# Staged impingement arrays for novel heat exchanger designs

**A numerical investigation**

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# What are staged impingement arrays? And what do they do?

- Impingement cooling is an established cooling feature for Turbine vanes and blades
- Free Jet impinges on a hot/cold target surface where heat is transferred
- A staged impingement array connects the outlet of one array to the inlet of the next
  - Enables higher heat loads at same mass flow
  - Smaller internal and external crossflow effects improve heat transfer

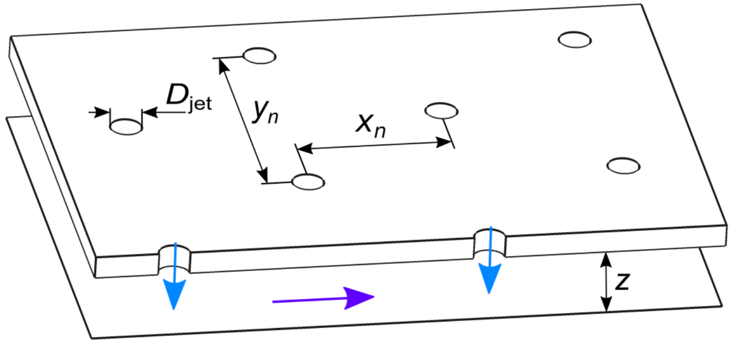



Fig. 1 Topology of an impingement array [1]

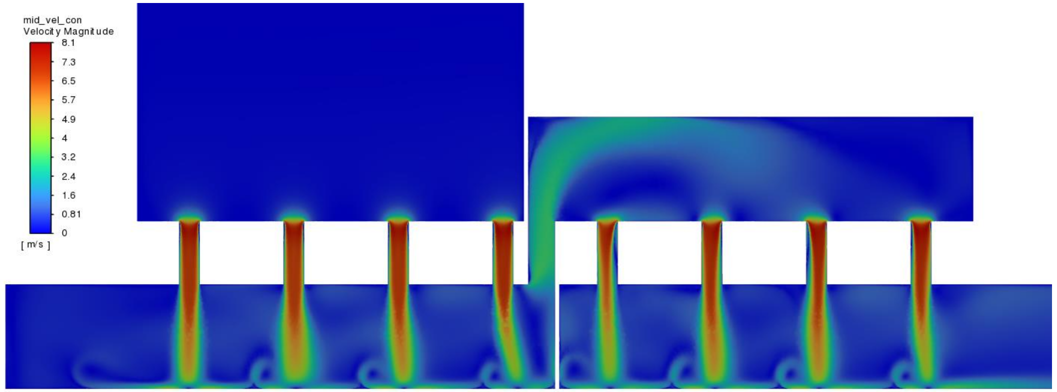



Fig. 2 Velocity field of a staged impingement configuration

[1] Schöffler, Robin und Brakmann, Robin und Grunwitz, Clemens (2022) *Development of a Predictive Model for Preliminary Gas Turbine Blade Cooling Design and Analysis.*

# Why do we care?

- Novel concept impingement Heat Exchange(iHEX)
  - Implementing staged impingement arrays enables a wide variety of possible solutions for a given mass flow and heat duty leveraging the advantages of impingement cooling
  - Very high gravimetric densities with low power ratios
  - Well suited for high temperature applications with modern materials like Ceramic Matrix Composites(CMC)
  - Comparatively small volumetric densities

