EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/PS 91-48 (HI)
November 14, 1991

THE LASER ION SOURCE TEST FACILITY AT CERN

Y. Amdidouche, H. Haseroth, A. Kuttenberger, K. Langbein, J. Sellmair, B. Sharkov*),
O. Sharmaev*), T.R. Sherwood and B. Williams

ABSTRACT

Due to the growing demand for high currents of highly charged heavy ions, the potential of laser ion sources is investigated at CERN. A test facility consisting of a 50J carbon dioxide laser, a versatile ion production chamber and electrostatic and magnetic analyzing systems has recently been put into operation. First results of charge state analysis as well as plasma temperature measurements are presented.

*) Institute for Theoretical and Experimental Physics, Moscow, USSR

Paper presented at the 4th International Conference on Ion Sources, Bensheim, Germany,
September 30 - October 4, 1991

1. INTRODUCTION

At the European Organisation for Nuclear Research (CERN), and also at other accelerator facilities, there is a growing demand for high currents of highly charged heavy ions. For the planned lead ion accelerator[1] for instance, 10^8 lead ions (ζ=28) are required per pulse. For the LHC project even higher intensities will be needed.

Electron cyclotron resonance (ECR) ion sources which are presently favoured for heavy ion injectors can provide tens of microamps per charge state in pulsed or continuous operation. As demonstrated at the Institute for Theoritical and Experimental Physics, Moscow[2] and the Technical University of Munich[3] laser ion sources can produce tens of milliamps per charge state within pulse lengths of 1-10μs.

Synchrotron accelerator operation requires the ion source to deliver the maximum intensity for a short period at a low repetition rate and the short pulse duration of the laser ion source can even be of advantage. Further advantages of laser ion sources are their comparative simplicity and low cost as well as the fact that there are no power reqirements on the high voltage platform.

At CERN a facility which aims at the investigation of the potential of the laser ion source has recently been put into operation and first results of charge state and plasma temperature measurements have been obtained.

2. LAYOUT

Figure 1 shows a scheme of the experimental setup. A Lumonics model TEA 601 CO2 laser provides a laser beam with a wavelength of 10.6μm and a total pulse energy of 50J. An initial spike lasts 70ns and contains ≈40% of the energy, giving a peak power of 280MW. This beam is transmitted through a sodium chloride vacuum window, 49mm thick and 245mm in diameter, into the vacuum tank.

The window has a slight inclination relative to the plane perpendicular to the tank axis, so that the light which is reflected off the window surfaces (≈ 10% of the energy) can be used to monitor the pulse shape during the experiment.

A precision copper parabolic mirror, focal length 300mm, focuses the laser radiation onto the target. The estimated spot size is 0.1mm in diameter giving a peak energy density of 0.6MJ.cm^{-2} and a peak power density of 2.10^{12}W.cm^{-2}.

The target (lead, tantalum, copper and aluminum have been used) is of cylindrical shape with diameter 25mm and height 10mm. It is mounted on a vertical stem of 3mm diameter and can be rotated as well as moved along this axis, thus allowing a fresh target surface to be exposed, as required.

An exploding plasma is created which expands mainly in a direction perpendicular to the target surface (i.e. from right to left on Figure 1) during several microseconds. Part of it is transmitted through a bore of diameter 30mm in the center of the mirror.

Neither the target, which is positioned on the laser beam axis, nor the central hole in the mirror reduce the deposited light energy as the laser produces a hollow beam with a rectangular cross-section of 100mmx80mm with an inner hole of 55mmx42mm.

The arrangement of laser, mirror and target on the same axis reduces the number of optical components outside the laser to just one making it comparatively easy to align. Complications arise, however, due to light reflected or emitted from the plasma and travelling back into the laser cavity.

Behind the mirror the plasma is allowed to expand for a further (variable) distance until it reaches an extraction system, where the electrons are retarded and an ion beam is formed. Various extraction systems can be installed, the simplest consisting of two grids made of fine wire mesh with a meshes of 25 or 50μm.

