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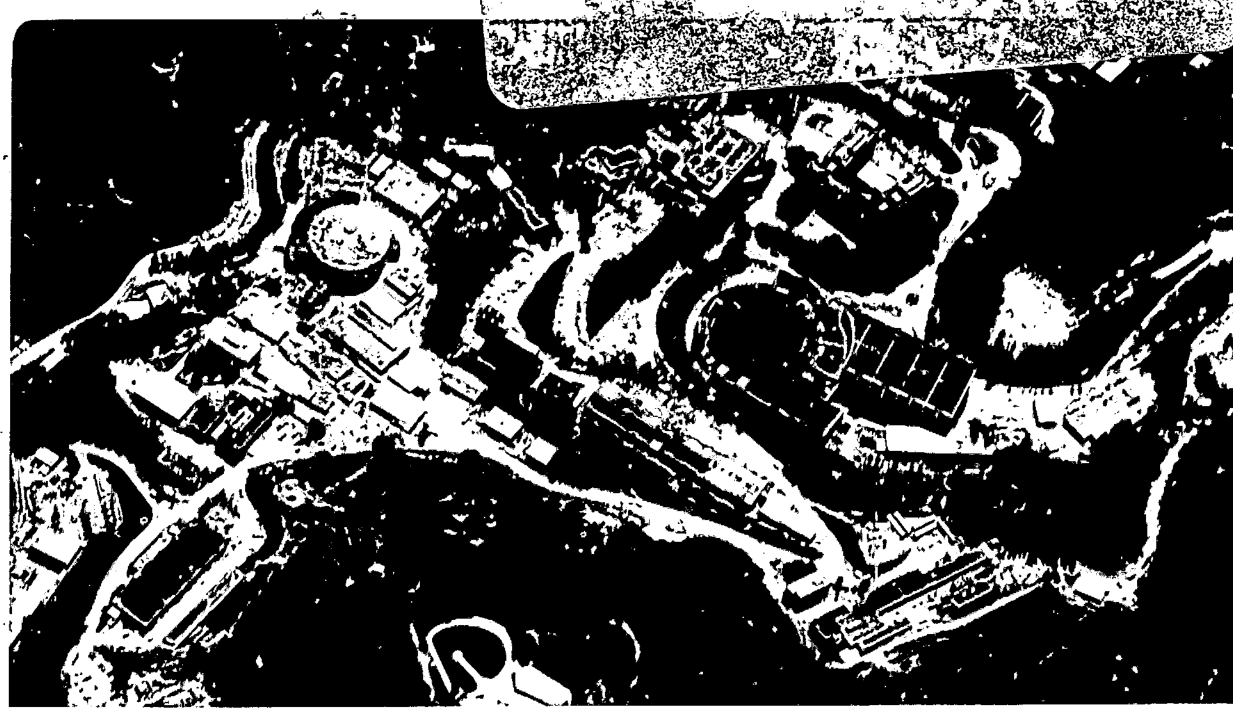

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NEUTRON STREAK CAMERA ELECTRON GUN DESIGN*

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ABSTRACT

Representative values for electrode voltages, time compensation, and transmission efficiency are obtained by computer simulation for a preliminary design of an electron gun to be used in a neutron streak camera application. The calculations indicate a time resolution on the order of 20 ps and a transmission efficiency of about 10 percent.

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I. INTRODUCTION

This paper describes a preliminary design of a neutron streak camera[1,2] electron gun consisting of a cathode, grid and anode terminated by a Neumann potential boundary 3.90 cm downstream from the cathode (see Fig. 1). The neutron source is 8 cm upstream from the cathode. The design goal was to determine if it is possible to compensate for the time spread of the electrons emitted from the cathode and to also pass a reasonable number of electrons through a pinhole located downstream from the accelerating focusing electrodes. Our results show that such a compensation can be obtained.

