Scaled Models: Space-Charge Dominated Electron Storage Rings

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Research sponsored by US DOE & DoD ONR

Institute for Research in

Electronics & Applied Physics

University of Maryland

(near Washington, DC)

Research Focus:

Interdisciplinary research in engineering and the physical sciences with emphasis on large and complex experiments. Faculty and students from Electrical & Computer Engineering, Physics and Materials Science.

Specialties:

- Chaos and Nonlinear Dynamics
- Nanoscience and Engineering
- Beam Physics
- Microwaves and Electronics
- Space & Fusion Plasmas
- Materials Processing (using microwaves, plasmas, ion beams)

REAP

The Charged Particle Beam Group

Maryland CPB Group: Projects Underway

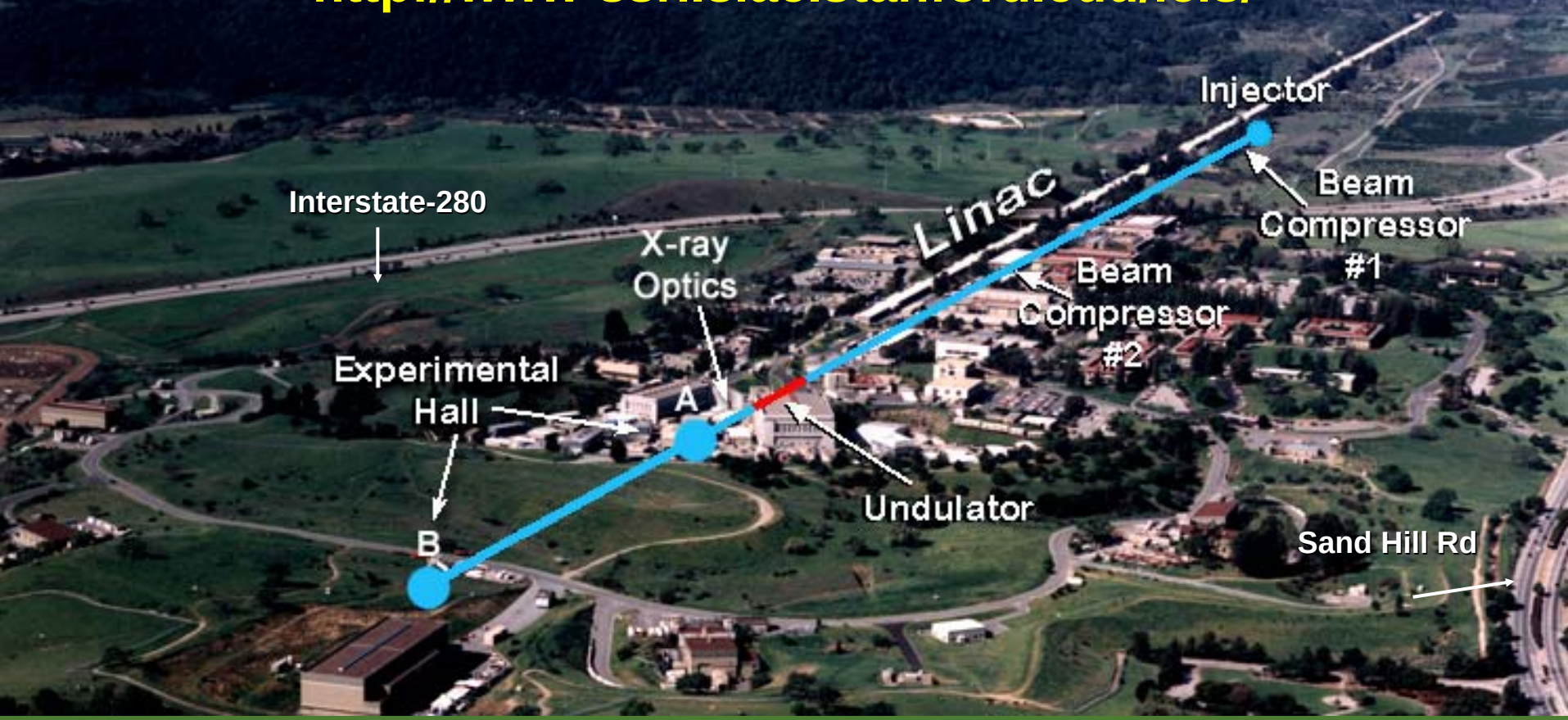
- High-brightness, durable, photocathode development
- Advanced diagnostic development
- Self-consistent modeling and simulation
- Scaled experimental studies of collisionality and energy spread evolution for Heavy Ion Inertial Fusion
- Multi-disciplinary studies of breakdown and multipactoring in high-gradient metal and dielectric structures
- UMER: The University of Maryland Electron Ring

UMER: a testbed for space charge dynamics

1. Bright electron beams and space charge effects
2. The University of Maryland Electron Ring
3. Status update
4. Sample results and experiments
5. Conclusion

Ultra short wavelength
Linac Coherent Light Source (Stanford)

http://www-ssrl.slac.stanford.edu/lcls/



Goal: 1Å with pulses of a few fs

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Requirements of an FEL beam

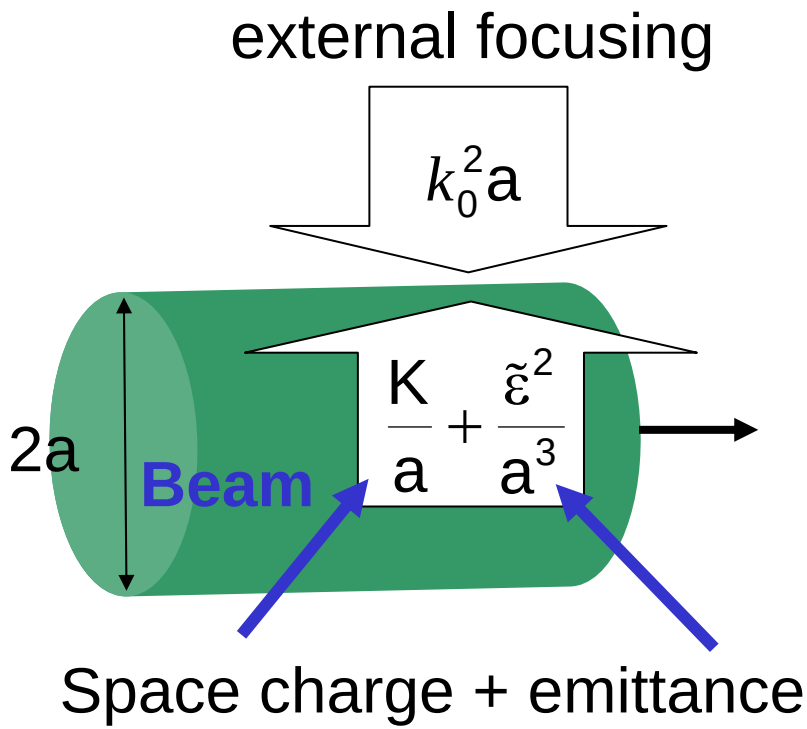
1. Bright electron beam
   - *intense space charge at the source*
2. In ERLs the injection energy is lost, so injection at lower energies preferable
   - *space charge*
3. Coherence for short wavelengths requires small emittance $(\varepsilon_n < \gamma\lambda/4\pi)$
   - *e.g. for LCLS, turns out $\varepsilon_n < 2$ μm for λ = 1 nm*

Dimensionless Space Charge Intensity

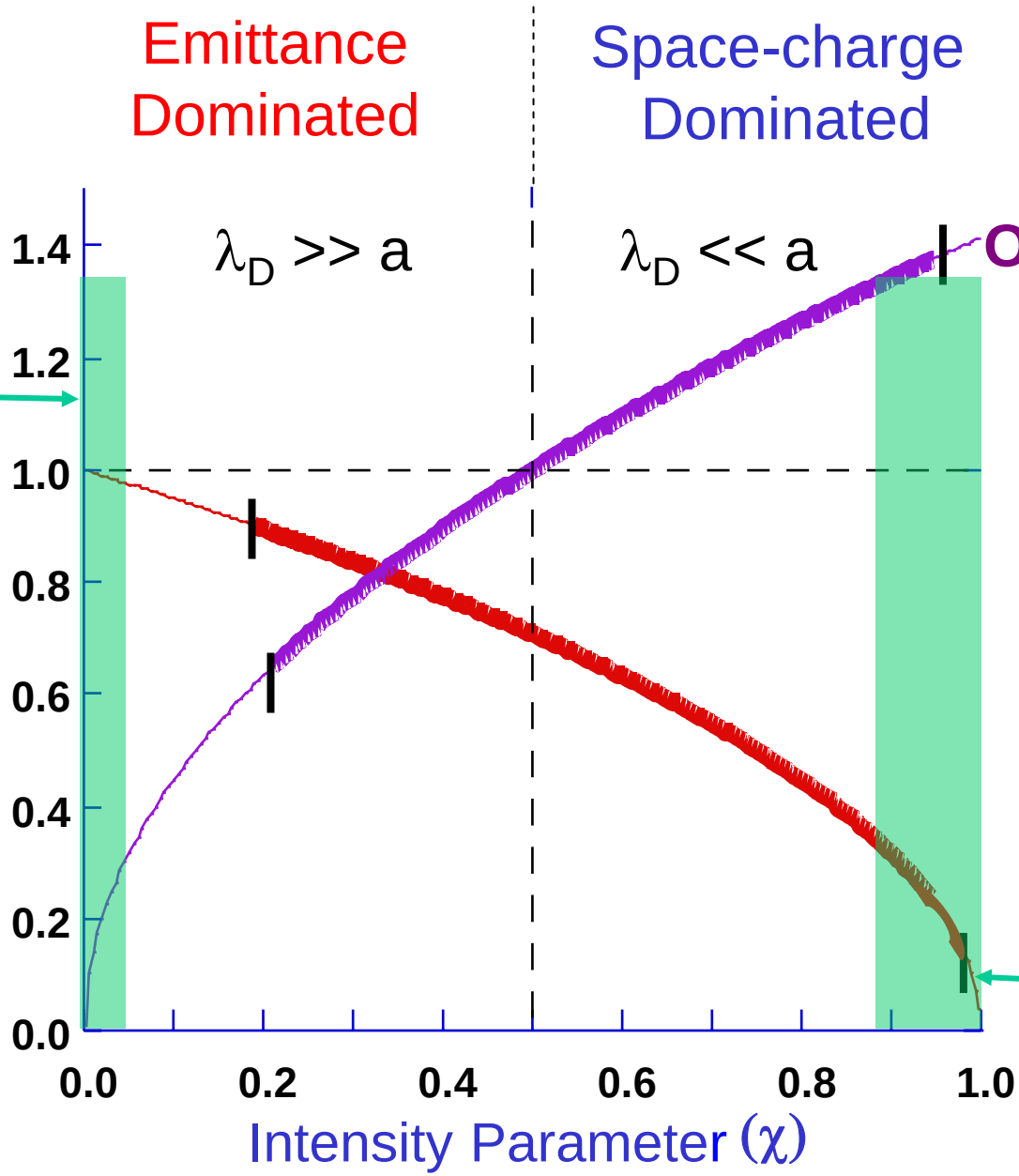
Intensity Parameter:

