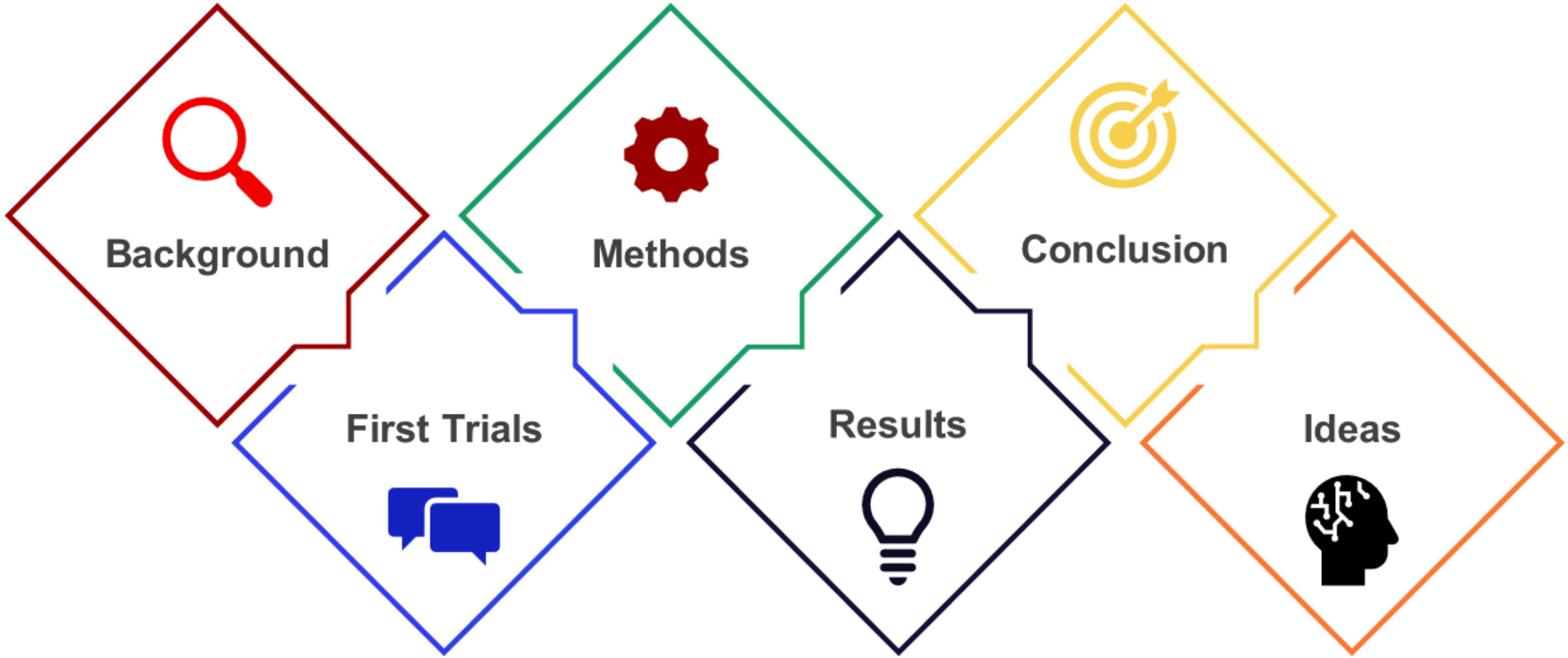

DTU

Quantitative Characterization of Hydrogel Layers on Antifouling Coatings

Presenter: **Shawn Lindner**

Research Group: CoaST, Chemical & Biochemical Engineering, DTU (Denmark)

Supervisors: Kim Dam-Johansen, Markus Schackmann, and Narayanan Rajagopalan


Background
Methods
Conclusion
First Trials
Results
Ideas


Background

Background

- **What is a hydrogel?**
  - Microporous hydrophilic three-dimensional polymer network
  - Containing large amount of water (typically 60-99 wt%)

- **Hydrogels as antifouling strategy?**

  Hydrated, soft surfaces resist fouling by mimicking biological tissues (e.g., fish and seaweed)
  - Protein/Polysaccharide adhesion is weak [1]
  - Organisms cannot detect the surface [2]
  - Softness of hydrogels can make barnacles peel off with balanced gel strength [3]
  - Synergy with Cu_2O (hydrogel can act as reservoir) [4]

→ Potential to reduce biocides

[1]S. Chen, L. Li, C. Zhao, and J. Zheng, "Surface hydration: Principles and applications toward low-fouling/nonfouling biomaterials", 2012
[2] A. Rosenhahn and G. H. Sendra, "Surface Sensing and Settlement Strategies of Marine Biofouling Organisms", 2012
[3] T. Murosaki, N. Ahmed, and J. Ping Gong, "Antifouling properties of hydrogels", 2011
[4] M. Butschle, S. Lindner, M. Schackmann, and K. Dam-Johansen, "Towards improved antifouling: Exploring xanthan gum hydrogel coatings", 2024

Background

Our Approach

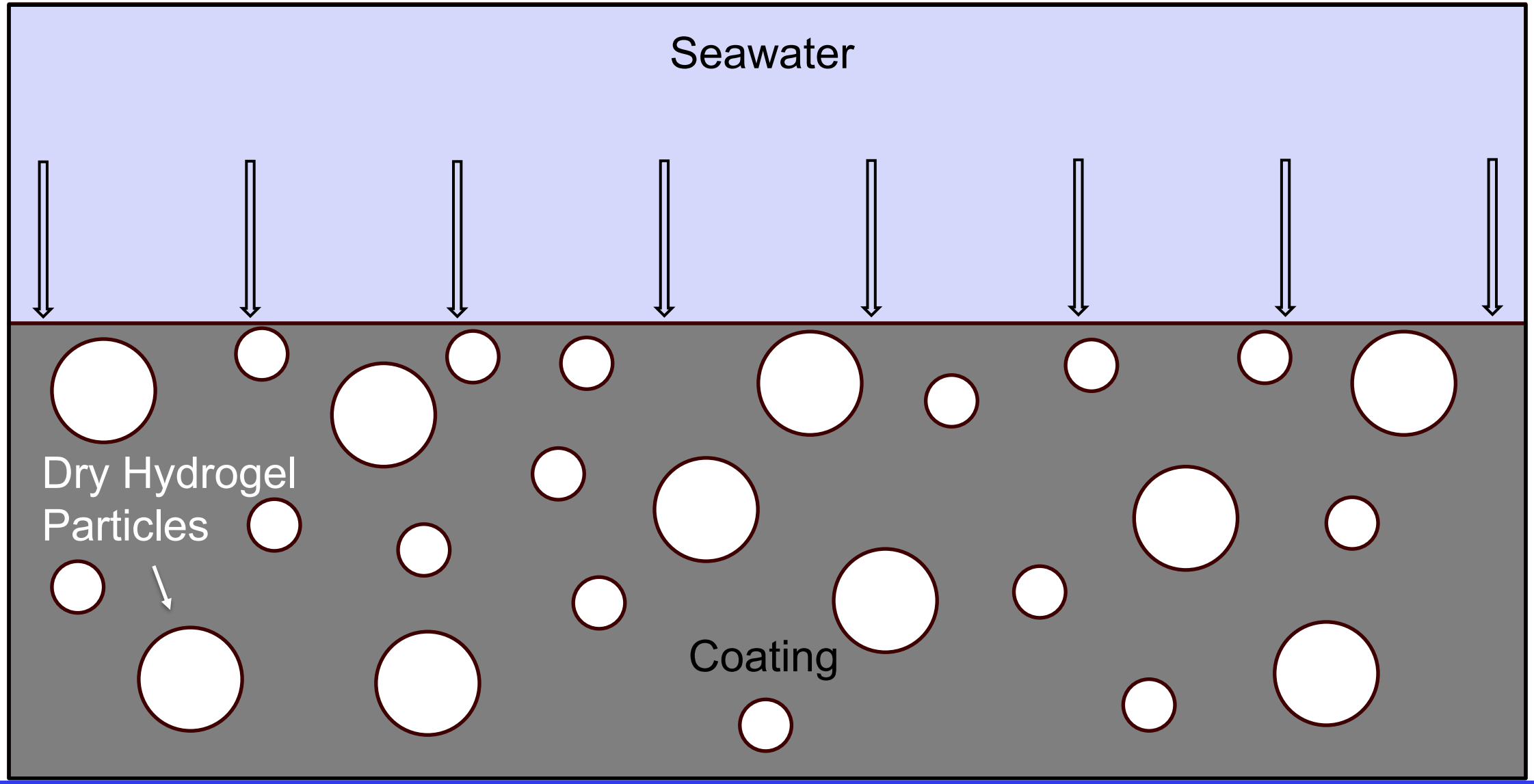
– Hydrogel is built in-situ upon seawater contact atop the coating

– Non-toxic hydrogel precursor particles (Xanthan Gum)

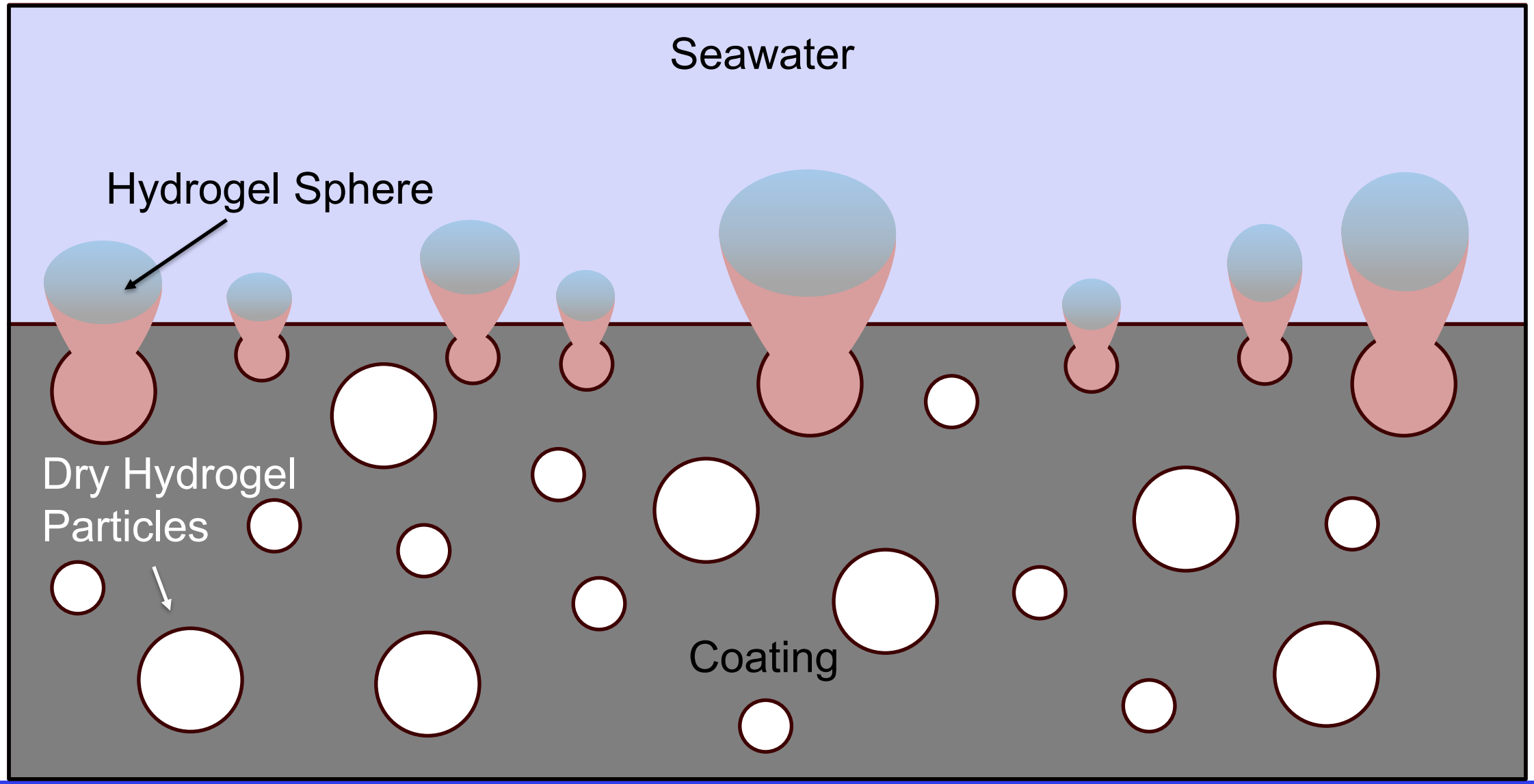
– Solid/gel transition instead of sol/gel

