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

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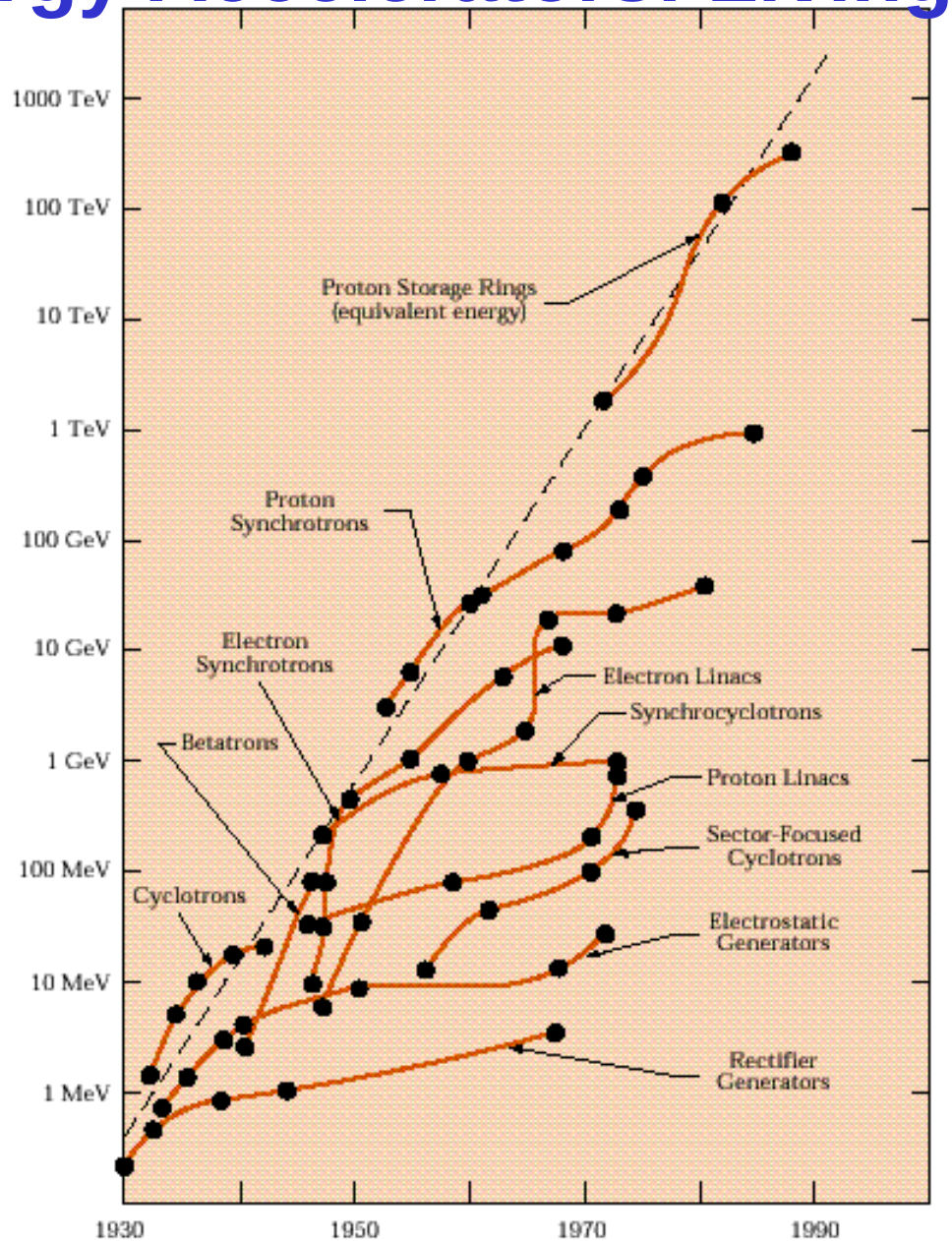
Outline

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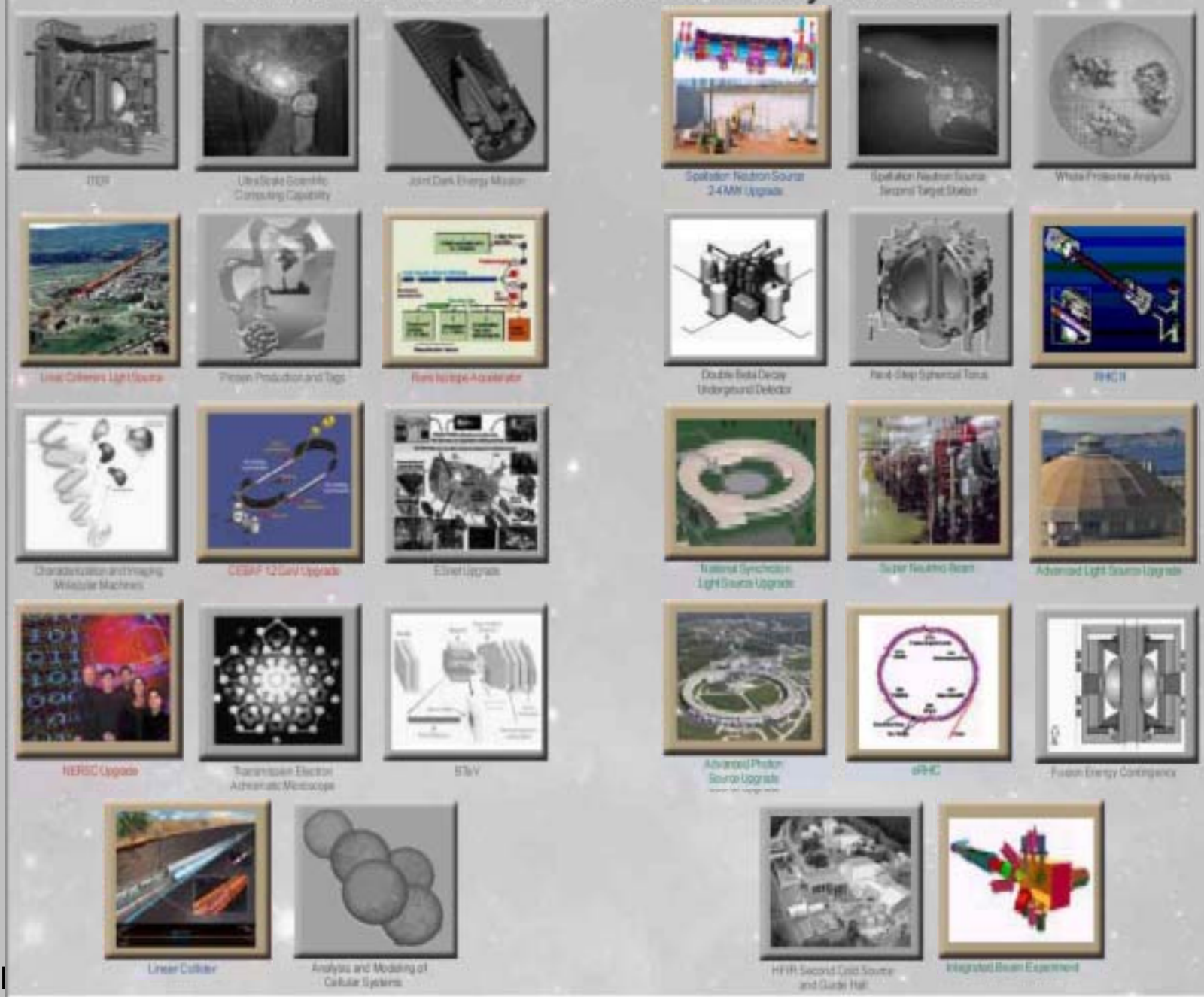
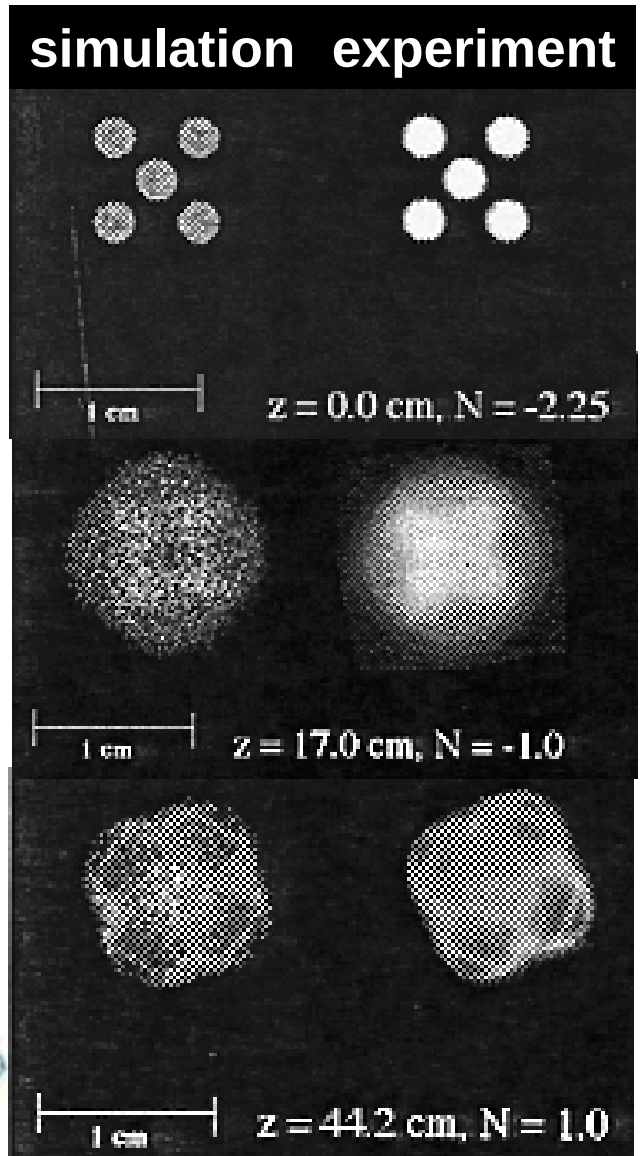
Facilities for the Future of Science: A Twenty-Year Outlook

