UMER Enters a New Regime of High Tune-Shift Rings

Rami A. Kishek
Institute for Research in Electronics & Applied Physics
University of Maryland, College Park, MD, USA

Research sponsored by US DOE HEP, DOE FES/HEDP, and DOD ONR

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Outline:

1. The need for high-quality beams
2. High Intensity: Terra Incognita
3. UMER: A tool for probing space charge physics
4. Results and issues

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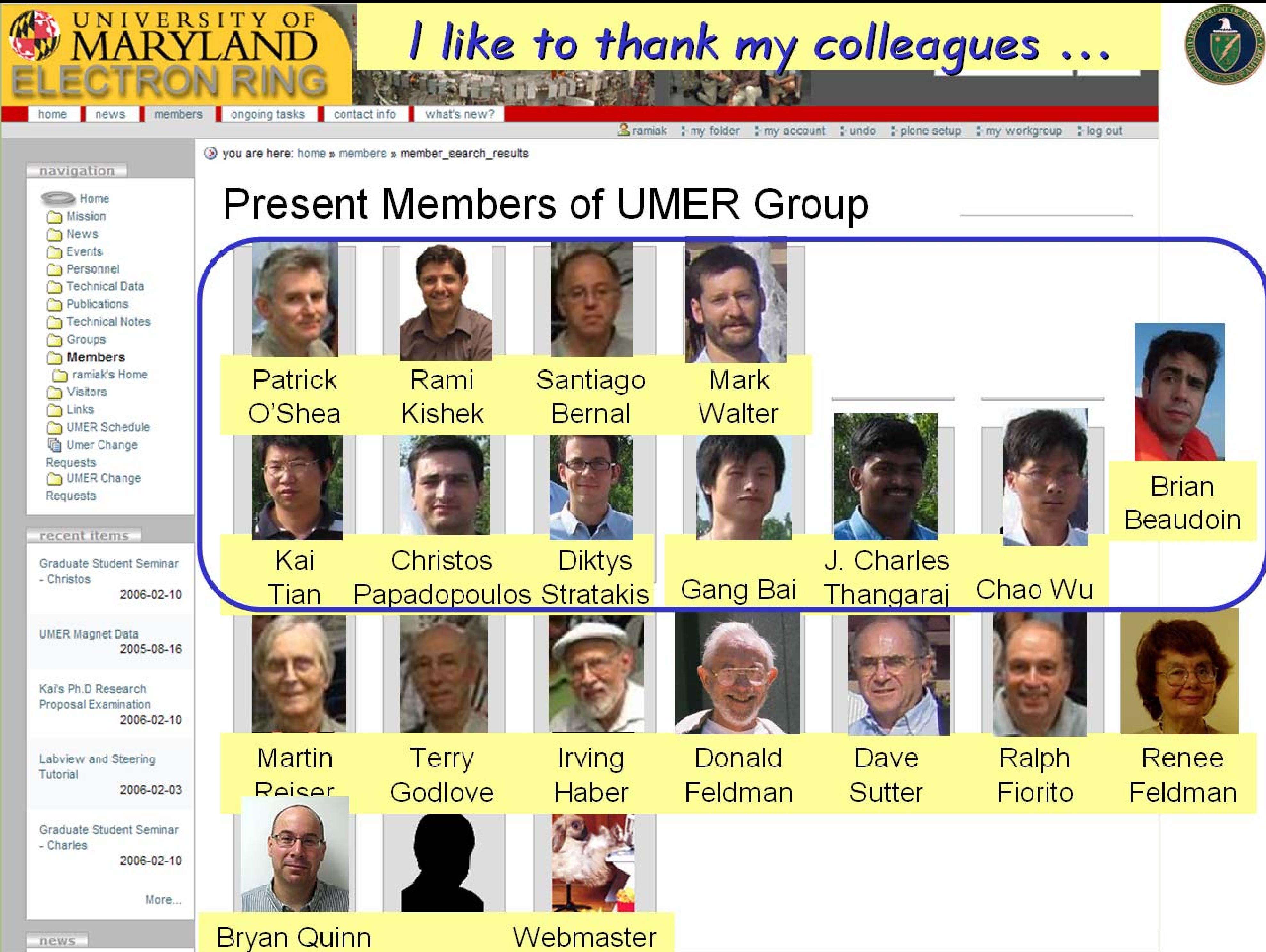
I like to thank my colleagues …



I like to thank my colleagues ...

UNIVERSITY OF MARYLAND
ELECTRON RING

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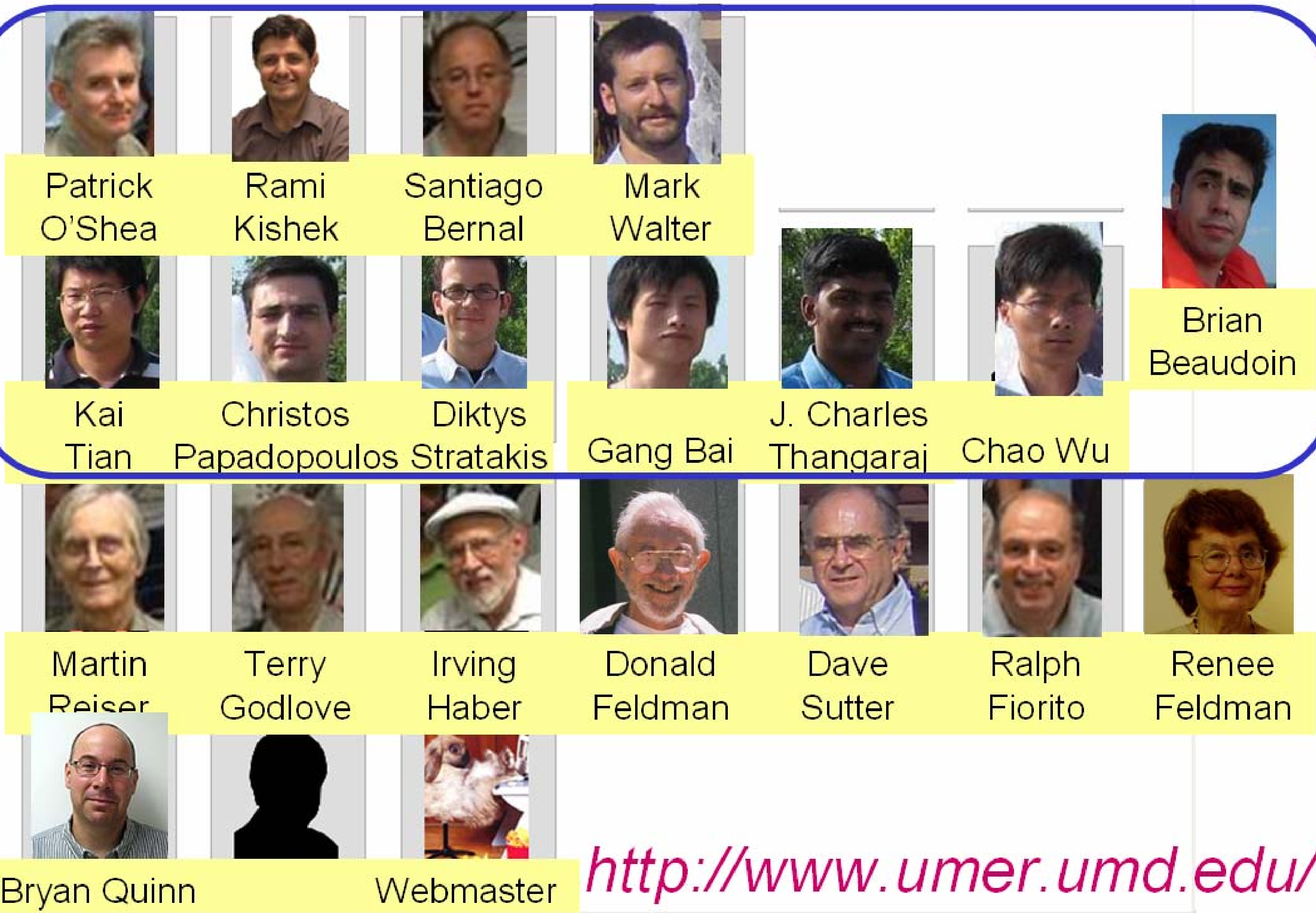


Graduate Student Seminar - Christos
2006-02-10

Labview and Steering Tutorial
2006-02-03

Graduate Student Seminar - Charles
2006-02-10

More...

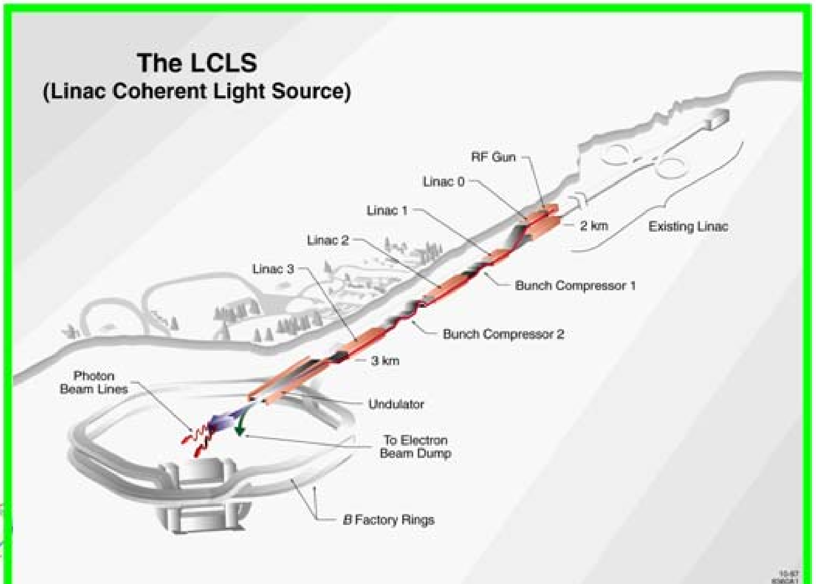
news

http://www.umer.umd.edu/

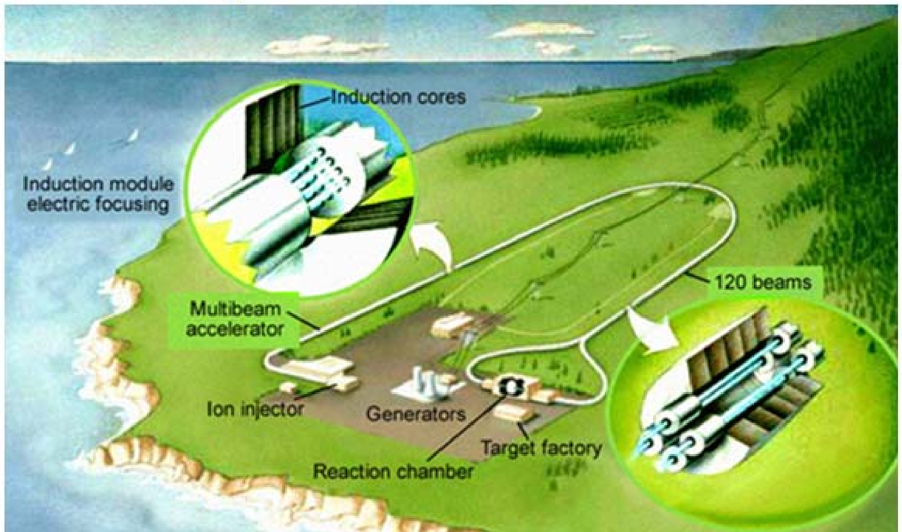
Benefits of High-Quality Beams

Spallation Neutron Source

Free Electron Lasers



Heavy Ion Inertial Fusion



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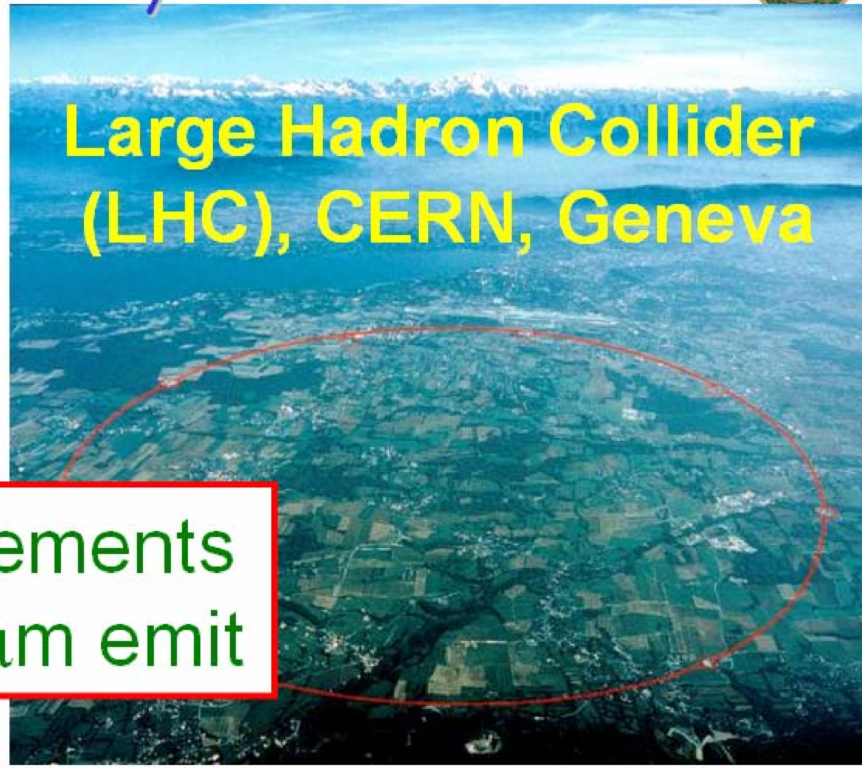
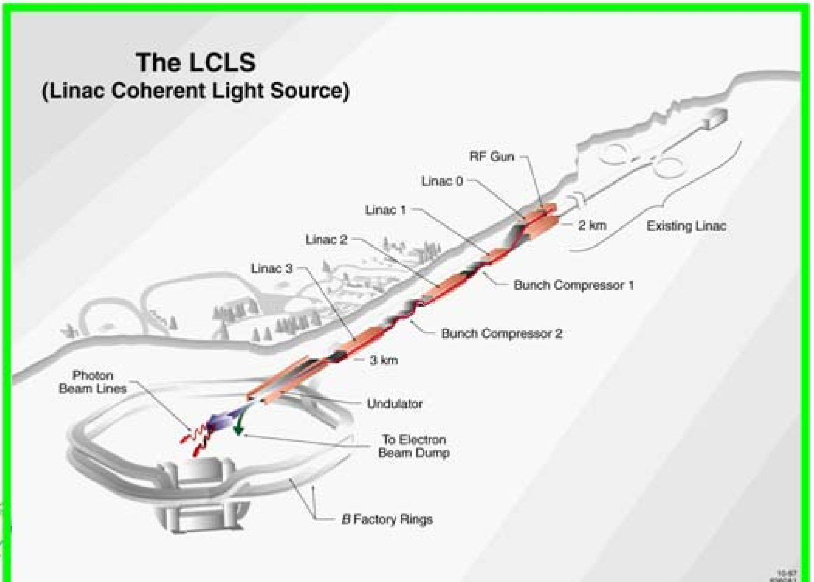


Typical requirements
1 nC, 1 ps, 1 μm emit

Free Electron Lasers



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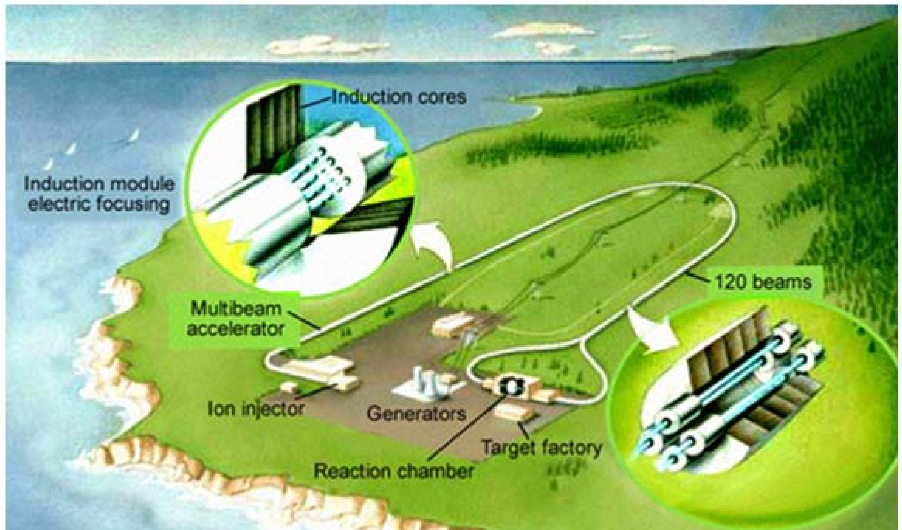


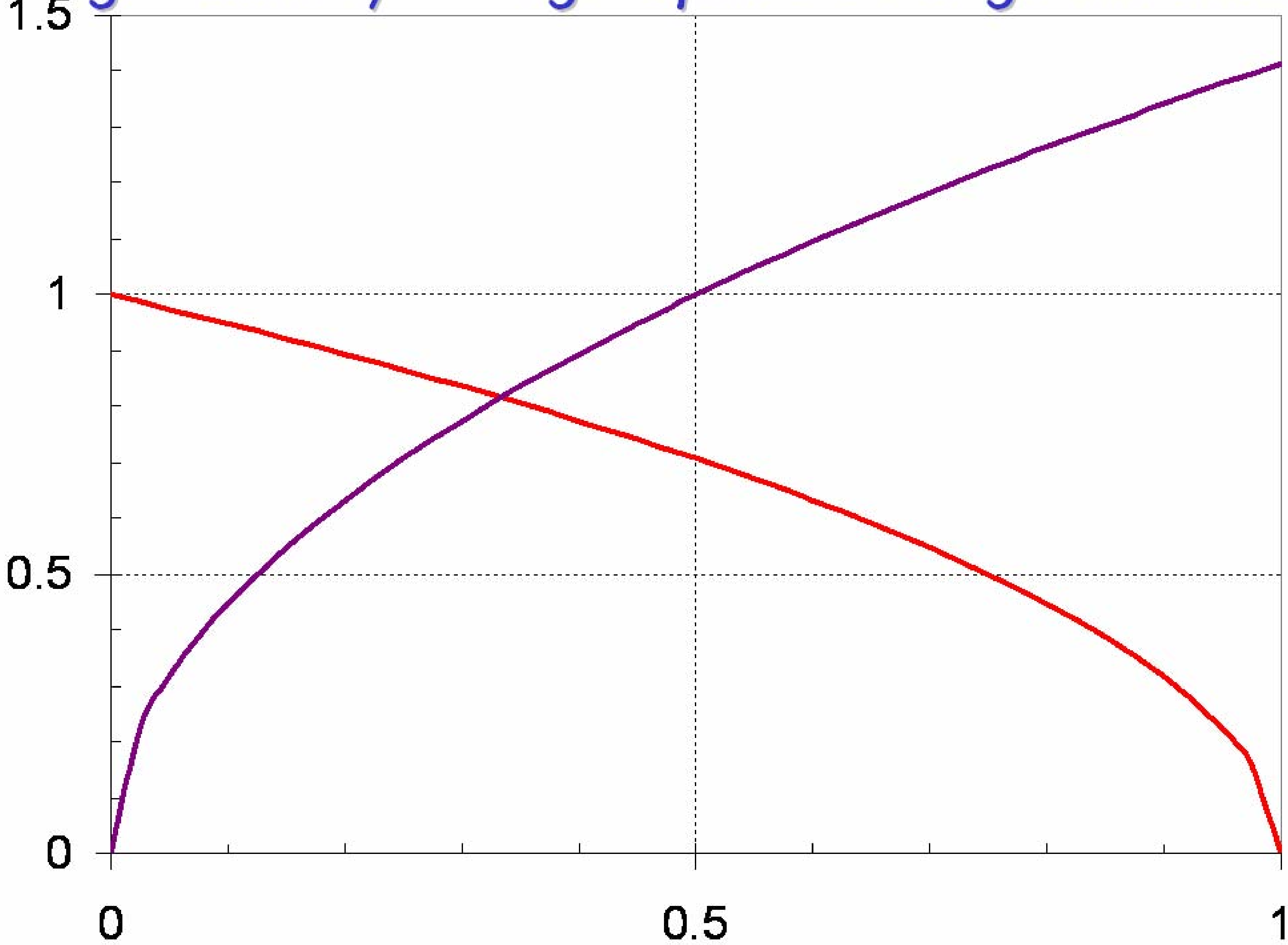
High Quality = High Space Charge Intensity

$$\chi = \frac{1}{1 + \frac{\beta\gamma I_o}{2I}\left(\frac{\varepsilon_n}{a}\right)^2}$$

Intensity Parameter

IREAP

High Quality = High Space Charge Intensity



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M. Reiser, et al., PAC '99.

