NAL PROPOSAL No. 266

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Inclusive Angle and Multiplicity Distributions of Charged Secondaries and of Neutral Pions Produced by Nucleons on Nuclei

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It is proposed to study inclusive prong distributions in number and angle as well as produced π's as functions of atomic weight with protons and neutrons at NAL using the wide-gap spark chambers currently operating in Experiment 230.

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I. Summary

We propose to study the inclusive number and angular distributions of hadrons produced in interactions of hadrons on complex nuclei. The experiment would employ the spark chambers currently in use in Experiment 230 together with targets of various solids (e.g., Ch_2, C, Al, Fe, Cd, Pb). We propose to use nucleon beams currently available in the Meson Laboratory; specifically the M1 and M3 beams. The beam utilization would be semi-parasitic. As little material would be in the beam ($\leqslant 0.05\lambda$), it could operate in the M3 beam upstream or downstream of E27 during the forthcoming tuneup of E27. In the M1 beam, it could operate beyond the end of E7, separated from the last elements of E7 by a shielding collimator. Low beam intensity is appropriate ($\sim 10^3 - 10^4$ per pulse) as every inelastic nuclear interaction would be a potentially useful event. Data would be taken with neutrons (M3), protons (M3 or M1).

We request a total of three calendar months or two six-week "periods" of running for this experiment. We believe that data collection will require 30-40 hours of beam time each in the neutron and proton beams.

II. Physics

It has been noted repeatedly that the key to understanding strong interactions at high energy may lie in using the nucleus as a laboratory, and in comparing the inclusive distributions of a number of parameters as functions of atomic number.[1] These points of view have been stressed most recently by K. Gottfried, who comments that the multiperipheral, the diffractive (Nova), and the hydrodynamical model all fail to explain even the meager existing inclusive data. While he proceeds to generate his own model, the important point to note is that there is now very little solid data, and good experiments are needed.[2] A recent conference report by Van Hove also stresses the importance of this class of experiments.[3]

A secondary reason for accumulating such data is the desire to more clearly interpret air shower and other cosmic ray data in terms of strong interactions in the 10^{13}-10^{19} eV energy range. Currently several parameters are involved in this physics; distributions of multiplicity, angles, momenta, and particle type from interactions in air, as well as primary cosmic ray composition. The present data and interpretation leads to the conclusion that there is a growing transverse momentum and a shorter mean free path with increasing energy and a multiplicity increasing at least as $E^{1/4}$ and perhaps as $E^{1/2}$. On the other hand, there is little guidance on relating phenomena on nitrogen to phenomena on free nucleons. Data even at 100-300 GeV can materially imporove this situation.[4]

III. <u>Discussion</u>

An earlier proposal from Michigan to place solid metal targets within the 30-inch bubble chamber was rejected by the program committee. While we believe that this experiment should be done eventually, we are impatient to move into this area at minimal cost to the Laboratory and to other ongoing experiments. Results from this proposed experiment will greatly amplify our existing knowledge of inclusive reactions and will guide future experiments in what we are confident will be a burgeoning area.

Specifically, we seek to study:

A) The angular distributions of secondaries

The rapidity distributions in available data appear to peak backwards in the center of mass for heavier nuclei, as if the multiplication or intranuclear cascading were entirely in the spectator frame.

B) The rapidity correlations

Available data (Appendix A) suggest a change in two-particle interval distributions with A, and this sort of data can be greatly augmented.

C) The ratio of γ's to charged secondaries, the total multiplicities, and the correlations between the γ (π°) multiplicity distributions and the charged prong ($\pi^\pm$) distributions.

This would be accomplished with the lead plates between the two wide-gap chambers as used in E230.

D) The charged particle average multiplicities and multiplicity distributions as functions of E, A, and incident hadron (n and p)

Momenta and secondary particle type would not be identified.

Only the last objective overlaps the objective of E178 (W. Busza, et al., of MIT). The bubble chamber data using a neon filling of the 30-inch chamber will yield one point on the various distributions as a function of A but will not map out the A-dependence.