The various components inside the vacuum tank are mounted on three insulated chariots which can be moved independently along the beam axis with high accuracy and reproducibility, from outside the vacuum tank, providing a high degree of flexibility. The target and the mirror are each mounted on a separate chariot allowing a movement of the target relative to the mirror for focal length adjustment.

If an ion beam is to be extracted, a high voltage is applied to the target, the mirror and the first grid of the extraction system and this region is surrounded by a Faraday cage.

The main vacuum tank is followed by a beam pipe of 1m length and then by a 77^0 magnetic and 90^0 electrostatic analyzer. Both analyzers have variable entrance and exit slits. Secondary electron multipliers (SEM) are used for particle detection.

3. METHOD AND EXPERIMENTAL RESULTS

3.1 CHARGE STATE MEASUREMENTS

These measurements were performed using both .the magnetic and the electrostatic analyzer (see Figure 1). The extraction system was discarded and no voltages were applied. The electrons are suppressed at the entrance of the analyzers.

By setting the electric or magnet field in the analyzer, only ions with a narrow range for the ratio momentum/charge or energy/charge, respectively, reach the detector. Since the time of flight to the detector is relatively long compared with the laser pulse length, the time of arrival, τ_ζ, of an ion with charge state, ζ, is either proportional to ζ^{-1} or $\zeta^{-½}$ depending on the type of analyzer. The velocity resolution of these analyzers is determined mainly by the slit widths and, for the lower velocity ions with small ζ, by space charge effects.

Figure 2 shows a recording using the magnetic analyzer. Since calibration of the SEM for highly charged ions impinging onto the first dynode have not yet been performed, data from the literature[4] were taken and extrapolated linearly to the range of energies and charge states observed. Because of this, together with the relatively low statistics (two laser shots per data point), the distributions displayed in Figure 3 for lead and aluminium respectively, represent only the overall behavior of charge states. As space charge has a strong influence in the analyzer, the number of ions in low charge states (ζ<4 or 5) with their inherently low energy is probably underestimated. The peak energy for the highest charge state is ≈300keV, while the widths of the distributions are comparable to the peak energy.

3.2 MEASUREMENT OF CURRENT DENSITY

For the normalization of the above results, electrical current measurements were carried out, also in the absence of any accelerating voltage. After letting the plasma drift through the beam line, the current density due to plasma ions was measured 3m from the target using a simple Faraday cup. A negatively biased grid (≈400V) in front of the cup, served both as plasma electron repeller and as suppressor for secondary electrons from the collector. Figure 4 shows the variation in ion current for lead ions measured through an aperture of $1cm^2$ corresponding to a solid angle of 10^{-5} str. The higher charged particles appear at the beginning of the current pulse. The ion species each have pulse durations, between 5 and 10 μs, which overlap. Similar current densities, but with a reduced time of flight were observed for aluminium ions.

The laser gas mixture has an influence on the distribution of lower charge states. The number of ions in lower charge states is reduced when the laser is operated without a long tail to the pulse.

Ion current extraction was also performed at a distance of approximately 45cm from the target, using a copper target. In this case, a double-grid extraction system, with a 5mm separation, was used to provide an ion beam with a relatively low energy (≈ 5keV). The electric fields were sufficient to eliminate all electrons from the ion beam. The cage and first extractor grid were at a positive voltage. The surrounding Faraday cage was used to prevent arcing towards the grounded vacuum tank. The observed increase in current density (up to $100mA.cm^2$) is accompanied by a reduction of ion current pulse length, as expected.

3.3 TEMPERATURE MEASUREMENTS

In order to characterize the properties of the laser produced plasma, an experiment, based of the method of Elton[5] was made to evaluate the electron temperature of the expanding plasma close to the metal target.

