Generation and Characterization of Magnetized Bunched Electron Beam from DC High Voltage Photogun for JLEIC Cooler

R. Suleiman and M. Poelker

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Motivation

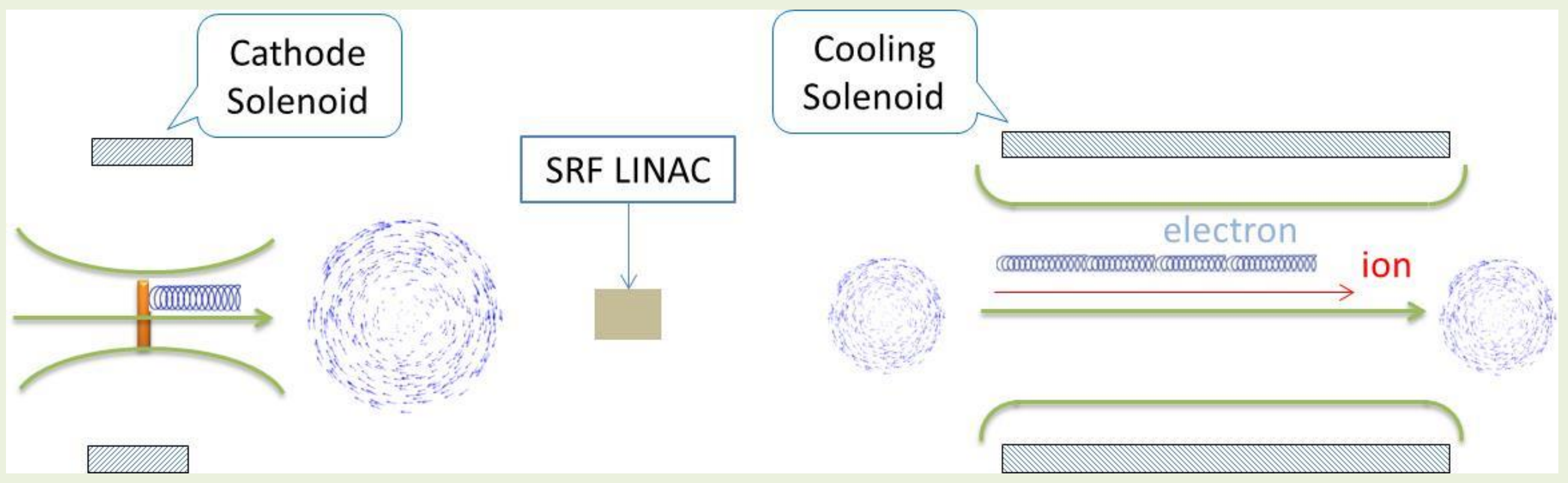
Jefferson Lab Electron Ion Collider (JLEIC) bunched magnetized electron cooler is part of Collider Ring and aims to counteract emittance degradation induced by intra-beam scattering, to maintain ion beam emittance during collisions and extend luminosity lifetime

Magnetized Cooling

Ion beam cooling in presence of magnetic field is much more efficient than cooling in a drift (no magnetic field):

- ➢ Electron beam helical motion in strong magnetic field increases electron-ion interaction time, thereby significantly improving cooling efficiency
- ➢ Electron-ion collisions that occur over many cyclotron oscillations and at distances larger than cyclotron radius are insensitive to electrons transverse velocity
- ➢ Cooling rates are determined by electron longitudinal energy spread rather than electron beam transverse emittance as transverse motion of electrons is quenched by magnetic field
- ➢ Magnetic field suppresses electron-ion recombination

Electron beam suffers an azimuthal kick at entrance of cooling solenoid. But this kick can be cancelled by an earlier kick at exit of photogun. That is purpose of cathode solenoid