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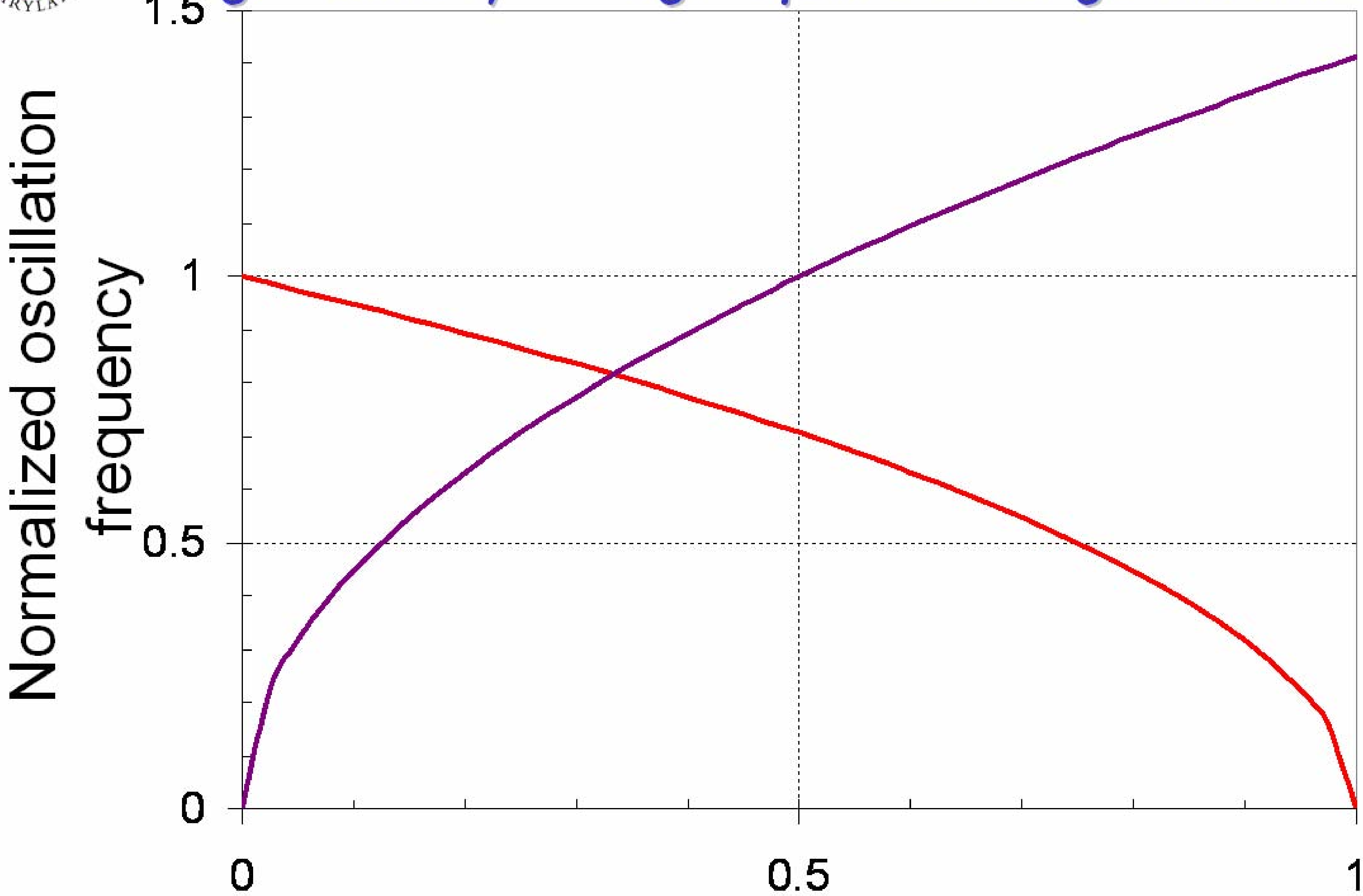

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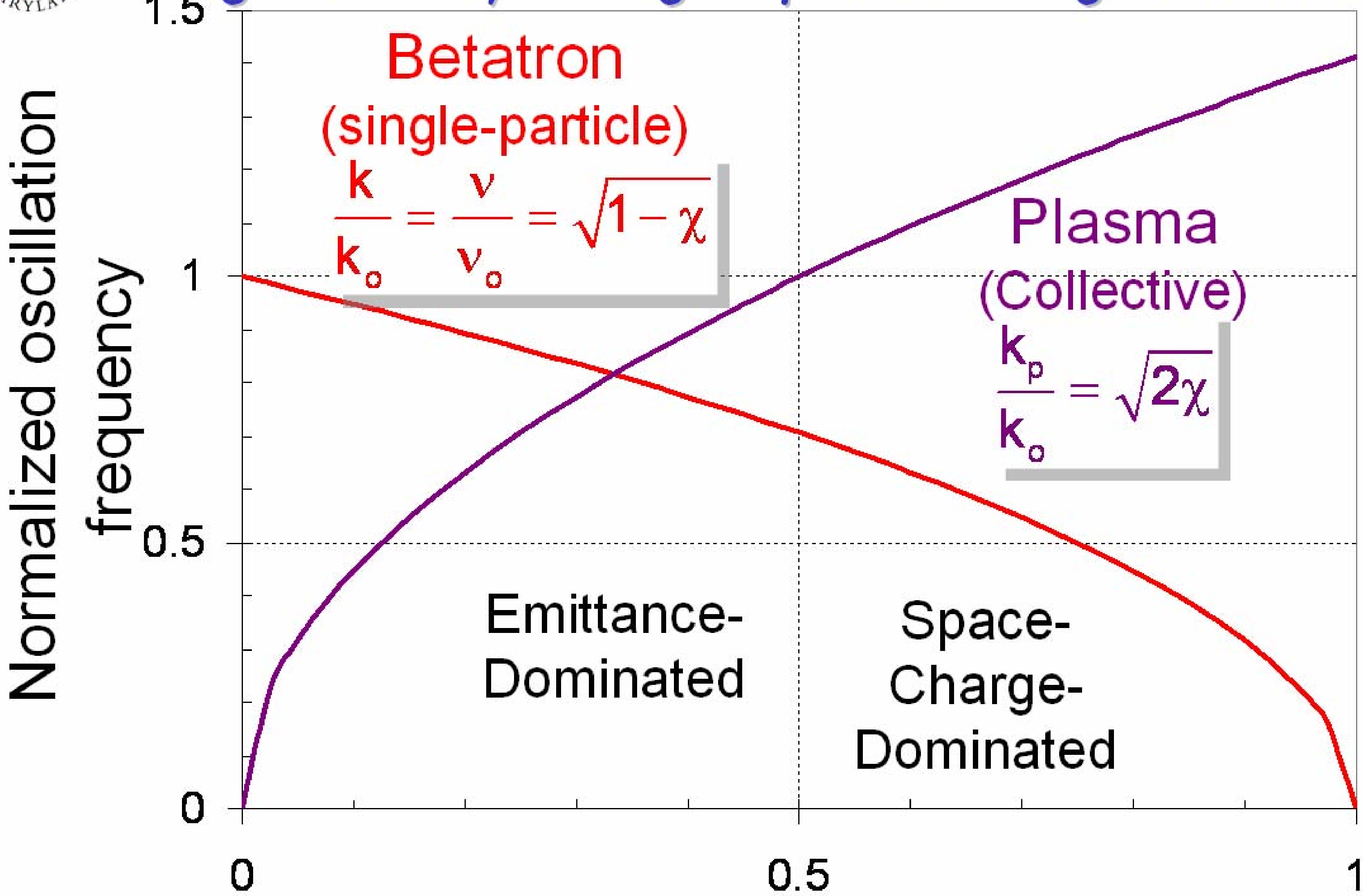

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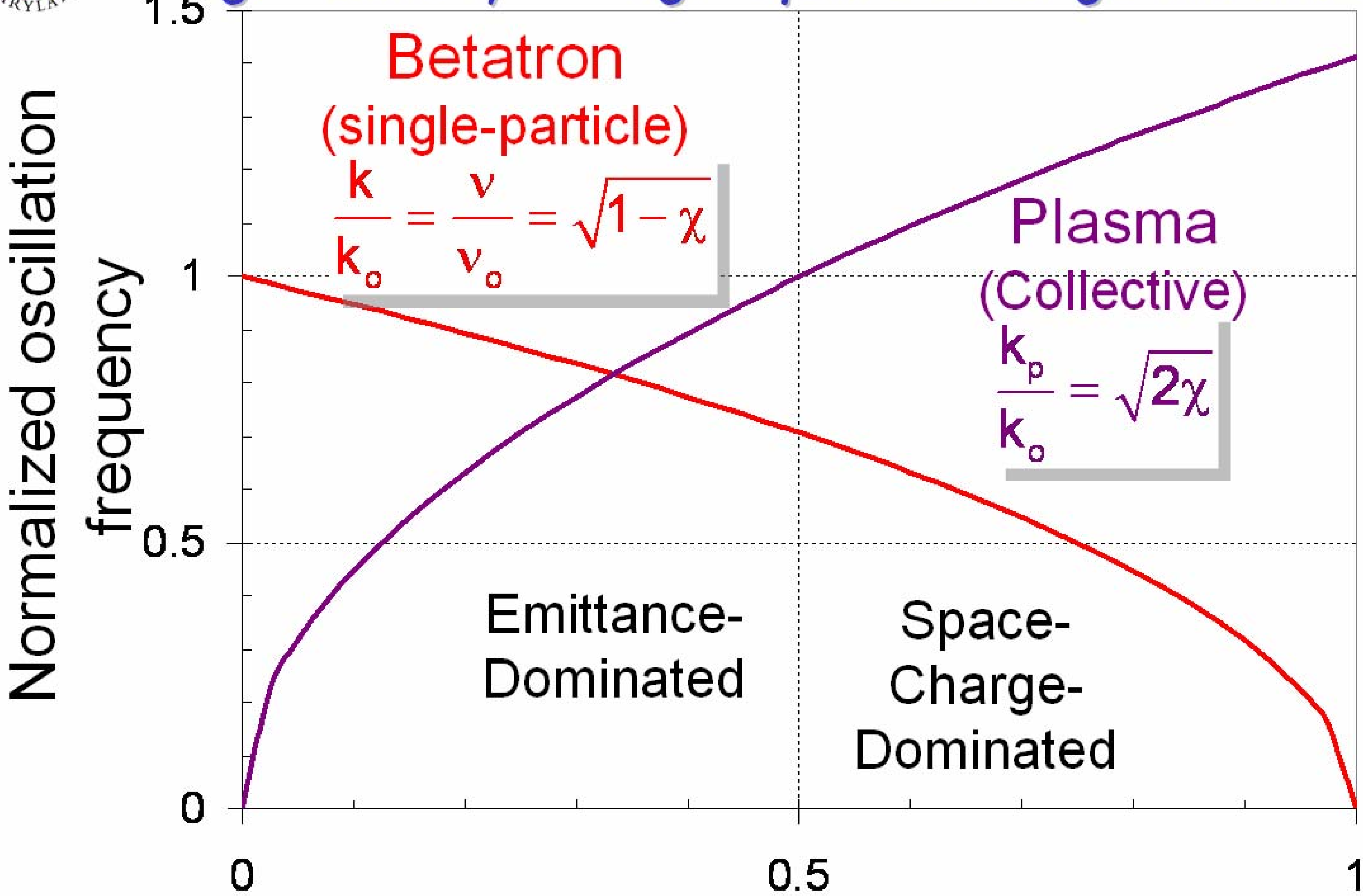

Rings

$$\chi = \frac{1}{1 + \frac{\beta\gamma I_o}{2I}\left(\frac{\varepsilon_n}{a}\right)^2}$$

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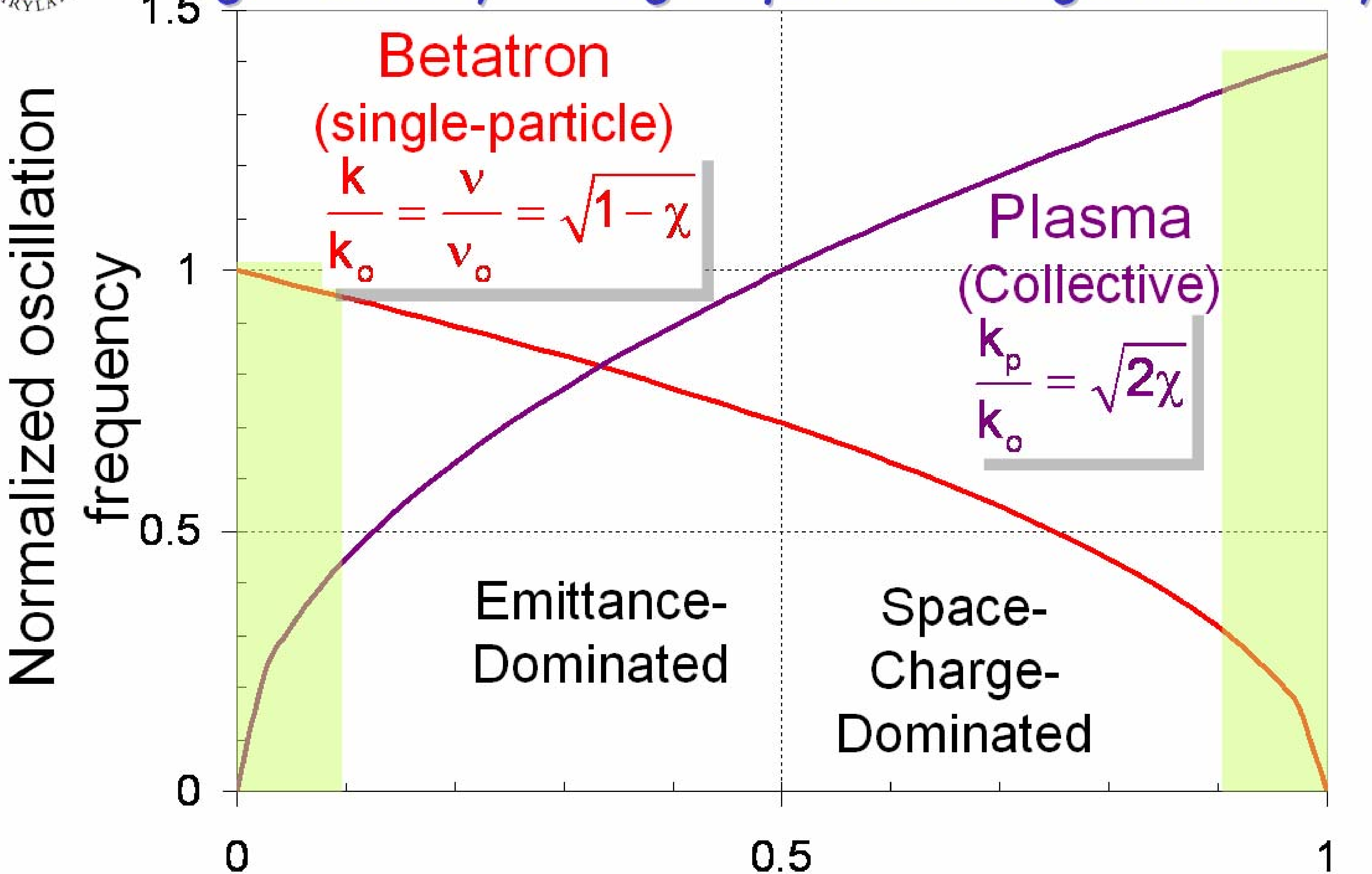

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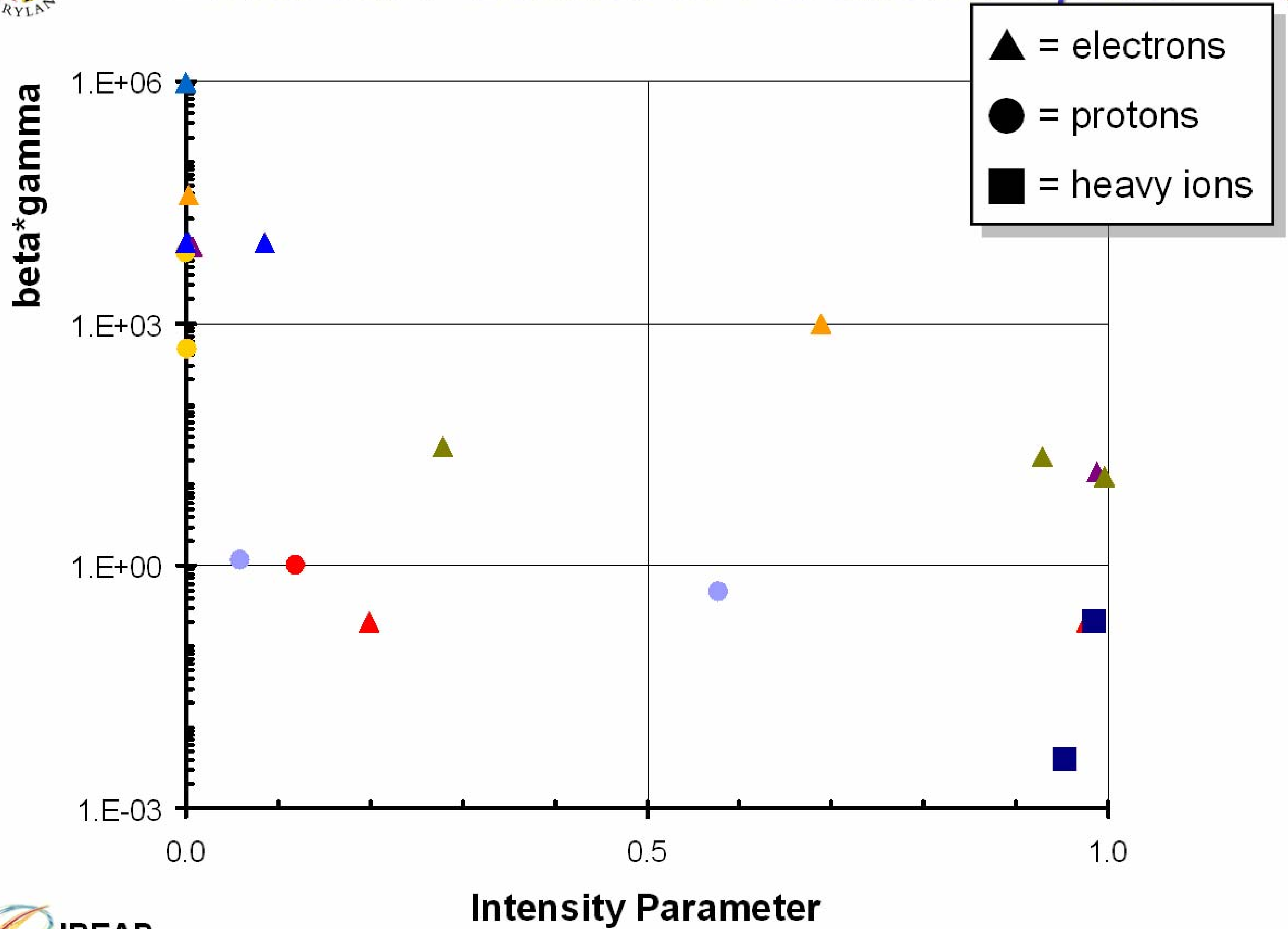
Different Machines in Parameter Space



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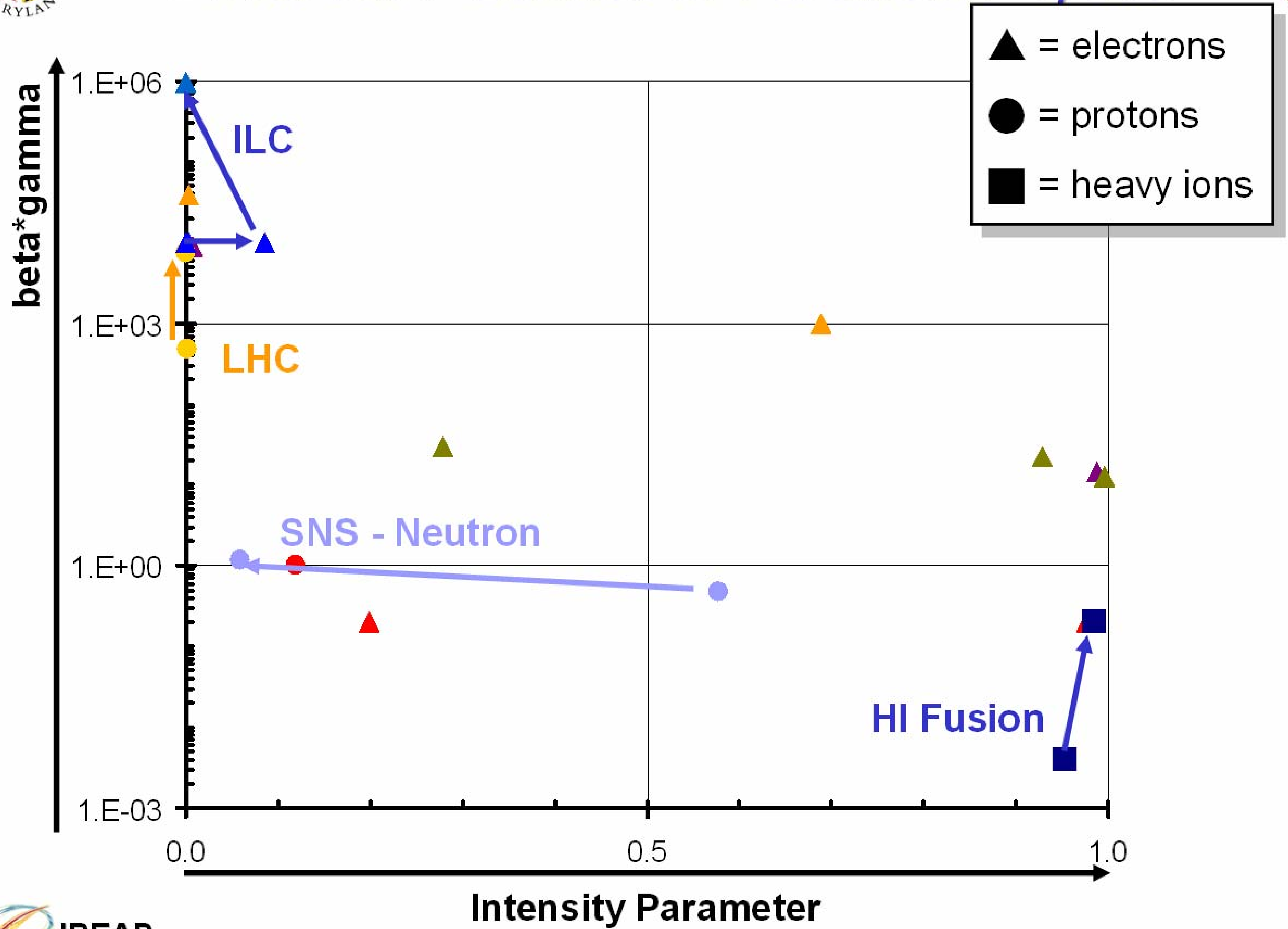

