Experimental Study of Halo Formation in Space Charge Dominated Beam

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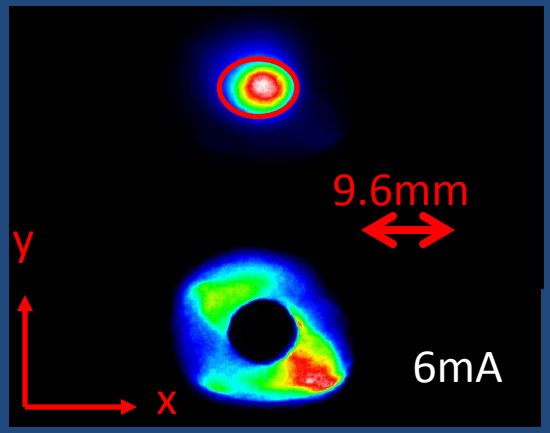
Outline

- Motivation
- Introduction to UMER
- Envelope match
  - Match through Trace3D
  - Empirical method
  - Beam rotation correction
- Halo formation from mismatch and rotation
- Pure breathing mode mismatch generation

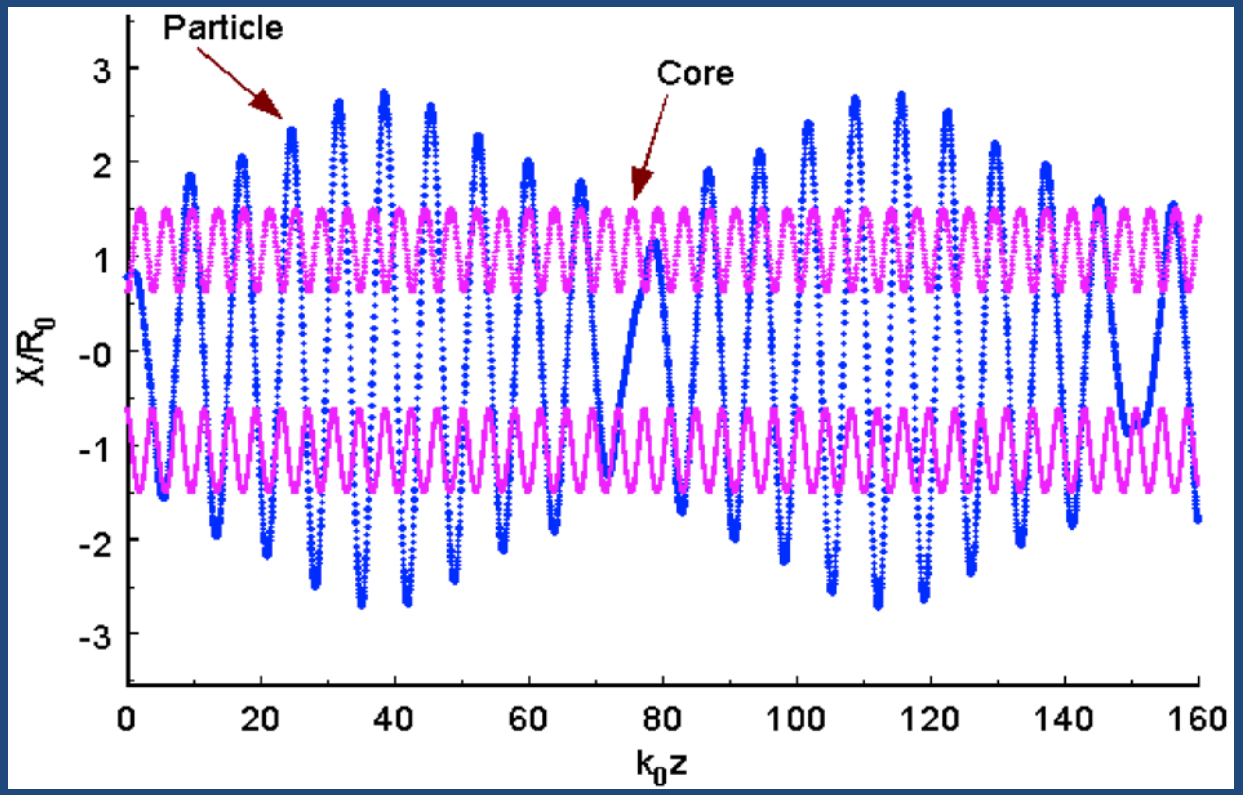
Motivation



- What is beam halo?
  - No well accepted definition
  - Particles outside the beam core (beam envelope)
  - Certain threshold of the highest intensity, e.g. less than 3%
- Consequences of halos
  - Emittance growth and beam loss
  - Nuclear activation of the transport channel
  - Emission of secondary electrons
  - Increasing noise in the detectors