Electrons born in strong uniform B_z

$$\langle L\rangle = \frac{eB_z a_o^2}{4}$$

$a_0 = R_{laser} = 3.14$ mm
$B_z = 0.50$ kG

Upon exit of Cathode Solenoid

$$\langle L\rangle = \gamma m_e \langle r^2\rangle \dot{\phi}$$

$$\varepsilon_d = \frac{eB_z a_o^2}{8 m_e c} = 36\ \mu\text{m}$$

Upon entering Cooling Solenoid

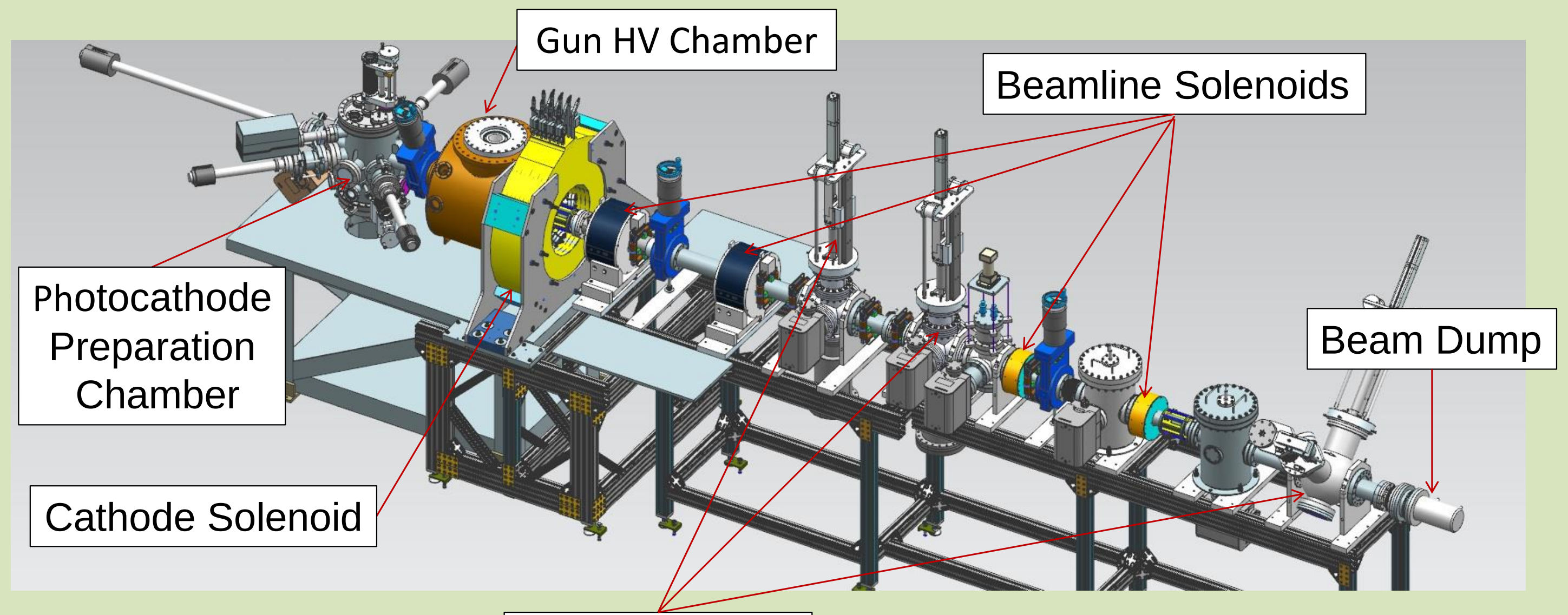
$$\langle L\rangle = \frac{eB_{cool} r_e^2}{4}$$

$r_e = 0.7$ mm
$B_{cool} = 1$ T

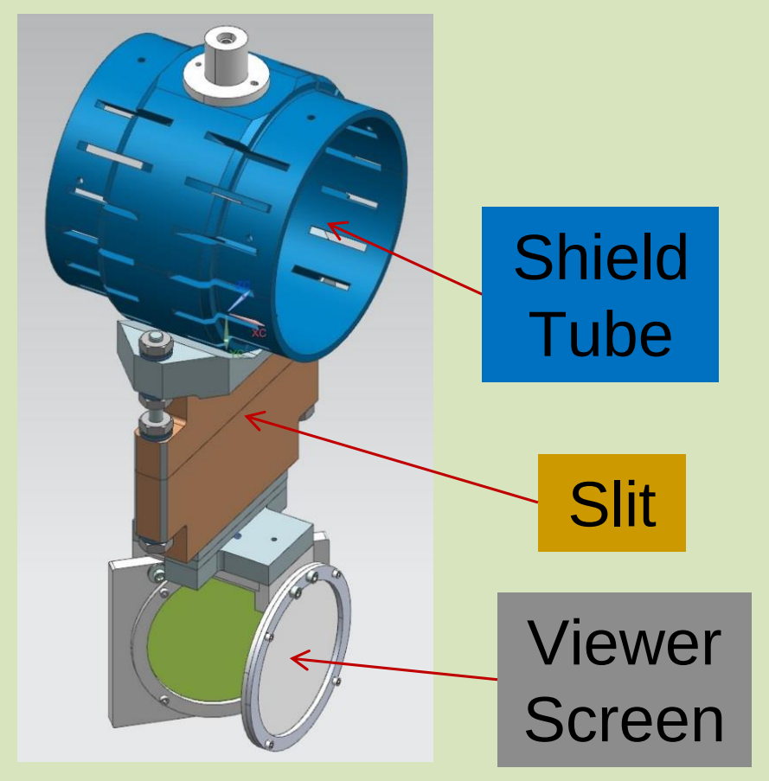
$$\frac{B_{cool}}{B_z} = \frac{a_0^2}{r_e^2}$$

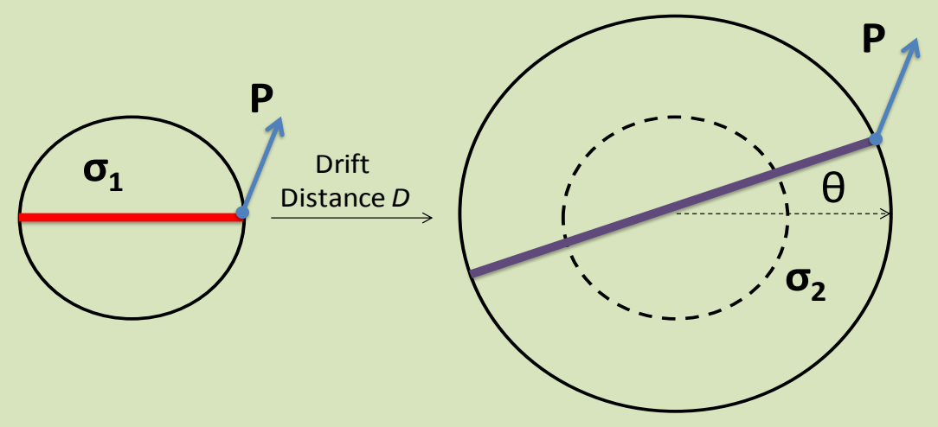
Parameter	JLEIC	LDRD (demonstrated)
Bunch length	60 ps (2 cm)	**25 – 60 ps**
Repetition rate	43.3 MHz	**100 Hz – 374.3 MHz**
Bunch charge	3.2 nC	**0.7 nC (75 ps FWHM, 25 kHz, 225 kV, 0.76 kG)**
Peak current	53.9 A	**9.3 A**
Average current	140 mA (400 kV)	**28 mA (50 ps FWHM, 374.25 MHz, 100 kV, 0.57 kG)**
Transverse normalized emittance	<19 microns	**<2 microns**
Normalized drift emittance	36 microns	**26 microns**
Cathode spot radius – Flat-top (a_0)	3.14 mm	**1.70 mm**
Solenoid field at cathode (B_z)	0.50 kG	**1.51 kG**

