This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

Design of the Electron gun for the GSI space charge compensation lens

ARIES Annual Meeting, 23.5.2018, Riga

Kathrin Schulte-Urlichs, GSI/IAP

Objectives

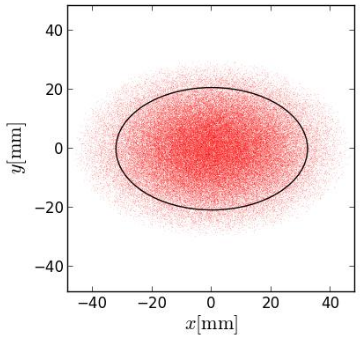
- Requirements for SCC gun
- Basic Gun Design
- Modulation Options & Challenges
- Commissioning of Electron Gun
- Outlook

Requirements for SCC gun

Electron beam for space charge compensation in SIS18

number of electron lenses	N=3
interaction region	l=3 m
electron beam current	**I_B = 10 A**

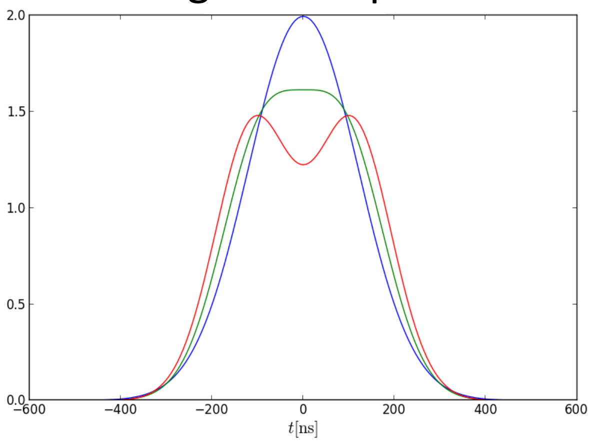
transverse profile



$2\sigma_x$ = 35 mm

$2\sigma_y$ = 20 mm

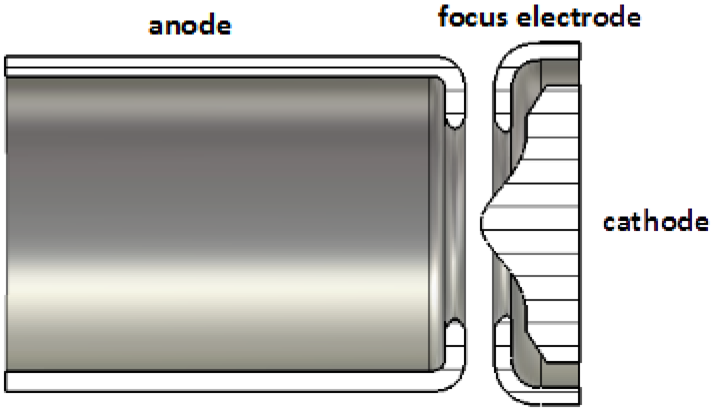
longitudinal profile

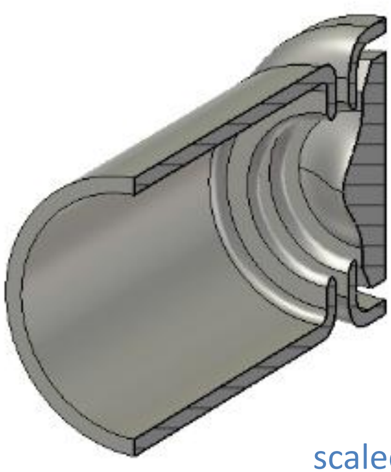


f =5 MHz

Basic Gun Design

Layout of electron gun

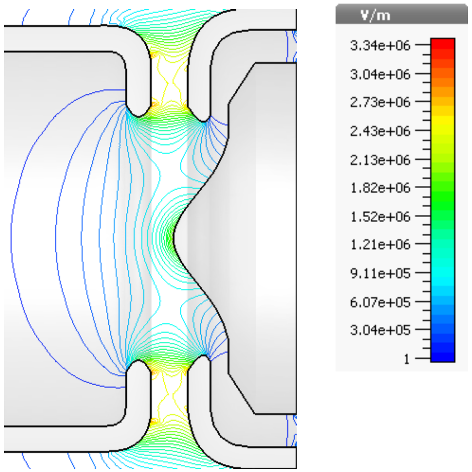




$P = 5.3 \cdot 10^{-6}\ A/V^{3/2}$
U= 30 kV
I = 30.8 A
B_z = 0.2 T
J_e = 2.2 Acm^{-2}
r_c= 35 mm

scaled design of BNL
e-gun by A. Pikin

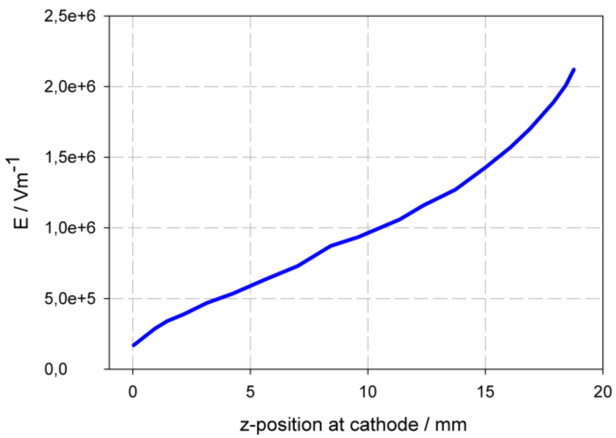
Gun electric field



E_{max} = 3.3 kV/mm
$E_{Kilpatrick}$=9.5 kV/mm

homogeneous
magnetic field
B_z=0.2 T

Electric field along cathode



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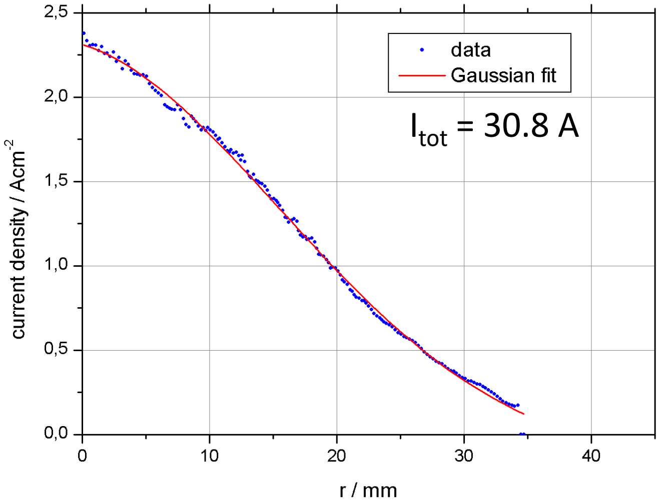
Basic Gun Design

Current density profile

TRAK (2D)

