XELERA

A Magnetized Electron Source for Ion Beam Cooling

DoE Phase II SBIR

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Outline

- ➢ Company Overview
- ➢ Need for magnetized beams
- ➢ Phase I: Injector design
- ➢ Phase II
  - Design
  - Fabrication
  - Testing at Xelera (Ithaca)
  - Testing at JLab
- ➢ Summary

Company Overview

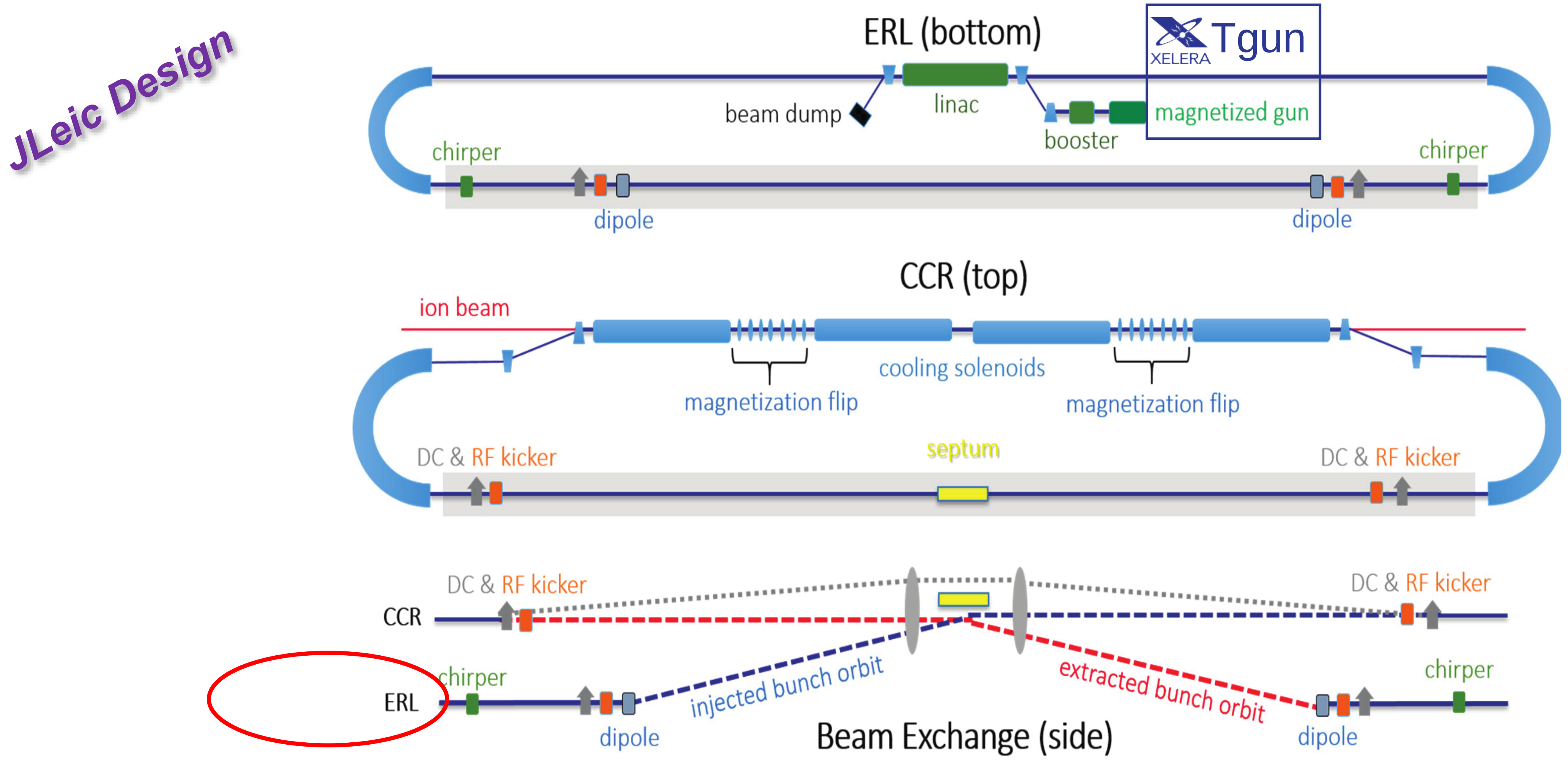
- Formed in 2013 by 5 partners – 150+ years of accelerator design expertise
- Most of Xelera were from the Cornell ERL development team, who designed and built the world’s highest current, high brightness photoinjector, which is being used now in the 4-pass ERL: CBETA
- Now at 9 total employees
- Focus Areas:
  - Accelerator design & simulations (EIC magnetized injector design) DOE SBIR (2020)
  - Radiation physics consulting (ASU BioDesign C safety systems design)
  - Accelerator hardware:
    - Electron & X-ray beam stops (ASU Graves Lab)
    - Cathode transport systems (ASU Karkare Lab)
    - Vacuum system designs, coatings (ASU / JLab, Poelker) DOE SBIR
    - Higher Order Mode loads (HZB, Germany)
    - Electron source design and fabrication (JLEIC Cooler Magnetized Gun) DOE SBIR (2016-2019)

EIC need for magnetized beam

- Electron cooling of the ion beam is a critical aspect of a successful electron-ion collider (EIC), possibly improving the luminosity by a factor of 5.

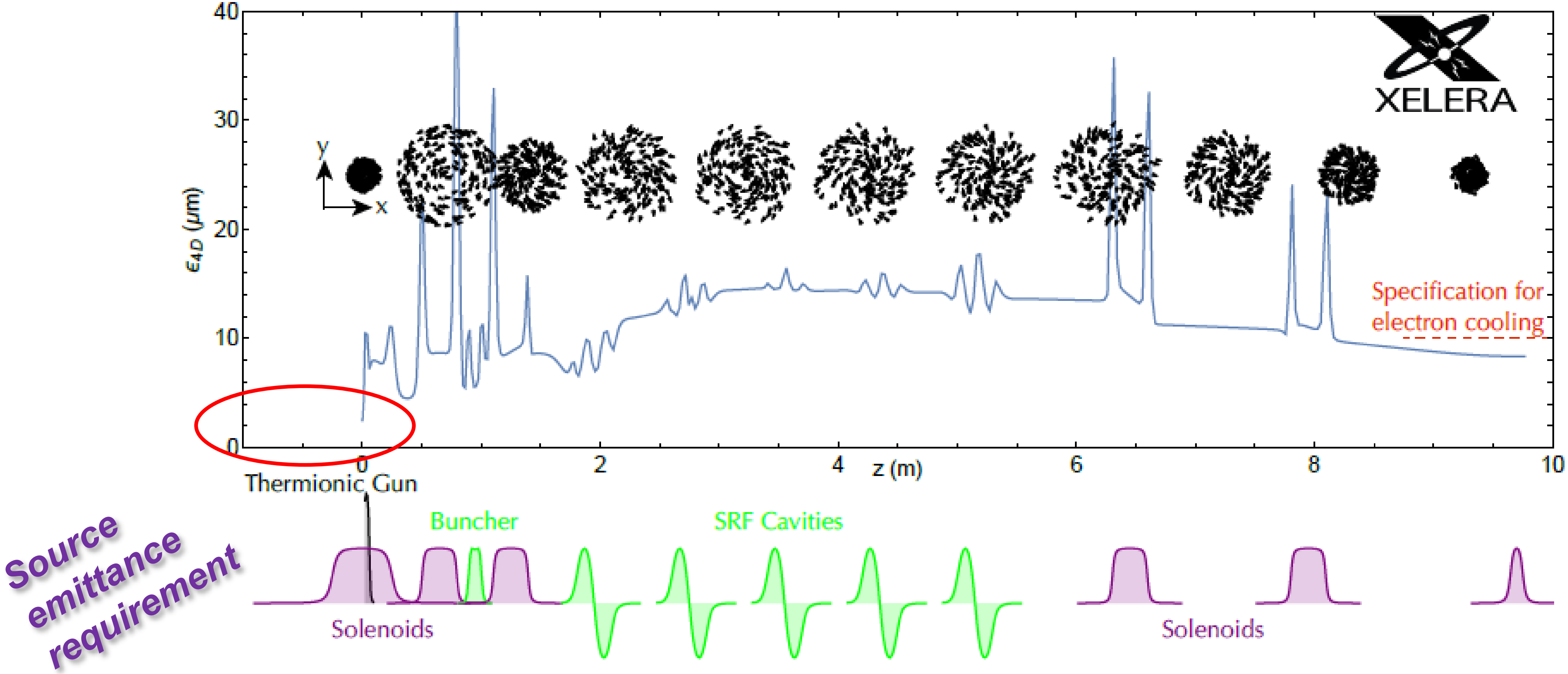
- A (pre)magnetized beam becomes still in the cooling solenoid. This is done by immersing the cathode in a solenoid field.
- Photoguns are highly flexible and offer control over the phase space of the bunch, but have not been proven reliable at very high currents.
- A Thermionic gun could be a viable (low risk) plan B.
- Xelera built a prototype Thermionic Gun (Tgun), and delivered it to JLab's Gun Test Stand (GTS) in July 2019.
- Testing at JLab has been underway for the past year.

