Redesign of Anode Electrode to Minimize the Beam Deflection Induced by the Electrostatic Filed Asymmetry

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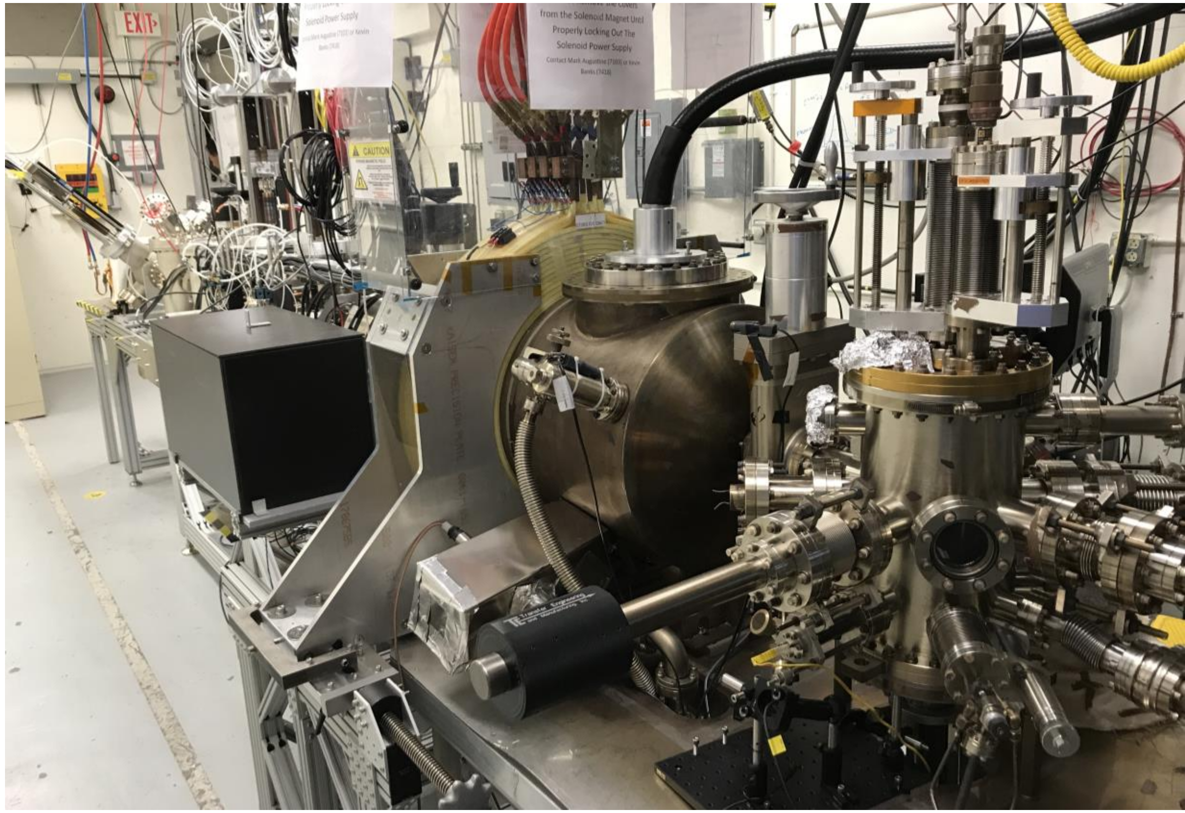

Jefferson Lab

B-Team Meeting, Tuesday, March 08, 2021

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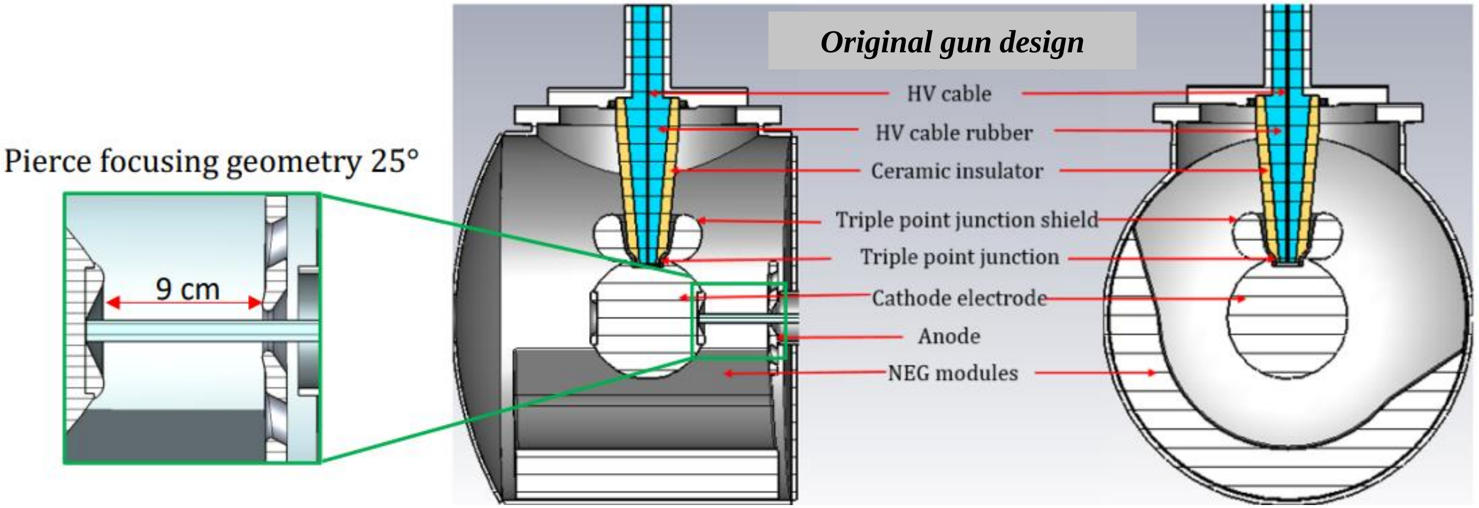
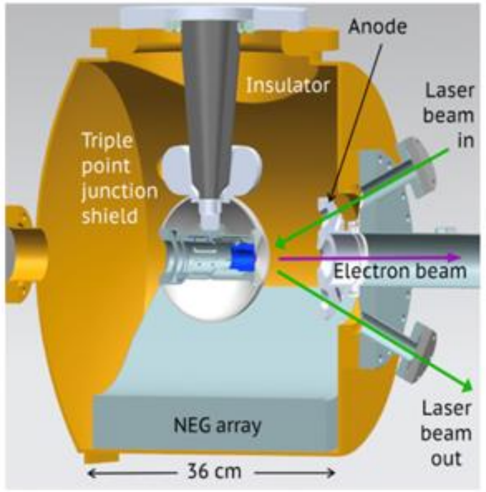
Motivation

