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AREVA thermo hydraulic testing capabilities and related OpenFOAM analysis

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AREVA NP GmbH, Thermal Hydraulics and Fluid Dynamics - PTCTT-G

Workshop “Multiphysical Modelling in OpenFOAM”

20th-21st October 2011

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Content

- Testing capabilities at AREVA Technical Center
- Examples of OpenFOAM® application:
  - Water film formation
  - Liquid jet in cross flow
- Summary

OpenFOAM® is a registered trademark of SGI Corp.

Testing capabilities at AREVA Technical Center

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AREVA Technical Center

- The AREVA Technical Center hosts experimental and measurement test facilities for qualification and quality control
- In the department of Thermal Hydraulics and Fluid Dynamics (PTCTT-G) researchers work closely together on both experiments and modeling
- It is acknowledged that the open structure of OpenFOAM facilitates cooperation and quicker development
  - Complex physics, programming and computer science
  - Quick debugging and testing of code
  - Cooperation with universities (master thesis etc.) easier to realize
  - More and more students “speak OpenFOAM”
- Main focus on complex rotational flow, multi phase flow and heat transfer
- Goal: Tight coupling of experimental results and CFD

Thermo Hydraulic Platform

Training → Consultancy → On-site services → Modeling - Numeric → Test - Engineering → Test Design - Construction

Accredited Test Body

Under the term of ISO 17025:2005

Accredited Inspection Body

Under the term of ISO 17020:2004

Internationally accepted according to

International Laboratory Accreditation Cooperation

Database Compilation → Systems- Qualification → Components- Qualification → Root cause analysis → Contracted Research

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Characteristics of world wide unique testing & qualification infrastructure

Accredited Test Body

Under the term of ISO 17025:2005

Accredited measurement range

Measurements	Range	Accuracy
Temperature	0℃ - 600℃	0,3 K
Pressure	10 Pa - 40 MPa	0,5 %
Volume flow rate	0,1 l/h – 1.500 m³/h	0,5 %
Mass flow rate	0,1 kg/h - 4.000 kg/s	0,5 %
Force	1 N - 10.000 kN	1%
Momentum	Up to 50.000 Nm	1%
Distance	1 µm bis 10 m	0,5 %
Velocity	1 mm/s – 100 m/s	0,5 %
Acceleration	0,5 – 1.000 g	1 %
Current	1 mA - 85.000 A	0,5%
Voltage	1 mV - 4 kV	0,5%
Electrical power	bis 20 MW	0,5%

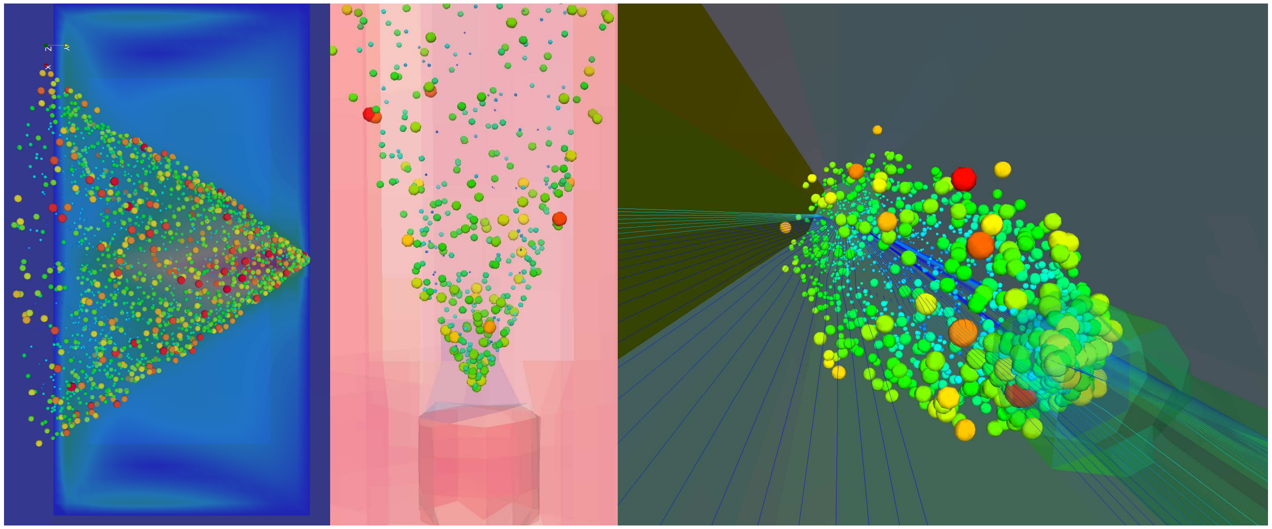
- **Test area > 2000 m²**
- **Test height > 30 m**
- **Crane capacity: up to 100 t**
- **Steam supply up to 22 MW**
- **Pressure volume up to 125m³ at 165 bar**
- **Electrical power up to 20 MW**

Accredited Inspection Body

Under the term of ISO 17020:2004

Evaluation of systems and components regarding defined acceptance criteria

Examples of OpenFOAM application: Wall film formation



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Multi phase flow:
Spray deposition and film formation

- **Task:**
  - **Development of a high pressure resistant film sensor**
- **Steps done:**
  - **Realisation of a suitable experimental test rig**
  - **Validation of numerical tools for further investigation**

- **Inlet conditions, including particle size distribution are known**
- **Film thickness is measured along the channel**
- **Lagrange particle tracking is used as simulation approach for the liquid phase**
- **Schlick hollow cone nozzle is used for spray atomisation**

By courtesy of Schlick GmbH

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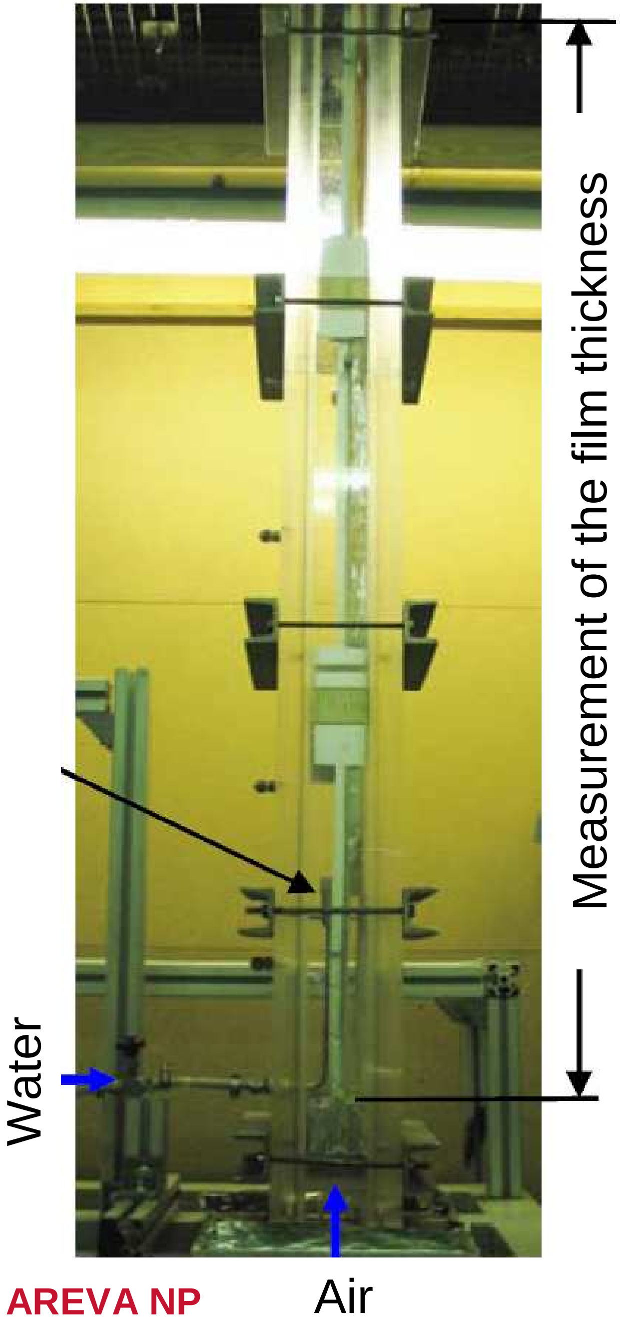
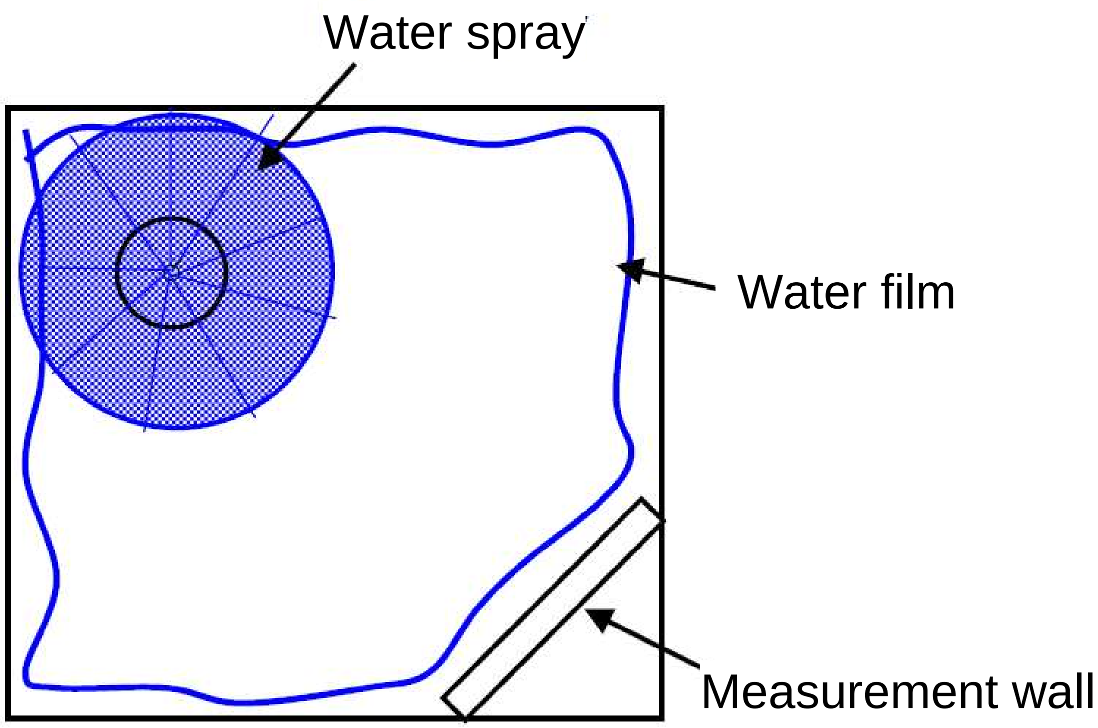
Film measurement test rig





