

# High temperature endoscopic-laser PIV/DIA technique for the study of hydrodynamics of gas-solid fluidized beds

**Citation for published version (APA):**

Campos Velarde, I., Gallucci, F., & Sint Annaland, van, M. (2014). High temperature endoscopic-laser PIV/DIA technique for the study of hydrodynamics of gas-solid fluidized beds. In *Proceedings NPS14, 3-5 November 2014, Utrecht, The Netherlands*

**Document status and date:**

Published: 01/01/2014

**Document Version:**

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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# High Temperature Endoscopic-Laser PIV/DIA Technique for the Study of Hydrodynamics of Gas-Solid Fluidized Beds

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**TU/e** Technische Universiteit  
**Eindhoven**  
University of Technology

**Where innovation starts**

# Contents

- **Motivation**
  - **Why high temperature Hydrodynamics?**
- **PIV/DIA**
  - **Working principle?**
- **Novel high temperature PIV/DIA**
  - **How to extend PIV/DIA?**
  - **Validation**
  - **Demonstration**
- **Conclusions and future work**

# Motivation

## Wide spread industrial application

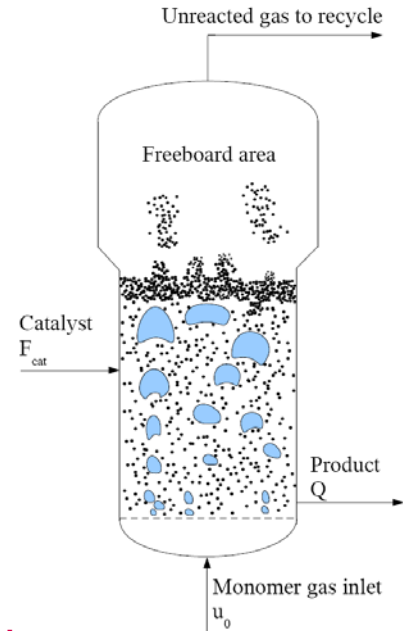
- Catalytic oil cracking
- Chemical Looping
- Polymerization
- .....
- High temperature process  $> 500^{\circ}\text{C}$

## Features

- Vigorous solids mixing
- Strong bubble and emulsion phase interaction
- Excellent heat and mass transfer
- Performance dependent on hydrodynamics
- Design relies on constitutive equations (K-L model)

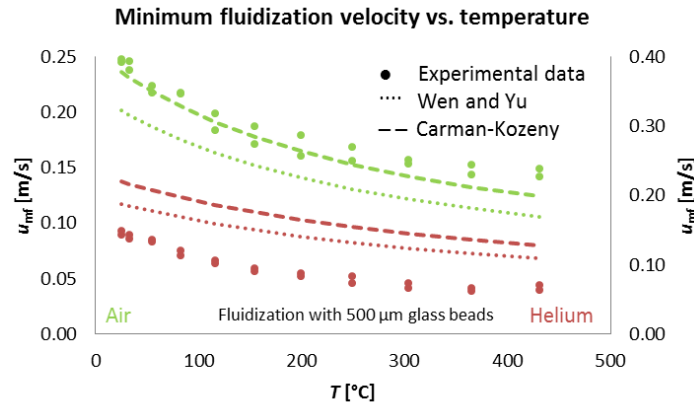
## Gaps

- Scarce quantitative information of macro scale circulation patterns
- Experimental research on hydrodynamics focused on emulsion OR bubble phase
- Constitutive equations obtained and validated at low temperatures with air



# Motivation

- Quality of minimum fluidization velocity predictions



## RESEARCH GOAL

- Study the hydrodynamics at elevated temperatures
  - Effect explained by gas viscosity and density? Inter particle interaction?

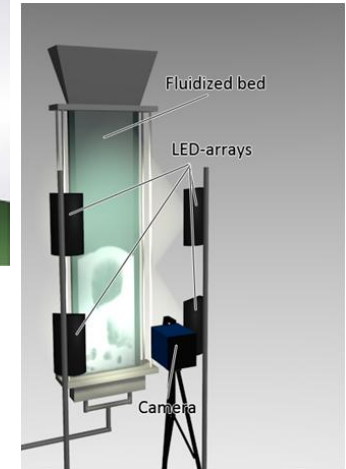
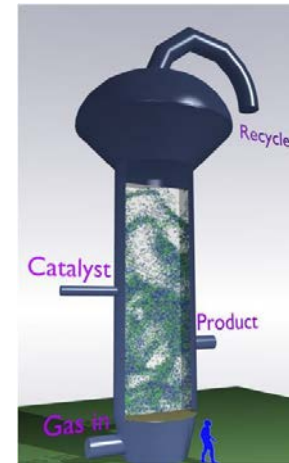
Characterization of bubble hold up and internal solids circulation.

