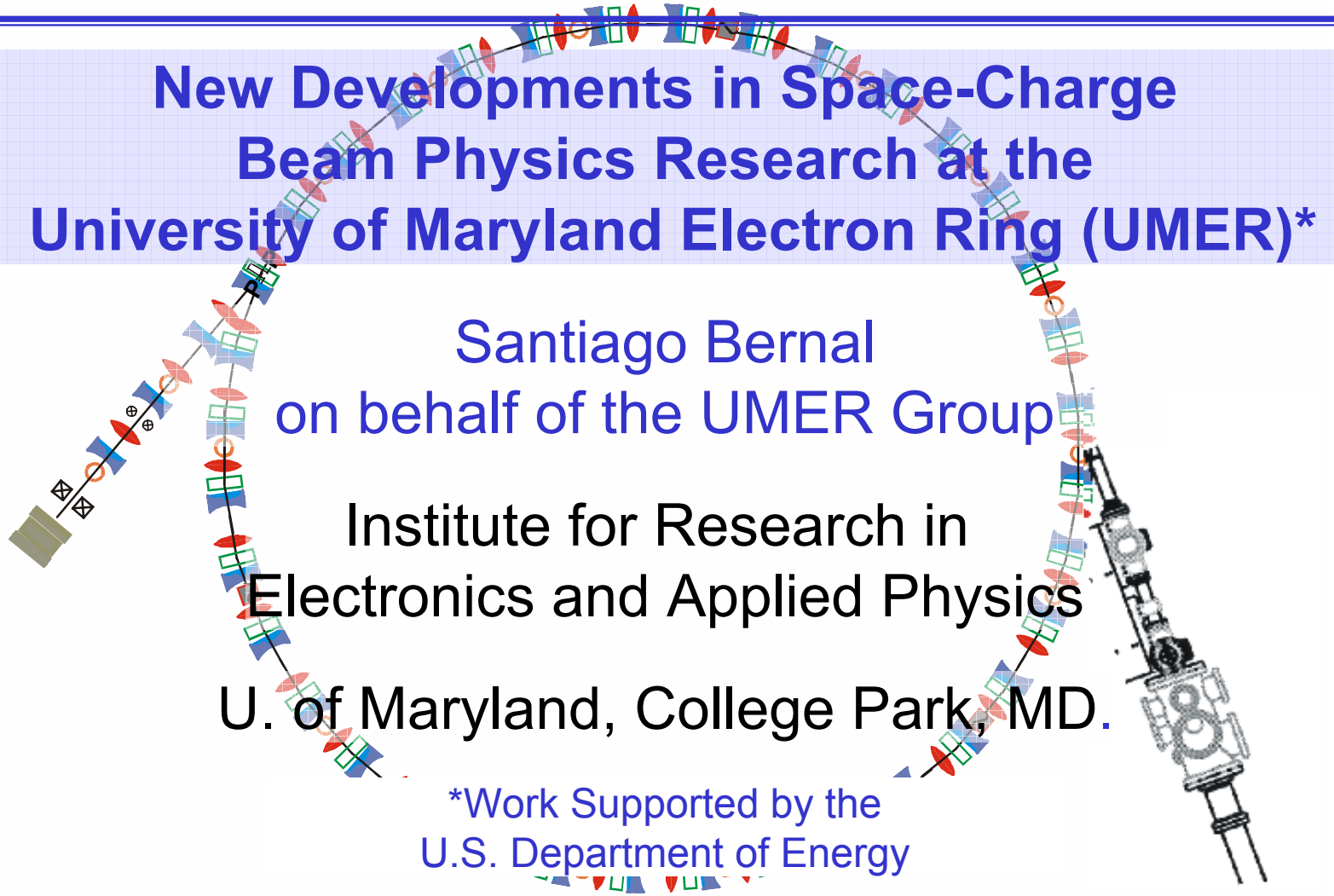
12th Advanced Accelerator Concepts Workshop,
Lake Geneva, WI, July 13th 2006

New Developments in Space-Charge Beam Physics Research at the University of Maryland Electron Ring (UMER)*



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on behalf of the UMER Group

Institute for Research in
Electronics and Applied Physics

U. of Maryland, College Park, MD.

*Work Supported by the
U.S. Department of Energy

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UMER Group Talks/Posters

Talks this afternoon (WG5):

Diktys Stratakis, Tomography as a Diagnostic Tool for Phase-Space Mapping of Intense Particle Beams,

Jaynkar Thangaraj, Beam Injection and Matching Studies at the University of Maryland Electron Ring (UMER),

Mark Walter, Beam Control and Steering in the University of Maryland Electron Ring (UMER).

Past talks and posters by Rami Kishek, Kai Tian, Gang Bai and Christos Papadopoulos.

Outline

- Goals and approach
- Beam physics
- UMER features and layout
- First-turn: DC injection
- Pulsed injection and multi-turn
- Summary and conclusions

Goals and Approach

Goals:	Study beam matching, emittance growth and halo formation, anisotropic beams, resonance crossing, emittance exchange and equipartitioning, energy spread evolution, space-charge waves, etc.
Approach:	We have designed and built a circular machine to transport **10 keV, 0.1-100 mA** e^- beams, within the capabilities of a university and with modest budget.
Target:	$\Delta h/h_{init}<4$ for 100 turns at low current, and 10 turns at full current.

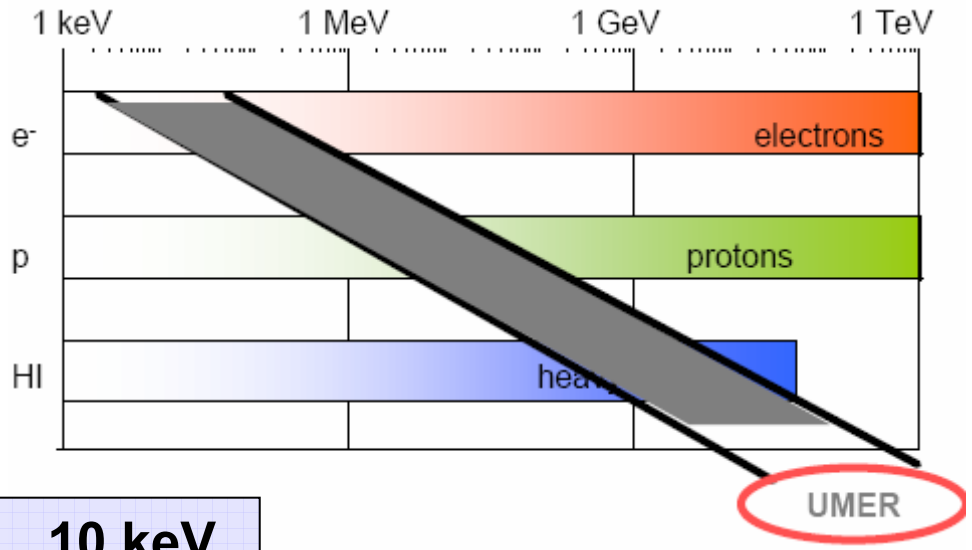
Beam Physics: scaling, tune shift and resonances, etc.

