FERMILAB-Proposal-0591

Broad Search for New Hadronic States Via High Resolution Charge and Mass Determination of Nuclear Fragments From P-Nucleus Collisions

Submitted by scientists at:

Purdue University and

Fermi National Accelerator Laboratory

Person to contact: L. J. Gutay

Phone: (317) 749-2961

Date: January 1978

37 pgs.

Names of the Experimenters

Member of Fermi National Laboratory: F. Turkot

Members of Purdue University:

Professors: L. J. Gutay

N. T. Porile

R. P. Scharenberg

Research Associates: A. Hirsch

A. T. Laasanen

T. V. Ragland

C. L. Wilson

S. Pandian

I. Abstract

We propose a high resolution study at the Internal Target Laboratory of the charge to mass ratio (Z/M) and energy spectra of nuclear fragments produced by proton heavy nucleus collisions from 20 to 400 GeV/c. Combining the MZ^2 determination scheme with time of flight we can achieve excellent charge (Z) and mass (M) resolutions ($\Delta Z = 0.05e$, $\Delta M = 0.20$ amu) over a large range of fragment charge and mass. This allows us to carry out a broad search for fragments of abnormal Z/M ratios which may result from (a) superdense nuclear matter, (b) new, heavy, moderately long-lived ($\tau \geq 100$ nsec) hadronic states bound to nuclear fragments, (c) new neutron-rich isotopes. The combination of high resolution and high event rate in an essentially unexplored domain is the unique feature of this experiment. We will use the warm jet target with H_2, Ne, CH_4, Ar, Kr, Xe gases. We request 200 hours of set-up time and 600 hours of running time. Similar to E442, this experiment will require only minimal support from the Internal Target Laboratory during data taking.

II. Introduction

The study of high energy phenomena has concentrated on the detection of energetic charged, neutral, stable, and unstable particles with spectacular results. Very little is known about the nuclear remnants which are produced when high energy protons collide with heavy nuclei. Pontocorvo[1] has pointed out that the study of particles trapped in matter has been largely overlooked. Such searches would be sensitive to charged as well as neutral particles.

The unique combination of the internal beam, a gas jet target, a double dE/dx particle identifier telescope (two independent measurements of dE/dx) and pico-second electronic time of flight techniques will permit a high resolution study of the charge to mass ratio (Z/M) and the energy spectrum of nuclear fragments produced in energetic proton-heavy nucleus collisions. A charge resolution of $\Delta Z = 0.05e$ and mass resolution $\Delta M = 0.20$ amu can be obtained over a wide range of Z and M values. The double dE/dx identifier system will permit the identification of fragments whose abundance is less than 10^{-4} of the most abundant species in a particular Z/M range. The study would be sensitive to fragments whose lifetime τ falls in the range $100 \text{ ns} \leq \tau \leq \infty$.

Jones[2] has reviewed the stringent limits that have been set in conventional quark searches, both charged and neutral, with lifetime $> 10^{-7}$ sec and masses ≥ 2 GeV/c. However, the possibility exists of partial confinement of new phenomena in the nuclear remnants. Consequently, we belive that the study of the nuclear remnants must be pursued when new techniques are available.[3] The luminosity of the circulating beam of the FNAL colliding with the warm gas jet would allow cross section limits of 10^{-32} cm^2/nucleus to be set on the production of normal and abnormal fragments. The cross section limits are three to six orders of magnitude lower and the beam momenta are two orders of magnitude higher than those possible in previous studies of nuclear fragments.

From the theoretical point of view the physics interest falls into three areas: (a) Abnormal nuclear matter. Lee, Wick[4] and Bodmer[5] have suggested that abnormally dense nuclear matter could have a binding energy which would manifest itself in Z/M ratios which lie on the proton rich side of ordinary nuclear matter. (b) De Rujula,[6] Garelik,[7] and Longo[8] have suggested that partially confined "elementary particles" may be attached to the nuclear remnants and produce Z/M ratios which lie on the neutron rich side of stable nuclear matter. (c) The study of the isotopic structure of the nuclear fragment[9] emission process is of interest from the nuclear point of view. This would extend the global survey of nuclear fragment emission which was conducted in E442.

In Section III we discuss in more detail the super dense matter arguments. Section IV sketches the kinds of theoretical arguments which connect quarks and gluons to nuclear remnants. Section V reviews the nuclear physics and chemistry interest in the isotopic structure of nuclear fragments. The capabilities of the high resolution fragment spectrometer coupled with the unique luminosity provided by the warm gas jet target are detailed in Section VI.

The support level requested from the Internal Target Laboratory is for one technician on standby during the running of this experiment. It does not need any He cryogenic support. We ask for 200 hours of testing and 600 hours of running time.

III. Superdense Nuclear Matter

Lee and Wick[4] have suggested, based on reasonable assumptions for the form of the mesonic interactions between nucleons, that it is possible that a super dense phase of nuclear matter could exist in stable or isomeric form. A possible signature for this abnormal state of nuclear matter would be a much greater than normal binding energy per nucleon manifesting itself in Z/M ratios of fragments which lie on the proton rich side of normal nuclear matter.[5] Estimates indicate that in this state the nuclear binding energy would increase by a factor of twenty or more.[4] This large increase in binding energy would allow the creation of nuclear fragments which are outside the known stable region[5] of ordinary matter. For example, the observation of a fragment with charge $Z = 9.0 \pm 0.05$ and $M = 15 \pm 0.1$ (F^{15}) would be the signature of a species which lies outside of the particle stable limits of ordinary nuclear matter (F^{16} is the lightest known fluorine isotope). Additional evidence of unusual behavior might also turn up in the shape of the energy spectrum and angular distribution of abnormal fragments as well as in the dependence of their production cross section on target Z. The observation of abnormal fragments would provide strong justification for a subsequent investigation of their decay modes.

In E442 we observed that the large total cross section for the production of nuclear fragments suggests that the proton-nucleus cross section is initiated by the total p-N interaction. The p-N cross section is largely inelastic in the energy range 20 to 400 GeV/c. Further, the diffractive inelastic interactions would scatter numbers of low energy pions and nucleons perpendicular to the incident proton direction.

Such a collective nuclear process[10] would involve the ejection of nuclear matter in preferential directions. Novel sideways peaking of nuclear fragment emission has been observed at these energies[11,12] and in E442. Theoretical speculations[13] suggest that shock phenomena could form superdense nuclear fragments (referred to as "density isomers").

We believe that these indications make it worthwhile to look for abnormal nuclear fragments as part of a broad study of nuclear fragment emission initiated by high energy protons. Such a high resolution study requires a long time of flight path and the appropriate luminosity. The Internal Target Laboratory is uniquely suited for these measurements.

IV. The Nucleus Bound Quarks and Heavy Mesons

Ever since the suggestion of Gell-Mann[14] *and Zweig*[15] *there has* been an unabating interest to demonstrate experimentally that constituents of nucleons (quarks) do exist and that they are not merely a theoretical abstraction. This enormous experimental effort has been recently reviewed by Jones.[2] A more recent search at high momentum transfer by Antreasyan et al.[16] has not found quarks. From the experiments quoted in the above literature no clear evidence has emerged for "liberated" hadronic constituents. The negative results of these experiments taken together with the discovery of Charmonium by Aubert et al.[17] and Augustin et al.[18] has given credence to quark confinement ideas. At the present, Quantum Chromodynamics (QCD) has emerged as the best theory to describe strong interactions. In this model the interaction between colored quarks is mediated by massless vector colored gluons. Within the framework of QCD proof for color and quark confinement does not exist. Thus to study under what conditions quarks can be liberated one must rely on intuition or on models such as the MIT[19,20] bag model as interpreted by De Rujula, Giles and Jaffe[6] (RGJ). They showed that single quarks can be produced by local breaking of gauge symmetry. They implemented a spontaneous breakdown of the local SU(3) color gauge symmetry and thereby generated a gluon mass μ. In turn the free quark and gluon masses are

$$M_q = \frac{1}{2\pi\alpha'\mu} \tag{1}$$

$$M_g = 3M_q/2 \tag{2}$$

where α' is the slope of Regge trajectories. Equations 1 and 2 express the Archimedes principles for quarks and gluons. The smaller the μ, the lighter the quarks and gluons are inside the *color singlet hadrons, but they are heavier outside.* Once a quark is liberated, a large number of nucleons are absorbed into the quark cavity. The number of quarks absorbed nucleons is $n \simeq M_q/m_p$. Thus if free quarks are very massive, we would expect to find quarks in association with nuclear fragments. Similar arguments hold for gluons. The gluon multinuclear system will also be heavy but will not have fractional charge. For example a neutral particle of mass 8 GeV attached to F^{19} could appear as a fragment Z = 9.0 ± .05 and M = 27.5 ± 0.10. This lies beyond the neutron rich side of the known fluorine isotopes.

Aside from any model it is not inconceivable that $q\text{-}\bar{q}$ separation can be achieved for distances of the order of several nucleon diameters inside the volume of a nucleus. Upon the breakup of the nuclear matter they will be separated and attached onto two different nuclear fragments. If it is the large $\bar{q}q$ binding energy, which prevents the dissociation of the $\bar{q}q$ pair in vacuum, it will appear as the agent to produce a very tightly bound quark fragment system whose mass may or may not be distinctive. In this case the fractional charge would be the unique signature which identifies fragment bound quarks.

The possible existence of new stable hadrons has been predicted by Cahn.[21] Interpreting the upsilon[22] as a manifestation of a fifth quark[23] denoted by q_5, Cahn suggested that the new mesons $d\bar{q}_5$ and $u\bar{q}_5$ do not couple to the old ones. Thus, whichever has the lower mass will be stable. The $d\bar{q}_5$ combination would simply combine with the nucleus to form a large heavy nucleus which lives for about 5 sec before the $d \rightarrow u$ beta decay takes place. A 5 GeV/c mass has been estimated for this hadron. This object would have a signature similar to that given for the 8 GeV example above.

