Halo Studies at the University of Maryland Electron Ring (UMER)

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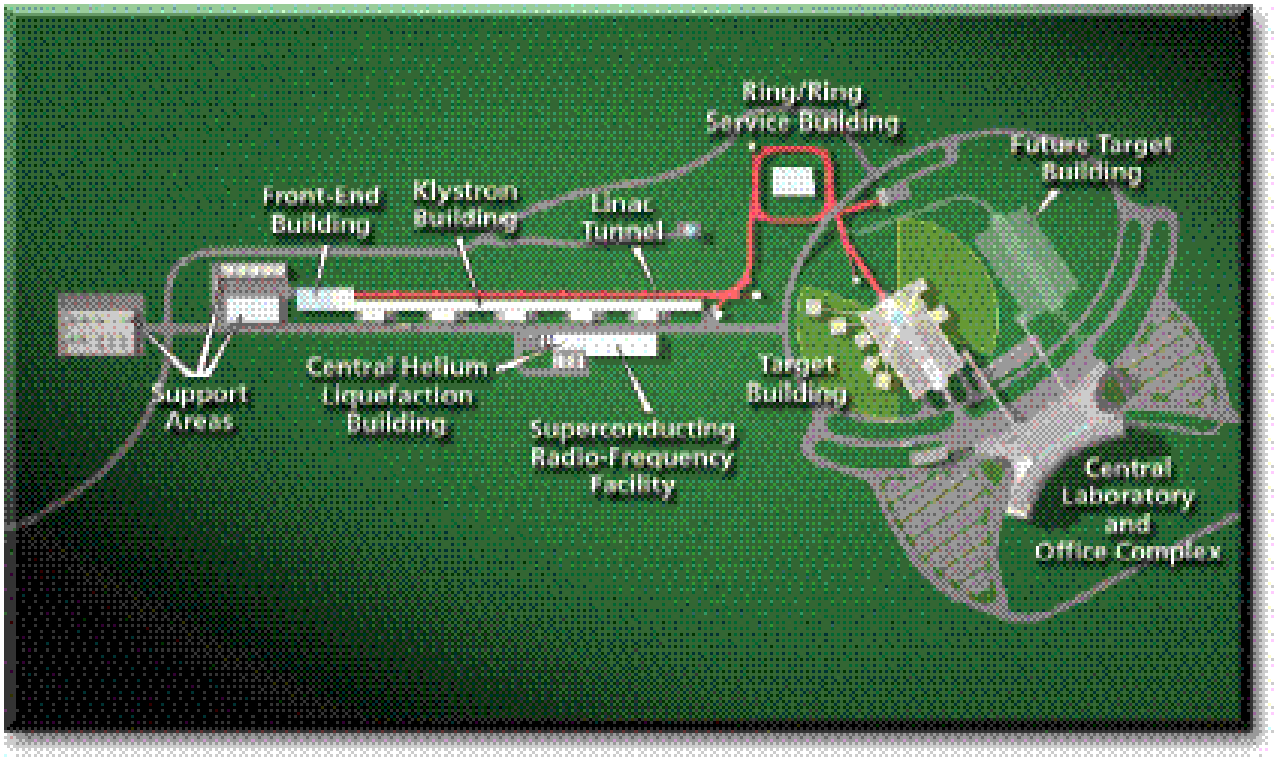
Work Sponsored by U.S. Dept. of Energy

Collaborators

***University of Maryland Electron Ring (UMER)* Team:**			
Patrick O'Shea **Martin Reiser** **Irving Haber**	Junior Scientists: **Santiago Bernal** **Bryan Quinn** **Agust Valfells** **Mark Walter** Yun Zou	Graduate: Yupeng Cui John Harris Hui Li Jon Neumann Matt Virgo	Undergraduate: B. Beaudoin A. Diep, D. Lamb M. Glanzer M. Qurius, R. Yun M. Snowel
Don Feldman Renee Feldman Terry F. Godlove			
Virtual National Lab for Heavy Ion Fusion (provided WARP)	Alex Friedman **Dave Grote** Jean-Luc Vay	Christine Celata Steve Lund **John Barnard**	***Thanks also to:*** **David Kehne** **Ingo Hofmann** **Tom Wangler** Rob Ryne Tom Antonsen
Fermilab / NIU	Court Bohn	Ioannis Sideris	
U. Florida (Astrophysics)	Henry Kandrup		

Scaled Experiments with Electrons



From Spallation Neutron Source, ORNL

Why electrons?

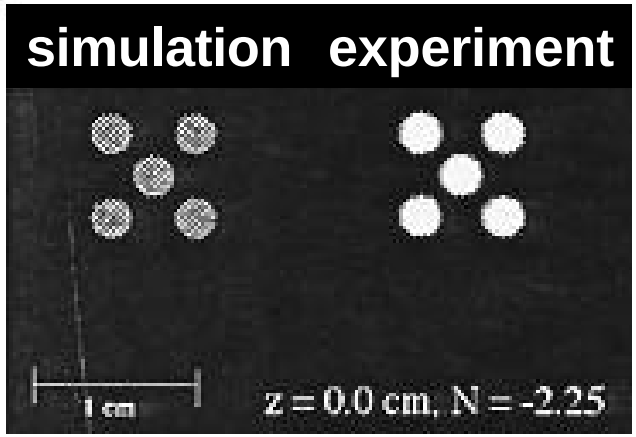
inexpensive

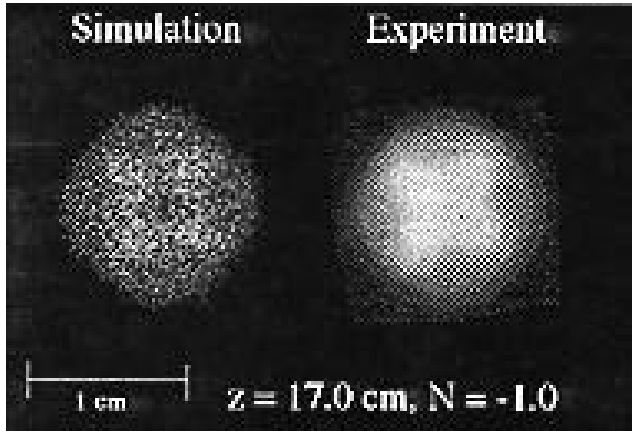
<u>Scaling laws</u>:

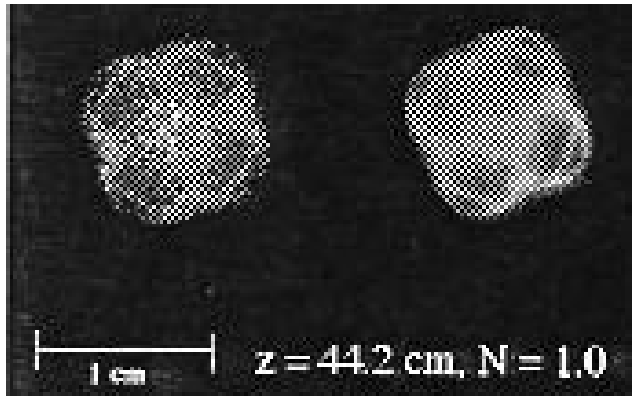
100-200 MeV, 50 A protons ≡ 10 keV, few mA electrons

