INSTITUTE FOR RESEARCH IN ELECTRONICS & APPLIED PHYSICS

Jefferson Lab
Thomas Jefferson National Accelerator Facility

High Dynamic Range Beam Imaging with a Digital Optical Mask*

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on behalf of

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JLAB, Newport News, Virginia

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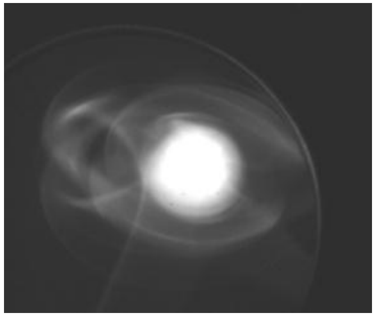
Outline

- Introduction
  - Motivation and Challenges of Halo Measurements
  - Current diagnostic techniques
- New Adaptive Halo Imaging Technique

  using Digital Micromirror Device (DMD)
- Experimental Results
  - University of Maryland Electron Ring (UMER)
  - JLAB FEL
  - Future Plans

Motivation and Challenges



Negative effects of Beam Halo

- Beam Loss
- Activation of Beam line components
- Emittance Growth
- Emission of Secondary Electrons
- Increased Noise in Detectors

Challenges to diagnostics of halos

- Need high dynamic range: >~10^5
- Adaptive to variable beam core

Previous Experimental Methods

Wire Scanner and Scraper Assembly

Low-Energy Demonstration Accelerator - LANL

DR: 10^5

T.P.Wangler, et. al., Proc. PAC01

Ionization beam profile monitor

DR: 10^3

P. Cameron, et al. *Proc. of PAC99*: 2114-2116, 1999

Imaging Techniques

High Dynamic Range Camera

Spectra-Cam CID $$

DR >10^5 measured with laser

C.P. Welsch, et. , Proc. SPIE 6616,9 (2007).

Passive Spatial Filtering

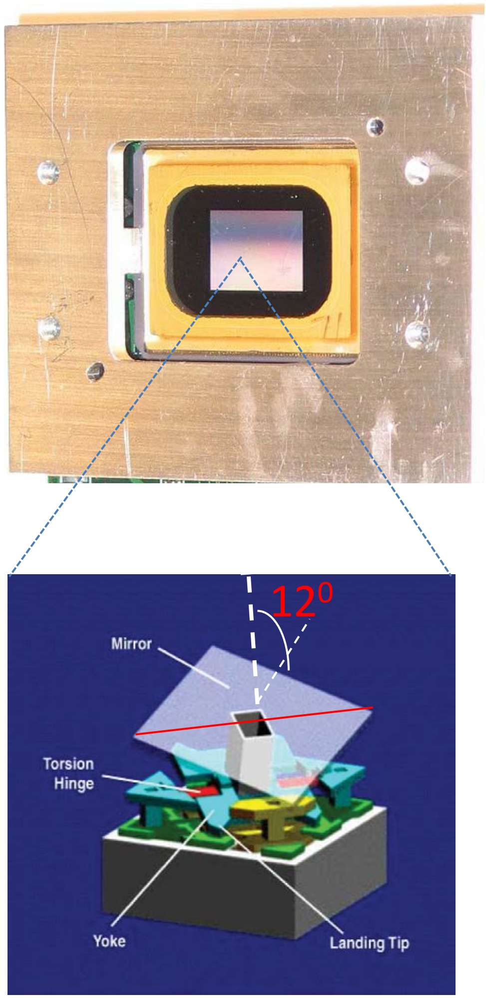
solar coronagraphy applied to beams

DR: 10^6-10^7

T. Mitsuhashi, EPAC 2004.

Digital Micro-mirror Device*

*DLP™ Texas Instruments Inc.



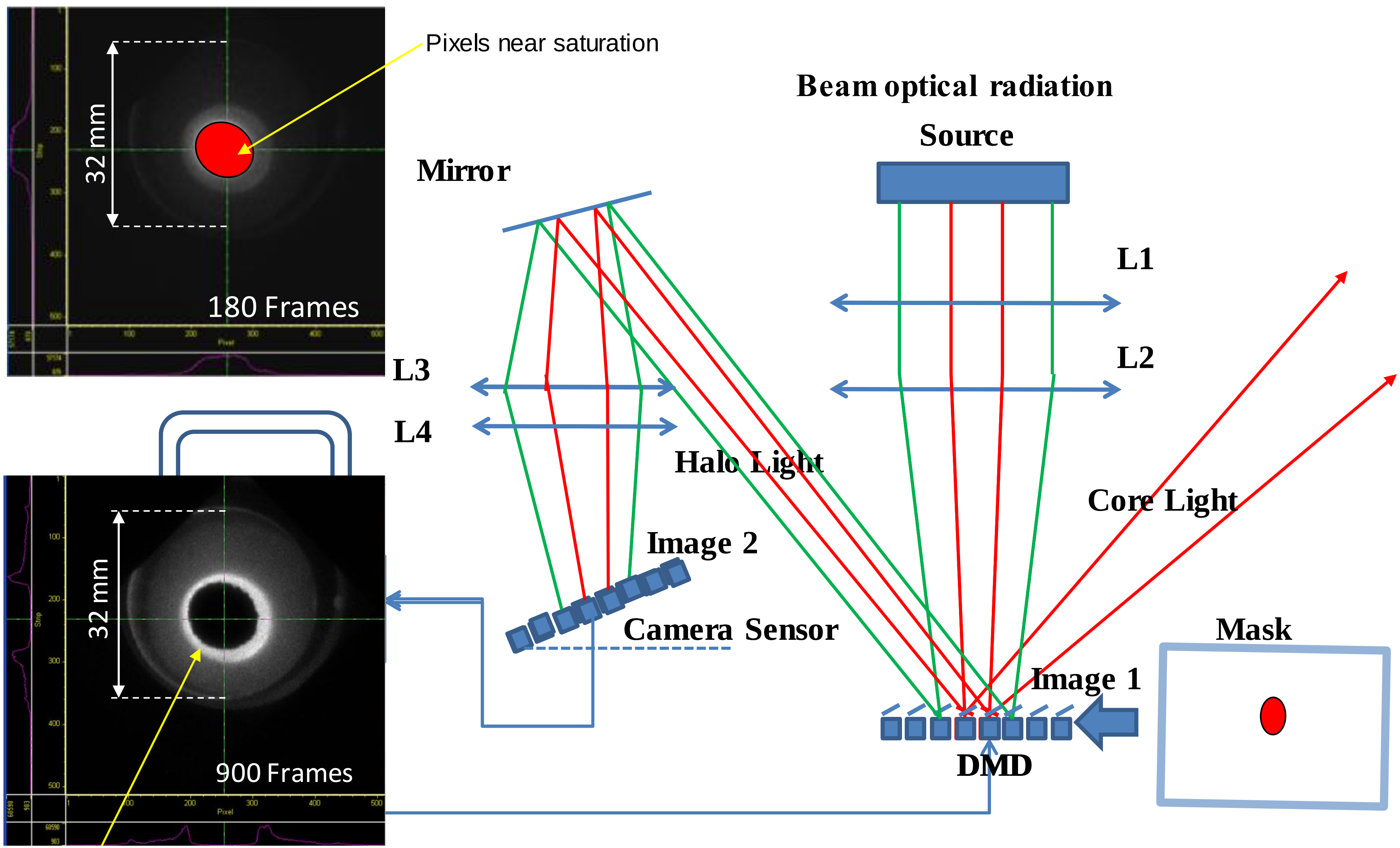
Array dimensions: 14 x 10 mm
Pixels: 1024 x 768,
Pixel dimension: 14x14 μm
Switching rate: 9600 fps
Individual pixel addressable

Used in HD TV & Projectors
Available as development 'kits'

