

## NUCLEON-NUCLEUS INTERACTIONS FROM JACEE

### *The JACEE Collaboration:*

T. H. Burnett<sup>h</sup>, S. Dake<sup>b</sup>, M. Fuki<sup>c</sup>, J. C. Gregory<sup>g</sup>, T. Hayashi<sup>g</sup>, R. Holynski<sup>e,i</sup>,  
 J. Iwai<sup>h</sup>, W. V. Jones<sup>e</sup>, A. Jurak<sup>e,i</sup>, J. J. Lord<sup>h</sup>, O. Miyamura<sup>d</sup>, T. Ogata<sup>a</sup>,  
 A. Olszewski<sup>e,i</sup>, T. A. Parnell<sup>f</sup>, T. Saito<sup>a</sup>, S. Strausz<sup>h</sup>, M. Szarska<sup>e,i</sup>,  
 T. Tabuki<sup>a</sup>, Y. Takahashi<sup>f</sup>, Y. Tominaga<sup>d</sup>, B. Wilczynska<sup>i</sup>,  
 J. P. Wefel<sup>e</sup>, R.J.Wilkes<sup>h</sup>, W. Wolter<sup>i</sup>, B. Wosiek<sup>e,i</sup>

a) Institute for Cosmic Ray Research, Tokyo; b) Kobe University; c) Okayama University of Science; d) Osaka University; e) Louisiana State University; f) NASA Marshall Space Flight Center; g) University of Alabama, Huntsville; h) University of Washington; i) Institute for Nuclear Physics, Krakow.

### ABSTRACT

Results on hadron-nucleus interactions from the JACEE experiment are presented. Angular distributions for charged particles, and angular and transverse momentum spectra for photons have been measured for a sample of events with  $\Sigma E_{\gamma} \geq 1$  TeV. Results on central rapidity density and transverse energy flow are discussed.

#### 1. Introduction

JACEE (Japanese-American Cooperative Emulsion Experiment) was organized to study cosmic ray nucleus spectra and interactions at total energies approaching 100 TeV. The use of conventional emulsion chamber techniques permits the observation of secondary charged particles and individual high energy gamma rays. The results presented here were obtained from a series of balloon flights at 3.5-8 g/cm<sup>2</sup> altitudes<sup>1</sup>.

The apparatus used in the experiment has been described in detail elsewhere<sup>2</sup>. All emulsion plates are made from 500~800  $\mu\text{m}$  acrylic bases, coated on both sides with Fuji emulsion. Incident particles are identified in the primary charge detector section using grain, gap and delta-ray counts from thick (150~200  $\mu\text{m}$ ) emulsion layers, as well as pit measurements from CR39 etchable plastics. Charge resolution is typically 0.2~2.0 units. The target section contains thin (50-75  $\mu\text{m}$ ) emulsion plates interleaved with acrylic or Fe target sheets. Thick emulsions and CR39 sheets are inserted at intervals to permit identification of projectile fragments. Interactions occurring in the upper Pb layers of the calorimeter can also be fully analyzed. The spacer section permits gamma rays to diverge before reaching the calorimeter section, so that individual photon cascades can be observed.

The calorimeter contains ~5 vertical radiation lengths of Pb interleaved with 18-20 layers of emulsion plates and x-ray films. Cascades of energy  $\geq 300$  GeV make spots visible to the naked eye in the x-ray films, which serve both as threshold detectors and as templates for locating events in the emulsions. In addition, densitometric measurements in x-ray films provide an estimate of the shower energy.

Once an event has been located, a region of diameter 1-2 mm (depending upon vertex height) around the event axis is scanned for lower energy cascades.

Accurate energy determinations are made by performing track counts in the emulsion layers and comparing the results with calibration curves obtained from analytical shower theory calculations<sup>3</sup> and monte carlo simulations<sup>4</sup> which have been checked by accelerator calibration experiments<sup>5</sup>. The error in a single cascade energy measurement is  $\sim 20\%$ . The directly measured event energy parameter is  $\Sigma E_\gamma$ , the total energy observed in the electromagnetic calorimeter. The primary energy  $E_0$  can be estimated from  $\Sigma E_\gamma$  by using the gamma-ray inelasticity factor  $k_\gamma$  derived from measurements on protons at Fermilab<sup>6</sup>, and independently from the charged particle angular distribution using the Castagnoli method.