Beryllium foils of 25μm and 50μ m thickness, respectively, are mounted in front of two of scintillators. The scintillators, which are fixed in the front of the photomultiplier (PM) tubes, convert the soft X-rays emitted by the plasma electrons into visible light and also act as vacuum windows. The PM tubes are mounted, one above the other, separated by 12cm on a vacuum flange whose axis perpendicular to the beam axis.

From the ratio, R, of the integrated intensities of the bremsstrahlung transmitted through two foils of different thicknesses , one can determine the electron temperature, under the assumption that the plasma have a Maxwellian energy distribution.

A result of a calculation for R, made for the given foils is shown in Figure 5. The ratio R of the relative intensity of both PM signals is plotted versus the electron temperature for soft X-Rays emission. Similar results can be found in the literature[5]. The highest plasma temperatures observed in our experiments are in the range of 200 to 300eV, as predicted from the calculated electron temperatures.

Figure 6 shows the intensity of the laser pulse and the PM signal versus time for different gas mixtures of the laser discharge, when using 50μm beryllium foil. The laser pulse shape was obtained by using a fast infrared detector.

When correlated to the soft X-Ray signal detected by the PMs, one can see that the structure of the laser pulse has an influence on the X-Ray emission from the plasma electrons. By increasing the nitrogen proportion in the gas mixture, one can obtain a longer tail of the laser pulse, which leads to an enhancement of the X-Ray emission, at later times (up to 5μs after the first peak pulse). However, the distribution of the high charge states did not show a significant dependence on the laser pulse shape.

4. ACKNOWLEDGEMENTS

The authors wish to acknowledge the interesting and stimulating discussions with H.Hora and C.Taylor. We would also like to thank GSI for the loan of the analyzing magnet.