– Cuprous oxide is stored in the hydrogel, making its use more efficient

Background – Gel formation



Background – Gel formation



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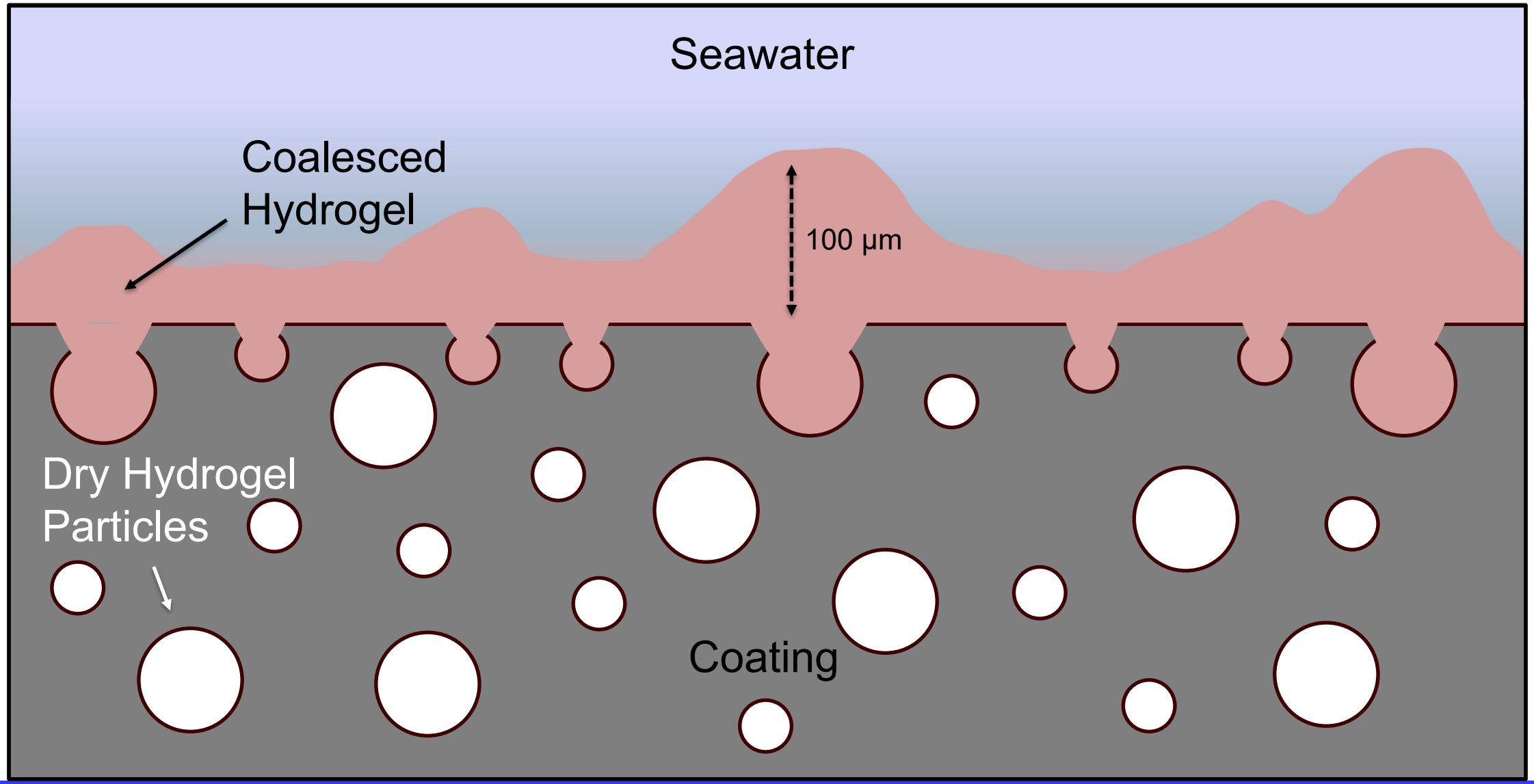

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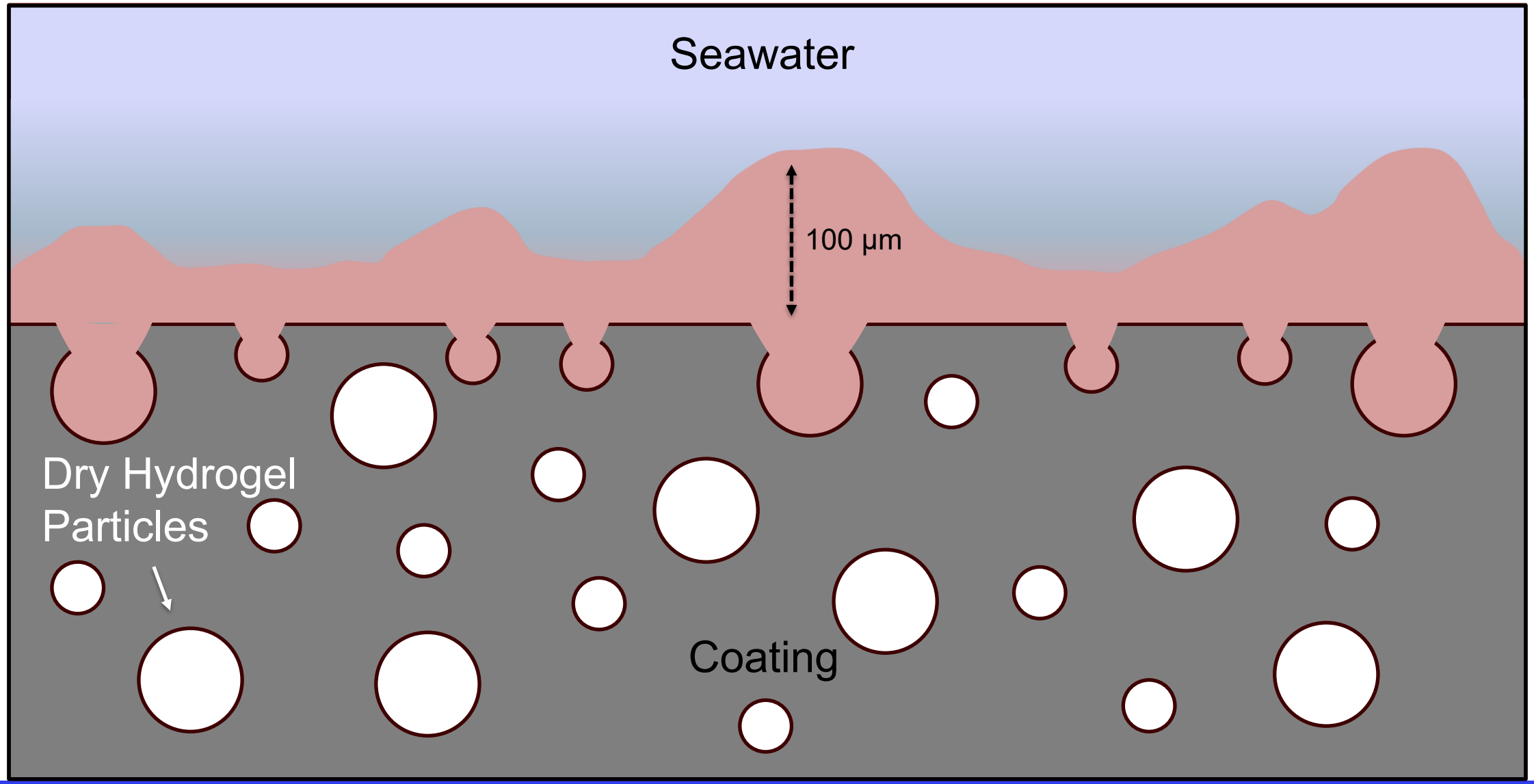
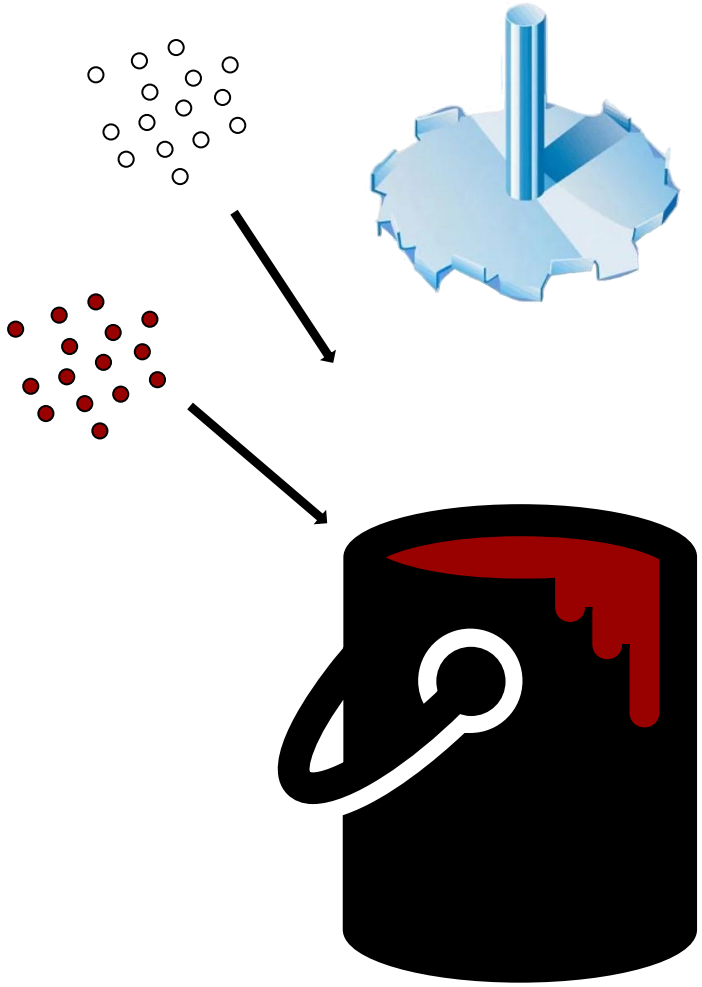


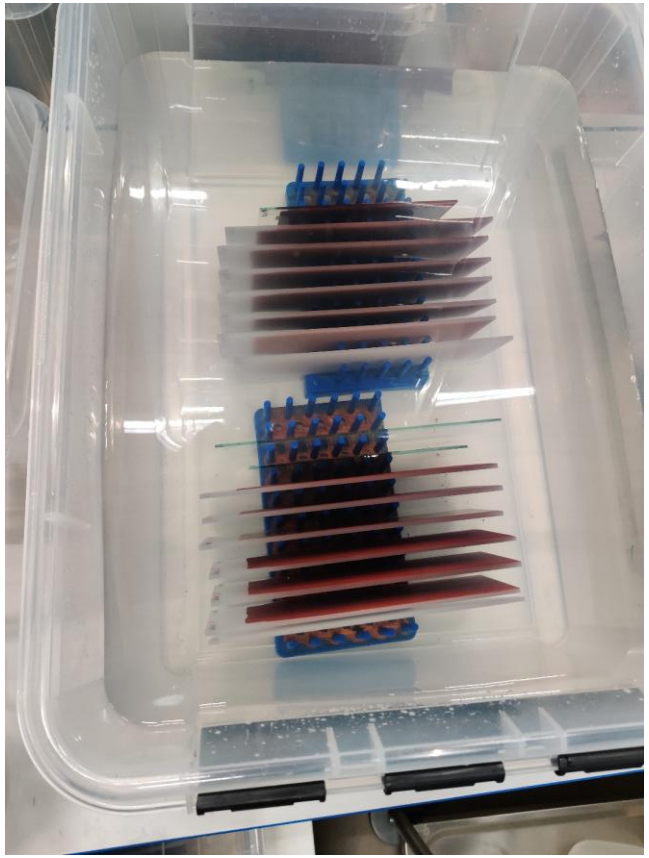
Background – Coating Production and Immersion

