Performance of the Cornell High-Brightness, High-Power Electron Injector

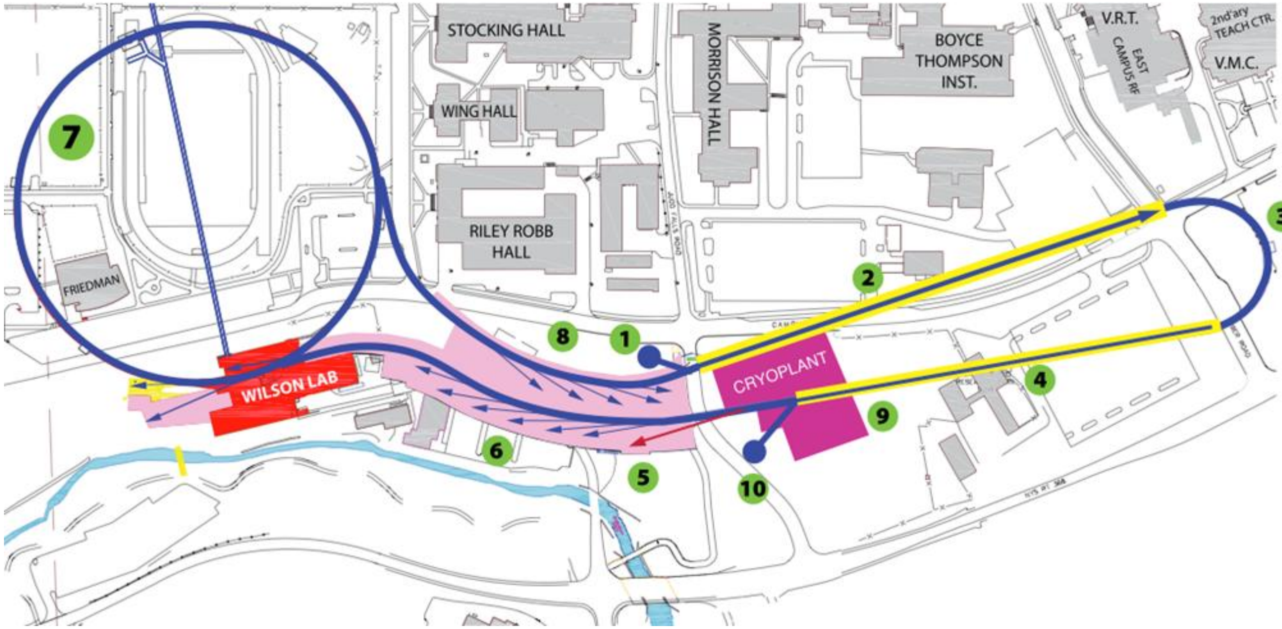
Bruce Dunham, for the Cornell ERL Team

May 21, 2012

Outline

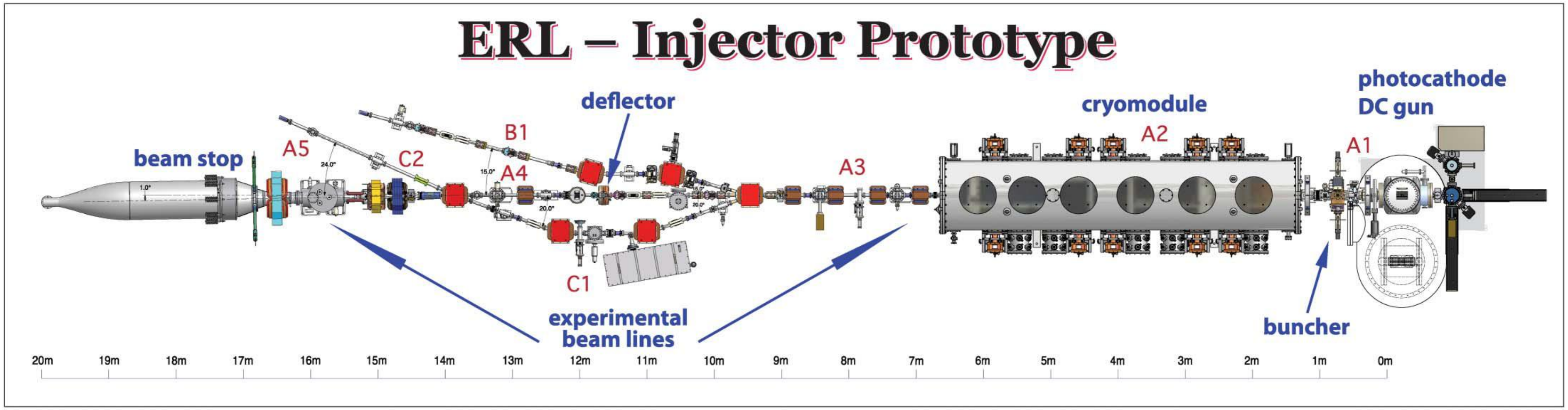
- Overview
- Emittance Measurements
- High Brightness Results
- High Power Operations and Results
- Conclusion