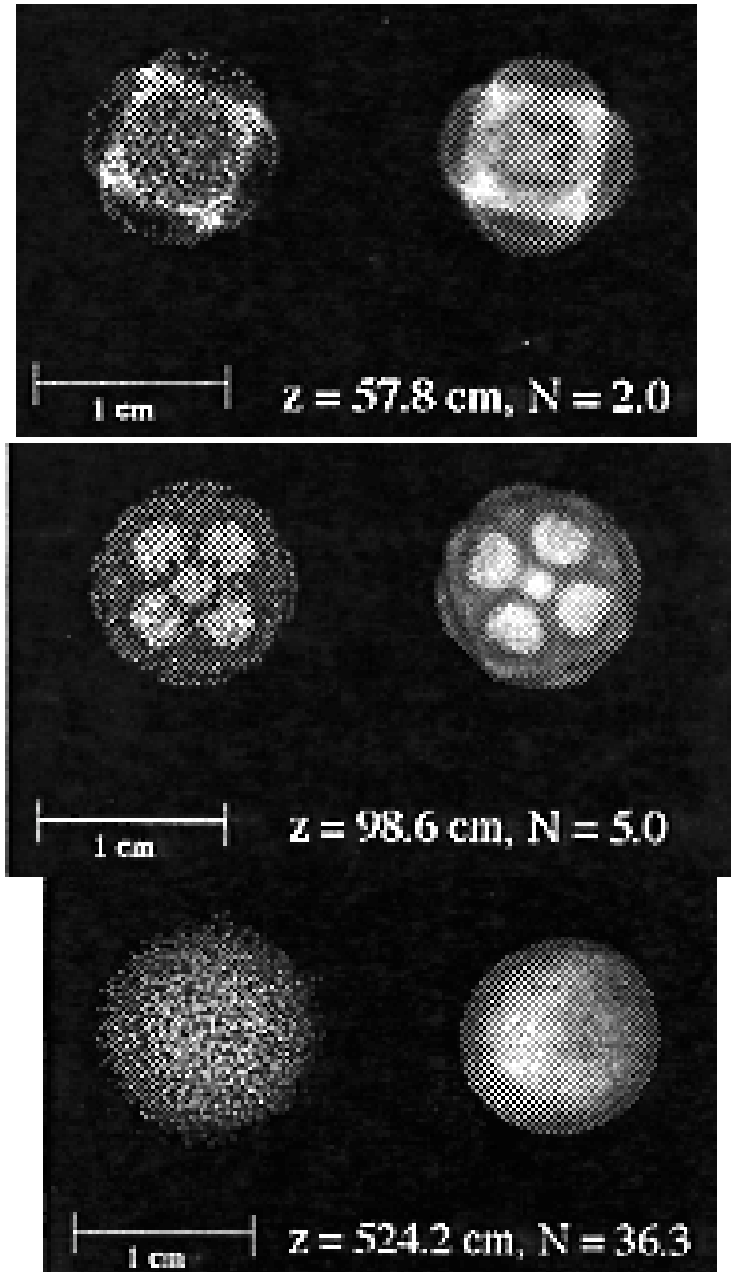


http://www.sc.doe.gov/

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

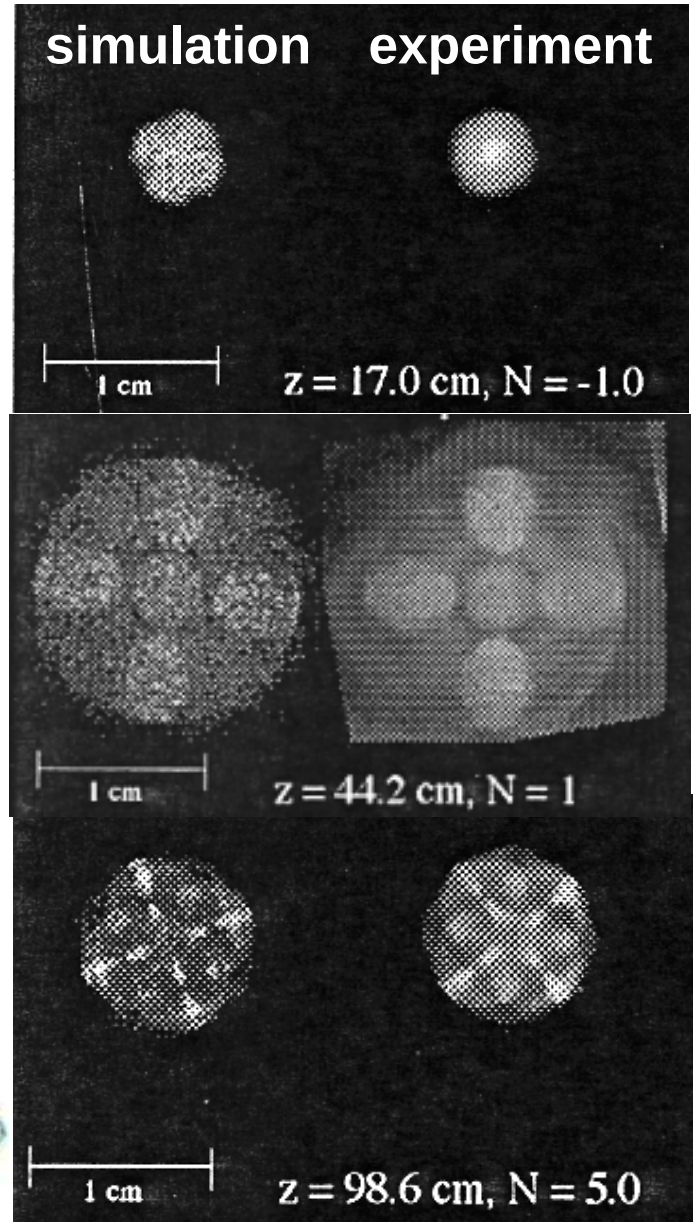
RMS Matched ~ 1989

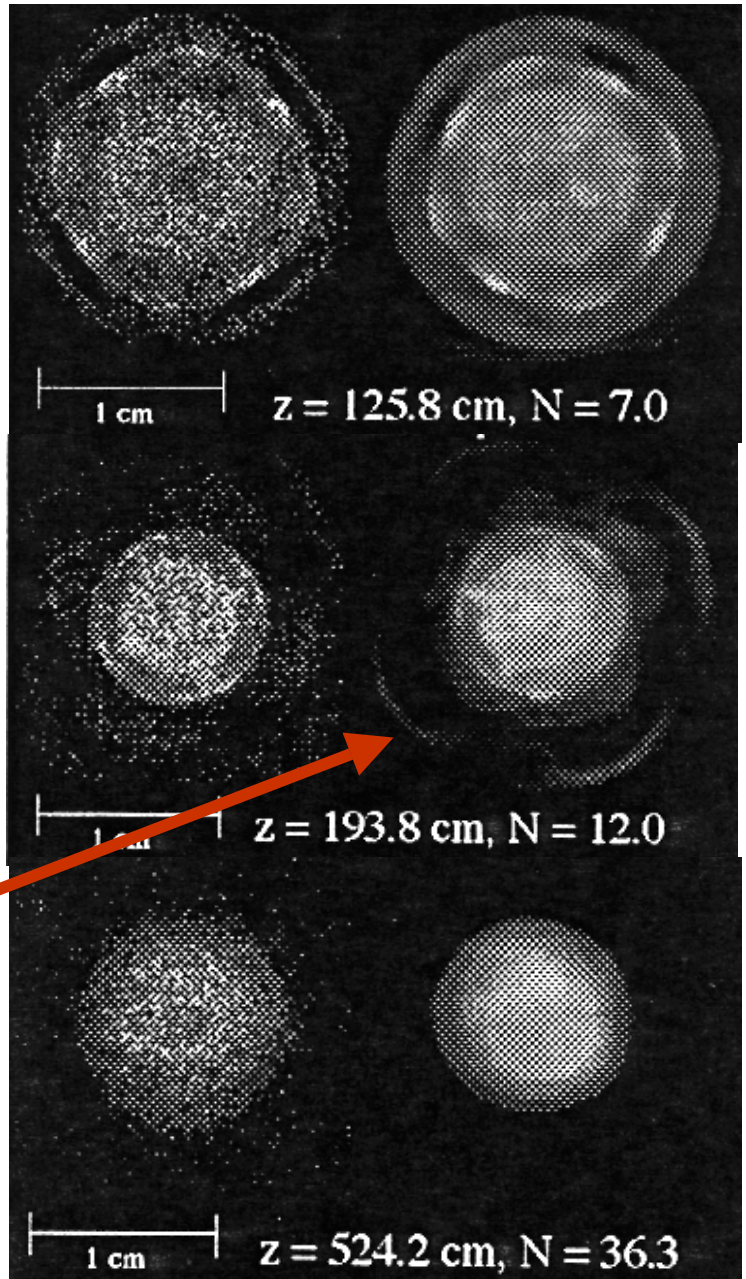




Larger Amplitude if Mismatched

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

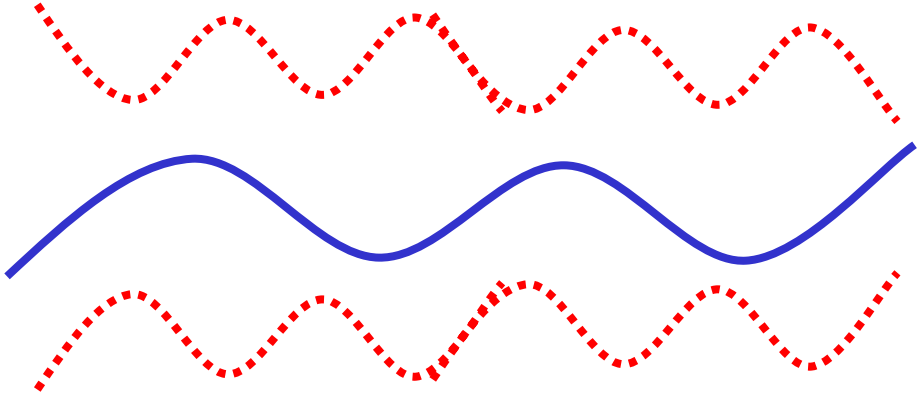
- **Mismatched Beams** ⇒ Emittance growth + Halo
  A. Cucchetti, M. Reiser, and T. Wangler, Proc. PAC 1991, p.251.

- **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).

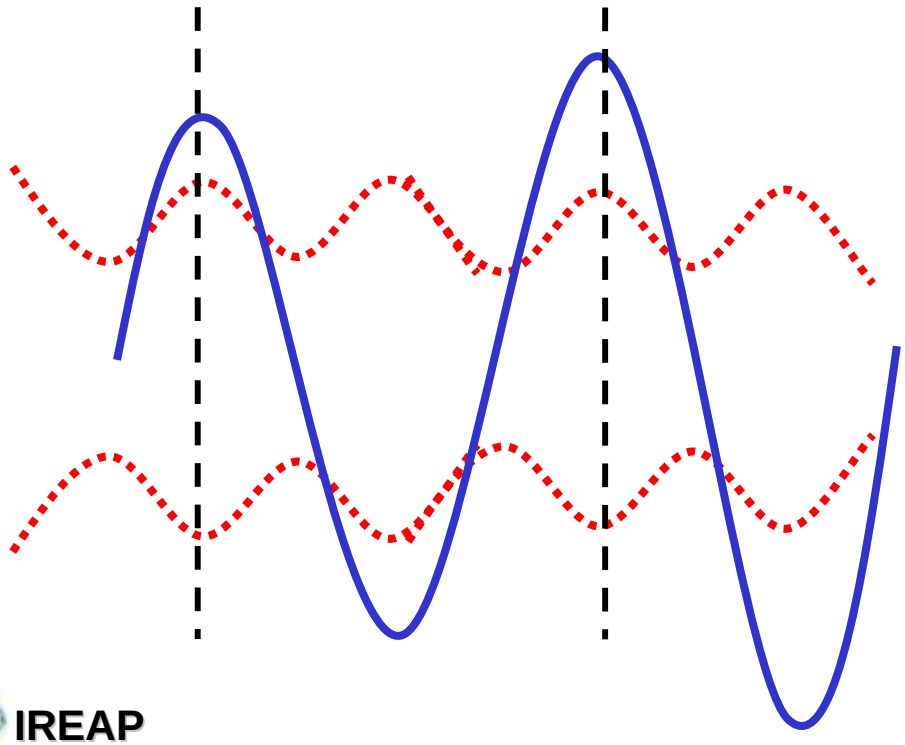
- **Particle-Core Model** ⇒ Emittance growth + Halo
  T.P.Wangler, K.R.Crandall, R.Ryne, and T.S.Wang, PRST-AB 1, 084201 (1998).
- Basic model predicts: Halo has a maximum extent

Parametric Resonance



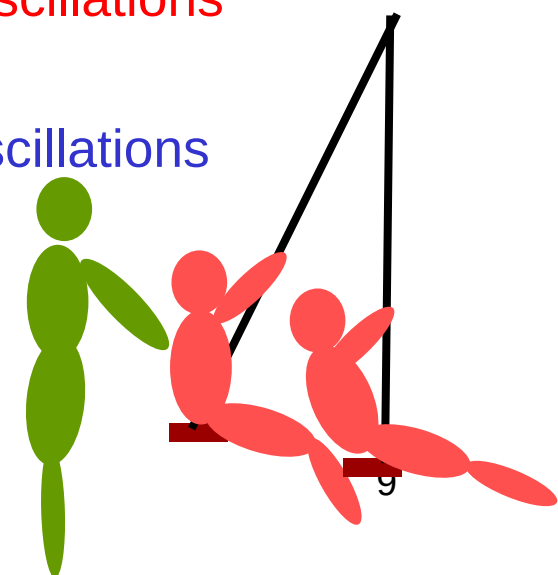
Envelope oscillations

Particle oscillations



Envelope oscillations

Particle oscillations



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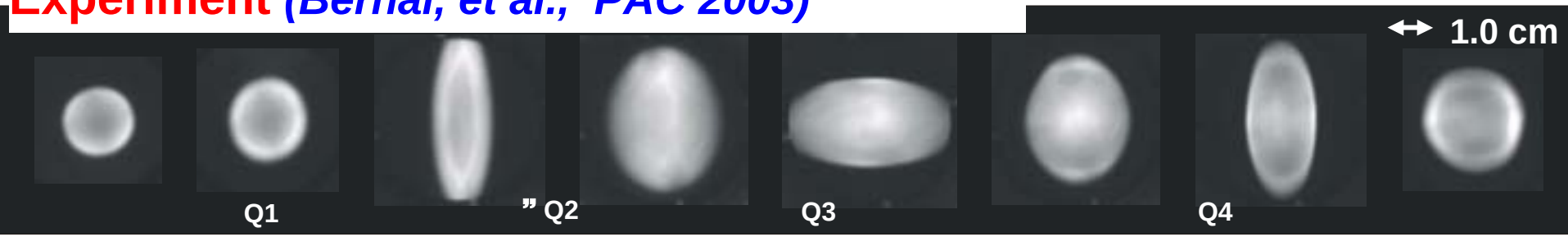
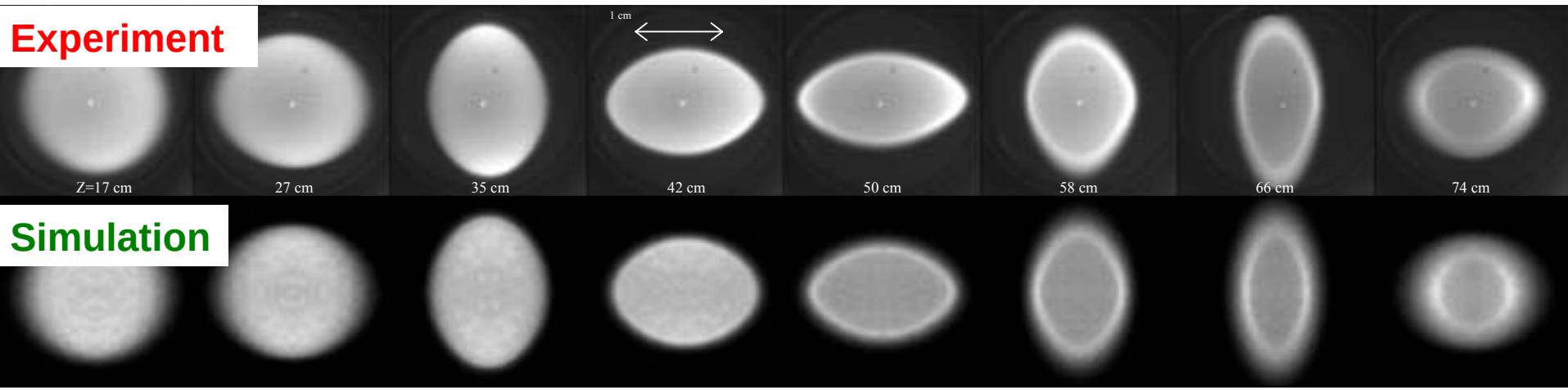
Intense Beams Carry Internal Modes

