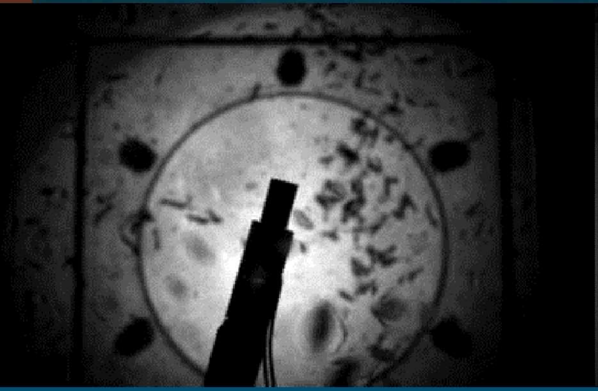
SAND2018-14188C

Refinement and application of 3D particle location from perspective-shifted plenoptic images



PRESENTED BY

Elise Munz Hall, Zu Puayen Tan, Daniel R. Guildenbecher, & Brian S. Thurow

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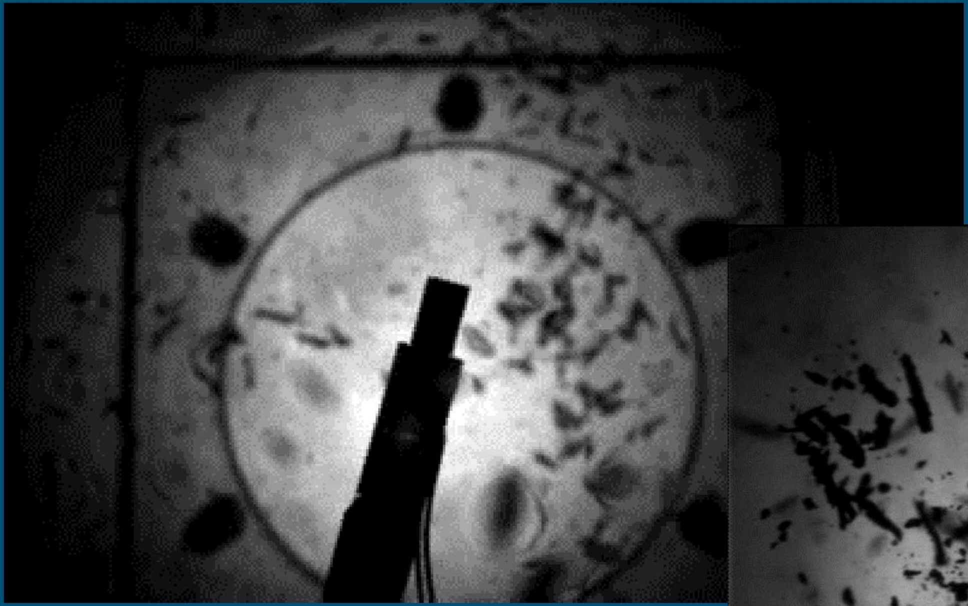
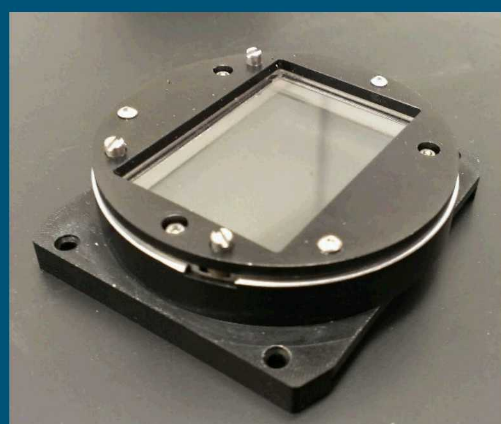


MOTIVATION

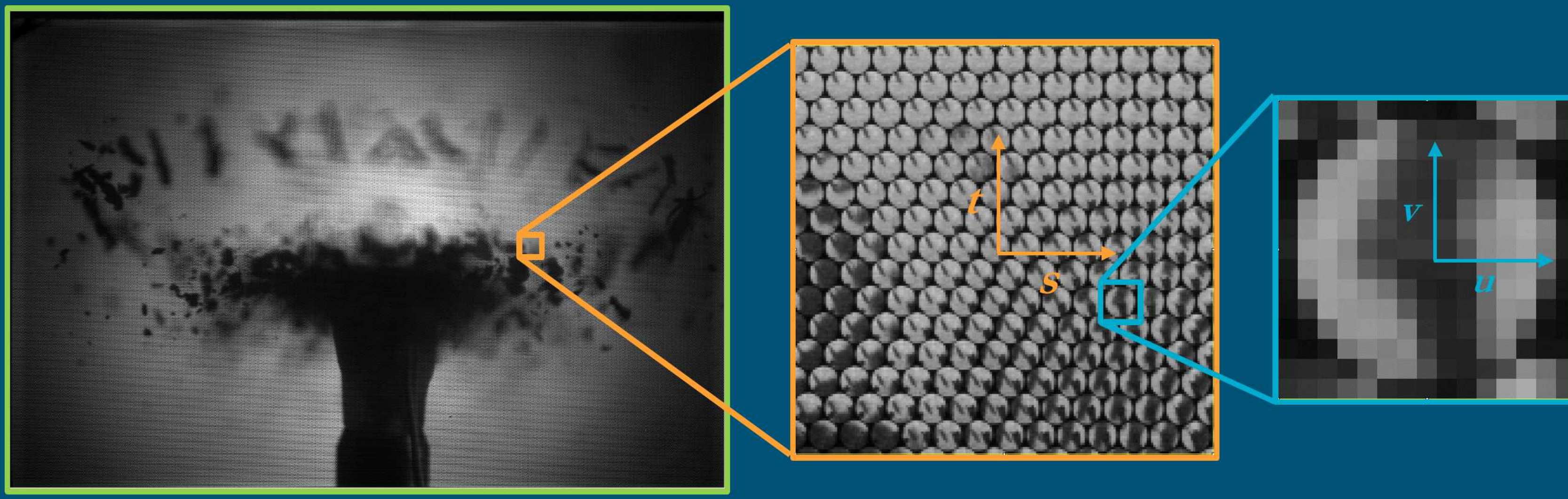
- Particle tracking for a variety of highly 3D applications
  - Explosion analysis
  - Explosion mitigation
  - Measurement of fragment size, shape, velocity

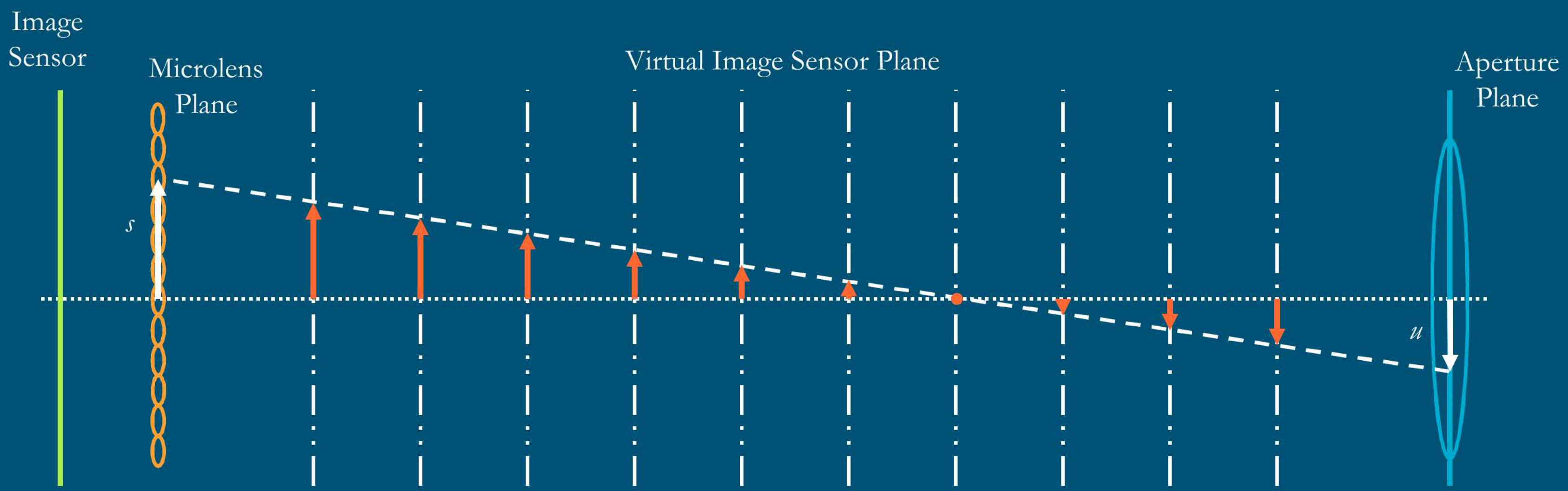
Plenoptic imaging



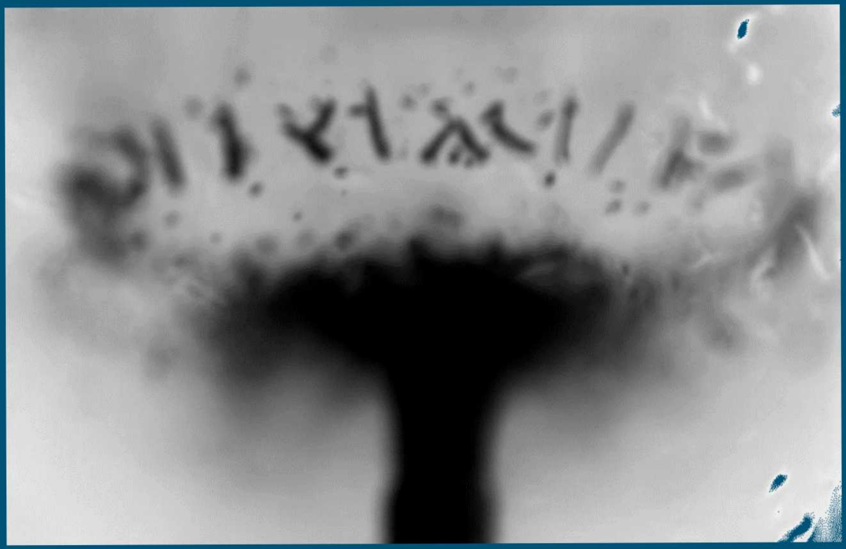
- Camera modified by the insertion of a ***microlens array*** between the main lens and image sensor
- Captures ***spatial and angular*** information which can be processed to extract 3D information
- Refocus and change perspective from a ***single snapshot in post processing***
- ***Single compact camera*** allows for experimental simplification and flexibility

Plenoptic imaging

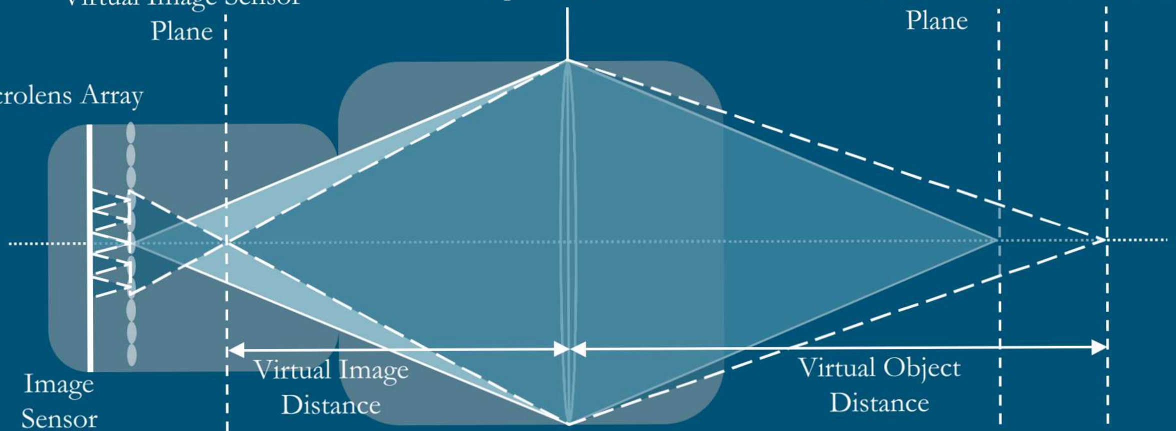




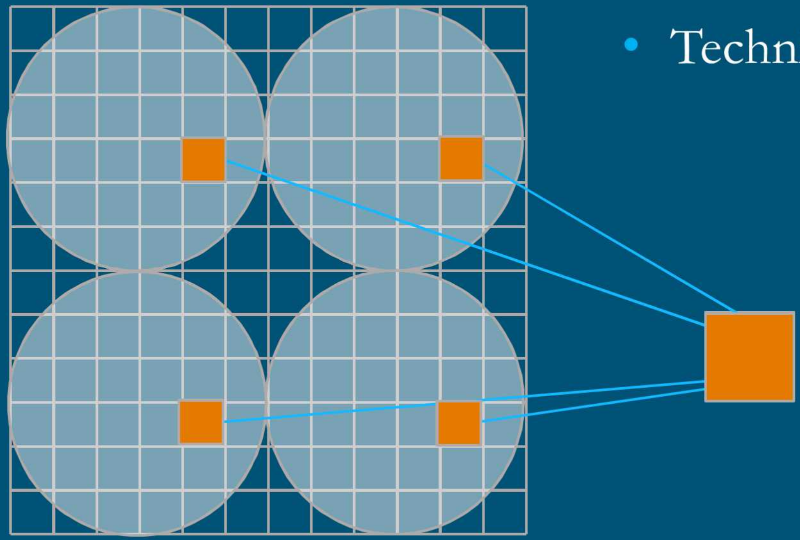
Refocusing



- Allows a change in the depth of the focal plane
- Resulting images are focused over a range of depths
- Object depth determined based on focus
- Integration = computationally expensive

