The University of Maryland Electron Ring: Overview

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Thanks to members of UMER team, esp. T. Koeth
Thanks to my FNAL hosts V. Shiltsev and S. Nagaitsev

Research sponsored by US DOE & DOD

Outline

1. Introduction to the Maryland Accelerator Research Group
2. UMER machine description
3. A glimpse of current research
   – PhD student work
   – Longitudinal space charge and instabilities
   – Beam loss studies
4. (Maryland's other accelerator research facilities)
5. Summary

University of Maryland Accelerator Research Group

B. Beaudoin, R. Fiorito, S. Bernal, L. Johnson, T. Koeth, E. Voorhies
R. Kishek, I. Haber, D. Sutter, D. Feldman, P. O’Shea, H. Zhang, M. Cornacchia

not shown: Y. Mo, K. Poor Rezaei, W. Stem, K. Ruisard

Education/Training: Recent PhD Graduates

Student	PhD year	Placement	Currently @
Yun Zou	2000	Industry	GE Global Research
Yupeng Cui	2004	KLA-Tencor	Velodyne Acoustics
Hui Li	2004	Microsoft	Embarcadero Technologies
John Harris	2005	NRL	Colorado State University
Jon Neumann*	2005	NRL	Naval Research Laboratory
Nathan Moody*	2006	LANL	Los Alamos National Laboratory
David Gillingham	2007	NRL	Institute for Defense Analysis
Kai Tian	2008	J-Lab	Stanford Linear Accelerator
Diktys Stratakis*	2008	BNL	Brookhaven National Laboratory
J. Charles Tobin*	2009	FNAL	Fermi National Accelerator Laboratory
Chao Wu	2009	FDA	Hillcrest Labs
Chris Papadopoulos	2009	LBNL	Lawrence Berkeley National Laboratory
Eric Montgomery*	2009	UMD	U. Maryland
Mike Holloway	2010	LANL	Los Alamos National Laboratory
Matt Virgo	2010	ANL	Argonne National Laboratory
Brian Beaudoin	2011	UMD	U. Maryland
Daniela Moody	2012	LANL	Los Alamos National Laboratory
Zhigang Pan *	2013	(NRL)	Naval Research Laboratory

** Received prestigious awards*

Includes both ONR-funded and DOE-funded students

Ongoing Collaborations

Institution	Point of Contact	Area of Common Interest
Lawrence Berkeley / Livermore National Laboratories	Alex Friedman, Dave Grote, Jean-Luc Vay	Development, benchmarking, and use of the WARP code.
Princeton Plasma Physics Laboratory	Ron Davidson, Ed Startsev	Study of solitons in electron beams
Los Alamos National Laboratory	Bruce Carlsten, Nathan Moody	Development of a 100 kW-class FEL
Thomas Jefferson National Accelerator Facility (FEL)	Dave Douglas, Shukui Zhang	Non-interceptive diagnostics
Fermi National Accelerator Laboratory	Gustavo Cancelo	Use of ESECON boards for fast beam control
Argonne National Laboratory, Advanced Wakefield Accelerator	John Power, Manoel Conde	Development of advanced accelerator diagnostics for space-charge-dom. beams
SLAC National Accelerator Laboratory (SPEAR3 and LARP/CERN)	Jeff Corbett, Alan Fisher Kai Tian	Development of high dynamic range beam imaging diagnostics, THz measurements
Naval Research Laboratory	Kevin Jensen, Phillip Sprangle	Cathode theory and simulation; rf thermionic injector development
FERMI@Elettra	Simone DiMitri, Marco Veronese	Development of advanced emittance and phase-space diagnostics
Calabazas Creek Research, Inc.	Lawrence Ives, Lou Falce	Precision machining of controlled-porosity reservoir cathodes

UMER Overview

Goals:

- Study space charge dynamics in a realistic environment, over long path lengths.
- Educate students in accelerator and beam physics, with emphasis on hands-on experience.
- Affordable and flexible experiments

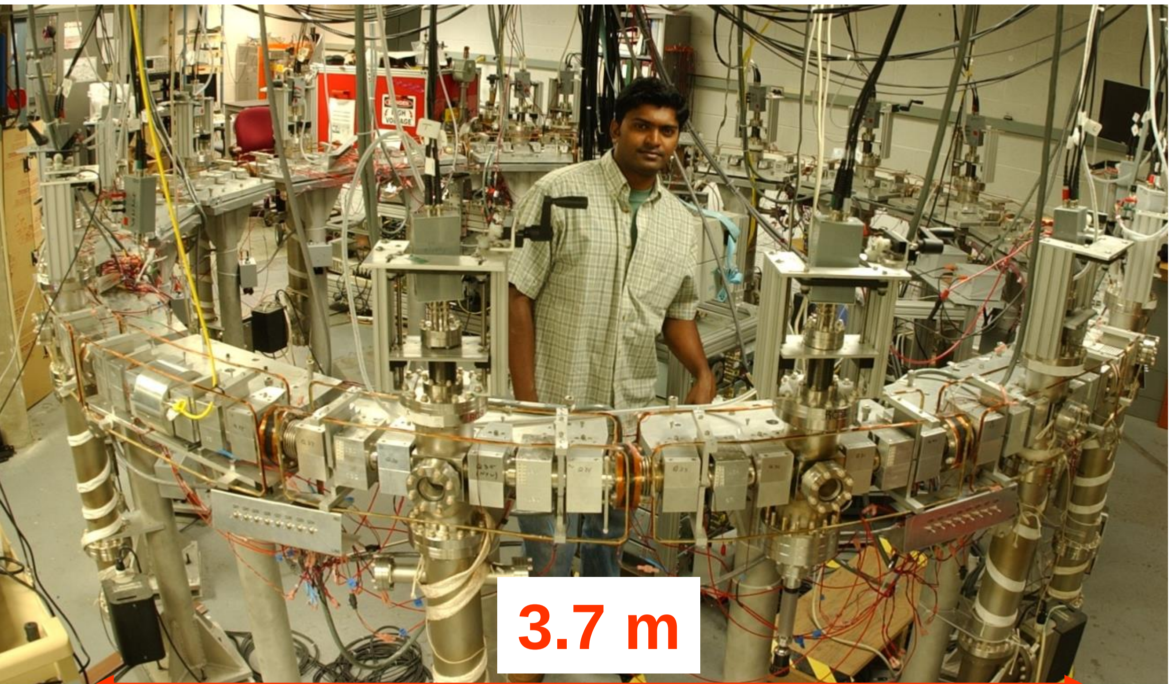
Approach:

- Scaled experiments using low-energy electron beams
- Close-coupling with theory and simulation

UMER – A Scale Model of a High-Intensity Ring

Mission: Study Space Charge Dynamics over Long Path Lengths

low energy	high current	low-emittance
10 keV	0.5-100 mA	0.3-3 μm



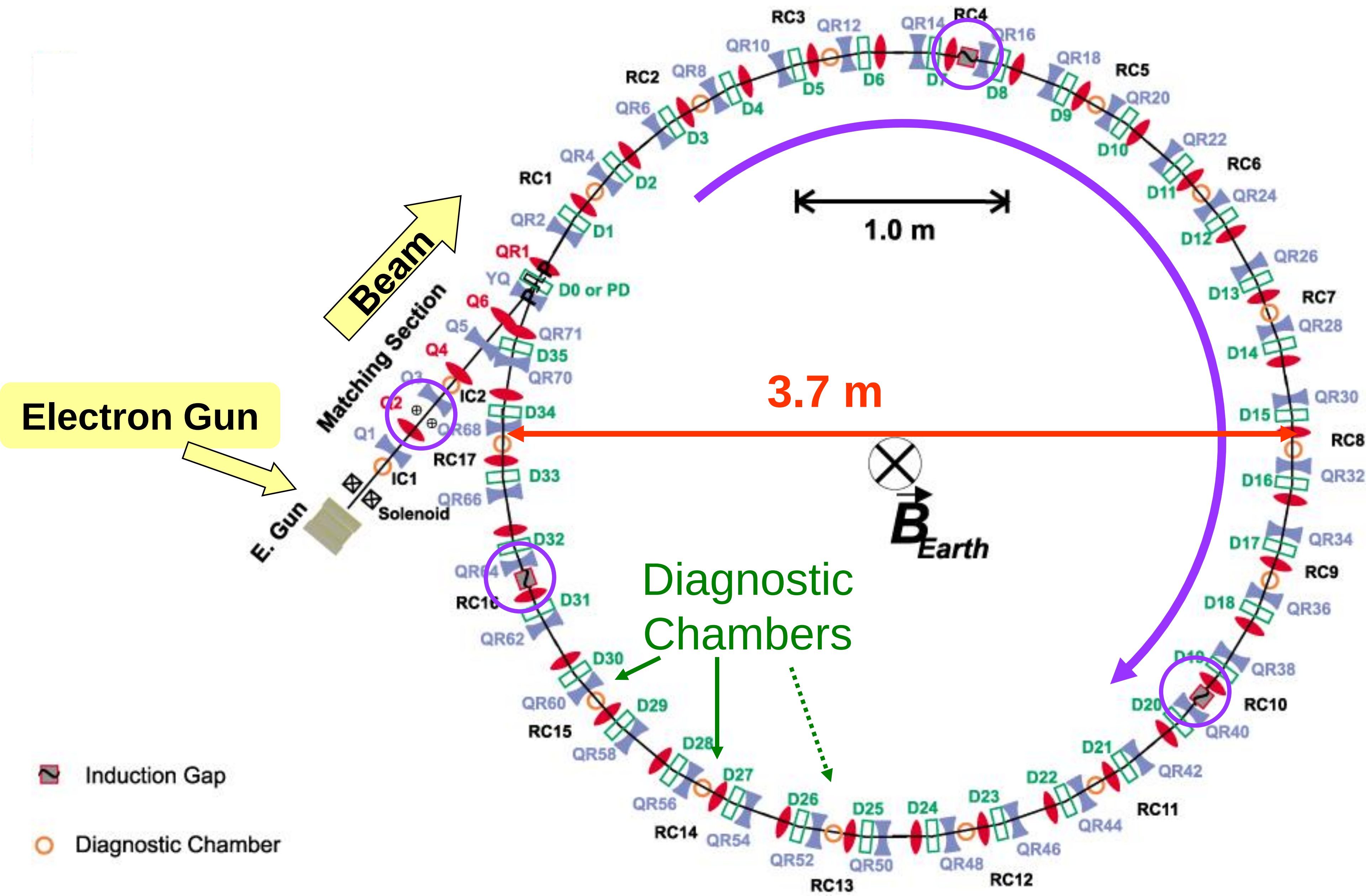
$\sim 10^{10}$ particles
or up to 14 nC

Lap time	=	197 ns, (5.08 MHz)
Pulse Length	=	15 to 145 ns,
Full-Lattice Period	=	0.32 m (std. lattice)
Vacuum Pipe radius	=	25.4 mm

- Safe
- Reproducible results
- Available: accelerator and beam physicists are the users
- Flexible: lattice, magnets, apertures

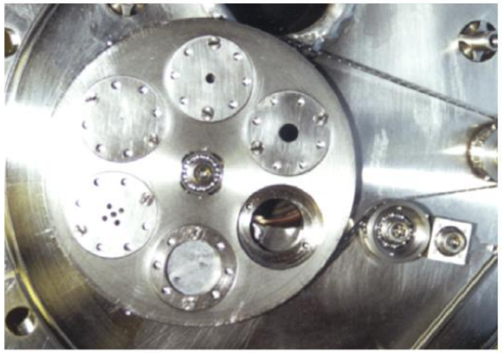
Shown: UMD graduate Charles Thangaraj (2009), now at FNAL

UMER – A Research Machine for Space-Charge Dynamics



UMER BEAM PARAMETERS

UMER spans a broad range of intensities through the use of an aperture plate.



