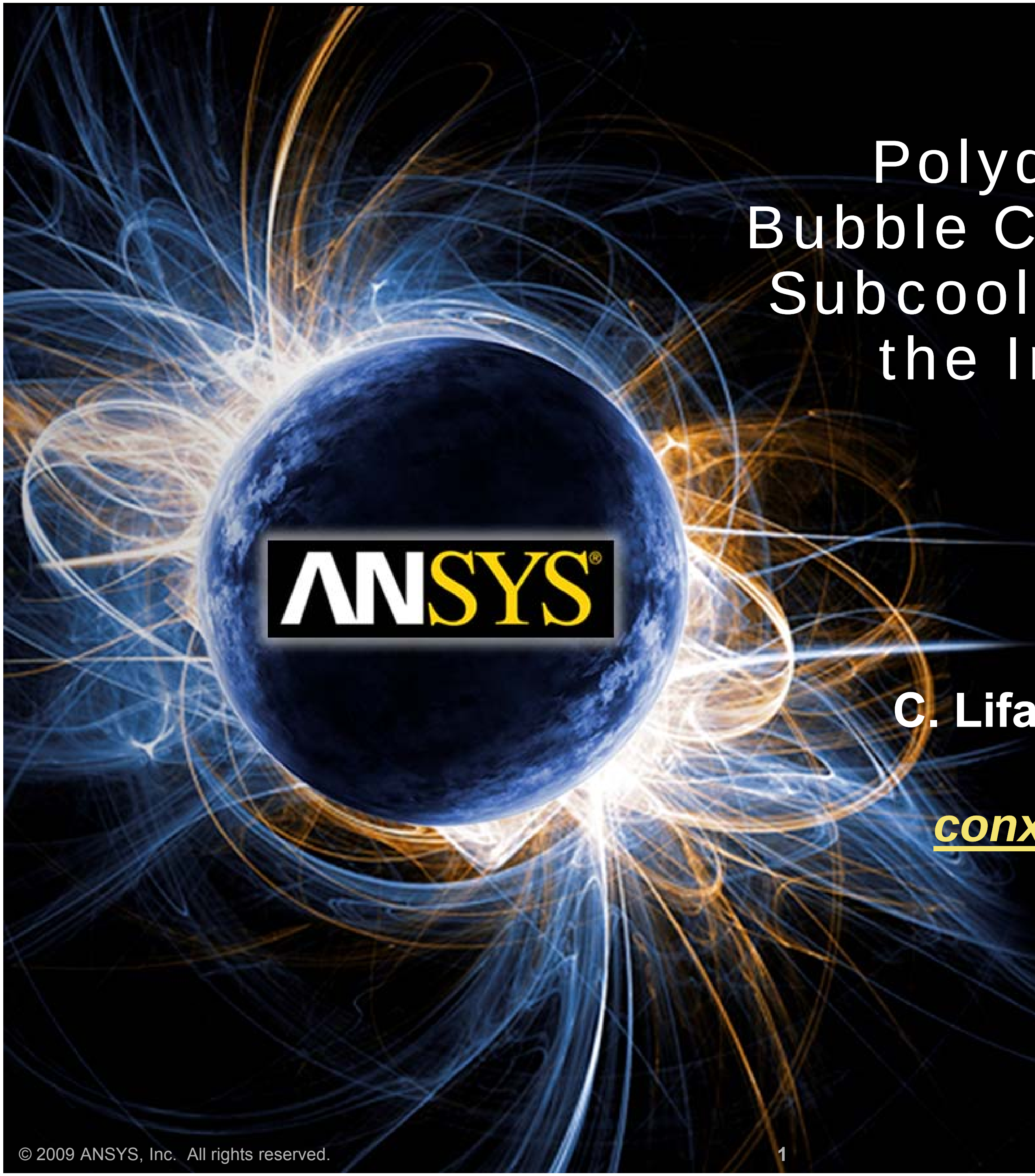


# Prediction of Polydisperse Steam Bubble Condensation in Subcooled Water using the Inhomogeneous MUSIG Model

**C. Lifante, T. Frank, A. Burns**
***ANSYS***
***conxita.lifante@ansys.com***

**D. Lucas, E. Krepper**
***Forschungszentrum Dresden-Rossendorf***

# Outline

- **Motivation**
- **Model description**
- **Validation**
  - – TOPFLOW facility & condensation experiment
  - – CFD ⇔ Experiment comparison
    - Previous approaches vs. extended MUSIG
    - Improvements in the extended MUSIG simulations
- **Summary & conclusions**

# Outline

- **Motivation**
- **Model description**
- **Validation**
  - TOPFLOW facility & condensation experiment
  - CFD ⇔ Experiment comparison
    - Previous approaches vs. extended MUSIG
    - Improvements in the extended MUSIG simulations
- **Summary & conclusions**

# Motivation

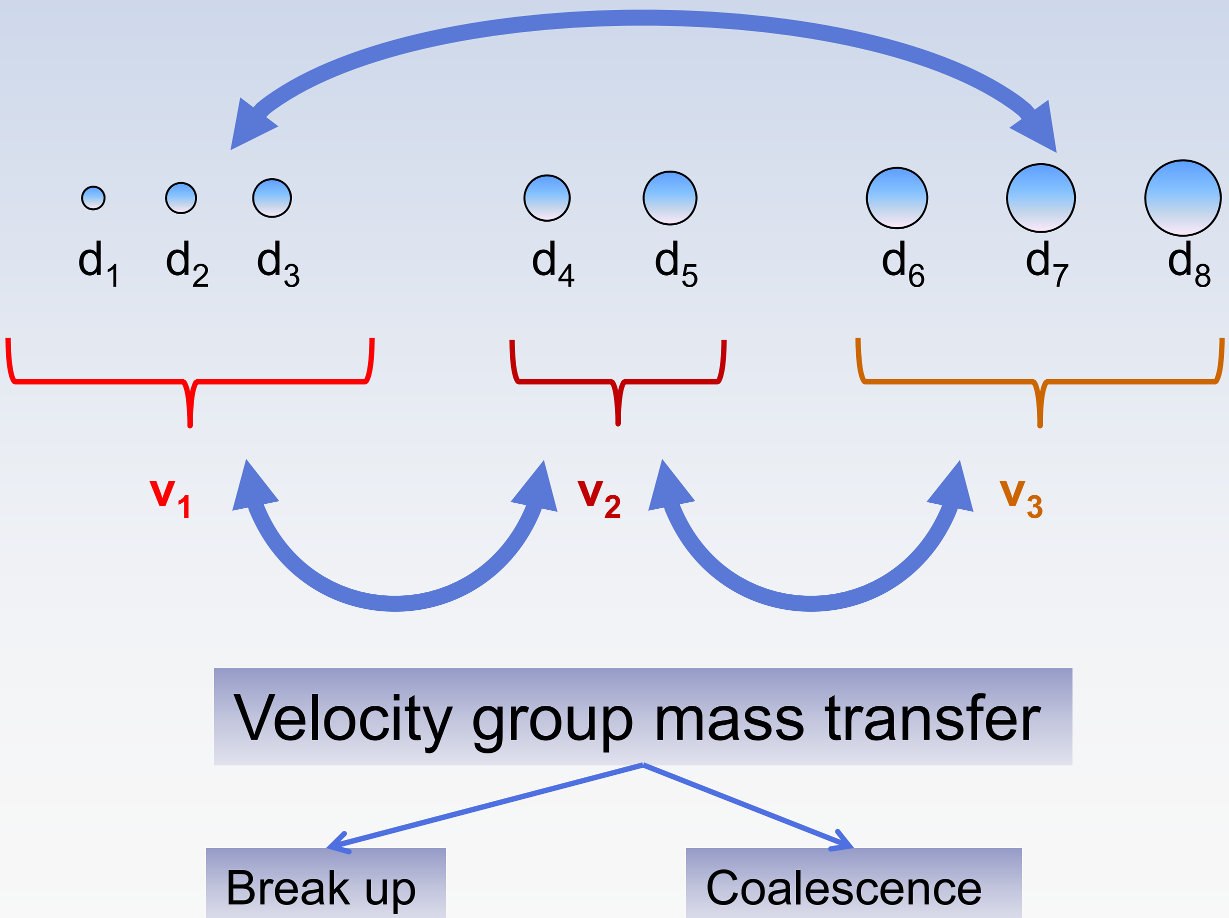
- **NRS applications:**
  – Subcooled boiling in nucl. react fuel assemblies
  – Steam injection into pools
  – Steam bubble entrainment in subcooled liquids by impinging jets
- **Cond./evap. rates depend on IAD → bubble size distribution**
- **Need of polydispersed inhomogeneous simulations**
- **Need to deal with phase change effects**

# Outline

- Motivation
- **Model description**
- Validation
  - TOPFLOW facility & condensation experiment
  - CFD ⇔ Experiment comparison
    - Previous approaches vs. extended MUSIG
    - Improvements in the extended MUSIG simulations
- Summary & conclusions

# Standard Inhomog. MUSIG Model

- **Polydisperse fluids**




- Small bubbles move with the fluid phase
- Large bubbles are more influenced by buoyancy
- Lift coefficient changes its sign at a critical size; depends on $\sigma(p,T)$

# Standard Inhomog. MUSIG Model

- **MUSIG setup:**
  - Definition of the initial diameter classes ($d_i$)
    - Mass classes used
  - Definition of velocity groups ($v_j$)
    - Homogeneous/Inhomogeneous
    - Which $d_i$ belong to each $v_j$
  - 1 size fraction equation for each bubble diameter
  - 1 momentum equation for each velocity group

# Model Extension description

New terms

- **Basic population balance equations**

$$\frac{dn(m,\vec{r},t)}{dt} = \frac{\partial}{\partial t} n(m,\vec{r},t) + \frac{\partial}{\partial \vec{r}}\left(U(m,\vec{r},t)n(m,\vec{r},t)\right) + \frac{\partial n(m,\vec{r},t)}{\partial m}\frac{\partial m(\vec{r},t)}{\partial t} = B_B - D_B + B_C - D_C$$

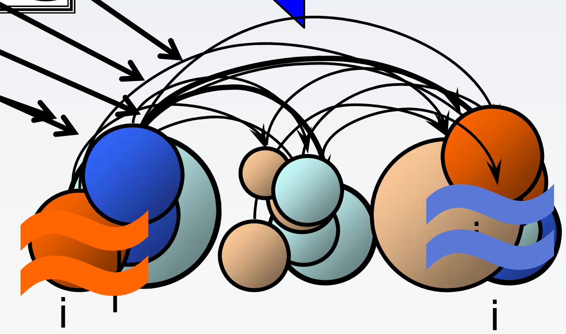
Bubble number density

Breakup/Coalescence terms

- **Size fraction equations**

$$\boxed{\frac{\partial}{\partial t}(\rho_i r_d f_i) + \frac{\partial}{\partial x^j}(\rho_i r_d U_i^j f_i) = S_{B_B} - S_{D_B} + S_{B_C} - S_{D_C} + S_i}$$