$$\chi \equiv \frac{K}{k_o^2 a^2} = \frac{\text{space charge force}}{\text{external focusing force}}$$

$$0 \le \chi \le 1$$



Intensity Scalings



Relativistic E-Beams

Plasma Oscillations Curve

$$\frac{\omega_P}{\omega_0} = \sqrt{2\chi}$$

Betatron Oscillations Curve

$$\frac{\omega}{\omega_0} = \sqrt{1-\chi}$$

Beam Sources

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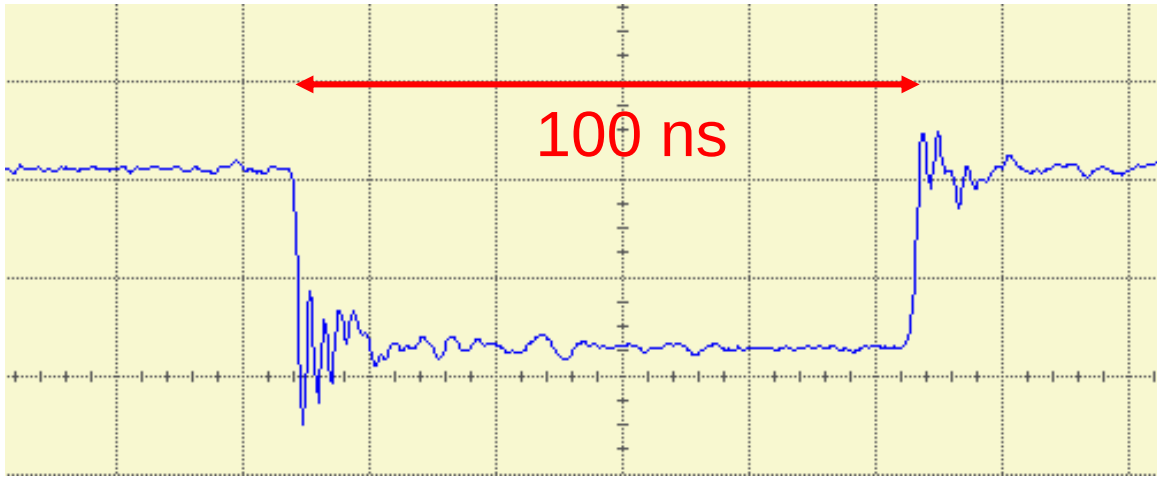
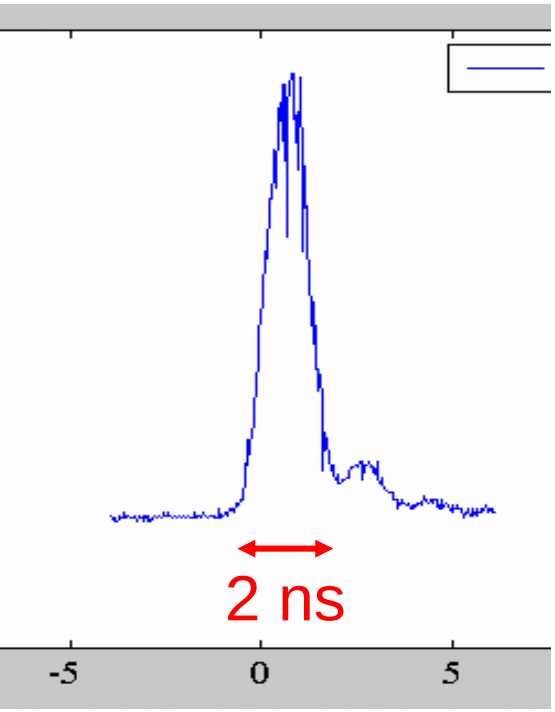
Realistic pulse shapes are not “clean”

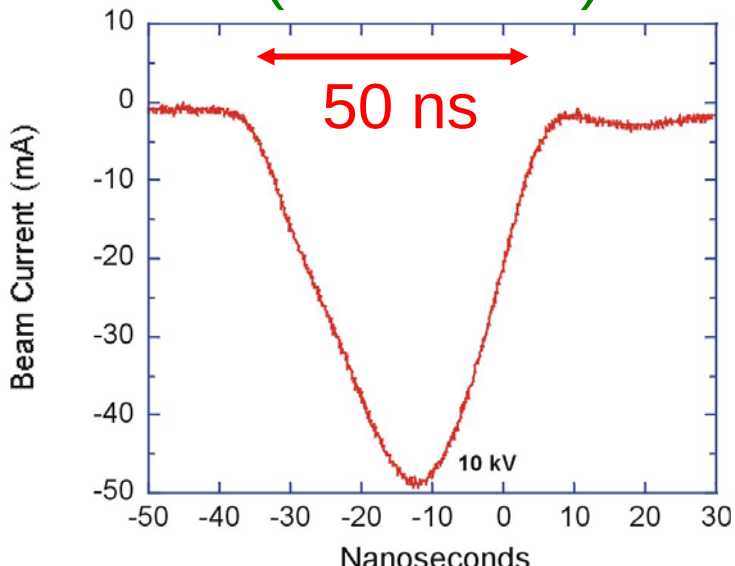
Rectangular Pulse
(thermionic)



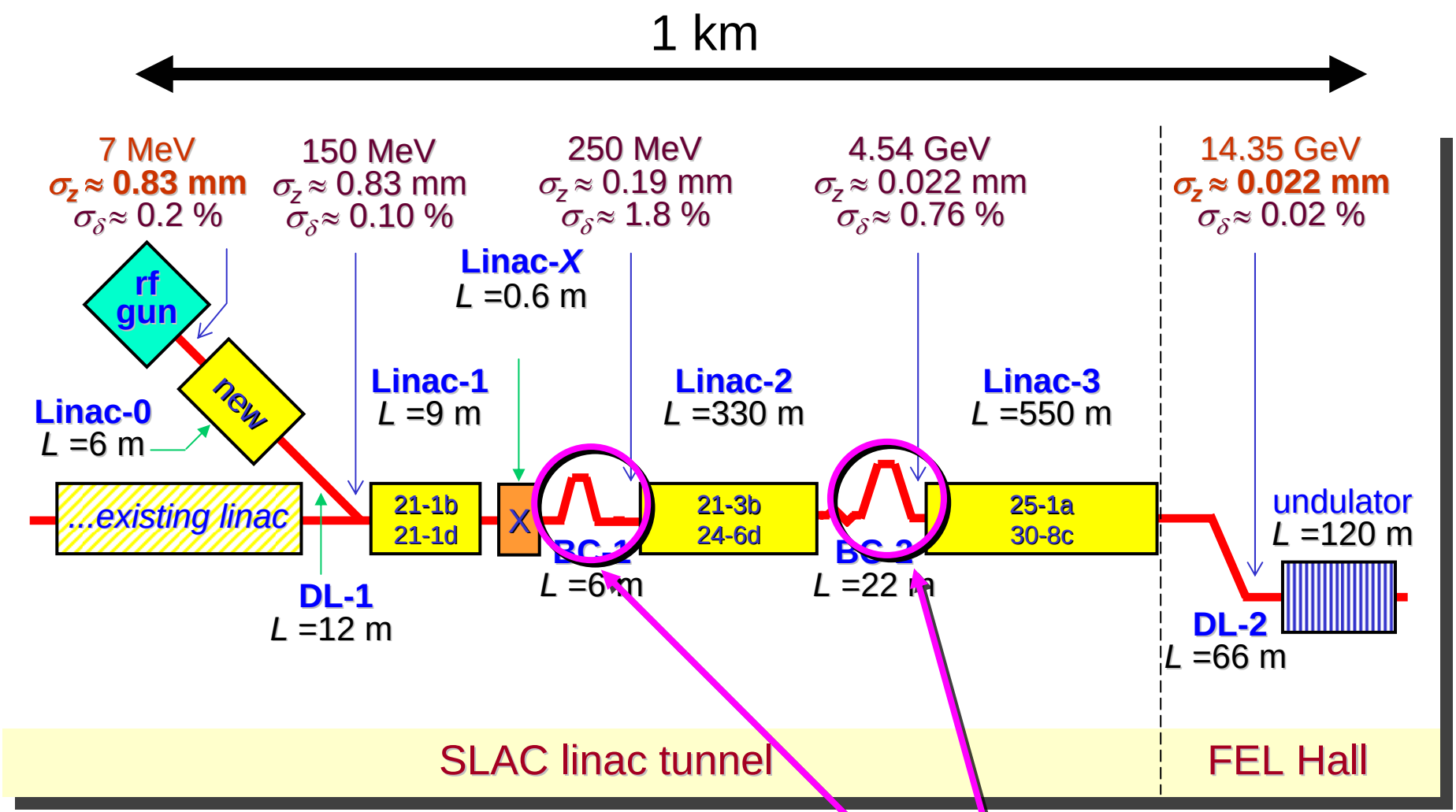
Photoemission Drive
Laser Pulse



Parabolic Pulse
(thermionic)



An X-Ray FEL is a complex Machine
= Many possibilities for emittance growth!



Two stages of chirped pulse bunch compression

Space Charge Raises Many Issues

- What is the ideal bunch shape?

  rectangular? ellipsoidal?
- How to model the source accurately?
- How will perturbations evolve?

