Modeling of Halos and Intense Beams

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Research sponsored by US Department of Energy

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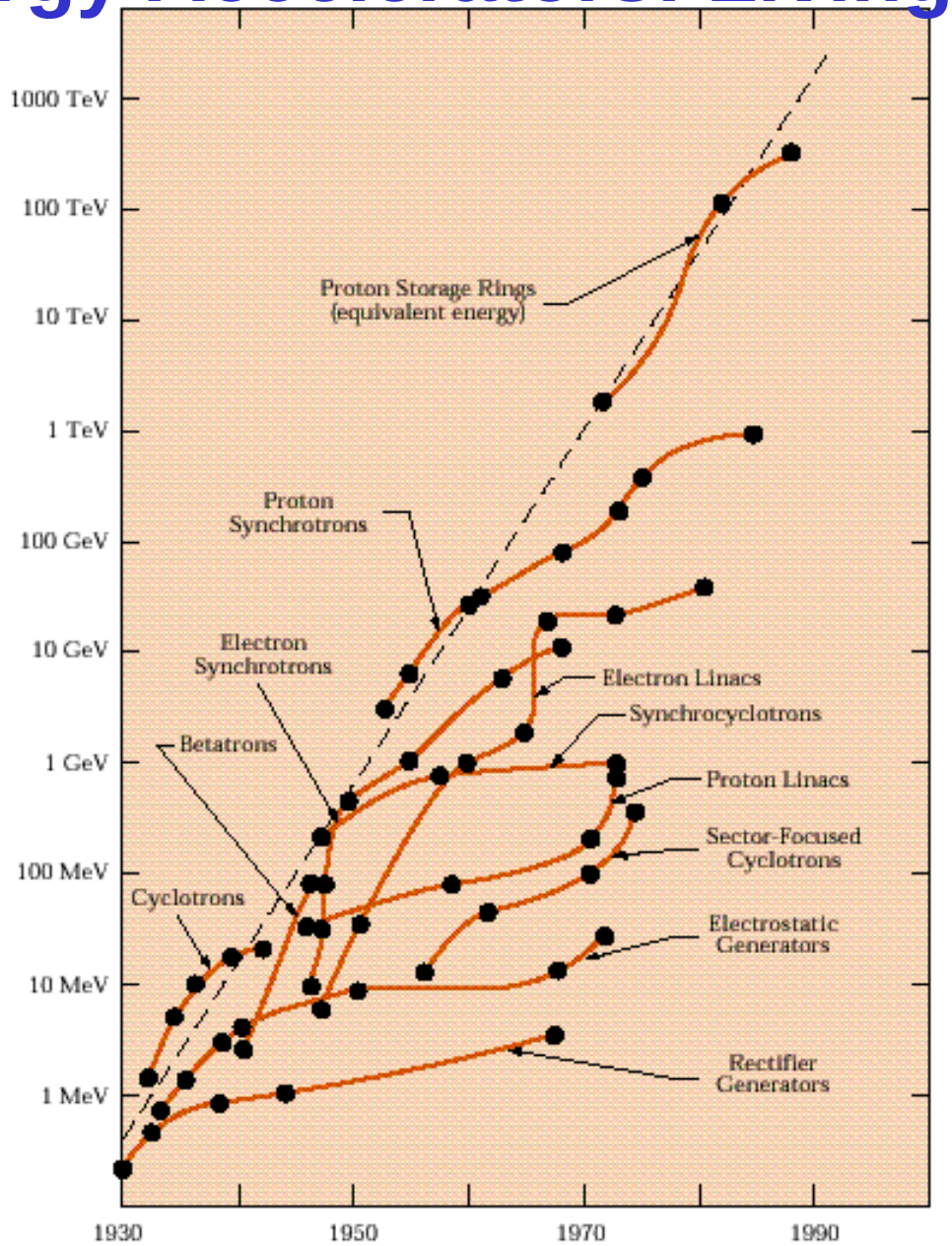
Outline

1. Halo? What is it and Why?
2. Earlier Work
3. Recent Observations

High Energy Accelerators: Livingston Plot



Energy

Year of commissioning

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


ITER


Ultra Scale Scientific Computing Capability


Joint Dark Energy Mission


Spallation Neutron Source 2.4 MW Upgrade


Spallation Neutron Source Second Target Station


Wide Problems Analysis


Linac Coherent Light Source


Protein Production and Tags


Rare Isotope Accelerator


Double Beta Decay Underground Detector


Next Step Spherical Torus


RHIC II


Characterization and Imaging Molecular Machines


CEBAF 12 GeV Upgrade


ESnet Upgrade


National Synchrotron Light Source Upgrade


Super Neutrino Beam


Advanced Light Source Upgrade

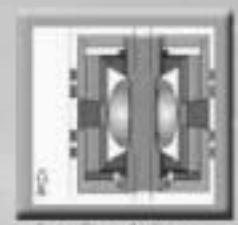

NERSC Upgrade


Transmission Electron Achromatic Microscope

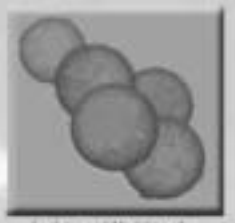

ILC


Advanced Photon Source Upgrade


eRHIC


Fusion Energy Contingency


Linear Collider


Analysis and Modeling of Cellular Systems

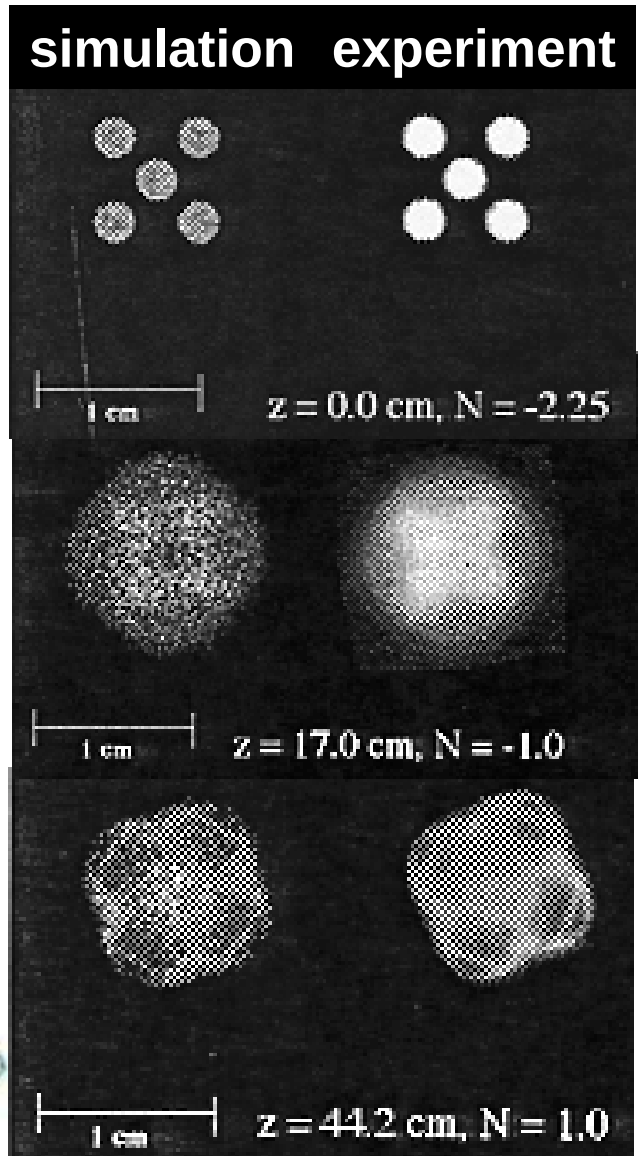

HFIR Second Cold Source and Guide Hall

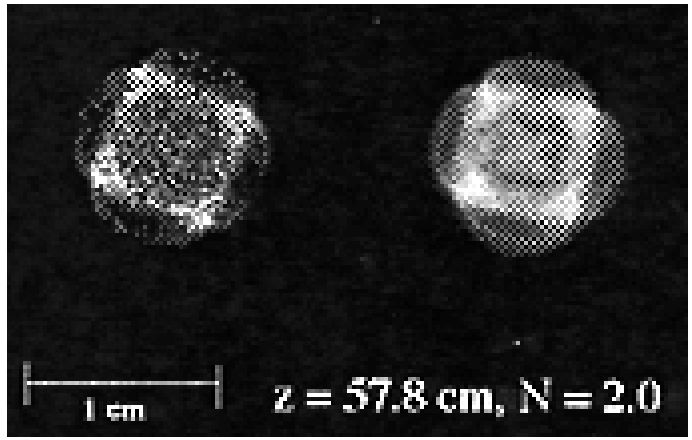

Integrated Beam Experiment

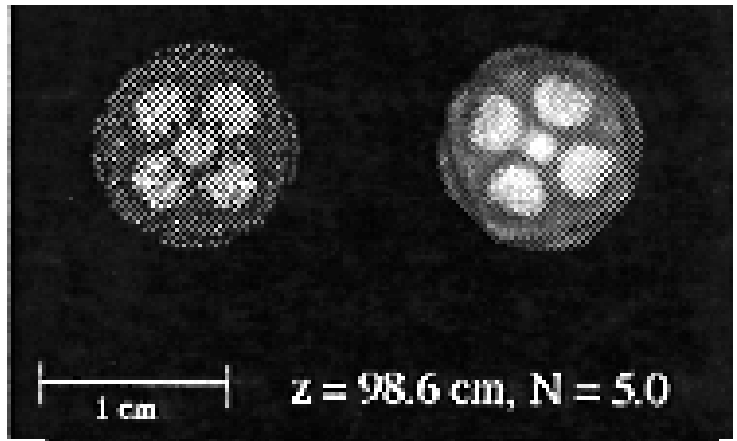
http://www.sc.doe.gov/

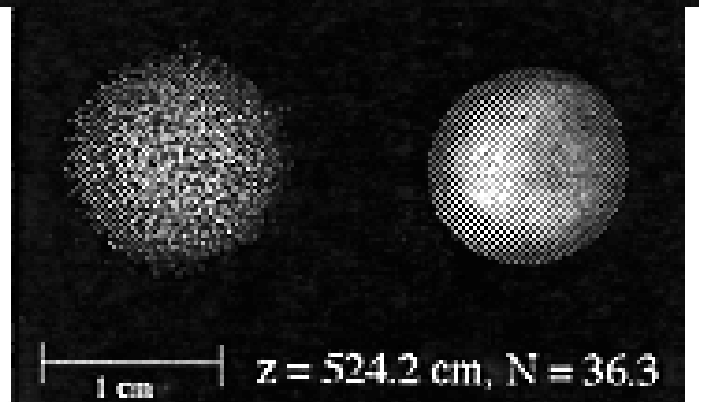
Example: D. Kehne, M. Reiser, & I. Haber