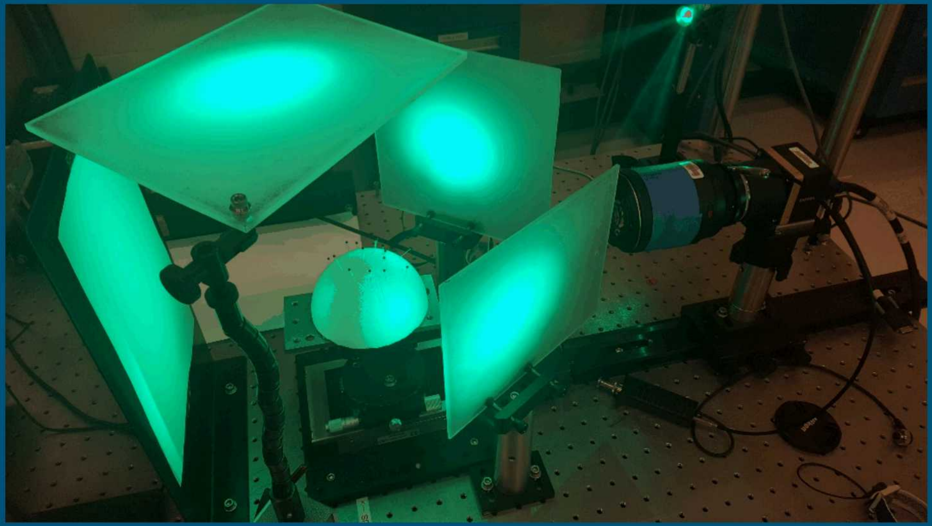


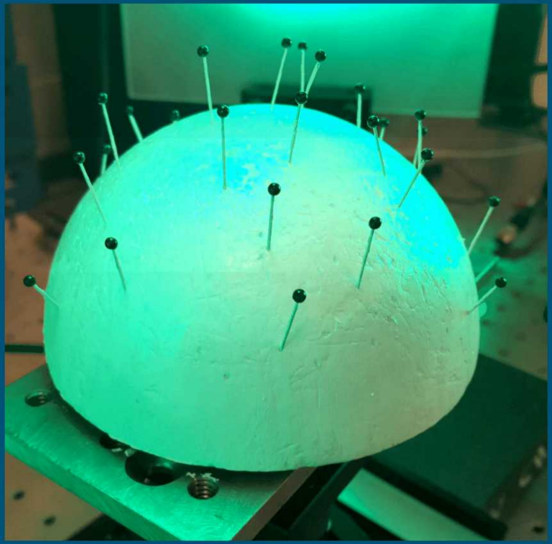
Perspective-shift



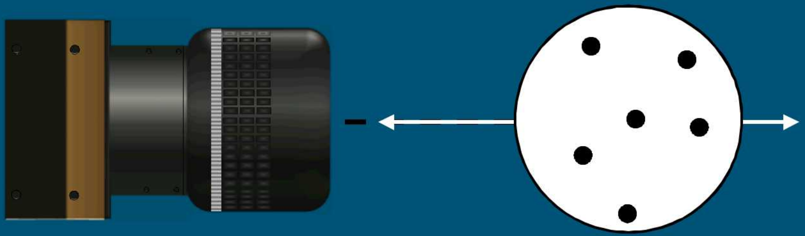
- Allows a change in perspective within the range of the aperture
- Resulting image as if from a small portion of the aperture
- Object depth can be determined based on apparent motion
- Selection of single pixels = computationally *inexpensive*
- Technique of choice in this work

Experimental configuration

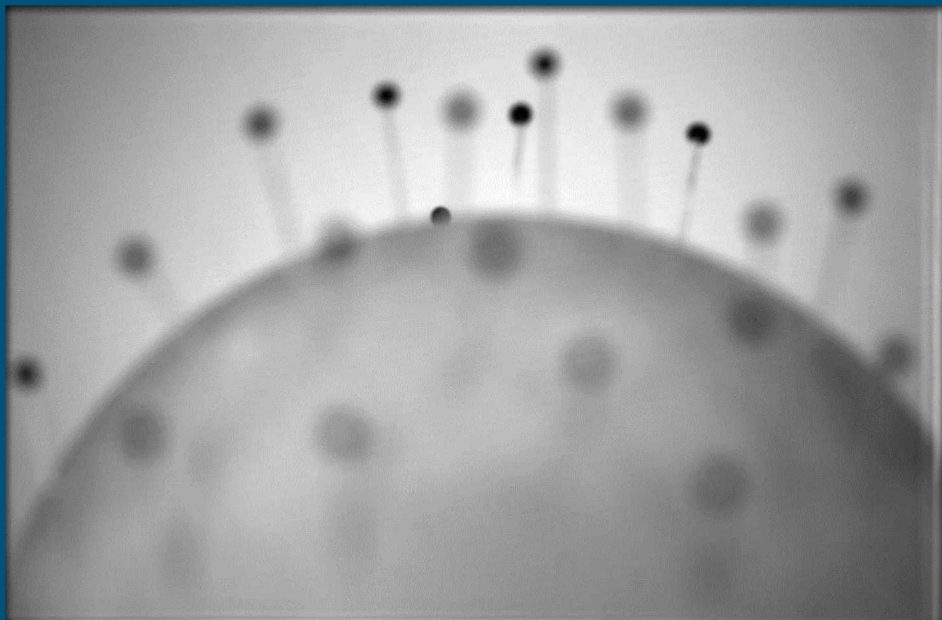




- Simulated static particle field
- Translated to provide known displacement
- Varied nominal magnification
- Large data set allows statistically significant quantitative measurements