Scaling

Envelope Equation:

$$R''(s)+k_0^2(s)R(s)-\frac{K}{R(s)}-\frac{\varepsilon^2}{R^3(s)}=0$$

$$K=2\frac{I}{I_0}(\beta\gamma)^{-3} \qquad K \sim 10^{-3}$$



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Energy:	**10 keV**
Current:	**100 mA**
Emittance*:	**3.0 pm**
Lattice period:	**0.32 m**
Zero-current σ_0:	**1.5 m**
Av. beam radius, *a*:	**10 mm**
Pulse Length:	**20-100 ns**
Lap time:	**197 ns**

Intensity Parameter:

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

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

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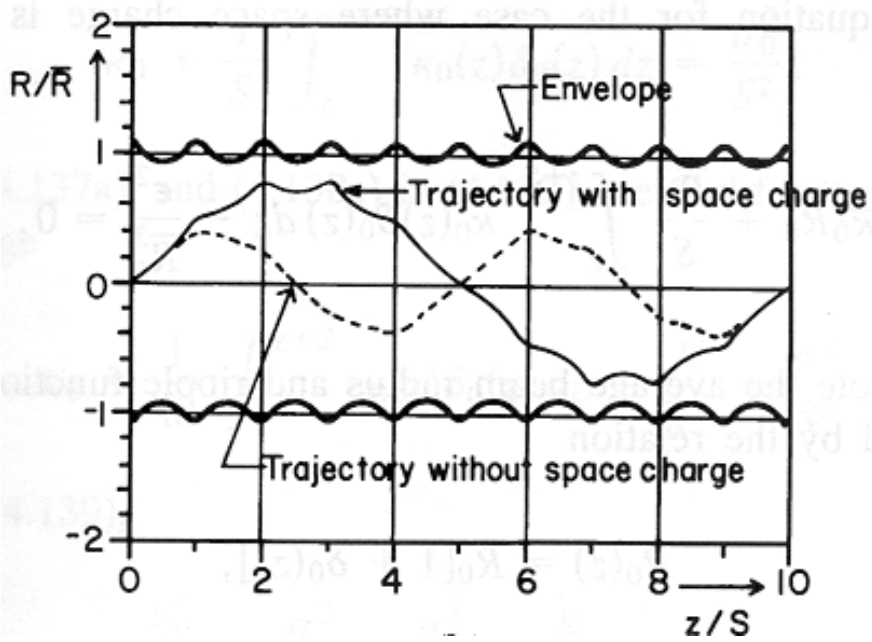
*norm., rms

Tune Shift & Resonances

Tune depression:

LINACS: λ_0/λ,

RINGS: ν/ν_0



Laslett tune shift criterion:

Space charge implies incoherent tune shift

$$\Delta\nu = \nu_0 - \nu,$$

$$\frac{\Delta\nu}{\nu_0} \approx \frac{\chi}{2}, \quad (\text{if } \Delta\nu \ll \nu_0).$$

Normally, $\nu_{Inj} = \nu$, $\nu_{fin} \approx \nu_0$.

Simple Res. Condition:

$\nu_0 = m/n$, m,n integers

Therefore, the criterion is:

$$\Delta\nu = \nu_{fin} - \nu_{Inj} \le 1/2,$$

or 0.25, more conservatively.

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Sp. Charge Tune Depression in UMER & Other Machines

MACHINE	Type	Tune Dep. ν/ν_0	Max. Tune Shift	Energy,Current @ Injection
LEDA (LANL)	p, L	**0.82-0.95**	NA	6.7 MeV, 75 mA
HCX (LBNL)	K^+, L	**0.10**	NA	1.0 MeV, 180 mA
FNAL BOOSTER	p, R	**0.94**	0.4	400 MeV, 4 μA
SNS Acc. Ring (ORNL)	p, R	**0.97**	0.15	1.0 GeV, 25 A
AGS Maschke[1] (BNL)	p, R	**0.79**	1.9	200 MeV, NA
e-model, p FFAG accel[2]	e^-, R	NA	0.5	218 keV, 21 mA
PTSX (PPPL)	C_s^+, PT	**0.40**	NA	400V, 100 kHz
SIR (MSU)	H_2^+, R	**0.36**	0.2	20 keV, 100 μA
UMER (Univ. of MD)	e^-, R	**0.16-0.84**	6.4-1.2	10 keV, 100-0.5mA

[1]Record for a circular machine - see BNL Rep. 50643, 1977.
[2]Model for 1.5 GeV, 4 A proton FFAG proposed for BNL AGS – A.G. Ruggiero, HB2006.

$\nu/\nu_0 = \sqrt{1-\chi}$, $\nu/\nu_0 < 0.71$ for space-charge dominated

Comparison of Proton Accelerators for High Power Applications

W. T. Weng
Brookhaven National Laboratory

ICFA-HB2006, KEK, Japan
May/29 – June/2, 2006

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Challenges and R&D Needed

A. Accelerator System
   1. Space Charge and Coherent Instabilities
   2. Generation for Short Bunch
   3. Beam Losses and Radiation Shielding
   4. Cost and Reliability

A. Target System
   1. Solid/Liquid Target
   2. Capture and Focusing of Secondary Beams

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UMER Features

- High density of focusing elements allows containment of intense beams

Emittance dominated $a_0 = \varepsilon^{1/2}\left(\frac{S}{\sigma_0}\right)^{1/2}$