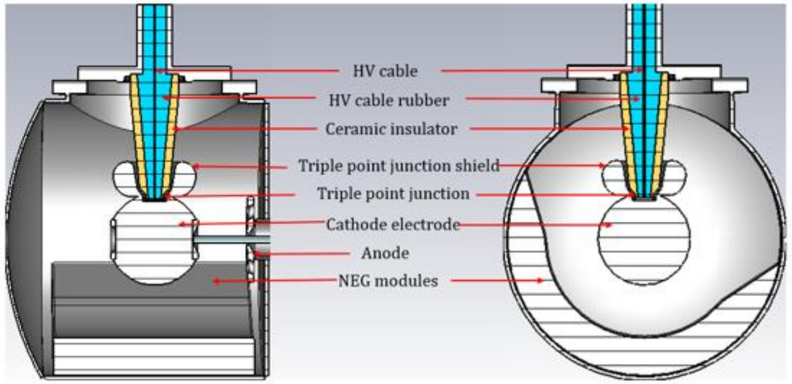
- The 300 kV DC high voltage photogun at Jefferson Lab was redesigned to deliver electron beams with much higher bunch charge and improved beam properties.
- Inverted insulator, triple point junction screening electrode, asymmetric NEG pumps altogether introduce asymmetric electric fields in between the anode-cathode gap which results in deflecting the beam vertically at the exit of the anode, difficulty in beam steering, and ultimately beam losses.
  - ➢ To correct the beam deflection with minimum changes, *the anode aperture is spatially shifted with respect to the beamline longitudinal axis in GTS photogun.*
- The required beam steering is measured for modified design and compared to the original design.