**Available techniques?**

- ⇒ No suitable correlation (among at least 63 available) exists that can predict the minimum fluidization velocity of different gas mixtures at elevated temperatures!
- ⇒ Note that all other correlations to describe hydrodynamics depend on  $u_{mf}$ !

# Measurement techniques

- **Capacitance probes**
  - + 3-D characterization
  - Invasive, several sampling points
  - Hard to calibrate
  - Correlate frequency to a bubble or particle
- **Radioactive Tracking Tomography**
  - + 3-D characterization
  - Hard to describe bubble hold up
  - Use of radioactive material, safety
- **Particle Image Velocimetry (PIV) & Digital Image Analysis (DIA)**
  - + Non-invasive technique,
  - + Whole field of measurement (bubble hold up and solids circulation)
  - Optical access, restricted to pseudo 2-D



# Contents

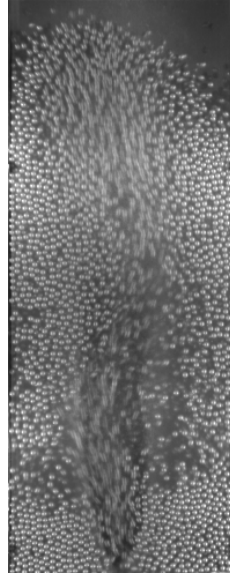
- **Motivation**
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  - **Demonstration**
- **Conclusions and future work**

# Coupling PIV and DIA

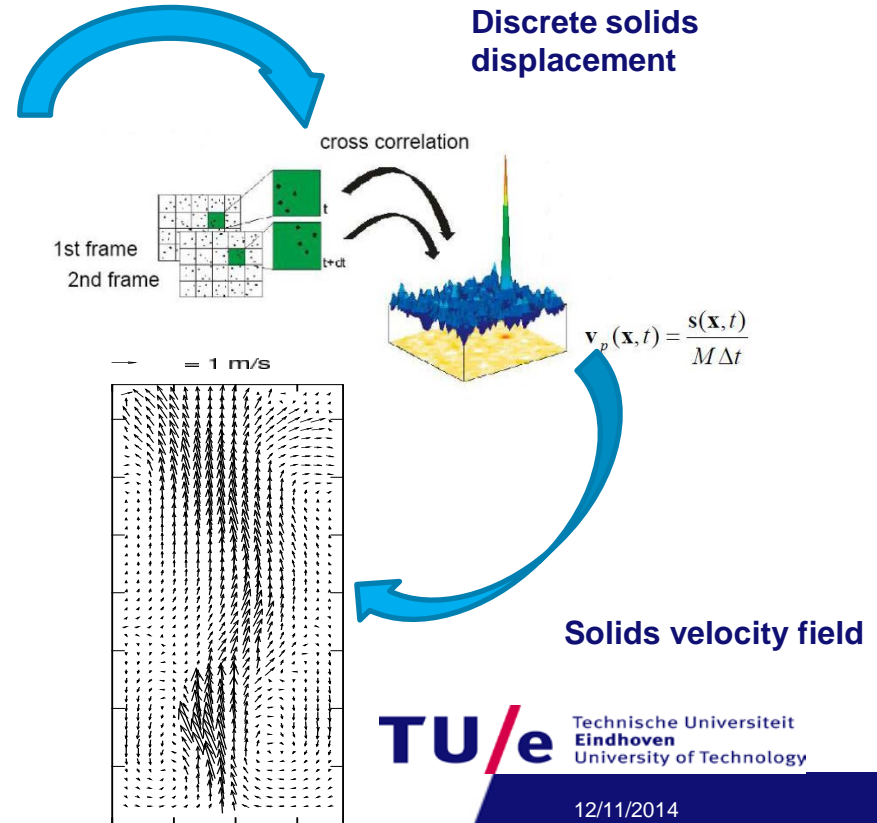
## PIV: Particle Image Velocimetry



Pseudo 2D PIV setup with visual high speed camera  
(2016 x 2016 px @1600 Hz)