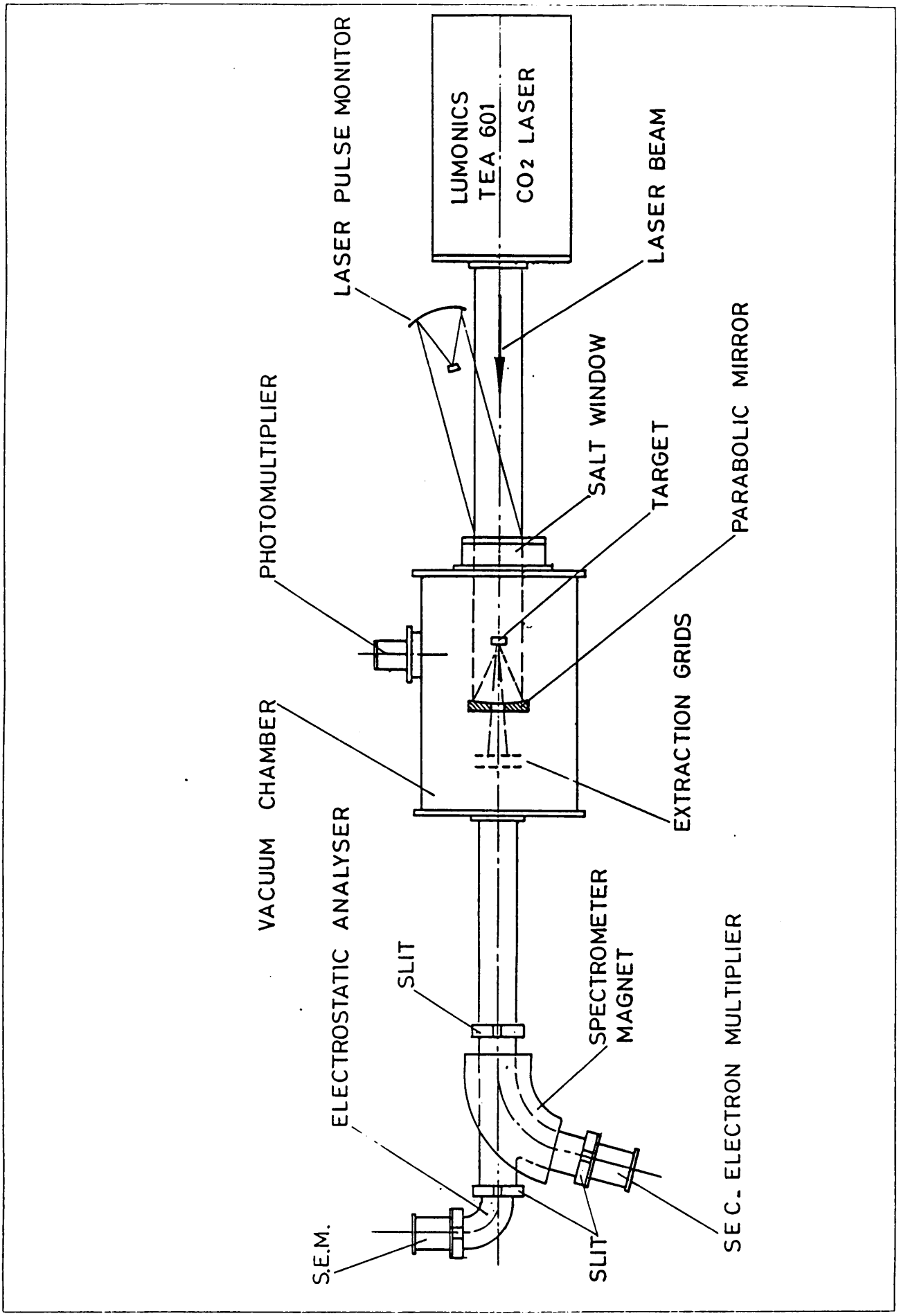

Figure 1. Layout

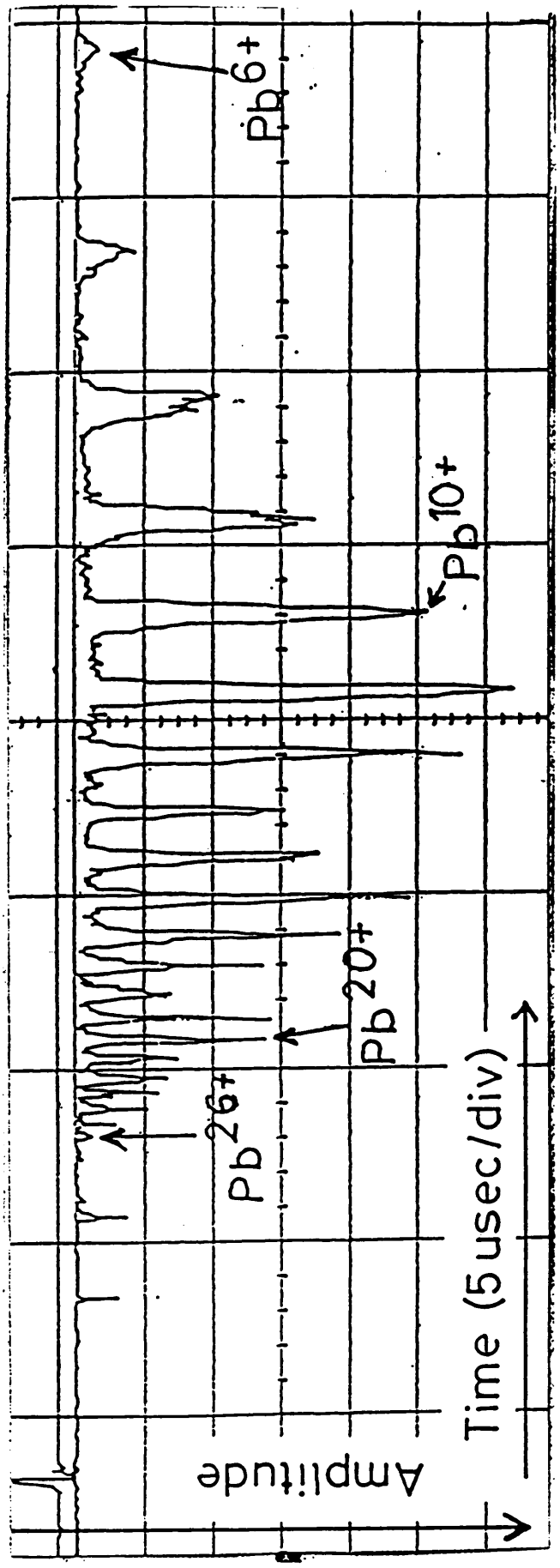

Figure 2. Time of flight spectrum for lead ions