1. Xanthan Gum (powder) is dispersed together with binder and other pigment with high speed dissolver



2. **Application** on acrylic panel

3. **Immersion** in artificial seawater



Background

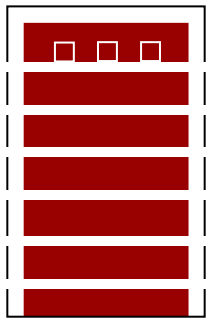
- **Goal:** Hydrogel visualization and thickness distribution measurement
- **Challenges:**

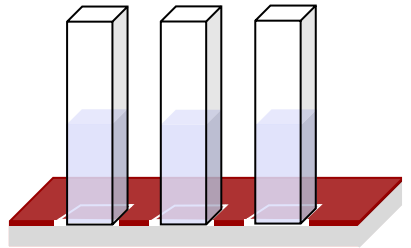
Hydrogel Property	Characterization Requirements
Thin (around 100 µm)	High resolution
Fragile (gel strength around 300 Pa)	Non-destructively
Transparent	High contrast
Fast drying	Measurement while being immersed in sea water

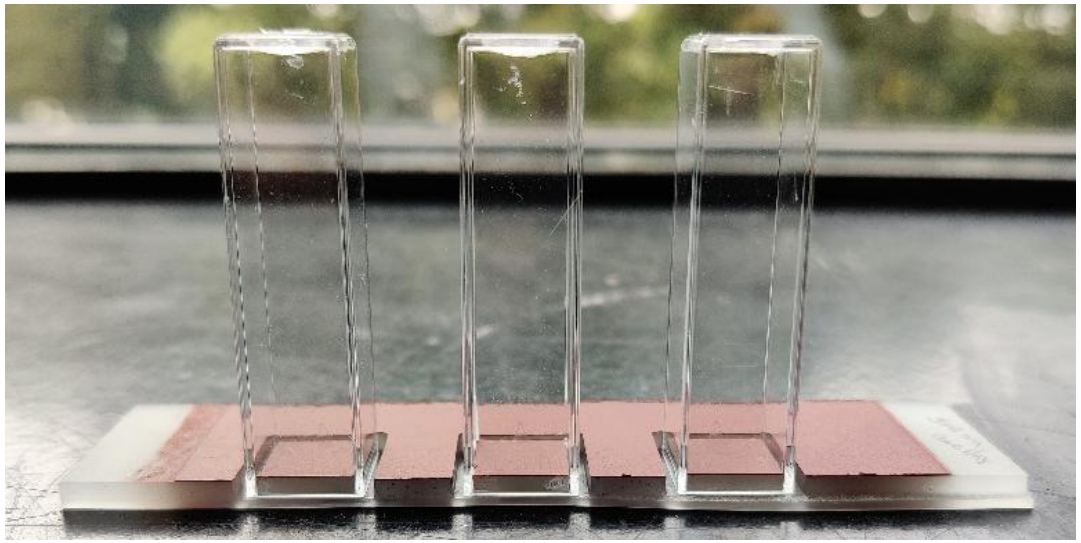
→ **First Trial Approach:** Light Microscopy?

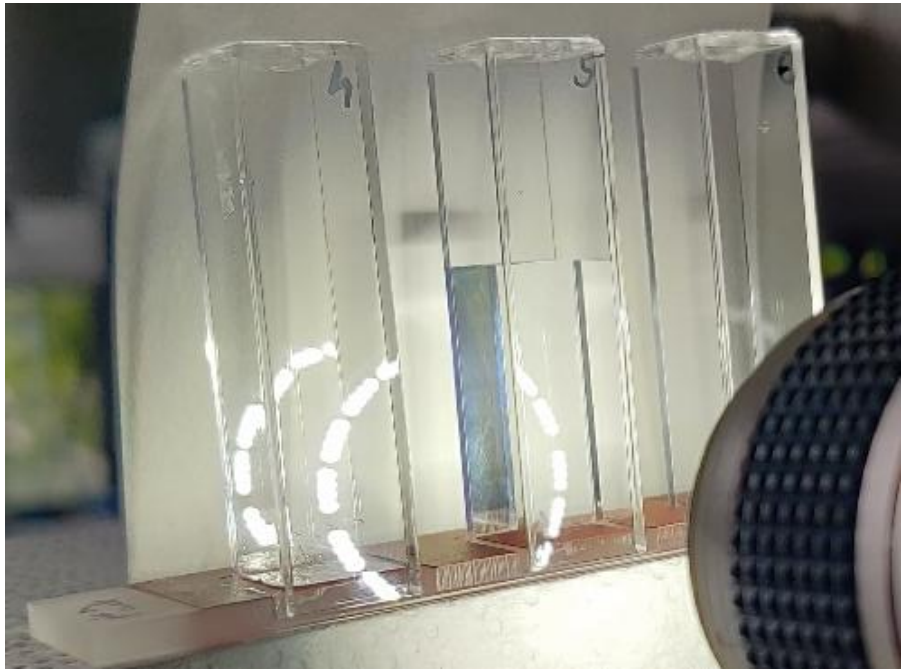

First Trials

(Crosscut) Microscopy

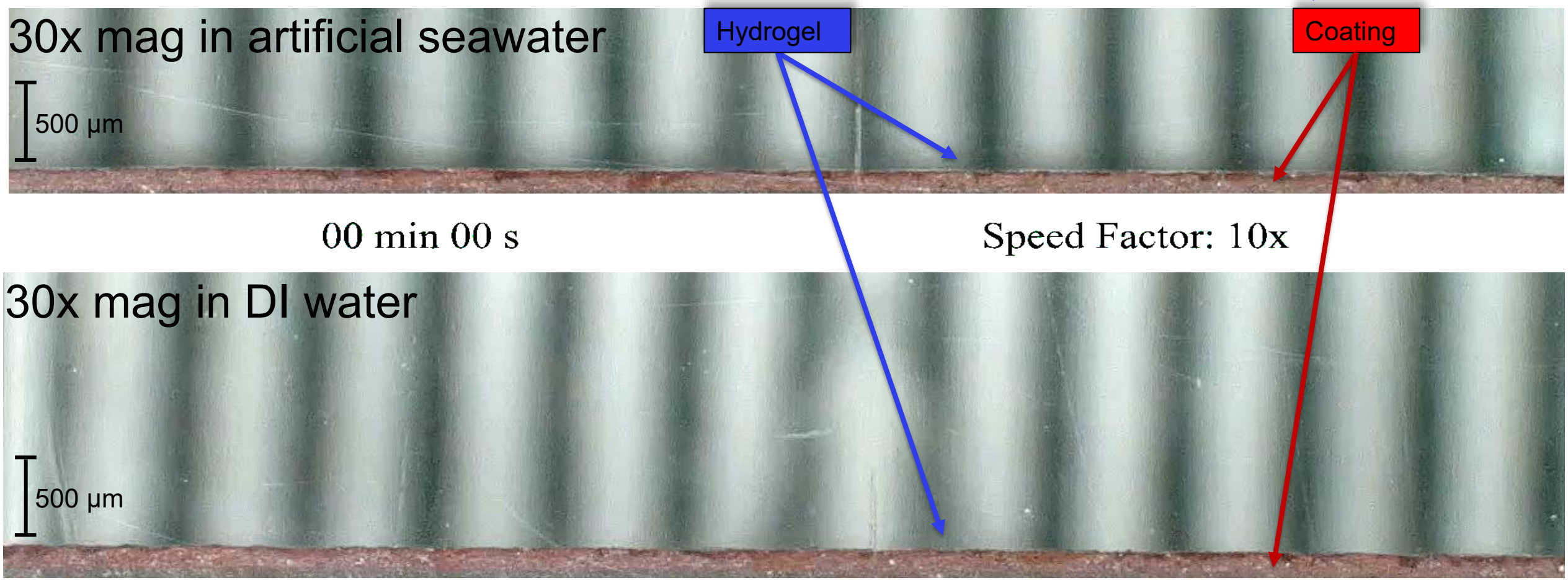








First Trial: Light Microscopy



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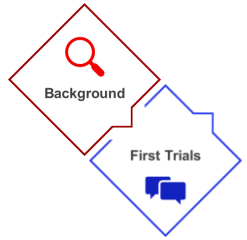