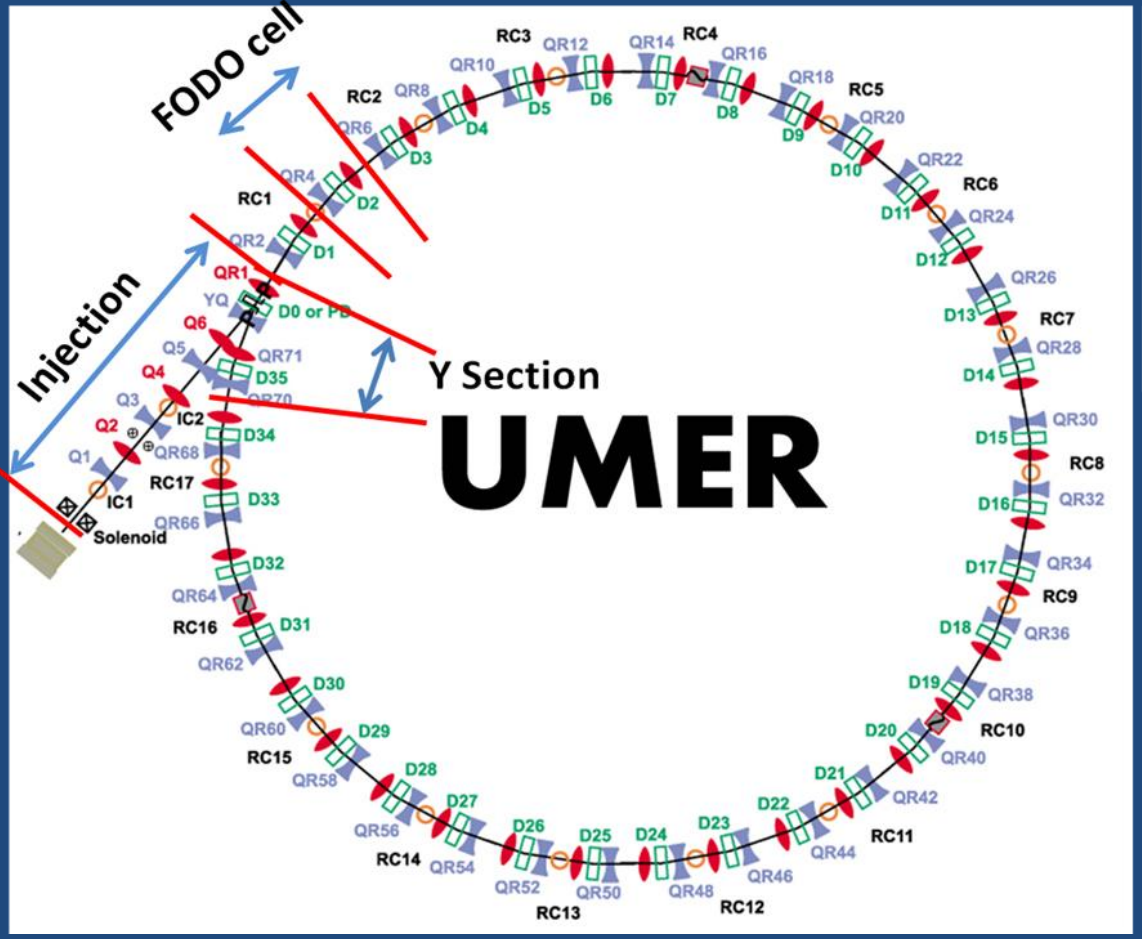
Background

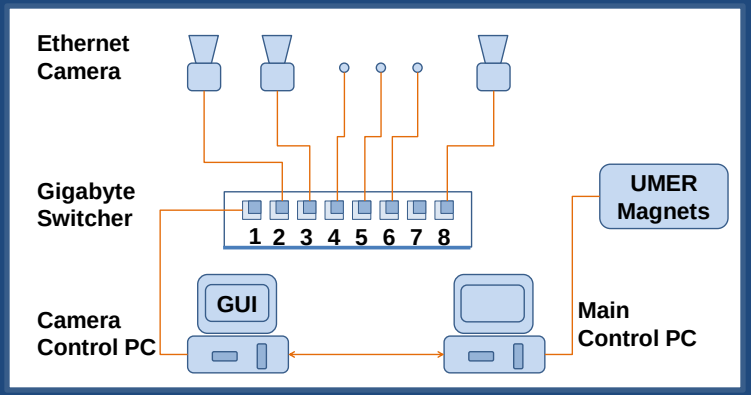
- Particle-core model
- Free energy model



R. Gluckstern. *Phys. Rev. Lett.,* 73 (1994)
M. Reiser. *Journal of Applied Physics*, 70 (1991).

UMER



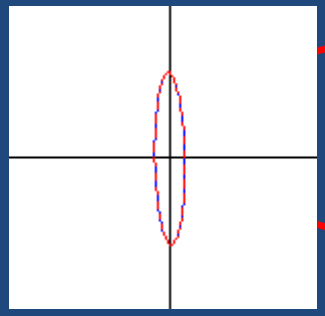


Aperture#	r_0 (mm)	I (mA)	ε (μm)	χ
1	0.875	6	16.8	0.605
2	1.5	21	30.0	0.901

Parameter	Value
$\beta = v / c$	0.2
Pulse Length	20-120 ns
Beam Energy	10 keV
Current	0.6-100 mA
Ring Circumference	11.52 m
Lap Time	197 ns
Pulse Repetition Rate	10-60 Hz
FODO Period	0.32 m
Zero-current Phase Advance	0.760

Envelope Match Using Trace3D

Electron Beam from gun

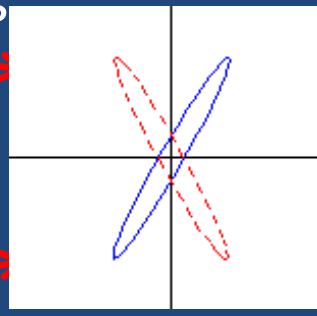


X_i, X_i'
Y_i, Y_i'

