Scaled Experiments with Electrons at the *University of Maryland*

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Outline

1. Introduction
2. Overview of UMD Program
   a. University of Maryland Electron Ring (UMER)
   b. Development of Diagnostics
   c. Selected Experimental and Simulation Results
   d. Other Studies
3. Future Directions

Where do we fit in?

	Short-Path	Long-Path (> 100 hlps)
Scaled	MBE-4 Beam Merging Final Focus	~~LLNL Recirculator~~ Princeton Paul Trap Transverse Phys.
Driver-Scale	HCX Injector Exp.	IBX, IRE Time horizon ~ ? years

UMER: ***scaled, long-path, low $$ experiment designed to access driver physics***

under construction

We Do Electrons!

What do ***electrons*** have to do with Heavy Ion Fusion?

- HIF Driver required to preserve 6-D Phase Space (**Quality**)
  - Need to understand mechanisms of 6-D emittance growth and energy transfer; instabilities; longitudinal capture and confinement, …
  - Beam Quality ⇒ Achievable **Spot Size**.
- Need to **develop confidence** in computer codes **(e.g. WARP)**

➢ Both requirements can be fulfilled by means of ***specially designed*** and ***well-diagnosed*** experiments

➢ e^- machines are an attractive ***low-cost*** alternative!

inexpensive

Scaling laws:

GeV, kA heavy ions ≡ keV, mA electrons

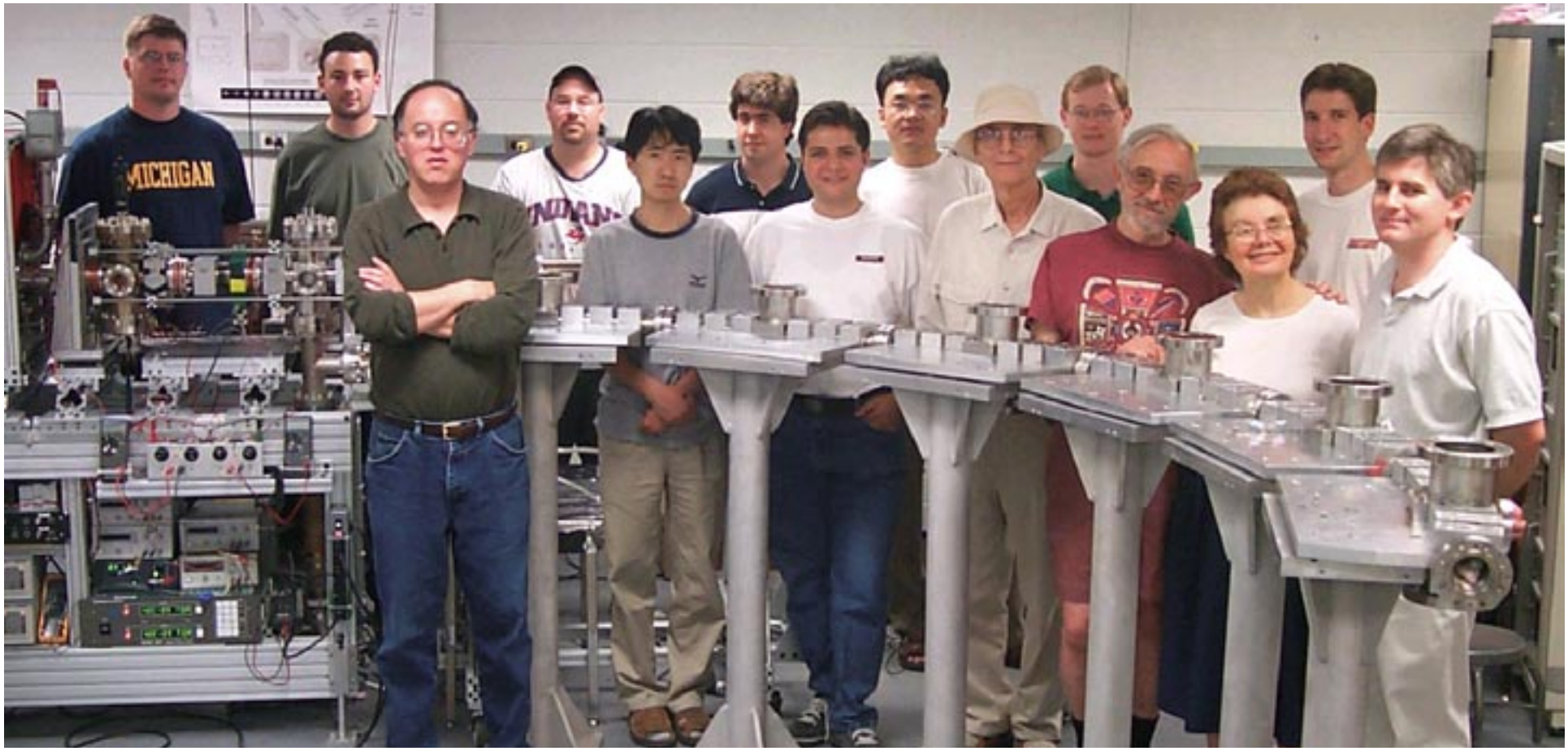
Accessible Research Topics

- Induction gap confinement and bunch-end effects
- Space-charge waves –

  longitudinal/transverse coupling
- Equilibrium distributions, mixing, & stability
- Halo formation
- Induction acceleration and resonance traversal

UMER

UMER: Concept ⇒ Reality



UMER Features

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

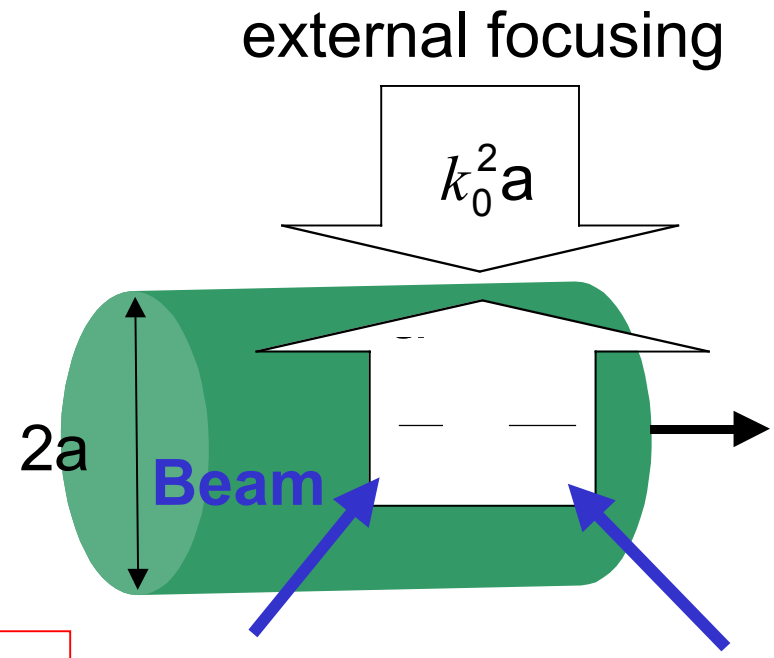
- Long Path
- Well-Diagnosed
- Variable-Parameter over a wide range
- Low-Cost!
  (easier to manipulate and introduce changes)

Energy	**10 – 50 keV**
$\beta\gamma$	**0.2**
Current	**100 mA**
Generalized perveance	**1.5×10^{-3}**
Emittance, 4x rms, norm	**10 mm-mr**
Pulse Length	**50 - 100 ns**
Bunch charge	**5 nC**
Circumference	**11.52 m**
Lap time	**197 ns**
Tune Depression (k/k_o)	**>0.15**

How Intense is the UMER Beam?

