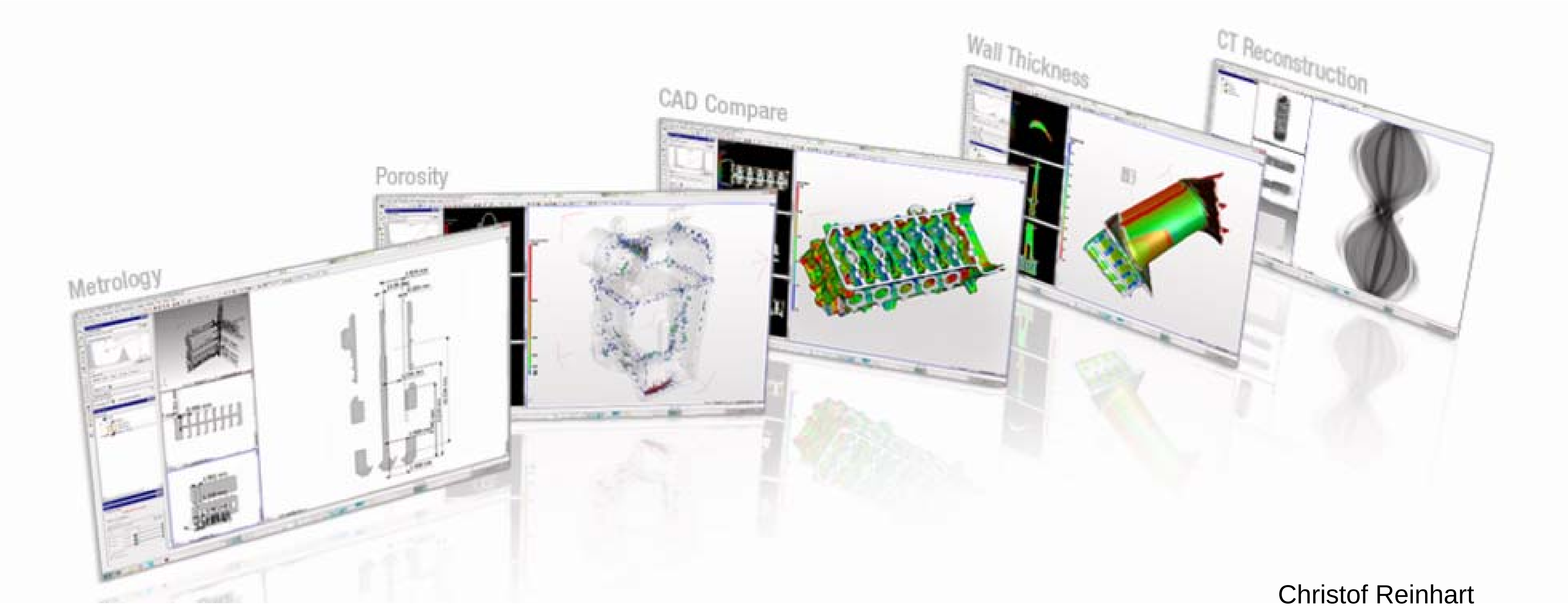
Conference in "Application of CT Scanning in Industry“
at Danish Technological Institute, 31. May 2011

Industrial CT & Precision



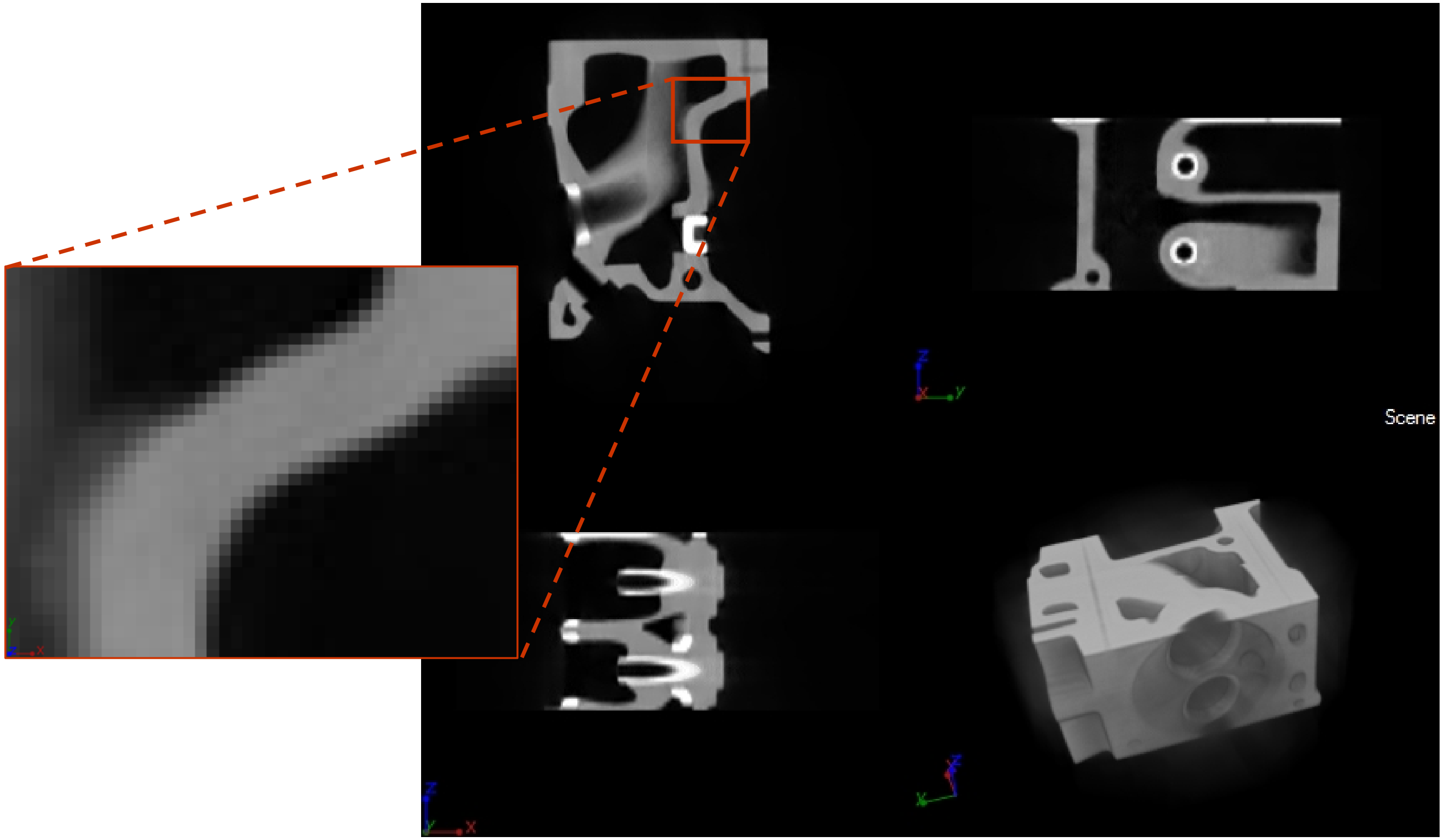
Christof Reinhart
Volume Graphics GmbH, Heidelberg

Industrial CT & Precision

- Overview:
  - Precision in CT-metrology.
  - Precision in defect analysis.
  - Precision in segmentation.
  - Bringing it together.

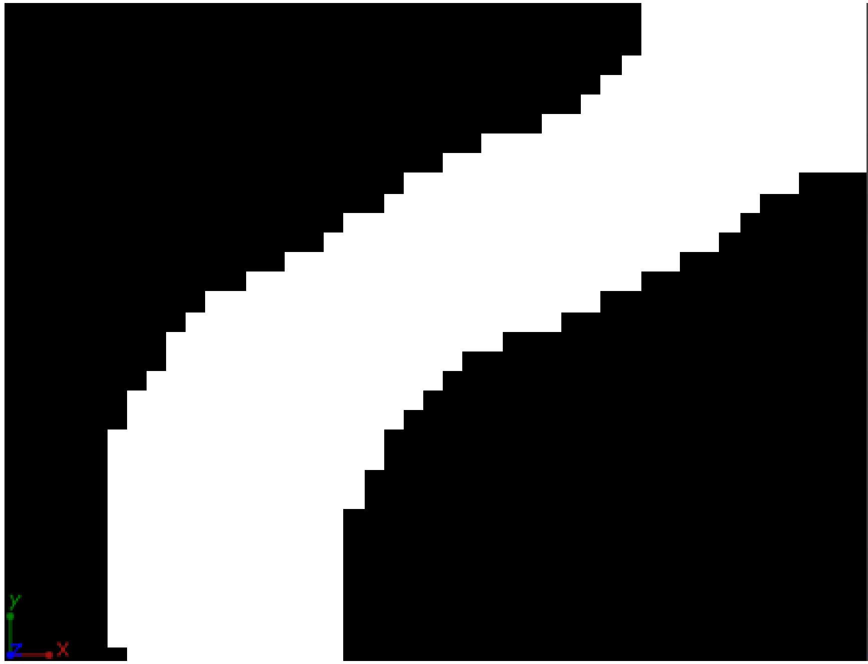
Industrial CT Data

- All precision comes with the image data!

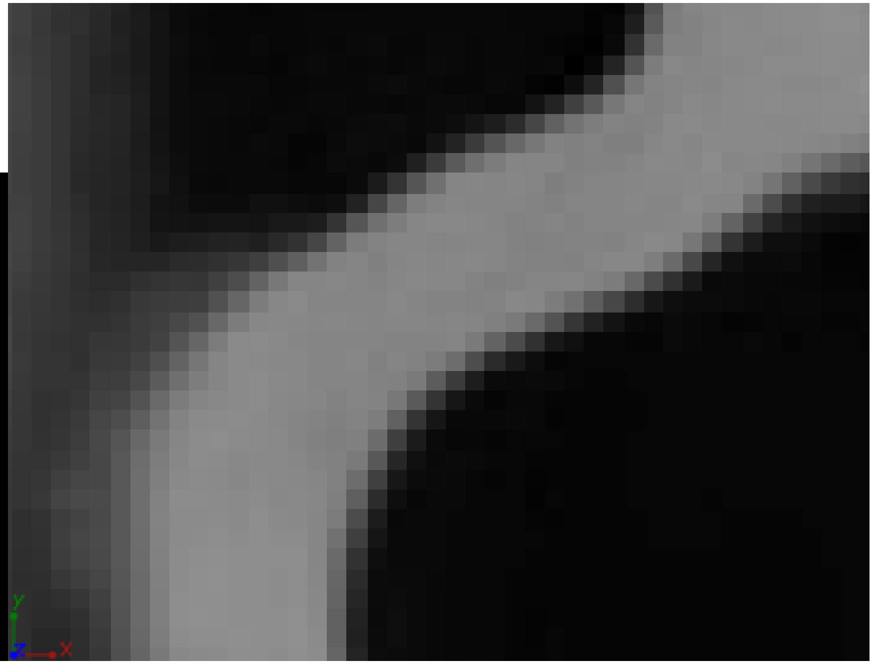


Industrial CT Data

- Luckily CT data contains more information than just the “voxel”. We get the grey values too.