## 2. Proton-Nucleus Interactions

Charged track angles are measured relative to the energy-weighted center of the event. Interactions occurring in acrylic base or target plates are assumed to be on carbon targets. Angular distributions are normally presented in terms of the pseudorapidity,  $\eta = -\log_e \tan(\theta/2)$ . In order to combine events of different energies, one can define a normalized pseudorapidity parameter,  $\eta^* = -\log_{10} \tan(\Sigma E_\gamma * \theta)$ . The normalized  $\log \tan \theta$  distributions for nucleon interactions in C and Pb are shown in Fig. 1. For this sample,  $\Sigma E_\gamma > 1$  TeV and  $\langle \Sigma E_\gamma \rangle = 4.9$  TeV (carbon) and 3.5 TeV (Pb).

The central pseudorapidity density  $\rho_c$  for each event has been estimated by excluding the forward 1.5 rapidity units (projectile fragmentation region) and calculating  $dn/d\eta$  over the next 2 rapidity units. In Fig. 2 we plot  $\langle \rho_c \rangle$  versus the target mass  $A$ . The data are well represented by the relation  $\langle \rho_c \rangle = kA^{0.31}$ .

For photons observed in the calorimeter, transverse energy flow as a function of rapidity  $y$  can be analyzed by defining an integral transverse energy flow parameter,

$$F(y) = \sum_{y_i > y} E_{ti}$$

where  $E_{ti} = E_i \sin(\theta_i)$ . Plotting  $F(y)$  vs  $\eta$  for individual events, and excluding the low- $y$  region where detection bias may be present, one finds that  $F(y)$  can be well represented by the form  $F(y) \sim e^{-by}$ . The fitted values for the slope parameter  $b$  have a bimodal distribution shown in Fig. 3, with about 15% of the events displaying a significantly steeper slope than the rest. In Fig. 4a we show several typical events displaying large  $b$ ; the low- $b$  events shown for comparison in fig 4b have been chosen to have a similar distribution of target mass and  $\Sigma E_\gamma$ . The data in Fig. 4 have been displaced vertically for clarity.

## 3. Acknowledgements

This work supported in part by DOE, NSF and NASA in the US, and JSPS in Japan.

## 4. References

1. T. Burnett, *et al*, paper HE-1.4-4, this conference.
2. R.W. Huggett, *et al*, 17th Int. Cosmic Ray Conf. (Paris), **8**, 80 (1981).
3. J. Nishimura, *Handbuch der Physik* **46/2**, 1 (1967).
4. S. Dake, private communication.
5. N. Hotta, *et al*, Phys. Rev. **D22**, 1 (1980).
6. S. Dake, *et al*, 15th Int. Cosmic Ray Conf. (Plovdiv), **7**, 322 (1977).

## 5. Figure Captions

1. Normalized angular distributions for charged tracks observed in p-Pb interactions (solid line) and p-C interactions (dashed line). The normalized pseudorapidity parameter is defined as  $\eta^* = -\log_{10}\tan(\Sigma E_\gamma * \theta)$ .

2. Central pseudorapidity density  $\rho_c$  versus target mass A. Interactions in plastic and emulsion are taken to be on A=12 and 82 respectively. The solid line shows the results of a fit to  $\langle \rho_c \rangle \sim A^\delta$ , with  $\delta=0.31$ .

3. Distribution of fits to slope parameter  $b$  in the relation  $F(y) \sim e^{-by}$ . See text for definition of the integral transverse energy flow parameter  $F(y)$ .

4. Plots of the integral photon transverse energy flow  $F(y)$  for individual events a) with slope parameter  $b > 1.25$  and b) with  $b < 1.25$ . The events have been displaced vertically for clarity; the scales shown apply to the lowest data set.