Magnetized Beams for EIC cooling



Modified figure from: S. Benson, S. Derbenev, et al., *Development of a bunched beam electron cooler for the Jefferson Lab electron-ion collider*, IPAC 2018, http://ipac2018.vrws.de/papers/mopmk015.pdf

Phase I: Magnetized Injector Design



Phase II

Phase II: Build a Magnetized Source –TGun

Proposal excerpts

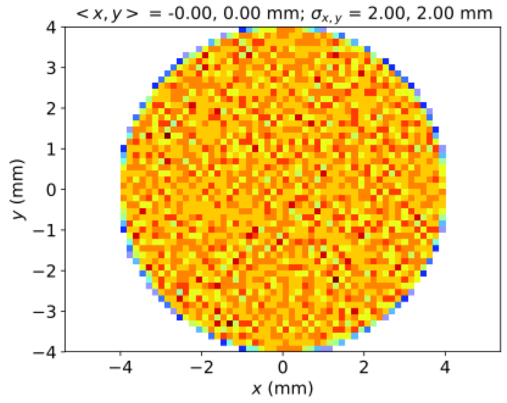
1 if the beam parameters could still be met by a less complex and cheaper device. As discussed in §1.3, Phase I results indicate that with voltages as low as 200 kV the required 4D beam emittance can still be achieved. In further simulations we will continue investigating lower beam energy with the goal of still meeting ion cooling emittance requirements.

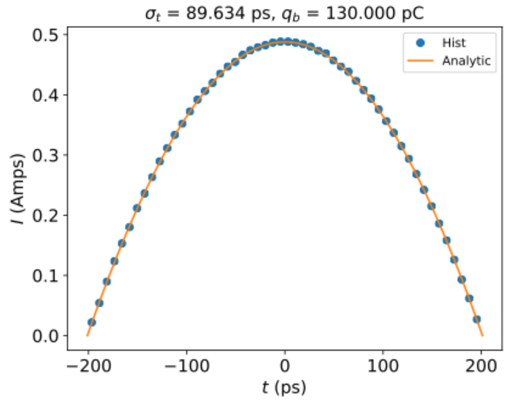
2 scientists, we decided to propose using gridded-thermionic gun with a 100 kV beam energy and 50 mA average current, as a first step towards the final goal. These

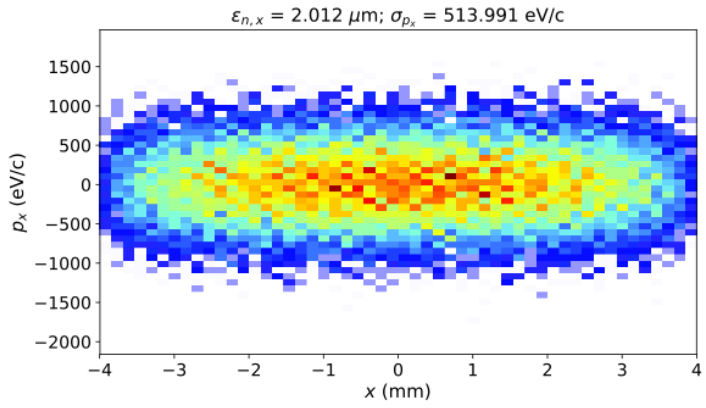
3 Once the gun is built and conditioned, it will be installed at JLab where its beam properties will be measured using their diagnostic beamline. If successful, a new

Optimization: Initial Beam/Gun Parameters

Subsystem	Parameter	Value
Cathode	Emission Radius R_e (mm)	4
	RF Voltage U_{rf} (Volt)	250
	RF Frequency f (MHz)	500
	Transconductance g_{21} (mA/Volt)	10
	Max Temperature T_c (Kelvin)	1500
	Maximum Peak Current $I_{p,\mathrm{max}}$ (A)	1.25
Cathode Solenoid	Cathode Field B_{cathode} (T)	0.0307
Gun	Voltage V (kV)	125
	Cathode-Anode Gap L (mm)	[5, 30]
	Cathode Angle θ_c (deg)	[15, 45]
	Anode Angle θ_a (deg)	[15, 45]
Initial Beam	Bunch Charge q_b (pC)	[0, 545]
	RMS Bunch Length σ_t (ps)	[0, 147]
	Half Emission Angle ψ (deg)	[0, 60]
	Thermal Emittance $\epsilon_{n,\mathrm{therm}}$ (μm)	1.0
	Initial Emittance $\epsilon_{n,x,0} = 2\epsilon_{n,\mathrm{therm}}$ (μm)	2.0
	Magnetized Emittance $\epsilon_{n,\mathrm{mag}}$ (μm)	36
	Canonical Angular Momentum $\langle \mathcal{P}_\theta \rangle$ (neV·s)	122.8
	Transverse Thermal Energy $k_B T$ (meV)	129.26
	Effective Mean Transverse Energy $\mathrm{MTE}_{\mathrm{eff}}$ (meV)	517.04