  Can they be controlled?
- What is the time scale for irreversible mixing in beams?

  How soon do we have to perform emittance compensation?
- How to maintain a low emittance and prevent halo formation?

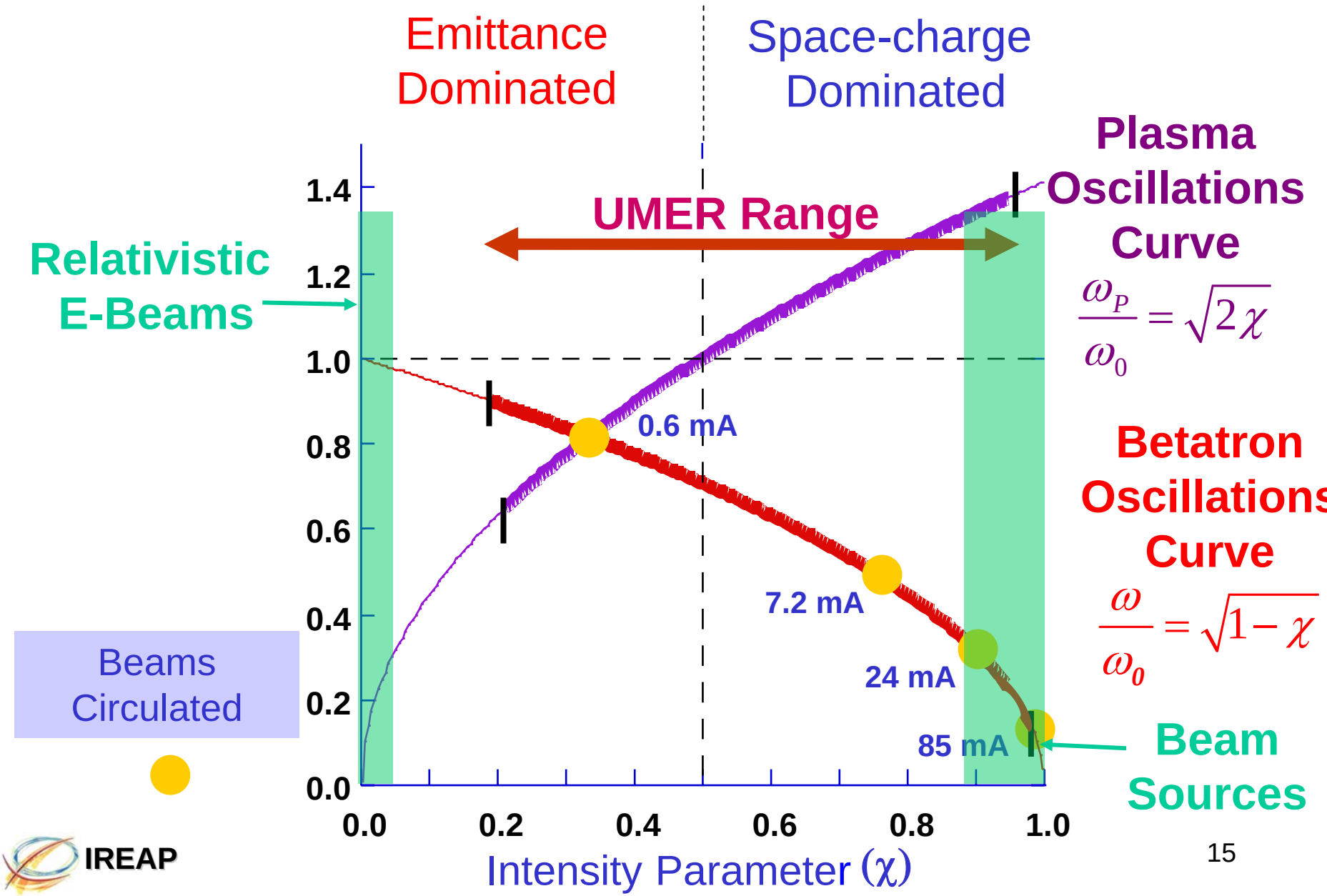

UMER:
a testbed for space charge
physics in bright beams

UMER Parameters

Energy	10 keV
Energy Spread	20 eV
Current Range	0.6-100 mA
rms Emittance Range	0.2-3 μm

Circulation time	200 ns
Pulse length	5-100 ns
Zero-Current Tune	7.6
Depressed Tune	1.5 – 6.5

Present UMER Operating Points



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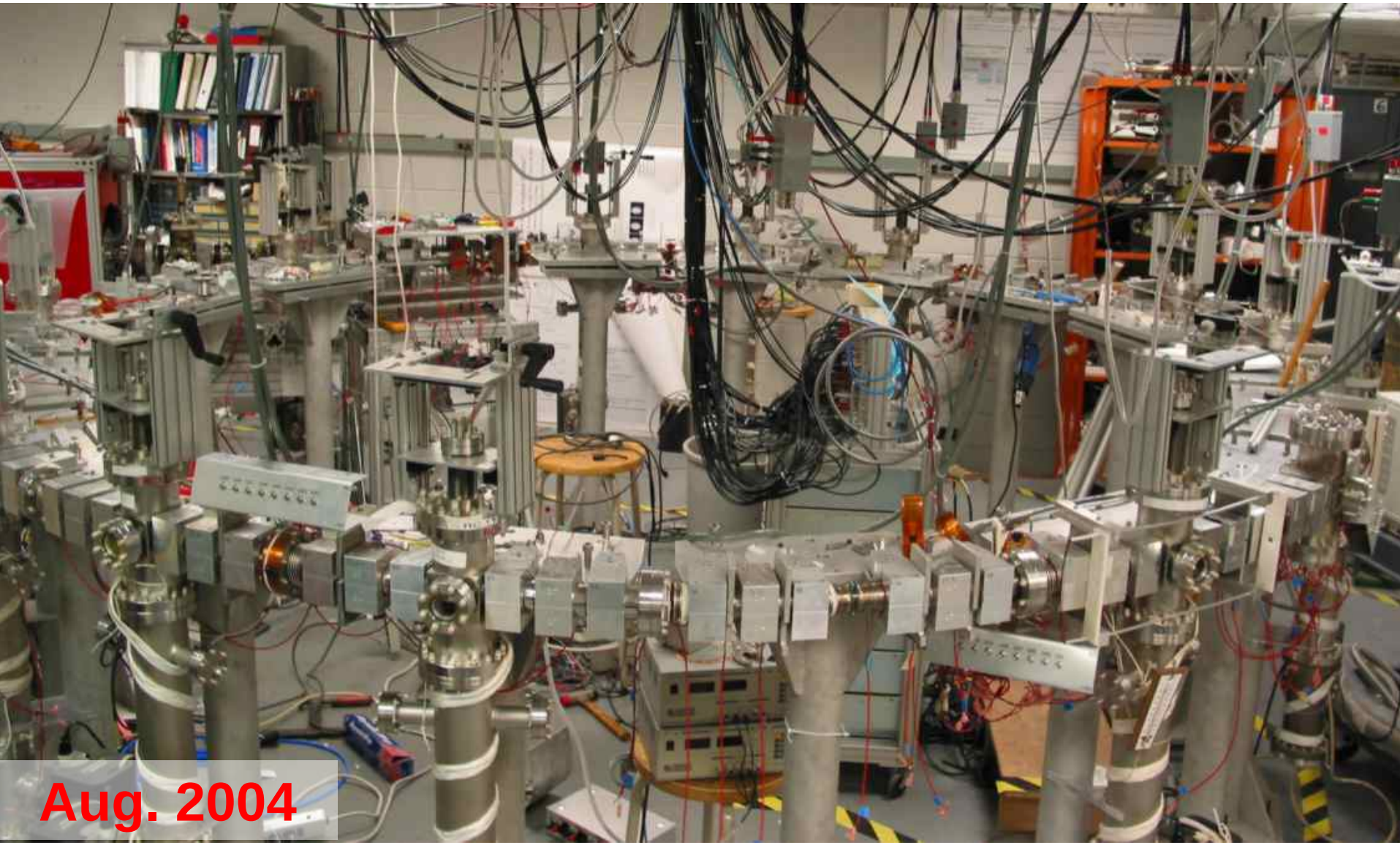
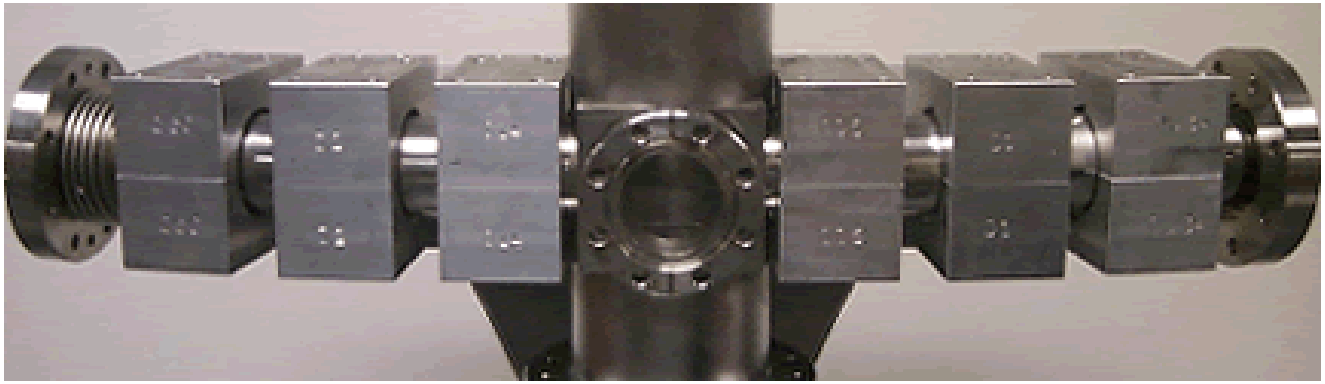
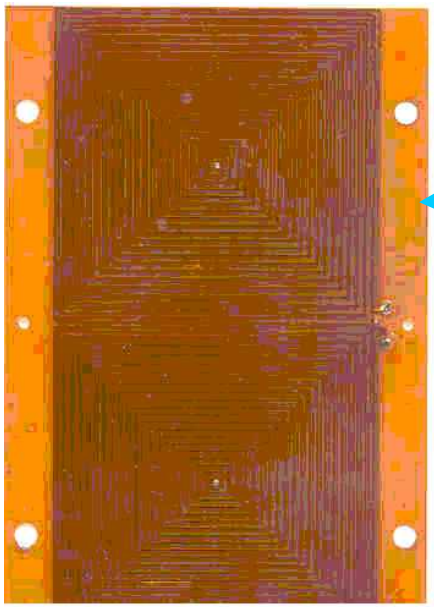
The University of Maryland Electron Ring

