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Transverse Energy Distributions in Si+Nucleus Collisions at 10 GeV/nucleon

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Abstract

Transverse energy distributions have been measured for collisions of 10 GeV/nucleon Si with targets of Al, Cu and Pb using a combination of a NaI wall and a uranium based sampling calorimeter. The measured cross sections $d\sigma/dE_T$ and $dE_T/d\eta$ are consistent with full stopping and an increase, with increasing values of E_T, of energy flow into large angles.

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INTRODUCTION

In this note we report first results of an experimental study by the E814 collaboration of transverse energy production in Si - nucleus collisions at an incident energy of 10 GeV/nucleon. The main emphasis of this investigation is the study of the angular - or pseudorapidity dependence of transverse energy production in order to determine the amount of stopping or thermalization reached in such collisions. In particular, we compare transverse energies produced by interactions of Si with targets of Al, Cu and Pb to obtain information on the amount of nuclear matter necessary to 'stop' the projectile.

EXPERIMENTAL SET-UP

Using components of the final set-up for experiment E814 presently under construction at Brookhaven National Laboratory we have measured in a first experiment the flow of energy in Si nucleus collisions. A schematic diagram of the apparatus is shown in Figure 1. The Si beam of intensity of approximately 10^5 particles per AGS spill (the spill length was approximately 1.5 s) is defined by a sequence of plastic scintillator detectors to hit targets of Pb, Cu and Al. From the scintillator response beam purity is estimated to be well above 90%. The total energy E and transverse energy E_T produced in such reactions are measured in a detector consisting of a wall of 20x30 NaI crystals backed by a uranium-copper-scintillator sampling calorimeter of a design modified from that developed by the R807 collaboration at CERN [1]. The uranium calorimeter was segmented into 6 towers, 20 cm wide by 120 cm high. The scintillator sheet in each tower was additionally subdivided into 24 cells, each of size 10 x 10 cm^2 and read out by separate wavelength shifters. This detector system covers approximately the forward hemisphere in the nucleon-nucleon center of mass system at 10 GeV/nucleon beam energy. More details about the acceptance of the detector system and the target thicknesses used are given in Table 1.

To select events corresponding to interactions in the target, a number of parallel triggers were formed. They were based on multiple discriminator thresholds on pulse height levels in the interaction scintillator R downstream from the target (see Figure 1) or on sums of each of the 144 cells in the uranium calorimeter, appropriately weighted to form a signal proportinal to transverse energy. The energy scale of the NaI crystals, read out by a vacuum photodiodes, was calibrated by selecting single minimum ionizing particles traversing each crystal and by sending beams of protons, pions and electrons of various energies directly into a few selected crystals. The energy scale of the uranium calorimeter was determined by calibration with beams of protons, pions, muons and electrons with incident momenta in the 0.5-10 GeV/c range and with the Si beam. Relative calibration of different towers is obtained by comparing the charge, integrated over an interval of 3μs, due to the natural radioactivity of the uranium. The overall energy resolution of the uranium calorimeter in the present experiment was about $\sigma/E=0.7/\sqrt{E(GeV)}$, mainly determined by the particular light decoupling used for the scintillator sheets and by attenuation in the wavelength shifter bars.

Cross sections were obtained from the measured beam flux and the known target thicknesses. In order to subtract events not originating in the target, data were taken at regular intervals with an empty target frame but with identical trigger and beam conditions. The target-out correction varied from approximately 50% at low transverse energy and/or low reaction trigger thresholds to less than 5% at large values of transverse energy and is applied to all cross sections presented below. One should also note that the transverse energy scale of the present data is not yet fully corrected for resolution and response of the detector system. We estimate possible corrections of up to 10% downward in E_T. Beam rate dependent effects, although clearly seen in the calorimeter response, were found to have little effect on the measured transverse energy distributions.

RESULTS

In Figure 2 we present the measured distributions in transverse energy for Si nuclei impinging on Al, Cu and Pb targets. Below transverse energy of about 15 GeV there is a sizeable systematic uncertainty in the data because of the large target out correction (see above and Figure 3). Typical error bars are indicated. The data presented in this figure are obtained by triggering on transverse energy in the uranium calorimeter cells. In Figure 3 we compare these data with those obtained by triggering on the reaction scintillator (see above). Above E_T=15 GeV the two sets of data for the Pb targets are very nearly identical implying that there is little trigger bias in the measured distributions. For comparison we include in this figure the normalized target-out correction (dashed line). The size of this correction approaches 50% for transverse energies below 20 GeV and is the main reason for the relatively large systematic errors at low transverse energies.

Also note that even at high transverse energies the measured cross sections are independent of target thickness as can be seen by comparing results for the thin and thicker Pb target presented in Figure 2. Reinteractions of secondaries or multiple interactions in the target are apparently not yet important at the E_T levels measured.

