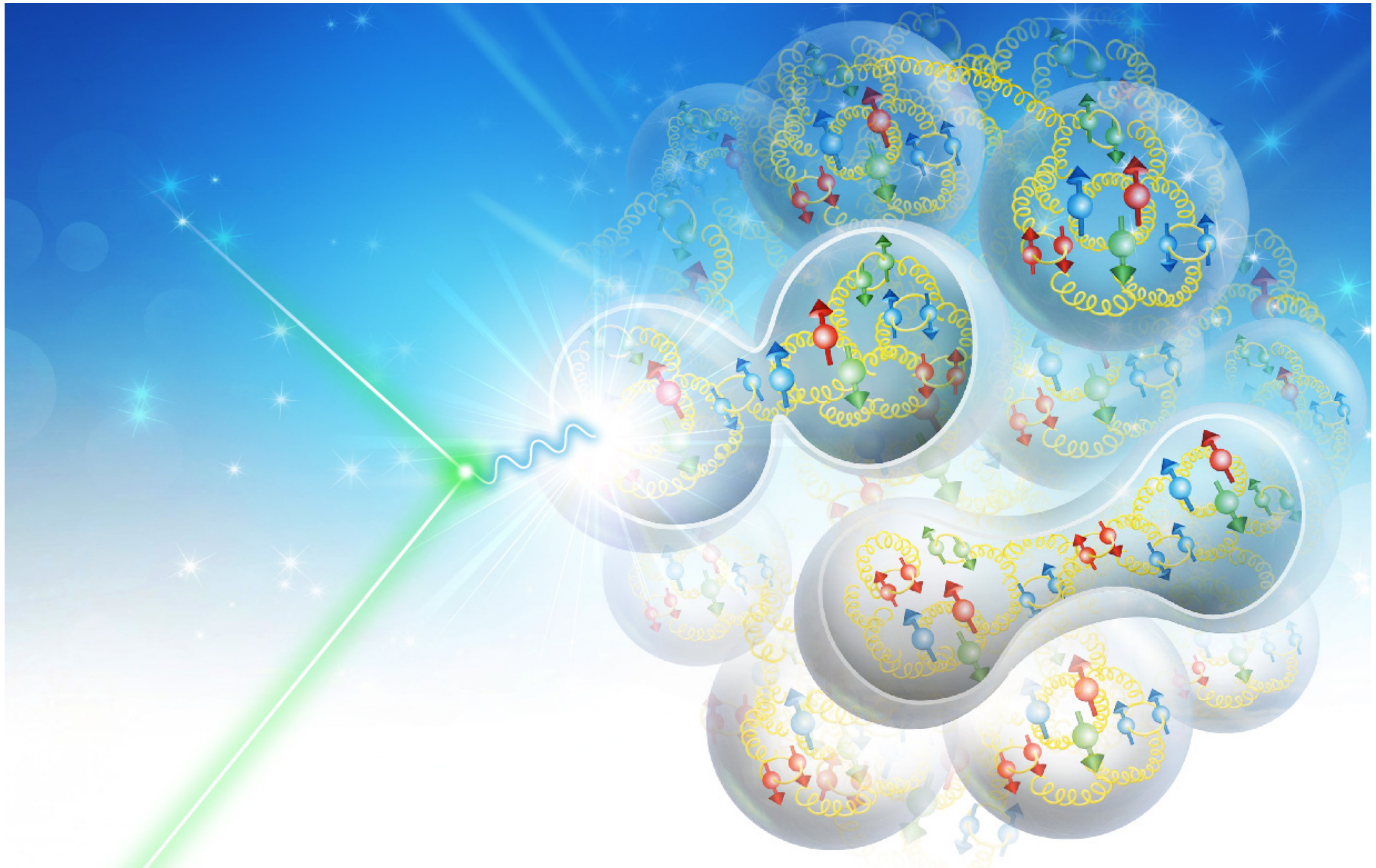
Magnetized Thermionic Electron Source for Ion Beam Cooling

Development and Testing of Gridded Thermionic Electron Source for JLEIC Bunch Beam Cooling



