

um
2026

RBF-FD meshless simulation of compressible flows

Riccardo Zamolo
Assistant Professor
University of Trieste



Agenda

Meshless Methods

Advantages & challenges

Addressed Applications

Problems & methods

Compressible Flows

(Few) equations & challenges

Use Case

Shape optimization of a diffuser

Concluding Remarks

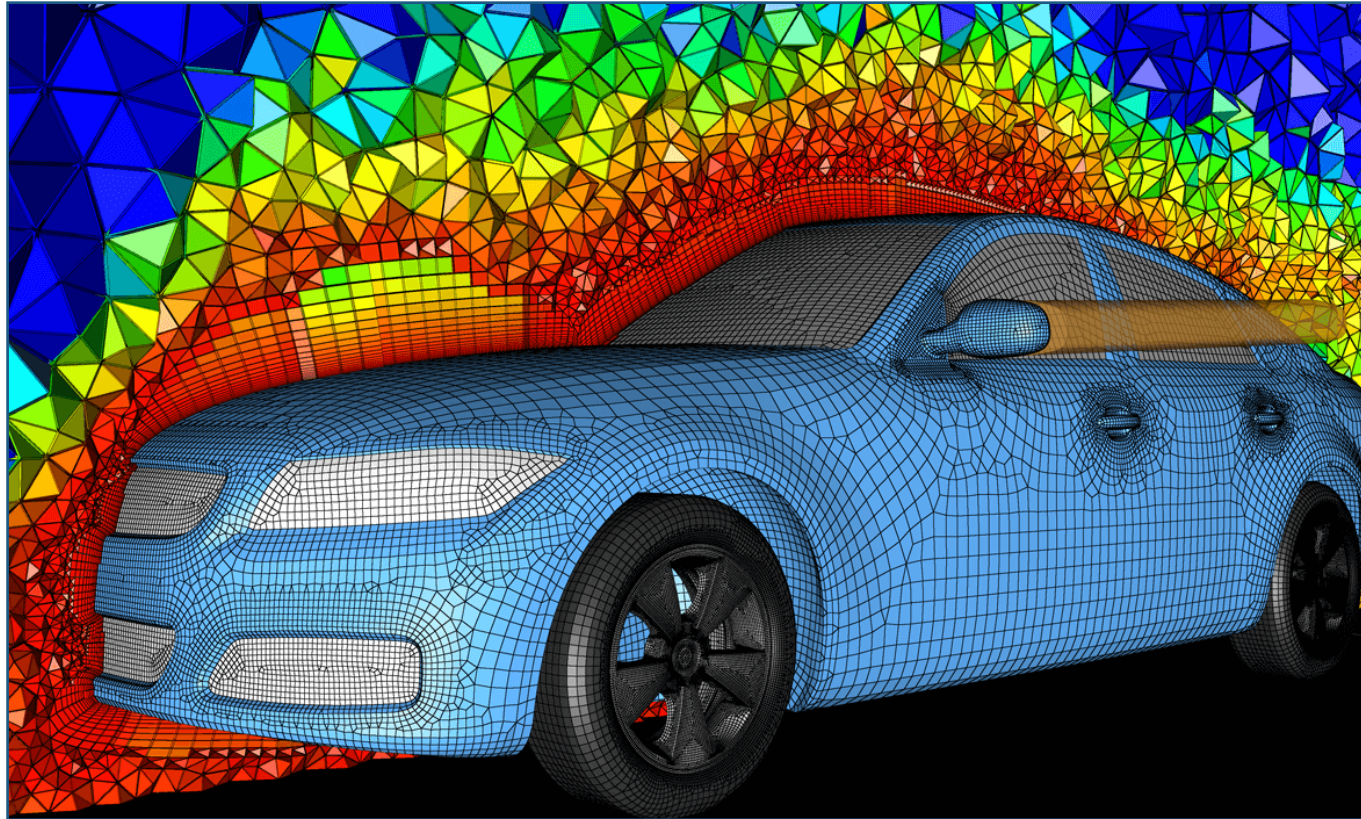


Meshless Methods

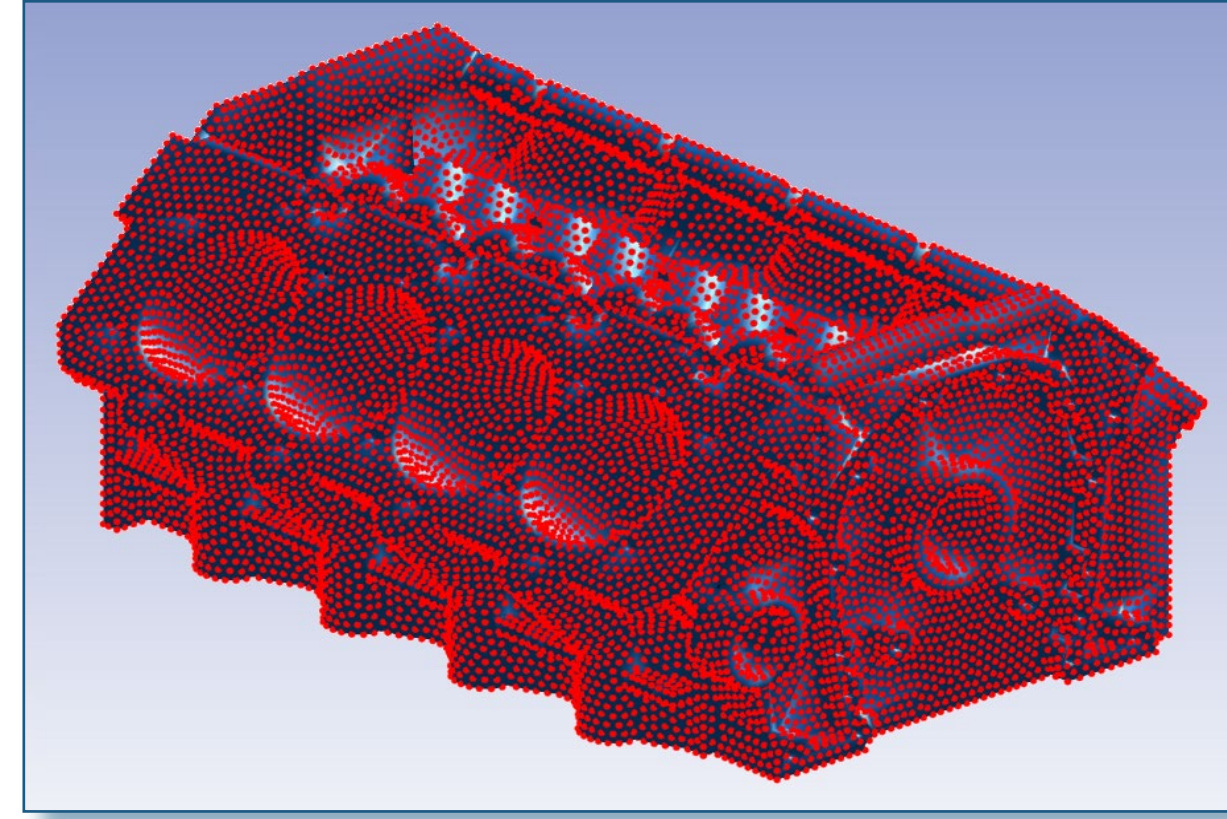


Meshless Methods: advantages & challenges

Mesh-based



Meshless

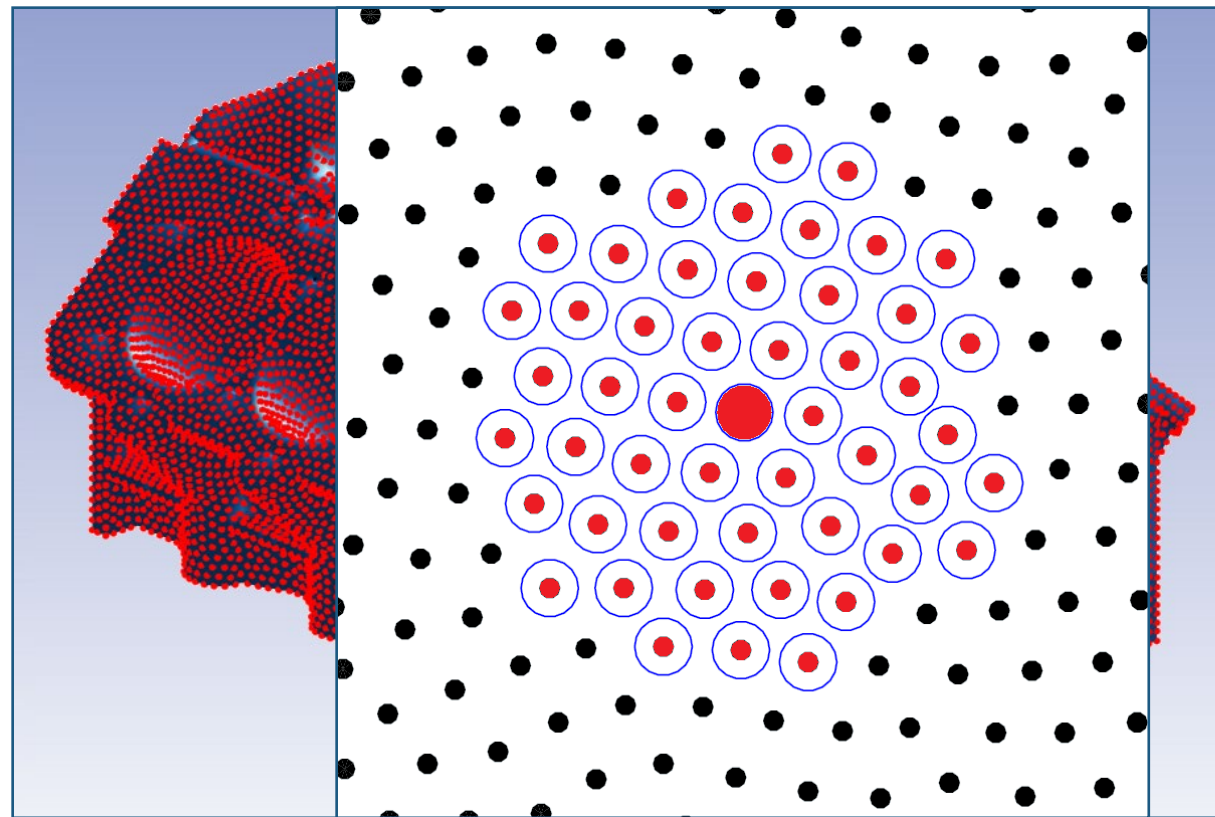


- 👎 Complex geometry → complex meshing
