Injector Status and Challenges for CBETA

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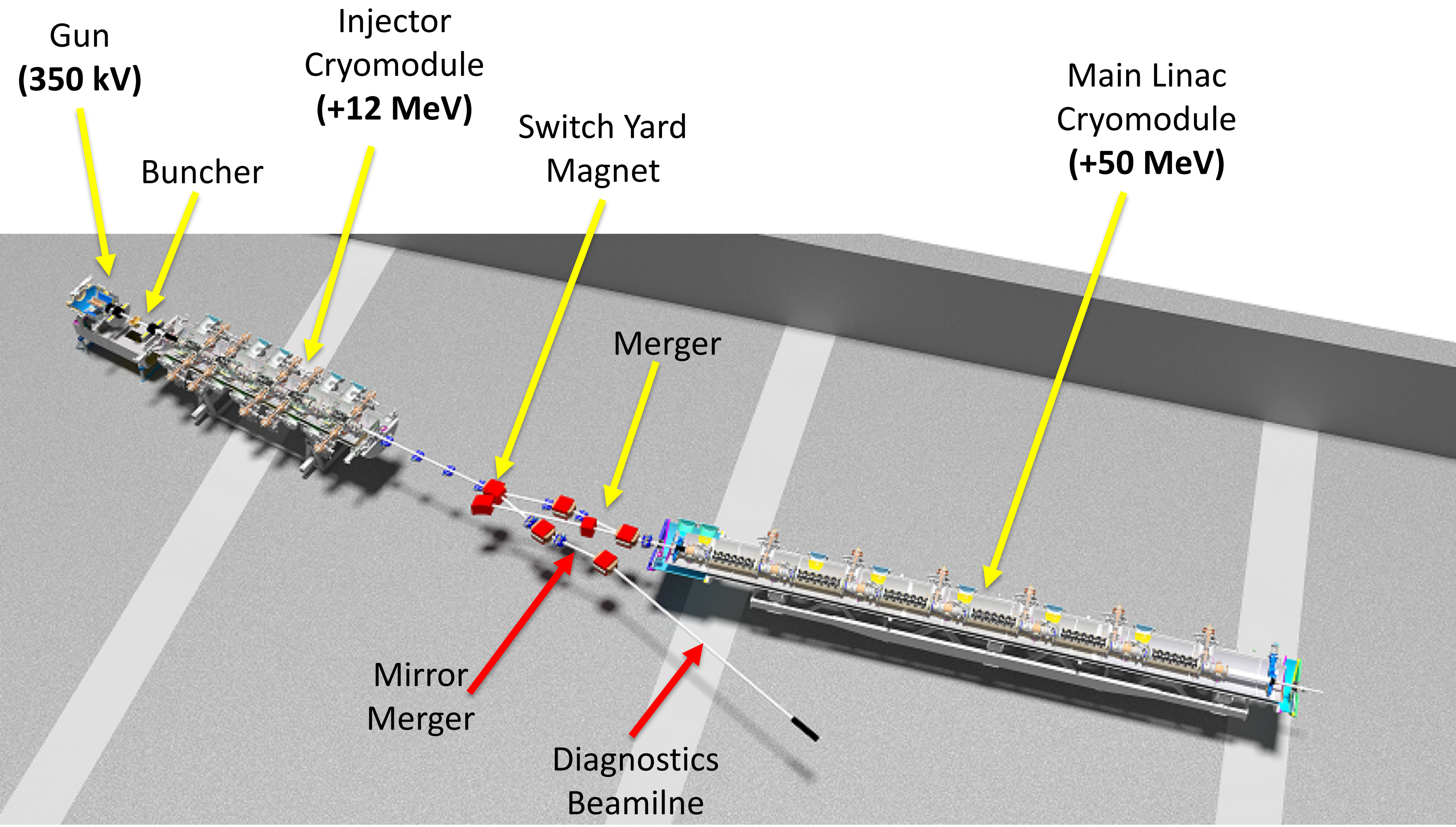
CBETA
CORNELL-BNL ERL TEST ACCELERATOR

BROOKHAVEN
NATIONAL LABORATORY

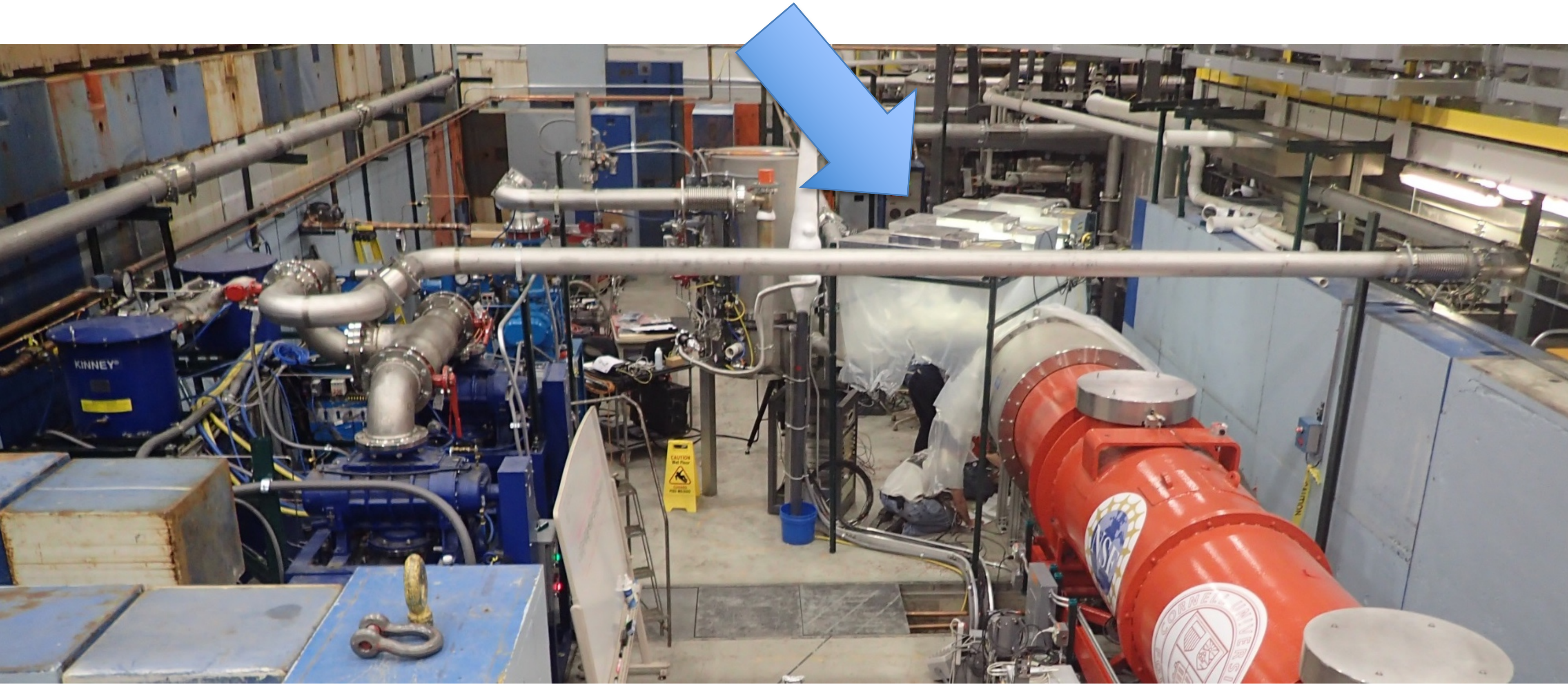
Outline

- Current Status
- Repurposing Cornell ERL Injector
- CBETA requirements
- Gun
- Laser
- Injector Cryomodule
- Lessons learned

