Benchmarking Space Charge Codes Against UMER Experiments

Rami A. Kishek
on behalf of the UMER team

Institute for Research in Electronics & Applied Physics
University of Maryland, College Park, MD, USA

Research sponsored by US DOE & DOD ONR

UMER: Benchmarks for Space Charge Codes

1. The Need for Benchmarking Space Charge Codes
2. UMER – an Experimental Facility for Space Charge
3. Examples of experimental validation of codes
4. Conclusion / More Information

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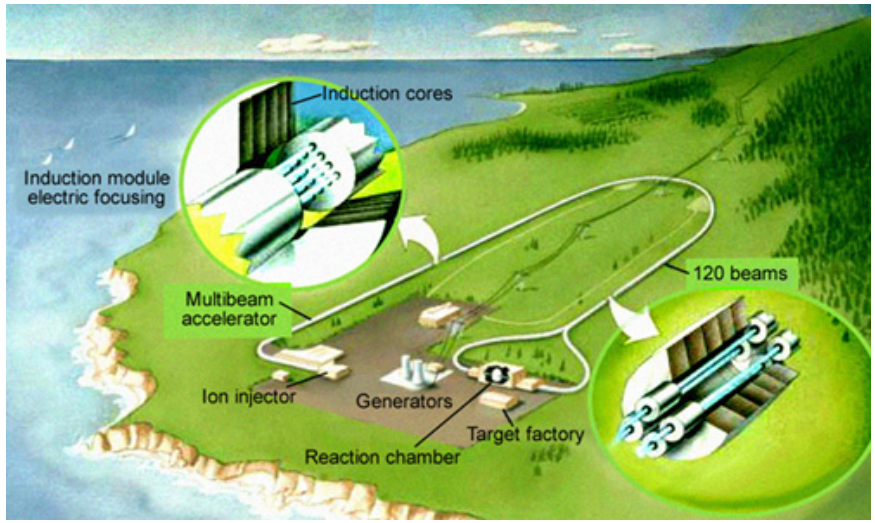
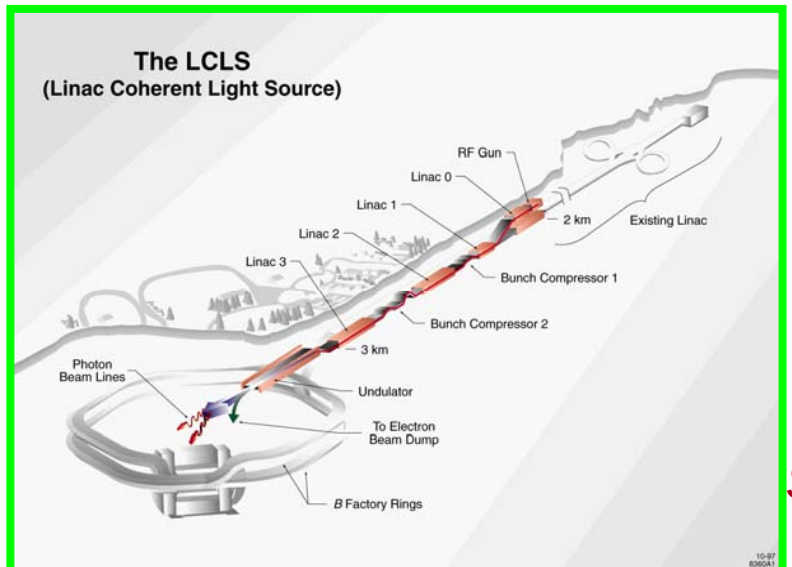
Demand for Understanding Space Charge

Spallation Neutron Source

Heavy Ion Inertial Fusion



X-Ray Free Electron Lasers



See talks by Holmes, Vay, Dohlus

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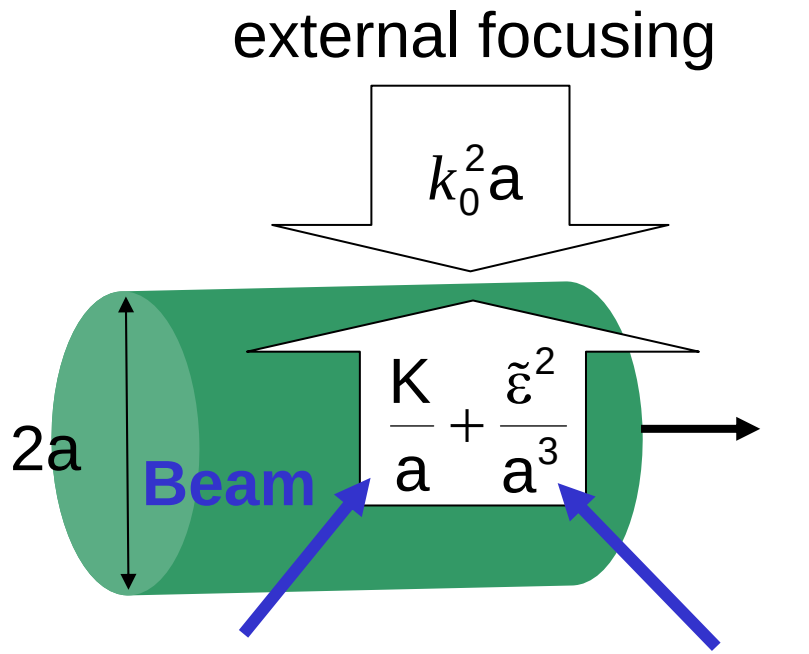
Effects of Space Charge

- Affects particle tunes
- Depends on beam distribution
  - *generally nonlinear*
  - *can result in spread of tunes*
- Beam can propagate waves



Consequences for accelerator design:

- emittance growth
- resonances
- halo and beam losses
- instabilities: modulations can grow

Computation is difficult since a realistic distribution constantly evolves

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Space Charge Codes

- WARP
- IMPACT
- ORBIT
- Vlasov Solvers
- MICROMAP
- Astra
- PARMELA
- Simpsons
- GPT

Physics models used in codes need to be validated against controlled experiments

Benchmarking difficult, see talks

- *Franchetti (ICAP06)*
- *Cousineau (PAC05)*

Most often, it is an issue of knowing what the experimental measurements mean.

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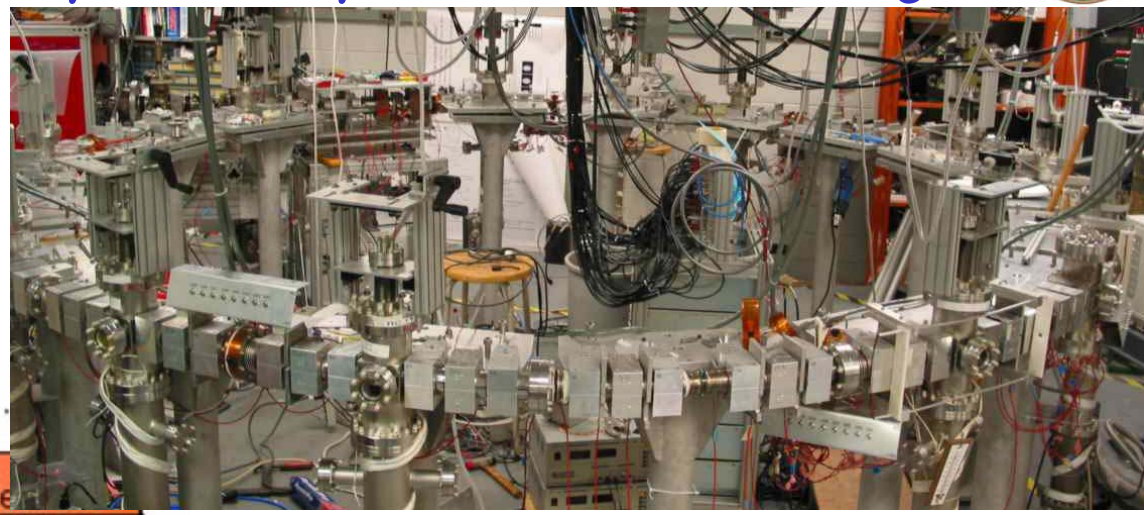
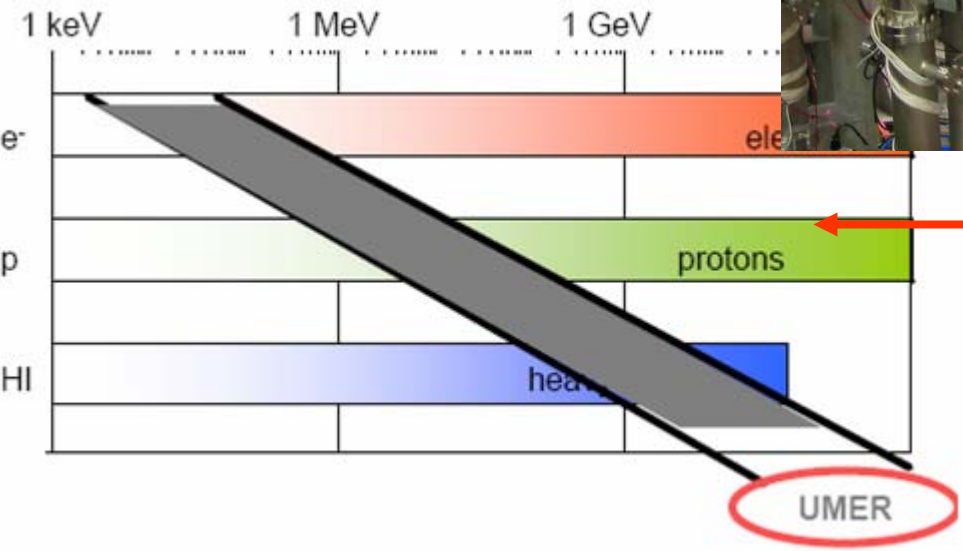
Model: The University of Maryland Electron Ring

Use 10 keV electrons to inexpensively model space charge effects in other accelerators