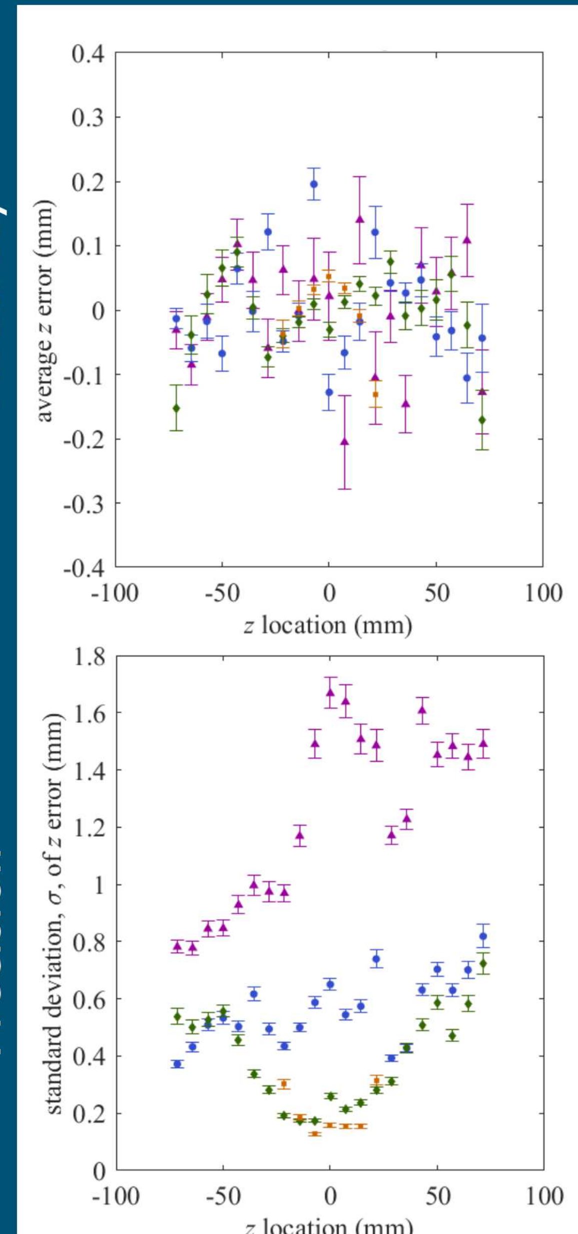


Refocusing based implementation



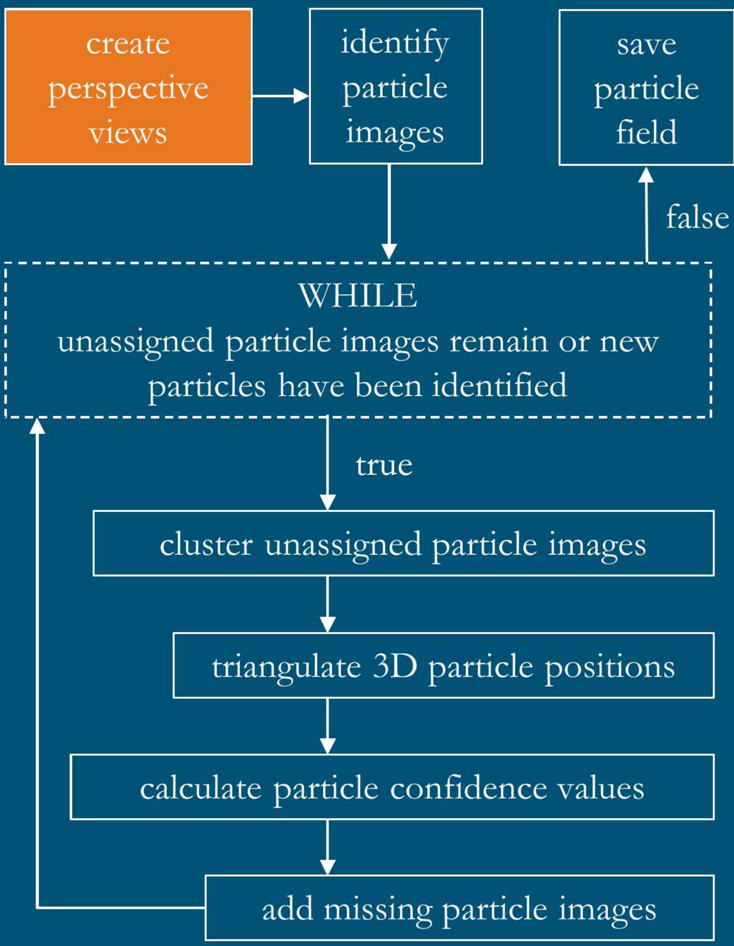
Accuracy

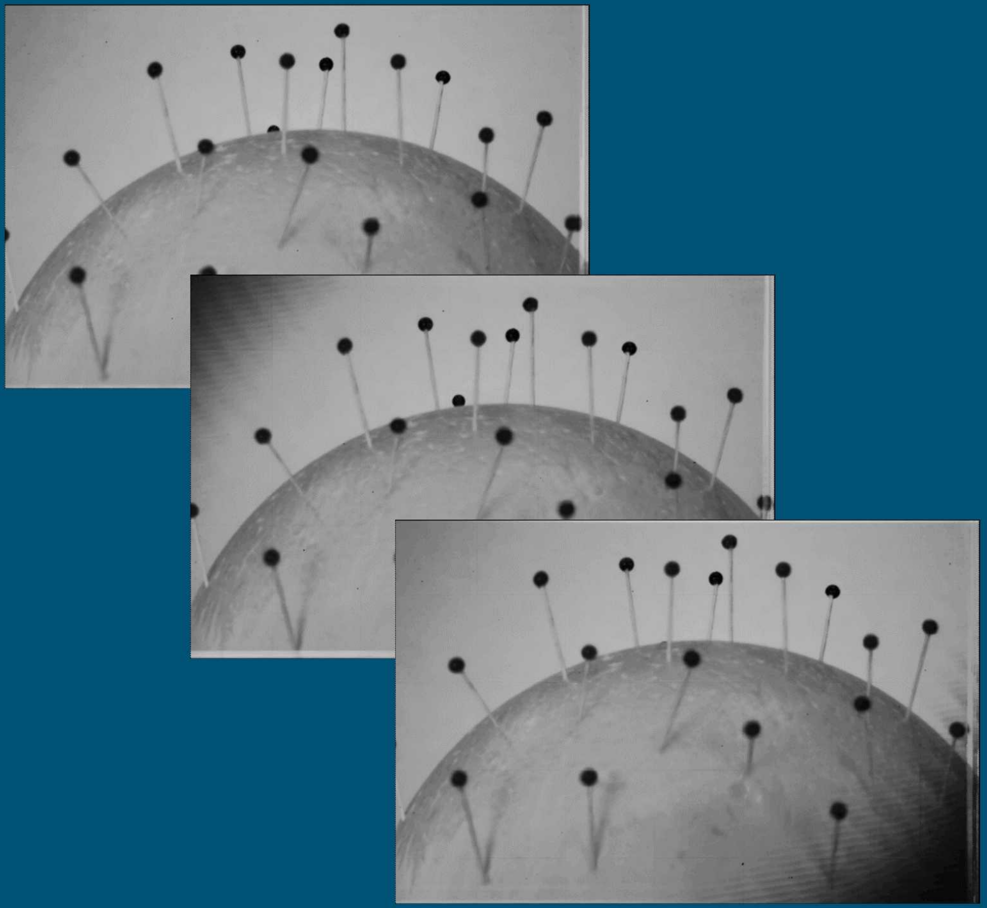
Precision



- Natural method of location identification
- Allowed use of established techniques
- **For depth ranges of 50 mm:**
  - **Accuracy: 0.2 mm**
  - **Precision: 1.7 mm**
- Computationally expensive
- Limited in cases of occlusions

Perspective-shift algorithm



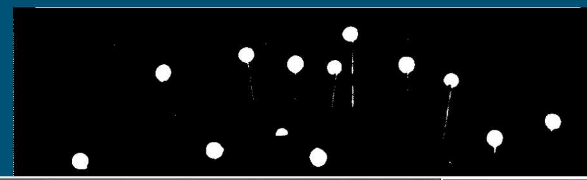


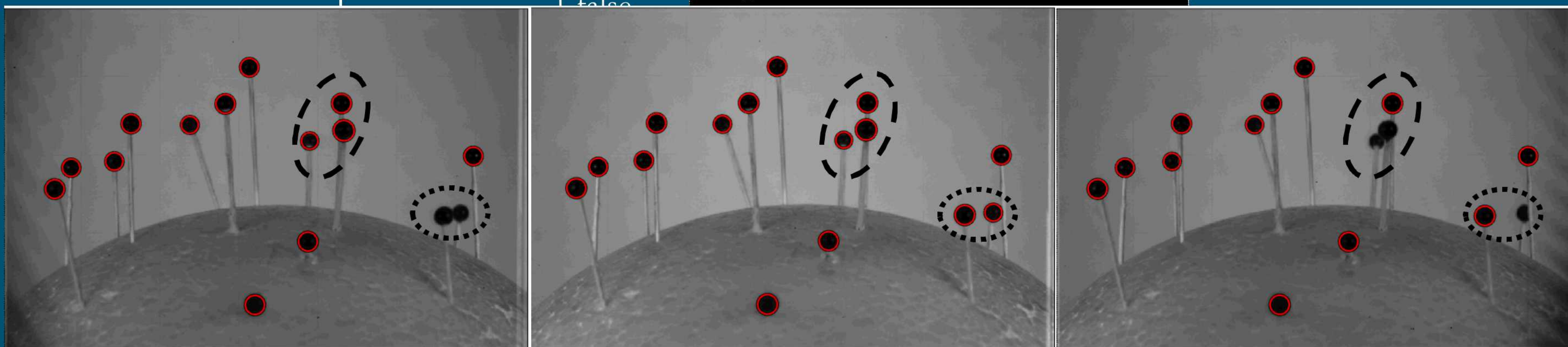
Perspective-shift algorithm

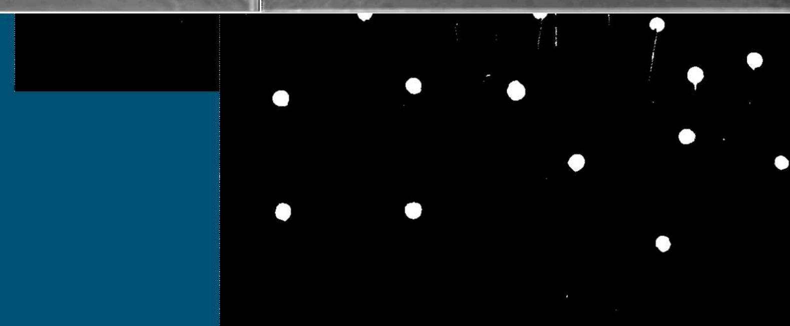
create perspective views → identify particle images

