Magnetized Electron Source, LDRD

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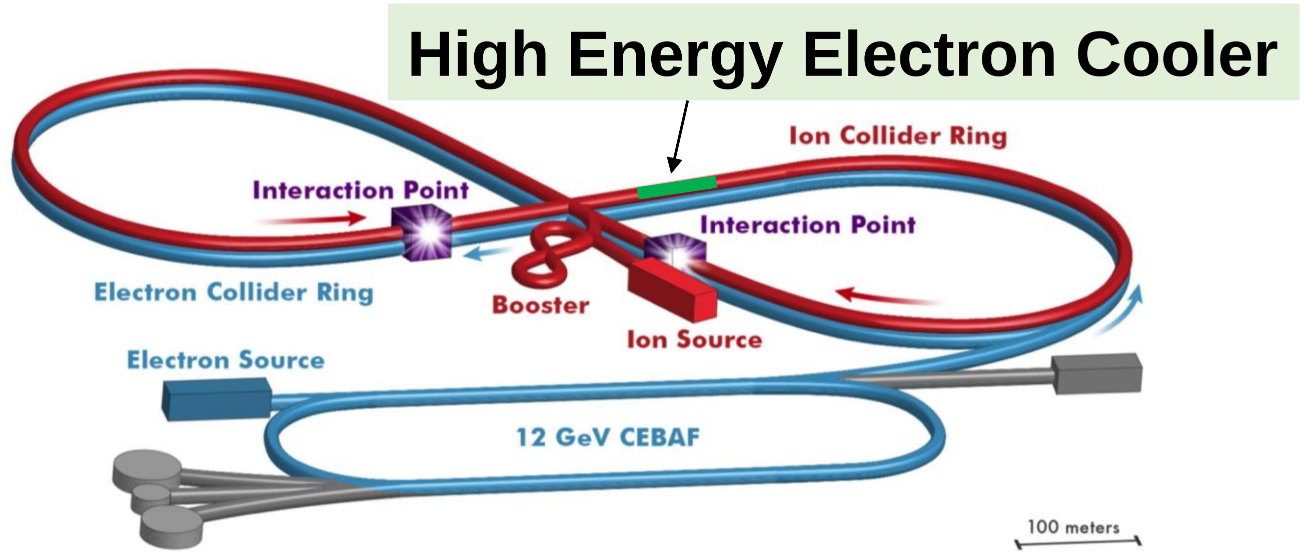
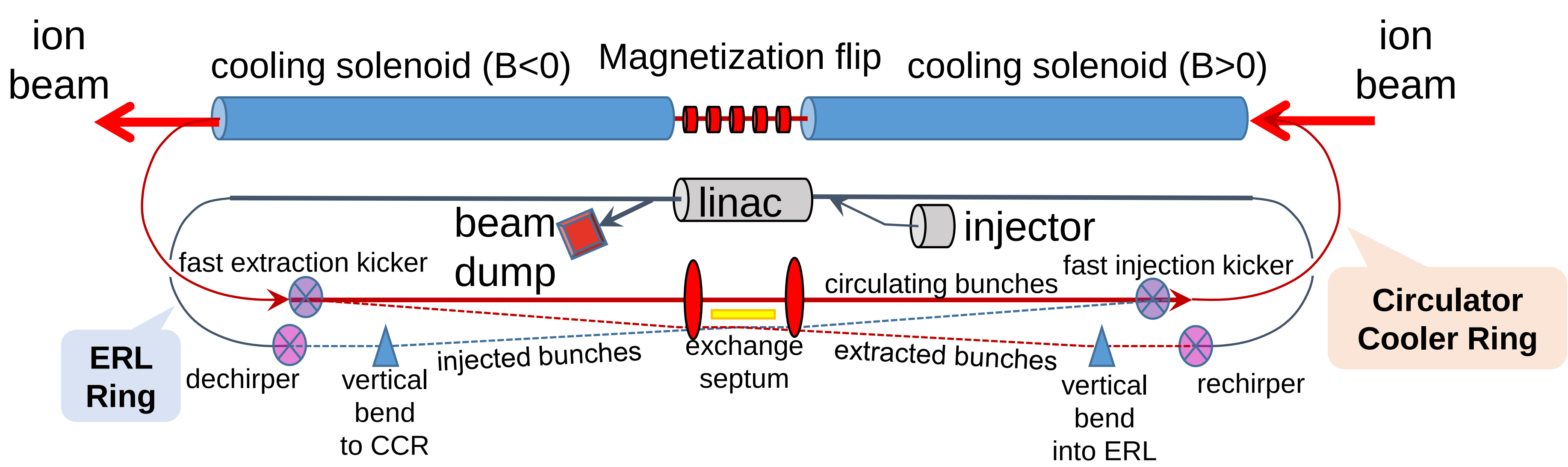
Outline

- Magnetized Bunched-Beam Electron Cooling
- LDRD Magnetized Electron Source
  I. K_2CsSb Photocathode and HV Chambers
  II. Gun Solenoid
  III. Beamline
- Generation of Magnetized Electron Beam
- Measuring Electron Beam Magnetization
  I. Slit and Viewscreens
  II. TE_{011} Cavity: new method
- Outlook
- Summary

JLEIC High Energy Electron Cooler





Magnetized Bunched-Beam Electron 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

