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(A)

PROPOSAL FOR HOLLOW CATHODE ELECTRON GUN FOR ELECTRON COOLING*

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I. PRINCIPLE

If we consider a magnetic shunt, an iron plate with a hole in it, sandwiched between two solenoids which are polarized in opposite direction, the resulting magnetic field would be as shown in Figure 1.

If we put a voltage between the magnetic shunt and two conducting plates perpendicular to the z-axis in a symmetric fashion, we would obtain the same shape of the electric field, because both E and B may be derived as gradient of a potential. We propose to explore this simple physical system, in which E and B are everywhere parallel, to obtain low temperature, magnetically confined electron beams.

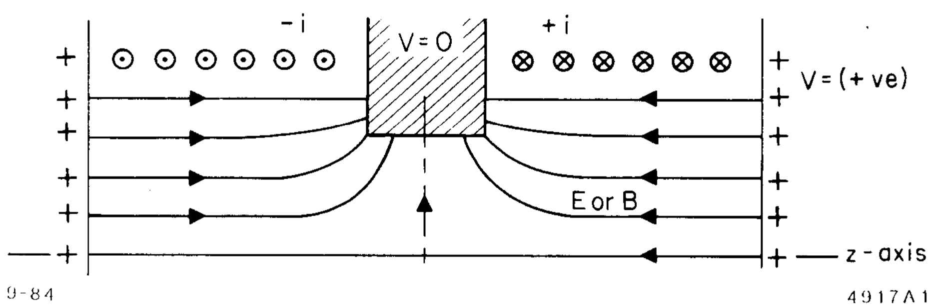

Figure 1. The Principle

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We arrange the cathode to lie on an equipotential surface, which could be for the sake of argument, the cylindrical boundary of the magnetic shunt. For a onesided gun, Figure 2, the cathode occupies only half of the magnetic shunt. Electrons are now accelerated by the electric field but stay more or less "frozen" on the magnetic field lines, so that they gain very little transverse energy, i.e. the beam will be cool.

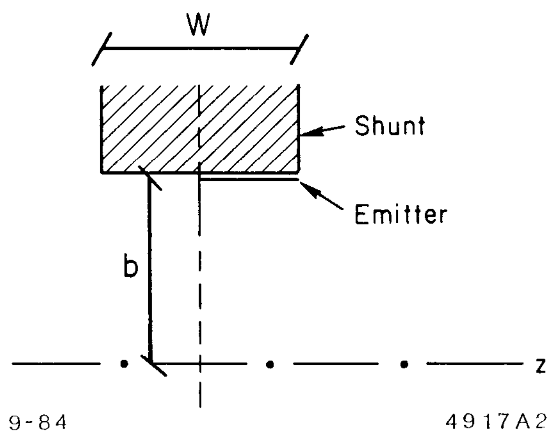

Figure 2. One–sided Gun

II. FEATURE

The hollow cathode has the feature that the ion beam may pass through it. Indeed the electron cooler could be arranged so that the gun, drift and collector sections are all in line and positioned in the straight section of the ion storage ring. The hollow collector was in principle realized, but not used, in the CERN electron cooler.[1]

One may appreciate the dramatic savings in space and cost if we compare the all–coaxial, in–line system with current electron coolers, Figure 3. Indeed, the two toroids needed there to bend the electron beam in or out, so that it is aligned with the coasting ion beam in the straight section, are costly and require a lot of trim. The in–line system may have the cathode at ground potential, so that the depressed collector potential is only a few kilovolt above ground. Hence we may dispense with the costly high voltage Faraday cage. Also the utilization of the straight section will be more efficient with the in–line system. For instance, in the CERN 7 m straight section only 3 m was effective for cooling, but the in–line version would need only an estimated 5 m of straight section.

