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# Towards Large-eddy Simulation of Wind Farm Flows for Industrial Applications

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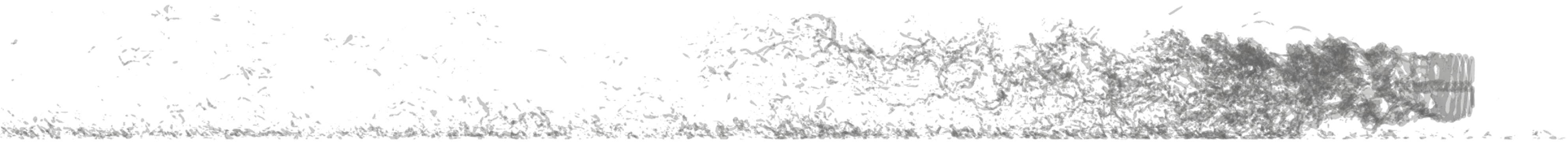

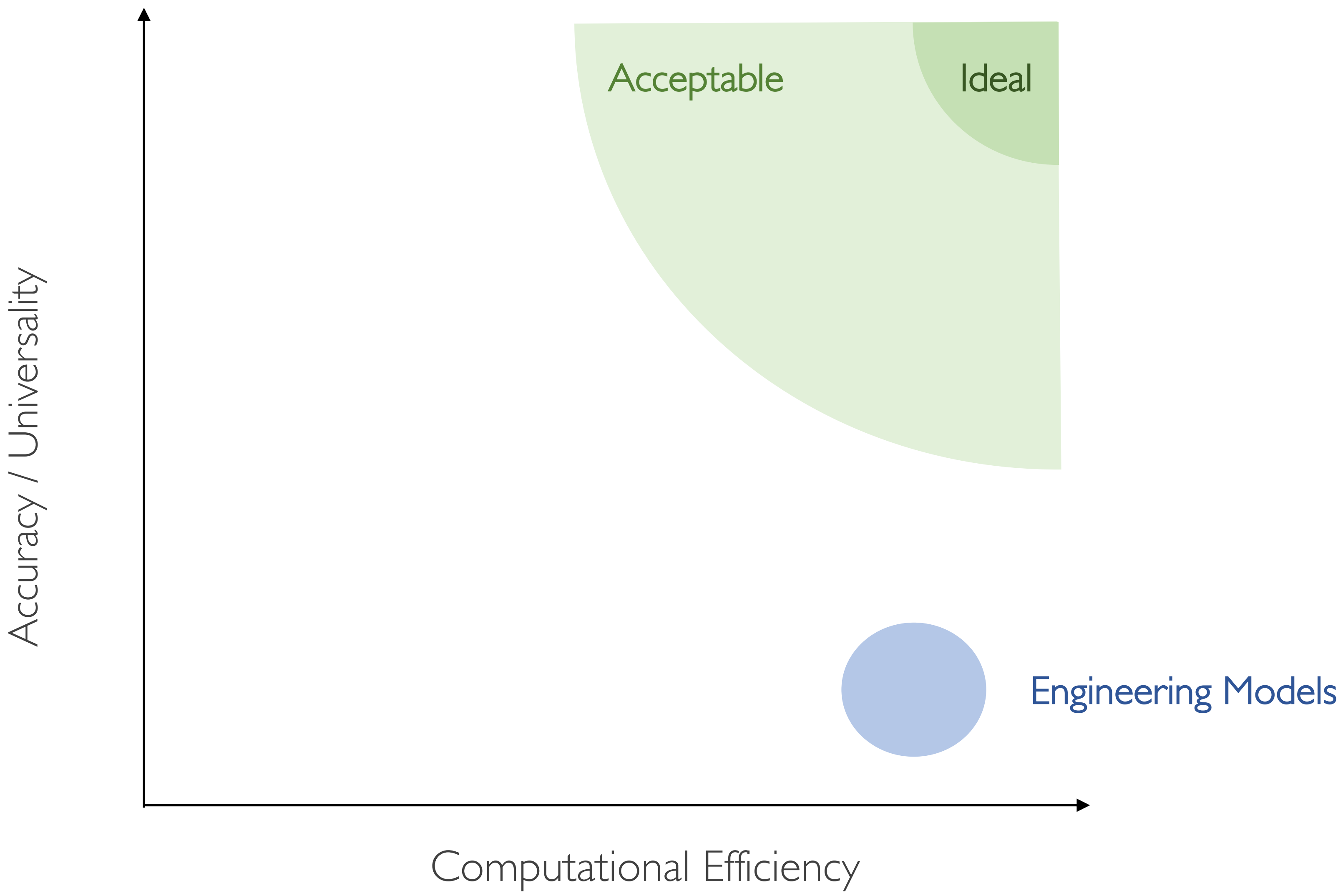
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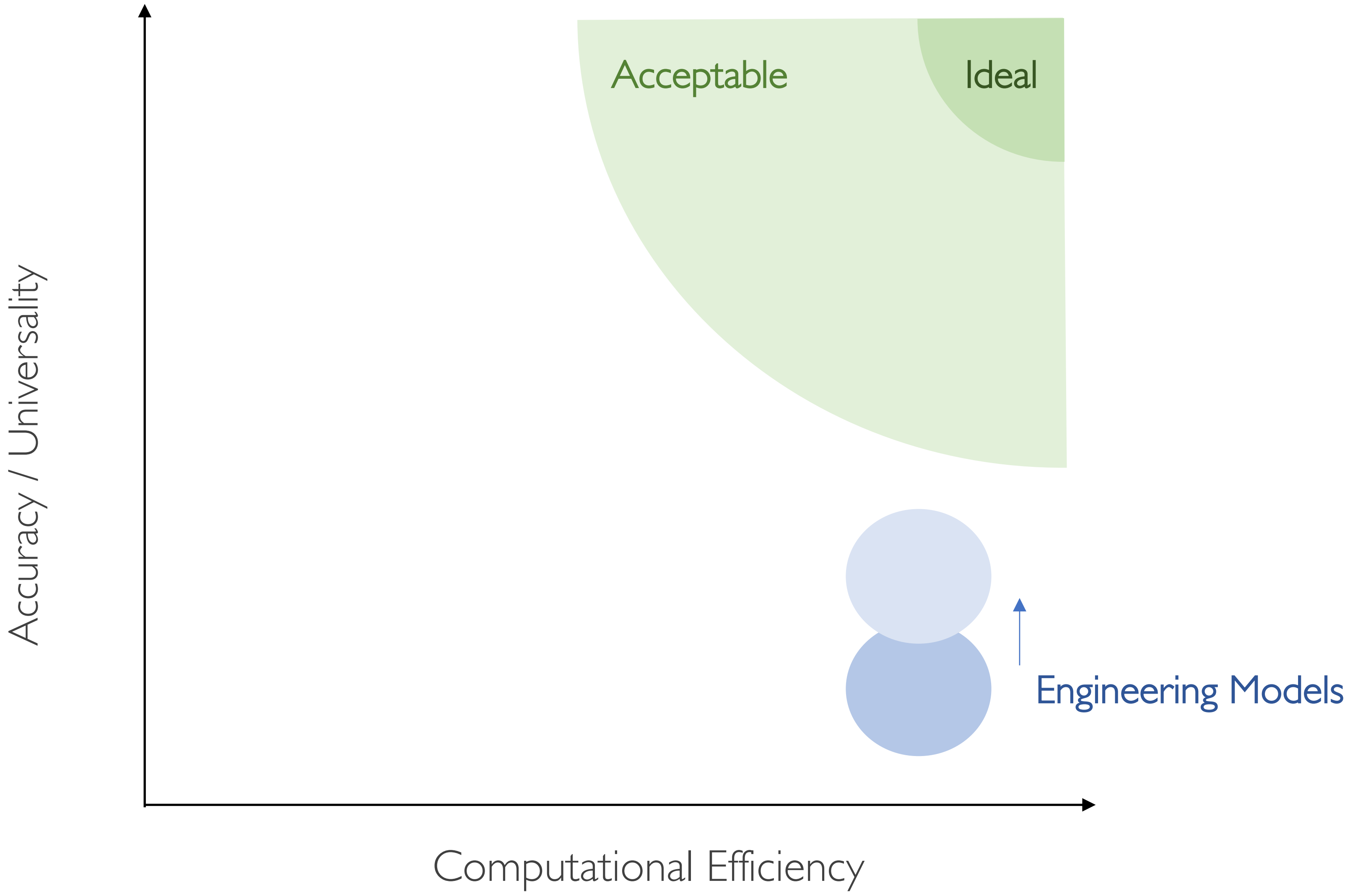
Engineering Models
Accuracy / Universality
Computational Efficiency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