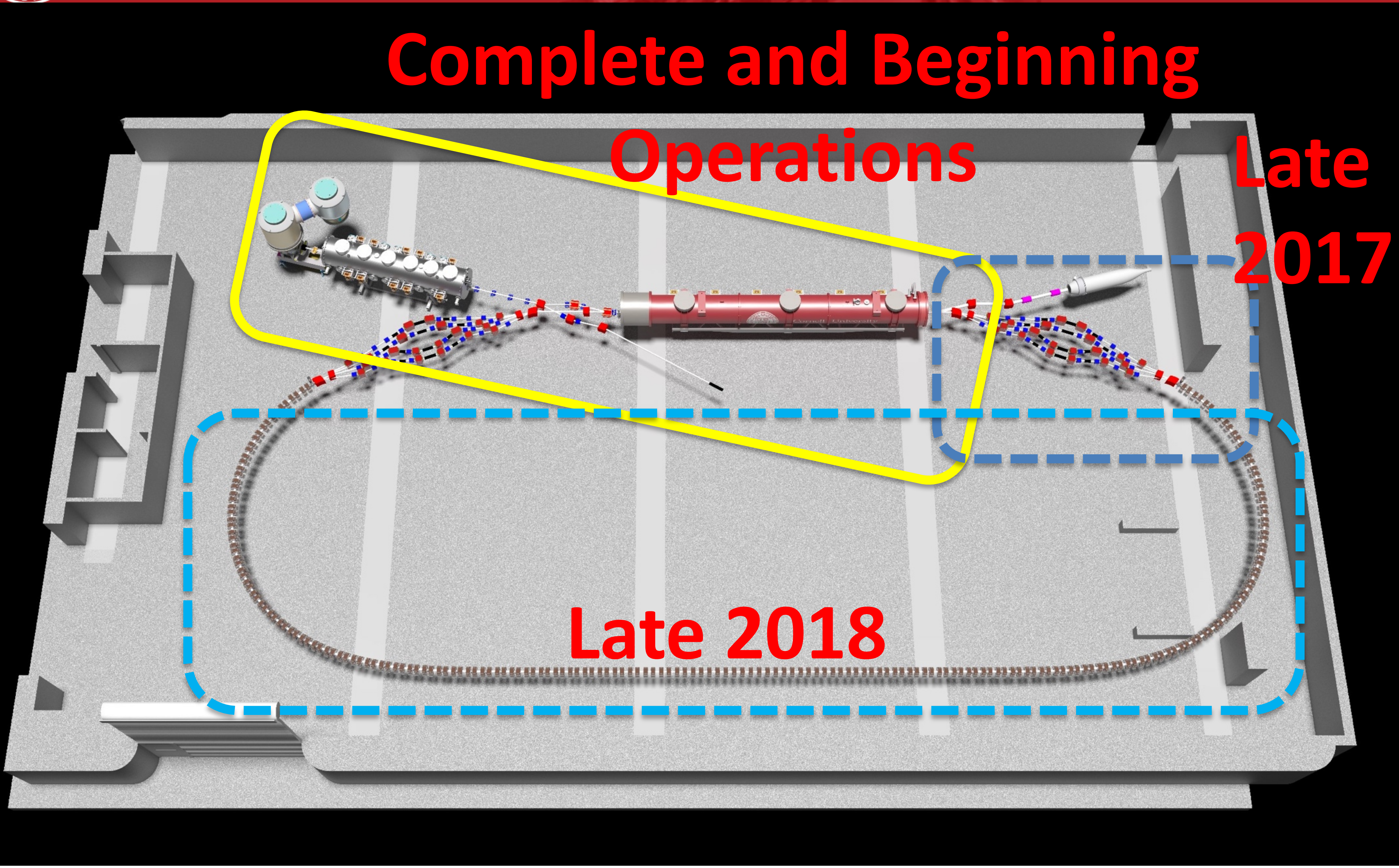
Present Injector Layout



Injector / Merger



CBETA Final Layout

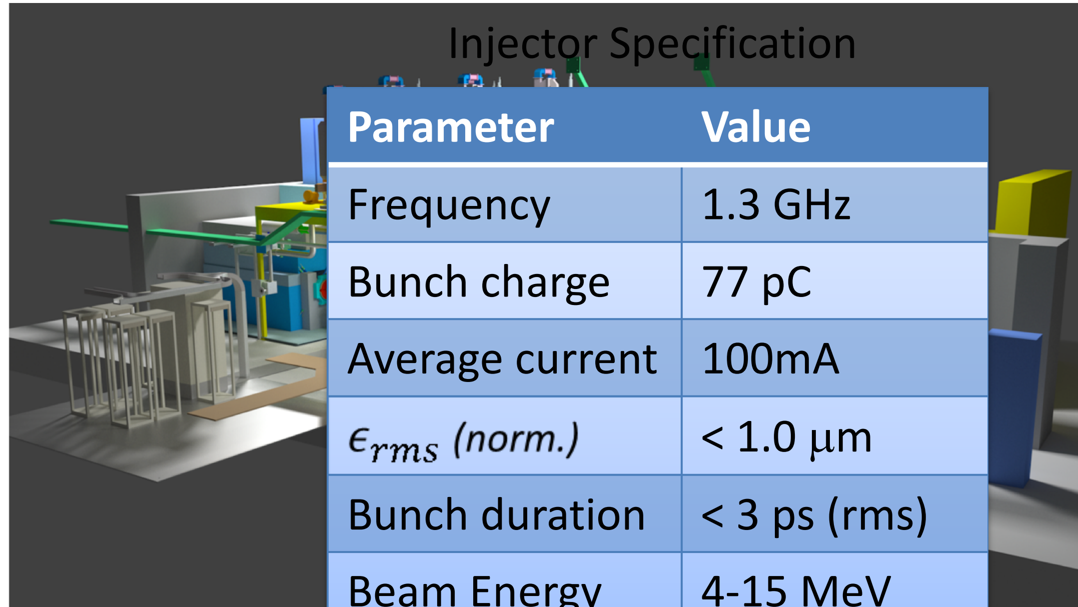


Original Design

Original design: ERL injector

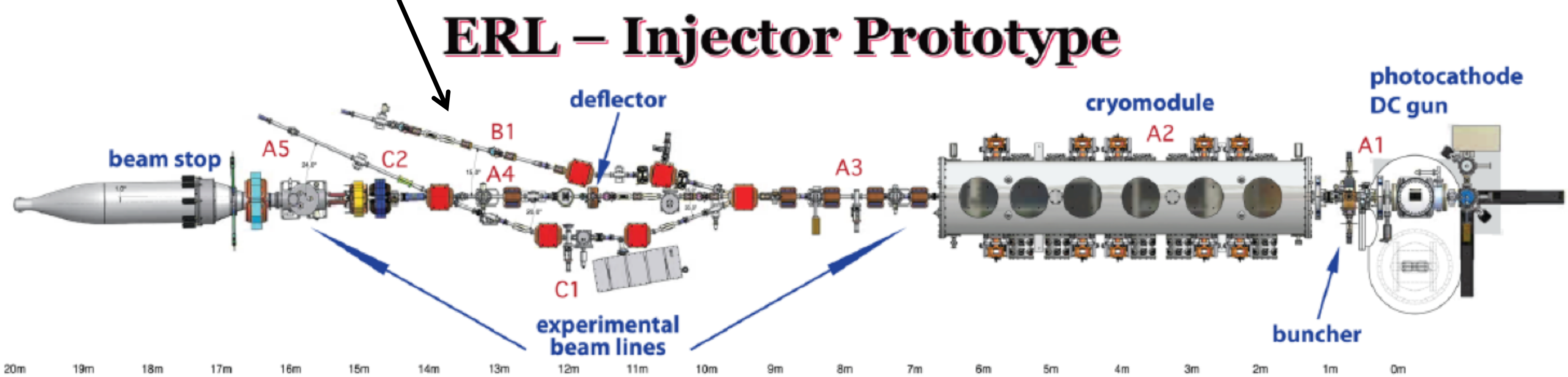
- Moderate charge
- High current

- Note: merger section (B1)

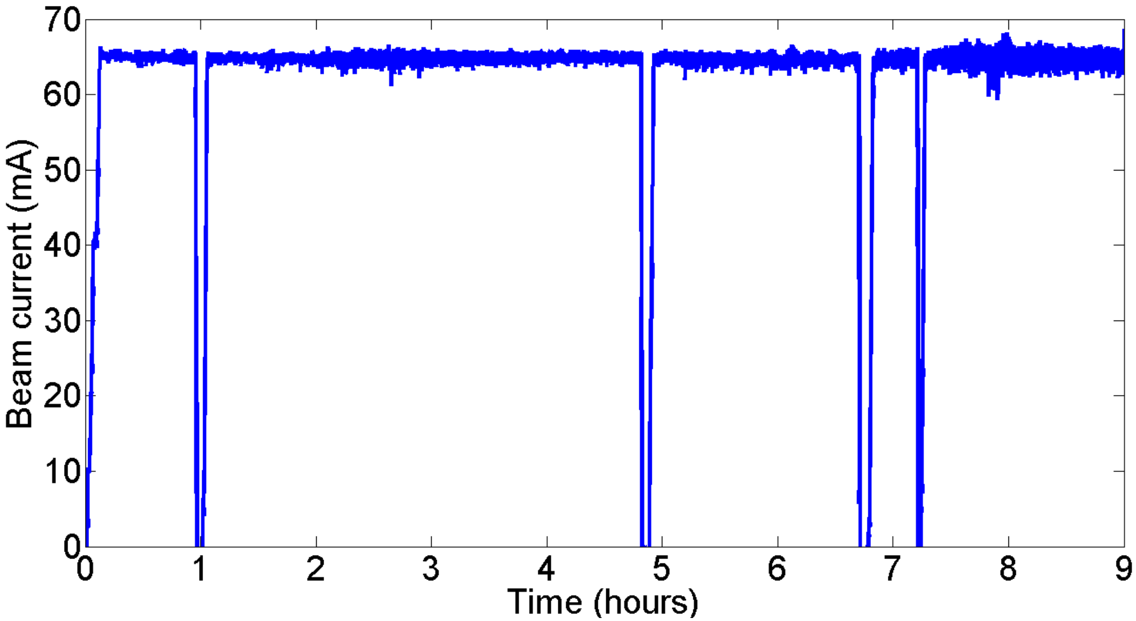


Injector Specification

Parameter	Value
Frequency	1.3 GHz
Bunch charge	77 pC
Average current	100mA
ϵ_{rms} *(norm.)*	< 1.0 μm
Bunch duration	< 3 ps (rms)
Beam Energy	4-15 MeV



High Current



- Peak current of 75mA (world record)

- NaKSb photocathode
- High rep-rate laser
- DC-Voltage source

Source achievements:

- 2.6 day 1/e lifetime at 65mA
- 8h at 65mA
- With only 5W laser power (20W are available)
- now pushing to 100mA

Simulations accurately reproduce photocathode performance with no free parameters, and suggest strategies for further improvement.

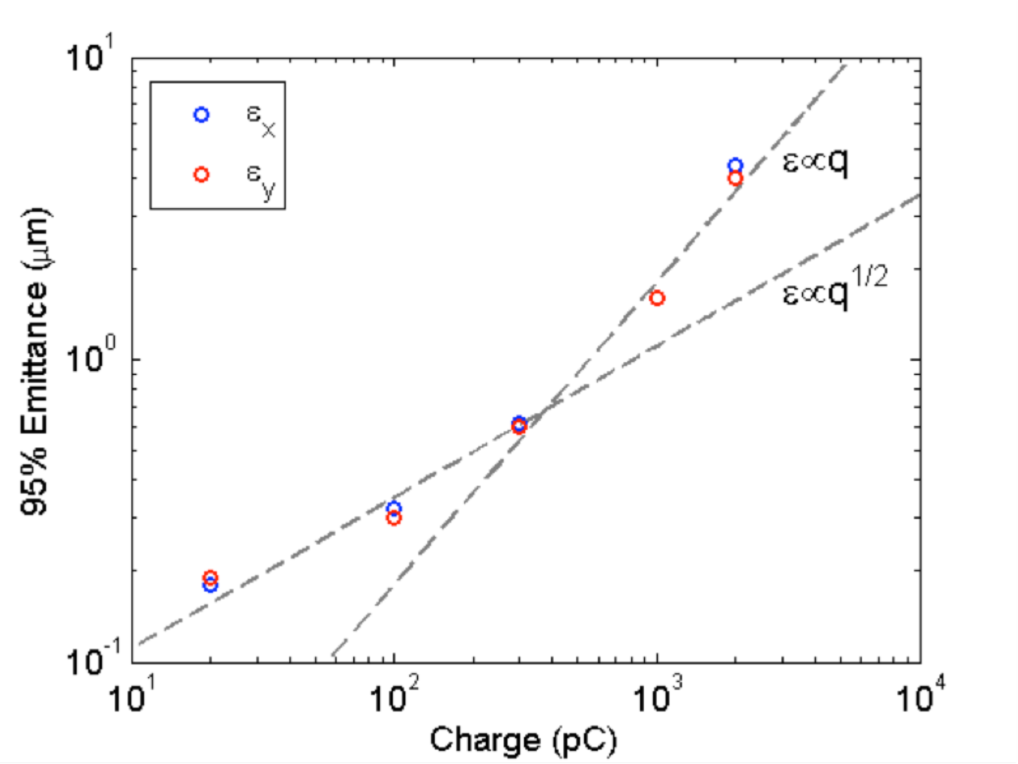
1. *Cultrera el al., Appl. Phys. Lett.* ***103****, 103504 (2013)*
2. *Gulliford el al., Phys. Rev. ST Accel. Beams* ***16****, 073401 – 2013*

✓ Meets all CBETA needs

Emittance summary

Trend becomes more linear around 300 pC…

Q (pC)	Peak current (A)	Emittance (95%, µm)
20	5	H: 0.18 V: 0.19
100	11.5	H: 0.32 V: 0.30
300	32	H: 0.62 V: 0.60
1000	50	H: 1.6 V: 1.6
2000	56	H: 4.4 V: 4.0



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CBETA Requirements

Table 1.2.1: Primary parameters of the Cornell-BNL ERL Test Accelerator.