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Title: Graduate User

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Ion Beam Cooler for JLEIC

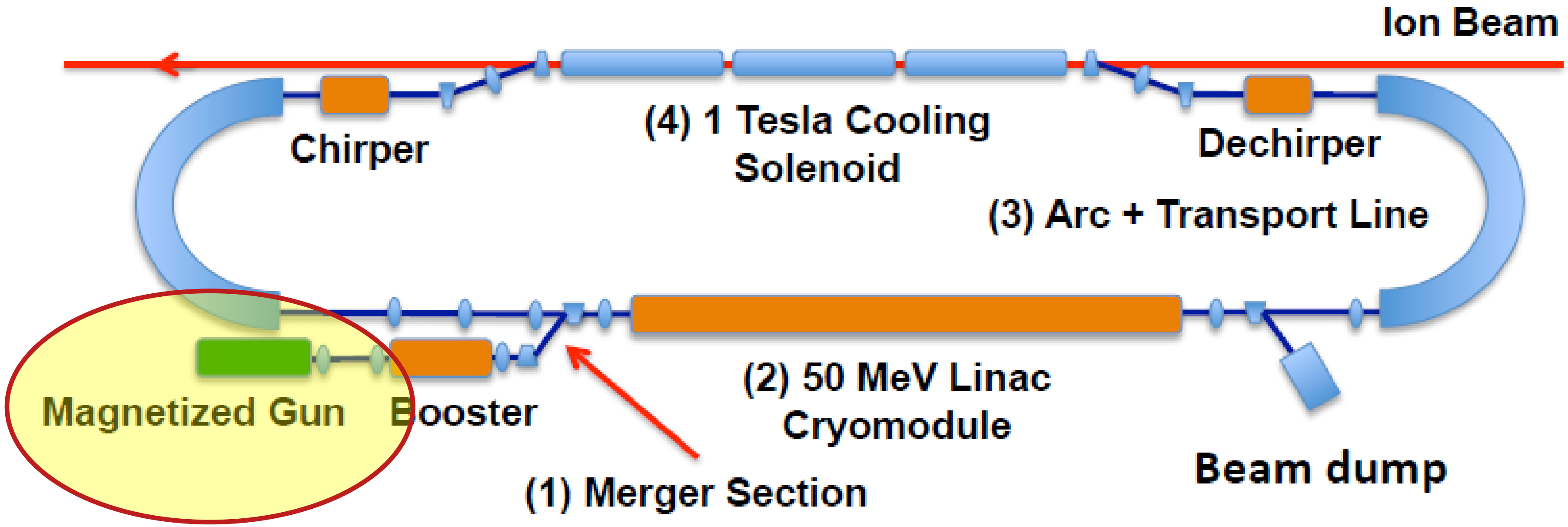

Figure 1.1: A schematic of a magnetized electron cooling system proposed for the JJefferson Lab Electron-Ion Collider (JLEIC) [5]. A magnetized beam is produced in the injector, merged (1) into the linac where it is accelerated to 55 MeV (2), and then transported (3) to the interaction region in the cooling solenoid (4).

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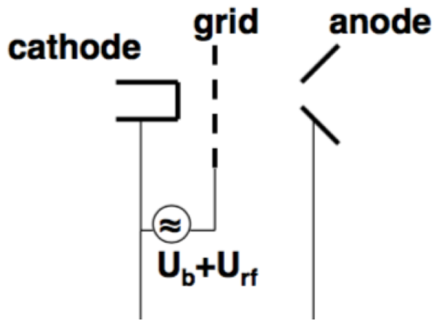
Why Use Magnetized Thermionic Gun?

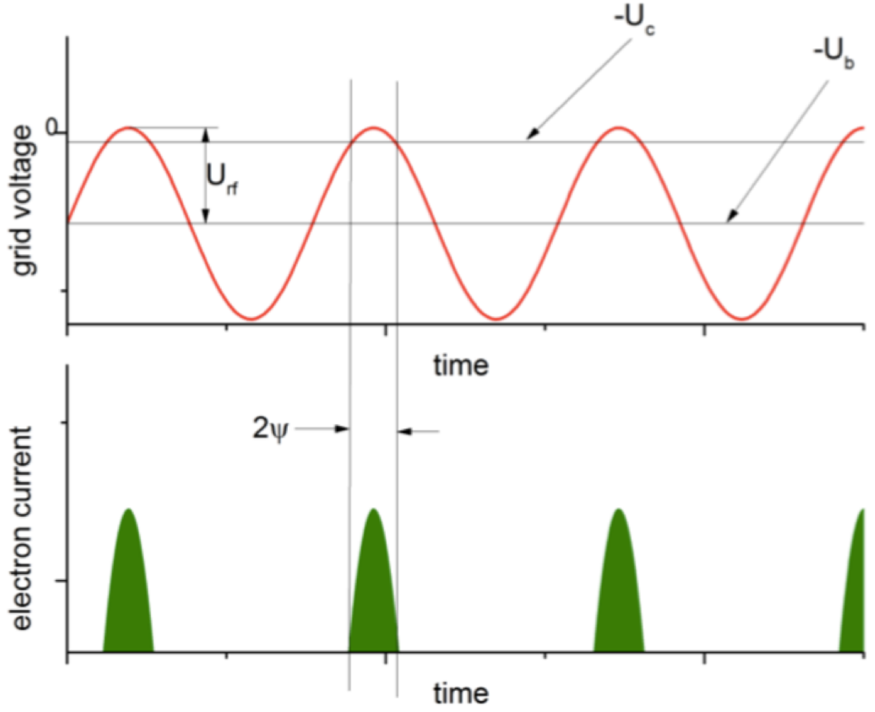
- Photoguns are highly flexible and offer control over the phase space of the bunch, but have not been proven continuously at very high currents.
  - Design calls for 3.2 nC bunch charge providing ~140mA.
- A thermionic gun could be a viable low risk plan; being a robust platform capable of producing the current required for effective cooling.
- A magnetized beam's fringe-field Lorentz-force kick cancels the fringe-field Lorentz-force kick at the cooling solenoid, increasing the cooling efficiency.
- Magnetization is achieved by immersing the cathode in a magnetic field perpendicular to the cathode surface.
  - $< L >= \frac{eB_z}{2} < r_c^2 >$
  - The larger emission radius of a thermionic gun means effective magnetization can be achieved at smaller magnetic field strengths.
- Thermionic sources do present challenges. One being long bunch lengths (200+ ps)

Bunch Current Profile From Gridded Thermionic Gun

- $I(t) = g\left(U_b + U_{rf}\cos\left(\omega_{rf} t\right) - U_c\right)$

- U_b: Grid Bias Voltage
- U_{rf}: Peak RF Voltage
- U_c: Cut-Off Voltage
- ω_{rf}: Angular Frequency of RF Signal
- g: Transconductance of the Triode System.