Our own experiment E230 has brought wide-gap spark chambers into efficient operation and has developed essentially all of the equipment necessary for this proposed experiment. In fact, total inclusive data on the targets used in E230 will be useful in interpreting the γ production events being collected there. Figures 1 and 2 show some events recorded in E230.

IV. Experimental details

Two wide-gap spark chambers, each of 40x40 inches containing two 6-inch gaps are separated by lead sheets of 1/4 inch and trigger counters. The last chamber is viewed end-on through a screen electrode to visualize a "beam's eye" view distribution of prongs. The photographs of E230 have recorded over 150 prongs (in the second chamber) from a single event, and tests of spark chamber efficiency confirm our excellent detection efficiency even for high prong numbers. For a target 100 inches ahead of the chambers, the chambers "see" angles from 0° to 127° in the nucleon-nucleon center of mass; closer target spacings permit more backward angles to be detected at the expense of tighter spacing of the forward tracks in the spark chambers.

Nuclear prongs (slow protons, alpha particles, etc.) generally have E < 100 MeV and would largely be absorbed in the target or would be absorbed or scattered in the 1/4" plywood of the spark chamber electrodes and the plastic scintillators so that they sould be readily separated from relativistic produced secondaries.

Events would be triggered with incident neutrons by requiring at least one charged particle emerging from the target with no incident charged particles. The effective (average) energy of the incident neutron beam is known from our present calorimeter data. With incident protons, a loose trigger requiring over 1.5 times average minimum ionization in two or three thin counters beyond the target would be used. Data would be taken at target distances of 100 inches and 30 inches, with and without lead converters between spark chambers and with different target thicknesses, especially in the case of high-Z targets (in order to correct for γ-conversion in the targets). Some of the running time would be used to vary other conditions in order to look for and evaluate experimental biases.

V. Historical notes

The qualitative fact of the low rise of multiplicity with atomic number has been known for over 20 years from cosmic ray exposures of nuclear emulsions. However, to our knowledge, the first reference to the quantitative study of inclusive distributions on nuclei as a tool for the study of the nature of the interaction mechanism was made by one of us (Lawrence W. Jones) at the Conference on the Expectations of the New Accelerators at Wisconsin in April, 1970.[5] In the only systematic attempt at such a study to date, targets of C, Al, Fe, Sn, and Pb were used in the Echo Lake cosmic ray experiment over the period 1969 - 1971 following the liquid hydrogen data collected. Mr. P. Vishwanath is currently completing his doctoral thesis at Michigan on these data, and a report on some of his results was presented at the 13th International Conference on Cosmic Rays at Denver in August. A copy of this report is appended hereto as Appendix A.

The present proposed experiment is an attempt by our group to significantly extend data of the sort collected earlier with cosmic rays.

