High Current Electron Source for Cooling

Jefferson Lab Internal MEIC Accelerator Design Review

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Outline

- MEIC Electron Beam Cooling Requirements
- Thermionic Gun
- Photogun
- Magnetized Beam
- Emittance Compensation for Magnetized Beam with Space Charge
- Summary

Bunched Electron Beam for Cooling

Bunch Length	100 ps (3 cm)
Repetition Rate	25 MHz
Bunch Charge	2 nC
Peak Current	50 A
Average Current	20 mA
Emitting Area	6 mm ϕ
Transverse Normalized Emittance	10s microns
Solenoid Field at Cathode	2 kG

Performance & Dependencies

- Thermal Emittance: Intrinsic property of a cathode. Depends on work function, surface roughness, laser wavelength, temperature.
  - Normalized Emittance: $\varepsilon_n = \beta\gamma\varepsilon_{geom}$
  - Thermal Emittance (normalized to emitting radius or the rms for a gaussian beam): $\varepsilon_{th} = \varepsilon_n / R$
- Achievable Current: QE, laser wavelength, laser power, laser damage, heating, temperature.
- Bunch Charge: laser peak power, repetition rate, active cathode area
- Cathode Lifetime: ion back bombardment, dark current, contamination by residual gas, evaporation, beam loss, halo beam

Thermionic Gun

Example 1: TRIUMF e-Linac for photo-fission of actinide target materials to produce exotic isotopes:

- BaO: 6 mm diameter, 775˚C
- Grid at 650 MHz
- Gun HV: 300 kV
- Average beam current: 10 mA
- Bunch charge: 16 pC
- Normalized emittance: 30 microns. Emittance is dominated by the electric field distortion caused by the grid.

Production target sets no requirement on beam emittance

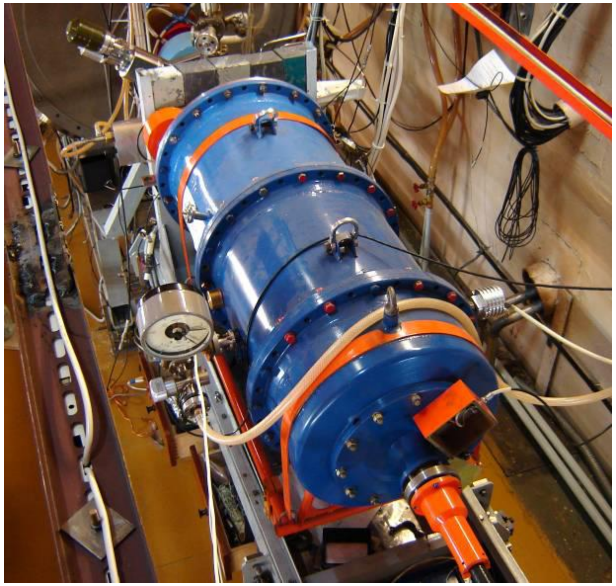
Example 2: MAX-LAB Thermionic – Photocathode RF Gun. Thorin *et al*., NIM A **606**, 291 (2009):

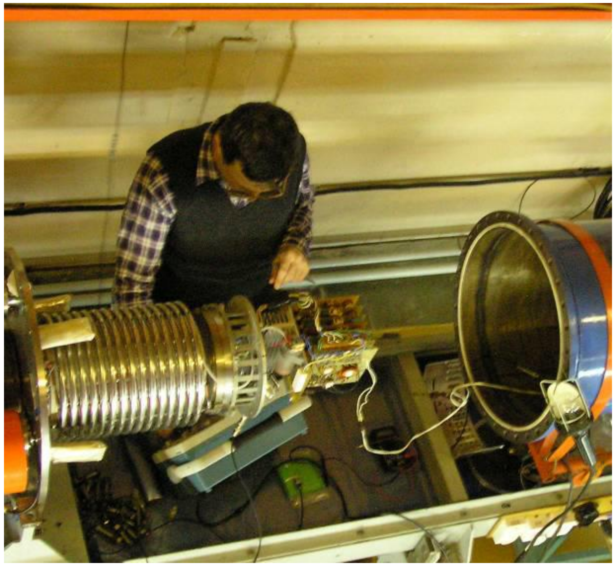
- Thermionic: for storage ring injection
  - BaO: 3 mm diameter, 1100˚C
  - 3 GHz and 1.6 MeV
  - Normalized emittance: 35 microns
  - Large energy spread (2%)