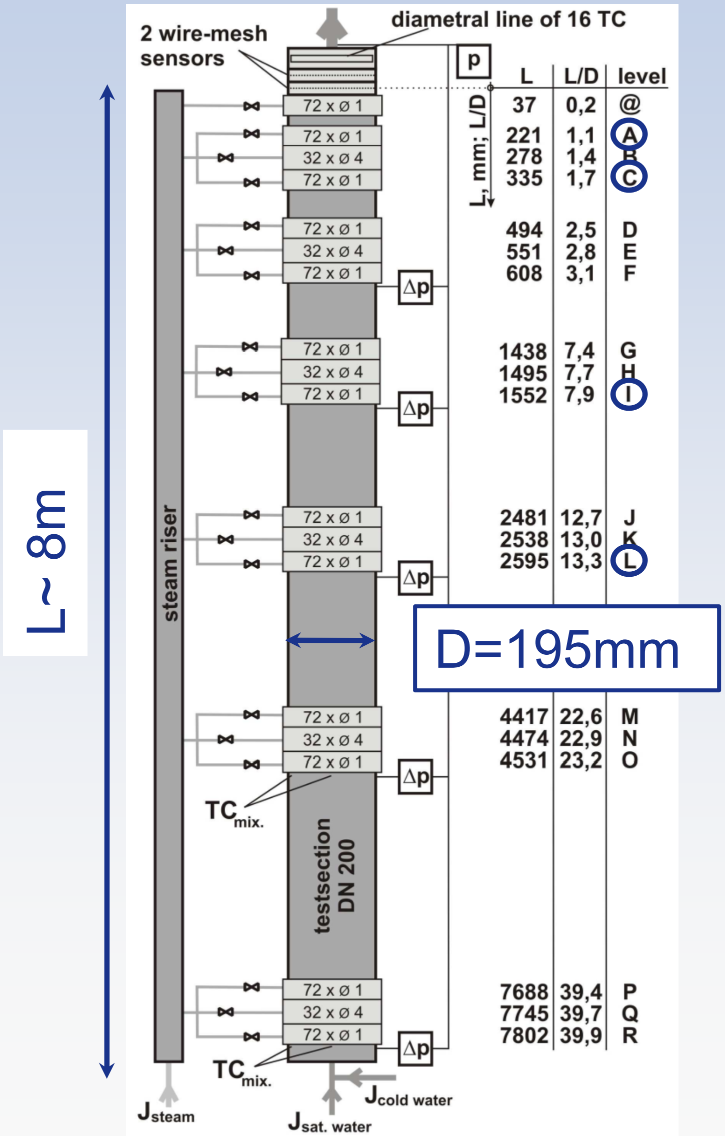
$$S_i = \begin{cases} \dfrac{m_i}{m_i - m_{i-1}}\Gamma_i - \dfrac{m_i}{m_{i+1} - m_i}\Gamma_{i+1} & \text{for evaporation} \\[2ex] \dfrac{m_i}{m_i - m_{i-1}}\Gamma_{i-1} - \dfrac{m_i}{m_{i+1} - m_i}\Gamma_i & \text{for condensation} \end{cases}$$

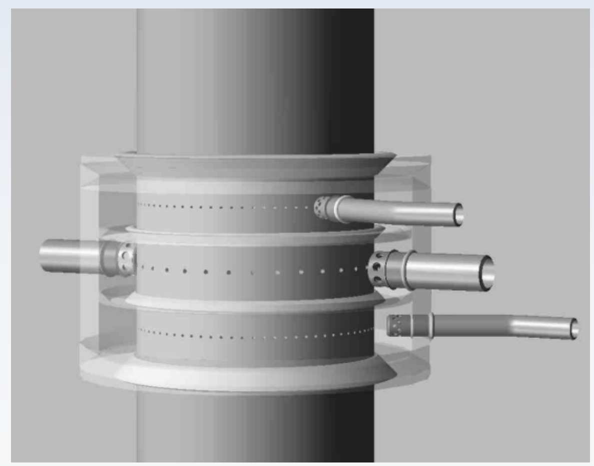


# Outline

- Motivation
- Model description
- **Validation**
  - TOPFLOW facility & condensation experiment
  - CFD $\Leftrightarrow$ Experiment comparison
    - Previous approaches vs. extended MUSIG
    - Improvements in the extended MUSIG simulations
- Summary & conclusions

# TOPFLOW Test Facility @ FZD

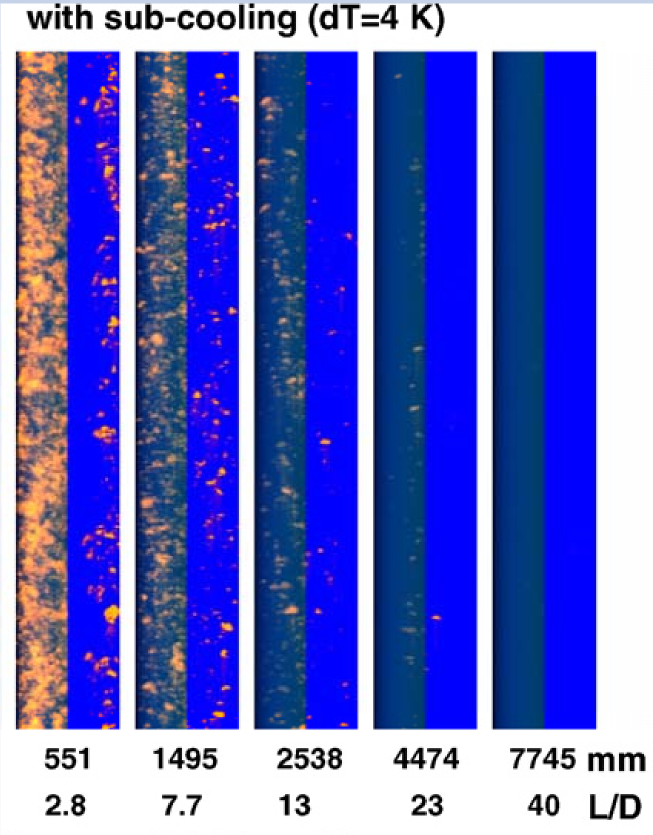


*Courtesy of FZD*

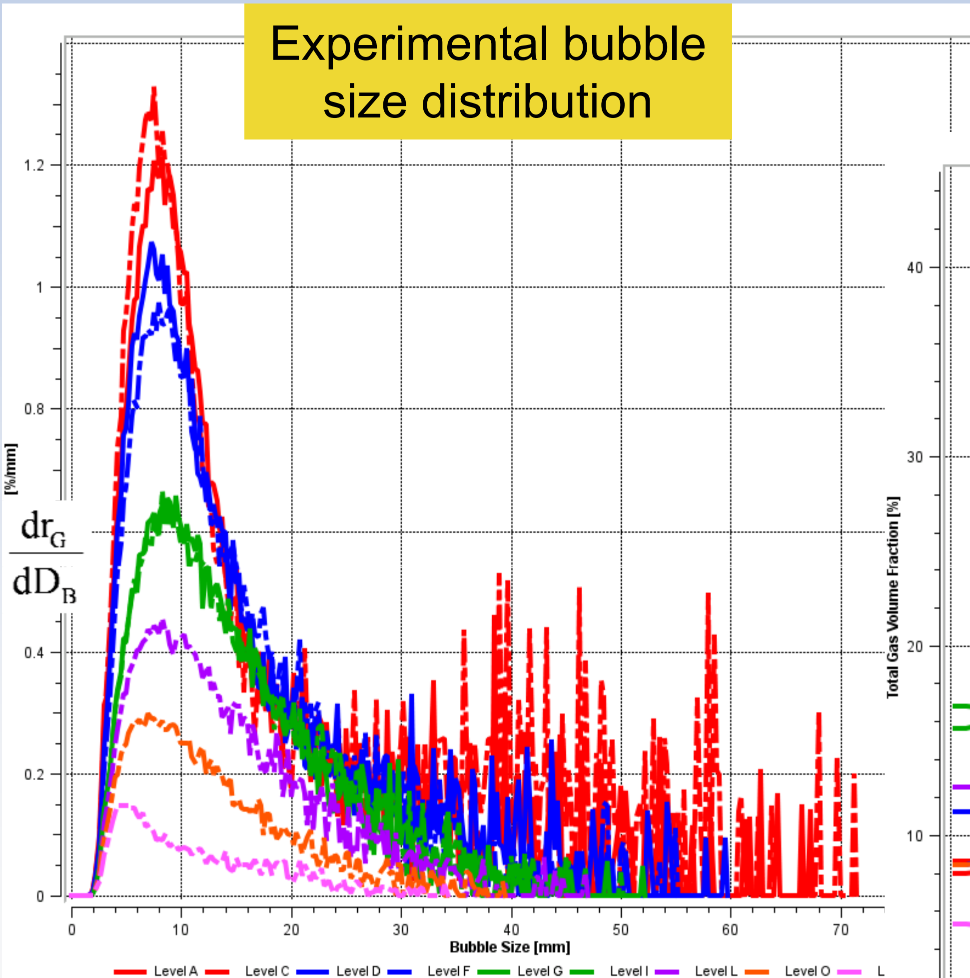
# Condensation Test Case

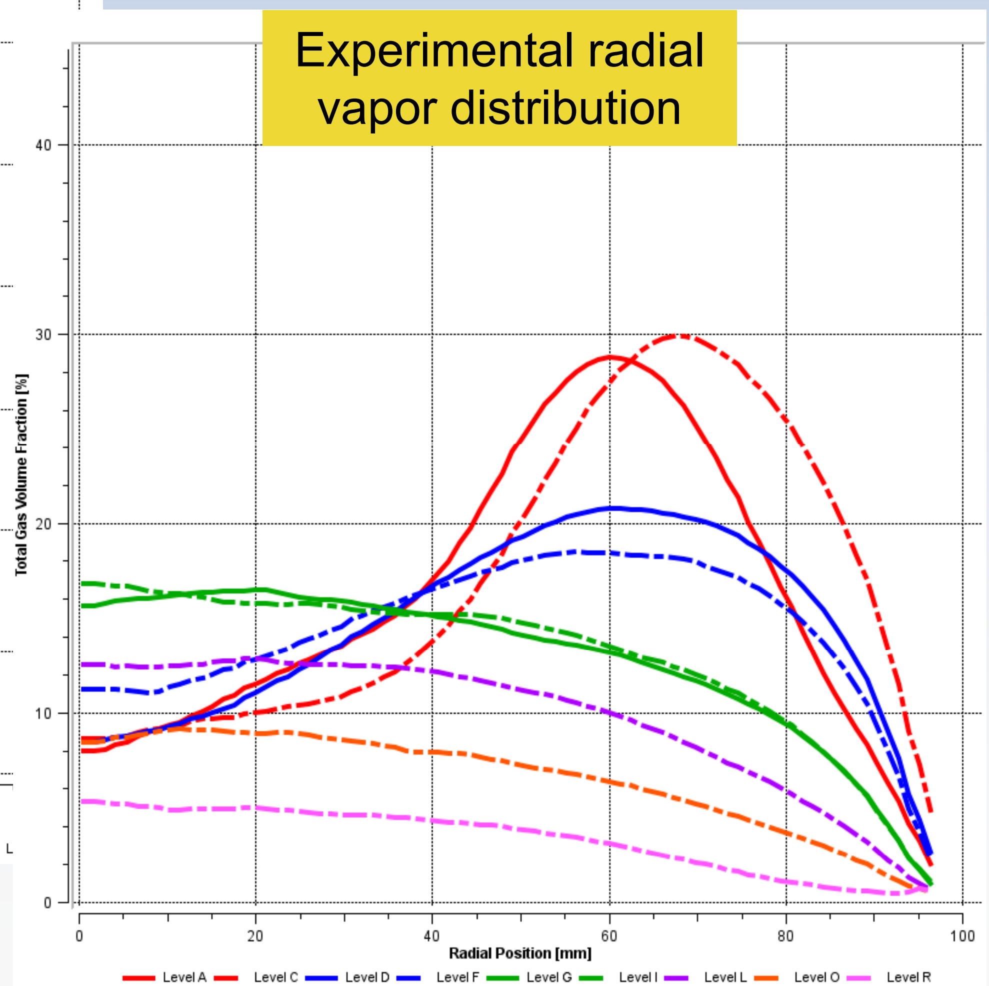
- **P=2 [MPa]**
- **$J_w$=1.0 [m/s]**
- **$J_s$=0.54 [m/s]**
- **$T_s$=214.4 [°C]**
- **$T_w$=210.5 [°C] → $\Delta T_w$=3.9 [K]**
- **$D_{inj}$ = 1 [mm]**
- **Detailed experimental data:**
  - Bubble size distribution
  - Radial steam volume fraction distribution