Injector

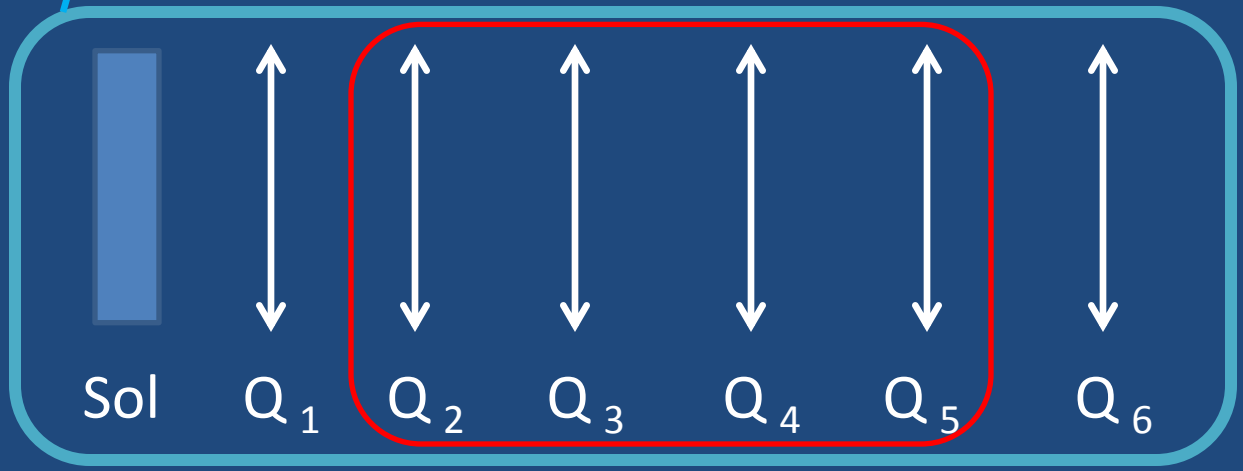
X_f, X_f'
Y_f, Y_f'

Starting point of ring



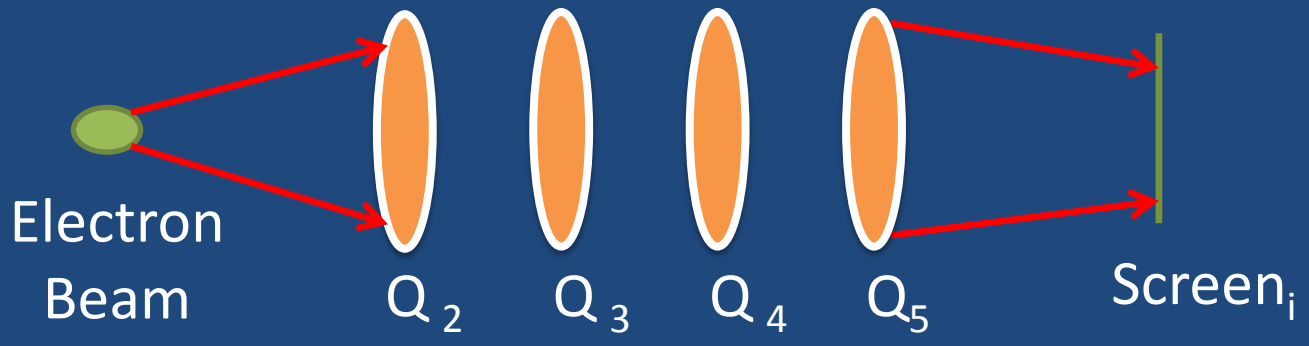
RMS match

$$k_0{}^2 R = \frac{\varepsilon^2}{R^3} + \frac{K}{R}$$



Use Q2-Q5 to optimize the beam to the matching solution

Empirical matching using screens



$$R_{W_i j} = \frac{\partial W_i}{\partial I_j}$$

$$W = X \text{ or } Y$$

Matched Beam size

$$\begin{pmatrix} X_i \\ Y_i \end{pmatrix}_{I_2, I_3, I_4, I_5} \approx \begin{pmatrix} X_m \\ Y_m \end{pmatrix} + \begin{pmatrix} R_{xi2} & R_{xi3} & R_{xi4} & R_{xi5} \\ R_{yi2} & R_{yi3} & R_{yi4} & R_{yi5} \end{pmatrix} \begin{pmatrix} \Delta I_2 \\ \Delta I_3 \\ \Delta I_4 \\ \Delta I_5 \end{pmatrix}$$

Beam size for current setting

Current difference of Quads from current setting to the matching setting

H. Li, Control and Transport of Intense Electron Beams, *Ph.D. Dissertation*, Univ. of Maryland, 2004.

Response Matrix

$$\begin{pmatrix} X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ \cdots \\ X_n \\ Y_n \end{pmatrix} = \begin{pmatrix} R_{x11} & R_{x12} & R_{x13} & R_{x14} & 1 & 0 \\ R_{y11} & R_{y12} & R_{y13} & R_{y14} & 0 & 1 \\ R_{x21} & R_{x22} & R_{x23} & R_{x24} & 1 & 0 \\ R_{y21} & R_{y22} & R_{y23} & R_{y24} & 0 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{xn1} & R_{xn2} & R_{xn3} & R_{xn4} & 1 & 0 \\ R_{yn1} & R_{yn2} & R_{yn3} & R_{yn4} & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \Delta I_1 \\ \Delta I_2 \\ \Delta I_3 \\ \Delta I_4 \\ X_m \\ Y_m \end{pmatrix}$$

