Dark current tracking simulations of PITZ guns

Outline

- Dark current tracking of PITZ gun 4.2 / 5
- Dark current tracking of PITZ gun with an over-inserted plug
- Conclusion

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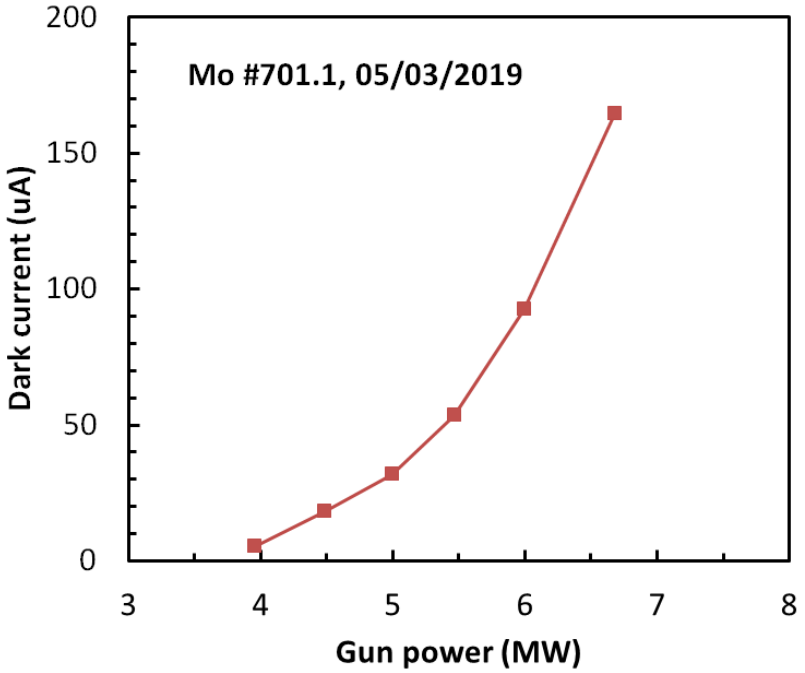
May 28, 2020

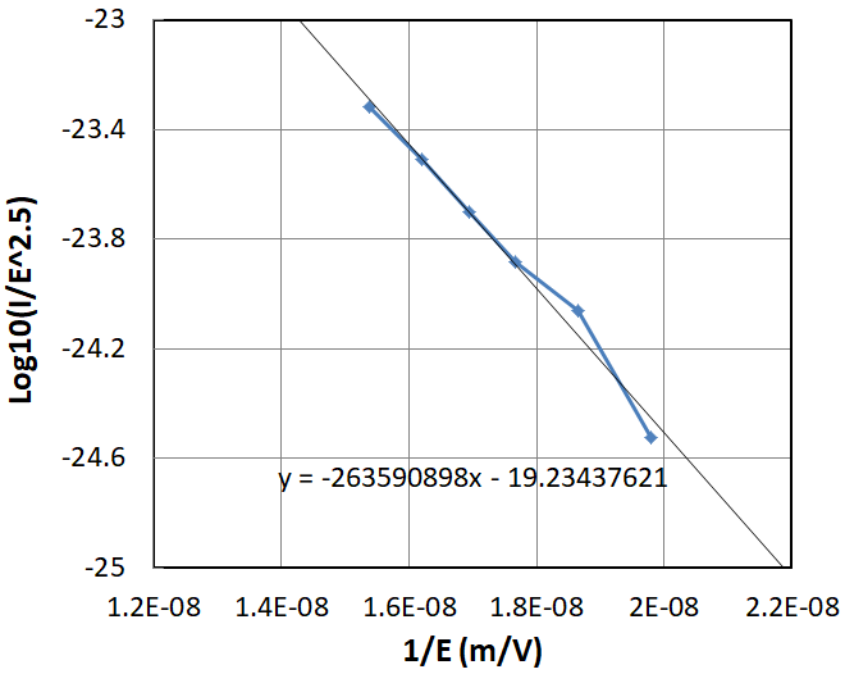
Dark current tracking of PITZ gun 4.2 / 5

Numerical simulation procedures

Combination of CST MWS and ASTRA

- CST MWS is used to generate 3D RF field
  - Precisely describe RF field which far off axis
  - Plug vicinity is main source of dark current (DC), RF field near plug vicinity is of great importance
- Field emission process
  - Fowler-Nordheim theory: surface E field, field enhancement factor (β), material work function (Φ)





Cu: Φ=4.6 eV, β=106, Ae=9.9E-15 m^2
Mo: Φ=4.2 eV, β=92, Ae=9.5E-15 m^2

β=100 is used in the following simulations

Numerical simulation procedures

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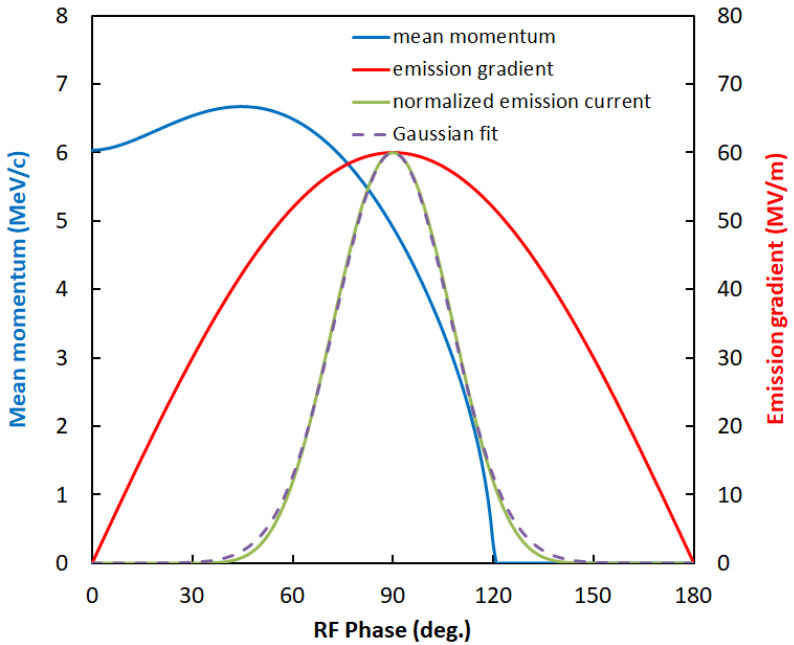
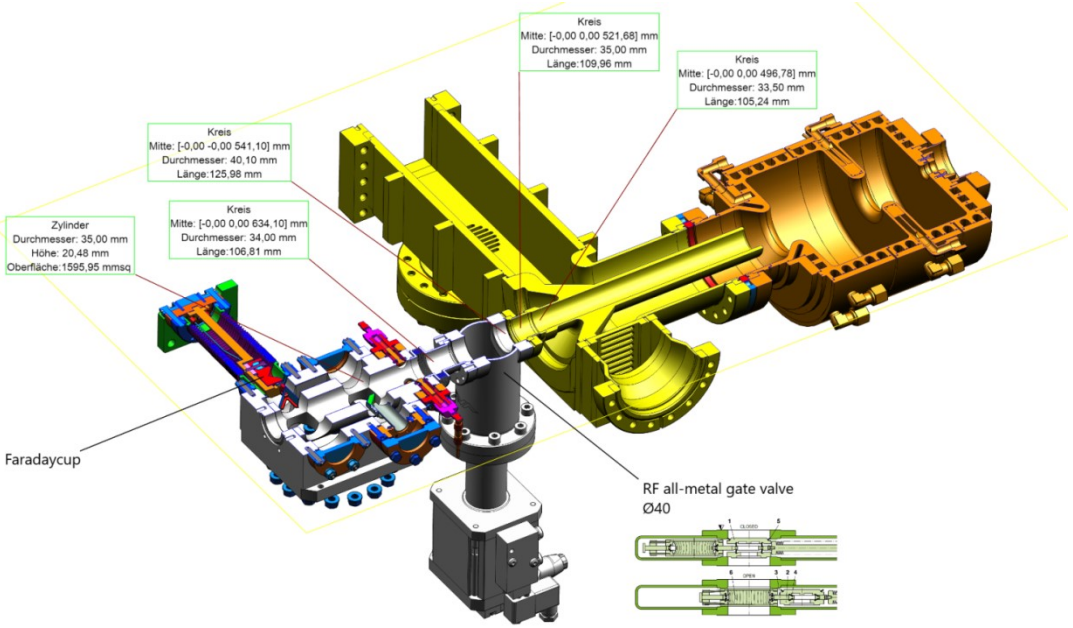
  - Plug vicinity is main source of dark current (DC), RF field near plug vicinity is of great importance
- Field emission process
  - Fowler-Nordheim theory: surface E field, field enhancement factor (β), material work function (Φ)
  - Gaussian fit is used as the DC longitudinal distribution (rms duration=17°), large energy spread



