Magnetized Electron Beam Development

JLEIC Collaboration Meeting

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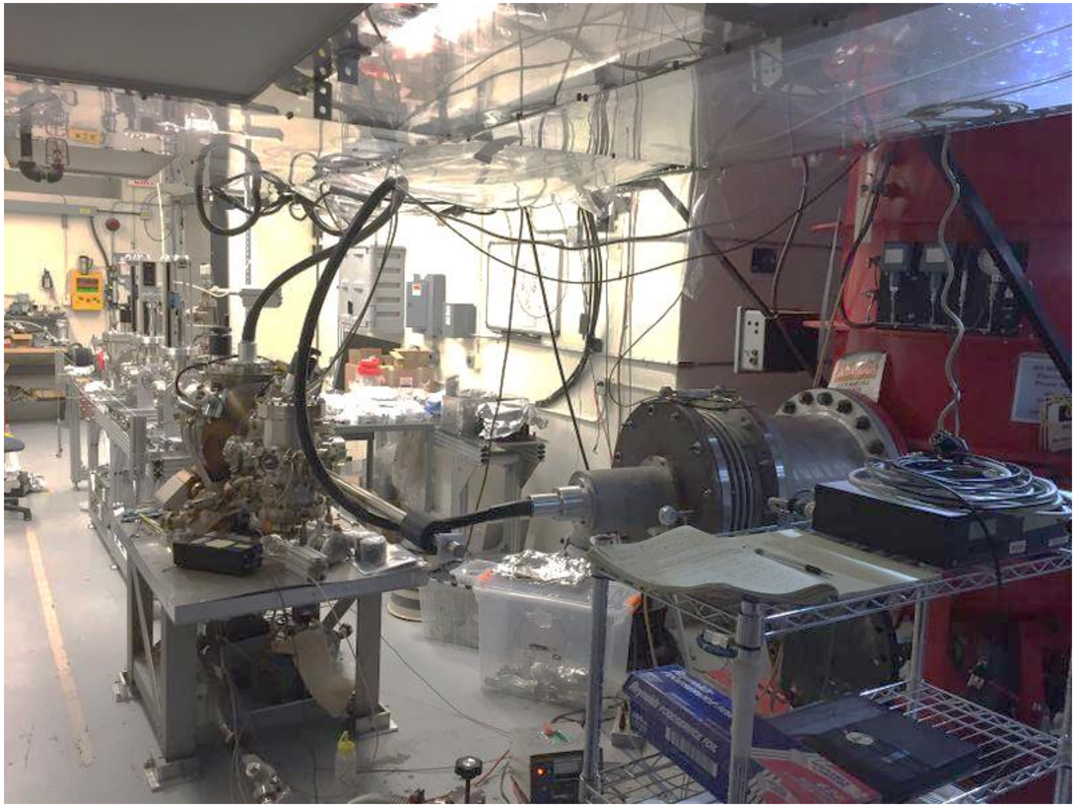
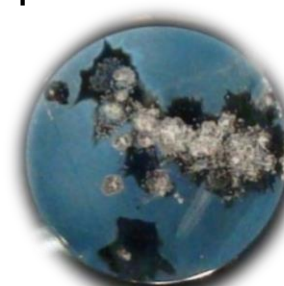
Recall Old Results – Summer 2016