V. Nuclear Physics and Chemistry of Fragment Emission

The determination of the energy spectra of isotopically resolved fragments is of great interest to an understanding of high-energy proton nuclear reactions. Fragment emission is one of the characteristic features of high-energy nuclear reactions and this process, in fact, accounts for a sizeable fraction of the total reaction cross section. Relatively little is known about fragment emission at Fermilab energies. The Nuclear Chemistry collaborations (Expts. 81A, 466) have shown that the yields of fragments are nearly the same at 300-400 GeV/c as at 10-30 GeV/c for targets ranging from silver to uranium[24-27]. Recoil studies indicate some significant differences between these energy regions. The forward-to-backward emission ratios of a number of fragments thus decrease to unity at 300-400 GeV/c indicating that the angular distributions must become symmetric about 90° in the laboratory frame.[28] At the same time, measurements at sideward angles[29] suggest that the angular distribution must, in fact, exhibit sideways peaking. This effect has already been observed for fragments emitted in the interaction of ^{238}U with 29 GeV/c protons[11] but the peaking appears to become more pronounced at Fermilab energies. Measurements of the double differential cross sections for fragments emitted in the interaction of 20-400 GeV/c protons with a xenon gas target (Expt. 442) are consistent with the 29 GeV/c observations. These interesting results, which appear to be a characteristic feature of Fermilab energies, remain to be explored in further depth. It may conceivably be indicated of the occurrence of a nuclear shock wave[10] or some other novel phenomenon.

While the nuclear chemistry experiments have provided information on isotopically resolved fragments, systematic data for a range of isotopes of a given element are not available. There are two principal features of interest in such measurements. The first of these is the variation of the energy spectra of fragments with their isotopic composition. It has been previously established in reactions induced by 2-6 GeV/nucleon projectiles[30,31] that the spectra of neutron deficient fragments are considerably flatter than those of neutron excessive ones. However, this conclusion is only based on data for fragments that cluster near the line of stability. This was clearly seen in E442 as shown in Fig. 1. The isotopic resolution that will be possible in the present experiment coupled with the high intensity of the internal beam should make it possible to perform such measurements for a broad range of isotopic fragments. The dependence of the nuclear temperature extracted from these spectra on isotopic composition, bombarding energy, and emission angle will provide a rich body of data with which to explore the properties of highly excited nuclear matter.

The mass resolution capabilities of our experiment should also make it possible to study the production of fragments near the limits of nuclear stability. The combination of dE/dX-E and time-of-flight techniques in high-energy reactions has led to the discovery of a number of new particle-stable isotopes[9,32]. While it appears that all particle-stable isotopes below A ~ 20-25 have already been found, the immediately heavier mass region still offers a good deal of promise. Butler et al.[9] have thus just recently reported the discovery of various isotopes ranging from ^{27}Ne to ^{39}P. The determination of the limits of nuclear stability provides critical information for a test of the validity of various mass formulae. Since the range of these somewhat heavier fragments are considerably lower than those having $Z \leq 10$, it will be necessary to use a gas dE/dX counter in this part of the experiment. The characteristics of these counters have been thoroughly explored and their usefulness in the measurement of fragment spectra has been established.[33,34]

VI. Experimental Details

In E442 we found that a wide range of nuclear fragments $4 \leq Z \leq 12$ were produced in proton heavy nucleus (Ne, Ar, Kr, Xe) collisions for 20 to 400 GeV/c incident protons. The observed fragments lie in the low energy range $E \leq 100$ MeV with peak energies of 2-3 MeV/nucleon. Because of the enormous luminosity provided by the circulating beam of the FNAL accelerator (10^{17} to 10^{18} protons/sec) and the thin targets (10^{14}nuclei/cm^2) provided by the warm gas jet which was designed by Mansch and Turkot,[35] it was possible to study in detail a broad range of fragments with excellent energy resolution. Up to now about $3 \cdot 10^7$ events have been analyzed. Typical energy spectra are shown in Fig. 2 for p + Xe collisions averaged over 50 to 400 Gev/c incident proton energy. Fig. 3 shows the distribution of the quantity $E \frac{dE}{dx}$ in the range $2 \leq Z \leq 8$. (Note that $\frac{dE}{dx} \sim MZ^2$.) The peak to valley values for this MZ^2 spectrum, obtained by a <u>single</u> dE/dx element in the particle identifier spectrometer, is in the range from 2500 to 1 for helium and from 150 to 1 for oxygen. The width of these peaks in MZ^2 is due to the isotopic structure of the fragments and instrumental factors. A long path (2m) time of flight system using thin (10^{-5} gm/cm^2) carbon foils and channel plates[3] would allow us to identify individual isotopic constituents. The remaining experimental width is limited by the resolution of the dE/dx detector.

Cerny et al.[36] have demonstrated that the unusual energy loss (Landau tail, blocking, channeling, etc. in the dE/dx detector) can be practically eliminated by the introduction of <u>two dE/dx elements</u> into the particle identifier spectrometer. Thus two <u>independent</u> MZ^2 determinations are required. Consequently a 200 to 1 peak to valley ratio can be improved by up to two orders of magnitude.

This requires rejecting 1 to 6% of the events. A schematic sketch of the spectrometer is shown in Fig. 4. A multiple time of flight determination is proposed. The long (2m) time of flight path is divided into two segments (C_1,C_2) and (C_2,C_4). Again agreement is demanded between independent measurements so that tails in the time resolution curve can be eliminated with the concomitant loss of a few percent of the events. Thus a 100 to 1 peak to valley ratio in a single time resolution curve can be improved by two orders of magnitude. The time of flight intervals include a short path measurement (C_3,C_4) which is used to eliminated possible ambiguities due to the bucket structure of the circulating beam.

The channel plate detector is based on the design of the Berkeley group[3] and has a time resolution of several hundred picoseconds. The thin carbon foils, 10 $\mu g/cm^2$, minimize the energy loss of the fragments (< 50 keV/detector) and the effects of multiple scattering. The channel plate assembly requires a differential pumping system to prevent the pressure rise in the target box associated with the warm gas jet from reaching the four channel plate detectors C_1-C_4

For the lighter fragments $2 < Z < 8$ the semiconductor detectors will consists of 200 mm^2 x 25 μ ΔE_1 and ΔE_2 detectors followed by a 200 mm^2 x 1000 μ ($E-\Sigma\Delta E$) semiconductor detector and finally backed by a 300 mm^2 x 1000 μ veto detector. For the heavier fragments $8 < Z < 30$ a gas ΔE_1 and ΔE_2 together with semiconductor $E-\Sigma\Delta E$ and veto detectors will be required. These gas proportional ΔE detectors have thicknesses that are equivalent to 3-8 μ Si detectors.

The mass M and charge Z resolution for the fragments are shown in Fig. 5a, 5b as a function of the energy/nucleon, E/A, of the fragment kinetic energy. These values are estimated using 100 keV energy resolution for the ΔE and E detectors and a 200 picosecond time resolution for the channel plate detectors. These are conservative estimates. Figs. 5a and 5b show the excellent M and Z resolution which can be obtained for fragment detection.

The spectrometer assembly C_1-C_4, ΔE_{1-2}, E-$\Sigma\Delta E$ and the veto detectors would be mounted on the carriage of the super conducting recoil spectrometer. In this way we have remote control in the range $33^\circ \leq \theta_{lab} \leq 76^\circ$.

We would run heavy gas-hydrogen mixtures (e.g. 90% H_2 and 10% Xe) for Xe, Kr, A, CH_4, and Ne using the room temperature gas jet. Consequently we require a minimum level of support very similar to the requirements of E442. During running we need one technician on standby. We estimate, based on our 442 data, that we would collect about 150 events/sec.

Data acquisition would be handled by a PDP-11 computer via a standard Camac interface and recorded on magnetic tape in an event mode. To carry out this proposal would require 200 hours of testing time and 600 hours of running time to acquire a $3 \cdot 10^7$ events. We would require the loan of a PDP-11 computer and support from PREP for the Camac system and for fast logic electronics. After approval we would fabricate the time of flight system and its associated vacuum module and propose to test it in the fall of 1978. We would like to run the experiment early in 1979.

