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Determination of Charge and Mass of Correlated Nuclear Fragments from P-Nucleus Collisions: A Search for Abnormal States of Nuclear Matter

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ABSTRACT

The primary objective of the experiment is to study the correlated fragment pair produced by 50 to 150 Gev/c protons incident on nuclear targets at the internal target laboratory (ITL). The novel features of this experiment are:

1. Mass and charge determination of both heavy fragments, permitting an unambiguous identification of the decaying system and therefore the possibility of observing the signature for an unusual hadronic state.
2. Energy spectra of the correlated fragments measured below the peak of the spectrum, enabling a determination of the Coulomb barrier and accurate fragment yields.
3. Energy spectra of the correlated fragments measured well above the peak of the spectrum, enabling a determination of the slope parameter.
4. A measurement of the fragment momentum transverse to the beam for the correlated fragments. This provides information on the velocity of the emitting system.
5. The use of evaporative molecular beam targets on the 400 Gev main ring beam line, allowing the escape of the heaviest fragments yet providing high event rates, a unique property of the ITL. The small spatial extent and tenuous nature of these targets will reduce the vacuum load on the accelerator by a factor or 30 to 100 compared to the existing warm jet.

The masses and charges of the heavy fragments will be determined

by two high resolution time-of-flight (TOF) ΔE-E systems on opposite sides of the beam. One side, designated the trigger, will consist of a microchannel plate (MCP) detector providing a start signal, and a ΔE-E gas detector, with a silicon E providing the stop. The opposite side will consist of an array of both high and low resolution telescopes. This assembly will be movable by remote control. The high resolution detectors will be similar to the trigger telescope. The low resolution detectors will consist of a TOF-silicon E combination (MCP start), enabling a determination of the angular extent of the fragment-fragment coincidences, and the possibility of detecting events in which there are multiple (>2) fragments involved. Both arrays will be about 1 meter from the beam. (fig.4)

Thin ($<10^{-9}$ grams/cm^2) evaporative targets will be used, allowing a wide variety of target masses ($27<A<210$) and target thicknesses. The target will be constantly monitored and controlled by electronic feedback.

The experimental configuration of this experiment will not require special maintenance by main ring personel. Only dry pumps will be used when the apparatus is in the dormant mode. The apparatus will not interfere with the abort line.

We will be ready to run in mid-late 1982, whether or not the Tevatron is operational. We will require two months of setup time, 400 hours of testing time, and 800-1000 hours of running time. The target will be installed on the 400 Gev beam line at the ITL. We propose to run parasitically either with standard 400 Gev operation or with Tevatron operation. In the latter mode of operation, energies would be restricted to those safely below the doubler injection energy.

2. SCIENTIFIC BACKGROUND

Single-fragment inclusive studies of the interaction of Gev protons with heavy nuclei have provided information that multiply-charged reaction products ($3 \leq Z \leq 35$) are produced by an unusual reaction mechanism. The basic features of fragment production are:

1. A production threshold of several Gev.[1] The concept of limiting fragmentation applies at energies above 30 Gev.
2. Kinetic energy spectra having a high energy tail characterized by $e^{-\beta E}$, where $1/\beta \sim 15$ Mev for a Xenon target.[2,3] (fig. 1)
3. Many events at low fragment kinetic energies, indicating little or no Coulomb barrier.[4]
4. Energy spectra consistent with the kinematics of two-body decay from a system nearly at rest in the laboratory.[2,5]
5. Fragment emission from a remnant of the proton-nucleus collision after 20-30 nucleons are removed from the target (for a mass 130 target).[2]
6. Fragment yields obey Q_{gg}^{+} systematics.[6] (fig 2)
7. Fragment yields, when averaged over isotopes for fixed mass number, obey a power law: yield α $A_{fragment}^{-5/2}$.[6]
8. Fragments are emitted in a low state of excitation.[7]
9. The fragment cross section is a significant fraction (20-30%) of the total cross section.[3]

An earlier Purdue-Fermilab experiment (E442) provided evidence for two-body decay from a nuclear remnant of the proton-nucleus collision. The data suggest that this remnant may be one in which A=2Z. The fact that these nuclear remnants do not ordinarily fission (Z^2/A is too small) suggests that fragmentation proceeds via an abnormal nuclear