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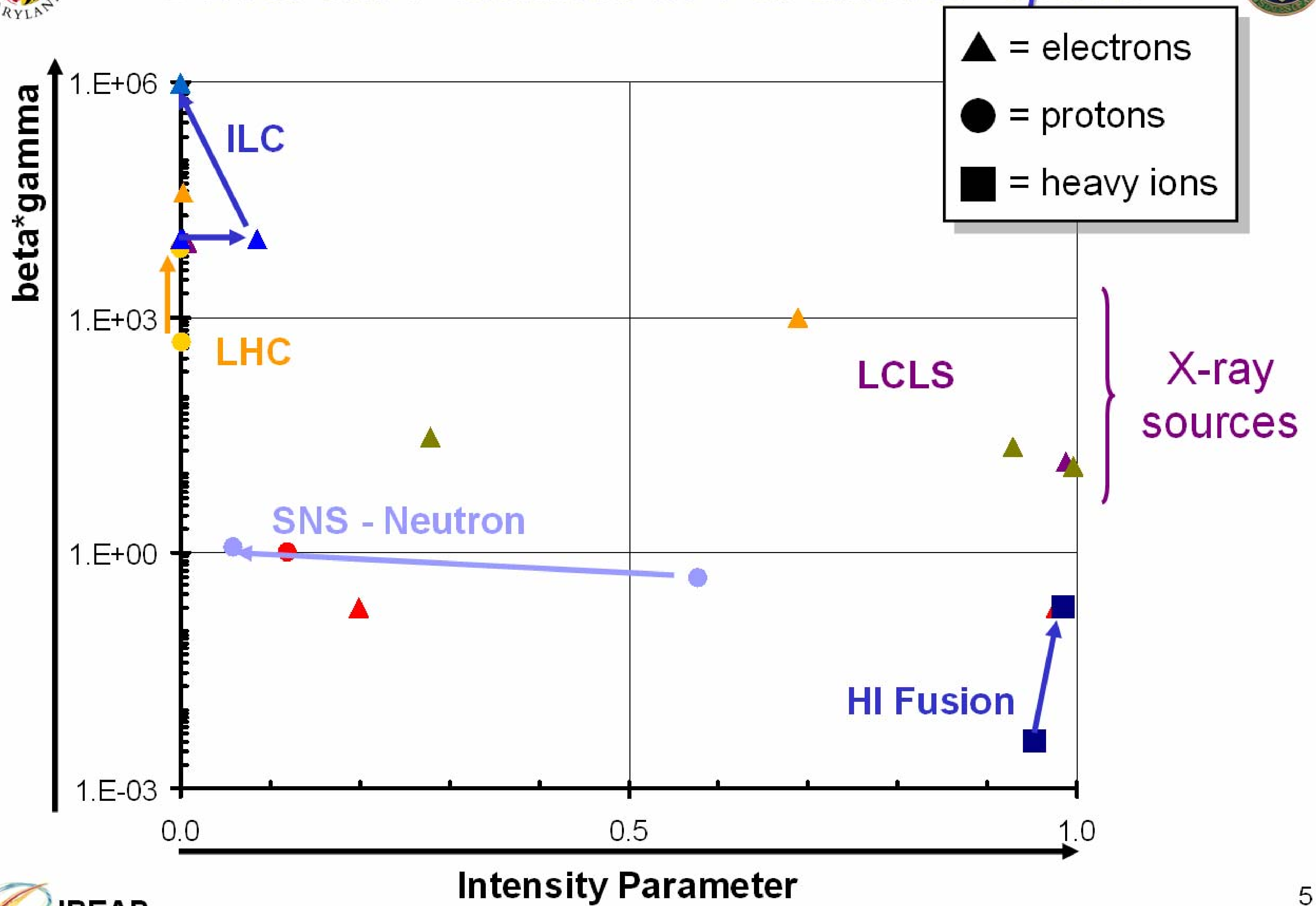

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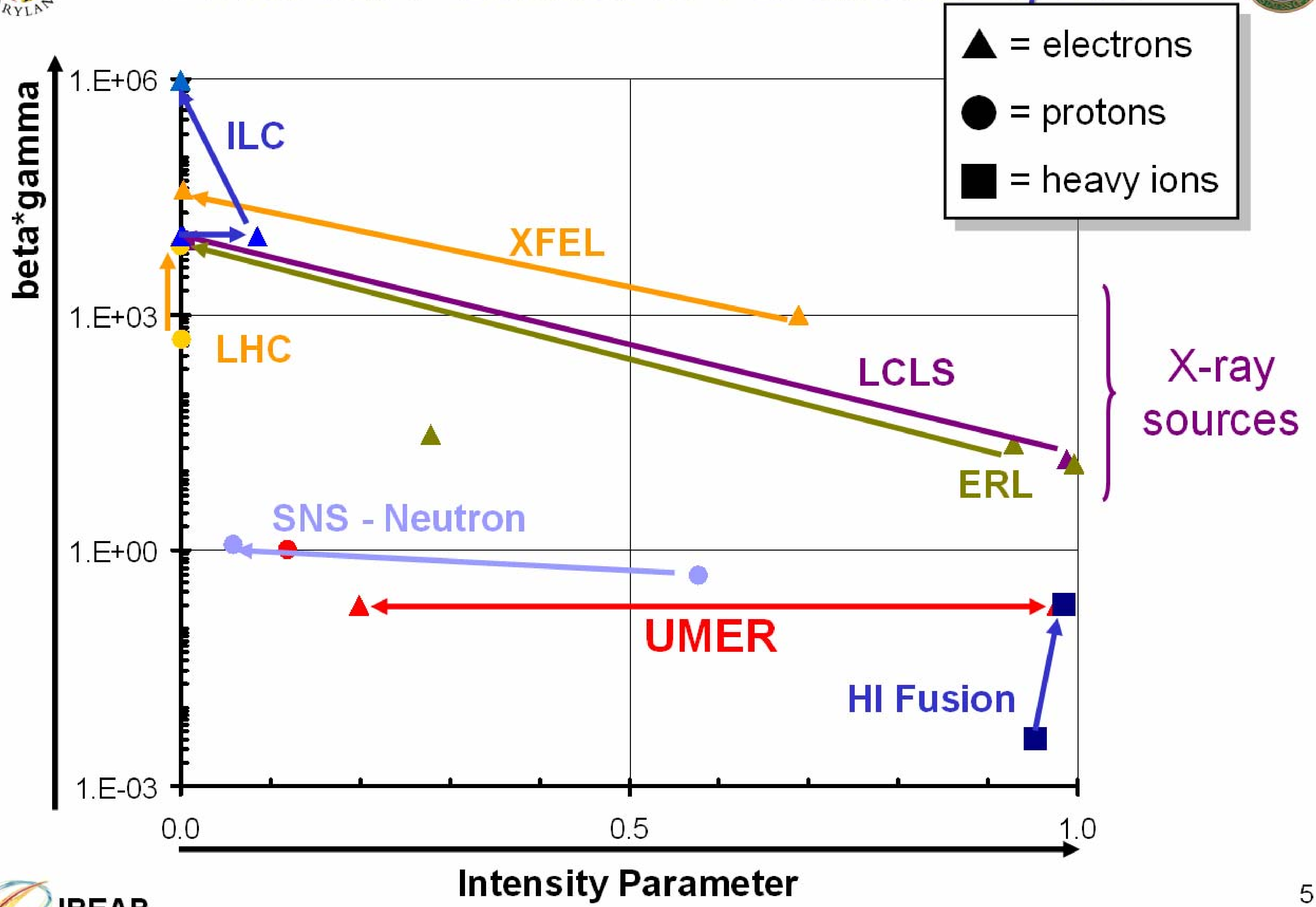

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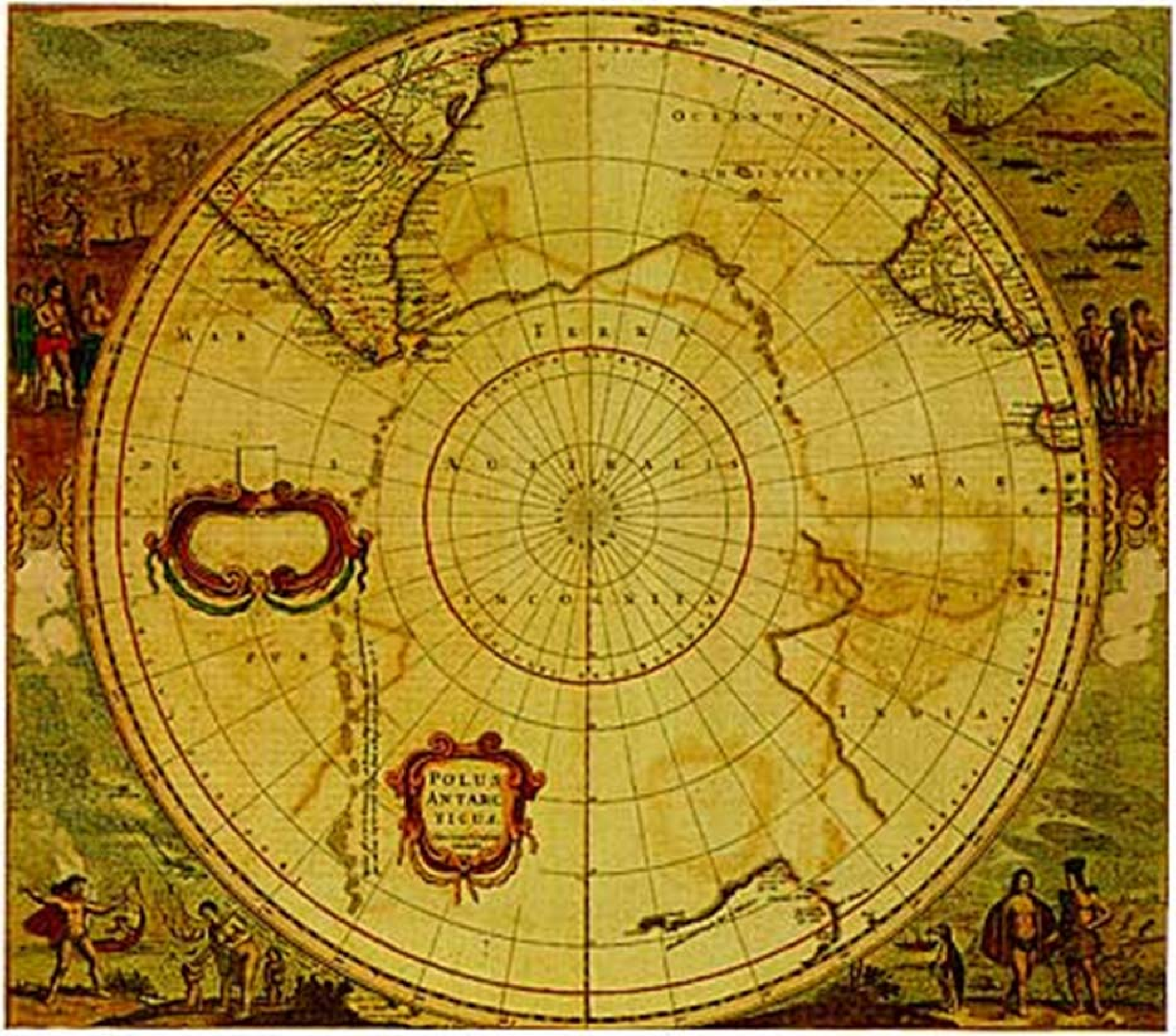
Intense Space Charge Rings – Terra Incognita

Henricus Hondius
Polus Antarcticus
(1639)



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Credits: http://www.pbs.org/wgbh/nova/shackleton/surviving/mapping3.html

What do we expect to happen? E.g., Resonances

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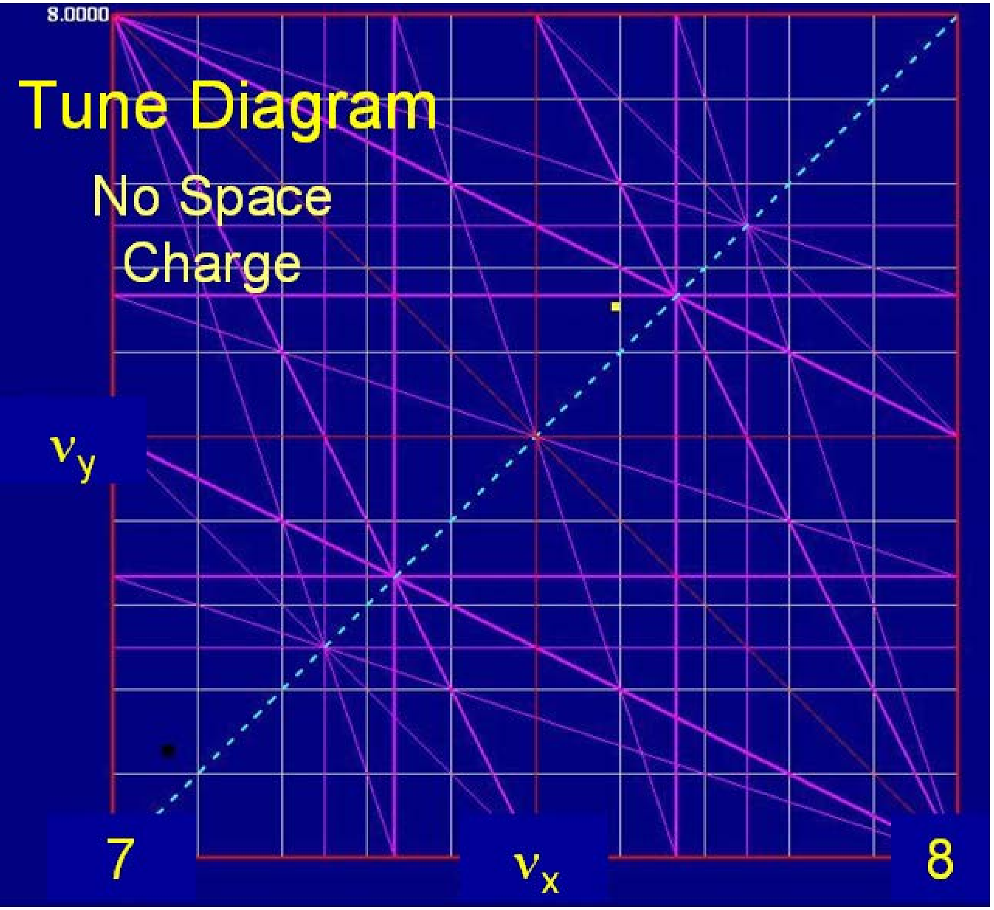

Credits: Santiago Bernal, output of WinAgile code

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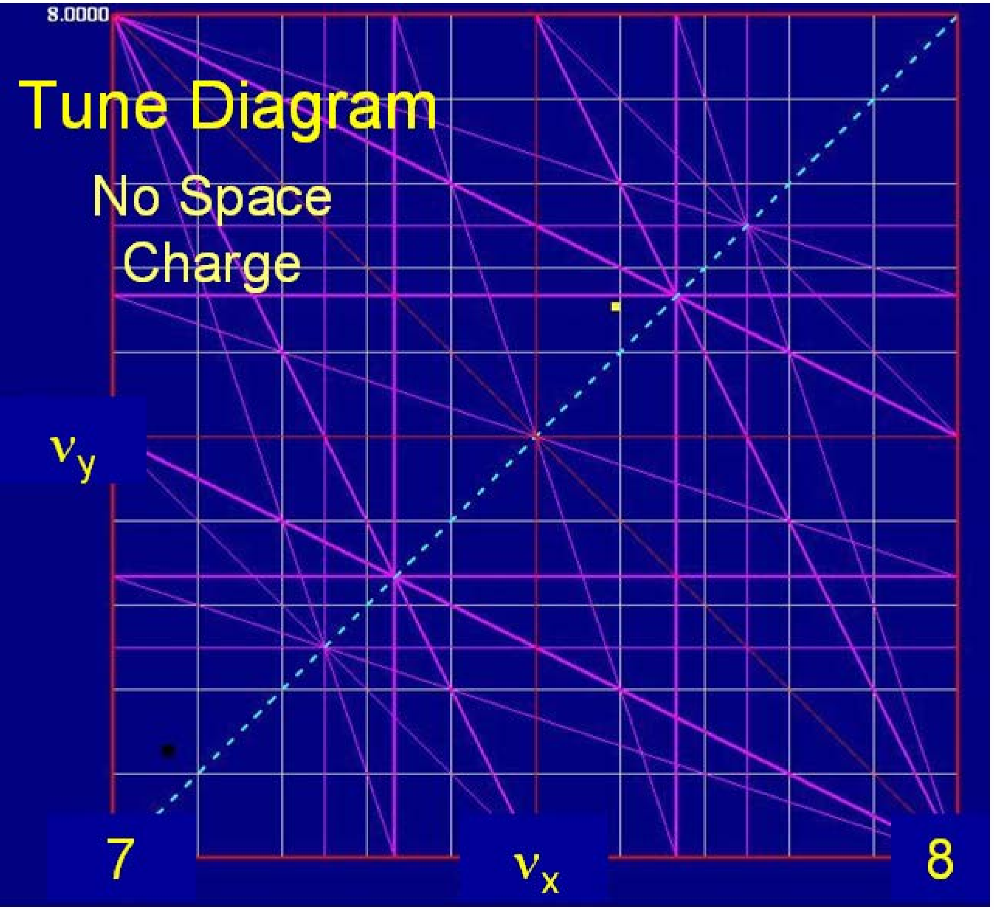

Jackson Laslett: Tune shift limit $\Delta\nu < 0.25$

$$\Delta\nu = \nu_o - \nu = \nu_o\left(1 - \frac{\nu}{\nu_o}\right) = \nu_o\left(1 - \sqrt{1-\chi}\right) \approx \nu_o\frac{\chi}{2}$$

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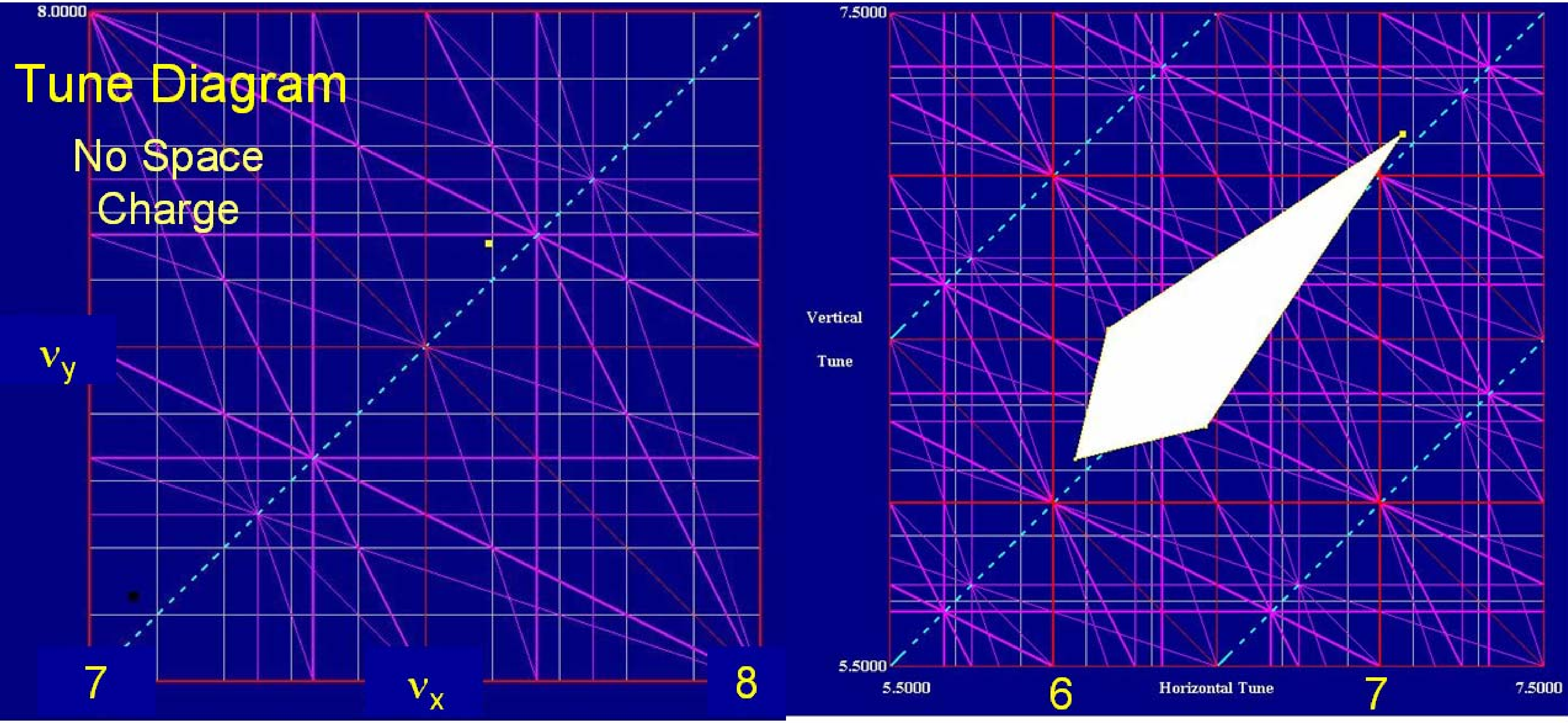

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Credits: Santiago Bernal, output of WinAgile code

Cheating Laslett – is it possible?

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Cheating Laslett – is it possible?

- Experiment: Rapid bunching at AGS $\Delta\nu = 1.9$

  Danby, Gill, Keane, and Maschke, BNL-50643, 1977.

- Simulation: Resonance crossing by rapid acceleration

  Month and Weng, 12th International Accel. Conf. , p. 324 (1983)

  Hofmann and Beckert, IEEE-NS **32** (PAC 85), 2264 (1985)

- Theory: Cannot simply replace ν_o by ν

  Baartman, (New York: AIP Press, no. 448, 1998), p. 56.

