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A SHORT COLUMN STUDY

To inject the proton beam into the Linac it is necessary to accelerate the beam up to an energy of 500 keV. Acceleration takes place in a 83 cm column with a gradient of about 6 kV/cm. Due to the weak focussing properties of this column, it is necessary to insert a focussing lens system between source and column.

A way of improving the many component pre-injector is a stronger focussing short column (12 - 14 cm) omitting the electrostatic lens.

Beam properties of various types of short columns were studied using IBM 709 programmes for computing :

a) the potential distribution in an electrostatic lens and

b) the trajectories through this potential field.

These studies have used the approximation that the beam charge does not modify the electric field. Within this approximation we can conclude that a three-electrode column (extractor, intermediate electrode with grid and end-electrode) possesses good focussing properties and produces an emittance which can easily be accepted by the first triplet of the beam transport channel, placed immediately behind the column.

1. Method

The properties of an optical system can well be described in terms of the shape in phase space of an ellipse which represents the incident beam originating from the source.

The differential equation of the trajectories of a homogeneous beam of protons in a rotational symmetric potential field V (r, z) in MKS units, with V in kV, is given by :

$$\frac{d^2r}{dz^2} + \frac{1}{2V}\frac{\partial V}{\partial z}\frac{dr}{dz} + \frac{r}{4V}\frac{\partial^2 V}{\partial z^2} + \frac{20.58\ I}{rV^{\frac{1}{2}}} = 0 \quad \ldots (1)$$

The last term represents the effect of space charge in which I is the beam intensity. The potential distribution V (r, z) in the "column" has been computed by an IBM 709 relaxation programme written by J.B. Hornsby (unpublished) and which we have checked in an electrolytic tank. A correspondance of the potentials better than 1 % was found.

Another IBM computer programme traces rays through a given potential field by resolving equation (1) step by step (J.B. Hornsby unpublished). A useful check of this programme is obtained by applying the theorem of Liouville in beam optical systems,which says that the region enclosed by the boundary curve in the phase space can only contract during its motion at increasing velocity or expand at decreasing velocity :

$$A\ (z_i)\ v\ (z_i) = A\ (z_0)\ v\ (z_0)$$

or $\quad (2)$

$$A\ (z_i) = A\ (z_0)\sqrt{\frac{E\ (z_0)}{E\ (z_i)}}$$

in which $A\ (z_i)$ and $E\ (z_i)$ are respectively the phase space area and beam energy at the position z_i

The distances between the electrodes must be chosen as short as possible but these lengths are limited by the electrical break-down in vacuum. Fig. 1 shows the empirical threshold between no-vacuum sparking and possible sparking published by Kilpatrick (1957 *). In Fig. 1 W is the maximum possible

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* Rev. Sc. Inst. 28, 825, 1957 W.D. Kilpatrick

ion energy and E the electric gradient. The cross in this plot corresponds to the maximum gradient which is used in this study viz. 50 kV/cm.

2. Results and discussion

2.1 A two-electrode short column

The shape of the first accelerating electrode or extractor was copied from the Bevatron duoplasmatron (W. Allison et al. 1961 **). The second electrode is a normal shaped accelerating electrode. The gradient in this column has a maximum value of 47 kV/cm.

Fig. 2 shows the potential distribution within the boundaries of the electrodes. One can see that the strong focussing action of the extractor starts about 5 mm behind its opening.

Fig. 2a indicates the potential distribution along the axis. The starting emittance of 375 μrad at 70 keV is a mean value from the data of Allison et al.

The envelopes through the column for homogeneous beam intensities of 100 and 200 mA are given in Fig. 3. There is relatively small influence of space charge on the beam properties due to the very large longitudinal forces.

The emittances of the source (at z = 0) and the column (at z = 122 mm) for 100 and 200 mA beams are given in Fig. 4. The very divergent beam (about 100 mrad) cannot fully be accepted by the first triplet of the beam transport channel whose diameter is 39 mm and 200 mm long ; so one has to improve the beam performances e.g. by inserting a third electrode with focussing action.