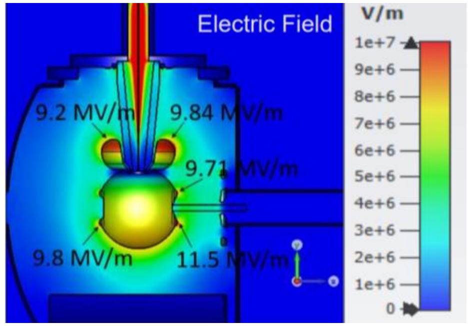


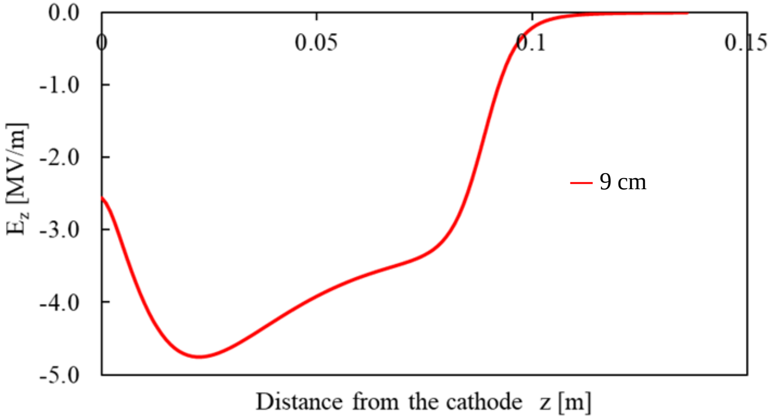


Photogun Design: Original vs. Modified

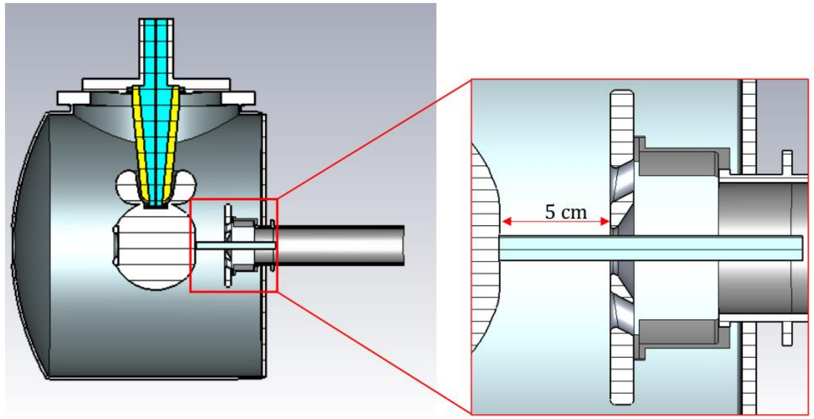
Original design

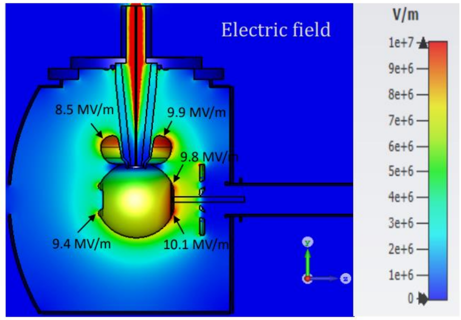


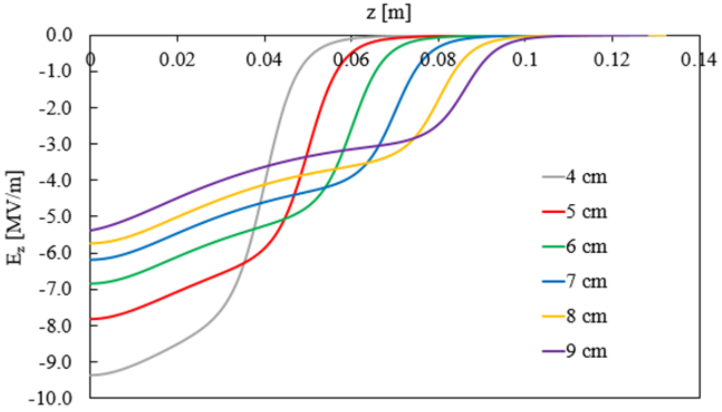




Modified design







(left) Side view cross section with the anode-cathode gap and front view cross section looking from the anode (right) electrostatic design of the cathode electrode.

E_z vs z between the anode cathode gap when biased at 350 kV.

To increase E_z at the cathode

- Removed the Pierce geometry → flat cathode front and flat anode front
- Reduced anode-cathode gap to 5 cm

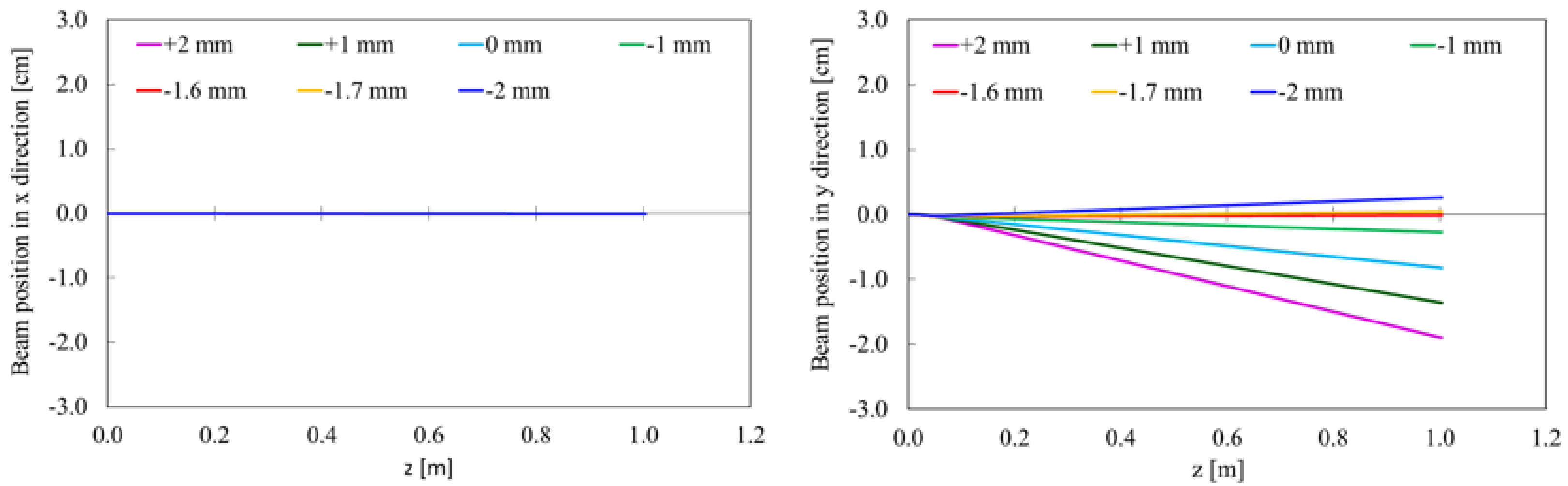
To correct the beam deflection with minimum changes on the existing design

- Y deflection → Shift anode -1.6 mm in vertical direction
- X deflection → Replace existing NEGs with thinner strips