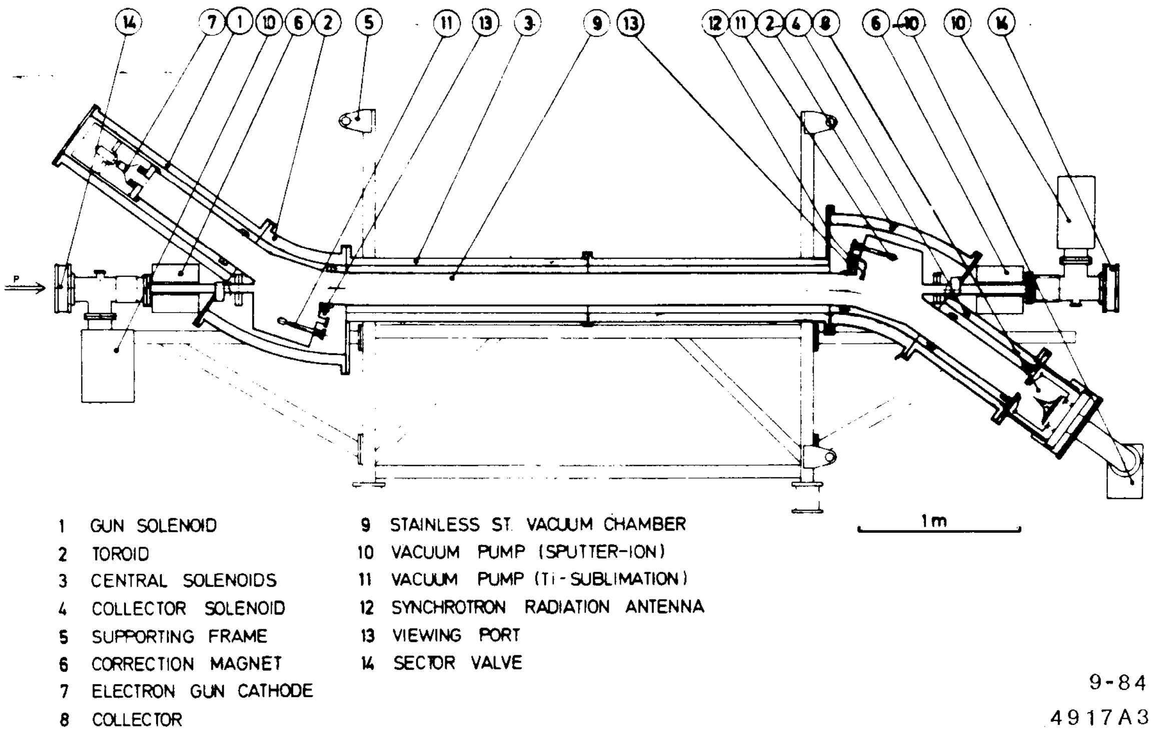

Figure 3. The ICE Electron Cooler

III. CORRECTIONS

Clearly several corrections have to be made:

Heat shields are needed between shunt and cathode, but the principle remains the same if the emitting surface coincides with a magnetic equipotential, Figure 4(a).

The space charge distortion of the Laplacian electrostatic field will require a focus electrode à la Pierce, to be worked out by trial and error, Figure 4(b).

— Presumably the rays near the z-axis will give problems, for the principle of freezing on a magnetic flux line is valid only if the radius of curvature $R = p/(eBc)$, (p in eV/c), is small compared to the radius of curvature of the flux line. Hence it may be better to suppress those rays altogether by reducing the emitting surface of the cathode accordingly, Figure 4(c). The ensuing hole in the electron beam is also an advantage for efficient collection on the depressed collector.

The current density across the beam may be adjusted by shaping the magnetic shunt profile. For instance, a rounded–off shunt, Figure 4(d), will boost the current density of the inner rays. A large aspect ratio of the width and the inner radius of the magnetic shunt will lower the perveance of the gun and reduce the current density of the inner rays, whereas the reverse would diminish the cathode area needed to obtain a given beam radius.

