Electron gun producing beams with controllable current density

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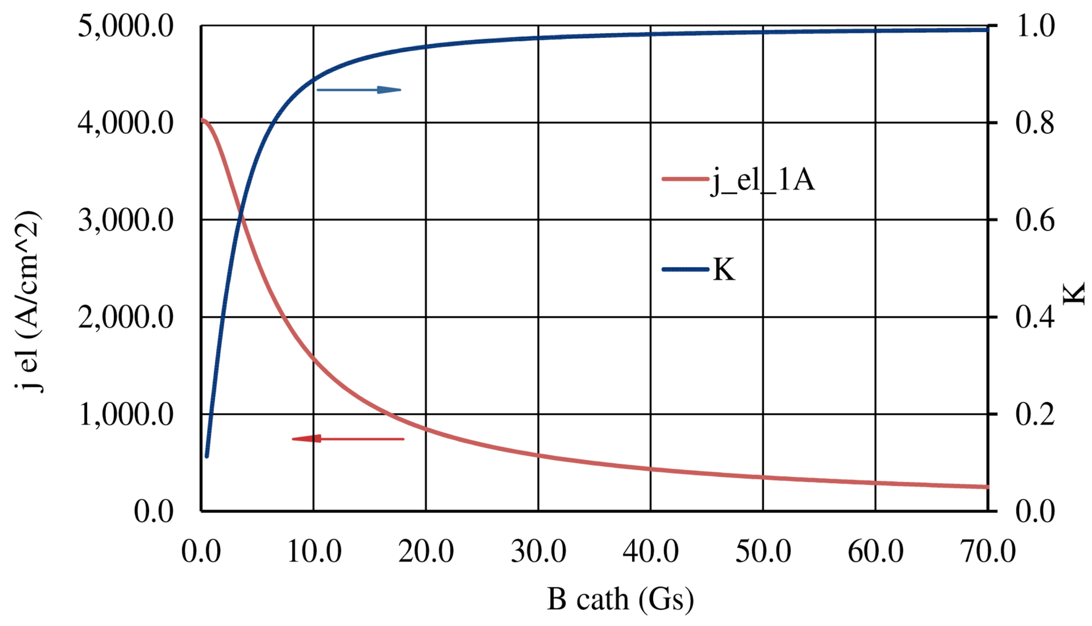
Alexander Pikin[1,2,*], Vittorio Bencini[1], Hannes Pahl[1,3], Fredrik Wenander[1]

1. BE Department, CERN, CH-1217 Geneva, Switzerland
2. Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Avenida Complutense 40, 28040 Madrid, Spain
3. Heidelberg Graduate School for Physics, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Abstract. The existing Brillouin-type electron gun at the TwinEBIS test bench is, according to Herrmann theory, capable of producing an electron beam with a current density of 3850 A/cm² in the 2 T solenoid. To control the electron beam current density and the magnetic flux inside the beam, the existing electron gun - now using purely electrostatic focusing - can be modified by permitting magnetic flux to reach the cathode. In such a configuration, the stabilizing magnetic flux inside the electron beam can be controlled by changing the current in the magnet coil surrounding the cathode. The radial oscillations of the electron beam, resulting from the increased magnetic field on the cathode, can be significantly reduced by employing a non-adiabatic magnetic field near the electron gun. This method has been recently developed and successfully used at REXEBIS at CERN. We present the computer simulations of such electro-optical system.

The Brillouin electron beams with very high current density in combination with the long ion traps typical for ion sources and ion breeders can be prone to ion-electron instabilities. Our **motivation** in this work is to provide the EBIS operating conditions when simultaneously both the ion trap remains stable, and the electron beam has maximum current density.

The **goal** is to find an optical solution, when we can experimentally control the density of the electron beam until we find a stable trap condition. Such current density control should be performed within some reasonable current density range, which we think is between 1000 and 300 A/cm² for our 2 T superconducting solenoid. The quality of the electron beam should be good enough for the transmission with low losses.