It is remarkable to note that transverse energies up to 50 GeV are observed in our limited solid angle for reactions with both copper and lead while clearly less transverse energy is produced in Si+Al reactions. The near equality of the cross sections for the Cu and Pb targets at high E_T suggests that similar "stopping" of the projectile is observed in both cases while the Al target is not thick enough to completely stop the projectile. We will discuss the implications of these data below in the framework of a hadronic fireball model.

To study the angular or pseudorapidity dependence of transverse energy production for the three different targets we make use of the fine granularity of the NaI wall in front of the uranium calorimeter. Although only a relatively small (<20%) fraction of the transverse energy of an event is deposited in this detector, this energy E_T^{NaI} is a good measure of the full transverse energy as can be seen from Figure 4. In the following we will therefore use the dependence of E_T^{NaI} on pseudorapidity η to investigate the degree of thermalization attained in the reactions studied.

In Figure 5 we present such pseudorapidity distributions for the three different targets and for four different windows on transverse energy E_T. Note the shift toward smaller η values (larger angles) of $dE_T^{NaI}/d\eta$ as the transverse energy in the event is increased. There is also a small shift towards smaller η values with increasing target mass (for a given E_T window) but because of the limited solid angle of our set-up the position of the peak is essentially determined by the acceptance in η (see Table 1). Similar shifts towards low pseudorapidities with increasing total transverse energy have been observed by the Helios collaboration for hadron-lead collisions at 200 GeV/c incident momentum [2] and for ^{16}O-lead collisions at 60 GeV/nucleon incident energy [3]. The data at 200 GeV/nucleon, on the other hand, show little shift if any [3].

DISCUSSION

To put our data into perspective we compare with our data predictions of the transverse energy produced by an isotropically decaying hadronic fireball formed in the reaction. Restricting ourselves to central collisions we assume that the projectile interacts with all nucleons in a cylinder cut through the center of the target nucleus to form a hot, compressed fireball with A_p+A_f baryons (see Table 2). The center of mass energy E_{cm}^f of the fireball and the total available energy T_{cm}^f are then completely determined by kinematics as is the rapidity y_f of the fireball in the laboratory system. Typical fireball parameters are given in Table 2, for the reactions studied. To compute transverse energy production from such a fireball we assume that all the nucleons and as many pions as are allowed by energy conservation are emitted isotropically in the fireball rest frame. The momentum spectrum of the emitted particles is Monte Carlo generated as an exponential spectrum with $\langle p_T \rangle = 0.35$ GeV/c. The four-vectors of the decay particles are then transformed to the laboratory system.

The transverse energy E_T^{acc} expected within our detector acceptance from this fireball prescription is compared with the experimental data in Figure 6. For central Si+Pb collisions we expect approximately 32 GeV of transverse energy in the rapidity interval covered by this experiment, in good agreement with the peak in the $d\sigma/dE_T$ spectrum. Note, however, that the fireball prescription would predict more transverse energy scattered into our acceptance for the lighter targets. For the Cu target, e.g., the fireball limit is reached only in about 10 % of the central collisions and with a much smaller fraction for Si+Al reactions, indicating that the Al nucleus does not fully stop the Si projectile.

The fireball model also reproduces rather well the measured $dE_T/d\eta$ distributions when gated on the highest transverse energy bins as shown in Figure 7. One should point out again that for $\eta<1.8$ the shape of the measured distributions is determined mainly by the instrumental acceptance (which is, of course, also built into the fireball calculations). To illustrate the degree of sensitivity to the source size in the measured $dE_T^{NaI}/d\eta$ distributions we compare, in Figure 7, the measured distributions for the Pb target with the predictions of the fireball model for both the Al and the Pb target, normalized to the same area. The discrepancy in the $1 < \eta < 2$ region indicates that the apparent source rapidity is significantly smaller than that of the N-N system. To further support this interpretation of our data in terms of an isotropically emitting hot source one needs to measure transverse energy production into all angles. Extrapolating from the present data we then expect to find more than half of the total transverse energy produced in a central collision at angles of $\theta_{lab}>30^0$.

In Figure 6 we also compare the predictions of the multiple collision model of Baym et al. [4] with the measured E_T distributions. In this model multiple nucleon nucleon collisions are generated according to the overlap of the nuclear densities of target and projectile. In each nucleon nucleon collision transverse energy is produced according to a simple parameterization of results from pp collisions. Energy degradation of the nucleons is included. With proper cuts in rapidity as determined by our acceptance this model predicts features which are in rather good agreement with our data for Si+Pb although the amount of transverse energy generated is somewhat less than observed for the lighter targets. Note, however, that the target mass dependence of the cross section is qualitatively similar to what is experimentally observed: the distributions for the Cu and Pb target approach each other at high values of E_T while for the Al target there is clearly less transverse energy production.

