

Fermilab Proposal No. 442

Scientific Spokesman:

F. Turkot
Department of Physics
Purdue University
West Lafayette, Indiana 47907

PH: (321) - 840-3527

Study of Nuclear Fragment Emission
in Proton Heavy Nucleus Collision
from 10 to 500 GeV/c

Physicists at:
Fermi National Accelerator Laboratory
and
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Person to Contact: F. Turkot

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ABSTRACT

We propose to measure the double differential cross section $\left(\frac{d^2\sigma}{d\Omega dE}\right)$ of nuclear fragments ($2 \leq Z \leq 16$), for a given incident momentum, produced by proton heavy nucleus ($20 \leq Z \leq 80$) collisions in the 10 to 500 GeV/c momentum range. Recent experimental results and theoretical speculations suggest collective nuclear motion is initiated by the passage of a fast proton through a heavy nucleus. The novel feature of this experiment is the determination of the energy dependence of the excitation mechanism. Because nuclear fragments are best studied from thin targets, one needs a very high beam flux to obtain sufficient event rates. These considerations make the Internal Target Area with a heavy gas jet target the ideal place to initiate our experimental program. The detection system will consist of four conventional $\Delta E - E$ semiconductor telescopes.

I. Names of the Experimenters

Members of the Fermi National
Accelerator Laboratory:

F. Turkot

J. McCrary

Members of Purdue University:

Professors: J. A. Gaidos

L. J. Gutay

R. P. Scharenberg

R. B. Willmann

Doctors: T. V. Ragland

Student: P. Leong

II. Physics Justification

Recent experimental evidence suggests that there is a significant change in the mode of proton-nucleus collisions with increasing energy.

The observation that forward production multiplicities at high energies are independent of target composition⁽¹⁾ is in direct contrast to conventional particle cascade models, but it is consistent with an "energy flux cascade"⁽²⁾ whereby energy associated with high rapidity propagates with little modification through the nuclear volume. From another aspect, studies of light fragments emitted from Au and U nuclei following the passage of 28 GeV/c protons⁽³⁾ reveals a peaking in the fragment angular distribution which is compatible with the predicted direction of collective motion induced by a "nuclear shock wave"⁽⁴⁾. A different experiment on heavy fragments, from thin foils, produced over a wide energy range has measured the forward/backward ratio and found it to be energy dependent⁽⁵⁾.

These experiments strongly suggest that the mechanism for energy deposition by a fast proton in nuclear matter occurs on an intranuclear time scale and that the emergence of particles or fragments is a correlated non-equilibrium phenomenon. The ability to produce a well-confined sharp nuclear discontinuity increases with energy and should be reflected in the energy and angular dependence of fragment emission. We propose to measure the double differential cross section $\left(\frac{d^2\sigma}{d\Omega dE}\right)$ of nuclear fragments initiated by the passage of 10 \rightarrow 500 GeV/c protons through a variety of heavy nuclear targets. An ideal target system which can provide various heavy nuclei and not impede the escape of high Z low velocity fragments is the warm gas jet⁽⁶⁾. Utilizing the full intensity of the circulating proton beam and a conservative operation of the warm

gas jet, an event rate of $\sim 18,000$ counts/ hour/fragment type (Z) is estimated for a single semiconductor $\Delta E - E$ telescopes.

If the measured angular distributions exhibit features compatible with the nuclear shock wave phenomena⁽⁴⁾ or if the energy dependence of the excitation mechanism for the emission of nuclear fragments indicates unusual structure, we will propose to incorporate a time-of-flight capability into the apparatus and search for abnormally dense nuclear fragments whose existence could be indicated by anomalous Z/M ratios⁽⁷⁾.