Dirk Lucas, Horst-Michael Prasser: "*Steam bubble condensation in sub-cooled water in case of co-current vertical pipe flow*",
Nuclear Engineering and Design, Volume 237, Issue 5, March 2007, Pages 497-508

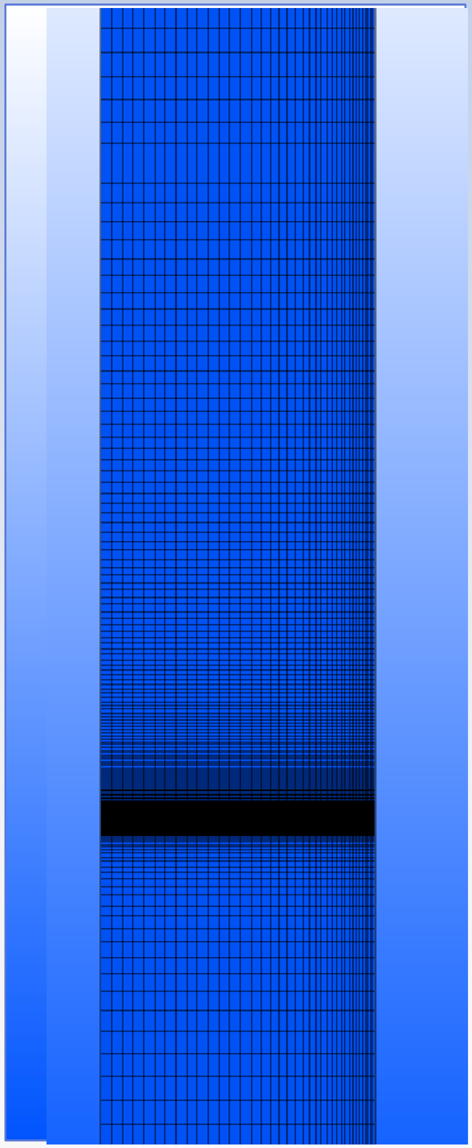
# Condensation Test Case



# Numerical Setup

- **1/6 of geometry simulated, 60°**
- **Symmetry b.c.**
- **260.442 elements***
- **12 x Injection nozzles modeled by SOURCE POINTS**
  - $D_{inj}$ modified (4mm) for $v_{inj}$
- **SST turbulence model**
- **$F_{drag}$, $F_{lift}$, $F_{TD}$ considered**



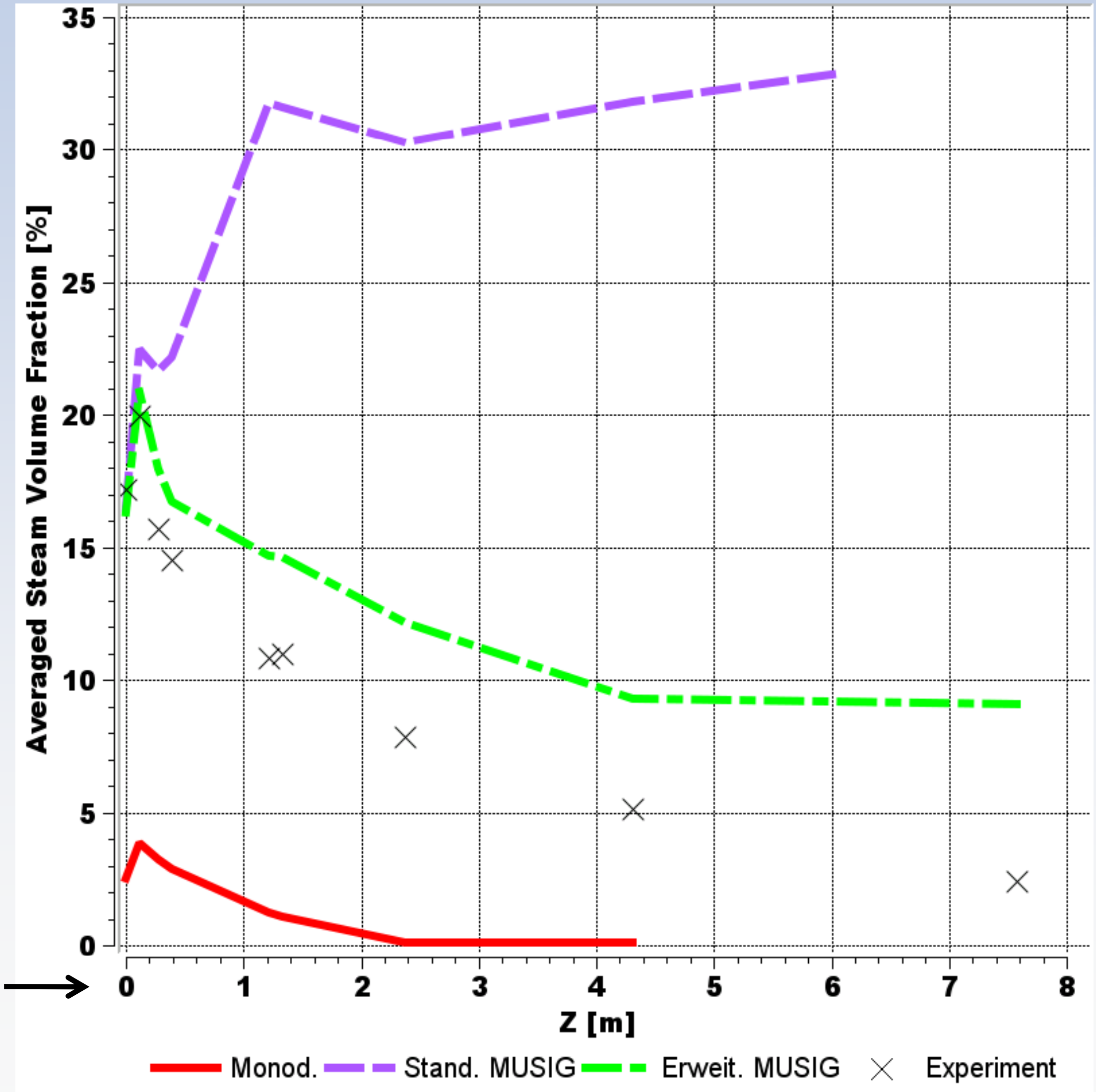
# Physical Model Setup

- **Locally Monodisperse**
  - Particle diameter: constant number of bubbles

    $d_P = d_P(d_P|_{Inlet}, N_P|_{Inlet})$
- **Standard MUSIG & Extended MUSIG**
  - 25 bubble size classes
  - 3 velocity groups:

    0→3 [mm],3→6 [mm], 6→30 [mm]
  - Break up model: Luo & Svendsen ($F_B$=0.025)
  - Coalescence model: Prince & Blanch ($F_C$=0.05)

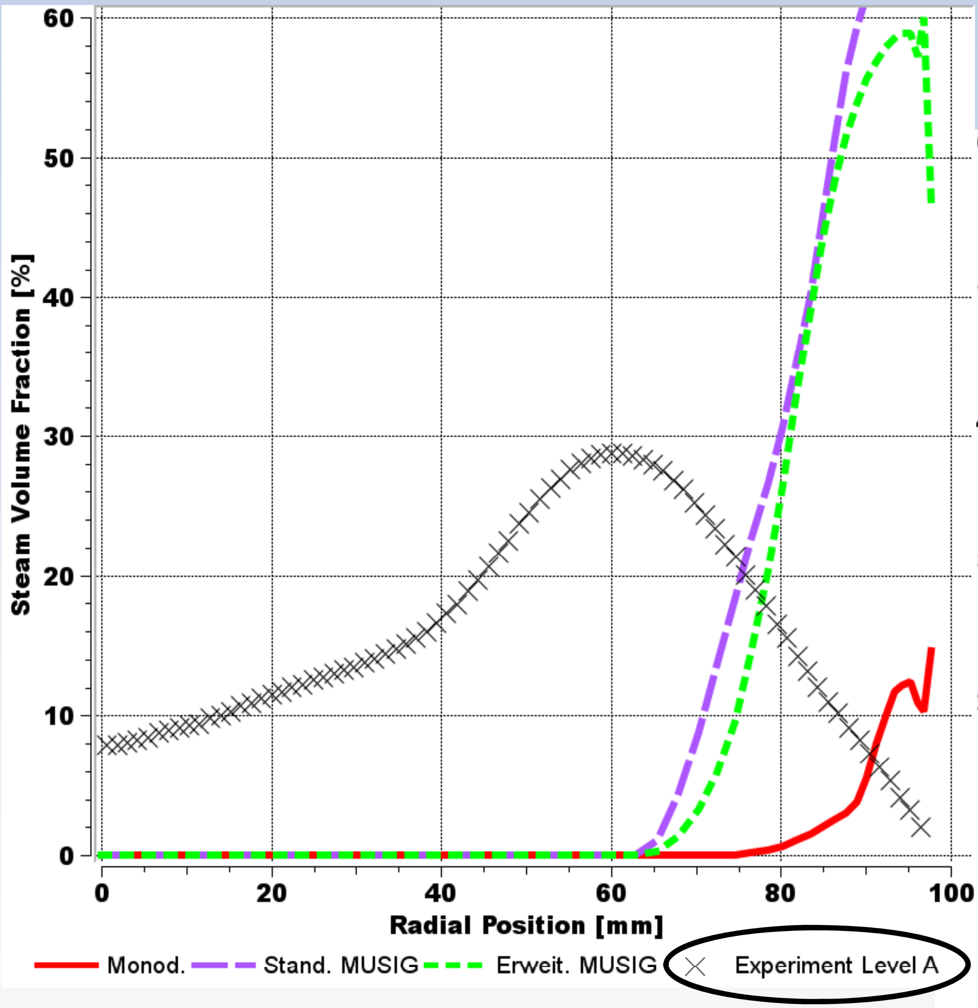
# Results: Vertical averaged steam distribution

