Generating of magneto-immersed electron beams

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Magneto-immersed electron beams are produced by the guns immersed in the magnetic field and propagate in the interaction region with magnetic confinement. Normally, the magnetic flux within the electron beam boundary preserves.

Applications in accelerator field:

- ***Electron beam ion sources (EBIS)***: need for high current density for fast ionization. Solution - use high magnetic compression.
- ***Electron lenses***: need for quiet and dense electron beams with controllable transverse density profile and size.
- ***Electron coolers***: need for as cold as possible electron beams.

Magnetic mirror

For typical electron guns most of transverse energy comes from the gun optics itself in the cathode-anode gap, while the other contributors like thermal energy from the hot cathode or emission non-uniformity are much smaller.

Limitation for magnetic compression – magnetic mirror, reflecting electrons outside of the transmission cone:

$$\frac{v_{transv}}{v} < \frac{1}{\sqrt{r_{mir}}} \qquad r_{mir} = \frac{B_{max}}{B_{min}}$$

Need for as low initial transverse energy as possible.
Reflected from the magnetic mirror electrons oscillate between the mirror and the cathode and can excite the primary beam with frequency determined by oscillating electrons.
Positive feedback : secondary electron emission from cathode and Wehnelt electrode.

Electron beam excitation

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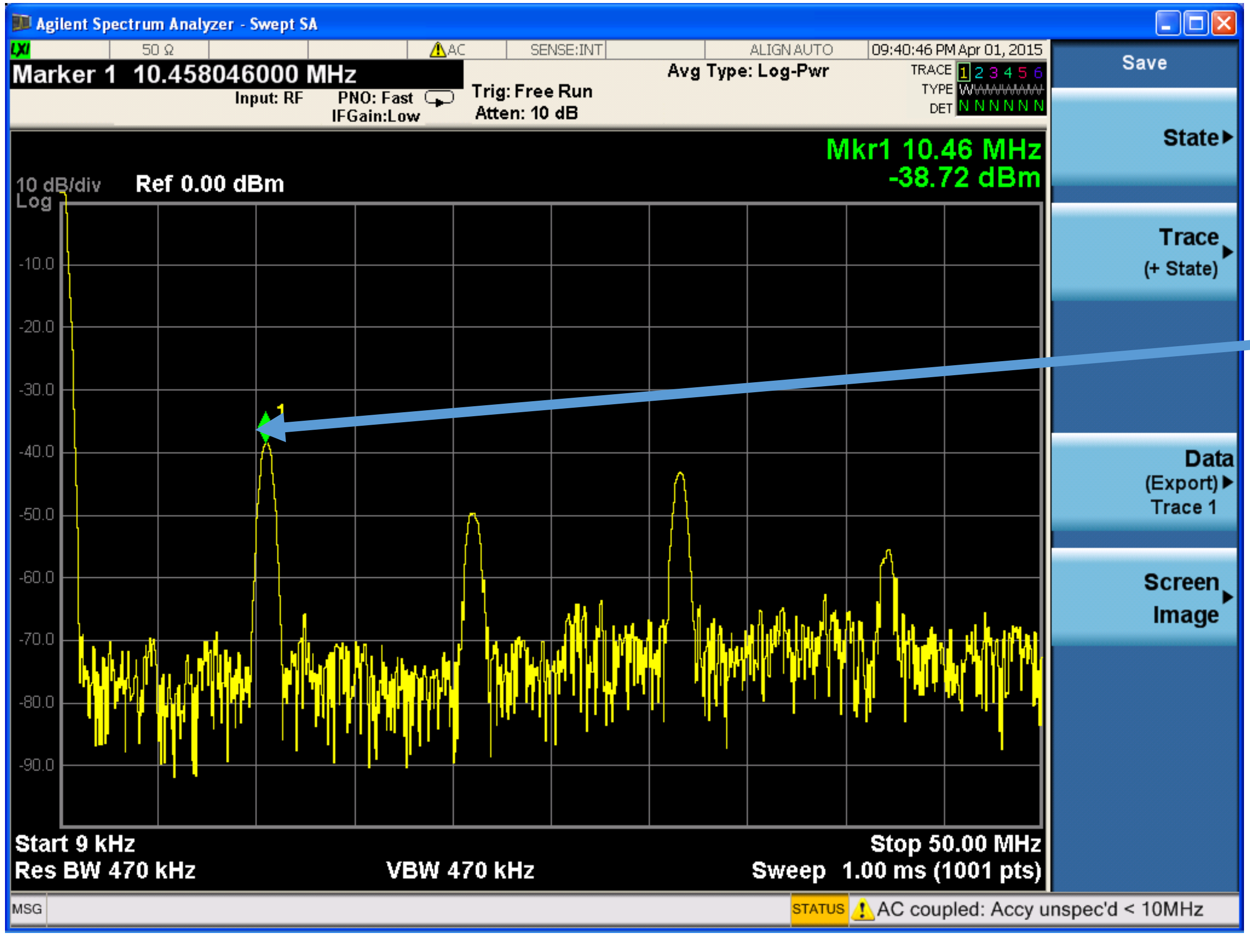


X. Gu & others, RHIC electron lenses upgrades, IPAC 2015, THPF059

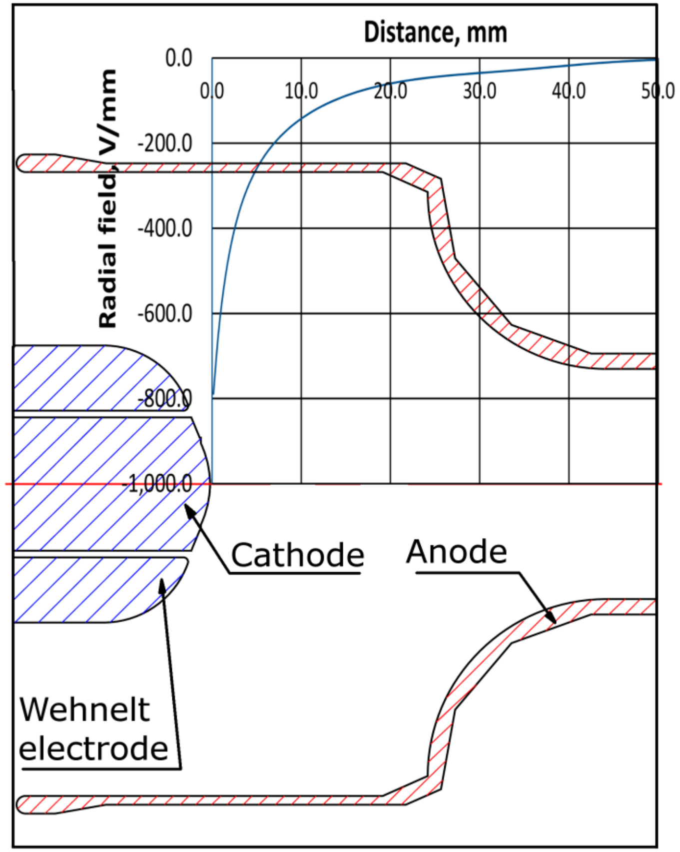
Period of electron oscillations between the magnetic mirror and the cathode f=10.46 MHz

Such excitations have been observed in several other places.

This excitation is detrimental for the intended application.

Goal: producing electron beams with small transverse energy.

Adiabatic gun of Budker Institute



For some time one of main criterion, a virtue of electron gun was as uniform as possible electrostatic field distribution in the cathode-anode (CA) gap - adiabatic gun.

As a result an electron gun has been developed in BINP (Novosibirsk) with very smooth electric field.

Features:

- anode coaxially overlapping the cathode
- spherical cathode.

Remains most popular in EBIS community.

Our gun: R_{cath}=4.6 mm, r_{sph}=10 mm, Perveance p=1.8e-6 A/$V^{1.5}$

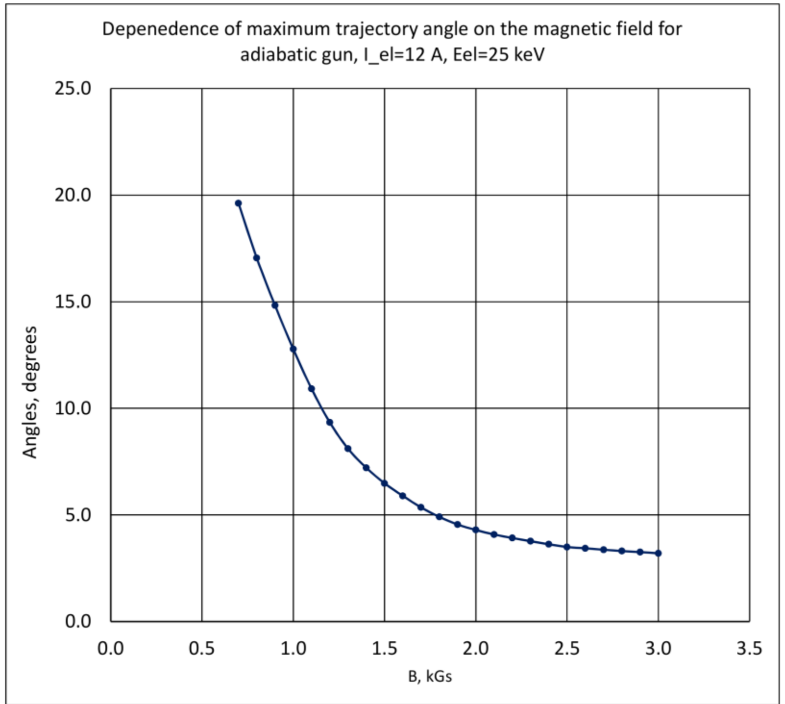
Analysis with 2D simulations: for every value of uniform magnetic field and electron current we measured angle of every electron trajectory with longitudinal axis. Plotted as a color-coded table for different magnetic fields and electron beam currents and normalized to a fixed electron energy 25 keV – map of gun performance.

