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Bubble Masks for Time-Encoded Imaging of Fast Neutrons

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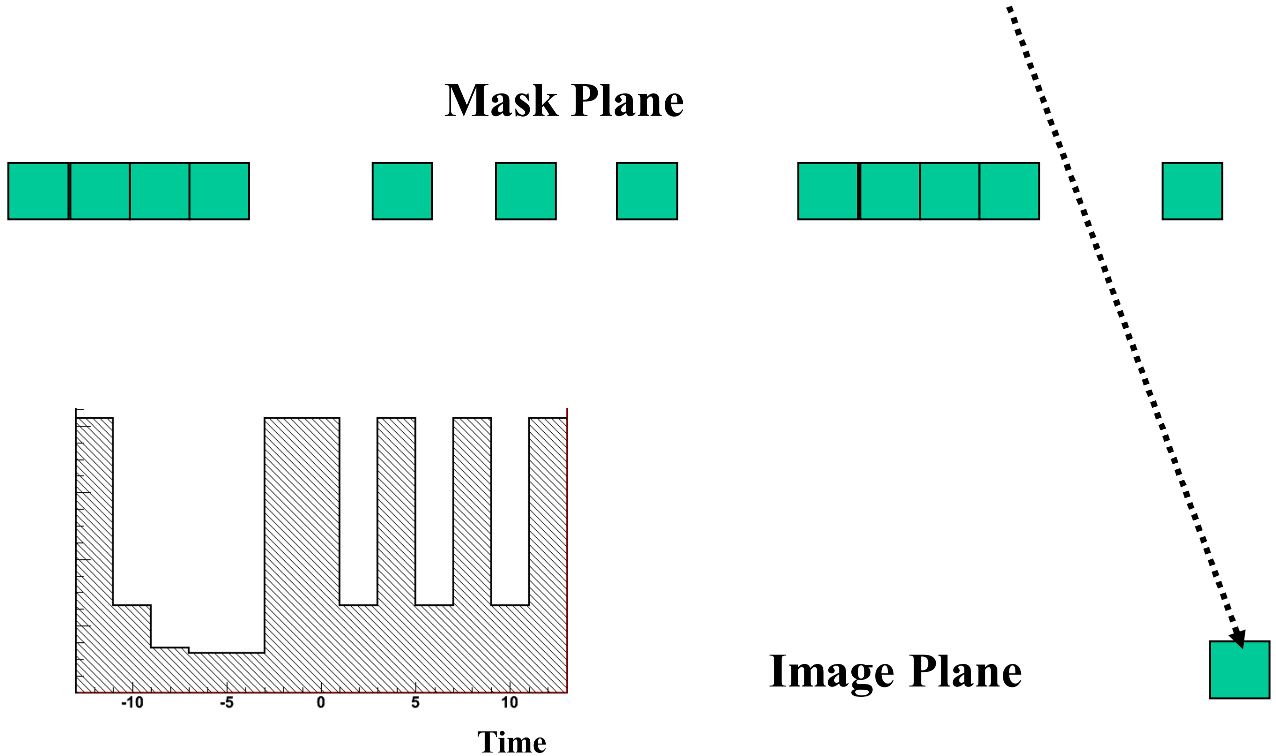
Time-Encoded Imaging

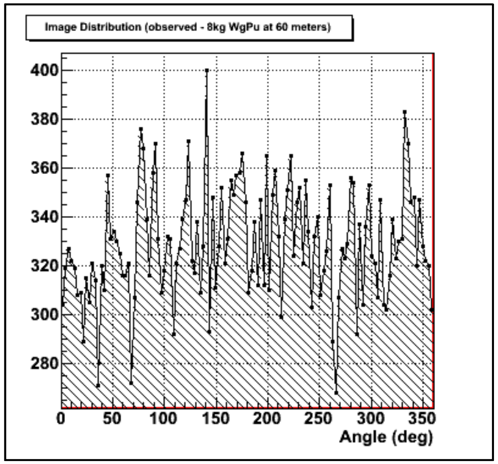


- TEI is related to coded aperture imaging, but switch spatial modulation for time modulation.
  - Spatial resolution in detectors is expensive. Time resolution is ~free!
  - To resolve spatial patterns needs precise inter-calibration of detector channels/regions. TEI uses a single detector; or if multiple, they are independent.
- Simple and robust, low-channel-count detectors.

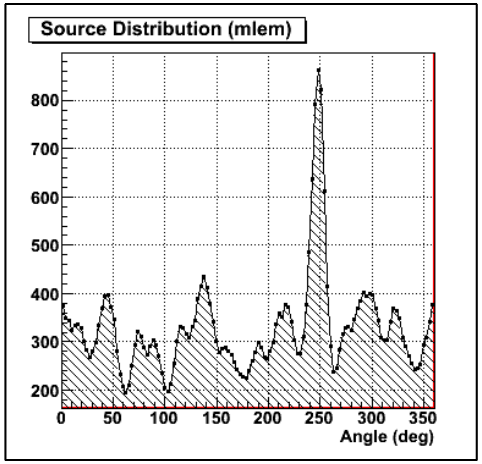
TEI Example

Early prototype TEI "imager" for fast neutrons in 1-D

Photo: 5"D x 5" LS cell at center inside cardboard box



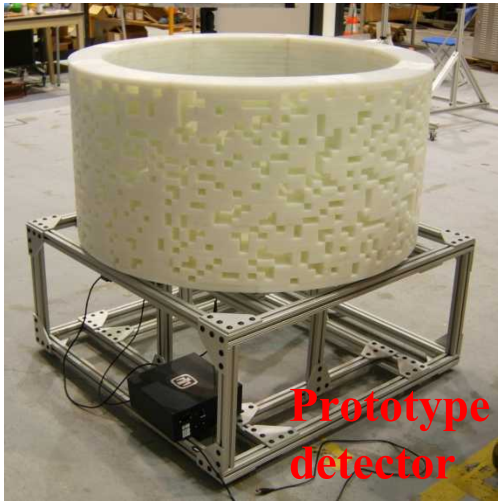
Raw neutron count rate as a function of mask rotation angle