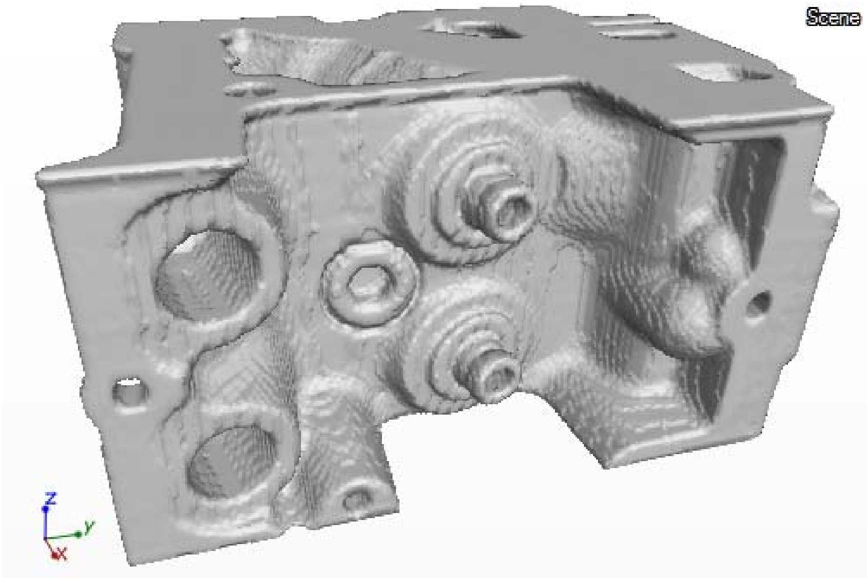
Voxels



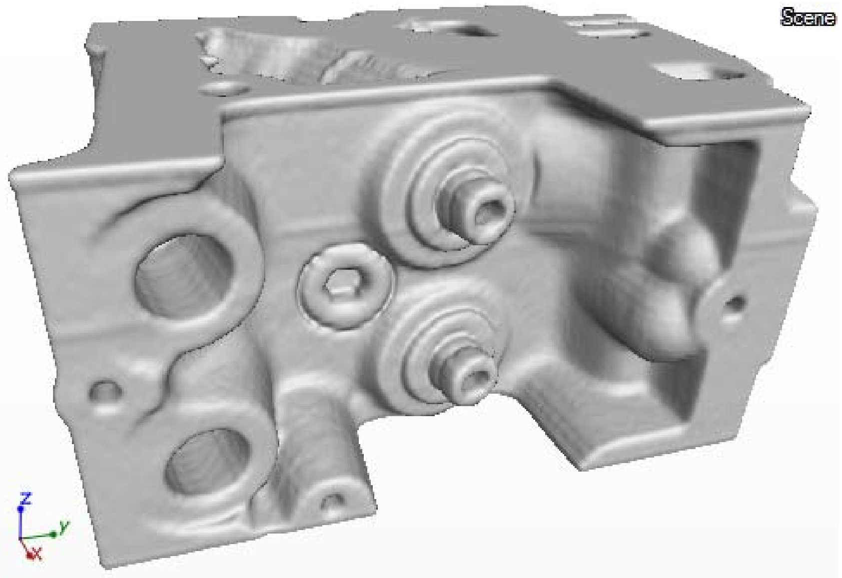
Grey Values

Industrial CT Data

- We can take advantage of the grey value information to make images look better and more important to make data analysis more precise.

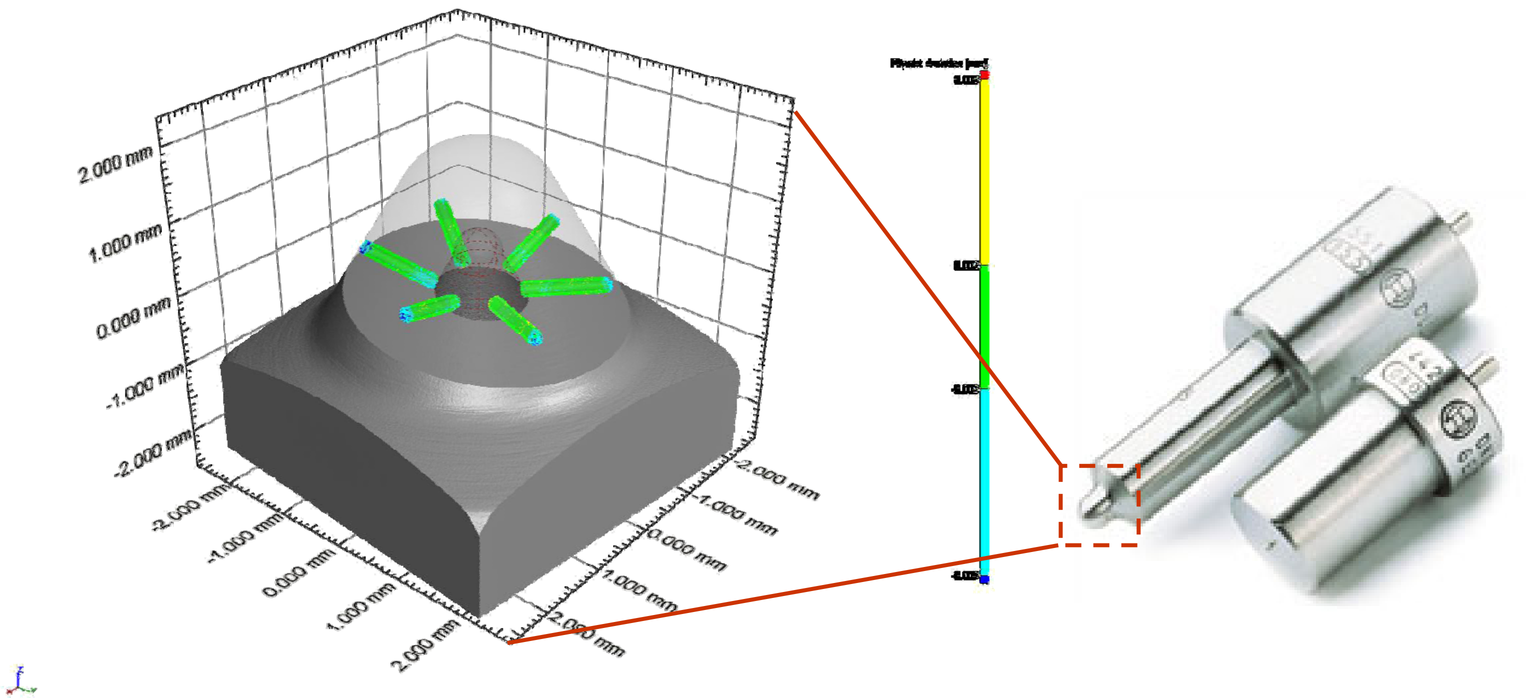


Voxels



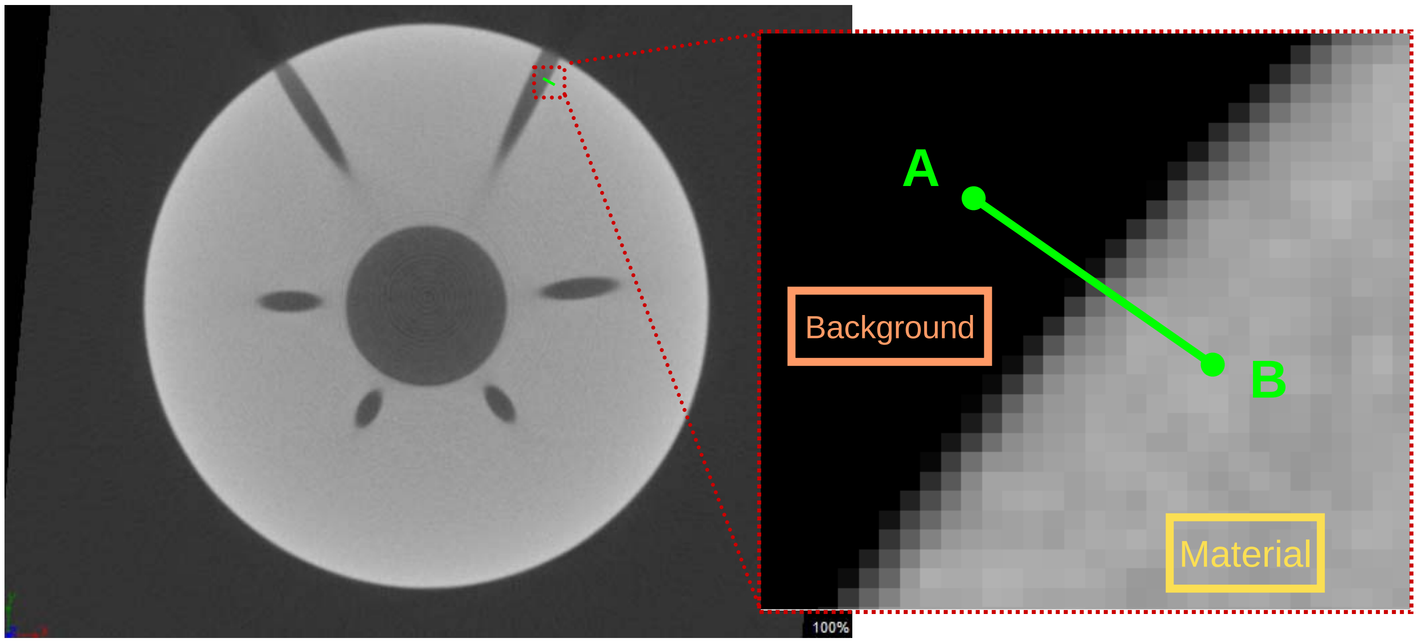
Grey Values

CT-Metrology



Surface Determination

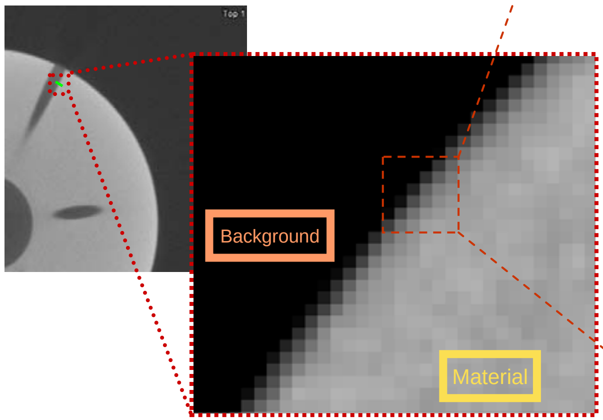
- Precise surface determination is essential for various analysis tasks, especially for the use of CT in metrology.
- How do we measure on CT image data?
  - We have to localize the “edges” in the images = the object’s surface in the images.