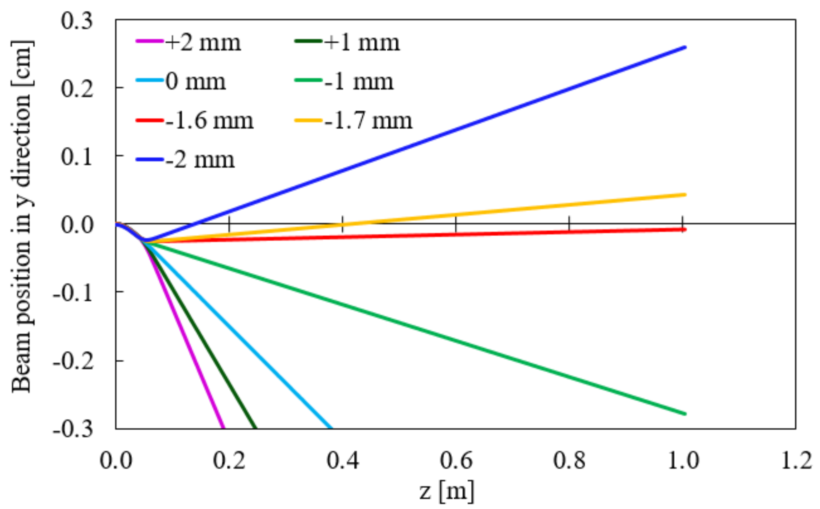
- CST was used to generate field maps for different anode offsets and used them in GPT to calculate beam deflections.
- A considerable increase in E_z at the cathode, compared to the original design, with the flat electrodes providing much of the benefit.

Beam deflection varies with anode shift

- CST was used to generate field maps for different anode offsets and used them in GPT to calculate beam deflection.
- For the anode displaced by -1.6 mm, the beam deflection caused by the photogun asymmetric design is nearly countered, and beam travels almost parallel to the beamline axis to minimize the need to steer beam at the photogun exit.



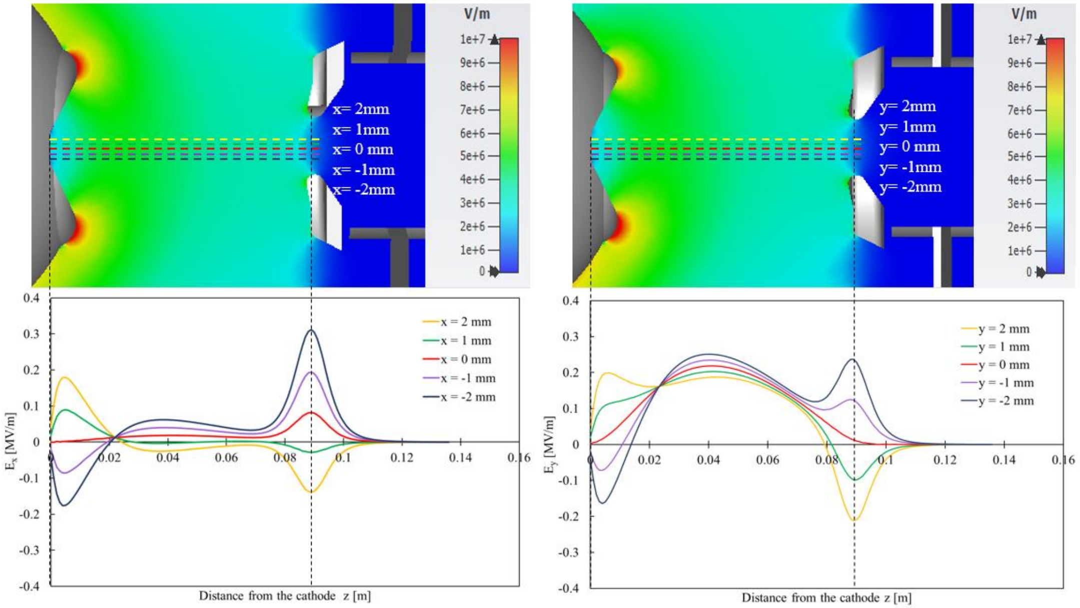
Beam deflection varies with anode shift x-deflection (left). y-deflection (right).



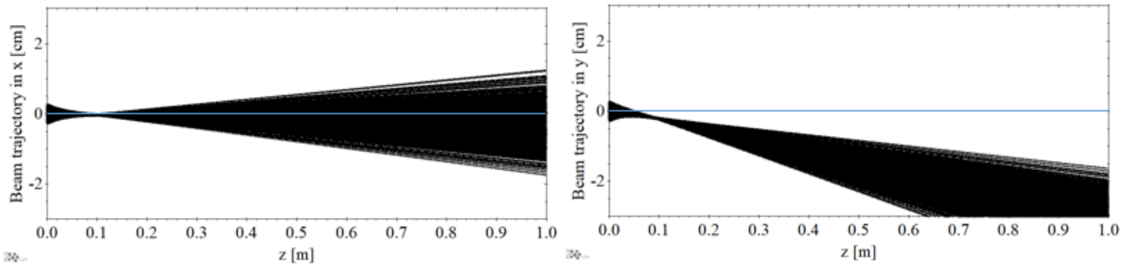
Closer look of the beam deflection in y-deflection.