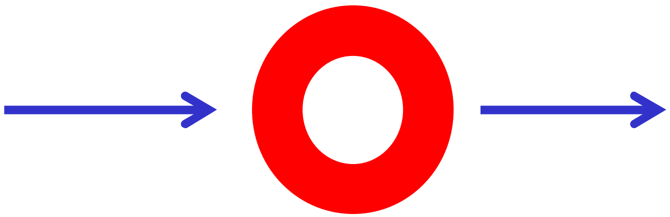
Reconstructed source distribution, identifying point source at 250°

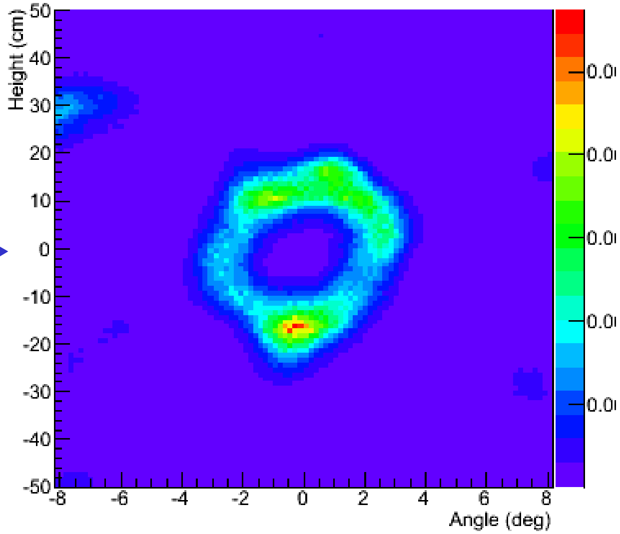
TEI for 2D imaging

- High resolution means small aperture/detector size, large pattern length.
- Ideally, use 1-D mask pattern "wrapped" over 2-D field of view.
  - Physically difficult to implement with mechanical masks.
- Approximation is a rotating cylindrical mask.

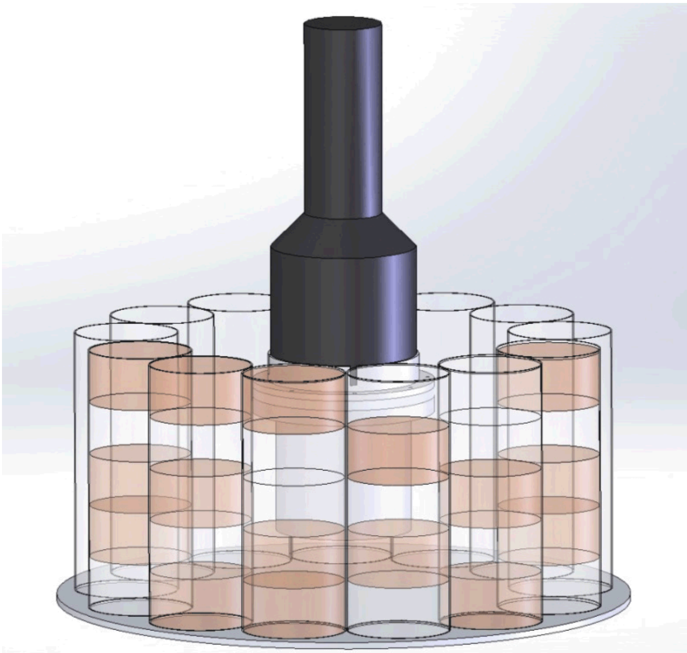


Simulate imaging a ring source





Bubble Mask Concept

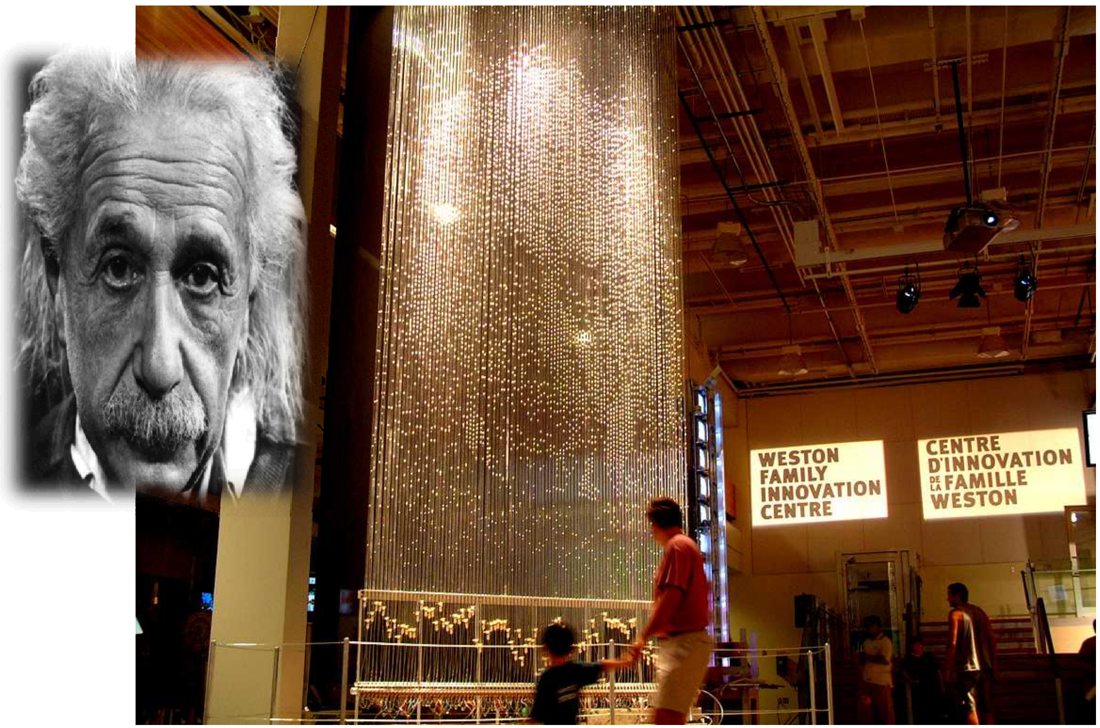


- Use air bubbles as “apertures” in a hydrogenous liquid “mask”!
- Control over mask pattern (within constraints of bubble motion).
- Potentially easy transport, fill on location
- Can change mask pattern on the fly: Adaptive encoding.