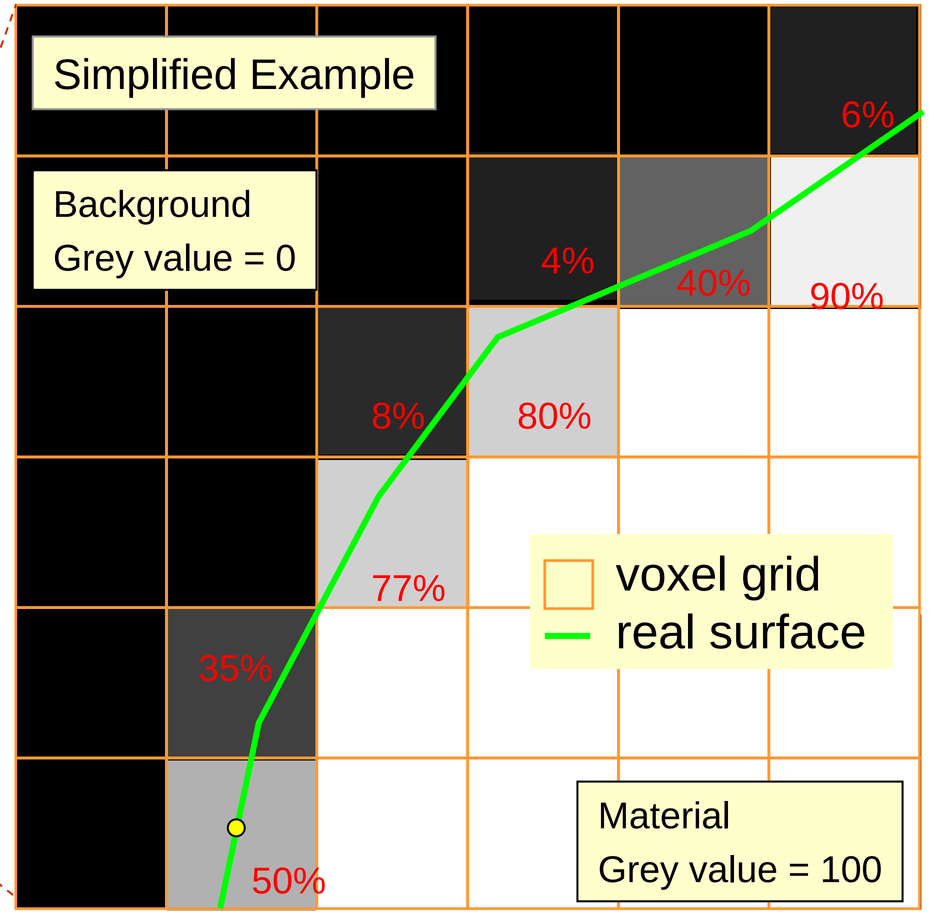


Surface Determination

- Why does the “surface look so blurred”?

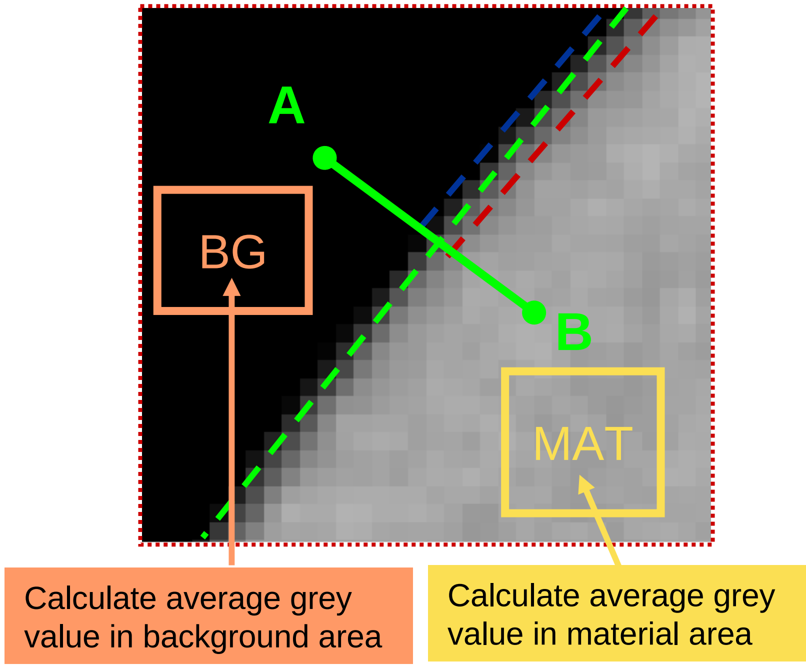
Because of the **Partial Volume Effect**. Voxels overlapping partially background and material receive an intermediate grey value according to the amount of material overlap.

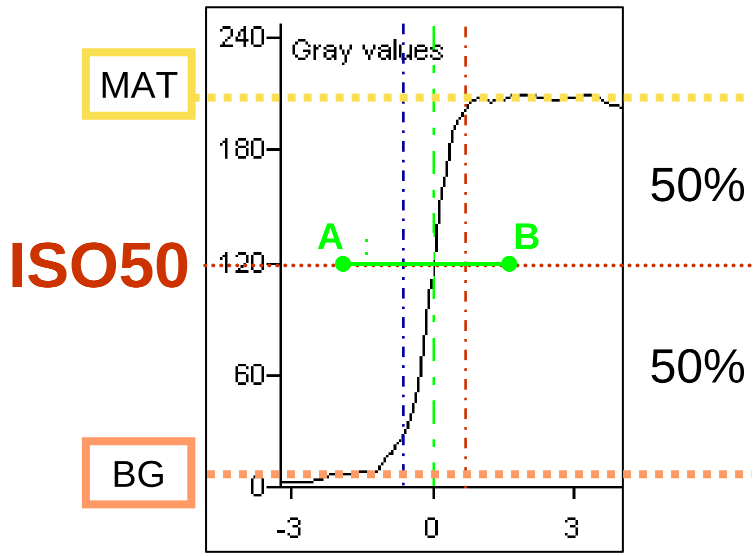




Surface Determination

- In theory: The object’s exact surface is described by a simple **grey value threshold → ISO50 threshold.**
  - ISO50=(average material grey value + average background grey value)/2

