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Research Proposal for the Fermi
National Accelerator Lab.

100 to 300 GeV PION INTERACTIONS IN EMULSION AND HEAVY ELEMENT TARGETS

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SUMMARY

It is proposed to study in nuclear emulsions the interaction of several hundred GeV pions with very small targets of pure elements imbeded in them. Target elements ranging from A = 12 to A = 232 will be employed. The purpose of the experiment will be to investigate the intranuclear cascade process as a function of the atomic mass of the target and the energy of the incident pion.

Comparisons will be made with previous experiments using the same techniques but with incident protons of two different energies, 200 GeV and 300 GeV.

INTRODUCTION

There is current theoretical interest[1-8] in the study of the collision of very high energy particles with heavy nuclei. The aim of these theoretical calculations is to learn something about the early space-time development of the multiparticle final state produced in the elementary hadron-hadron interaction. This knowldege can provide additional constraints on the models for multiparticle production.

In the simple cascade models the incident hadron is envisioned as colliding successively with several nucleons as it passes through the nucleus. The secondary particles produced in each collision are assumed to be full-fledged hadrons and may interact with other nucleons in the nucleus. This leads to the build-up of an intranuclear cascade. Such models predict much higher values for the average number of secondary particles produced than are observed experimentally.

Several models[3-8] have attempted to take the short-term collective nature of the hadron-nucleon final state into account. That is, the final state is not assumed to consist of individual hadrons during the time it crosses the nucleus.

The experimental data on the multiplicity and angular distributions in very high energy collisions with heavy elements are sparse. Busza[9] has studied the collisions of negative pions of 100 and 175GeV with heavy elements with a novel Cerenkov counter technique. Elliott et al[10] have carried out similar experiments with negative pions on Neon.

In two previous experiments[11] we used emulsion techniques to study the collisions of 200 and 300 GeV protons with heavy element targets imbeded in the emulsion. The targets were small granules and wires ($\sim$15 microns) ranging in Atomic Mass from A = 12 to A=232. This technique allows one to observe not only the relativistic ($\beta > 0.7$) charged

In this report we present some preliminary results for two elements: tungsten and silver. The results are preliminary in that we have not completed the necessary studies to be able to correct for possible systematic biases. We also hope to increase the number of events in our sample.

Small granules (~15μm) of a variety of pure elements were sandwiched between two layers of nuclear photographic emulsion[12] and exposed to a beam of 300 GeV protons at the Fermi National Accelerator Laboratory. This technique allows one to observe not only the relativistic ($\beta>0.7$) charged particles produced in the collision, but also the slow, heavily ionizing (>1.4 times minimum, $\beta<0.7$) particles that are emitted from the struck nucleus. The numbers of each are denoted by n_{ch} and N_h respectively.

In Table I we present the number of events measured, the average number of relativistic charged particles $\langle n_{ch}\rangle$ produced in the interaction, and the average number of heavily ionizing particles $\langle N_h\rangle$ accompanying the interaction for each of the elements. In Fig. 1 we present histograms of the n_{ch} and N_h distributions.

The average values of N_h for both tungsten and silver are approximately one-half of our previous value[12] of 29.4±4.3 for eight events in tungsten at 200 GeV. In spite of this, there are fewer events at small values of N_h than

	A	Events	$\langle n_{ch}\rangle$	$\langle N_h\rangle$	$D/\langle n_{ch}\rangle$	R
W	184	32	22±2	16±2	0.47±0.06	2.6±0.2
Ag	108	30	19±2	14±2	0.44±0.05	2.3±0.2

Table I. The atomic weight, number of events measured, average n_{ch}, average N_h and the dispersion D divided by $\langle n_{ch}\rangle$. R is defined in Eq. 1.