Assess the feasibility of bubble masks for high-resolution time-encoded imaging of fast neutrons. Demonstrate controlled bubble propagation in hydrogenous fluid medium and/or effective bubble position tracking.

Making patterns with bubbles?

Bubble propagation expert



Pipedream III permanent art installation. Photo from: http://taomc.com/art/permanent_installations/pipedream_series/pipedream_iii/pipe_hires_200.jpg

"Pipedream" permanent art installations by Bruce Shapiro:

- Clear vertical tubes filled with mineral oil
- Valve at the bottom of each tube introduces bubbles
- Bubbles propagate consistently enough to produce rasterized images

We were encouraged by these examples.

Bubble mask feasibility roadmap

1. Find best way to make bubbles
2. Find best way to track bubbles
3. Find best way to use bubbles
4. Demonstrate value of bubbles

Components Needed

Solenoid Valves

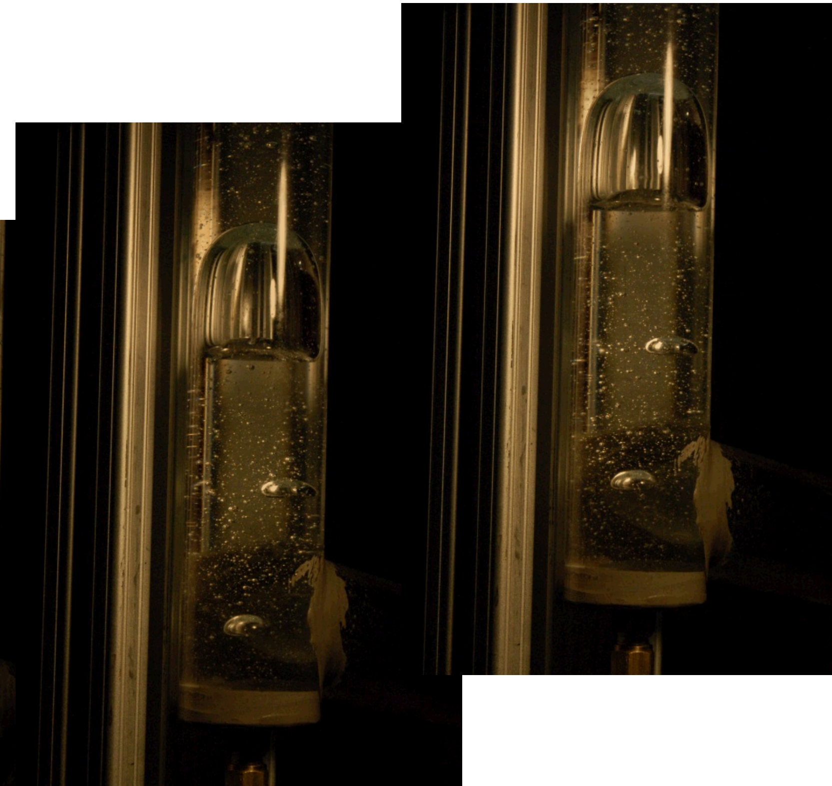
Tubes

Liquid

Bubbles

First attempt bubble propagation

1.5” ID Tube

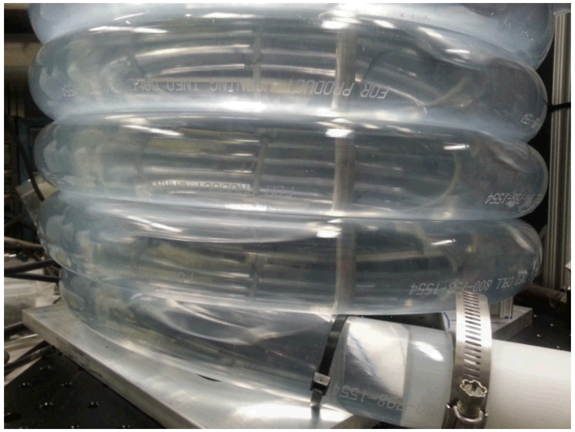


- Bubble velocity is very consistent along tube
- Single bubble shape is reproducible
- Small bubbles form after main bubble
- Subsequent bubbles disturb bubbles in tube
- Air pressure/pulse width affects previous bubbles