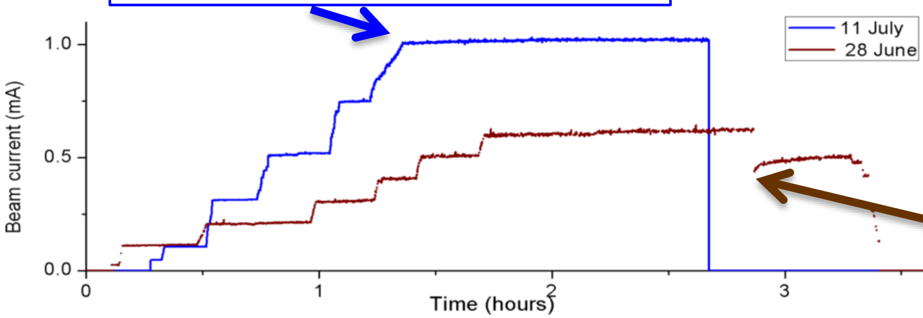


First insulator conditioned to 325 kV

Learning how to use new photocathode



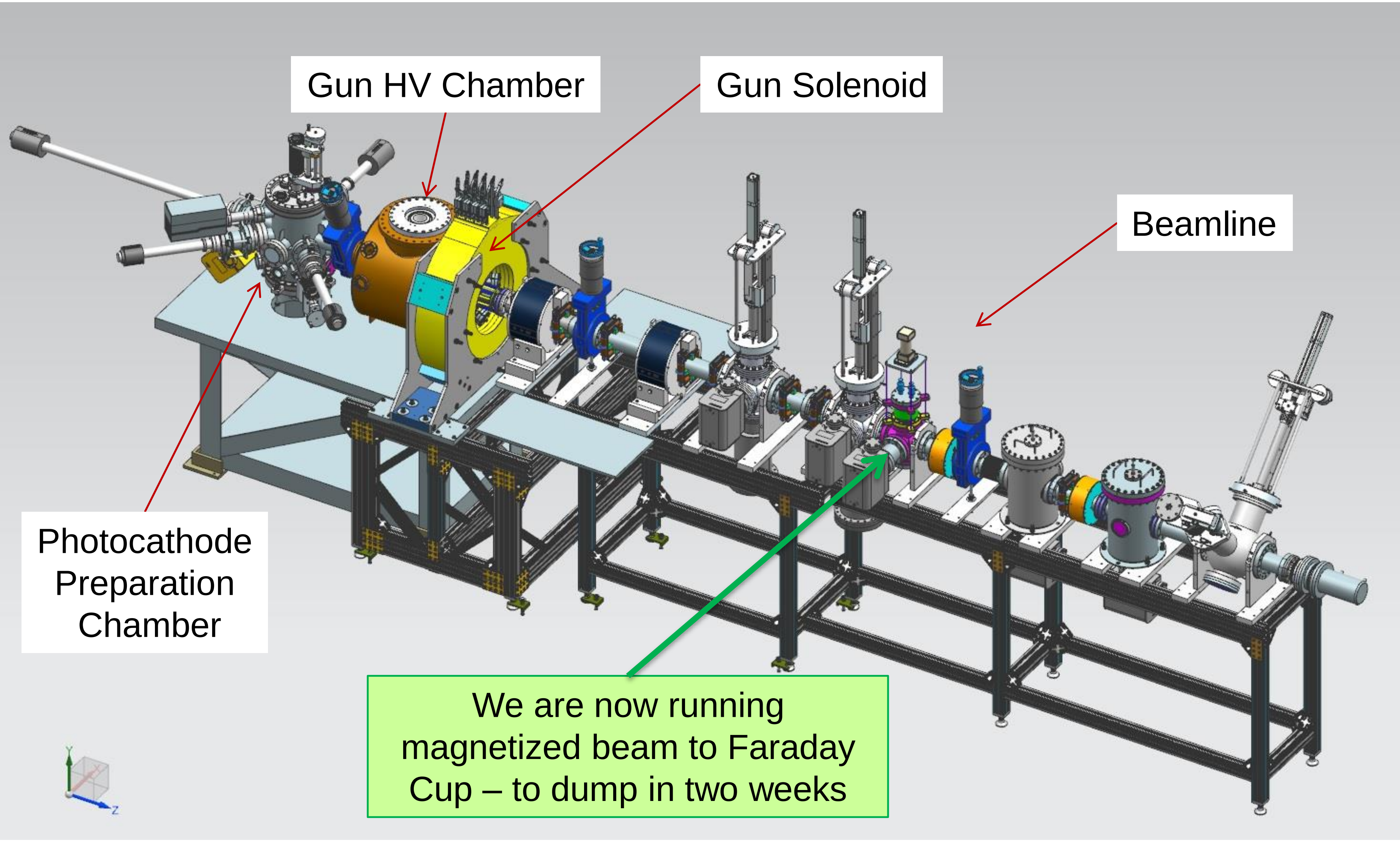
1 mA non-magnetized



Need mask and ion precipitator

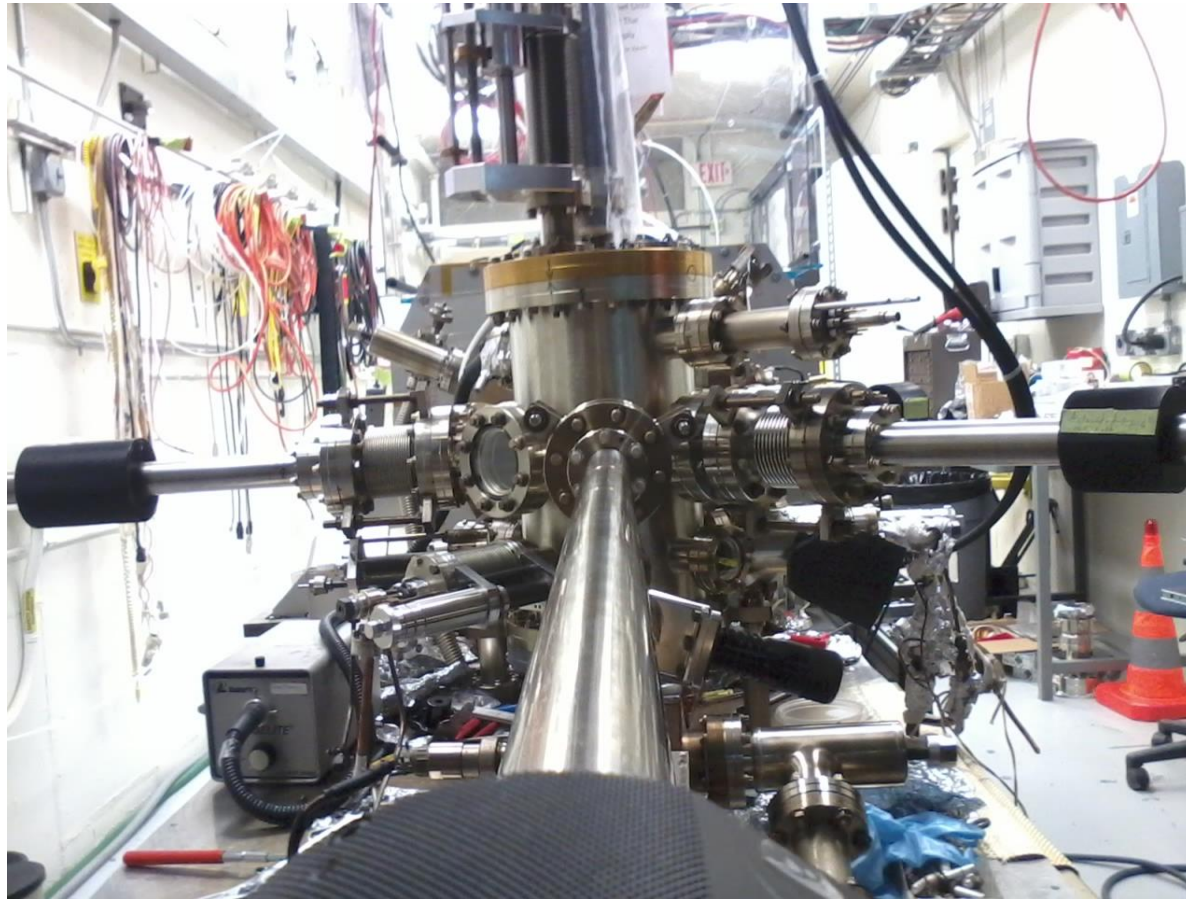
Outline

- Magnetized Electron Source
  I. K_2CsSb Photocathode
  II. Gun HV Chamber
  III. Gun Solenoid
  IV. Steel Photocathode Holders (Pucks)
  V. Beamline
- Generation of Magnetized Beam
- Measuring Magnetization
  I. Slit and Viewscreens
  II. TE_{011} Cavity: new method
- Outlook

