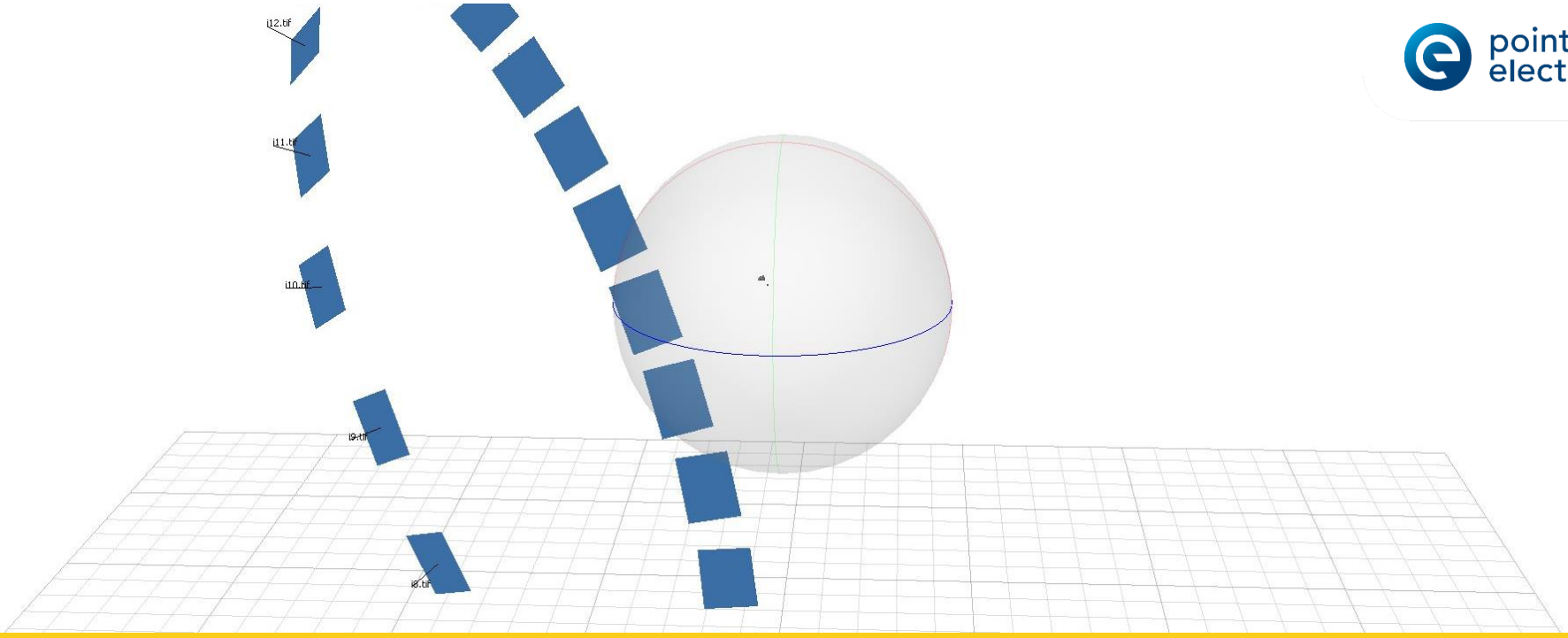

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3D scanning in SEM

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Why 3D scan in SEM?

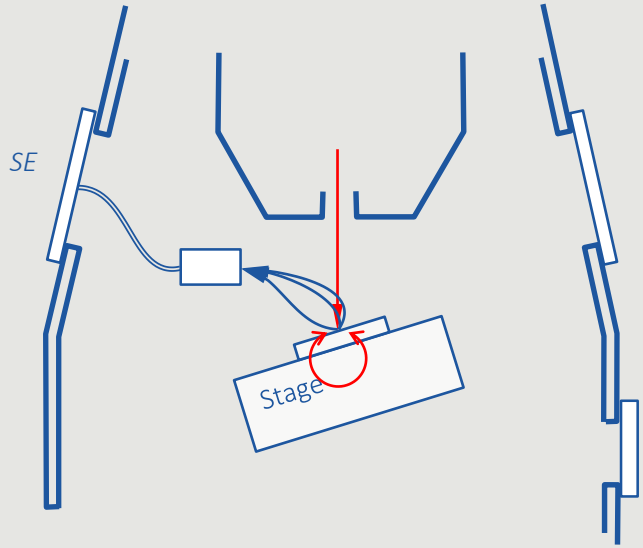
Stereoscopy, topography, photogrammetry and related 3D shape techniques have a long history in SEM.[1] Main motivations are

- Modelling
  - Analysis: 3D distances, volume, texture, morphology…
  - Animation: nature/science documentaries, game characters
- Visualisation
  - 3D screen/headset: present or publish complex shape information
  - 3D print: natural interaction with microscopic shapes
- Resolution
  - Light-based 3D scanning: resolution limited to sub-millimeter range
  - TEM tomography: thickness limited sub-micron range

[1] A Boyde and H F Ross, The Photogrammetric Record 8 (1975) p. 408

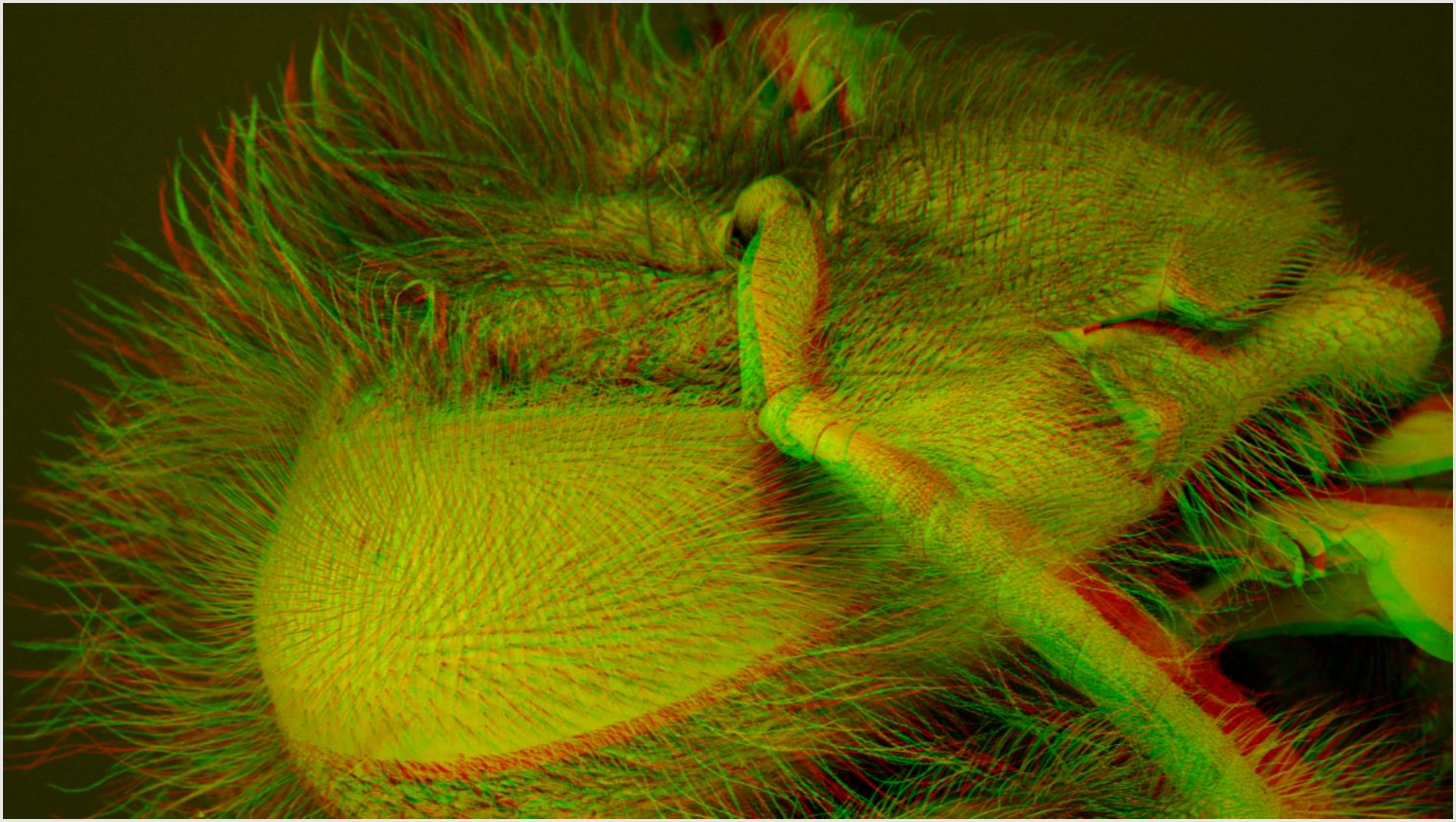
SEM stereoscopy: technique

Provides illusion of depth from pairs of SE images at slightly different tilt – only illusion



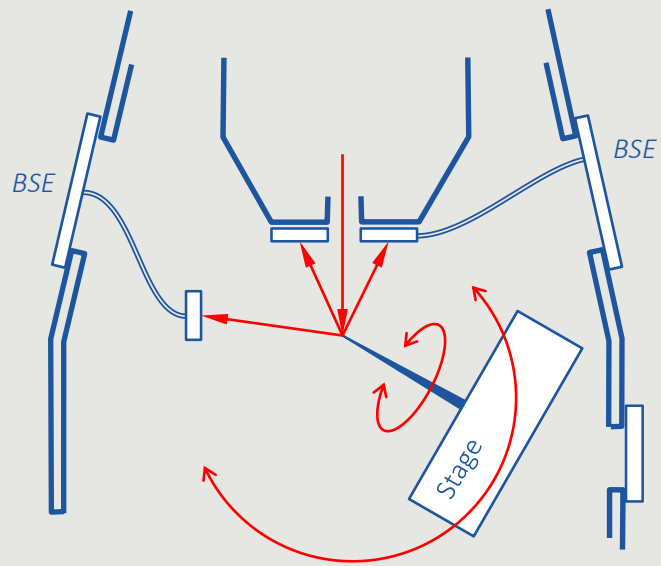
1. Two images are taken at slightly different tilt (stage or detectors).
2. Left and right images are delivered to left and right eye, respectively.
3. Illusion of depth is achieved naturally – perception.

