



Applying Ray Tracing Based Reconstruction to Particle Image Velocimetry Measurements of Gaseous Flow in Packed Beds

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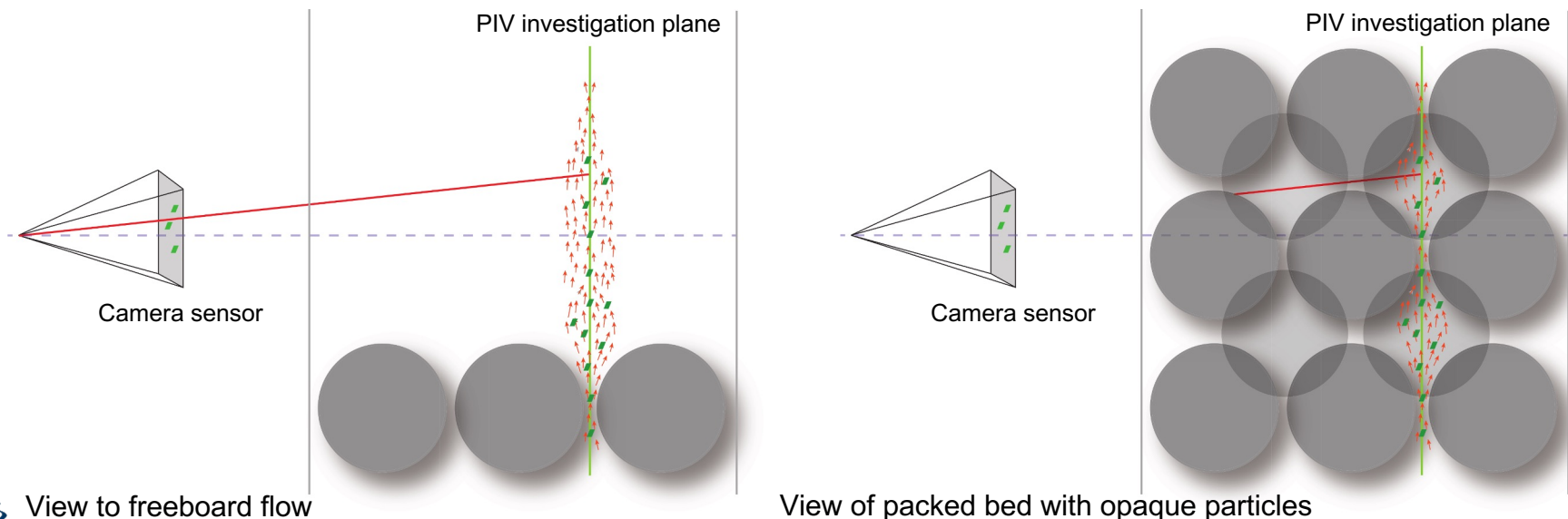
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Introduction

Flow field measurement in packed beds

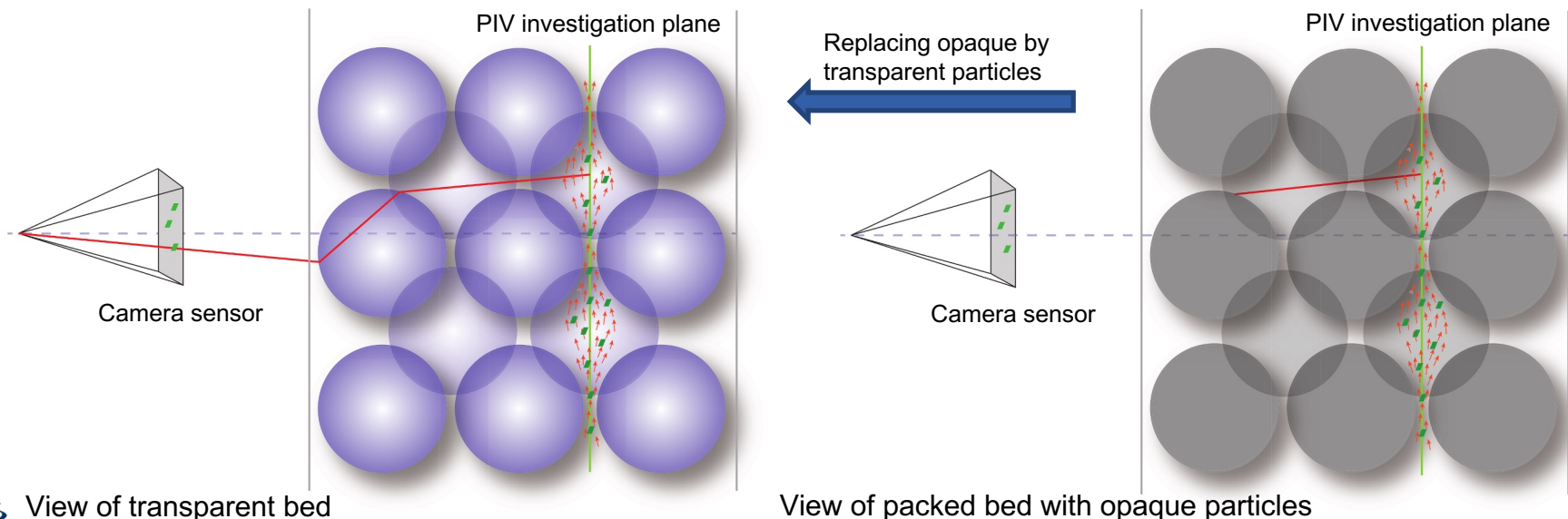
- Gaseous flow strongly impacts on processes inside packed beds: heat and mass transfer, turbulence
- Intrusive measurement methods change the flow field