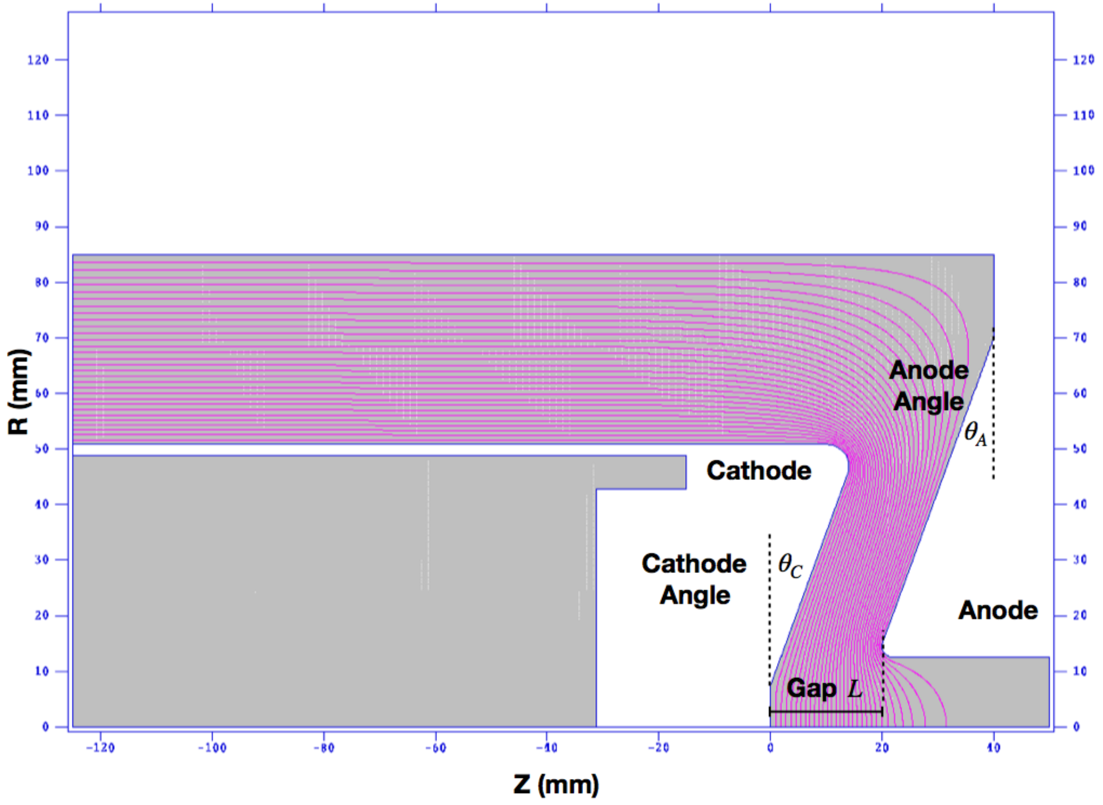






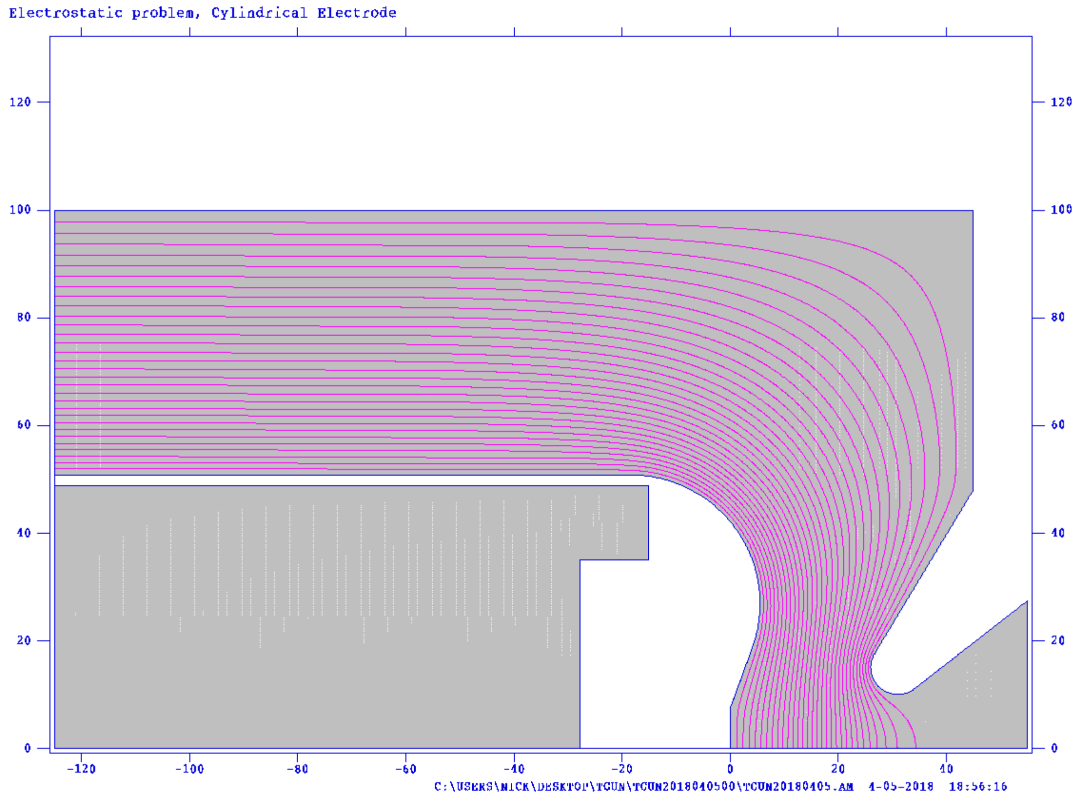
Optimization of Gun Parameters

- Cathode Anode Gap: 5-30 mm
- Cathode Angle: 15 - 45 deg
- Anode Angle: 15 - 45 deg
- Solenoid Strengths
- Optimized @ screen z = 2.5 m

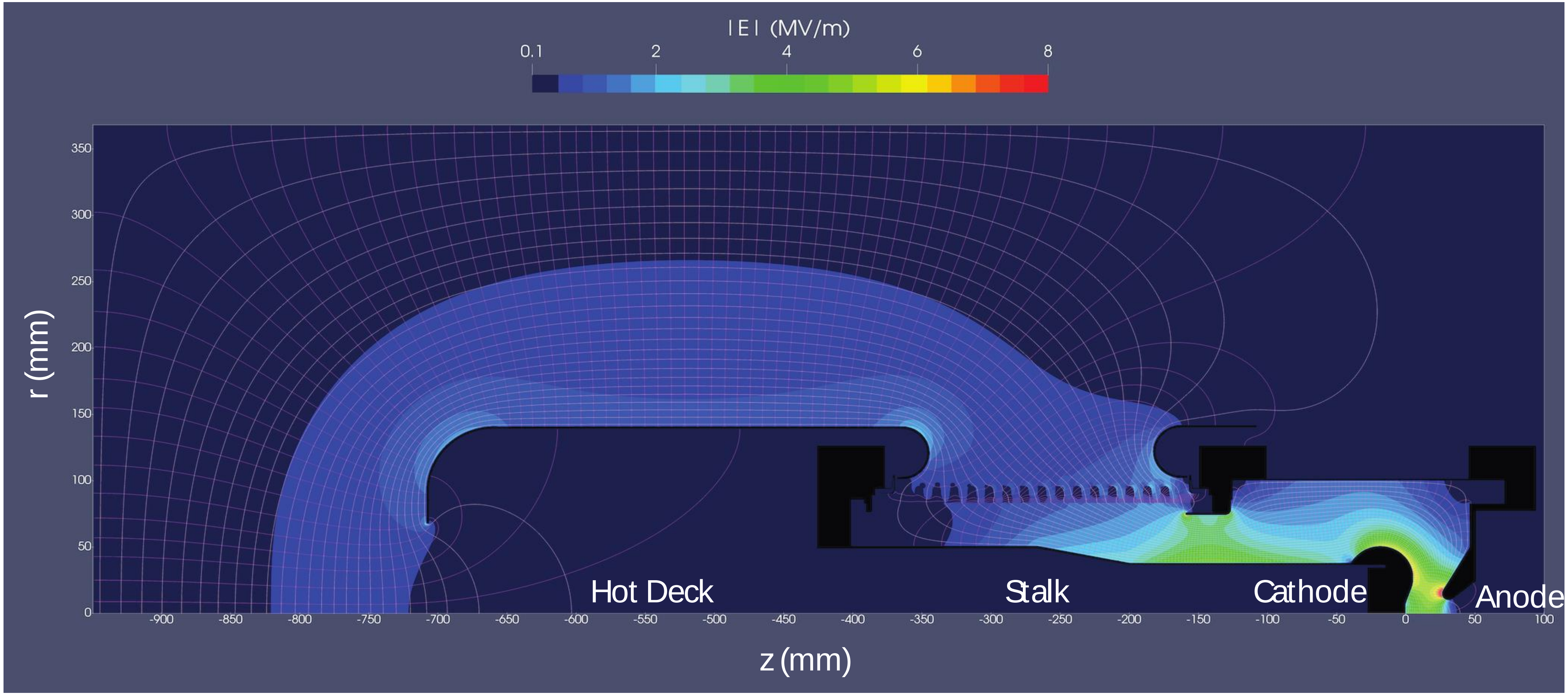


Optimal Solution

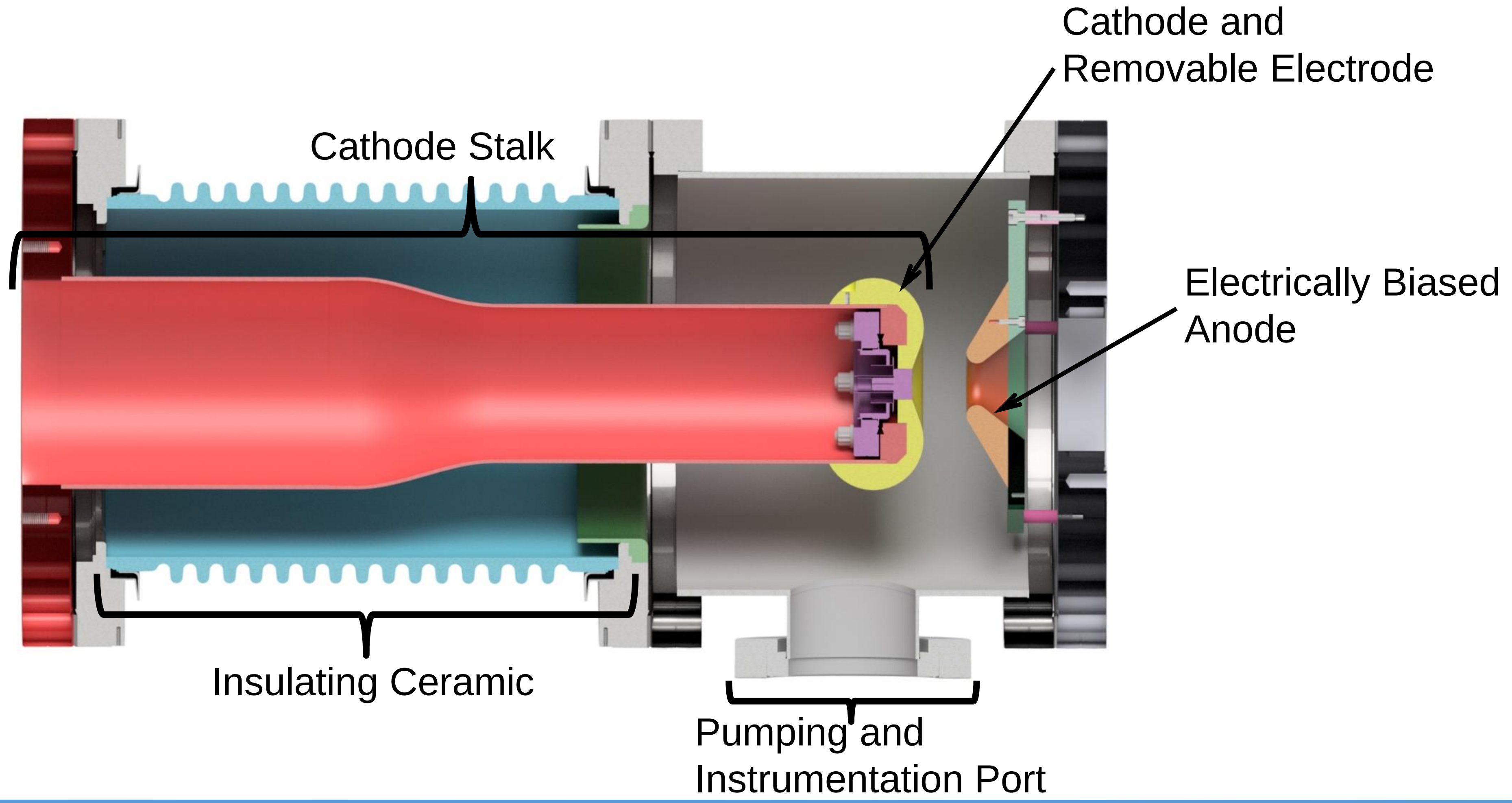
- After several parallel Multi-Objective Genetic Algorithm Optimizations, fixed on a single electrode design
- Gap 26 mm (Optimal: 20 mm, but keeps fields down, negligible penalty to emittance)
- Meets beam dynamics requirements:
    1. Magnetized beam
    2. Bunch charge sufficient for high current demonstration