Solution:

1. Increase magnetic field on the cathode and make it controllable in a range of B_{cath}=(17 -58) Gs

Herrmann formula calculations for r_c=6.0 mm, B=2.0 T, I_{el}=1.0 A, E_{el}=10 keV

$$r_e = \frac{r_B}{\sqrt{2}}\left\{1+\left[1+4\left(\frac{8mkTr_c^2}{e^2B^2r_B^4}+\frac{B_c^2r_c^4}{B^2r_B^4}\right)\right]^{1/2}\right\}^{1/2} \qquad r_B = 0.01477\frac{\sqrt{I_{el}}}{BE_{el}^{1/4}}$$

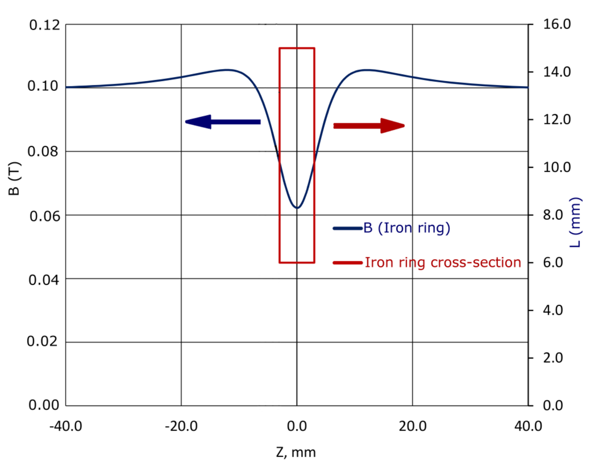
D.A. Knapp, R.E . Marrs, S.R. Elliott, E.W. Magee and R . Zasadzinski, Nuclear Instruments and Methods in Physics Research A 334 (1993) 305-312

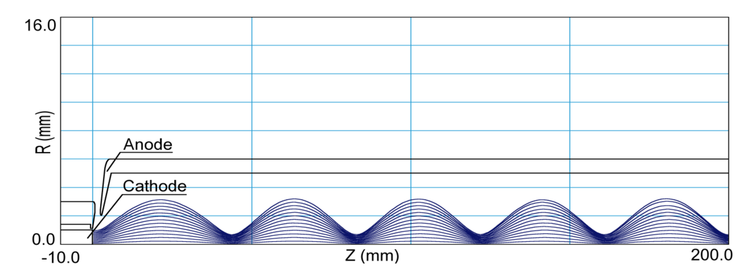
$K=(j_{trap}/j_{cath})/(B_{trap}/B_{cath})$

2. Suppress the radial ripples of the beam using a nonadiabatic magnetic field. This field modification is created with an iron ring or coil, producing a dip in magnetic field in the area of descending part of the cyclotron oscillation. Used successfully on RexEBIS.

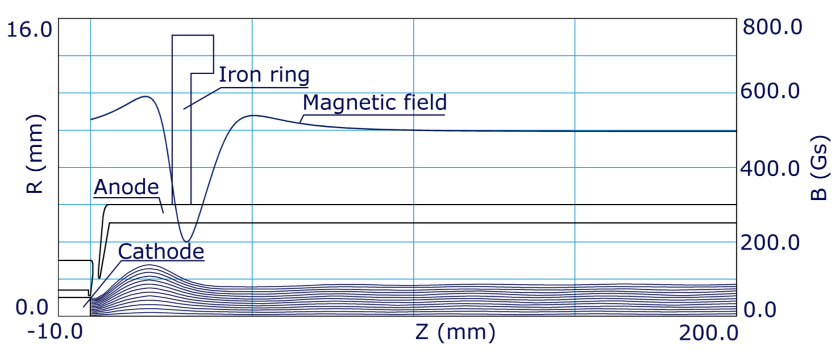
Method

Axial magnetic field distribution with an iron ring



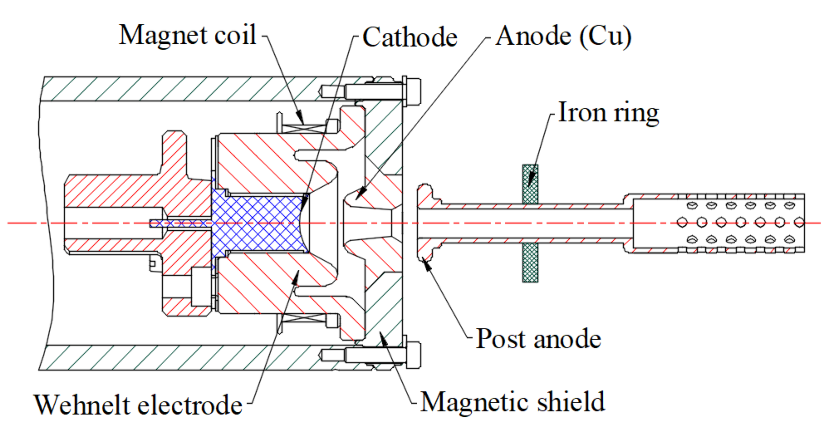


Uniform magnetic field
No iron ring, 1.0 A, B= 700 Gs
I_{el}=0.7 A, d_{cath}=2.0 mm

