

PFC/JA-91-23

Neutral Hydrogen Density Measurements in TMSPP

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August 1991

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ABSTRACT

The neutral hydrogen density N_0 has been measured by laser fluorescence diagnostic in the exhaust of a tandem mirror space plasma propulsion device (TMSPP). Experiments have been performed using laser induced resonance fluorescence detection of H_α (6563Å). The fluorescence signal has been separated successfully by eliminating the H_α radiation from plasma and laser stray light using differential method of two optical paths presented. The resolution of the signal is greatly enhanced. The radial distribution of hydrogen density has been obtained and the neutral density decreases from the edge toward the center.

INTRODUCTION

Neutral hydrogen density N_0 is important to the particle and energy balance in high temperature plasma. Measuring the H_α laser induced resonance fluorescence scattering from plasma is a method to determine the neutral hydrogen density. This method has been applied to toroidal tokamak plasma^[1-3]. Same results have been obtained in the tandem mirror TARA for the conditions that electron temperature and electron density are lower than that of tokamak^[4,5].

Neutral hydrogen is very important in the exhaust of a tandem mirror space plasma propulsion device (TMSPP)^[6,7]. The injection of neutral jet in exhaust radially is considered as the method to cause the plasma to be disconnected from the field line. And neutral hydrogen has an effect to insulate the wall from the hot plasma in the exhaust. This report presents the experiment of measuring the radial distribution of neutral hydrogen density in exhaust of propulsion device.

The laser fluorescence signal is usually much smaller than the H_α signal from plasma and the laser stray light. To extract the data is difficult and inaccurate. Using the method of two optical paths, i.e. one path records the H_α signal from plasma, laser stray light and fluorescence signal and another one records the H_α signal and stray light, differentiating the signals we are able to eliminate the laser stray light and any noise from plasma so that a clear fluorescence signal can be obtained.

EXPERIMENTAL SETUP AND CALIBRATION

The experiment is performed in the TMSPP device (Fig. 1). Hydrogen gas is filled from the north end of the central cell. The plasma is initially created by breaking down the gas with ECRH at frequency of 2.45GHz and input power of 1kW. The plasma ion is heated by ICRH at power of 10kW and pulse duration of 20ms. Neutral gas flowing passes the ECR and ICR resonance and the plasma endloss to exhaust. The laser fluorescence diagnostic system is located in the south exhaust of the machine at a

distance of 25cm from the peak magnetic field of the mirror. The electron temperature and density were measured by Langmuir probe simultaneously.

The laser beam and detection optical system is shown in Fig. 2. The laser used here is a flashlamp-pumped dye laser (Candela EDL-6) tuned by an angle-tuned $40\mu\text{m}$ air-spaced etalon. A telescopic system in front of laser improves the divergence of laser beam. The beam can be focused at different radial position in the vacuum chamber by moving the concave lens. Three copper knife-edge baffles were arranged in input port to minimize the stray light level. A gate valve was placed in front of the baffles to prevent the laser input window. The scattering system box with big lens on top of vacuum chamber can be moved radially. The 7cm-diam, 10cm focal length big collection lens is mounted across a $30 \times 10\text{cm}$ observation window. The radial scan can be made from $r = 0$ to $r = 4.5\text{cm}$ because of 10cm top aperture. The $30 \times 10\text{cm}$ viewing dump was made of stacked non-magnetic razor material and was located on the opposite wall of scattering system box. The beam dump consisted of two disks of absorbing OB10-type glass, set at Brewster's angle to the incident laser direction, in such a way that both polarization components were attenuated. A monochromator is used to monitor the wavelength of the laser output. A photodiode, mounted directly behind the 99.9% reflecting rear cavity mirror of the laser is used to monitor the power of each laser pulse.

The schematic of scattering system is shown in Fig.3. The optical paths consist of a big lens, a filter, a prism and two small lenses. The surface of the prism is deposited a thin coating of aluminum. The reflectivity of surface is 95%. The prism was adjusted so that image of the two paths fall on the entrance slits of the photomultipliers, PM1 and PM2. If laser wavelength does not equal to 6563\AA , i.e. it is not at resonance (i.e. wavelength of the laser light is not same as H_α), two photomultipliers receive same stray light and noise from plasma including H_α . However, at resonance frequency the fluorescence light induced by the laser is led to PM2. The differential amplifier (Tektronix 502) with gain=10 takes the difference of the two path signals and therefore the stray light and background from plasma were subtracted. A narrow band filter,

having a bandpass of 5\AA and transmission of 53%, was placed at a space between the big lens and the prism to reduce the plasma background contribution to the scattered signal. The Hamamatsu R928 photomultiplier tubes is shielded magnetically with high μ material. The optical parts of two pathes were mounted in a box, called the scattering system box, shielded optically and magnetically. The output from the differential amplifier and the power monitoring signal are processed by 6MHz digitizer and 100KHz digitizer respectively.