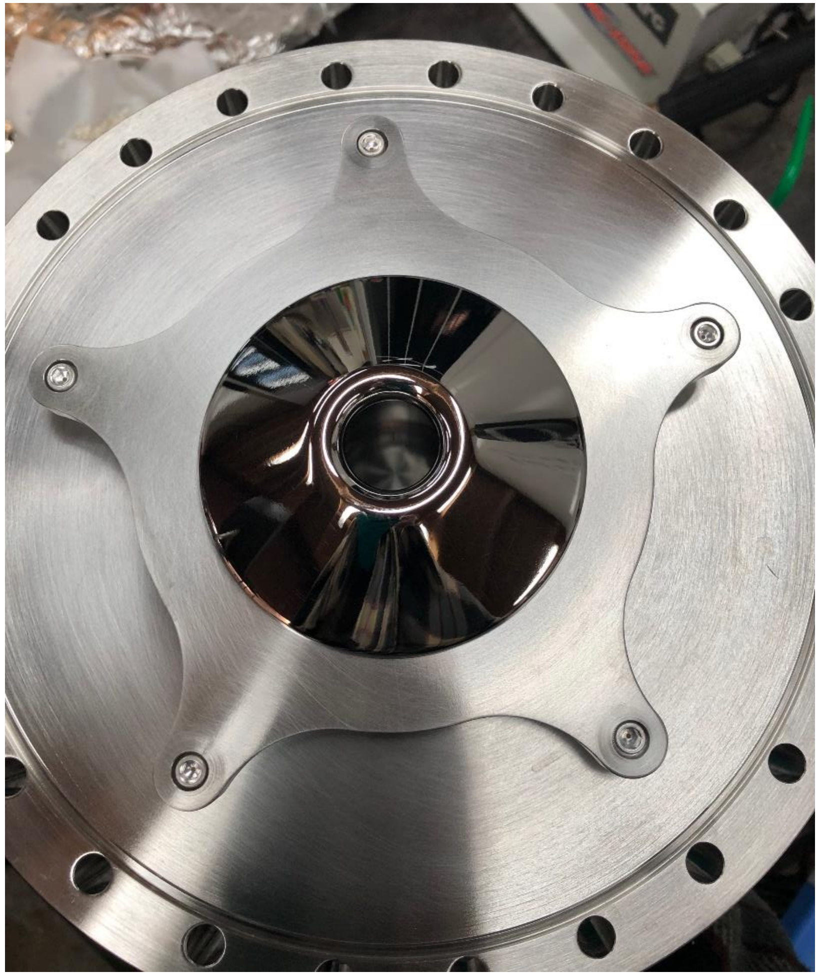
Electrostatic Design



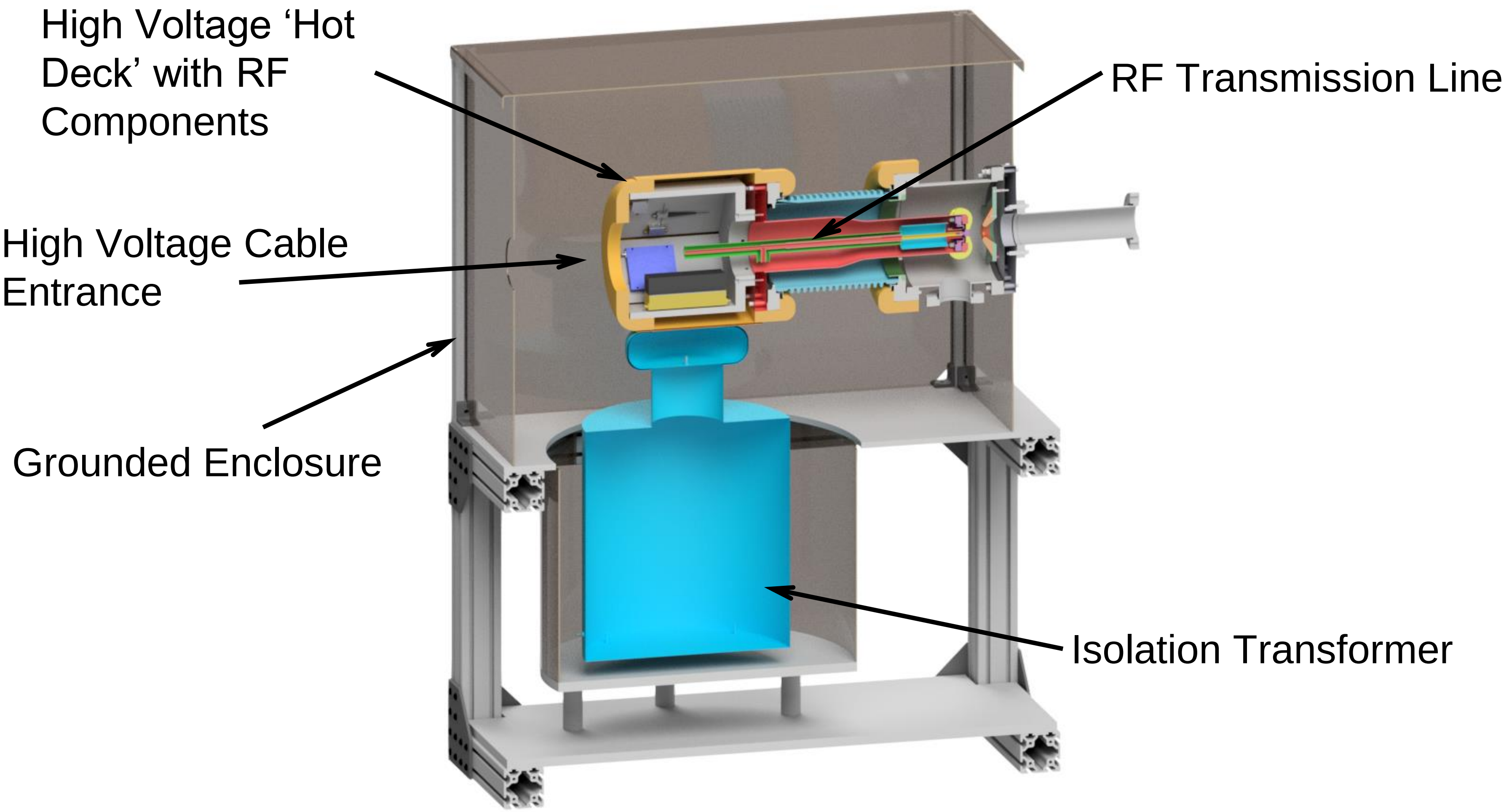
Vacuum System Mechanical Design



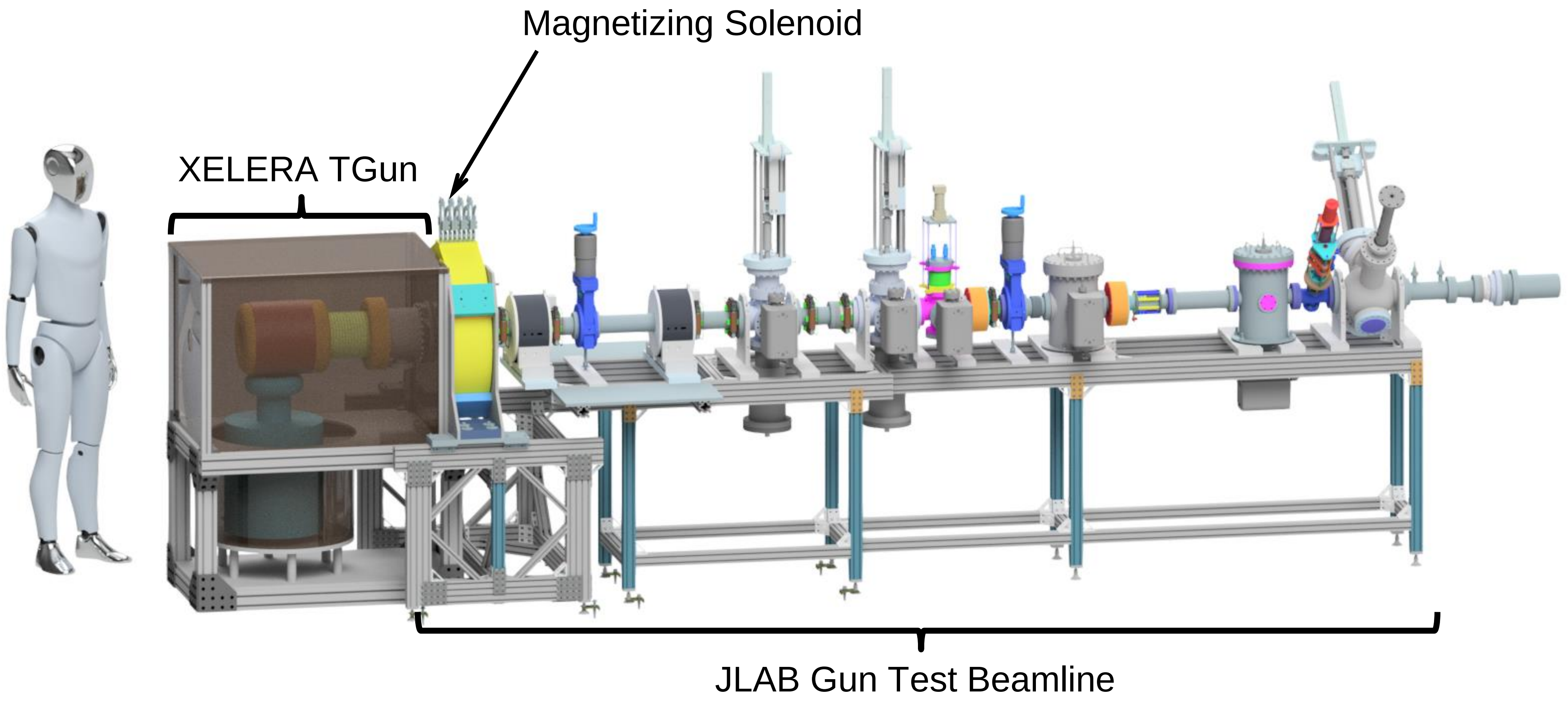
Cathode & Anode, Vacuum Chamber



Full Gun Design