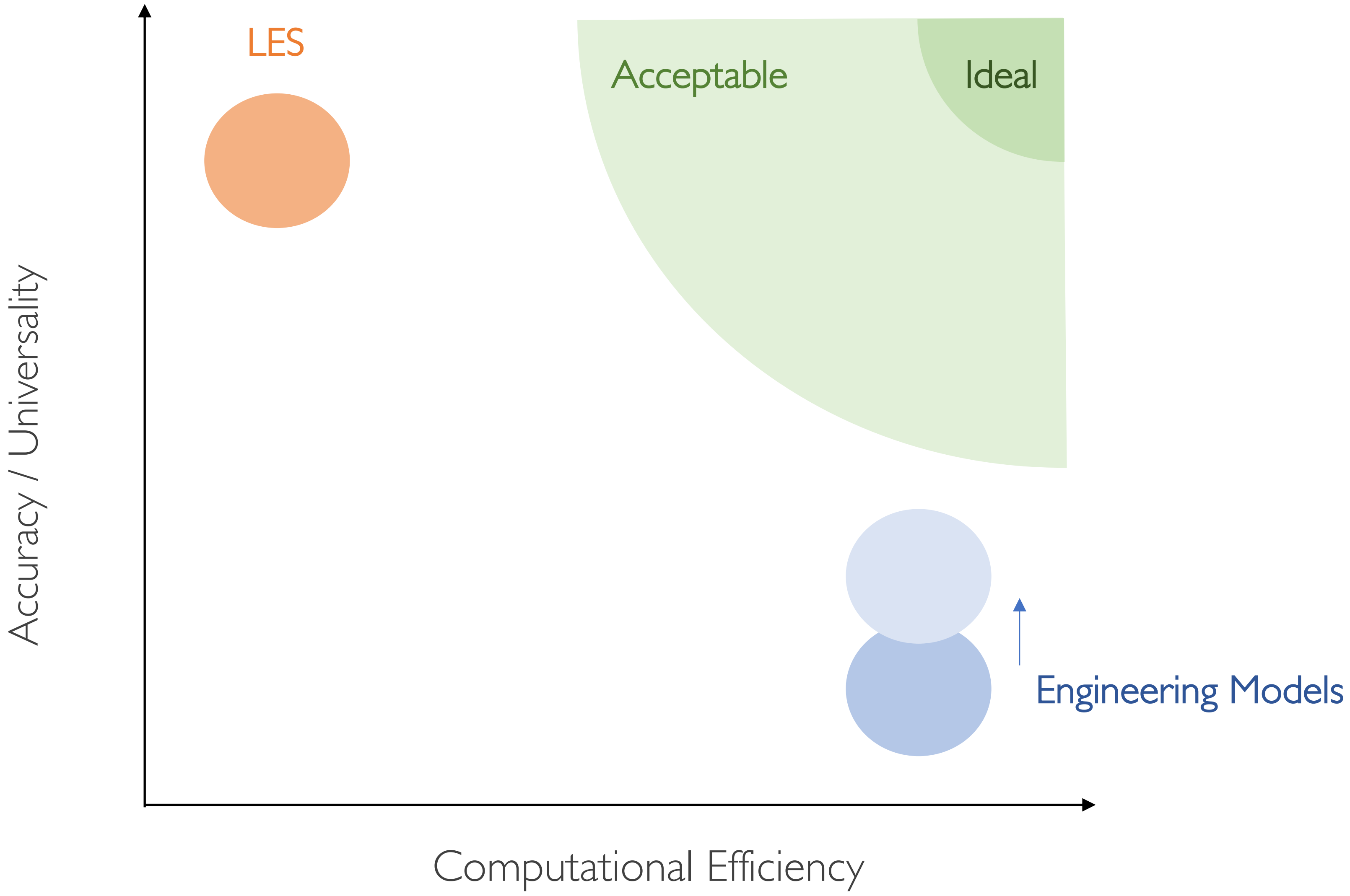
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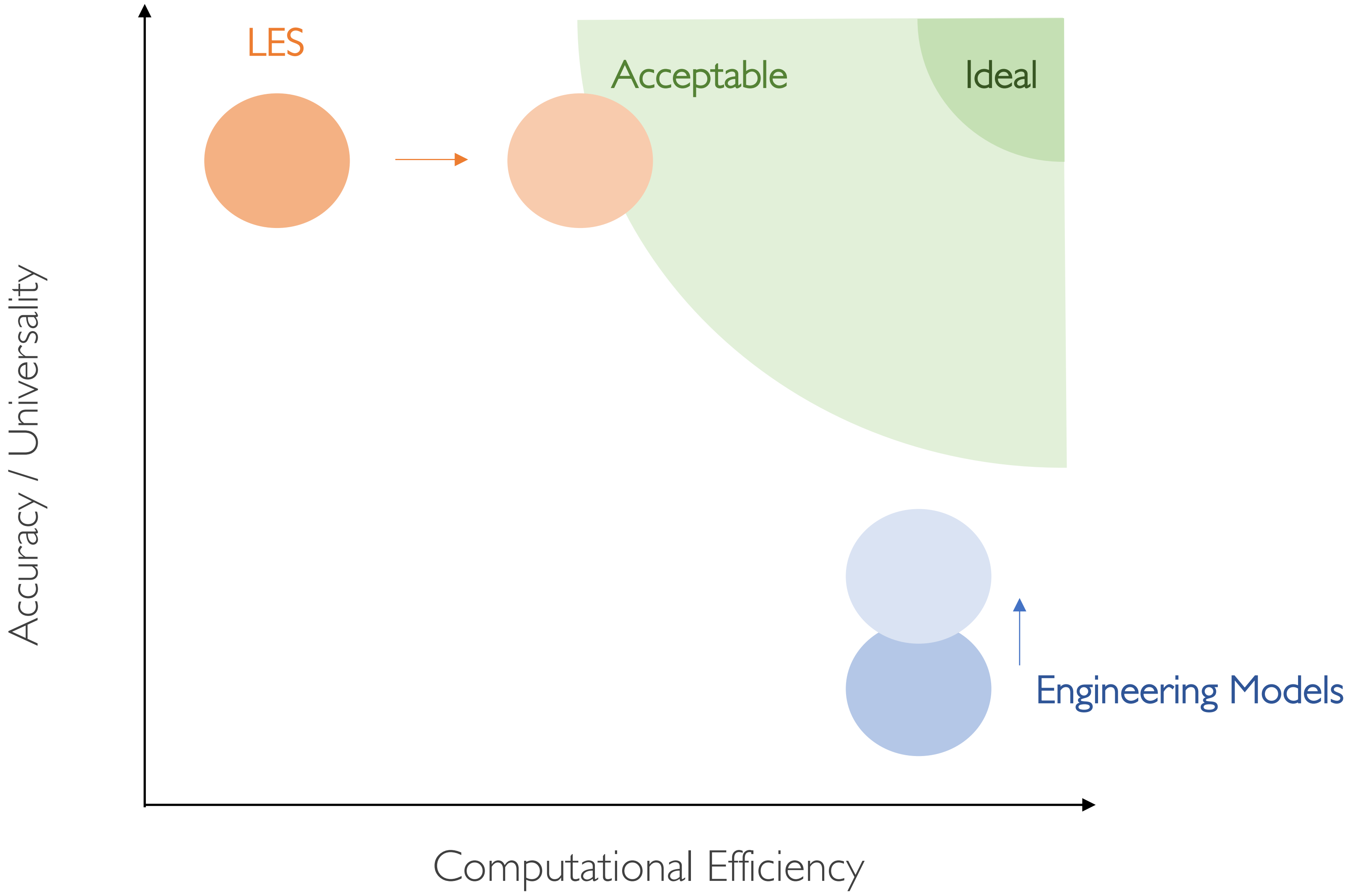
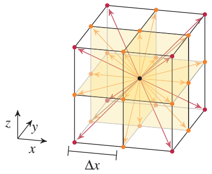
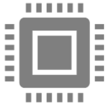