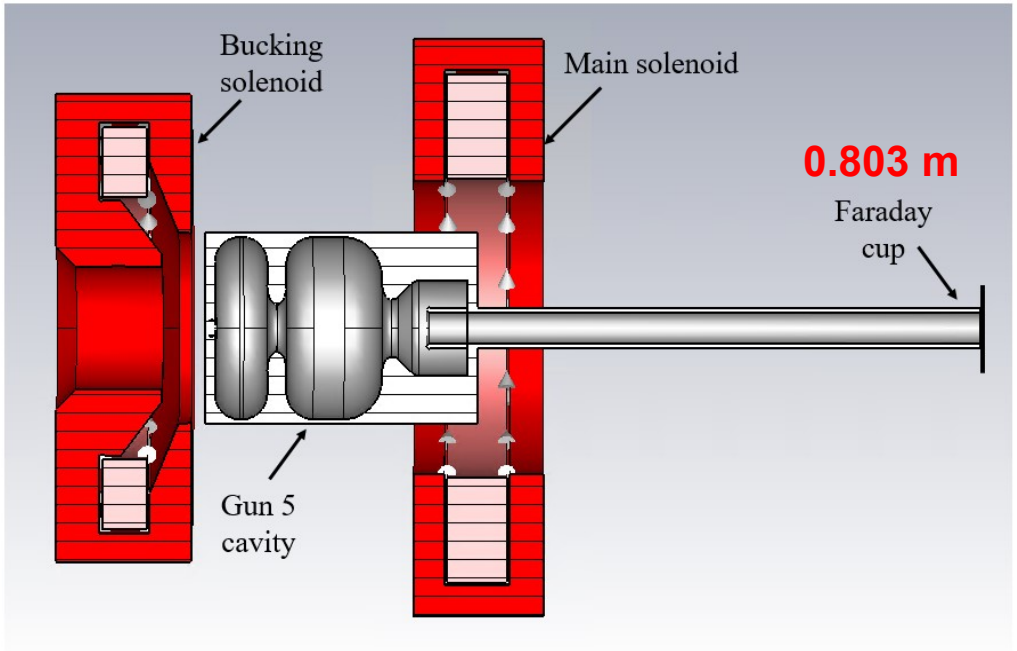
Numerical simulation procedures

Combination of CST MWS and ASTRA

- Tracking in ASTRA
  - Simplified model
  - Longitudinal distribution: Gaussian, 1 eV initial energy
  - 3D field from CST MWS, cathode center Ez = 60 MV/m
  - Space charge effect and secondary emission are neglected in the tracking
  - Solenoid scan from 0~500 A (MaxB=-(3.72e-5+0.985*5.88e-4*Imain) from M. Krasilnikov)
  - DC **transmission ratio** (TR = charge captured by Low.FC1 / emitted charge)

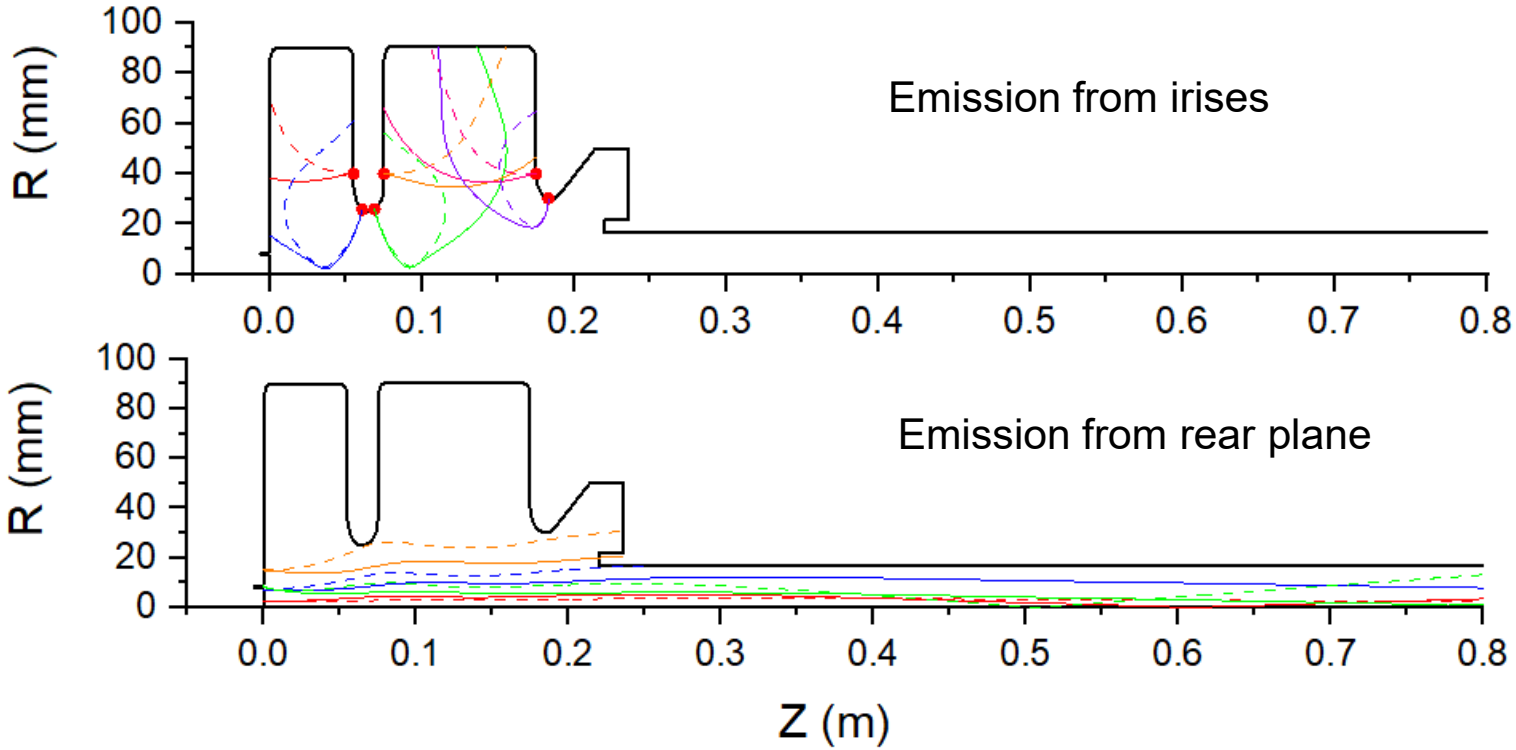


model simplification →

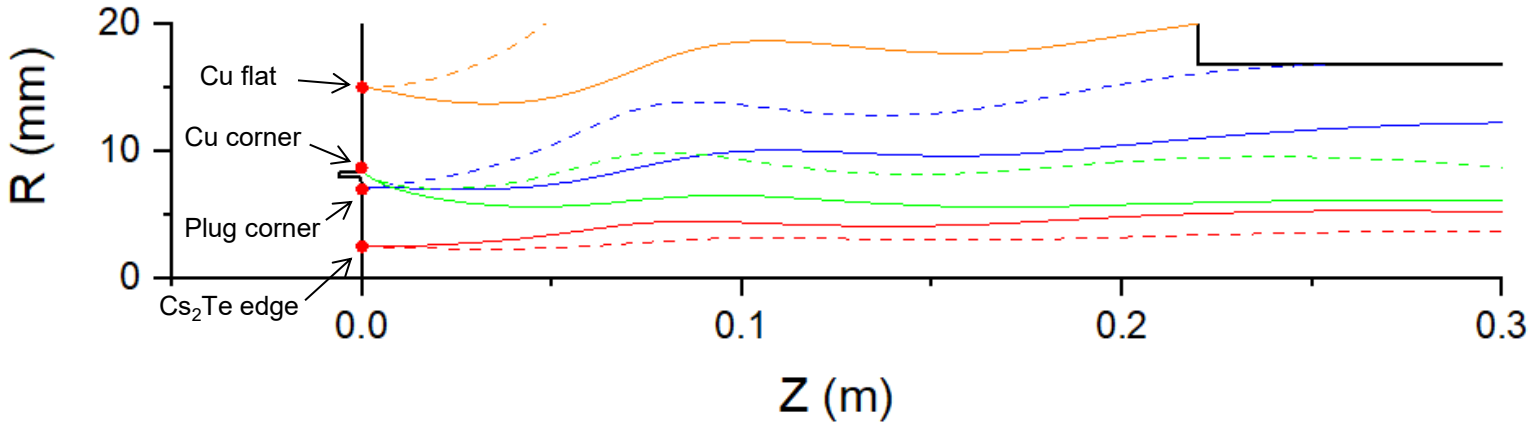


DC tracking of Gun 4.2

Field emission trajectories at 370 A, Ecath = 60 MV/m

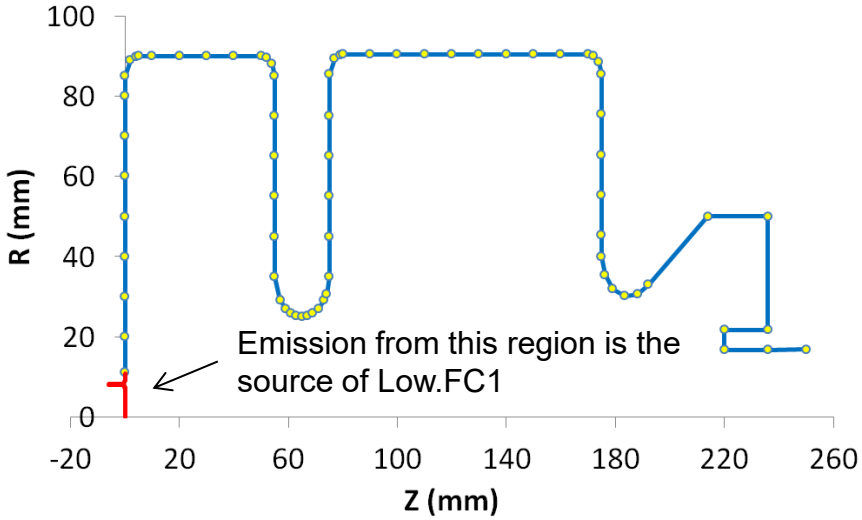


Red dot: emission points
Solid line: emission at RF phase 45° (~MMMG phase)
Dash line: emission at RF phase 90°