Introduction

Flow field measurement in packed beds

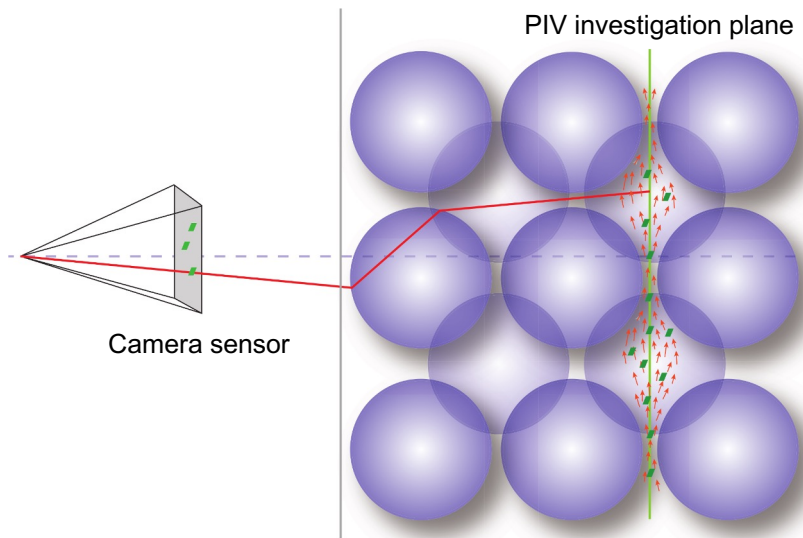
- Gaseous flow strongly impacts on processes inside packed beds: heat and mass transfer, turbulence
- Intrusive measurement methods change the flow field
- Transparent geometries for optical measurement techniques introduce distortions
→ Incorrect results e.g. for velocity calculation via PIV



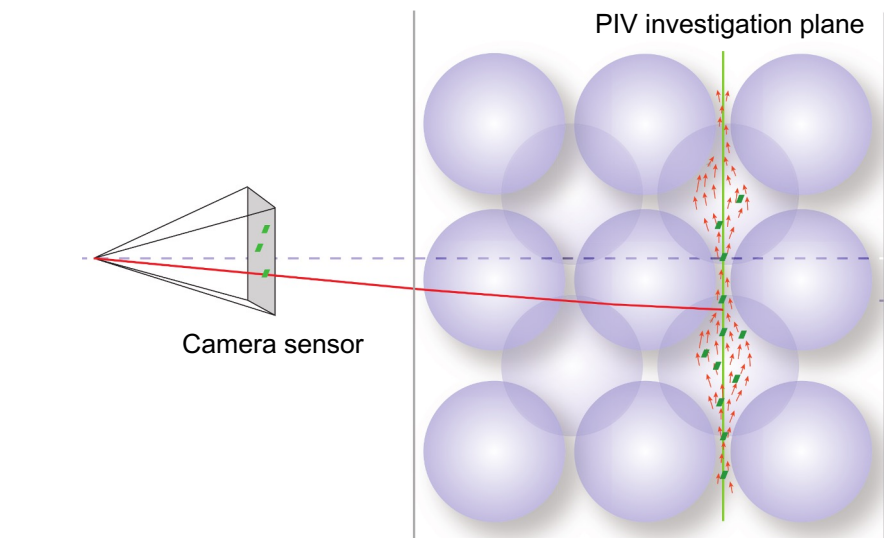
Introduction

Flow field measurement in packed beds

- Gaseous flow strongly impacts on processes inside packed beds: heat and mass transfer, turbulence
 - Intrusive measurement methods change the flow field
 - Transparent geometries for optical measurement techniques introduce distortions
- Incorrect results e.g. for velocity calculation via PIV
- ❓ **Solution: correct distorted particle images using ray tracing**
 - ❓ **Application to more complex measurement setting**