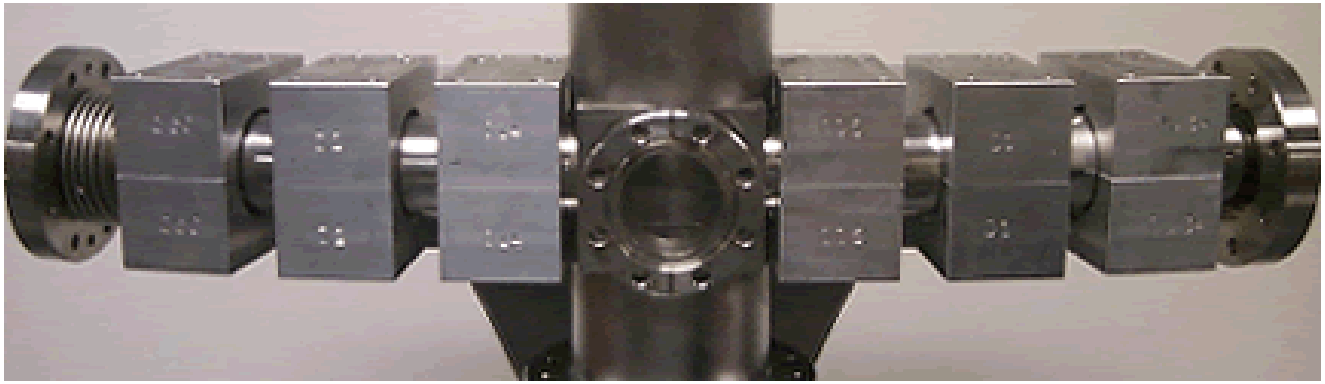




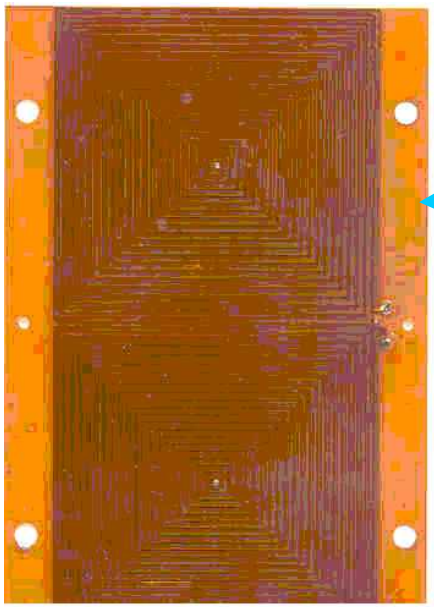
3.7 m

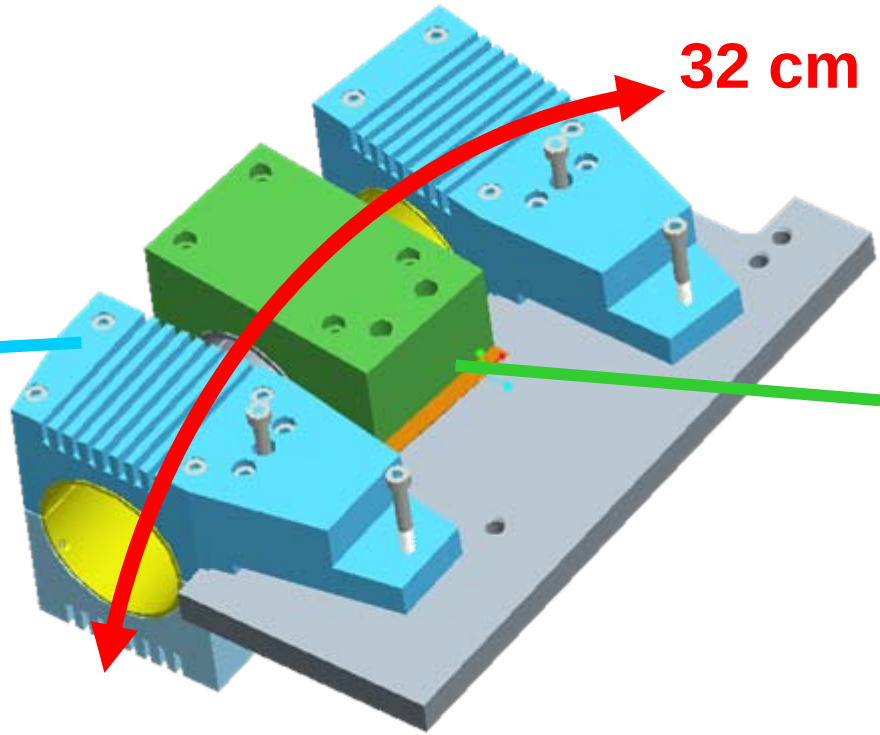
Energy	10 keV	Circulation time	200 ns
Energy Spread	20 eV	Pulse length	5-100 ns
Current Range	0.6-100 mA	Zero-Current Tune	7.6
rms Emittance	0.2-3 μm	Depressed Tune	1.5 – 6.5

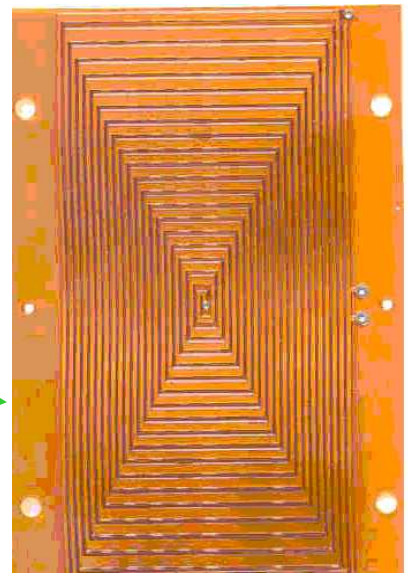
UMER Magnets & Lattice



72 Quads
(~ 7.8 G/cm)







36 Dipoles
(~ 15 G)

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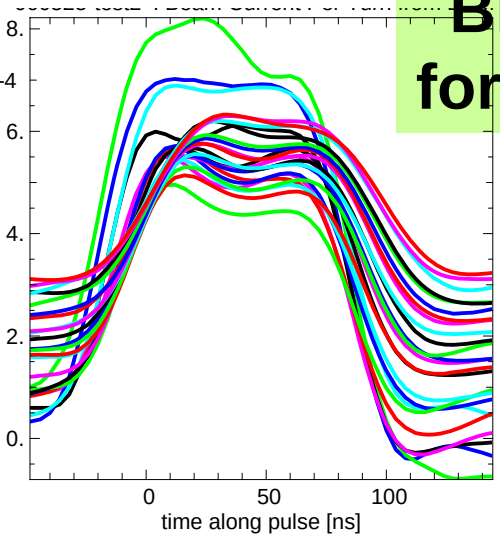
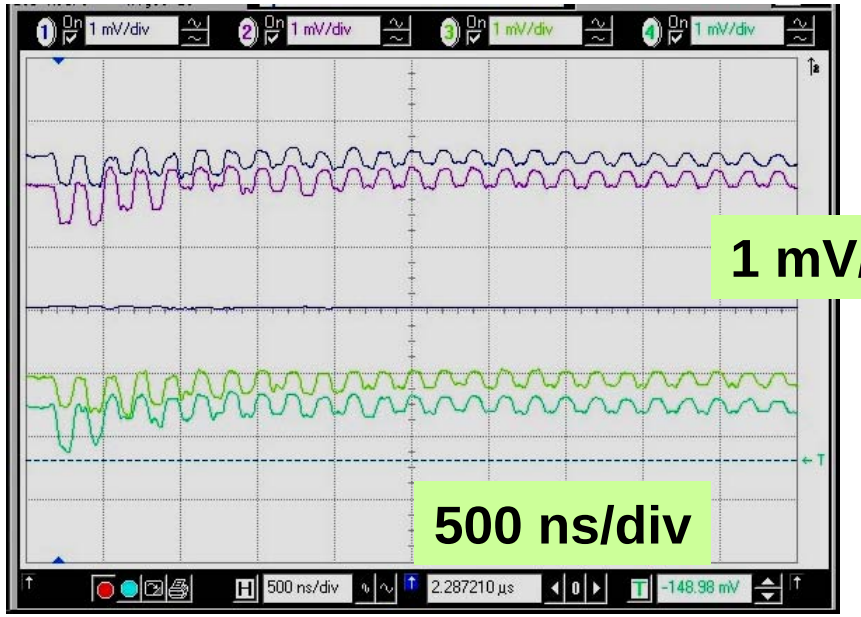
UMER Multi-Turn: "Low-Current" Results

(Work in Progress)

Typical BPM signals for low current



up to 125 turns



1 mV/div

500 ns/div

Zero-current Tune=7.3	Beam Current	Estimated Emittance*	Tune Depression	Tune Shift
Injected	690 µA	5.6 µm	0.89	0.80
After 25 turns	300 µA	4.6 µm	0.94	0.45