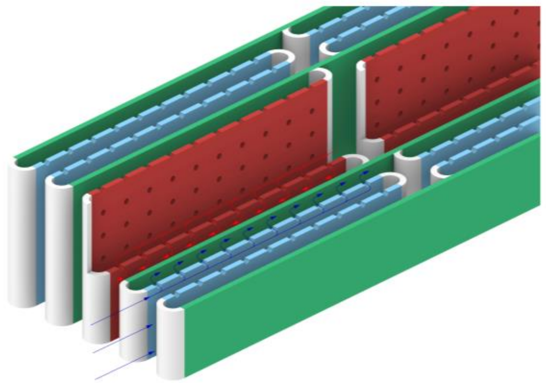


Fig. 3 iHEX configuration

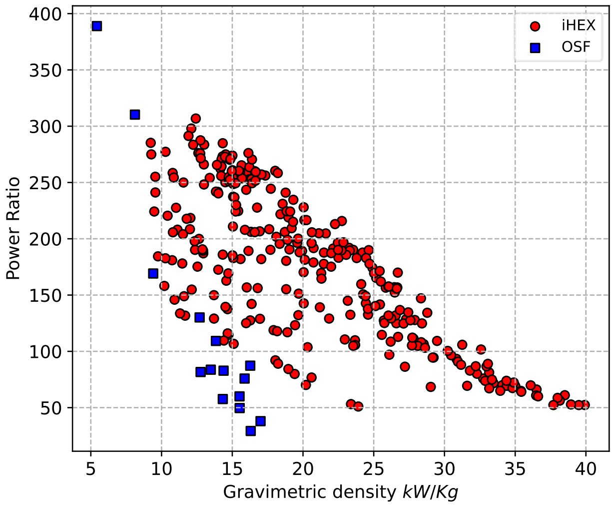
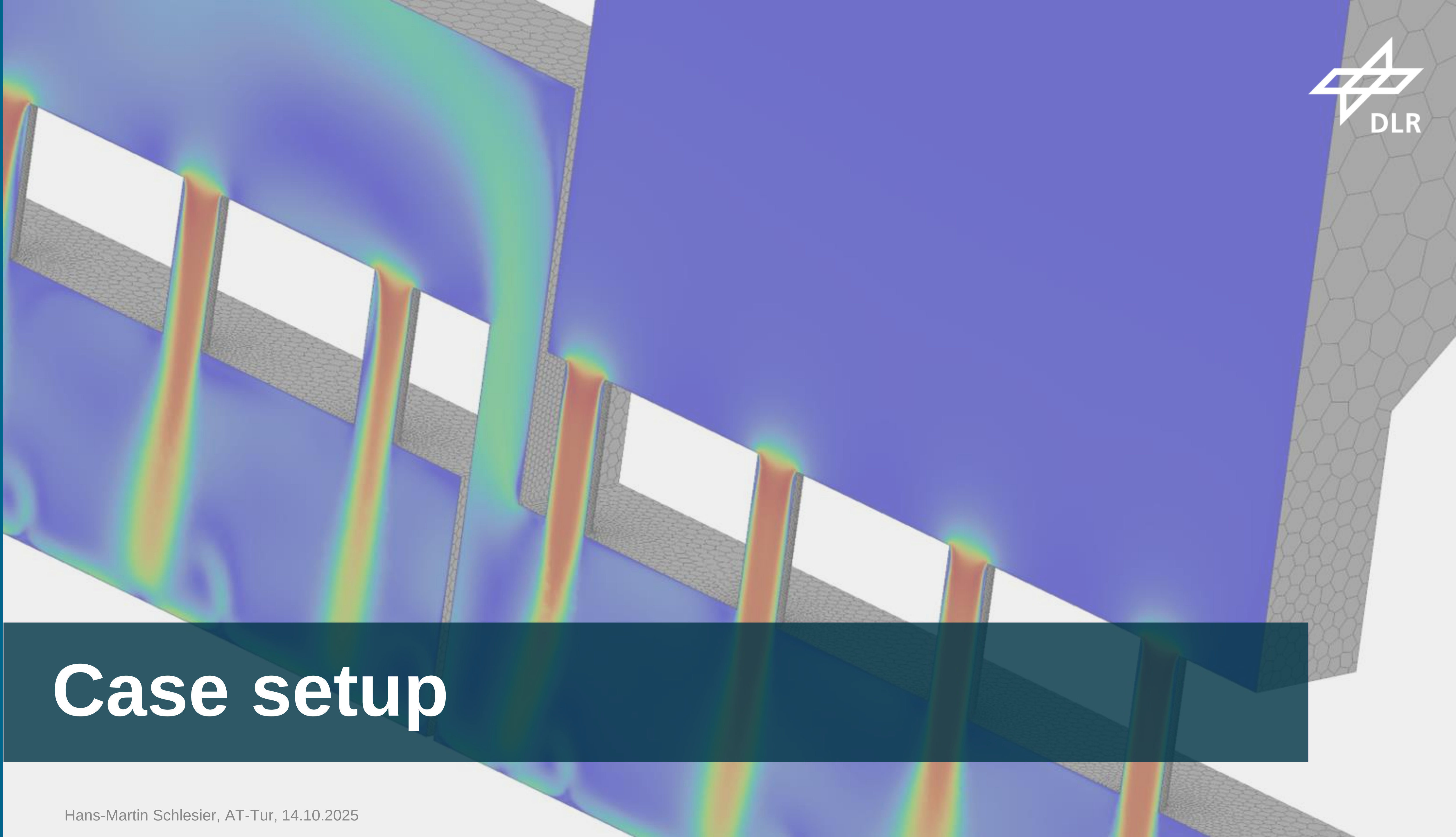



Fig. 4 Case study optimization results

# So, what‘s the problem?

- Predesign and sizing is using established correlations to predict heat transfer and pressure loss
  - Heat Transfer is predicted with the established Florschuetz[2] correlation
  - Pressure loss over one array is predicted with Idelchik [3] correlation
- Prediction and CFD for staged arrays show overestimation of pressure loss and underprediction of heat transfer
- Knowledge gap in predicting Heat transfer performance and pressure loss of staged impingement configurations