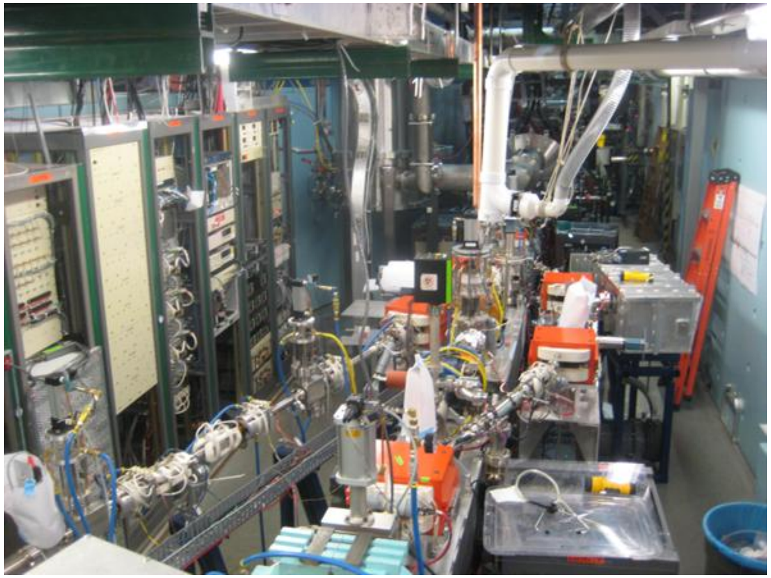
ERL @ Cornell



- Our long-term goal is to build an ERL-based x-ray light source to replace our existing machine (CESR/CHESS).
- Our proposal is complete and ready to go . . . (MOPPP025)
- In the meantime, we are working on prototypes for the injector, SRF cavities, and undulators, plus gun and cathode R&D

Cornell ERL Injector





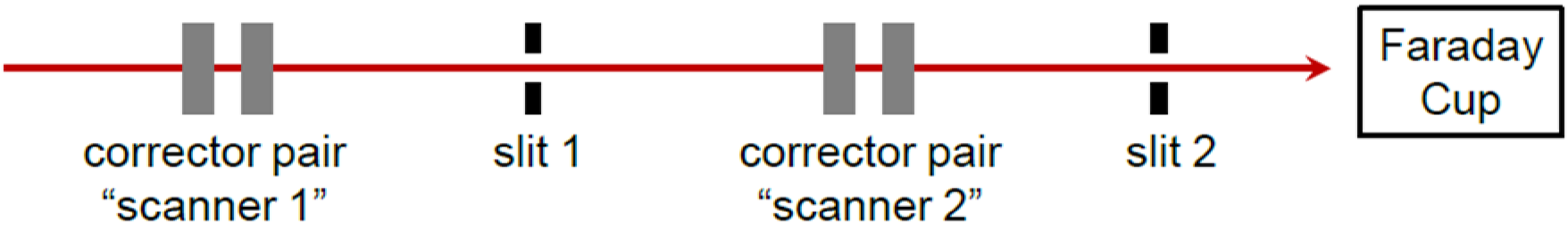
ERL Injector Prototype:
Achievements to date:

- *50 mA average current @ 5 MeV*
- *0.8 μm emittance @ 77 pC, 5 MeV*

Injector Requirements

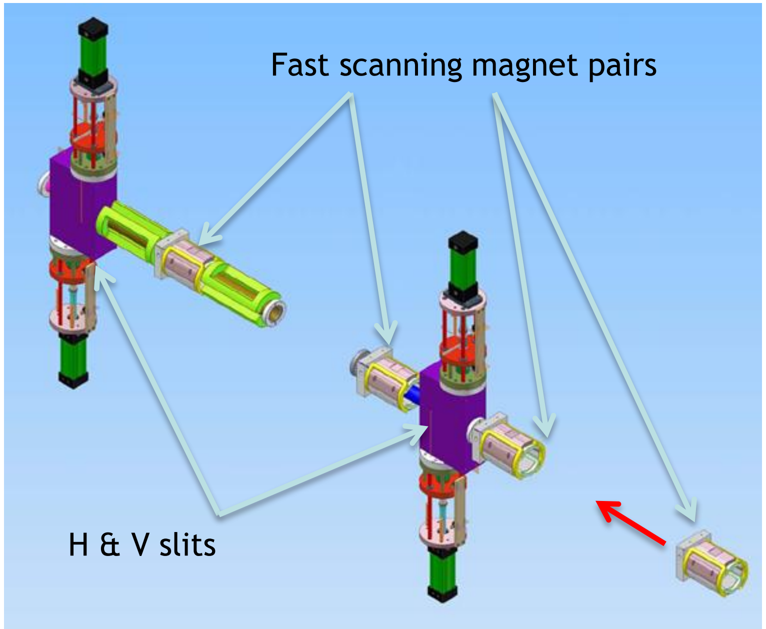
Parameter	Metric	Status	Notes
Average Current	100 mA*	yellow	50 mA at 5 MeV (1300 MHz)
Bunch Charge	77 pC	green	Pulsed mode (50 MHz)
Energy	5 to 15 MeV	green	14 MeV max (due to cryo limits)
Laser Power	> 20 W	green	> 60 W at 520 nm (1300 MHz)
Laser Shaping	beer can dist.	green	Adequate for now
Gun Voltage	500-600 kV	yellow	Currently operating at 350 kV
Emittance	< 2 μm (norm, rms)	green	Ultimate ERL goal 0.3 μm, with merger
Operational Lifetime	> 2000 C/cm^2	yellow	Recent improvements with new cathodes