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$^{+}Q_{gg}$ is the difference between initial and final ground state masses.

state. Data from a recently completed Purdue-Fermilab experiment (E591) indicate that fragment isotopic yields obey the Q_{gg} systematics. The yield for the isotopes for a fixed fragment charge can be described by yield $\propto e^{\alpha Qgg}$. The parameter α is found to be nearly constant for a given target, and increases with target mass. It also is a measure of the remnant excitation in certain models, and yet in general it does not agree in value with the parameter β discussed in 2. above. The Q_{gg} dependence implies that fragment emission is a process involving a partial statistical equilibrium and that it may occur at relatively small excitation energies. Statements 1-9 above lead one to consider that fragments may result from a gross restructuring of the nucleus.

The coincidence measurement will enable us to:

1. Determine the remnant charge and mass which is emitting the fragments.
2. Determine the center of mass motion of this emitting system.
3. Knowing the remnant identity, one can determine if systematic variations from Q_{gg} systematics can be explained by changes in the binding energy from the values expected for normal nuclear matter.

It should be noted that heavy fragment production correlates with high multiplicity[8] and that events where the target nucleus disintegrates have been observed.[9] Consequently, the information from inclusive data can only give inferences about the "dominant" mode of fragment production. Preliminary analysis of E591 inclusive data indicates that Q_{gg} systematics may indicate an absence of normal pairing energies.

Theoretical interest in pion condensates suggests that isotopically symmetric nuclear matter, Z=N, would decay by a fission mode in a region

of A and Z where the fissile parameter Z^2/A is very much smaller than the critical value.[10] Consequently, a high resolution fragment correlation experiment which critically tests the information extracted from inclusive data is of fundamental importance.

More generally, no known model of the nucleus can account for features 1-9, and the elucidation of a new high energy reaction mechanism which has not received theoretical attention is of fundamental importance.

A futher description of the underlying general physics questions can be found in Fermilab proposal E591.[11]

3. EXPERIMENTAL APPARATUS

The detection system will consist of two telescope types: high resolution heavy fragment telescopes measuring time-of-flight and ΔE-E, and low resolution fragment telescopes measuring TOF and E. The high resolution telescopes will consist of a micro-channel plate time zero detector[12] providing the timing start signal. This detector will be about 50 cm from the beam. A gas ionization-silicon E chamber similar in design to the one used in E591 will provide both ΔE-E and the timing stop. The flight path will be about 50 cm long. The low resolution array will consist of MCP-silicon detector combinations. A sketch of the experimental apparatus is shown in Figs. 4 and 5. Detector characteristics and expected resolutions are given in Table 1.

The detector system, when running in the coincidence mode, will be triggered by heavy fragment events. A single high resolution telescope will be located successively at 45, 90 and 135 degrees with respect to the beam direction on the tunnel side of the main ring. High and low resolution telescopes will be distributed approximately 180 degrees opposite to the single high resolution telescope. The high resolution detectors will be positioned to capture the peak of the kinetic energy spectrum, while the low resolution detectors will be positioned to capture the low energy end of the spectrum. Kinematics of two-body decay imply that the low energy events will lie forward of the 180 degree coincidence in the laboratory.

The heavy fragment detector array opposite the trigger will be movable by remote control. The channel plate detectors require a vacuum of approximately 10^{-6} microns to ensure their long-term operation, thus necessitating one stage of differential pumping between the molecular beam target and the MCPs and one stage between the MCPs and the gas detectors. The electronics will be essentially the same as used in E591. Purdue will provide a PDP 11/60 computer, assorted peripherals, and software for data acquisition.

The fundamental advantage of the ITL for fragmentation is the unique combination of high data rate using a very thin target. An essential feature of this proposal is to introduce a very thin 10^{-9} gram/cm^2 target

using a molecular beam which intersects the proton beam. Using evaporative techniques, it is possible to prepare molecular beams from materials throughout the periodic table. In this experiment, the gas load will be reduced by a factor of 30 to 100 from the values used with the traditional warm gas jet. Under these circumstances, the target beam interference effects will be negligible. The amount of material entering the target chamber is a fraction of a gram for 24 hours of operation.

