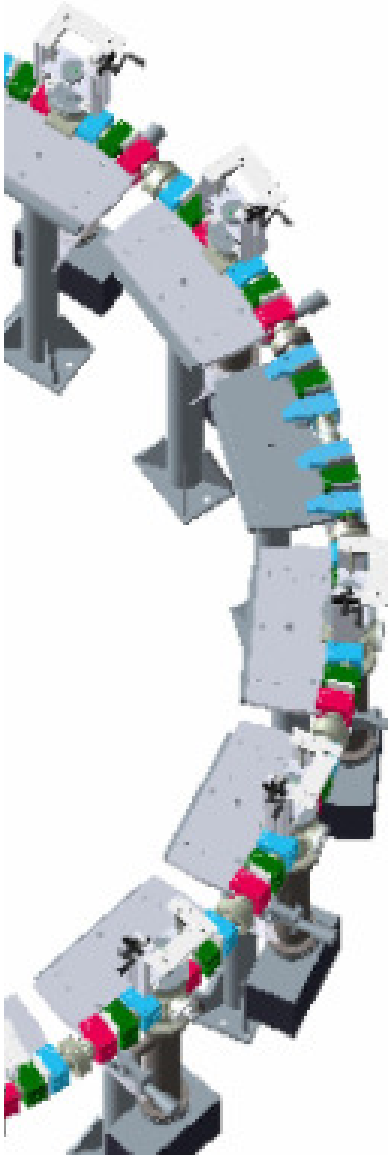
The University of Maryland Electron Ring Experiment – a Plasma in Motion



Rami A. Kishek

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

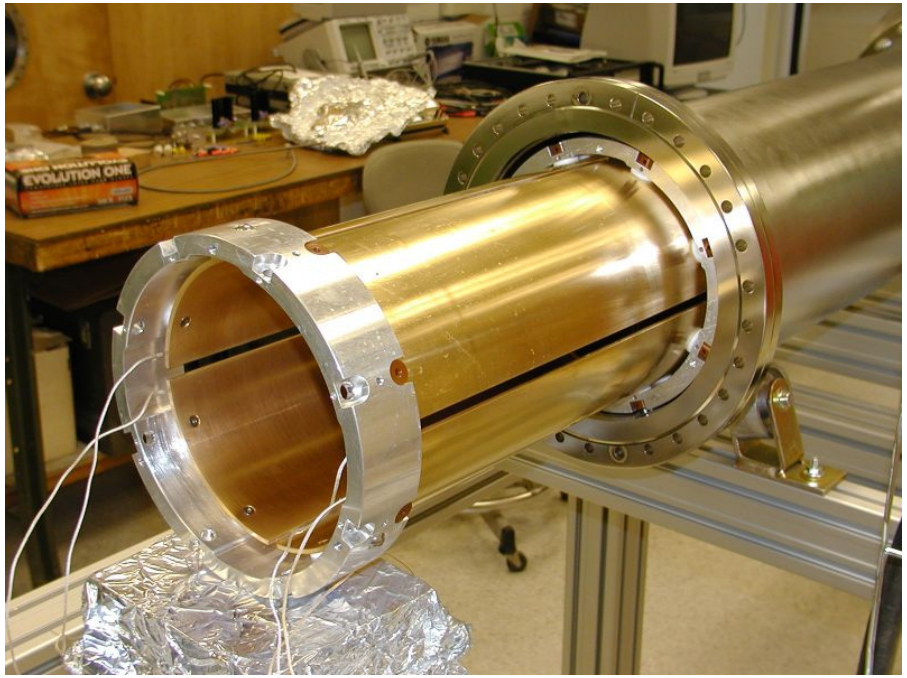
Outline:

1. High-quality beams and Plasmas
2. UMER – what is it?
3. Recent Results

Research sponsored by US DOE HEP, DOE FES/HEDP, and DOD ONR

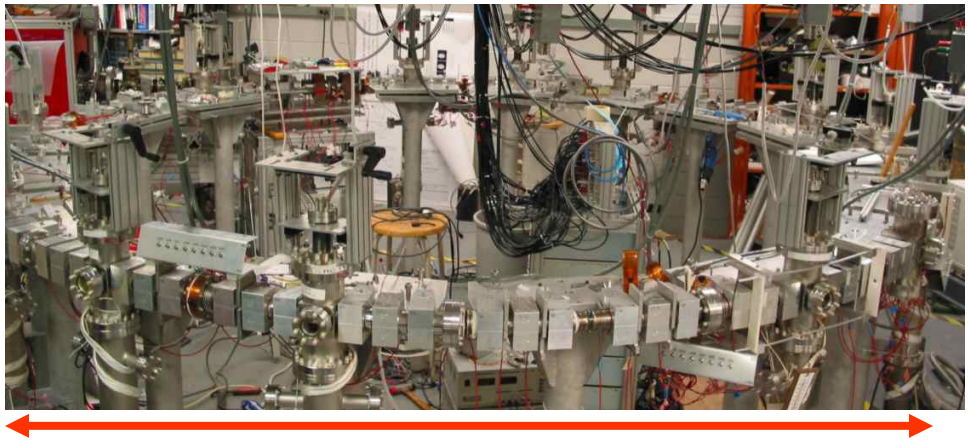
Close Cousins

Princeton Paul Trap



A Beam in the beam-frame

U. Maryland Electron Ring



3.7 m

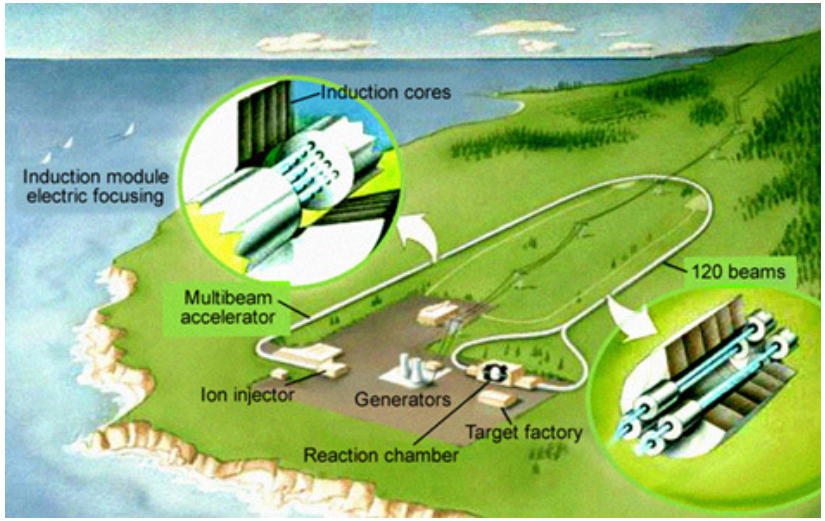
An Accelerated Plasma

Benefits of Intense Beams

- Solving the Energy Crisis / Global Warming
- Material Characterization
  - Pulsed neutron sources
  - Short-pulse intense X-ray lasers
- Nanoscience / biosciences
- High Luminosity Colliders

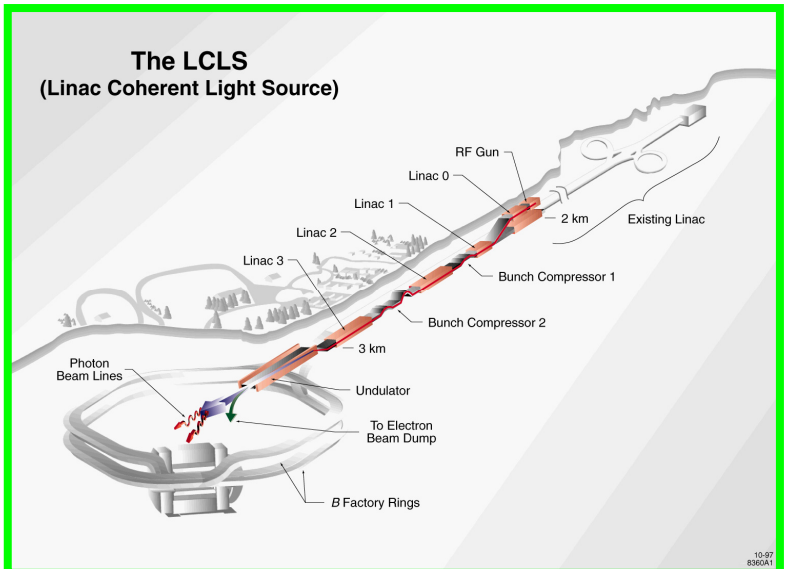
Typical requirements
1 nC, 1 ps, 1 μm emit