E R Δ

Current difference of Quads from current setting to the matching setting

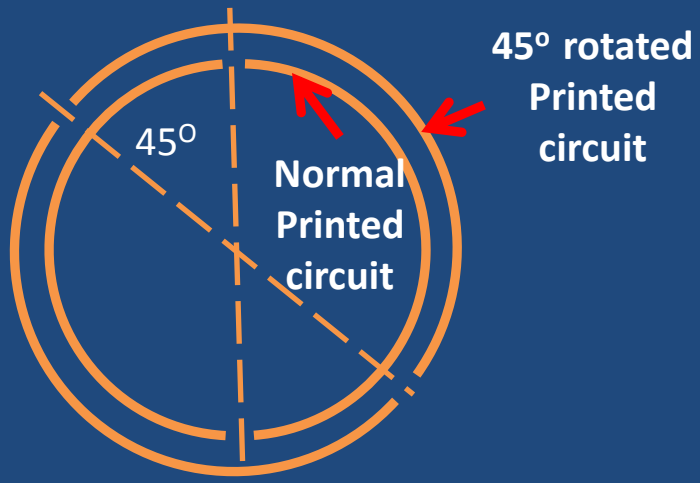
Matched beam size

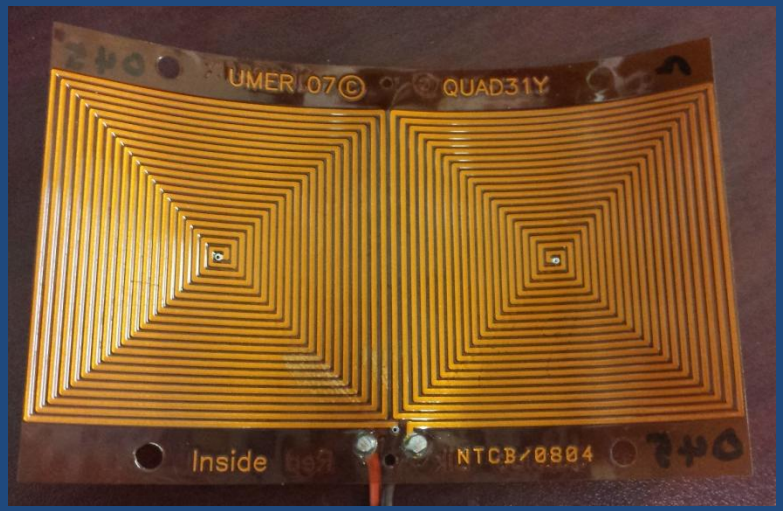
Beam size in each screen for current setting

Response matrix

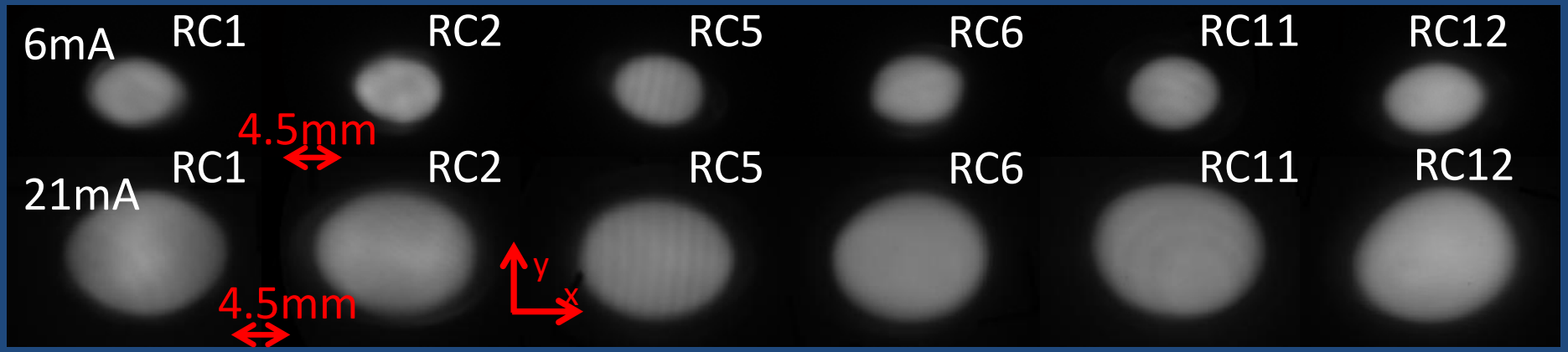
$$\Delta = (R^{\mathsf{T}}R)^{-1}R^{\mathsf{T}}E$$