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



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



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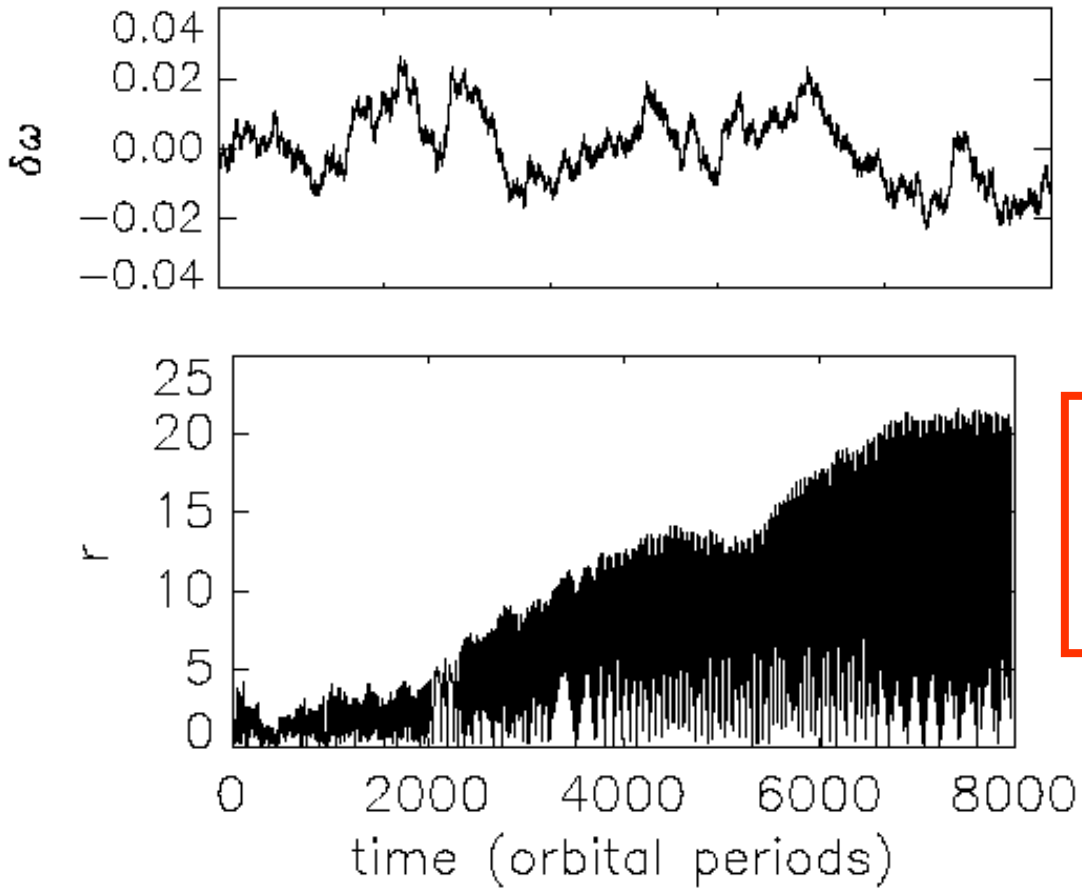
Bernal, Kishek, Reiser, and Haber, PRL, 82, 4002 (1999)

NIU: Addition of Colored Noise Changes Particle-Core Model



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

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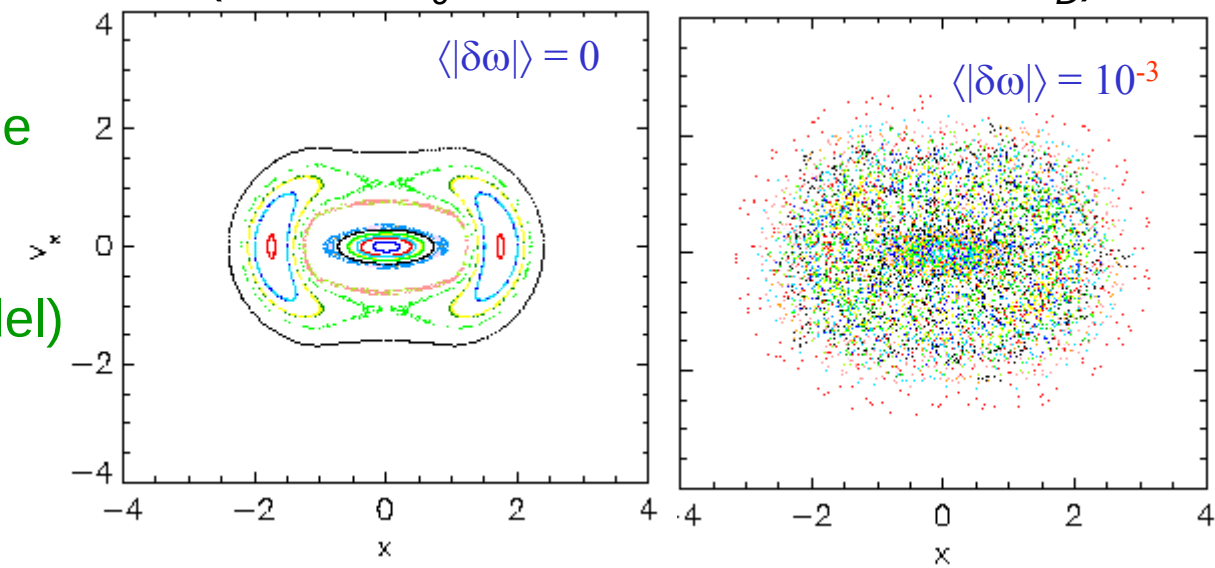
C.L. Bohn, talk Wed. 10:30 AM, Rm. 305

NIU: Effects of Internal Structure

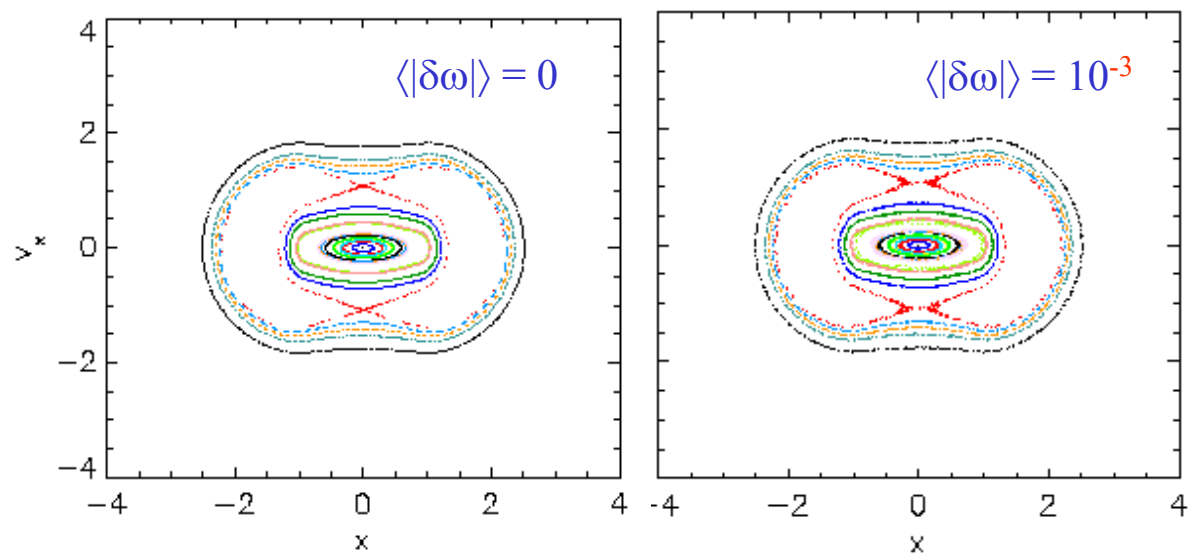
POINCARÉ SECTIONS
(Γ=0.05, t_c=80, 18 orbits over ~250 t_D)

No rms Mismatch!
But internal collective mode

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



rms Mismatch



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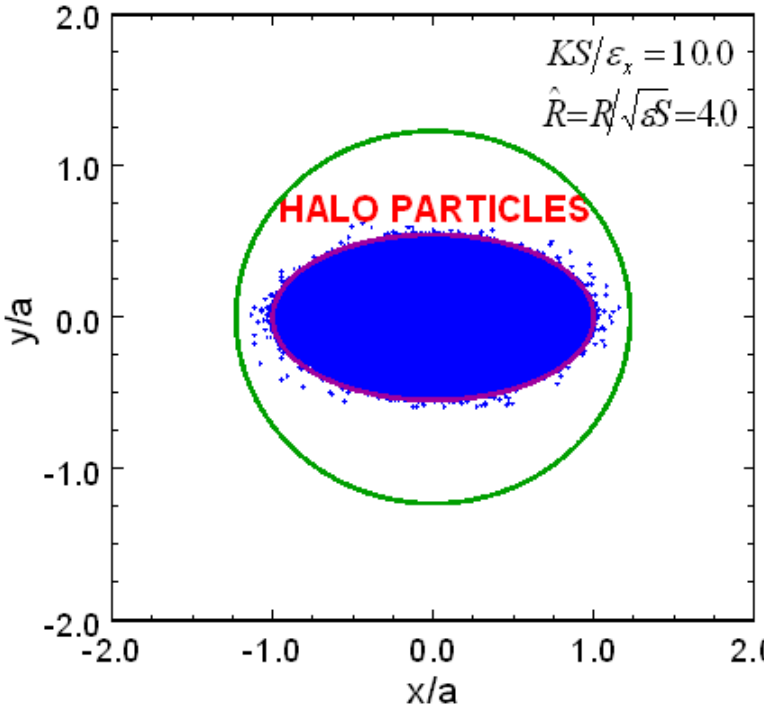
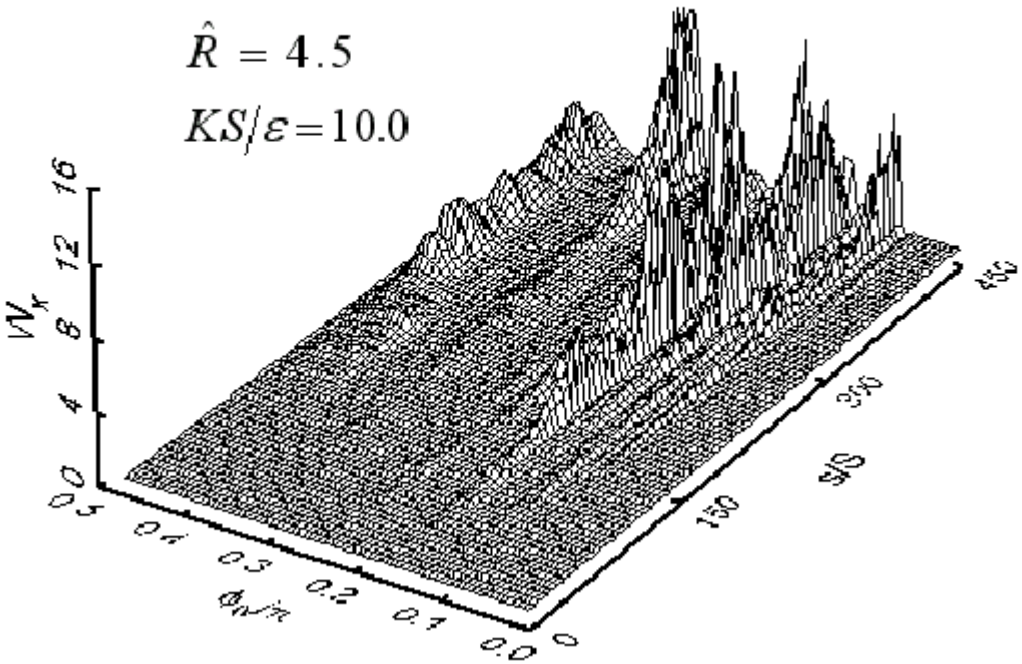
C.L. Bohn