Map of adiabatic gun

B, kGs (columns); Iel, A (rows)

Iel, A	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
1	2.56	2.09	1.82	1.65	1.53	1.46	1.41	1.38	1.36	1.34	1.33	1.32	1.31	1.30	1.29	1.28	1.28	1.27	1.27	1.27	1.27	1.26	1.27	1.27
2	4.64	3.74	3.13	2.66	2.36	2.17	2.02	1.92	1.85	1.79	1.76	1.72	1.70	1.69	1.68	1.66	1.65	1.64	1.64	1.63	1.63	1.62	1.63	1.62
3	6.74	5.32	4.40	3.75	3.23	2.85	2.62	2.44	2.30	2.19	2.12	2.06	2.02	1.99	1.96	1.94	1.93	1.92	1.91	1.90	1.89	1.88	1.88	1.88
4	8.71	6.94	5.65	4.78	4.13	3.61	3.21	2.95	2.75	2.60	2.46	2.38	2.32	2.27	2.23	2.19	2.16	2.15	2.14	2.11	2.10	2.10	2.09	2.07
5	10.47	8.52	6.92	5.77	4.99	4.38	3.86	3.45	3.19	2.99	2.83	2.69	2.59	2.52	2.46	2.42	2.37	2.35	2.32	2.31	2.30	2.29	2.27	2.26
6	12.04	9.99	8.21	6.80	5.81	5.10	4.51	4.02	3.64	3.37	3.18	3.02	2.88	2.77	2.70	2.63	2.59	2.54	2.51	2.48	2.47	2.45	2.44	2.43
7	13.50	11.38	9.45	7.84	6.65	5.79	5.13	4.58	4.12	3.78	3.52	3.32	3.17	3.04	2.93	2.85	2.78	2.73	2.68	2.64	2.63	2.60	2.58	2.57
8	14.83	12.63	10.64	8.88	7.48	6.49	5.75	5.13	4.61	4.17	3.87	3.63	3.44	3.29	3.16	3.06	2.98	2.91	2.86	2.83	2.78	2.75	2.72	2.70
9	16.10	13.82	11.77	9.90	8.35	7.18	6.34	5.68	5.10	4.61	4.22	3.96	3.72	3.55	3.39	3.27	3.18	3.09	3.03	2.97	2.93	2.89	2.85	2.84
10	17.31	14.95	12.83	10.89	9.21	7.90	6.93	6.20	5.59	5.04	4.60	4.25	4.00	3.79	3.63	3.48	3.36	3.26	3.19	3.13	3.08	3.05	2.98	2.96
11	18.47	16.01	13.85	11.85	10.07	8.62	7.53	6.71	6.05	5.48	4.98	4.57	4.28	4.04	3.86	3.69	3.55	3.44	3.35	3.28	3.21	3.17	3.12	3.09
12	19.62	17.05	14.83	12.78	10.92	9.34	8.11	7.21	6.48	5.90	5.35	4.91	4.55	4.30	4.08	3.92	3.77	3.62	3.49	3.44	3.37	3.31	3.26	3.20
13	20.68	18.00	15.75	13.67	11.73	10.08	8.73	7.72	6.96	6.32	5.76	5.25	4.86	4.54	4.31	4.11	3.95	3.81	3.69	3.59	3.52	3.43	3.37	3.32
14	21.70	18.94	16.64	14.52	12.55	10.80	9.34	8.24	7.41	6.71	6.13	5.59	5.15	4.81	4.55	4.34	4.14	3.99	3.84	3.73	3.65	3.59	3.52	3.46
15	22.24	19.41	17.09	14.98	13.02	11.25	9.72	8.56	7.66	6.96	6.35	5.81	5.34	4.94	4.66	4.42	4.24	4.08	3.93	3.79	3.70	3.62	3.54	3.49

Map of adiabatic gun. Maximum trajectory angles are normalized to 25 keV. (Uniform electric and magnetic fields).



Map scan at I_{el}=12.0 A (current of interest):

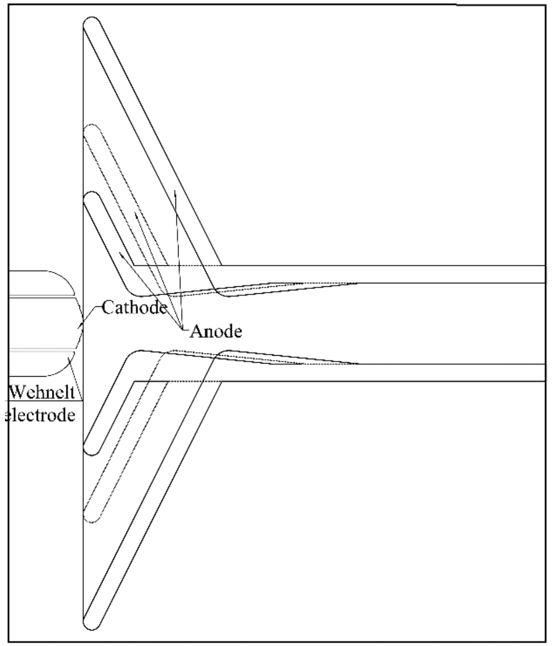
Dependence of maximum trajectory angle on the magnetic field.

For magnetic compression from 1.5 kGs to 6T the acceptance cone is 9^0, this include all transvers components.

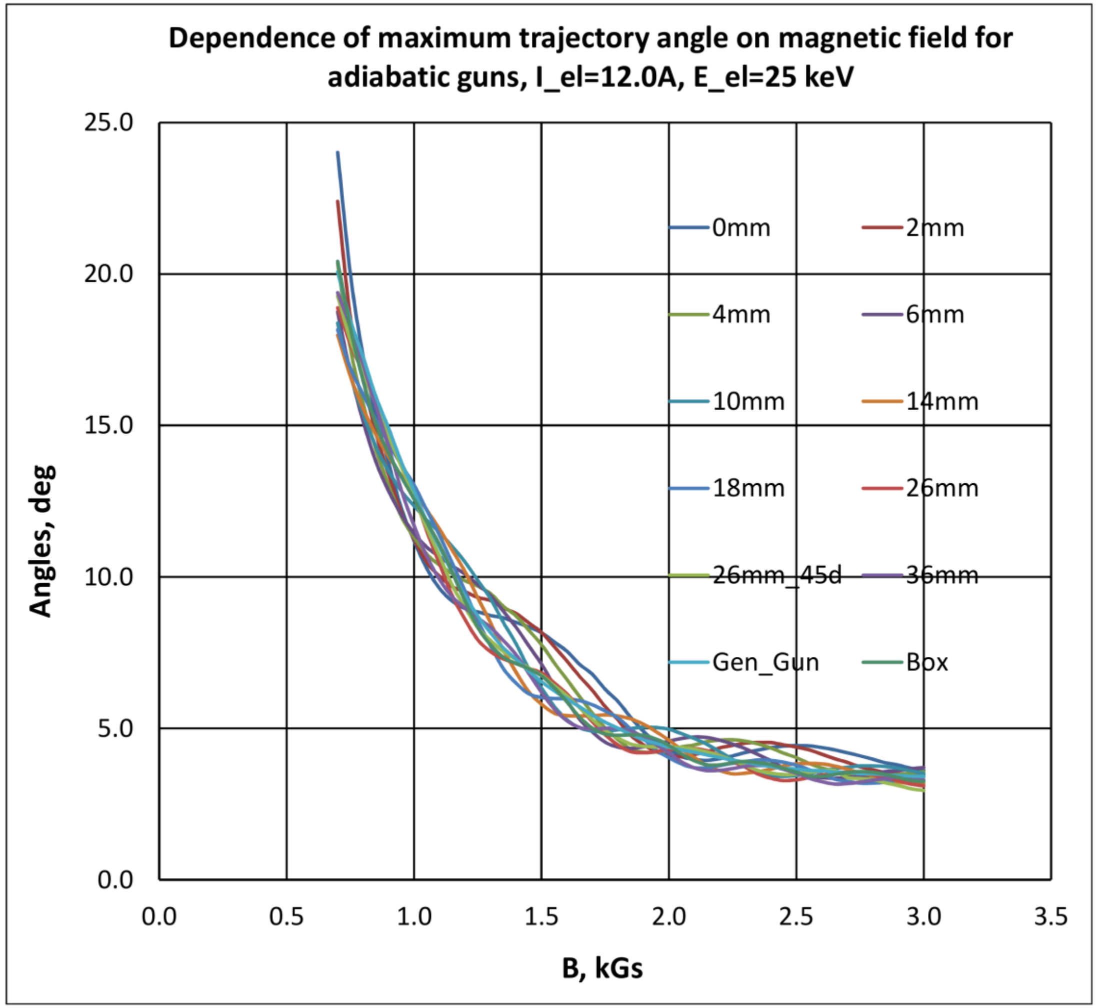
Typical operating magnetic field is close to 2 kGs (angle 4^0).

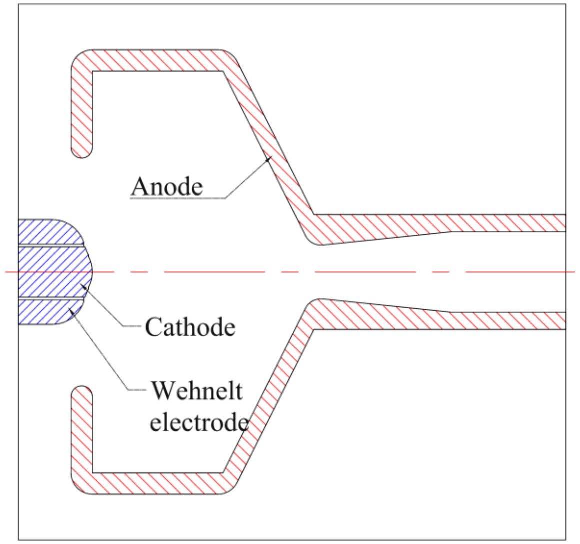
We need lower magnetic field.

Analysis of adiabatic guns



A family of adiabatic guns with different C-A gaps



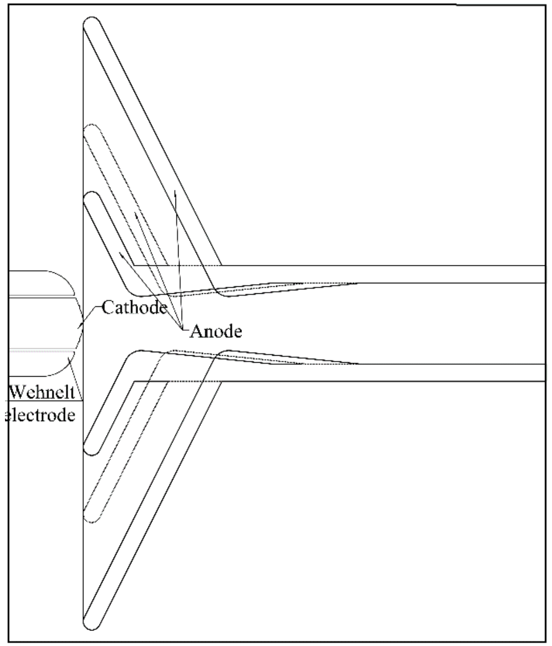


Adiabatic gun with box-shaped anode

+different cone angles…

All tested adiabatic guns have similar dependence of maximum trajectory angle on the magnetic field: no angle reduction in the low magnetic field