save particle field

false







triangulate 3D particle positions

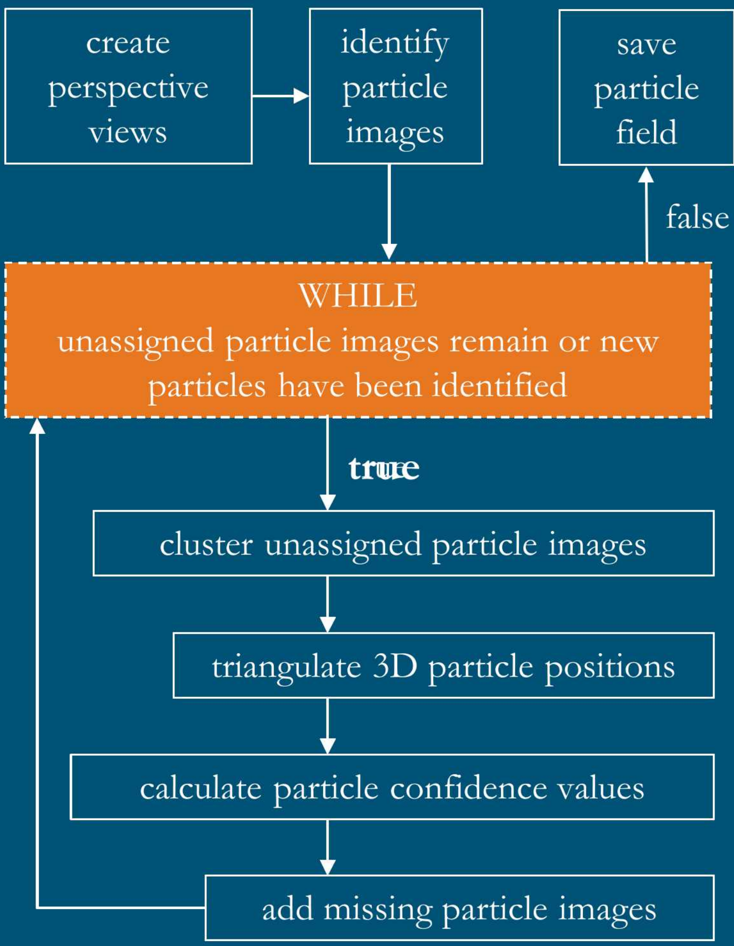
↓

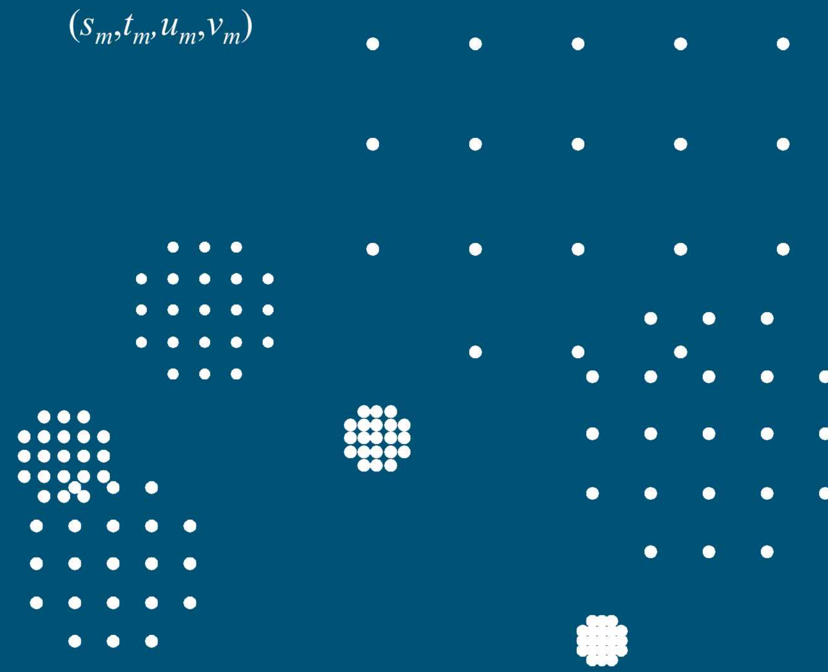
calculate particle confidence values

↓

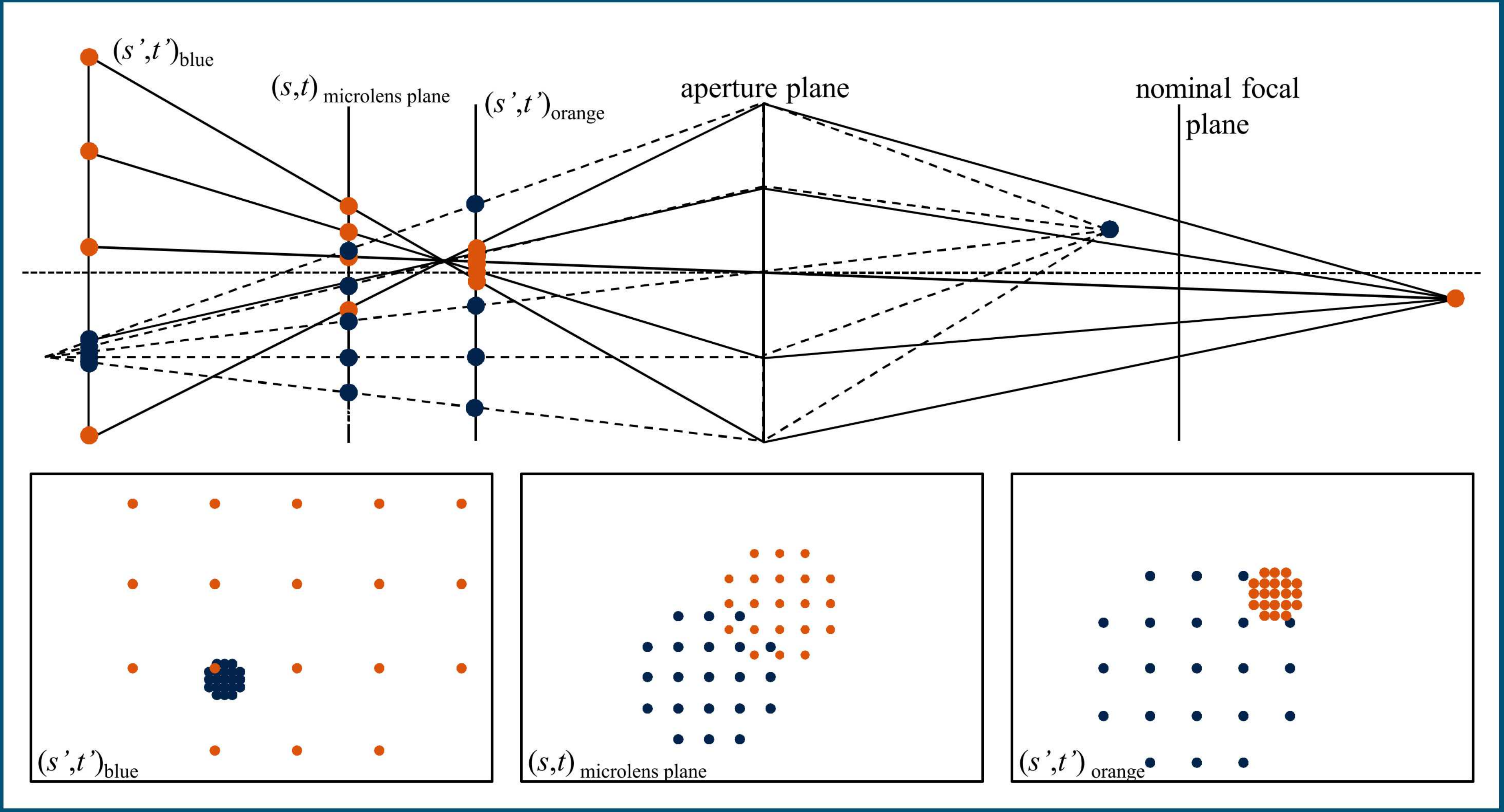
add missing particle images

Perspective-shift algorithm

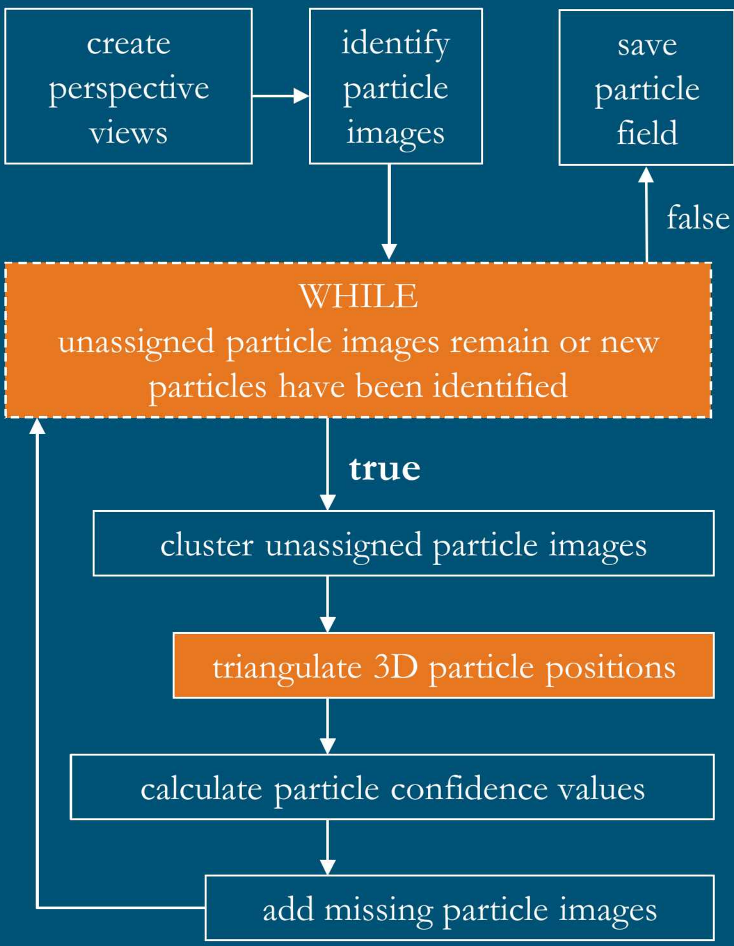


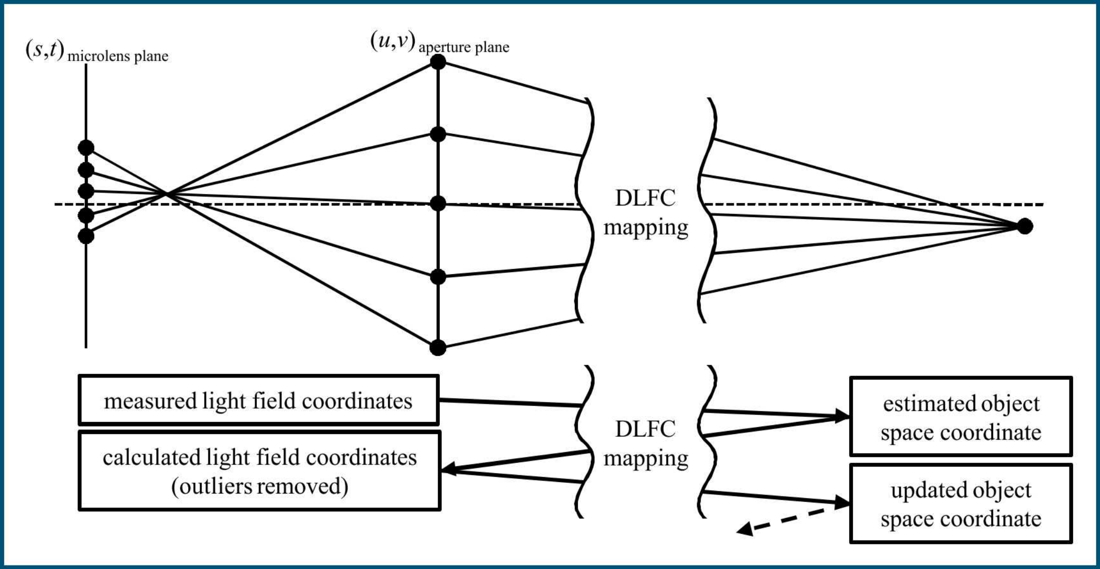


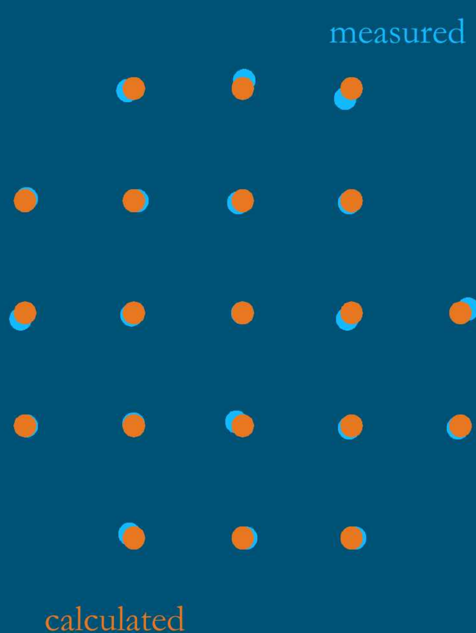
Perspective-shift algorithm

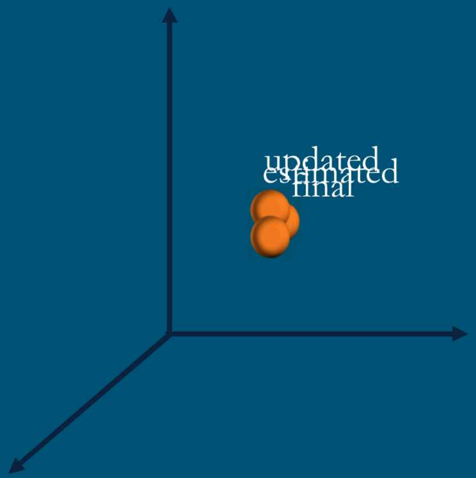


Perspective-shift algorithm

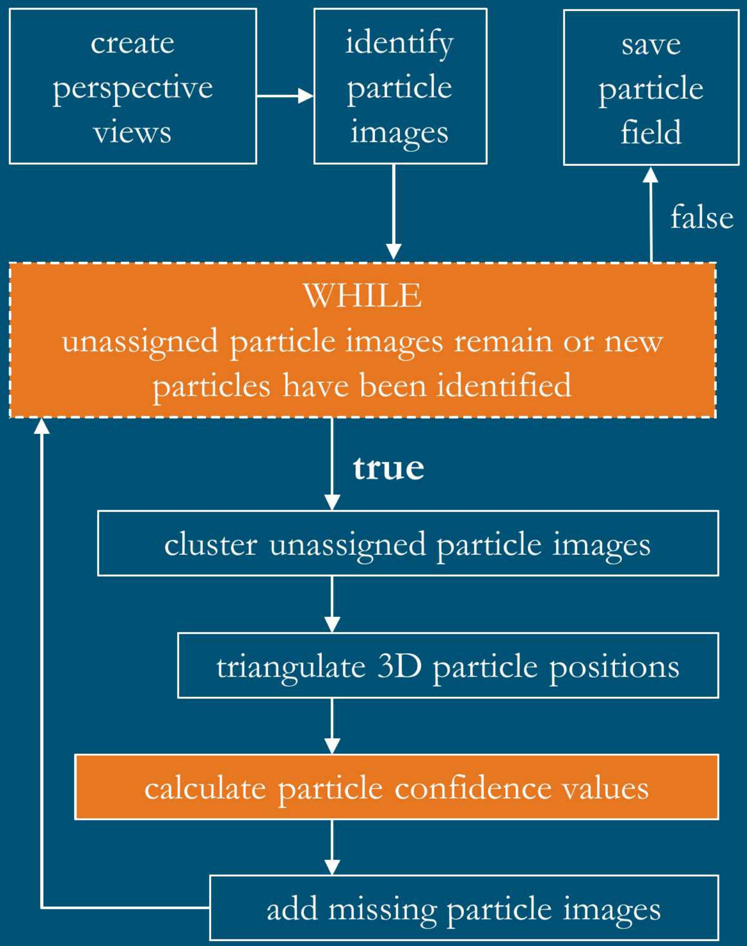


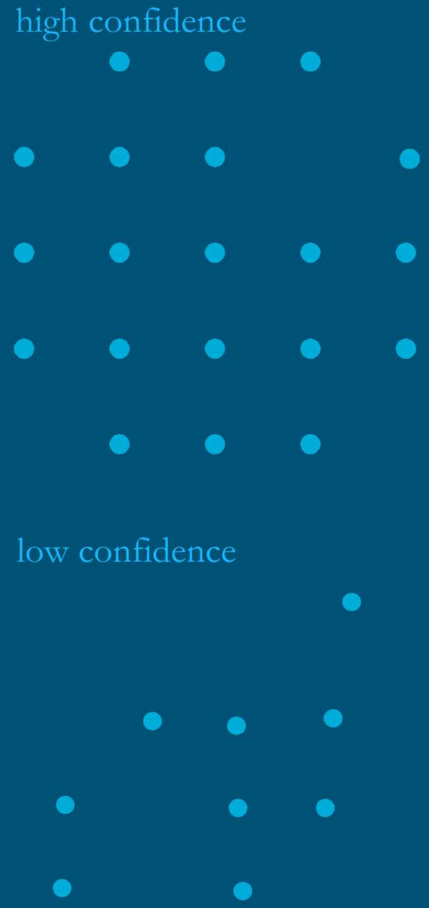




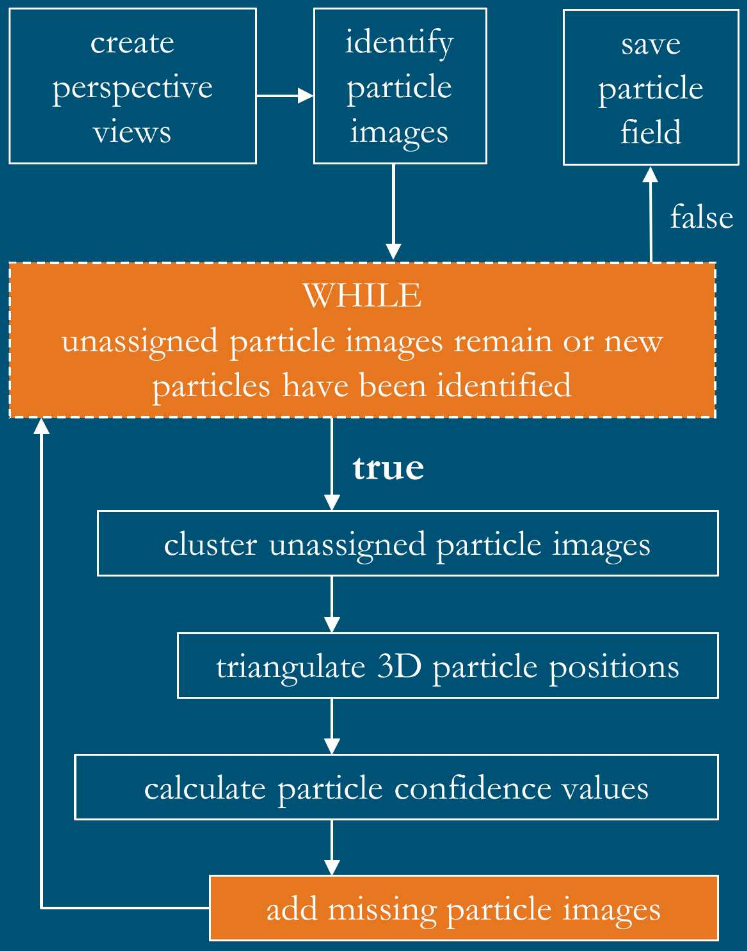


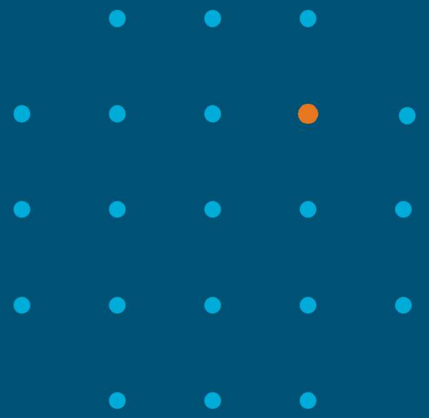
Perspective-shift algorithm



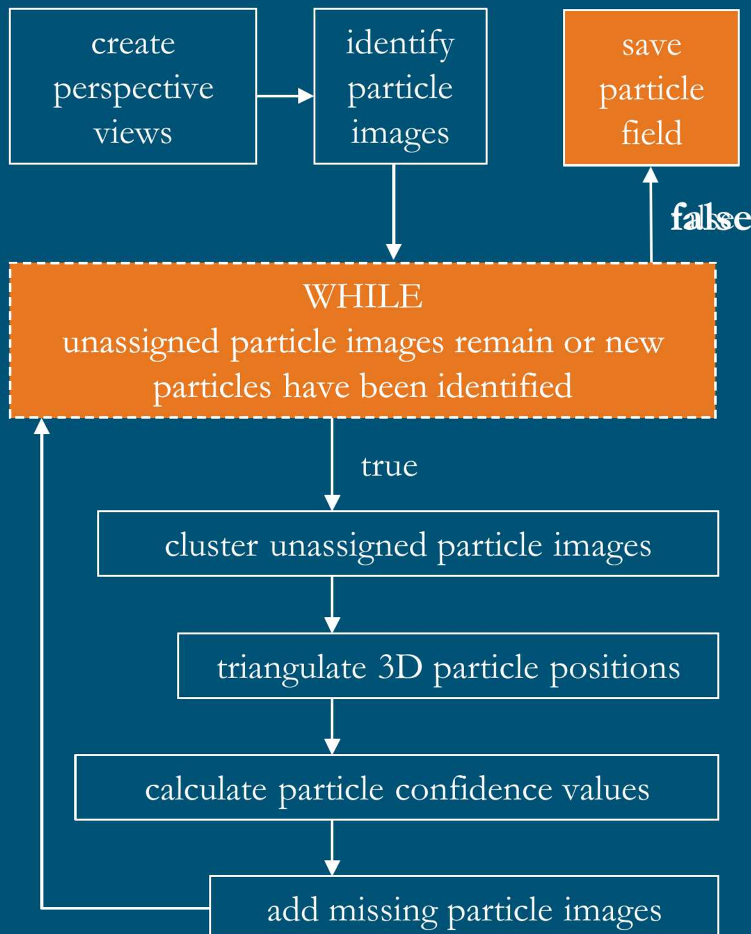


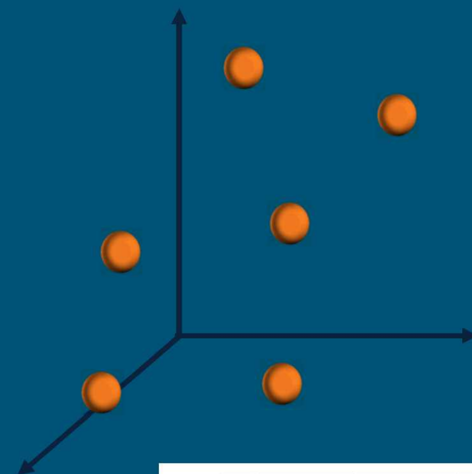