***4rms, unnormalized**

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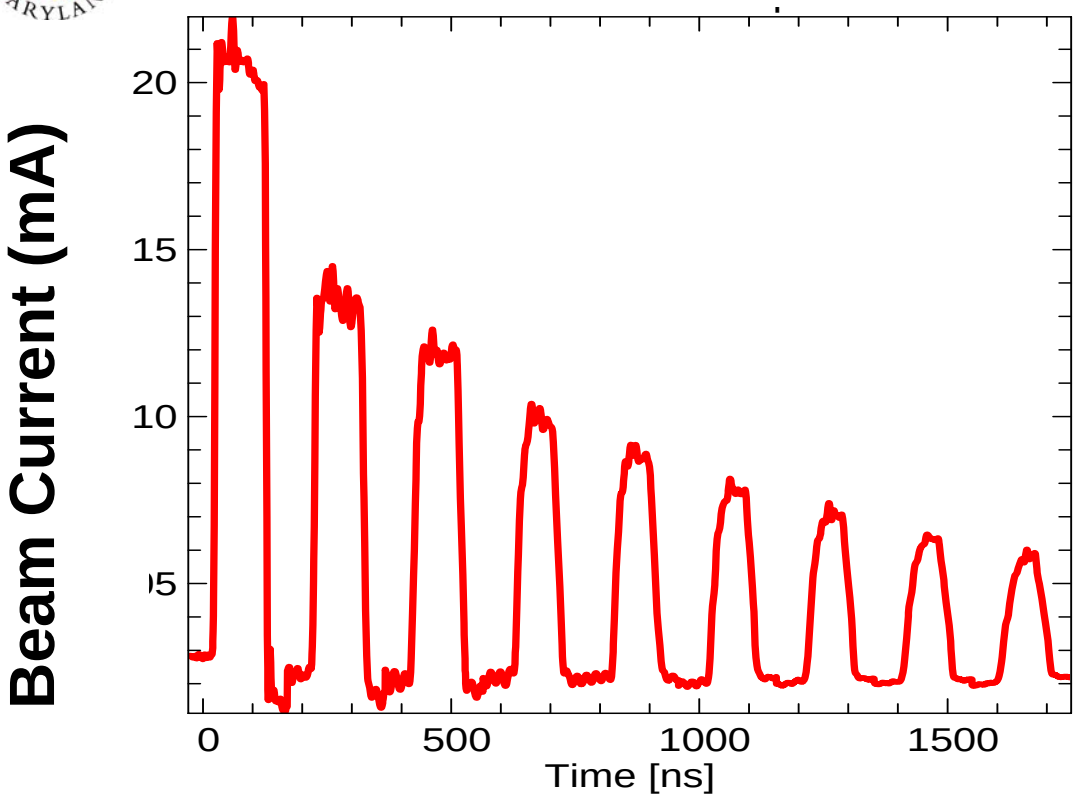
S. Bernal, Proc. Advanced Accelerators Concepts Wkshp 2006.

Multi-Turn: More Intense Space Charge



(Work in Progress)

up to 60 turns

Zero-current Tune=7.3	Beam Current	Estimated Emittance *	Tune Depression	Tune Shift
Injected	18.6 mA	24 μm	0.55	**3.3**
After 9 turns	3.6 mA	10-25 μm	0.72-0.87	**2.0-0.9**

***4rms, unnormalized**

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M. Walter, Proc. Advanced Accelerators Concepts Wkshp 2006.

UMER Diagnostics

Imagers:

- Fluorescent Screen Imagers
- Optical Transition Radiation (OTR) Imagers

Beam pickups:

- Capacitive Beam Position Monitors
- Bergoz Current Monitors

Phase-Space Mappers:

- Tomographic Quad-scan (⊥)
- Slit-slit (⊥)
- Pepper-pot (⊥)
- Retarding Potential Energy analyzers (//)

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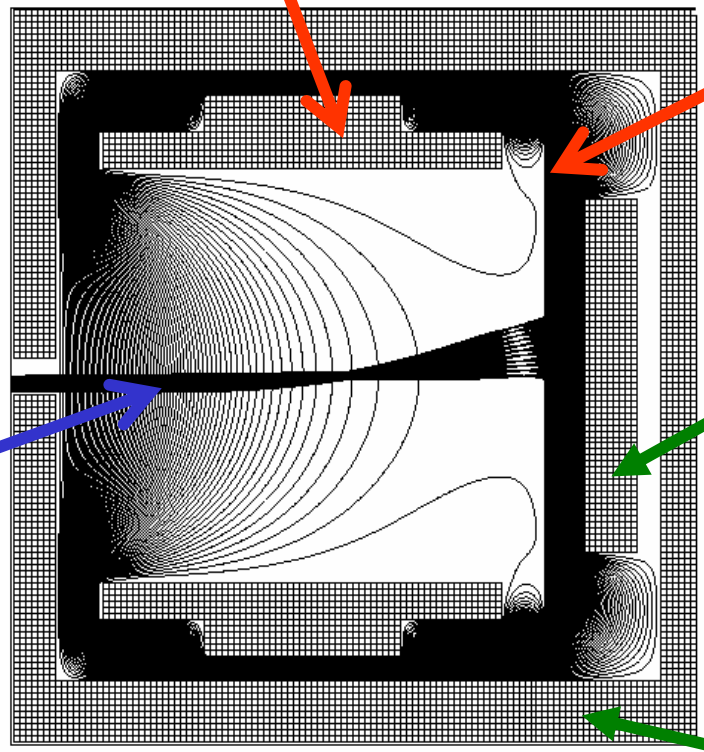
Novel Retarding-Potential Energy Analyzer

(high time, space, and energy resolution)

Collimating Cylinder
-10.13kV

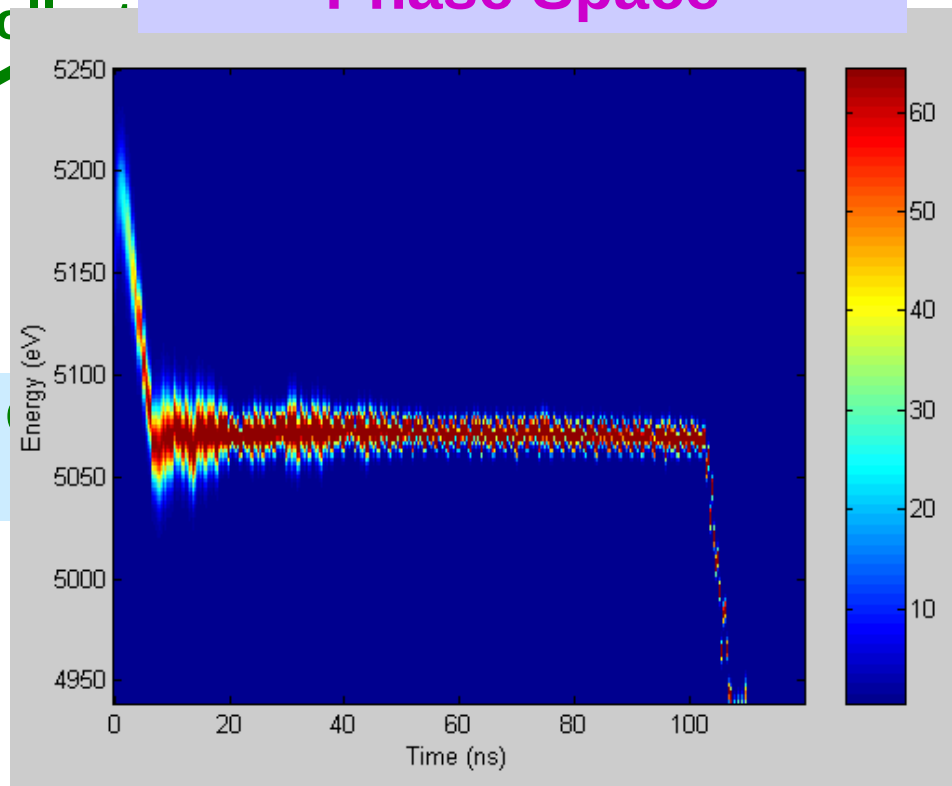


Retarding Mesh
-9999.5 V

10 keV **Beam**

3rd Generation: Res. < 1 eV

Measured Longitudinal Phase Space



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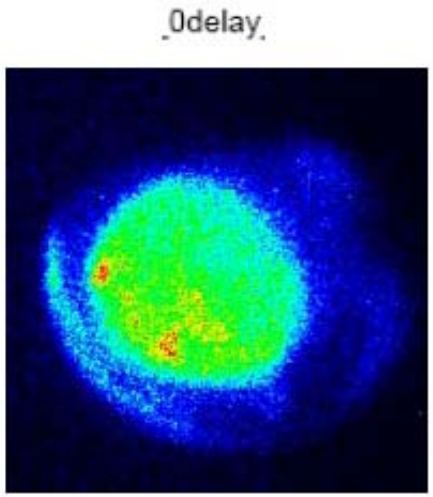
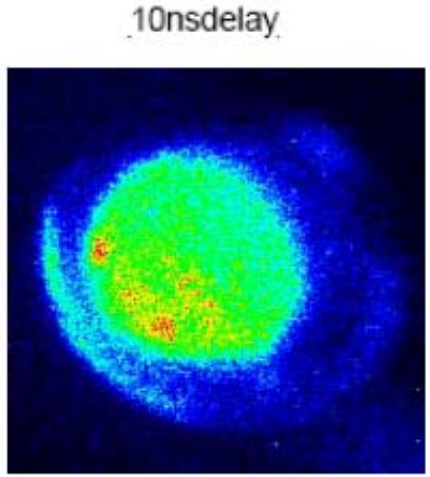
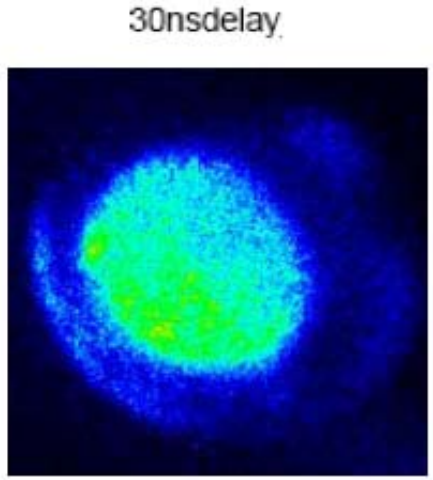
*Y. Cui, RSI, **75(8),** 2736 (2004).*