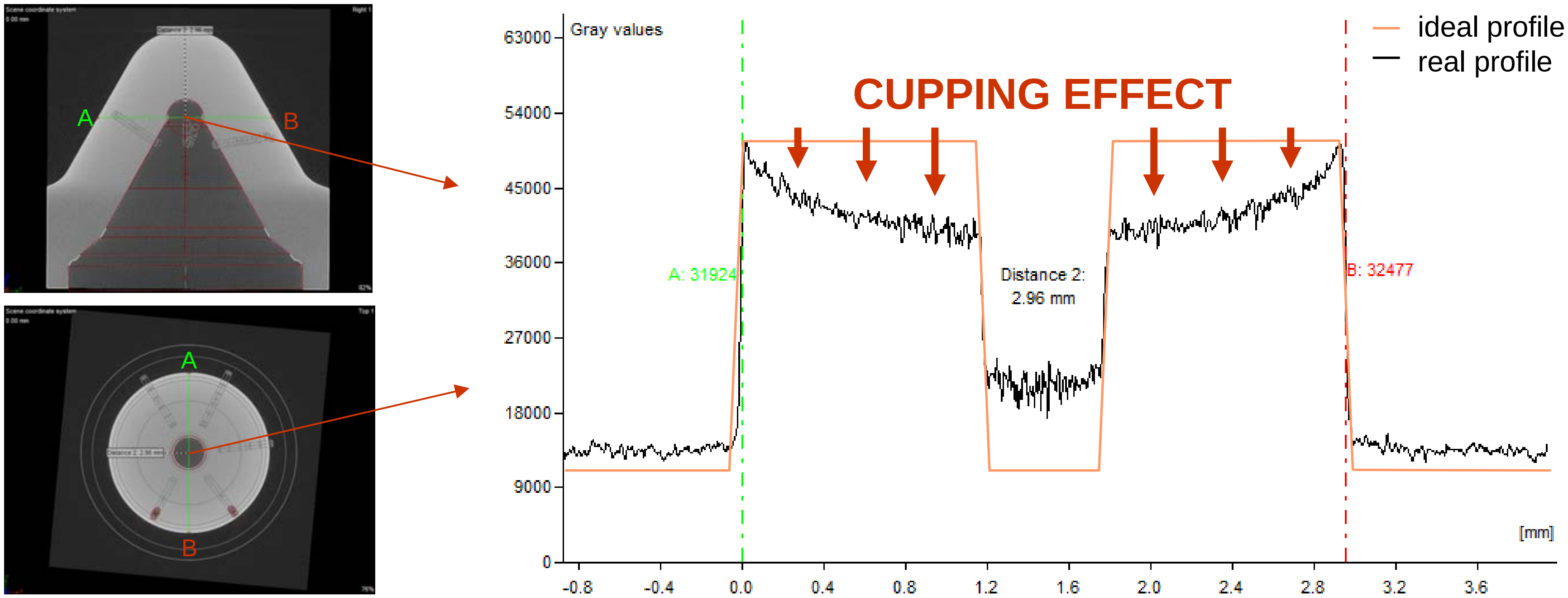




Grey value profile along line A-B

CT Artifacts

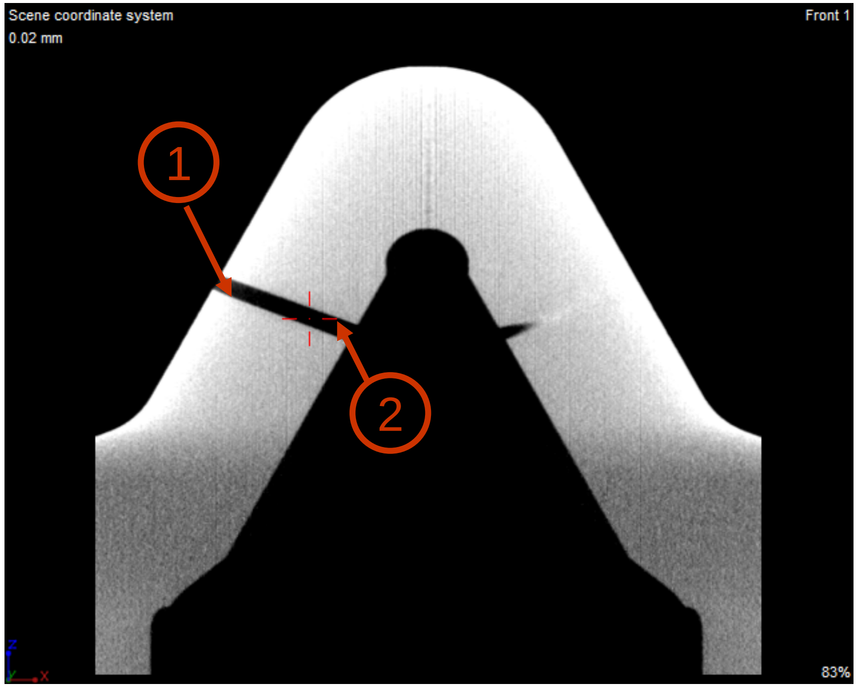
- Real data unfortunately contains artifacts
  - Beam hardening / Cupping: Nozzle material grey value become imaged darker radial to the inside.



Grey value profile along line A-B

CT Artifacts

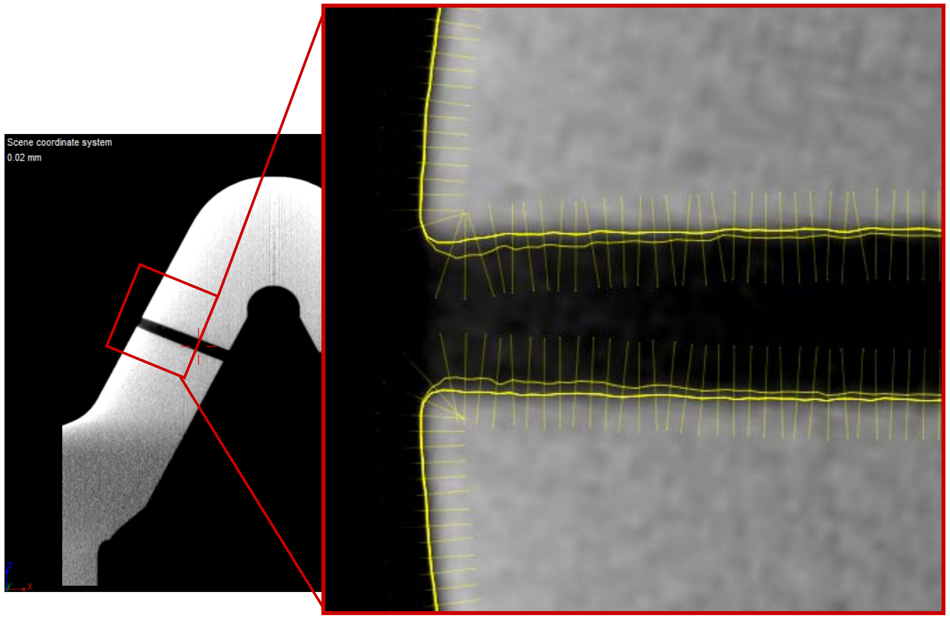
- A ISO50 threshold applied globally will typically cause geometry errors on “real data” since the local surface threshold at position (1) differs from the one at position (2), e.g. due to beam hardening artifacts.



- Fuel nozzle example: locally measured ISO50 threshold at:
  (1) = 38900
  (2) = 32700

Precise Surface Determination

- Our surface determination uses a local adaptive edge detection algorithm to minimize measurement uncertainty.
- The upcoming 2.2 release uses higher computation accuracy to better support higher dynamic range CT data.
- All geometry related tools in our software take full advantage of this feature to reduce measurement uncertainty.

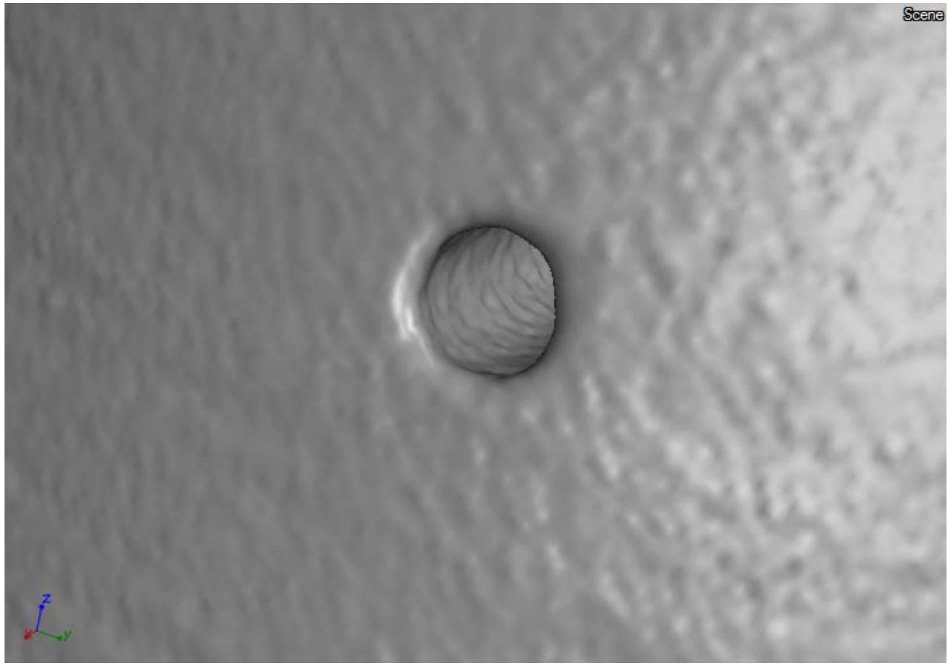


Thin yellow line = ISO50 surface

Thick yellow line = adaptive surface.

Precise Surface Determination

- What difference precise surface determination makes?
  - **Visually**: Injector borehole with and without local adaptive surface determination.

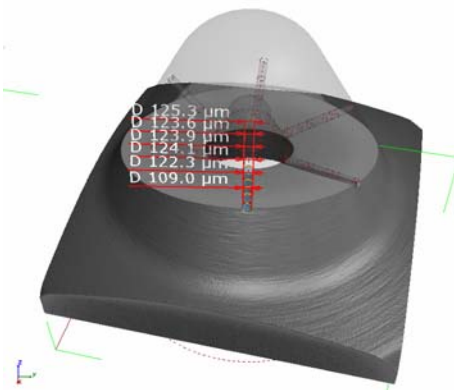


Precise Surface Determination

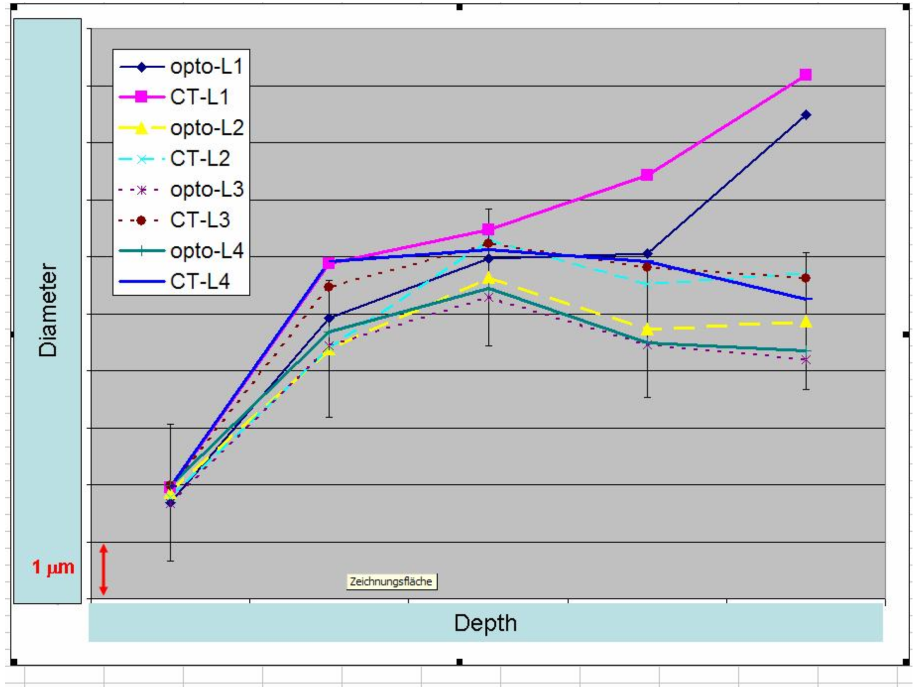
- What difference precise surface determination makes?
  - **In numbers:** Diesel fuel injector scanned on opto-tactile measurement system (today's established test method).
  - Diesel fuel injector scanned on a CT system with:
    - 225 keV micro-focus x-ray tube
    - 2048x2048 flat panel detector
    - Pre-adjusted scanner geometry
    - Post-scan scaling error correction (Scaling error as low as 1.00075)
  - Using ISO50 and adaptive surface determination.
  - Comparison of the results.

