



Scaled Models: Space-Charge Dominated Electron Storage Rings

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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)

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**

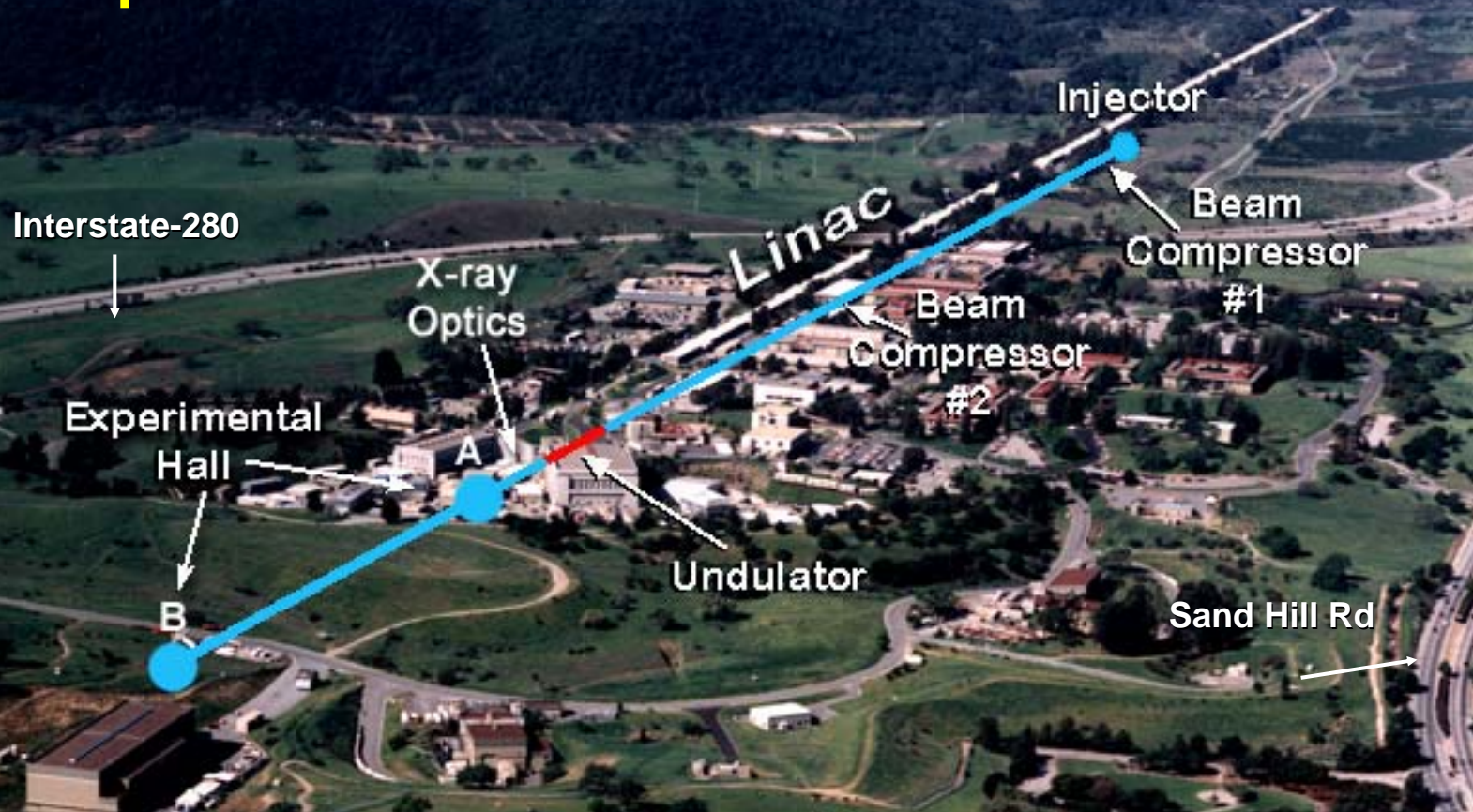


UMER: a testbed for space charge dynamics

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: 1 \AA with pulses of a few fs

Requirements of an FEL beam

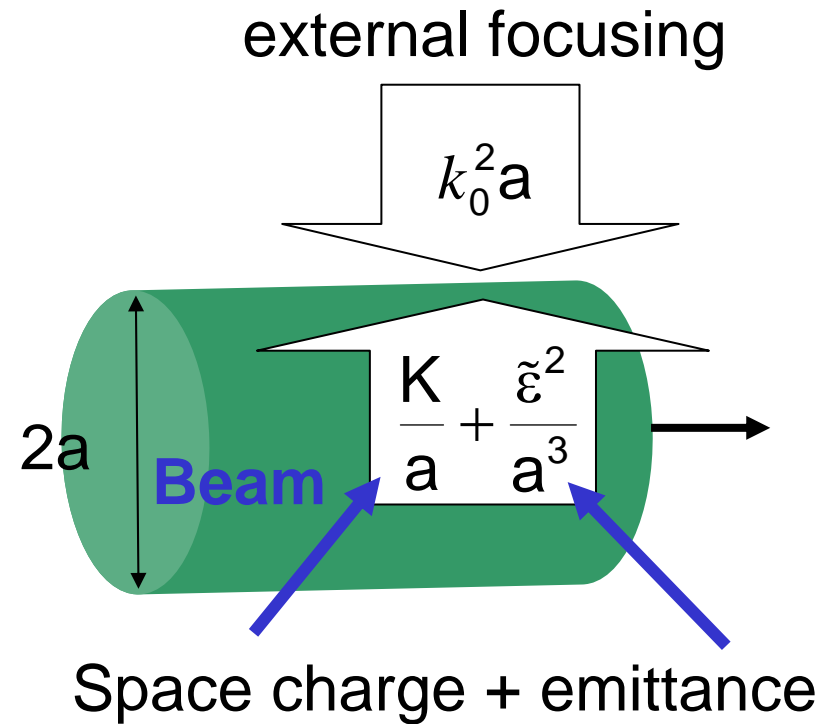
1. Bright electron beam
 - *intense space charge at the source*
2. In ERLs the injection energy is lost, so injection at lower energies preferable
 - *space charge*
3. Coherence for short wavelengths requires small emittance ($\varepsilon_n < \gamma\lambda/4\pi$)
 - *e.g. for LCLS, turns out $\varepsilon_n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

Dimensionless Space Charge Intensity

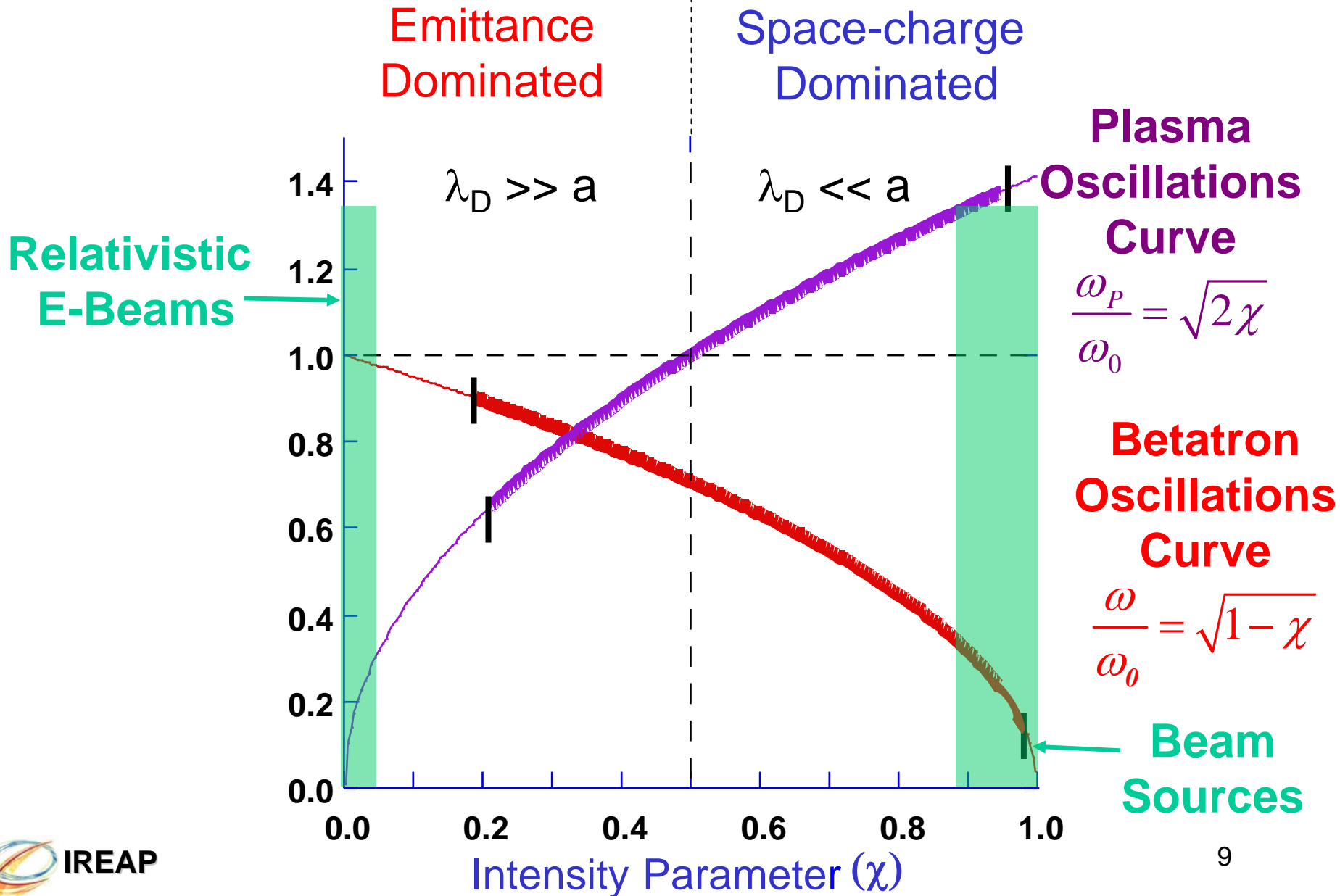
Intensity Parameter:

$$\chi \equiv \frac{K}{k_0^2 a^2} = \frac{\text{space charge force}}{\text{external focusing force}}$$

$$0 \leq \chi \leq 1$$

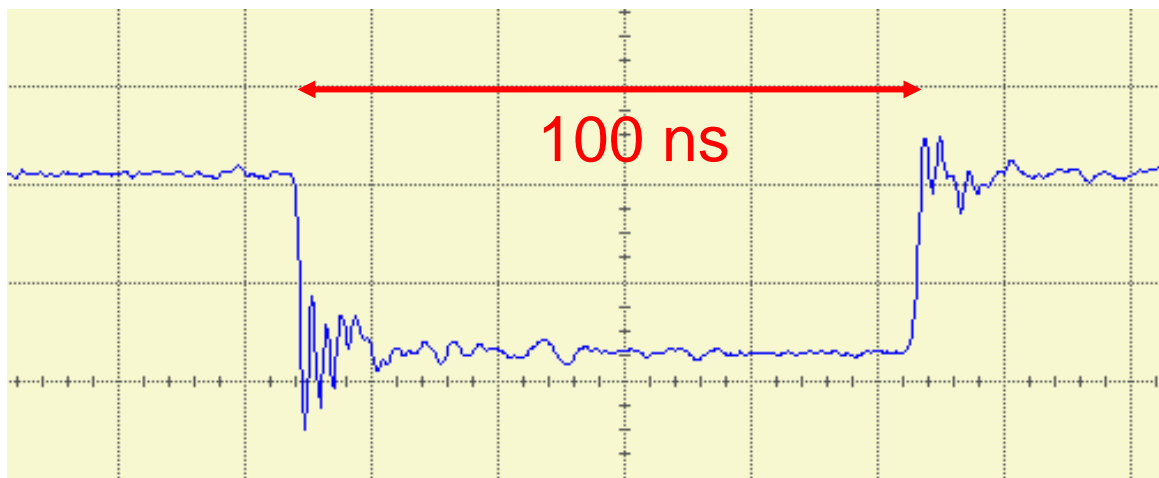


Intensity Scalings

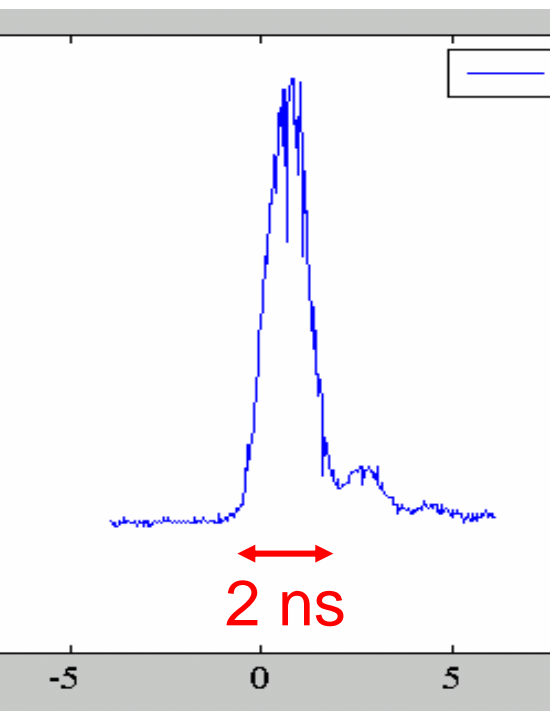


Realistic pulse shapes are not “clean”

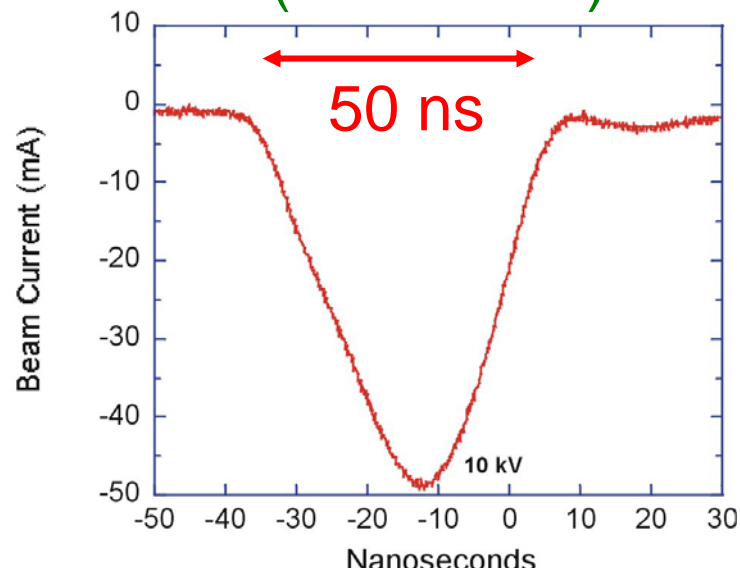
Rectangular Pulse
(thermionic)



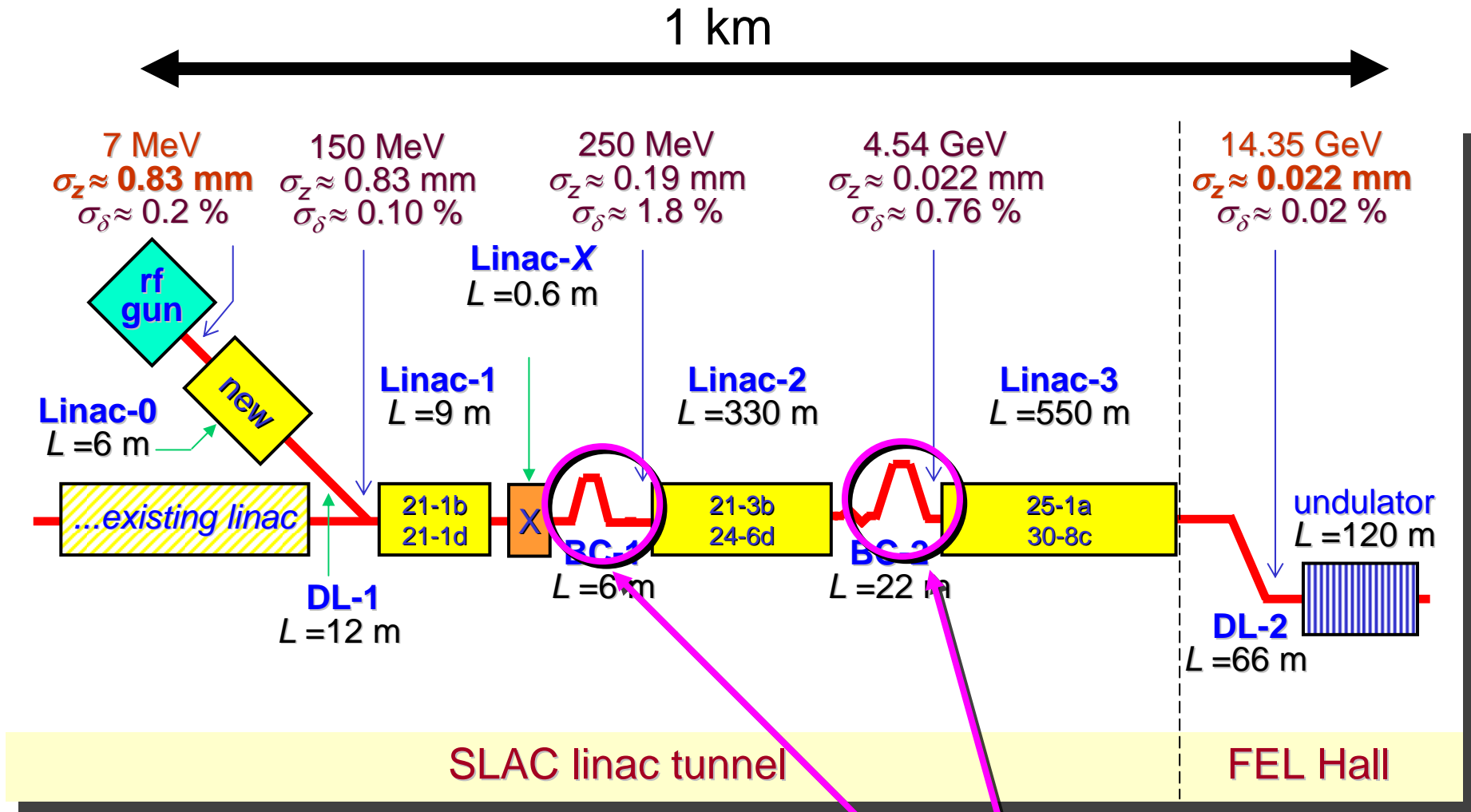
Photoemission Drive
Laser Pulse



Parabolic Pulse
(thermionic)



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



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?