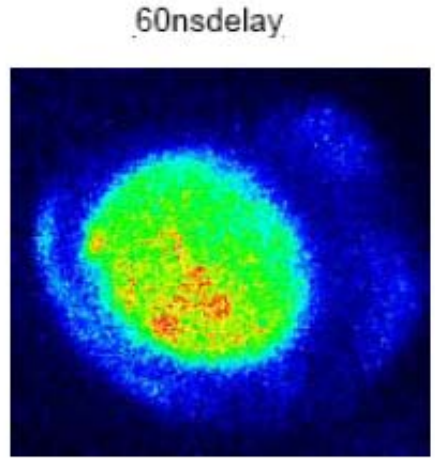
Optical Transition Radiation Diagnostic

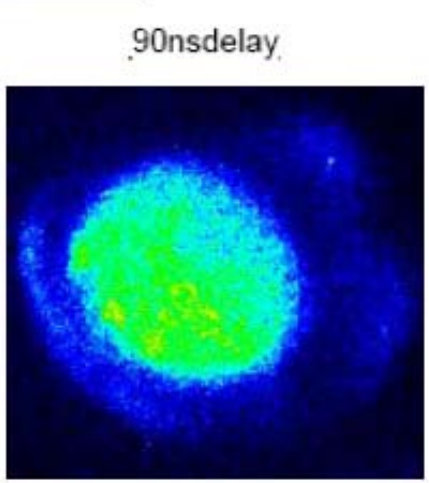
Comparison of 10 ns slice with full beam projection

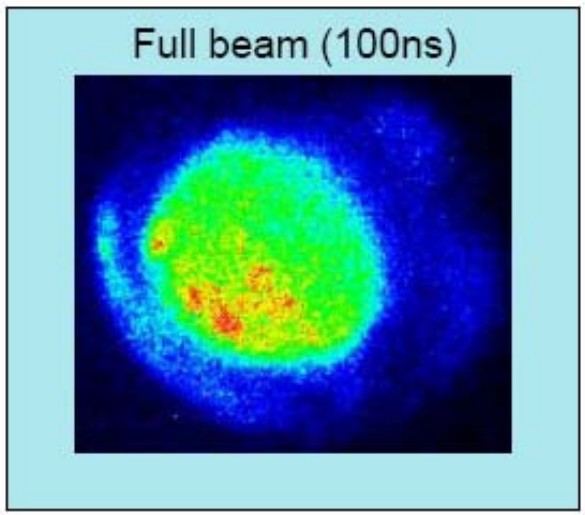












Gun parameters:

45 V bias,
22 mA

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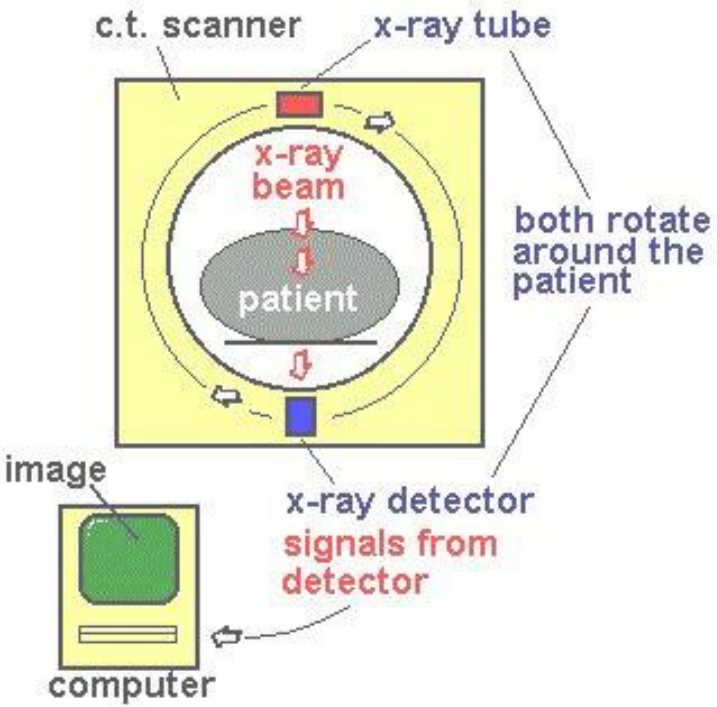
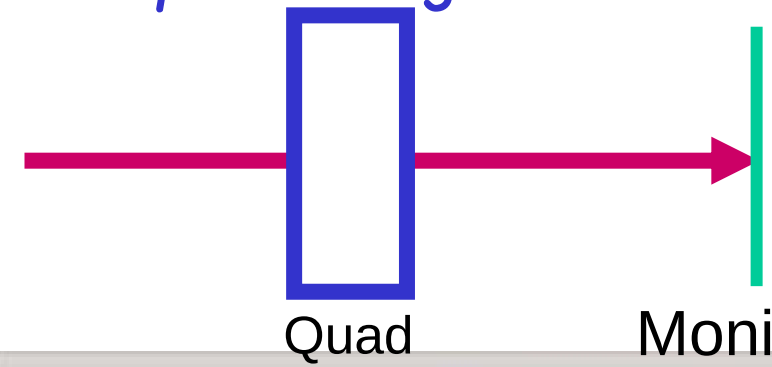
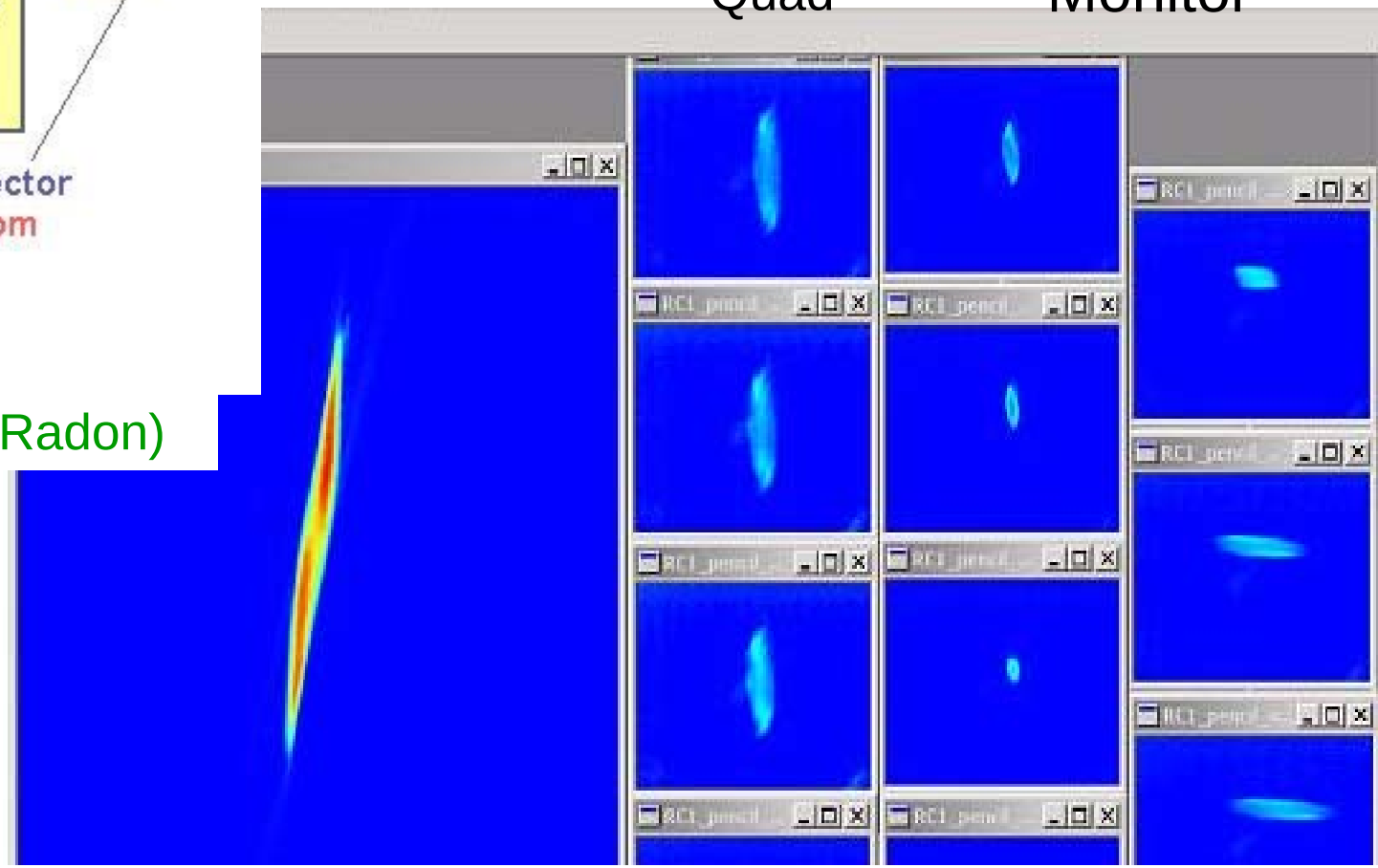
Fiorito & Feldman, to be published

Tomography Phase-Space Imager





(1826 Abel, 1917 Radon)



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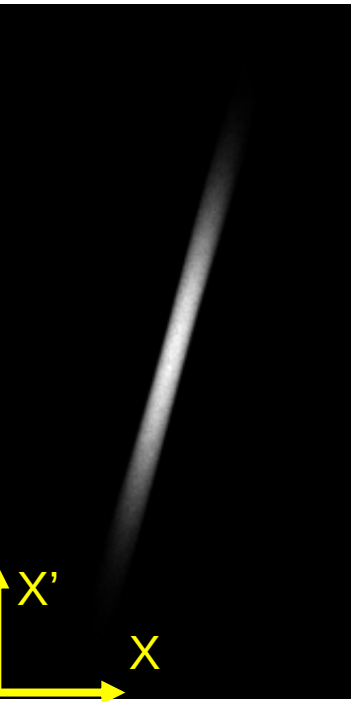
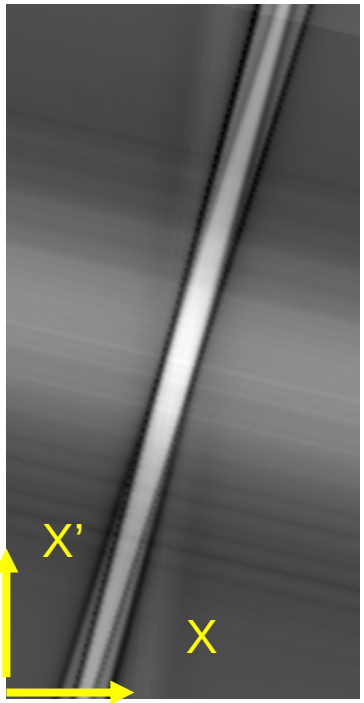
Hui Li, Ph.D. Thesis, University of Maryland, 2004.