SEM stereoscopy: example



Nanoflight: technique

Provides the impression of a slow-motion fight around nano-scale objects – only illusion

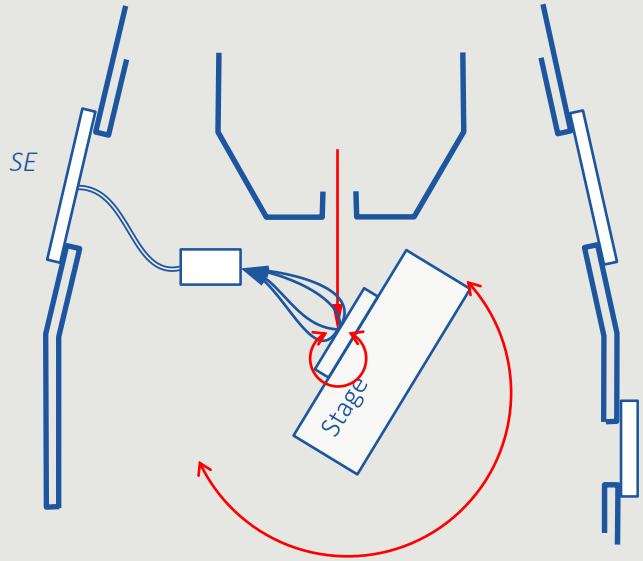


1. Multiple on- and off-axis BSE images are acquired simultaneously
2. Images are colour mixed - each detector is assigned a single colour
3. Sample is rotated/translated on a calculated trajectory
4. Illusion of flight is achieved naturally - perception

Nanoflight: nanoflight® movie, S. Diller

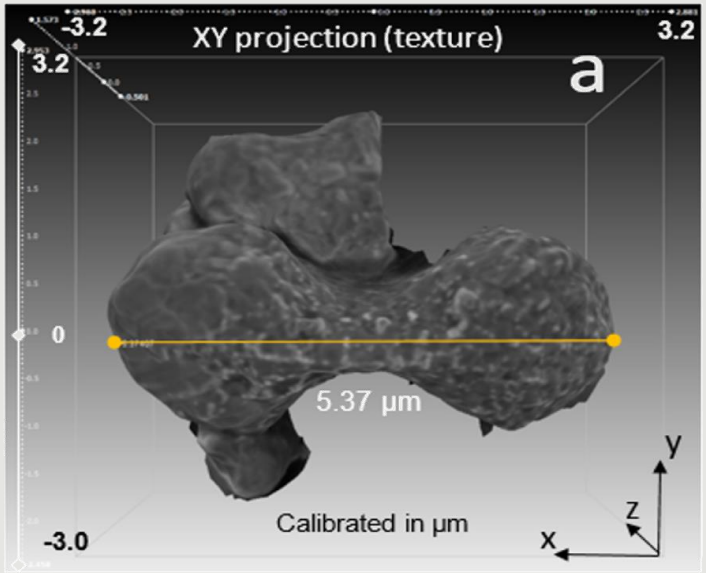
SEM photogrammetry: technique

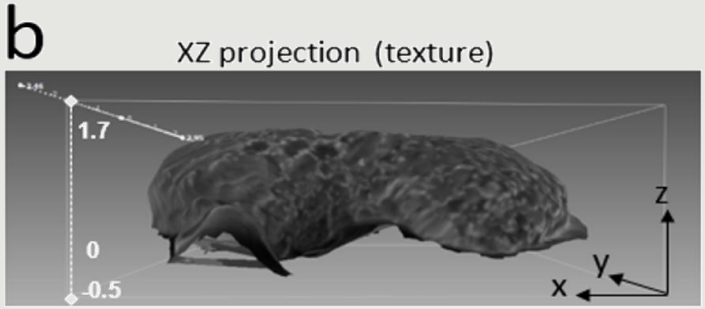
Provides 3D models from SE images at different tilt and rotation – limited by edge effects, charging, long working distance



1. Sample is mounted on stub, titled, rotated and imaged
2. Acquisition geometry is determined from point matching in SE images
3. Fine points/mesh are extracted/calculated from SE images
4. Texture is extracted from SE signal

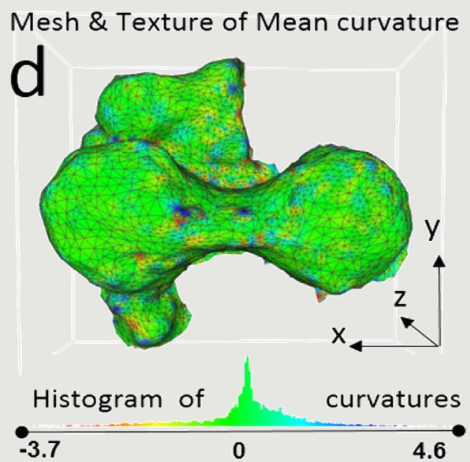
SEM photogrammetry: example





c

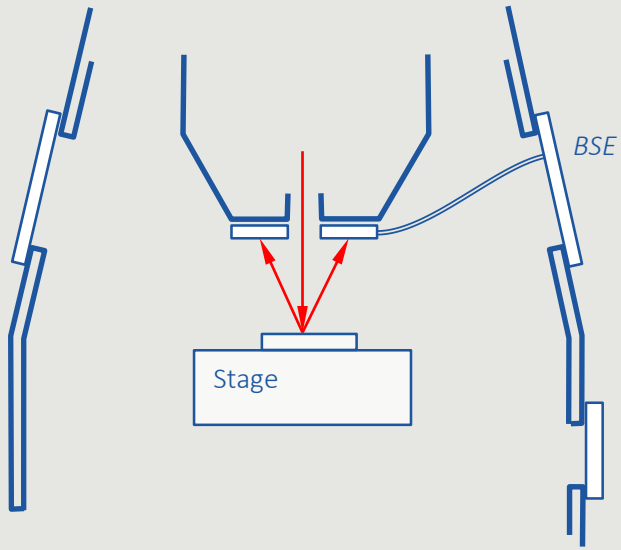
Geometrical measures	
Mesh volume	16.18 µm³
Mesh surface	54.19 µm²
Thin shell barycenter	(-0.39, 0.34 ,0.45)
Center of mass	(-0.53, 0.33, 0.54)
Inertia Tensor	$\begin{vmatrix} 16.95 & 2.79 & -1.80 \\ 2.79 & 36.62 & 1.39 \\ -1.80 & 1.39 & 47.70 \end{vmatrix}$
Principal axes	$\begin{vmatrix} 0.99 & -0.14 & 0.06 \\ 0.15 & 0.98 & -0.10 \\ 0.05 & -0.11 & -0.99 \end{vmatrix}$
Axis momenta	(16.43 36.89 47.94)



Lionel C Gontard et al., Ultramicroscopy 169 (2016) p. 80

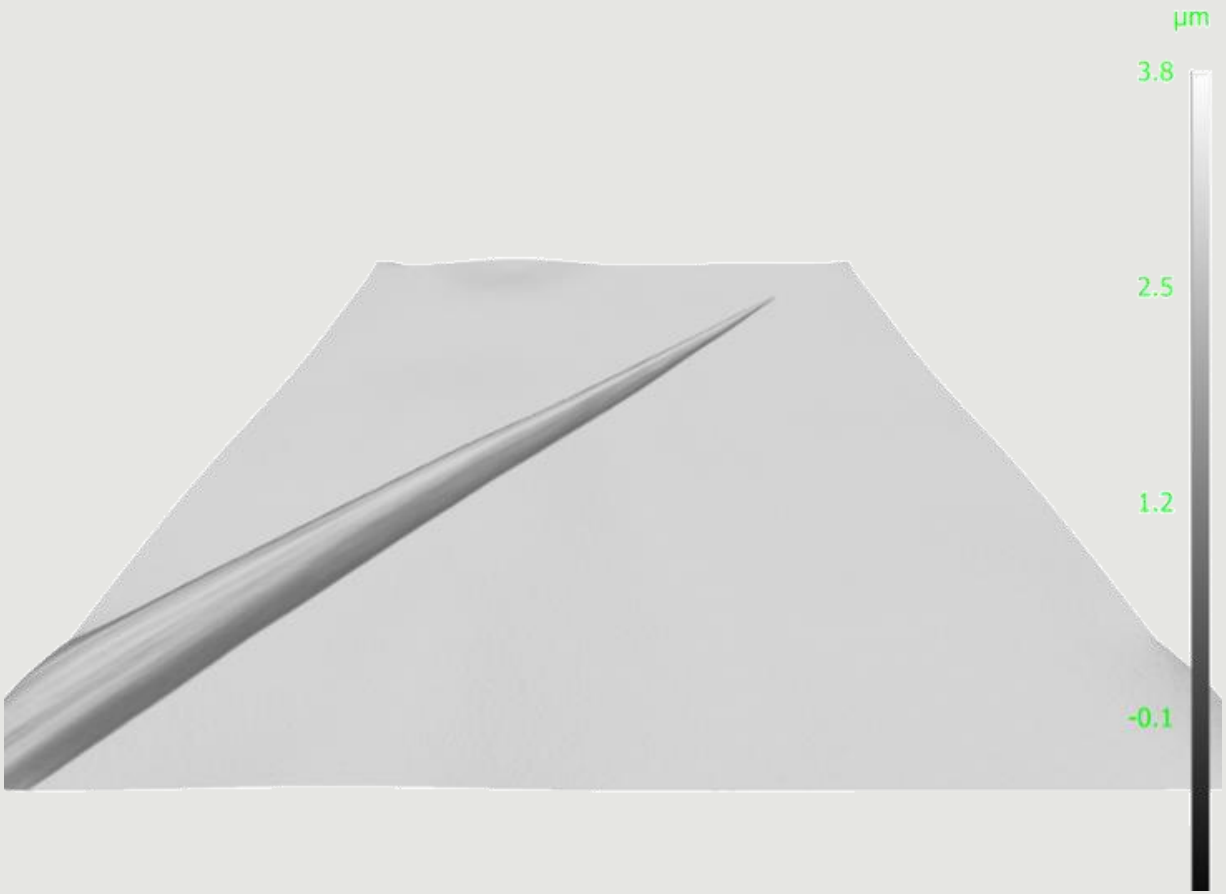
SEM topography: technique

Provides measurements of depth from BSE images at different view angles – only 2½D