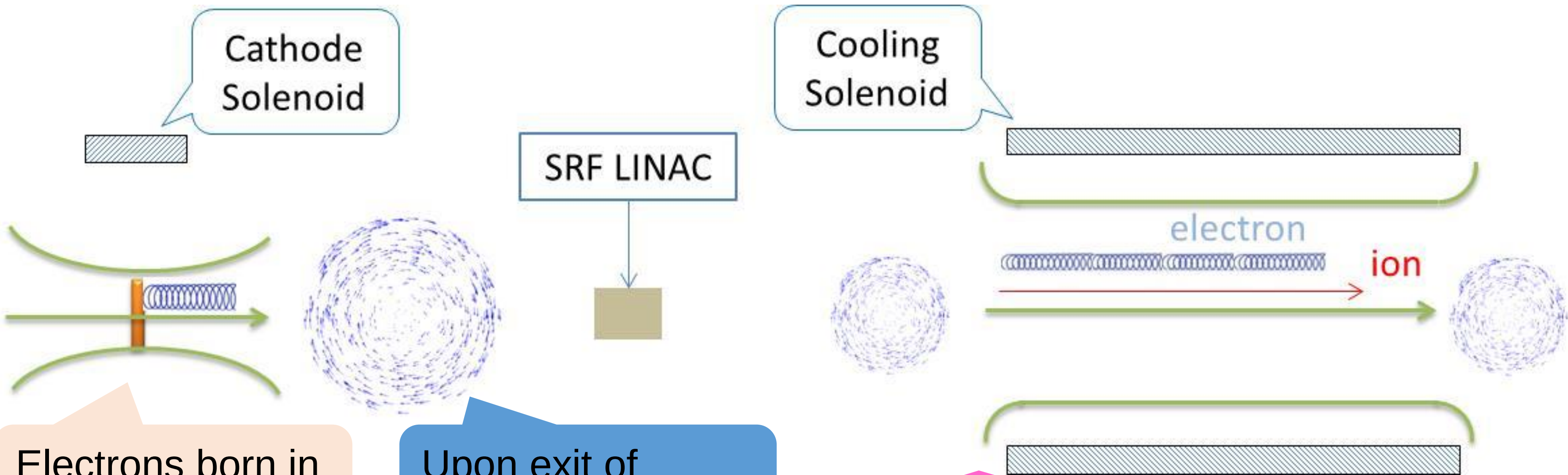
- Long cooling solenoid provides desired cooling effect:
  - Counteracting emittance degradation induced by intra-beam scattering
  - Maintaining ion beam emittance during collisions and extending luminosity lifetime
  - Suppressing electron-ion recombination

<u>but putting electron beam into cooling solenoid represents a challenge</u>

- Solution: Beam rotation in cooling solenoid is compensated by creating electrons inside a longitudinal magnet field

Magnetized Cooling Schematics

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 = 0.5 kG

Upon exit of Cathode Solenoid

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

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

Upon entering Cooling Solenoid

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

r_e = 0.7 mm
B_{cool} = 1 T

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

JLEIC Magnetized Source Requirements

Bunch length	60 ps (2 cm)
Repetition rate	43.3 MHz
Bunch charge	3.2 nC
Average current	140 mA
Transverse normalized emittance	<19 microns
Cathode spot radius – Flat-top (a_0)	3.14 mm
Solenoid field at cathode (B_z)	0.5 kG

- Cornell University demonstrated 65 mA and 2 nC, but not at same time, and non-magnetized

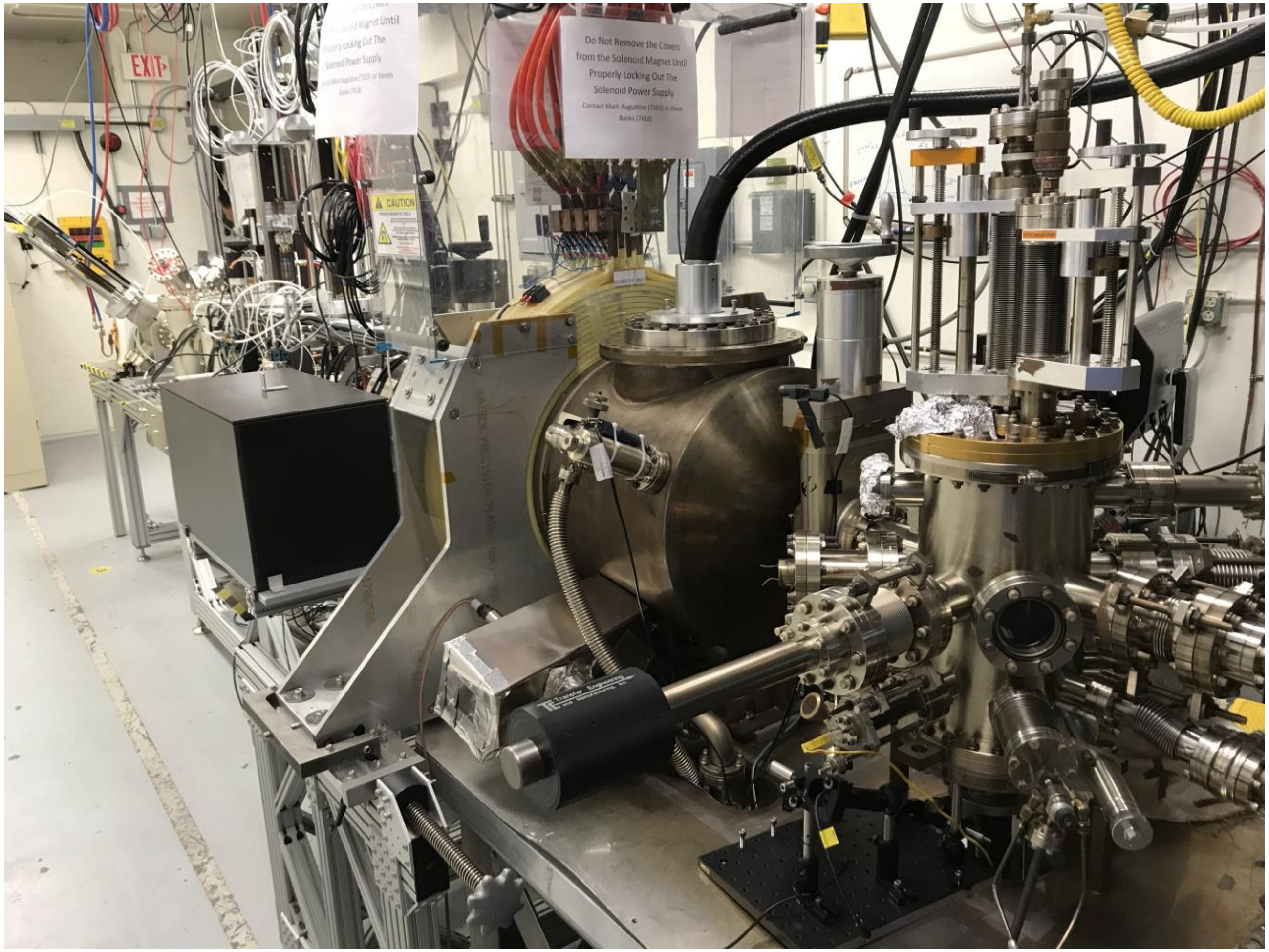
- Fermilab Magnetized Photoinjector Laboratory:
  - Pulsed NCRF gun with Cs_2Te photocathode and UV laser (λ=263 nm)
  - Bunch charge: 0.5 nC and bunch length: 3 ps
  - 0.5% duty factor (average current: 7.5 μA)
    - Bunch frequency: 3 MHz
    - Macropulse duration: 1 ms
    - Number of bunches per macropulse: 3000
    - Macropulse frequency: 5 Hz

