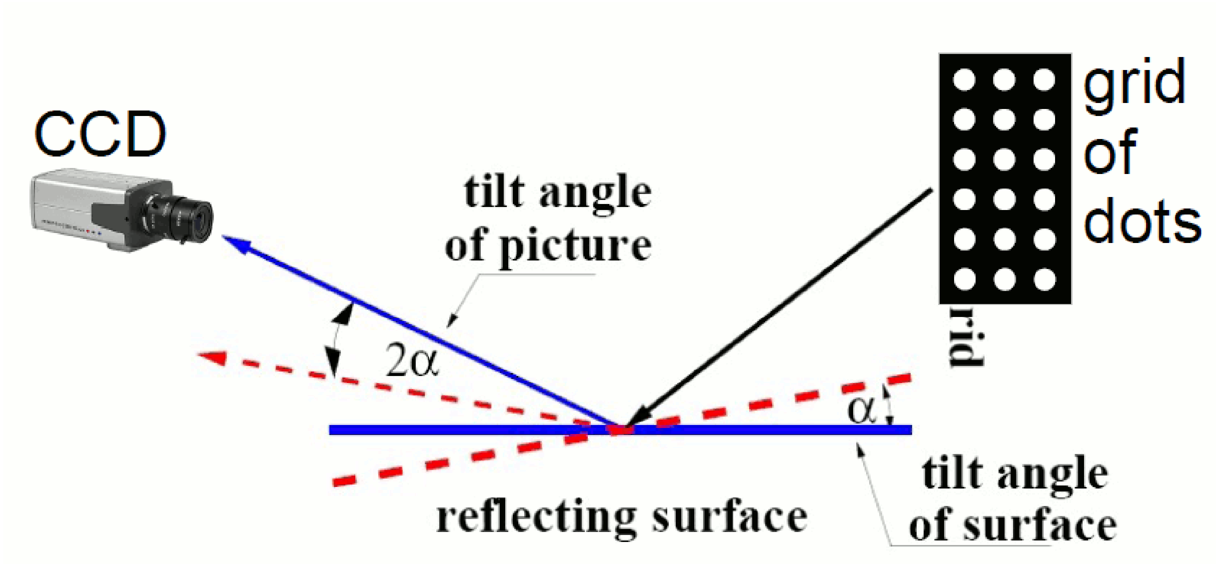
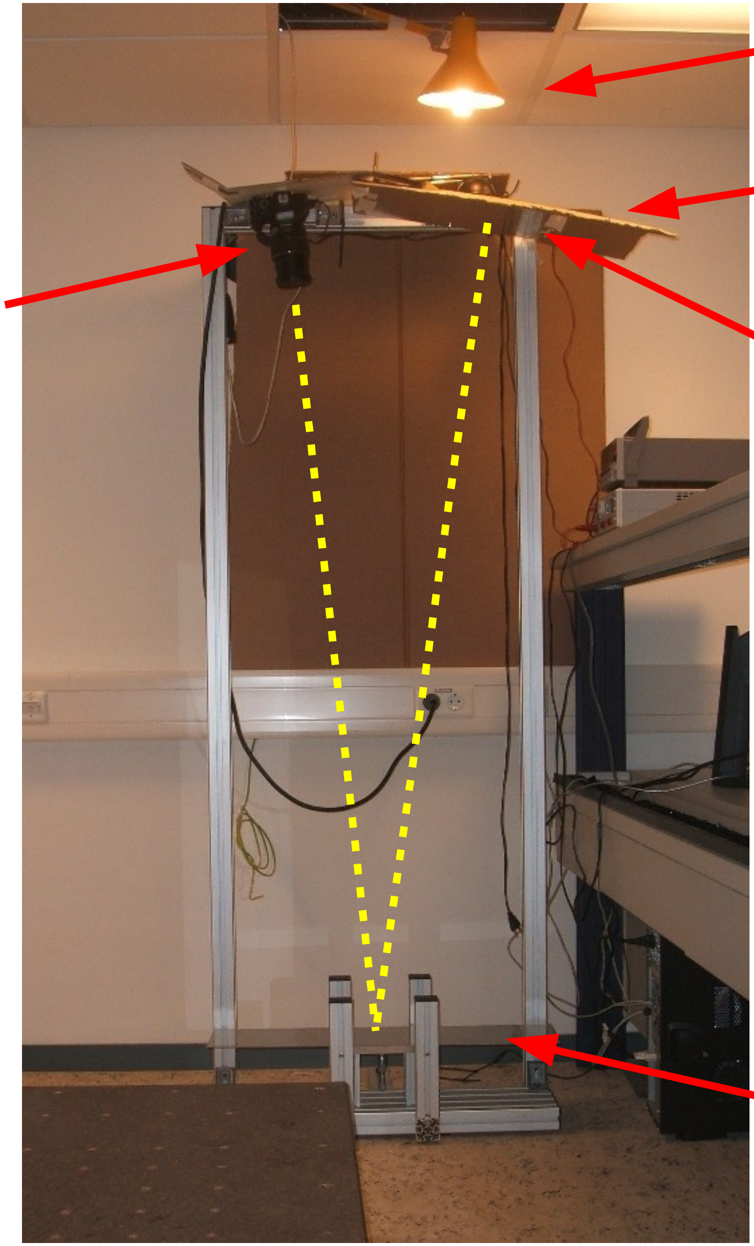
Status of the deformation measurement setup & software

