

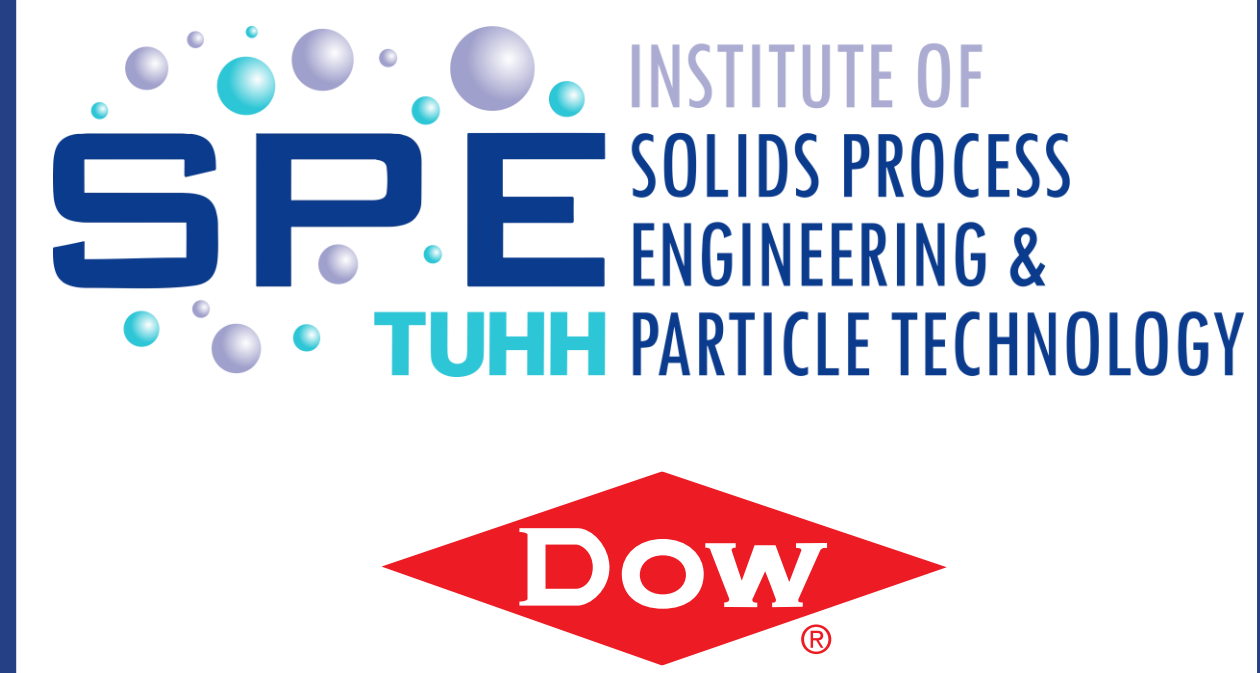
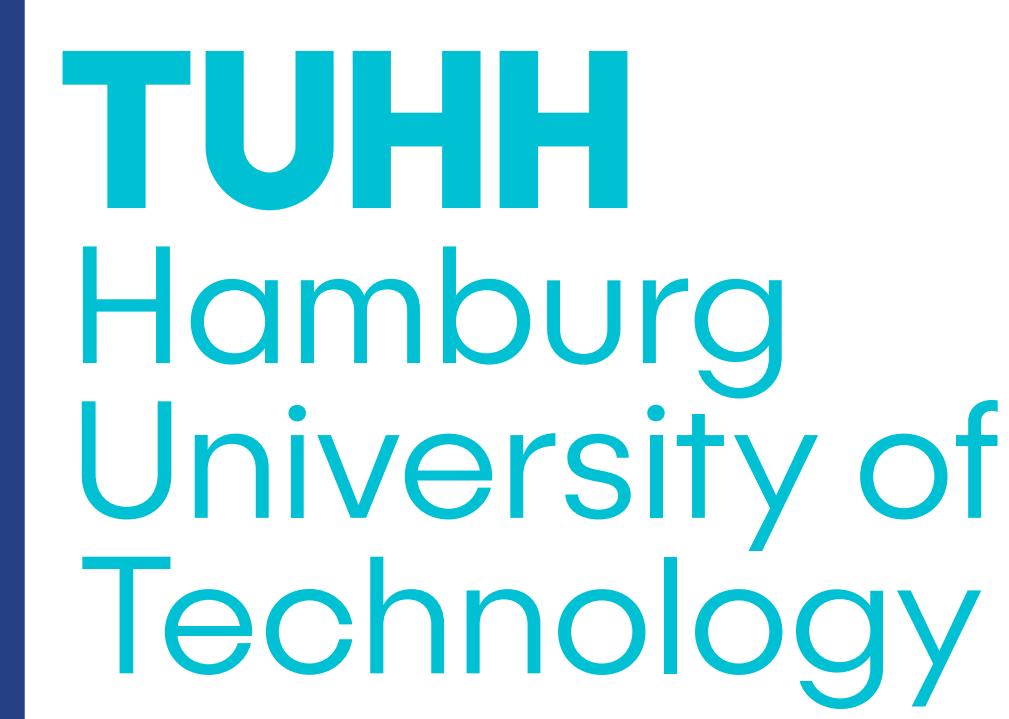
Dynamic Bubble Tracking in Fluidized Beds via Electrical Capacitance Volume Tomography