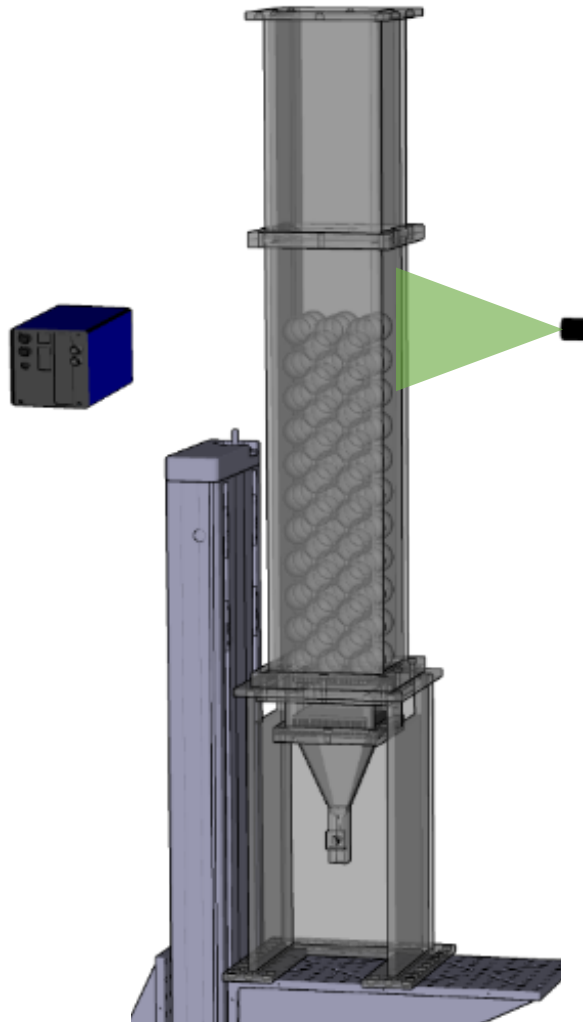


View in transparent bed



Apparent position of a particle

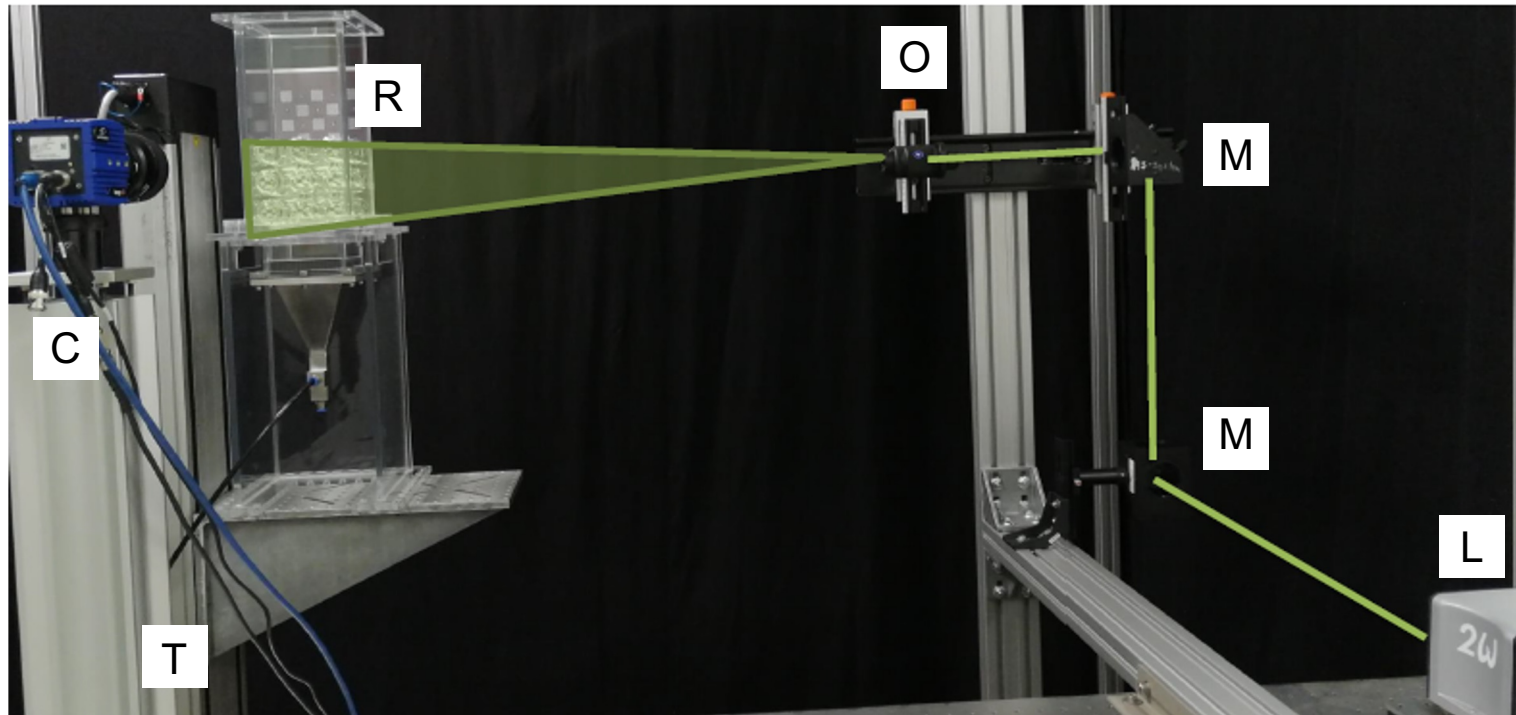
Experimental Setup



Bulk Reactor

- Optical access through transparent material (acrylic glass and N-BK7 40mm spheres as packing material)
- Body centred cubic packing (bcc)
- Flow inlet conditions defined by a diffusor, honeycombs, irregular 4mm glass sphere packing and a 4mm hole pattern

Experimental Setup

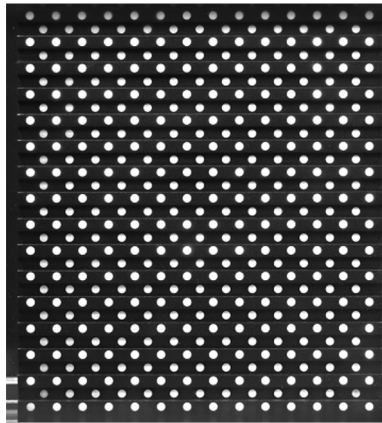


PIV Setup

R - Bulk reactor (bcc)
C - Imager LX 8M camera
L - Nd:YAG PIV-laser
T - 3D-traversing unit

M – Mirror
O - Light sheet optics
DEHS tracer

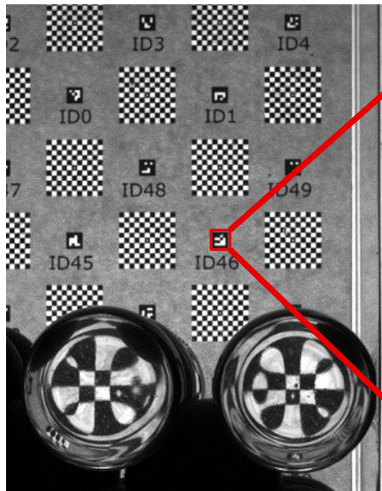
Image Acquisition - Calibration



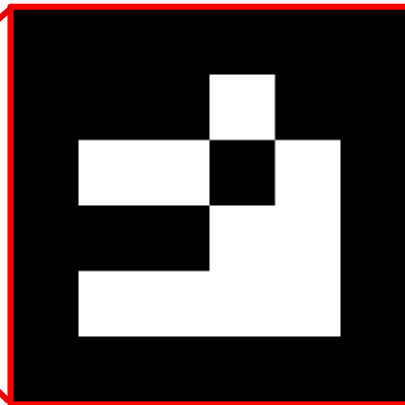
Calibration target Type 106-10 from LaVision