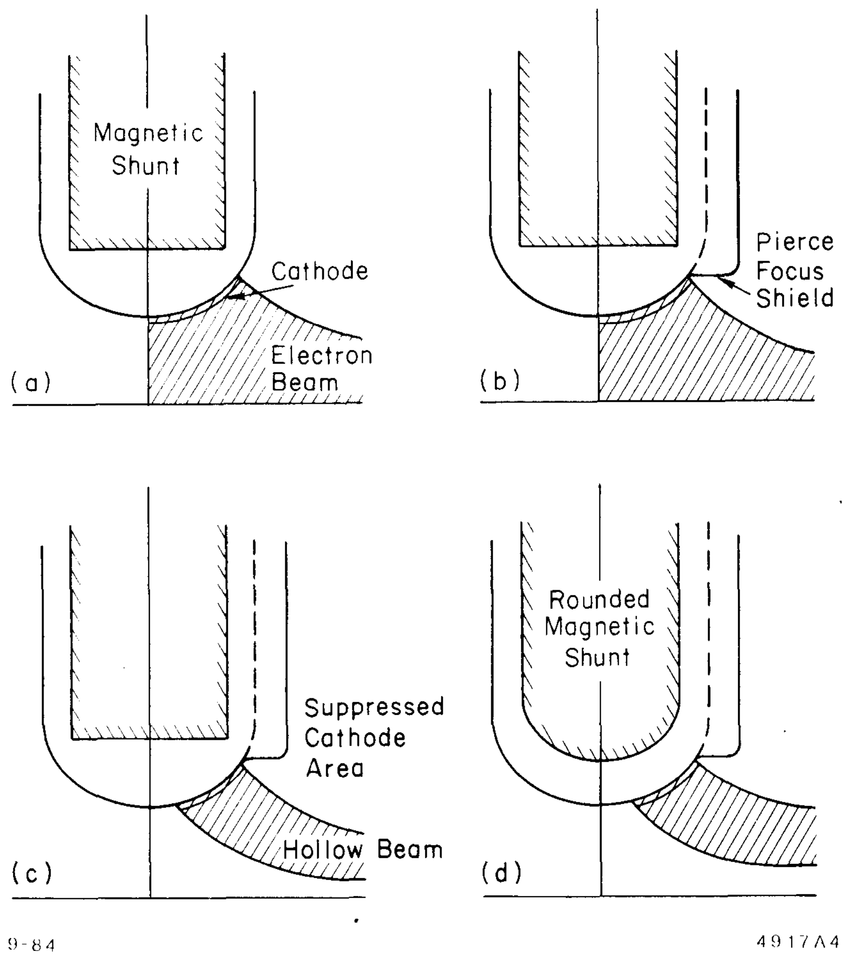

Figure 4. Gun Development

IV. OTHER ASPECTS

Unless one wants to make a double sided gun, the plane of mirror symmetry of the magnetic field pre–suppose a set of dummy anodes on the left to obtain parallelism of the E and B lines. However, this requirement may be less exacting in view of a) the space charge correction, b) the hollow anode and c) the poor ratio of the curvatures near the axis. Hence it may be possible to simplify somewhat the dummy side of the system, i.e. lower voltages with respect to the cathode. For instance, a hollow beam may be terminated with a low voltage dummy as shown in Figure 5.

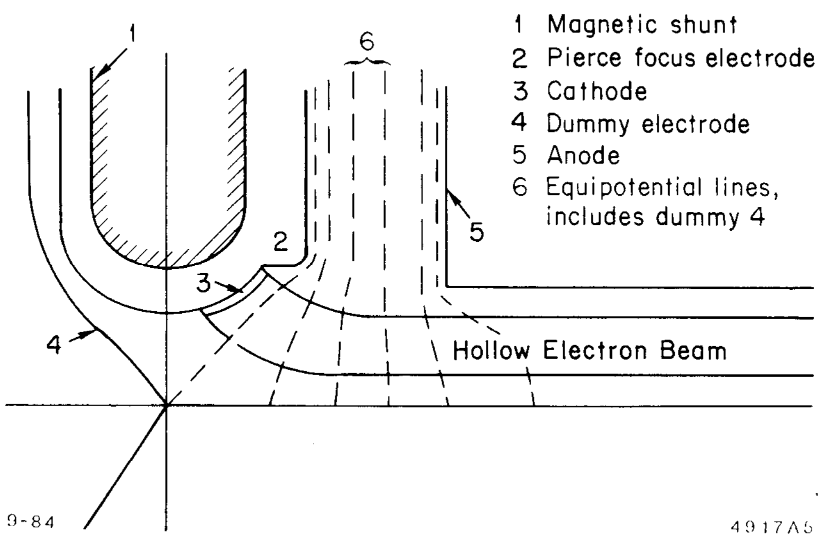

Figure 5. Lowest Voltage Dummy

The temperature may not be equally low everywhere across the beam, however, we may relax considerably on this requirement. In the initial stage of cooling, the average transverse cooling should be comparable to the angular divergence of the coasting ion beam, but if the beam cools and thus shrinks, it should see a progressively better quality electron beam. Thus we arrange the relative position of the two beams so that the ion beam shrinks on the spot where the electron beam is coolest.

The hole in the electron beam may, under some circumstances, prevent cooling part of the coasting ion beam. We would remedy this by having zero dispersion in the straight section, and off–set the electron beam so that the equilibrium orbit coincides with the coolest radius of the electron beam.

Field shaping anodes would be needed to remove the remaining scallops of the electron beam. It may be worthwhile to pursue the finding,[2] that cavities in the drift tube have a weak focusing action, so that one may need fewer anodes.

The collection of the hollow electron beam may be done following the CERN ICE cooler,[1] i.e. catch the electron on the same magnetic flux line where it was during its passage in the drift tube. The spike in this design may be suppressed since the beam is hollow, leaving therefore the coasting ion beam free of this obstruction.

V. PRELIMINARY RESULTS

The magnetic field is calculated on a grid of 4 mesh to the inch. The electric field and the trajectories are calculated on a grid of 8 mesh to the inch. The method is that of Ref. 3. We used an anode voltage of 100 kV and a solenoidal magnetic field of 1000 gauss. We considered only hollow beams with an approximate outer radius of 1 inch and a hole radius of 3/8 inch. Figure 6 shows some preliminary results, which are tabulated below:

Figure	pole	micro perv.	$\frac{j\ \max}{j\ \min}$	Remarks
6(a)	square	.27	2.0	Symmetry in B and E
6(b)	round	.77	1.6	Symmetry in B and E
6(c)	round	.91	2.2	Symmetry in B only, terminated on the left with cavity at cathode potential.