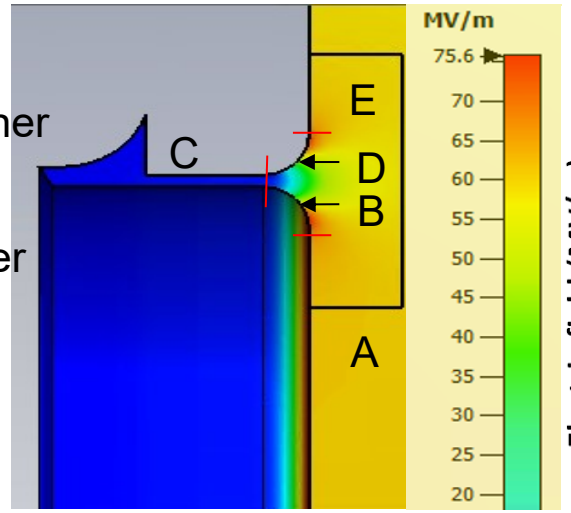


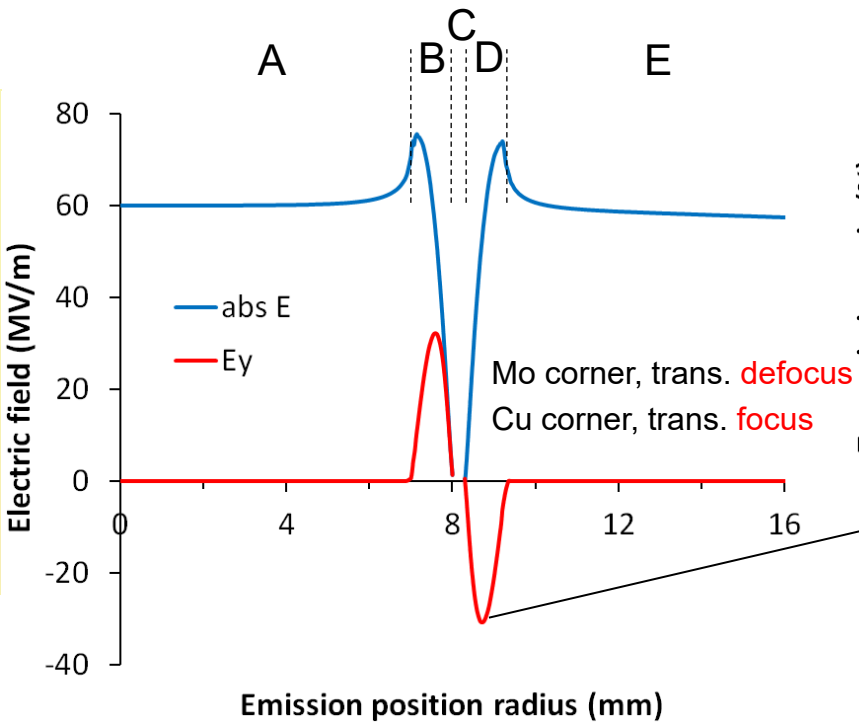
DC tracking of Gun 4.2

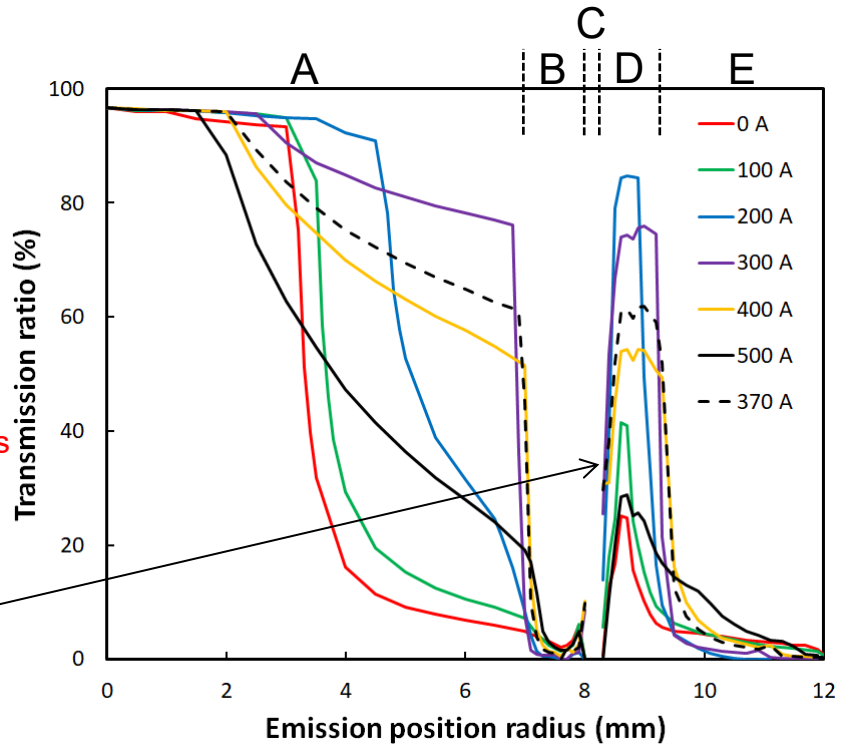
- Emission from cavity wall / 1st / 2nd iris can not escape from cavity (rough solenoid scan from 0~500 A with a step of 100 A)
- Emission from plug vicinity is the DC source
  - TR of plug is high, but rapidly reduced in the corner due to transverse defocusing E field
  - TR of Cu corner is high due to transverse focusing E field
    - Current roughness is ~0.2 um in flat backplane, unknown in round corner.
    - Improved polish technique is desired (β↓).