RMS Matched ~ 1989



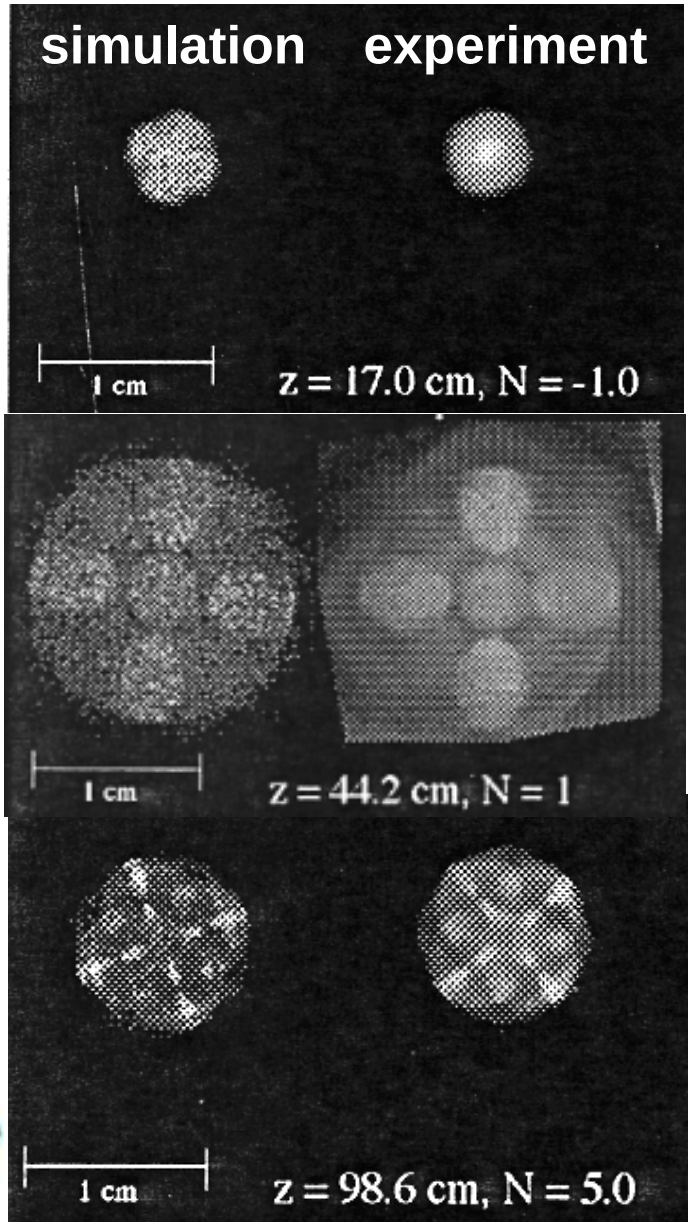




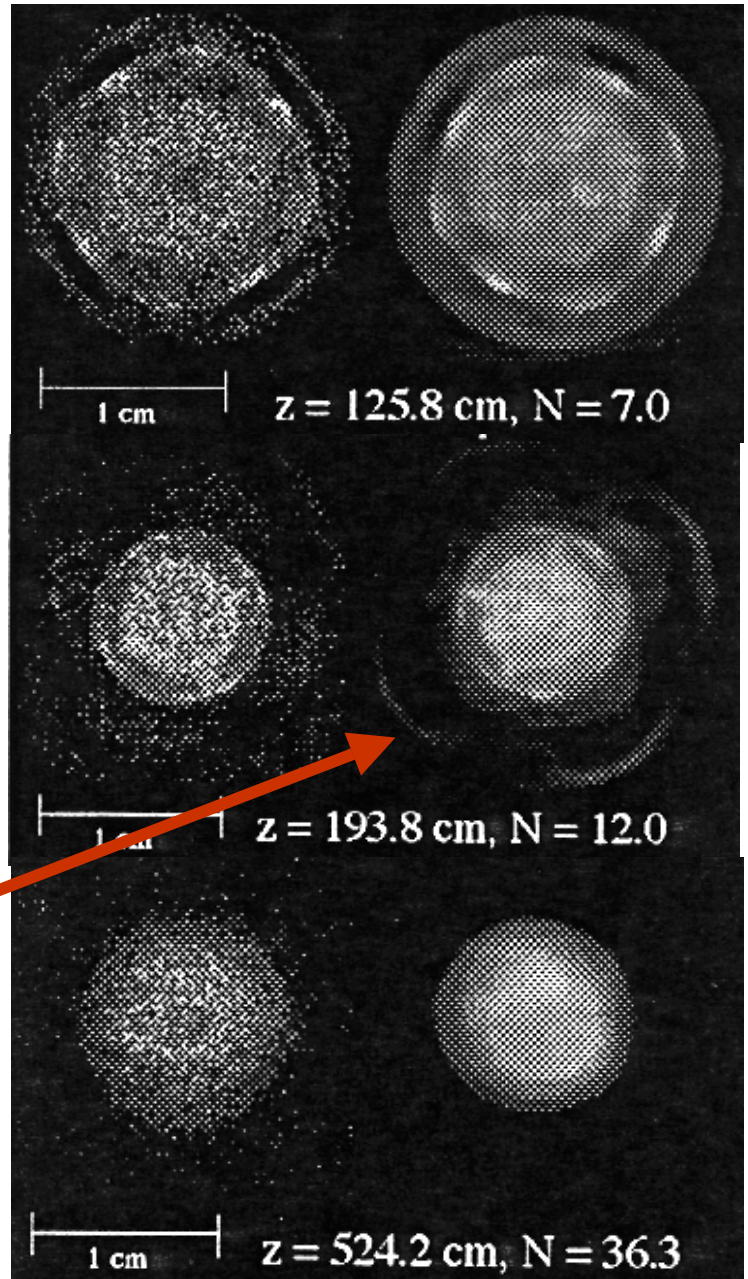


Larger Amplitude if Mismatched

RMS Mismatched



Halo



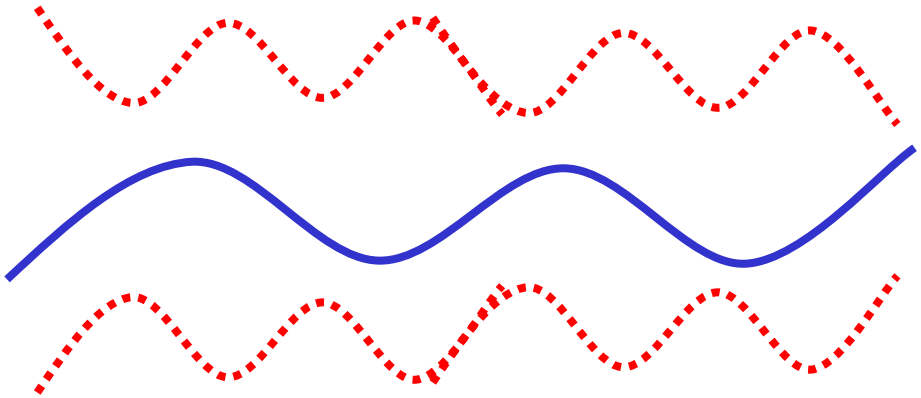
Why Care?

- Beam losses, quality deterioration
- Halo particles can scrape wall:
  - Activation: More difficult maintenance
  - ≙1 in 10^6 / m
  - Electron Cloud: Beam breakup
- Larger aperture = higher cost
- Collimation – Will it work?

Theoretical Background

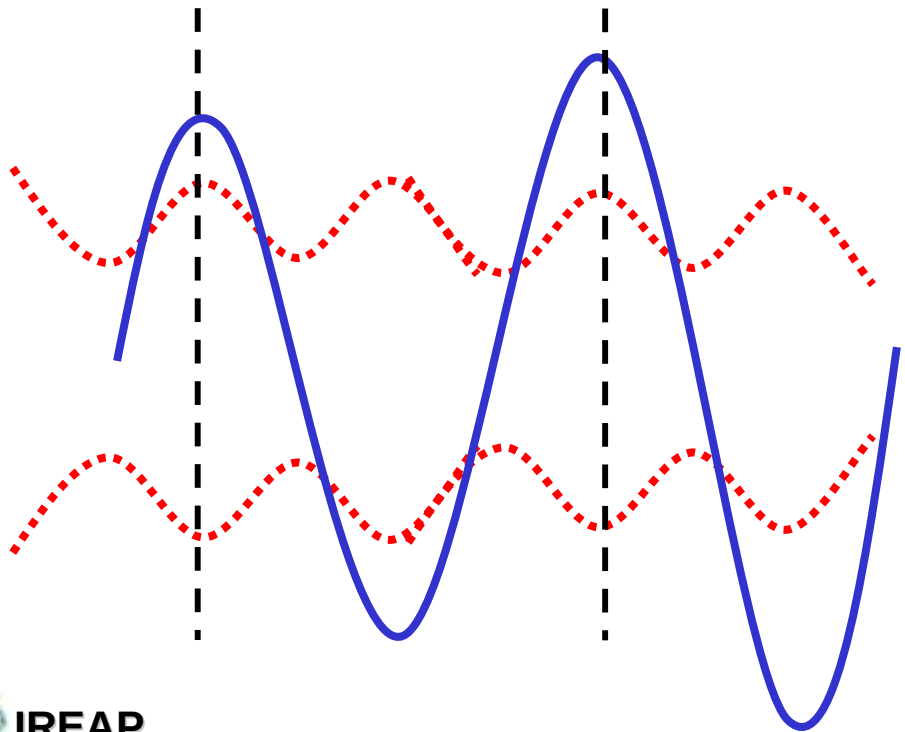
- **Mismatched Beams** ⇒ Emittance growth + Halo
  A. Cucchetti, M. Reiser, and T. Wangler, Proc. PAC 1991, p.251.
- **Free-Energy Model** predicts emittance growth
  M. Reiser, J. Applied Phys. 70, 1919 (1991).
- rms envelope modes from mismatch ⇒ **parametric resonance** b/w particle orbits & envelope 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



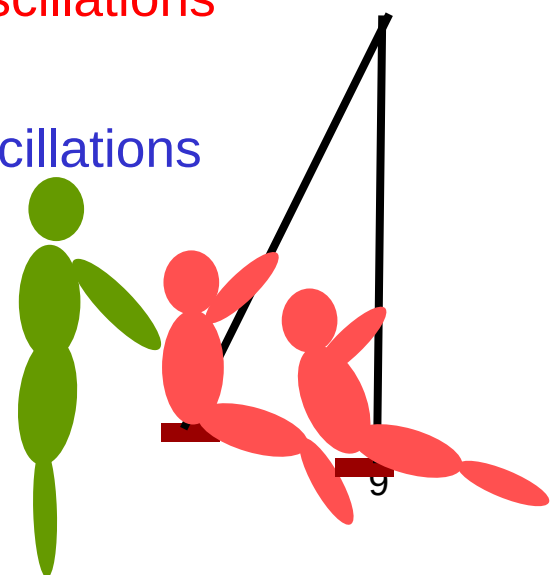
Envelope oscillations

Particle oscillations



Envelope oscillations

Particle oscillations



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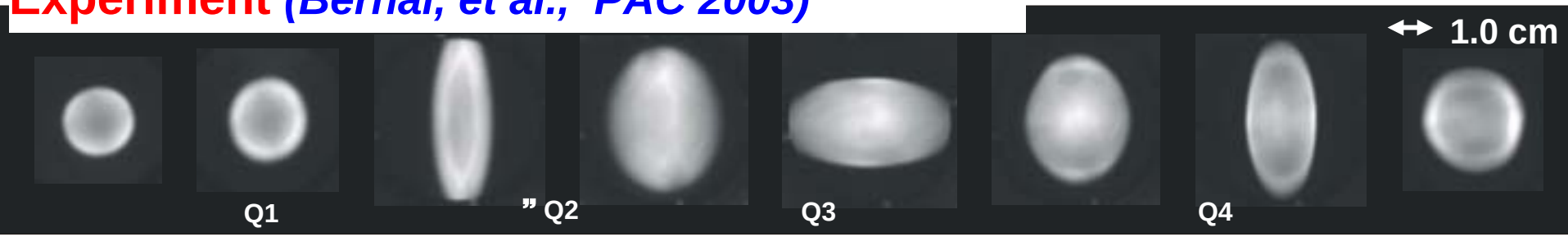
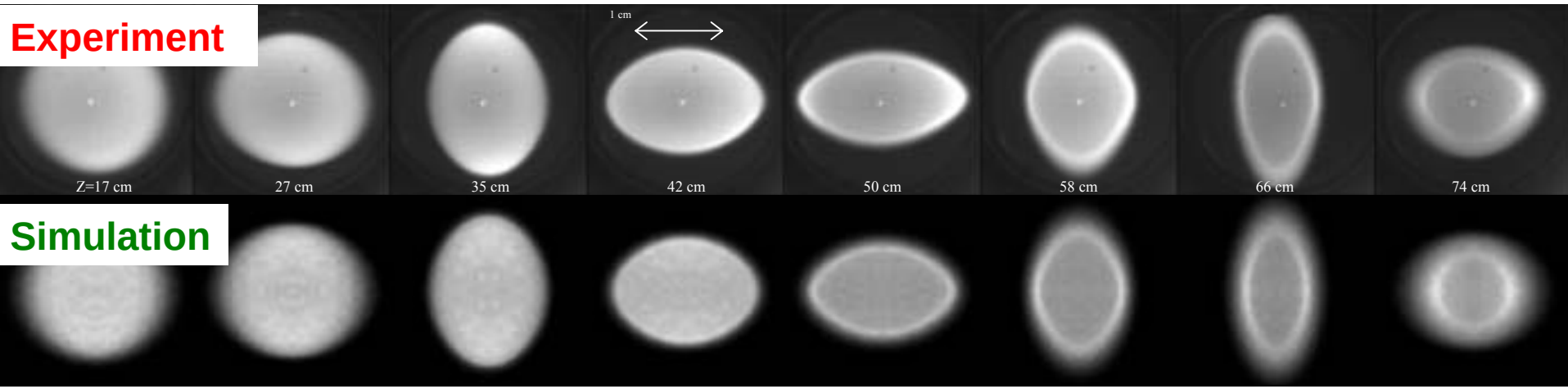
Intense Beams Carry Internal Modes