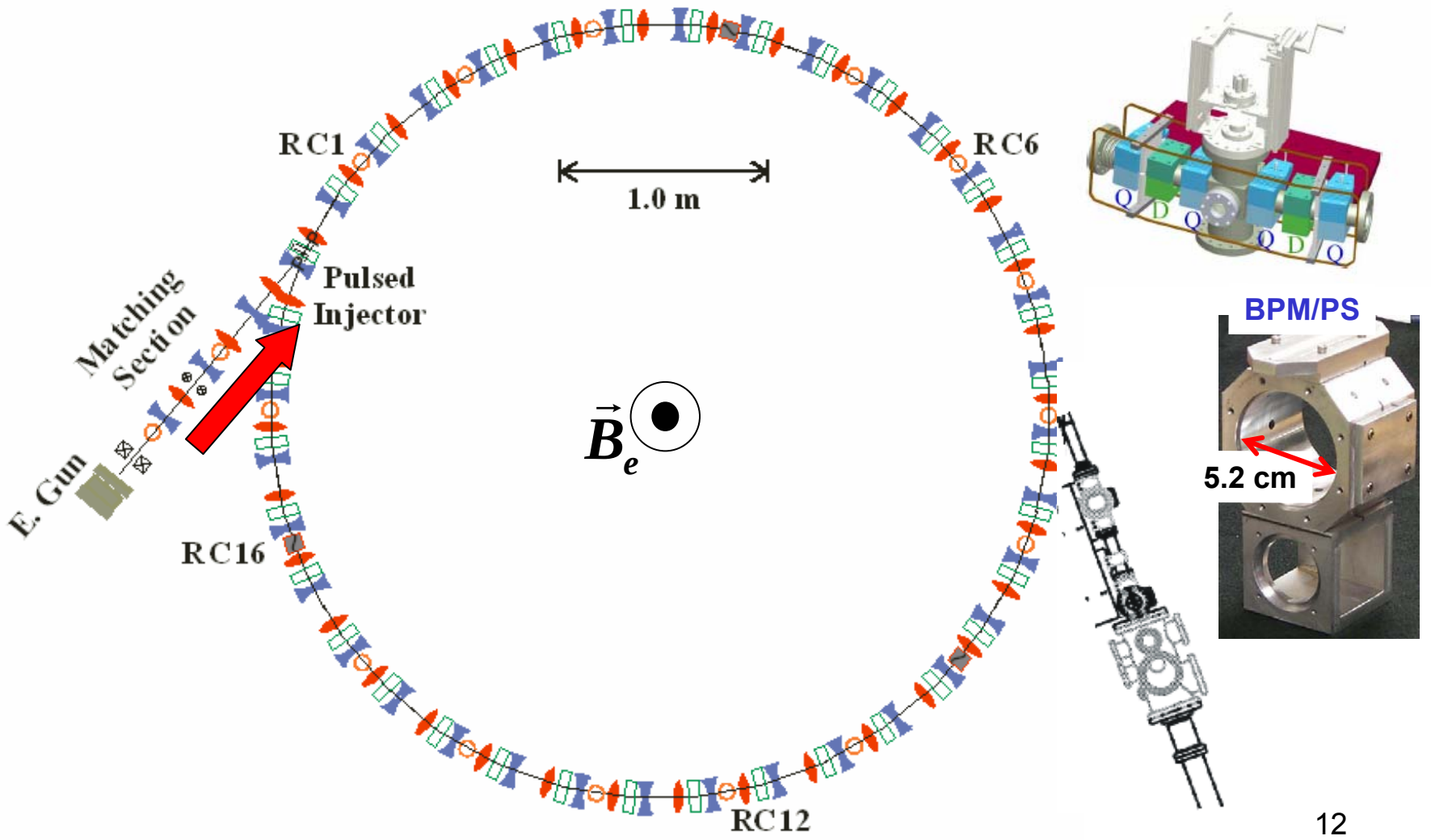
Sp. Charge dominated $a_B = K^{1/2}\left(\frac{S}{\sigma_0}\right)$

- Thus, space charge is *not* a perturbation under UMER's typical operation

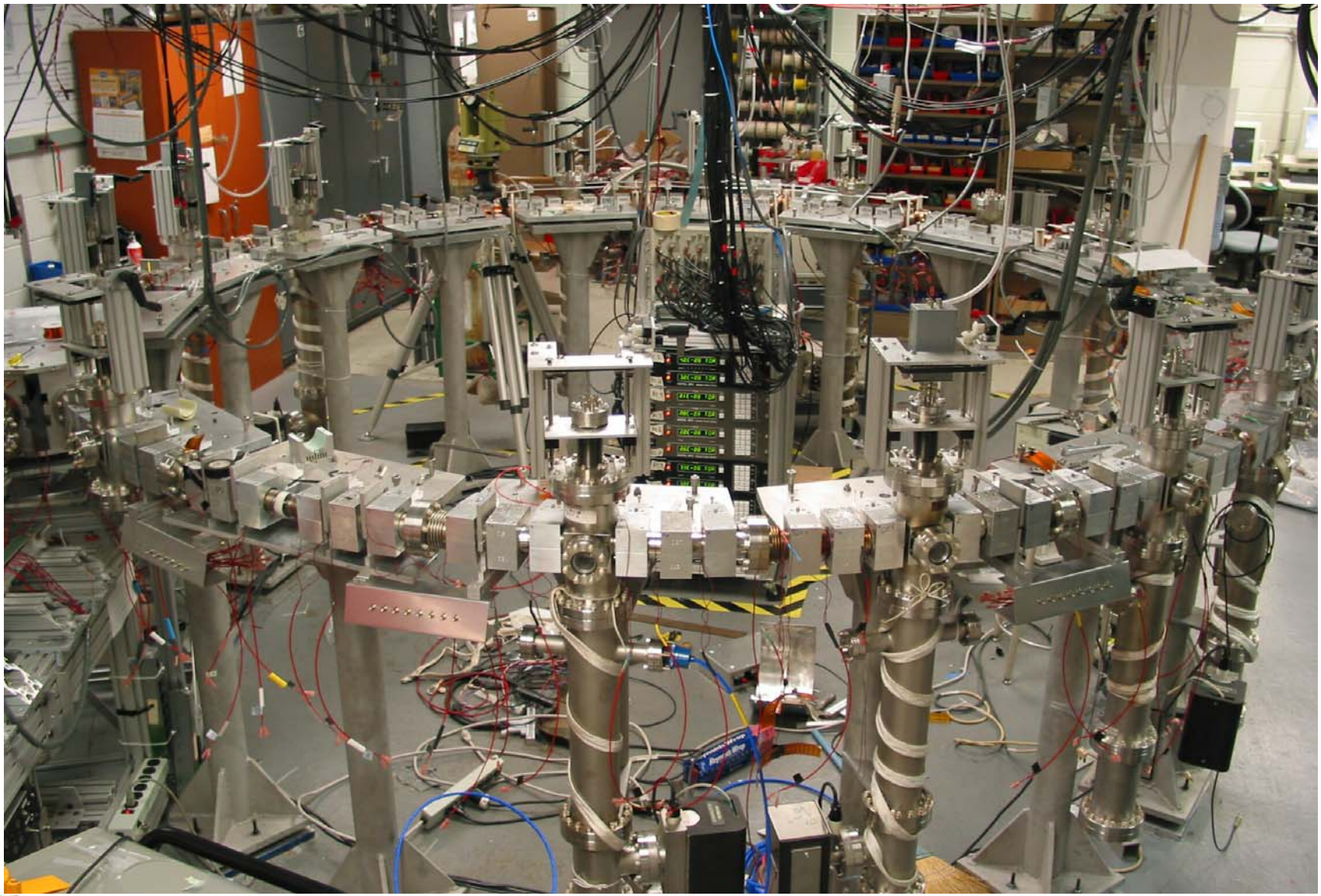
- Diagnostics optimized for low energy, high current e^- beams (20-100ns p.l.)