A: plug flat
B: plug corner
C: gap
D: Cu corner
E: Cu flat



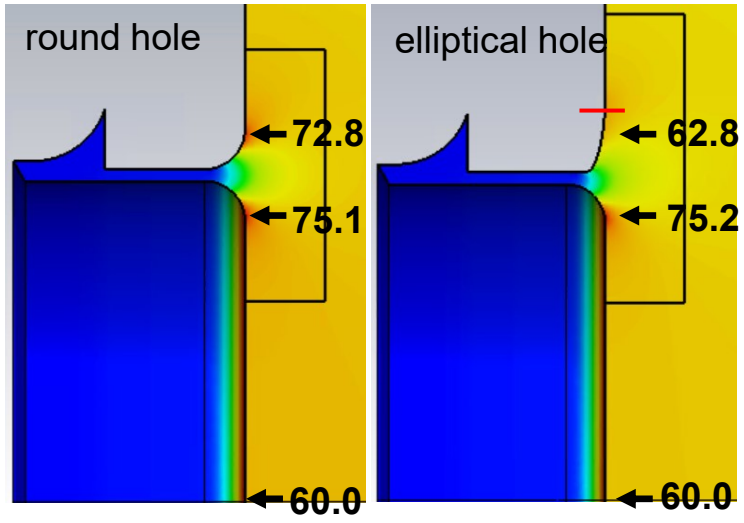


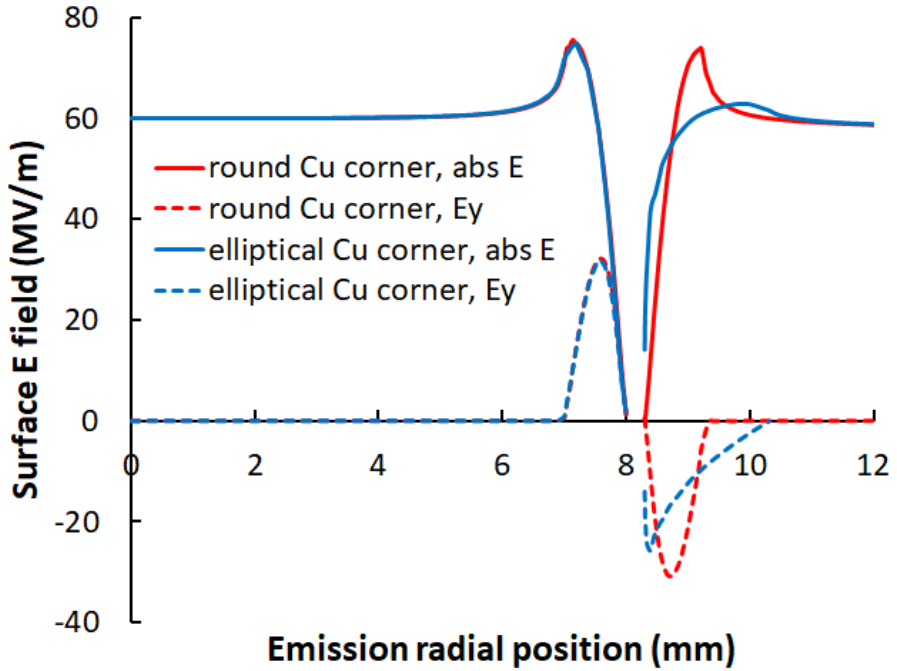


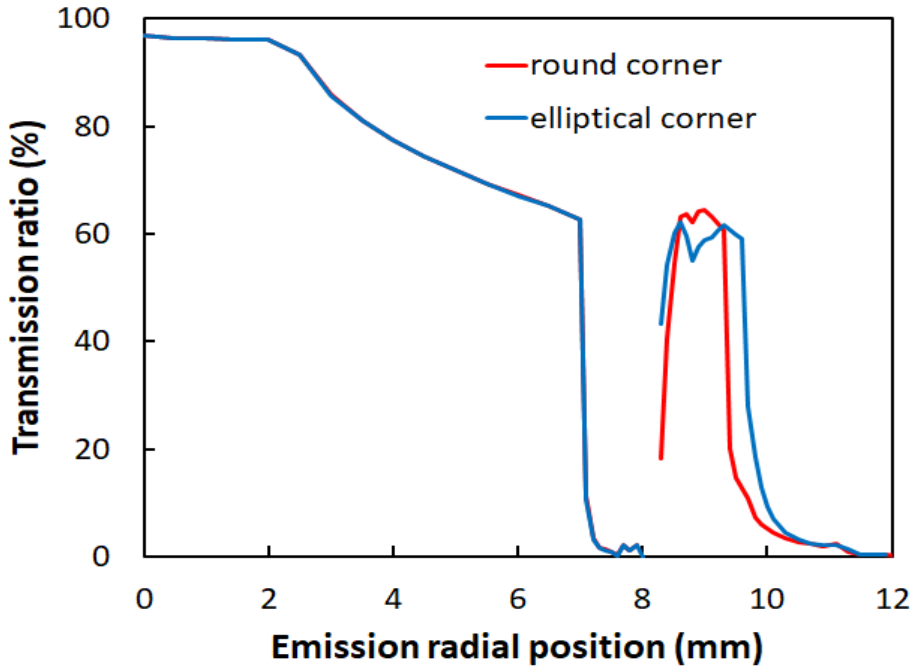
DC tracking of Gun 5

Cu corner adopted elliptical profile

- Cu corner optimization
  - Keep E field on plug constant, reduce peak E on Cu corner by 14%.
  - Ey field area on Cu corner is extended resulting a wider high TR region.
  - Surface quality of region (R<12 mm) is critical. Improved surface polish can effectively reduce dark current generation.



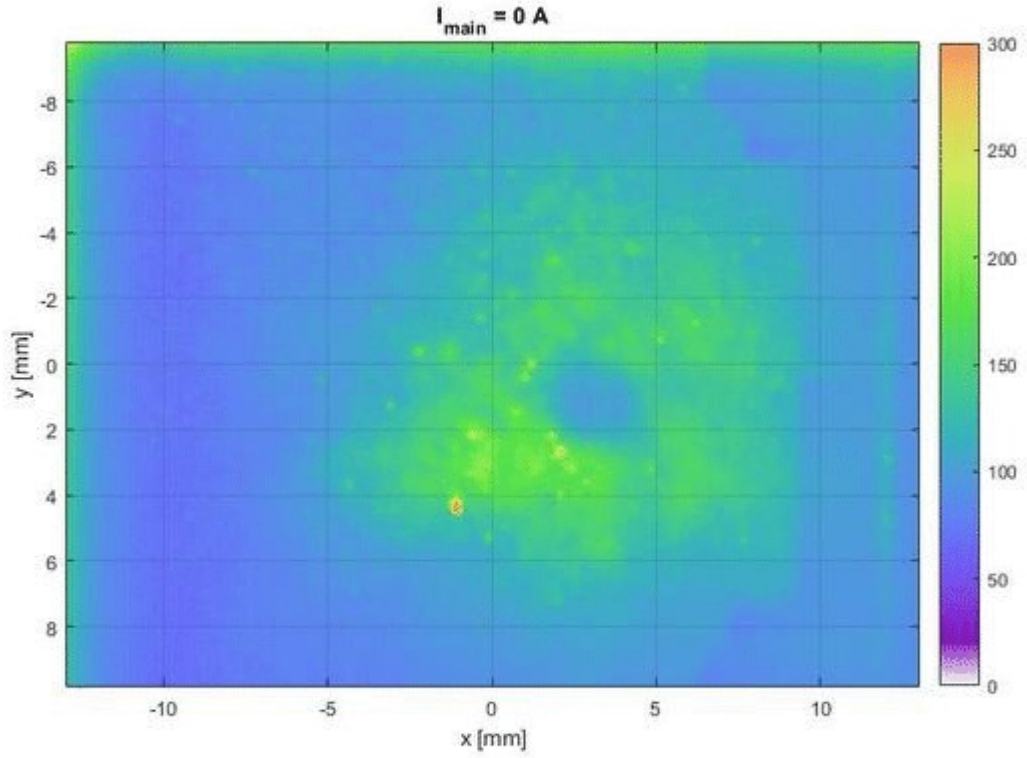


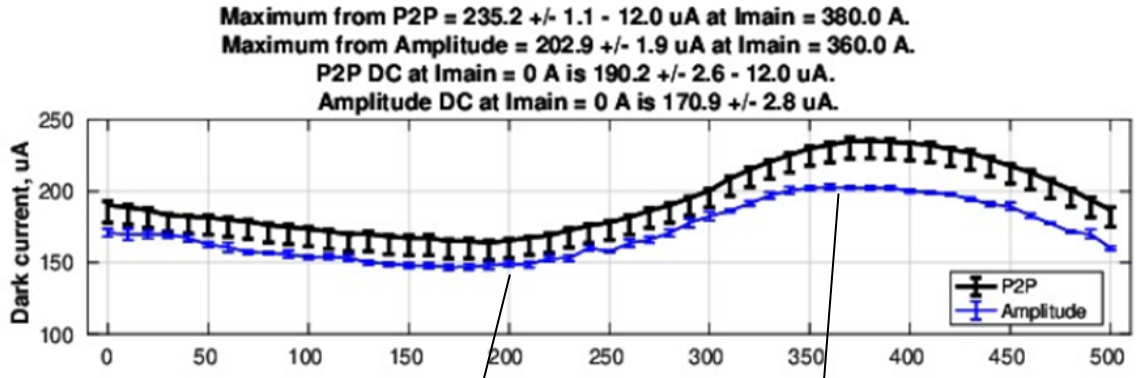


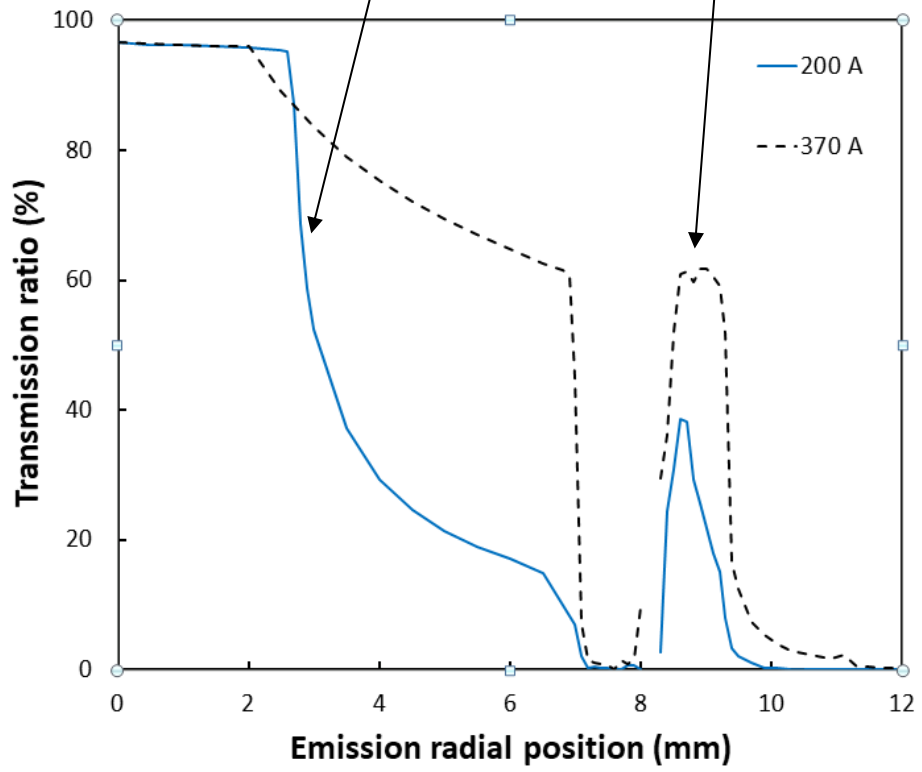
DC image on Low.S1

Measurement vs. simulation, 20191015A saved to ..\Conditioning\DarkCurrent\2019\20191015A\