2.2 A three-electrode column

The shape of the extractor and the last electrode are not changed ; their mutual distance has been increased with 20 mm.

** Rev. Sc. Inst. 32, 1331, 1961 R.W. Allison et al.

The shape of the focussing intermediate electrode is about the same as that of the extractor ; the opening angle is smaller (14^{o}) and its length is somewhat longer (20 mm). See Fig. 5.

A tungsten grid (95 % transparency ***) which prevents a defocussing section within the column is fixed in front of the electrode. The position of this electrode must be as near the extractor as possible for getting maximum focussing action. A potential of 160 kV was chosen with a maximum gradient of 50 kV/cm between it and the extractor. The gradient along the axis shows clearly the focussing effect of the middle electrode (see Fig. 7a).

Fig. 5 indicates the envelopes of a 200 mA beam with and without grid and Fig. 6 the emittances at the end of the column. The emittance at $z = 0$ (source exit) is identical as given in Fig. 4. The shape of the grid (circular, parabolic, etc..) hardly influence the shapes of the emittances. The aberrations of the outer rays due to the focussing effect of the middle electrode are clearly shown in the emittances of Fig. 6. If one compares these results with the emittances of a two-electrode system, than the most important improvement of the three-electrode system is the much smaller divergence (about 50 % less). These emittances can easily be accepted into the triplet of diameter 39 mm which is immediately behind the last electrode.

The essential difference between the short column and the conventional types of pre-injectors can be shown by comparing the gradients along the axis in the various pre-injectors.

Fig. 7a, 7b and 7c give the gradients as a function of the distance to the ion source in respectively the short column, the Berkeley lens plus column and the Septier lens plus column.

The maximum gradient in the short column is about three times higher than the maximum gradient in a standard lens. The total length of a short column is about seven times shorter than the conventional types.

*** These grids of 0.001" wires and a mesh of 0.5 x 0.5 mm are used in the pre-injector focussing system of the AGS machine at Brookhaven.

3. Conclusion

A good approach for a short column with reasonable end-performances seems to be a 14 cm column with three electrodes and grid focussing.

However, one must consider this study as a guide to the principles which can be applied in the design of a short column. For instance it is not at all excluded that the emittances of the source are smaller than 375 μrad at 70 keV (U. Tallgren 1962 ****). The end performances of a 200 mA beam (with starting emittance of 250 μrad instead of 375 μrad at 70 keV) are now very reasonable in a two-electrode column viz. r_{max} = 12.6 mm and $(\Delta r/\Delta z)_{max}$ = 79 mrad. In a three-electrode column they become of course more favourable : r_{max} = 11.5 and $(\frac{\Delta r}{\Delta z})_{max}$ = 51 mrad.

4. Acknowledgments

I am indebted to Mr. J.B. Hornsby and Mr. M. Weiss who have provide me with the tools of this study viz. the IBM programmes and Mr. C.S. Taylor for his stimulating interest in this work.