Analysis of adiabatic guns



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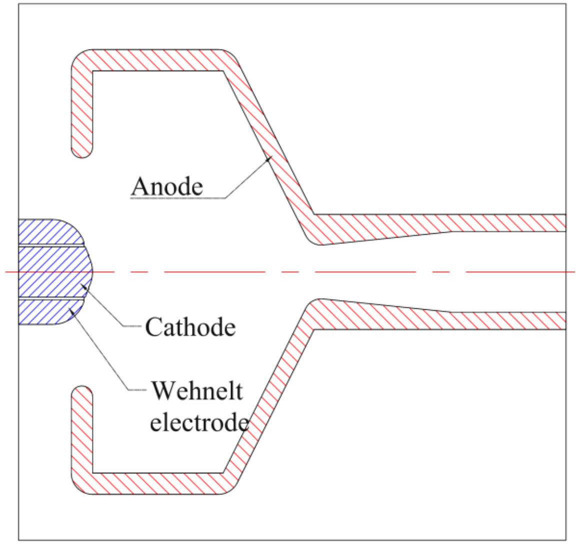
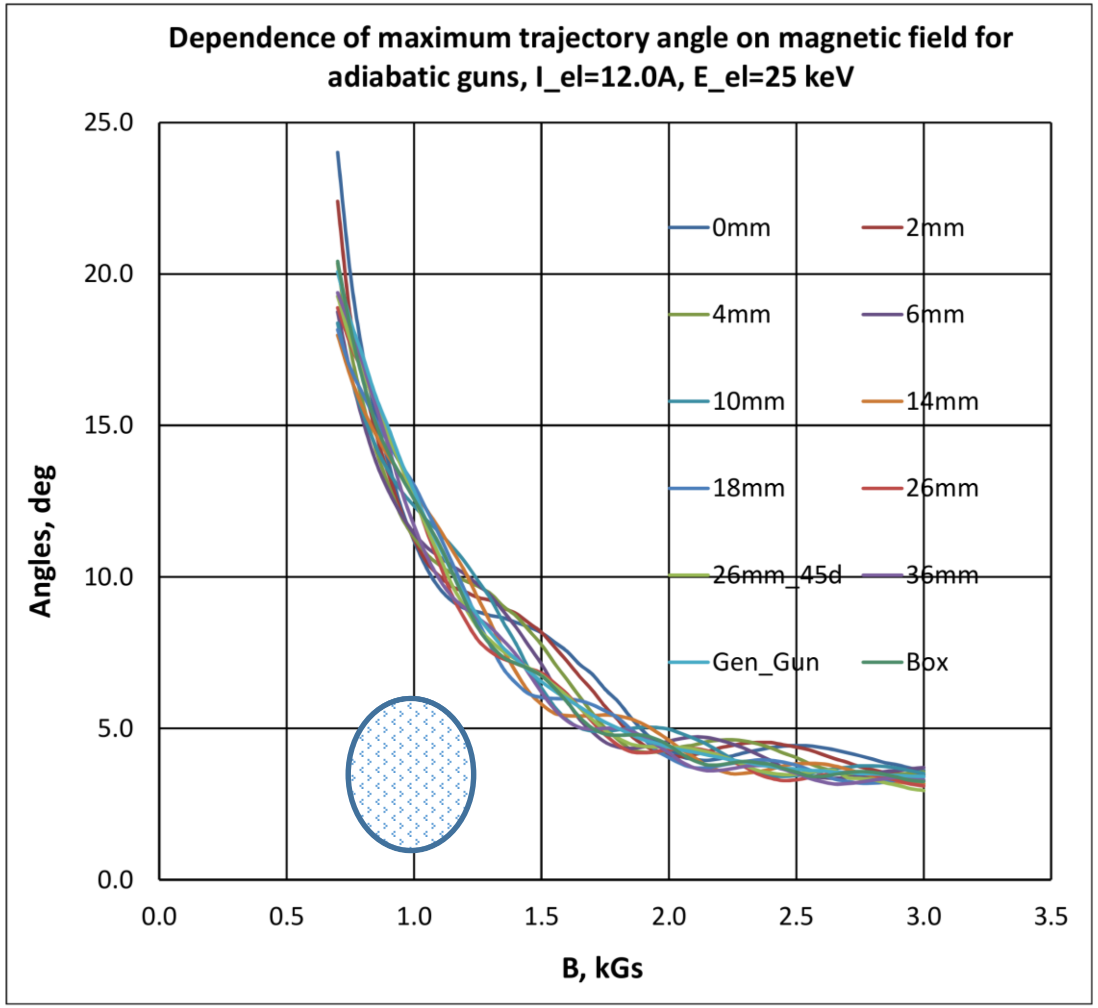


Adiabatic gun with box-shaped anode

+different cone angles…

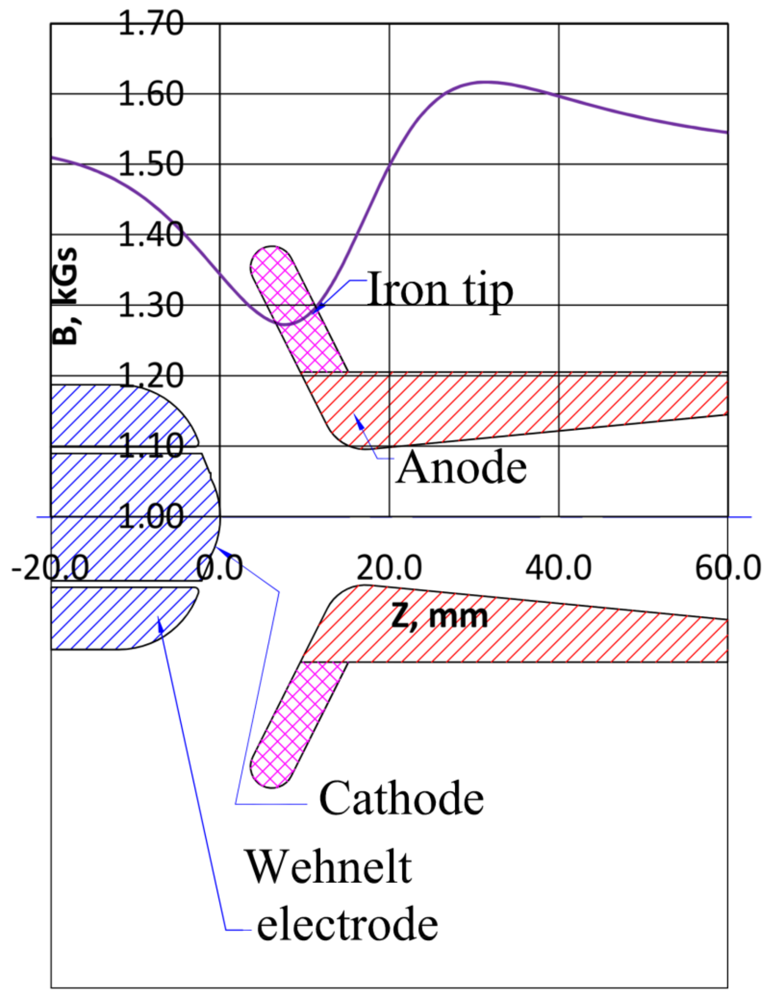


All tested adiabatic guns have similar dependence of maximum trajectory angle on the magnetic field: no angle reduction in the low magnetic field

Magnetically non-adiabatic electron gun

Attempt: break away from adiabatic field.

Try to use non-adiabatic fields in C-A gap. Hope: will work in some range.