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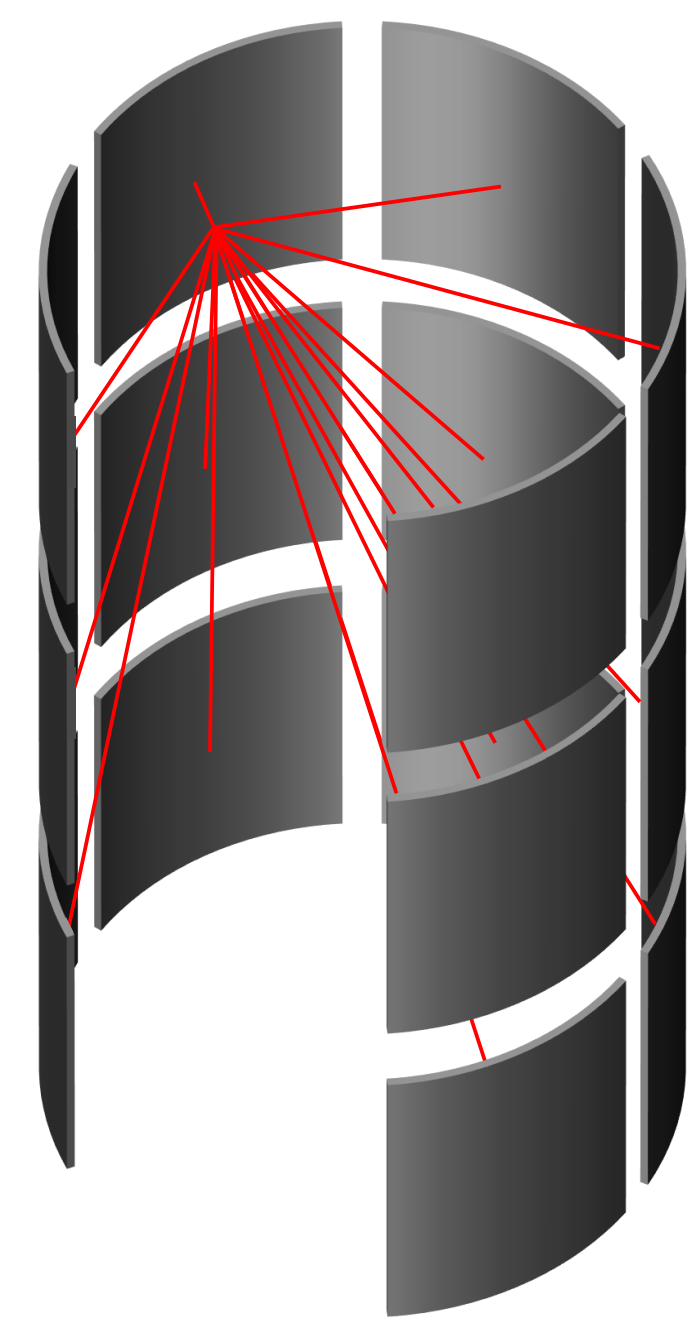


Introduction and motivation

Detailed knowledge of the dimensions and velocities of bubbles in fluidized beds is invaluable for the development and validation of correlations and CFD-DEM simulations of phenomena in fluidized bed systems. Invasive measurement methods like two-electrode capacitance are well established; however, they usually only provide one dimensional data. To avoid the issues associated with invasive techniques while also increasing the dimensionality, electrical capacitance volume tomography (ECVT) was developed.

This work sets forth the development of a novel, dynamic bubble detection algorithm for use with ECVT sensors for bubbling fluidized beds. The so-called *3D Fluxion* phase detection method was developed to address the shortcomings of other published methods by more fully utilizing the three-dimensional capability of the sensors.

This new method should also identify defined phases (bubbles, slugs, clusters) in three dimensions across all fluidization regimes (e.g., bubbling or turbulent) and particle classes.



ECVT principle

Rings of electrodes around fluidized bed

Capacitance proportional to solids content
→ Produces 3D solids content distributions

Soft-field technique
→ Accuracy and precision dependent on measurement position

Fig. Interaction of ECVT sensor plates at one position

ECVT Phase detection methods

New *3D Fluxion* phase detection approach uses full 3D potential of ECVT.

Detection Method	Invariant	Iterative Axial	3D Fluxion
Found in literature	most common	Agrawal et al. ^[1]	new
Single threshold for	all voxels	each radial cross section	each voxel
Accounts for soft-field nature of sensor	no	partly	partly
Detects multiple bubbles per cross section	no	no	yes
Applicable for cluster detection in a CFB	no	no	yes

[1] Agrawal V, et al. (2018). Estimation of Bubble Properties in BFB Using ECVT Measurements. Ind. Eng. Chem

Experimental setup

Bubbling Fluidized Bed

10 cm inner diameter
1 m height
Porous distributor plate
30 cm bed height

ECVT Sensor

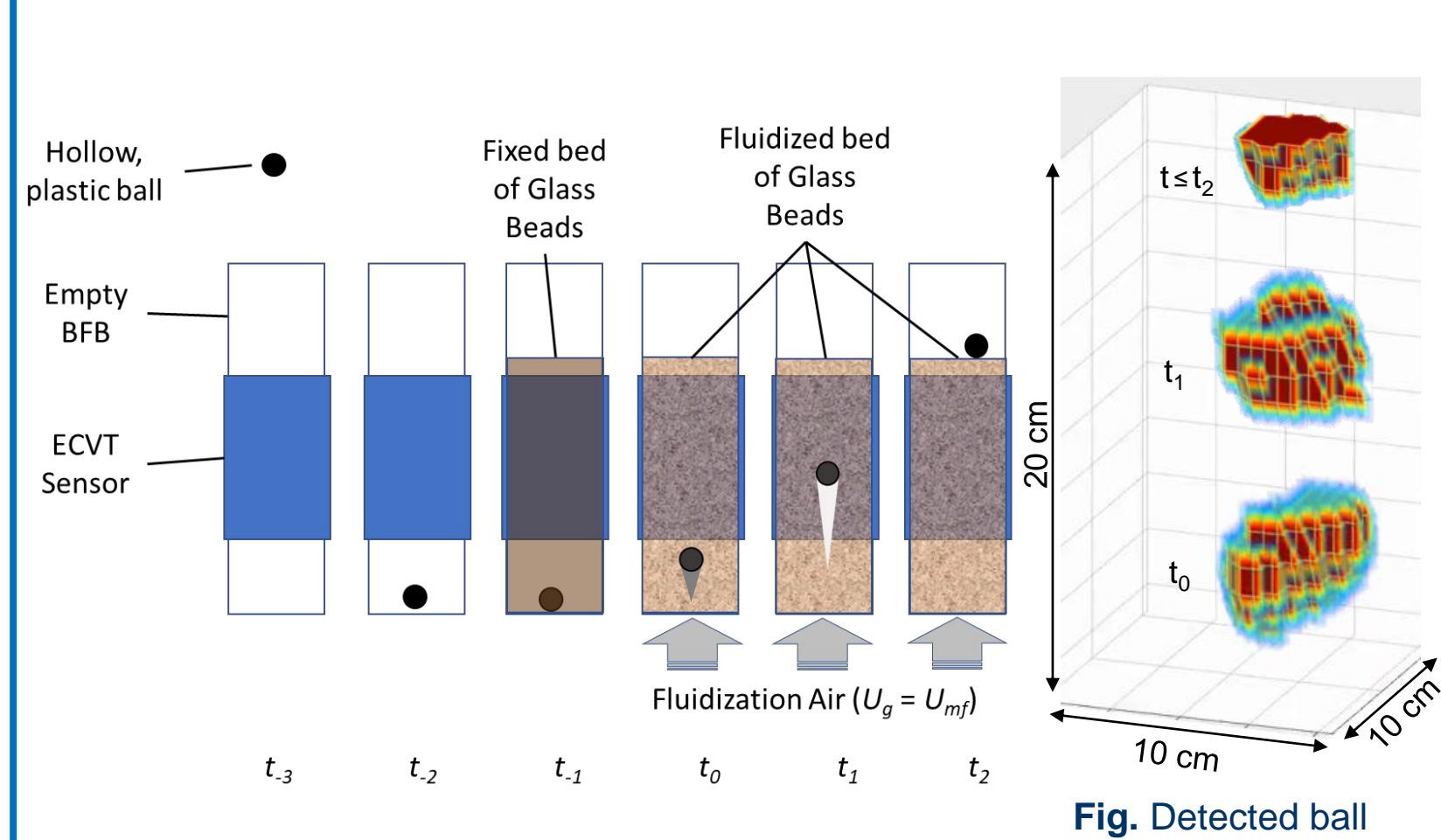
Model 4RD Cold Flow by Tech4Imaging
24 electrodes
4 axial, staggered rows
 $d_i = 110$ mm, $h = 215$ mm