Although beam 6(a) is the coolest, $< 100\ eV$ average, a lot of optimization has to be done before we can start at the fine trim to reach 1 eV temperature. Upon studying the waviness of the rays, we notice that for a first trial, they run reasonably in phase so that one may expect that the goal is within reach.

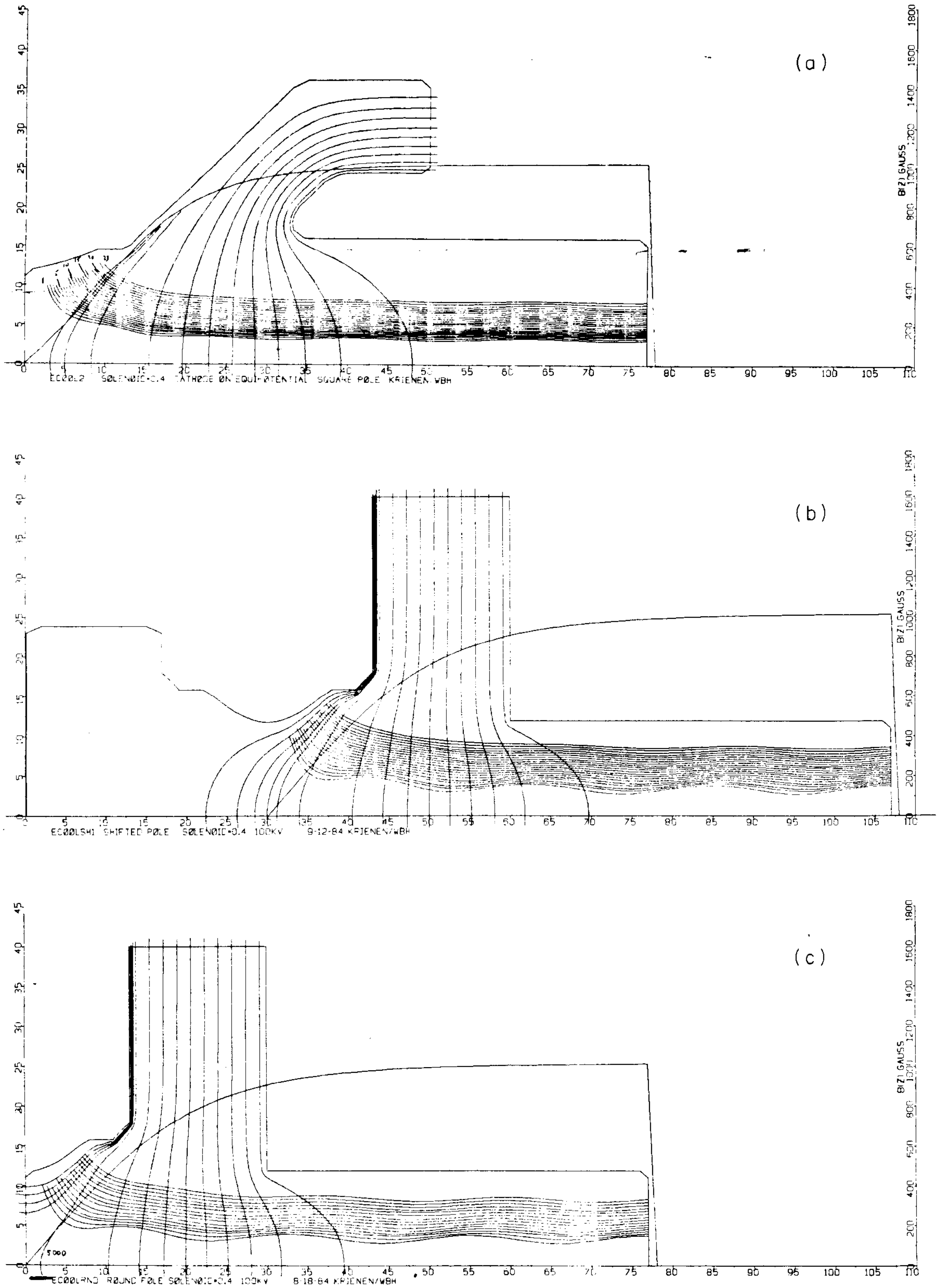

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Figure 6. Preliminary Results

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1. M. Bell et al., Nucl. Instrum. Methods 190 (1981) 237.
2. F. Krienen, Karlsruhe Workshop Electron Colling, KfK 2836 (1979) 43.
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