To switch, reduce T=1100˚C to T=700˚C

- Photocathode: for FEL
  - Bunch charge: 0.2 nC
  - Laser: 9 ps, 10 Hz, 263 nm
  - Average beam current: 2 nA
  - Normalized emittance: 5.5 microns
  - QE: 1.1 x 10^{-4}

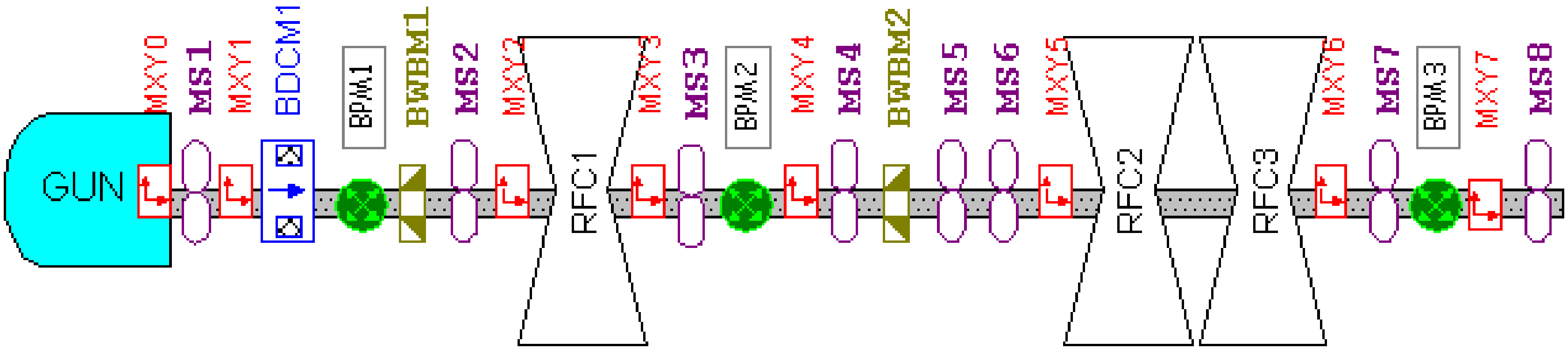
Example 3: Thermionic Gun and 1.5 MeV Injector of BINP's NovoFEL. B.A. Knyazev *et al*., Meas. Sci. Tech. **21**, 054017 (2010):





Gun HV	300 kV
Maximum peak current	1.8 A
Maximum average current	30–45 mA
Maximum bunch repetition rate	22.5 MHz
Bunch length	1.3 ns
Bunch charge	1.5-2 nC
Normalized emittance	10 microns

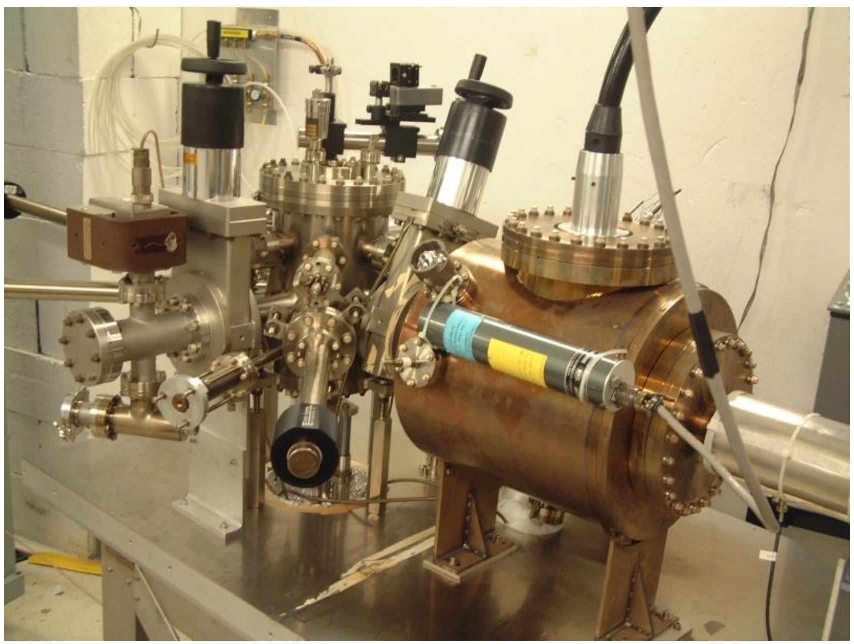
- RF system consisting of 3 identical 180.3 MHz cavities powered by different generators
  - Bunching/chirping cavity RFC1 with a voltage of up to 100 kV
  - Two accelerating cavities RFC2 and RFC3 with a voltage of up to 800 kV
  - Phase of RFC3 adjusted to also de-chirp removing correlated energy spread
  - 1.5 ns bunch from the gun compressed to 100 ps at the exit from the injector
  - Final bunch energy is 1.5 MeV