# Outline




The Lattice Boltzmann Method + GPUs

Validation against full-scale measurements



Computational Performance

# Fundamentals of the Lattice Boltzmann Method

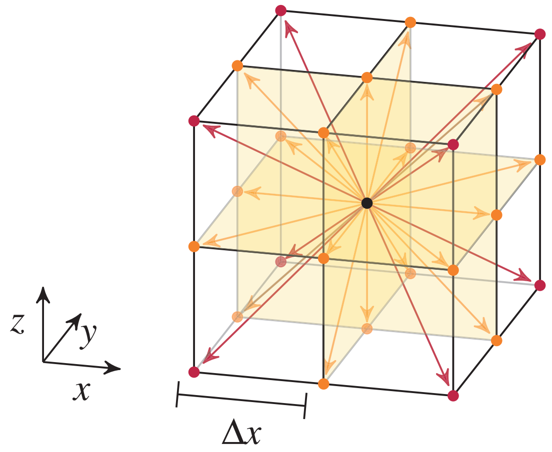
The particle distribution function

$$f(x_\alpha, \xi_\alpha, t)$$

$$\frac{d}{dt}$$

The Boltzmann equation

$$\frac{\partial f}{\partial t} + \xi_\alpha \frac{\partial f}{\partial x_\alpha} + \frac{F_\alpha}{\rho}\frac{\partial f}{\partial \xi_\alpha} = \Omega(f)$$



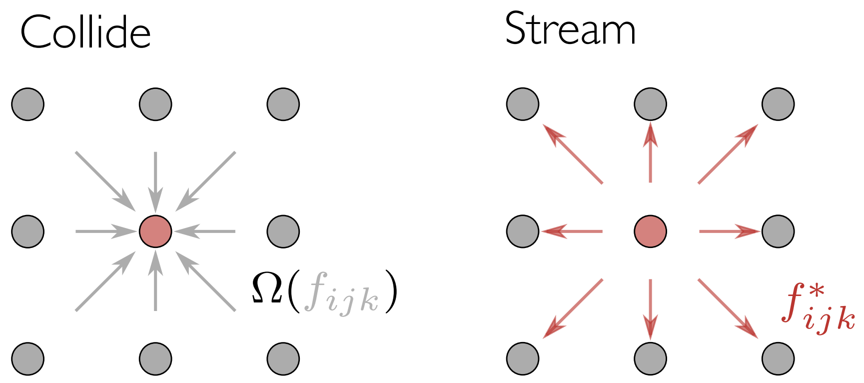

- Discretize space and time
- Discretize velocity space: $f \to f_{ijk}$

  with $\boldsymbol{e}_{ijk} = \Delta x/\Delta t\,(i,j,k)$

The Lattice Boltzmann equation

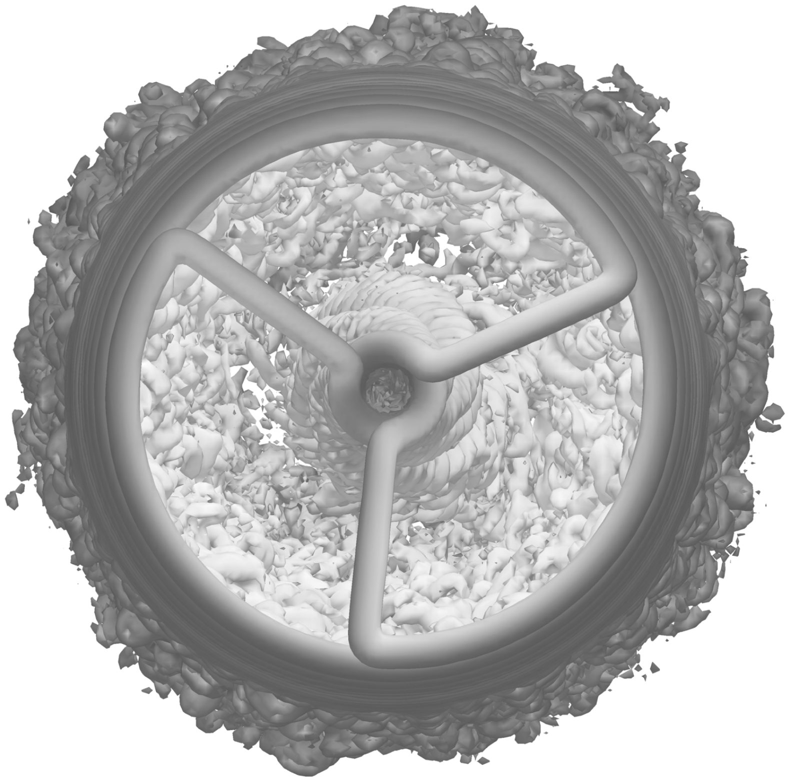
$$f_{ijk}(t+\Delta t, \boldsymbol{x} + \Delta t\, \boldsymbol{e}_{ijk}) = f_{ijk}(t, \boldsymbol{x}) + \Delta t\, \Omega_{ijk}(t, \boldsymbol{x})$$

# Why LBM?




- Recovers the weakly-compressible Navier-Stokes
- Explicit in time & exact advection
- Local non-linearity (the collision operator)
- Efficient numerical scheme, excellent parallelisation, very suitable for GPUs