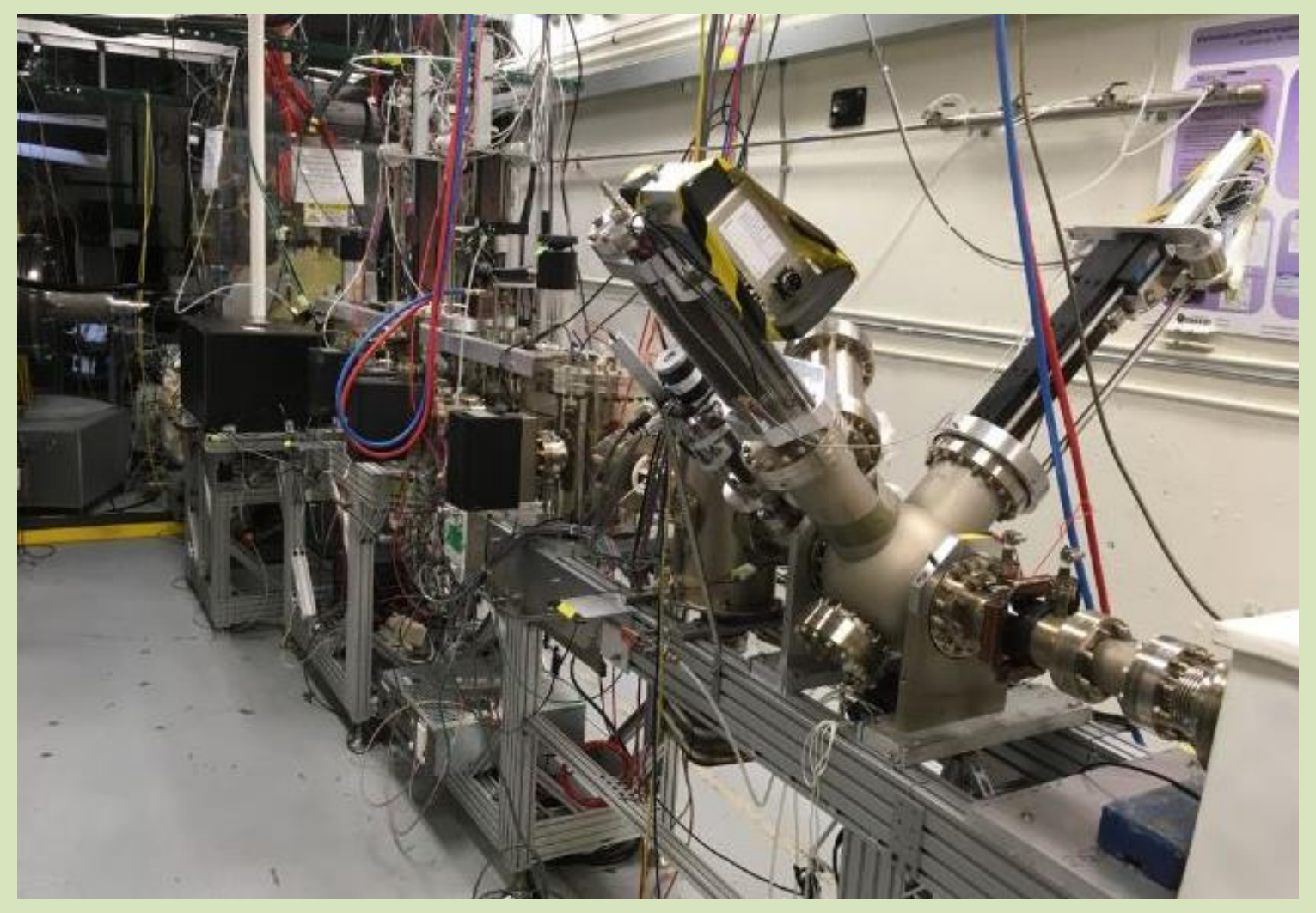
Experimental Overview



Viewer Screens



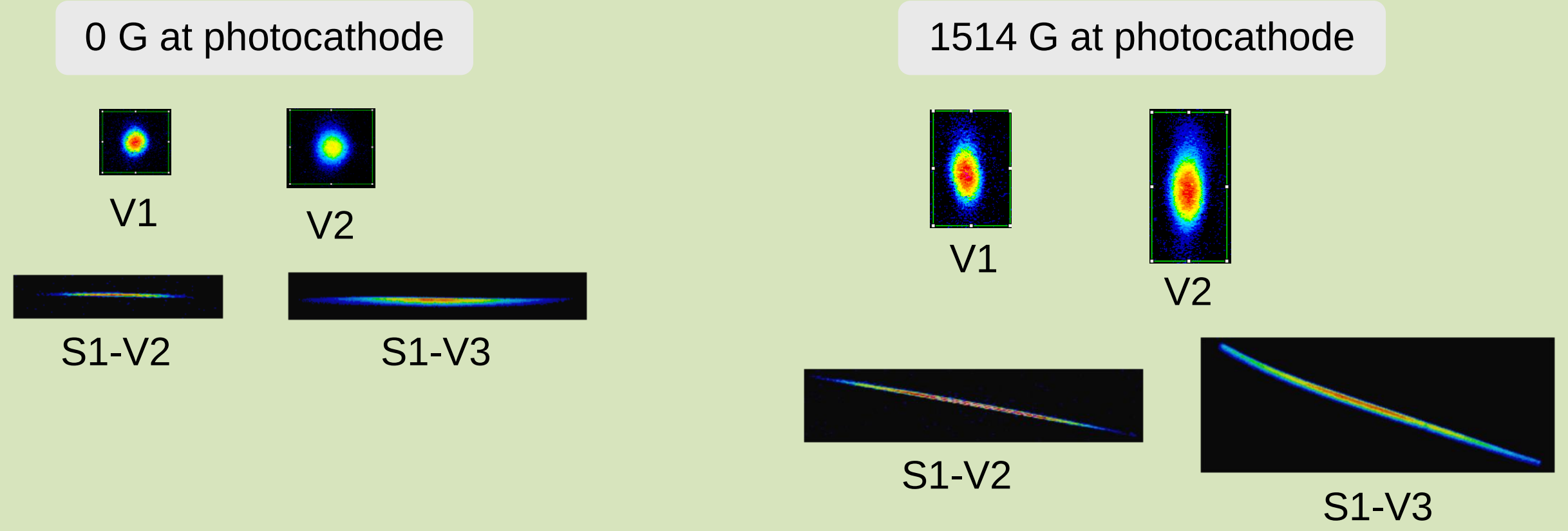




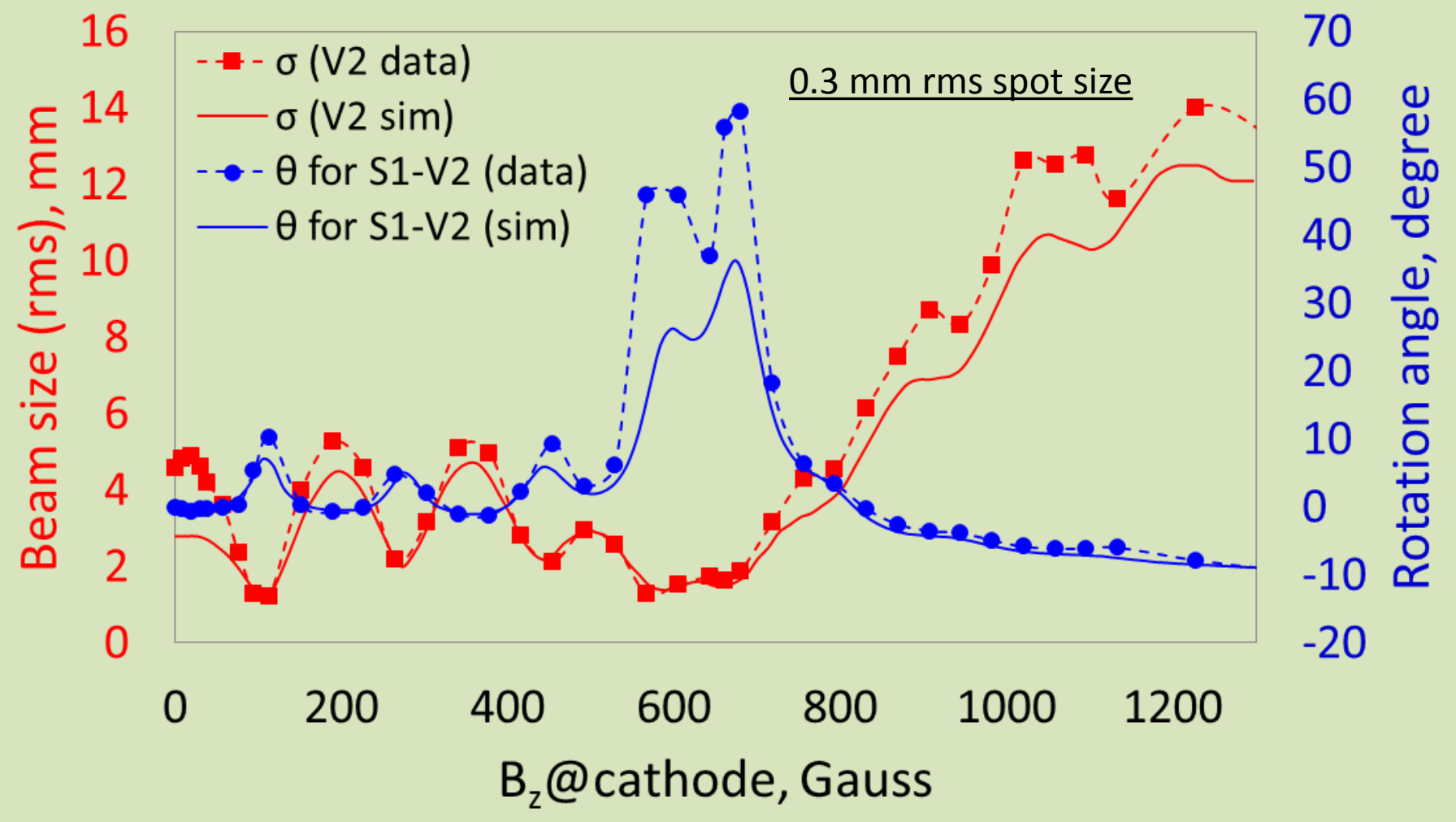
- ➢ Use slit and viewer screens to measure mechanical angular momentum
- ➢ Use beamline solenoid and viewer screen to measure drift emittance