- 👎 Mesh-quality issues
- 👍 Well-established

- 👍 Only nodes → geometric flexibility
- 👍 Limited node sensitivity
- 👎 No consolidated approach

Meshless Methods: RBF-FD

Radial Basis Function-generated Finite Difference (RBF-FD) method



$$u(\mathbf{x}) = \sum_{\text{neighbors}} a_i \varphi(\|\mathbf{x} - \mathbf{x}_i\|) + \text{poly}_P(\mathbf{x})$$

$$\frac{\partial u}{\partial \mathbf{x}} = c_1 u_1 + c_2 u_2 + \dots$$

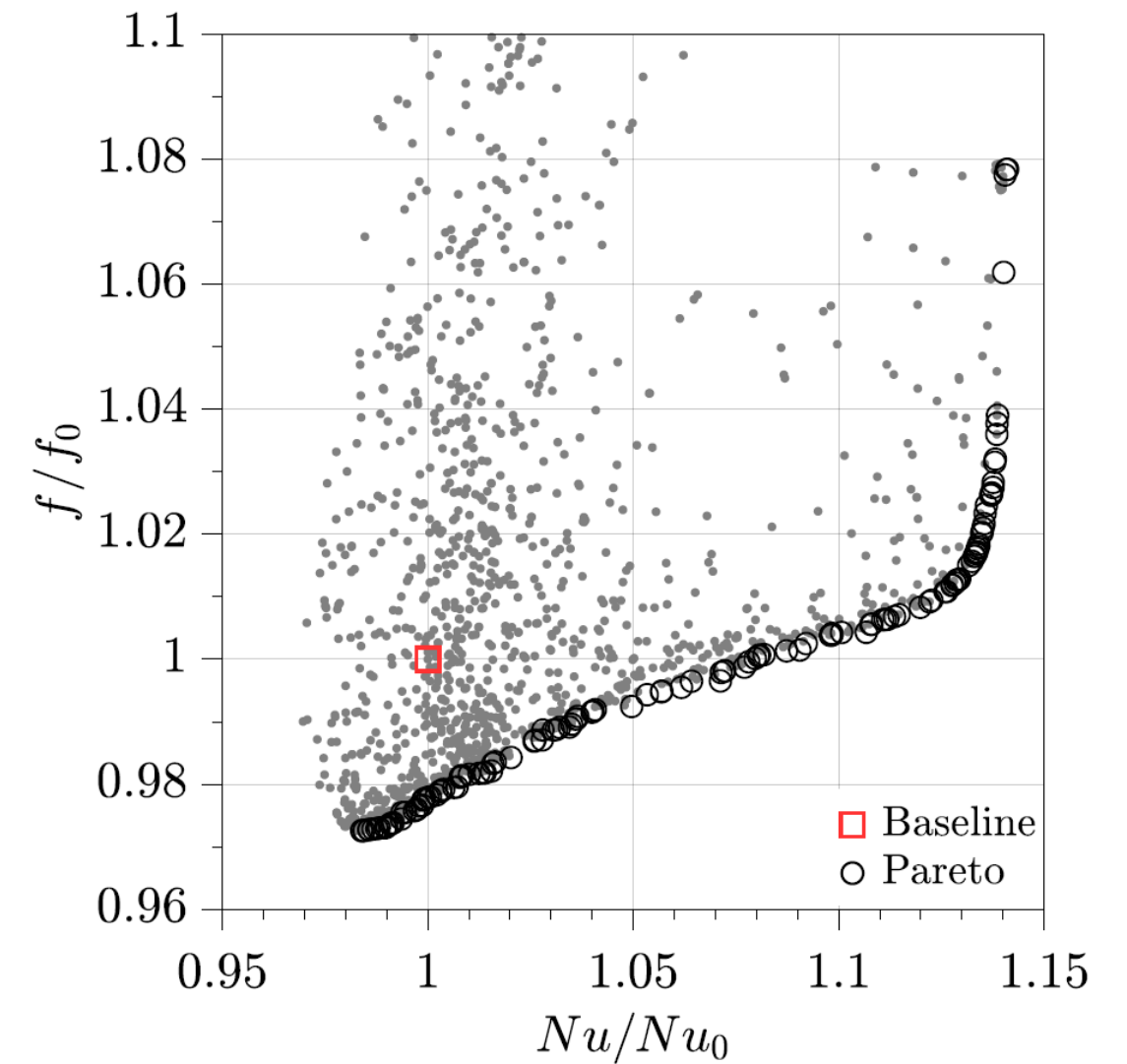
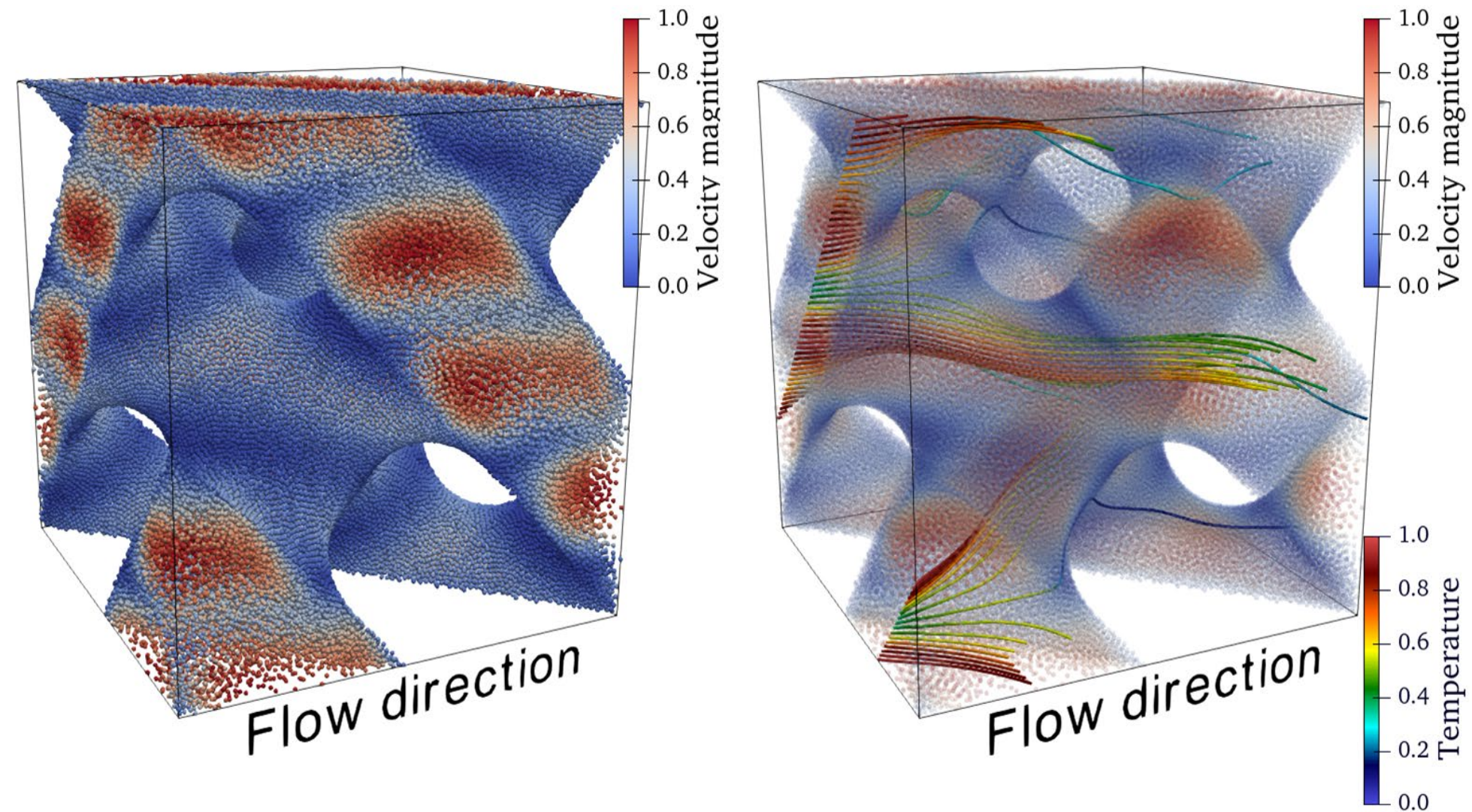
Linear PDE \rightarrow Sparse linear system ($\mathbf{K}\mathbf{u} = \mathbf{f}$)