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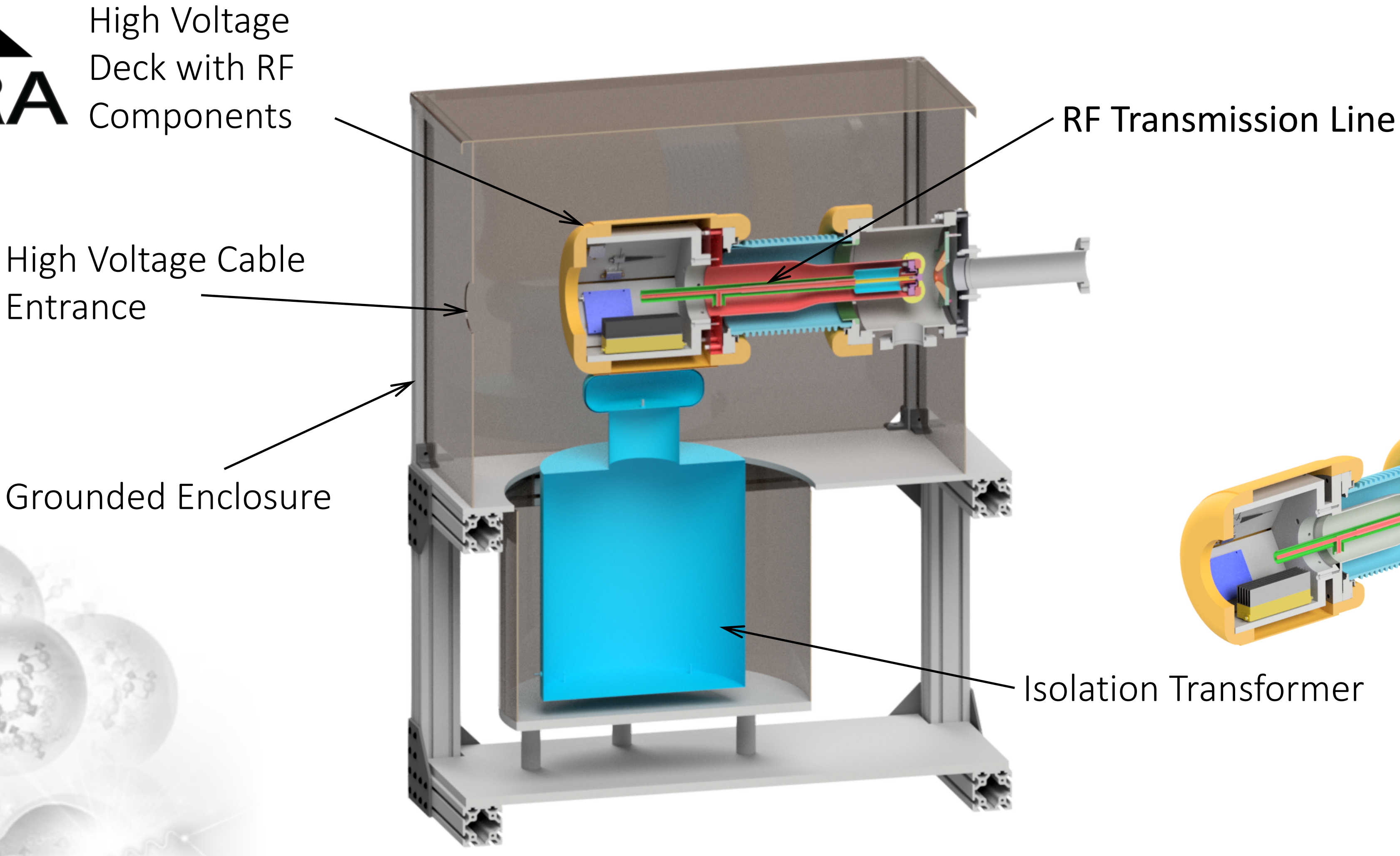
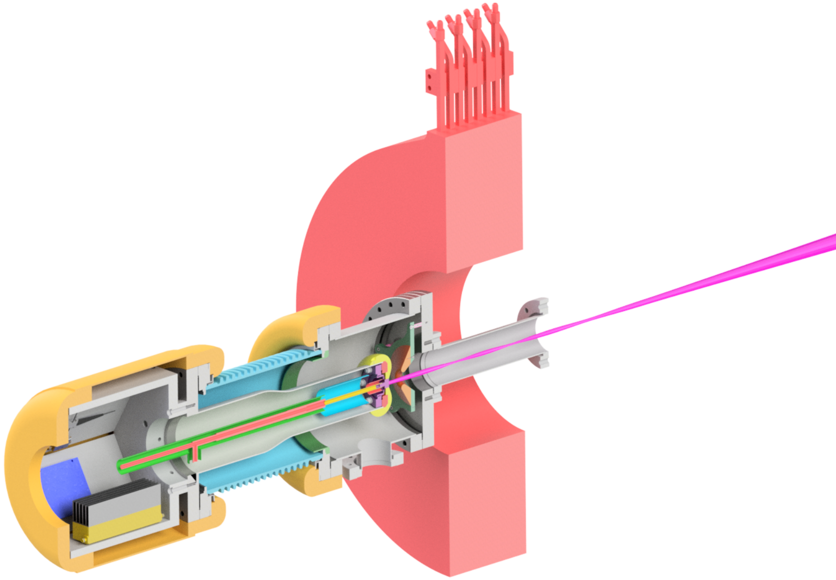
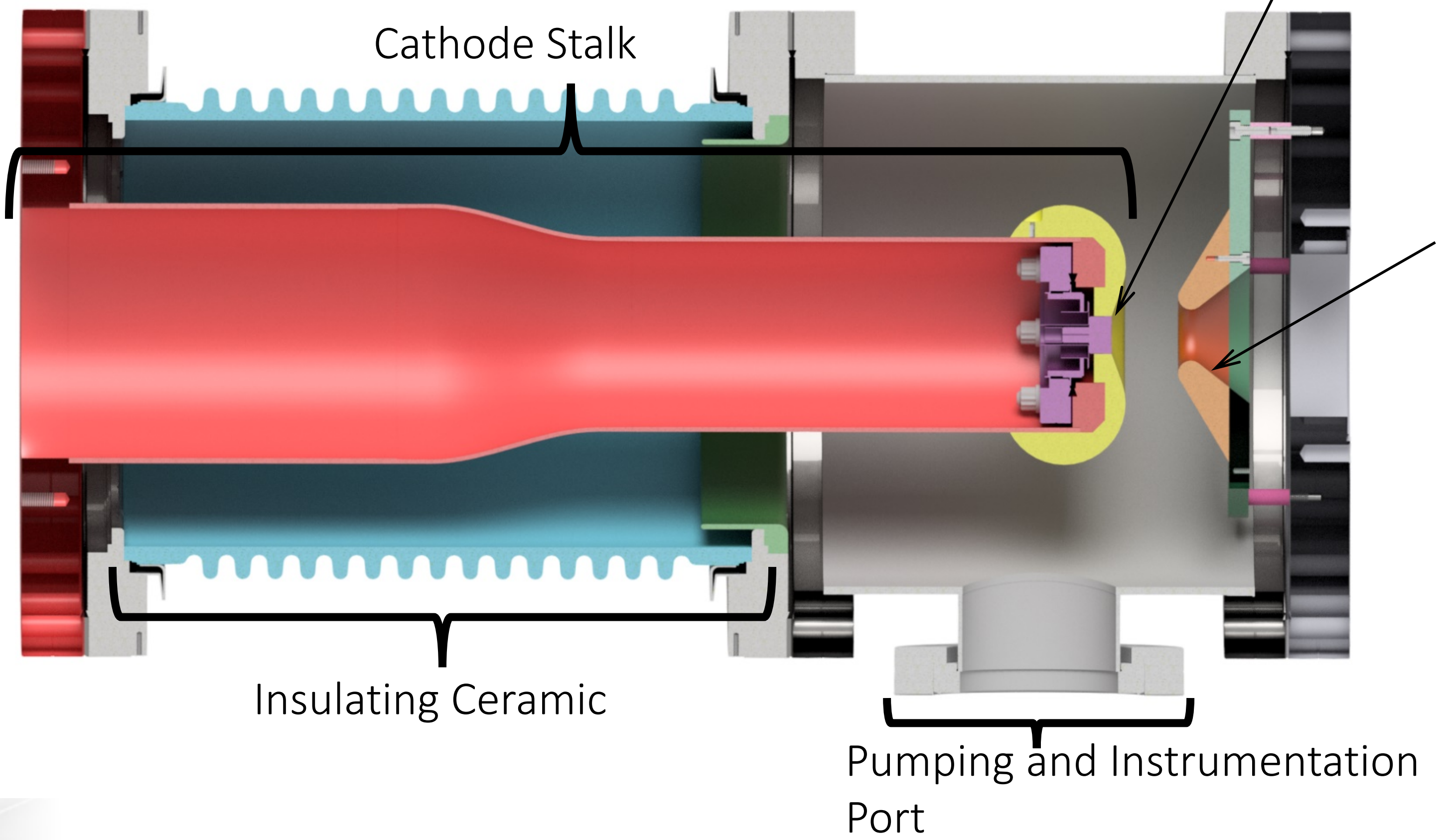
Schematic of Thermionic Gun