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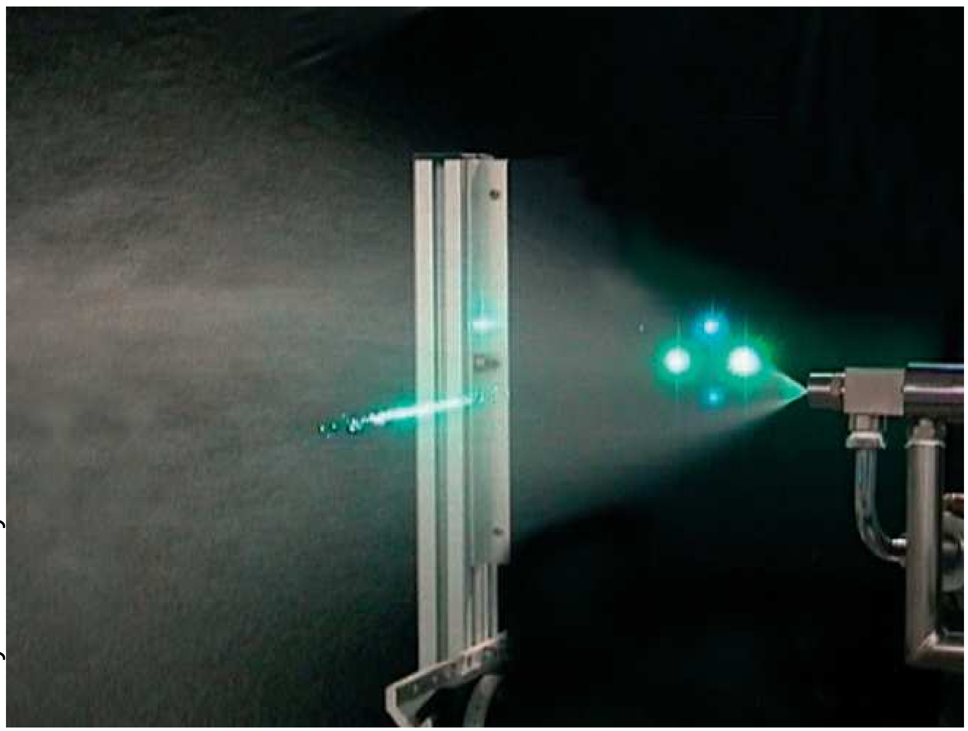
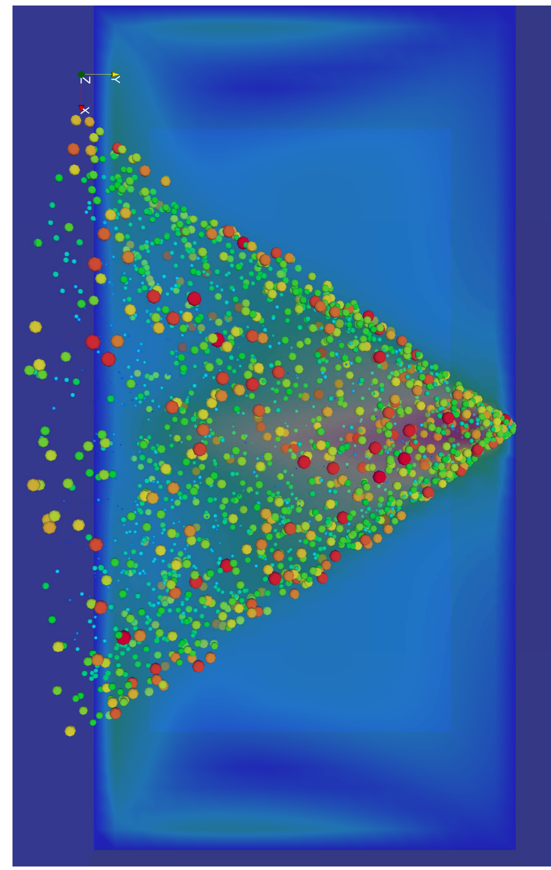
Multi phase flow:
Nozzle simulation for particle size distribution

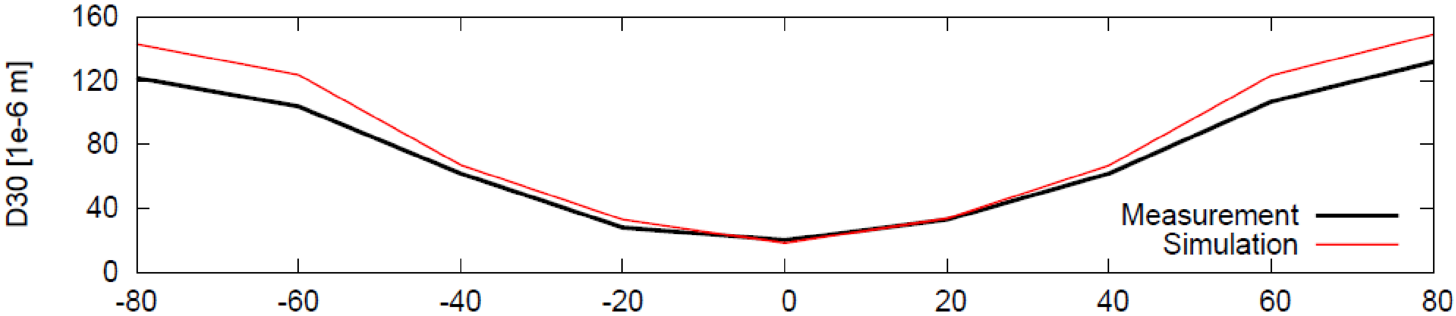
- Measurement data from the manufacturer available
- Used to characterize particle size distributions and inlet velocity of the particles
- Simulation inside an ideal box with slip wall BC



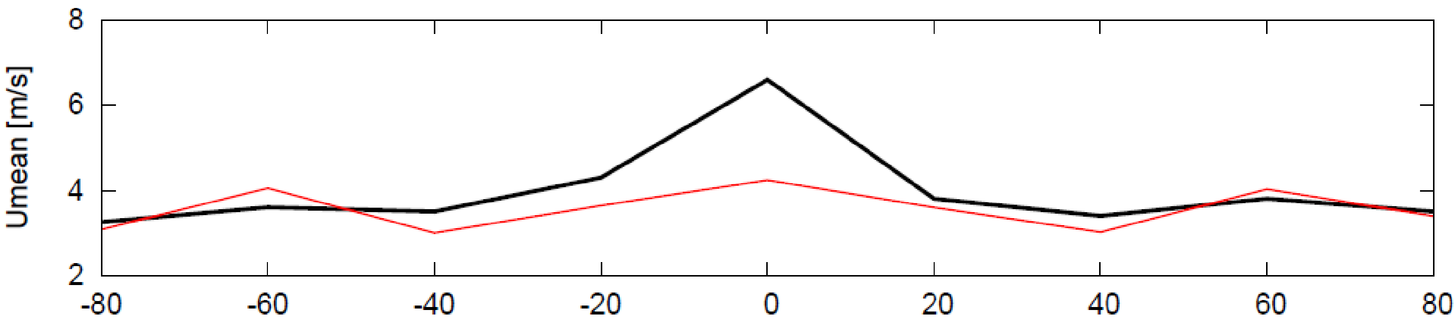
By courtesy of Schlick GmbH



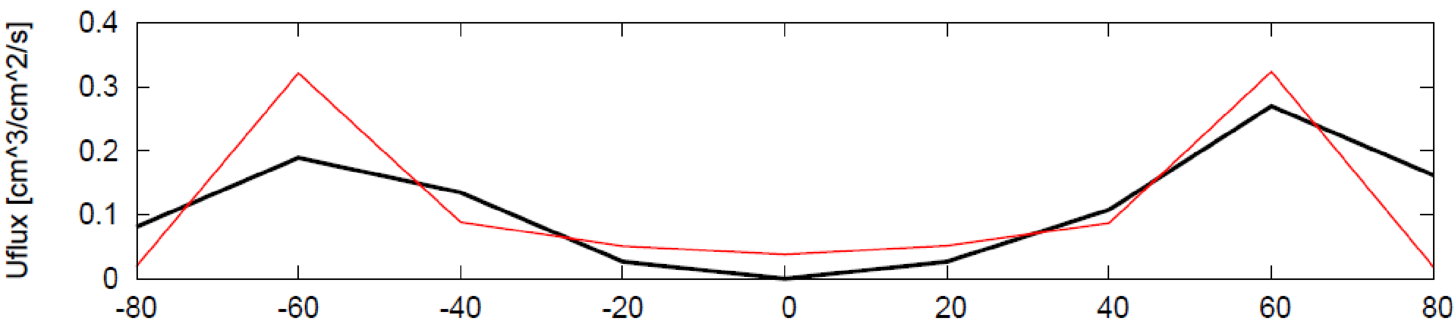
Nozzle simulation and comparison with experiment at the sampling plane