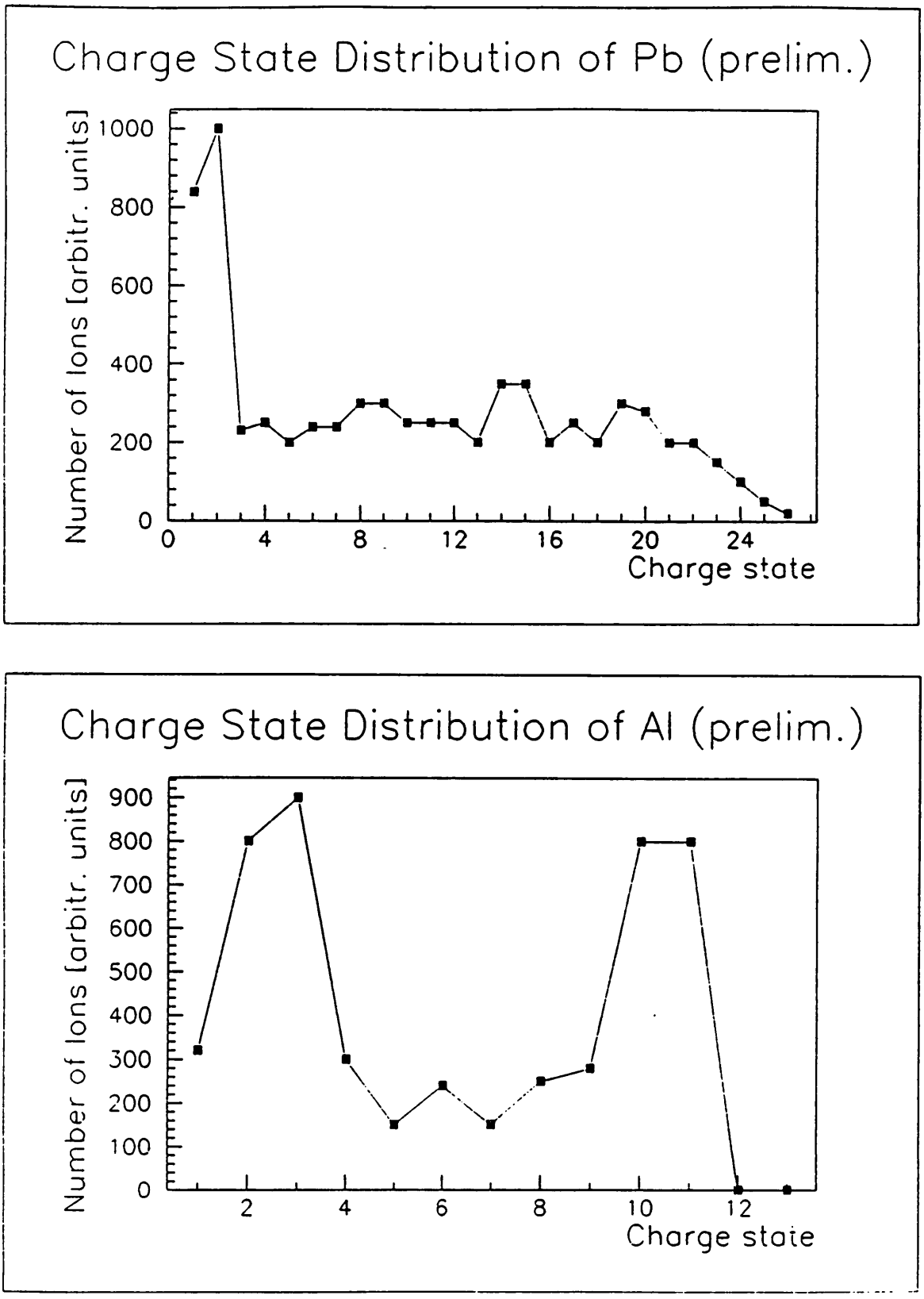

Figure 3. Charge state distributions.
Upper: lead. Lower: aluminium.