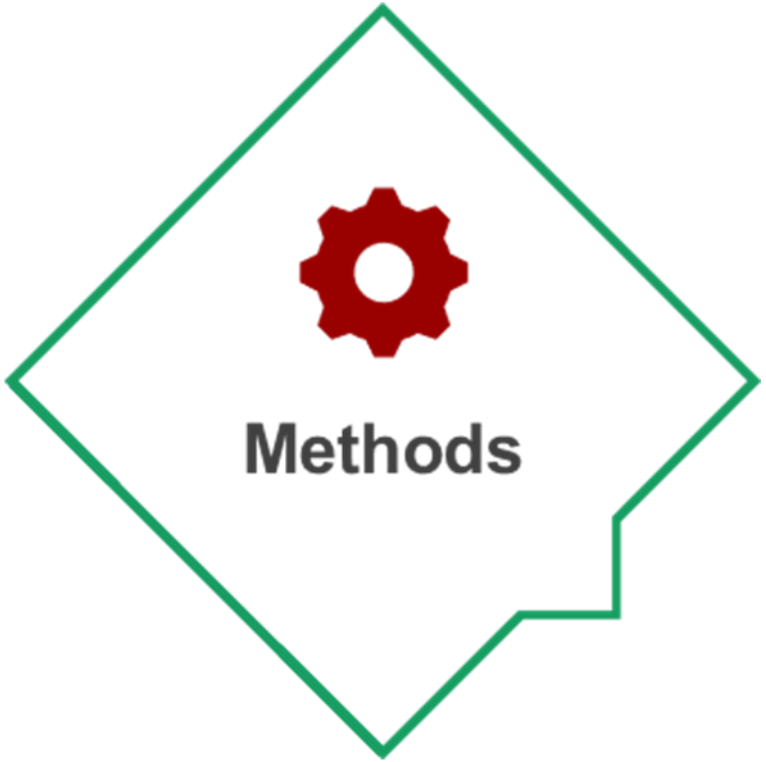
Low contrast to environment

Conclusion…

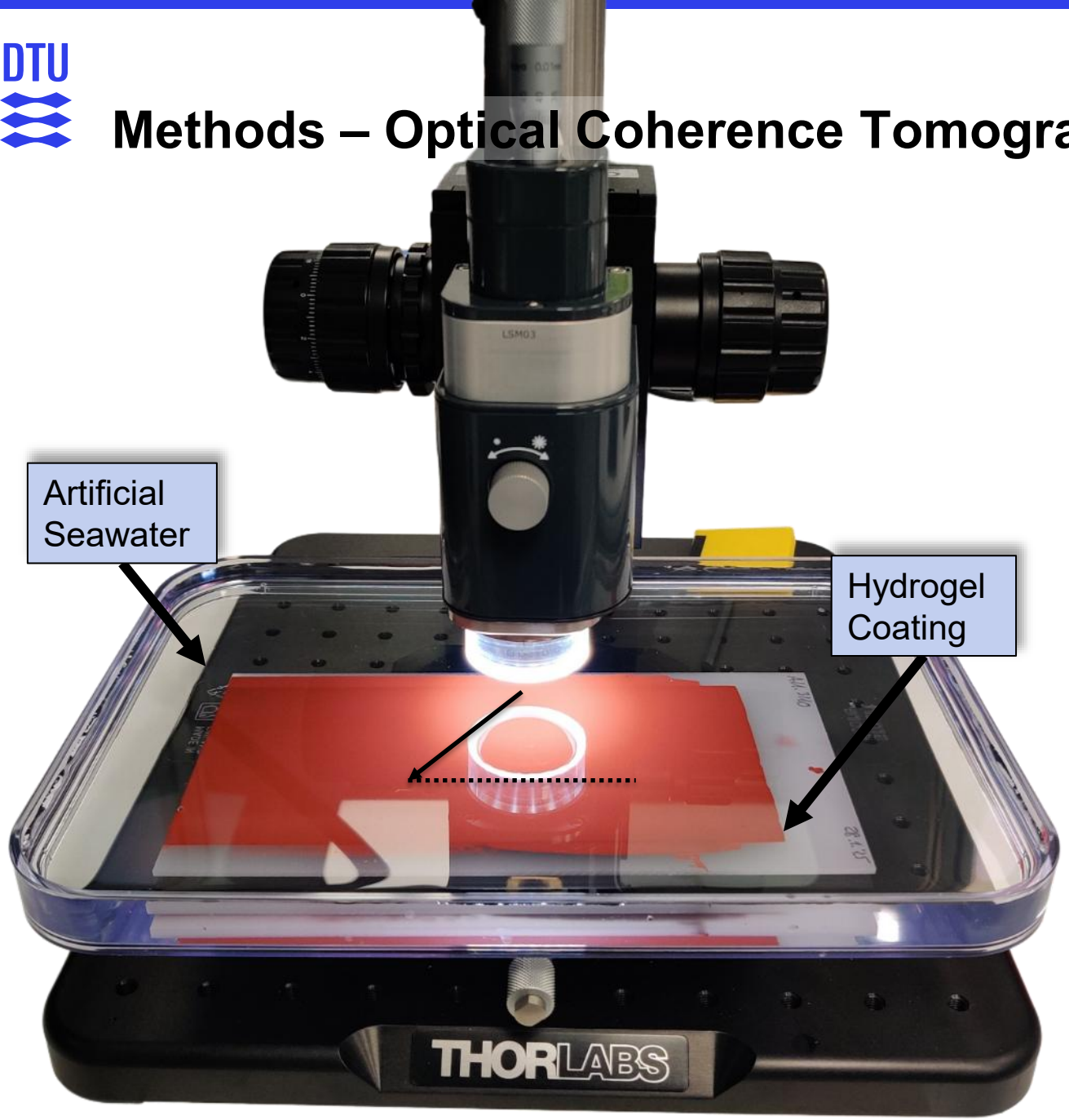
Rough edge due to milling

Seeing through the hydrogel landscape

→ Tough to detect and quantify the hydrogel


Methods

Methods – Optical Coherence Tomography (OCT)



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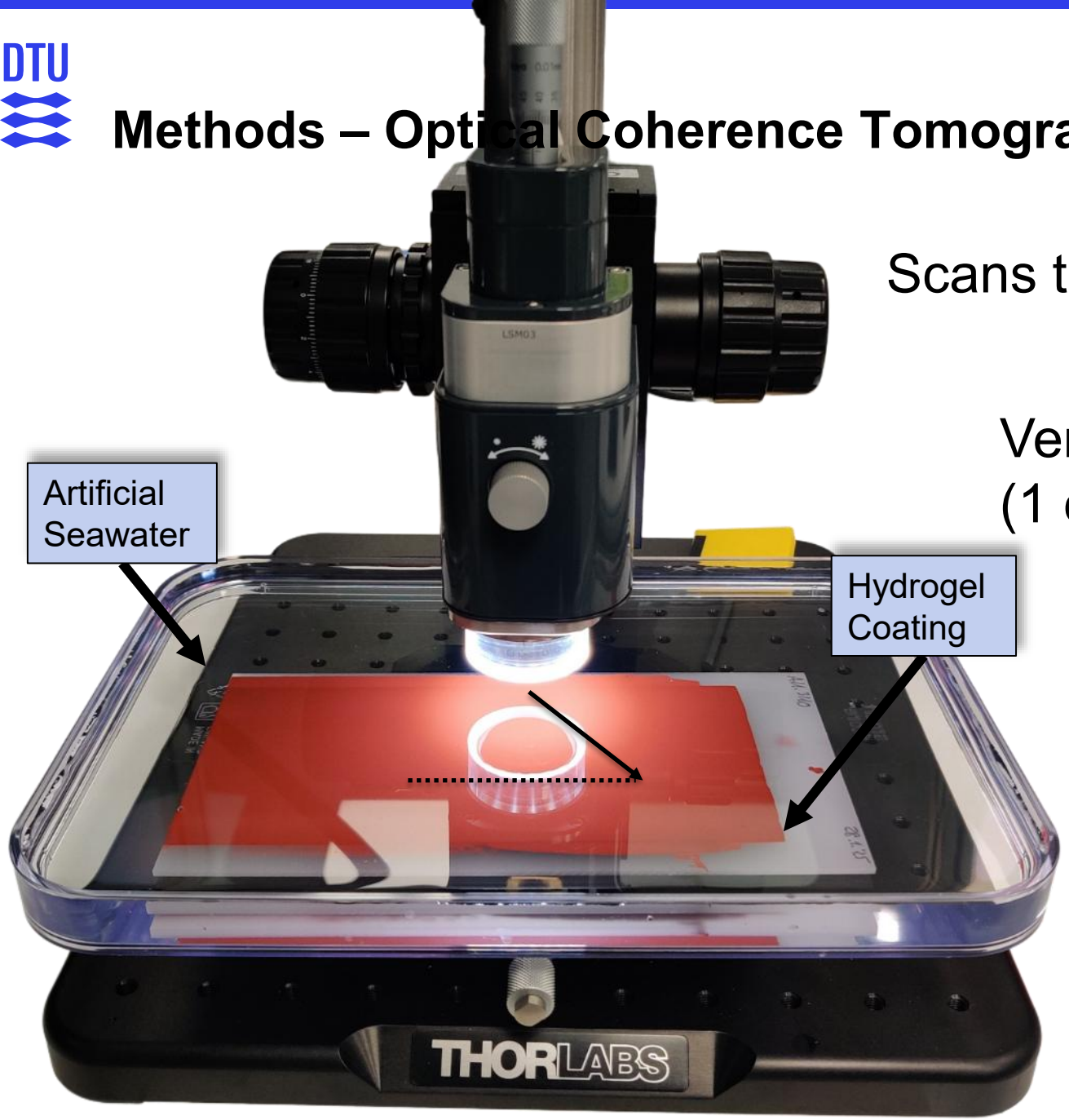
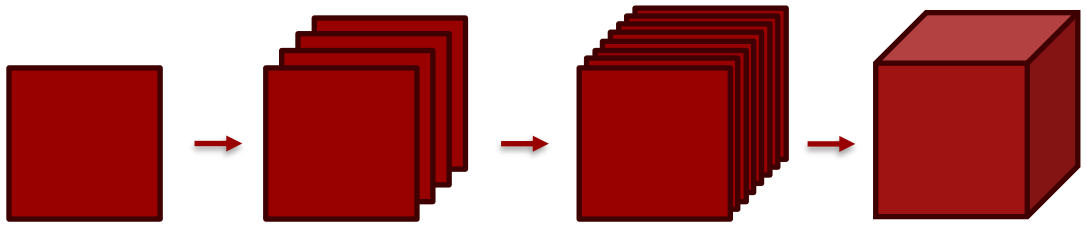


Scans the coating with a laser under water

Very fast measurement
(1 cm in under 1 second)

Micrometer-scale depth imaging

Creates 2D (crosscut-like, B-Scan)
or 3D images (C-Scan)



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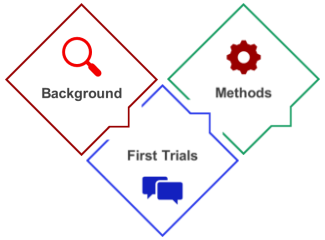