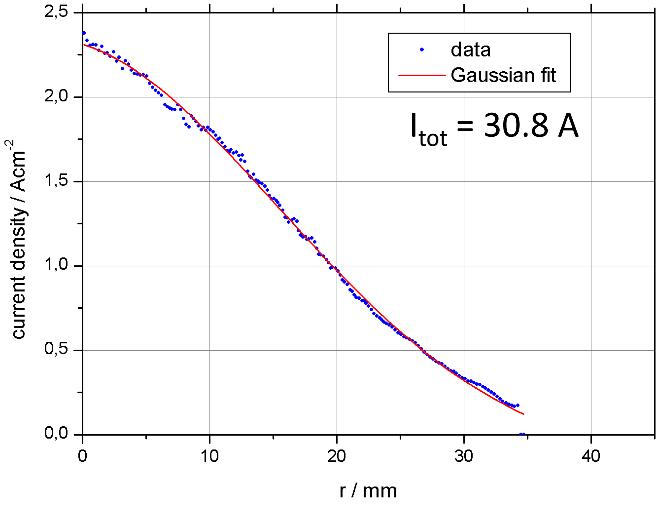


Gun parameters:
$U_c = 0$ V
$U_{CE} = 0$ V
$U_a = 30$ kV
$B_z = 0.22$ T

Basic Gun Design

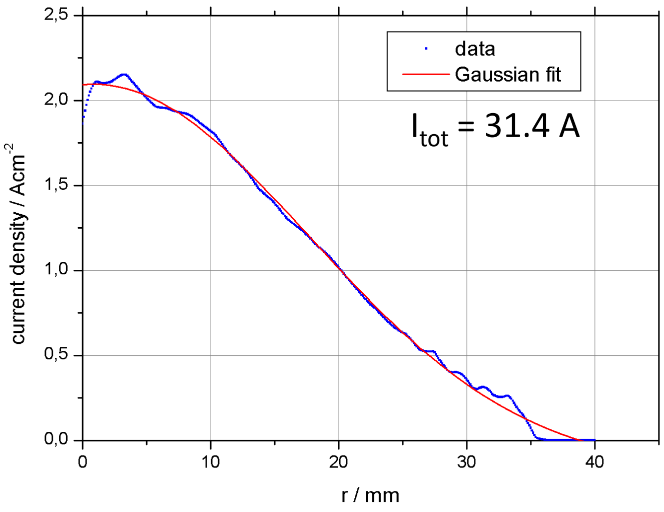
Current density profile

TRAK (2D)



Gun parameters:
$U_c = 0$ V
$U_{CE} = 0$ V
$U_a = 30$ kV
$B_z = 0.22$ T

CST PS (3D)



Two codes (2D and 3D) are used

- validation of simulation results using CST PS
- Basic design studies using 2D code
- Advanced studies (elliptical beam, modulation) using 3D code

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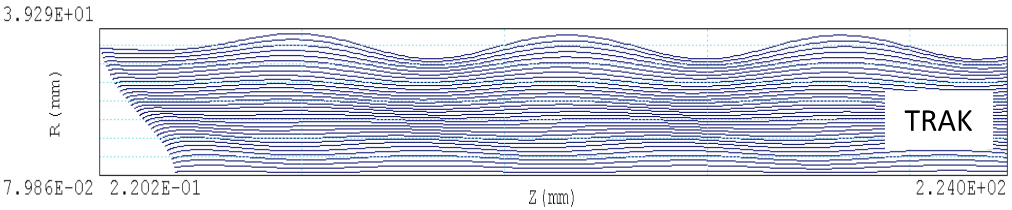
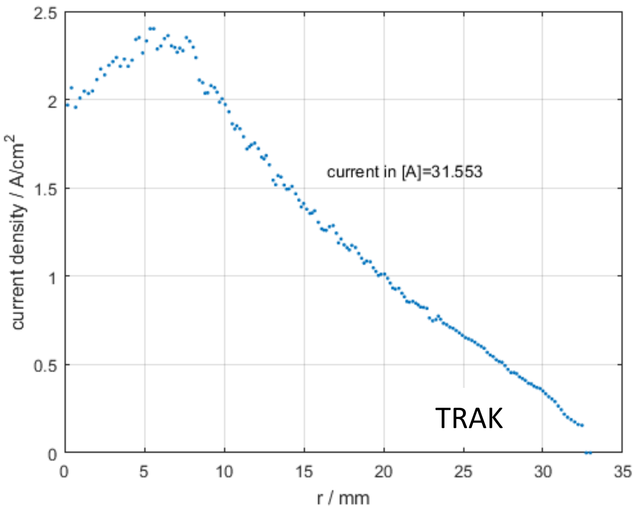
Basic Gun Design

Influence of magnetic field on current density profile

Electron trajectories for B_z=0.05T

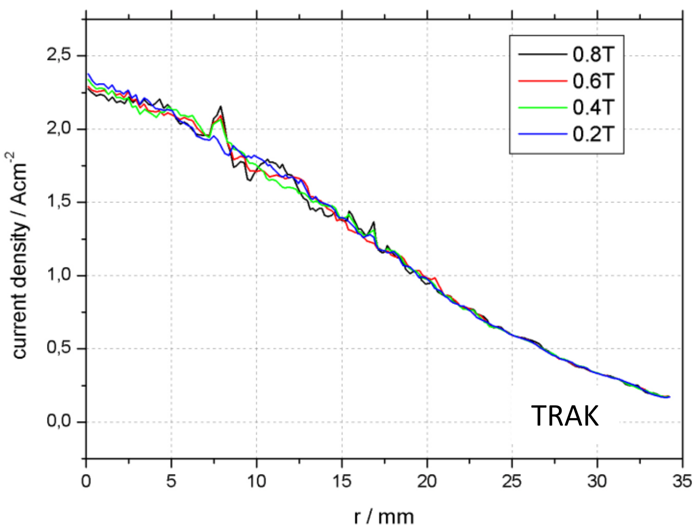


Current density profile for B_z=0.05T



Gun parameters:
U_c = 0 V
U_{CE} = 0 V
U_a = 30 kV

Current density profiles for B_z=0.2-0.8T



Above certain threshold only minor changes in current density profile are observed.