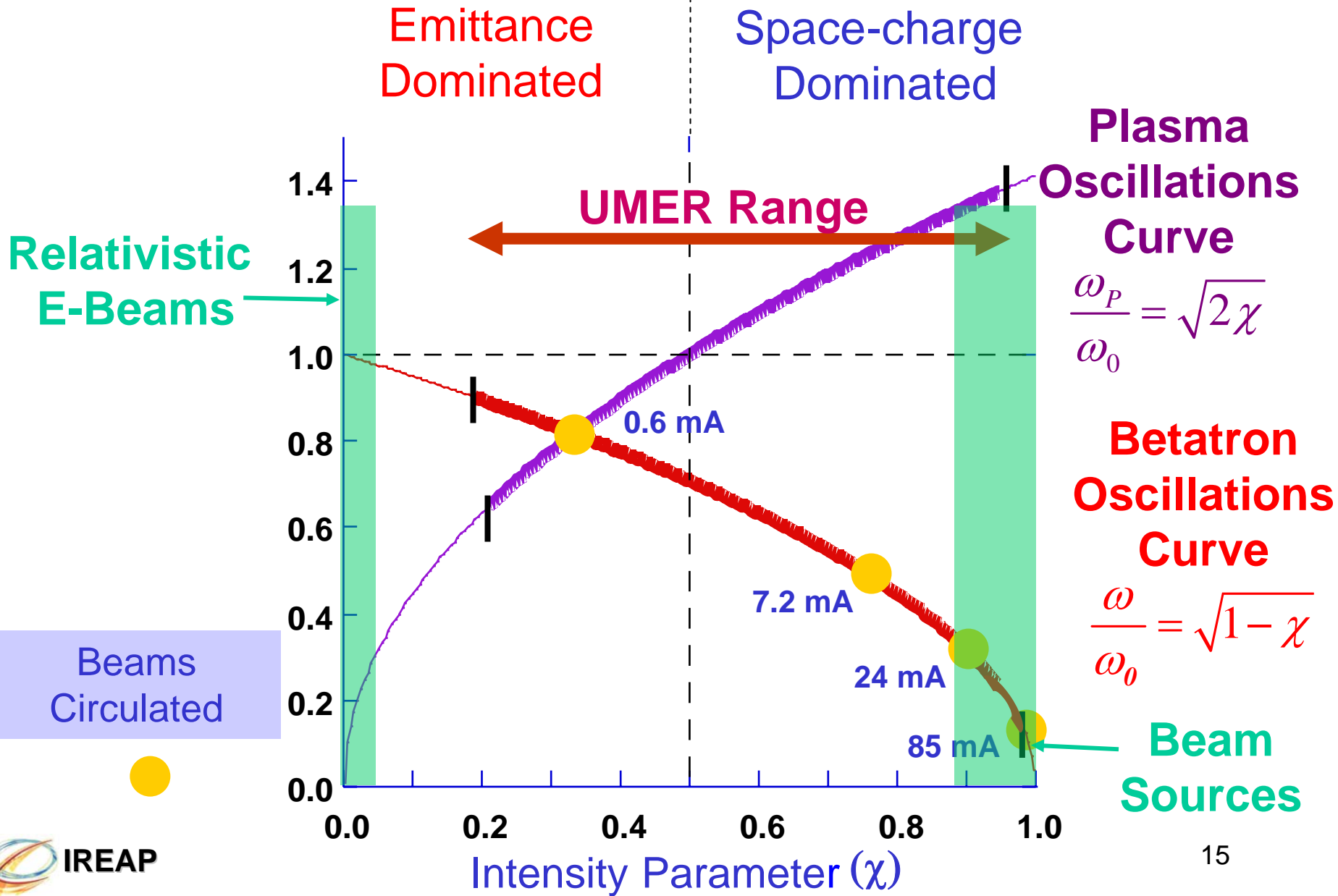
UMER:
a testbed for space charge
physics in bright beams

UMER Parameters

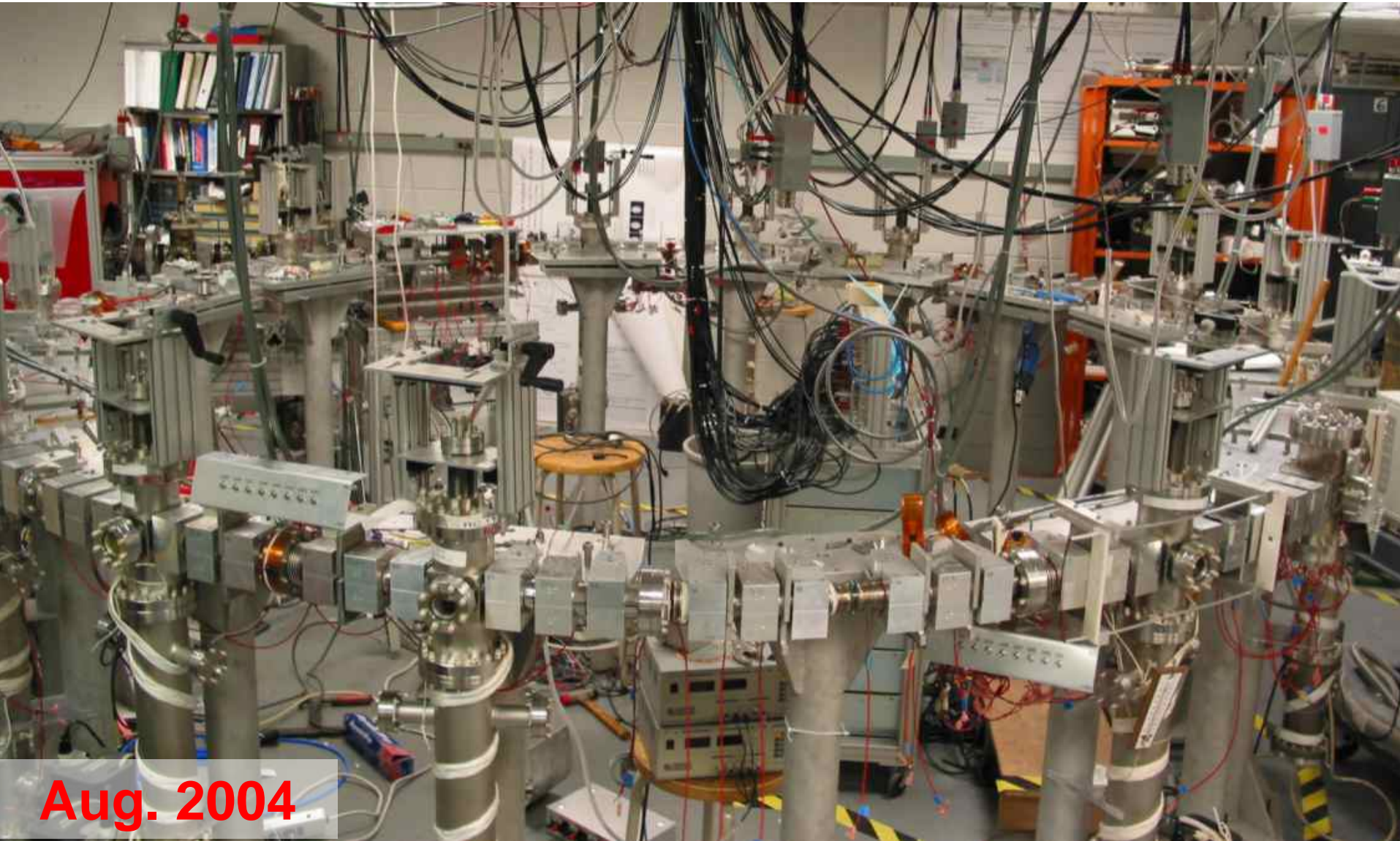
Energy	10 keV
Energy Spread	20 eV
Current Range	0.6-100 mA
rms Emittance Range	0.2-3 μm

