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## Accelerator & Fusion Research Division

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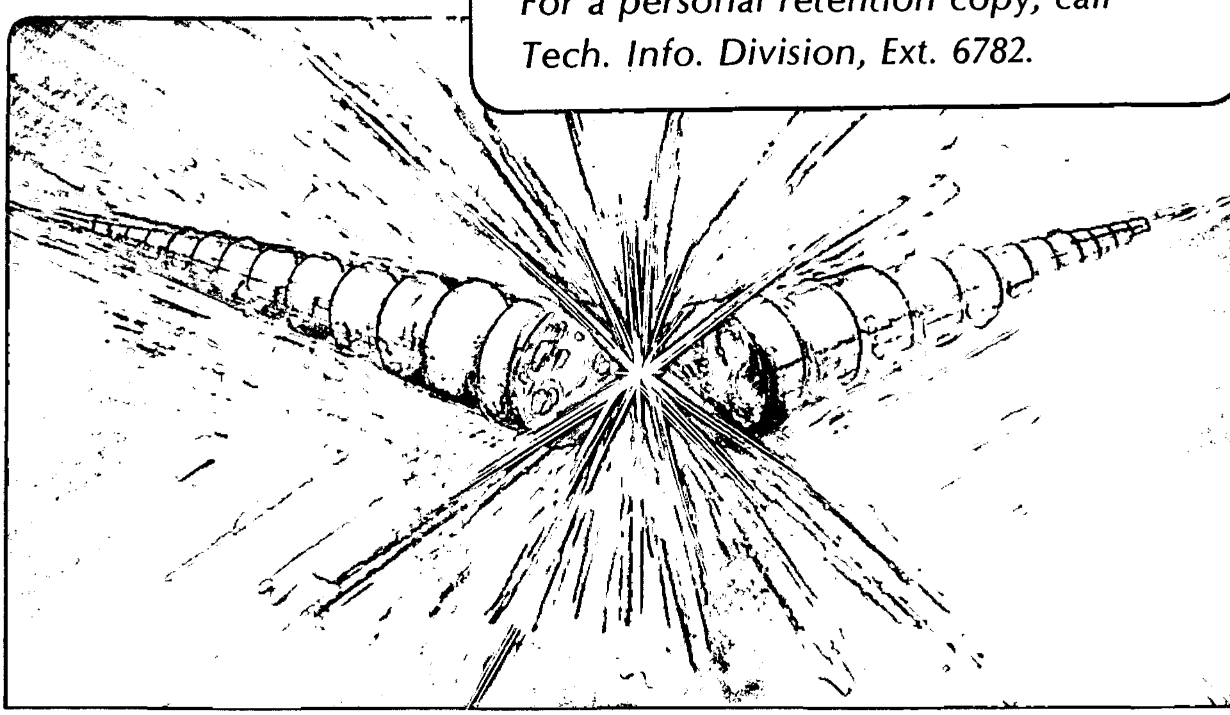

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# Electron Beam Probe for Charge Neutralization Studies of Heavy Ion Beams*

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Abstract

The design and operation of an Electron Beam Probe for ion beam diagnostics is described. Advantages of this method for the analysis of space charge neutralization studies are discussed and examples of its applications to heavy ion beams are shown.

## I. Introduction

The increased interest in intense ion beams for inertial confinement fusion has called for the development of nondestructive diagnostics of the beam space charge distribution. Charge neutralization measurements are necessary in schemes that call for neutralized ion beams(1), as well as schemes that call for unneutralized beams(2). Both space and time resolution are required. Conventional methods for measuring the space charge distribution rely on Faraday cups and other charge collectors. The difficulty with such methods is the interaction of the measuring devices with the ion beam, which lead to the creation of secondary electrons and a

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change in the space charge potential. In this paper we describe the development and operation of an Electron Beam Probe (EBP) that has been used to study the space charge distribution of the $Cs^{+1}$ beam at the Lawrence Berkeley Laboratory. The EBP is a nondestructive diagnostic tool that uses a low current electron beam traversing the ion beam. The deflection of the probing beam in the field of the ion beam provides information about the space charge distribution, while leaving the ion beam unchanged. In principle, either ions or electrons can be used, and both space and time resolution can be achieved. The application of the EBP to an ion beam differs from its application to a quasi-neutral plasma(3) in that the deflection of the electron beam by the ion beam is highly non-linear and the data inversion is more complex. The EBP is sensitive to both radial and longitudinal electric fields of the ion beam, and time information is achieved by chopping the electron beam.

