HIGH BRIGHTNESS AND HIGH AVERAGE CURRENT PERFORMANCE OF THE CORNELL ERL INJECTOR

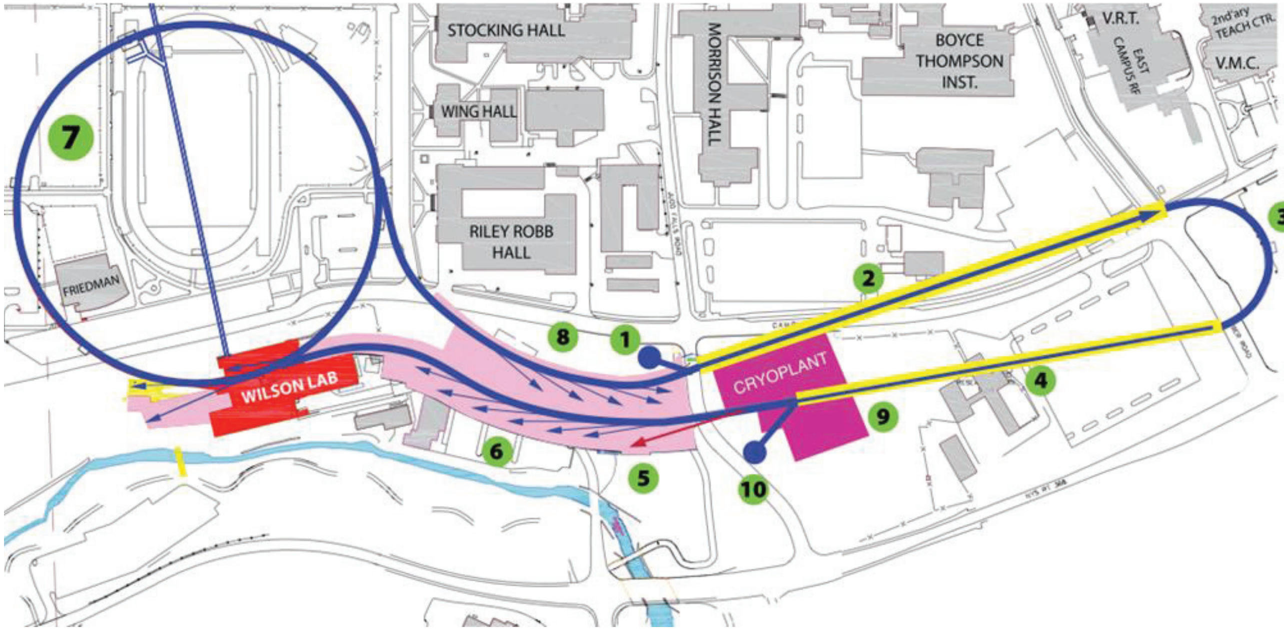
Bruce Dunham, for the Cornell ERL Team

August 27, 2013

Outline

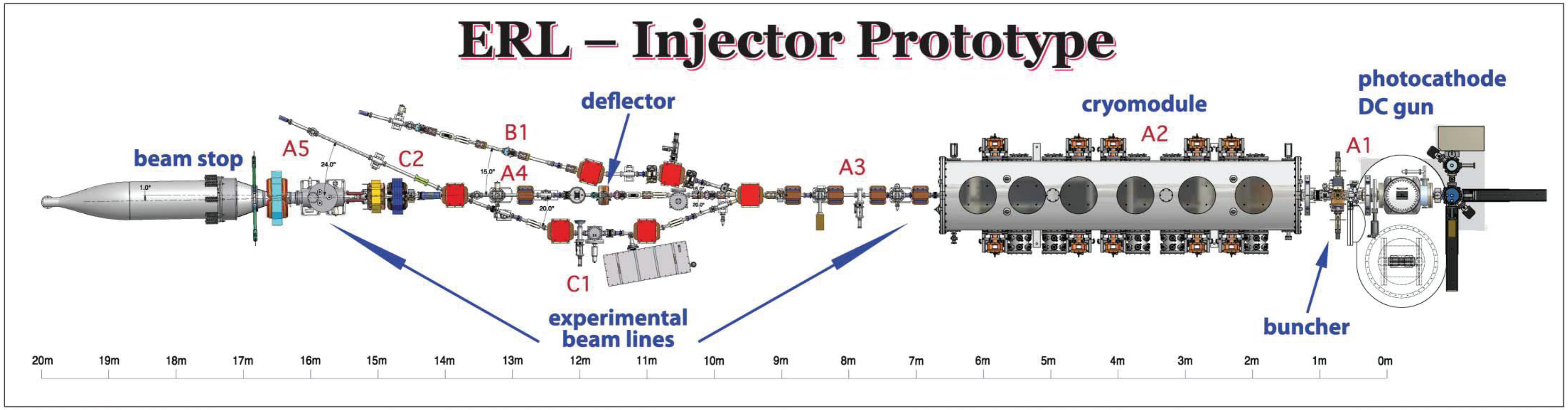
- Overview
- High Brightness Results
- High Power Operations and Results
- Conclusion