- ▶ Mean droplet diameter



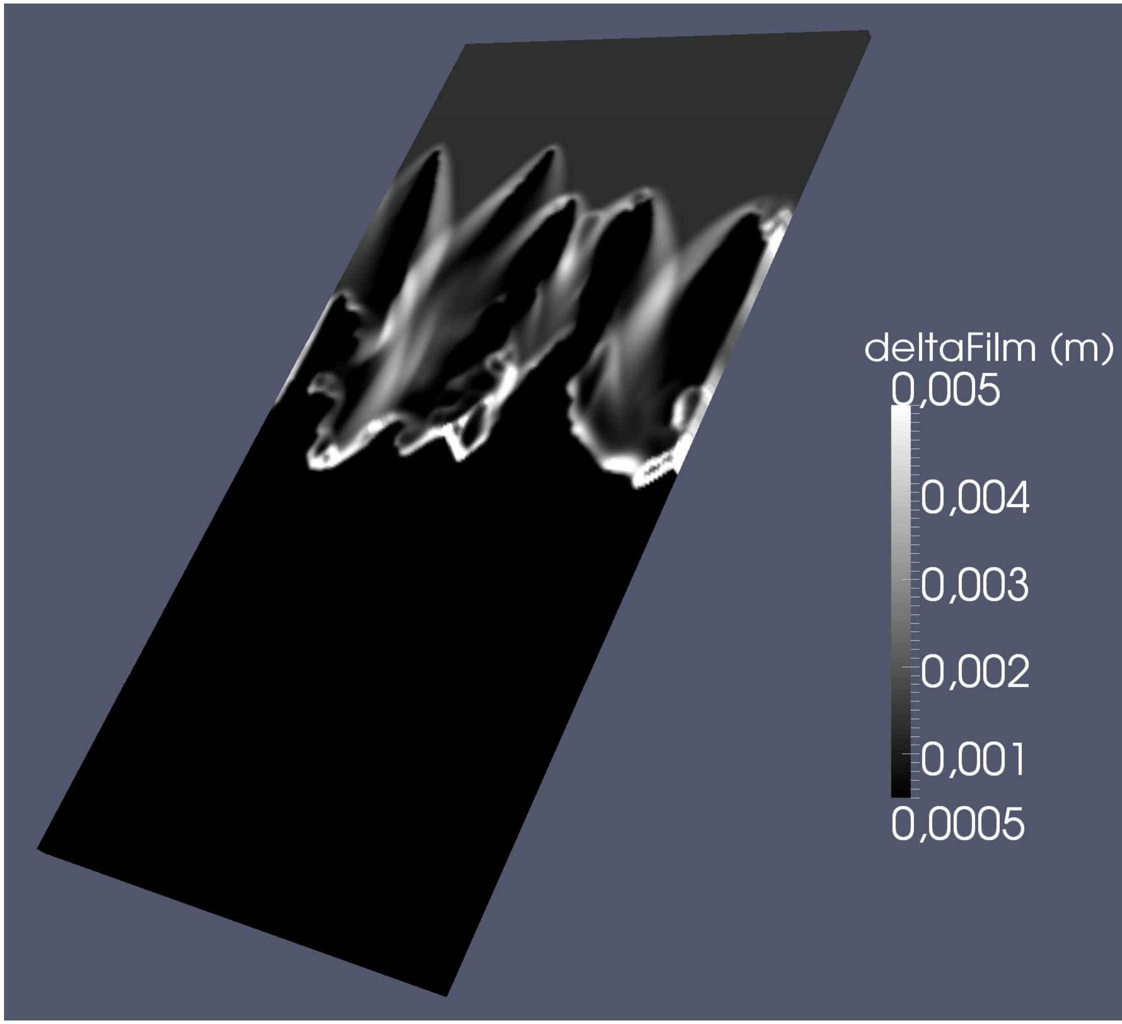
- ▶ Mean droplet velocity



- ▶ Mean flux

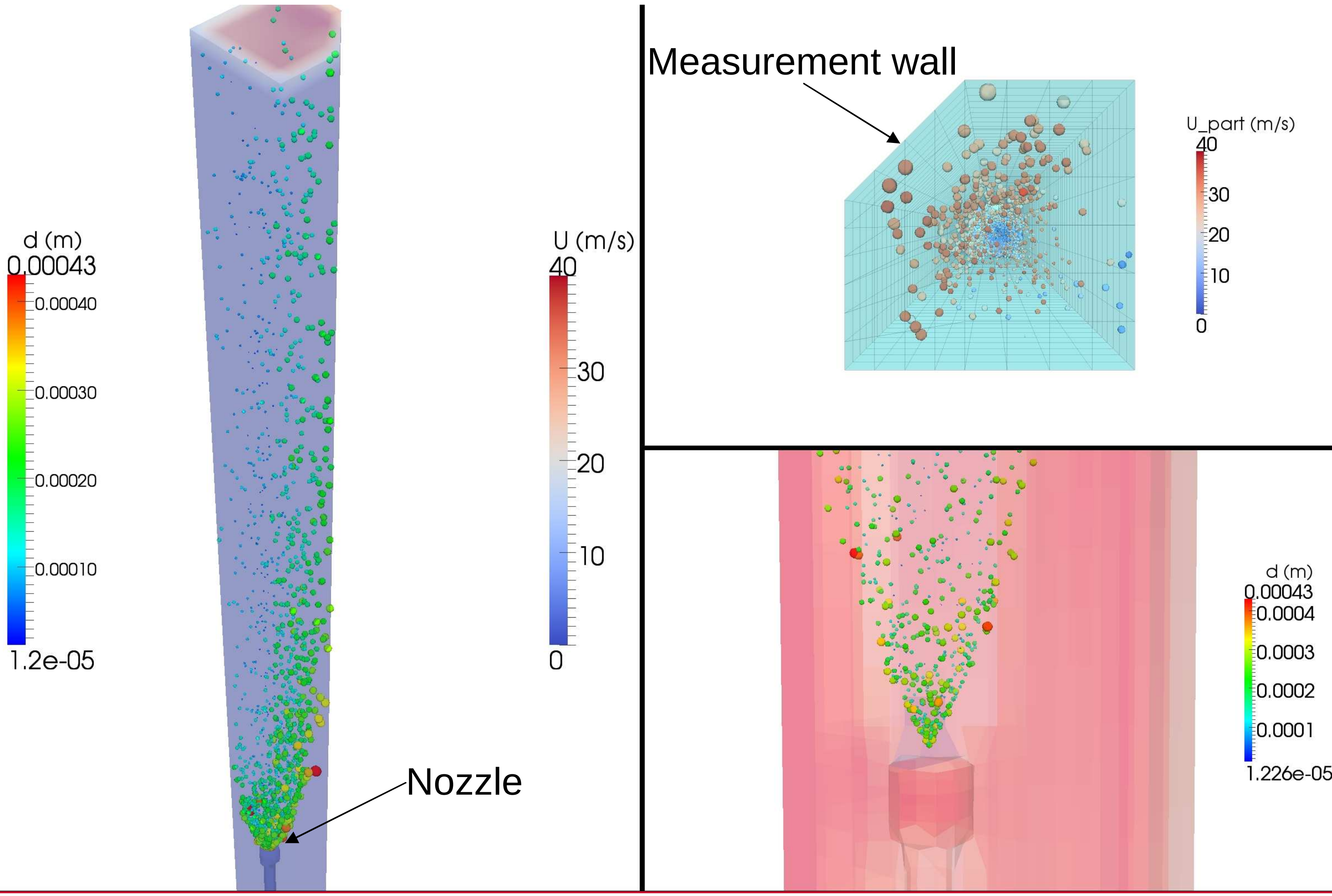
Droplet - film calculations

- For thin films a layer of one-cell-thickness can be calculated
- Example test case inclined plate
- BC at the top: deltaFilm=1.4 mm
- Model from FMGlobal[1] includes film transport, particle deposition, ejection and flow coupling (now also available in OF 2.0.x)
- Comparison with analytical Nusselt solution performed[1]



AREVA NP 1 Meredith, 2010. 5th OpenFOAM Workshop, www.openfoamworkshop.org.

Discrete particle simulation



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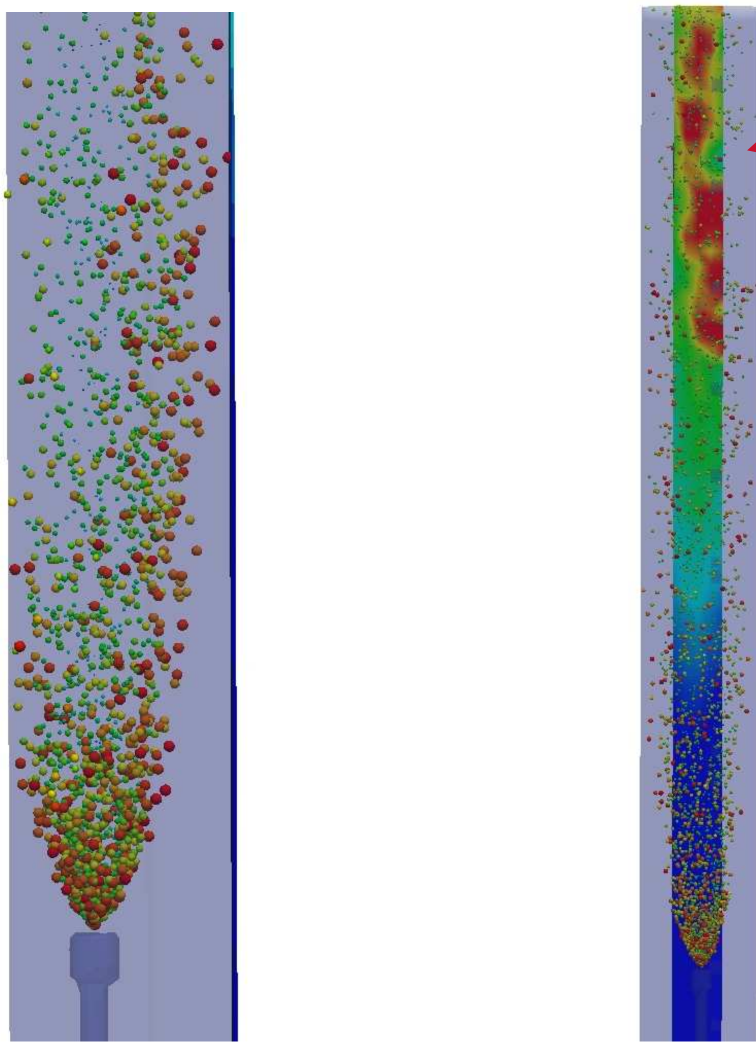
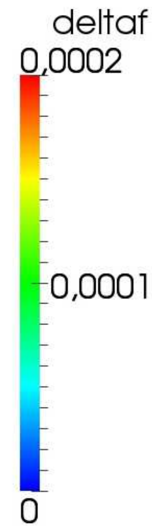
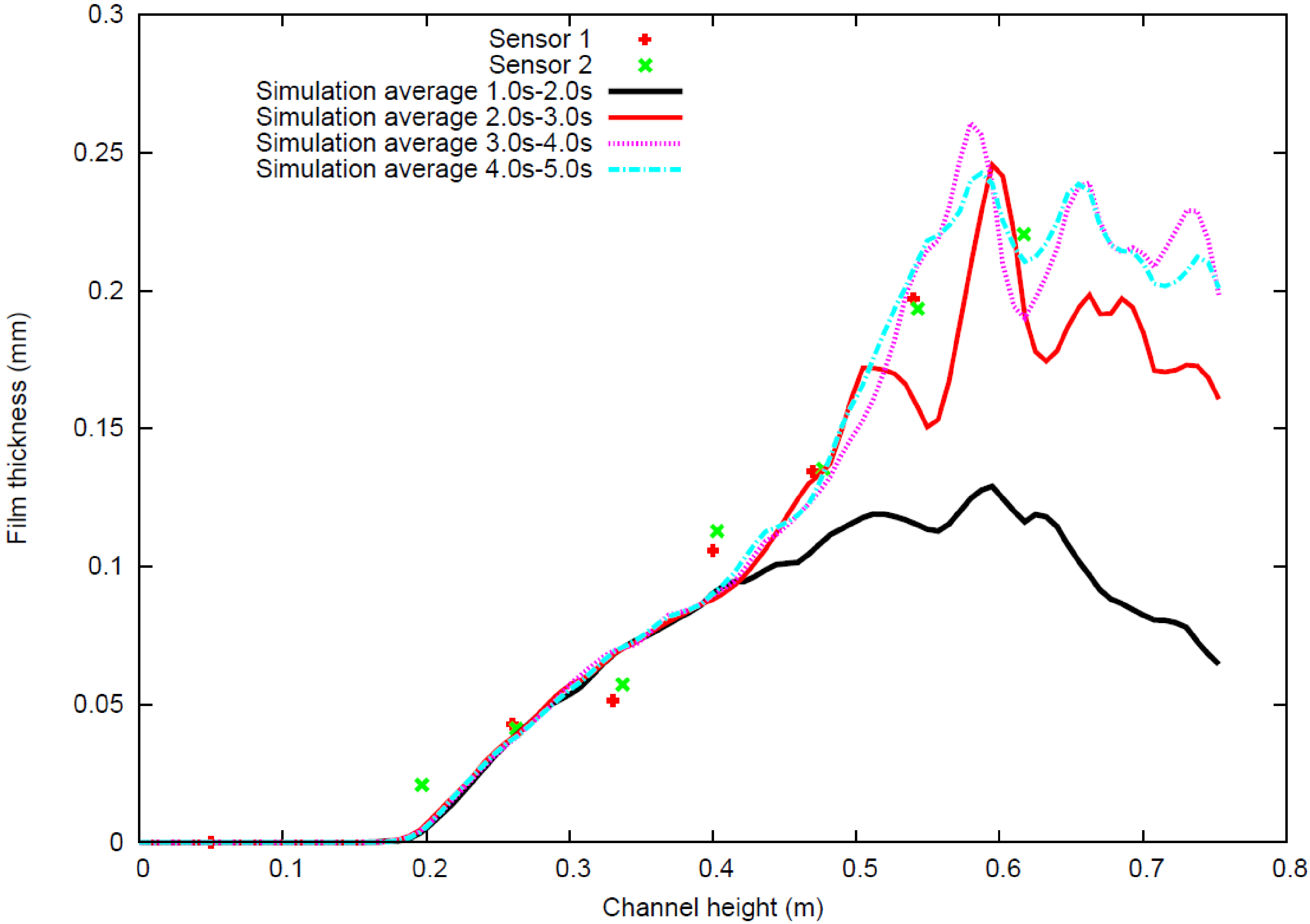
Discrete particle simulation