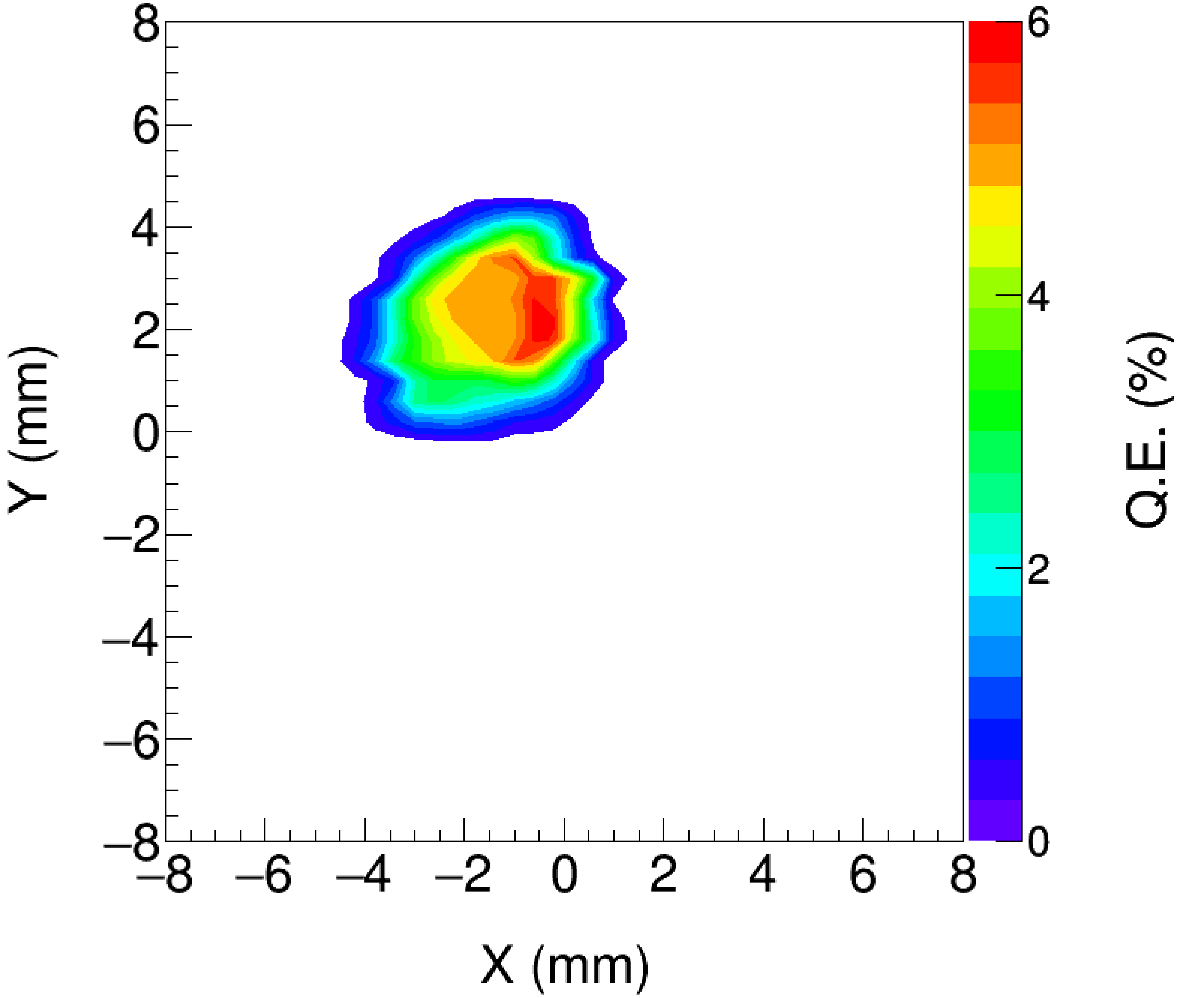

Gun HV Chamber
Gun Solenoid
Beamline
Photocathode Preparation Chamber
We are now running magnetized beam to Faraday Cup – to dump in two weeks

Photocathode Preparation Chamber

- Bias puck to monitor photocurrent during activation and measure QE in-situ
- Control gap between puck and Cs-K effusion source for precise film growth
- Use a mask for reducing active area to minimize beam halo



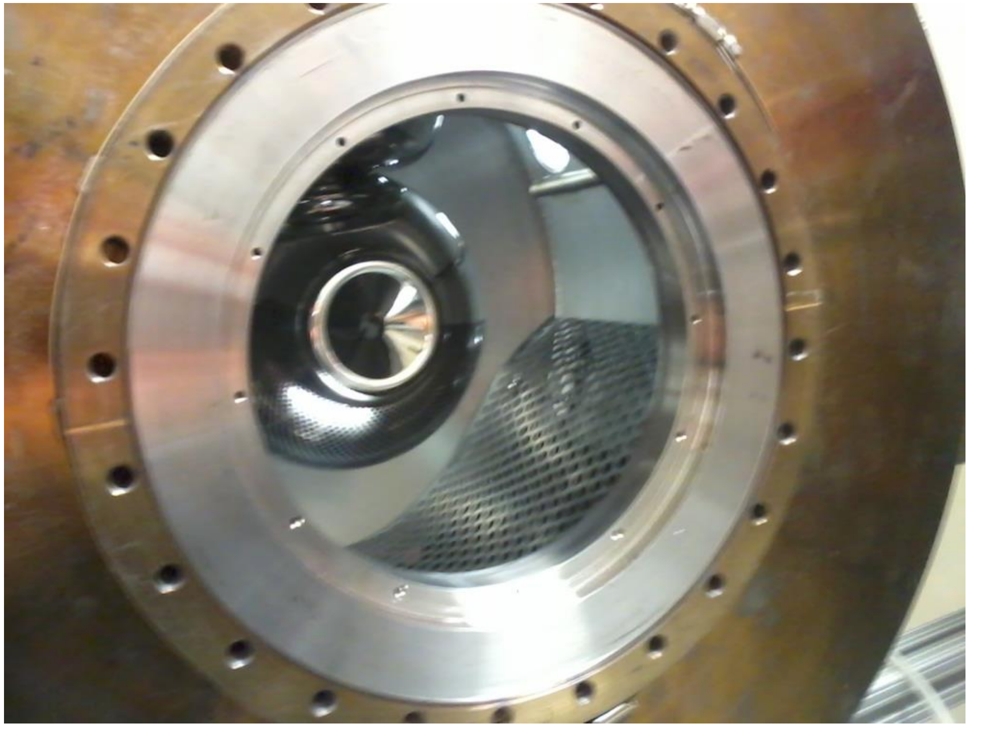
K_2CsSb Quantum Efficiency ~ 6%



- K_2CsSb grown with a mask – limit photocathode active area (3 mm ϕ) to reduce beam halo
- Active area can be offset from electrostatic center
- 5 mm active area also available
- Entire photocathode can be activated too

