Image Processing Alignment Algorithms for the Optical Thomson Scattering Laser at the National Ignition Facility

ICALEPCS

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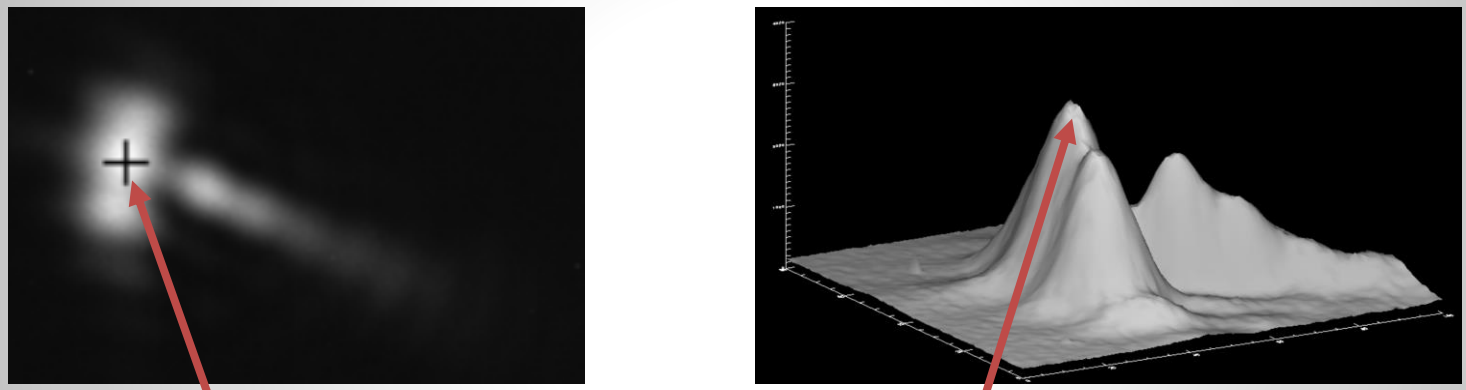
Motivation for Building a Plasma Diagnostic Using Thomson-Scattering (TS)

- Fusion is one of the grand challenges
- TS enables measurement of both ion and electron temperatures
- Thomson-scattering laser-pulses can be timed to probe the plasma at key points during the plasma evolution
- Short wavelength laser (5w) avoids self-emission background from the experiment

Loop 1: Alignment of the pointing beam in the OTSL



Desired detection spot is within the head of the dragonfly which is generally the brightest

Centroiding Algorithm

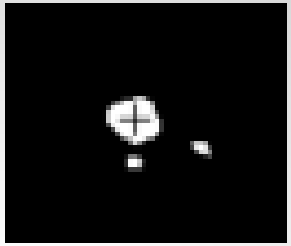
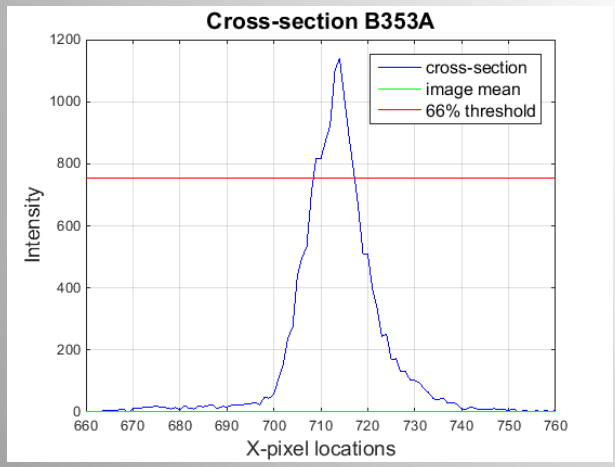
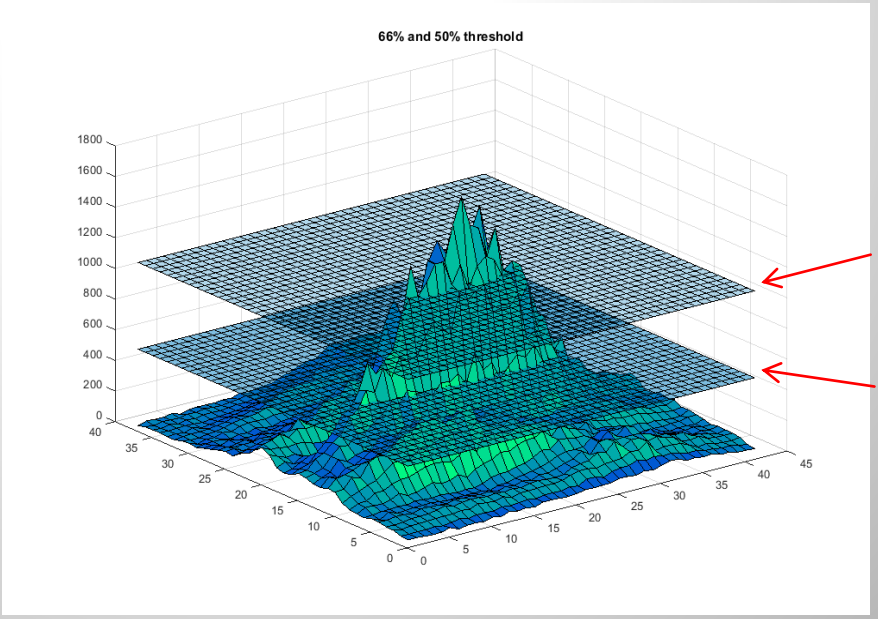