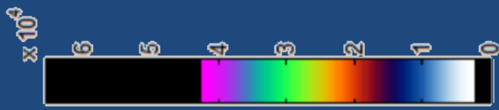
Calculated for operating tune $\nu_{ox} = \nu_{oy} = 6.6 = k_0 R$

I	$\varepsilon_{n,rms}$	a_{ave}	ν_i / ν_o	$\Delta\nu_{coh}$	$\Delta\nu$
[mA]	[μm]	[mm]			
0.6	0.4	1.6	0.85	−0.005	−0.94
6.0	1.3	3.4	0.62	−0.05	−2.4
21	1.5	5.2	0.31	−0.17	−4.5
78	3.0	9.6	0.18	−0.67	−5.4
104	3.2	11.1	0.14	−0.91	−5.6

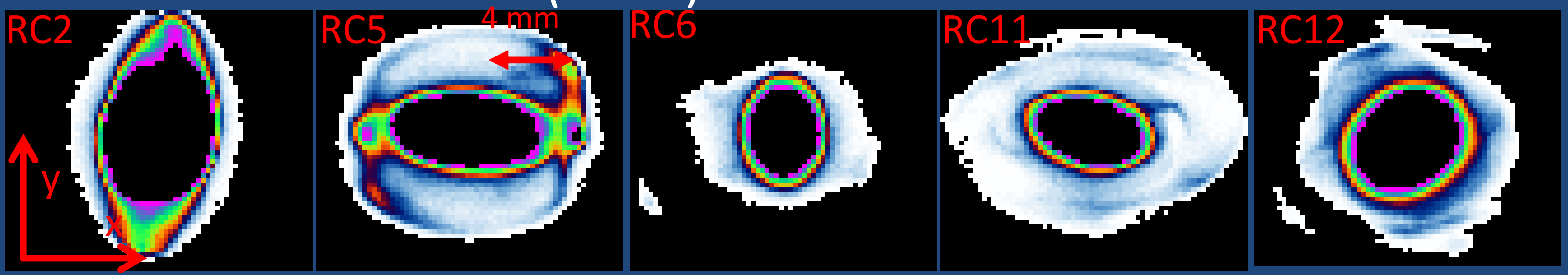
$$\frac{\nu_i}{\nu_0} = \sqrt{1-\chi},$$

