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CHARGE-EXCHANGE MEASUREMENTS OF MHD ACTIVITY DURING
NEUTRAL BEAM INJECTION IN THE PRINCETON LARGE TORUS,
AND THE POLOIDAL DIVERTOR EXPERIMENT

By

R.J. Goldston, R. Kaita, P. Beiersdorfer,
G. Gammel, D.L. Herndon, D.C. McCune, and D.D. Meyerhofer

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ABSTRACT

The horizontally scanning, multiangle charge-exchange analyzers on the Princeton Large Torus (PLT) and the Poloidal Divertor Experiment (PDX) were used to study the effects of MHD activity on the background ion distribution function and on the beam ion slowing-down process during high-power neutral injection. Sawtooth oscillations were observed in the fast ion flux on PLT and PDX, and measurements with neutral beams providing local neutral density enhancement indicate that ions are transported radially when these events occur. With near-perpendicular injection in PDX, at the lower toroidal fields necessary to maximize beta, rapid, repetitive bursts of greatly enhanced charge-exchange flux were observed. These are associated with the "fishbone" MHD instability, and a substantial depletion of the perpendicular slowing-down spectrum below the injection energy was seen. A simple phenomenological model for this loss mechanism was developed, and its use in simulation codes has been successful in providing good agreement with the data. The behavior and characteristics of this model are well matched by the direct theoretical calculations.

MASTER

1. INTRODUCTION

The horizontally scanning charge-exchange analyzer on PLT measured the fast ion flux along sightlines at four radii of tangency (Fig. 1).[1] The neutral beam injectors were oriented tangentially with respect to the plasma. A similar analyzer existed (with five channels) on PDX,[2] and the layout of the analyzer and the four near-perpendicular heating beams, oriented for co-injection, are shown in Fig. 2. The PDX system had a large aperture geometry, adjustable channel spacings, and faster electronics, permitting up to 50 microsec time resolution, compared to 0.5 msec for the PLT system. A horizontally scanning diagnostic neutral beam was also installed on PDX, and it was capable of injecting neutrals at energies up to 35 keV in the counter direction with the plasma current in its standard orientation.[3] Two additional single-channel charge-exchange analyzers were installed on PDX. The nearly vertical sightlines of the outside (ODE) and inside (IDE) detector skimmed the outer and inner plasma edges, respectively: they were chosen to determine the direction along the major radius that the fast ions were lost during fishbone bursts.[4]

Sawtooth oscillations have been measured previously in the passive (undoped) charge-exchange signal from other tokamaks over a limited range of energy and angle.[5] They were clearly observed in the passive fast neutral flux from beam particles and ions near thermal energies in both PLT and PDX, in directions perpendicular and tangential to the magnetic axis. The PDX analyzer was able to view across one of the near-perpendicular heating beams, and the local neutral density enhancement (doping) allowed us to observe "upright" and "inverted" sawtooth oscillations inside and outside a resonant surface, respectively.

In the low q , high beta regime in PDX, bursts of greatly enhanced charge-exchange flux occurred in the perpendicular direction every 2 to 3 msec in conjunction with the "fishbone" MRD oscillations, and the near perpendicular slowing-down spectra under these conditions often showed substantial depletion below the injection energy.[6] Of the two vertically viewing analyzers, furthermore, only ODE typically detected large, periodic signals when fishbones occurred,[4] an observation consistent with the White model.[7] These bursts were not seen at higher toroidal fields and plasma currents or lower beam powers. Repetitive bursts of neutrals were also found during H-mode discharges, correlated with " H_{α} -spikes" or "Edge Relaxation Phenomena" (ERP's),[8] but they were generally of lower amplitude. In contrast to the charge-exchange signals associated with fishbones, they were isotropic in angular dependence, and did not cause the loss of beam particles observed during the high beta experiments.[9] Monte-Carlo beam orbit calculations, which included a phenomenological "loss-cone" model to account for the observed loss of energetic ions, were performed, and the results were in good agreement with the data.

2. SAWTOOTH OSCILLATIONS

Sawtooth oscillations were observed in the undoped flux of charge-exchange neutrals from beam and thermal plasma ions, in both the parallel and perpendicular direction, in PLT and PDX. One of the clearest examples of this phenomenon with beam ions occurred when the horizontally scanning diagnostic neutral beam was used to counter-inject 27 keV deuterium neutrals into a low density deuterium plasma with electron cyclotron harmonic (ECH) heating. The injection was tangential to the magnetic

axis, and since the density was low, the charge-exchange neutrals detected along closely spaced sightlines were largely from the point of closest approach to the center of the plasma. During the period of ECH heating in this discharge, strong electron temperature sawteeth were observed, and "up" and "down" sawtooth oscillations were measured along two adjacent tangential sightlines. This demonstrated that the parallel moving beam ions were rapidly transported during each sawtooth event (Figs. 3 and 4), with the drop in the charge-exchange signal occurring within 200 microsec.

The neutral beam injectors on PDX were oriented near-perpendicular to the plasma, and the trajectory of the neutrals from the Northwest beamline crossed the sightlines of the analyzer (Fig. 2). The effect of this local enhancement of the neutral flux ("doping") is evident in Fig. 5, which shows the difference in the flux between the time this beam is on and off. The beam faulted in this shot at 385 msec.

Using this capability of making local measurements, charge-exchange neutrals were observed at energies up to approximately twice the ion temperatures of PDX plasmas heated with near-perpendicular neutral beams. At a minor radius near the plasma center, the sawtooth oscillations were "upright" (Fig. 6), but near the plasma edge (Fig. 7), they were clearly inverted as in the preceding case of tangential injection (Fig. 3). Expanded views of the "up" and "down" sawteeth with time are shown with Figs. 8 and 9. The time lag between the fall of the "inside" signal and the rise of the "outside" signal is on the order of 100 microseconds or less. This time corresponds to approximately 11 circumnavigations of the torus by 4.2 keV protons. Fig. 10 displays the 5 kilohertz precursor oscillation that occurred before the sawtooth drop. These results provide unambiguous evidence for the participation of parallel

moving ions at near thermal energies in all aspects of sawtooth activity, including the high frequency oscillations which precede the fall in signal at the sawtooth event.

The neutral beam injectors on PLT were oriented tangentially with respect to the plasma, and data were obtained with the analyzer sightlines varying from parallel (near the injector tangency radius of 124 cm) to more perpendicular ($R_{can} = 42$ cm) to the magnetic axis. Deuterium neutral beams were injected into a hydrogen plasma, and in this "undoped" tangential injection case, large amplitude sawtooth oscillations were again seen in the charge-exchange flux. The 17 keV signal from the parallel moving beam ions is shown in Fig. 11, and the data from the more perpendicular analyzer position is displayed in Fig. 12. Similar results were obtained with an undoped perpendicular view on PDX with perpendicular injection.

In both cases, the charge-exchange flux appears to exhibit inverted sawtooth oscillations, since these passive signals at moderate plasma densities are weighted toward the region of higher neutral density near the plasma edge. The near-perpendicular data are similar to those obtained at tangential angles, and the transport of parallel-moving ions was demonstrated on PDX (as discussed above) with doping beam measurements. Therefore, the simplest interpretation for the signal from ions with a large perpendicular velocity component is that they are also transported during sawtooth events.

3. HIGH BETA STUDIES

The experimental program on PDX had the maximizing of "beta," or the ratio of the plasma pressure to the magnetic pressure, as one of

its main objectives. Up to 8 megawatts of near-perpendicular neutral beams were available in PDX, and at values of β_{Tq} above 0.045, the onset of an MHD instability that was accompanied by rapid, periodic bursts of fast neutrals was observed.[6]

Fig. 13 shows the raw charge-exchange signal as a function of time at a near-perpendicular angle ($R_{tan} = 20$ cm). The detection energy was held constant at 44 keV, and a strong depletion after each spike, followed by a recovery, is seen. The integration time was 100 microseconds. The spike at 542 msec was a sawtooth, and in general, the first "pure" fishbones after a sawtooth are weaker than those which precede it. These spikes have a strong angular dependence as shown in Fig. 14. The final spike at 505 msec, which is approximately the same at all angles, corresponds to the disruptive termination of the discharge. The flux was clearly highest along the most perpendicular sightline (Fig. 14a), and both the spike and the depletion of the signal after each fishbone burst are no longer evident along the most tangential view (Fig. 14d).

In H-mode discharges, bursts of fast neutrals correlated with spikes in the hydrogen Lyman- α (H_{α}) emission (ERP's)[8], were observed (Fig. 15). Unlike fishbones, however, these fast neutral bursts did not have any detectable internal structure. In addition, their size relative to the background signal was consistent with the variation in the neutral density as reflected in the magnitude of the H_{α} spikes. The fast neutral bursts correlated with ERP's also do not have a significant angular dependence (Fig. 16), and are thus most likely associated with neutral hydrogen density fluctuations. Since they were not correlated with substantial depletion of circulating beam ions, they do not appear to be a manifestation of a significant fast ion transport mechanism.

The fishbones caused a depletion of the slowing-down spectrum between

the full beam injection energy and half the injection energy and only at near-perpendicular angles (Fig. 17). The spikes in the experimental slowing-down spectrum (solid line) do not imply that the fishbone bursts occurred only at the distinct energies shown. To obtain the spectrum, the plate voltage of the electrostatic analyzer, and hence the energy of the measured ions, were swept as a function of time, and the spikes coincided with the energy the analyzer was set to detect at the particular time in the sweep. The dashed lines are from simulations which will be discussed in the next section.

We interpret this data to imply that near perpendicular beam ions, between the full injection energy and above half of this value, are ejected by the mechanism described by White and coworkers.[7] Once outside the plasma, they constitute a very unstable energetic distribution, subject to ion cyclotron instabilities.[10] These instabilities are believed to be responsible for the acceleration of ions above the injection energy and the presence of bursts in the flux below half the injection energy. Since fast ions well above the injection energy are detected with the ODE analyzer at $B(R_0 + a) < B(R_0)$, [4] such a non- μ -conserving mechanism is required for fast ions to be accelerated to these high perpendicular energies.

4. DISCUSSION

The features of the ion sawtooth oscillations are analogous to those explained by Kadomtsev for the electrons.[11] The inversion from "up" to "down" oscillations at minor radii beyond a resonant surface is seen, as are the 5 kHz precursor oscillations before the "crash." (The high frequency of this oscillation is associated with beam-driven plasma

rotation.) This fall time, which was typically 100 to 200 microsec in PDX, is consistent with measurements from the electron cyclotron emission (ECE)[12] and X-ray diode array diagnostics. The corresponding sharp rise in the signal outside the resonant surface was clearly detectable along the outermost analyzer sightline in PDX (Fig. 7 and 9). Since this is approximately five centimeters from the plasma edge, it suggests a "mixing radius" for these thermal ions that extends across most of the plasma during sawtooth events. The edge $q_{\text{cylindrical}}$ in this discharge was 2.53.