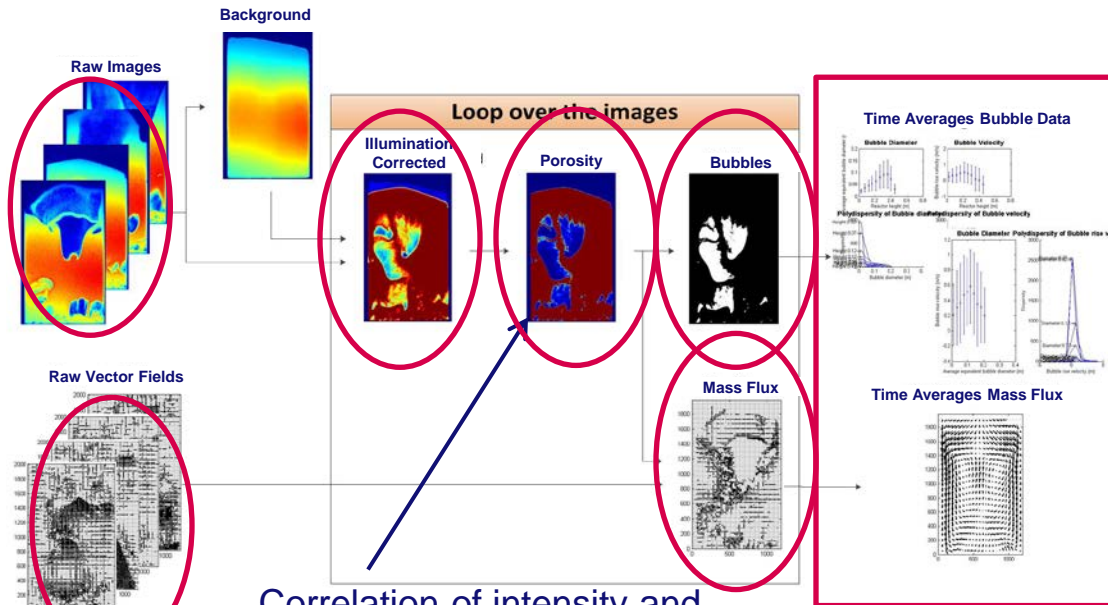
Double frame with small time delay  
( $\Delta t = 1$  ms)





# Coupling PIV and DIA

## Digital Image Analysis (DIA)



Correlation of intensity and porosity, based on DPM simulations [de Jong et al]

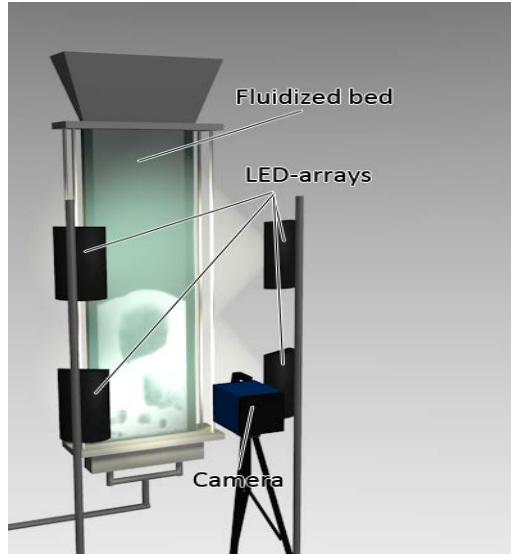
- In-house Matlab script
- Distinguishes between bubble and emulsion phase
- Conversion of pixel intensity to bed porosity
- Bubbles can be tracked

**How to extend PIV/DIA to high temperature?**

# Contents

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# PIV/DIA at High Temperature



**LED PIV/DIA**

**Heating**

**Acqu**

**Supply**

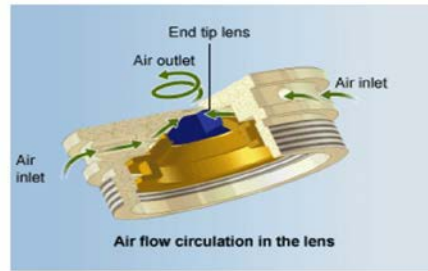
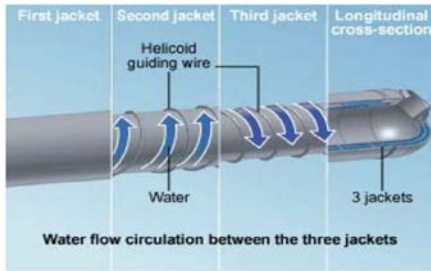


→ Heat losses  
↓  
**Furnace**

→ Camera outside  
↓  
**Endoscope**

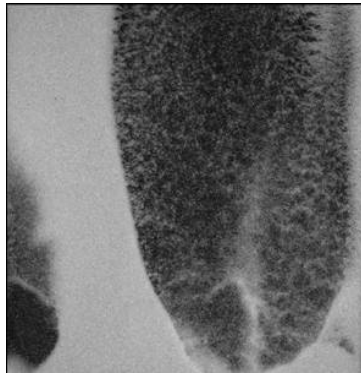
➤ Led lights  
➤ **Laser**

# Endoscopic PIV/DIA



- Can we run PIV/DIA?