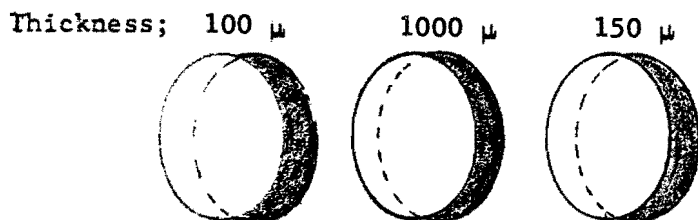
III. Method and Apparatus

Fragment identification in the range $2 < Z < 16$ will be accomplished by the conventional $T \, dE/dx$ ($T \equiv$ kinetic energy) method using semiconductor telescopes. In order to measure down to $T \sim 40$ MeV, a dE/dx counter of thickness $\sim 2 \text{ mg/cm}^2$ is required. Since $T dE/dx \sim M Z_{\text{eff}}^2$ it is in general not feasible to resolve individual isotopes at each Z, but Z separation up to $Z \sim 12$ has been shown to be fairly good. For those fragments with $\beta \geq 0.1$ (~ 4.7 MeV per nucleon) Z_{eff} is quite close to Z, e.g. $Z_{\text{eff}} = .96Z$ for Ne at $\beta = 0.1$. The semiconductor telescopes will be calibrated at the Purdue Tandem Van de Graaf Accelerator using a variety of ion beams.

A sketch of the experimental apparatus is shown in Fig. 1. It utilizes much of the hardware of the superconducting spectrometer system presently being constructed for E-198 and E-313. The telescopes are mounted inside the vacuum chamber (20 cm I.D.) where it passes through the Quad Doublet (see Fig. 2). Thus we use the same gas jet target, most of the vacuum system, and the remote angle-changing capability of the spectrometer bed, but we do not energize magnet (i.e. no liquid He required).

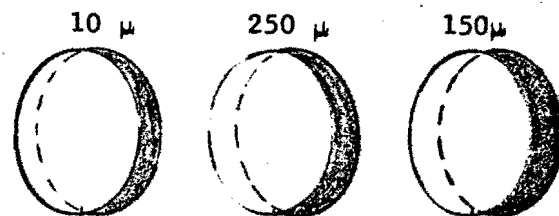
Four telescopes will be employed, two for $Z \leq 6$ and two for $Z \geq 6$ with dimensions as shown.

$Z \leq 6$ TELESCOPES



Surface Area; 200 mm²

$Z \geq 6$ TELESCOPES



50 mm²

The four telescopes will be mounted on a common carriage which moves along the spectrometer axis pointing towards the target (see Fig. 3); the distance from the front detector to the target (and pivot point of the spectrometer) can thus be varied from 1.5 to 2.8 m. The final choice of the target to detector distance will depend on the background levels.

The room temperature gas jet target (for a description of its operating characteristics see Ref. 6) will be run with Ar, Kr, and Xe gases. Using the 0.004" throat Los Alamos de Laval nozzle with Xe, the target will have the following parameters:

FWHM of jet at beam = 5 mm

$$Q \text{ (gas flow)} = 0.80 P_0 \text{ (atm)} \frac{\text{cm}^3\text{-atm}}{\text{sec}}$$

$$n \text{ (target density)} = 1.6 \times 10^{15} P_0 \text{ (atm)} \frac{\text{atoms}}{\text{cm}^3}$$

when P_0 is the gas pressure just before the nozzle. For $P_0 = 3$, we will have $n \approx 5 \times 10^{15}$ atoms/cm³, and a $Q = 1.8 \frac{\text{Torr-}\ell}{\text{sec}}$, which should allow D.C. operation of the jet with an ambient vacuum of $< 10^{-4}$ Torr. We plan to mix H₂ with the target gas in order to monitor on pp elastic scattering with a fixed-angle detector at $\theta = 85^\circ$; this will enable us

to calculate absolute cross sections for the produced fragments.

The data acquisition system will consist of a PDP-11 Bison System with standard Camac interface. Pulse heights for each counter will be recorded on magnetic tape; the system should be capable of recording ~ 800 events per second.