  *M. Venturini and R. Gluckstern, Phys. Rev. ST-AB, **3**, 034203 (2000).*

  Fedotov,

  Franchetti,

  Hofmann,

  Holmes,

  Machida,

  ...

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Cannot Simply Extrapolate

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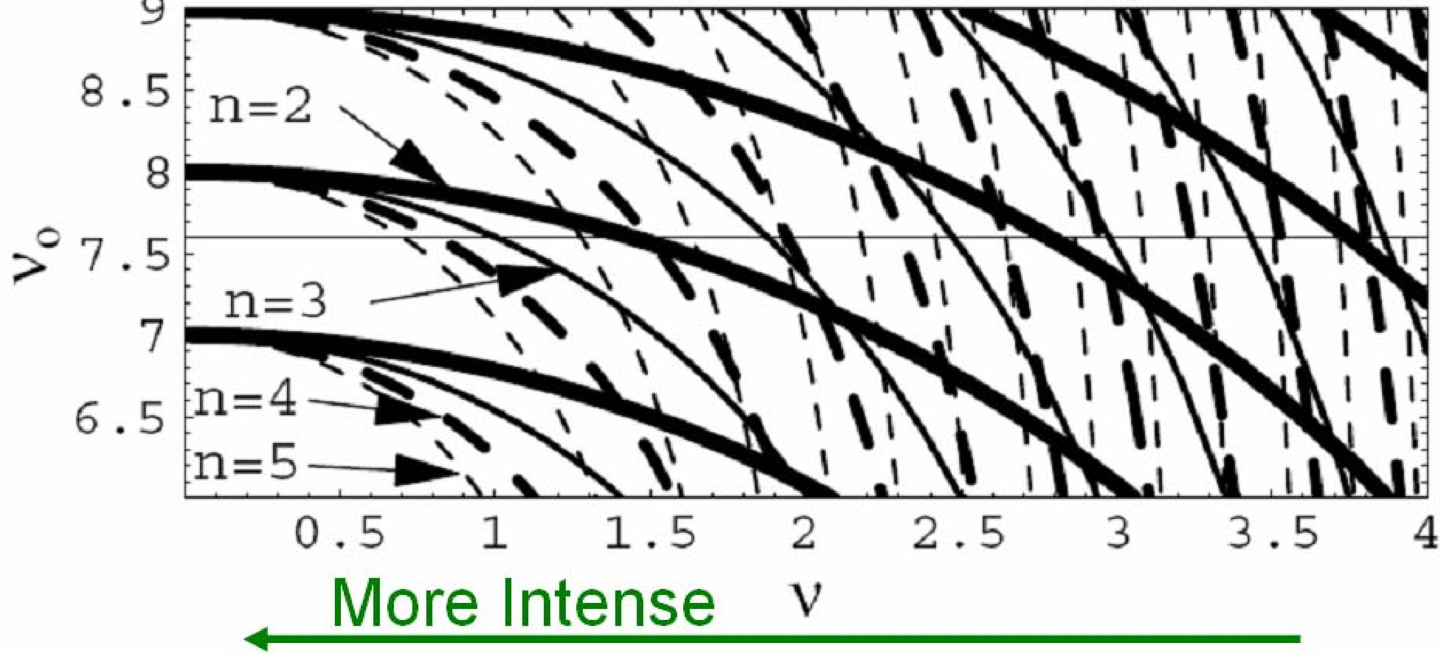
Cannot Simply Extrapolate

Venturini & Gluckstern: Resonances spaced further apart



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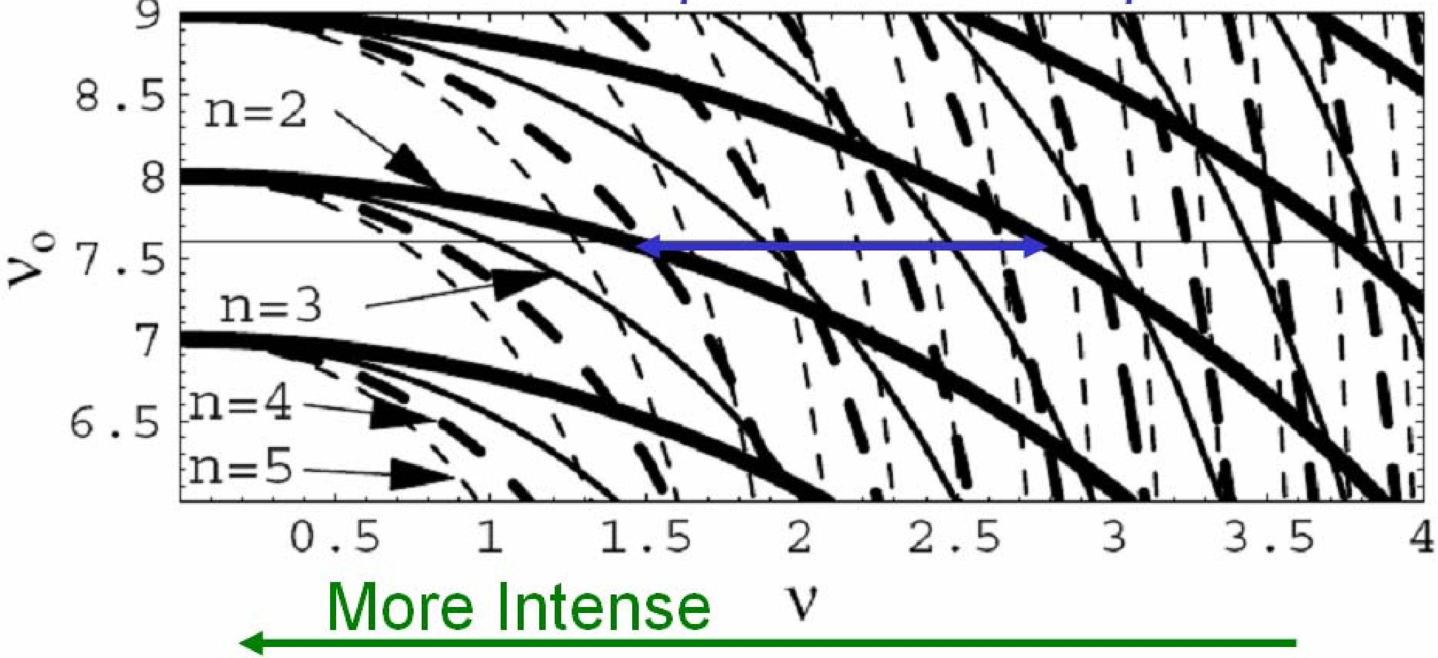


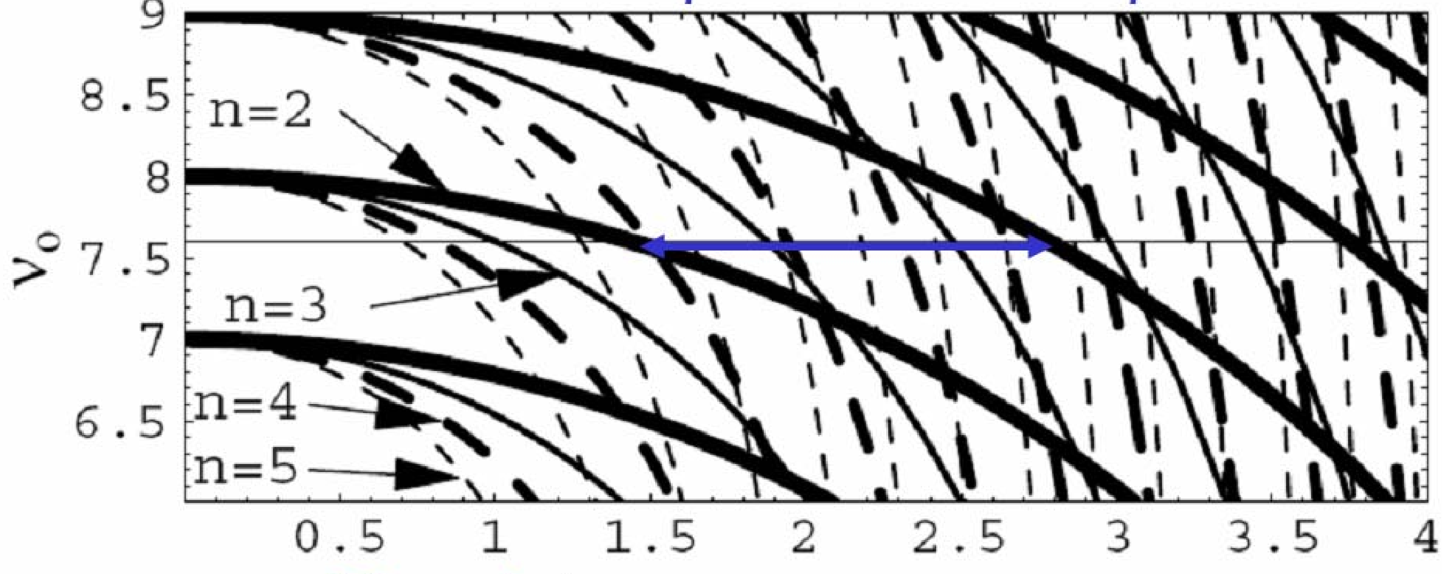
Hofmann:

Resonances broaden at higher intensities

*Hofmann, et al., PRSTAB, **6**, 024202 (2003).*

Cannot Simply Extrapolate

Venturini & Gluckstern: Resonances spaced further apart

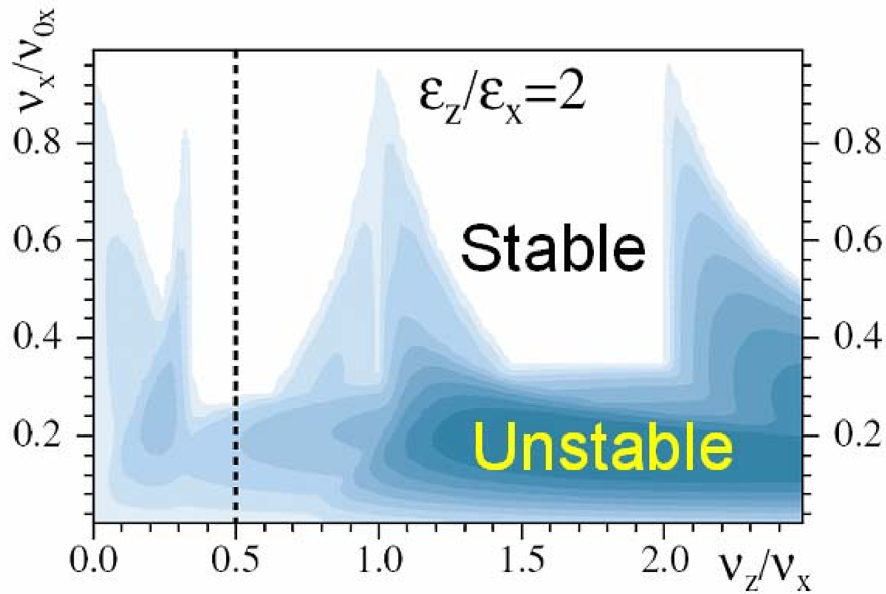


More Intense

Hofmann:

Resonances broaden at higher intensities

Hofmann, et al., PRSTAB, **6**, 024202 (2003).



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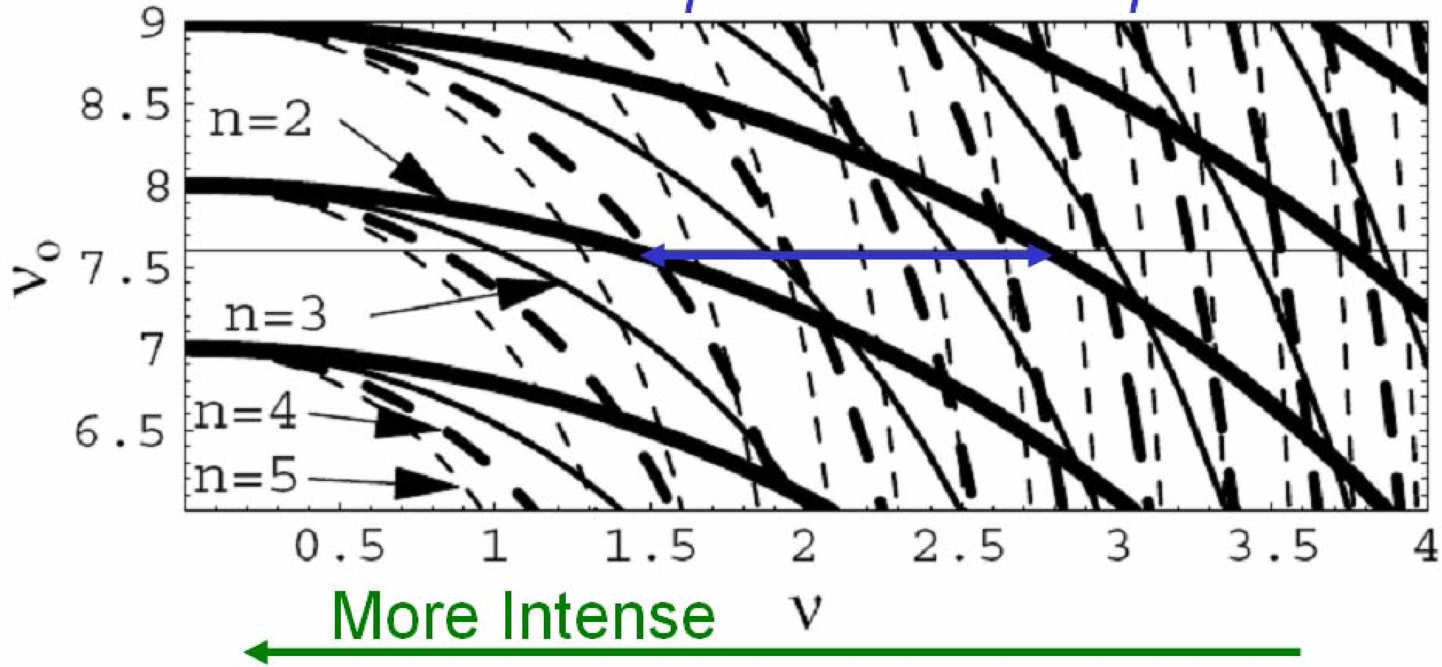

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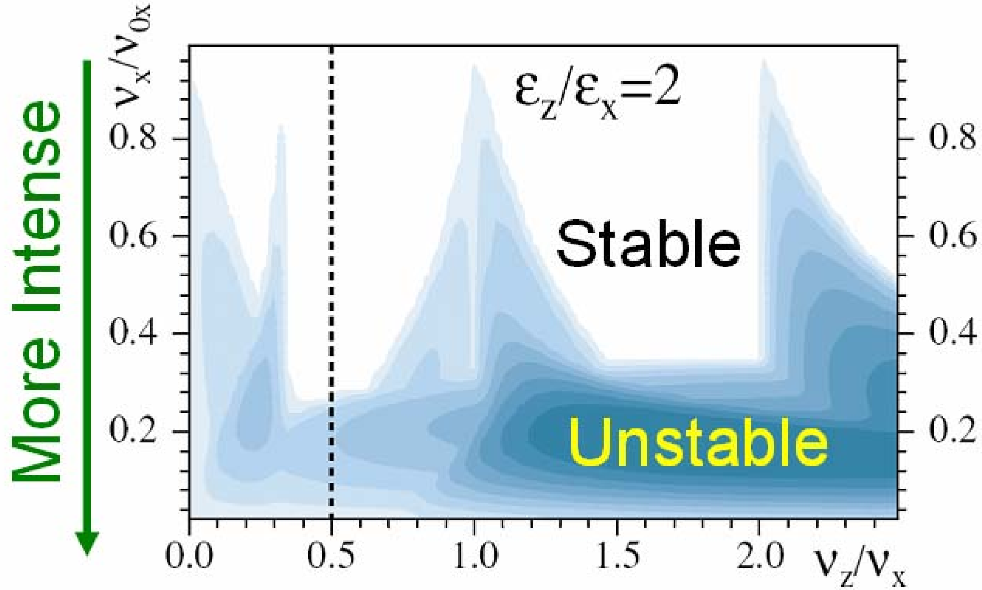

Importance of the Particle Distribution

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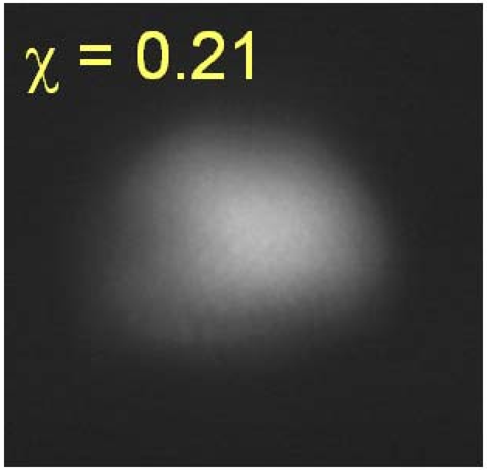
Importance of the Particle Distribution

Emittance-dominated:

Resonances property of
lattice

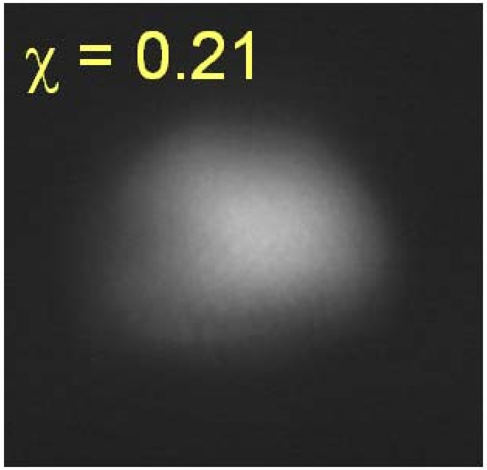
Intense beams have more complex distributions

Intense beams have more complex distributions

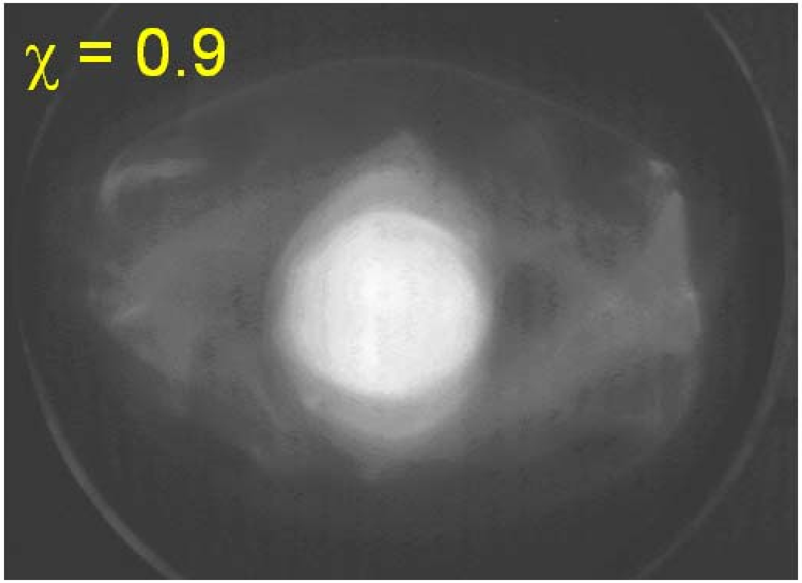


Emittance-
Dominated

Intense beams have more complex distributions

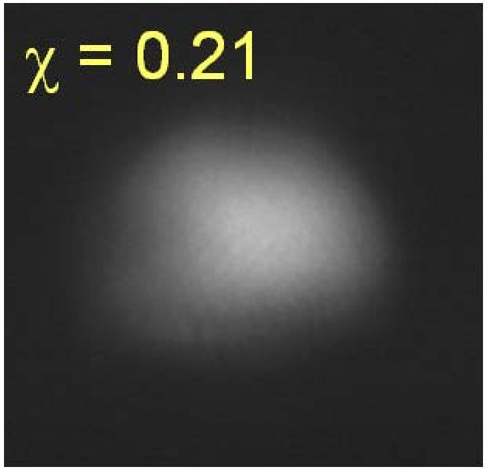


Emittance-
Dominated

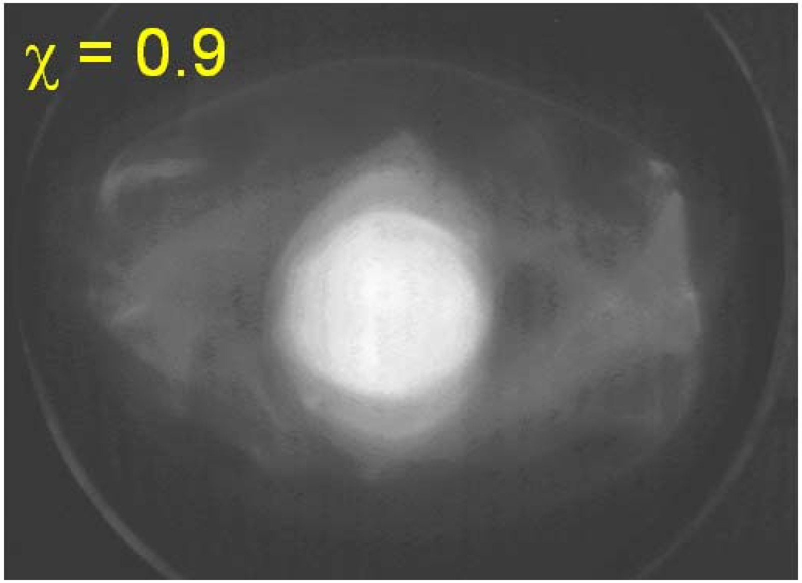


Space-Charge-Dominated

Intense beams have more complex distributions



Emittance-Dominated



Space-Charge-Dominated

Nebula

What do we Need to Understand?

What do we Need to Understand?