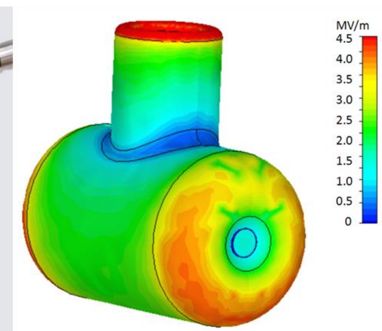


Photogun

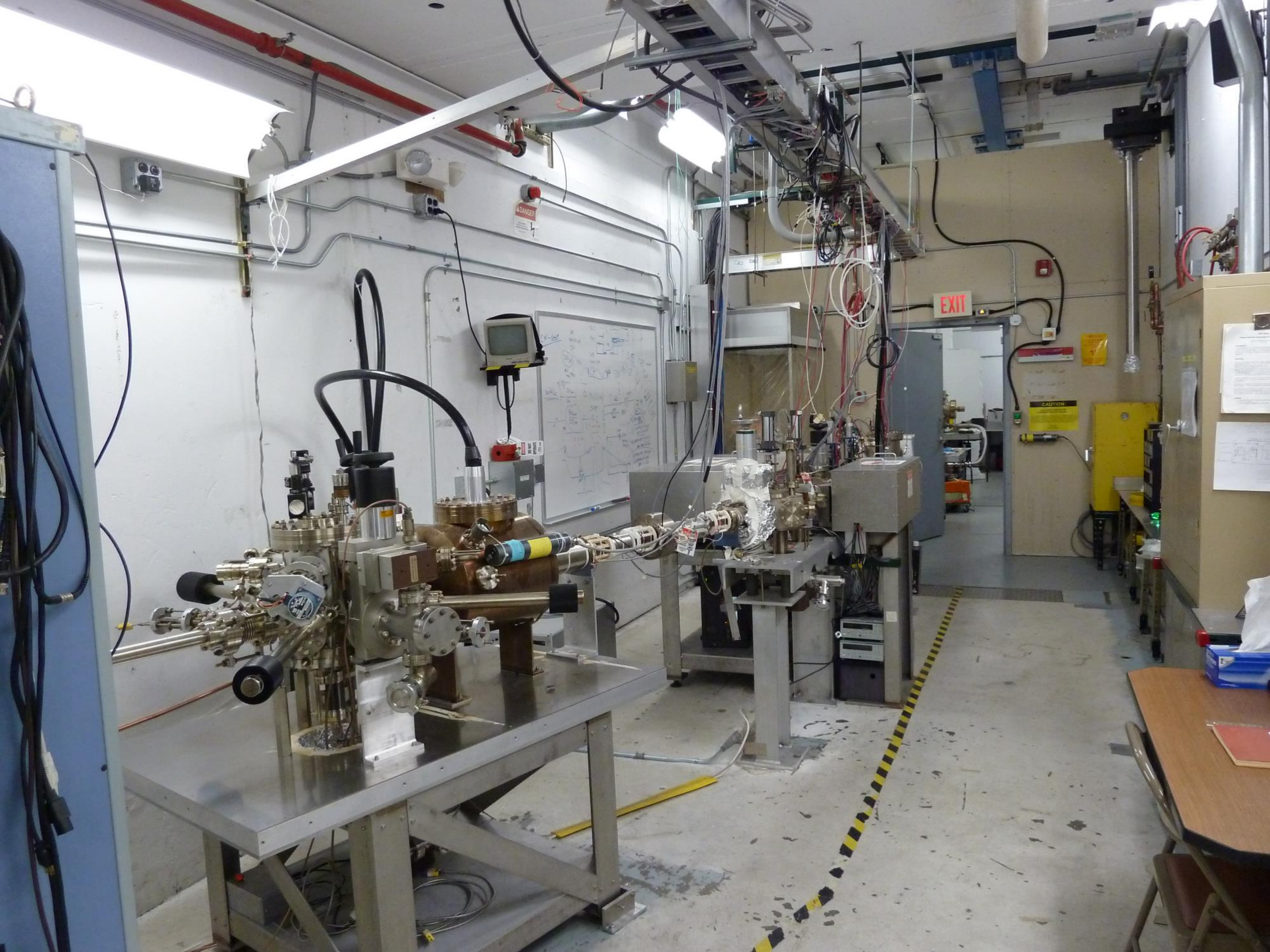
<u>Example 1:</u> JLab 200 kV Inverted dc Gun with K_2CsSb photocathode:

- Average beam current: 10 mA
- Laser: 532 nm, dc
- Lifetime: very long (weeks)
- Thermal emittance: 0.7 microns/mm(rms)





Mammei *et al*., Phys. Rev. ST AB **16**, 033401 (2013)


EXIT
DANGER
CAUTION

Example 2: JLab 350/500 kV Inverted Gun:

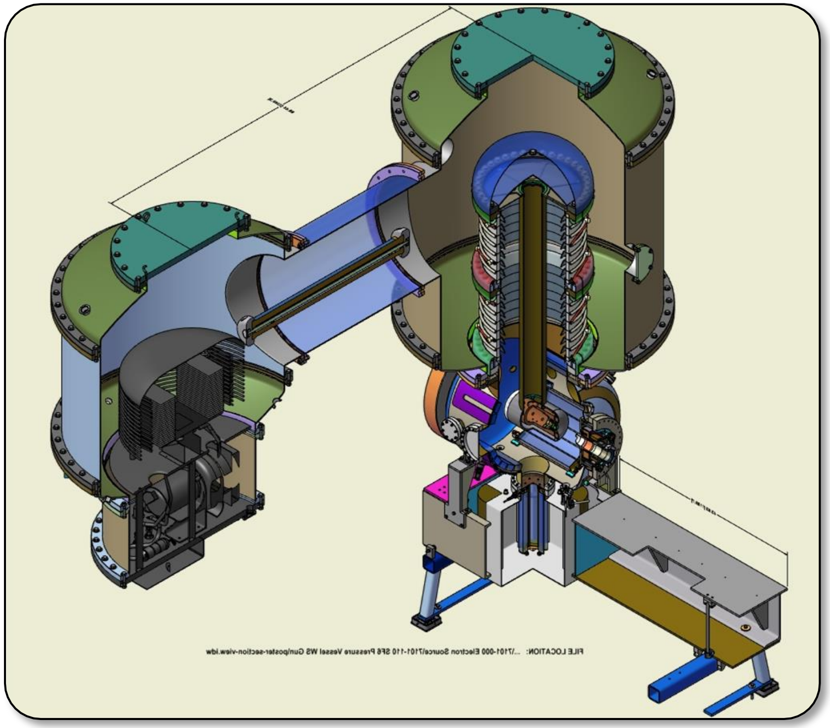
	200 kV Gun	350/500 kV Gun
Chamber	14” ϕ	18’’ ϕ
Cathode	2.5” T-shaped	6” ϕ Ball
Cathode Gap	6.3 cm	6.3 cm
Inverted Ceramic	4” long	7” long
HV Cable	R28	R30
HV Supply	Spellman 225 kV, 30 mA	Glassman 600 kV, 5 mA
Maximum Gradient	4 MV/M	7 (10) MV/m

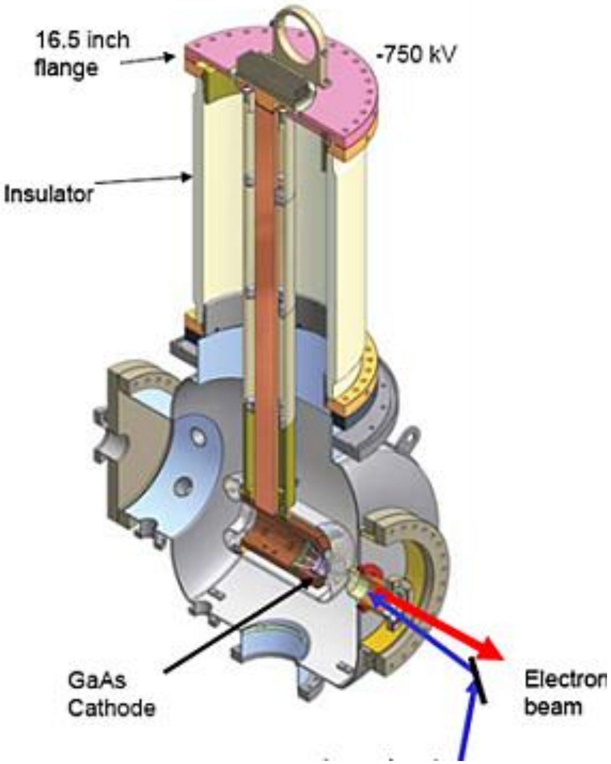
Achieved 350 kV with no FE (December 2013), next:

- Keep pushing to reach 500 kV
- Run beam with K_2CsSb photocathode

Example 3: Cornell dc Gun with K_2CsSb photocathode:

- Gun HV: currently operating at 350 kV (designed 500-600 kV)
- Average beam current: 100 mA
- Bunch charge: 77 pC
- Bunch length: 10 ps, 1.3 GHz
- Normalized emittance: <0.5 microns

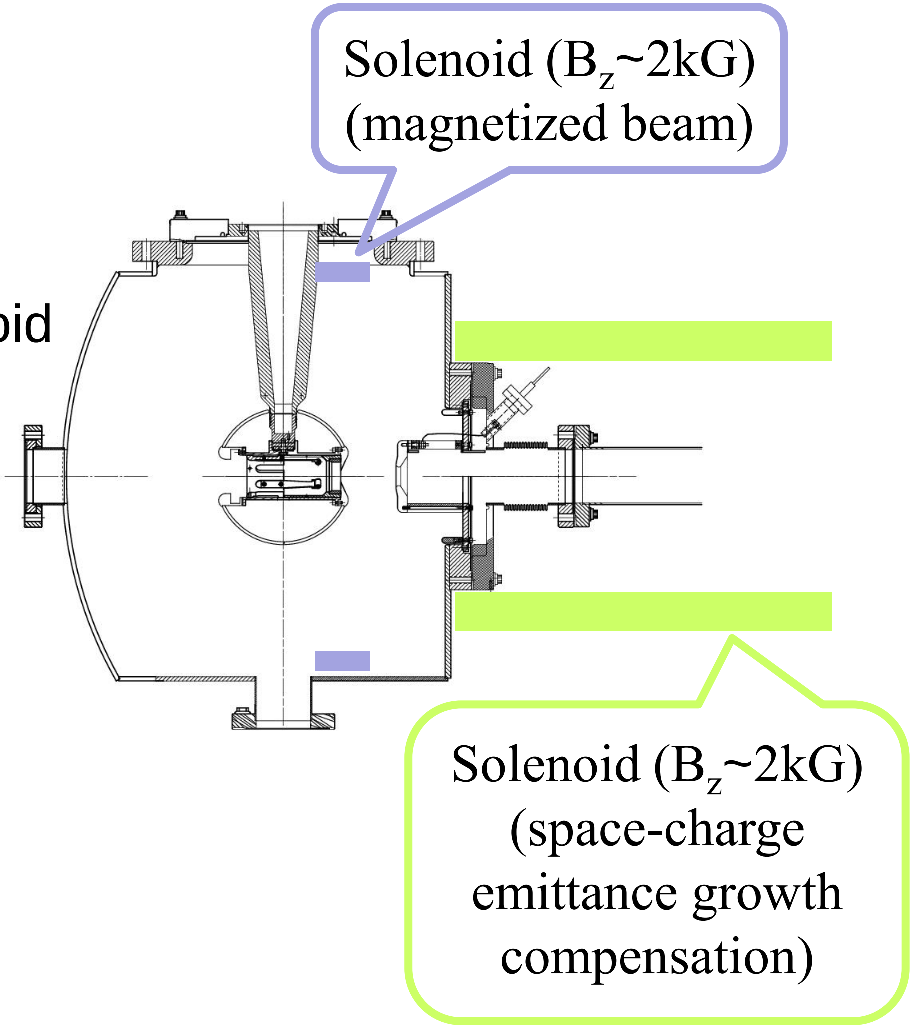




Magnetized Beam and Emittance Compensation

I. Magnetized Cathode:
  - ➢ To produce magnetized electron beam (to ensure zero angular momentum inside cooling-solenoid section)

II. Magnetized Injector:
  - ➢ To compensate space-charge emittance growth



Summary

I. Thermionic gun would be our first choice (less maintenance but may need complicated injector):

- **TRIUMF/BINP Gun with Inverted Ceramic**

II. To allow for laser pulse shaping, a photogun could be an option:

- **JLab 350/500 kV Inverted Gun and JLab K_2CsSb**