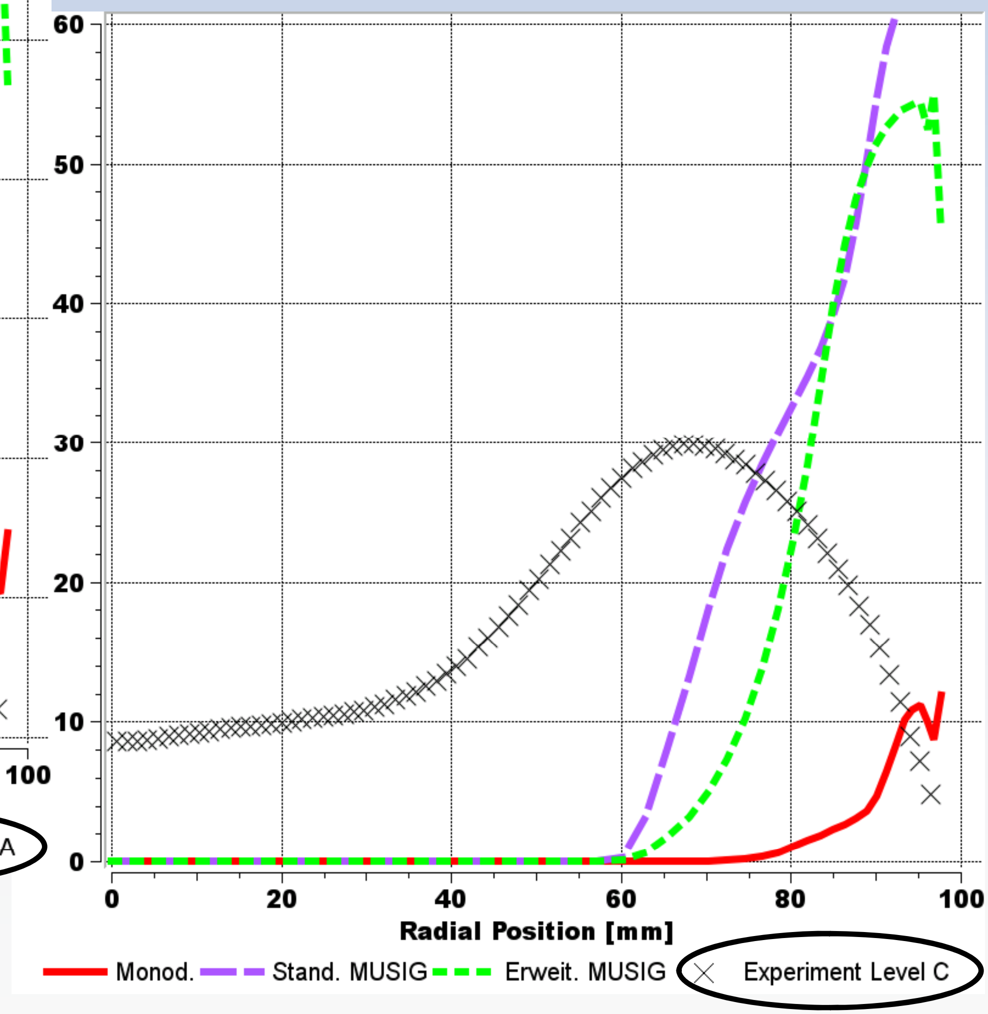



Injection nozzles →

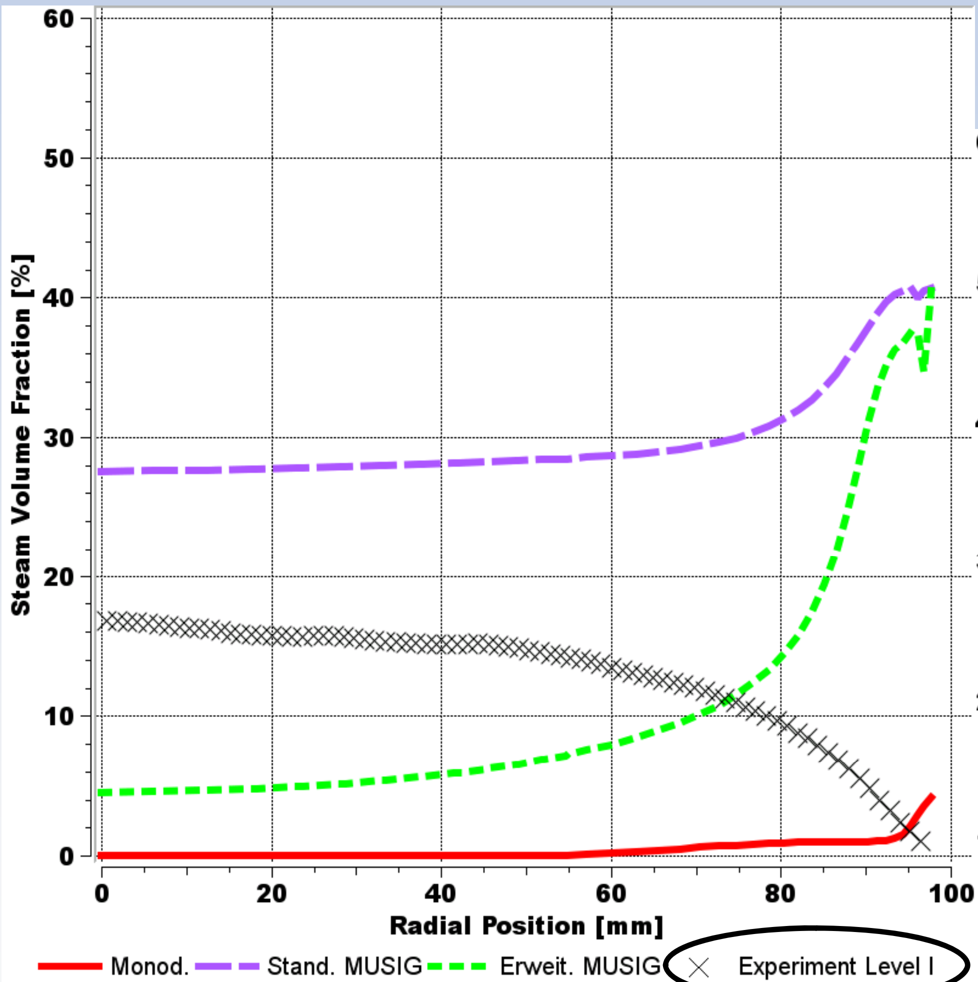
← Pipe end

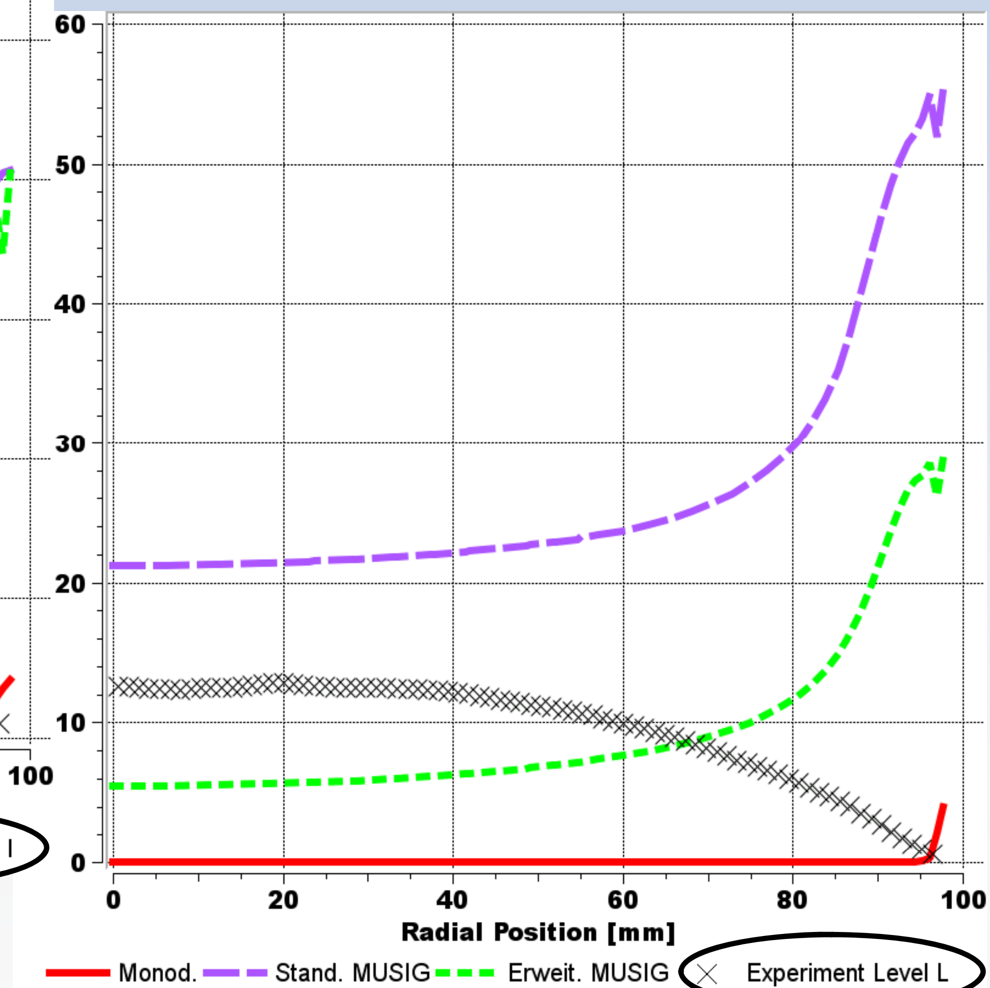
# Results: Radial steam distribution



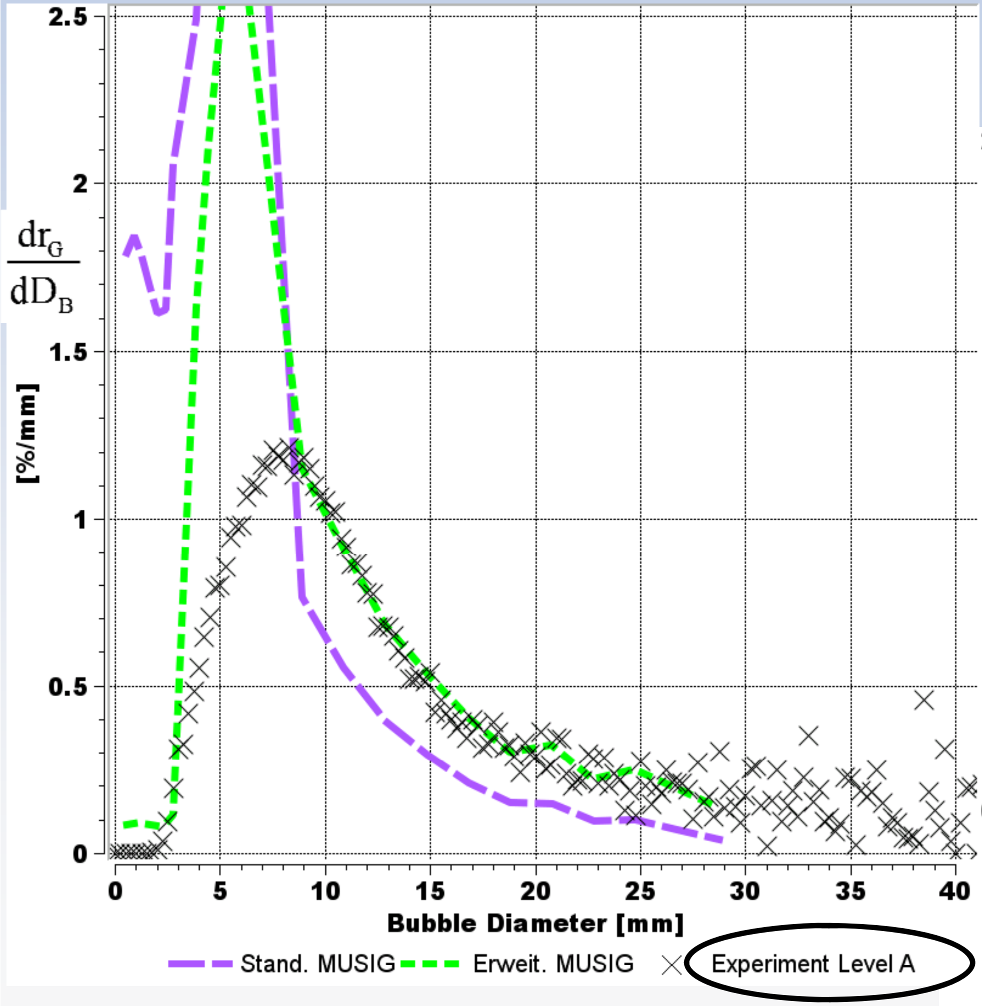



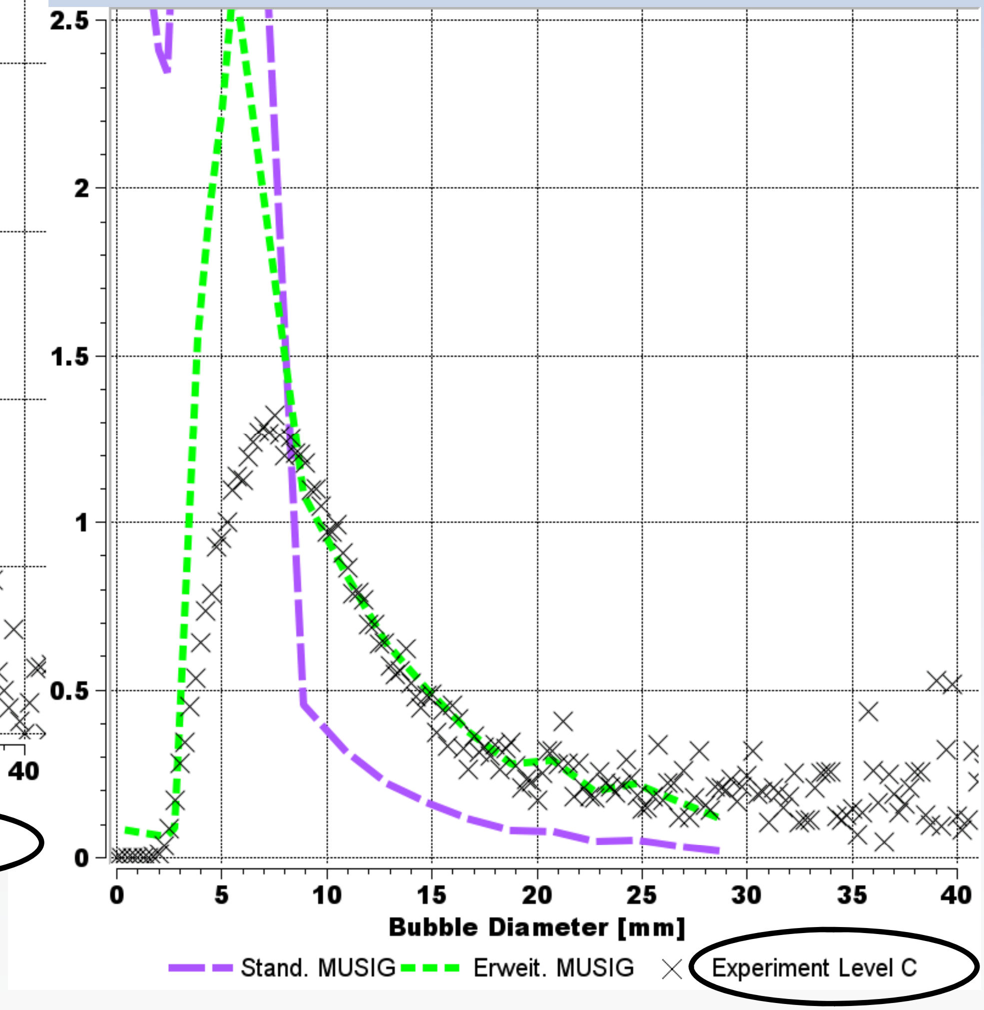
# Results: Radial steam distribution



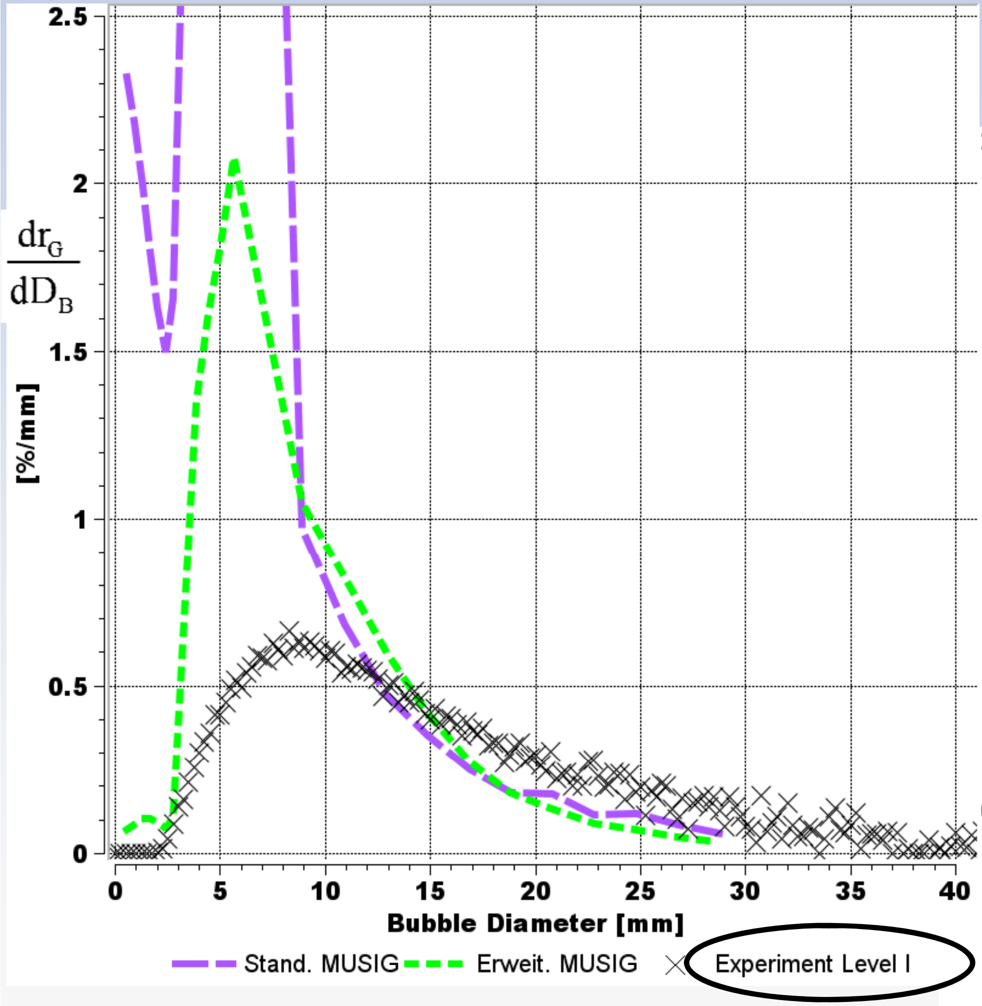



