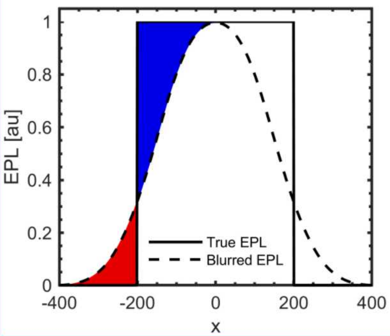
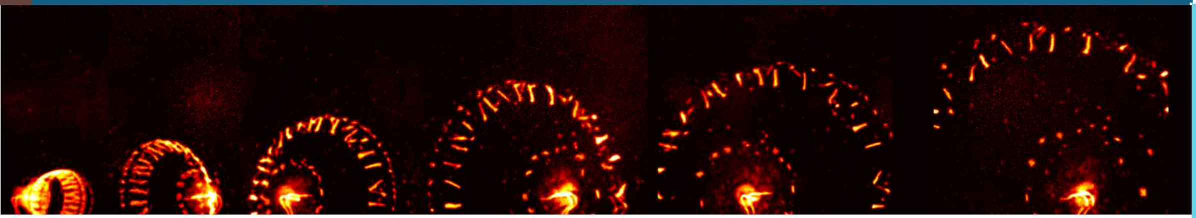
SAND2019-5013C

Preliminary Investigation of Apparent Mass Loss in Objects Due to Image Blur using X-ray Radiography





PRESENTED BY

Benjamin R. Halls (1512)

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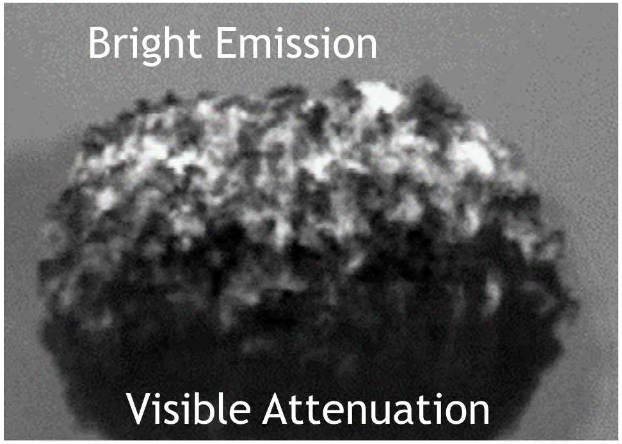
Motivation

GOAL: Understand highly dynamic multiphase flows, inherently stochastic and three dimensional

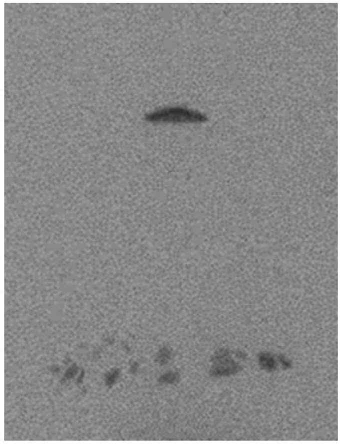
OBJECTIVE: Measure particle mass, velocity, acceleration, shape, and time history

CHALLENGES: Visible emission, particulate scatter, shock waves

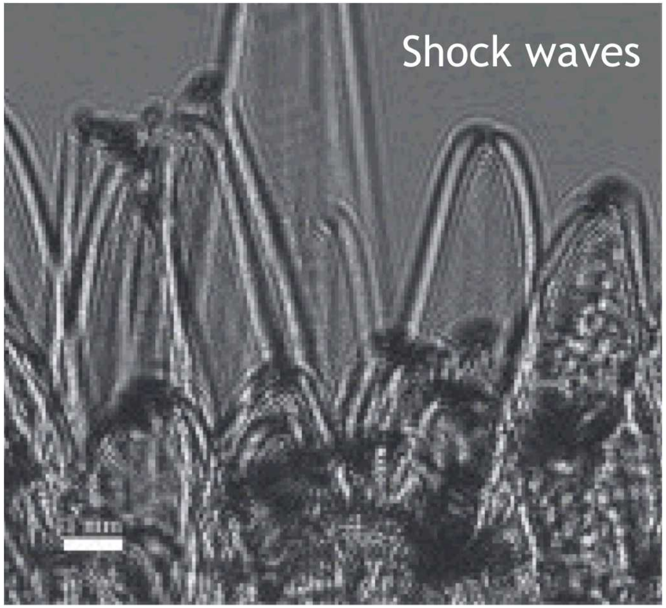
OUTCOME: Time-resolved, three-dimensional, quantitative mass distribution



Diffuse Back Lit Imaging



X-ray Imaging



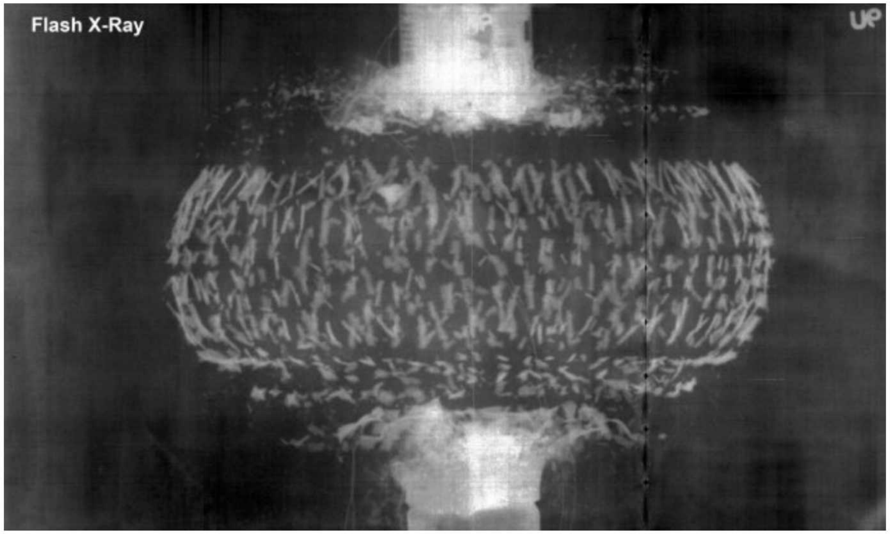
Digital Inline Holography

Guildenbecher et al., 2017

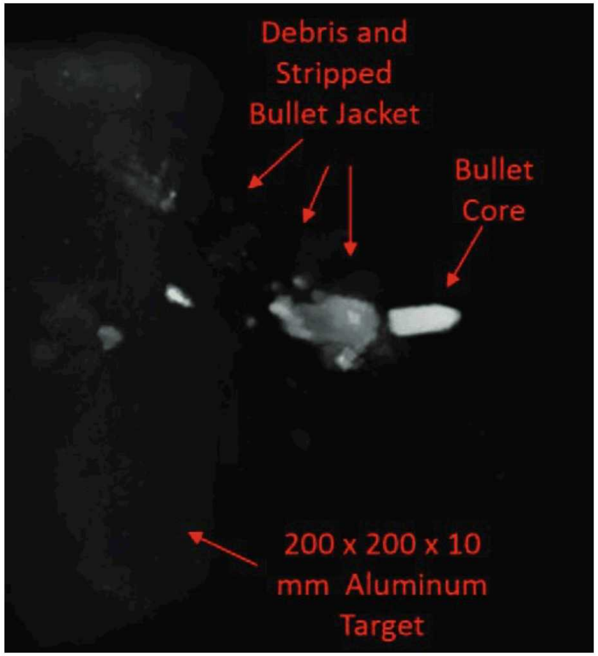
Flash X-ray Imaging

BENEFITS: Overcome visible light perturbations, density-based interaction enables mass measurements, short exposures