Parameter	Value	Unit
Largest energy	150	MeV
Injection energy	6	MeV
Linac energy gain	36	MeV
Injector current (max)	40	mA
Linac passes	8 (4 accel. + 4 decel.)	
Energy sequence in the arc	$42 \to 78 \to 114 \to 150 \to 114 \to 78 \to 42$	MeV
RF frequency	1300.	MHz
Bunch frequency (high-current mode)	325.	MHz
Circumference harmonic	343	
Circumference length	79.0997	m
Circumference time (pass 1)	0.263848164	μs
Circumference time (pass 2)	0.263845098	μs
Circumference time (pass 3)	0.263844646	μs
Circumference time (pass 4)	0.265003298	μs
Normalized transverse rms emittances	1	μm
Bunch length	4	ps
Typical arc beta functions	0.4	m
Typical splitter beta functions	50	m
Transverse rms bunch size (max)	1800	μm
Transverse rms bunch size (min)	52	μm
Bunch charge (min)	1	pC
Bunch charge (max)	123	pC

Repurposing

- Since 2015
  - Moved Injector to new experimental hall
  - Moved laser room 50m closer to gun
  - Installed 2nd generation - segmented insulator gun
  - Preparing for CBETA Installation
  - Dedicated diagnostics beamline

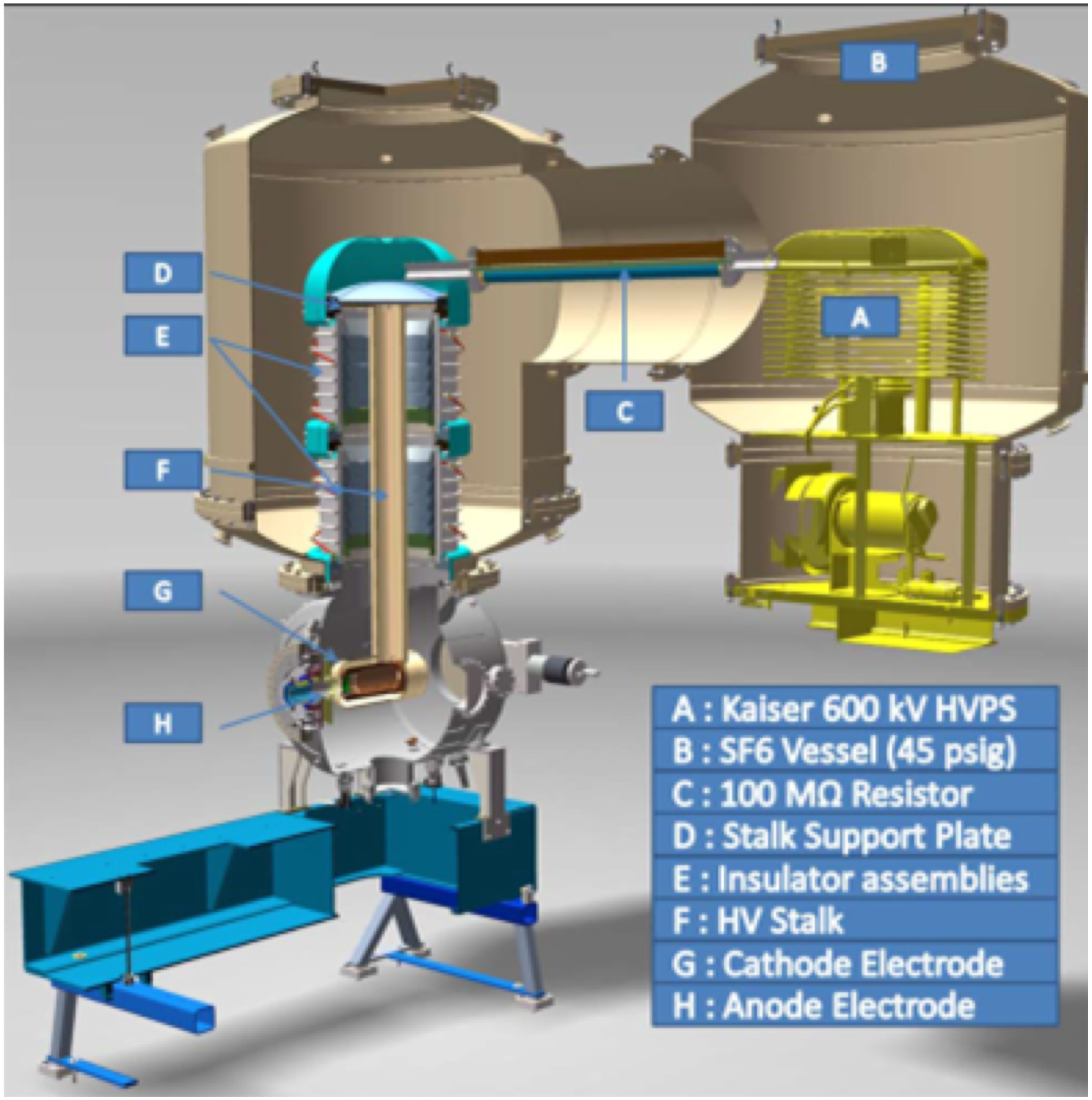
Cornell DC Guns

- 1st Generation Gun – emittance and high current studies
  - Suffered (at least) 3 ceramic punch-through failures
  - Operated ~2005-2015 (will continue in new gun dev. lab)
  - Local cathode preparation

- 2nd Generation Gun (2012-Current)
  - Segmented Insulators with integral shielding
  - Modular SF6 tank design for flexibility and service access
  - Scaled up diameter, but retains original electrode and cathode puck design
  - No local cathode preparation – all delivered by vacuum suitcase
  - Operational Margin (350kV operation)

- Third Gun built (2016) – *(next talk)*
  - Simplified duplicate for BNL LEReC program

2nd Generation DC Gun



DC electron source

Based on scaled up DC-gun technology with:

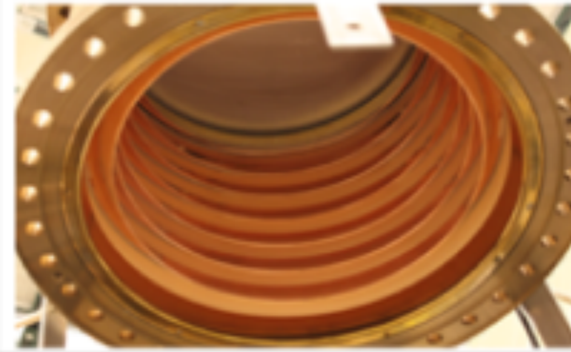
- Load-locked cathode transfer
- Compact power supply
- Shielded insulator
- Shaped cathode and anode

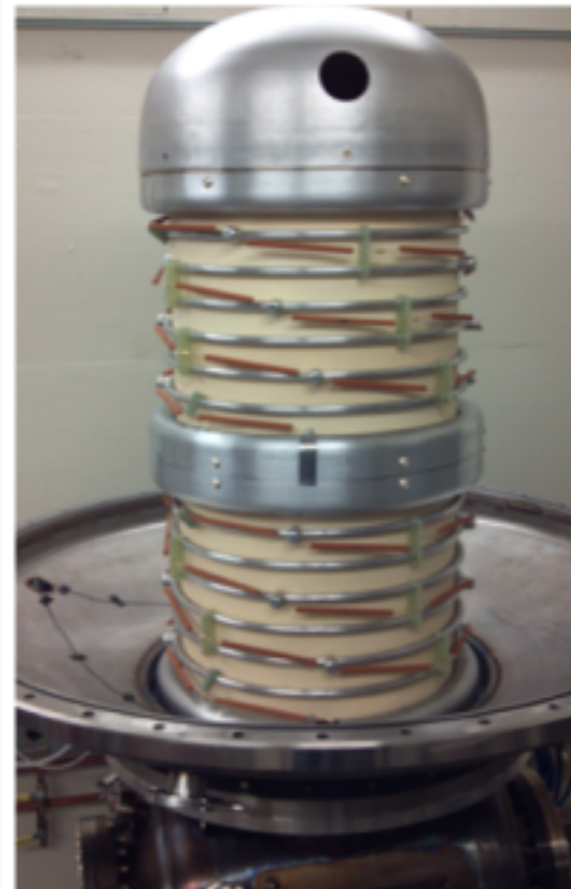
Duplicate for BNL's low energy electron cooler project.

Holds world record in current and normalized brightness.