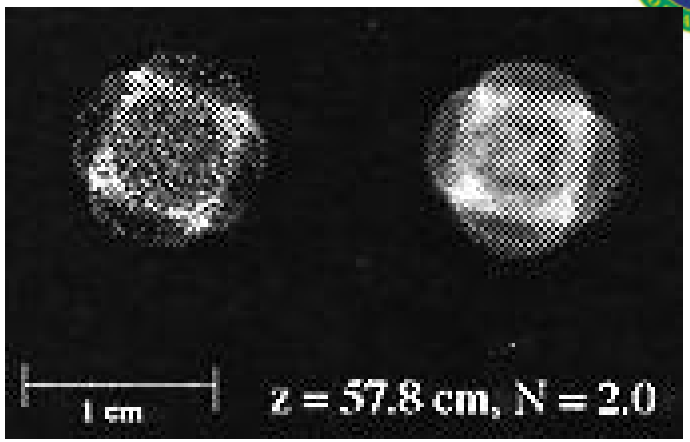
D. Kehne Exp.: RMS Matched Beam

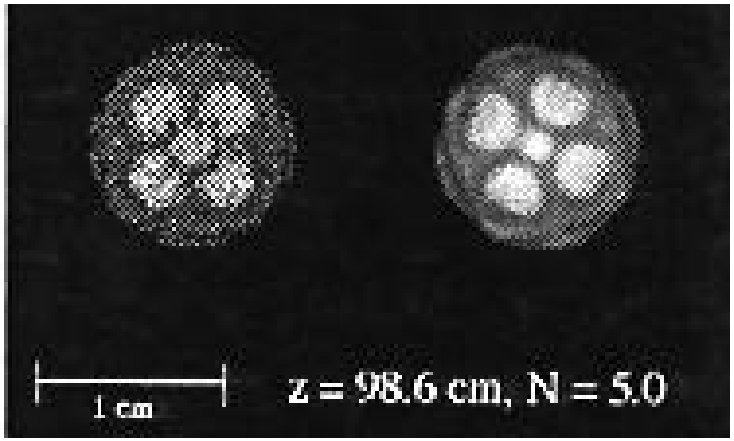
~ 1989

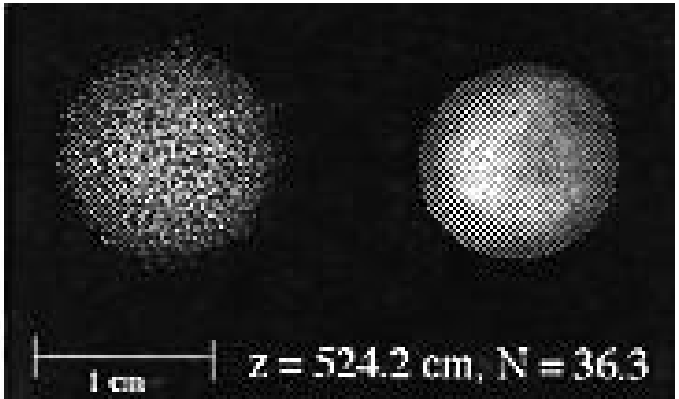




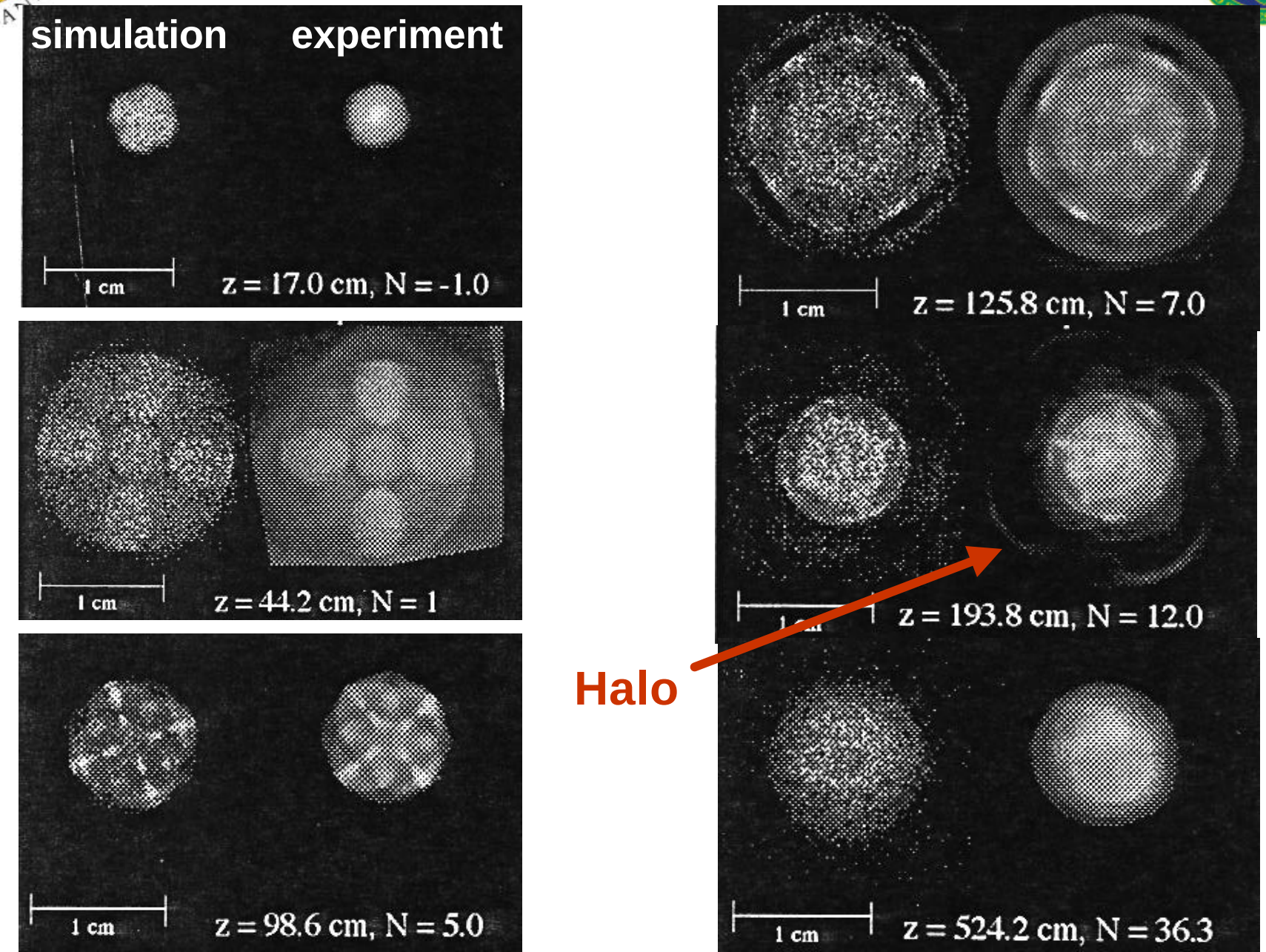








Kehne Exp.: RMS Mismatched Beam



Dec. 2002

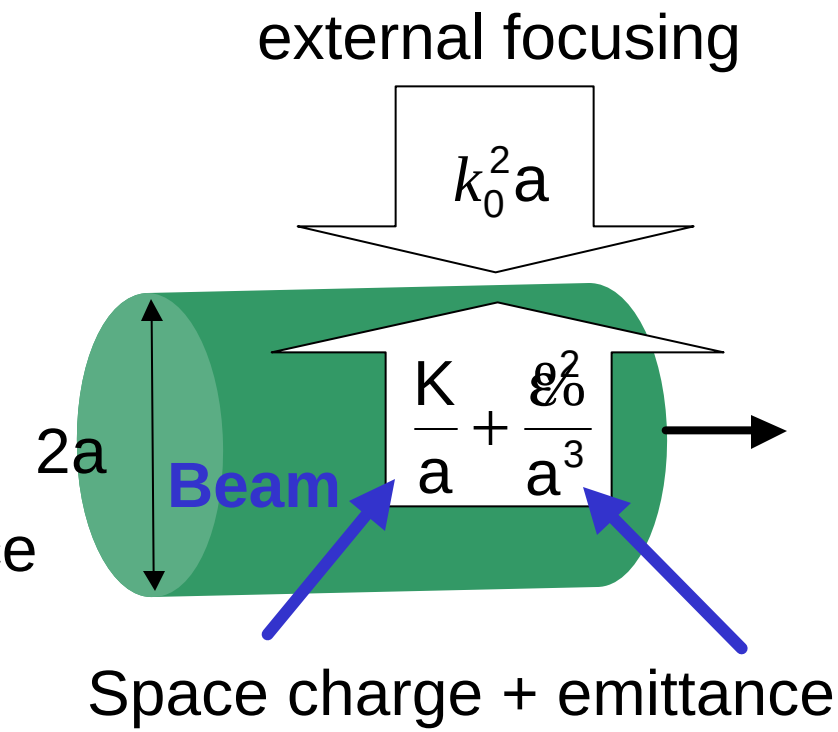
Dimensionless Space Charge Intensity

Matched Beam envelope equation (force balance):

$$k_o^2 a = \frac{K}{a} + \frac{e^2}{a^3}$$

$$K = \frac{2I}{I_o (bg)^3} = \text{Generalized Perveance}$$

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



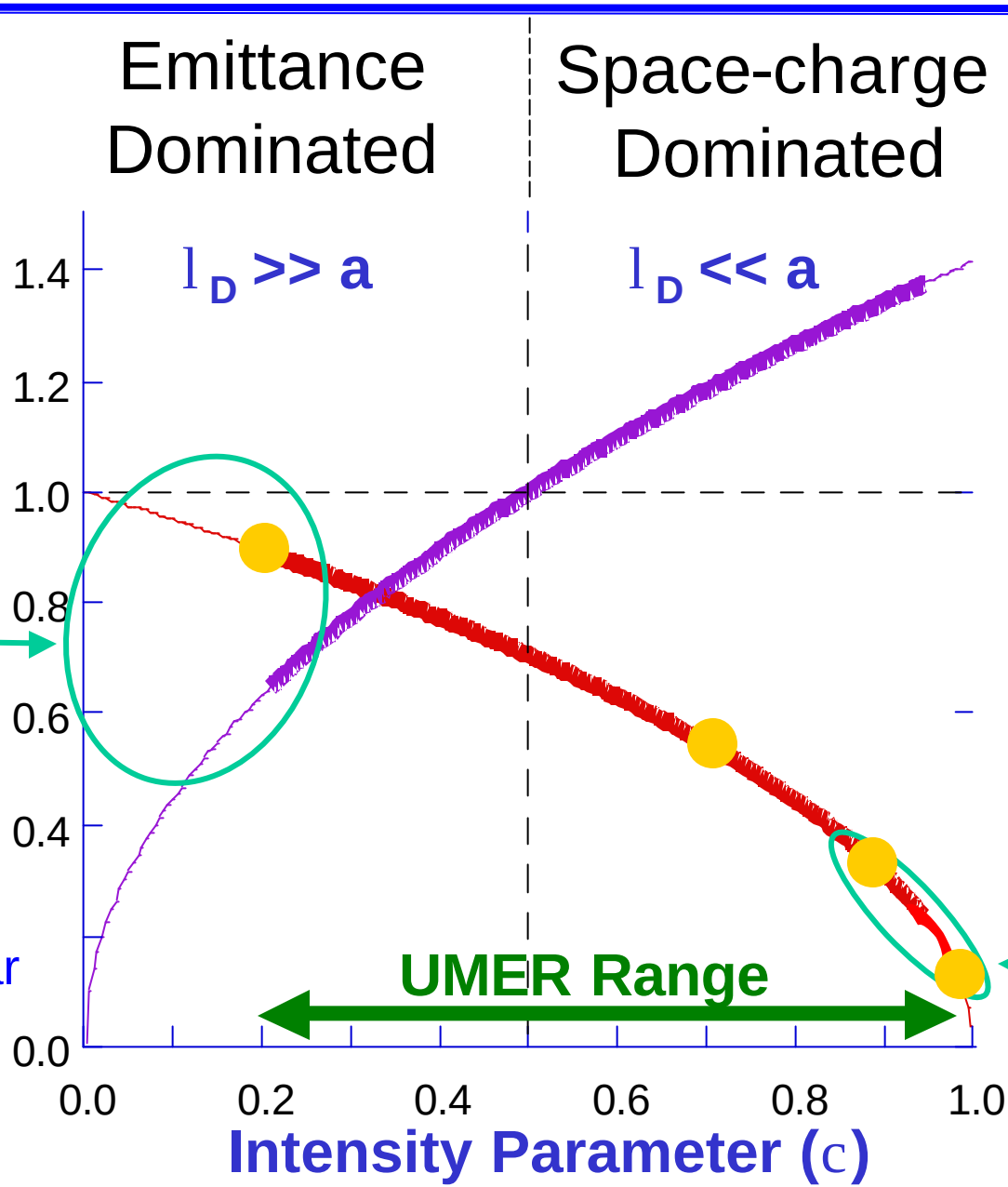
0 £ c £ 1

In UMER, force from Space charge can be as much as 55 times force from thermal pressure (emittance)!

Scalings with Space Charge Intensity

Intensity Parameter:

$$c = \frac{K}{k_o^2 a^2}$$



Plasma Oscillations Curve

$$\frac{w_P}{w_0} = \sqrt{2c}$$

Betatron Oscillations Curve

$$\frac{k}{k_0} = \sqrt{1-c}$$

Existing rings

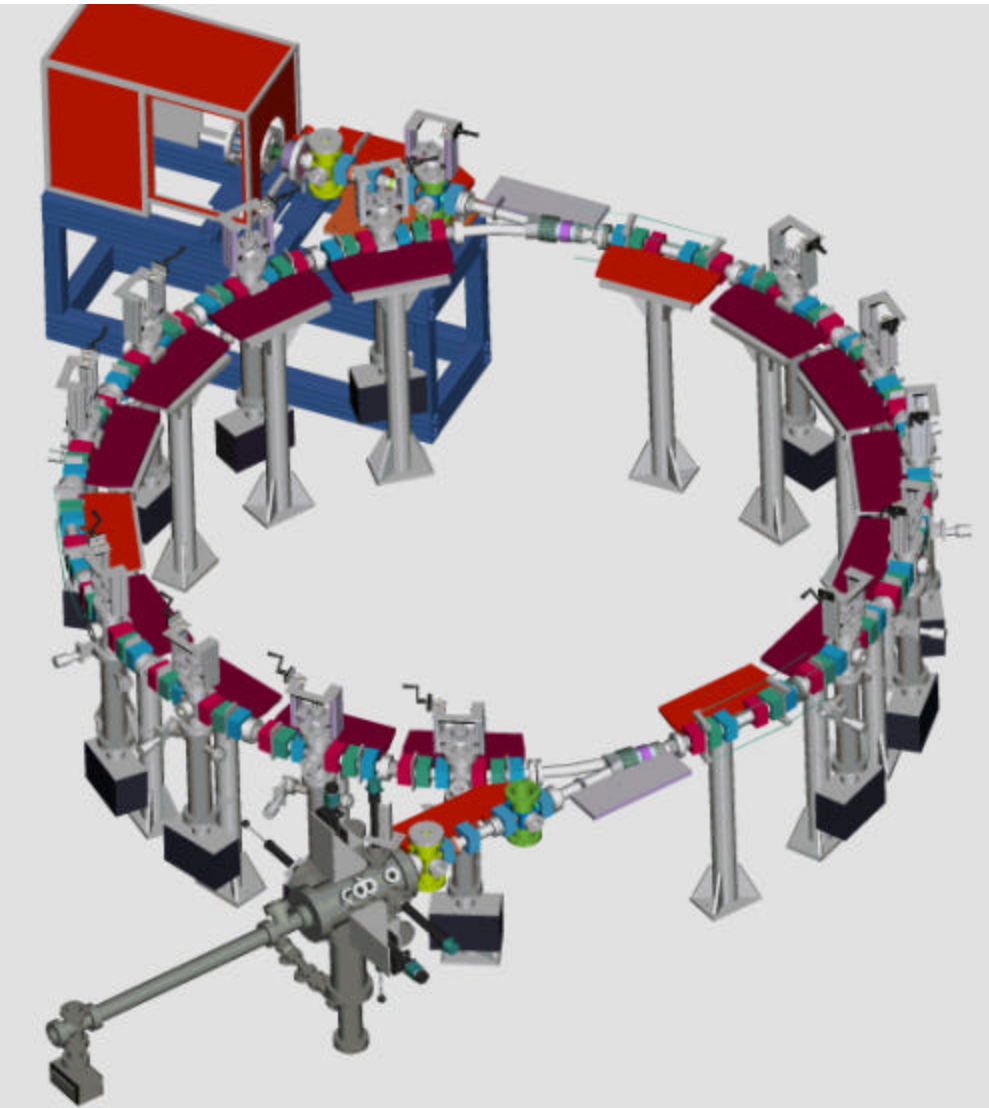
Experiments Conducted so far

HIF Drivers

University of Maryland Electron Ring

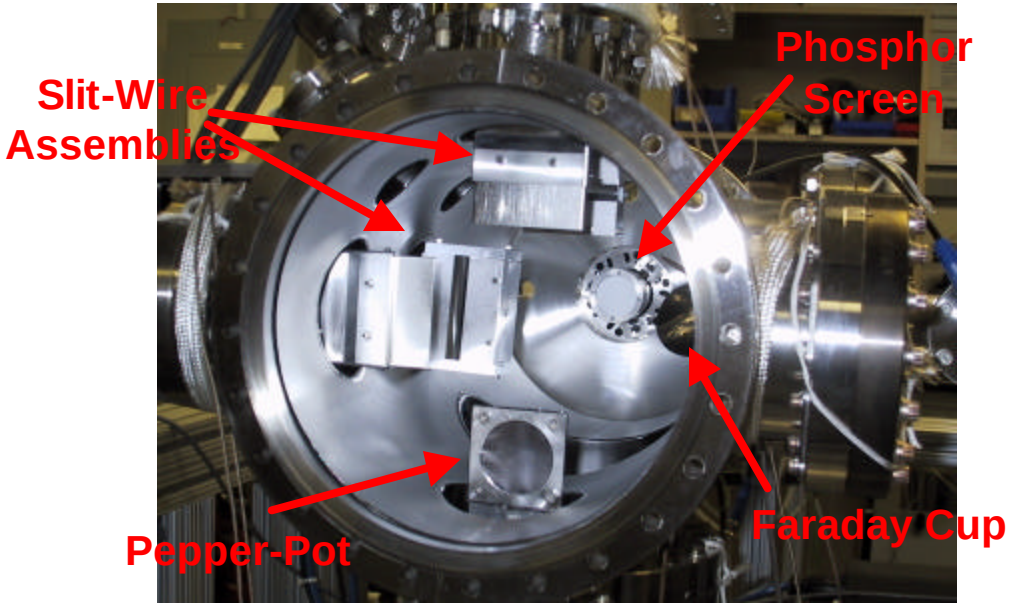
UMER designed to serve as a **research platform** for intense beam physics

