



Benchmarking Space Charge Codes Against UMER Experiments

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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



UMER: Benchmarks for Space Charge Codes

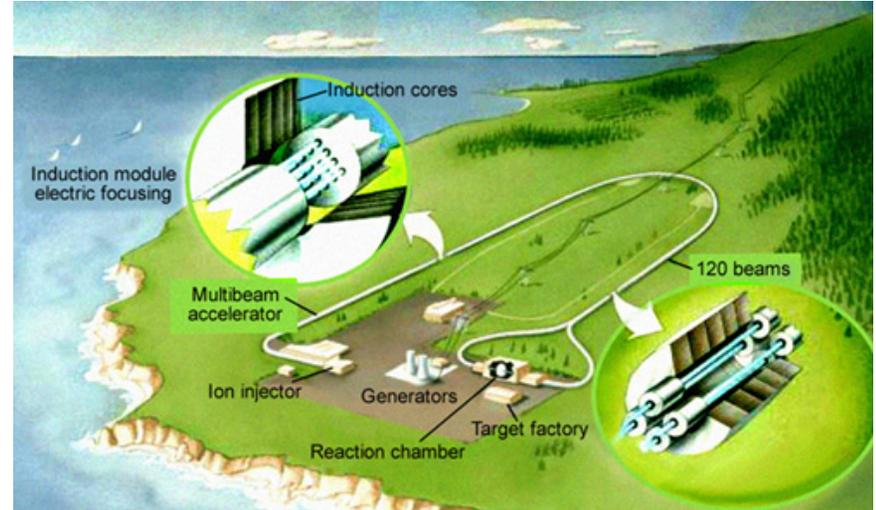
1. **The Need for Benchmarking Space Charge Codes**
2. UMER – an Experimental Facility for Space Charge
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Demand for Understanding Space Charge

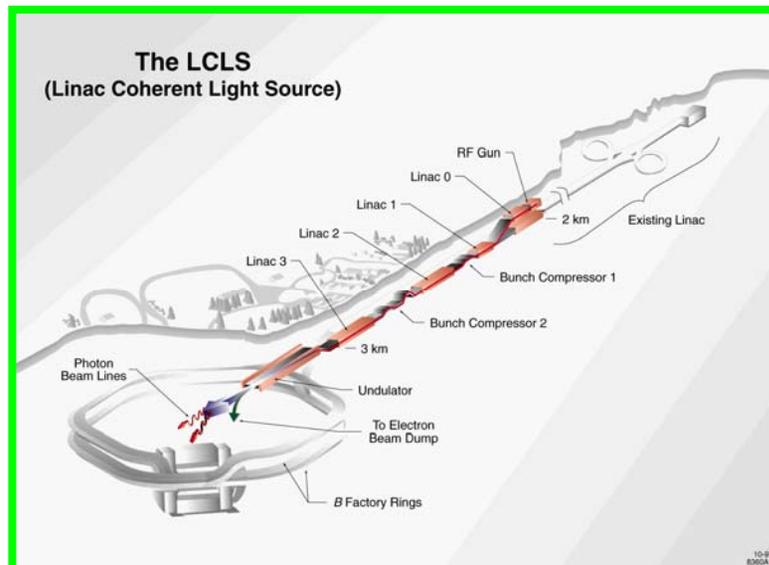
Spallation Neutron Source



Heavy Ion Inertial Fusion



X-Ray Free Electron Lasers

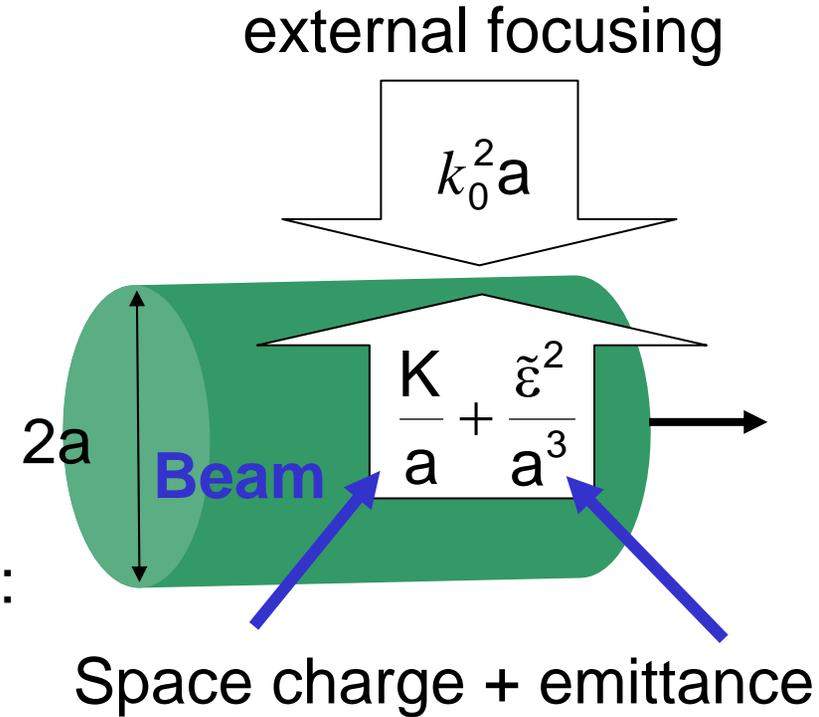


Effects of Space Charge

- 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

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.

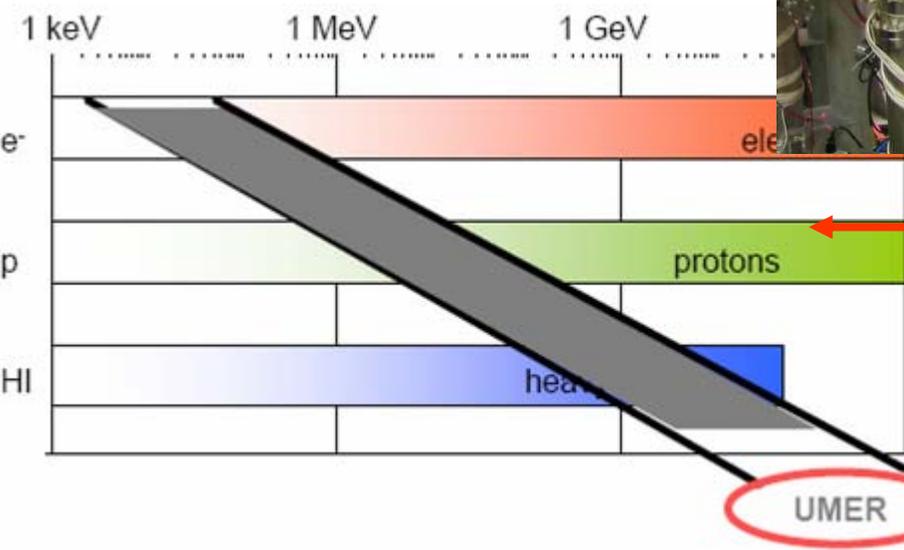
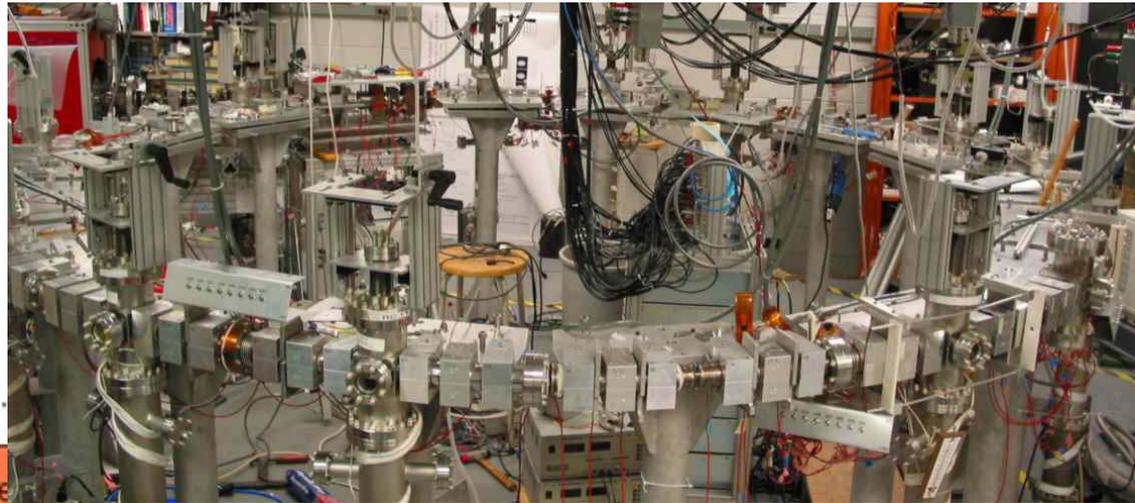