References

1. B. Pontocorvo, Sov. J. Nucl. Phys. 11, 473 (1970).
2. L. W. Jones, Rev. Mod. Phys. 49, 717 (1977).
3. A. M. Zebelman et al., Nucl. Inst. and Met. 141, 433 (1977).
4. T. D. Lee, Rev. Mod. Phys. 47, 267 (1975).
5. A. R. Bodmer, Phys. Rev. D. 1601 (1971).
6. A. De Rujula, R. C. Giles, and R. L. Jaffee, Phys. Rev. D., to be published.
7. D. Garelik, "A new idea searching for free quarks", Northeastern University Report NUP, 2303 (Sept. 1976).
8. M. Longo, "Do nuclei with fractional atomic-number exist," University of Michigan Report UM HE 77-7, (Feb. 1977).
9. G. W. Butler, D. G. Perry, L. P. Remsberg, A. M. Poskanzer, J. B. Natowitz and F. Plasil, Phys. Rev. Lett. 38, 1380 (1977).
10. A. E. Glassgold, W. Heckrotte, and K. M. Watson, Ann. Phys. (New York) 6, 1 (1959).
11. L. P. Remsberg and D. G. Perry, Phys. Rev. Lett. 35, 361 (1975).
12. N. T. Porile, private communication.
13. J. Hofmann, H. Stricher, W. Scheid, W. Greiner, Report on the workshop on BeV/nucleon collisions of heavy ions, p. 39. Brookhaven National Lab. BNL 50445 TID-4500 (1974).
14. M. Gell-Mann, Physics Lett., 8, 214 (1964).
15. G. Zweig, CERN Report, 8419/Th 412 (1964).
16. D. Antreasyan, G. Cocconi, J. W. Cronin, H. J. Frisch, K. Olive, M. J. Shochet, L. Kluberg, J. Mueller, P. A. Pirué, and R. L. Sumner. Phys. Rev. Lett. 39, 513 (1977).
17. J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu, Phys. Rev. Lett. 33, 1404 (1974).
18. J. E. Augustin, A. M. Boyarski, M. Breindenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie, R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, F. Vannucci, G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre, G. H. Trilling,

J. S. Whitaker, J. Wiss, and J. E. Zipse, Phys. Rev. Lett. 33, 1406 (1974).

19. A. Chodos, R. L. Jaffe, K. Johnson, C. B. Thorn, and V. F. Weisskopf, Phys. Rev. D9, 3471 (1974).

20. W. A. Bardeen, M. Chonowitz, S. D. Drell, M. Weinstein, and T. M. Yan, Phys. Rev. D11, 1094 (1975).

21. R. N. Cahn, Phys. Rev. Lett. 40, 80 (1978).

22. S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens, H. D. Snyder, J. K. Yoh, J. A. Appel, B. C. Brown, C. N. Brown, W. R. Innes, K. Ueno, T. Yamanouchi, A. S. Ito, H. Jostlein, D. M. Kaplan, and R. D. Kephart, Phys. Rev. Lett. 34, 252 (1977). W. R. Innes, J. A. Appel, B. C. Brown, C. N. Brown, K. Ueno, T. Yamanouchi, S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens, H. D. Snyder, J. K. Yoh, R. J. Fisk, A. S. Ito, H. Jostlein, D. M. Kaplan and R. D. Kephart, Phys. Rev. Lett. 39, 1240 (1977).

23. D. B. Lichtenberg, J. G. Wills, and J. T. Kiehl, Phys. Rev. Lett. 39, 1592 (1977).

24. G. English, Y. W. Yu, and N. T. Porile, Phys. Rev. Lett. 31, 244 (1973).

25. S. K. Chang and N. Sugarman, Phys. Rev. C9, 1138 (1974).

26. G. English, Y. W. Yu, and N. T. Porile, Phys. Rev. C10, 2281 (1974).

27. S. B. Kaufman, M. W. Weisfield, E. P. Steinberg, B. D. Wilkins, and D. Henderson, Phys. Rev. C14, 1121 (1976).

28. O. Scheidemann and N. T. Porile, Phys. Rev. C14, 1534 (1976).

29. D. R. Fortney and N. T. Porile, Phys. Rev. C14, 1652 (1976).

30. A. M. Poskanzer, G. W. Butler, and E. K. Hyde, Phys. Rev. C3, 882, (1971).

31. J. Gosset, H. H. Gutbrod, W. G. Meyer, A. M. Poskanzer, A. Sandoval, R. Stock, and G. D. Westfall, Phys. Rev. C16, 629 (1977).

32. J. D. Bowman et al., Phys. Rev. Lett. 31, 614 (1973).

33. M. M. Fowler and R. C. Jared, Nucl. Instr. Meth. 124, 341 (1975).

34. J. Barrette, P. Braun-Munzinger and C. Gelbke, Nucl. Instr. and Meth. 126, 181 (1975).

35. P. Mantsch and F. Trukot, FNAL Report TM-582-0710.0 and FNAL Report TM 586-0710.0.

36. J. Cerny et al., Phys. Rev. Lett. 16, 469 (1966).

List of Figures

Fig. 1

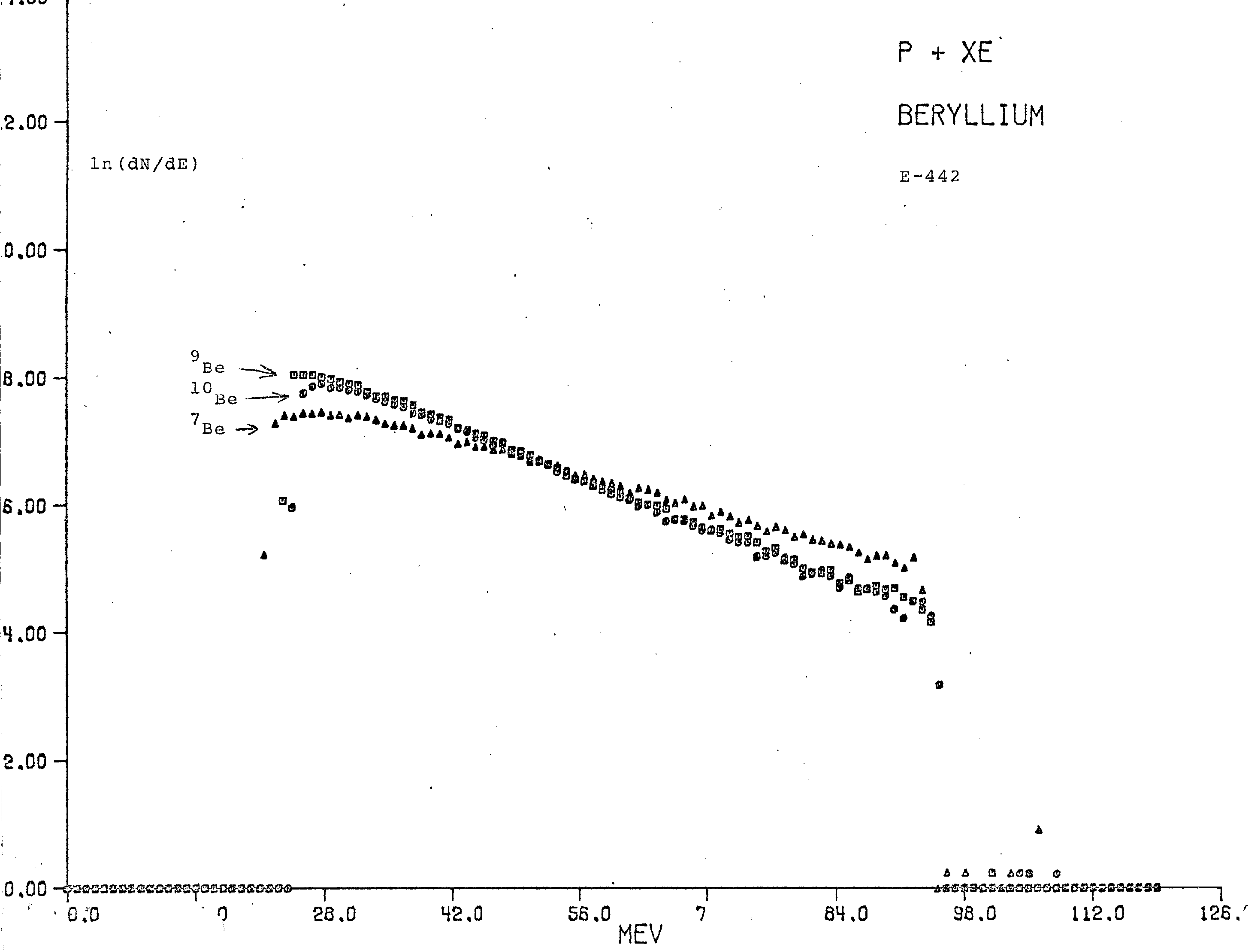
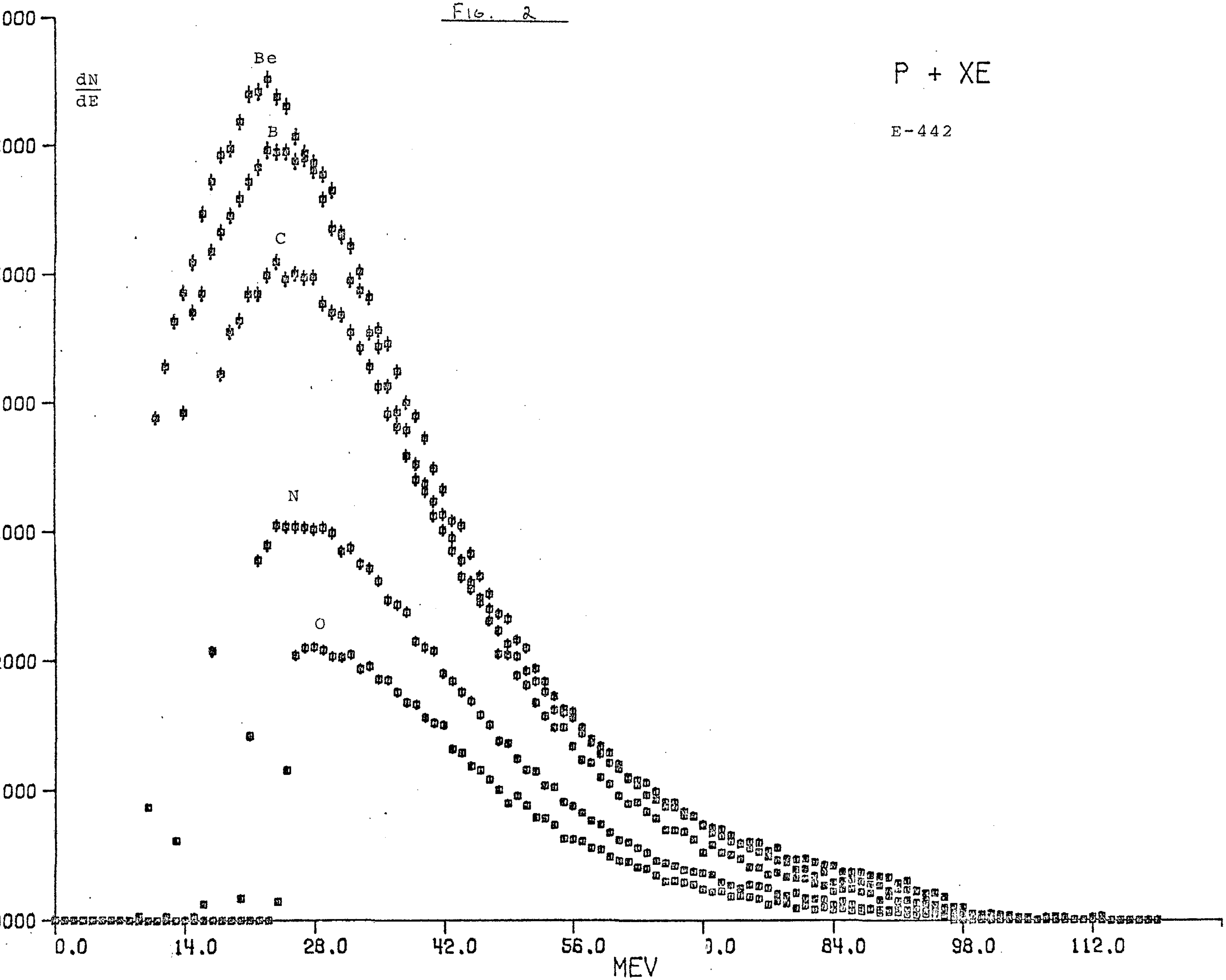