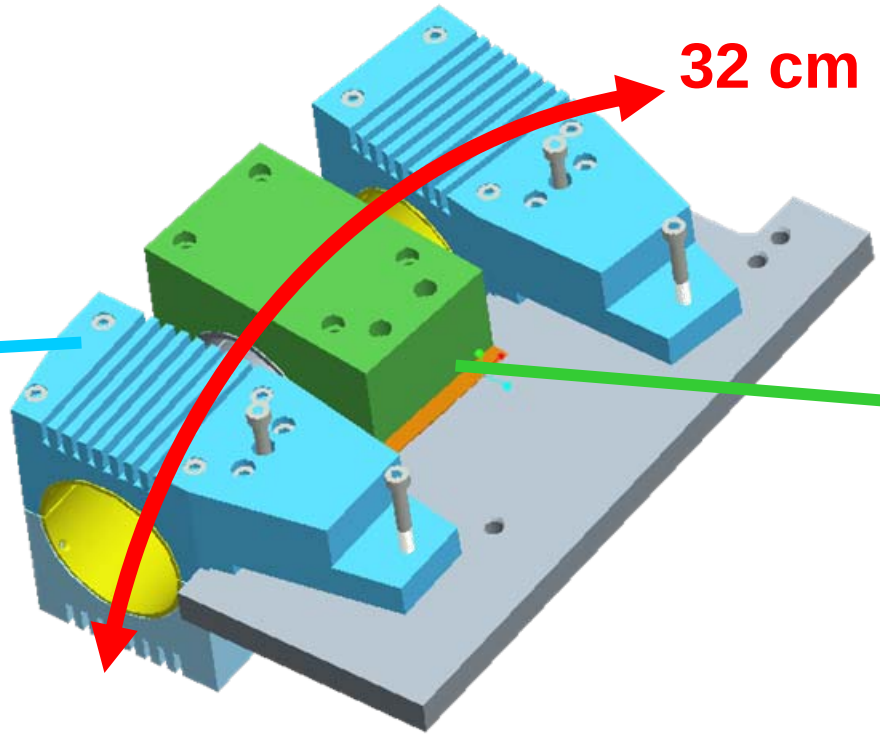


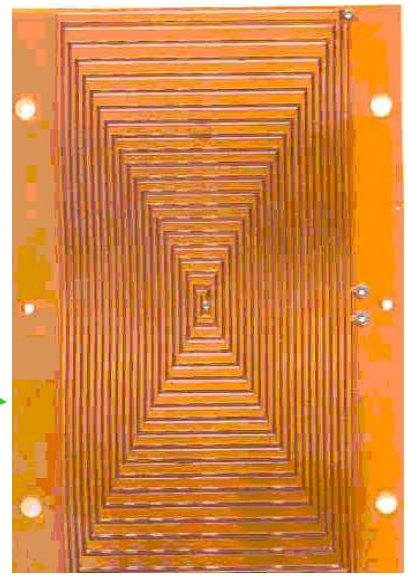
UMER Magnets & Lattice



72 Quads
(~ 7.8 G/cm)







36 Dipoles
(~ 15 G)

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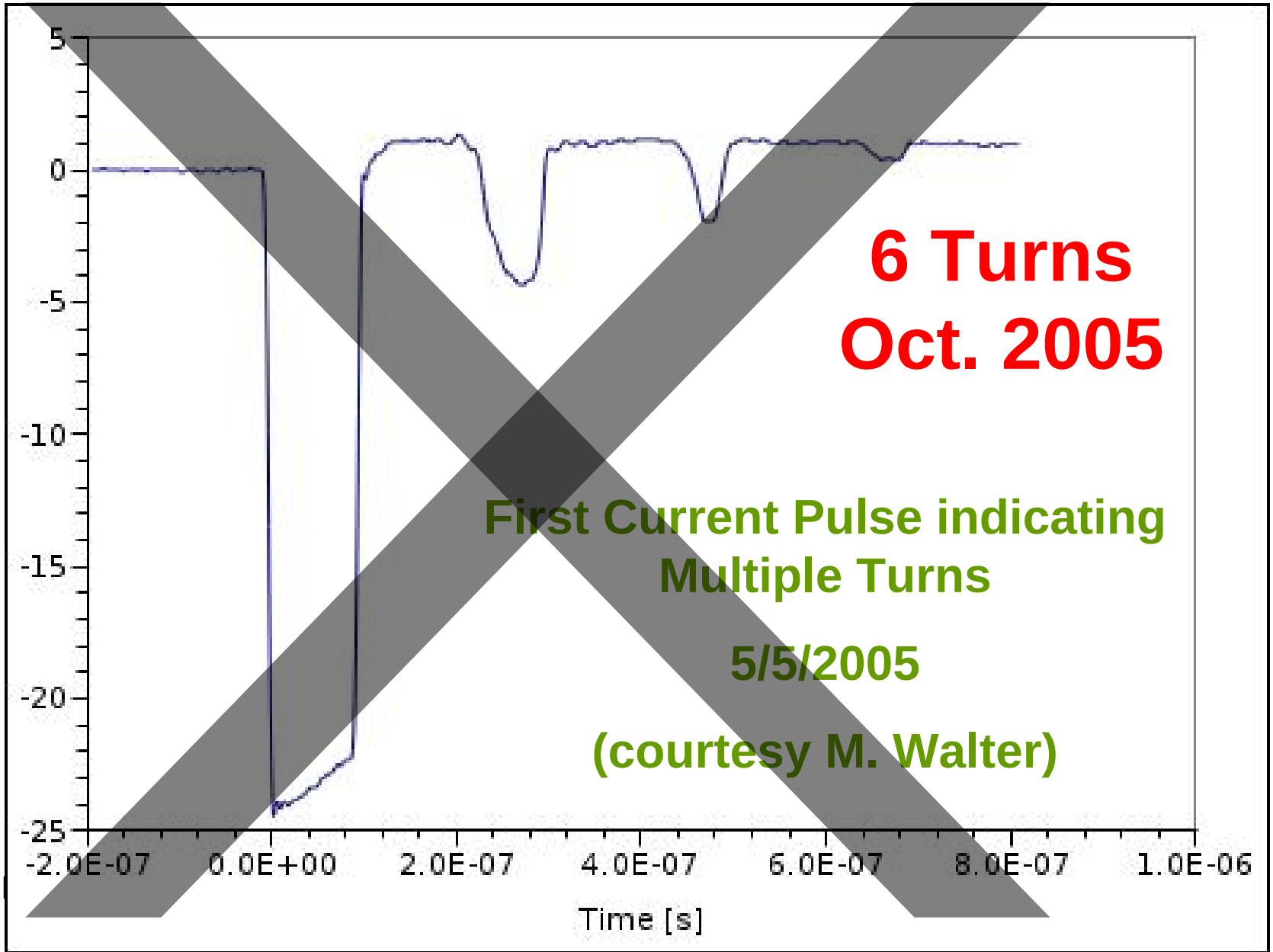
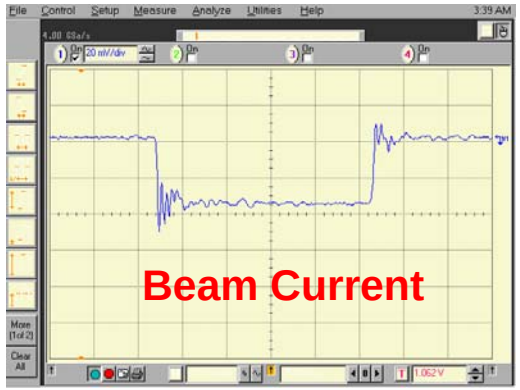
Commencement of Multi-Turn Operation
(Work in Progress)

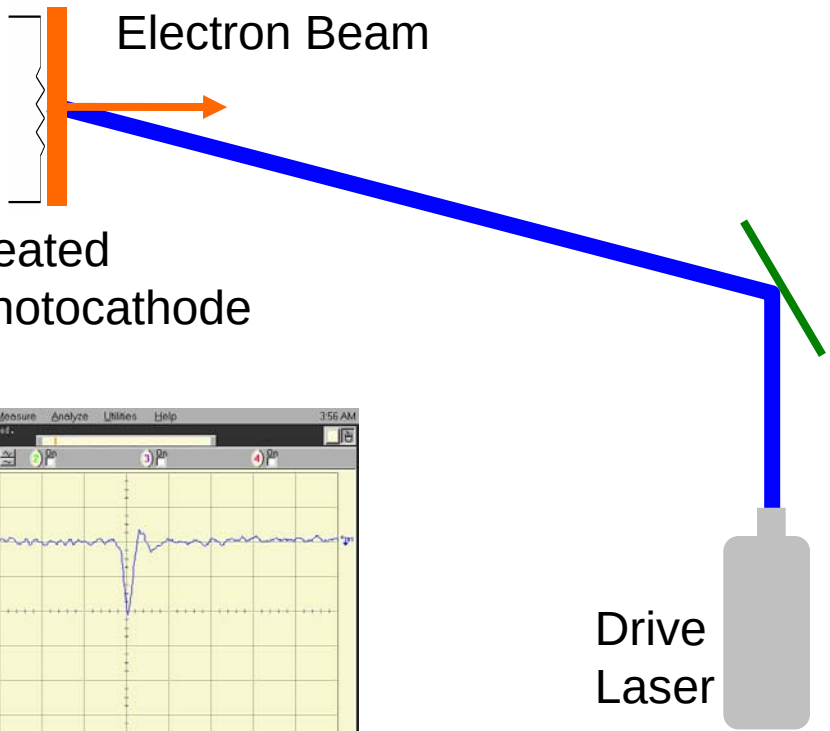


Example Results and Experiments

Generating Perturbations with Lasers



Thermionic only, 100ns pulse



Photoemission +
Thermionic 5ns pulse

Photoemission only
(Cool cathode)