Assuming the formation of a hadronic fireball as discussed above we can estimate the energy density ε and baryon number density ρ reached in central Si-Pb collisions at 10

GeV/nucleon. Since $\gamma_{cm}{}^{f} = 1.58$ we get for the volume of the fireball $V^{f} = 260\ fm^{3}$ and, consequently, $\varepsilon = 212/260 = 0.8$ GeV/fm^3 and $\rho = 107/260$ nucleons/fm^3 $= 2.7 * \rho_0$, where ρ_0 is the density of normal nuclear matter.

CONCLUSION

We have presented transverse energy distributions for collisions of Si nuclei with Al, Cu and Pb targets at a bombarding energy of 10 GeV/nucleon. Both the transverse energy production probabilities and the distributions of transverse energy in pseudorapidity or angle are in qualitative agreement with a scenario in which, for the heaviest target at least, the Si nucleus is fully stopped in the average central collision. Energy densities of approximately 0.8 GeV/fm^3 are estimated from the transverse energy distributions. With our upcoming measurements, covering a much wider angular range, we will be able to address in more detail the interesting questions of stopping and thermalization.

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REFERENCES

[1] T. Akesson et al., Nucl. Instr. Meth. **A252**(1985)17
[2] T. Akesson et al., CERN-EP/87-170
[3] T. Akesson et al., CERN-EP/87-176
[4] G. Baym, P. Braun-Munzinger and V. Ruuskanen, Phys. Lett. **190B**(1987)29.

FIGURE CAPTIONS

Fig. 1: Experimental Set-up

Fig. 2: Transverse energy distributions for Si+Al, Cu and Pb. For the Pb target results with a thin and a thicker target (see Table 1) are shown, as open and solid circles, for comparison.The pseudorapidity coverage is given in Table 1. Data are taken with the E_T trigger and typical error bars are indicated (for

further details see text).

Fig. 3: Comparison of results for the R and the E_T trigger using the thicker Pb target. Also shown in this figure is the normalized target-out correction (dashed line). For $E_T < 20$ GeV this correction is approximately 50%

Fig. 4: Scatter plot of transverse energy as measured in the NaI-wall E_T^{NaI} versus total transverse energy E_T.

Fig. 5: Distribution of transverse energy in the NaI detector as a function of η for the Al, Cu and Pb target and various E_T bins.

Fig. 6: Comparison of measured $d\sigma/dE_T$ distributions with predictions of the model of [3]. Expected transverse energies from a hadronic fireball are also shown (bell shaped distributions) for the three targets. The cross section scale of the fireball curves is adjusted to the data.

Fig. 7: Comparison of the measured $dE_T^{NaI}/d\eta$ distributions with the predictions of the fireball model. The distribution for the Pb target is also compared to the prediction for Si+Al to indicate the sensitivity of the data to the fireball source size.

Table 1: Details about the experimental set-up.

a) Geometric acceptance:
x: horizontal
y: vertical

	θ_x	θ_y	η_x	η_y
NaI	0.-24.7°	0.-16.3°	1.5-4.2[a]	1.9-4.2[a]
U-cal	0.-23.8°	0.-23.8°	1.5-2.5[a]	1.5-2.5[a]

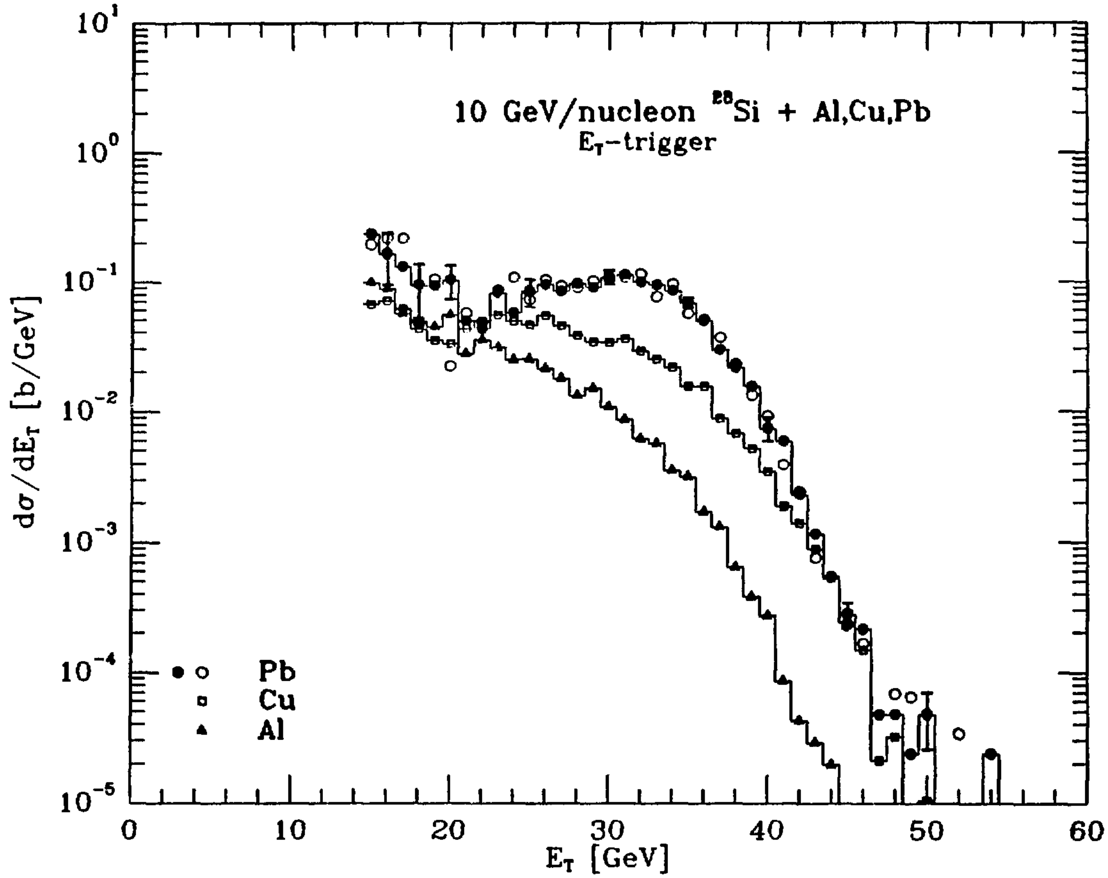
[a] limits in η are calculated disregarding the central four modules of each calorimeter