Reconstructed images:
8000 voxels
(20×20×20 array)
5.5 mm×5.5 mm×11 mm
(length, width, height)



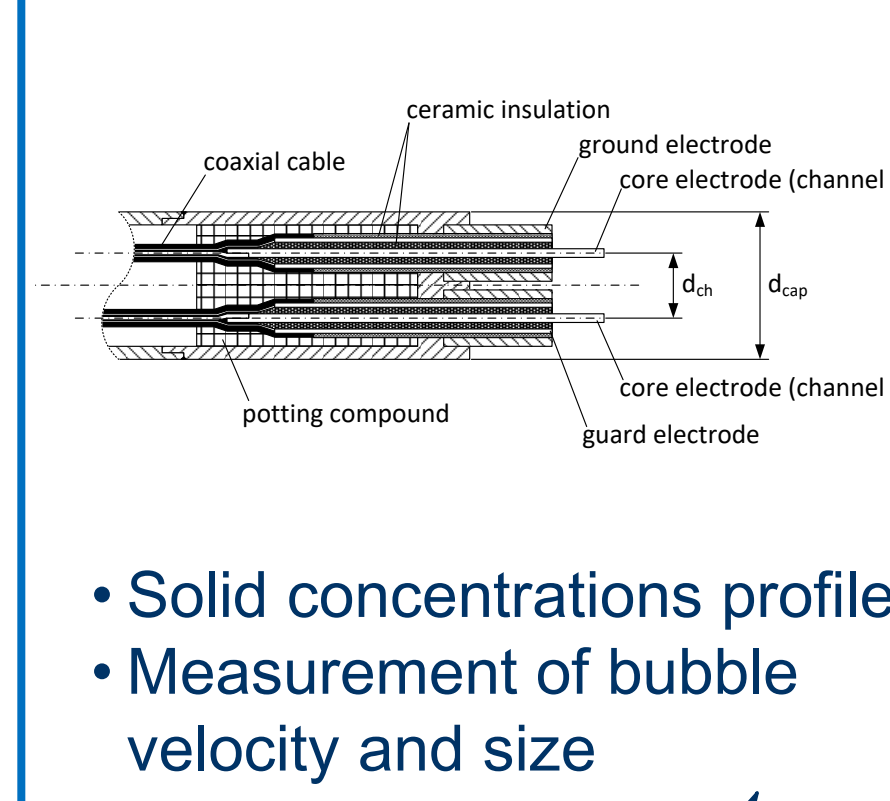
Fig. Experimental setup

Hollow plastic ball



- Plastic ball detected
- Diameter larger due to air around ball

Capacitance probe



- Solid concentrations profile
- Measurement of bubble velocity and size

Validation + parameter optimization of new bubble detection method

Virtual bubbles

Bubbles as step function

- Simple
- Sharp transition

Smooth bubbles:

- Closer to real bubble:
- Concentration gradient (Gaussian function)
- Background noise

