A Magnetized Electron Source for Ion Beam Cooling

DoE Phase II SBIR

Joseph Conway, Bruce Dunham, Ralf Eichhorn, Colwyn Gulliford,
Val Kostroun (PI), Christopher Mayes, Karl Smolenski, Nicholas Taylor

Outline

- Company Overview
- Need for magnetized beams
- Phase I: Injector design
- Phase II Design
  - Beam physics
  - Electrostatic
  - RF
  - Mechanical
- Phase II Fabrication Schedule
- 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 (EIC magnetized injector design)
  - Radiation physics consulting (ASU BioDesign C safety systems design)
  - Electron source design and fabrication (JLEIC Cooler Magnetized Gun)

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 continuously at very high currents
- A Thermionic gun could be a viable (low risk) plan B
- Xelera is building a prototype Thermionic Gun (Tgun), to be tested at Jlab's Gun Test Stand (GTS) in November.

Magnetized Beams for EIC cooling

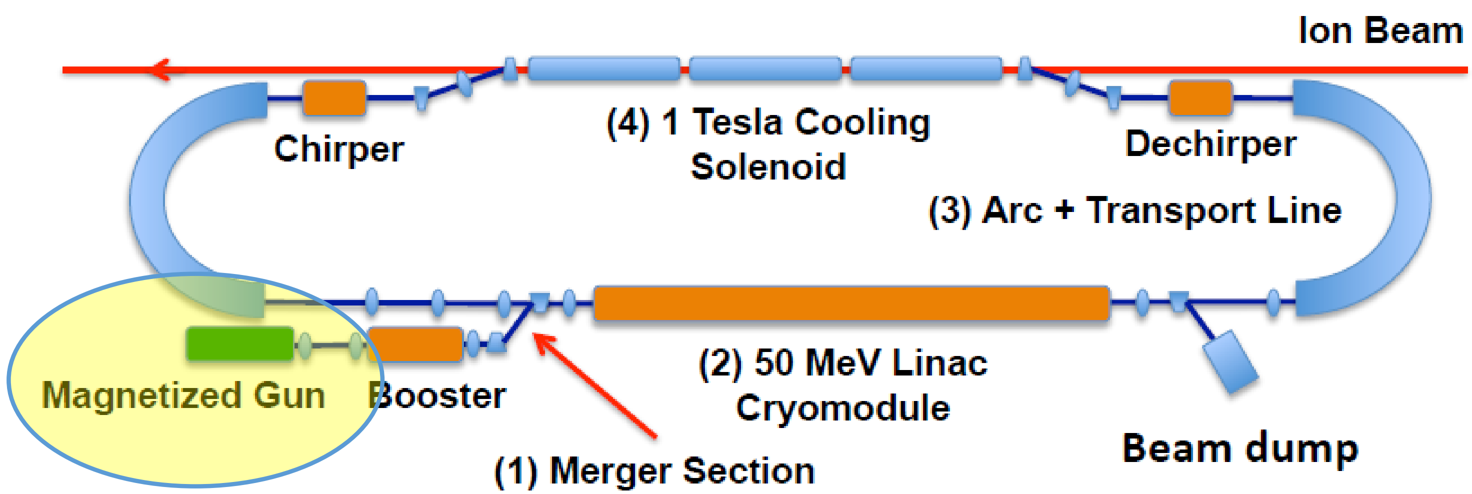
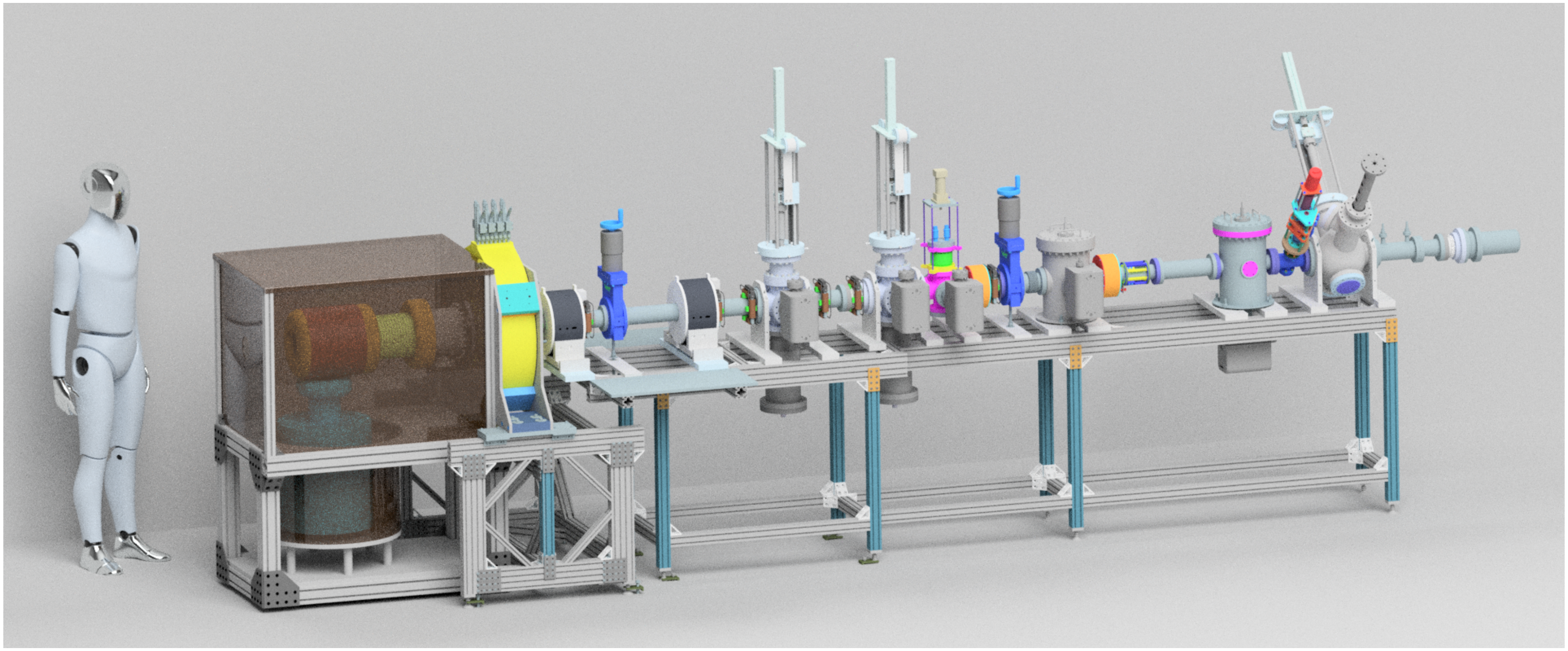
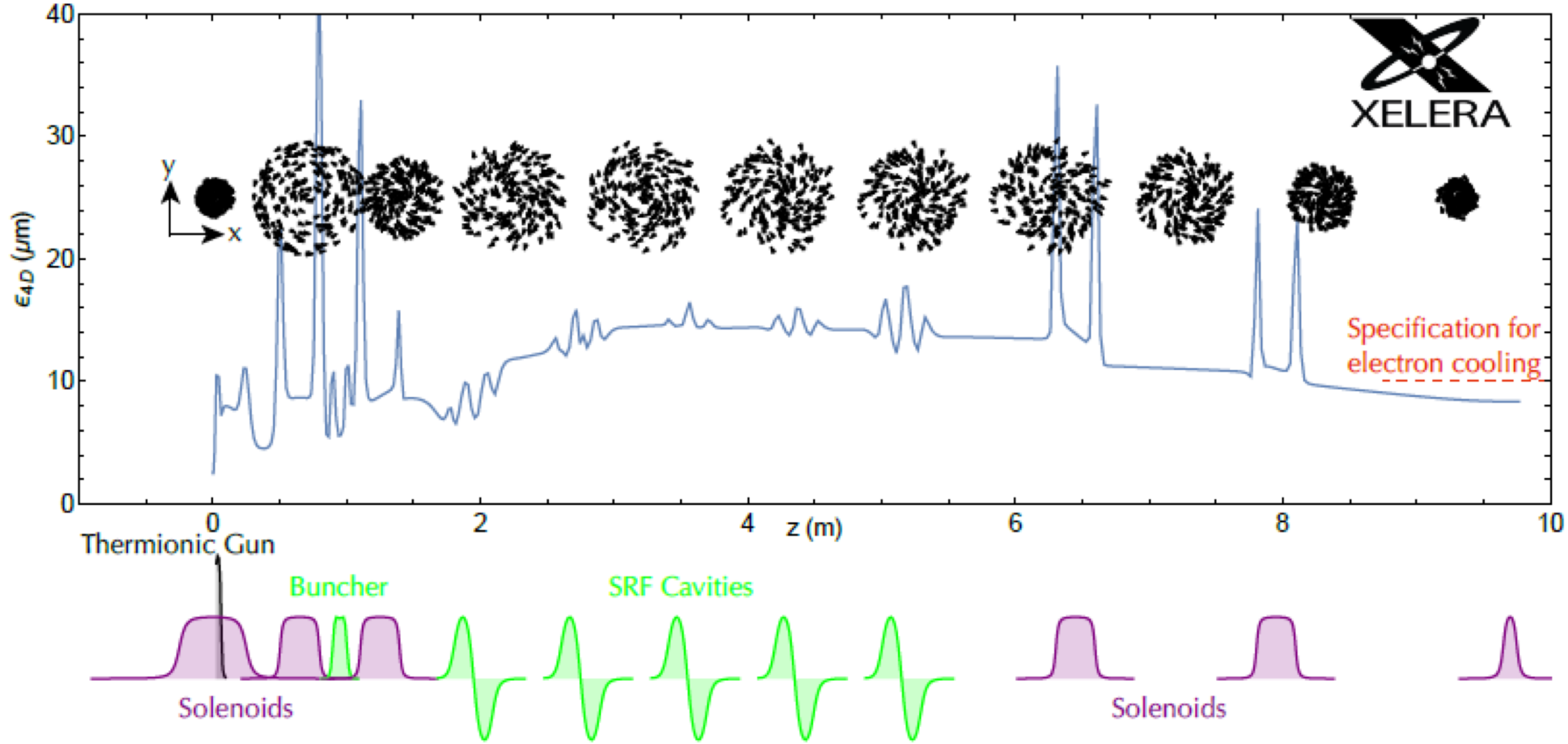