Matched Beam envelope force balance equation:

Generalized perveance



Space charge + emittance

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

$$0 \le \chi \le 1$$

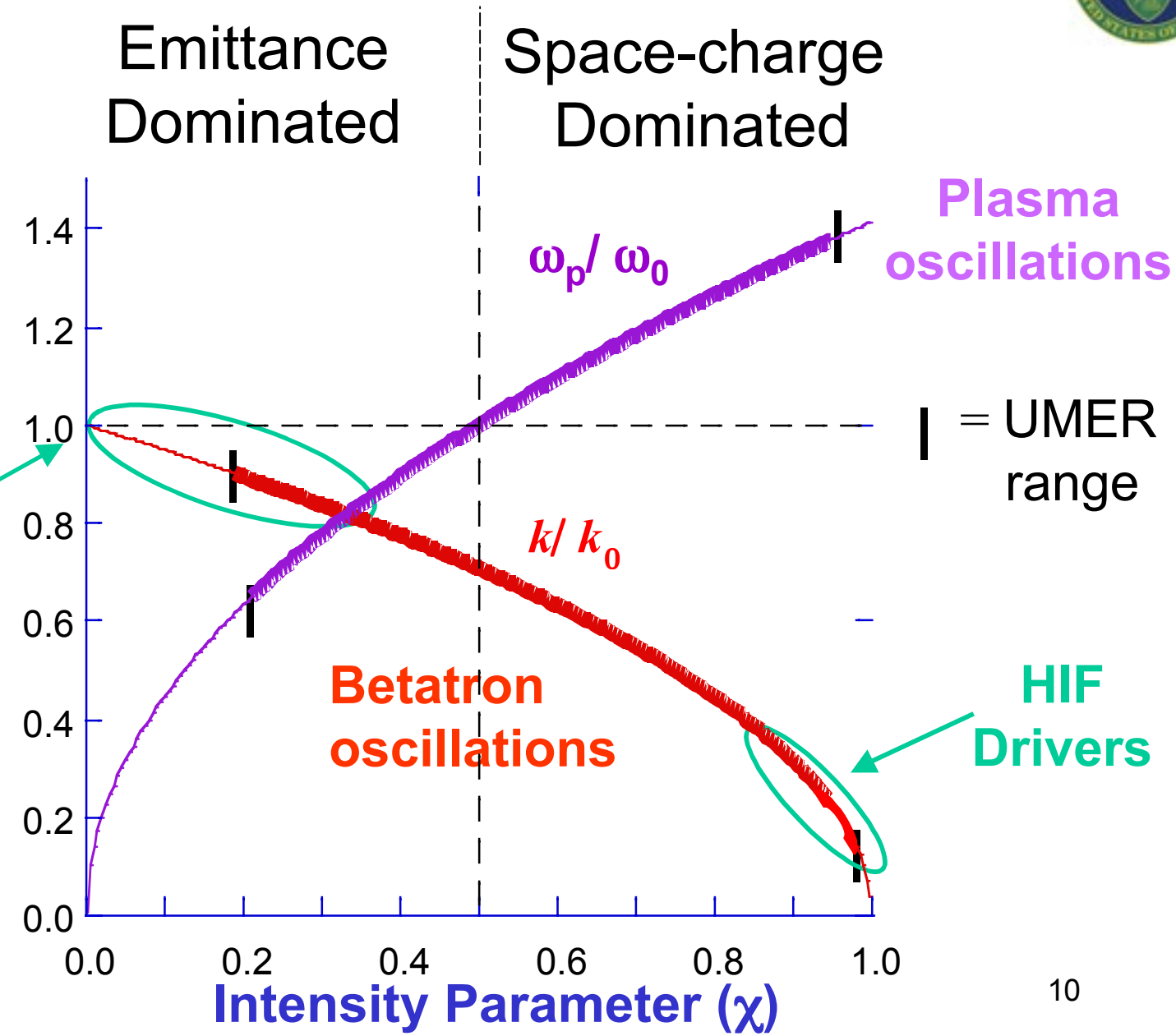
χ Is equivalent to the s_b parameter of Davidson

