Modeling of Halos and Intense Beams

Rami A. Kishek
S. Bernal, I. Haber, H. Li, P.G. O'Shea, M. Reiser

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

Research sponsored by US Department of Energy
Outline

1. Halo? What is it and Why?
2. Earlier Work
3. Recent Observations
High Energy Accelerators: Livingston Plot

Energy

Year of commissioning
Facilities for the Future of Science: A Twenty-Year Outlook

http://www.sc.doe.gov/
RMS Matched ~ 1989

Example: D. Kehne, M. Reiser, & I. Haber
Larger Amplitude if Mismatched

RMS Mismatched

Simulation vs Experiment
Why Care?

• Beam losses, quality deterioration
• Halo particles can scrape wall:
  – Activation: More difficult maintenance
  – $\Omega 1 \text{ in } 10^6 / \text{m}$
  – Electron Cloud: Beam breakup
• Larger aperture = higher cost
• Collimation – Will it work?
Theoretical Background

• **Mismatched Beams** ⇒ Emittance growth + Halo
  

• **Free-Energy Model** predicts emittance growth
  

• **rms envelope modes from mismatch** ⇒ **parametric resonance** b/w particle orbits & envelope modes
  
  *R. Gluckstern, Phys. Rev. Lett. 73, 1247 (1994).*

• **Particle-Core Model** ⇒ Emittance growth + Halo
  
  *T.P.Wangler, K.R.Crandall, R.Ryne, and T.S.Wang, PRST-AB 1, 084201 (1998).*

• Basic model predicts: Halo has a maximum extent
Parametric Resonance

Envelope oscillations

Particle oscillations

Envelope oscillations

Particle oscillations
Intense Beams Carry Internal Modes

Experiment (Bernal, et al., PAC 2003)

- Particles experience **nonlinear, time-dependent**, forces

Experiment and Simulation

Bernal, Kishe, Reiser, and Haber, PRL, 82, 4002 (1999)
NIU: Addition of Colored Noise Changes Particle-Core Model

Colored noise REMOVES the hard upper bound to the halo amplitude!

C.L. Bohn, talk Wed. 10:30 AM, Rm. 305
NIU: Effects of Internal Structure

No rms Mismatch!
But internal collective mode
(Lund, Davidson, and Strasburg warm-fluid model)

C.L. Bohn
MIT: Studies of Halo Formation from Image Charge Effects

100 Test-Particles Motion over 400 Periods

\[ KS/\varepsilon_x = 10.0 \]
\[ \hat{R} = R/\sqrt{\varepsilon} = 40 \]

\[ \hat{R} = 4.5 \]
\[ KS/\varepsilon = 10.0 \]


C. Chen
LANL: LEDA Experiment

RFQ-6.7 MeV

52 quadrupole FODO lattice

Beam-profile diagnostics in red

Matching/mismatching quads Q1 to Q4

Emittances obtained from measured profiles at Q20 and Q45


T. Wangler
Halo Formed even with rms Match

The graph shows the normalized charge (dimensionless) plotted against the horizontal position (mm). Two sets of data points are represented: matched (solid black dots) and mismatched (open red circles). The x-axis represents the horizontal position in millimeters, while the y-axis represents the normalized charge.
University of Maryland Electron Ring

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

- Long Path
- Variable-Parameter over a wide range
- Well-Diagnosed
- Modest Cost

Energy 10 keV
Peak Current 100 mA
Bunch charge 5 nC
rms Emittance $3 \, \mu m$

S. Bernal talk Friday (at BNL)
First Experiments (during construction)

24 mA, 10 keV

Rotated Beam

RMS Mismatched

S. Bernal (PAC ’03)
Skew Quadrupole (Rotational) Errors

Skew Quadrupole

Standard x, y 4*rms emittances, $\varepsilon_{nx}, \varepsilon_{ny}$

Generalized emittances, $\varepsilon_{ng}, \varepsilon_{nh}$

Kishek, Barnard, and Grote, PAC 1999
Inject Beam Rotated 10°
Injecting Rotated Beams $\Rightarrow$ Halo

Simulations
R. Kisheek
Proc Halo ‘03

Inject Beam Rotated $10^\circ$

Inject Beam Rotated $20^\circ$

Experiment – (Bernal, Li) shows similar features
LBNL/NTX: Halo forms in Exp.

