A temporal fluids-parcel backwards-tracking method for the study of cyclical variations

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Background

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Assesment of cyclical variations

- Aim is the assessment of cyclical variations
- Study focuses on convectively transported causes of CCV
- Flowfield and mixture composition during the ignition are crucial of the flame formation and propagation -> used for this study
- Temporal recreation of momentum and scalar fields is highly memory intensive
- Identify fluid which is involved in an event of interest (e.g. ignition)
- (directly on the run or using a restart)
- Simulate the parcels as Lagrangian Particles

Workflow

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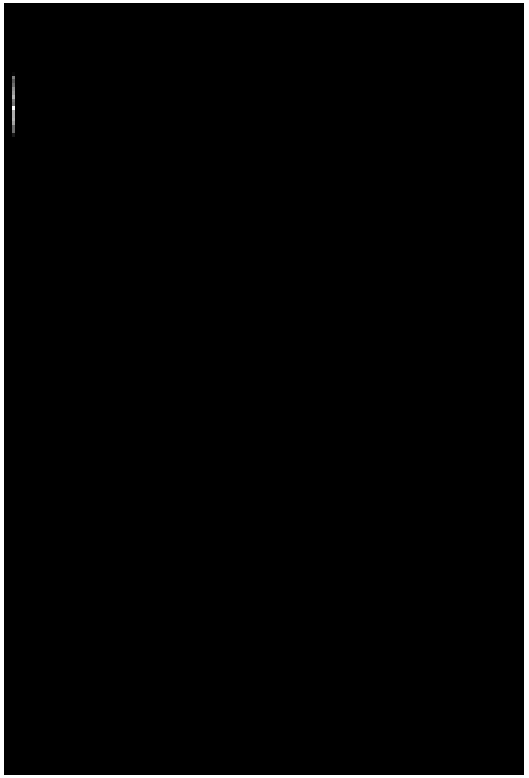
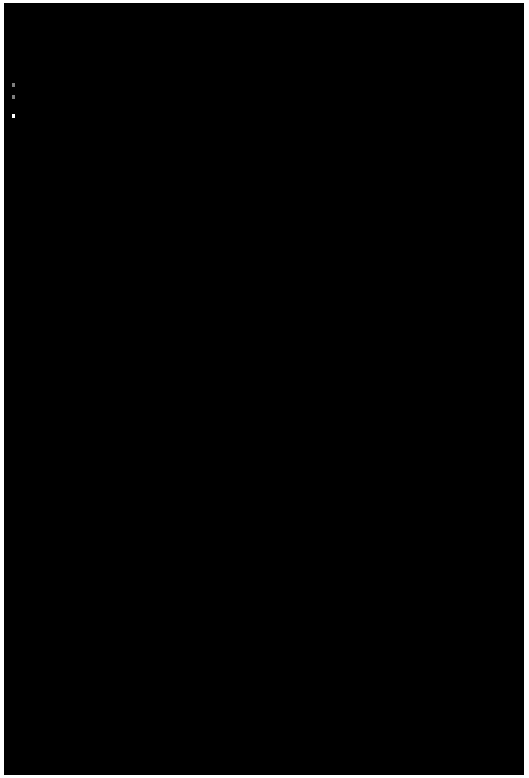
Lagrangian Tracers – Manifold initialization

- Tracers are randomly generated in the intake manifolds
- Tracers are transported convectively
- (Detect particles nearby spark-plug during ignition)
- (Save particles to a protocol file)
- (Restart simulation and load particles from file)
- Save temporal and spatial information to a file
- Reconstruct fluid-/thermodynamical trajectory

Simulation procedure



All tracers



Detected tracers

Numerical solver

PsiPhi

- In-house code
- FVM for (in)compressible NSE
- Equidistant cubic grid
- Low-storage Runge-Kutta scheme for time integration
- Flexible choice of turbulence models (Smagorinsky, SES, Sigma, Clark, KKK1/2)
- Has been compared with other codes and many experiments
- Used in this study:
  - CDS8 stabilized using a tenth-order filter
  - Sensor-enhanced Smagorinsky model