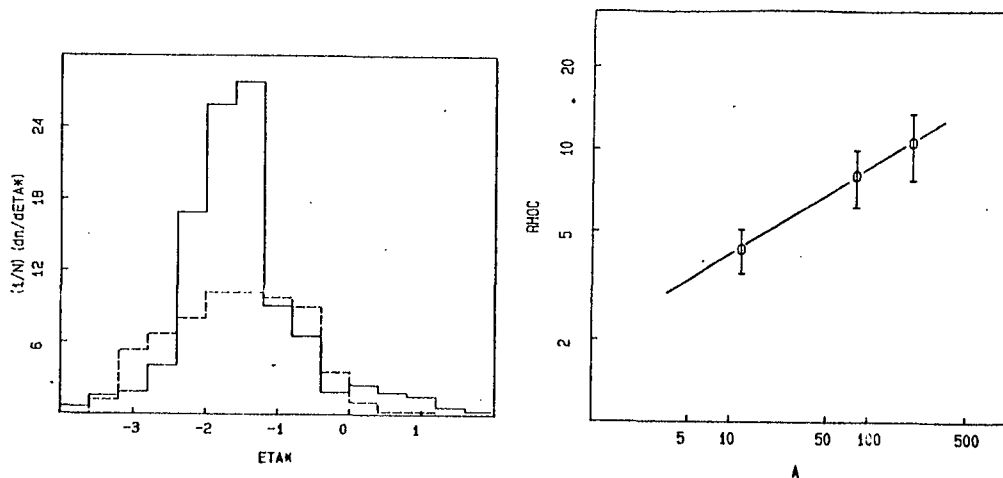


Figure 1

Figure 2

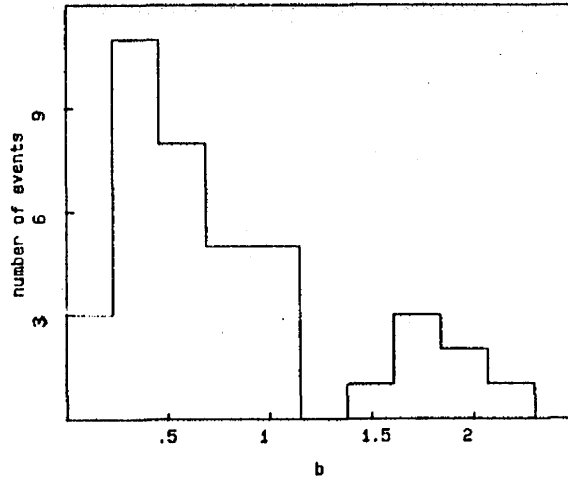


Figure 3

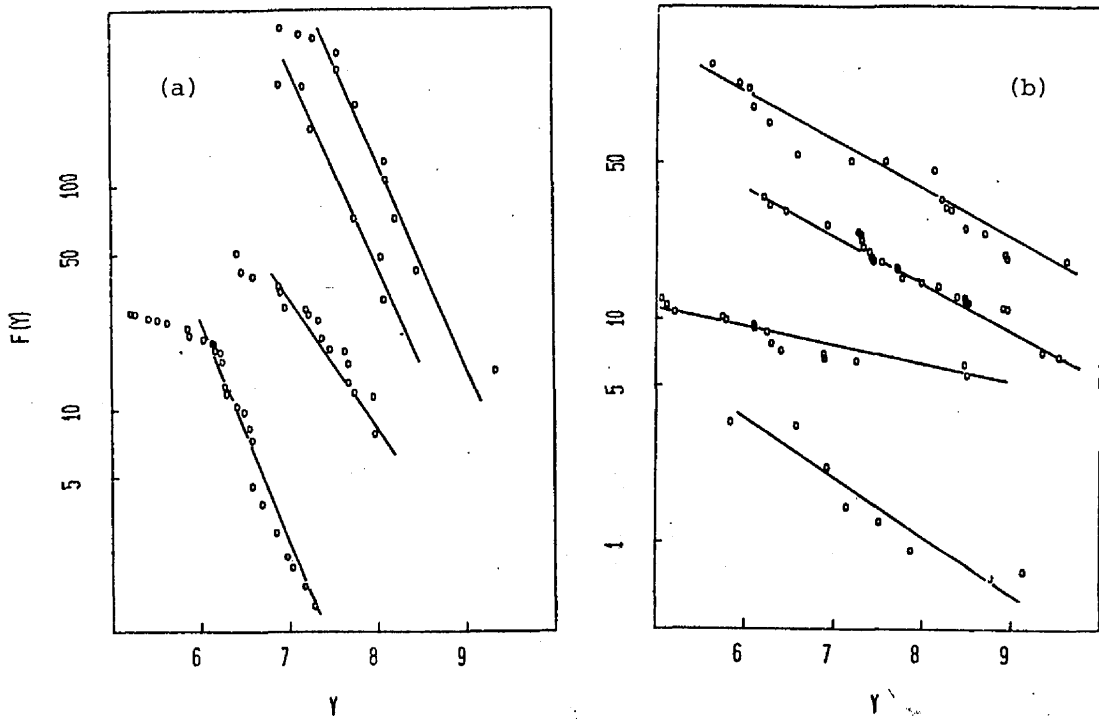


Figure 4