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Model: The University of Maryland Electron Ring

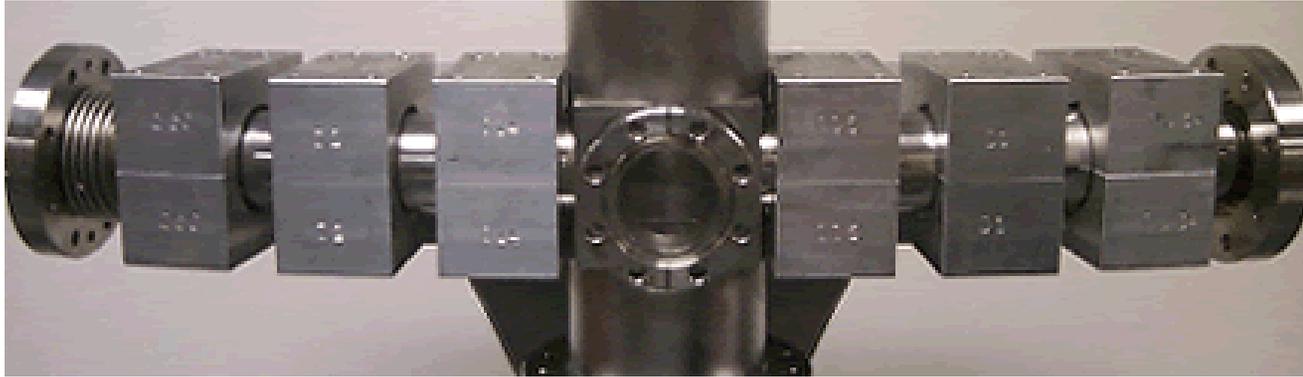
Use 10 keV electrons to inexpensively model space charge effects in other accelerators



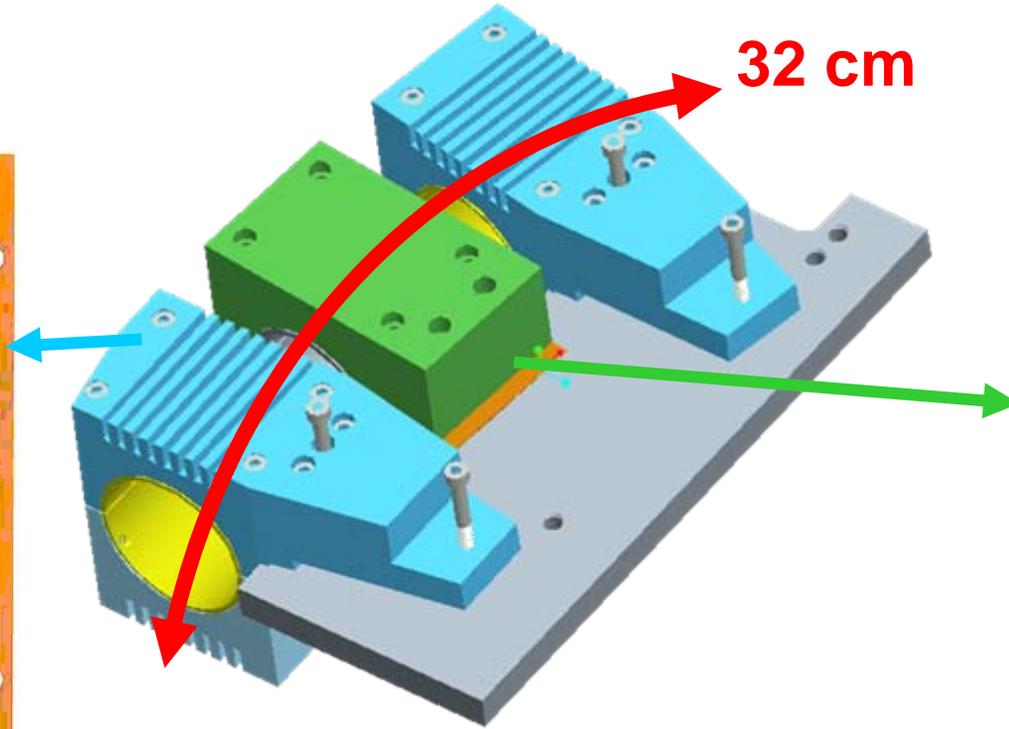
3.7 m

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

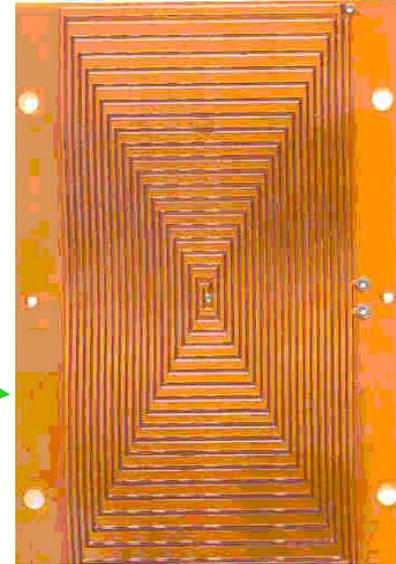
UMER Magnets & Lattice



72 Quads
(~ 7.8 G/cm)



32 cm



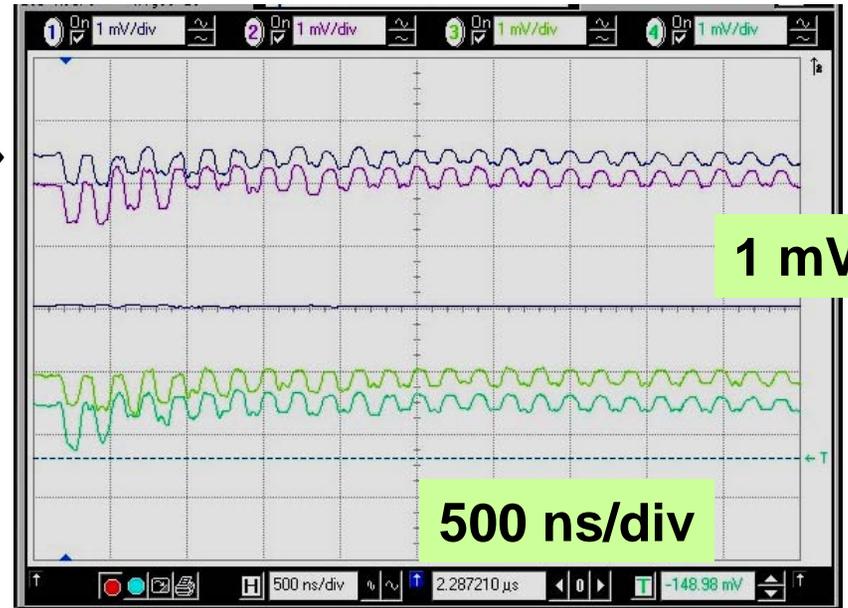
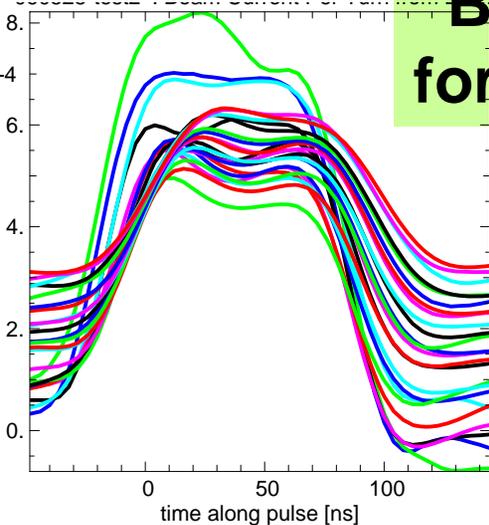
36 Dipoles
(~ 15 G)

UMER Multi-Turn: "Low-Current" Results

(Work in Progress)