Sample bubbles



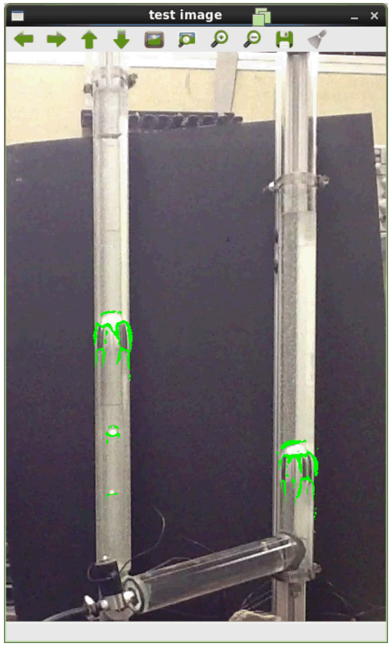


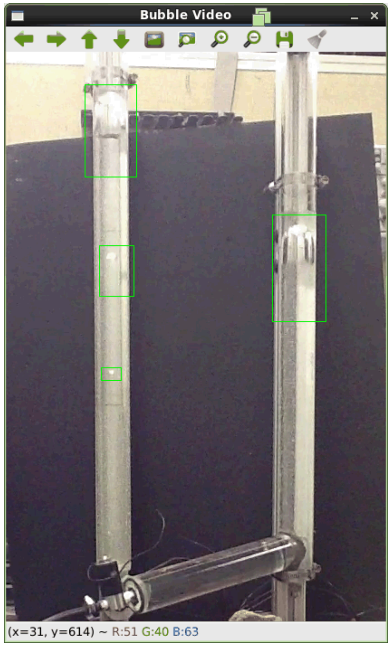


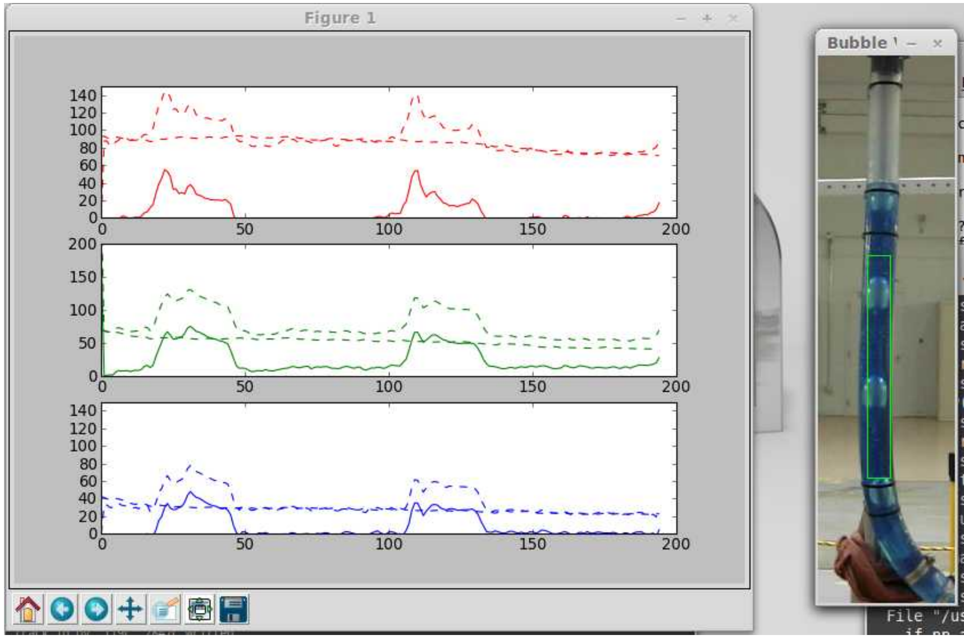
- Successes:
  - Consistent bubble propagation
  - Bubbles maintain shape
  - Fluid viscosity controls bubble velocity, shape
- Open issues:
  - Behavior worsens as tube size increases
  - Bubbles do not fill square cross-section
  - Helical shape has poor bubble dynamics

Tracking Bubbles

- General approach:
  - Subtract average image over recent frames to find areas of motion (left)
  - Draw and combine boxes around moving shapes (right)
  - Very generic but not precise or robust.
- Specific approach:
  - Consider known and fixed tube volume
  - Plot pixel value (e.g. r,g,b,h,s,b) averaged across the tube, apply threshold on change from base
  - Fast, quantitative.
  - Works in real time.