Experiment ***(Bernal, et al., PAC 2003)***



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



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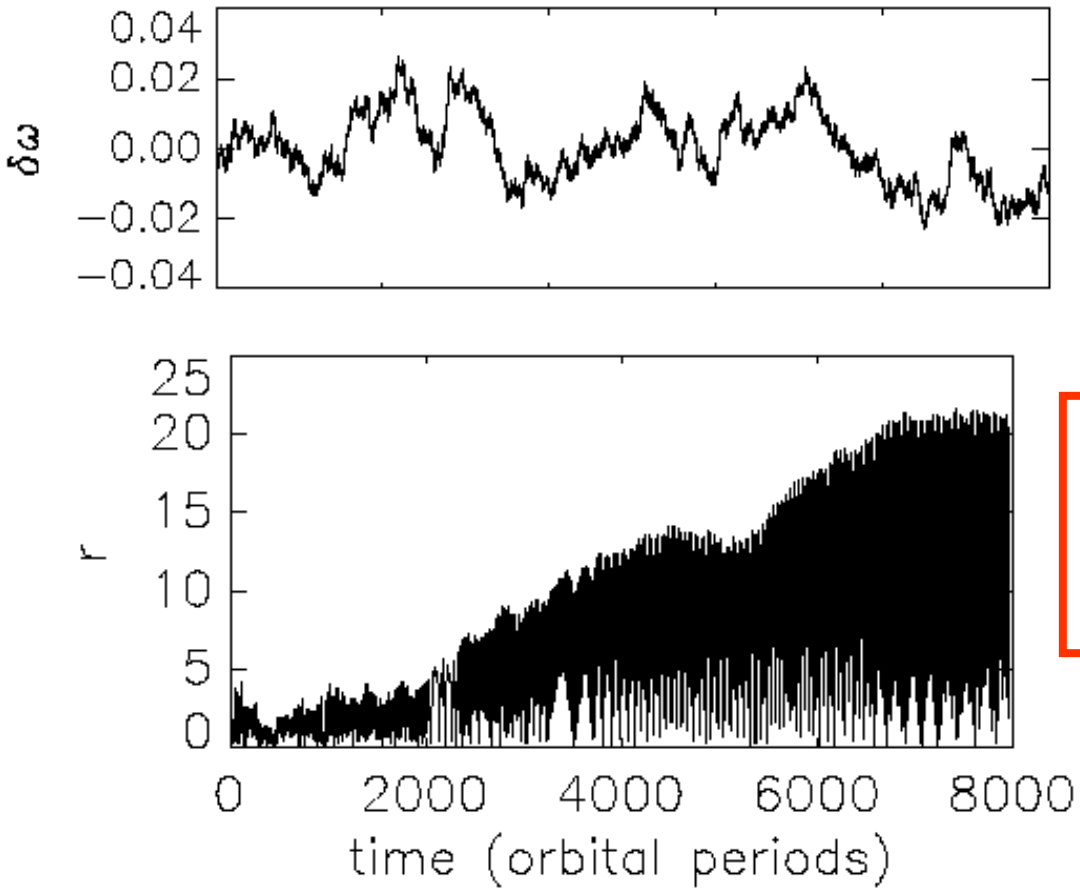
Bernal, Kishek, Reiser, and Haber, PRL, 82, 4002 (1999)

NIU: Addition of Colored Noise Changes Particle-Core Model



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

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C.L. Bohn, talk Wed. 10:30 AM, Rm. 305

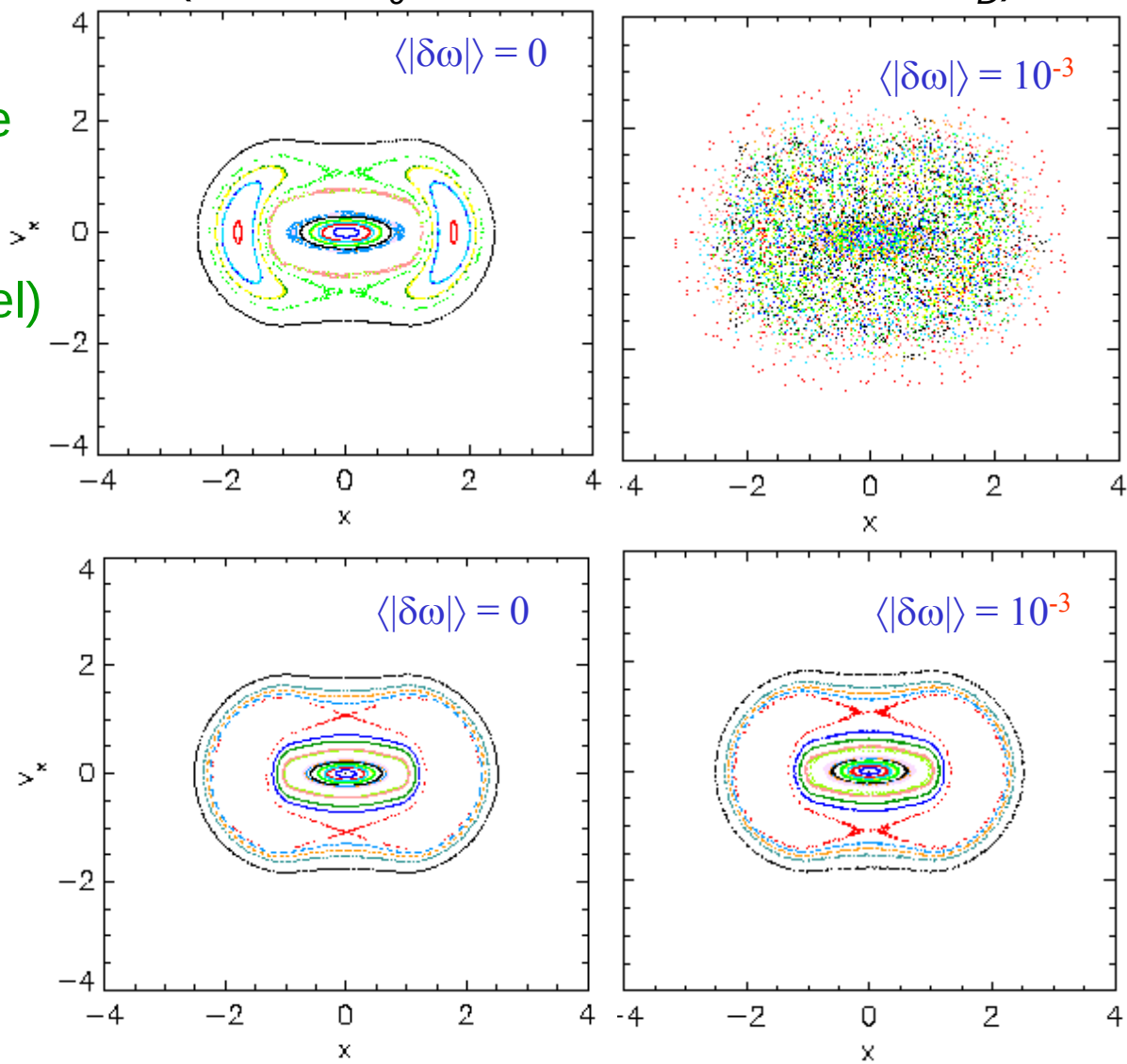
NIU: Effects of Internal Structure

POINCARÉ SECTIONS
(Γ=0.05, t_c=80, 18 orbits over ~250 t_D)

No rms Mismatch!
But internal collective mode

(Lund, Davidson, and Strasburg warm-fluid model)

rms Mismatch



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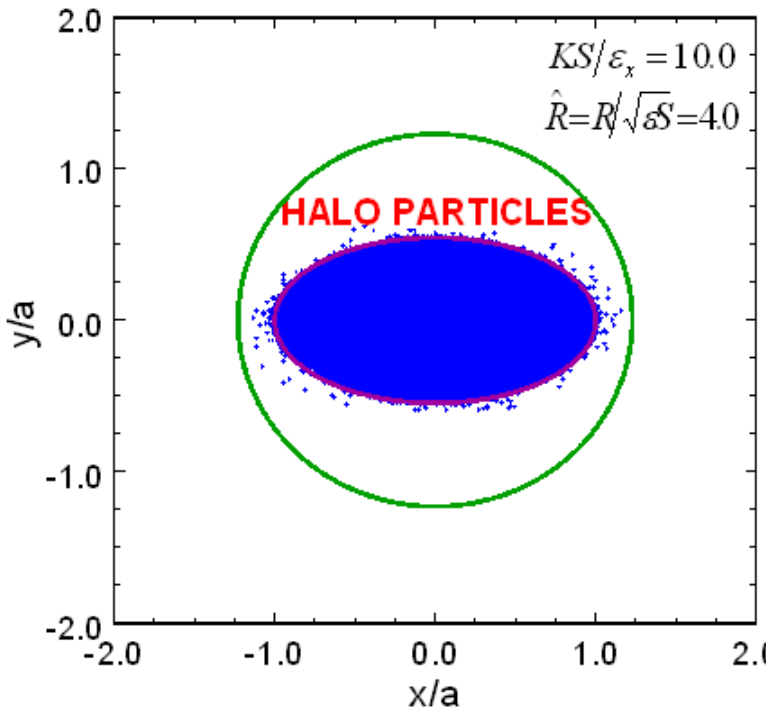
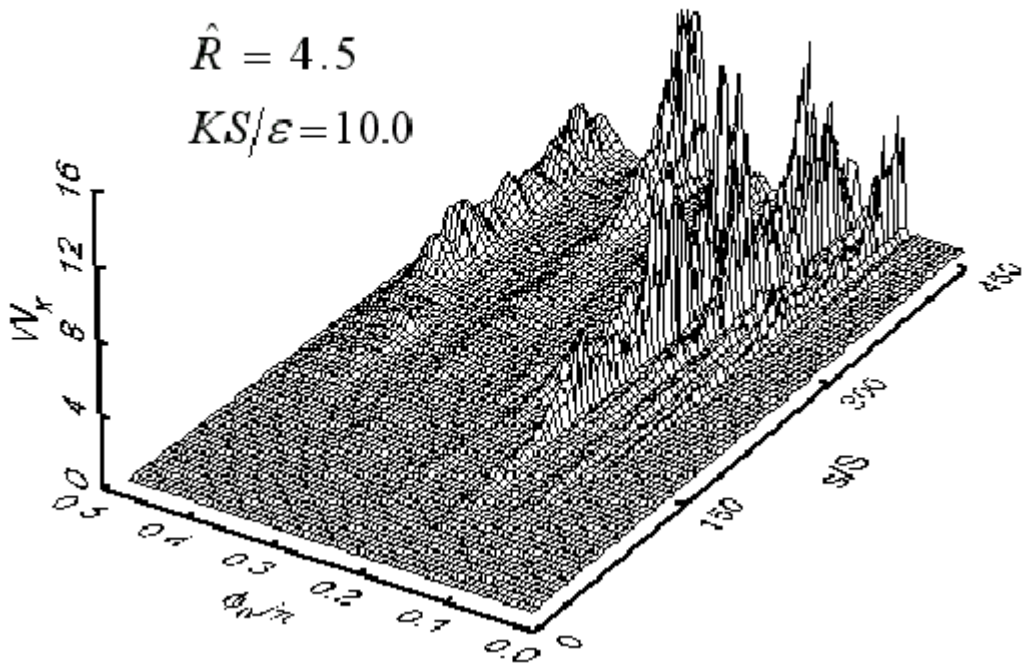
C.L. Bohn

MIT: Studies of Halo Formation from Image Charge Effects

100 Test-Particles Motion over 400 Periods





J. Zhou, et al., Physics of Plasmas 10, 4203 (2003).

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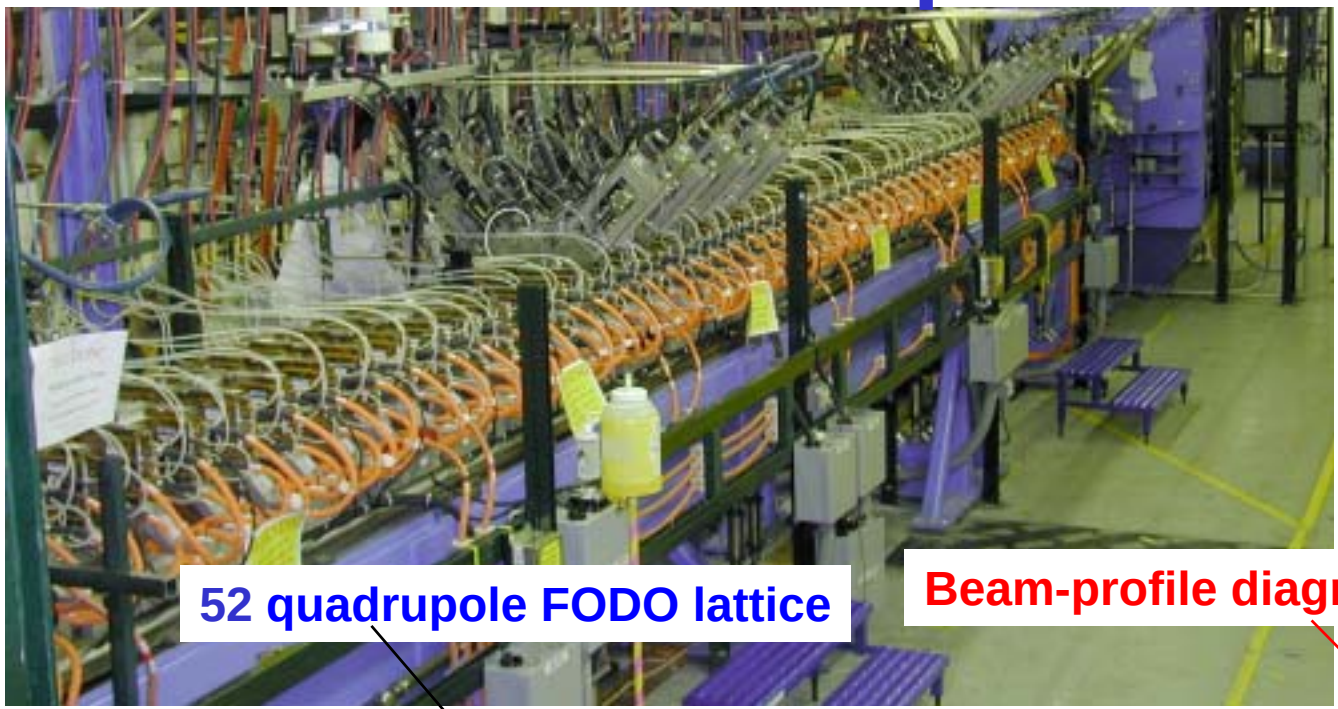
C. Chen