Work of M. Mamun and Y. Wang

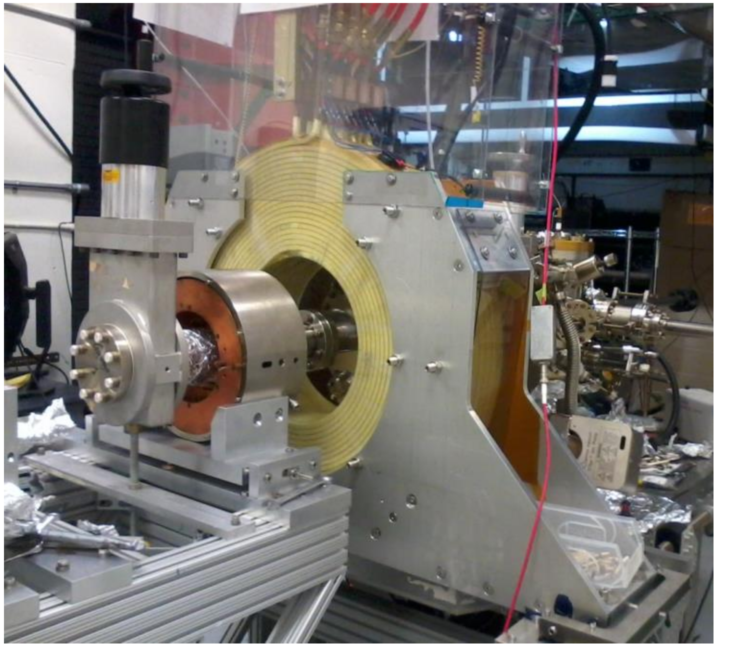
Gun HV Chamber



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

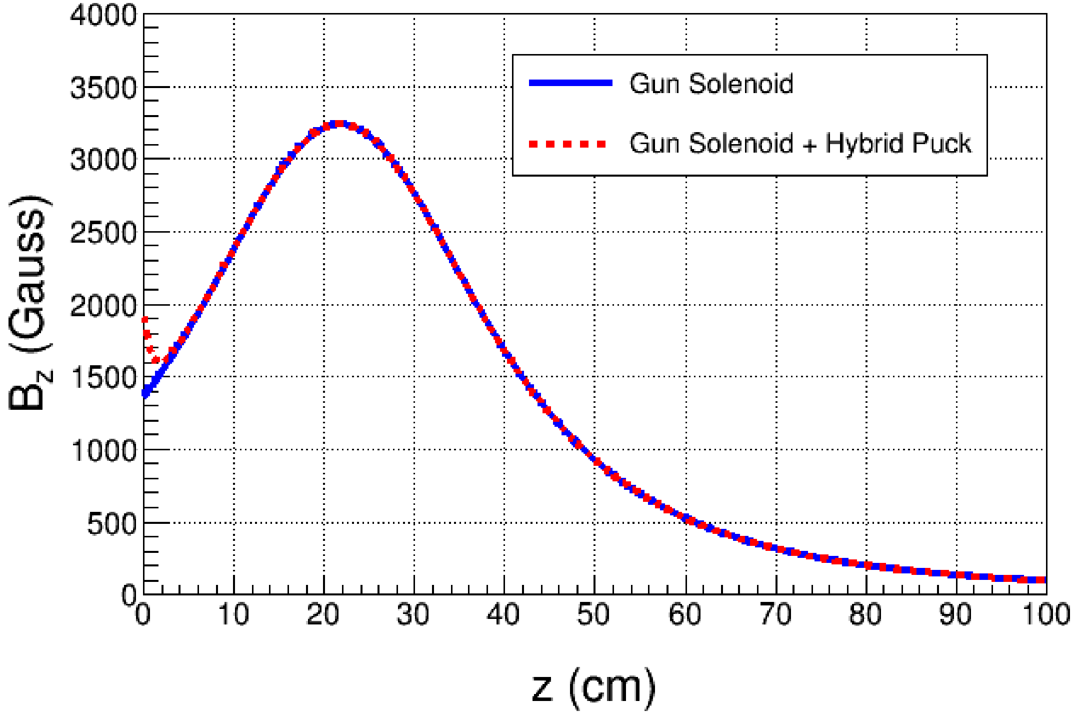
Gun Solenoid

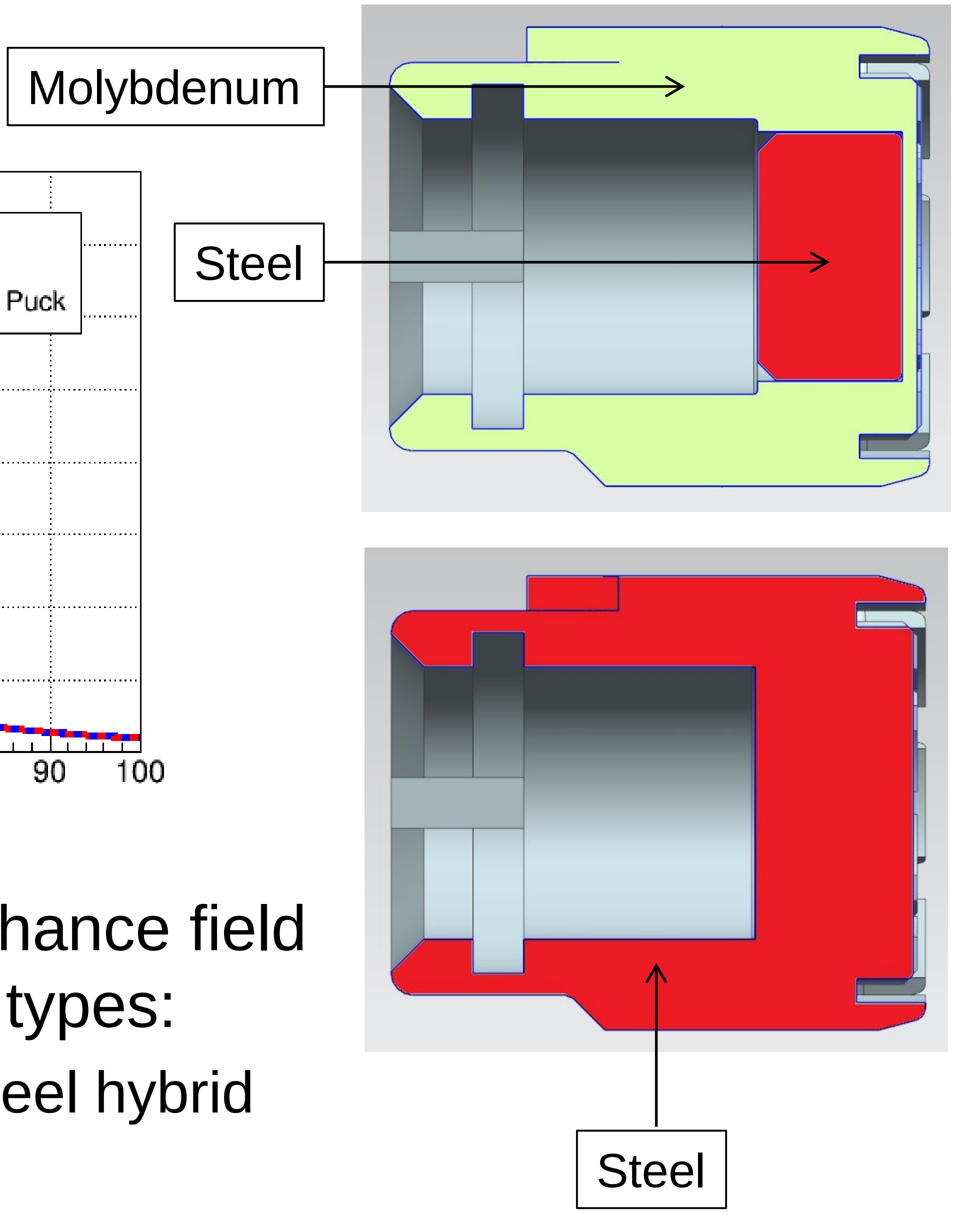
Size	11.811" ID, 27.559" OD, 6.242" Z
Conductor	L=500 m, A=0.53 cm^2 16 layers by 20 turns
Coil Weight	254 kg (560 lbs)
Resistance	0.198 Ω
Field at Photocathode	1.4 kG
Voltage	79 V
Current	400 A