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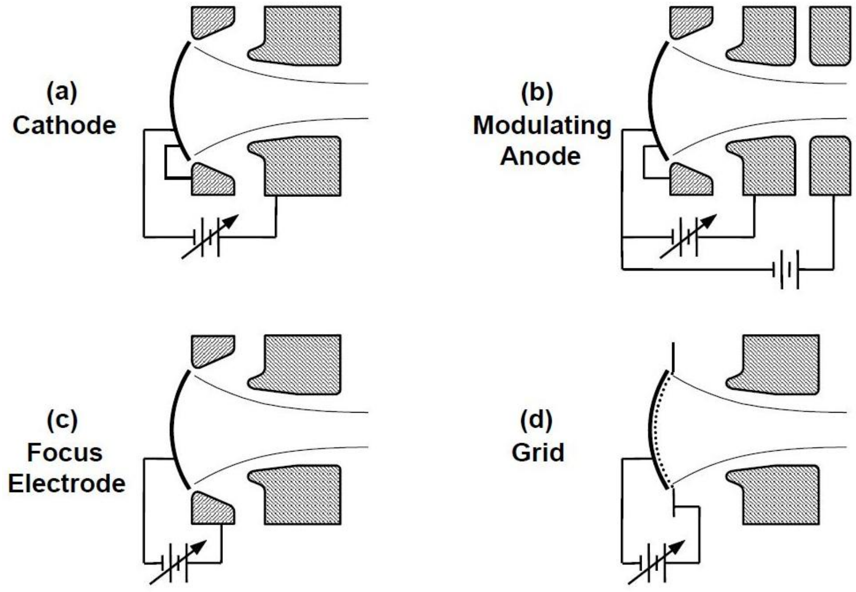
Modulation Options & Challenges

Typical Modulation Options



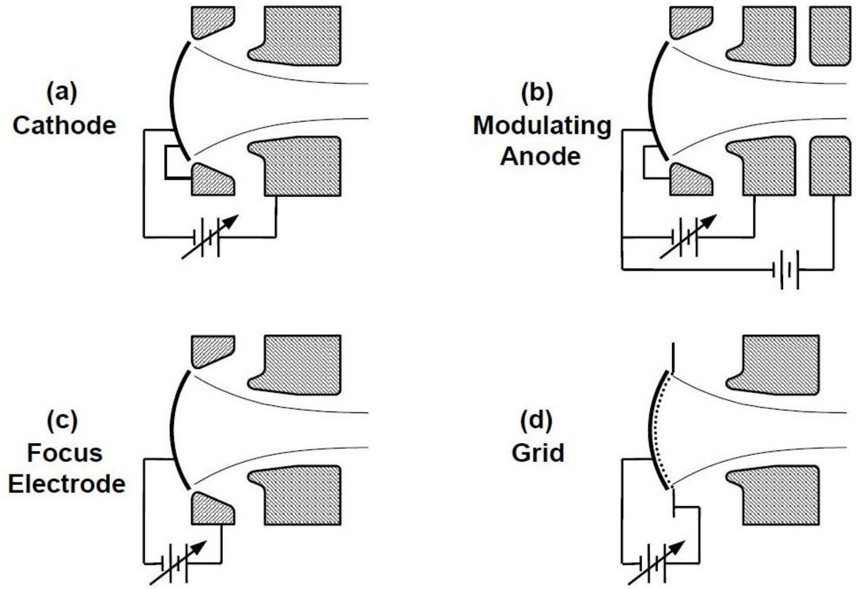
Anode modulation:

$$P_{diss} = {}^{1}/_{2}\, C U_a^2 \cdot f$$

$$P_{diss} = {}^{1}/_{2} \cdot 200\text{pF} \cdot 25kV^2 \cdot 5MHz = 313kW$$

Modulation Options & Challenges

Typical Modulation Options



Anode modulation:

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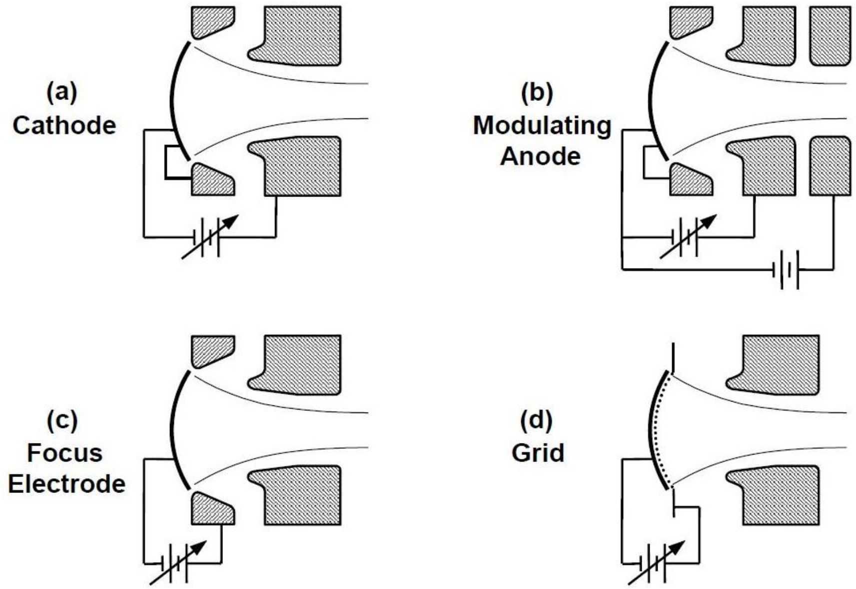
Modulation Options & Challenges

Typical Modulation Options



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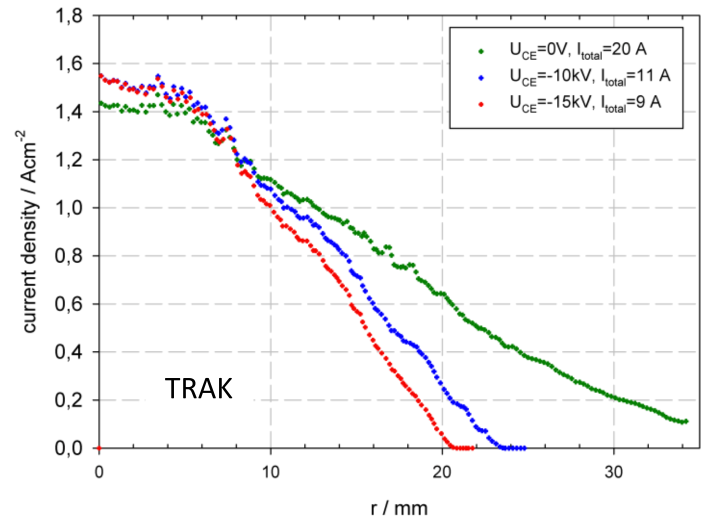
Focus electrode modulation

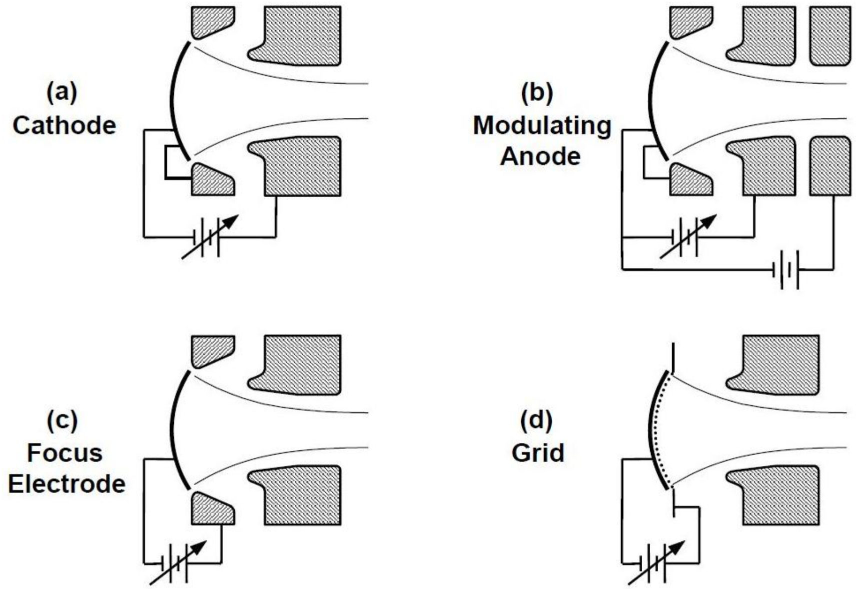


Gun parameters:
U_c = 0 V
U_a = 22 kV
B_z = 0.4 T

High voltages required to depress beam current.