- Benchmarking of codes (e.g., WARP)

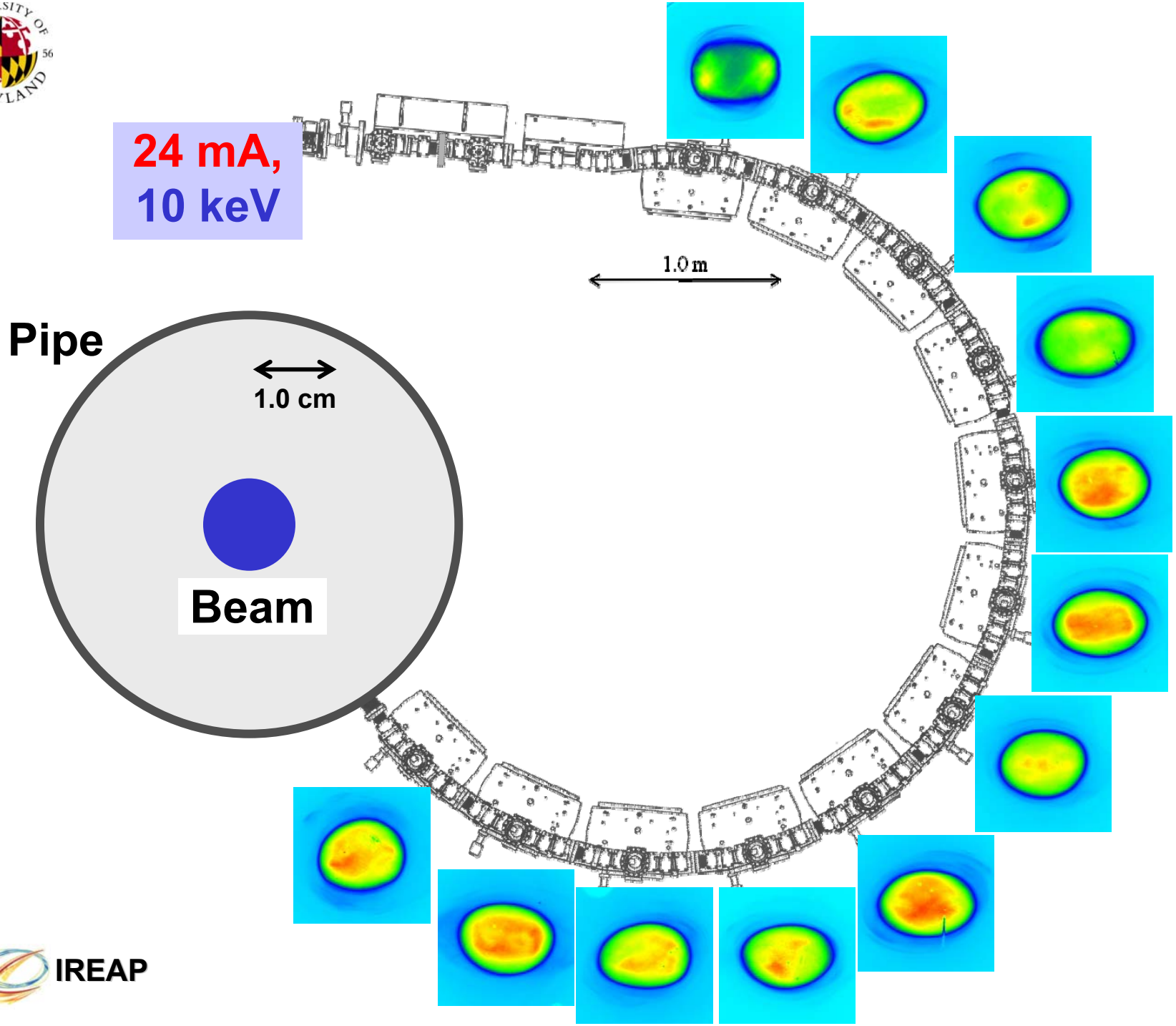
UMER Layout


RC1
RC6
RC12
RC16
1.0 m
Pulsed
Injector
Matching
Section
E. Gun
$\vec{B}_e$
Q D Q Q D Q
BPM/PS
5.2 cm