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The models predict the magnitude of $\langle n_{ch} \rangle$ for an element of atomic weight A in the form

$$R = \langle n_{ch} \rangle / \langle n_{pp} \rangle, \qquad (1)$$

where $\langle n_{pp} \rangle$ is the average charged multiplicity for pp interactions. It is found experimentally that R is essentially energy independent. The value of $\langle n_{pp} \rangle$ has been measured[11] to be 8.50±0.12 at 303 GeV.

Defining ν to be the average number of collisions that a hadron makes as it passes through the nucleus, Gottfried[4] derives the result that

$$R = \frac{2}{3} + \frac{1}{3}\nu \; ; \qquad (2)$$

while Fishbane and Trefil[3,8] and others[5] believe that

$$R = \frac{1}{2} + \frac{1}{2}\nu . \qquad (3)$$

Since ν depends on the inelastic cross section for p-nucleon interactions, R is predicted to rise only slowly with energy.

In Fig. 1 are shown the curves corresponding to Eqs. (2) and (3) for two different calculations of ν. The solid curves were calculated[12] using a Wood-Saxon form for the nuclear density distribution, while the dashed curves were generated[13] by using a Gaussian form. The upper curve in each case corresponds to Eq. (3).

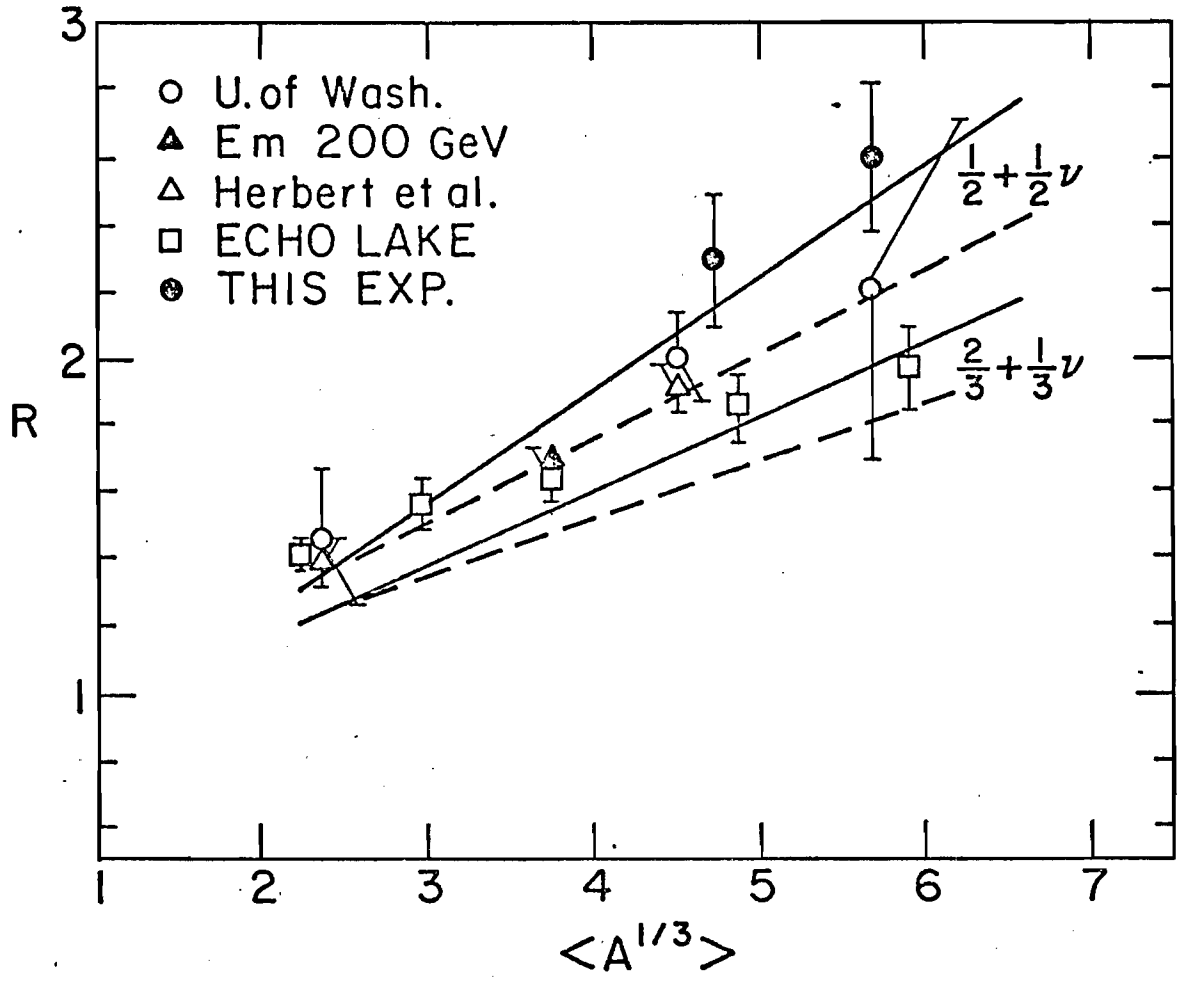


Fig. 1 Plot of the ratio R of the average number of charged particles in a nucleus A to that on hydrogen vs. average $A^{1/3}$. The data are for targets of Ag and W (○, Ref 17 ; ●, this exp.), emulsion (▲, Ref 12), events in emulsion separated into CNO and AgBr groups (○, △), and C, Al, Fe, Sn, and Pb (□ , Ref 16). See the text for the explanation of the curves.

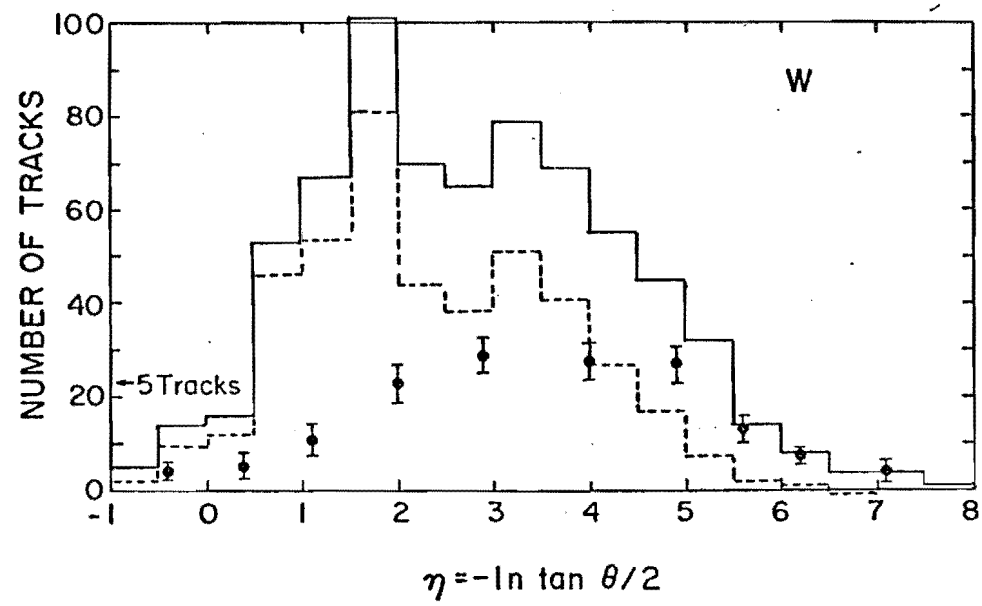
Our data on silver and tungsten and the emulsion data[14,15] (including the points obtained by separating the emulsion events into those occuring on the CNO group and the AgBr group) support Eq. (3). The Echo Lake[16] data obtained with cosmic rays on targets of C, Al, Fe, Sn, and Pb show much less of an A dependence and support neither model.