Injector Scan Results

- Measure 6 fuel injector nozzle boreholes diameters in 5 positions.
  - Scan/Voxel resolution 8 µm
  - CT measurement with local adaptive surface compared to standard opto-tactile measurement < 1µm



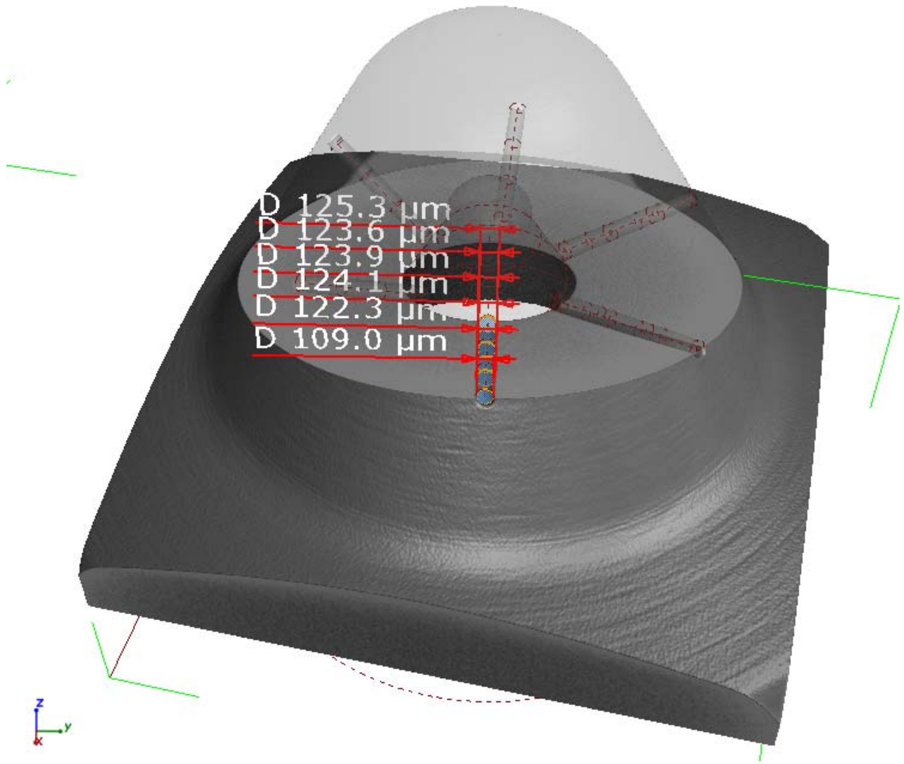
The graph shows the comparison of 4 classical **opto-tactile** drill hole diameter measurements with **CT** based measurements.



Injector Scan Results

- Final result:
  CT is able to reproduce classical measurements.
  - Measurement uncertainty >= 5 µm by using a global ISO50 surface threshold.
  - Measurement uncertainty <= 1 µm by using local adaptive surface determination.

2003 Forµprod & PhD Thesis,
Dr. Heinz Steinbeiß, UTG Munich



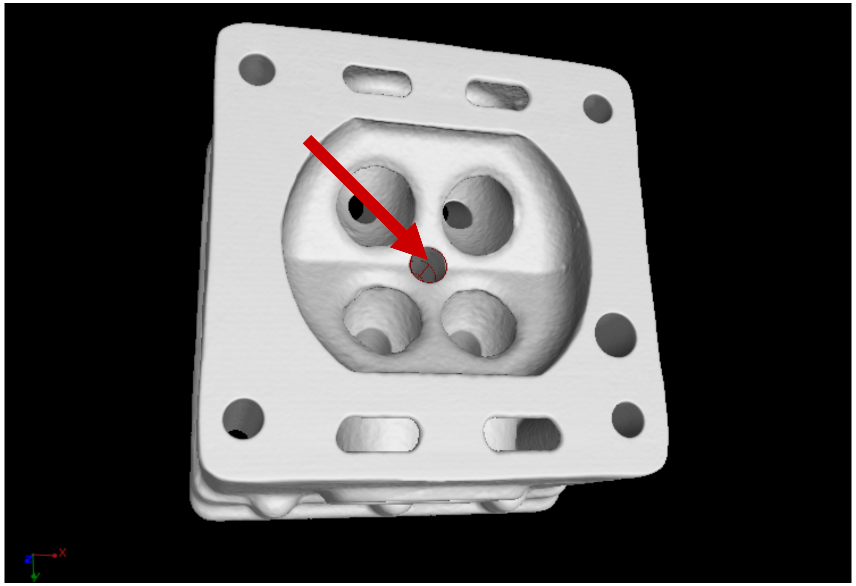
What Is “The Truth”

- Local adaptive surface determination is today’s accepted standard and used by many vendors.
- As a simple rule of thumb we tell that: “you can reach about 1/10 of a voxel in measurement uncertainty with good image quality CT data”.
- But, is this the final limit and what is the “true” nominal value?

What Is “The Truth”

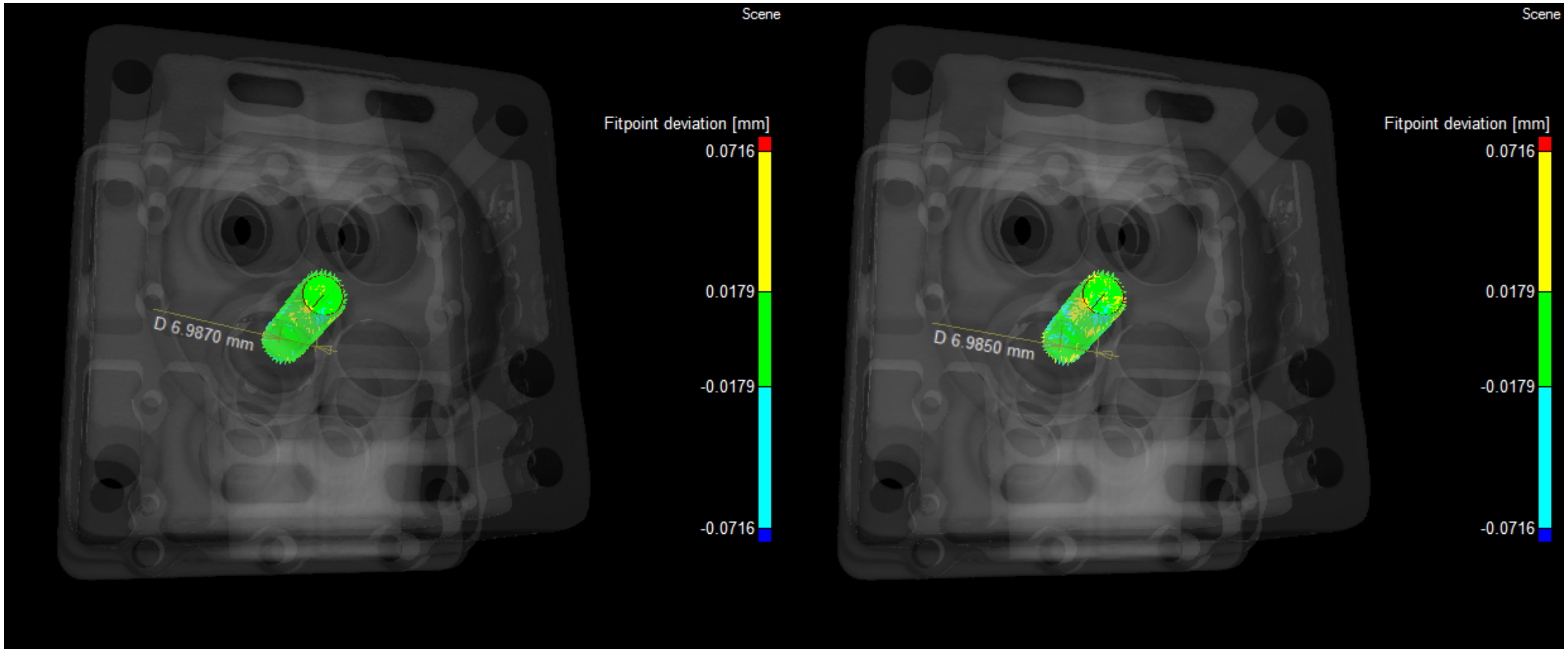
- We have to rely on today’s accepted standards as “the truth” and compare CT measurements with them.
- Measurement task: Measure the diameter of a borehole in an aluminum cylinder head calibrated by a DKD laboratory.

- Measured “CT-style”, probing the complete cylinder surface with e.g. 1000 points.



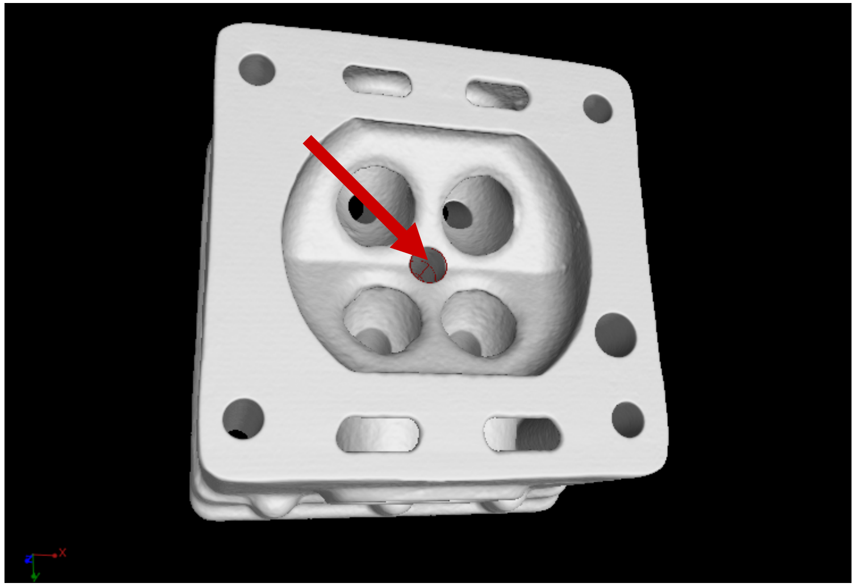
What Is “The Truth”

- Nominal by DKD Z14-DM = **6.9966 +/- 0.001 mm**
- Scan 1 (0.140mm resol.) Z14-DM = 6.9870 mm
- Scan 2 (0.220mm resol.) Z14-DM = 6.9850 mm