The laser can be tuned to Balmer-alpha line 6563\AA by etalon and have a linewidth of about 0.75\AA . The laser output power is about 80 kW and 1/3 of that power can focused on the plasma. The foused spot is $0.4 - 0.5\text{cm}^2$. The laser power of $10\text{kWcm}^{-2}\text{\AA}^{-1}$ is sufficient to saturate the $n = 2$ to $n = 3$ transform of hydrogen atom. The fluorecence intensity does not dependent on the laser power.

The laser fluorecence signal was absolutly calibrated by Rayleigh scattering in nitrogen gas. The ratio of the fluorecence signal, F and Reyleigh scattered signal, R is

$$\frac{F}{R} = \frac{\Delta N_3 A_{32} T_L \pi r^2}{N_2 N_{N_2} \sigma_R}$$

Where ΔN_3 is the difference in the $n = 3$ population of hydrogen atom with and without laser, $A_{32} = 4.4 \times 10^7 \text{sec}^{-1}$ is the induced transition probability from $n = 3$ to $n = 2$, $\sigma_R = 2.16 \times 10^{-27} \text{cm}^2$ is the Reyleigh scattering cross section, $T_L = 5\mu\text{s}$ is the duration of the laser pulse, $r = 0.5\text{cm}$ is the radius of laser spot, $N_{N_2} = 3.54 \times 10^{16} P$ (with P in Torr) is the molecular number density of nitrogen in Reyleigh scattering, $N_L = 7.9 \times 10^{17}$ is the input photon number for Reyleigh scattering for the laser of energy $E_L = 480\text{mJ}$ used in our experiment. The Reyleigh scattered signal R was found to be $R = 7.8P$ (with P in Torr). Thus, $\Delta N_3 = 4.49 \times 10^4 F$, where F is fluorecence signal related to the Reyleigh scattered signal. According to the theory of the collisional-radiative mode^[8], the ground state population of neutral hydrogen is depedent on the electron temperature and density of plasma. They can be measured

by Langmuir probe setting at same radial position.

RESULTS

The experiment was performed at central cell coil current $I_{CC} = 290A$ and mirror coil current $I_{MIRR} = 1200A$. The laser was fired at 12ms after ICRH at about the middle of flat top. Fig.4 shows the signal through path PM1 which includes the stray laser light, H_{α} and background light and the signal through optical path PM2 which is the sum of laser induced fluorescence light, the stray light and H_{α} . It can be seen that PM2 signal is slightly higher. The difference of PM2 and PM1 signals is the fluorescence signal as shown in Fig.5 which is seen much smaller than either PM1 and PM2 signal. However, the signal is clear and free of noise. Fig.6 shows the signal profile using 6MHz digitizer. The Langmuir probe current signal is shown in Fig.7.

The radial profile of the fluorescence signal is shown in Fig.8(a). The radial profile of electron temperature T_e and density N_e measured by Langmuir probe are shown in Fig.8(b) and (c).

The neutral hydrogen density N_0 is inferred from ΔN_3 with electron temperature T_e and density N_e . Fig.8(d) shows the radial distribution of N_0 . The electron temperature T_e is about 40-50eV and density N_e is $2 - 3 \times 10^9 cm^{-3}$ which is an order magnitude lower than that in the center cell because the plasma was expanded in the exhaust. The neutral density near the center is one order of magnitude smaller than that at $r = 4.5$. The plasma is fully ionized on the axis.

ACKNOWLEDGMENT

The author wish to thank Dr. Q.X.Zu for the assistance of taking the Langmuir probe measurement and Mr. H. Lander for the many technical problems.

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FIGURE

Fig. 1: Tandem mirror space plasma propulsion machine (TMSPP).

Fig. 2: The laser beam and detection optical system.

Fig. 3: The schematic of scattering system.

Fig. 4 Two pathes non-differential signals(without 50Ω terminal).

Fig. 5: The signals of laser background and fluorescence using 100KHz digitizer(with 50Ω terminal).

Fig. 6: The signal profile using 6MHz digitizer.

Fig. 7: The signals of Langmuir probe current and fluorescence.

Fig. 8: The radial distributions of fluorescence(a), electron temperature(b), electron density(c) and neutral density(d).