Typical
BPM signals
for low current

up to
125 turns



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

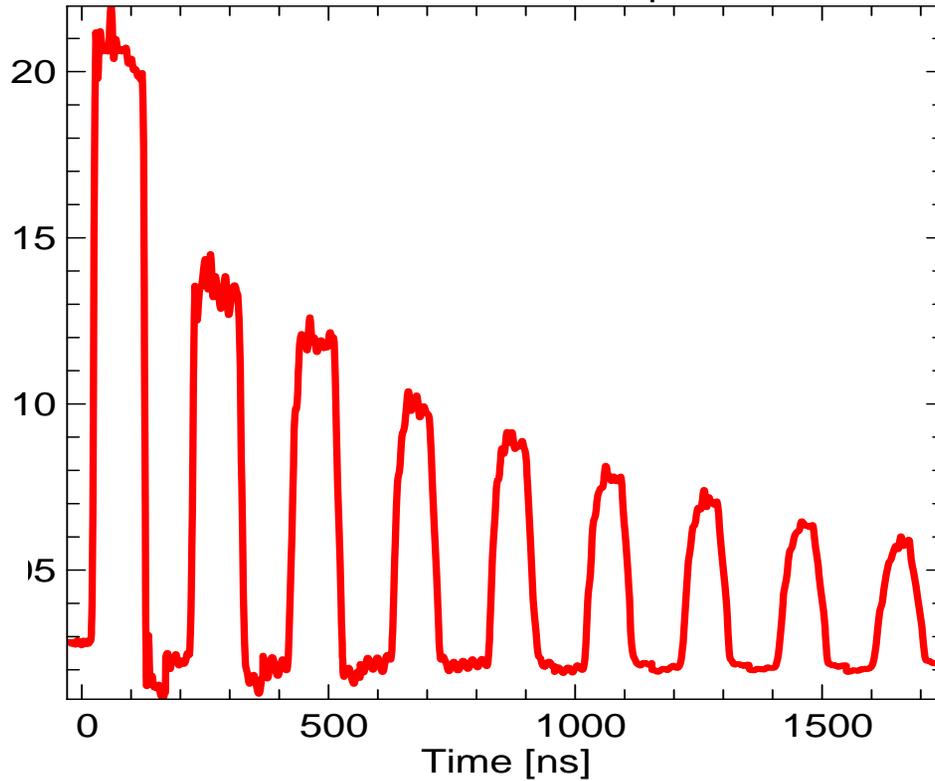
*4rms, unnormalized

Multi-Turn: More Intense Space Charge

(Work in Progress)

*up to
60 turns*

Beam Current (mA)



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



UMER Diagnostics



Imagers:

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

Beam pickups:

- Capacitive Beam Position Monitors
- Bergoz Current Monitors

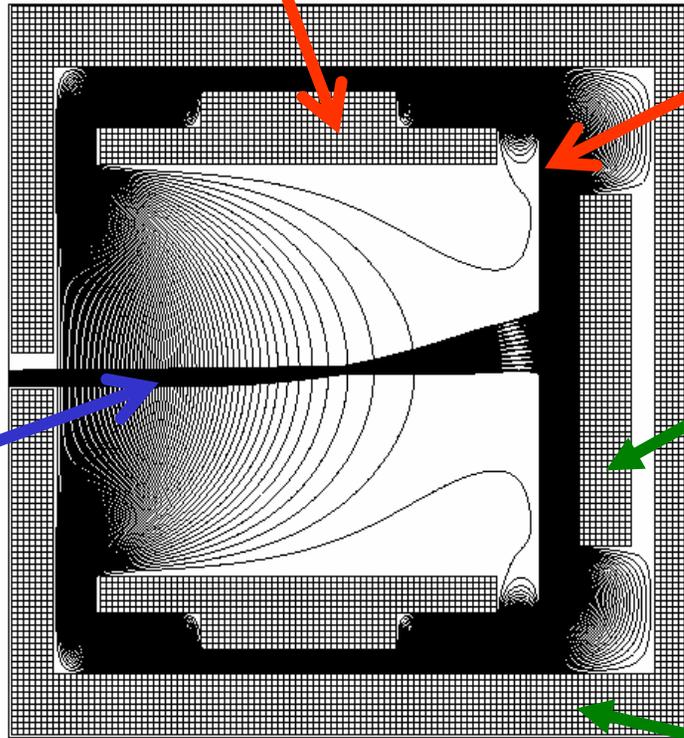
Phase-Space Mappers:

- Tomographic Quad-scan (\perp)
- Slit-slit (\perp)
- Pepper-pot (\perp)
- Retarding Potential Energy analyzers ($//$)

Novel Retarding-Potential Energy Analyzer

Collimating Cylinder (high time, space, and energy resolution)