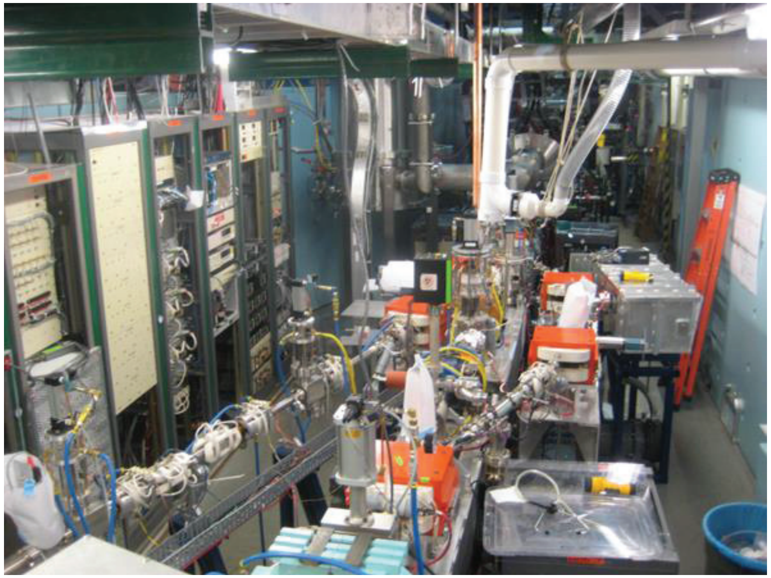
ERL @ Cornell



- 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 . . .
- 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:

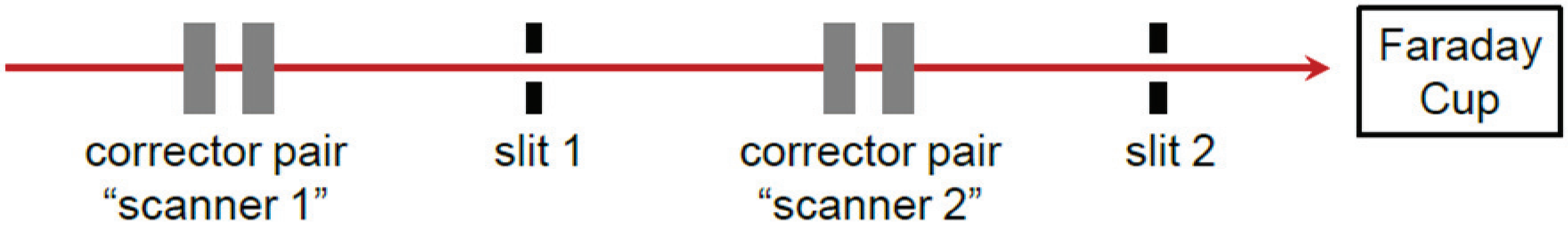
- *75 mA average current @ 4 MeV*
- *0.3 μm emittance @ 77 pC, 8 MeV*