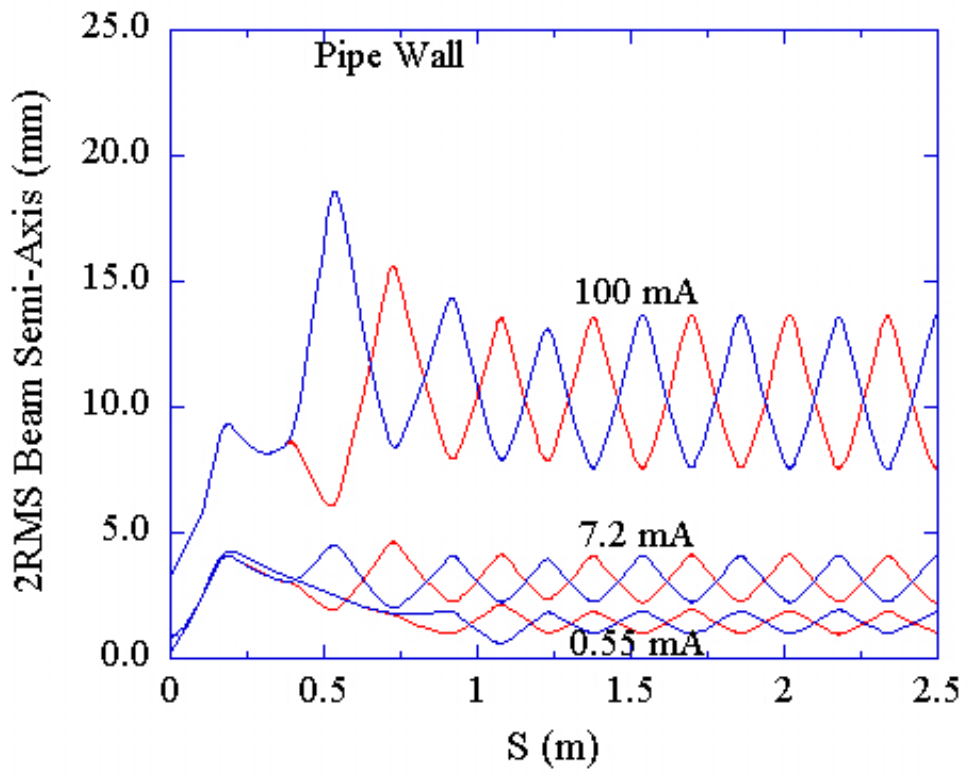
UMER

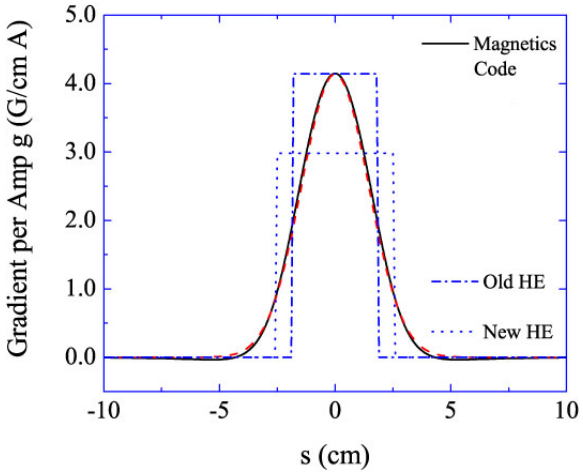


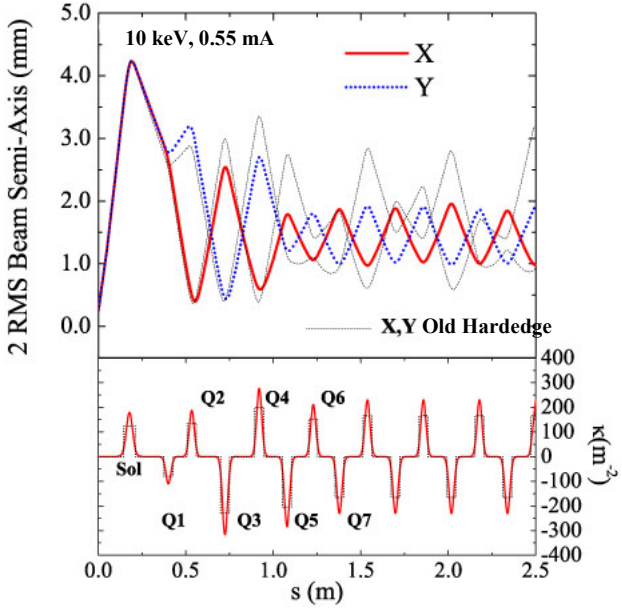
First Turn: matching, halos, x-y coupling, asymmetric focusing


24 mA,
10 keV
1.0 m
Pipe
1.0 cm
Beam

Beam Envelope Matching







S. Bernal et al, PRST AB 064202 (2006)

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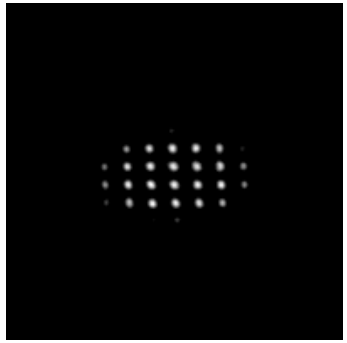
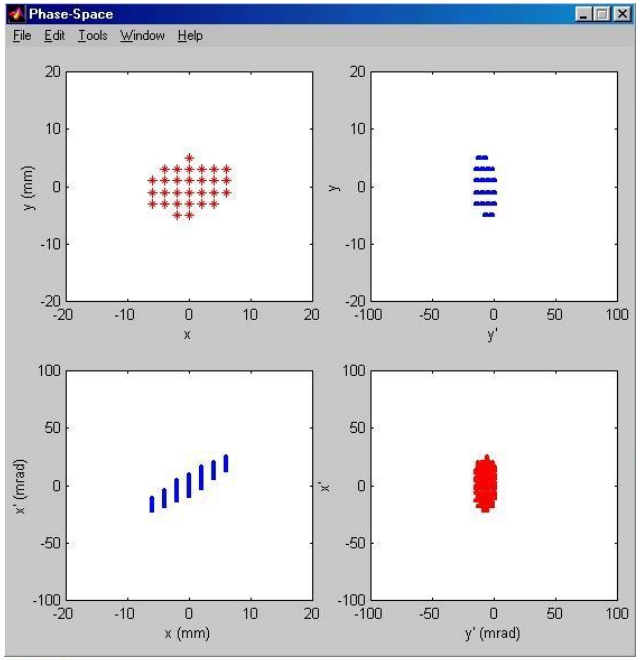
Emittance Measurements (DC Injection)





24 mA, 10 keV, χ=0.9

Location	S (m)	h_x (pm)	h_y (pm)
Aperture Plate	0	30ß5	30ß5
After 1/4 turn	3.8	30	36
After 1/2 turn	7.0	42	28
After 2/3 turn	9.0	33	51

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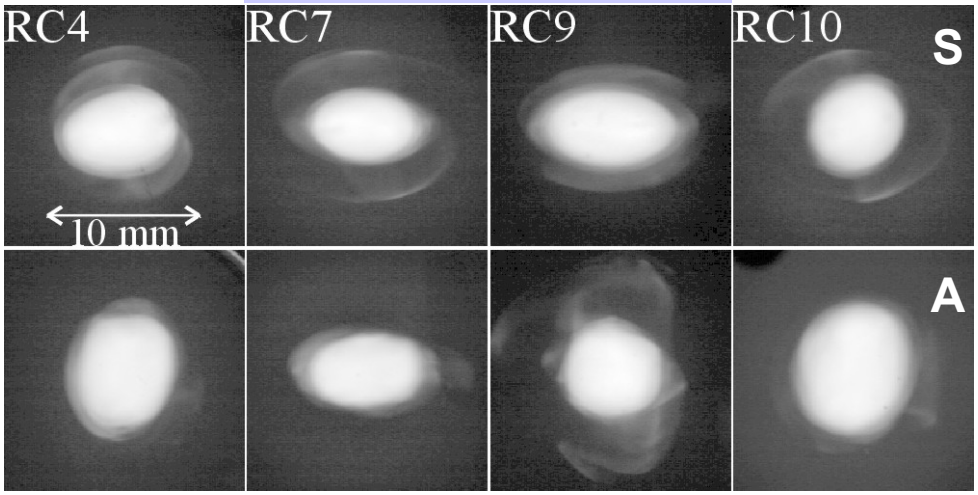
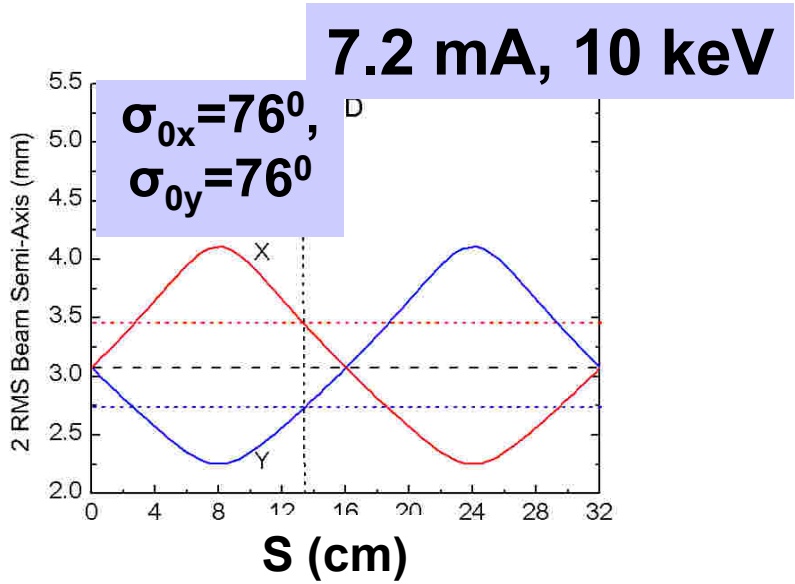
Highly Asymmetric Focusing