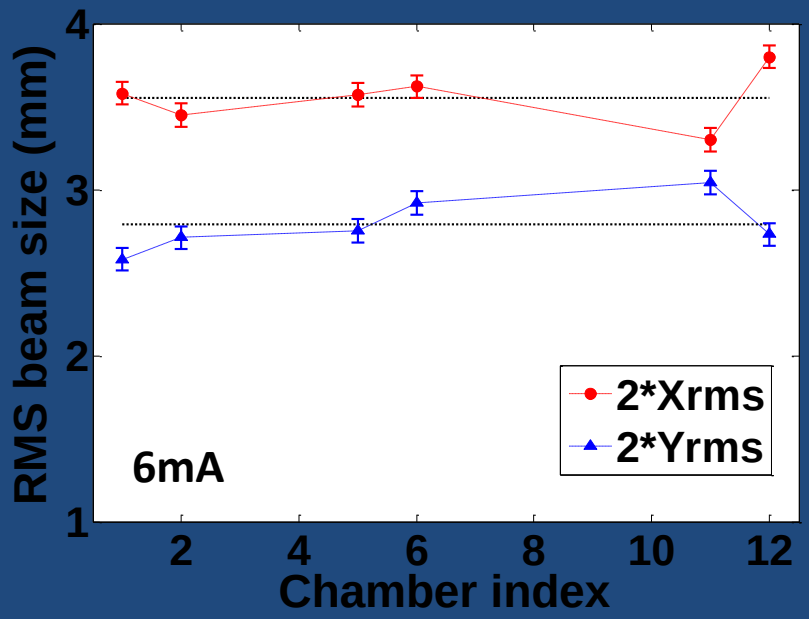
Rotation Correction Using Skew Quad

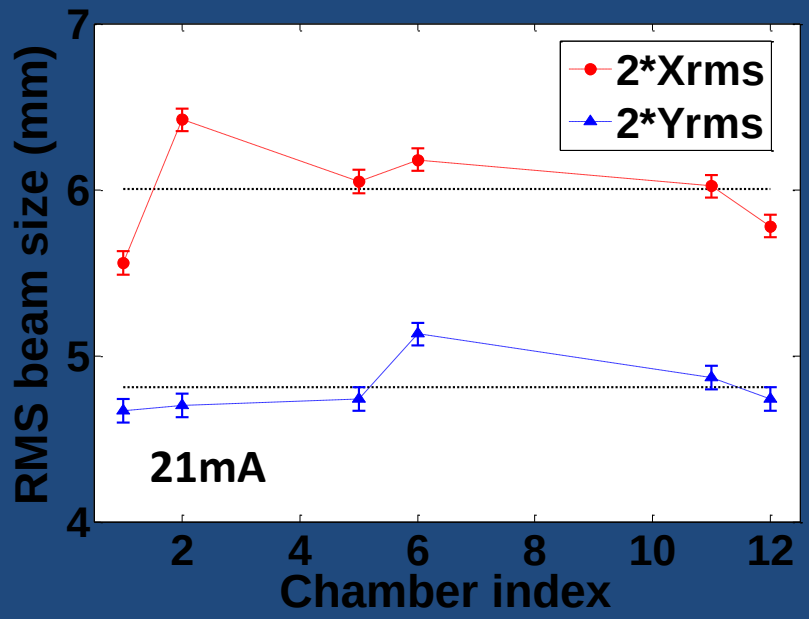




Matched Beam

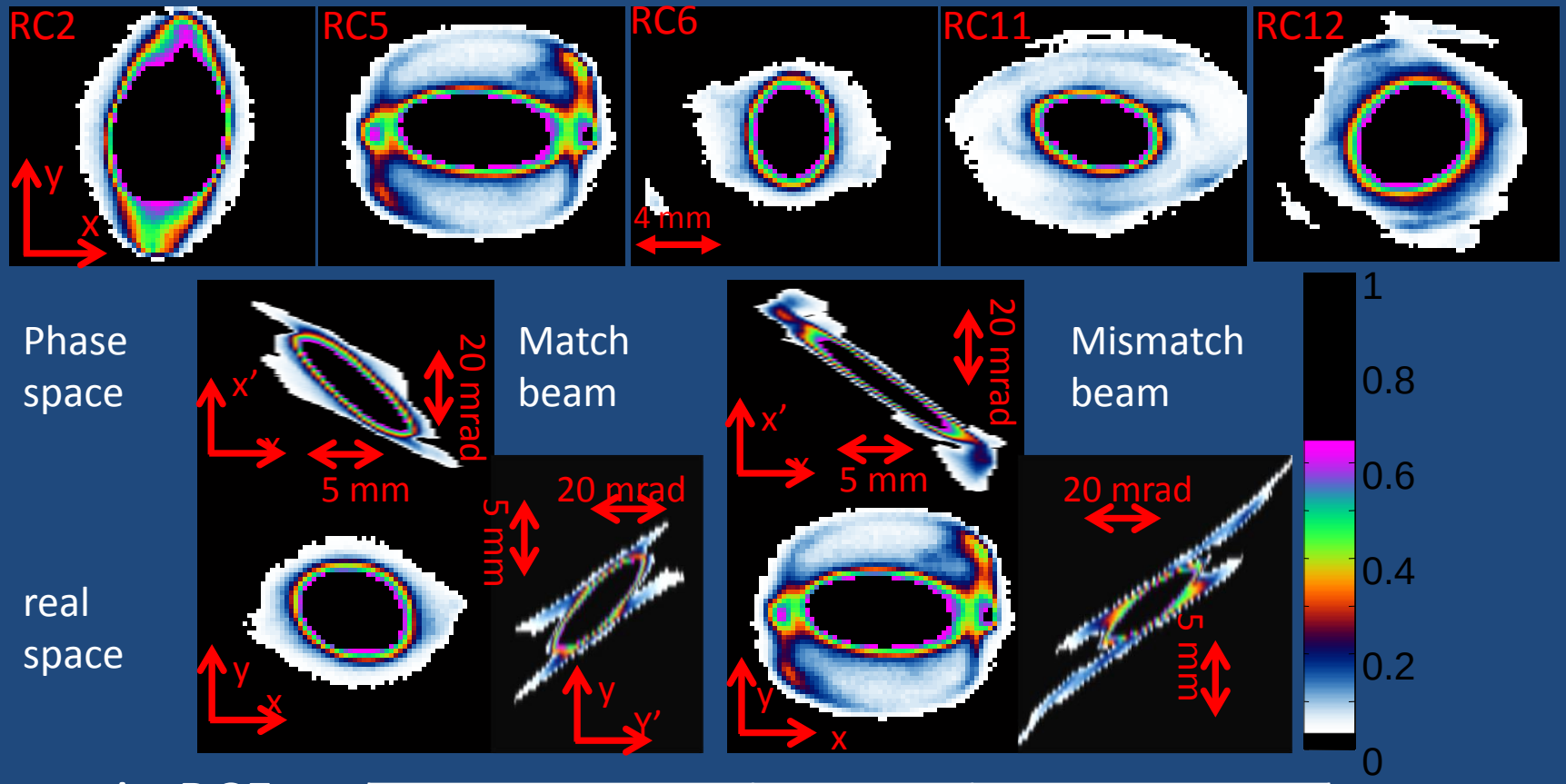






Halo Formation from Mismatch in Experiment