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

UMER ⇐ HIF Driver Physics

$$\frac{k}{k_0} = \frac{\nu}{\nu_0} = \sqrt{1-\chi}$$

$$\frac{\omega_p}{\omega_0} = \sqrt{2\chi}$$



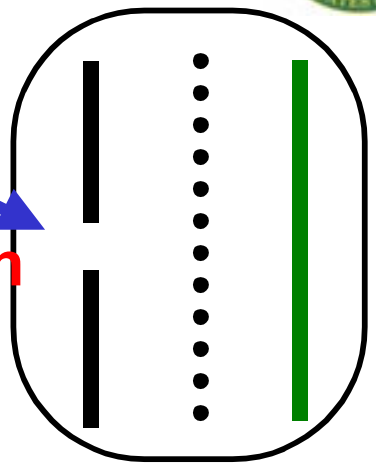
Diagnostics

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

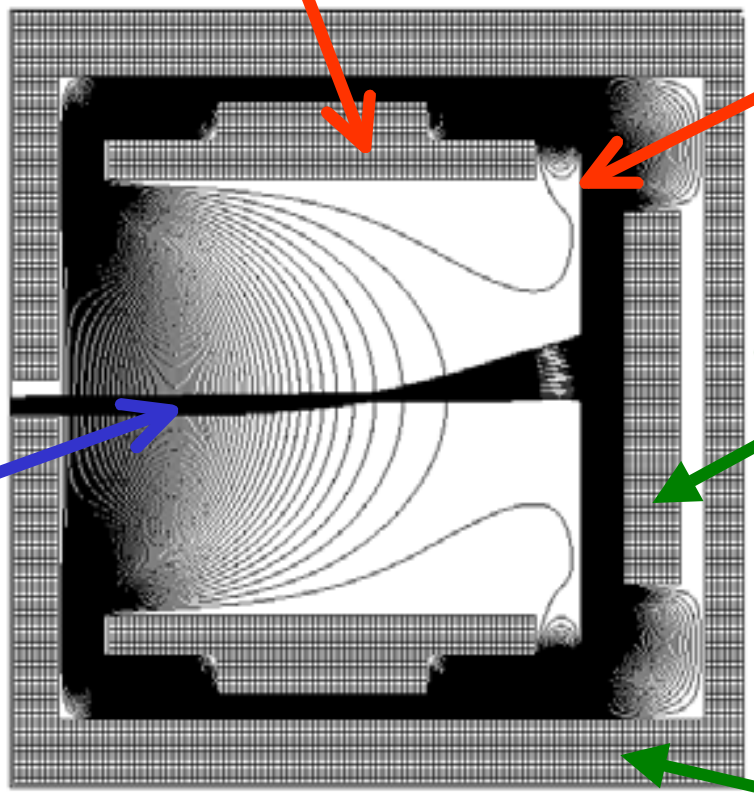
Energy Analyzer Development

1st Generation:
Parallel-Plate Retarding EA
> 20 eV Resolution



Collimating Cylinder
-10.13kV

Y. Cui



Retarding Mesh
-9999.5 V

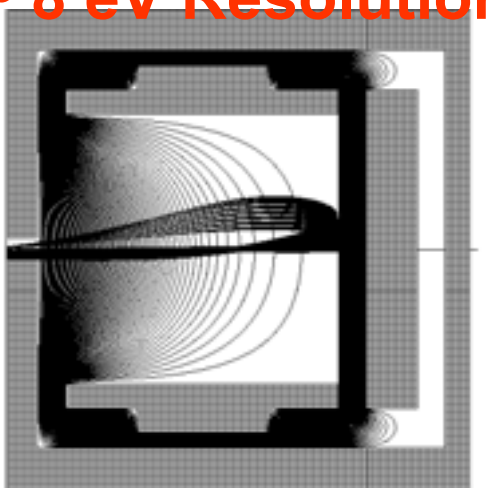
Collector

10 keV
Beam

Grounded Housing

2nd Generation
~ 8 eV Resolution

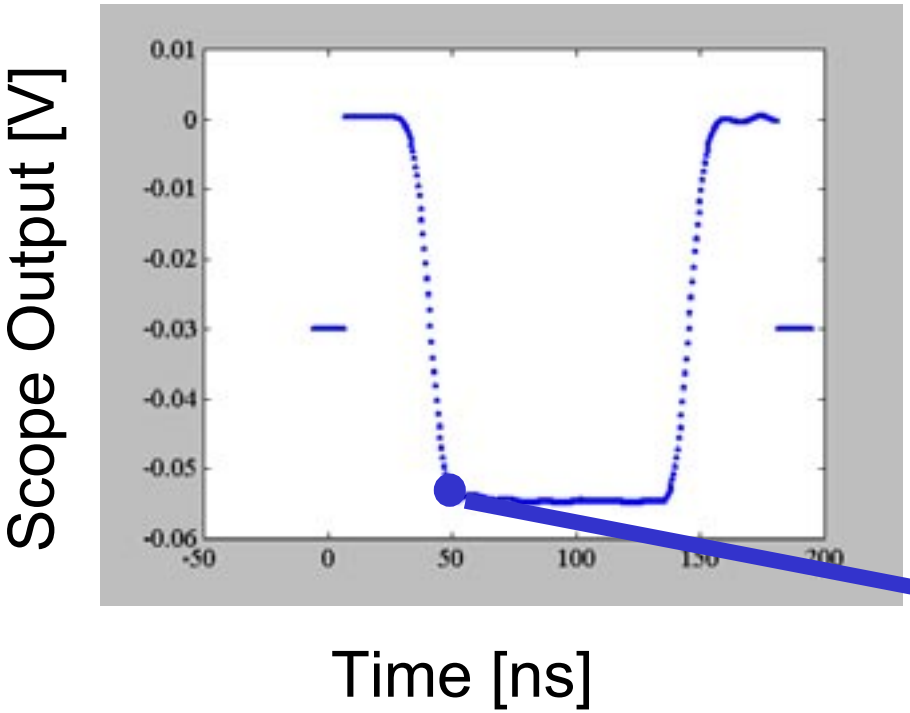