II. COMPUTATIONAL MODELS

A. Timing Adjustment of the Cathode Surface

Neutrons emitted from the source at a particular time t arrive at the cathode at a time $t + \Delta t$, where $\Delta t = 0$ at the cathode center and Δt is greater than zero for off-axis cathode points. Our principal goal was to compensate for this late arrival. Preliminary runs which varied the voltages and shapes of the cathode, grid and anode have led us to a parabolic cathode defined by

$$z = \alpha x^2 - R \tag{1}$$

where R = 2.5 cm. Rotation of this parabola about the z axis produces a surface of revolution which, when $\alpha = 0.21$, very well approximates a spherical cathode of radius 2.5 cm, radial extent x = 1.0 cm. Changing the value of α varies the position and angle of electron emission causing emitted electrons to arrive at the pinhole at different times. The value $\alpha = 0.25$ effectively cancels Δt_n, the electron emission time. Table 1 tabulates the cathode to pinhole transit times t, the difference in arrival times Δt, and emission times Δt_{ng} all referenced to the cathode axis of revolution. The pinhole, located 3.35 cm from the cathode surface, is at an approximate waist for 6 eV electrons emitted normal to the cathode surface.

Table 1 is for 6 eV electrons starting normal to the cathode surface. Estimating the actual time spread at the pinhole requires running other energies and, for each energy, tracking particles emitted at angles which are not normal to the surface. We have used the energies 3, 6, and 9 eV and angular spreads sufficient for transmission through 0.01 and 0.02 cm radius pinholes. This enables us to determine the overall transit time spread at the pinhole, which is shown in Fig. 2. The total spread is seen to be on the order of 13 ps for a pinhole of 0.01 cm radius and about 16 ps for a radius of 0.02 cm. The major spread occurs in the central region, $0 \leq x \leq 0.2$ cm, of the cathode. This suggests that if this region were non-emitting, then the time spread could be on the order of 10 ps.

B. Calculation of Neutron Arrival Times

Neutrons that leave a source located upstream from the cathode arrive at times proportional to their energy and to the distance R_n of the cathode surface from the source. See Fig. 1. This causes electrons to be emitted at times that depend on how far the emission point is from the center of the cathode. To compensate for this difference Δt in emission times, it is necessary to know the neutron arrival times at the cathode.

These are calculated from

$$\Delta t_n = \Delta d / v_n ; \Delta d = (R_n + (z - z)^2 + x^2 - R_n ; v_n = \beta c \qquad (2)$$

where $R_n = 8$ cm, $z = 0.01$ cm, $\beta = 0.171$ for 14.1 MeV neutrons, and $c = 2.997929 \times 10^{10}$ cm/sec. The values of x and z are those defining the cathode surface for the EBQ[2] runs. Note that $\Delta z = 0.01$ cm is the cathode surface in the EBQ coordinates. These times are tabulated in Table 1 as Δt_n.

C. Transmitted Beam Calculation

The EBQ ray tracing runs provide enough information to estimate what fraction of the total beam emitted from the cathode will pass through a pinhole located downstream from the anode. The results needed for this calculation are given in Fig. 3.

For electron starting energies of 3, 6, and 9 eV this figure shows which rays go through a pinhole of radius 0.01 cm located 3.35 cm downstream from the cathode. For each of the three energies are plotted the initial radius and angle of the emitted electron; i.e., the initial conditions for rays on the cathode at the time of emission. Rays that go through a 0.01 cm radius hole are plotted as points "•"; those that do not go through a 0.01 cm radius hole, but go through a 0.02 cm radius hole are plotted with a circle around a point "ʘ"; and those that do not pass through either of the holes are plotted with a "+". Thus, the beam emitted from the cathode which goes through a 0.01 cm radius hole is the totality of all the "•" points; that which goes through a 0.02 cm radius hole is the totality of all the "•" and "ʘ" points. The actual transmitted fraction of the total beam emitted from the cathode is estimated by using the transmitted points to calculate the transmitted beam and then dividing that quantity by the total emitted beam.

The transmitted beam calculation is a discrete summation of the integral of the emitted electron distribution function over angle, space, and energy. The transmitted angles are determined by EBQ runs, the areas are circular bands around the axis of revolution, and the energies are 3, 6, 9 eV. Let A_i be the area of emission for which the number of electrons emitted is N_i per unit area. Let F_{ij} be the angular fraction of emitted electrons that is actually transmitted at energy εj for area A_i, and let E_j be the fraction of the electrons emitted at energy ε_j. Let g_i be the geometric factor that takes into account the angle and distance of the emitting area A_i with respect to the neutron source. Let N_0 be the number of electrons emitted per unit area on the axis. Then the number of transmitted electrons is

$$I = N_o \Sigma_j (\Sigma_i A_i g_i F_{ij}) E_j \tag{3}$$

and for the total number emitted is

$$I_T = N_o \Sigma_i A_i g_i \tag{4}$$

and the fraction transmitted is

$$f = I/I_T \tag{5}$$

where i is summed over all areas and j is summed over all energies of emission.