# Actuator Line Simulations



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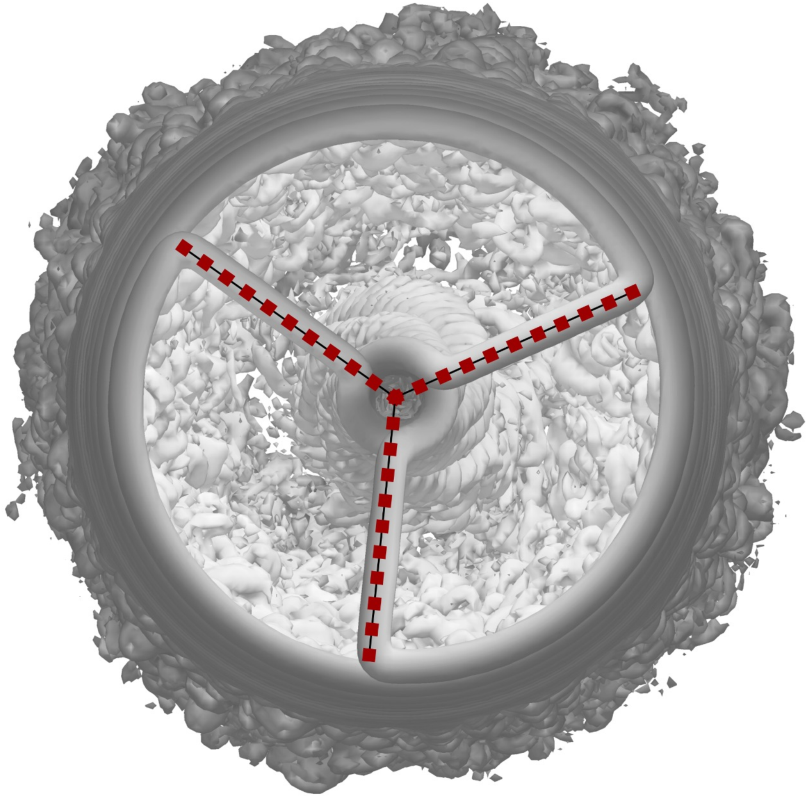
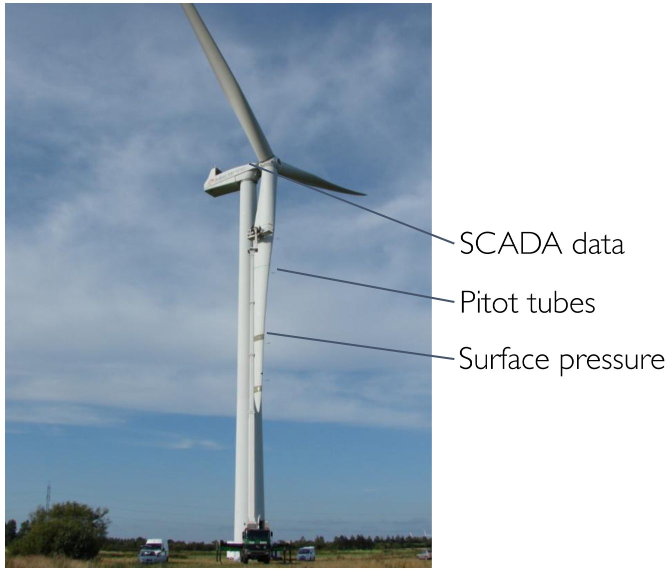
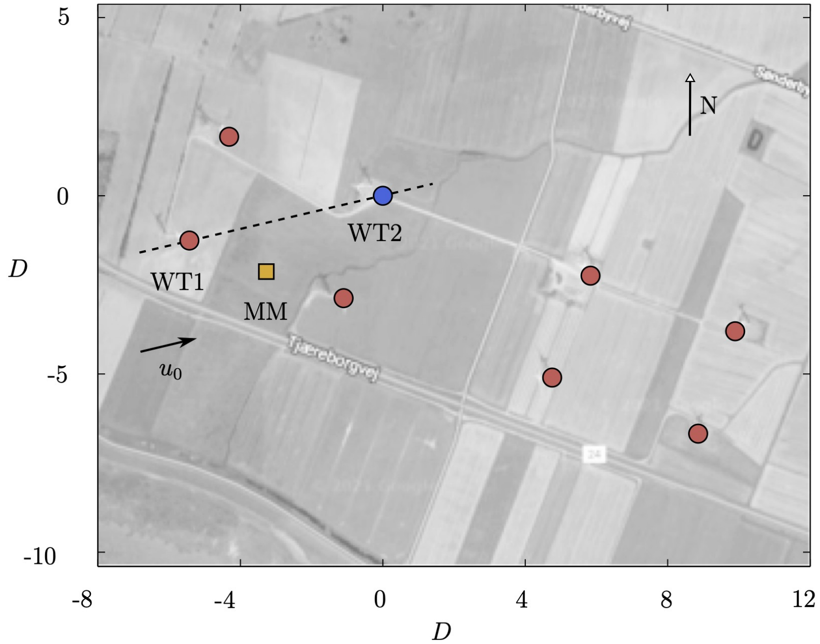