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

Present UMER Operating Points

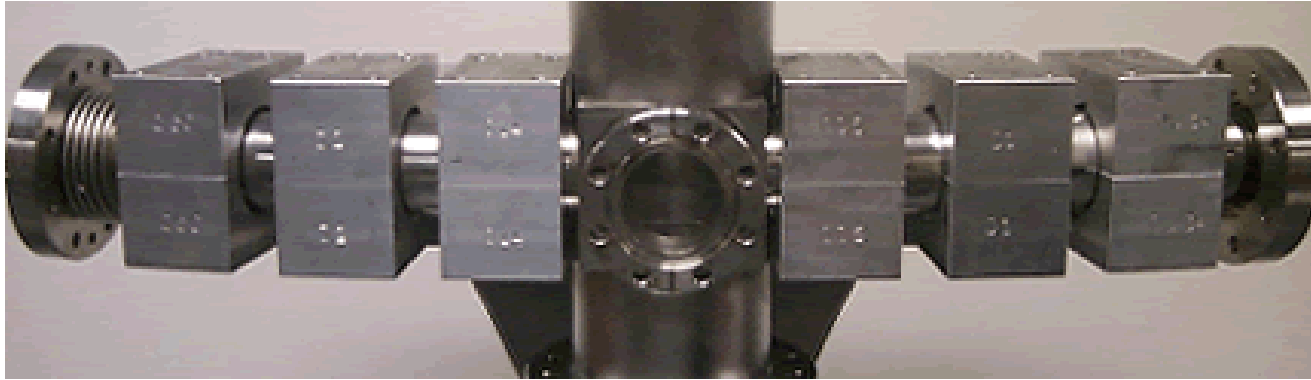


The University of Maryland Electron Ring

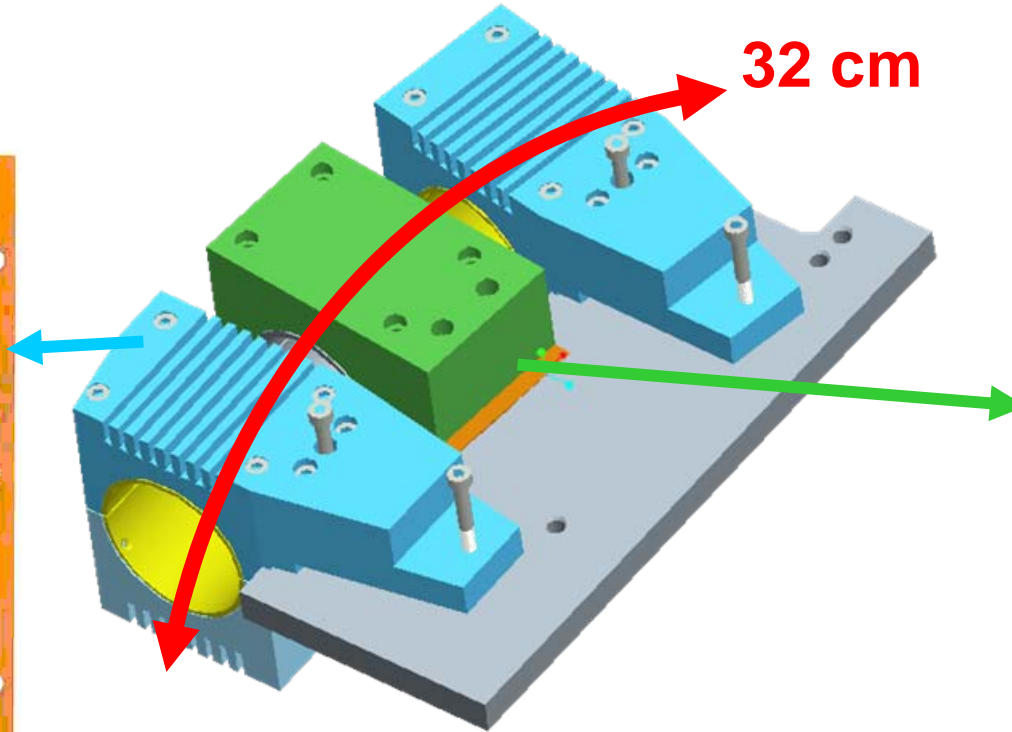


Aug. 2004

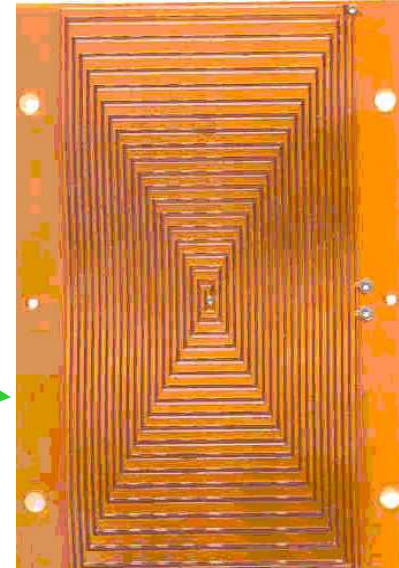
UMER Magnets & Lattice



72 Quads
(~ 7.8 G/cm)

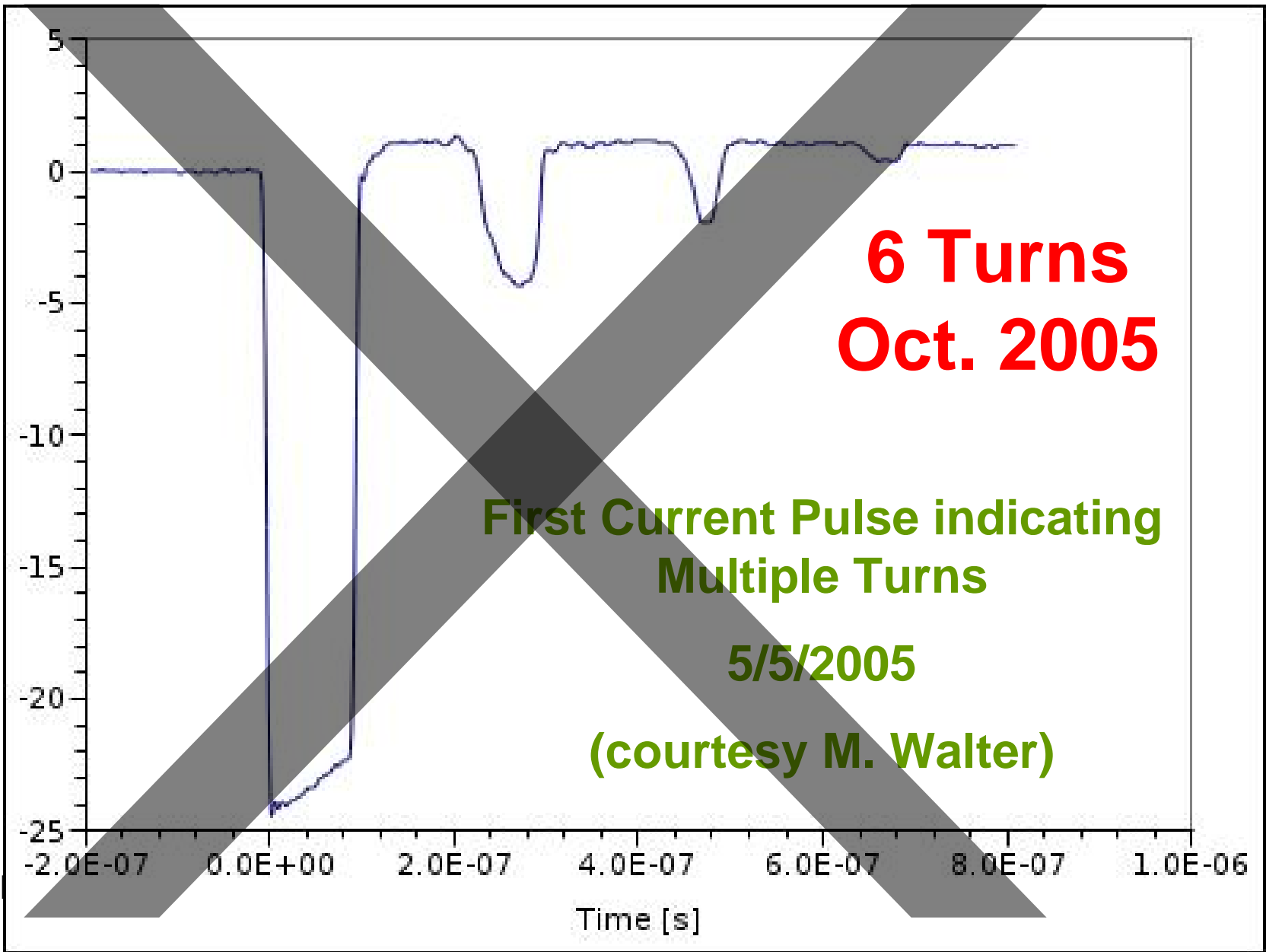


32 cm



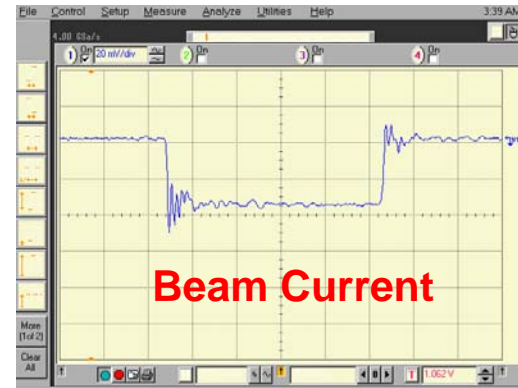
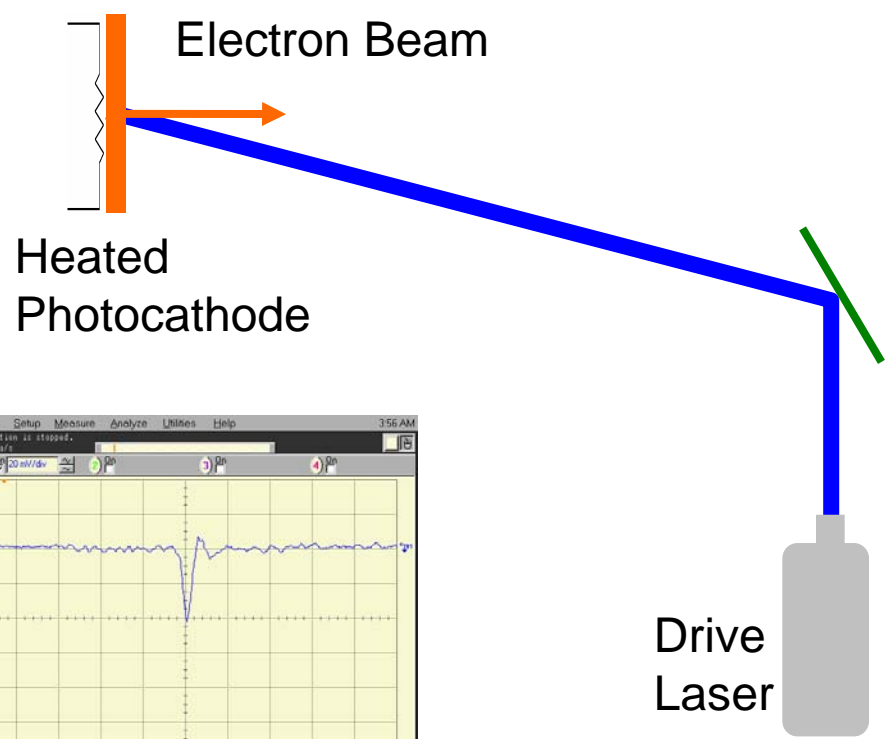
36 Dipoles
(~ 15 G)

Commencement of Multi-Turn Operation (Work in Progress)