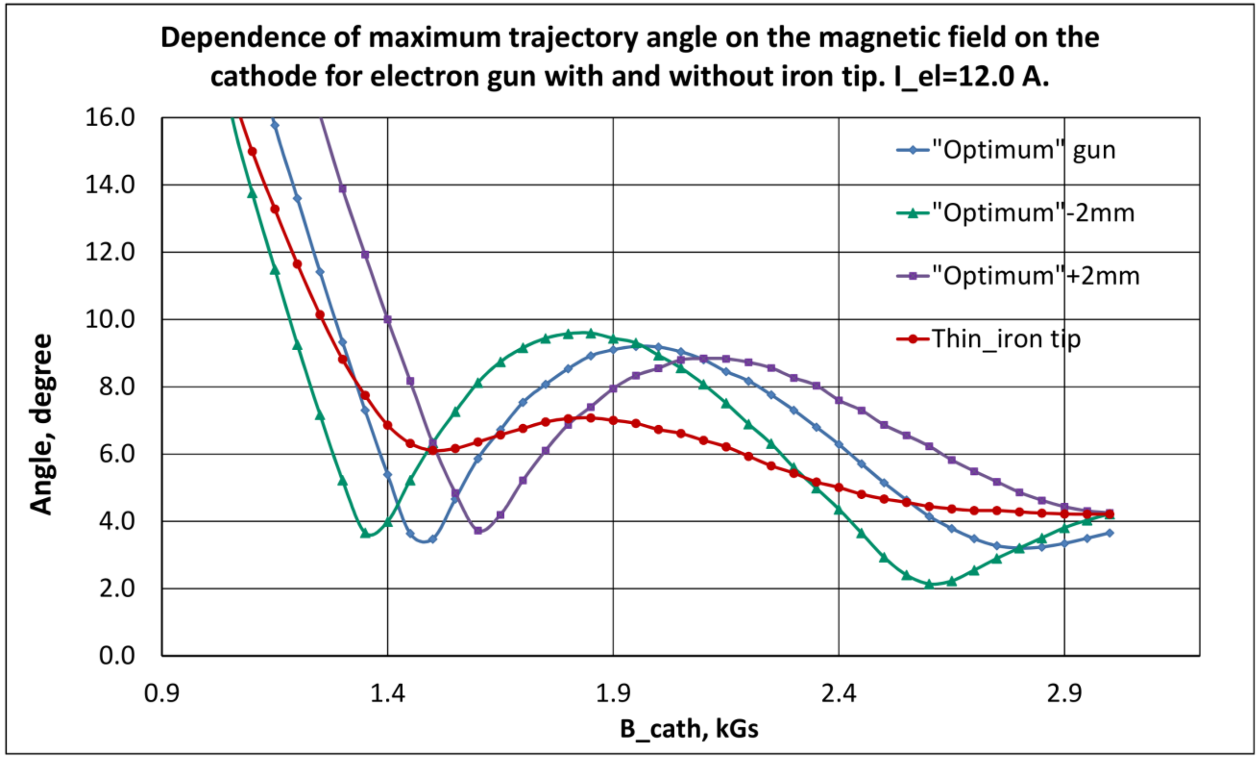


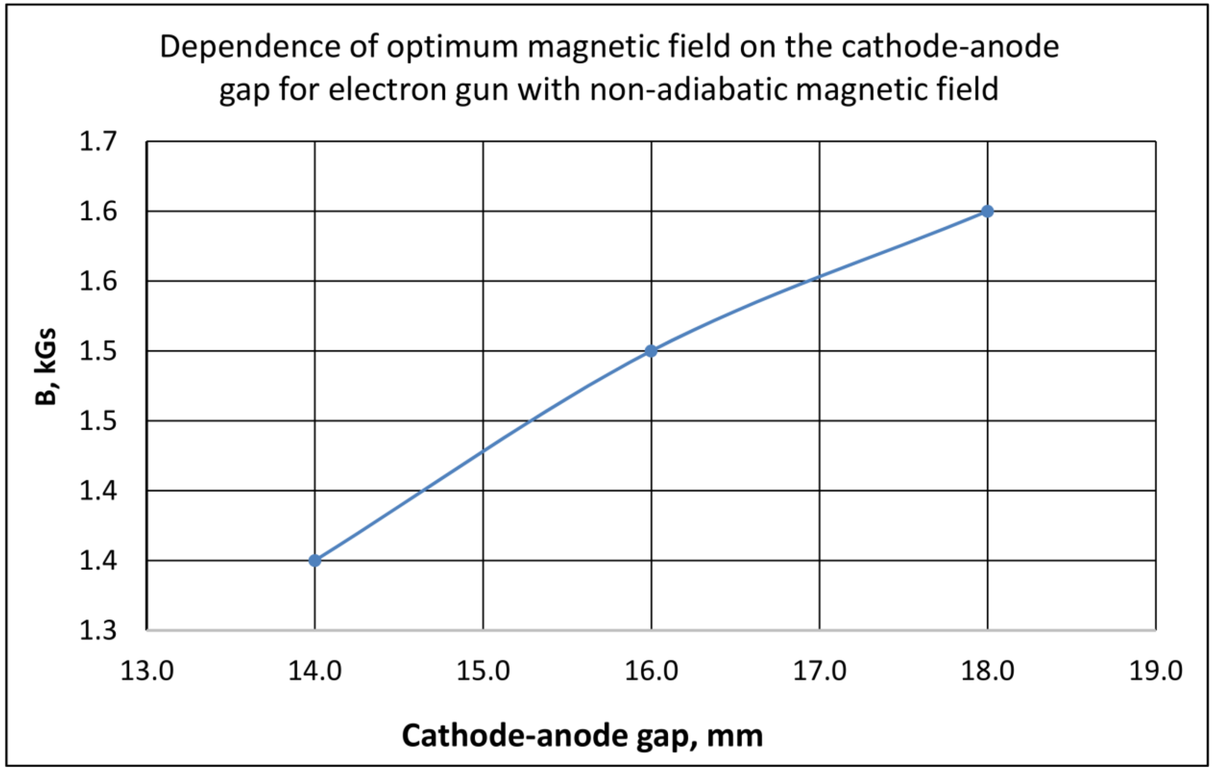
Our electrostatically adiabatic gun was equipped with magnet shim in anode (soft iron). Shim absorbed some magnetic flux, reduced magnetic field in C-A gap.

Map of electron gun with non-adiabatic magnetic field

	B, kGs																							
	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00
2.0	10.06	3.24	6.33	8.49	8.98	8.07	6.48	4.60	3.35	3.30	3.82	4.24	4.29	4.19	3.97	3.80	3.71	3.67	3.70	3.71	3.74	3.69	3.68	3.70
3.0	17.28	10.20	4.13	5.54	7.93	8.96	8.76	7.84	6.35	4.64	3.45	3.21	3.65	4.06	4.28	4.31	4.19	4.00	3.85	3.76	3.72	3.70	3.70	3.73
4.0	32.59	15.16	9.08	3.67	5.53	7.75	8.85	9.00	8.23	7.09	5.55	4.09	3.27	3.23	3.67	4.07	4.27	4.30	4.23	4.08	3.93	3.82	3.76	3.73
5.0	36.57	20.61	12.94	7.51	2.72	5.85	7.90	8.95	8.99	8.35	7.37	6.06	4.61	3.54	3.14	3.44	3.80	4.16	4.31	4.32	4.27	4.11	3.96	3.85
6.0	39.93	33.01	16.30	10.72	5.73	3.80	6.41	8.16	8.93	9.02	8.37	7.48	6.20	4.83	3.76	3.21	3.29	3.70	4.01	4.28	4.34	4.31	4.23	4.11
7.0	40.17	35.70	20.14	13.43	8.40	3.95	4.74	7.12	8.37	8.99	8.95	8.29	7.44	6.25	4.93	3.84	3.24	3.24	3.59	3.92	4.22	4.34	4.35	4.29
8.0	39.18	37.52	29.55	15.83	10.87	6.26	3.13	5.78	7.62	8.62	9.03	8.87	8.24	7.32	6.13	4.86	3.86	3.25	3.22	3.54	3.87	4.20	4.32	4.38
9.0	39.51	40.22	34.20	18.30	12.82	8.34	4.18	4.44	6.67	8.19	8.90	9.08	8.79	8.05	7.08	5.96	4.79	3.83	3.27	3.23	3.55	3.88	4.18	4.34
10.0	38.47	39.78	35.81	22.52	14.74	10.20	6.02	3.17	5.69	7.43	8.49	9.04	9.09	8.54	7.82	6.82	5.71	4.60	3.70	3.22	3.22	3.54	3.86	4.17
11.0	38.41	40.23	37.20	30.04	16.57	11.85	7.68	3.86	4.53	6.59	8.08	8.84	9.10	8.93	8.34	7.52	6.51	5.42	4.37	3.60	3.21	3.26	3.59	3.90
12.0	37.96	39.35	38.91	34.08	18.32	13.50	9.26	5.35	3.45	5.82	7.48	8.47	9.03	9.11	8.74	8.11	7.25	6.24	5.11	4.12	3.46	3.18	3.32	3.63
13.0	37.30	39.24	40.55	35.19	21.13	14.86	10.61	6.74	3.30	4.83	6.78	8.05	8.86	9.08	9.00	8.47	7.82	6.85	5.83	4.79	3.92	3.35	3.19	3.39
14.0	36.75	38.94	40.56	36.29	26.22	16.23	11.98	8.11	4.53	3.97	6.03	7.60	8.52	9.06	9.16	8.80	8.22	7.47	6.48	5.44	4.46	3.71	3.25	3.20

Gun with non-adiabatic magnetic field



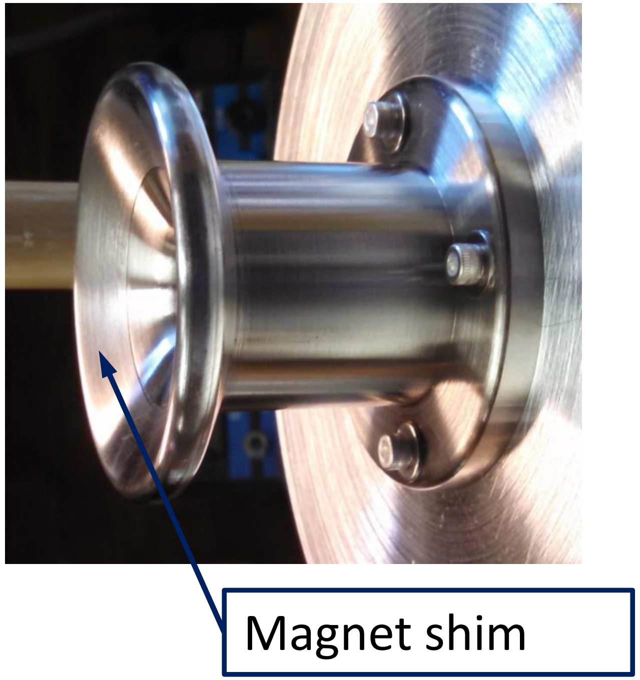


Simulations also show, that the non-adiabatic magnetic field can be also produced with magnet coil in the volume of the shim.

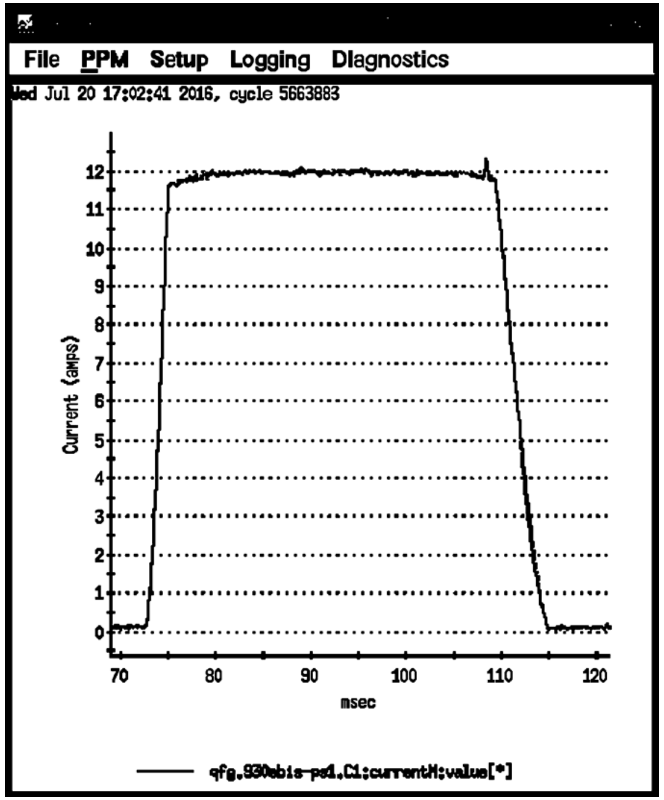
Optimum magnetic field decreases with decreasing the C-A gap.

Region of optimum magnetic field seems to be higher than for guns with non-adiabatic electrostatic field.