Horizontal and vertical electric field distributions in the anode cathode gap

Original design

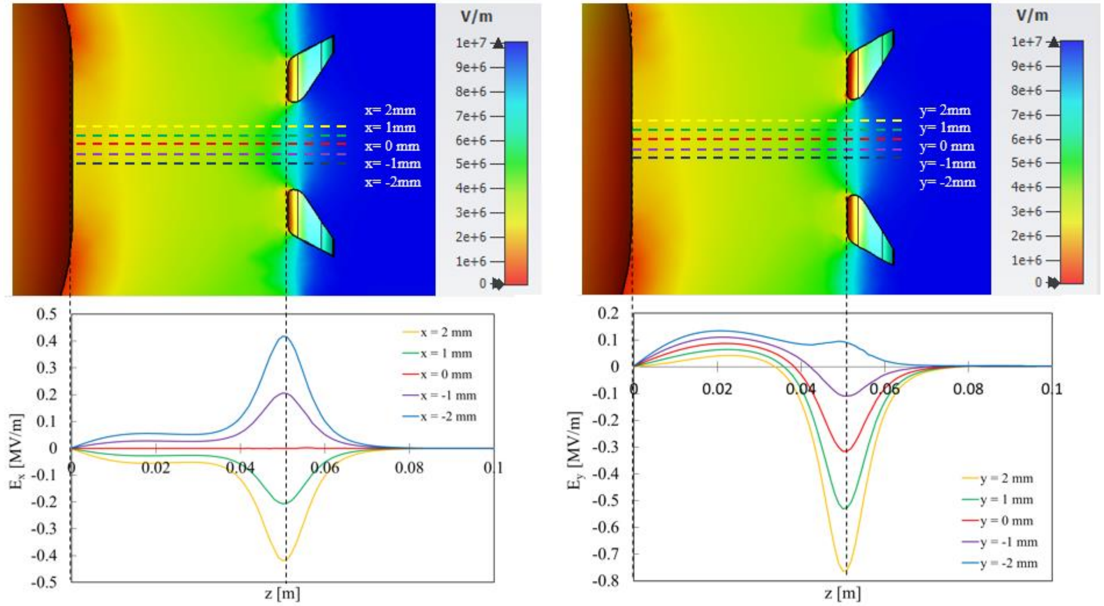


Ex (left), Ey (right) variations along the dotted colored lines between the anode cathode gap when biased at 350 kV where each color line position is indicated with respect to the x-axis (left) and y-axis (right). The color represents the electric field strength in V/m.

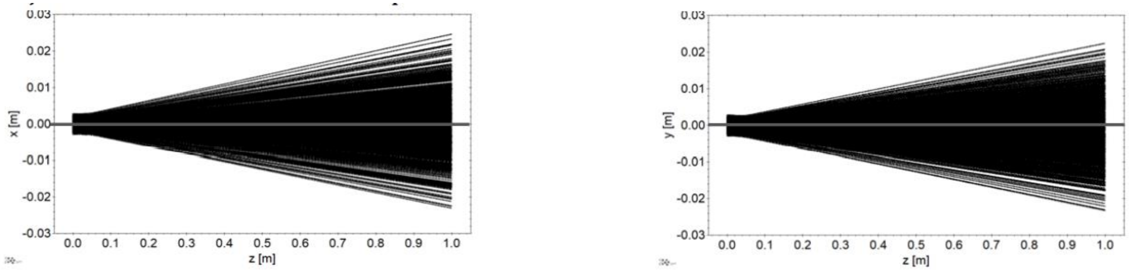


Beam trajectories with the original field map.

Modified design



Ey (right) variations along the dotted colored lines between the anode cathode gap for the final design with -1.6 mm anode shift when biased at 350 kV where each color line position is indicated with respect to the x axis (left) and y axis (right). The color represents the electric field strength in V/m.



Beam trajectories with the modified field map.

Modified cathode front face and anode

Front surface of the flat cathode which mates the spherical ball electrode.

The flat anode. The anode aperture is shifted by -1.6 mm. The anode can be biased with wire visible in the photo.

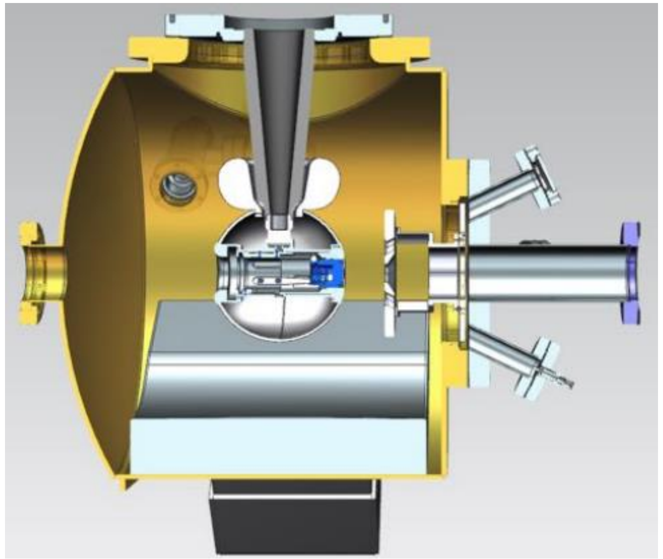
Original electrode and modified electrode