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EXP 230 APPARATUS

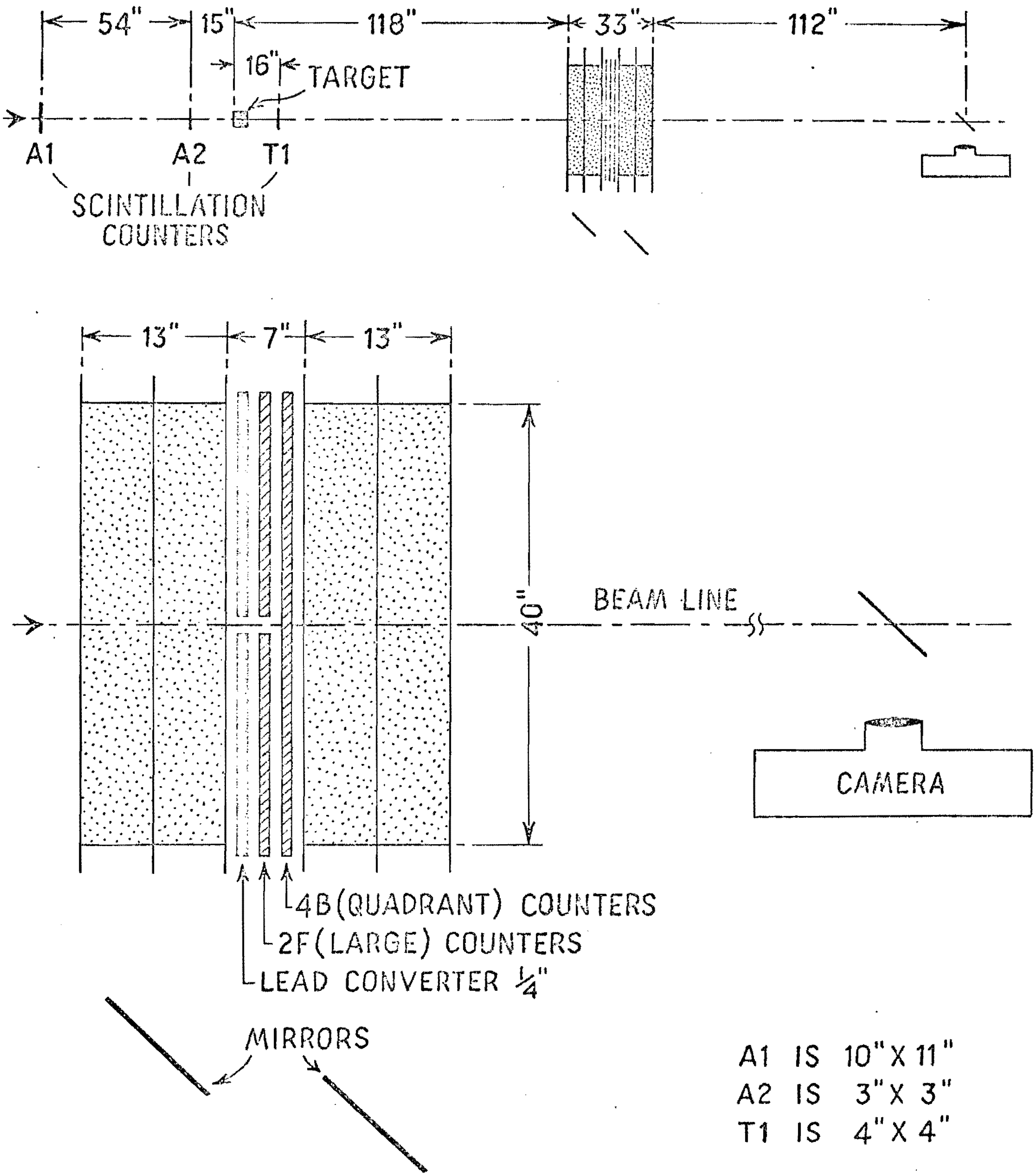

Figure 1. The wide-gap spark chamber configuration proposed. The upper sketch illustrates the relative orientation of the counters, target, spark chambers, and camera to scale. The lower sketch is an enlarged detail of the spark chambers. The stippled area represents the sensitive regions of the chambers.