Vacuum Design



Design Parameters of Thermionic Gun

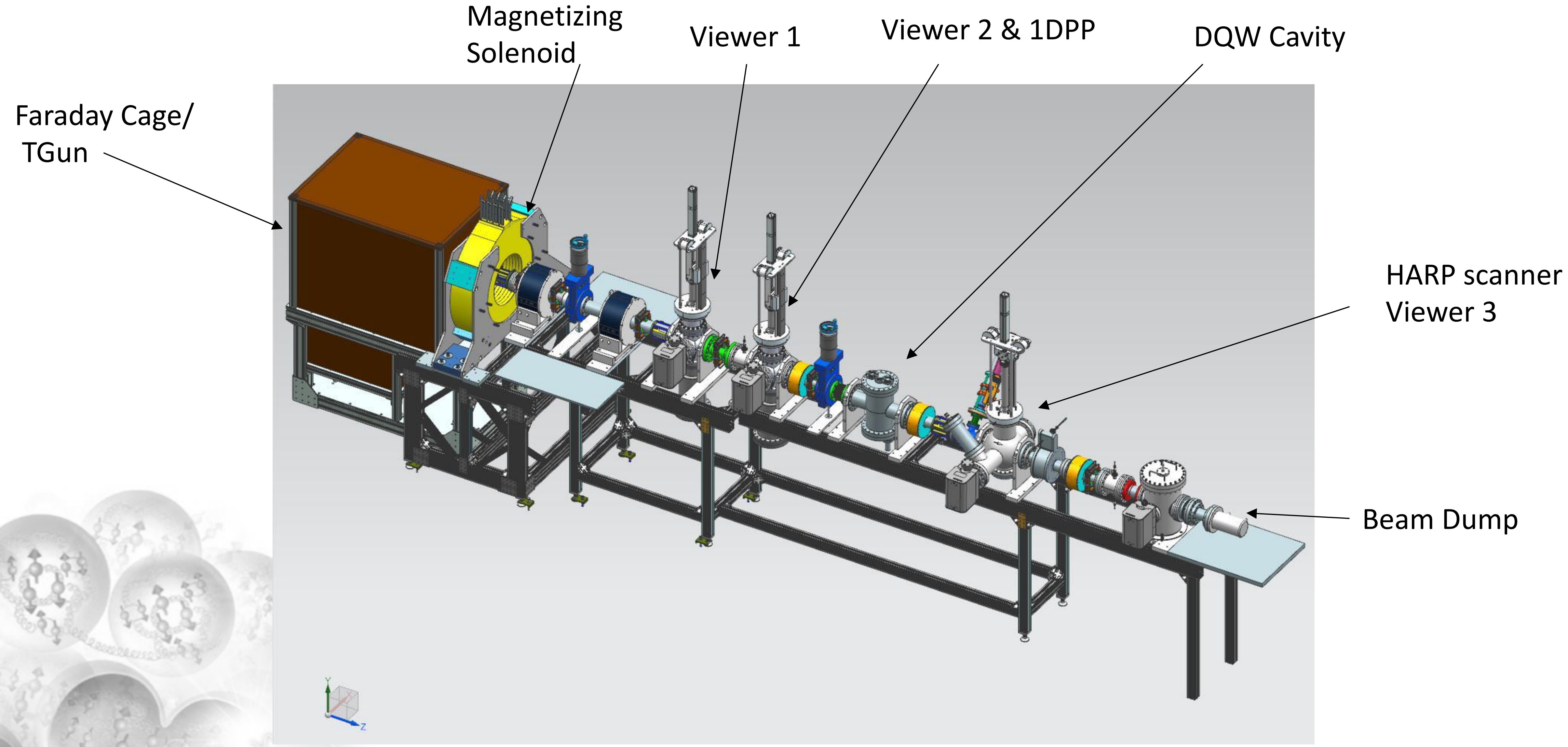
- RF Frequency: 500 MHz (CEBAF frequency – also close to the frequency of the ERL – 476MHz (not CCR) back up option design)
- Cathode: CPI Y-845, R = 0.4 cm.
- Nominal bunch charges: 20 pC, 130 pC (CW Current 65 mA)
- Cathode/Electrode geometry determined by Multi-Objective Genetic Optimization (MOGA):
- Gap = 26 mm,
- Cathode Angle 20 deg,
- Anode Angle = 31 deg
- Thermal Emittance: ~ 4 micron
- Magnetized Emittance: ~36 micron

The Goal: Characterization of Thermionic Gun

Properties of Interest:

- Current (High current magnetized beam)
  - Current read-back from the beam dump
- Magnetization (angular momentum, linearity)
  - 1 Dimensional Pepper-Pot (1DPP) beamlet rotation
- Bunch length and bunch current profile
  - 1DPP with Double Quarter Wave (DQW) TEM (fundamental) mode deflecting cavity
- Normalized Transverse Emittance
  - 1DPP Phase Space Reconstruction
- Uncorrelated Transverse Emittance
  - Uncorrelated emittances is the resulting emittance when the correlation between x,/Py and y/Px is removed. (effective emittance in cooling solenoid)
  - Post Processing of 1DPP Phase Space Reconstruction.