Without Endoscope



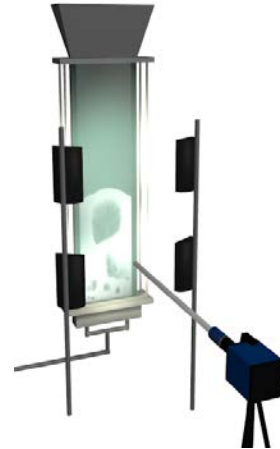
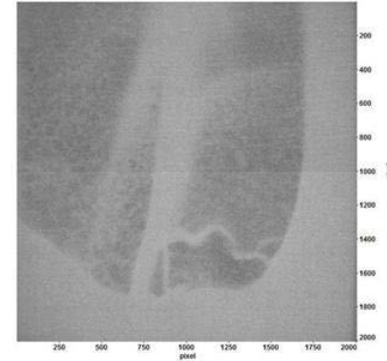
at room Temperature

5x inter frame time

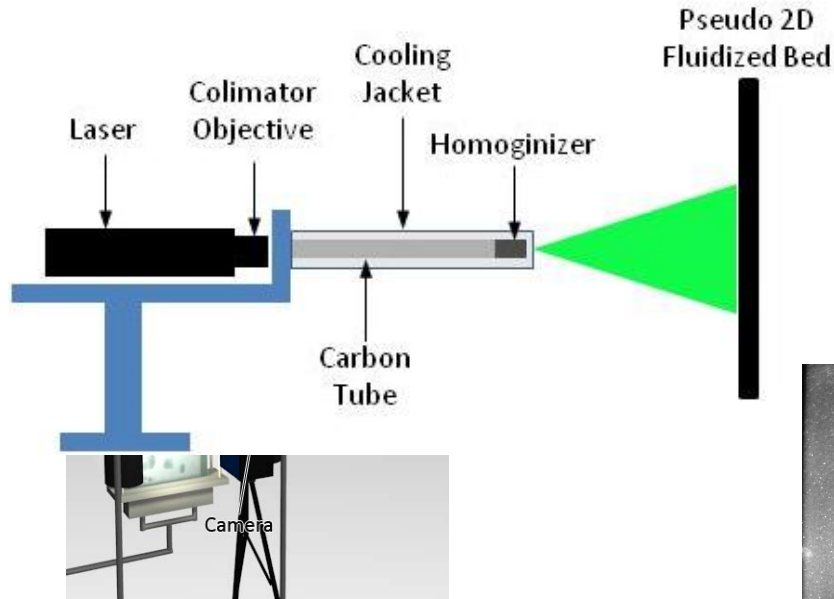
20x exposure time

**FAIL TO RUN PIV/DIA**  
**MORE ILLUMINATION REQUIRED**

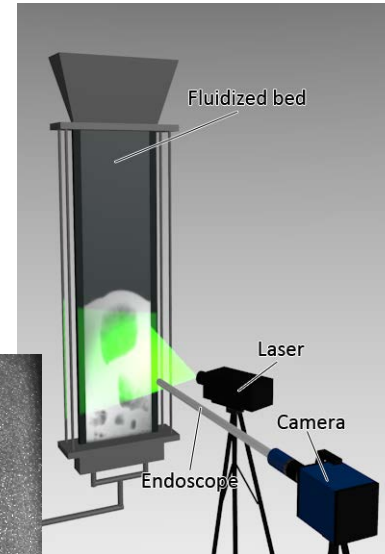
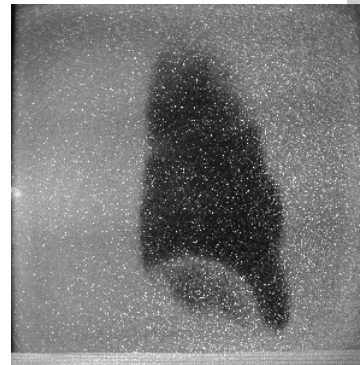
With Endoscope