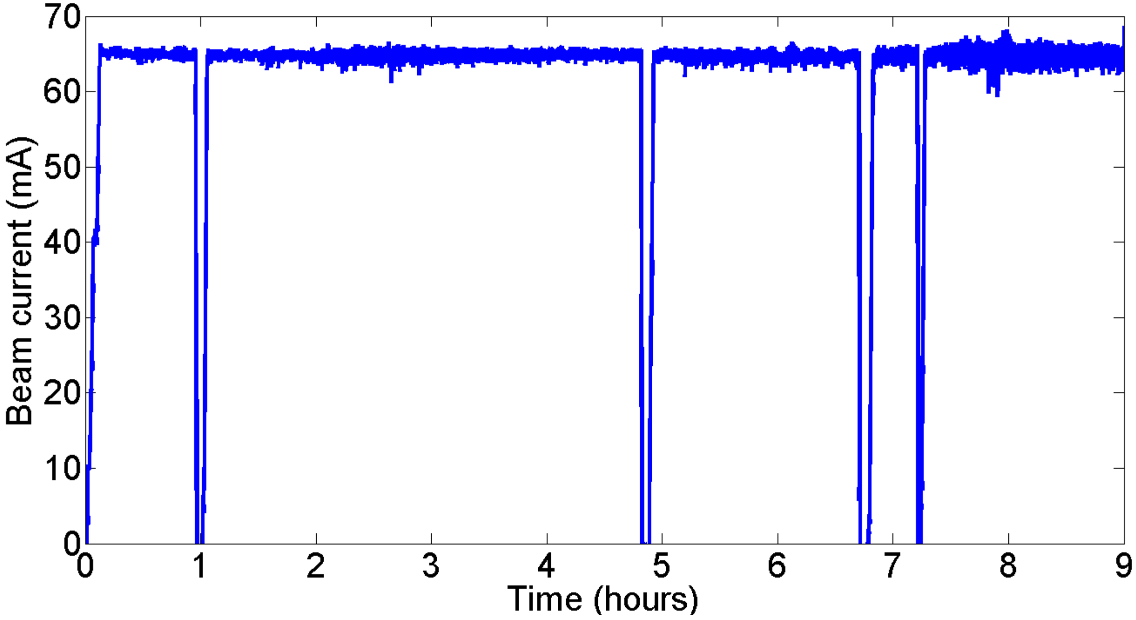
Segmented insulator

- Mitigate punch-through: shield the ceramic
- Brazed Alumina segments with kovar ring in each joint.
- Inside: Cu protection rings entirely shield ceramic from field emitted electrons
- Outside: Mount 500MΩ resistors between each segment (1GΩ / 2 in parallel)
  - Allows differentiation between field emission going to ground or going to the rings!
  - If anode floats, can distinguish between emission from stalk, cathode, and direct to ground.





High-Current Operation



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Source achievements:
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- With only 5W laser power (20W are available)
- now pushing to 100mA

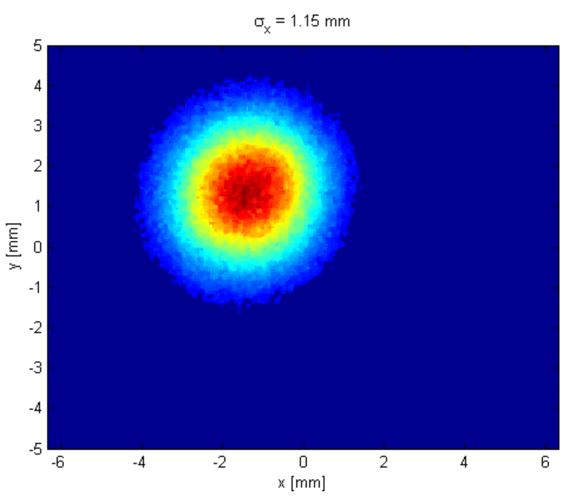
Simulations accurately reproduce photocathode performance with no free parameters, and suggest strategies for further improvement.

✓ Source current can meet ERL needs

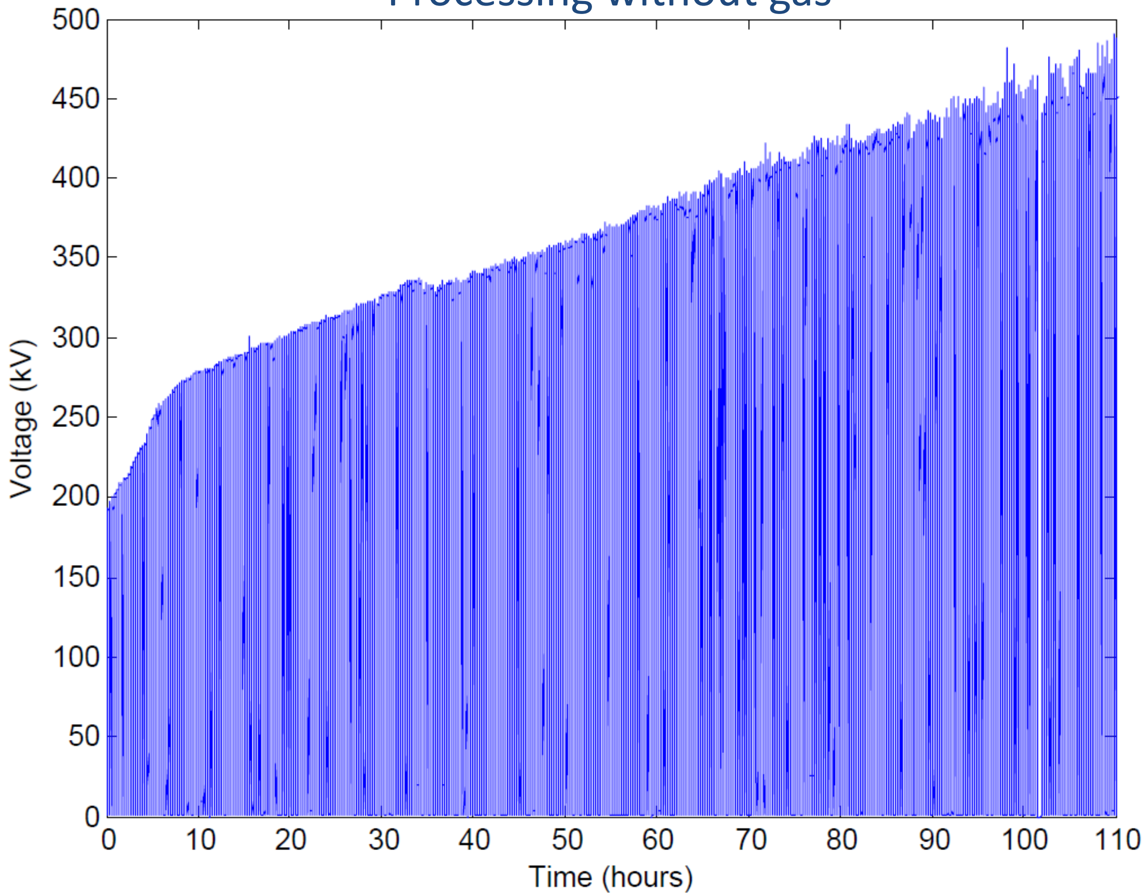
2nd Generation Gun Processing

- Used SRF cleanroom facility (class 10)
- Processed up to 485 kV (03/14/2014)
- Processing rate 2kV/Hr. (vertical lines are trips – high density)