Comparisons of the flow field

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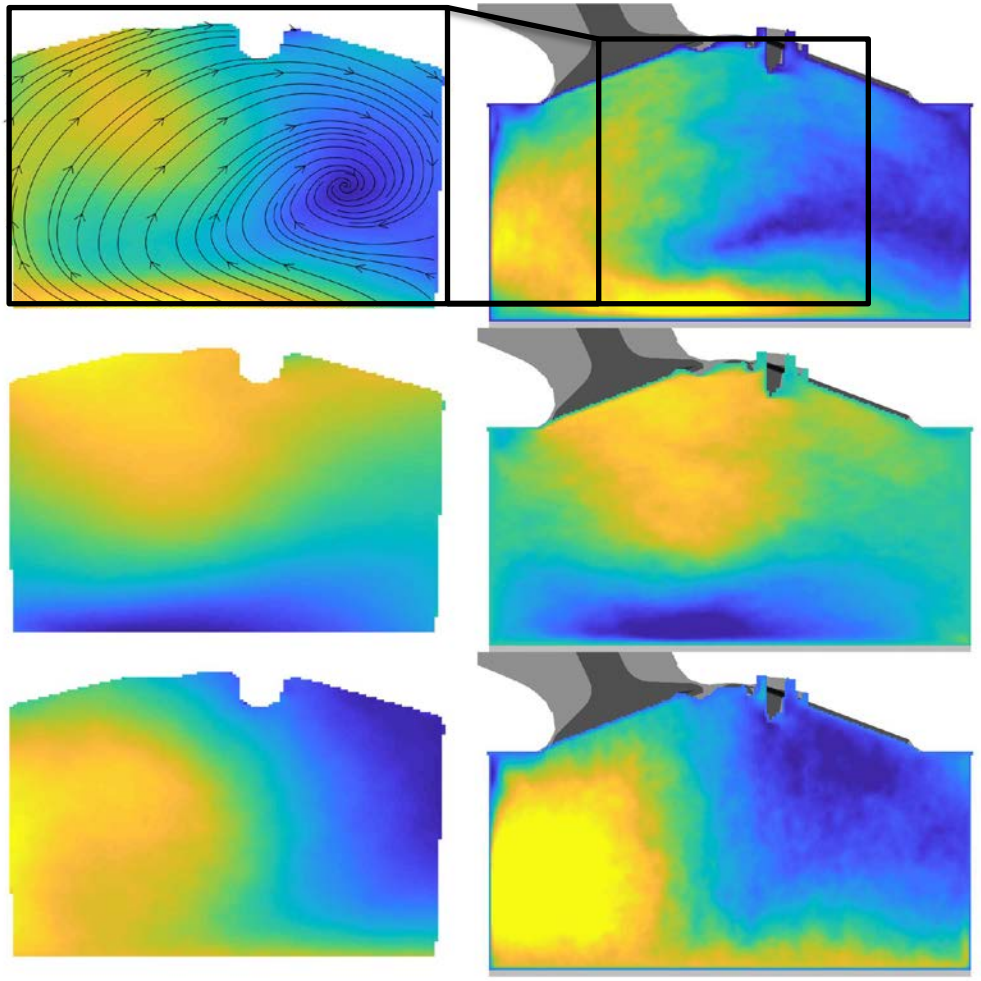
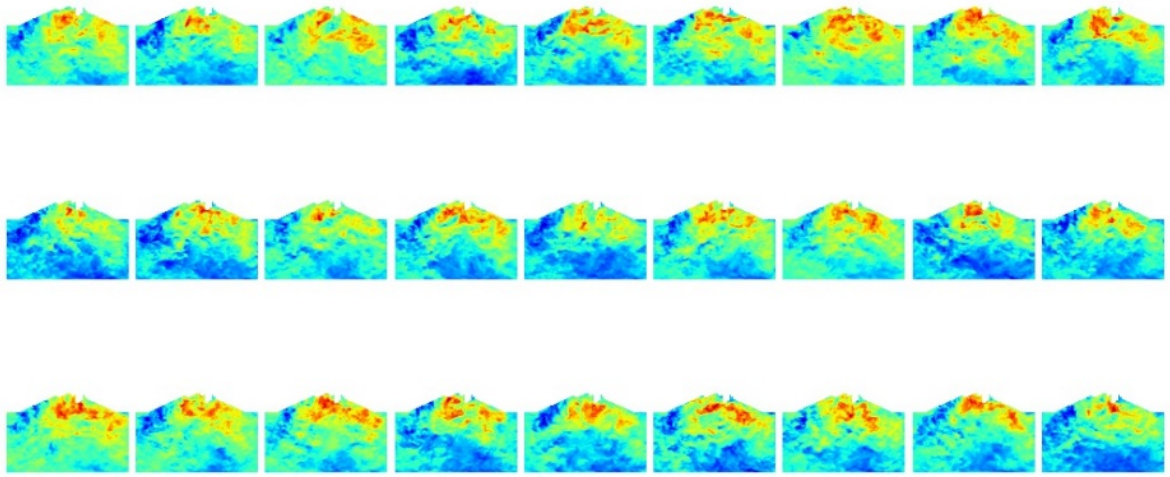
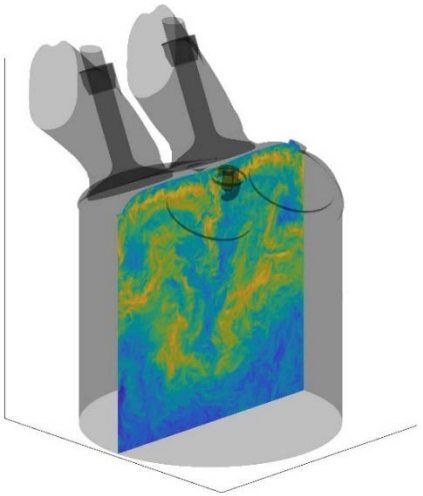