P + XE
BERYLLIUM
E-442
ln(dN/dE)
9Be
10Be
7Be
MEV
0.00
2.00
4.00
6.00
8.00
0.0
28.0
42.0
56.0
84.0
98.0
112.0

FIG. 2



P + XE
E-442
dN/dE
Be
B
C
N
O
.7000
.6000
.5000
.4000
.3000
.2000
.1000
0.0000
0.0
14.0
28.0
42.0
56.0
70.0
84.0
98.0
112.0
MEV

FIG. 3

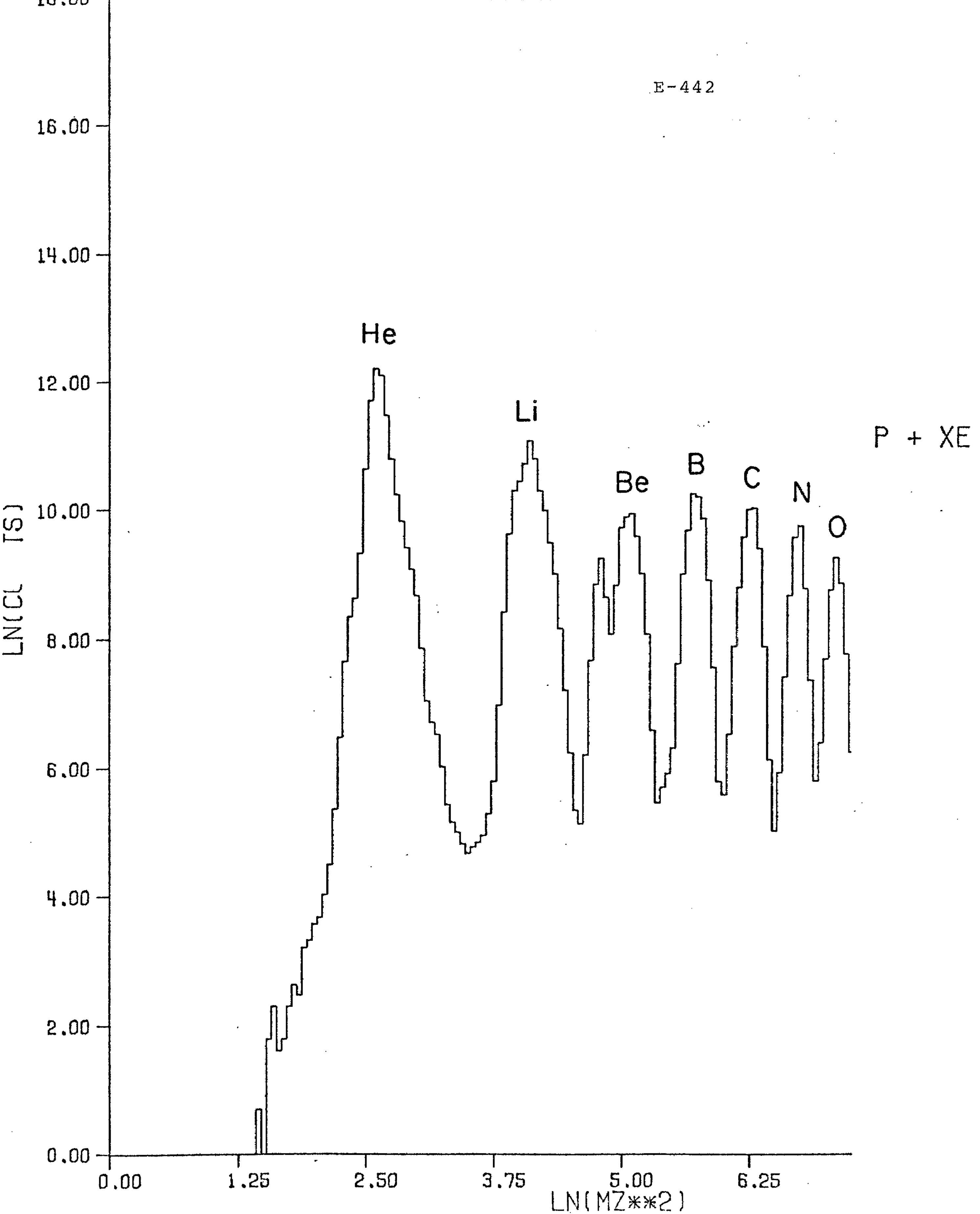

E-442
He
Li
Be
B
C
N
O
P + XE
LN(CL TS)
LN(MZ**2)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
1.25
2.50
3.75
5.00
6.25