MIT: Studies of Halo Formation from Image Charge Effects

100 Test-Particles Motion over 400 Periods

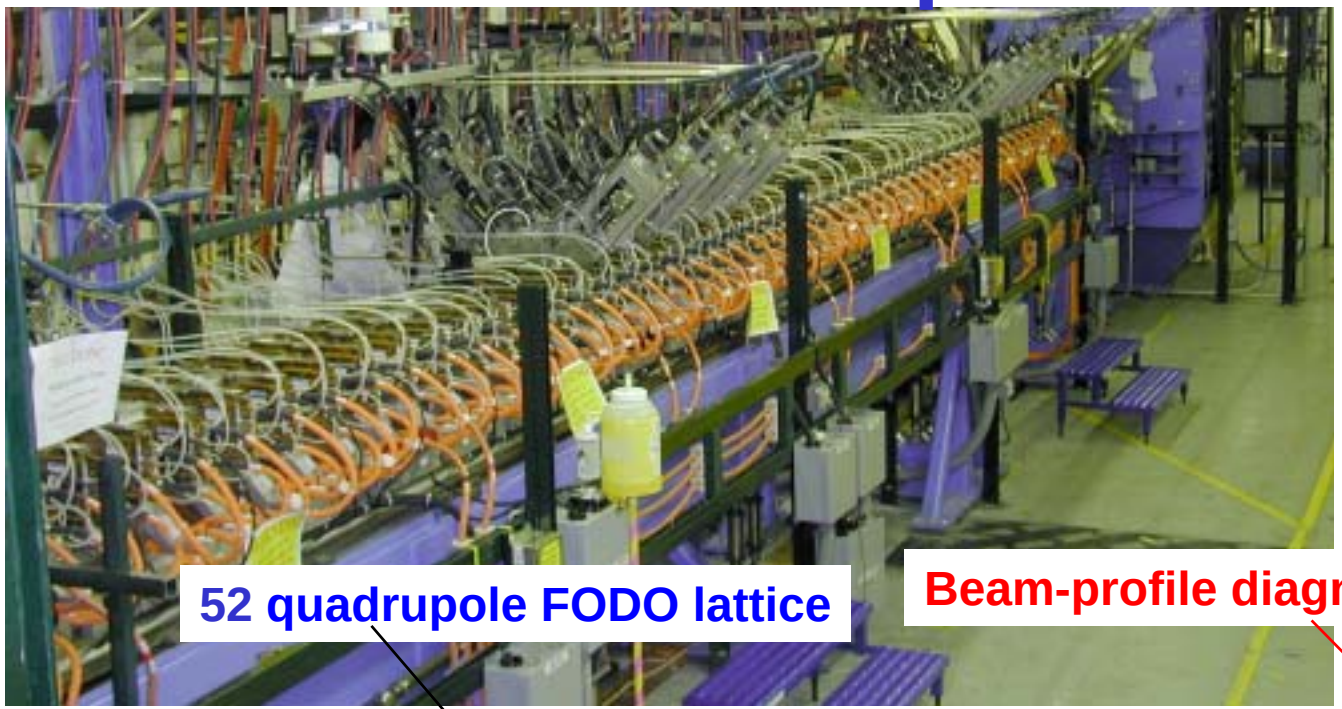


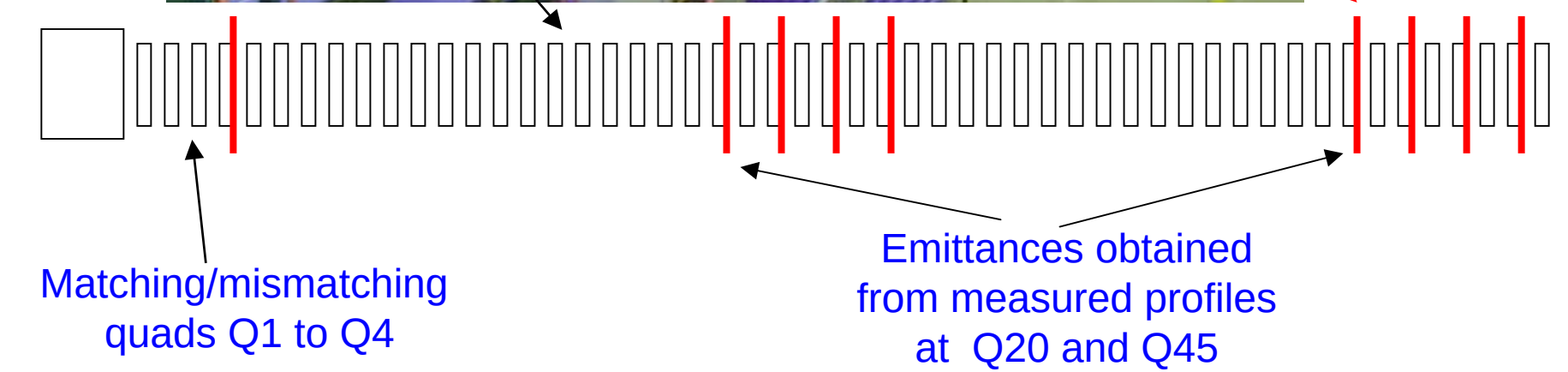


J. Zhou, et al., Physics of Plasmas 10, 4203 (2003).

C. Chen

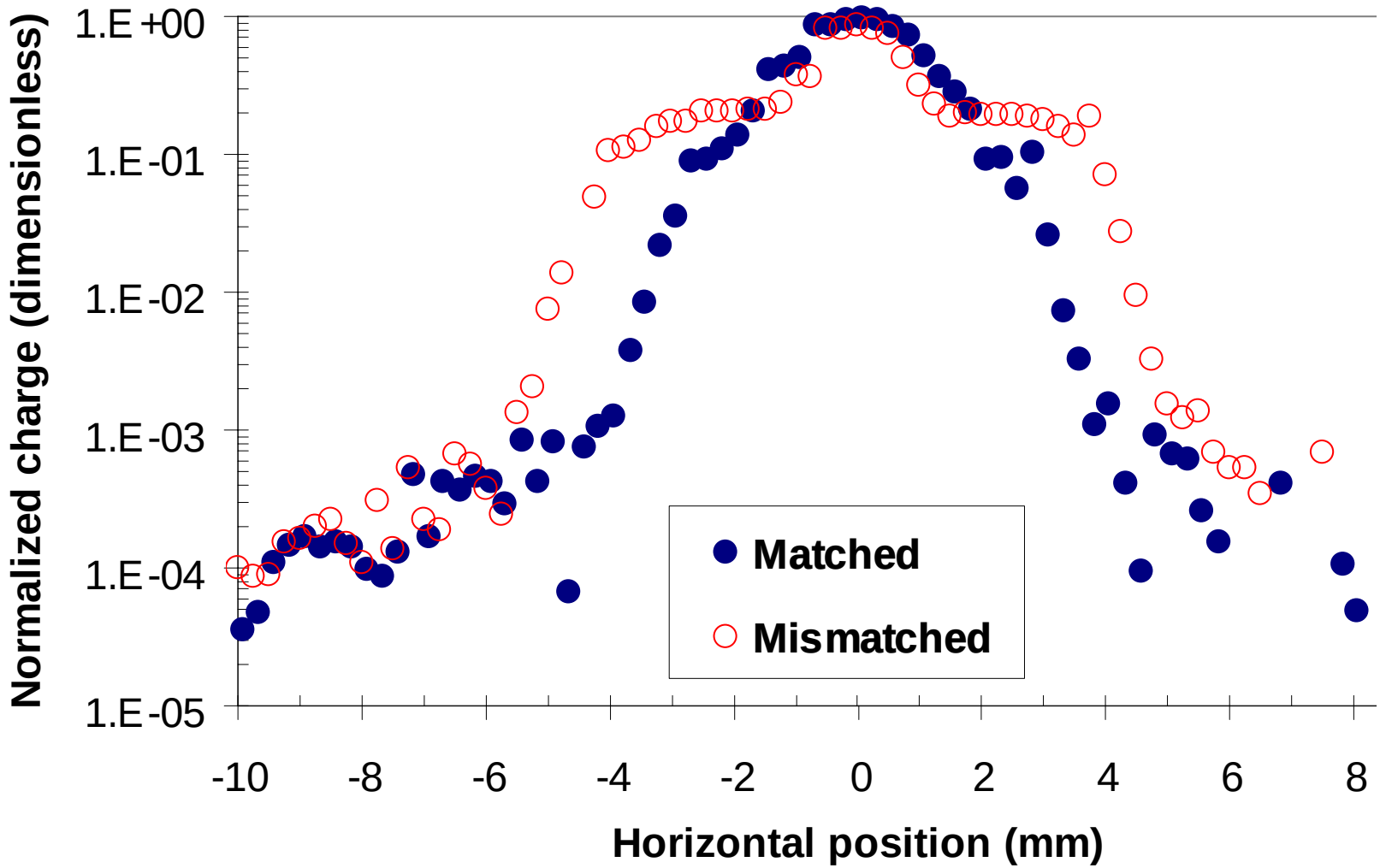
LANL: LEDA Experiment





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

Halo Formed even with rms Match



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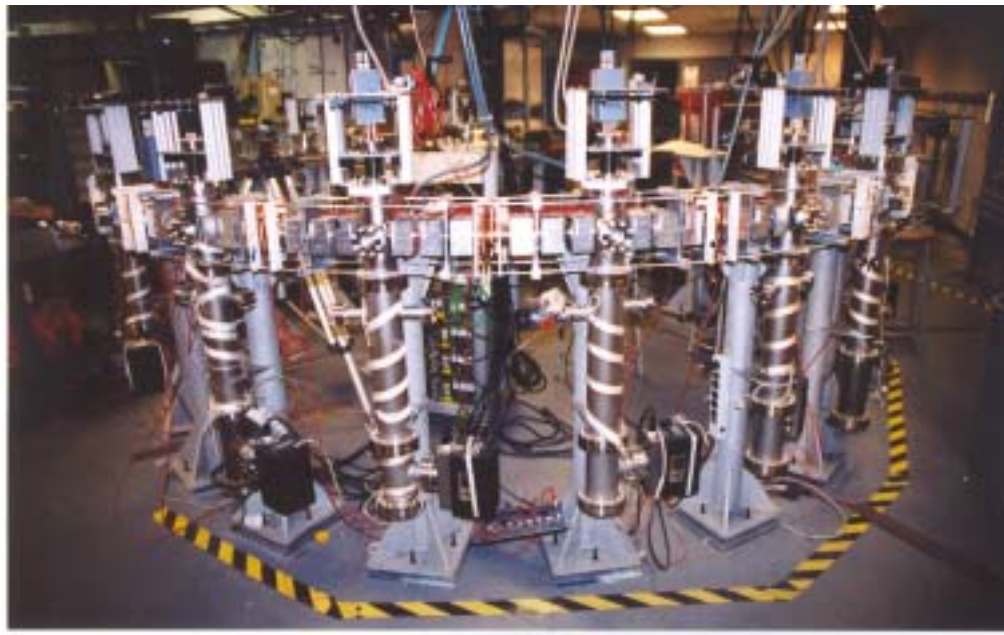
T. Wangler