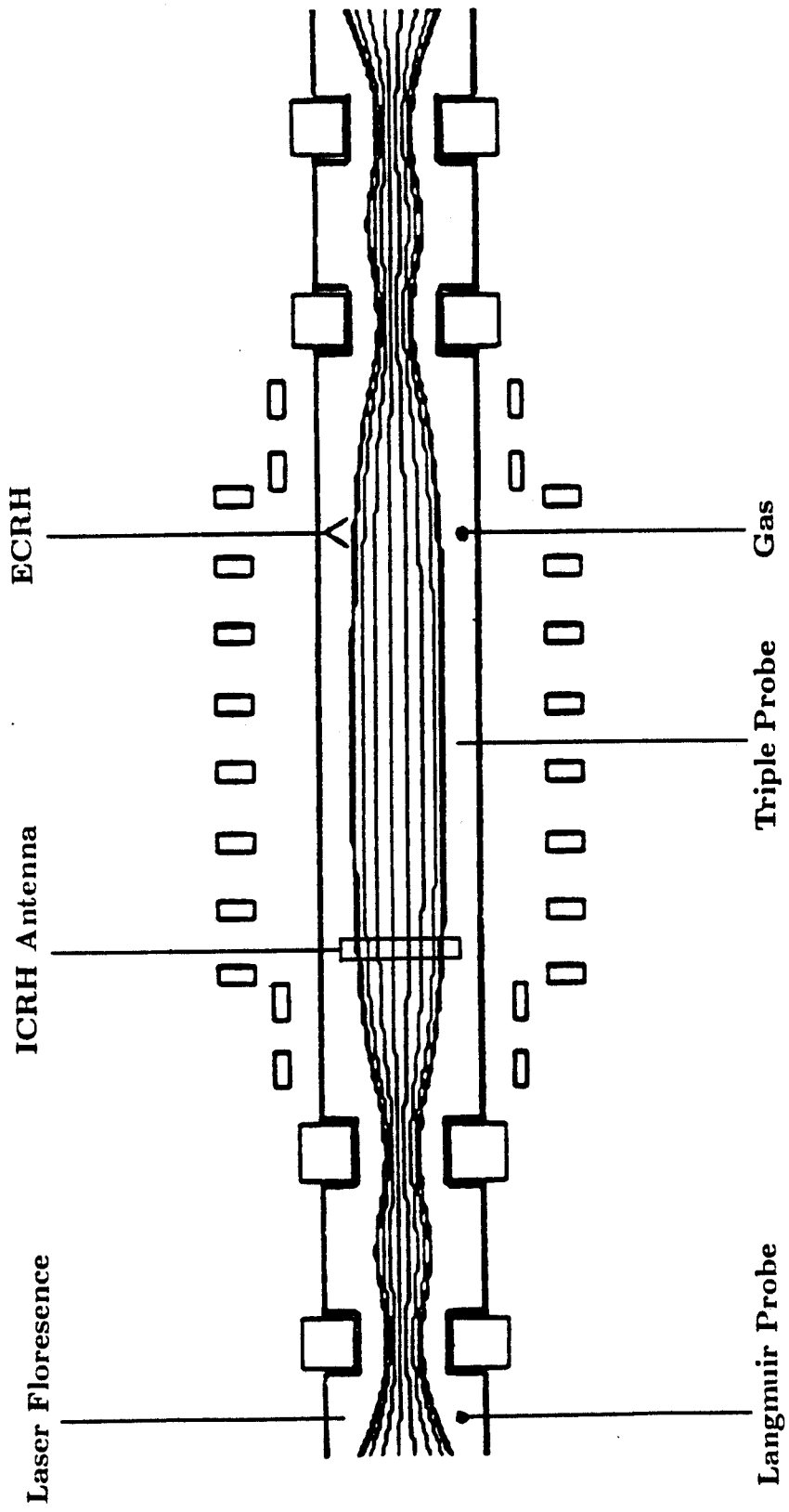


Figure 1