-10.13kV



Retarding Mesh

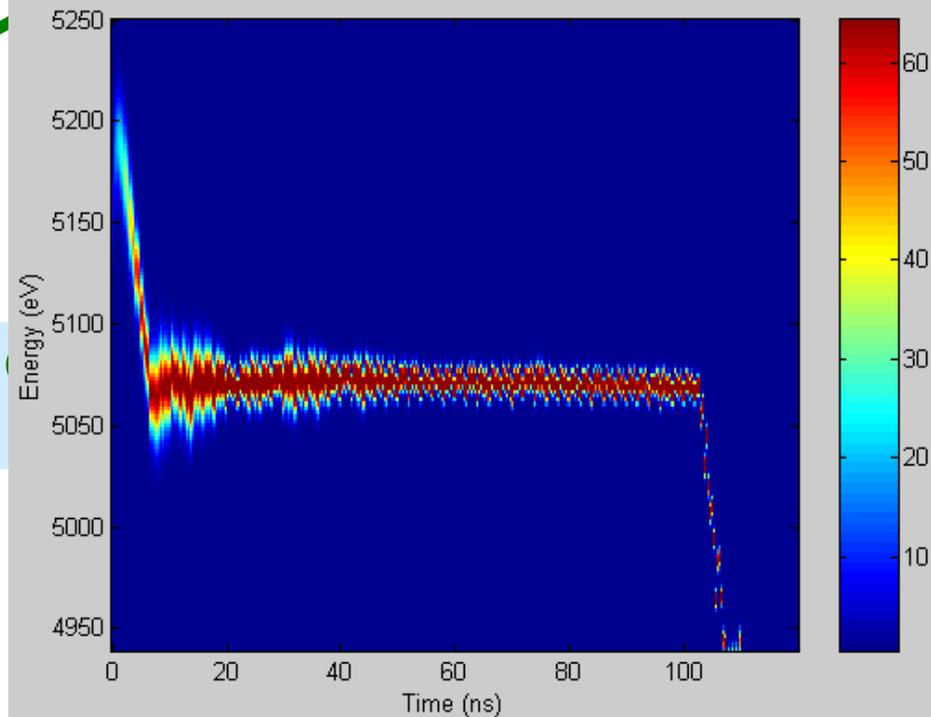
-9999.5 V

Measured Longitudinal Phase Space

Collimating Cylinder

10 keV Beam

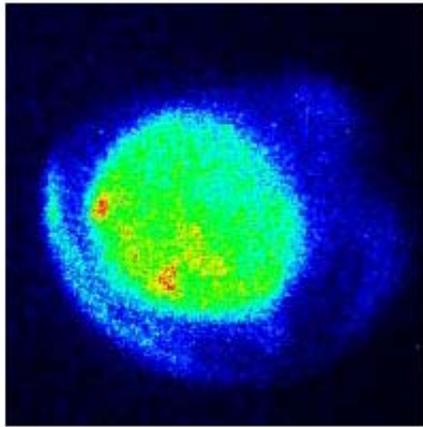
3rd Generation: Res. < 1 eV



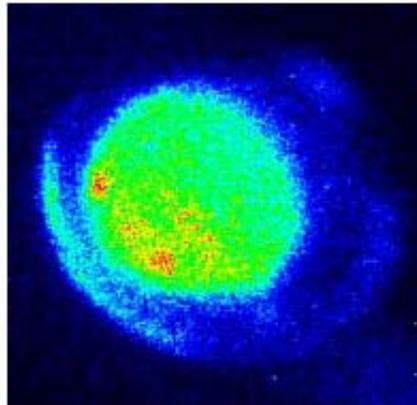
Optical Transition Radiation Diagnostic

Comparison of 10 ns slice with full beam projection

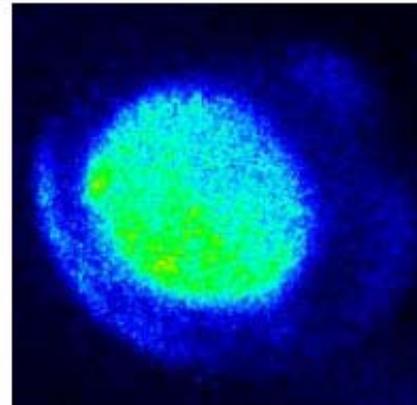
0delay



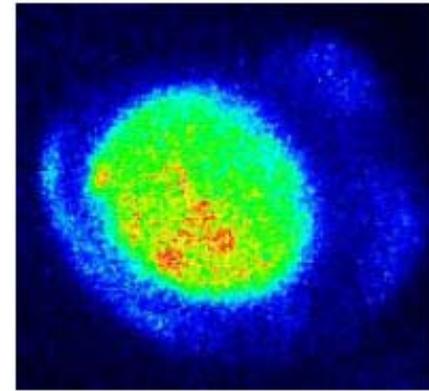
10nsdelay



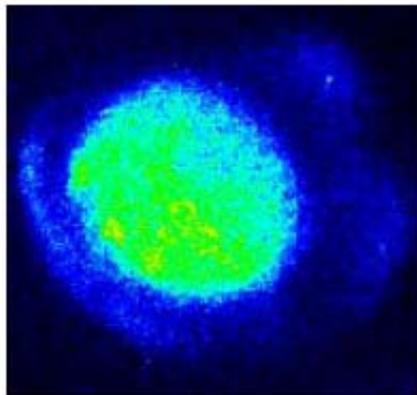
30nsdelay



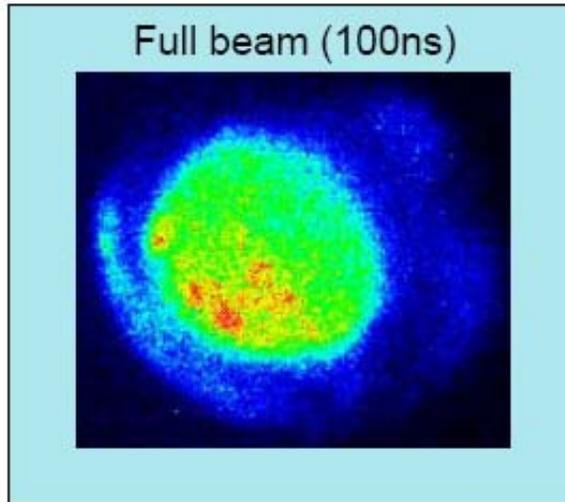
60nsdelay



90nsdelay



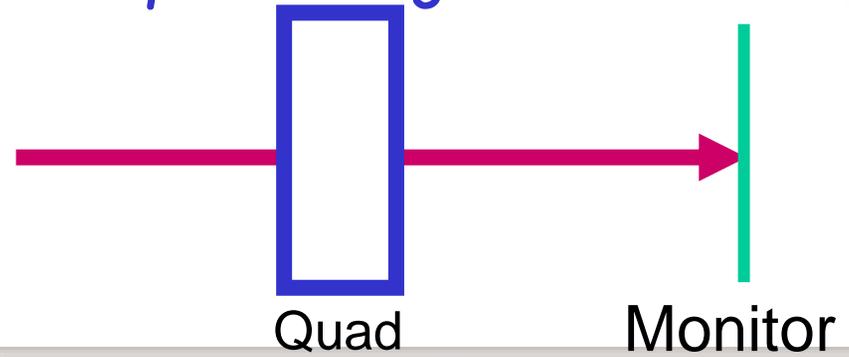
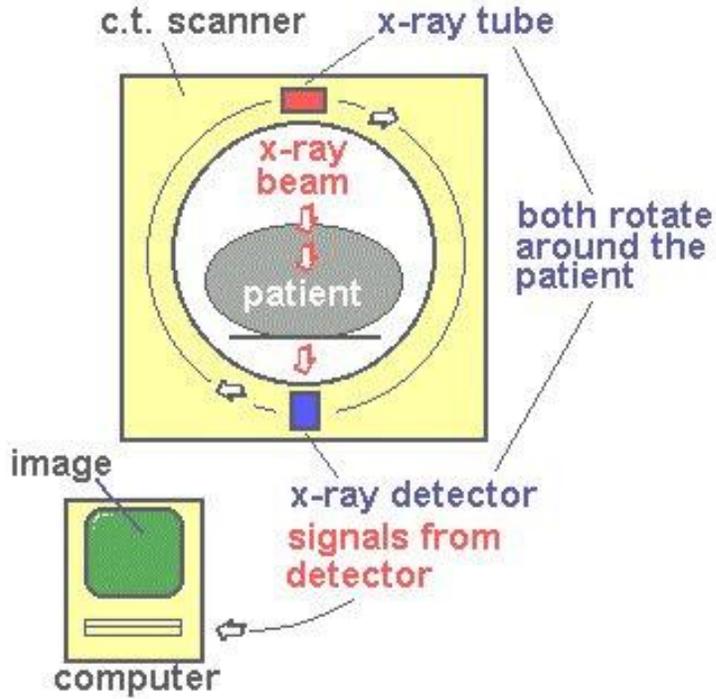
Full beam (100ns)



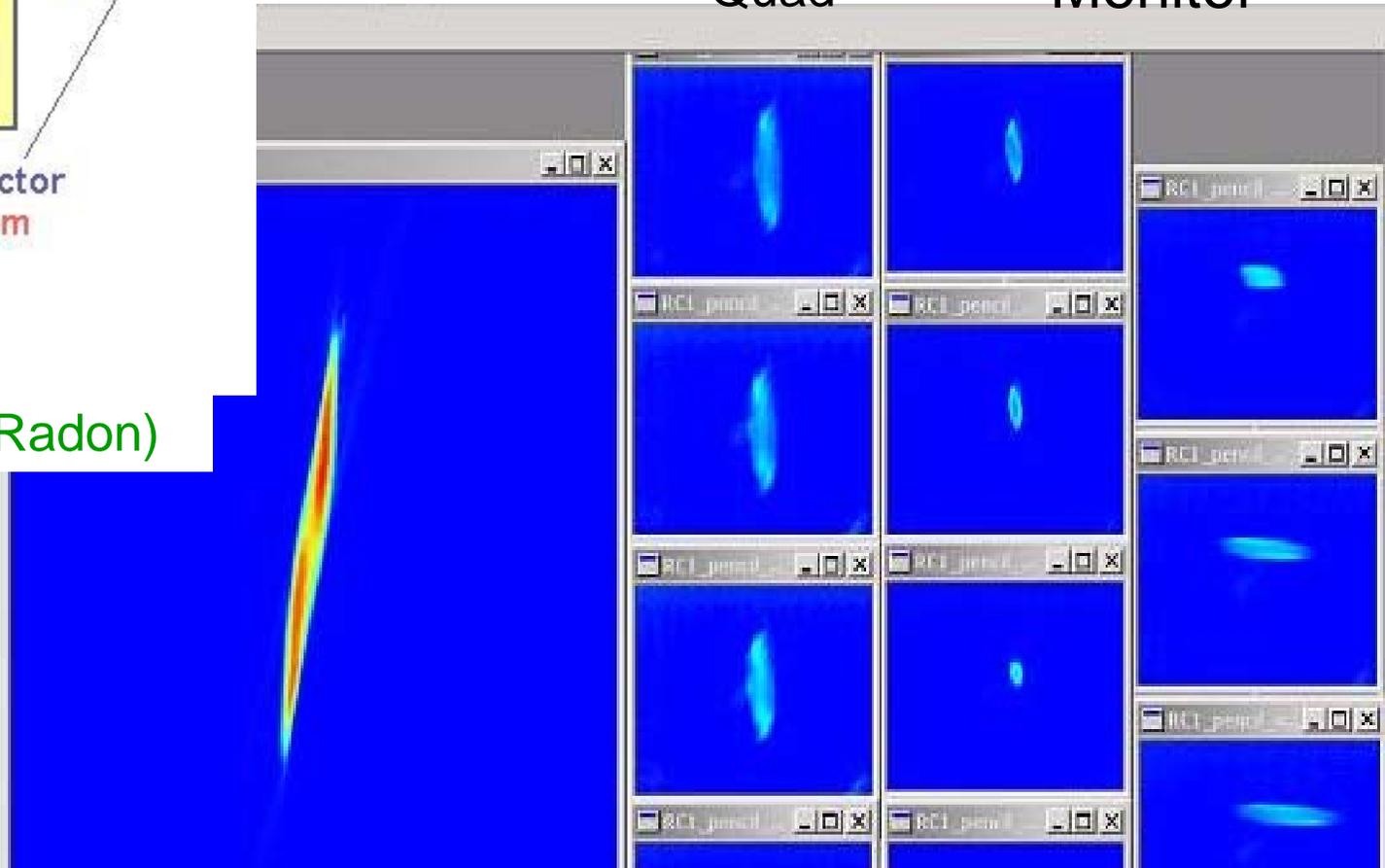
Gun parameters:

45 V bias,
22 mA

Tomography Phase-Space Imager

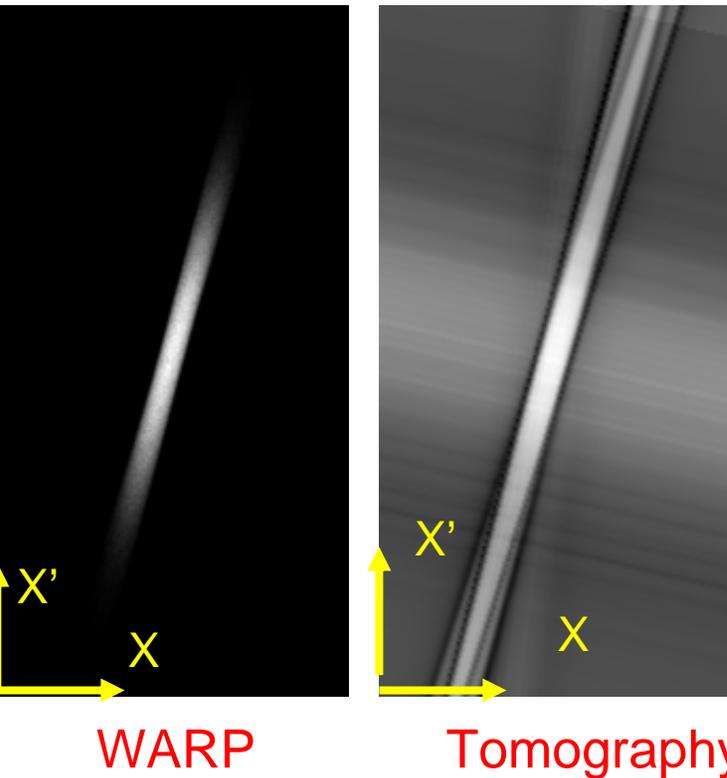


(1826 Abel, 1917 Radon)



Simulation of Tomography

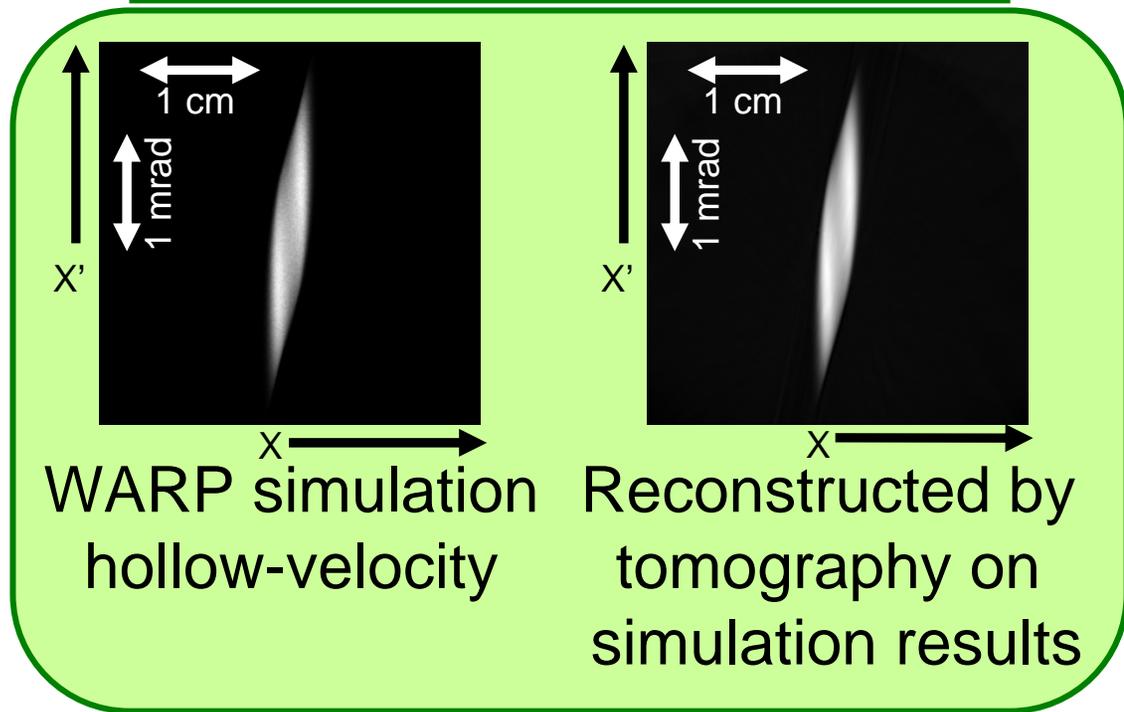
Additional projections at different angles add information to our image of the phase space



WARP

Tomography

Different Distribution



WARP simulation
hollow-velocity

Reconstructed by
tomography on
simulation results



UMER: Benchmarks for Space Charge Codes

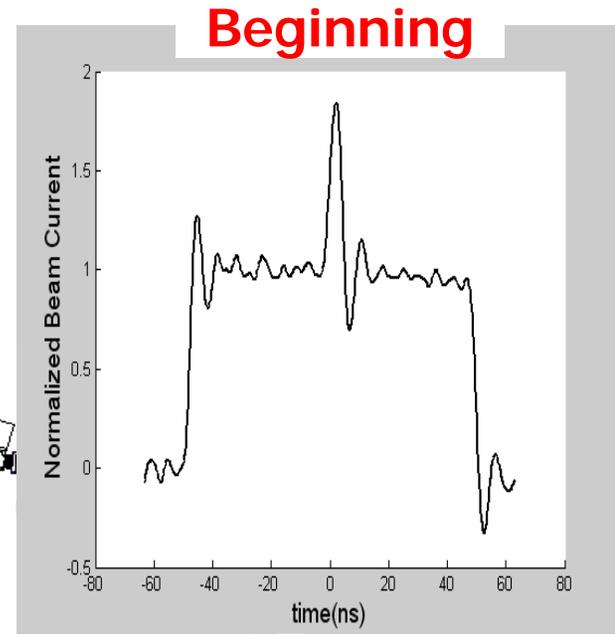
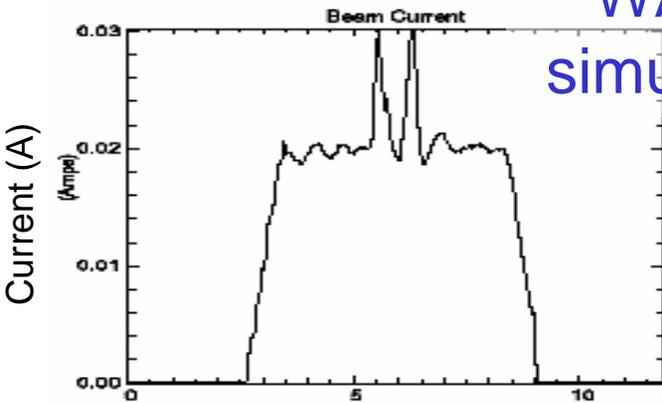
1. The Need for Benchmarking Space Charge Codes
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Propagation of Density Perturbation on Beam