Actually, two molecular beams will be produced from the same oven: one which is directed to intersect the proton beam, the other of which will be monitored by a gas ionization sensor. In this way the molecular beam can be controlled independently of the focal plane shutter which is synchronized with the data gate. The target assembly which can be quite small compared to the existing warm gas jet will be isolated from the target box by a differential pumping system. Thus essentially only the molecular beam will enter the target box. For these target materials, room temperature surfaces will pump cryogenically.

The experimental arrangement is shown in Fig. 5. The target box is positioned in the 400 Gev/c beam line centered at C_o and is above the Tev beam line. Differential pumping systems are located to isolate the target box from the beam line.

The target module is above the target chamber. The single high resolution telescope is on the tunnel side of the target box at either 45°, 90° or 135°. The movable arm consisting of a 15 detector array is contained in the target chamber. The entire system will fit into the C_o environment. The expected arrangement of the beam above the system is also indicated in Fig. 5.

The individual components in this experiment have been tested and operated successfully in E-591. The background rates for the various detectors can be scaled from measured values and jet target parameters experienced in E-591. Singles counting rates can be predicted. The reliability of these components is demonstrated by the operation of 8 MCP detectors over a period of more than 1000 hours together with thin window (35 $\mu g/cm^2$) gas ionization detectors. An example of the isotopic resolution is shown in Fig. 3.

REFERENCES

1. O. Scheidemann and N.T. Porile, Phys. Rev. C14, 1534, (1976).
2. J.A. Gaidos, et al, Phys. Rev. Lett. 42, 82, (1979).
3. G.D. Westfall, et. al. Phys. Rev. C17, 1368, (1978).
4. A.S. Hirsch, FNAL E591, private communication.
5. A.M. Poskanzer, et al. Phys. Rev. C2, 882, (1971).
6. R.W. Minich, FNAL E591, private communication.
7. B.D. Wilkins, et al. Phys. Rev. C19, 856, (1979).
8. W.G. Meyer, et al. Phys. Rev. C22, 179, (1980).
9. K.D. Tolstov, Comm. JINR PI-9286, (1975).
10. A.B. Migdal, Rev. Mod. Phys., 50, 107, (1978).
11. Fermilab-Purdue collaboration, Fermilab proposal for E591.
12. A. M. Zebelman, et al. Nucl. Inst. and Meth. 141, 433 (1977).

TABLE 1

EXPERIMENTAL PARAMETERS

Average Beam Intensity	5×10^{12}
Target Thickness - Mass 100	.3-1.0 ng/cm^2
Solid Angle/detector	3×10^{-4}
Number of Detectors	∿15
Average Heavy Fragment Cross Section	10mb
Counting Rate for 20 Fragment Species/detector assuming 1.0 ng/cm^2 target	7/sec
Flight Times over 50 cm flight path for fragments between .2 and 4.0 Mev/nucleon	18-80 ns
Fast trigger resolving time	60 ns
Coincidence/Accidental rate	>100/1
Time of Flight resolution	<300 ps
Gas Detector ΔE resolution	∿3%
Mass resolution	2%
Charge resolution	3%

BEAM TIME ESTIMATES

Set-up Time:

A period of two months will be required for the installation of the detector array and associated vacuum system, cabling, testing and calibration of detectors and electronics.

Test Runs:

About 400 hours of testing will be required with full intensity ($>5\times10^{12}$) beam.

Data Runs:

We plan to run 4 targets; mass 200, 100, 50, 25. Approximately 200 hours per target will be required for sufficient statistics. We note that we have been conservative in our counting rate estimate. The following factors may improve the counting rate by as much as a factor of 300:

1. the addition of a 5 second "front porch" to the 400 Gev beam.
2. evaporative targets 10 times thicker may be increased, i.e., 10 ng/cm^2, if there is no interference with accelerator operation
3. an average beam intensity of 2×10^{13} protons instead of 5×10^{12}.

We will be ready to run by mid 1982. We can run either before the Tevatron is operational, in the event there is another 400 Gev running period, or during the Tevatron program at a somewhat lower energy.

LIST OF FIGURES

1. Fragment Kinetic Energy Spectrum: $P + Xe \rightarrow {}^{14}_{7}N + X$.

The inverse logarithmic slope of the high energy tail from the spectrum yield apparent temperatures ($1/\beta$ in text) $\sim$ 15 MeV. This may be indicative of highly excited hadronic matter. Data from E591.