If we assume that the angular emission is a cosine distribution, then for any radius x the angular fraction of electrons transmitted is $\int K \cos\Theta \, d\Theta$, $-\pi/2 \leq \Theta \leq \pi/2$, where K = 0 if the beam is not transmitted and K = 1/2 if it is. We use Fig. 3 to evaluate this integral for each value of x.

The sample rays in the EBQ runs were at radii 0, 0.2, 0.4, 0.6, 0.8, and 1.0 centimeters. When estimating the transmitted beam, we assumed that the rays at 0.0 cm represent the emission from a parabolic cap of radius 0.1 cm, the rays at 0.2 cm are for a band from 0.1 to 0.3, etc. The last band is from 0.9 to 1.0 centimeters. The cathode is a surface of revolution about the z axis, see Eq. 1, the area of which is given by

$$A_p = (\pi/6\alpha^2)(1 + 4\alpha^2 x^2)^{3/2} - 1.0 \tag{6}$$

The band areas were obtained using $\alpha = 0.25$. For $\alpha = 0.21$ the areas are very close to spherical areas. We also assumed that the neutrons that hit the cathode are emitted from a point source upstream from the cathode a distance R_n, see Fig. 1, and that the neutron emission is isotropic.

If we know the neutron flux passing through the center of the cathode, where $\Theta = 0$, we can estimate N_o the number of electrons emitted per unit area from the center of the cathode. Then N_i, the number emitted per unit area from band i located x_i from the center, is

$$N_i = N_o g_i, \qquad g_i = \cos(\Theta) R_n^2/r^2 \tag{7}$$

The geometric factor g_i takes into account both the distance and the angle Θ

of the cathode surface with respect to the neutron source.

To complete the estimate of the transmitted beam, it is necessary to know the fraction of electrons emitted at each of the three energies. This information was not readily available, so we assumed E_3 = fraction at 3 eV = 1/6, E_6 = fraction at 6 eV = 4/6, E_9 = fraction at 9 eV = 1/6. Using the results of our runs and the above assumptions, we obtain from Eq. 3, $I = 1/6(0.4729) + 4/6(0.26432) + 1/6(0.20204)$, $I = 0.2887\ N_0$; and from Eq. 4, $I_T = 2.9369\ N_0$ for the total possible transmitted beam.

The fraction transmitted is then given as $I/I_T = 0.2887/2.9369 = 0.0983$. Thus, we estimate that 9.8% will go through a pinhole of radius 0.01 cm located 3.35 cm downstream from the cathode. This result is dependent on the actual energy distribution. If we take $E_3 = E_6 = E_9 = 1/3$, then $I/I_T = 0.3131/2.9369 = .107$.

Thus, a reasonable estimate is that 9-10% of the beam is transmitted. Reference 3 contains tables of the quantities used to arrive at these answers.

III. EBQ INPUT DATA AND OUTPUT

Program EBQ was used to do the design runs. The basic data set consists of geometrical considerations and potential distributions as explained in reference 3. Fig. 1 gives the geometric layout corresponding to our electron gun. Potentials are specified for the cathode, extractor, and anode. The 6 rays used to establish the beam behavior start on the parabolic cathode surface at given starting energies and angles. Values for the complete data sets and further computational details are in Ref. 3. All runs were made by activating and deactivating the starting energy and angles as required. A ray tracing plot obtained is shown in Fig. 4.

The cell size chosen for the solution of Laplace's equation, 0.04 x 0.04 cm, is fairly large; a more detailed study of the effect of the surfaces on the electrons should refine this to ensure that the electric fields are sufficiently accurate and smooth during the orbit integration; also, the runs were made without space charge effects.

The program results used here were taken from the computer printout at z = 3.450 cm corresponding to an approximate waist located 3.35 cm downstream from the center of the cathode. The quantities of most interest for us were the transit time T in ps, the radial position x in cm, the energy E in eV, the path length S in cm, and the divergence $X' = \tan^{-1}(P_x/P_z)$. Other tabulated quantities are given in reference 3. A set of results was generated for each of the energies 3, 6, and 9 eV, the analysis of which produced the results in this report.