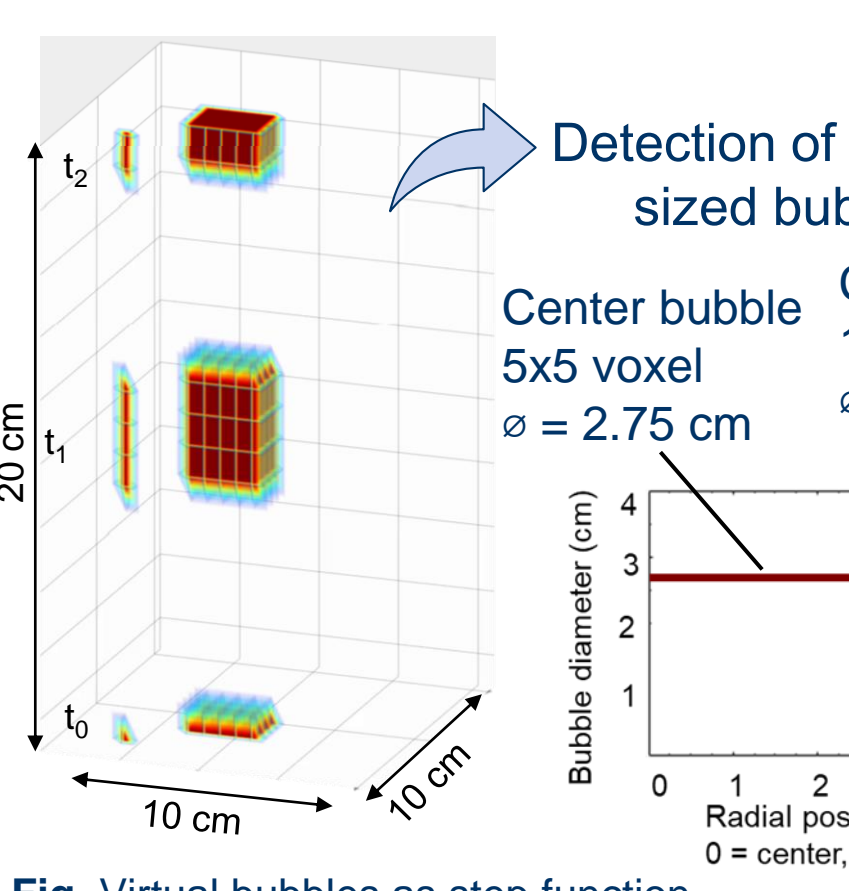


Fig. Virtual bubbles as step function

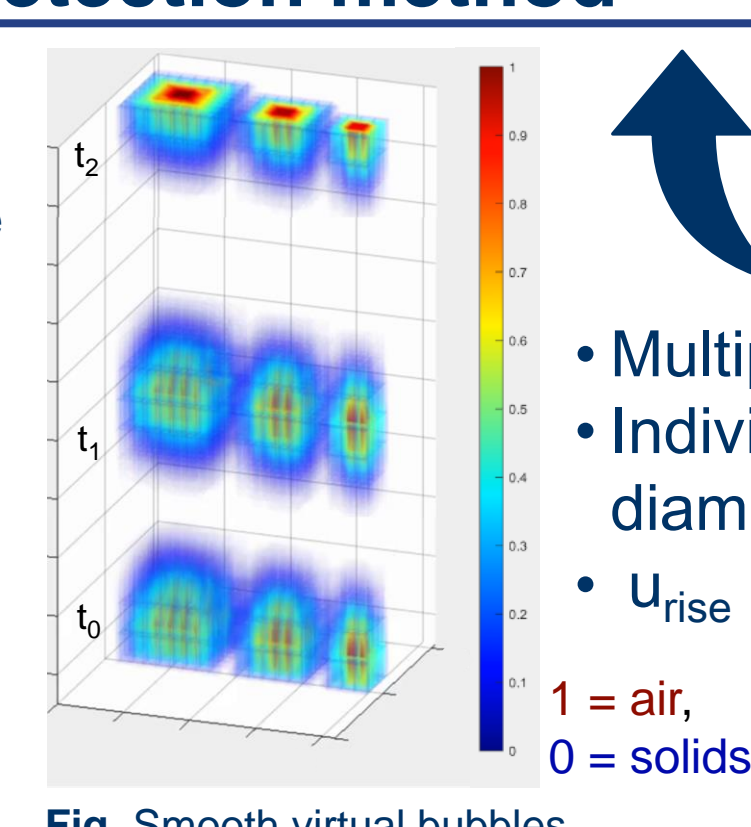


Fig. Smooth virtual bubbles

- Multiple bubbles seen
- Individual and average diameter correct
- U_{rise} correct