1. Acquisition geometry is calibrated (mag., working distance, detector)
2. Simultaneous images are acquired from 4-quadrant BSE detector
3. Surface normal at each scan point is calculated by image photometry
4. Height is reconstructed by assembling all surface normals

SEM topography: example



Surface topography of W nanoprobe tip

3D scanning: SEM photogrammetry, but no SE

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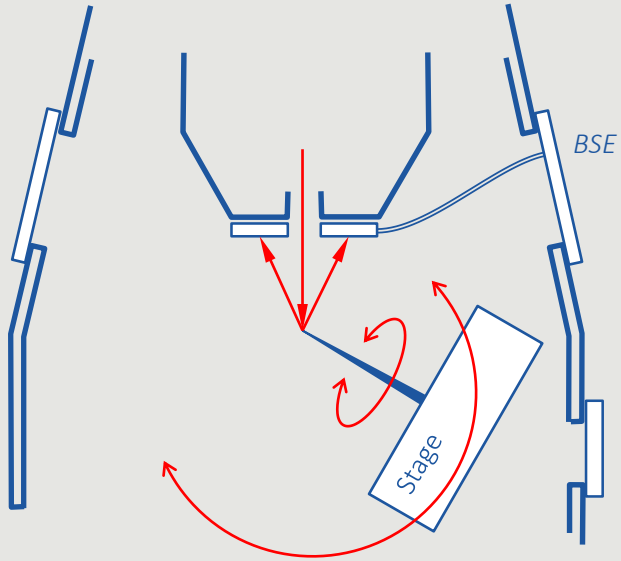
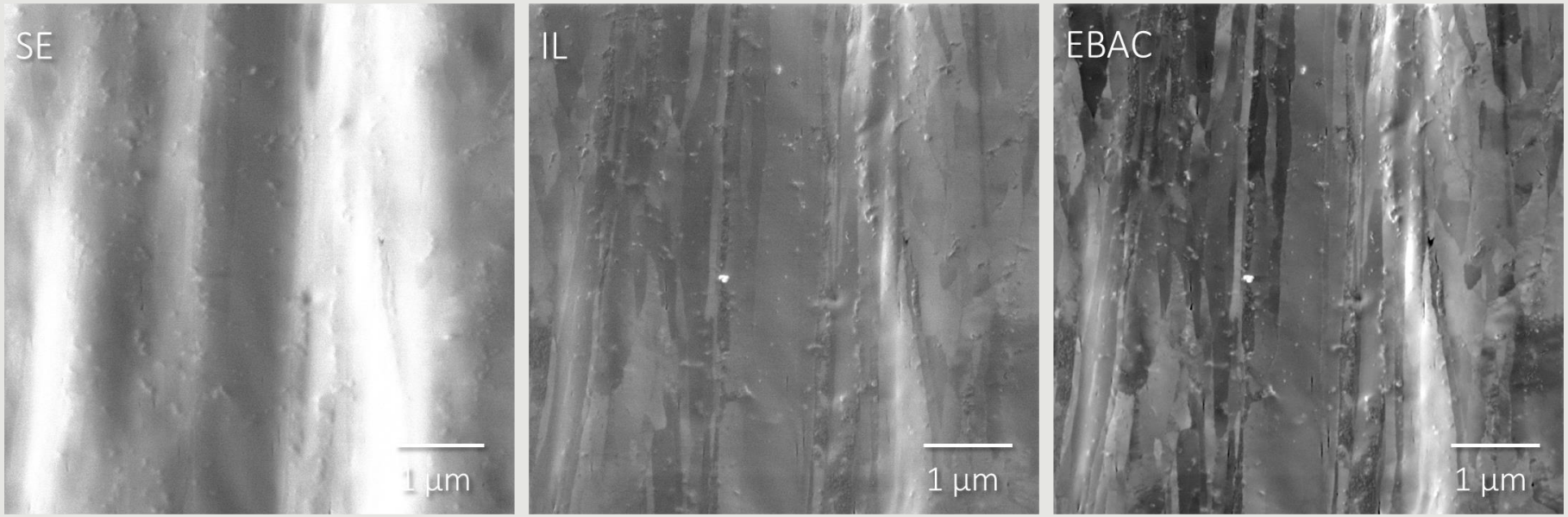
‘3D scanning’ term is used to distinguish from SE-based techniques



1. Sample is mounted on a nanotip, titled, rotated and imaged
2. Acquisition geometry is determined from point matching in BSE images
3. Fine points/mesh are extracted/calculated from the BSE images
4. Texture is extracted from BSE signal

EBAC signal: resolution

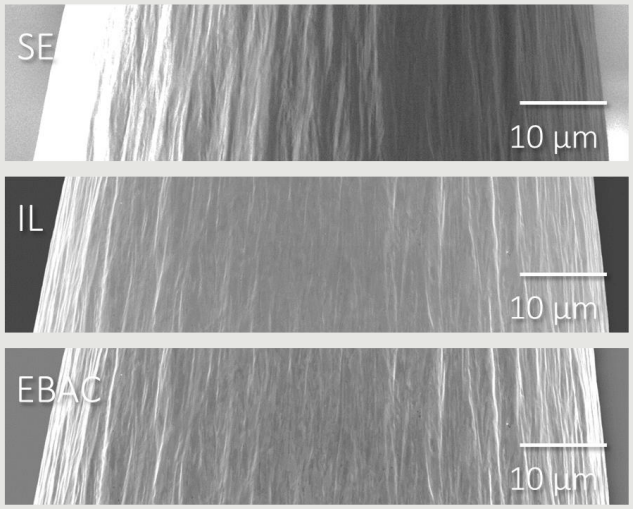
Electron Beam Absorbed Current (EBAC) is a common signal for failure analysis of CMOS devices. Example below is from a W nanoprobing tip

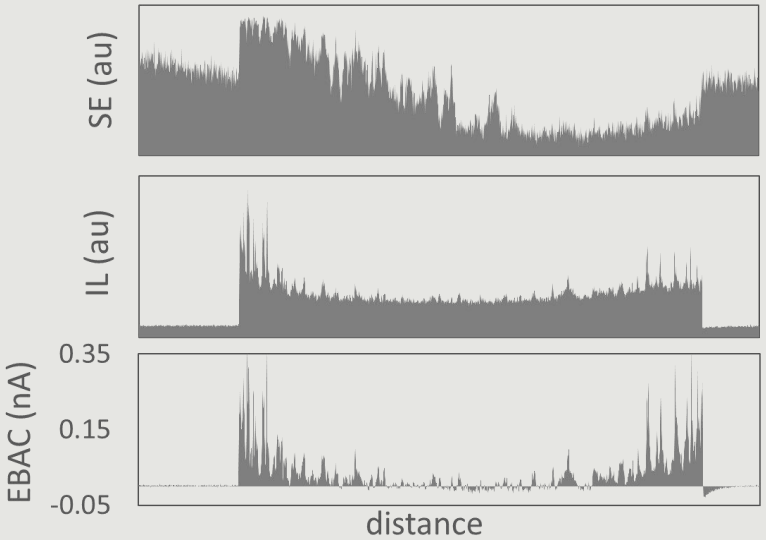


- Good resolution is maintained even at very long working distance
- Contrast is independent from working distance
- Signal is quantitative (nA, pA, fA)

EBAC signal: edge effects

EBAC signal has a uniform apparent illumination, as there is no added contribution from detector geometry





- There is no apparent side illumination
- Edge effects appear to be similar to those of IL signal
- Background is entirely removed from images

3D scanning: SEM photogrammetry, but no SE

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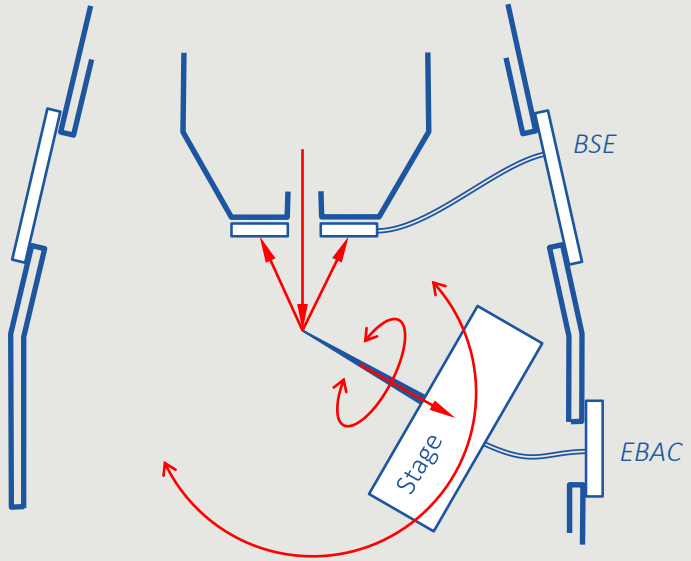
'3D scanning' term is used to distinguish from SE-based photogrammetry