b) Targets:

material	ρ(mg/cm^2)	% of interaction length
Pb	394	0.35
Pb	746	0.66
Cu	596	1.06
Al	423	1.30

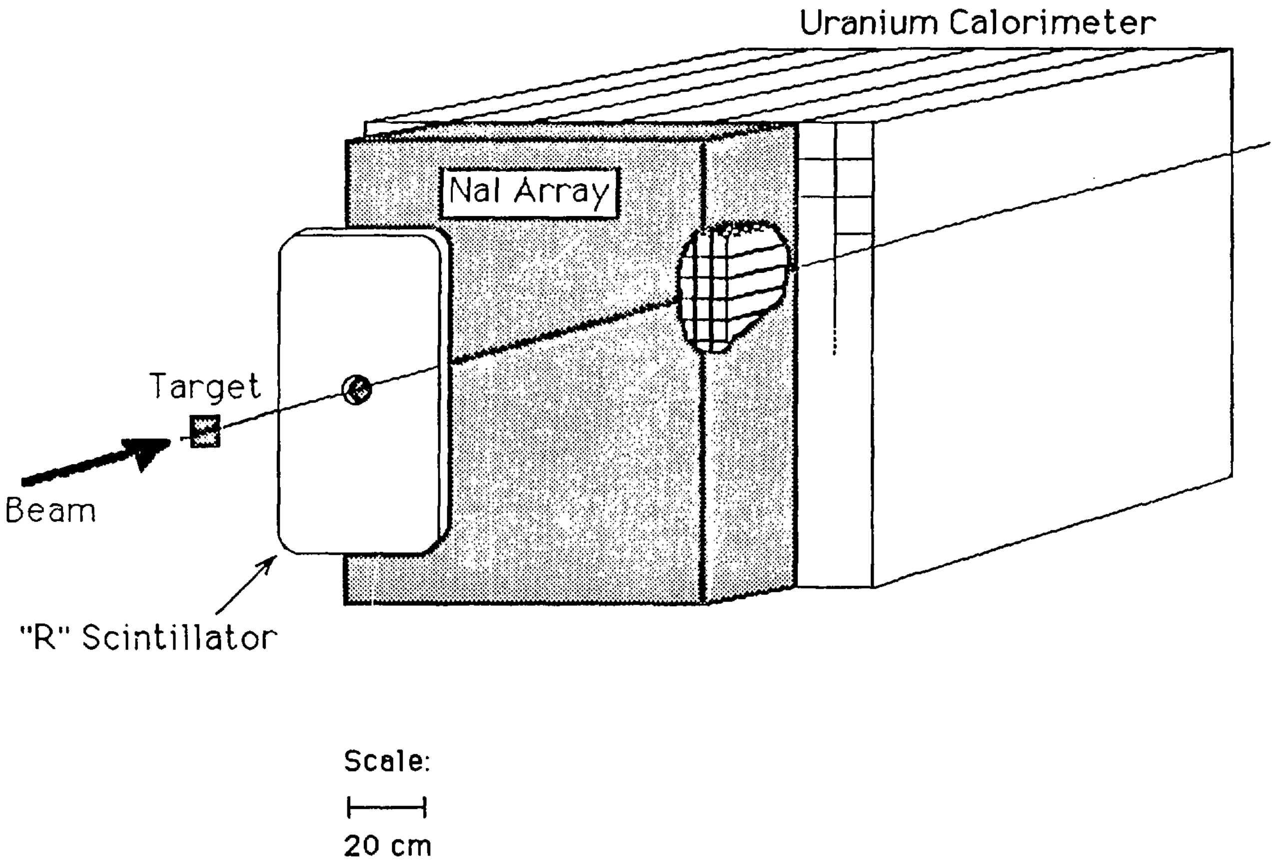
Table 2: Relevant parameters of a hadronic fireball of ($A_p + A_f$) nucle ons formed in reactions of 10 GeV/nucleon ^{28}Si (γ=10, y_{beam}=3.0) with targets of mass number A_t.

