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

LINAC 2016
28th Linear Accelerator Conference
September 25th - 30th, 2016
East Lansing, MI, USA

Trapped Ion Effects and Mitigation During High Current Operation in the Cornell DC Photoinjector

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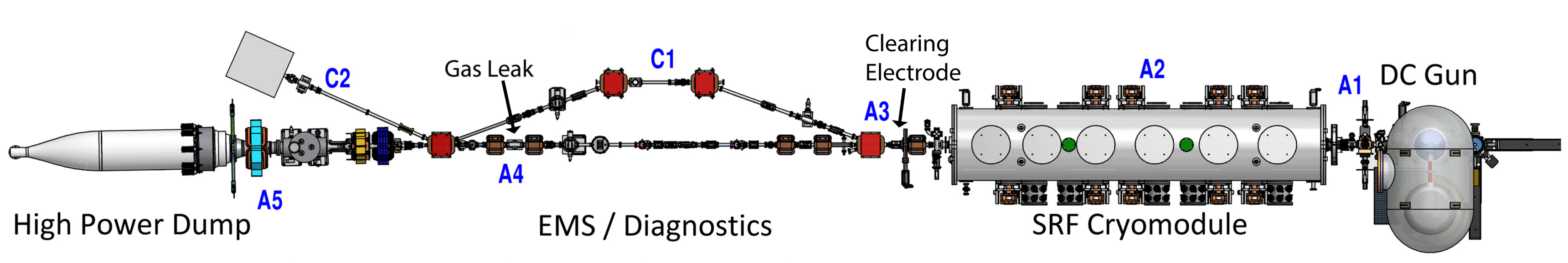
Introduction

The Cornell high intensity photoinjector is a low energy linac originally designed to be the injector for Cornell's proposed ERL, but has since been repurposed for use in Cornell's new multipass ERL collaboration project with Brookhaven, CBETA.

Parameter	Experimental	Nominal
Beam energy	350 keV/ 4 MeV	5-15 MeV
Beam size	1 mm – 4 mm	~ mm
Bunch length	~ 3 ps	< 3 ps
Bunch charge	7.7 – 15.4 pC	77 pC
Current	10 – 20 mA	100 mA
Repetition rate	1.3 GHz	1.3 GHz
Gas pressure	1.2 x 10^{-7} torr	1 x 10^{-9} torr

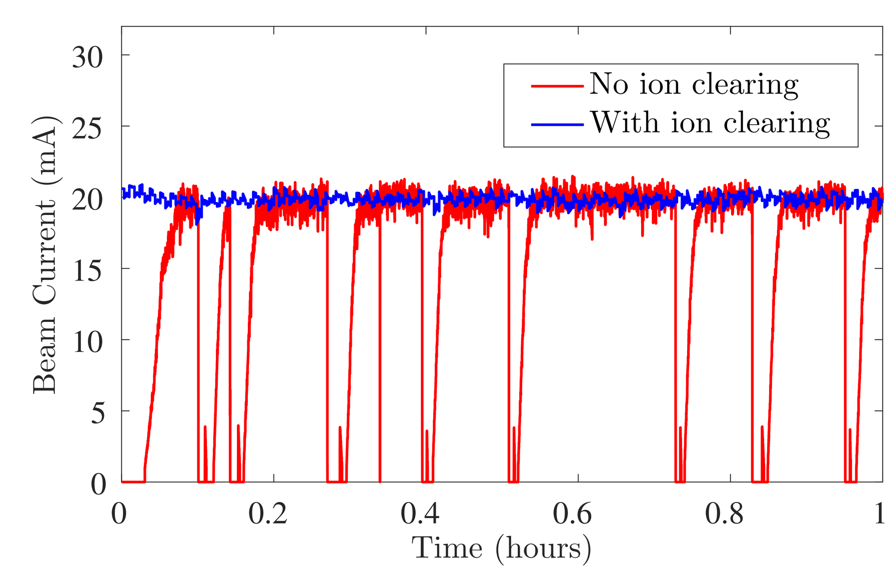
Unlike previous linacs, the photoinjector reaches a new regime of beam parameters where high CW electron beam currents lead to ion trapping. Once trapped, the ions can cause a variety of issues including beam losses, tune shifts or even beam instabilities. Our studies focus on understanding how ions behave when trapped, how they impact beam quality, and how we can ultimately mitigate these effects.