Diagnostic Beamline located at the Gun Test Stand



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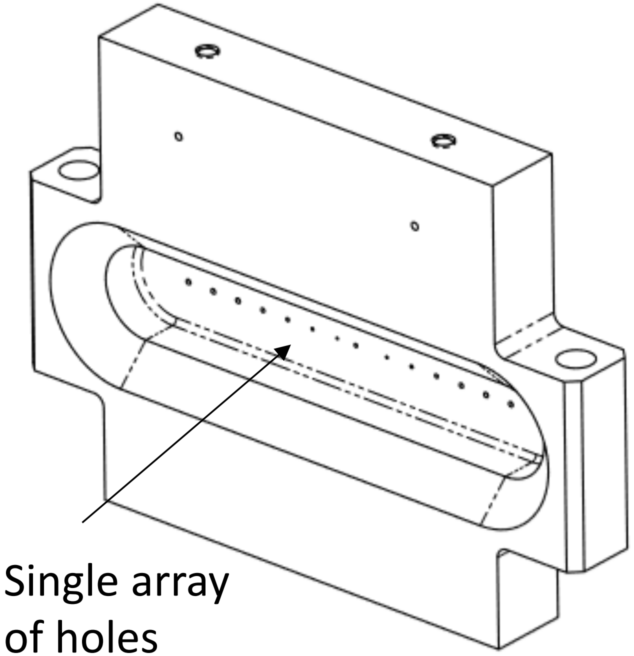
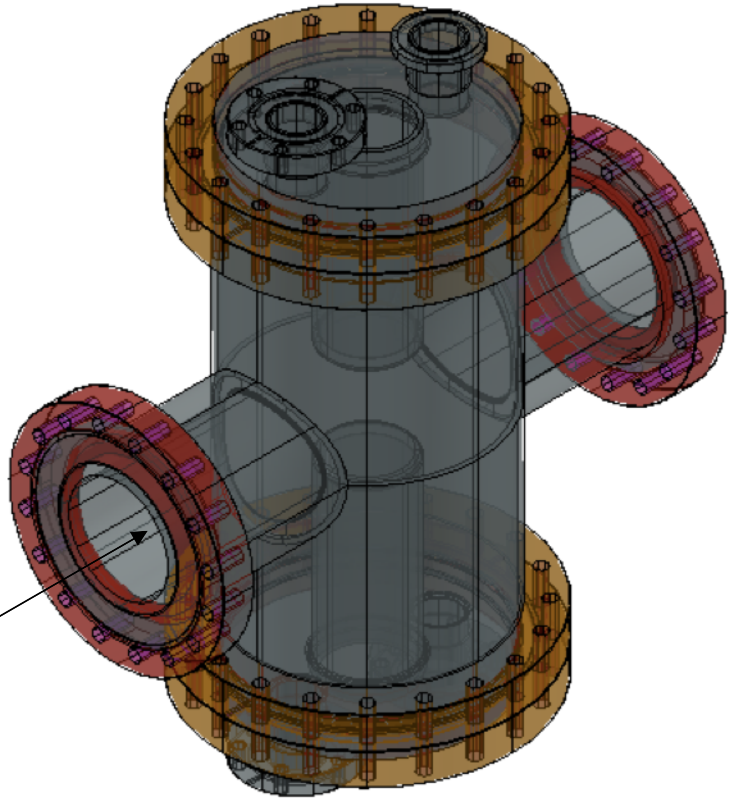
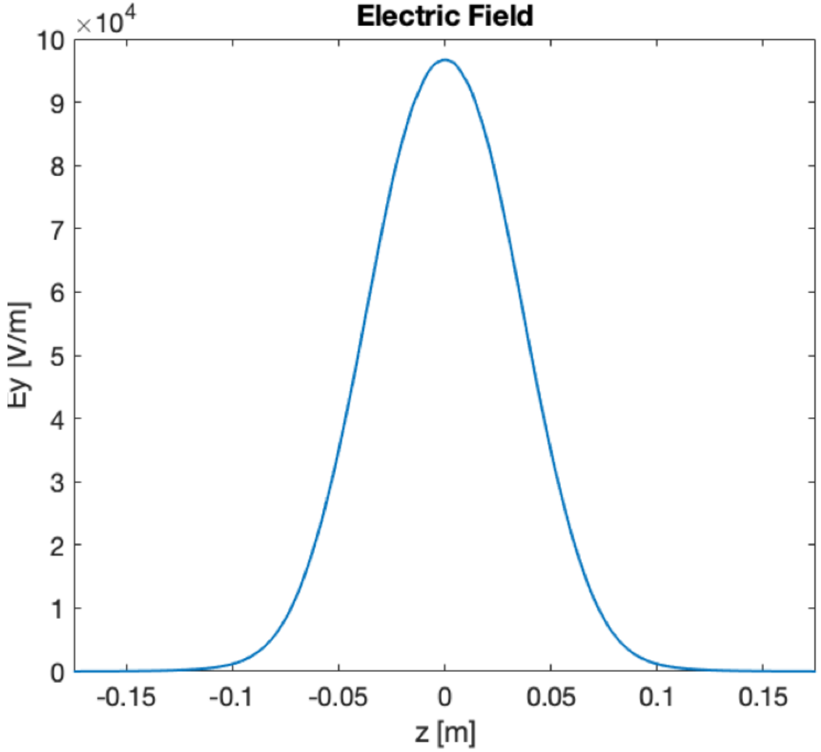
1 Dimensional Pepper-Pot and TEM Deflecting Cavity