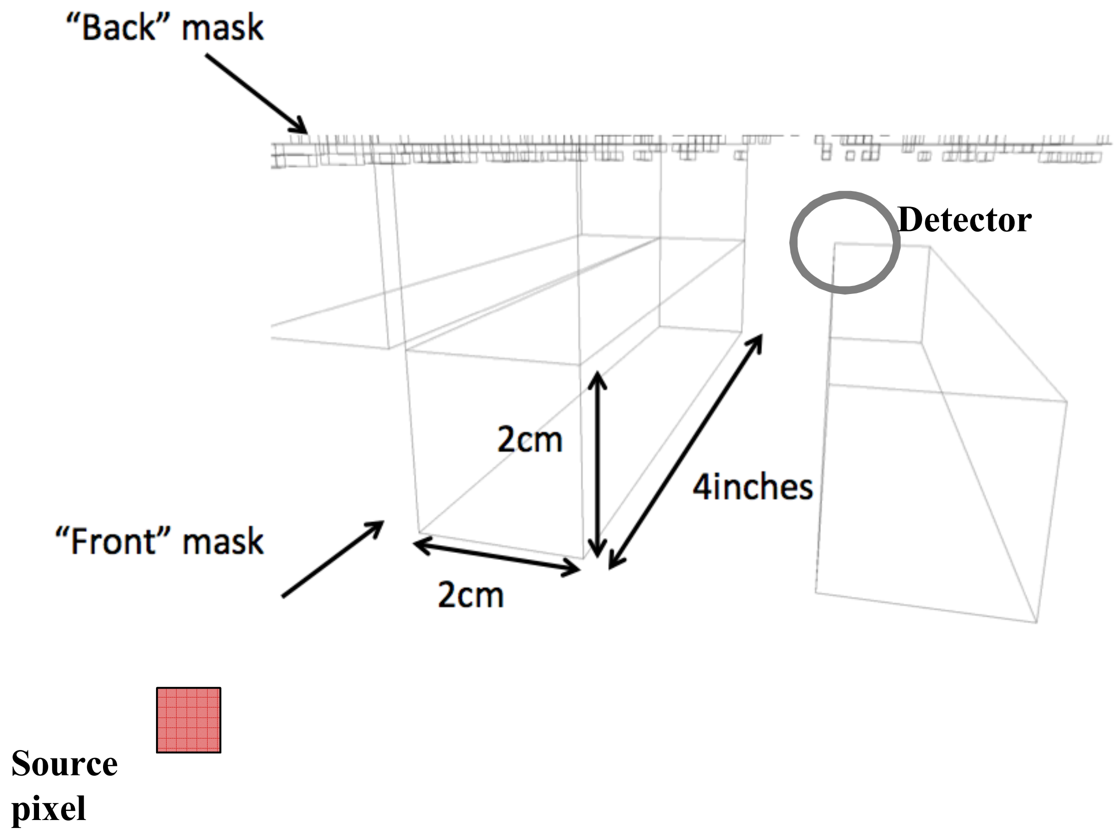






Reconstructing images

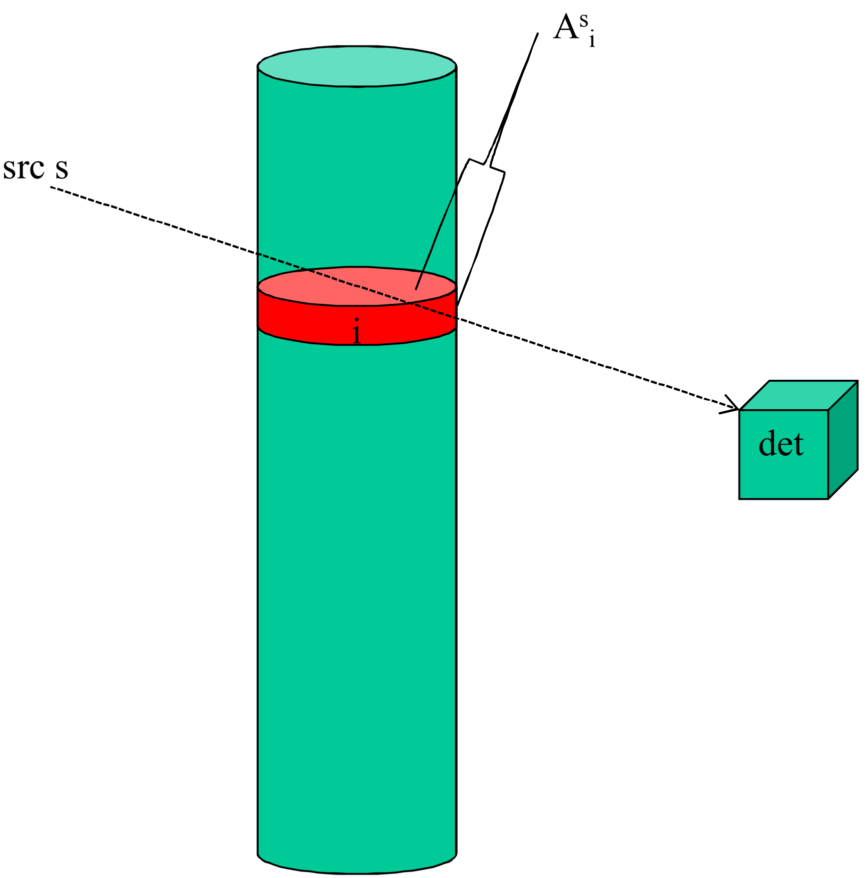
- We know how to use MLEM to reconstruct images from fixed mask patterns.
  - Even quasi-simulation approach can require days of CPU
- How to handle arbitrary bubble patterns in real time?



For each source pixel and each mask rotation position, build probabilities of detection by integrating attenuation of mask over possible particle trajectories. Accounts for imperfect opacity and finite pixel/detector size, but *not* scattering.

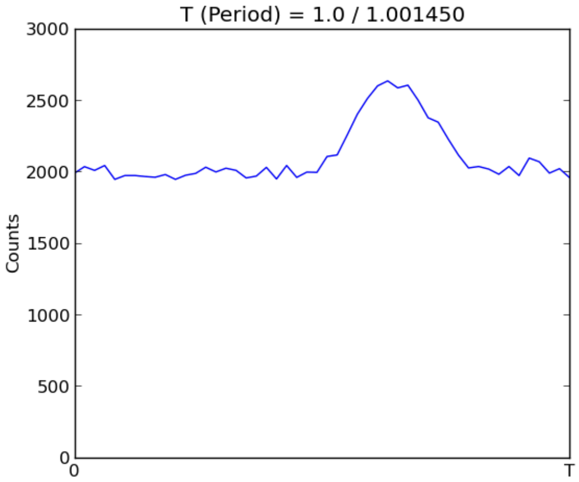
Response function in real time

- Determine average attenuation length A^s_i between each source position (s) & the detector, due to each "section" (i) of liquid in tube.
- Overall detector response for one snapshot in time is
  - $R_s = e^{\frac{\sum A^s{}_i}{\lambda}}$
- Time-consuming calculation done once, summing attenuation is easy.