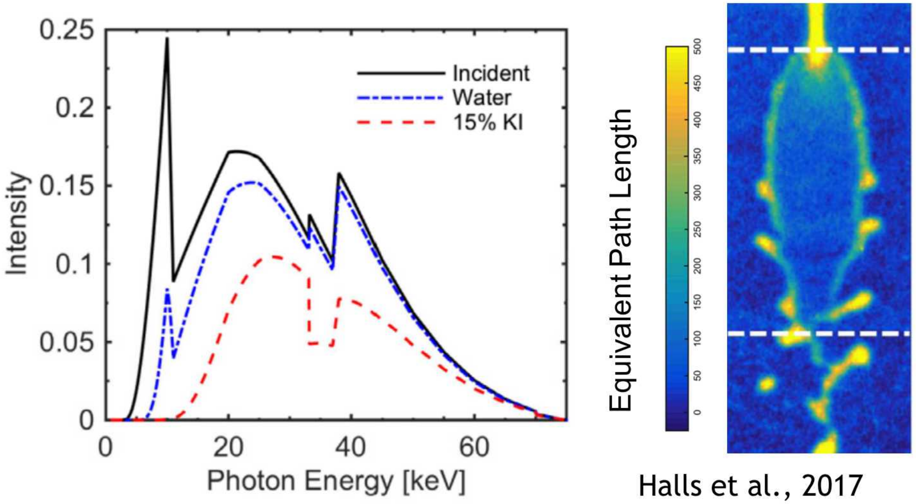
CHALLENGES: Limited number of images, multiple images requires multiple sources causing image parallax and need for phase locking



https://www.army.mil/article/163257/redstone_test_center_prepares_to_open_new_x_ray_facility



Zellner, et al., 2018



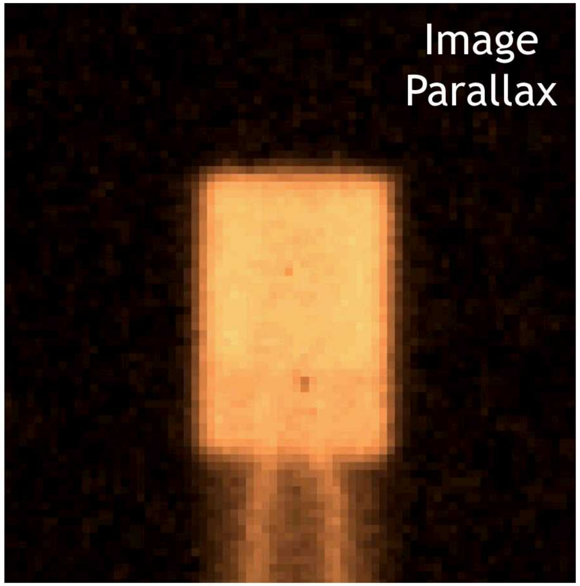
Halls et al., 2017

Three-Dimensional Imaging

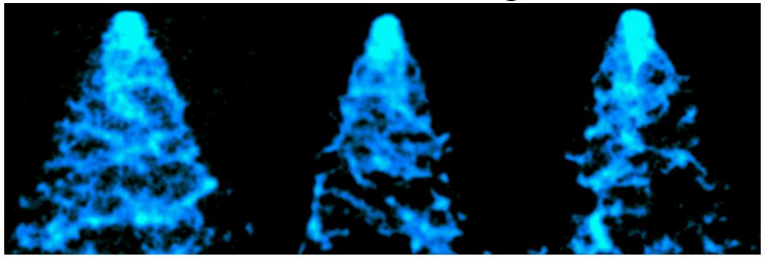
Traditional tomography requires simultaneous views from multiple perspectives

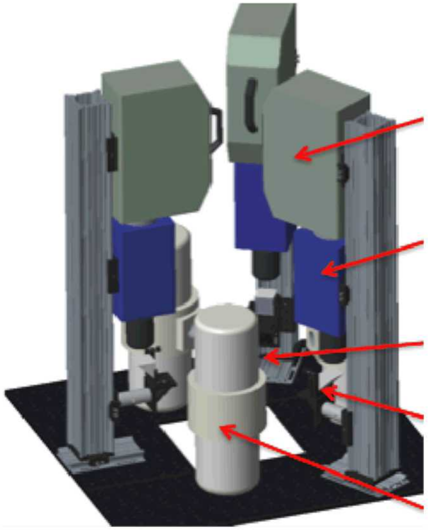
Flash radiography suffers from image parallax

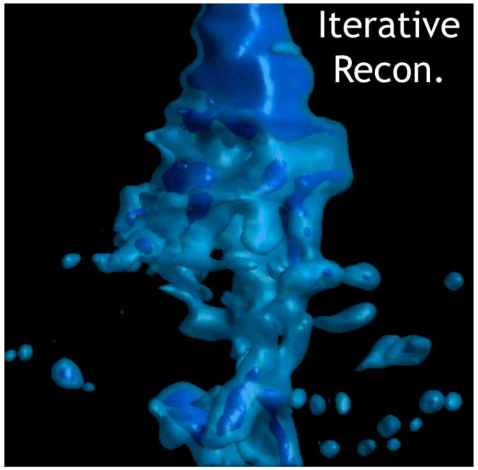
Is there a technique that relaxes these concerns?



Simultaneous Images







Space-Time Interlaced Tomography

Image parallax becomes a benefit, holds 3D information

Flexible imaging systems: size, location, dynamic range…

X-ray Sources
- L3, 150 kVp, W anode, Be window
- ~70 ns pulse width

Spatial Resolution
- 10–90% Rise dist. = 1.2 mm, Vol. ~ 1.6 mm

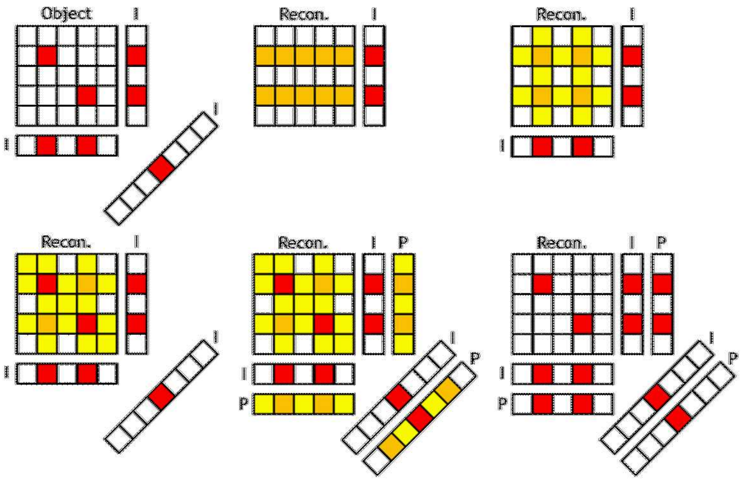
Explosive Device
- Fragment size = 4–20 mm