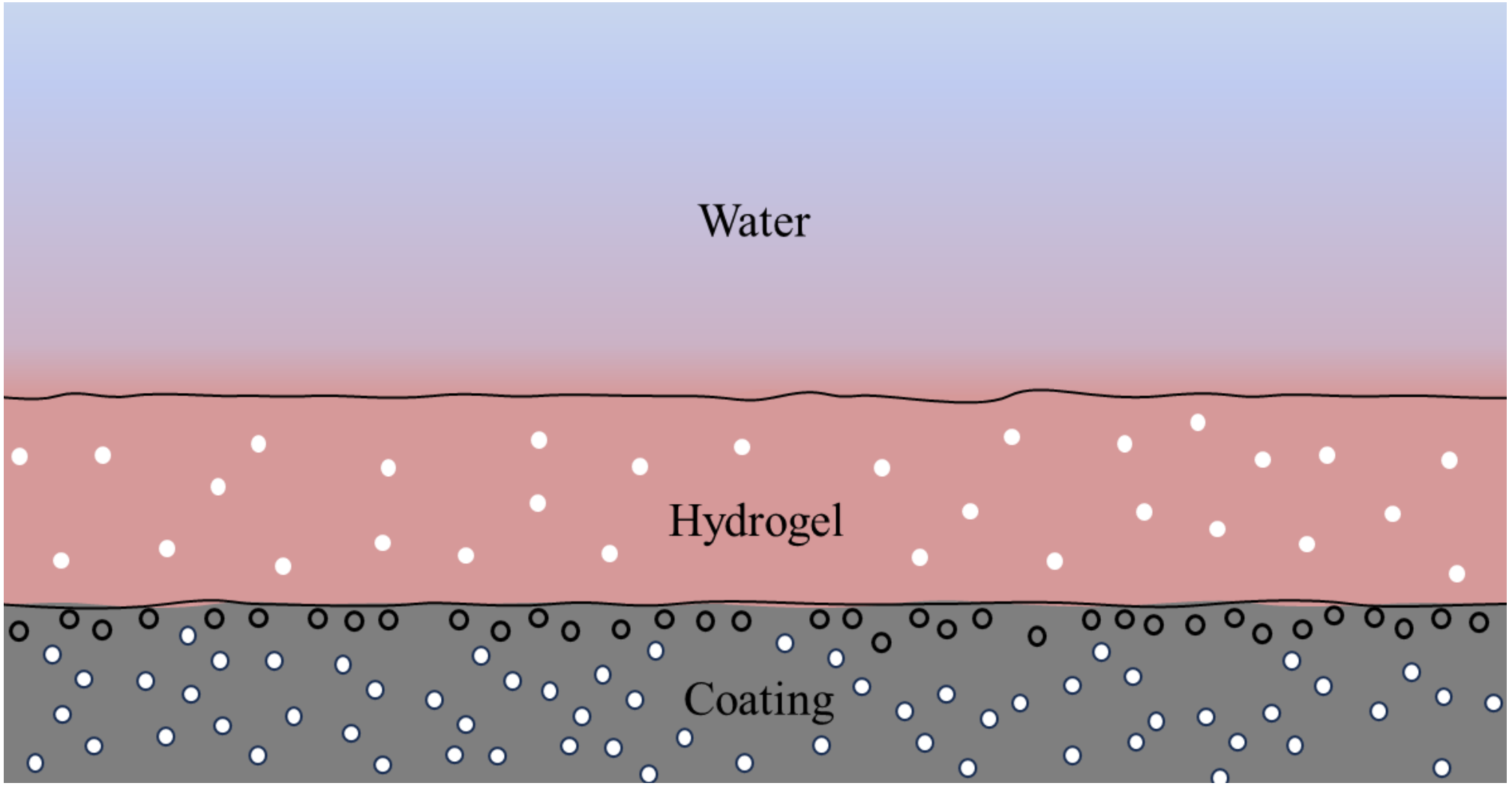

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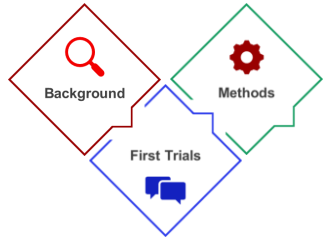
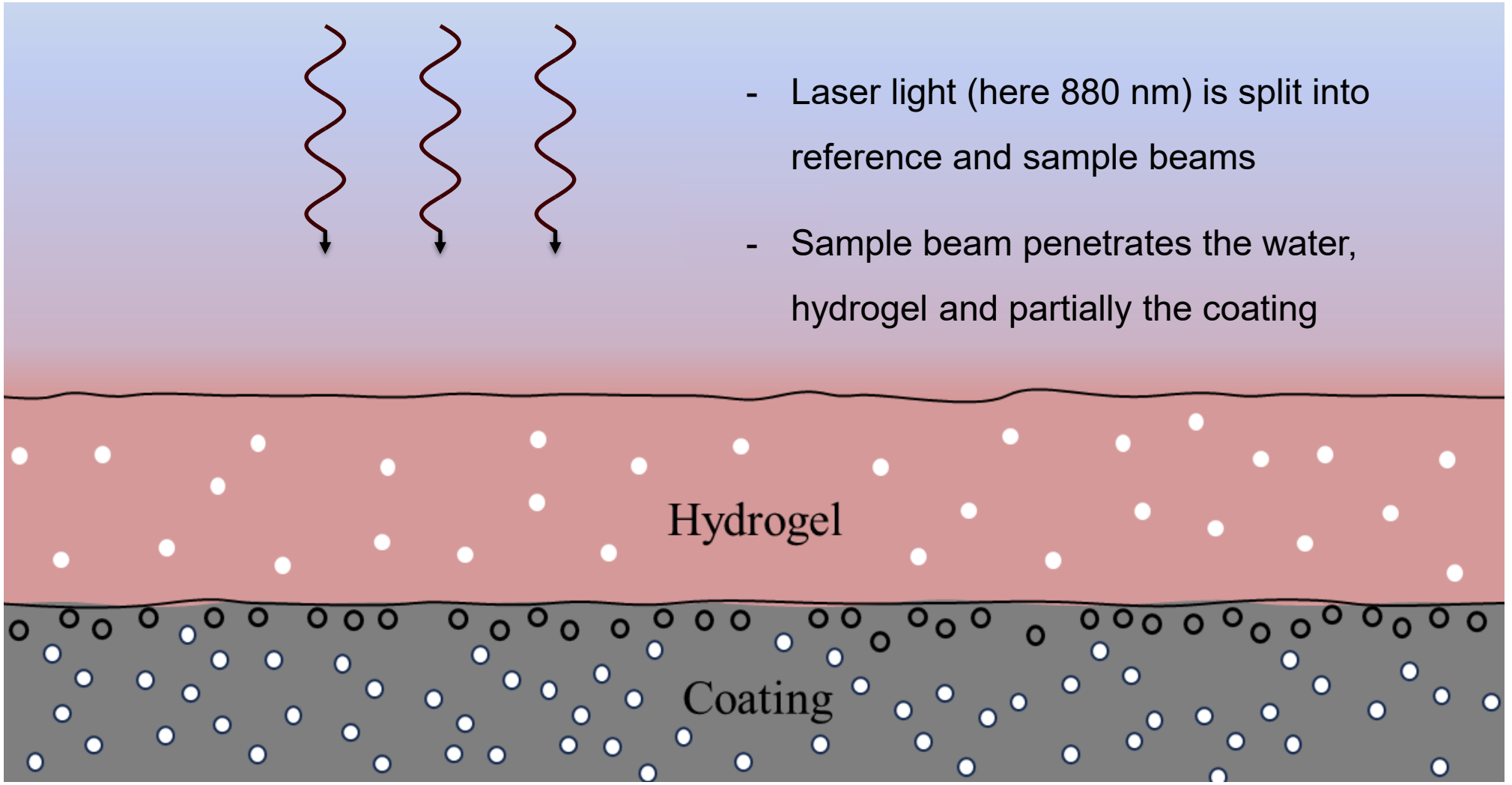


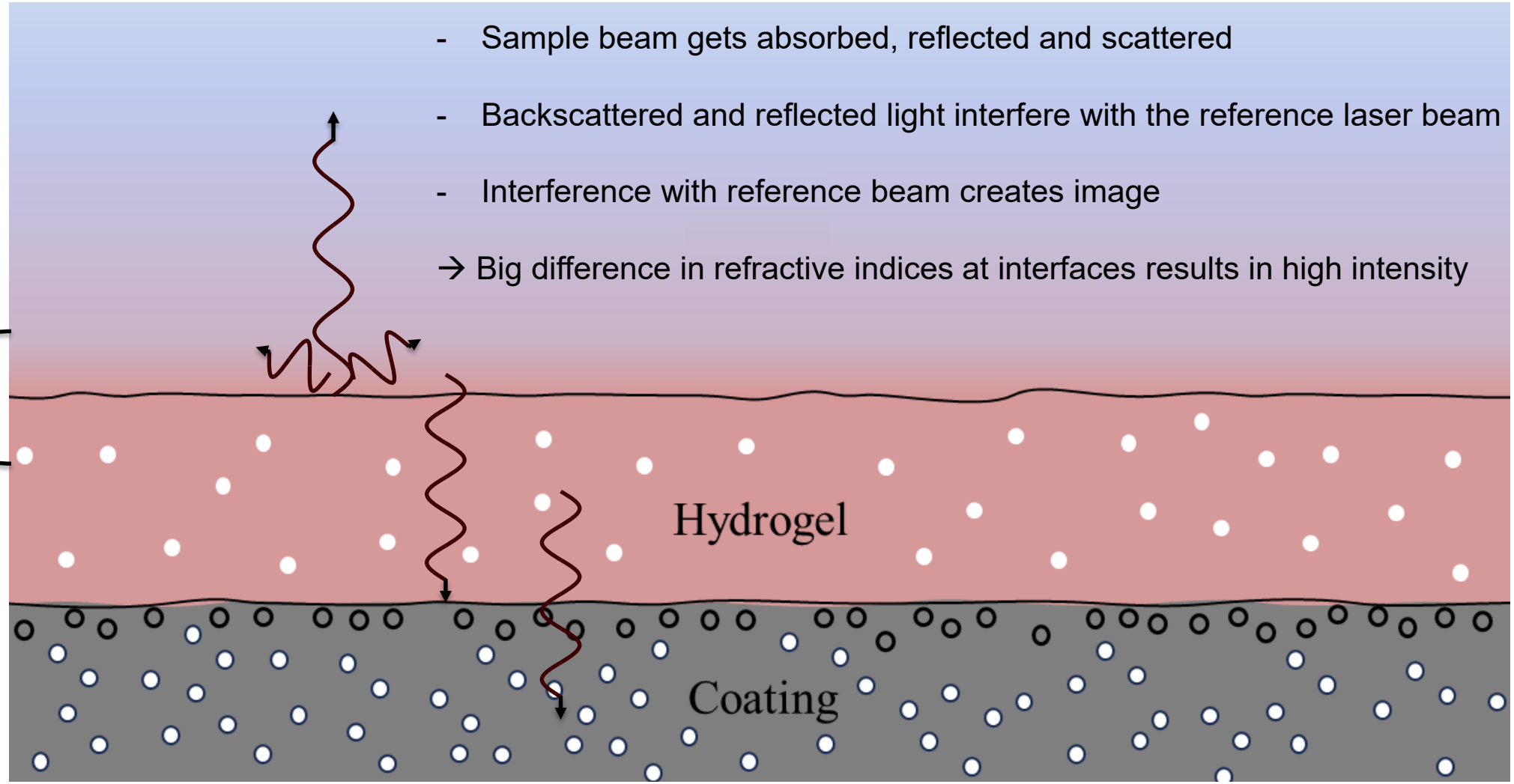


Methods – Optical Coherence Tomography (OCT)

- Sample beam gets absorbed, reflected and scattered
- Backscattered and reflected light interfere with the reference laser beam
- Interference with reference beam creates image

→ Big difference in refractive indices at interfaces results in high intensity

Δ n is small = weak signal



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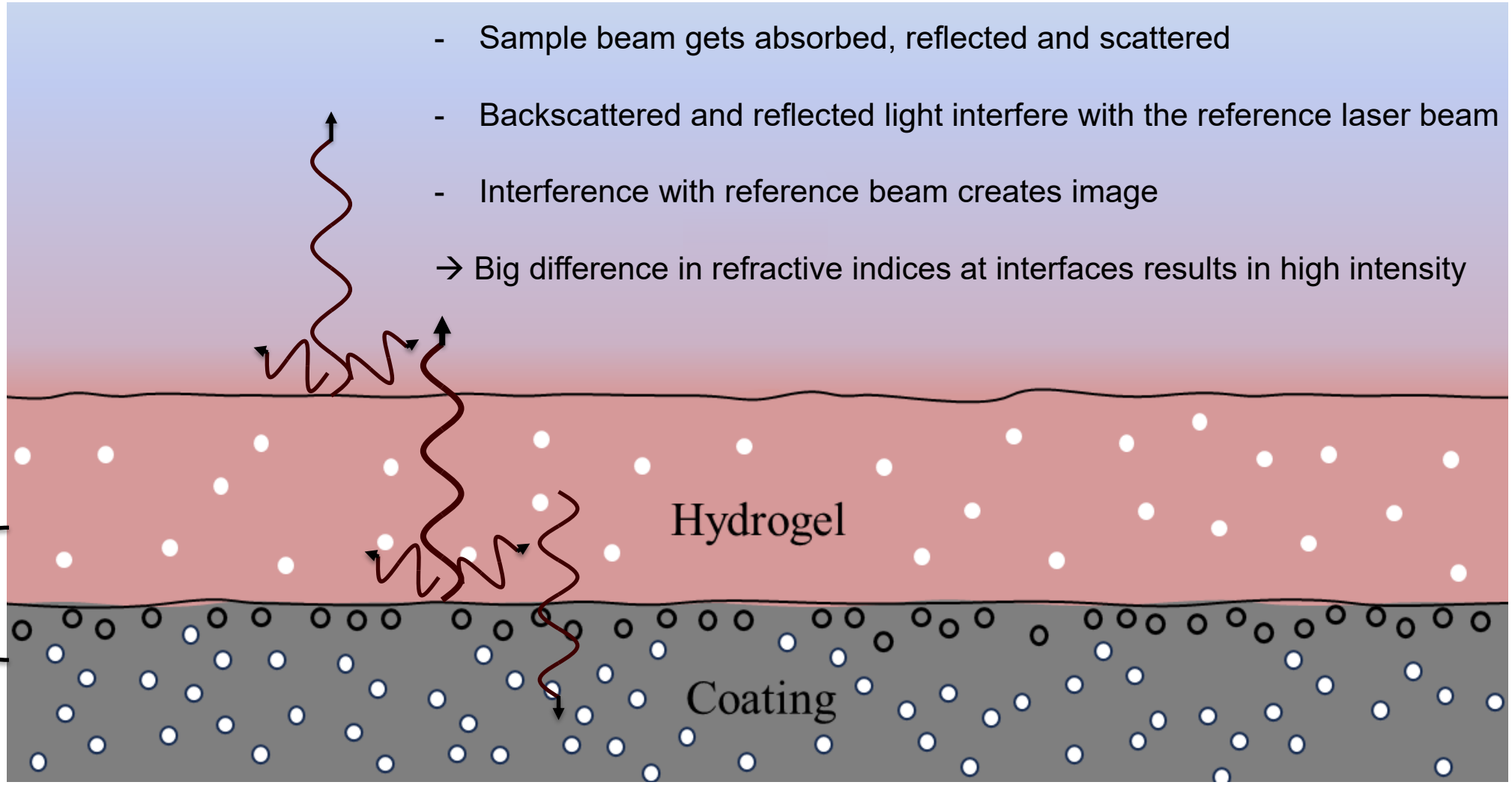
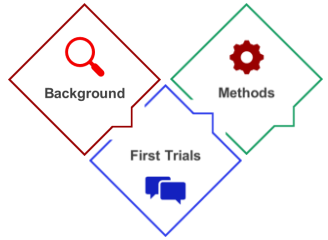