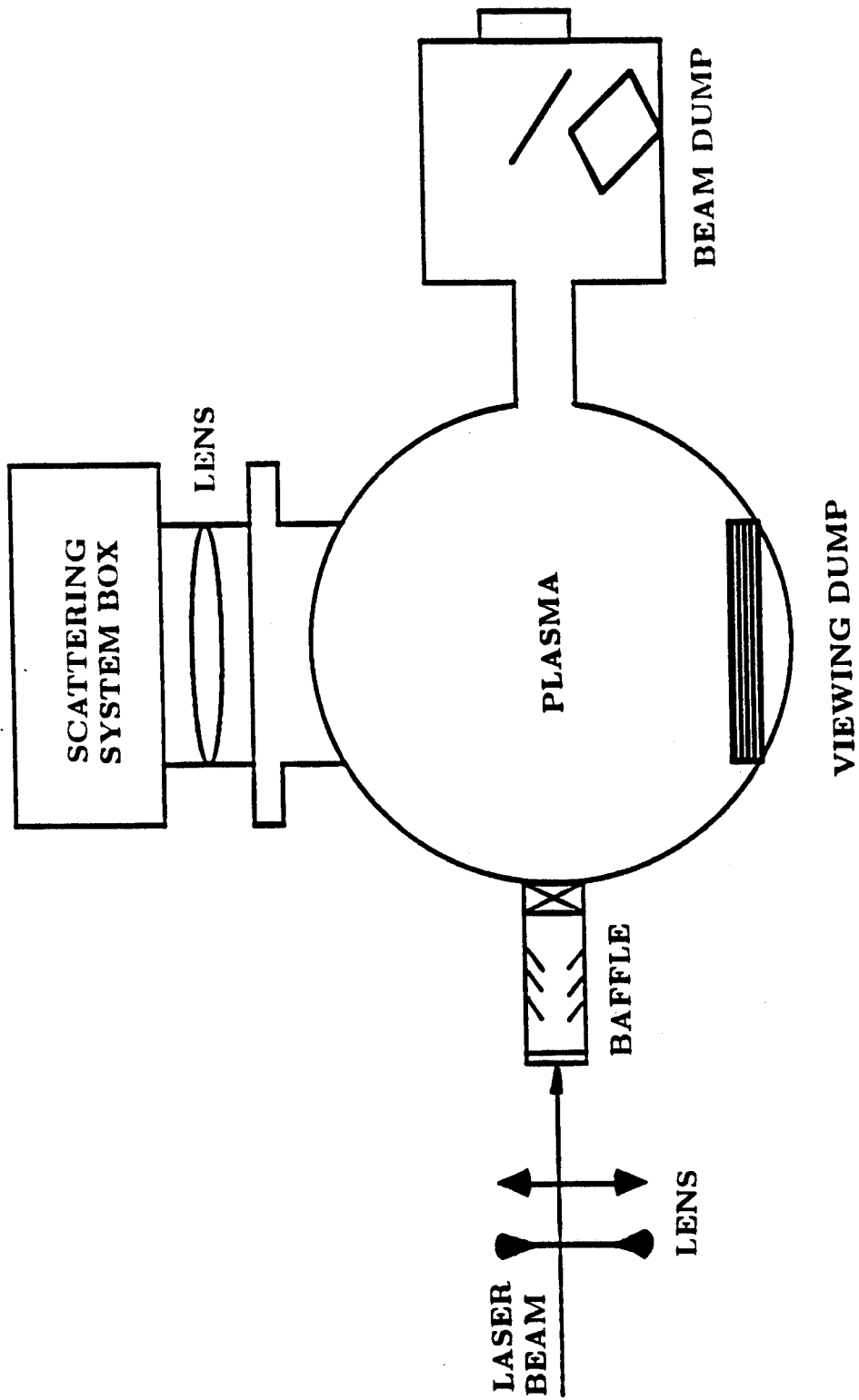


Figure 2