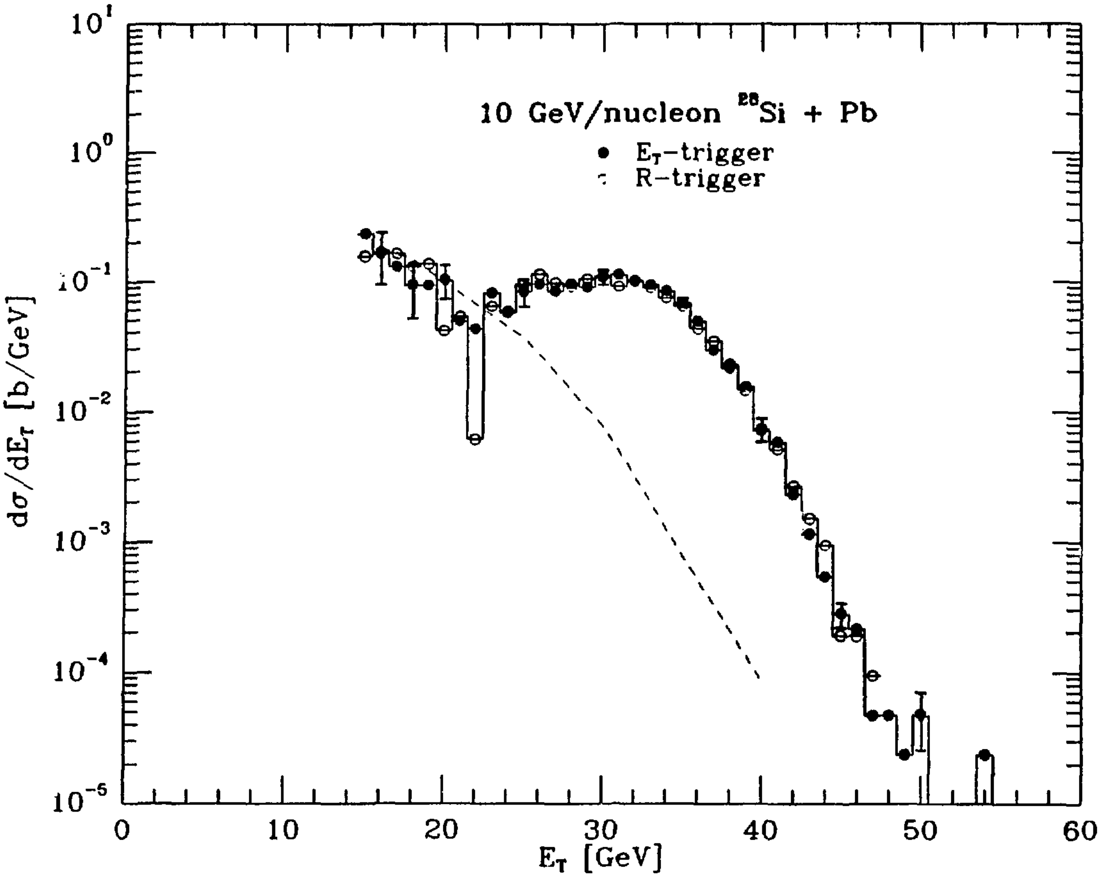
A_p	A_t	A_f	y_f	E_{cm}^f (GeV)	T_{cm}^f (GeV)	E_T^{acc} (GeV)
28	27	27	1.51	121	70	38
28	65	48	1.26	162	91	36
28	208	79	1.03	212	112	32