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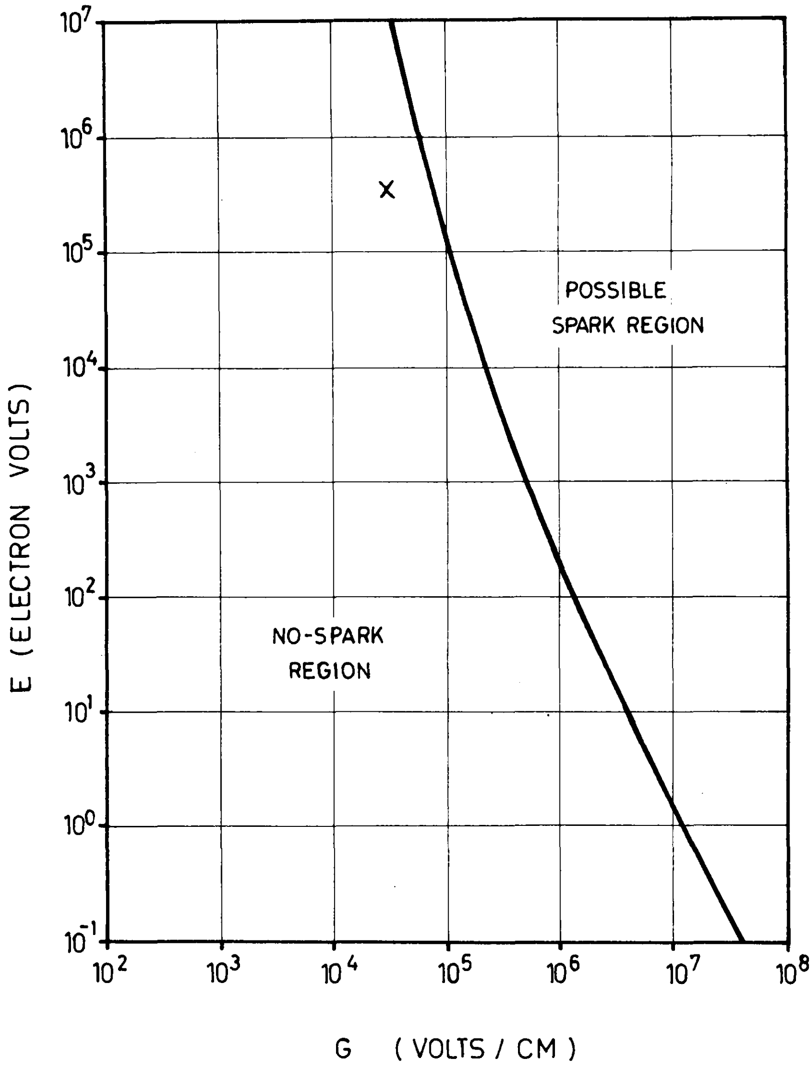

FIG.1 THE MAXIMUM ION-ENERGY 'E' AS A FUNCTION OF THE GRADIENT 'G'.

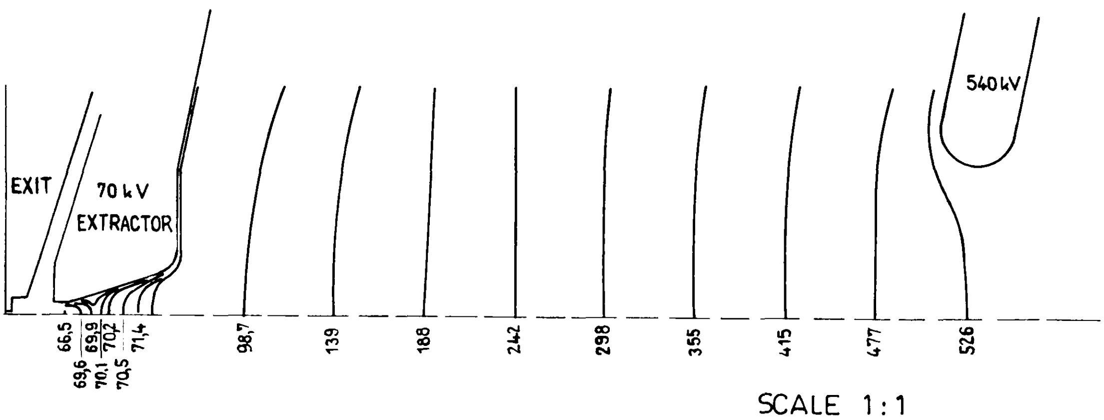

FIG. 2 THE POTENTIAL DISTRIBUTION IN A TWO-ELECTRODE SHORT COLUMN.