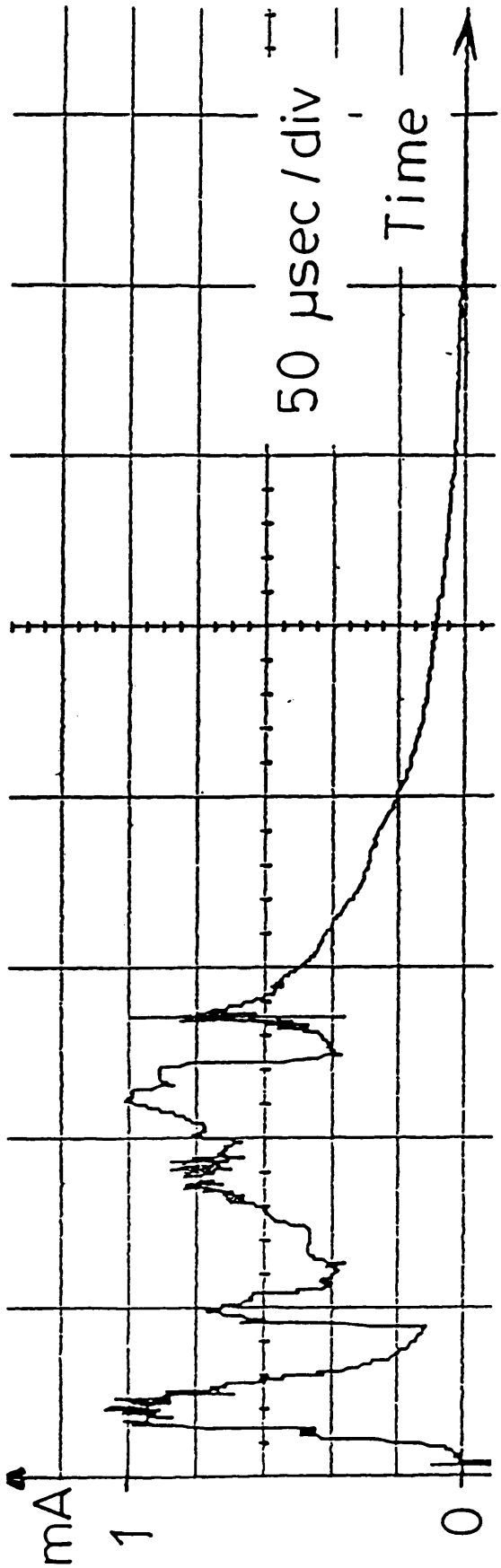

Figure 4. Ion current from a lead ion plasma, 3m from the target. Aperture 1cm² and solid angle 5.10-5str.