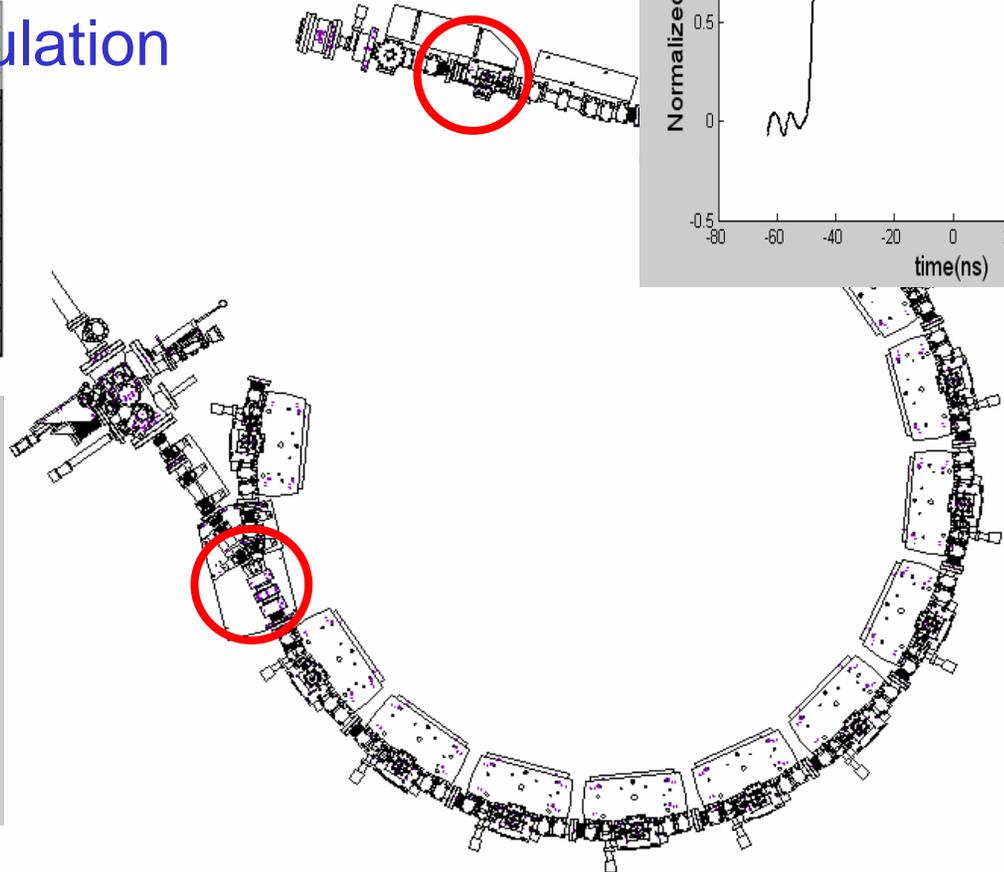
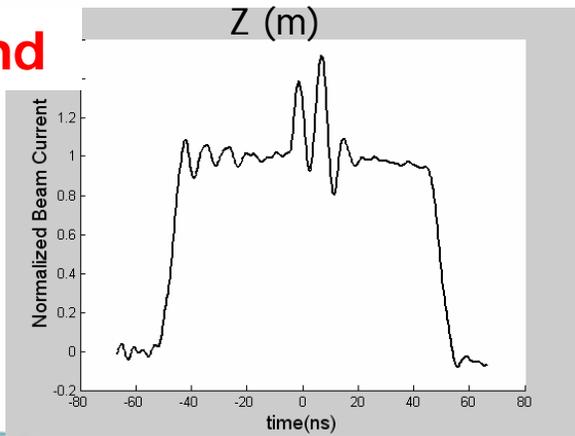
20 mA thermal-emission beam current

20 mA photo-emission beam current

WARP simulation

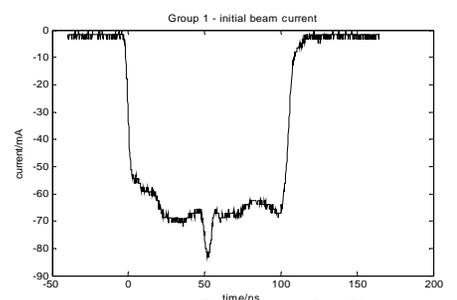


End

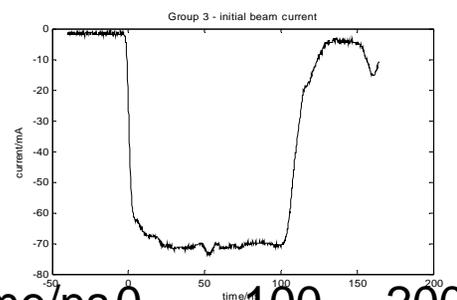


Space charge converts *density* perturbation to an *energy* perturbation

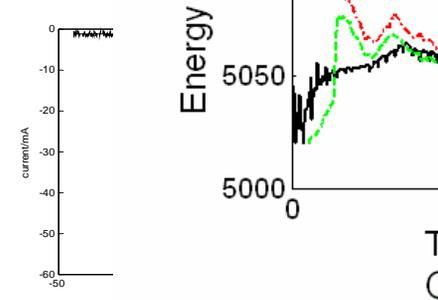
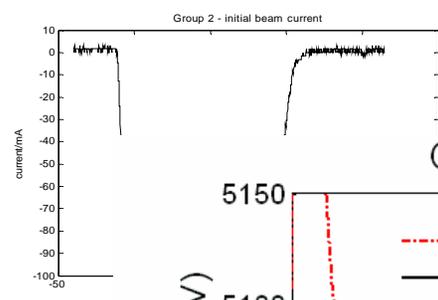
Current/A



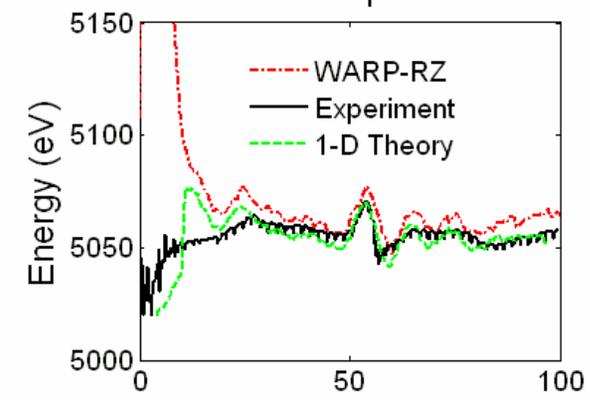
Initial Current vs.