Perspective-shift algorithm

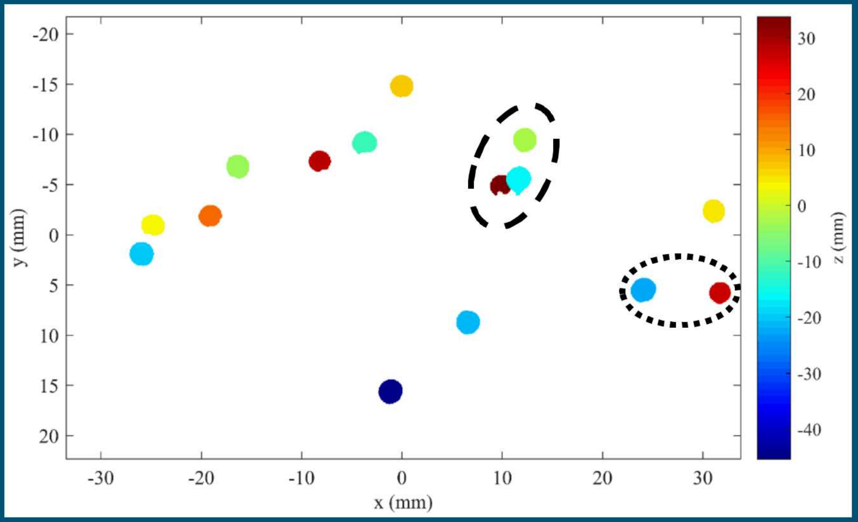




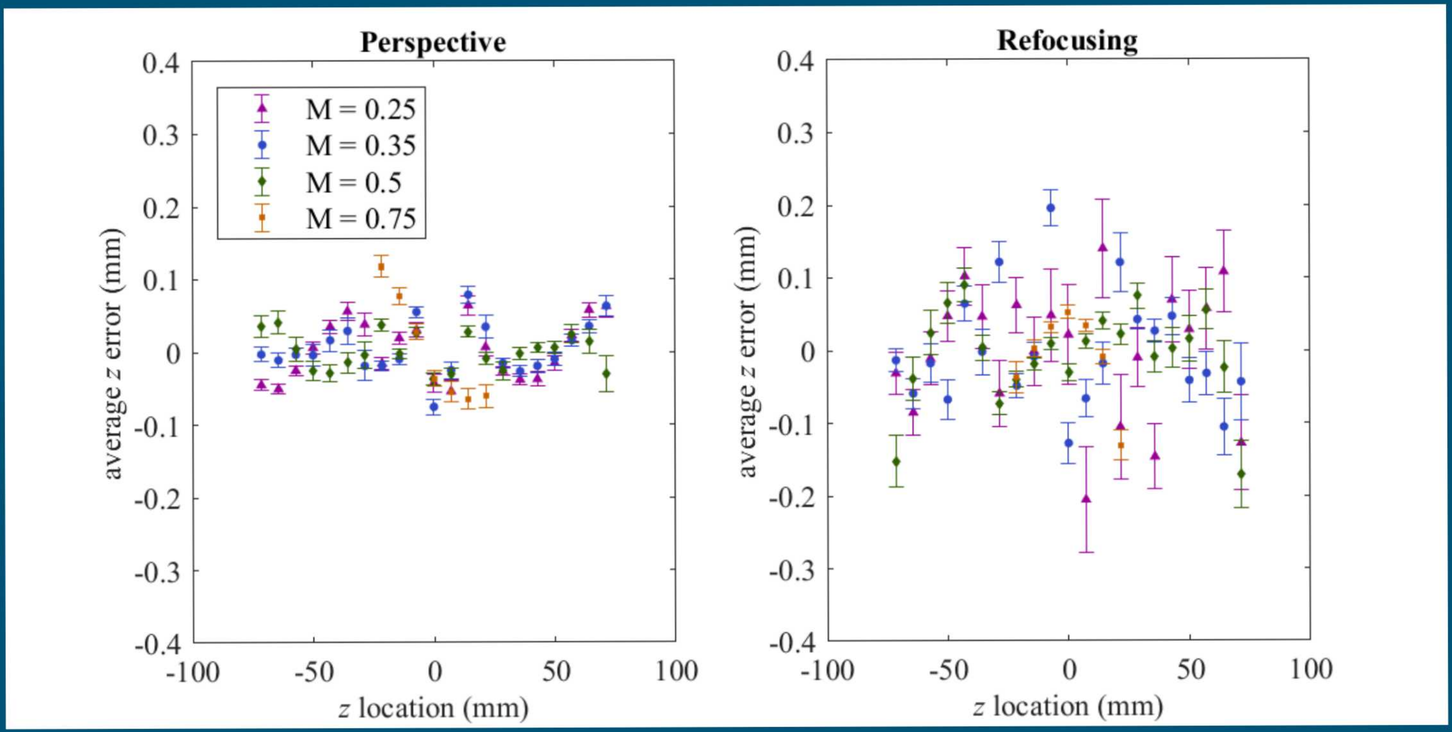
Perspective-shift algorithm





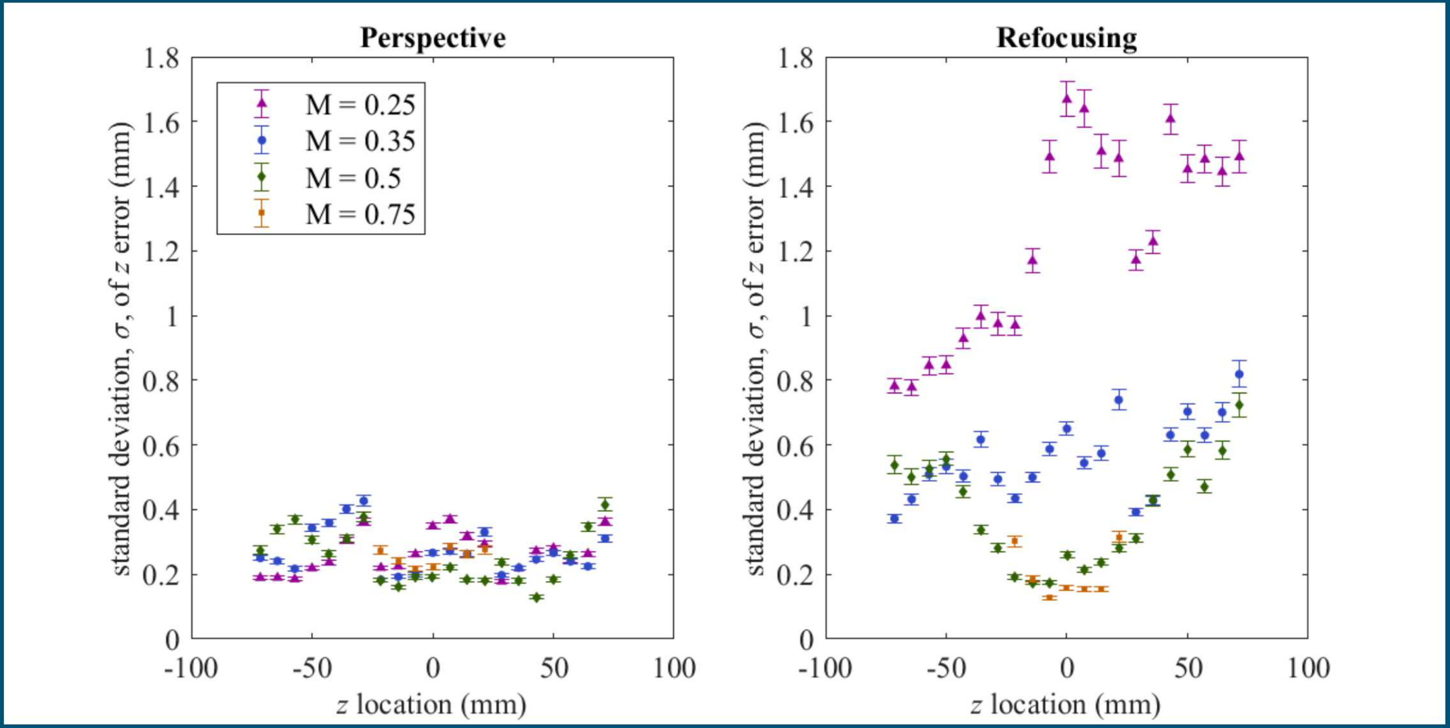


Depth displacement accuracy



- Smaller average errors with perspective shift
- Narrower confidence intervals
- **Perspective shift accuracy: 0.1 mm**
- **Refocusing accuracy: 0.2 mm**

Depth displacement precision



- Smaller standard deviations and narrower confidence intervals with perspective shift
- Perspective shift results more consistent with depth
- **Perspective shift precision: 0.4 mm**
- **Refocusing precision: 1.7 mm**

Computational efficiency

For a single image, from raw image to 3D particle positions:

by refocusing…

pre-processing (1 minute)

creation of focal stack and particle identification (1 hour)