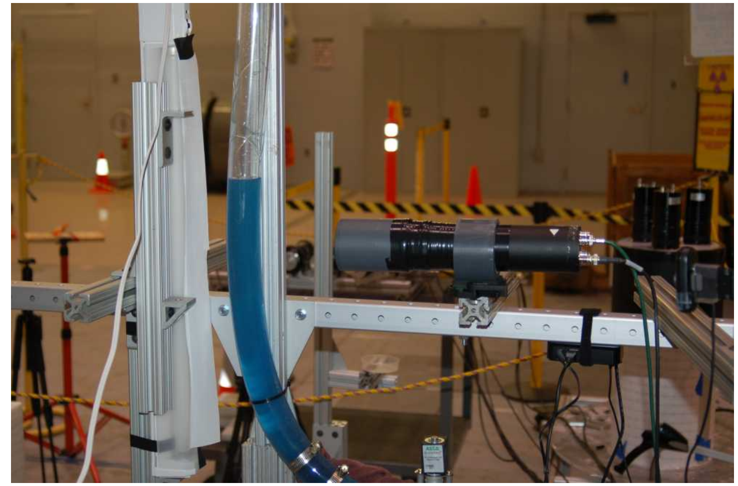
Experimental checks

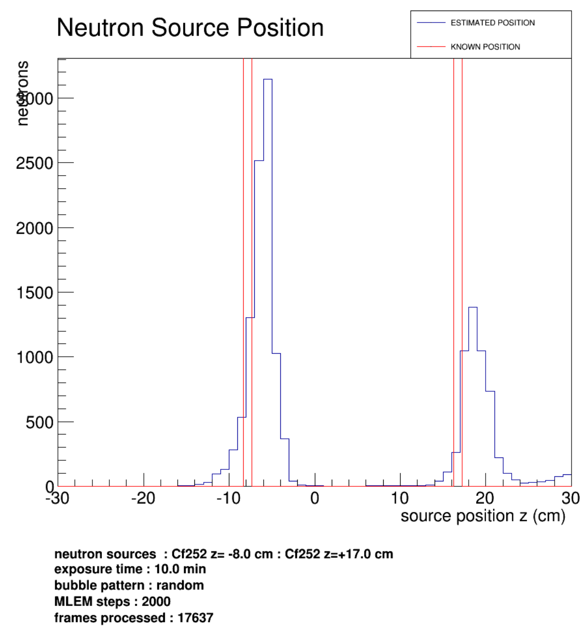
- Goal is to tie simulations to experiment
  - Provide confidence in simulations of full imaging system.
- Single tube (1.5”D) with bubbles, fixed bubble pattern (1 Hz).
- Detector (1”D x 1” LS) viewing source (AmBe) through center of tube.
- Fourier transform of detected neutron rate finds peak at 1 Hz.
- Plot of counts vs time-modulo-period shows shape of response to a single bubble.
  - Contrast ~30%: can we increase it?
- Does it match simulations?



Imaging experiment

- Full imaging chain:
  - Random bubble pattern (size and spacing)
  - Real-time bubble tracking via video
  - Generate system response for observed bubble pattern
  - MLEM reconstruction of acquired data
- Two Cf-252 sources imaged in 1D with slight offset.





Red = actual source z

Blue = MLEM reconstruction

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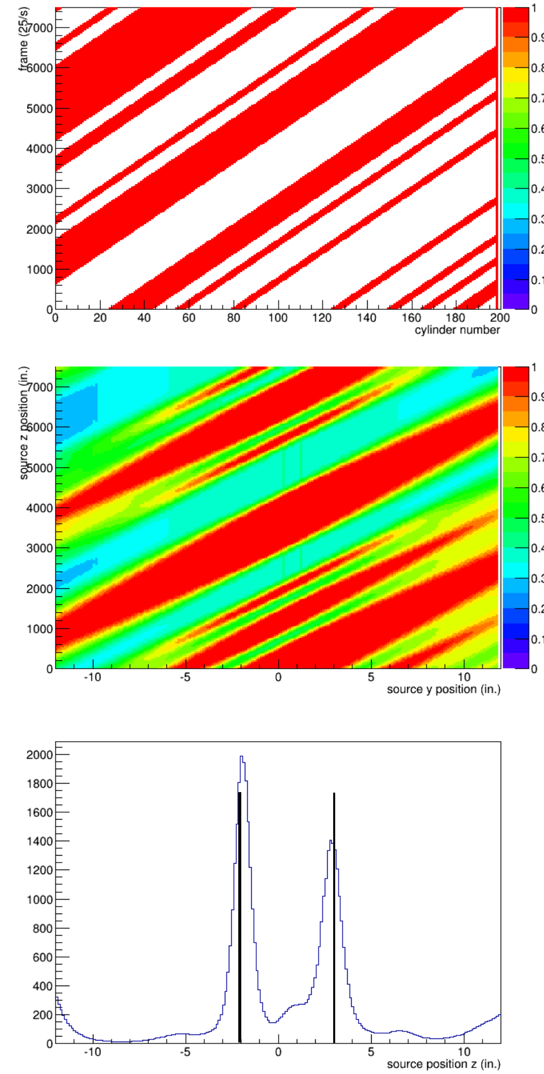
Modeling single-tube imaging

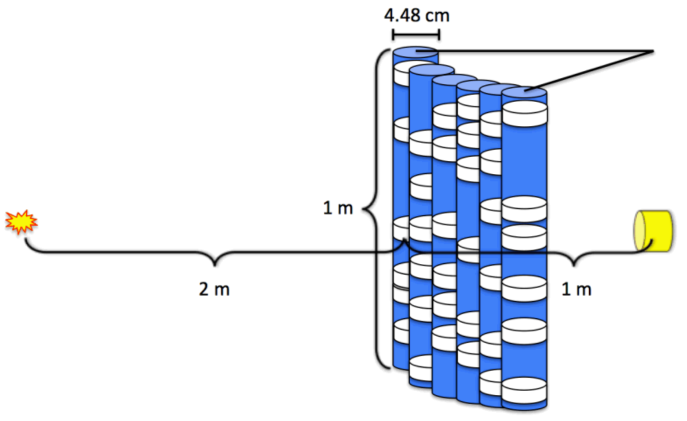
- Test attenuation, response, and reconstruction code machinery.
- Random bubble pattern represented in top right plot: time vs position of liquid density. (Cf. Aaron's results)
- Calculated system response in middle right plot: time vs source position shows relative n rate on detector.
- Reconstructed source distribution on bottom right: input was two sources at z=3 cm, z=-2 cm.