XELERA TGun in JLAB GTS Beamline



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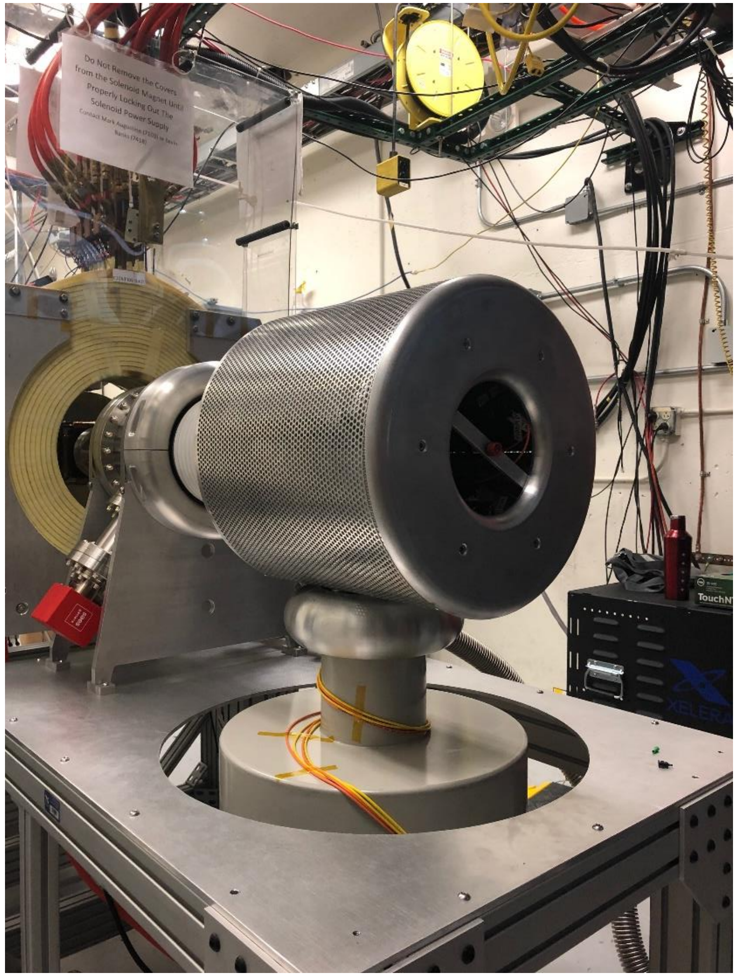
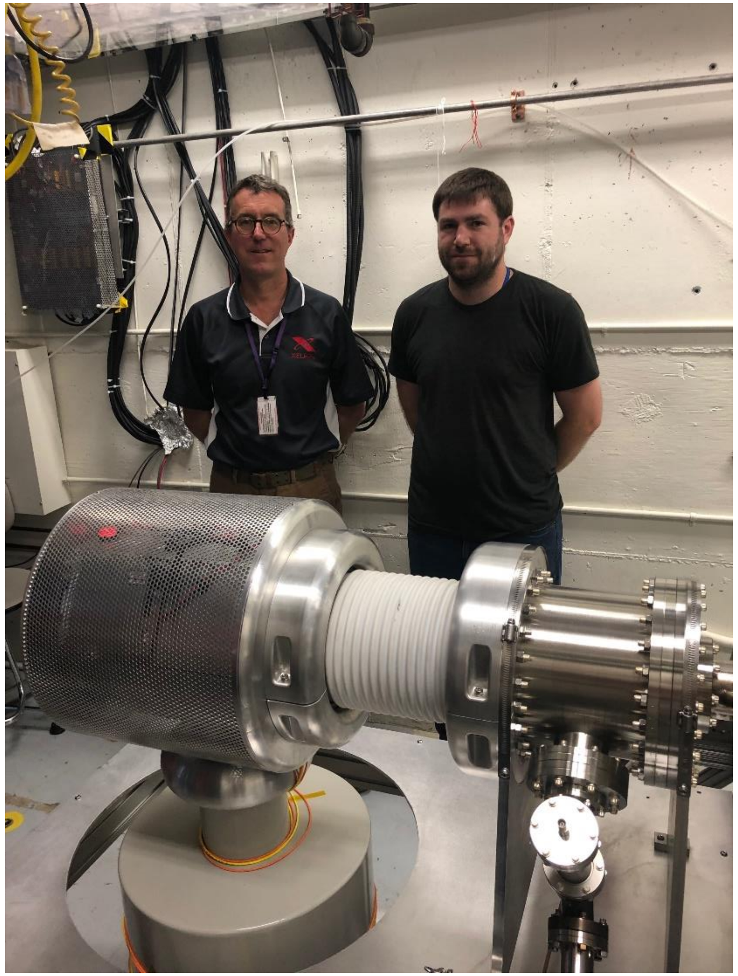
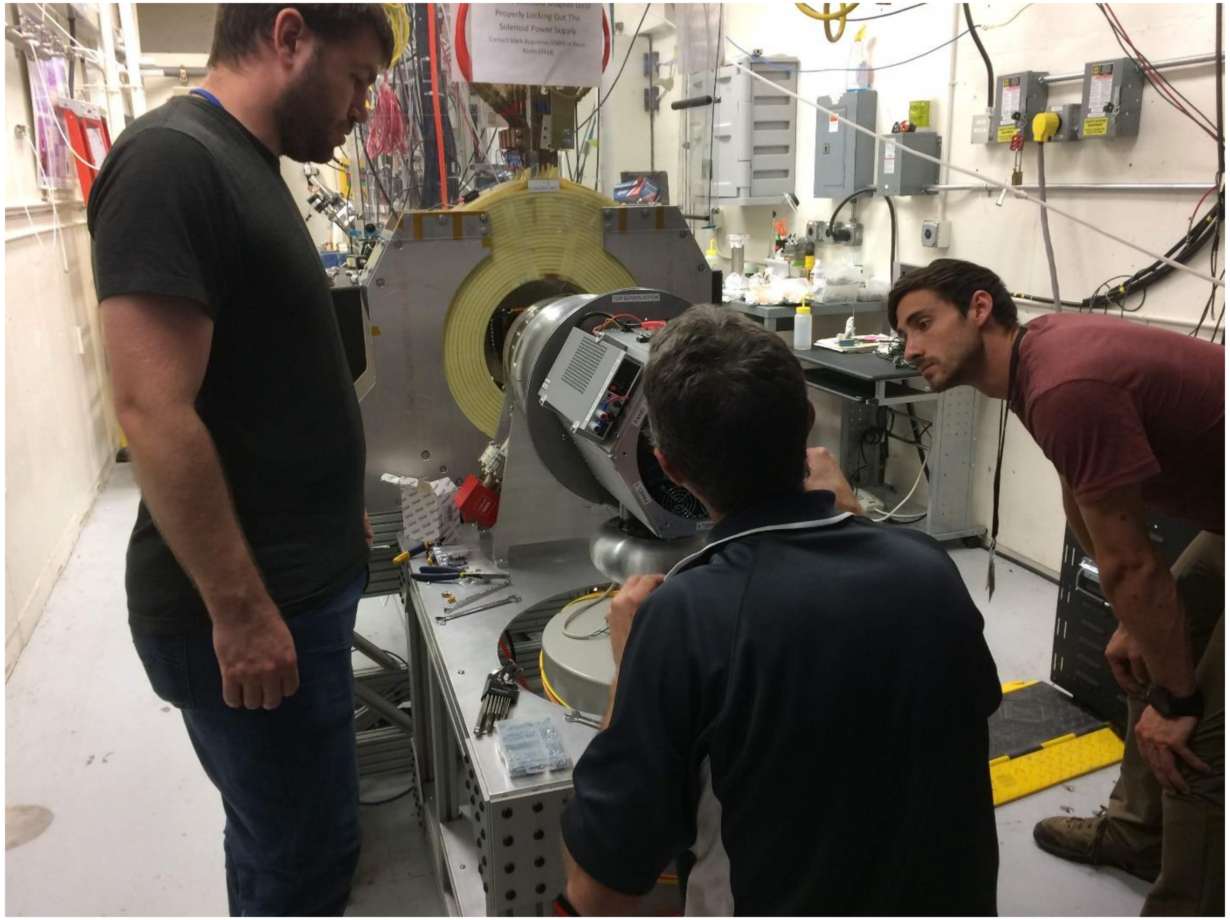
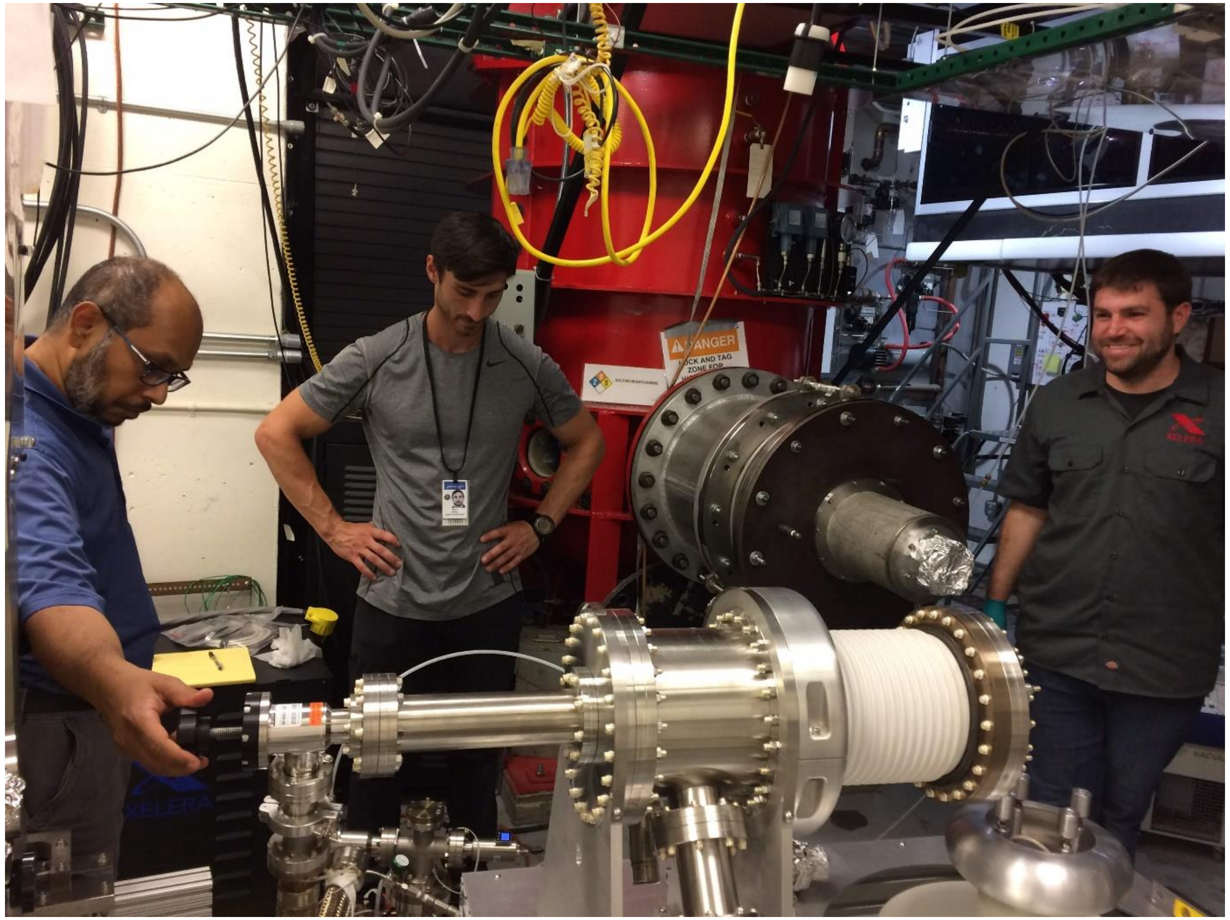
Delivery and Installation at JLab (July 2019)





Testing in JLab's Gun Test Stand





Test Results from JLab GTS

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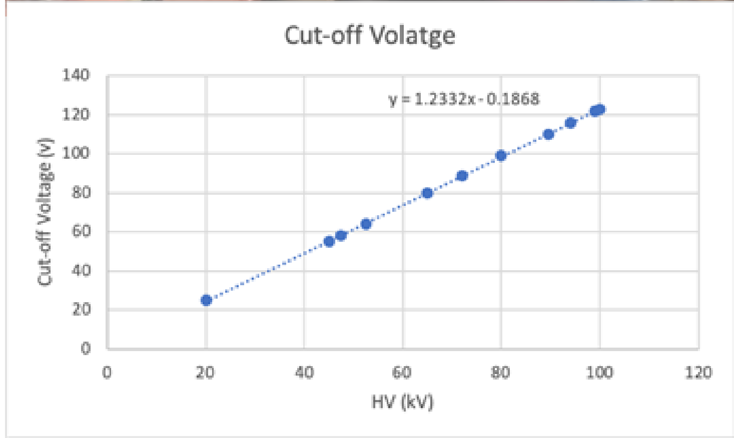
First significant beam: December 4, 2019