Single array
of holes



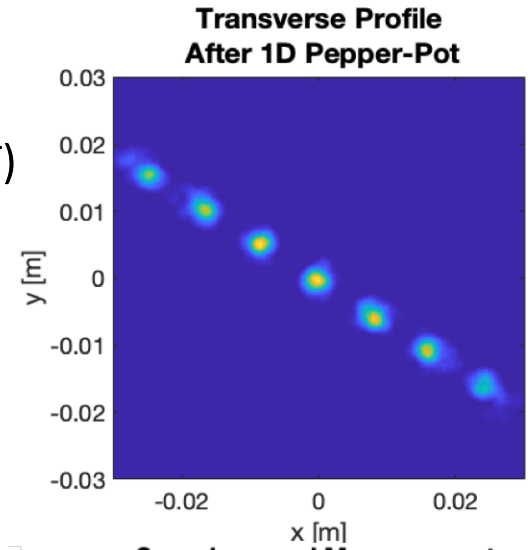
Beamline axis

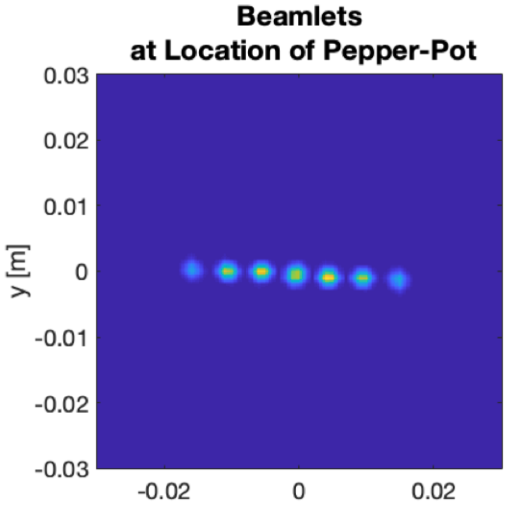


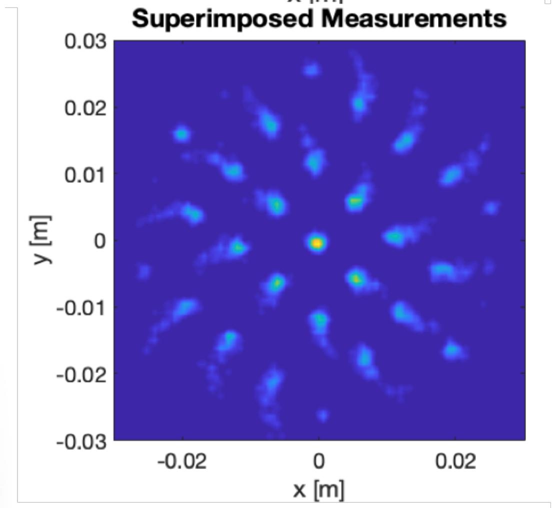
Simulated Measurements

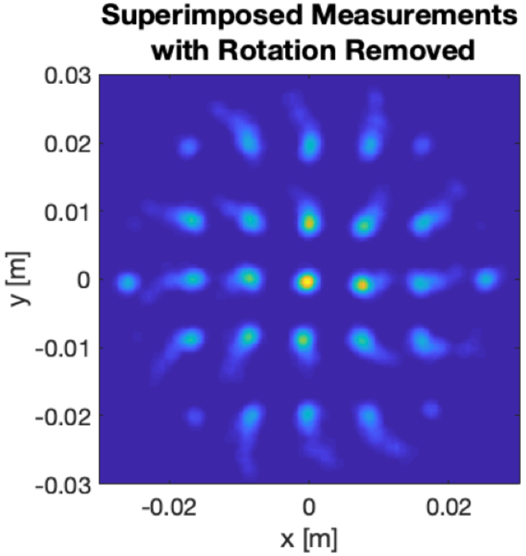
General Particle Tracer (GPT)
100,000 particles
125 keV
130 pC Bunch Charge
Frequency 500 MHz
Magnetizing current 81A

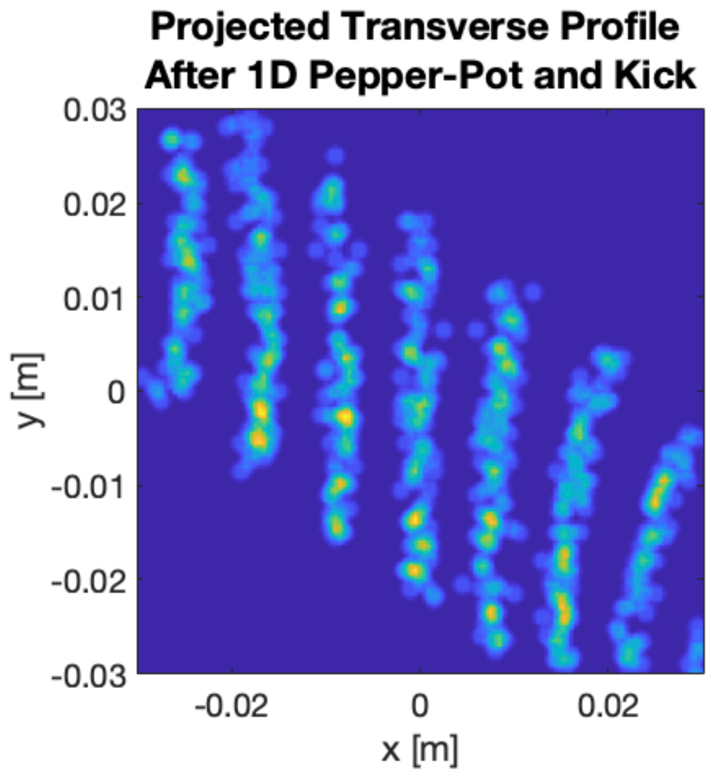
Simulation data taken at Viewer 3 and 1DPP