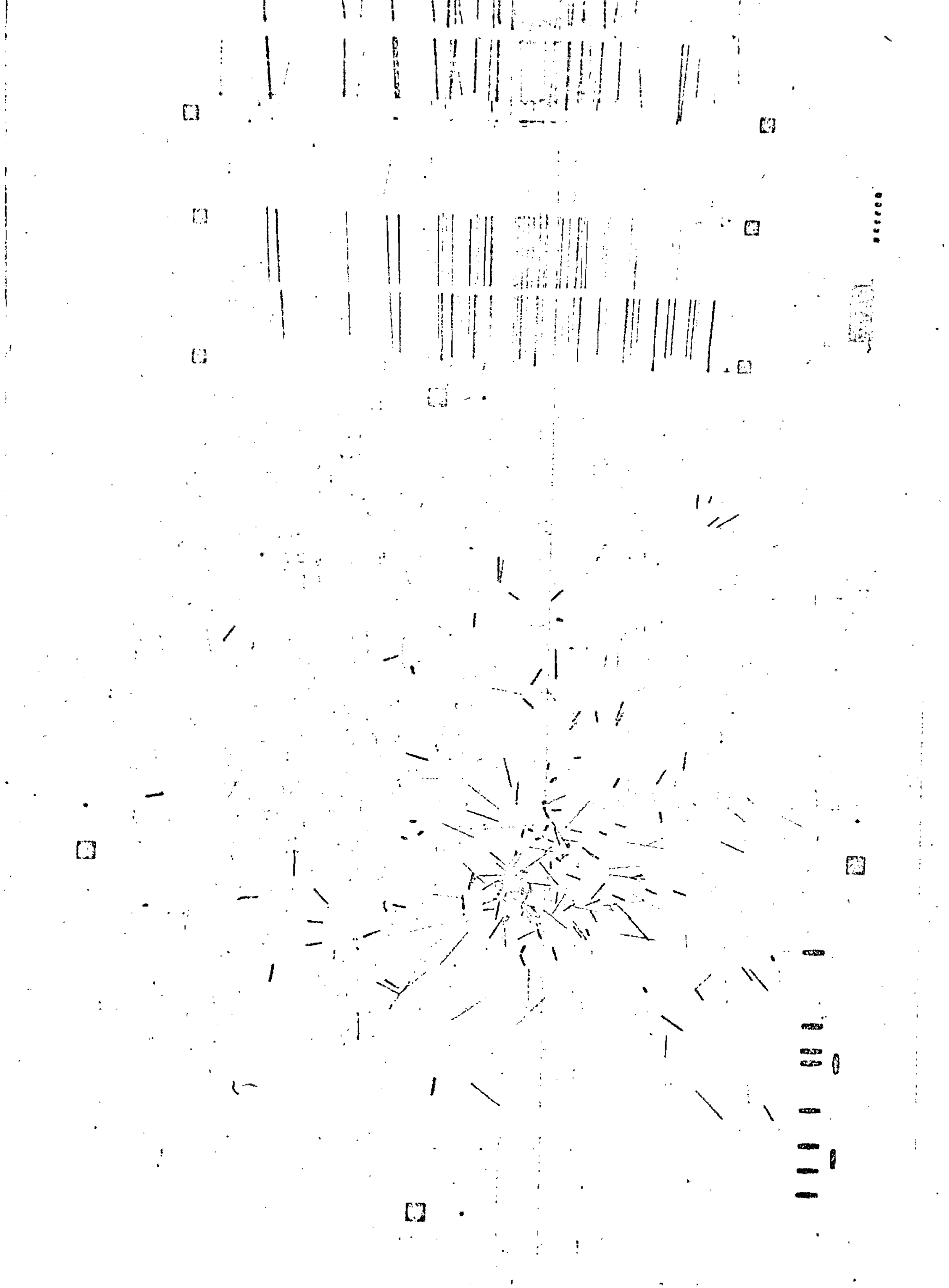

Figure 2. An event with a very high multiplicity. The side views of the two chambers are seen at the top of the field, and the direct view (through a screen electrode) of the last gap is at the bottom of the field. In the original negative, over 175 separate sparks are visible in the direct view.

APPENDIX A

HADRON INTERACTIONS WITH NUCLEI

Paper to be presented at the 13th International Conference on Cosmic Rays, Denver, Colorado, August 17 - 30, 1973.

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HADRON INTERACTIONS WITH NUCLEI*

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ABSTRACT

After initial studies of hadron-proton interactions in the Echo Lake Cosmic Ray Project, hadron-nucleus interactions have been pursued by replacing the liquid hydrogen target with targets of heavier elements. The elements used were aluminum, iron, tin, and lead. An attempt has been made to study the inclusive properties of the interaction as functions of atomic weight and energy. In particular, the angular distributions, multiplicity distributions, and average multiplicity will be reported. The predictions of different high energy interaction models will also be examined in connection with these results. The data contain about 200 events from each heavy element target at energies above 100 GeV.