Y. Zou



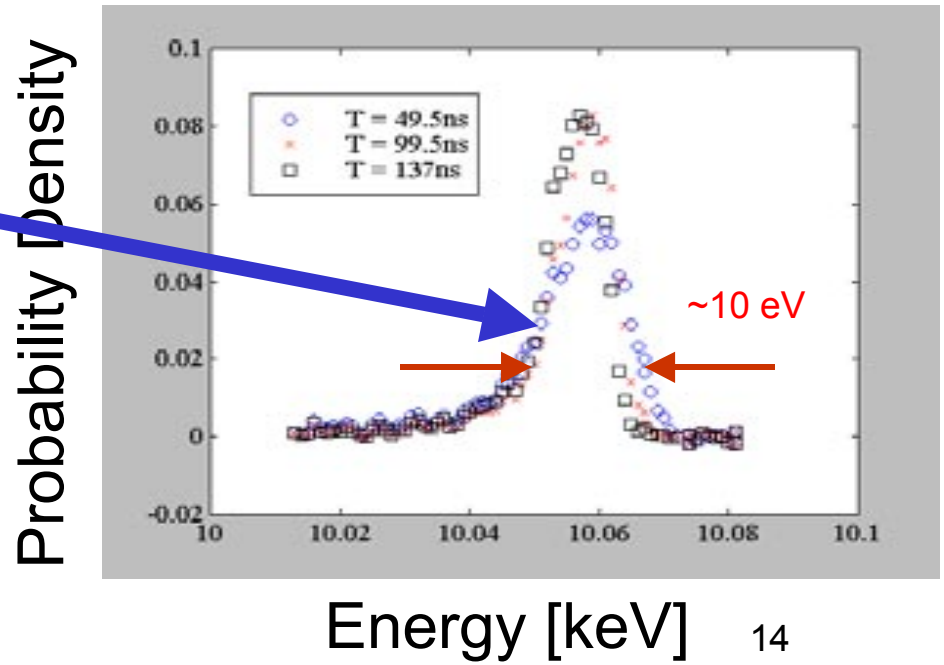
3rd Generation: Res. < 1 eV

Energy Spread: Special Retarding Voltage Energy Analyzer

Current Pulse

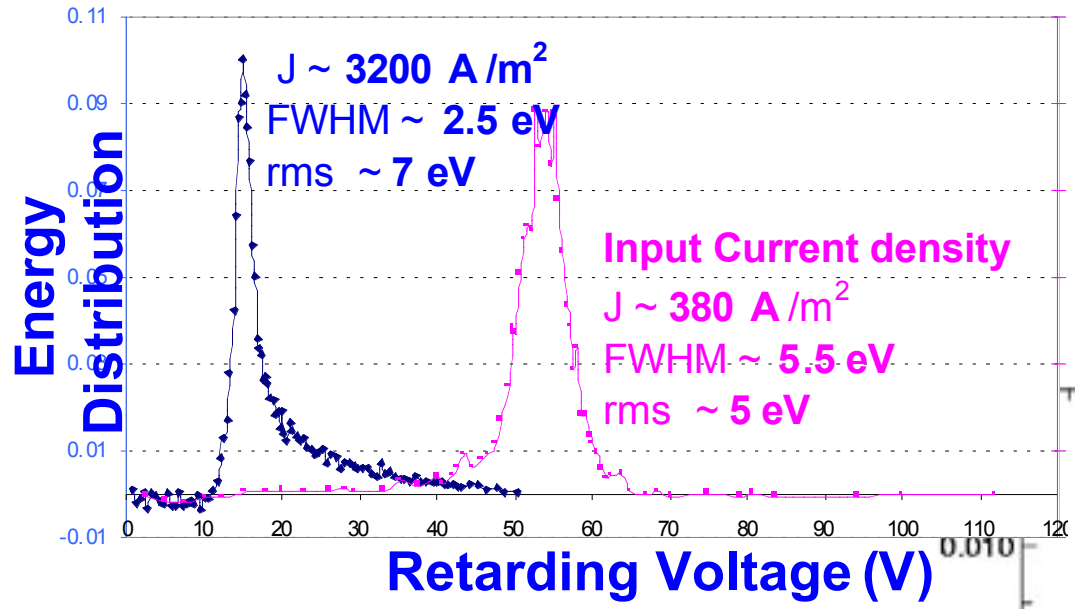


Energy Distribution

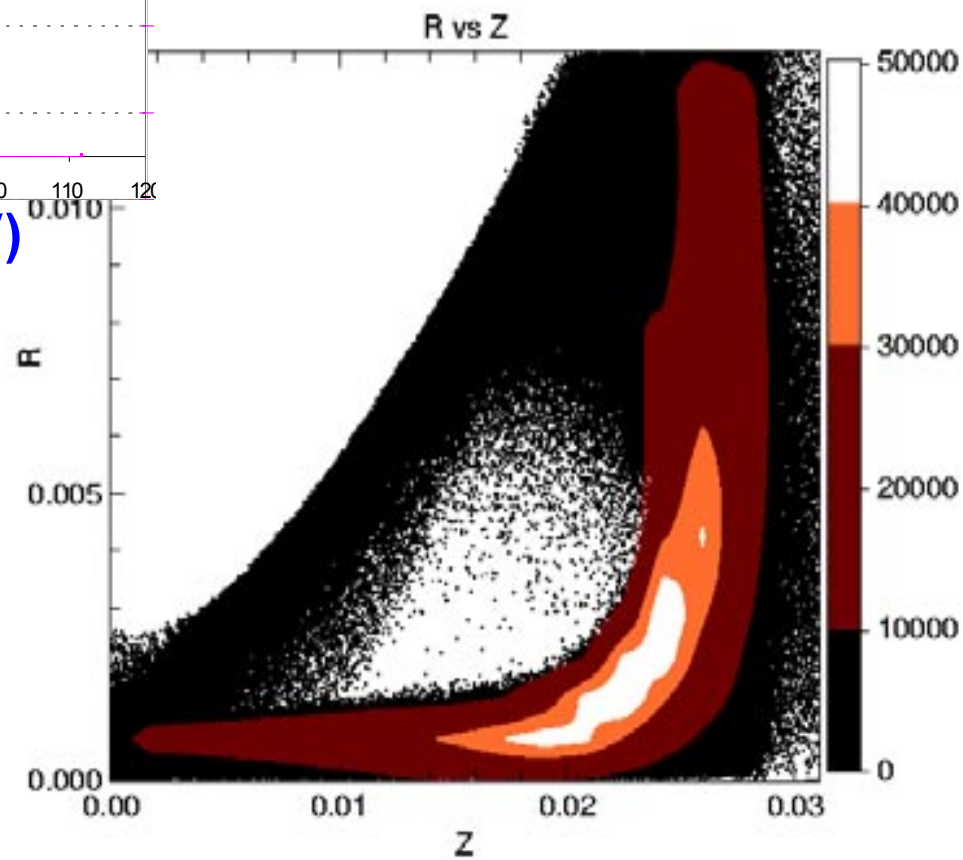


Experimental data

New EA Results and Simulation with WARP

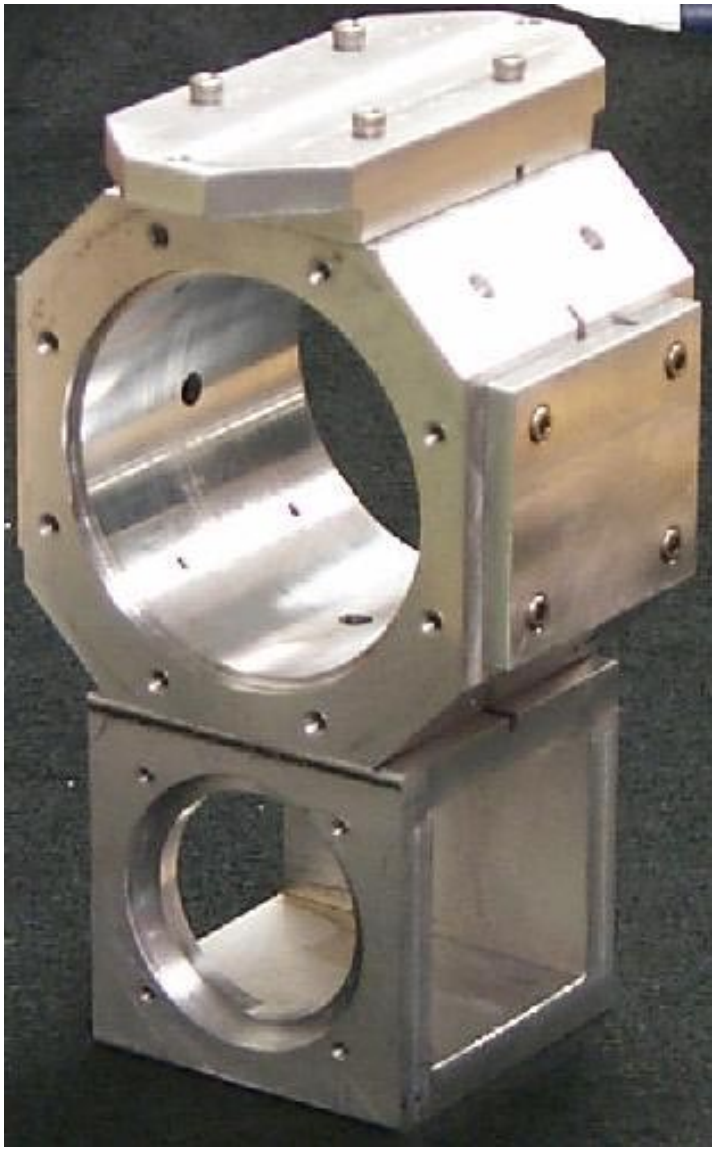


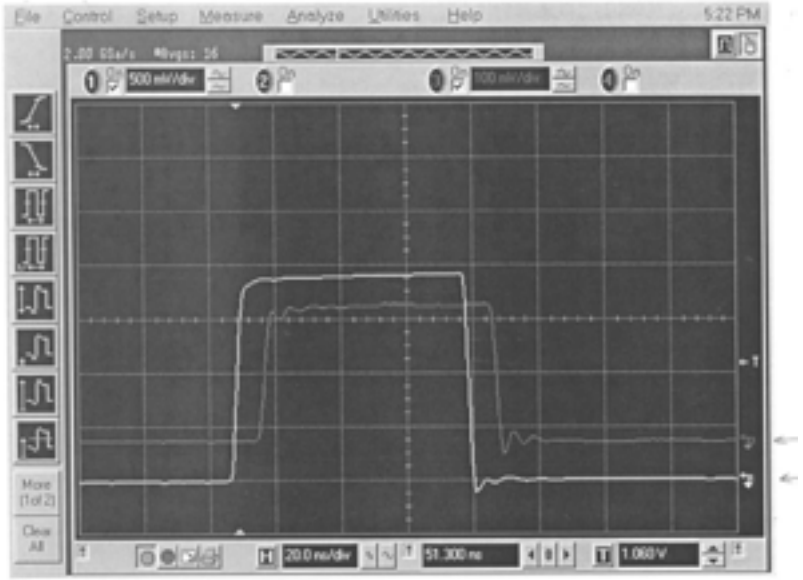
Simulation with WARP R-Z: Space charge effects inside EA need be well-understood

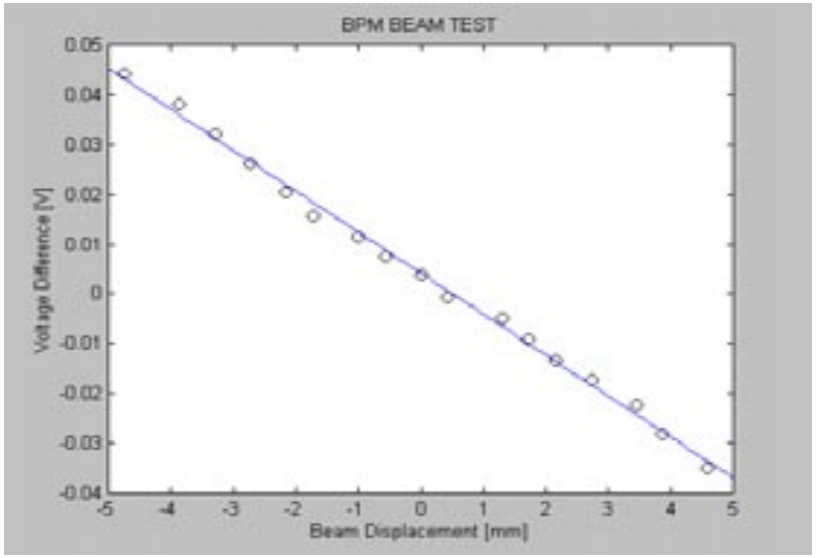


Experiment: By changing the input current density into the energy analyzer, obtained characteristically different behavior