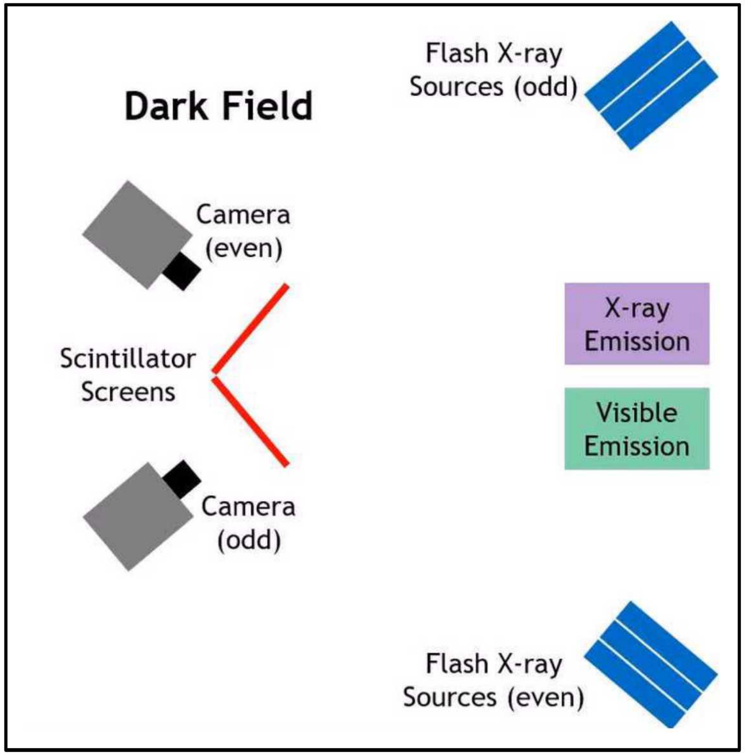
Scintillator Screens
- 45 ns decay time, 415–425 nm emission

High-Speed Cameras
- Phantom 2512, 50 mm f/1.4 Nikon
- 62 kHz imaging with 31 kHz frame rate

Phantom 2512
62 kHz
480 x 768

Phantom 2512
31 kHz
768 x 1024





X-ray Image Processing

Dot Target Calibration
- LaVision software

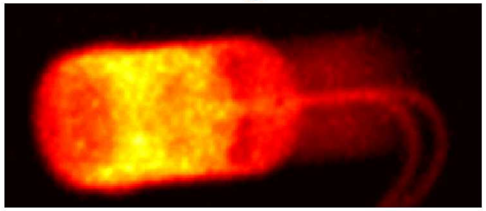
Remove Salt Noise

Normalization
- 2D Gaussian fit

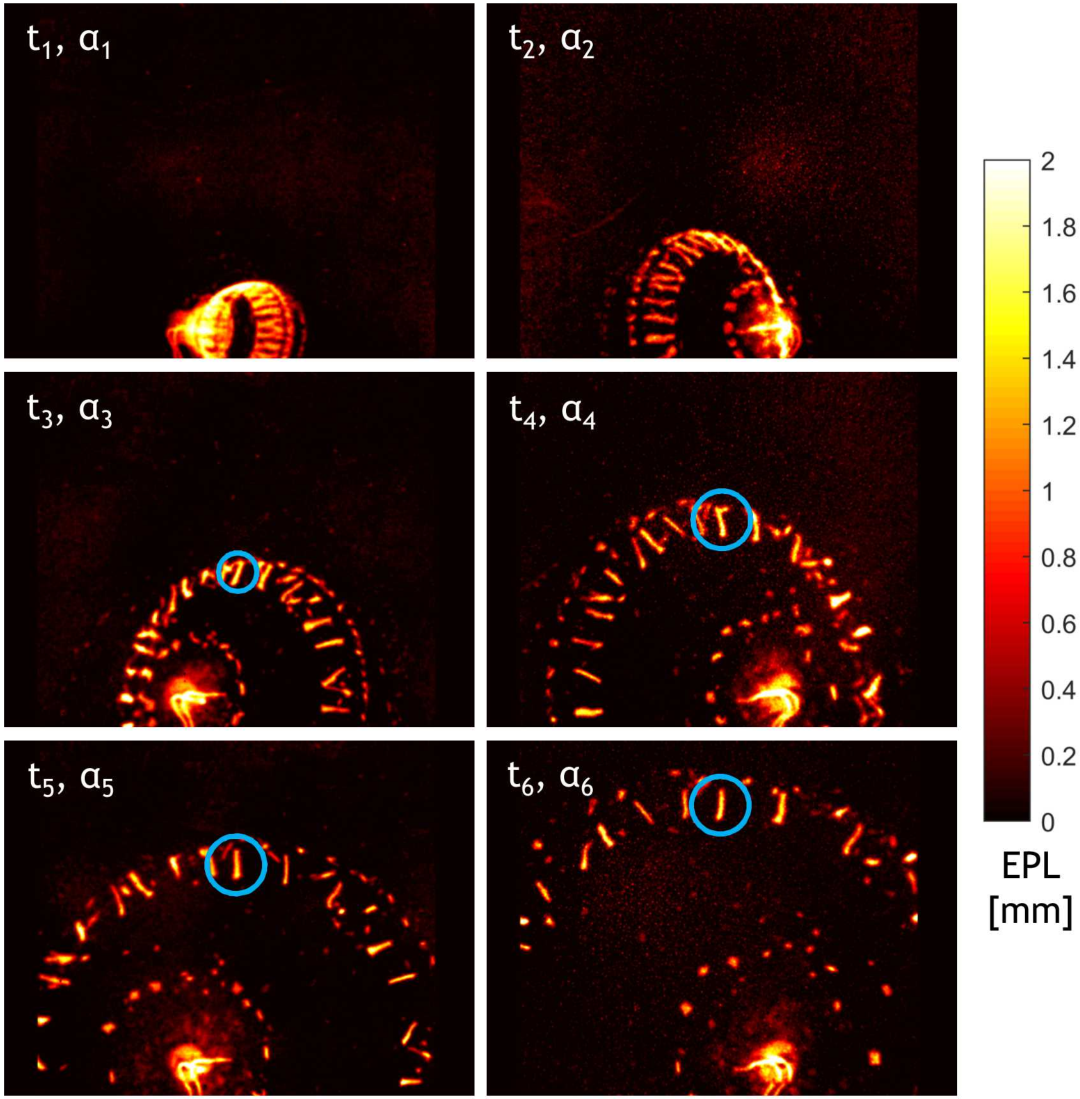
Equivalent Path Length
- Spectrally resolved atten. coeff.
- Beer-Lambert law

Particle Segmentation
- Binarize image
- Click particles
- Center of mass = location

Static Image of Det.