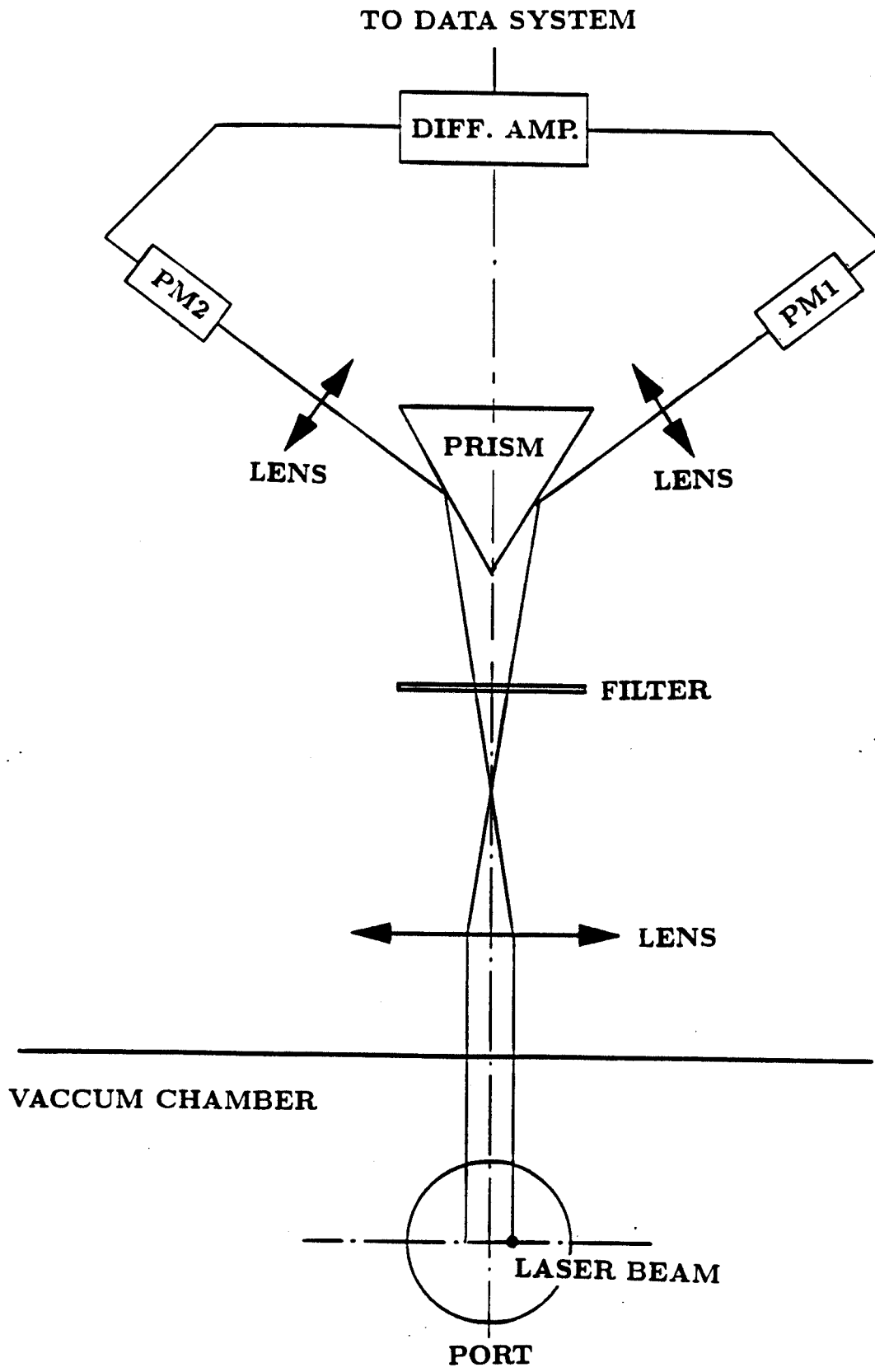


Figure 3