Calibration Image

- Commercial calibration target in the measurement plane for calculation of initial pinhole calibration parameters



Ray tracing reference image



ArUco Marker

Ray Tracing Reference Images

- Custom made target (checkerboard pattern/ ArUco marker) in background and measurement plane
- Allows for pose estimation and optical verification of simulation setup

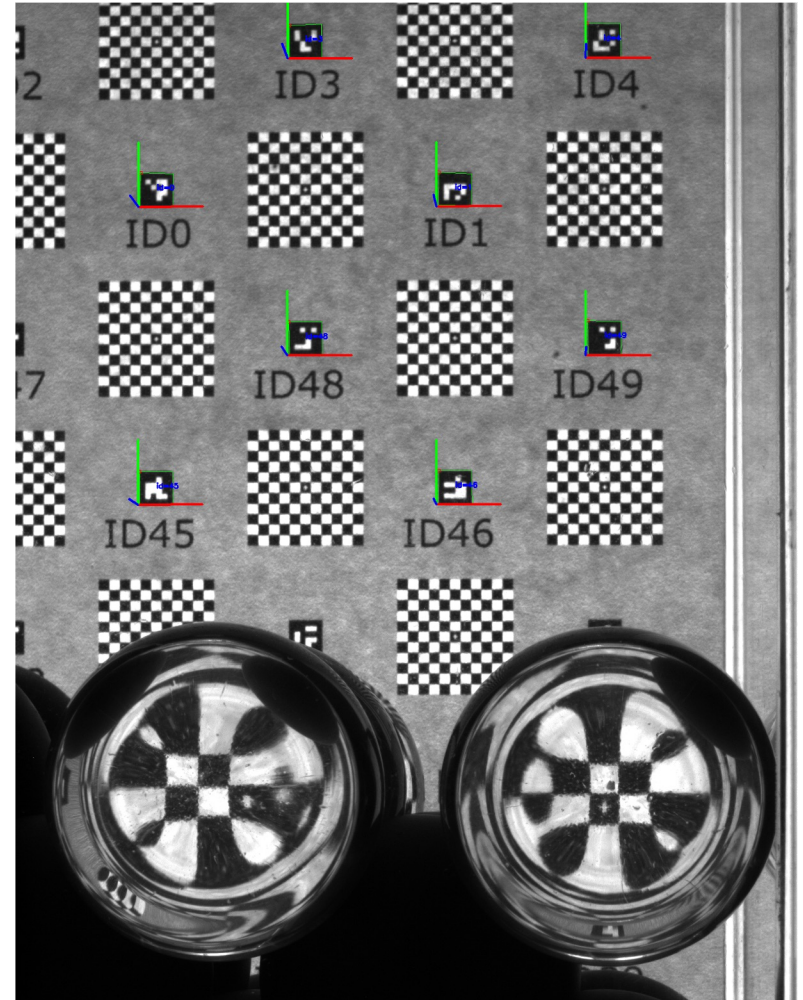
Calibration

Calibration

- Best results when using a combination of commercial software (DaVis) and OpenCV library:
 - Commercial calibration target to determine focal length and optical centre
 - Ray tracing reference target for distortion parameters and pose estimation (orientation)