Optimized to visible, IR, UV

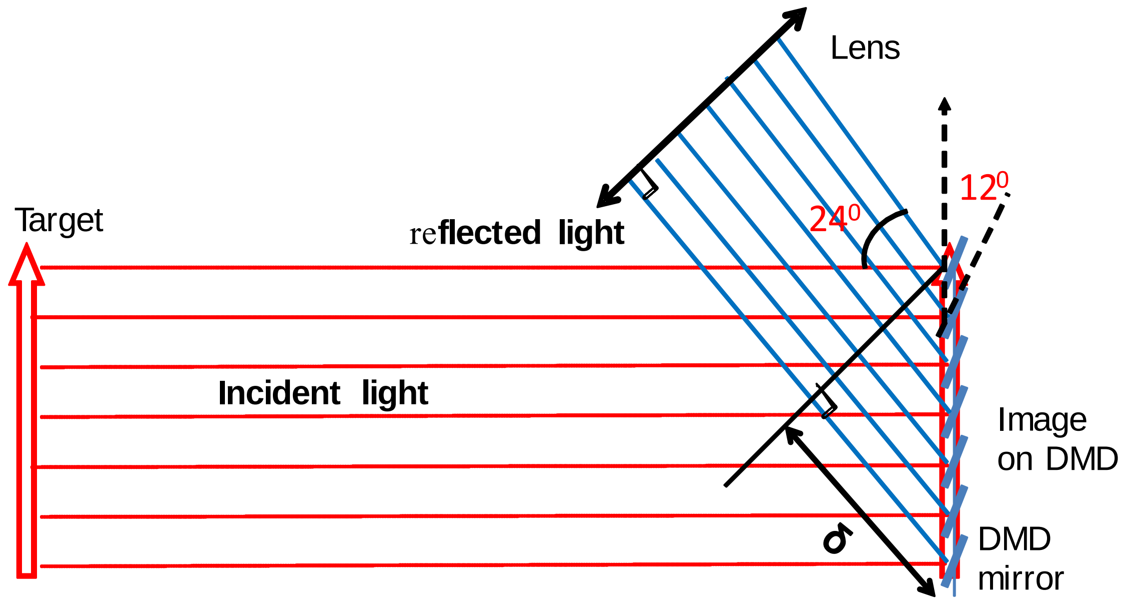
Beam Halo Imaging System using DMD developed at UMD*

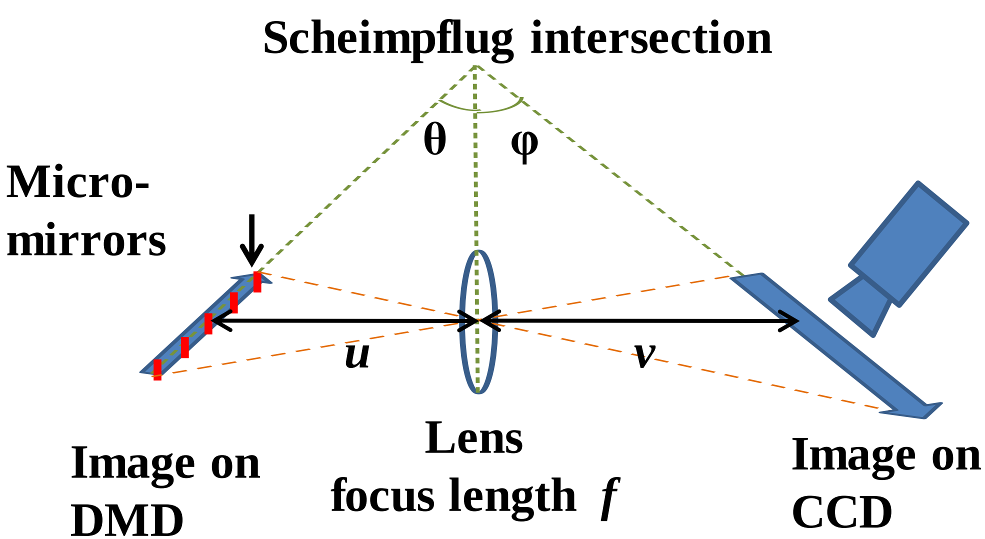
*R.Fiorito, H.Zhang, A. Shkvarunets, et. al. Proc. BIW2010



Pixels near saturation DR >10^5 Two compensations are needed, DMD rotated 45^o & path length