- Low.S1 position = 0.803 m, same with Low.FC1
- Cs_2Te cathode plug #678.1
- Ecath = 60.4 MV/m, photo beam Pz = 6.77 MeV/c

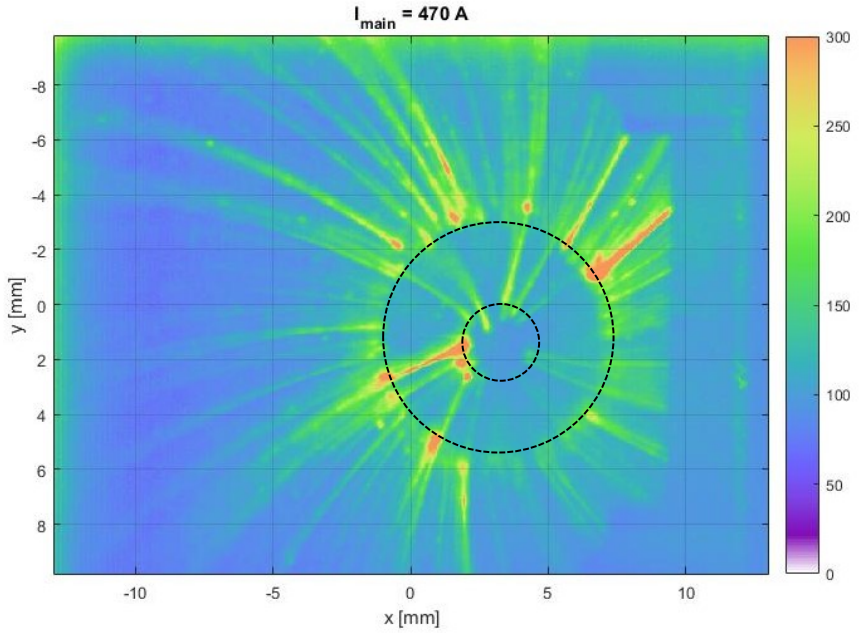


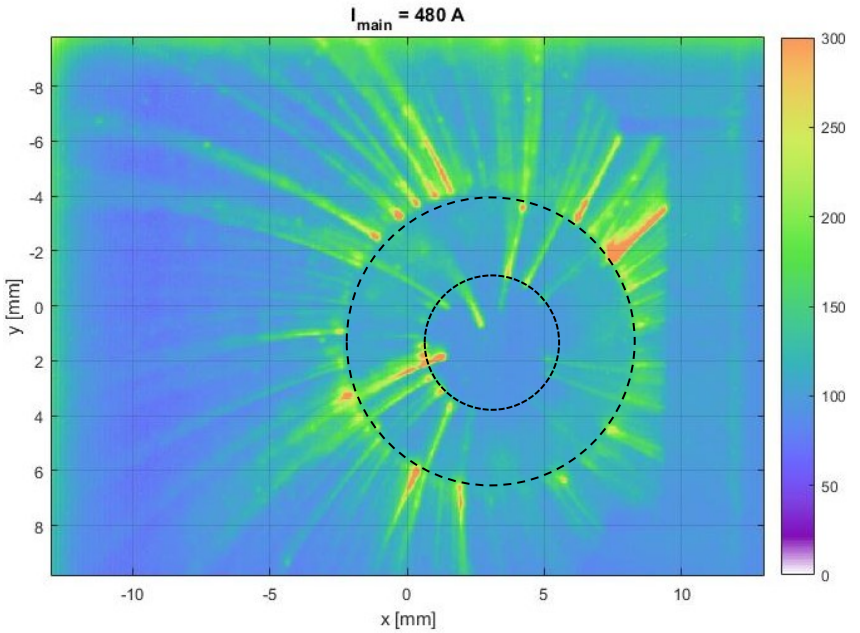


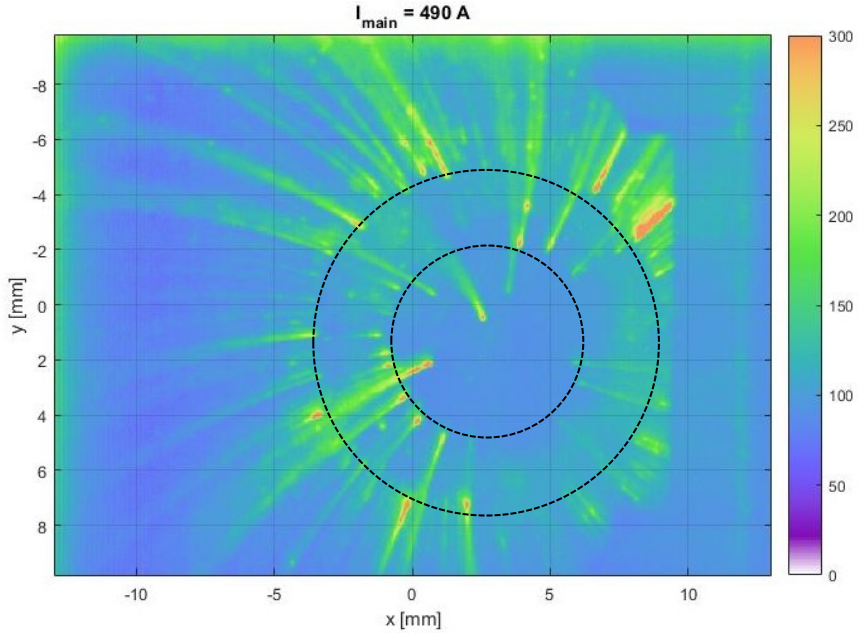


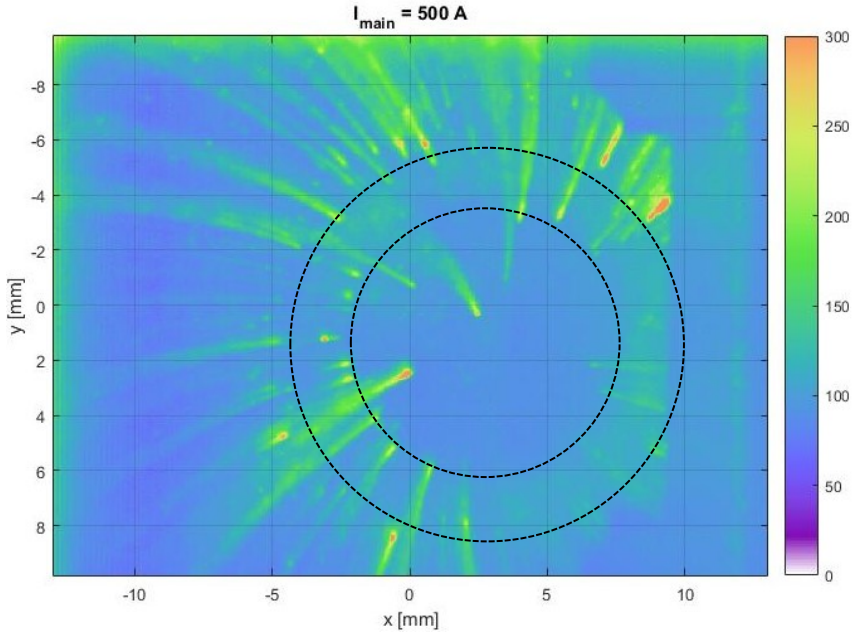
w/ 10 mm collimator

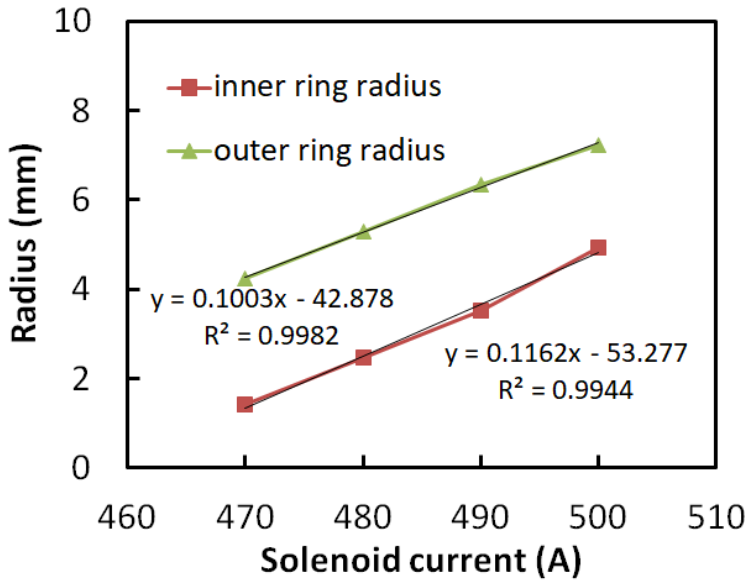
DC image on Low.S1, measurements at 20191015A