Fig. 4

Schematic of channel plate,
semi-conductor spectrometer

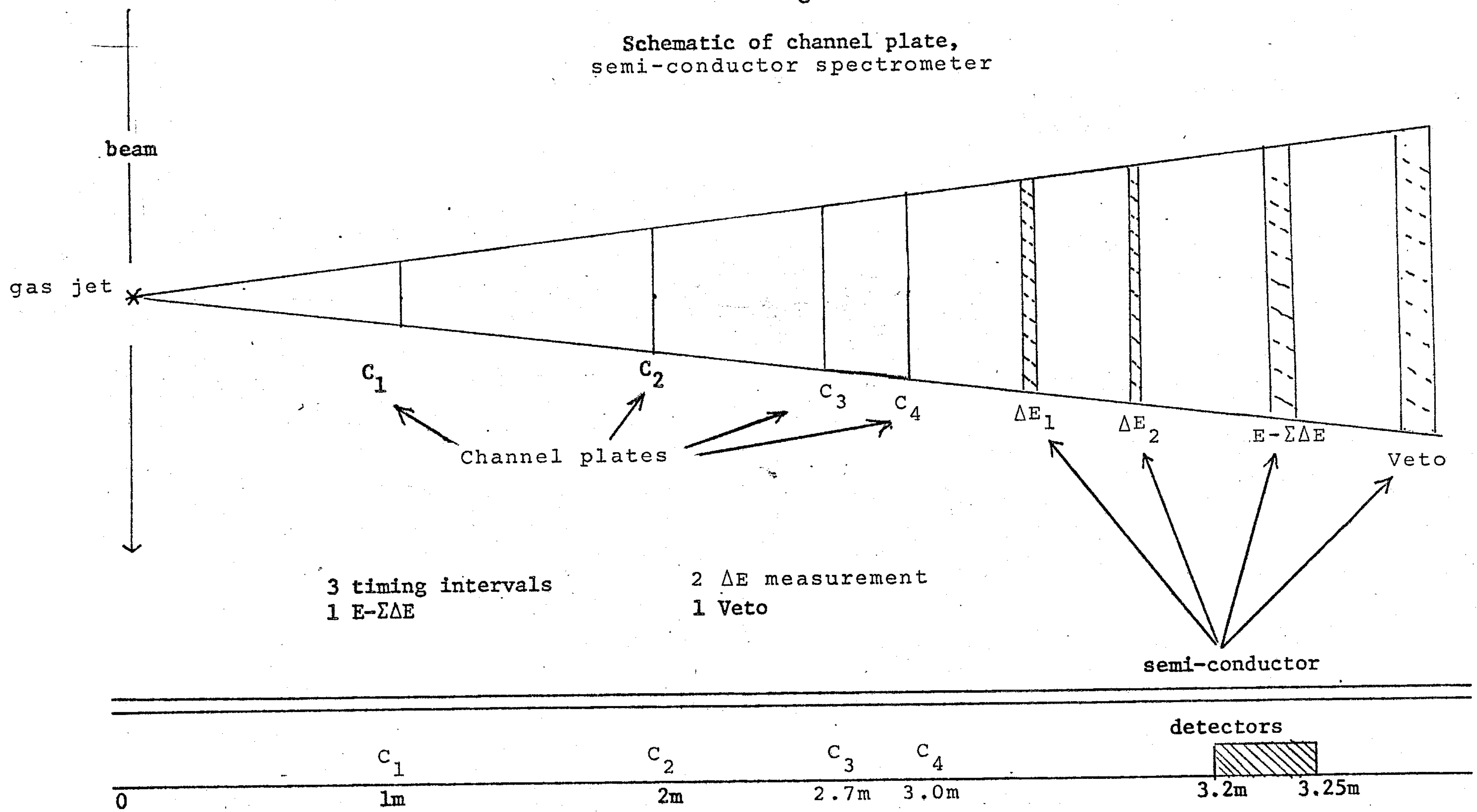


FIG. 5 A

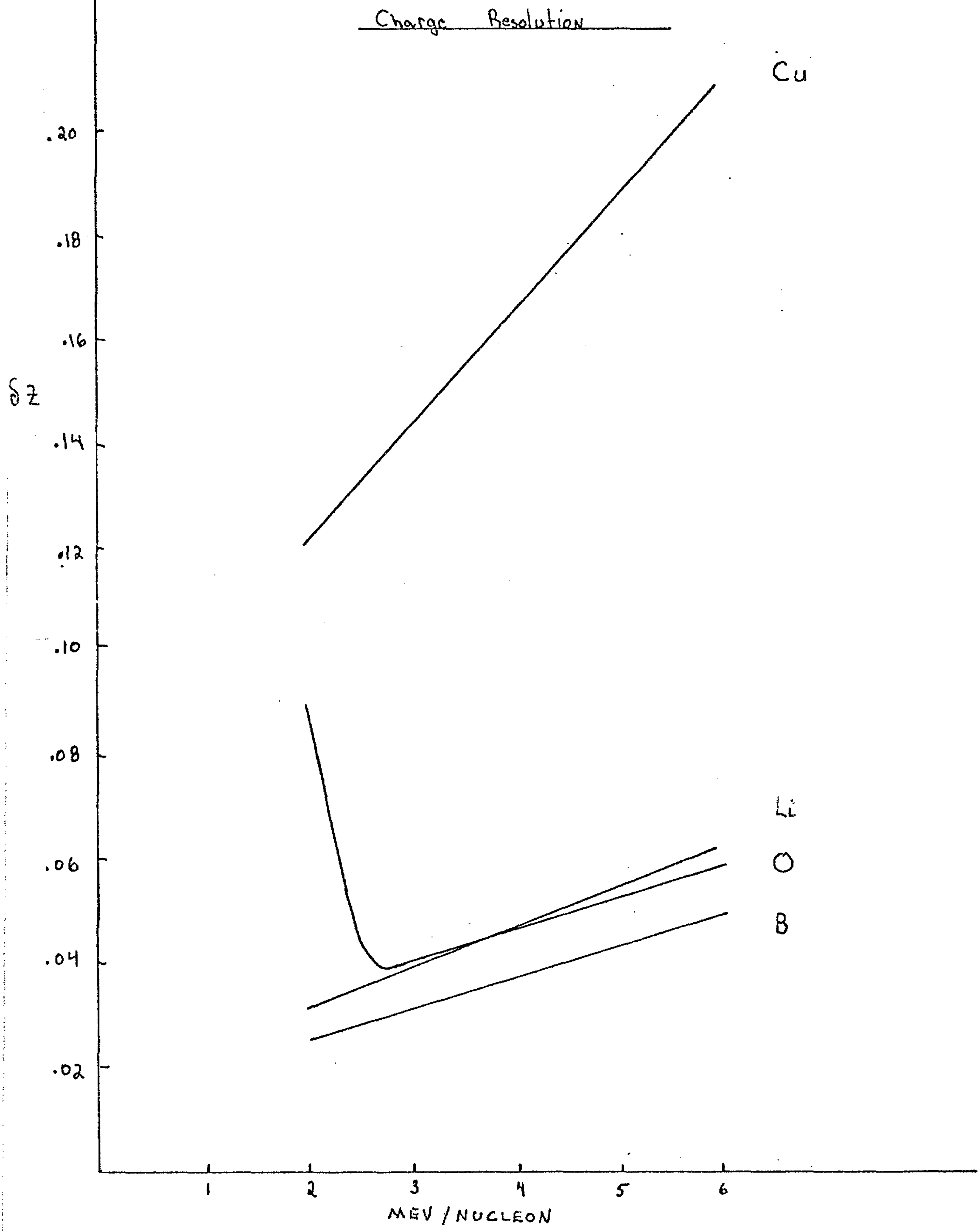
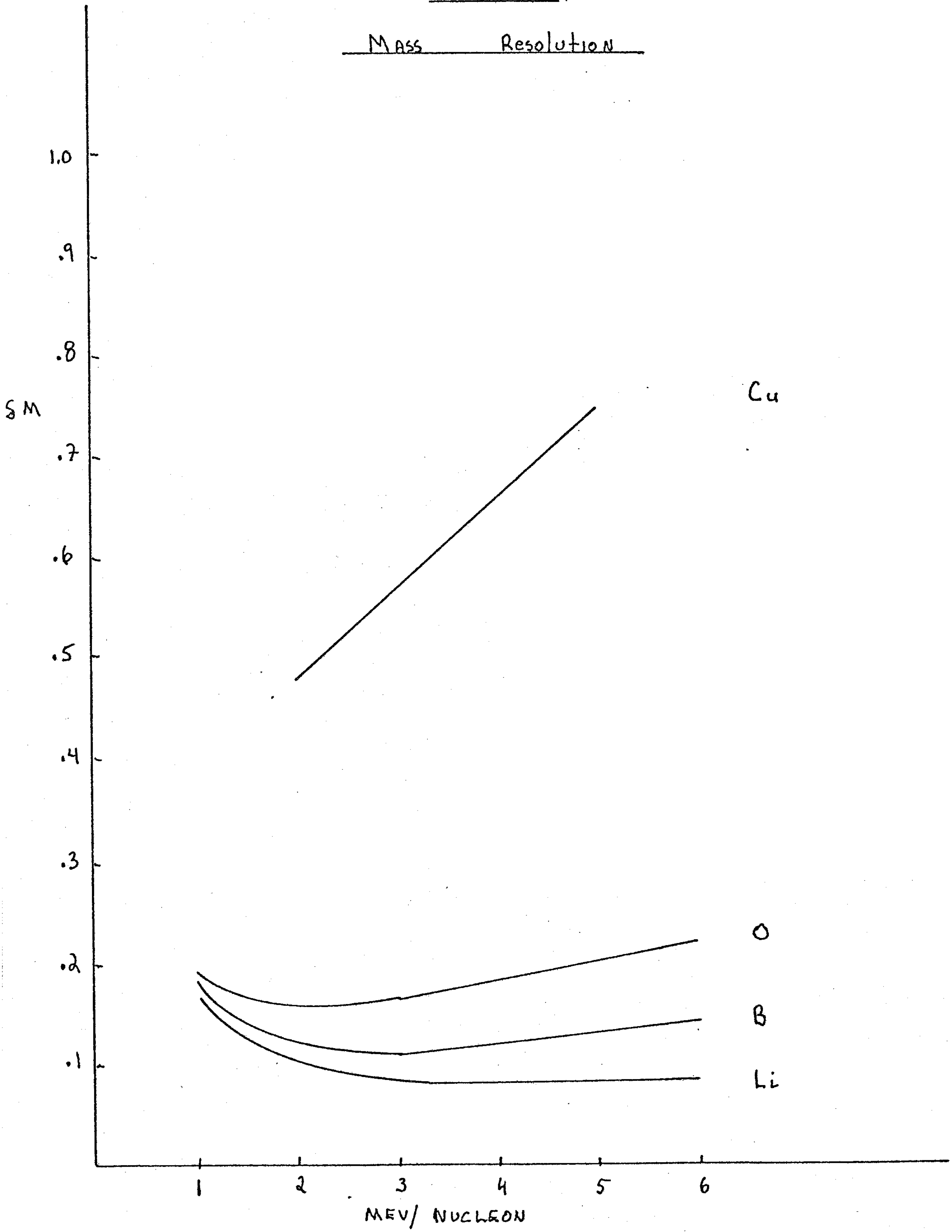
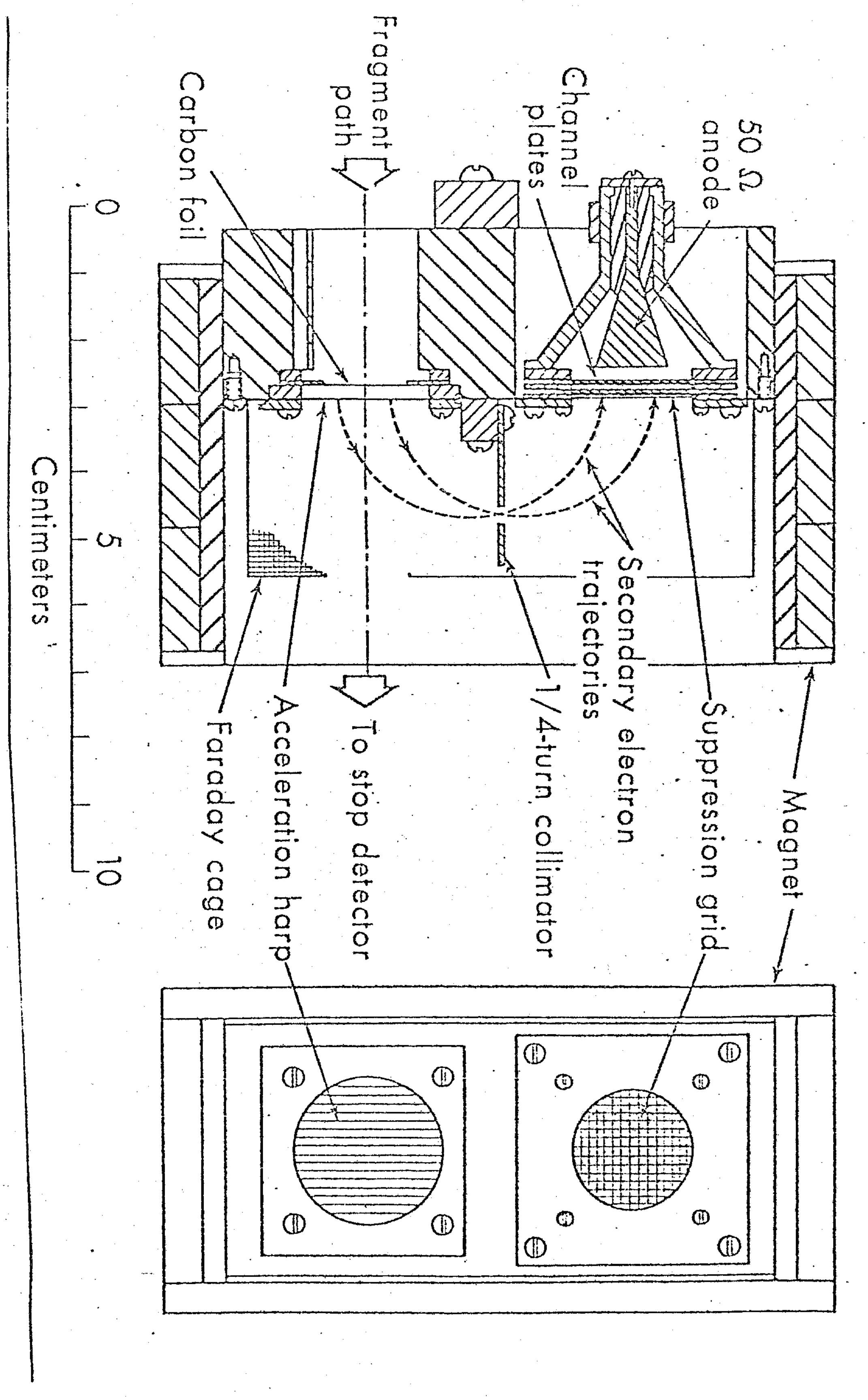