Dynamic Images of ED



Search Process

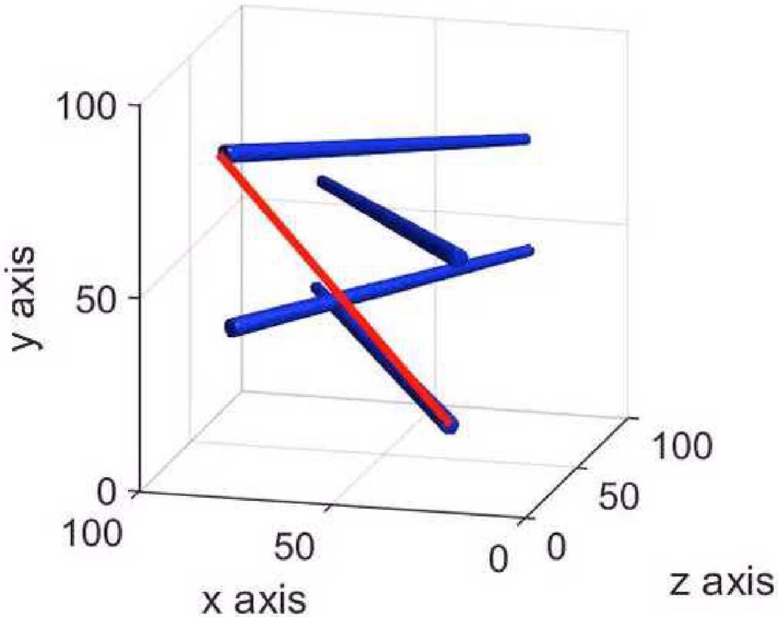
Indices of centers of mass are back projected through the volume

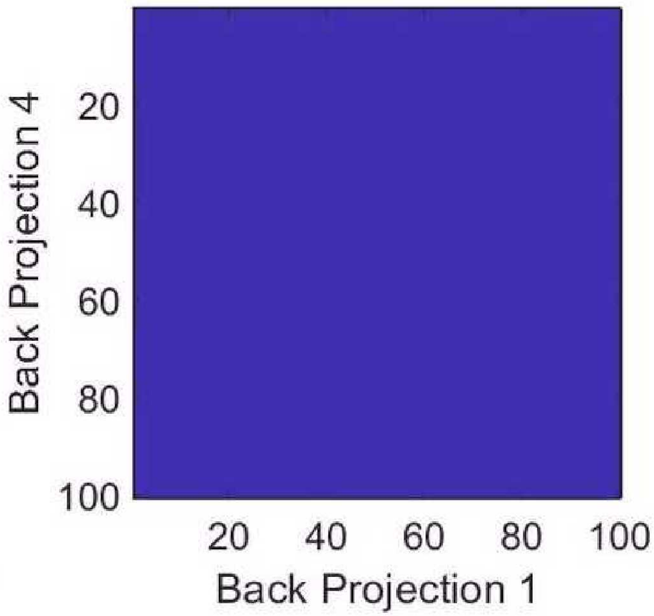
No lines intersect since the particle has moved in time

1) Locate the possible particle location along the first and last projections

2) Map the space between to locate the other possible locations of the particle

3) The peak in the map marks the trajectory





Search Process Complete

Good: You always get a reconstruction

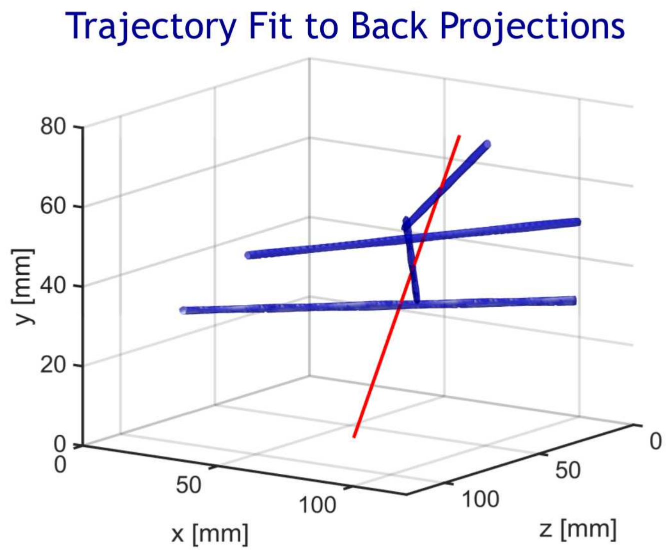
Bad: You always get a reconstruction

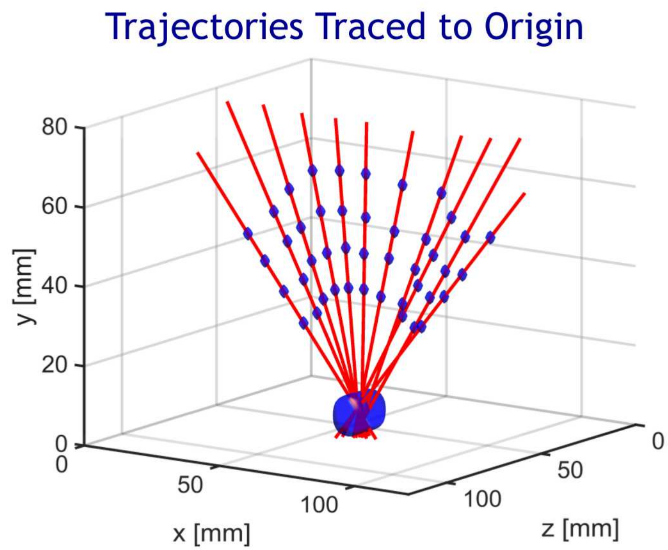
Uncertainty

- Volume resolution ~1.6 mm
- Spread of trajectories ~5 mm

Causes of Uncertainty

- Velocity / Direction
  - Camera–source calibration (dot target)
  - Particle segmentation and
  - Center of mass determination
  - Spatial resolution
- **Mass**
  - **Attenuation model / calibration**
  - **Image blur, image characteristics**
  - **Noise**