Materials

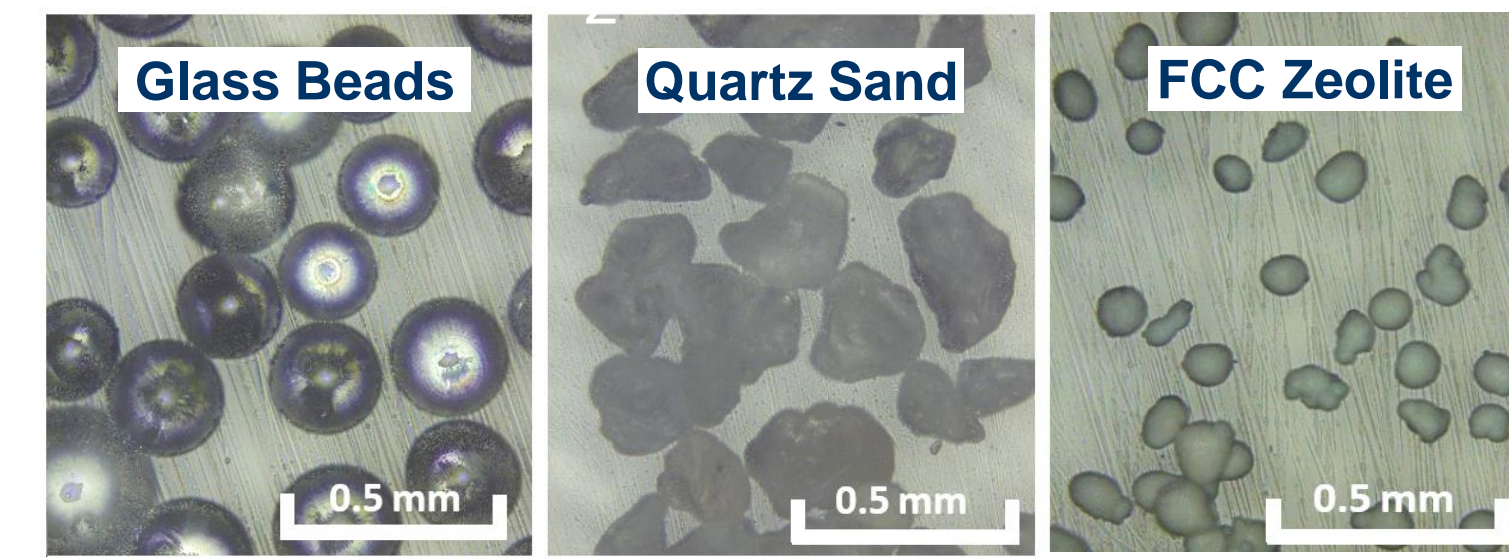


Fig: Microscopy of used particles

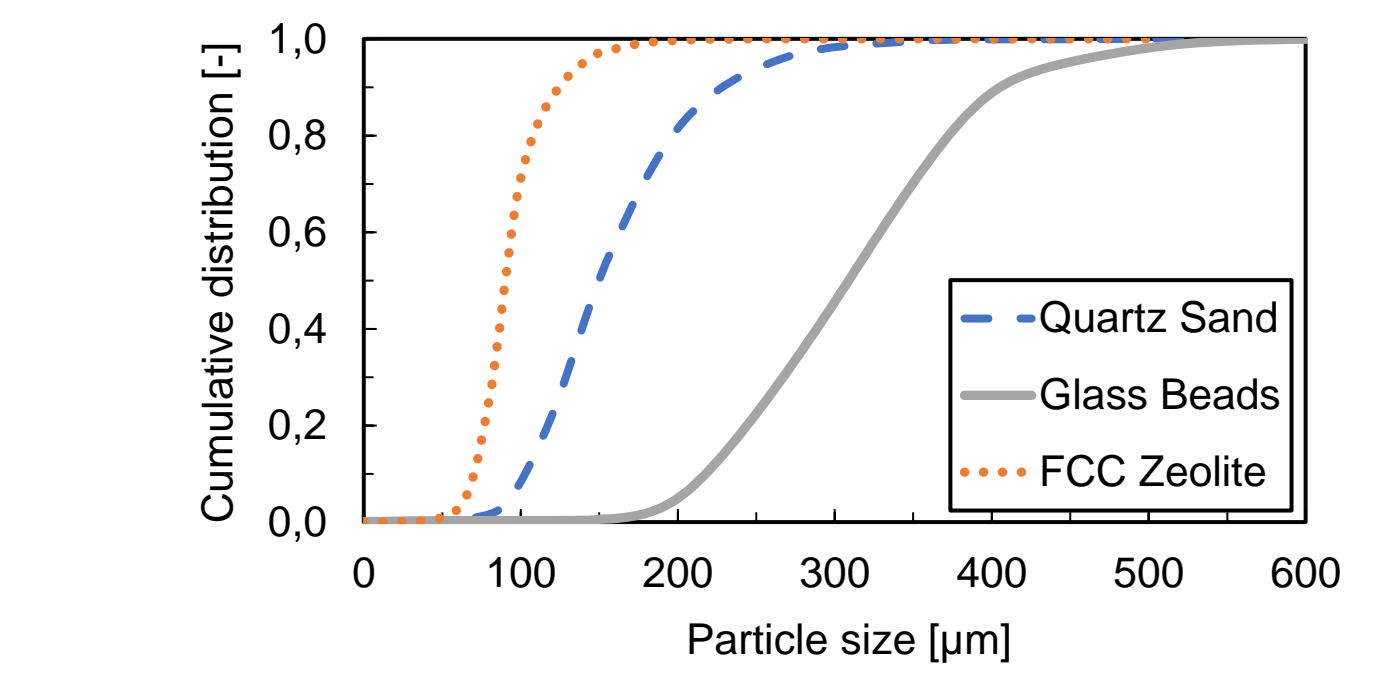


Fig. Particle size distribution of the used materials

Property	Glass Beads	Quartz Sand	FCC y-zeolite
Sauter diameter (μm)	263	189	91
Sphericity (-)	0.94	0.79	0.89
Min. fluid. velocity (cm/s)	7.0	3.8	0.4

New phase detection method

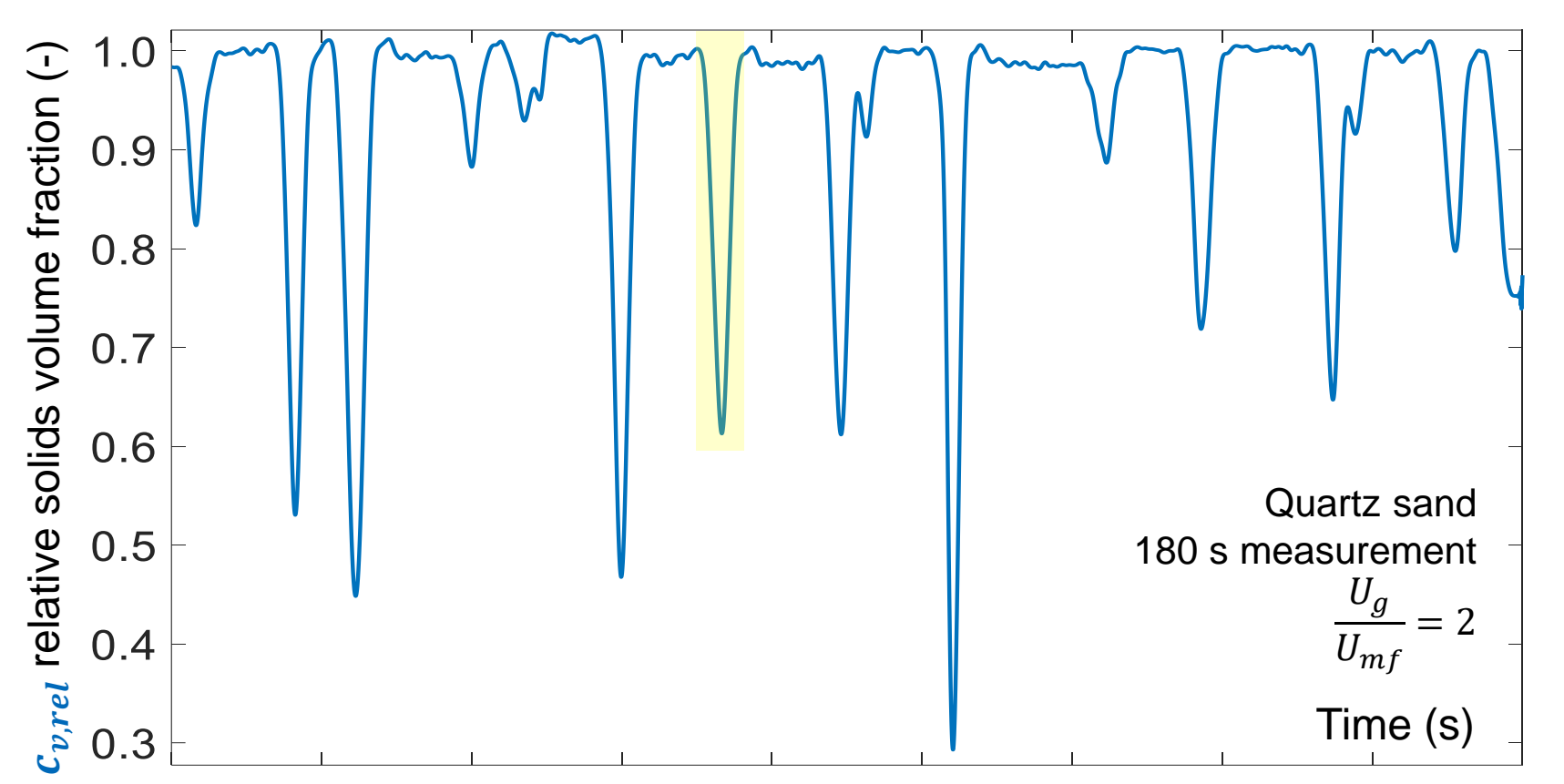


Fig: Temporal relative solids volume fraction $c_{v,rel}$ of a single voxel. Peaks show bubbles passing. Orange: Example bubble