Several authors have expressed their results for the A dependence of R in the form

$$R = A^x . \qquad (4)$$

Our values for x are 0.17±0.02 and 0.18±0.02 for silver and tungsten, respectively. As the value of x appears to be essentially energy independent[12,16] for the incident energy $E > 100$ GeV, these values can be compared to the value 0.131±0.005 obtained[12] for emulsion at 200 GeV and 0.129±0.004 obtained at Echo Lake[16] for average energies in the range 85-520 GeV.

The solid histograms in Fig. 2 show the distributions in pseudo-rapidity ($\eta = -\ln \tan \theta/2$). For purposes of comparison, we have scaled the distribution for protons on hydrogen from 205 GeV to 300 GeV by displacing the right half of the former distribution 0.4 pseudo-rapidity units to the right. The added area under the curve re-normalizes the distribution to the experimentally determined multiplicity at 300 GeV. The result is shown by the data points. The dashed curves show the excess of the p-nucleus distribution over that for p-nucleon. The depletion at large rapidity in silver is due to distortion in the silver loaded emulsion which makes it difficult to measure extremely small angles. Thus tracks which actually have $\eta = 6$ or 7 are measured to have $\eta = 4$ or 5.



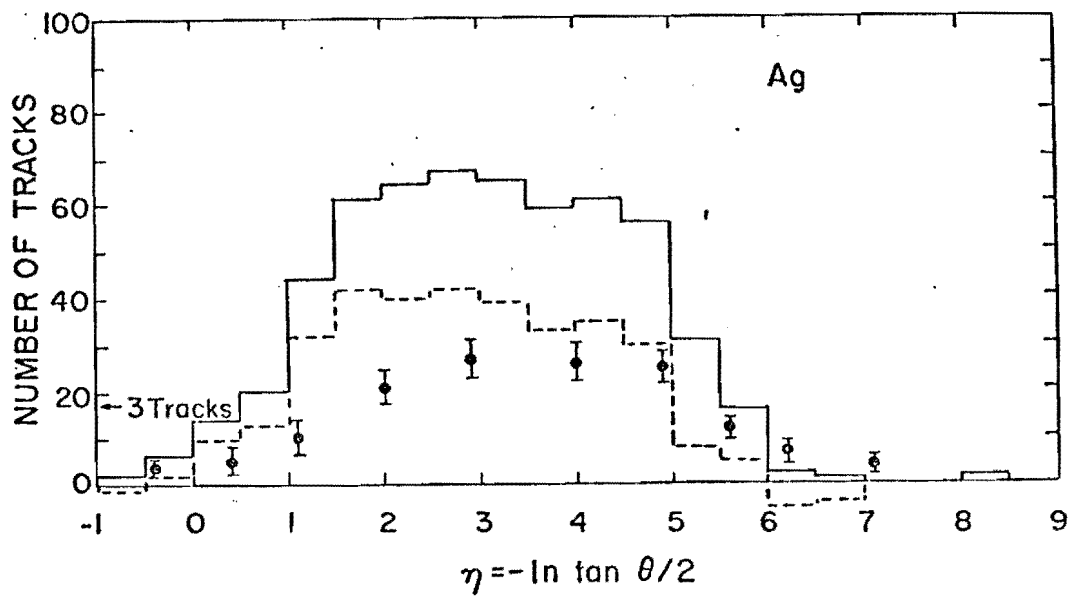


Fig. 2 The solid histograms show the distributions in pseudo-rapidity for proton collisions in tungsten and silver at 300 GeV. The data points indicate the 205 GeV hydrogen data scaled up to 300 GeV. The dashed histograms show the excess production on a nucleus over that on a nucleon. The depletion at large rapidity in silver is due to distortion in the silver loaded emulsion.

In predicting the rapidity distribution for proton-nucleus interactions, the theorists have assumed that the proton-nucleon distribution is uniform over the allowed rapidity interval. The EFC prediction[4] is that the excess is pread uniformly over the backward one-third of the rapidity interval. The CPM[3] prediction has the uniform excess spread over the backward one-half. The TPM[8] prediction has an excess in the shape of a right triangle with no excess in the forward direction and maximum excess in the backward direction.