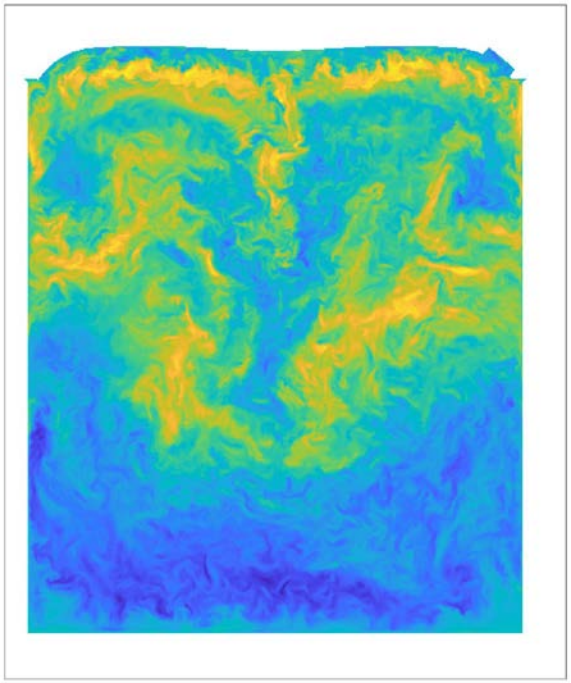
- Darmstadt Engine (Operation point C) used for reference
- Motored simulation
- Convective study: flow-fields have to be predicted adequately
- Statistics have been obtained sampling over 30 cycles