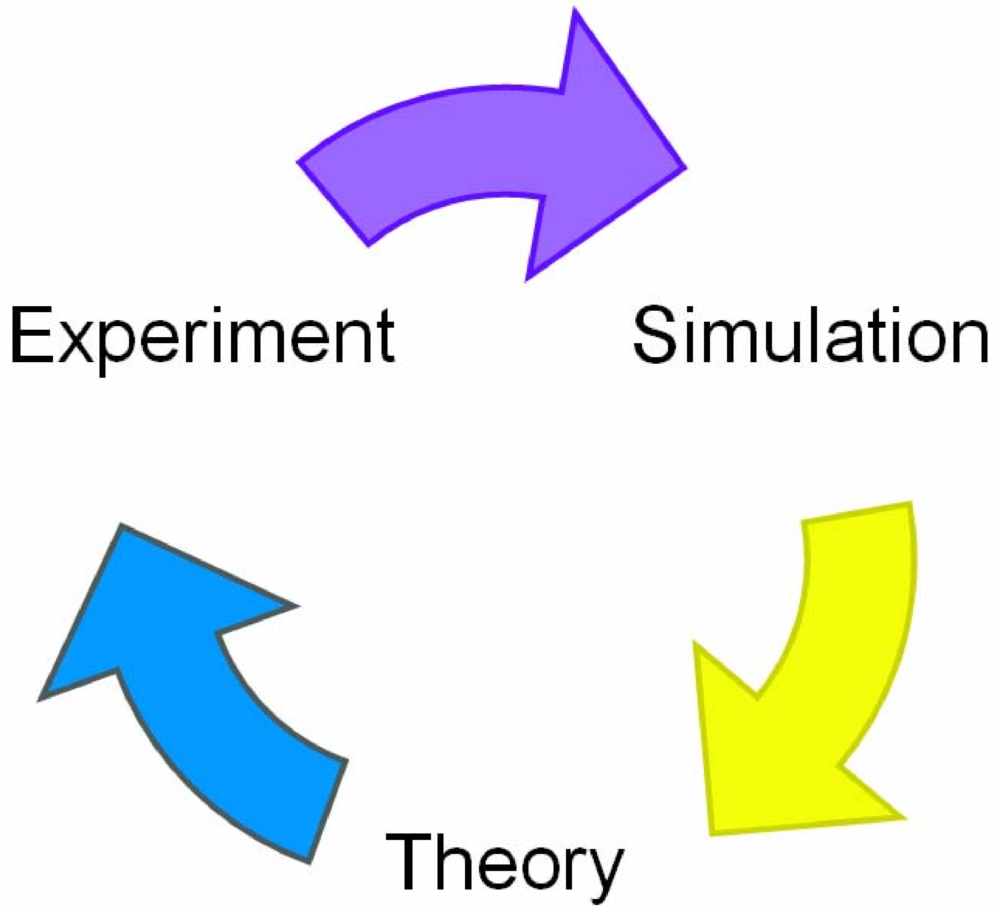
Effects

- Emittance Growth / Energy Spread
- Halo formation and evolution
- Stability

Possible Causes

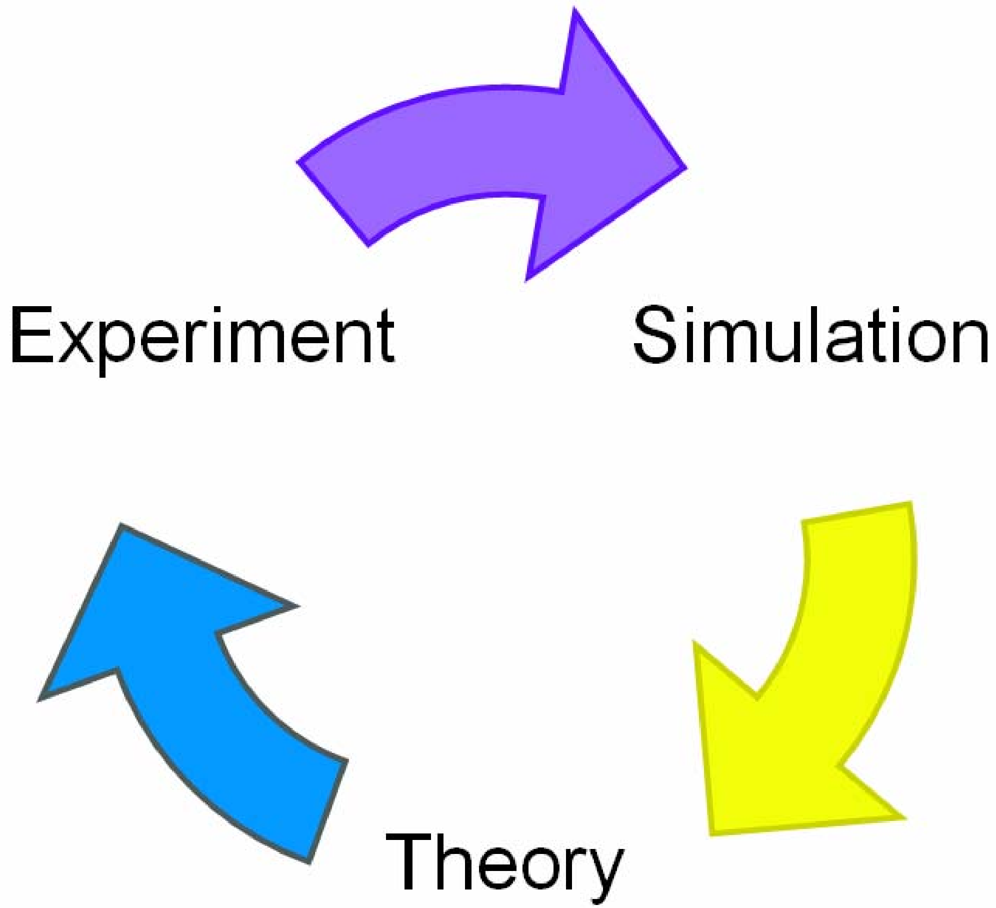
- Density or energy modulations
- Anisotropy
- Machine Errors and Control
- Resonances

The UMER Concept



The UMER Concept

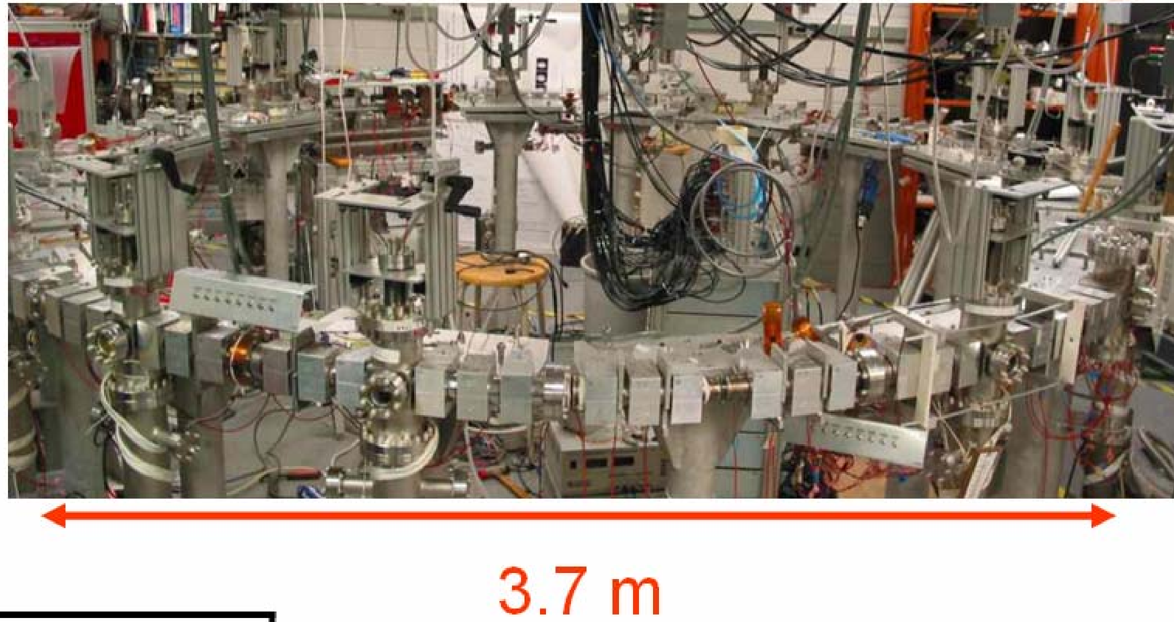
Martin Reiser: *"Let there be a ring"*
(with extreme tune shifts)



 M. Reiser, Fusion Engineering & Design ***32-33****, 293 (1996).*

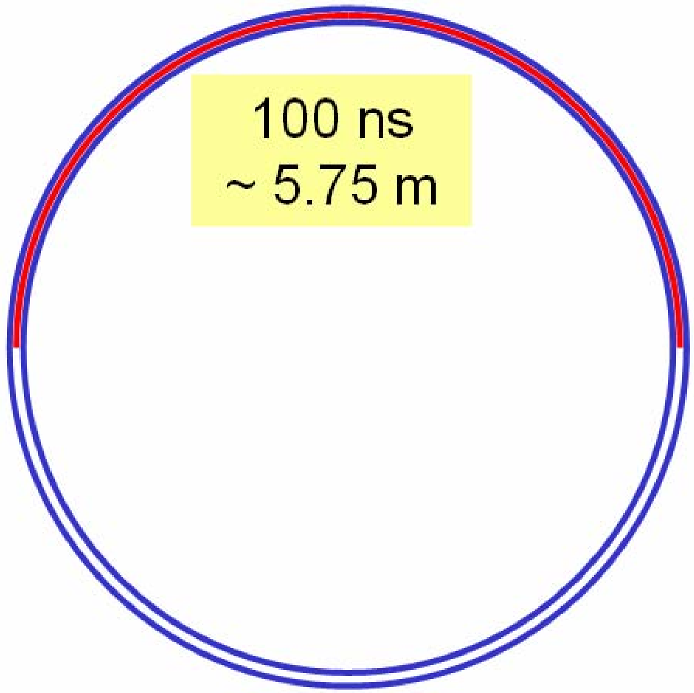
The University of Maryland Electron Ring

<u>UMER Mission</u>:
Use 10 keV electrons to inexpensively model space charge effects, i.e., to probe unknown territory



Energy	10 keV ± 0.2 %
Current Range	0.6-100 mA
rms Emittance ($_n$)	0.2-3 μm

Circulation time	200 ns
Pulse length	5-100 ns
Nominal Tune	7.6
Depressed Tune	1.5 – 6.5



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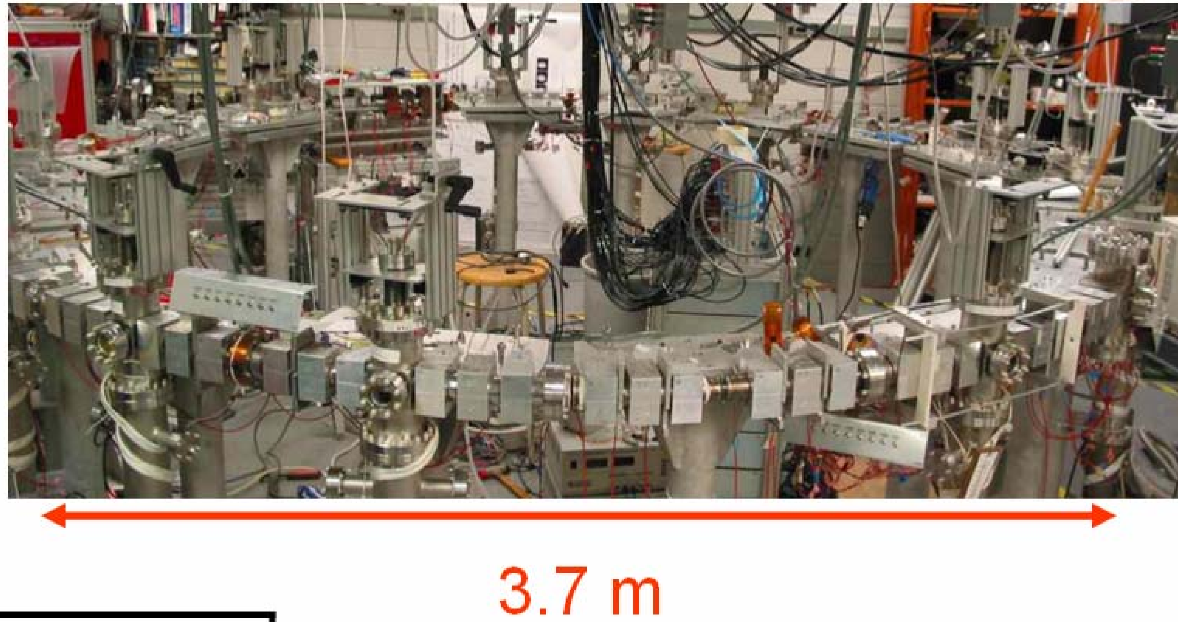

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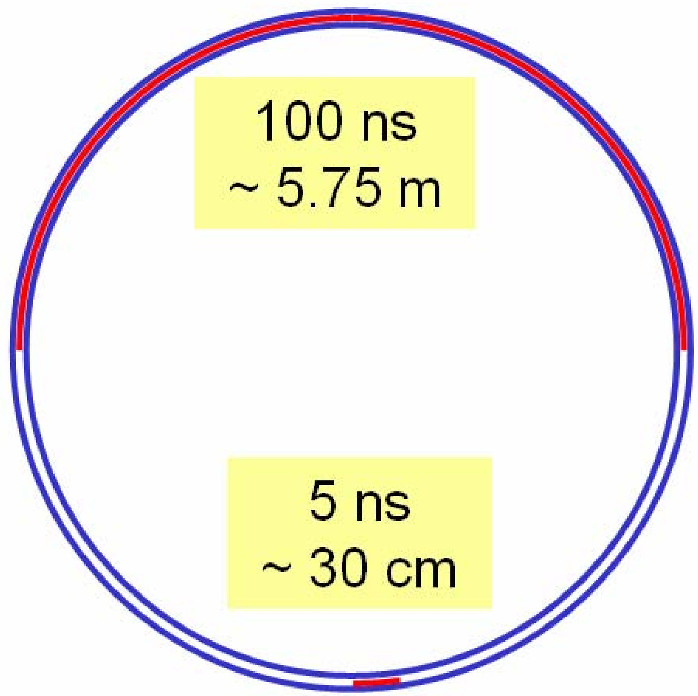

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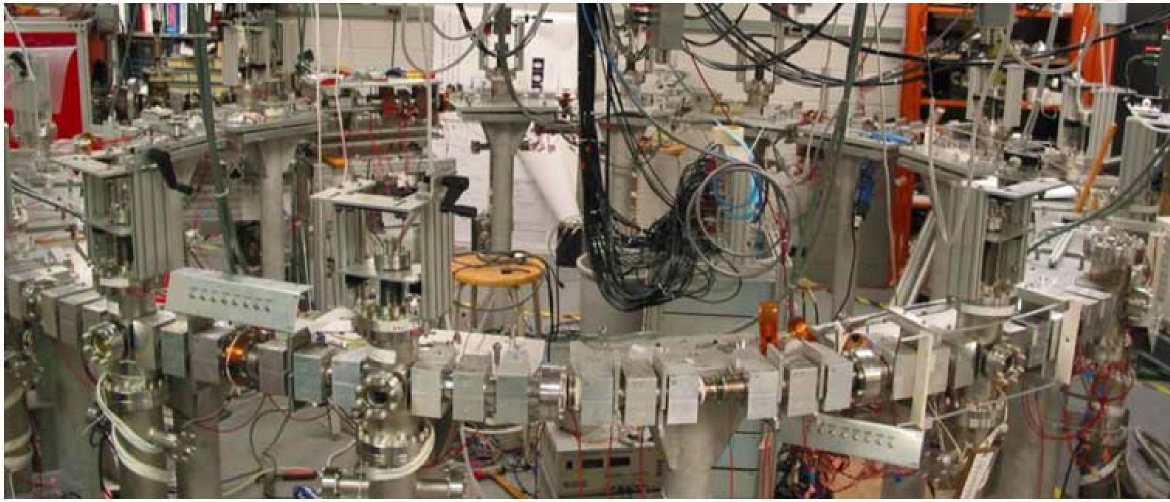

3.7 m

Energy	10 keV ± 0.2 %
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Circulation time	200 ns
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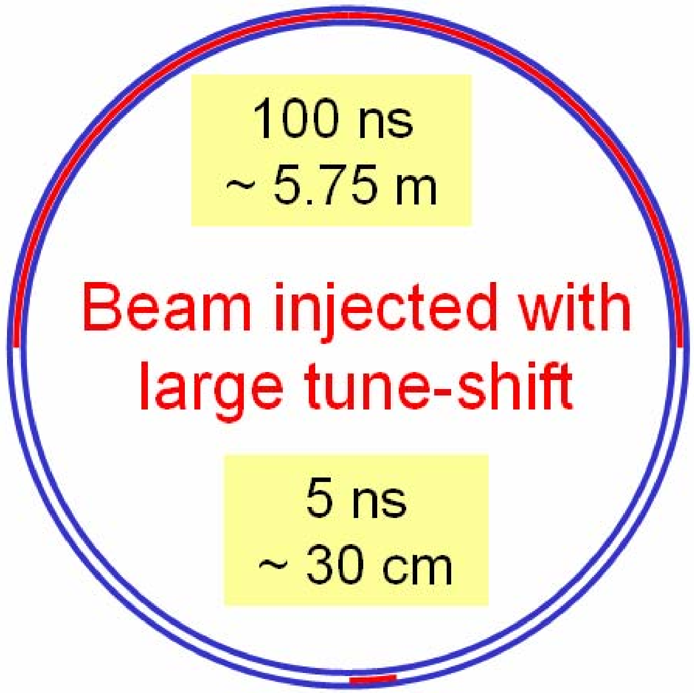

Design Goal

- Lowest-Current (1 mA): 100 Turns
- High-Current (100 mA): 10 Turns

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Low-Current Operation Exceeds Design Goal

$\chi = 0.37$

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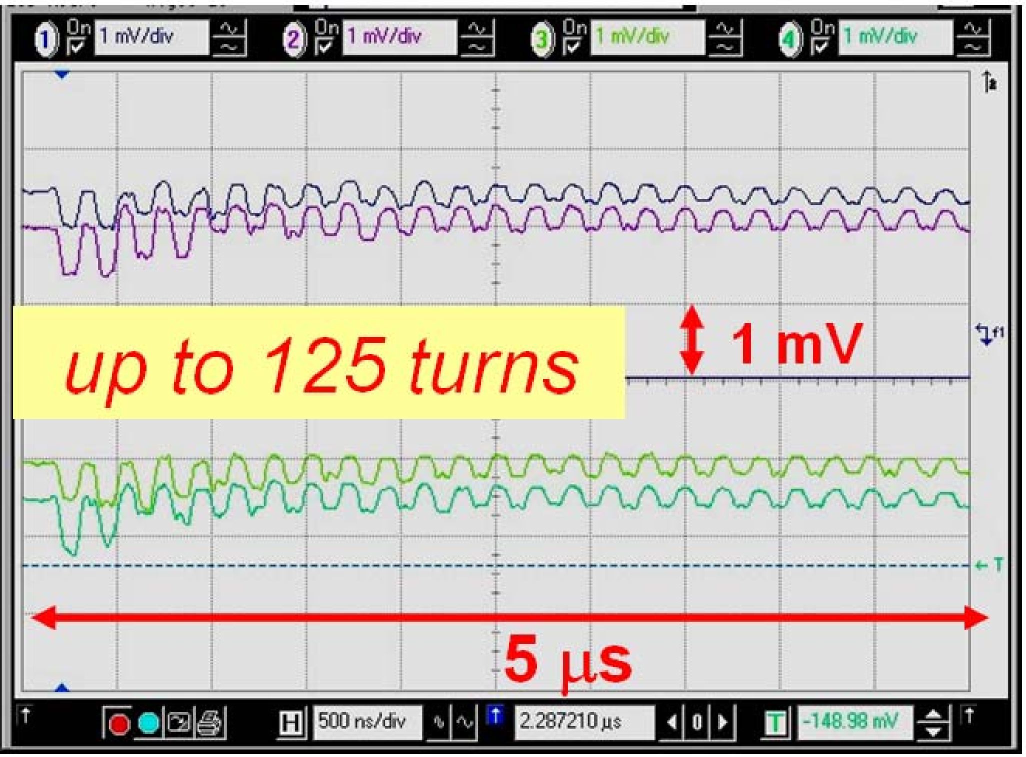
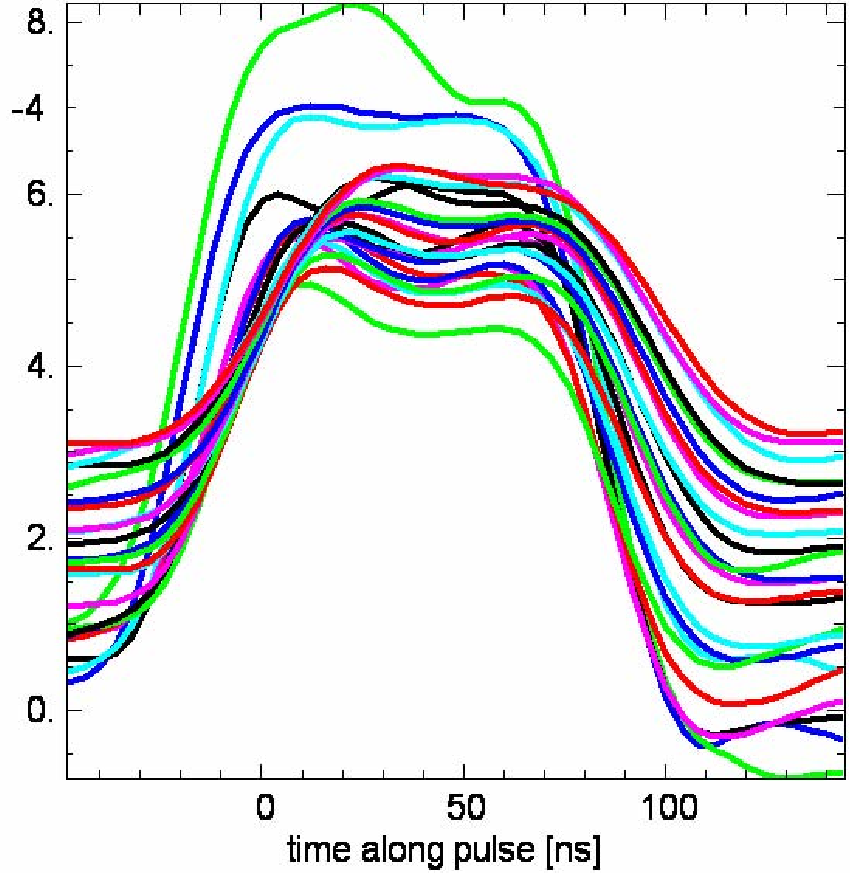
Low-Current Operation Exceeds Design Goal