Figure 1.1: A schematic of a magnetized electron cooling system proposed for the JJefferson Lab Electron-Ion Collider (JLEIC) [5]. A magnetized beam is produced in the injector, merged (1) into the linac where it is accelerated to 55 MeV (2), and then transported (3) to the interaction region in the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

Tgun at the Gun Test Stand at JLab



Phase I: Magnetized Injector Design



Phase II: Build a Magnetized Source -TGun

Proposal excerpts

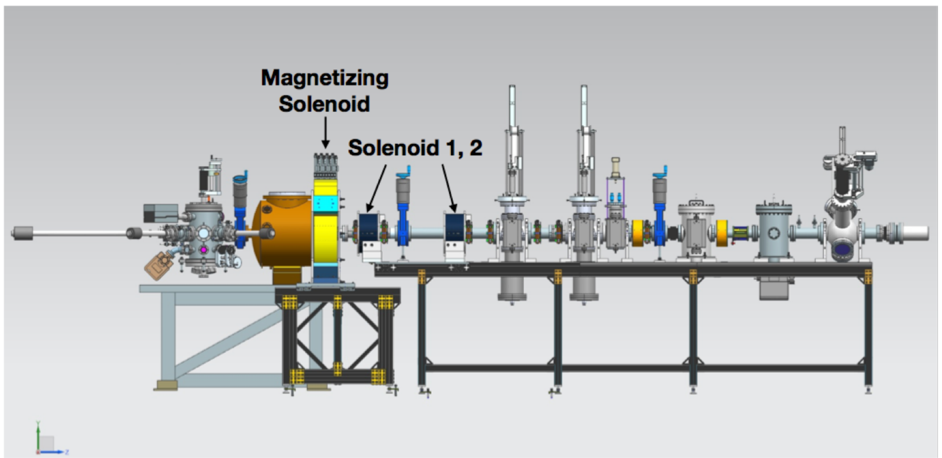
1 if the beam parameters could still be met by a less complex and cheaper device. As discussed in §1.3, Phase I results indicate that with voltages as low as 200 kV the required 4D beam emittance can still be achieved. In further simulations we will continue investigating lower beam energy with the goal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

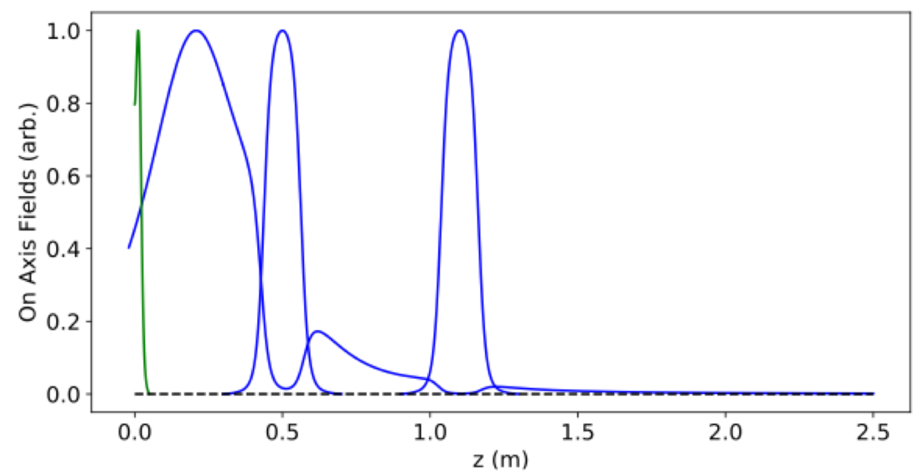
3 Once the gun is built and conditioned, it will be installed at JLab where its beam properties will be measured using their diagnostic beamline. If successful, a new

Beam Physics Design

Want optimal solution for low energy gun that works in GTS

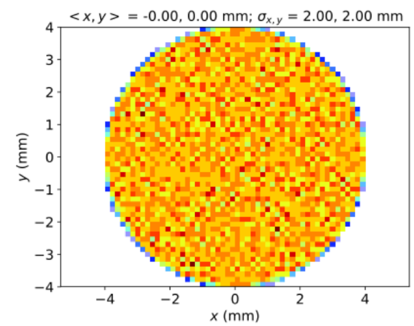


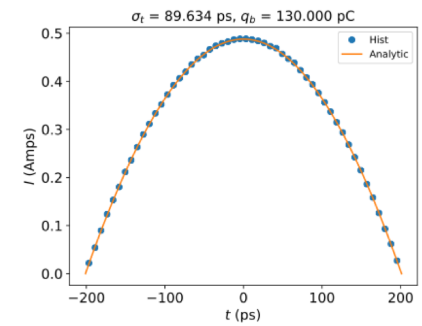
Gun and Magnetizing Solenoid: 2D field maps

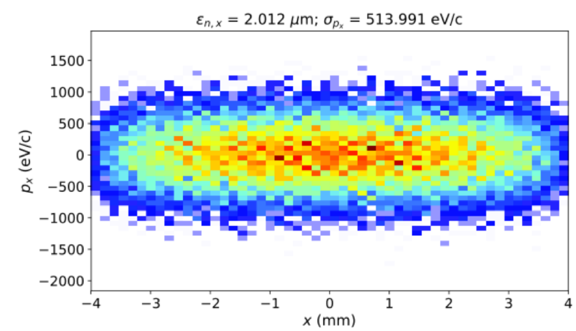


Optimization: Initial Beam/Gun Parameters

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 $I_{p,\max}$ (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 $\mathrm{MTE_{eff}}$ (meV)	517.04