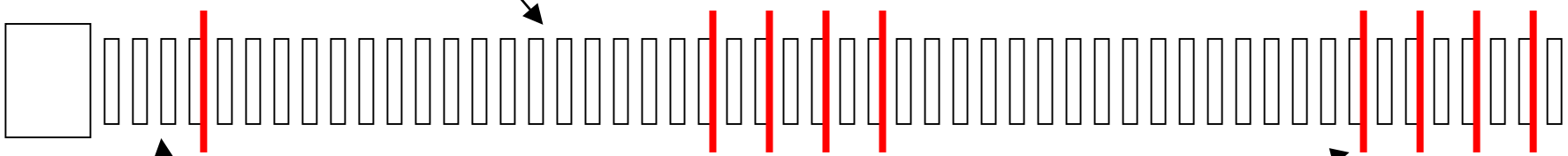
LANL: LEDA Experiment



52 quadrupole FODO lattice

Beam-profile diagnostics in red

RFQ-
6.7 MeV



Matching/mismatching
quads Q1 to Q4

Emittances obtained
from measured profiles
at Q20 and Q45

C.K. Allen, et al., Phys. Rev. Letters, 89, 214802 (2002).

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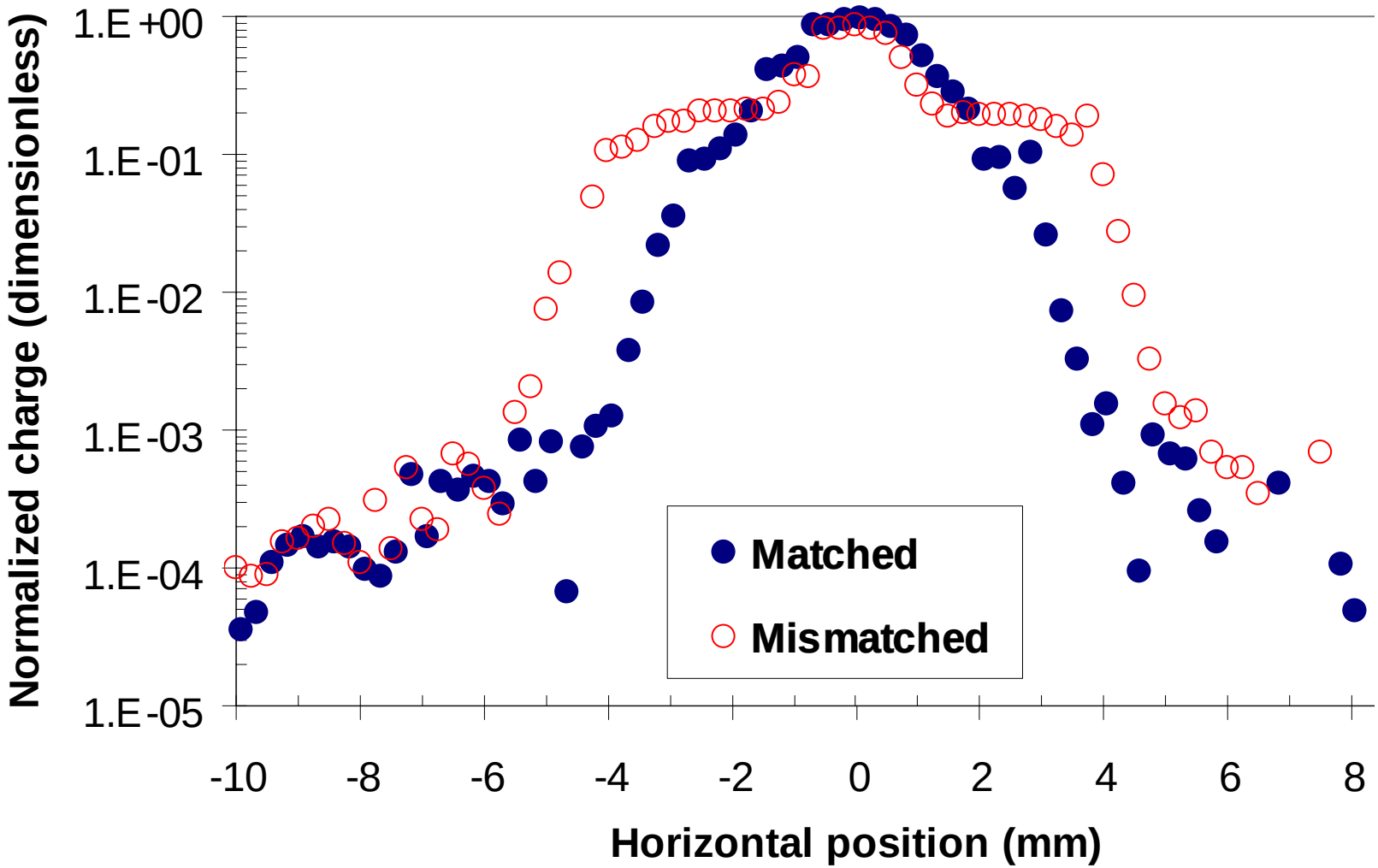
T. Wangler

Halo Formed even with rms Match



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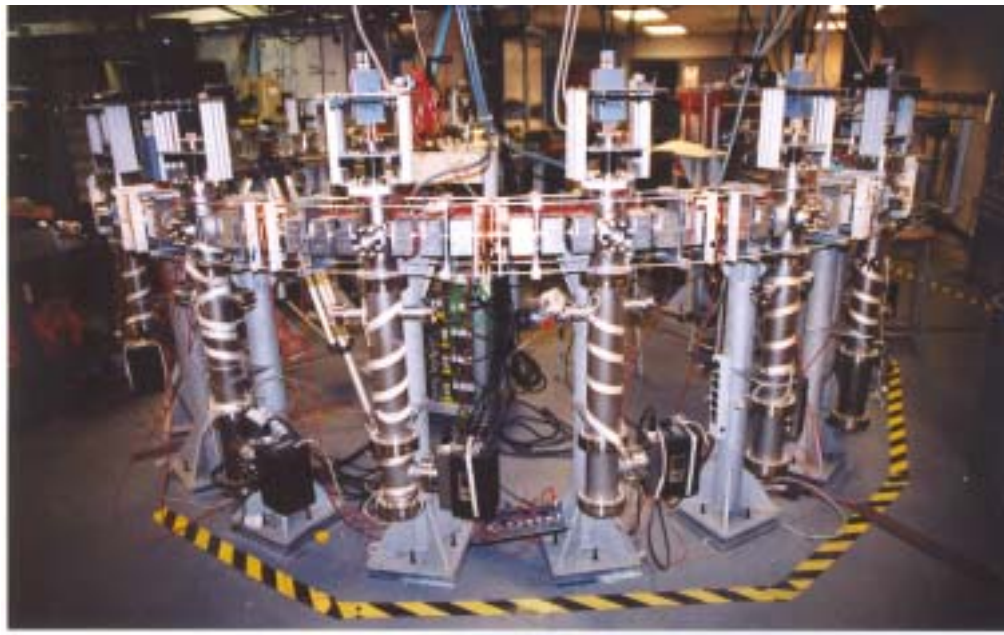
T. Wangler

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$_n$	**3 μm**



S. Bernal talk Friday (at BNL)

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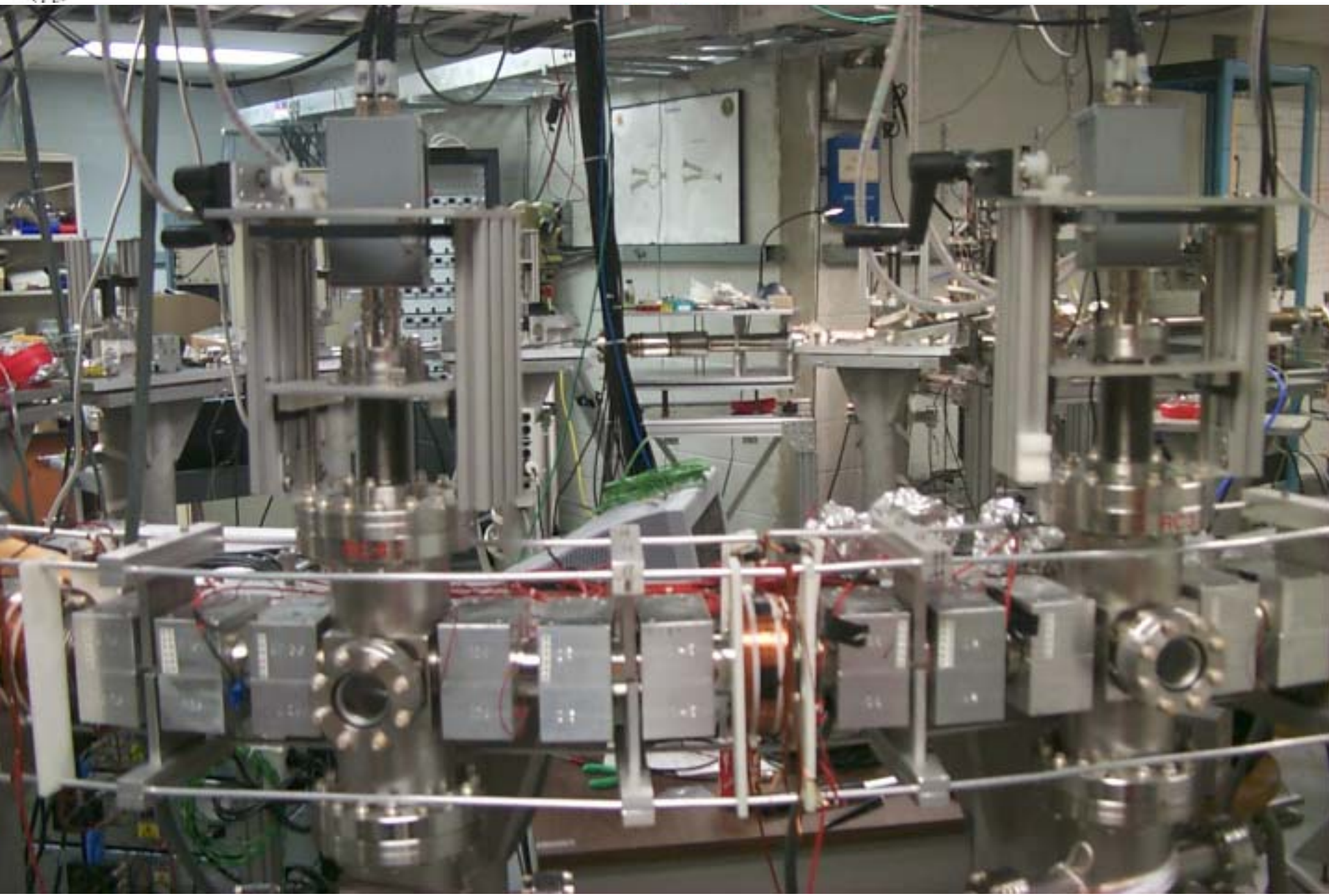
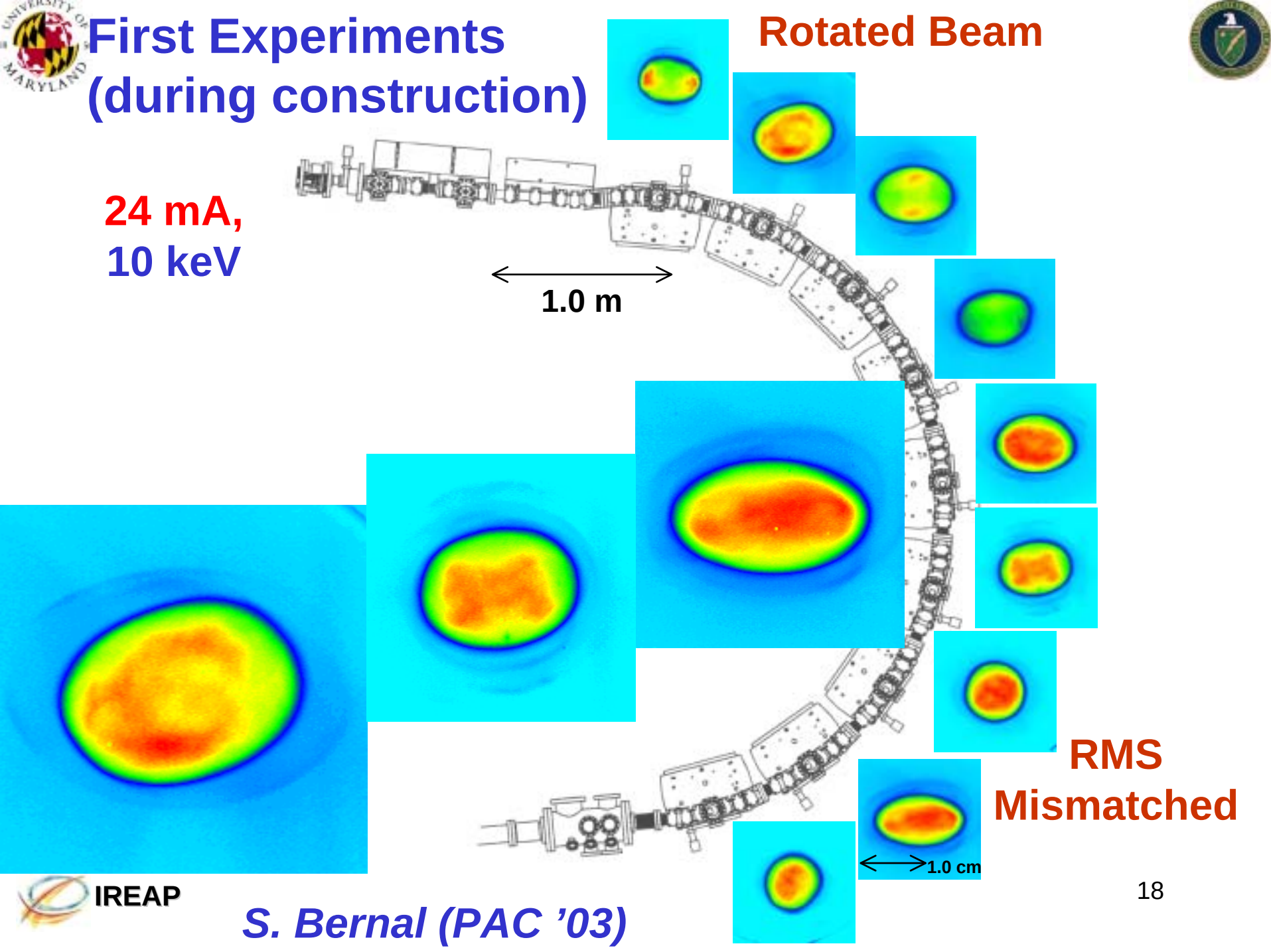
UMER Schematic