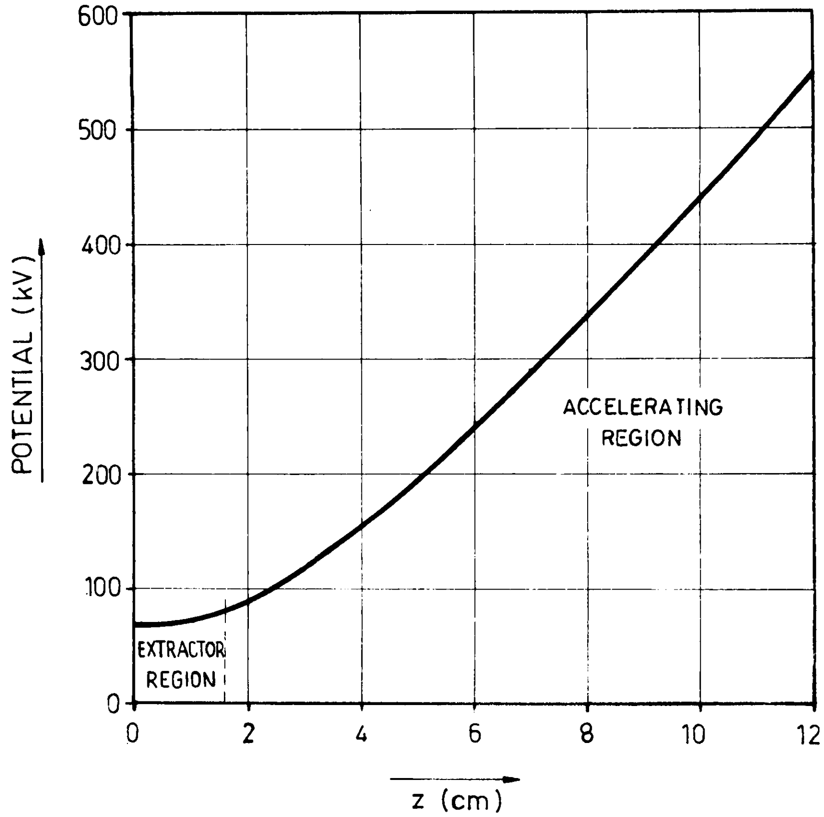

FIG. 2a POTENTIAL DISTRIBUTION ALONG THE AXIS.

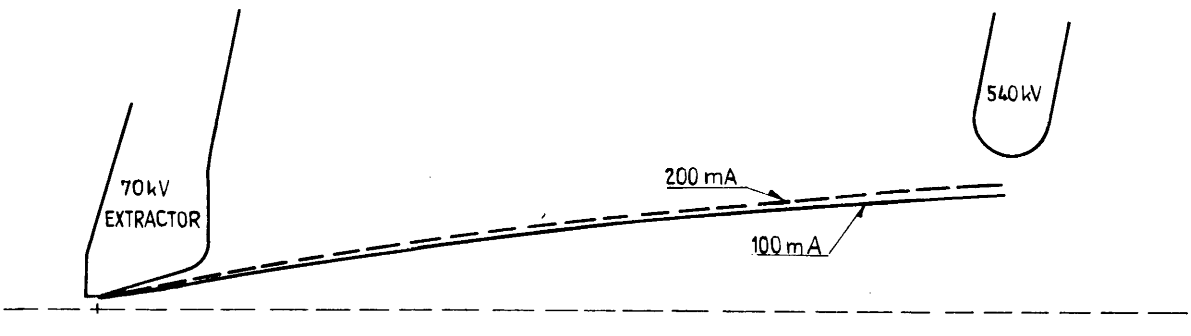

FIG.3 BEAM ENVELOPES FOR A 100mA AND 200mA PROTON BEAM IN A TWO-ELECTRODE SHORT COLUMN.