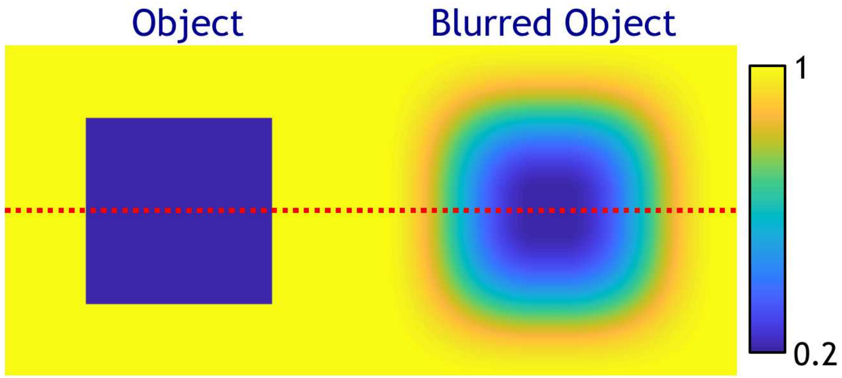
Mass Loss

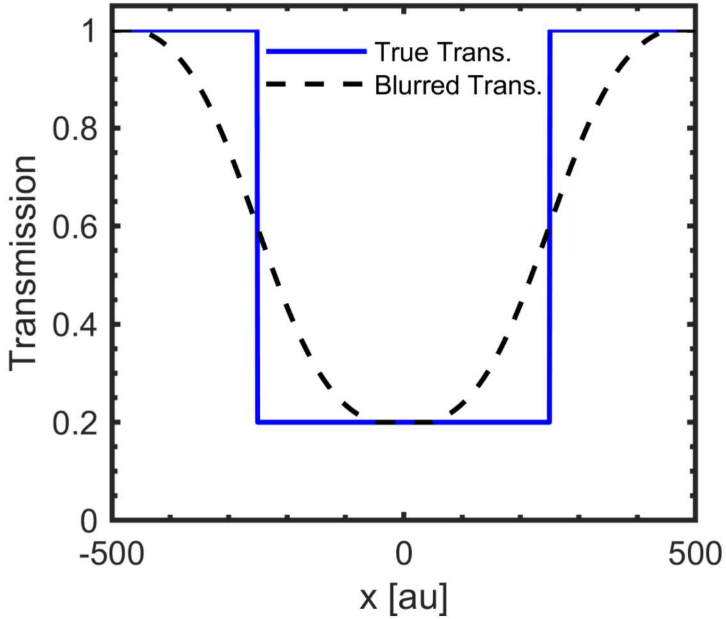
Mass from spatially integrated EPL image

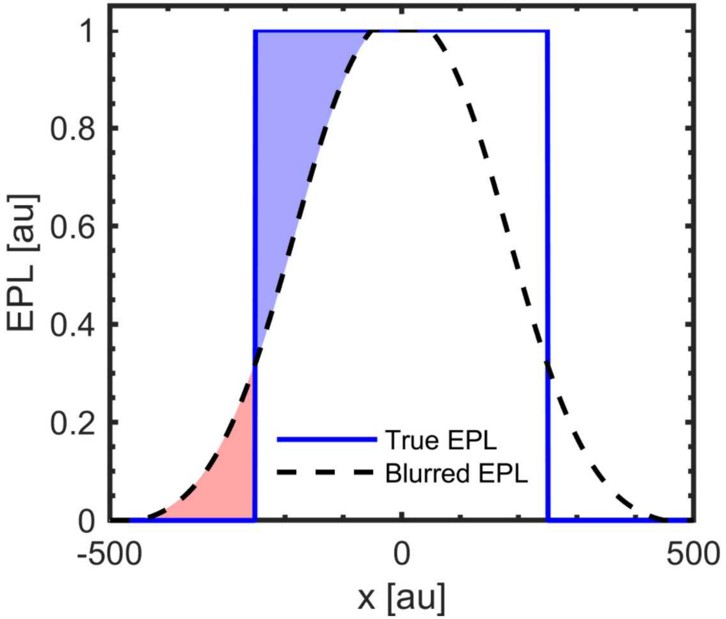
Blurred transmission image corrupted during nonlinear conversion

Effects to consider

- Object size
- Image blur
- Level of transmission (degree of nonlinearity)
- Variance of transmission
- Pixel size
- Noise (gain)







Sources of Blur

Penumbra (geometric blur)

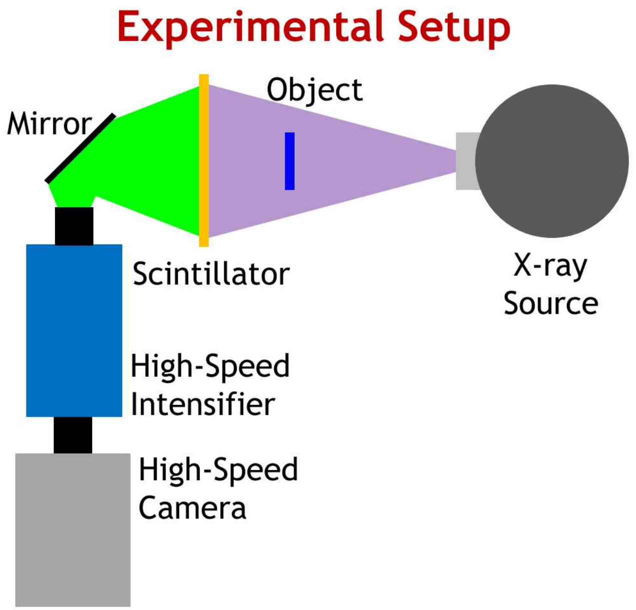
- Absolute value
- Size of the anode and position of the object between the anode and the scintillator

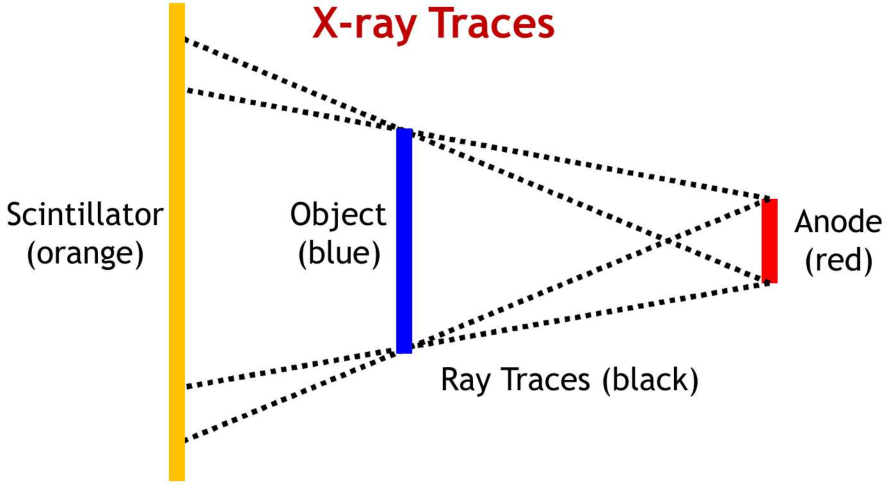
Scintillator Blur

- Absolute value
- Scatter in the scintillator

Detector Blur

- Relative Blur (changes with image magnification)
- Objective / lenses
- Intensifier
- Camera