Experimentally, we see that the excess starts near the forward direction and reaches a maximum near the backward direction. This is quite compatible with the TPM prediction and contradicts that of the EFC.

Concerning theoretical implications, the observed A dependence of R supports the CPM or the TPM and the parameterization $R = 1/2 + 1/2\,\nu$. The rapidity distributions support the TPM, but do not exclude the CPM. These results do not agree well with the EFC predictions. However the observed A independence of $D/\langle n_{ch}\rangle$ appears to conflict with all of these models, which predict $D/\langle n_{ch}\rangle$ decreasing with A.

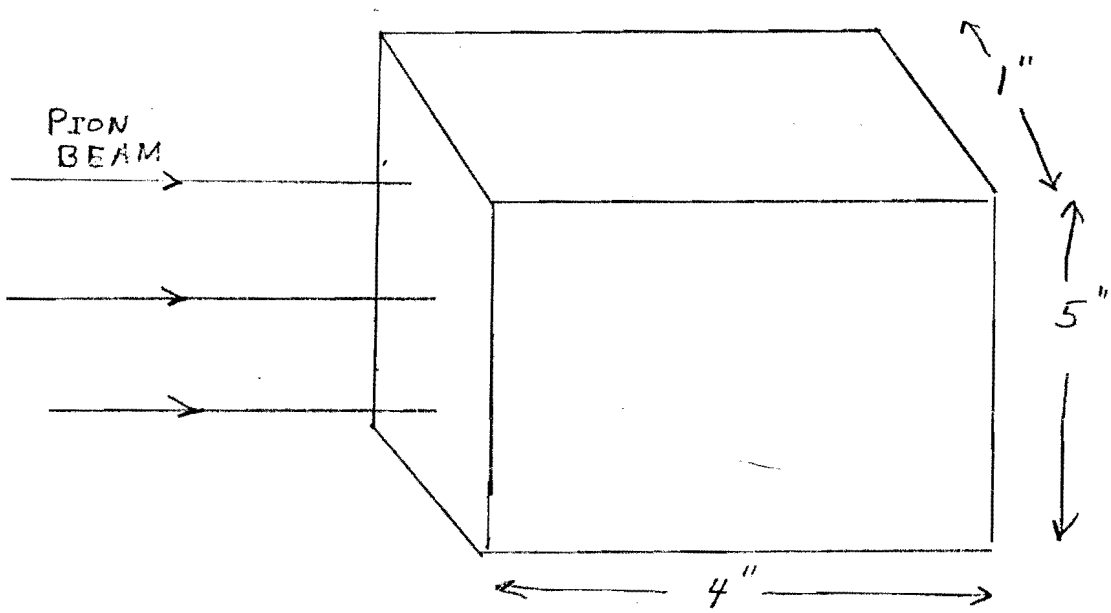
The recent results of Busza[9] seem to show that the R values for pions seem to have a different dependence on ν from that for incident protons in our previous experiments. In addition the rapidity distributions for incident pions are different from those for protons. Perhaps the differences in technique may be the answer. At any rate, it is important to check out the observations for both pions and protons with the same method.

PROPOSED EXPERIMENT

It is proposed to carry out an emulsion experiment on the study of intranuclear cascades produced by pions of two different energies (perhaps 100 and 300 GeV although any two similar energies would be satisfactory). The emulsions prepared for this experiment would made up with granule targets (about 15 microns diameter) of diamond, silicon, silver, chromium, wolfram, bismuth, and thorium. The amount of the granule targets would be about 1/2% by volume of the emulsion so that an intense pion beam would be required to obtain sufficient statistics.

Additional targets for the light elements would be obtained by placing fine wires of nylon and berylium in the emulsion. The wires would have diameters of about 15 microns.

About 6 stacks of emulsion would be needed at each energy. The dimensions of a stack would be 1"x5" cross section and 4" lengthwise to the beam. We need about 150,000 pions per cm^2 for the exposure of each stack.



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