- Variable-Parameter over a wide range
- Long Path
- Well-Diagnosed
- Low-Cost!
- Expected Completion:
  Late 2003



Diagnostics Available

- Fast Current Monitors (2+)
- Beam Position Monitors (17 BPMs)
- Phosphor Screens (18+ P-Screens)
- End Diagnostic Chamber:
  - **Energy Analyzer**
  - **Pepper-pot Emittance (Phase Space) Monitor**
  - **Slit-Wire Emittance (Phase Space) Monitor**
  - **Faraday Cup**



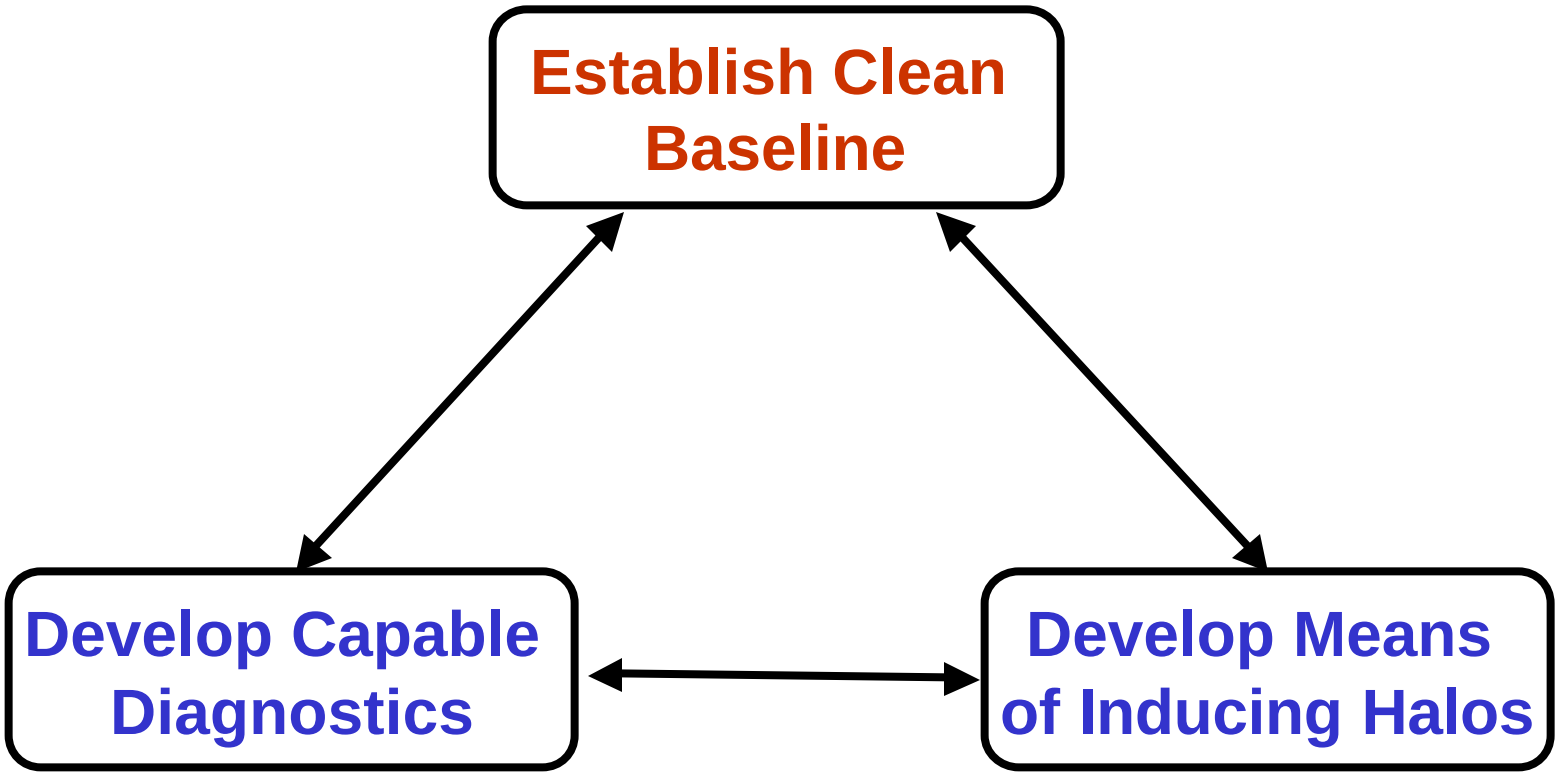
UMER Research Goals

Beam Dynamics Modeling:

- Multi-turn dynamics – *bunch capture and shaping*; beam end confinement using induction gaps
- **Code benchmarking**
- Energy Spread
- Space Charge Waves: Transverse and Longitudinal
- Generation of arbitrary perturbations using laser
- Resonances, **Halos**, Anisotropy

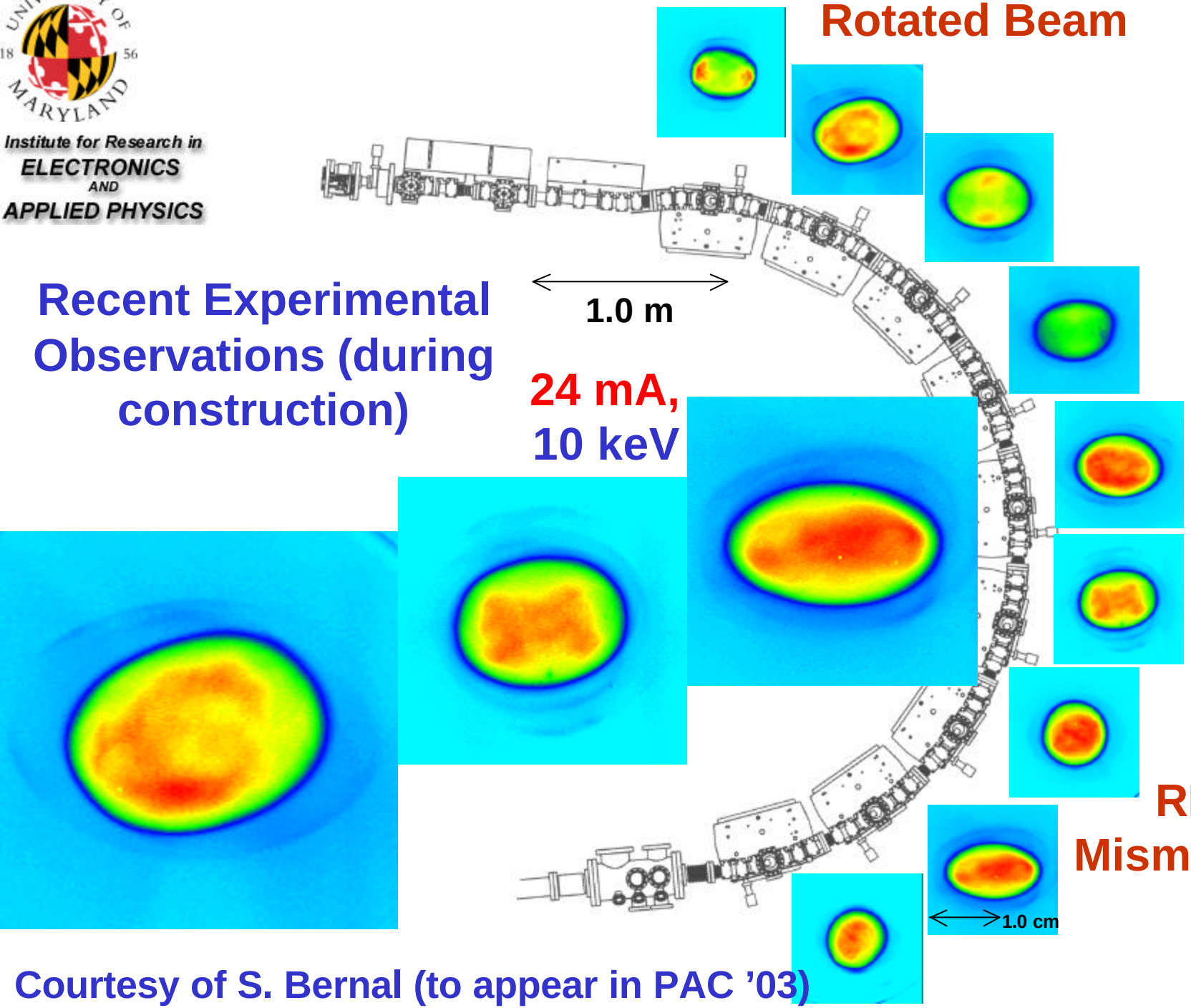
Eventually: Induction acceleration and resonance traversal

Prerequisites for a Halo Experiment



Institute for Research in ELECTRONICS AND APPLIED PHYSICS

Recent Experimental Observations (during construction)



Courtesy of S. Bernal (to appear in PAC ’03)

Simulation with WARP

WARP combines features of a plasma simulation and an accelerator code

PIC with self-field in moving window (electrostatic; Darwin planned)		
WARP3d x, y, z, p_x, p_y, p_z warped Cartesian	**WARPrz** r, z, p_r, p_q, p_z	**WARPxy** x, y, p_x, p_y, p_z

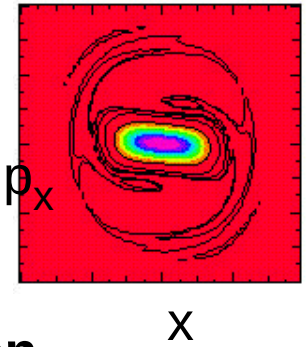
"lattice" of focusing, bending, and accelerating elements			
sharp edged	axially varying multipole moments	data on a 3D grid	first-principles electrostatic elements at subgrid scale

user-programmable interpreter interface (Python)

parallelization and advanced algorithms

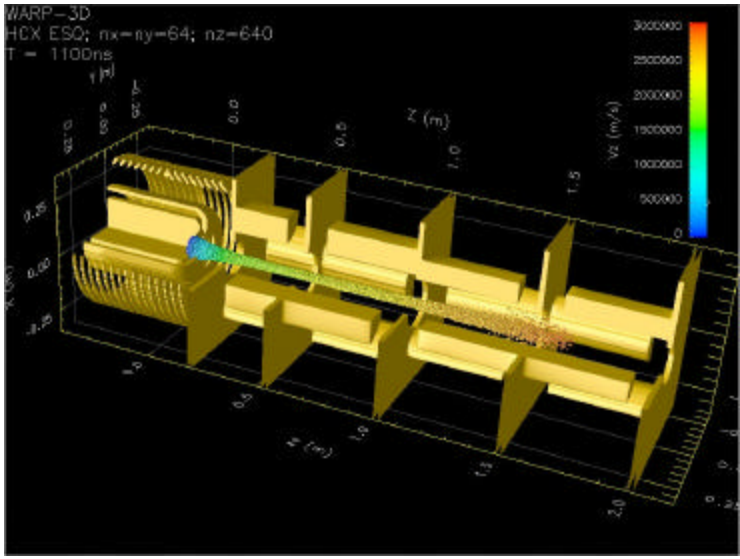
Courtesy Alex Friedman

Key aspects of WARP3d



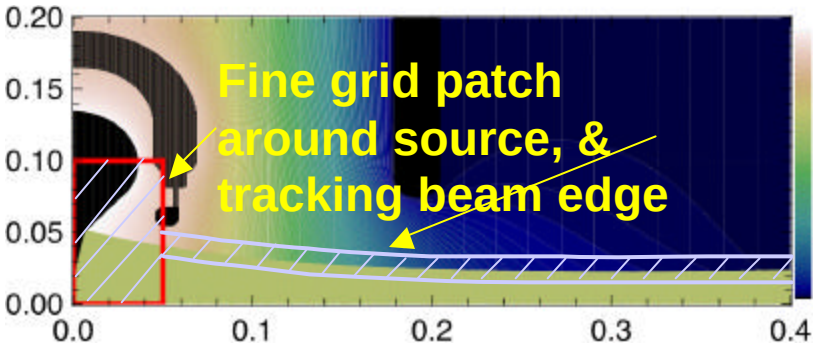
Techniques

- "Warped"Cartesian mesh
- Time is independent coordinate for particle motion
- Subgrid-scale conductor edge resolution
- Adaptive Mesh Refinement (AMR)
- Time-dependent and steady-state modes
- One- and two-plane symmetries
- Linking of simulations
- Large Dt algorithms
- Parallel processing