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1. Introduction. The Echo Lake cosmic ray experiment has been used to study the interaction of hadrons (mostly protons) of above 100 GeV with targets of heavy nuclei: Al, Fe, Sn, and Pb. Earlier cosmic ray data had explored the nature of strong interactions at high energy primarily with targets of nuclear emulsion or of metallic elements from which the nature of free nucleon interactions were inferred indirectly. Recently the Echo Lake cosmic ray data and the excellent accelerator results from N.A.L. and C.E.R.N. have greatly elucidated the nucleon-nucleon interaction from 100 to 1500 GeV. It is now recognized that the interpretation of this data in terms of various models of inclusive reactions would be clarified by quantitative inclusive data on heavier elements.[1]

2. Experimental Details. The Echo Lake apparatus as previously described[2] was used in this experiment except that the liquid hydrogen target was replaced by a target of metal plates (Fig. 1). Two runs were taken, one with a target of Al and Fe plates side by side, and the other with a target of Sn and Pb plates. Each target consisted of 6 plates, spaced about 15 cm vertically and totalling about 20% of a nuclear interaction mean free path. The event vertex reconstruction permitted determination of the particular target element and plate number. (Earlier, data had also been taken on a carbon target.)

Data were taken during 1969 and 1970. From the raw data sample, useful events were selected as was done with the hydrogen data. Table I lists the number of events of above 100 GeV finally used in the data analysis.

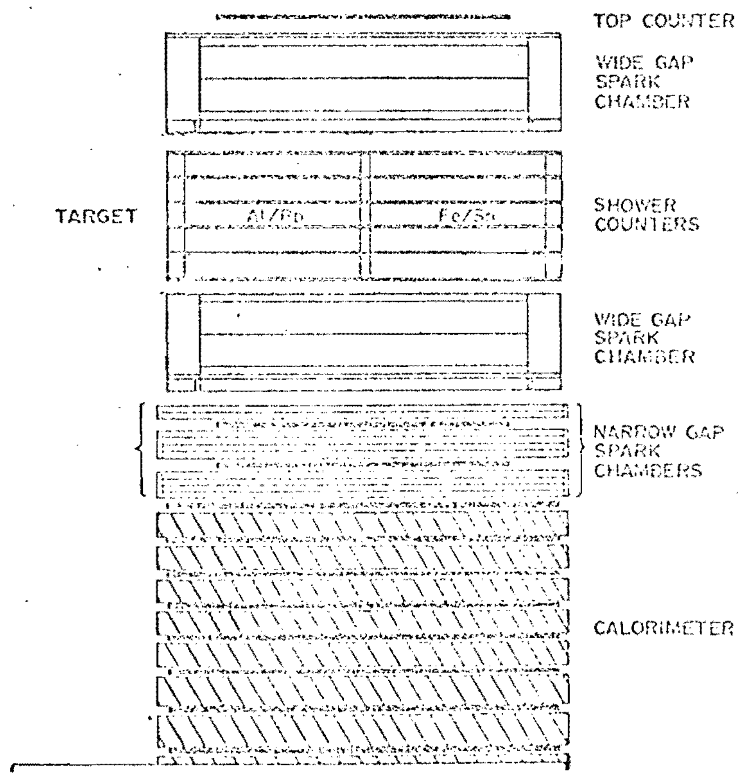

Fig. 1. Vertical section of the experimental configuration. (Shower counters are around the target mid plane and are not shown explicitly in the diagram.

Table I

Useful Interactions above 100 GeV

Element	Al	Fe	Sn	Pb
Number of Events	230	220	185	139

3. Biases. (a) The Echo Lake results on pp interactions[2] differ somewhat from those obtained at N.A.L.[3] in average multiplicity and multiplicity distributions. It has been determined that the difference is due to the inefficiency of the spark chambers for large prong numbers. From the data on spark efficiencies in the separate gaps vs. prong number, we have developed a self consistent prong correction program. We have undertaken to correct the prong number distributions for the heavy elements with the same bias program which brings the Echo Lake pp data into agreement with the N.A.L. bubble chamber data.

(b) From earlier results, we have determined that the incident flux contains a mixture of pions and protons, with $\pi/p = 0.3$.

(c) There is an energy bias in interactions due to secondary prongs which miss the calorimeter geometry. This is understood and corrections are applied based on a Monte Carlo program.

4. Results. Average prong multiplicities and multiplicity distributions are still being analyzed to properly include effects of these biases. The raw data show an increase in average prong number with atomic weight. Preliminary results on the increase in average charged prong number with atomic weight suggest $\langle n \rangle \propto A^x$ with $0.1 < x < 0.25$. We believe that nuclear fragments (black and grey prongs in emulsions) are not included in the observed distributions in view of the average range required (several g cm^{-2}) to escape the target.