If further design work is done on the neutron streak camera, it would be desirable to more precisely locate the beam waist and also to output the corresponding (X,X') phase plot at that waist. The value z = 3.45 cm is approximate and the transmission efficiency might be improved by locating the pinhole at the exact waist instead of an approximate position as we have done.

IV. SUMMARY OF RESULTS

The principal results are summarized below. For a 14.1 MeV neutron source located 8 cm upstream from a 1 cm radius cathode that is a parabolic surface of revolution (see Fig. 1) we have, at a pinhole located 3.35 cm downstream from the cathode, a time spread Δt of 13 ps for a hole radius of 0.01 cm and 16 ps for a hole radius of 0.02 cm. Transmission estimates for the 0.01 cm hole indicate that about 10% of the emitted beam is transmitted through the hole. With the cathode voltage taken as 0 volts, the corresponding grid voltage is 8 kV and the anode voltage is 25 kV. This study indicates that it is possible to significantly change the electron transit times by changing the cathode surface and still achieve a reasonable electron transmission through a small pinhole which can then serve as a source for the next stage of a neutron streak camera. The results also suggest that better transit time compensation can be obtained by using a non-emitting surface in the center region, $0 \leq x \leq 0.2$ cm, of the cathode. The resultant loss in transmitted electrons would not be significant. Without these center region electrons the percentage transmitted is 9% of the total which includes this center region. These results cover emission energies of 3, 6, and 9 eV; they do not include any Δt_s arising from the straggling of electrons from the surface.

Using as a source the transmission characteristics of this electron gun, we attempted to propagate this beam to the phosphor plate of a streak camera with magnification close to one and time spreads within the design limits. Basically, this section consisted of an einzel type lens approximately 20 cm long with potentials of V_2 = 25 kV and V_3 = 1.0 kV (see Fig. 1). Our results are very preliminary, but they indicate that we can produce a collimated, focussed beam at the plate with magnification close to one and a transit time spread of about 5 ps.

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Radial Position (x) cm	Transit Time (t) ps	Time Spread t ps	Δt_n ps
0	810	0	0
0.2	807	3	−2.45
0.4	800	10	−9.80
0.6	787	23	−22.02
0.8	770	40	−39.07
1.0	749	61	−60.90

Δt_n = Time spread at emission, ps, for 14.1 MeV neutron source 8 cm upstream from the cathode

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Table 1. Transit times and time differences at pinhole for 6 eV electrons emitted normal to the cathode, $\alpha = 0.25$.