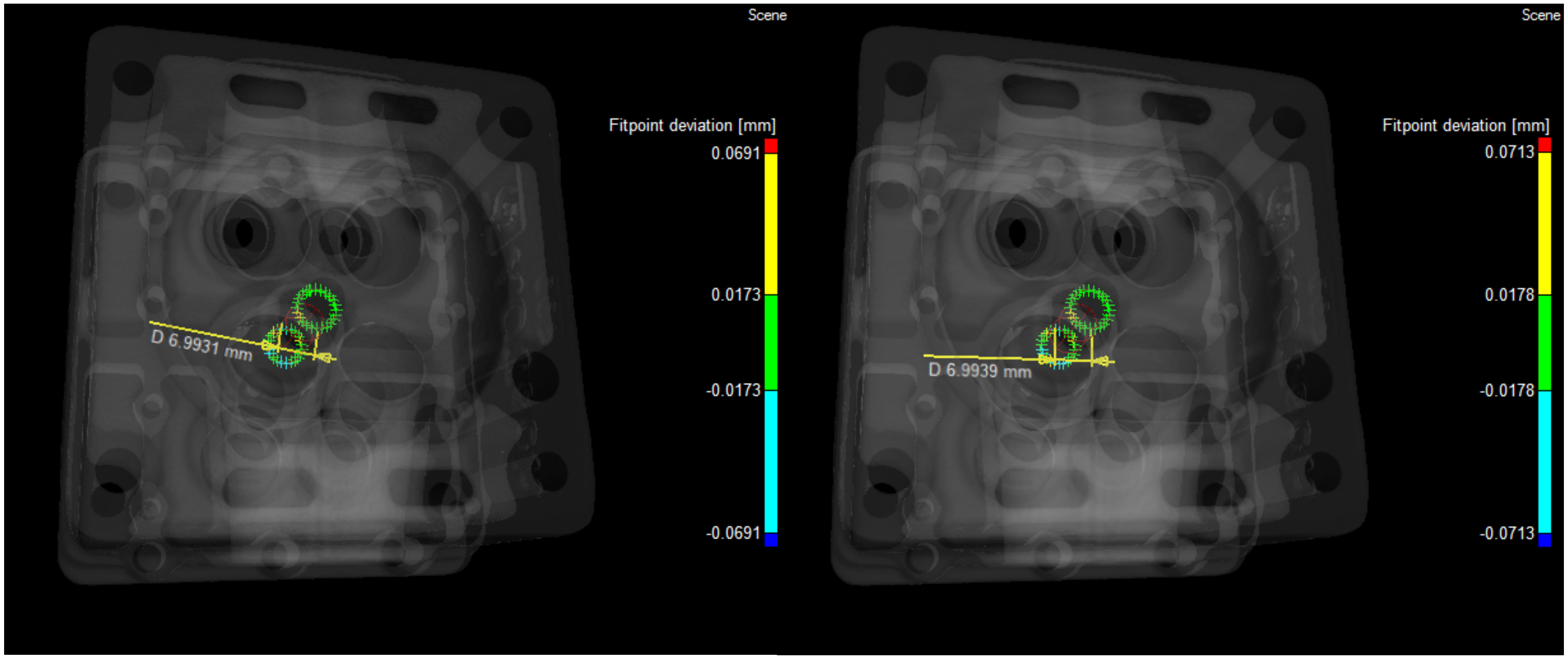
What Is “The Truth”

- Measured “CM-style”, create a cylinder by probing two circles with 24 points in y=18 mm and 43 mm, following the DKD measurement strategy.



What Is “The Truth”

- Nominal by DKD   Z14-DM = **6.9966 +/- 0.001 mm**
- Scan 1 (0.140mm resol.)   Z14-DM = 6.9931 mm
- Scan 2 (0.220mm resol.)   Z14-DM = 6.9939 mm



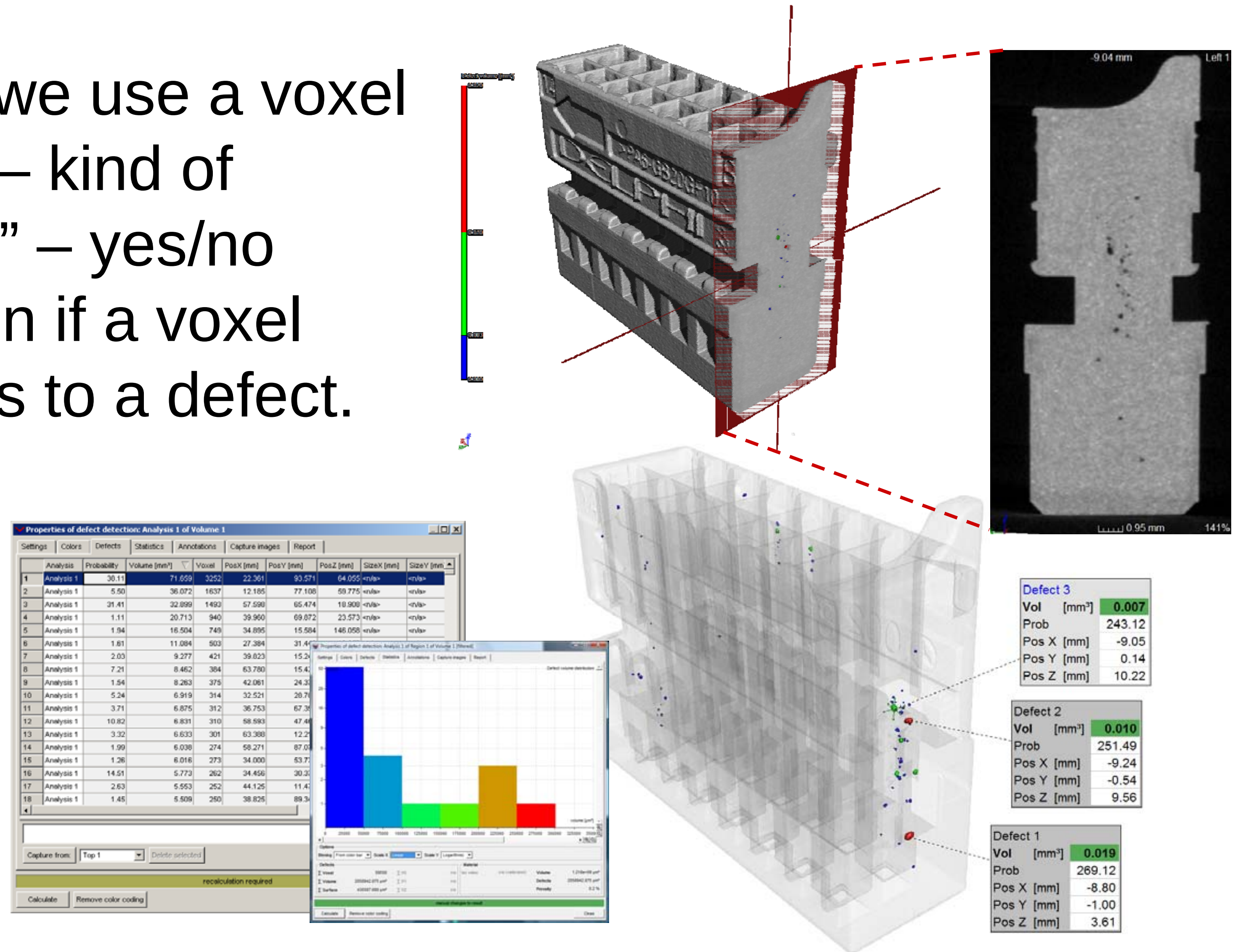
What Is "The Truth"

- This example shows two important things:
  1. The measurement strategy is one of the most important aspects when we continue seeking for even lower measurement uncertainty in CT-metrology.
  2. A 1/10 of a voxel is not the limit once we get even better image quality.

Sub-Voxel Precise Defect Analysis

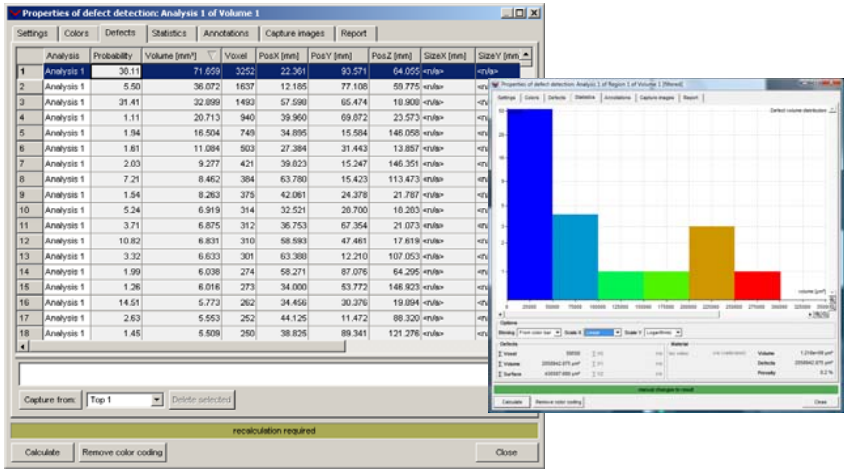
Defect/Inclusion Analysis

- So far we use a voxel based – kind of “binary” – yes/no decision if a voxel belongs to a defect.



Defect/Inclusion Analysis

- However in our 3D defect analysis tool we already used a local adaptive threshold to localize defects within environments with different levels of contrast.
- Statistically – across large samples of defects – the e.g. total volume or percentage of porosity was calculated quite accurate. Some defects volumes calculated in voxels are too big while some others are too small.

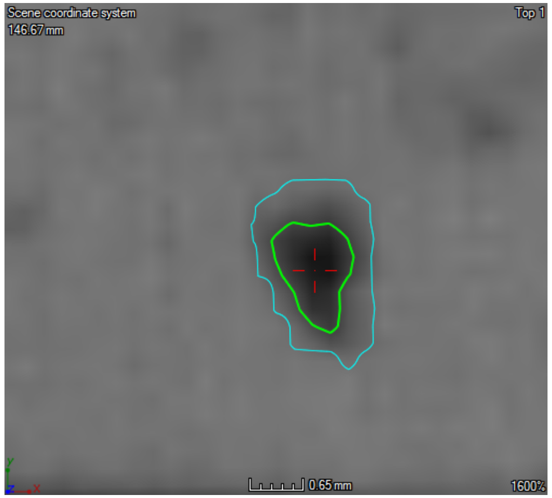


Sub-Voxel Precise Defect Analysis

- **P201 / VW 50097**
  2D defect analysis now comes with sub-voxel precision.
- P201 uses features of individual defects like the defect circumscribing circle's diameter, etc.

Sub-Voxel Precise Defect Analysis

- The comparison between voxel and sub-voxel precise defect analysis shows significant differences and is essential for the analysis on the scale of individual defects.



Cyan color line =
voxel based defect contour.

Green color line =
Sub-voxel defect contour.

- This is essential if you want to compare “high resolution” micrograph section results with “low resolution” CT analysis results.