Original electrode

Modified electrode

Modified anode

Modified gun



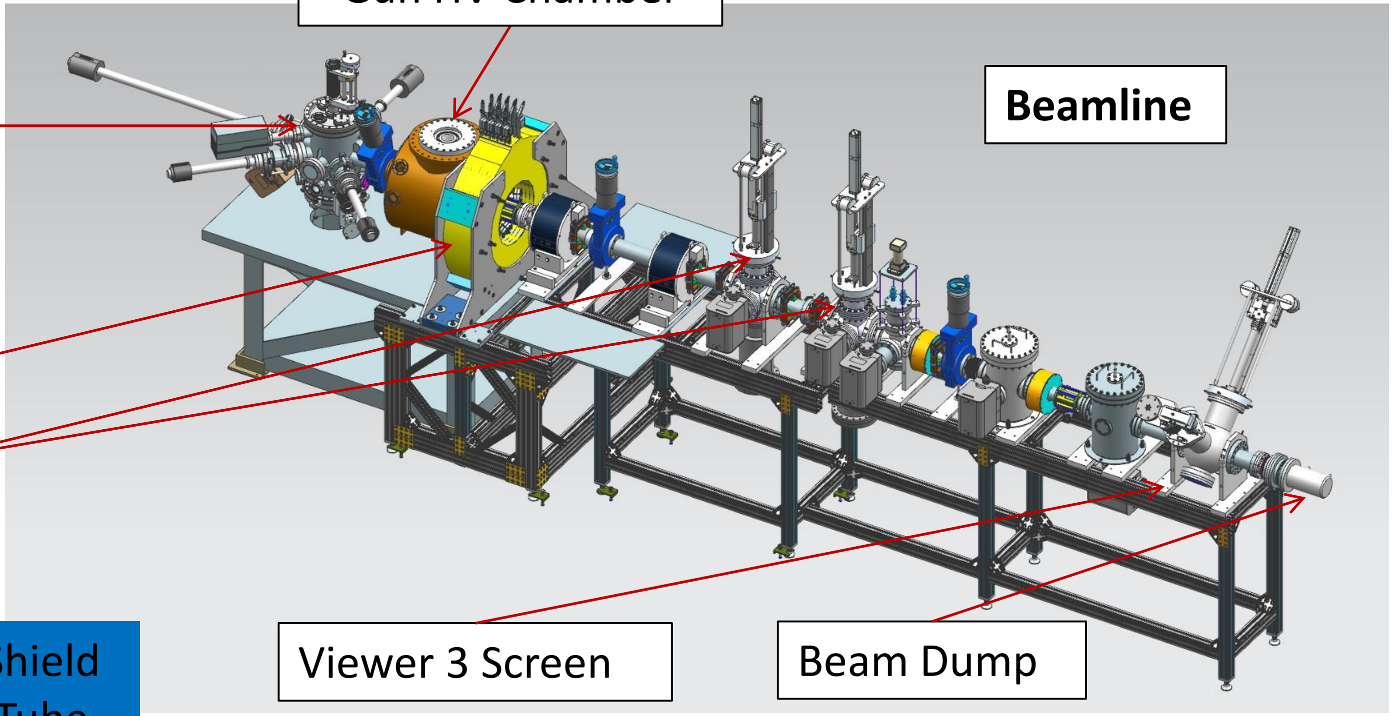
<u>GTS 350 kV Gun</u>

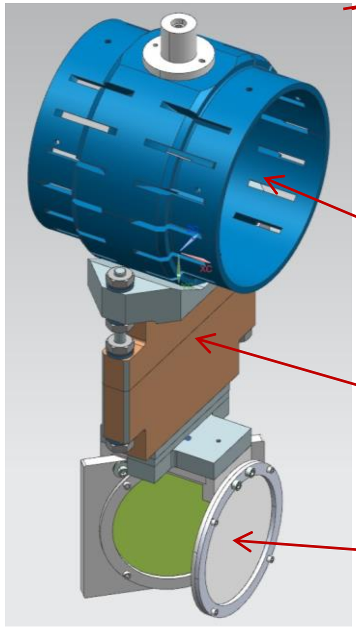
<u>28 mA beam!</u>

<u>Magnetized Beam</u>

with CsK_2Sb photocathode

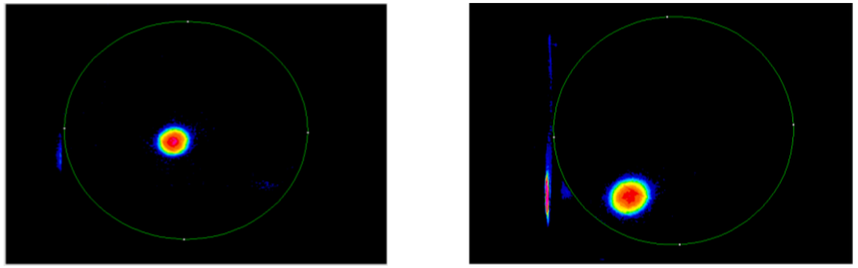
Magnetized Source Schematics



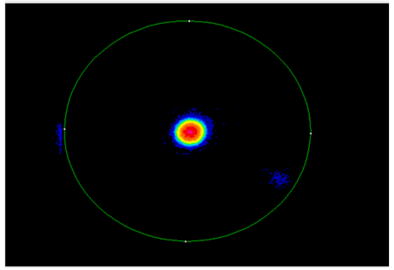


Beamline Components	Distance w.r.t. Gun, cm
MBHGT01	24.5
MCRGT01	41.4
MFGT02	50
MCRGT02	61
MFGT03	110
MCRGT03	120
MBHGT03	135
Viewer 1	150
MCRGT04	182.3
Viewer 2	200

Beam deflection minimized in the modified gun



Beam on viewer 1 (left) and viewer 2 (right) for all magnets at zero after design modification. Gun HV=200 kV, 0.35 mm laser spot at the center of photocathode.