Fast Emittance Measurements

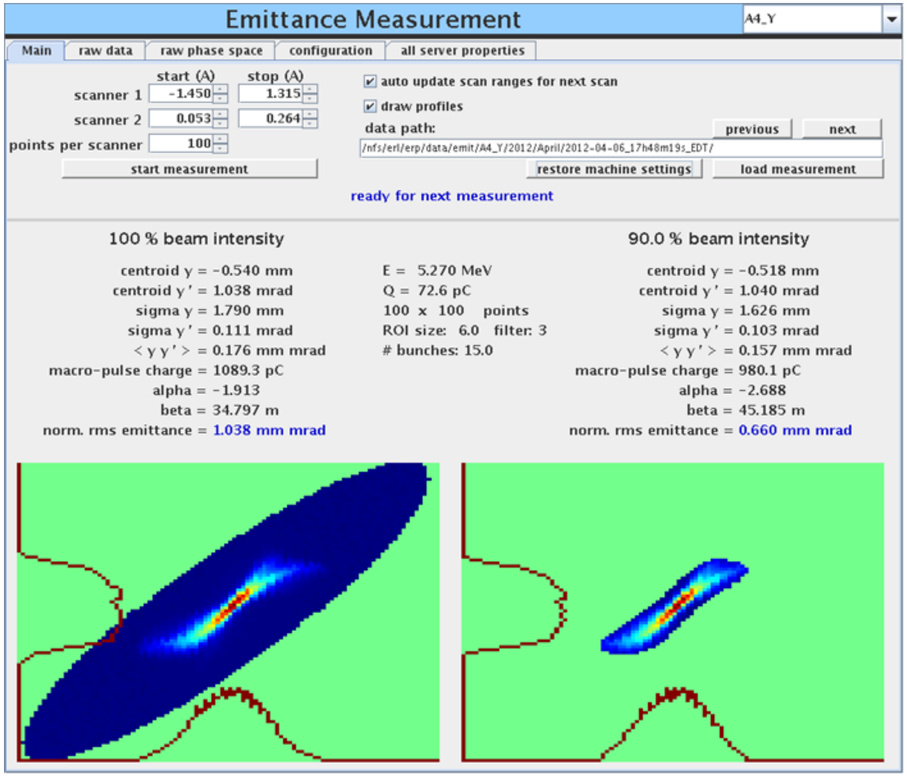


Leave the slits stationary and scan the beam across them. Can measure charge ranges from 0.1 pC up to 100 pC. Measurements take ~10 seconds.

This turns our injector into an analog computer for performing multi-parameter optimizations.