[2] L.W. Florschuetz, D.E. Metzger und C.R. Truman. “Jet array impingement with crossflow-correlation of streamwise resolved flow and heat transfer distributions”. In: (1981)
[3] I.E. Idelchik. Handbook of Hydraulic Resistance. Gosudarstvennoe Energeticheskoe Izdatel’stv, 1960



# Case setup

# Case Setup

- General setup
  - 4 different configurations (1-8 stages) with 4 Reynolds numbers ($1500 \geq Re_{jet} \geq 10000$)
  - Overall case setup from literature for single stage impingement
- Numerical setup
  - RANS $k - \omega\ SST$ with Ansys Fluent24/r1
  - Polyhedral mesh
  - Local and global Grid-convergence Index for pressure loss and Nusselt number
  - Symmetry case

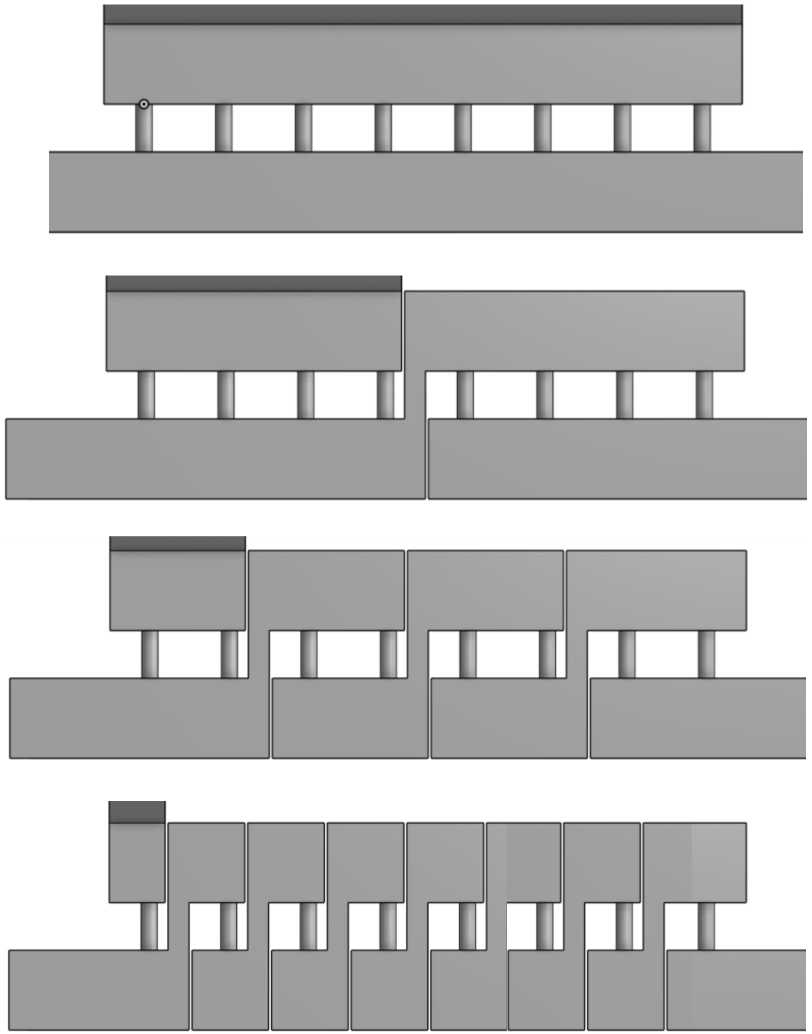


Fig. 5 staged impingement array setups

# Grid Convergence Index

- General setup
  - 4 different configurations (1-8 stages) with 4 Reynoldsnumbers ($1500 \geq Re_{jet} \geq 10000$)
  - Overall case setup from literature for single stage impingement
- Numerical setup
  - Rans $k - \omega\ SST$ with Ansys Fluent24/r1
  - Polyhedral mesh
  - Local and global Grid-convergence Index for pressure loss and Nusselt number
    - Global $GCI_{\mathrm{NU}} = 0{,}1\%, GCI_{\Delta P} = 4{,}5\%$
    - Local $\overline{GCI_{\mathrm{NU}}} = 6{,}9\%,$