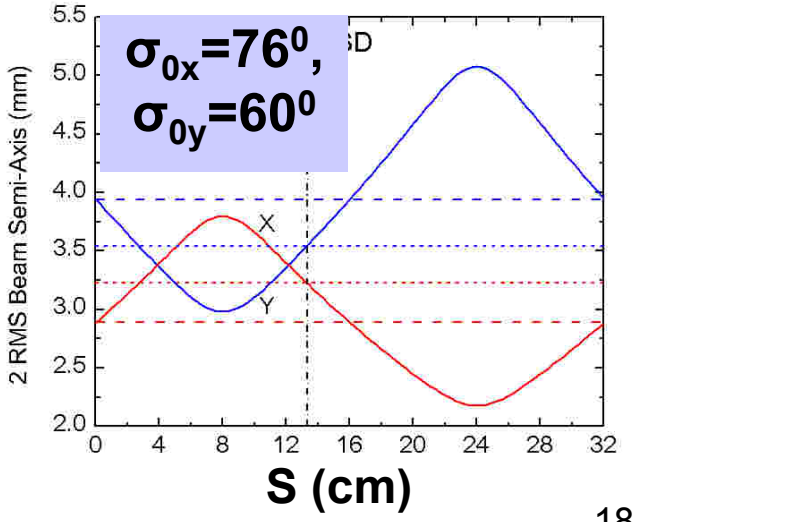
Beam Current	$\varepsilon_x = \varepsilon_y^*$ 4rms, unnor.	b/a	σ_x/σ_{0x}, σ_y/σ_{0y}
85 mA	55 μm	1.6	0.22, 0.12
24	30	1.5	0.36, 0.23
7.2	16	1.4	0.52, 0.37
0.55	6	1.2	0.86, 0.80

7.2 mA, 10 keV



7.2 mA, 10 keV





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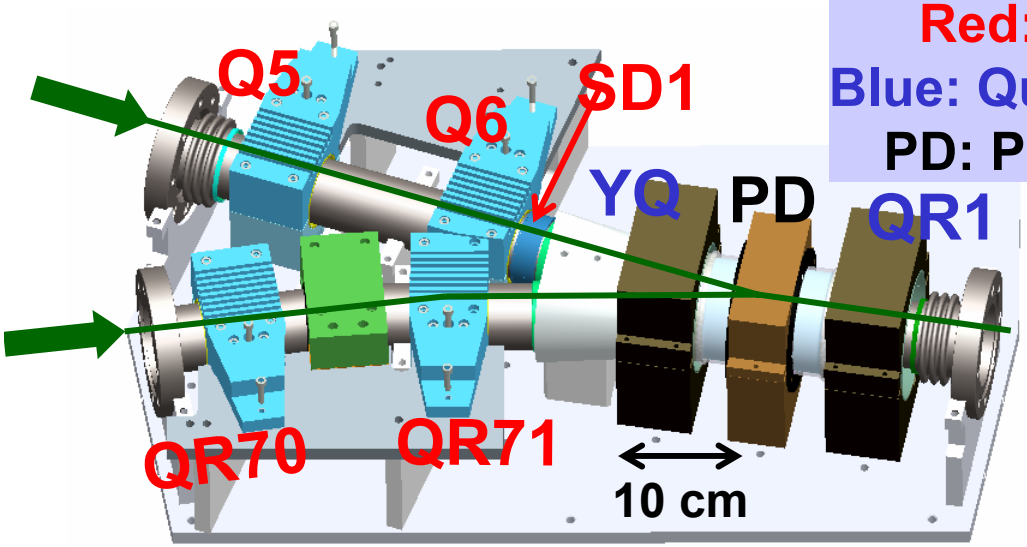
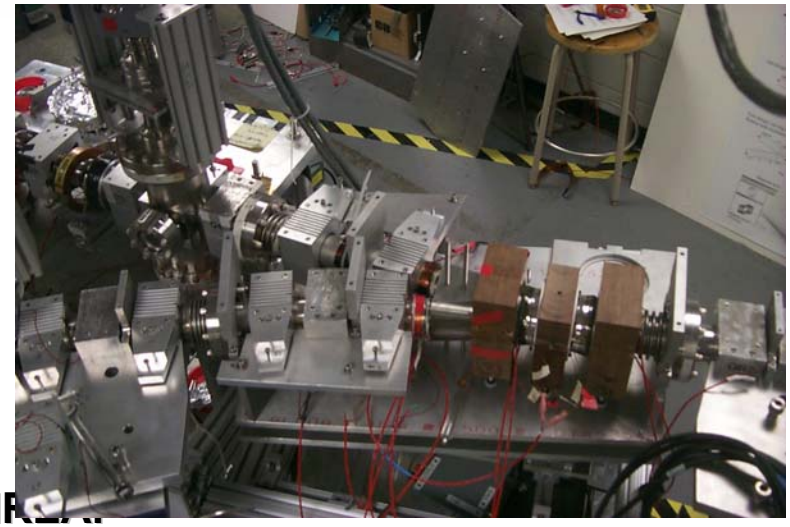
S. Bernal et al, PAC05

Pulsed Injection and Multi-turn

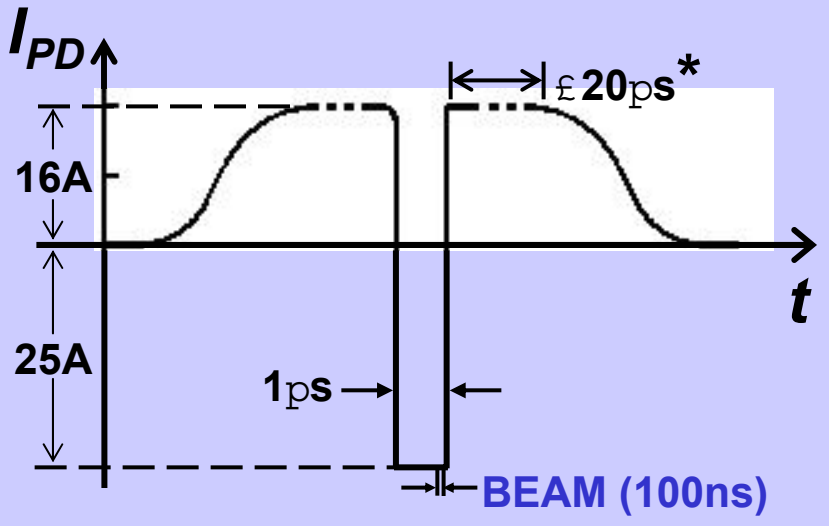
Pulsed Injection



Red: DC
Blue: Quasi-DC
PD: Pulsed



Timing Scheme:



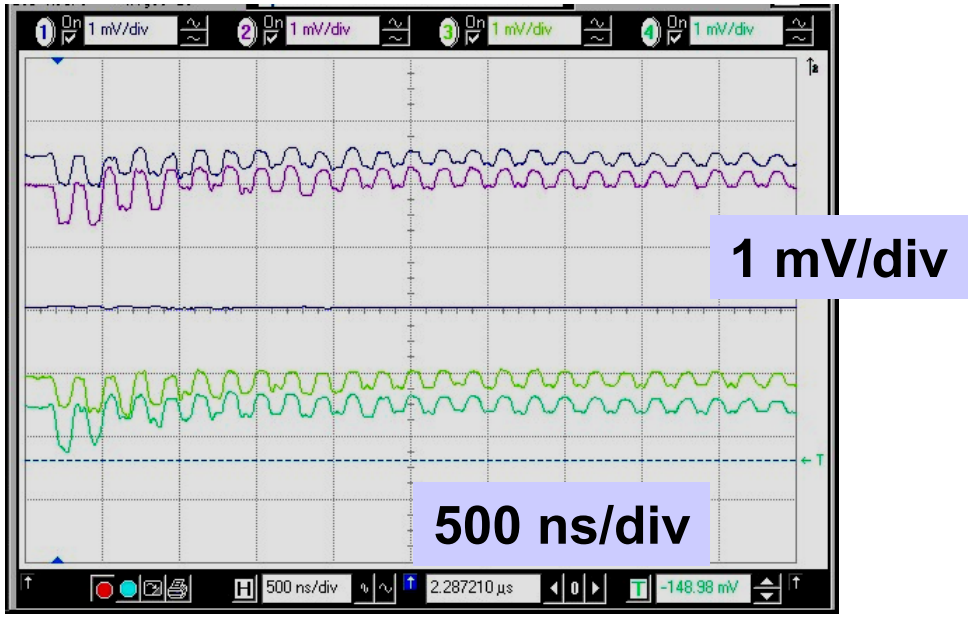
*Currently, good for ≤ 100 turns! (1.2 km)

Multi-turn with Weak Sp. Charge

Zero-curr. Tune=7.3	Beam Current	Estimated Emitt.*	Int. Param., Tune Dep.	Tune Shift
Injected	690 μA	5.6 μm	0.20, 0.89	0.80
After 25 turns	300 μA	4.6 μm	0.12, 0.94	0.45

***4rms, unnorm.**

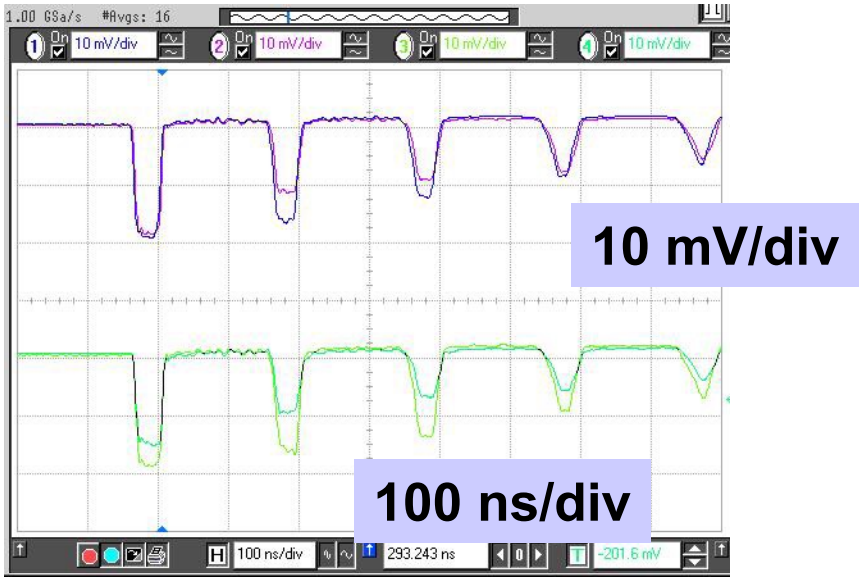
Typical BPM signals for low current



Multi-turn with Strong Space Charge

Bare Tune=7.3	Beam Current	Estimated Emitt.*	Intensity Parameter, Tune Depression.	Tune Shift
Injected	18.6 mA	24 μm	0.70, 0.55	3.3
After 9 turns	3.6 mA	10-25 μm	0.48-0.24, 0.72-0.87	2.0-0.9

***4rms, unnorm.**



Multi-turn Issues

- Preliminary estimates indicate that the **Laslett tune shift** of **0.25** is amply exceeded.
- Direct tune measurements will show that **UMER** can be operated with **a strong space charge tune shift.**
- **Injection** and **steering** errors, sensitivity to **matching,** and **halo** formation may explain the beam losses.
- Evidence of **damping and stabilization** phenomena observed, without catastrophic beam loss.
- Exploration of **resonance phenomena** remains to be done.
- Beam **Extraction**…

Plans

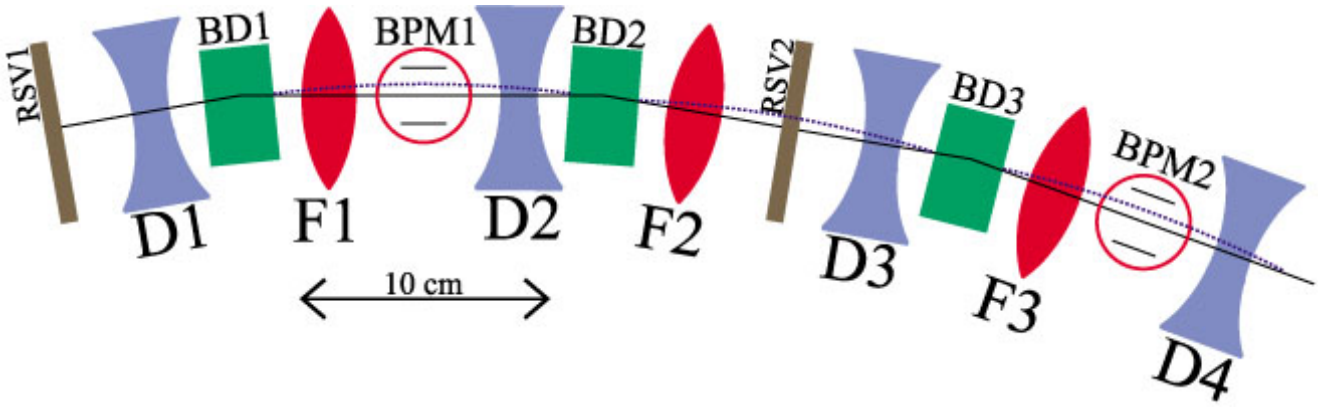
- Optimize first-turn base line: injection, rms envelope matching, beam steering for closed orbit, and correction of skew quadrupole errors.
- Coherent and incoherent tune-shift studies.
- Continuation of longitudinal structure studies.
- Additional electron source and halo formation studies.
- Implementation of new diagnostics and beam extraction.
- Full stability analysis with and without space charge.
- Experiments with anisotropic beams to search for coupling resonances (Montague), emittance exchange and equipartitioning.