Capabilities

- Time-dependent space-charge limited injection, inc. AMR
- Arbitrary applied fields in space & time
- Multi-species
- Overlapping beam-line elements
- Non-paraxial treatment

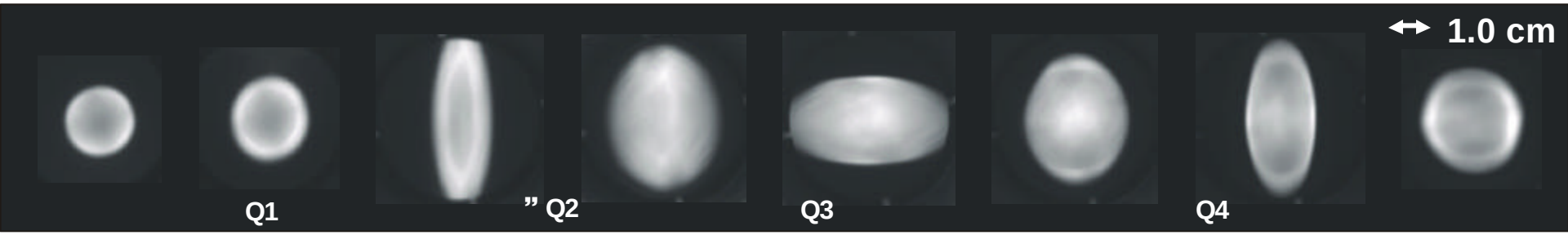


Courtesy Alex Friedman

WARP Simulation Agrees Well

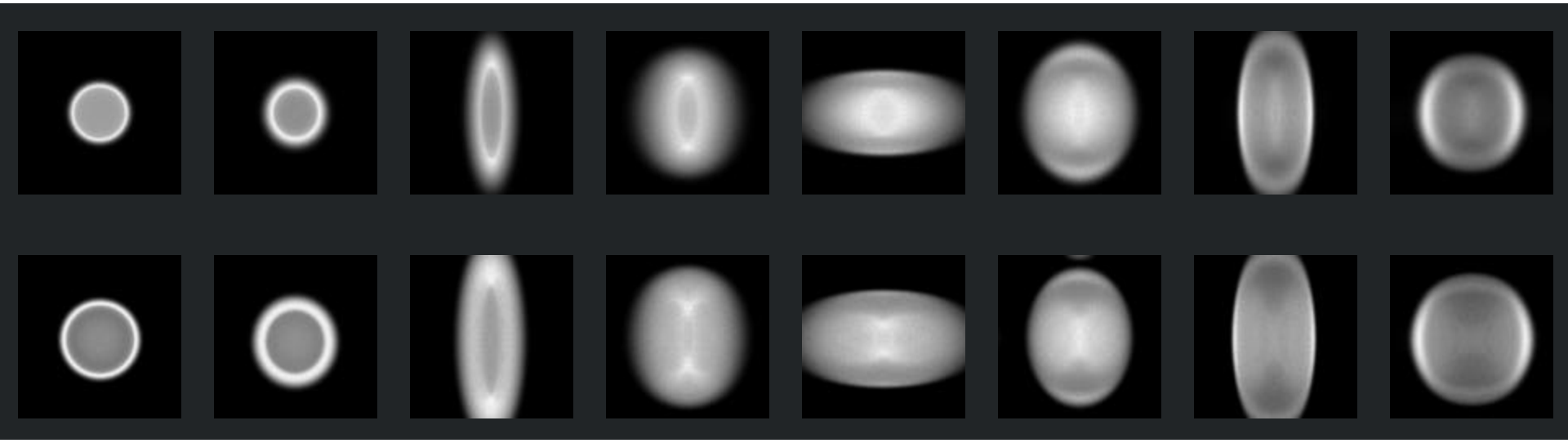
Beam patterns sensitive to initial velocity distribution!

Experiment (100 mA) (top)



WARP Simulation (below)

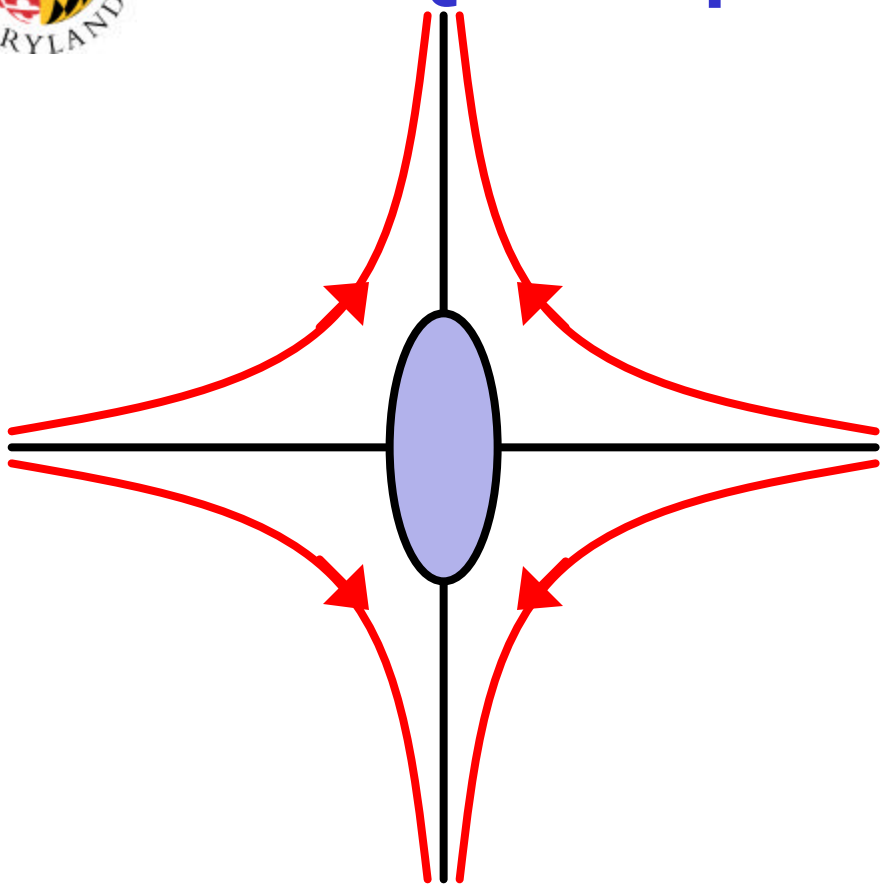
Semi-Gaussian Distribution



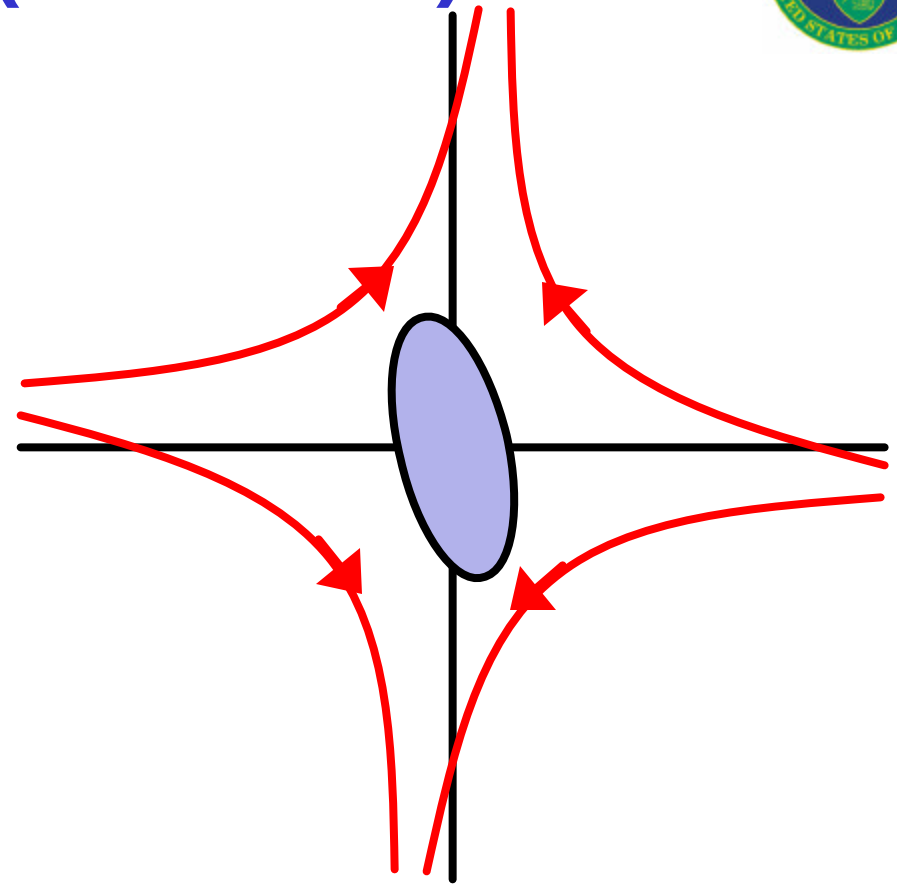
Hollow-Velocity Distribution

Experiment Photos Courtesy of S. Bernal (to appear in Proc. CPO-6)

Skew Quadrupole (Rotational) Errors



Regular Quadrupole

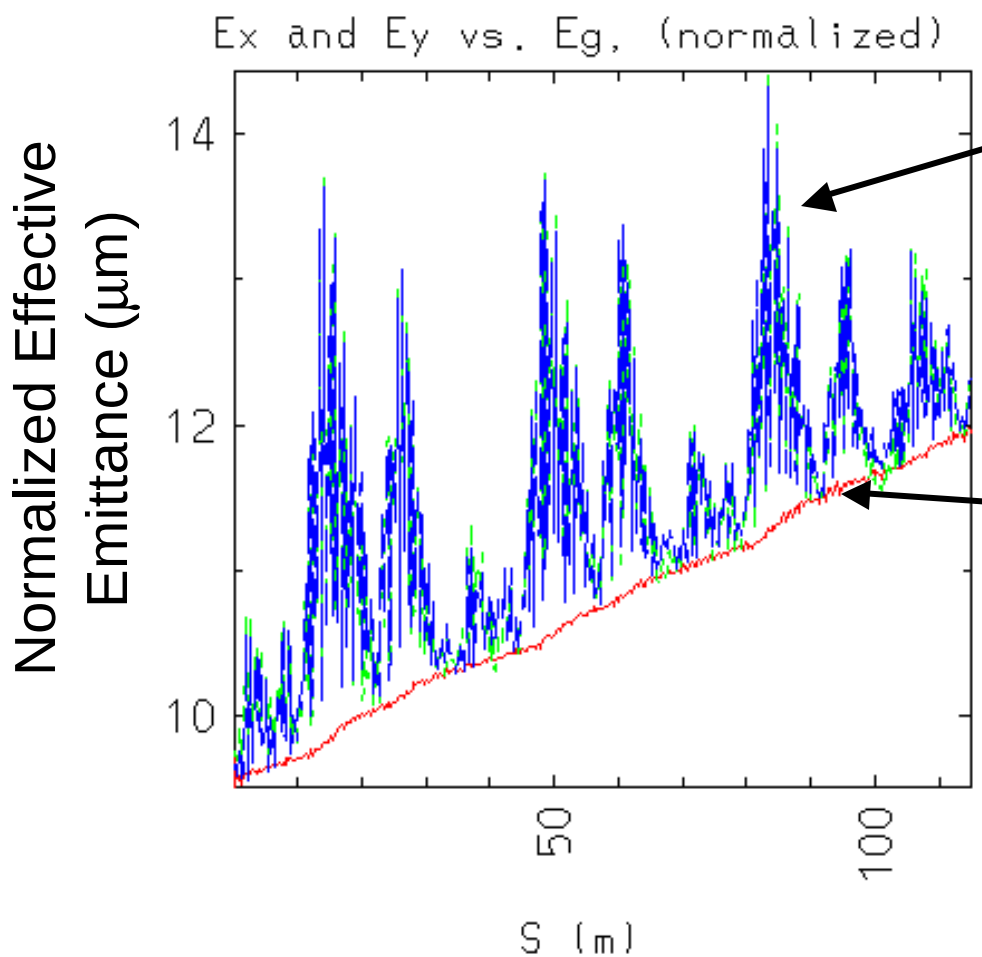


Skew Quadrupole

Cross-moments, e.g. <xy> or <x'y> nonzero, so emittance not conserved

Can defined generalized emittances ε_g, ε_h which are conserved (see J.J. Barnard, *et al.*, PAC'95)