Scheimpflug compensation

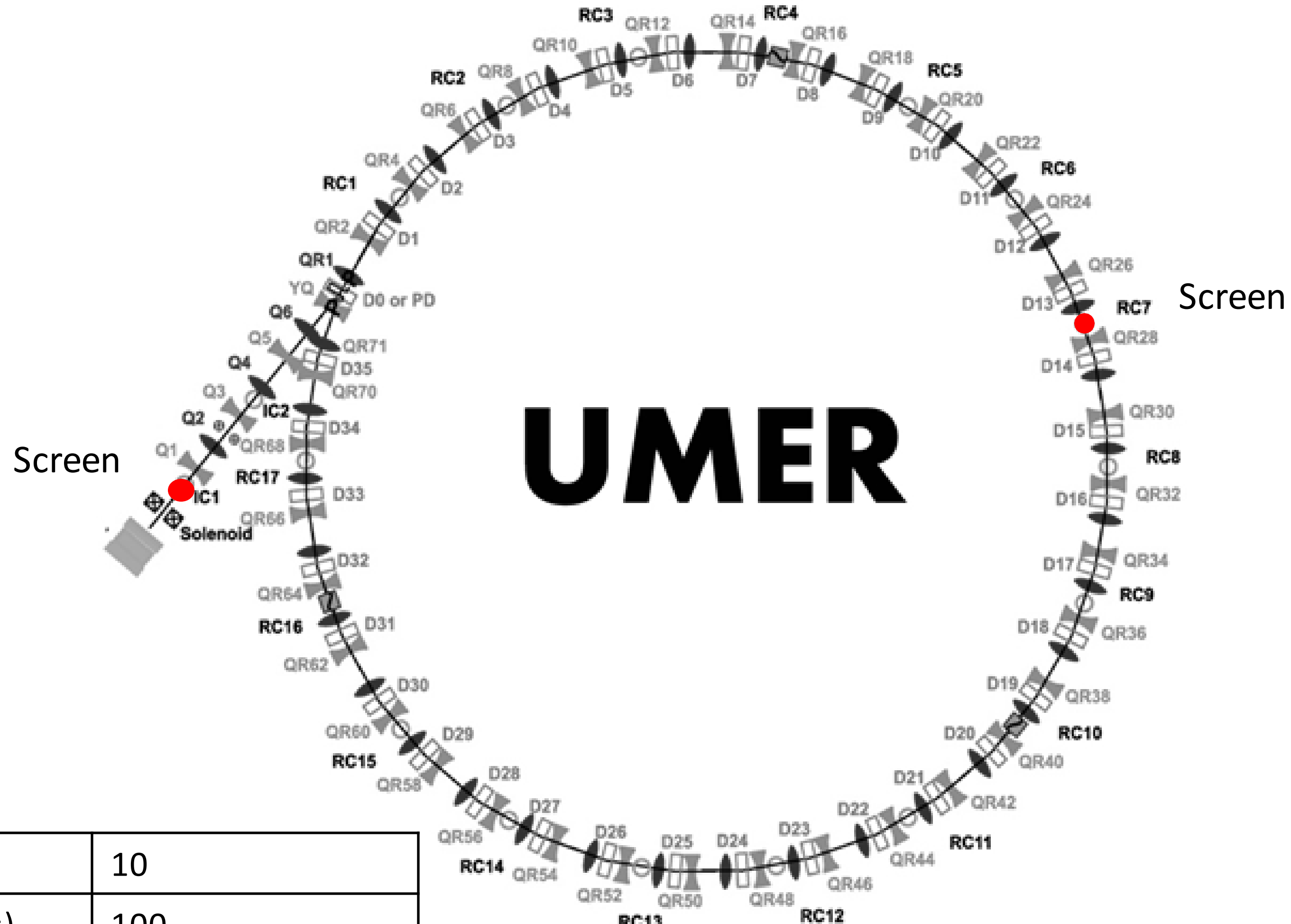




$$\varphi = \arctan\left(\frac{u}{v}\tan\theta\right)$$

$$\theta = 24^0$$

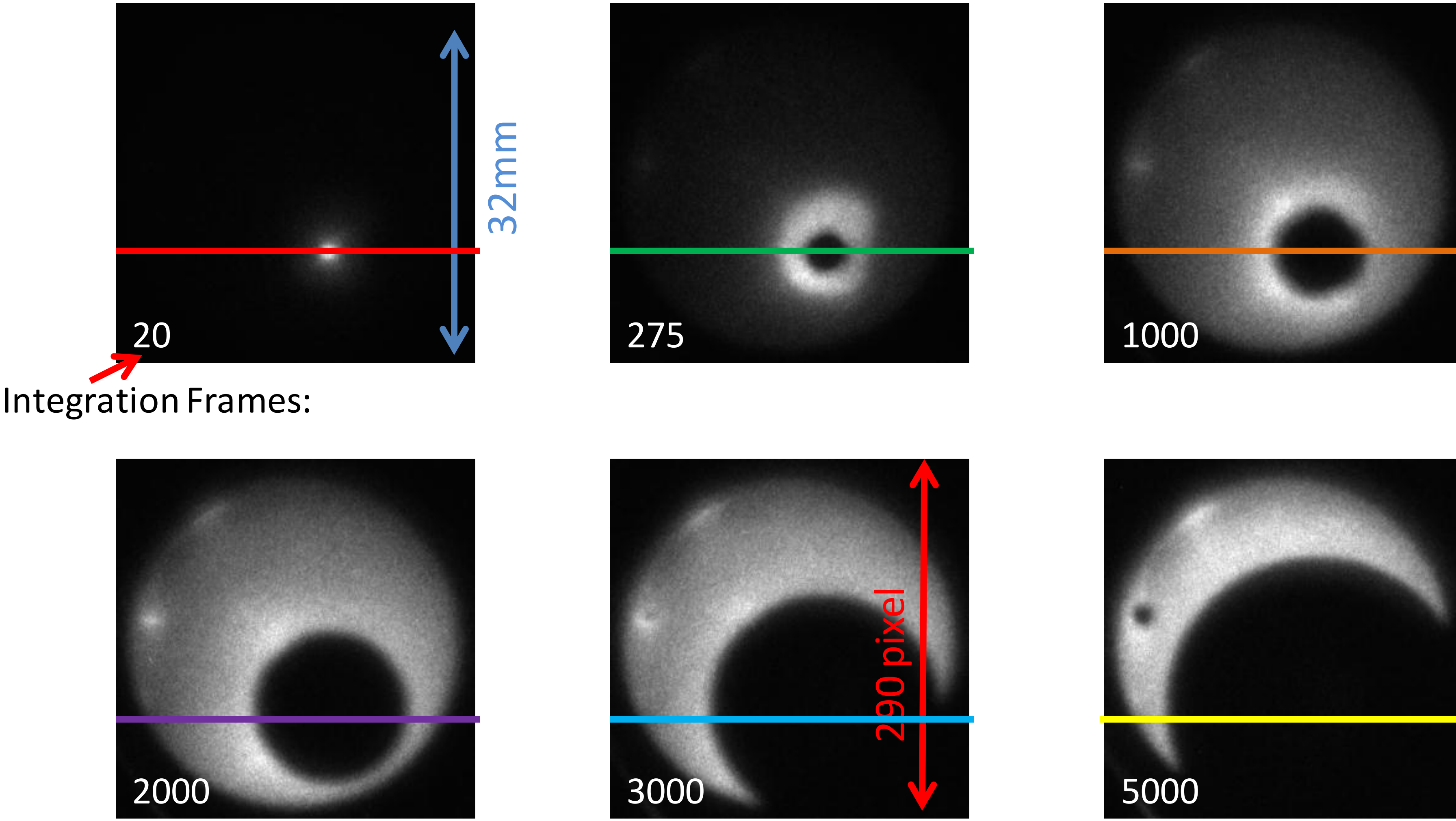
DMD Imaging Experiments on University of Maryland Electron Ring (UMER)



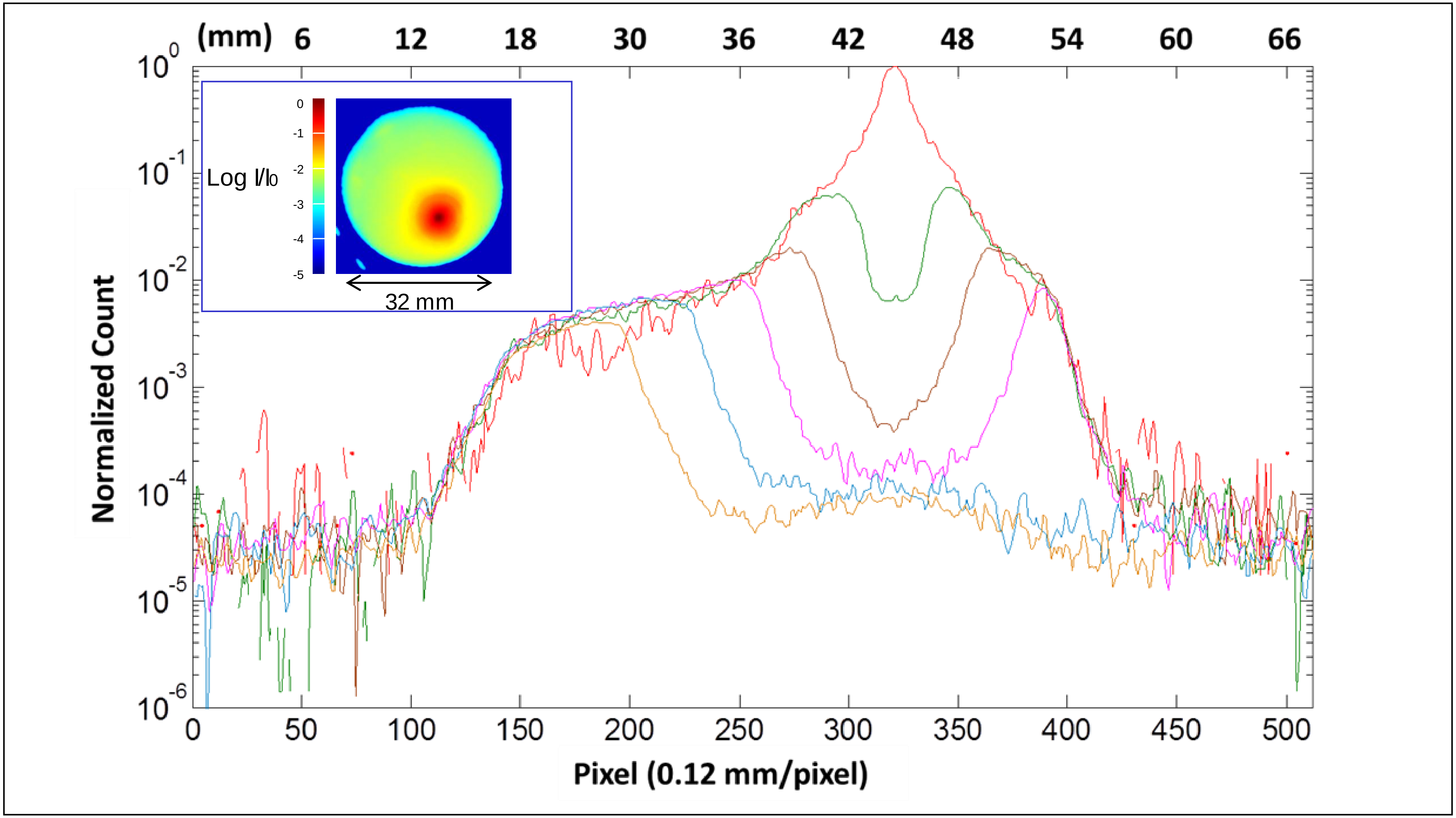
Energy (keV)	10
Pulse width (ns)	100
Repetitive rate (Hz)	20-60
Beam current (mA)	0.6 , 6, 21,80