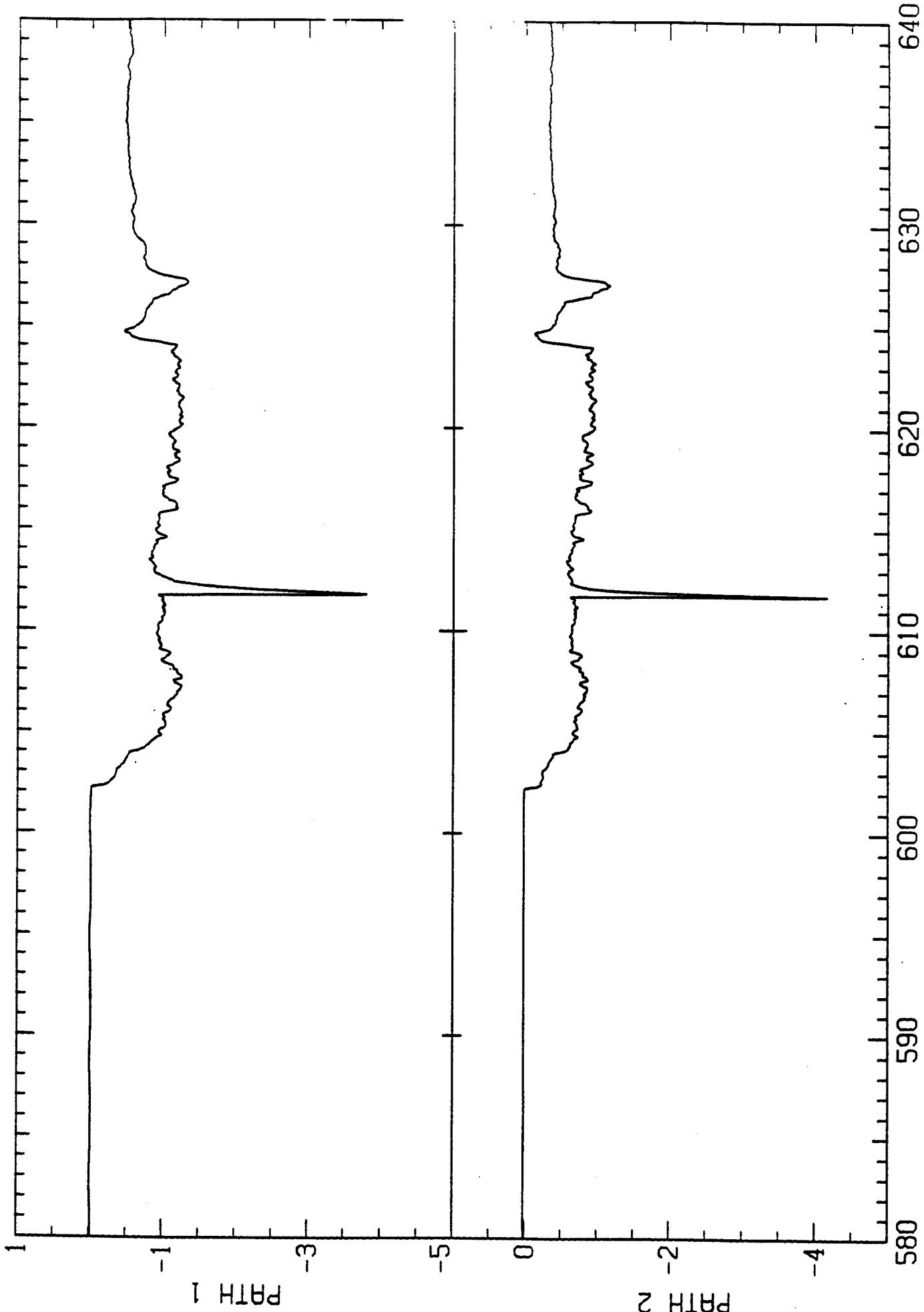


Figure 4

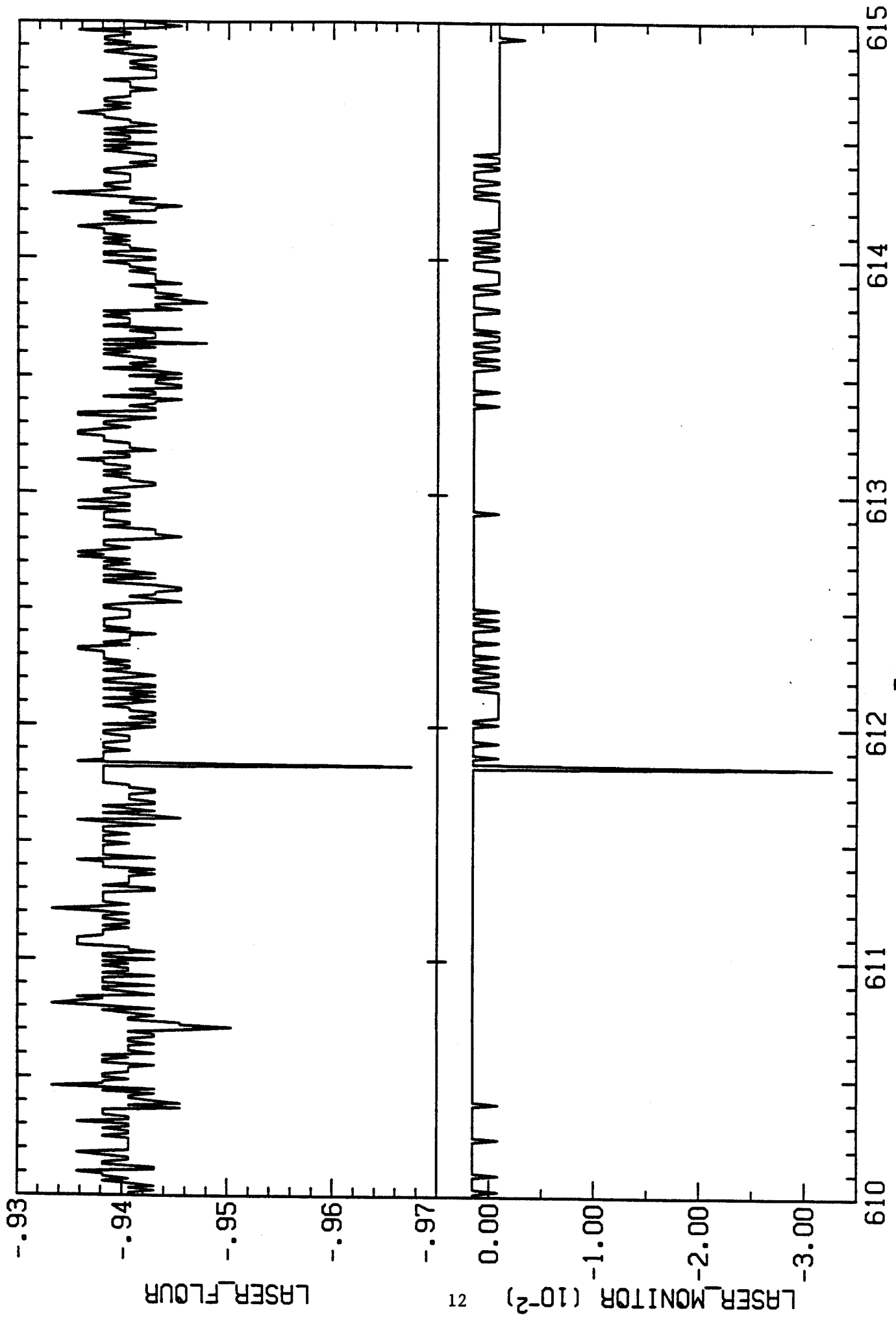