Injector Requirements

Parameter	Metric	Status	Notes
Average Current	100 mA	yellow	75 mA (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	> 1 day	green	Recent improvements with new cathodes

Emittance Measurement Results

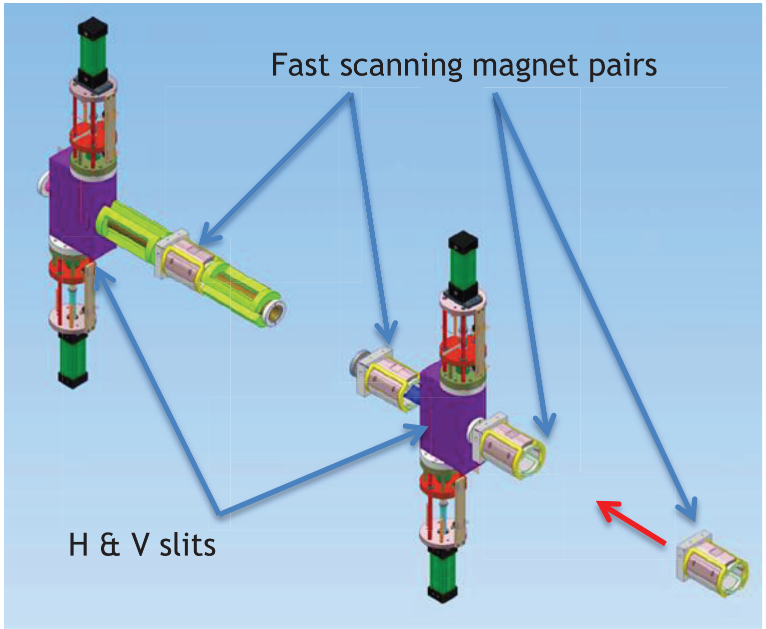
Emittance Measurement System (EMS)



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.

By adding a deflection cavity after the slits, we can also do slice emittance measurements



Goals for Experiment

- Measure low emittances at the end of the merger
  - Emittances $\leq$ 0.3 micron
  - Bunch Length $\leq$ 3 ps
  - Energy Spread ~ 1e-3
- Demonstrate $\varepsilon_{n,x} \propto \sqrt{q}$, take 19 pC and 77 pC data, corresponds to 25 and 100 mA
- Demonstrate agreement between measurement and simulation