Reduce Q5 by 20%

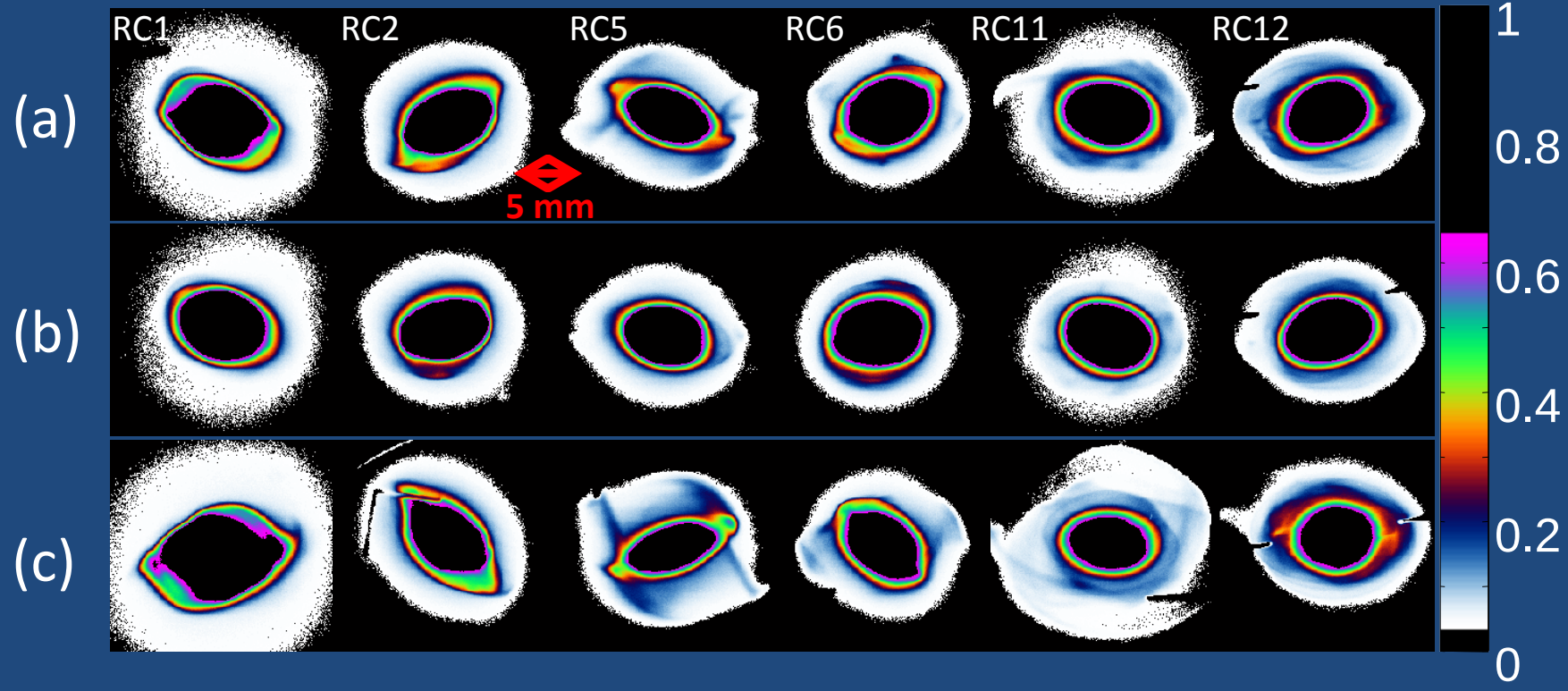


At screen in RC5

4*Emittance (mm mrad)	Match beam	Mismatch beam
x	20.9	29.0
y	27.5	33.9

Halo Formation from Rotation in Experiment