Modulation Options & Challenges

Typical Modulation Options



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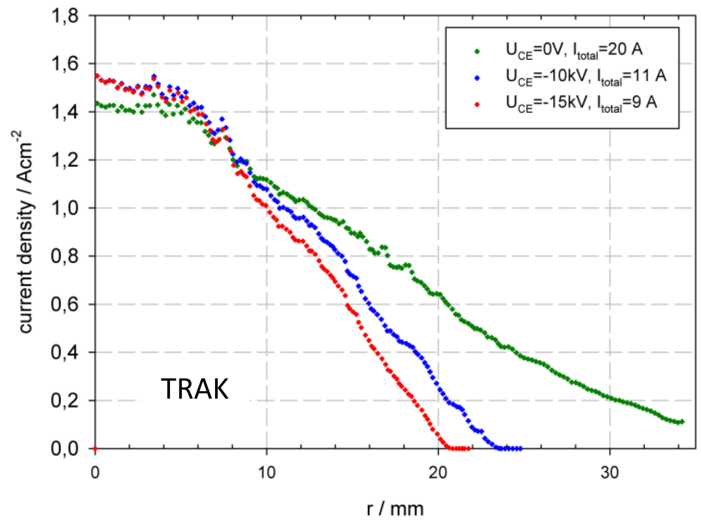

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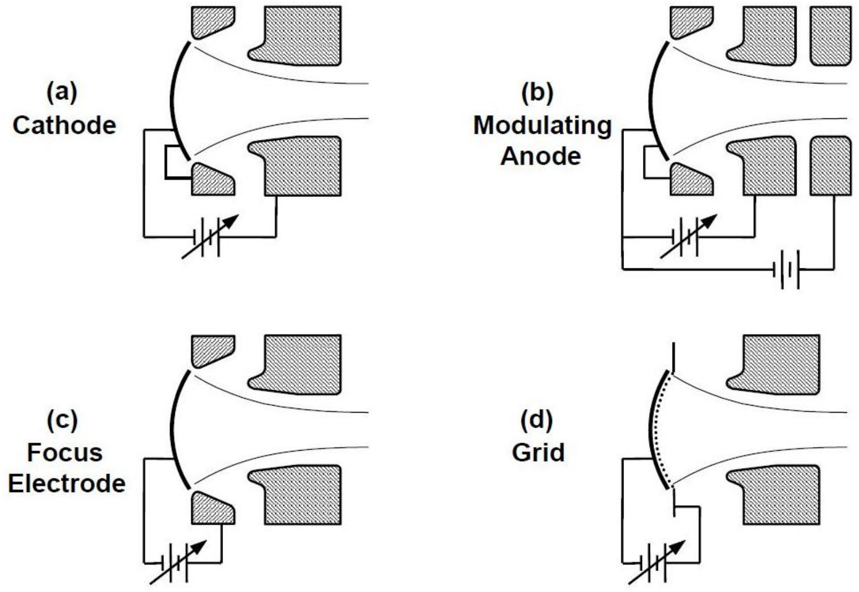
Modulation Options & Challenges

Typical Modulation Options

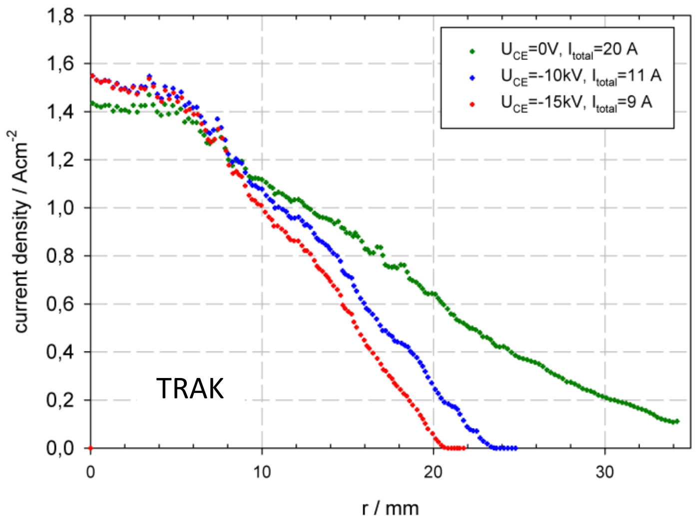


Anode modulation:

$$P_{diss} = {}^1/_2\, C U_a^2 \cdot f$$

$$P_{diss} = {}^1/_2 \cdot 200\text{pF} \cdot 25kV^2 \cdot 5MHz = 313kW$$

Focus electrode modulation



Gun parameters:
U_c = 0 V
U_a = 22 kV
B_z = 0.4 T

High voltages required to depress beam current.

Grid modulation:

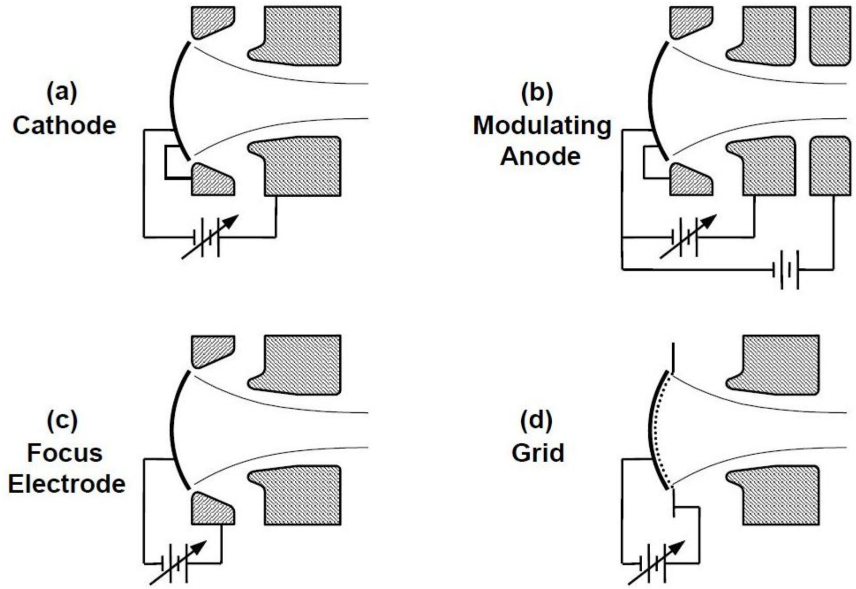
Low grid voltages, low disspated power

$$P_{diss} = {}^1/_2\, C U_g^2 \cdot f$$

$$P_{diss} = {}^1/_2 \cdot 150\text{pF} \cdot 1kV^2 \cdot 5MHz = 375W$$

Modulation Options & Challenges

Typical Modulation Options

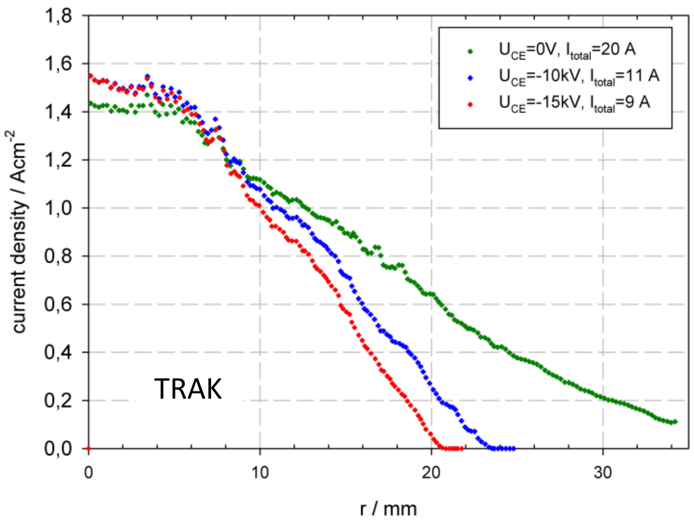


Anode modulation:

$$P_{diss} = {}^1/_2\, C U_a^2 \cdot f$$

$$P_{diss} = {}^1/_2 \cdot 200\text{pF} \cdot 25kV^2 \cdot 5MHz = 313kW$$

Focus electrode modulation



Gun parameters:
U_c = 0 V
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High voltages required to depress beam current.

Grid modulation:

Low grid voltages, low disspated power

$$P_{diss} = {}^1/_2\, C U_g^2 \cdot f$$

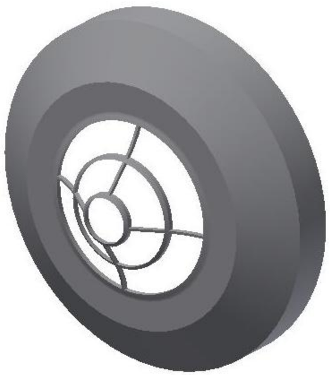
$$P_{diss} = {}^1/_2 \cdot 150\text{pF} \cdot 1kV^2 \cdot 5MHz = 375W$$

reduced current, beamlets

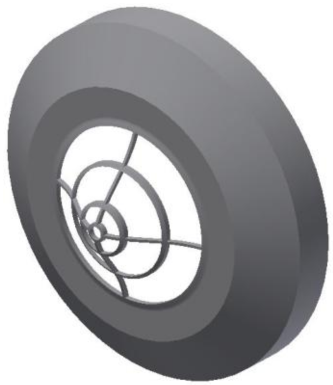
Grid Design

Different grid designs are studied:

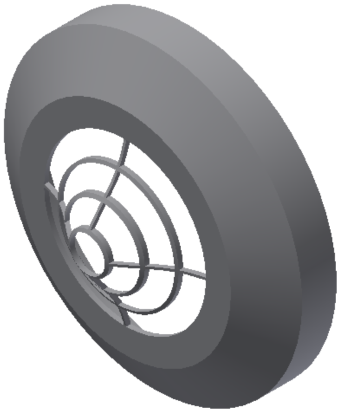
Grid 1



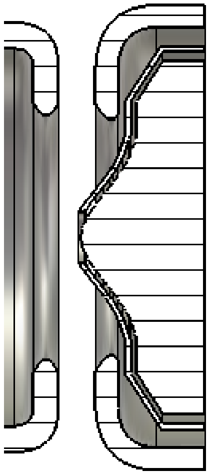
Grid 2



Grid 3



Grid 4



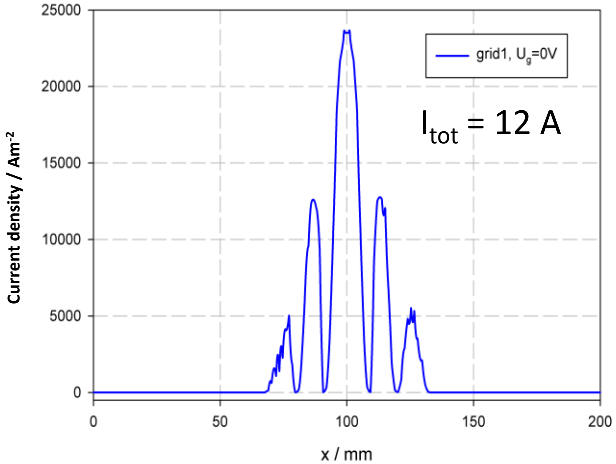
distance cathode-grid d_{cg}=2mm

Transverse current density preserved?
Total emitted current?
Grid voltages to depress current?
Losses on grid?

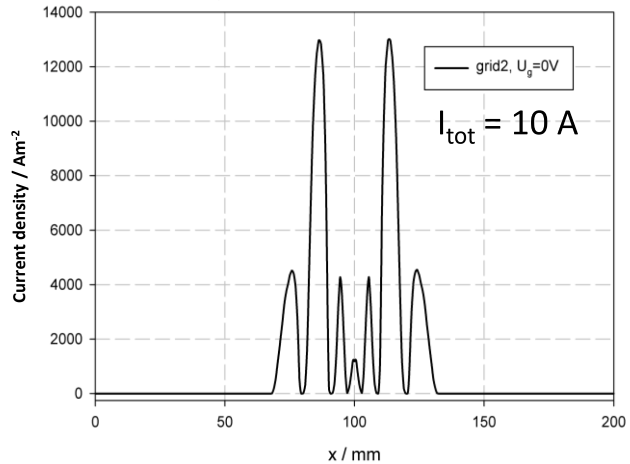
Grid Design

Current density profile for U_g=0V and total emitted current:

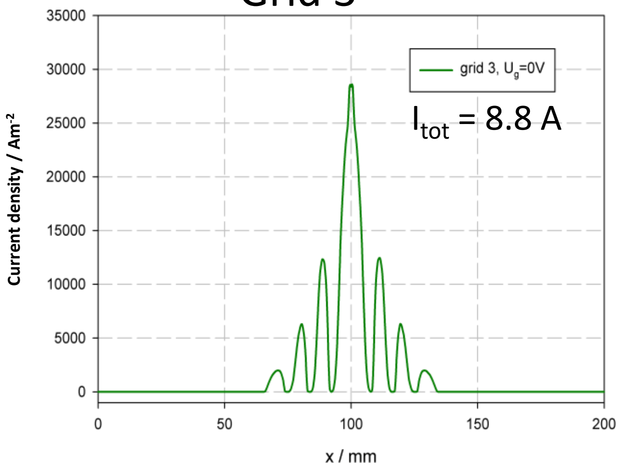
Grid 1



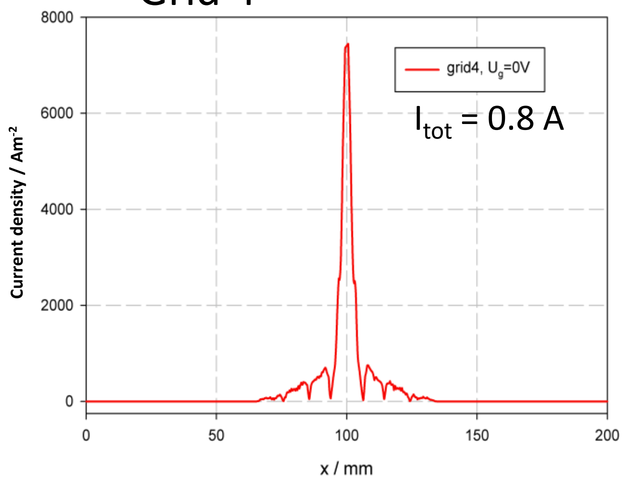
Grid 2



Grid 3



Grid 4

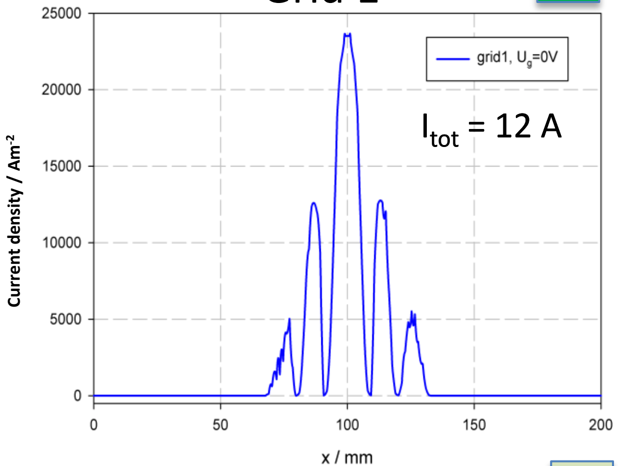


Gun parameters:
U_c = 0 V
U_{CE} = 0 V
U_a = 25 kV
B_z = 0.2 T

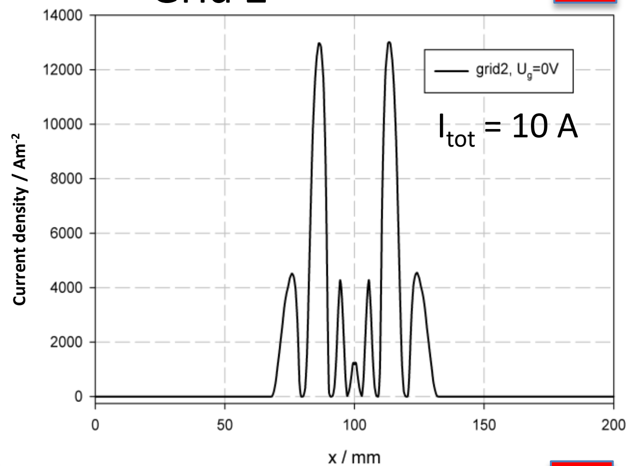
Grid Design

Current density profile for U_g=0V and total emitted current:

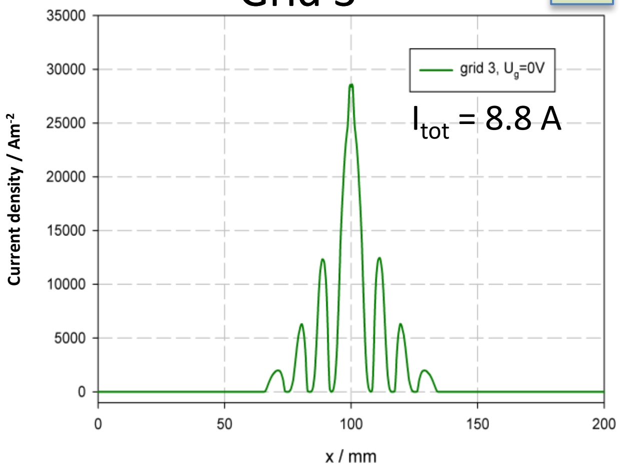
Grid 1



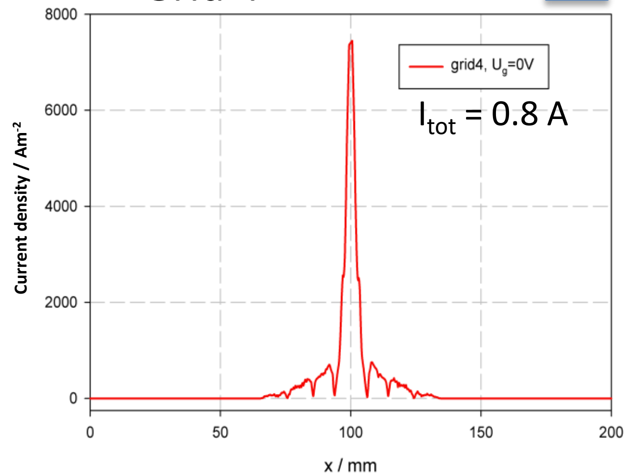
Grid 2



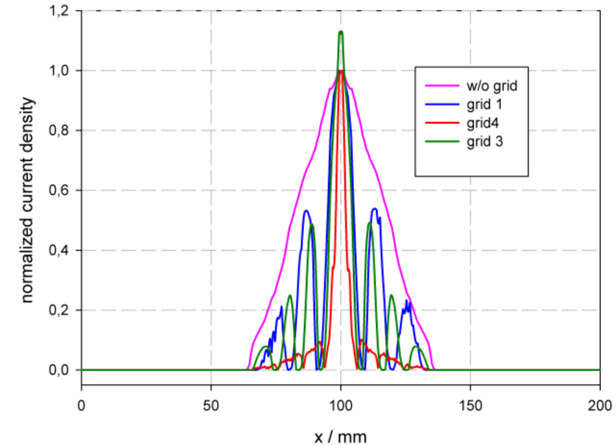
Grid 3



Grid 4



Perservation of current density profile



Gun parameters:
U_c = 0 V
U_{CE} = 0 V
U_a = 25 kV
B_z = 0.2 T

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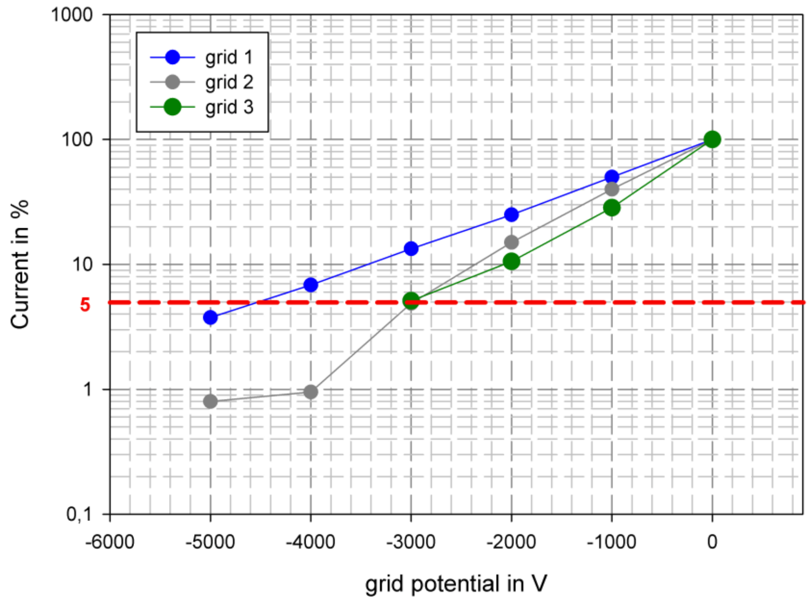
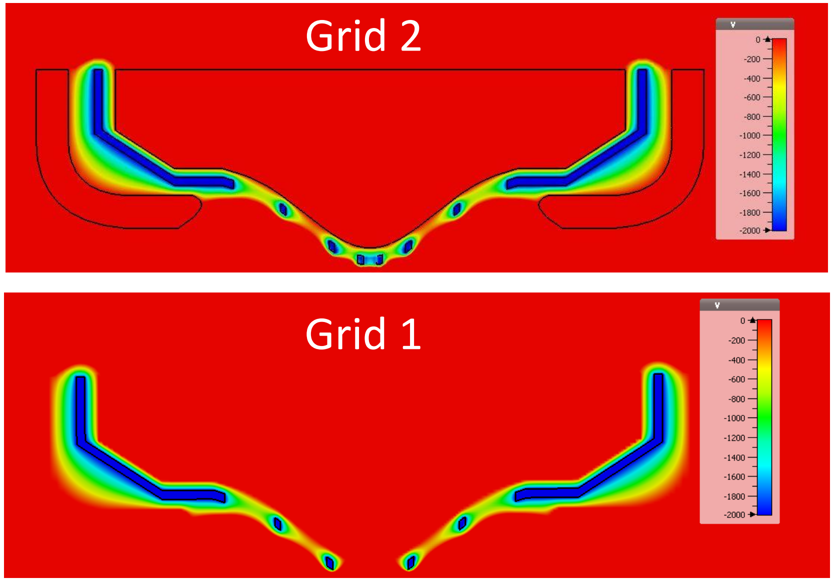
Grid Design

Required grid voltages to suppress electron current:



Example of potential distribution

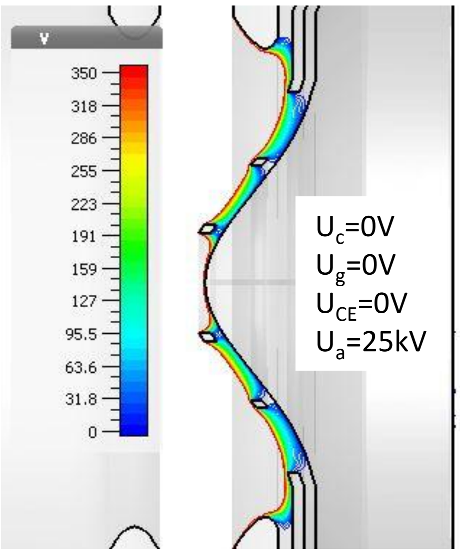


Grid 3 nearly preserves transverse current density profile and requires U_g=-3 kV to depress current to 5% of initial value. This leads to a dissipated power of 1.7kW for C_g=75pF.

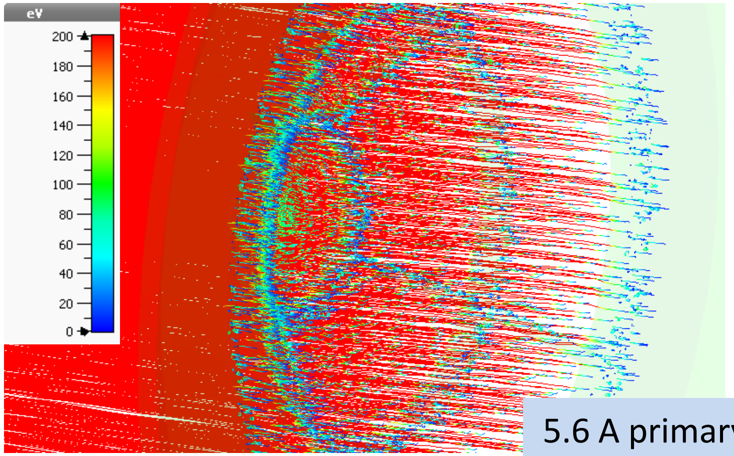
The design of grid 3 still needs to be improved in order to exactly match Gaussian current density profile. Furthermore, the final results have to be validated by simulations performed with smaller mesh size.

Grid Design

Potential distribution at grid1 for U_g=0V:



Secondaries produced at tungsten grid for U_g=100V:



5.6 A primary electrons
→ 5.1 A secondaries

Grid temperature estimate:

$$I_l = 6A, U = 100\ V$$

$$P/_A = 156 \cdot 10^3\ W/_{m^2}$$

$$T = \sqrt[4]{P/_{A \cdot \sigma_{SB}}} = 1288\ K$$

if only radiation is assumed as cooling mechanism

cathode temperature ~1273K

further studies needed

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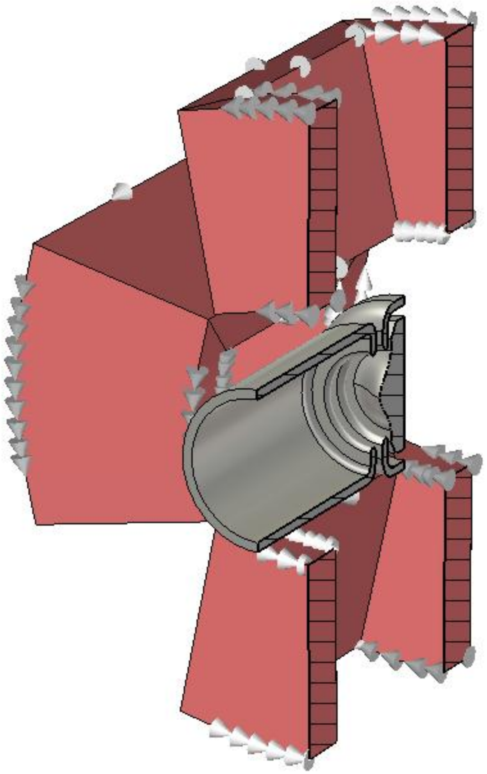
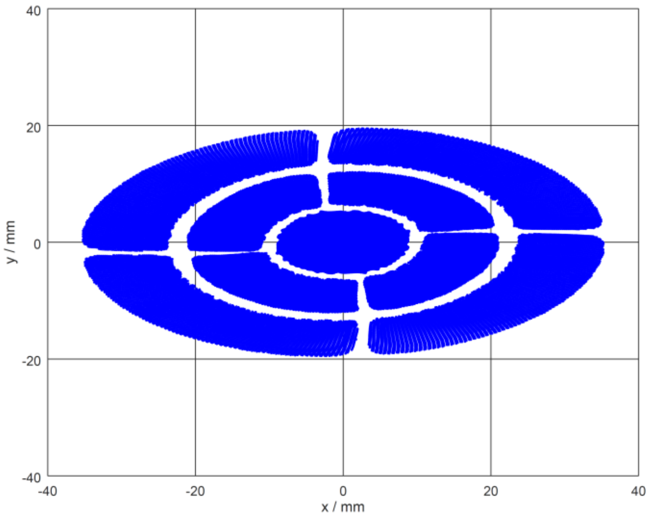
Beam Shaping Options