Dynamic Range measurement of imaging system

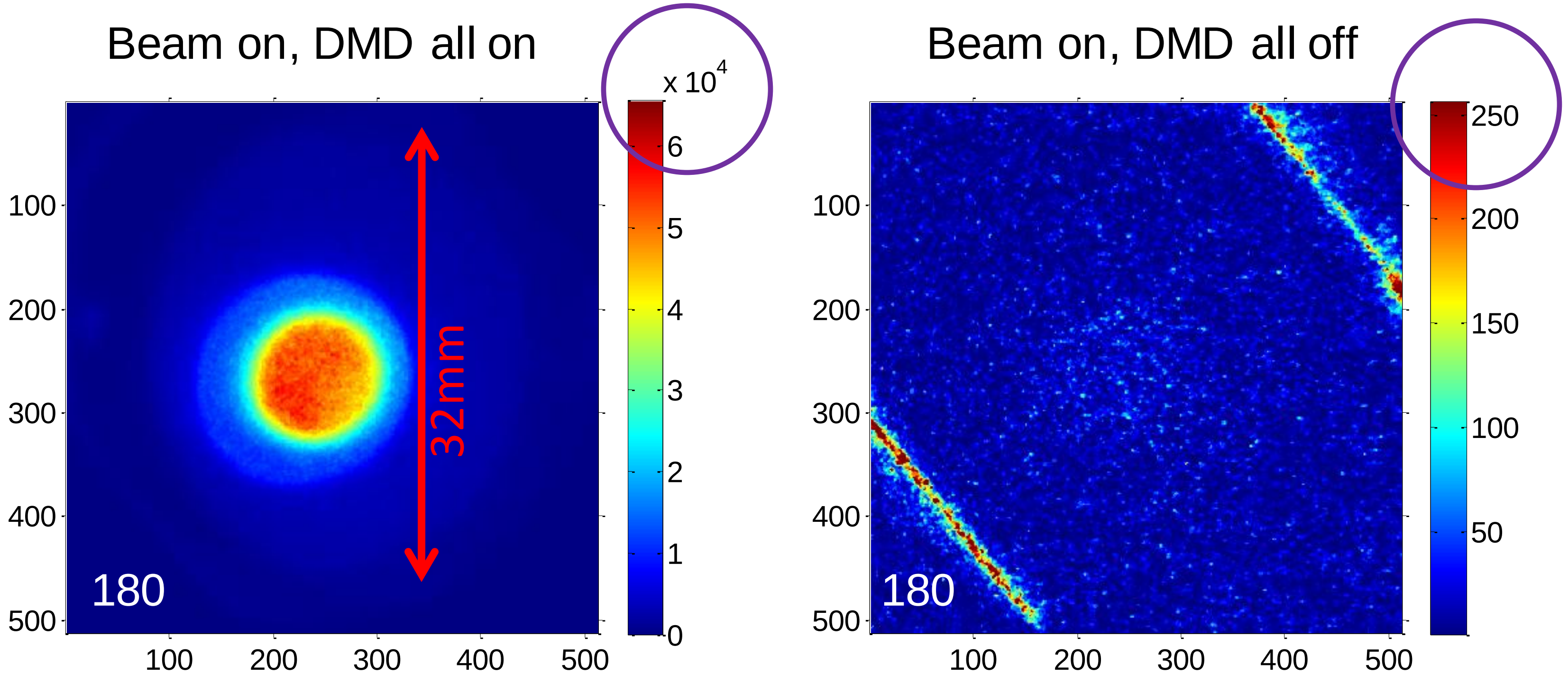
Phosphor screen image of 21 mA beam



Dynamic Range Measurement at UMER



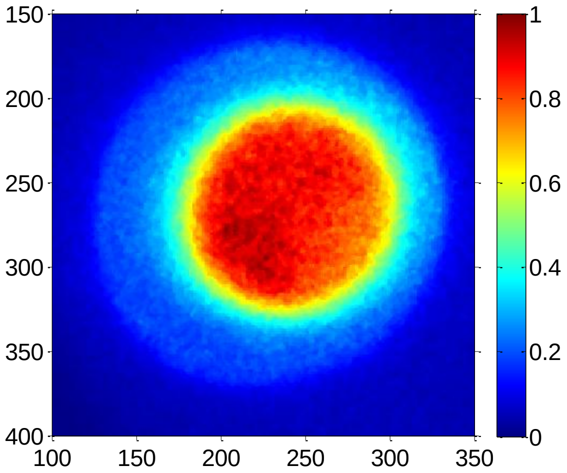
Spatial Filtering Ability of DMD



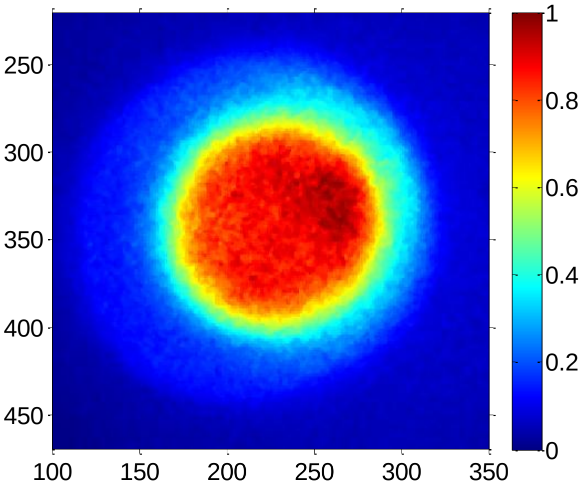
21 mA beam

Comparison of Images obtained with DMD and Mirror

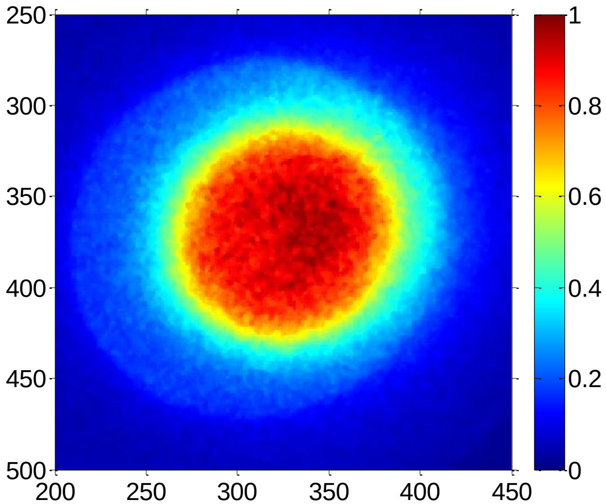
DMD **all on**
(with Scheimplug compensation)