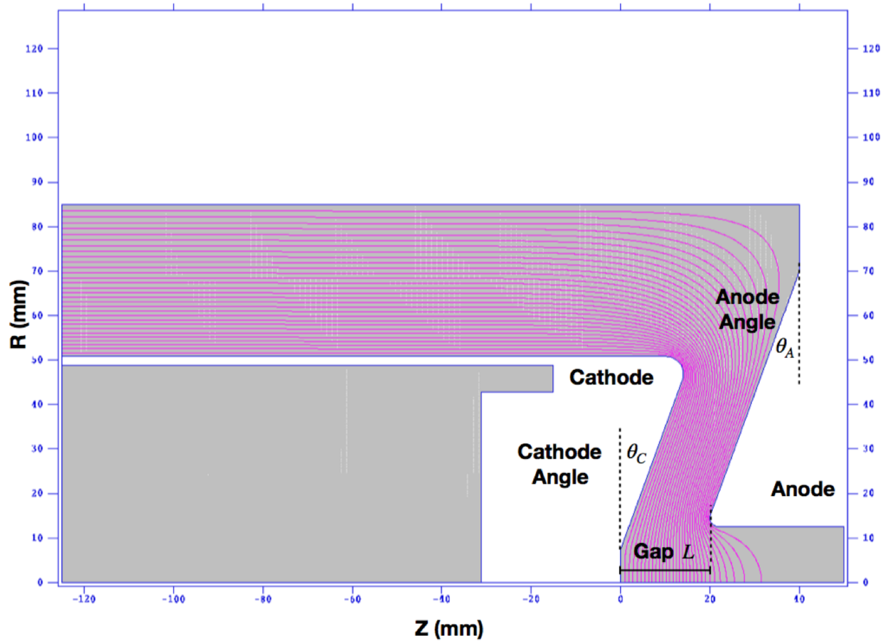






Optimization of Gun Parameters

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

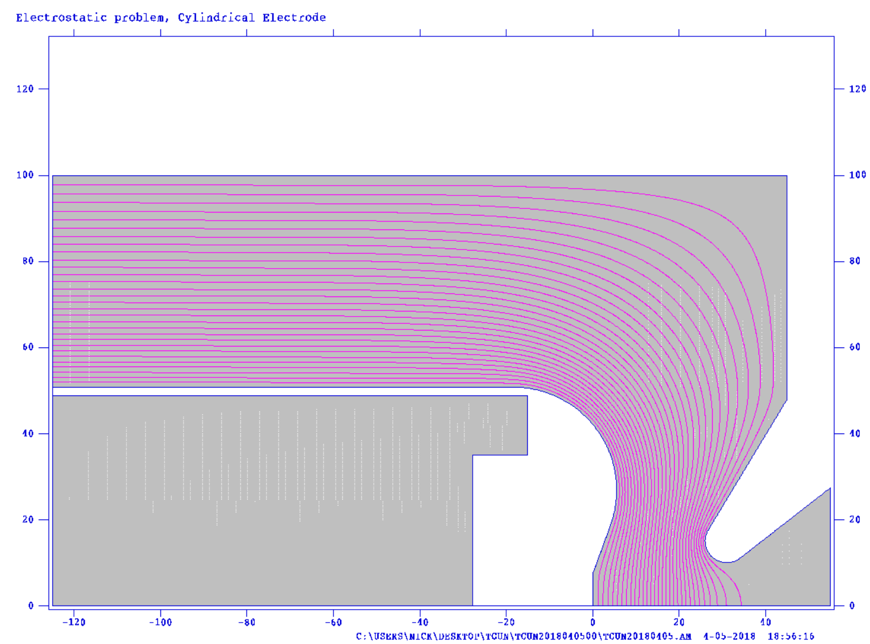


Optimal Solution

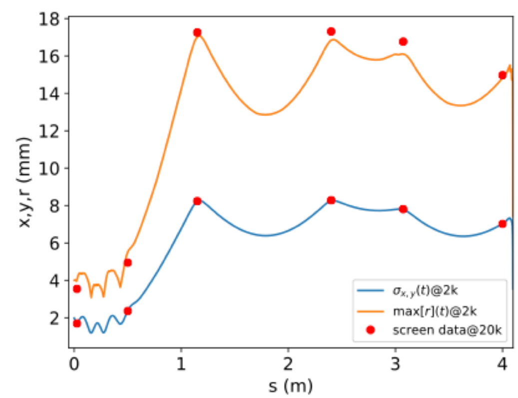
- After several parallel Multi-Objective Genetic Algorithm Optimizations, fixed on a single electrode design

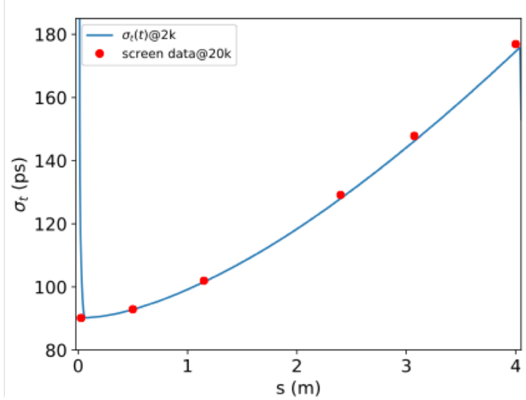
- Gap 26 mm (Optimal: 20 mm, but keeps fields down, negligible penalty to emittance)

- Meets beam dynamics requirements:
  1. Magnetized beam
  2. Bunch charge sufficient for high current demonstration

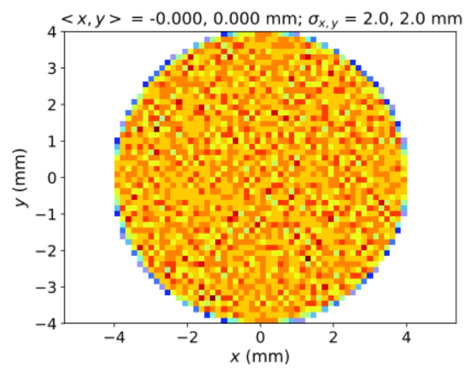


130 pC Solution: Beam Size Evolution through GTS

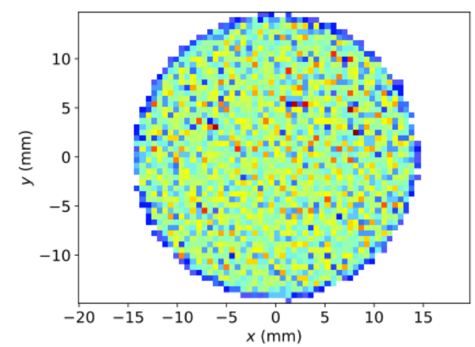




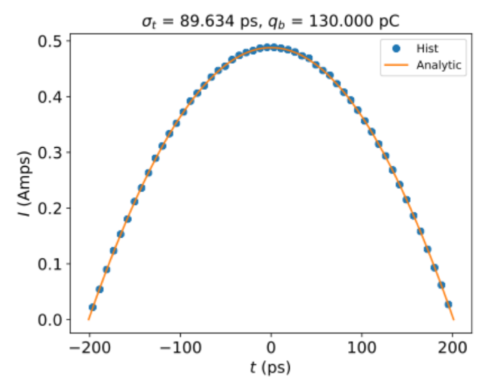
Transverse Profile (Cathode)