Angular distributions have been obtained for the four heavy targets in the form of $\eta_p = \log \tan \theta_p$ plots, where θ_p is the angle of a secondary relative to the incident particle projected into a plane containing the incident trajectory and a normal to the optic axis. Fig. 2 contains η_p distributions for the four elements for incident energies 100 - 300 GeV. Three sets of plots are given; one for the "leading particle" (most negative η_p), one for all prongs from events with $n \leq 6$ and one for $n > 6$.

The plots for the leading particle are very similar from element to element. The simplest interpretation of

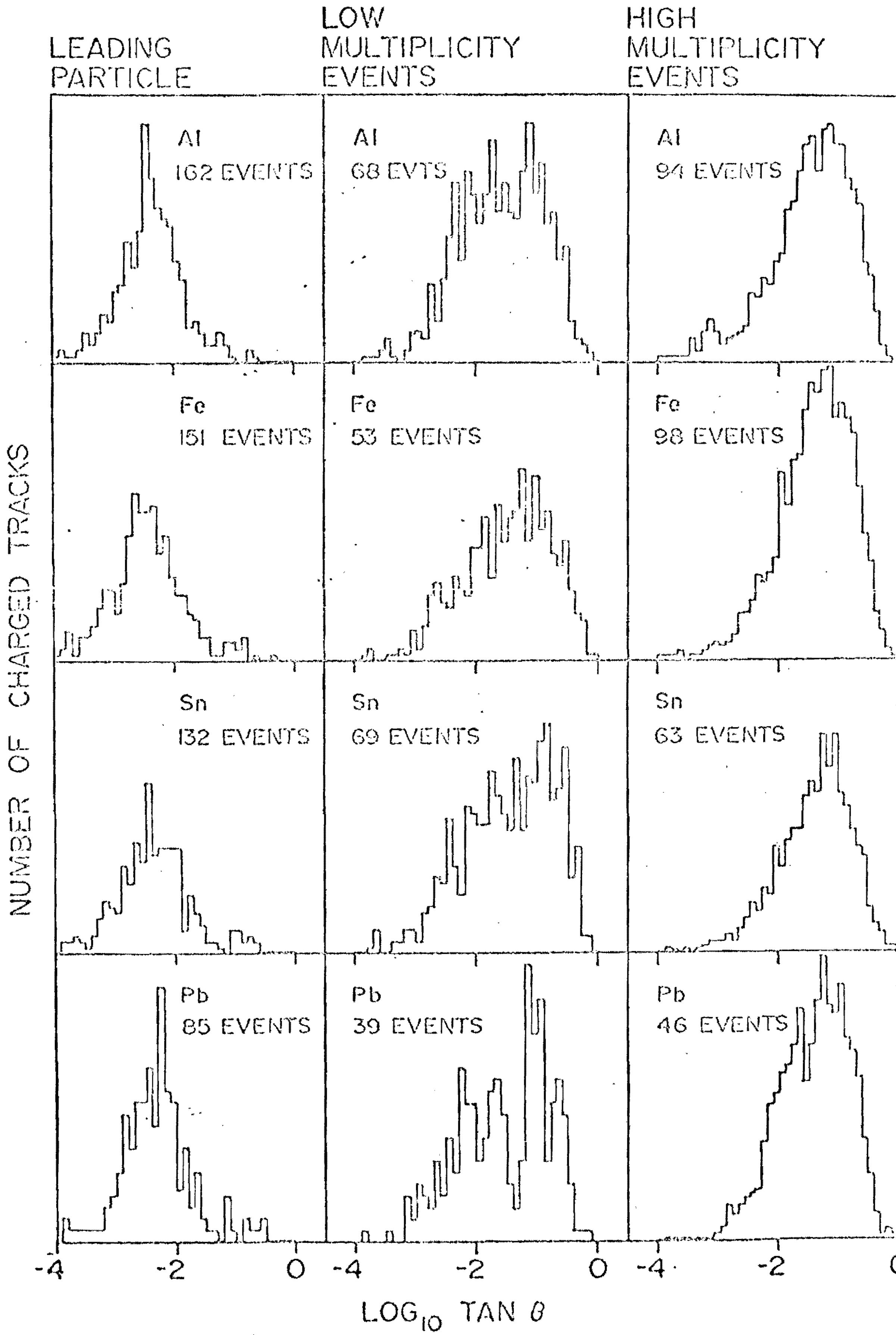

Fig. 2. $\log_{10}$ tan θ_p plots. The mean energy is 200 GeV.