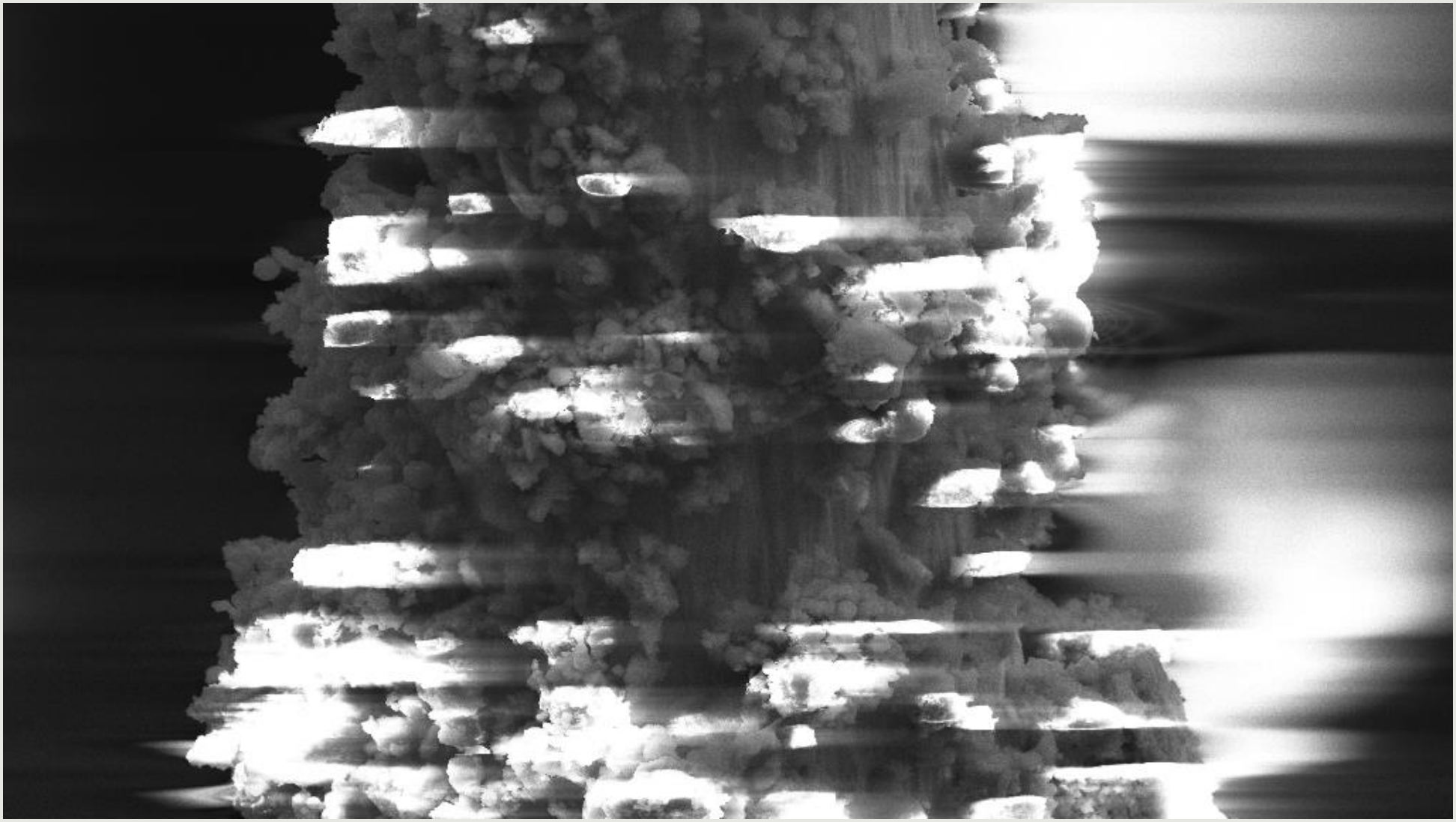
1. Sample is mounted on a nanotip, titled, rotated and imaged
2. Acquisition geometry is determined from point matching in EBAC images
3. Fine points/mesh are extracted/calculated from the raw EBAC images
4. Texture is extracted from BSE signal

3D scanning: experimental

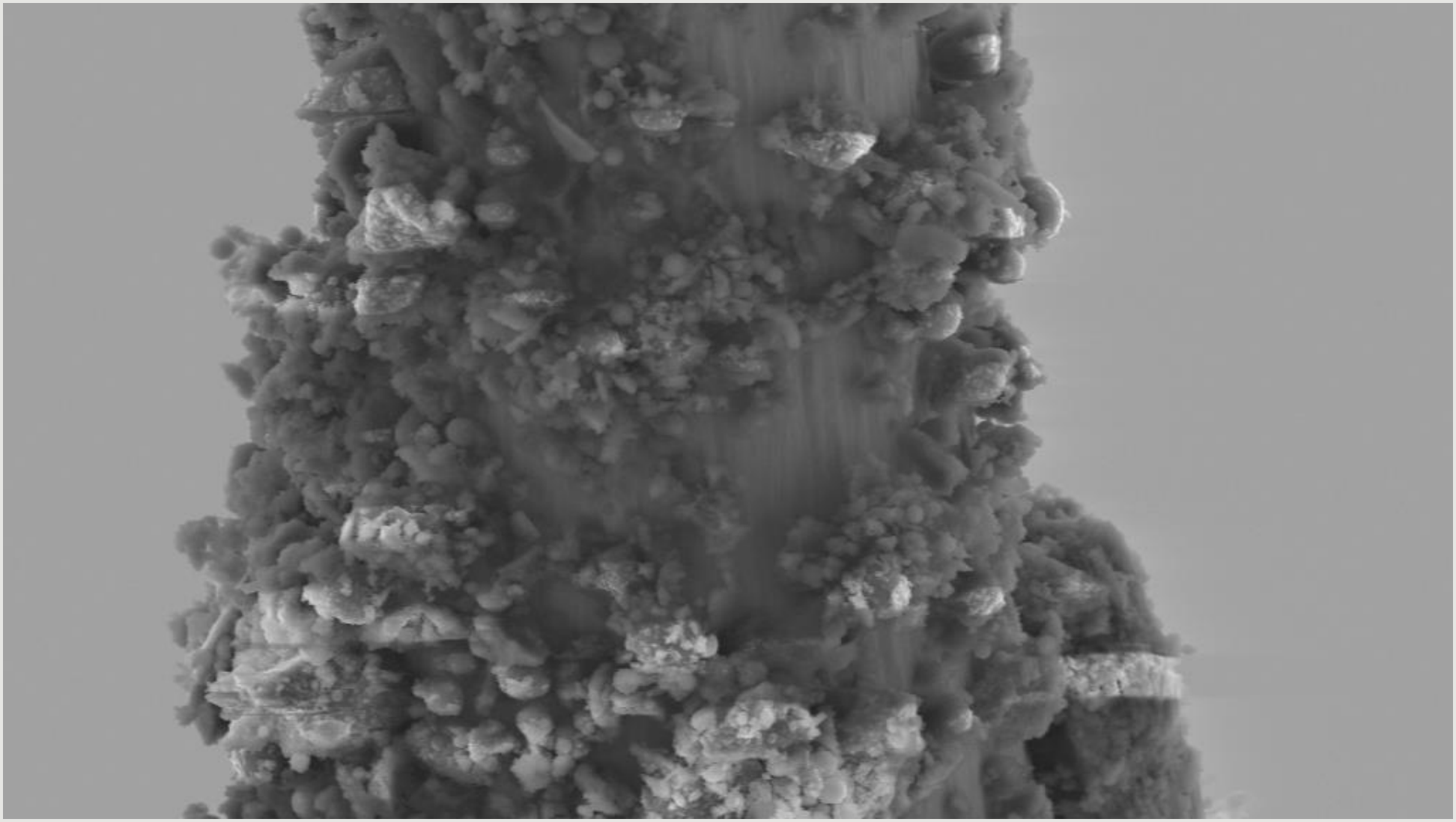
Uncoated Portland cement powder is used here as a test case, as it has particles of complex 3D shapes on a wide range of dimensions, and it is prone to charging.

- SEM
  - upgraded DSM982 Zeiss FEG-SEM
  - sample on nanoprobe needle
  - 20kV accelerating voltage
  - 20mm working distance
- BSE detector
  - 4-quadrant Si sensor
  - SUM signal (compo. mode)
- Quantitative EBAC electronics
  - 10^7 V/A in-situ preamplifier gain
  - 0.1…100 ex-situ amplifier
- Stage controller
  - Automated XY placements
  - Automated 360° R with 15° steps
  - Manual 80° tilt
- Image acquisition – DISS5
  - min. 2x simultaneous signals
  - min. 1,024 x 1,024 pixels
  - 12-bit digitization, 16-bit TIF files
- Agisoft PhotoScan Standard
  - Manual input of pixel size and focus
  - Complete automated reconstruction

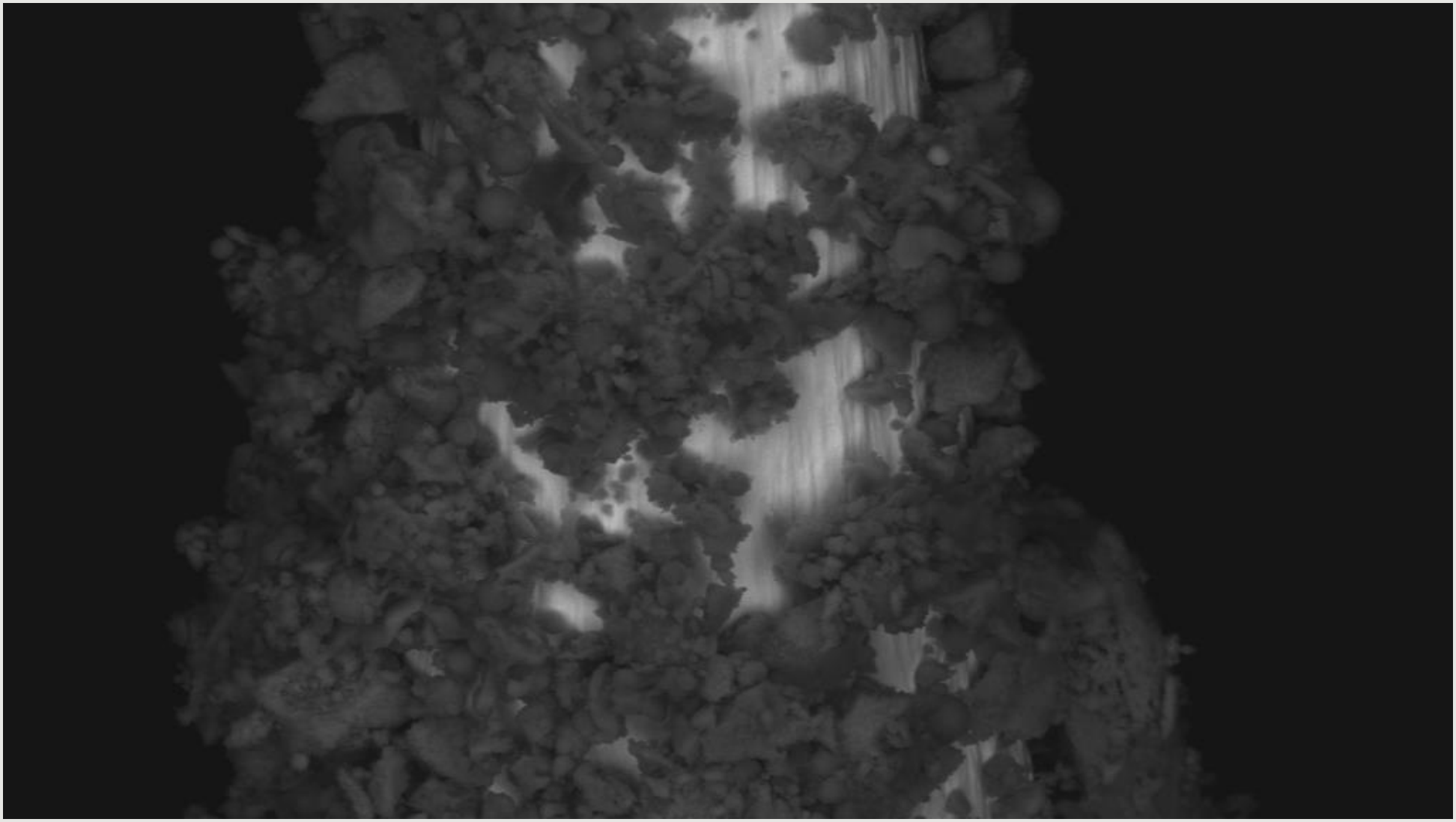
Raw images: SE (317.5µm FOV, 310nm/pixel)



