The University of Maryland Electron Ring

UMER is a fully functional electron storage ring!

It is a unique scientific instrument: capable of addressing a wide range of beam dynamics research!
Experimental Capability

Designed, and constructed to operate from the emittance dominated regime to the highly space charge dominated regime.

- Beam current range: 60 micro amperes to 100 milliampere.
- Pulse lengths from 20ns to 130ns.
- Incoherent tune shifts from 0.01 to > 5.0.
- Operation beyond conventional Laslett tune limits are routine!
- Routine kinetic energy operation from 9 to 11 keV

Experiments can move step-by-step from low to high space charge to quantitatively study effects on beam performance.

UMER is, in fact, the only storage ring in the U.S. with such a capability over such a broad range.
UMER Systems and Layout

- 167 Magnets, with individual power supplies & controls.
- 15 BPM sensors & electronics.
- 14 Helmholtz coils & electronics.
- High pulsed current magnet injection supply.
- 15 phosphor screen monitors with insertion actuators.
- Electron gun energy source:
  - Kinetic energy control.
  - Pulse length electronics.
- High vacuum system – Ion pumps, controls & gauges.
Planned Research

• Nonlinear Optics in Accelerators
• Longitudinal Barrier Compression
• Beam – Structure Interactions
• Space Charge & Resonance Crossing
• Optimizing Beam Optics
Nonlinear Optics In Accelerators

• **Goal:** To experimentally demonstrate that strong nonlinearities will detune resonant particles and limit halo growth.

• **Impact to the Accelerator Community:** Accelerators at the intensity frontier face beam current limitations because of particle losses from various resonant mechanisms that include the production and growth of beam halo. Recent theoretical results argue that lattices with strong nonlinearities will detune resonant particles, stabilizing the beam, limiting halo growth without loss of stable orbital motion or reduction in dynamic aperture.

• **Application to other Future Facilities:** An Integrable Rapid-Cycling Synchrotron (RCS) would be an effective replacement for the FNAL booster ring, as part of a plan to reach multi-MW beam power for the FNAL high-energy neutrino program.

-J. Eldred and A. Valishev, Design Considerations for Proposed Fermilab Integrable RCS, NAPAC2016.
Nonlinear Optics In Accelerators

Octupole Channel Field Profile

Extruded Octupole Channel Designed UMER Lattice Solution - Beam Size (x, y)

Octupole strength

Beam size

T-insert

z-axis (mm)

- K. Ruisard, Design of a nonlinear quasi-integrable lattice for resonance suppression at the University of Maryland Electron Ring, PhD 2018.
- K. Ruisard, Tuning low-current beam for nonlinear quasi-integrable optics experiments at the University of Maryland Electron Ring, IPAC2018.
Longitudinal Barrier Compression

• **Goal:** To investigate a novel scheme of bunch compression to create high-current bunches in a storage ring.

• **Impact to the Accelerator Community:** Barrier buckets are routinely utilized in storage rings and synchrotrons as a means of accumulating charge to increase the peak intensity, employing traditional stacking techniques. The presence of longitudinal space-charge improves the efficiency of the compression by taking advantage of the shock front that develops.

• **Application to other Future Facilities:** Other rings with similar barrier bucket schemes include: the GSI Darmstadt SIS18 and SIS100, or a ring like the FNAL recycler.

-B.L. Beaudoin, Barrier Shock Compression, IPAC2015.
Longitudinal Barrier Compression

Single sided compression

$t_2 < \tau_1$

$t_3 < \tau_2$

Current as a function of time

No compression

Shock front

Compression

Longitudinal Phase Space
Slightly after Injection

Turn n

Turn n+1

Turn n+2

Turn 45

Turn 46

Vz vs Z

Vz vs Z
Beam – Structure interactions

• **Goal:** To characterize effect of surrounding structures on beam stability.

• **Impact to the Accelerator Community:** Beam stability is a generic issue. Examples include resistive wall instability, beam break-up instability, and emittance growth due to wall-space charge interactions.

• **Application to Future Facilities:** Other storage rings that will be impacted by the UMER studies in wakefields include: The FNAL IOTA ring with 2.5 MeV proton storage. The GSI Darmstadt SIS100 ring. The ORNL neutron source accumulator ring. A proposed low energy accumulator ring proposed by FNAL as an alternative to the PIP linac.
Beam – Structure Interactions

Sylphon Bellows

**Plans:**

- Will compare simulation to measurements in UMER for the resistive wall effect, varied by changing ferrite structures.
• **Goal:** To investigate space charge shifts of betatron resonances; study onset and evolution of nonlinear resonances; and resonance crossing by fast acceleration, and by rapid tune shift from shock compression.

• **Impact to the Accelerator Community:** The effects of space charge on tune resonance structures are relevant to high intensity, cyclic accelerators. Most investigations, have dealt with weak space charge. Experiments over the broader range of space charge intensities accessible to UMER should lead to new insights on the dynamics of resonances.

• **Application to other Future Facilities:** Cyclic accelerators are designed and built in such a way as to avoid crossing low order resonances during acceleration. Experimentally demonstrating the feasibility to safely cross resonances will reduce design and cost constraints of future upgraded accumulator/booster rings.
Space Charge & Resonance Crossing

Time-integrated current after 50 turns

Horizontal tune

Vertical Tune
Optimizing Beam Optics

• **Goal:** To develop a highly efficient numerical approach to optimizing focusing magnetic fields and electrode shapes.

• **Impact to the Accelerator Community:** Focusing lattices have many variable parameters. Optimization generally requires calculating gradients in high dimensional parameter spaces requiring many computations. Using adjoint methods the number of computations required can be reduced substantially, allowing rapid and efficient optimization.

• **Application to other Future Facilities:** This technique can be used in the design of any focusing system, whether it is magnetic or electrostatic.
Sensitivity of Beam Radius to Electrode Shape

\[ \sum_j \frac{I_j}{I} \left( \delta p_j^{(X)} \cdot \delta x_j^{(Y)} - \delta p_j^{(Y)} \cdot \delta x_j^{(X)} \right) = -\frac{q\varepsilon_0}{l} \int_B d^2x \delta \phi^{(X)} \cdot n \cdot \nabla \delta \phi^{(Y)} + q \int d^3x \delta j_m \cdot \delta A^{(Y)} \]

\[ -\lambda \sum_j \frac{I_j}{I} \delta x_j^{(X)} \cdot \mathbf{x}_\perp = -\frac{\lambda}{2} \delta \langle |\mathbf{x}_\perp|^2 \rangle \]

T. M. Antonsen, D. Chernin, J. Petillo, IVEC 2017, PRL to be submitted
Personnel & Expertise

- **Thomas Antonsen**: Professor, Contour integrals
- **Rami Kishek**: Research Professor, Simulations
- **Brian Beaudoin**: Associate Research Professor, Electrical & mechanical engineering, vacuum system, beam instrumentation & beam optics.
- **Santiago Bernal**: Associate Research Scientist, Magnets, high vacuum system & beam optics.
- **Irv Haber**: Visiting Research Scientist, electron gun physics and beam optics.
- **Dave Sutter**: Visiting Research Scientist, Mechanical design, circuits, beam instrumentation & beam optics.
- **Eric Montgomery**, Assistant Research Scientist
- **David Mathew** – Graduate Student
- **Levon Dovlatyan** – Graduate Student
- **Undergraduate students**