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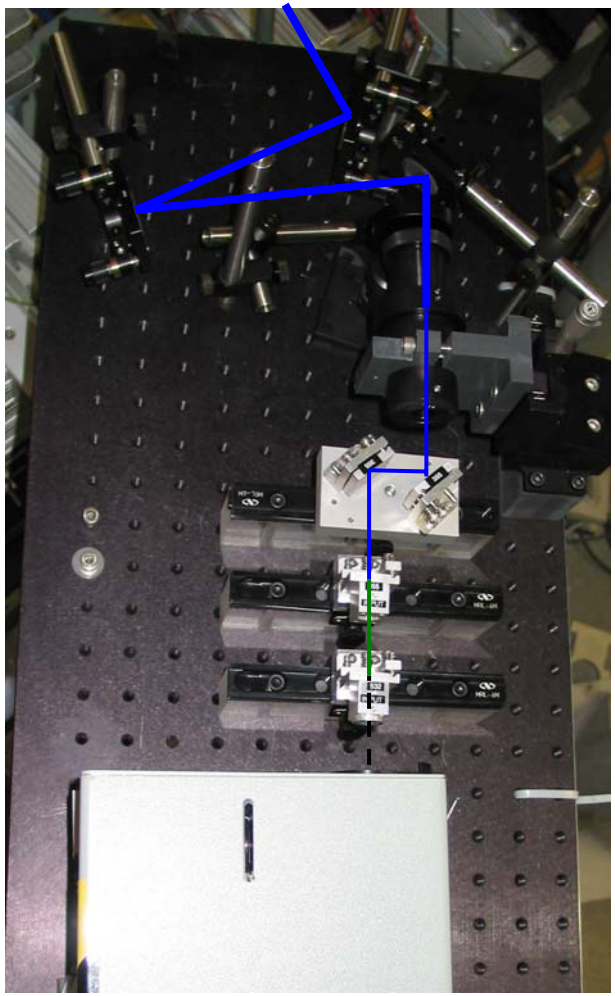
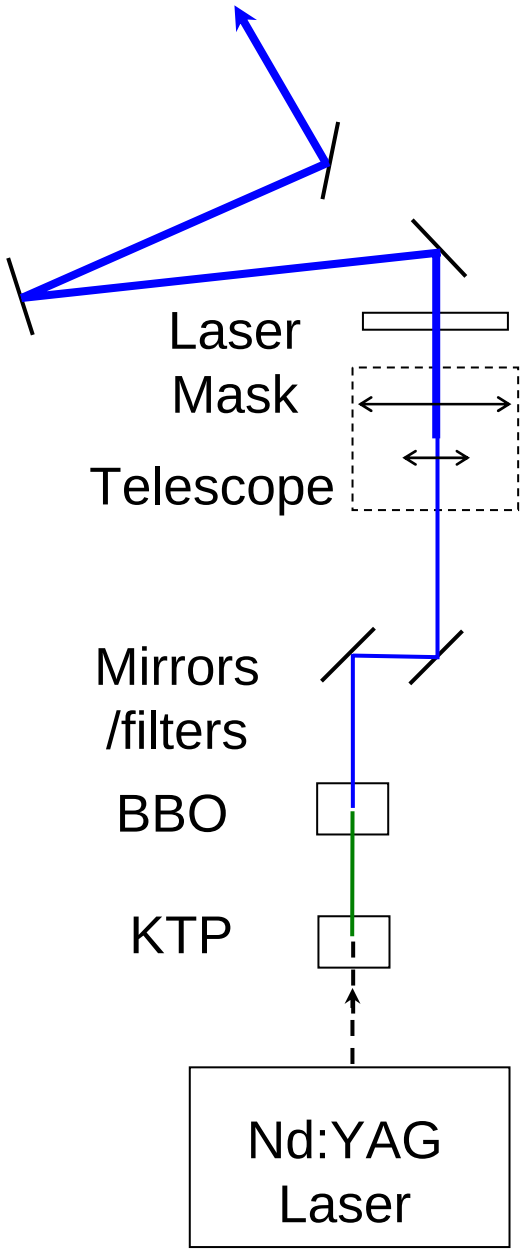
Drive Laser Setup





UV (355nm) Laser
Photon energy: 3.5 eV
Work function: 2.7 eV

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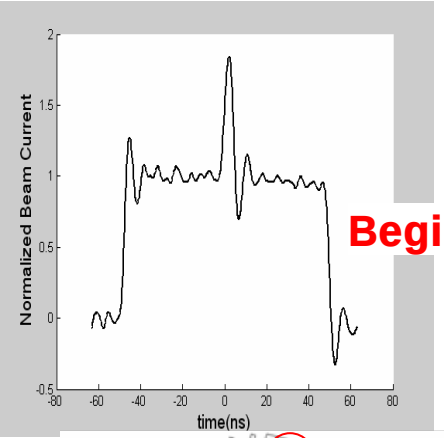
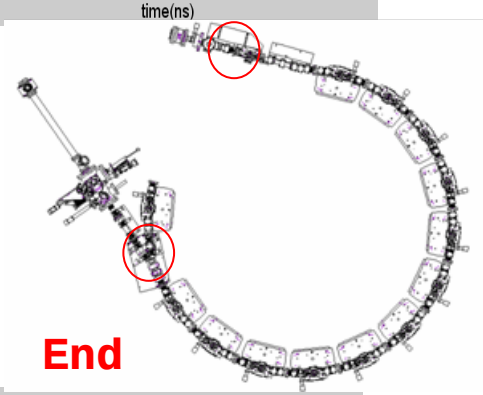
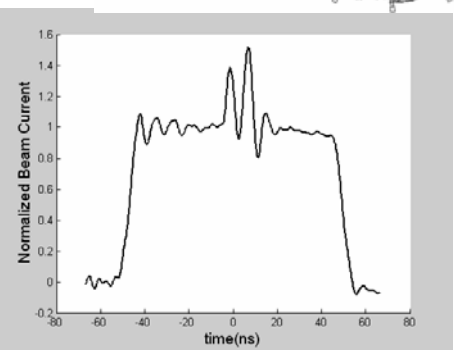
Experiment: Propagation of Perturbed Beam