Magnetization Measurements

Beam and beamlet observed on successive viewers

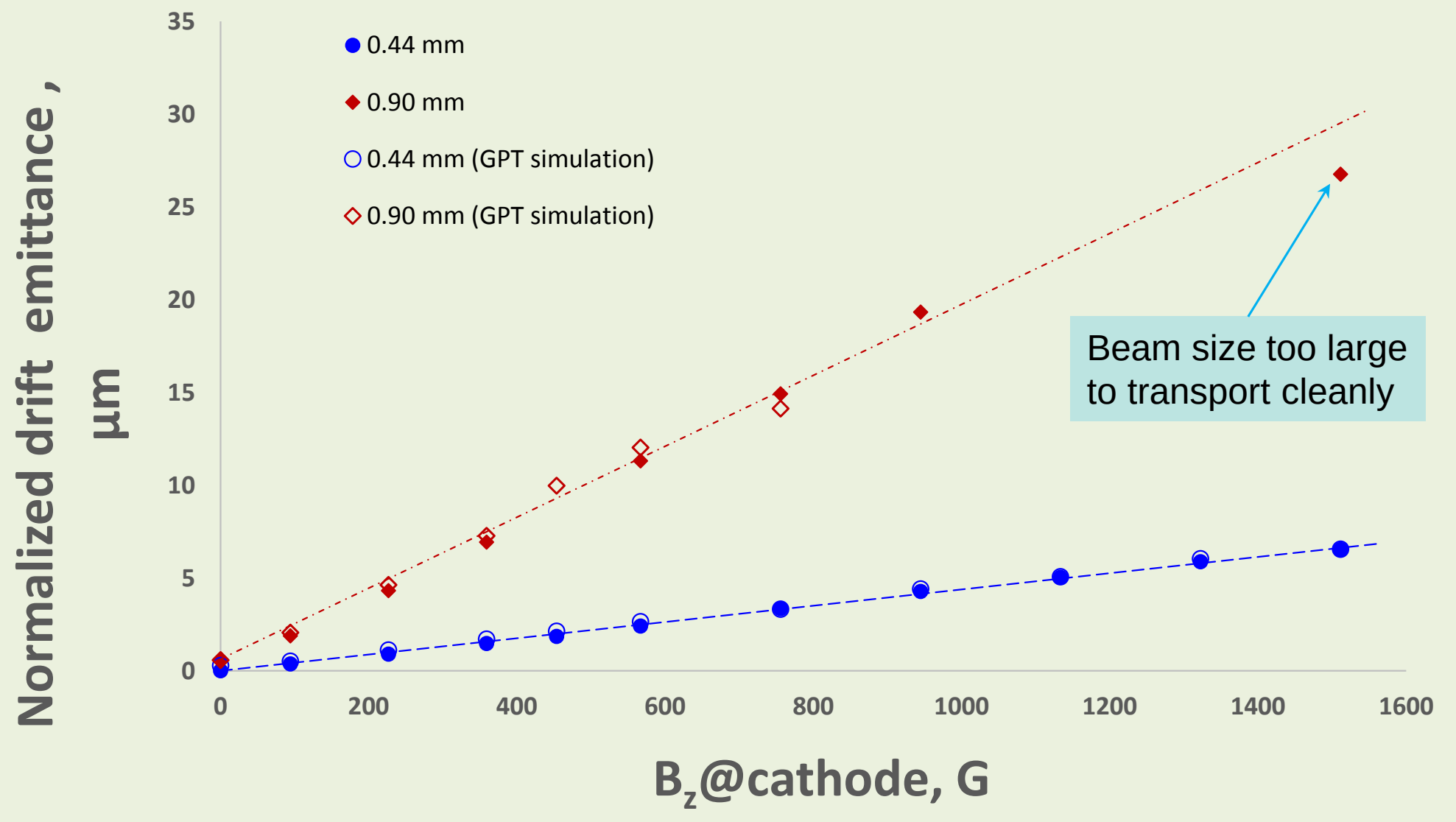


Beam Size and Rotation: Experiment vs GPT simulation



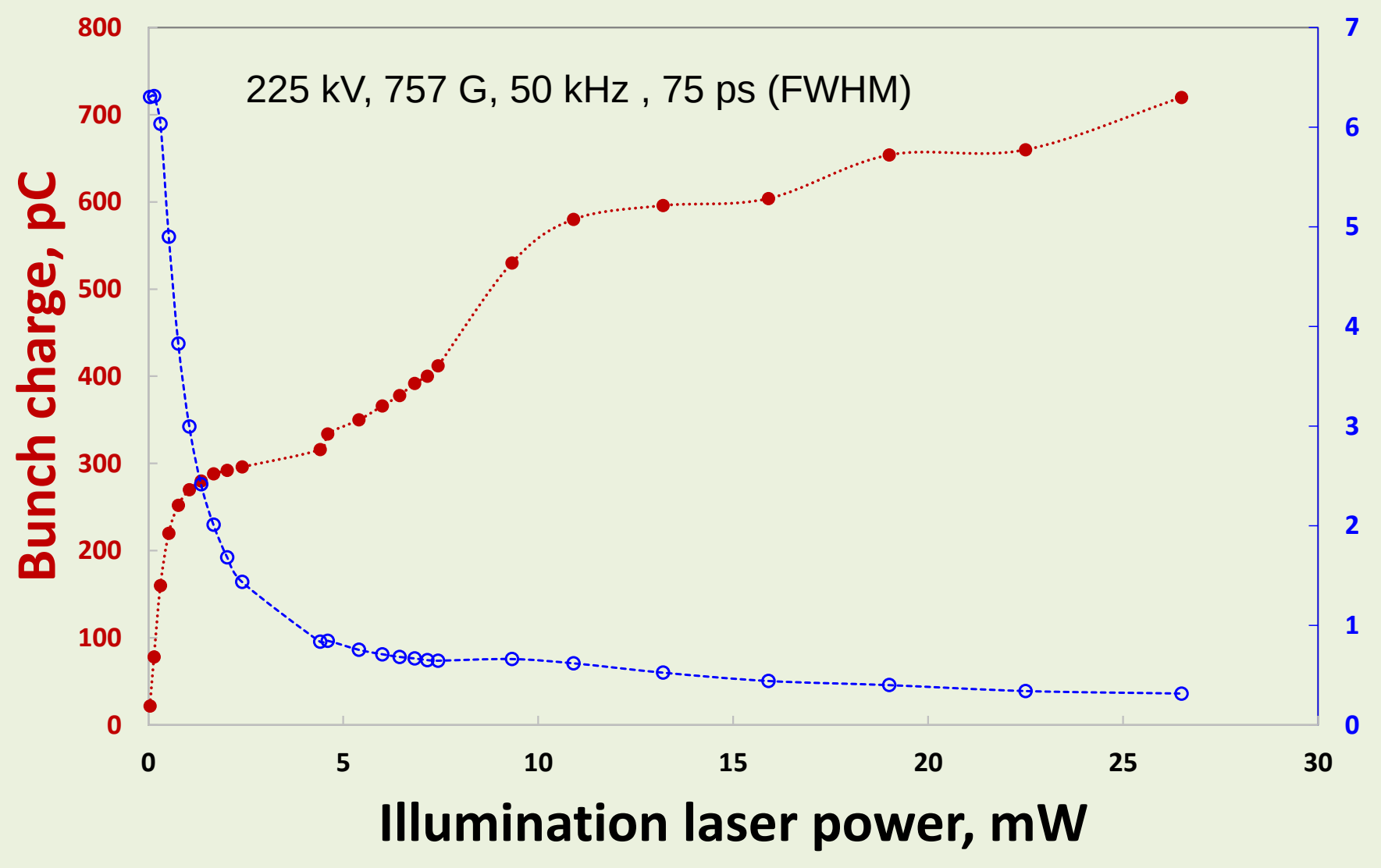
- ➢ Focusing by cathode magnetic field causes mismatch oscillations resulting in repeated focusing inside cathode solenoid field which affects beam size at exit of solenoid field and resulted in varying beam expansion rate in field free region
- ➢ Rotation angles are influenced by focusing in cathode solenoid
- ➢ Modelled apparatus using ASTRA & GPT