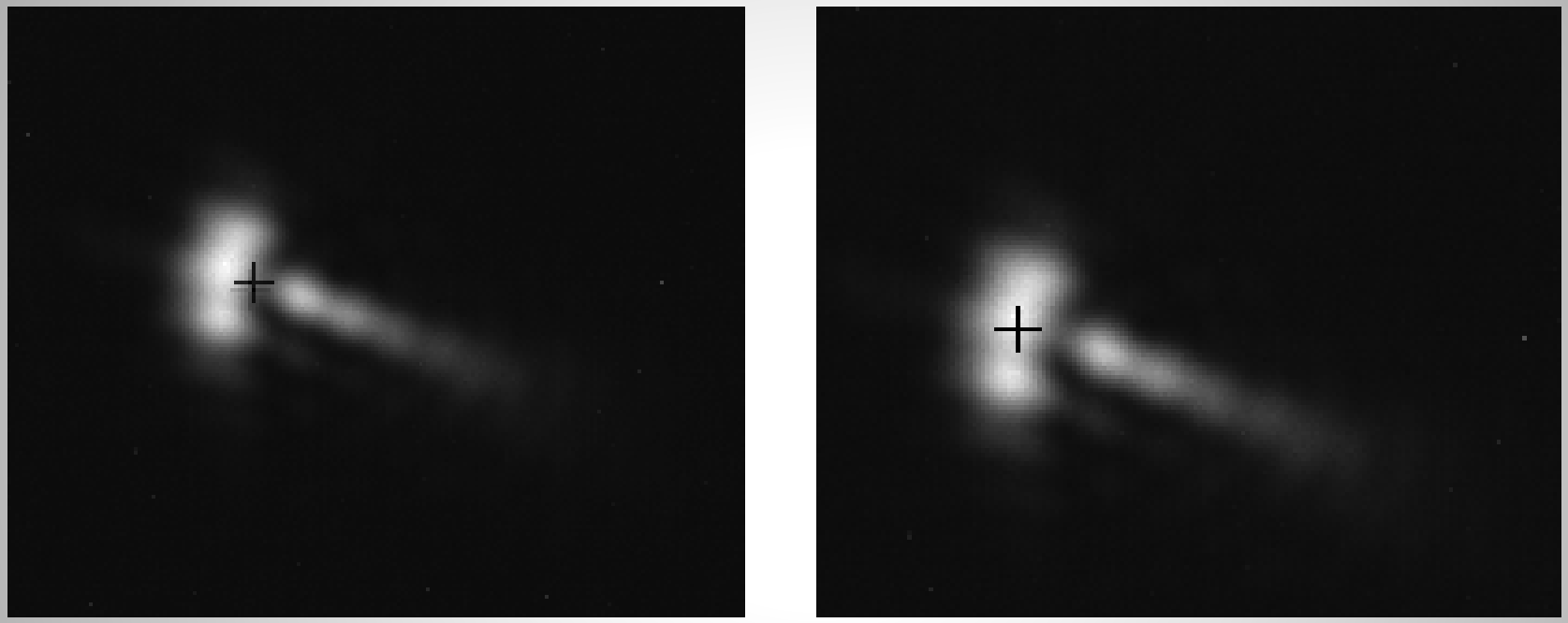
image → **T% Threshold** → **Region selection** (largest connected area at T% intensity level) → **Weighted Centroid**





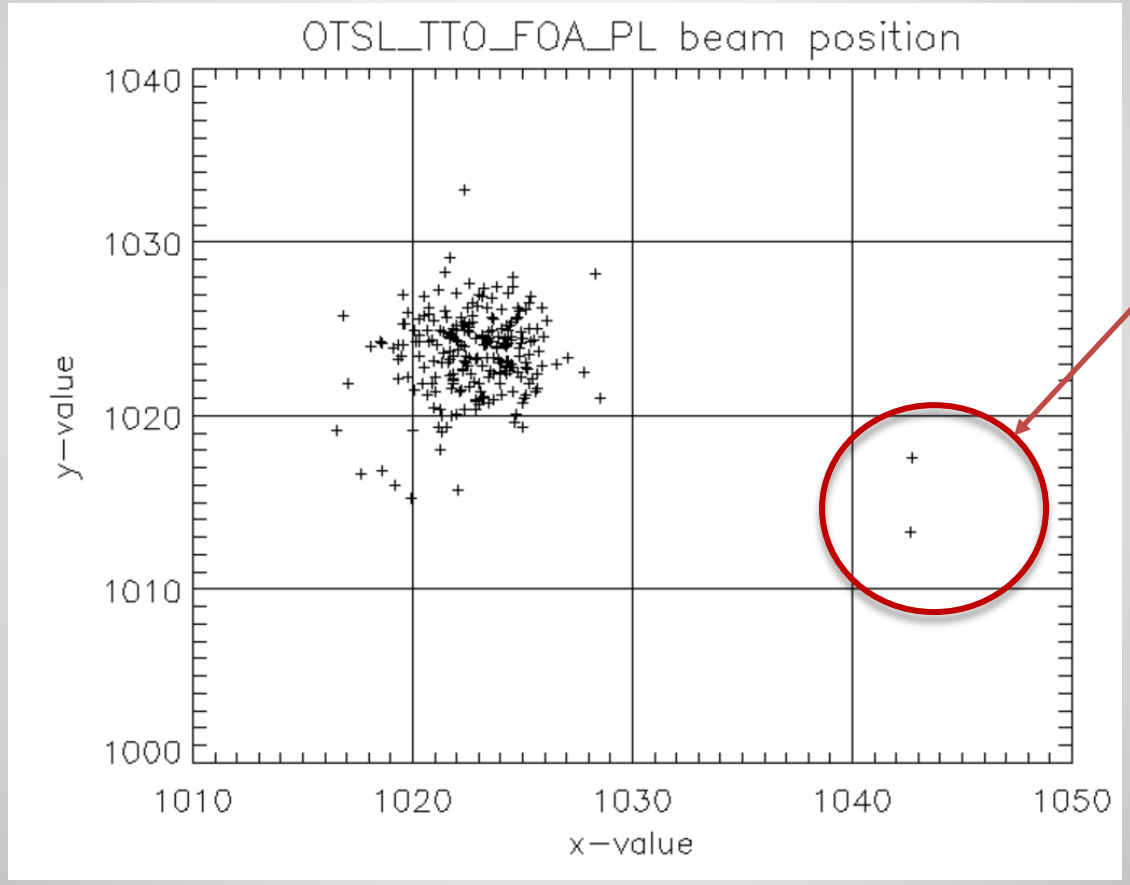
Threshold for each image = (maxValue - meanValue) * th + meanValue; where th=0.66

Position with nominal threshold of 0.3 shows the detection spot is off the required position



Threshold was raised to 0.75 to mitigate (right)

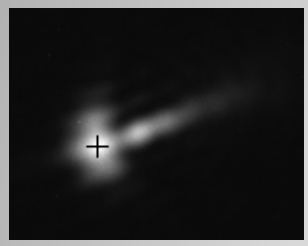
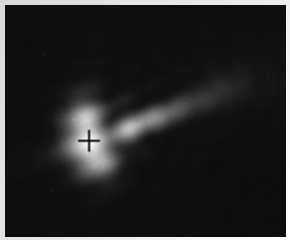
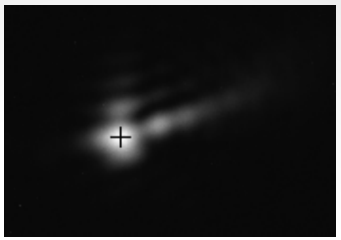
Data taken repeatedly at the same position reveals two significant outliers

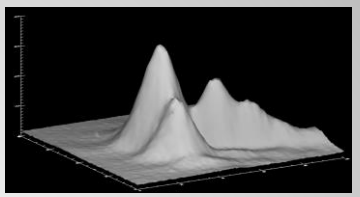


Instability

Analysis of the two unstable images point to smearing as the cause

Normal images



Normal image (58th)

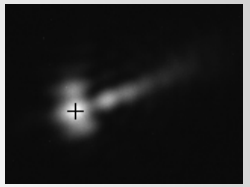


Image 58

Smeared images

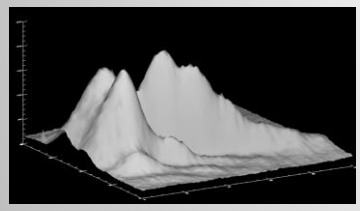



Image 59

Smeared image: brightest spot moves to the tail (19 pixels)

What causes the smearing as shown below ?