Super-Periodic UMER lattice
High Current (100 mA), 0.2° rms errors

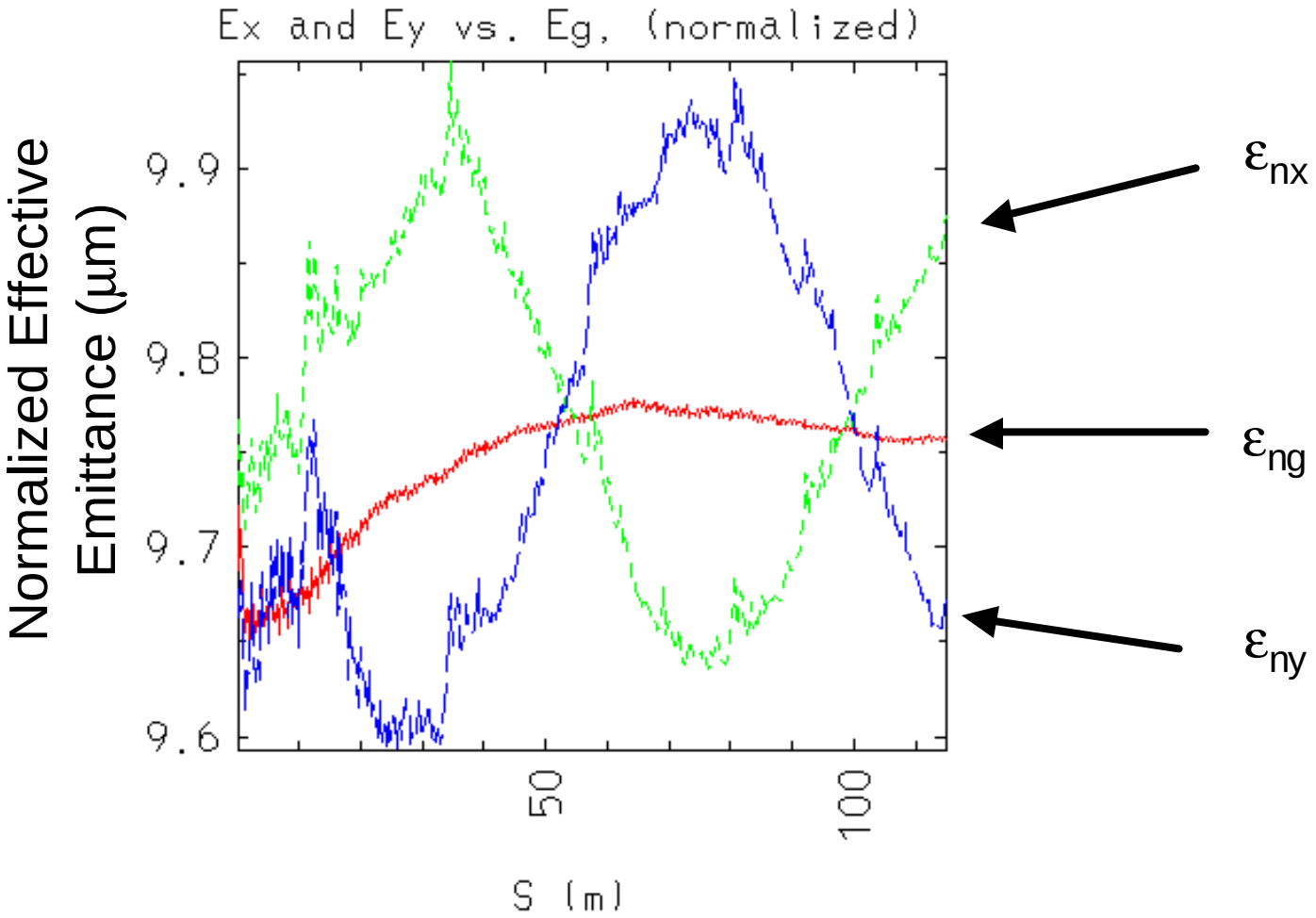


Standard x, y 4*rms emittances, ε_{nx}, ε_{ny}

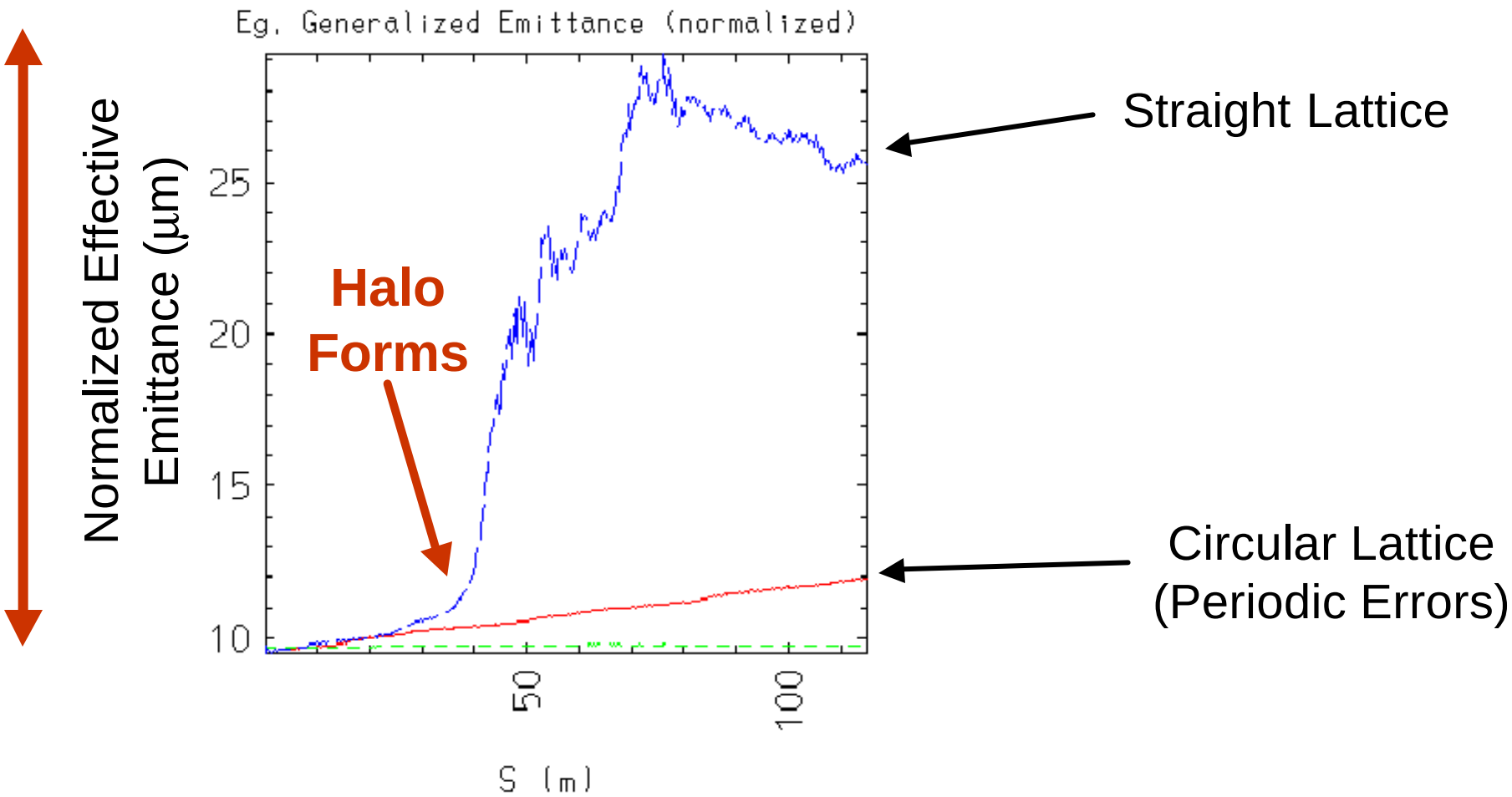
Generalized emittances, ε_{ng}, ε_{nh}

Kishek, Barnard, and Grote, PAC 1999

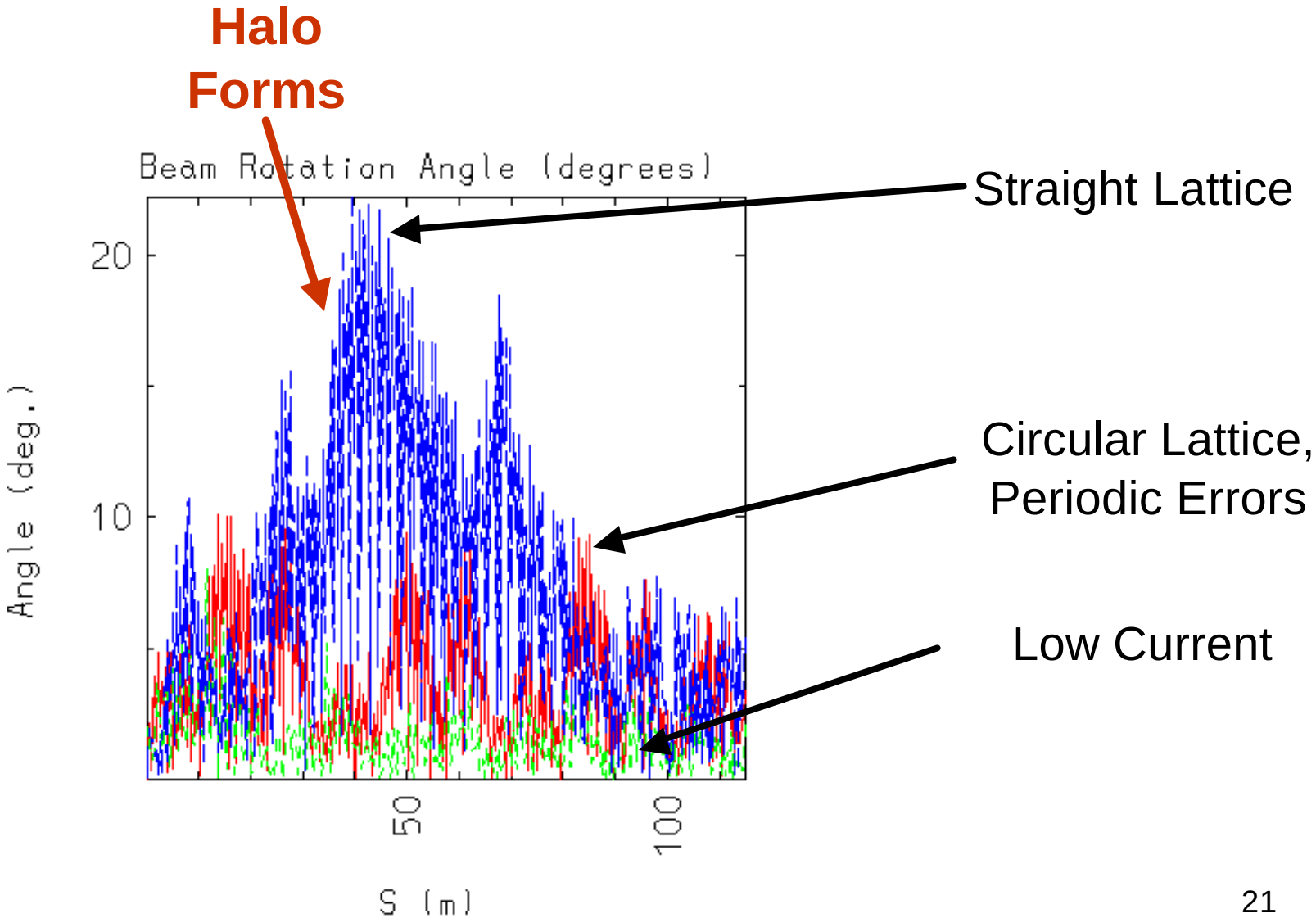
Low Current (1 mA), 0.2° rms errors



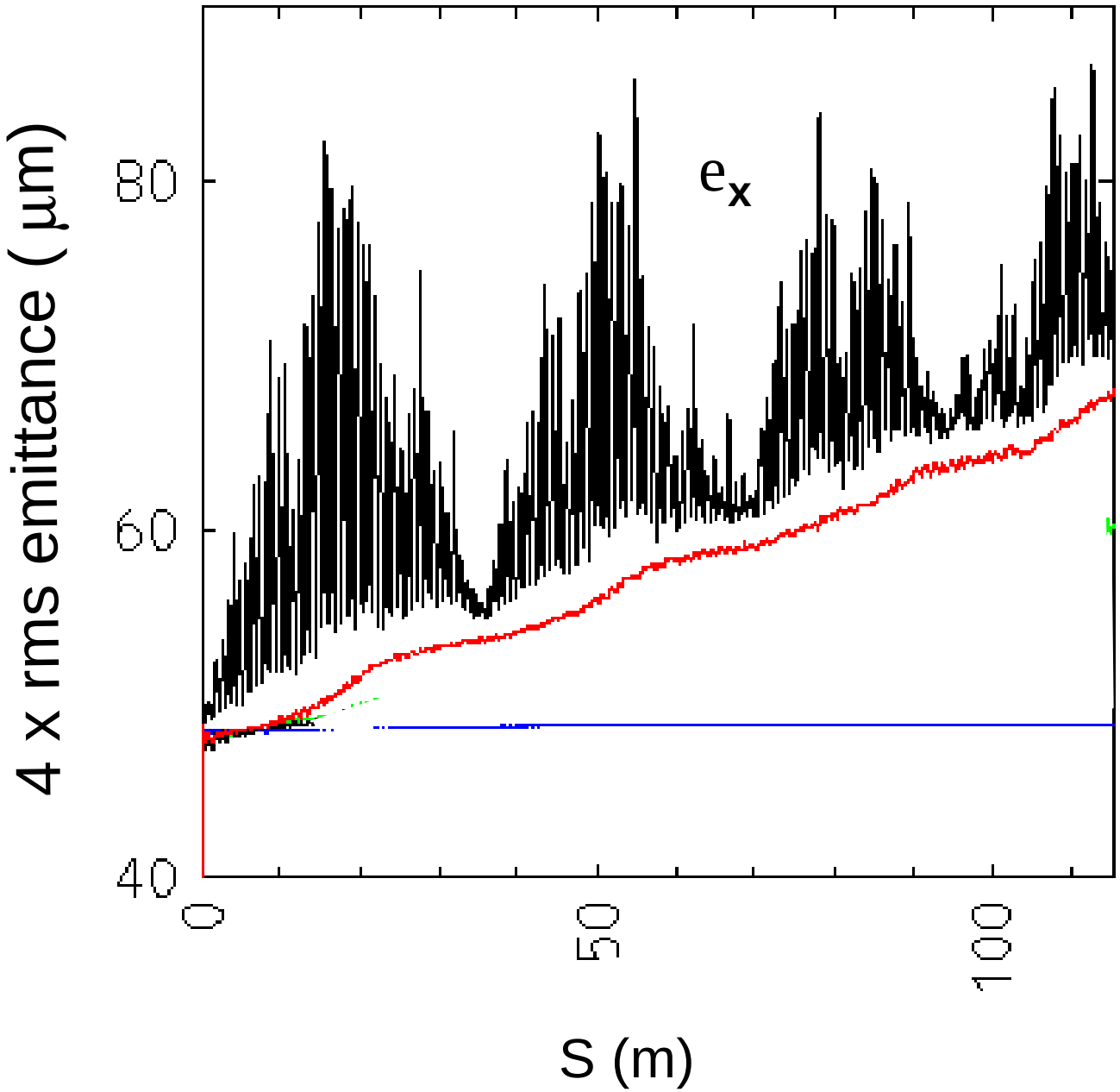
Super-Periodicity removed (straight)
Low Current (1 mA), 0.2° rms errors



Beam Rotation Angles



Correction of Random Skew Quad Errors



0.2° rotation errors

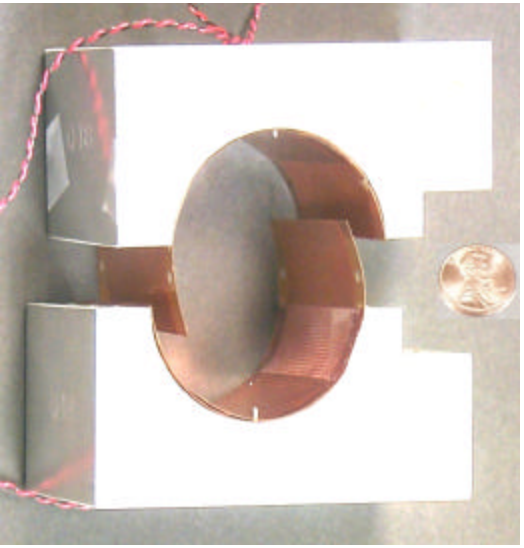
ε_g (100mA)

100 mA corrected

98 mA off-resonance

ε_g zero current

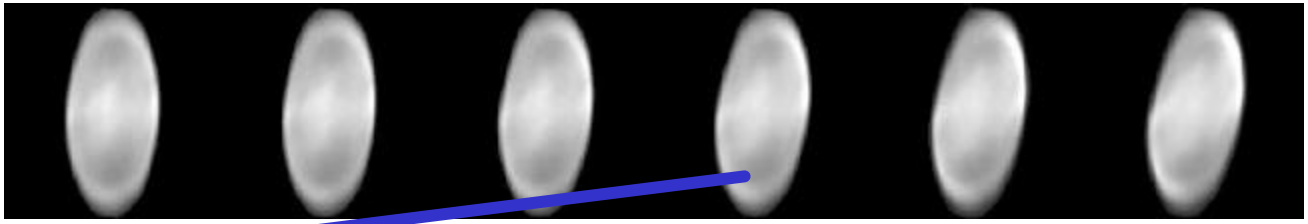