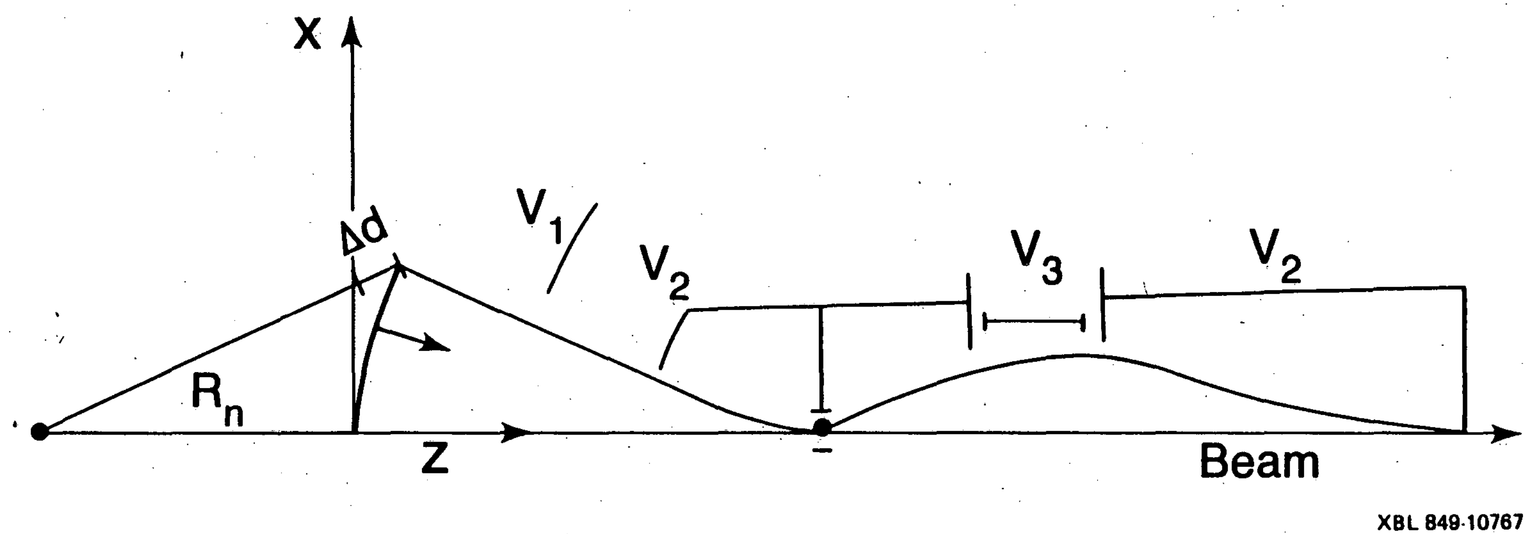

Fig. 1. Electron gun plus einzel lens.

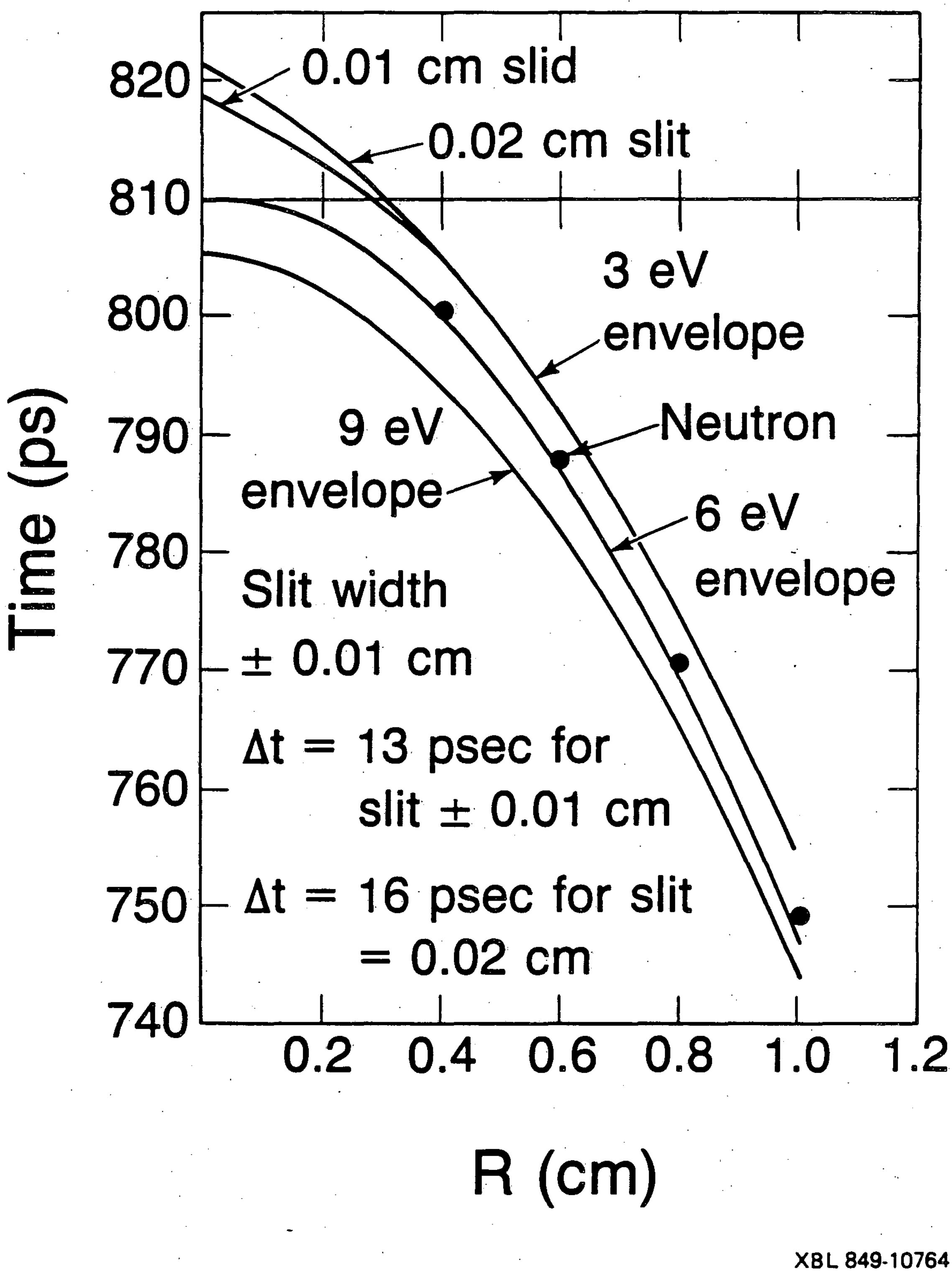

Fig. 2. Transit times versus radial emission point.