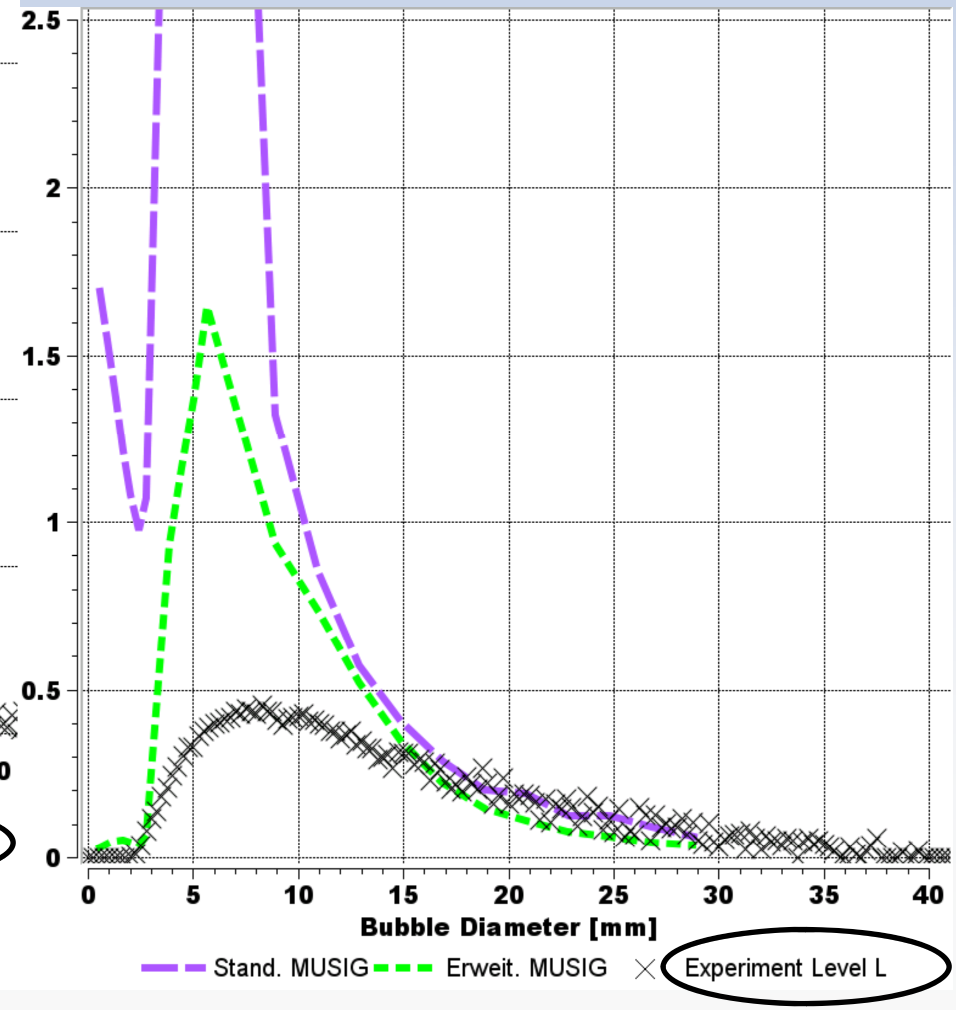
# Results: Bubble size distribution



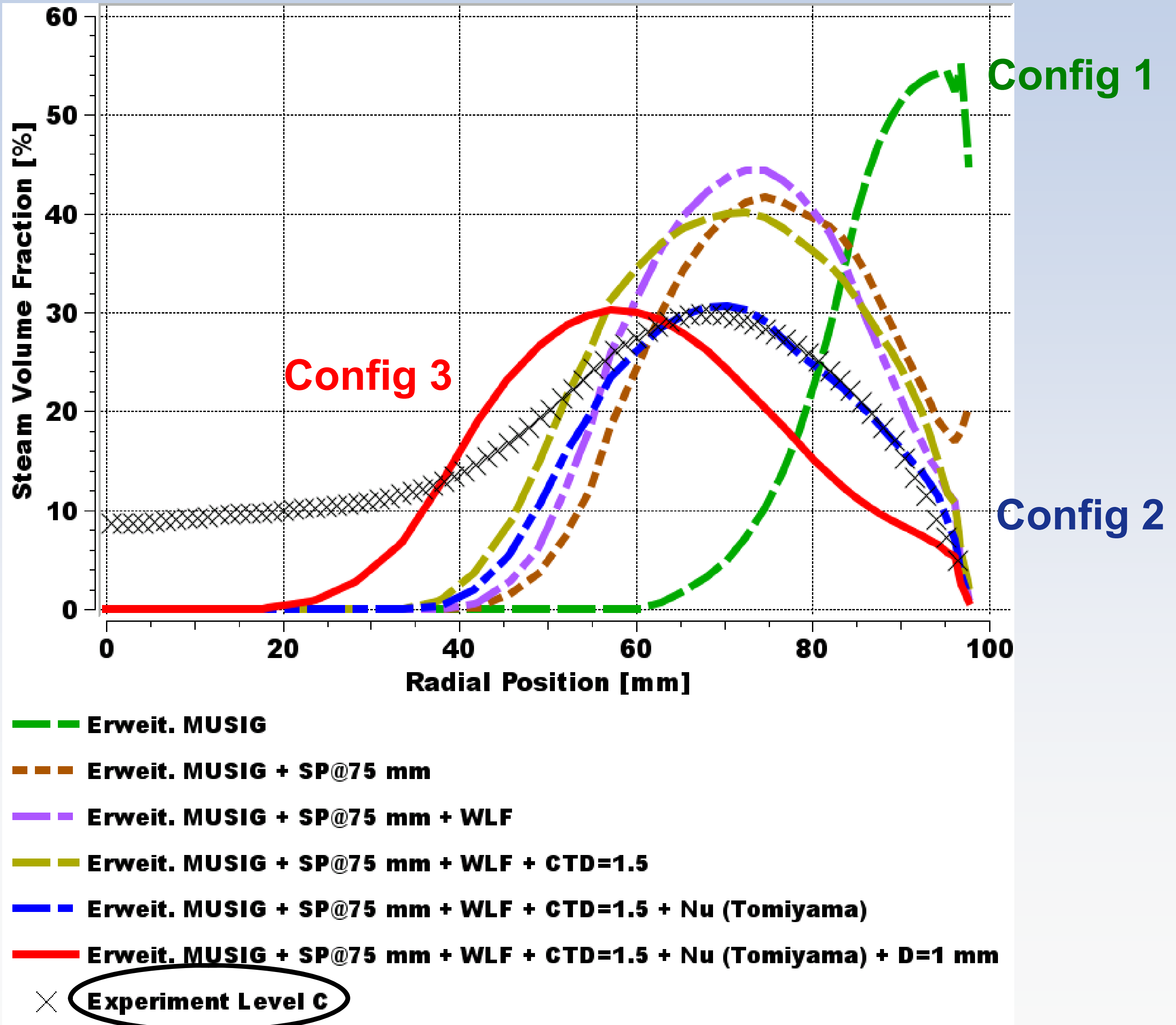



# Results: Bubble size distribution



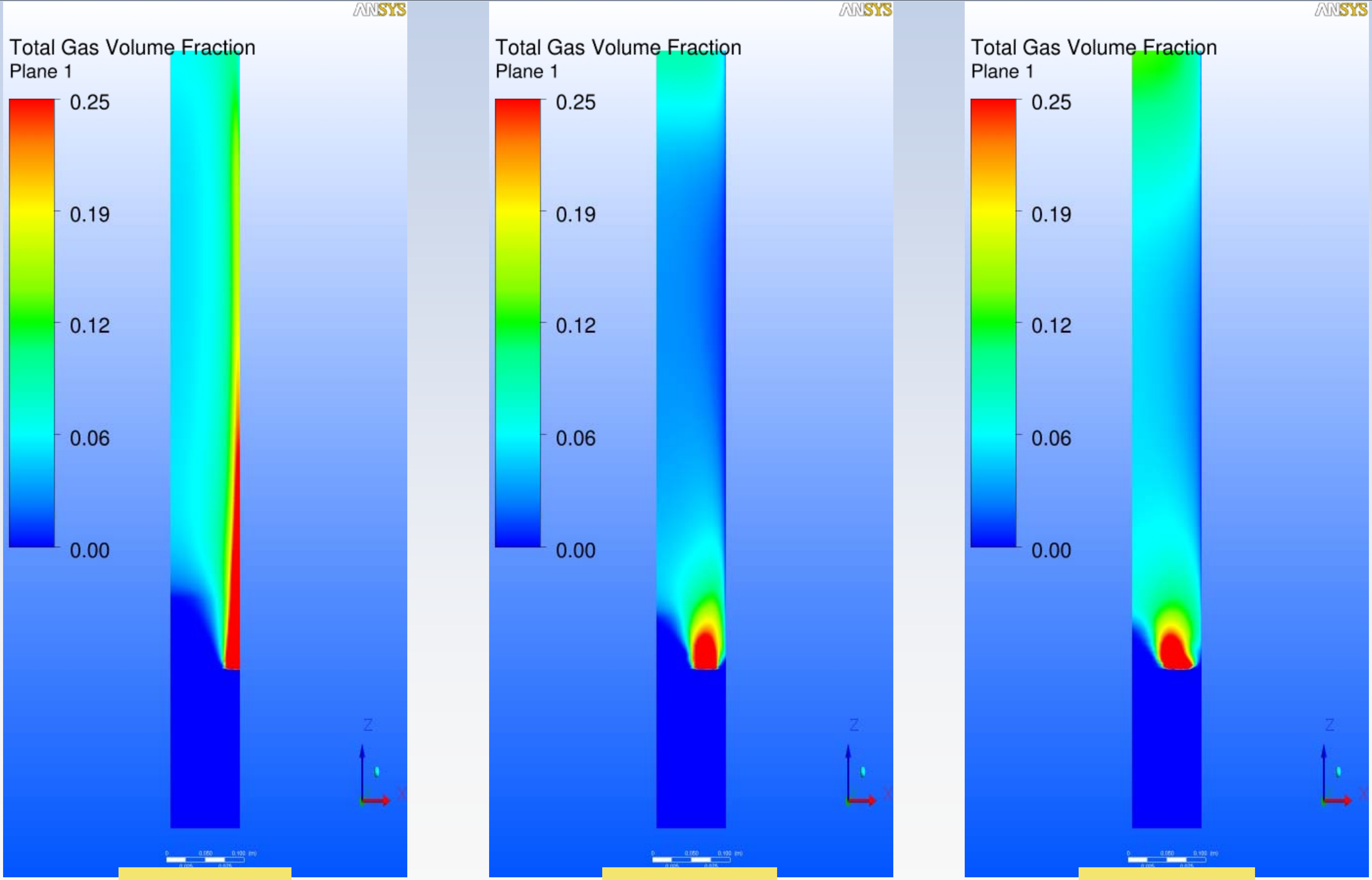
# Results: Tests Comparison



# TOPFLOW Condensation case

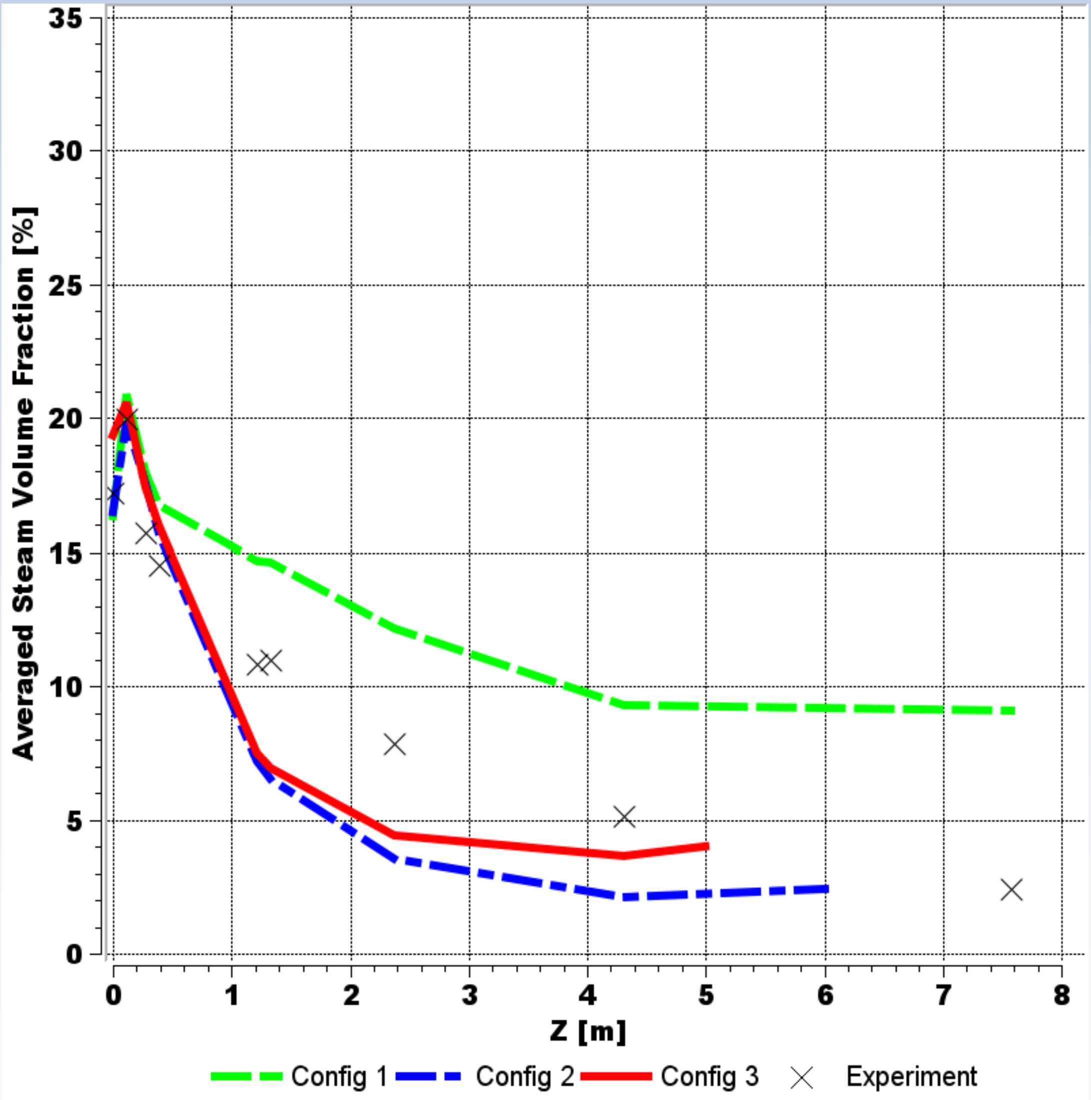
| | | | | | |
|---|---|---|---|---|---|
| **Config 1** | $D_{inj}$ = 4mm | Source point @ Wall | - | - | - |
| **Config 2** | $D_{inj}$= 4 mm | Source point @ 75 mm | $F_{WLF}$ | CTD=1.5 | $Nu=2+0.15Re_p^{0.8}Pr^{0.5}$ |
| **Config 3** | $D_{inj}$= 1 mm | Source point @ 75 mm | $F_{WLF}$ | CTD=1.5 | $Nu=2+0.15Re_p^{0.8}Pr^{0.5}$ |