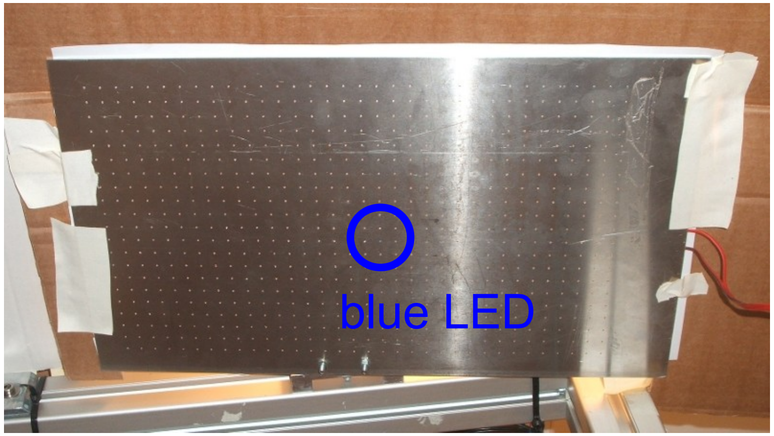
Basic principle



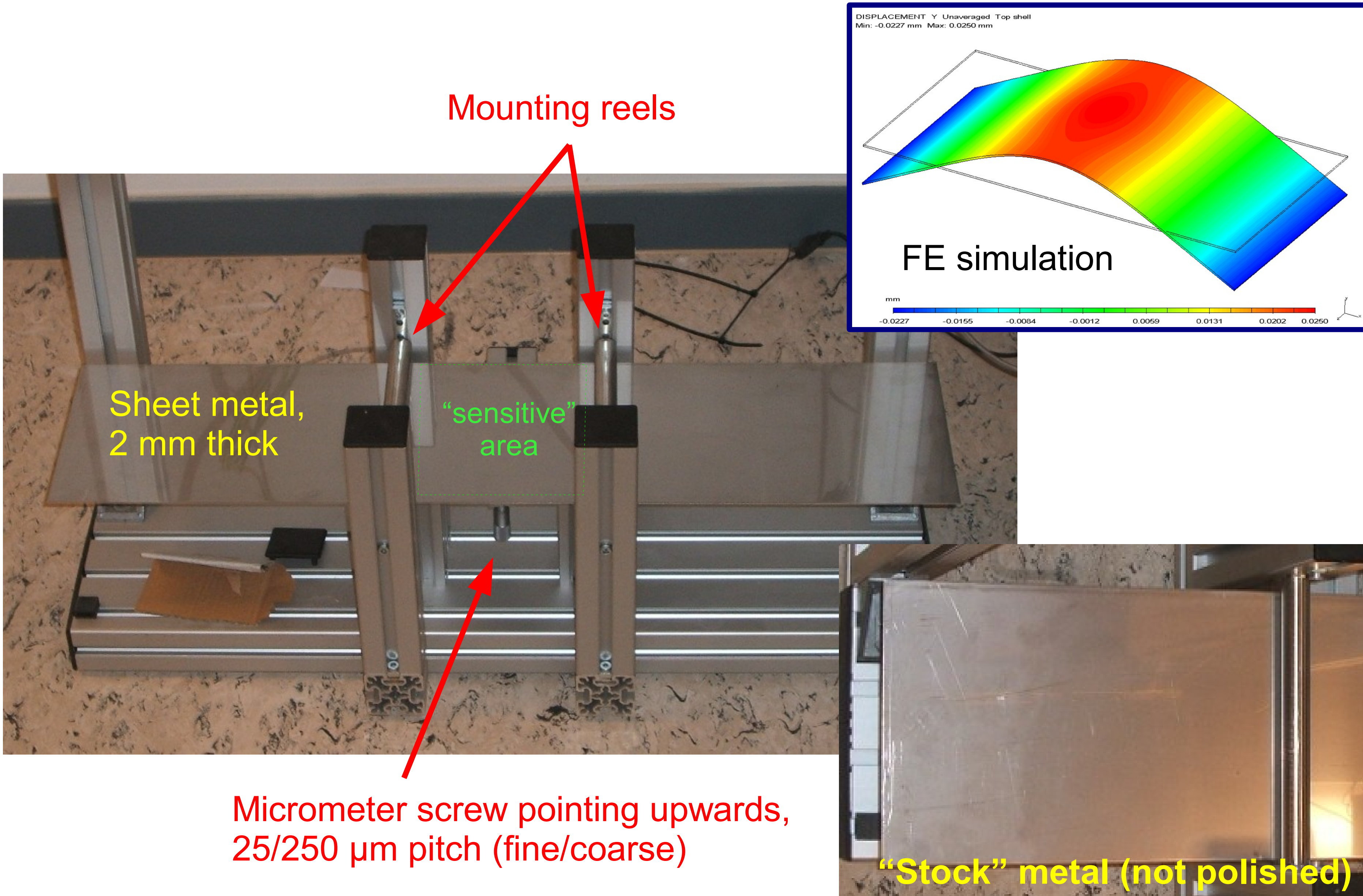
- surface under test reflects a grid of dots or LEDs, observed by a CCD
- tilt of surface elements (deformations) lead to a displacement of the dots on the CCD
- full 3D “sampled” surface reconstruction possible –
  - **relative to a reference shape/image** (typically at room temperature)
  - **accuracy ~10 µm** can be reached
  - only “intrinsic” deformation – global offsets or tilts cannot be reconstructed