Addressed Applications



Addressed Applications

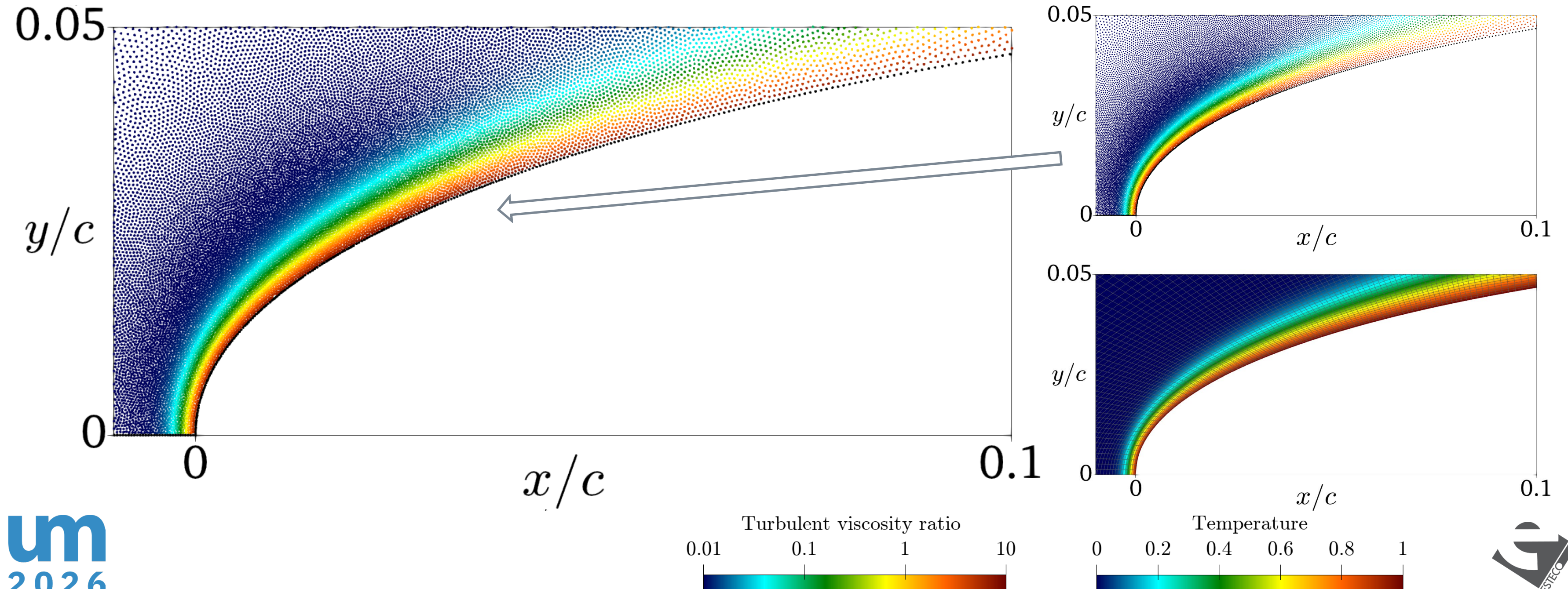
3D Fluid flow and heat transfer in TPMS-based compact heat exchangers & optimization



Addressed Applications

2D Fluid flow and heat transfer on airfoil, Spalart-Allmaras turbulence model

Meshless:

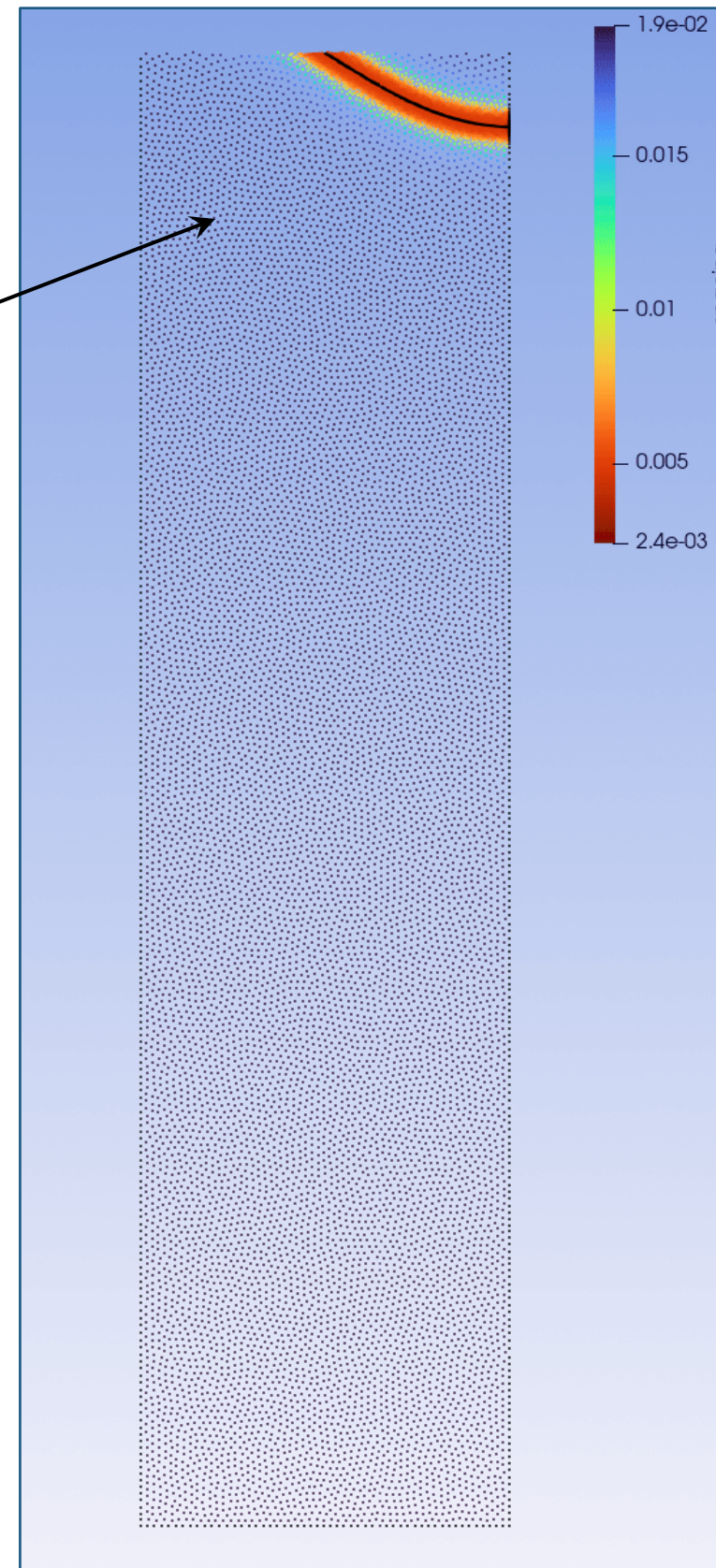


Addressed Applications

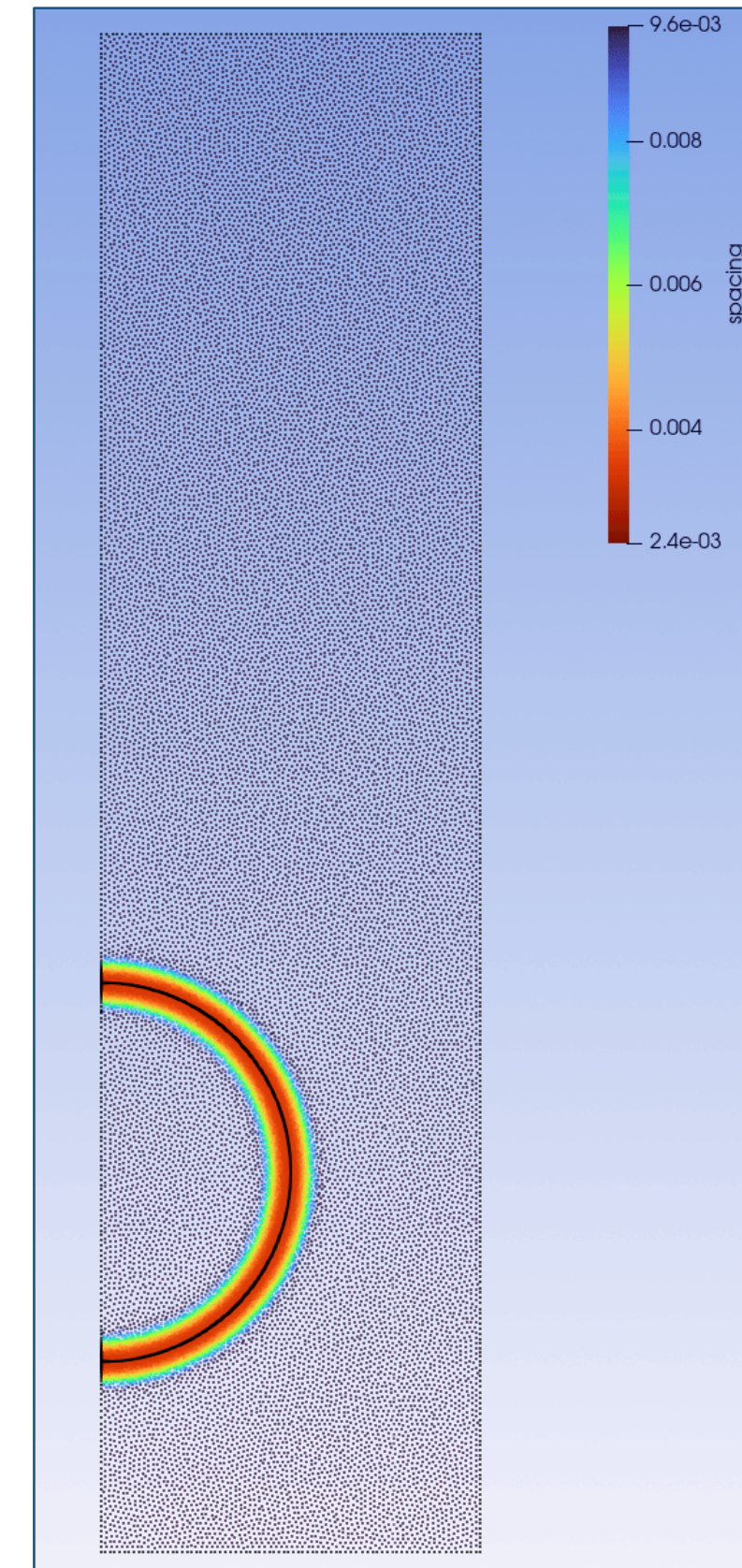
Adaptive simulation of two-phase flows

- Cahn-Hilliard Navier-Stokes model
- intermittent node regeneration
- **high node density** @ interface

Rayleigh-Taylor inst.



Rising bubble



Compressible Flows



Compressible Flows

Compressible Euler equations for adiabatic and inviscid flow

Simplification: isentropic (no shock waves) $\xrightarrow{CPG} \frac{p}{\rho^\gamma} = \text{const.}$

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{j} &= \delta \nabla^4 \rho \\ \frac{\partial \mathbf{j}}{\partial t} + \nabla \cdot (\mathbf{u} \otimes \mathbf{j}) + \nabla p &= \delta \nabla^4 \mathbf{j} \\ (\mathbf{j} = \rho \mathbf{u}) \end{aligned}$$

No dissipation terms



Strong advective instabilities



Hyperviscosity stabilization

Use Case



Shape Optimization of a Diffuser

Parameterization of top wall:

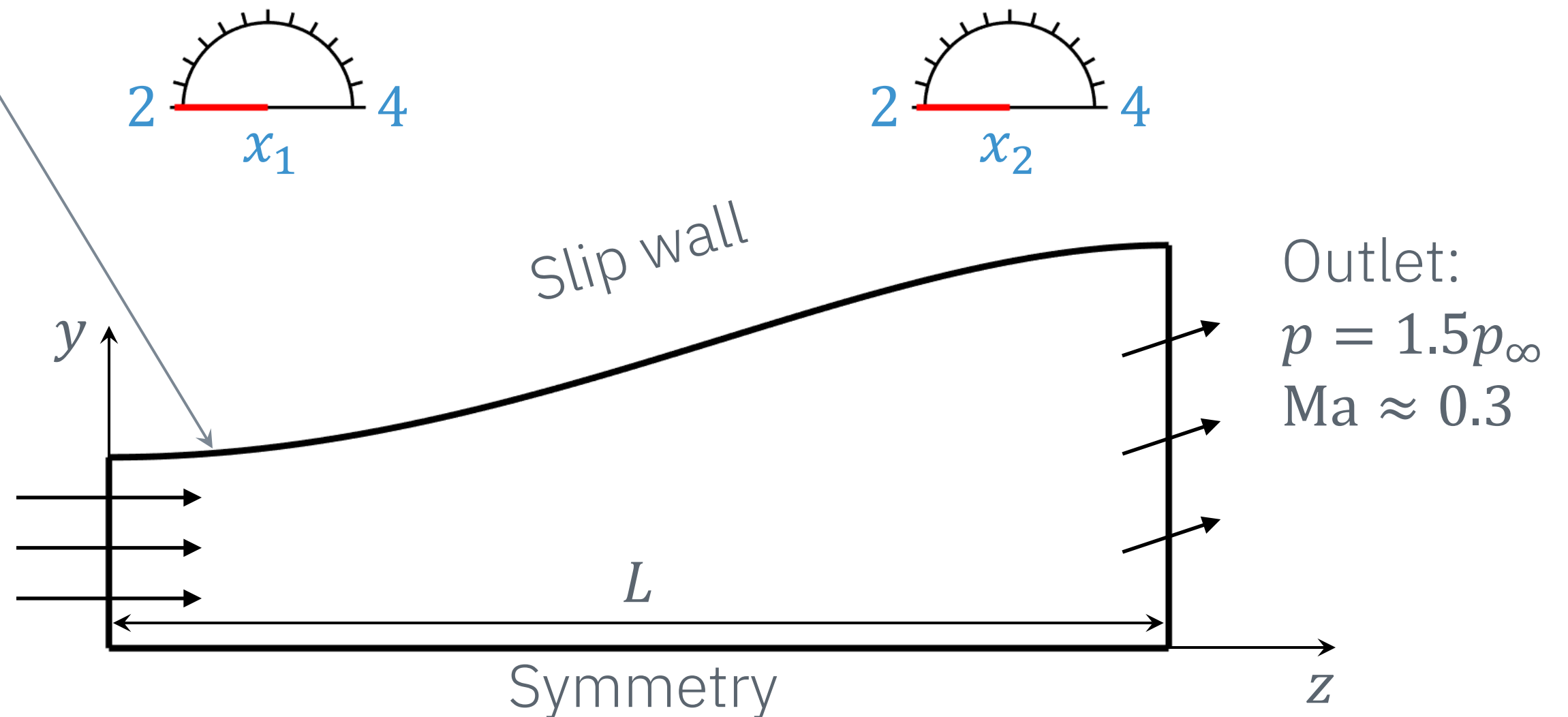
$$\frac{y - y_{in}}{y_{out} - y_{in}} = 1 - \left[1 - \left(\frac{z}{L} \right)^{x_1} \right]^{x_2}$$

Inlet:

$$p_{\infty} = 50 \text{ kPa}$$

$$\rho_{\infty} = 0.5 \text{ kg/m}^3$$

$$\text{Ma} \approx 0.95$$

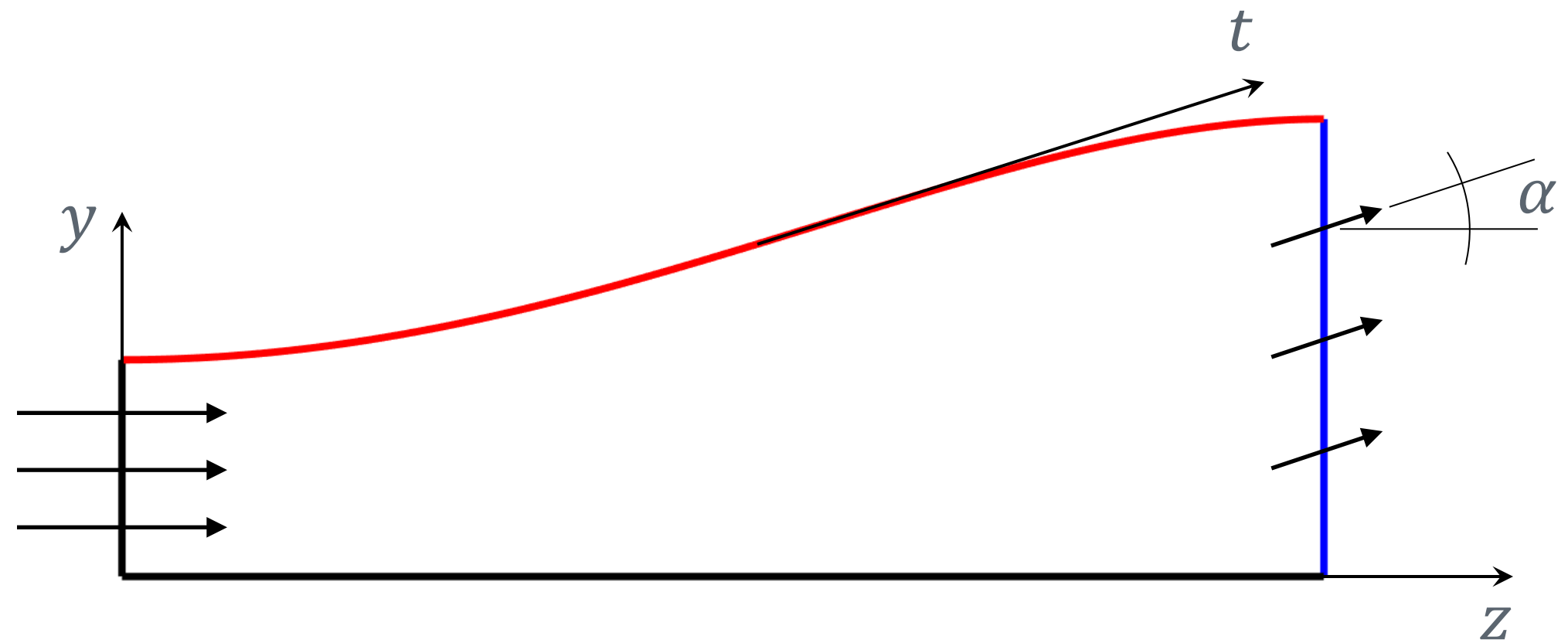


Shape Optimization of a Diffuser

Objective functions

$$\downarrow f_1 = \text{RMS} \left(\frac{\partial p}{\partial t}, \text{top wall} \right) / \left(\frac{q_\infty}{L} \right)$$