Experimental Setup

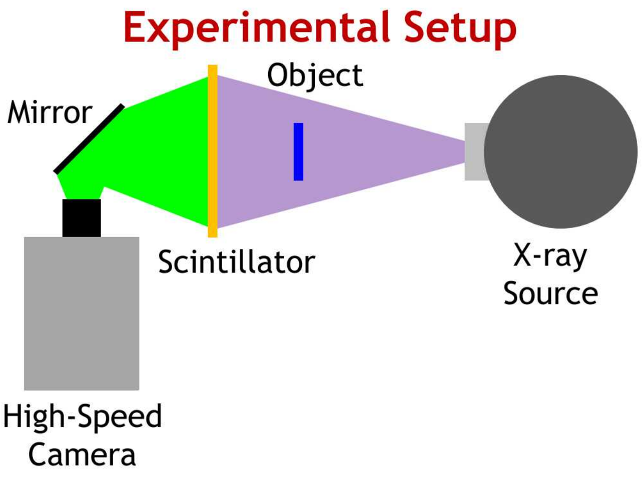
X-ray Source
- 150 kV, 160 mA

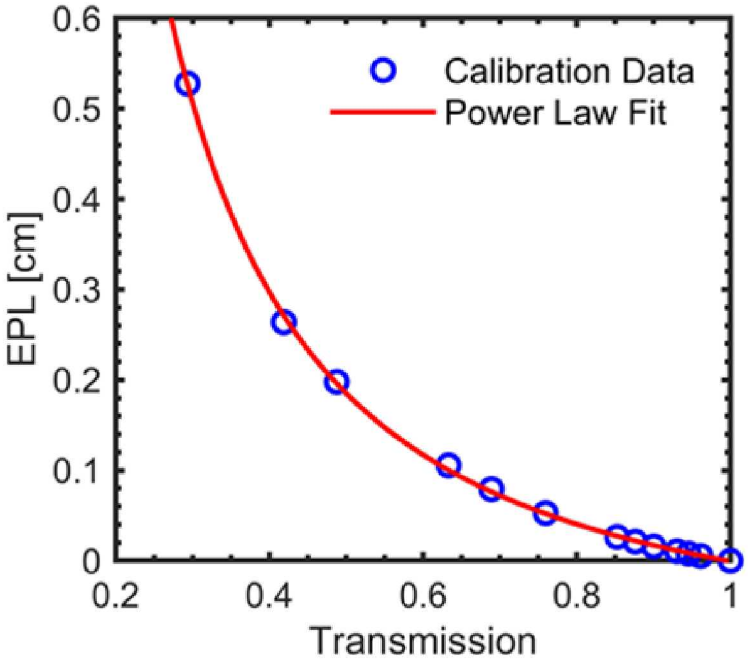
Scintillator
- GOS:Pr
- ~4 μs decay time

Detector
- 50 mm f/2 Nikon Objective
- Phantom 2512
- 1 kHz, 990 μs

Spatial Blur
- Blur controlled by defocusing the lens
- All other image parameters kept constant

Image Processing
- Averaged 200 flat-field normalized images
- Spatial resolution: 10–90% rise distance
- Mass based on calibration curve
  - Varied thickness of stainless steel plates





Preliminary Results

Relative Blur is the ratio of spatial resolution (10–90% rise distance) divided by the area-to-perimeter ratio

$$Rel.\,Blur = \frac{rise}{\left(area/_{perimeter}\right)}$$

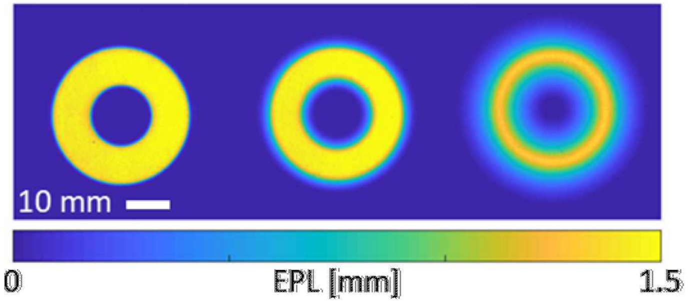
$$Rel.\,Blur = 1, rise = \frac{r}{2} = \frac{d}{4}$$

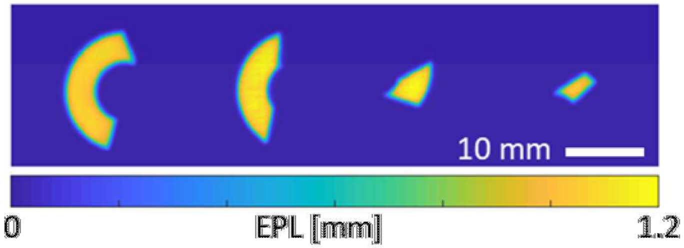
Relative Mass Loss is the ratio of true mass to measured mass

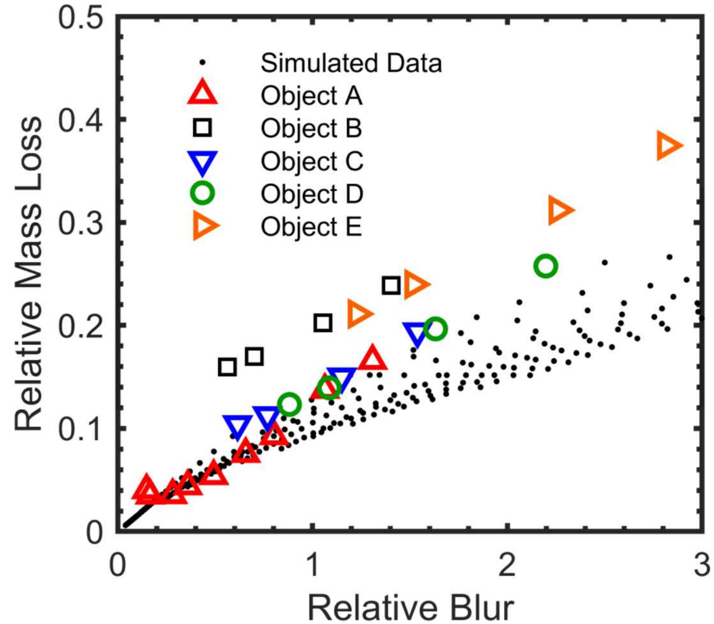
$$Rel.\,Mass\ Loss = \frac{(true - measured)}{true}$$