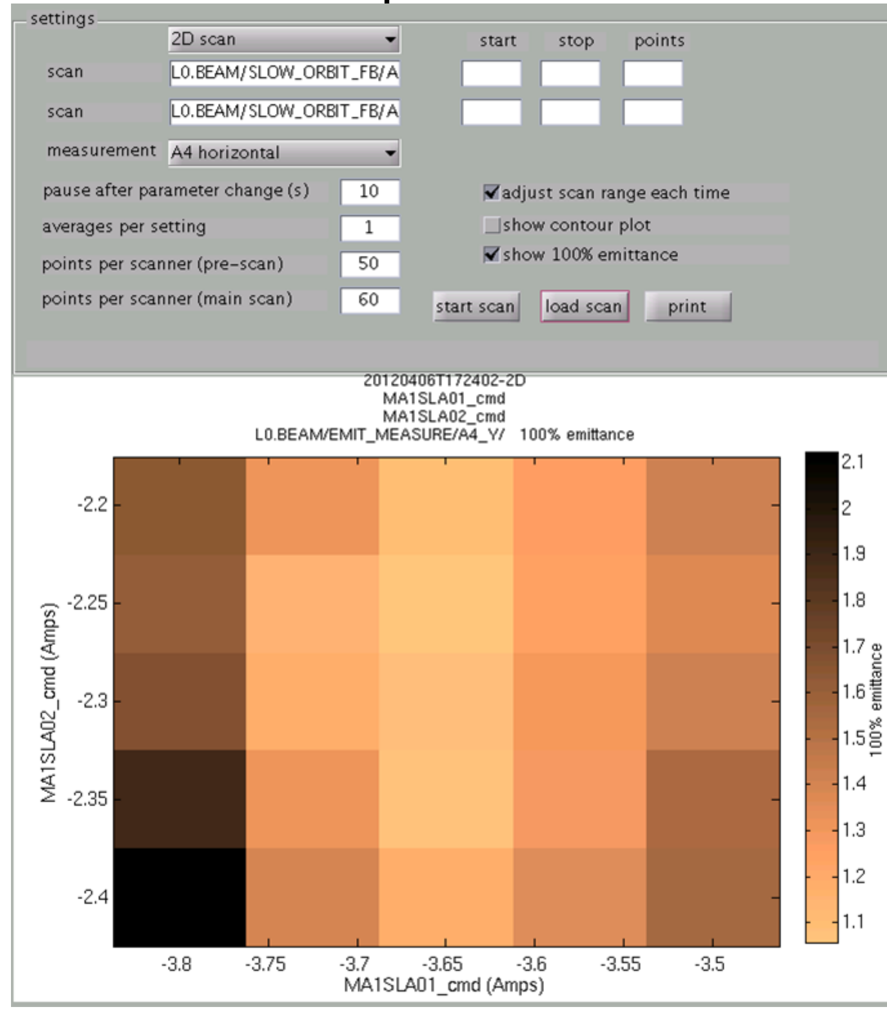


Emittance Scans

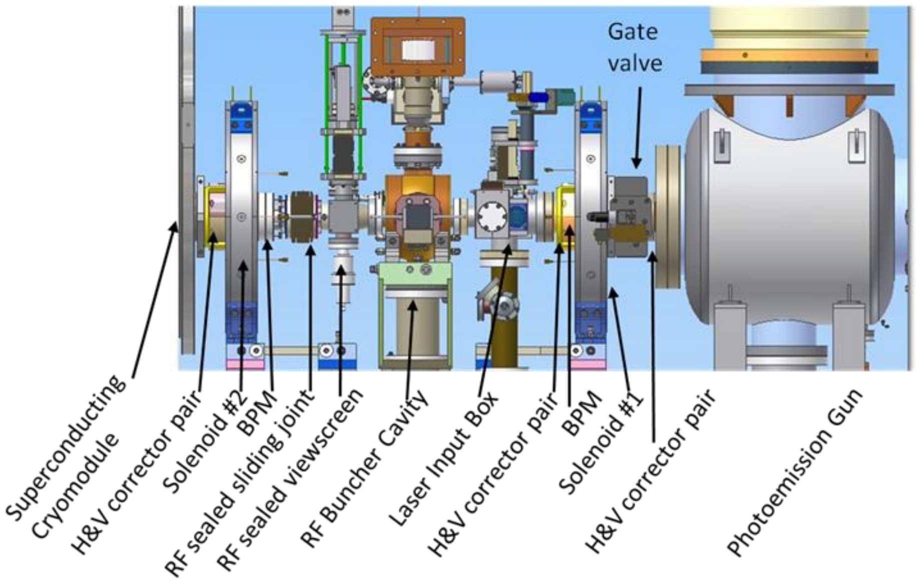


Single emittance scan GUI

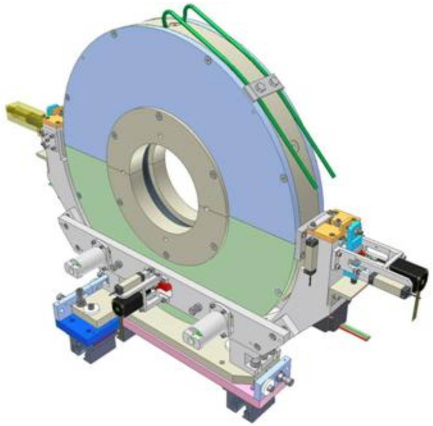
This GUI performs 1D and 2D parameter scans and displays an emittance plot.



Alignment Accuracy



Aligning the magnetic and electrical centers of all elements to the beam axis is crucial for obtaining low emittance and minimizing aberrations.



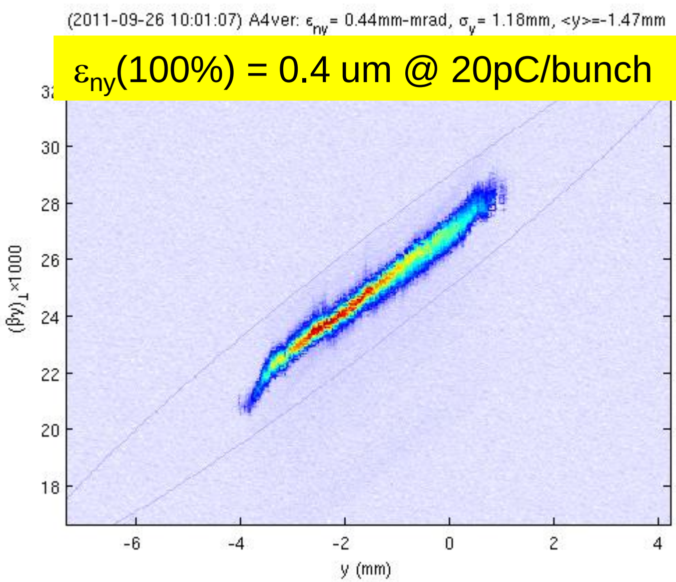
Had to add remote control of the solenoids