Heavy Ion Inertial Fusion



Spallation Neutron Source

X-Ray Free Electron Lasers



Measures of Beam Quality

Emittance	$\tilde{\varepsilon}_{x,n} = \frac{1}{mc}\sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2}$	Phase space volume - compactness
Generalized Perveance	$K \equiv \frac{2I}{I_o(\beta\gamma)^3}$	space charge energy / total kinetic energy
Brightness	$\bar{B}_n = \frac{2I}{\pi^2\varepsilon_{x,n}\varepsilon_{y,n}}$	Phase space density
Intensity	$\chi \equiv \frac{K}{k_0^2 a^2}$	Dimensionless, transport dynamics

$$\chi = \frac{1}{1+\frac{1}{K}\left(\frac{\varepsilon_n}{\beta\gamma a}\right)^2}$$

$$\bar{B}_n = \frac{I_o}{\pi}\frac{\beta\gamma}{\pi a^2}\left(\frac{\chi}{1-\chi}\right)$$

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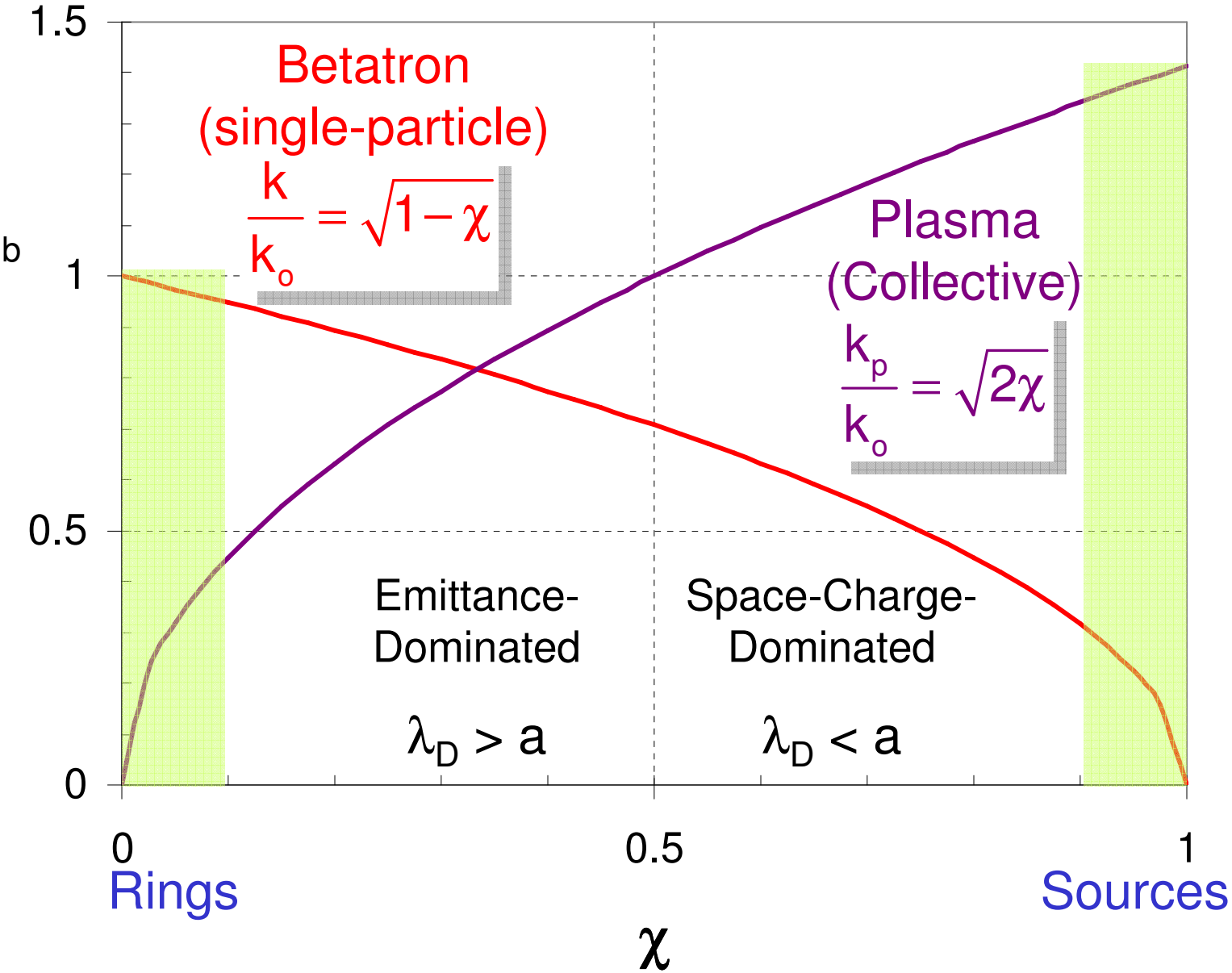
Plasma Physics of Beams