$$\downarrow f_2 = \text{RMS}(\alpha, \text{outlet})$$



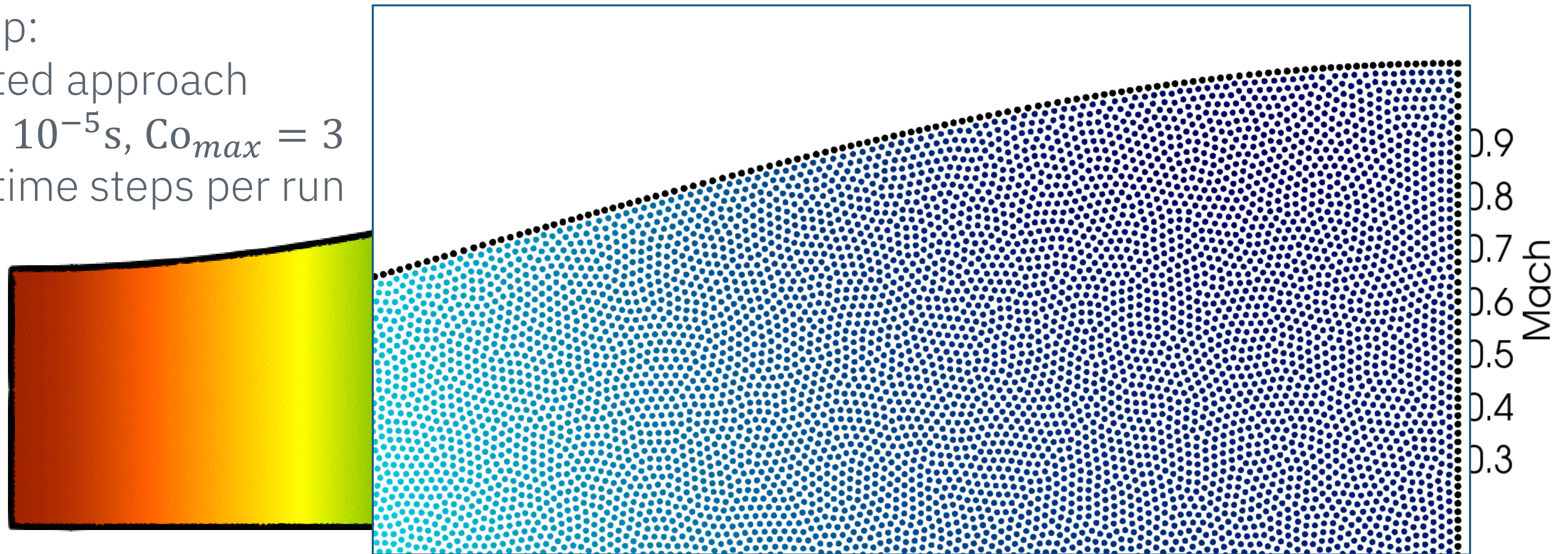
Shape Optimization of a Diffuser

RBF-FD meshless setup:

- $\approx 30,000$ nodes
- $P = 3$ polynomial degree (stencil = 20 nodes)

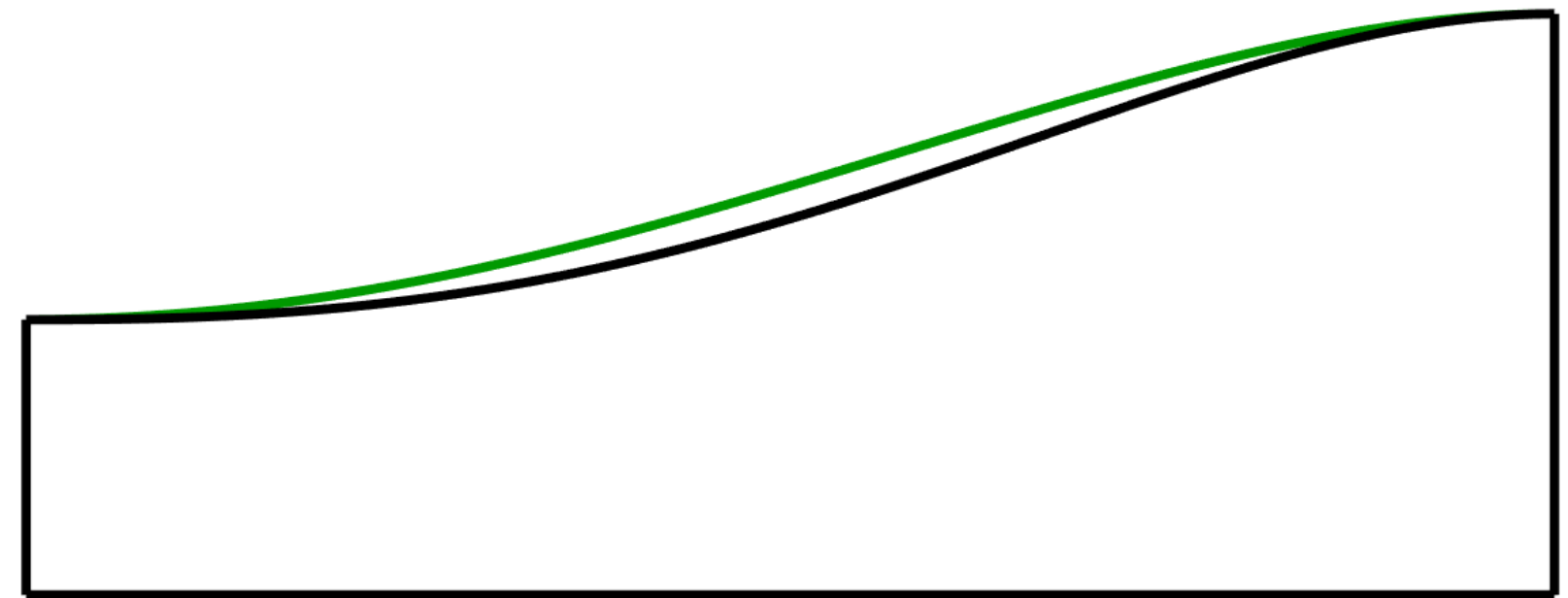
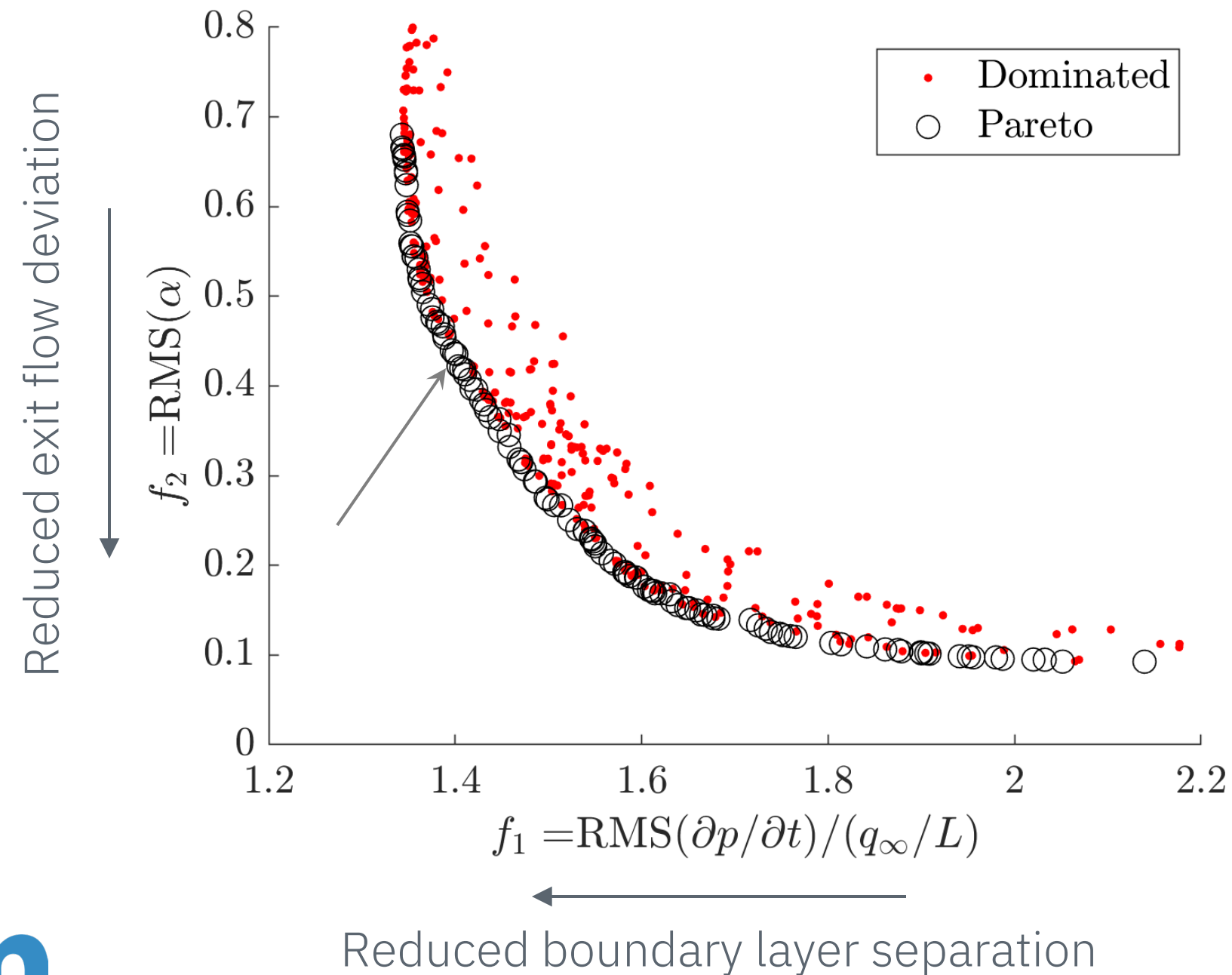
Solver setup:

- Segregated approach
- $\Delta t = 3 \times 10^{-5} \text{ s}$, $Co_{max} = 3$
- ≈ 2000 time steps per run



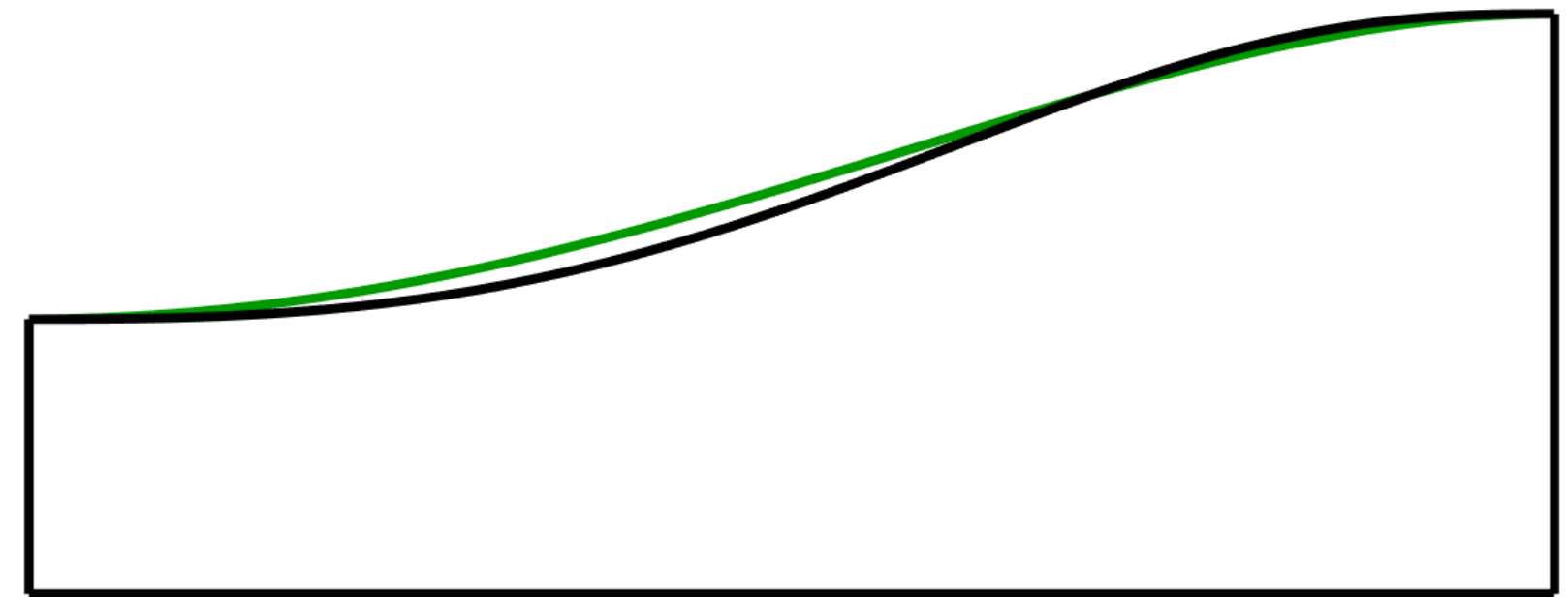
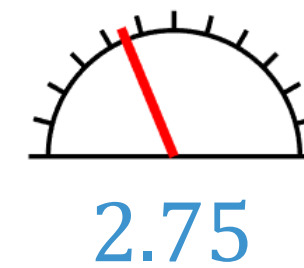
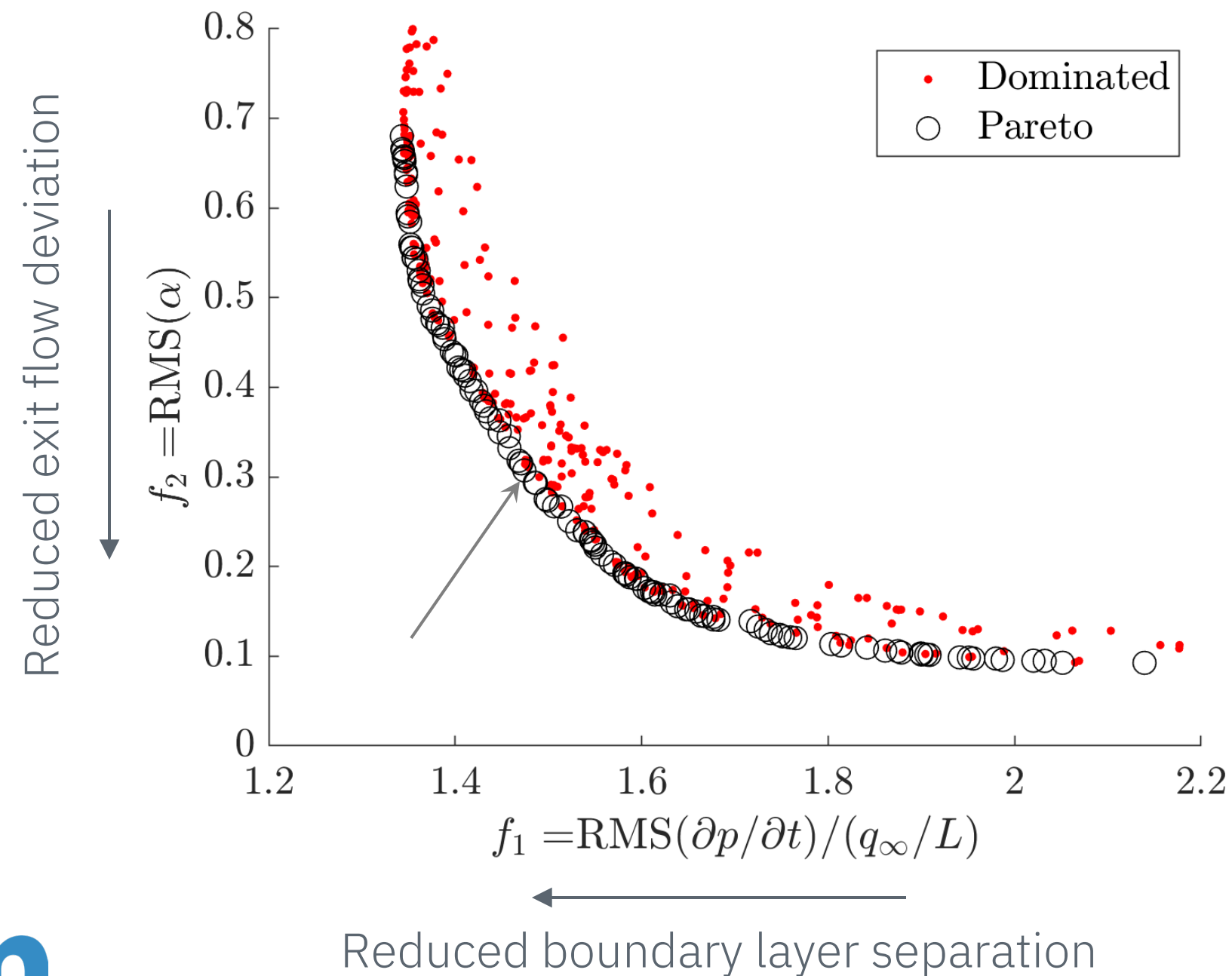
Shape Optimization of a Diffuser

Results (pilOPT, 500 evaluations, 8 hours)