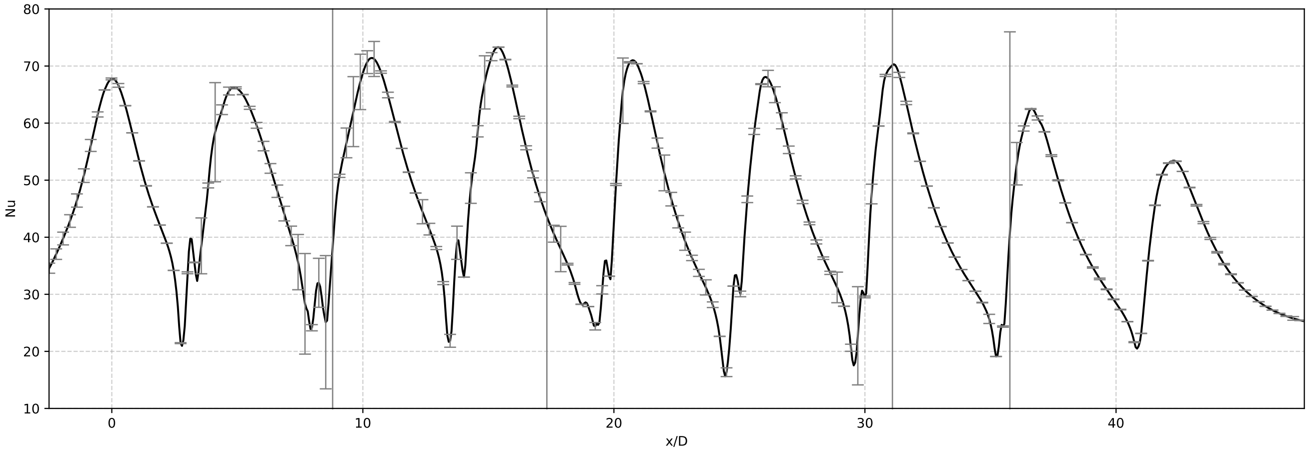
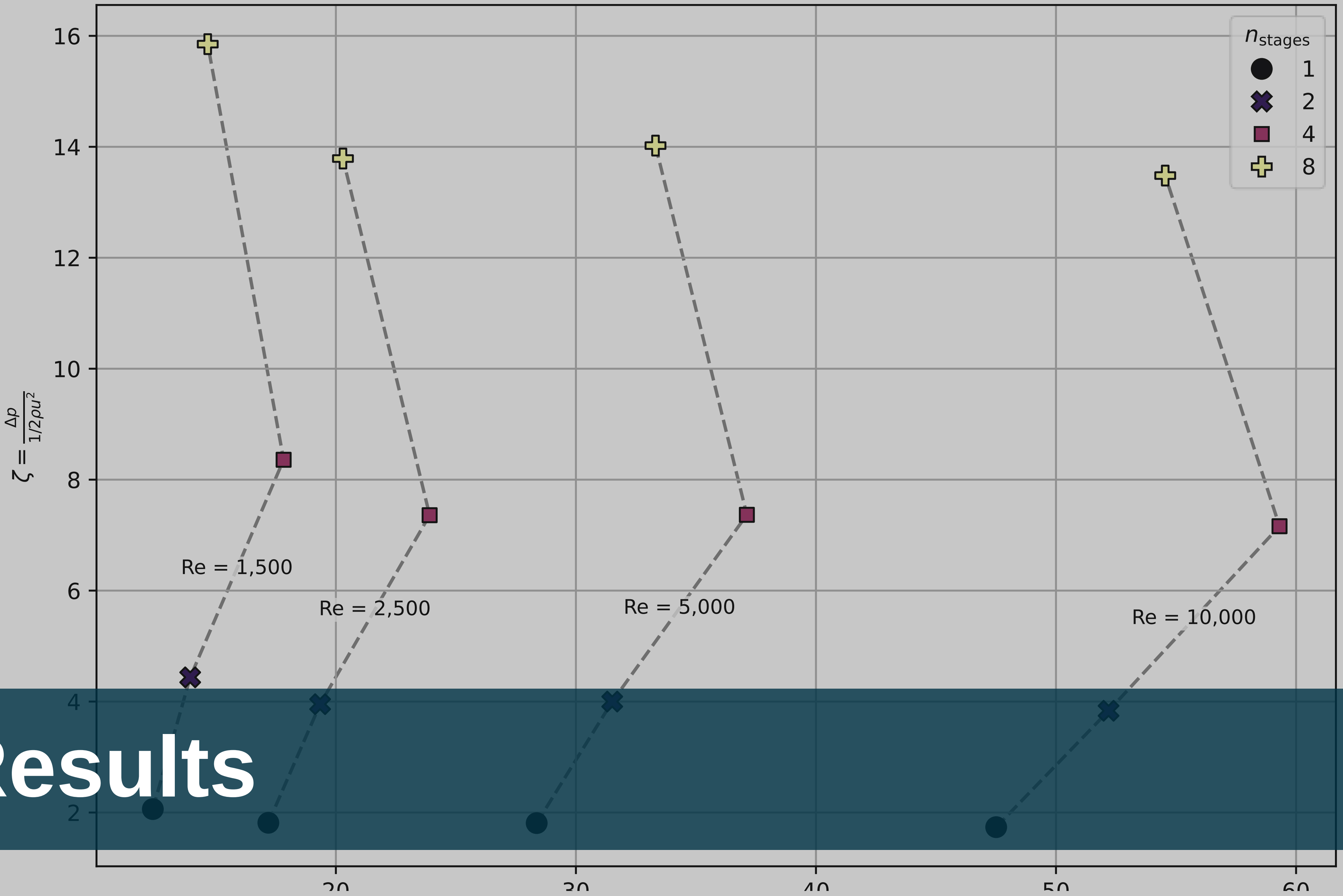