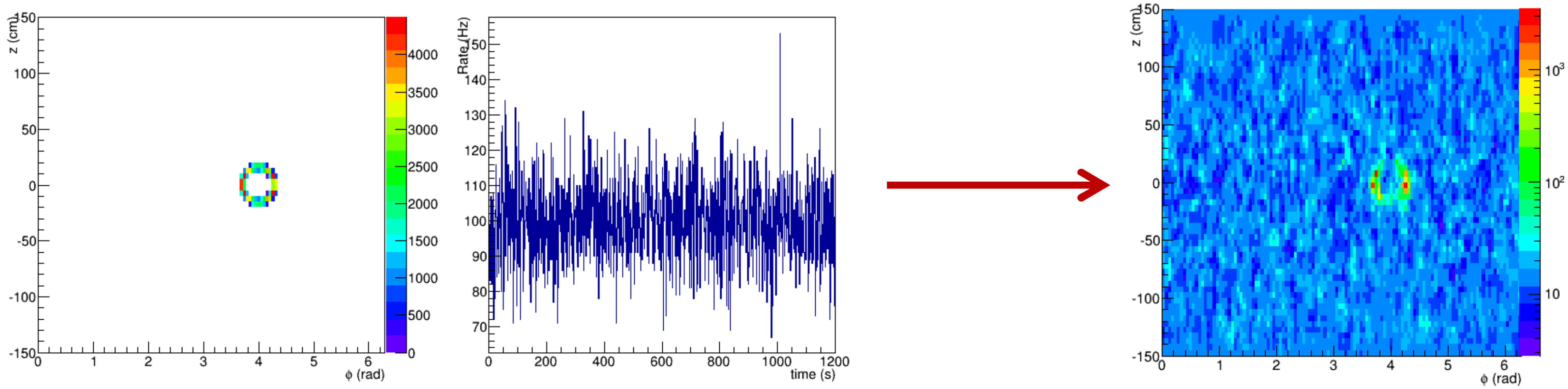


Modeled results

Simulations of 2-d imager

- Simulated a full 2-d imaging system.
- Tube geometry has many regions with poor contrast.
- Annulus geometry better.
- Random bubble pattern, 20 min @ 100 Hz detected rate





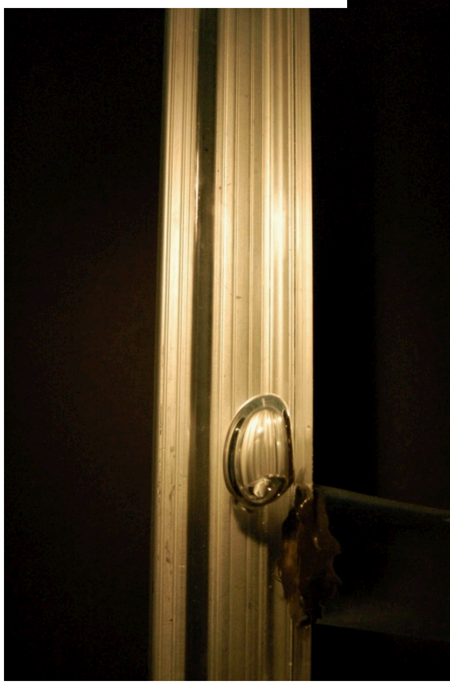
Put it all together

1. Find best way to make bubbles
   - Consistent propagation
   - Thick mask elements
   - Few disturbances
2. Find best way to track bubbles
   - Video processing
   - Ask a simple question
3. Find best way to use bubbles
   - Generate system response on the fly
   - MLEM reconstruction
4. Demonstrate value of bubbles
   - Cheap, "simple", flexible time-encoded mask
   - Adaptive encoding?

Additional Slides

Side Inject Tube Style

2” ID Tube





- Bubble velocity remains consistent along tube
- Single bubble shape remains reproducible
- Small bubbles that formed after main bubble are eliminated
- Subsequent bubbles disturb bubbles already in tube
- Air pressure/pulse width affects previous bubbles

Some Tube designs

2” Square   2” Square Side In

2” ID   1.5” ID

2” ID

Flexible Tube Design

Curved Tube - Mineral Oil

- Smooth tube transition allows bubbles to completely form before transitioning up the tube.
- Left tube has the original end air injection point.
- Right tube has the top tube injection point.