# Endoscopic-Laser PIV/DIA (ePIV/DIA)



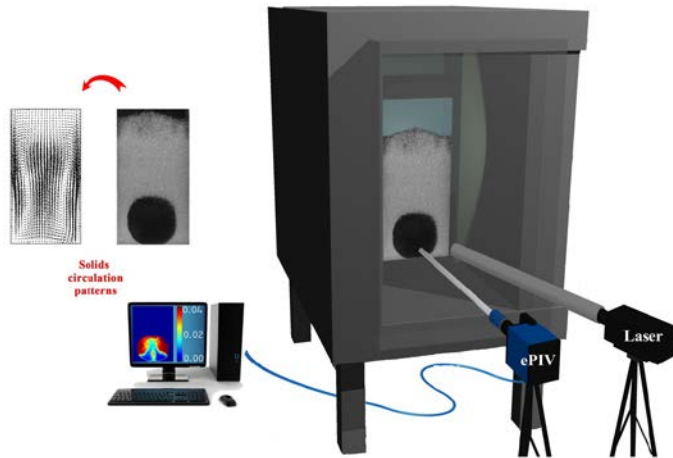
inate the  
lized bed



# High Temperature ePIV/DIA

- **Extension of PIV/DIA/IR to high temperatures and reactive conditions!**

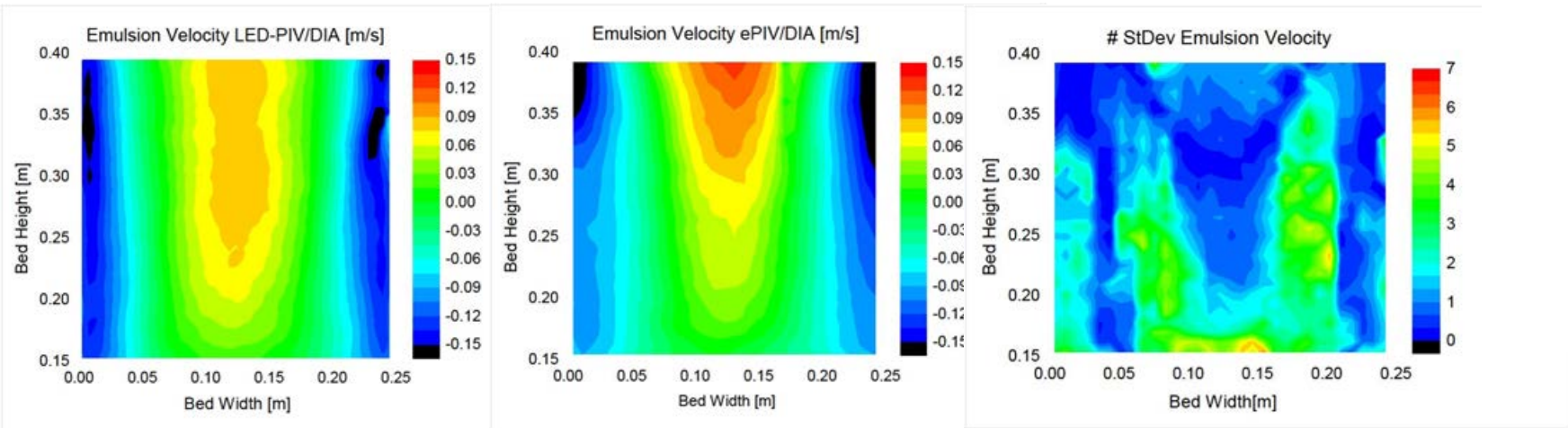
Essential to have non-invasive, whole-field measurements of gas and solids phases simultaneously!



**DOES IT WORK?**

# Validation

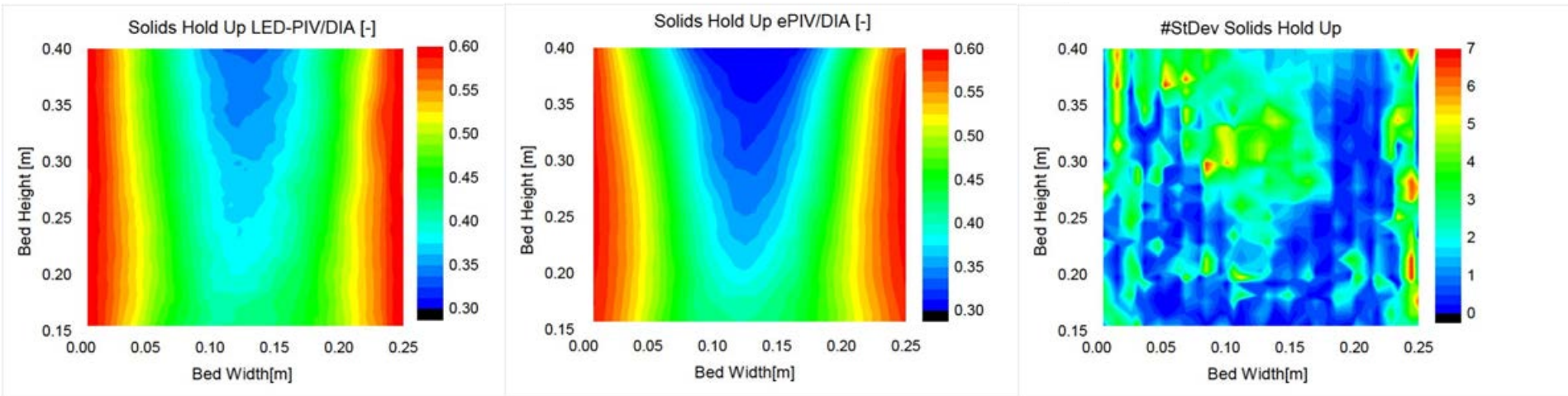
Time Averaged Emulsion Velocity at room temperature