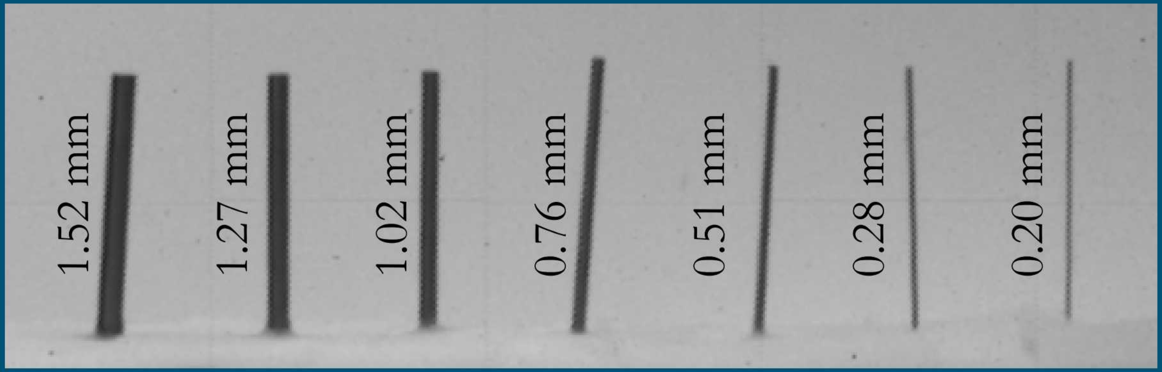
by perspective-shifting…

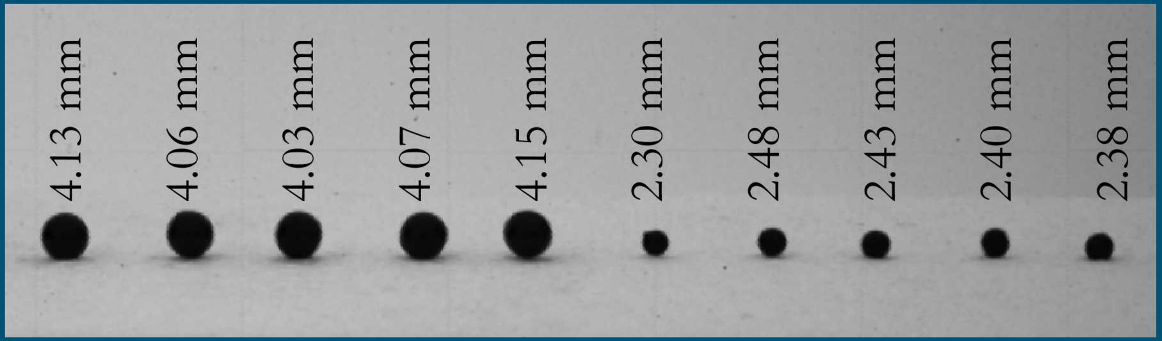
pre-processing (1 minute)

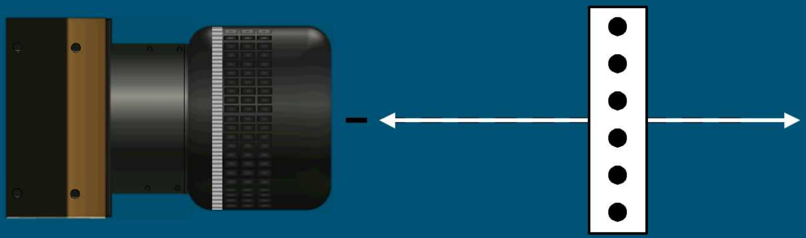
creation of perspective views and particle identification (10 seconds)

Elongated particles

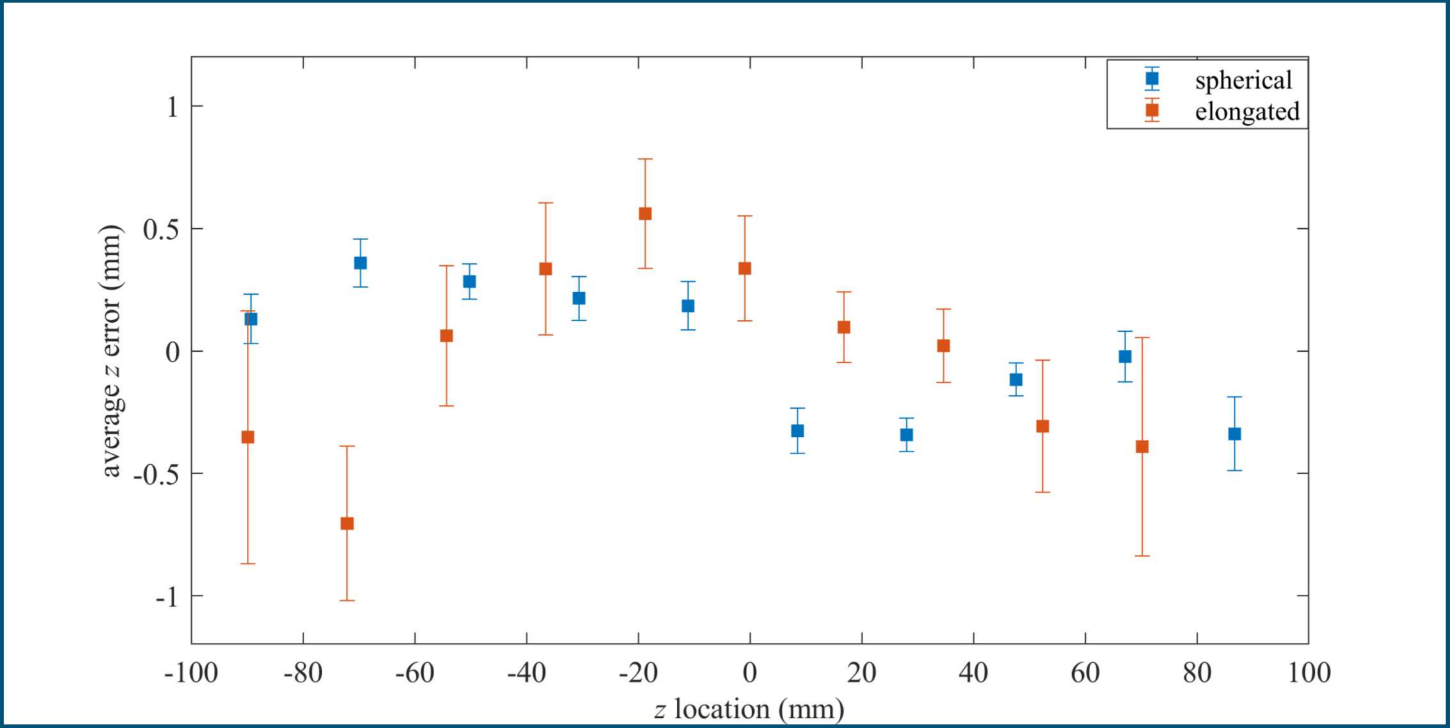
- Pin gages as elongated fragment simulants
  - Accurately known diameters
- Pinheads repeated in same configuration for comparison
- Translated over an extended depth range of 200 mm
  - Allowing assessment of measurements outside the effective depth of field





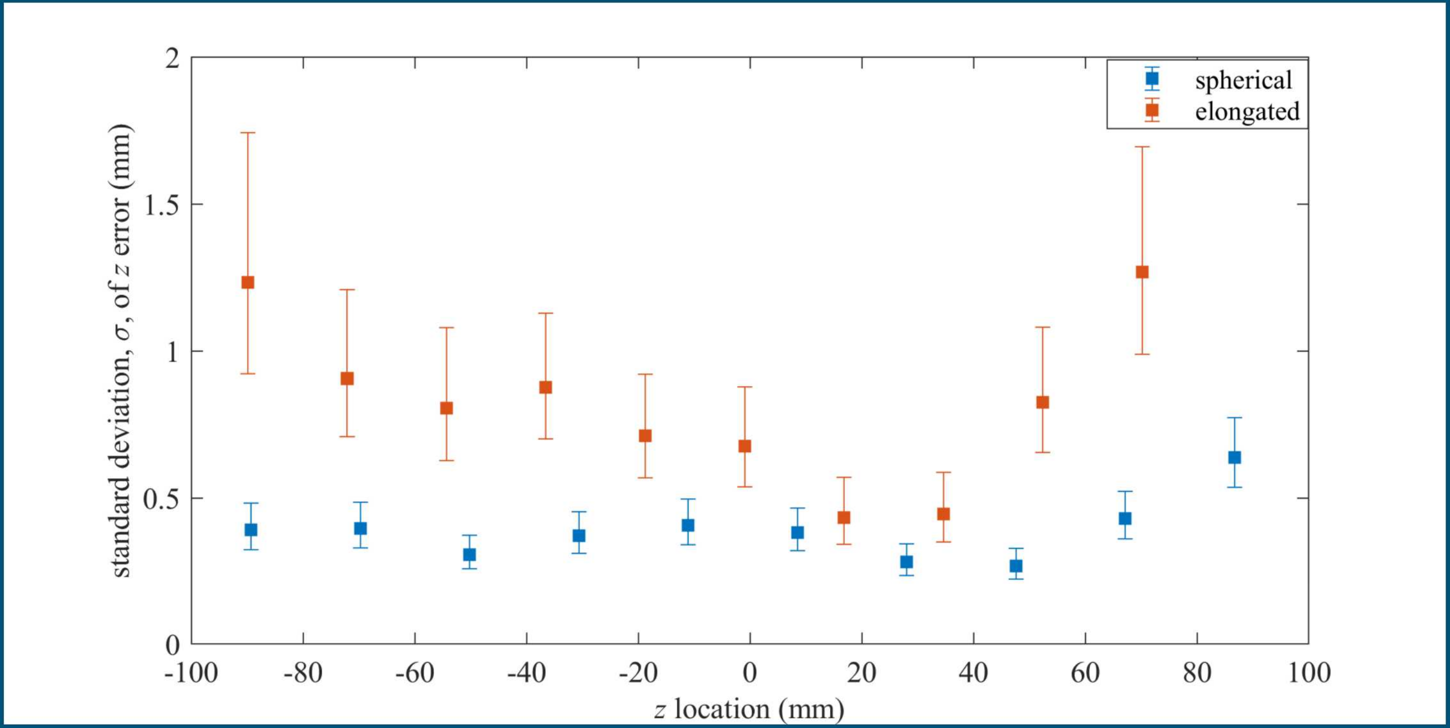


Depth displacement accuracy



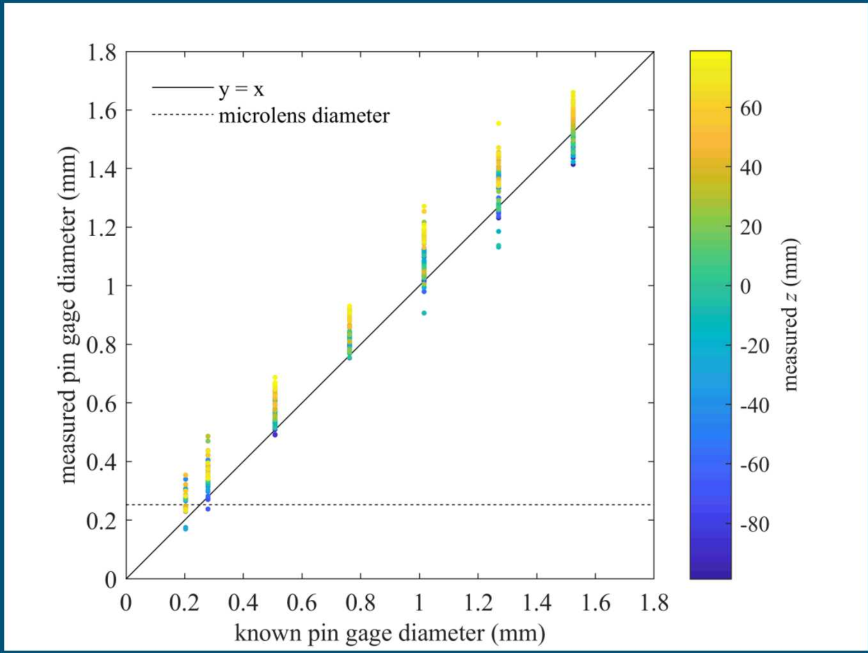
- Larger errors in elongated fragment measurements
- Errors increase with distance from focal plane in elongated fragments
- Within ~1 mm over a total depth of 200 mm