Sub-Voxel Precise Defect Analysis

- Here sub-voxel precision is essential and will better support/allow the comparison between classical polished micrograph section based and CT based porosity analysis.
- Besides the wish to follow established standards this will build up more trust in CT based defect analysis.

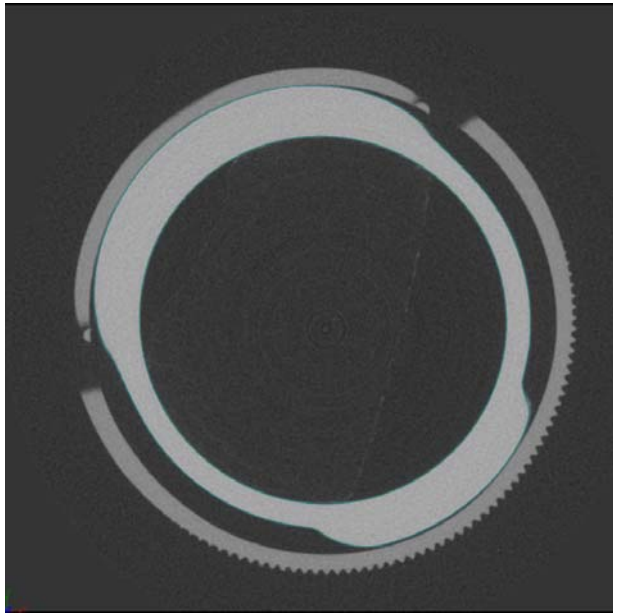
Sub-Voxel Precise Segmentation

Sub-Voxel Precise Segmentation

- Measure water bottle cap contact surface area.

Photo

40 μm CT-scan

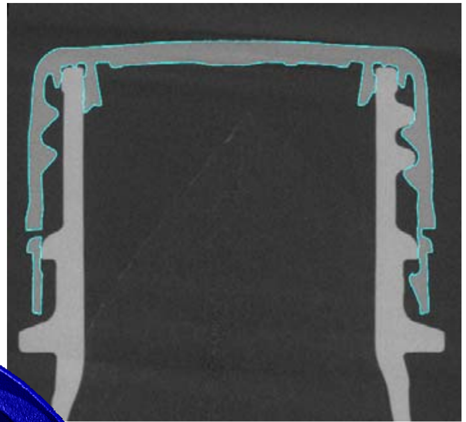


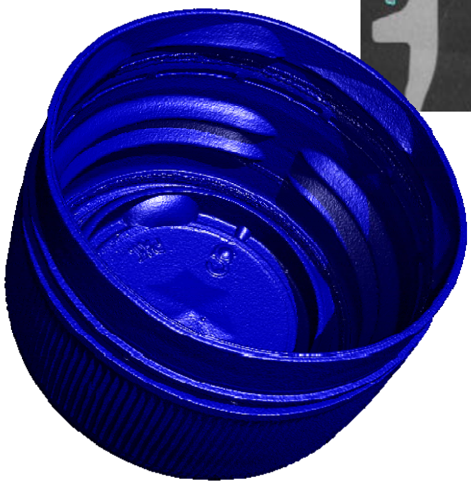
slice image not aligned

Sub-Voxel Precise Segmentation

- Measure water bottle cap contact surface area.

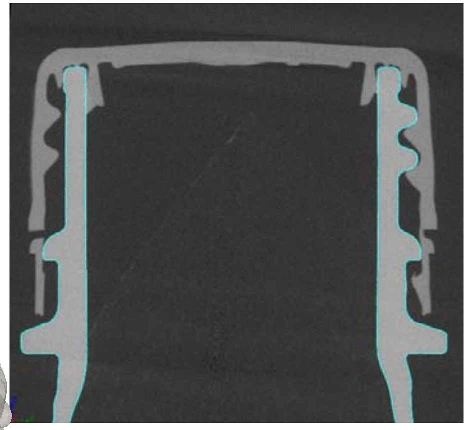
Cap Region Of Interest (ROI) manually segmented





Cap surface determined by using cap ROI.

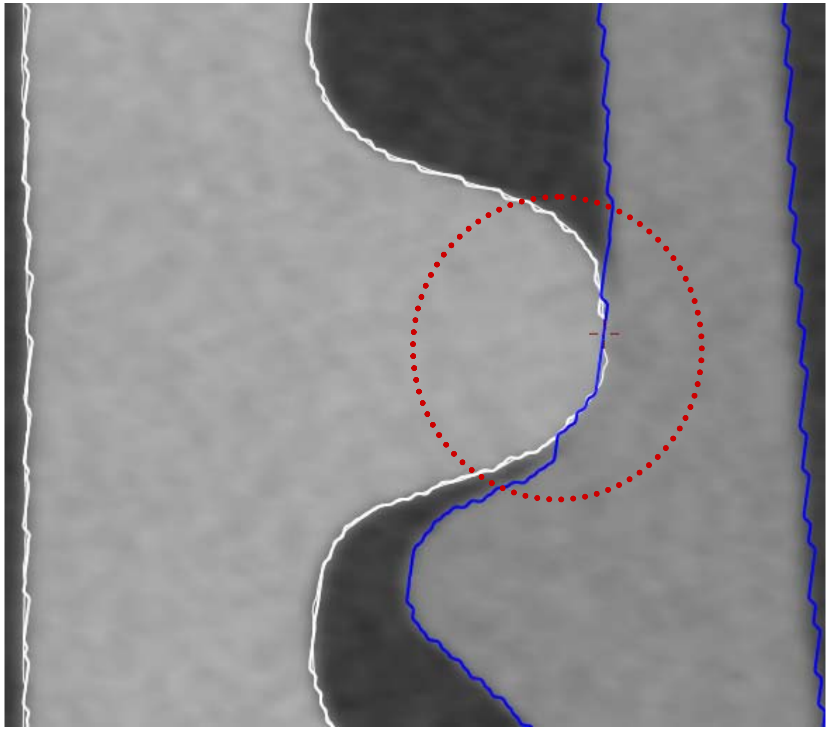
Bottle Region Of Interest (ROI) manually segmented



Bottle surface determined by using bottle ROI.

Sub-Voxel Precise Segmentation

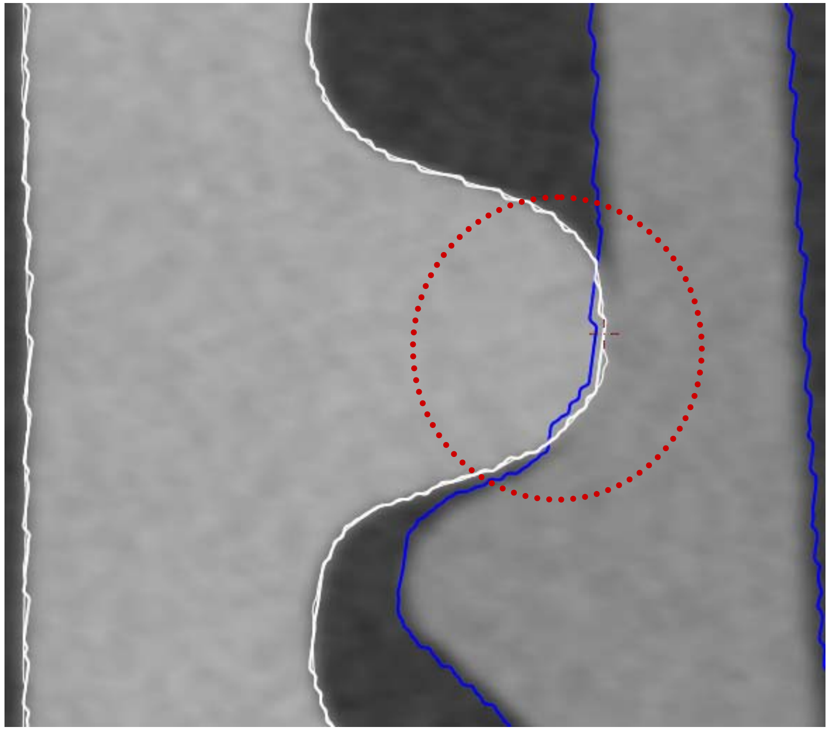
- Measure water bottle cap contact surface area.



White outline: bottle surface.
Blue outline: bottle cap ROI.

Sub-Voxel Precise Segmentation

- Measure water bottle cap contact surface area.

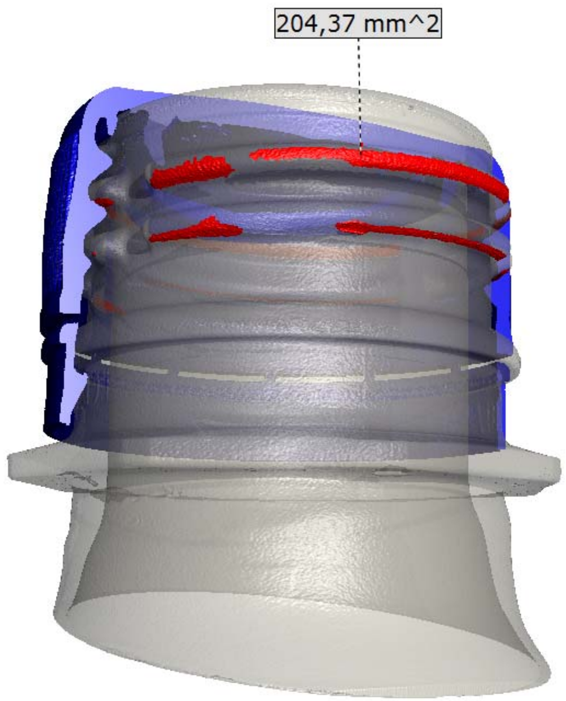


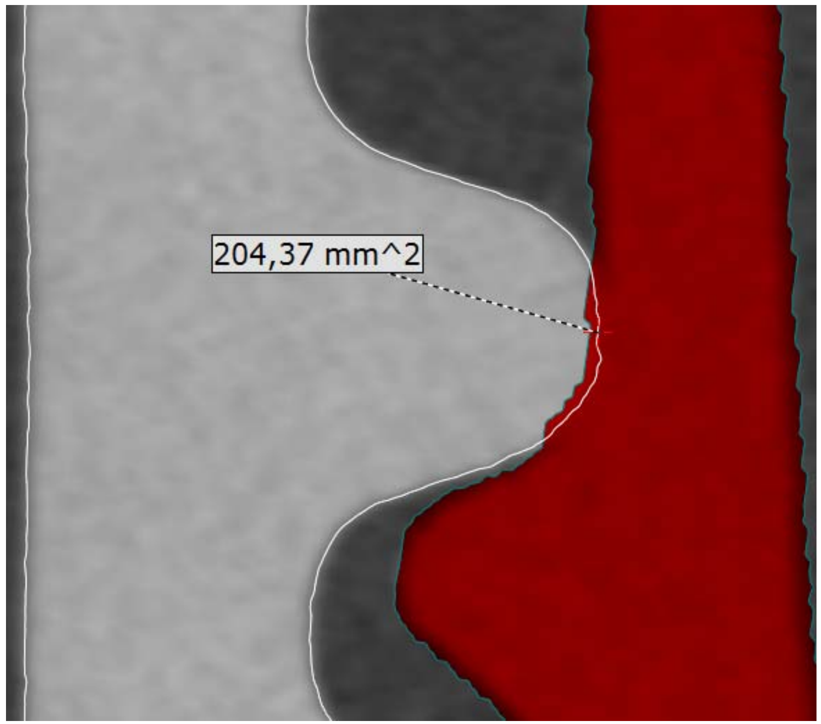
Expand bottle cap ROI by one voxel.

