Optimization of the injection strategies in DISI engines

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Summary

- GDI engine: mixture formation
- Injector model
- Injectors comparison
- 3D engine simulation approach
- CFD results and experimental data
- Conclusions

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Mixture formation

fast and correct mixture formation in GDI engine:

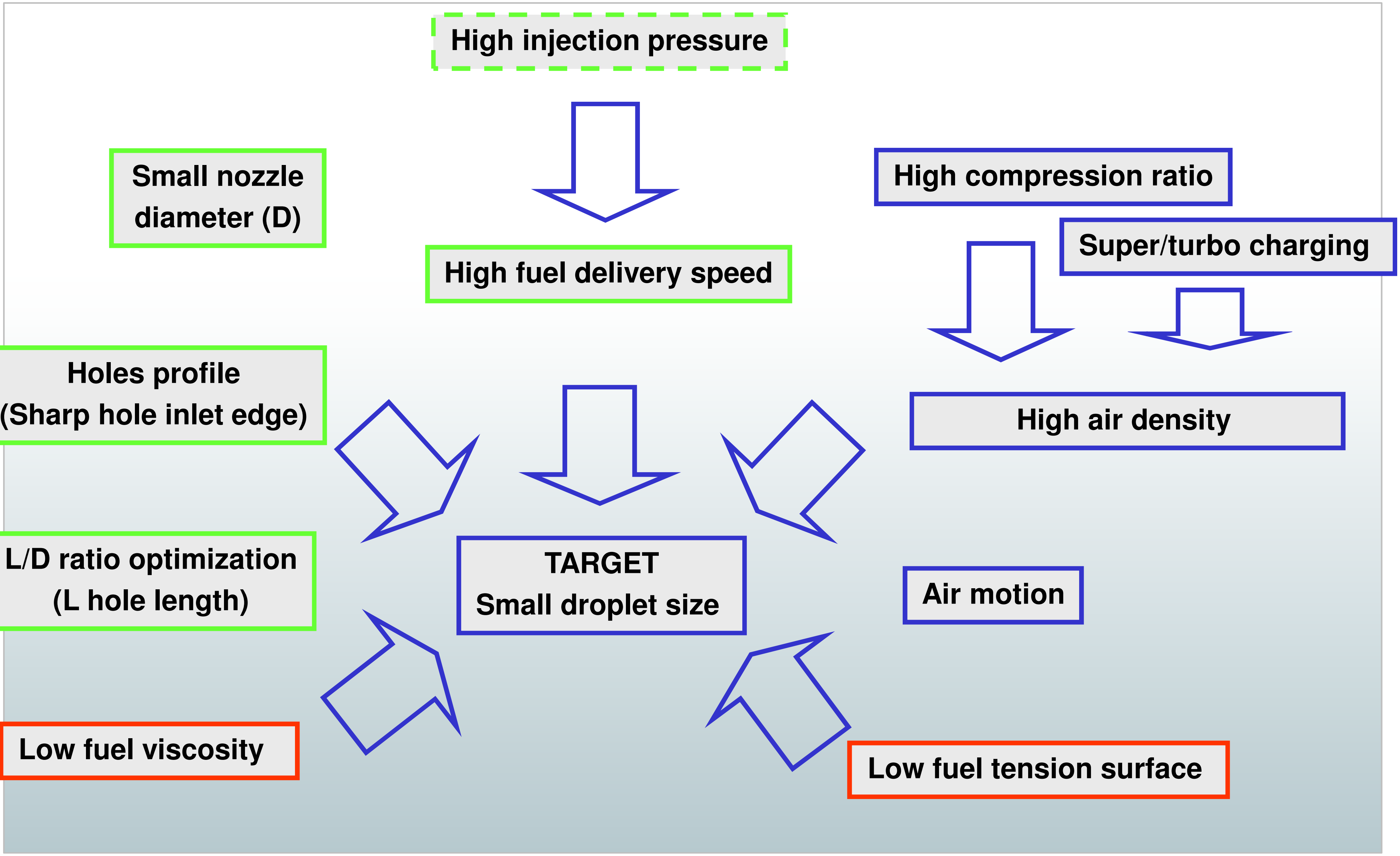
- spray orientation
- spray penetration
- spray droplet size

TARGET
Small droplet size

TARGET
fuel atomization and evaporation
(in all operating condition)