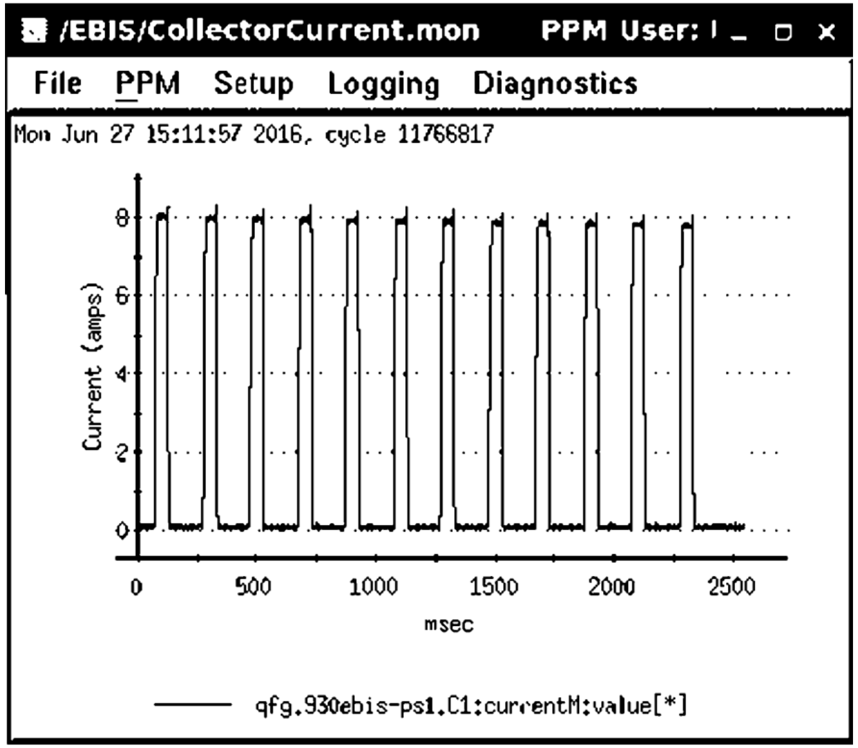
Anode of the gun



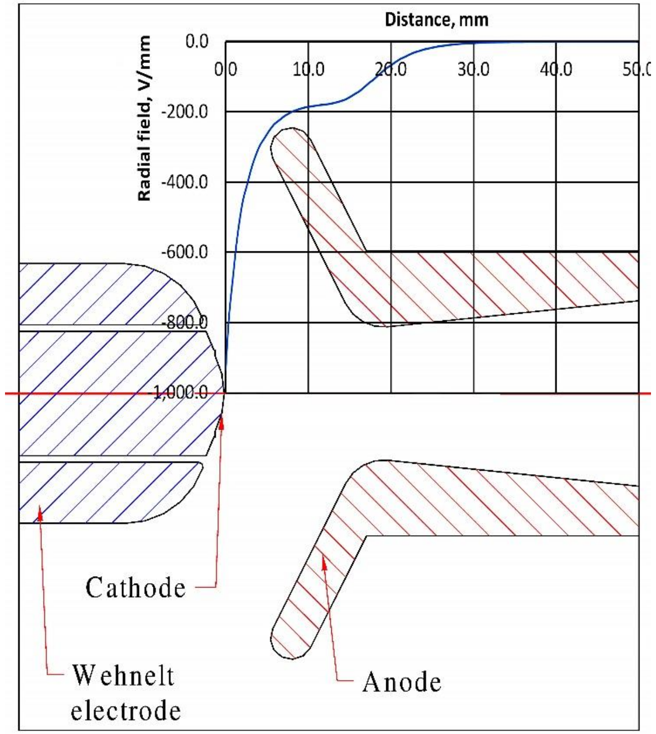
Electron pulse



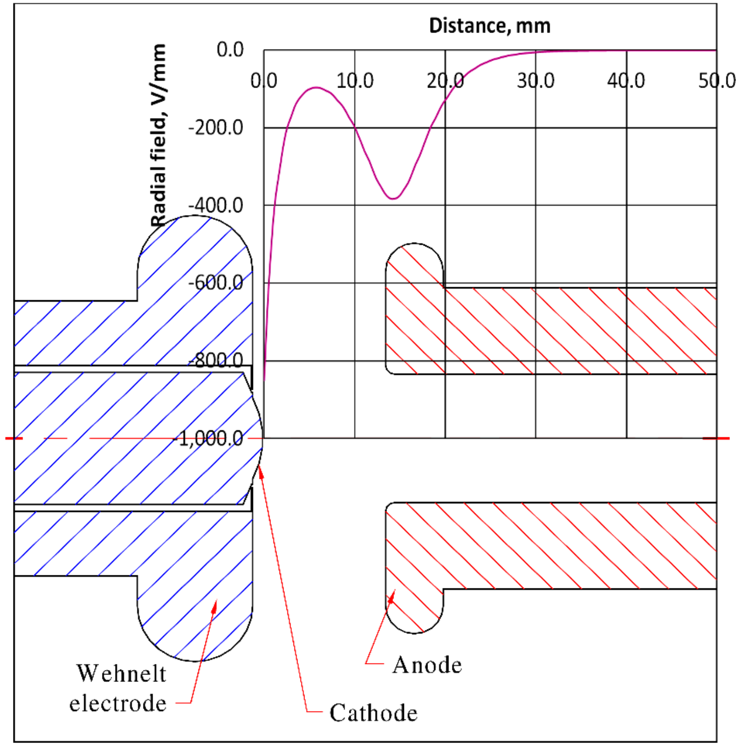
Train of 12 pulses



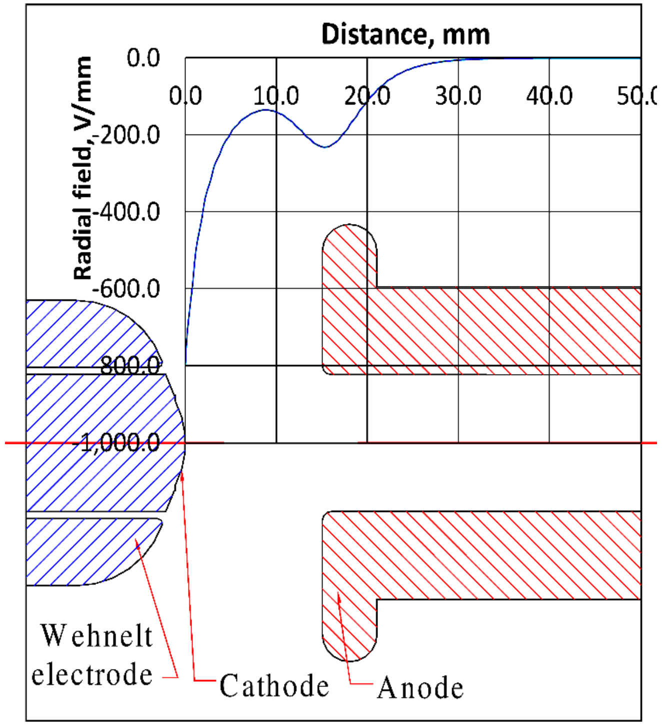
Testing electron guns with non-adiabatic electrostatic field. Magnetic field is uniform.



Adiabatic gun



Non-adiabatic gun



Intermediate (hybrid) gun

Radial electrostatic field scan is taken at r=3.0 mm from the axis.

Map of gun with non-adiabatic electrostatic field

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B, kGs	0.7	0.75	0.8	0.85	0.9	0.95	1	1.05	1.1	1.15	1.2	1.25
1	3.32	3.14	2.82	2.32	1.80	1.27	0.88	1.19	1.54	1.78	1.92	1.94
2	3.22	3.74	4.05	4.18	4.14	3.93	3.60	3.17	2.63	2.09	1.59	1.16
3	2.36	3.03	3.69	4.22	4.57	4.77	4.79	4.69	4.48	4.12	3.68	3.12
4	3.86	2.66	2.96	3.70	4.29	4.79	5.08	5.25	5.29	5.19	4.99	4.66
5	5.67	4.24	3.05	3.07	3.73	4.44	4.94	5.38	5.60	5.72	5.73	5.59
6	7.55	5.81	4.49	3.18	3.24	3.92	4.59	5.16	5.60	5.92	6.06	6.10
7	9.00	7.47	5.88	4.49	3.27	3.49	4.12	4.83	5.38	5.84	6.19	6.38
8	10.47	8.80	7.35	5.71	4.39	3.40	3.73	4.42	5.08	5.66	6.12	6.45
9	11.91	10.19	8.72	7.01	5.66	4.21	3.56	4.07	4.70	5.39	5.92	6.42
10	13.19	11.46	9.86	8.30	6.73	5.34	4.00	3.82	4.37	5.09	5.70	6.24
11	14.42	12.69	11.02	9.35	7.91	6.26	4.96	3.93	4.11	4.75	5.42	6.04
12	15.57	13.83	12.17	10.51	9.10	7.33	6.00	4.59	4.06	4.47	5.10	5.79
13	16.81	14.95	13.29	11.56	9.89	8.39	6.83	5.47	4.35	4.31	4.84	5.54
14	17.66	15.93	14.31	12.57	10.99	9.45	7.83	6.26	5.05	4.35	4.60	5.26

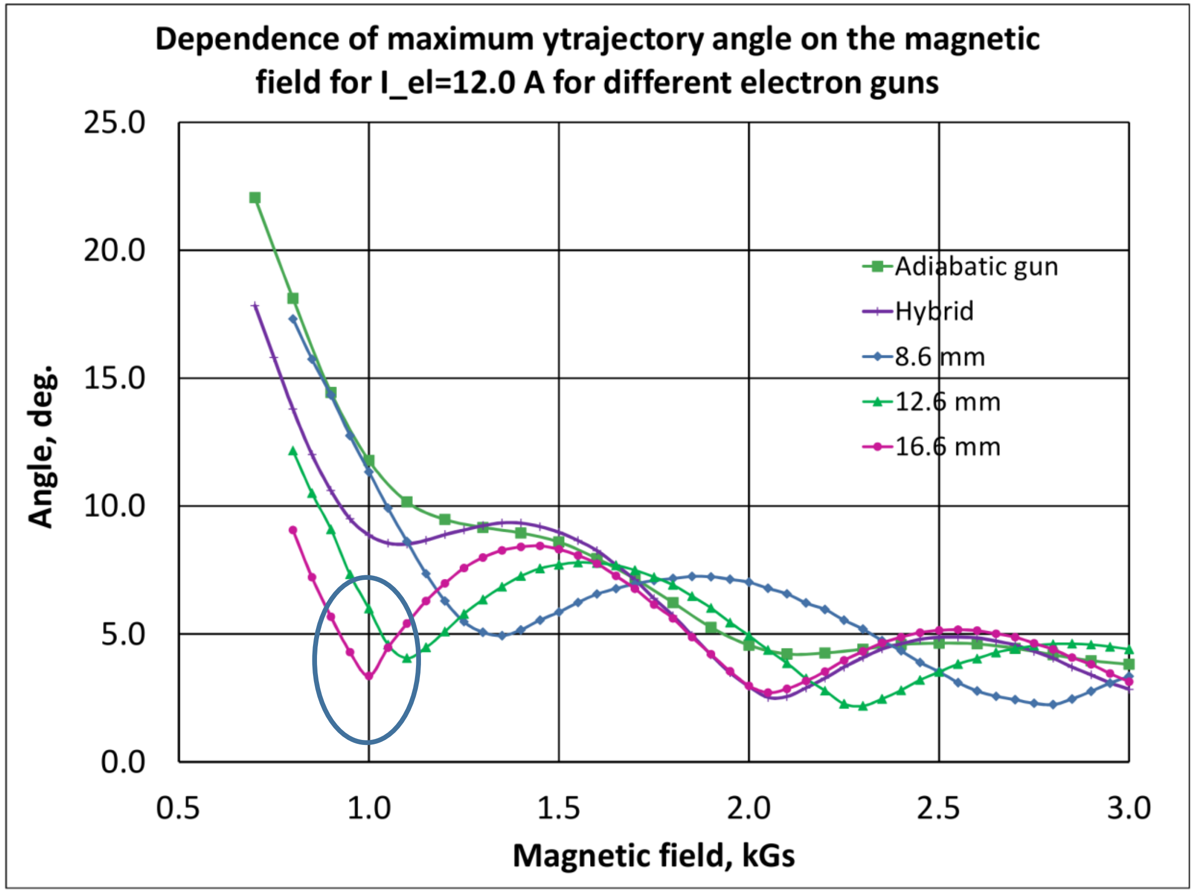
B, kGs	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9
1	1.87	1.72	1.52	1.30	1.11	0.97	0.92	1.09	1.26	1.39	1.44	1.43	1.39
2	1.32	1.72	2.02	2.27	2.41	2.46	2.44	2.34	2.20	1.99	1.78	1.54	1.36
3	2.60	2.04	1.56	1.29	1.61	2.01	2.31	2.56	2.72	2.81	2.83	2.79	2.68
4	4.24	3.71	3.18	2.63	2.14	1.63	1.44	1.79	2.16	2.50	2.75	2.95	3.06
5	5.37	5.00	4.61	4.08	3.53	3.00	2.50	1.94	1.58	1.74	2.10	2.47	2.76
6	6.04	5.85	5.59	5.24	4.81	4.23	3.71	3.15	2.65	2.11	1.70	1.79	2.13
7	6.44	6.41	6.28	6.02	5.74	5.32	4.85	4.25	3.75	3.19	2.70	2.15	1.76
8	6.63	6.73	6.73	6.62	6.43	6.13	5.76	5.27	4.80	4.17	3.68	3.13	2.65
9	6.73	6.93	7.04	7.03	6.94	6.75	6.49	6.13	5.69	5.17	4.65	4.07	3.55
10	6.69	6.99	7.18	7.30	7.30	7.21	7.02	6.77	6.45	5.95	5.49	4.94	4.41
11	6.55	6.99	7.28	7.46	7.55	7.54	7.45	7.25	7.01	6.67	6.30	5.78	5.29
12	6.35	6.85	7.27	7.57	7.72	7.80	7.77	7.68	7.50	7.23	6.92	6.48	6.02
13	6.15	6.72	7.17	7.56	7.82	7.97	8.04	8.02	7.90	7.68	7.45	7.09	6.73
14	5.92	6.53	7.08	7.51	7.85	8.07	8.21	8.26	8.19	8.06	7.87	7.60	7.27