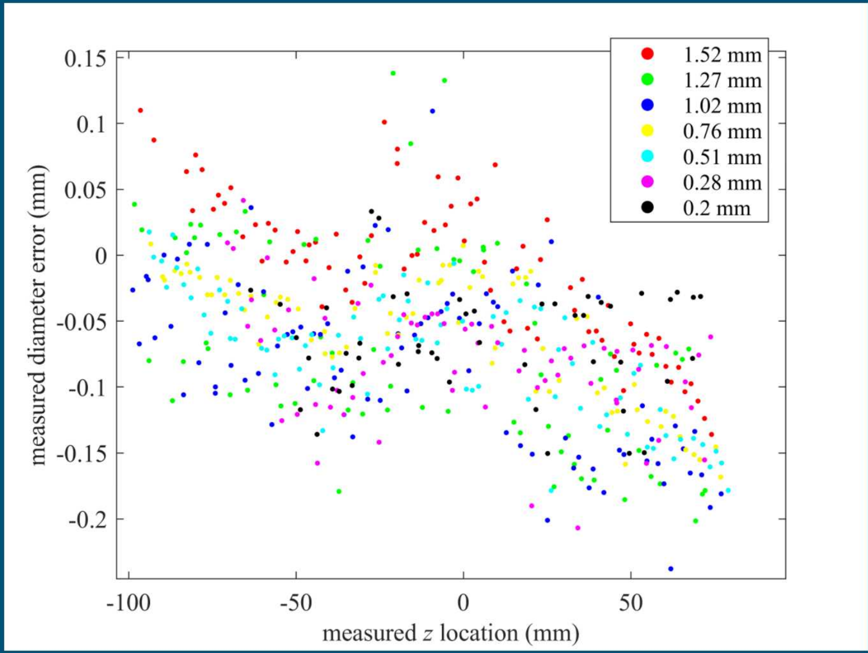
Depth displacement precision



- Larger standard deviations in elongated fragment measurements
- Increase with distance from focal plane more prominent
- Within ~1.5 mm over a total depth of 200 mm

Diameter measurement

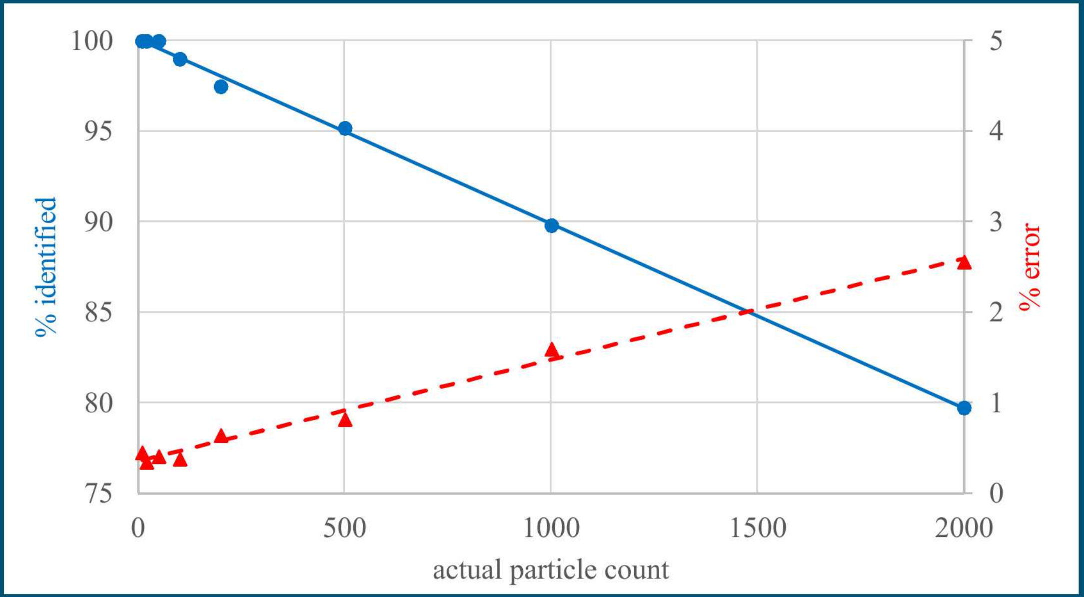


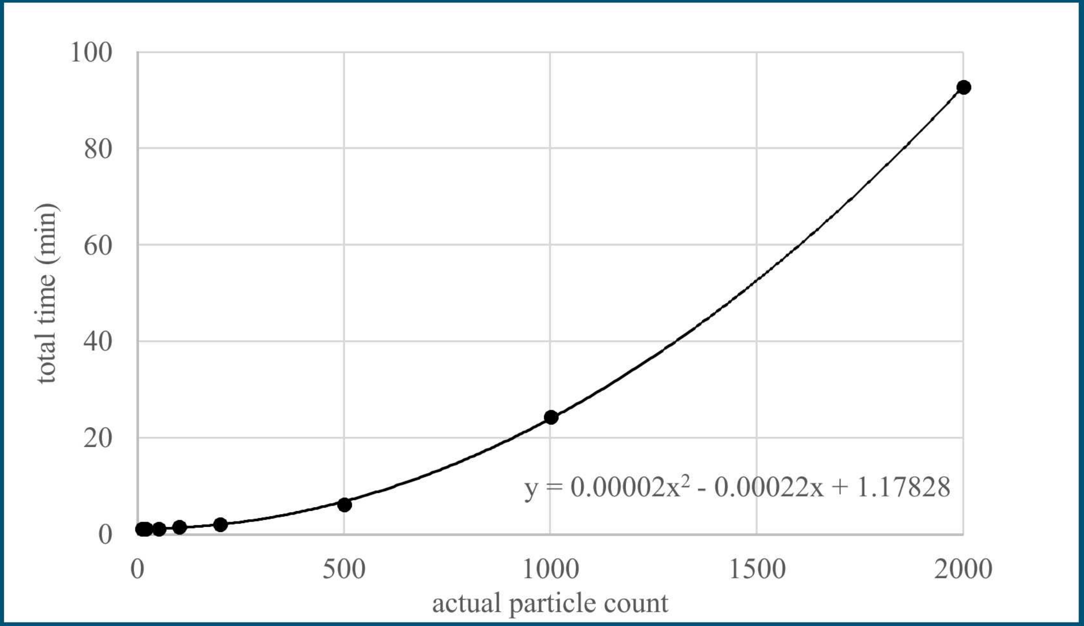


- In-plane pixel locations scaled using DLFC polynomial relationship
- Capable of measurement of pin gage smaller than microlens pitch in object space (0.252 mm)
- Diameter measurements generally within ~0.15 mm, less than microlens pitch in object space
- Errors likely affected by image segmentation method

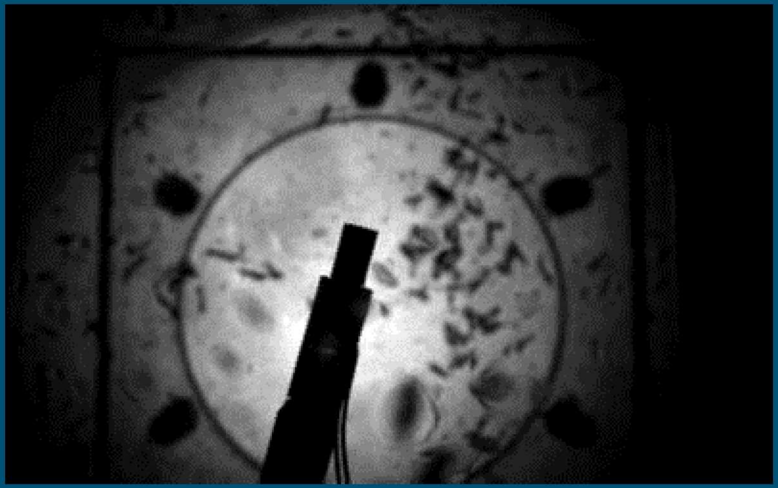
Synthetic particle measurment

- Synthetically generated plenoptic data images
- Images containing 10:2000 point source images
- % of successfully identified particles & % error follow linear trends
- Processing time increases dramatically at high densities