2. Fragment Yields from Xenon versus Q_{gg}.

The Q_{gg} value is the ground state separation energy for removing fragment A_f from the remnant of the proton-nucleus collision. Values were obtained from mass tables. Data from E591.

3. Fragment Mass Spectrum: $P + Xe \rightarrow$ Neon + X. Data from E591.

4. Experimental Apparatus: Schematic of Detector Array.

5. Experimental Layout at Cϕ.

Fig. 1

$$P + Xe \longrightarrow {}^{14}_{7}N + X$$

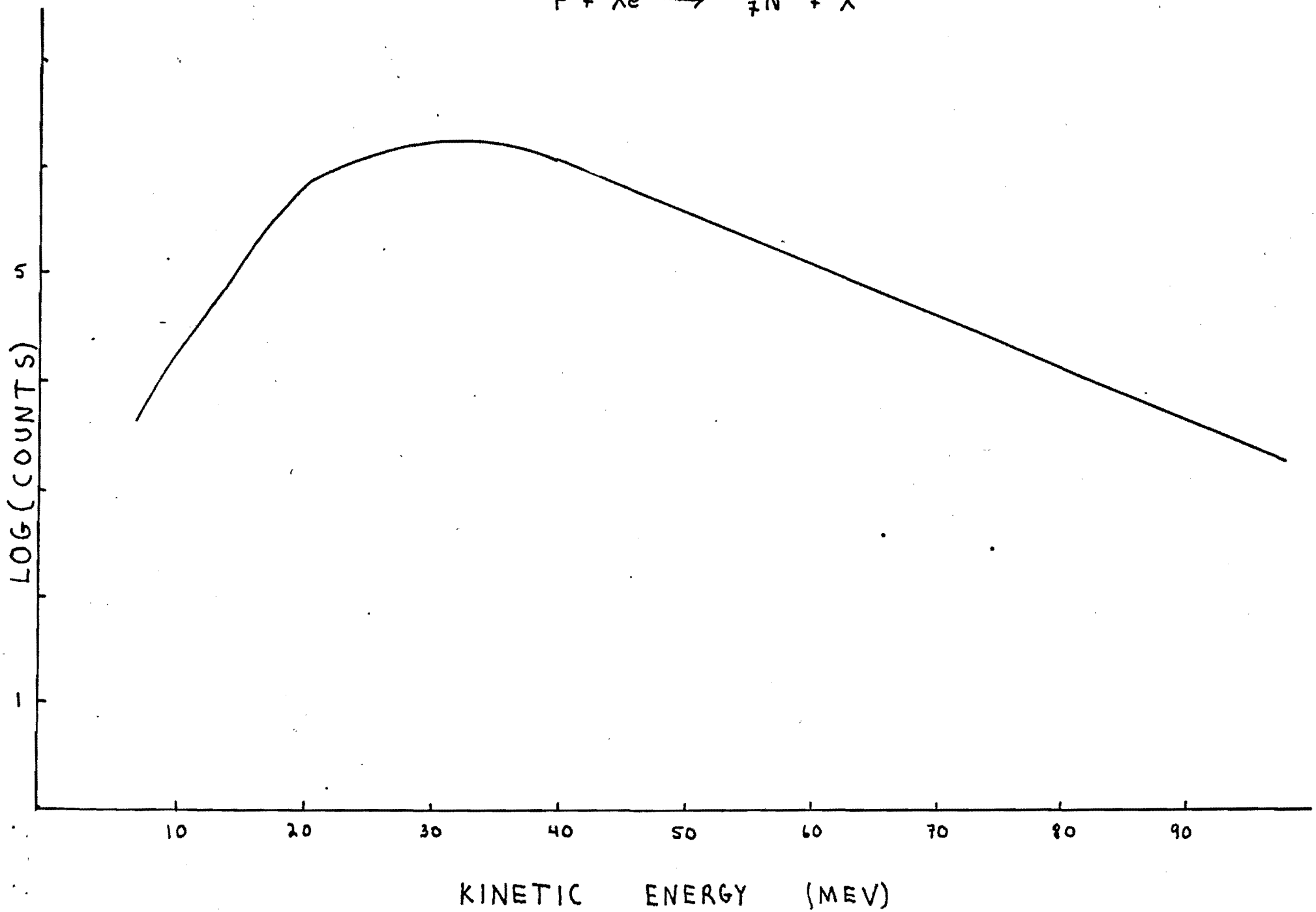
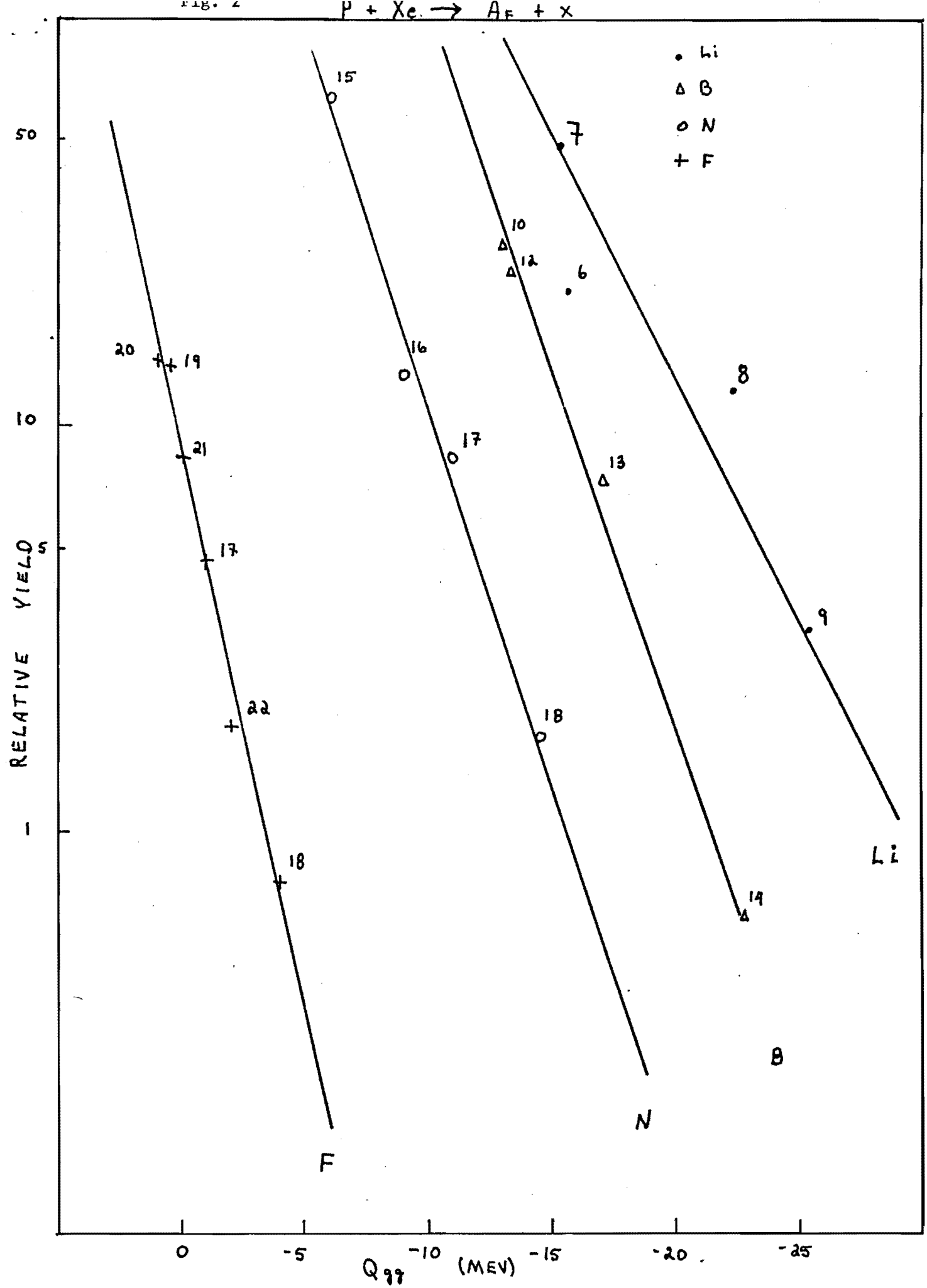