Magnetized Beam LDRD

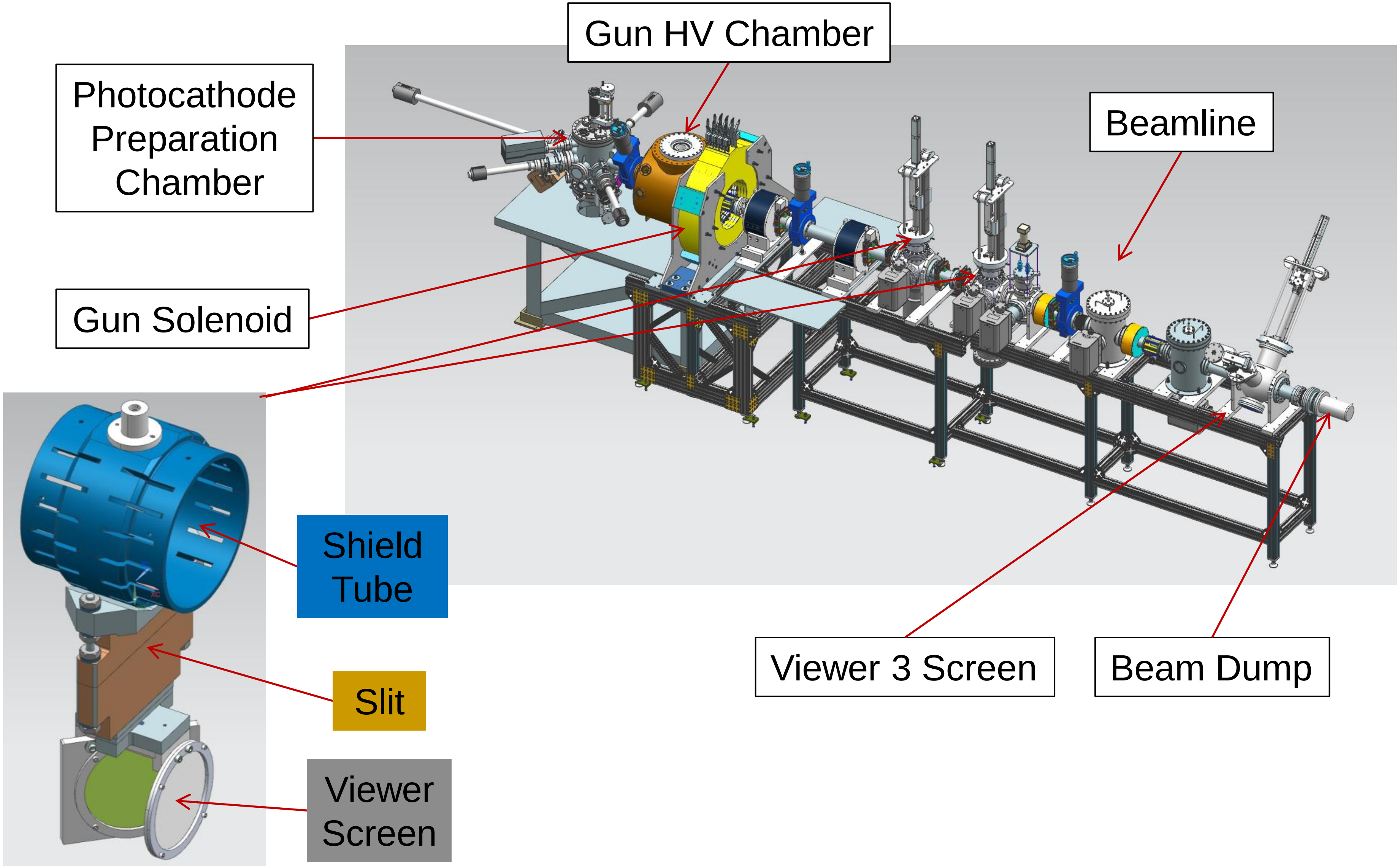
- Three-year project (FY16 – FY18):
  - Generate magnetized electron beam from dc high voltage photogun and measure its properties
  - Explore impact of cathode solenoid on photogun operation
  - Simulations and measurements will provide insights on ways to optimize JLEIC electron cooler and help design appropriate source
  - JLab will have direct experience magnetizing electron beams at high current