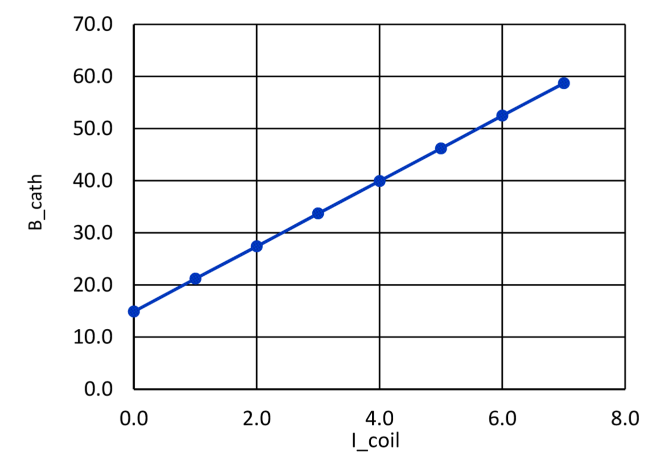


Same parameters, with an iron ring

Alexander Pikin, Hannes Pahl, and Fredrik Wenander
Method of controlling the cyclotron motion of electron beams with a nonadiabatic magnetic field, Phys. Rev. Accel. Beams **23**, 103502, 2020

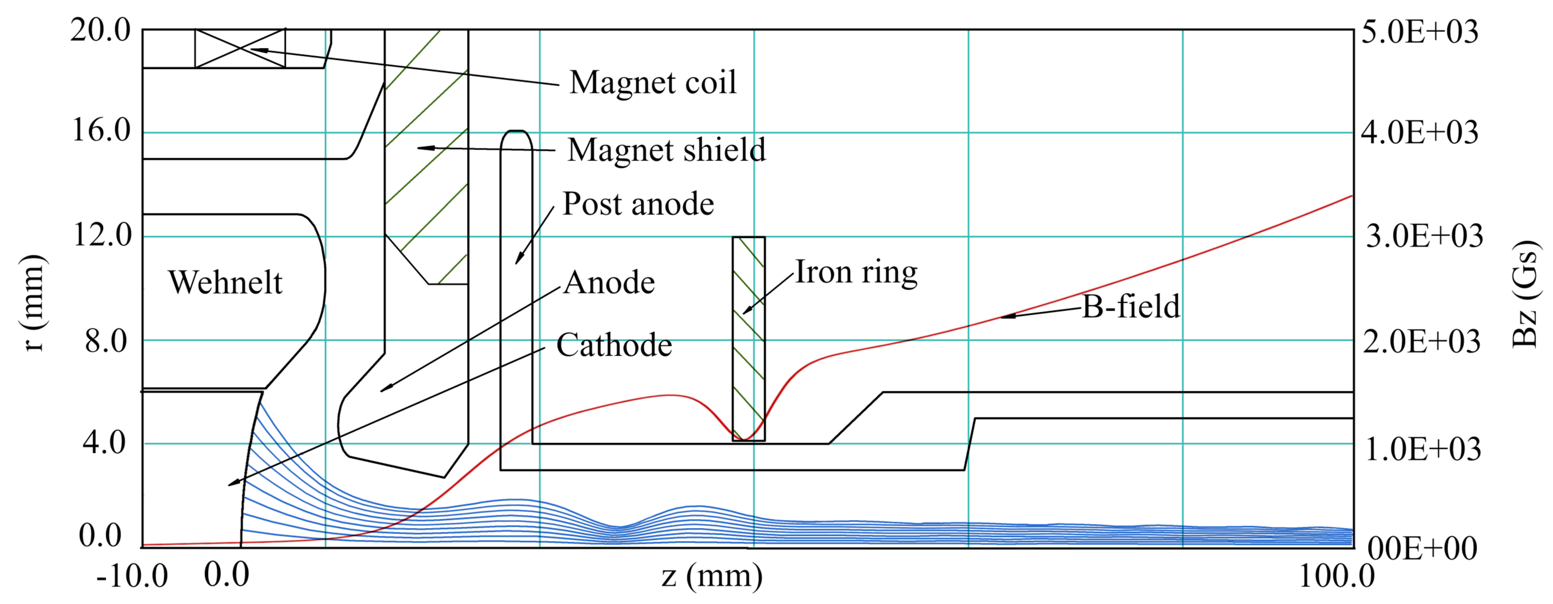


The cathode and perveance in a proposed design remain the same as in the existing gun.
Differences with the existing TwinEBIS gun:
1. Increased anode aperture,
2. Increased ID of aperture in the magnetic shield.
3. Added the iron ring producing non-adiabatic magnetic field.