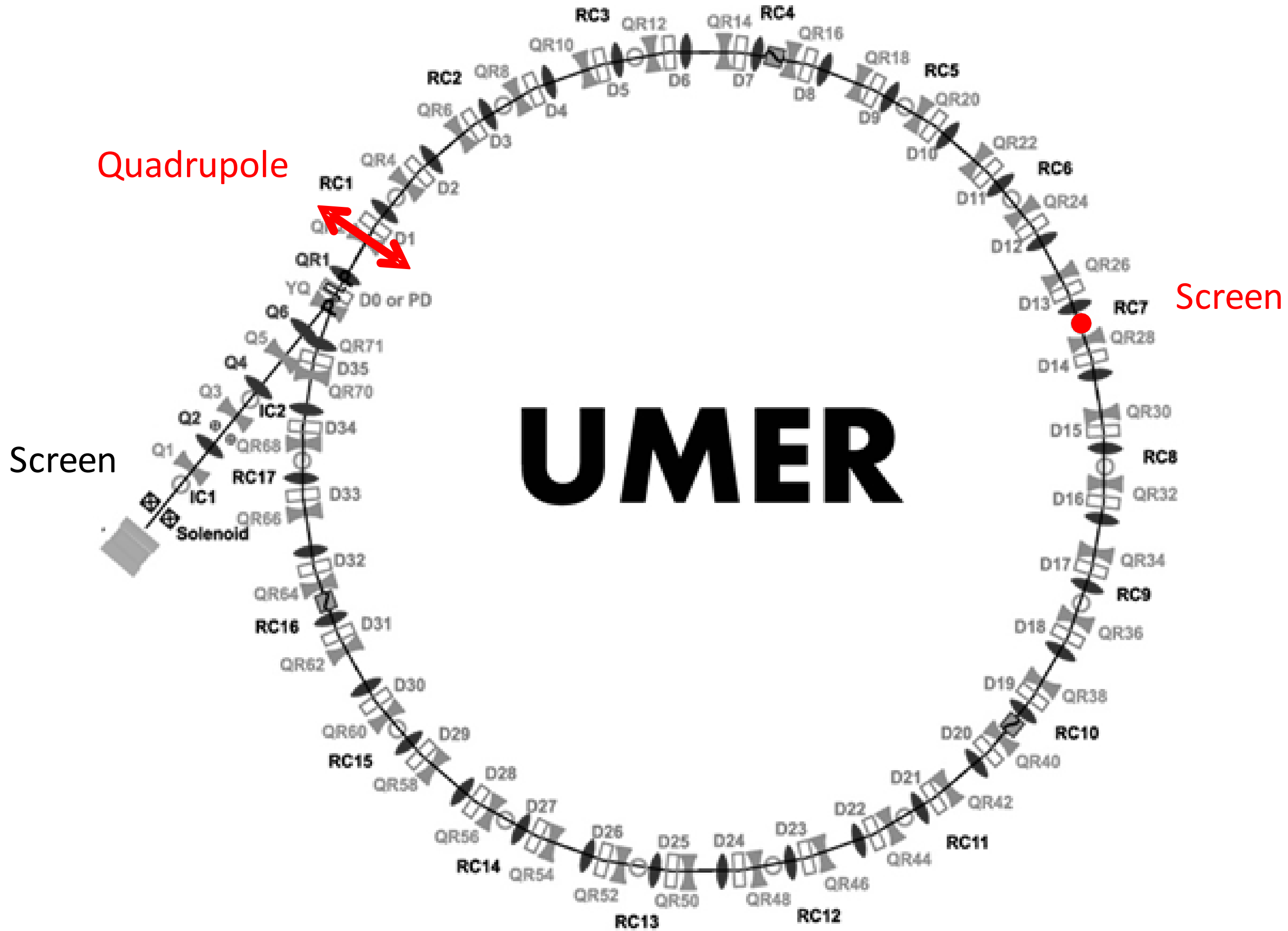
DMD **all floating**
(no compensation)



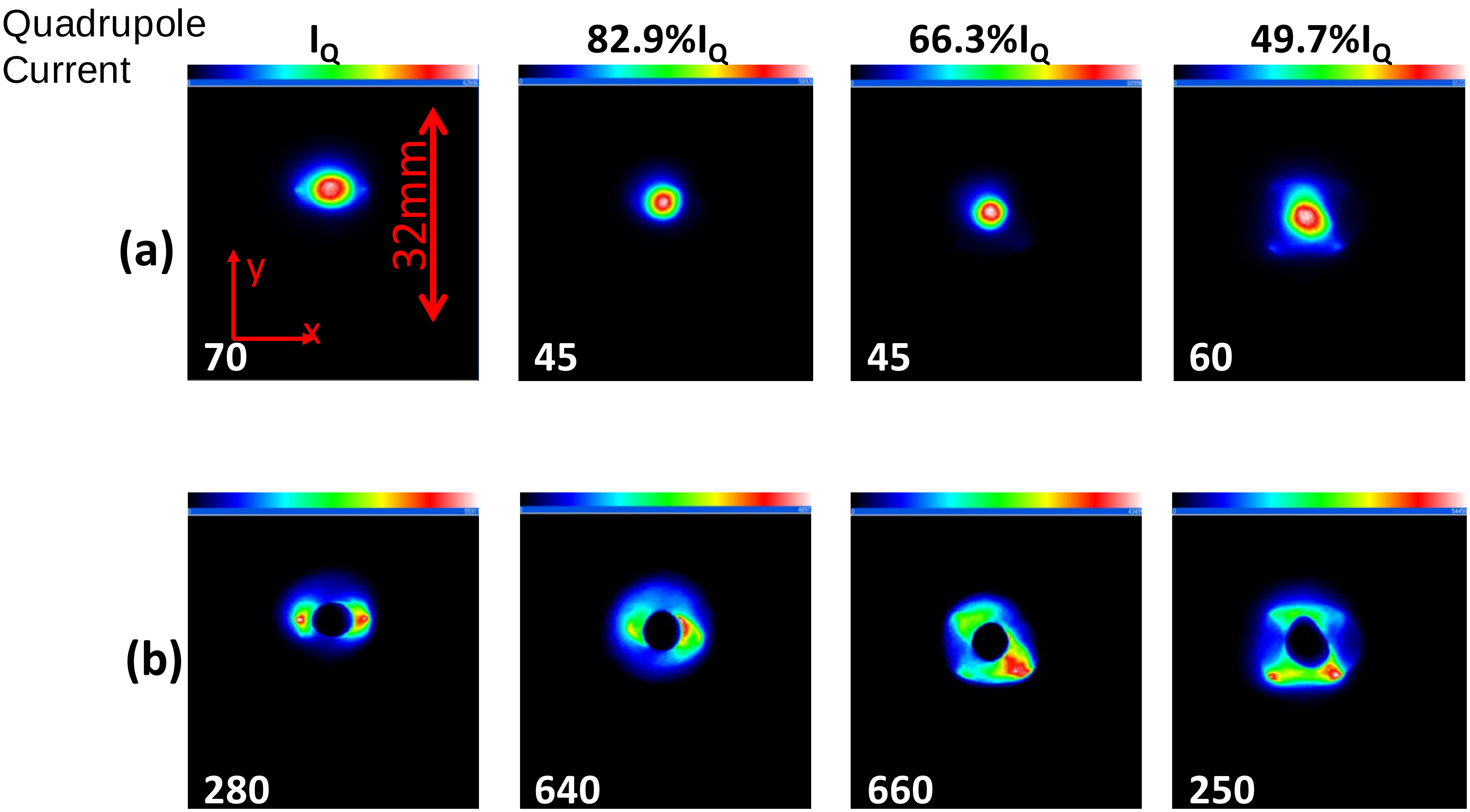
Simple Mirror
(no compensation)