Drift Emittance



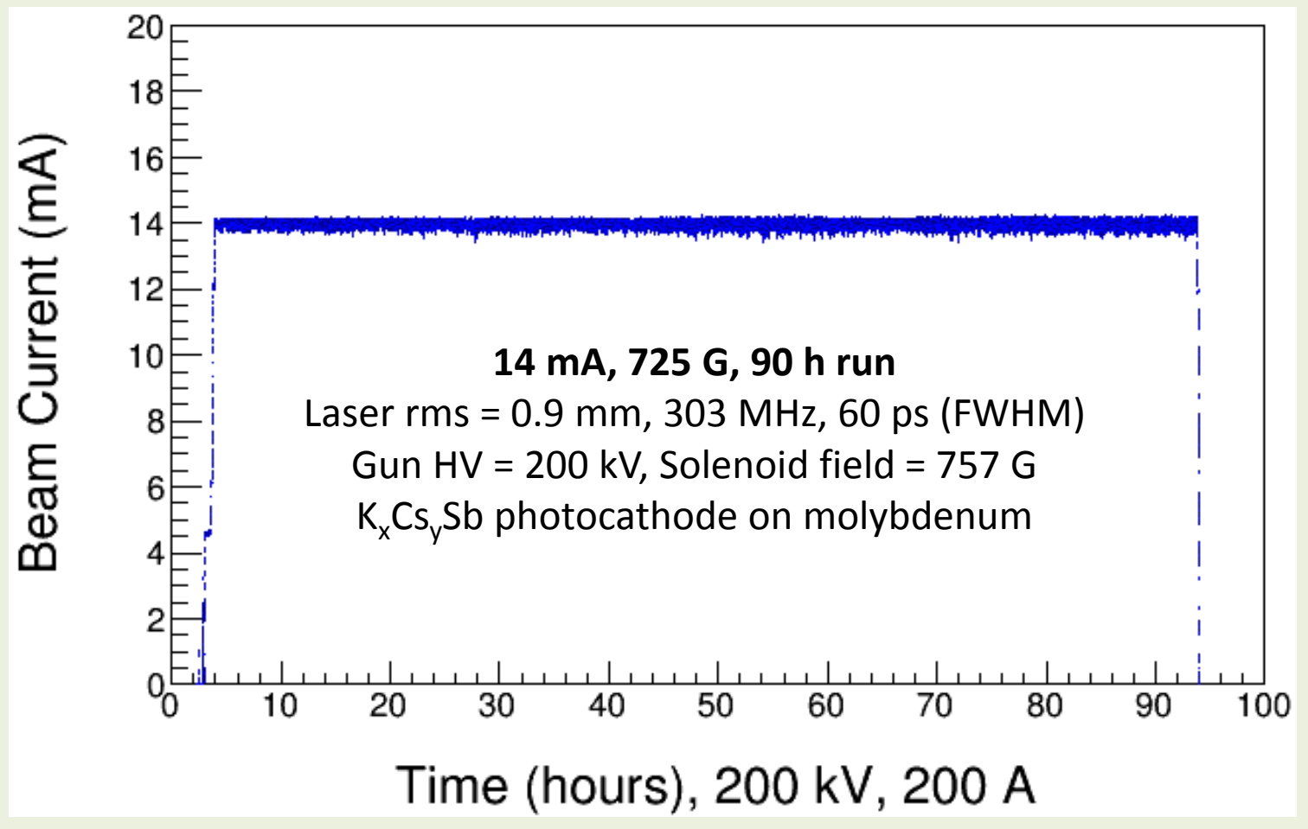
- ➢ Measured drift emittance for different spot sizes (rms) at 200 kV
- ➢ GPT simulation and experimental results show encouraging agreement

High Bunch Charge



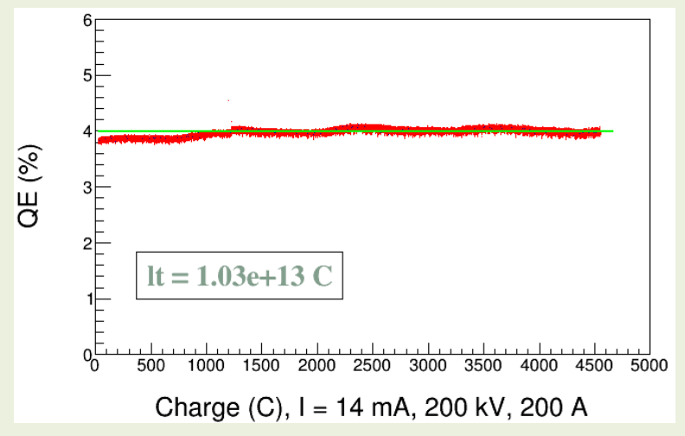
- ➢ Encountered space-charge-limited regime between 100 – 300 pC
- ➢ Need longer laser pulses and higher gun voltage to get nC bunches

High Average Current Magnetized Beam

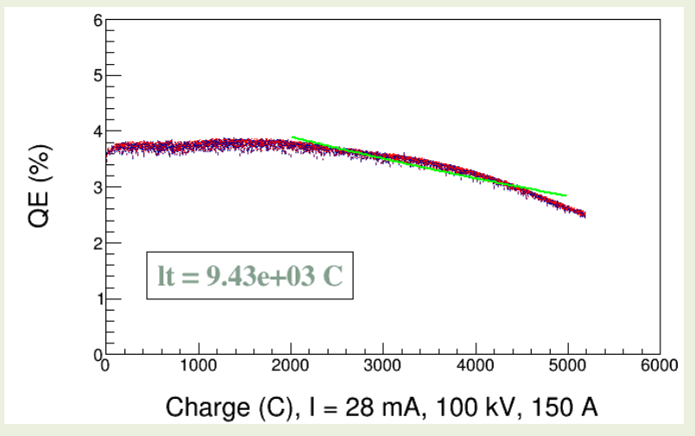


14 mA, 725 G, 90 h run
Laser rms = 0.9 mm, 303 MHz, 60 ps (FWHM)
Gun HV = 200 kV, Solenoid field = 757 G
K_xCs_ySb photocathode on molybdenum