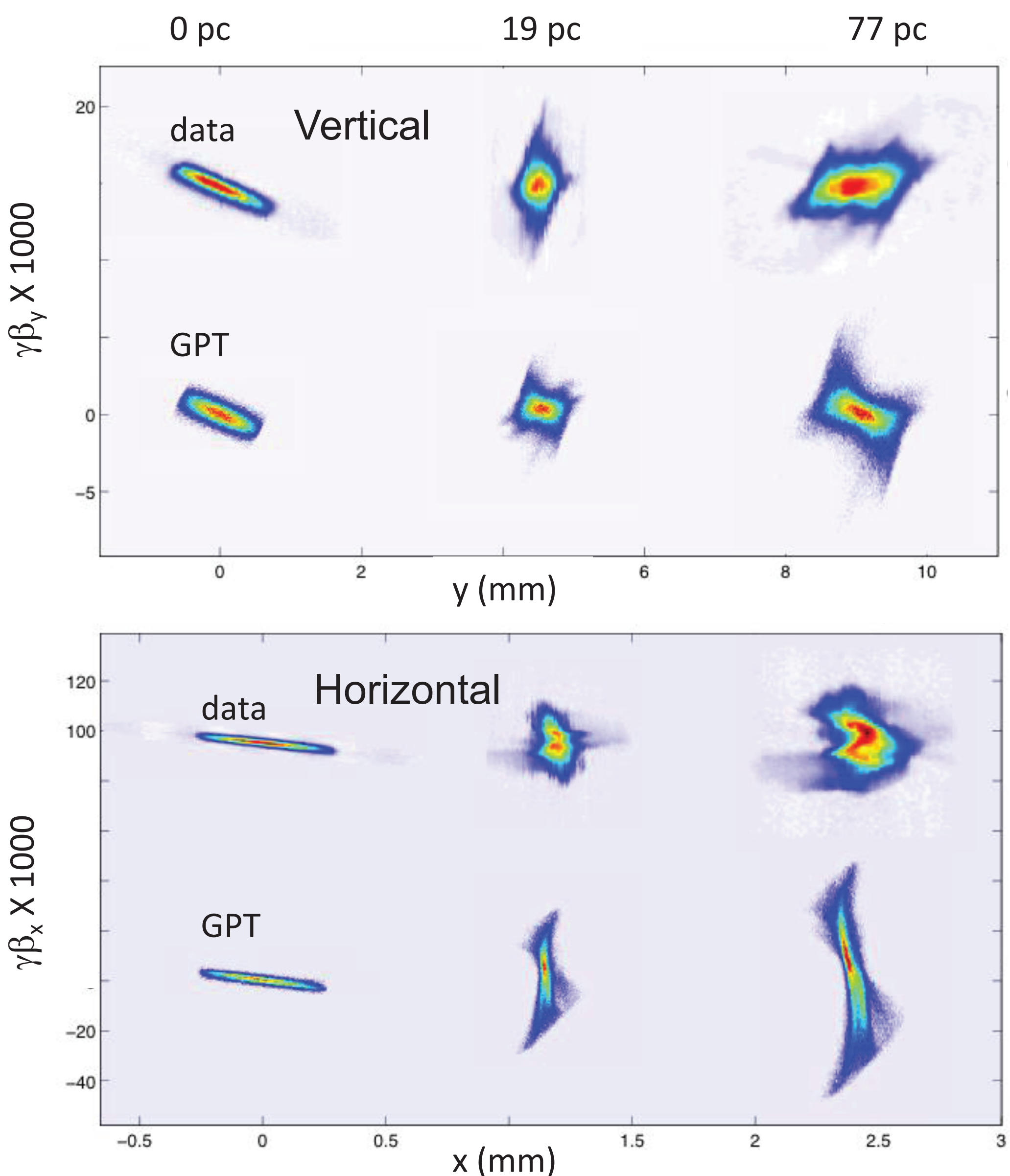
Baseline Emittance

Baseline Measurement at ‘zero’ charge

Three methods for comparison

Measurement	Horizontal Emittance [microns]	Vertical Emittance [microns]
Solenoid Scan after the gun (350kV)	0.12	0.11
Projected emittance (EMS) in merger(8 MeV)	0.11	0.12
Slice emittance (EMS) in merger (8 MeV)	0.11	N/A

Emittance Results – Projected



Projected Emittance for 19 (77) pC:

Vertical Phase Space

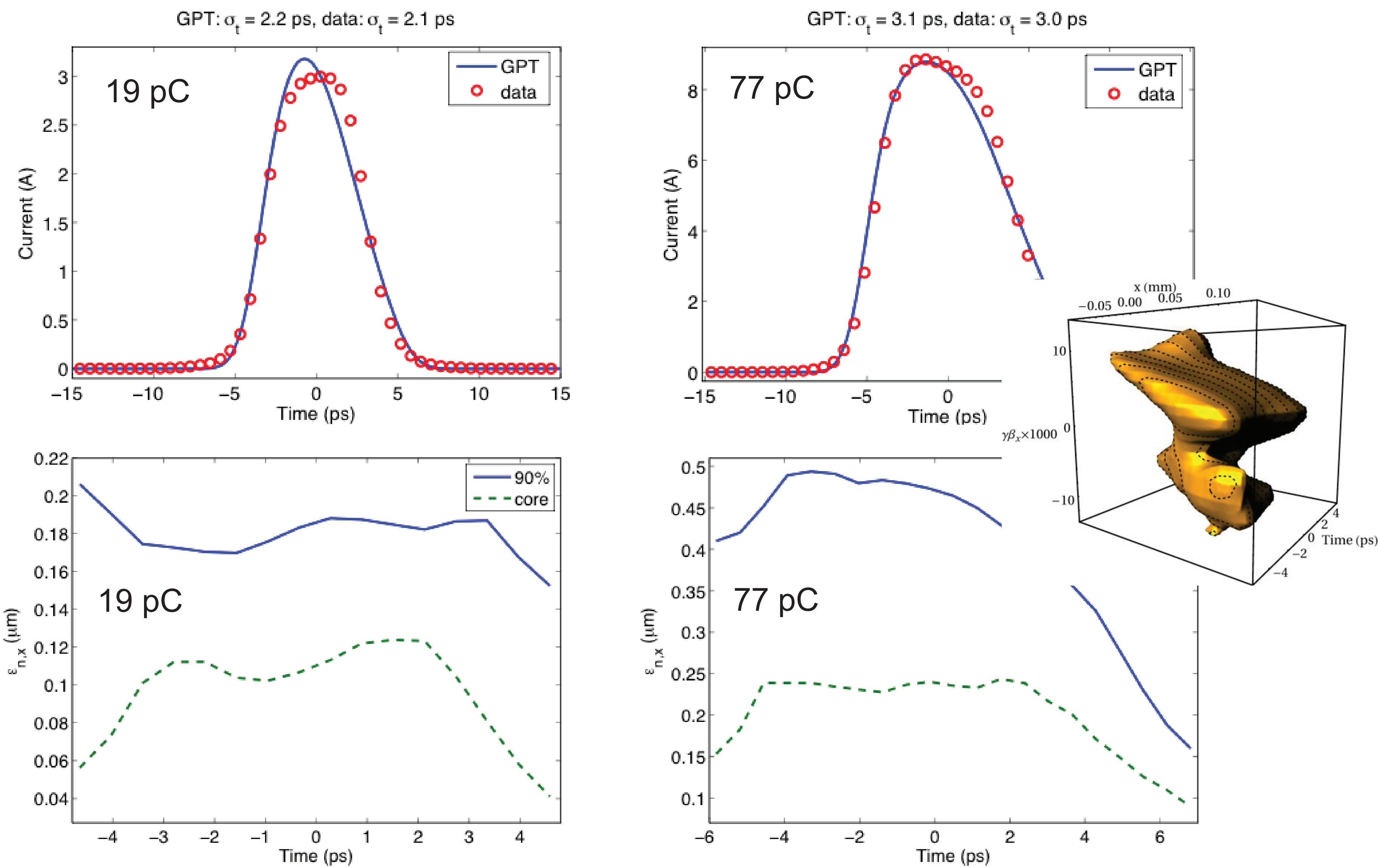
Data Type	en(100%) [microns]	en(90%) [microns]
Projected (EMS)	0.20(0.40)	0.14(0.29)
GPT	0.16(0.37)	0.11(0.25)

Horizontal Phase Space

Data Type	en(100%) [microns]	en(90%) [microns]
Projected (EMS)	0.33(0.69)	0.23(0.51)
GPT	0.31 (0.72)	0.19(0.44)