Grad-Student
Mark Stefani



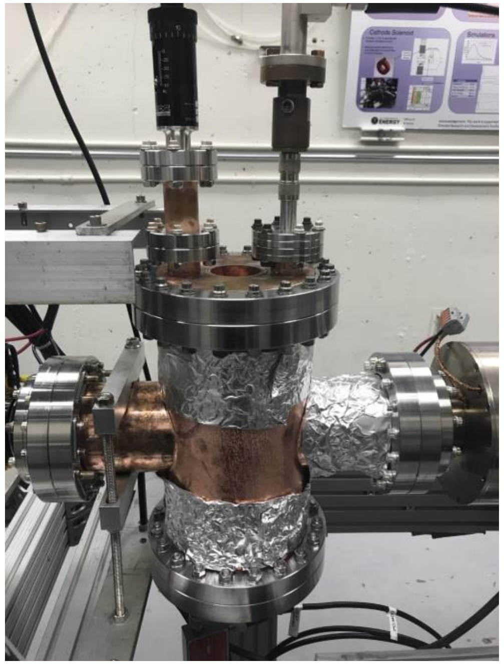
Dear All,

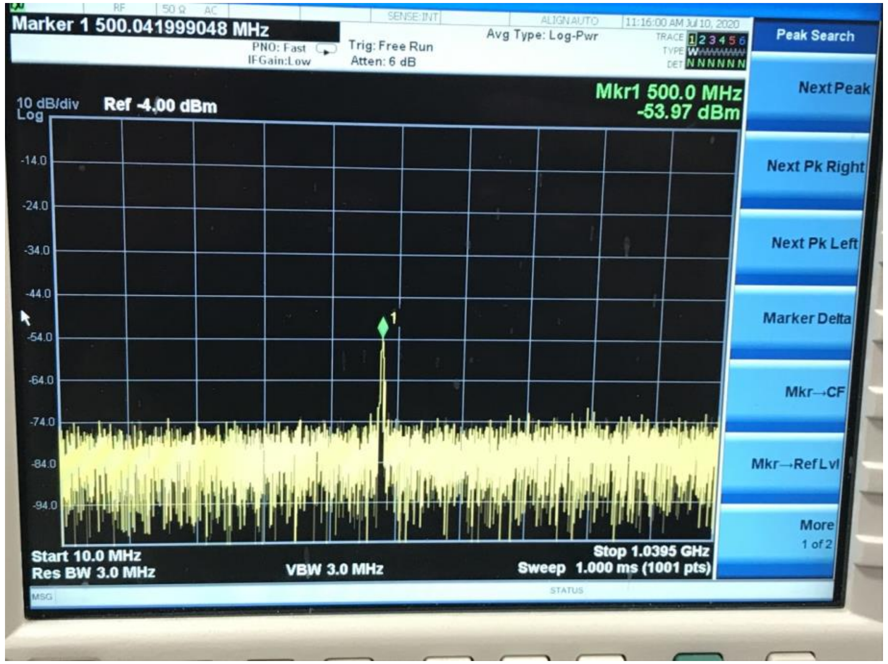
A happy update - we did it! Yesterday, with Mark driving, we saw first beam from the Xelera SBIR thermionic gun. A huge amount of work and effort went into producing this first graph of the emission cut-off voltage as a function of gun high-voltage, and we are immensely proud and excited. Congratulations and thank you to the extended team at Xelera and JLab. This is just the beginning – watch this space!

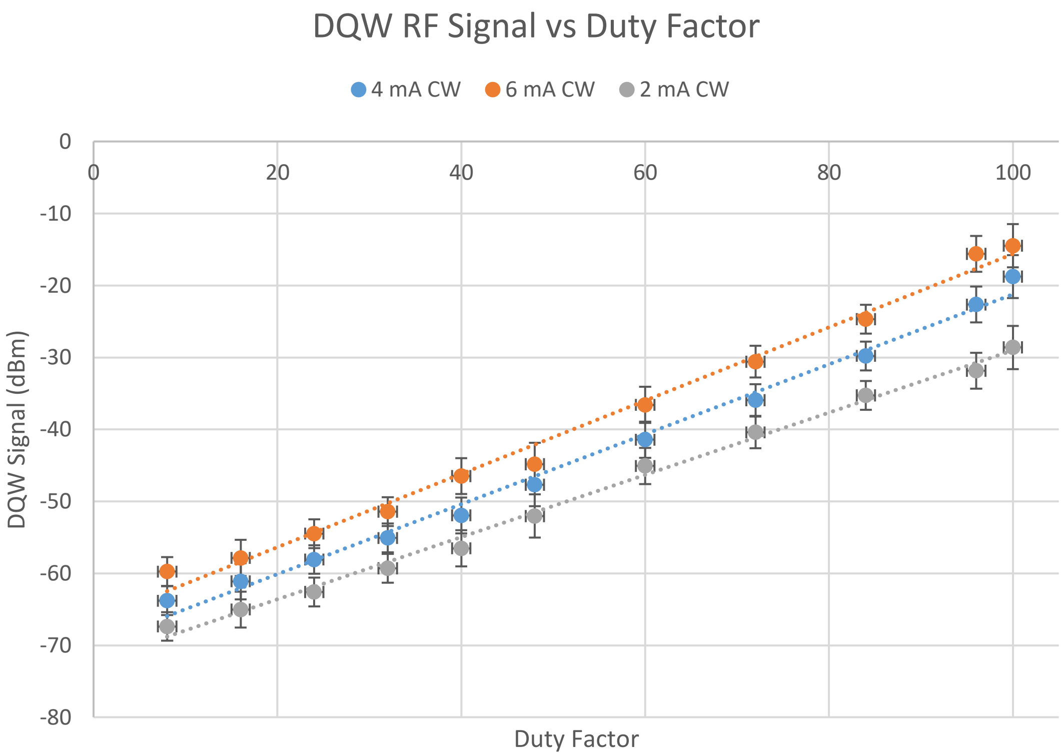
Come join us in the LERF breakroom, Monday 9th @ 11am, to celebrate with donuts.