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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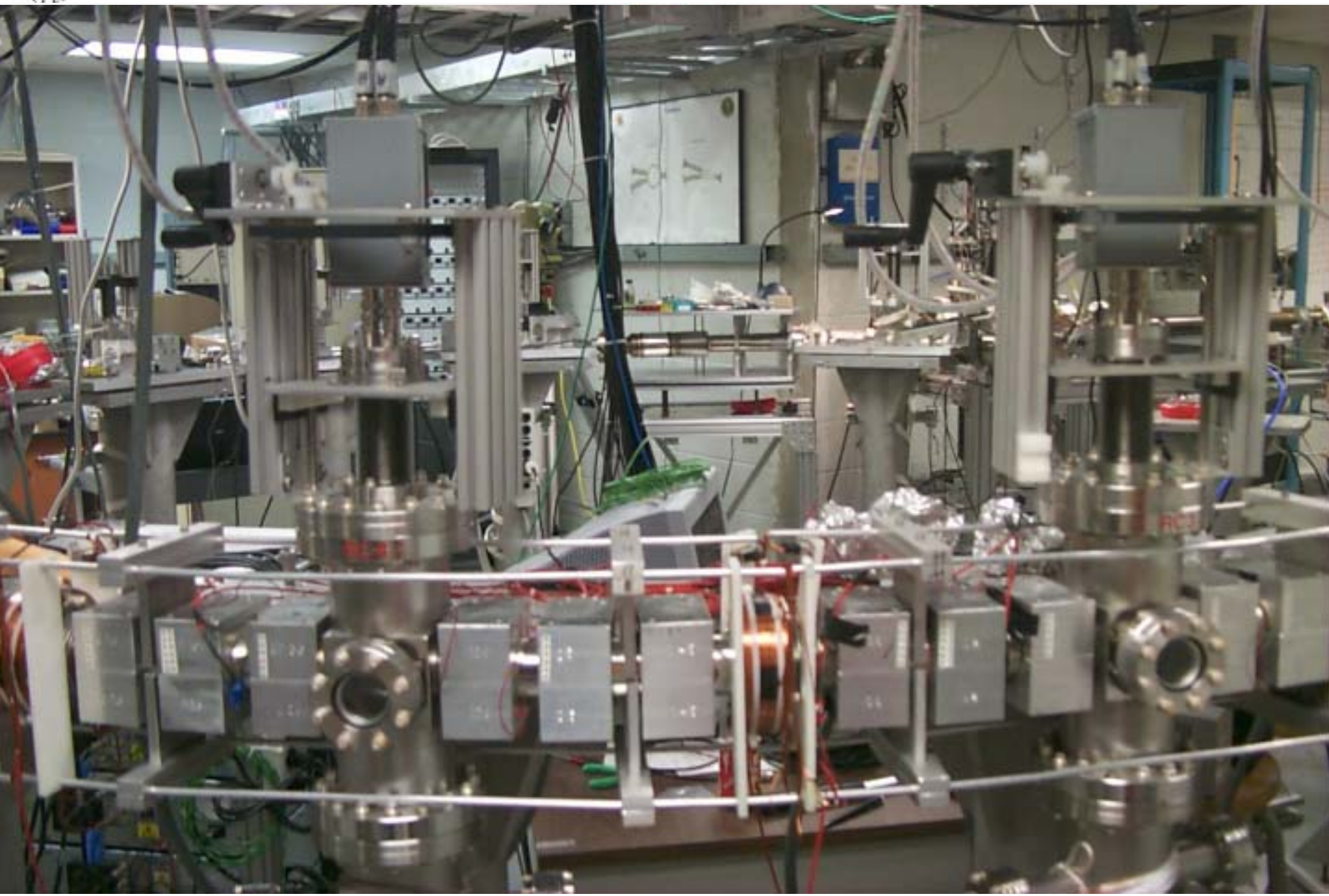
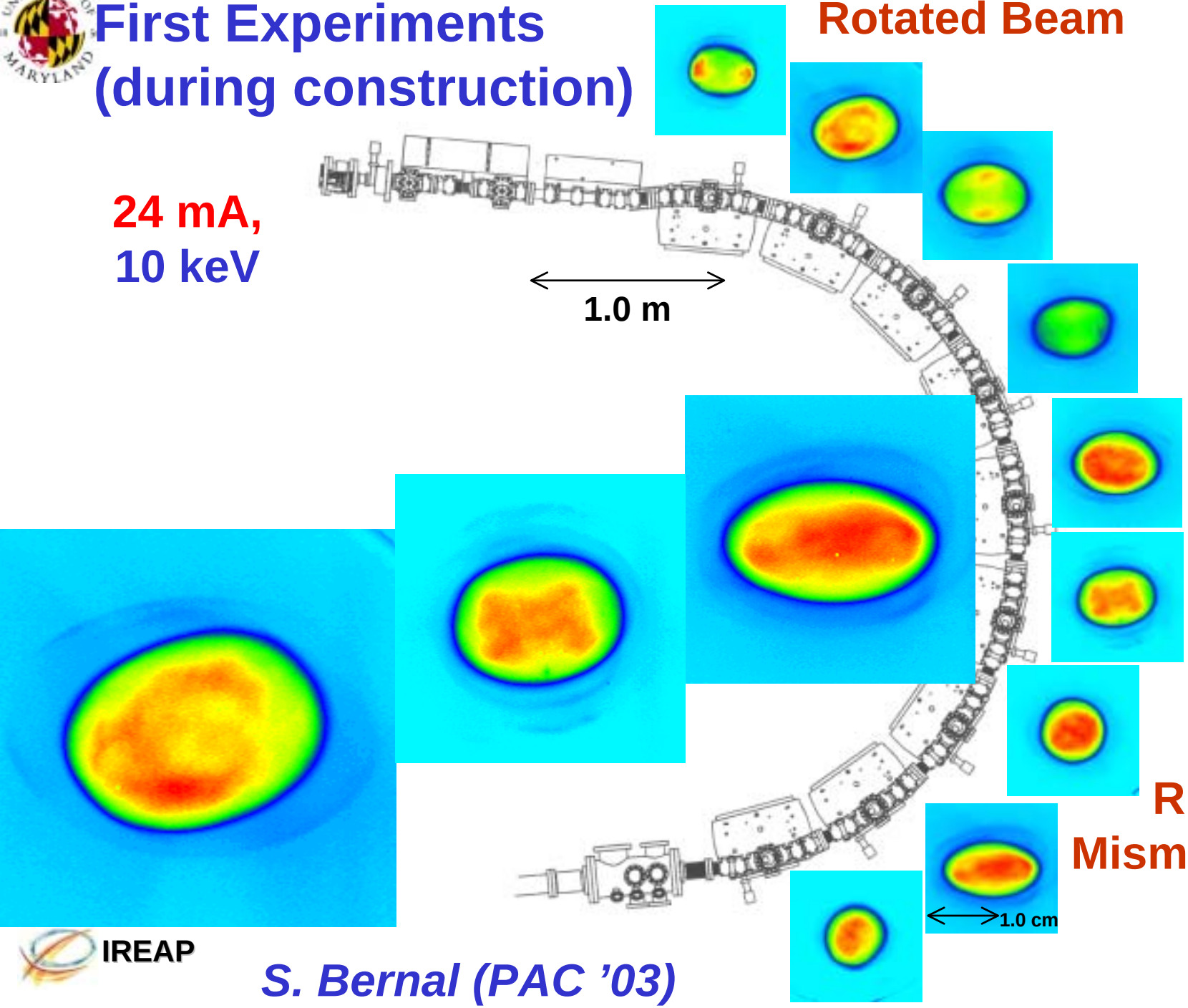
UMER Schematic



First Experiments (during construction)

24 mA, 10 keV



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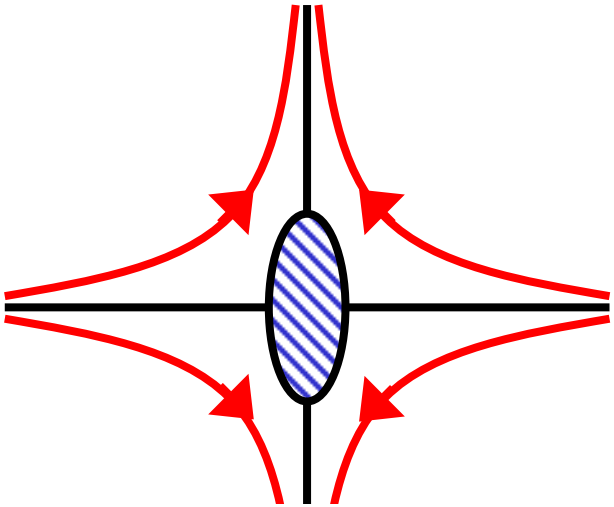
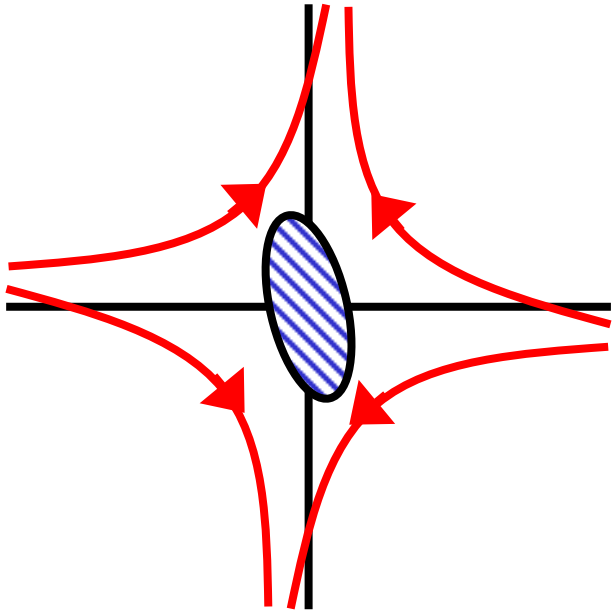
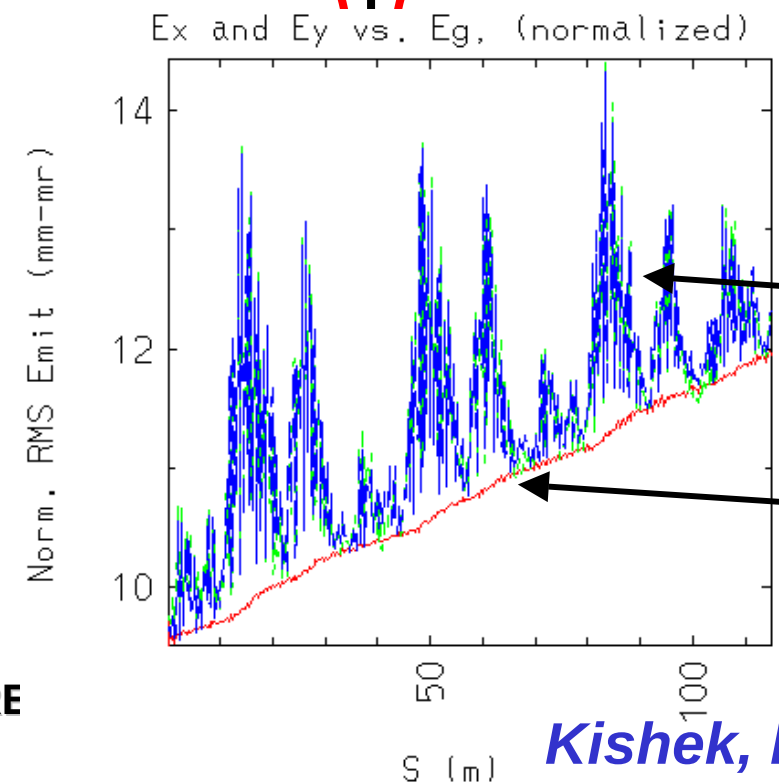
S. Bernal (PAC '03)

Skew Quadrupole (Rotational) Errors





Skew Quadrupole



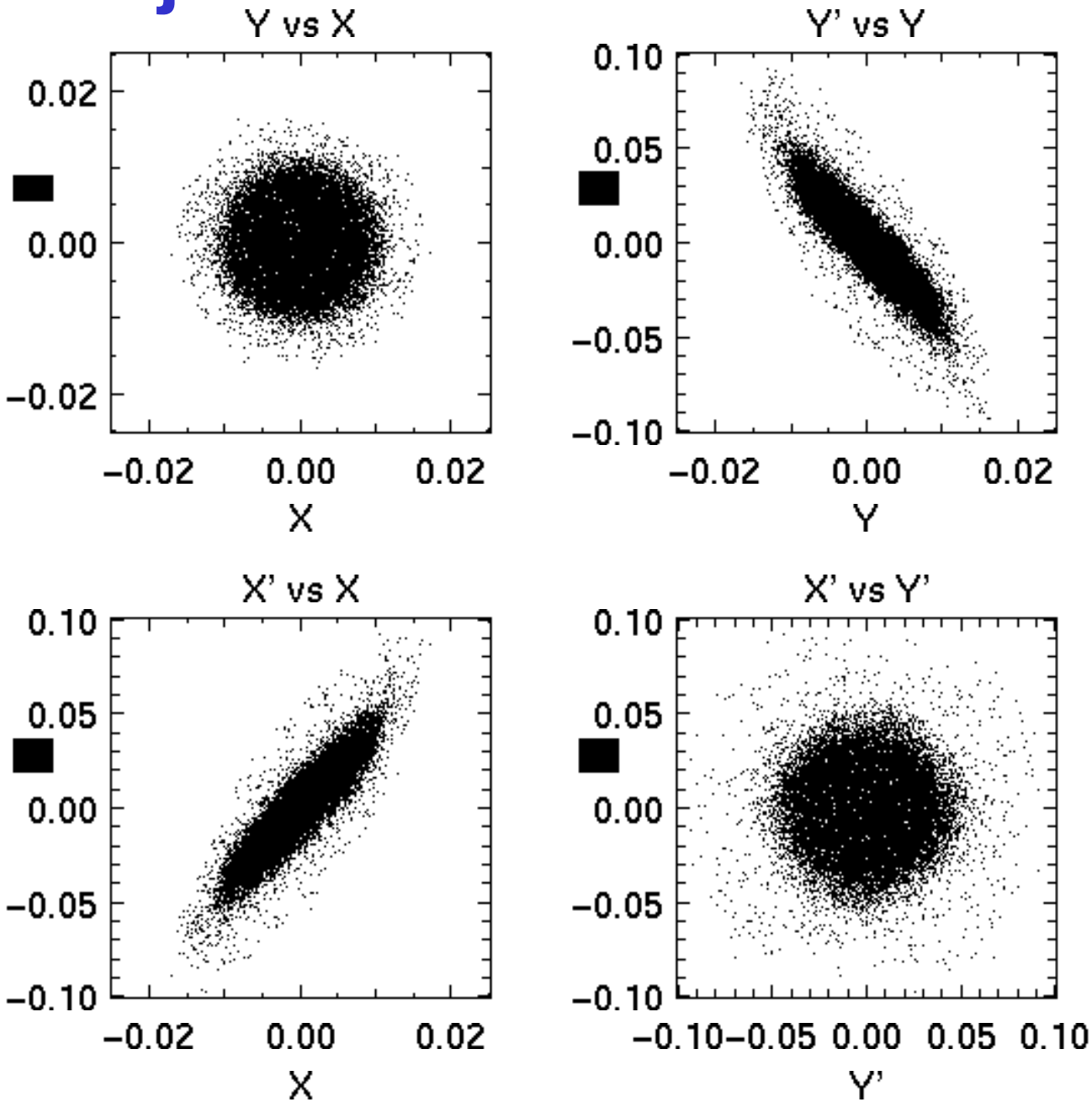
Standard x, y 4*rms emittances, ε_{nx}, ε_{ny}