Teststand mock-up





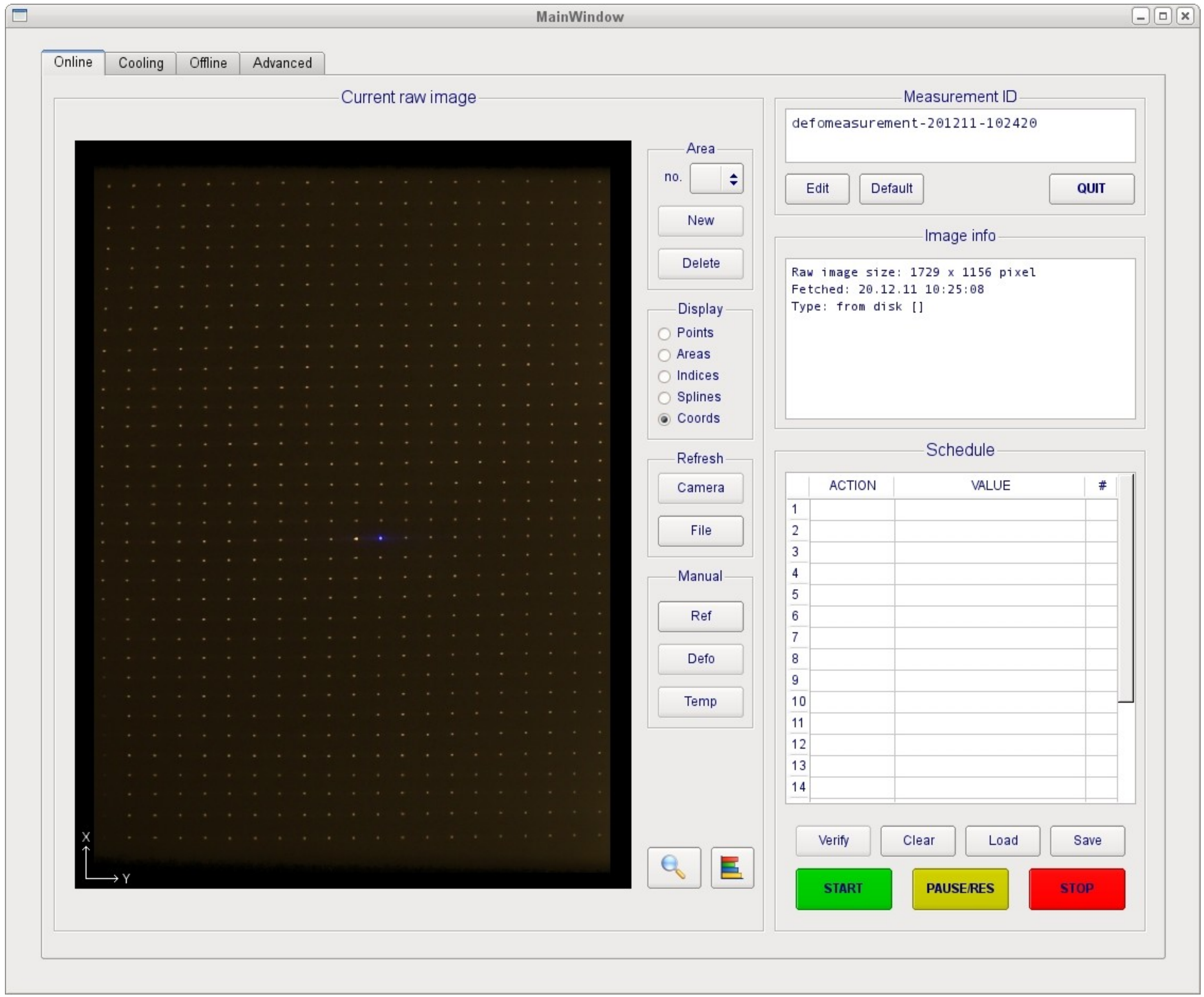
Calibration surface



Reconstruction: reference image

Reference image:

- micrometer screw gently touches sheet (slight bias)
- for thermal defo measurements, reference would typically be at room temperature

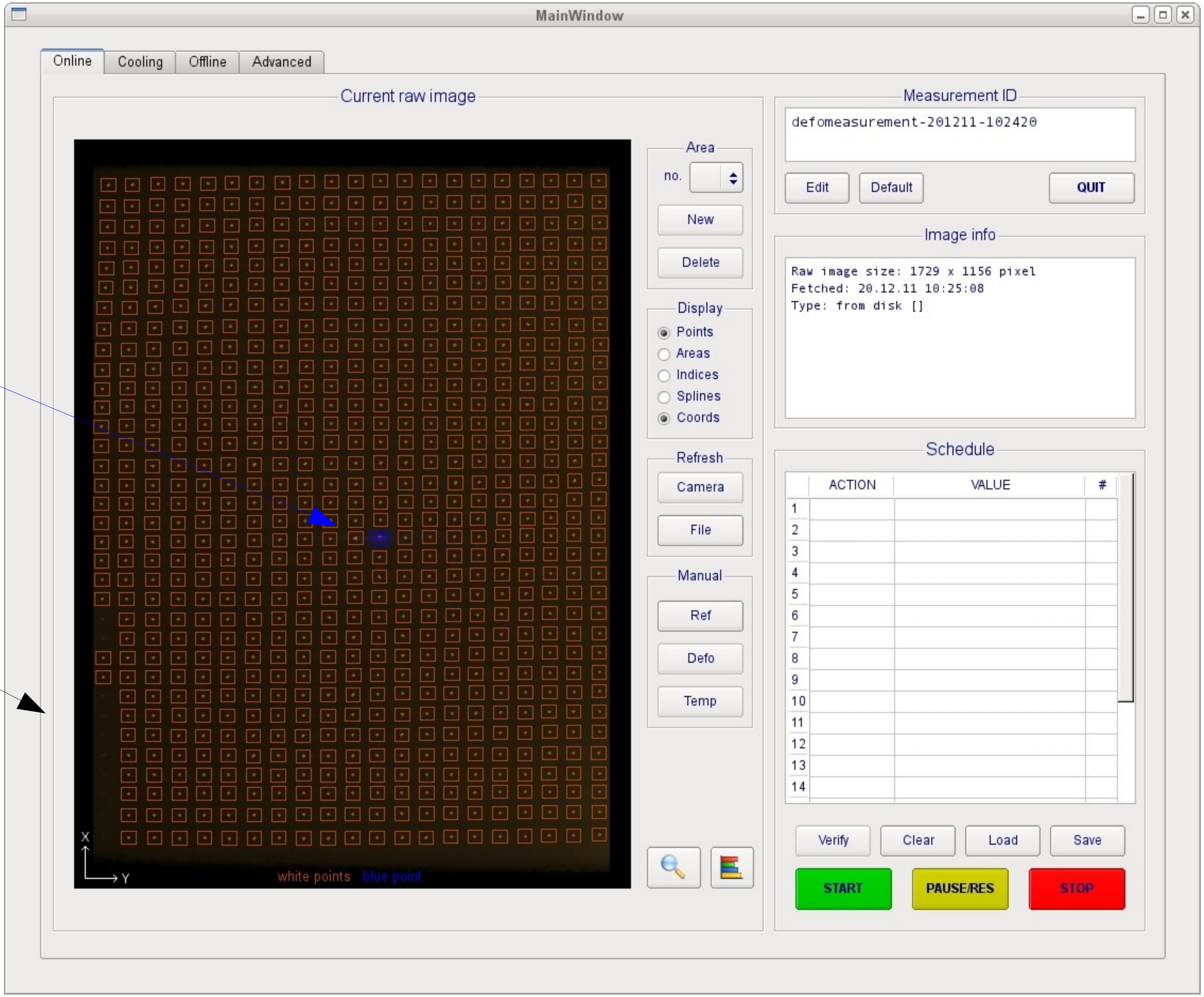


Reconstruction: reference image

point reconstruction successful

blue point as coordinate reference

some points not found (too low contrast)