LDRD Magnetized Electron Source

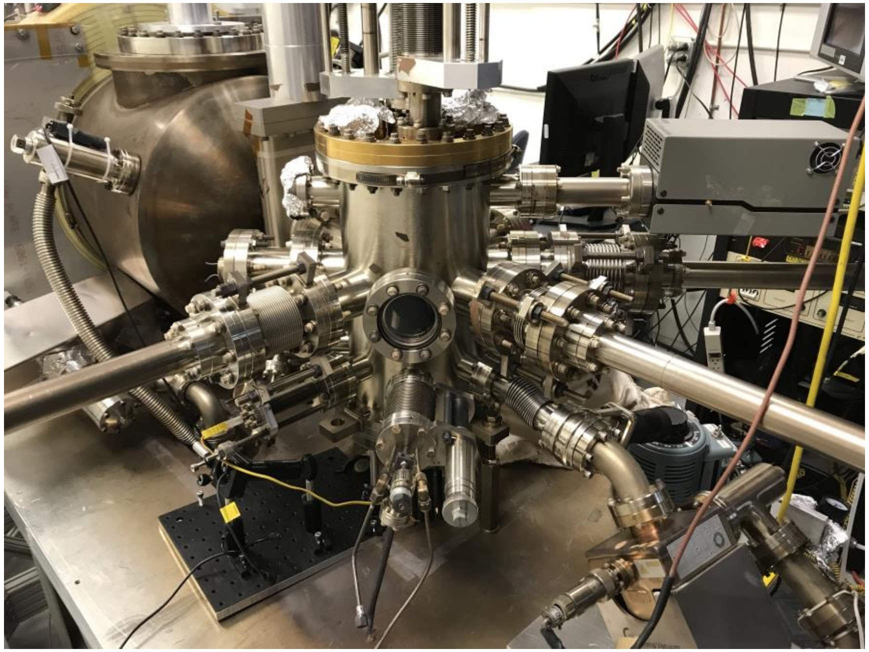
- K_2CsSb Photocathode Preparation Chamber, Gun, Solenoid and Beamline are all operational

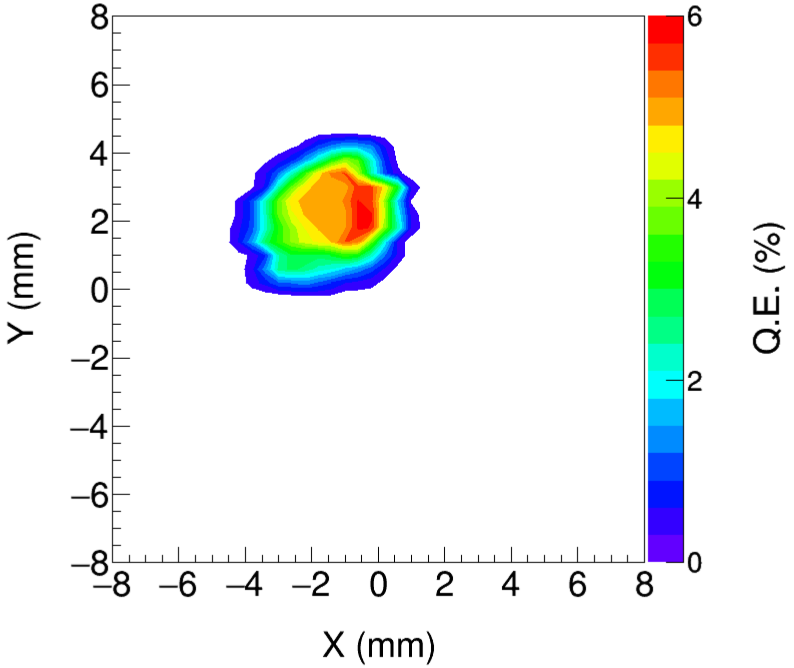


Magnetized Source Schematics



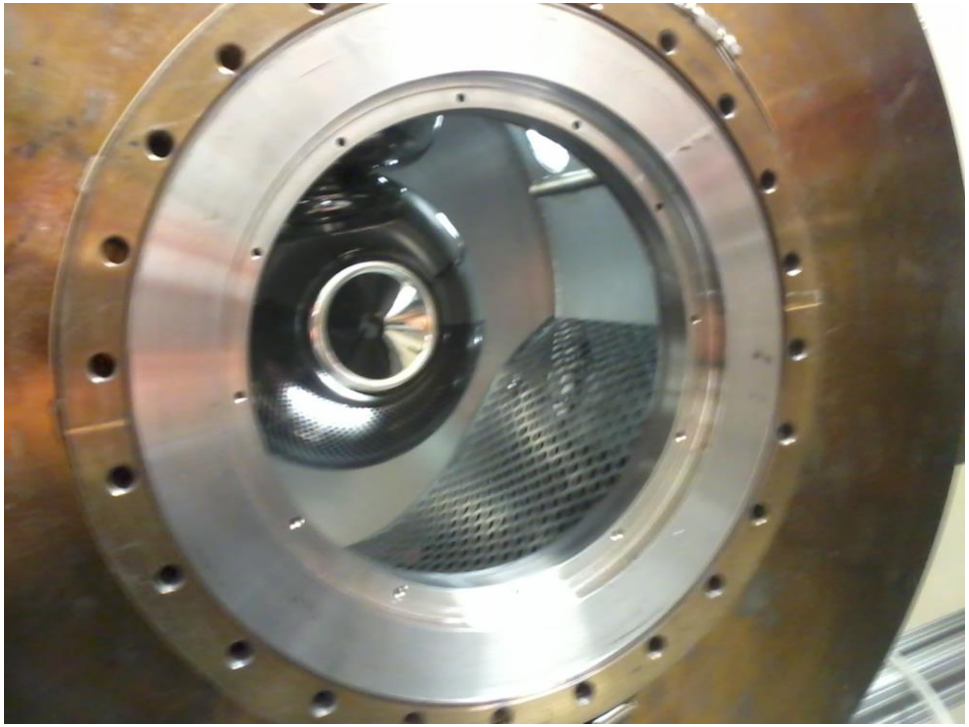
Photocathode Preparation Chamber





- K_2CsSb grown with a mask – limit photocathode active area (3 mm diameter) to reduce beam halo, minimize vacuum excursions and high voltage arcing, prolong photogun operating lifetime
- Active area can be offset from electrostatic center
- 5 mm active area also available
- Entire photocathode can be activated too