First Experiments (during construction)



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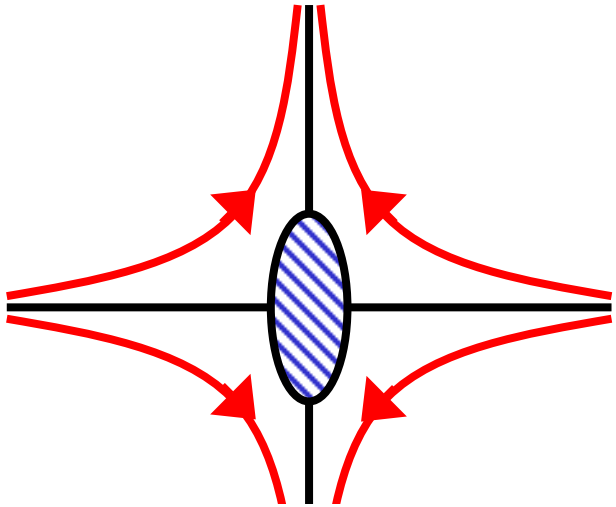
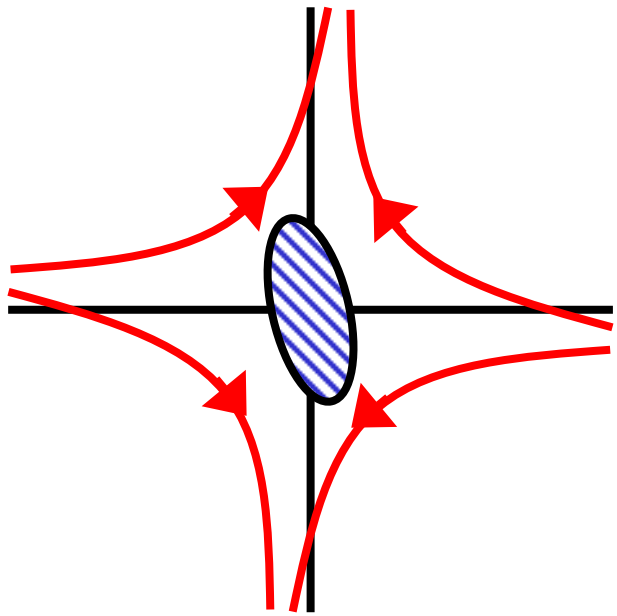
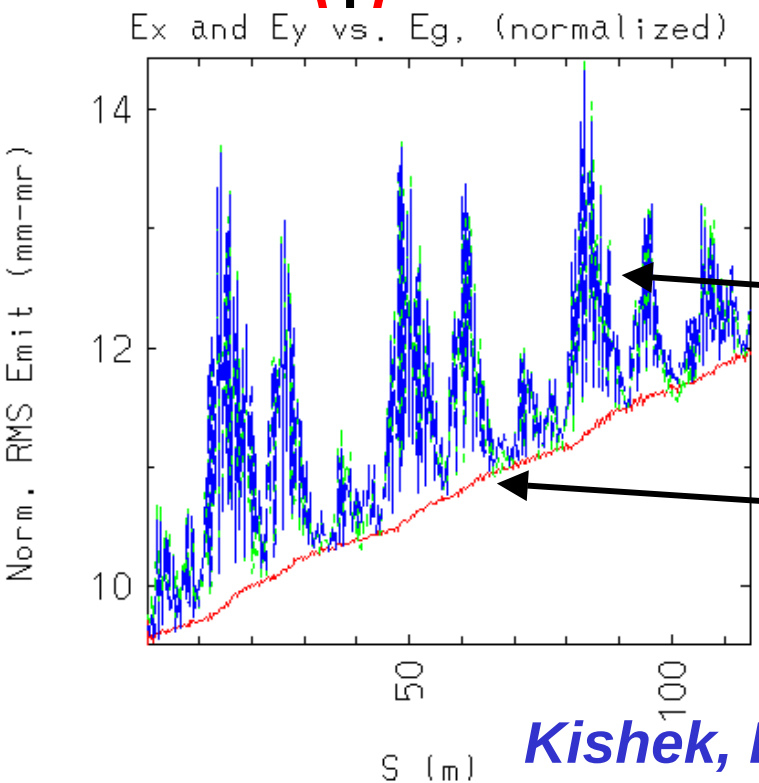
S. Bernal (PAC '03)

Skew Quadrupole (Rotational) Errors





Skew Quadrupole



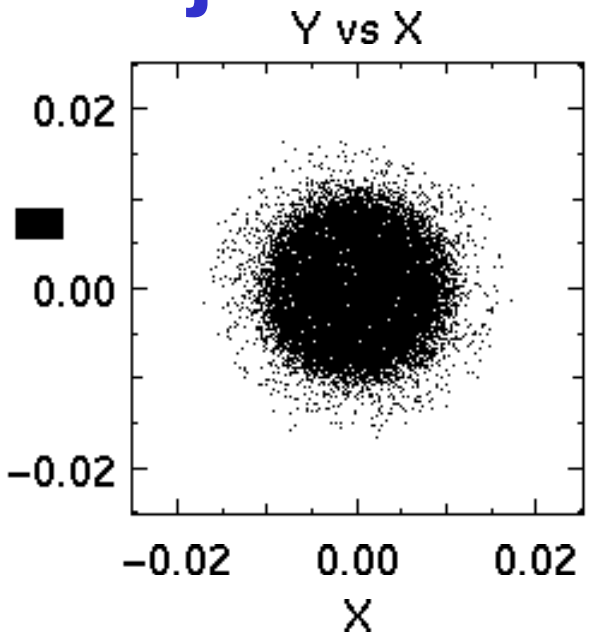
Standard x, y 4*rms emittances, ε_{nx}, ε_{ny}

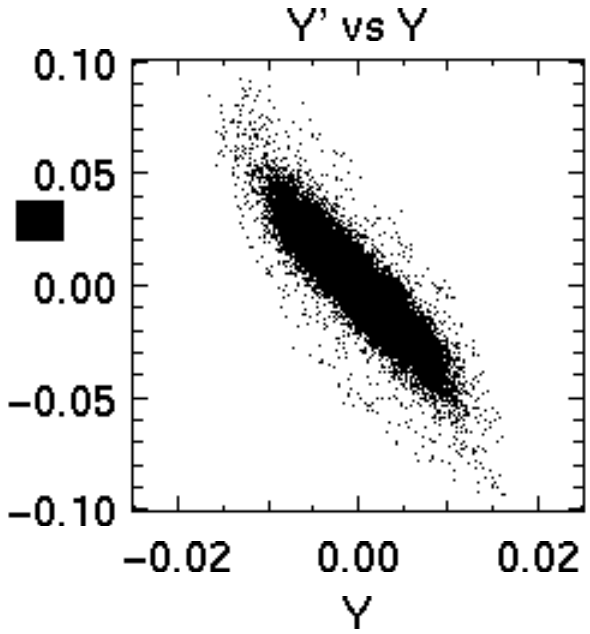
Generalized emittances, ε_{ng}, ε_{nh}

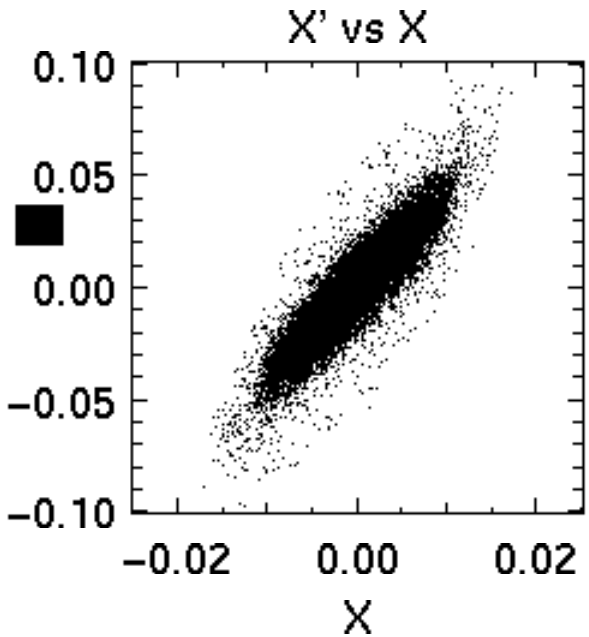
Kishek, Barnard, and Grote, PAC 1999

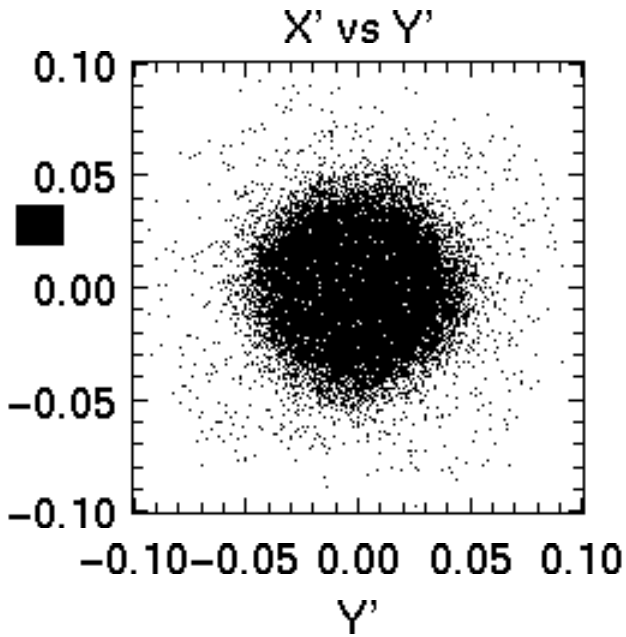
Inject Beam Rotated 10°

0.0 m
1.6 m
2.0 m
2.4 m
2.8 m
3.2 m
3.6 m
4.0 m
4.4 m
4.8 m









5.2 m
5.6 m
6.0 m
8.0 m
25.9 m
230.0 m

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Injecting Rotated Beams ⇒ Halo