Beam Position Monitor (BPM)





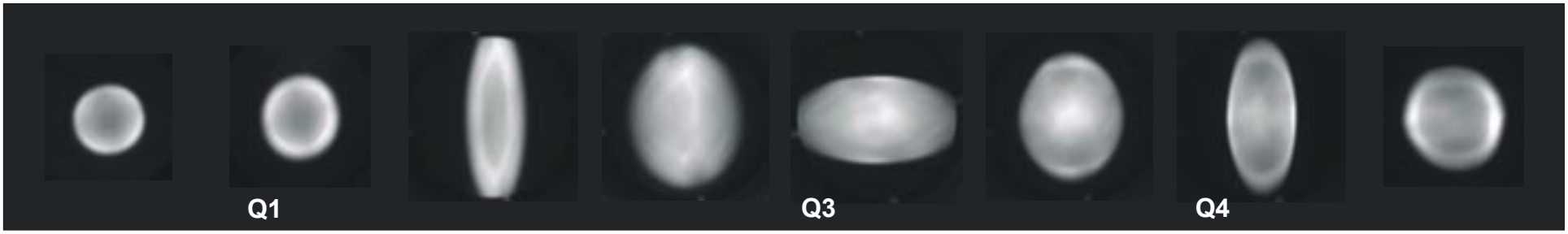


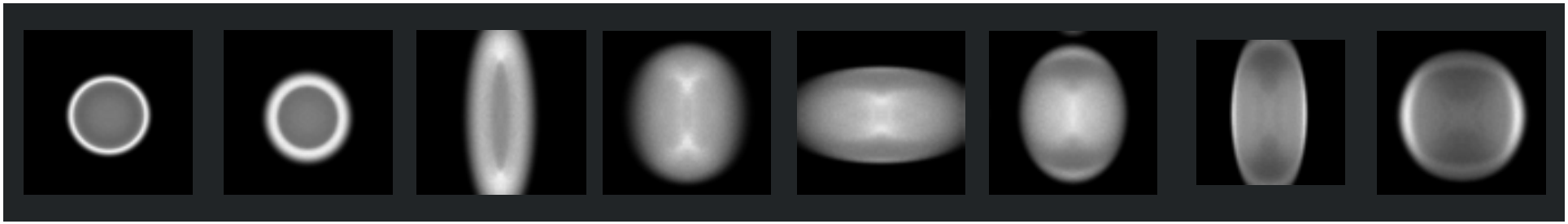
Quinn; Harris; V. Yun; Pruessner

Selected Results

Beam Images from P-Screen

Experiment (100 mA) (top) ***Bernal; Quinn***

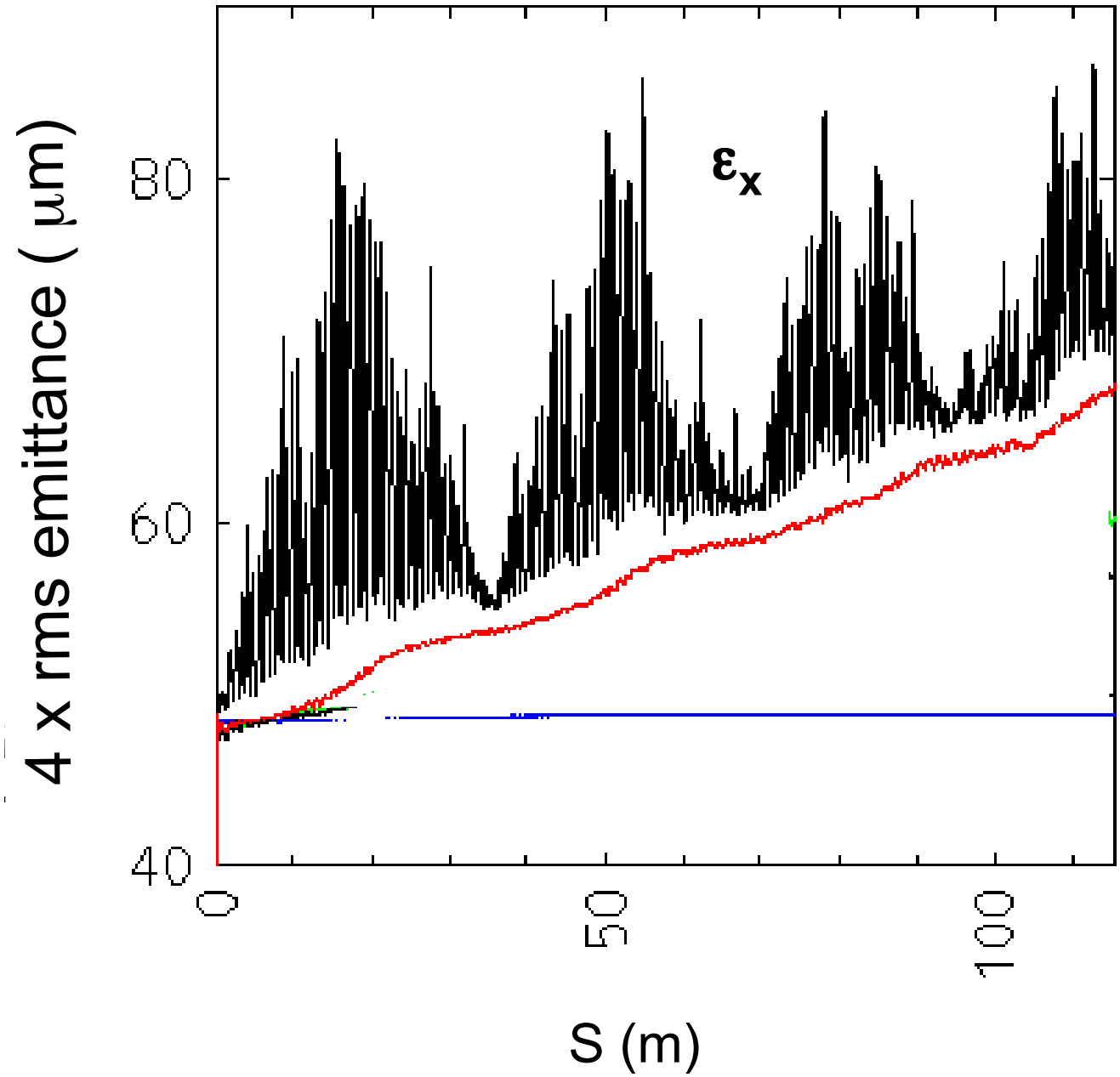




WARP Simulation (bottom) ***Kishek***

Changing the input beam distribution in simulation resulted in patterns different from the experiment!

