Development of High Current Bunched Magnetized Electron DC Photogun

MEIC Collaboration Meeting

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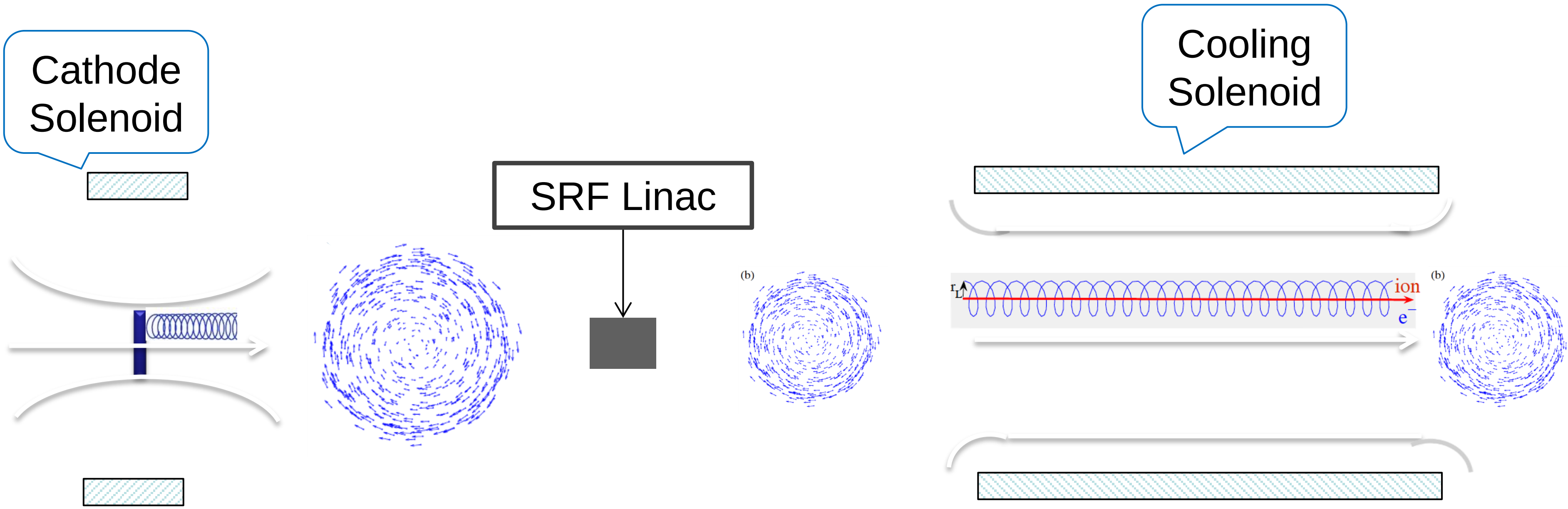
Magnetized Cooling

- MEIC bunched magnetized electron cooler is part of Collider Ring and aims to maintain ion beam emittance and extend luminosity lifetime

- Electrons 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

- This cyclotron motion also provides suppression of electron-ion recombination



Electrons born in strong uniform B_z

$$\langle L \rangle = eB_z a_o^2$$

a_0 = R_{laser} = 3 mm
B_z = 2 kG

Upon exit of Cathode Solenoid

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

$$\varepsilon_d = \frac{eB_z a_o^2}{2m_e c} = 528\ \mu\text{m}$$

Upon entering Cooling Solenoid

$$\langle L \rangle = eB_{cool} \sigma_e^2$$

σ_e = 0.95 mm
B_{cool} = 2 T

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

Magnetized Bunched Electron Beam Requirements

Bunch length	100 ps (3 cm)
Repetition rate	476 MHz
Bunch charge	420 pC
Peak current	4.2 A
Average current	200 mA
Transverse normalized emittance	10s microns
Emitting radius (a_0)	3 mm
Solenoid field at cathode (B_z)	2 kG

Magnetized Guns

1. Fermilab Photoinjector Laboratory:
   - Pulsed NCRF gun
   - Cs_2Te photocathode and UV laser (λ=263 nm)
   - Bunch length: 3 ps
   - Bunch charge: 0.5 nC
   - 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

➢ No CW beam at high average current

2. Magnetized beam R&D Mainz just started

LDRD Proposal

Laboratory Directed Research and Development (LDRD) proposal: *"Generation and Characterization of Magnetized Bunched Electron Beam from DC Photogun for MEIC Cooler"* was funded