Charge Resolution
Cu
Li
O
B
δZ
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
MEV / NUCLEON

FIG. 5B





50 Ω anode
Channel plates
Fragment path
Carbon foil
0
5
10
Centimeters
Magnet
Suppression grid
Secondary electron trajectories
1/4-turn collimator
To stop detector
Acceleration harp
Faraday cage

Fig. 6

ADDENDA-1 TO PROPOSAL-591

Broad Search for New Hadronic States Via High Resolution Charge and Mass Determination of Nuclear Fragments from p-Nucleus Collisions

Submitted by scientists at:

Purdue University and

Fermi National Accelerator Laboratory

Person to contact: L. J. Gutay

Phone: (317) 749-2961

Date: March 1978

Sensitivity of the Experiment

The range of isotopes which are expected to be stable are shown in Fig. 1. The estimates are based on the Garvey-Kelson mass formula.[1,2,3] The observed experimental limits[4,5,6,7,8] are also indicated on this plot for nuclei $9 < Z < 26$. The estimates for the isotopic yield curves for heavy (Fig. 2), light (Fig. 3) and intermediate mass targets (Fig. 4) are obtained from the most accurate data to date[4,5,6,7]. This high sensitivity diffusion *technique can be used only for alkaline fragments; while our* technique is applicable over a large fragment mass range. Further, we not only can identify a mass peak but also measure its energy distribution, thus gain information on the fragment production dynamics. Next we show that our sensitivity for identification of an isotope is comparable with the above high senstivity alkaline diffusion technique. Using the following input parameters;

Flux of the circulating protons/sec = $2 \times 10^{13} \times 47 \times 10^{3}$/sec

Duration of the jet pulse during a ramp = 2.5 sec

Number of ramps in 400 hours = $400 \times 3600/12$

Solid Angle = $2/(4\pi \times 320^{2})$

M = atomic number

Avogadro's number = 6×10^{23}

and the assumption that 10 clustered events is evidence for a new fragment (Poskanzer criterion) we obtain that our sensitivity (σ) is:

$$\sigma \simeq M \times 7.6 \times 10^{-34} \text{ barn} \qquad (1)$$

Using a Xenon target (M = 131) from equ. 1 we can estimate that the lowest crossection *limit* σ_{limit} where *we can identify a fragment is:*

$$\sigma_{\text{limit}} = 100 \times 10^{-33} \text{ barn} = 100 \text{ nb} \qquad (2)$$

Inspection of Figs. 2-4 reveals that the peak crossections are of the order of

$$\sigma_{peak} = 10 \text{ mb} \quad (3)$$

Thus we can expect to observe an isotope which is

$$\sigma_{limit}/\sigma_{peak} \cong 10^{-5}$$

of the most abundantly produced species. This sensitivity is comparable to the lowest cross sections which has been reported in the literature! As noted earlier, our time of flight approach is also applicable to a much wider range of fragmented nuclei, than the on-line alkaline diffusion technique.[4,5,6,7]

In E442 we examined the background events by studying fragment production backgrounds using an H_2 jet. We found that heavy fragments production ($Z > 2$) was reduced by factors $> 10^4$. This is consistent with the ratio of the residual gas density in the main ring (10^{-7} torr) to the gas jet pressures (10^{-3} torr). For a heavy gas jet this background should also be improved because the fragment cross sections follow the $A_{target}^{2/3}$ law. This suggests an additional factor of 10 in background reduction. Above O^{16} we would expect no contribution from the residual gas. The channel plate trigger systems would provide additional rejection of events induced by ≥ 100 MeV nucleons produced in high energy proton heavy nucleus collisions. We looked for events of this type in E442 where a simple ΔE, E semiconductor telescope was used and found that there were no background events to one part in 10^4.

Time Allocation

We propose to allocate the running time by dividing the experiment into 3 sections. The division is indicated by the event rates for various fragment ranges. Since the individual fragment cross sections vary from ~ 1 barn to 10 mb we propose to divide the fragment range into groups as shown in Table 1. The physics interest also divides in a similar manner. In the

Li → O fragment range we are dealing with copiously produced fragments. If ^{4}He were included the counting rate would be five times higher. The F - Cu range would use the bulk of the requested running time. The total mass spectrum Li → A_T would of course produce the highest event rates. In actuality we would have some overlap in fragment ranges so that the event rate as seen by the PDP-11-45 computer would be higher. When the monitor detector is included the total event rate can exceed 1500 events/sec.

References

1. G. T. Garvey, W. J. Gerace, R. L. Jaffe, I. Talmi, and I. Kelson, Rev. Mod. Phys. 41, 1 (1969).

2. I. Kelson and G. T. Garvey, Phys. Lett. 689 (1966).

3. C. Thibault and R. Klapisch, Phys. Rev. C9, 793 (1974).

4. R. Klapisch, C. Thibault, A. M. Poskanzer, R. Prieels, C. Rigaud and E. Roeckl, Phys. Rev. Lett. 29, 1254 (1972).

5. R. Klapisch, R. Prieels, C. Thibault, A. M. Poskanzer, C. Rigaud and E. Roeckl, Phys. Rev. Lett. 31, 118 (1973).

6. R. Klapisch, Ann. Rev. Nucl. Sci. 19, 33 (1969).

7. J. Chaumont, These Orsay, 726 (1970).

8. J. Cerny and J. C. Hardy, Ann. Rev. Nucl. Sci. 27, 333 (1977).

TABLE 1

Fragment Range	Li → O	F → Cu	Li → ~ A_T
ΔE Configuration	Double semi-conductor	Double gas proportional	None
Target (A_T)	Xe - H_2	Xe - H_2	(Xe,Kr,Ar,Ne,C) - H_2
$\Sigma\sigma_f$	~ 400 mb	~ 150 mb	~1300 mb
Event rate/sec	130	50	400
Total events	~ 1×10^7	~ 1.5×10^7	~ 3.3×10^7
Hours allotted	100	400	100
Physics interest	abnormal fragments	Fragment production dynamics and rare isotopes	Total mass spectrum
Angles	3	3	3

Figure Captions

Fig. 1 The range of isotopes which are expected to be stable are designated by a circle. They are obtained from Refs. 1, 2, 3. The observed experimental limits are shown as squares. The experimental limits are derived from Refs. 4, 5, 6, 7, 8.

Fig. 2 Expected isotopic yield curve from Uranium target for fragments in the Sodium range. The estimate is based on the experimental results of Ref. 4. ΔA denotes the variation of the mass number relative to the most abundantly produced isotope. Proton induced reaction at 24 GeV/c.

Fig. 3 Expected isotopic yield curve from Argon-Krypton targets and fragments in the Potassium range. The estimate is based on the experimental results of Ref. 7. ΔA denotes the variation of the mass number relative to the most abundantly produced isotope. Proton induced reaction at 24 GeV/c.

Fig. 4 Expected isotopic yield curve from Xenon-Tungsten targets for fragments in the Potassium range. The estimate is based on the experimental results of Ref. 7. ΔA denotes the variation of the mass number relative to the most abundantly produced isotope. Proton induced reaction at 24 GeV/c.

Fig. 5 Fragment mass yield curve from Silver target. Proton induced reaction based on radio-chemical data. (Compilation by N. Porile.)