Quadrupoles with *Electronically* Adjustable Skewness



Two sets of coils at 45 deg

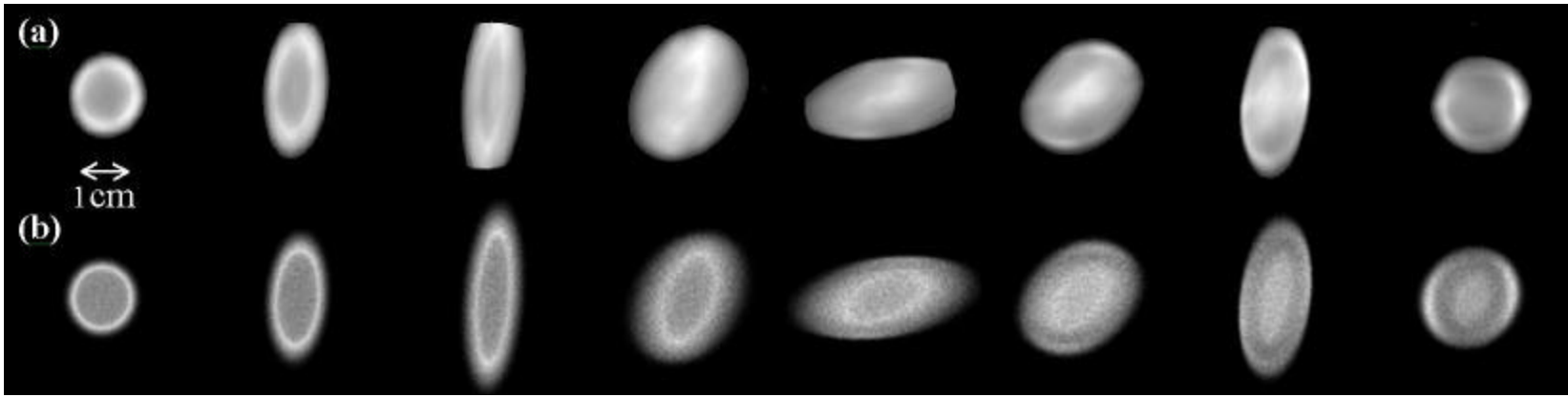
Exp. data **Skew angle:**

0.93º 1.86º 2.79º 3.72º 4.66º 5.60º



Experiment

Simulation

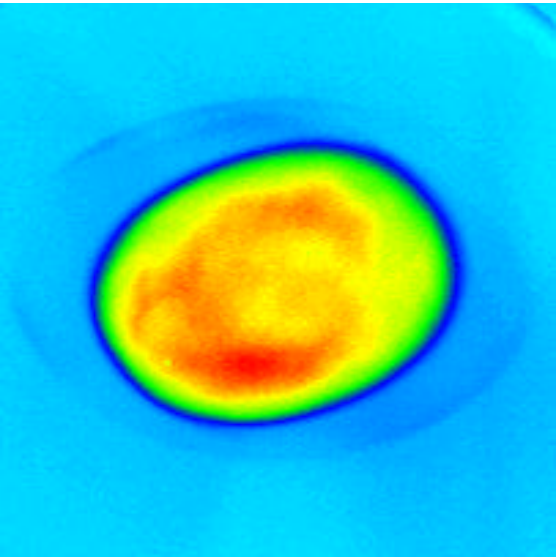


Q1 is electronically rotated 3.72^0

H. Li, S. Bernal, et al., PAC 2001

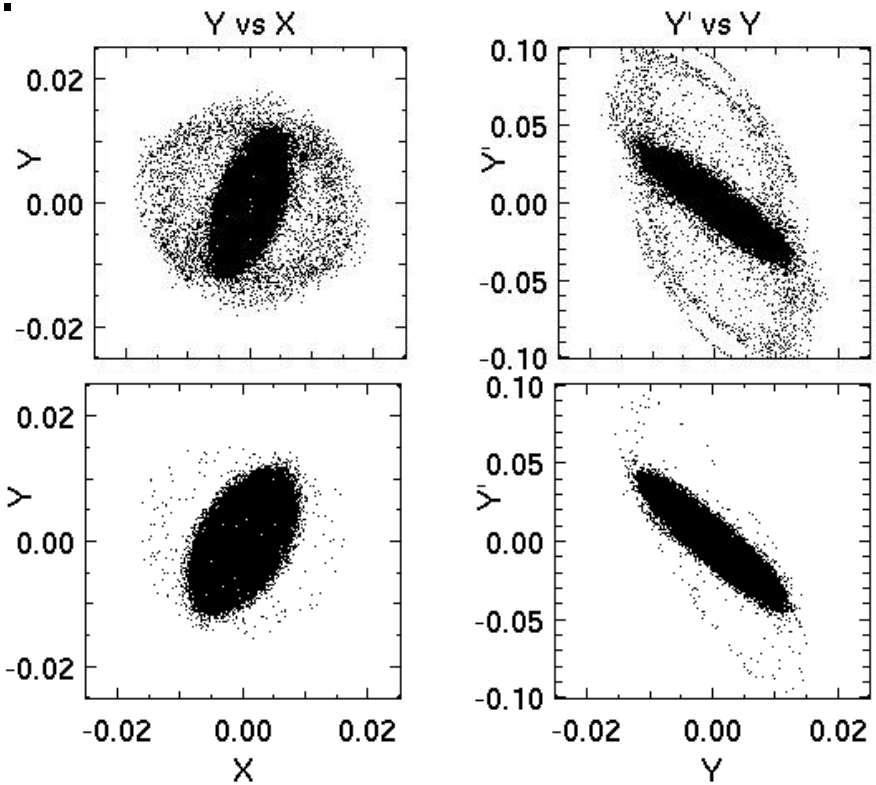
Injecting Rotated Beams – in Progress

- In **periodic lattice**, small errors in a single magnet are OK
- In **injector matching section**, even a 2 mrad error in one quad can result in a large beam rotation (20°) downstream!
- *Injecting a beam with large rotation can be detrimental*, even if periodic lattice is perfect.