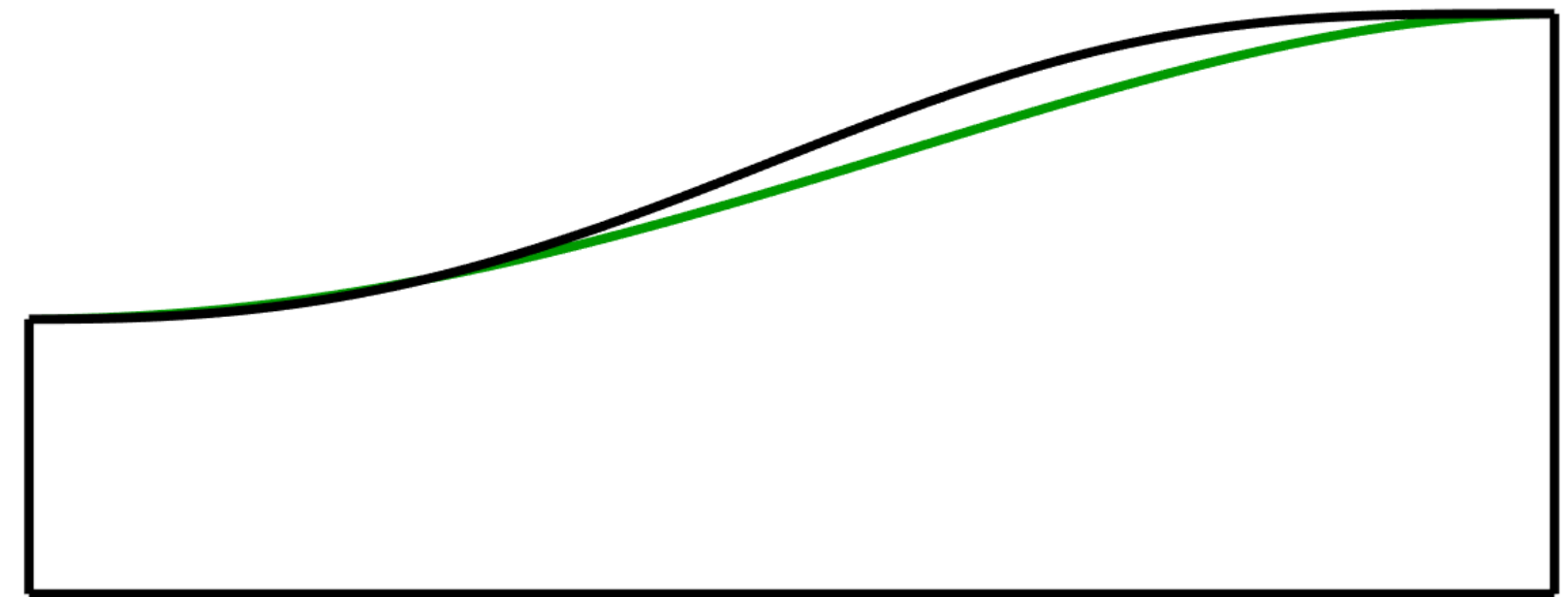
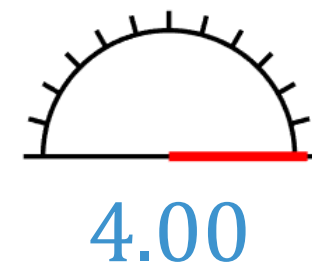
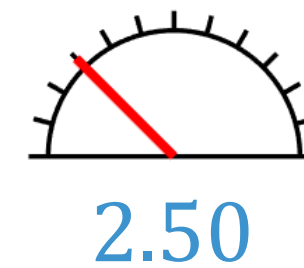
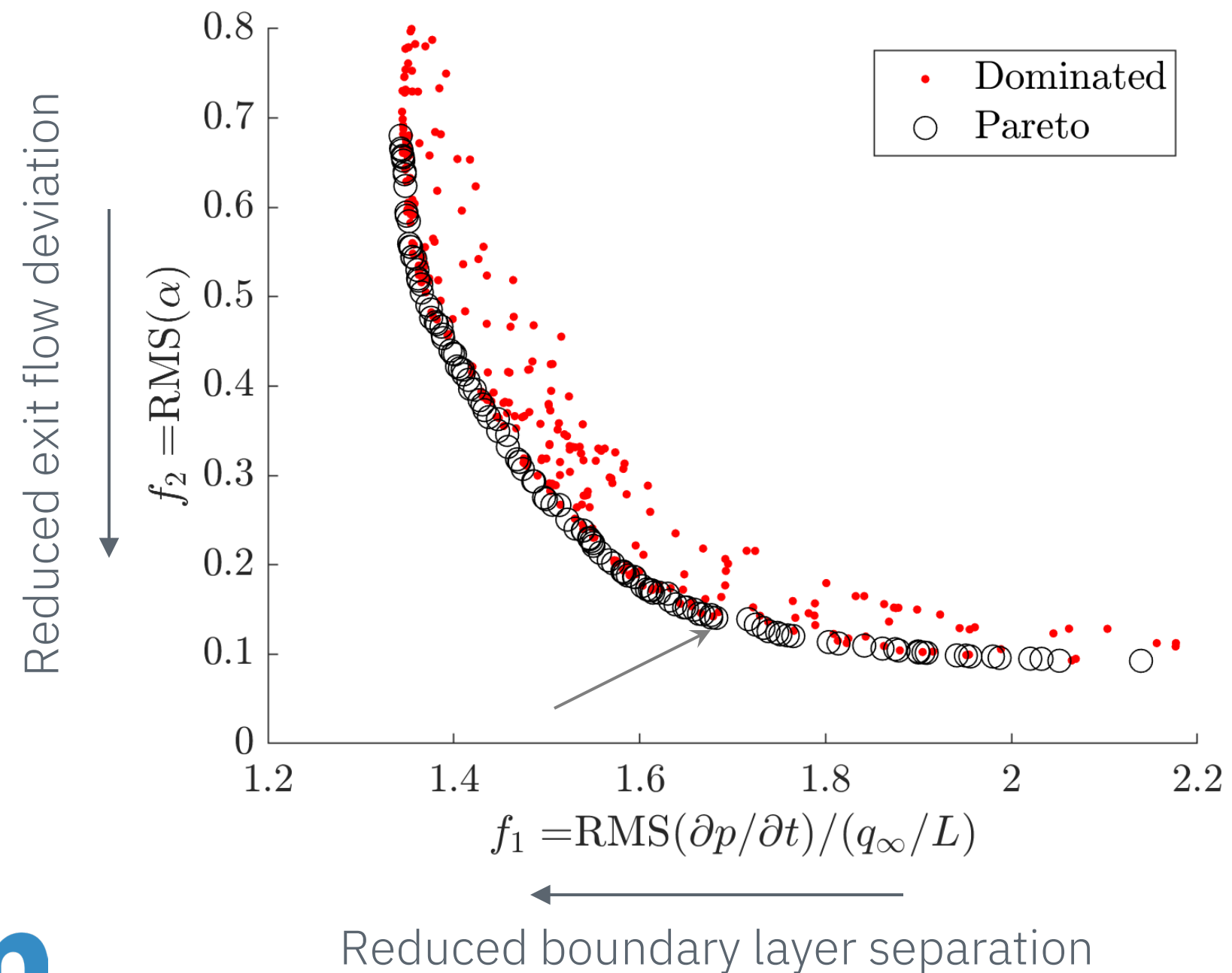
Shape Optimization of a Diffuser

Results (pilOPT, 500 evaluations, 8 hours)



Shape Optimization of a Diffuser

Results (pilOPT, 500 evaluations, 8 hours)



Concluding Remarks



Concluding Remarks

RBF-FD meshless method is used to simulate **compressible fluid flow** in an intake diffuser:

- stable computations for high-speed (high-subsonic) compressible flows
- straightforward node generation
- straightforward coupling with modeFRONTIER for shape optimization

Future work:

- transonic & supersonic flows
- adaptive shock-capturing

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Thank you

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