Fig. 6 GCI for span-averaged Nusselt numbers



$\zeta = \frac{\Delta p}{1/2 \rho u^2}$
16
14
12
10
8
6
4
2
20
30
40
50
60
$n_{stages}$
1
2
4
8
Re = 1,500
Re = 2,500
Re = 5,000
Re = 10,000


# Results

# Heat transfer for single-stage case

- Very slow flow in the plenum with no external crossflow
- Strong influence of internal cross flow for the downstream jets
  - Jets get skewed
  - Average velocity in outlet channel increases
- Deformation of jets also impacts heat transfer performance

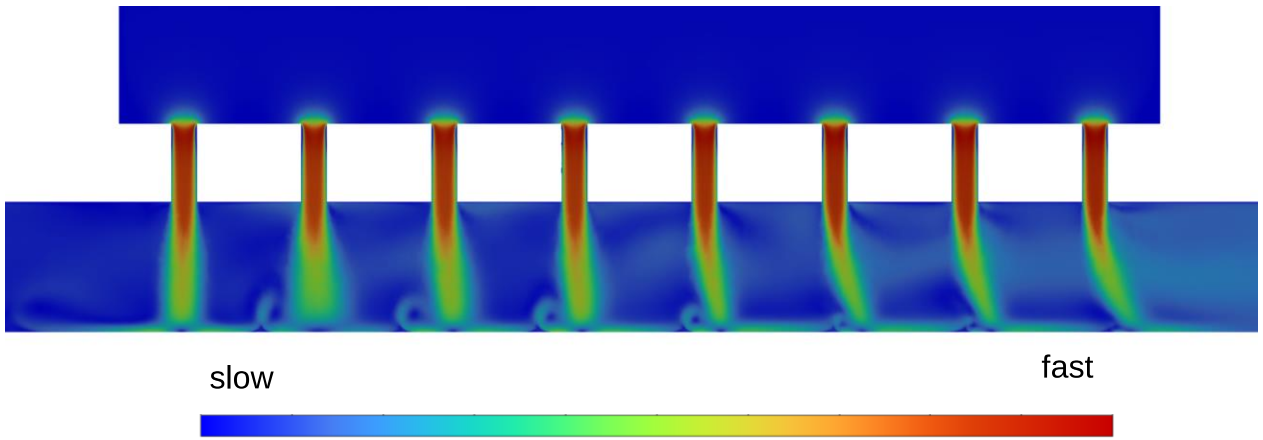



Fig. 7 Velocity field of a single stage impingement array

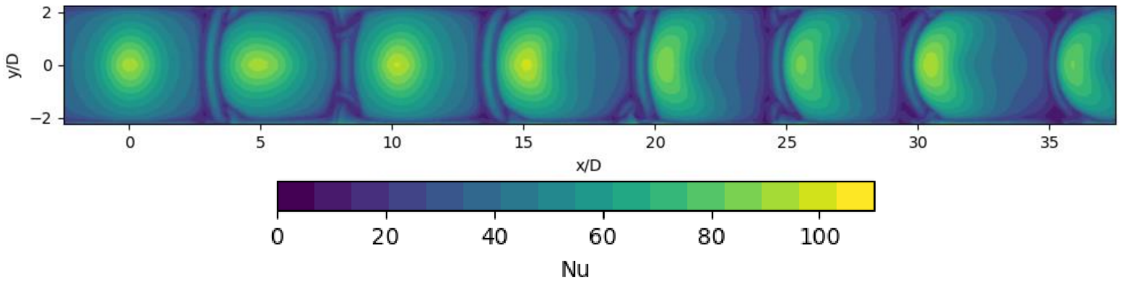



Fig. 8 Nusselt number of a single stage impingement array

# Heat transfer for multi-stage cases

- Crossflow effects can be diminished by staging
- Optimum for heat transfer with 2 holes per stage in this study
  - With staging the added thermal energy of a stage is increasing the total pressure → increase in Jet Velocity → Increase in heat transfer in consecutive stage
  - Single hole stages underperform due to influence of connection element