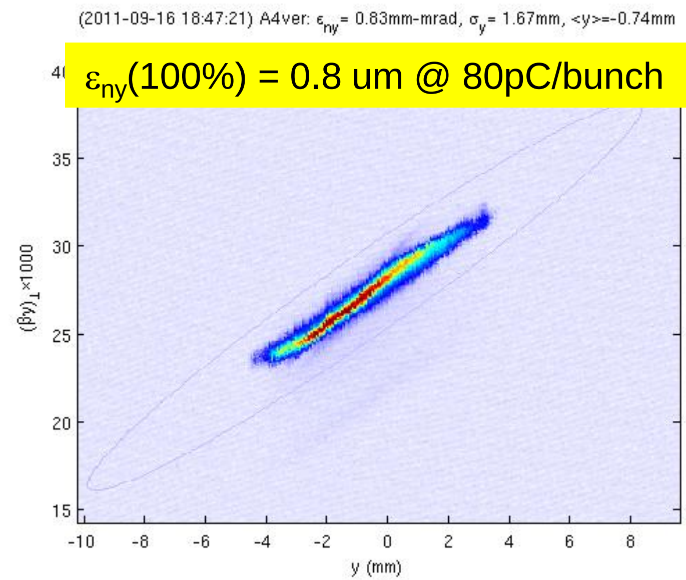
Procedure:

1. Align laser at cathode center
2. Center on buncher using correctors
3. Center on first 2 SRF cavities using correctors
4. Center solenoid #1 by physical adjustments
5. Center solenoid #2 by physical adjustments

Emittance Results

- Keys to obtaining low emittance
  - Beam-based alignment
  - Fast emittance measurements for online optimizations
  - Laser shaping
  - Improvements to machine stability





At 5 Mev, 80 pC we are within 40% of the simulated emittance and 80% above the thermal emittance of the cathode.

What is important for running high currents?

- Halo is a major problem (tuning, radiation shielding and machine protection)
- Beam dump monitoring and protection
- Fast shutdown – want to block the laser before anything else trips . . .
- Catching transients (due to FE, ions, scattering, ...) for troubleshooting
- RF trips (mostly due to coupler arcs)
- Feedback for bunch charge, laser position and beam orbit
- Current measurement
- Measurements of RF response to the beam, HOM's
- Monitoring HV power supply ripple and frequency response
- Vacuum monitoring, fast and slow
- Personnel protection
- Overall machine stability

Dynamic Range and Halo

100 mA
Design current:
Non-intercepting or minimally intercepting diagnostics

100 μA
Phase space measurements:
Non-intercepting or fully intercepting diagnostics