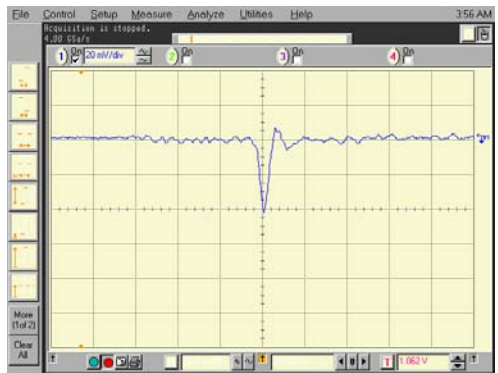


Example Results and Experiments

Generating Perturbations with Lasers



Thermionic only, 100ns pulse

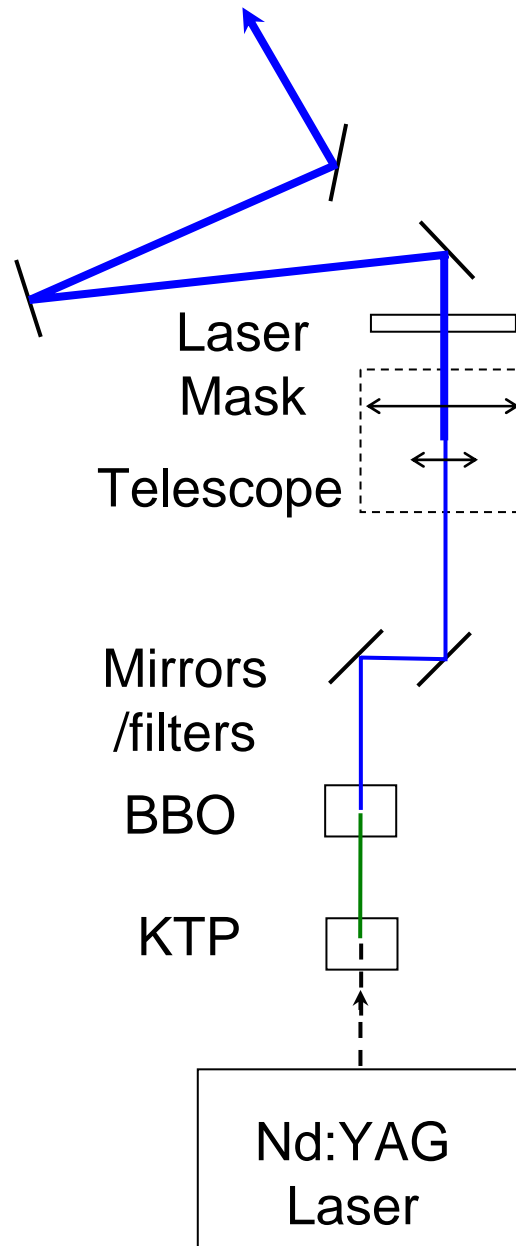
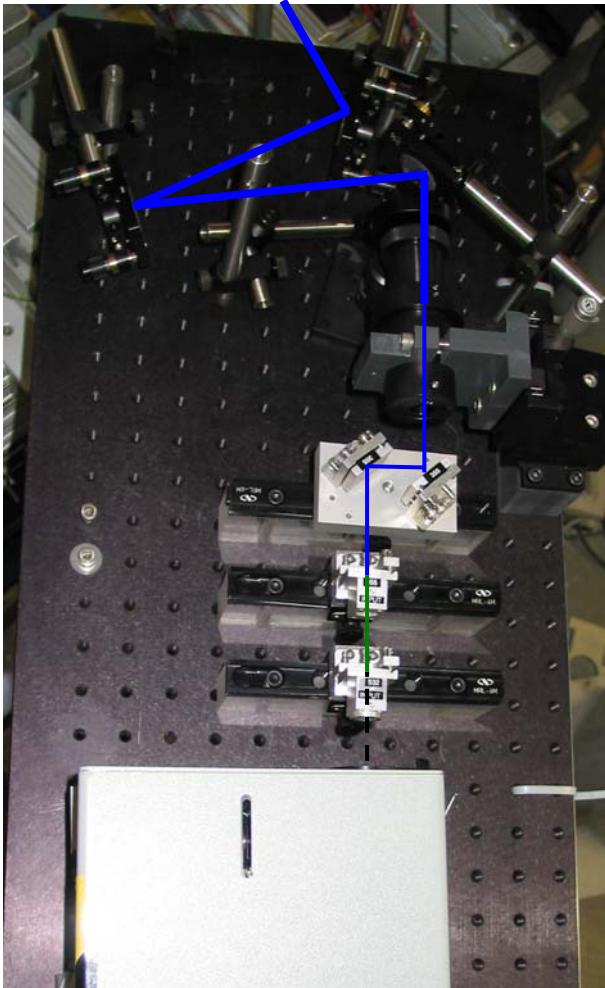


Photoemission only
(Cool cathode)



Photoemission +
Thermionic 5ns pulse

Drive Laser Setup

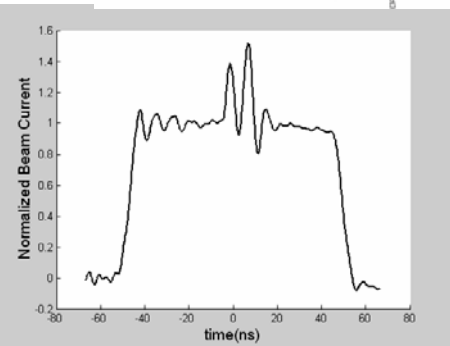
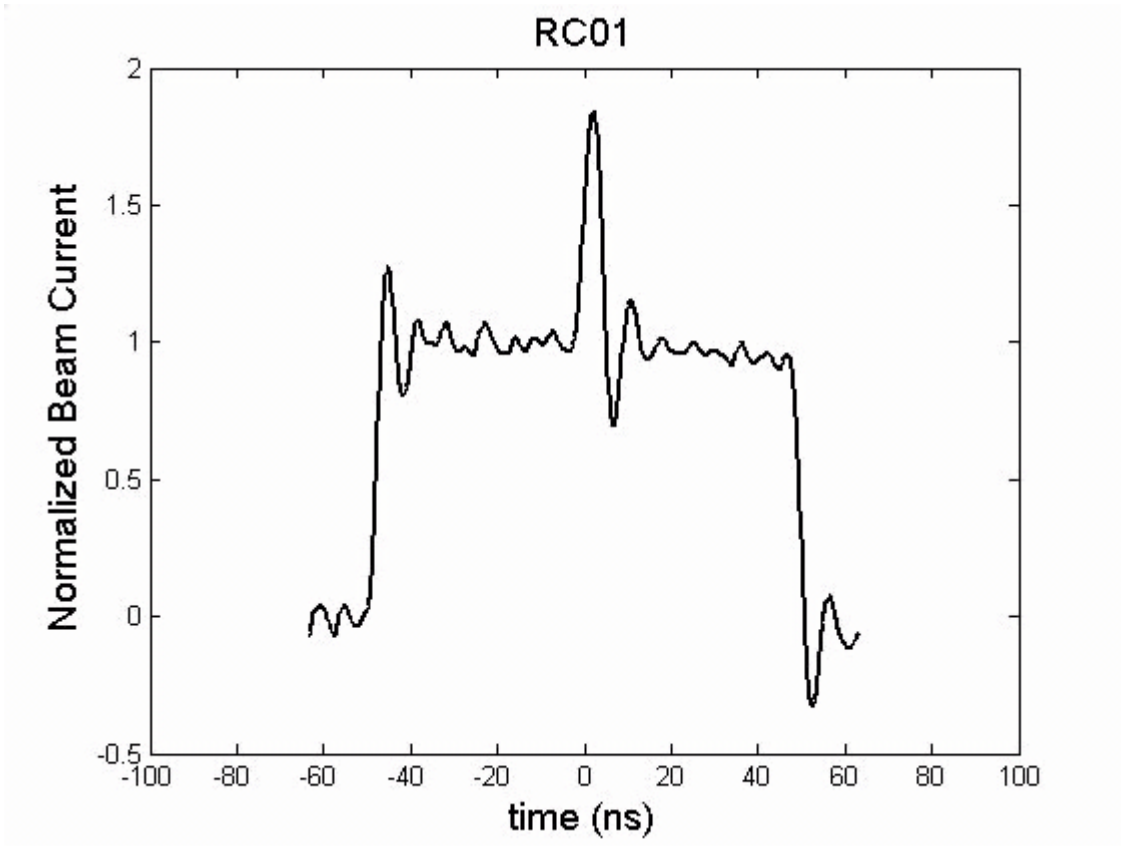
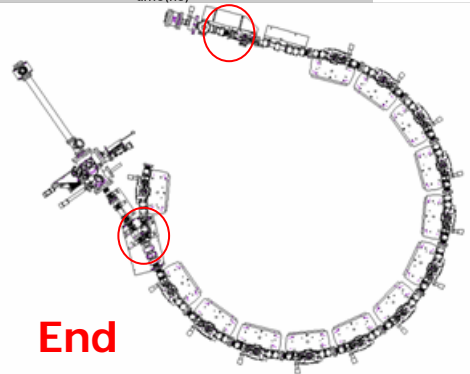
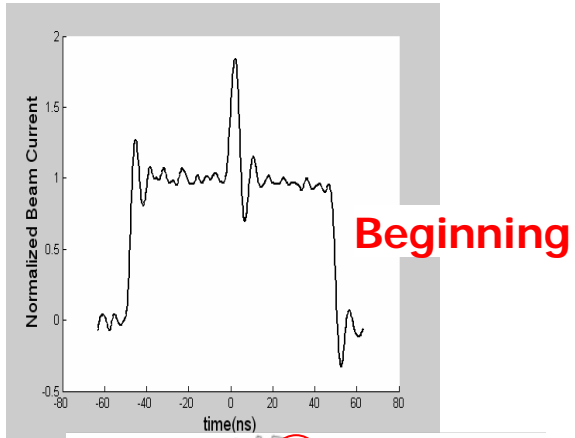