$$\chi = \frac{K}{k_0^2 a^2}$$

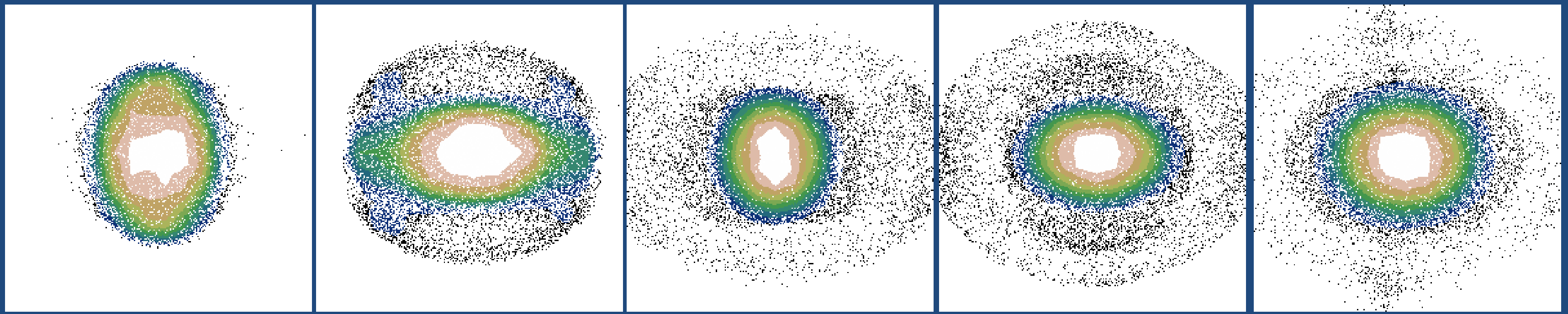
Beam Halo Studies



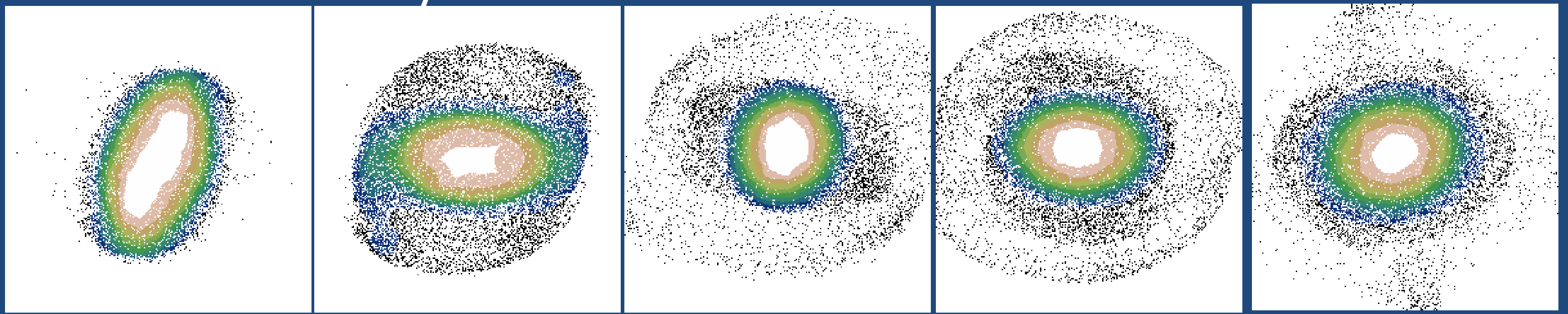
Experiment with Mismatched (6 mA) Beam



Simulations with WARP

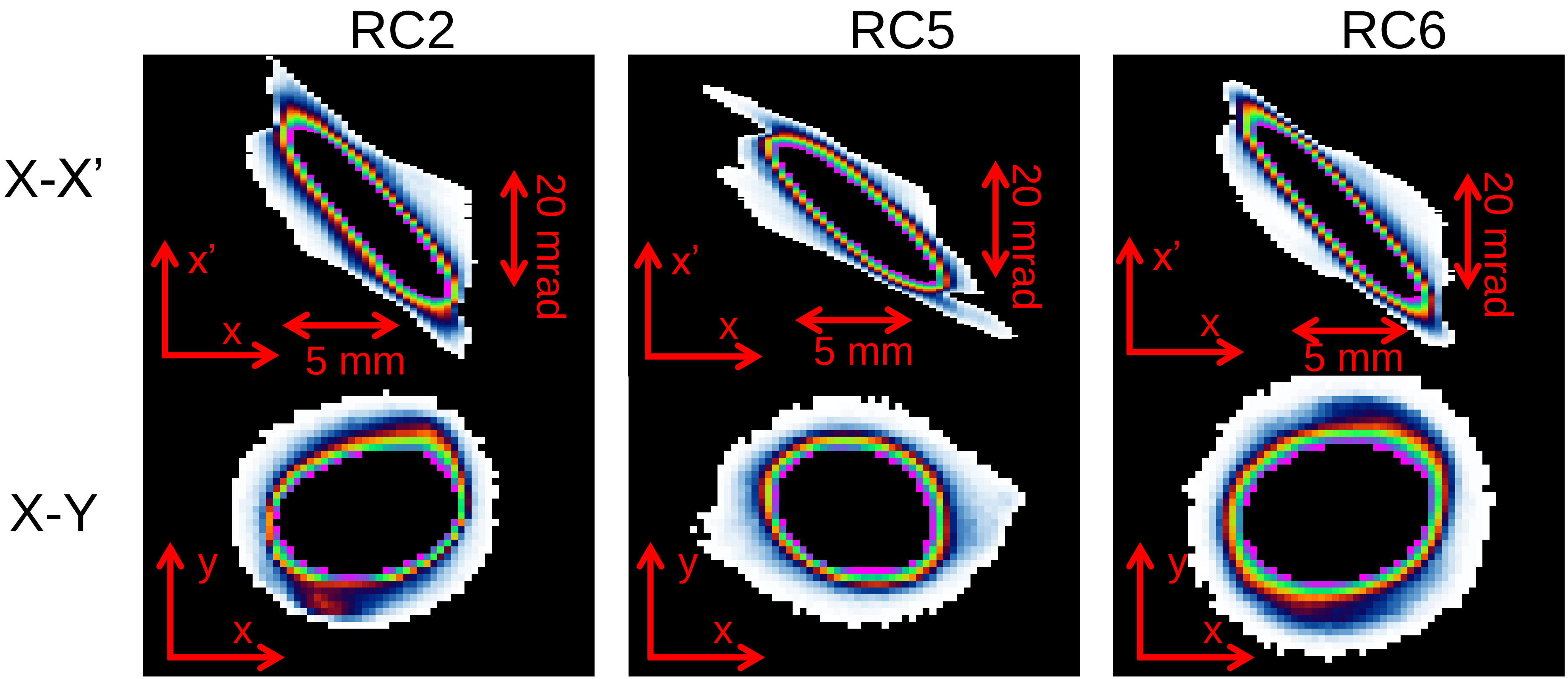


Injected Beam Skewed by 11°



Hao Zhang, Ph.D. Thesis Research

Halo Phase Space Reconstruction with Tomography

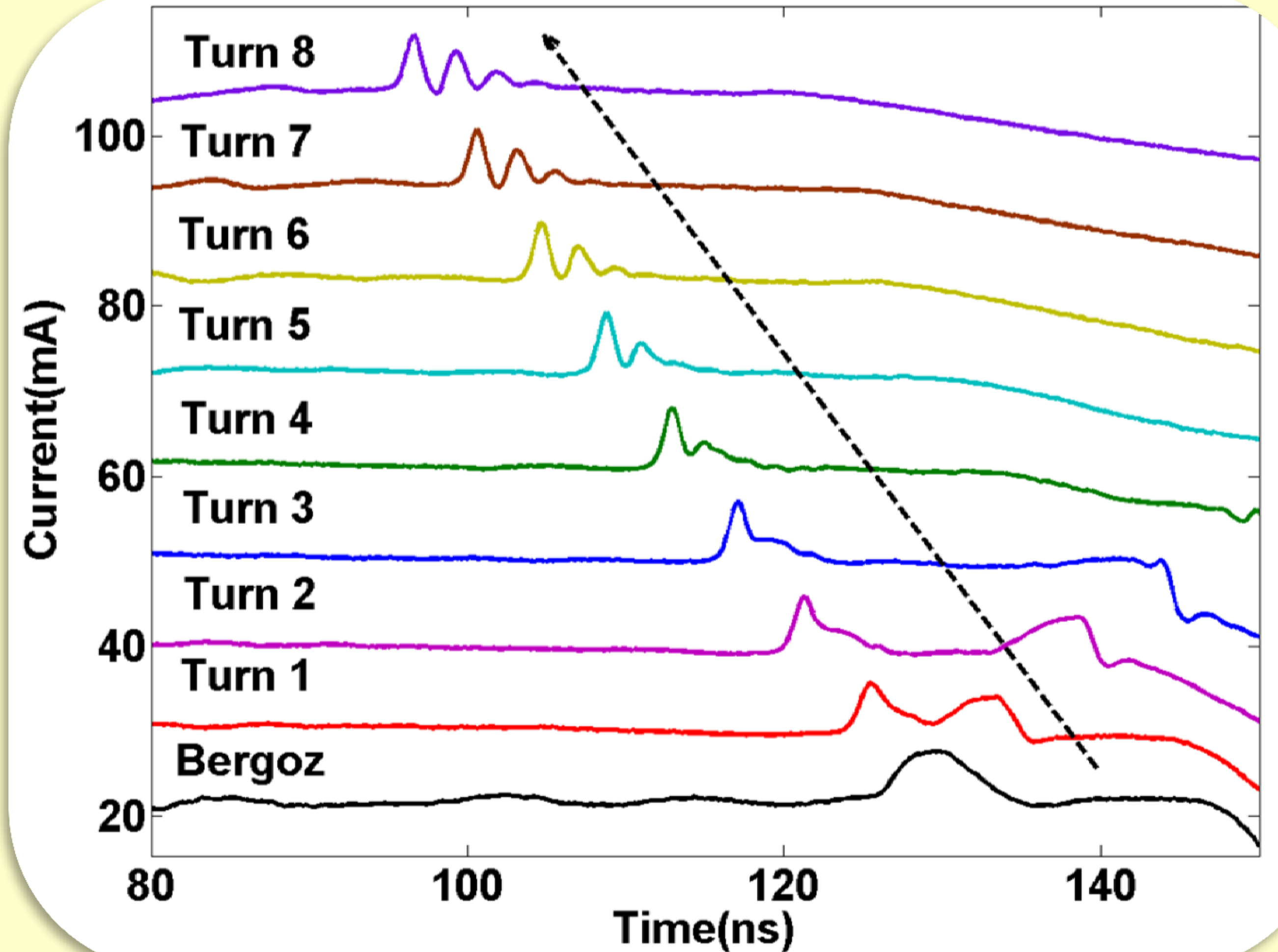


Each phase space map is obtained from ~50-100 X-Y photos at different quadrupole settings, using the filtered back-projection algorithm for reconstruction.

Hao Zhang, Ph.D. Thesis Research

Experimental Observation of Soliton Wave Train in UMER

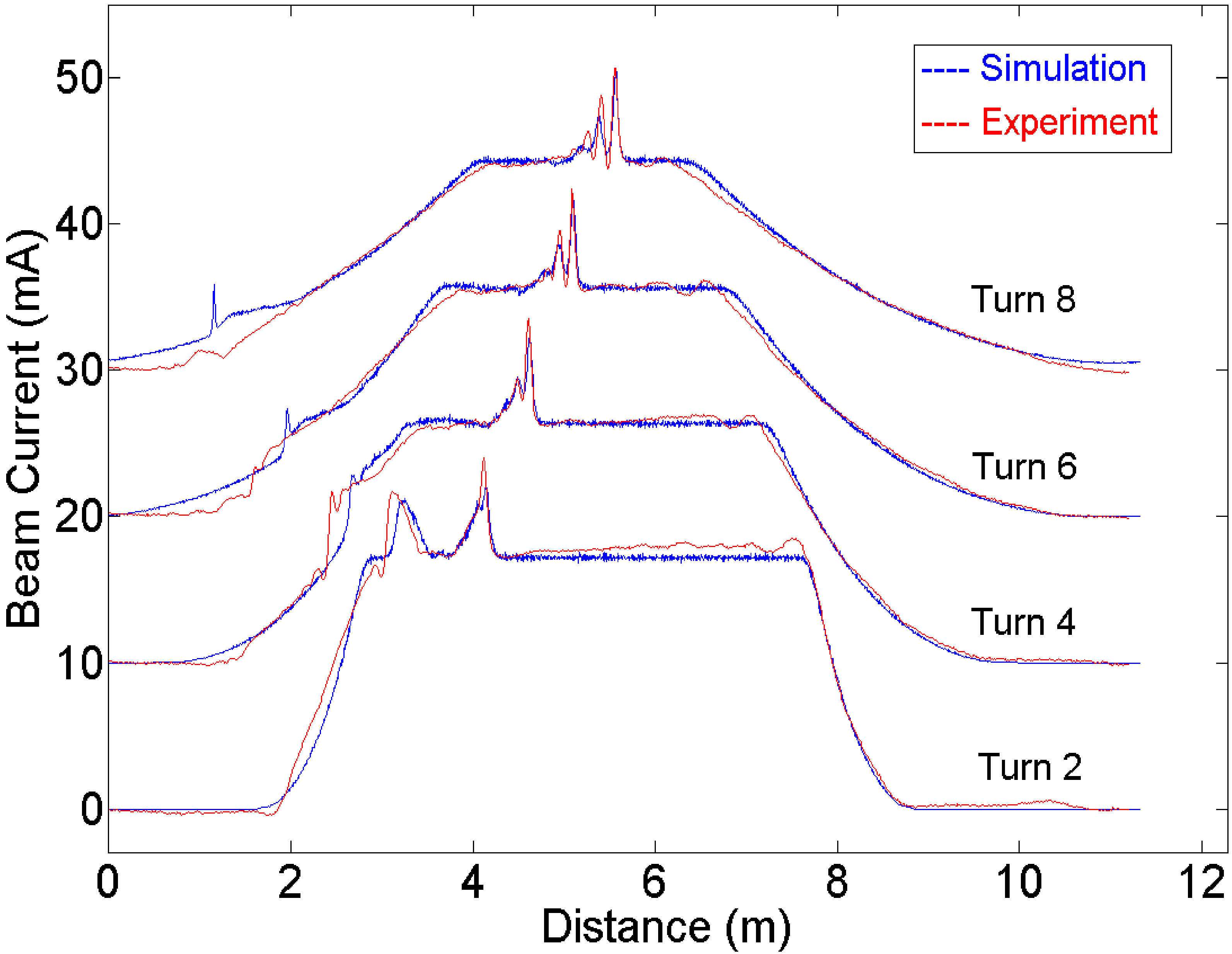
Nonlinear steepening balances wave dispersion



22 mA beam, 25% density perturbation

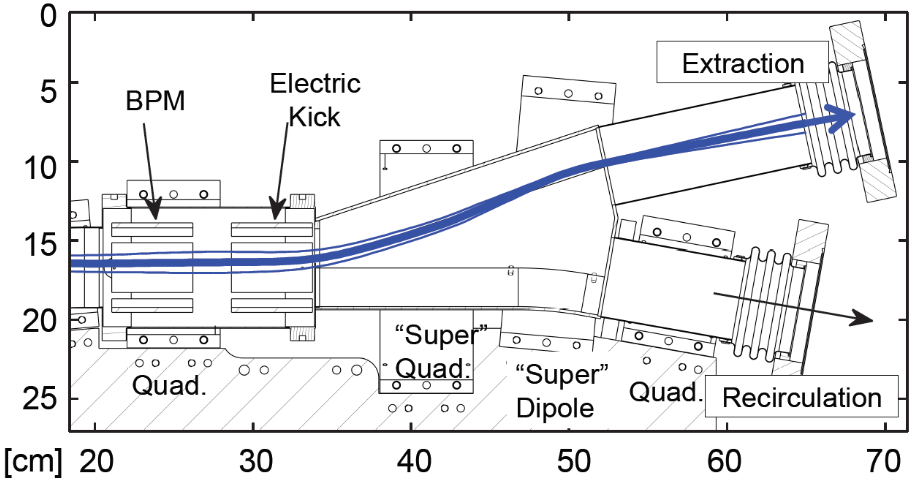
Y.C. Mo, R.A. Kishek, D. Feldman, et al., Phys. Rev. Lett., ***110,*** *084802 (2013).*

Simulation of Soliton Experiment



Yichao Mo, Ph.D. Thesis Research

UMER Extraction Section

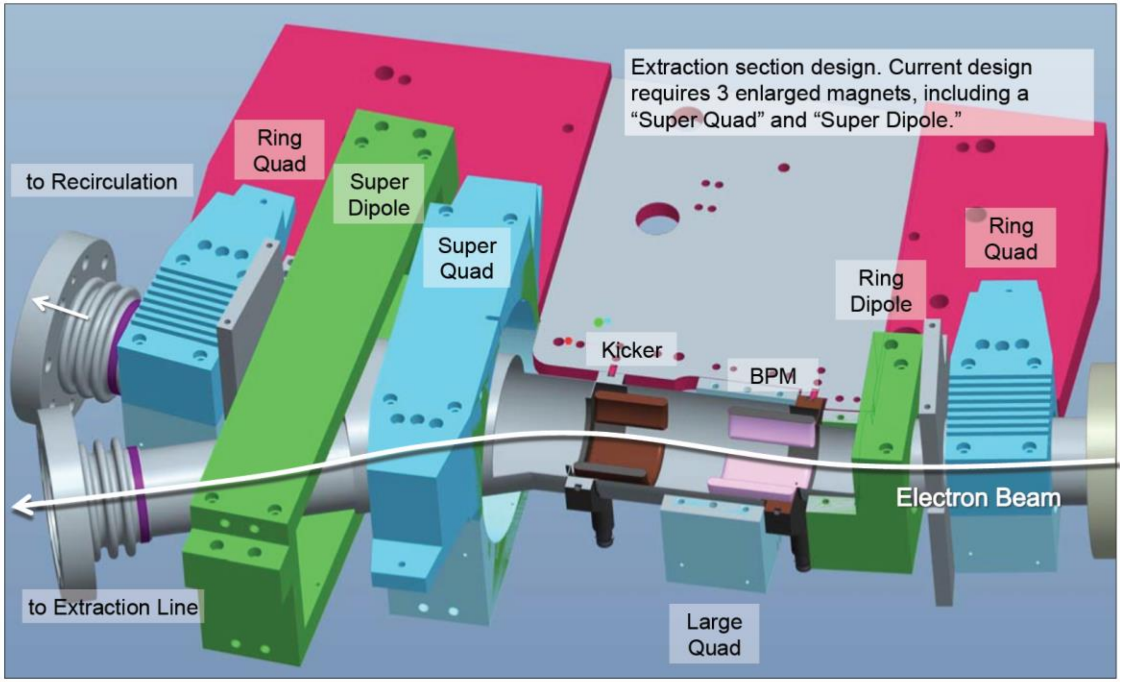


Goals:

- Minimize perturbation to recirculation
- Exceed rings admittance
- Transport full range of UMER beams

Status:

- WARP space charge model finished
- Mechanical design complete
- Ready to cut metal…

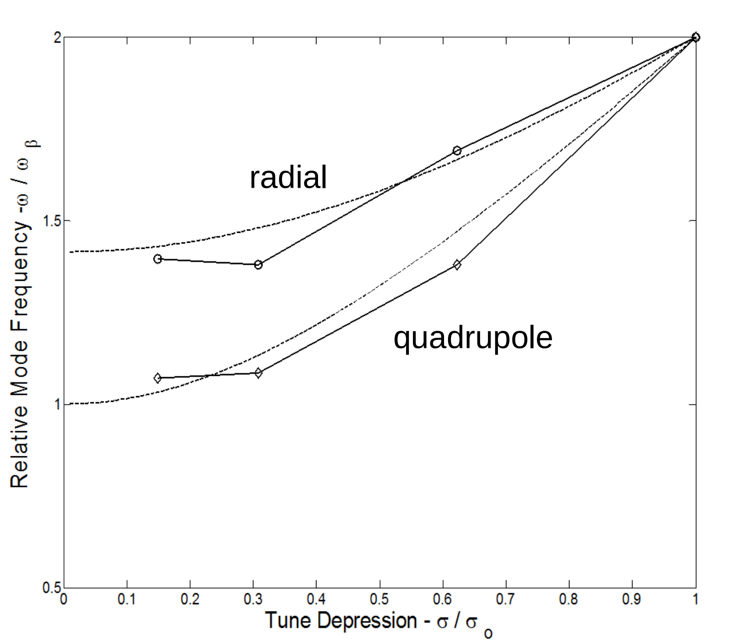


Kiersten Ruisard's Master's research

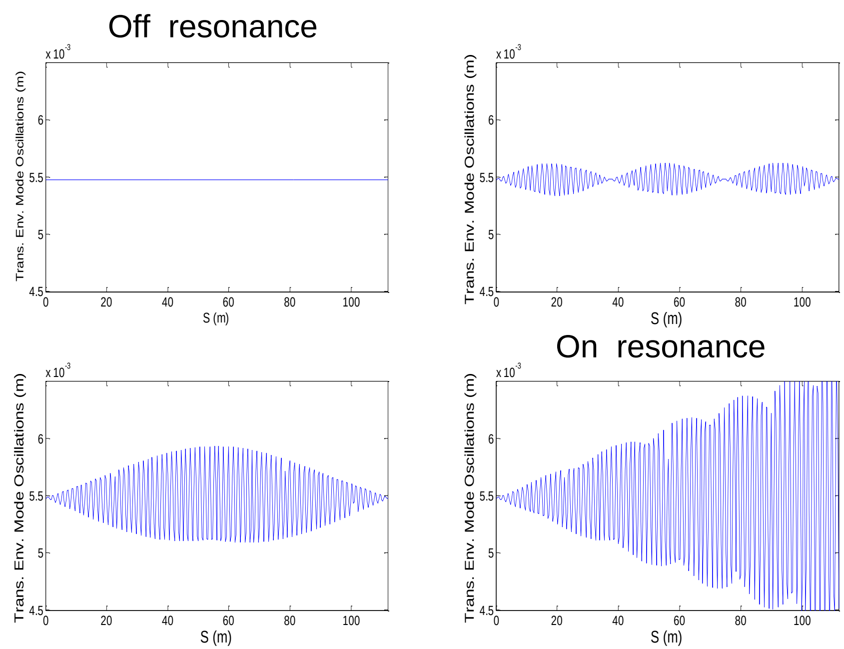
Driving Envelope Resonances

We have simulated effects of space charge on envelope resonances in an A-G lattice using WARP's envelope and particle-in-cell (PIC) codes.

Comparing Theory with A-G Envelope Simulation

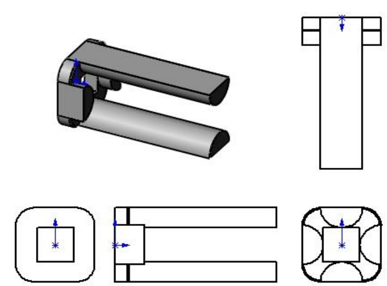


Driving quadrupole mode: envelope growth for 23 mA



(FWHM ~ 500 kHz)

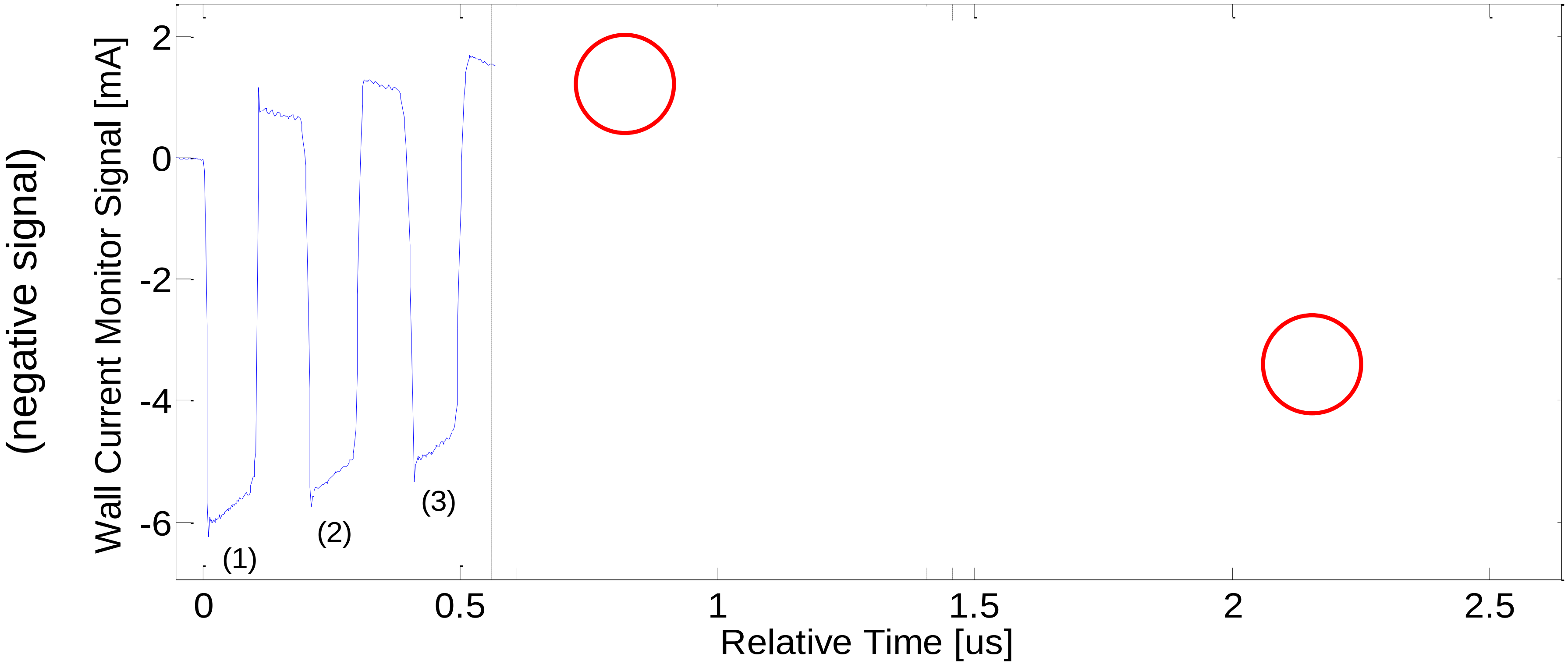
Next, we are designing the an RF driven electric quadrupole to experimentally measure resonant modes in UMER.



Will Stem, Ph.D. Thesis Research

Longitudinal de-bunching from space charge

Beam current at RC10 with no longitudinal confinement



Truncated turns to discern subtle features

<u>Injected beam:</u>

6 mA_{peak},

100 ns (197 ns revolution time)