- Sudden movement of the beam
- Long exposure time
- Other camera problems

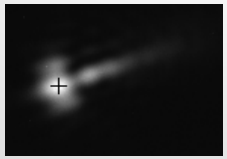


Image 228

Image 229

Smeared image: brightest spot moves to one side

Motivation for testing to determine potential improvement using matched filtering

- An intensity insensitive approach
- Approach based on tracking shape

Appling a single, image-based template overcomes effect of smearing

Normal Image

Image 64

Image 240

Horizontal smear

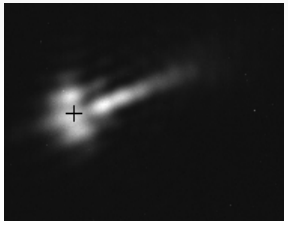


Image 59 (using centroiding resulted in a 19 pixel displacement

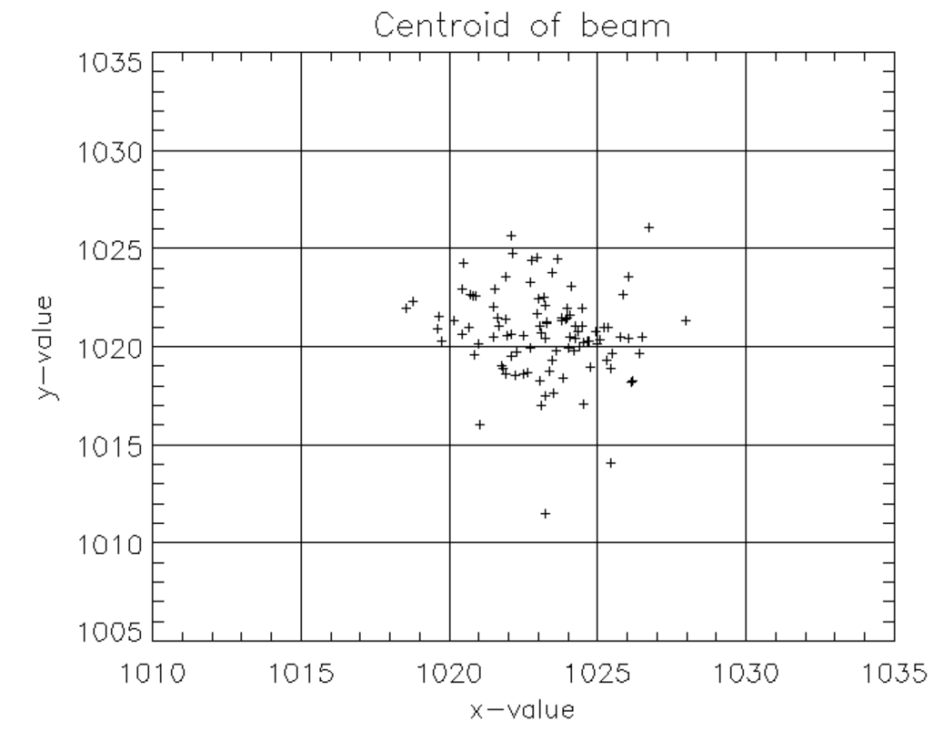
Image 229 (using centroiding resulted in a 21 pixel displacement from mean position

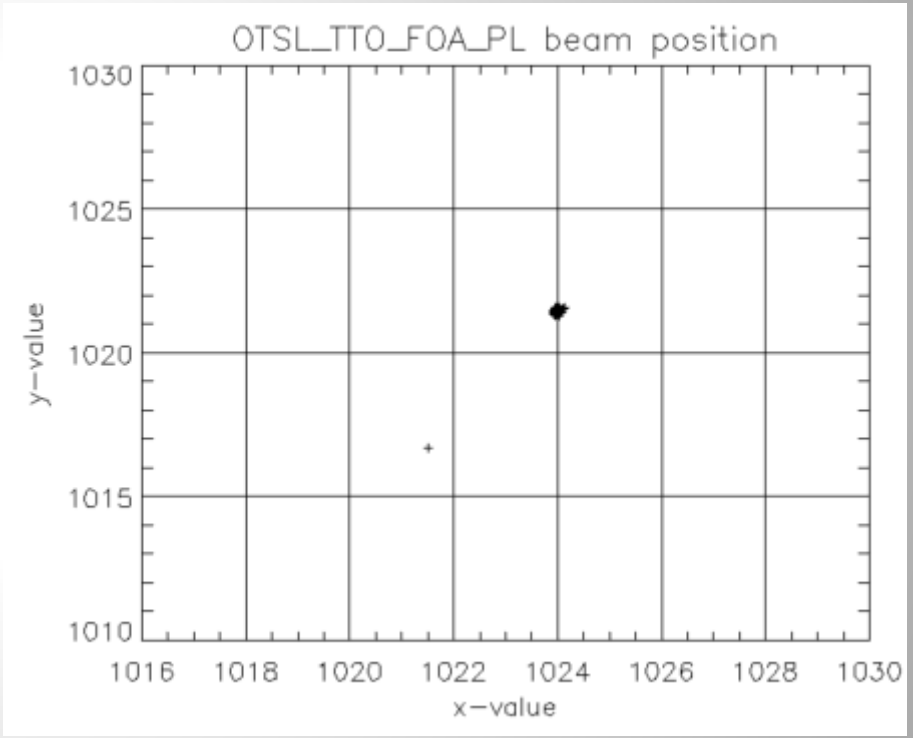
Vertical smear

Image 91

Centroid indicates large movement, but matched filter results in 99% aligned images within 0.3 pixels