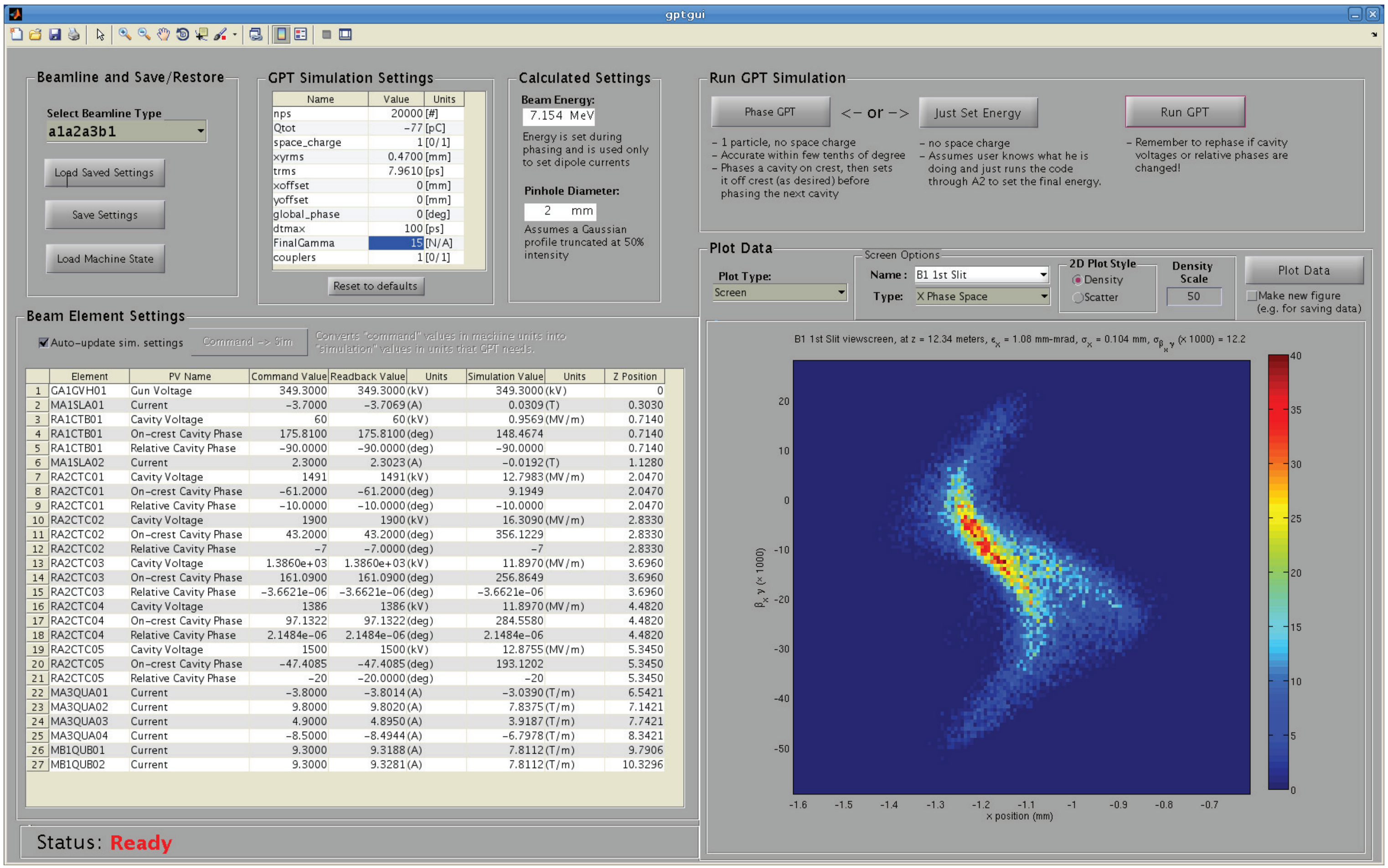
*C Guilliford, *et al*, PRST-AB **16**, 073401 (2013)

Slice Emittance and Bunch Length



GPT – Machine Interface

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



High Current Results

High Current Operation

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

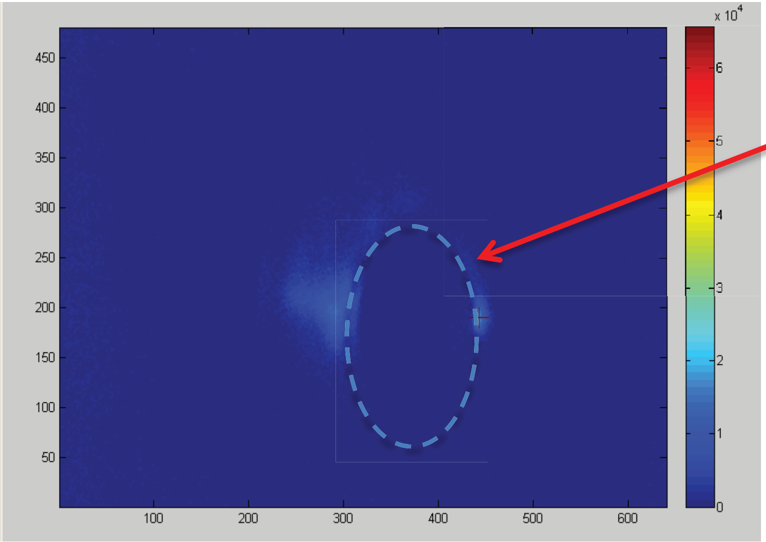
100 μA — Phase space measurements: Non-intercepting or fully intercepting diagnostics