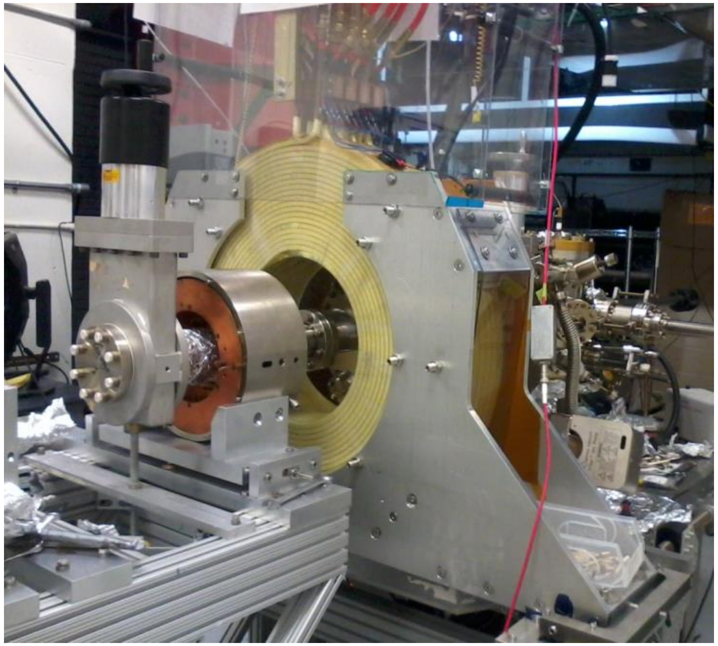
Gun HV Chamber

- Upgraded HV Chamber with new doped-alumina inverted insulator and newly designed screening electrode (triple point junction shield) to lower gradient from 12 MV/m to 10 MV/m at 350 kV
- Photogun now operating at 300 kV with gun solenoid at 400 A

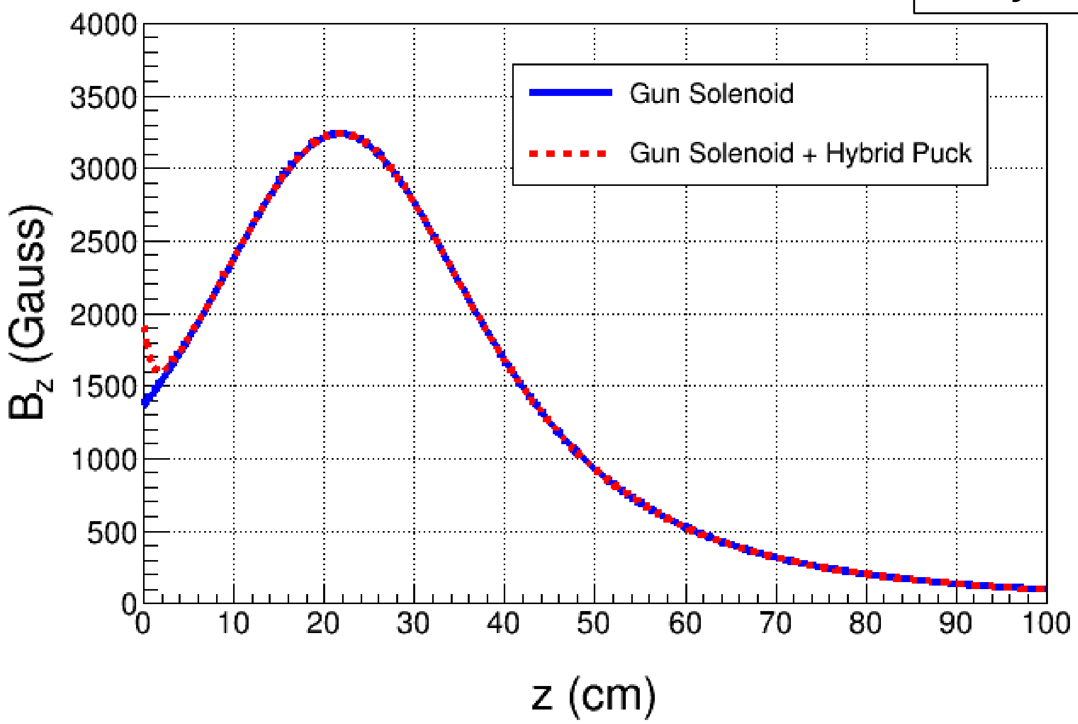
Gun Solenoid

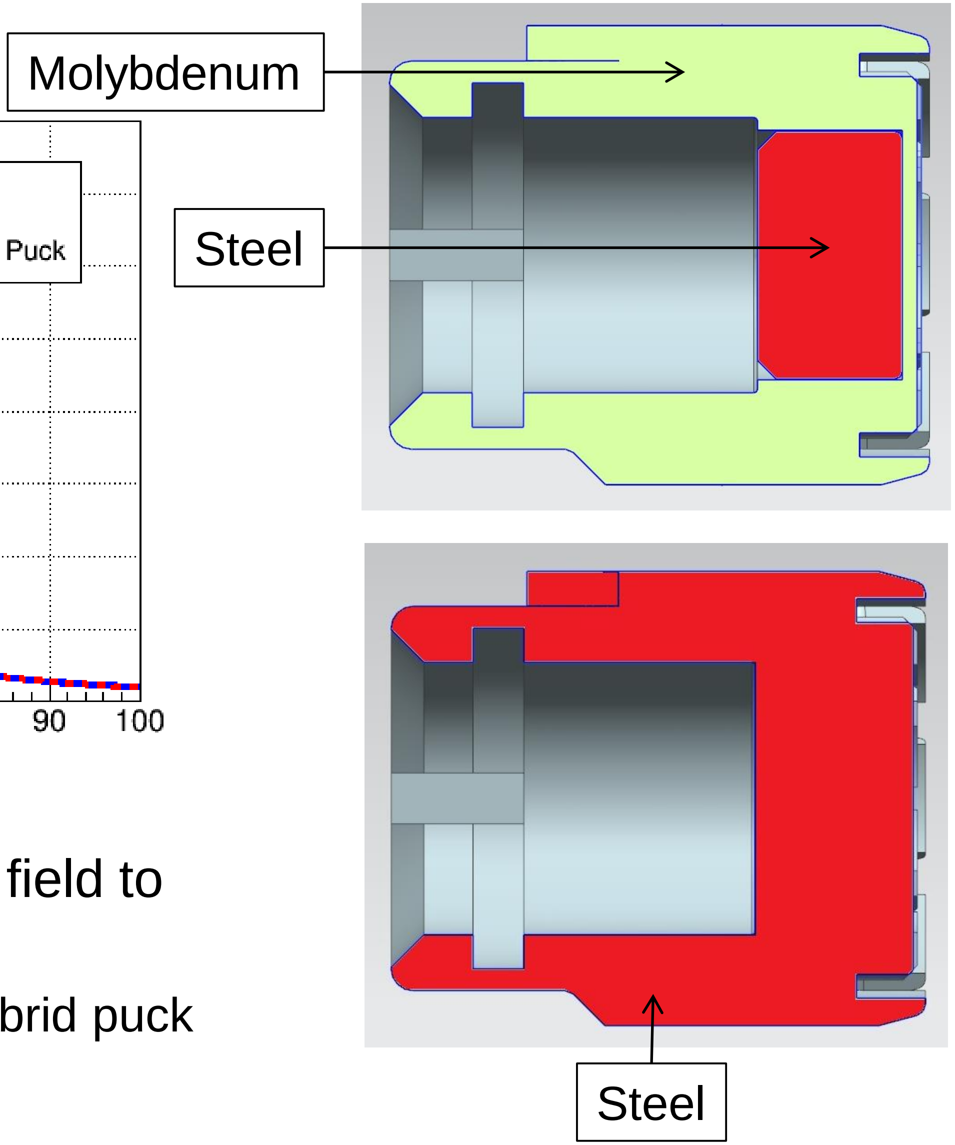
Size	11.811" ID, 27.559" OD, 6.242" Z
Conductor	L=500 m, A=0.53 cm^2 16 layers by 20 turns
Coil Weight	254 kg (560 lbs)
Resistance	0.198 Ω
Field at Photocathode	1.4 kG
Voltage	79 V
Current	400 A