Discrepancy in objects B and E result of EPL conversion error

- <u>Non-uniform scintillator</u>
- Non-uniform source
- Stray light



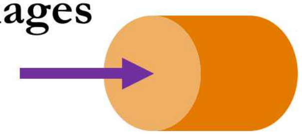


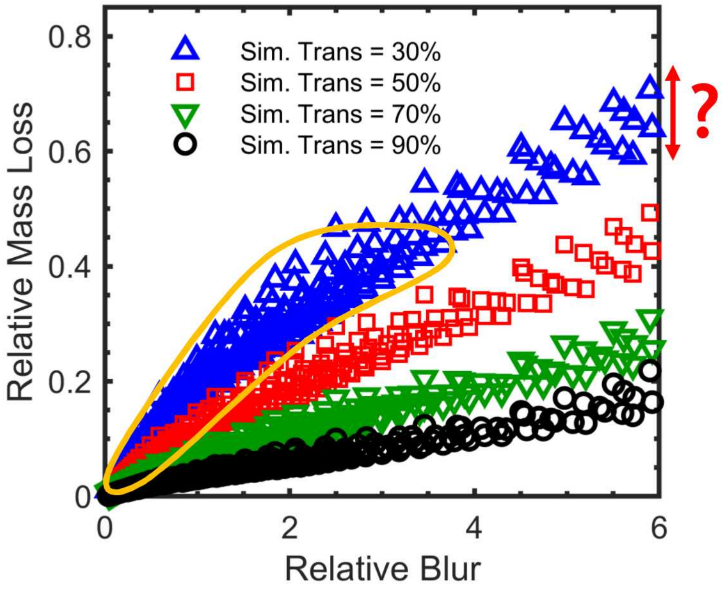


Effect of Transmission

Based on simulated cylinder images

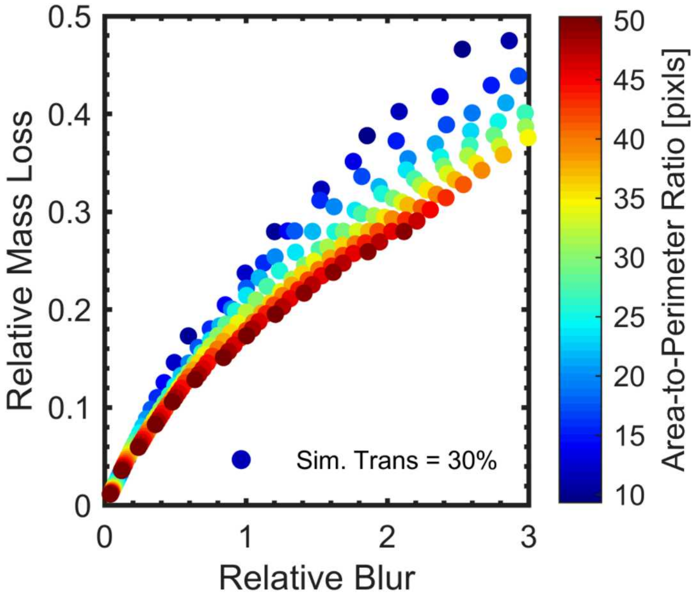
- End on cylinder images
- Variables: diameter, thickness (transmission), degree of spatial blur, pixilation (secondary)





Transmission varied to determine effect on mass loss

- Increased transmission leads to increased mass loss
- Spread in data attributed to degree of object pixilation



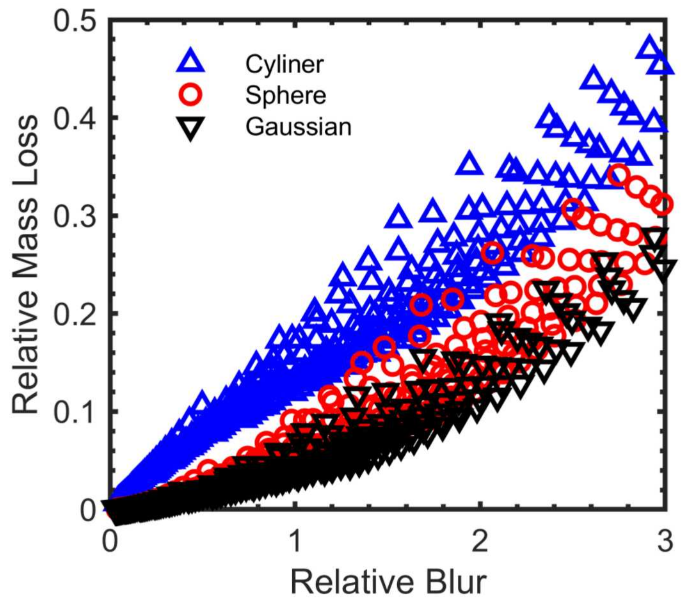
Effect of Object Shape (Average Attenuation)

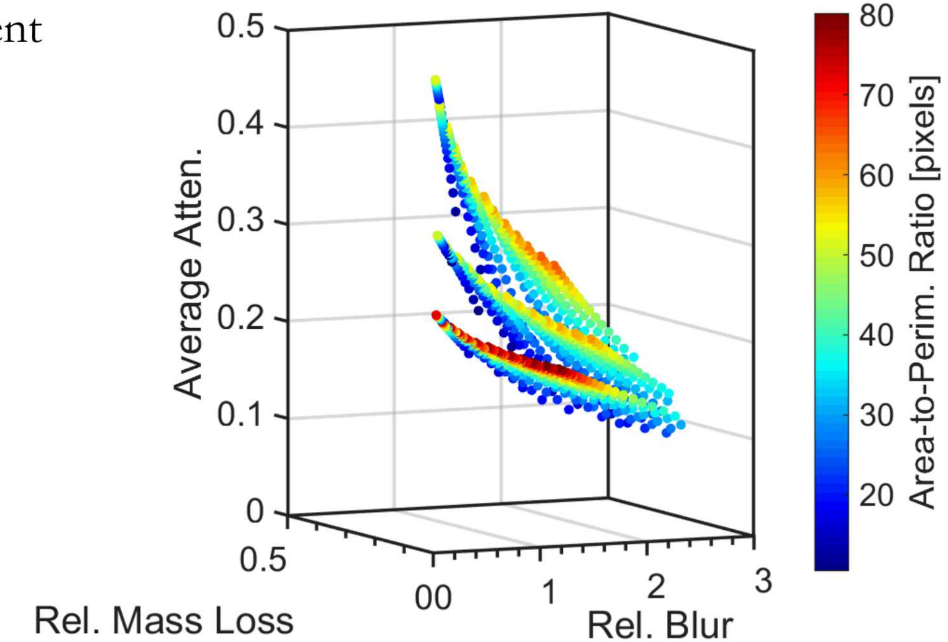
The shape of an object will effect the mass loss

- Steep gradients will be more effected by spatial blur

Three shapes investigated

- Cylinder, Sphere, 2D Gaussian
- Mass loss tracks well with average attenuation
- Further investigation required, different shapes with same average attenuation