The effects of fishbones on fast ions were first simulated using a loss cone model (Fig. 18) in the bounce-averaged Fokker-Planck code. The loss cone boundaries deduced were consistent with the predictions of the theory for the instability,[7] as was the fact that the cone needed to be "opened" every 2 or 3 msec to simulate the data. All ions with energies between the injection energy (47 keV) and three-quarters of this energy (35 keV) were lost when this event occurred. The results showed many similarities with experiment, both in the degree of the depletion and the phase relations of the signals at different energies, which are associated with the finite slowing-down time of the beam ions. The 44 keV flux rises (Fig. 19a) until the fishbone occurs (shaded region) and subsequently drops. The 32 keV signal, however, is lower prior to the event than after it (Fig. 19b). The reason for this is that fishbone losses directly cause oscillations in the beam ion distribution (f_b) at 44 keV, which is within the loss cone (Fig. 18). Since it takes a finite amount of time for these ions to slow down to 32 keV, the rise and fall of f_b at this energy are shifted with respect to the variations in the 44 keV ions. They thus differ in their timing relative to the fishbone spikes, which are also evident at 32 keV (Fig. 19b). These

bursts are presumably due to particles expelled at higher energies, but shifted down in energy by $W_{\perp} \propto B \propto 1/R$ as they escape.

The simulations (dashed lines in Fig. 19), which did not include a model for the large increase in signal at each fishbone (shaded area), show the same time behavior as the experimental data. The energy range of the depletion was constrained to be between the full energy and three-quarters of this energy, in accordance with fishbone theory.[7] This model was then incorporated into the Monte-Carlo beam orbit calculation in the Princeton transport analysis code TRANSP,[13,14] and comparing the two broken curves in Fig. 17, the agreement with the measured spectra is improved. Indeed, the depletion is slightly overestimated, so an assumption of somewhat less than the almost 100% efficiency of ion expulsion used in the TRANSP calculation is more appropriate. The fluctuations in the simulations in both of these figures are from Monte-Carlo statistics, and are not due to any attempt to follow the fishbone structure in the experimental data.

5. CONCLUSIONS

Radially resolved charge-exchange measurements were made in PLT and PDX plasmas that exhibited a variety of MHD activity. The time behavior of the tangential and perpendicular fast ion flux during sawtooth oscillations suggests that these particles participate directly in these events in essentially the same manner as electrons.

Fast ion losses were also observed during fishbone activity in PDX and PBX. The theory for this phenomenon predicts the energies and time intervals at which the bursts occur, and these have been included in Fokker-Planck codes through a phenomenological loss cone which expels

ions at the fishbone period. Using this model improves the agreement between the simulated and experimental slowing-down spectra. In contrast, bursts in the charge-exchange flux that are correlated with ERP's are most probably associated with hydrogen neutral density fluctuations, and are not related to any depletion of circulating beam ions.

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REFERENCES

- [1] Goldston, R. J., Phys. Fluids 21 (1978) 2436.
- [2] Kaita, R., Goldston, R. J., Meyerhofer, D. D., Eridon, J.,
Rev. Sci. Instrum. 52 (1981) 1975.
- [3] Nudelman, A., Goldston, R., Kaita, R., J. Vac. Sci. Technol. 20
(1982) 1218.
- [4] Beiersdorfer, P., Kaita, R., Goldston, R. J., Nucl. Fusion 24
(1984) 487.
- [5] Grigor'ev, A. V., Kislyakov, A. I., Shchemelinin, S. G., Kardon,
B., and Petravic, G., Sov. J. Plasma Phys. 9 (1983) 80.
- [6] McGuire, K., Goldston, R. J., Bell, M., Bitter, M., Bol, K.,
et al., Phys. Rev. Lett. 50 (1983) 891.
- [7] White, R. B., Goldston, R. J., McGuire, K., Boozer, A. H.,
Monticello, D. A., Park, W., Phys. Fluids 26 (1983) 2958.
- [8] Fonck, R., Beiersdorfer, P., Bell, M., Boyd, D., Buchenauer, D.,
et al., Proc. 4th Int. Symp. on Heating in Toroidal Plasmas,
Rome, Italy, (March, 1984), ed. H. Knoepfel and E. Sindoni,
Vol. I, p. 37.

- [9] Kaita, R., Goldston, R. J., Beiersdorfer, P., Herndon, D. L.,
Kaye, S. M., et al., Nucl. Fusion 25 (1985) 939.
- [10] Buchenauer, D., Ph. D. Thesis, Princeton University (1985)
unpublished.
- [11] Kadomtsev, B. B., Sov. J. Plasma Phys. 1 (1975) 389.
- [12] Cavallo, A., private communication.
- [13] Hawryluk, R. J., "An Empirical Approach to Tokamak Transport,"
in Course on Physics of Plasma Close to Thermonuclear Conditions,
Varennna, Italy (1979).
- [14] Goldston, R. J., McCune, D. C., Towner, H. H., Davis, S. L.,
Hawryluk, R. J., Schmidt, G. L., J. Comput. Phys. 43 (1981) 61.

FIGURE CAPTIONS

1. Schematic of PLT, showing the direction of injection for the three neutral heating beams and the orientation of the horizontally scanning charge-exchange analyzer. (82X0325)
2. Layout of PDX, showing the relative positions of the four near-perpendicular neutral beam injectors and the horizontally scanning neutral particle analyzer (five sightlines not shown). (81X0483)
3. "Normal" sawtooth oscillations in the flux of 27 keV charge-exchange neutrals at a minor radius of 5 cm, measured along a tangential sightline in PDX ($R_{tan} = 135.0$ cm). (85X1481)
4. "Inverted" sawtooth oscillations in the flux of 27 keV charge-exchange neutrals at a minor radius of 17 cm, measured along a tangential sightline in PDX ($R_{tan} = 122.7$ cm). (85X1480)
5. Loss of beam "doping" after the Northwest neutral beam faulted on PDX. (82X0257)
6. "Normal" sawtooth oscillations in the 4.2 keV charge-exchange flux during neutral beam injection on PDX. (82X0227)
7. "Inverted" sawtooth oscillations in the 4.2 keV charge-exchange flux during neutral beam injection on PDX. (82X0226)

8. Expanded view of one of the sawtooth oscillations shown in Fig. 6.
(82X0224)
9. Expanded view of one of the sawtooth oscillations shown in Fig. 7.
(82X0223)
10. Example of rapid precursor oscillations prior to a sawtooth in a PDX plasma. (81X1272)
11. Flux of 17 keV neutrals measured along a tangential sightline during neutral beam injection (three beams) on PLT. (82X0327)
12. Flux of 17 keV neutrals measured along a near perpendicular sightline during neutral beam injection (three beams) on PLT. (85X1478)
13. Flux of 44 keV neutrals as a function of time during fishbone activity in PDX. The injection energy was 45 keV. (82X0679)
14. Flux of 44 keV neutrals as a function of time along sightlines from (a) near perpendicular ($R_{\text{tan}} = 14.8$ cm) to (d) tangential ($R_{\text{tan}} = 62$ cm) in the presence of fishbone activity. The injection energy was 45 keV. (85X2094)
15. Comparison between bursts in the charge-exchange flux correlated with a fishbone and a spike in the H_{α} emission. (83X0565)

16. Comparison between the angular dependence of the signal during a fishbone burst (right) and a spike in the H_{α} emission (left). The tangency radii were (a) 14.8 cm and (b) 20 cm. (85X2092)

17. Slowing-down spectrum from the most perpendicular analyzer channel ($R_{\text{tan}} = 14.8$ cm) during near-perpendicular deuterium injection (four beams) in a hydrogen PDX plasma. The dashed and dotted curve is from a TRANSP simulation without the phenomenological fishbone loss model, and the dashed curve is from a calculation that included fishbone losses. (86X0877)

18. Illustration of the phenomenological fishbone loss cone in phase (velocity) space. (83X0247)

19. Flux of (a) 44 keV and (b) 32 keV charge-exchange neutrals measured during fishbone activity (solid lines). A loss cone that was "opened" every few milliseconds to simulate the fishbone loss mechanism was used in the calculation (dashed lines). (86X0580)