In Section II the experimental set-up and the choice of parameters are described. Section III describes some of the observations, and in Section IV the data analysis is discussed.

## II. Experimental Set-Up

A low current (~ 10μA) electron beam is injected in a plane perpendicular to the ion beam, at different angles, and is detected on a phosphor plate placed on the other side of the ion beam (Fig. 1). The radial electric field of the ion beam deflects the electron beam for gun angles $\theta \neq 0^{o}$, if the beam is cylindrically symmetric. Prior to the experimental work, a parameter study was carried out with computer program that calculates the electron beam trajectories through the ion beam. Figure 2 depicts the trajectories of the electrons for 10 angles and for an infinitely long ion beam carrying uniform current density. The ion beam used in this experiment is a $Cs^{+1}$ beam at 1 MeV energy, 0.25 amp current, and 20 cm diameter, emerging from the Heavy Ion Fusion drift tube accelerator at the Lawrence Berkeley Laboratory(4). For typical ion beam parameters, reasonable deflection occurs at electrons energy of 5-10kV. In reality, the ion beam has finite length (~ 3 m), and the electron beam will respond to the beam longitudinal field as well as its radial field. The actual path traced out by the electron beam on the phosphor as a function of time provides information on both the radial and longitudinal fields of the ion beam.

The electron gun cathode is held at a negative potential of 5-10kV and the accelerating electrode is at ground potential, so that the electron beam has 5-10 keV kinetic energy when it leaves the gun. The electron beam is detected on a P22 phosphor coated on a curved stainless steel plate that follows the curvature of the tank (tank diameter = 60cm). This geometry allows cylindrical boundary conditions to be assumed in analyzing the data. Grid lines on the phosphor, at 25 mm separation, provide spatial information concerning the location of the electron beam striking the phosphor. The image on the phosphor is recorded with a camera on a polaroid film. In order to prevent burnt spots on the phosphor and overexposed pictures, the gun grid is normally biased at -40 V with respect to the cathode, so that no electrons are emitted. For the duration of the ion beam (~ 3 μs), an unblanking pulse of +40 V is applied to the grid providing a short burst of electrons. The initial electron beam angle is set by using electrostatic deflection plates or by mechanically rotating the gun. Scanning of the beam angle provides spatial information as discussed in Section IV. Temporal information is provided by chopping the electron beam at 10 MHz frequency. The chopping is achieved by modulating the unblanking pulse driving the grid.

## III. Experimental Results

A typical image of the electron beam on the phosphor is shown in Fig. 3a. As the ion beam approaches the location of the electron gun, both the longitudinal and the radial fields are increasing. The longitudinal field pulls the electron beam to the left while the radial field pulls it towards beam center (downward in Fig. 3). The superposition of the two forces results in a motion of the image towards the left and down. As the beam passes by the gun position, the longitudinal field diminishes while the radial field is still increasing. The decreasing longitudinal field combined with the still increasing radial field causes the electron beam spot to turn and move to the right and down. When the maximum radial deflection is reached, we expect the electron beam to draw a symmetric pattern to the right, on the phosphor plate. Instead, the electron beam slowly moves up. This is a clear indication of neutralization of the beam space charge as a function of time. The overshoot at the bottom of the picture is due to a current spike at the beginning of the pulse. Figure 3b exhibits a similar pulse with a modulated gating pulse to provide temporal information. The origin of the neutralizing electrons is believed to be secondary emission from the walls of the tank. More detailed studies of the neutralization process will be published elsewhere.

As an example of time-resolved controlled neutralization, we show the effect of the beam striking a large Faraday cup at the end of the diagnostic tank (Fig. 4). The Faraday cup is normally biased positively to keep secondary electrons that are generated on the collector (Fig. 4a). However, in Fig. 4b the collector is biased negatively so as to eject the secondary electrons towards the beam. As the beam strikes the cup the neutralization process accelerates.