~ 50% duty cycle

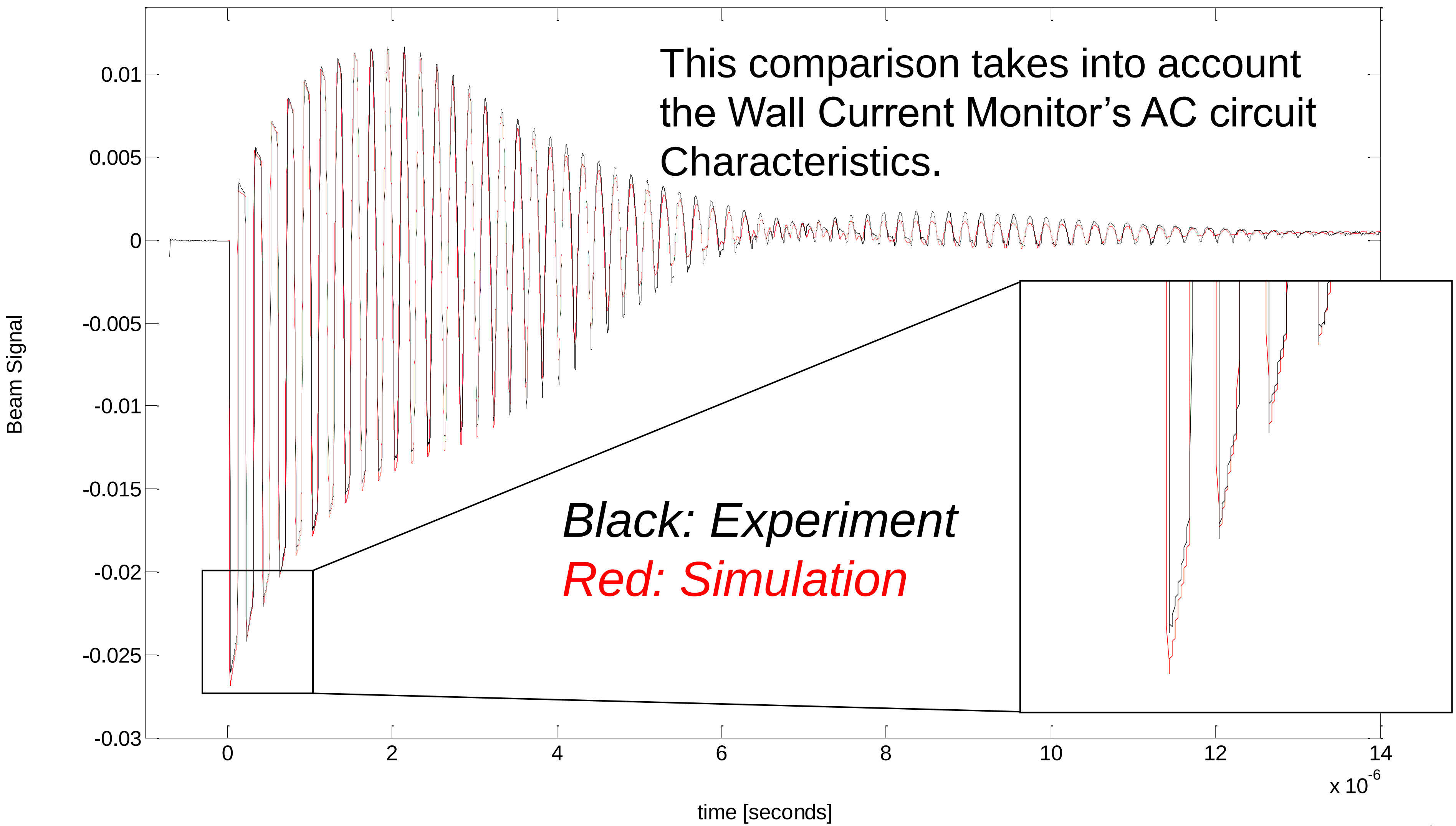
We have to accommodate the AC and transient characteristics of the wall current monitor circuitry.

- DC ‘blind’

- Transient response

Simulation/Code Comparison

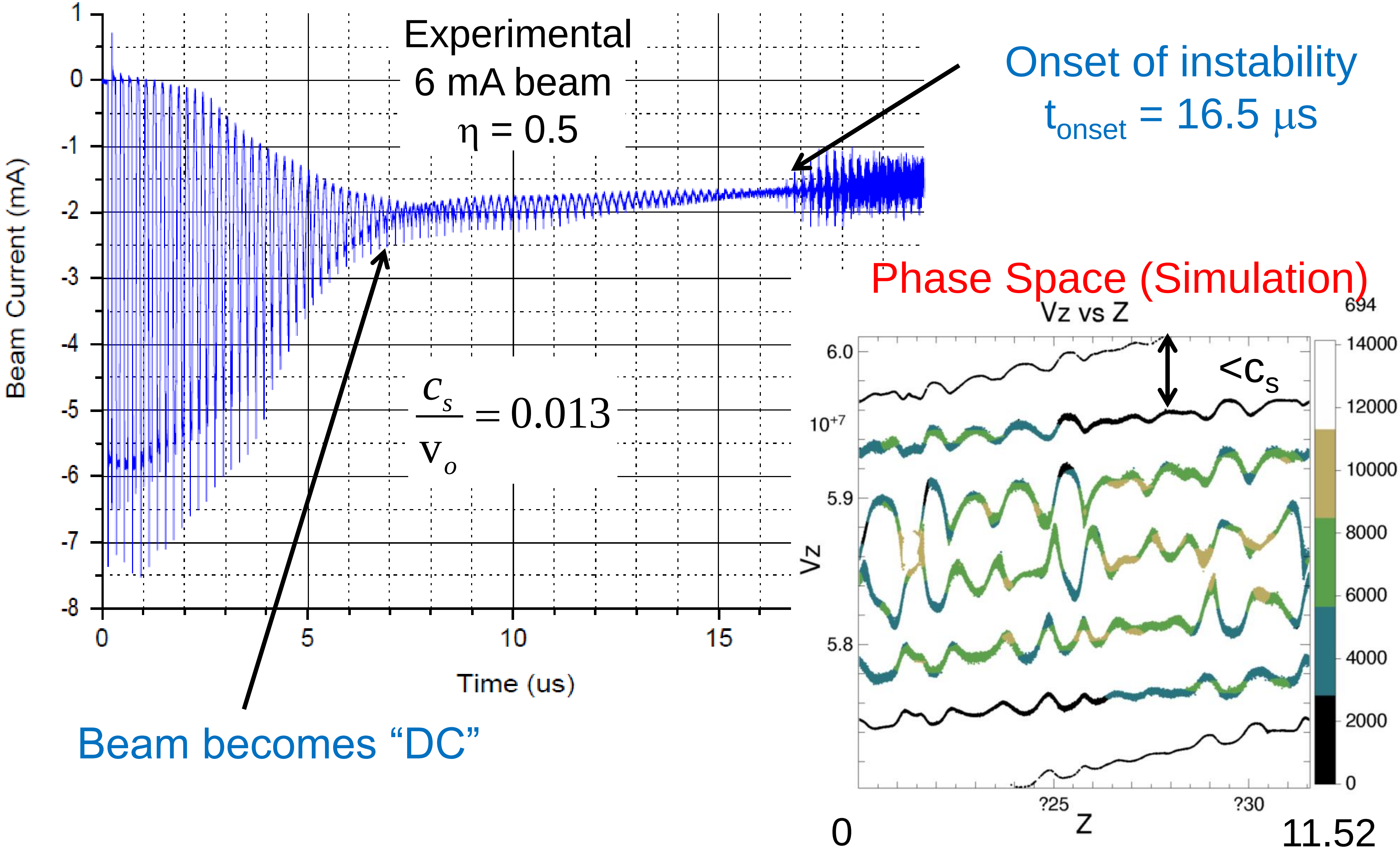
Bunch-lengthening without Longitudinal Focusing



Koeth, Haber, et al., PAC 2011.

Observation of a Multi-stream instability

No longitudinal focusing – Beam expands and wraps around ring



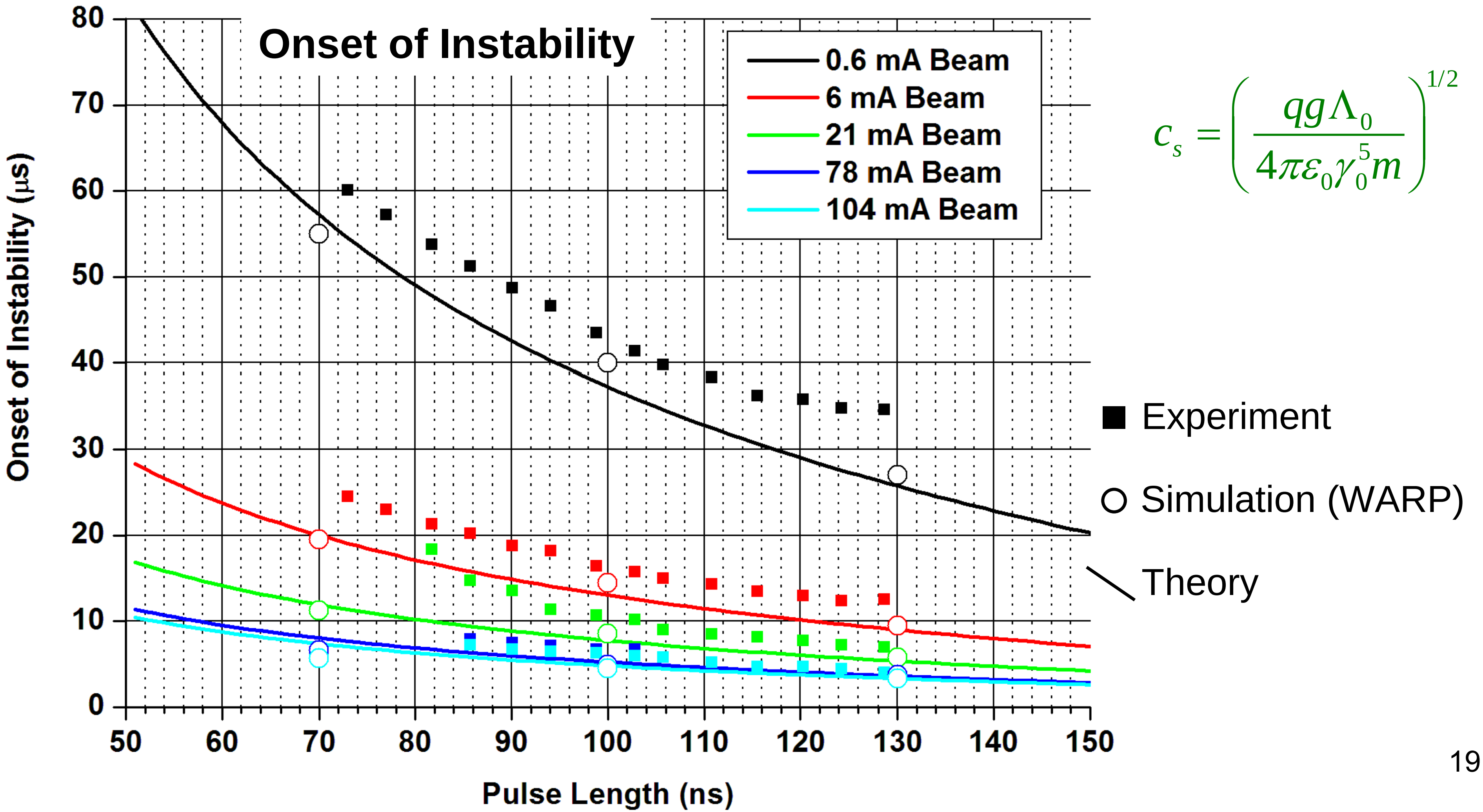
B.L. Beaudoin, R.A. Kishek, I. Haber, T.W. Koeth, submitted (2012).