this is the conclusion that the momentum distributions of the leading particle are nearly independent of A and consequently that the inelasticity does not vary significantly with A. (This agrees with older cosmic ray data.[4]) The plots for low multiplicity events do show significant shifts with A, with a significant shift of prongs toward larger angles for heavier elements.

That there remains a "leading particle" and that the secondary particles are degraded through intranuclear cascading is also apparent from studies of the ordered log tan θ_p distributions, prepared as for the pp data.

Even at this stage of analysis, our results confirm the remarkably slow change in inclusive parameters with nuclear size, both as reflected in multiplicities and in angular distributions.

5. Acknowledgements. The authors wish to thank Dr. Mario Iona and the University of Denver for their continued hospitality and the use of the Echo Lake High Altitude Laboratory.

6. References.

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Hadron Interactions with Nuclei

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Addendum to the Paper to be Presented at the 13th International Conference on Cosmic Rays

(1) Variation of $\bar{n}_c$ with Atomic Weight

A simple Monte Carlo model has been used to correct the raw data for extra tracks arising from secondary interactions and gamma conversions and for tracks missing due to spark chamber inefficiency for large prong events. This corrected data is presented in Fig. 3 for two energy ranges: 100-200 GeV and 200-400 GeV. The events from the bottom-most plate of the target need very little correction and they have also been shown in the figure. J.R. Florian et al (a recent paper submitted to 1973 meeting of the Division of Particles and Fields) report a coherent production model put forth by Fishbane and Trefil. This model in which an intermediate excitation propagates through the nucleus before it decays, predicts

$$\bar{n}_s = \frac{1}{2}(0.5\ A^{1/3}+1)\bar{n}_H$$

where $\bar{n}_H$ is the multiplicity on a hydrogen target. $\bar{n}_H$ found in the Echo Lake p-p interaction study has been corrected recently for the spark chamber inefficiencies and is now more consistent with the accelerator data at energies $\lesssim$200 GeV. At higher energies, other effects set in and Echo Lake multiplicities are still lower than the Bubble Chamber multiplicities. The data points in Fig. 3 do not disagree with the CPM model when one uses these corrected p-p multiplicities given by the Echo Lake data. While the present values of the absolute multiplicities could be still lower than the true multiplicities, the observed slopes are not expected to be very much different from the true slopes. Florian et al. do see higher multiplicities with 200 GeV protons on emulsions but their slopes are compatible with the CPM model. Carbon data have been taken from older Echo Lake results and have been corrected for spark chamber inefficiencies.

(2) Angular distributions

Additional material on the Angular distributions is presented in Fig. 4. At a fixed charged multiplicity the observed secondary tracks were ordered by their individual $\log_{10}\tan\theta_p$ values and plotted separately. The first plot contained the track from each event that had the closest angle relative to the beam direction, the next plot contained the track from each event that had the second closest angle relative to the beam direction and so on. If the momentum distribution of all the particles is of form dPL/E, the average values of these distributions should be equally spaced. Fig. 4 shows a plot of the differences between the average values of these distribution for fixed charged multiplicities of 5, 6, 7 and 8 prongs. There is obviously a leading particle as evidenced by the larger first interval in most of the cases. There is also a uniform decrease in the average interval for lighter elements. In Pb, there seems to be no apparent correlation between the average intervals.

VARIATION OF $\overline{n_c}$ WITH AT. WT.