Wall film formation:
film thickness deltaf
in mm

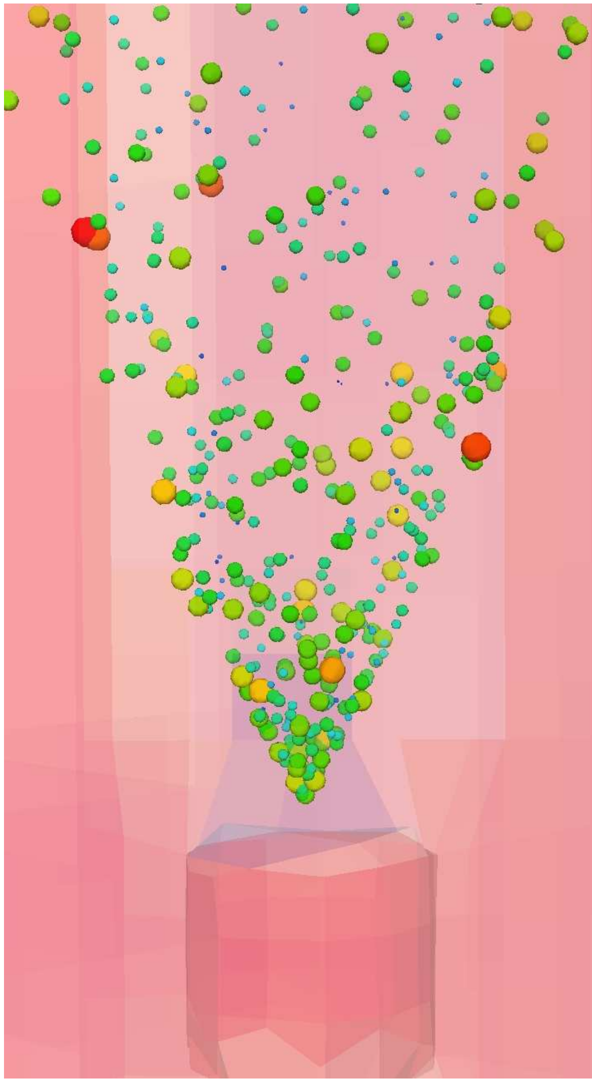


Film thickness results

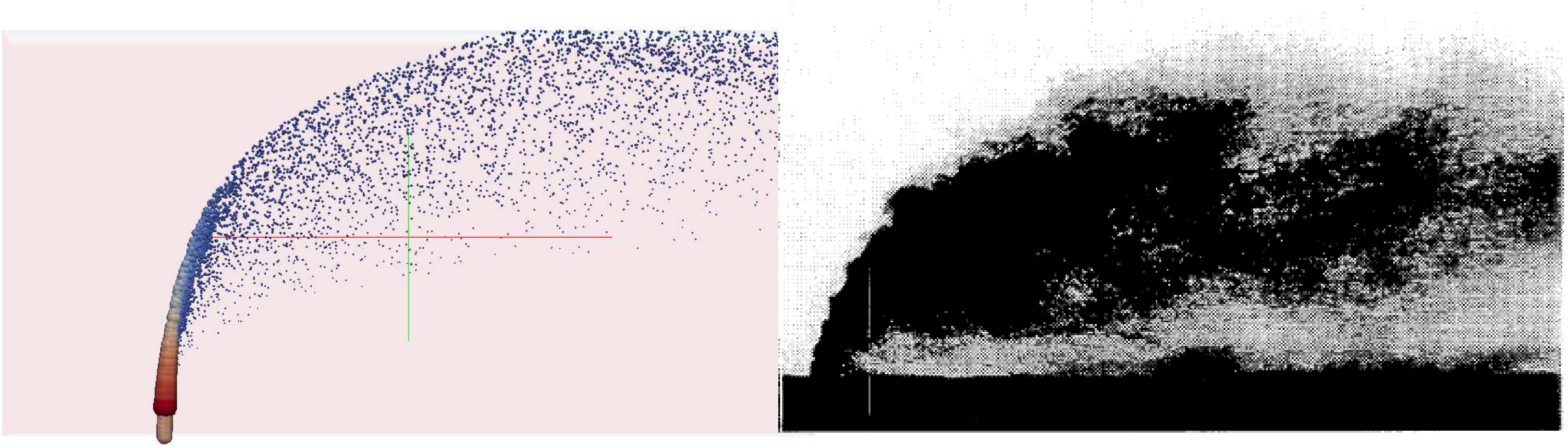


Conclusion
droplet and film simulation

- **Complex multi phase flow with LTP and film formation was calculated and validated with experimental results**
- **Has to be further investigated to make it a predictive tool (results are sensitive regarding grid size, nozzle spray, film shear stress)**
- **Future goal: use this functionality in advanced measurement techniques**

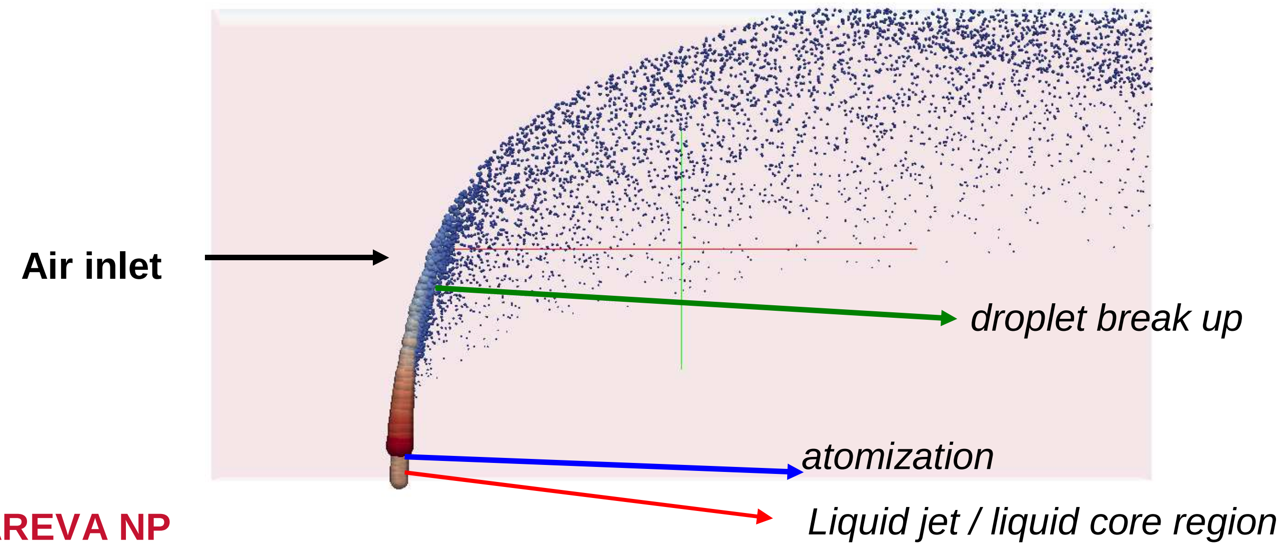


Examples of OpenFOAM application: Liquid Jet in Cross Flow (LJCF)



LJCF (Liquid Jet in Cross Flow)

- LJCF is chosen to investigate break up
- Experimental data used
  - Set "A" from: "Momentum Coherence Breakdown of Bending Atomizing Liquid Jet", R. Ragucci et al., 2003, Proceedings of the 9th ICLASS Conference.
  - Set "B" from: "Breakup and Atomization of a Kerosene Jet in Crossow at Elevated Pressure", Becker J. and Hassa C., 2002, Atomiztion and Sprays.
- Included processes: atomization, break up, droplet transport



$$\mathrm{We_{aero}} = \frac{\rho_g D_{\mathrm{inj}} u_g^2}{\sigma}$$

$$q = \frac{\rho_l w_{l,\mathrm{inj}}^2}{\rho_g u_g^2}$$

OpenFOAM Results LJCF Euler-Euler simulations

- **First calculations used Euler Euler framework of OpenFOAM (bubbleFOAM) and the data set A of Ragucci**
- **Techniques from [1] adapted for successful simulation:**
  - **BIM (Broadened Injection Model): artificially enlarging the injection diameter**
    - Avoid very small grid cells at the injection orifice
    - Avoid to get a very high volume fraction in the near field
  - **Liquid Column Model: reduced drag coefficient is used to calculate the drag force of the liquid column region**