S. Yu (1.5 mA beam, 5 mm initial radius, Ne ~ 1.2x10^{11}/cm^3, 20mm-20mr)
Quadrupoles with *Electronically Adjustable Skewness*

Two sets of coils at 45 deg

**Exp. data**  
Skew angle:  
0.93°  1.86°  2.79°  3.72°  4.66°  5.60°

Q1 is electronically rotated 3.72°  

H. Li (PAC ’01)
Beam Rotation Correction

24mA Beams (RC1-12)

Before Skew Correction

After Skew Correction

Hui Li, S. Bernal, et al., Proc 2004 HIF Symposium
UMER Electron Gun

TRIODE ELECTRON GUN: CATHODE DRIVEN, PIERCE TYPE

APERTURE PLATE

CATHODE AND ANODE GRIDS

IREAP
UMER Gun Characterization

GRID BIAS = 40 V

PINHOLE SCAN

Z = 28.8 cm

GRID BIAS = 50 V

S. Bernal and I. Haber
Phase Space at Source Exit

Experiment:
Beam exiting pinhole

3-D Simulation of K-G:
Beam velocity space

Irv Haber poster; also Proc 2004 HIF Symposium
UMER Research Program

Transverse:
- Quadrupole Rotations
- Halos
- 5-Beamlets
- Anisotropic Beams
- Chaotic Mixing

Longitudinal:
- Electron Gun
- Beam Ends
- Perturbations & Waves
- Energy Spread
Conclusions

• Halos can form early: particle-core model only partially correct
• Skew quadrupole mismatches and errors significant
• Halo collimation at best a temporary solution
• UMER promises exciting results – other UMD presentations:
  – Today PM (Haber, Cui, Huo) - posters
  – Thu 11:30 AM (Zou) – talk Rm. 304
  – Fri 5:15 PM (Bernal) – talk, BNL

Website: http://www.ireap.umd.edu/umer
Publications: http://www.umer.umd.edu/
We Thank:

<table>
<thead>
<tr>
<th>University of Maryland Electron Ring (UMER) Team:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patrick O’Shea</td>
</tr>
<tr>
<td>Martin Reiser</td>
</tr>
<tr>
<td>Irving Haber</td>
</tr>
<tr>
<td>Rami Kishek</td>
</tr>
<tr>
<td>Terry F. Godlove</td>
</tr>
<tr>
<td>Don Feldman</td>
</tr>
<tr>
<td>Renee Feldman</td>
</tr>
<tr>
<td>Junior Scientists:</td>
</tr>
<tr>
<td>Santiago Bernal</td>
</tr>
<tr>
<td>Mark Walter</td>
</tr>
<tr>
<td>Yun Zou</td>
</tr>
<tr>
<td>Bryan Quinn</td>
</tr>
<tr>
<td>Graduate:</td>
</tr>
<tr>
<td>Yupeng Cui</td>
</tr>
<tr>
<td>Hui Li</td>
</tr>
<tr>
<td>John Harris</td>
</tr>
<tr>
<td>Yijie Huo</td>
</tr>
<tr>
<td>Gang Bai</td>
</tr>
<tr>
<td>Kai Tian</td>
</tr>
<tr>
<td>Undergraduate:</td>
</tr>
<tr>
<td>D. Lamb</td>
</tr>
<tr>
<td>W-T. Lee</td>
</tr>
<tr>
<td>A. Gregory</td>
</tr>
<tr>
<td>M. Holloway</td>
</tr>
<tr>
<td>W. Tze</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Virtual National Lab for Heavy Ion Fusion (also provided WARP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simon Yu</td>
</tr>
<tr>
<td>Alex Friedman</td>
</tr>
<tr>
<td>Dave Grote</td>
</tr>
<tr>
<td>Jean-Luc Vay</td>
</tr>
<tr>
<td>Prabir Roy</td>
</tr>
<tr>
<td>Christine Celata</td>
</tr>
<tr>
<td>Steve Lund</td>
</tr>
<tr>
<td>John Barnard</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NIU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Court Bohn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LLNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom Wangler</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiping Chen</td>
</tr>
</tbody>
</table>
New 5-Beamlet Experiment

Experiment $\Rightarrow$ Simulation

$\downarrow$ Simulation

$z = 99 \text{ cm}$

$\varepsilon_n = 3.6$  $\varepsilon_n = 4$

$\varepsilon_n = 4.5$  $\varepsilon_n = 6$

galaxy cluster C0337-2522

Bernal; Haber; Kishek

Measured and Calculated Beam Profiles Agreed Well

5mm diameter aperture, 265keV horizontal profile

5mm diameter aperture, 265keV vertical profile

5mm diameter aperture, 283keV horizontal profile

5mm diameter aperture, 283keV vertical profile

S. Yu