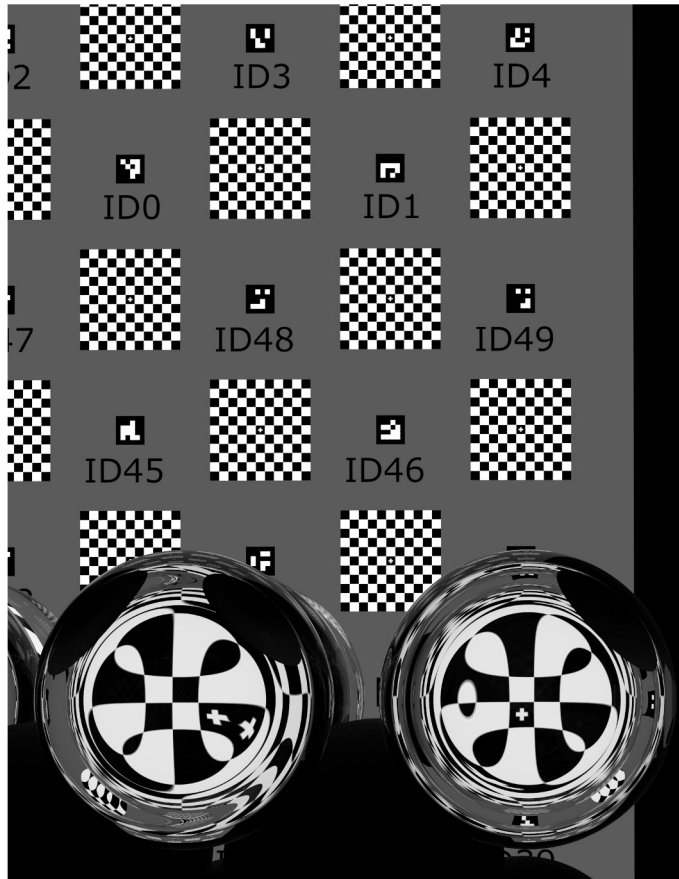


All Parameters known to simulate the 3D scene

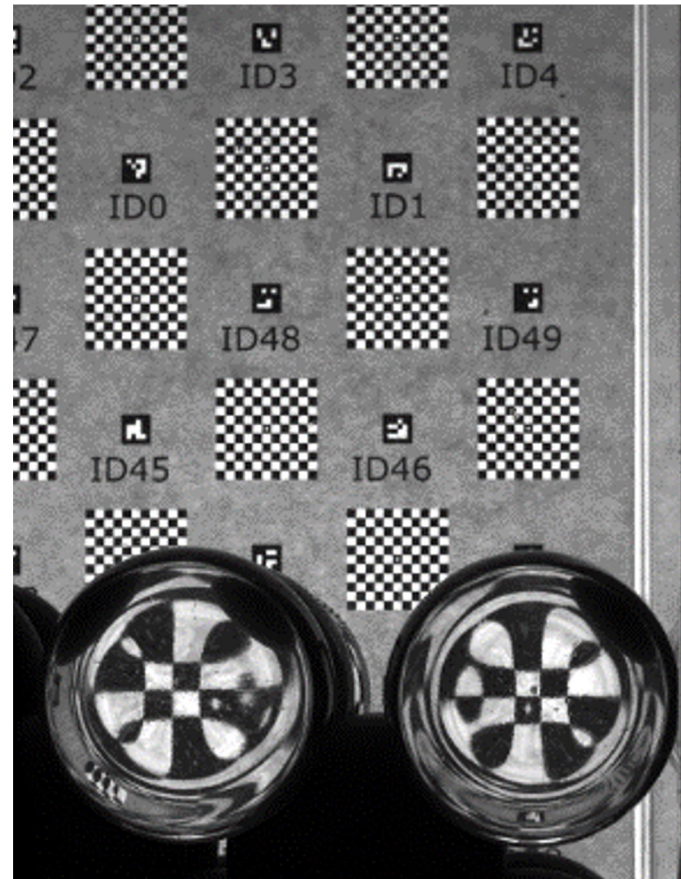


Marker detection on the ray tracing reference target

Sanity Check



Simulated image



Captured image



Good Agreement between simulation and acquired image

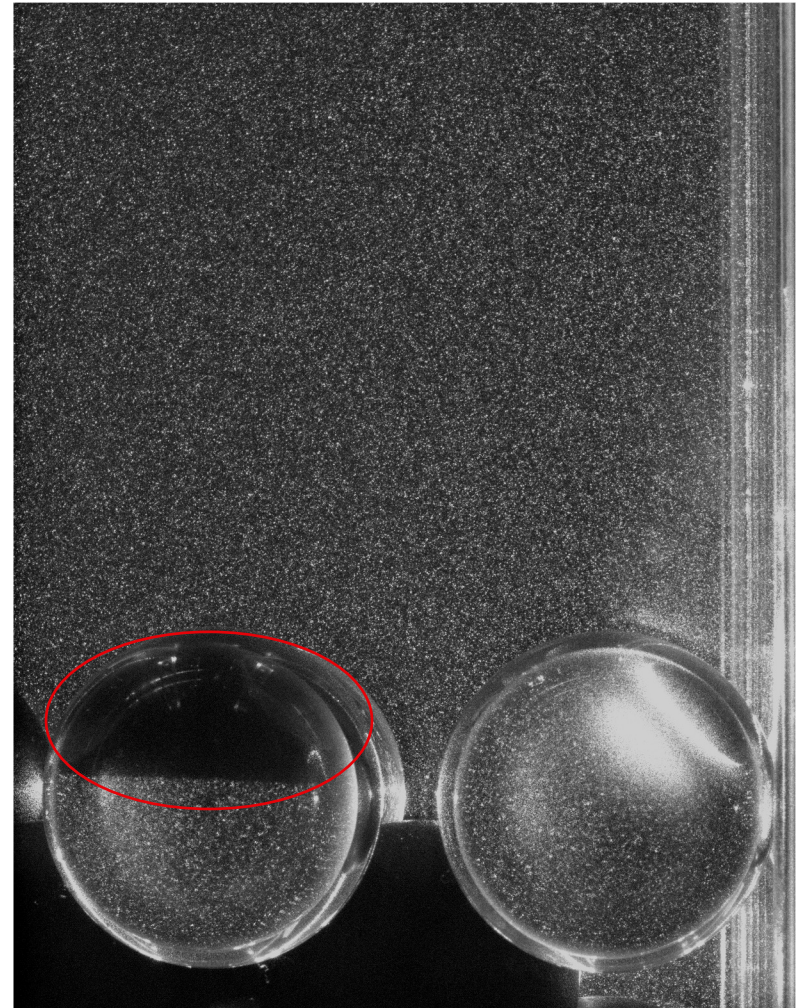
Image Acquisition - Particle Fields

Tracer Particle Field Images

- Double frame images of tracer particles in the flow illuminated in the measurement plane behind two spheres by a light sheet
 - Distortion effects behind the spheres are clearly visible

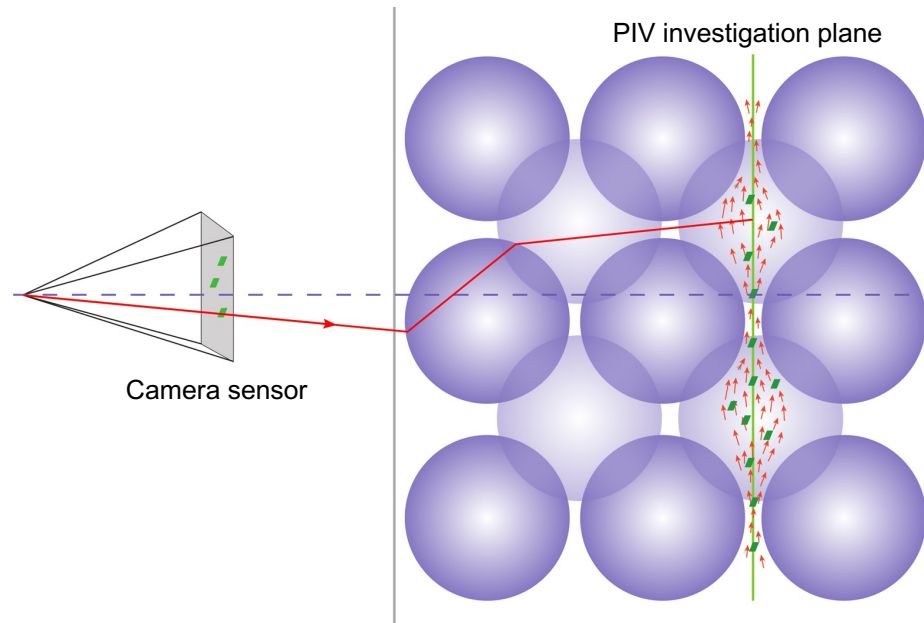


Apply correction to the particle fields



Particle field image (one frame)