FY16	$339,211
FY17	$265,850
FY18	$212,025
Total	**$817,086**

Materials and Supplies:

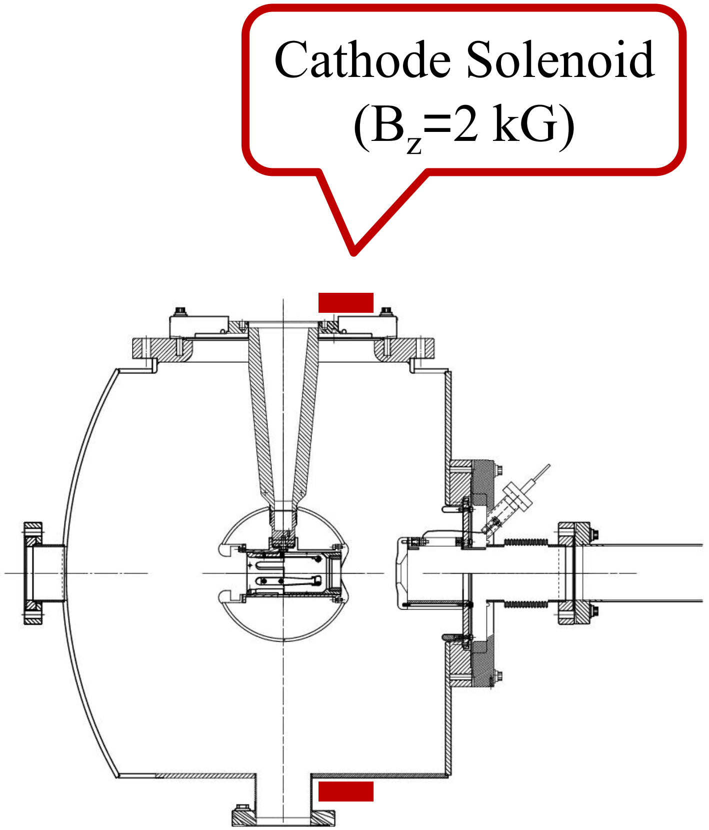
1. Solenoid magnet, or Helmholtz coil-pair
2. Three skew quadrupoles
3. Components for three diagnostics crosses

Labor:

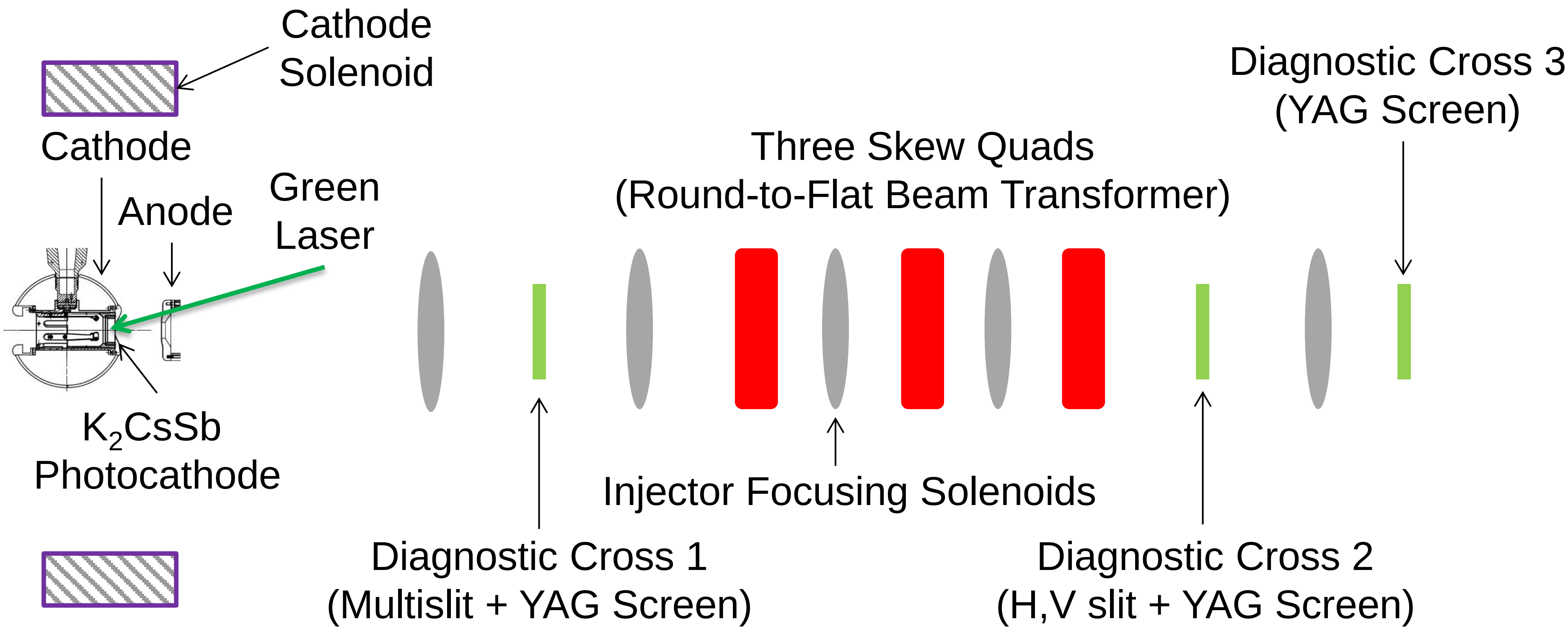
1. Gun magnet design and installation
2. Relocate old CEBAF arc dipole power supply
3. Mechanical designer for skew quad magnets and slits
4. ASTRA and GPT modeling
5. Postdoc