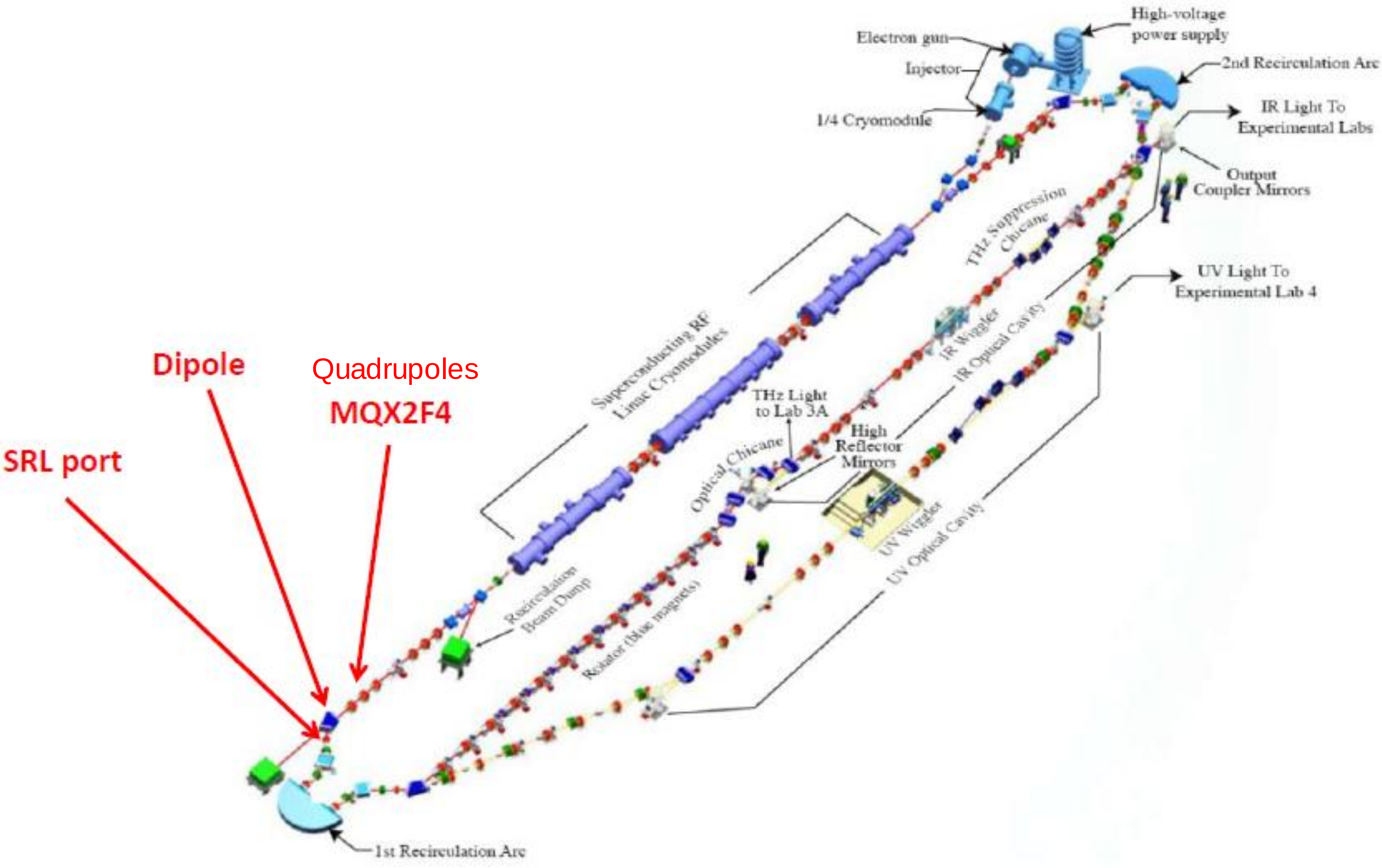
Quadrupole Induced Halo Experiments on UMER