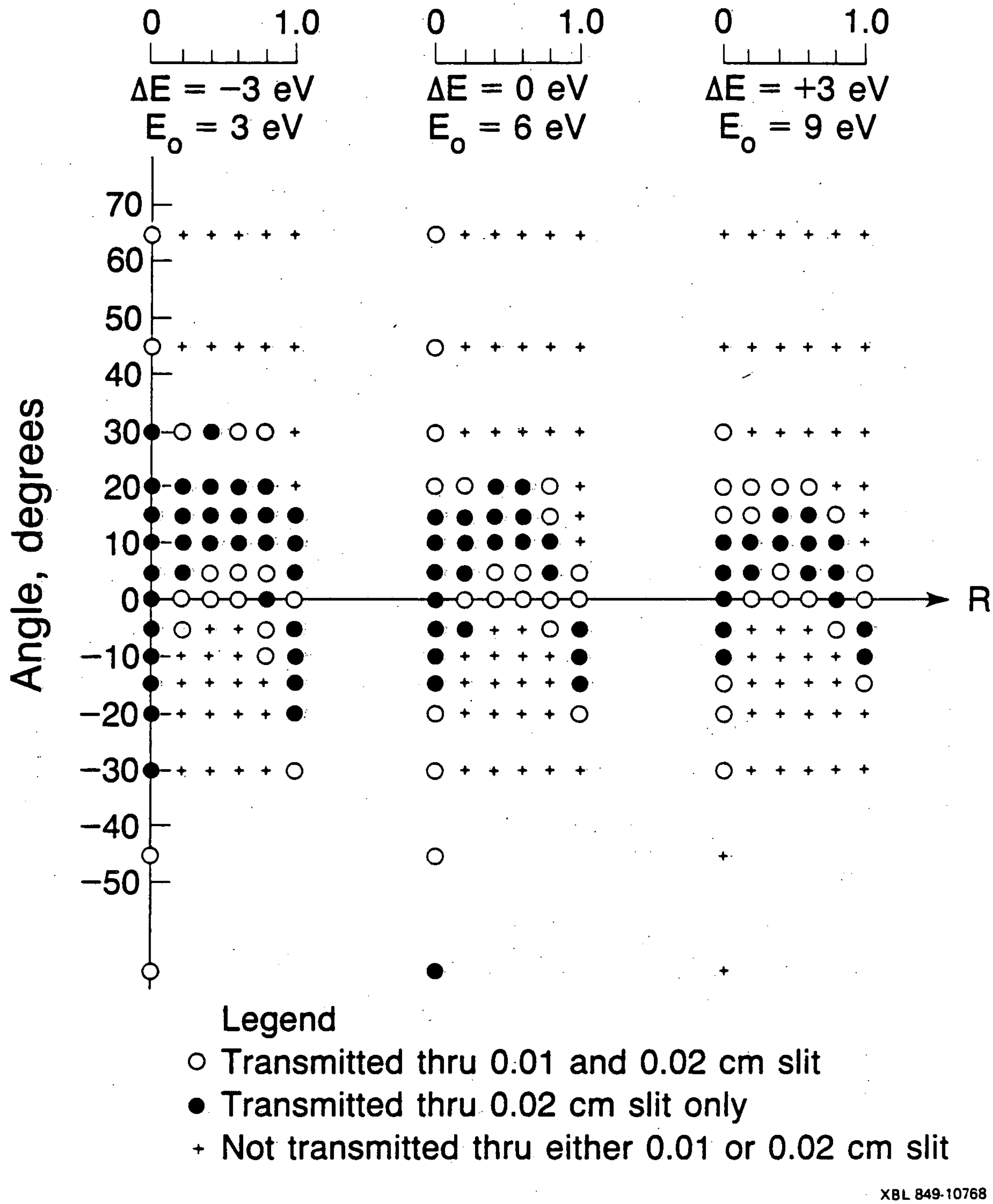

Fig. 3. Initial values of transmitted and rejected electrons at the cathode surface for 3, 6, and 9 eV energies. Pinhole is located at 3.35 cm from the cathode surface.