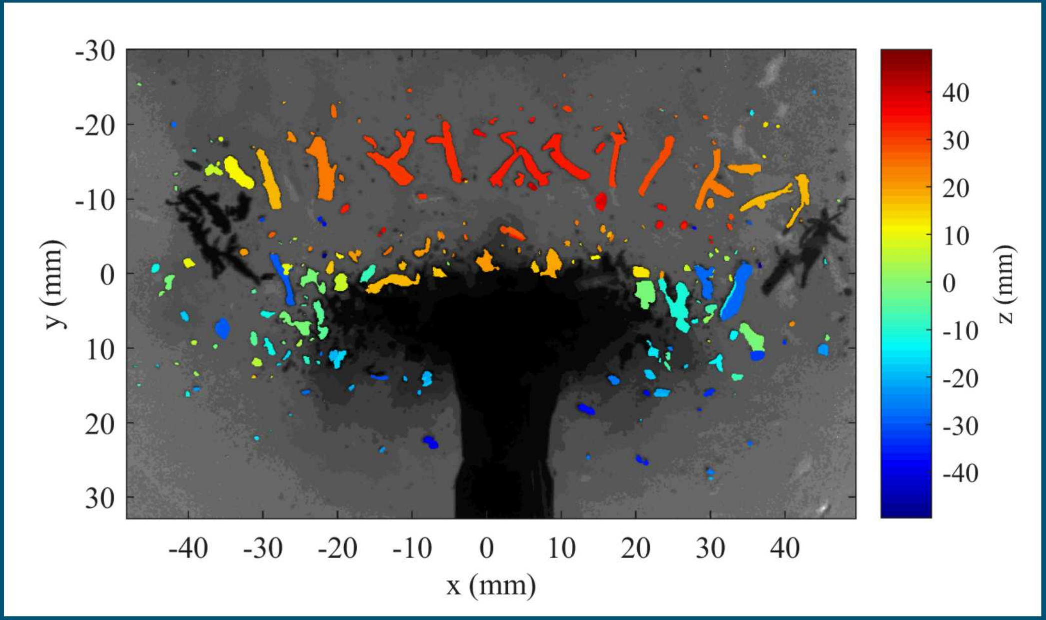


Detonator experiment



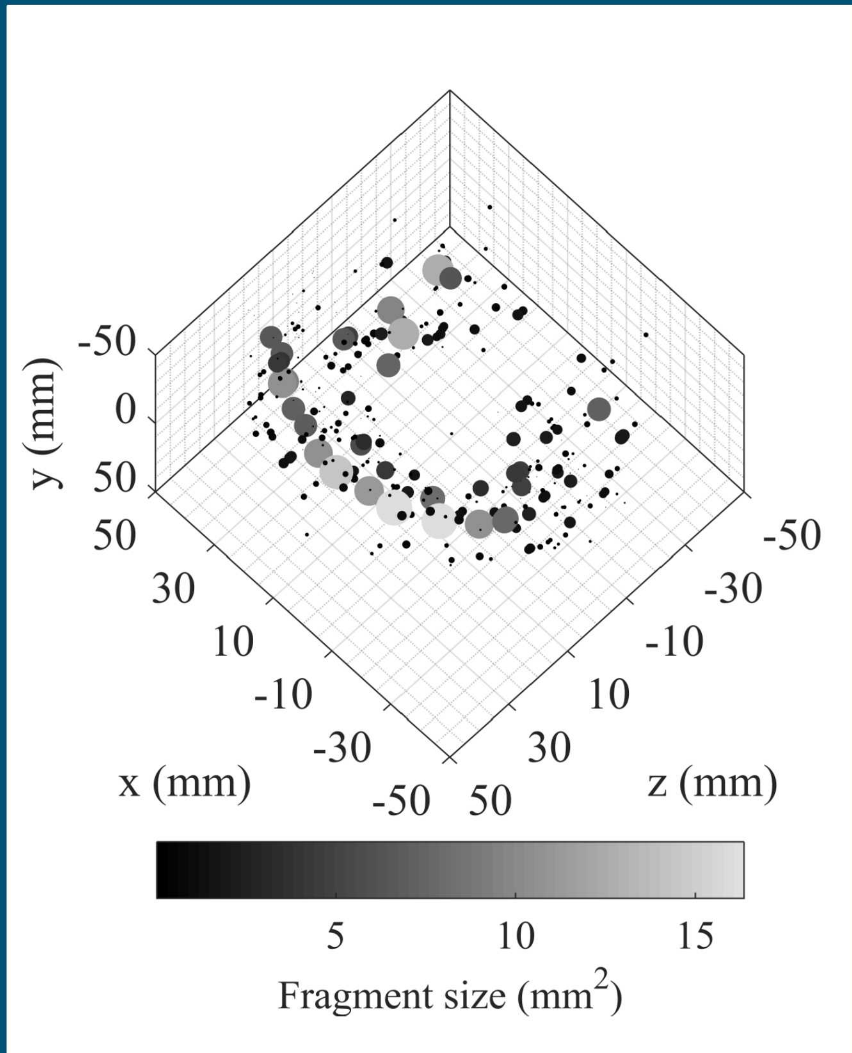
High-speed video

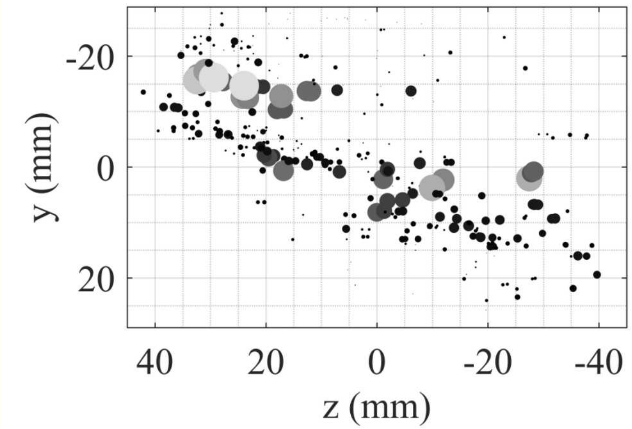
Plenoptic perspective shift

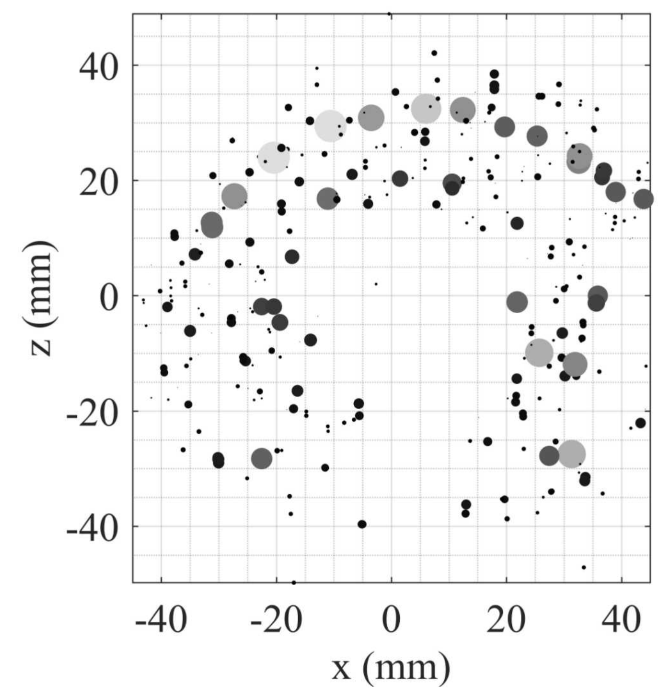


Depth map

Detonator experiment

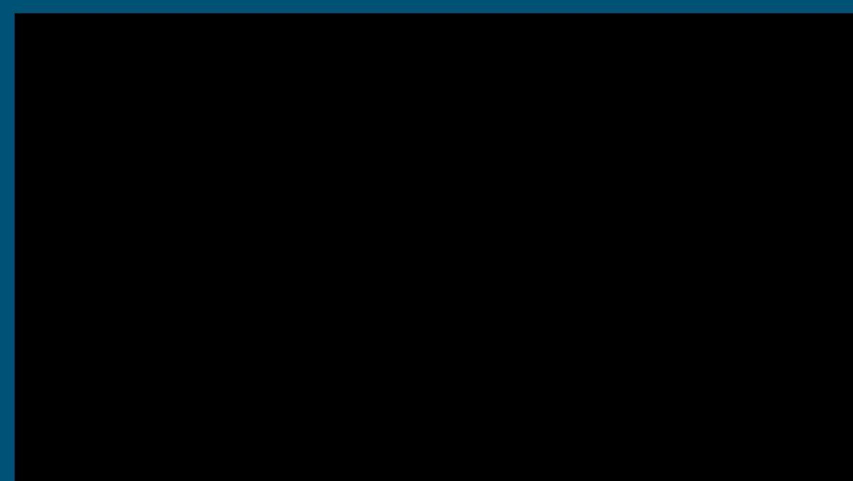


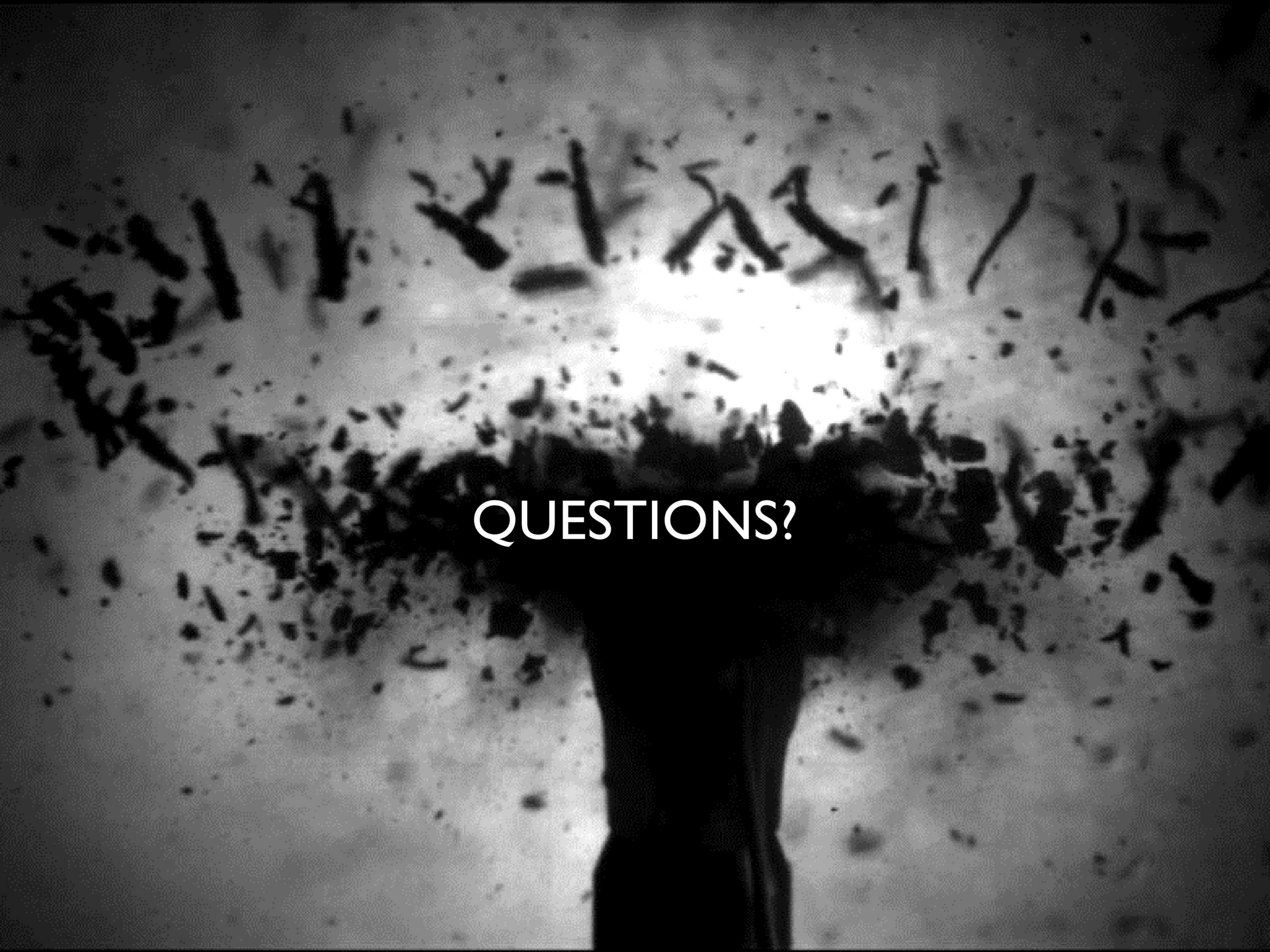




Conclusions

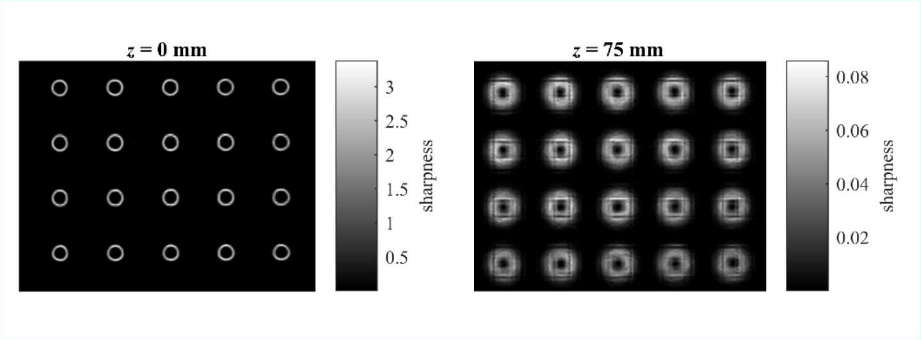
- Compared to refocusing, perspective shifting:
  - Improves depth displacement uncertainty:
    - Accuracy **(0.2 mm vs 0.1 mm)**
    - Precision **(1.7 mm vs 0.4 mm)**
  - Reduces computational efficiency **(~1 hour/image vs ~1 min/image)**
- Future directions:
  - Further examination of the effects of particle size and shape on uncertainty
  - Continued development of shape measurement capabilities
  - Combination of high speed and fragment measurement plenoptic capabilities



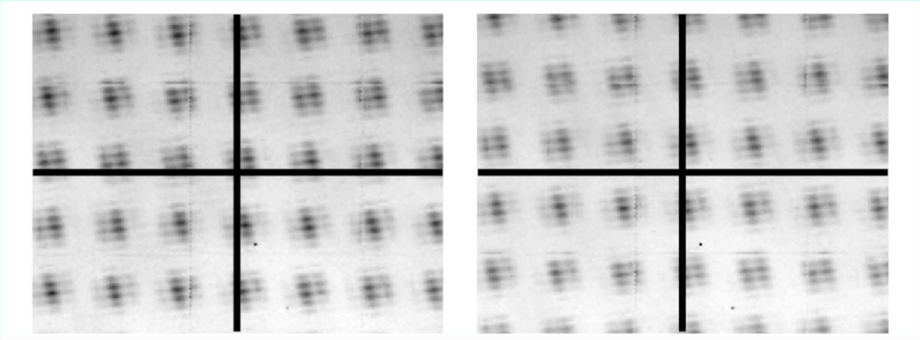

QUESTIONS?

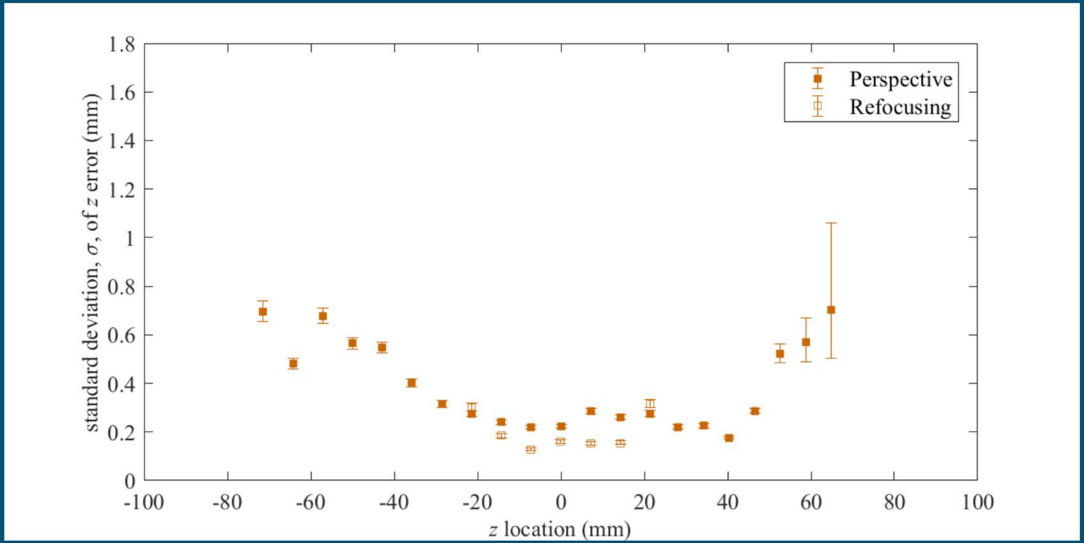
Measurable depth range

Sharpness maps from refocusing at center and extreme depths



Perspective views at extreme depth





- Perspective shift allows particle location at greater depths
- Result of location metrics: sharpness vs. location