Simulation of Tomography



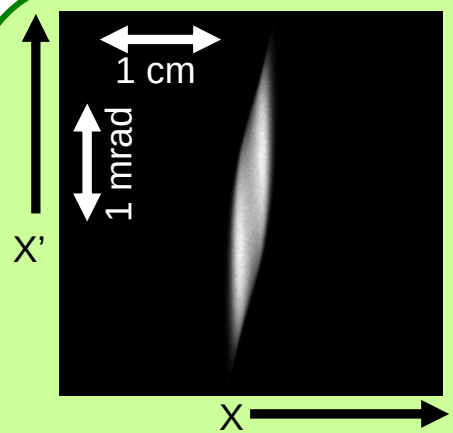
WARP



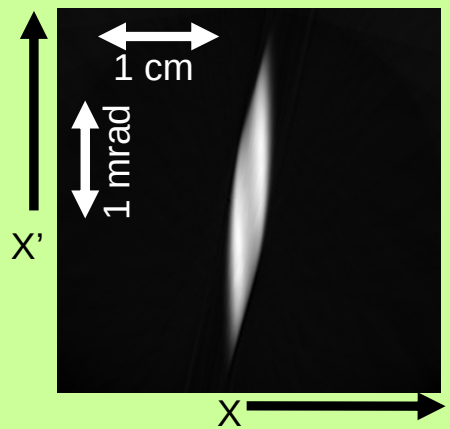
Tomography

Additional projections at different angles add information to our image of the phase space

Different Distribution



WARP simulation hollow-velocity



Reconstructed by tomography on simulation results

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D. Stratakis, PRSTAB, to appear (2006).

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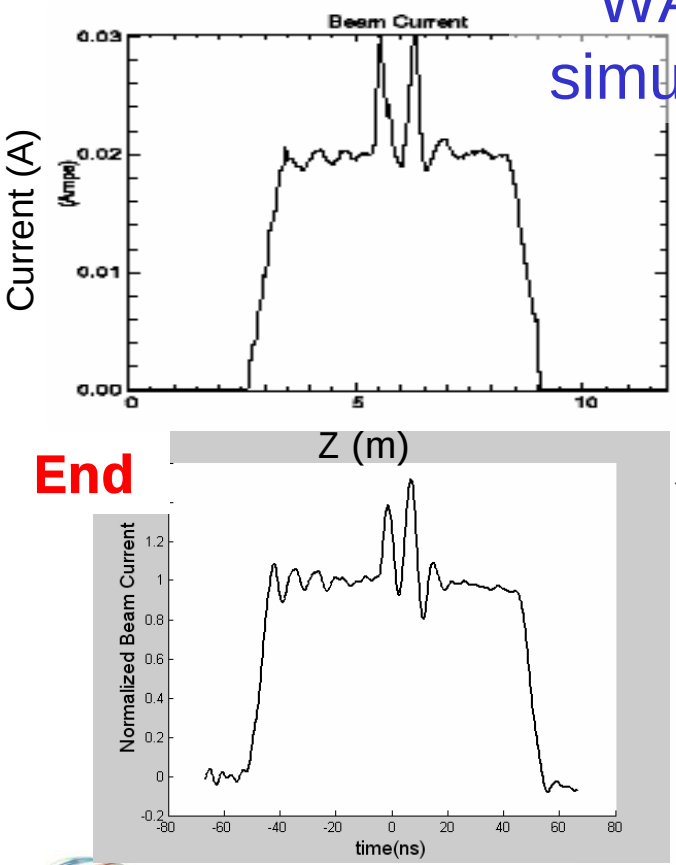
Propagation of Density Perturbation on Beam

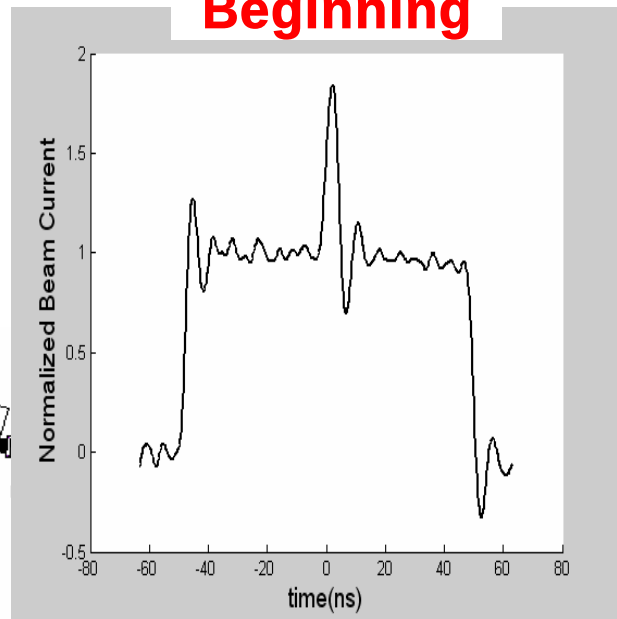
20 mA thermal-emission beam current

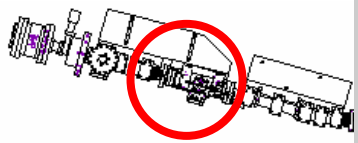
20 mA photo-emission beam current

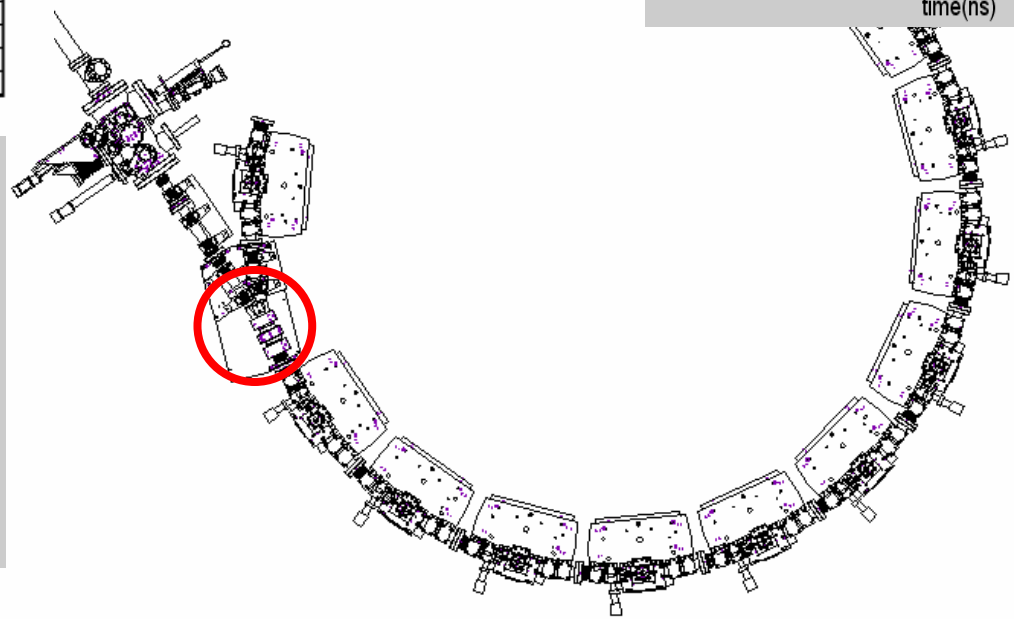
WARP simulation



Beginning







End

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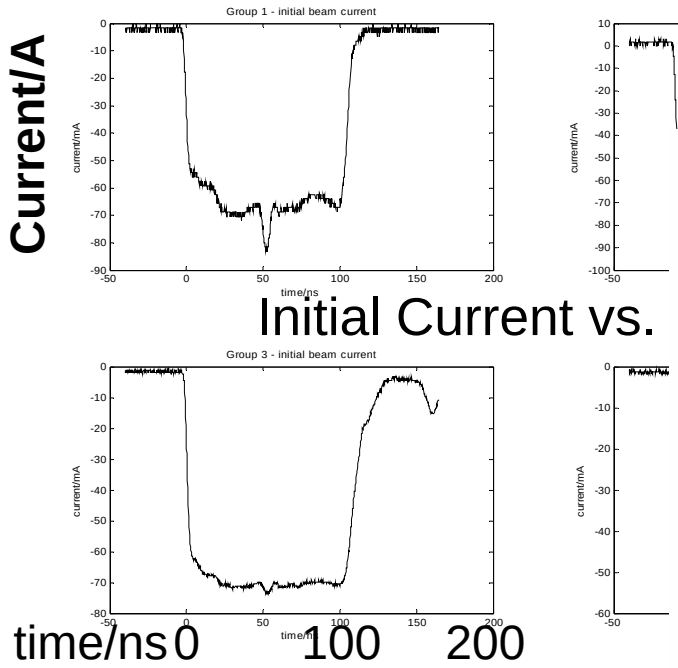
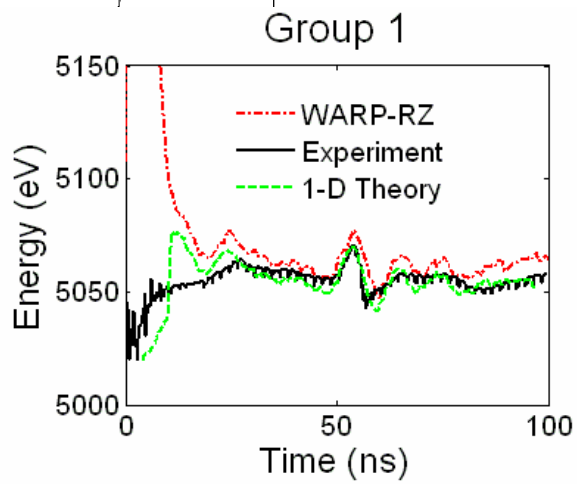
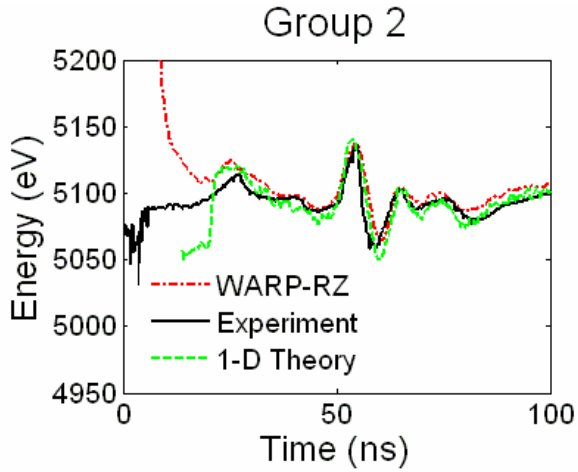
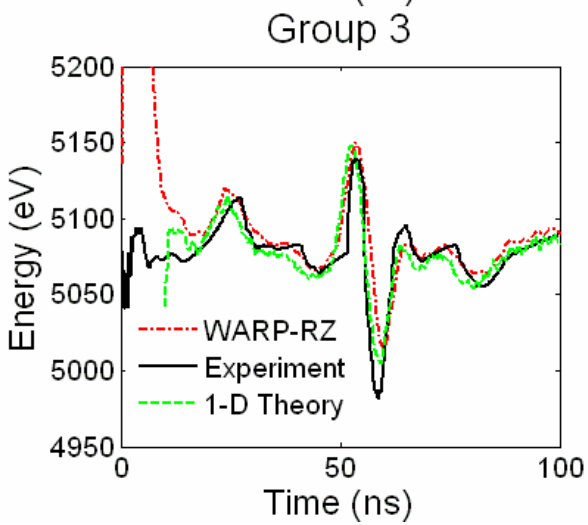
Y. Huo, to be published