Testing with 100 Image sets





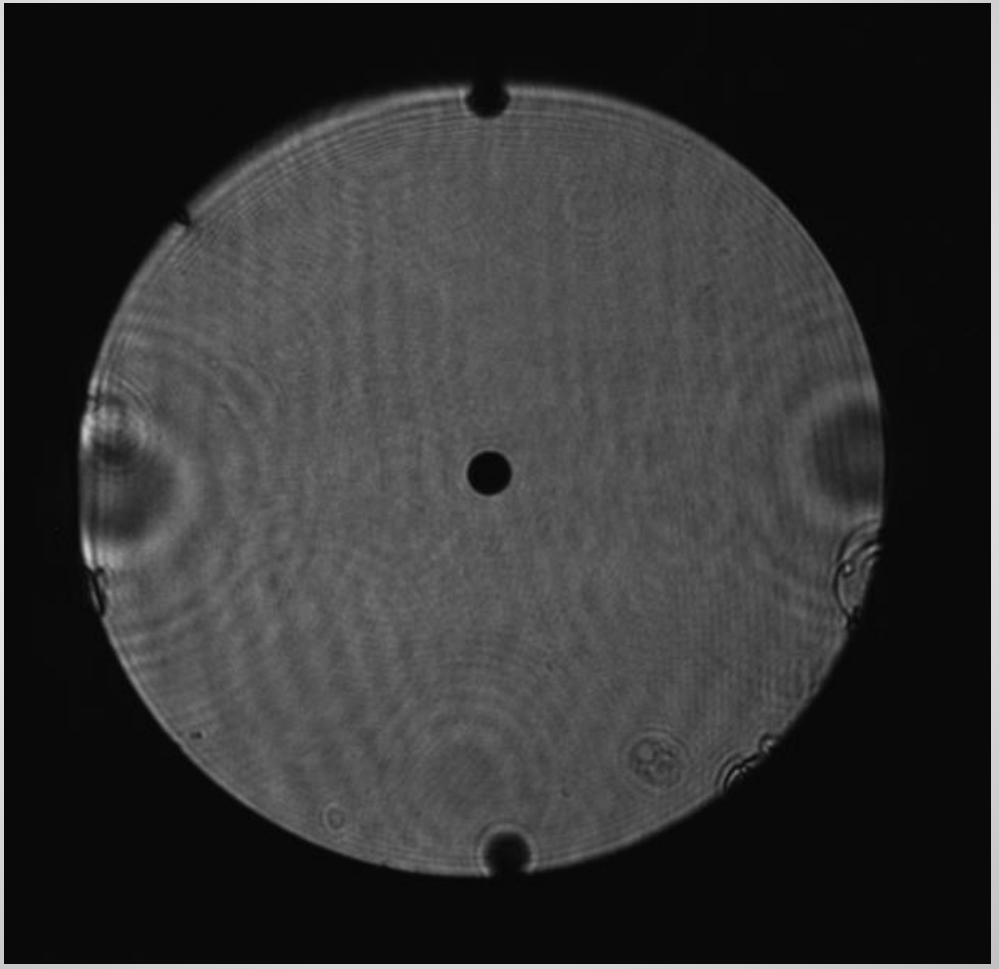
99% within 7-pixel radius vs 0.3-pixel radius for matched filtering

Observation

- **Matched filter with certain templates reports 89% locations within 0.3 pixels**

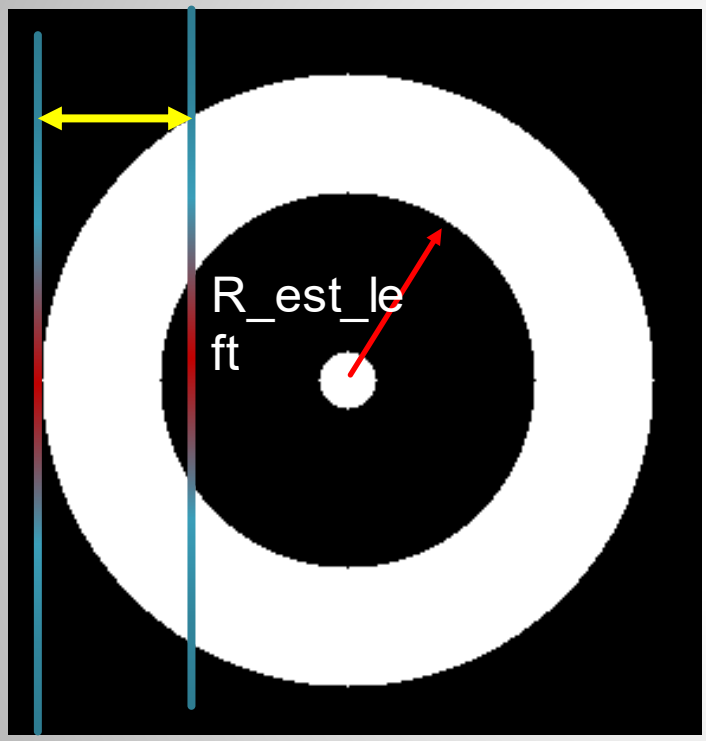
Loop 2:An OTS_ISP_TTI_PL beam with two diffraction rings