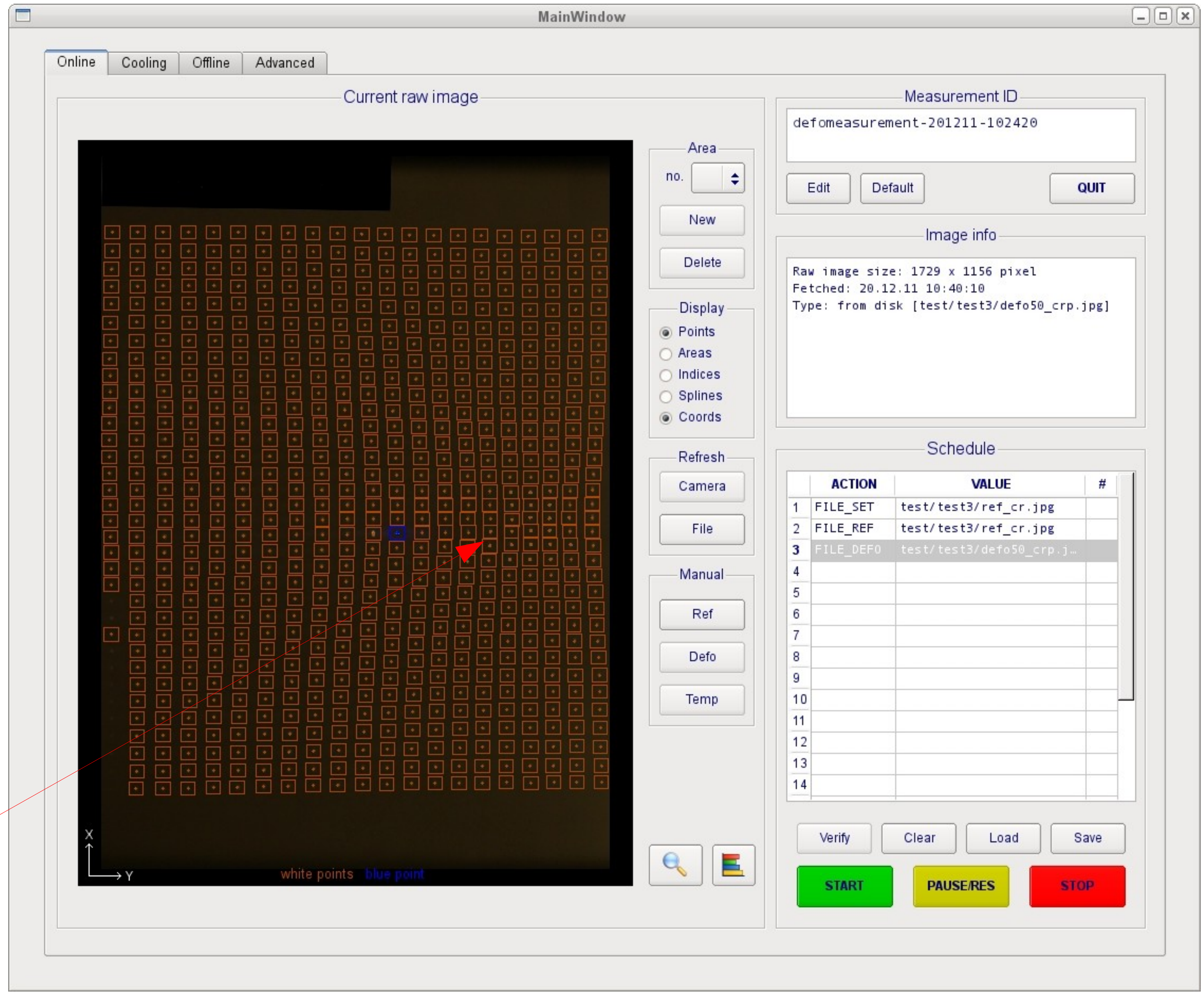


Reconstruction: deformation image

Deformation image:

• micrometer screw **500 µm** upwards

• some postprocessing necessary due to very low contrast and bad ambient light conditions (few points manually enhanced)