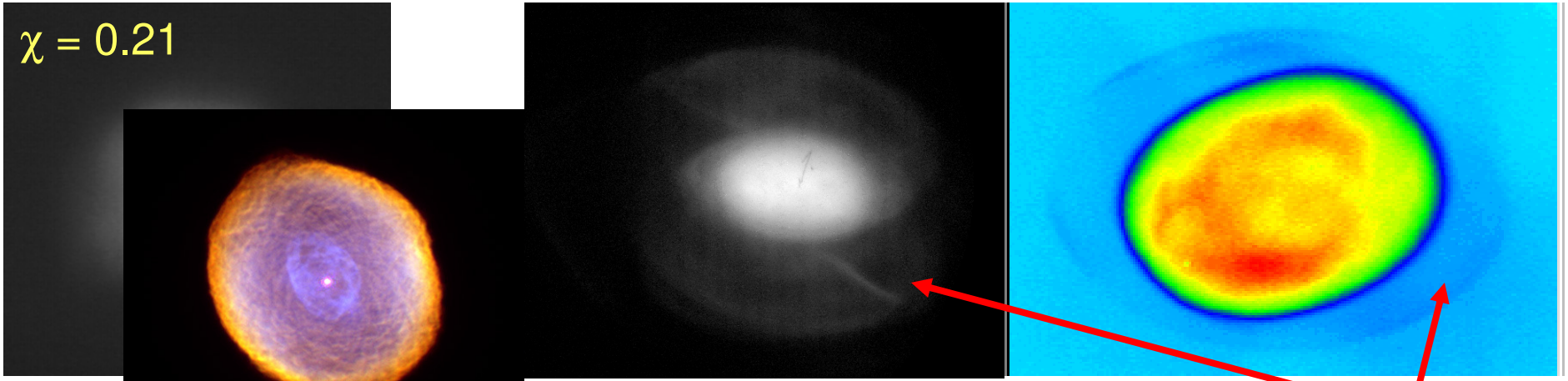
$$\chi \equiv \frac{K}{k_0^2 a^2}$$

Davidson: s_b



*M. Reiser, J. Appl. Phys., **52**, 555 (1981); M. Reiser, et al., PAC '99.*

Intense Beams = Plasmas

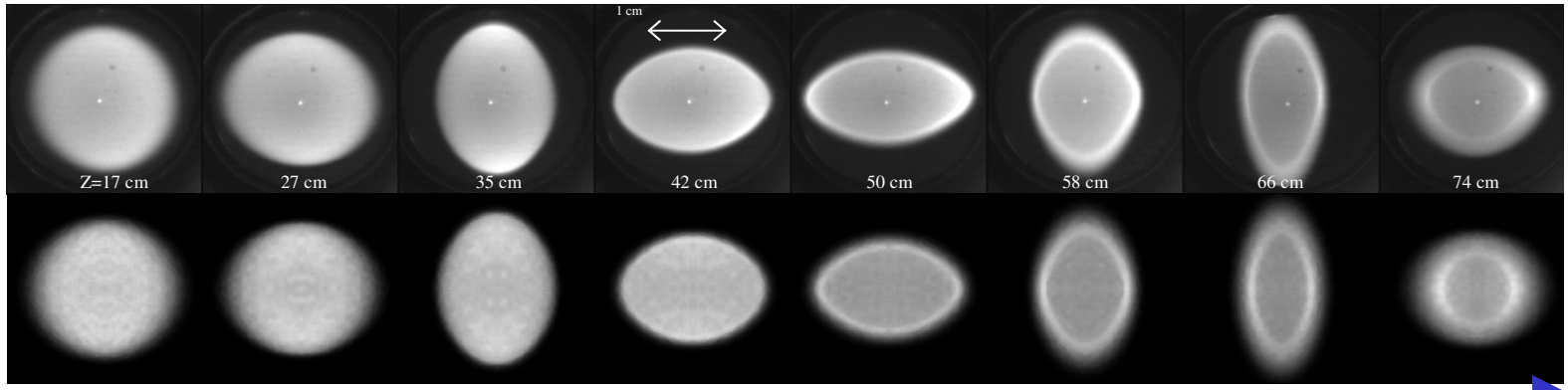


Nebulae

Space-Charge-Dominated

χ = 0.7 - 0.9

Halo



Experiment

Cathode

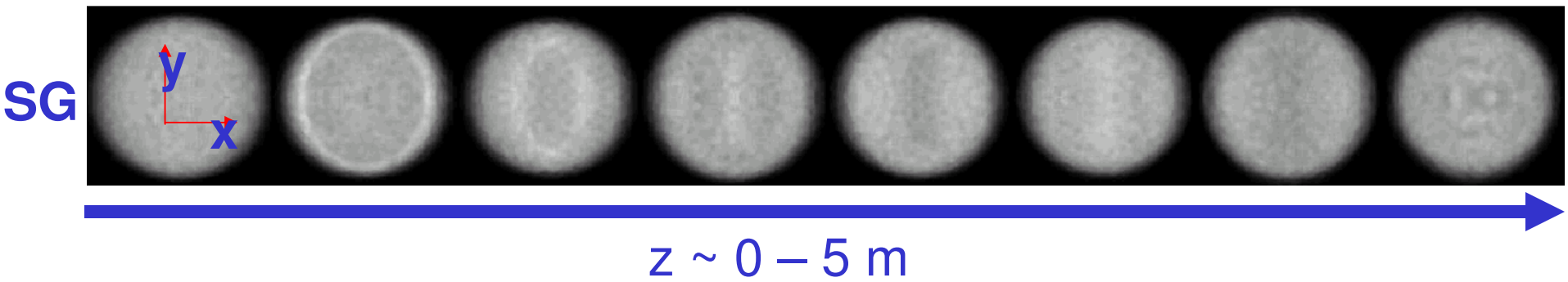
Simulation

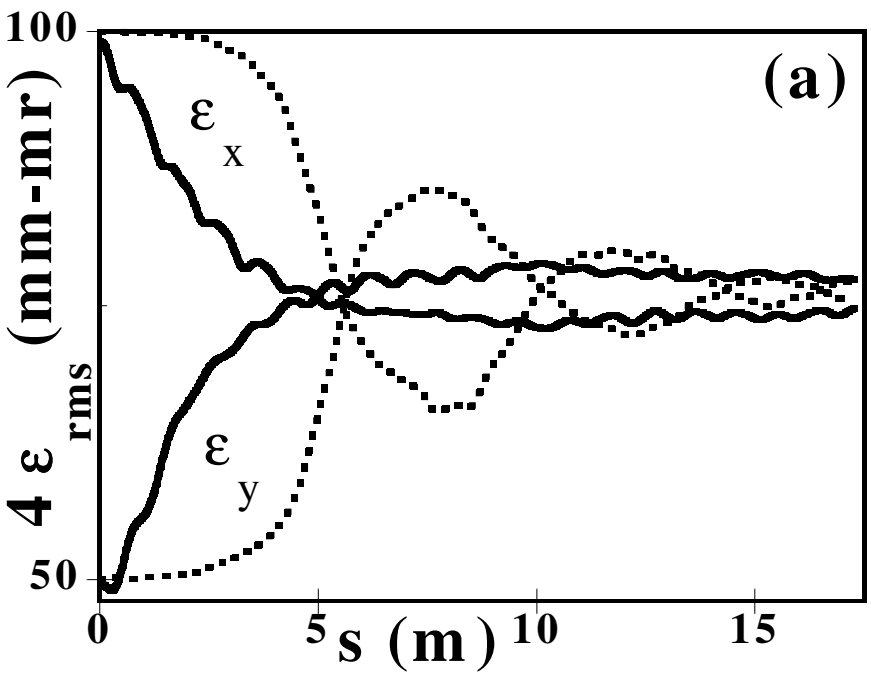
z ~ 0.15 – 1 m

*Bernal, Kishek, Haber, and Reiser, PRL, **82**, 4002 (1999).*

These oscillations can result in nonlinear x-y coupling

$\chi = 0.98$

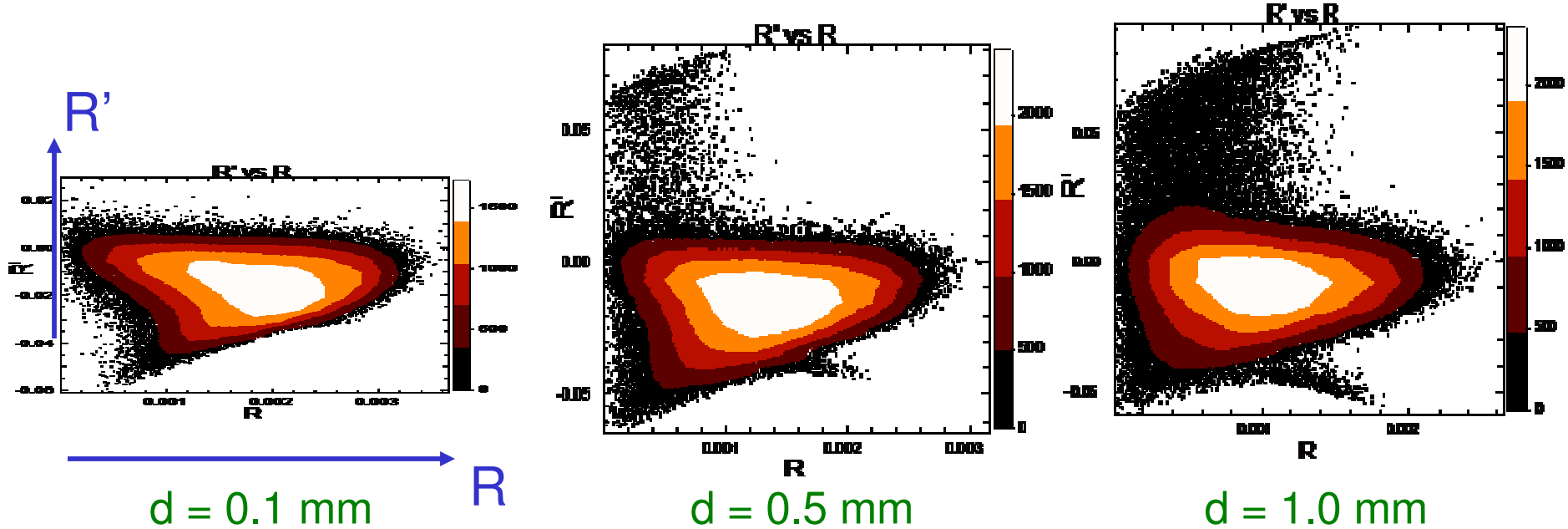


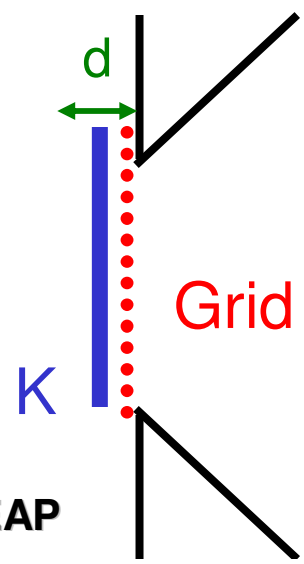


oscillation scale length
~ plasma wavelength

*Kishek, O'Shea, Reiser, Physical Review Letters, **85**, 4514 (2000).*

WARP3D Simulations: Source of Halo Identified



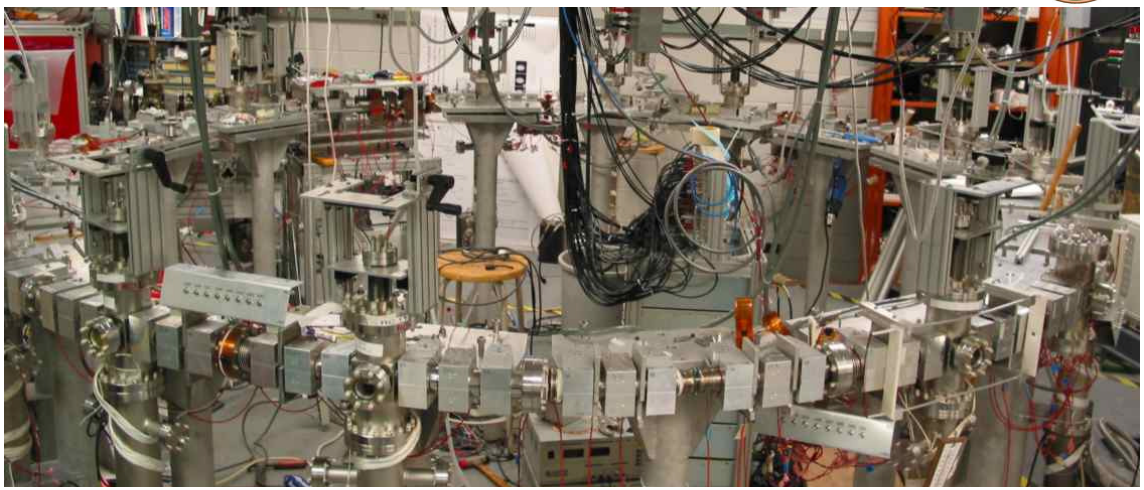


R-R' phase space at gun exit.
Halo shows sensitivity to cathode alignment

WARP simulations, I. Haber

The University of Maryland Electron Ring (UMER)