Best wishes,
Fay

RF Modulation & Macro-pulse

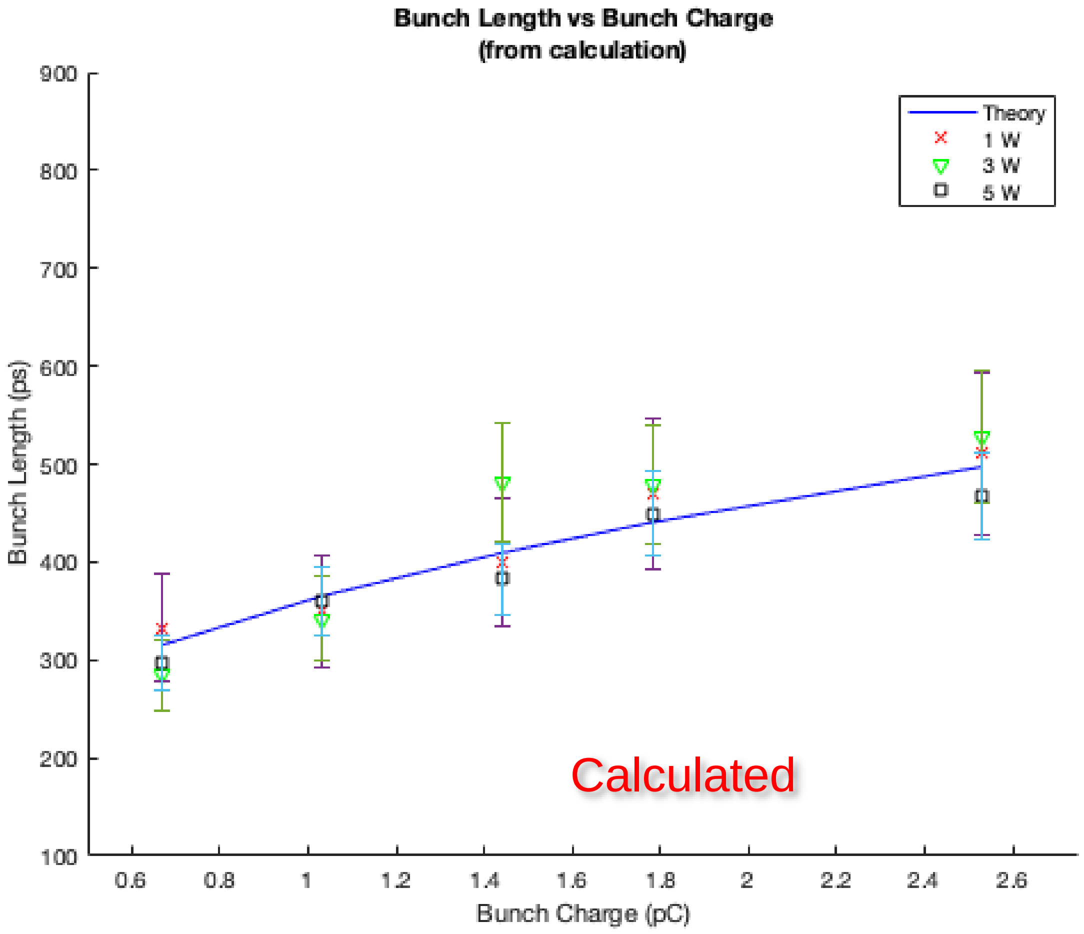


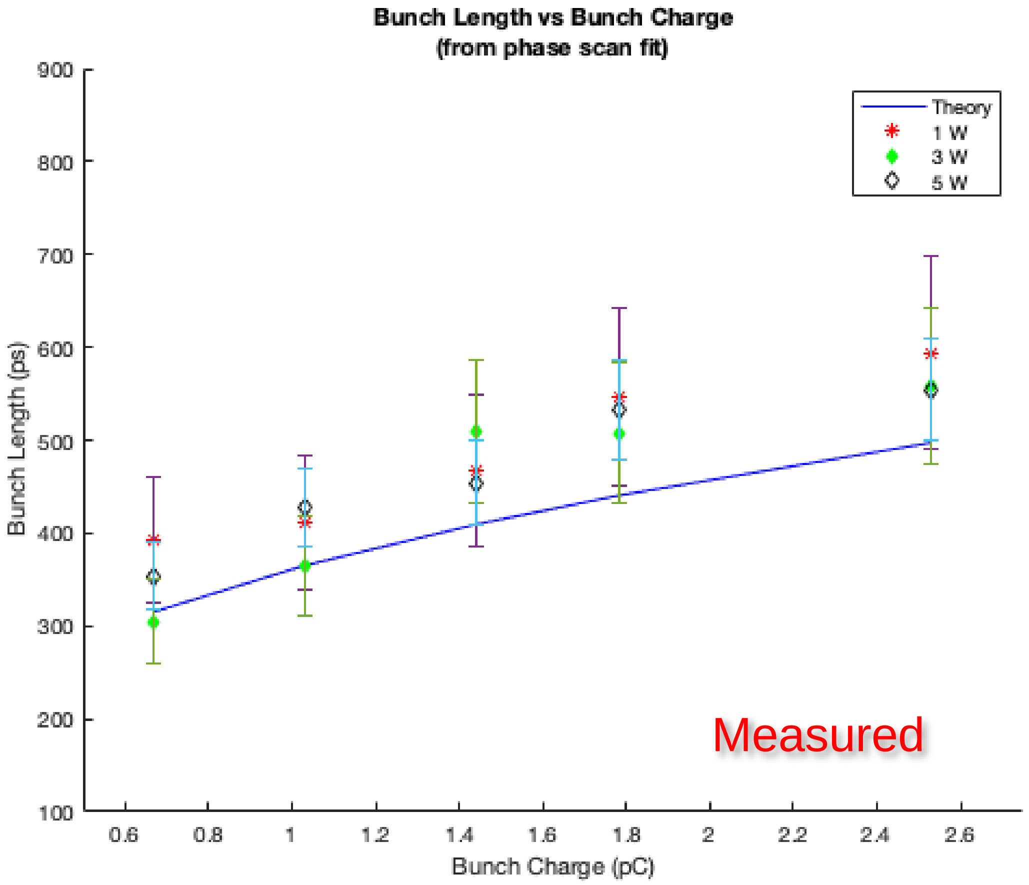




Verification of 500MHz bunch frequency

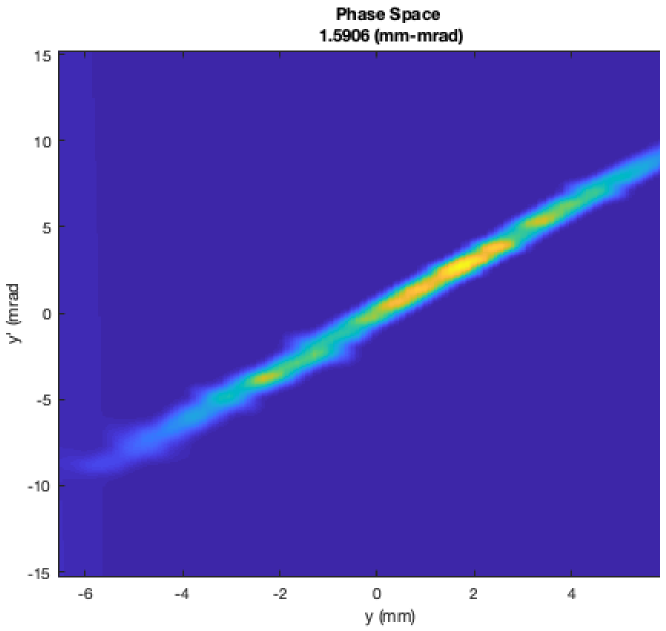
Bunch Length

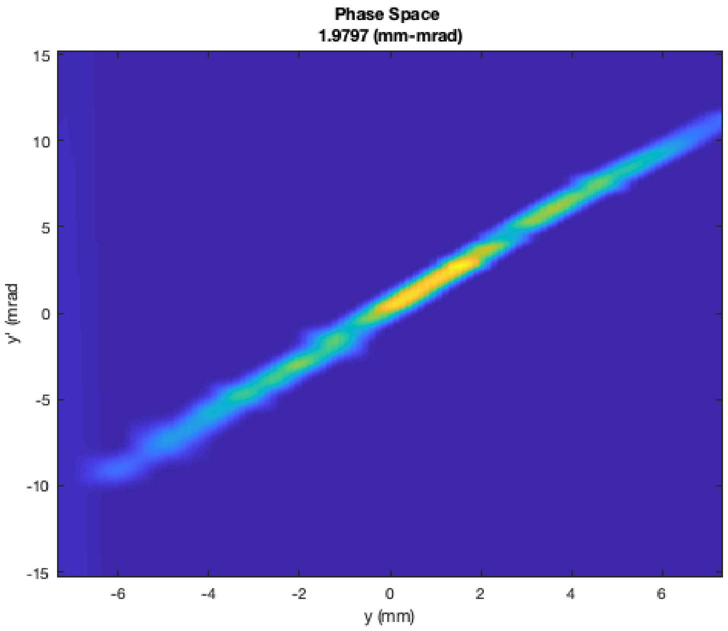


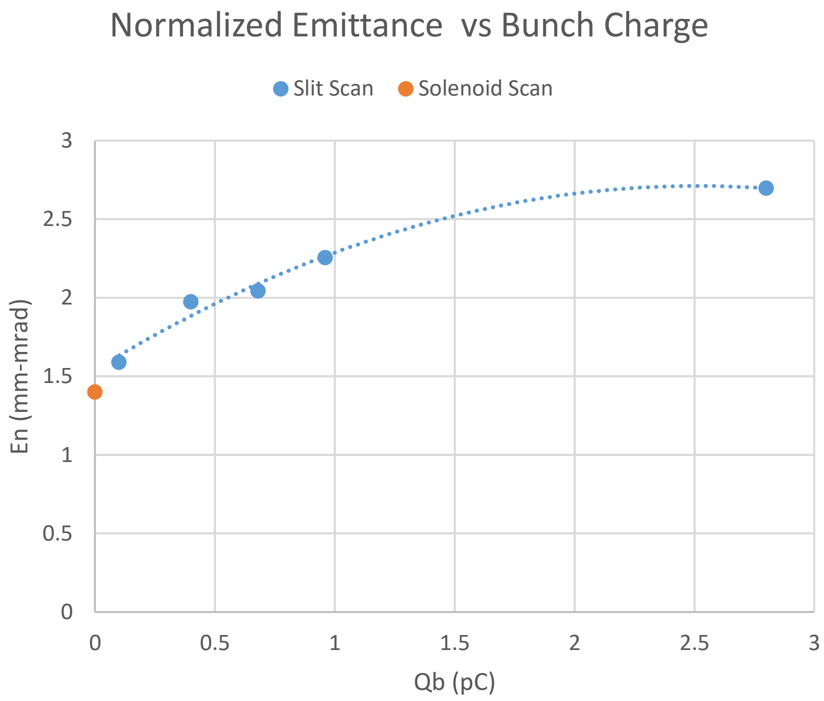


Verification of predicted bunch length

Transverse Emittance







Verification of design emittance

Remaining Work

- Bunch length of Magnetized beam
  - Show any effect magnetization may have on bunch length
- High current Magnetized beam run
  - Demonstrate long term stability of a high current magnetized beam.

Currently in progress

Summary

- In house developed highly parallel cloud-based software tools for accelerator optimization and design.
- Mechanical design and fabrication expertise: including cleanroom, vacuum lab, and machine shop for low volume manufacture.
- Phase I: Design studies and optimizations for a magnetized injector (complete).
- Phase II: Build a prototype Thermionic gun (Tgun) to produce a magnetized beam.
- Specifications and design developed in close collaboration with JLab injector group.
- Delivered and installed at JLab in July 2019 for characterization.
- Results in agreement with calculation and specification – work continues as graduate student Mark Stefani wraps up the measurements and begins writing his thesis for graduation in May 2021

END