# Results: Vapor Volume Fraction

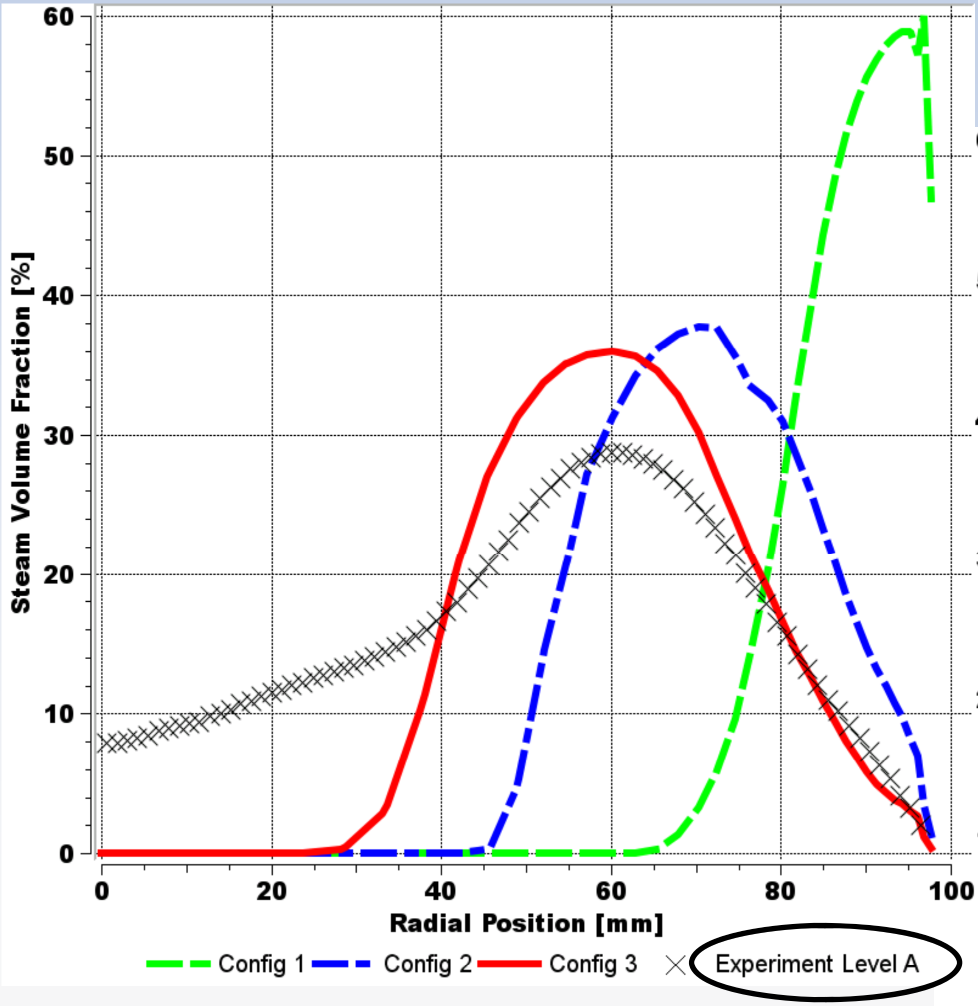


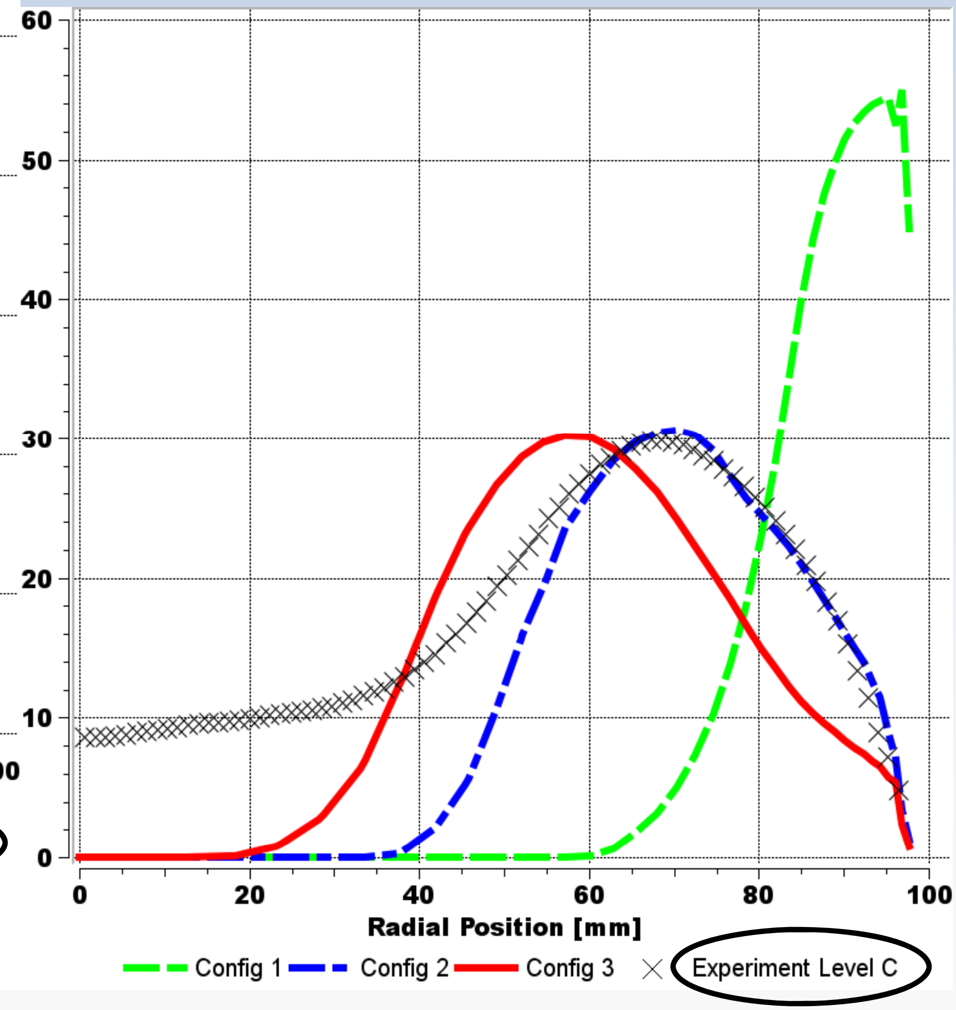

Config 1 Config 2 Config 3

# Results: Vertical averaged steam distribution

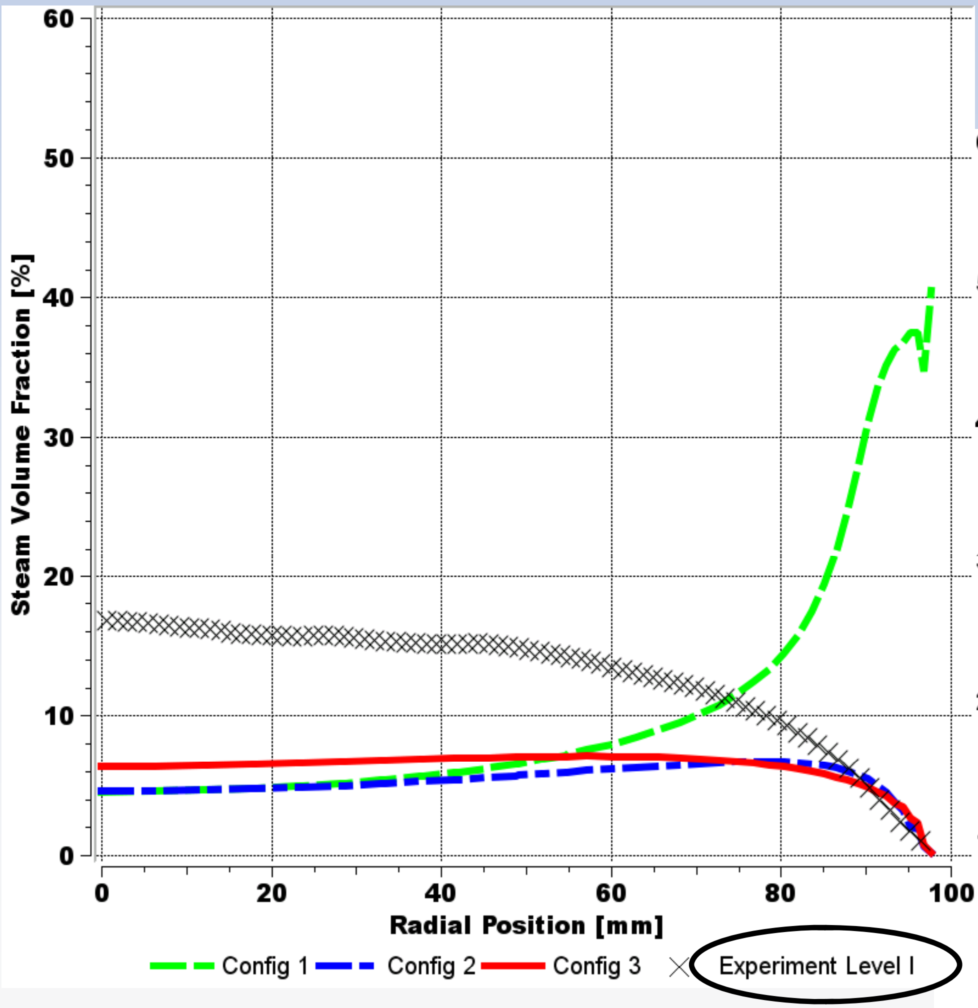


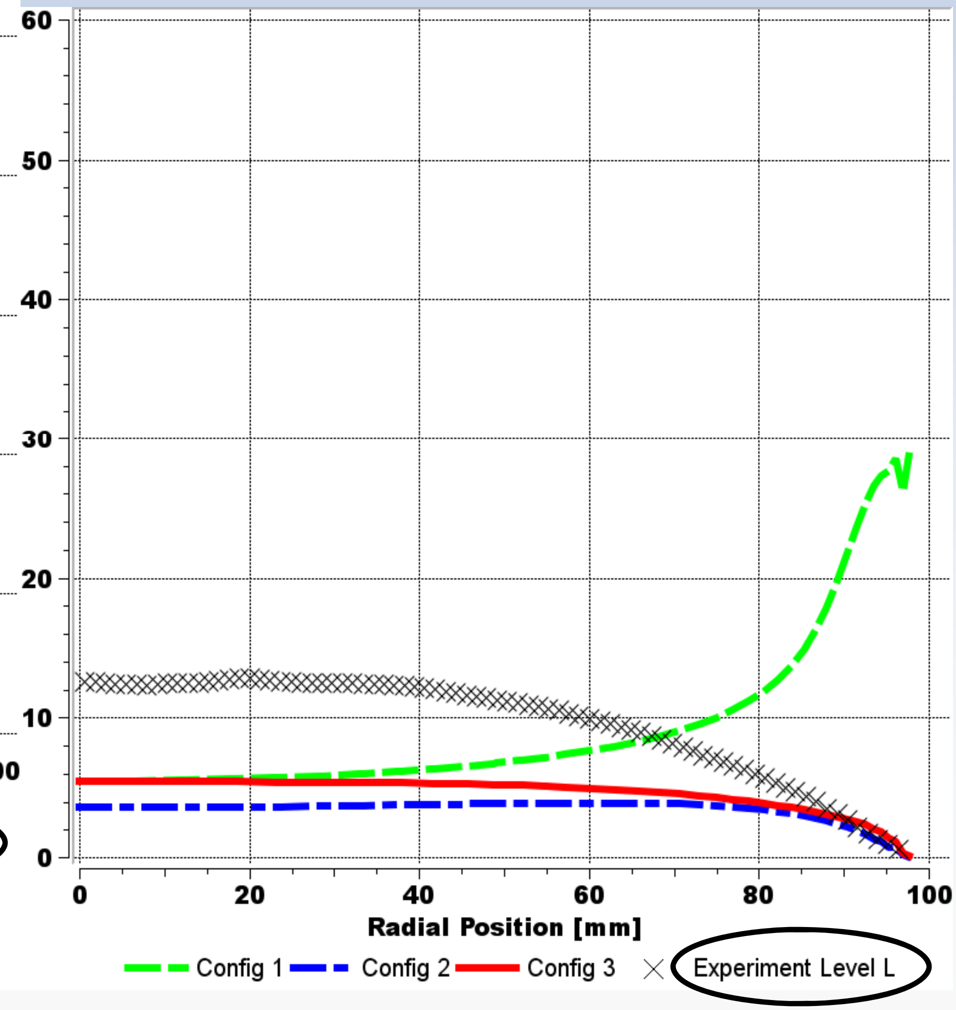
# Results: Radial steam distribution



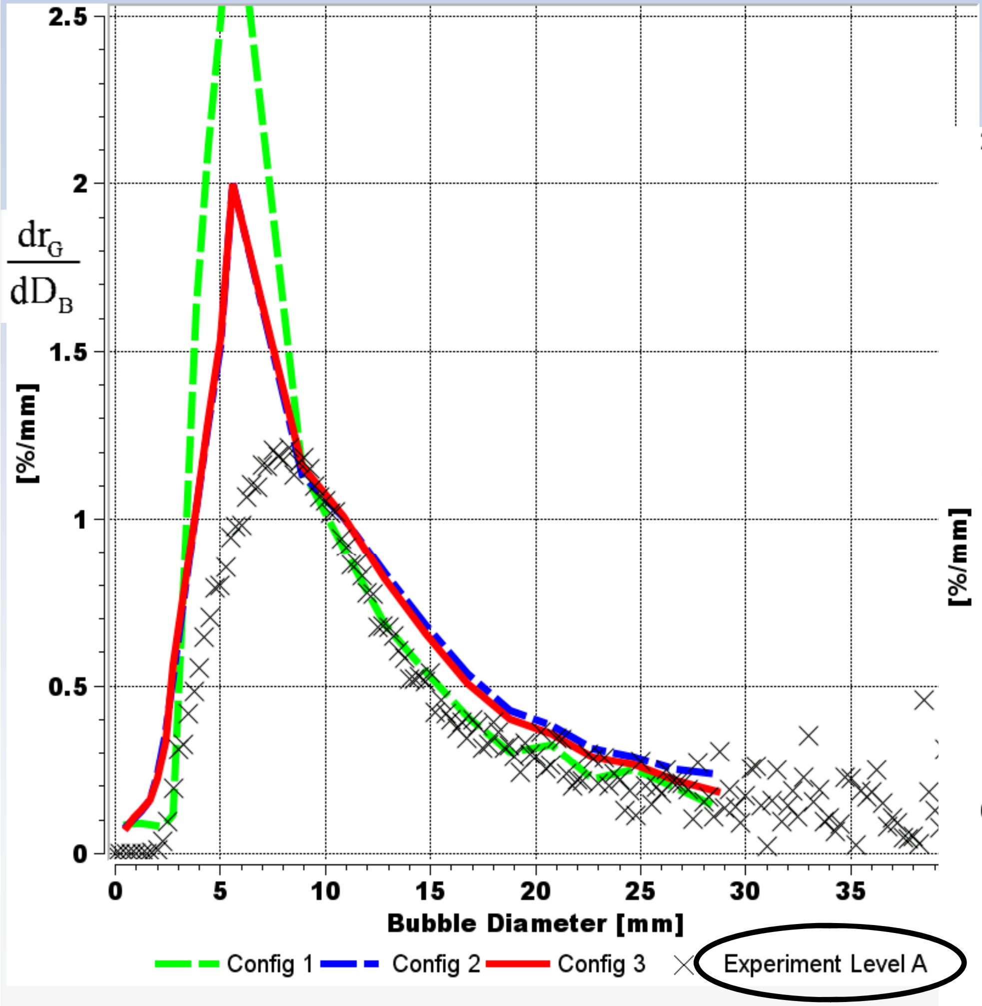



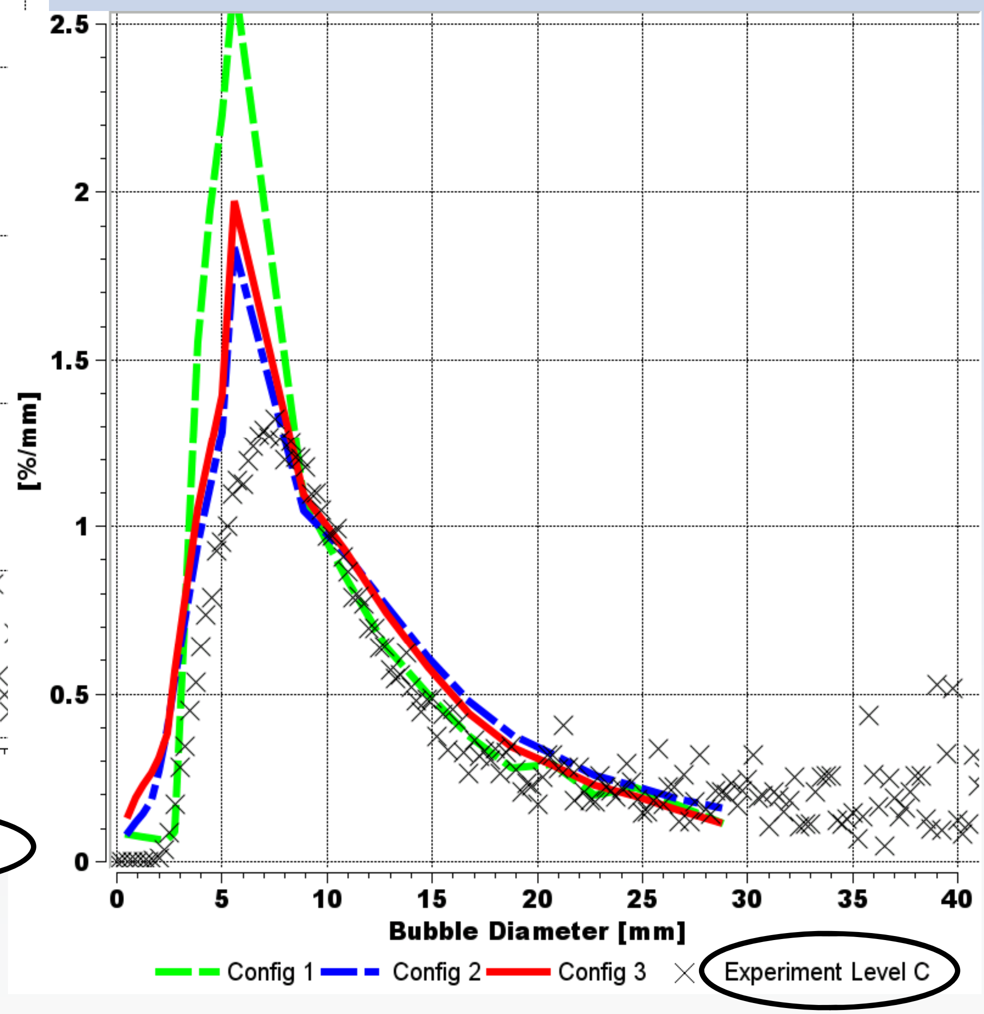
# Results: Radial steam distribution



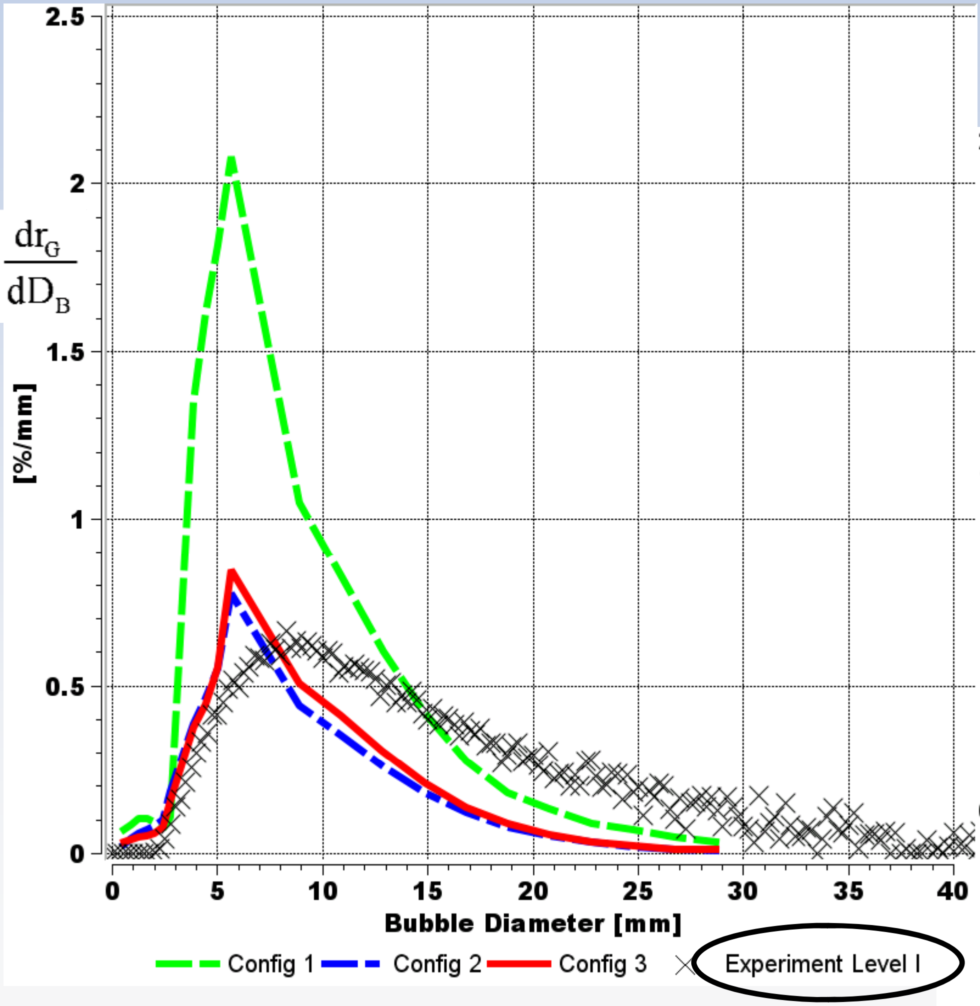



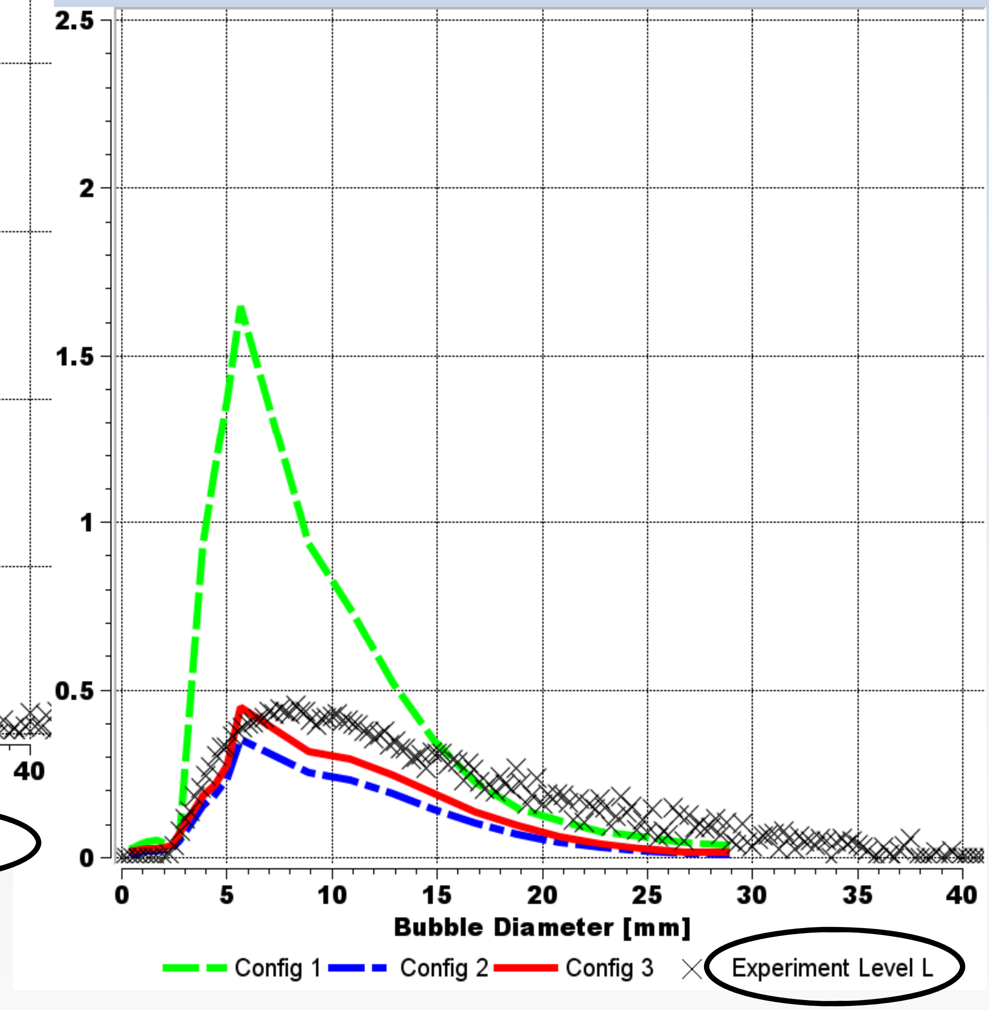
# Results: Bubble size distribution



# Results: Bubble size distribution



# Outline

- Motivation
- Model description
- Validation
  - TOPFLOW facility & condensation experiment
  - CFD ⇔ Experiment comparison
    - Previous approaches vs. extended MUSIG
    - Improvements in the extended MUSIG simulations
- **Summary & conclusions**

# Summary & Conclusions

- **An extension of the MUSIG model in ANSYS CFX in order to catch phase change effect was implemented**
- **Condensation case at the TOPFLOW geometry used for validation**
    - The comparison with previous approaches proved the necessity of the extension
    - Qualitatively better results, however improvements in the Setup were required
    - A parameter study led to also quantitative satisfactory results
- **Implementation performed in a customized solver based on ANSYS CFX 12**

# Thank You!