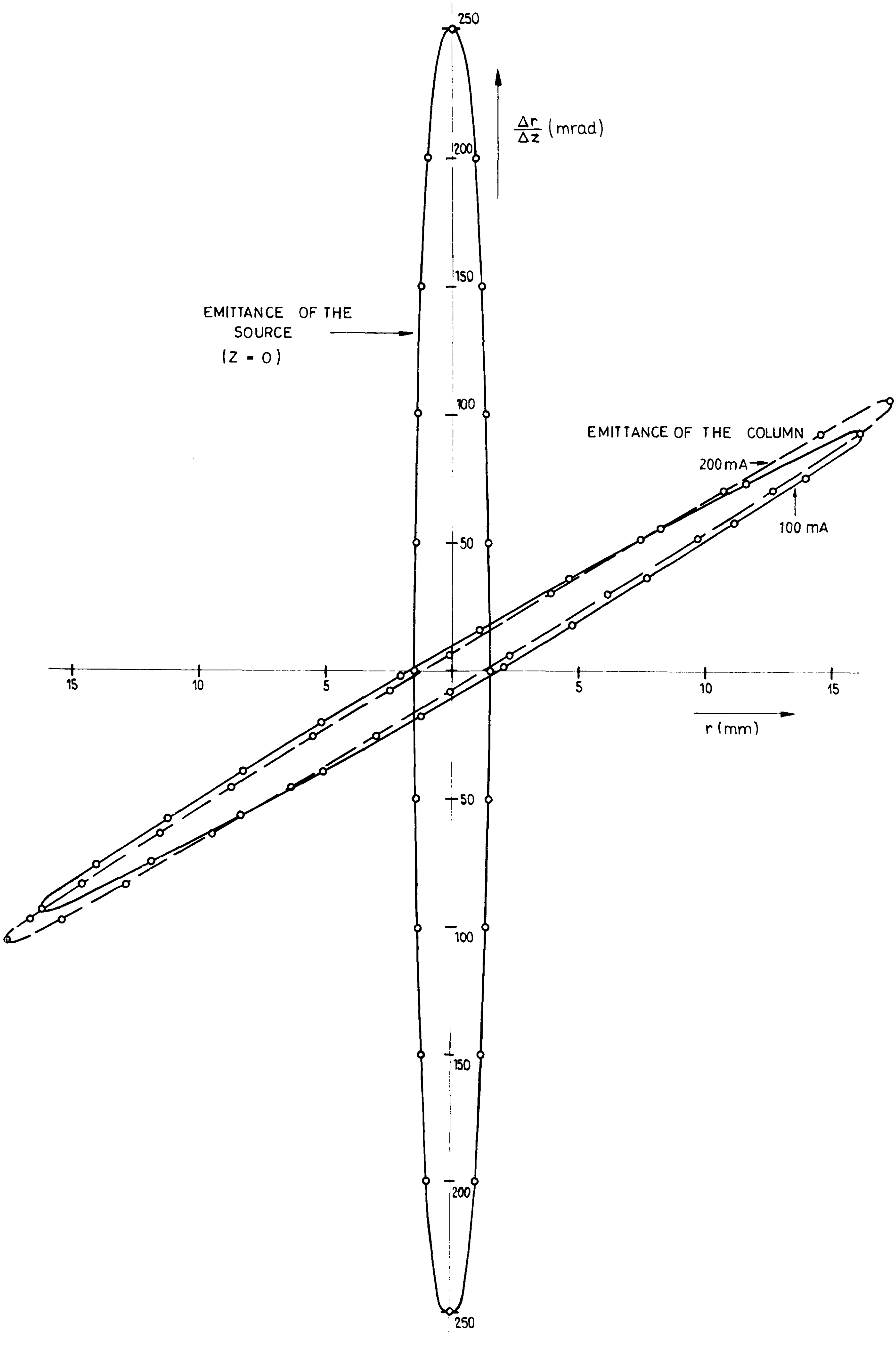

FIG. 4 EMITTANCES OF THE SOURCE AND A TWO-ELECTRODE SHORT COLUMN.