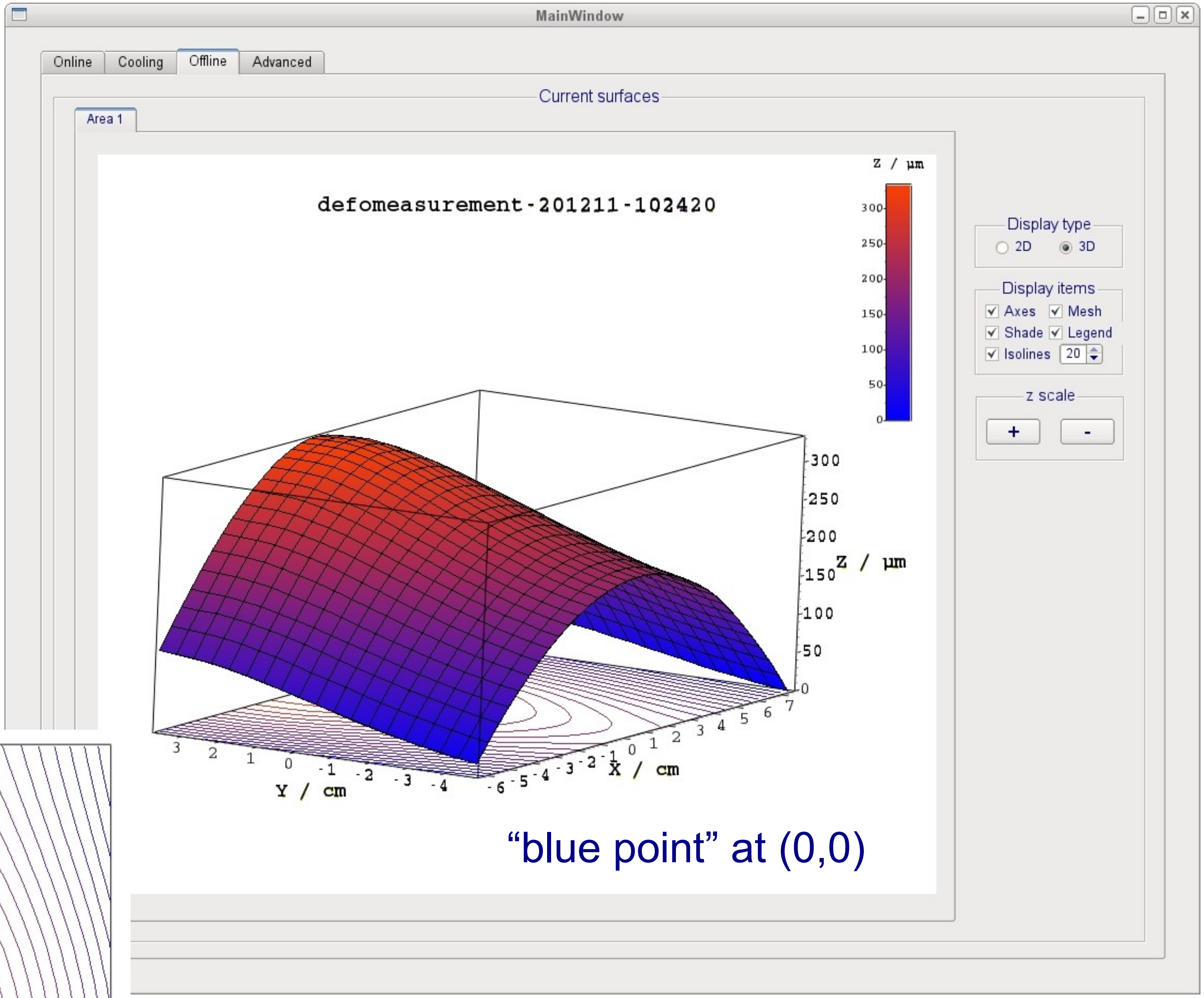


"bump" from the pressure point

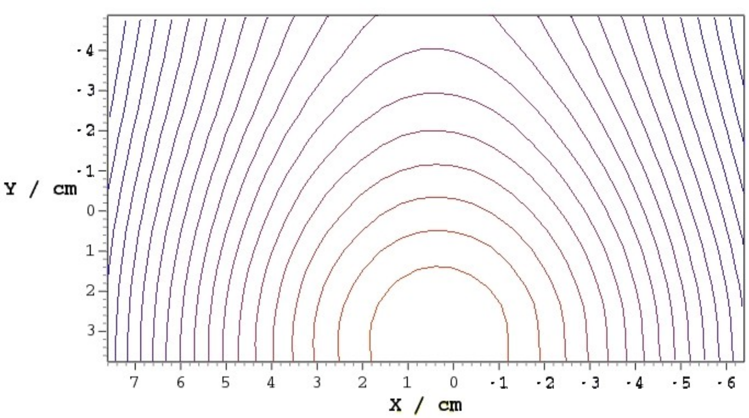
Reconstruction: surface

Result yields ~320 µm deformation amplitude

- reconstruction parameters (setup geometry) not yet properly adjusted
- metal sheet too stiff and not uniform (kinks)
- postprocessing might have introduced a bias (“bump” might be more protruding)
- parts of the surface obstructed by reels



“blue point” at (0,0)



→ **systematic measurements at various amplitudes**

Software developments

Already functional:

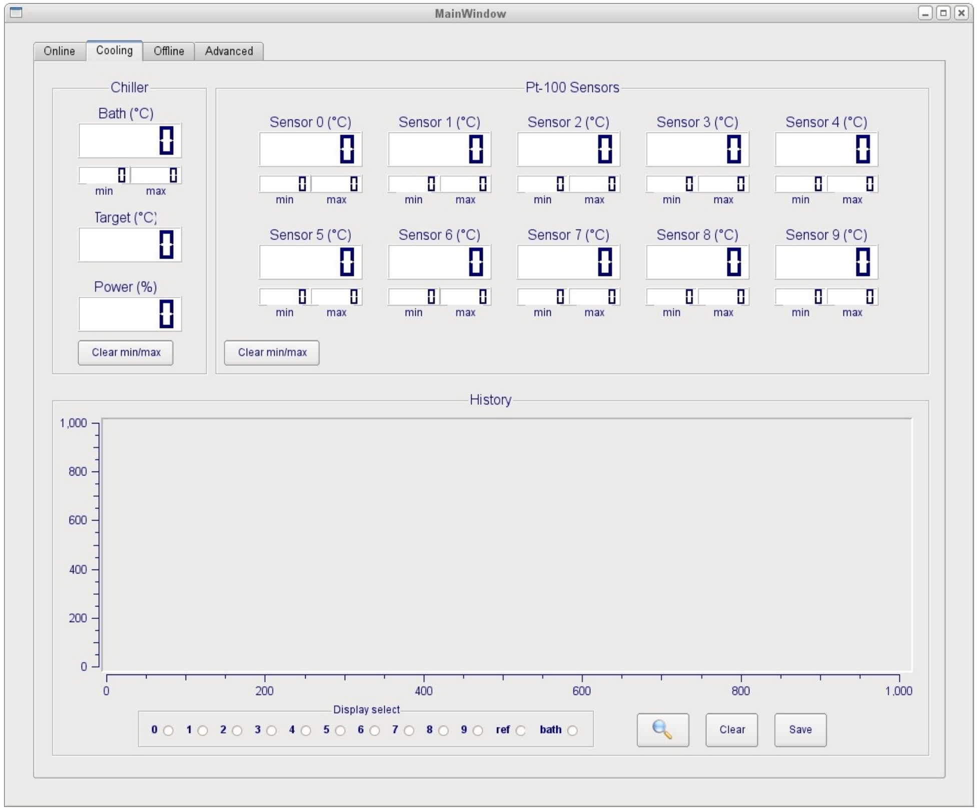
- remote operation of camera
- image analysis (histograms, etc.)
- file & reconstruction results output
- restrict reconstruction to areas
- programmable schedule (automatic measurement series, temperature cycles, etc.)
- ...

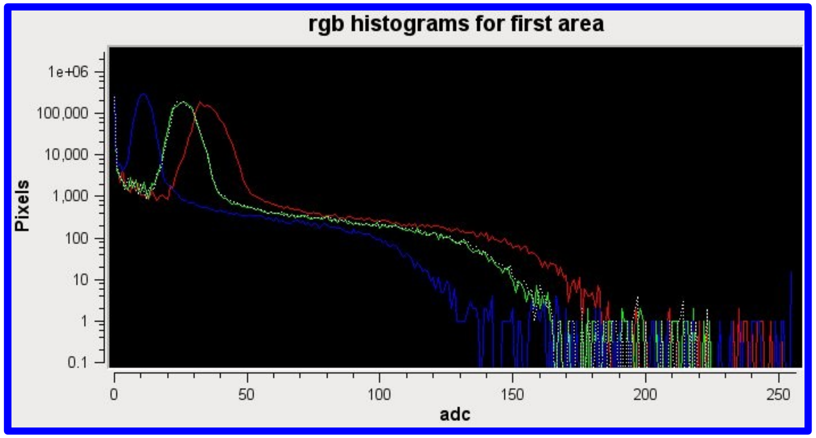
Upcoming:

- chiller remote control
- temperature probes

} partly done

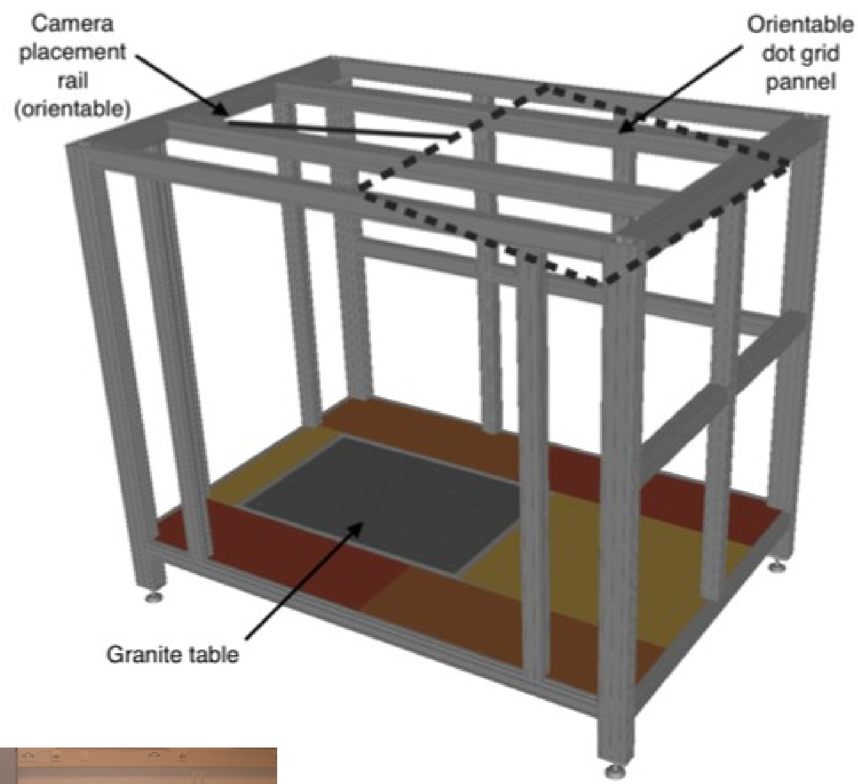
- standalone result "viewer"
- camera whitebalance
- multiple simultaneous areas processing
- whatever else is needed ...





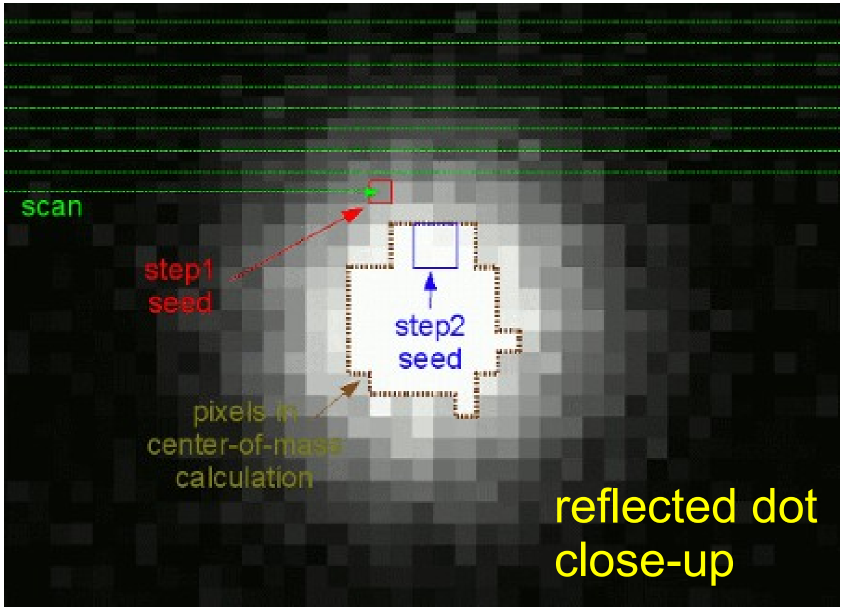
Final setup

- for large scale application up to ~ 80 x 80 cm (ATLAS petals)
- dark environment, low ambient light through LED backlight illumination
- some scaffolding parts already delivered
- need to duplicate temperature probe readout
- time scale ~ 2 months