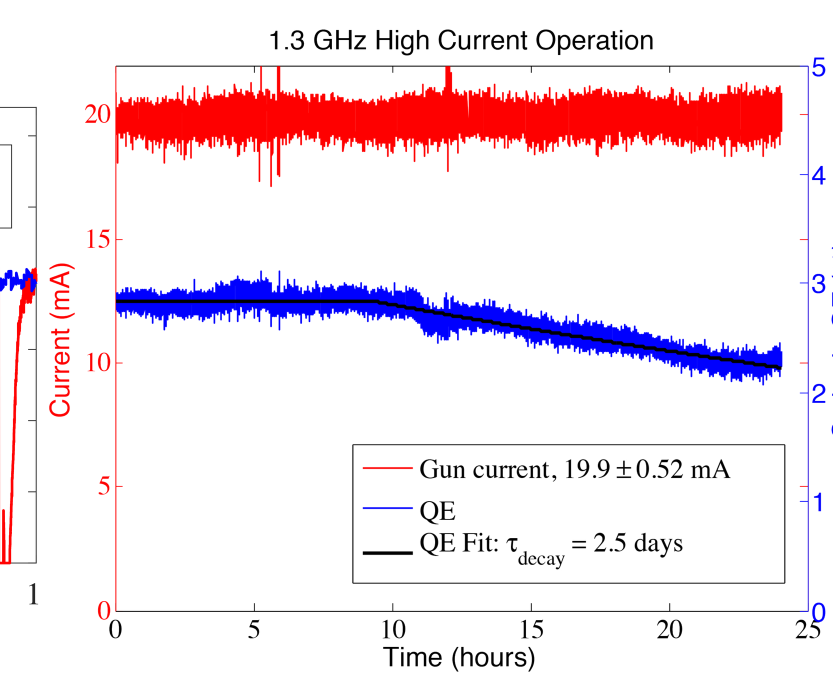


Evidence of Ion Trapping

Above 20 mA during 350 keV runs, we have observed beam trips that limit stable machine operation to approximately 10-15 minutes. Employing ion clearing techniques allowed stable beam operation for at least 24 hours, leading us to believe that ions are the cause of the trips.

Out present theory is that trapped ions drift backwards and strike the cathode, ultimately leading to gun high voltage power supply trips.