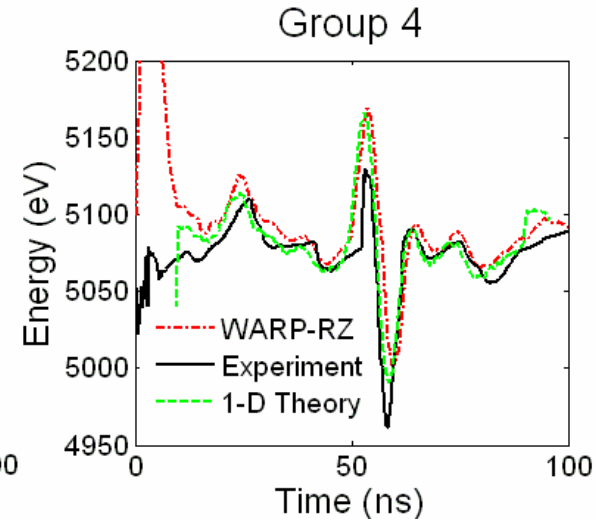
Space charge converts density perturbation to an energy perturbation











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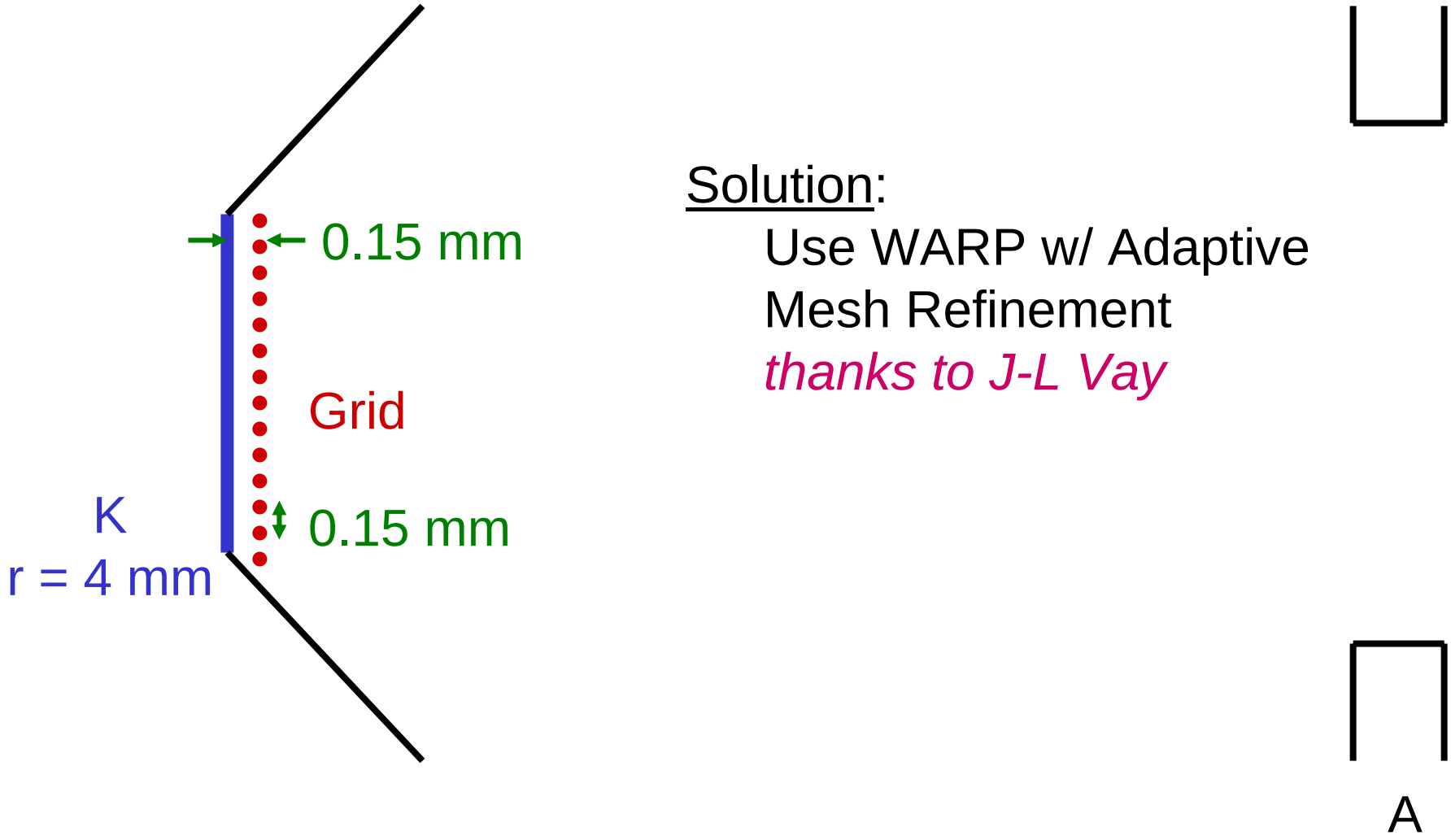
*K. Tian, et al., PRSTAB **9**, 014201 (2006).*

UMER Gun Simulation Challenge



Solution:

Use WARP w/ Adaptive Mesh Refinement

thanks to J-L Vay

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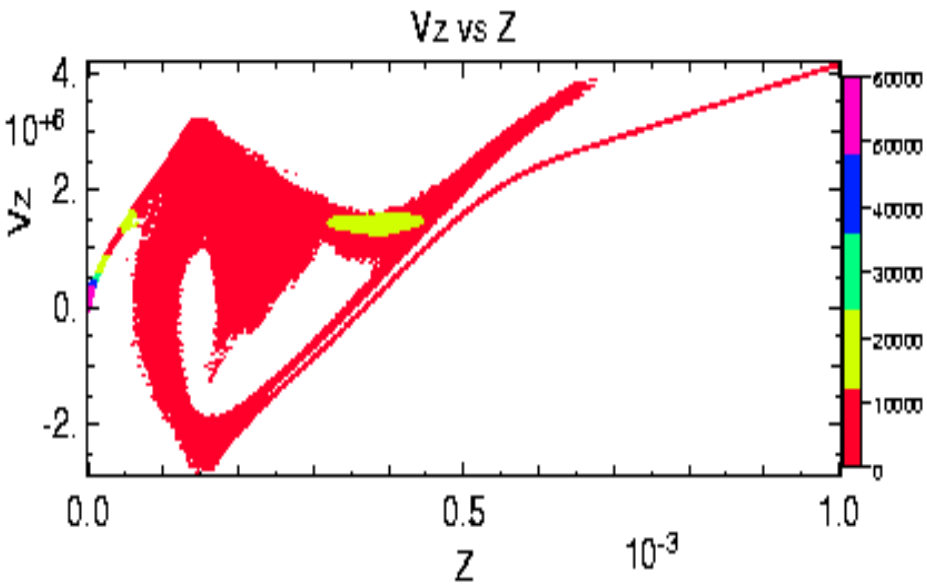
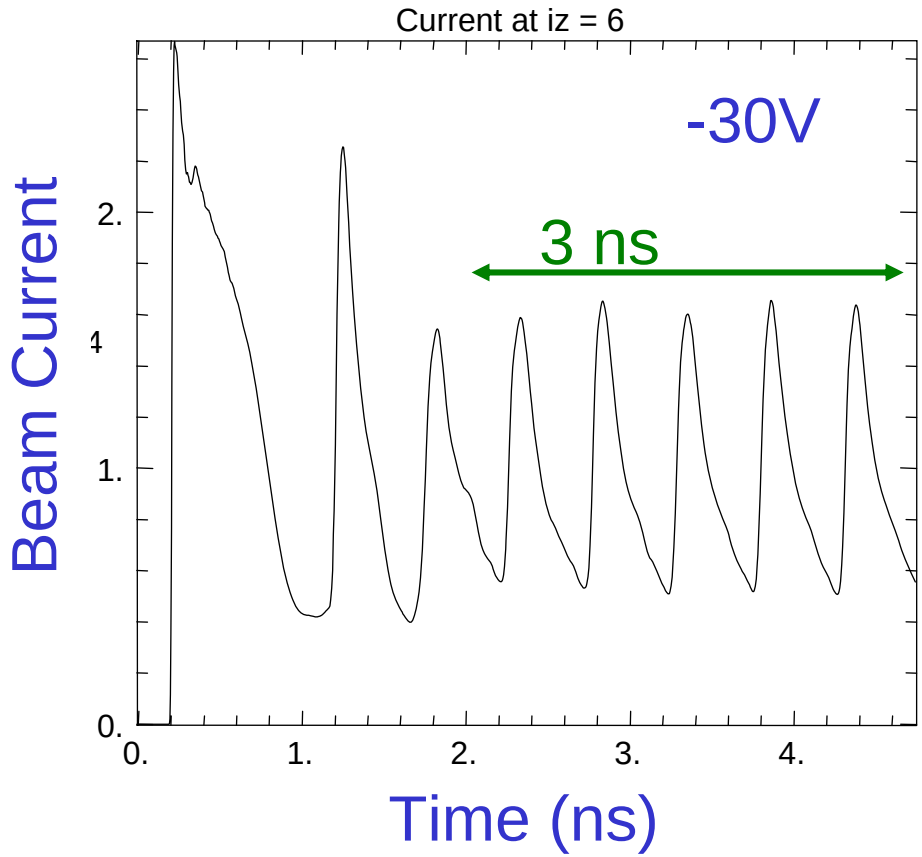
Prediction of Virtual Cathode Oscillations