- Mapped and installed at GTS
- Using new spare CEBAF Dogleg magnet power supply (500A, 80V)
- Learned that gun solenoid **can** influence field emission
- First trials with gun at HV and solenoid on resulted in field emission and vacuum activity
- HV conditioned gun with solenoid up to 400 A

New Steel Photocathode Holders



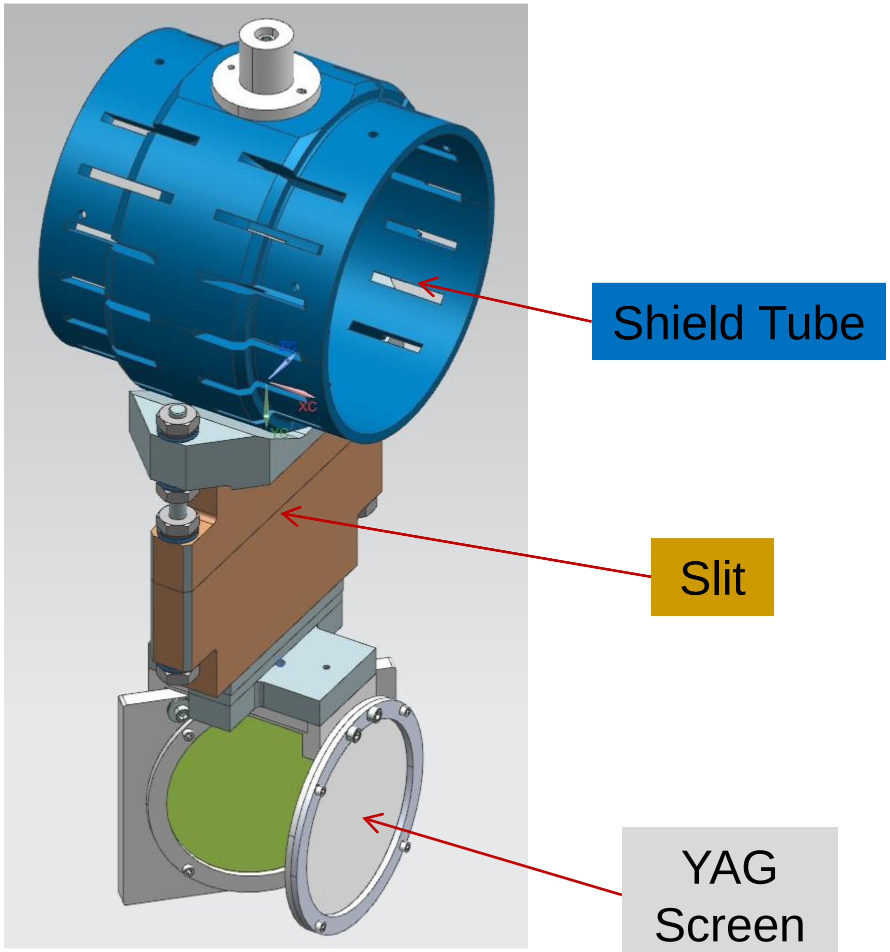


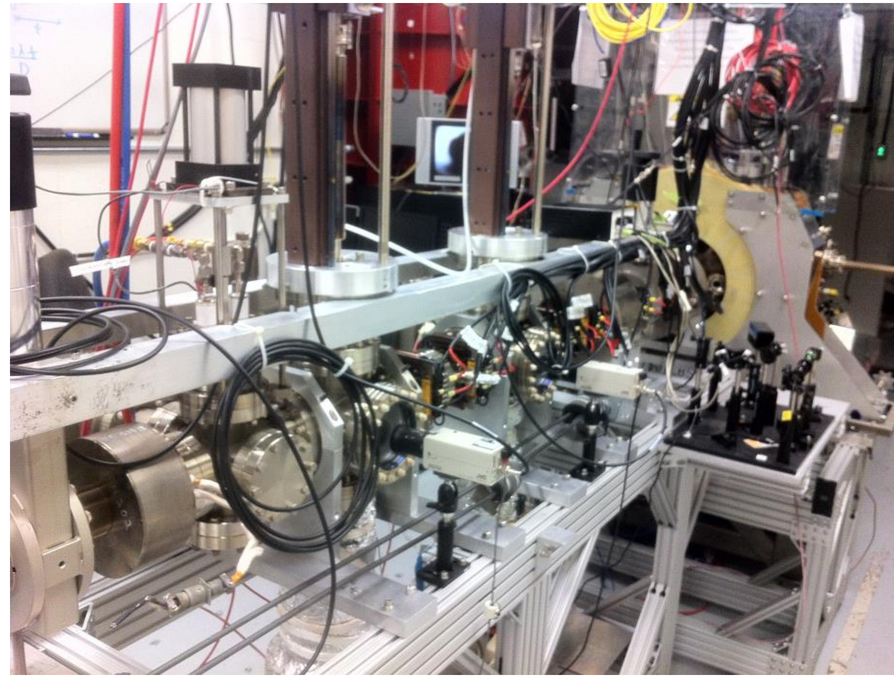
New steel holders (pucks) to enhance field to 2.0 kG at photocathode. Two types:

I. Molybdenum and carbon steel hybrid puck

II. Carbon steel puck

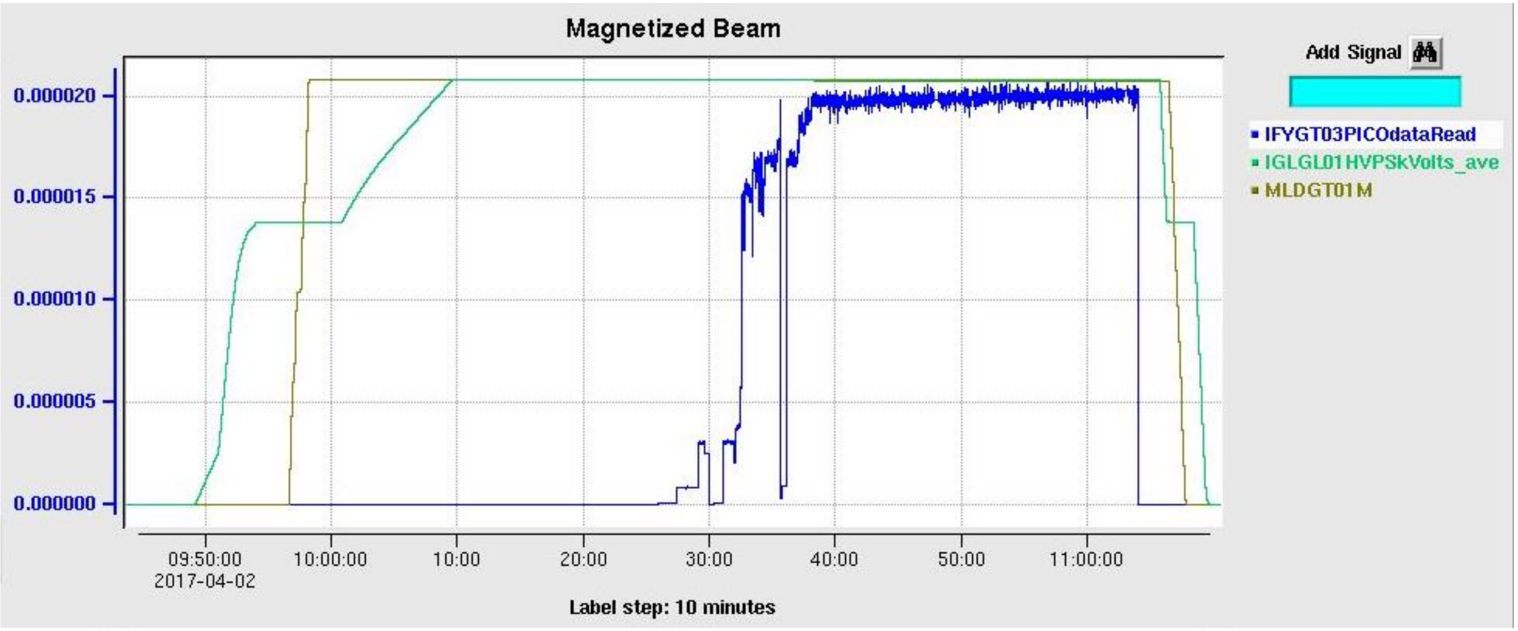
Beamline





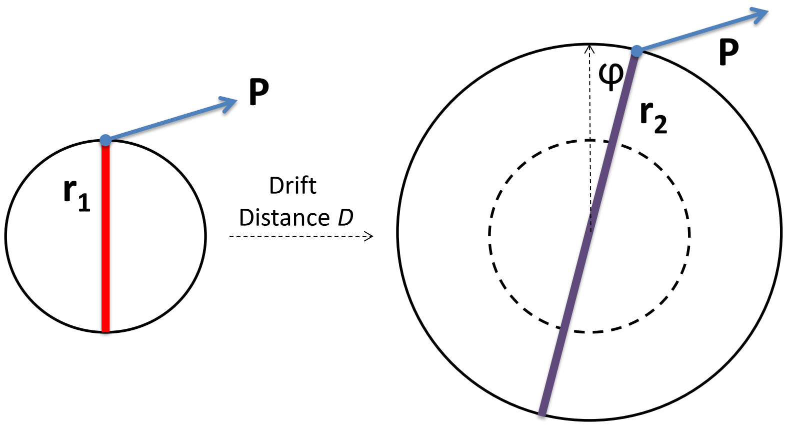
Magnetized Beam at GTS

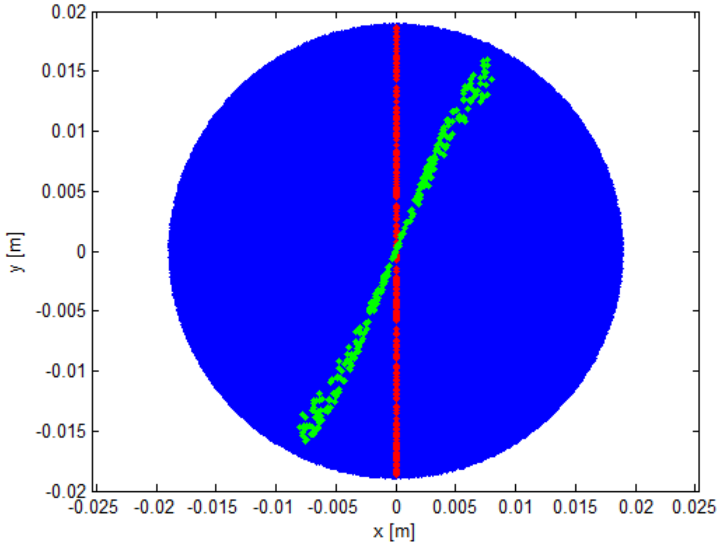
- Generated magnetized beam on March 8
- Measured magnetization at 300 kV and solenoid field from 0 – 1.4 kG
- Delivered 20 µA to Faraday Cup – higher currents once beamline to dump is ready