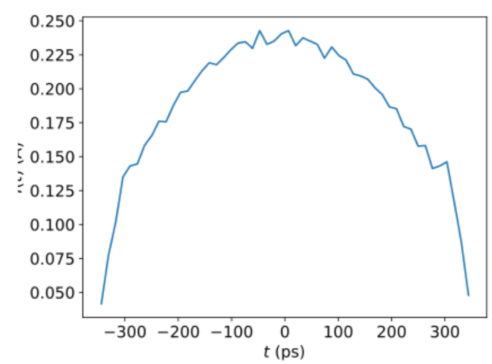
Transverse Profile (4.0 m)



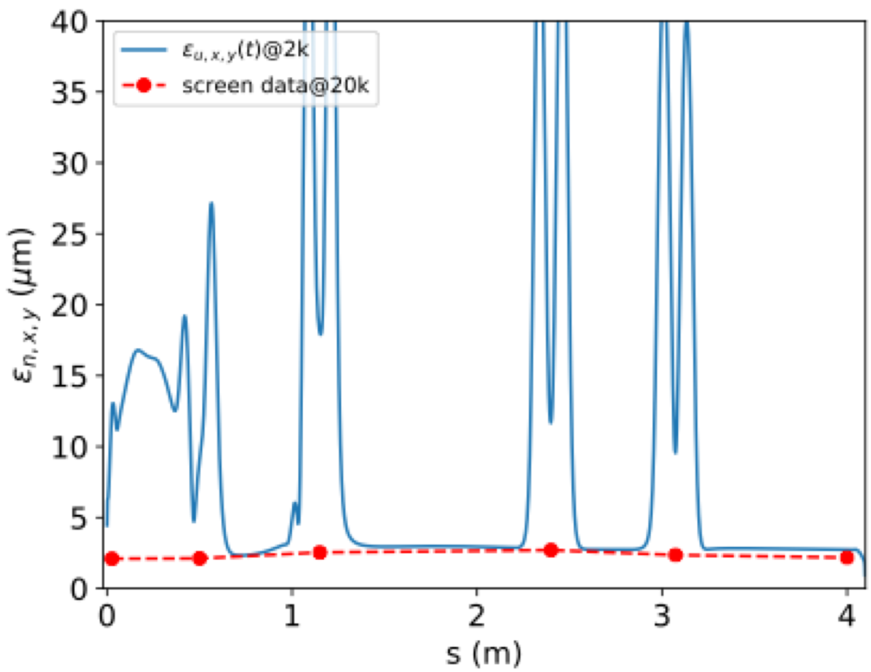
Current Profile (Cathode)



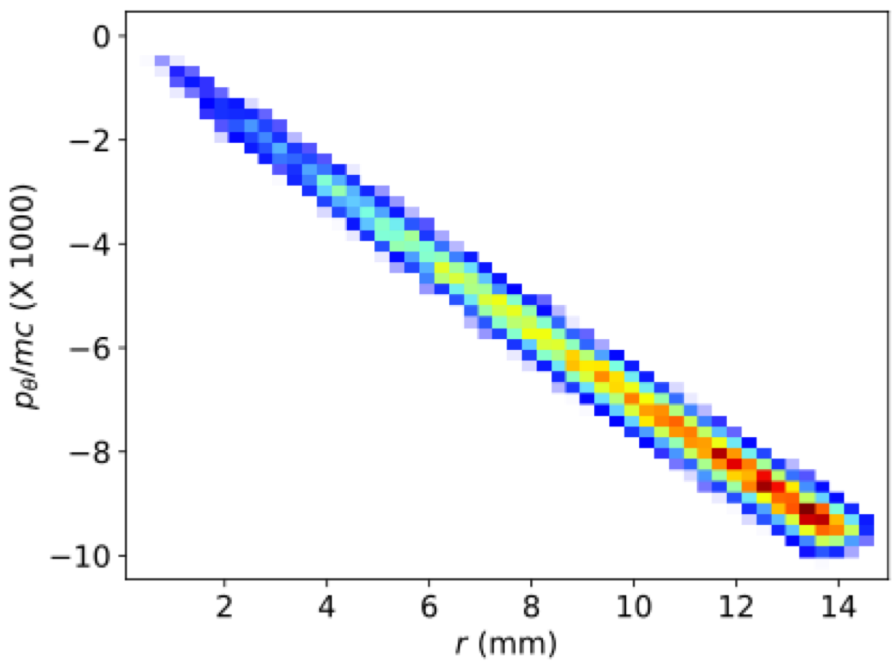
Current Profile (4.0 m)



130 pC Solution: Emittance Evolution



Magnetization (4 m)



Physics design summary

RF Frequency: 500 MHz (subharmonic of 1500 MHz)

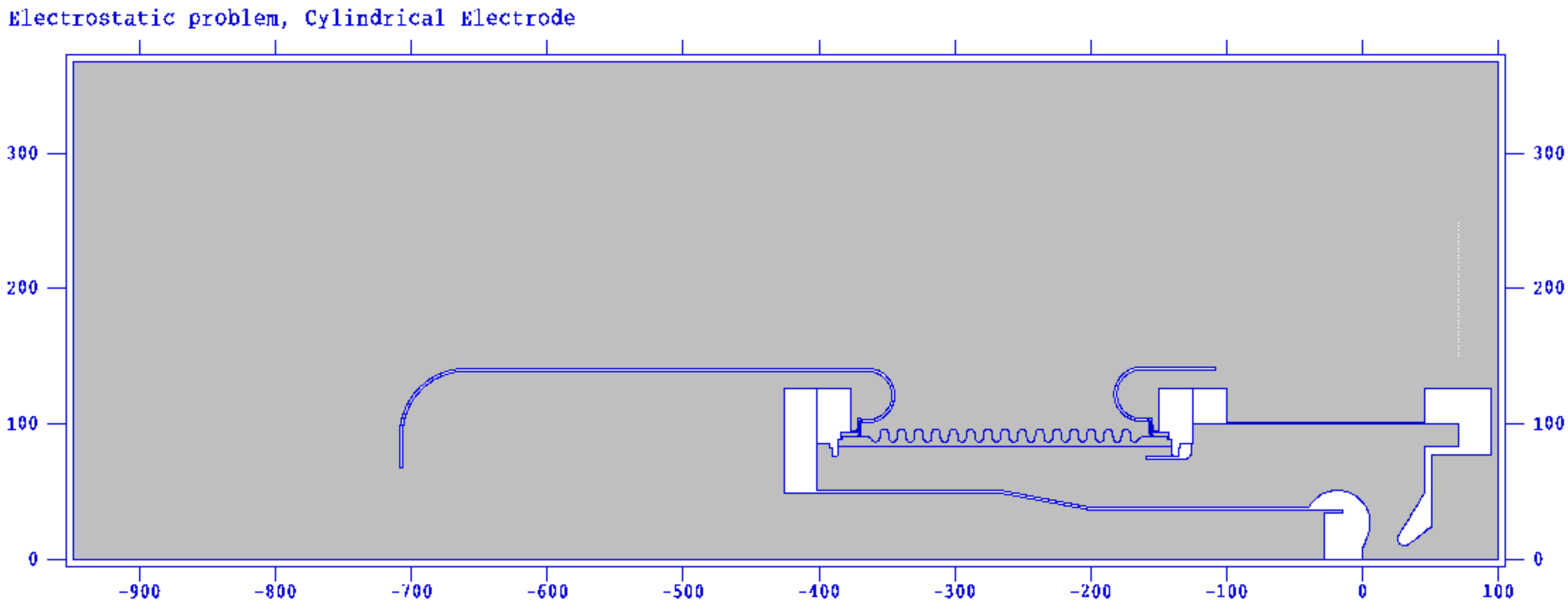
Cathode: CPI Y-845, R = 0.4 cm.