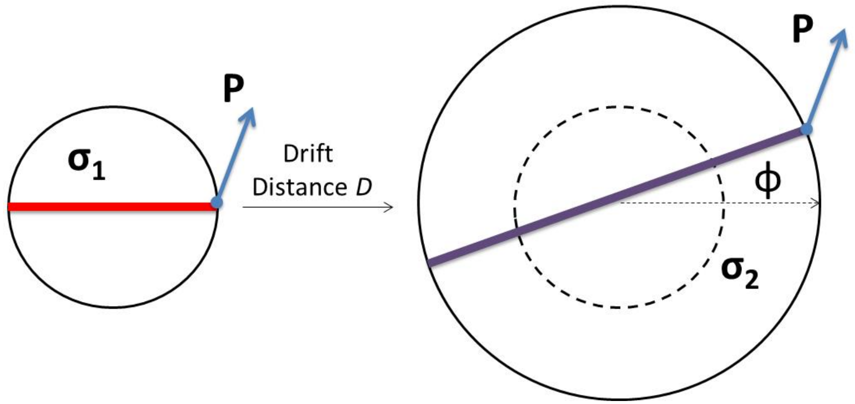




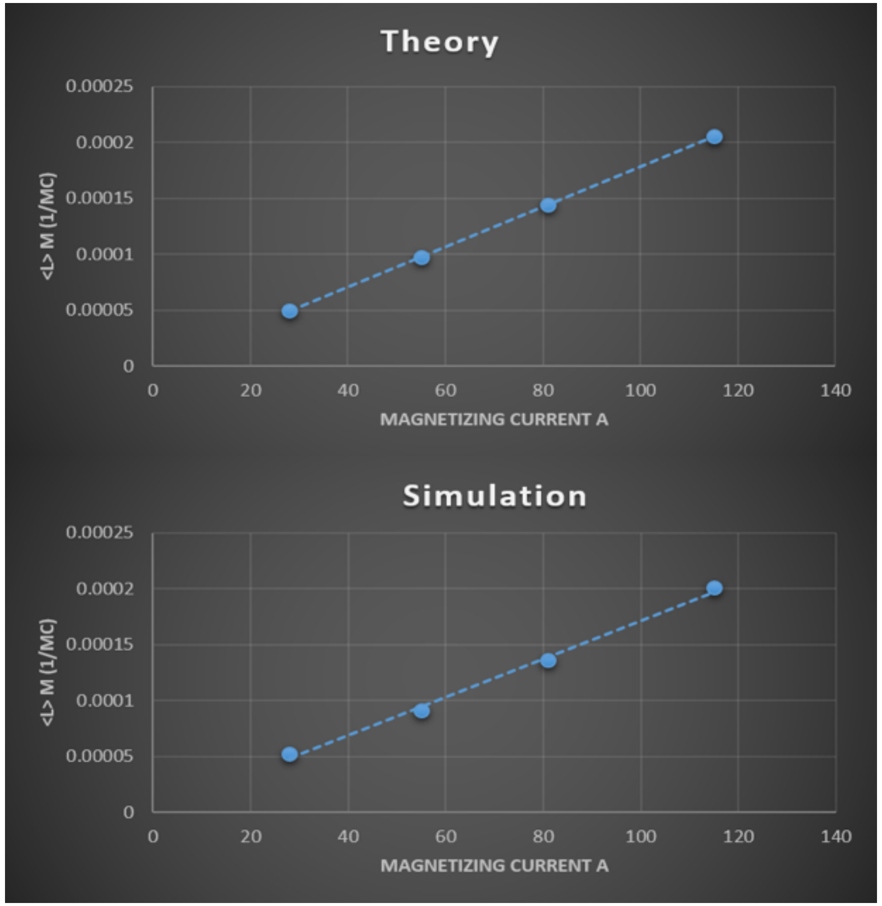


Simulated Measurement : Angular Momentum

- $P_\phi = p_z \dfrac{\sigma_1 \sigma_2 \sin(\phi)}{D}$



σ_i: beam size on i -th viewer
ϕ: rotation (sheering) angle



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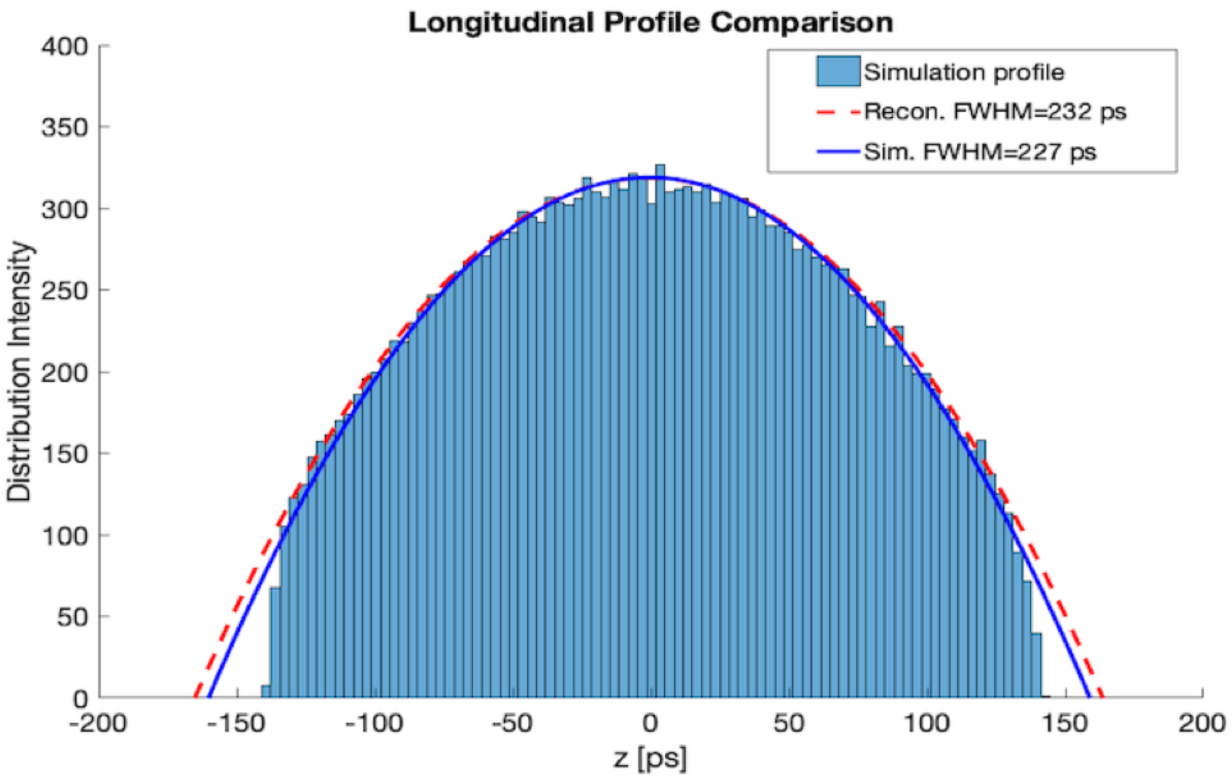
Simulated Measurement : Longitudinal Profile