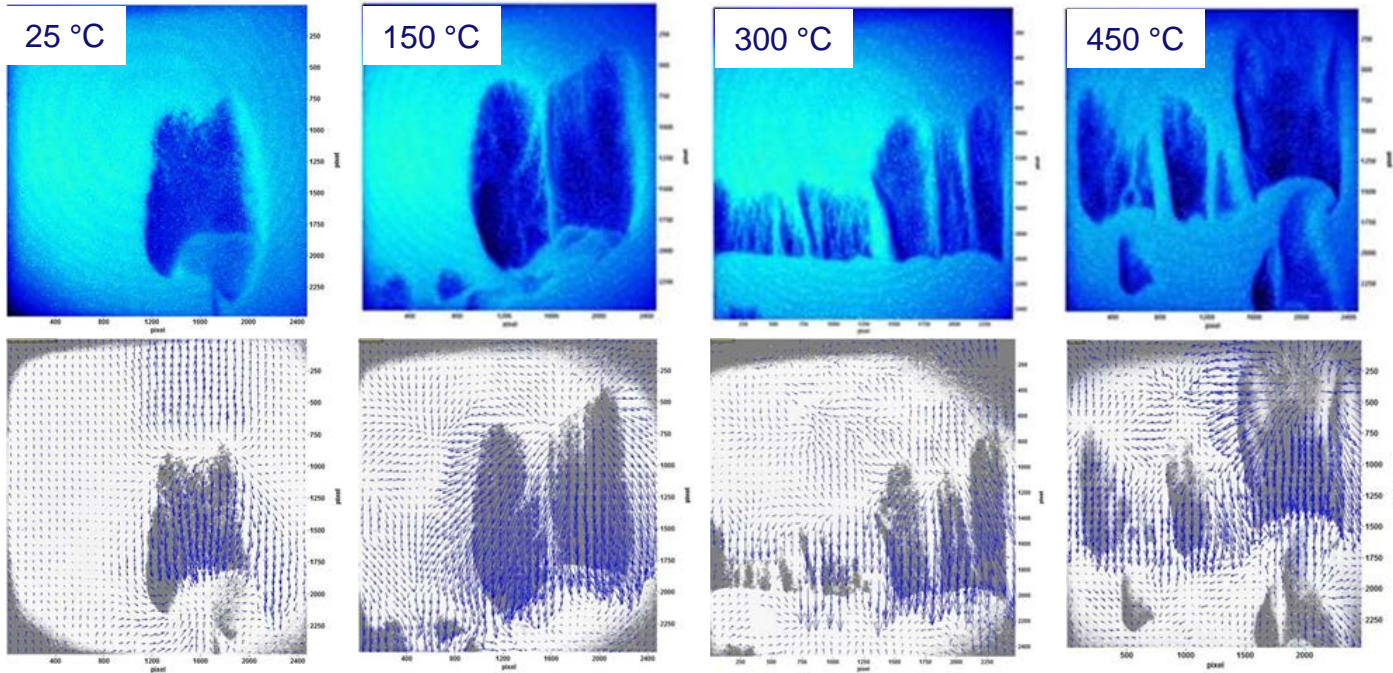
# Validation

## Time Averaged Emulsion Velocity at room temperature





# Demonstration HT-ePIV/DIA



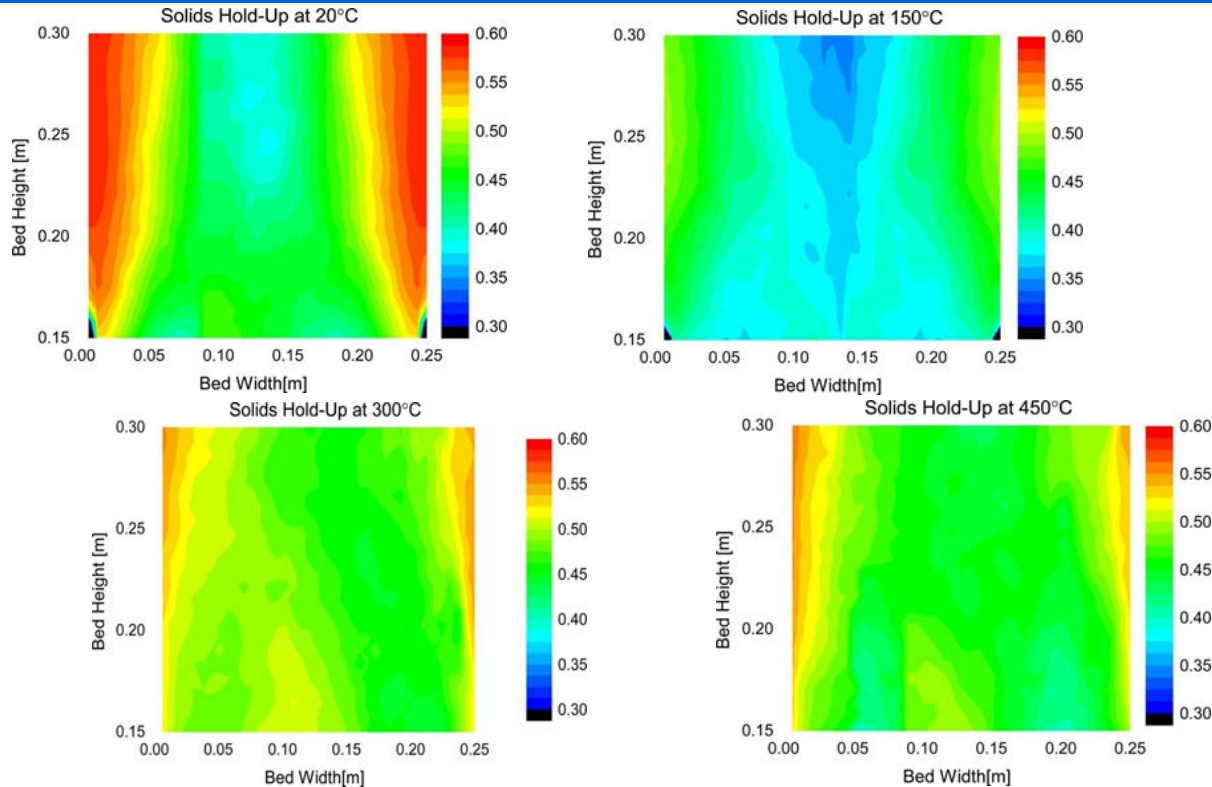
$$u = 3u_{mf}$$

⇒  $u_{mf}$  measured at different temperatures

⇒ Completely different bubble behaviour as function of temperature!!!

⇒ **Adaptation of closures required!**

# Demonstration HT-ePIV/DIA



- ⇒ Expected similar porosity
- ⇒ Completely different bubble behaviour as function of temperature!!!
- ⇒ Porosity estimation need to be revized!!!!

# High Temperature ePIV/DIA

## CONCLUSION

- Development and demonstration of the novel non-invasive High Temperature ePIV/DIA
- Difference in bubble behavior
- Closures have to be revised