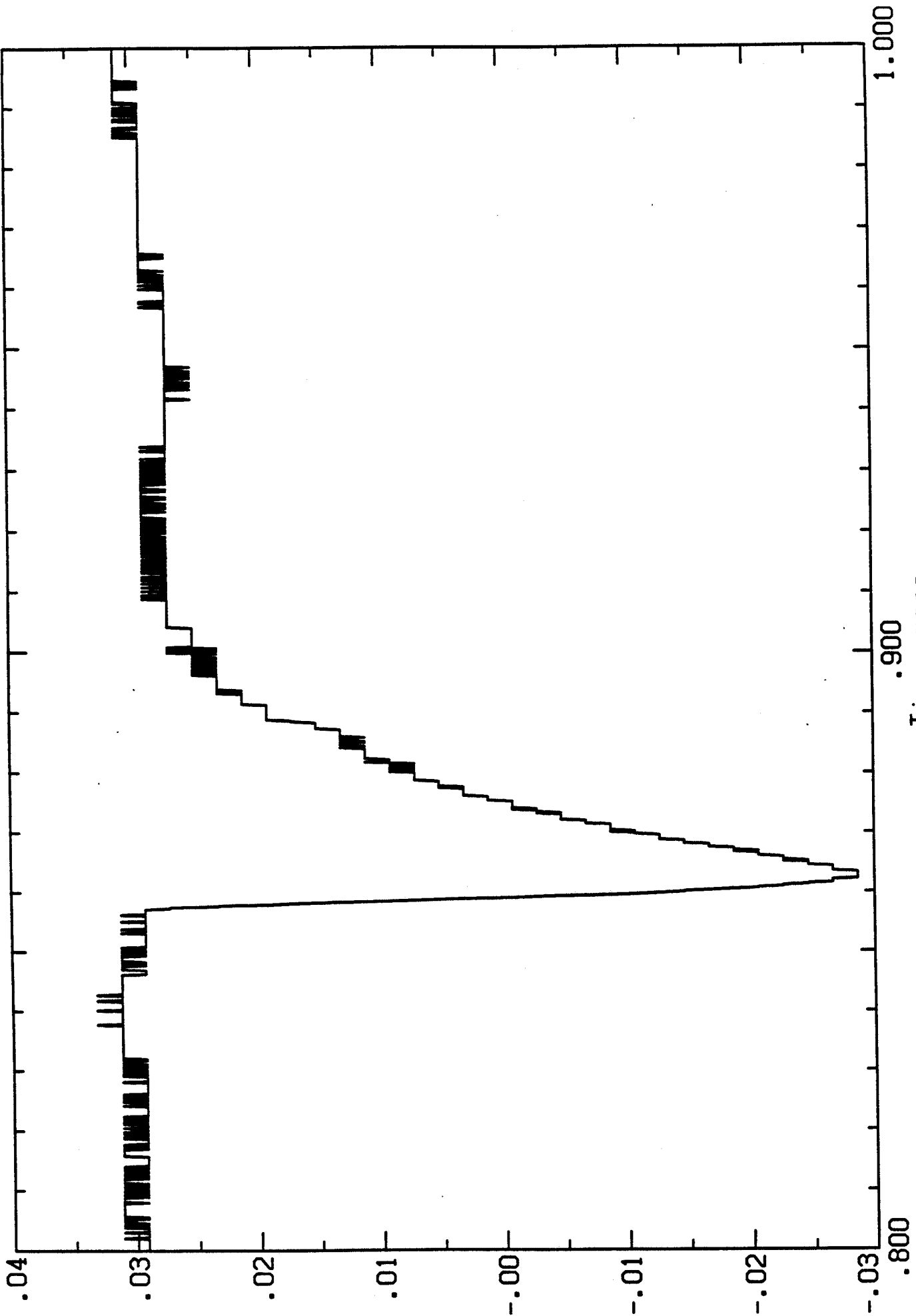