UV (355nm) Laser
Photon energy: 3.5 eV
Work function: 2.7 eV

Experiment: Propagation of Perturbed Beam

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

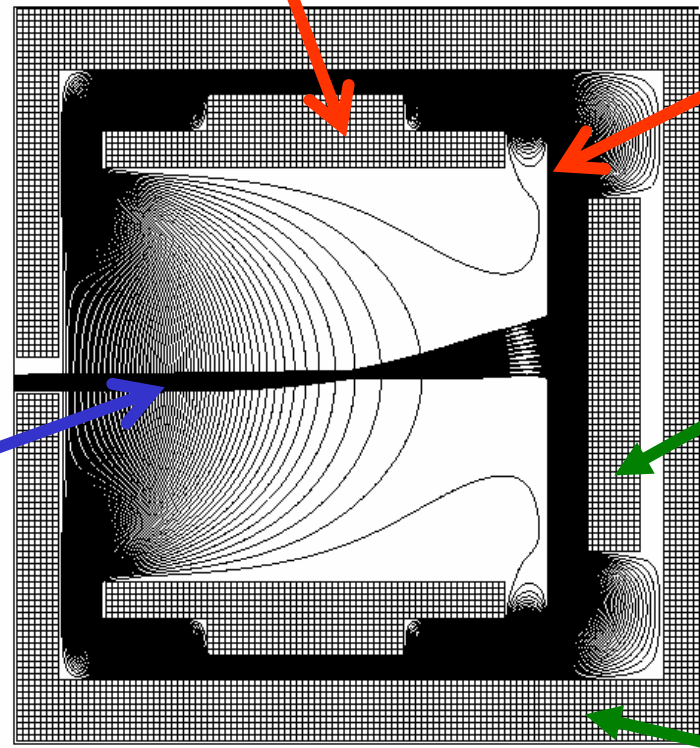
Retarding Mesh

-9999.5 V

Collector

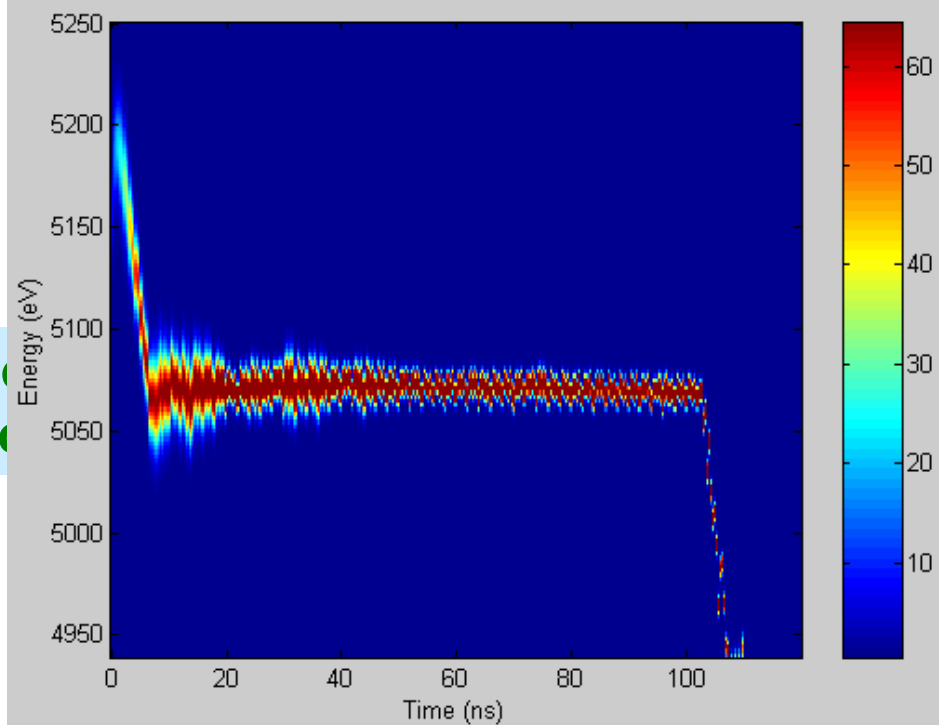
**Grid
Hole**

keV
beam



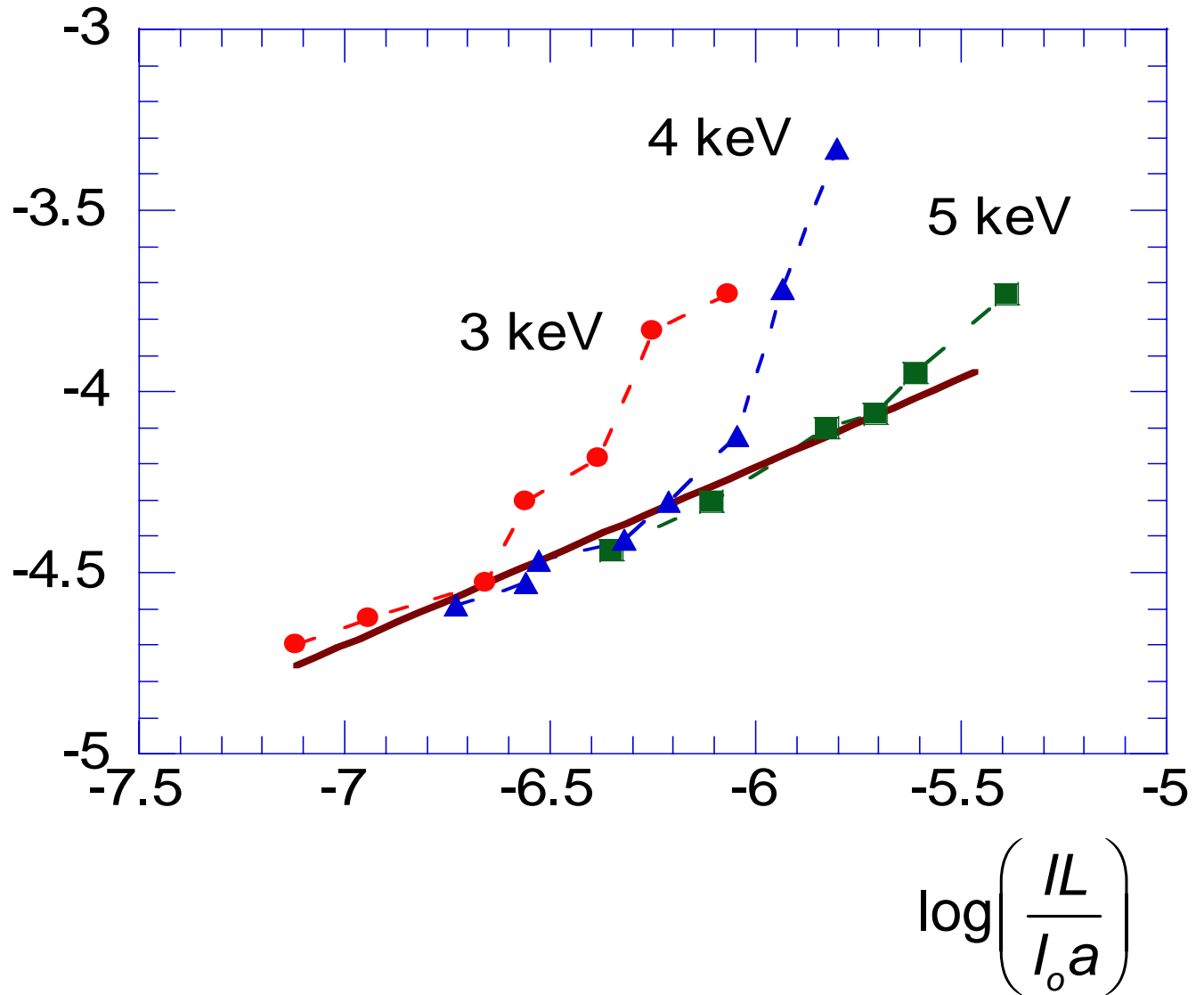
3rd Generation: Res. < 1 eV

**Measured Longitudinal
Phase Space**

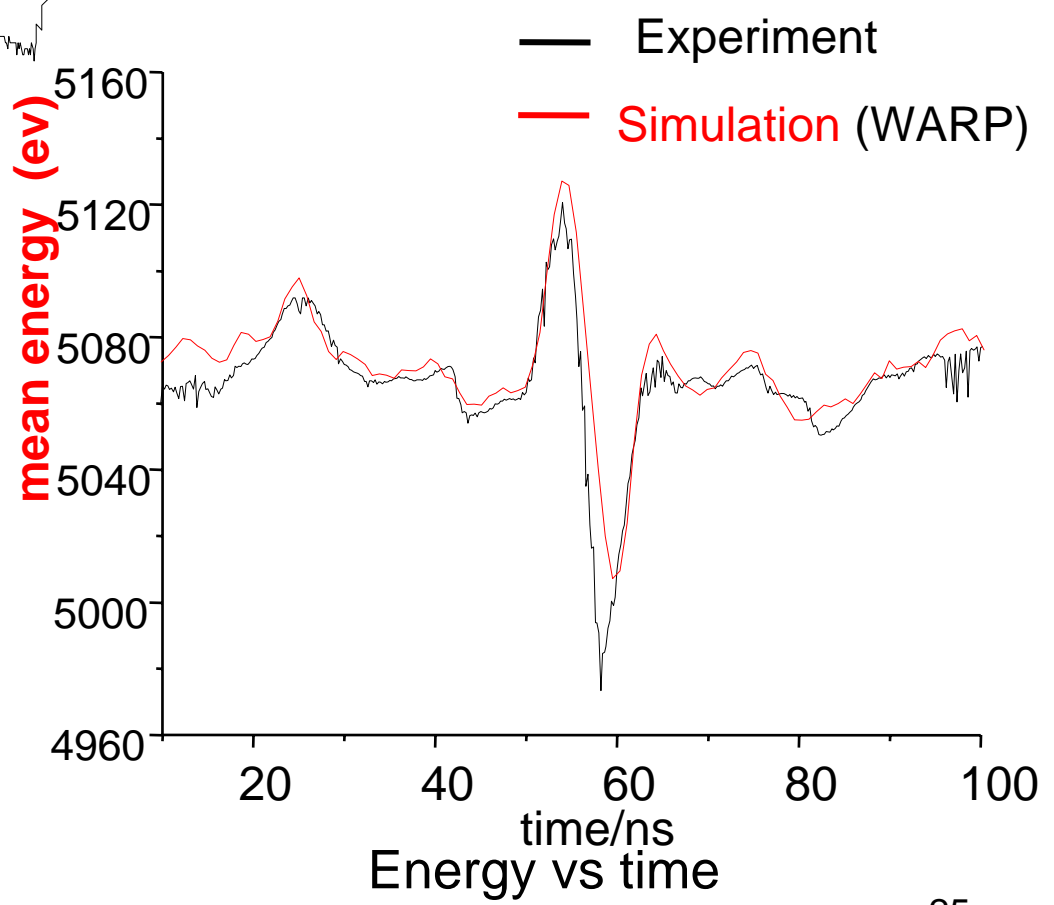
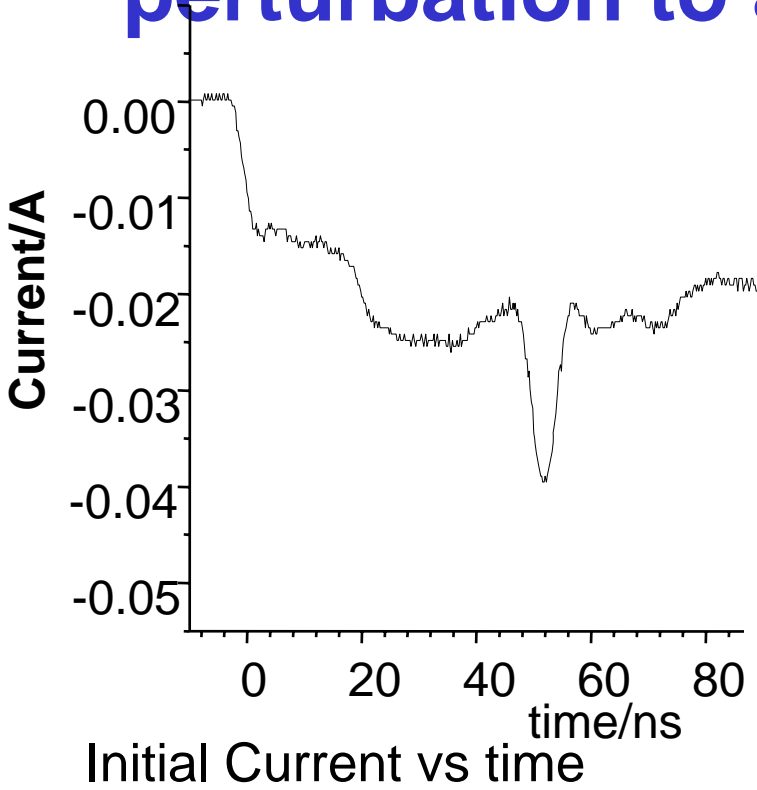