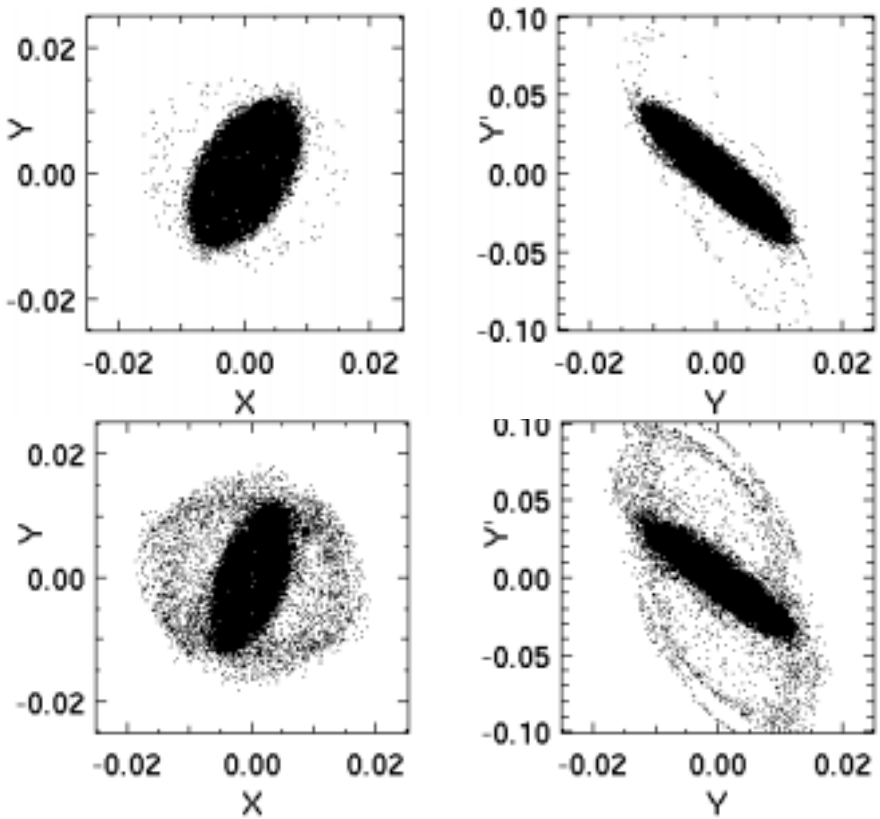
Simulations

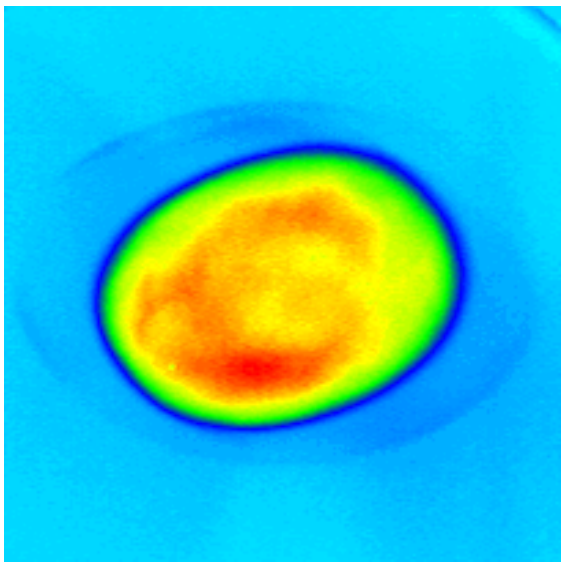
R. Kishek

Proc Halo '03

Inject Beam Rotated 10°

Inject Beam Rotated 20°





Experiment –

(Bernal, Li)

shows similar features

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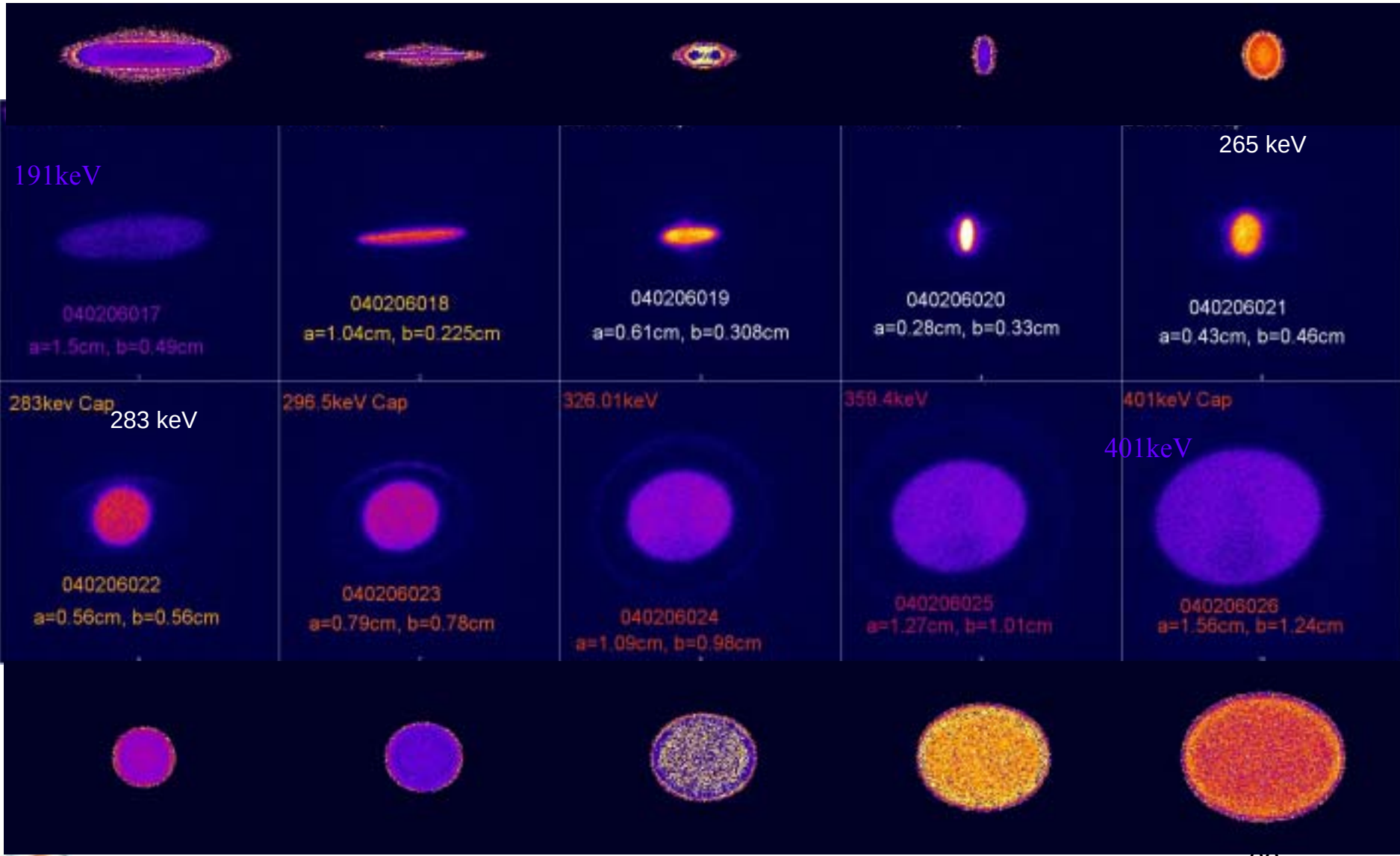
LBNL/NTX: Halo forms in Exp.



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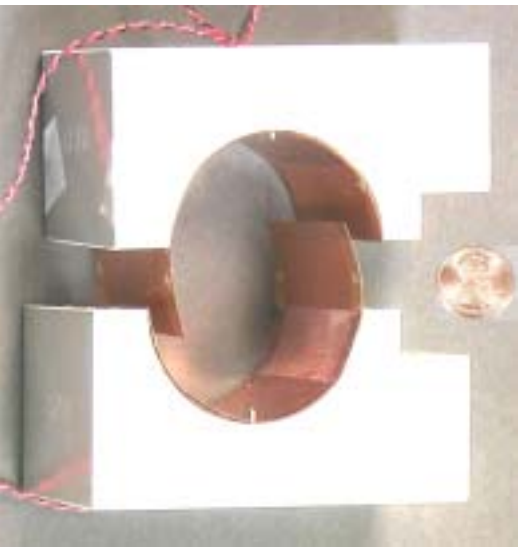
S. Yu

(1.5 mA beam, 5 mm initial radius, Ne ~ 1.2x10^{11}/cm^3, 20mm-20mr)

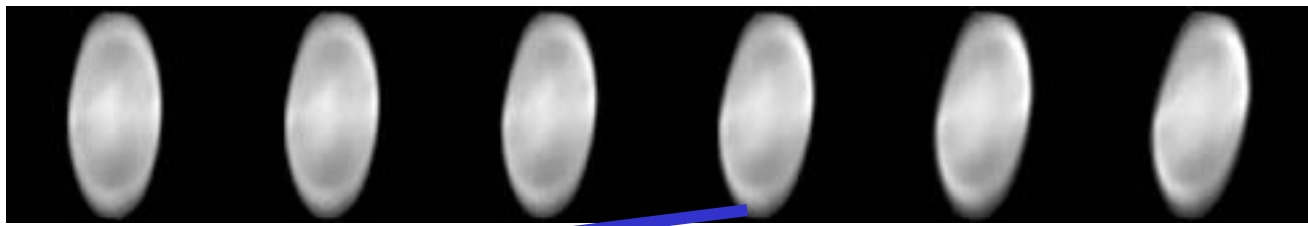
Quadrupoles with *Electronically* Adjustable Skewness