Nominal bunch charges: 20 pC, 130 pC

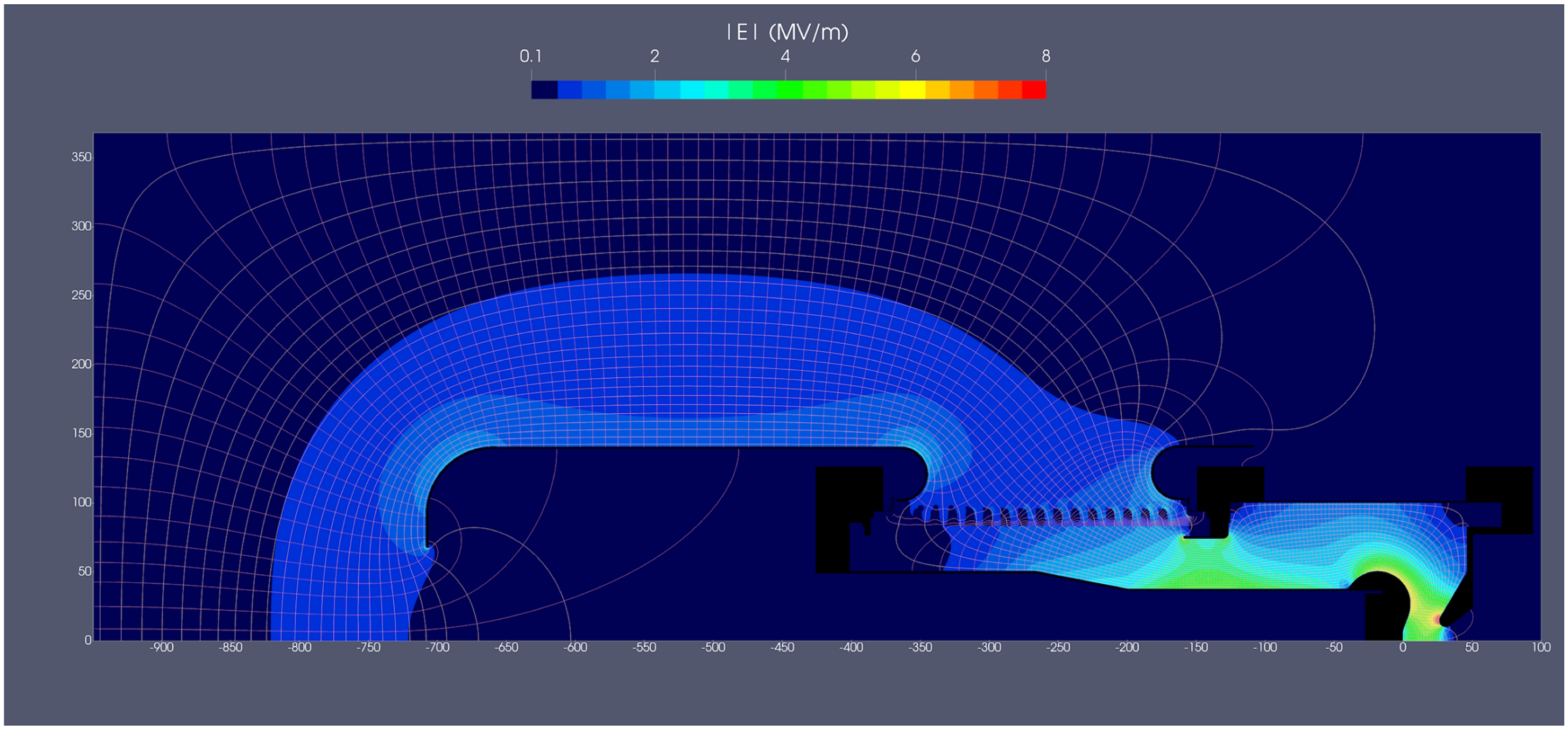
Cathode/Electrode geometry determined by Multi-Objective Genetic Optimization (MOGA):
- Gap = 26 mm,
- Cathode Angle 20 deg,
- Anode Angle = 31 deg

Emittance (~2 micron) preserved along 4 meters of GTS for a magnetized emittance of about 36 micron.

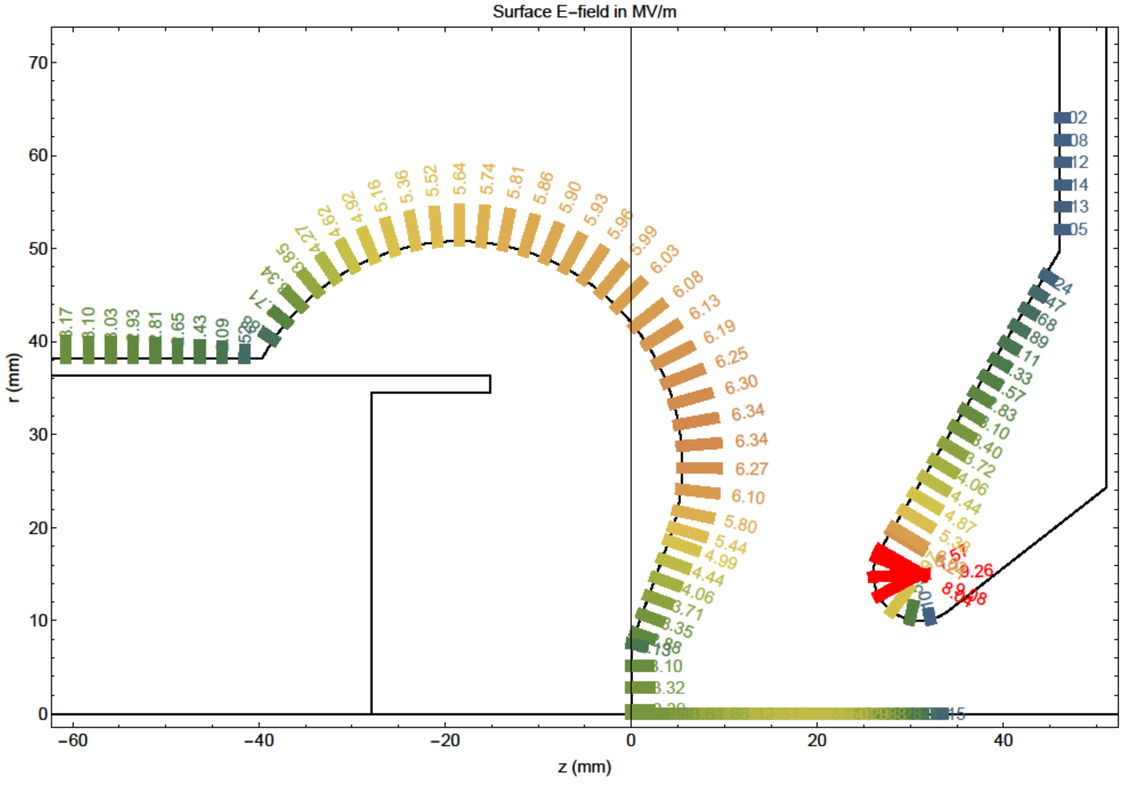
Complete Model in Poisson (LANL)