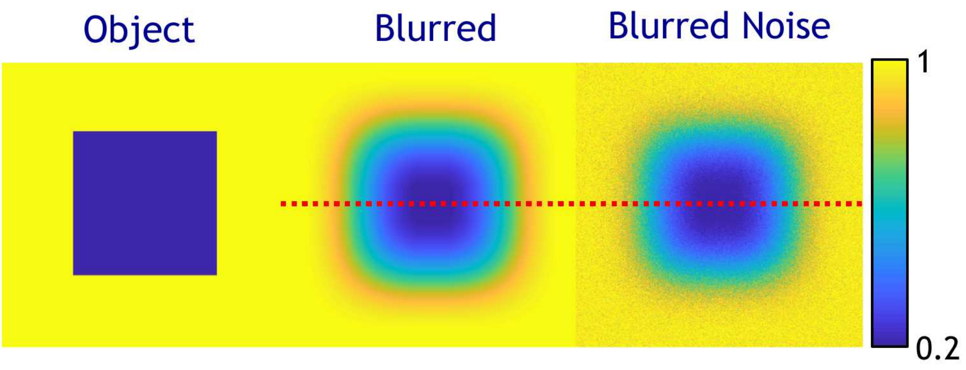


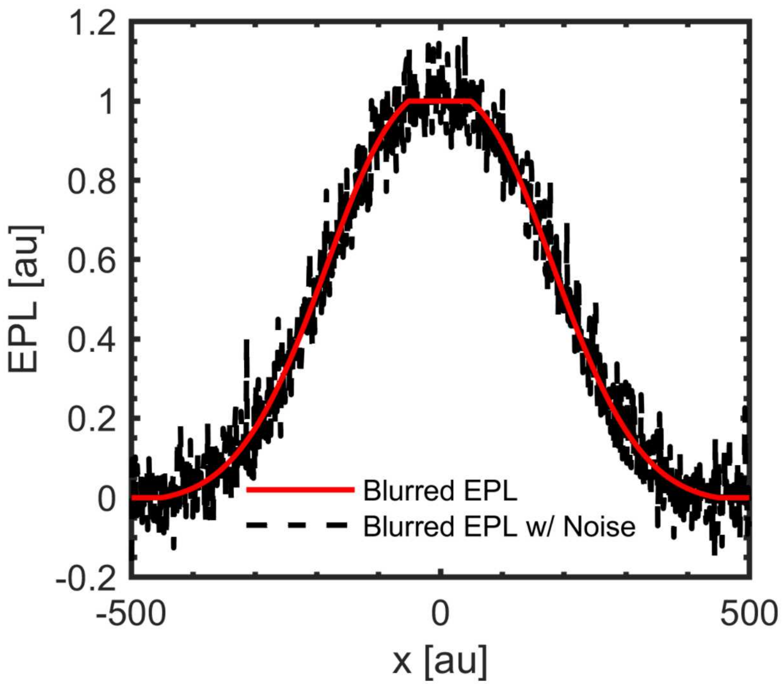
Effect of Noise on Mass Loss

Random noise will increase the measured mass of an object due to same nonlinear conversion from transmission to path length

- Example: CNR = 5, Mass Gain ~1%
- Not a major concern du to other uncertainties

Noise will also effect the determination of image blur





Implementation

Variable	Tractable (Y/N)	Experimental
X-ray Transmission	Yes (mono. Spec.) No (poly. spec.)	Constant conversion
Length / Blur	Yes	Variable
Pixilation	Yes	Constant pixel size
Blur Shape	No (spatial) Yes (temporal)	Constant

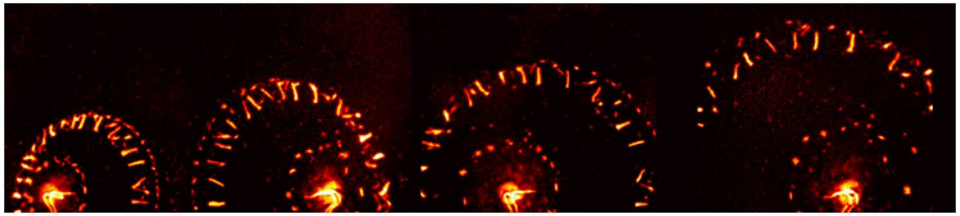
Not practical to simulate all possibilities, but can on case by case basis

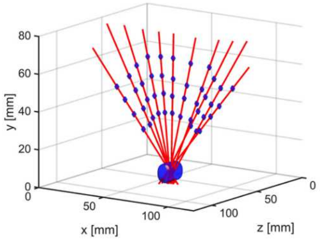
Develop frame work to account

- Framework inputs:
  - Particle segmentation
  - Transmission calibration, pixel size, blur shape
- Framework outputs:
  - Program applies inputs to wide range object shapes and sizes
    - Potentially bounded by *a priori* knowledge of imaging field
  - Generates mapping function to correct the mass of each object

Summary

High-speed particle tracking using Space–Time Interlaced Tomography





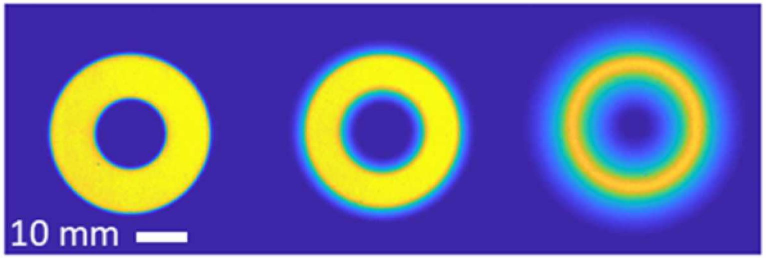
Quantitative mass distribution using x-ray radiography hindered by spatial blur

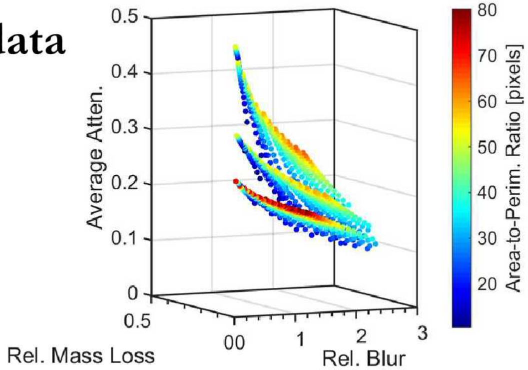
Uncertainty in mass measurements has been investigated

- Size and shape of particles
- Average attenuation of particles
- Degree of spatial blur

Further investigation of variance in attenuation needs to be considered

Framework needs to be validated against experimental data





Thanks to Dan Guildenbecher, Luke Lebow, Kyle Lynch, Enrico Quintana and Adam Jimenez for technical discussions.

Thank you for your attention!

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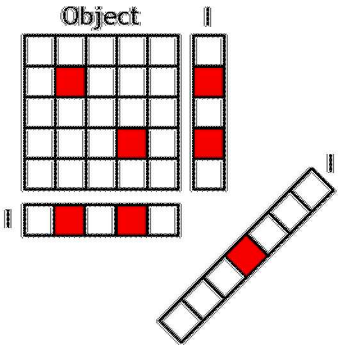
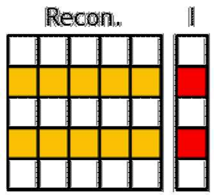
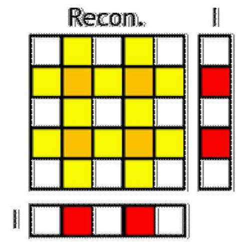
Object & Images



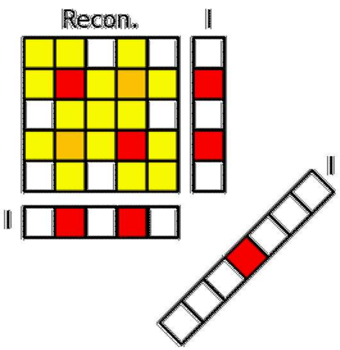
Back Projection 1



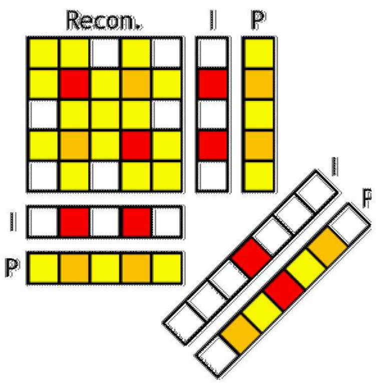
Back Projection 2



Back Projection 3



Guessed Images



Iterative Recon.