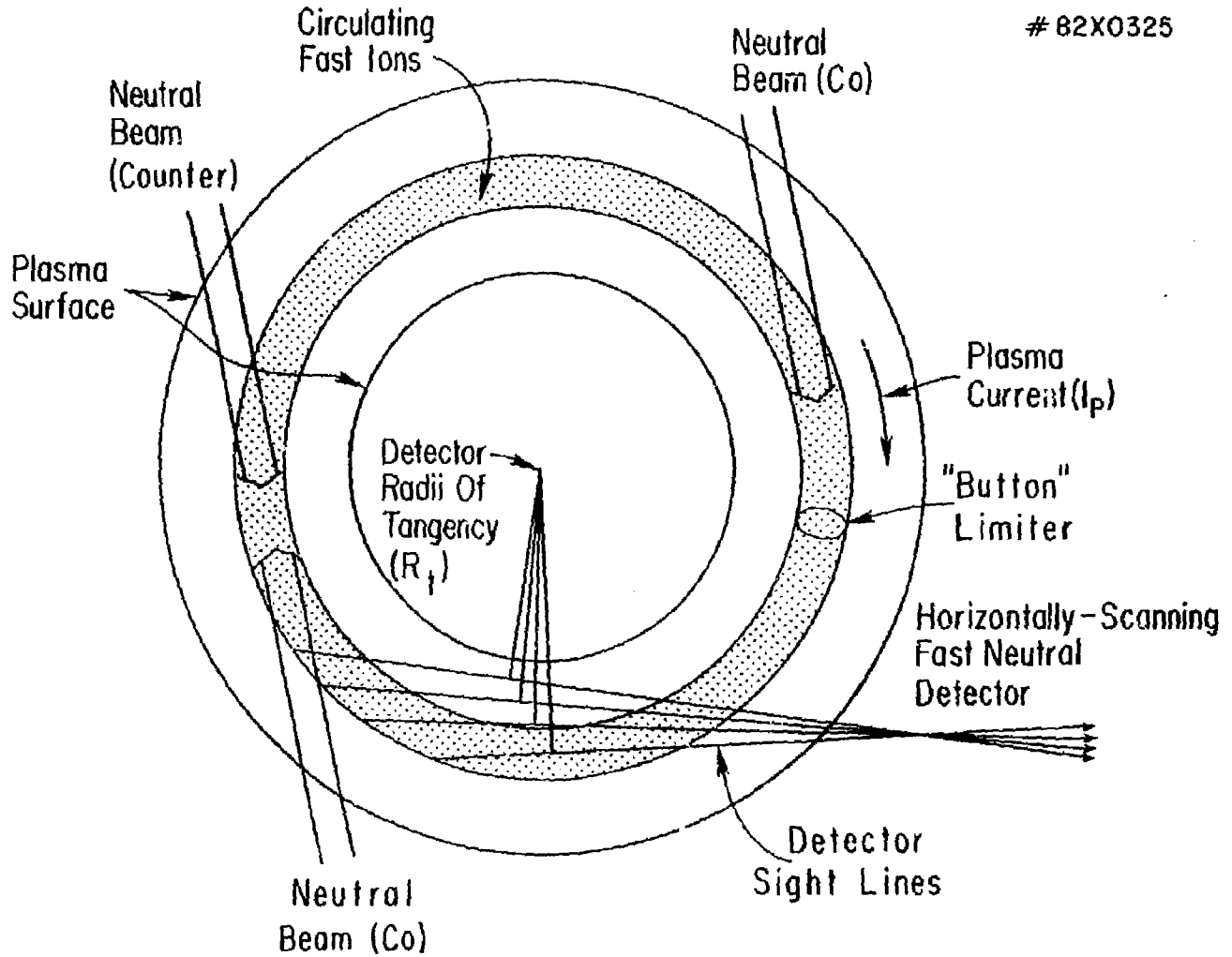


Fig. 1

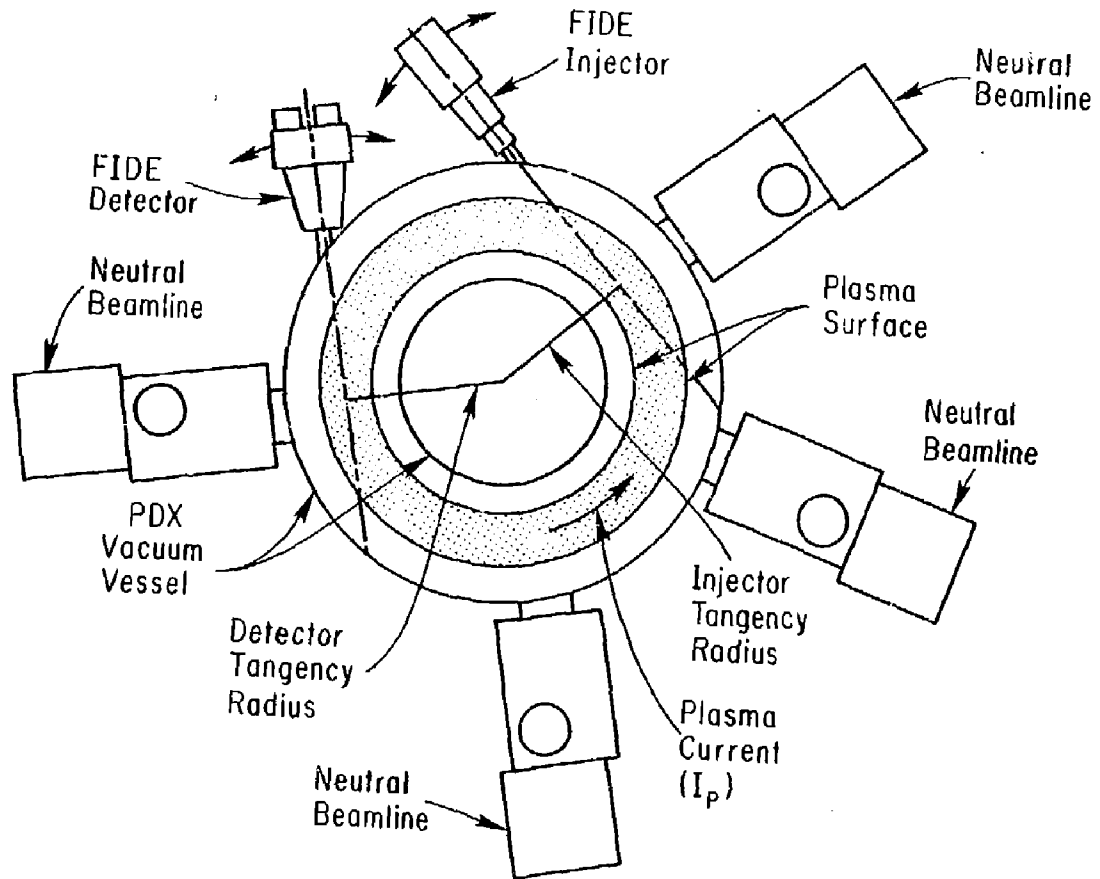


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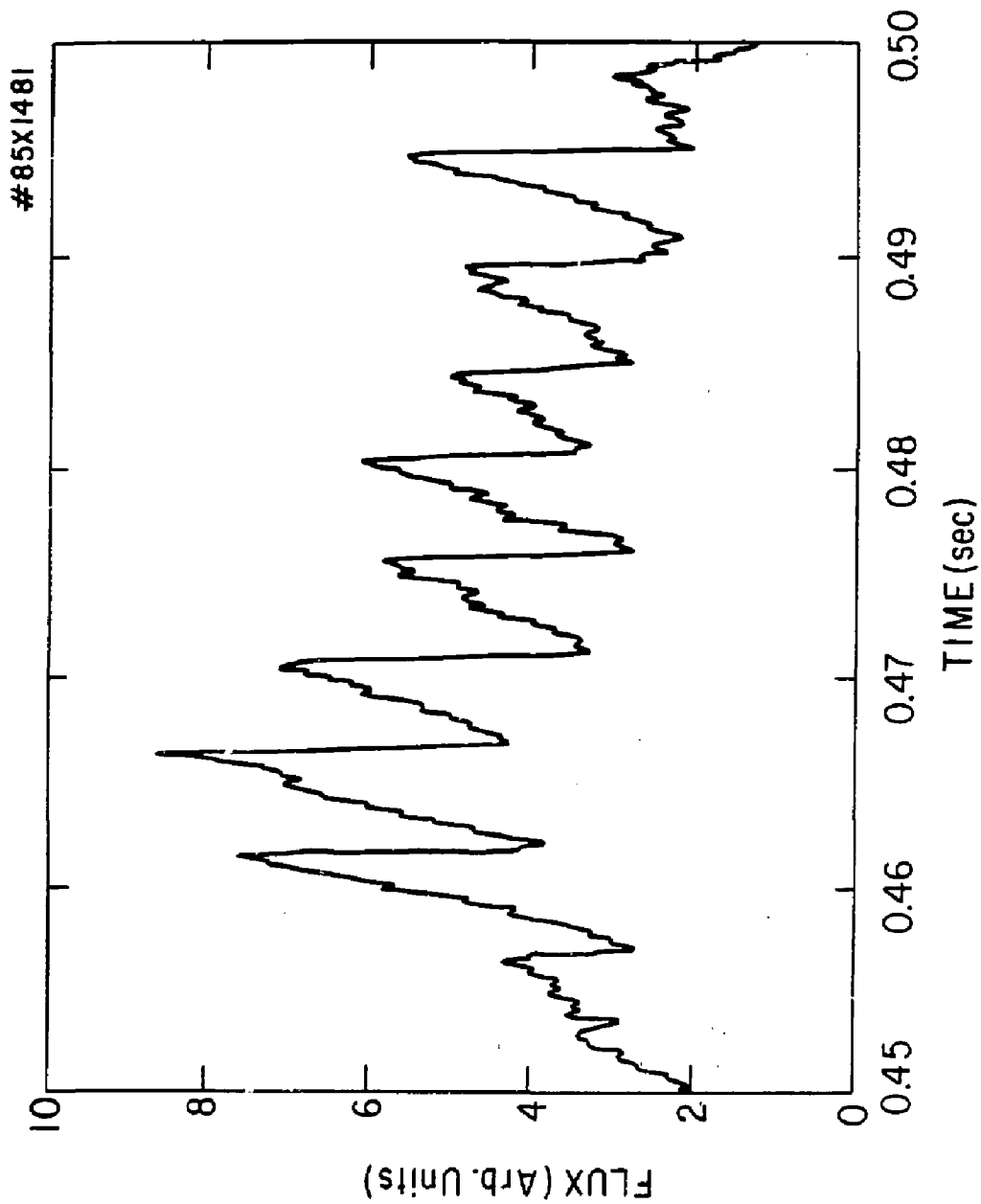


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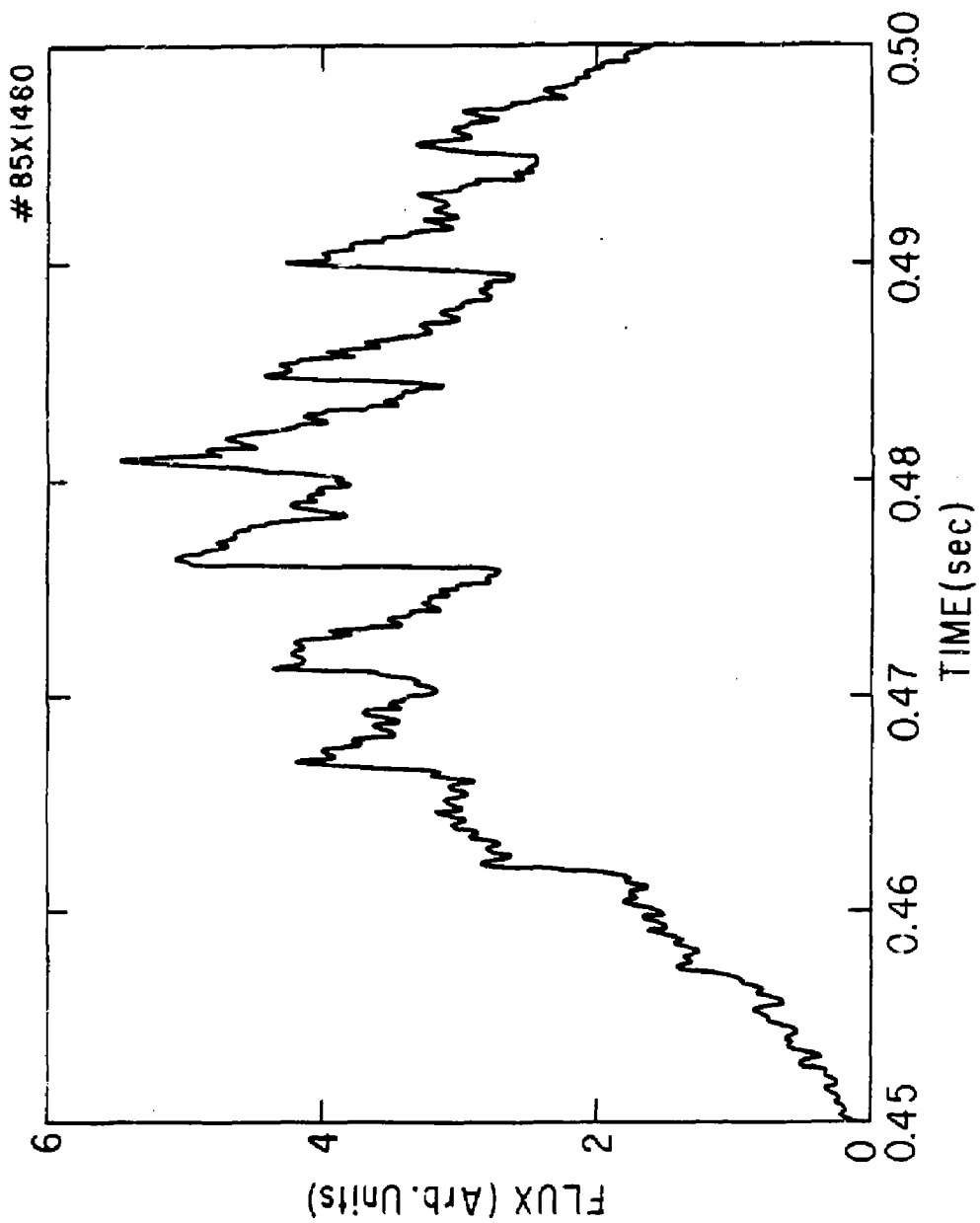