MEIC Magnetized Gun R&D

- Generate magnetized electron beam and measure its properties
- Explore impact of cathode solenoid on photogun operation
- Simulations and measurements will provide insights on ways to optimize MEIC electron cooler and help design appropriate electron source
- JLab will have direct experience magnetizing high current electron beam



Experimental Overview



- Generate magnetized beam:
  - a_0 = 0.1 – 3 mm, B_z = 0 – 2 kG
  - Bunch charge: 1 – 500 pC
  - Frequency: 1 – 476 MHz
  - Bunch length: 50 – 150 ps
  - Average beam currents up to 32 mA
  - Gun high voltage: 200 – 350 kV

Simulation Plan

1. Design beamline to locate magnets and diagnostics at optimum positions

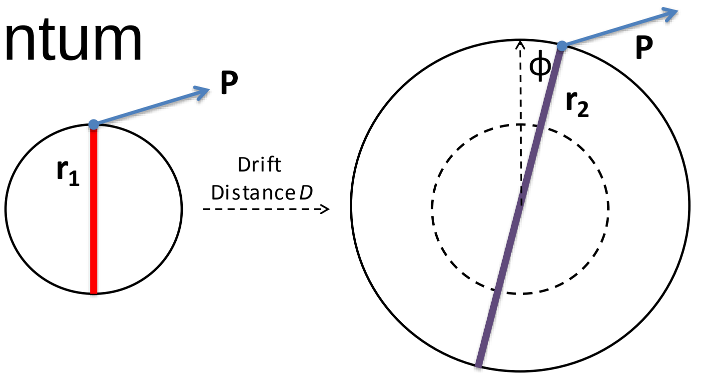
2. Benchmark simulation (of different operating scenarios of bunch charge, magnetization, bunch shape etc.) against measurements

3. Quantify how good or complete RTFB transform can be made for different settings – as beams will be space charge dominated, there will be some limit to emittance aspect ratio that can be achieved

- These results will guide injector design for MEIC magnetized electron cooler

Measurement Plan

1. Measure mechanical angular momentum (skew quads off)

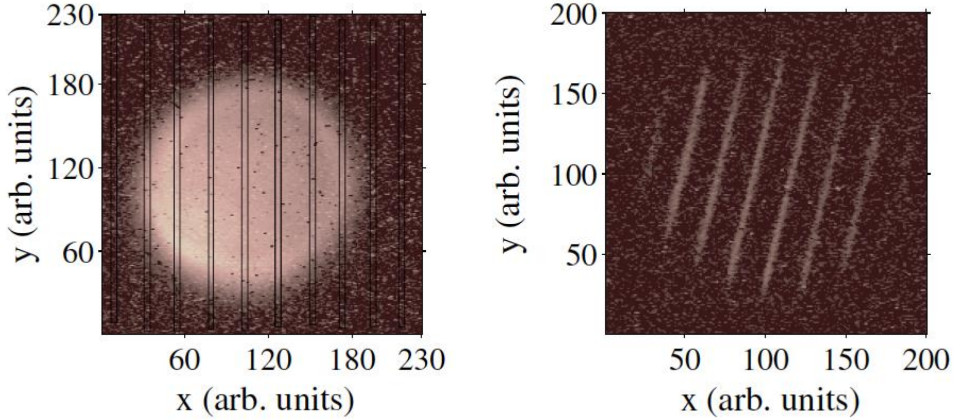


σ_1 beam radius measured at Diagnostic Cross 1
σ_2 beam radius measured at Diagnostic Cross 2
D drift between two crosses
p_z beam longitudinal momentum

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

- Angular rotation ϕ is measured from beam image at Cross 2 when multislit is inserted at Cross 1

Example of mechanical measurement at Fermilab (Piot et al.)