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

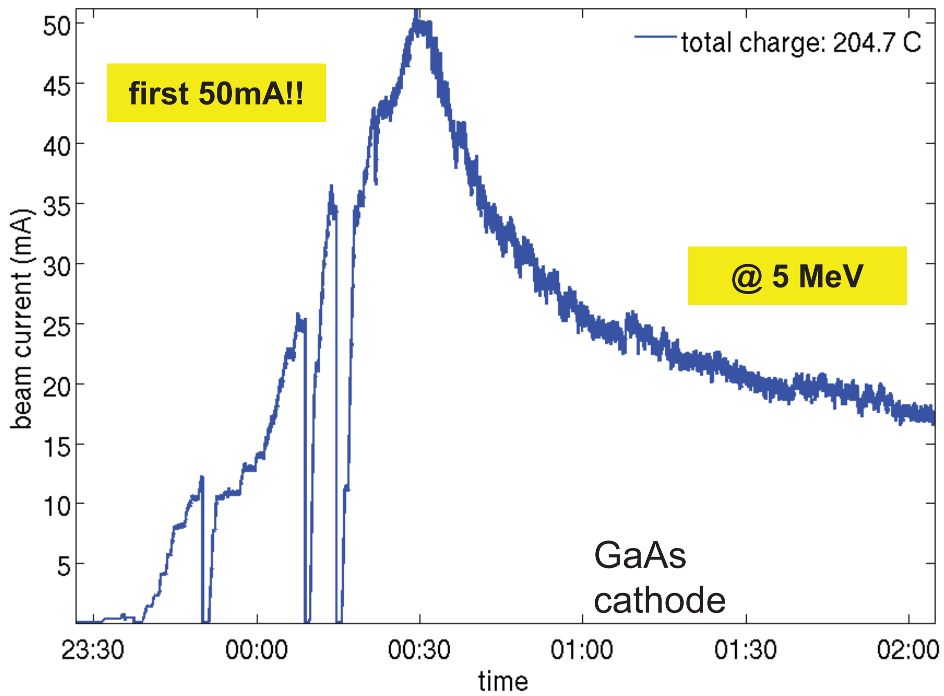
A viewer with a hole for imaging halo



High Currents - GaAs

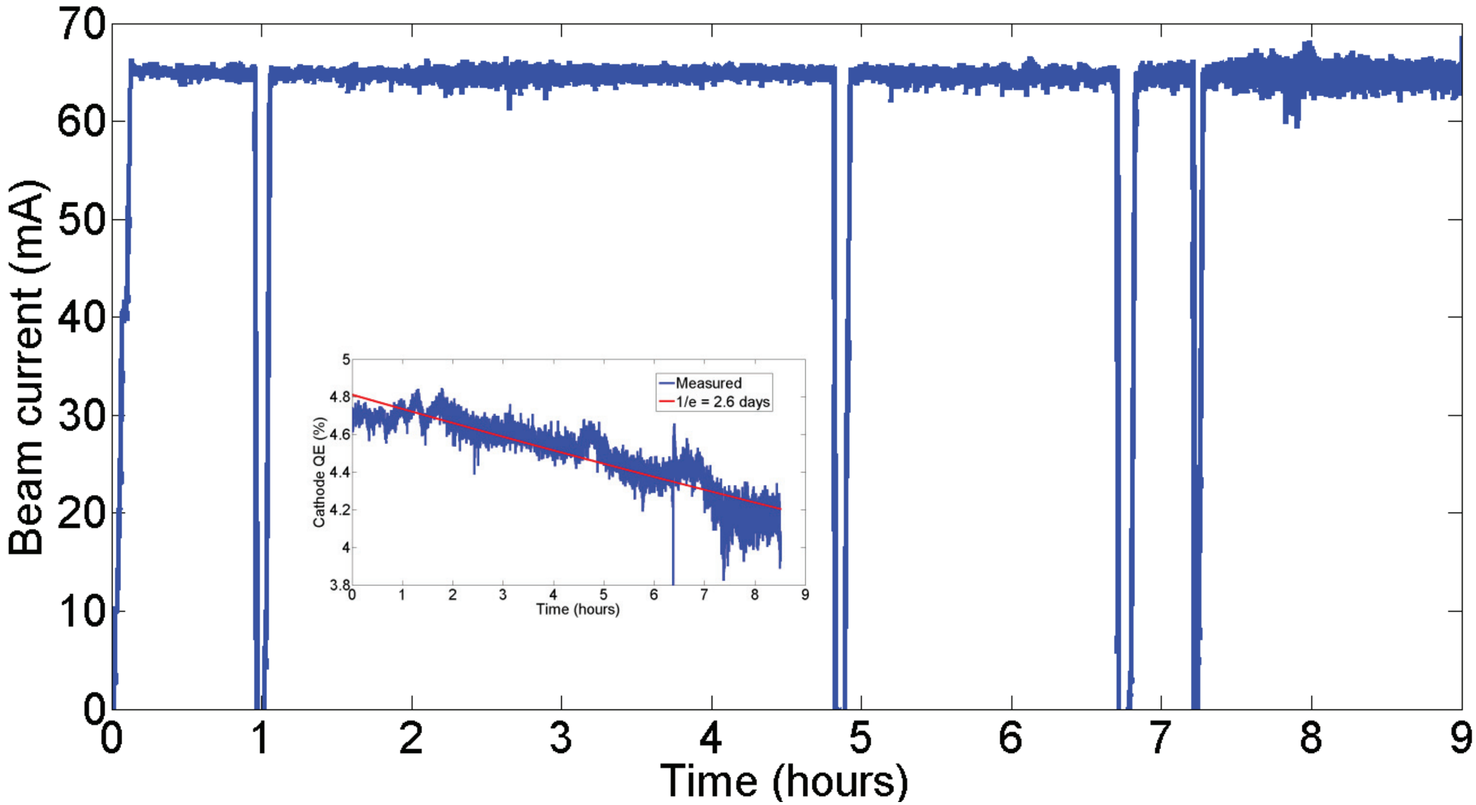
<u>Key developments</u>

- 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 GaAs photocathode!

High Currents – Na_2KSb



Using a Na_2KSb photocathode, ran over 8 hours at 65 mA (2000 C) with a 2.6 day 1/e cathode lifetime. Reached as high as 75 mA for a short time.

*L. Cultrera, *et al.*, *Appl. Phys. Lett.*, in publication
*B. Dunham, *et al.*, *Appl. Phys. Lett.*, 102, 034105 (2013)

Lessons Learned

- High average currents with good lifetime from a photocathode are a reality
- Low emittance (near thermal) beams (with reasonable bunch charge) from a DC gun/SRF booster are a reality
- Extremely high DC voltages are not necessary to achieve our requirements (350 kV okay)
- Space charge simulations + genetic optimizations match experiments accurately
- Halo/beam loss can be maintained below 1 part in 10^7 to 10^8
- Cathodes are still the key for any photoemission gun

Conclusion

Just in the last year . . .

- *Average current of 75 mA* from a photoinjector demonstrated – new record!
- Demonstrated feasibility of high current CW operation (65 mA for >8 hours from a single cathode spot)
- Emittance specification achieved

DC photoemission guns with SRF boosters provide proven performance for high average current, high-brightness beams for moderate bunch charge applications

Acknowledgements

This work is supported by the National Science Foundation grant DMR-0807731

and Department of Energy grant DE-SC0003965