Δ n is big = strong signal

Methods – Optical Coherence Tomography (OCT)



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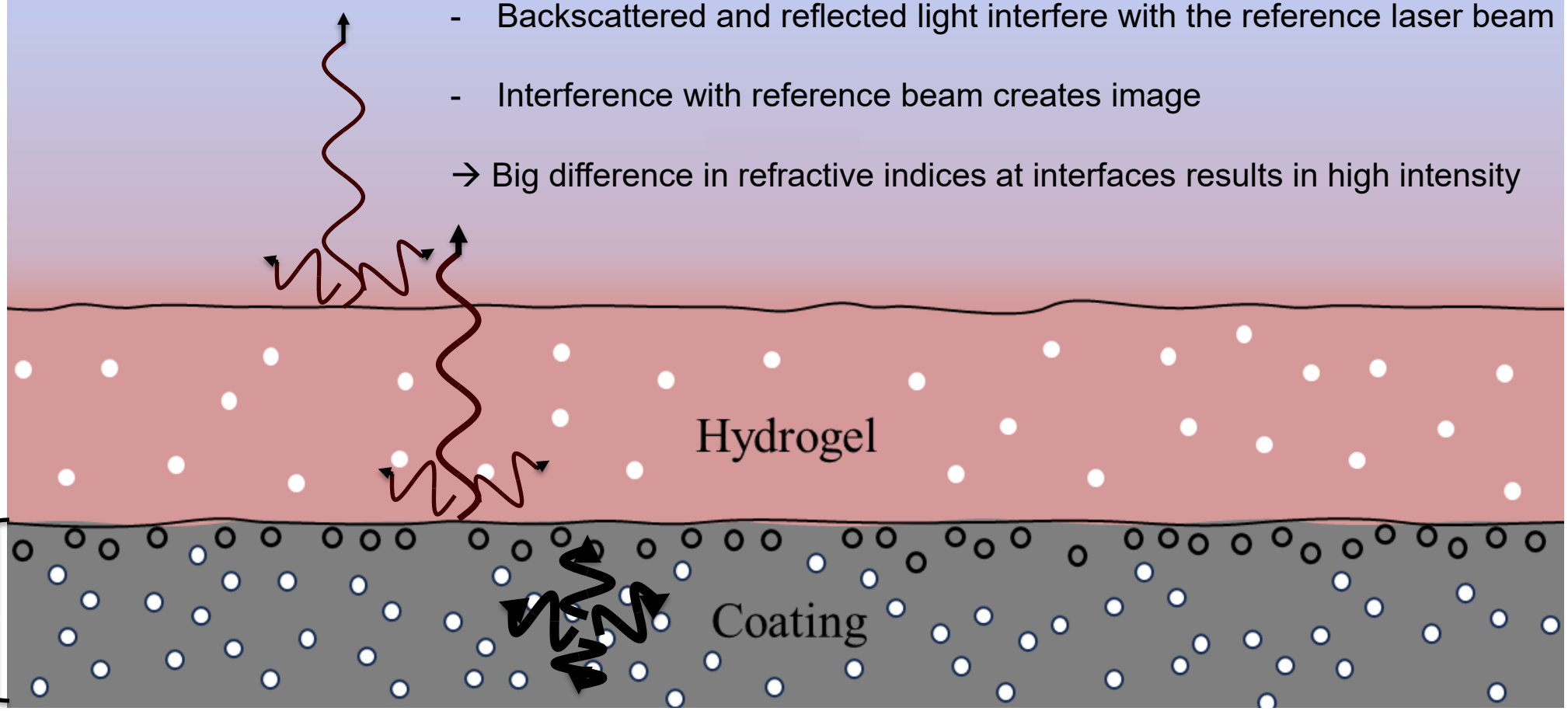
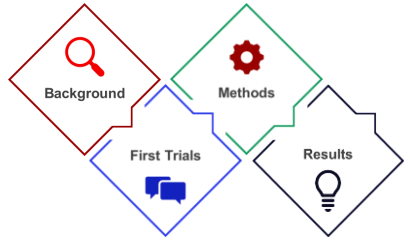
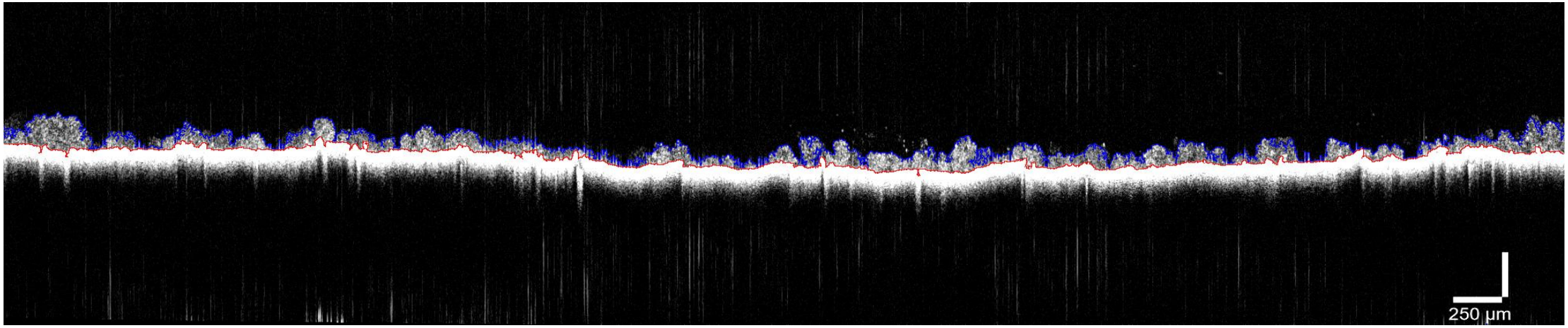


Strongly scattering pigments = no depth resolution


Results

Results

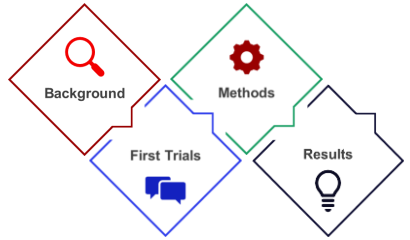




Quantification of hydrogel parameter with **B-Scans** on different spots on panel

Detection of **interfaces**, short wavelength **smoothing** and XZ **coordinate extraction** with ImageJ

Results

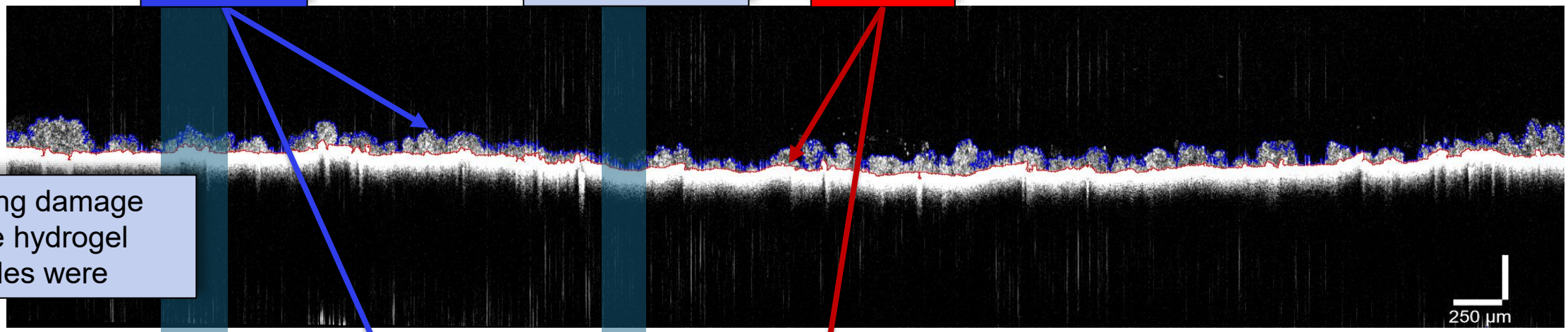


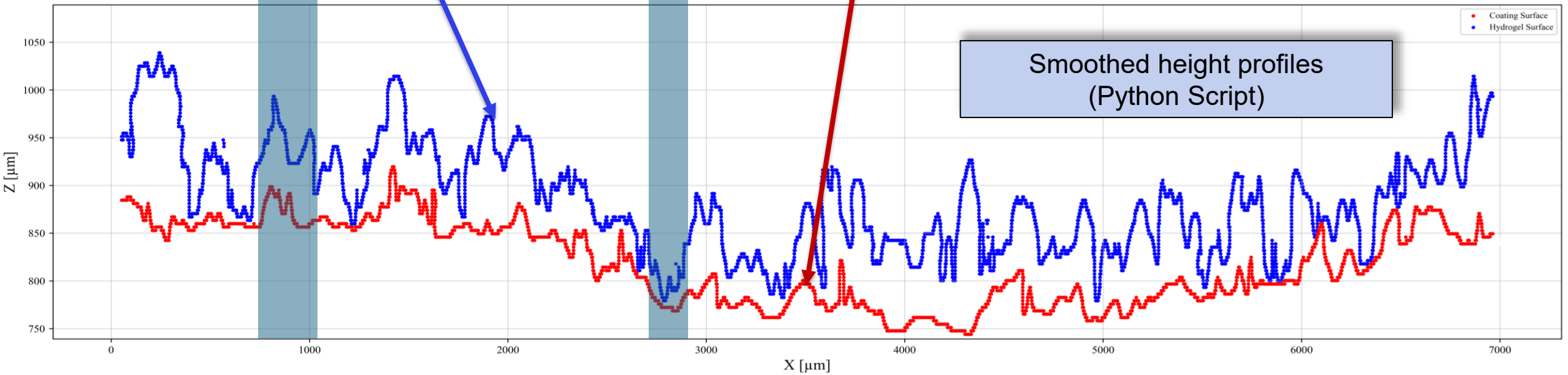
Hydrogel

No gel on coating

Coating

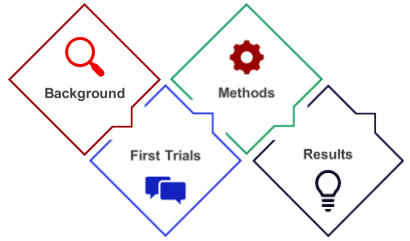
Coating damage where hydrogel particles were



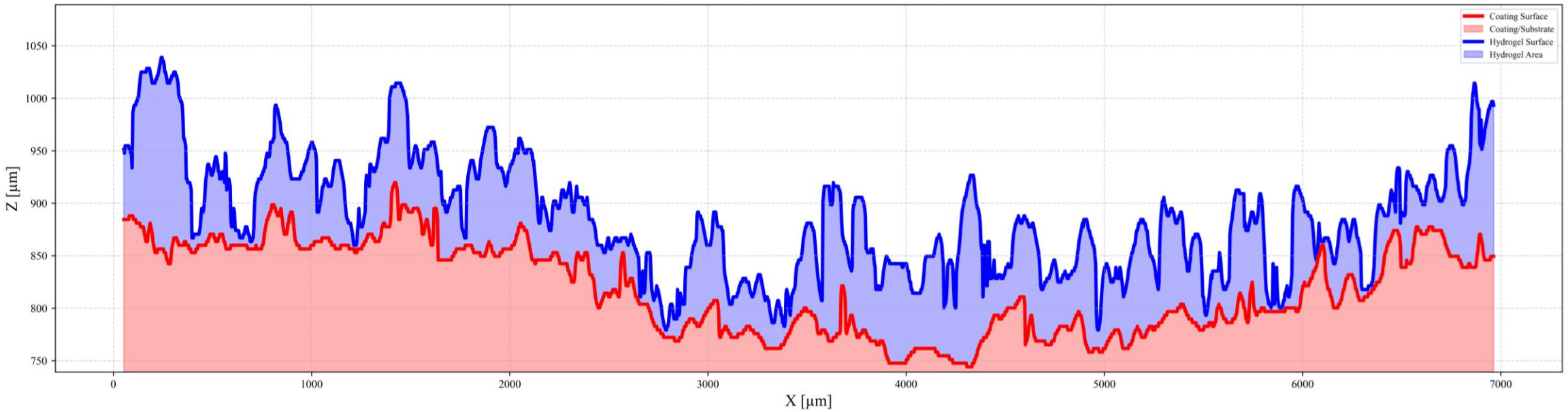


Smoothed height profiles (Python Script)