ISP=ISP laser
TTI = transport Telescope Input (gimbal)
PL=pointing loop

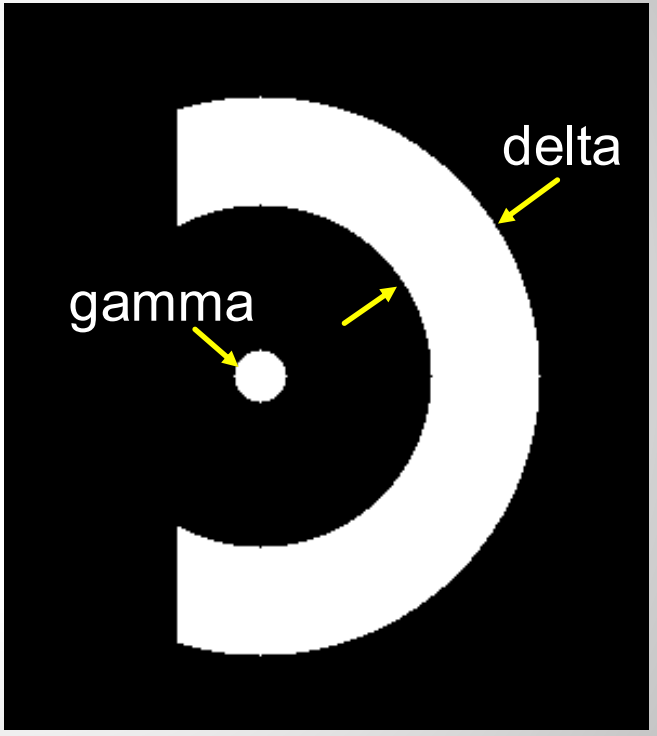


Template defined

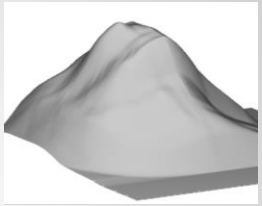
Left fraction



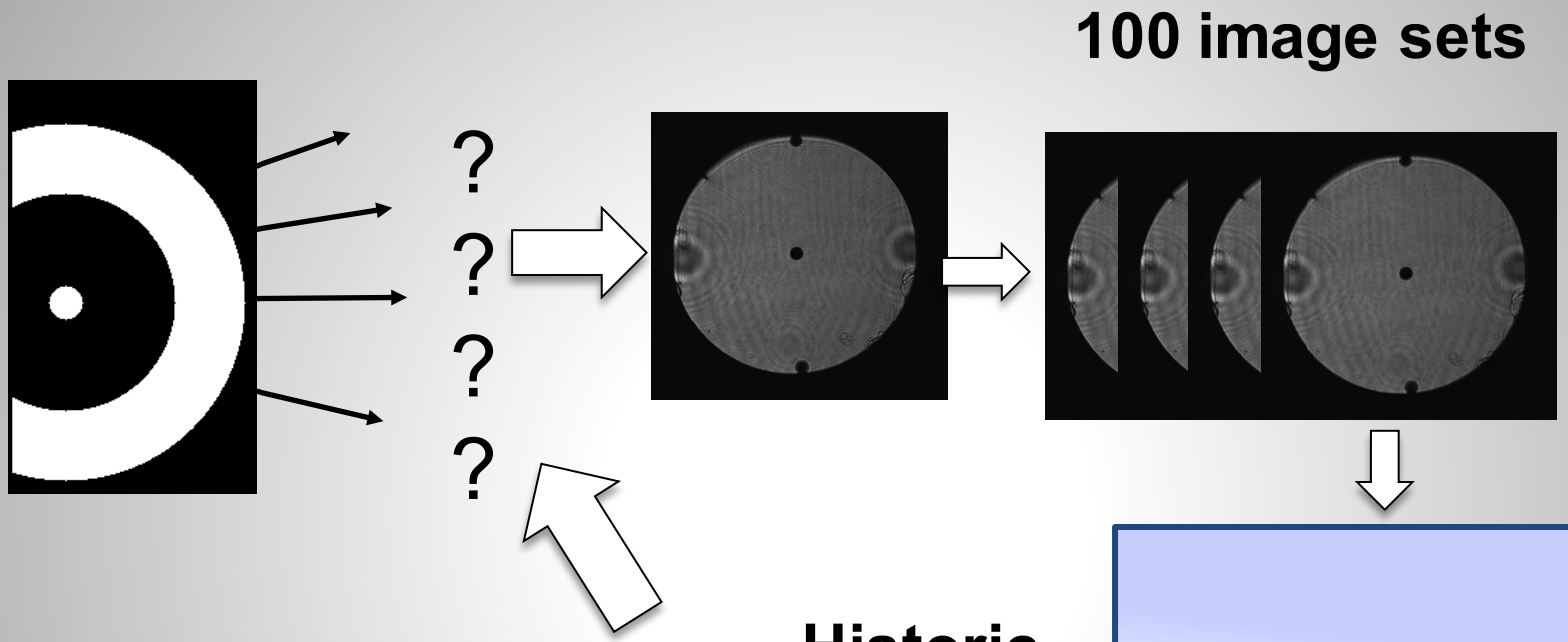
Left fraction =0.35



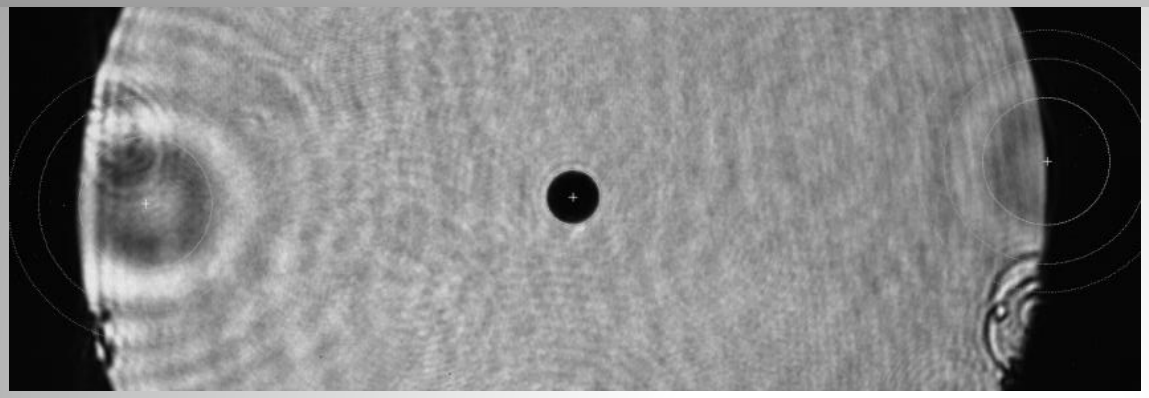
Segmentation, correlation, peak selection, distance check, output positions



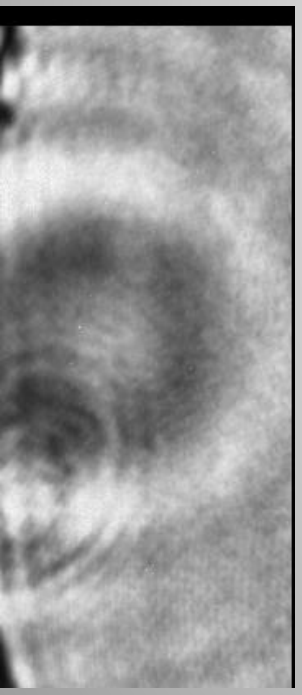
Optimization ..