Demonstration of adaptive threshold masking

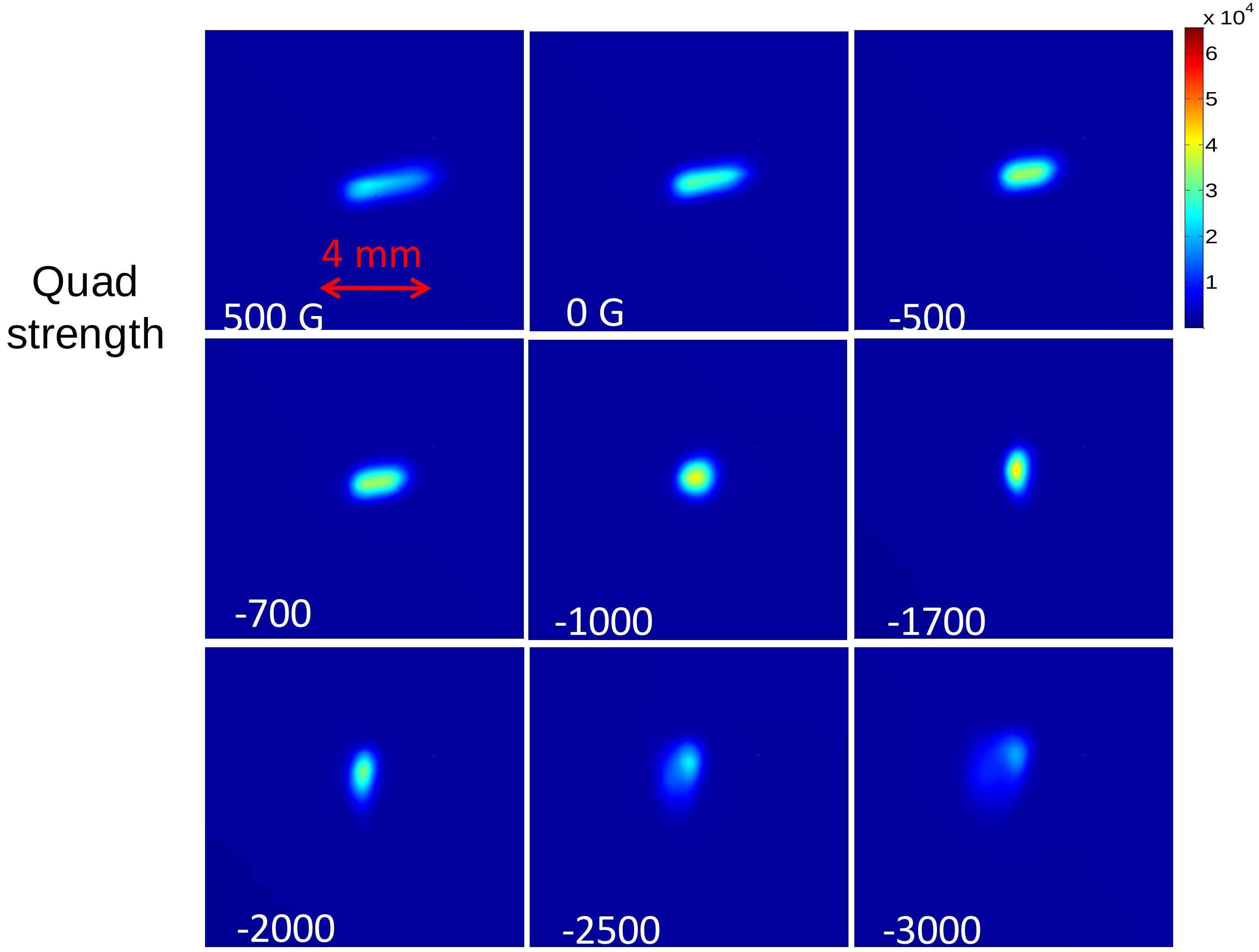


Non Interceptive Beam/Halo Imaging at JLAB using Optical Synchrotron Radiation



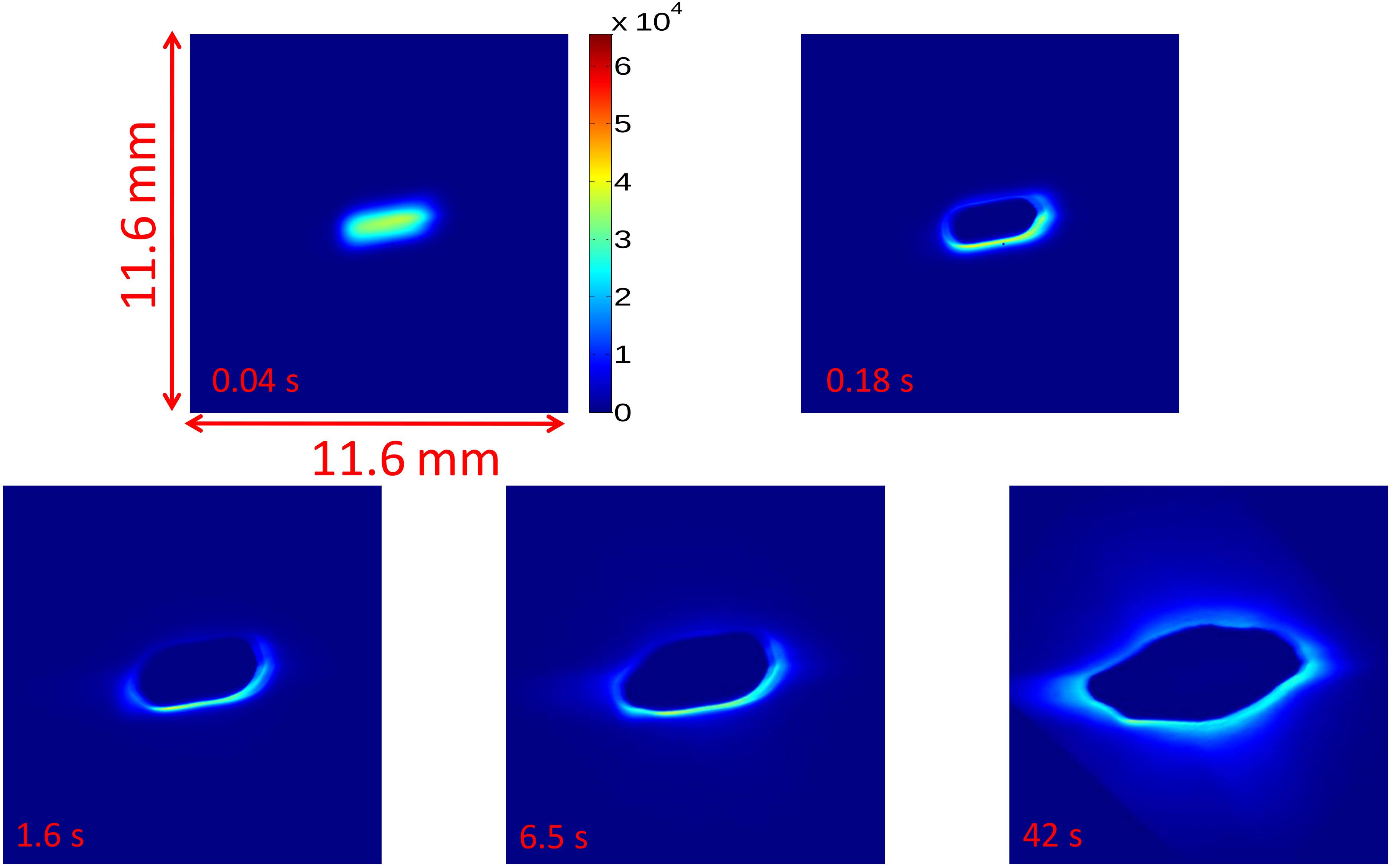
Quadrupole Scan Using OSR with Tune-up Beam

(E=135 MeV, I= 0.32mA: 2Hz rep-rate, 250μs macro, 4.68MHz micro, 135pC/micro)