Measuring Magnetized Beam – I

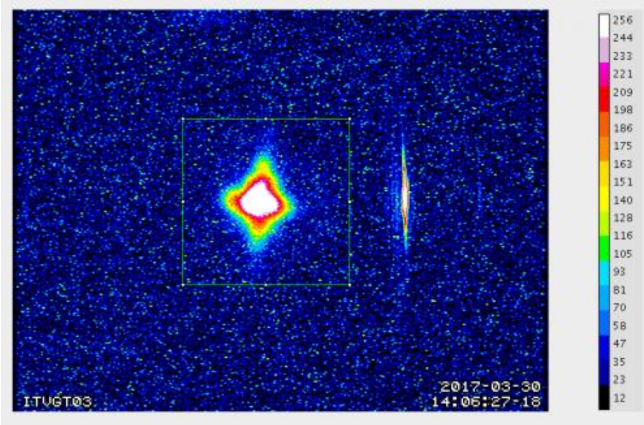
- Use slit and viewscreens to measure mechanical angular momentum:





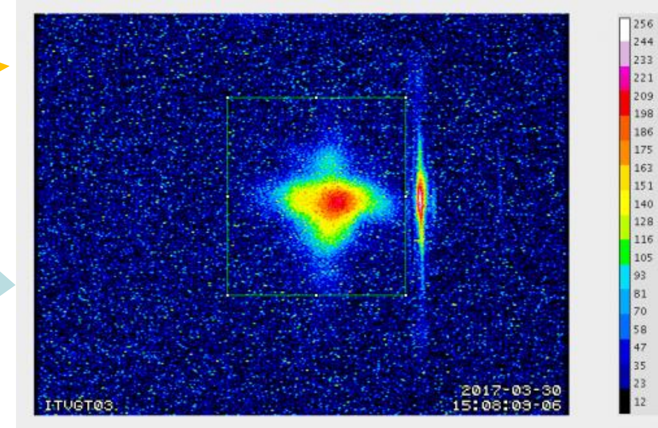
$$\langle L \rangle = 2 p_z \frac{\sigma_1 \sigma_2 \sin\varphi}{D} = e B_z a_o^2$$