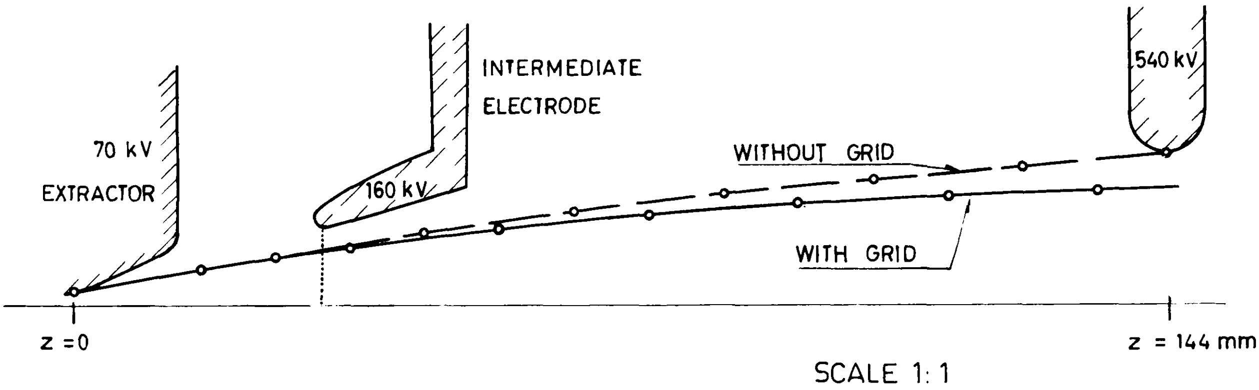

FIG. 5 BEAM ENVELOPES FOR A 200 mA BEAM IN A THREE-ELECTRODE COLUMN.

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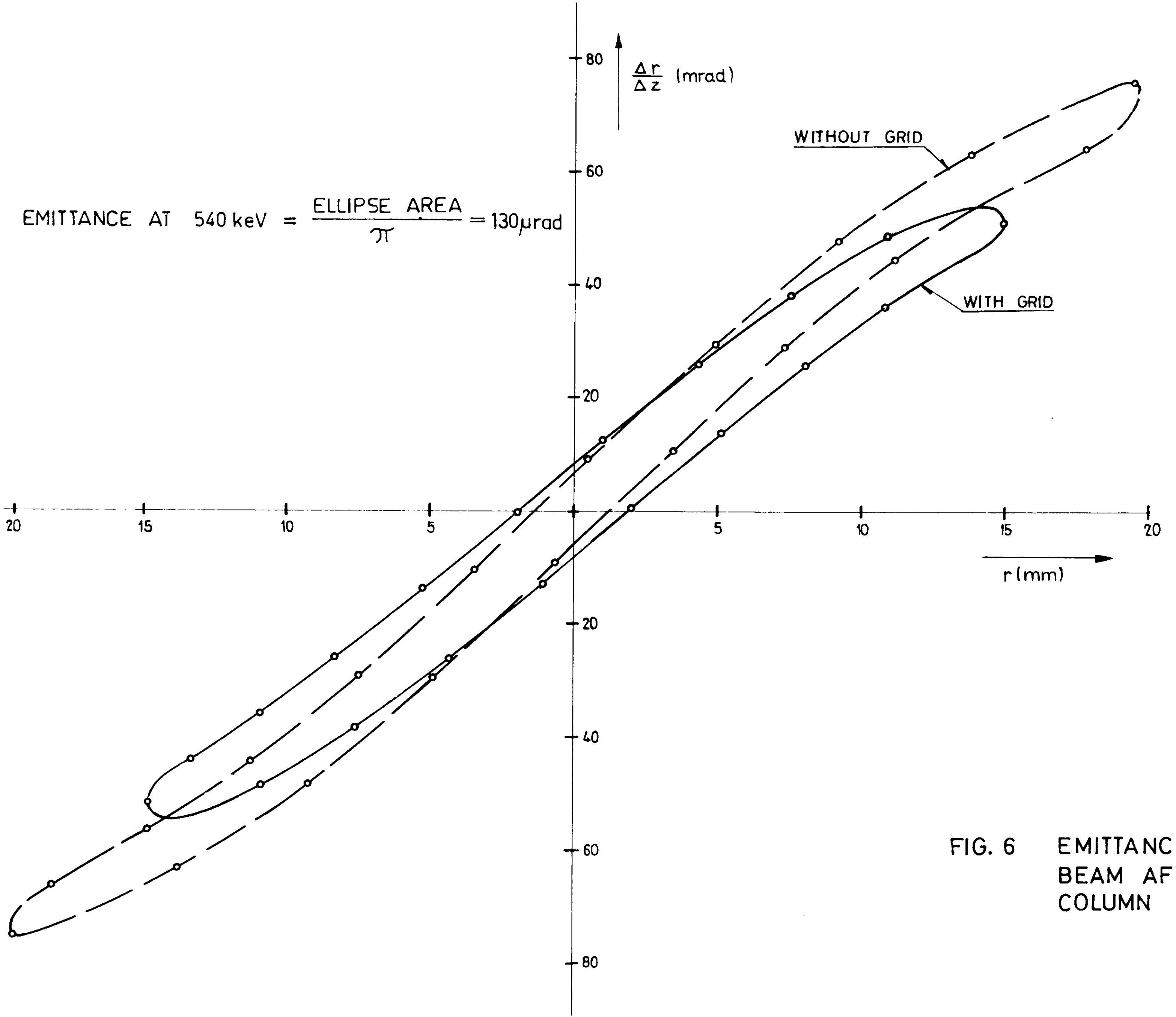