Two sets of coils at 45 deg

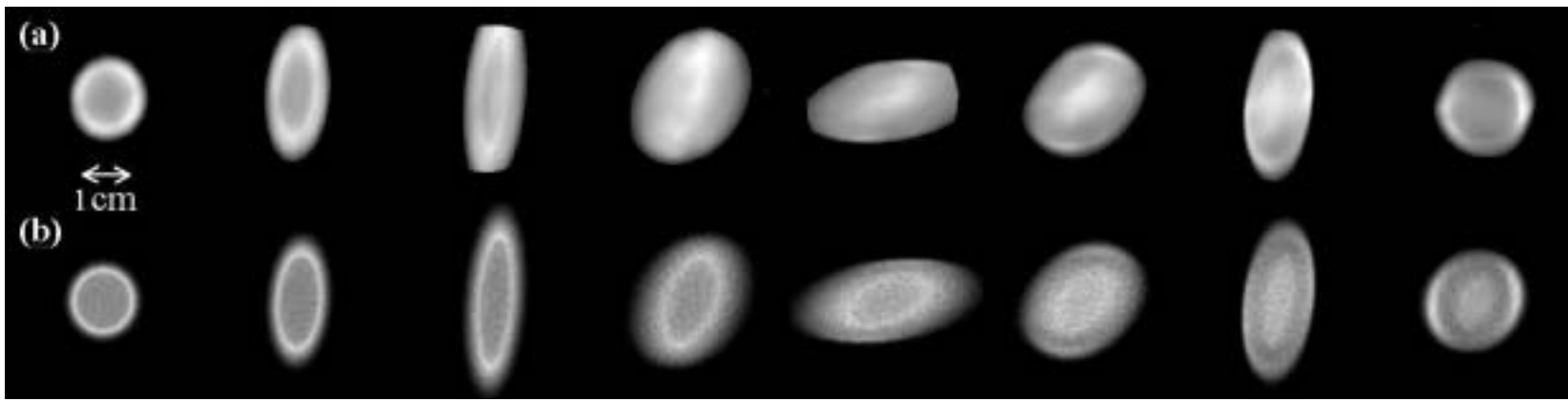
Exp. data **Skew angle:**

0.93º **1.86º** **2.79º** **3.72º** **4.66º** **5.60º**



Experiment

Simulation



Q1 is electronically rotated 3.72⁰

H. Li (PAC '01)

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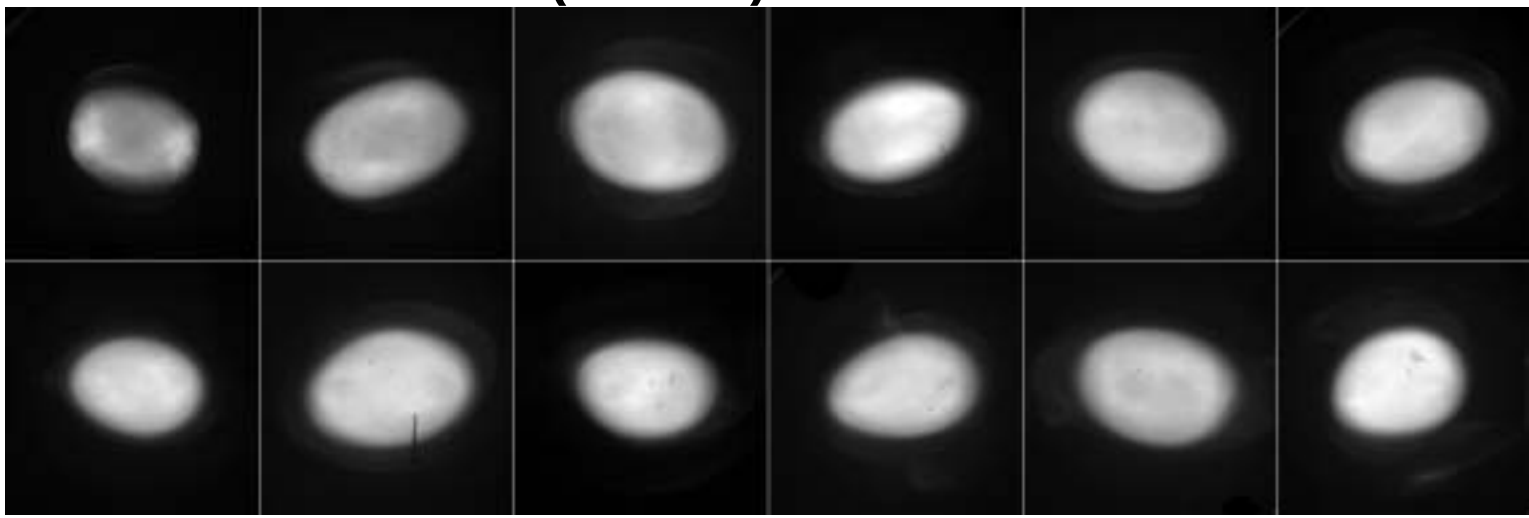
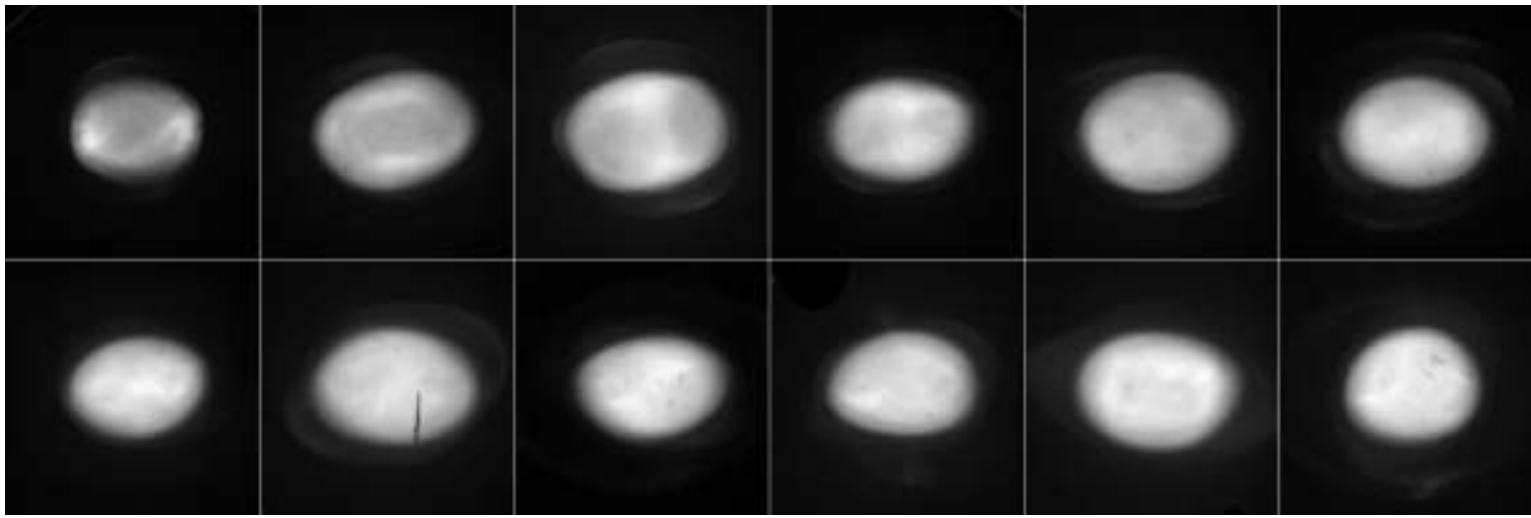
Beam Rotation Correction

24mA Beams (RC1-12)

Before Skew Correction



After Skew Correction



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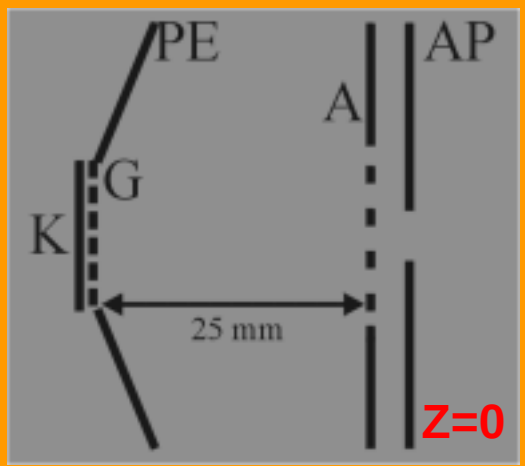
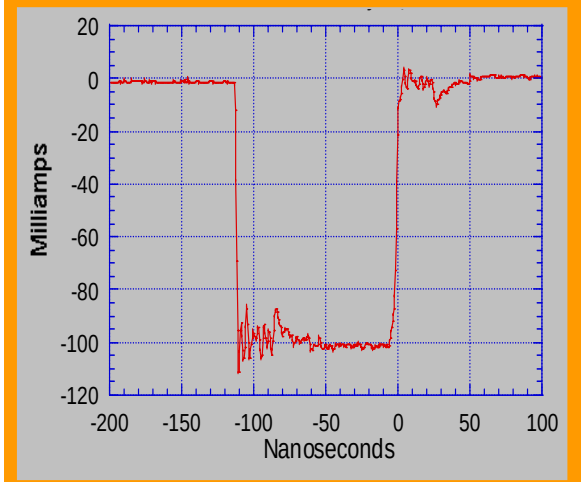
Hui Li, S. Bernal, et al., Proc 2004 HIF Symposium

UMER Electron Gun

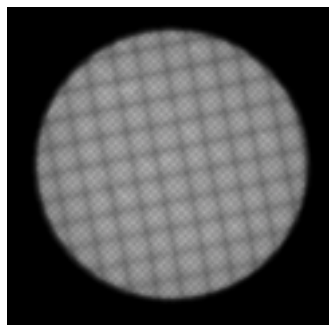
TRIODE ELECTRON GUN: CATHODE DRIVEN, PIERCE TYPE



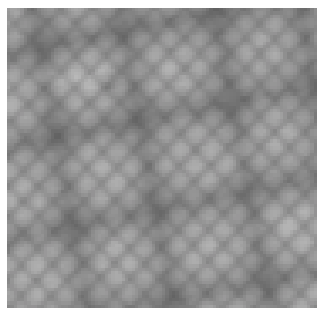


APERTURE PLATE

CATHODE AND ANODE GRIDS



8 mm



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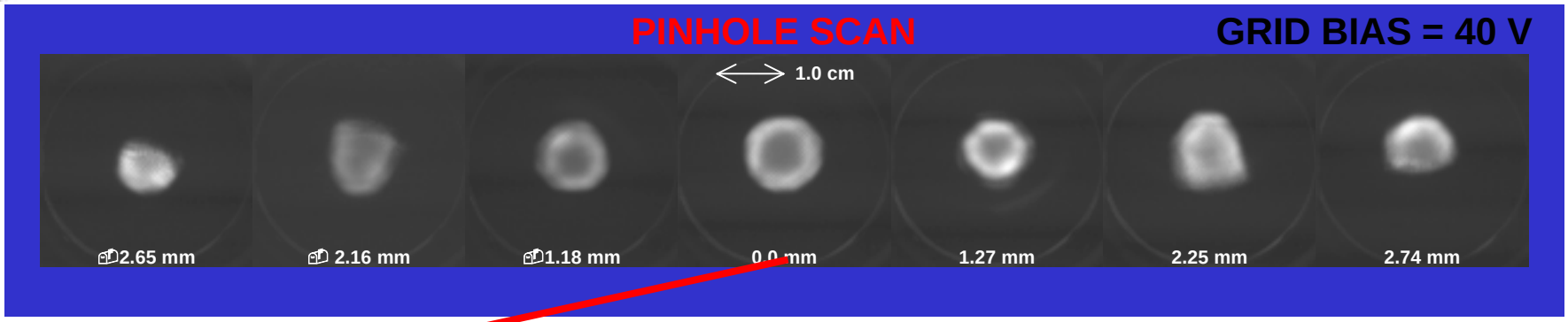
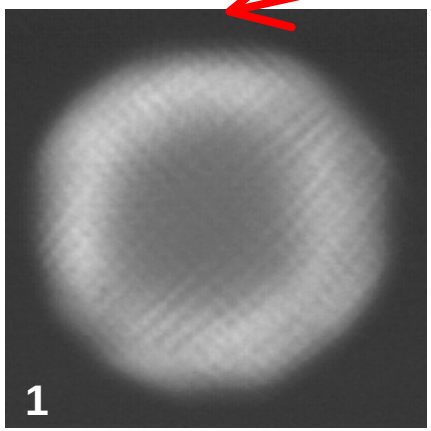
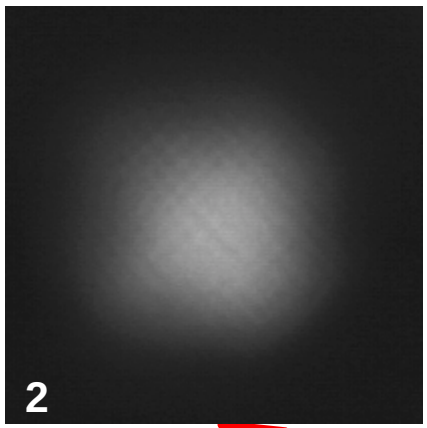
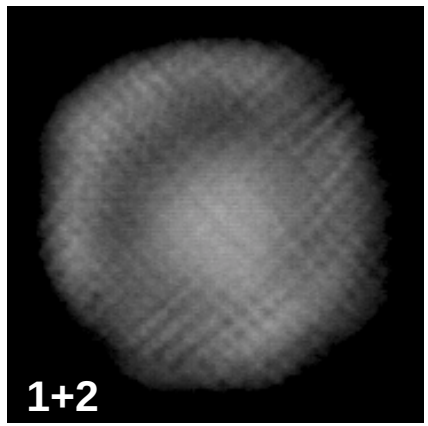
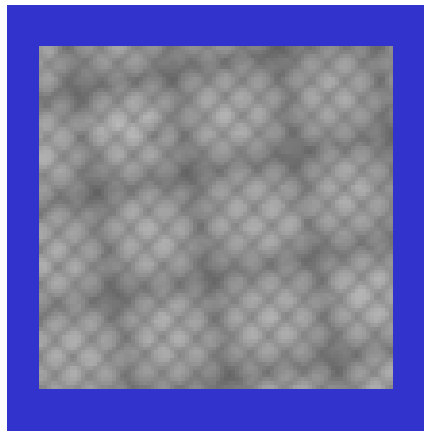
UMER Gun Characterization