Aside: Anomalous Growth of Energy Spread

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

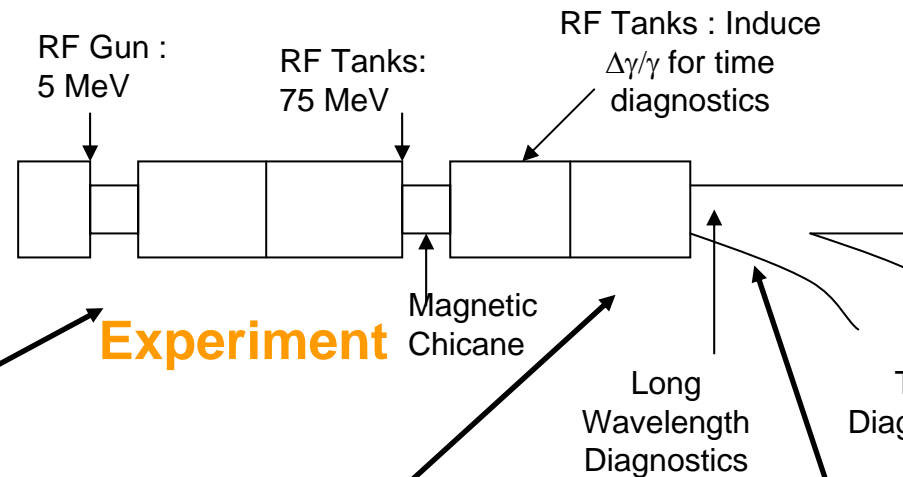
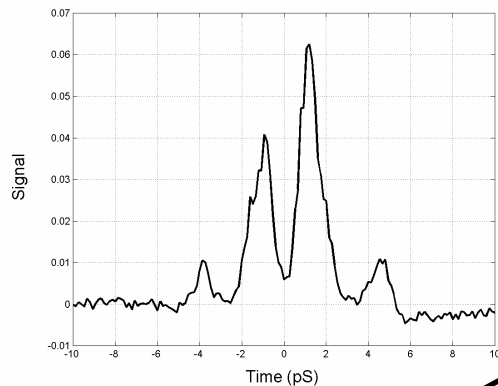


Space charge converts density perturbation to an energy perturbation



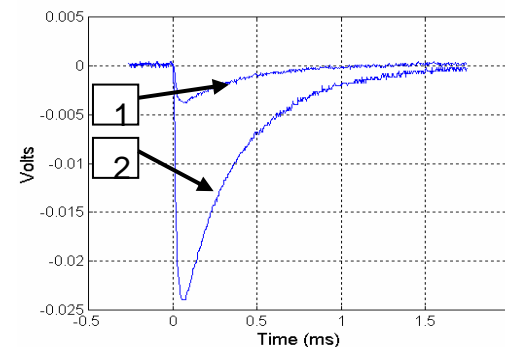
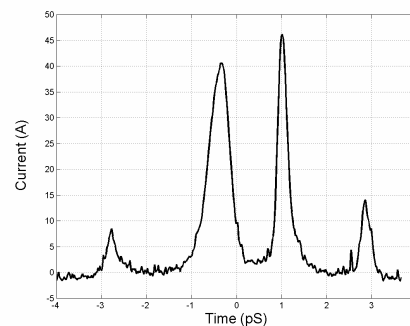
K. Tian

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



J. Neumann

Laser Pulse Shaping on sub ps time scale



Electron Beam Dynamics
Laser structure preserved through linac

THz Radiation Measurements

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

INJECTOR				RING QUAD			
QNAME	QTYPE	QLENGTH	QSTRENGTH	QNAME	QTYPE	QLENGTH	QSTRENGTH
Q1	Q1	1.213	40.000	Q1	Q1	1.884	70.000
Q2	Q1	1.884	40.000	Q2	Q1	1.884	70.000
Q3	Q1	1.884	40.000	Q3	Q1	1.884	70.000
Q4	Q1	1.745	40.000	Q4	Q1	1.884	70.000
Q5	Q1	1.884	40.000	Q5	Q1	1.884	70.000
Q6	Q1	1.884	40.000	Q6	Q1	1.884	70.000
Q7	Q1	1.884	40.000	Q7	Q1	1.884	70.000
Q8	Q1	1.884	40.000	Q8	Q1	1.884	70.000
Q9	Q1	1.884	40.000	Q9	Q1	1.884	70.000
Q10	Q1	1.884	40.000	Q10	Q1	1.884	70.000
Q11	Q1	1.884	40.000	Q11	Q1	1.884	70.000
Q12	Q1	1.884	40.000	Q12	Q1	1.884	70.000
Q13	Q1	1.884	40.000	Q13	Q1	1.884	70.000
Q14	Q1	1.884	40.000	Q14	Q1	1.884	70.000
Q15	Q1	1.884	40.000	Q15	Q1	1.884	70.000
Q16	Q1	1.884	40.000	Q16	Q1	1.884	70.000
Q17	Q1	1.884	40.000	Q17	Q1	1.884	70.000
Q18	Q1	1.884	40.000	Q18	Q1	1.884	70.000

network

Central Control Platform

Background = 0
 xmu/px = 0.0000
 Screen Center = 320, 240
 Screen Size = 240

Centroid = 0.0, 0.0
 Radius = 0.0, 0.0 (0.00m)
 Angle = 0.00 deg
 Total Intensity = 0

Opened Image: |xy=379,235,v=0| 400*400

Opened Image: |xy=264,41,v=0| 400*400

```

=====
# QuadScan To Find Phase Space Tomography #
# 03/26/2004 #
=====
Input 3 quad name to be scanned: (Example: QR1 QR2 QR3)
>>
  
```

Dipoles Control

MAGNET 10V 20k Steering Dipole Control				LAMBDA 20P 80V 35k Steering Dipole Control				MAGNET 10V 4k Ring Dipole Control			
Channel	Name	Current Setpt	Current Preset	Channel	Name	Current Setpt	Current Preset	Channel	Name	Current Setpt	Current Preset
1	SD10V	2.000	0.000	1	R017	0.000	N/A	1	D1	1.620	0.000
2	SD10V	2.000	0.000	2	R016	0.000	N/A	2	D2	2.010	0.000
3	SD20V	4.140	0.000	3	R015	0.000	N/A	3	D3	2.290	0.000
4	SD20V	6.670	0.000	4	R010	1.200	N/A	4	D4	2.030	0.000
5	SD20V	0.000	0.000	5	R011	2.900	N/A	5	D5	2.420	0.000
6	SD20V	0.210	0.000	6	R012	0.000	N/A	6	D6	2.240	0.000
7	SD20V	0.000	0.000	7	R013	0.000	N/A	7	D7	2.430	0.000
8	SD20V	0.000	0.000	8	R014	0.000	N/A	8	D8	2.430	0.000
9	SD20V	0.000	0.000	9	R015	0.000	N/A	9	D9	2.430	0.000
10	SD20V	0.000	0.000	10	R016	0.000	N/A	10	D10	2.430	0.000
11	SD20V	0.540	0.000	11	R017	2.070	0.000	11	D11	2.320	0.000
12	SD20V	0.910	0.000	12	R018	2.430	0.000	12	D12	2.430	0.000
13	R019	1.100	0.000	13	R019	2.320	0.000	13	D13	2.320	0.000
14	R010	1.900	0.000	14	R018	2.430	0.000	14	D14	2.430	0.000
15	R011	1.400	0.000	15	R019	2.290	0.000	15	D15	2.290	0.000
16	R012	1.800	0.000	16	R018	2.430	0.000	16	D16	2.430	0.000
17	R013	1.600	0.000	17	R019	2.390	0.000	17	D17	2.390	0.000
18	R014	2.000	0.000	18	R018	2.430	0.000	18	D18	2.430	0.000
19	R015	2.000	0.000	19	R018	2.430	0.000	19	D19	2.430	0.000
20	R016	2.000	0.000	20	R018	2.430	0.000	20	D20	2.430	0.000

network

BPMs Control

BPM Switch: OFF | BFM0

Scope: DFF

Measuring Method:
 T, B, R, L Auto
 Diff. Sum: Auto
 Diff. Sum: Search

Right, Left Channel:
 R - L
 R + L
 (R-L)/(R+L)