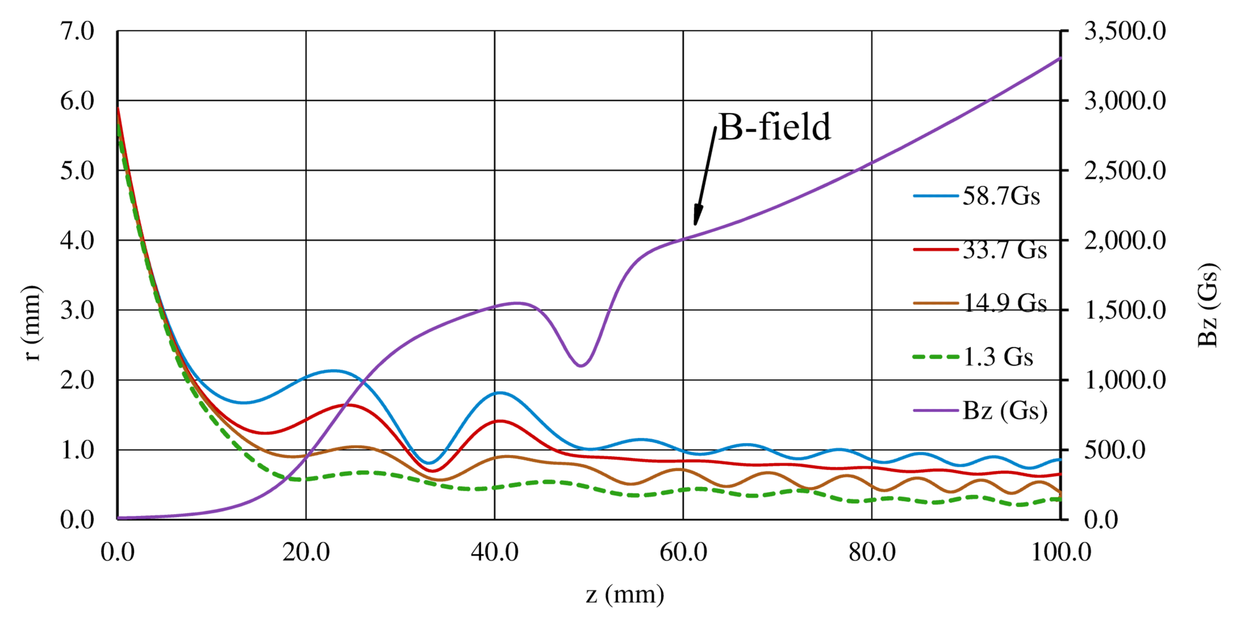


Calculated dependence of the cathode magnetic field on the current in the cathode coil. It has 16 turns of Kapton-insulated copper wire.
Linear fit: B_{cath} =14.9+6.29I_{coil}

Simulated electron beam transmission for the electron beam with current 1.0 A, energy 10 keV, magnetic field on the cathode is 58 Gs