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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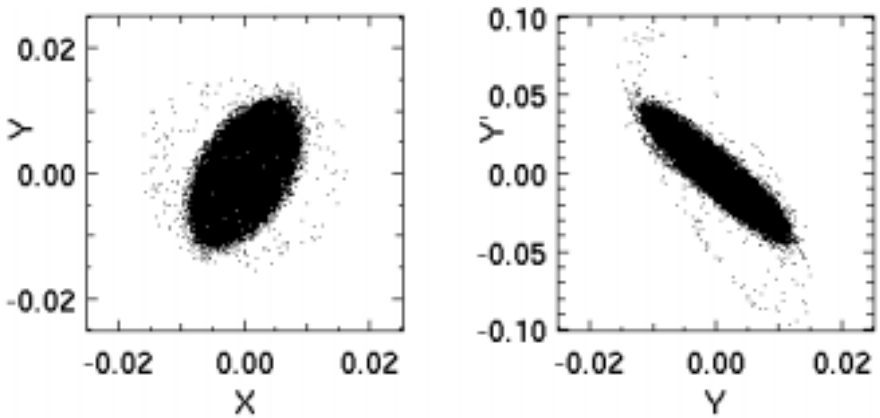
Injecting Rotated Beams ⇒ Halo

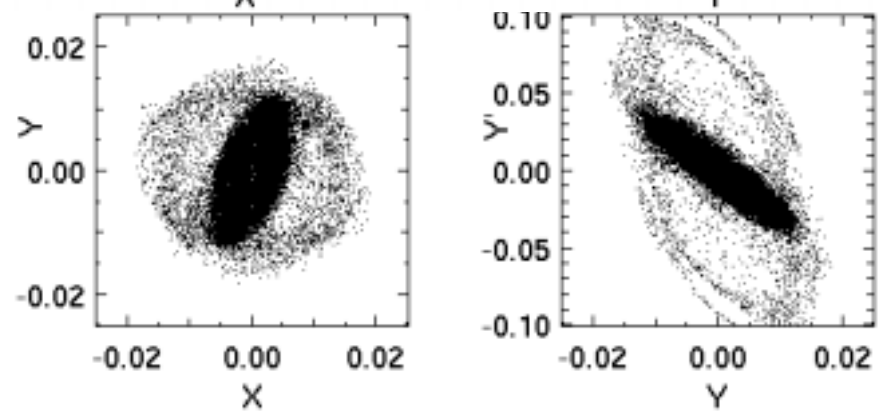
Simulations

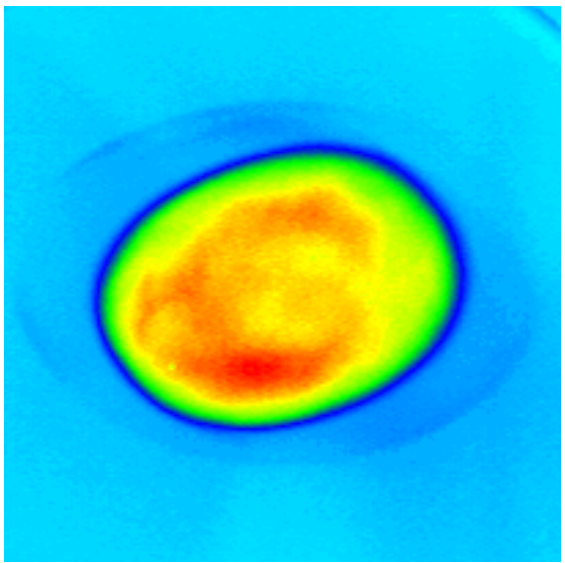
R. Kishek
Proc Halo '03

Inject Beam Rotated 10°



Inject Beam Rotated 20°





Experiment –
(Bernal, Li)
shows similar features

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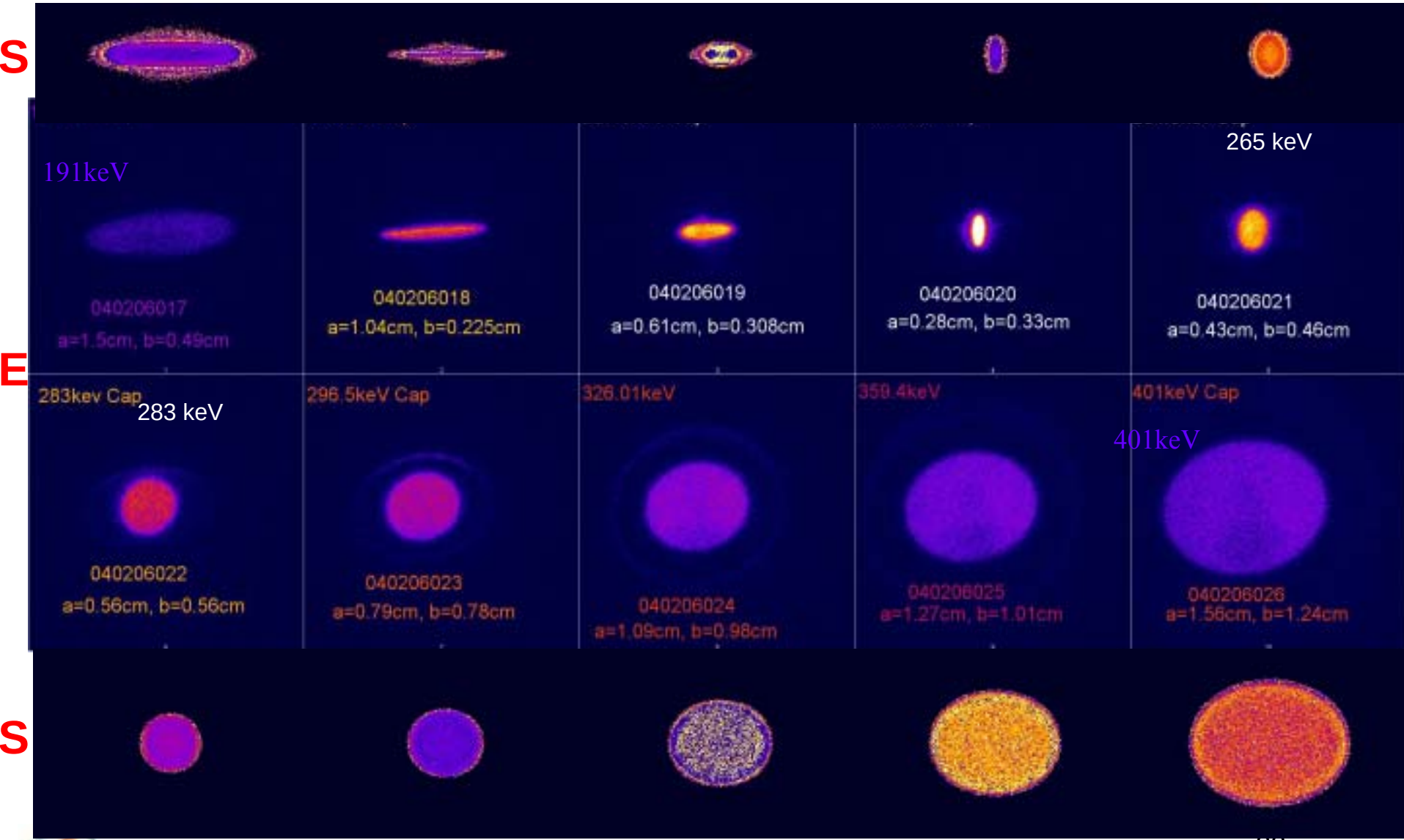
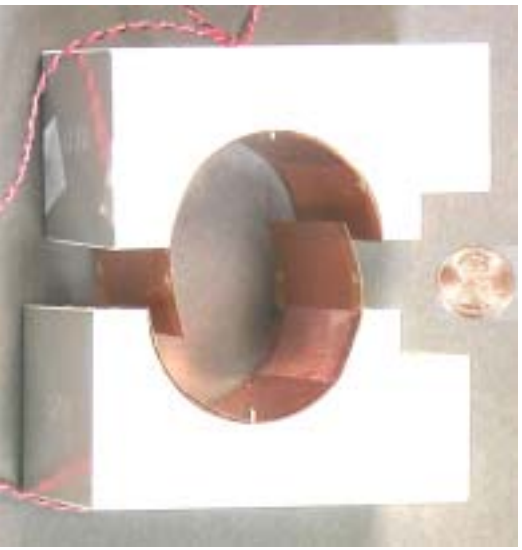
LBNL/NTX: Halo forms in Exp.



S. Yu

(1.5 mA beam, 5 mm initial radius, Ne ~ $1.2\times10^{11}/cm^3$, 20mm-20mr)

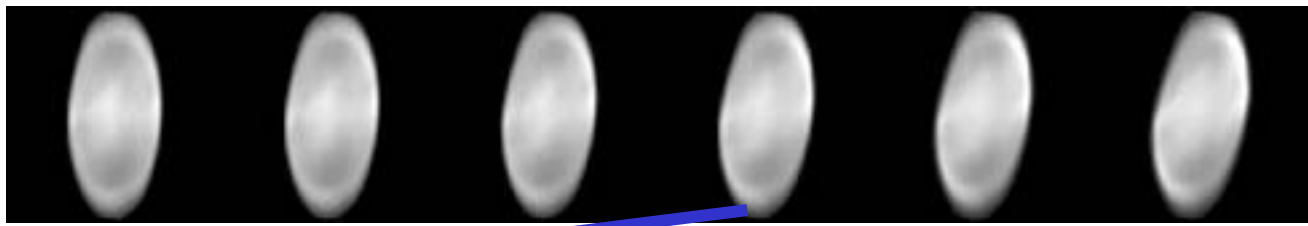
Quadrupoles with *Electronically* Adjustable Skewness