Beginning

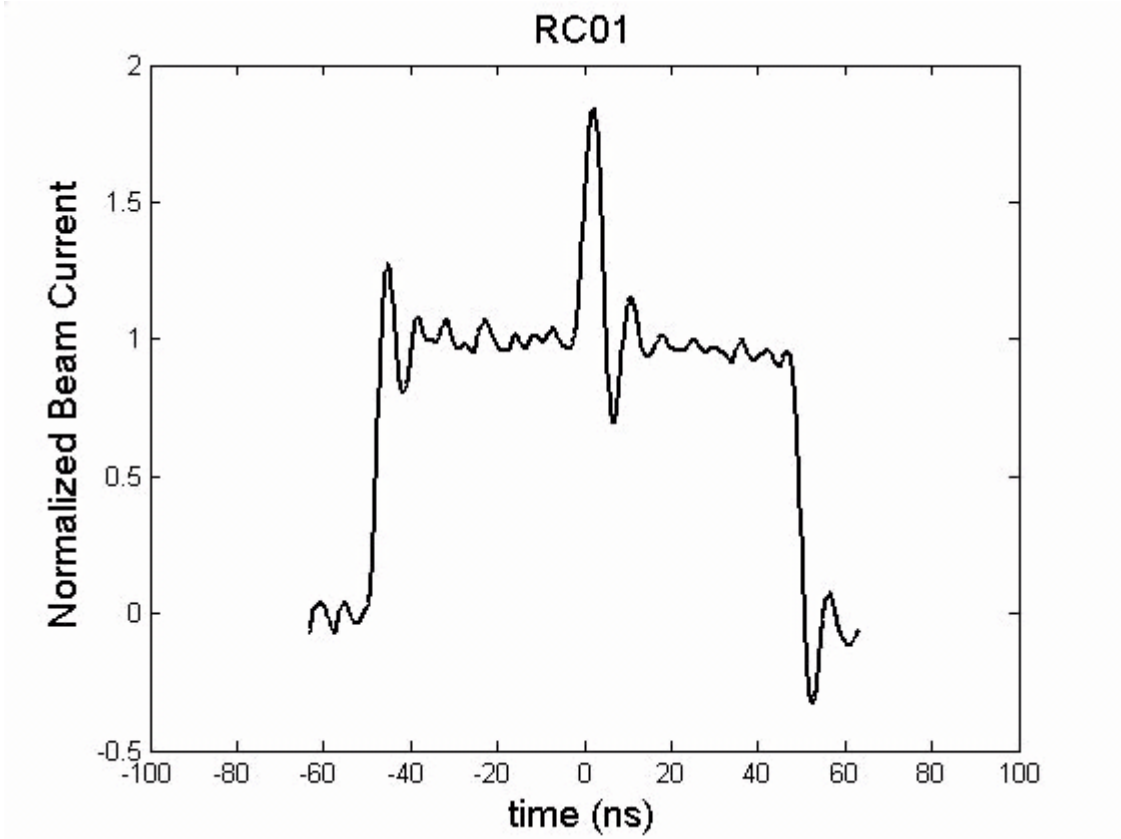


End



20 mA thermal-emission beam current

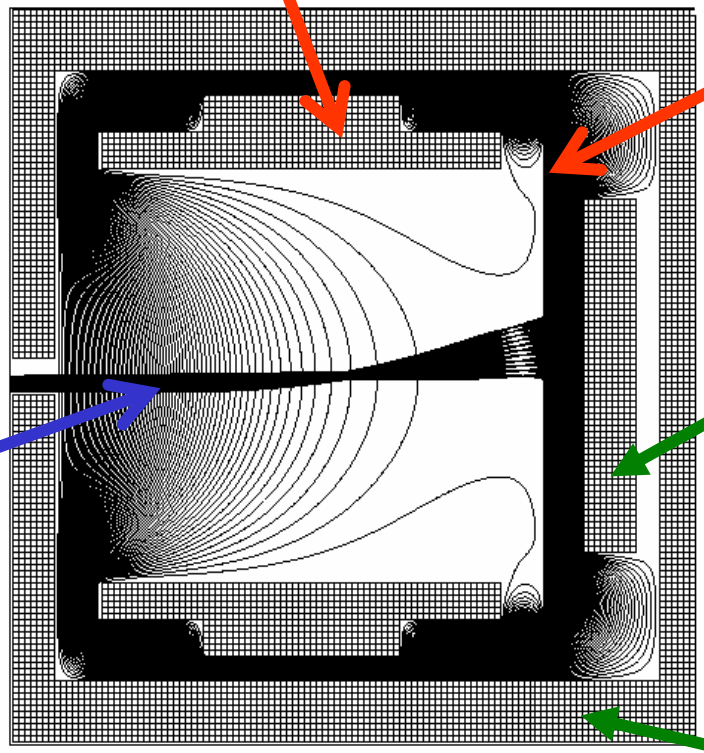
20 mA photo-emission beam current



Experimental Study of Beam Energy Spread Energy Analyzer Design

Collimating Cylinder

-10.13kV



Retarding Mesh

-9999.5 V

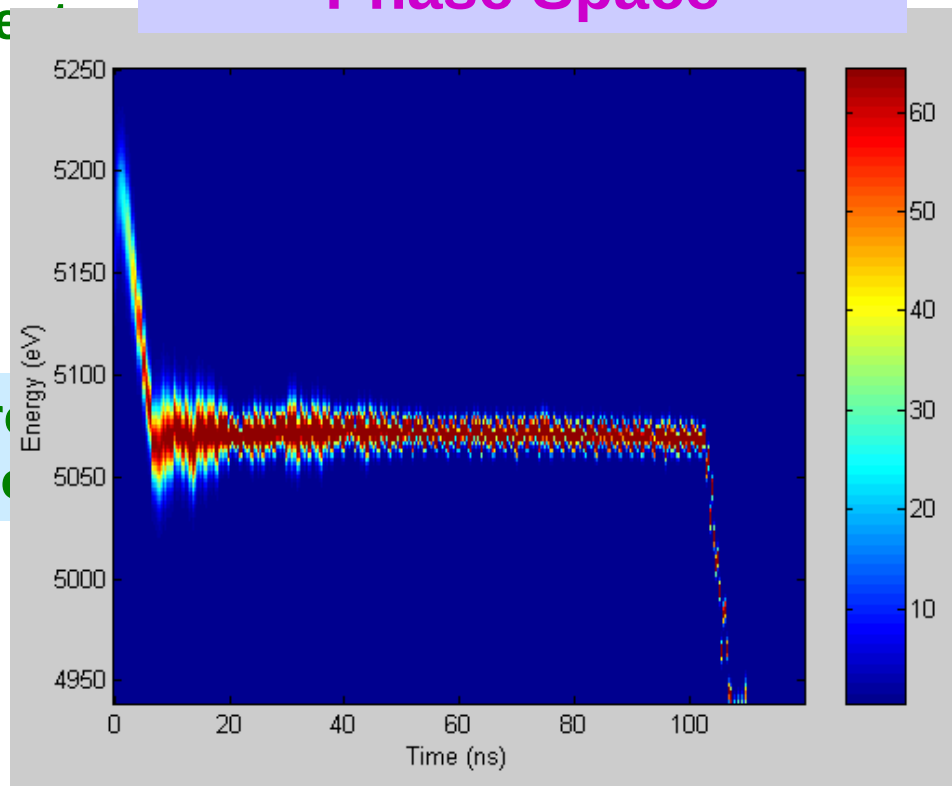
Colle

) keV eam

Gr He

3rd Generation: Res. < 1 eV

Measured Longitudinal Phase Space



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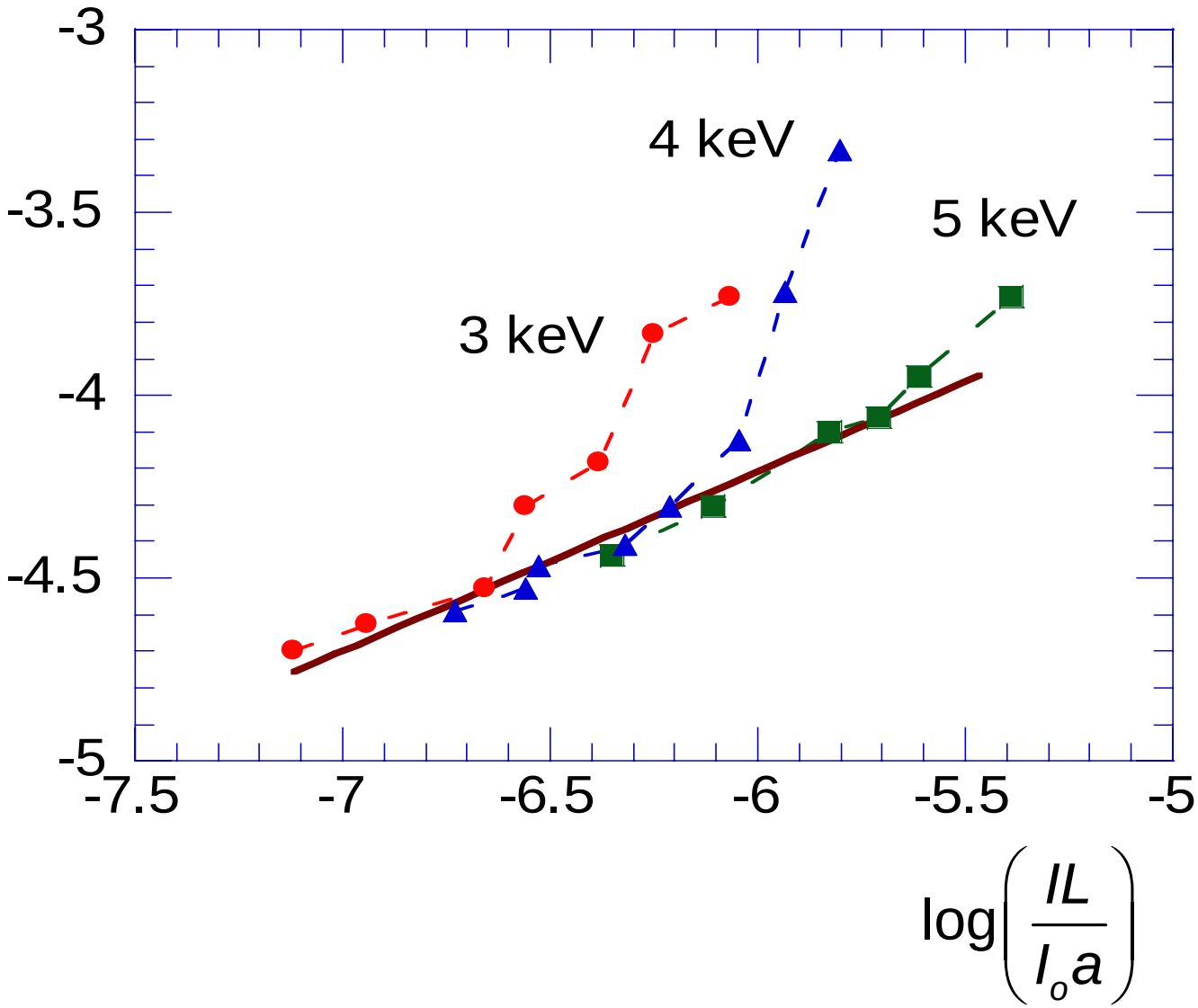
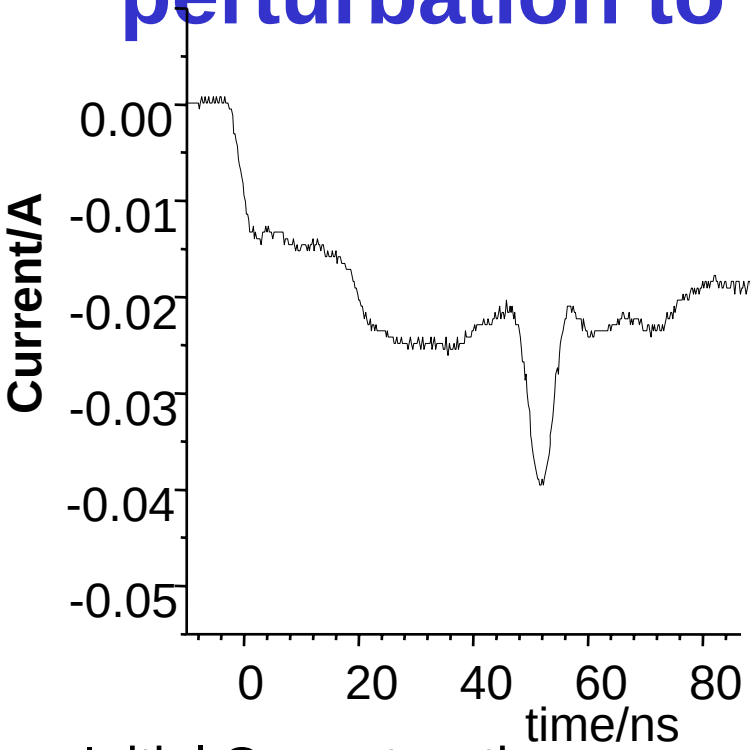
Y. Zou and Y . Cui