## IV. Data Analysis

The analysis of transverse experimental data taken with the EBP consists of finding the radial charge density distribution of the heavy ion beam, given a certain set of measurements of electron beam transverse deflections at the phosphor-coated plate. Since the space-charge effects of the electron beam are small enough to be ignored, an important simplification may be made by assuming cylindrical symmetry for the ion beam space charge distribution. First, the ion beam charge distribution must be described by some appropriate set of parameters. Then, given any set of values of these parameters, it is a simple task to integrate the equations of motion of the electrons to derive the electron trajectories. In this fashion, the electron beam deflections (measured at the phosphor - coated plate) may be calculated for any electron gun angle. The data analysis task, then, is to find that set of ion beam parameters which yields the electron beam deflections that most closely approximate the measured deflections, in the least squares sense.

The primary difficulty of the analysis of the transverse data is caused by the non-linearity of the physical system. That is, the electron beam deflections are highly non-linear functions of the ion beam parameters. The selection of an appropriate set of ion beam parameters presents a secondary problem, which requires some trial and error.

The EBP data analysis computer program[5] consists of two main sections: a system analysis program which calculates electron deflections, and a Program for Inversion of System Analysis (PISA) which calculates ion beam parameters. PISA[6] finds the non-linear least squares solution by repeatedly linearizing the problem and changing the parameters in small steps. Figure 5a shows a fit to some measured data, and Figure 5b shows the corresponding ion beam radial charge distribution, which is modelled as the sum of a gaussian distribution and a trapezoidal distribution.

## Acknowledgment

The authors wish to acknowledge useful discussions with D. Keefe, and the mechanical design of the gun assembly by D. Vanecek.

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## Figures

(1) Experimental set-up.

(2) Electron beam trajectories in the field of an ion beam for different angles. The angles are: $\theta$ = $0^o$, $10^o$, $20^o$, $30^o$, $40^o$, $50^o$, $60^o$, $70^o$, $80^o$. Electron beam energy = 5 kV and ion beam line charge density is $2.5 \times 10^{-7}$ C/m.

(3) Typical electron beam spot on the phosphor screen for $\theta = 17^o$. The spot starts at the topmost point and moves to the left (towards the incoming beam) and down (towards beam center). It then drifts slowly back towards the starting point.

   a. Continuous beam – 3 $\mu$s long gating pulse without modulation.
   b. Chopped beam – 3 $\mu$s gating pulse with 10 MHz modulation.

(4) Neutralization effect due to secondary electrons from the Faraday cup, with the cup biased positive and negative. The beam strikes the cup at t = 1870 ns.

(5) Data inversion.
   a. Experimental data and best 5-parameter fit.
   b. Best 5-paramenter fit to radial charge density.

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(6) K. Halbach, Lawrence Berkeley Laboratory Report UCRL-7436 (1967).