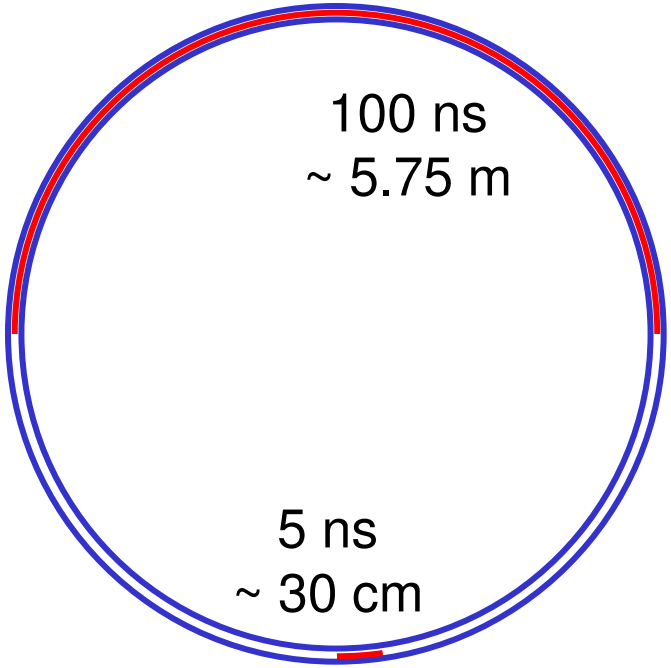
Use 10 keV electrons to inexpensively model space charge effects in other accelerators



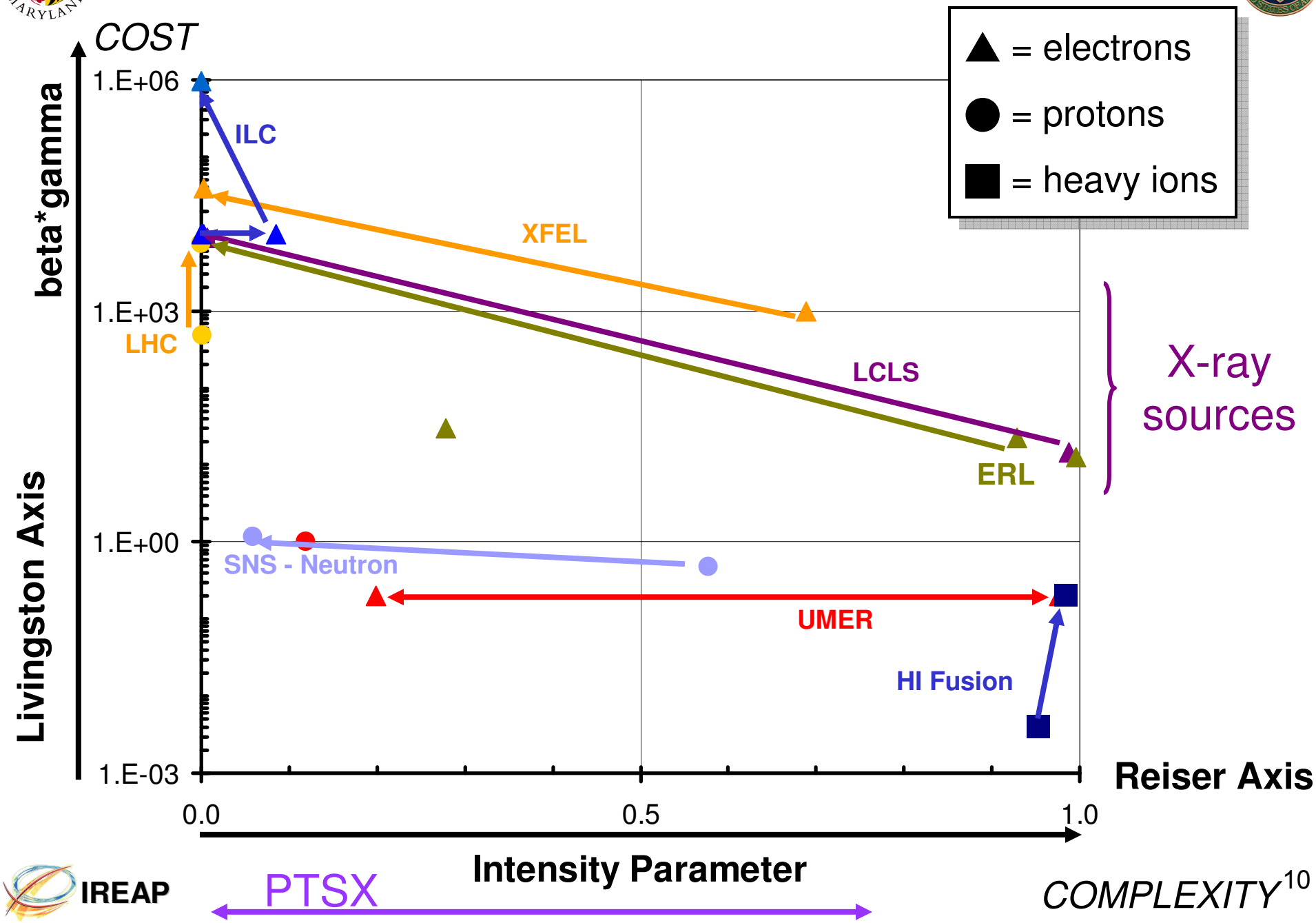
3.7 m

Energy	10 keV ± 0.2 %
Current Range	0.6-100 mA
rms Emittance ($_n$)	0.2-3 μm

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



Parameter Space is Multi-Dimensional



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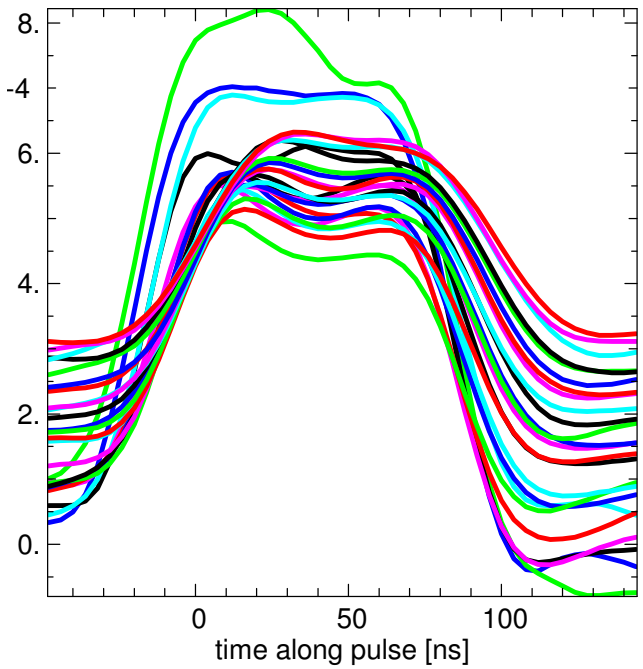
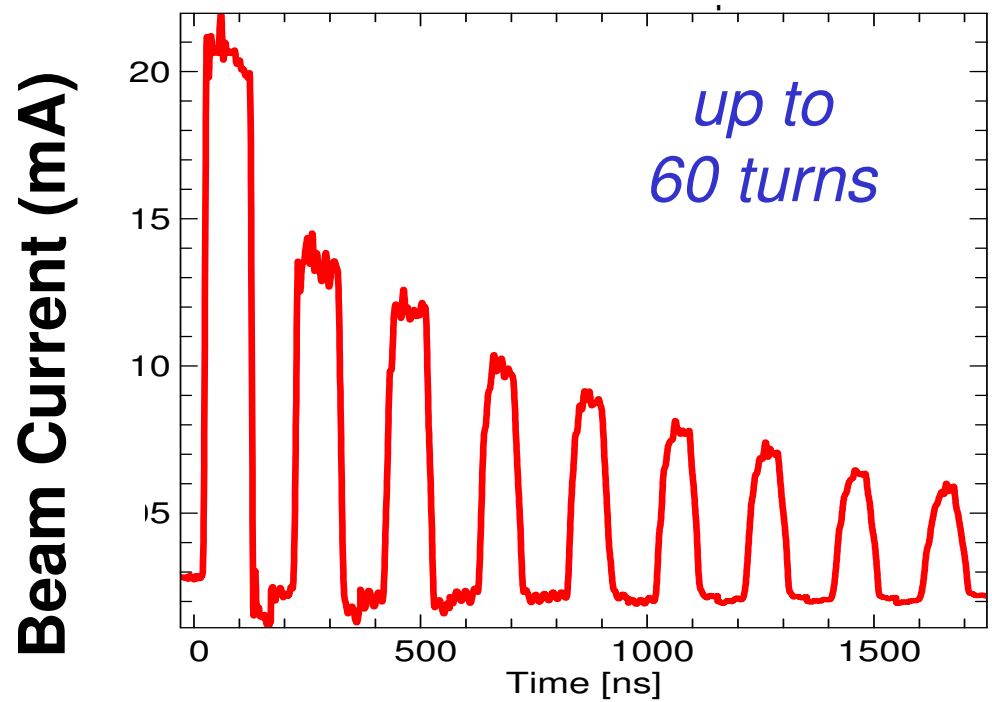
UMER Multi-Turn Results (in progress)