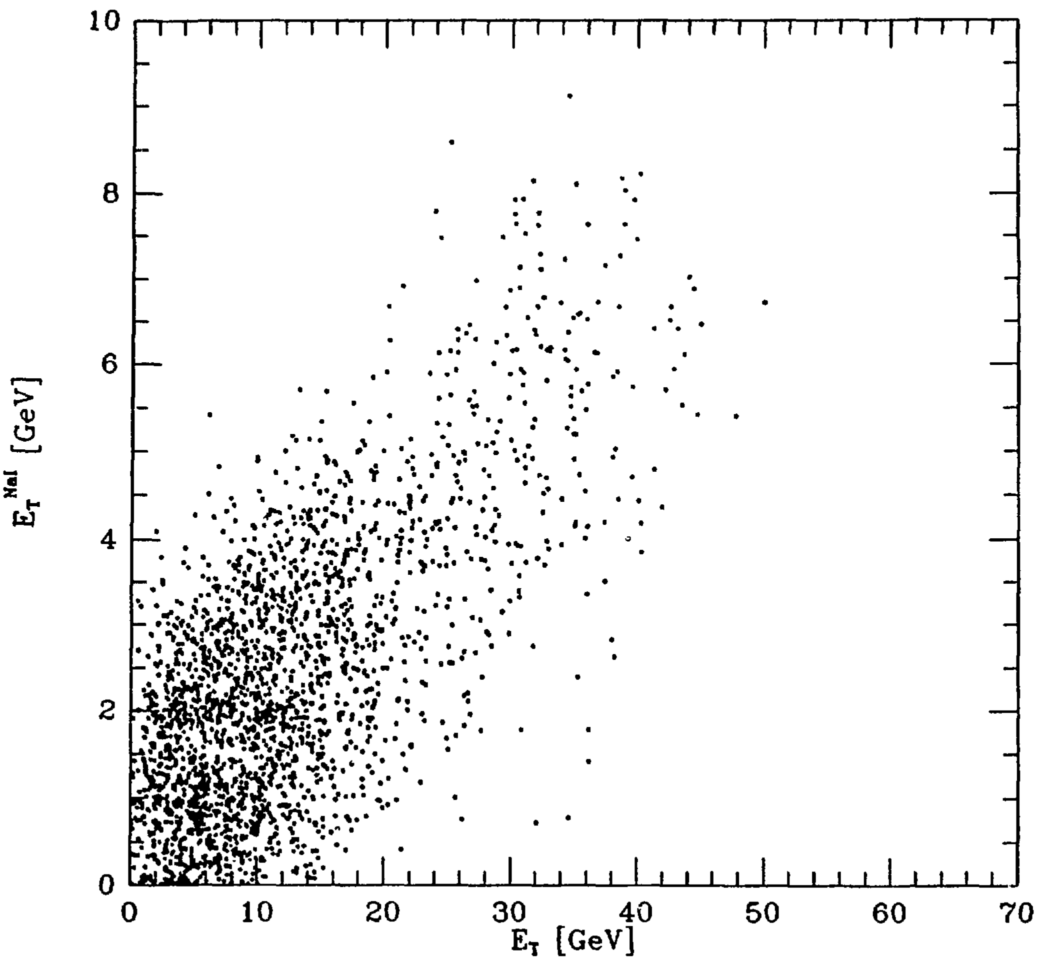


10 GeV/nucleon ²⁸Si + Al,Cu,Pb
E_T-trigger
dσ/dE_T [b/GeV]
E_T [GeV]
Pb
Cu
Al

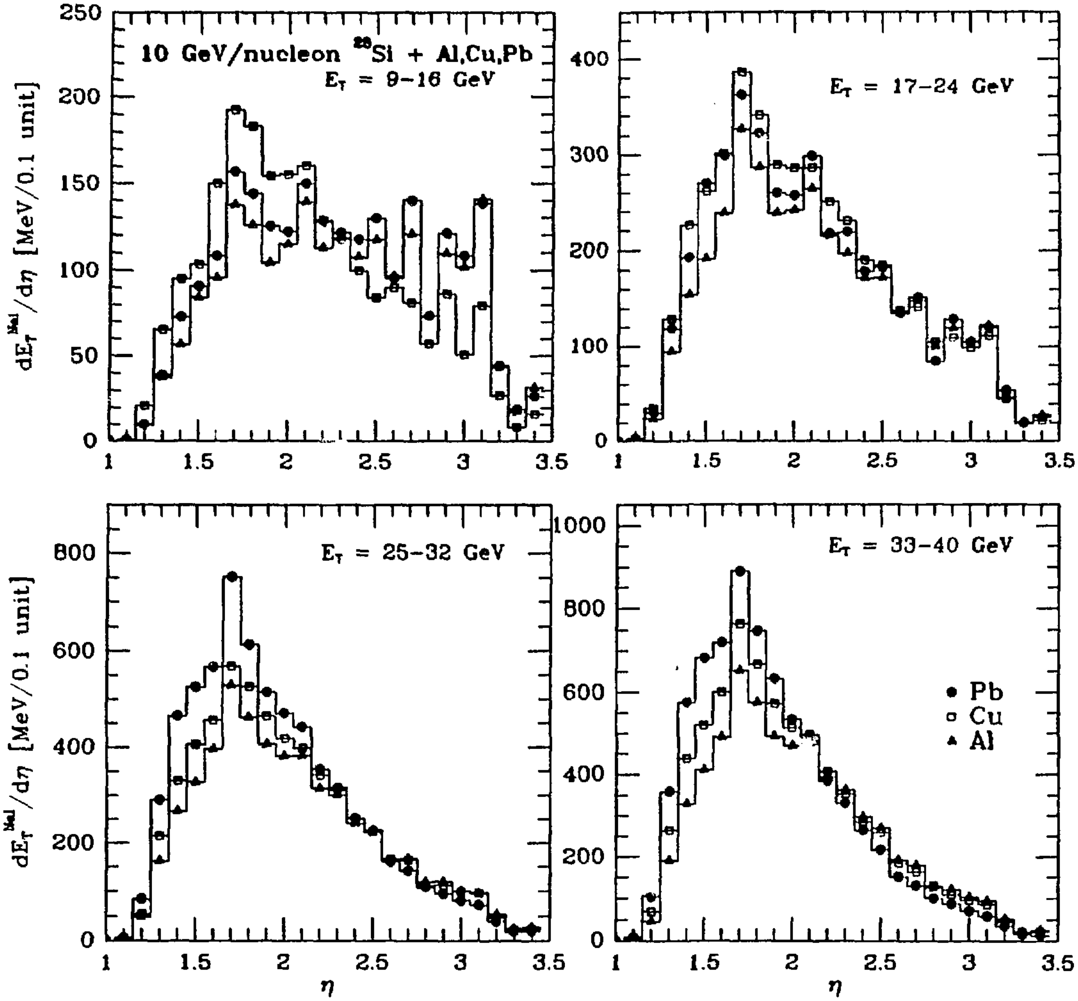
Experimental Set-up