# Validation Against Full-scale Measurements

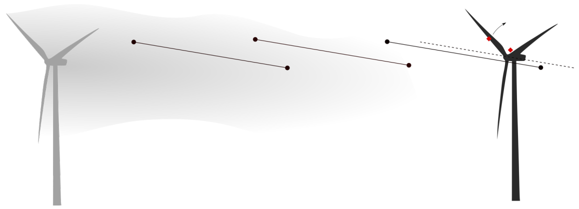


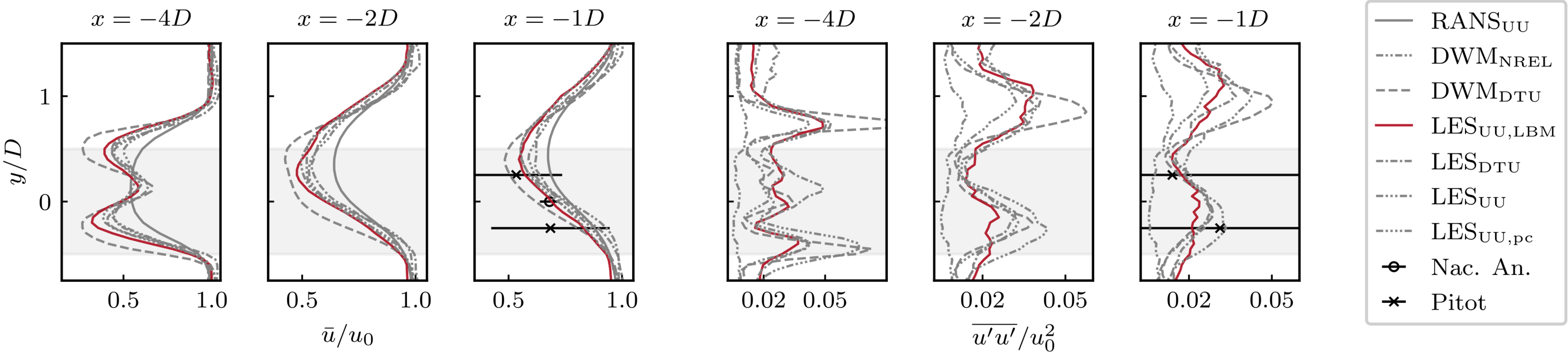

The DanAero experiment



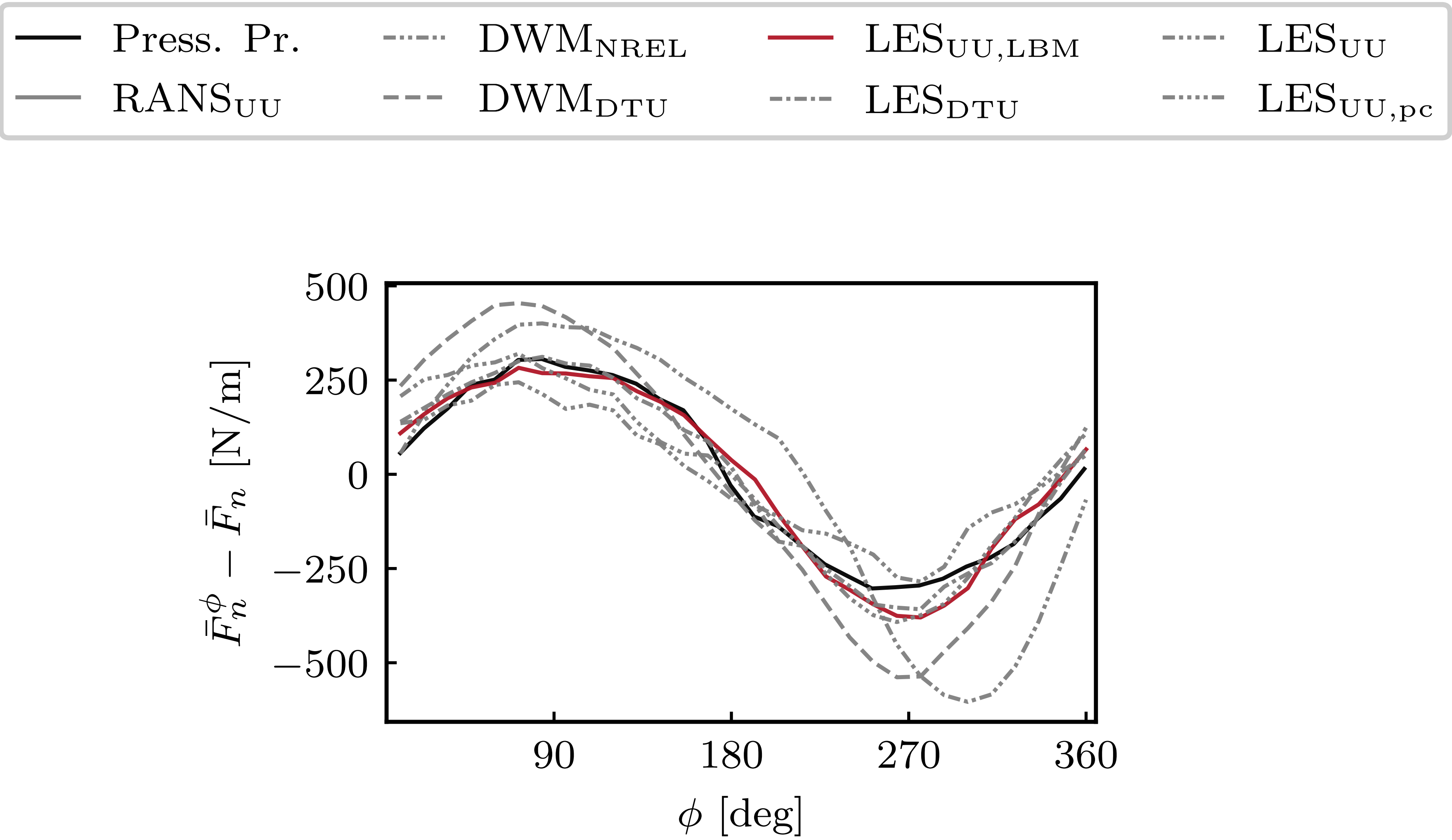

- Comparison of wake inflow cases
- 6 different models: LES, RANS, DWM
- Validation + code-to-code comparison