$\chi = 0.21$

up to 125 turns



$\chi = 0.7$



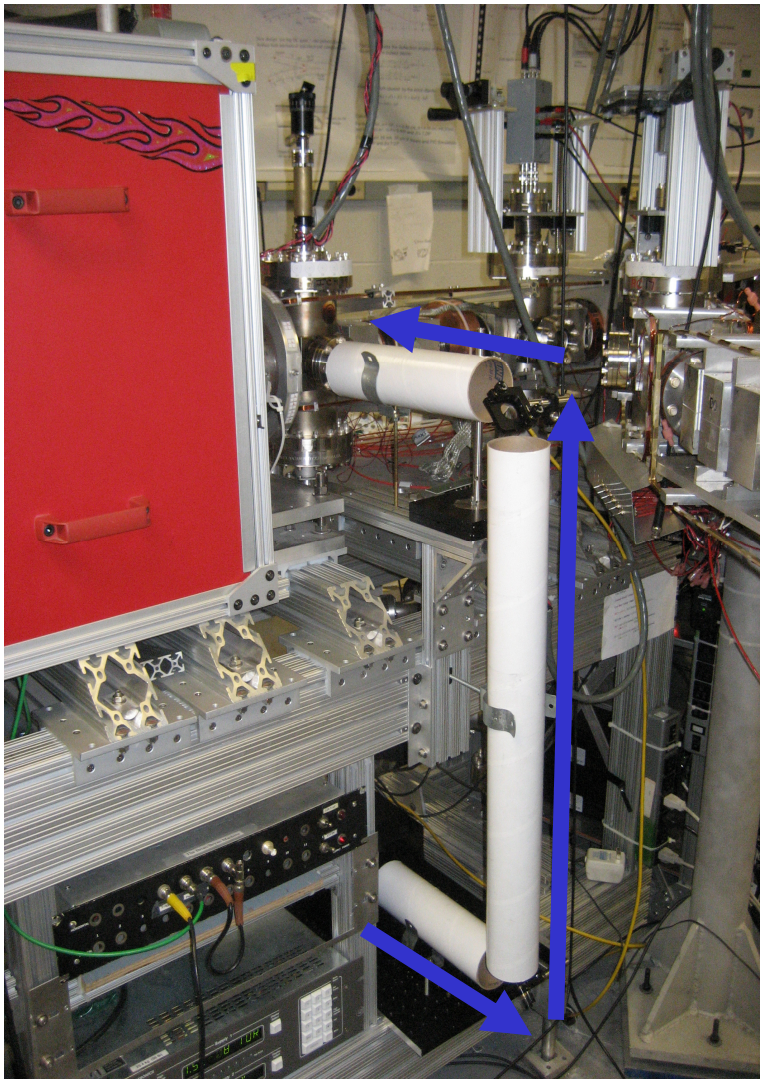
Tune Shift

Injected	0.80
After 25 turns	0.45

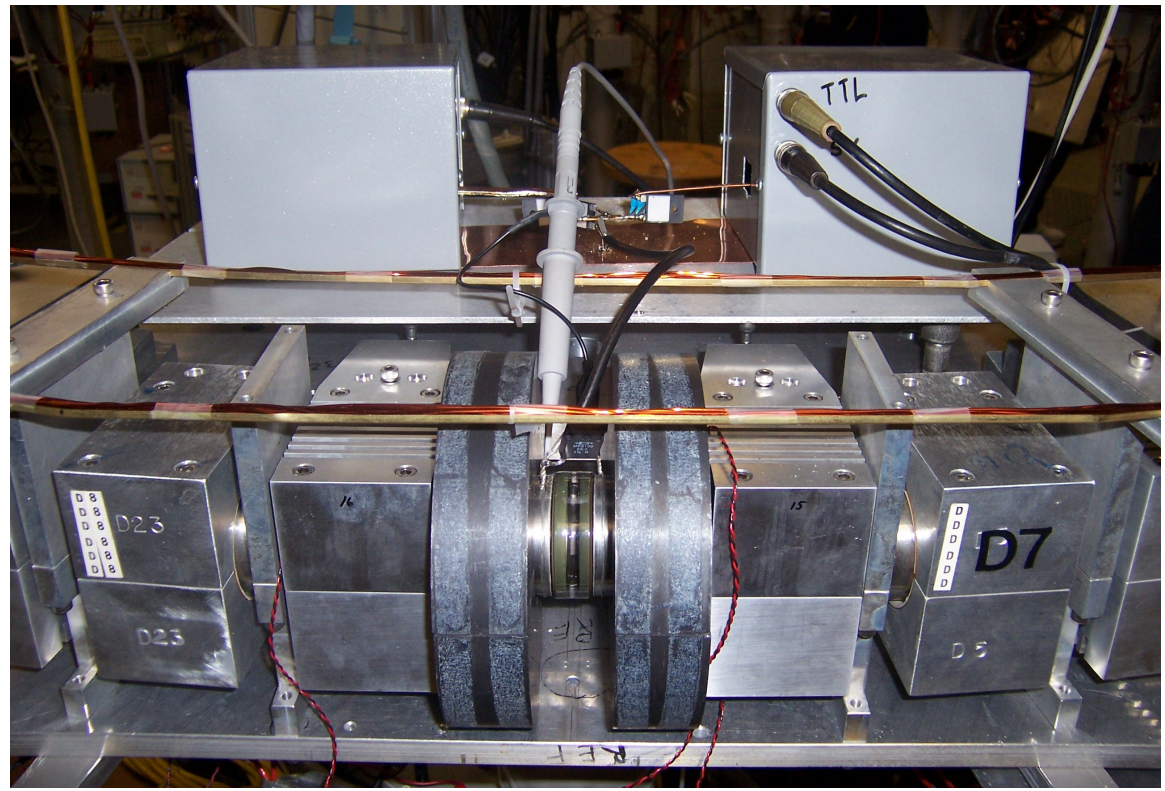
Tune Shift

Injected	3.3
After 25 turns	0.9-2.0

Ability to modulate beams in a controlled fashion



Laser Beam adds 5 ns perturbation on 100 ns pulse



Induction module can add 10-ns energy perturbations

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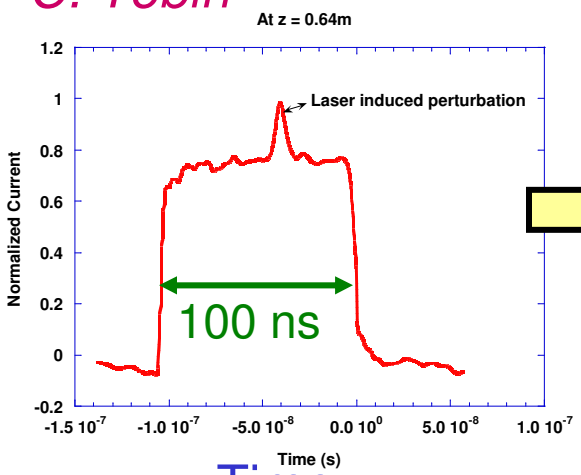
Longitudinal Space Charge Waves