WARP: 1 mm downstream of cathode

Longitudinal Phase Space





Modulated at 6/3 = 2 GHz

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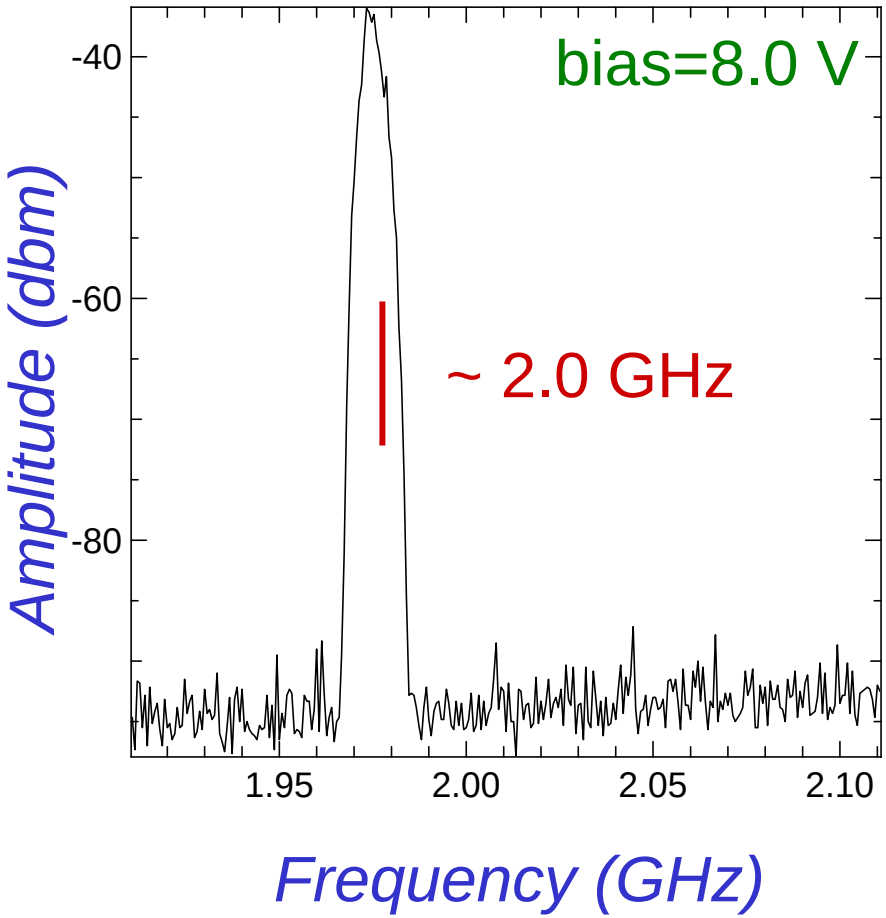
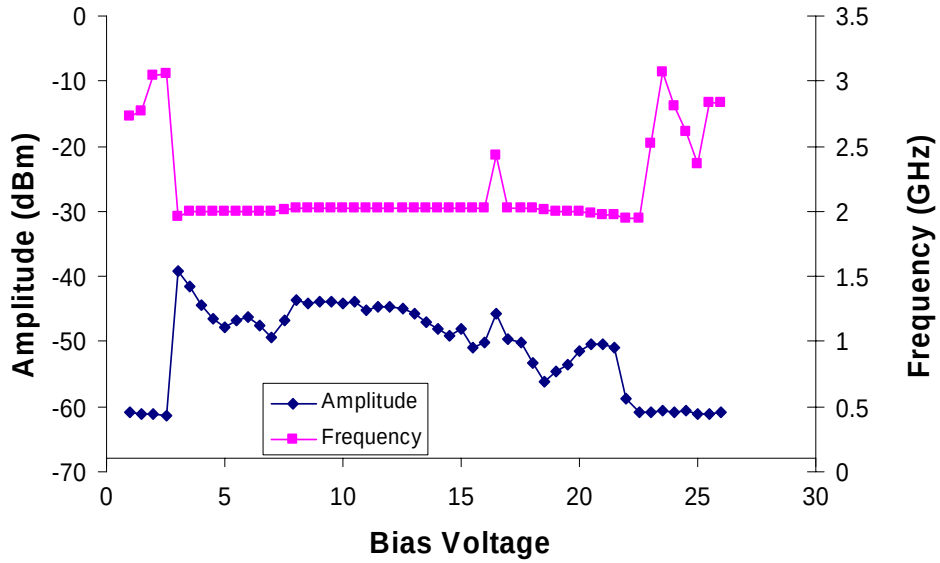
I. Haber, et al., Proc. PAC 2005

Experimental Verification w/ Spectrum Analyzer



Measured Spectrum



Peak present over limited range of grid voltages

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Visit Our Website for More Information

UNIVERSITY OF MARYLAND ELECTRON RING

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search

you are here: home

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

navigation

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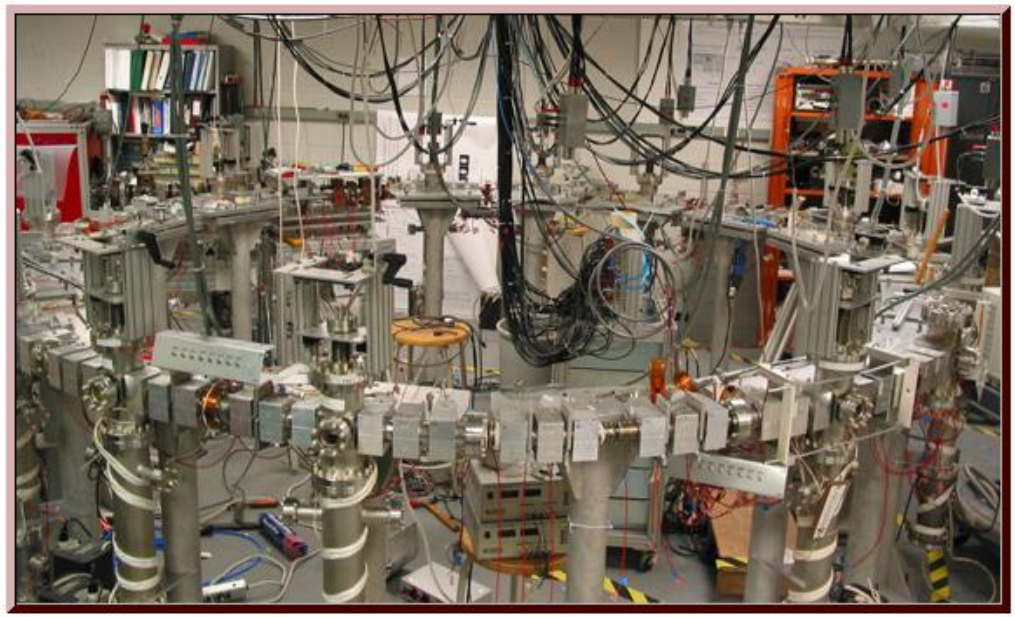
Welcome to UMER

The University of Maryland Electron Ring (UMER) is a world-class research facility in beam and accelerator physics at the Institute for Research in Electronics and Applied Physics, on the University of Maryland, College Park campus. Using a scaled low-energy electron beam, UMER cleverly accesses the intense, high-brightness, regime of beam operation in accelerators, at a much lower cost than larger and more energetic machines. UMER therefore makes an ideal testbed for experimenting in pushing up the brightness of existing and future accelerators.



Funding for the project is provided by the U.S. Department of Energy.