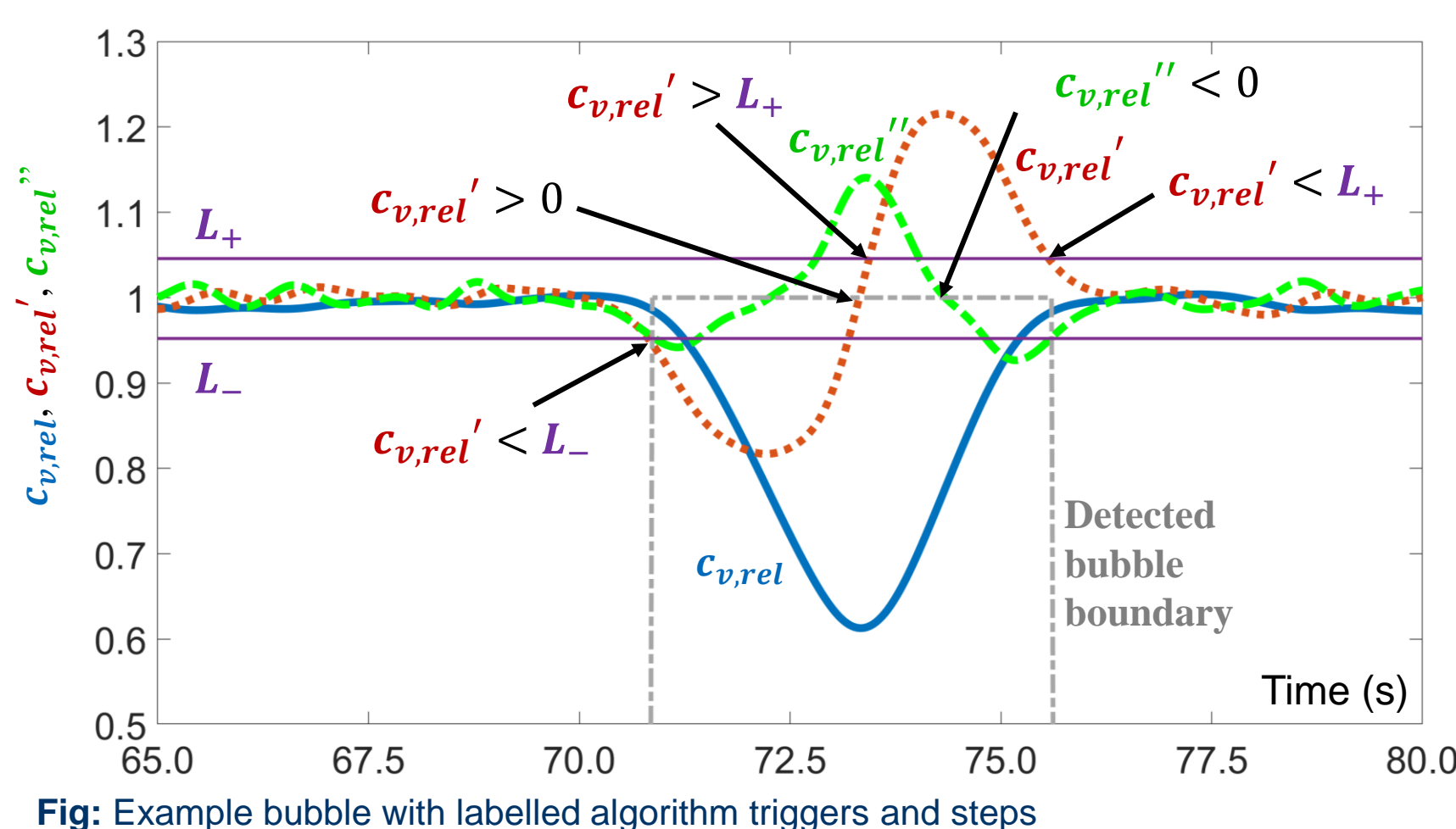


Fig: Example bubble with labelled algorithm triggers and steps

Bubble entry detected at steep decline of $c_{v,rel}$ ($c_{v,rel}' < L_-$)

Four successive steps required for bubble exit detection ($c_{v,rel}' > 0$) → ($c_{v,rel}' > L_+$) → ($c_{v,rel}'' < 0$) → ($c_{v,rel}' < L_+$)

Bubble boundary more accurately detected.

Boundary closer to true emulsion phase.

Bubble rise velocity

Direct axial bubble rise velocity method:

- Utilizes previous bubble definition
- Calculates rise velocity for every voxel

$$u_{bubble} = \frac{\Delta h}{t_R} = \frac{h_b - h_v}{t_3 - t_2}$$

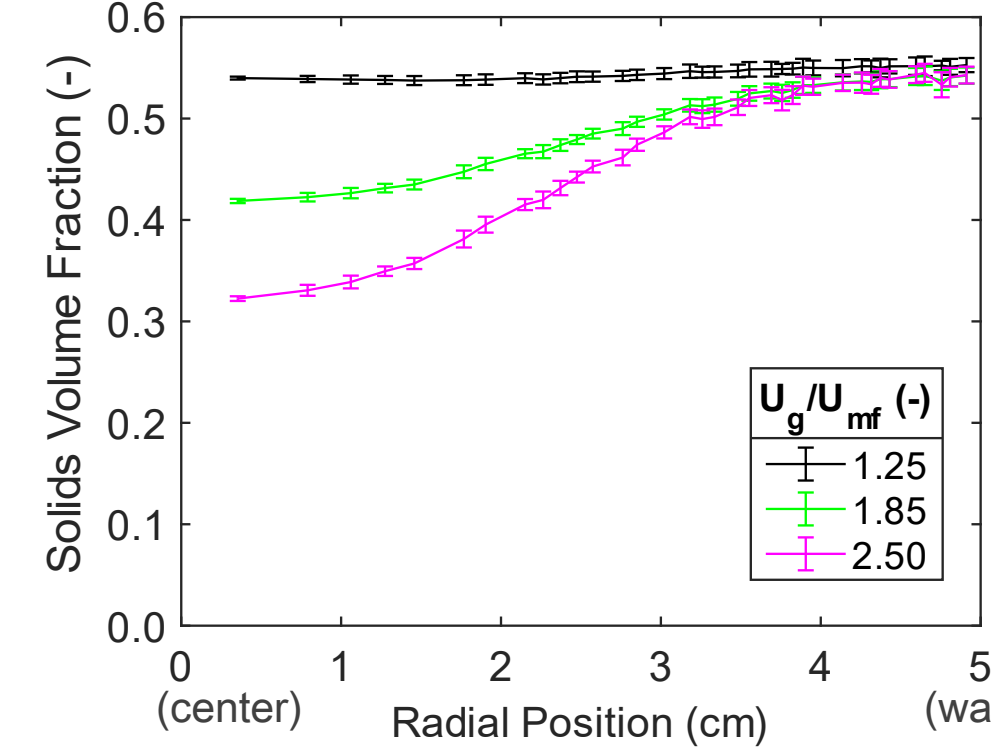
h_b : axial bubble length
 h_v : height of voxel
 t_r : bubble residence time (per voxel)