2. Use three skew quads – RTFB Transformer – to generate a flat beam with transverse emittance ratios of:

$$\frac{\varepsilon_x^n}{\varepsilon_y^n} >> 1$$

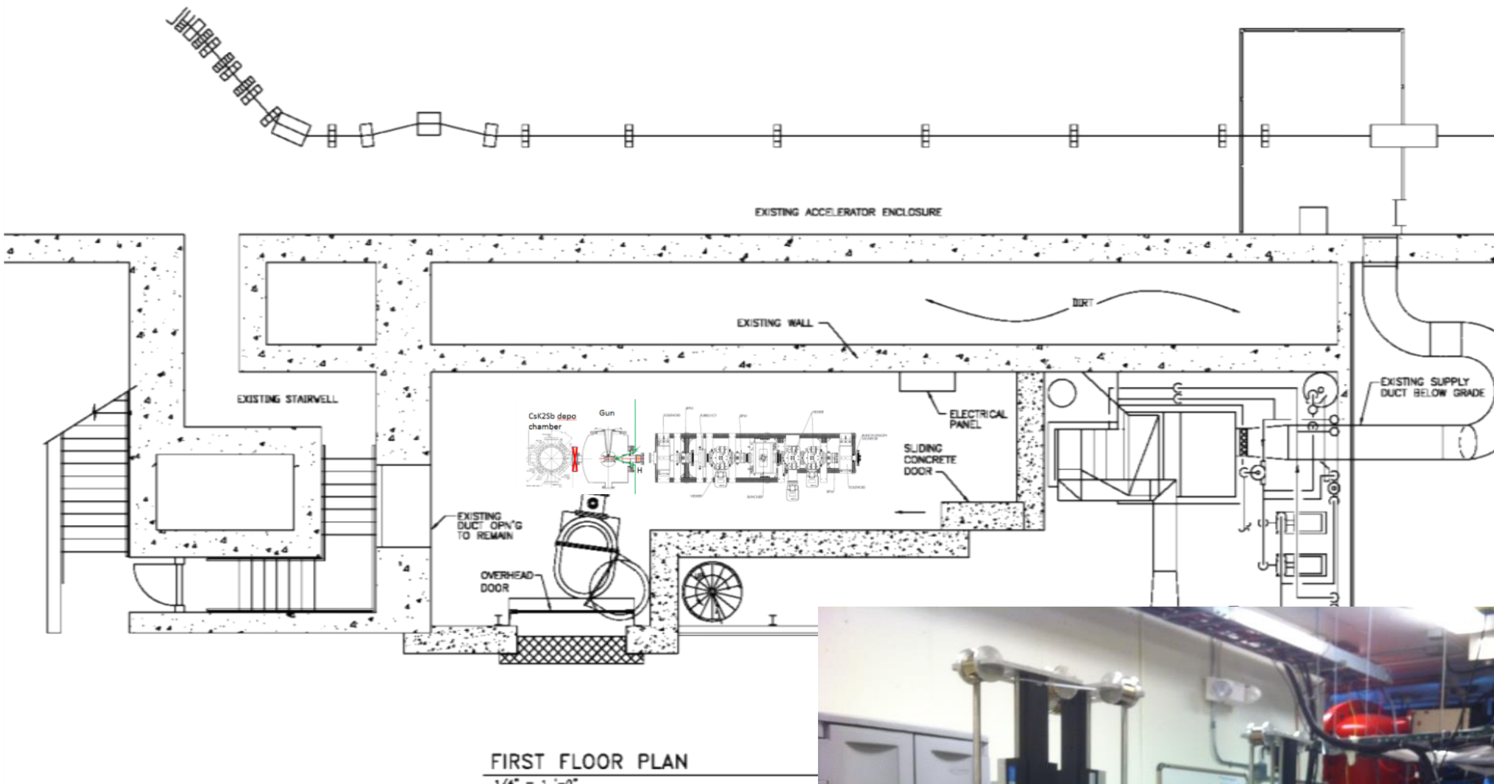
   Measure horizontal and vertical emittances using slit method