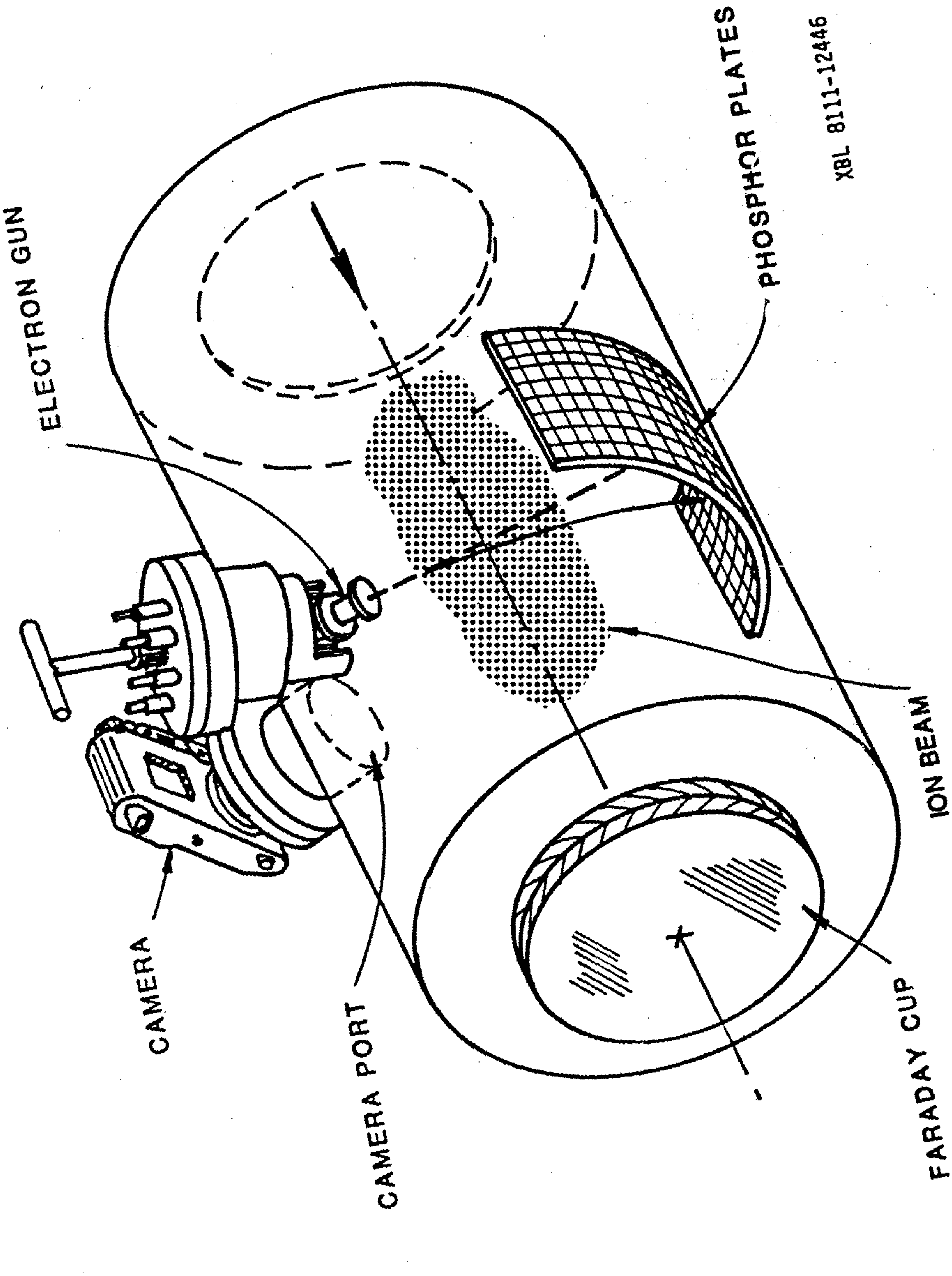

ELECTRON GUN
PHOSPHOR PLATES
XBL 8111-12446
ION BEAM
FARADAY CUP
CAMERA PORT
CAMERA

Figure 1