- Cathode shaping
- Beam pipe shaping
- Internal quadrupol field



Elliptical beam distribution created by quadrupol field

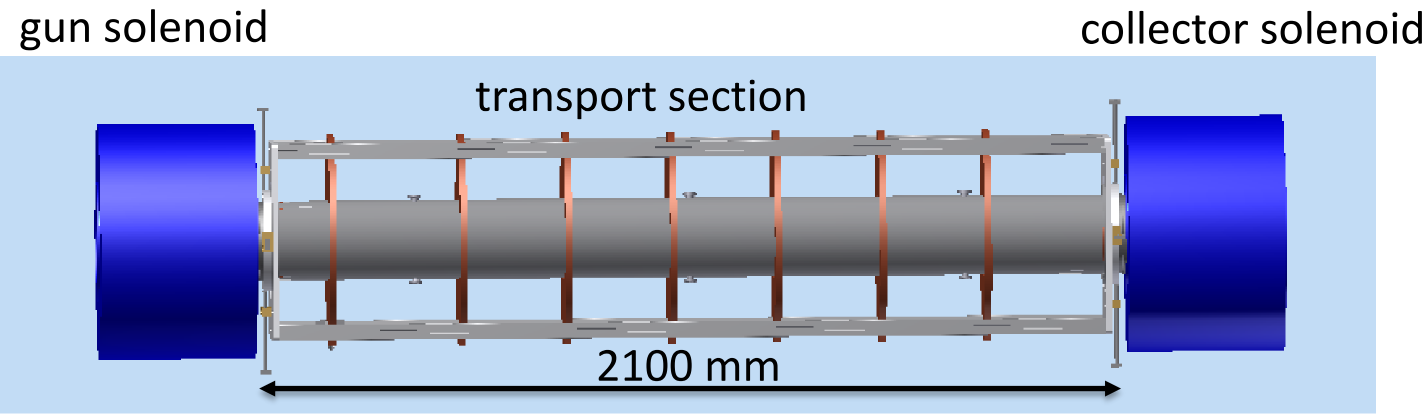


Gun parameters:
$U_c = 0$ V
$U_{CE} = 0$ V
$U_a = 25$ kV
$B_z = 0.2$ T
$B_{x,Q} = 0.07$ T

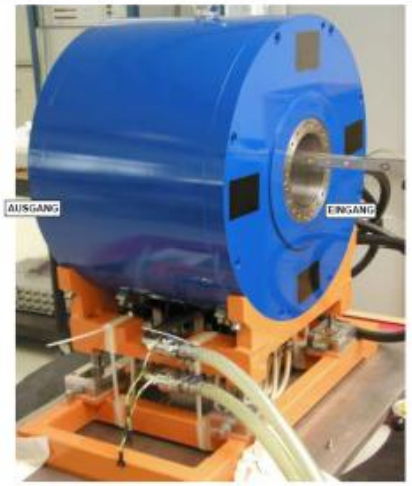
- adjustable of beam distribution
- reduction of cathode radius from 35 mm to 26.5 mm

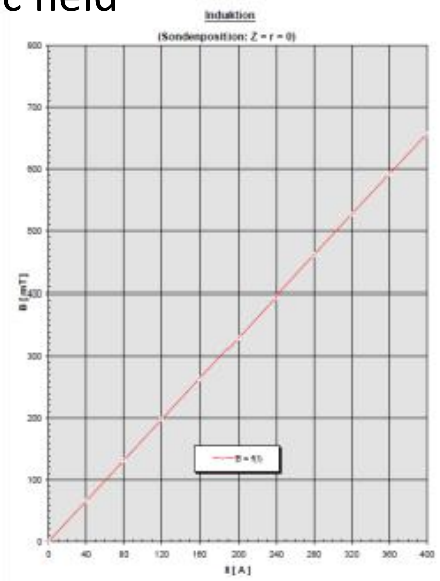
- needs to be integrated into solenoid chamber

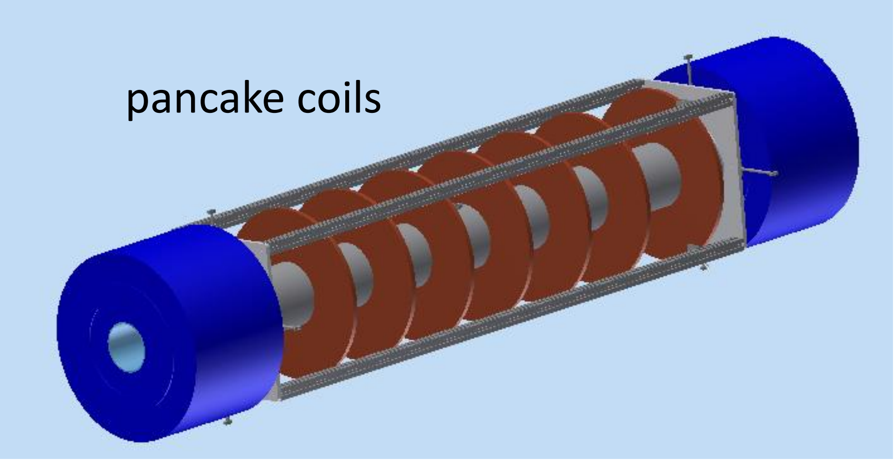
Electron gun comissioning at IAP



Magnetic field







- Finalization of test bench layout
- Purchasing of gun and collector solenoids
- Preparation of diagnostics and data acquisition

Outlook

Electron gun

- Grid design to be finalized (affects also U_a)
  - simulations performed with smaller mesh size
  - beam load and grid material
  - Secondary electron emission
  - cut-off frequency
- Technical integration of quadrupol magnet
- Adaptation of present design to allow for exchange of cathode to deliver homogeneous beam as well
- Choice of cathode material
- Technical layout

Test Bench

- Finalization of design
- Purchasing solenoids

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This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

Thank you!

Thanks to my colleagues from IAP and GSI supporting this work.

My special thanks go to A. Pikin for helping to get started with my studies on electron gun design and for fruitful discussions!