« February 2006 »

Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

upcoming events

Christos Papadopoulos
2006-02-10
IREAP Large Rm,
2006-02-10

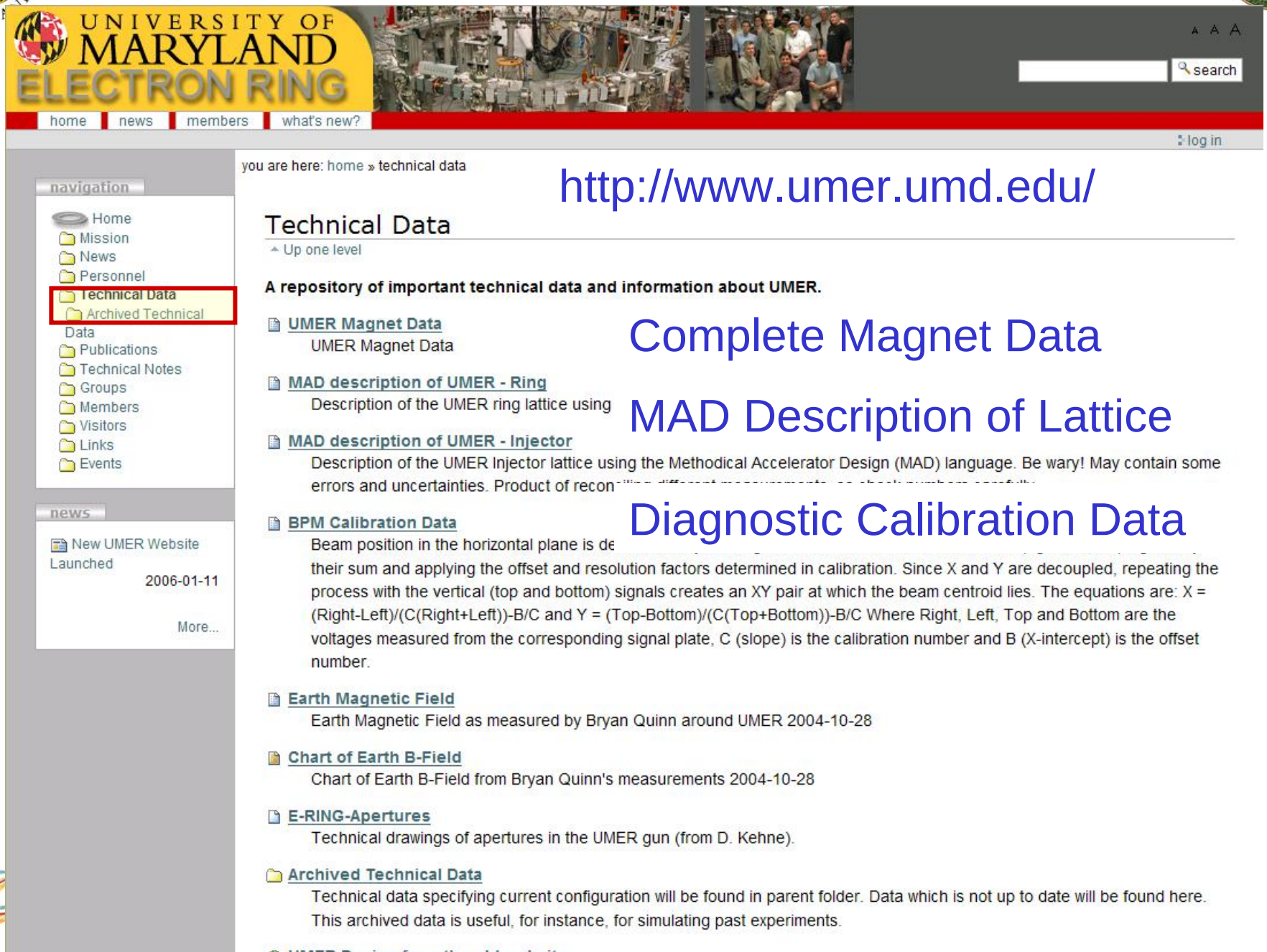
Labview and Steering Tutorial
UMER Lab,
2006-02-24

news

New UMER Website Launched
2006-01-11

More...

Lots of Technical Data Online



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

Complete Magnet Data

MAD Description of Lattice

Diagnostic Calibration Data

E.g., Magnet Information

navigation
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Publications
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news
New UMER Website Launched 2006-01-11
More...

UMER Magnet Data

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

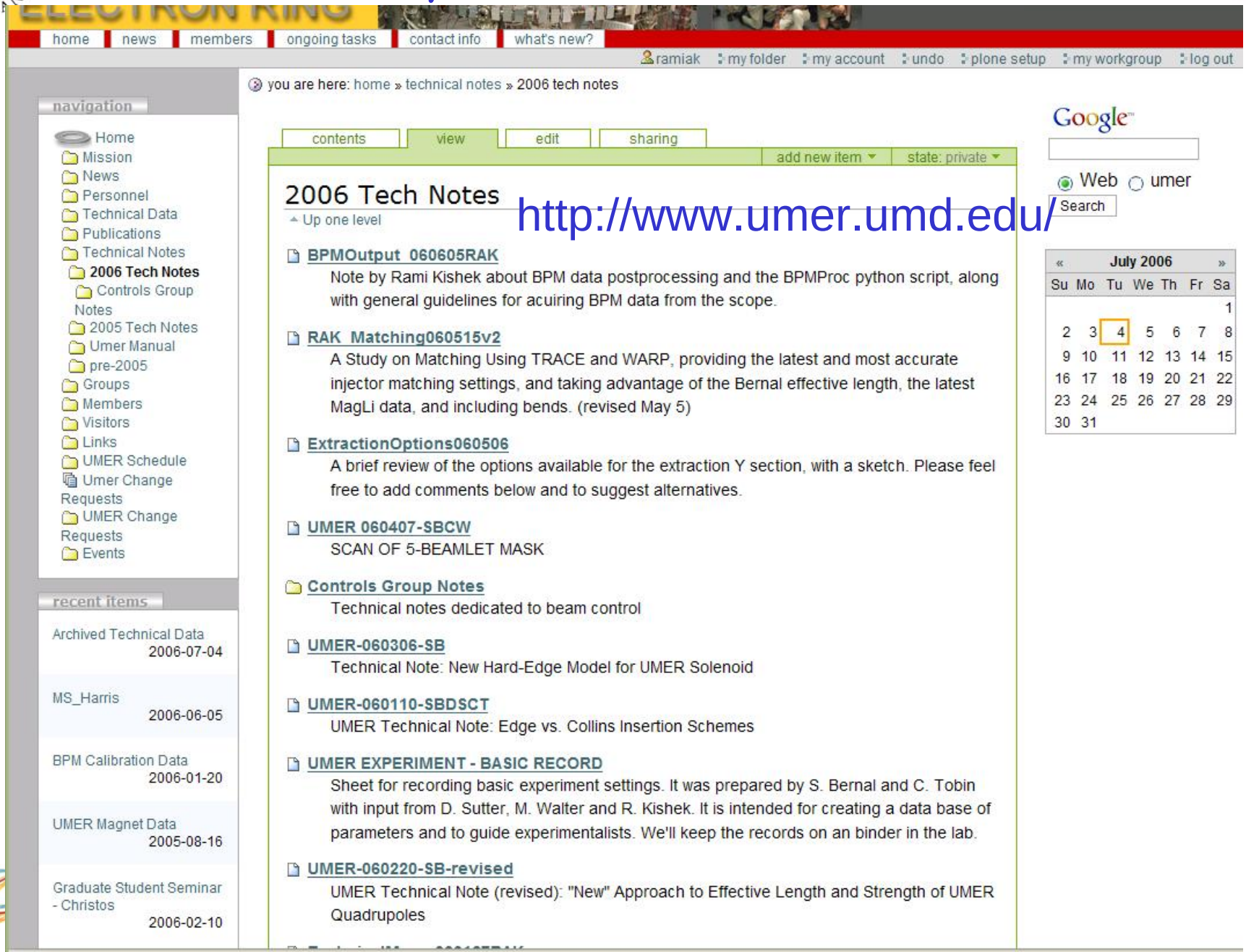
UMER Magnet Data

Below are the primary parameters for the UMER printed-circuit magnets currently installed. All the magnets were designed by Terry Godlove. More details on the magnet deisgn and specifications can be found in the technical note by Godlove dated July 28, 2004, from which the following data is extracted. Any discrepancies in the numbers are due to slight corrections by Rami Kishek after verification of the calculations using MAG-Li.

Quads	l_{eff} (cm)	SB l_{eff} [e] (cm)	SB field [e] factor, f	Peak Gradient per Amp (G/cm/A)	Integrated Gradient per Amp (G/A)	Physical Length (cm)	Physical Radius (cm)	MagLi File (linked)
Old Ring [a]	3.63	5.043	0.7206	4.14	15.022	4.65	2.79	QMAG62.spc
New Ring	3.72	5.164	0.7208	3.61	13.438	4.65	2.95	QMAG31.spc
YQ *	4.91 [c]	?	?	1.12	5.488 [c]	5.40	5.00	QMAG83.spc
QR1 *	5.38	7.45	0.7224	1.01	5.438	5.40	5.00	QMAG83.spc
BD (Quad Term)	4.07	?	?	x/y = 0.032/0.152	x/y = 0.145/0.559	-	-	DMAG02.spc
PD (Quad Term)	2.374	?	?	x/y = 0.0053/0.0175	x/y = 0.0127/0.0411	-	DMAG67.spc	

Dipoles	l_{eff} [b] (cm)	l_{eff} [c] (cm)	Peak Field per Amp (G/A)	Integrated Field [d] per Amp (G-cm/A)	Physical Length (cm)	Physical Radius (cm)	MagLi File
Bending	3.757	3.82	5.22	19.93	4.437	2.872	DMAG02.spc
Short Steerer	3.063	-	1.18	3.627	1.54	2.79	DTMAG02.spc
3-3/8" Flange	5.183	-	0.640	3.317	2.37	4.726	DTMAG20.spc
4-1/2" Flange	5.67	-	0.685	3.886	3.80	5.75	DTMAG22.spc
Pulsed Dipole *	5.18	5.00	0.383	1.913	4.40	4.40	DMAG67.spc
YQ (Dip Term) *	-	5.01	1.530	7.665	-	-	QMAG83.spc

Another Layer of Access: Technical Notes



Conclusion

- UMER is poised to provide a wealth of multi-turn data on beam dynamics with space charge
- Results to date point to complex, exciting science
- Open for benchmarking of space charge codes

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Benchmarking Challenges

- Need clear idea of physics model to be validated
- Experiment need to be devised such that 10 keV electron beam captures the right physics
- Need accurate interpretation of diagnostic output from experiment
- Requires close collaboration between code group and UMER group.

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I like to thank my colleagues …