Aside: Anomalous Growth of Energy Spread

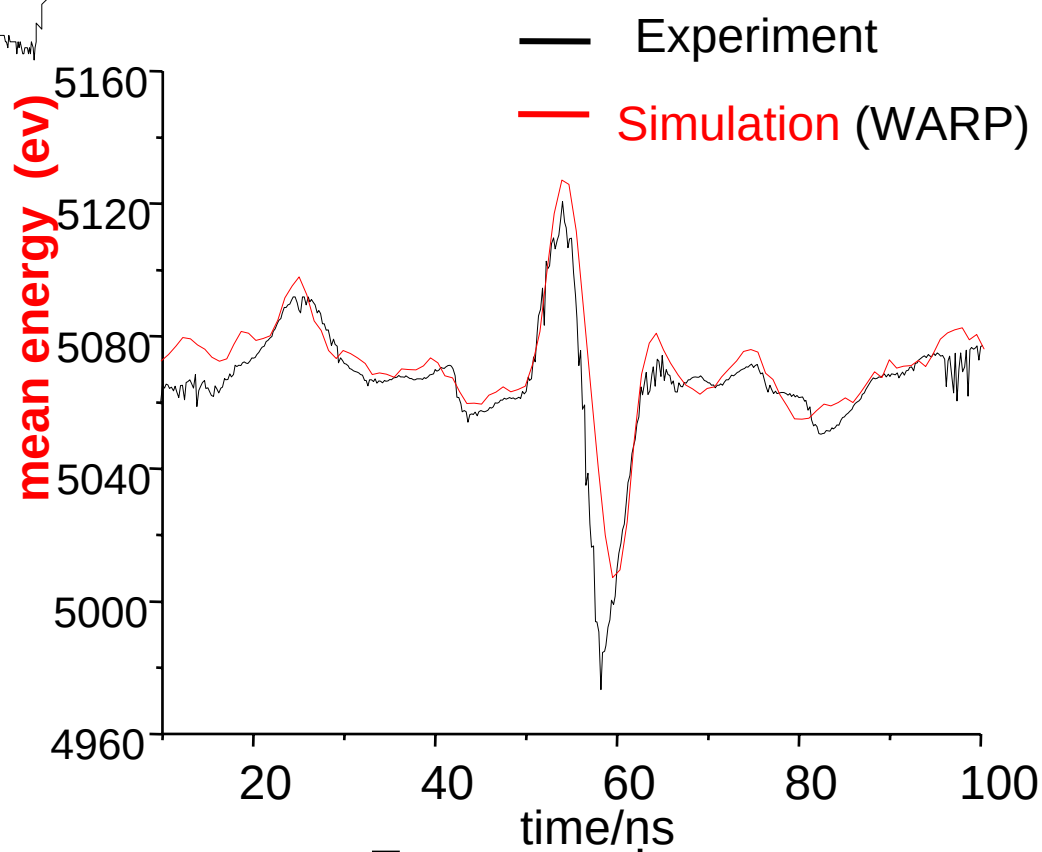
$$\log\left(\frac{\Delta\tilde{E}_{\|f}}{\Delta\tilde{E}_{\|o}}\right)$$



Space charge converts density perturbation to an energy perturbation



Initial Current vs time



Energy vs time

2-m downstream

K. Tian

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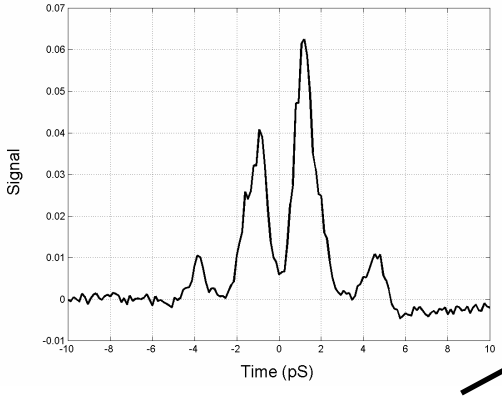
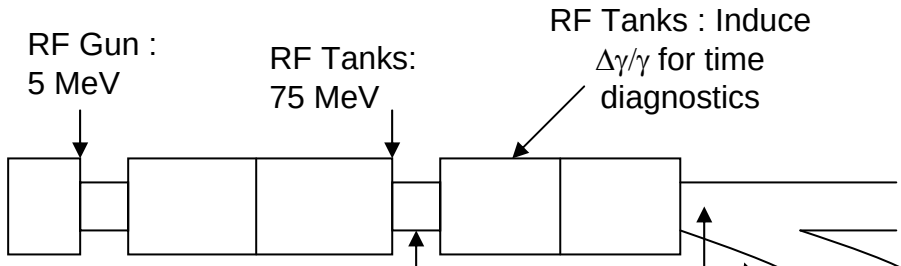
Direct Electron Beam Modulation at Cathode using a Ti:Sap driver laser





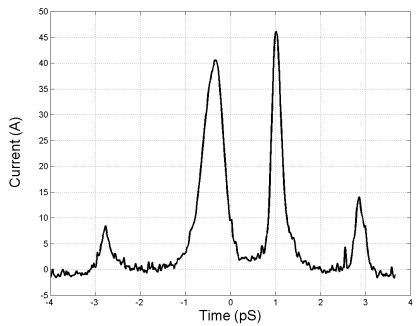
J. Neumann

Experiment

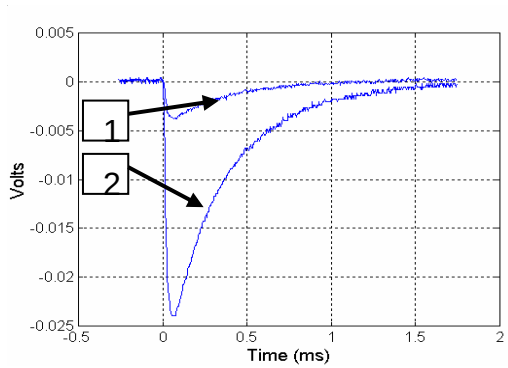
Long
Wavelength
Diagnostics

Time
Diagnostics

Laser Pulse Shaping
on sub ps time scale



Electron Beam Dynamics
Laser structure preserved through linac



THz Radiation Measurements

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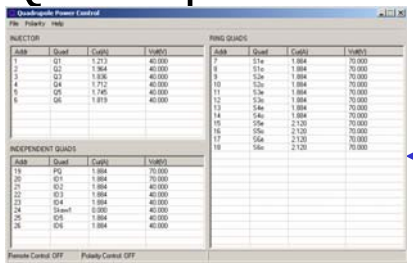
Production of Photoemission-Modulated Beams in a Thermionic Electron Gun, .J.G. Neumann, J.R. Harris, B. Quinn, and P.G. O'Shea, Review of Scientific Instruments, **76**, 033303 (2005).