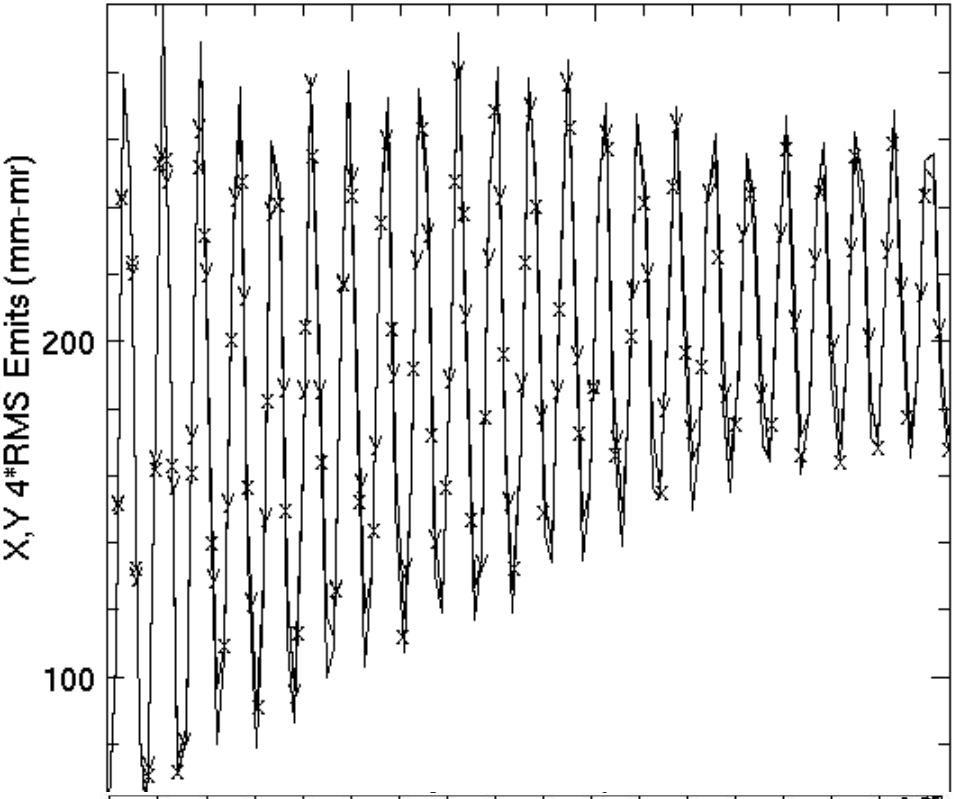
Inject Beam Rotated 20°

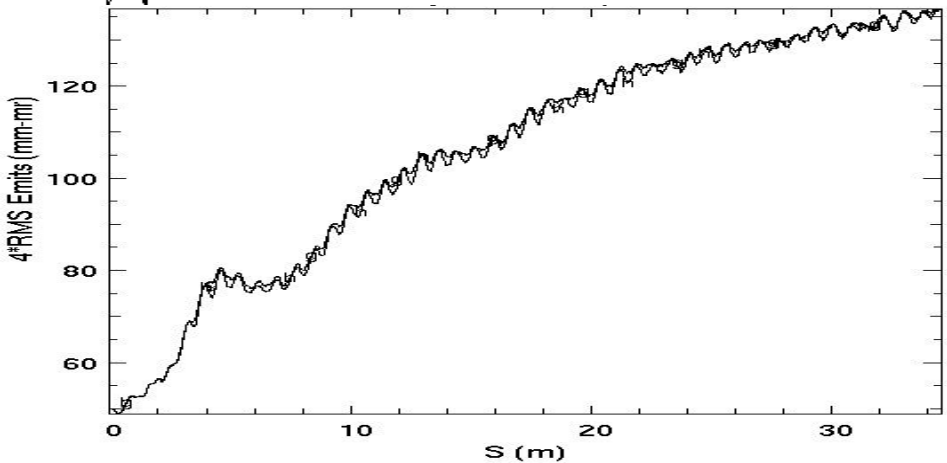
Inject Beam Rotated 10°

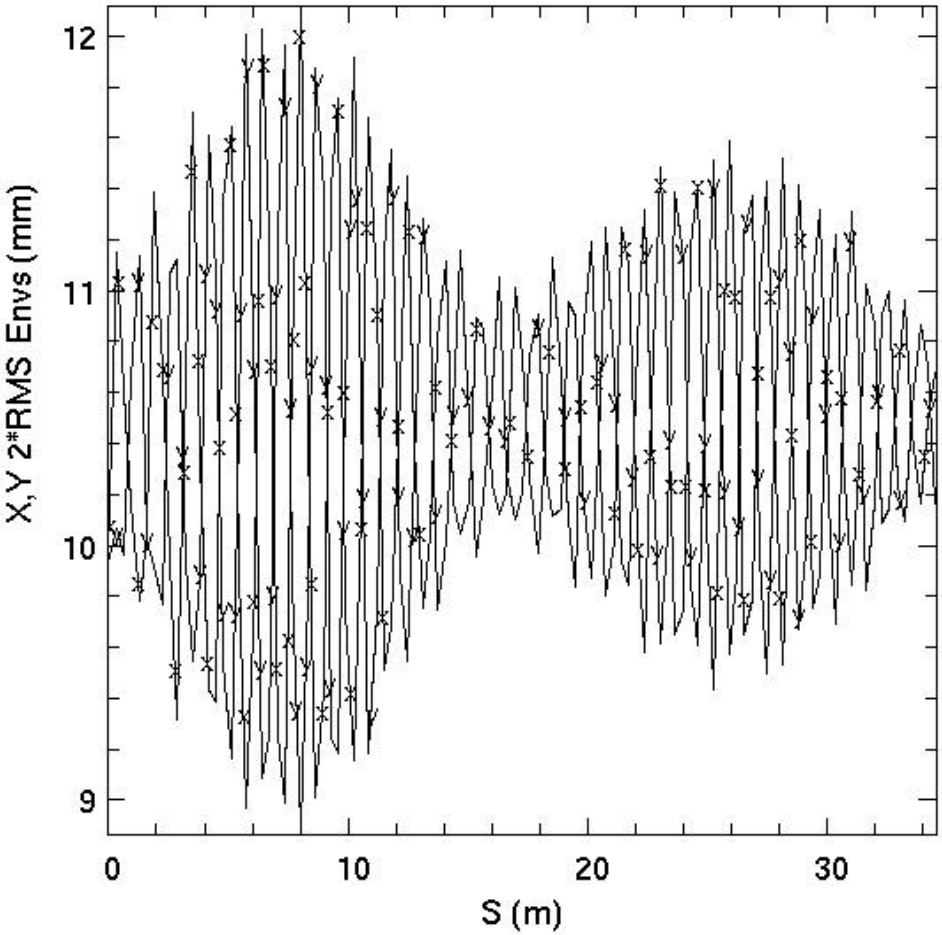


S = 8.64 m from injection point

Emittance and Envelope – 10° injection







Conclusions

- Controlled halo experiments require a clean baseline:
  - **controlling and correcting skew quad errors**
  - **careful matching**
  - **thorough simulation**
- Currently exploring different diagnostics
- Developing methods to control initial distribution (apertures and laser photoemission)
- Also interested in anisotropy effects
- Feedback and Collaborations welcome!

Much More to Come!