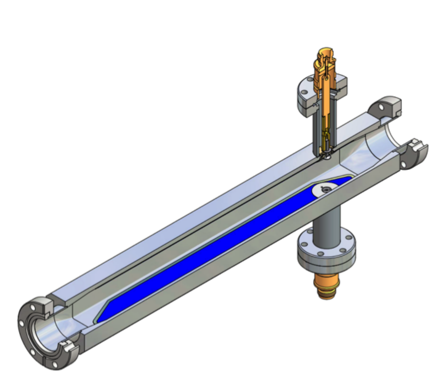
Testing of Ion Clearing Methods

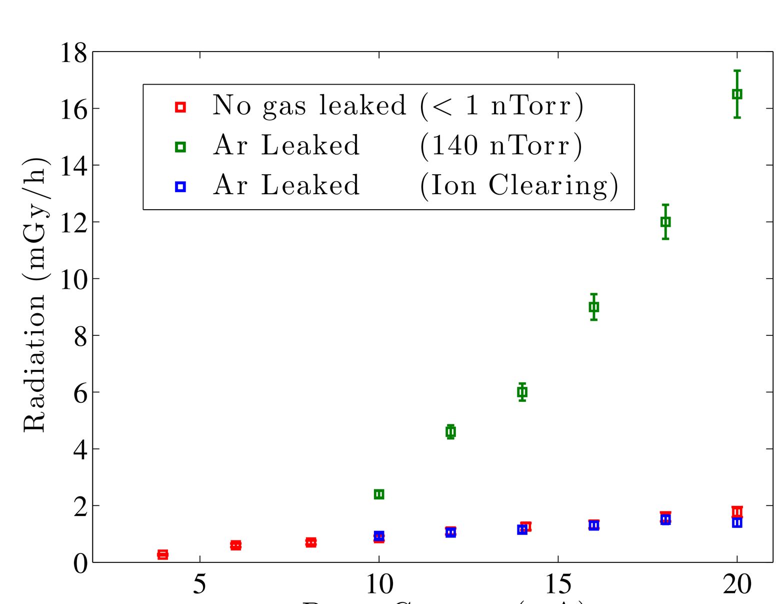
Measurement Scheme

We have conducted experiments to explore the three most common methods of ion mitigation: clearing electrodes, bunch gaps and beam shaking.

We relied on two measurment techniques to determine the trapped ion density:

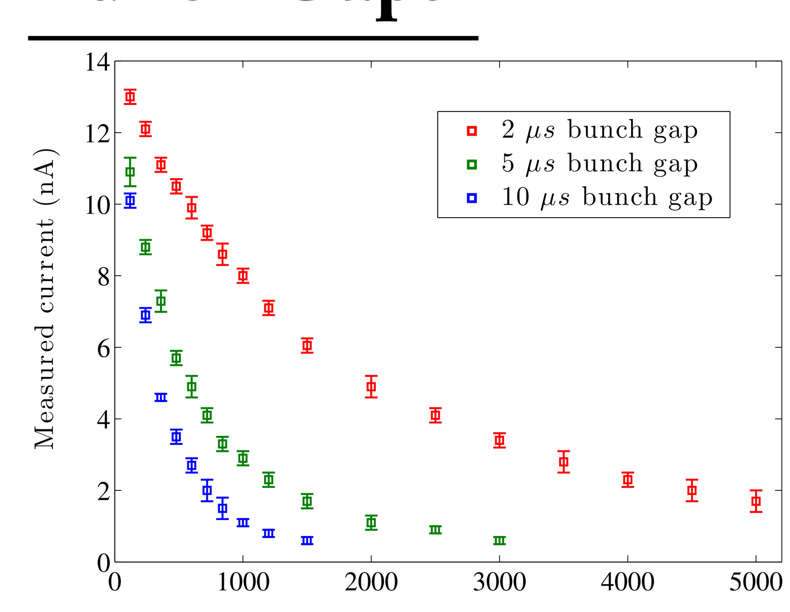
1. The ion current removed by a clearing electrode
2. A reduction in bremsstrahlung radiation caused by beam-ion interactions.