- Using spare CEBAF Dogleg magnet power supply (500 A, 80 V)
- Learned that gun solenoid **can** influence field emission
- First trials with gun at high voltage and solenoid ON resulted in new field emission and vacuum activity
- Procedure to energize solenoid without exciting new field emitters

New Steel Photocathode Holders





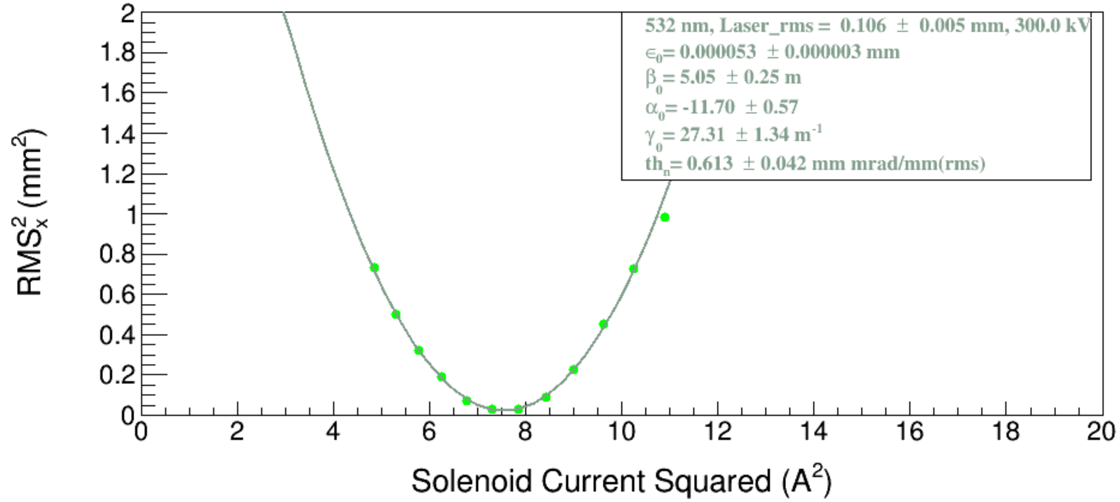
New steel holders (pucks) to enhance field to 2.0 kG at photocathode. Two types:

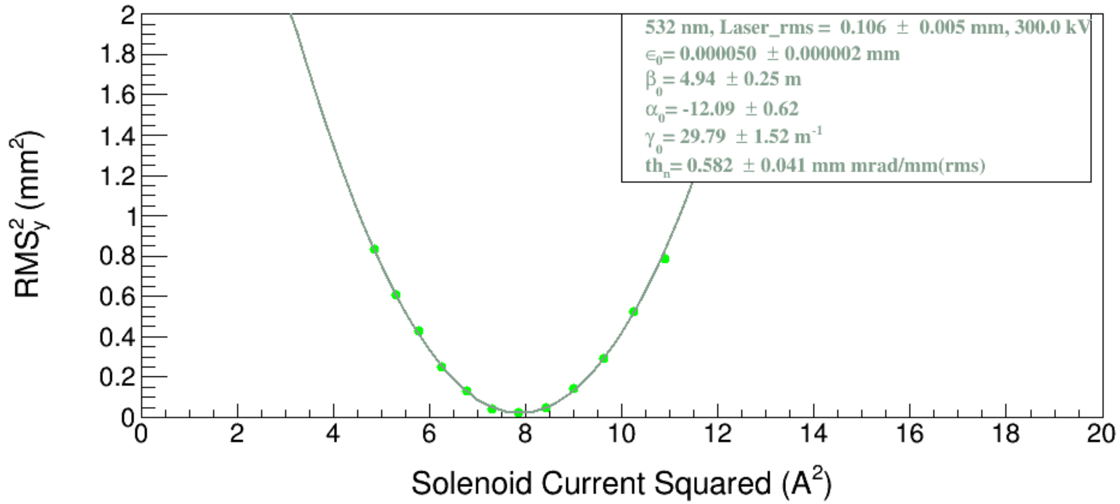
I. Molybdenum and carbon steel hybrid puck