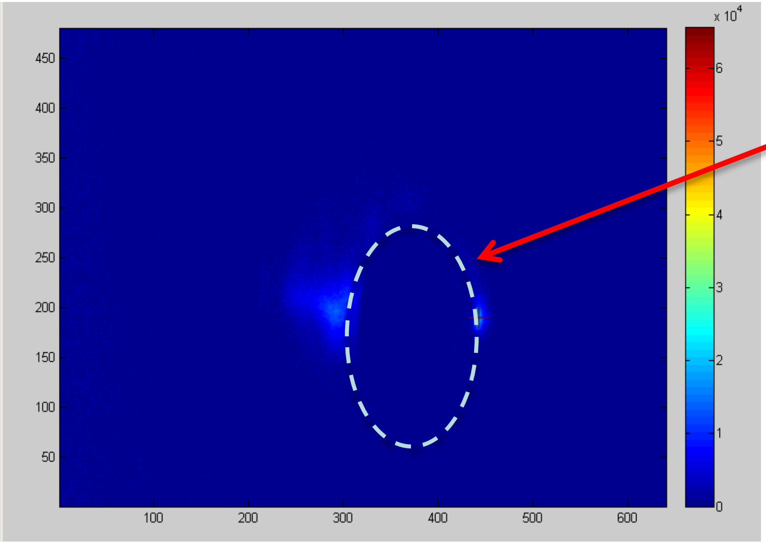
100 nA
Beam setup: viewers, cameras

100 pA
Halo, cathode lifetime: viewers, PMT's

10^3 10^3 10^3

10^6 to 10^9

A viewer with a hole for imaging halo

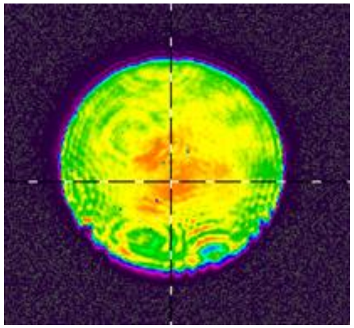


Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Halo – Vacuum Laser Mirror

IPAC'12

Image on the cathode using normal dielectric mirror



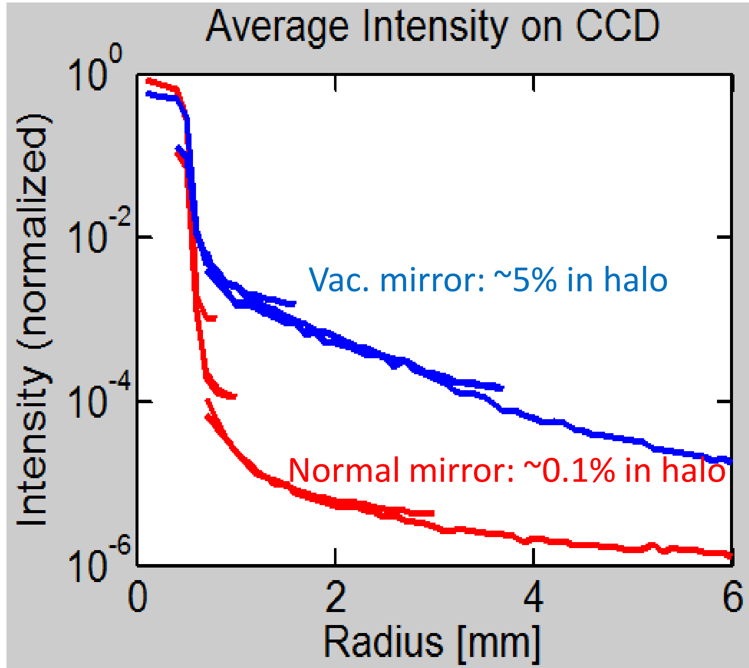
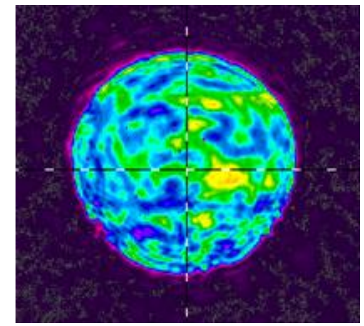


Image on the cathode using coated metal mirror



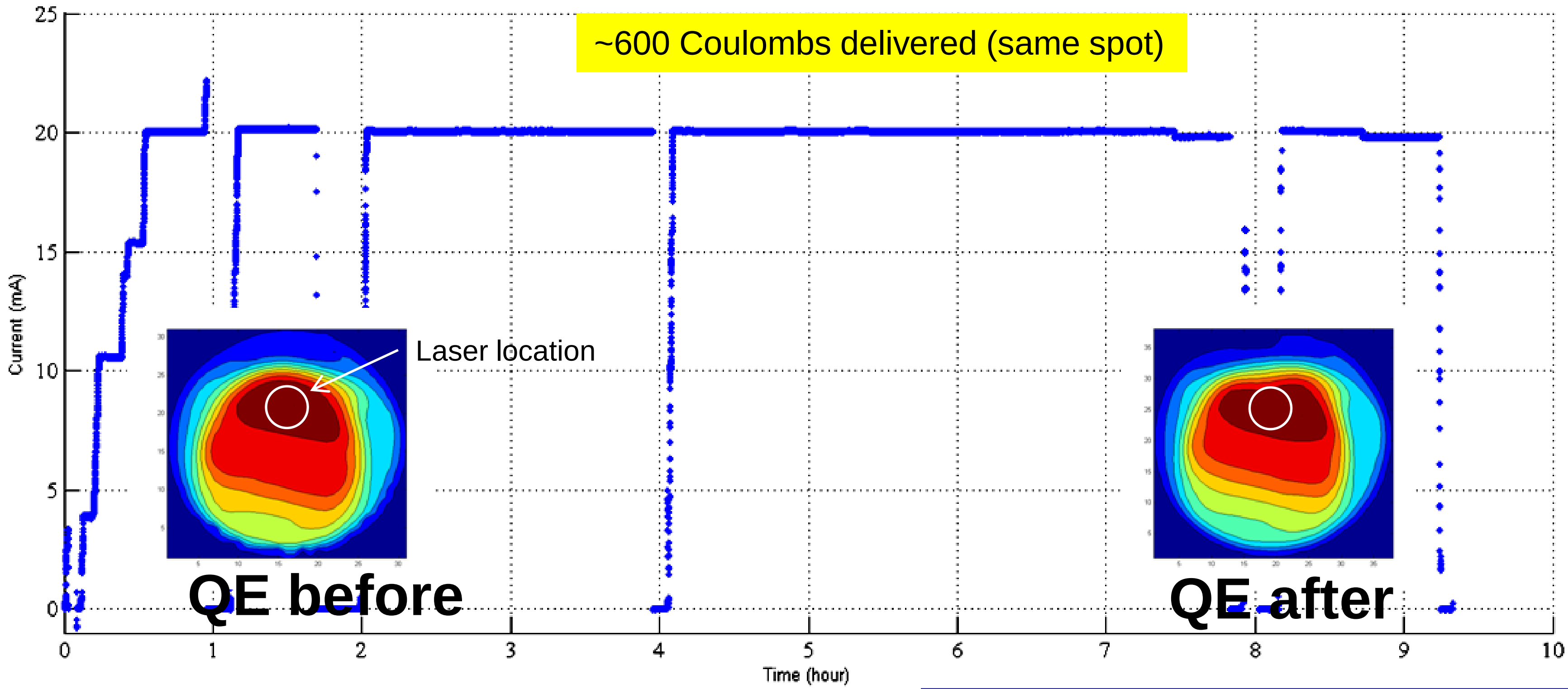
Our final laser mirror scattered ~50x more light compared to dielectric mirrors (which we cannot use). A new mirror with 2 nm-rms surface roughness was installed to fix the problem