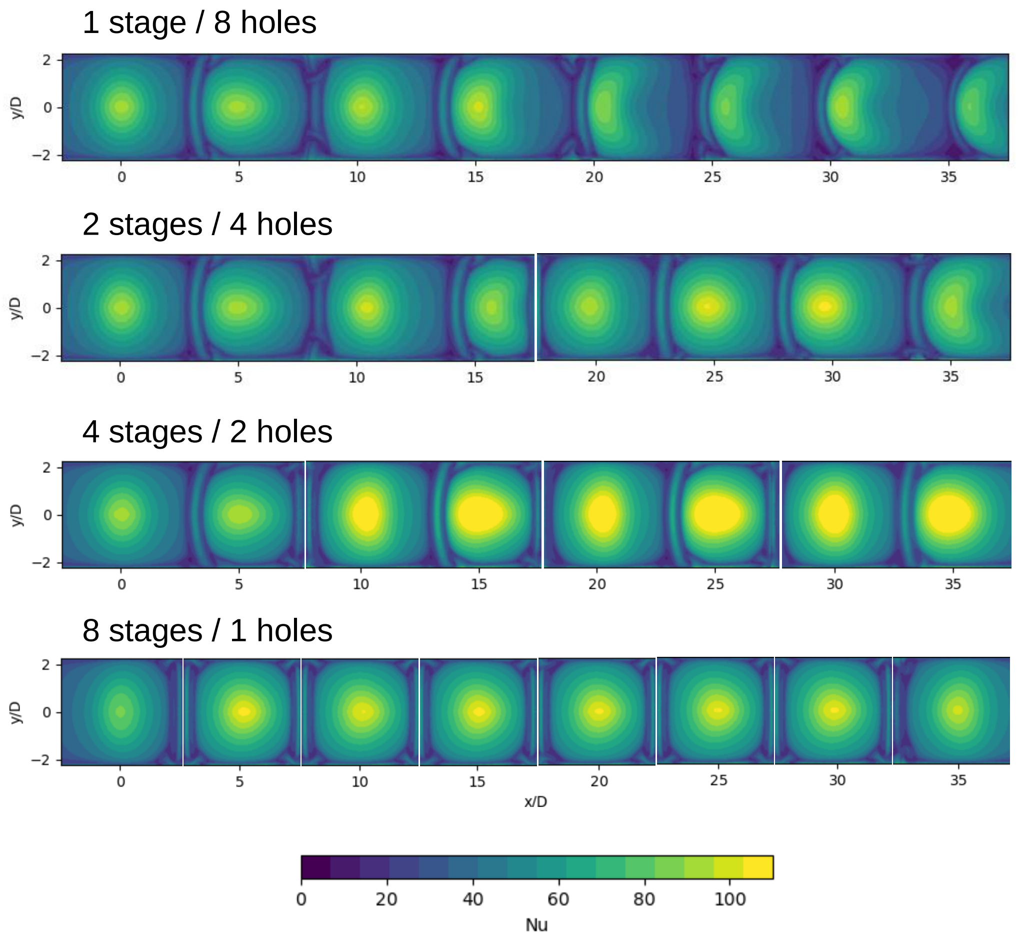



Fig. 9 Nusselt numbers for several staged configurations

# Pressure loss and Heat transfer quantification

- Addition to Idelchik-pressureloss coeffiecent is pruposed
  - Old: $\zeta = \frac{\Delta p}{\frac{1}{2}\rho u^2}$
  - New: $\zeta_{\text{staged}} = \frac{\Delta p}{\frac{1}{2}\rho u_{\text{jet}}^2 n_{\text{stages}}}$
- Low Reynolds numbers have high pressure loss compared to their jet velocity
- Underperformance of single hole stages is consistent
- Best ratio of heat transfer to pressure loss is shown by stages with two holes