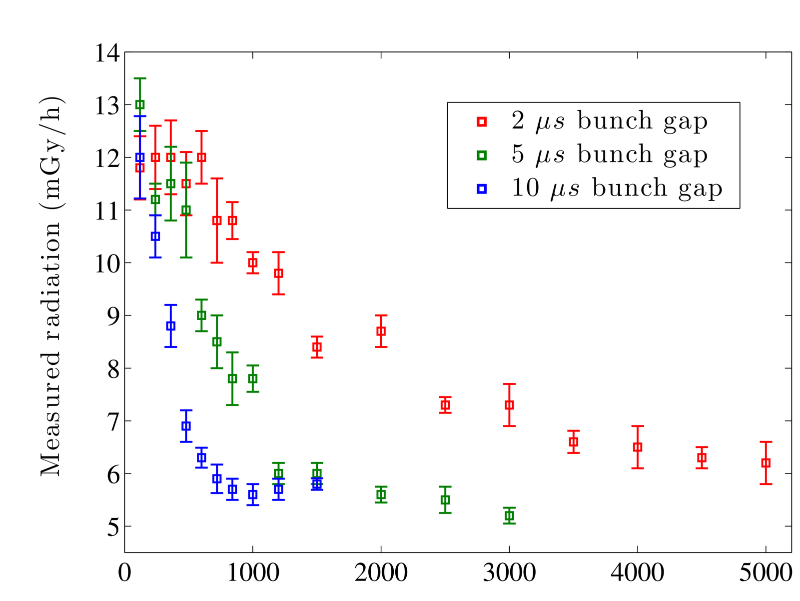




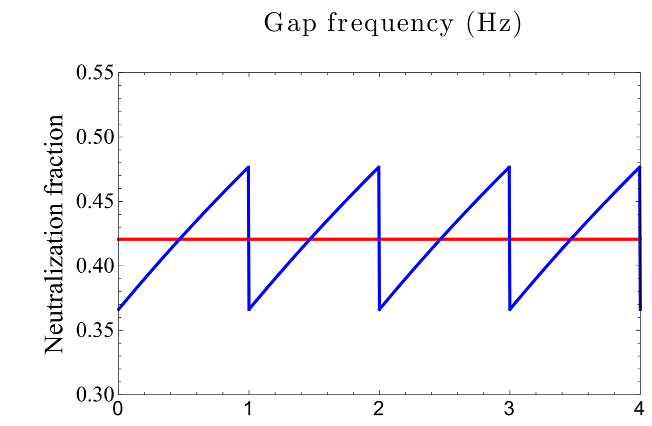
After leaking gas into the beam pipe, background radiation levels rose dramatically due to bremsstrahlung generated by beam-ion interactions. Removing the trapped ions reduced this excess radiation to normal background levels.

Bunch Gaps

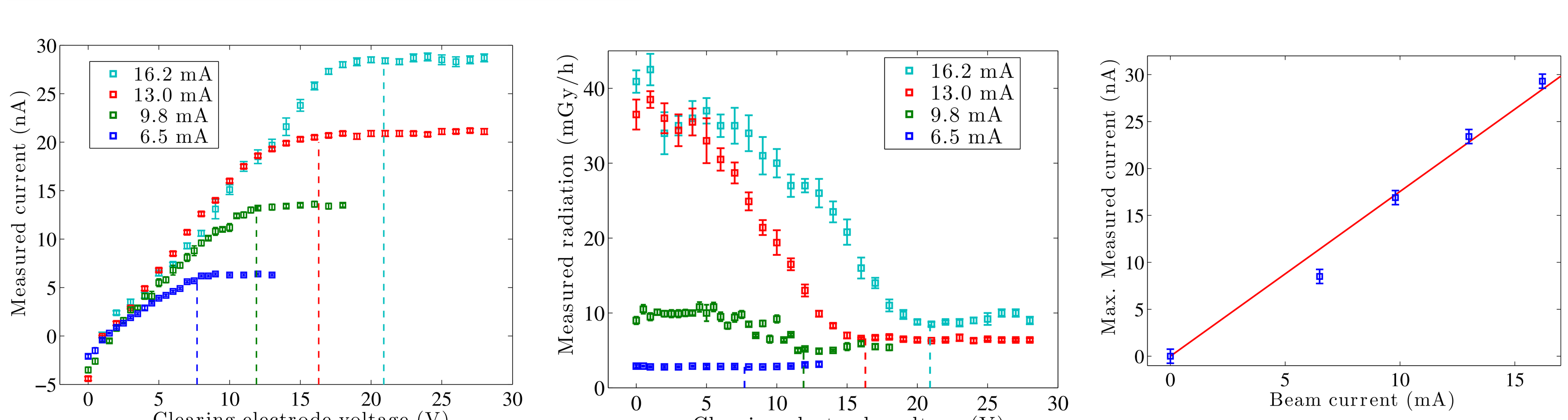




Introducing short bunch gaps reduced the number of trapped ions that reach the clearing electrode, and reduced beam-ion generated radiation. Ions are created via collision ionization while the beam is on and decay exponentially during the bunch gaps. The equilibrium neutralization fraction (in red) is what we ultimately measured.