Skew quadrupole errors



4 mrad rotation errors

ε_g (100mA)

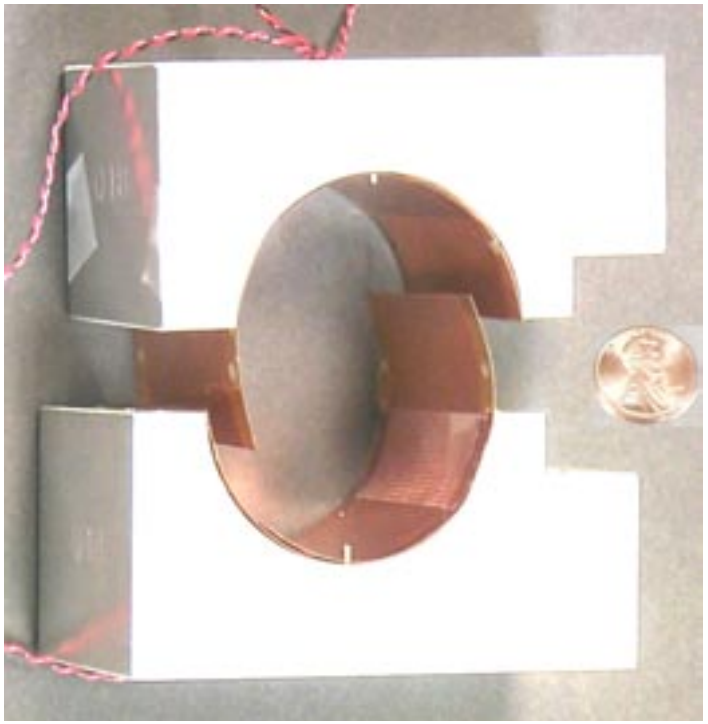
ε_g (100 mA) with corrector quads

ε_g (98mA)

ε_g zero current

Quadrupoles with *Electronically* Adjustable Skewness

H. Li; Bernal; Kishek

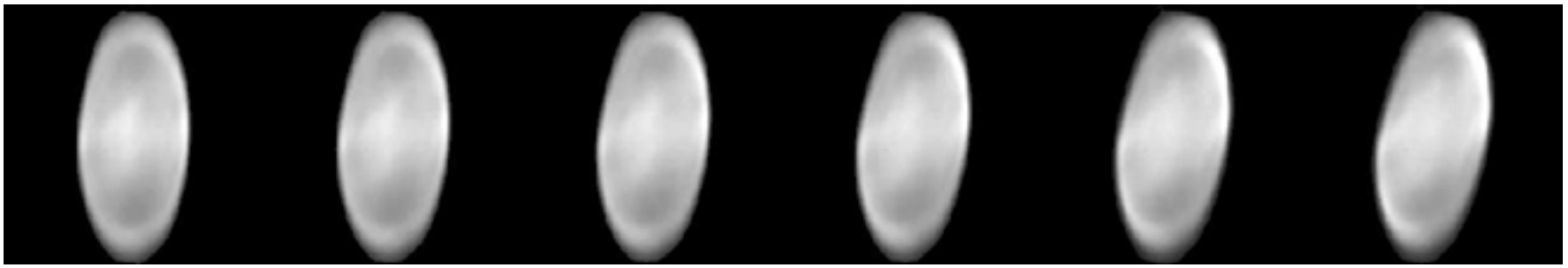


Two sets of coils at 45 deg

Exp. data

Skew angle:

0.93° 1.86° 2.79° 3.72° 4.66° 5.60°

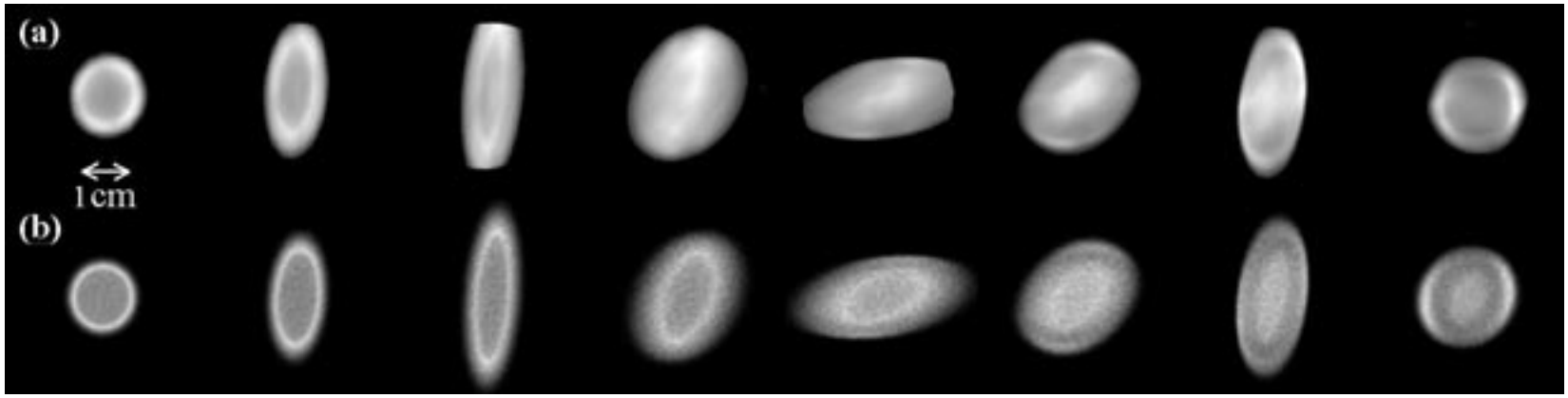


Quadrupole Rotation Experiment

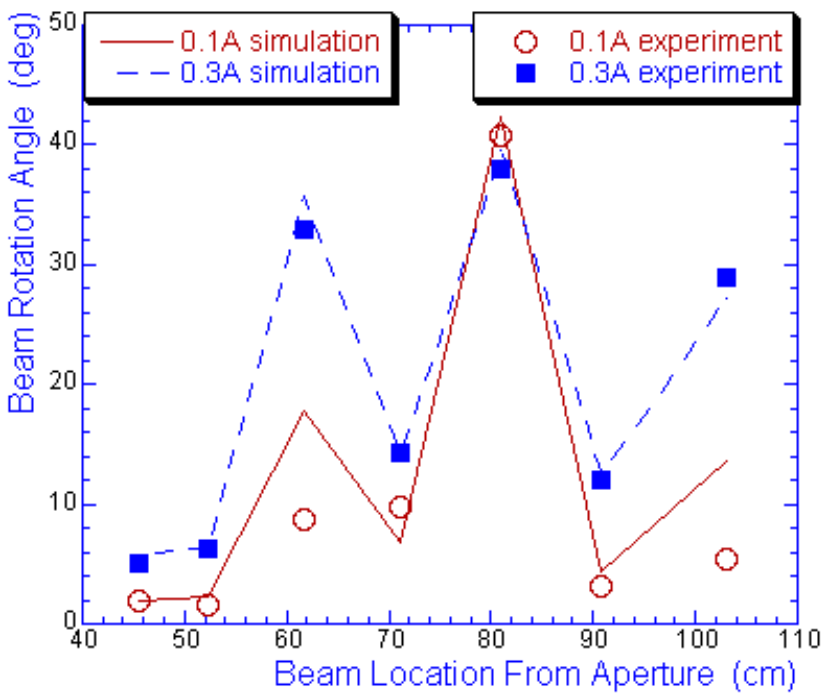
Q1 is electronically rotated 3.72^0

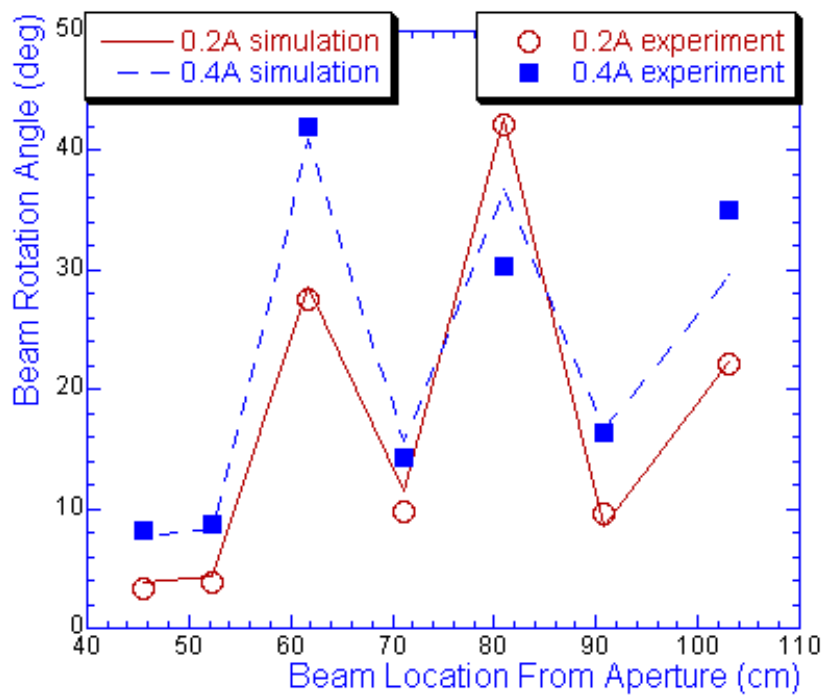
Experiment

WARP Simulation



Q1 **Q2** **Q3** **Q4**

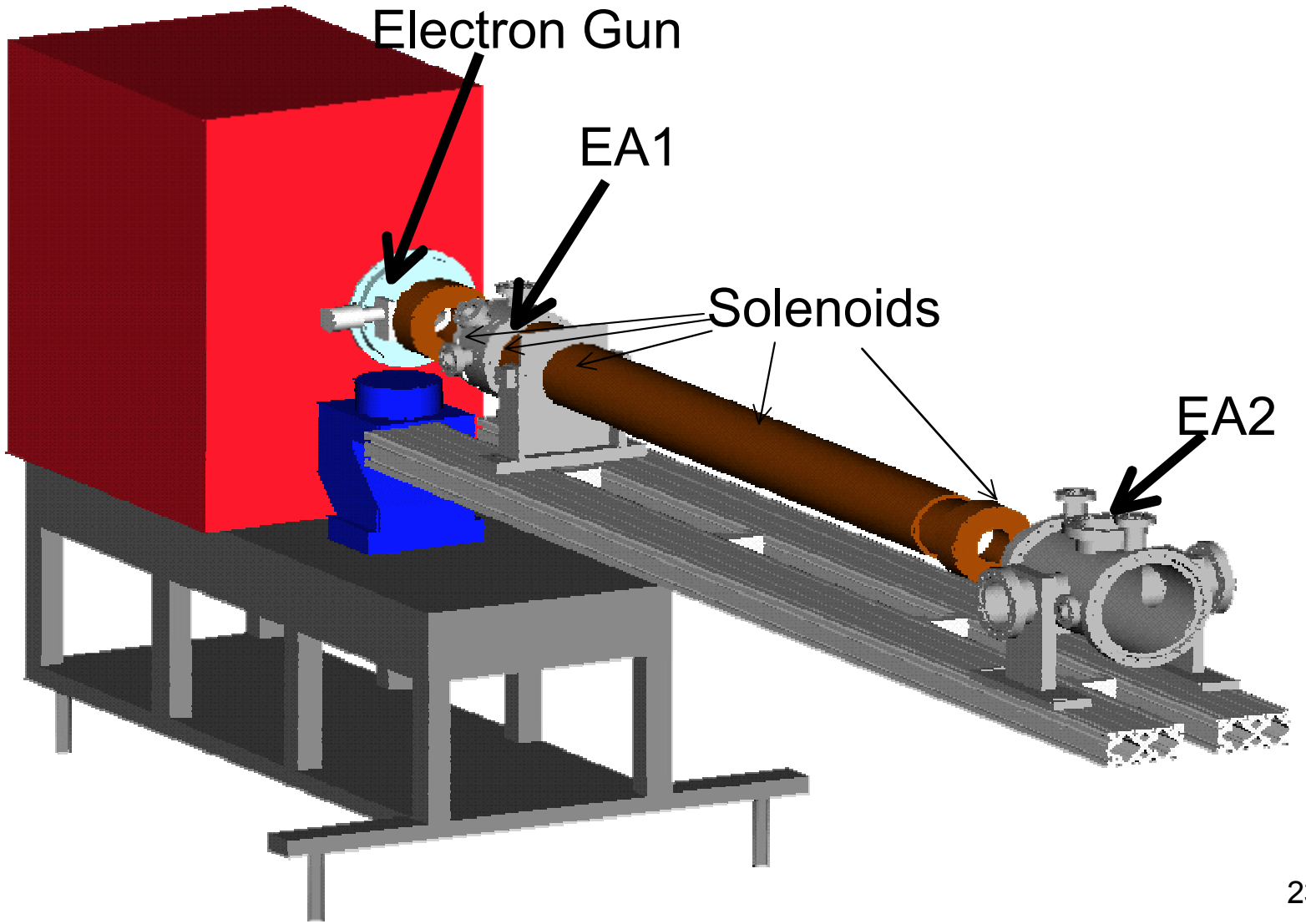




Other Studies

Long Solenoid Experiment (LSE)

Y. Cui



LSE Goals

To provide a ***controlled*** environment for experiments on longitudinal beam physics.

- **Short; No Bends; Few Magnets**
- **Heavily Diagnosed**

Currently used as to beam test energy analyzers

<u>Planned Experiments</u>:

- Transverse-Longitudinal Coupling; Energy Spread across pulse, including beam ends
- Wave Propagation and Longitudinal Perturbations

Laser Generation of Perturbations

Ability to induce arbitrary **perturbations** useful as a diagnostic / research tool.

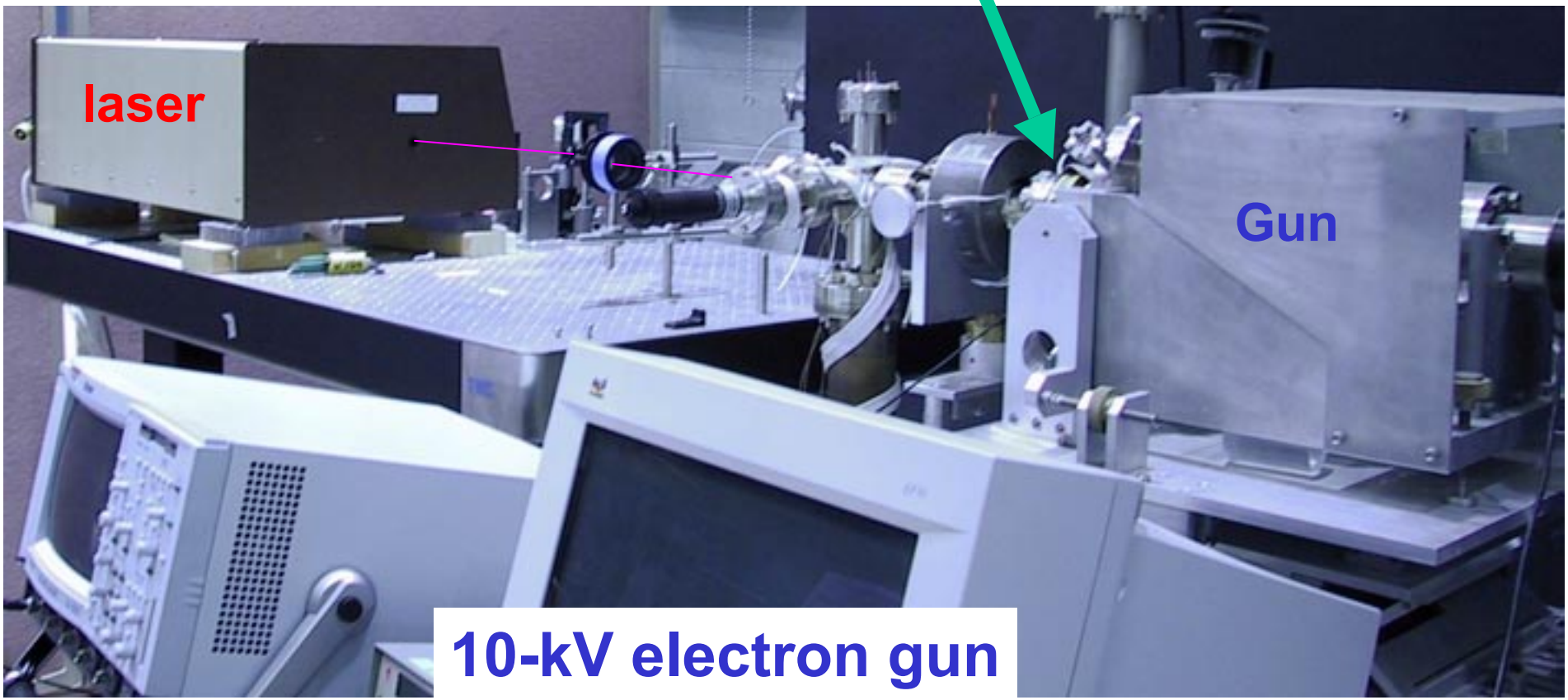
- Previously used (cathode) grid pulser
- New method: ***Laser on Cathode***.
- Advantage: **variable** transverse and longitudinal perturbations by manipulating laser.