First beam

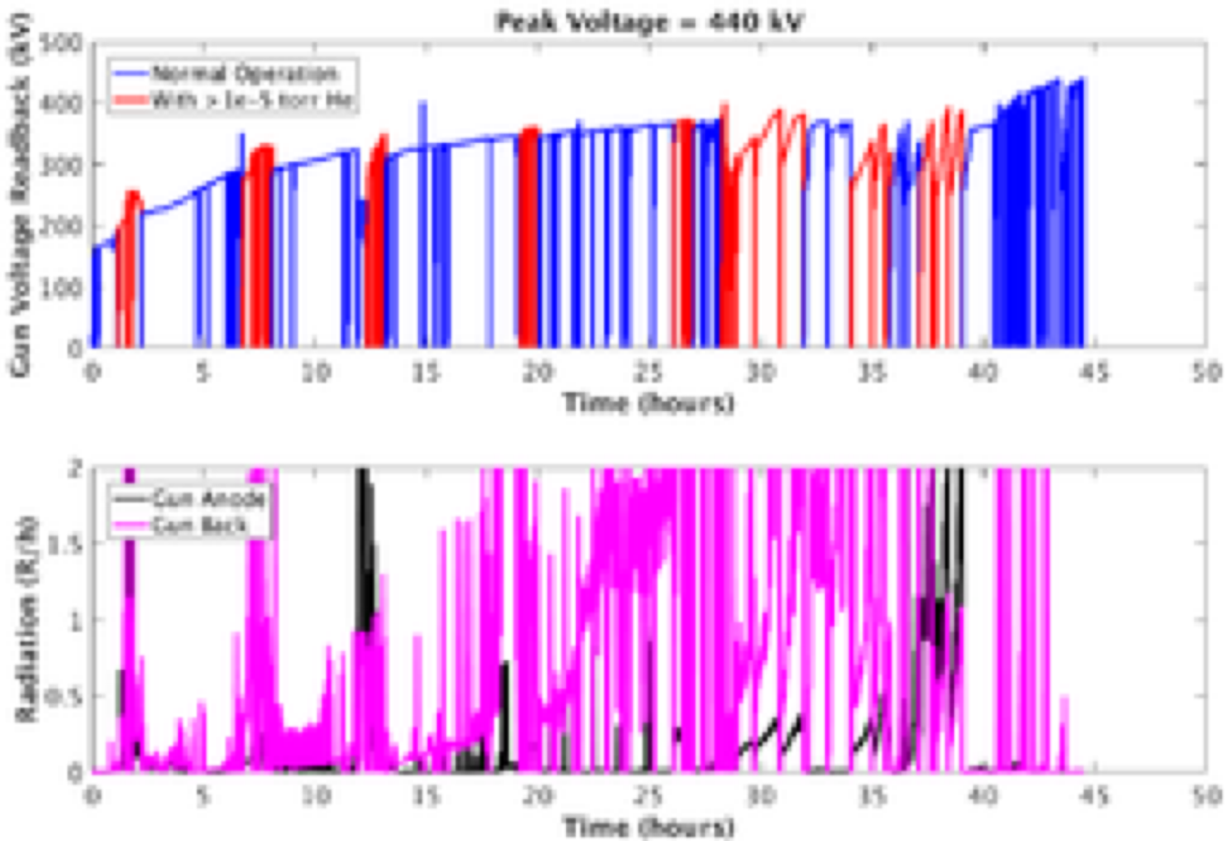


Processing without gas



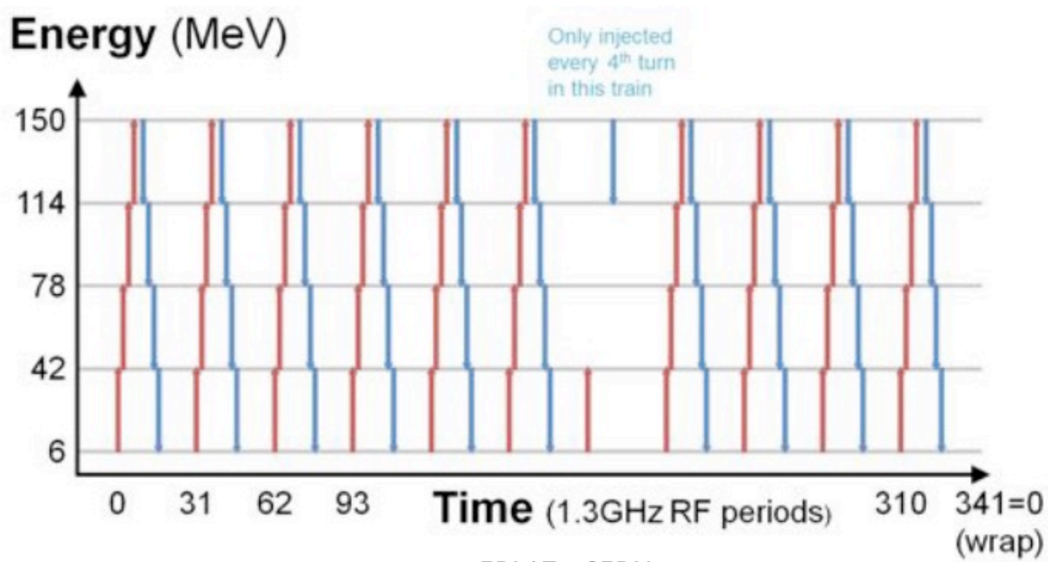
LEReC Gun processing

- Most recent processing (BNL LEReC gun) – See next talk
- Ave. rate of 6kV/hr. (lower density of trips) – automated scripts
- Result of more effective use of gas processing?
- Result of improved clean room handling? – Single Person



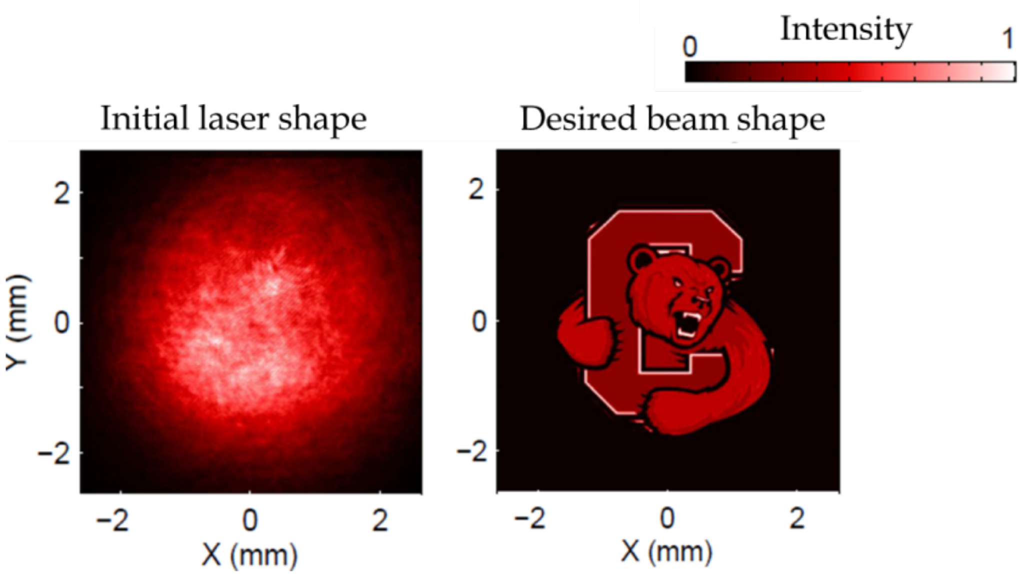
Drive Laser Status

- New Laser Room Installed adjacent to gun
- New oscillator 42 MHz = (1300 MHz / 31).
- E/O Modulator for arbitrary pulse structure - flexibility for bunch timing for BPM operations
- Shaping possible if potential uses identified



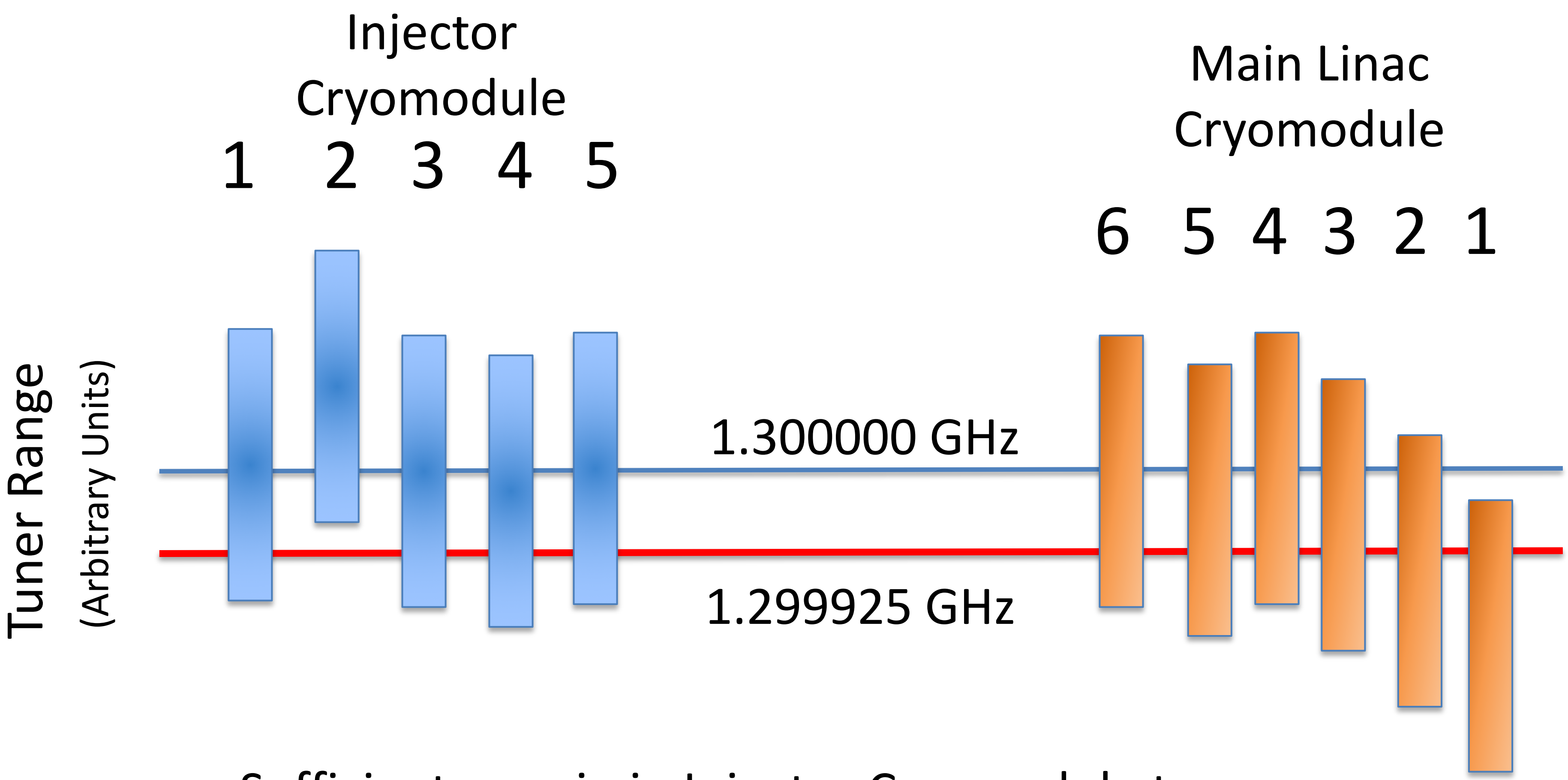
Fancy Laser Shaping

- Used in test set-up with segmented DC gun
- Tested with low charge e- beam
- Increase emittance performance
- Adaptively fix spatial QE irregularities



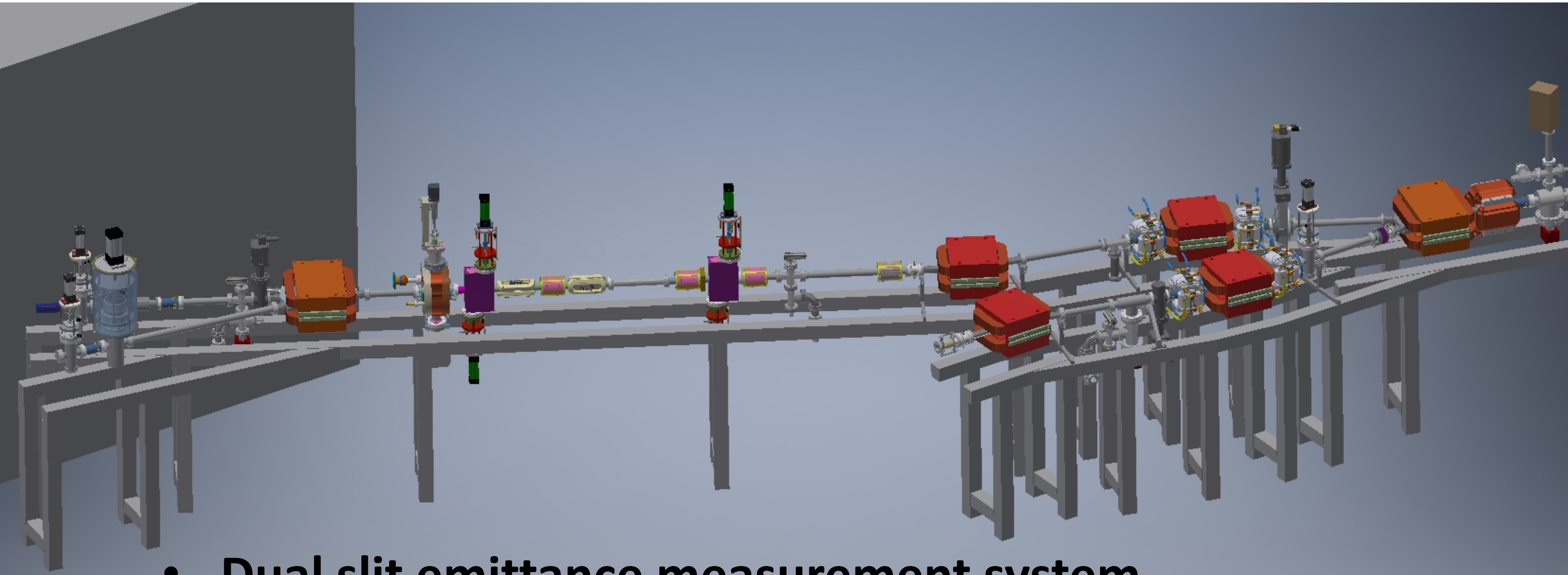
J. Maxson et al., Phys. Rev. ST Accel. Beams **18**, 023401 (2015).