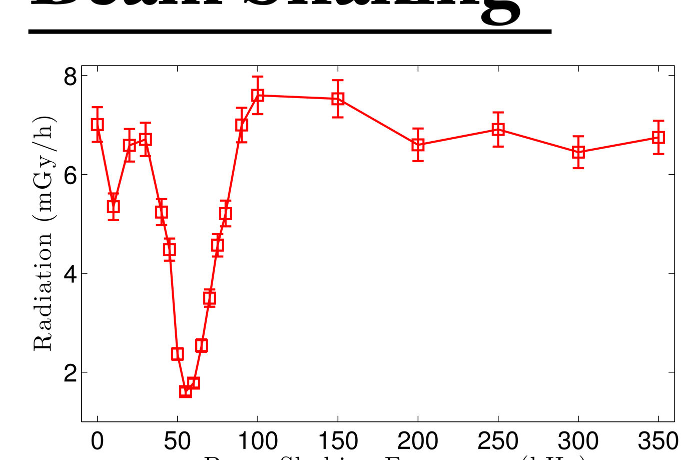


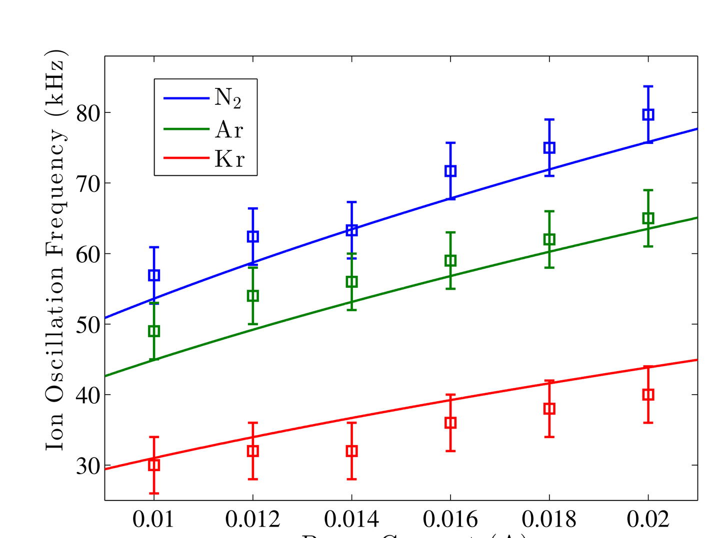
Clearing Electrodes



A picoammeter was attached in series with the clearing electrode and used to measure the ion current striking the electrode for different applied voltages. The vertical dotted lines mark the minimum voltage required for full ion clearing, and were calculated by considering the electric field necessary to overwhelm the transverse potential of the beam.

Beam Shaking





Because the ions oscillate transversely inside of the beam's potential well, they possess a natural ion oscillation frequency. By sinusoidally shaking the beam at this frequency, a resonance is induced and the ions are shaken out of the beam, as evidenced by a decrease in radiation (left). A simple linear oscillation model can be used to predict the ion oscillation frequencies required for clearing, and the model agrees well with experimental data (right).

Publication: S. Full, A. Bartnik, I. V. Bazarov, J. Dobbins, B. Dunham, and G. H. Hoffstaetter
Phys. Rev. Accel. Beams 19, 034201 – Published 3 March 2016

Acknowledgements: CLASSE facilities are operated with major support from the National Science Foundation.
Student travel grants were provided to present this work at LINAC 2016.