B_z: solenoid field at photocathode
a_0: laser rms size

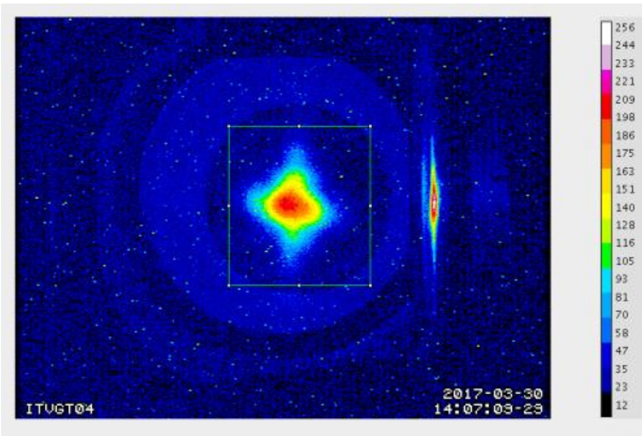


0 A

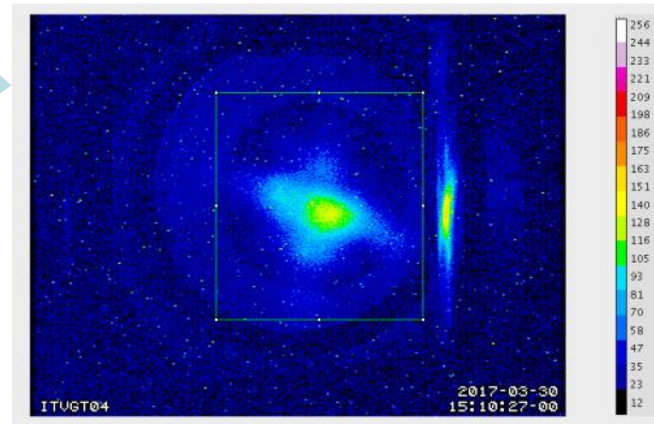
400 A

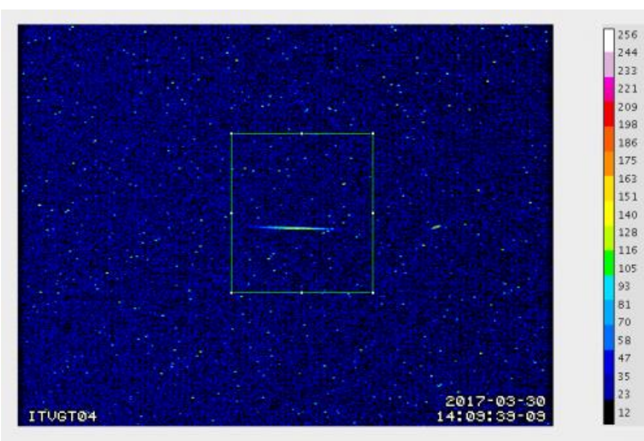


$\sigma_1 = 3.7$ mm



$\sigma_2 = 4.9$ mm

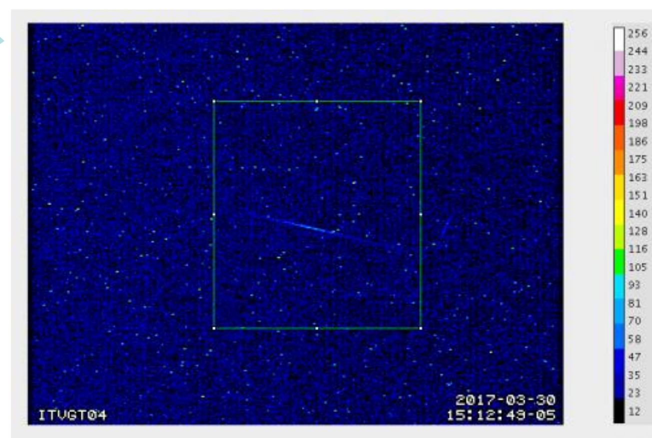




$\varphi = 15°$

$\langle L \rangle = 38$ neV s

$eB_z a_0^2 = 38$ neV s



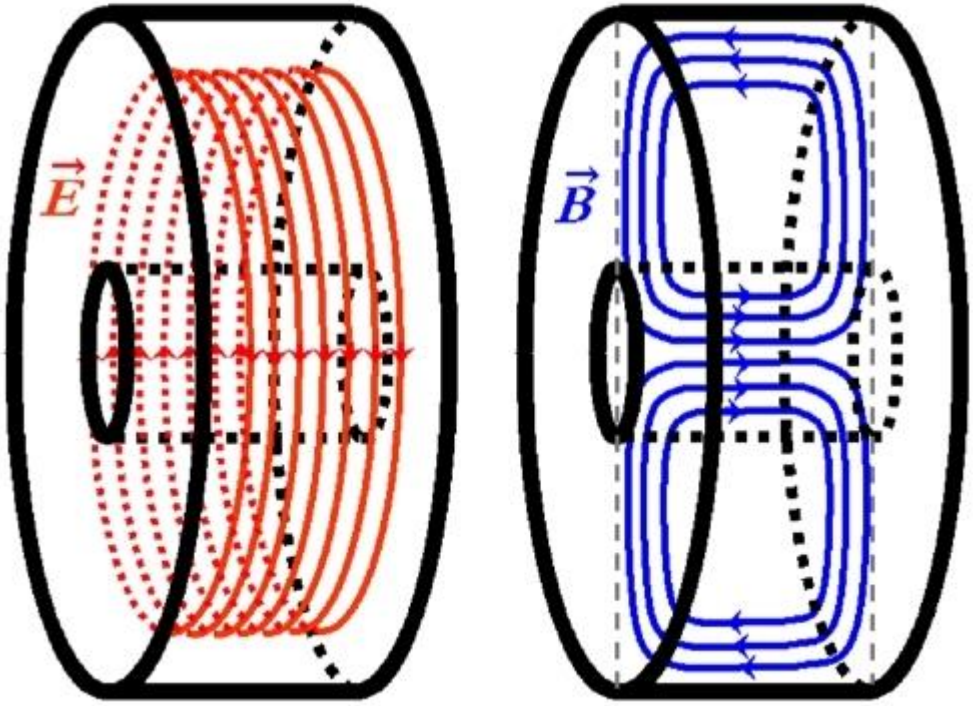
Measuring Magnetized Beam – II

- Having a non-invasive technique to measure beam magnetization is very critical for JLEIC e-cooler. An RF cavity could be right device. Cavities distributed around e-cooler will monitor magnetization and others installed inside cooling solenoid will ensure magnetization is completely removed during cooling process. Once beam exists solenoid, cavities measure whether magnetization is fully restored.

- RF field will be excited by rotating bunched beam producing an easily detectable signal – beam will deposit longitudinal energy into cavity, but not angular momentum

- Coupling to both electric and magnetic fields – expect main contribution to signal from electric field

TE_{011} Mode in Pill-box Cavity



$$E_r = 0$$

$$E_\varphi = \frac{i\omega\mu}{k_c} A J_0'(k_c r) e^{-ik_z z}$$

$$E_z = 0$$

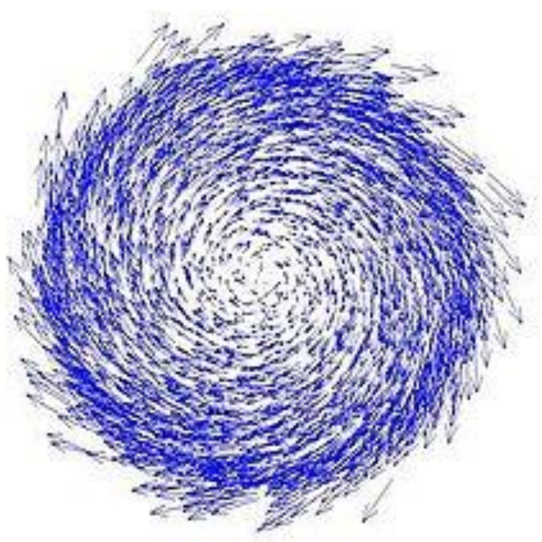
$$H_r = \frac{i\omega\epsilon}{k_c} A J_0'(k_c r) e^{-ik_z z}$$

$$H_\varphi = 0$$

$$H_z = A J_0(k_c r) e^{-ik_z z}$$

Magnetic Moment of Magnetized Beam

- Magnetic moment along beam axis:



$$\mathrm{M} = \frac{e}{2mc} L$$

$$\mathrm{L} = \frac{1}{2} B_z r^2$$

at photocathode

$$\mathrm{L} = \gamma m r^2 \dot{\varphi}$$

at cavity

- For Gaussian beam with sigma of a_0= 1 mm and B_z= 2 kG :
  - Average canonical angular momentum is $\langle L \rangle = eB_z a_0^2$ = 200 (neV s) at photocathode
  - After exiting solenoid $\langle L \rangle = 2\gamma m_e a_0^2 \dot{\varphi}$ = 200 (neV s) = $3\mathrm{x}10^8$ ħ
  - Beam angular frequency, $\dot{\varphi}$ = $1.1\mathrm{x}10^{10}$ rad/s

TE_{011} Cavity Magnetized Beam Test

- Plan to build and install a cavity at GTS to measure beam magnetization in collaboration with Electrodynamic, NM (Brock Roberts) and SRF Institute (Jiquan Guo et al.) – good project for a student

- **Will be part of year 3 LDRD proposal – requires $20k for shop and materials**

Can we generate magnetized beam with TE_{011} cavity?

- Axially-symmetric electric field mode **cannot** create angular momentum for a passing electron beam – one must take into account presence of associated RF magnetic field – due to *conservation of canonical angular momentum* before and after cavity

Outlook: April – September

- Measure magnetization vs gun solenoid field and laser size
- Benchmark simulation against measurements
- Measure photocathode lifetime vs magnetization at 5 mA and 300 kV
- Measure magnetization with steel/hybrid puck
- Study beam halo and beam loss vs magnetization
- Install RF laser
- Install TE_{011} cavity and commission with magnetized beam

➢ Sajini Wijethunga, student from ODU started her Ph.D. thesis on magnetized beam (advisor: Jean Delayen, funded by 75% JLab + 25% ODU)

➢ **Plan to submit LDRD proposal for 3rd year funding – TE_{011} cavity included**