FIG. 6 EMITTANCES OF A 200mA PROTON-BEAM AFTER A THREE-ELECTRODE COLUMN WITH AND WITHOUT GRID.

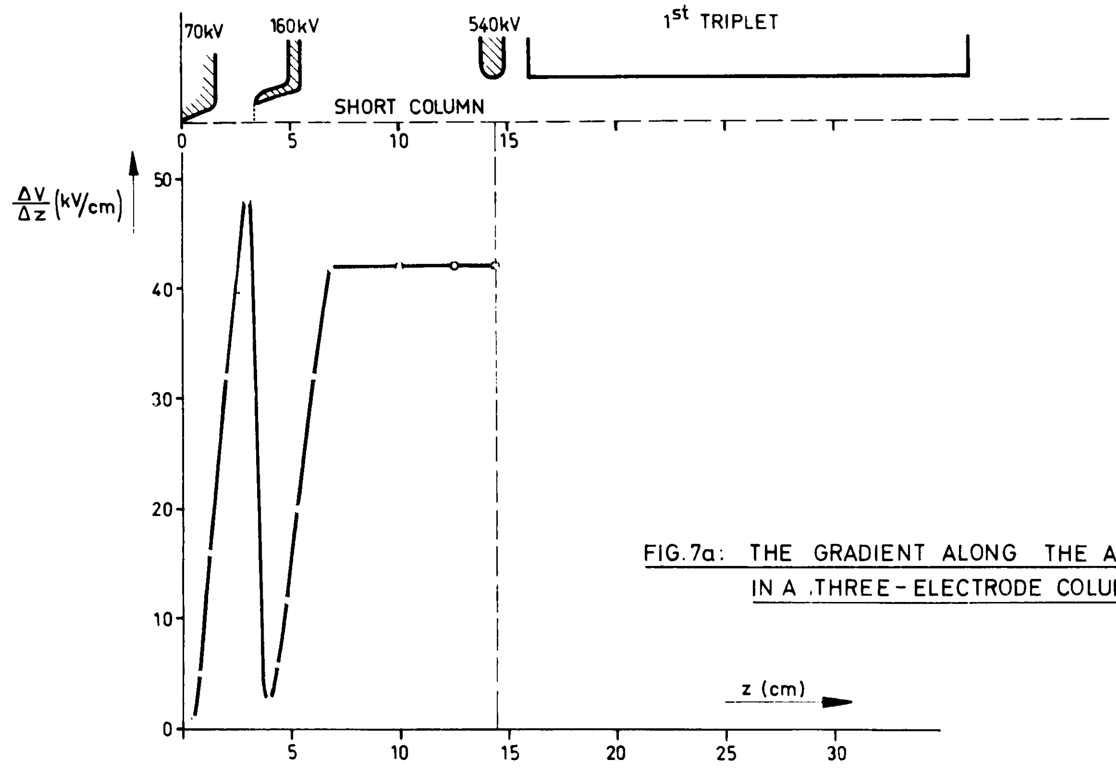

FIG. 7a: THE GRADIENT ALONG THE AXIS IN A THREE-ELECTRODE COLUMN.