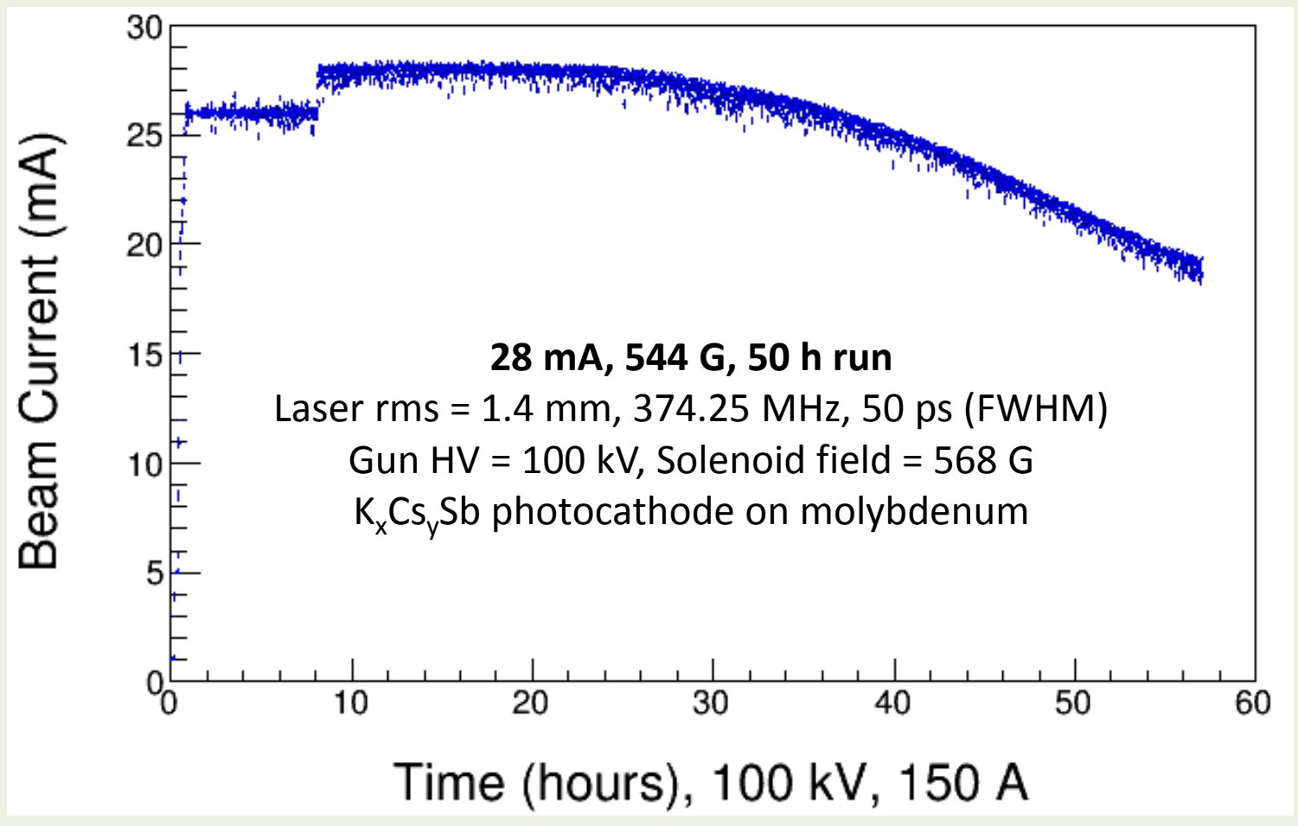
Time (hours), 200 kV, 200 A



Charge (C), I = 14 mA, 200 kV, 200 A



Charge (C), I = 28 mA, 100 kV, 150 A

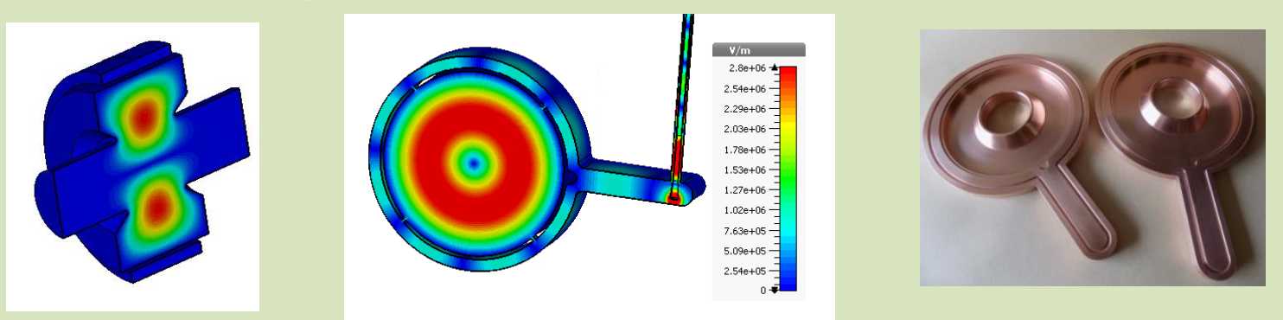


28 mA, 544 G, 50 h run
Laser rms = 1.4 mm, 374.25 MHz, 50 ps (FWHM)
Gun HV = 100 kV, Solenoid field = 568 G
K_xCs_ySb photocathode on molybdenum

Time (hours), 100 kV, 150 A

Summary

- K_xCs_ySb photocathode preparation chamber, gun, solenoid and beamline - all operational
- Photogun operated reliably up to 300 kV
- Cathode solenoid can trigger field emission but we have learned how to prevent this
- Have successfully magnetized electron beams and measured rotation angle and drift emittance
- Used a gain-switched drive laser (374.25 MHz, 50 ps FWHM) to generate 28 mA magnetized beam with RF structure at 100 kV (using 30 mA / 225 kV Spellman Supply, 3 kW power limited)
- Successfully fabricated bialkali antimonide photocathode with QE ~ 9% on molybdenum substrate that provided longer charge lifetime
- Positive bias on anode helps to prevent sudden QE loss from ion-induced micro-arcing events
- Demonstrated high bunch charge up to 0.7 nC
- Designed and built non-invasive magnetometer - TE_{011} Cavity - to measure beam magnetization. To be installed and commissioned:



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