Beam centered on viewer 1 with very little steering at the first corrector after design modification, Gun HV=200 kV, 0.35 mm laser spot at the center of photocathode.

Integrated field set point required in the correctors (Gauss-cm). Gun HV=200 kV.

	Original Gun	Modified Gun
MBHGT01H	21.3	-4
MBHGT01V	83	3

Integrated field (Gauss-cm) set point required in modified gun at different laser spot location to center beam on viewer 1. Gun HV=200 kV.

Laser spot position =>	Center	12 O'clock	6 O'clock	3 O'clock	9 O'clock
MBHGT01H	-4	-3.2	-8	-9.6	-6
MBHGT01V	3	5	0.8	3.6	3

Integrated field (Gauss-cm) set point required in the modified gun, beam centered on focusing solenoids and viewer 1, laser spot at the center of the photocathode. Gun HV=200 kV.

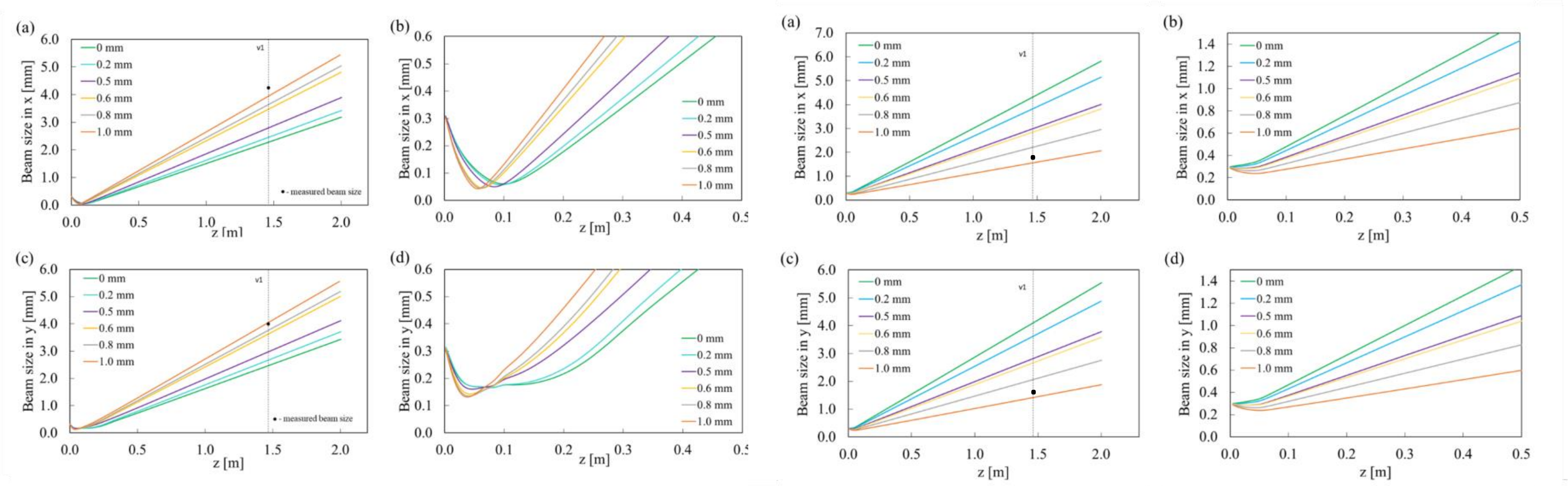
Laser spot position =>1	Center	12 O'clock	6 O'clock	3 O'clock	9 O'clock
MBHGT01H	-29.8	27.8	32	29.2	28.8
MBHGT01V	27.7	23.4	23.2	22.4	26.6
MCRGT02H	-90.7	-85	-85	-89	-85
MCRGT02V	-34.6	-35	-35	-23	-30
MCRGT03H	47	48	22	31	31
MCRGT03V	-65	-25	-54	-58	-74

Integrated field (Gauss-cm) set point required in the original and modified gun to center the electron beam on all focusing solenoids and viewer 1 for laser spot positioned at the center of the photocathode. Gun HV=200 kV.

Magnets	Modified gun	Original gun	Original gun	*Magnet distance (Z)*, cm
MBHGT01H	-29.8	-18	-0.53	24.5
MBHGT01V	27.7	-101	73.2	
MCRGT01H			-16.5	41.4
MCRGT01V			23.7	
MCRGT02H	-90.7	-40	-42.93	61
MCRGT02V	-34.6	-47	-49	
MCRGT03H	47	-3.32	72	120
MCRGT03V	-65	45	54	
MBHGT03H		1	-10	135
MBHGT03V		2	0	

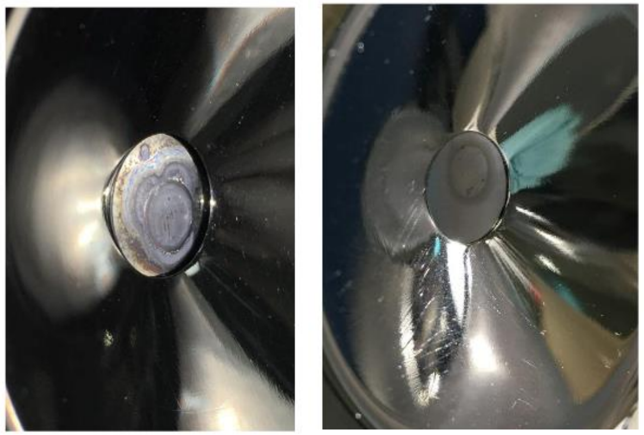
Beam size on viewer 1

- Average photocathode surface recess: 0.826 ± 0.127 mm
- Beam size on viewer 1, σ_x= 1.774, σ_y =1.685 mm for 0.3 mm laser spot at center of photocathode and Gun at 200 kV.