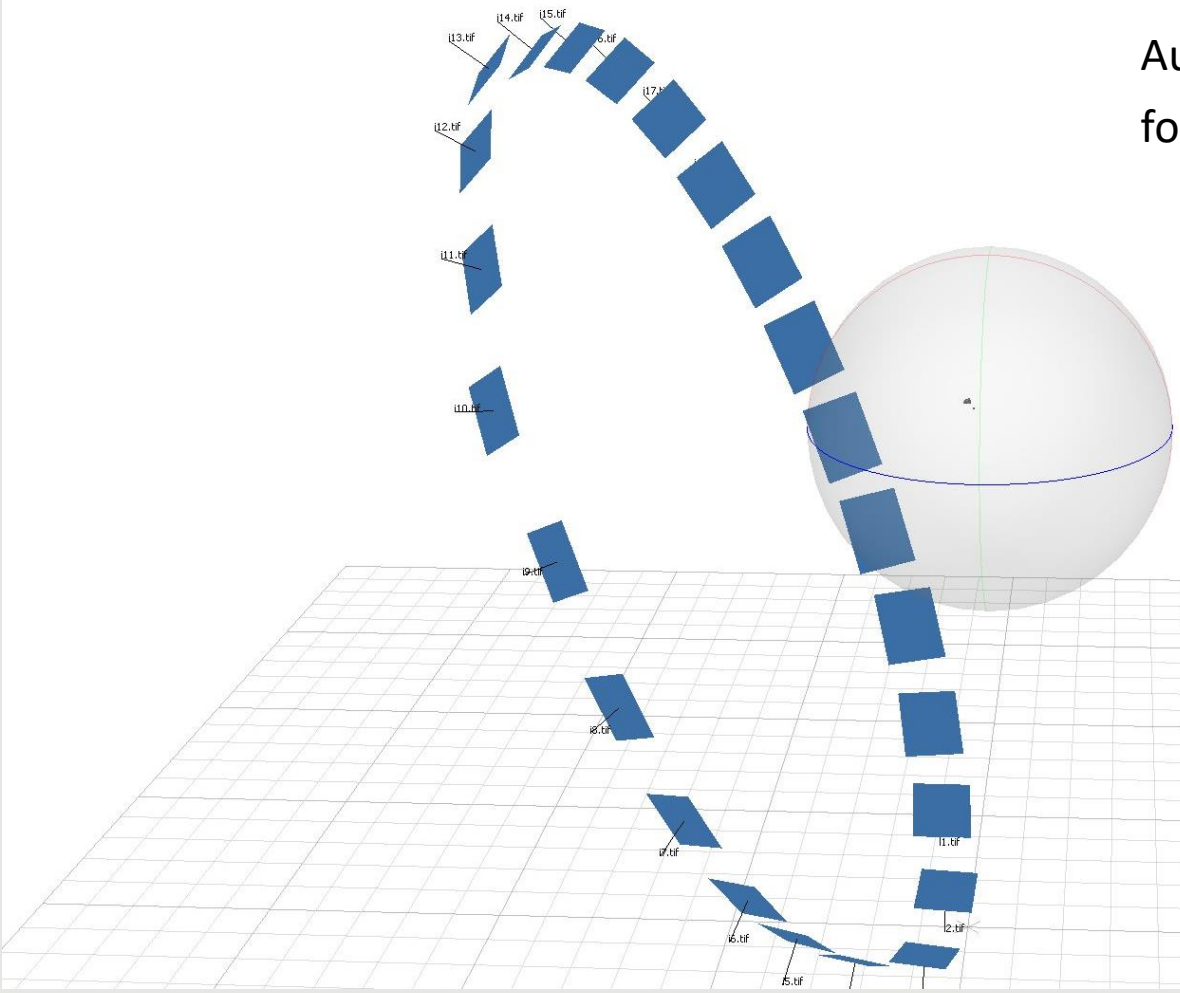
Raw images: EBAC (317.5µm FOV, 310nm/pixel)



Raw images: BSE (317.5µm FOV, 310nm/pixel)