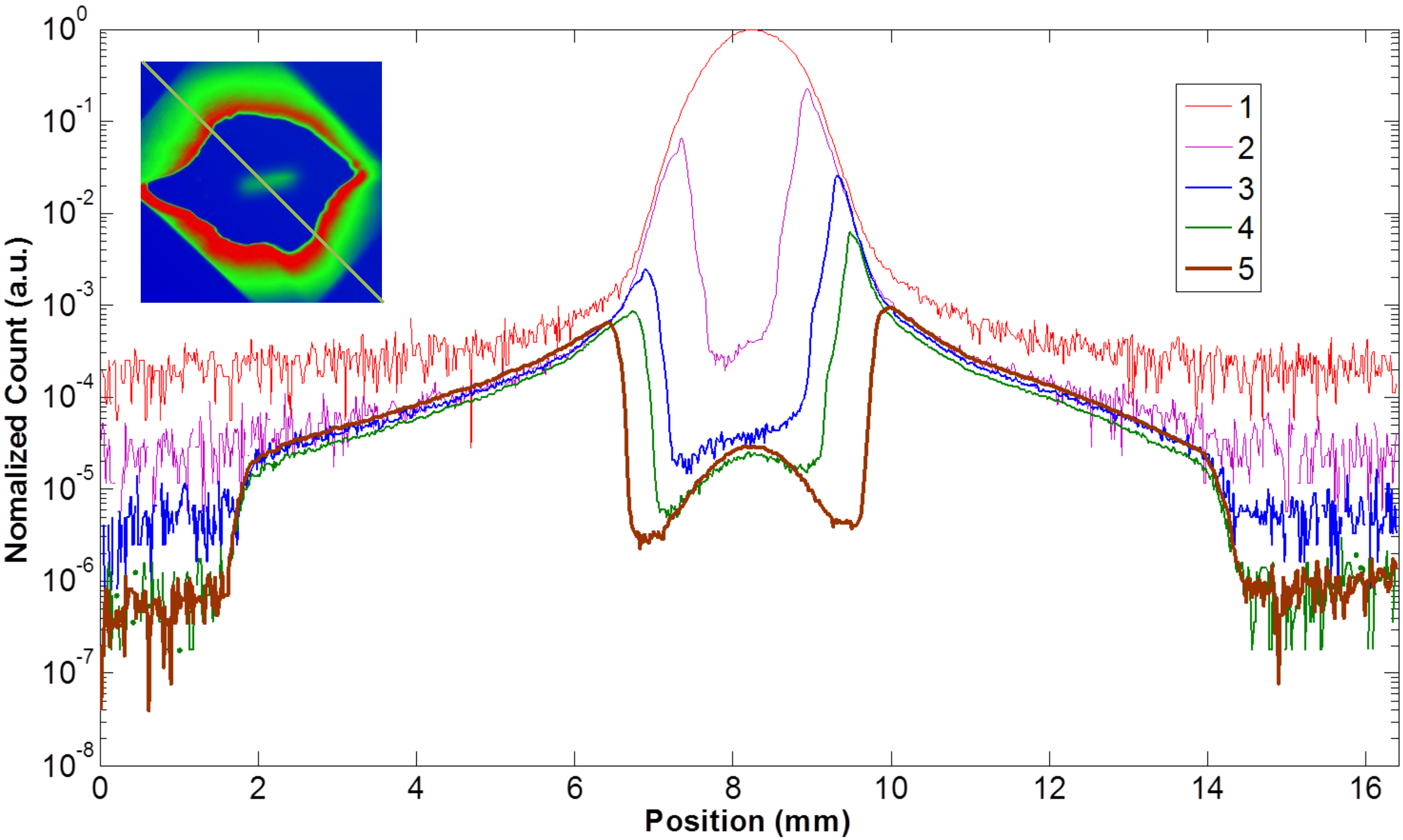


OSR Halo Imaging of JLAB CW beam with DMD threshold mask

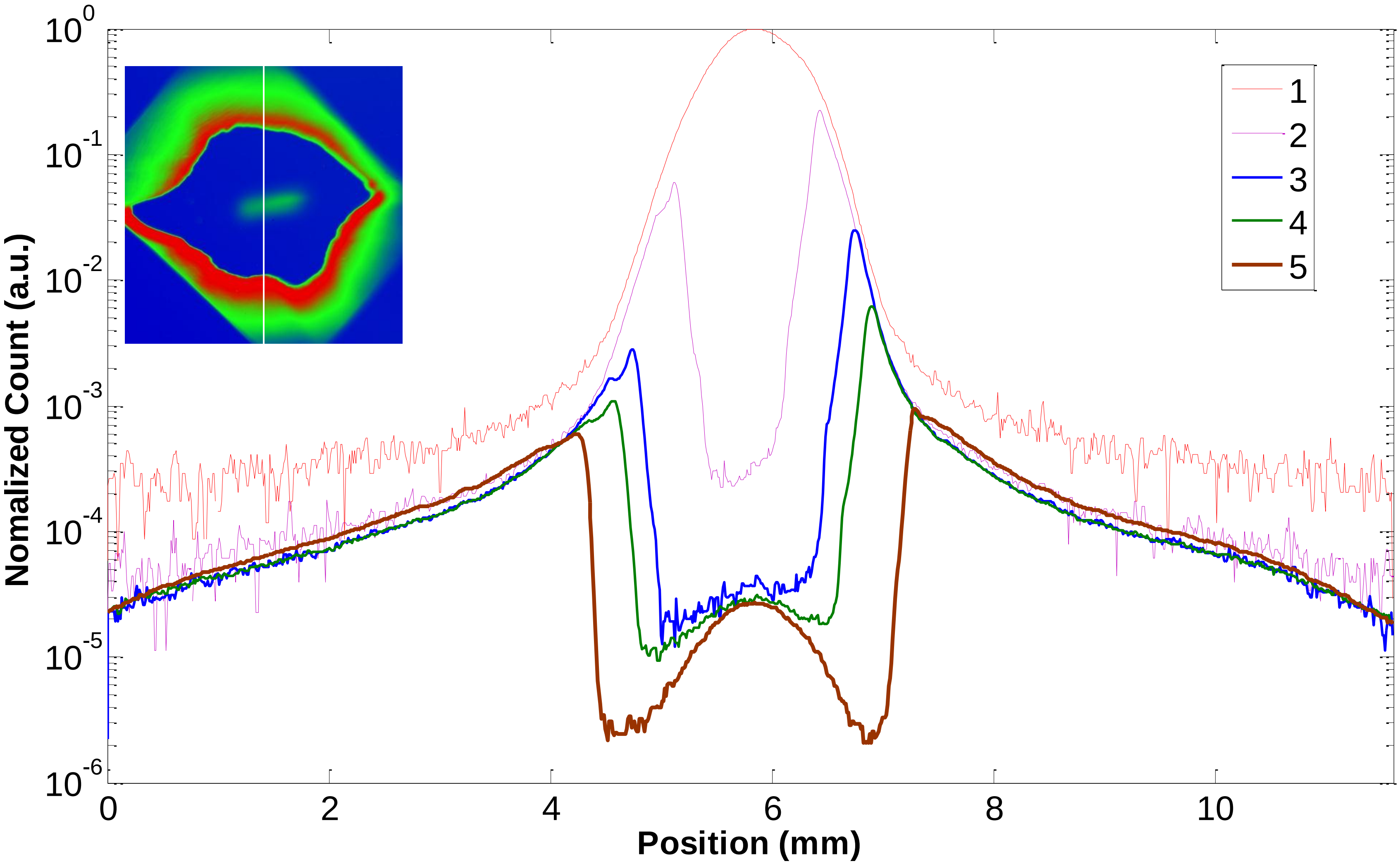
(I = 0.63 mA, 4.68MHz, 65pc/micropulse, $\lambda = 654$nm x 90nm , ND=0.4)



Measurement of Dynamic Range of imaging system

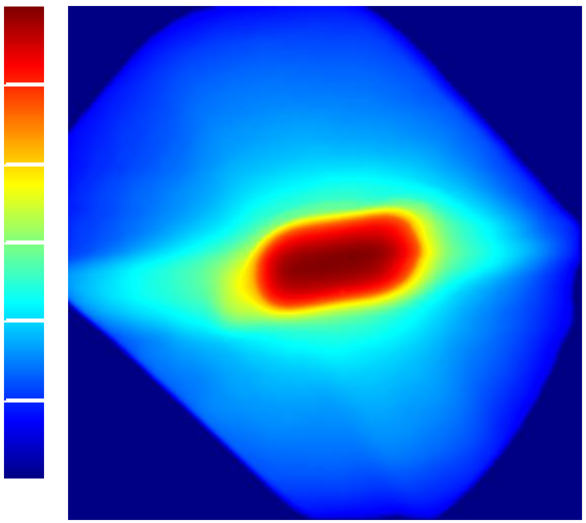


Measurement of Dynamic Range of 0.6 mA CW Beam

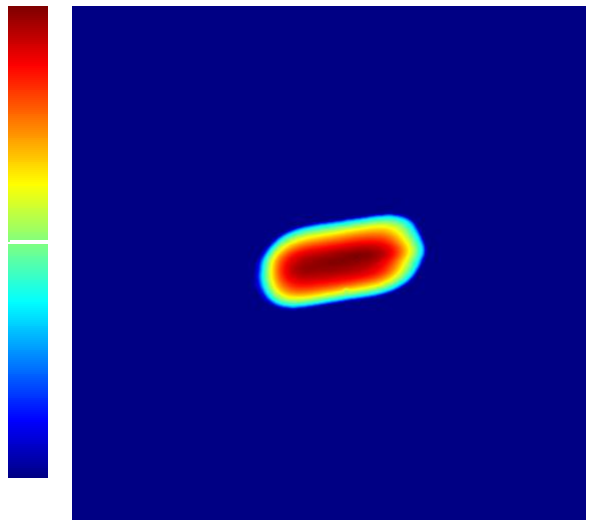


Reconstructed intensity distribution $J(x,y)$ and calculated total radiant energy E_{Total}

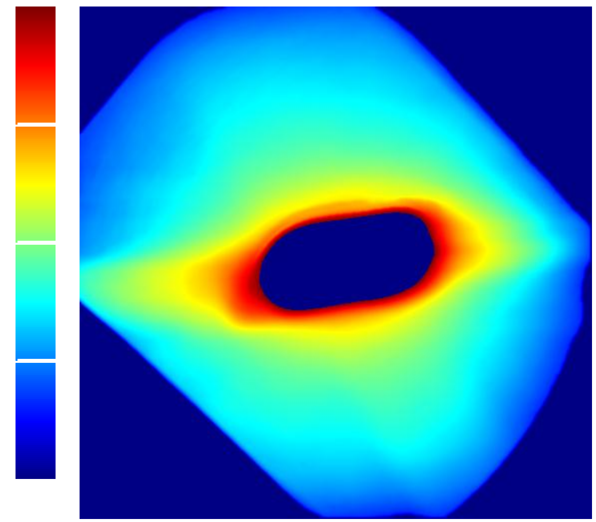
$(1- 10^{-6}) J_{max}$



$(1 -10^{-2}) J_{max}$



$(10^{-2} -10^{-6}) J_{max}$



$$E_{Total} \equiv \int_S J(x,y)dxdy$$

$$E \sim 0.99\,E_{Total}$$

$$E \sim 0.01\,E_{Total}$$

Summary

- Results
  - Developed and tested high-dynamic range (DR ~10^5) halo diagnostic imaging system using a phosphor screen + DMD at UMER
  - Developed a non interceptive OSR DMD imaging system to observe beam halo at JLAB FEL under CW operating conditions; with measured DR > 10^6 .
  - Performed quad scan of JLAB tune-up beam using OSR
- Future plans
  - UMER: Do time-resolved halo imaging and multi-turn halo evolution studies at UMER using DMD to study/mitigate factors effecting halo
  - JLAB:

    Short terms: Verify and possibly improve DR >~10(5) of present system

    1a) Improve background measurements and verify halo is not due to stray light from upstream internal sources

    1b) decrease optical magnification onto DMD and /or increase current density via current, focusing/tune;

    Long term: Extend DR of halo measurement to limit:

    1) add Lyot and/or apodizing stops to decrease effect of diffraction

    2) improve optical transport with enclosures and antireflection coating on optics port to further reduce any external stray light
  - Compare emittance measurements using OTR and OSR quad scans
  - Explore possibility of using DMD to measure halo/core emittances and to do optical phase space mapping (optical analogy of pepper pot technique)