Change Skew Quad at Q6 from (a) 0.5, (b) 0.1 and (c) -0.4



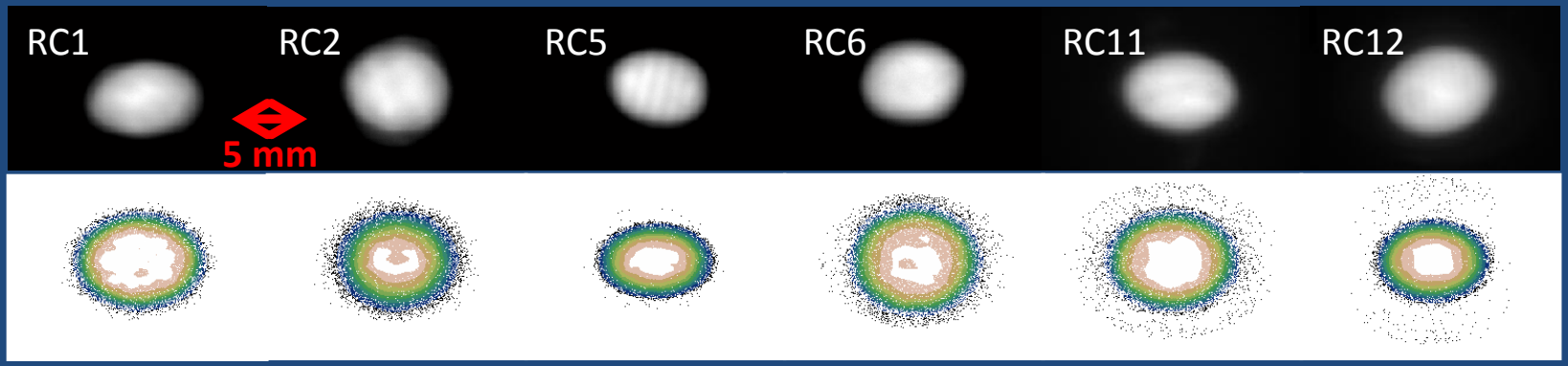
Pure Breathing Mismatch Mode

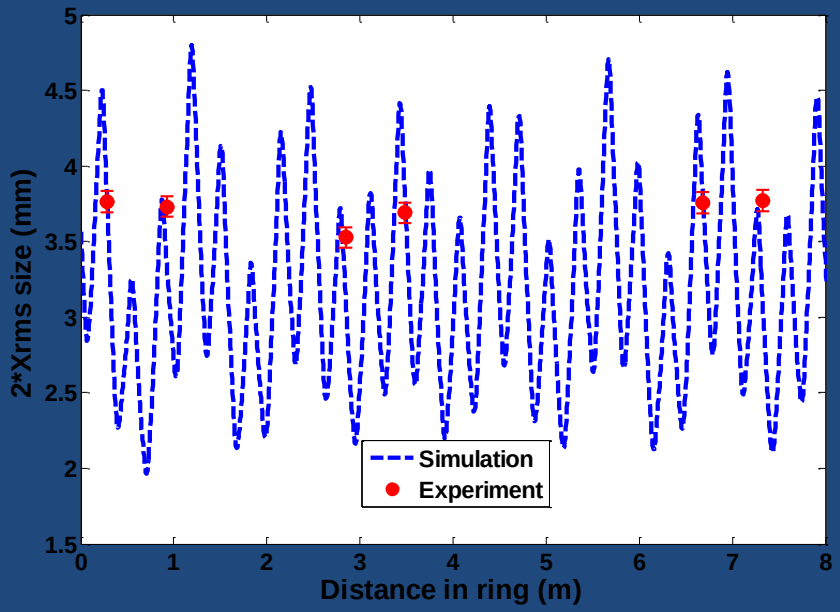
(a)

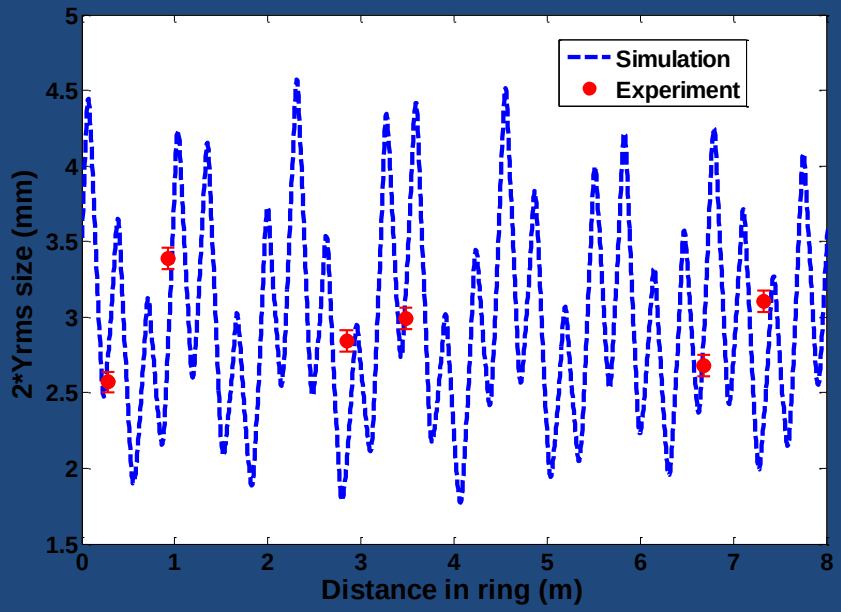
Experiment

(b)