Fig. 4

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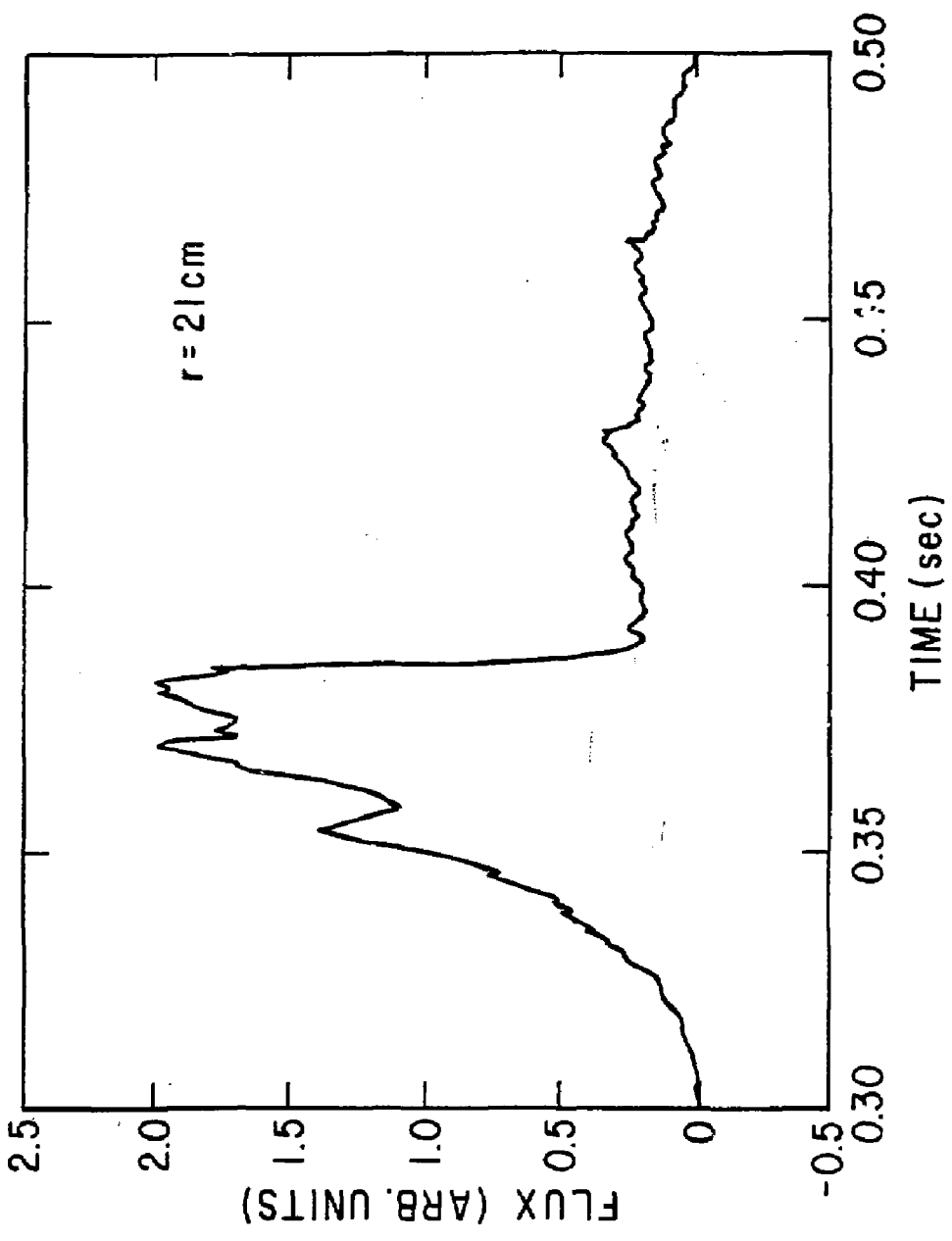


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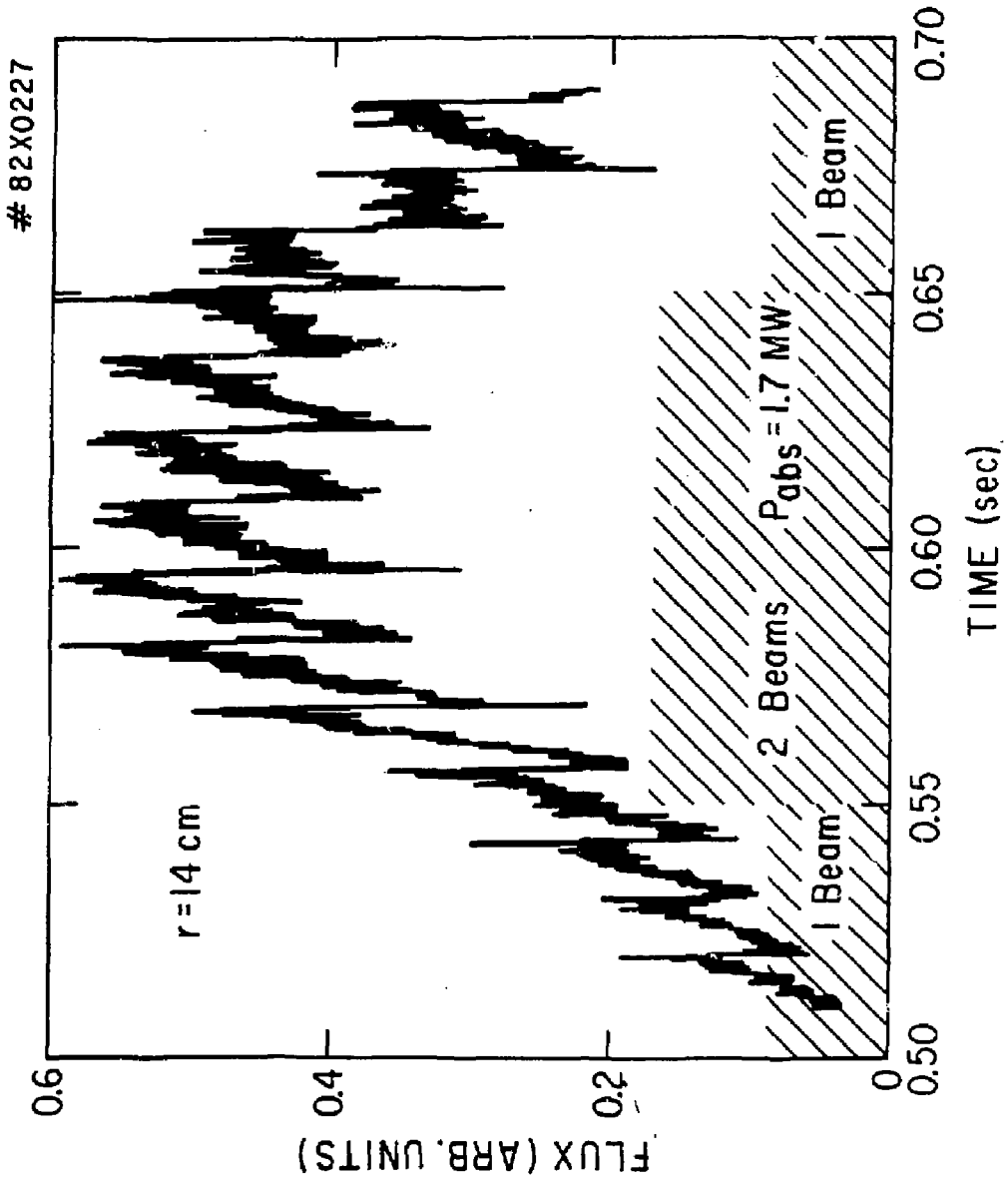