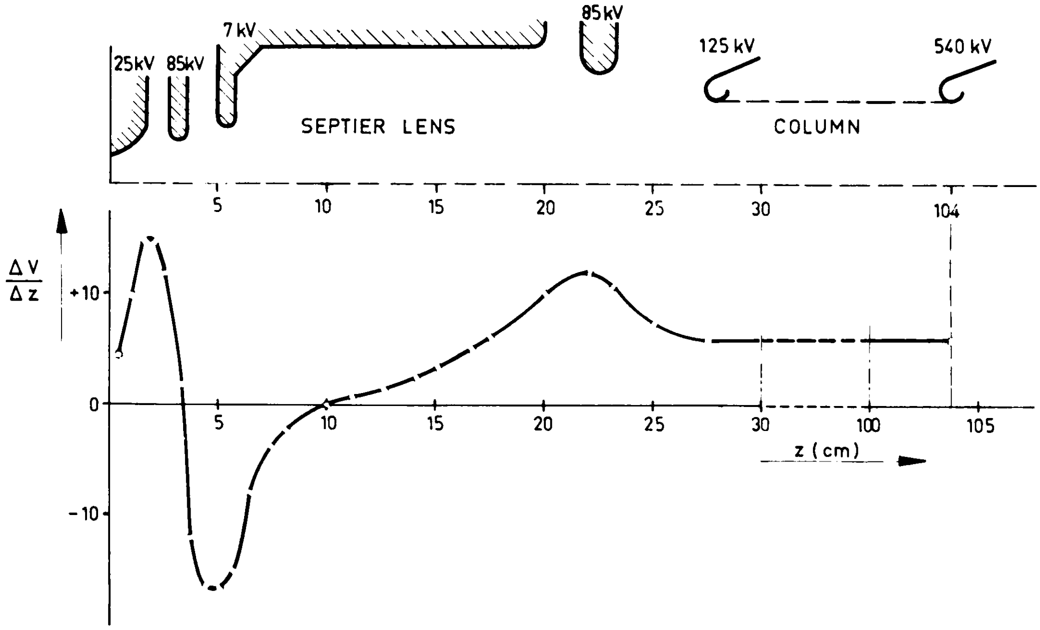

FIG. 7b: THE GRADIENT ALONG THE AXIS IN THE SEPTIER LENS AND COLUMN. (CERN)

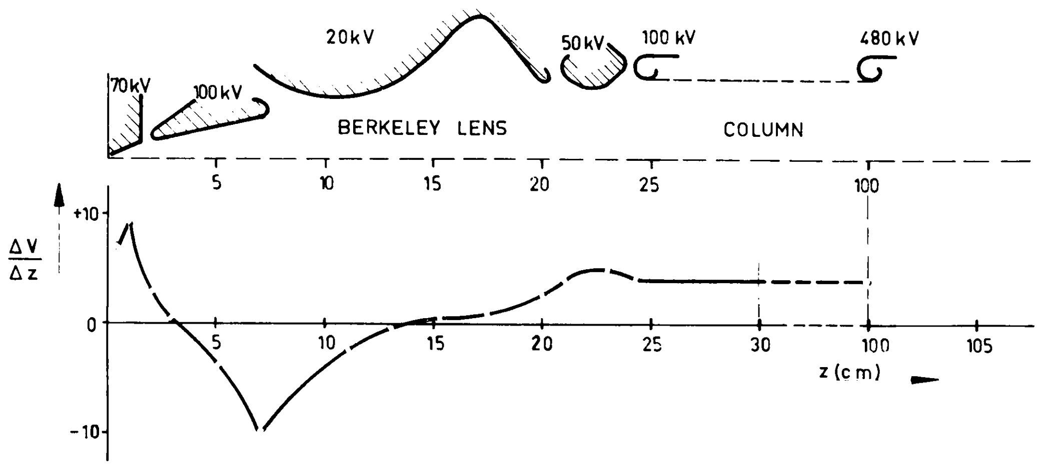

FIG. 7c: THE GRADIENT ALONG THE AXIS IN THE BERKELEY LENS AND COLUMN. (BERKELEY)

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