Warp (PIC) simulation

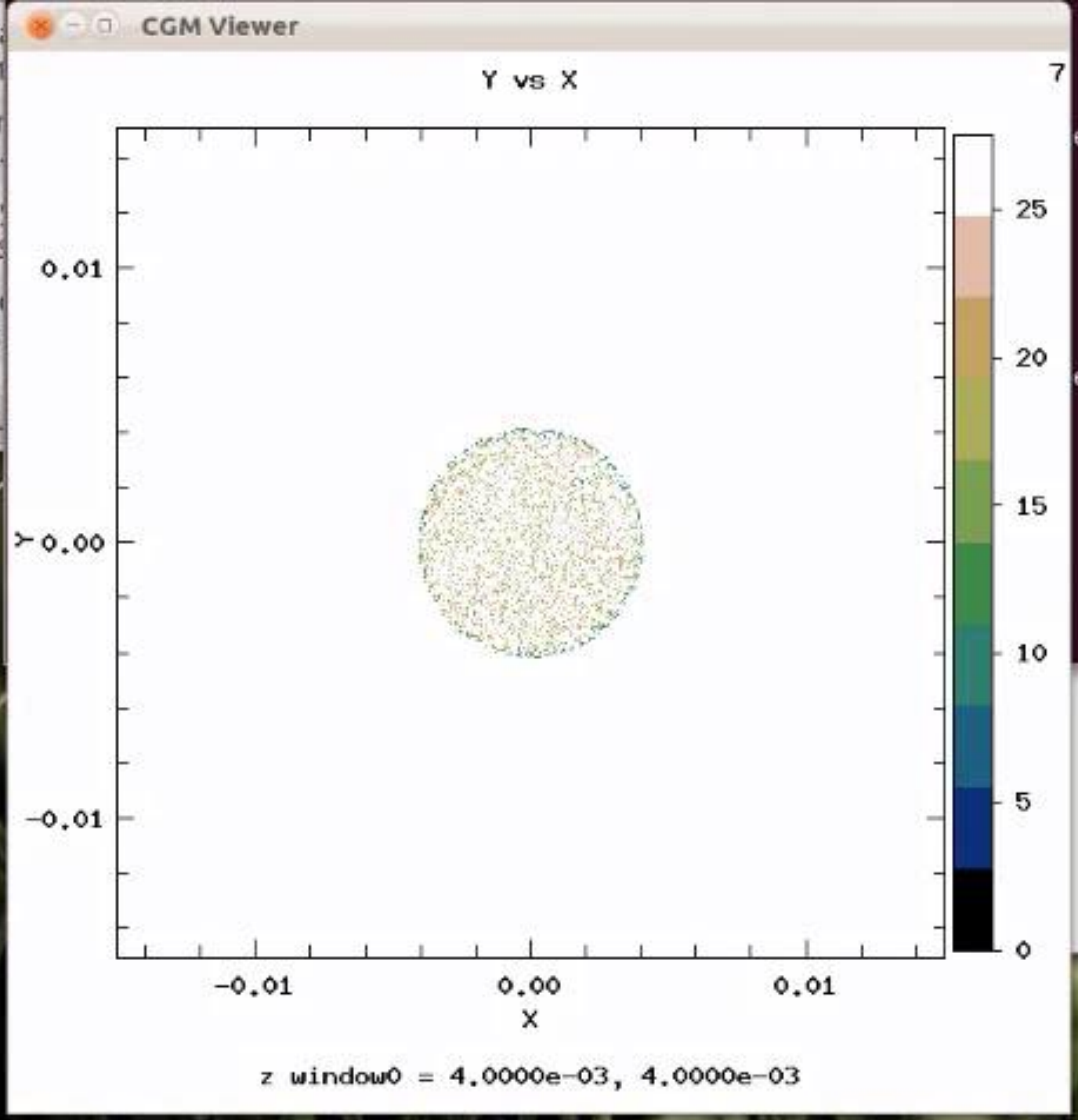






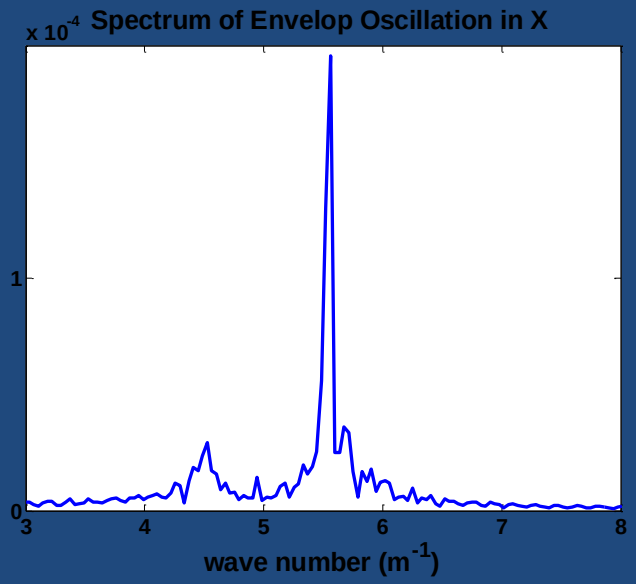
D.P. Grote, et al. *Nucl. Instr. and Meth. A*, vol. 415, p. 428 (1998)

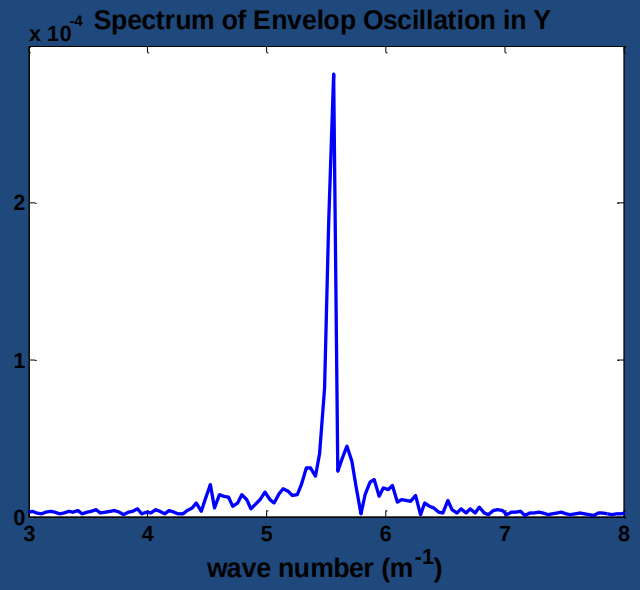
Private conversation with T. Wrangler


CGM Viewer
Y vs X
7
25
20
15
10
5
0
0.01
0.00
-0.01
Y
-0.01
0.00
0.01
X
z window0 = 4.0000e-03, 4.0000e-03

FFT Analysis(sampling in lattice period)

$$k_{breathing} = \sqrt{2k_0^{\,2} + 2k^2}$$





Analytic model	Simulation
5.775 m^{-1}	5.561 m^{-1}

Summary

- Conclusion
  - Developed a method for beam match in UMER
  - Found out the primary halo sources in UMER
  - Generated a breathing mode envelope mismatch using 6mA beam
- Future work
  - Study breathing mode mismatch with higher beam current or with different mismatch parameter.
  - Generate quad mode mismatch.
  - Study halo formation in frame of pure mismatch mode.

Acknowledgement

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Thank You