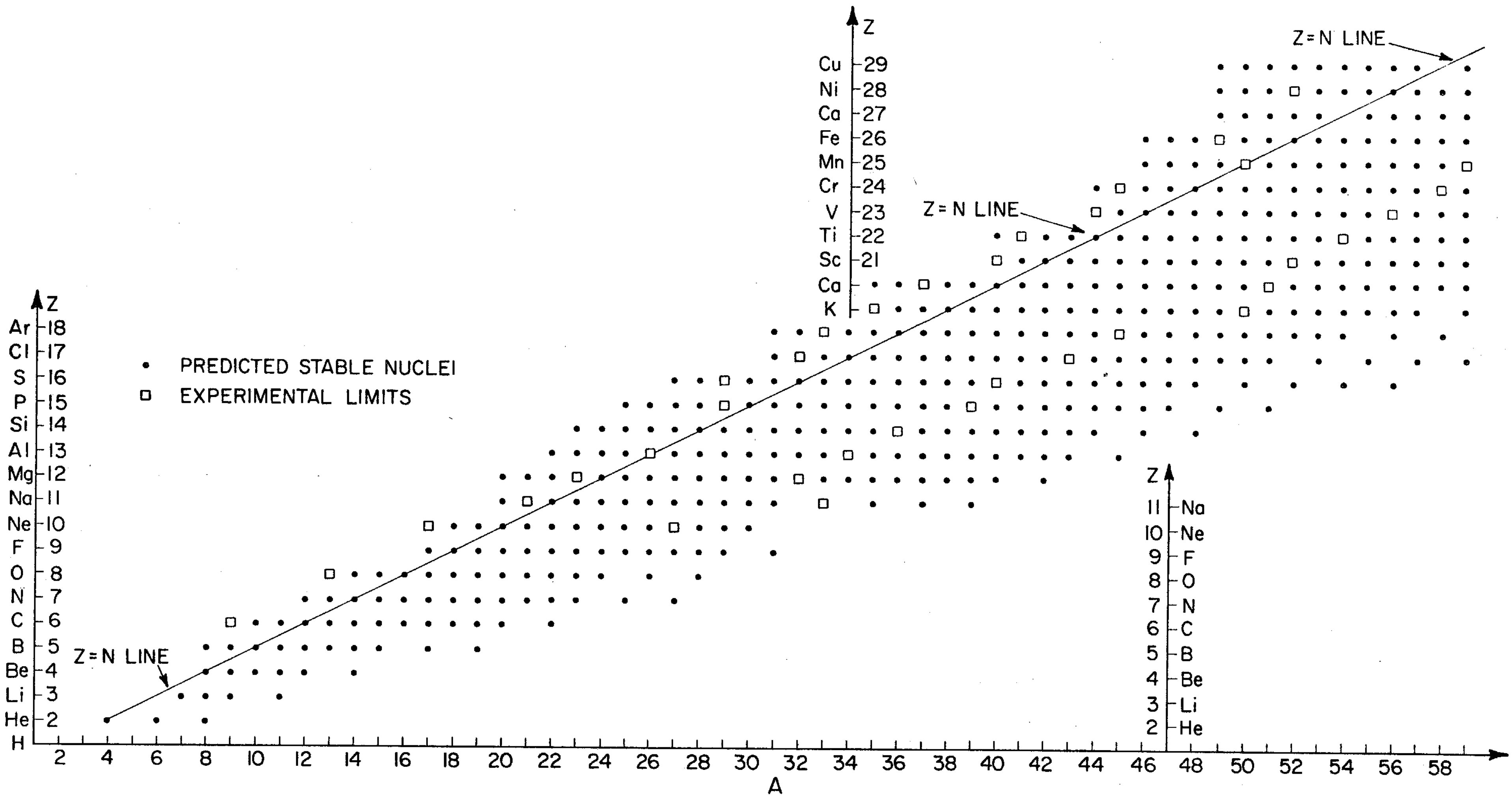
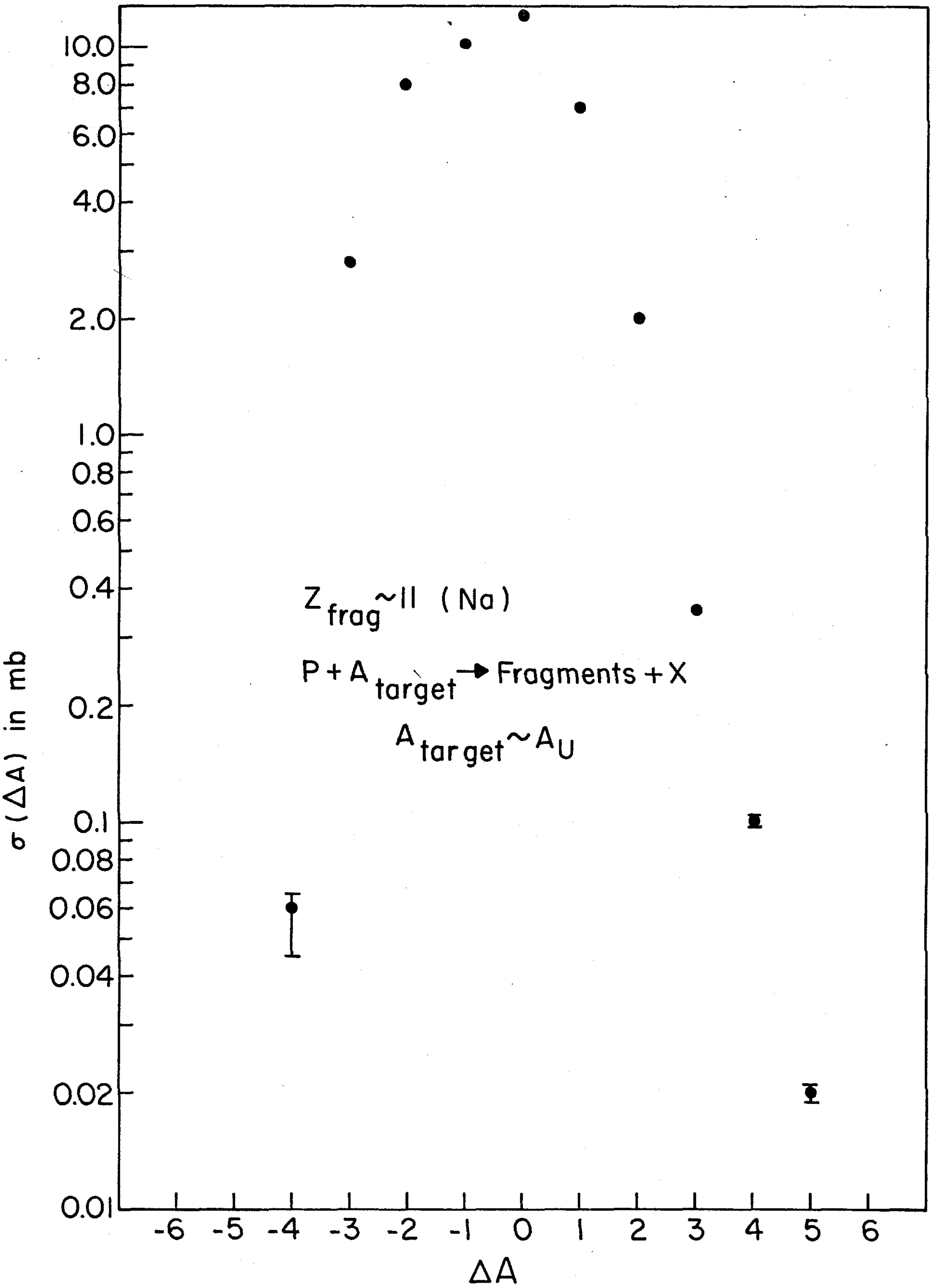
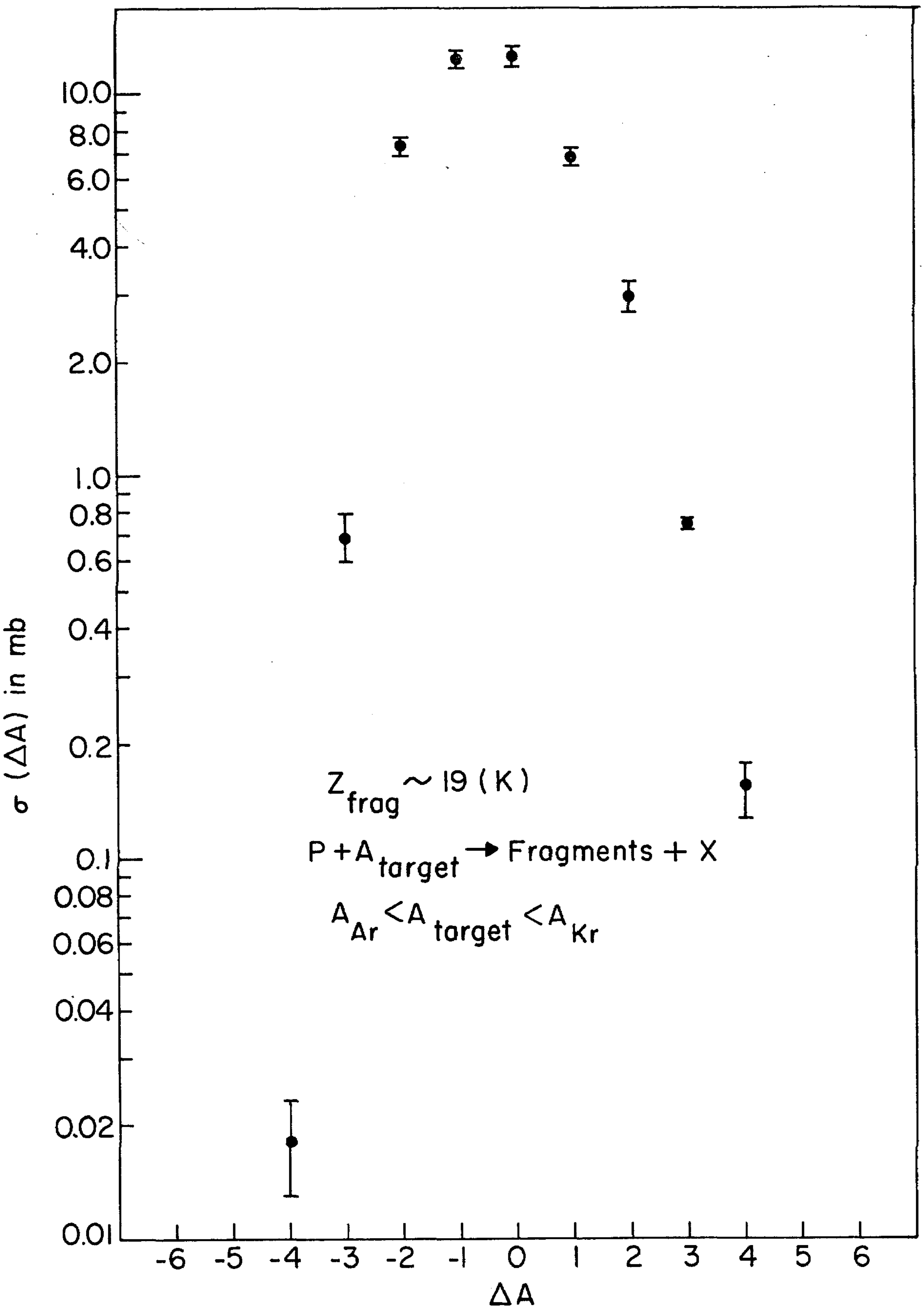