Ray Tracing Based Reconstruction – Image Correction

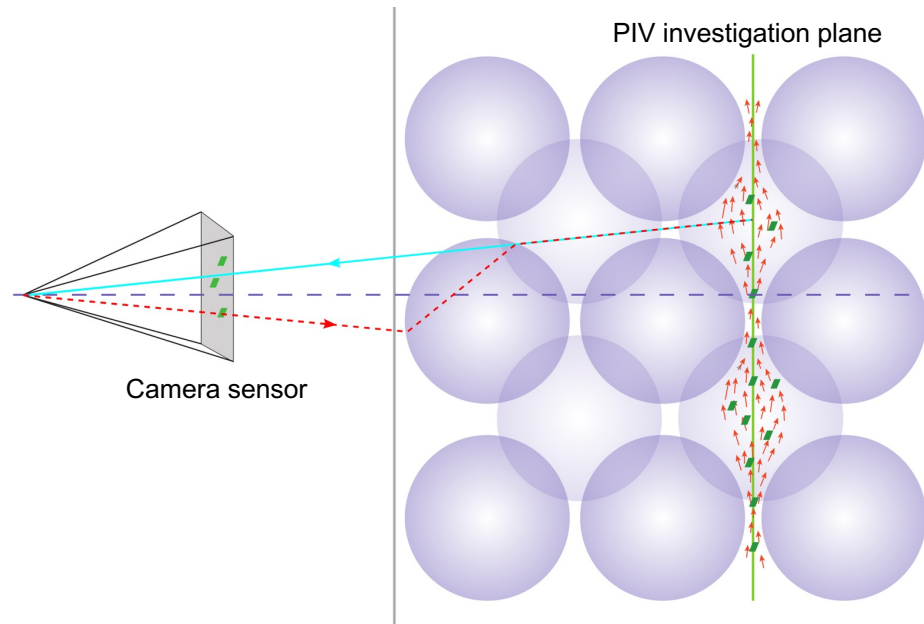


Principle of the ray tracing based reconstruction – forward pass

Image Correction

- Reconstruct light field on the investigation plane
- Use ray differentials as weighting for samples

Ray Tracing Based Reconstruction – Image Correction



Principle of the ray tracing based reconstruction – backward pass

Image Correction

- Reconstruct light field on the investigation plane
- Use ray differentials as weighting for samples
- Backward ray tracing step to remove distortions

Ray Tracing Based Reconstruction – Image Correction

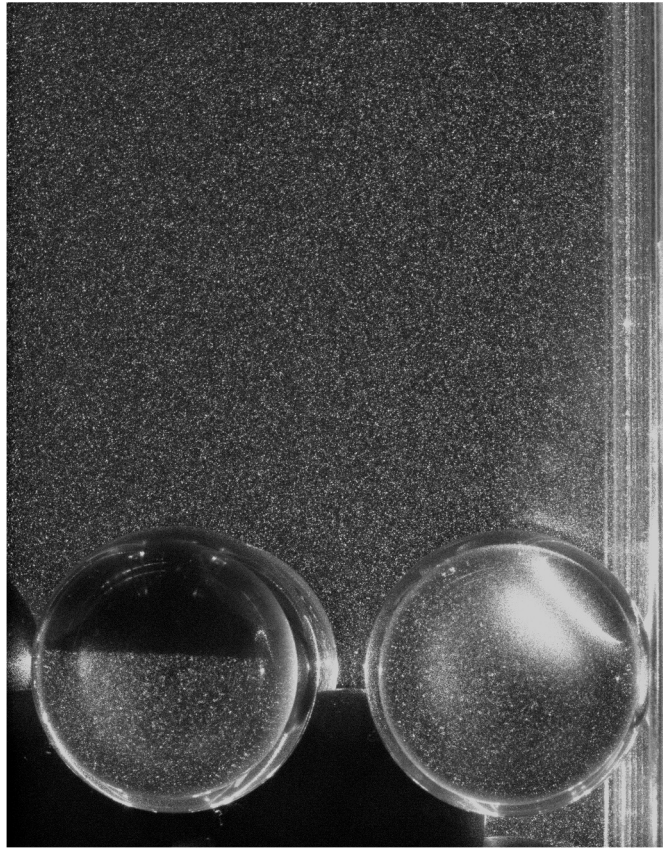
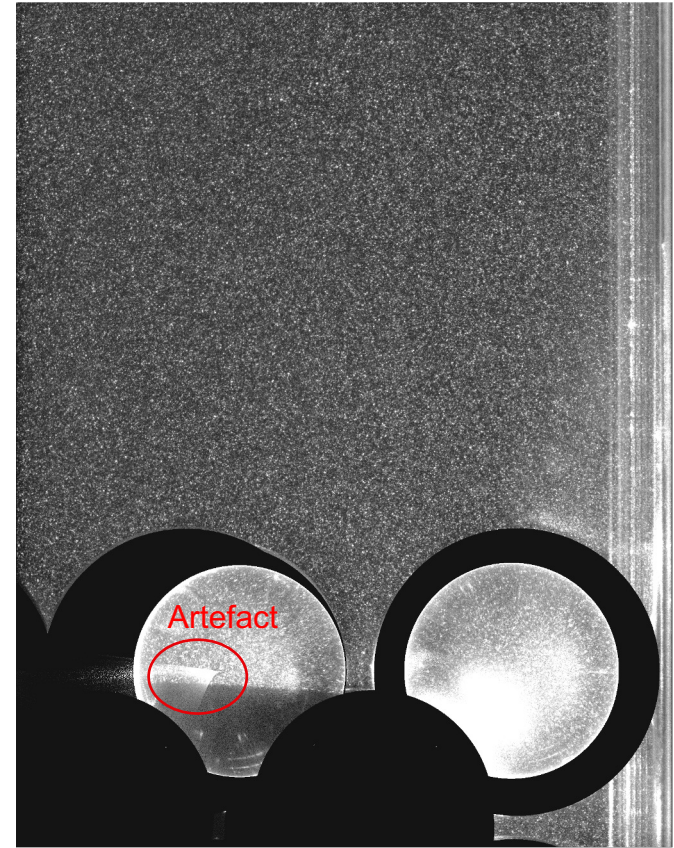