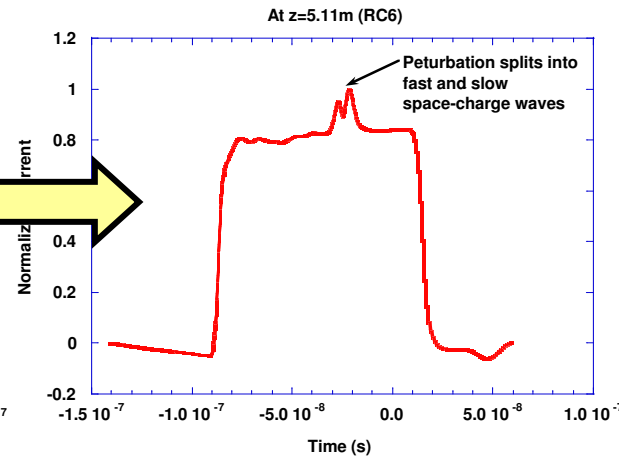
Interchange of energy and density modulations

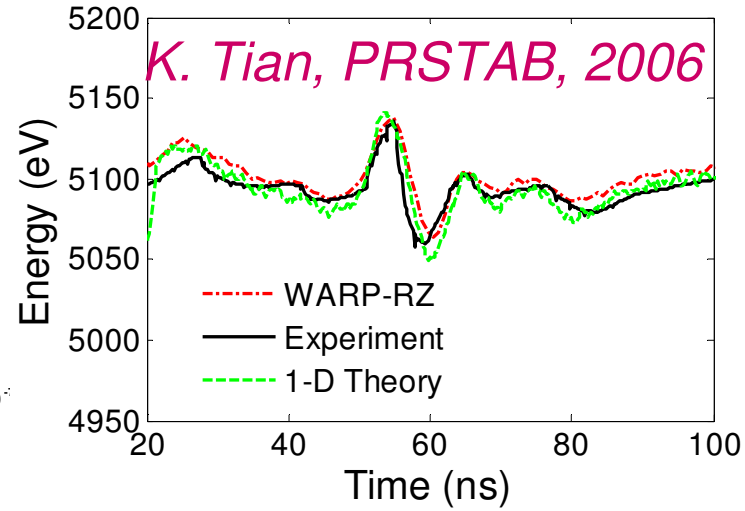
Beam Current

Average Energy

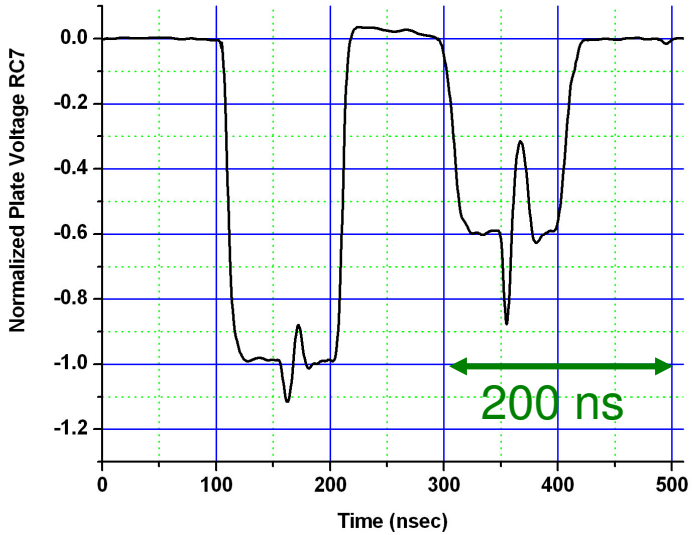
C. Tobin



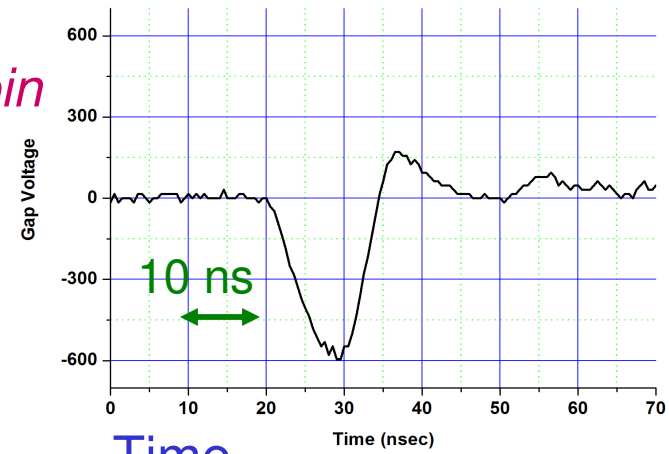




Time



B. Beaudoin

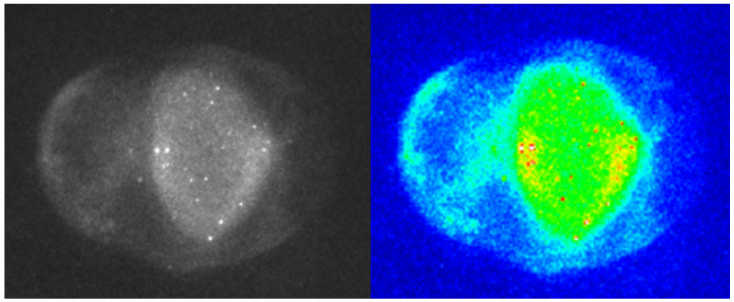


Time

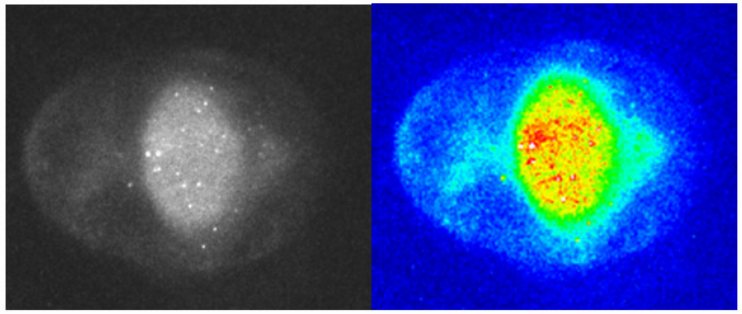
Fast Imaging

Time-Resolved Imaging with Optical Transition Radiation (3ns)