PREDICTED STABLE NUCLEI
EXPERIMENTAL LIMITS
Z=N LINE
Z=N LINE
Z=N LINE
Z
A

Fig. 1



10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
σ (ΔA) in mb
Z_{frag} ~ 11 (Na)
$P + A_{target} \rightarrow$ Fragments + X
$A_{target} \sim A_U$
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
ΔA

Fig. 2



10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
σ (ΔA) in mb
Z frag ~ 19 (K)
P + A target → Fragments + X
A Ar < A target < A Kr
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
ΔA

Fig. 3

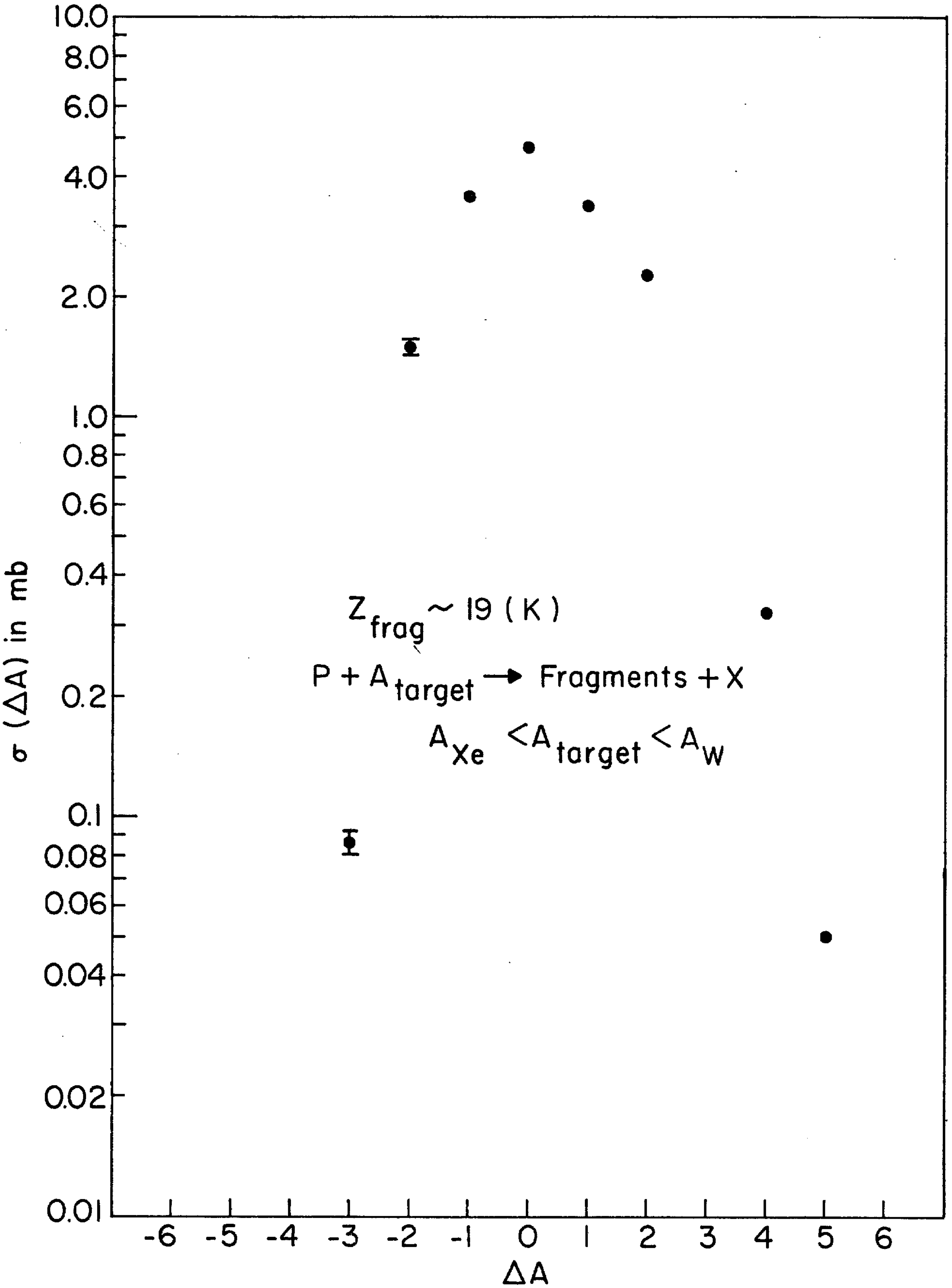

10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
σ (ΔA) in mb
Z frag ~ 19 (K)
P + A target → Fragments + X
A Xe < A target < A W
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
ΔA

Fig. 4

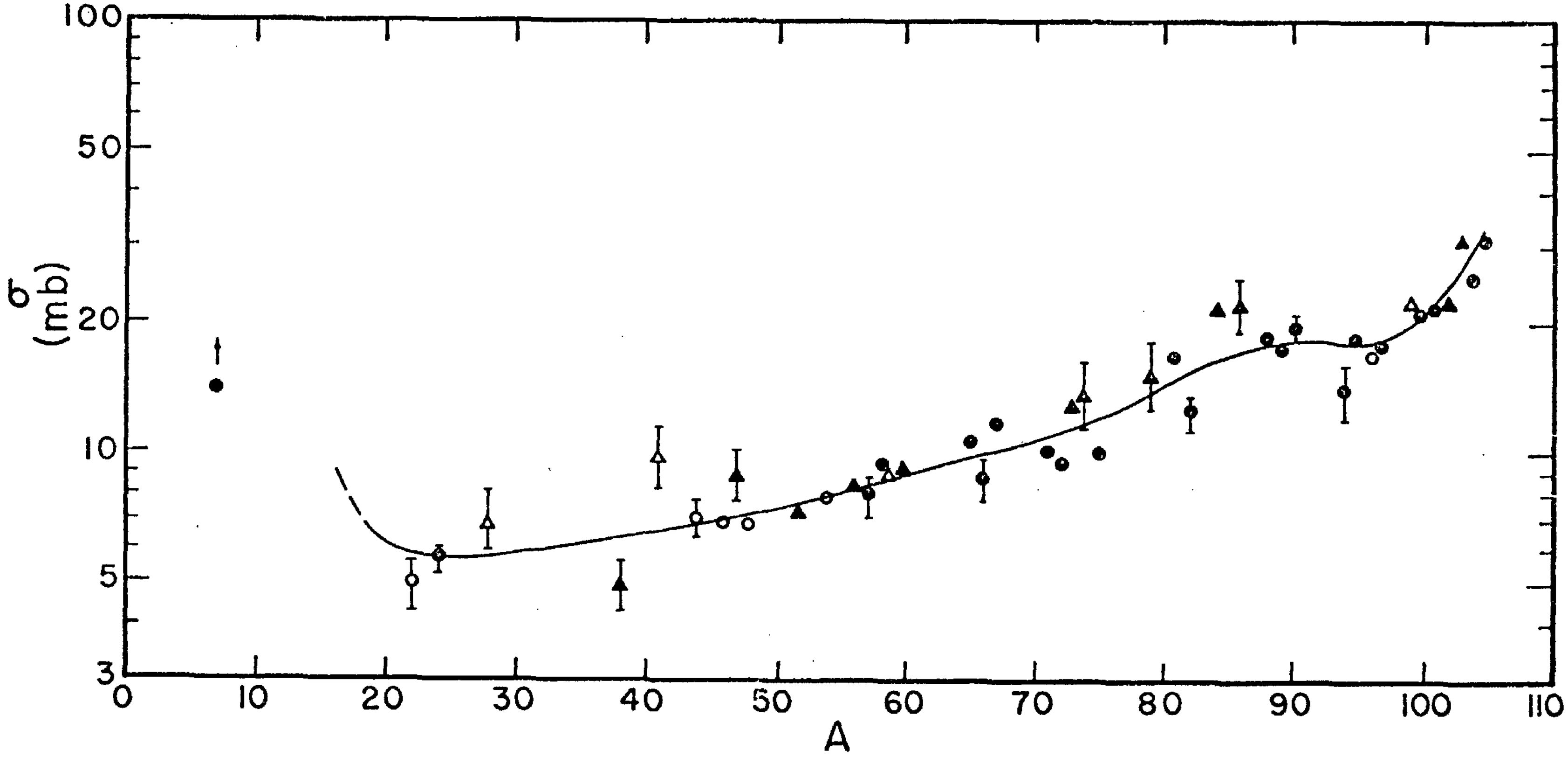


FIG. 5