$\chi = 0.37$

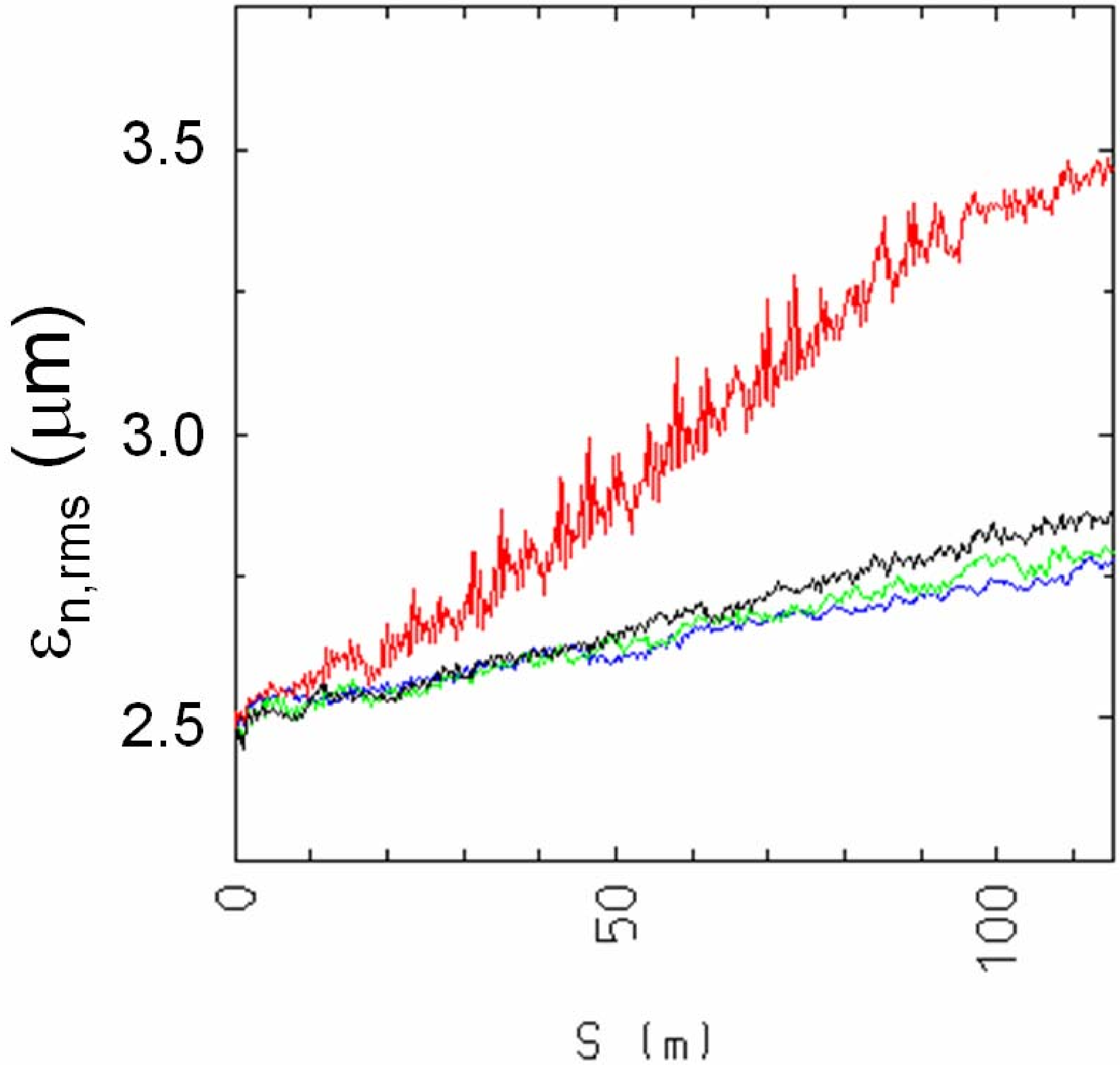
Tune Shift

Injected	1.5
After 25 turns	0.7 - 1.0





Design Simulations Show UMER Works

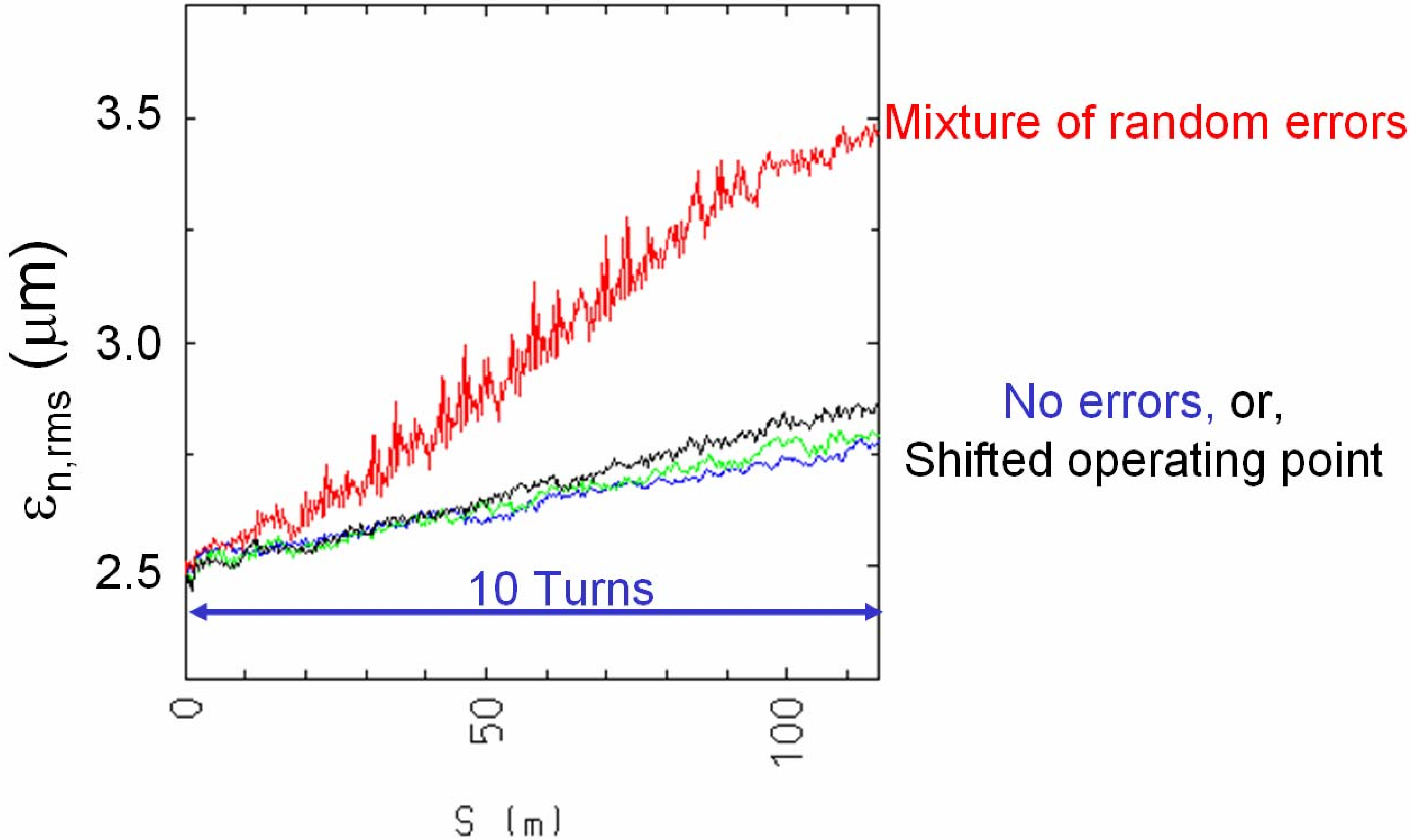


Mixture of random errors

No errors, or,
Shifted operating point

R. Kishek, et al., NIM-A **464**, 484-492 (2001).

Design Simulations Show UMER Works



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Experiment Complex: Many Lessons Learned

Issue: Sensitivity to Ambient Field (e.g., Earth B-Field)

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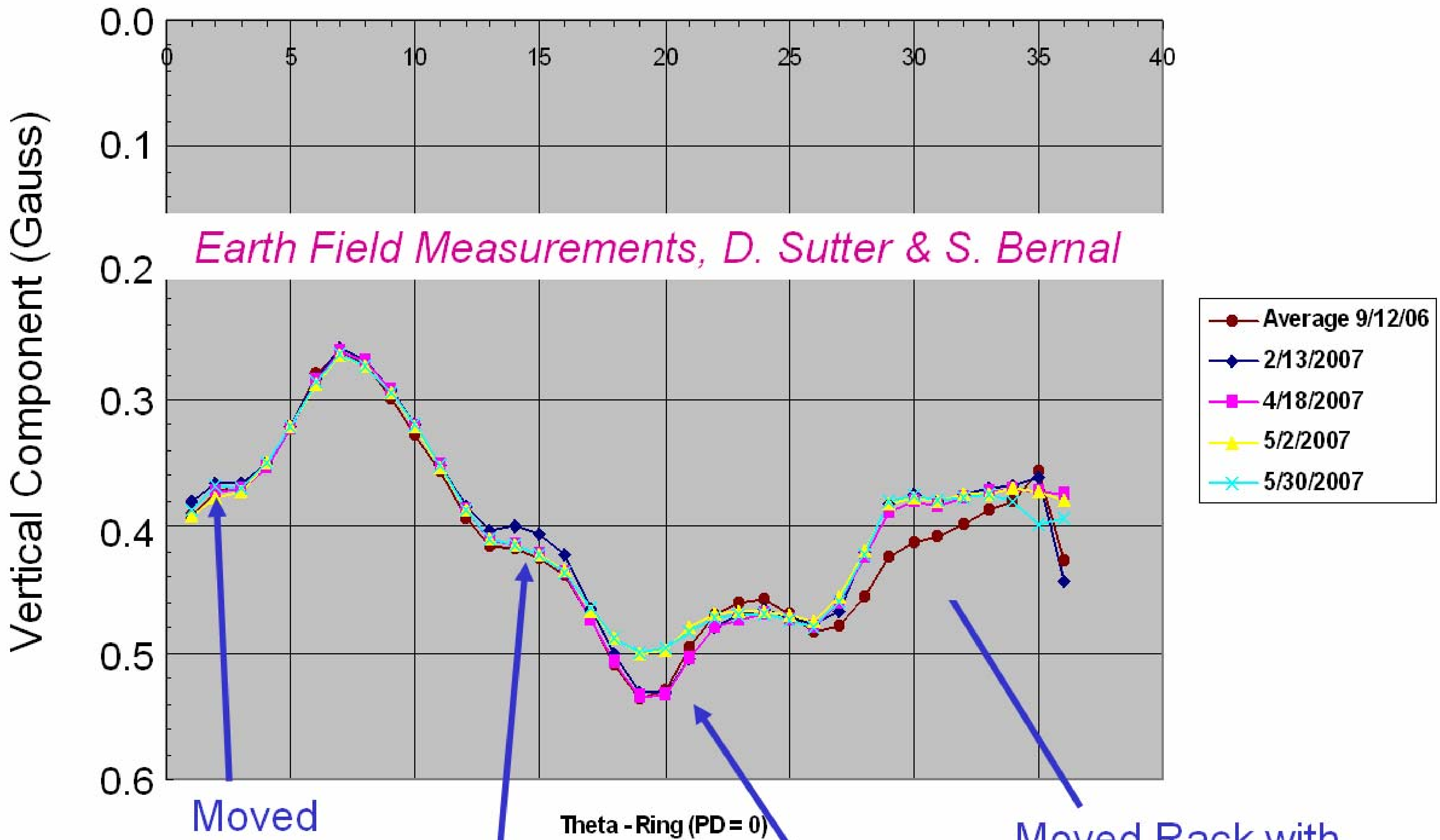

Moved Scope Cart

Moving Optical Table

Moved Rack with Imaging Computer

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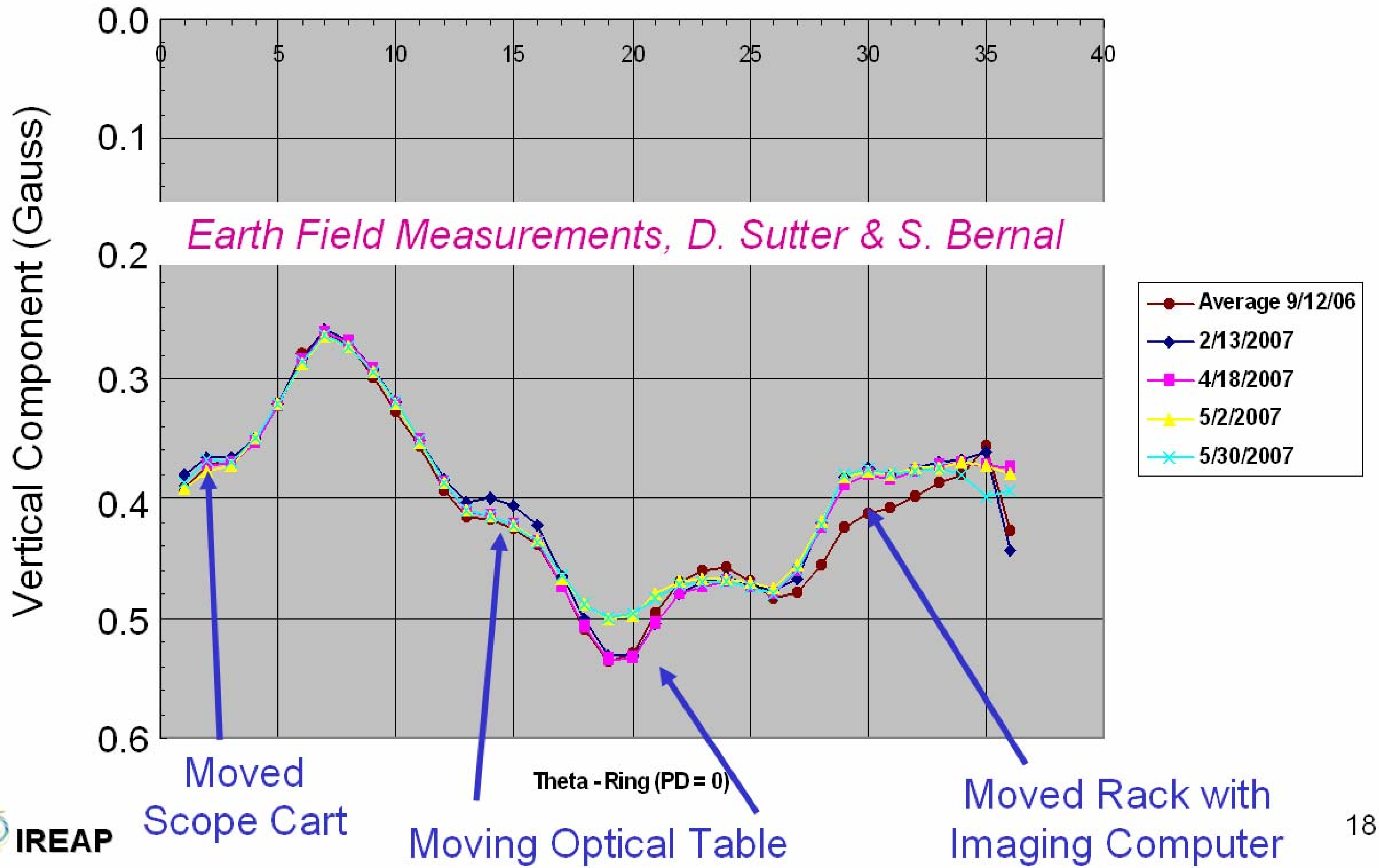
Experiment Complex: Many Lessons Learned

Issue: Sensitivity to Ambient Field (e.g., Earth B-Field)



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Space Charge Requires Dense Lattice

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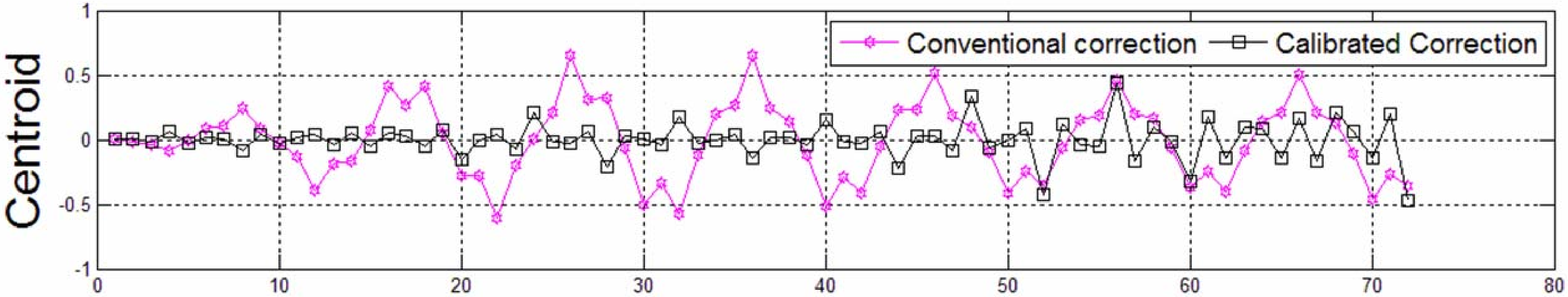
Issue: Little room for diagnostics

Solution: Systematized quad-scan technique

Hui Li
Mark Walter, TUPAS047
Chao Wu, MOPAS033



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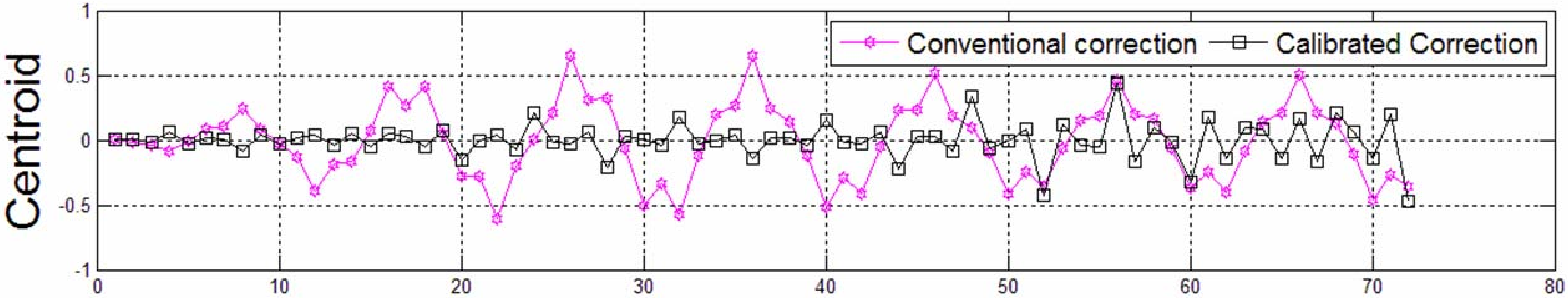