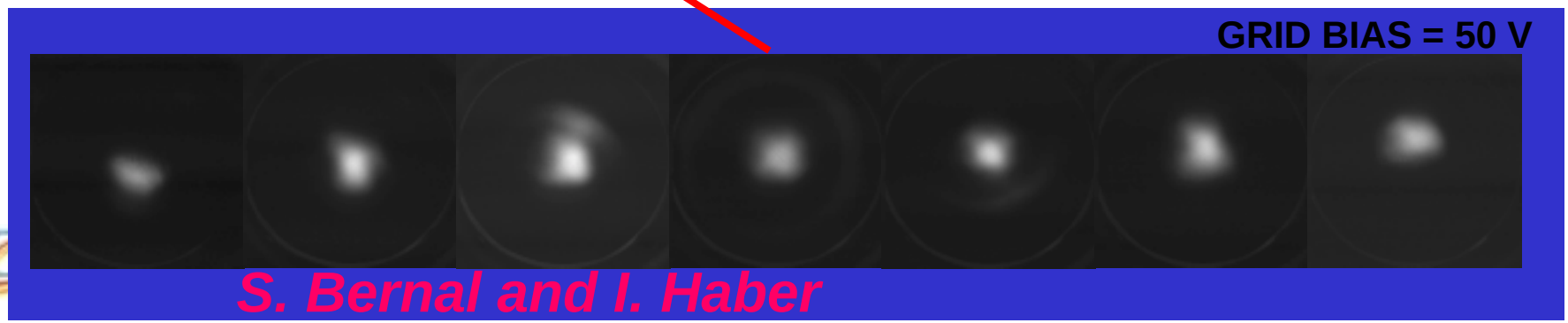






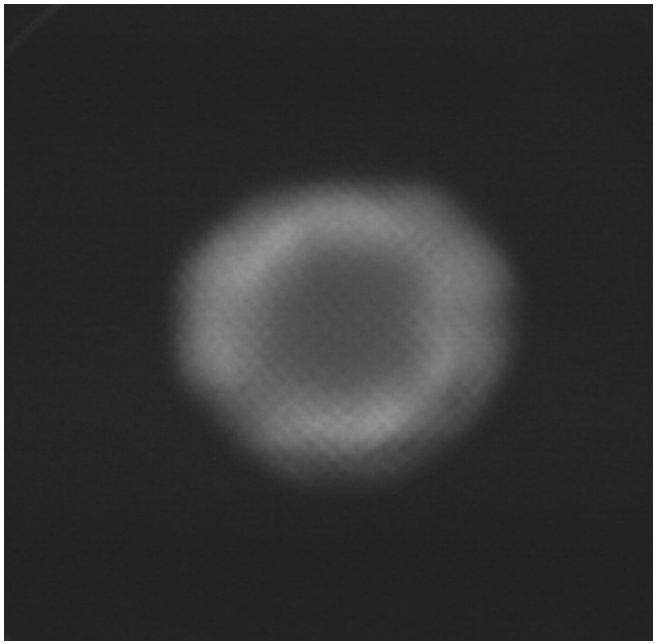






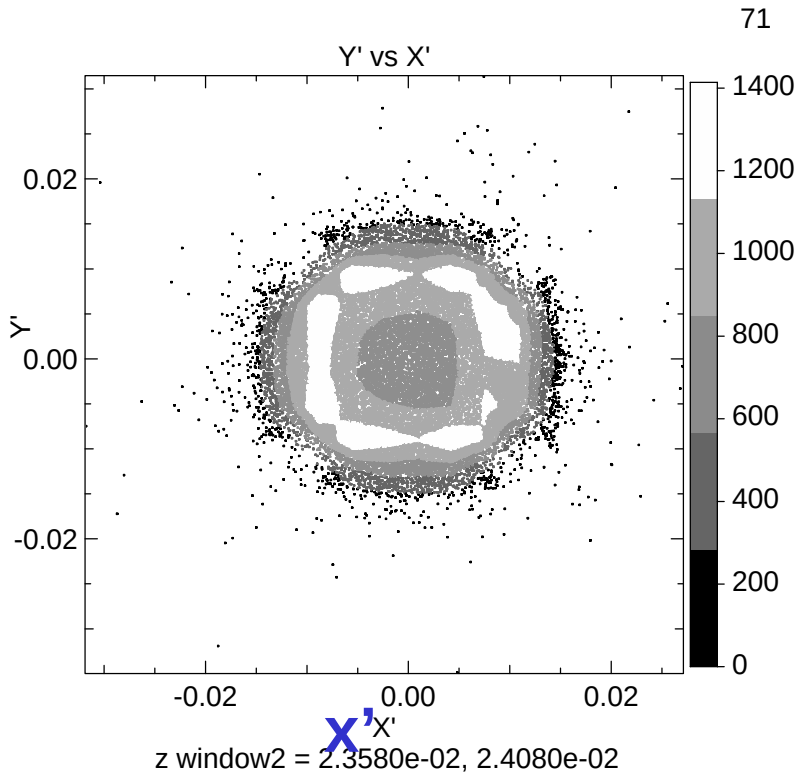
S. Bernal and I. Haber

Phase Space at Source Exit



y

x



y'

x'

Experiment:

Beam exiting pinhole

3-D Simulation of K-G:

Beam velocity space

IREAP

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/**

IREAP

We Thank:

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

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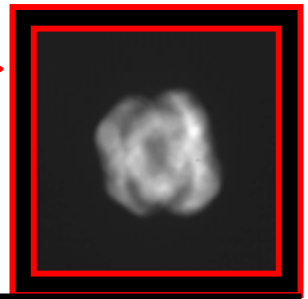
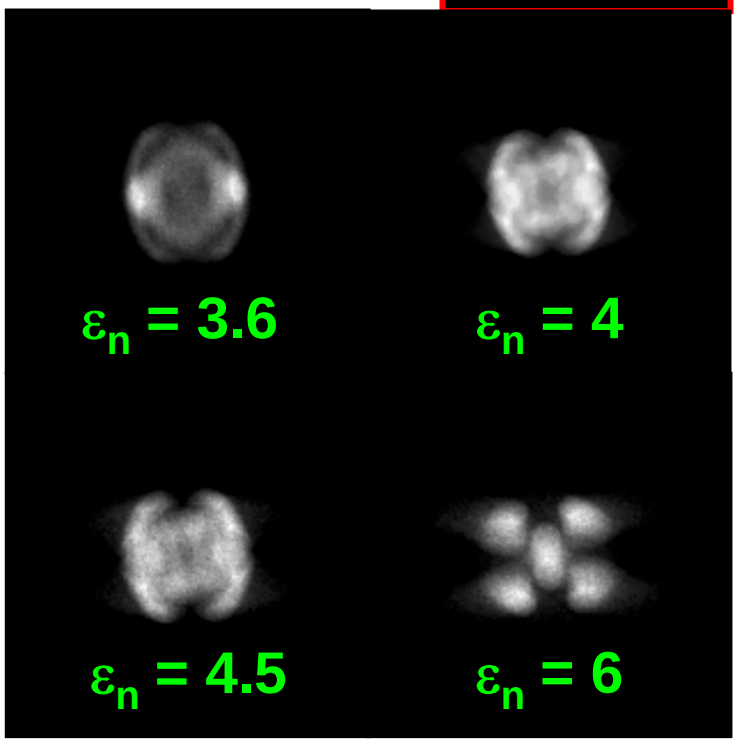
NIU	**Court Bohn**	Ioannis Sideris
LLNL	**Tom Wangler**	
MIT	**Chiping Chen**	

New 5-Beamlet Experiment

Experiment⇒

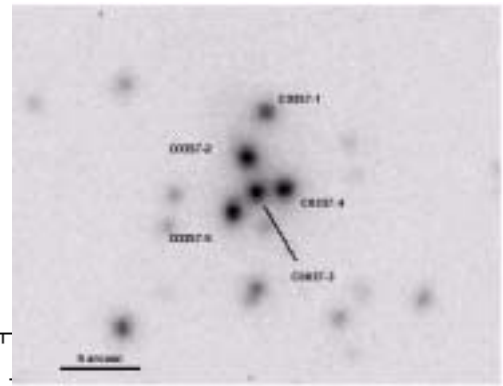


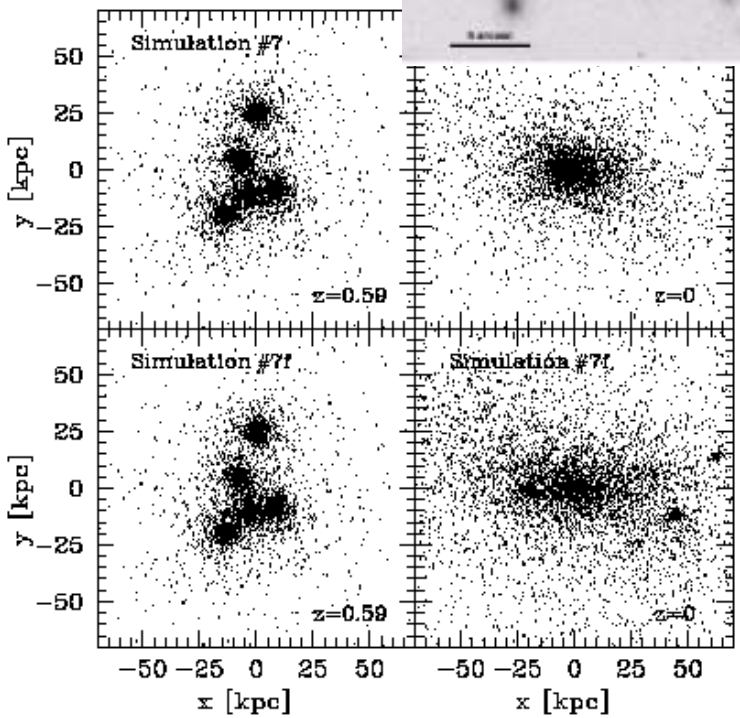
⇓ Simulation



z = 99 cm

galaxy cluster
C0337-2522

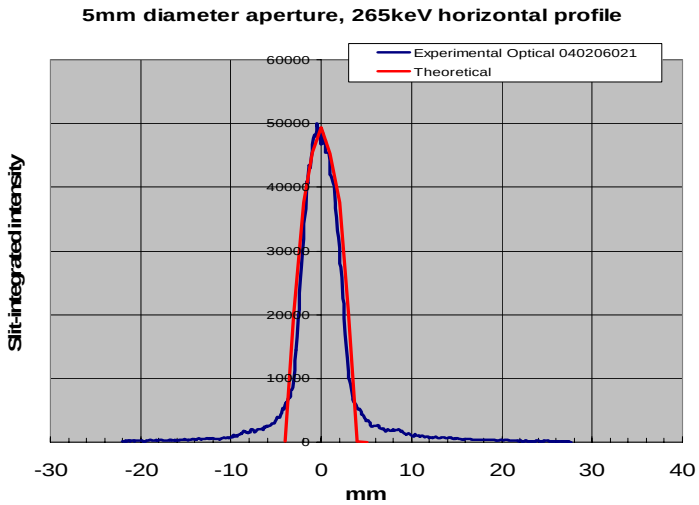




*Nipoti, et al., Mon. Not. R. Astron. Soc., **344**, 748-760 (2003).*

IREAP *Bernal; Haber; Kishek*

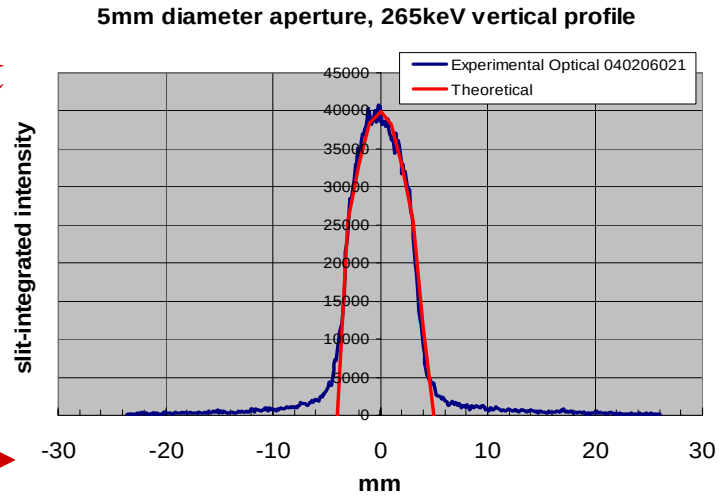
Measured and Calculated Beam Profiles Agreed Well

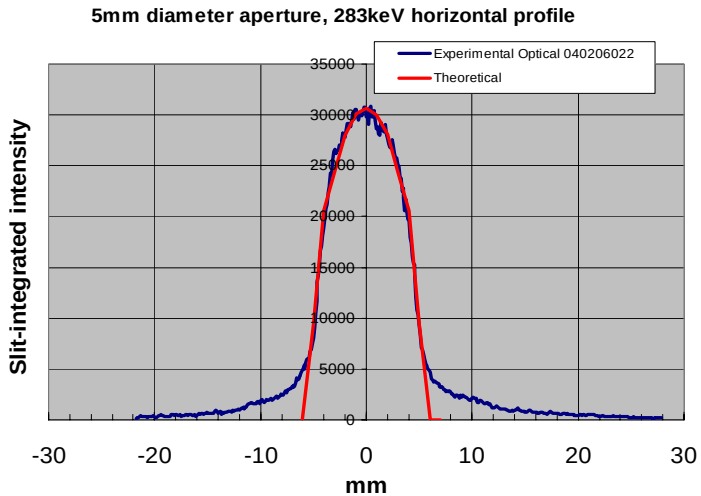


Horizontal densit profile

265keV

Vertical

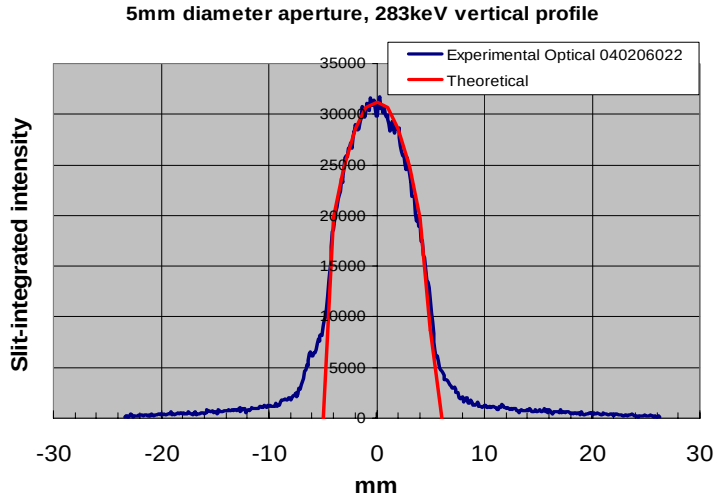




Horizontal

283keV

Vertical



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S. Yu