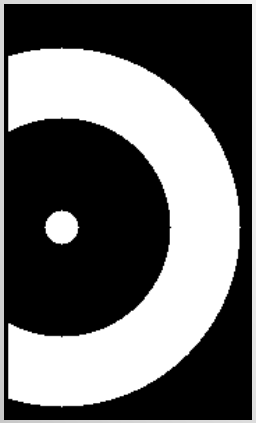


Parameters for the template after optimization

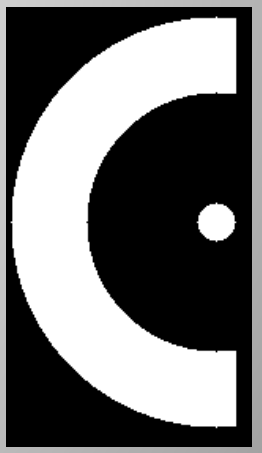


right_frac=0.45
Gamma=12
R_est_right=82
Delta2=48

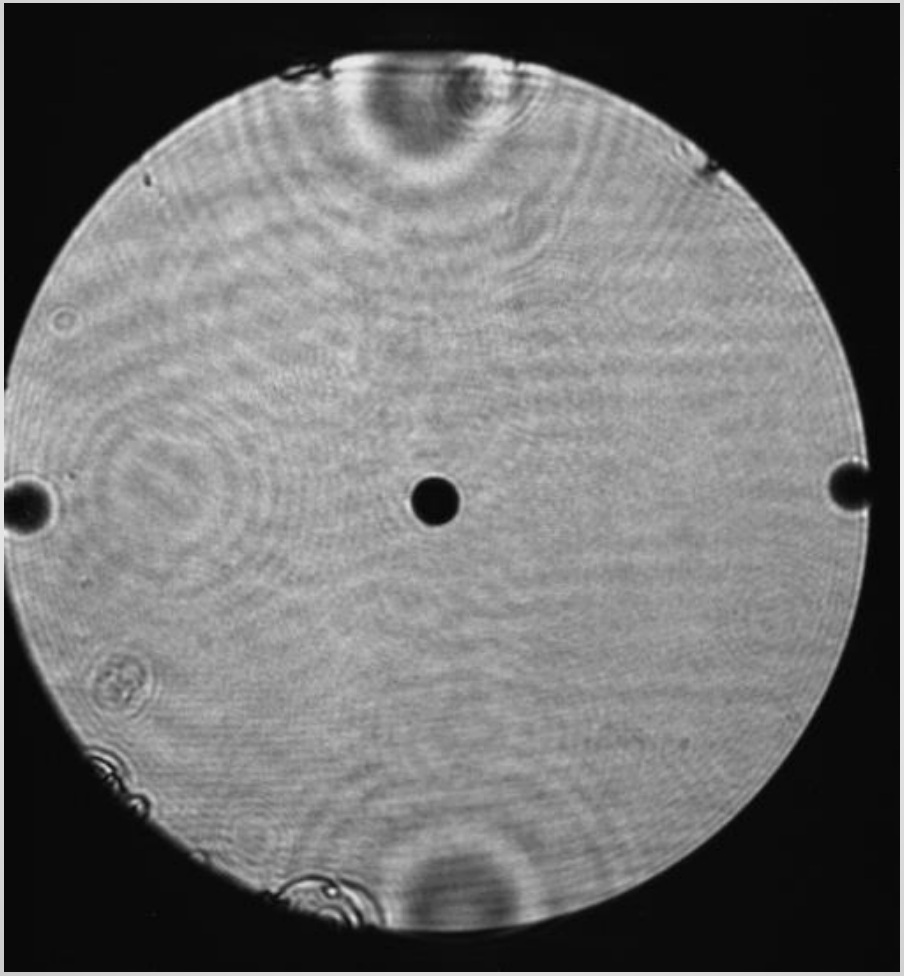




left_frac=0.35
Gamma=12
R_est_left=78
Delta1=50

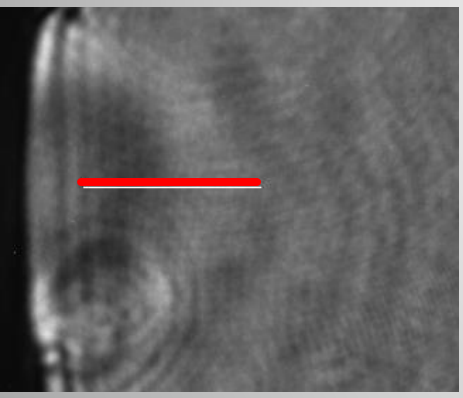


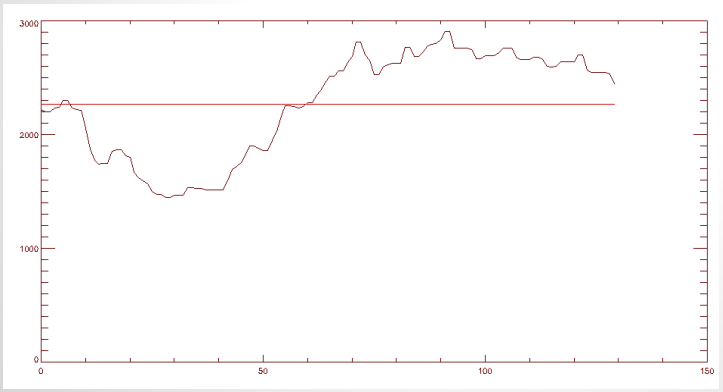
When image is rotated, a certainty detector is needed

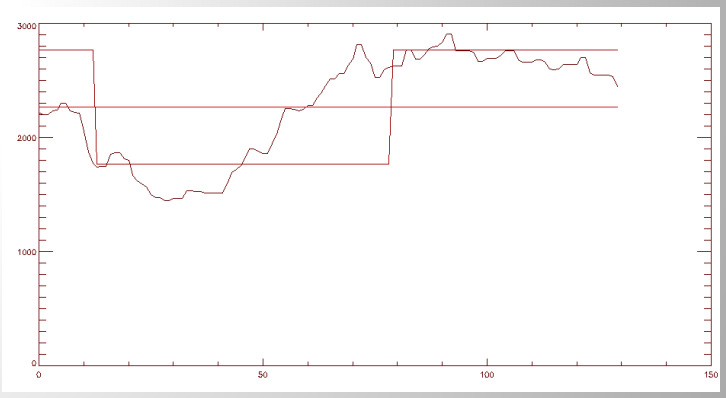


Detector produces high score when valid detection and negative when false

- Design a reliability detector: stored pattern bipolar binary (+1,-1)
- Input pattern (-1,0,+1)