Coherent Production Model

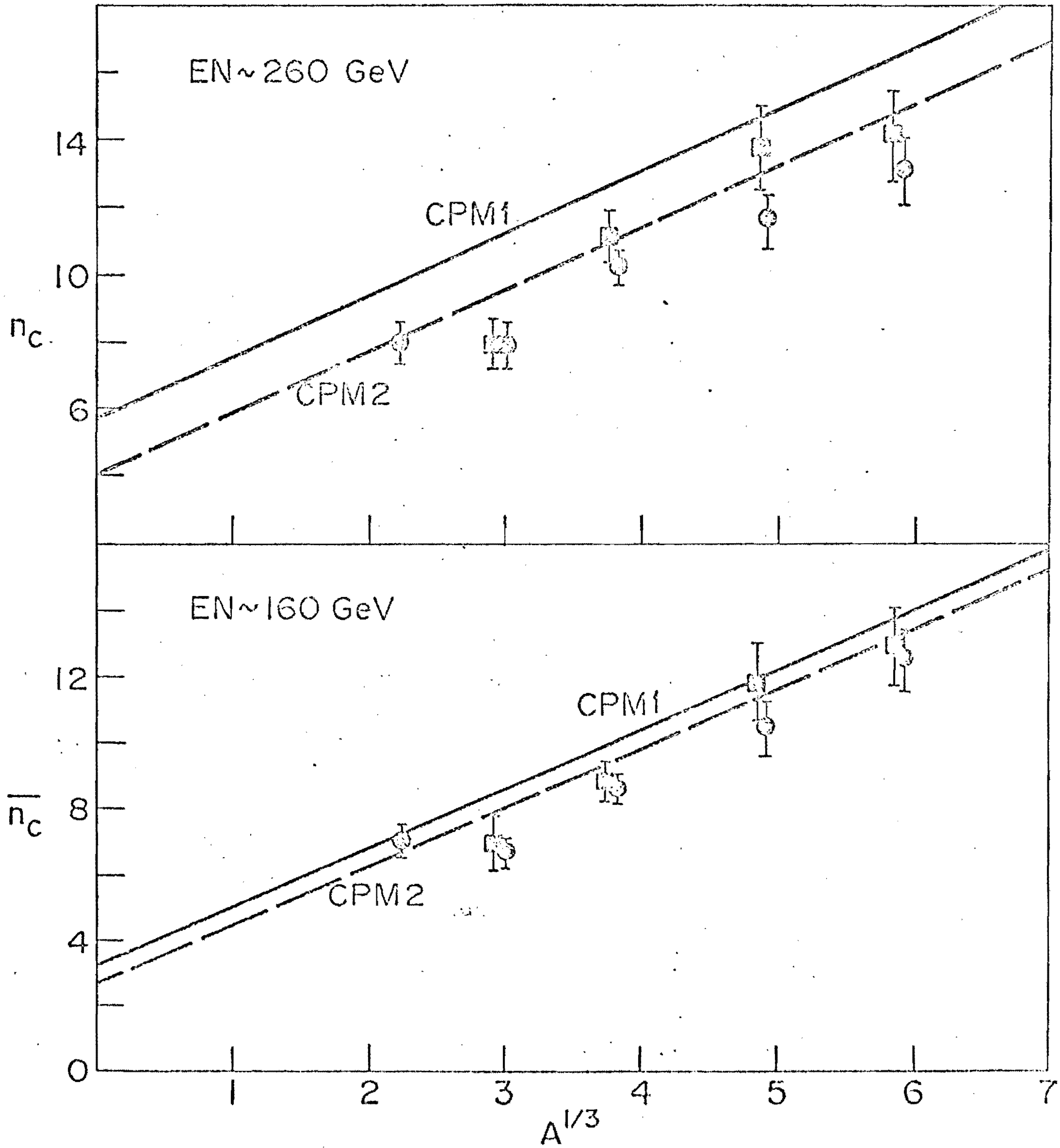
Predicts $\overline{n_c} = 0.5(0.5A^{1/3}+1)\,\overline{n_{HY}}$

CPM1 → CPM Model with $\overline{n_{HY}}$ from Accelerators

CPM2 → CPM Model with $\overline{n_{HY}}$ from Echo Lake

▫ Evts from Bottommost Plate of the Target

○ All Evts



Average Interval is the Difference Between the Average Valu[e]
of the Ordered $Log_{10} Tan \theta_P$ Plots.