Fig: Bubble (blue) rising through single voxel

Experimental results from one measurement (glass beads)

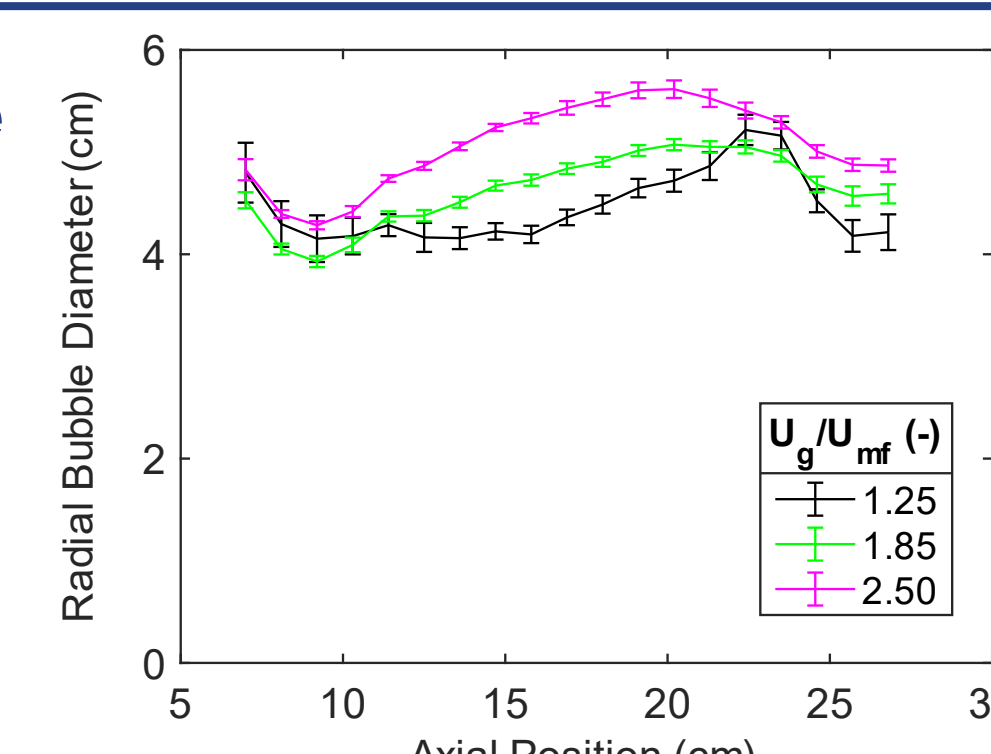
Radial profiles of solids concentration

- Low solids at center and high airflow
- 7x more data points than previous work^[1] due to voxel-by-voxel analysis



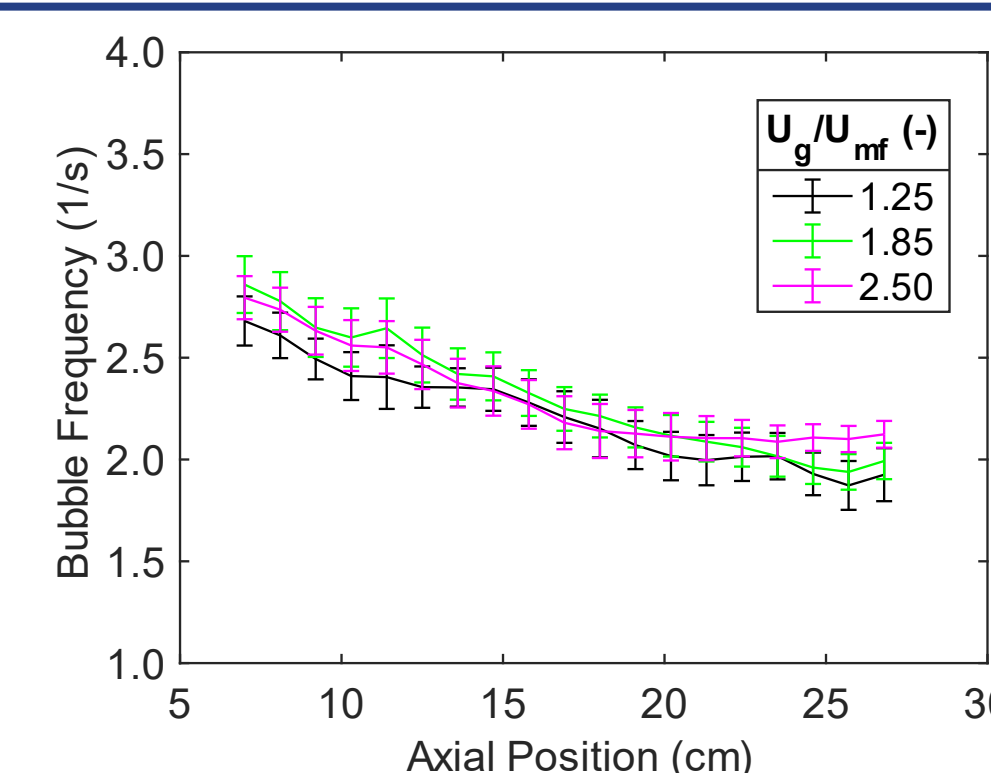
Axial profiles of radial bubble diameter

- Increasing bubble size with airflow
- Axial position of maximum bubble diameter decreases with increasing airflow