Fig. 2



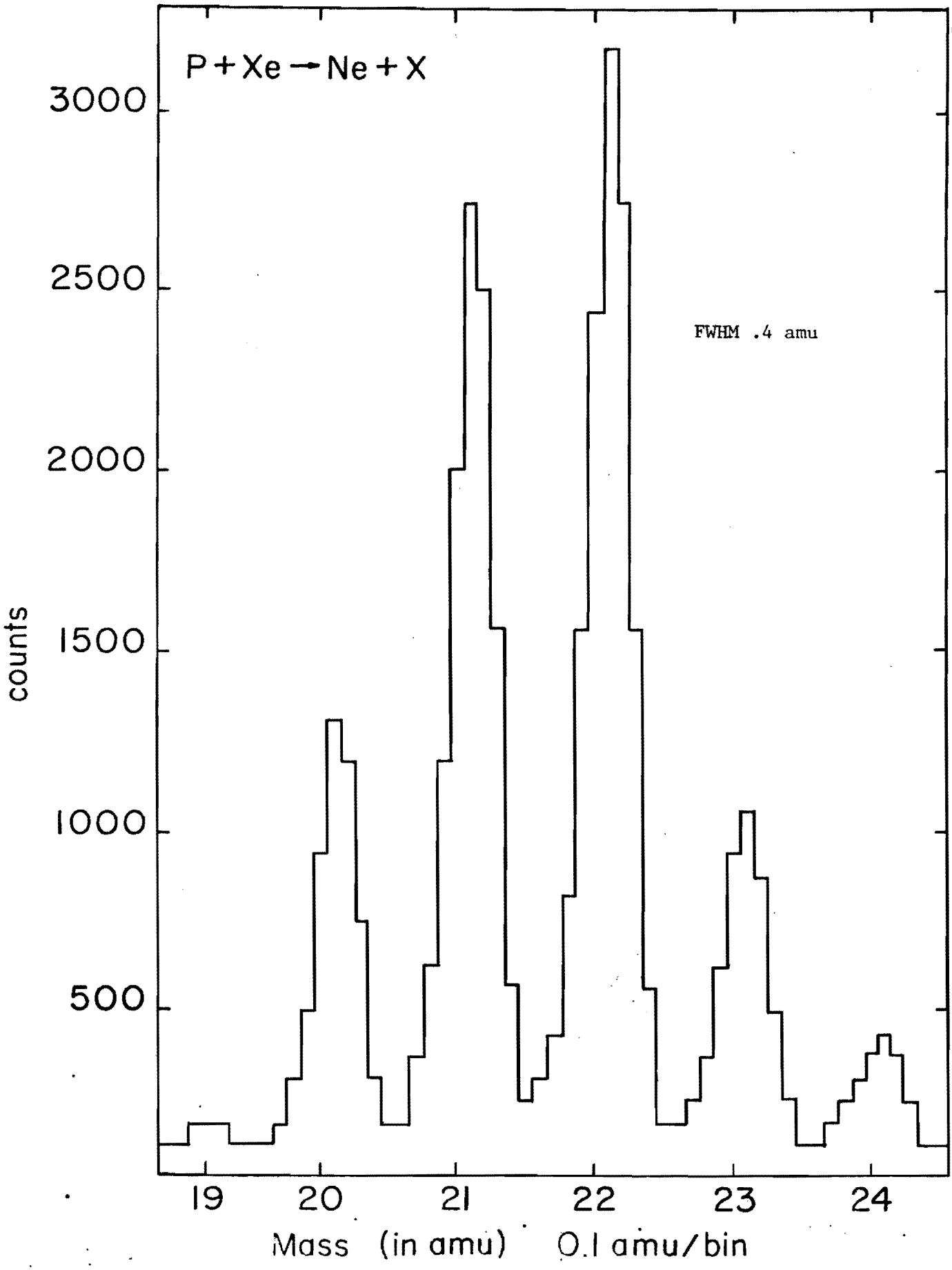

P + Xe → Ne + X
FWHM .4 amu
counts
3000
2500
2000
1500
1000
500
19
20
21
22
23
24
Mass (in amu) 0.1 amu/bin