Injector Cryomodule



Sufficient margin in Injector Cryomodule to run without Cavity #2 with minor emittance penalty

Diagnostics Beamline



- **Dual slit emittance measurement system**
- **Deflecting cavity**
- **Spectrometer magnet**
- **Faraday cup**
- **Viewscreens**

Full 6D Phase Space Mapping Retained

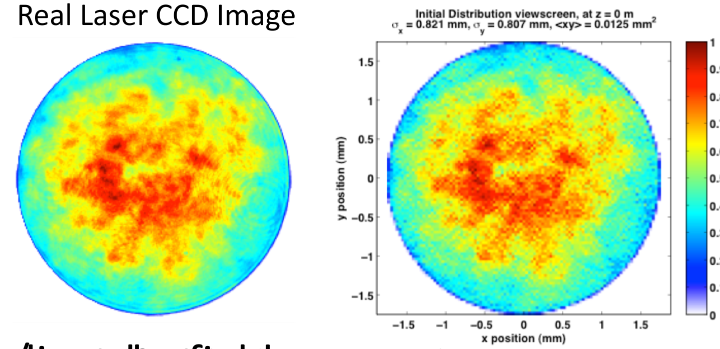
Diagnostics Beamline

3D GPT Injector Model

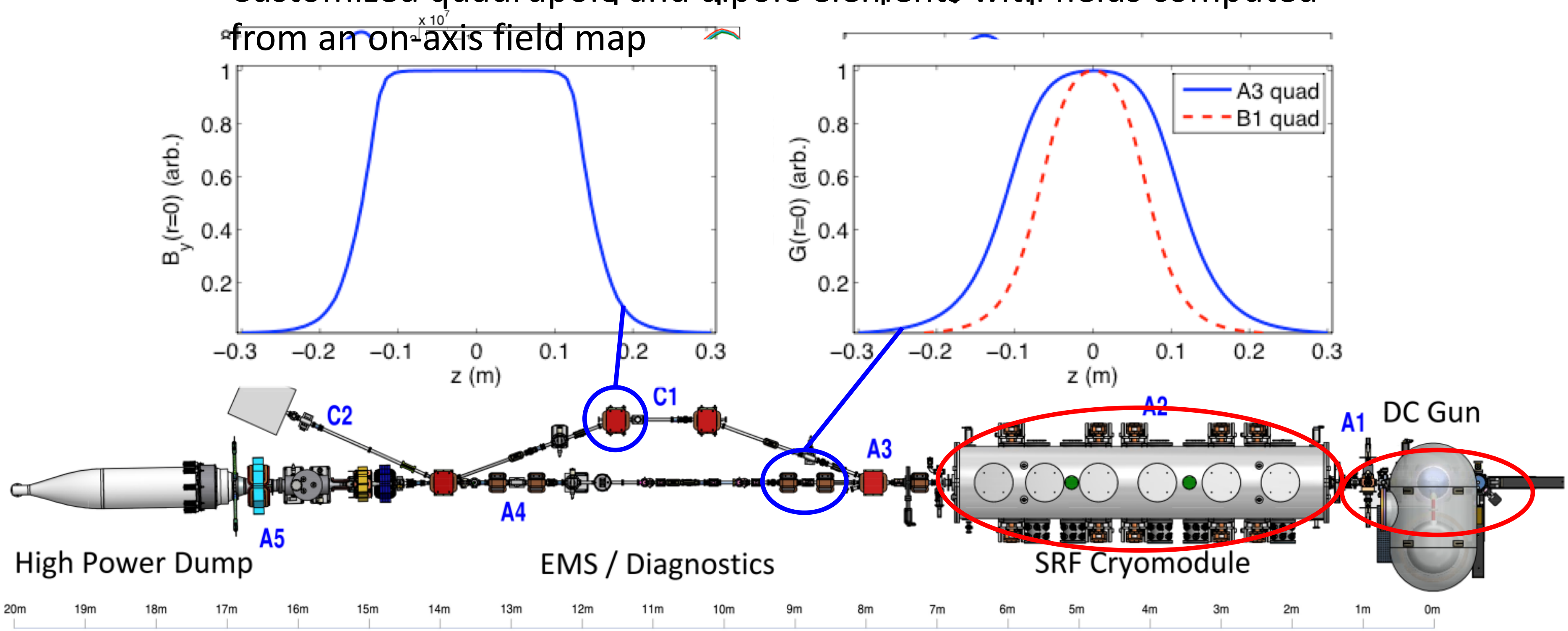
Code of choice: General Particle Tracer

- 3D Space Charge algorithm
- Load/Create Realistic Particle Distributions
- Overlap field maps and position them in 3D space
- Customizable (define new beamline elements)

Real Laser CCD Image



Customized quadrupole and dipole elements with fields computed from an on-axis field map



Integration into the Control System

GPT/ASTRA Virtual Accelerator GUI: load machine settings, load optimizer settings, save/restore, independently simulate machine in (near) real time

Save / Load from file or optimizer

Control Tabs

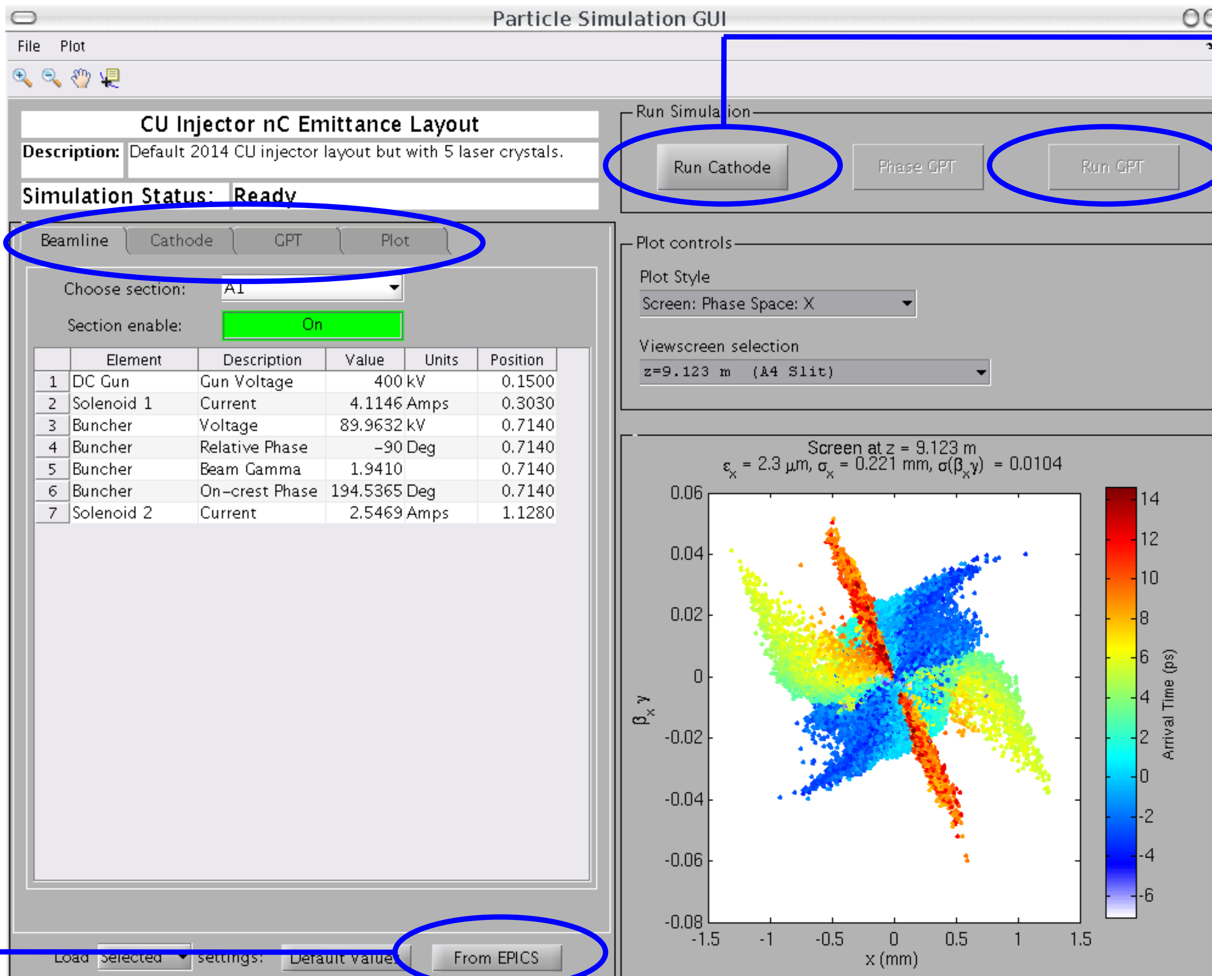
Beamline Settings

Load from EPICS

Create Particles

Run GPT

Plotting + Analysis



Lessons

- DC Gun technology satisfies existing requirements for many applications
  - Flexible temporal structure
  - High currents, flexible bunch charge
  - Robust, long lifetime cathodes
- Design-in diagnostics
- Cleanroom religion

- How can we increase ERL cooperation between labs?