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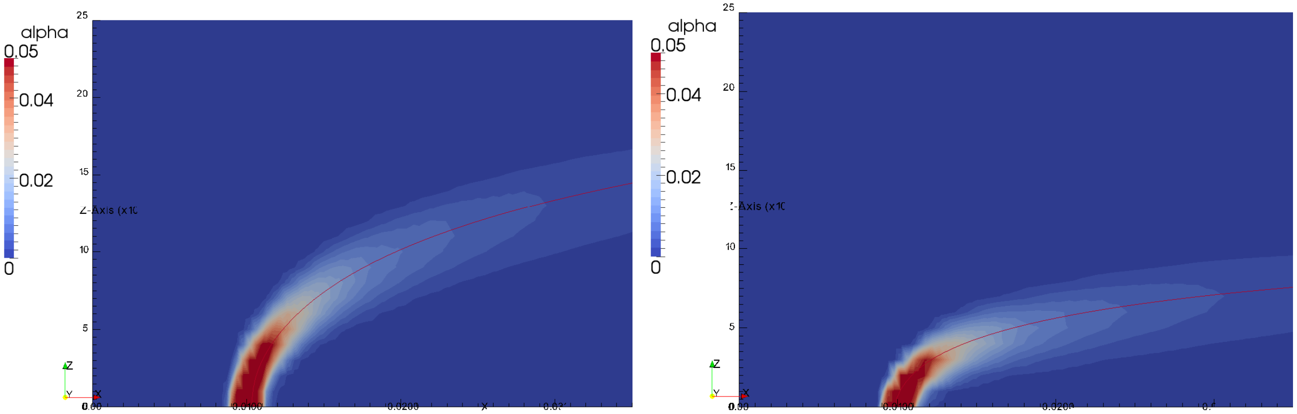
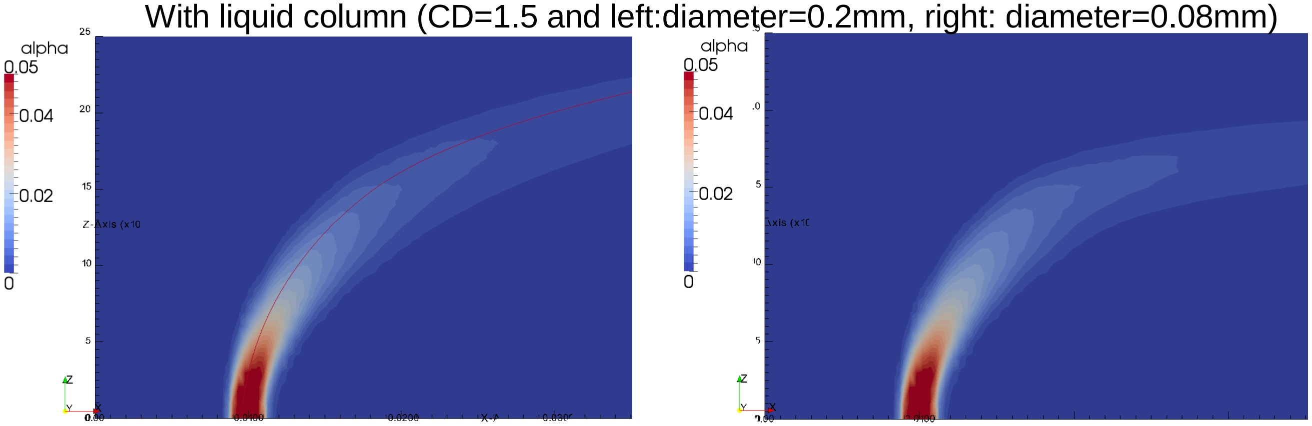
[1] Jaegle et al., Comparison of Euler-Euler and Euler-Lagrange methods for liquid jet injection in a cross flow.

LJCF penetration with Euler Euler (bubbleFOAM)

Without liquid column (CD=1.5 and left:diameter=0.2mm, right: diameter=0.08mm)



With liquid column (CD=1.5 and left:diameter=0.2mm, right: diameter=0.08mm)



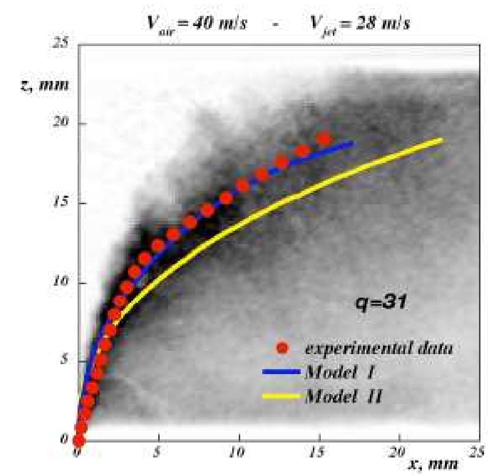


Figure: Experimental data for q=31

Figure: the volume fraction distribution from bubbleFoam,

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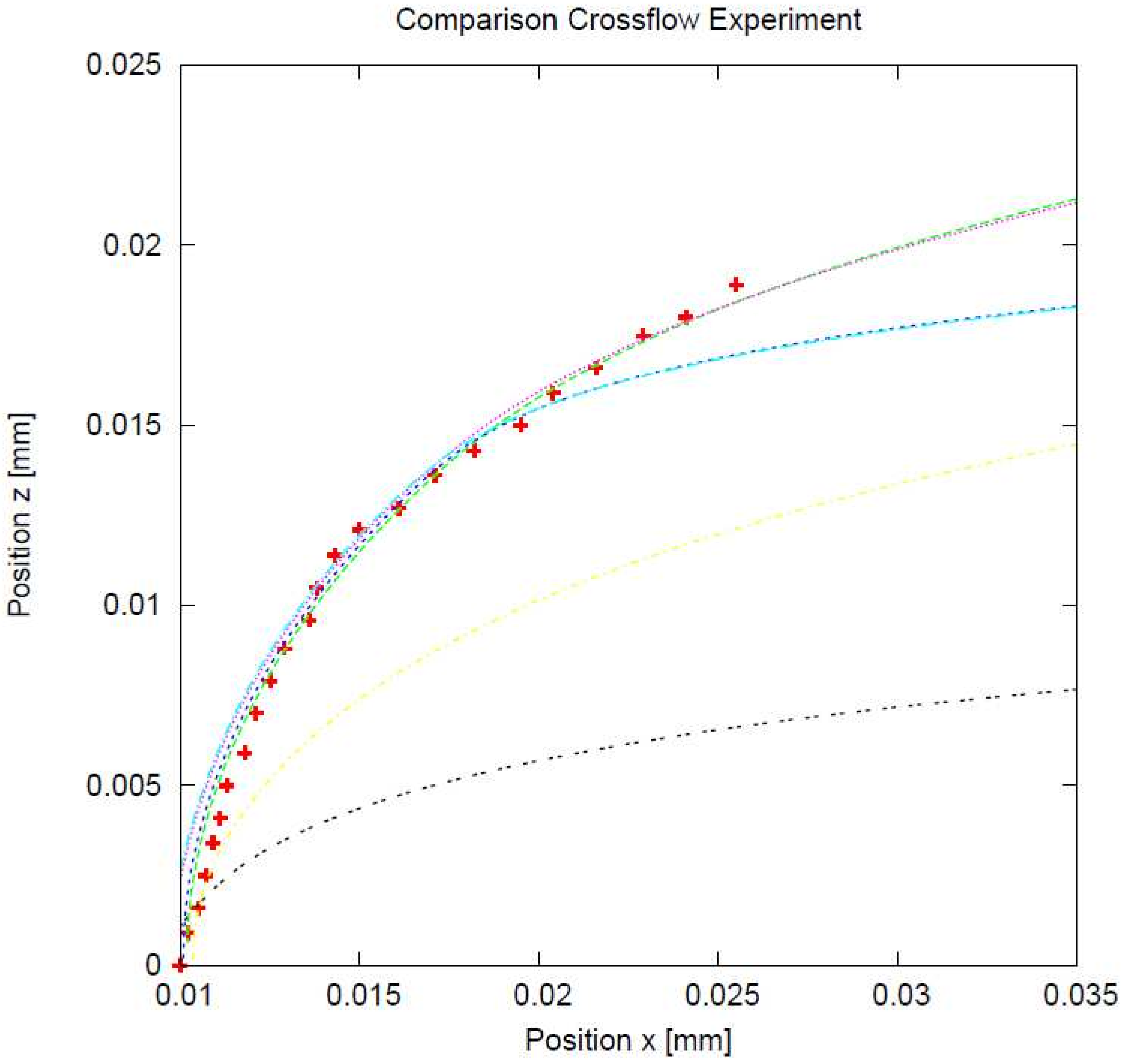
LJCF penetration with Euler Euler (bubbleFOAM)



Name	Mesh	Column Model /Cd	Particel Diameter for Cd
A_f_with_200	fine	Yes/CD=1.5	200 µm
B_f_with_80	fine	Yes/CD=1.5	80 µm
C_g_with_200	coarse	Yes/CD=1.5	200 µm
D_g_with_80	coarse	Yes/CD=1.5	80 µm
E_g_without_200	coarse	no	200 µm
F_g_without_80	coarse	no	80 µm

LJCF with Euler-Lagrange in OpenFOAM

- The recently introduced spray class of OF 2.0.x was used
- Three configurations from set B (kerosene jet) were simulated:

	p (bar)	u_g (m/s)	q (-)	w_l (m/s)
LJCF-B1	6	100	6	23.3
LJCF-B2	6	100	2	13.46
LJCF-B3	6	100	18	40.38

$$\mathrm{We}_{\mathrm{aero}} = \frac{\rho_g D_{\mathrm{inj}} u_g^2}{\sigma}$$

$$q = \frac{\rho_l w_{l,\mathrm{inj}}^2}{\rho_g u_g^2}$$

- A wide range of atomization models and break up models was tested

	ReitzKHRT	ReitzDiwakar	PilchErdman_Original	PilchErdman_Modified
InjectionModel	coneInjection RRD	coneInjection const. diameter	coneInjection const. diameter	coneInjection const. diameter
AtomizationModel	BlobSheet	LISA	LISA	LISA