Summary/Conclusions

- **UMER** is a platform for scaled experiments and code benchmarking in beam physics.
- **Multi-turn** operation of emittance (>100 turns) as well as space-charge dominated (>10 turns) e^- beams was demonstrated recently in UMER.
- Preliminary estimates indicate that the **Laslett tune shift** of 0.25 is amply exceeded, without evidence of serious **resonances or instabilities**.
- **Work in progress…**

Backup Slides

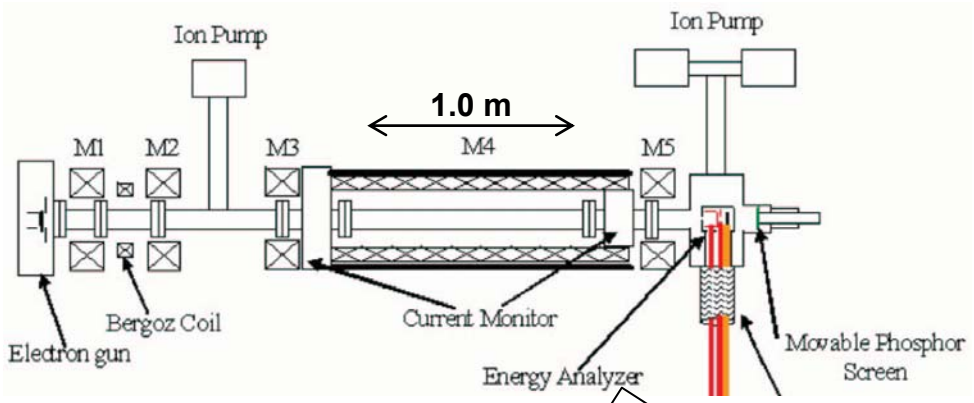
Beam Steering

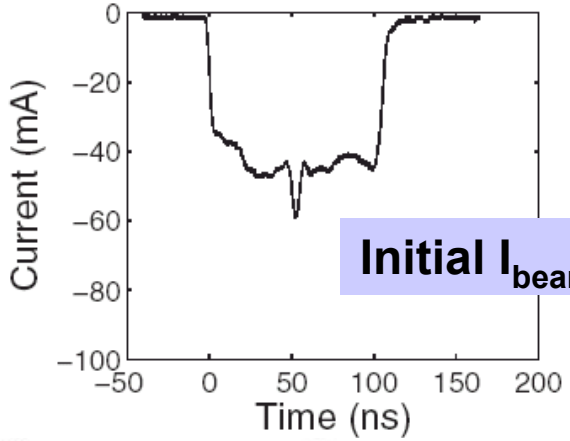


Longitudinal Beam Dynamics and Diagnostics

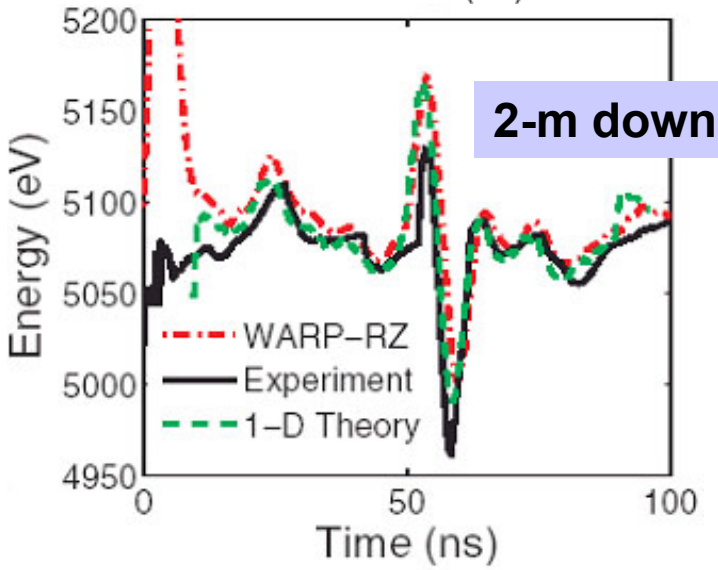
Longitudinal Beam Dynamics

Space charge converts density perturbation to an energy perturbation





Initial I_{beam} vs. time



2-m downstream

Y. Cui et al, PRST AB 7, 072801 (2004)

K. Tian et al, PRST AB 9 014201 (2006)

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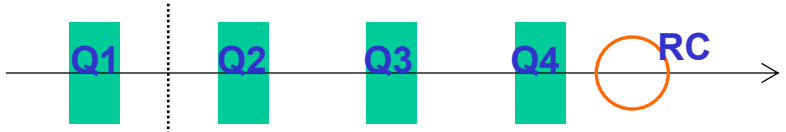
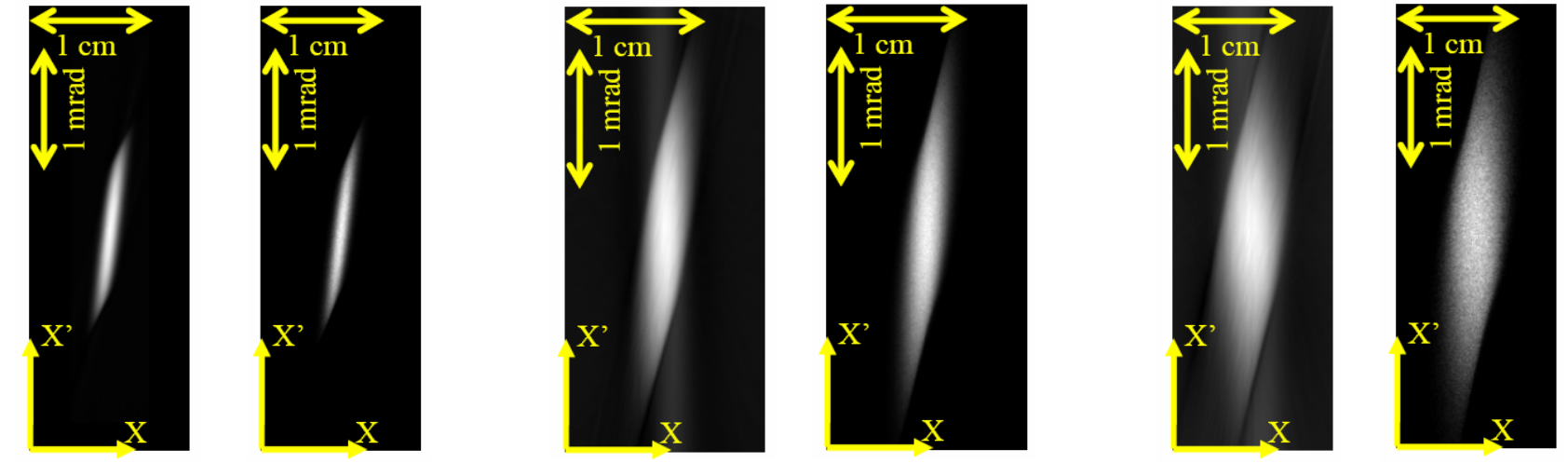
Diagnostics: Tomography

Validation of TOMOGRAPHY with WARP: Phase space at RC with (initial) S-G particle distribution



Pencil Beam (χ=0.30)		7 mA, 10 keV (χ=0.72)		24 mA, 10 keV (χ=0.90)	
Tomography	WARP	Tomography	WARP	Tomography	WARP



D. Stratakis et al, submitted to PRST AB (2006)

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