Fig. 3

Fig. 4

SCHEMATIC of FRAGMENT TELESCOPES

TOP VIEW

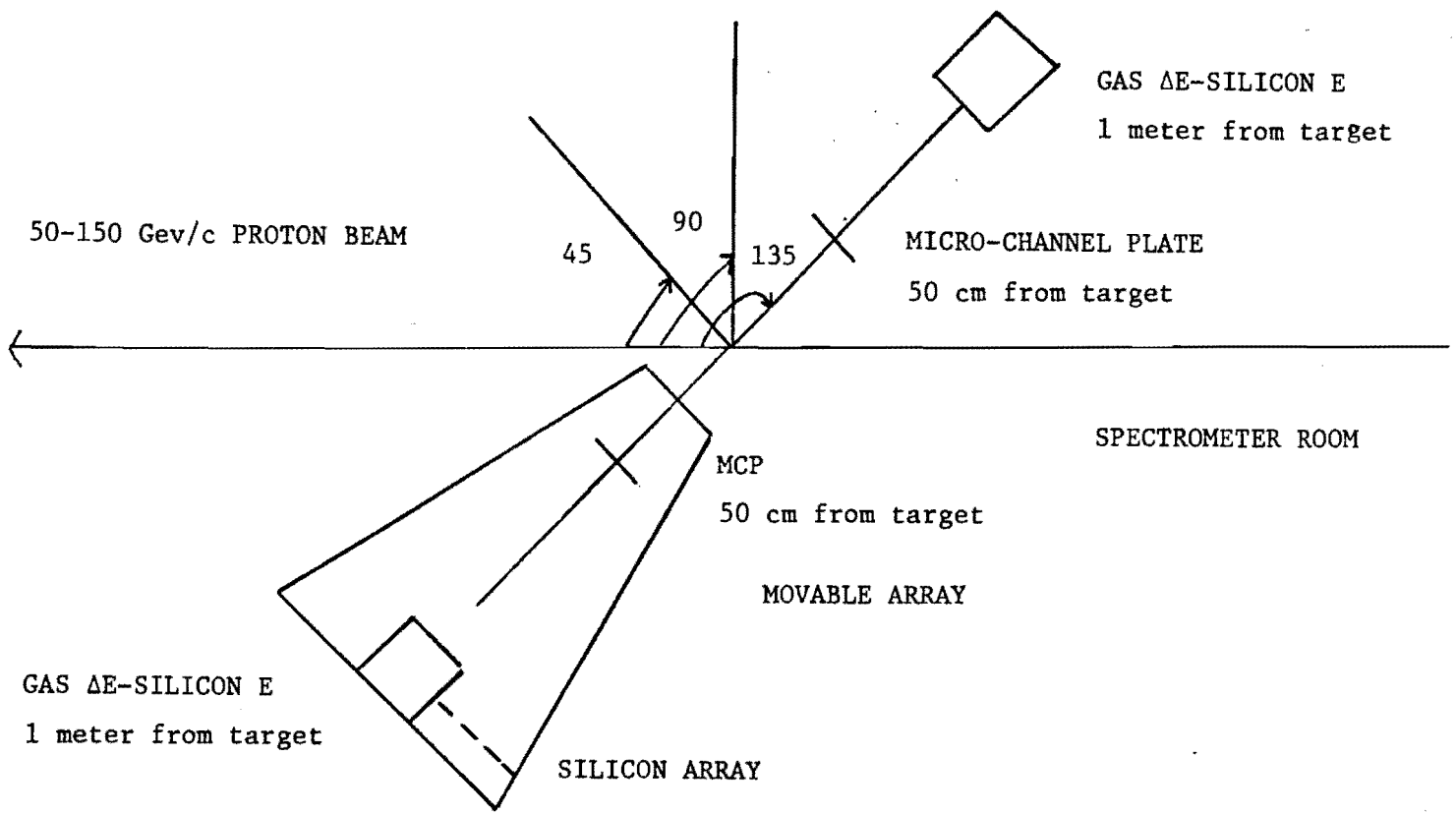
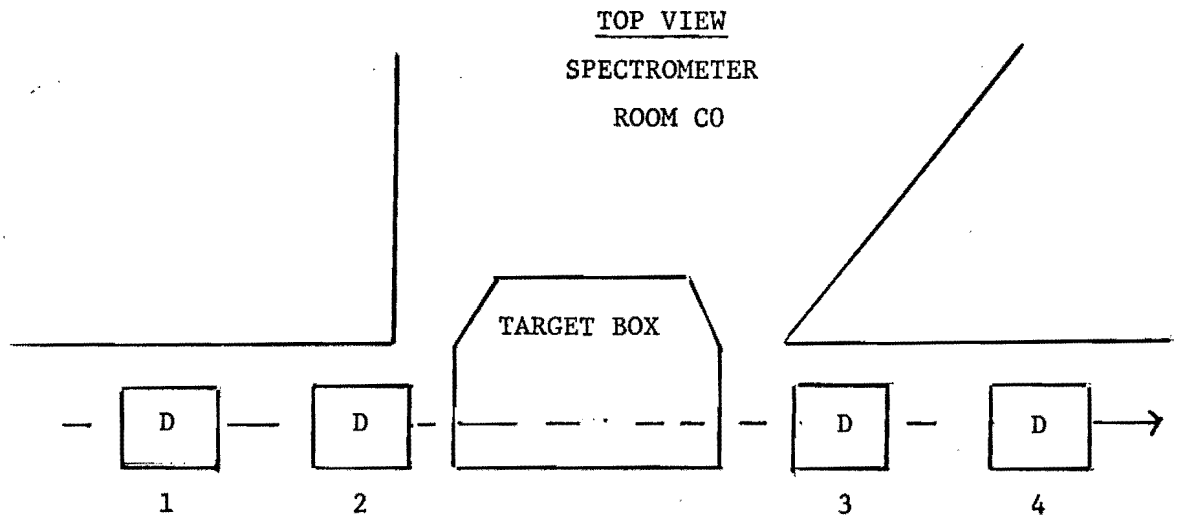