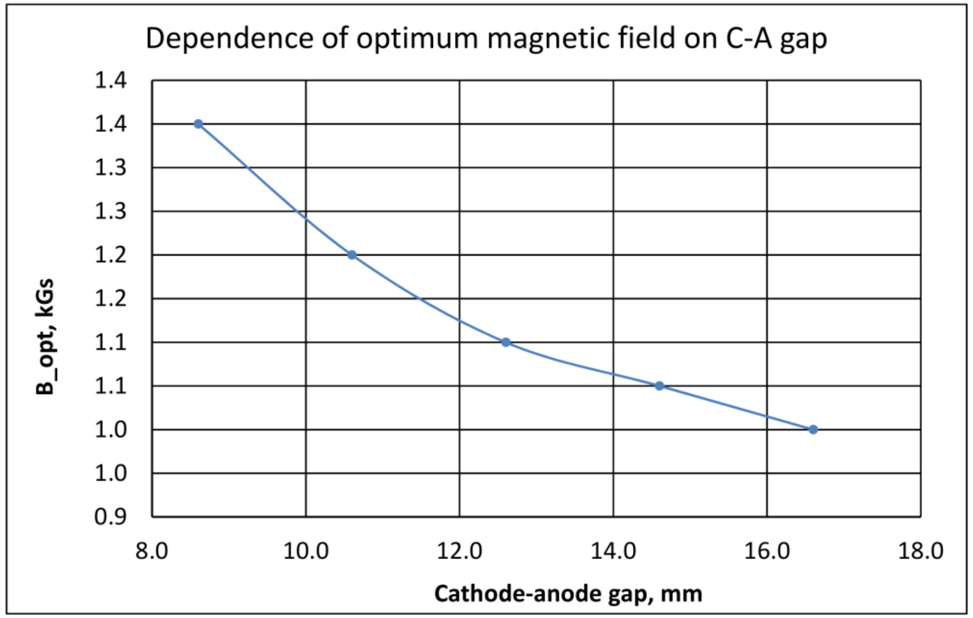
B, kGs	2	2	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6
1	1.30	1.22	1.12	1.08	1.03	1.02	1.10	1.17	1.24	1.26	1.25	1.23	1.19	1.15
2	1.23	1.17	1.26	1.45	1.64	1.74	1.82	1.83	1.81	1.76	1.67	1.59	1.49	1.41
3	2.51	2.31	2.06	1.87	1.63	1.49	1.37	1.34	1.46	1.66	1.85	1.98	2.07	2.10
4	3.12	3.11	3.04	2.92	2.75	2.55	2.31	2.10	1.86	1.70	1.58	1.50	1.46	1.65
5	3.01	3.19	3.32	3.39	3.36	3.32	3.18	3.03	2.83	2.64	2.39	2.18	1.95	1.79
6	2.54	2.85	3.13	3.31	3.48	3.56	3.59	3.57	3.51	3.38	3.19	3.03	2.80	2.58
7	1.92	2.26	2.66	2.97	3.27	3.46	3.64	3.74	3.80	3.79	3.75	3.65	3.48	3.32
8	2.11	1.84	2.10	2.44	2.84	3.13	3.44	3.63	3.81	3.93	3.99	3.99	3.95	3.87
9	2.99	2.49	2.02	1.98	2.32	2.67	3.06	3.34	3.61	3.81	3.99	4.09	4.15	4.16
10	3.87	3.36	2.79	2.30	2.03	2.20	2.58	2.94	3.30	3.57	3.83	4.02	4.18	4.29
11	4.67	4.17	3.61	3.09	2.53	2.13	2.18	2.48	2.89	3.22	3.55	3.81	4.06	4.22
12	5.45	4.94	4.38	3.86	3.26	2.79	2.27	2.19	2.47	2.80	3.21	3.52	3.83	4.05
13	6.16	5.70	5.09	4.58	4.02	3.51	2.93	2.45	2.26	2.44	2.82	3.16	3.53	3.80
14	6.84	6.40	5.82	5.29	4.70	4.20	3.63	3.13	2.57	2.33	2.46	2.78	3.18	3.51

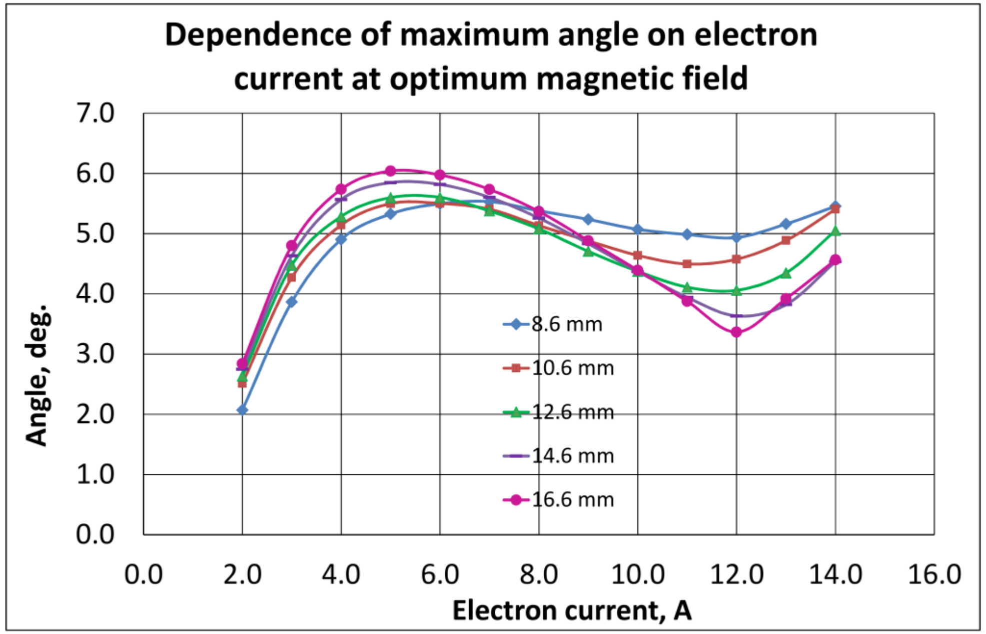
Dependence of maximum trajectory angle on the magnetic field and electron current.
R_{cath}=4.6 mm, C-A gap is 12.6 mm.
Green roads with small trajectory angles at different magnetic fields

Observation: at optimum magnetic field there is a second minimum in distribution of trajectory angles on cathode radius, which is close to outside cathode radius. This position of trajectory with minimum Larmor motion remains throughout all green areas of the map.

Map scans for guns with non-adiabatic el-stat. field



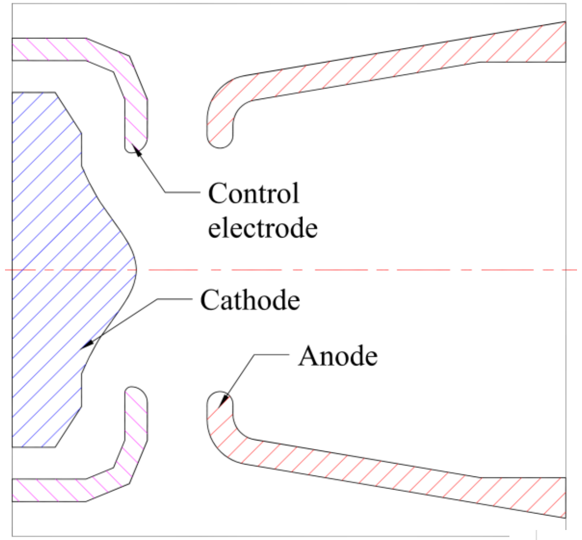


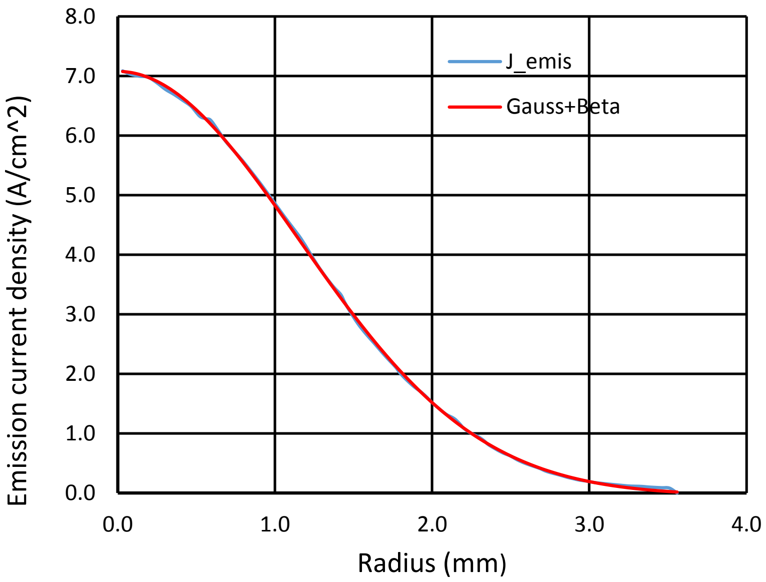


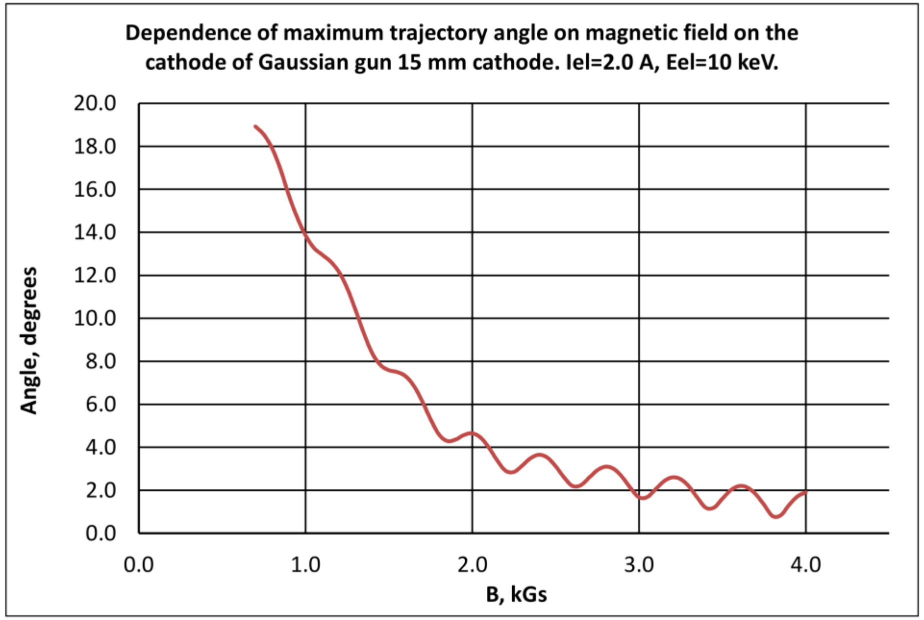
- Control of contrast with the strength of radial field.
- Increasing the C-A gap is beneficial for optimum B.
- Price – gun perveance and larger angles at ramps.