Without perturbation

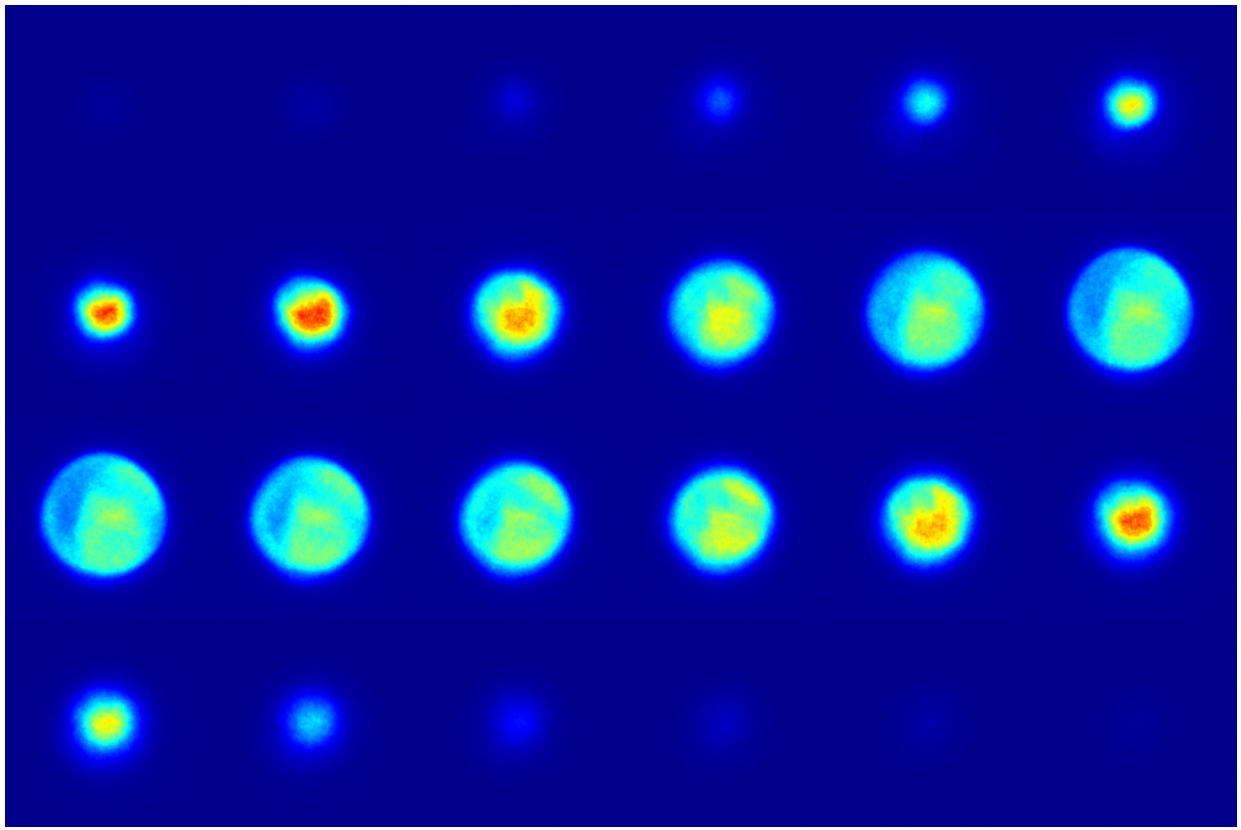


With perturbation



K. Tian, PAC 2007.

Sliding 3-ns gate along parabolic bunch



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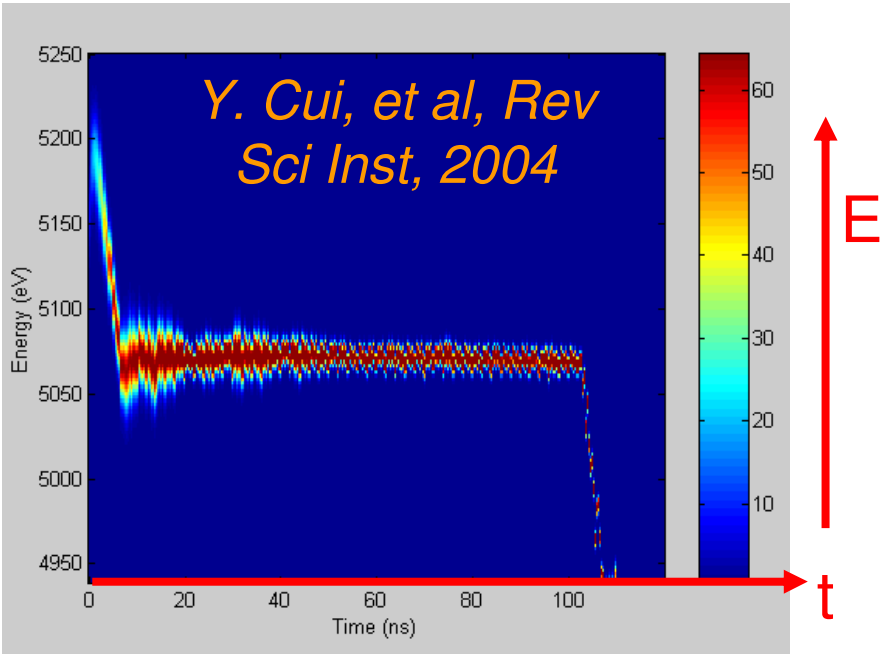
Examples of Phase Space Measurement

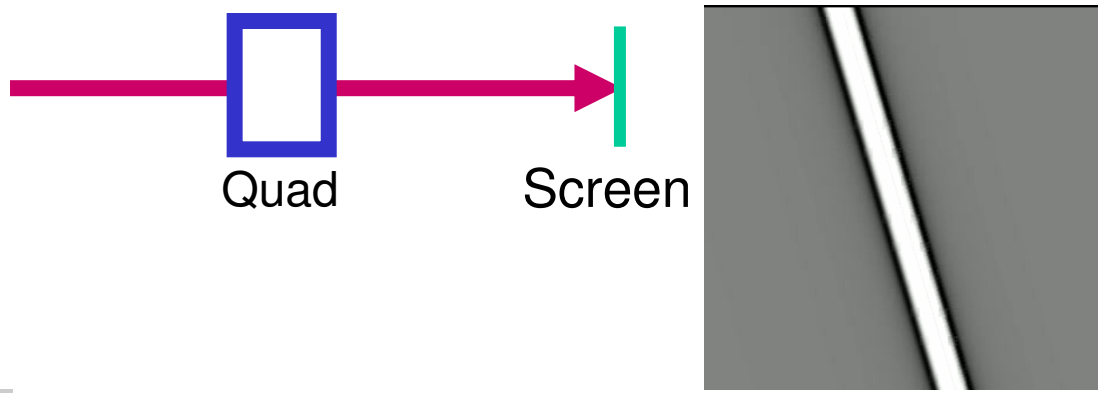
Compact Energy Analyzer

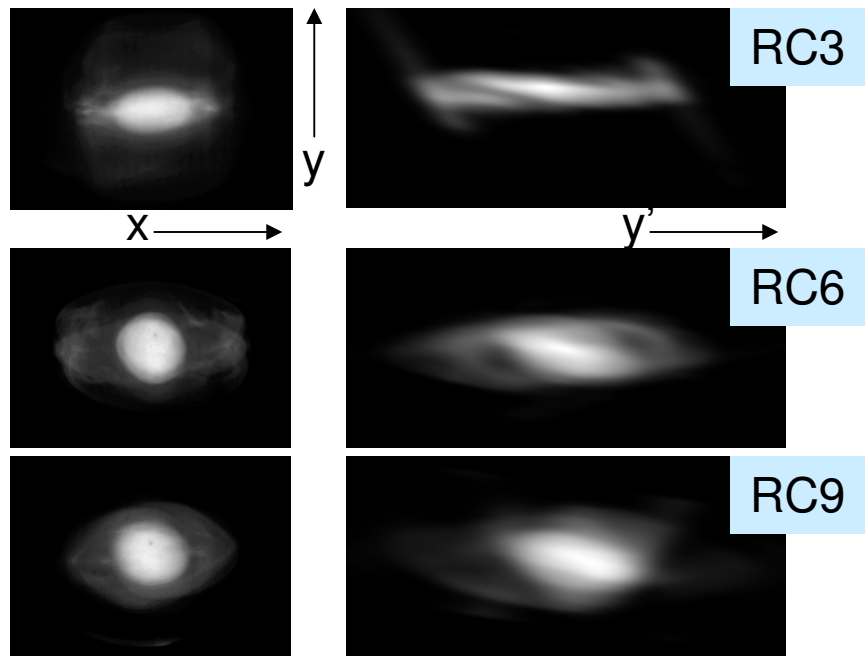
High resolution:

- 10^{-4} energy
- 1 mm spatial
- few ns time



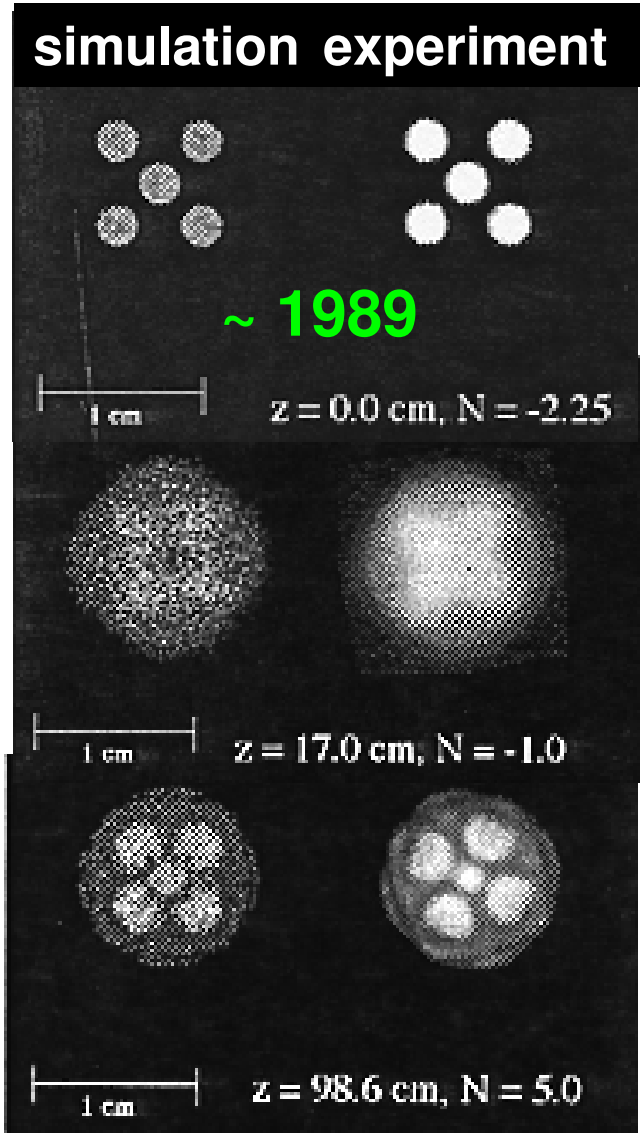
High-Fidelity Tomography



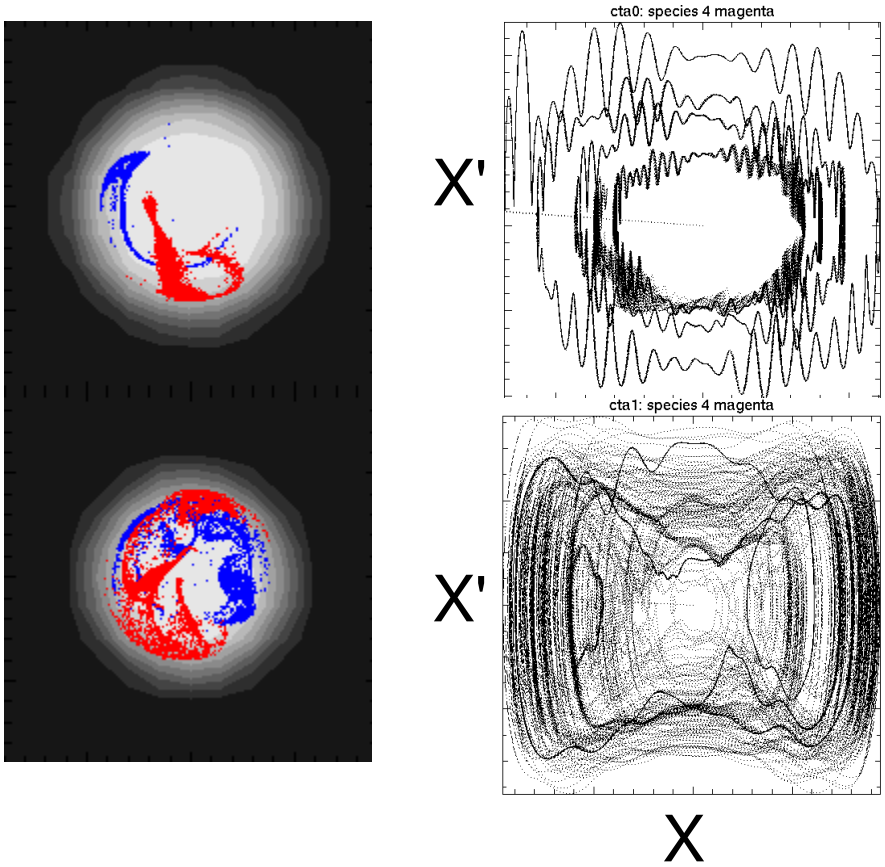


D. Stratakis, R. Kishek, et al., to appear

Chaos in Beams and Galaxies



Kehne, Haber, Reiser



C. L. Bohn, in The Physics of High Brightness Beams, (WS, Singapore: 2000), p. 358.

R.A. Kishek, *et al.*, *PAC 2001, 151-153 (2001).*

H.E. Kandrup, *et al.*, Annals of the New York Academy of Sciences **1045**, 12–33 (2005).

R.A. Kishek, *et al.*, *ibid.*, 45-54 (2005).

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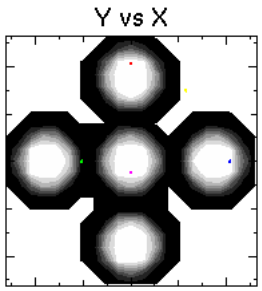
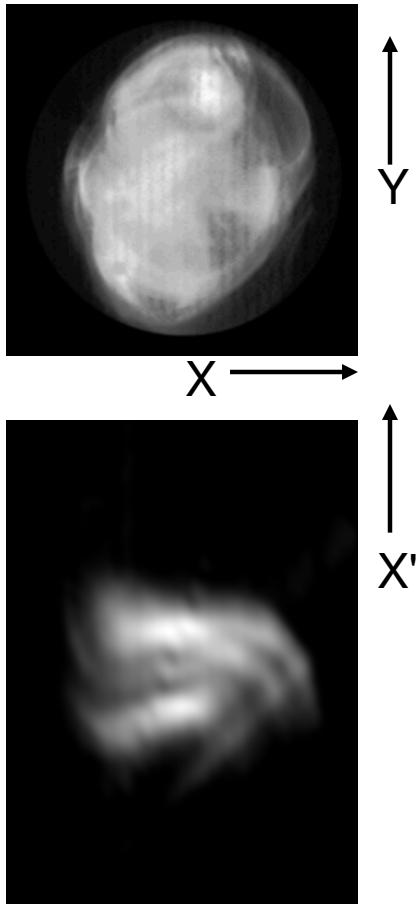
Recent Results

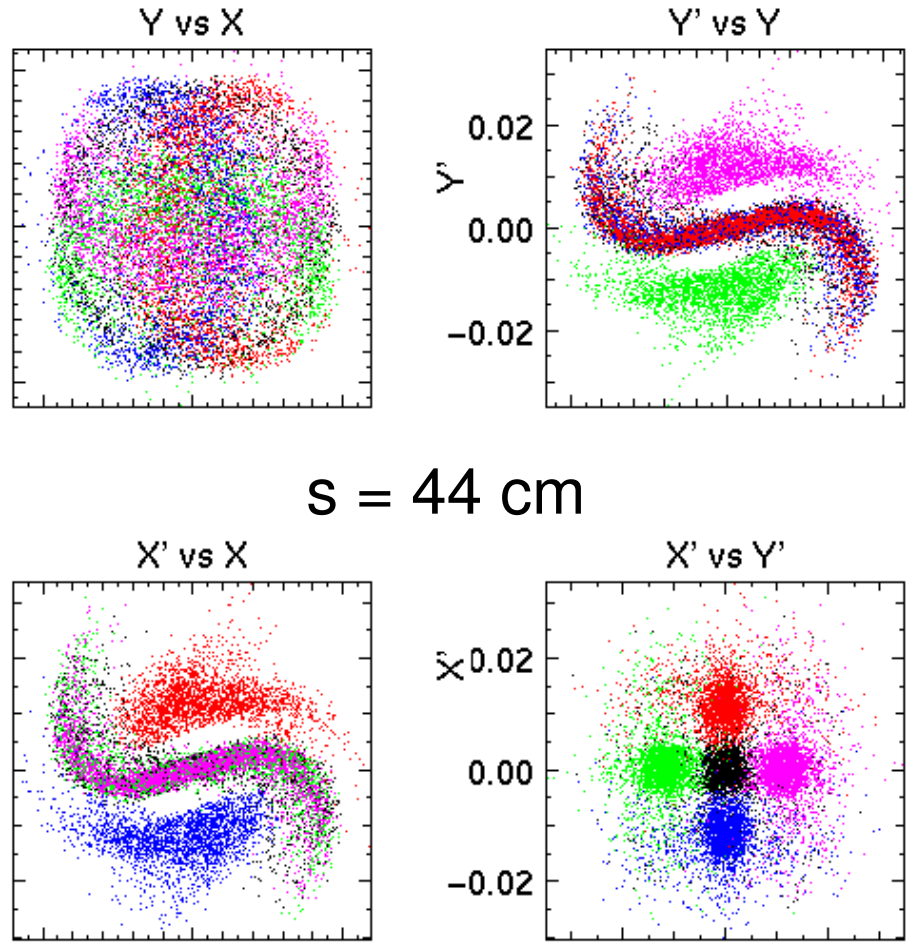


Merger of 5 beamlets

Experiment in IC2



Simulation in uniform channel



D. Stratakis, 2007

R. Kishek, AAC 2002

Conclusion

- UMER is an exciting and sophisticated facility

  "There is obviously so much that can be learned from UMER; … be prepared for a growing production rate of scientific papers!" -- UMER Advisory Committee*, 12/06

- Future of accelerators is very bright

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** CL. Bohn, D. Douglas, A. Friedman, T. Shea, T. Smith, B. Weng*

UNIVERSITY OF MARYLAND ELECTRON RING

I like to thank my colleagues …

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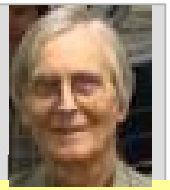
news

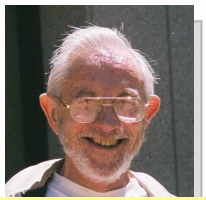
Present Members of UMER Group

Faculty Part-Effort


Martin Reiser

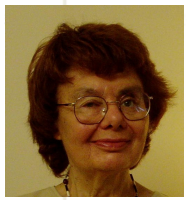
Terry Godlove

Irving Haber


Donald Feldman

Dave Sutter

Ralph Fiorito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Rami Kishek

Santiago Bernal

Mark Walter

Graduate Students

Kai Tian

Christos Papadopoulos

Diktys Stratakis

Gang Bai

J. Charles T. Thangaraj

Chao Wu

Brian Beaudoin

Faculty Part-Effort (more)

Bryan Quinn

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