## FUTURE WORK

- Record larger area of the fluidized bed (whole bed if possible)
- Influence of temperature on hydrodynamics - bubble properties and solids circulation (different particles and gases)
- .....

# Acknowledgements

ADEM PROJECT for the financial support



A Green Deal in  
Energy Materials

Technicians at SMR group (Joris, Joost, Lee)  
Master students Jeroen, Sven, Jason

# High Temperature ePIV/DIA

**THANKS FOR YOUR ATTENTION!!!!!!**

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Chemical Process Intensification

## QUESTIONS?



A Green Deal in  
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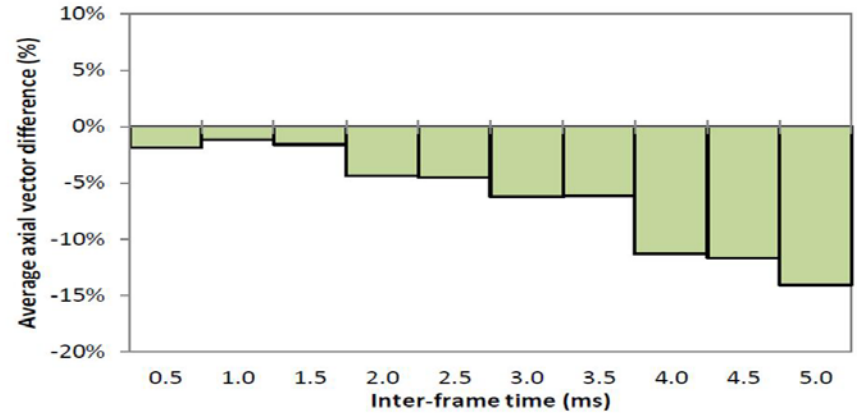
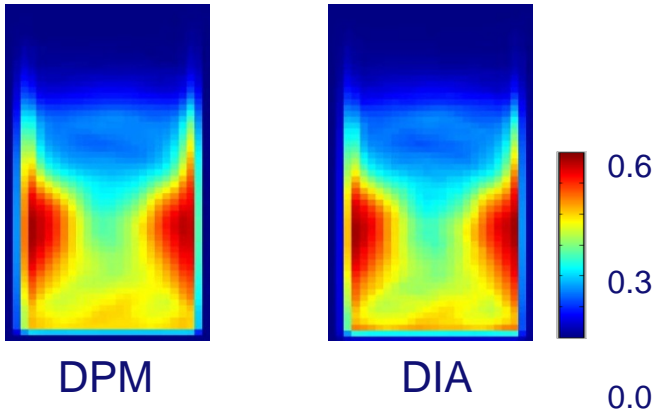