Gaussian gun (electron lens)

Gaussian electron gun model







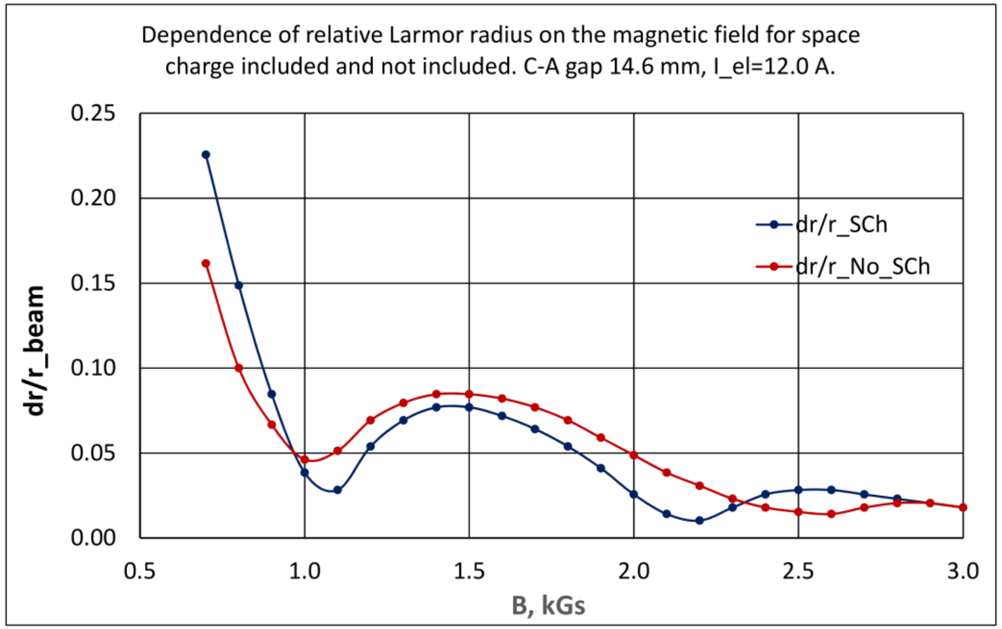
Complex cathode shape: combination of many radii

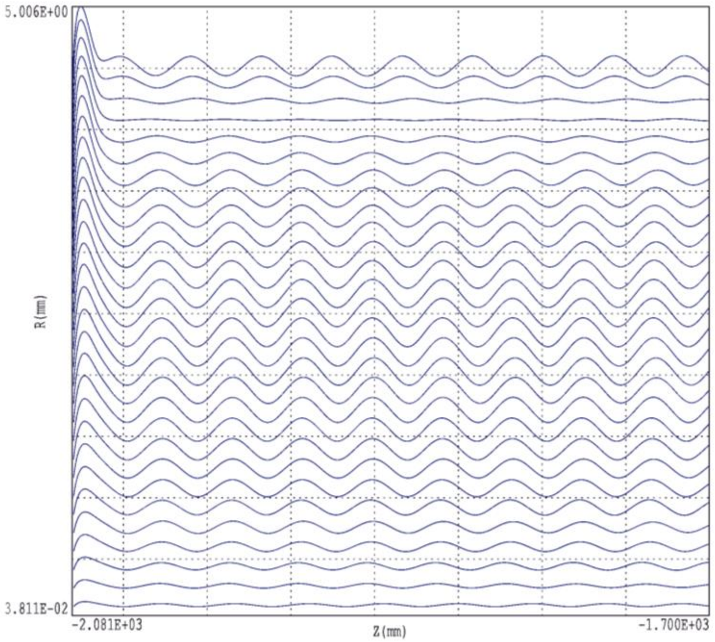
I_el, A \ B, kGs	1.9	2	2	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	2.9	3	3	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.9	3.9	4	4
0.1	0.36	0.37	0.17	0.34	0.34	0.20	0.33	0.32	0.22	0.32	0.30	0.24	0.31	0.29	0.25	0.31	0.29	0.26	0.31	0.29	0.27	0.31	0.29	0.28	0.31	0.30	0.30	0.32	0.31	0.31	0.33	0.32	0.33	0.34	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.39	0.40
0.2	0.67	0.26	0.44	0.66	0.50	0.13	0.48	0.58	0.37	0.24	0.49	0.50	0.28	0.32	0.48	0.43	0.26	0.37	0.46	0.37	0.29	0.41	0.44	0.35	0.33	0.43	0.41	0.34	0.37	0.44	0.40	0.36	0.41	0.44	0.40	0.39	0.44	0.44	0.41	0.43	0.46	0.46	0.44
0.3	1.03	1.00	0.60	0.40	0.79	0.87	0.60	0.19	0.59	0.77	0.60	0.21	0.45	0.67	0.60	0.31	0.34	0.59	0.60	0.39	0.30	0.51	0.58	0.44	0.31	0.46	0.55	0.48	0.35	0.42	0.53	0.50	0.40	0.41	0.52	0.53	0.44	0.43	0.51	0.54	0.49	0.46	0.52
0.4	1.39	1.03	0.61	0.87	1.16	1.09	0.67	0.41	0.80	0.99	0.82	0.39	0.41	0.77	0.84	0.61	0.19	0.49	0.74	0.72	0.45	0.26	0.56	0.70	0.61	0.36	0.37	0.59	0.66	0.52	0.35	0.46	0.61	0.61	0.47	0.40	0.53	0.62	0.58	0.46	0.48	0.59	0.63
0.5	0.98	1.19	1.52	1.50	1.11	0.68	0.88	1.22	1.24	0.92	0.45	0.65	1.00	1.05	0.78	0.31	0.52	0.86	0.92	0.70	0.28	0.44	0.76	0.83	0.65	0.31	0.42	0.70	0.77	0.62	0.36	0.43	0.66	0.73	0.61	0.41	0.46	0.65	0.71	0.62	0.47	0.50	0.65
0.6	1.97	1.62	1.14	1.11	1.49	1.66	1.47	1.00	0.71	1.04	1.34	1.31	0.95	0.49	0.67	1.04	1.14	0.93	0.49	0.38	0.80	1.00	0.91	0.58	0.19	0.60	0.86	0.88	0.66	0.32	0.46	0.74	0.84	0.72	0.45	0.40	0.65	0.80	0.76	0.56	0.43	0.59	0.76
0.7	1.74	2.06	2.08	1.73	1.24	1.14	1.49	1.74	1.65	1.25	0.79	0.91	1.30	1.44	1.27	0.83	0.47	0.83	1.16	1.20	0.95	0.49	0.41	0.83	1.06	1.00	0.70	0.25	0.52	0.85	0.97	0.83	0.51	0.31	0.64	0.87	0.89	0.70	0.43	0.47	0.73	0.87	0.81
0.8	1.68	1.59	1.93	2.19	2.14	1.76	1.27	1.21	1.57	1.83	1.76	1.37	0.88	0.87	1.27	1.51	1.43	1.07	0.58	0.65	1.07	1.28	1.19	0.85	0.35	0.56	0.96	1.13	1.03	0.70	0.25	0.56	0.90	1.03	0.92	0.61	0.32	0.59	0.88	0.97	0.85	0.57	0.41
0.9	2.50	2.00	1.63	1.78	2.15	2.32	2.13	1.68	1.25	1.32	1.70	1.91	1.81	1.42	0.92	0.90	1.30	1.56	1.54	1.21	0.71	0.58	1.01	1.30	1.32	1.07	0.61	0.34	0.81	1.11	1.18	0.99	0.59	0.25	0.69	1.00	1.09	0.94	0.61	0.34	0.64	0.93	1.03
1	2.84	2.73	2.29	1.80	1.72	2.05	2.36	2.36	2.04	1.54	1.24	1.49	1.86	2.00	1.81	1.38	0.91	0.97	1.38	1.63	1.60	1.28	0.77	0.57	0.99	1.32	1.40	1.20	0.78	0.30	0.69	1.08	1.24	1.15	0.83	0.37	0.48	0.88	1.12	1.12	0.90	0.53	0.40
1.1	2.66	2.92	2.88	2.51	2.00	1.74	1.97	2.33	2.49	2.31	1.87	1.39	1.35	1.71	2.02	2.05	1.77	1.28	0.89	1.10	1.51	1.72	1.63	1.28	0.78	0.60	1.03	1.37	1.46	1.28	0.88	0.36	0.62	1.06	1.28	1.26	0.99	0.56	0.32	0.78	1.10	1.21	1.08
1.2	2.39	2.70	2.99	3.01	2.69	2.18	1.81	1.93	2.31	2.55	2.49	2.13	1.62	1.34	1.57	1.94	2.14	2.02	1.63	1.13	0.93	1.28	1.65	1.78	1.63	1.23	0.71	0.67	1.12	1.44	1.51	1.32	0.90	0.38	0.62	1.06	1.32	1.33	1.09	0.67	0.24	0.70	1.08
1.3	2.53	2.44	2.75	3.06	3.10	2.82	2.32	1.90	1.93	2.28	2.59	2.62	2.33	1.84	1.42	1.47	1.86	2.15	2.18	1.91	1.43	0.99	1.08	1.49	1.78	1.82	1.57	1.11	0.63	0.80	1.25	1.53	1.56	1.32	0.87	0.36	0.68	1.12	1.37	1.38	1.15	0.73	0.25
1.4	3.09	2.58	2.52	2.82	3.14	3.20	2.92	2.44	1.98	1.94	2.28	2.61	2.71	2.50	2.03	1.56	1.44	1.77	2.13	2.27	2.12	1.70	1.19	0.98	1.31	1.70	1.90	1.80	1.45	0.94	0.61	0.99	1.40	1.62	1.57	1.28	0.79	0.33	0.79	1.21	1.44	1.42	1.17
1.5	3.68	3.10	2.62	2.59	2.92	3.22	3.27	3.01	2.52	2.05	1.97	2.29	2.65	2.78	2.62	2.20	1.69	1.45	1.70	2.09	2.32	2.26	1.93	1.42	1.02	1.17	1.59	1.89	1.93	1.70	1.26	0.75	0.74	1.20	1.56	1.68	1.54	1.18	0.66	0.42	0.93	1.32	1.50
1.6	4.13	3.68	3.07	2.64	2.68	3.02	3.31	3.34	3.07	2.58	2.11	2.02	2.33	2.68	2.85	2.72	2.33	1.81	1.49	1.66	2.07	2.34	2.36	2.11	1.63	1.14	1.07	1.47	1.85	2.00	1.89	1.53	1.01	0.64	0.98	1.43	1.69	1.71	1.47	1.03	0.48	0.60	1.11
1.7	4.38	4.15	3.63	3.04	2.67	2.77	3.13	3.39	3.41	3.11	2.61	2.15	2.06	2.36	2.74	2.91	2.80	2.43	1.91	1.54	1.65	2.04	2.36	2.44	2.24	1.81	1.29	1.05	1.37	1.78	2.02	2.02	1.74	1.27	0.76	0.80	1.27	1.63	1.78	1.68	1.33	0.82	0.37
1.8	4.46	4.44	4.12	3.57	2.99	2.71	2.88	3.24	3.48	3.46	3.14	2.63	2.17	2.11	2.43	2.79	2.98	2.88	2.50	2.00	1.59	1.65	2.04	2.38	2.50	2.35	1.95	1.43	1.07	1.29	1.72	2.03	2.10	1.90	1.49	0.95	0.69	1.10	1.54	1.79	1.80	1.56	1.12
1.9	4.42	4.56	4.46	4.07	3.48	2.95	2.76	3.01	3.37	3.57	3.50	3.14	2.62	2.20	2.17	2.50	2.87	3.03	2.94	2.57	2.05	1.64	1.67	2.04	2.40	2.56	2.44	2.08	1.56	1.13	1.23	1.66	2.02	2.15	2.03	1.67	1.15	0.71	0.96	1.43	1.77	1.88	1.74
2	4.36	4.57	4.65	4.45	3.98	3.38	2.91	2.86	3.15	3.50	3.65	3.52	3.12	2.60	2.21	2.23	2.58	2.93	3.10	2.99	2.61	2.09	1.67	1.69	2.06	2.43	2.60	2.51	2.17	1.66	1.19	1.20	1.61	2.01	2.20	2.13	1.81	1.32	0.81	0.84	1.32	1.72	1.91