Image Correction →



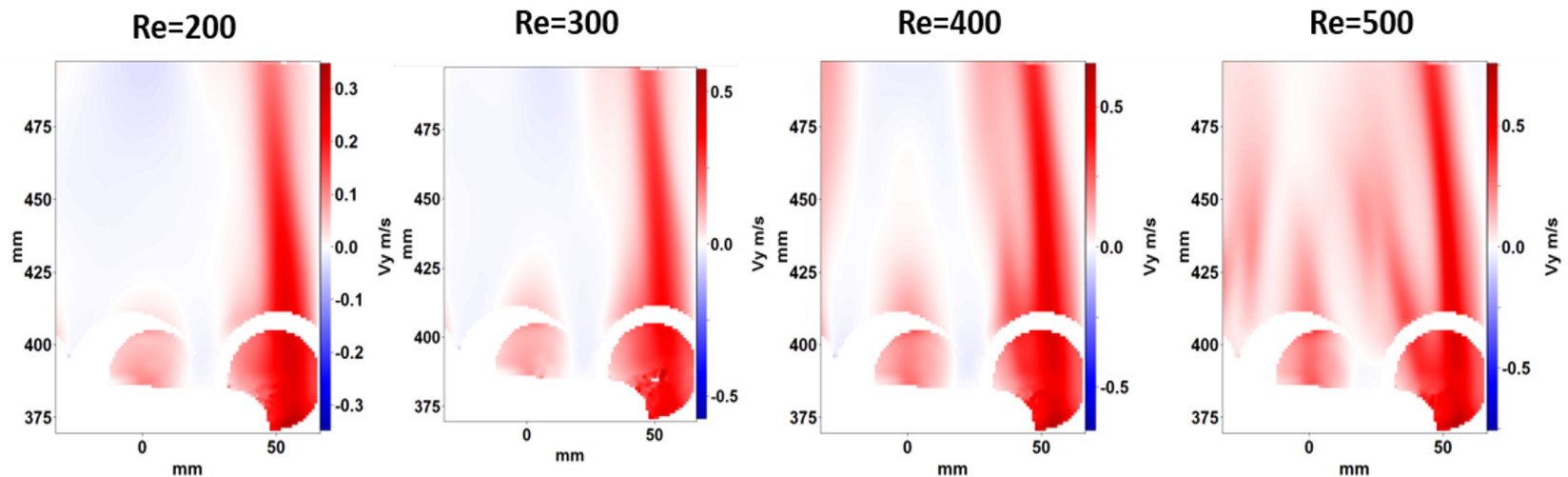
Particle field image (one frame)

Corrected particle field image (one frame)

Vector Field Calculation

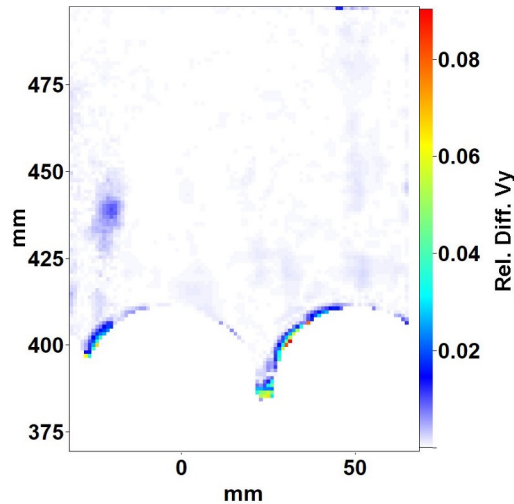
Processing

- Reimport of corrected images to PIV-software (DaVis)
- Application of masks and time filters to remove areas where no evaluation is possible (reflections, no measurement signal, no reconstruction)
- Vector field calculation by a classical cross-correlation method with decreasing interrogation windows, 50% overlap and post processing