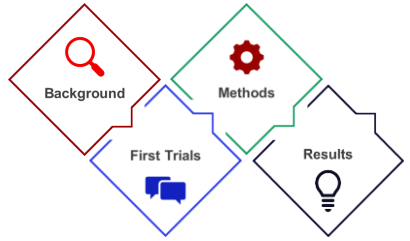
Results – Filled overhangs



Height profiles with filled overhangs (more than one Z-coordinates)



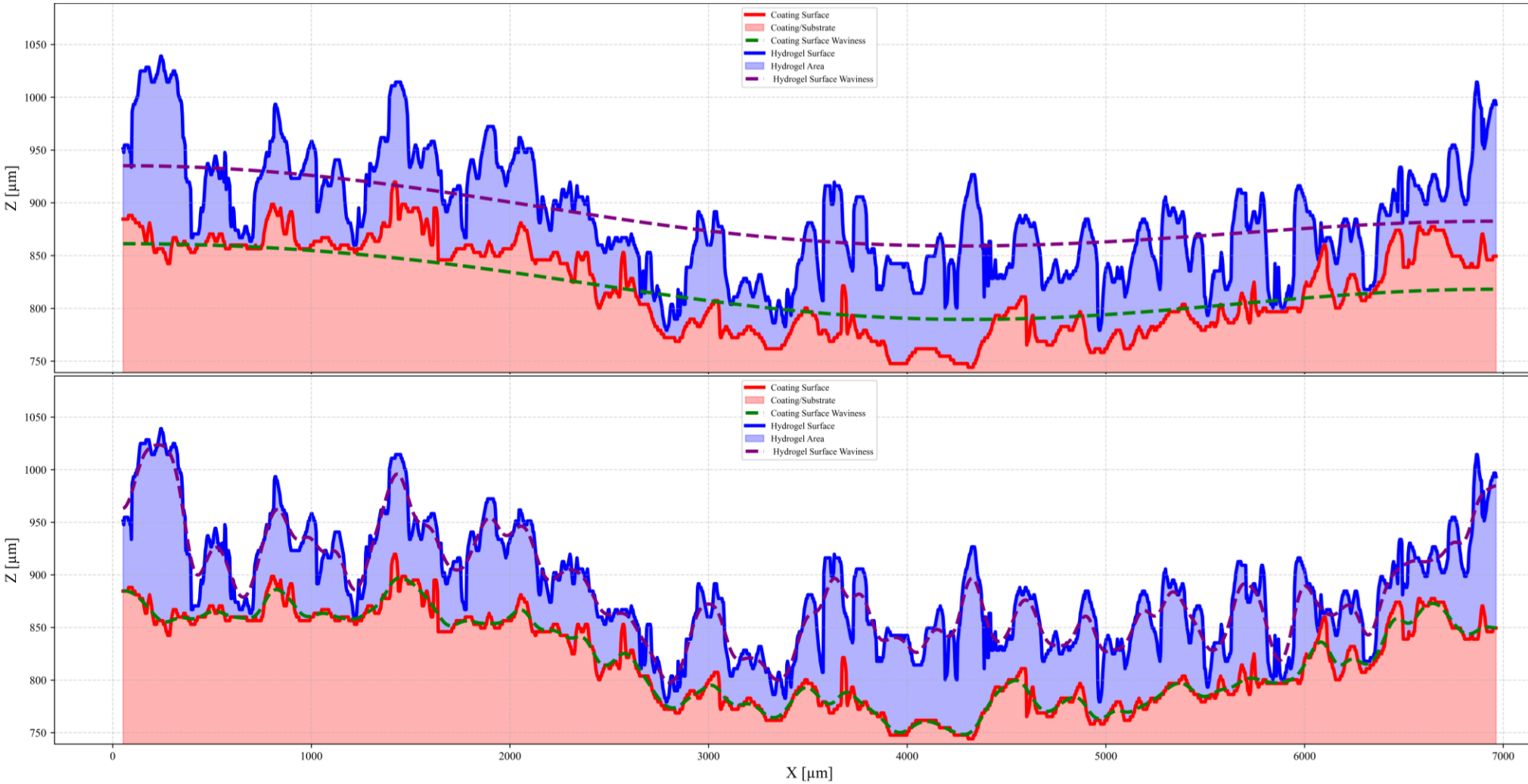
Results - Waviness correction



Waviness cut-off wavelength:

8.0 mm

0.25 mm



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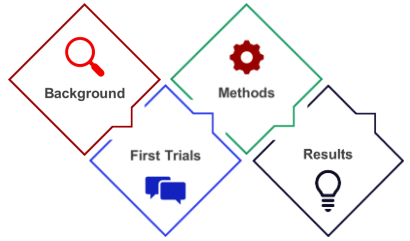


8.0 mm

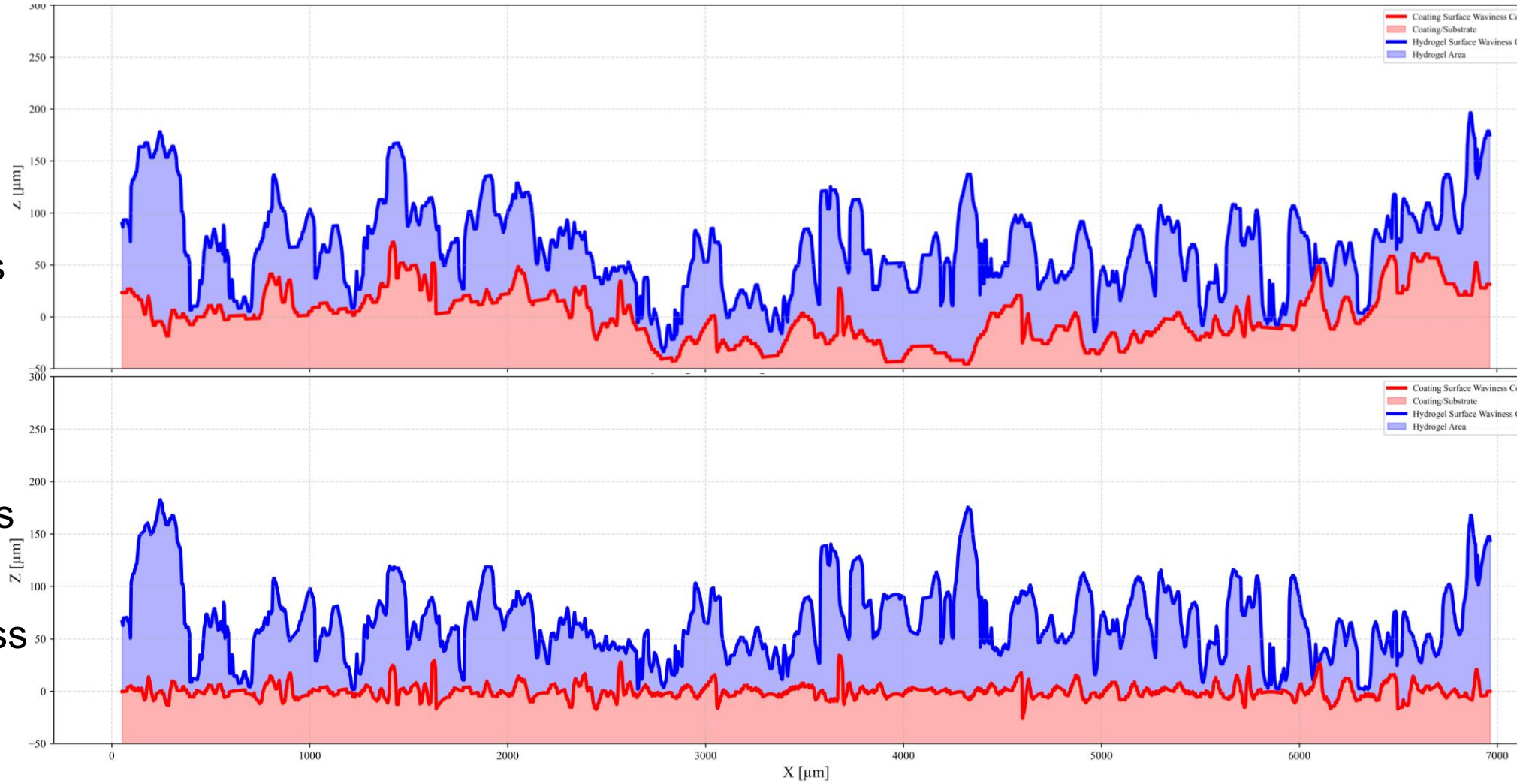
→ Coating Waviness
W_q: 24.0 µm

→ Coating roughness
R_q: 24.8 µm

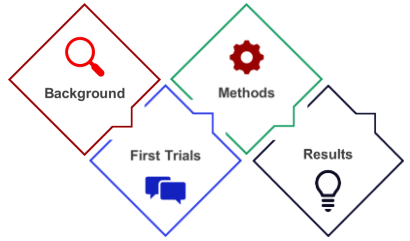
0.25 mm

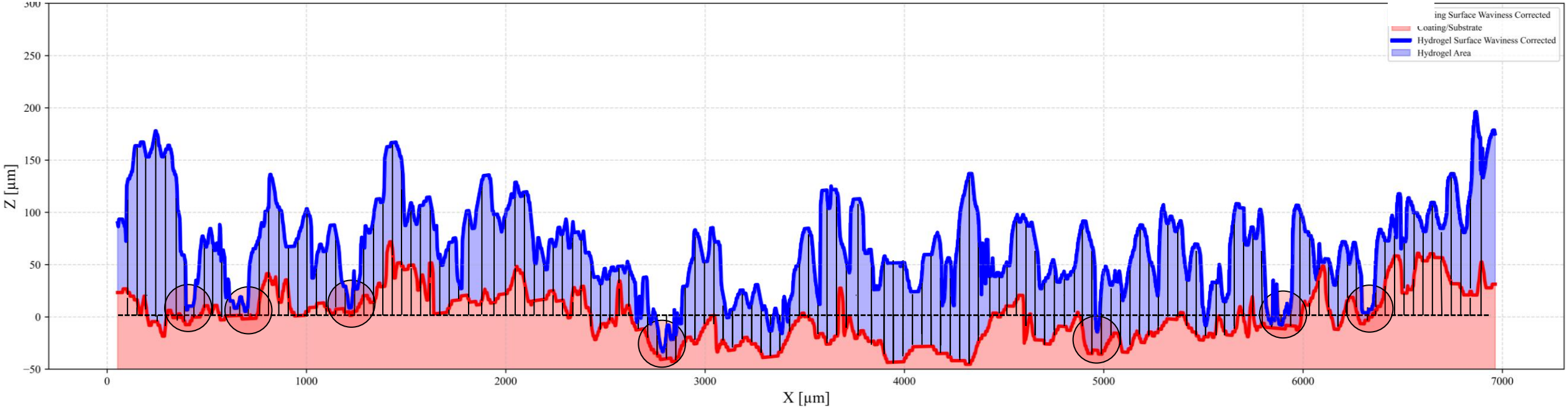
→ Coating Waviness
W_q: 41.5 µm

→ Coating roughness
R_q: 6.9 µm



Results - Analysis of parameter

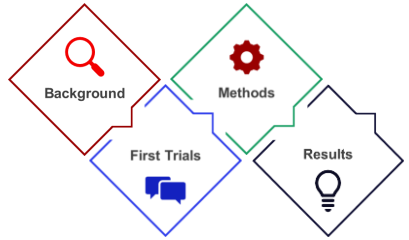




Analysis of parameter

- **Coating Roughness R_q** (Root mean square roughness) → Distance between height and base line squared for each pixel
- **Hydrogel Height Distribution & Area** → Distance between coating and hydrogel interface for each pixel
- **Hydrogel Coverage** → Coating length without hydrogel