Electrostatic Design



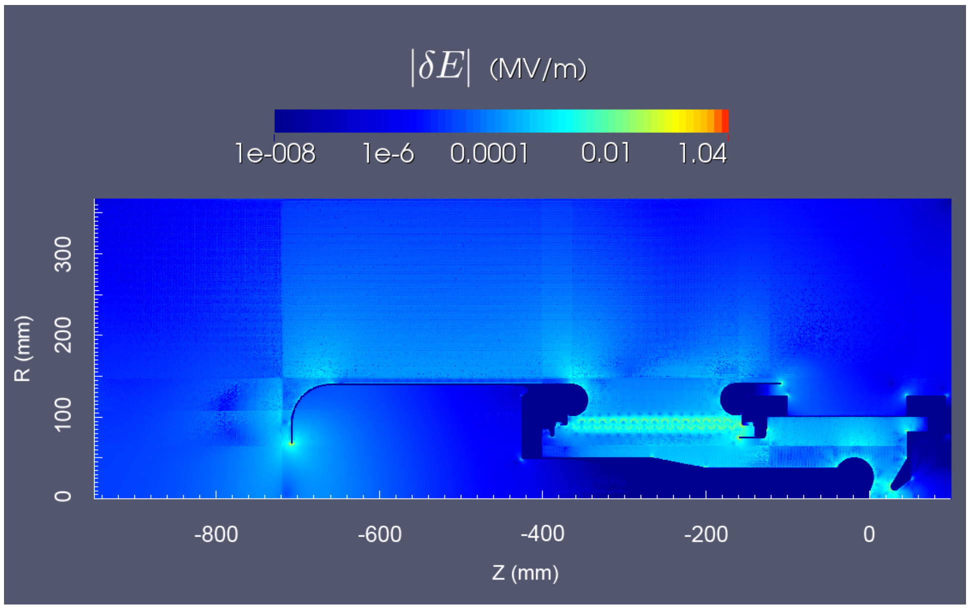
Close up on Anode-Cathode Gap Region



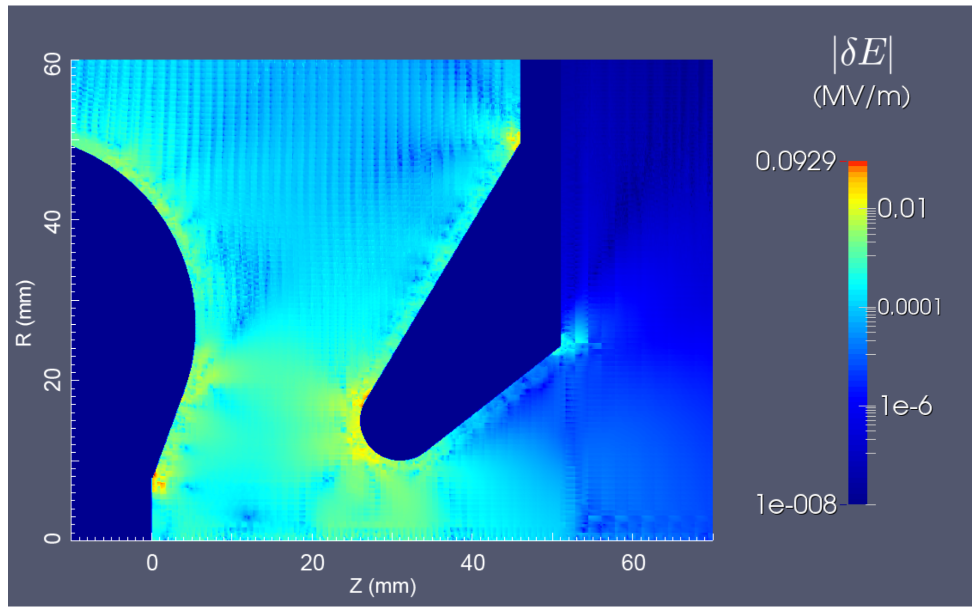
Max surface field on Cathode about 6.3 MV/m

Poisson Convergence Study

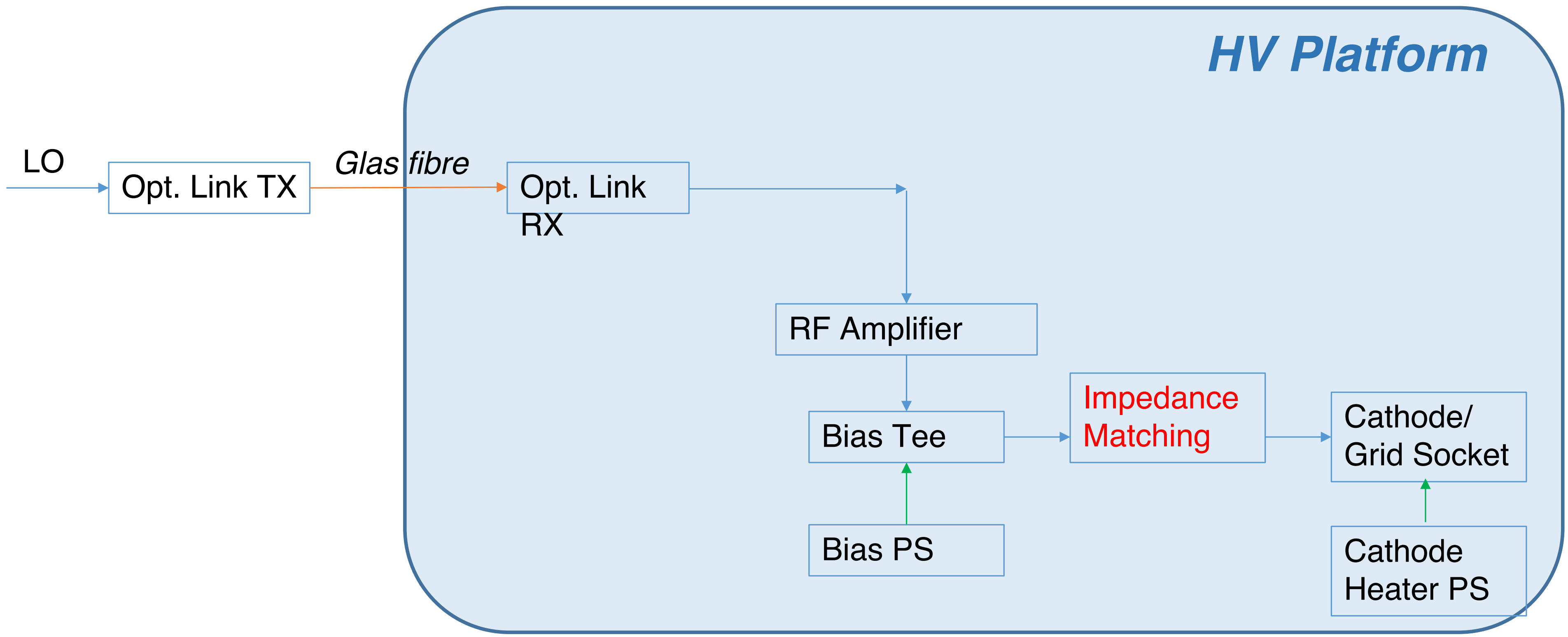
Full Geometry



Cathode Detail

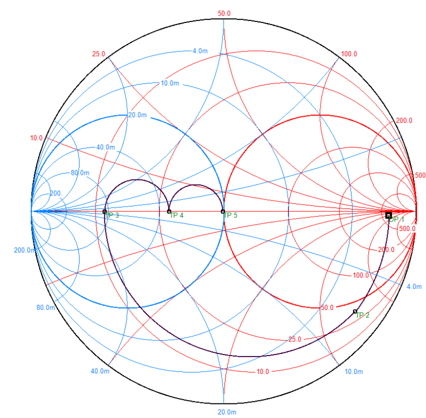


Conceptual RF Drive Layout

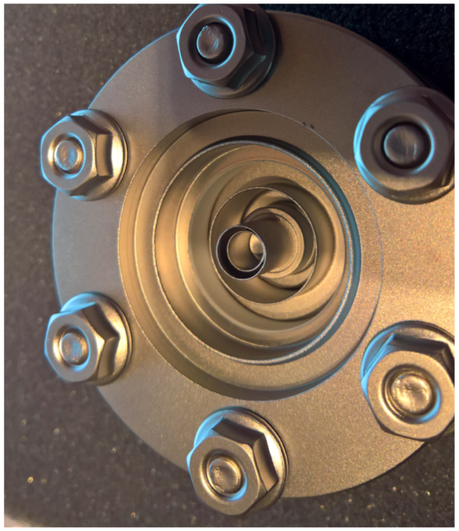


RF design

- RF Design is mostly done
- RF Components and suppliers have been identified
- Long lead time items have been ordered (fibre link, power amplifiers)
- Other components are typically off the shelve or less than 4 weeks ARO
  -> order will be placed shortly after the review
- Impedance matcher is (RF)-designed, mechanical design is progressing