/ name of department

# PIV/DIA validation

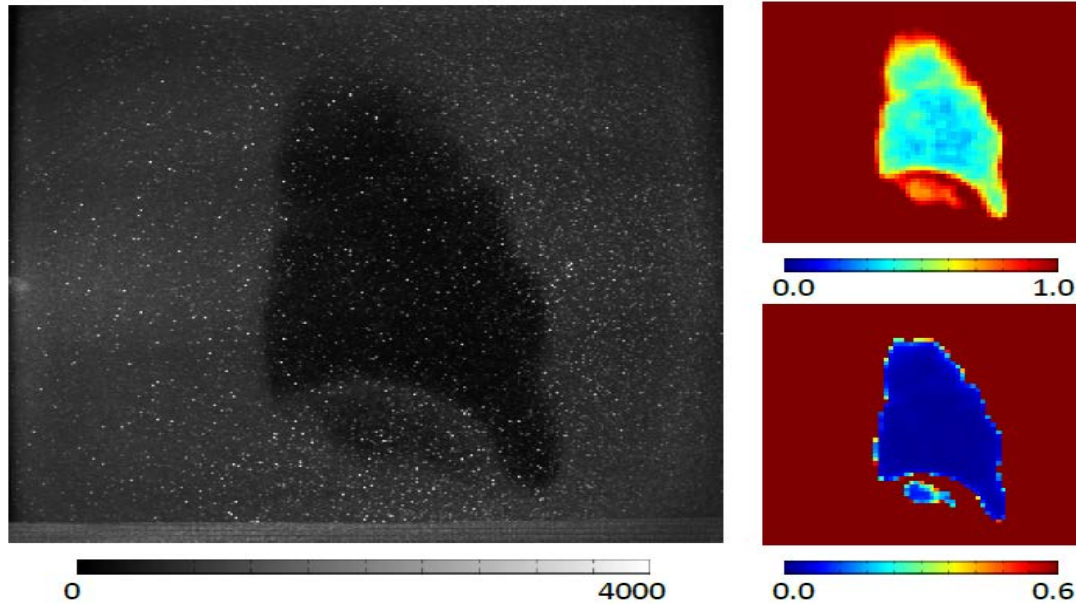
- Artificial images from DPM simulation  
+ Exact location of particles

## Time average porosity plot



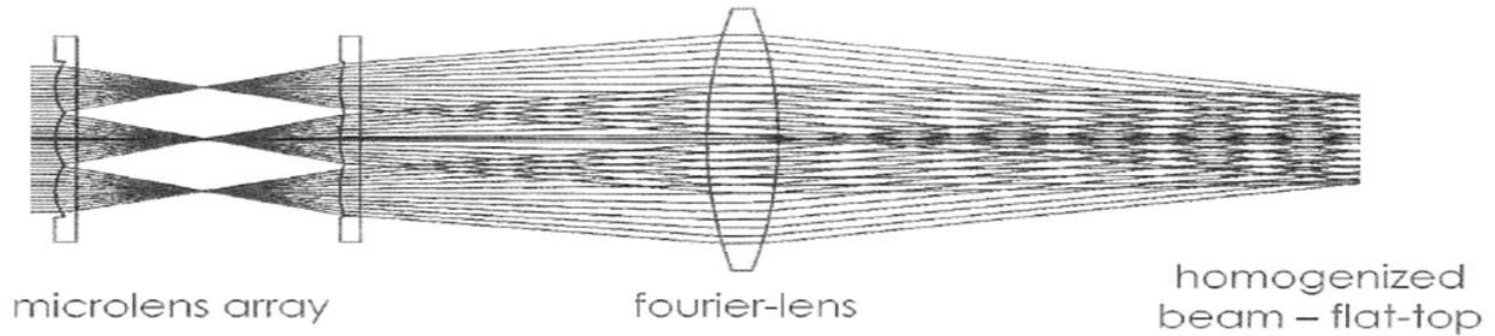
# Endoscopic-Laser PIV/DIA

## Porosity Plots – Bubble hold up at room temperature





# Homoginizer



Bayerisches Laserzentrum