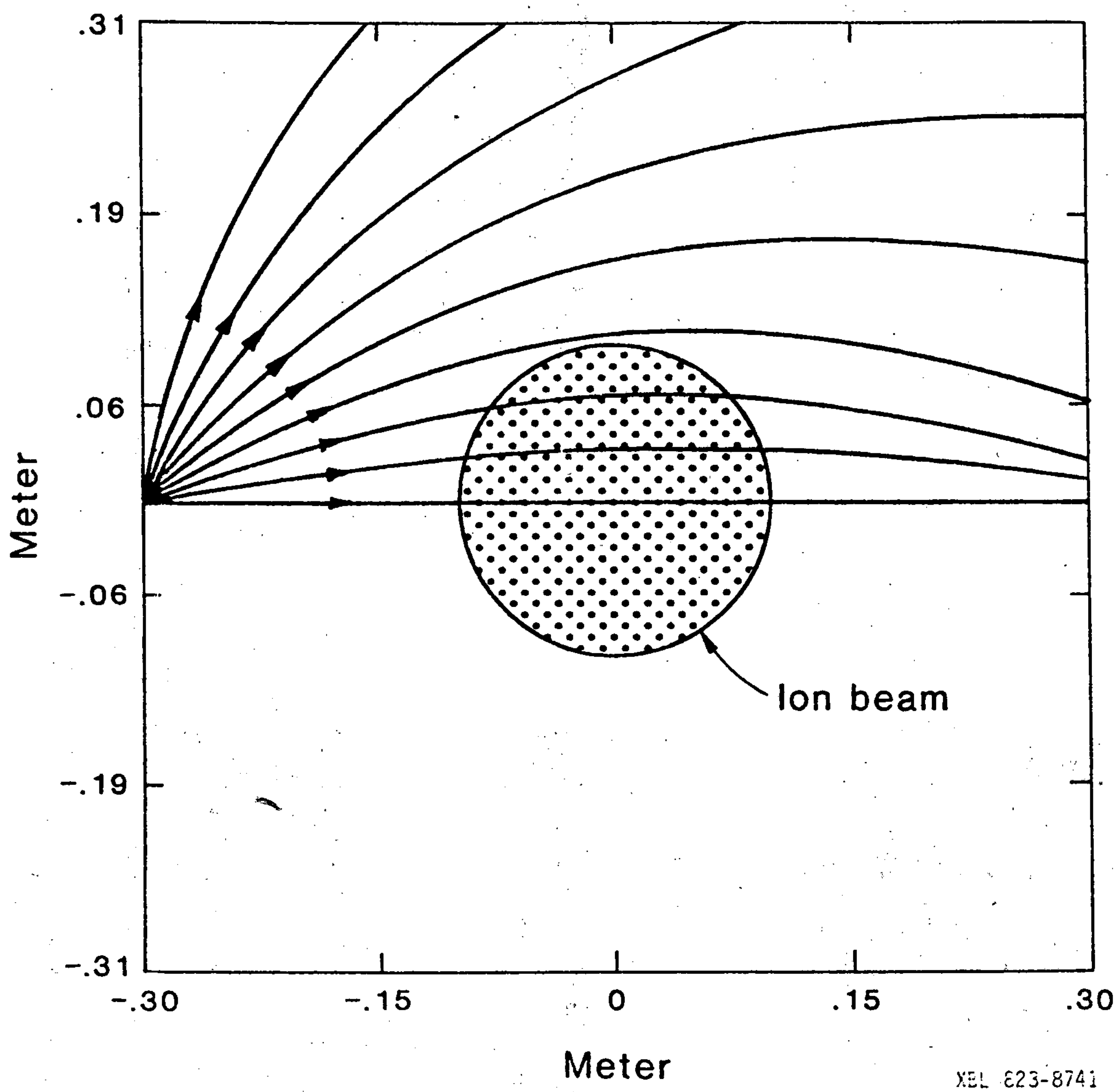



Figure 2

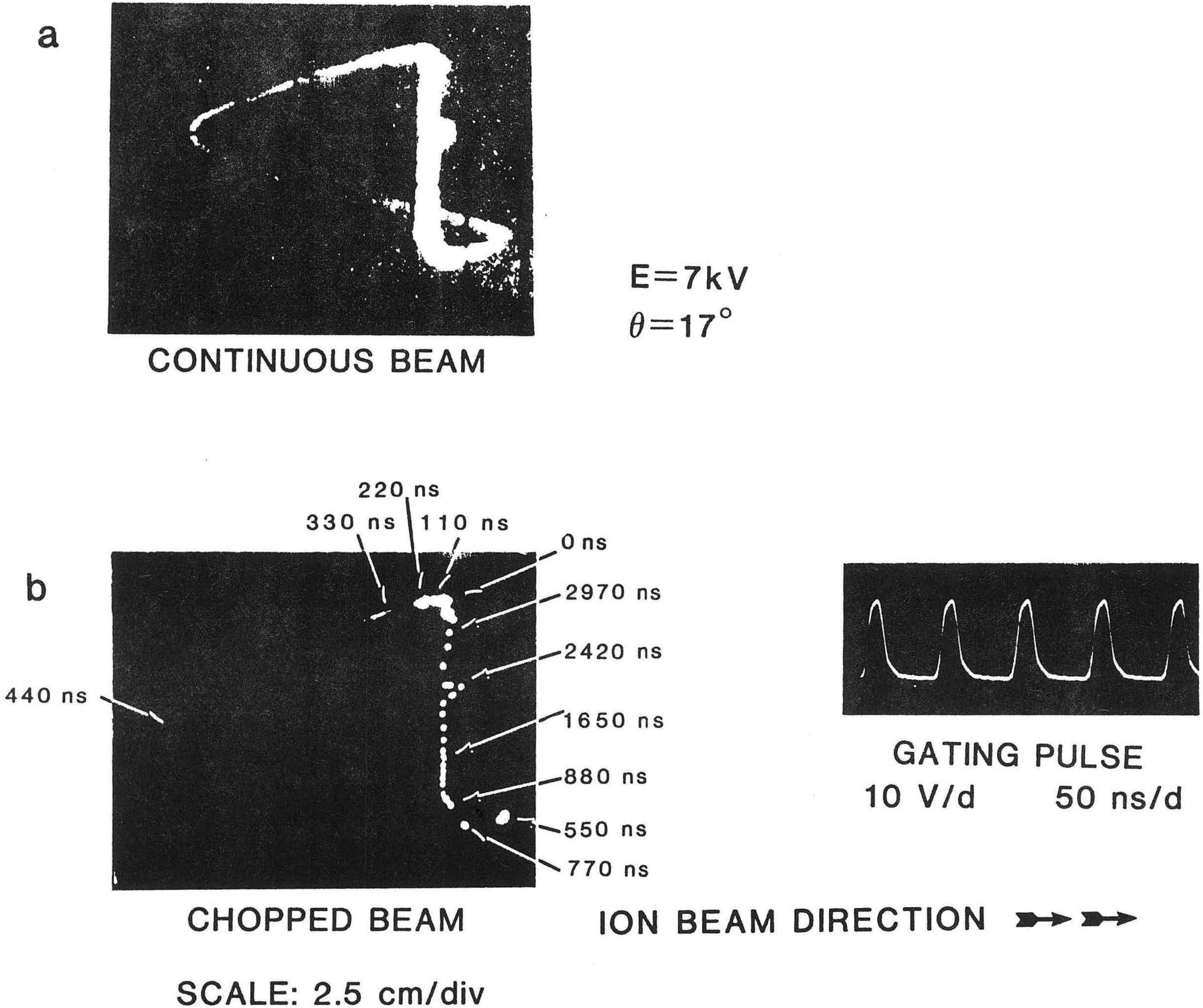
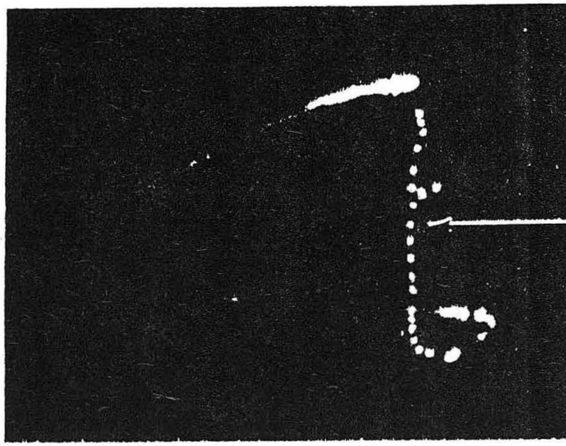

a
CONTINUOUS BEAM
E=7kV
θ=17°
b
220 ns
330 ns
110 ns
0 ns
2970 ns
2420 ns
440 ns
1650 ns
880 ns
550 ns
770 ns
CHOPPED BEAM
GATING PULSE
10 V/d 50 ns/d
ION BEAM DIRECTION
SCALE: 2.5 cm/div