Fig. 6

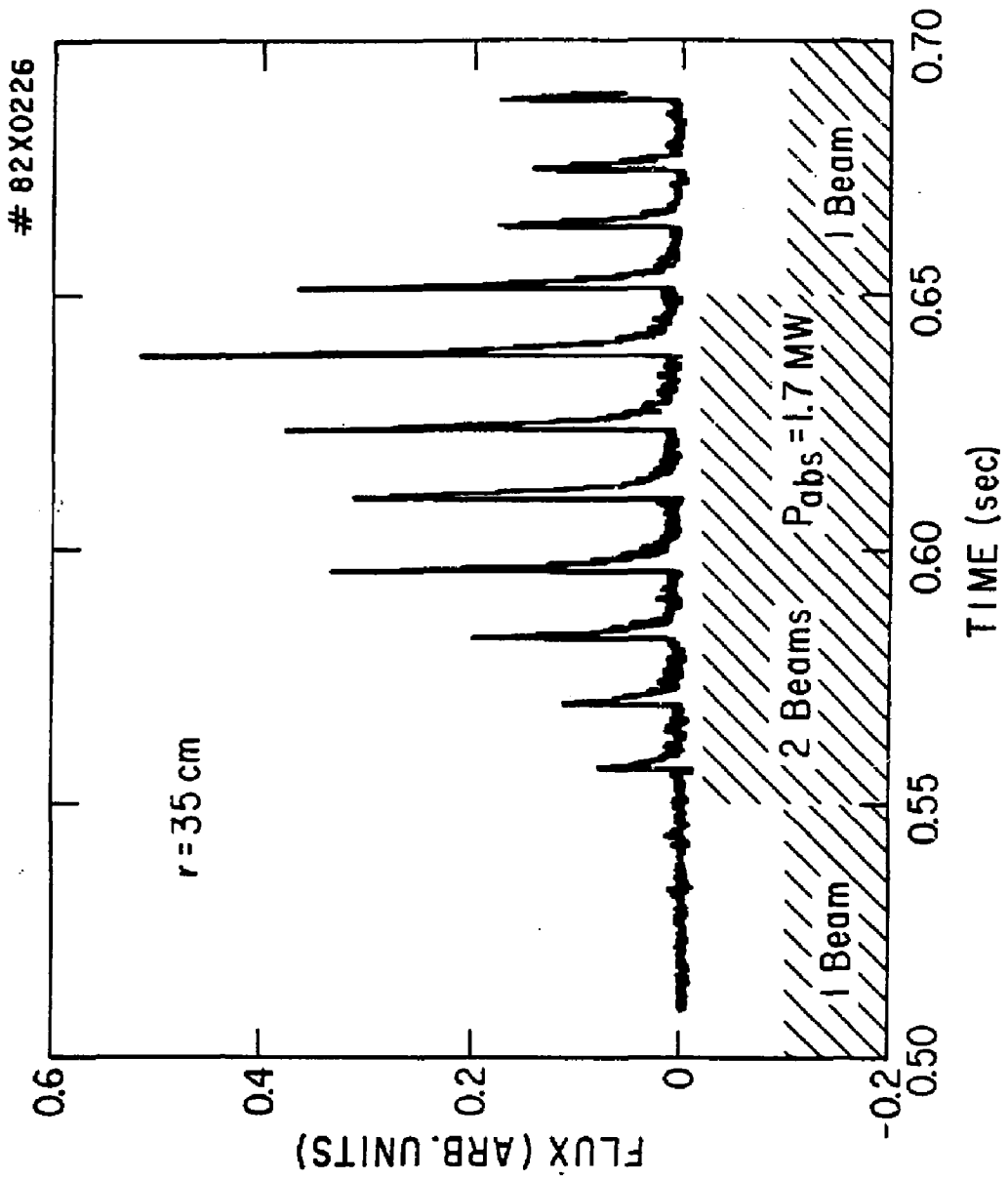


Fig. 7

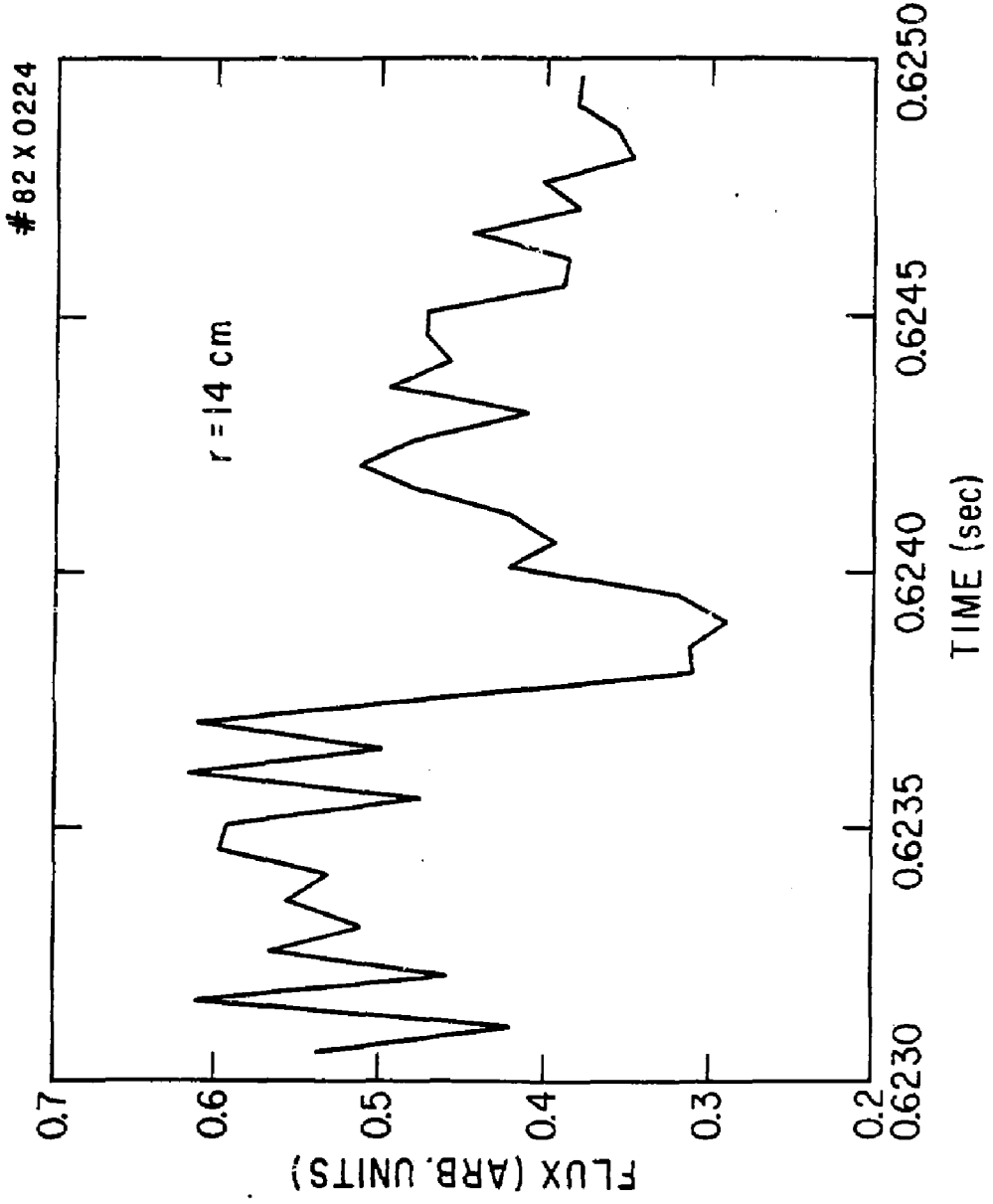


Fig. 8

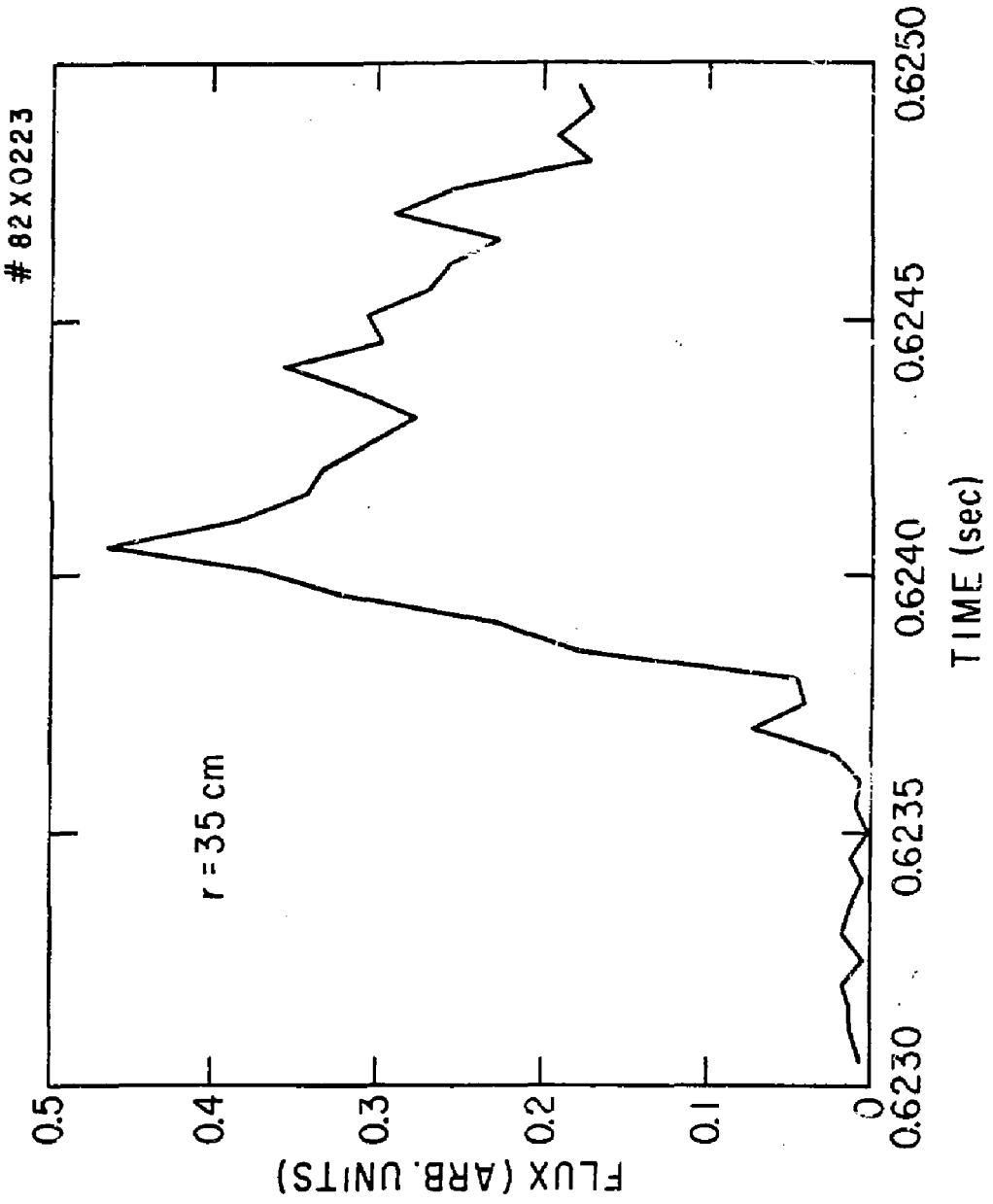


Fig. 9

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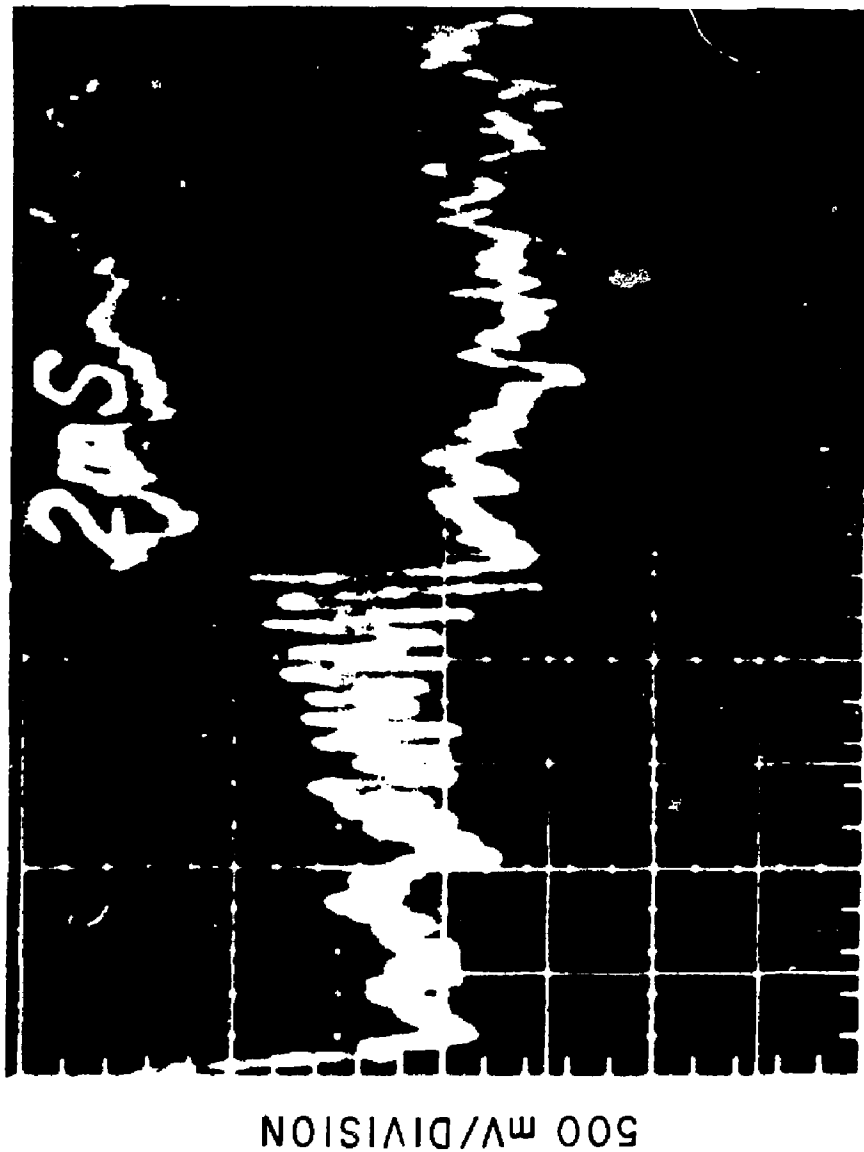