II. Carbon steel puck

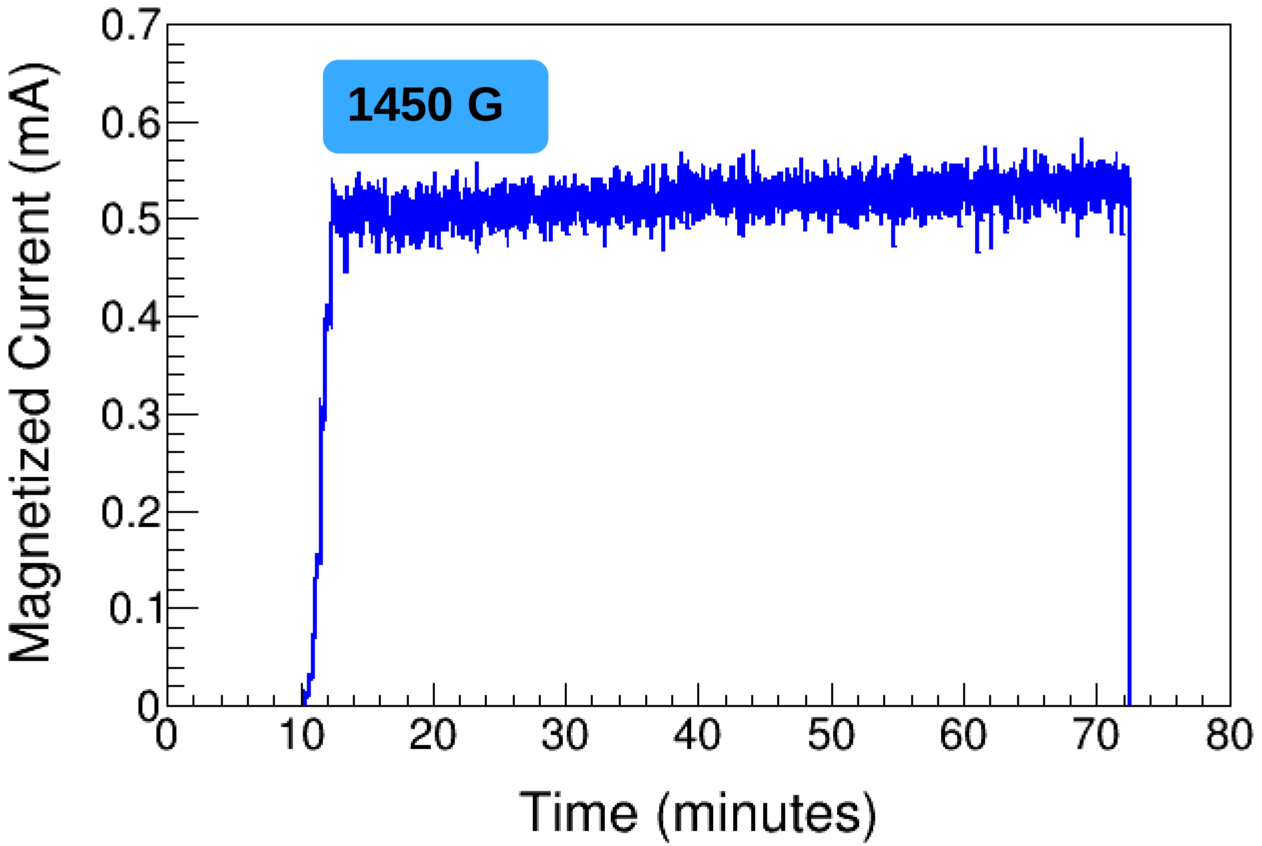
Non-magnetized Beam

- Commissioned beamline
- Measured beam emittance, typical thermal angle (th_n) value of 0.6 mm mrad/mm(rms), consistent with published data
- Delivered 1.0 mA dc





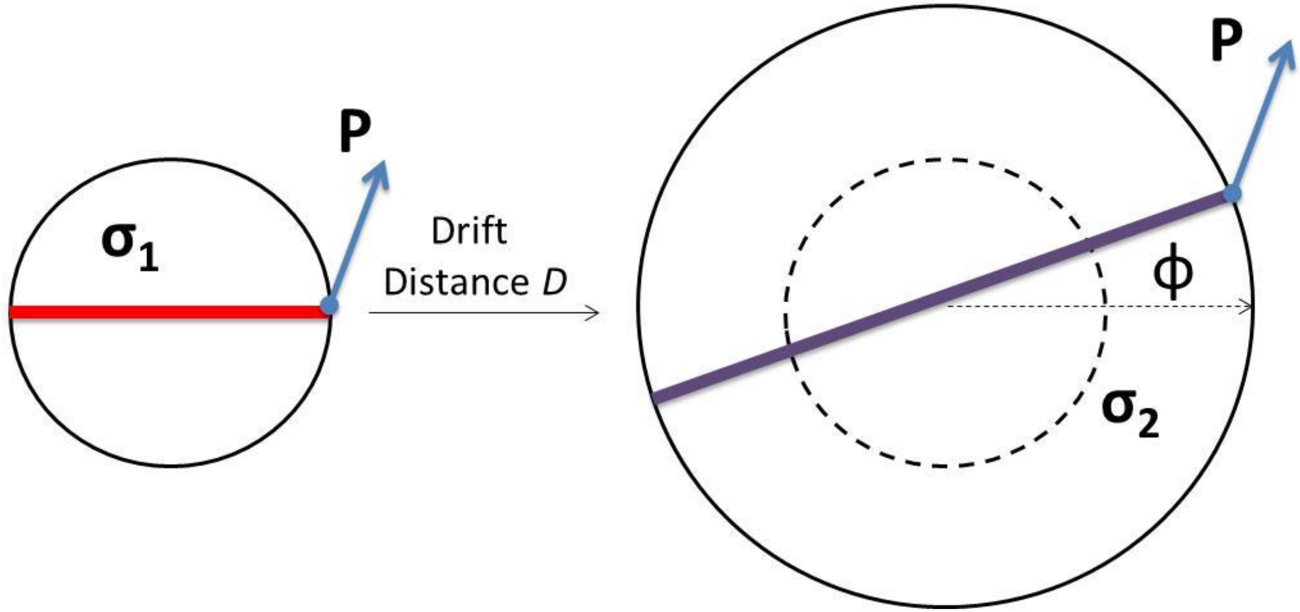
High Current Magnetized Beam



- Delivered 0.5 mA dc
- Plan for 5 mA by end of summer – installed dc ion-clearing electrodes to stop ions in beamline from reaching gun and causing HV arcs