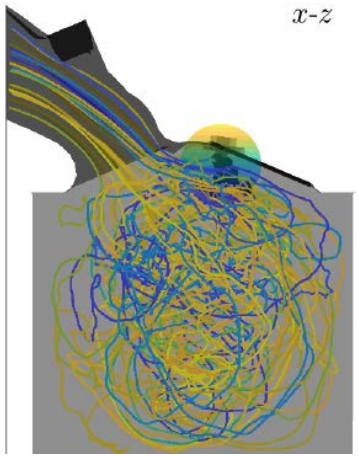
Comparisons of the flow field

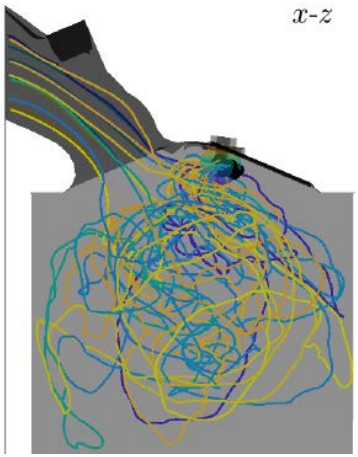


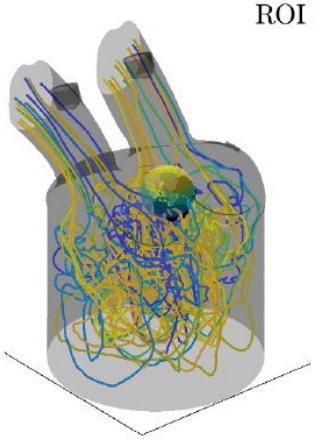


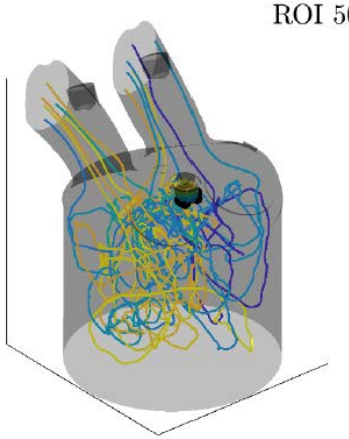


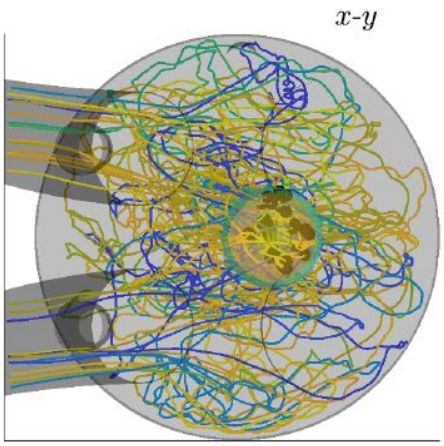
Spatial trajectories of the tracers

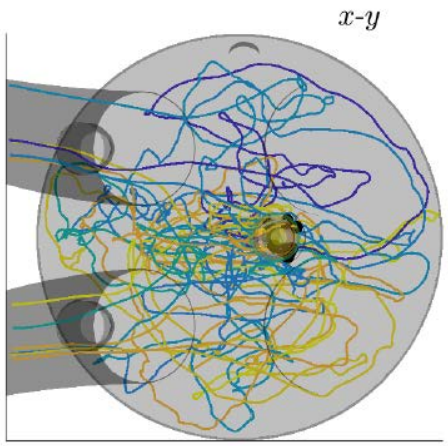








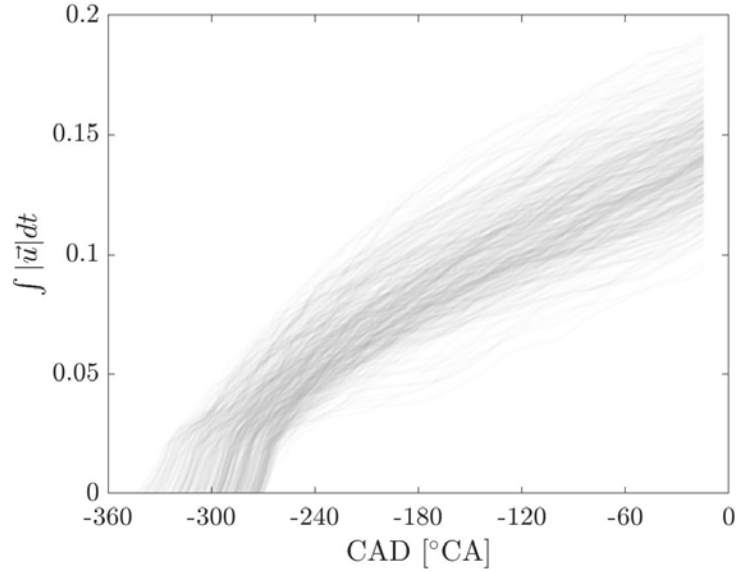


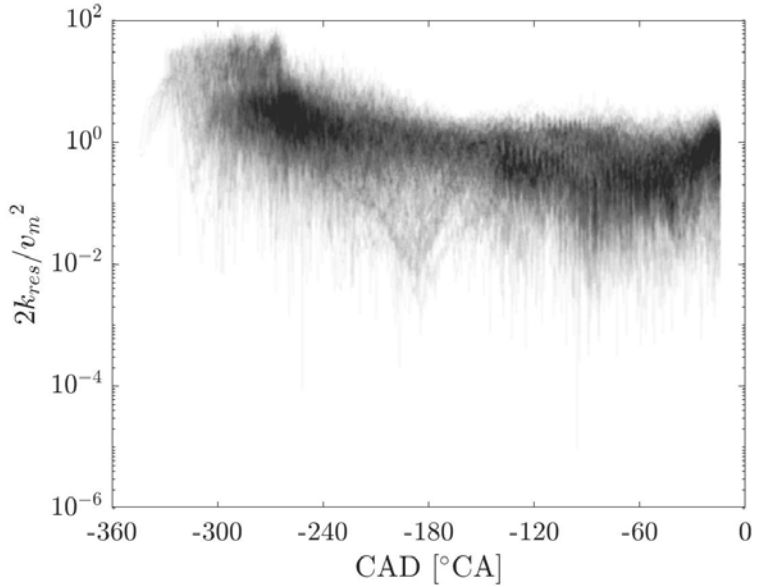


- Spherical ROI around spark plug
- Particles are obtained at time of ignition
- Two runs for comparison using a full and a radius reduced by 50%