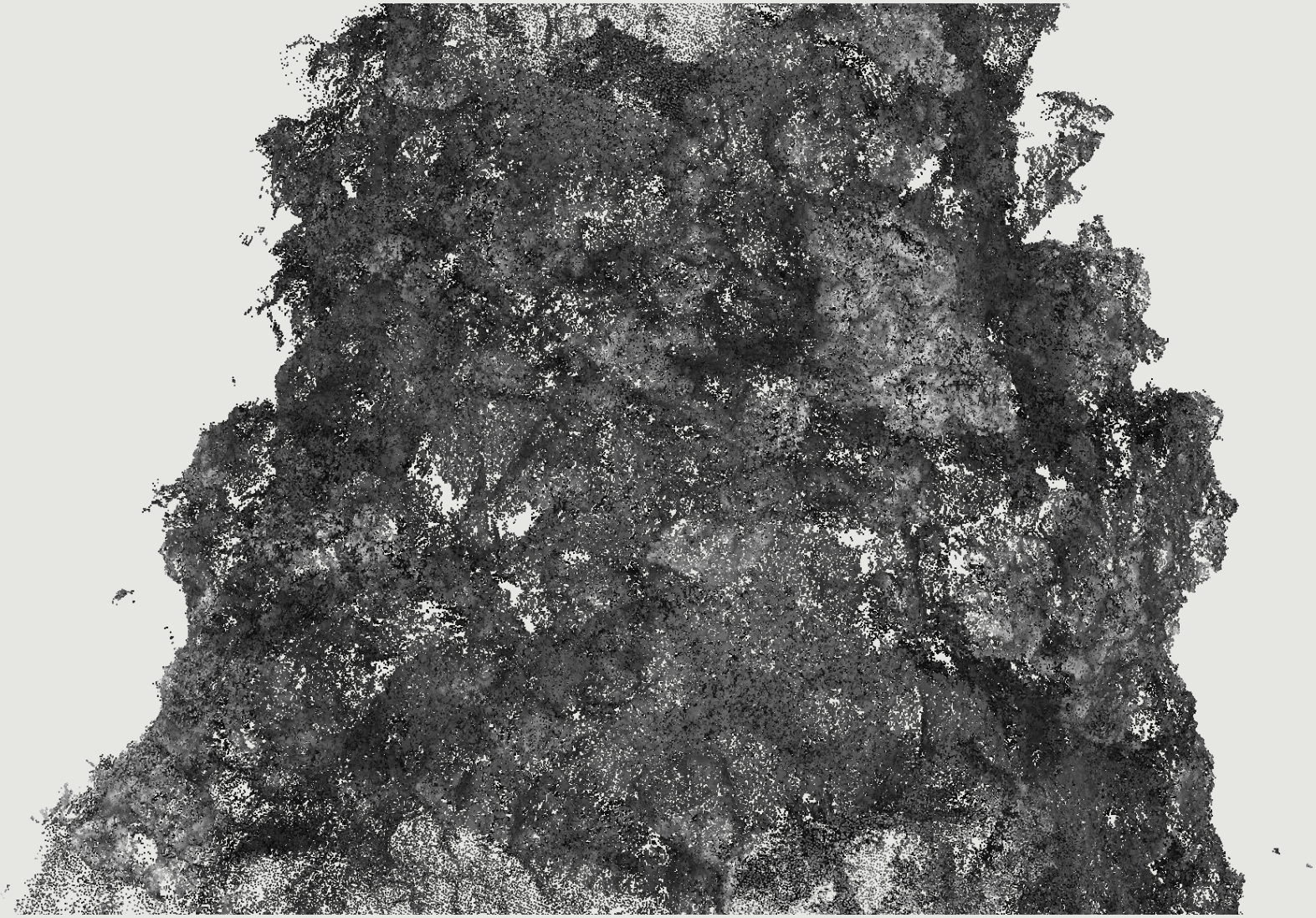
Acquisition geometry: automatic



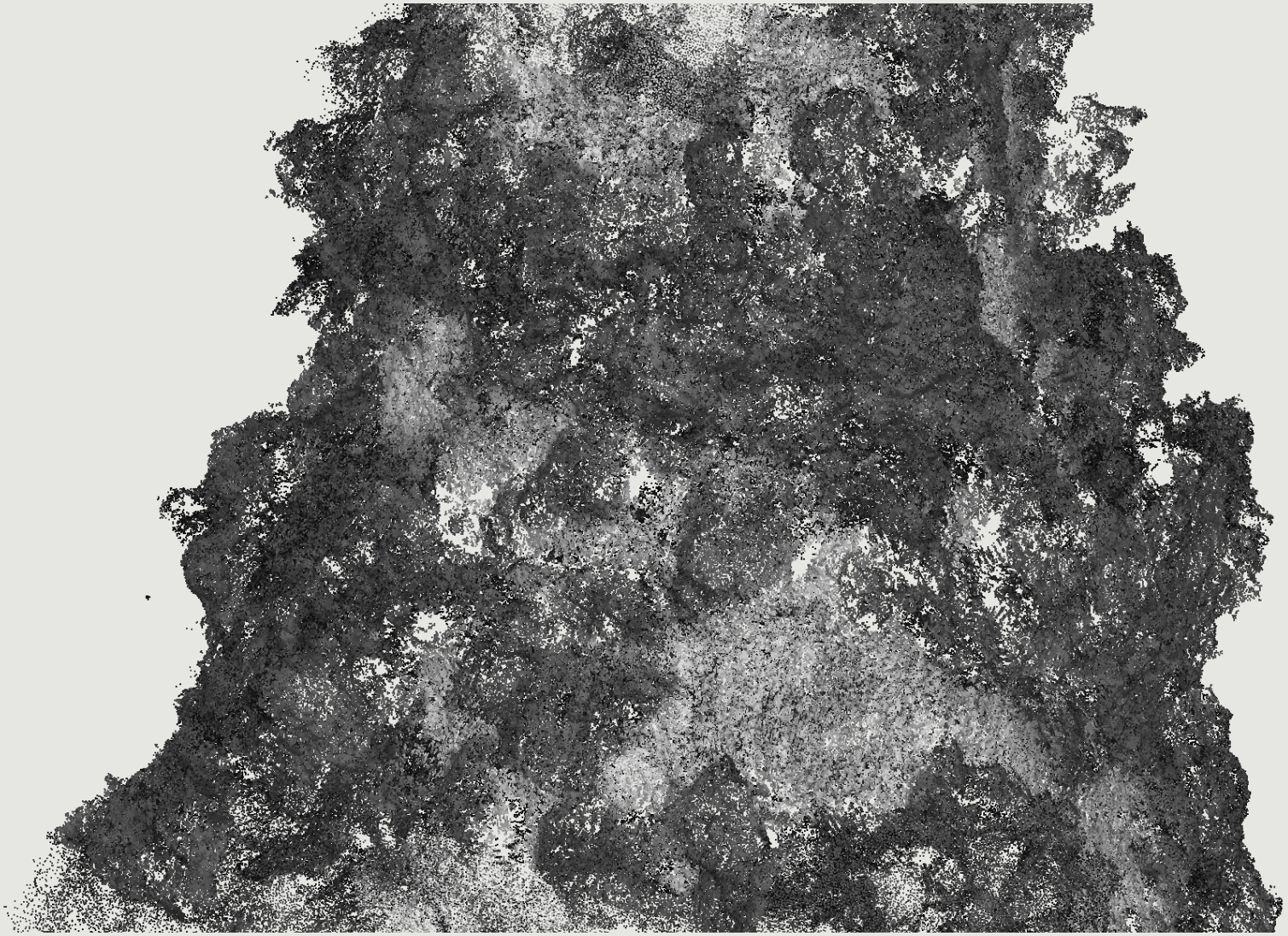
Automated “camera model” accounts for distortions/aberrations, including

- Focal length
- Centre of projection
- Radial distortions
- Tangential distortions