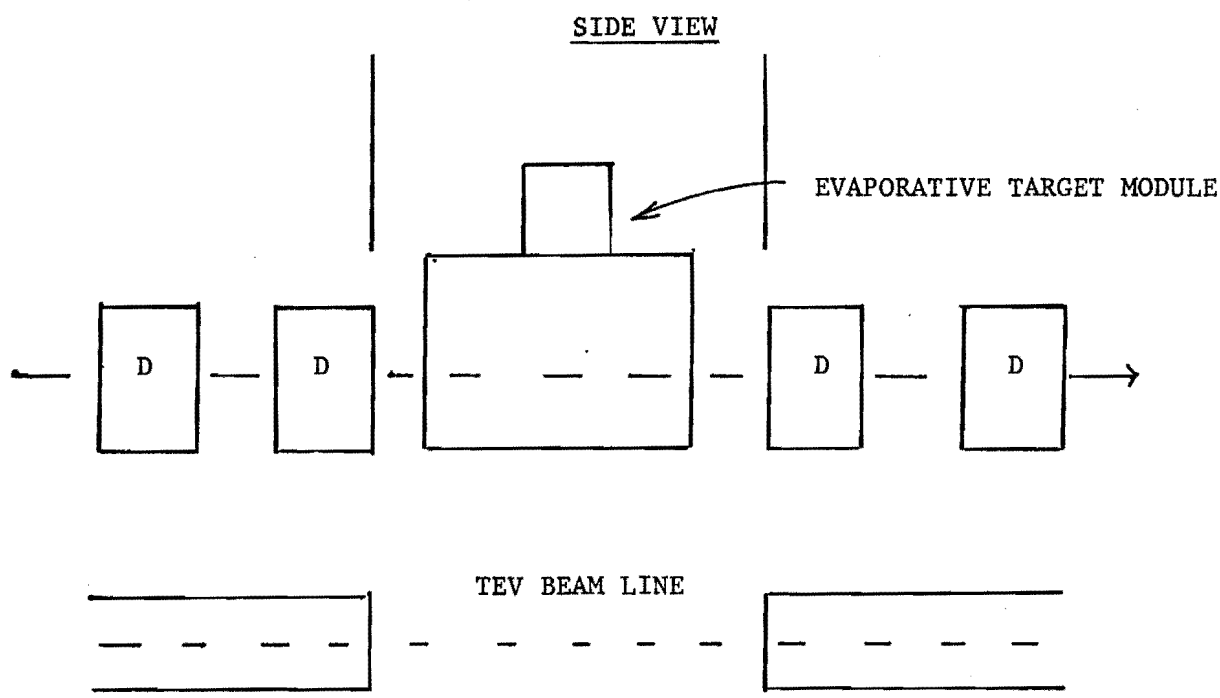


FIG. 5



1 - 4 Low maintenance differential pumping on the 400 Gev line