Following work by a group at DESY

Bruce Dunham, Cornell University

Cathode Stability

High current operation using a CsK_2Sb photocathode

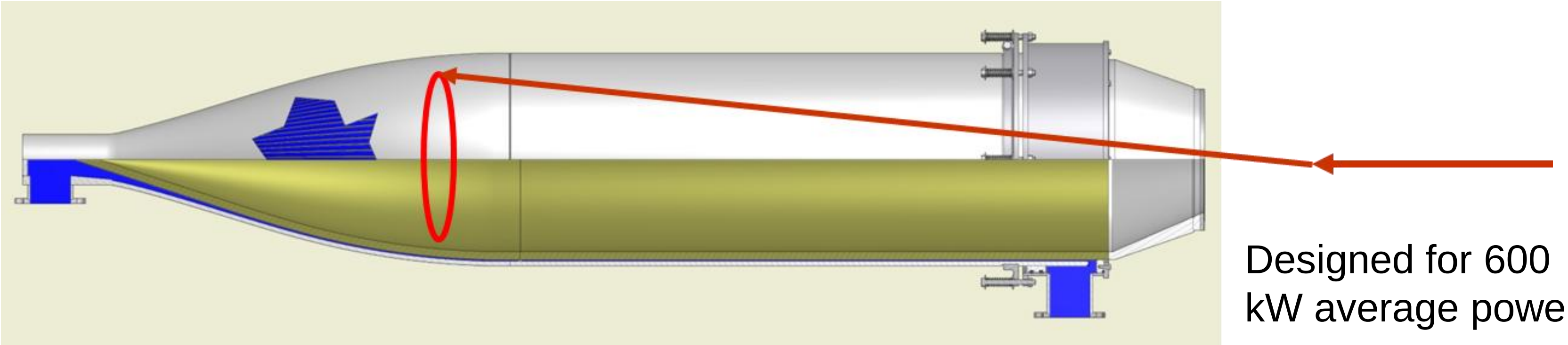


L. Cultrera, et al., PRST-AB 14 (2011)

Cathode QE maps showed little change over 8 hours

Bruce Dunham, Cornell University

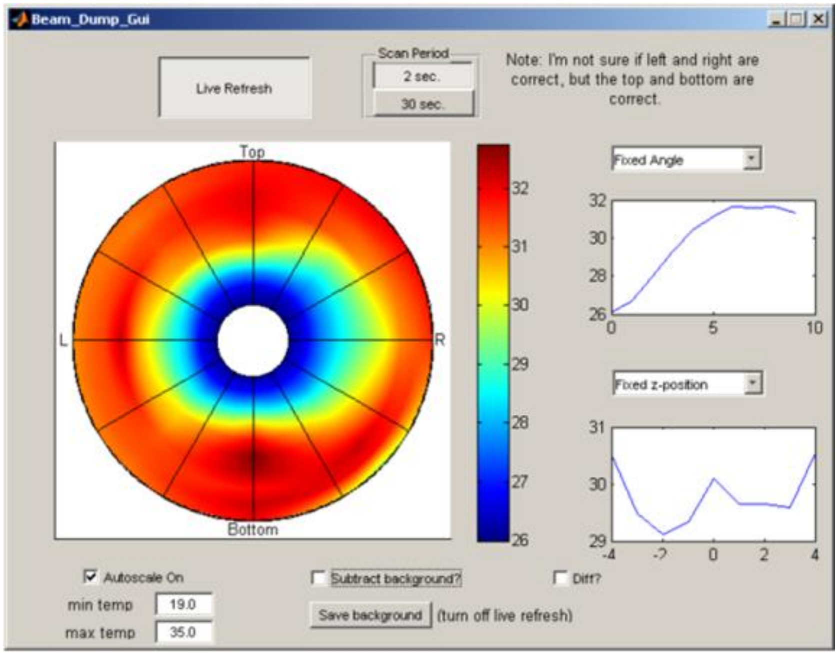
Beam Dump Damage



Designed for 600 kW average power

We burned a hole in the aluminum dump at 25 mA. This was due to the incorrect setup of the raster/defocusing system, and one shorted magnet.

