
<td>8.1</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>±0.7</td>
<td>±0.4</td>
<td>±0.4</td>
<td>±0.3</td>
<td>±0.3</td>
<td>±0.5</td>
<td>±0.3</td>
</tr>
<tr>
<td>Mean # of jets (degrees)</td>
<td>146</td>
<td>152</td>
<td>147</td>
<td>146</td>
<td>145</td>
<td>141</td>
<td>139</td>
</tr>
<tr>
<td>E_{miss} in GeV</td>
<td>12.8</td>
<td>12.9</td>
<td>13.3</td>
<td>13.4</td>
<td>13.8</td>
<td>14.2</td>
<td>13.9</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>30.0</td>
<td>29.3</td>
<td>29.8</td>
<td>31.4</td>
<td>31.9</td>
<td>32.4</td>
<td>32.4</td>
</tr>
<tr>
<td>Planarity</td>
<td>0.76</td>
<td>0.74</td>
<td>0.74</td>
<td>0.72</td>
<td>0.72</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Multiplicity per jet</td>
<td>9.2</td>
<td>8.9</td>
<td>9.0</td>
<td>9.6</td>
<td>9.7</td>
<td>10.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>
increase with $E_T$. A comparison of the planarity distributions from the two global triggers (8 GeV and 14 GeV) shows a possible jet signal at higher $E_T$. In the case of the lead target we find an average planarity of $0.33_{-0.005}^{+0.005}$ for the 8 GeV trigger and $0.38_{-0.004}^{+0.004}$ for the 14 GeV trigger despite the average multiplicities being 33 and 44 respectively. One would expect, for non-jet events that the average planarity decreases as multiplicity increases.

**Table 5**

*Fraction of two jets shown as a function of multiplicity and $A$. (Expressed as a percentage)*

<table>
<thead>
<tr>
<th>TARGET</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 to 30</td>
<td>7.6</td>
<td>7.8</td>
<td>8.3</td>
<td>7.2</td>
<td>7.2</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>±0.6</td>
<td>±0.6</td>
<td>±0.5</td>
<td>±0.5</td>
<td>±0.7</td>
<td>±0.4</td>
</tr>
<tr>
<td>Multi.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 to 40</td>
<td>12.8</td>
<td>14.0</td>
<td>12.1</td>
<td>11.9</td>
<td>10.6</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>±1.0</td>
<td>±1.0</td>
<td>±0.7</td>
<td>±0.7</td>
<td>±0.9</td>
<td>±0.5</td>
</tr>
<tr>
<td>Multi.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 to 50</td>
<td>17.5</td>
<td>13.2</td>
<td>11.8</td>
<td>12.1</td>
<td>10.4</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>±3.0</td>
<td>±2.2</td>
<td>±1.4</td>
<td>±1.4</td>
<td>±1.5</td>
<td>±0.9</td>
</tr>
</tbody>
</table>

Table 5 shows the fraction of jet events decreasing at multiplicities of 40 to 50. (These correspond to $E_T > 13$ GeV.) These numbers are not conclusive however, as they have sizable errors. A correction taking into
account the varying efficiency of the two-high trigger will have to be done. Another correction that needs to be made is the estimation and removal of background fluctuations. This is done by applying the jetfinder to scrambled data. A slightly different scrambling method has been employed.\(^{10}\) The results are displayed in Table 6. The average multiplicity of the "scrambled jets" is only slightly higher than that of jets from the data indicating that the jetfinder is effective at cutting out the isotropic high multiplicity events.

As a follow-up to the work already done, the dependence of the fraction of jet events will have to be corrected for both background and trigger efficiency.
<table>
<thead>
<tr>
<th>TARGET</th>
<th>Empty</th>
<th>Be</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>Sn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>507</td>
<td>4927</td>
<td>4712</td>
<td>5918</td>
<td>3097</td>
<td>6359</td>
<td>4861</td>
</tr>
<tr>
<td>2-jet</td>
<td>18</td>
<td>131</td>
<td>175</td>
<td>265</td>
<td>125</td>
<td>228</td>
<td>206</td>
</tr>
<tr>
<td>Percentage of jets</td>
<td>±0.8</td>
<td>±0.2</td>
<td>±0.3</td>
<td>±0.3</td>
<td>±0.4</td>
<td>±0.2</td>
<td>±0.3</td>
</tr>
<tr>
<td>Mean θ of jets (degrees)</td>
<td>147</td>
<td>145</td>
<td>147</td>
<td>145</td>
<td>144</td>
<td>142</td>
<td>141</td>
</tr>
<tr>
<td>E_m in GeV</td>
<td>13.3</td>
<td>13.0</td>
<td>13.0</td>
<td>13.6</td>
<td>13.7</td>
<td>13.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>31.2</td>
<td>30.7</td>
<td>29.6</td>
<td>31.0</td>
<td>31.0</td>
<td>32.3</td>
<td>31.4</td>
</tr>
<tr>
<td>Planarity</td>
<td>0.73</td>
<td>0.72</td>
<td>0.70</td>
<td>0.71</td>
<td>0.69</td>
<td>0.69</td>
<td>0.70</td>
</tr>
<tr>
<td>Multiplicity per jet</td>
<td>8.5</td>
<td>8.5</td>
<td>8.3</td>
<td>8.7</td>
<td>9.0</td>
<td>9.3</td>
<td>9.0</td>
</tr>
</tbody>
</table>

**TABLE 6**

Results of applying the jetfinder to scrambled data.
CONCLUSION

The presence of a jet signal is confirmed by (a) the high planarity distribution left over after subtracting the background from the data in the scrambling method and (b) the decreased fraction of two-jet events found by the jetfinder when applied to scrambled data. The value of \( \alpha \) for the jet signal is lower than that of all two-high triggered events but is still greater than one. All the three methods we have used to determine the jet fraction have shown a decreasing fraction with increasing \( A \) although in the third (jetfinder) method this is only seen at high multiplicities (High \( E_T \)). A more careful study of the jetfinder needs to be done, and the corrections mentioned in the last chapter need to be applied. The response of the jetfinder at different Gaussian widths and jet \( P_T \) thresholds should be looked into more thoroughly and the correct method of executing the background subtraction needs to be determined.
REFERENCES


4) K. A. Johns, Master's Thesis Rice University (1983)