Results

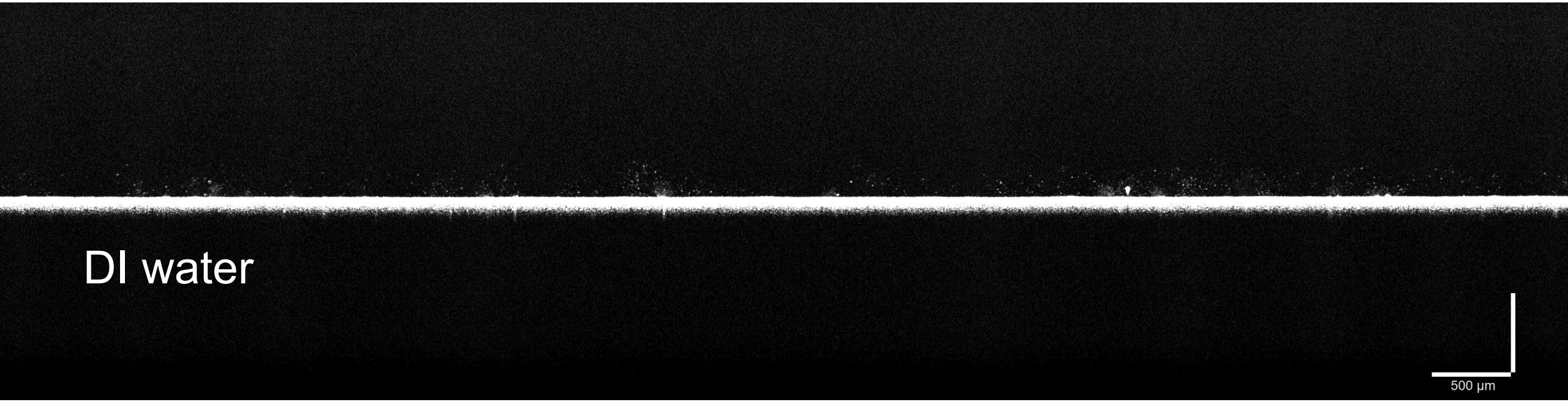


Limitations

- Hydrogel thickness **under 15 µm increases uncertainty** for quantification

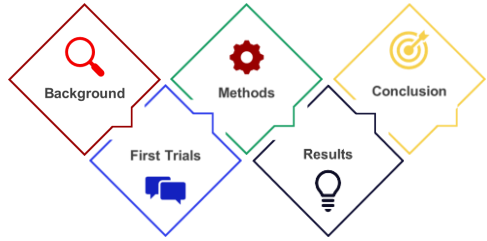
  (hydrogel/coating ImageJ workflows are conducted separately hence border detection errors add up)
- **Resolution limit** of the OCT with the given setup is around **4 µm**
- Low contrast images due growing **out of focus** with unclear interface are difficult to handle

  → E.g., hydrogel system in DI water




Conclusion

Conclusion

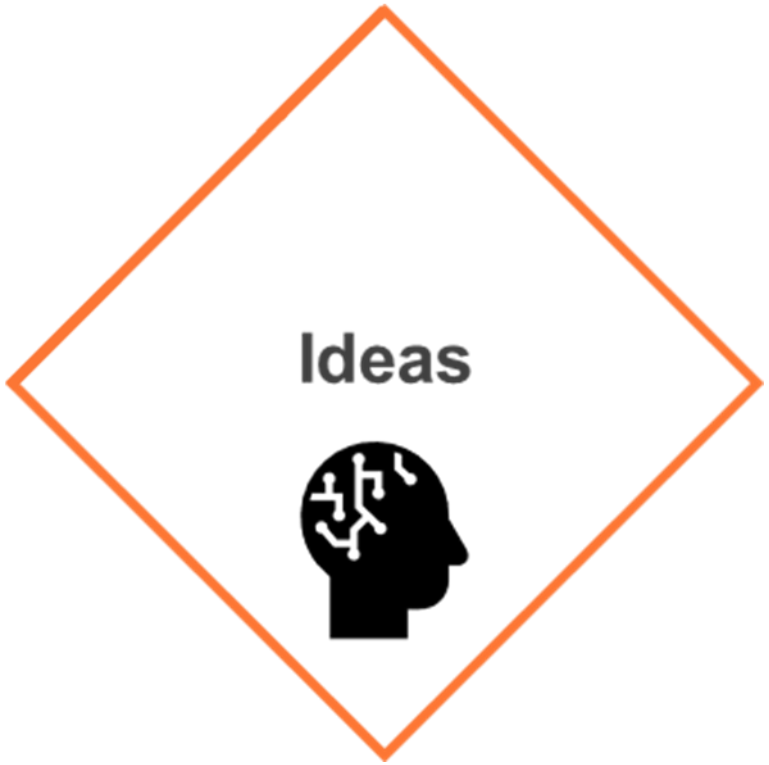


OCT visualizes gel formation process which is needed to understand and improve the hydrogel coating system

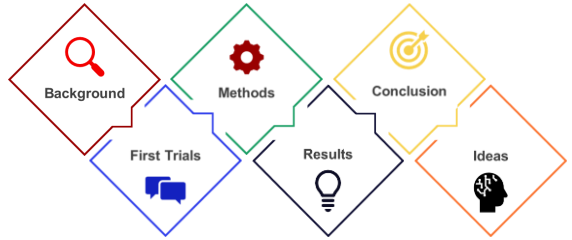
- Real-time monitoring of hydrogel systems
- Hydrogel thickness and volume
- Hydrogel coverage
- Roughness of the coating

Rheological hydrogel analysis adds value by revealing mechanical properties

- Together, these methods provide robust characterization of hydrogels and can be applied to other systems

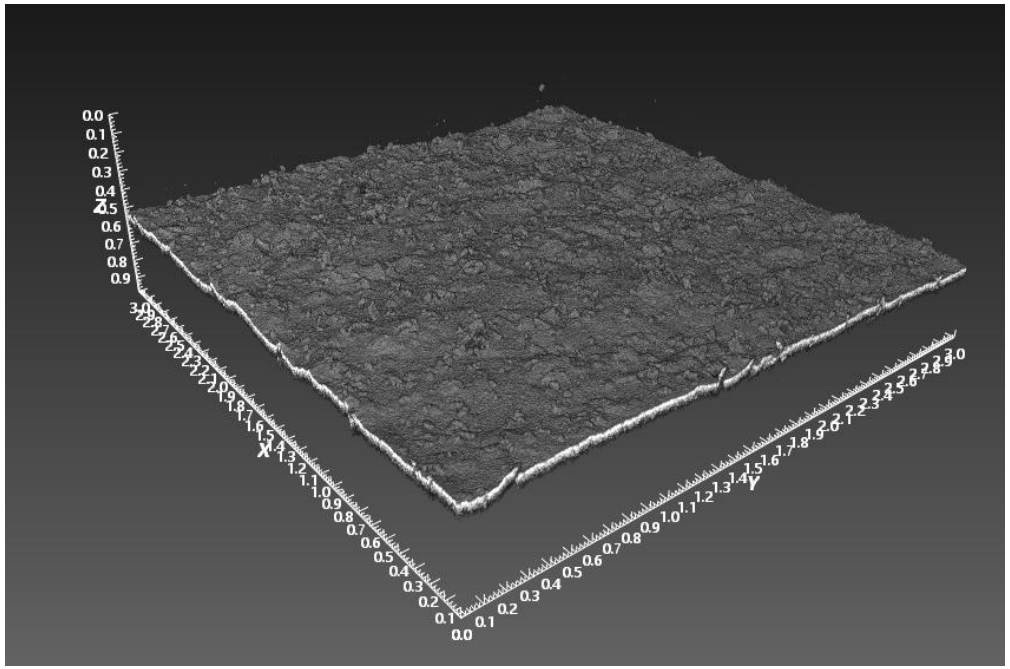

Ideas

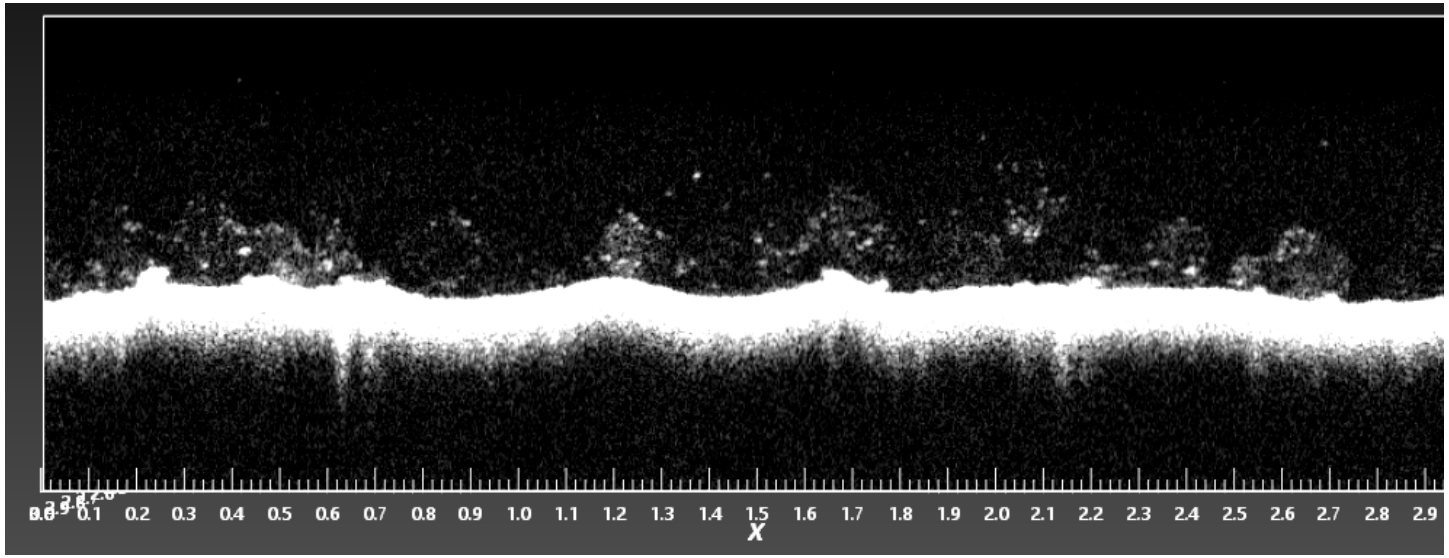
Ideas

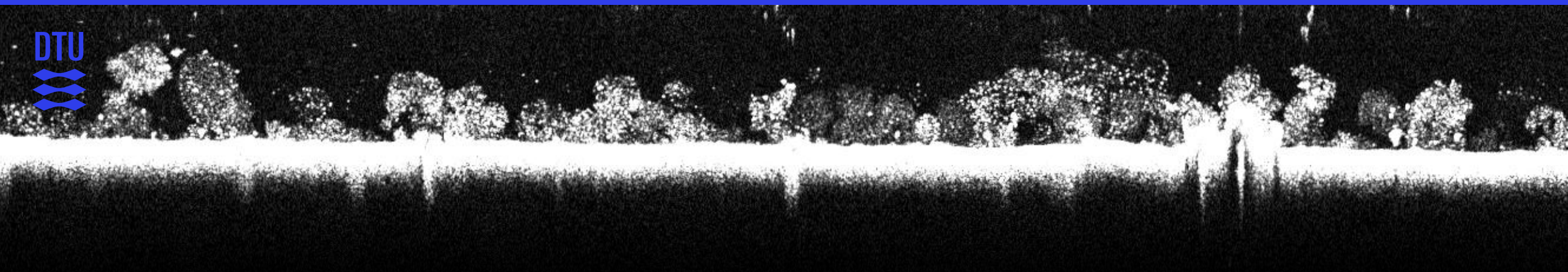


Process Optimization

- Quantify overhang structures
- Refining coating/hydrogel interface detection and full automation for live quantification
- Applying C-Scan analysis to be independent of homogeneity assumption across the sample







Thank You!

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