IV. Calculation of Event Rates

In order to get a statistically convincing result we would like to sweep the angular region of 10° steps in the 85° to 35° angular range (five steps). Ten thousand events per angle per 10 GeV energy interval would be sufficient (fifty steps), thus the number of events of a given fragment Z.

$$N = 5 \times 50 \times 10,000 = 25 \times 10^5$$

We would like to study ~ ten fragment types and at least two heavy gas targets, corresponding to ~ 50 million events. In estimating the time required we used the following values:

Input data

$$n = 10^{13} \text{ (n = number of circulating protons)}$$

$$\nu = 50,000 \text{ (}\nu \text{ = frequency of circulation of the beam)}$$

$$\left(\frac{dE}{dt}\right)_{\text{beam}} = 100 \text{ GeV/sec}$$

$$\frac{d\sigma}{d\Omega} = 1 \text{ mb/sr (} d\sigma/d\Omega \text{ = cross section for given fragment Z)}$$

$$d\Omega = 1/40,000 \text{ (} d\Omega \text{ = solid angle of } 100 \text{ mm}^2 \text{ counter 2 m for target)}$$

$$n_0 = 3.10^{15} \text{ (} n_0 \text{ = number of nuclei per cm}^3 \text{)}$$

$$p = 0.1 \text{ torr (the gas pressure).}$$

Using the above numbers and a 0.5 cm jet thickness we obtain

$$\frac{dN}{dt} \approx 4 \text{ events per 10 GeV interval per accelerator pulse}$$

for two counter telescopes per fragment type (Z).

V. Logistics

We would commence detector procurement and fabrication of detector mounts upon approval; the basic semiconductor detectors are commercially available. We estimate that the construction of the final detector system and calibration at the Purdue Tandem could be accomplished in four months (i.e. by April 1976). We then expect to need three-four calendar months of set-up and testing time in the Internal Target Area followed by a three-month period for data taking (400 hours) at ~ 50% duty cycle. It may well be feasible to carry out all of the testing phase and much of the data-taking phase by running simultaneously with E-289.

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FIG. 1

EXPERIMENTAL APPARATUS
(SIDE VIEW)