Top, Bottom Channel:
 T - B
 T + B
 (T-B)/(T+B)

Measure

Remote Control: OFF

network

Steering Module

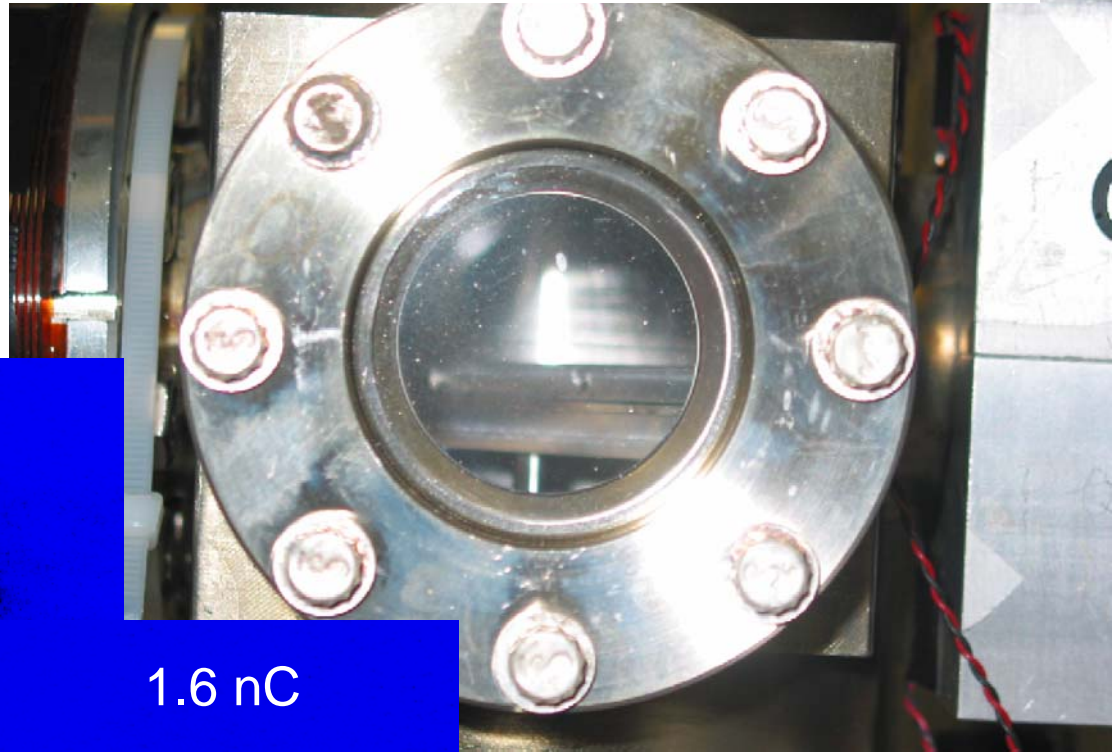
Skew Correction Module

Matching Module

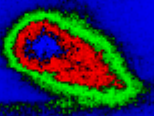
Tomography Module

Low Energy (10 kV) Optical Transition Radiation Images

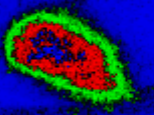
Ideal for exploring the fast time structure of low energy beams in injector



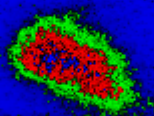
8.5 nC



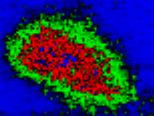
3.8 nC



1.6 nC



0.12 nC



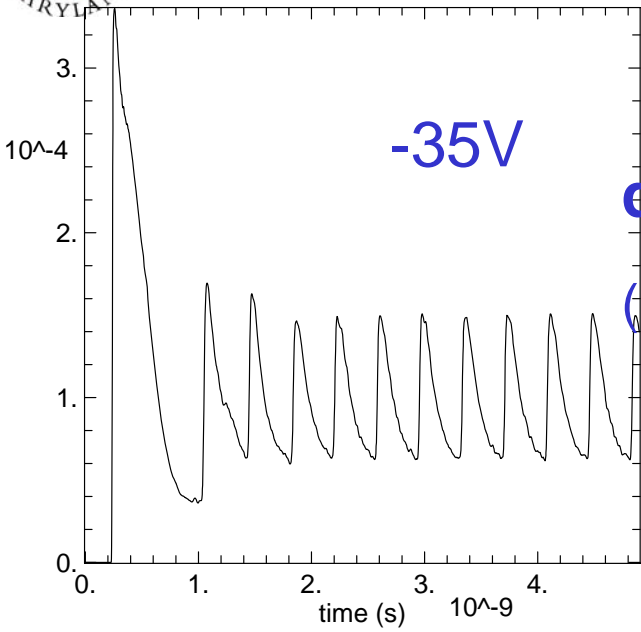
Fiorito & Feldman



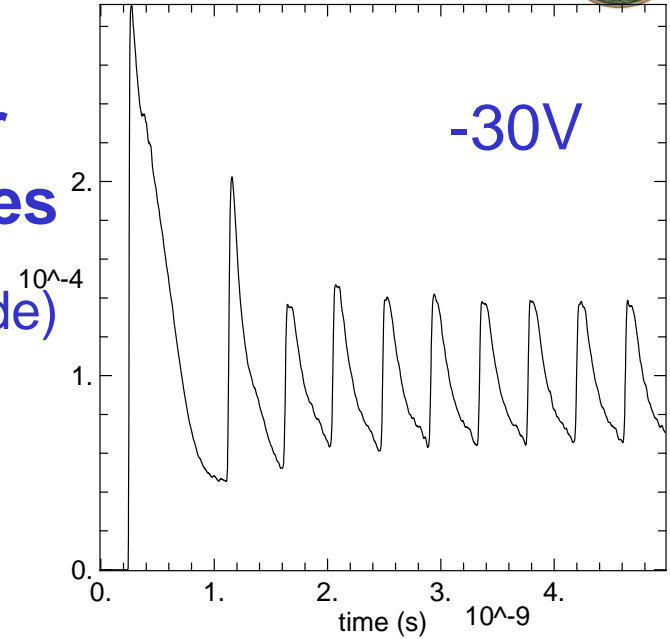
Self-Consistent Gun Simulations



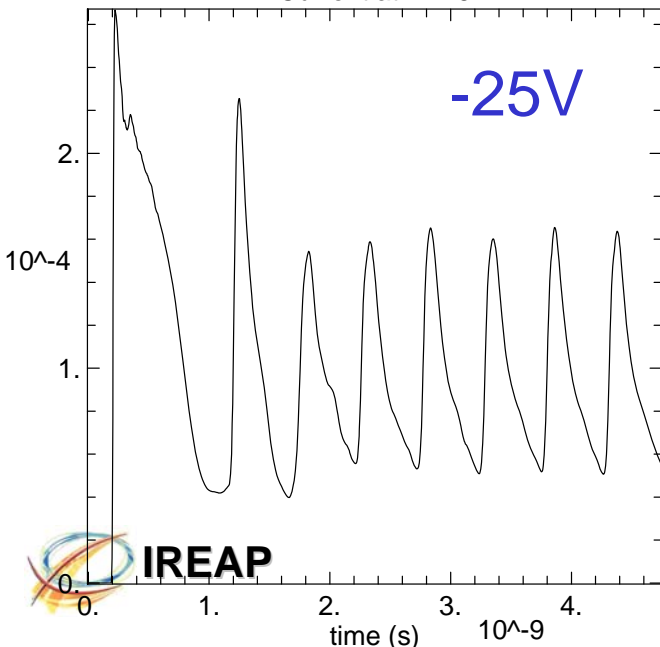
Current at iz = 12



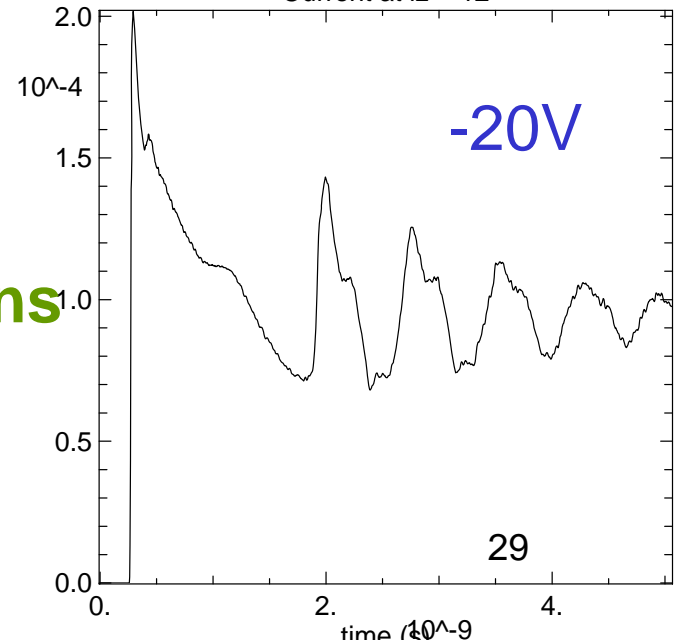
Current at iz = 12



Current at iz = 6



Current at iz = 12



WARP Simulations
Irving Haber





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>

 IREAP Publications: <http://www.umer.umd.edu/>



Virtual Cathode Movie