Air Pressure / Pulse Width Test

Higher pressure – Short Pulse

Air Pressure / Pulse Width Test

Lower pressure – Long Pulse

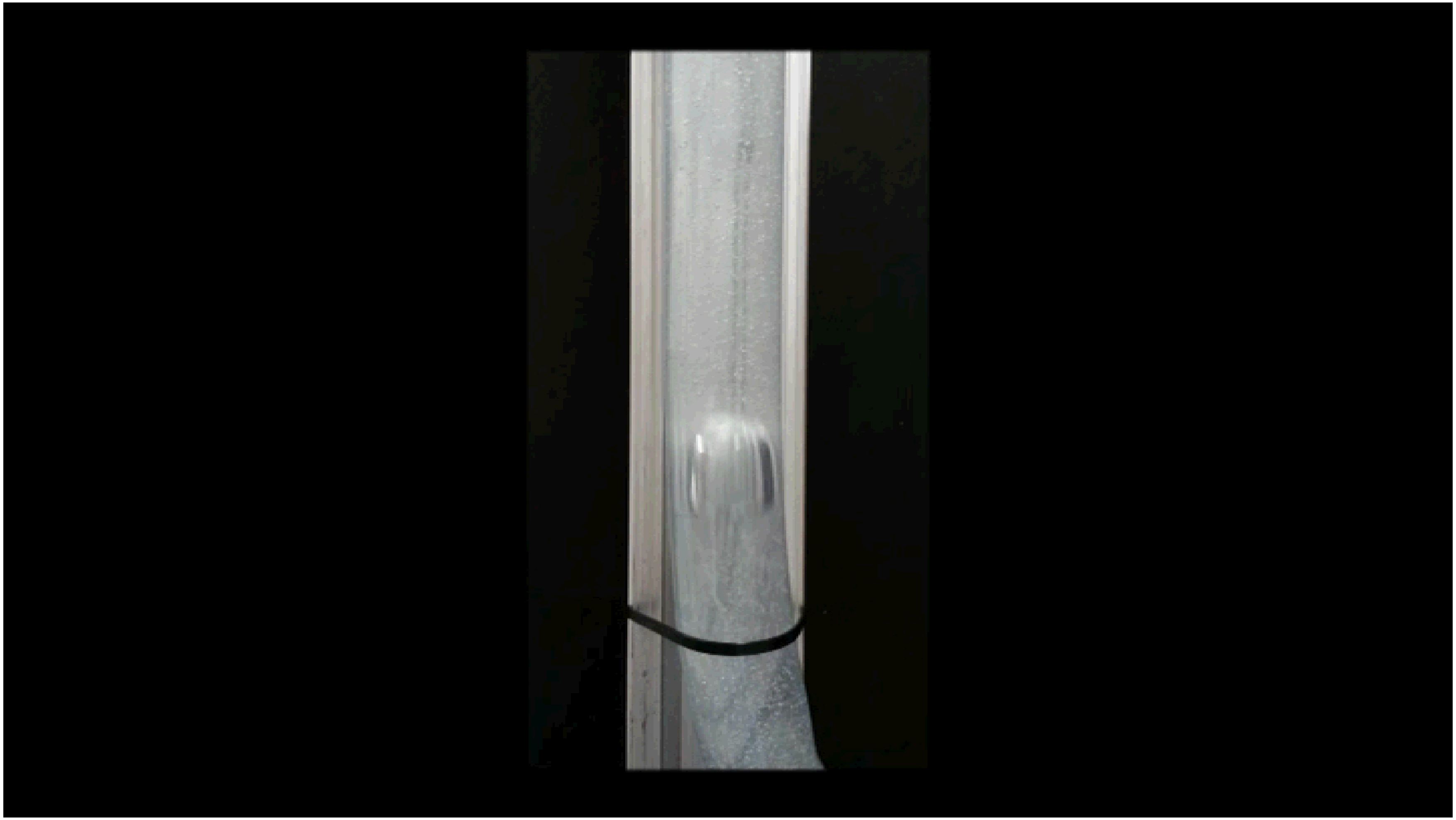
Thin vs. Thick Bubble Shape

Heavy Mineral Oil

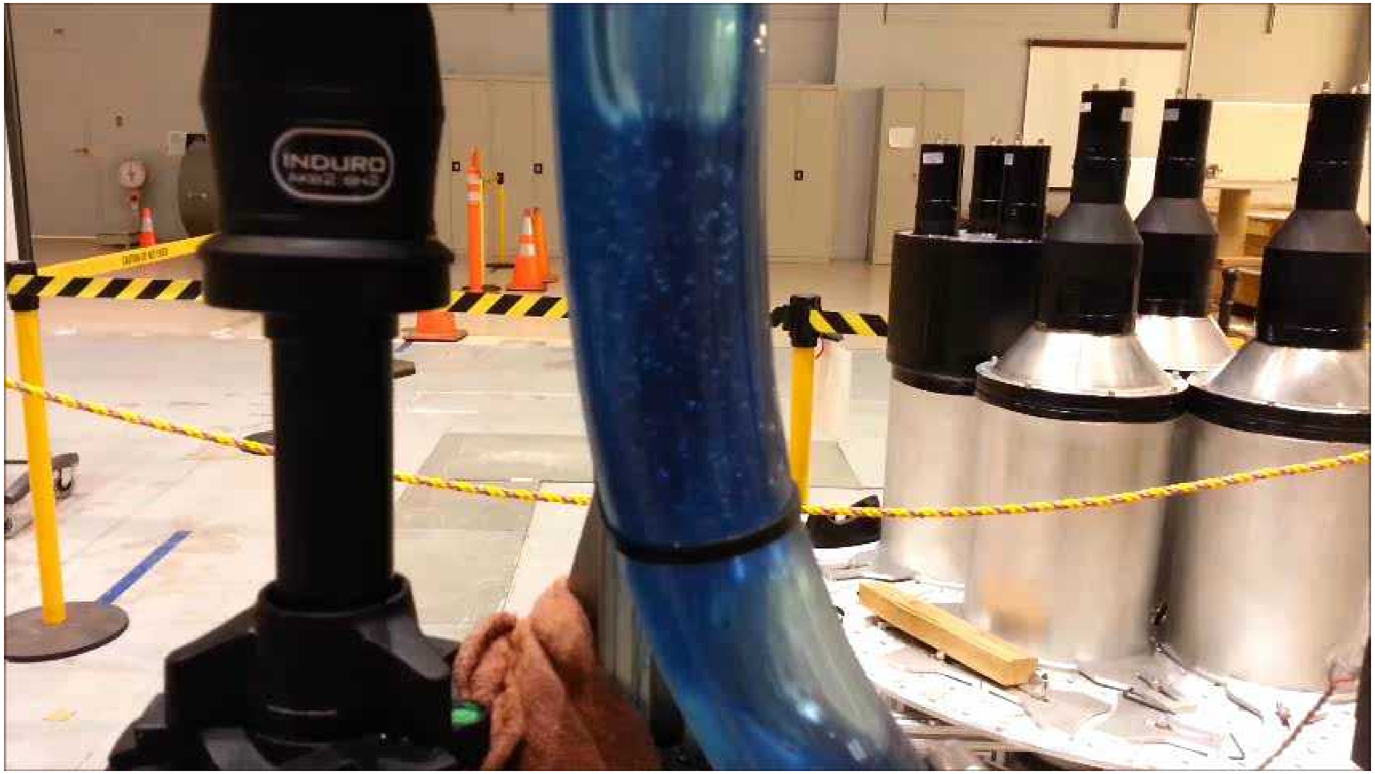
Glycerine

Thin vs. Thick
Bubble Dynamics

Heavy Mineral Oil



Glycerine Tube



Adjusting with Bubble Spacing

Helical Bubble Mask