Beam Dump



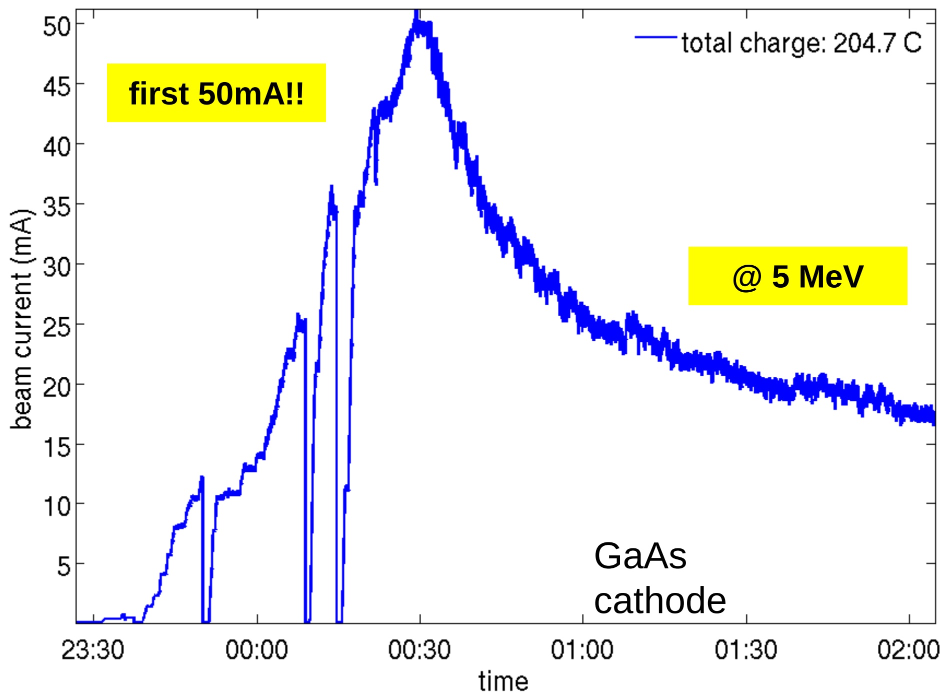
In this view, the water flows from the center (end of dump) to the outside (front of dump)

We added an array of 80 thermocouples around the dump, and read them out at 0.5 Hz using an 80 channel Keithley meter. Response time is surprisingly fast, making this an important tool for monitoring the dump temperature and temperature uniformity.

New Average Current Record!

Key developments

- Expertise in several different photocathodes (both NEA and antimonides)
- Improvements to the laser (higher power)
- Feedback system on the laser
- Minimization of RF trips (mainly couplers)
- Minimizing radiation losses due to halo
- Improved beam dump diagnostics



Highest ever average current from a photocathode gun!

Conclusion

Just in the last year . . .

- *Average current of 50 mA* from a photoinjector demonstrated – new record!
- Demonstrated feasibility of high current CW operation (20 mA for 8 hours from a single cathode spot)
- Original emittance spec achieved: now getting x1.8 the thermal emittance values, close to simulation results

Acknowledgements

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DMR-0807731

List of other Cornell ERL-related talks and posters

MOPPP026 Cryogenic Distribution System for the Proposed Cornell ERL Main Linac (Smith)
TUPPR045 Multi-cell Vertical Electropolishing Results (Furuta)
WEEPPB015 Temperature Dependence of the Superheating Field (Valles)
WEPPC070 Automated Experimental Cavity Test Suite for Cornell's ERL Program (Gonnella)
WEPPC071 Investigation of radiation-free mid-field quenches of a SRF cavity (Gonnella)
WEPPC072 High Current effects in the Cornell ERL SRF Injector Cryomodule (Liepe)
WEPPC073 Progress on SRF Work for the Cornell ERL (Liepe)
WEPPC074 HOM Studies on the Cornell ERL Prototype Cavity (Liepe)
WEPPC075 Testing of the Main Linac Prototype Cavity for the Cornell ERL (Liepe)
WEPPC078 Recent developments in the Cornell Nb3Sn Initiative (Posen)
WEPPC079 Residual Resistance Studies at Cornell (Posen)
WEPPC080 Minimizing Helium pressure sensitivity in elliptical SRF cavities (Posen)
WEPPC081 Measurement of the mechanical properties of SRF cavity in operation (Posen)
WEPPD082 Characterization of photocathode damage during high current operation (Maxson)
WEOAB02 Photocathode R&D at Cornell University (Cultrera)
MOPPP024 Invest. into multiple beam breakup instabilities for the Cornell ERL (Crittenden)
MOPPP025 Cornell ERL Project Definition Design Report (Hoffstaetter)
MOPPR078 Stabilization of the Cornell ERL High Current Injector (Loehl)
WEPPP077 Control of RF transients in cavities induced by pulsed high currents (Loehl)