Fig. 10

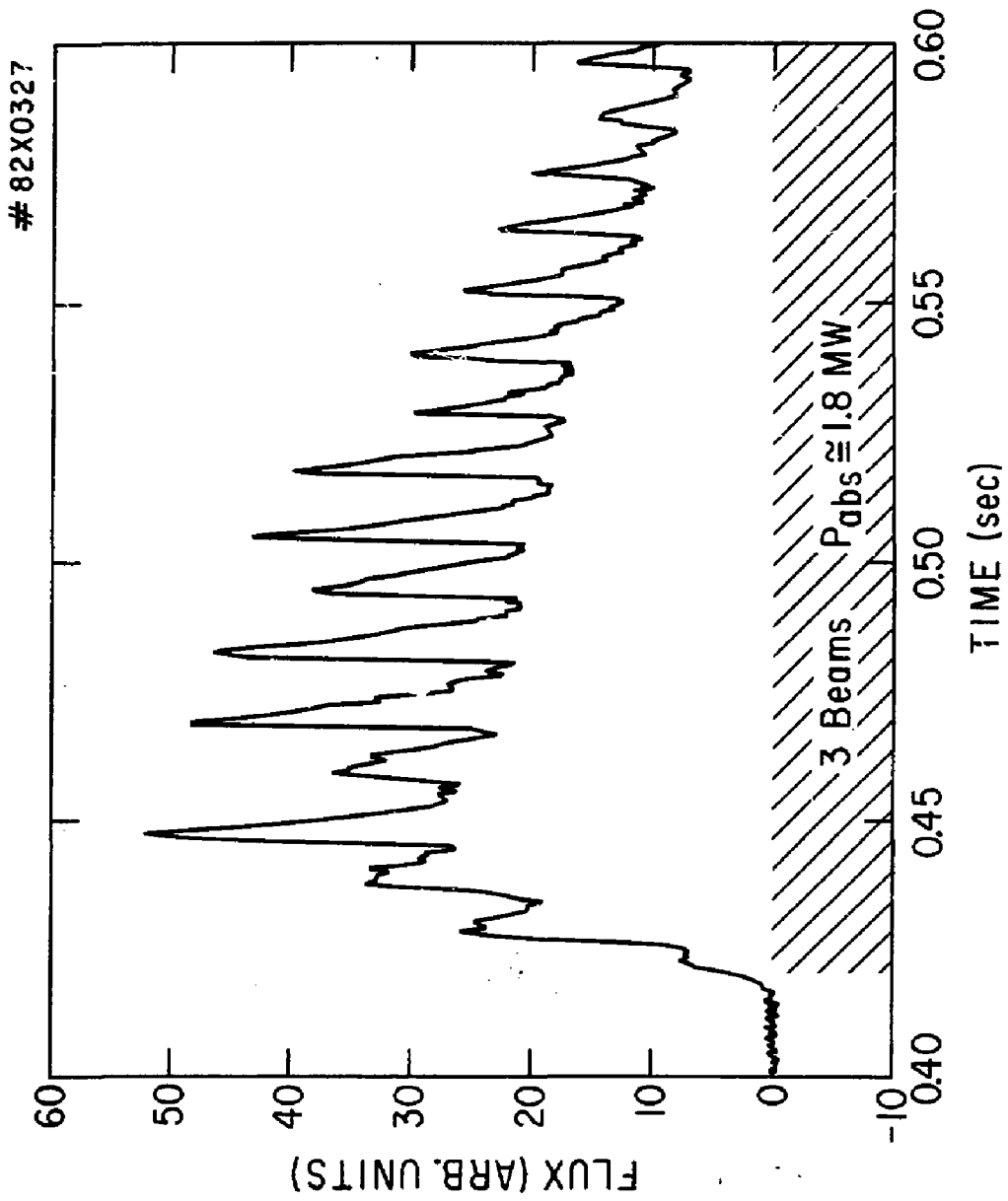


Fig. 11

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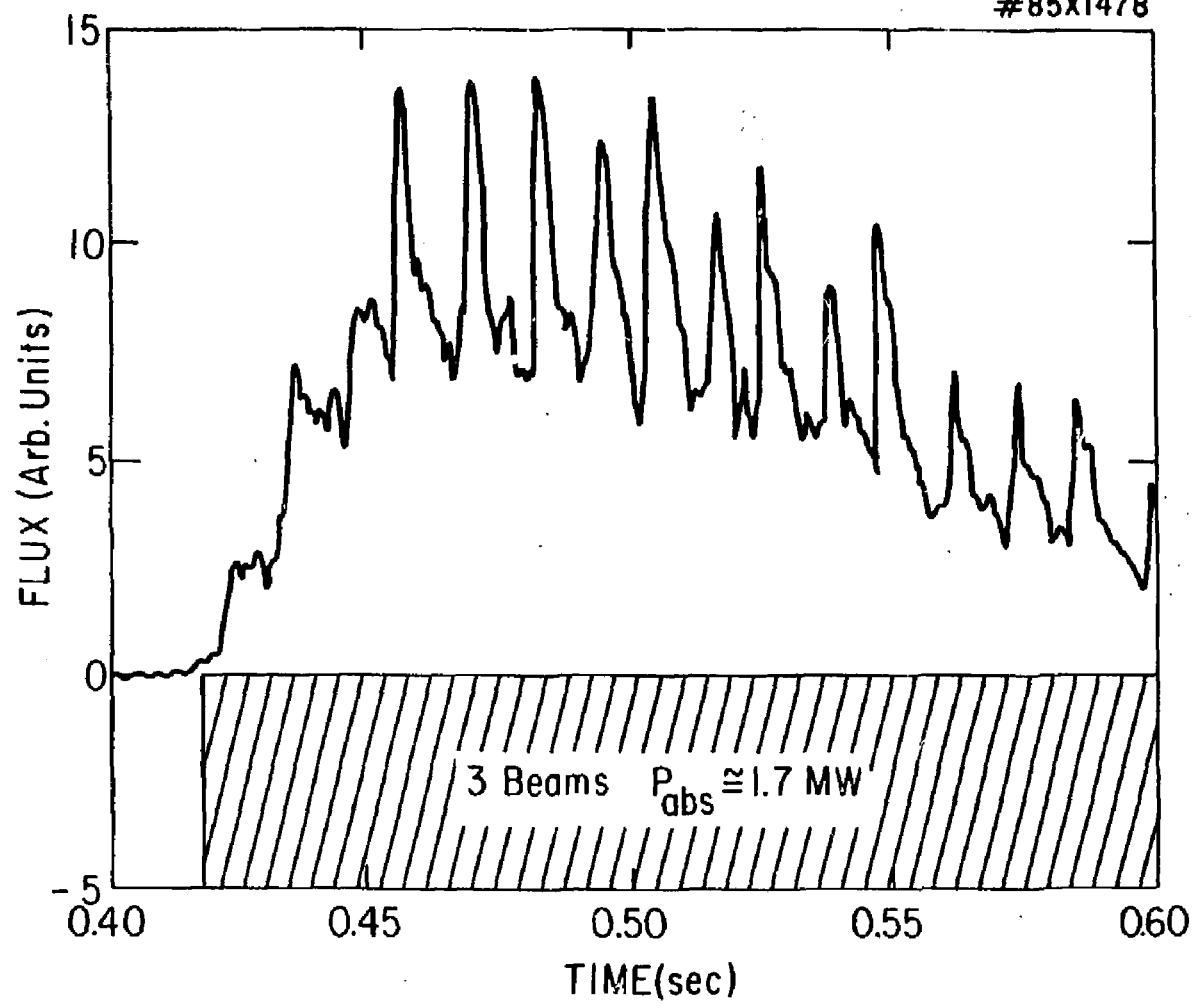


Fig. 12

82 X 0679

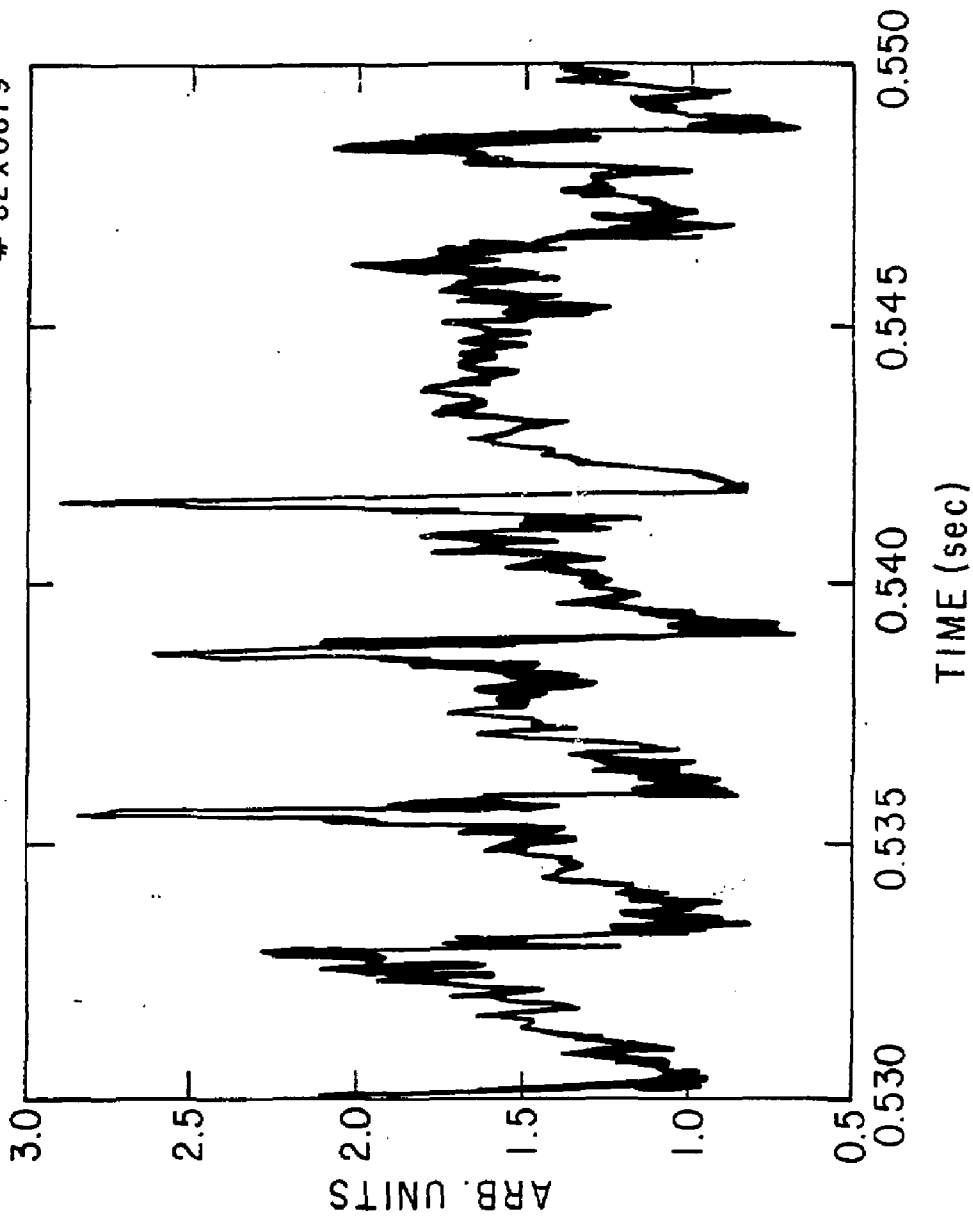
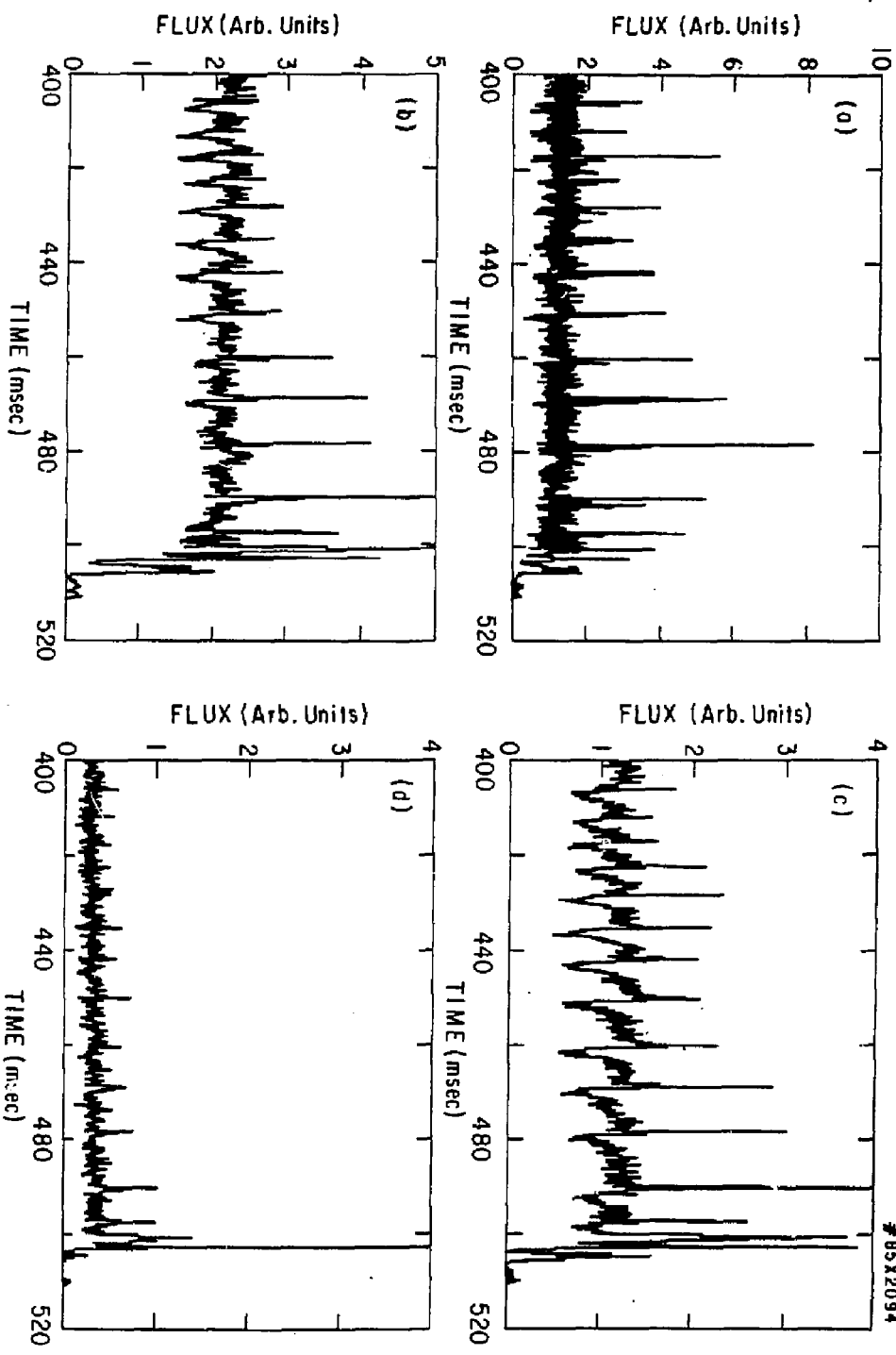