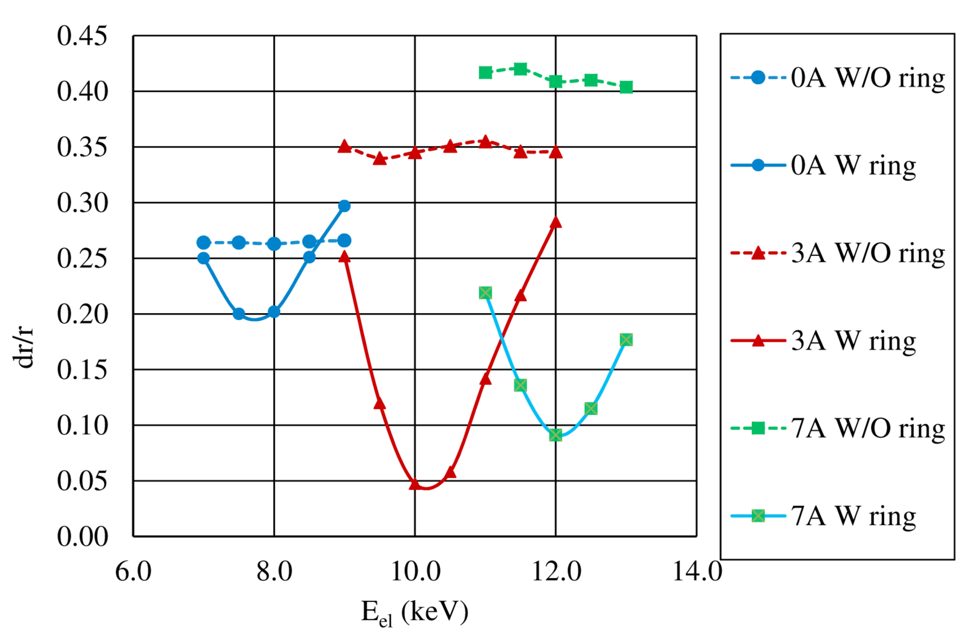


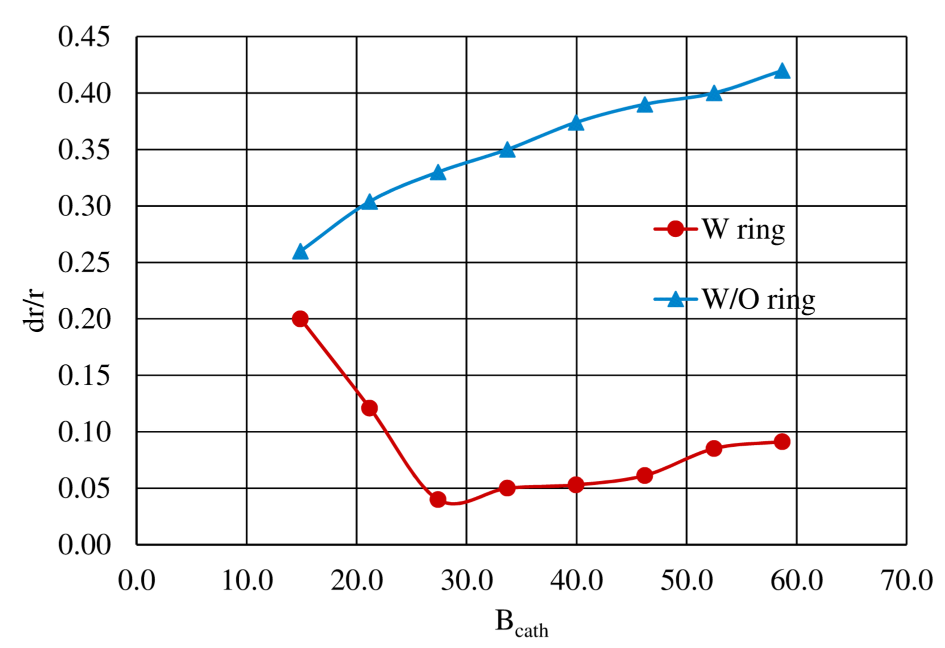
Simulated electron beam envelopes for different magnetic fields on the cathode of the gun. The beam envelope has minimum oscillations with magnetic field on the cathode B_{cath}=33.7 Gs, corresponding to the electron beam density in the ion trap (2 T magnetic field) j_{el}=500 A/cm²



It appears, that the amplitude of the radial depends on the electron energy. With bigger amplitude of oscillations (at higher magnetic field on the cathode) the share of electron energy in axial direction becomes smaller and the phase of oscillations shifts to the cathode. To move it back forward one needs to increase the electron energy. Without the iron ring the dependence of radial oscillations on the electron energy is anemic. It has pronounced minimum at each magnetic field if the iron ring is engaged.

Dependencies of the electron beam radial oscillations amplitude on the cathode magnetic field for cases with and without the iron ring. I_{el}=1.0 A. For a case with ring the oscillations amplitude is taken for an optimum energy, when it is minimal.





Conclusion: Our simulations demonstrate that the operating range of the magnetic field on the electron gun cathode can be extended to provide an electron beam density in the range of 300 to 1000 A/cm². A combination of a nonadiabatic magnetic field on the back slope of the radial beam oscillation and an adjustment of the electron energy allows us to attain an acceptable electron beam quality in a required range of current density in the ion trap.