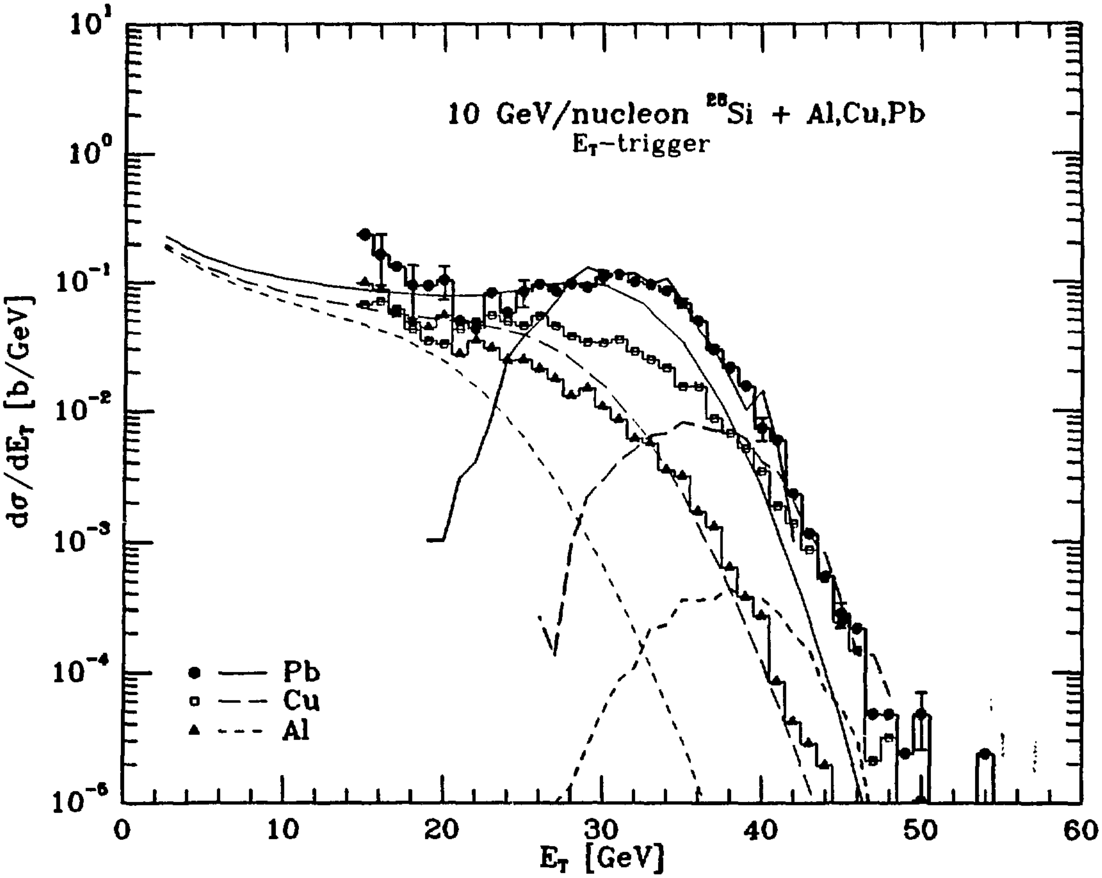

10 GeV/nucleon ^{28}Si + Pb
E_T-trigger
R-trigger
$d\sigma/dE_T$ [b/GeV]
E_T [GeV]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60