Two sets of coils at 45 deg

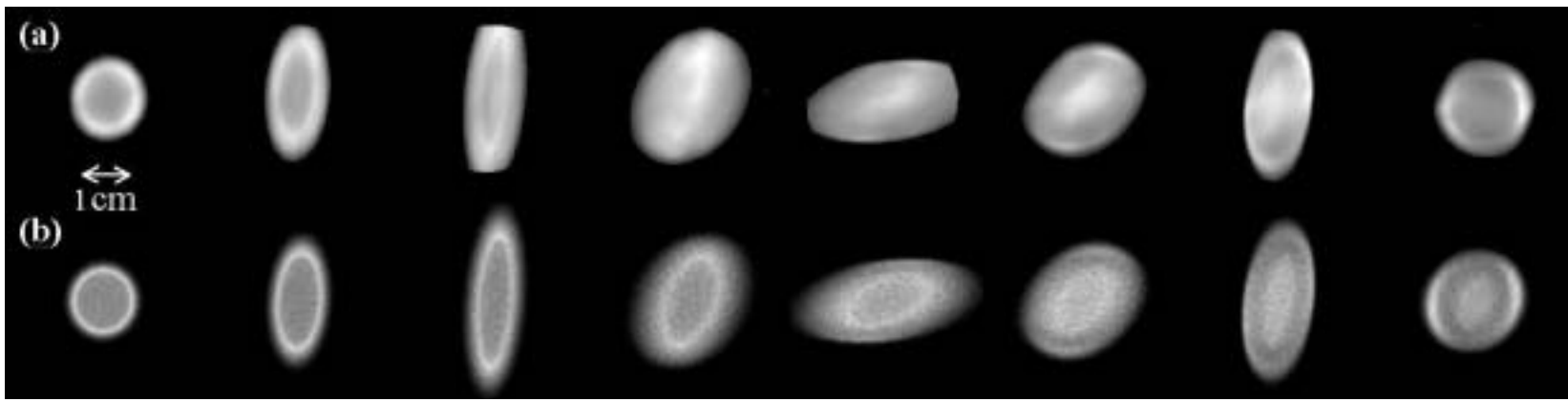
Exp. data **Skew angle:**

0.93º 1.86º 2.79º 3.72º 4.66º 5.60º



Experiment

Simulation



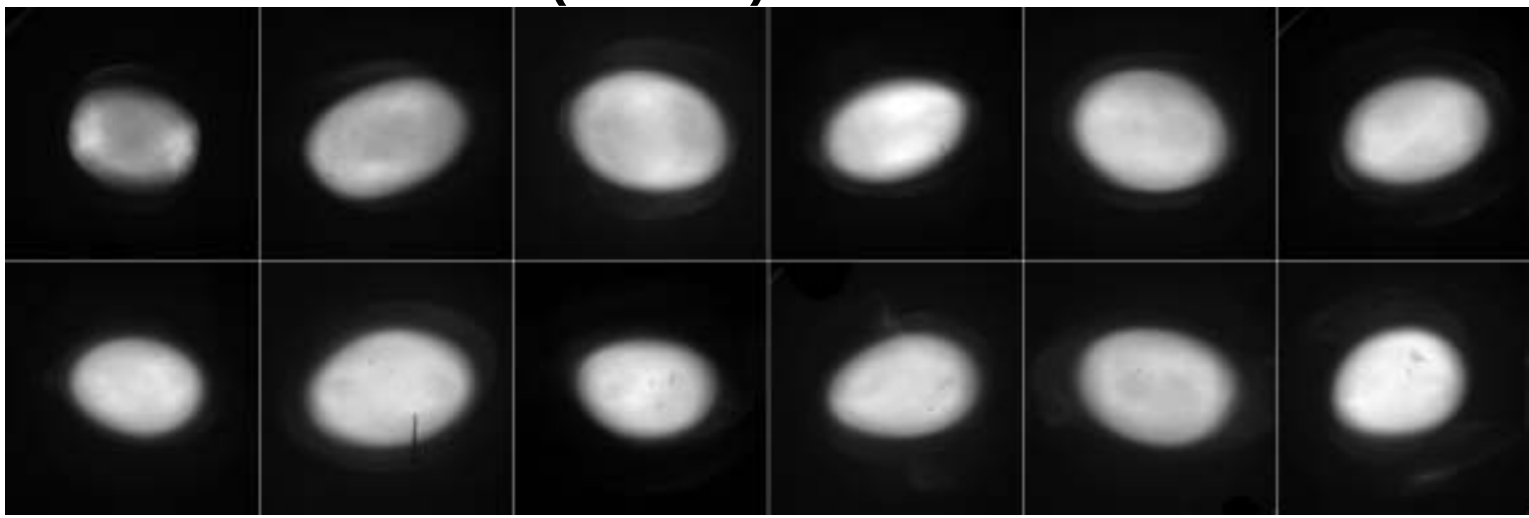
Q1 is electronically rotated 3.72^0

H. Li (PAC '01)

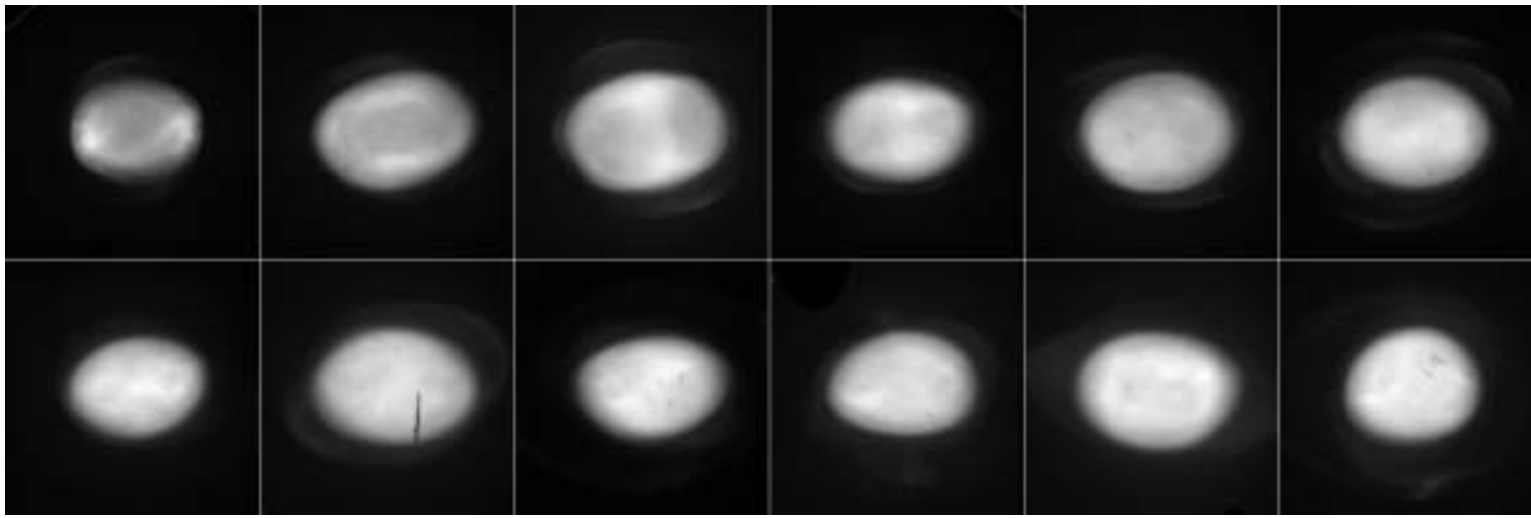
Beam Rotation Correction

24mA Beams (RC1-12)

Before Skew Correction



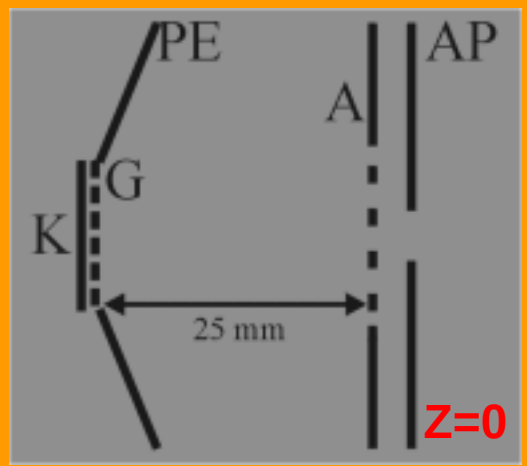
After Skew Correction

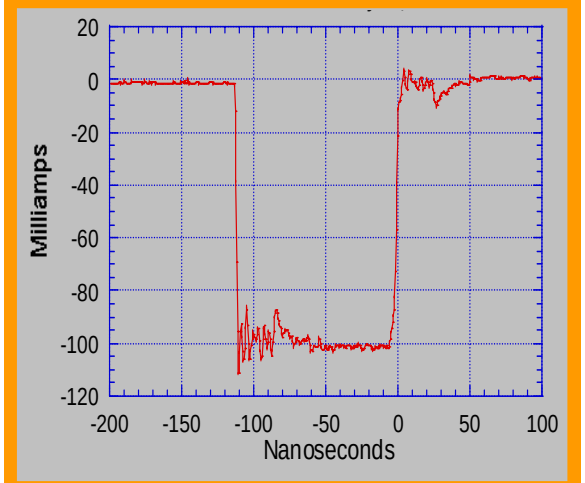


Hui Li, S. Bernal, et al., Proc 2004 HIF Symposium

UMER Electron Gun

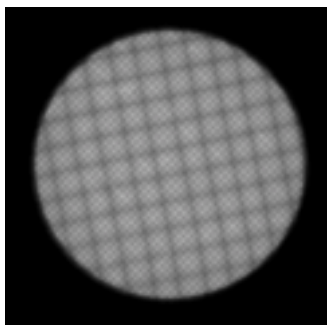
TRIODE ELECTRON GUN: CATHODE DRIVEN, PIERCE TYPE



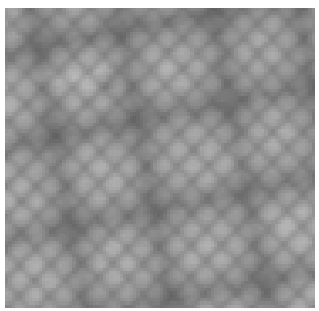


APERTURE PLATE

CATHODE AND ANODE GRIDS



8 mm



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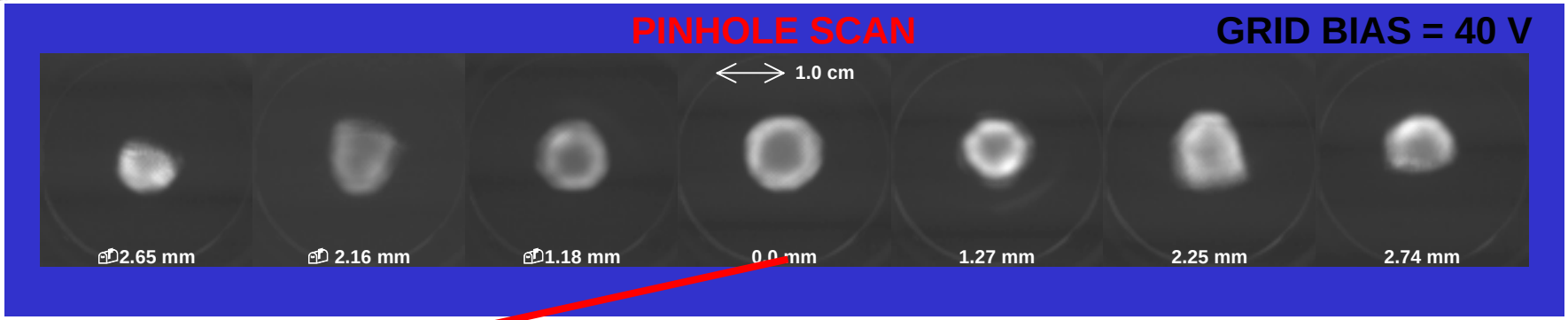
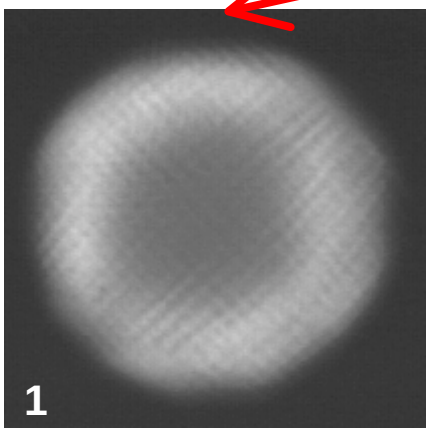
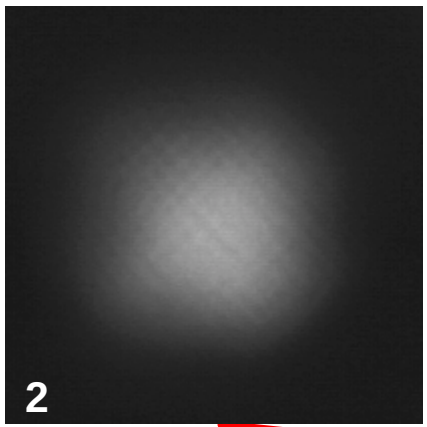
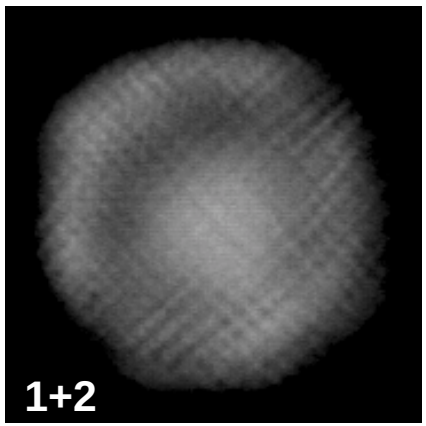
UMER Gun Characterization