Acknowledgements

nyserda
Energy. Innovation. Solutions.

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CBETA
CORNELL-BNL ERL TEST ACCELERATOR

Thanks to the Cornell High-brightness Beam Group:

Thank you for your attention!

Backup Slides

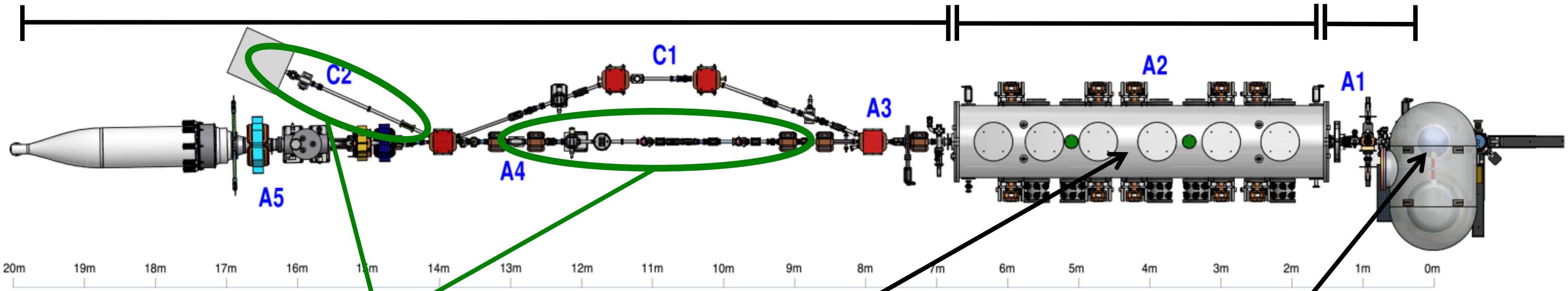
Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Injector Layout

6 Dimensional Phase Space Diagnostics + High Power Beam Dump + Chicane (Compton Scattering)

Short SRF Linac
5 – 15 MeV

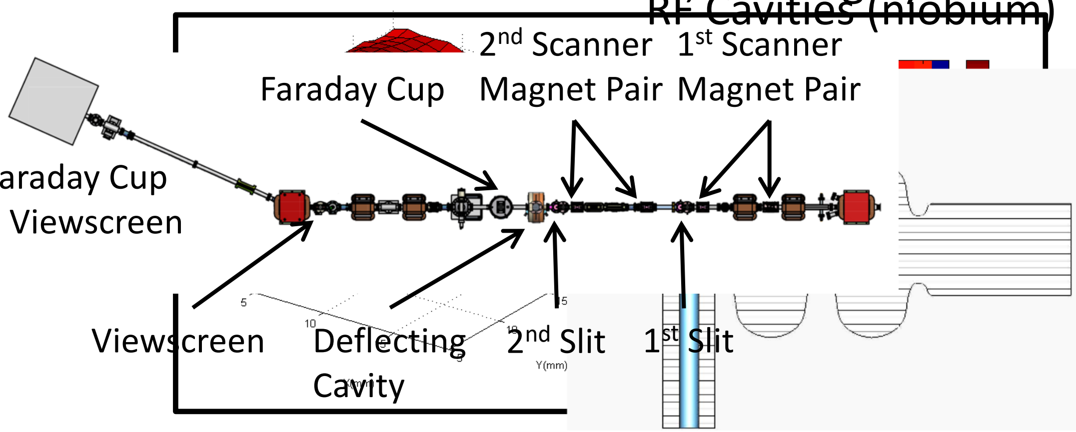
395 kV DC Gun + Bunching/Focusing



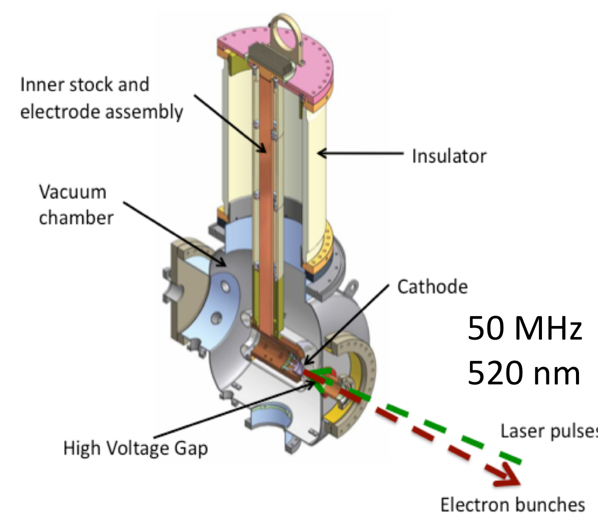
Emittance Measurement System

Superconducting RF Cavities (niobium)

NaKSb: MTE = 140 meV, QE roughly 5%

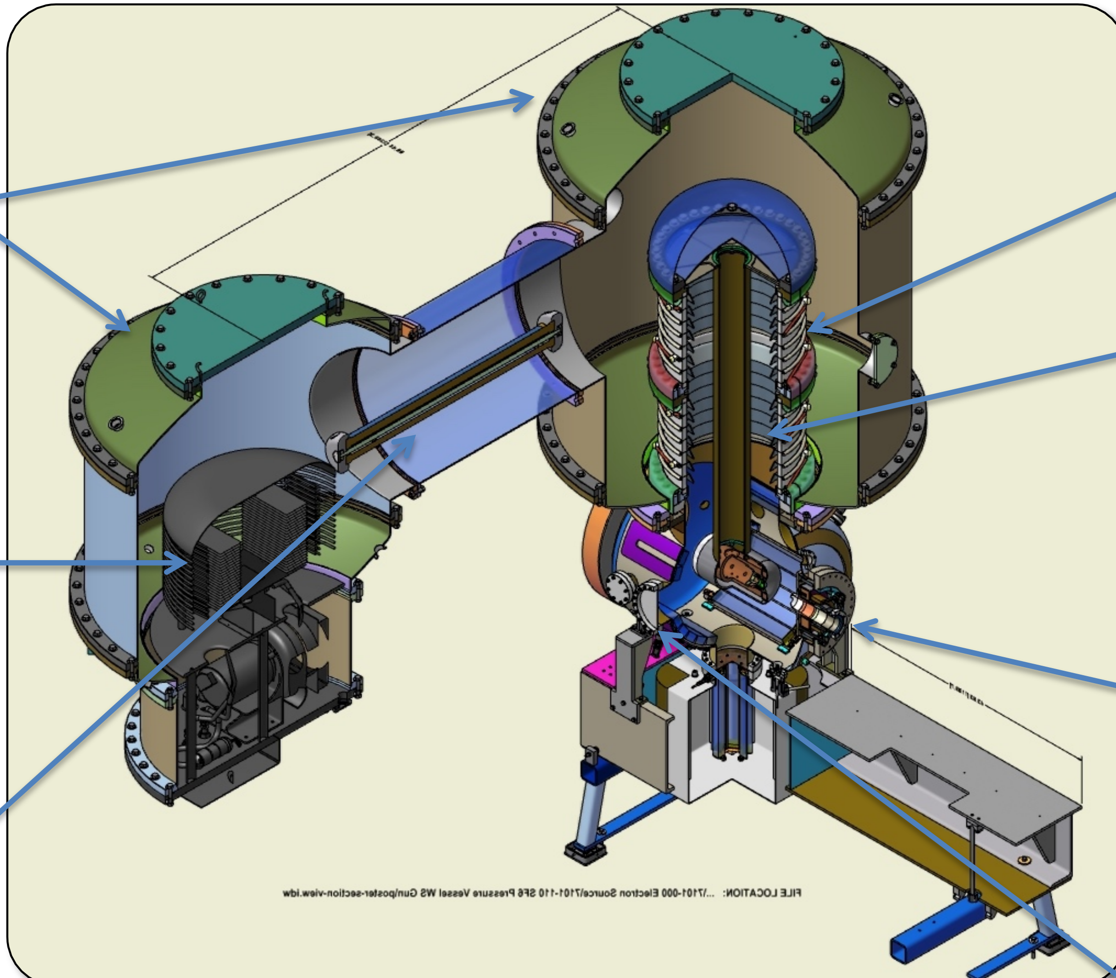


395 kV DC Gun



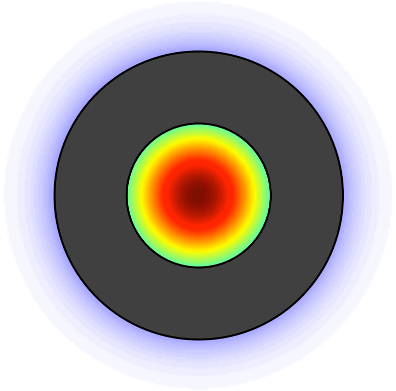
50 MHz
520 nm

New gun overview

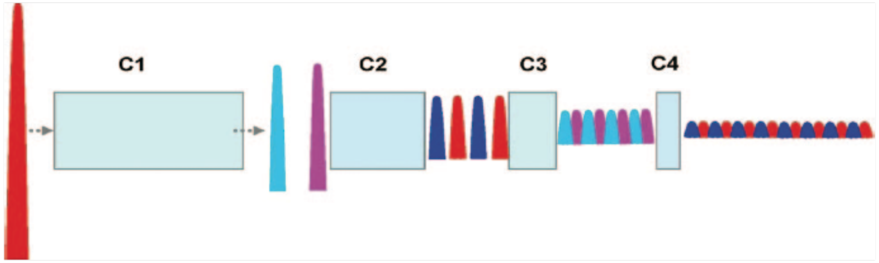


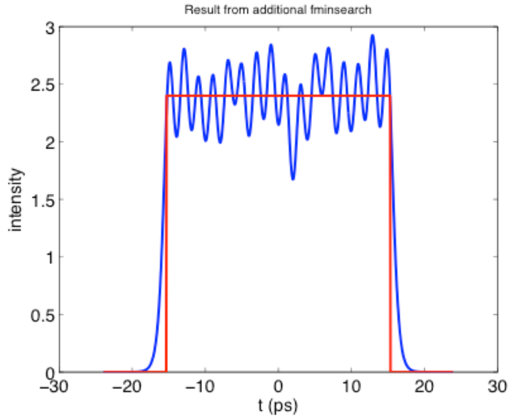
Laser Shaping

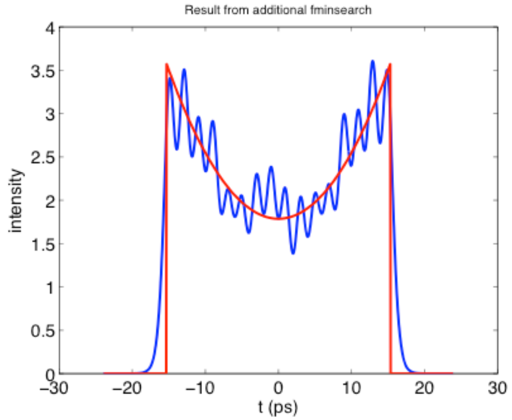
Transversely: clip Gaussian laser profile at a given intensity fraction (typically 50%)