Bubble frequency

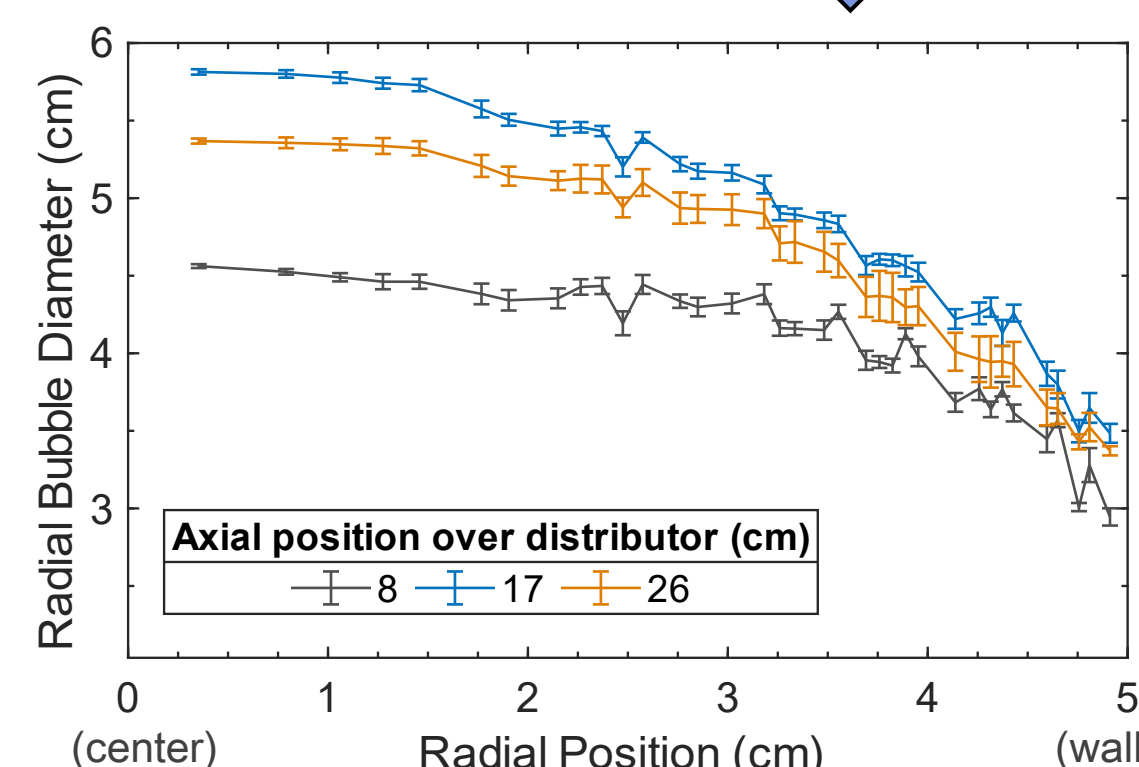
- Linear decrease with increasing axial position due to increased bubble coalescence



Properties obtained from one ECVT measurement with new phase detection method.

Bubble property	Published before ^[1]	
	Axial	Radial
Solids volume fraction	yes	yes
Radial diameter	yes	NEW
Axial length	yes	NEW
Residence time	yes	-
Rise velocity	yes	-
Frequency	yes	-

- No wide bubbles at wall
- Radial bubble coalescence yields wider bubbles at center
- Maximum diameter not at the highest position → bubble splitting (also seen with sand and FCC)



Easy tool for 3D tomographic evaluation of bubbles in fluidized bed.

Project partners

The authors would like to thank The Dow Chemical Company for funding the project and the University of Michigan for the cooperation.

Download the pdf of the poster here



Outlook

Comparison and validation of ECVT methods for bubble detection with Magnetic Resonance Imaging (MRI).

Measurement of zeolite clusters in an 8 m circulating fluidized bed riser with ECVT and endoscopic Particle Image Velocimetry (PIV) system.

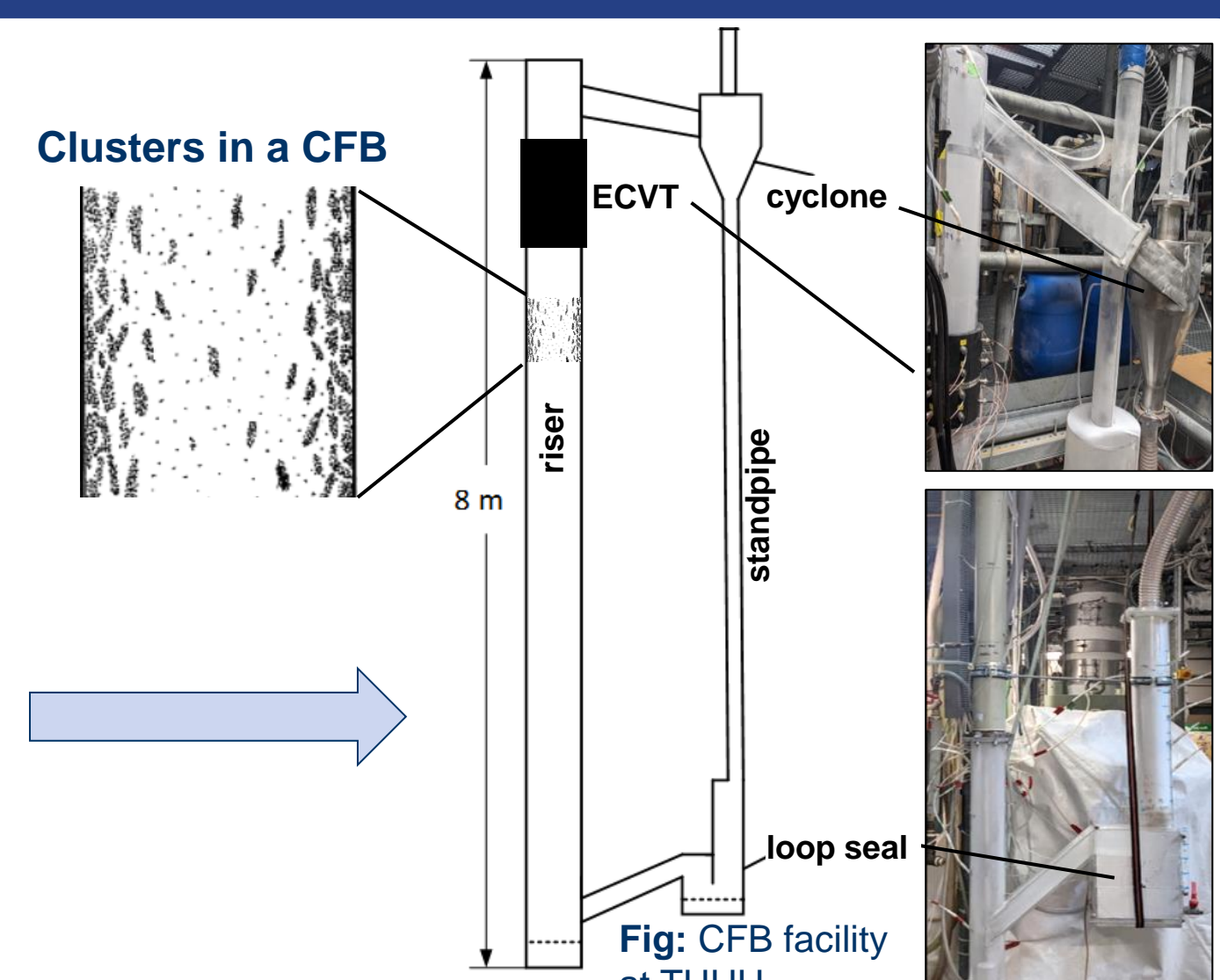


Fig: CFB facility at TUHH