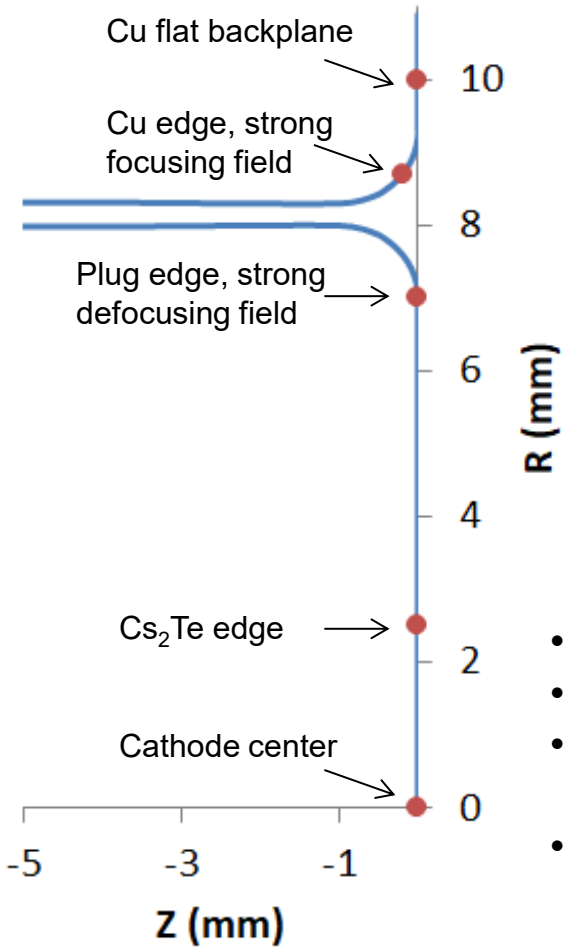


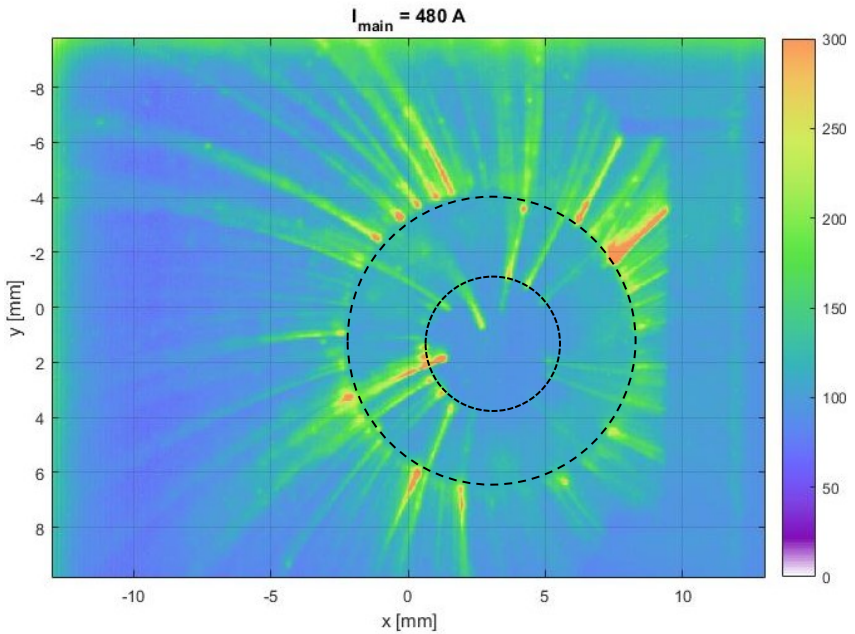
Ring radius growth is linear to solenoid current growth.