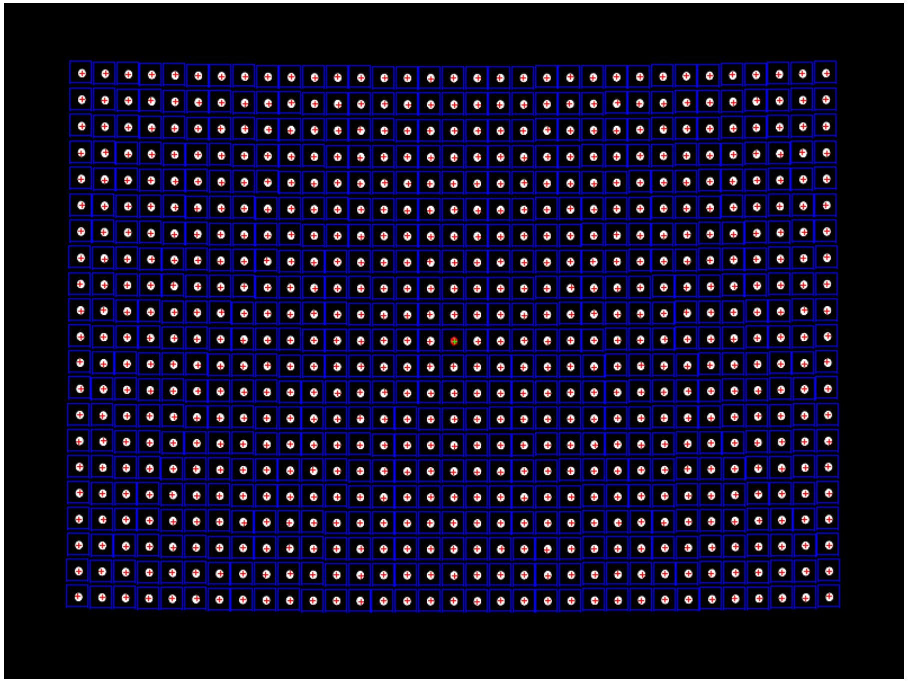


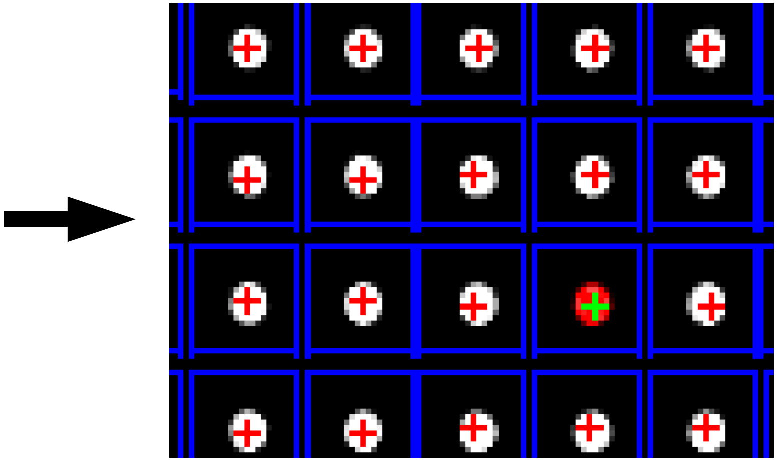
more slides

surface reconstruction: point finding



- scan along x,y row-wise and compute grayscale ADC values
- stop at pixel > threshold **T1** (step1 seed)
  - evaluate group of pixels in vicinity
  - if average > threshold **T2** (step2 seed)
    - accept point
    - determine point position by center-of gravity of all pixels around seed2 with grayscale ADC > threshold **T3**
    - average red/cyan ratio of pixels to determine if the point is “red”

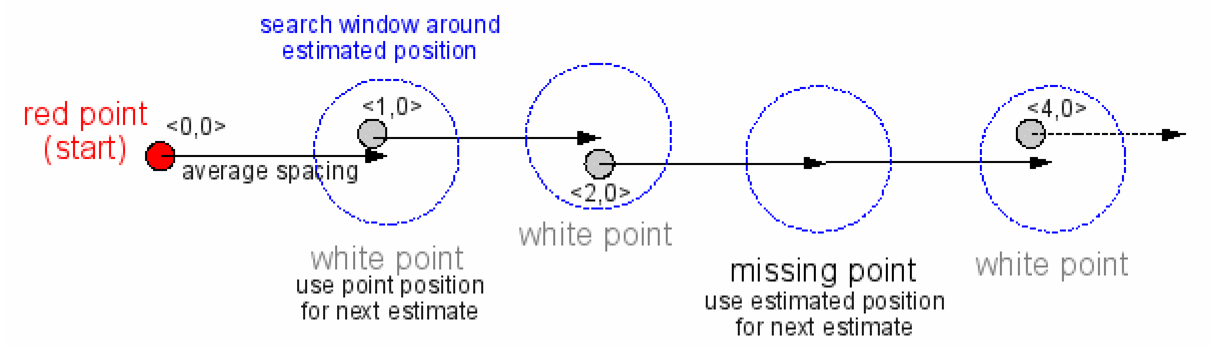




surface reconstruction: point indexing

Must consider that points might be missing:
- gaps in multi-component surfaces
- points not properly reflected (diffraction, surface quality, …)

Indexing assigns position indices (0..N, 0..M) to the reconstructed points:
- 1:1 matching of reflected points to the grid
- red point in the middle is used as reference (0,0)
- average spacing along x and y is determined to estimate the positions of the next point(s)



Indices are used to match points in reference and "current" image

Requires proper tuning of reconstruction & setup parameters
(size of search window, distance of dots in grid, etc.)

surface reconstruction: calculating the surface slope

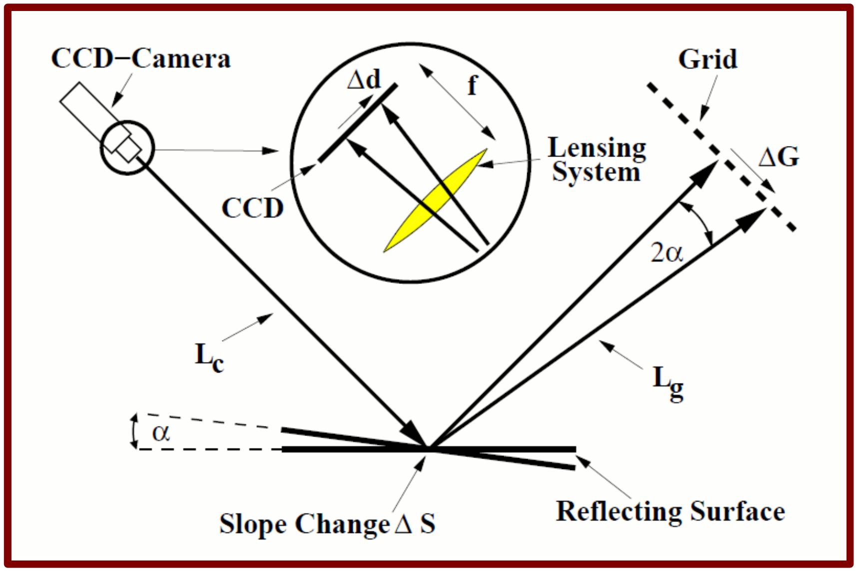
Parameters for determining the surface slope:

- focal length of camera lens f
- CCD pixel pitch P
- distance camera-sensor Lc
- distance sensor-grid Lg

(Lc and Lg: depend on viewing angle)

Point shift on sensor Δd (between current & reference image) is measured

$$\tan\left[2\cdot\arctan\left(\Delta S\right)\right]\cdot L_g\left(\delta\right)=\frac{\Delta d\cdot P}{f}\cdot\left[L_g\left(\delta\right)+L_c\left(\delta\right)\right]$$



Gives the surface slope changes ΔS between reference and current state at the position of a point
→ spatial integration required