Comparison between Theory, Simulation and Experiment

$$t_{onset} = \frac{C}{4c_s}\left(\frac{2}{\eta} - \eta\right)$$

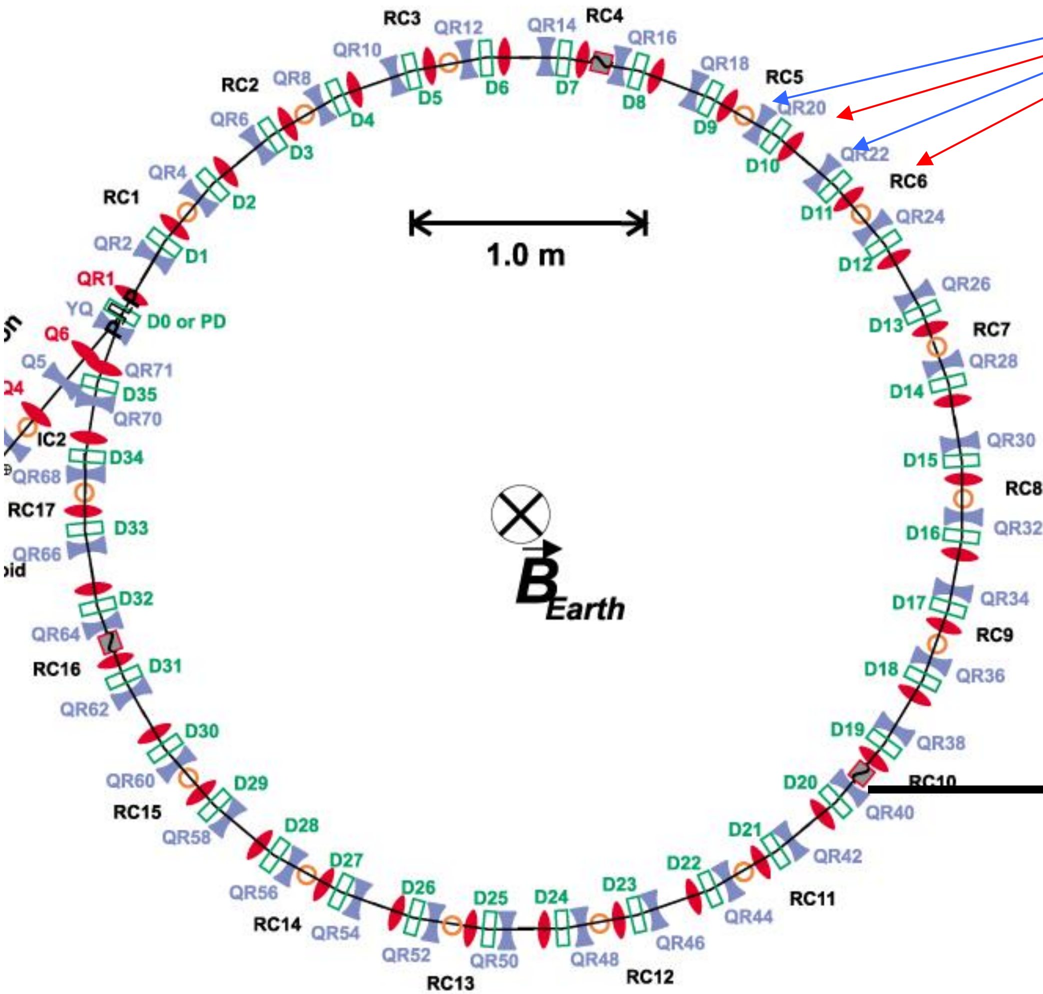
η = fill factor
= injected pulse length / ring lap-time

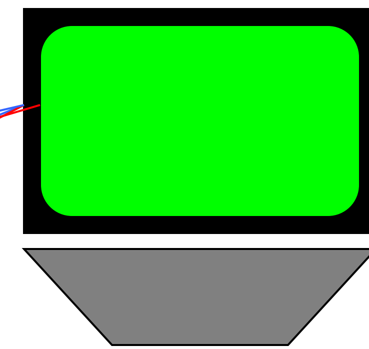
$$c_s = \left(\frac{qg\Lambda_0}{4\pi\varepsilon_0\gamma_0^5 m}\right)^{1/2}$$



Beam Lifetime and Losses (No Longitudinal Focusing)

Automated Scans ~ 24 hours





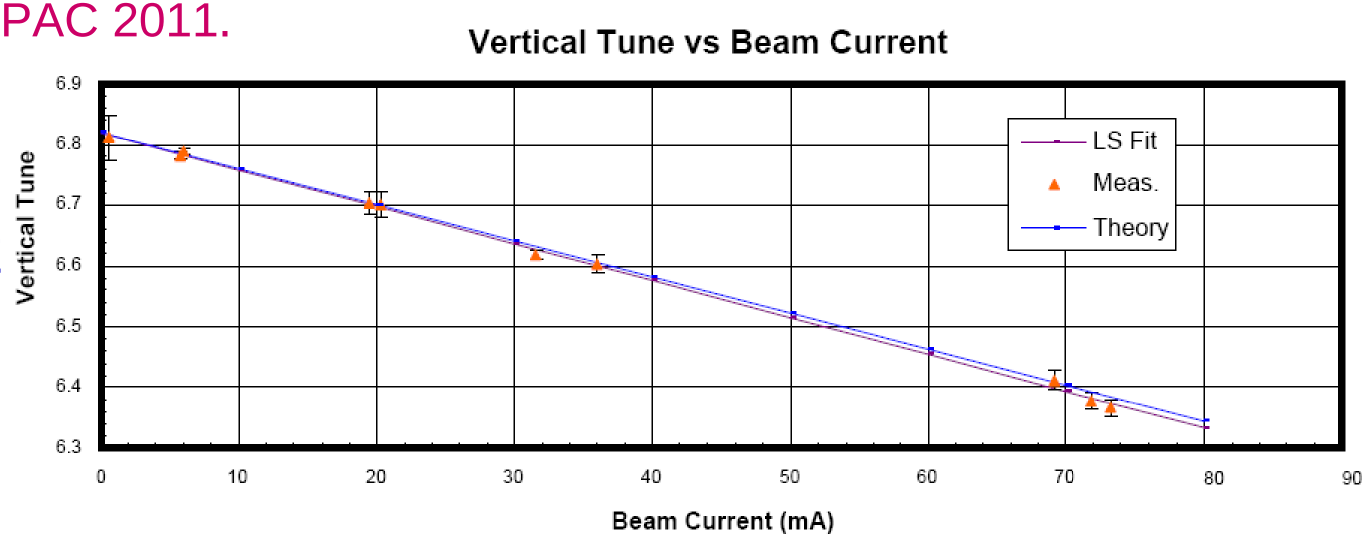
Quad Scan

1. Set even quads (D)
2. Set odd quads (F)
3. Measure beam intensity every turn (norm to 1st turn)
4. Repeat at new D,F Quad values

Current Dependence of Tune Diagrams

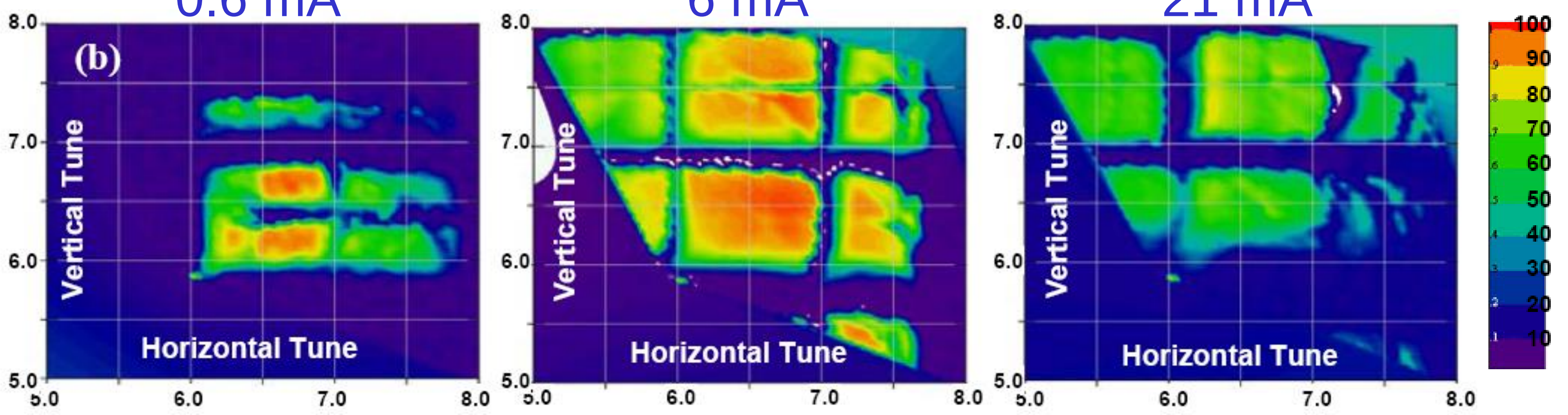
Dave Sutter, *et al.*, Proc. PAC 2011.

Coherent Tune Shift Measurement



S. Bernal, *et al.*, Proc. AAC 2010, (New York: AIP Press **1299**, 2010), p. 580.
survival after 20th turn (before the alignment, and with some defective magnets)

0.6 mA 6 mA 21 mA



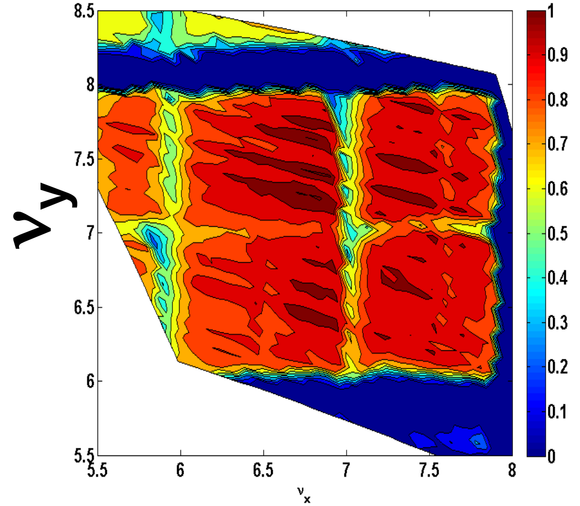
Mapping of Resonances over Wide Range of Tunes

Work in Progress

Shown: fraction of transmitted current after **10 turns**
For each of 2000 operating tunes

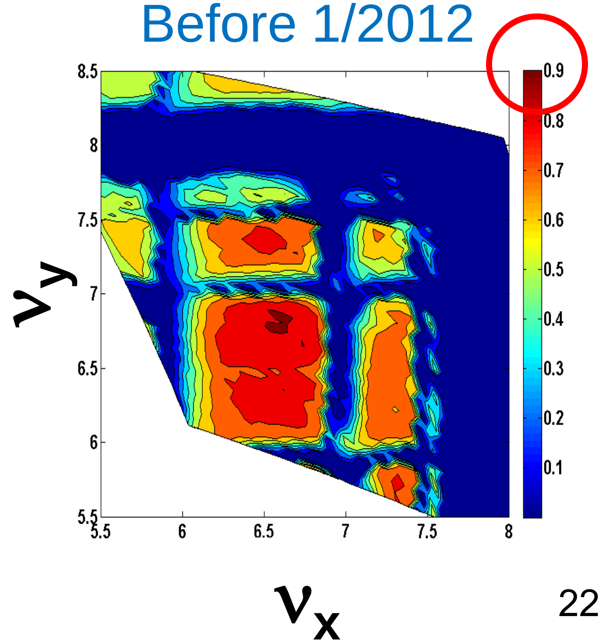
6 mA beam: $\chi \sim 0.8$, $\sigma/\sigma_o \sim 0.45$
Injected incoherent tune shift from space charge **> 3.0**