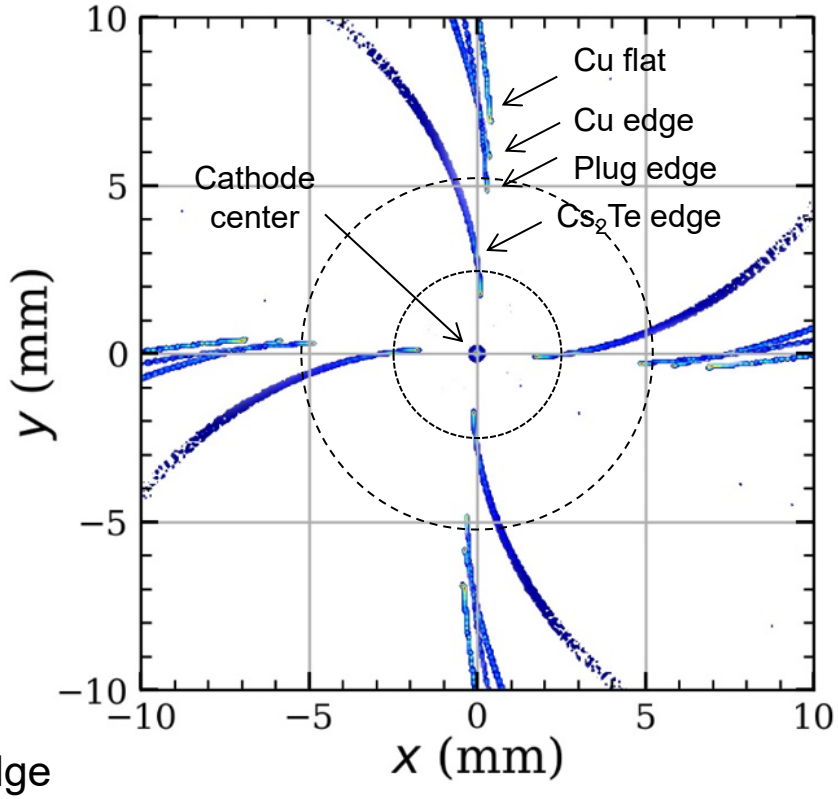
DC image on Low.S1, ASTRA simulations

Iman = 480 A

$B_{z,peak}$ = 0.2780436 T in simulation, Imain=480 A





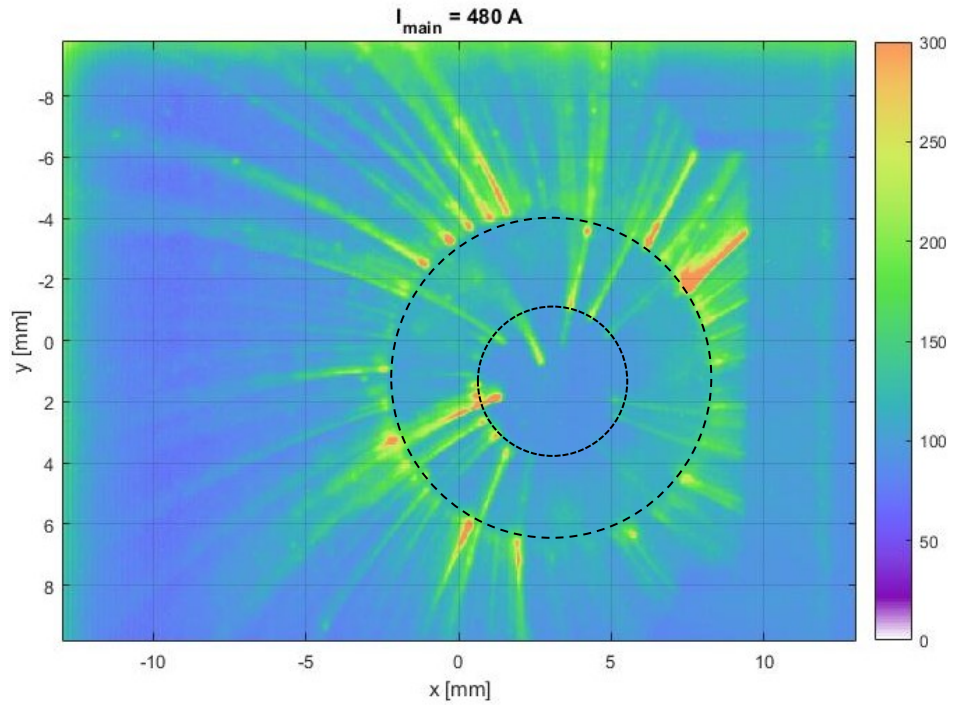


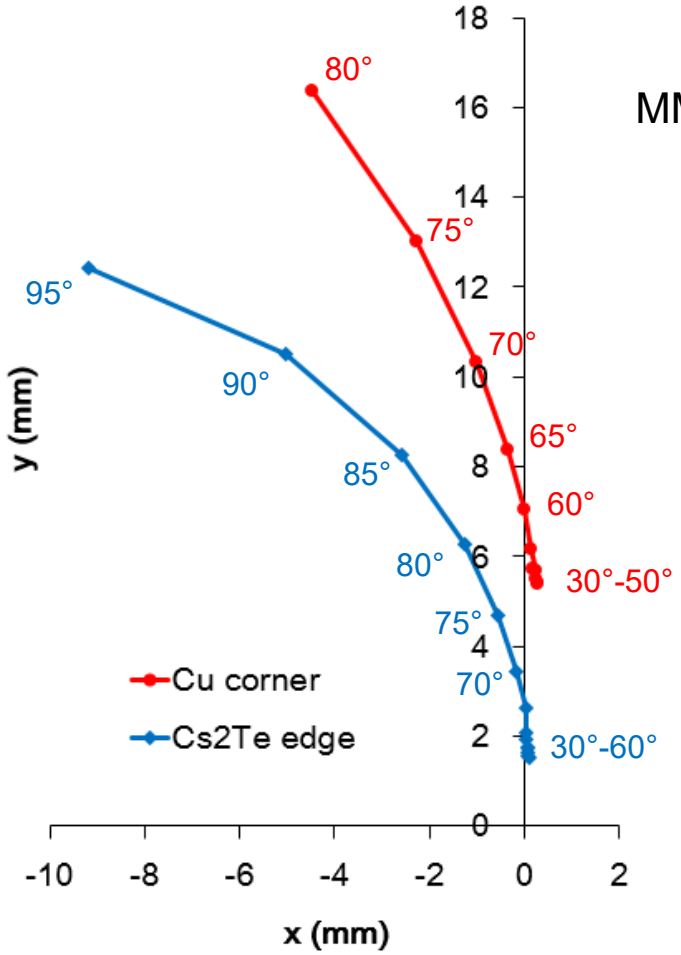
- Hot spots of the inner ring comes from Cs_2Te edge
- Several hot spots are observed in the Cs_2Te coating area
- Surface quality of Moly flat region (7.0 mm > R > 2.5 mm) is very good, no obvious hot spot
- Hot spot of the outer ring comes from plug and Cu corner vicinity. Field emission images of plug corner and Cu corner are overlapping. It is hard to locate the emission position from DC image.

Proposal: rotate plug by 180° and compare images to locate the outer ring hot spot source

DC image in ASTRA simulations

Iman = 480 A





MMMG phase ~ 45°

In the image mode, beam is under over focusing

- Under over focusing, high energy electron located inside, low energy electron located outside
- Compared to lower energy electrons, high energy electron has weaker over focusing and lower energy spread, so focusing is better and appears as hot spot in the dark current trace

Dark current tracking of PITZ gun with an over-inserted plug

How to characterize the field emission properties of various materials in an RF gun?

Answer: By an over-inserted plug, change the Cu backplane field emission trajectories. Field emission from plug is the only source for the Faraday cup.

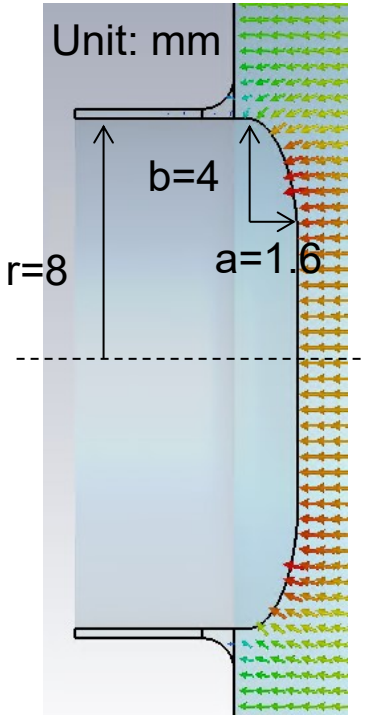
Plug insertion = 2 mm

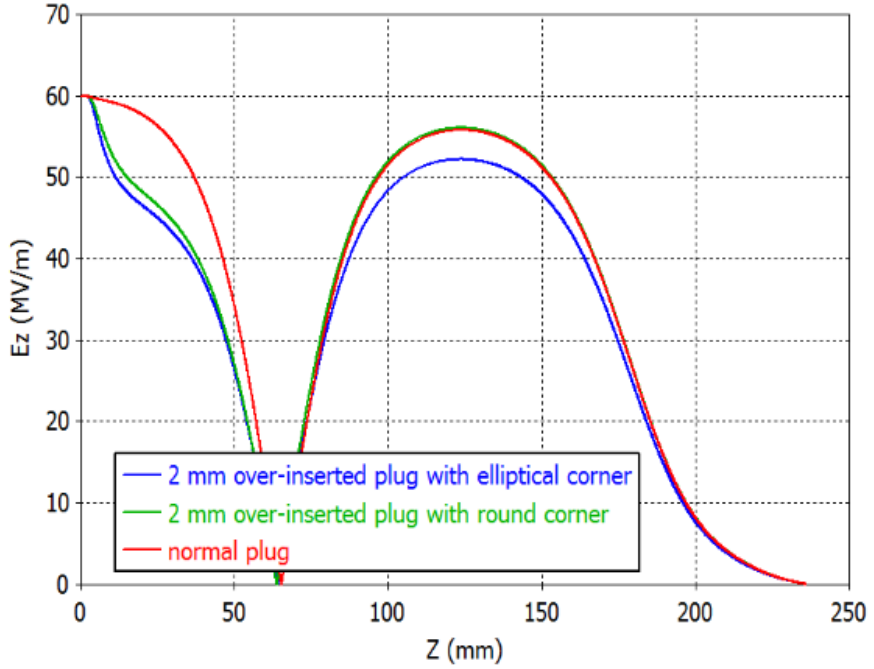
	Normal plug	Over-inserted plug with round corner	Over-inserted plug with elliptical corner
Freq. (MHz)	1300.00	1299.65	1299.71
Cathode E (MV/m)	60	60	60
Peak E on plug (MV/m)	74.8	104.3	72.6
Peak E on Cu (MV/m)	72.6	45.3	44.2