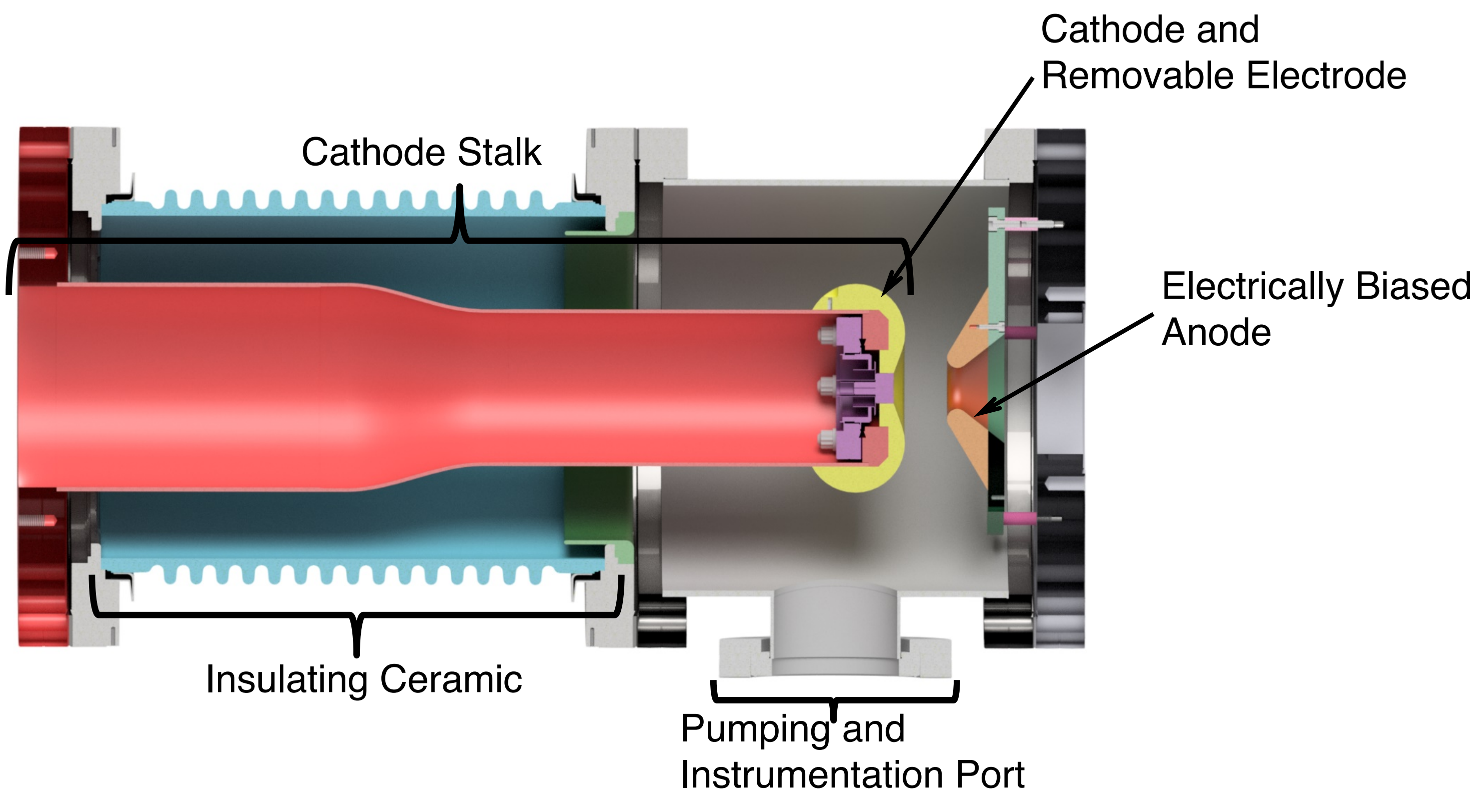


Impedance matching design

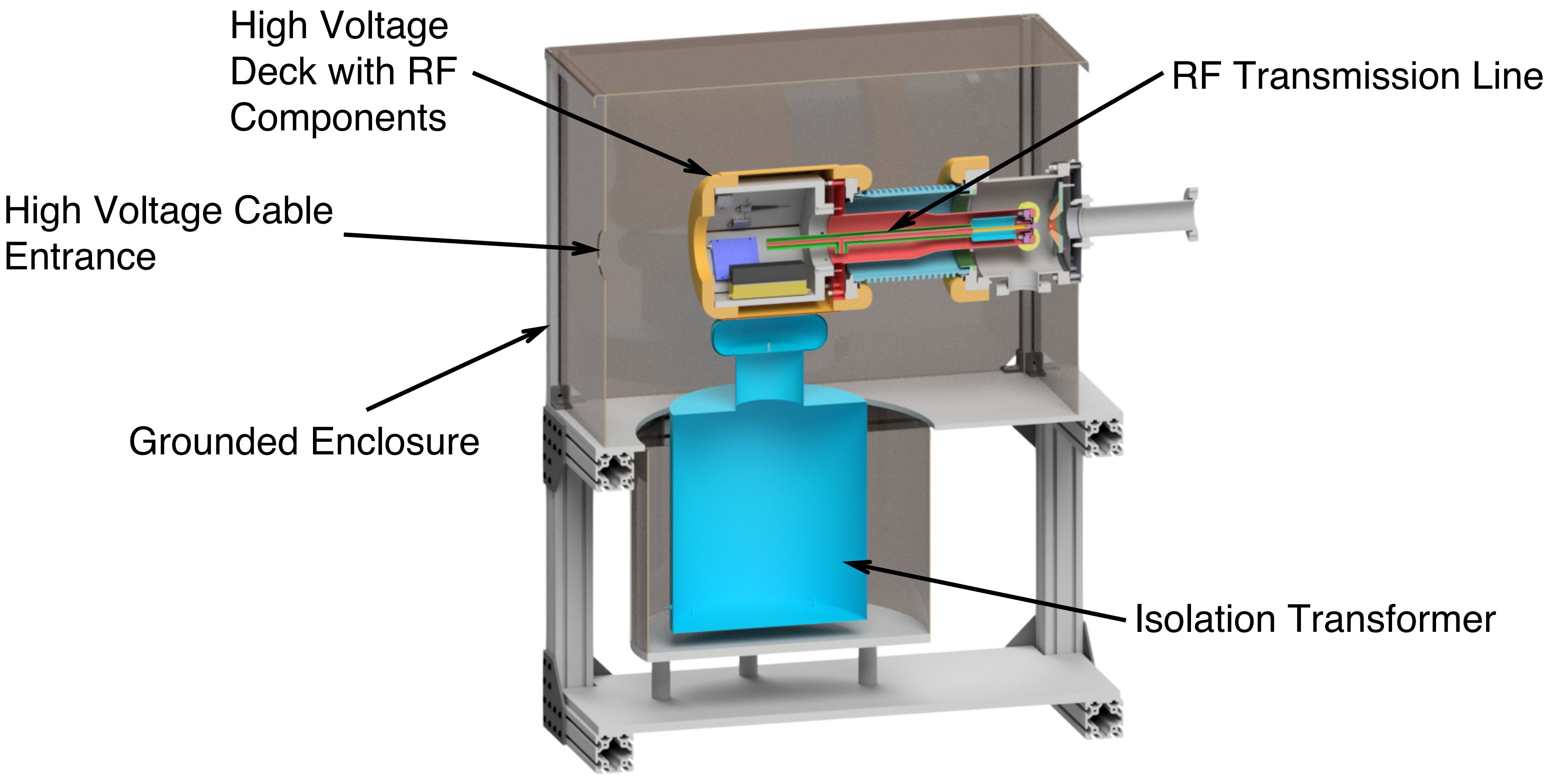


Back of Cathode as received

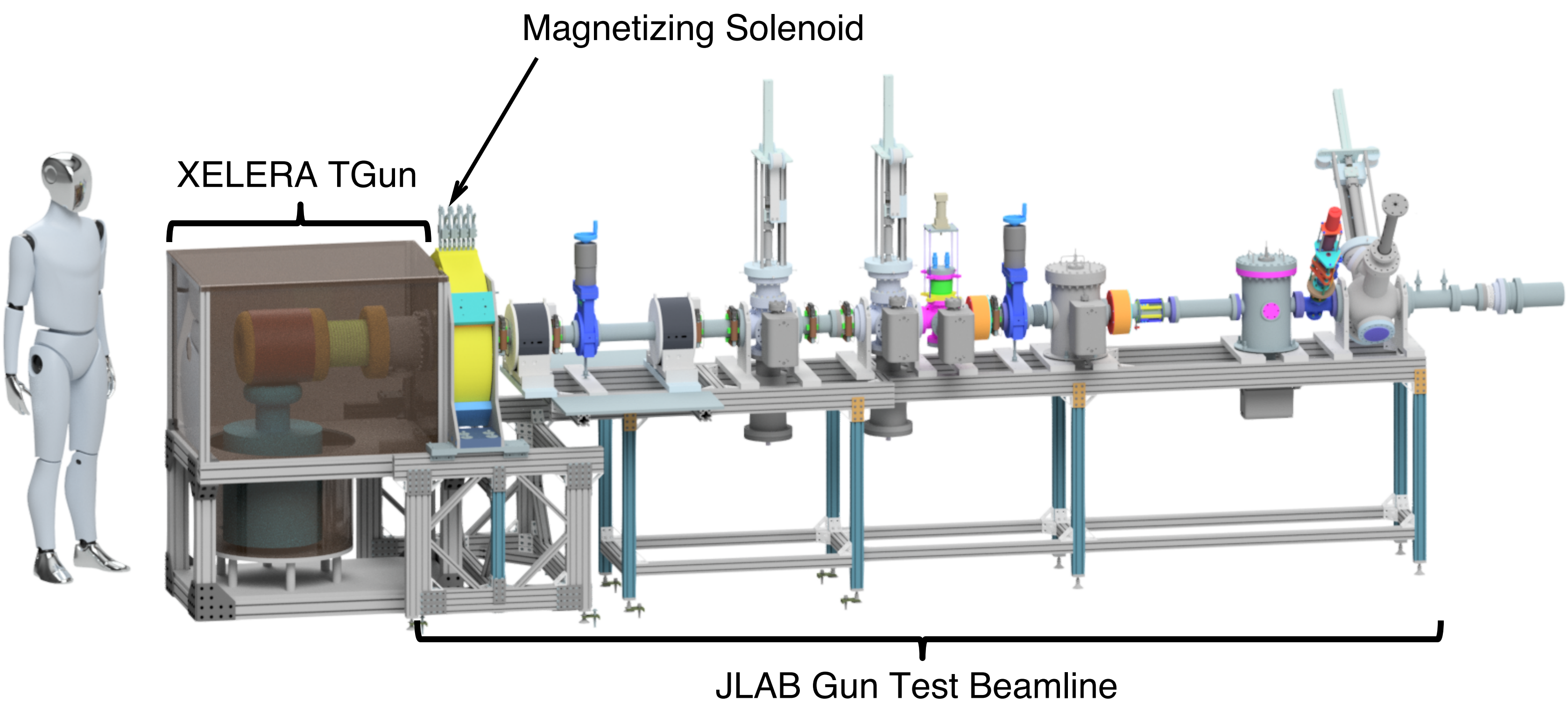
Vacuum System Mechanical Design



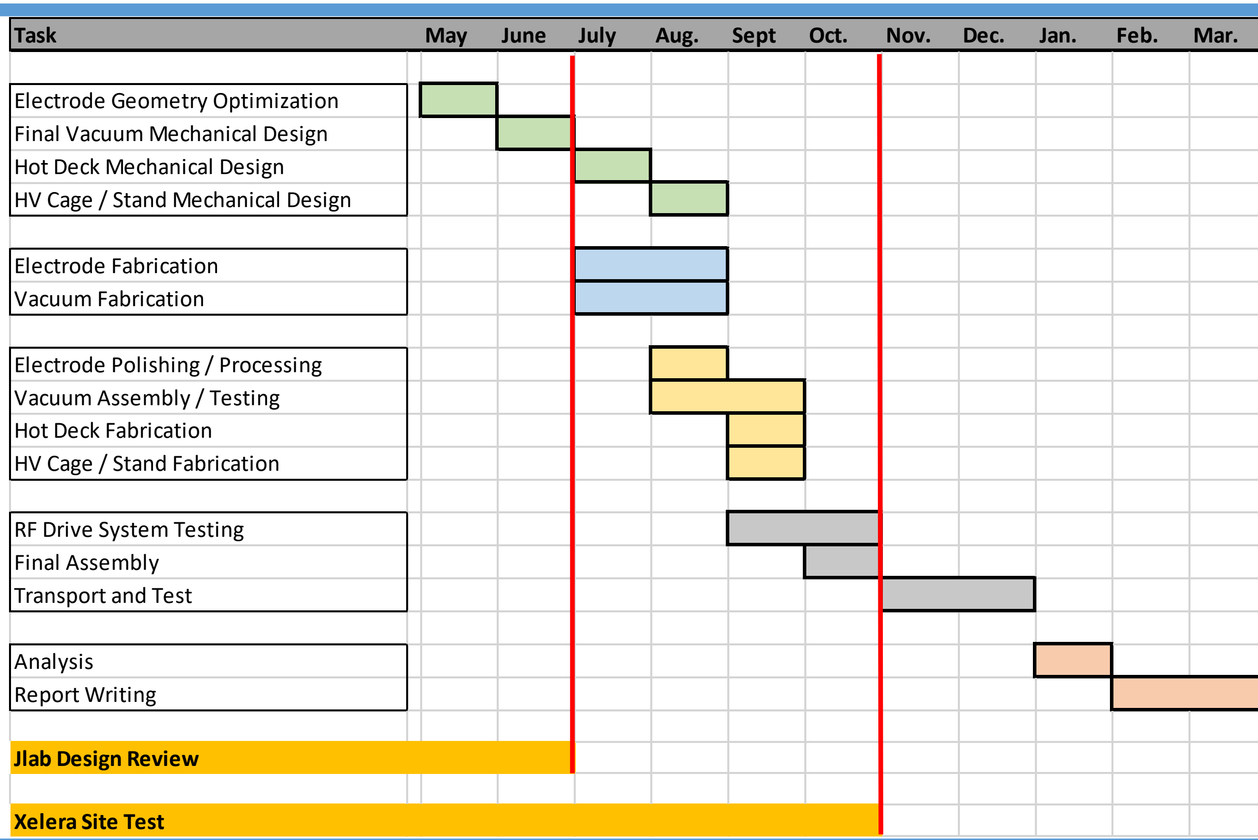
Full Gun Design



XELERA TGun in JLAB GTS Beamline



Schedule


Task
May
June
July
Aug.
Sept
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Electrode Geometry Optimization
Final Vacuum Mechanical Design
Hot Deck Mechanical Design
HV Cage / Stand Mechanical Design
Electrode Fabrication
Vacuum Fabrication
Electrode Polishing / Processing
Vacuum Assembly / Testing
Hot Deck Fabrication
HV Cage / Stand Fabrication
RF Drive System Testing
Final Assembly
Transport and Test
Analysis
Report Writing
Jlab Design Review
Xelera Site Test

Summary

- Xelera formed from the former Cornell ERL team in 2013.
- 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.
- Design is complete, beginning fabrication now.
- JLab test at the Gun Test Stand (GTS) late this year.

END