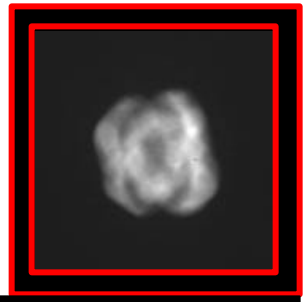
http://www.ireap.umd.edu/umer/

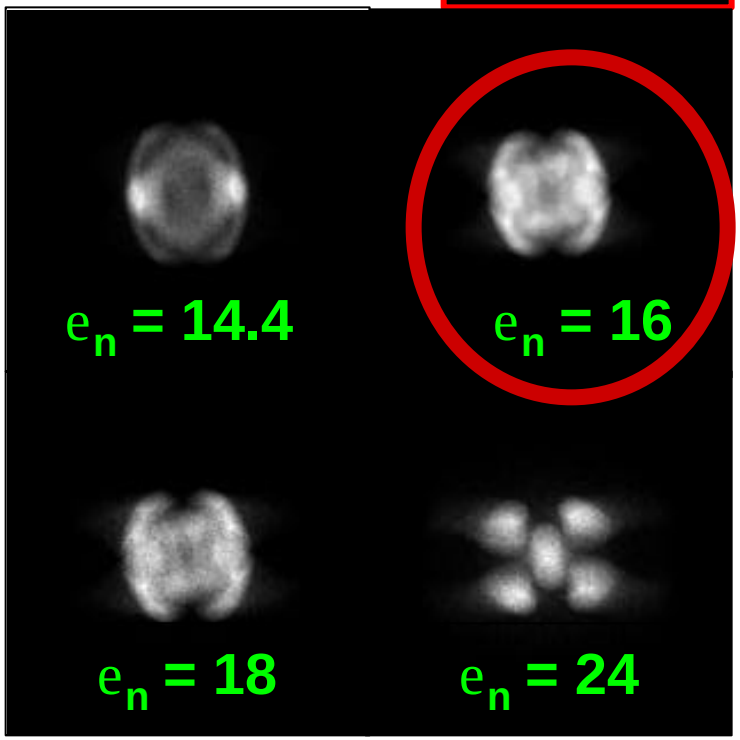
New 5-Beamlet Experiment

Experiment Þ

99 cm from mask

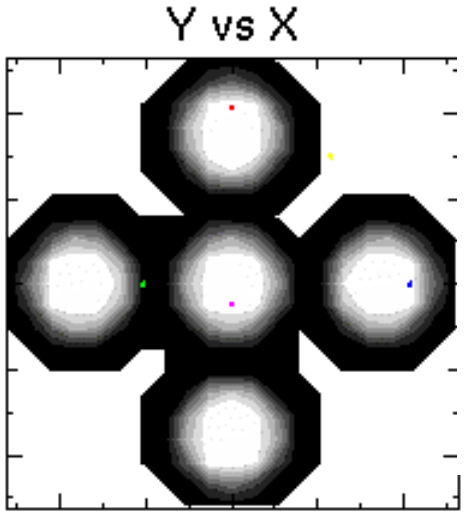
ß Simulation



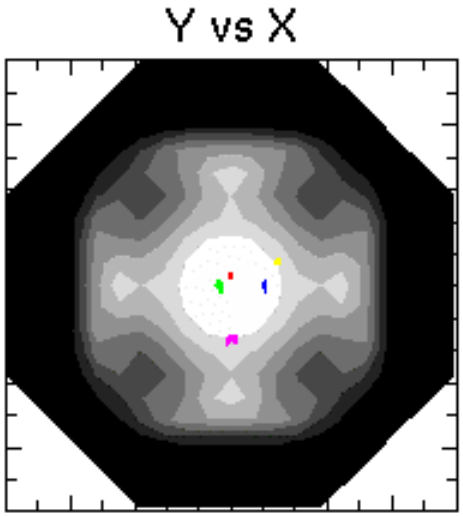


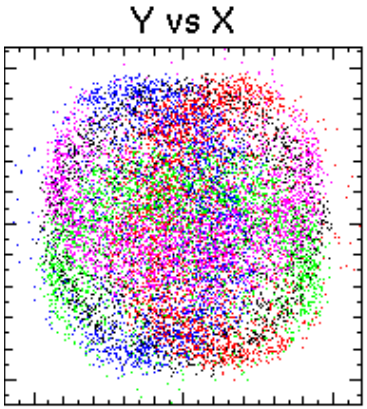
5-Beamlet Particle Tracking Simulations

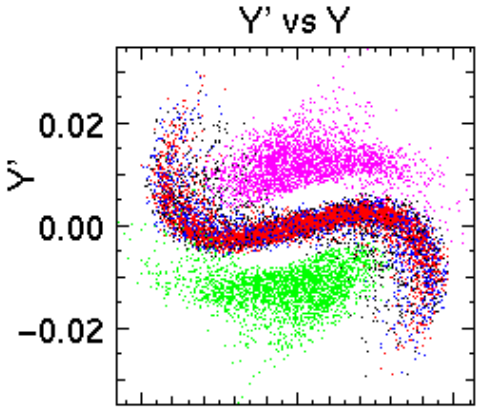
Matched



0.0 m

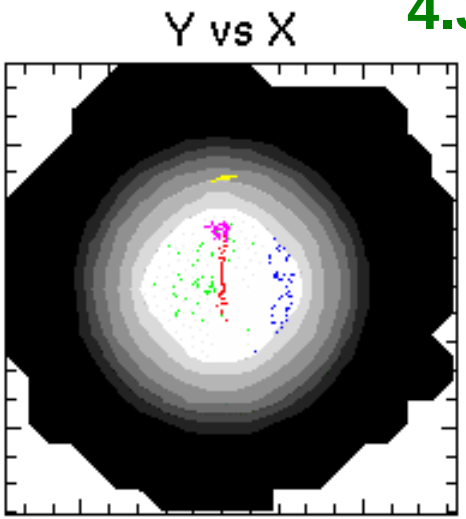


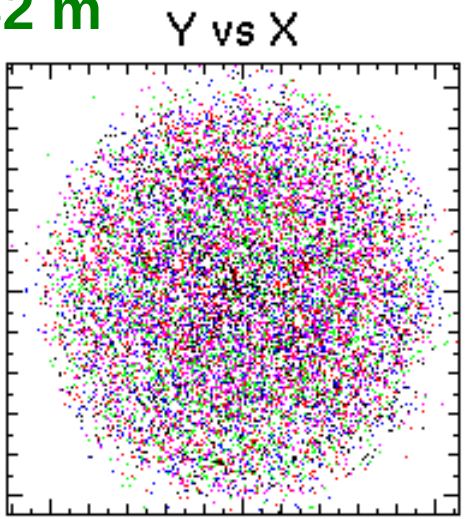


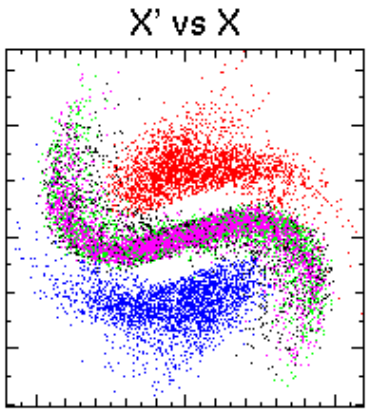


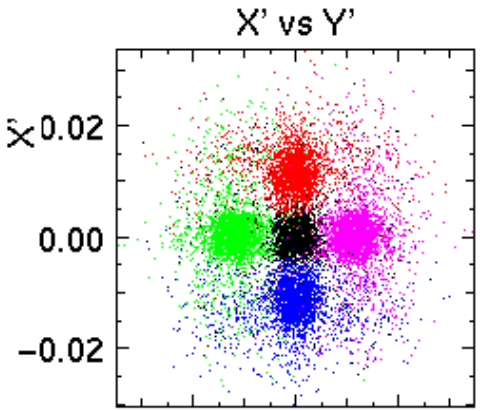
0.44 m

4.32 m



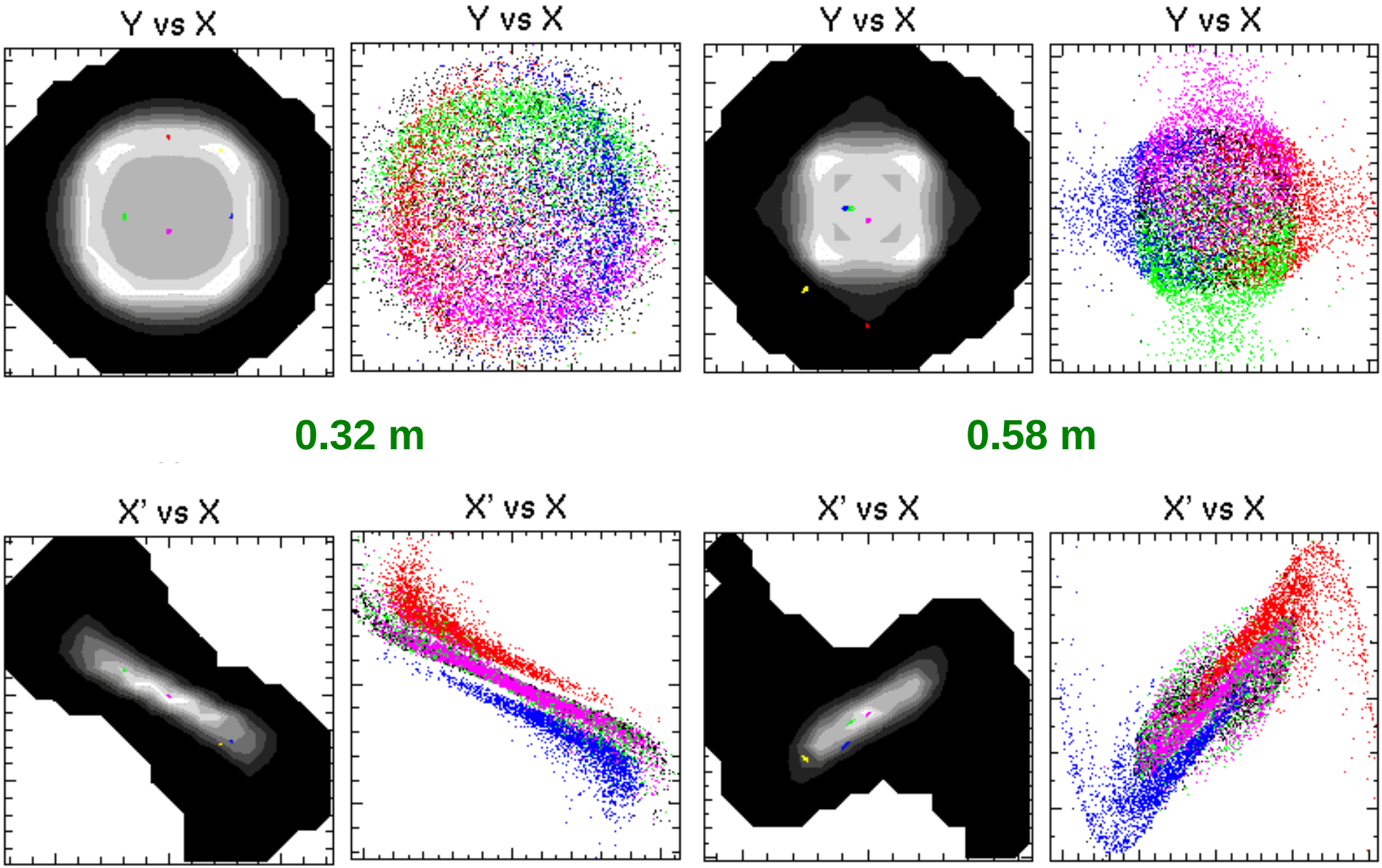






5-Beamlet Particle Tracking Simulations

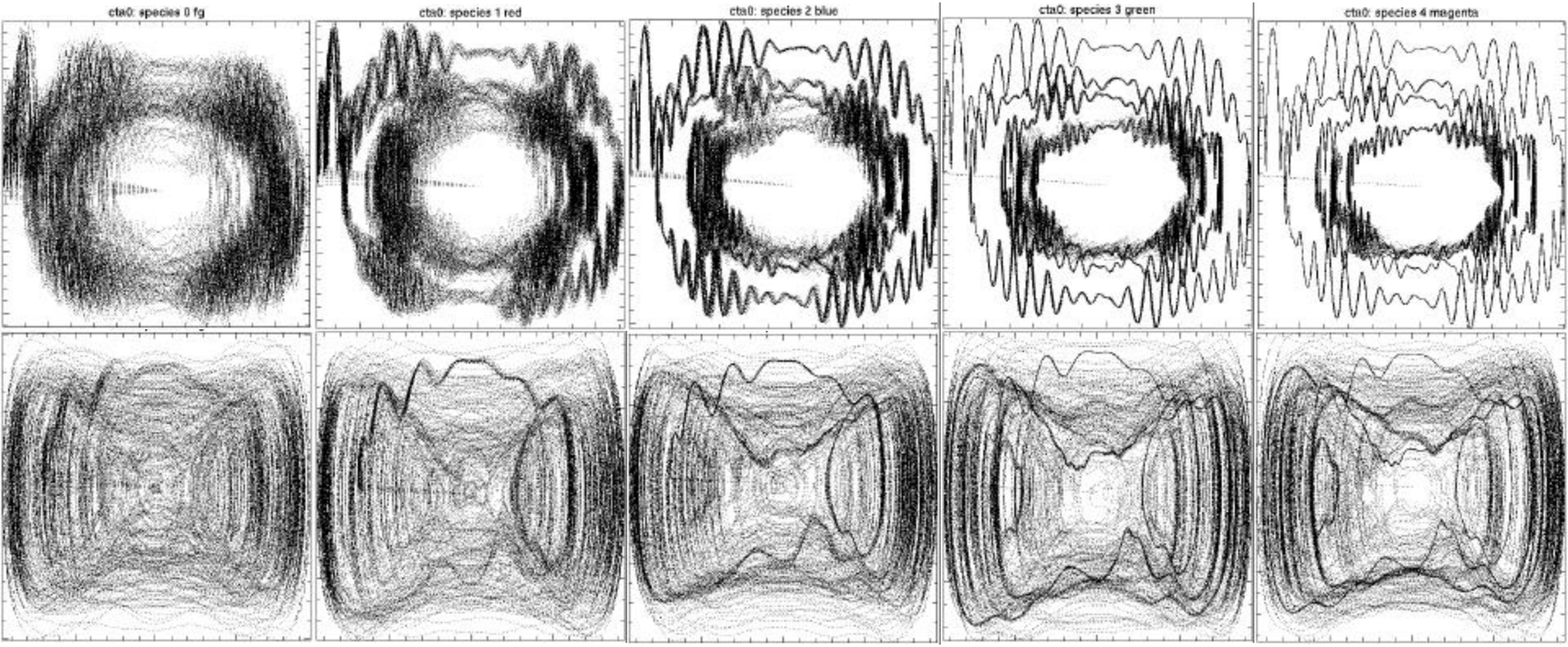
Mismatched



Particle Trajectories: x-x' Phase Space

Decreasing initial clump emittance

Isotropic



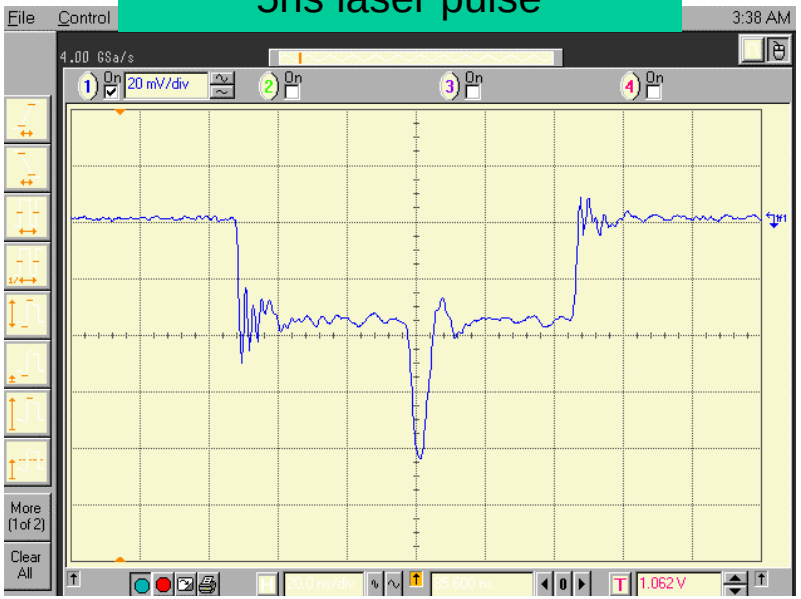
Anisotropic

First Photoemission at UMER (2/2003)

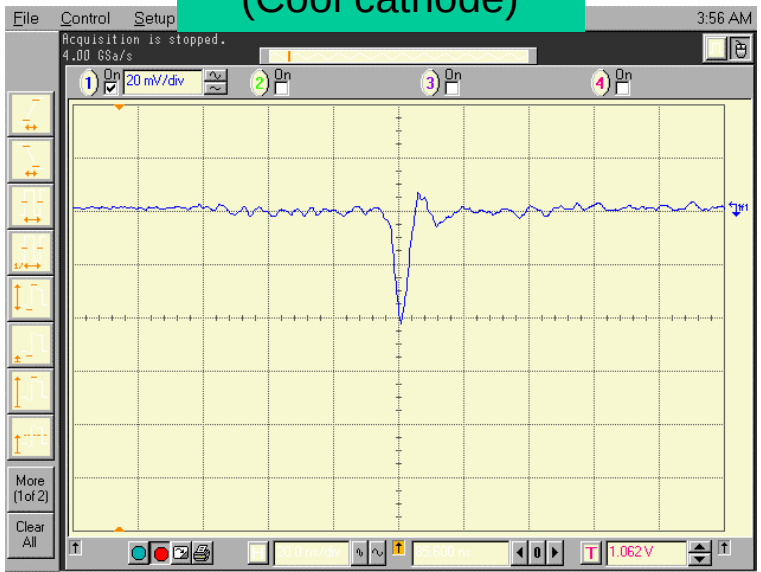
Thermionic only, 100ns pulse

Current measurements with a fast (<ns) Bergoz current monitor

Photoemission +Thermionic 5ns laser pulse



Photoemission only (Cool cathode)



Courtesy of D. Feldmann and Yijie Huo