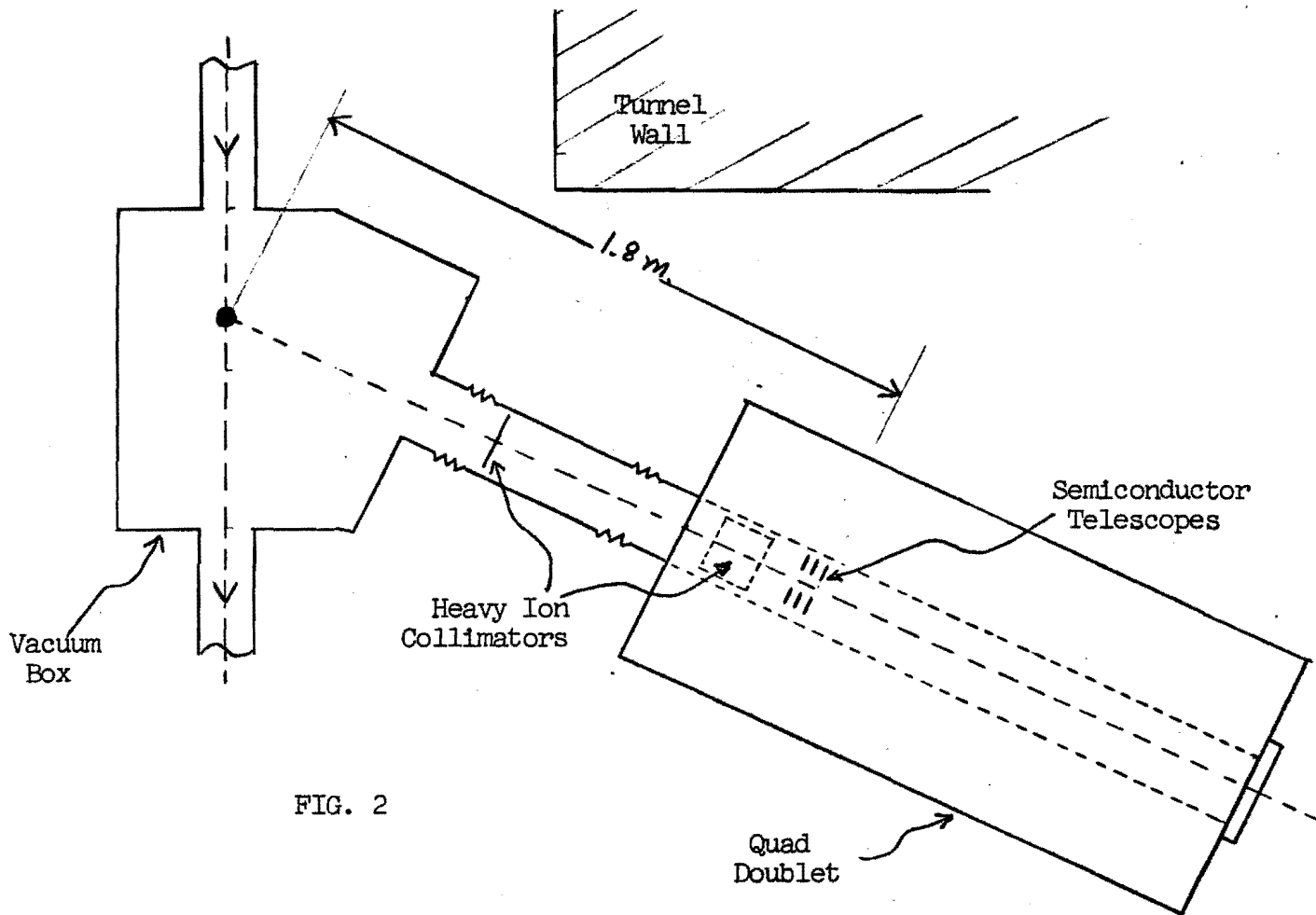
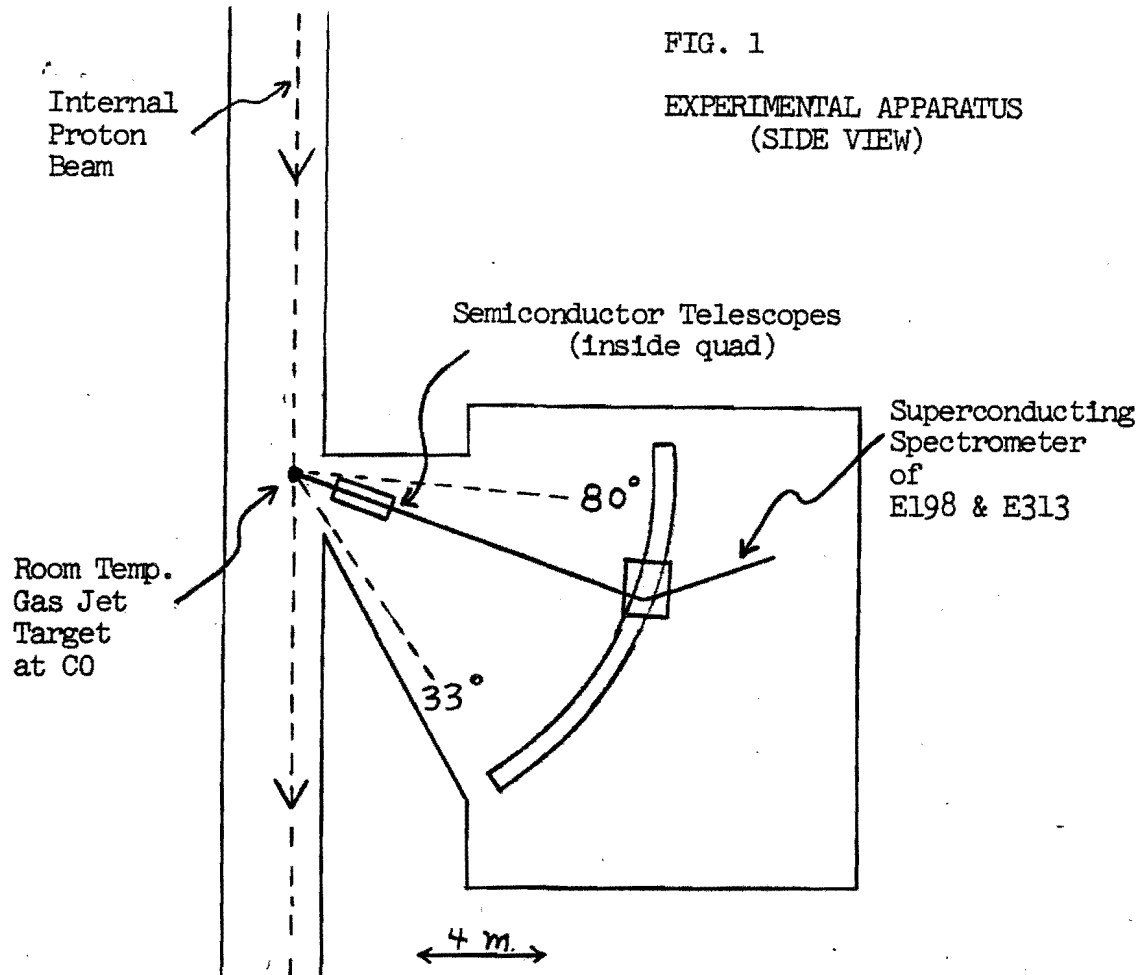