Fig. 13



#85X2094

Fig. 14

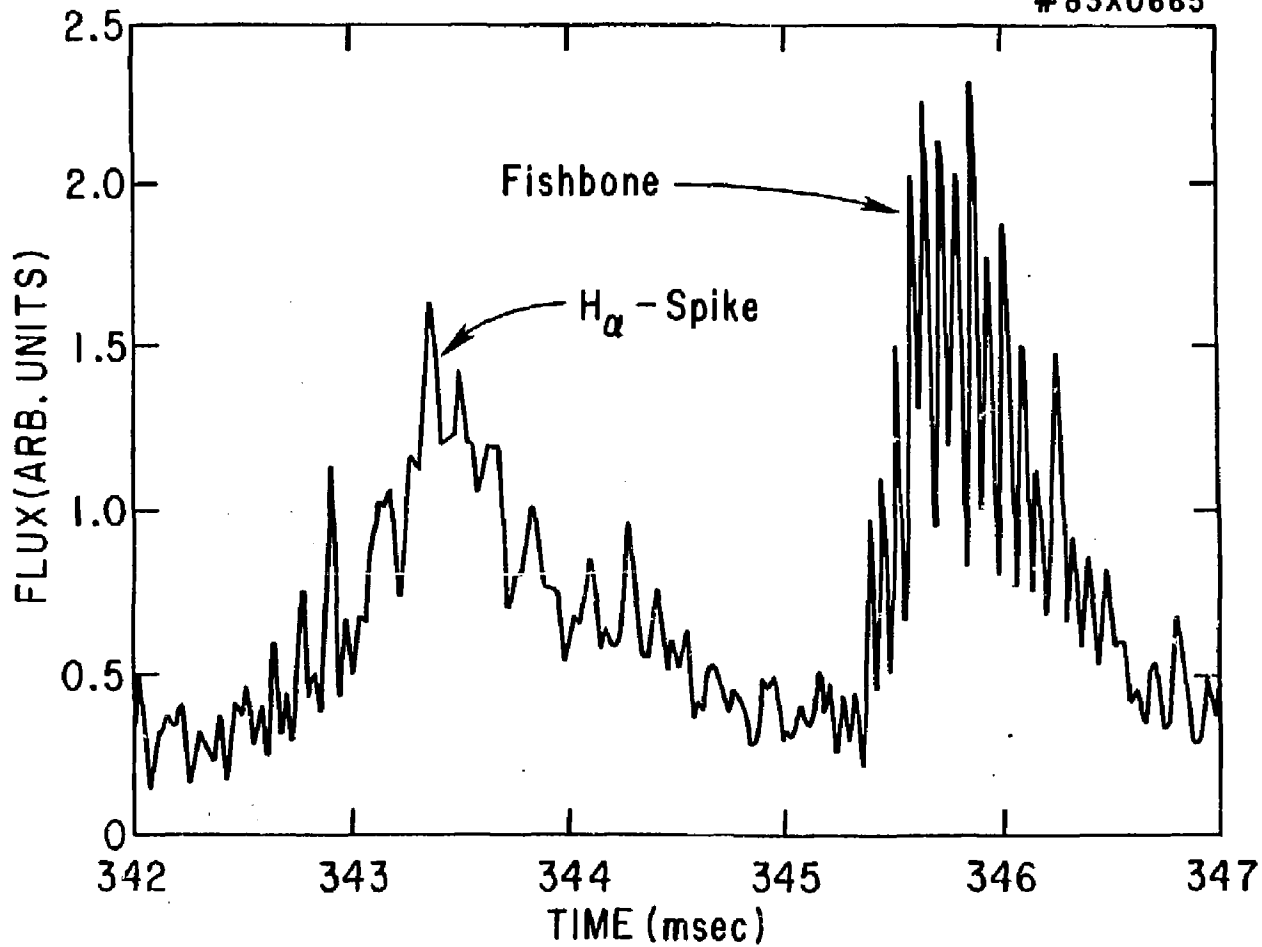


Fig. 15

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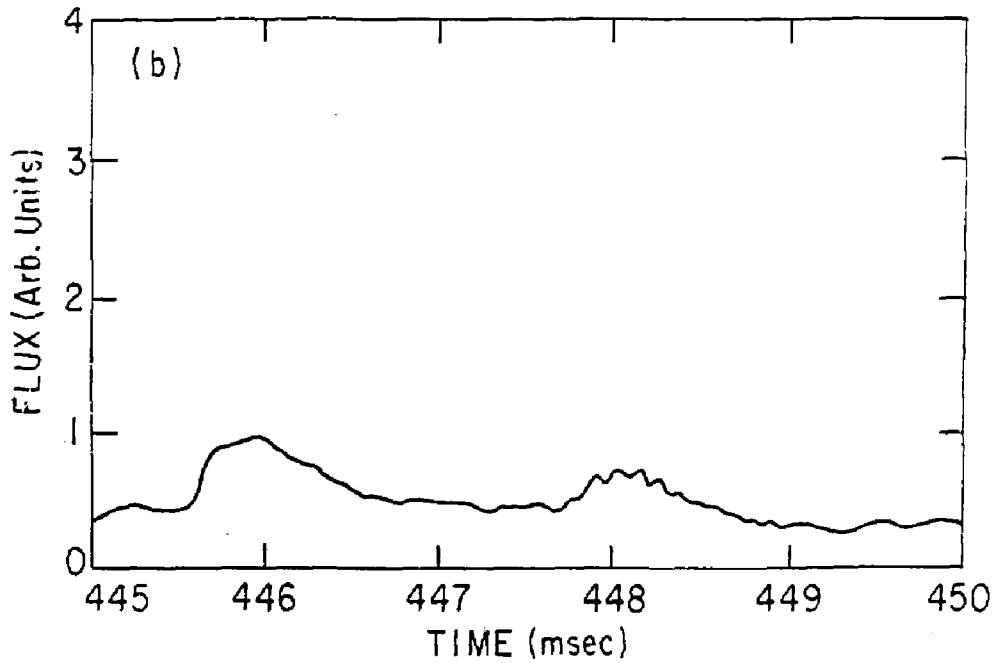
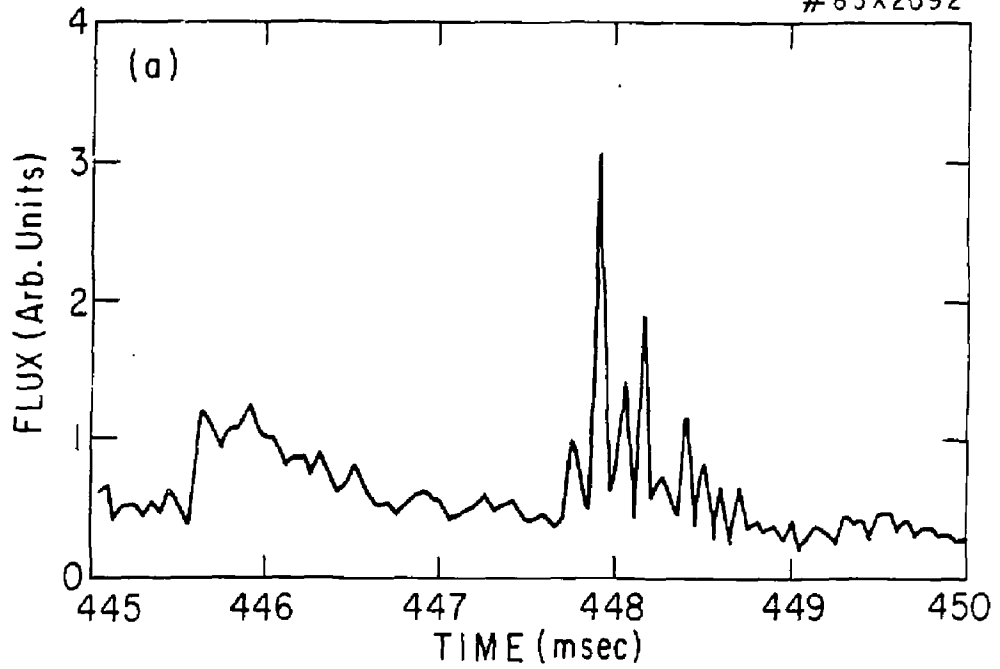