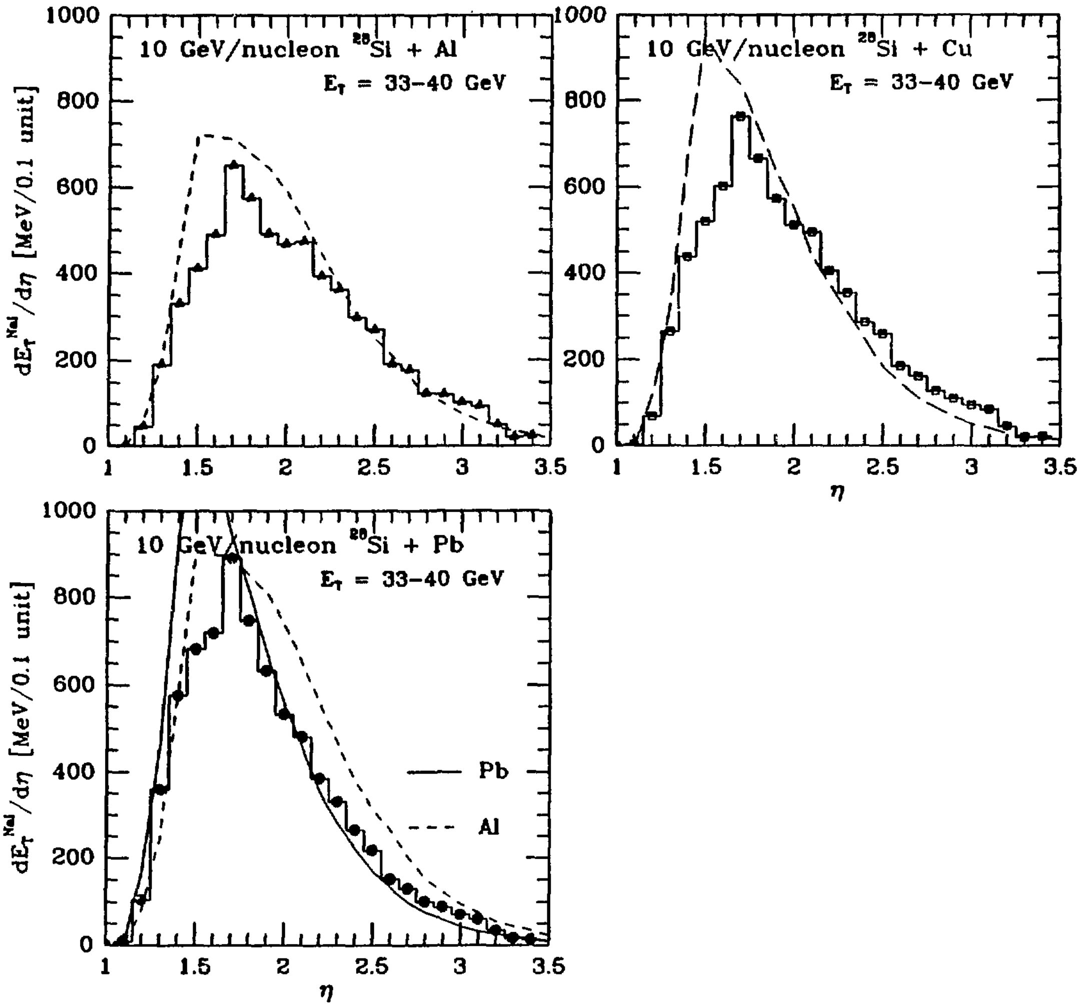
10
8
6
4
2
0
E_T^{NaI} [GeV]
0
10
20
30
40
50
60
70
E_T [GeV]



10 GeV/nucleon ^{28}Si + Al,Cu,Pb
E_T = 9–16 GeV
E_T = 17–24 GeV
E_T = 25–32 GeV
E_T = 33–40 GeV
$dE_T^{NaI}/d\eta$ [MeV/0.1 unit]
η
Pb
Cu
Al



10 GeV/nucleon ^{28}Si + Al,Cu,Pb
E_T–trigger
$d\sigma/dE_T$ [b/GeV]
E_T [GeV]
Pb
Cu
Al


10 GeV/nucleon ^{28}Si + Al
E_T = 33-40 GeV
10 GeV/nucleon ^{28}Si + Cu
E_T = 33-40 GeV
10 GeV/nucleon ^{28}Si + Pb
E_T = 33-40 GeV
Pb
Al
$dE_T^{NaI}/d\eta$ [MeV/0.1 unit]
η
0
200
400
600
800
1000
1
1.5
2
2.5
3
3.5