FIG. 2

TARGET VIEW OF TELESCOPES

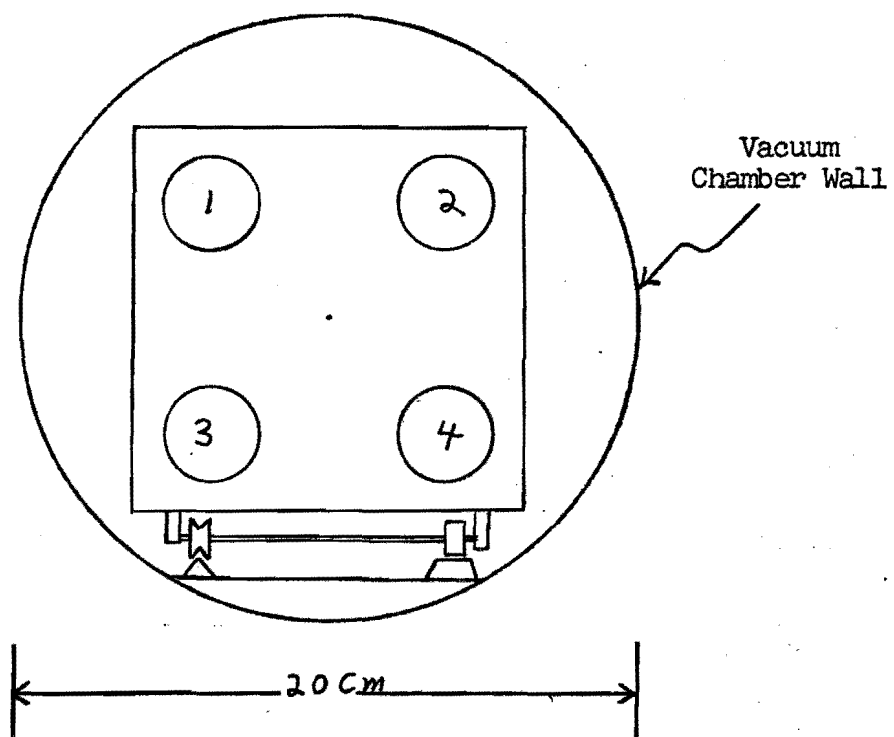


FIG. 3