- $V_\perp = \int_{-\infty}^{\infty} \frac{E_\perp}{\beta_z} e^{\frac{ikz}{\beta_z}} - icB_\perp e^{\frac{ikz}{\beta_z}} dz$
- $\sigma_z = \frac{\lambda \sqrt{(T^2 + 2Tm_e c^2)(\sigma_y^2 - \sigma_{y0}^2)}}{2\pi e\, V_\perp D}$

- σ_z: Bunch length
- σ_y: Final transverse bunch size
- σ_{y0}: Initial transverse bunch size
- T: Kinetic energy
- D: Drift length
- λ: Frequency wavelength



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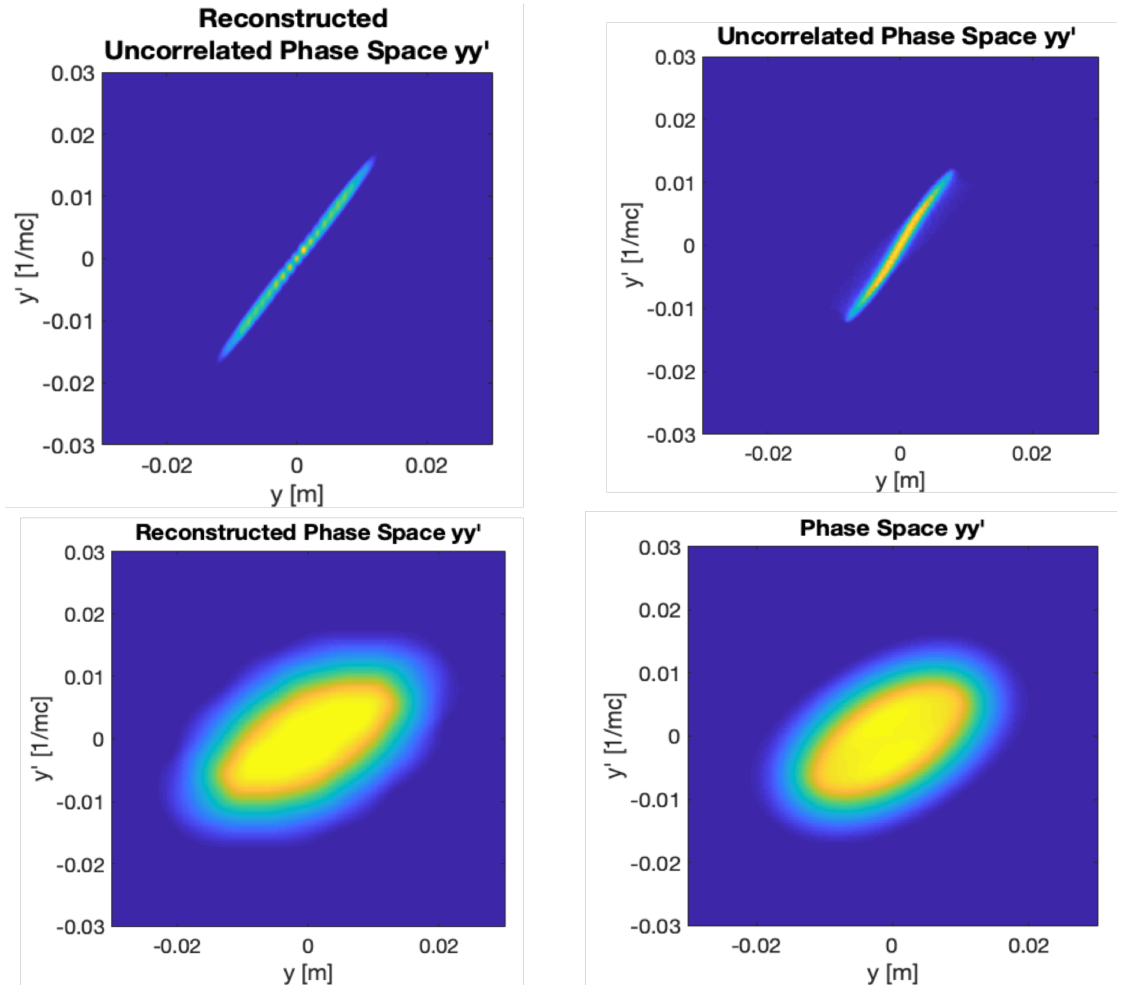
Simulated Measurement : Normalized Emittance & Uncorrelated Emittance

- $\varepsilon_n = \frac{1}{m_e c}\sqrt{< x^2 >< p_x^2 > - < x p_x >^2}$

  Normalized Emittance is calculated by an image analysis of the reconstructed phase space.
  ~36 micron, 1% error

- $p'_x = p_x - C_{y p_x} y$

  Post processing removes the rotation from angular momentum and re-evaluates the emittance to give the uncorrelated emittances
  ~5 micron, 5% error



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Future work

- The gun will arrive in the Next few weeks.
- Perform physical measurements on real system at GTS to confirm simulations and design goals.
- Begin work on Xelera Phase IIB Thermion Gun with design specifications closer to cooler requirements (43.3 MHz, 3.2 nC)

Acknowledgements

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