Figure 5



Time, msec
Figure 6

Shot 3541 21-AUG-1991 13:17:06.26

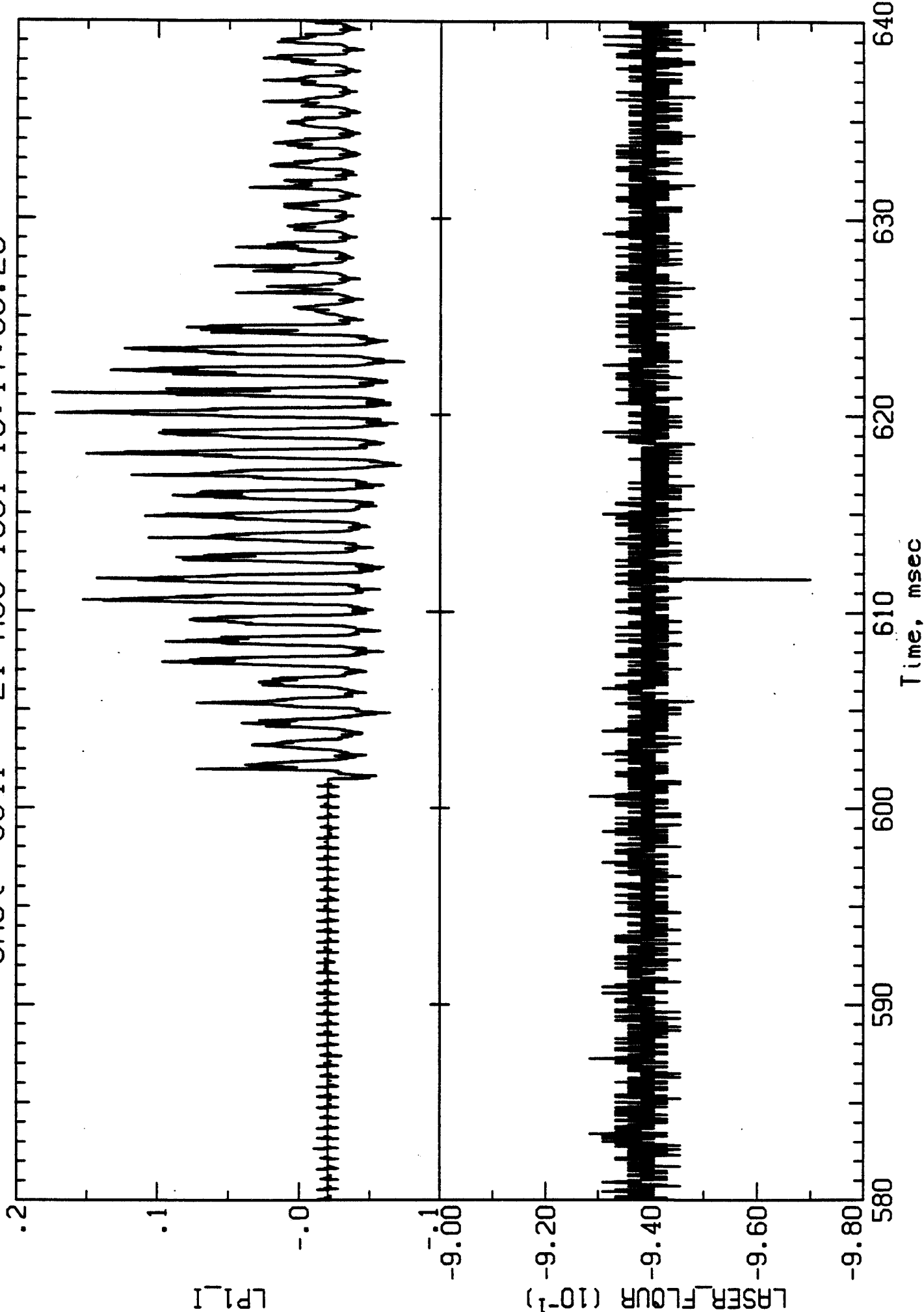


Figure 7

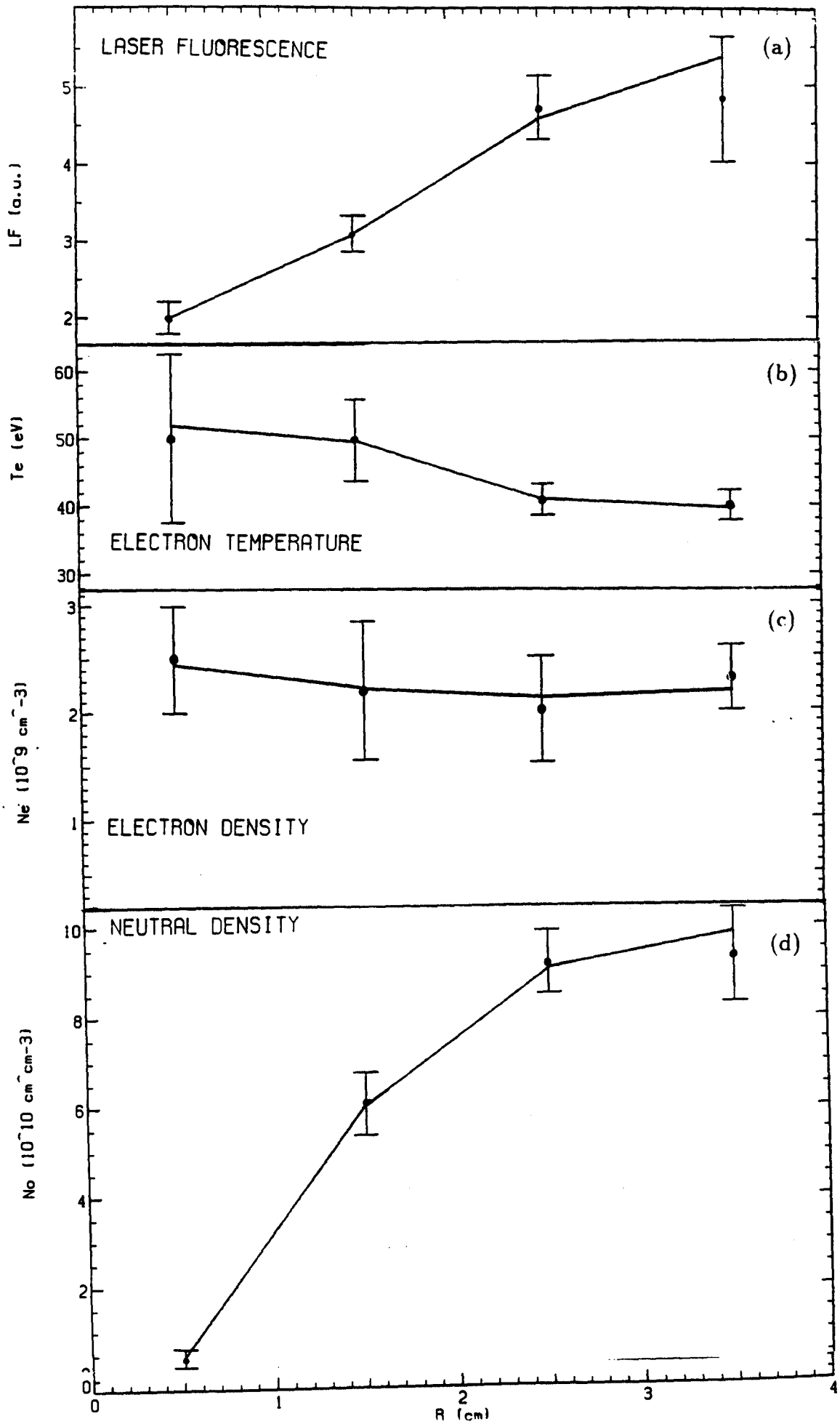


Figure 8