Effect of electron space charge

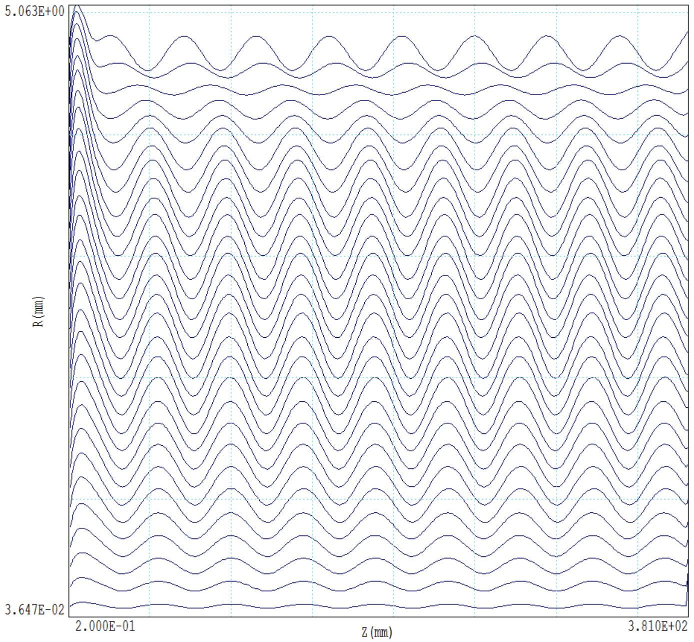
To study the contribution of space charge to the gun performance the simulations have done for a case of a gun with non-adiabatic electrostatic field for electrostatic field used to generate a 12 A electron beam with space charge.

Electron trajectories at optimum magnetic field (minimum angles)





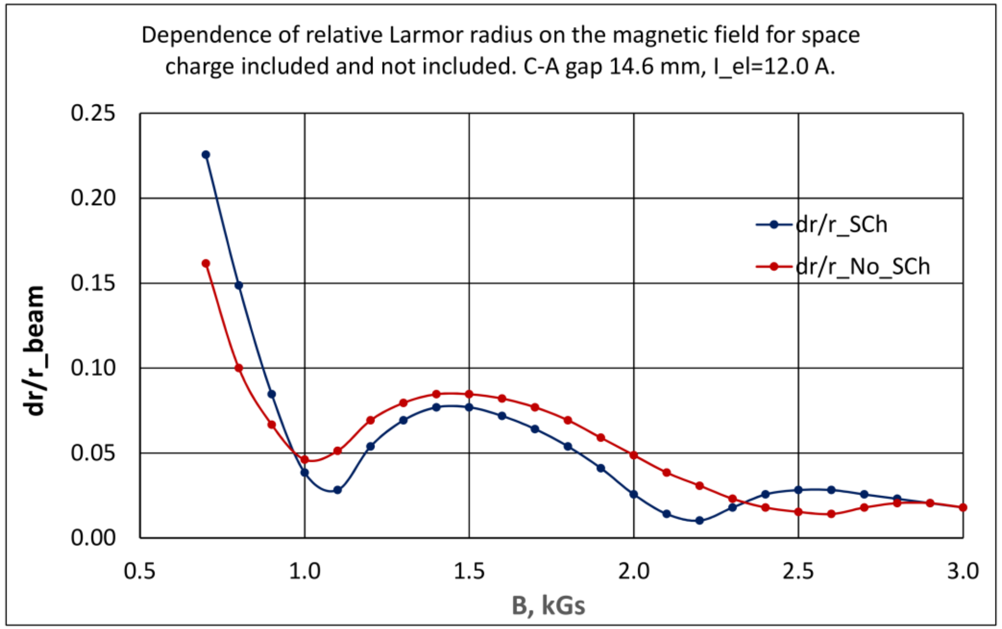
With space charge



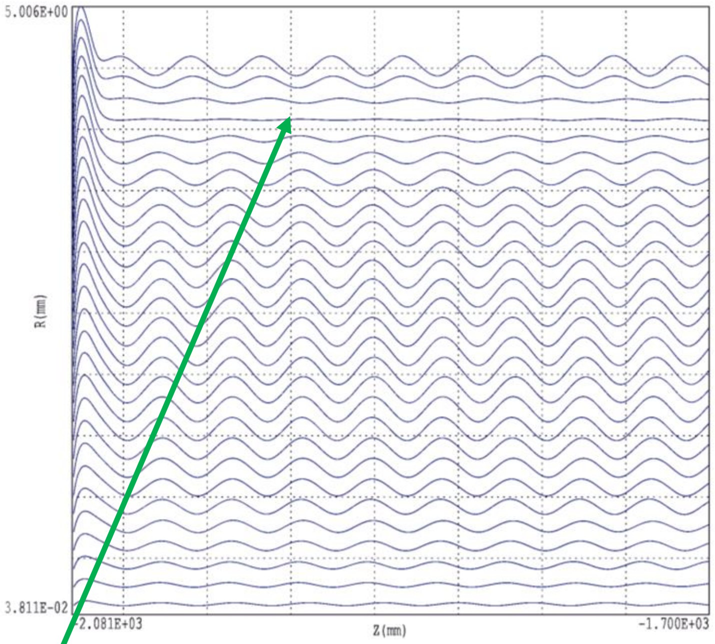
Without space charge

Effect of electron space charge

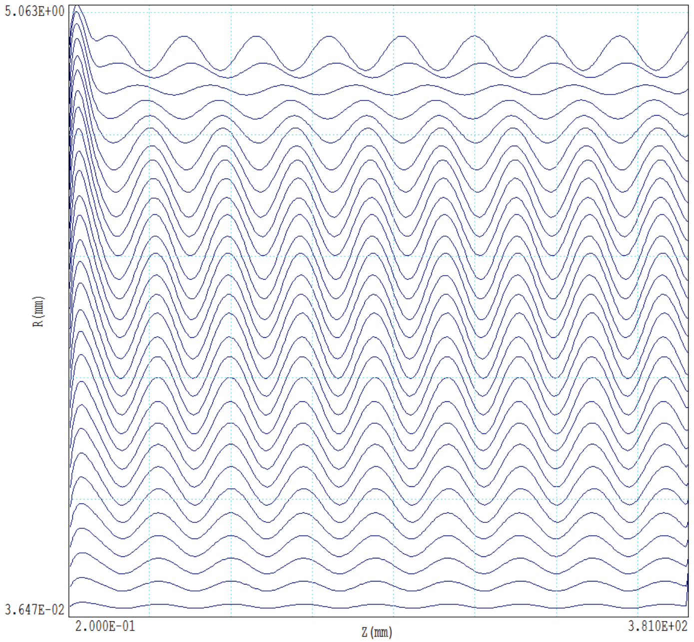
To study the contribution of space charge to the gun performance the simulations have done for a case of a gun with non-adiabatic electrostatic field for electrostatic field used to generate a 12 A electron beam with space charge.



Electron trajectories at optimum magnetic field (minimum angles)



With space charge



Without space charge

There is a special beam radius, where electrons have the largest range of trajectory angles variations at different magnetic fields.

Summary

- Introducing a controllable electrostatic or magnetostatic non-adiabatic field in a C-A gap can reduce the optimum operating magnetic field of the electron gun.
- At the same time the Larmor motion at not-optimum magnetic fields or electron currents will have larger radii or angle. Smaller angles at lower optimum fields come at a cost of larger angles at ramps. Caution: low magnetic field on the gun carry risk of magnetron discharge.
- The depth of deviation the trajectory angle in non-adiabatic gun compare to adiabatic electron gun depends on the strength of radial field modification. Demonstrated, that by selecting the optimum radial field and the length of the C-A gap one can optimize both the value of optimum magnetic field and the contrast of the map (deviations of trajectory angles in adjacent areas).
- The dominant factors in the pattern of the gun map are external fields. The electron space charge affects the value of the trajectory angles and slightly affect the values of optimum magnetic fields.

Mathematical model?

Quest for a perfect electron gun