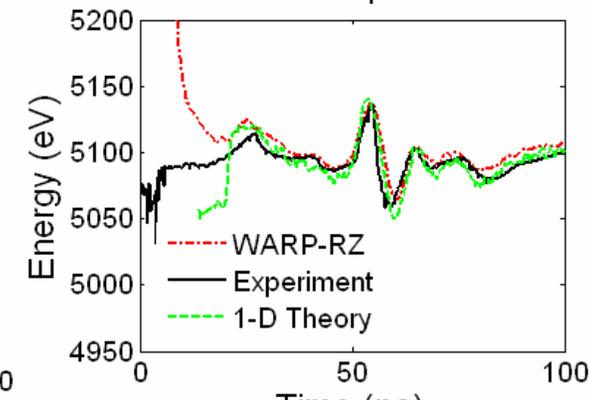
time/ns 0 100 200



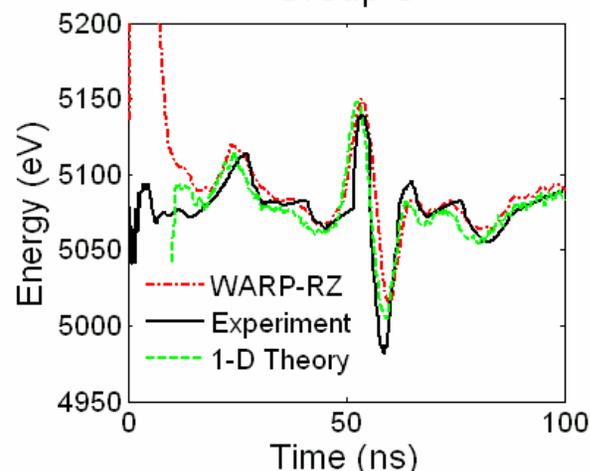
Group 1



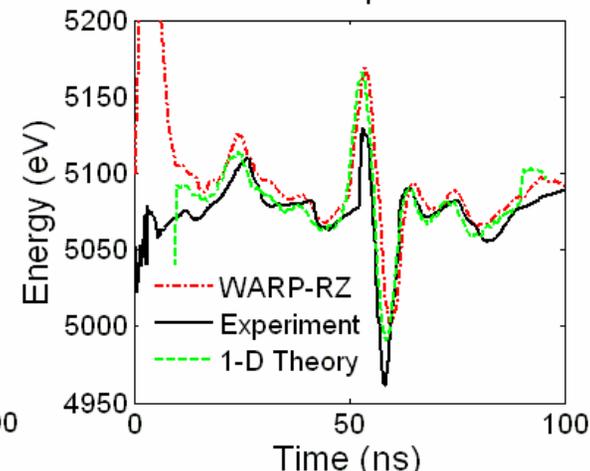
Group 2



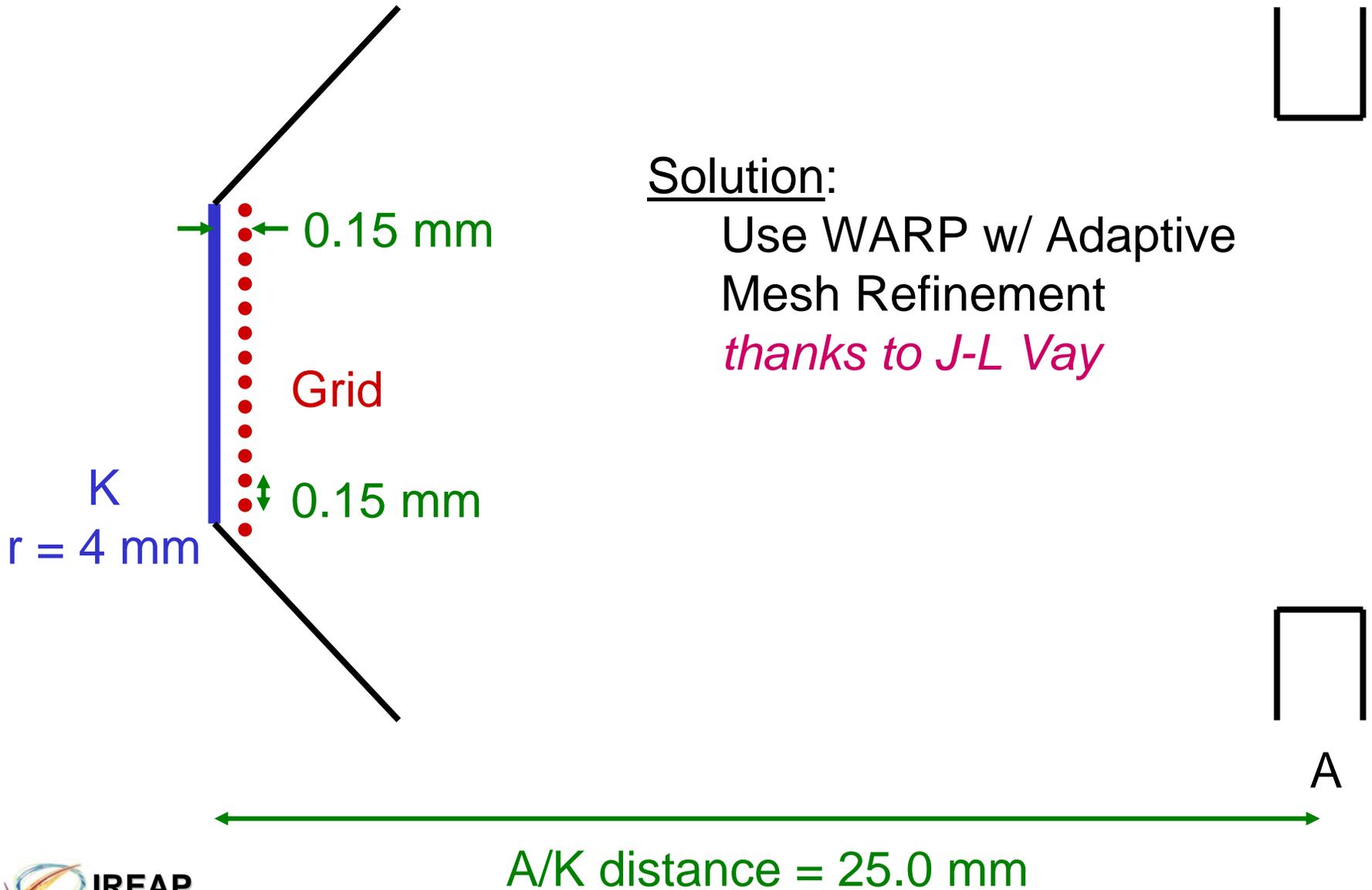
Group 3



Group 4



UMER Gun Simulation Challenge



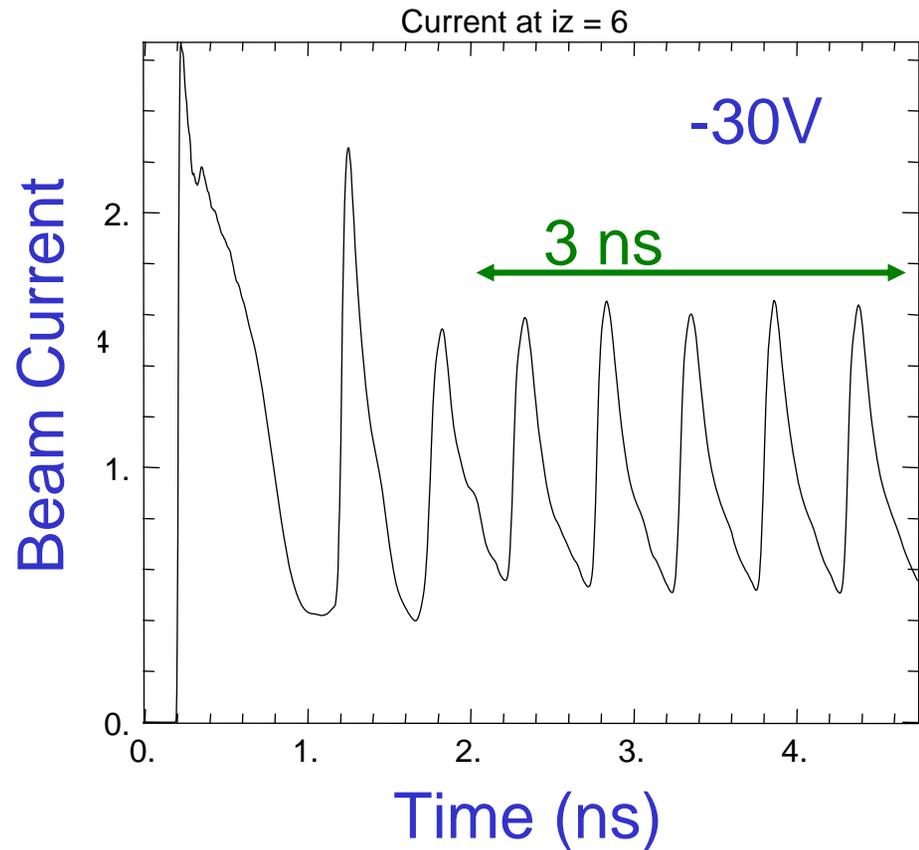
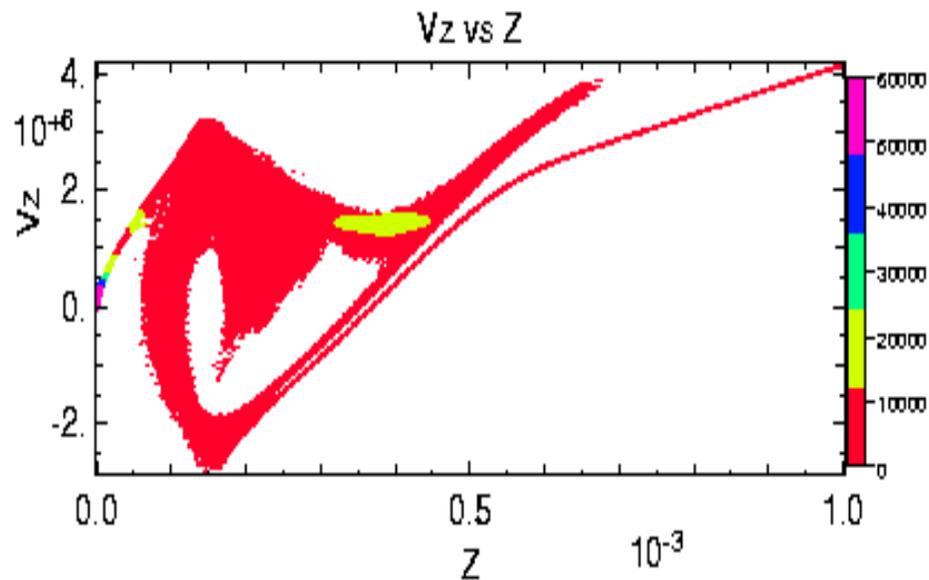
Solution:

Use WARP w/ Adaptive Mesh Refinement
thanks to J-L Vay

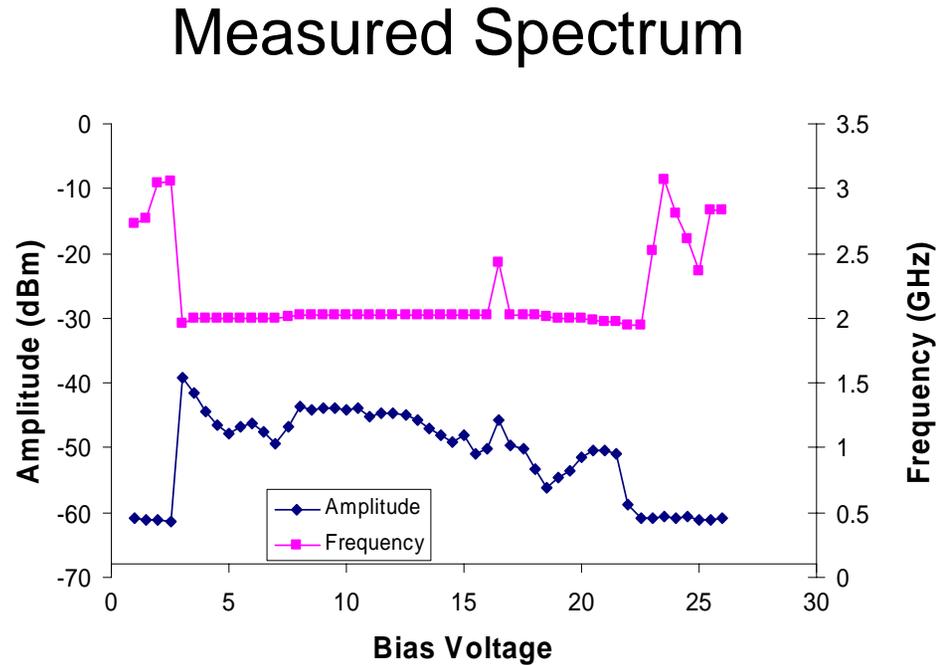
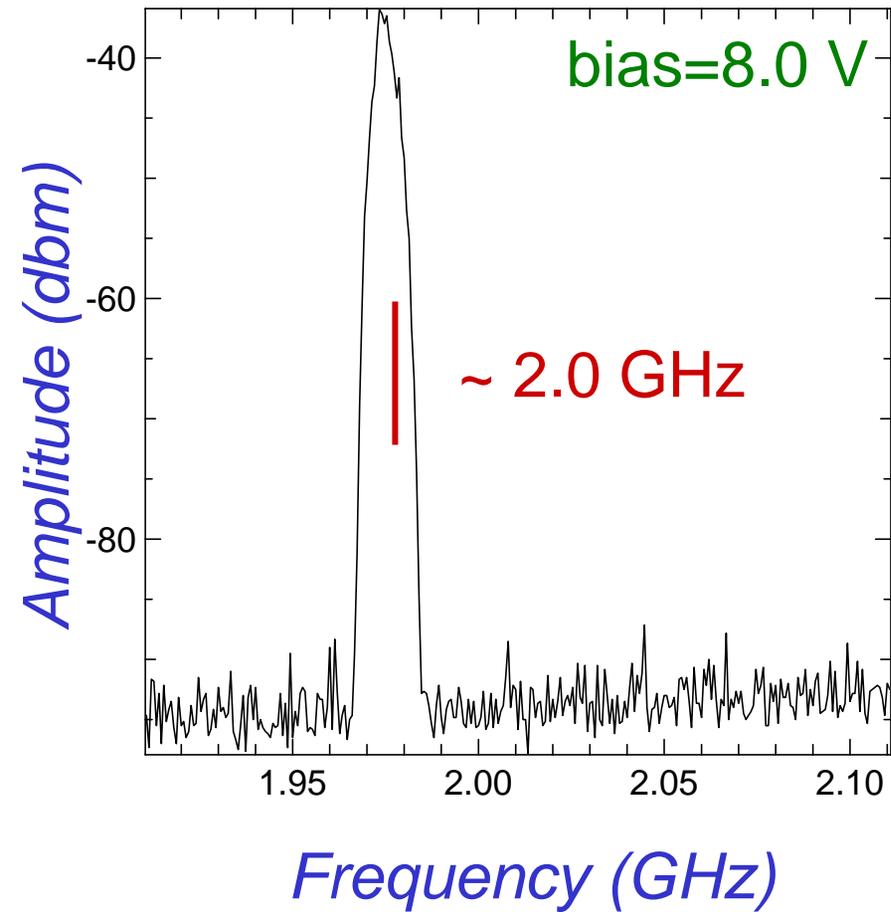
Prediction of Virtual Cathode Oscillations

WARP: 1 mm downstream of cathode

Longitudinal Phase Space



Modulated at $6/3 = 2$ GHz



Peak present over limited range of grid voltages



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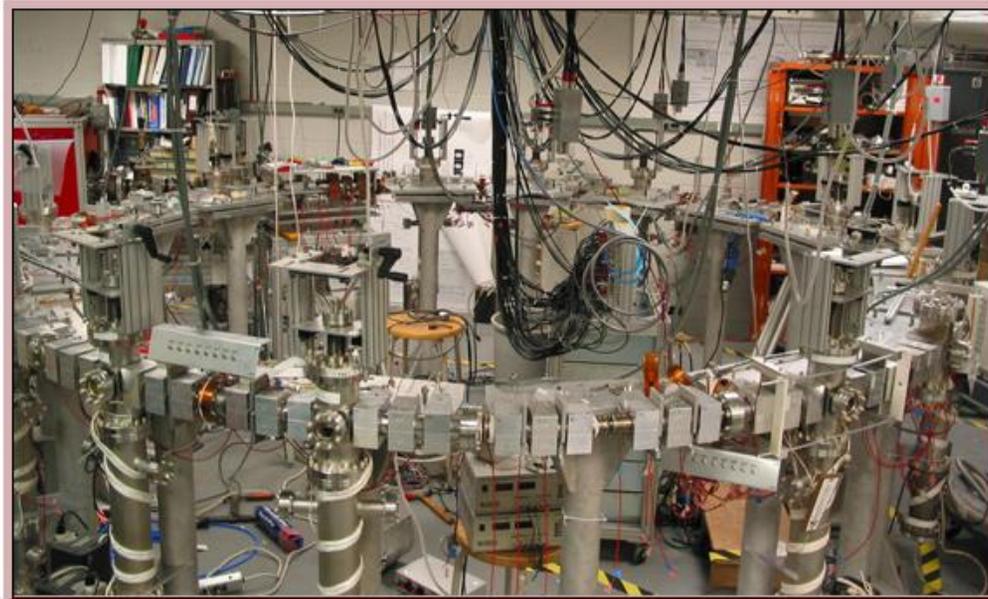
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Welcome to UMER

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.



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- #### upcoming events
- Christos Papadopoulos
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IREAP Large Rm,
2006-02-10
 - Labview and Steering Tutorial
UMER Lab,
2006-02-24

- #### news
- New UMER Website Launched
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Lots of Technical Data Online



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news

New UMER Website Launched
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Technical Data

▲ Up one level

A repository of important technical data and information about UMER.

- UMER Magnet Data**
UMER Magnet Data
- MAD description of UMER - Ring**
Description of the UMER ring lattice using
- MAD description of UMER - Injector**
Description of the UMER Injector lattice using the Methodical Accelerator Design (MAD) language. Be wary! May contain some errors and uncertainties. Product of recon...
- BPM Calibration Data**
Beam position in the horizontal plane is de...
- Earth Magnetic Field**
Earth Magnetic Field as measured by Bryan Quinn around UMER 2004-10-28
- Chart of Earth B-Field**
Chart of Earth B-Field from Bryan Quinn's measurements 2004-10-28
- E-RING-Apertures**
Technical drawings of apertures in the UMER gun (from D. Kehne).
- Archived Technical Data**
Technical data specifying current configuration will be found in parent folder. Data which is not up to date will be found here. This archived data is useful, for instance, for simulating past experiments.

Complete Magnet Data

MAD Description of Lattice

Diagnostic Calibration Data



E.g., Magnet Information

you are here: home » technical data » umer magnet data

UMER Magnet Data

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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 design 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	I_{eff} (cm)	SB I_{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	I_{eff} ^(b) (cm)	I_{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

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New UMER Website Launched
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Another Layer of Access: Technical Notes

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2006 Tech Notes

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

- BPMOutput 060605RAK**
Note by Rami Kishek about BPM data postprocessing and the BPMPProc python script, along with general guidelines for acuring BPM data from the scope.
- RAK Matching060515v2**
A Study on Matching Using TRACE and WARP, providing the latest and most accurate injector matching settings, and taking advantage of the Bernal effective length, the latest MagLi data, and including bends. (revised May 5)
- ExtractionOptions060506**
A brief review of the options available for the extraction Y section, with a sketch. Please feel free to add comments below and to suggest alternatives.
- UMER 060407-SBCW**
SCAN OF 5-BEAMLET MASK
- Controls Group Notes**
Technical notes dedicated to beam control
- UMER-060306-SB**
Technical Note: New Hard-Edge Model for UMER Solenoid
- UMER-060110-SBDSCT**
UMER Technical Note: Edge vs. Collins Insertion Schemes
- UMER EXPERIMENT - BASIC RECORD**
Sheet for recording basic experiment settings. It was prepared by S. Bernal and C. Tobin with input from D. Sutter, M. Walter and R. Kishek. It is intended for creating a data base of parameters and to guide experimentalists. We'll keep the records on an binder in the lab.
- UMER-060220-SB-revised**
UMER Technical Note (revised): "New" Approach to Effective Length and Strength of UMER Quadrupoles

Google™

Web umer

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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



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.

I like to thank my colleagues ...