After 1/2012



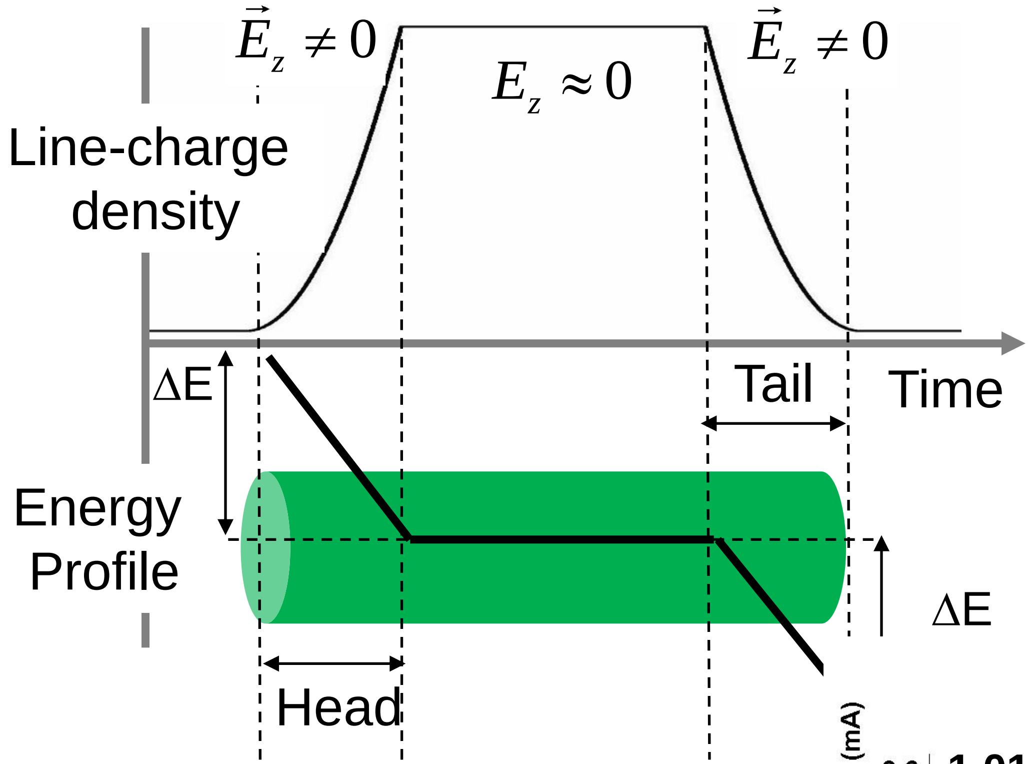
Stop bands narrowed and growth rates reduced after detailed mechanical survey and alignment in 1/2012

Before 1/2012



Sutter, Beaudoin, Bernal, Koeth 2012

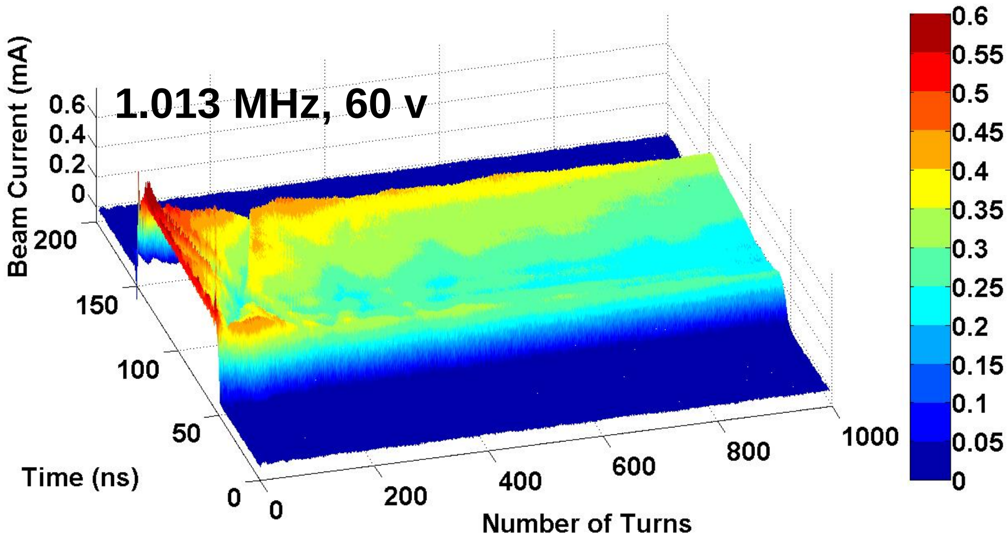
Longitudinal Confinement with Induction Cells



Long Wavelength Limit

$$E_z \propto -\frac{d\lambda}{dz}$$

0.6 mA beam

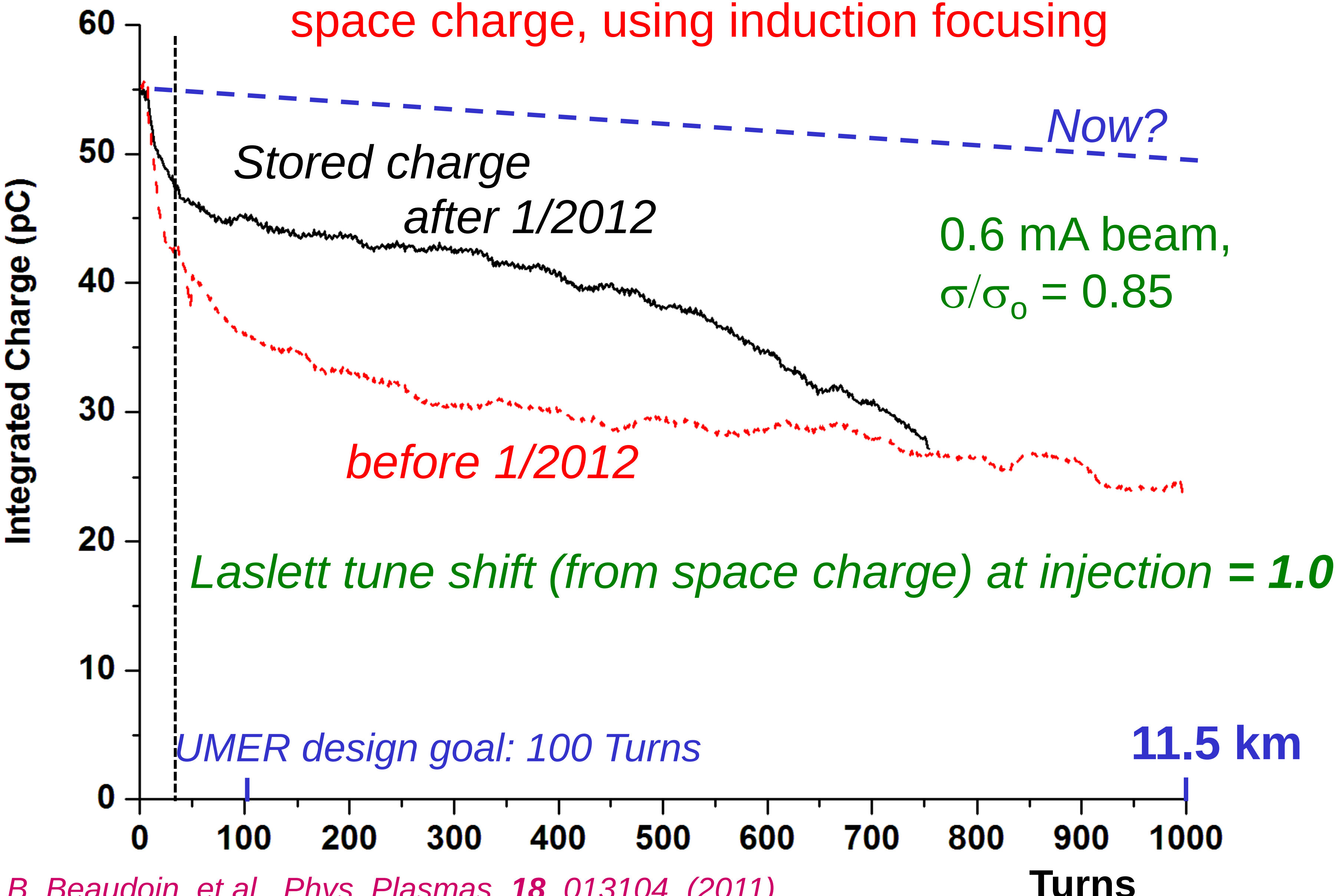


Application of Induction cell Ear fields keeps beam confined for > 1000 turns

*B. Beaudoin, I. Haber, R.A. Kishek, et al., Physics of Plasma, **18**, 013104 (2011).*

Beam Losses with Longitudinal Containment

Demonstrated long-distance recirculation of a beam with high space charge, using induction focusing



*B. Beaudoin, et al., Phys. Plasmas, **18**, 013104 (2011)*

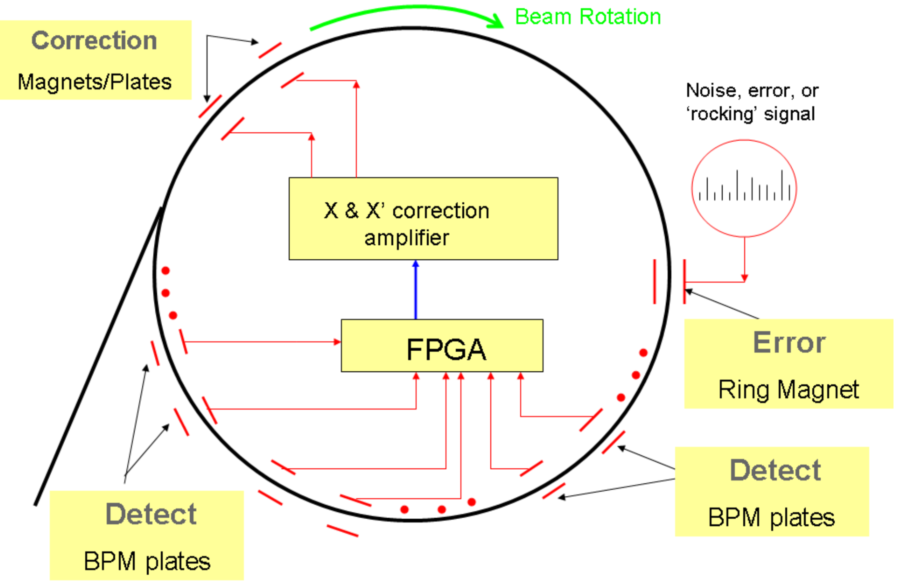
Automated Beam Control at UMER

Experiments in Active Control:

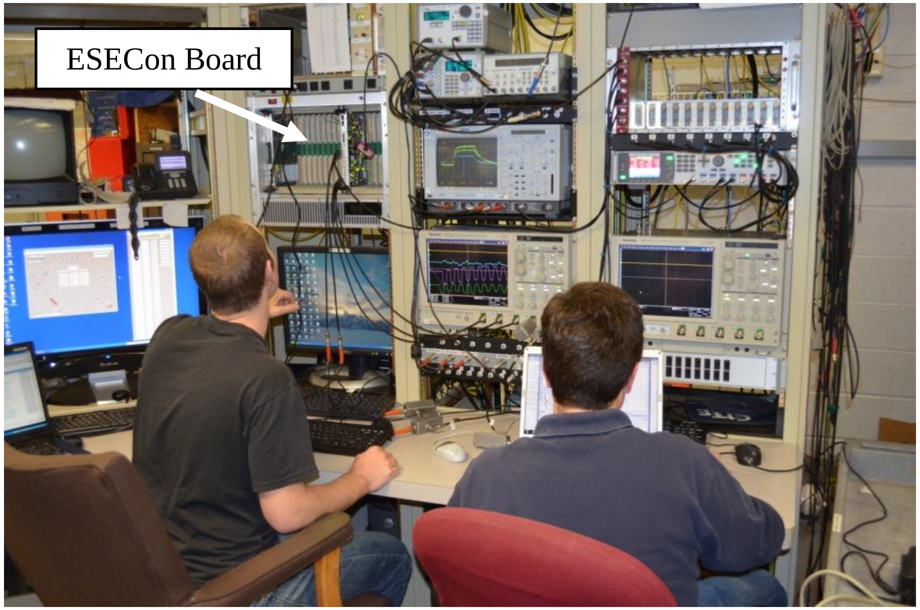
- Using Fermilab's ESECon FPGA controller installed in UMER control system (ten 125 MHz ADC, for 250 MHz DAC)

- Automated Orbit correction

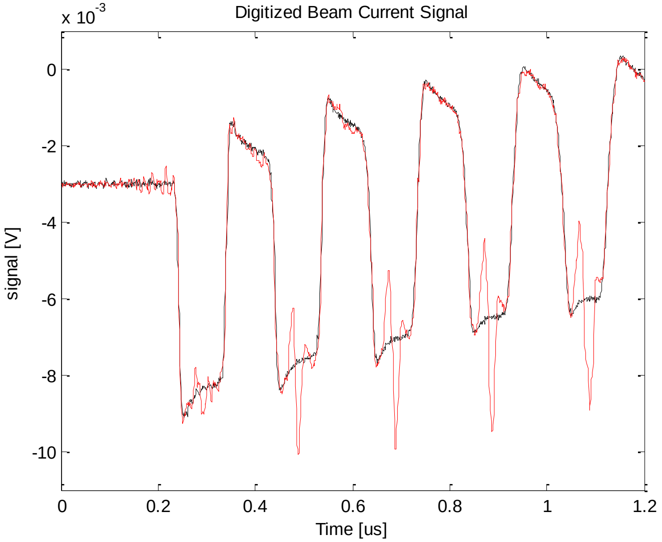
- Active Longitudinal focusing control



UMER Controls with ESECon Board



Longitudinal beam manipulations:

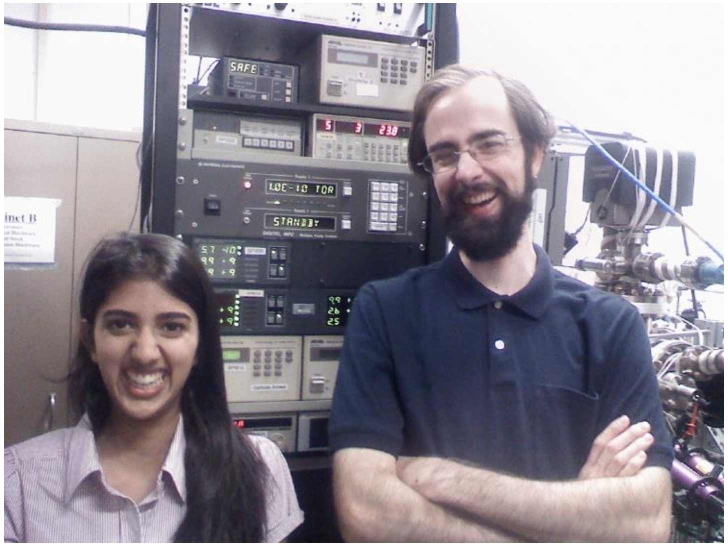


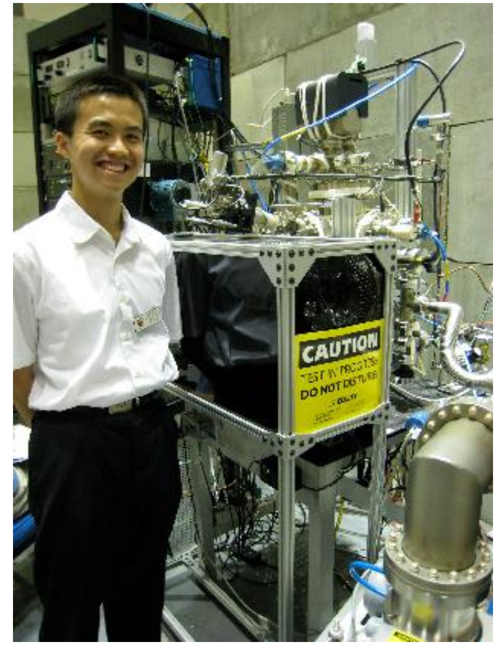
T. Koeth and B. Beaudoin

Other Facilities at Maryland

Laboratory for Photocathode Research

Advanced facility for preparation and testing of self-healing photocathodes.





Recent Achievements:

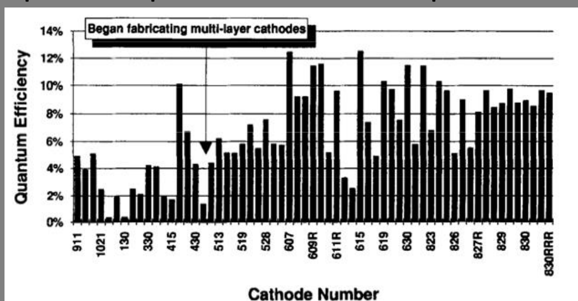
- Best-in-class lifetime dispenser photocathode [>30Khrs @ 0.1% QE] (2012)
- Robust demonstration of self-healing of dispenser photocathodes (2012)
- Discovery of high QE (1%) Cesium Auride photocathode (2010-12)
- Developed novel, fast, hi-res (20 μm) QE mapping technique (2012)
- Advanced QE theory, emittance models with NRL (2008-2012)

S. Khan, E. Montgomery, Z. Pan. Not Shown: K. Jensen, D. Feldman, B. Riddick

Maryland Innovates Photocathodes
Long-Lived, Robust, High Quantum Efficiency

Reliable Quantum Efficiency

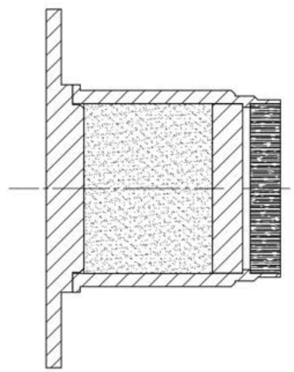
Inconsistent K_2CsSb [1] *continues* to haunt. UMD's dedicated facility, free from user constraints, will find reliable, replicable production techniques.

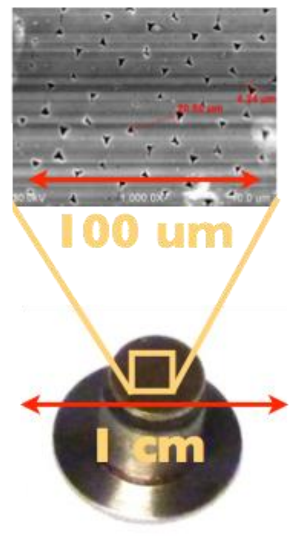


[1] Dowell et al., NIMPRA 356, p172 (1995)

Self-Healing CPR Cathodes

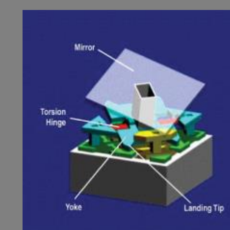
UMD's CPR cathode lifetime is now over 30,000 hours: with higher QE to meet FEL demands.

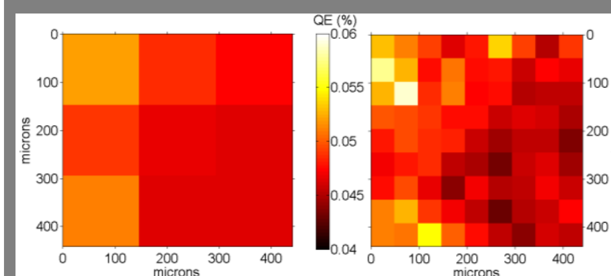




Spatially Adaptive Drive

UMD pioneered Digital Micro-mirror Device (DMD) to pattern cathode drive laser with ~20 micron resolution.





Beam Diagnostics Development Laboratory

Development of advanced intercepting and non-intercepting diagnostics in support of UMER and collaborative experiments at other national and international accelerator labs (JLAB, SLAC, ANL, LANL, FERMI@Trieste).

Recent Accomplishments

- Developed a novel noninvasive high dynamic range beam/halo imaging method using digital micro-mirror array (DMD) and optical synchrotron radiation; successfully tested it at JLAB FEL and the SLAC/SPEAR3 synchrotron
- Developed a novel all optical technique to map transverse phase space using optical transition radiation interferometry.
- Developed concept of a noninvasive emittance measurement method using an “S” bend OSR interferometer useful for high power FEL accelerator operations
- Developed concept of a non invasive, single shot-capable technique to measure fs – ps bunch lengths using the angular distribution of coherent diffraction radiation; successfully tested it on rep rated 100 MeV rf linac beam at the Swiss Light Source

Conclusions

- The UMER research program is geared towards study of key problems at the Intensity frontier.
- We are interested in Collaborations with FNAL
- UMER is available for experiments and for code benchmarking
- We are also interested in sending students and other personnel to FNAL, possibly with the aid of joint proposals.