Fig. 16

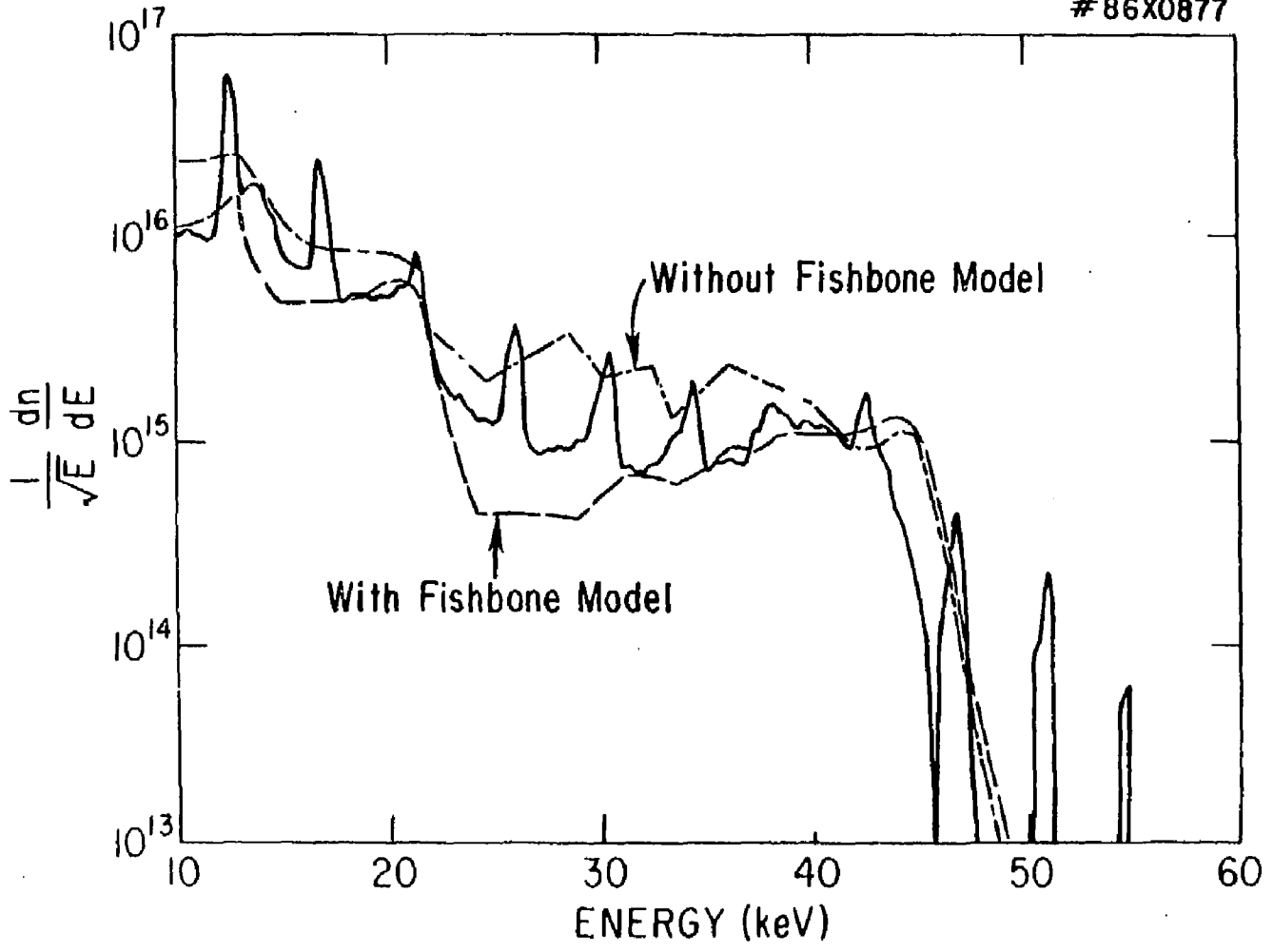


Fig. 17

#83X0247

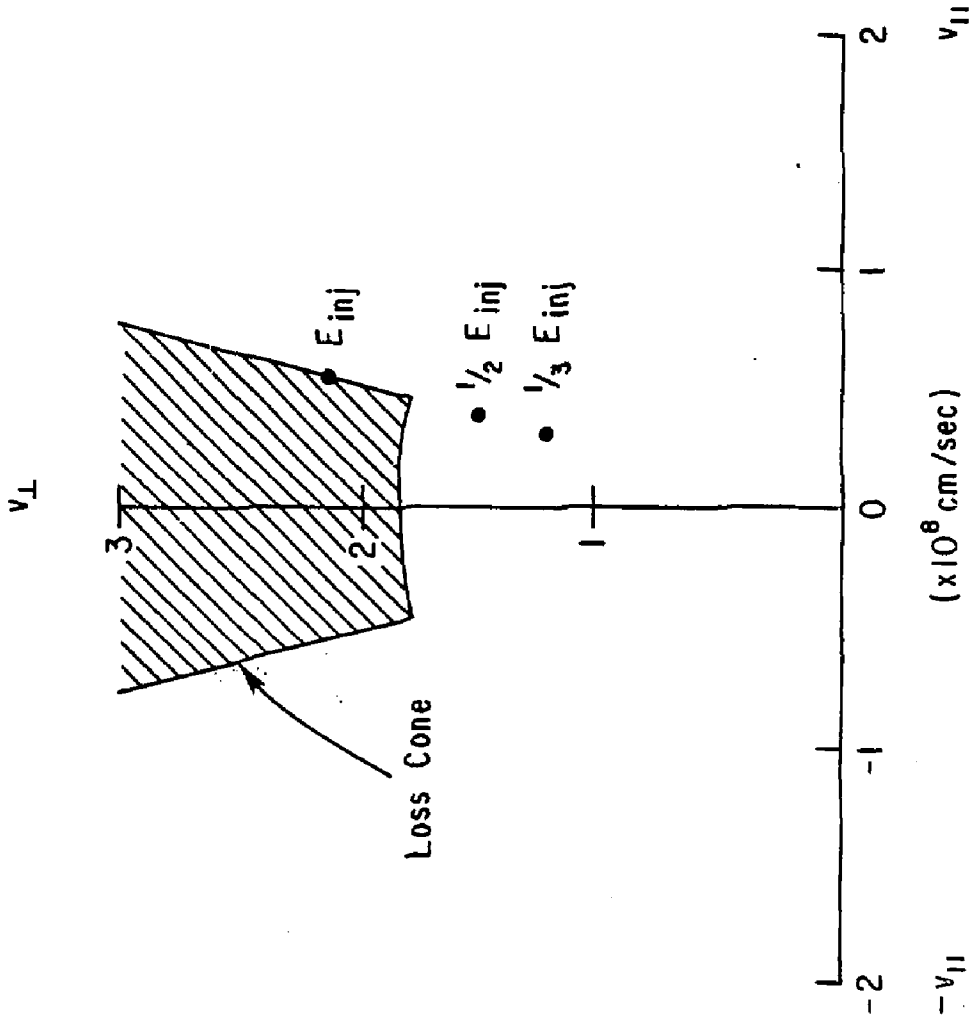


Fig. 18

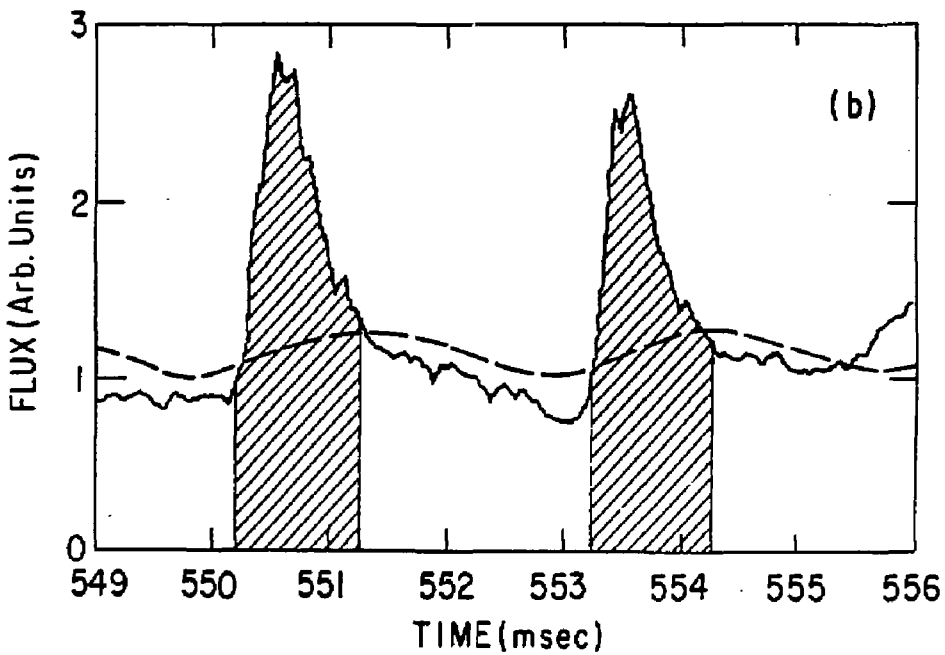
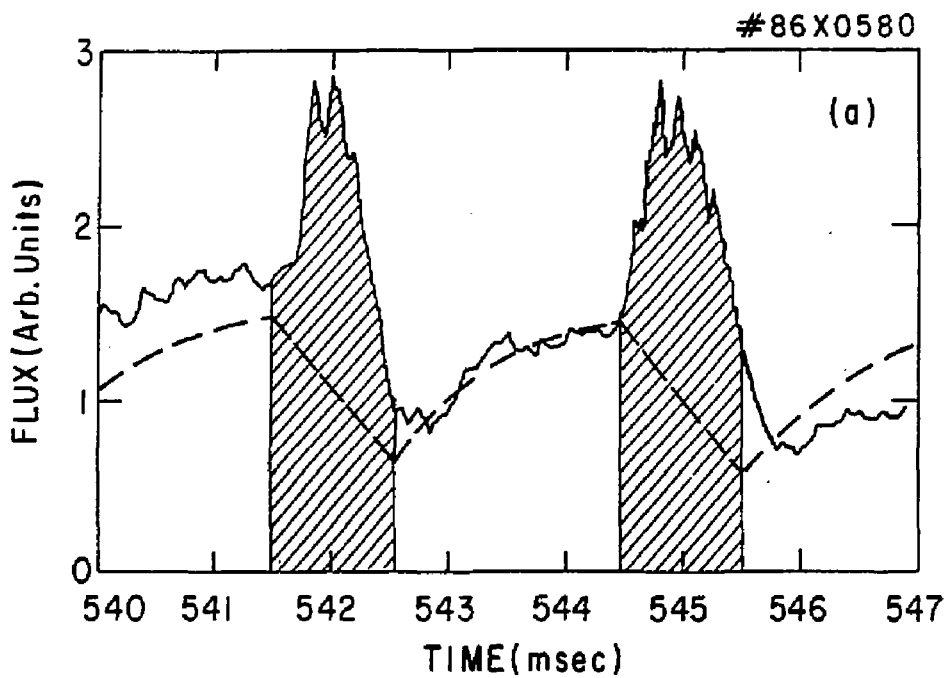


Fig. 19

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