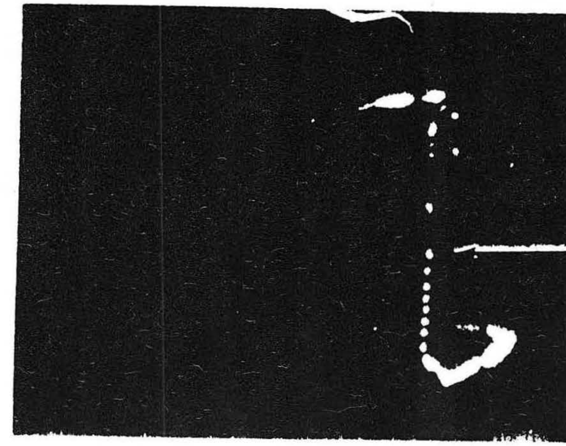
**Figure 3**

a




FARADAY CUP BIAS POSITIVE

b



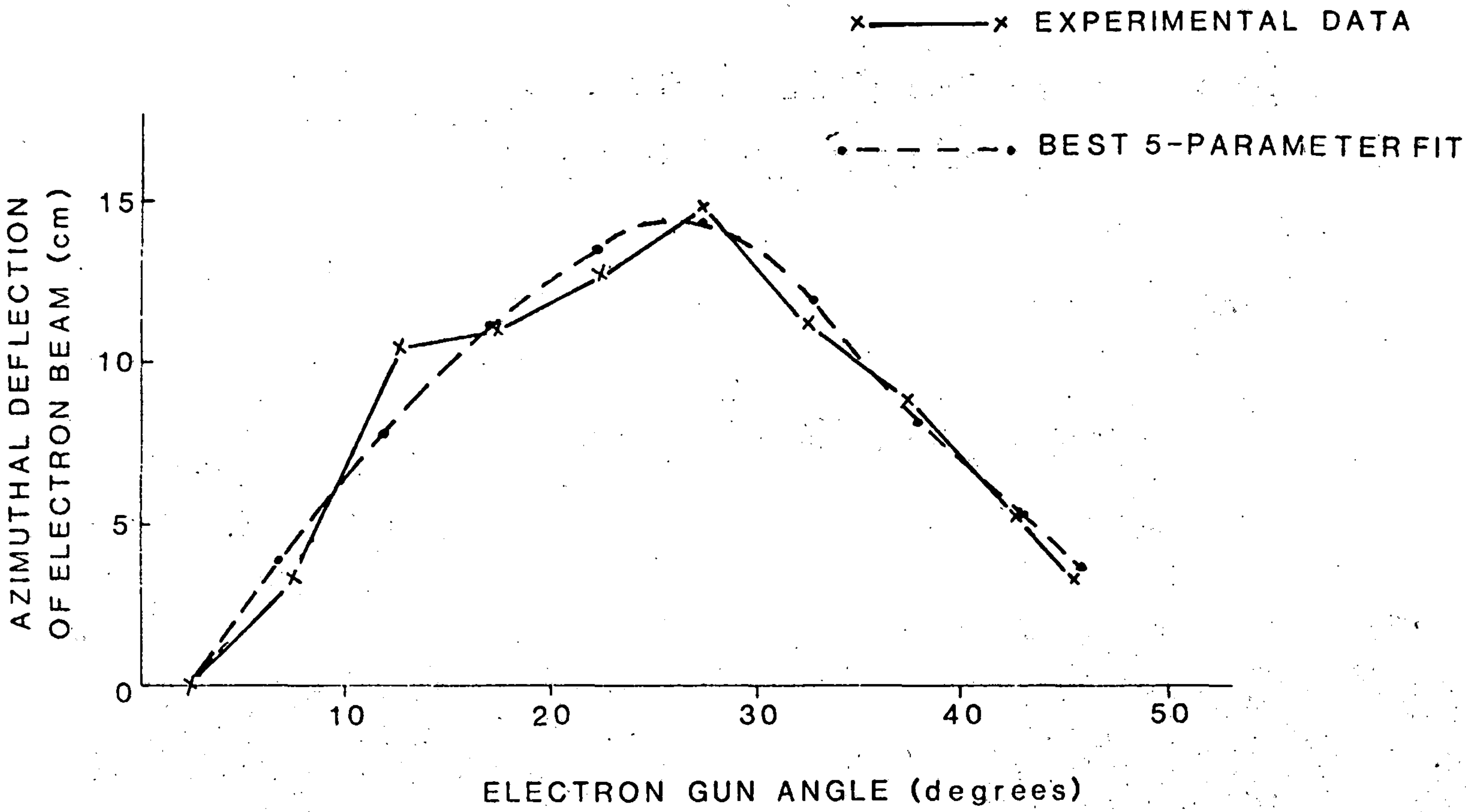

FARADAY CUP BIAS NEGATIVE

SCALE: 2.5 cm/div
E=7.5 kV
$\theta=16^\circ$

ION BEAM DIRECTION ➤➤➤➤

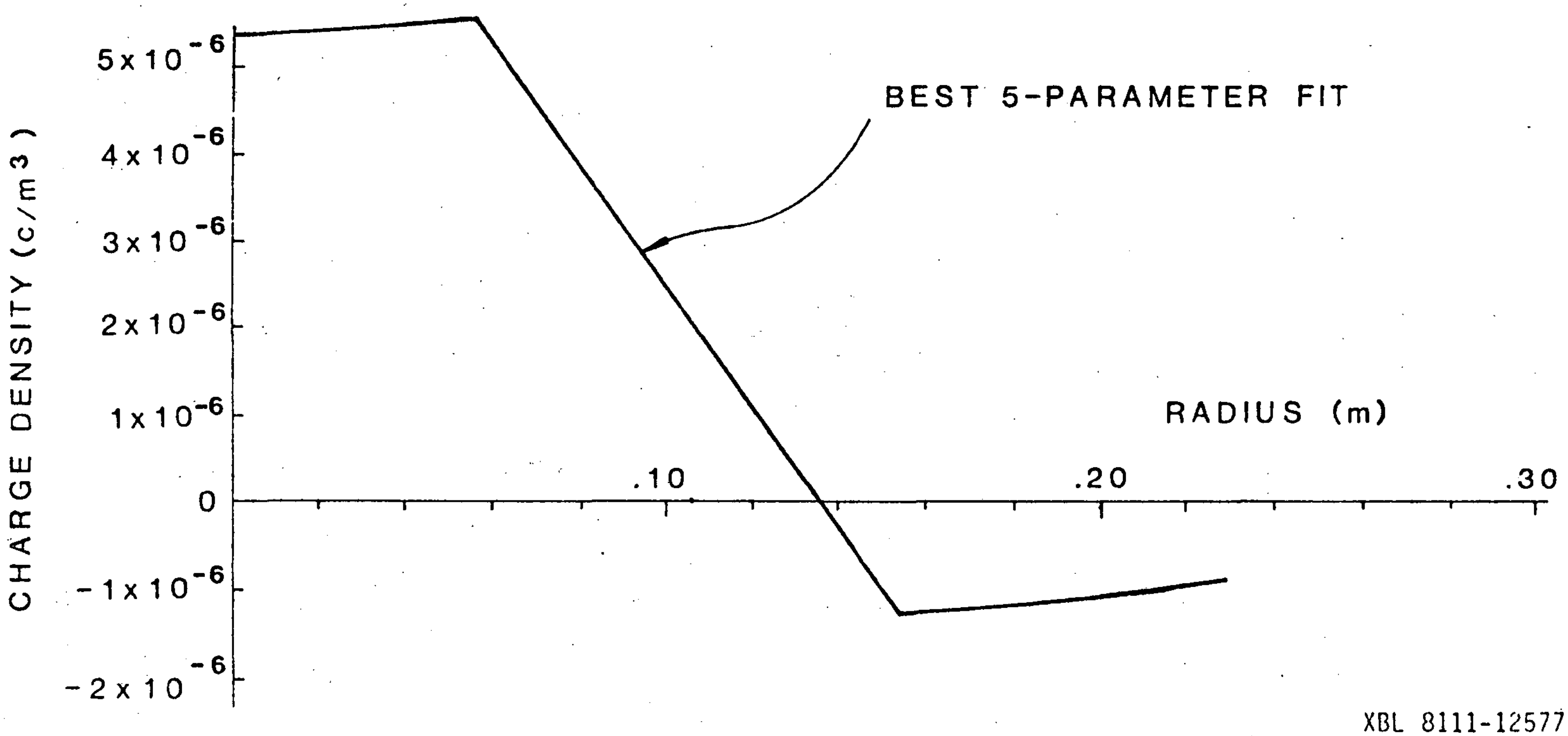
NEUTRALIZATION EFFECTS
DUE TO THE BEAM HITTING THE FARADAY CUP

Figure 4




XBL 8111-12578

Figure 5a



CHARGE DENSITY (c/m3)
5x10-6
4x10-6
3x10-6
2x10-6
1x10-6
0
-1x10-6
-2x10-6
BEST 5-PARAMETER FIT
RADIUS (m)
.10
.20
.30
XBL 8111-12577


Figure 5b

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