Alternative: Operate at longer betatron wavelengths

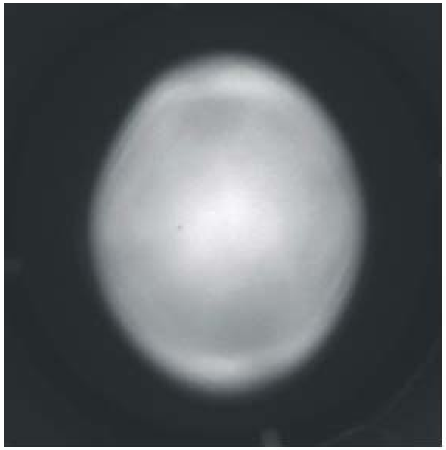
Santiago Bernal, THPAS030

Halo can be created at source

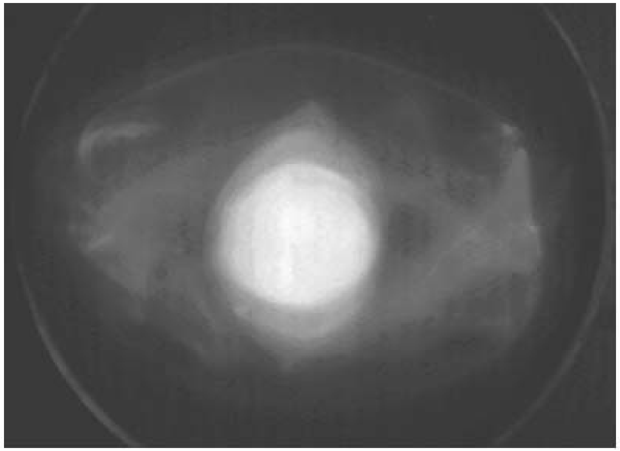
Halo can be created at source

Issue: Halo very sensitive to cathode placement

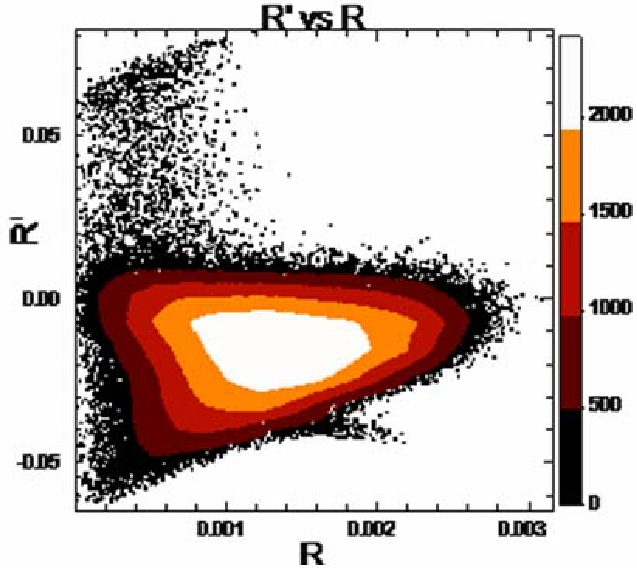
Irv Haber, THPAS031



2001



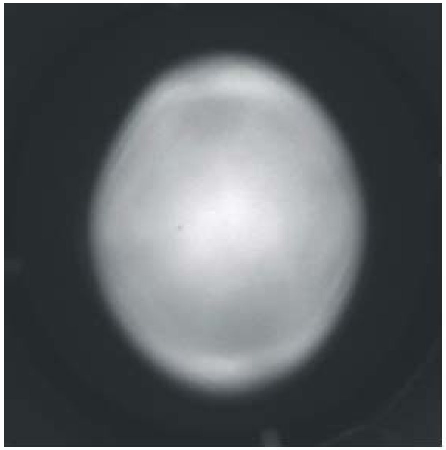
2006



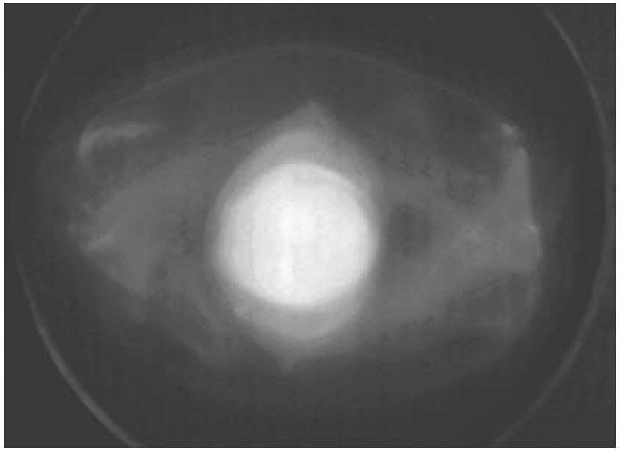
Halo can be created at source

Issue: Halo very sensitive to cathode placement

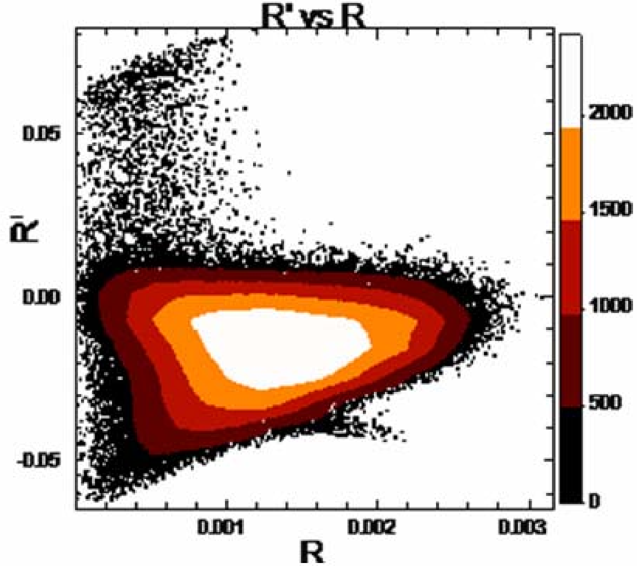
Irv Haber, THPAS031



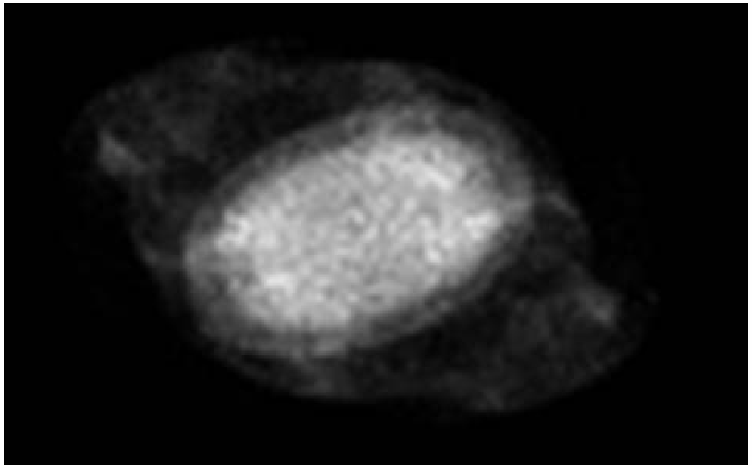
2001



2006



Incorporate more realistic initial distribution into codes



Christos Papadopoulos, THPAS032

WARP Simulation

IREAP

High-Current Operation

Tune Scan Results

Inject Same Beam: 5 mA, 10 keV, 60 ns

Nominal Tune: $\nu_o = 76.0°$

Tune Scan Results

Inject Same Beam: 5 mA, 10 keV, 60 ns

Nominal Tune: $\nu_o = 76.0°$

$\nu_o \sim 71.5°$

$\nu_o \sim 70.8°$

Importance of Beam Distribution (Reprise)

Importance of Beam Distribution (Reprise)

Detailed Phase Space Measurement

- Time-resolved Energy Analyzer
- Tomography (transverse)
- Fast Imaging

Ability to manipulate distribution

- electronics
- laser photoemission
- induction modules

Examples of Phase Space Measurement

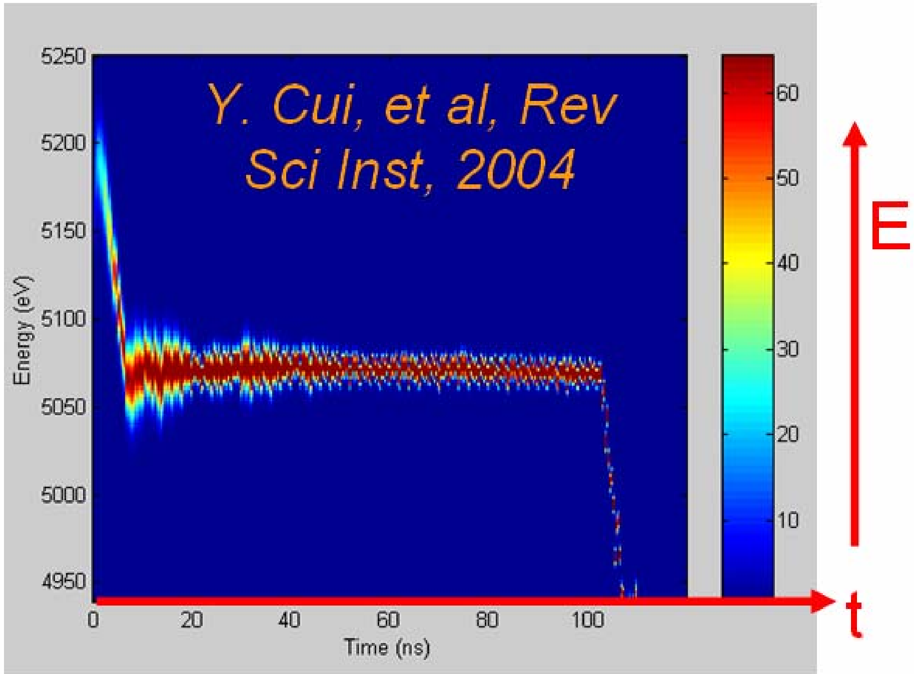
IREAP

Examples of Phase Space Measurement

Compact Energy Analyzer

High resolution:

- 10^{-4} energy
- 1 mm spatial
- few ns time

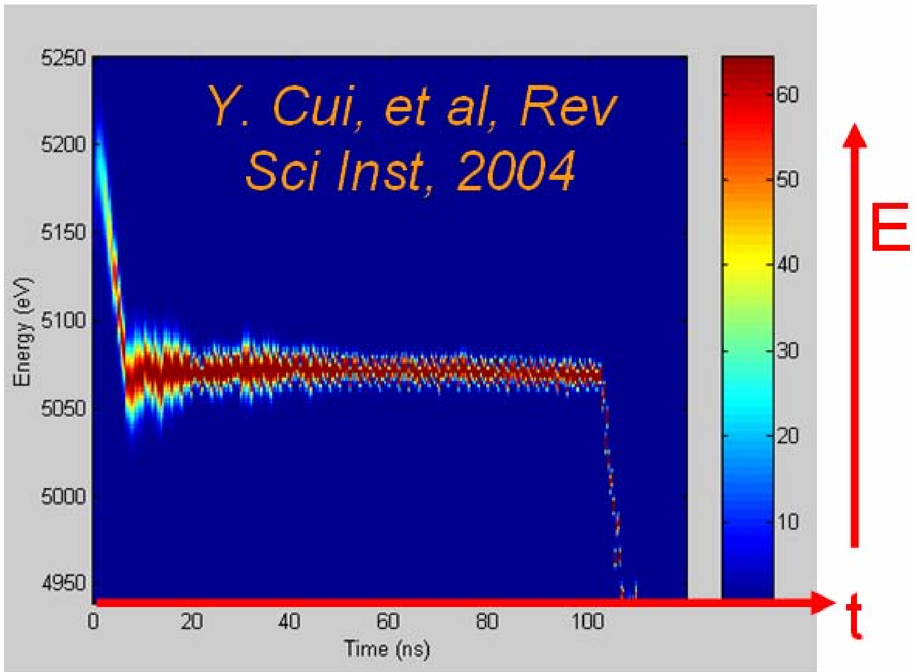


Examples of Phase Space Measurement

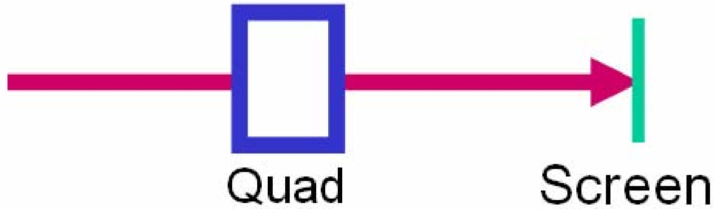
Compact Energy Analyzer

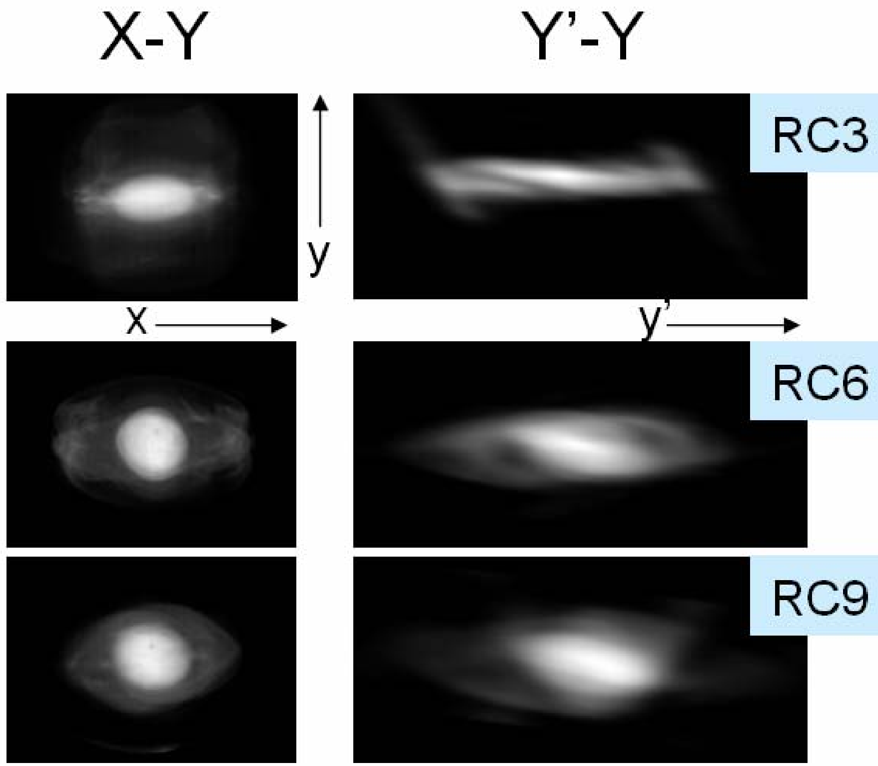
High resolution:

- 10^{-4} energy
- 1 mm spatial
- few ns time



High-Fidelity Tomography

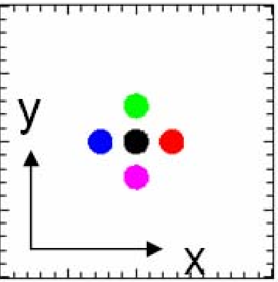




Diktys Stratakis, Invited Talk, WEZC01
2 PM Tomorrow (Room C)

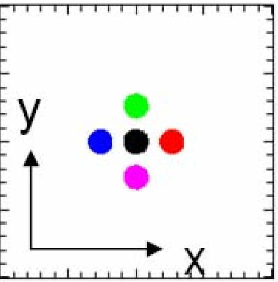
IREAP

Predictive Power of Simulation



Initial distribution

Predictive Power of Simulation

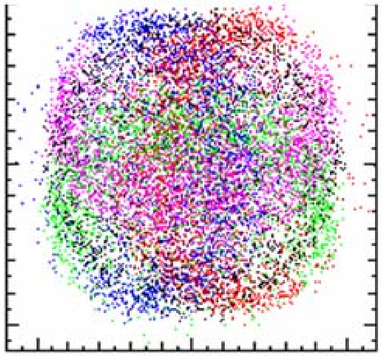


Initial distribution

Simulation Prediction

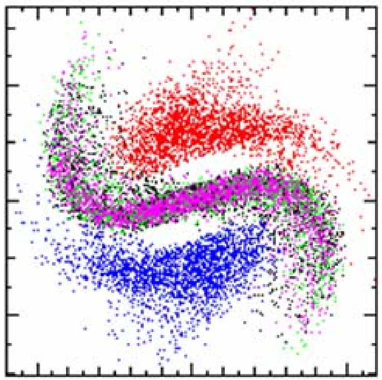
Downstream

X-Y

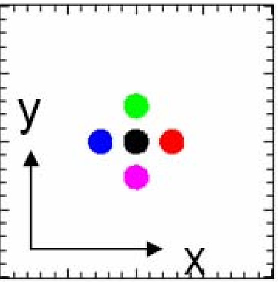


R. Kishek, AAC 2002
Uniform Focusing

X-X'



Predictive Power of Simulation



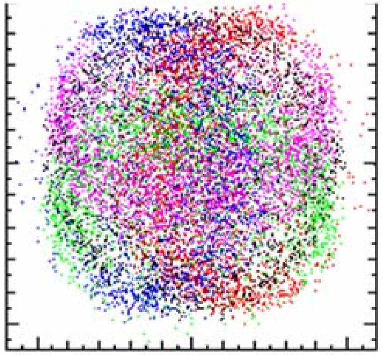
Initial distribution

Homogenization of beam is different in configuration and phase space

Simulation Prediction

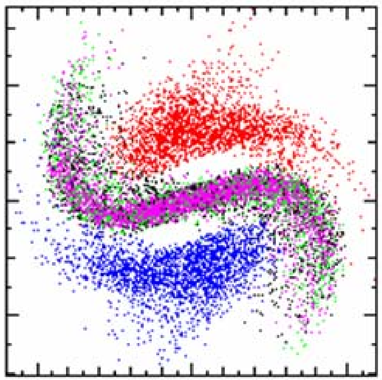
Downstream

X-Y



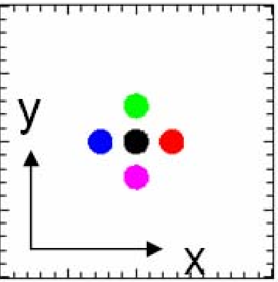
R. Kishek, AAC 2002
Uniform Focusing

X-X'



Predictive Power of Simulation

Homogenization of beam is different in configuration and phase space



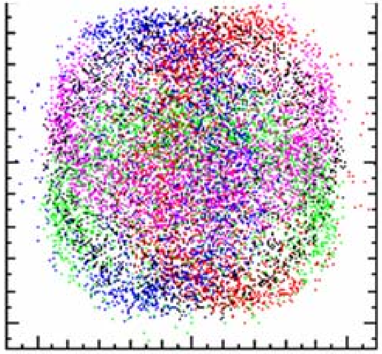
Initial distribution

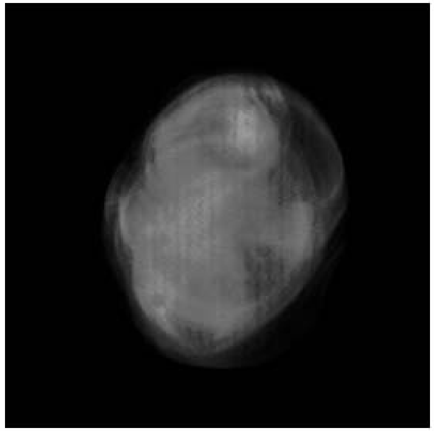
Simulation Prediction

Experiment

Downstream

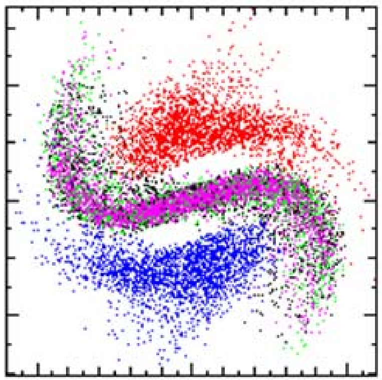
X-Y

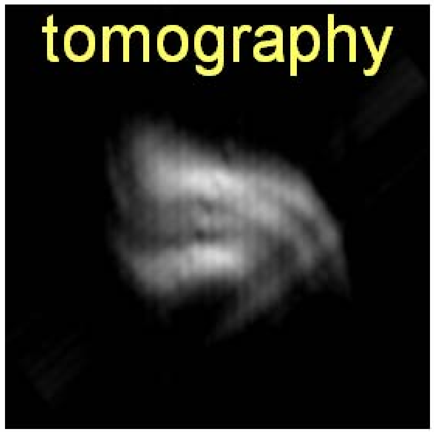




R. Kishek, AAC 2002
Uniform Focusing

X-X'