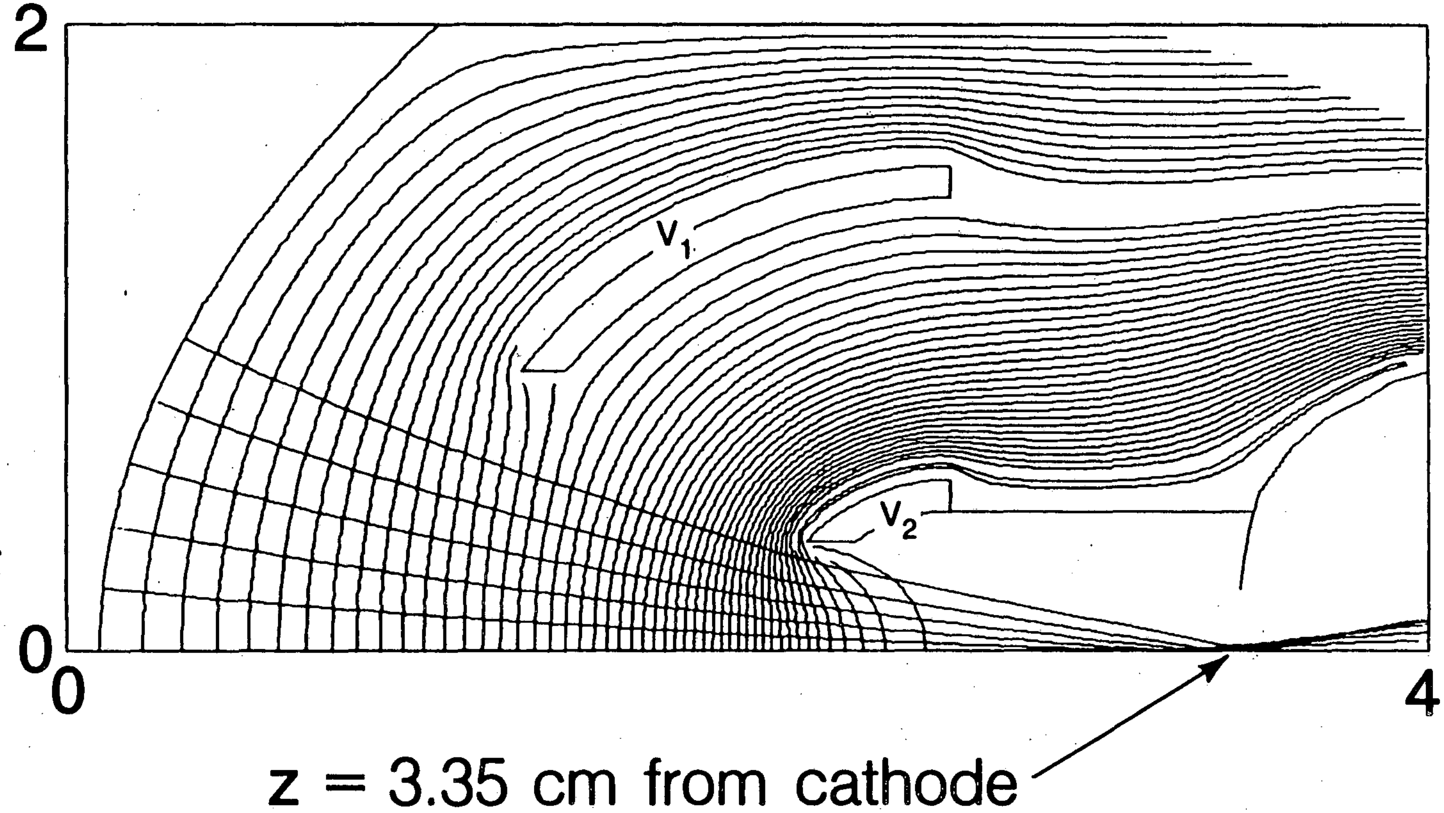

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Fig. 4. Electron trajectories for front end.

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