Quantities experienced by tracers

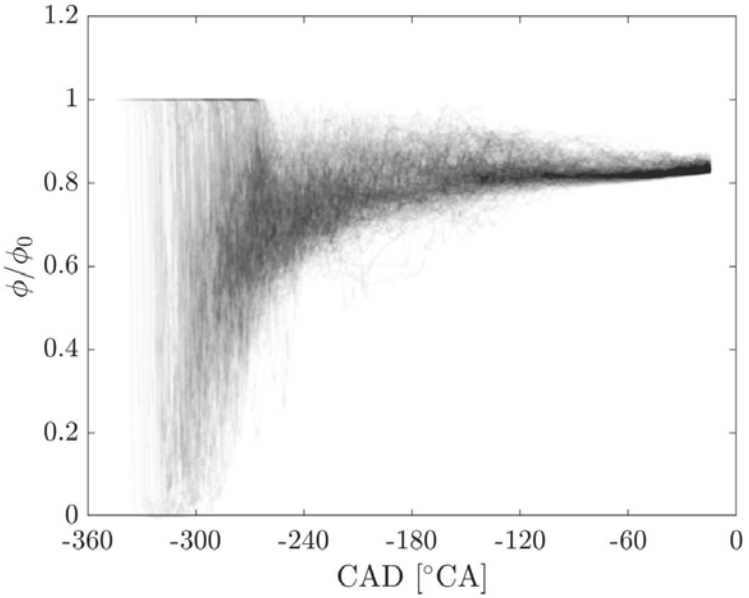
- Visualization of total travelled distance and kinetic energy of the flowfield
- Transparency of the values chosen to investigate collective behavior
- High color intensity indicates a characteristic held by many tracers
- Curves reveal features like passage through manifold and valve gap

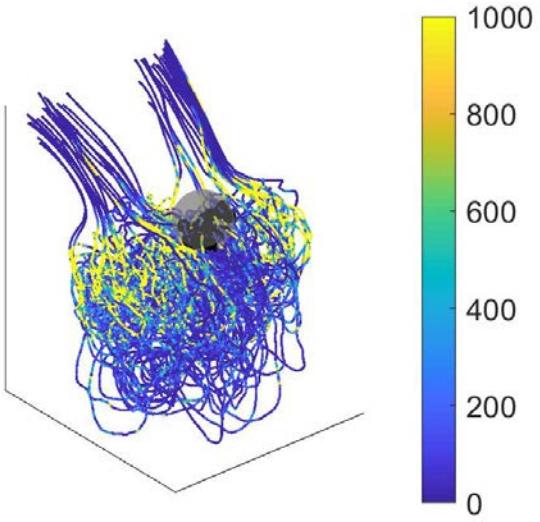




Quantities experienced by tracers

- Passive scalar is assigned for fresh gas entering the cylinder
- Old gas is assigned with 0 at the beginning of the cycle
- Spatial trajectory is colored with the time derivative of the passive scalar at the very location