D. Stratakis, 2007

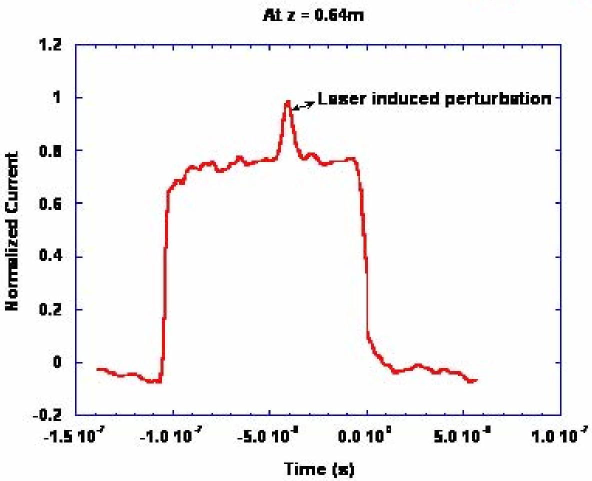
IREAP

Deliberate Manipulation of Beam Distribution

Deliberate Manipulation of Beam Distribution

Beam Current

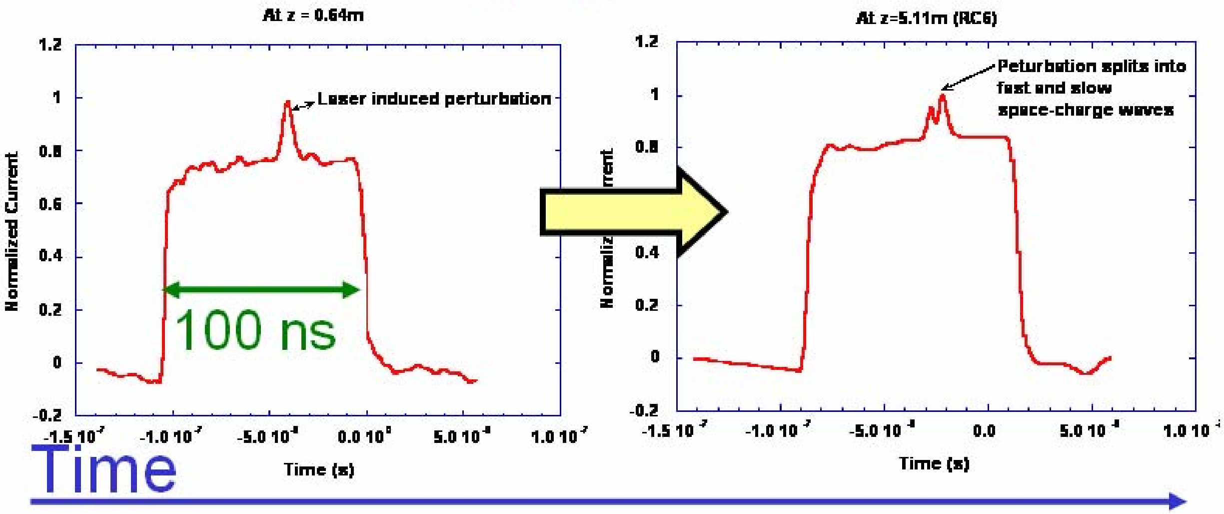
J. Charles T. Thangaraj, THPAS033



Deliberate Manipulation of Beam Distribution

Beam Current

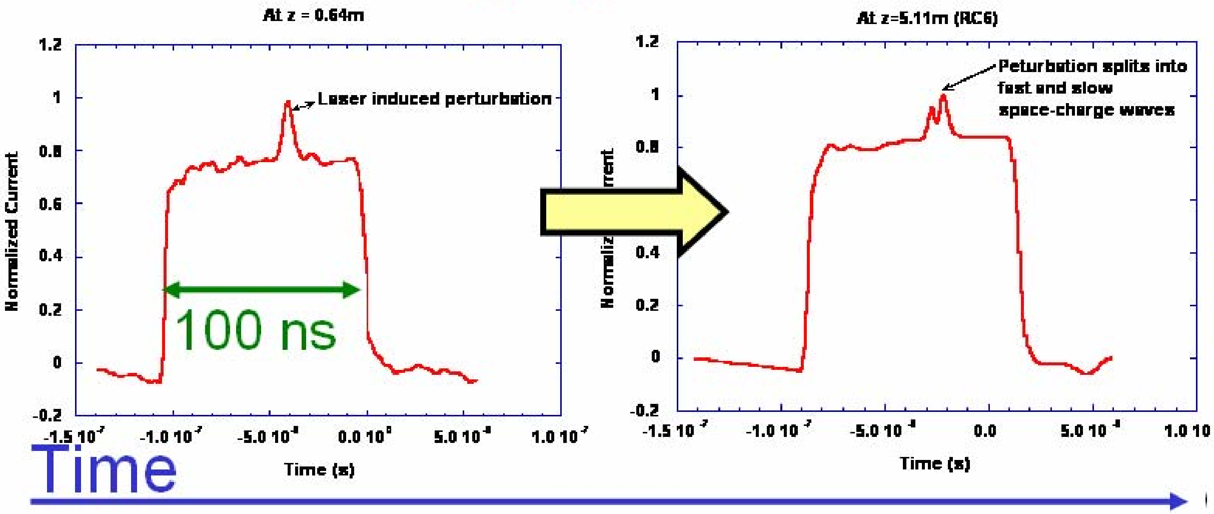
J. Charles T. Thangaraj, THPAS033



Deliberate Manipulation of Beam Distribution

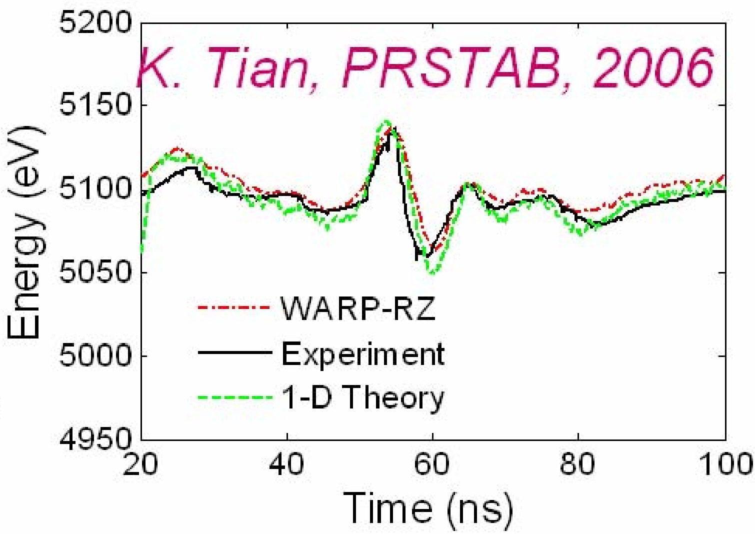
Beam Current

J. Charles T. Thangaraj, THPAS033



Average Energy

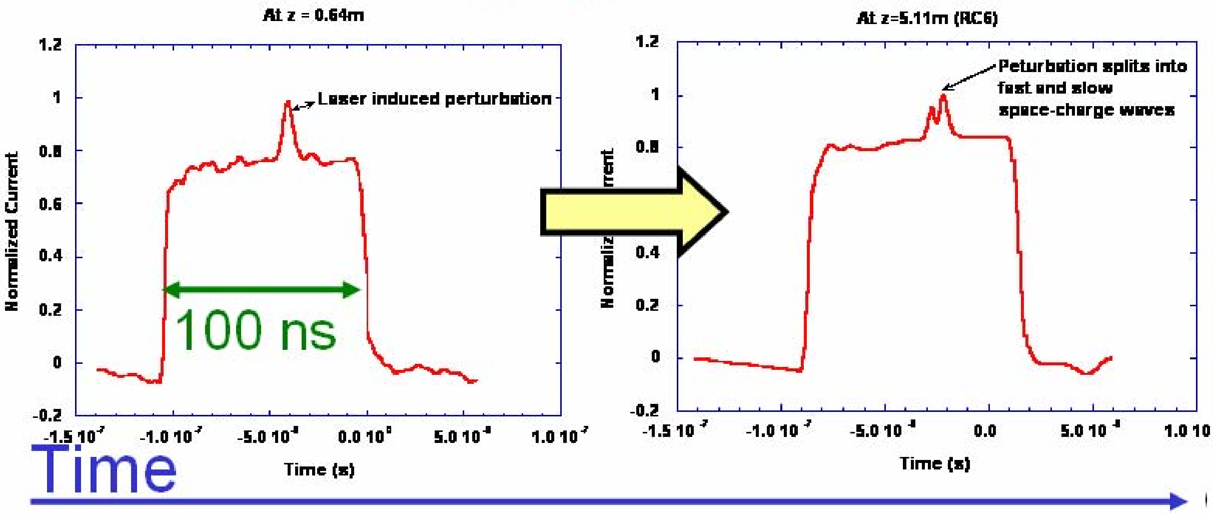
K. Tian, PRSTAB, 2006



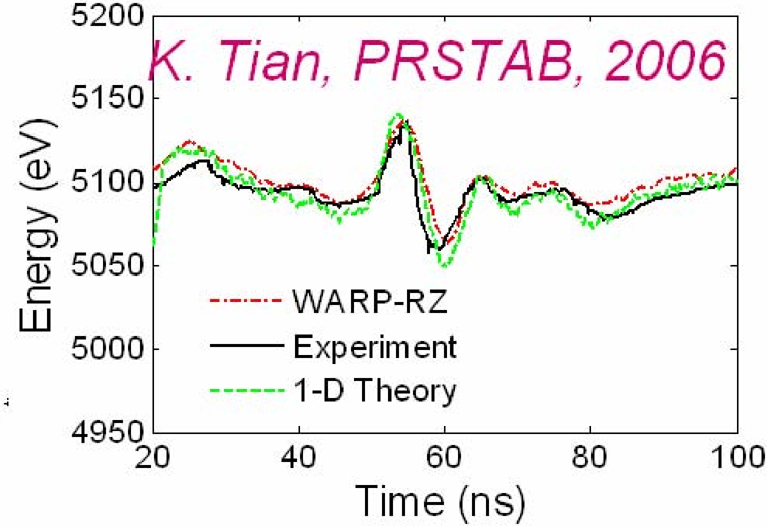
Deliberate Manipulation of Beam Distribution

Beam Current

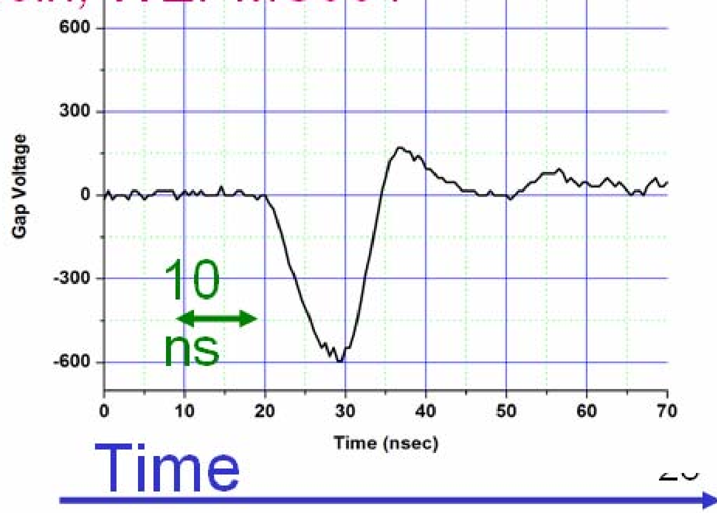
J. Charles T. Thangaraj, THPAS033



Average Energy



Brian Beaudoin, WEPMS001

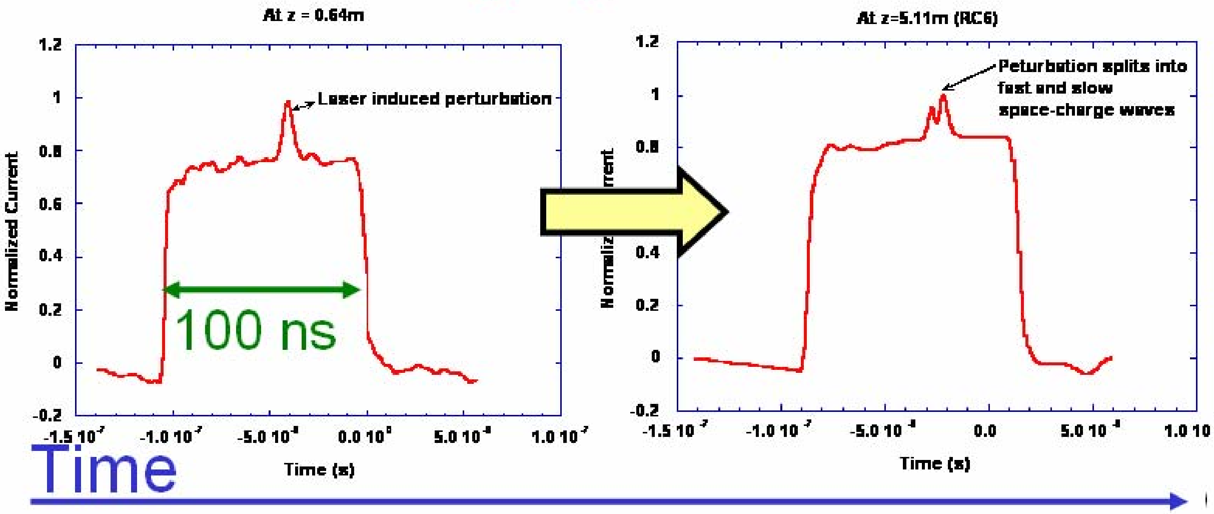


IREAP

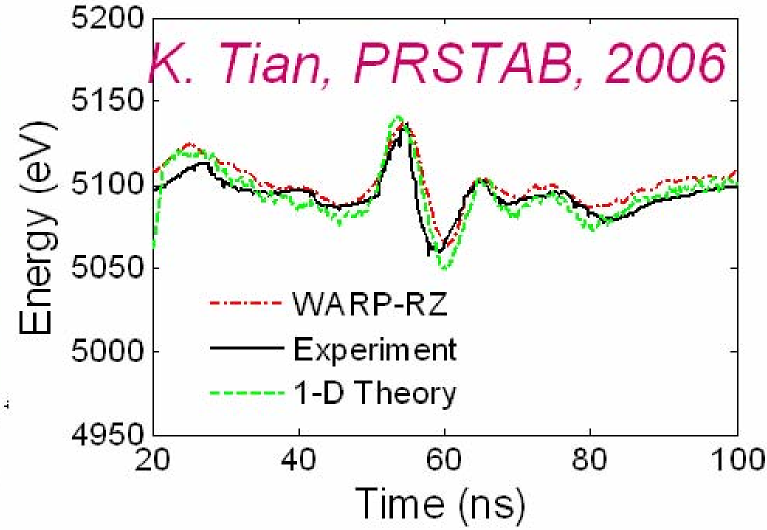
Deliberate Manipulation of Beam Distribution

Beam Current

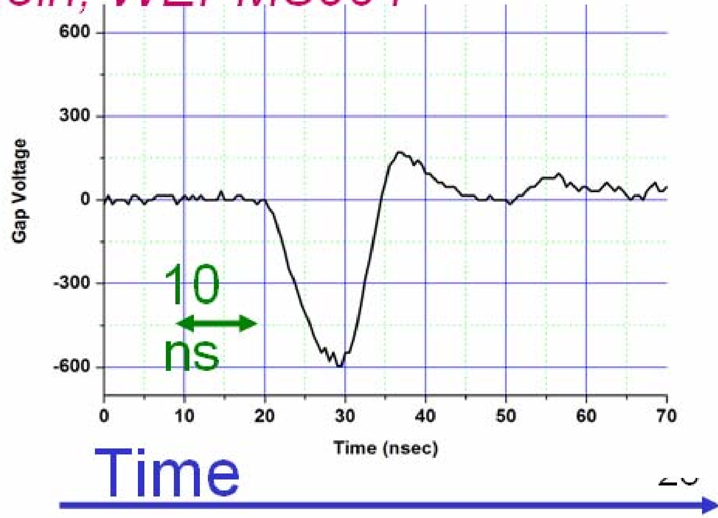
J. Charles T. Thangaraj, THPAS033



Average Energy



Brian Beaudoin, WEPMS001

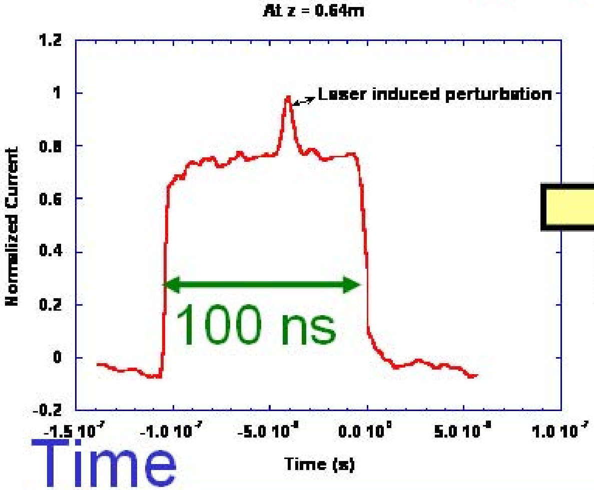


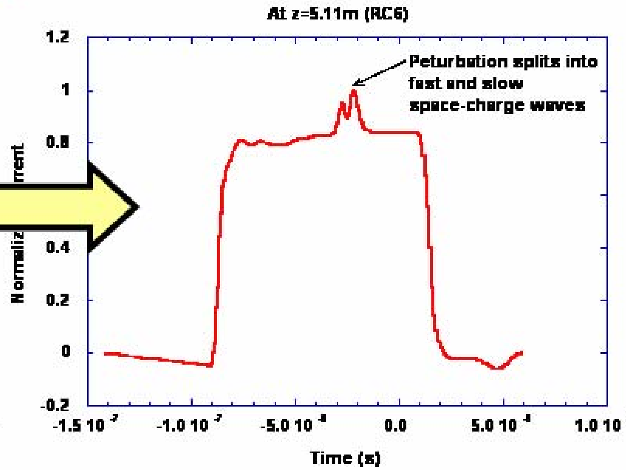
IREAP

Deliberate Manipulation of Beam Distribution

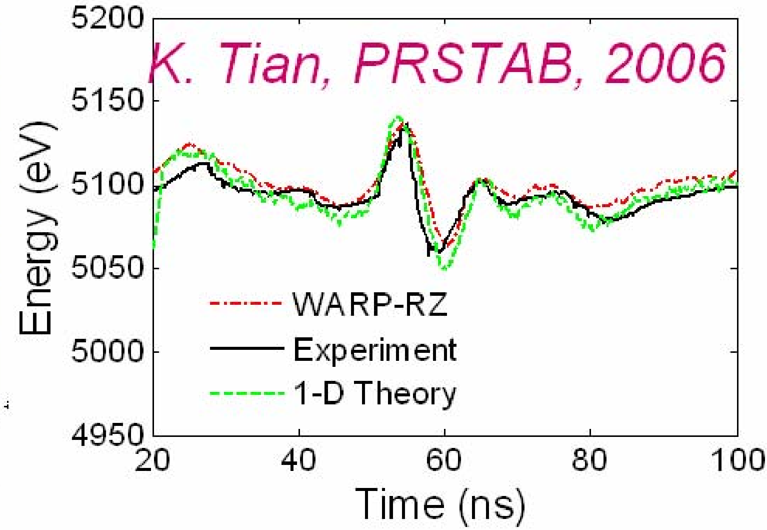
Beam Current

J. Charles T. Thangaraj, THPAS033

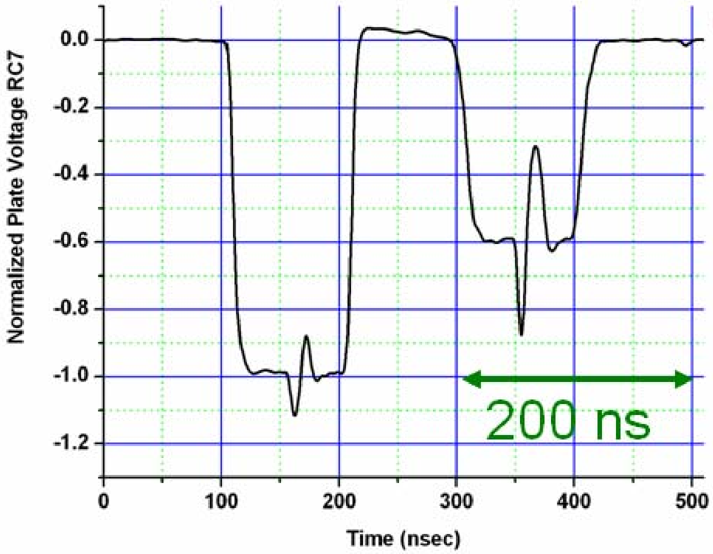


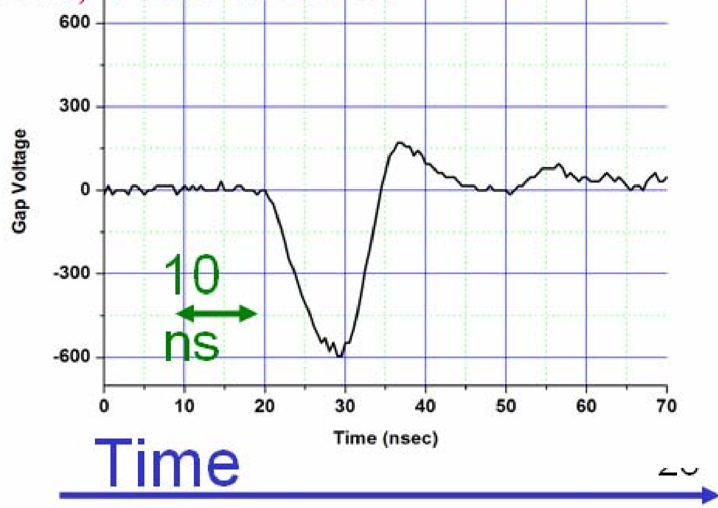


Average Energy



Brian Beaudoin, WEPMS001

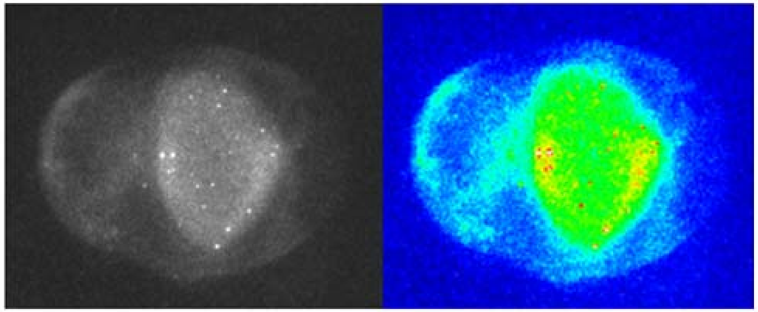




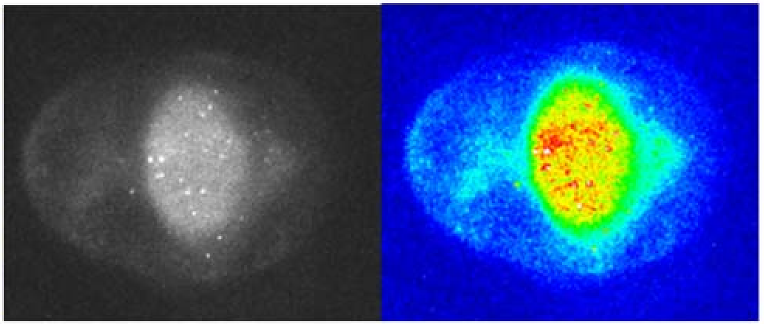
Fast Imaging

Time-Resolved Imaging with Optical Transition Radiation (3ns)

Without perturbation



With perturbation



Ralph Fiorito, FRPMS033
Kai Tian, THPAS034

Conclusion

Conclusion

- Beams with intense space charge are largely unexplored territory, especially in rings
- Particle distribution is of fundamental importance

List of UMER-Related Presentations

Invited Talks:

5:30 PM Tue (Rm. A+B): Rami Kishek (UMER overview),TUZBAB03

2:00 PM Wed (Room C): Diktys Stratakis (Tomography), WEZC01

Posters:

MON PM:
Chao Wu, MOPAS033 (Controls)

TUE PM:
Mark Walter, TUPAS047 (Controls)
Mark Walter, TUPAS048 (Extraction)

WED AM:
Brian Beaudoin, WEPMS001 (Energy perturbations)

THU PM:
Santiago Bernal, THPAS030 (Low-current beams)
Irv Haber, THPAS031 (Halos)
Christos Papadopoulos, THPAS032 (Skew quadrupoles, Halos)
J. Charles Thangaraj, THPAS033 (Density perturbations)
Kai Tian, THPAS034 (Fast imaging)

FRI AM:
Ralph Fiorito, FRPMS033 (OTR)