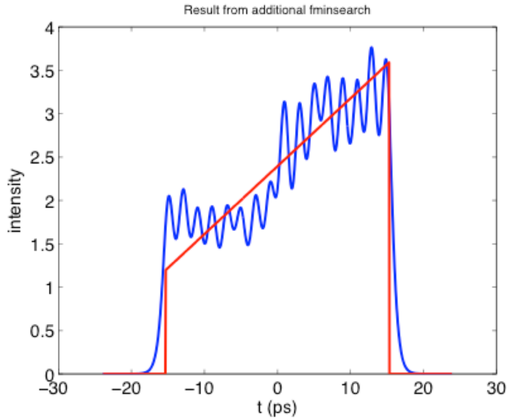


Longitudinally: Birefringent Crystals for pulse stacking:





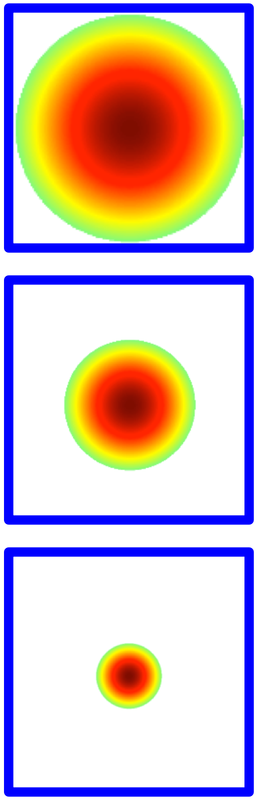


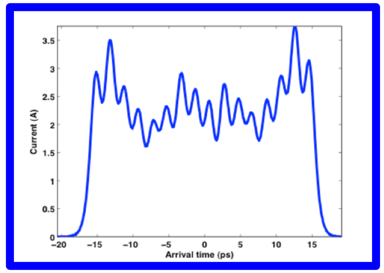


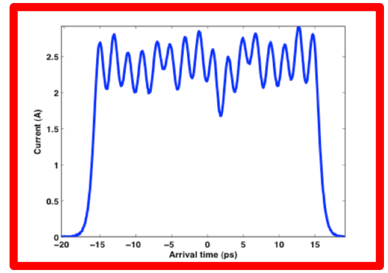
Effects of the Laser Shape

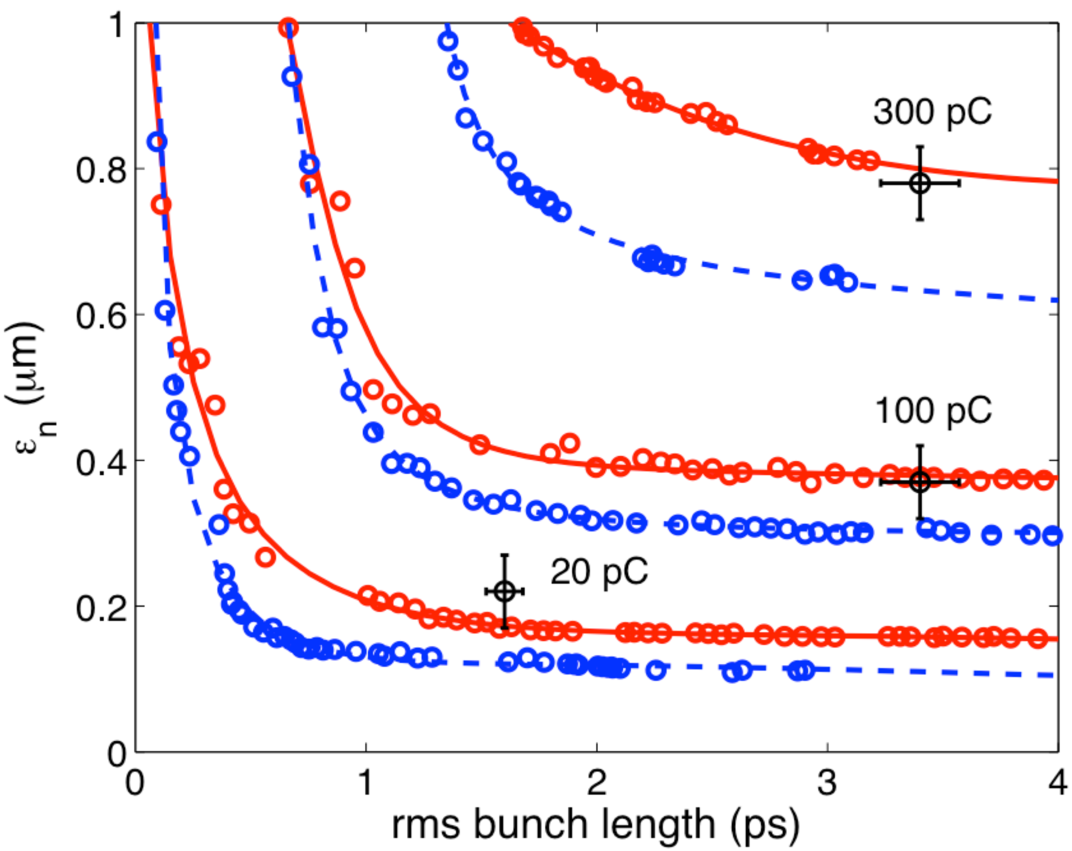
$$\varepsilon_n = \frac{1}{2}\left(\varepsilon_{n,x} + \varepsilon_{n,y}\right)$$

Ideal Shape

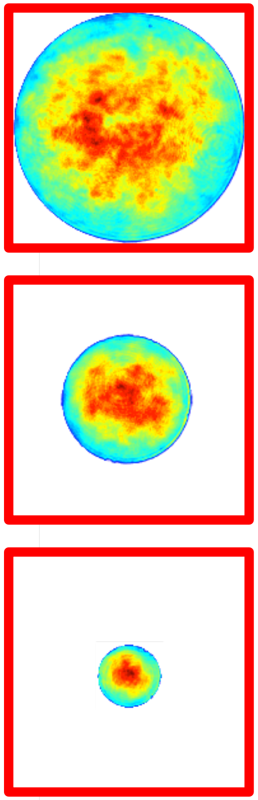






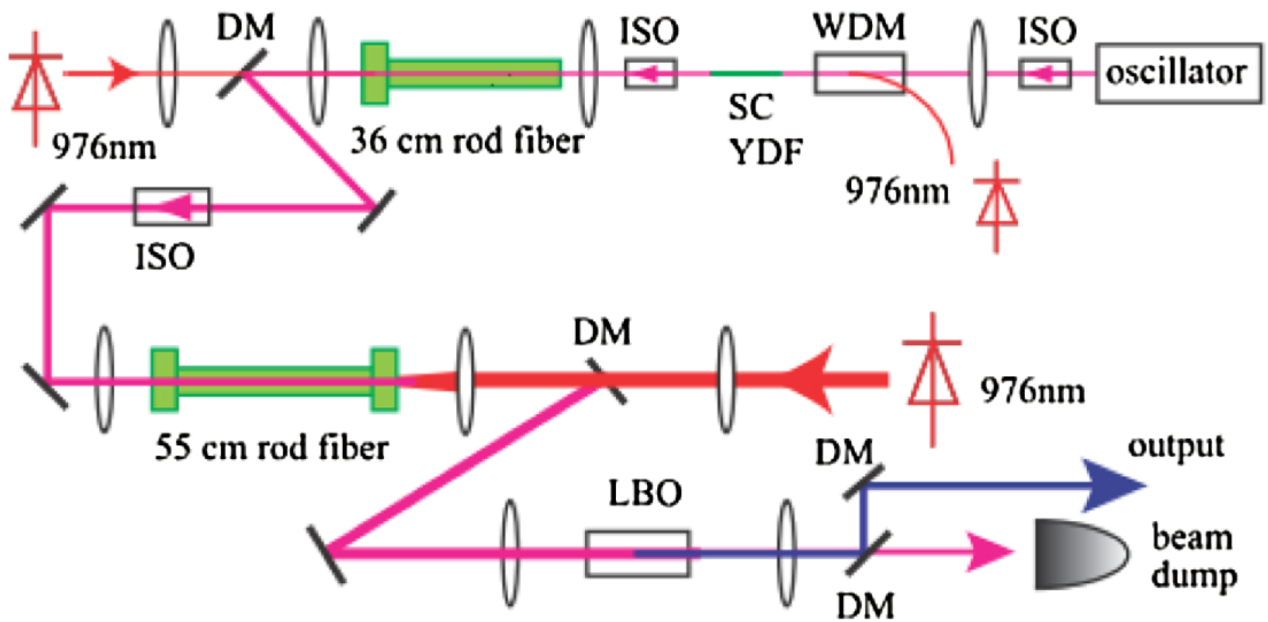


Measured Shape



Laser upgrade

- Drive laser was incapable of reaching pulse energies needed for nC bunches
- Upgraded using Yb-doped rod amplifiers
  - Capable of 150 W average power (IR) and 1 MW peak power
  - Limited to 50 W due to damage threshold of downstream optics



Zhi Zhao, et. al, JOSA B, **31**, 33-37 (2014)