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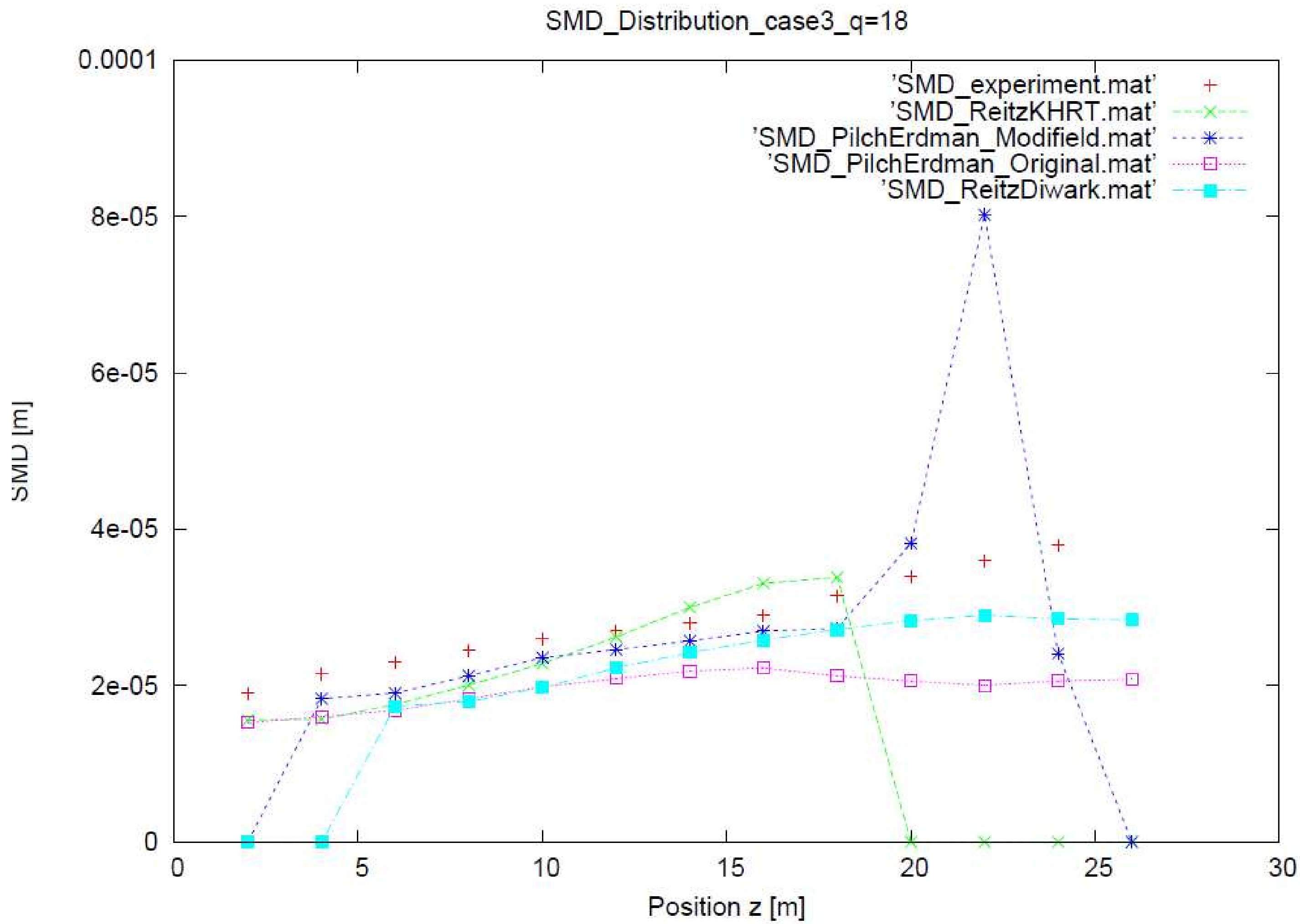
Results LJCF-B3 at the channel outlet

► Channel height vs. Sauter mean diameter (SMD)

$$SMD = \frac{\sum n_i \cdot d_i^3}{\sum n_i \cdot d_i^2}$$



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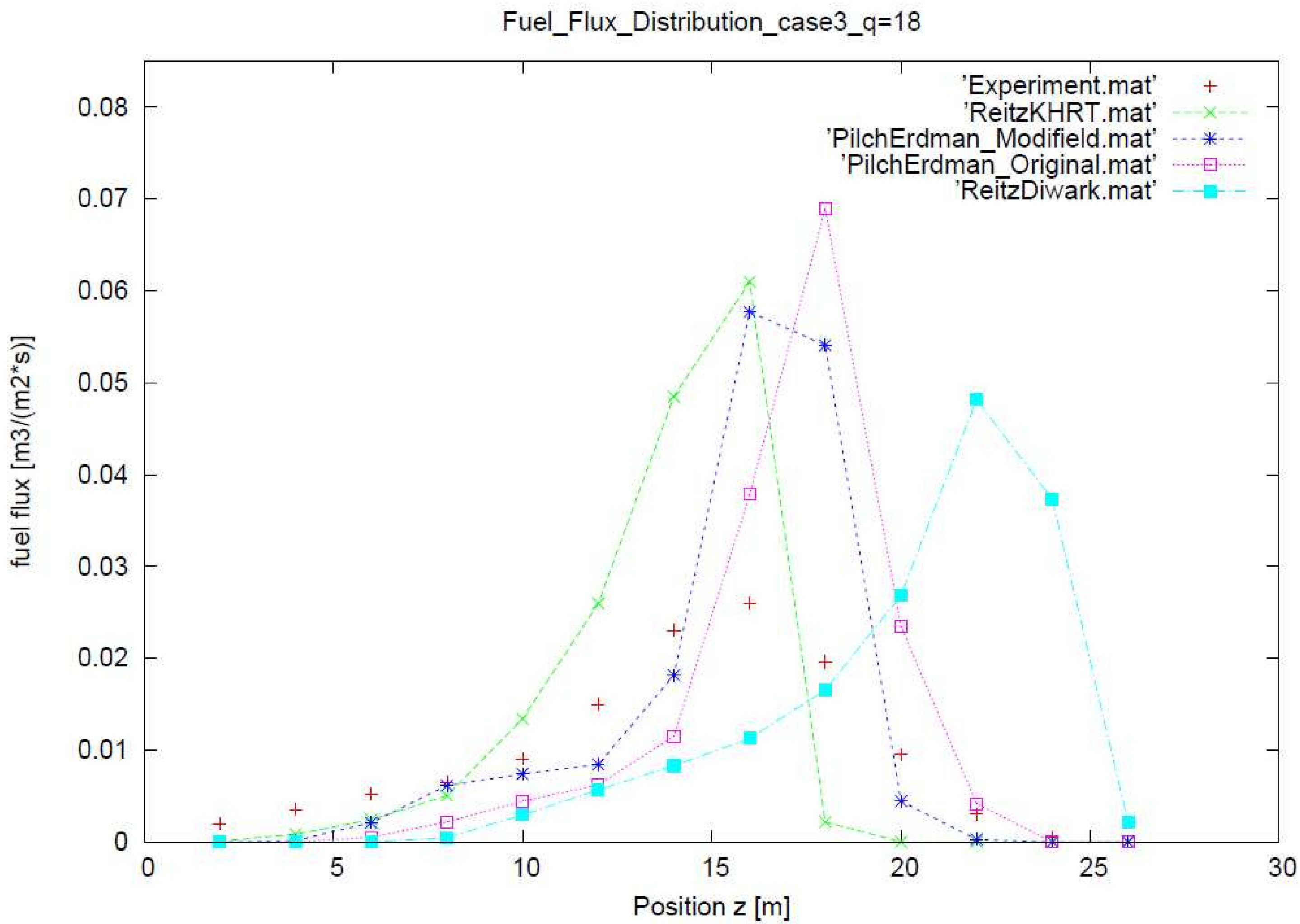
Results LJCF-B1 at the channel outlet

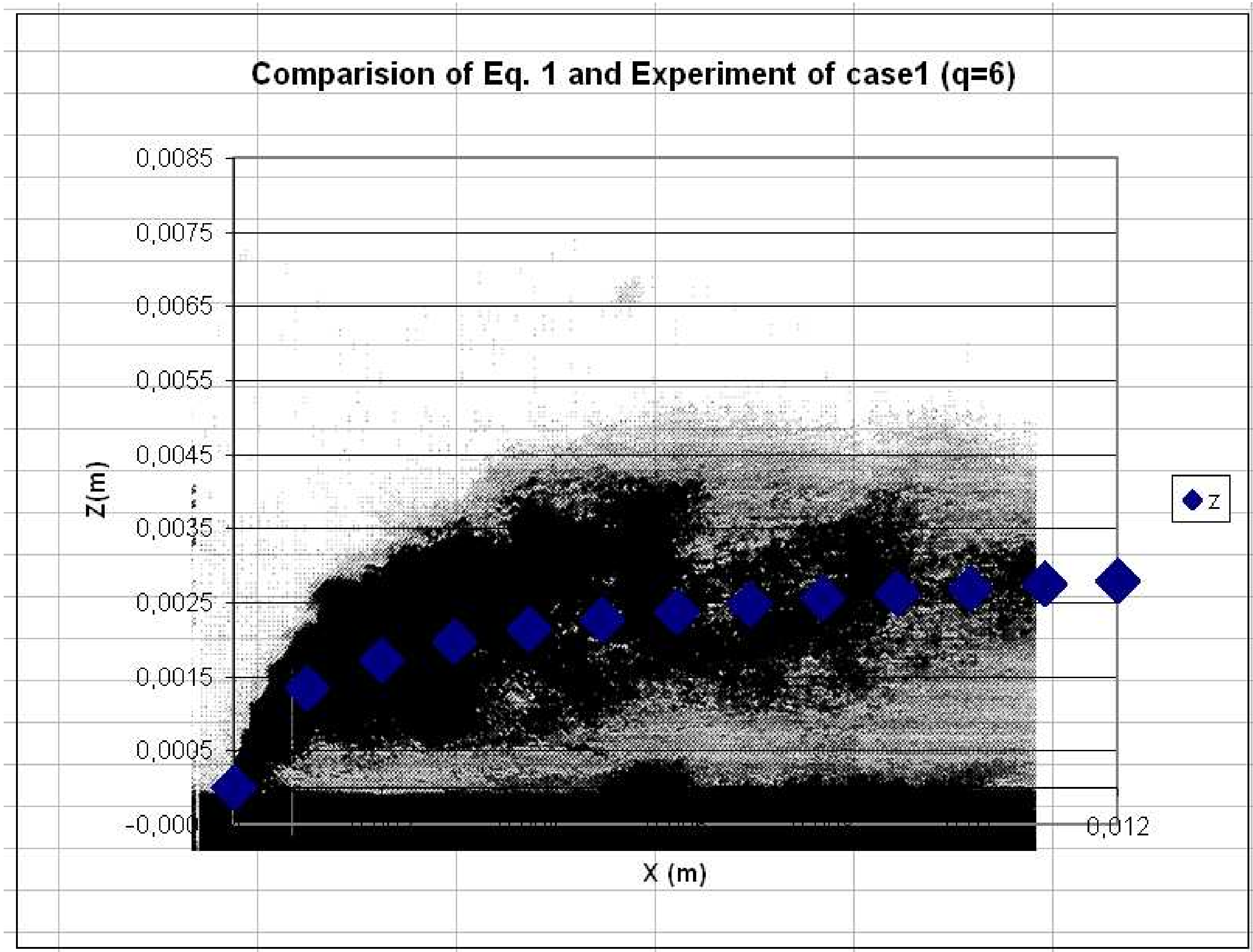
► Channel height vs. fuel volume flux

$$Fuel\_Flux = \frac{\sum n_i \cdot \frac{1}{6}\pi \cdot d_i^3}{Area \cdot \Delta t}$$