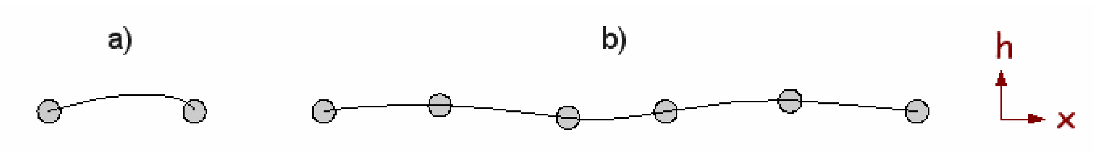
Viewing angle corrections to Lc and Lg currently not applied (need to calculate)

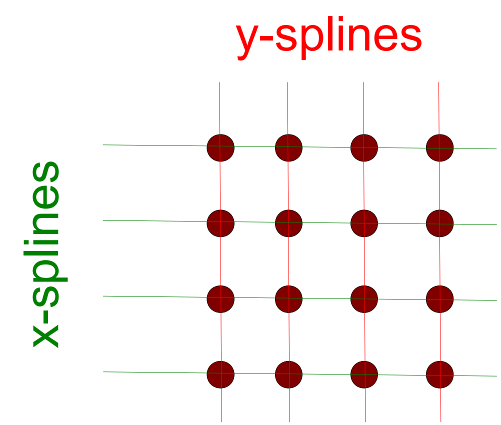
surface reconstruction: spline fitting

Indexed points are grouped in "rows" (along x) and "columns" (along y)
→ fit a quadratic spline to each group

$$h(x) = A \cdot x^2 + B \cdot x + C$$

h := surface height (deformation amplitude)





For all splines along a "row" or "column" :

$$h_j(x_{j+1}) = h_{j+1}(x_{j+1}) \text{ for } j = 1..N-1$$

continuity at the intersections

$$\frac{\delta h_j}{\delta x}(x_{j+1}) = \frac{\delta h_{j+1}}{\delta x}(x_{j+1}) = h_{j+1} \text{ for } j = 1..N-1$$

continuity of 1st derivative

$$\frac{\delta h_1}{\delta x}(x_1) = s_1, h_1 = 0$$

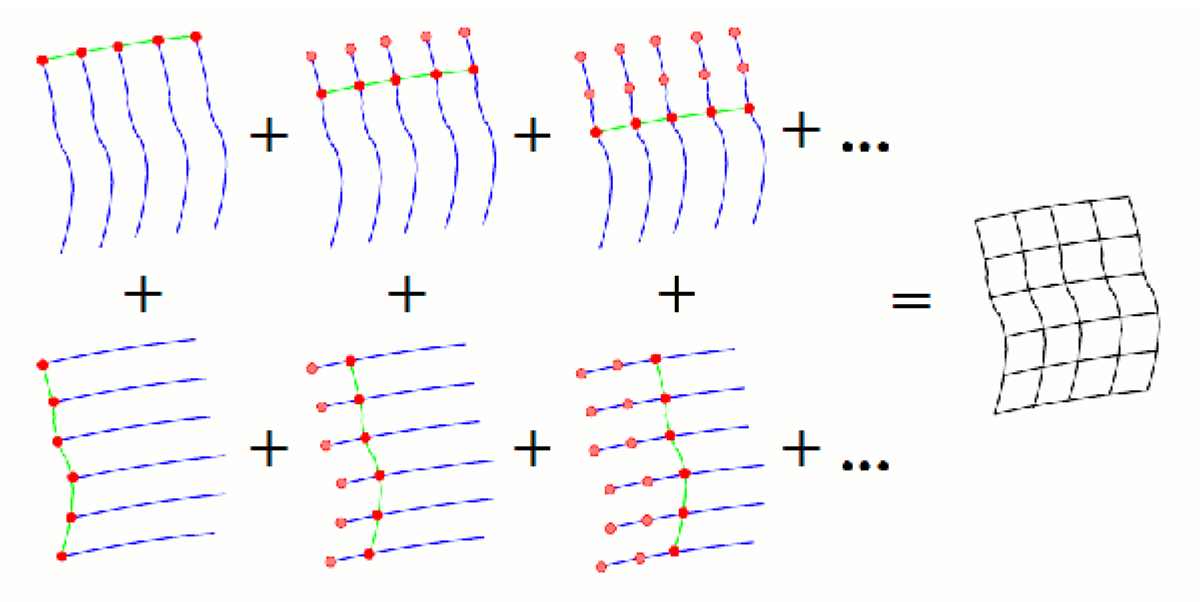
freedom of choice for global height (parameter C)
which cannot be reconstructed
since we have changes in slope ΔS only

→ equation system can be solved to obtain surface profile along spline

surface reconstruction: spline cross-mounting

Splines are “cross-mounted” on each other:

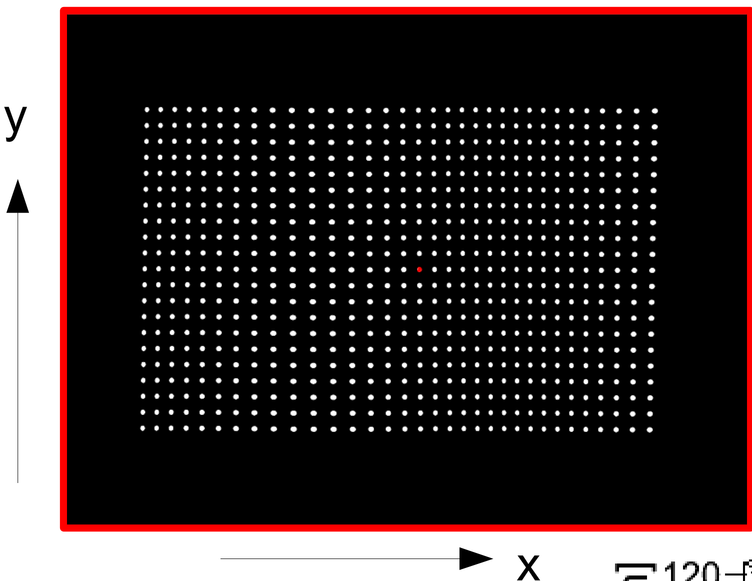
- take 1st spline along x and adjust the height of all perpendicular y-splines at the shared point (“mount” them on the x-spline)
- take 2nd spline along x ...
- …
- repeat procedure in perpendicular direction



The average of all adjustments determines the global height of a spline
→ smooth surface

Finally, correct for global surface height offset (lowest point set to 0)
and tilt (rotate surface such that average normal is perpendicular to x-y-plane, TODO)

simulation examples: a sine "wave" along y



Simulated surface:
z = 50 µm * sin(6 / cm * x)