Beam Control System Software

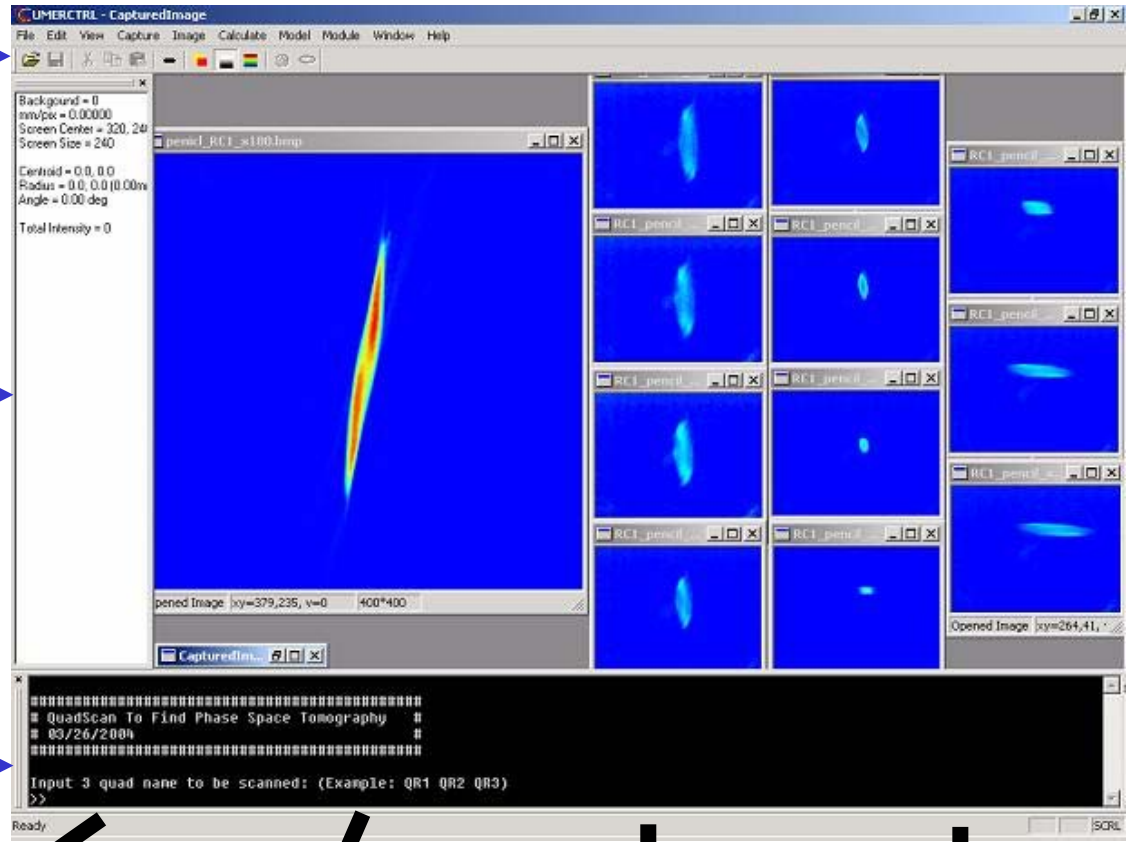
Hui Li

Quadrupoles Control

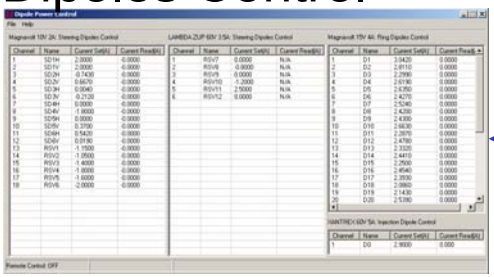


network

Central Control Platform

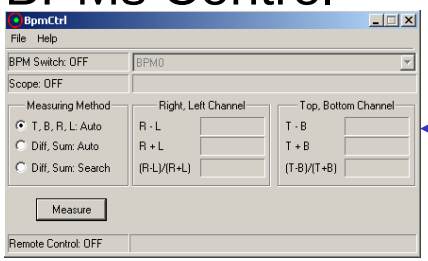


Dipoles Control



network

BPMs Control



network

Steering Module

Skew Correction Module

Matching Module

Tomography Module

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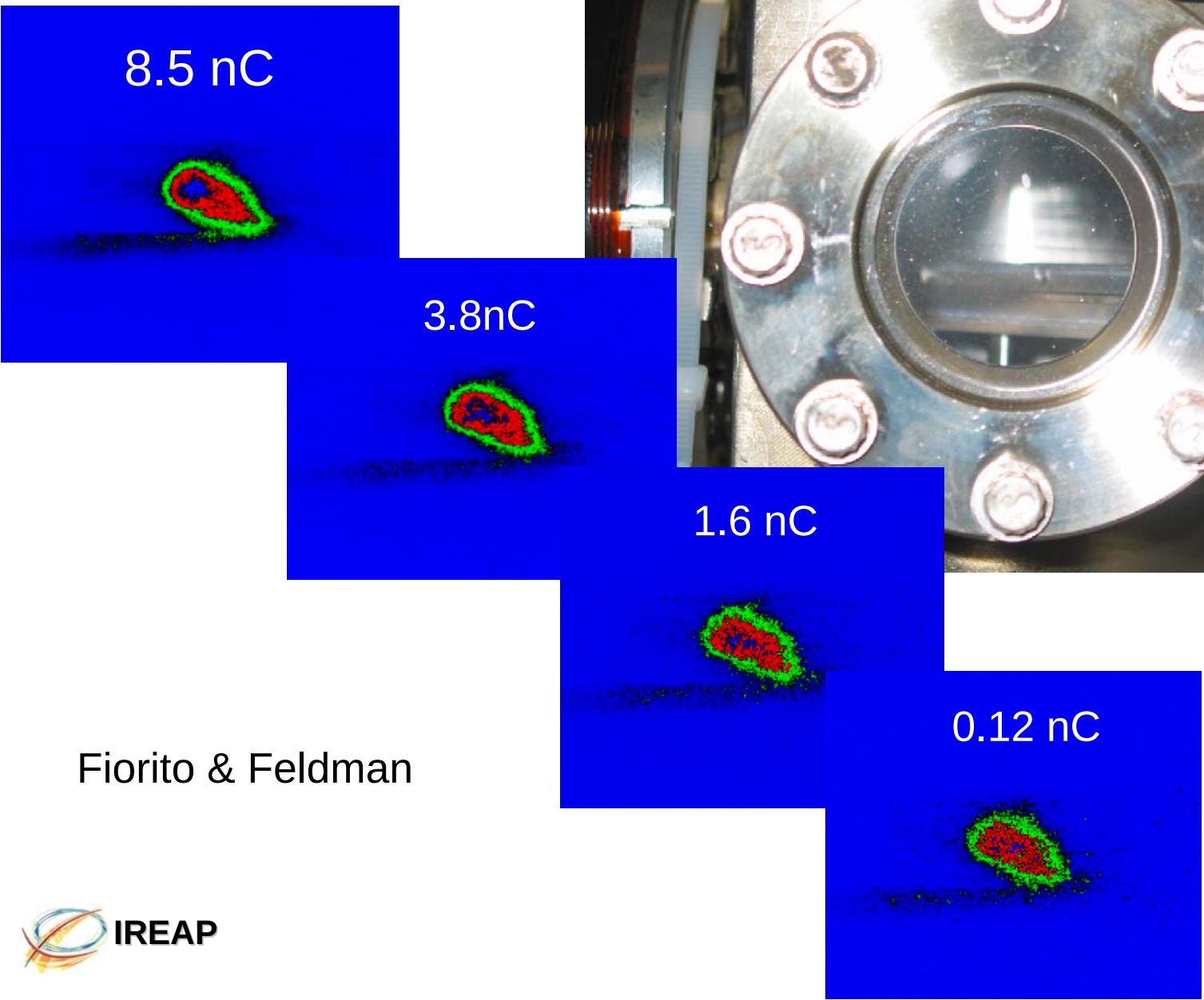
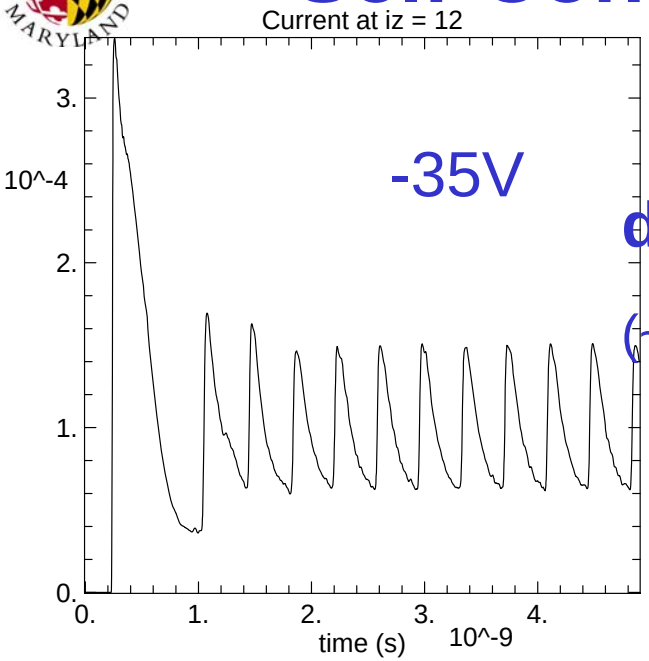
Low Energy (10 kV) Optical Transition Radiation Images

Ideal for exploring the fast time structure of low energy beams in injector



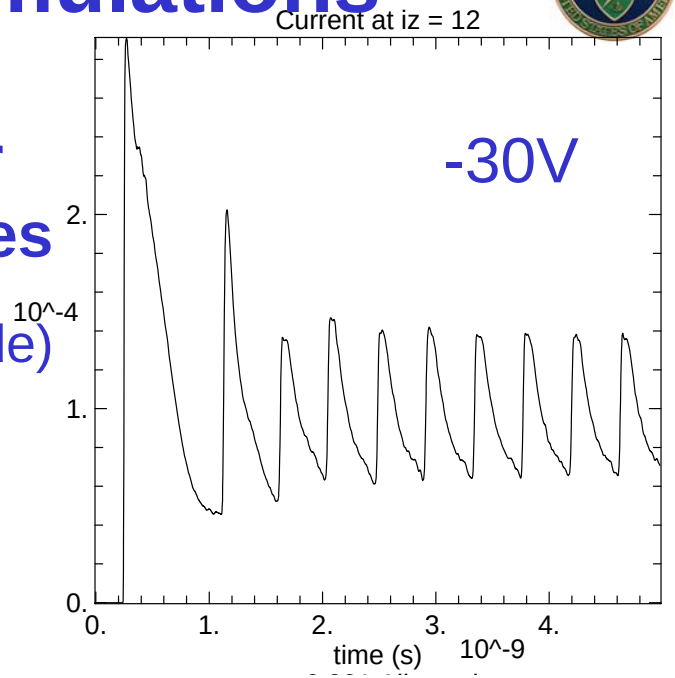
Fiorito & Feldman

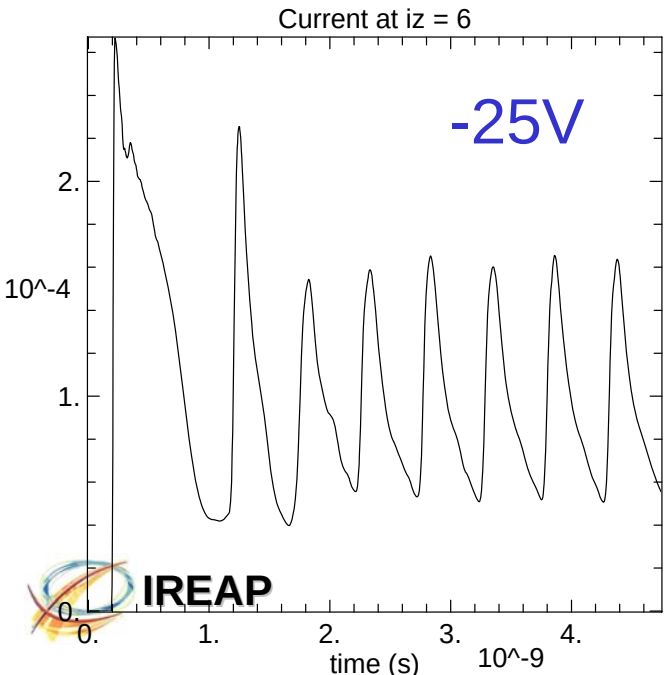
Self-Consistent Gun Simulations



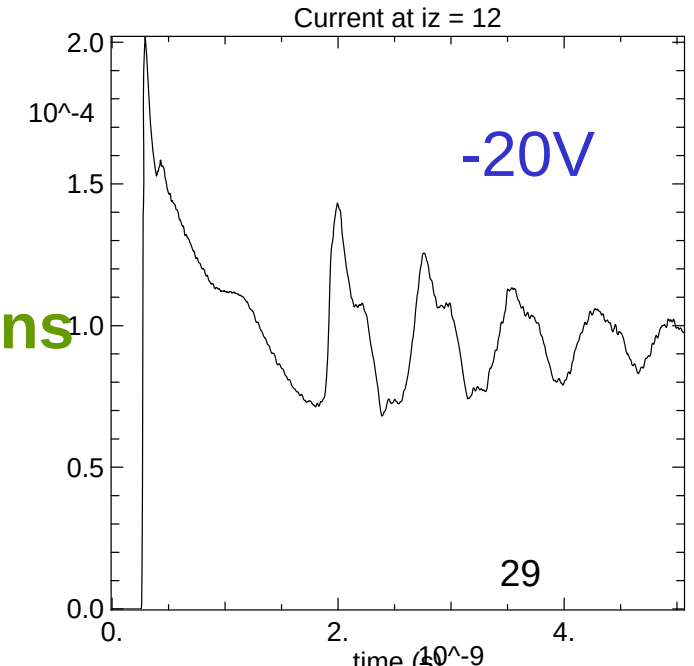
Current vs. time for different grid voltages

(~ 0.6 mm from the cathode)





WARP Simulations
Irving Haber



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Conclusion

- Brighter electron beams can result in smaller, less expensive FELs
- UMER is a unique, well-diagnosed and flexible testbed for experimenting with space charge-dominated beam dynamics at reasonable time scales
- UMER can produce benchmarks for space-charge codes
- Collaborations welcome!

Website: http://www.ireap.umd.edu/umer

Publications: http://www.umer.umd.edu/

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Virtual Cathode Movie