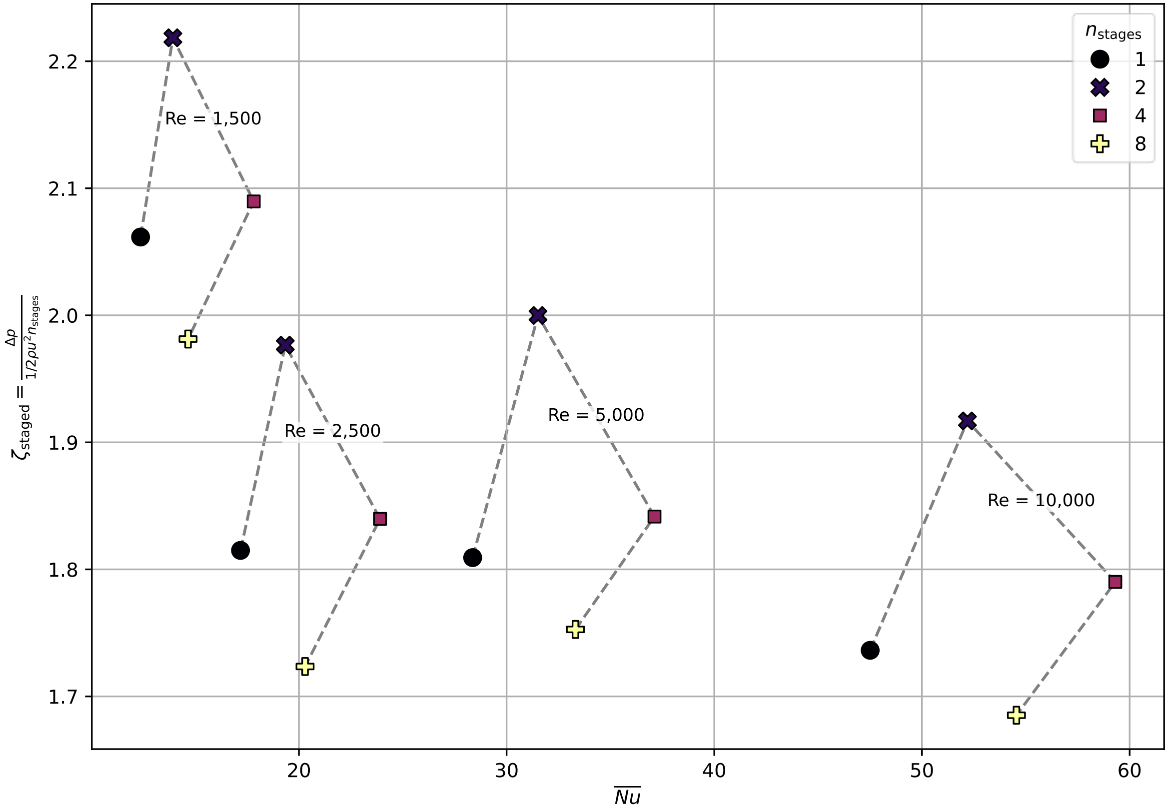



Fig. 10 Pressure loss coefficient over Nusselt number

# Compating CFD and correlations

- Nusselt number in good agreement with Florschuetz Correlation
- Slight deviations from ideal match due to Reynolds number increase in staging
- Idelchik correlation is overpredicting pressure loss significantly
    - Case setup with no external crossflow
    - General knowledge gap of pressure loss in impingement arrays