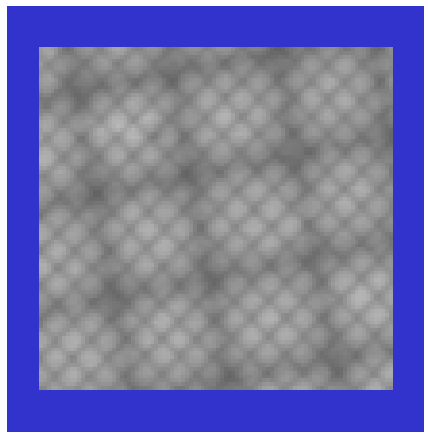
Z=28.8 cm

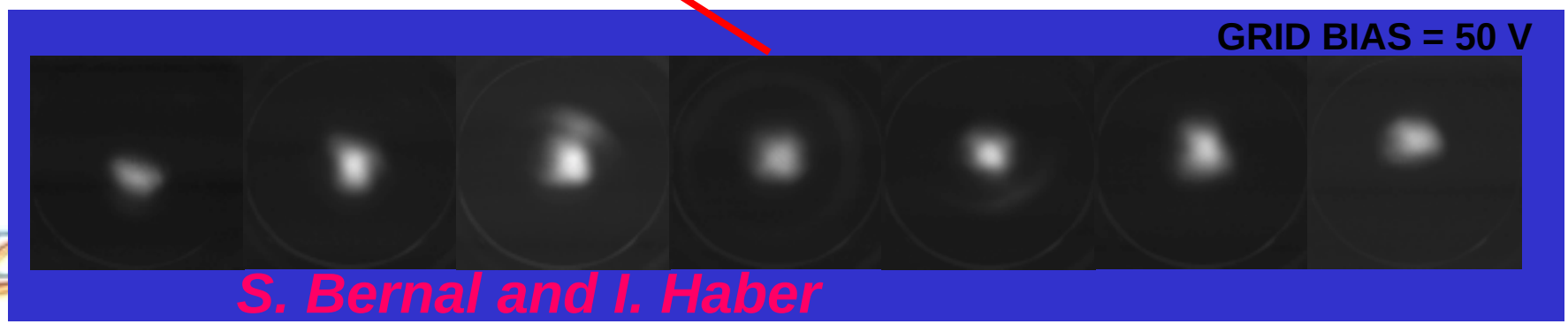








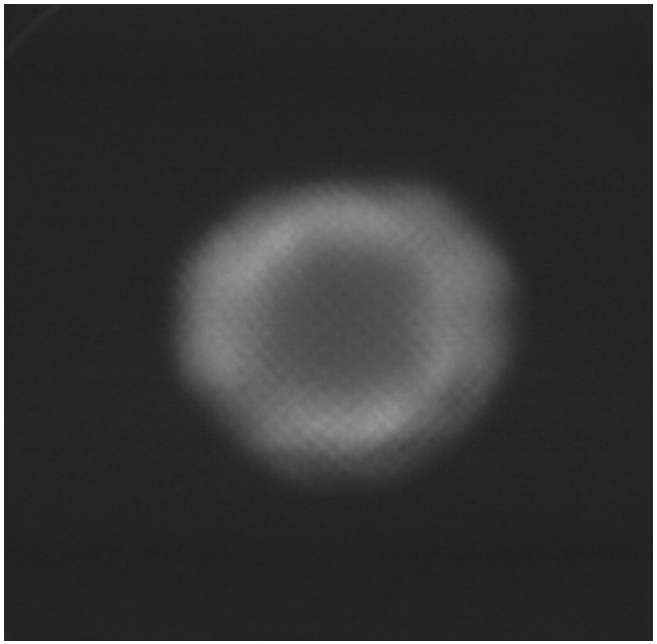




S. Bernal and I. Haber

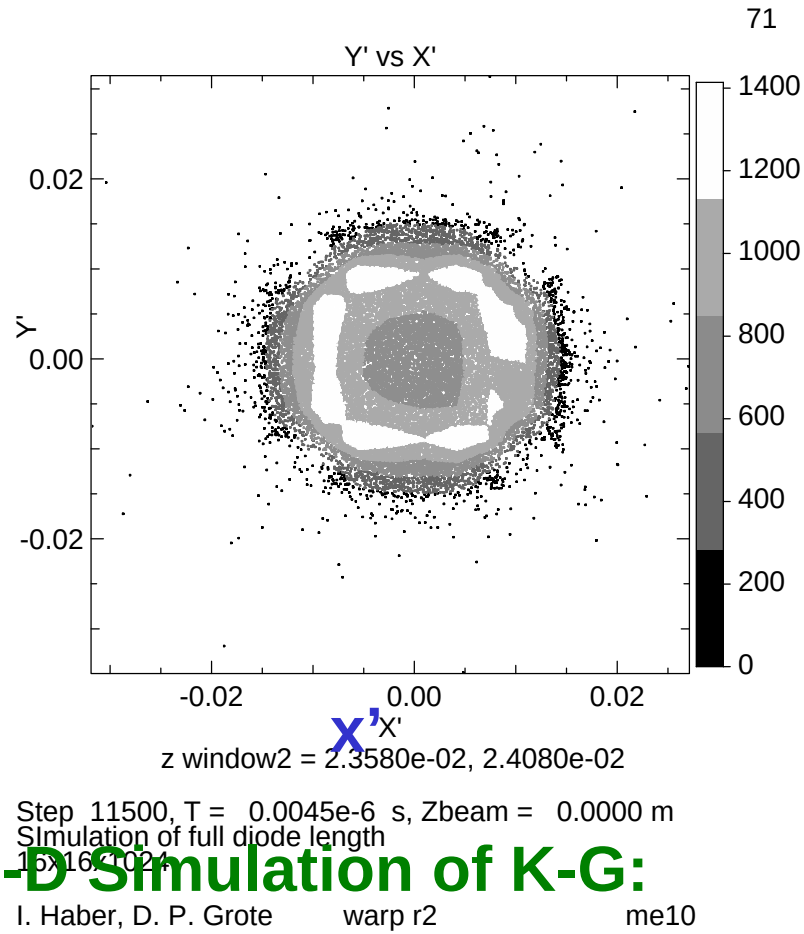
Phase Space at Source Exit

y



x

y'



x'

Experiment:

Beam exiting pinhole

3-D Simulation of K-G:

Beam velocity space

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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/**

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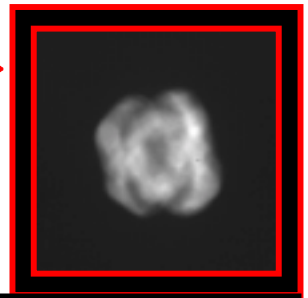
We Thank:

***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			

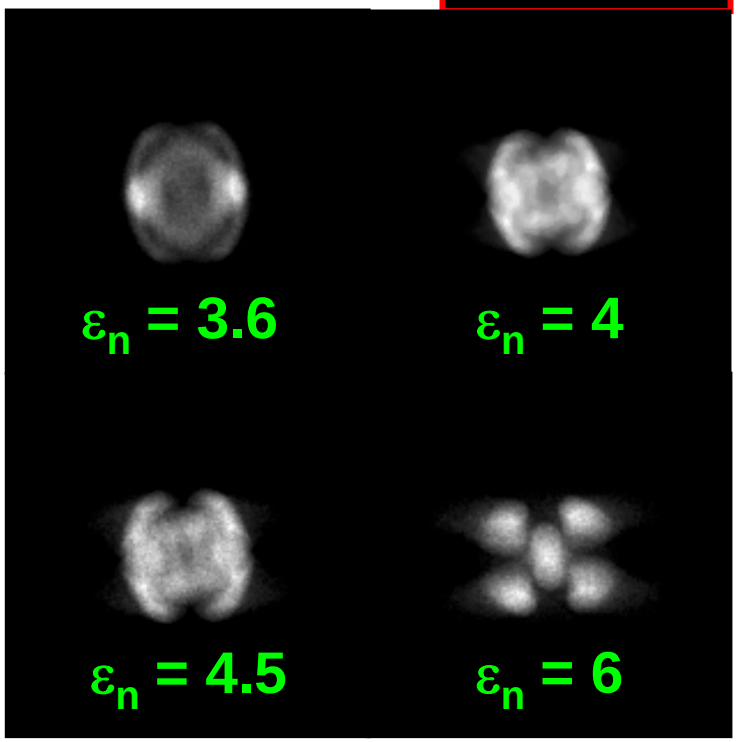
Virtual National Lab for Heavy Ion Fusion (also provided WARP)	**Simon Yu** Alex Friedman Dave Grote Jean-Luc Vay	Prabir Roy Christine Celata Steve Lund John Barnard
NIU	**Court Bohn**	Ioannis Sideris
LLNL	**Tom Wangler**	
MIT	**Chiping Chen**	

New 5-Beamlet Experiment

Experiment⇒

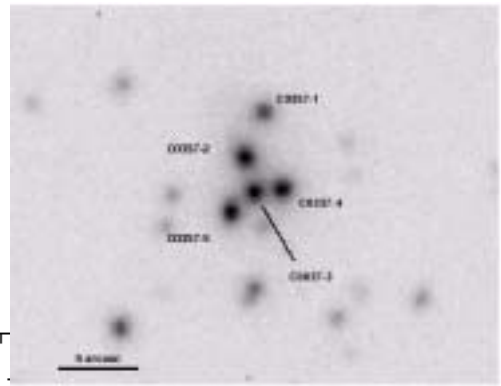


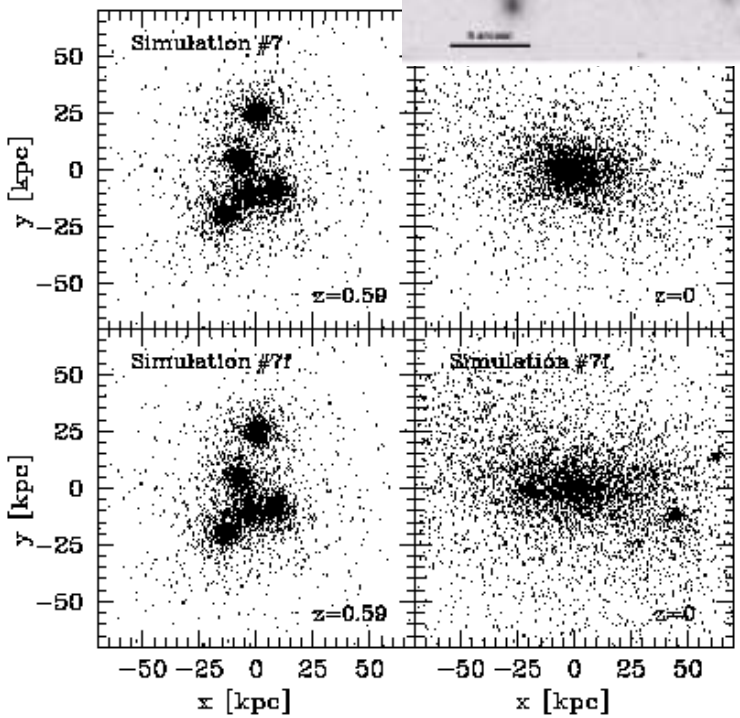
⇓ Simulation



z = 99 cm

galaxy cluster C0337-2522

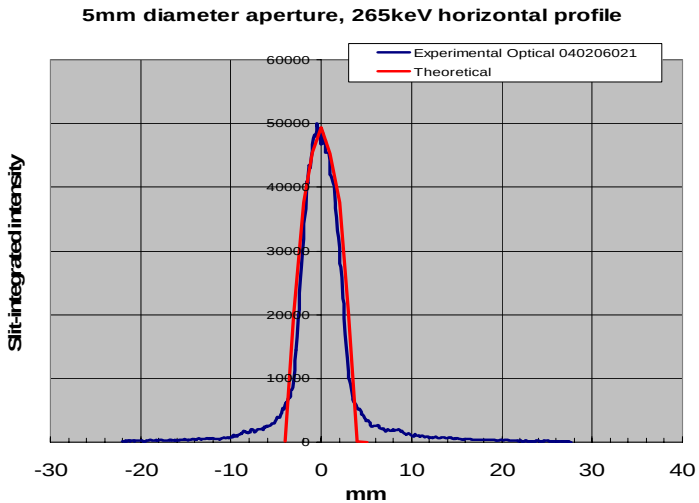




*Nipoti, et al., Mon. Not. R. Astron. Soc., **344**, 748-760 (2003).*

IREAP ***Bernal; Haber; Kishek***

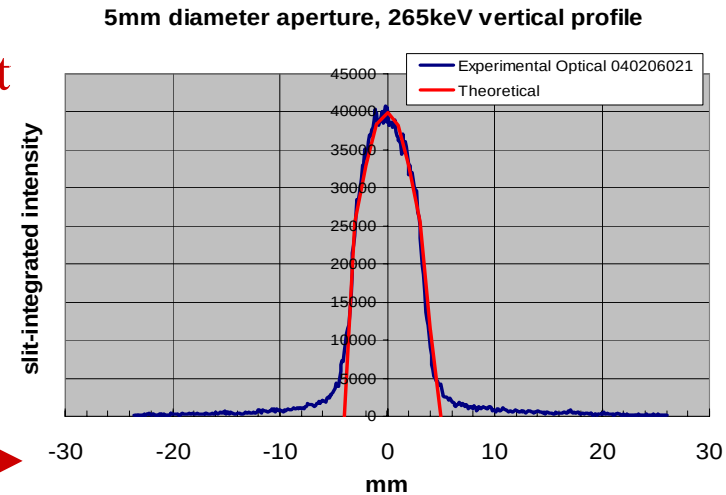
Measured and Calculated Beam Profiles Agreed Well

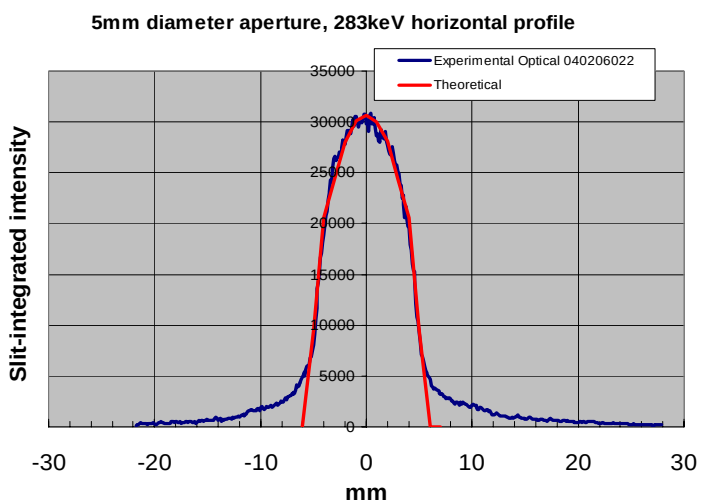


Horizontal densit profile

265keV

Vertical

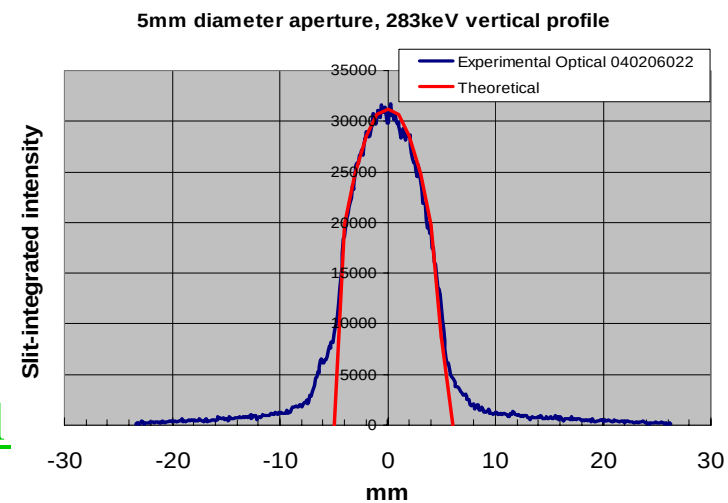




Horizontal

283keV

Vertical



IREAP

S. Yu