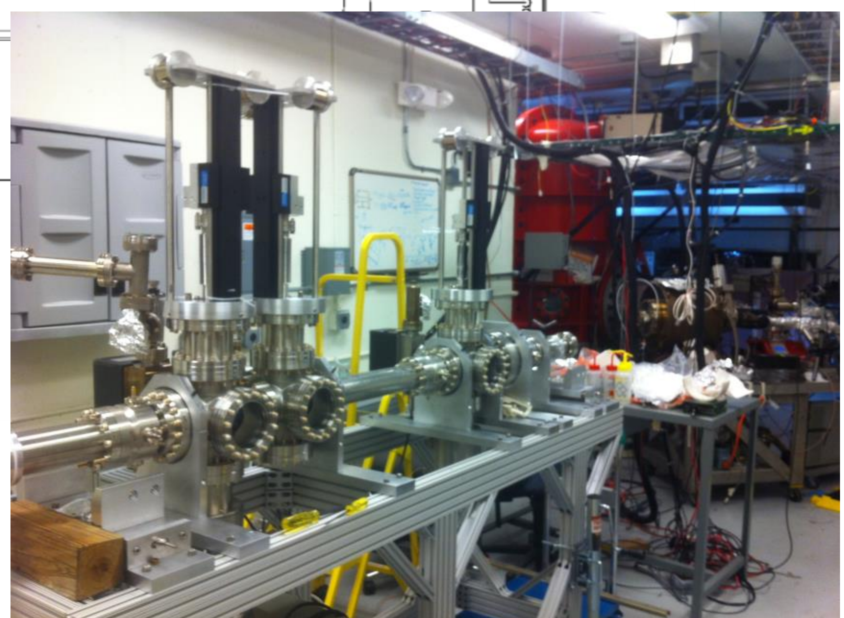
3. Generate very high currents magnetized beam and study beam transport and RTFB transformation versus electron bunch charge

4. Measure photocathode lifetime versus solenoid field at high currents (up to 32 mA) and high voltages (200 – 350 kV) limited by in-house HV supplies

5. Study beam halo and beam loss versus magnetization

Location of Work: LERF Gun Test Stand





Milestones

Year 1 Milestones

- Q1 (Oct, Nov, Dec):
  1. HV condition gun at 350 kV and commission k_2CsSb preparation chamber
  2. Design beamline to locate magnets and diagnostics at optimum positions
  3. Design gun solenoid magnet or Helmholtz coil-pair
  4. Design skew quad magnets and slits

- Q2 (Jan, Feb, Mar):
  1. Connect existing beamline to gun and complete hot checkout
  2. Relocate old CEBAF arc dipole power supply to GTS
  3. Procure gun solenoid magnet or Helmholtz coil-pair
  4. Procure skew quad magnets and slits

- Q3 (Apr, May, Jun):
  1. Commission exiting beamline with beam
  2. Measure photocathode lifetime at 5 mA and 350 kV (not magnetized)

- Q4 (Jul, Aug, Sep):
  1. Assemble new beamline and commission with beam
  2. Install gun solenoid magnet or Helmholtz coil-pair

Year 2 Milestones

- Q1 (Oct, Nov, Dec):
  1. Generate magnetized beam
  2. Measure mechanical angular momentum vs magnetization and laser size
  3. Benchmark simulation against measurements

- Q2 (Jan, Feb, Mar):
  1. Measure mechanical angular momentum vs bunch charge and bunch length
  2. Benchmark simulation against measurements

- Q3 (Apr, May, Jun):
  1. Generate very high currents magnetized beam and study beam transport vs electron bunch charge

- Q4 (Jul, Aug, Sep):
  1. Measure photocathode lifetime vs magnetization at 5 mA and 350 kV
  2. Study beam halo and beam loss vs magnetization

Year 3 Milestones

- Q1 (Oct, Nov, Dec):
    1. Generate flat beam with three skew quads – RTFB Transformer – and measure horizontal and vertical emittances using slit method

- Q2 (Jan, Feb, Mar):
    1. Measure RTFB transformation versus electron bunch charge
    2. Use simulation to quantify how good or complete RTFB transform

- Q3 (Apr, May, Jun):
    1. Change to HV Supply of 32 mA and 200 kV

- Q4 (Jul, Aug, Sep):
    1. Measure photocathode lifetime vs magnetization at 32 mA and 200 kV
    2. Study beam halo and beam loss vs magnetization