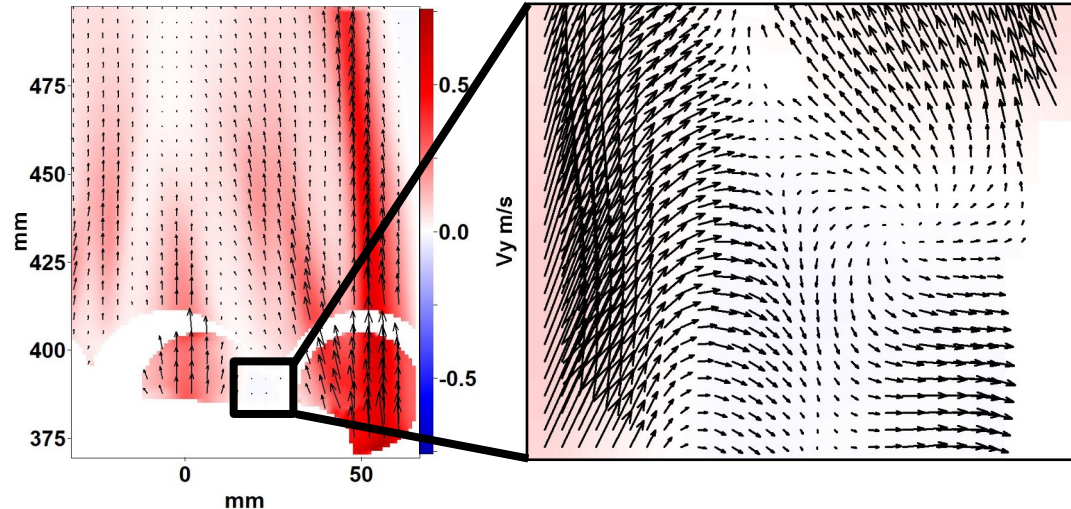


Averaged flow field of the main velocity component above 17 layers of spheres for particle Reynolds number 200 to 500 after ray tracing based reconstruction

Validation



Relative Difference between the freeboard flow of uncorrected and corrected particle fields



Corrected vector field for $Re_p=500$ above 17 Layers

Zoom inside the gap between centred and exterior spheres

Results

- No significant influence of the correction on the results for the freeboard flow
 - Averaged relative differences between uncorrected and corrected freeboard flow results do not exceed 0.08%, especially in the rim region, due to incorrect mask function
- Distorted region is corrected and matches well the freeboard flow
- Perspective applied to centred sphere allows for correction of rim region

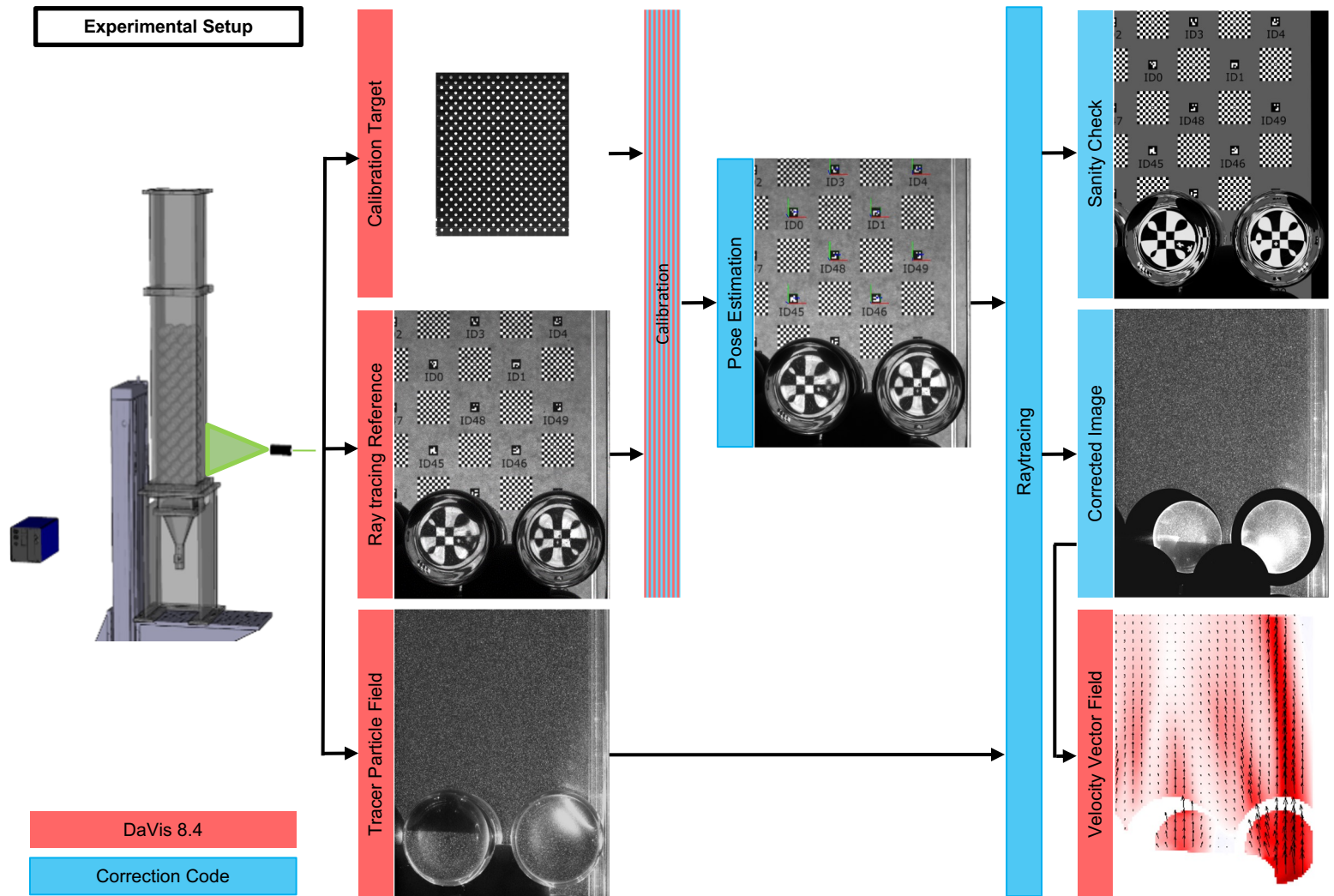
Conclusion and Outlook

Conclusion

- Application of ray tracing PIV on the surface of a bcc spherical packing
- Presentation of a complete correction routine
- Extension of previously used correction method
- Successful validation by comparison between the flow field of the free board and distorted regions behind the top layer spheres

Outlook

- Application of the method to volumetric measurement techniques
- Access to the interstices inside the packed bed
- Investigation of perspective to recover highly distorted regions
- Further optimization and enhancement of the ray tracing based correction routine



Thank you for your attention!

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