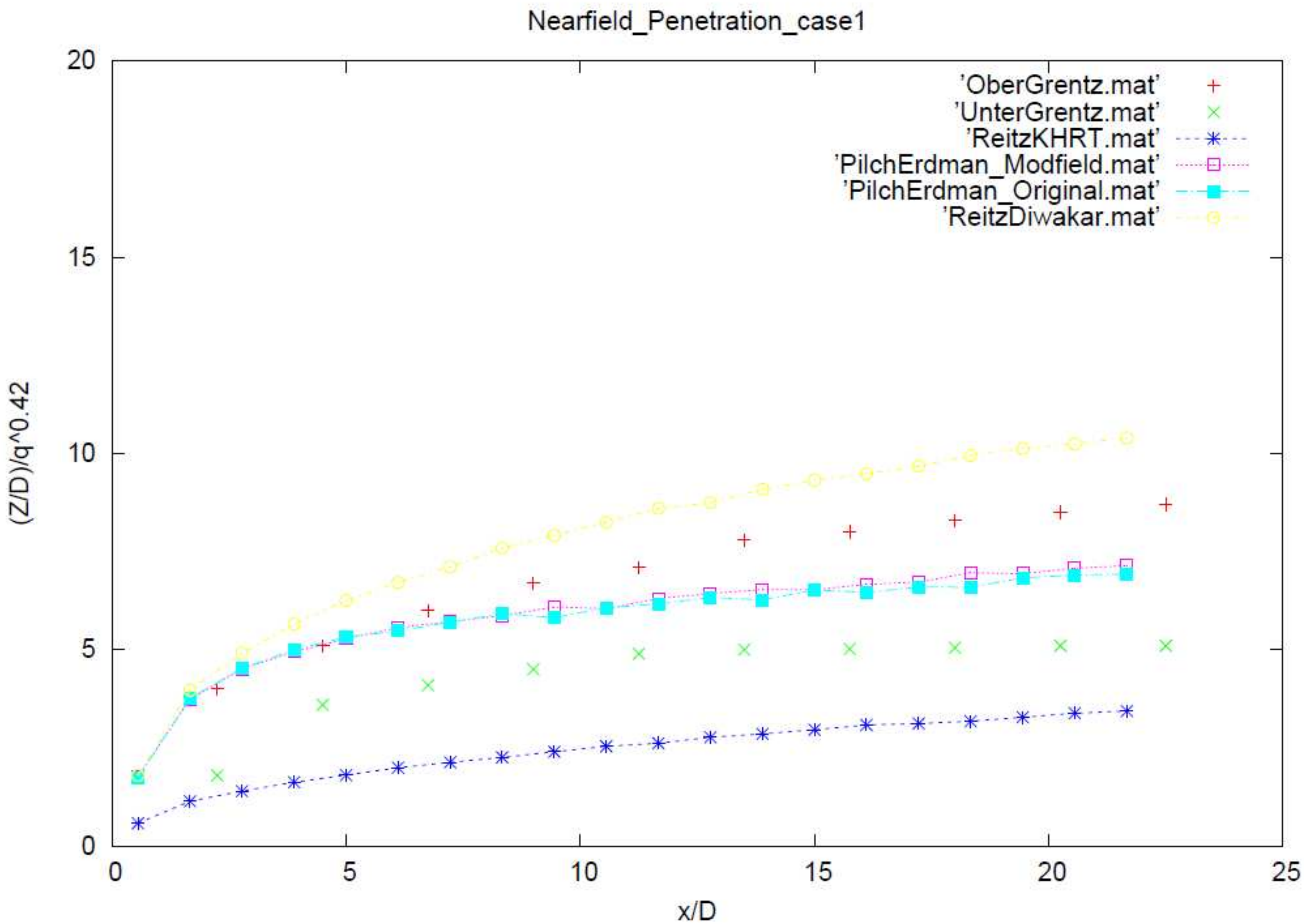
Near field penetration LJCF-B

► Used the correlation shown below with min and max values



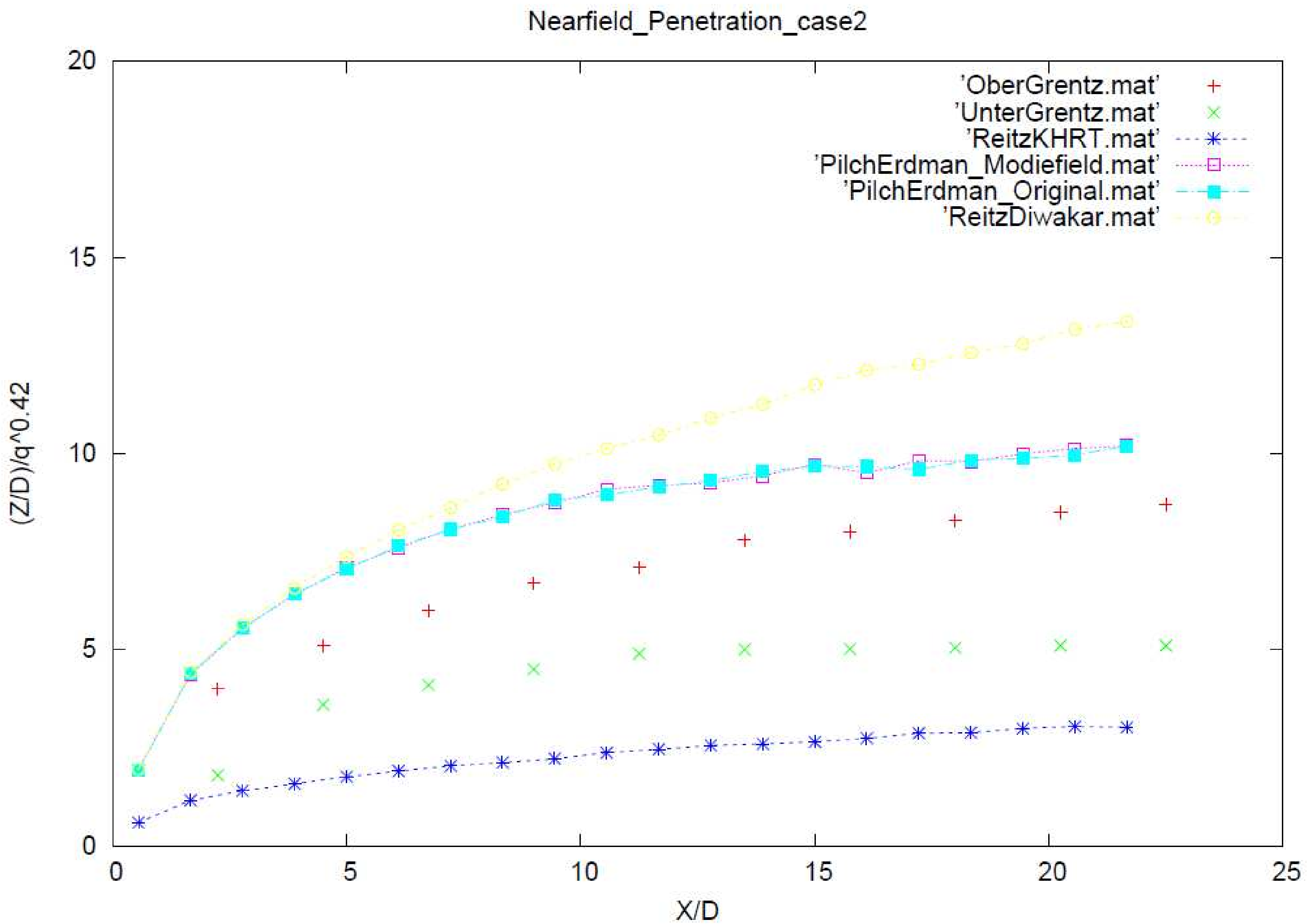
Near field penetration LJCF-B1

► Near field penetration



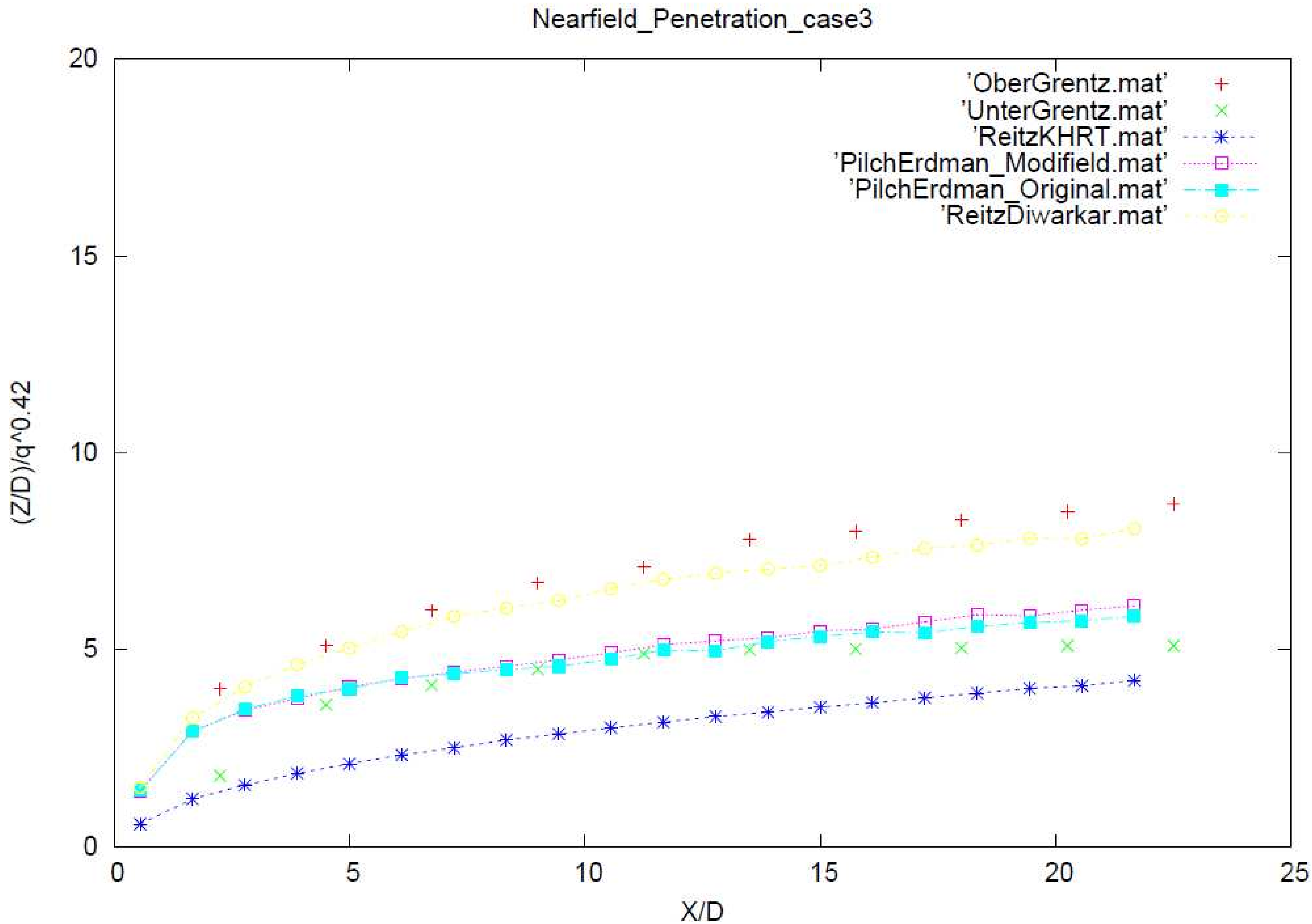
Near field penetration LJCF-B2

► Near field penetration

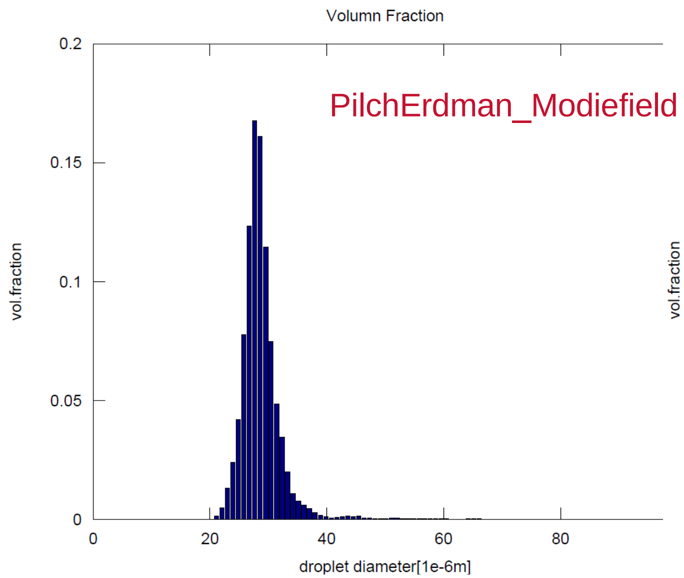


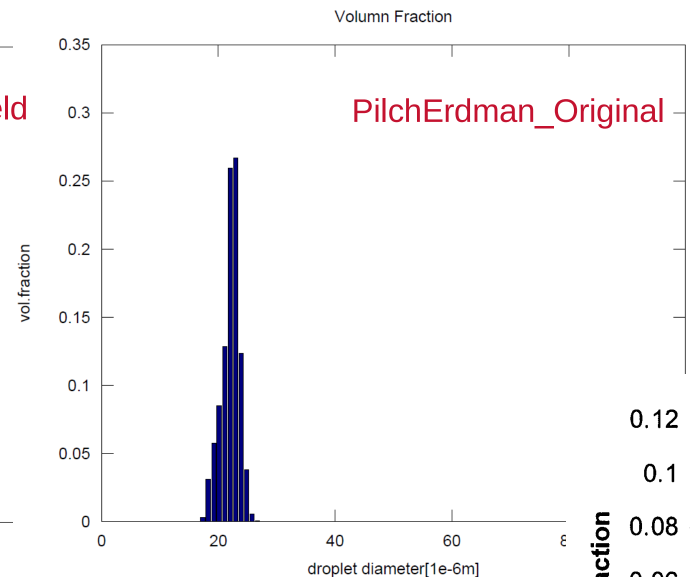
Near field penetration LJCF-B3

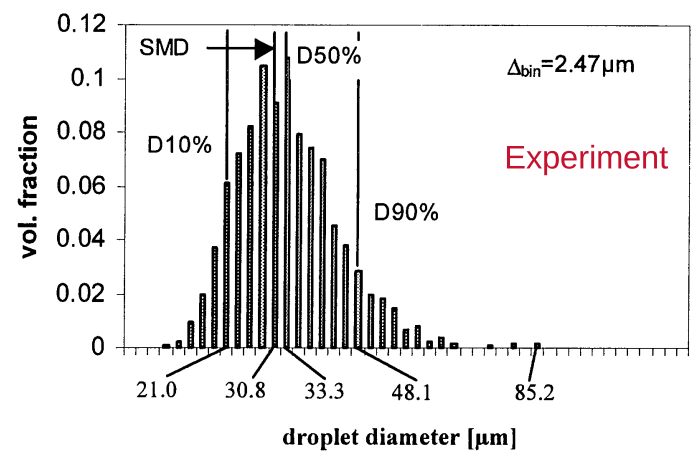
- ►Near field penetration

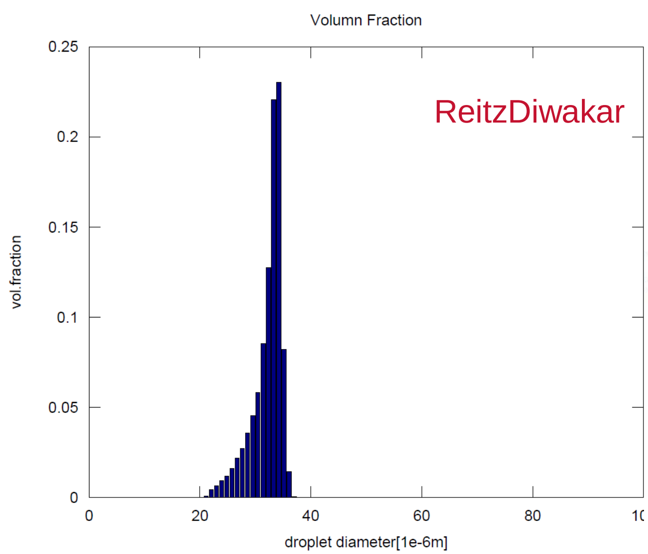


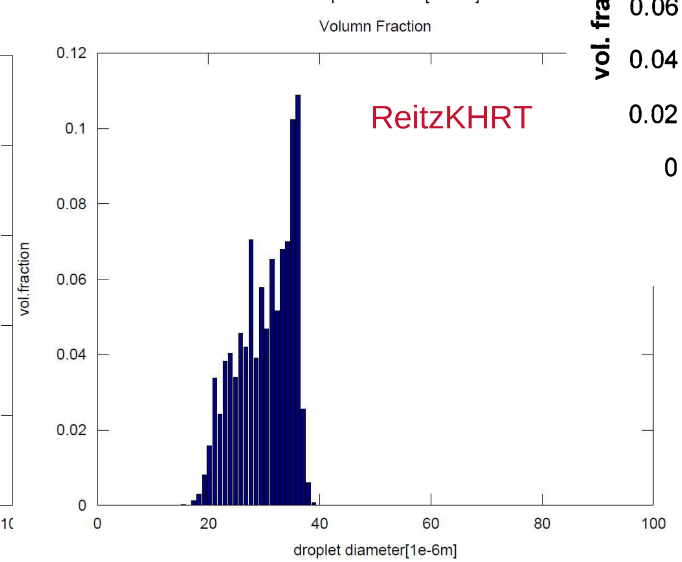
Droplet size distribution at the outlet LJCF-B1





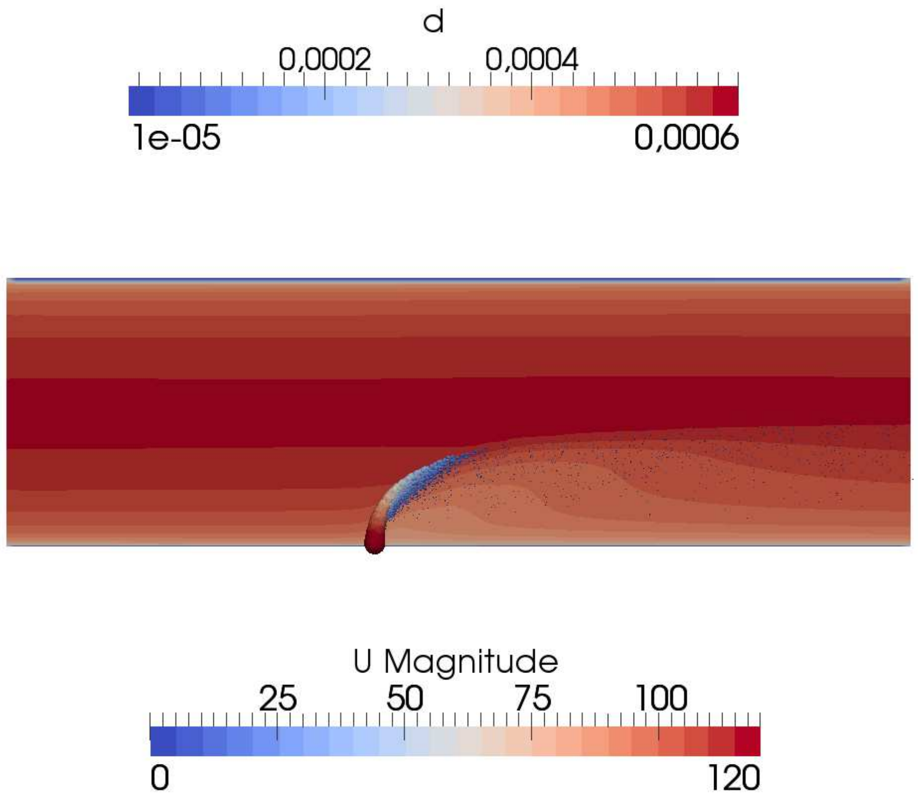






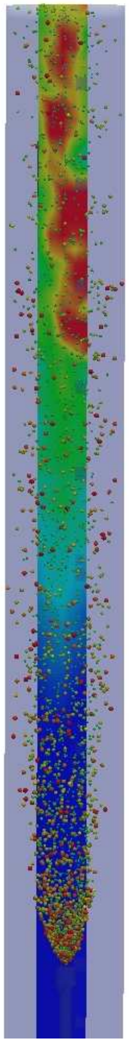
Conclusion validation of LJCF

- **Euler-Euler simulations with "quick" bubbleFoam simulation showed reasonable agreement**
- **Euler-Lagrange simulations showed good agreement but no model was able to fit all experiments perfectly**
  - **Particle size distribution was rendered best with extended Pilch Erdmann mod.**
  - **For penetration both Pilch Erdmann models did well**
  - **For higher q the quality of simulation results was better in general**
  - **LES techniques may achieve better results due to unsteady behavior**



Summary

- Many tasks within AREVA technical center can be done with the OpenFOAM toolbox
- Thin film module introduced with OpenFOAM 2.0.x shows promising results for a in house case
- LJCF simulations showed good agreement with results from literature



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End of presentation: AREVA thermo hydraulic testing capabilities and related OpenFOAM analysis

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