Proof-of-Concept Experiment

- Is it Possible??
- What is the **critical current** density for the onset of space charge **instabilities**?

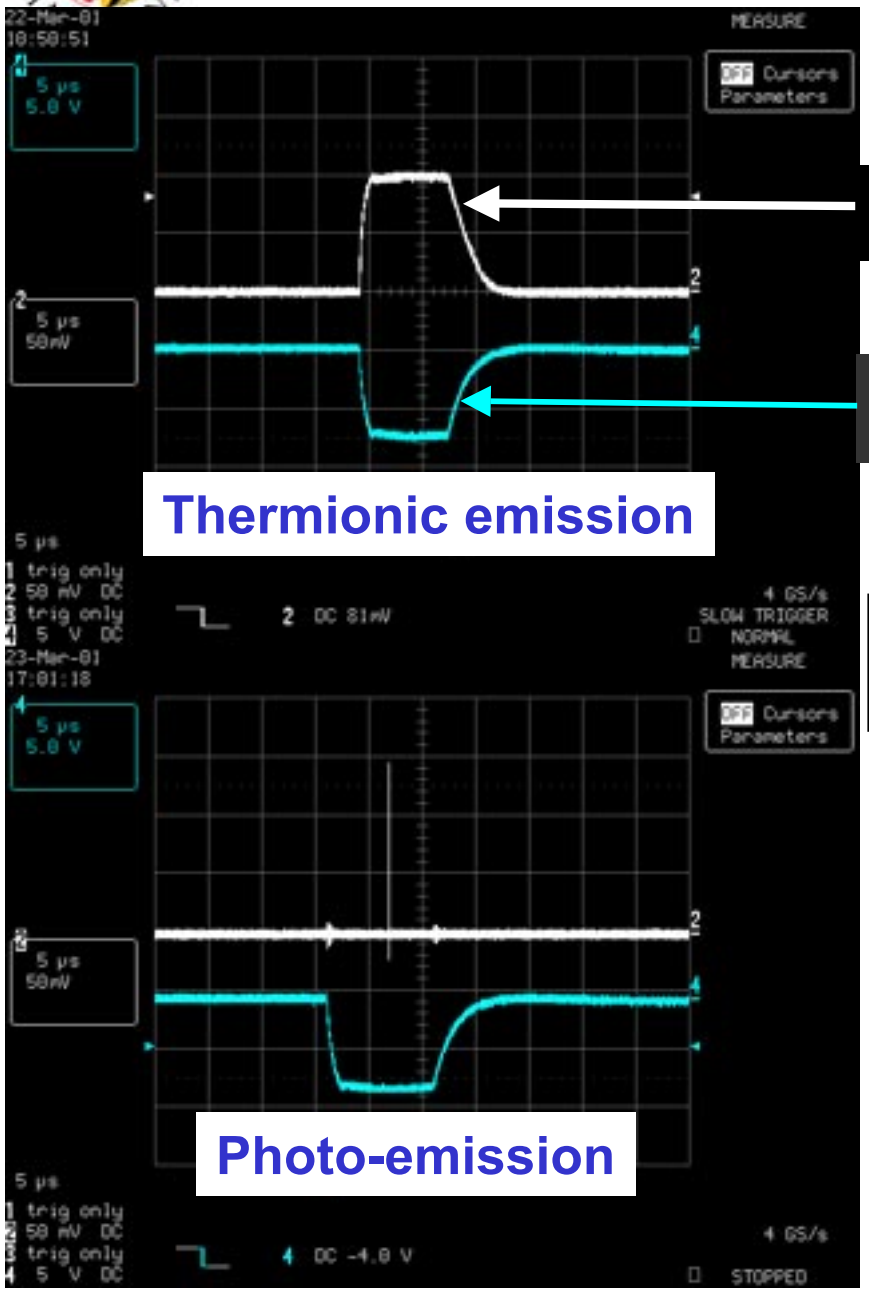
Photoemission from Thermionic Cathode (WBaCaO)

Feldmann; Virgo ; Valfells Bergoz toroid < 200 ps rise time



Nitrogen Laser (337nm) pulse is 660 ps FWHM
several hundred μJ of UV per pulse

Preliminary Results



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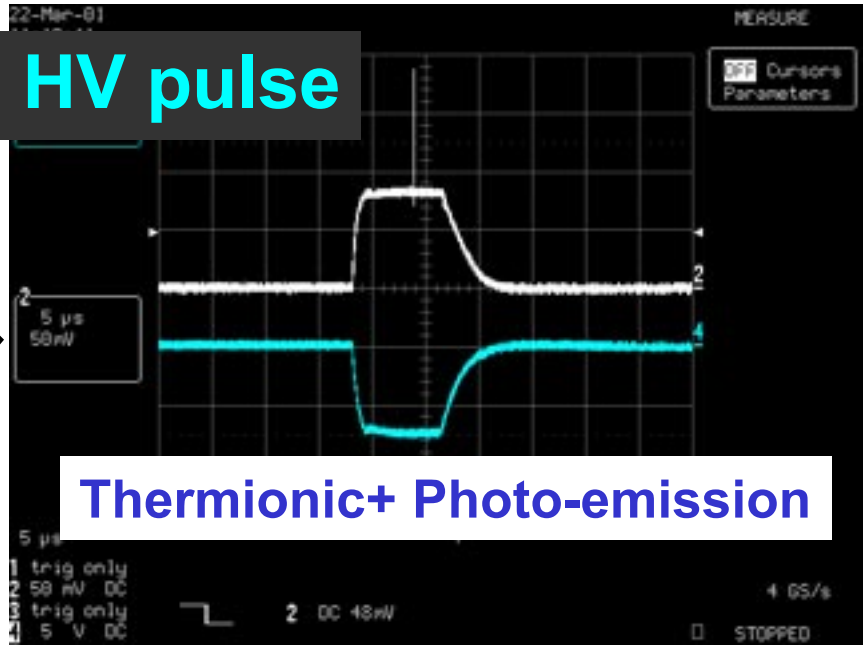

Experimental data

Future Plans

- Sub-1-turn operation of UMER: till mid-'03
    - Equilibrium distributions & stability
    - Space-charge waves – longitudinal/transverse coupling
    - Halo formation
- Multi-turn dynamics – ***bunch capture and shaping***; beam end confinement using induction gaps.
- LSE: Longitudinal wave propagation; use laser to generate? Effect on velocity distribution … ***control of thermal energy spread*** by laser?

Much More to Come!

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