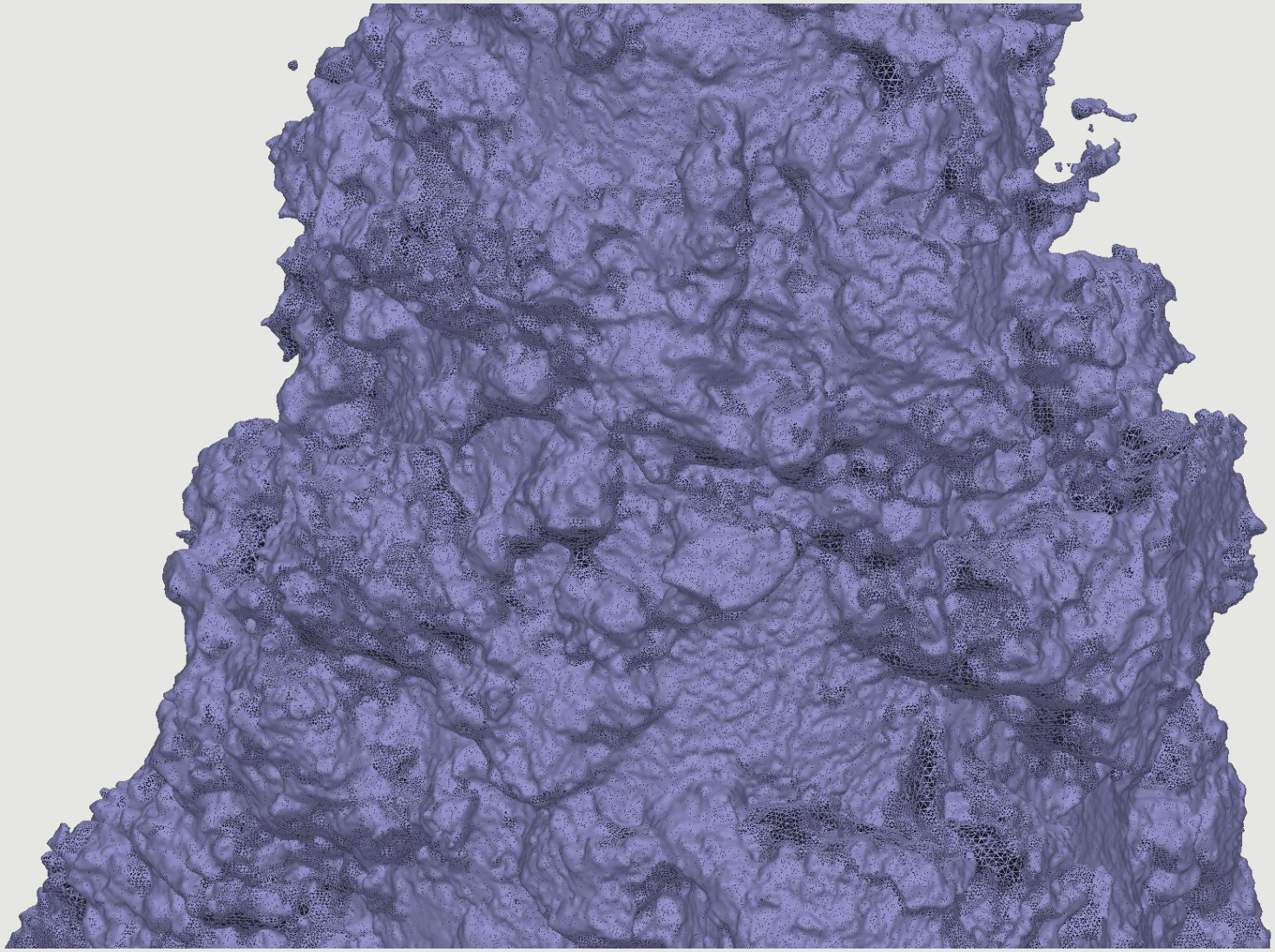
Points cloud: EBAC



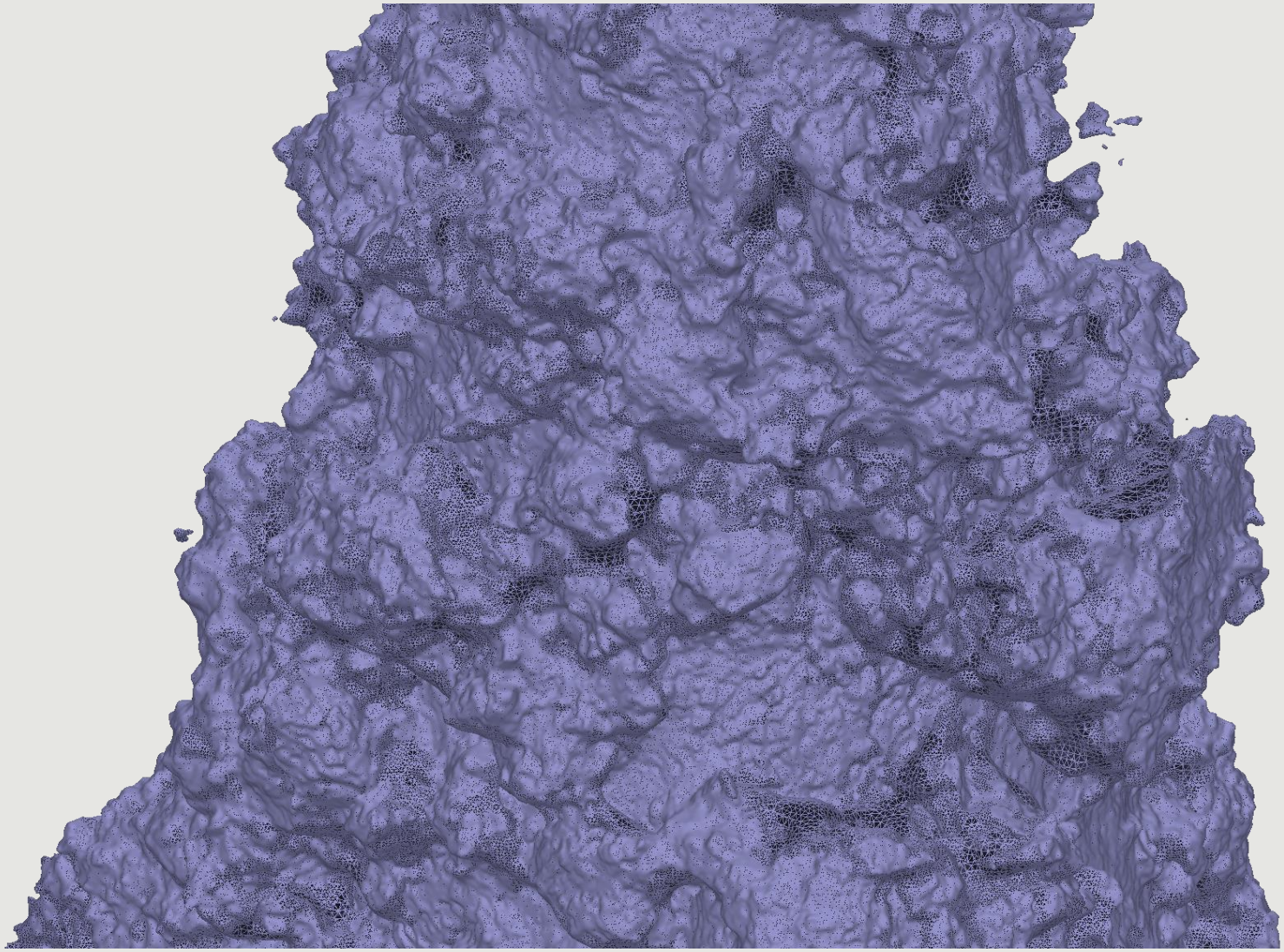
Points cloud: BSE



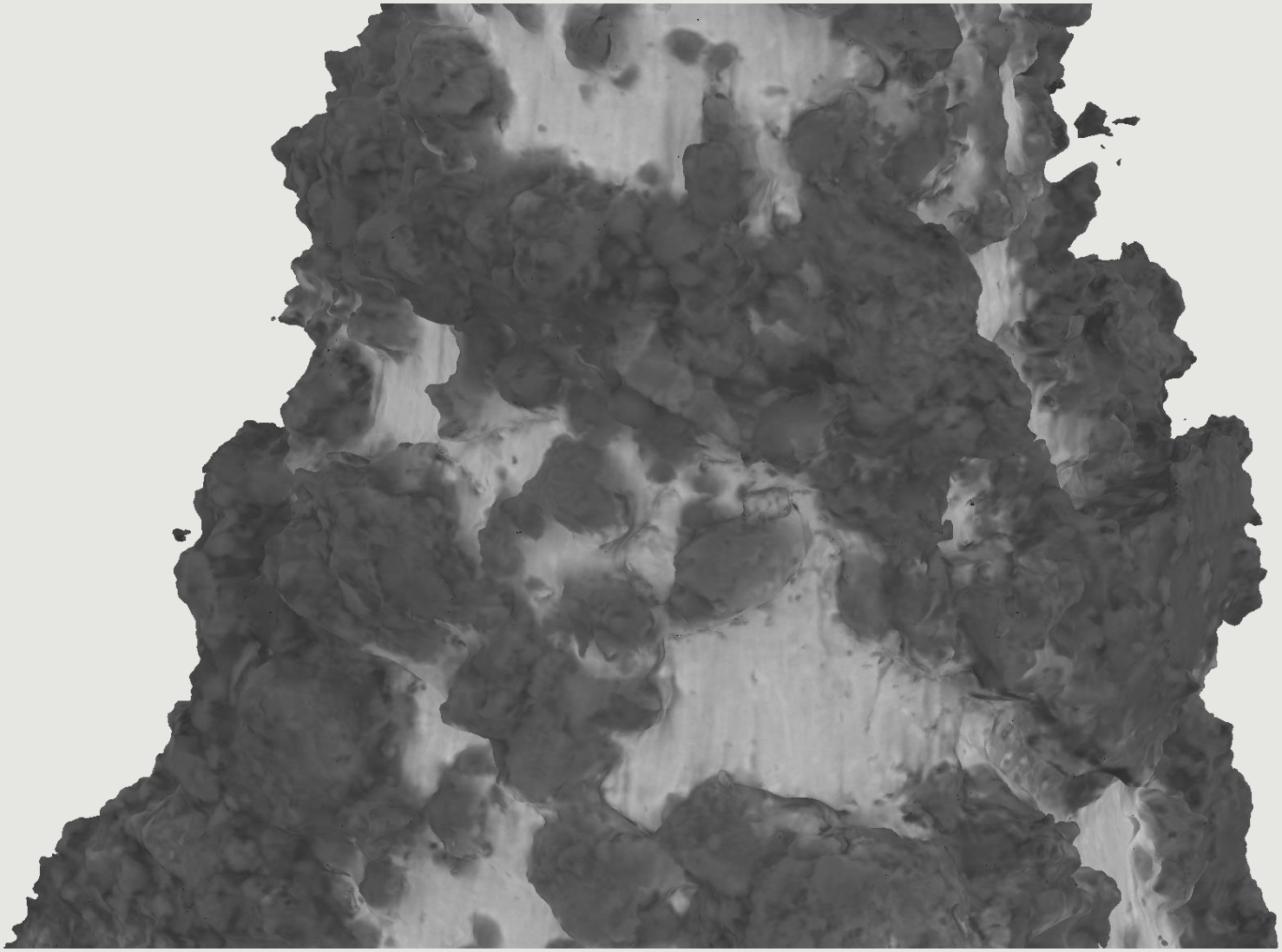
Wireframe: EBAC



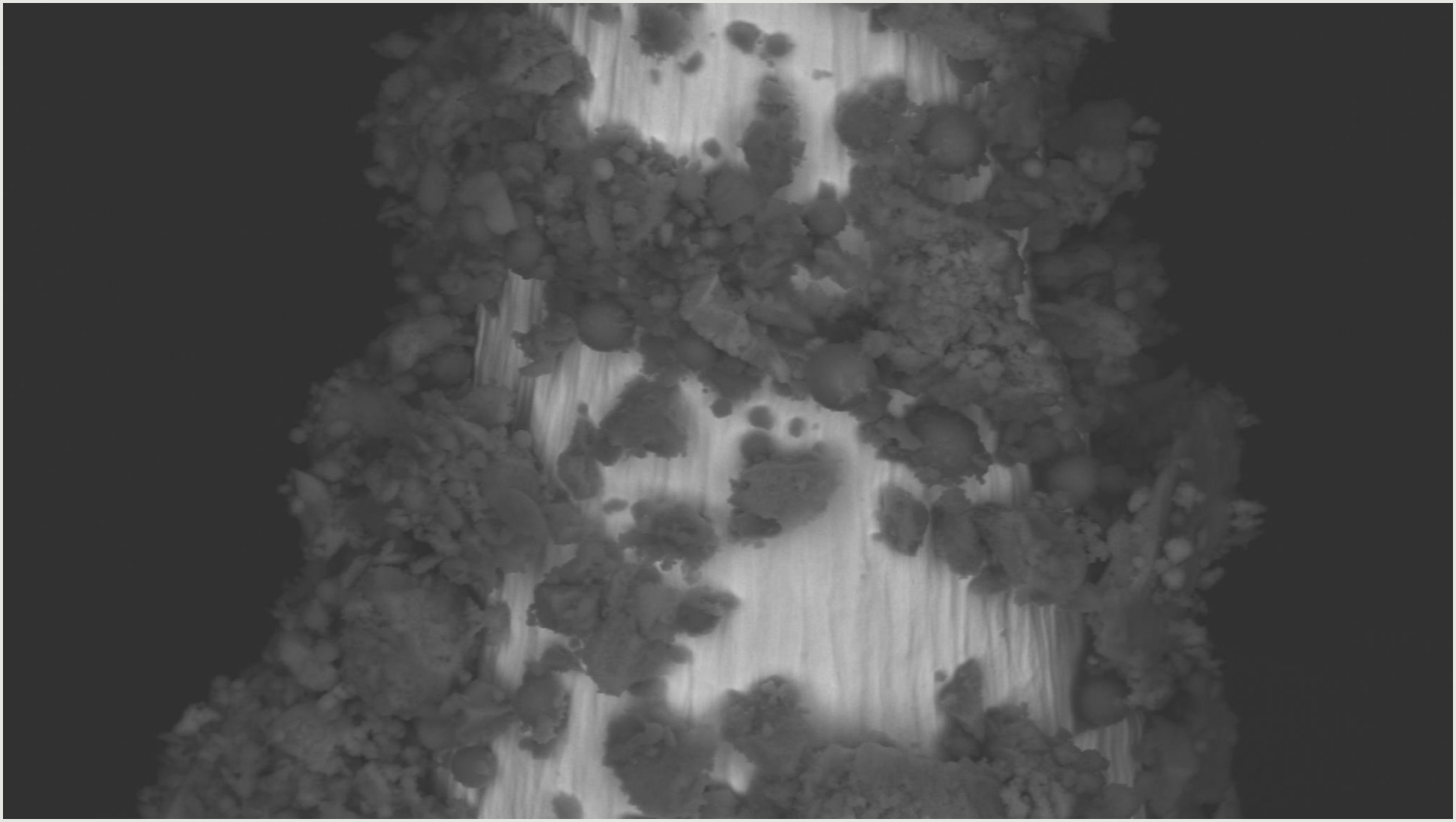
Wireframe: BSE



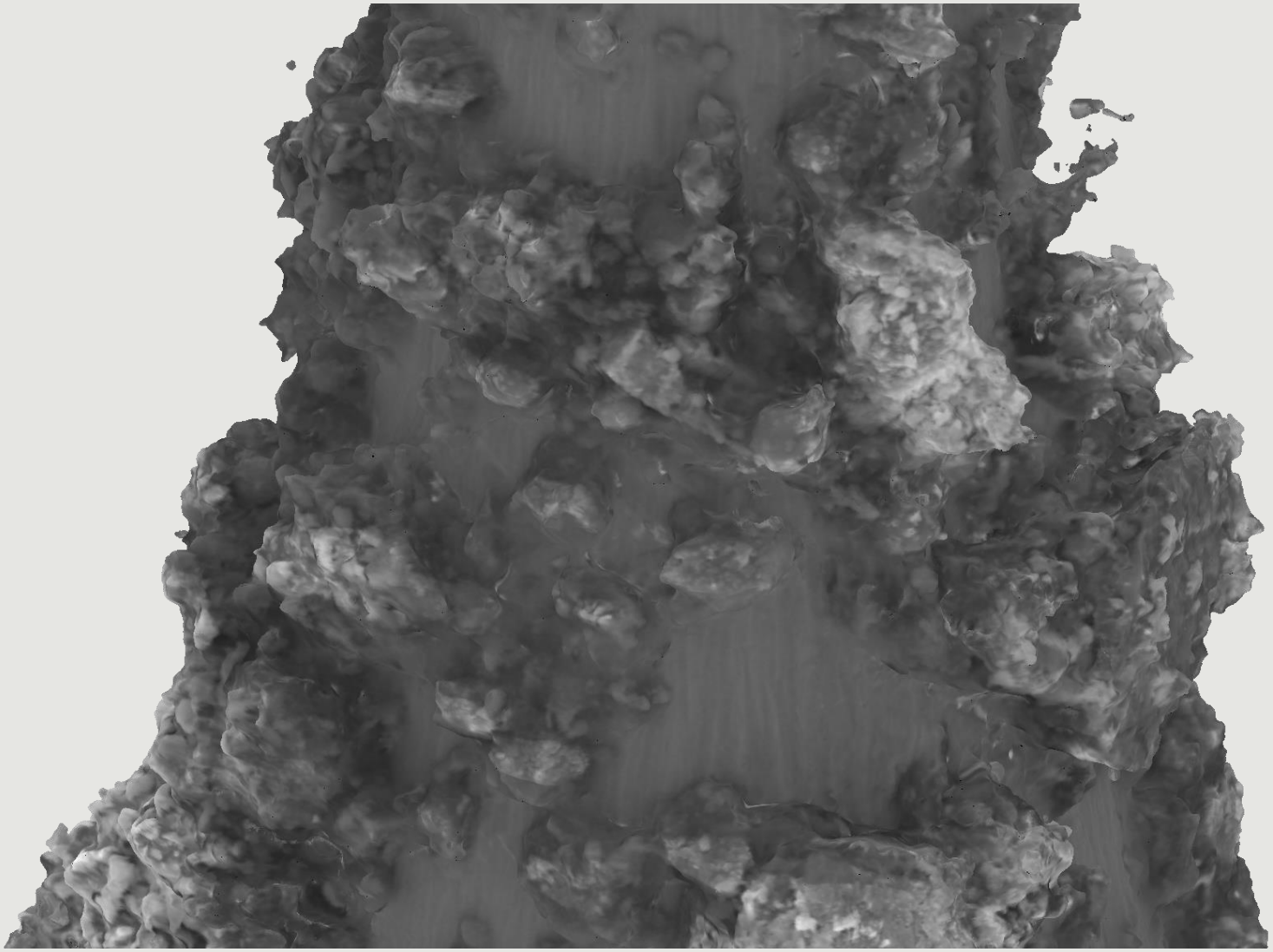
Texture: BSE



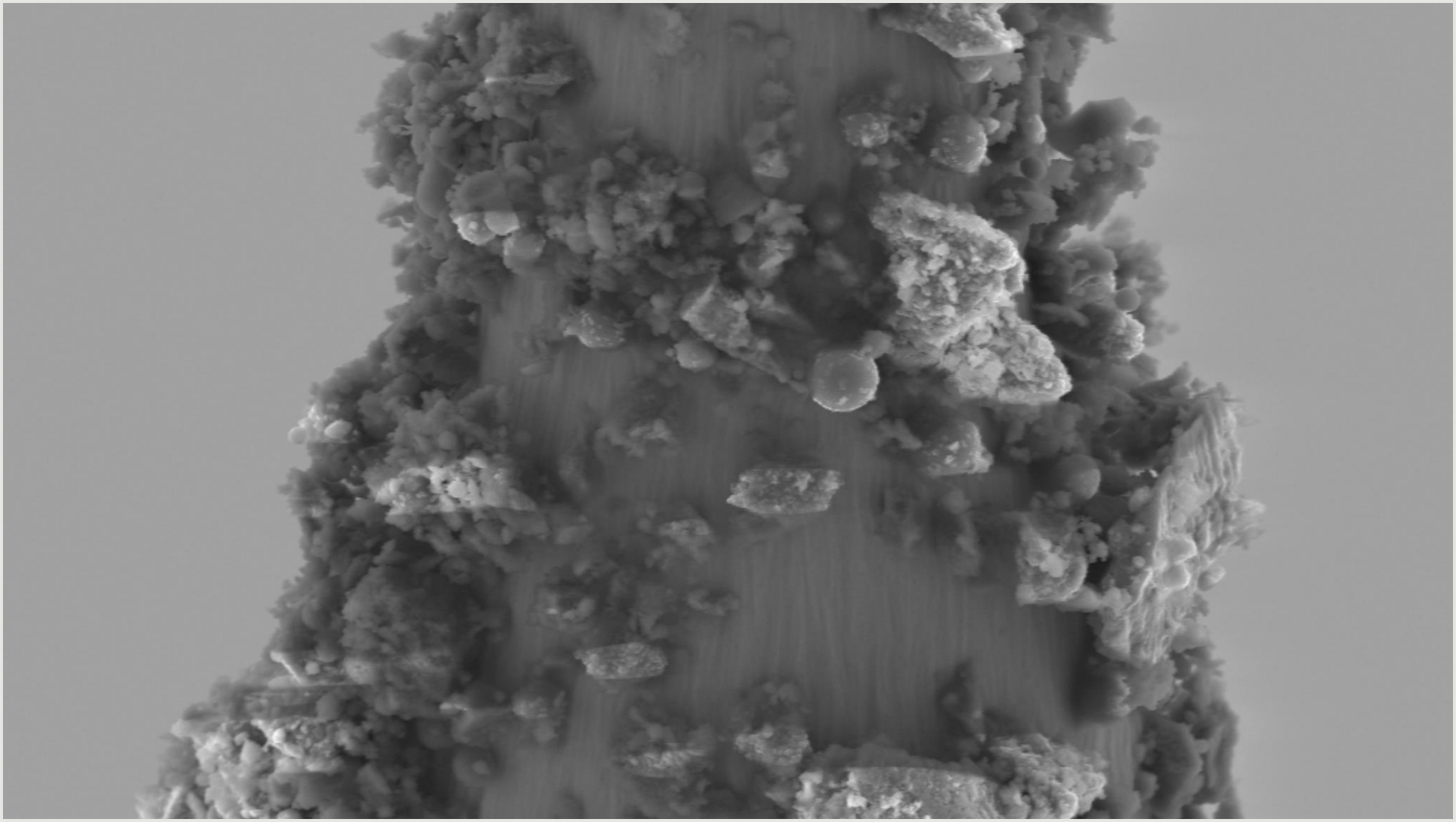
BSE data



Texture: EBAC



EBAC data



Conclusions

A simple and robust approach to 3D scanning in SEM is detailed, taking advantage of established light-based photogrammetric reconstruction

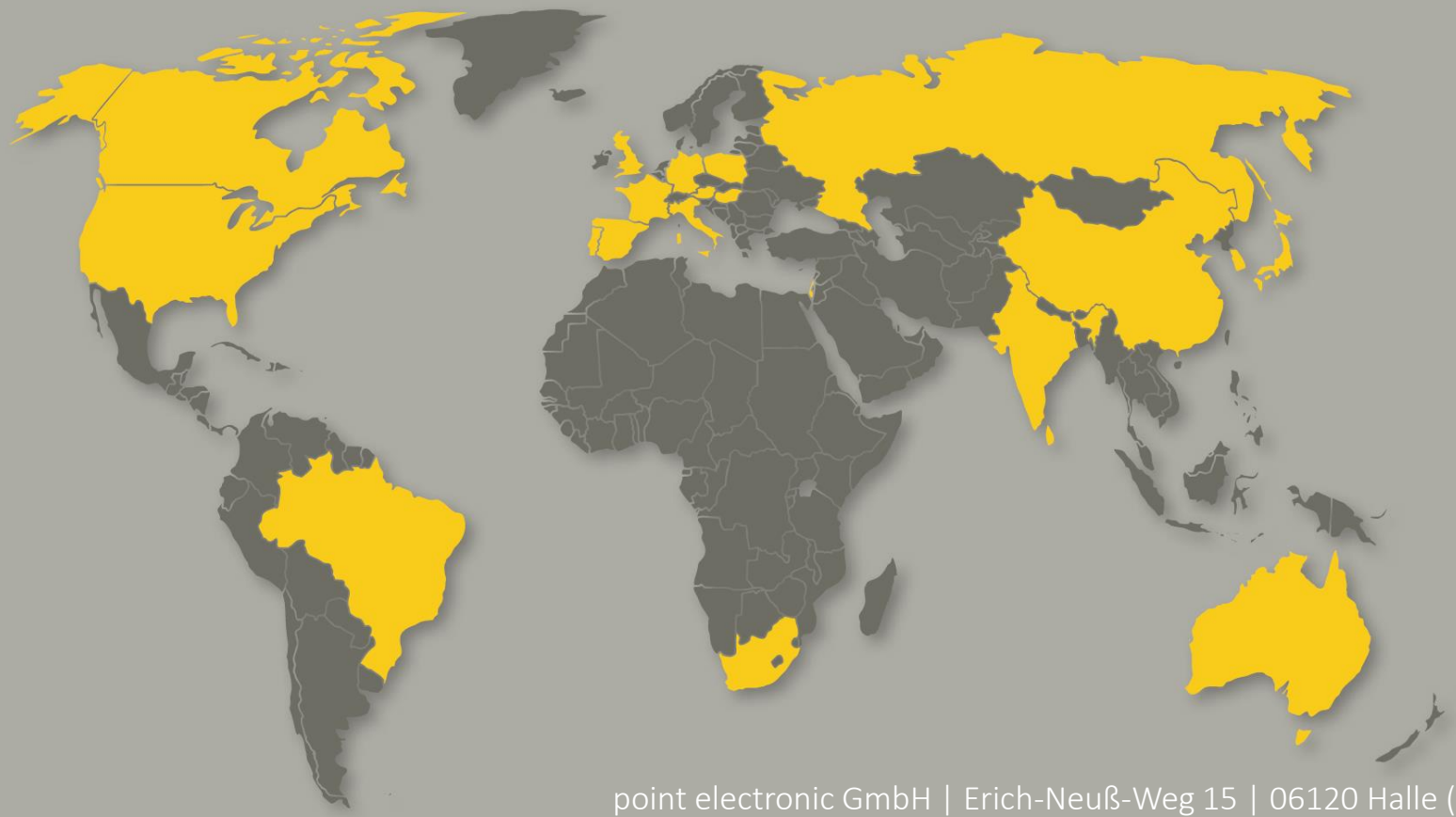
- SEM signals
  - SE is less suitable for 3D work
  - BSE and EBAC signals are more resilient to charging and edge effects

- 3D model can be reconstructed automatically
  - Very high density points cloud and wireframe
  - BSE texture adds density/atomic number contrast
  - EBAC mesh brings higher resolution than BSE

- SEM distortions/aberrations can be determined with photogrammetry
  - Centre of projection
  - Radial distortions
  - Tangential distortions

Acknowledgements

- **Wolfgang Joachimi**, **Uwe Grauel** (point electronic) for design of EBAC electronics
- **Matthias Hemmleb** (m_2c) for discussions on photogrammetry



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