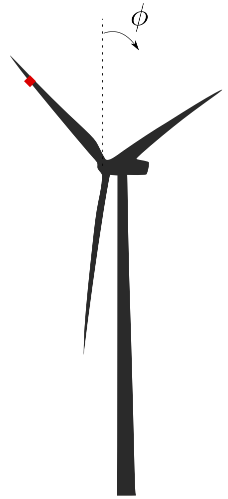
[2] Asmuth et al. (2021), *Renew. Energy*, 191, 868-887






Mean stream-wise velocity (left) and velocity variance (right) upstream of WT2



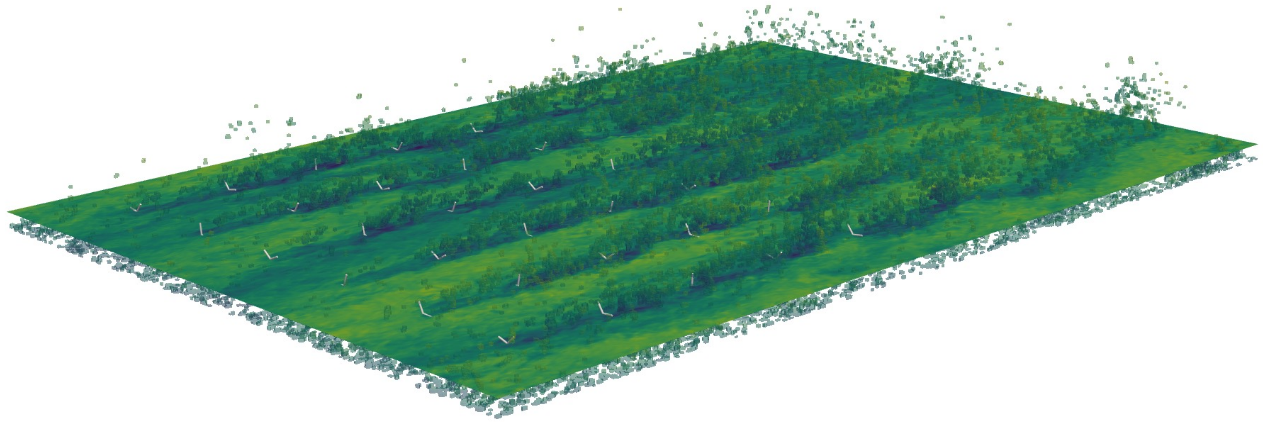

Azimuthal variation of the mean normal force at $r/R = 0.75$

# Computational Performance

# Performance optimizations for wind farm simulations

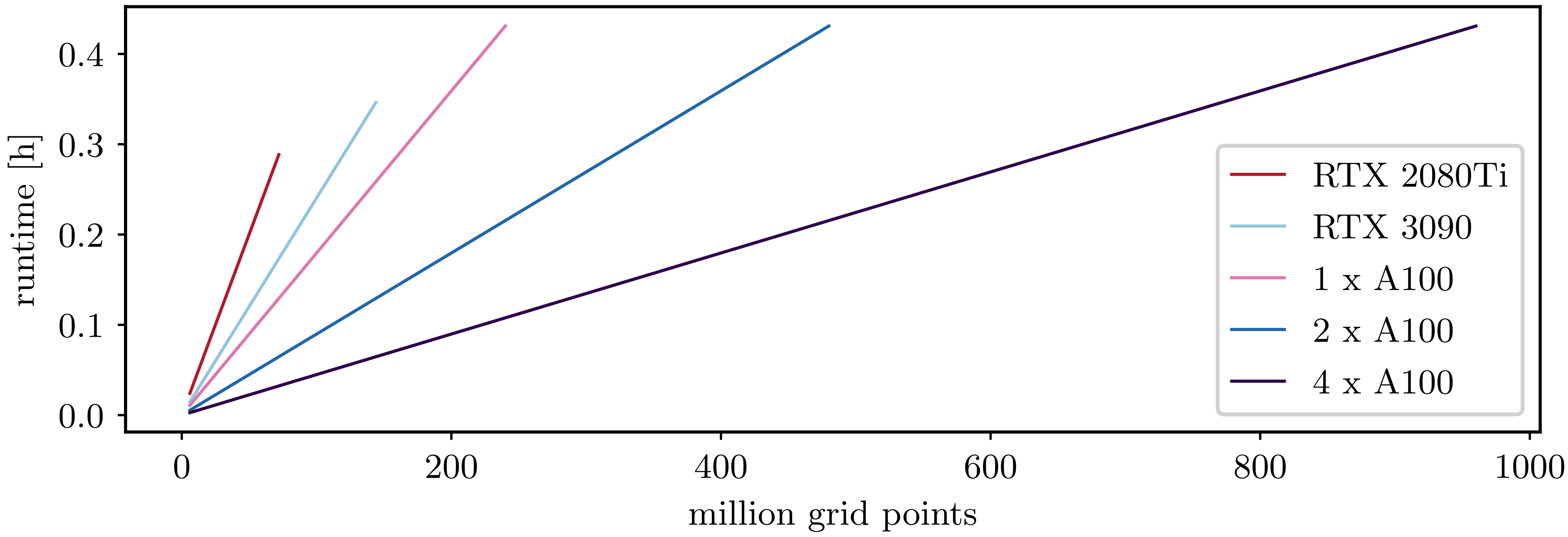
Overhead of non-LBM subroutines:

- Turbulence model
- Write macroscopic variables
- Read/write body forces
- Read precurser flow fields
- ALM + aeroelastic solvers



# Performance Projection

- Simulation of 1h
- Finest spatial resolution of 10m



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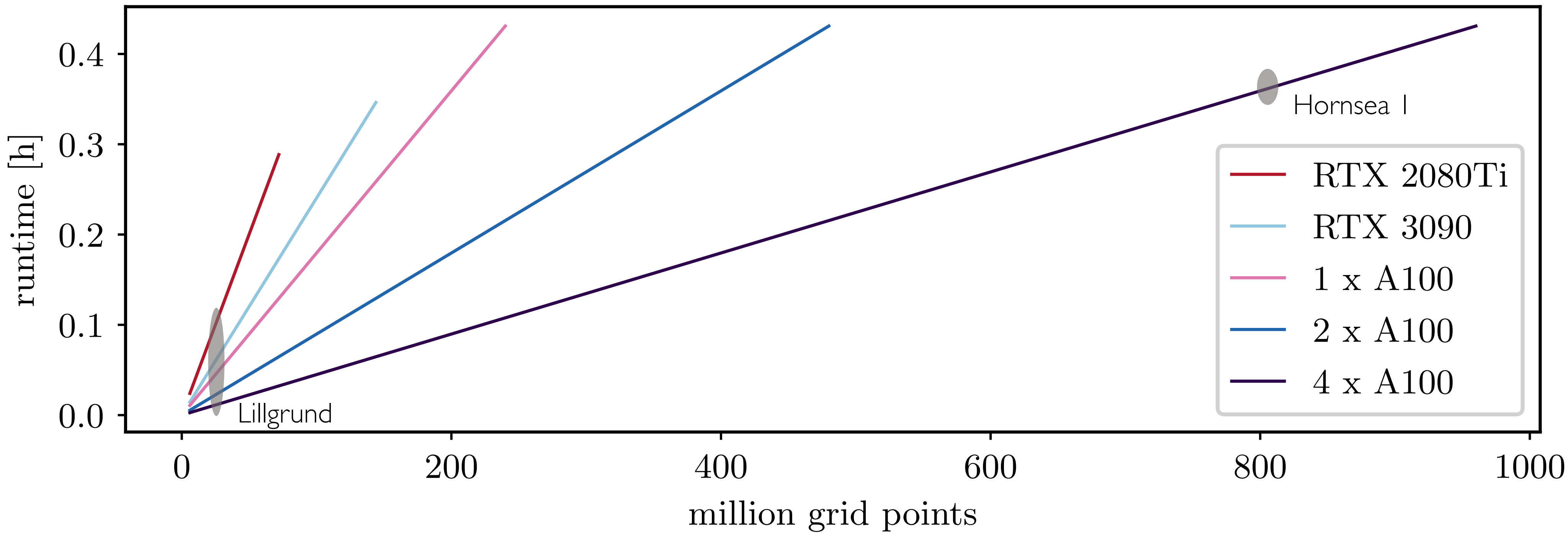

# Summary & Conclusion

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- Turbine models (ALM) in LBM
- Wall model for atmospheric boundary layers
- Verification and Validation
- Industry LES of wind farms is possible ✓

# Outlook

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- Stratification
- Canopy models
- Aeroelastic coupling of turbine models
- Extend wall model to complex terrain
- More validation

**ToDo!**

# Industry Perspective

- What is the biggest added value?
- What are potential industrial use cases ?
- How fast is fast enough?

▸ Online survey, please participate!

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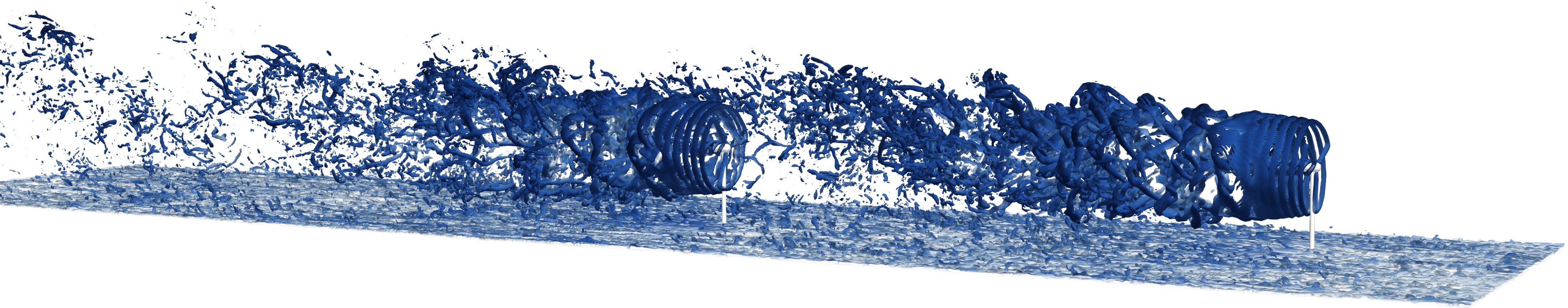
# Thanks for listening



## References


[1] Asmuth et al. *Wind Energy Sci.*, 5, 623–645 (2020).

[2] Asmuth et al. *Renew. Energy*, 191, 868-887 (2021).

[3] Asmuth et al. *Phys. Fluids*, 33, 105111 (2021).

[4] Asmuth and Korb. *J. Phys.: Conf. Ser.*, 2265, 022066 (2022).