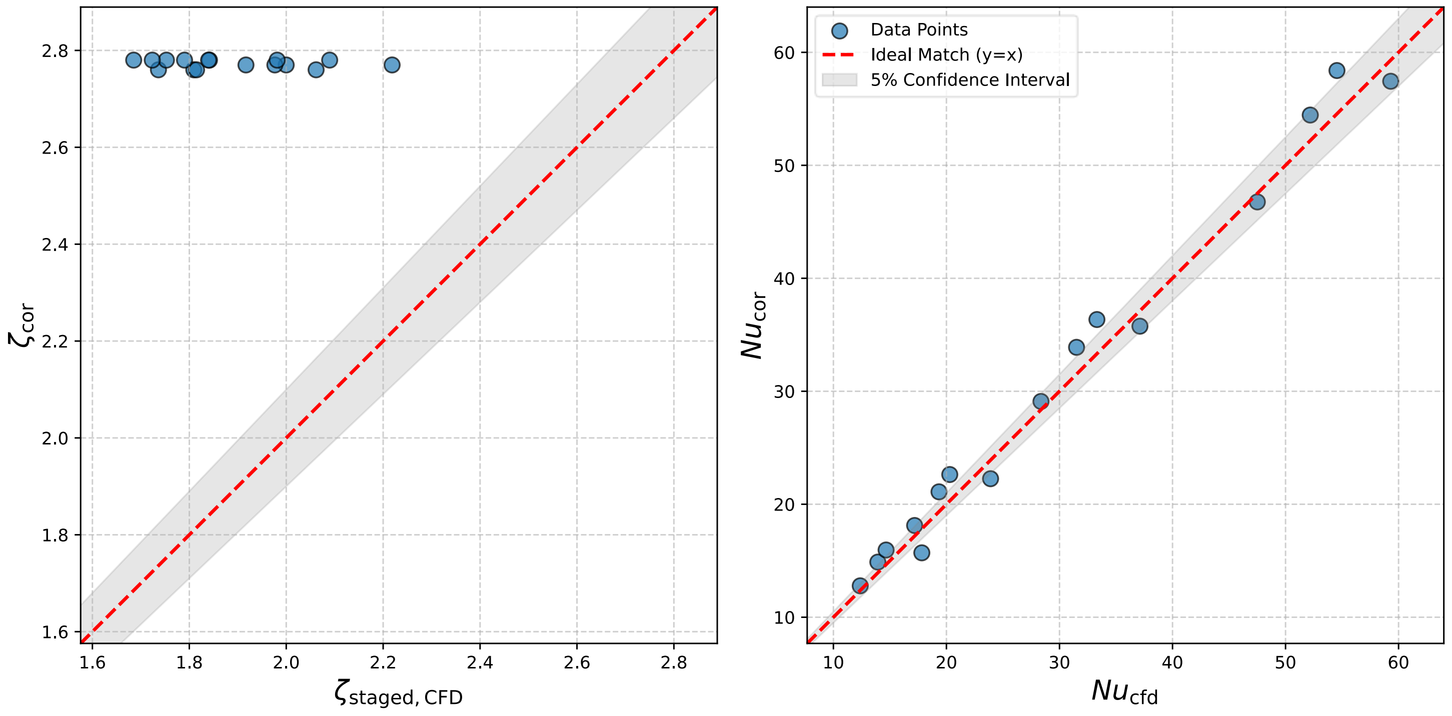



Fig. 11 Comparing correlation to CFD results

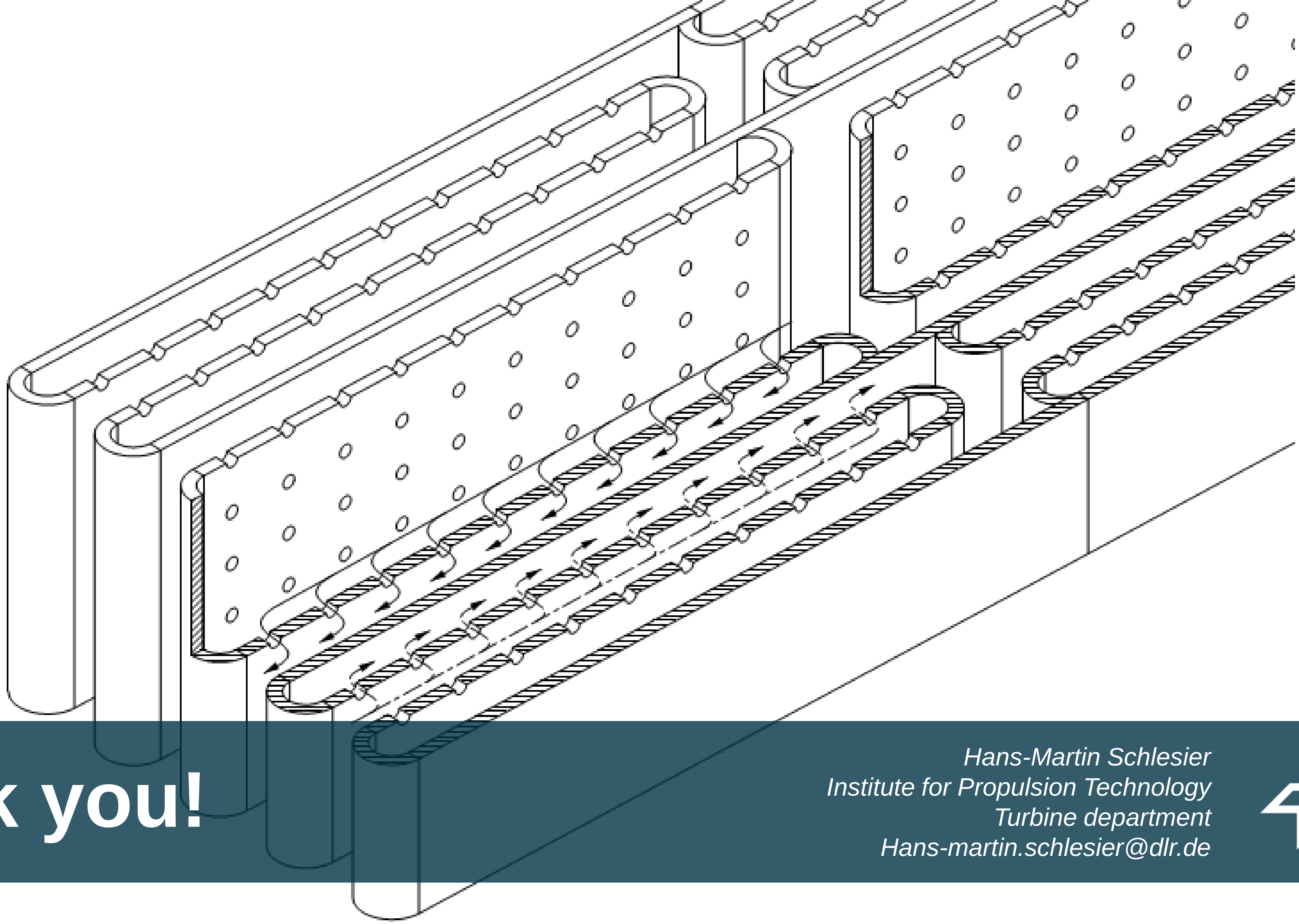
# Conclusion & outlook

Conclusion

- Single stage and multi stage impingement setups need to be treated differently in correlations
- Single hole stages underperform in both pressure loss and heat transfer
- Potential has been shown to improve iHEX competitiveness
  - Big gains can be achieved by correctly predicting pressure loss
  - Heat transfer is mostly predicted slightly too low

Outlook

- Extend study into higher Reynolds numbers and different topologies
- Investigate influence of external crossflow
- Establish a custom correlation for staged impingement arrays
- Revisit predesign and sizing routines to implement findings



# Thank you!

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# Imprint

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