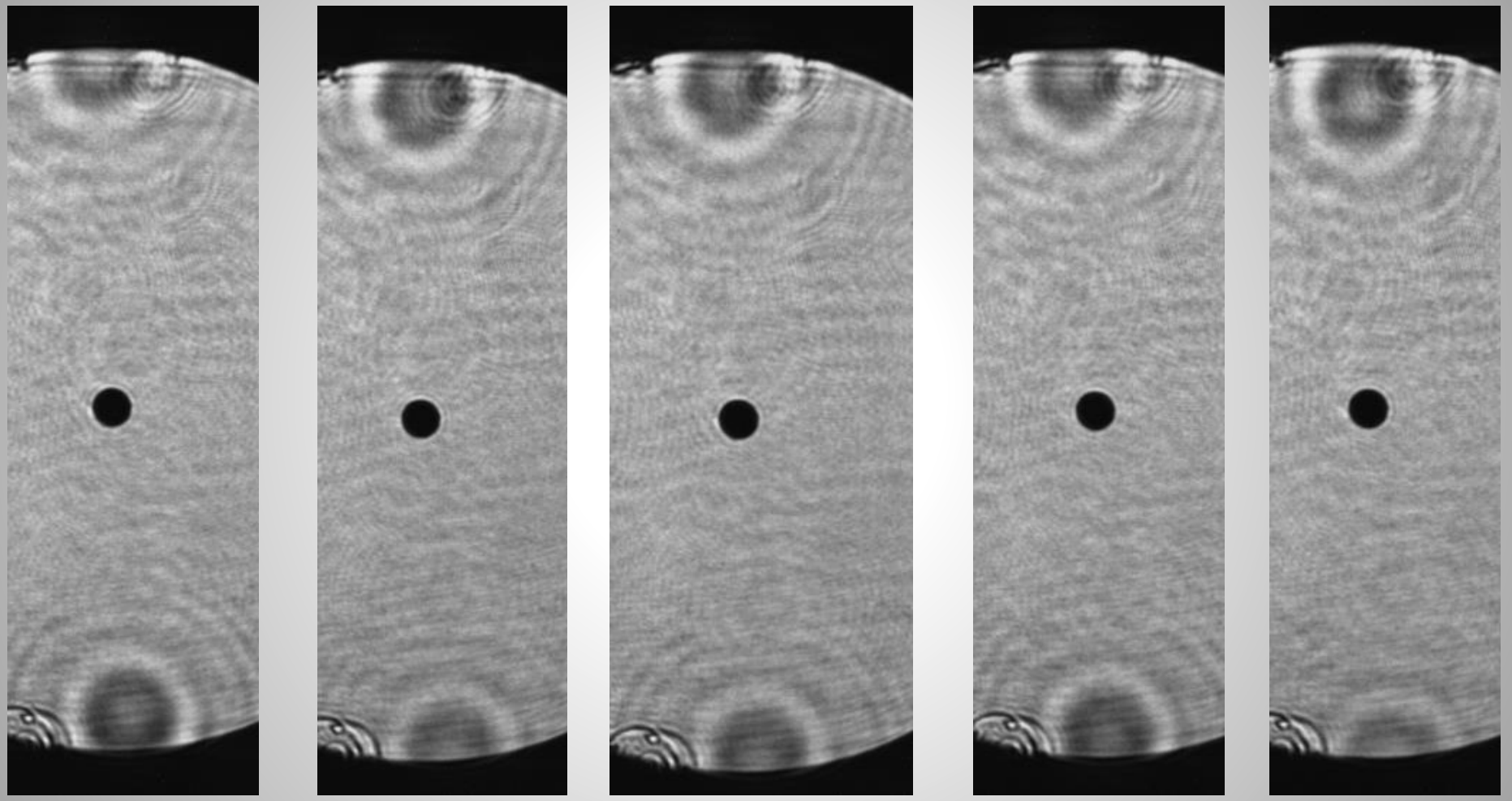






- Inner product (0 1 -1 -1) . (1 1 -1 -1) = 3, correct detection gives 80+ value and incorrect a -50 or less

New Requirement: Diffraction ring moves and has variable missing fraction

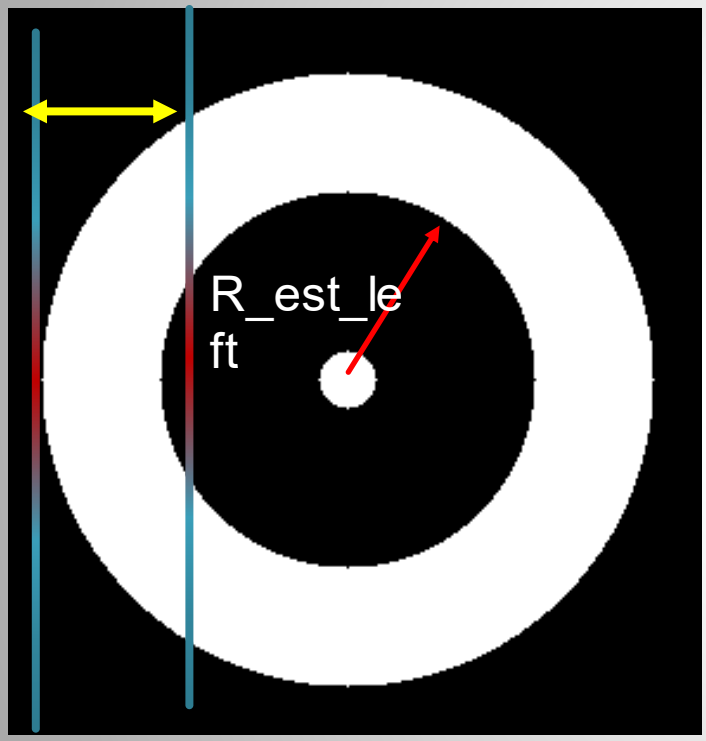


Effect of ring movement

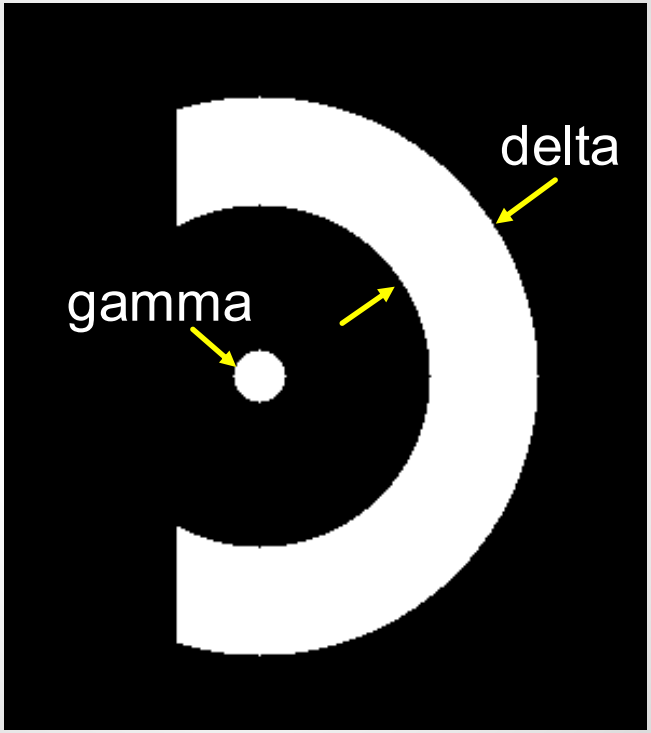
- Optimization difficulty increases
- Begin optimizing with one set (aligned)
- Apply other sets for minimum divergence
- Missing fraction varies
- If one spot is sparse, we must know the other spot is correct before estimating the unknown spot