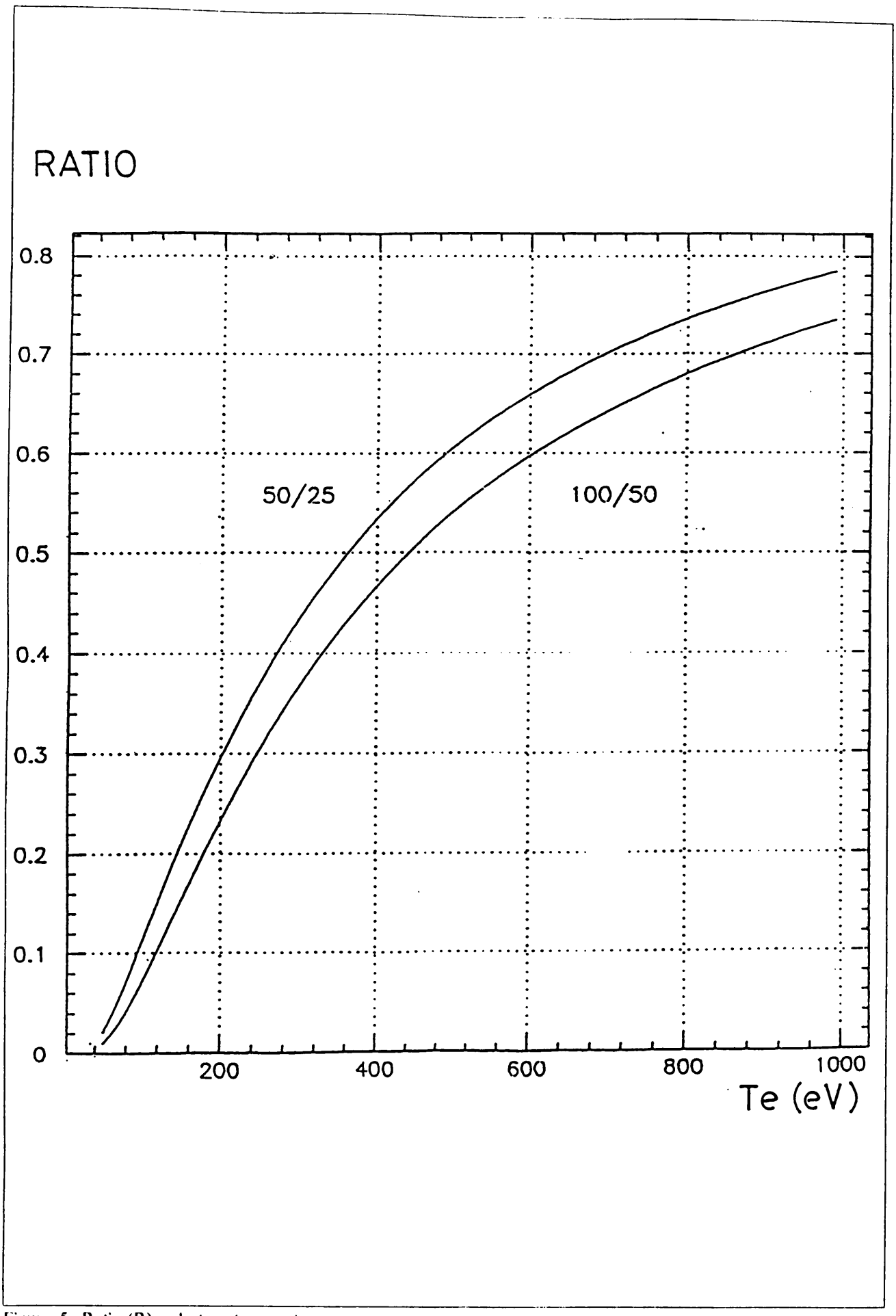

Figure 5. Ratio (R) v electron temperature

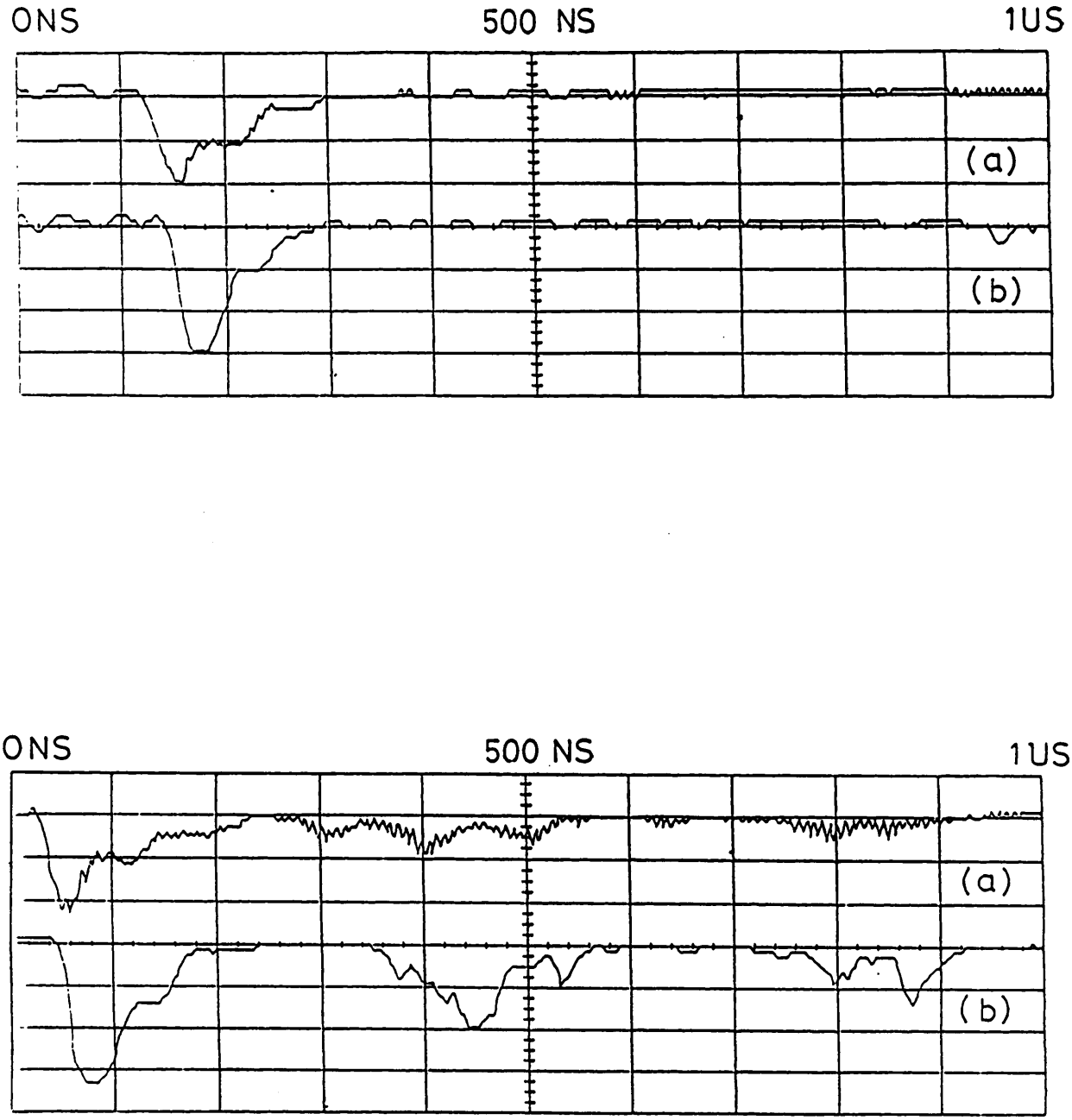

Figure 6. (a)Laser waveforms, (b)Photomultiplier signals.
Upper: without nitrogen in the laser gas mixture.
Lower: with nitrogen.

Bibliography

[1] H. Haseroth, *Concept for a Lead-ion Accelerator Facility at CERN*, CERN 90-01, 1990.

[2] A. A. Golubev et al, *Current measurements and charge components in beams made by laser-plasma*, ITEP 134-88, Moscow, 1988.

[3] G. Korschinek and J. Sellmair, Nucl.Instr. and Meth. **A268**, 473 (1988).

[4] G. O. Cano, J.Appl.Phys **44**, 5293 (1973).

[5] R. C. Elton, *Determination of electron tempratures between 50eV and 100KeV X-Rays continuum radiation in plasmas*, NRL 6738, 1968.