Beam size variation along the z for different recess lengths (a) in x and (c) in y. Closer look of the beam size variation (b) in x and (d) in y. The measurement of beam size at first viewer is also shown for original design (left) and modified design (right).

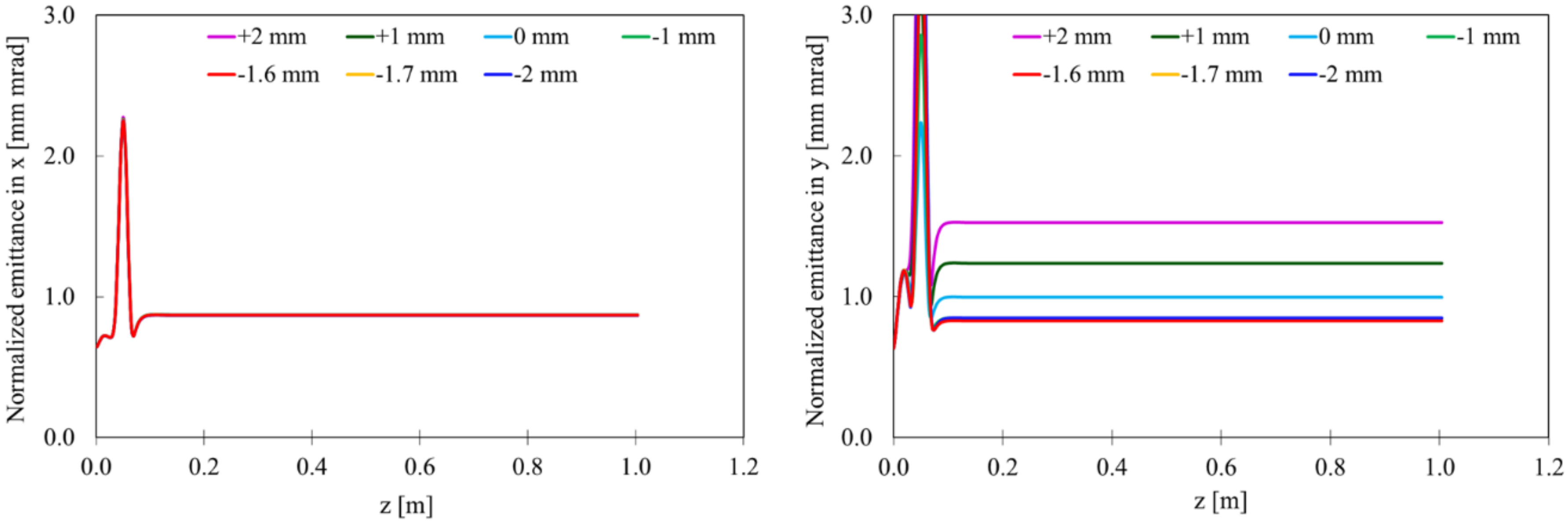
GaAs wafer *Moly wafer*



There is a visible space in between photocathode and cathode front face.

- A recessed photocathode inside the cathode electrode can affect E_z at the photocathode and the focusing inside the photogun. 1 mm recess reduces E_z at the photocathode from -2.19 MV/m to -1.67 MV/m at 300 kV (with Pierce geometry) which will limit the maximum charge density extractable from the photocathode.
- A small displacements of the photocathode from intended position can have significant impact on measured beam sizes. It however has negligible effect on beam emittance.

Photocathode recess has negligible effect on beam emittance



Normalized emittance variation with the anode shift x (left) and y (right). Since all the anode shifts are in y-direction there is no effect on the normalized emittance in x-direction thus, all the plots lie on top of each other.

Conclusion

- The 300 kV photogun was re-designed using CST and GPT software to obtain a higher E_z at the photocathode for high bunch charge operations and to correct beam trajectory.
- The longitudinal electric field magnitude E_z was increased from -2.5 MV/m to -7.8 MV/m by removing the Pierce geometry and decreasing the anode-cathode gap from 9 cm to 5 cm.
- It was relatively easy to implement a modest downward shift of just 1.6 mm to eliminate beam deflection, a relatively simple modification to provide improvement in photogun performance by reducing beam loss at anode and thus improving the photocathode lifetime, particularly those at high bunch charge.
- A tilted anode can be used to accomplish the same goals of eliminating beam deflextion, and that is being studied by the group.
- Finally, the photocathode position inside the cathode electrode can affect E_z at the photocathode and the focusing inside the photogun. Very small displacements of the photocathode from intended position can have very big impact on measured beam sizes and negligible effect on beam emittance.