Measuring Electron Beam Magnetization

- Use slit and viewscreens to measure mechanical angular momentum:

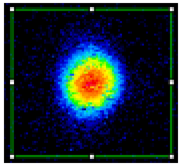
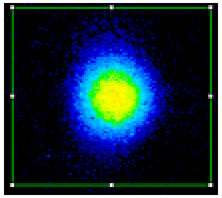
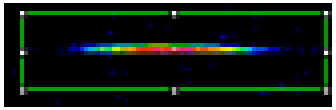


$$\langle L \rangle = 2 p_z \frac{\sigma_1 \sigma_2 \sin\varphi}{D} = e B_z a_o^2$$

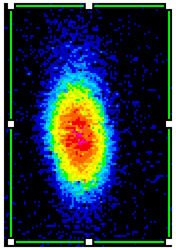
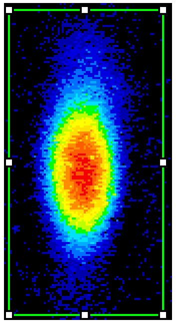
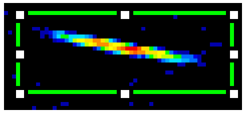
B_z: solenoid field at photocathode
a_0: laser rms size
φ: rotation (sheering) angle

Slit and Viewscreen Measurement

0 G at photocathode

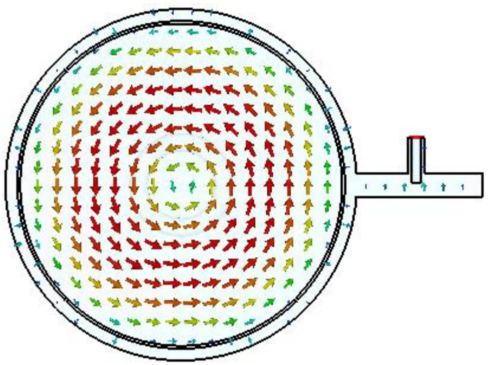
1450 G at photocathode

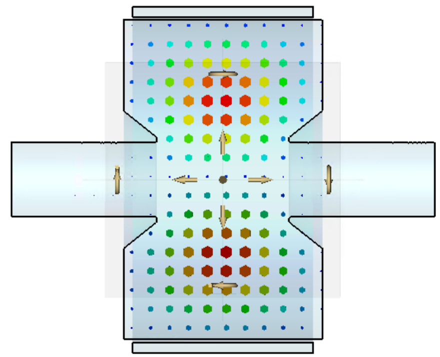




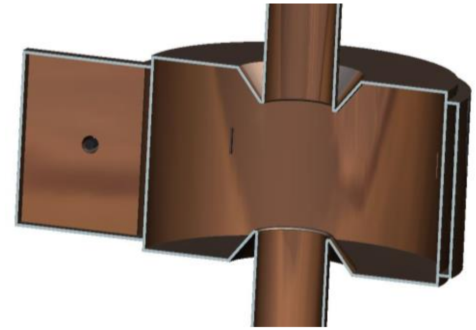
TE_{011} Cavity: Non-invasive Technique

- New non-invasive technique to measure electron beam magnetization
- Filed inventor disclosure entitled “Non-invasive RF Cavity to Measure Beam Magnetization”

E-field: only in azimuthal direction

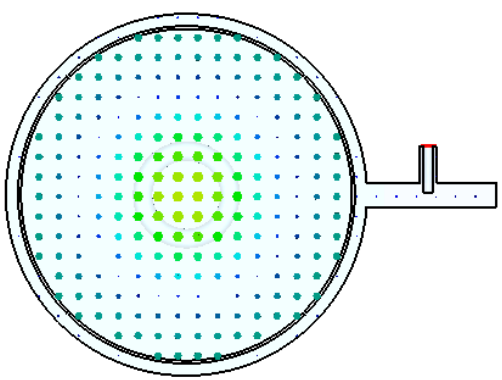


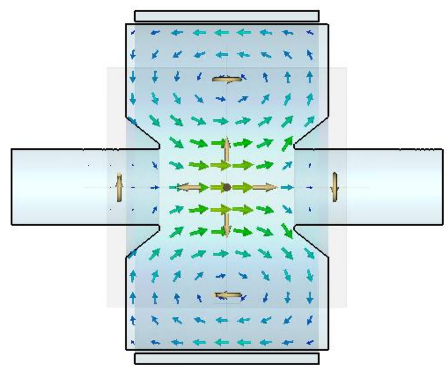


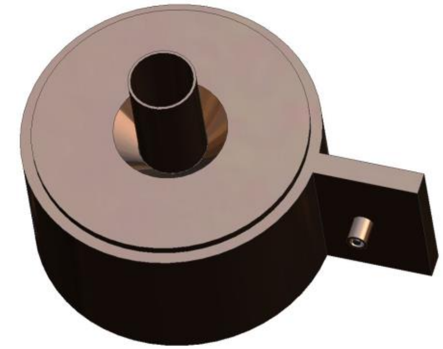


Copper cavity in progress

H-field: only in longitudinal and radial direction







Waveguide-coax out-coupler

Outlook

- Continue to characterize magnetized beam and cross check measurements with simulation
- Test magnetic puck (i.e., steel photocathode holder), which should enhance beam magnetization for given solenoid current
- Install RF pulsed laser
- Build and install TE_{011} cavity to measure beam magnetization in collaboration with JLab SRF Institute and Brock Roberts (Electrodynamics LLC)
- Demonstrate 32 mA magnetized beam

<u>**Next:**</u> Funded Phase-II SBIR with Xelera, to develop rf-pulsed dc high voltage thermionic gun to be installed at Gun Test Stand (GTS) in FY19 – will use LDRD beamline

Summary

- K_2CsSb Photocathode Preparation Chamber, Gun, Solenoid and Beamline are all operational
- Photogun operates reliably at 300 kV
- Cathode solenoid can trigger field emission but we have learned how to prevent this
- Have successfully magnetized electron beam and measured rotation angle

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