Template Redefined

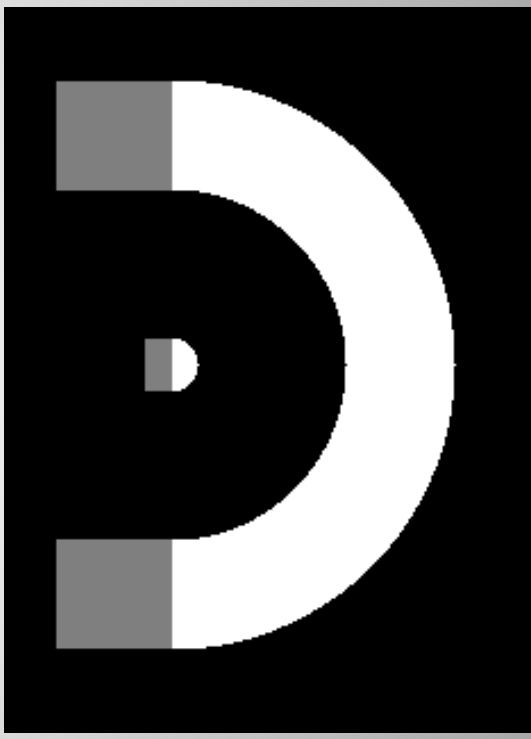
Left fraction



Left fraction =0.35



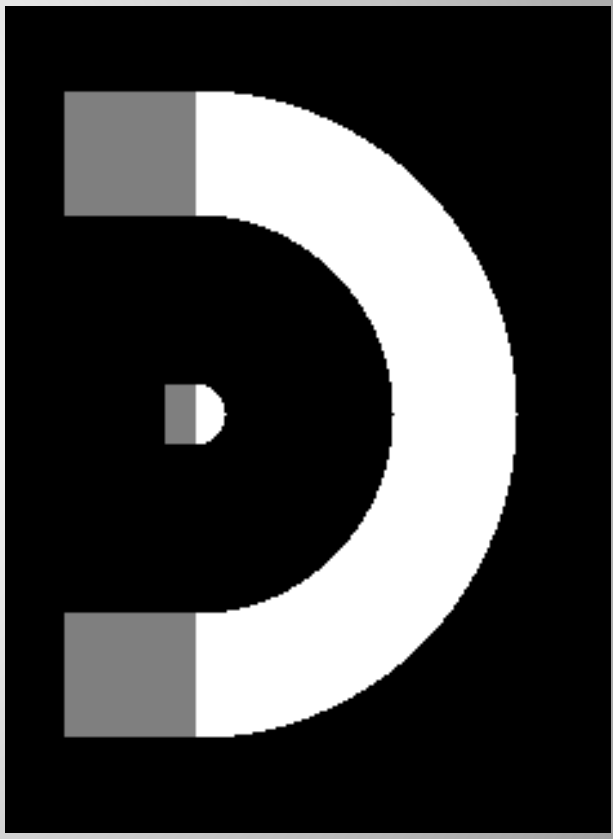
New template



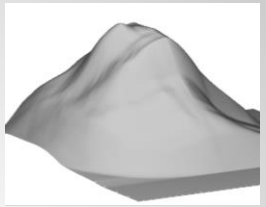
Template redesigned: from simulated diffraction shape also from the top set of 500-image set

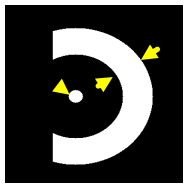
Top template radius= 77 width= 48
missing fraction= 0.3 gamma= 12

Bottom template radius= 73 width= 45
missing fraction= 0.6 gamma= 12



Two additional blocks: Reliability detector and missing fraction estimator





Pre-processing

Segmentation

Matched filter

Output positions

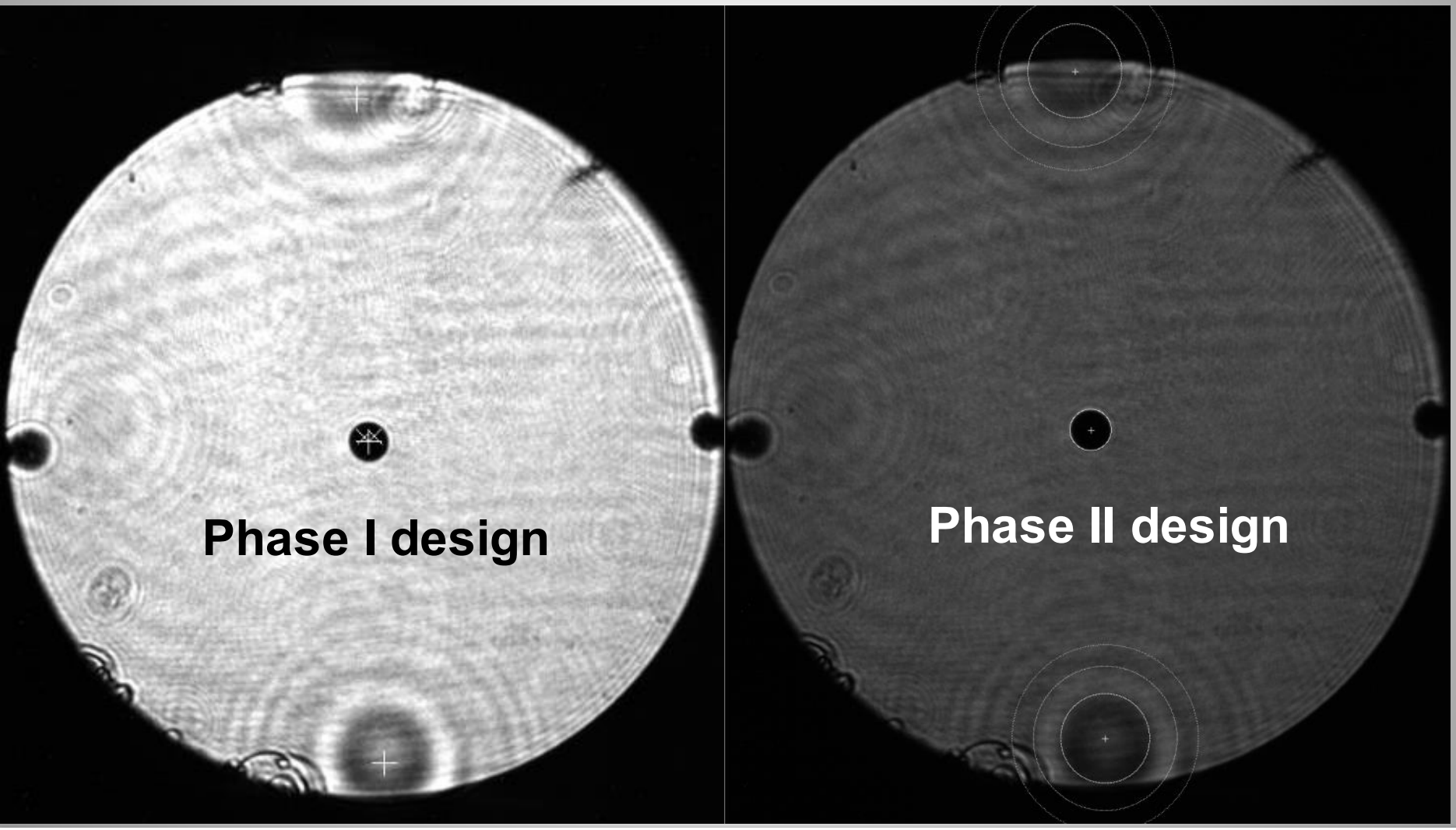
Post-processing

Reliability detector

Missing fraction estimator

New positions

New template and missing fraction calculator provides better detection of the rings



Summary

- An OTS laser pointing loop compared a weighted centroid and matched filtering for a pointing beam
- Template based Algorithm for diffraction ring detection
  - Optimization for parameter selection
  - Reliability detector

Acknowledgements

- Alexandra Saabye, Tris Sunardi


Thank you!
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