- The upcoming 2.2 release supports sub-voxel precise ROIs.

Sub-Voxel Precise Segmentation

- Measure water bottle cap contact surface area.

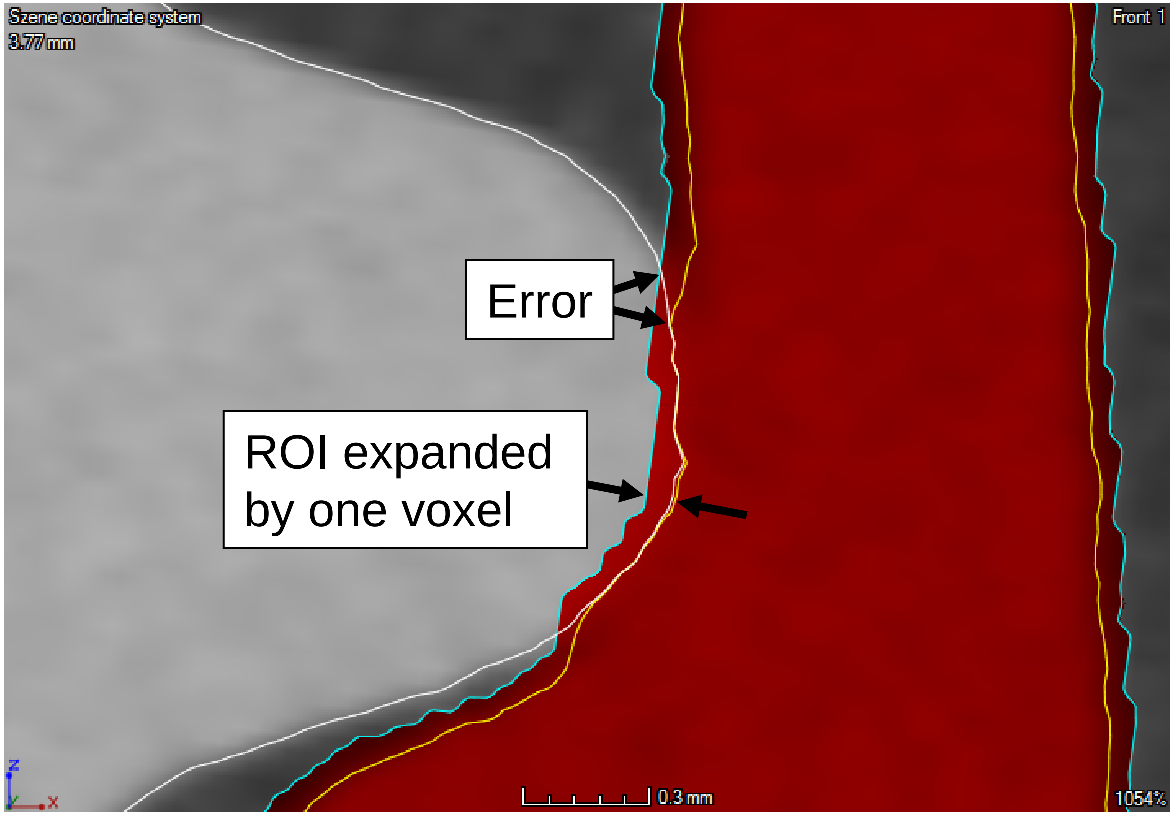




Measure amount of bottle surface area within red expanded bottle cap ROI.

Sub-Voxel Precise Segmentation

- Contact surface area is measured to large.
- Sub-voxel precise segmentation will reduce this error.



Sub-Voxel Precise Segmentation

+

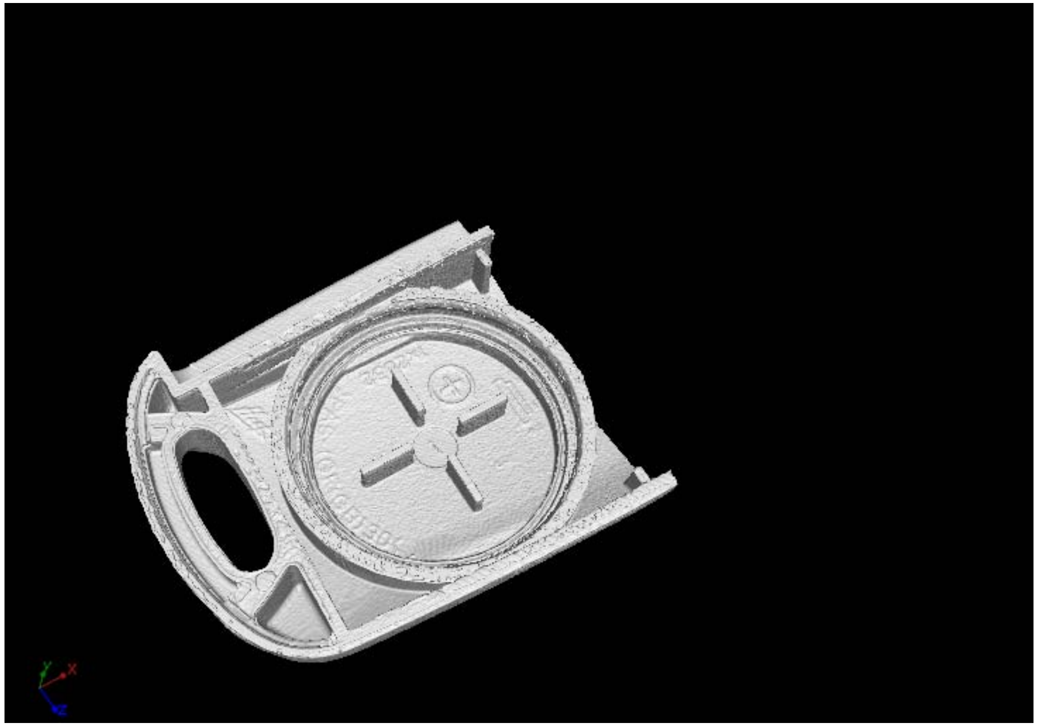
Local Adaptive Edge Detection

+

CAD Support

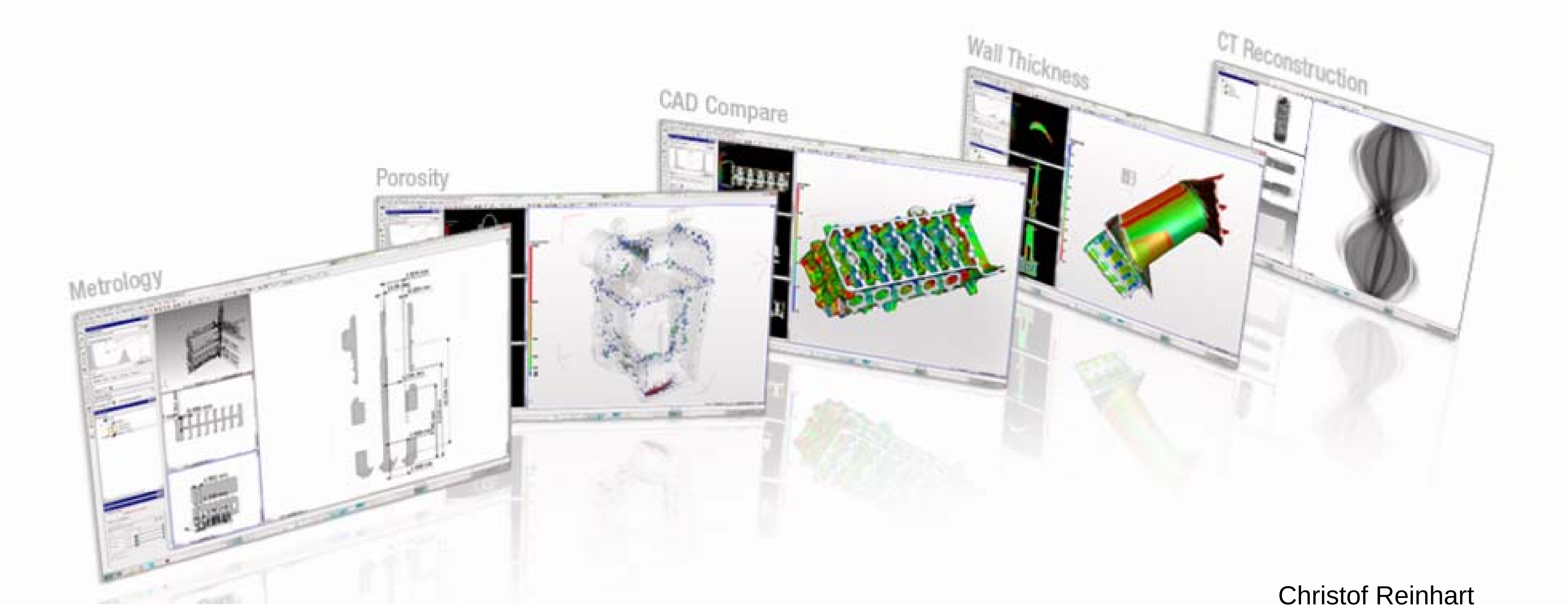
CAD Support

- VGStudio MAX 2.2 will offer CAD (STEP, IGES,…) assisted surface determination, sub-voxel precise segmentation.



CAD Support

Thank you for your attention!



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