Quantities experienced by tracers

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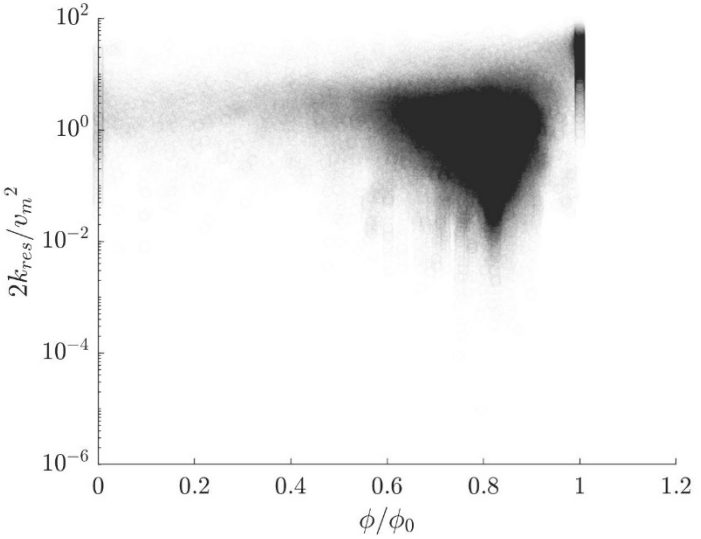
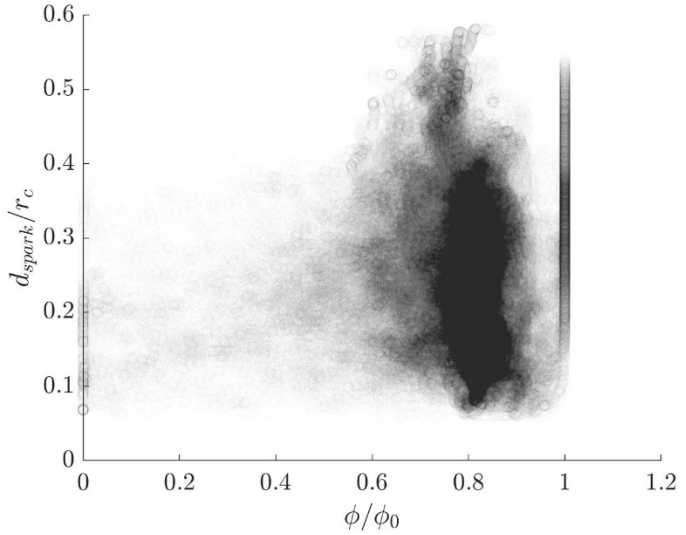
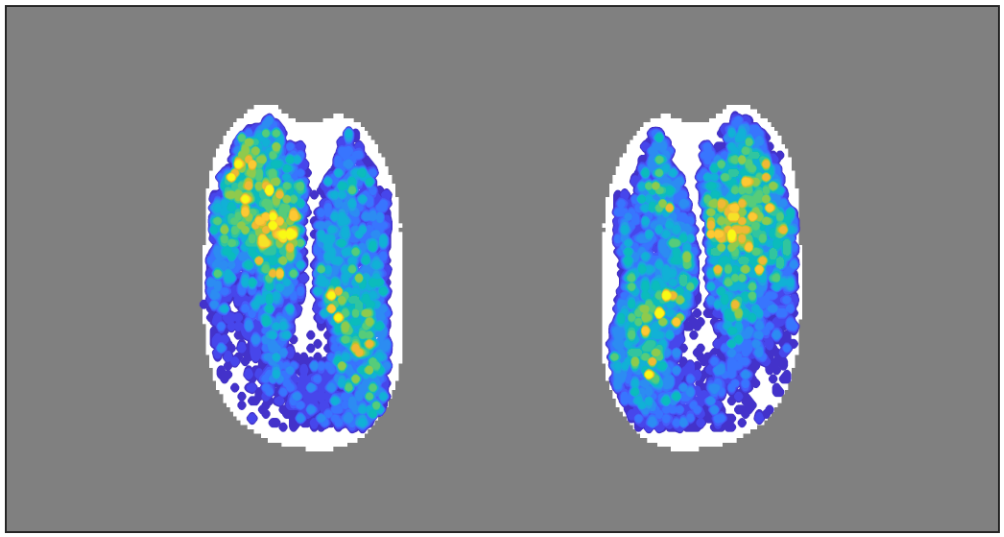
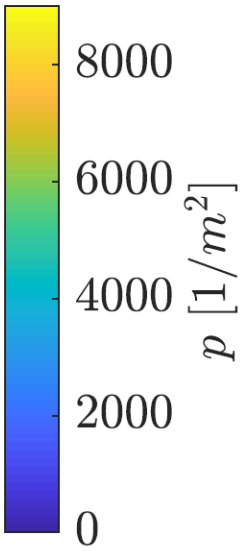
- Scatter plots to investigate for correlations and common behavior
- Passive scalar vs. resolved kinetic energy
- Distance from spark-plug vs. Passive scalar





Success-rate of tracer reaching spark





- Particles reaching the spark-plug during ignition have been observed regarding their seeding location
- Results are sampled over full simulation time
- Color white indicates areas where no samples reaching the spark-plug have been obtained

Overview and Future work

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- A robust and efficient reverse Lagrangian tracking approach has been developed and demonstrated
- The new technique enables the analysis of (convectively transported) causes of phenomena observed at a later time
- The new technique is expected to shed new light on cyclical variations
- Future work will extend the analysis to fired simulations with direct injection

Thank you for your attention!

The authors gratefully acknowledge:
Fundings by DFG through FOR2687
Computational ressources through CCSS
Helpful discussions with Markus Klein, Benjamin Böhm and Cooper Welch