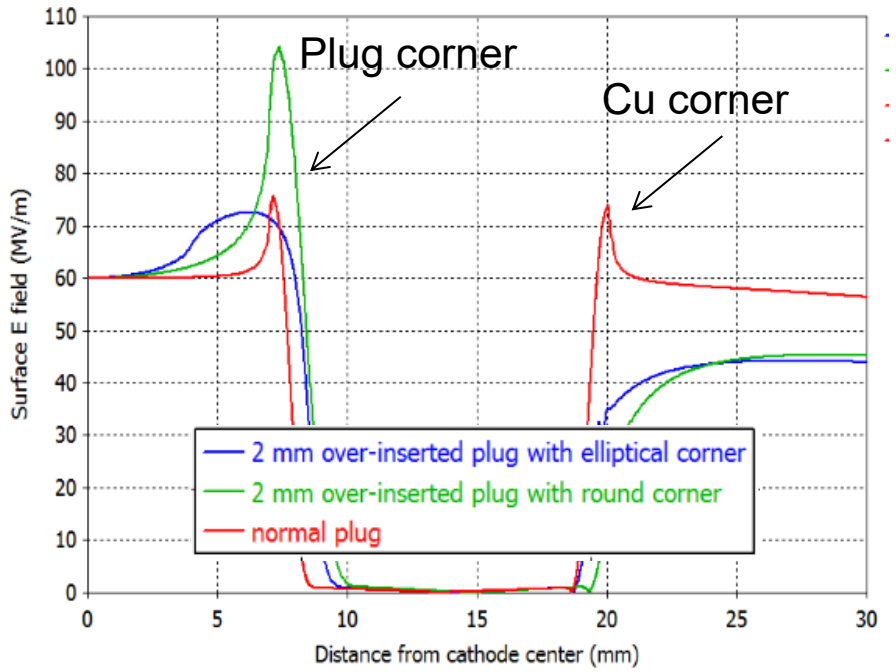
→ Water T ↓13°C

→ RF breakdown risk is reduced

→ Field emission from Cu is reduced

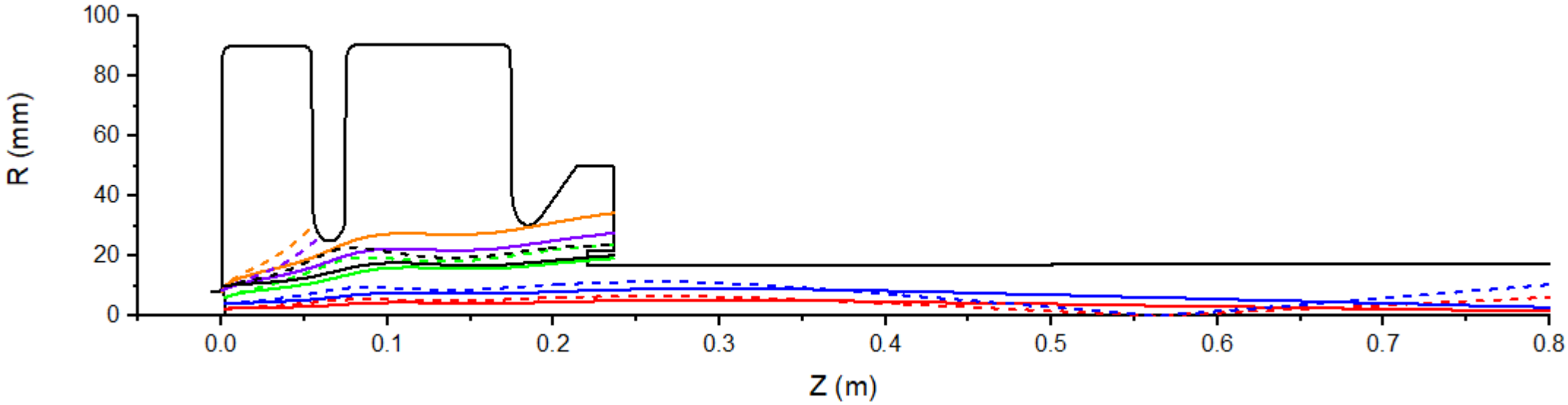


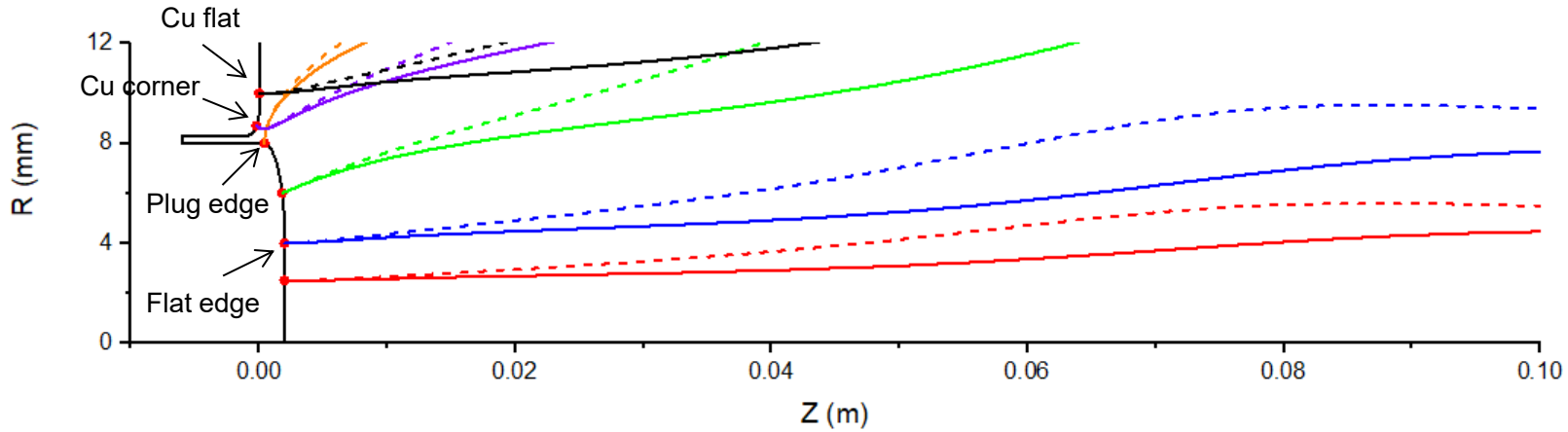




DC tracking of Gun 4.2 with over-inserted plug

Field emission trajectories at 370 A, Ecath = 60 MV/m

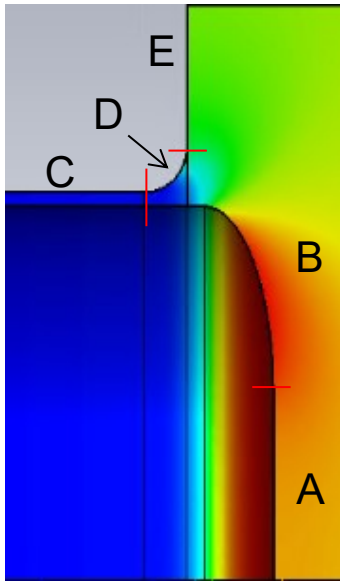


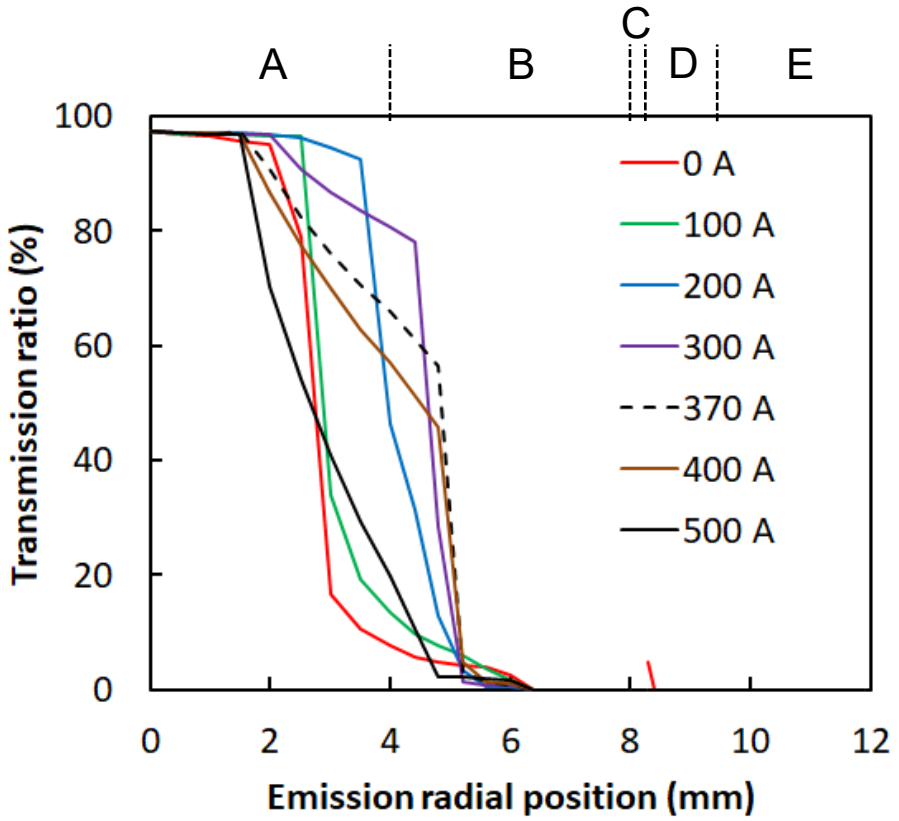


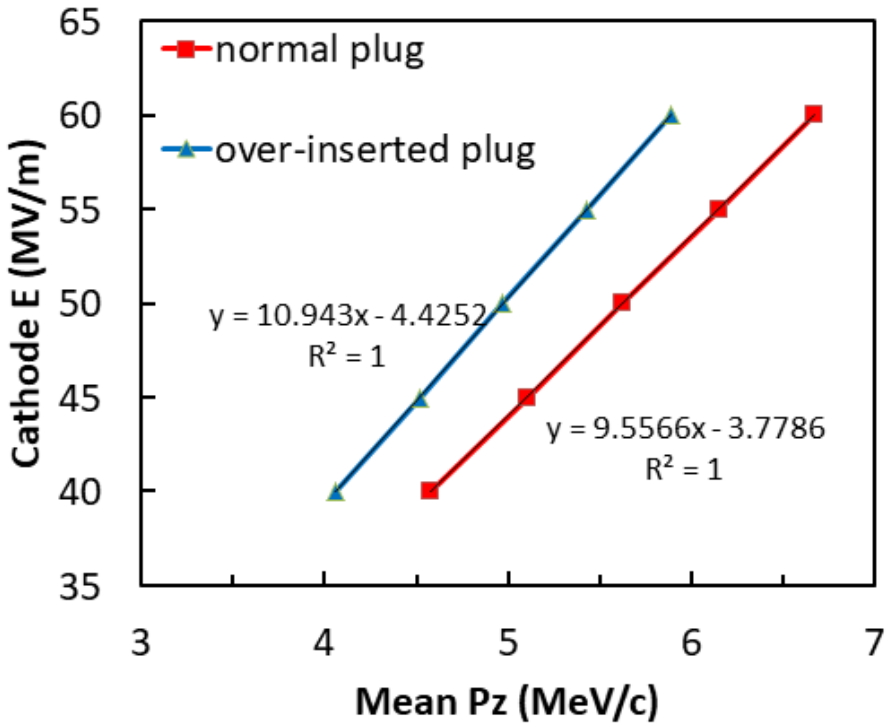
Red dot: emission points
Solid line: emission at RF phase 45° (~MMMG phase)
Dash line: emission at RF phase 90°

Gun 4.2 with an over-inserted plug

A: plug flat
B: plug corner
C: gap
D: Cu corner
E: Cu flat







For an over-inserted plug:

- Peak E on Cu is reduced, field emission strength is reduced
- RF field in the plug vicinity is changed and the DC trajectories are influenced, TR of Cu backplane is zero. Plug is the only source for Low.FC1. Field emission studies of soft Cu and hard Cu is possible.

Conclusion

- DC tracking simulations were performed both for PITZ gun4.2 and 5
  - Field emission of cathode plug vicinity is the only source of Low.FC1.
  - Improve polishing near the cathode gap region is important to reduce dark current.

- DC tracking simulations were performed for PITZ gun4.2 with an over-inserted plug
  - Cavity frequency can be compensated by water T (↓13°C)
  - Peak E on plug can be reduced by an elliptical profile to reduce breakdown risk
  - DC transmission ratio of Cu backplane is zero, field emission from plug is the only source for Low.FC1. Characterization of the field emission properties of various materials in an RF gun is possible.

Outlook

- Use plug #678.1 in next run, take Low.S1 images at 480 A. Rotate plug by 180° and take images again. → Hot spots of outer ring comes from plug or Cu side?