TARGET
Quick mixture formation

Small droplet size



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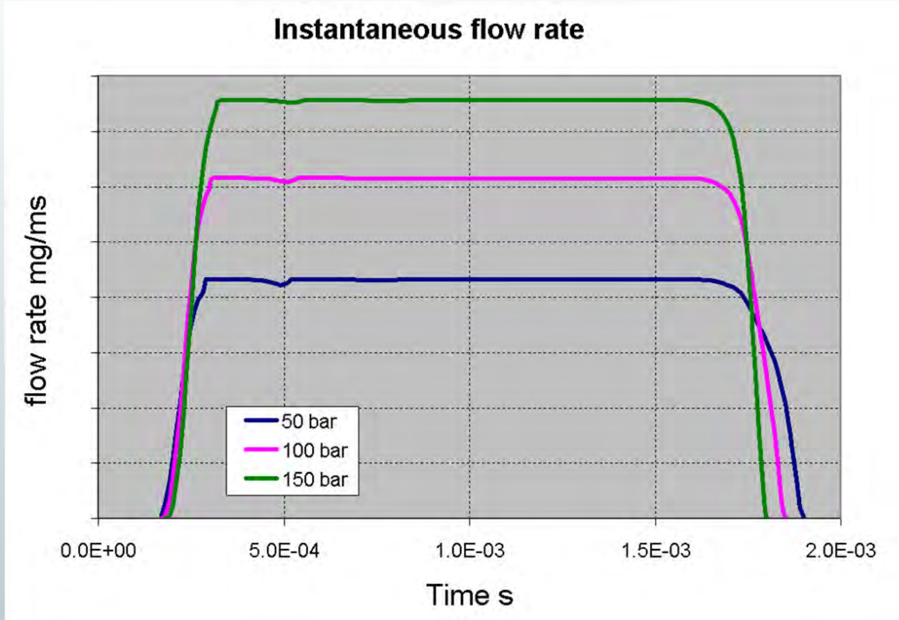
Injector model

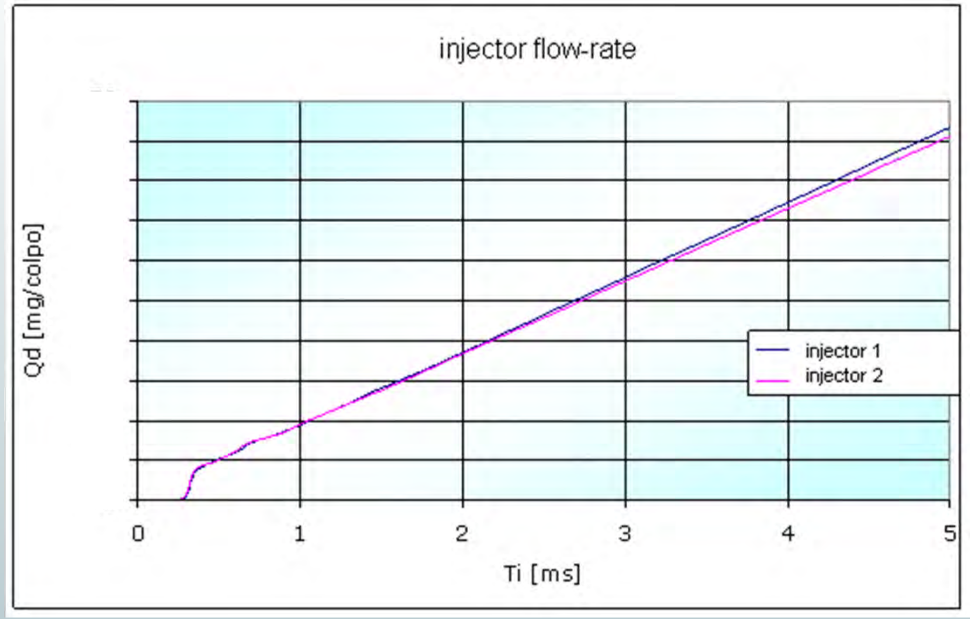
Two multi-hole injectors considered for the analysis (injector 1 and injector 2), with different spray patterns

Flow-rate from 1D injector model (EVI curves)

Instantaeous flow-rate



Similar injection flow rate



Spray test on bench

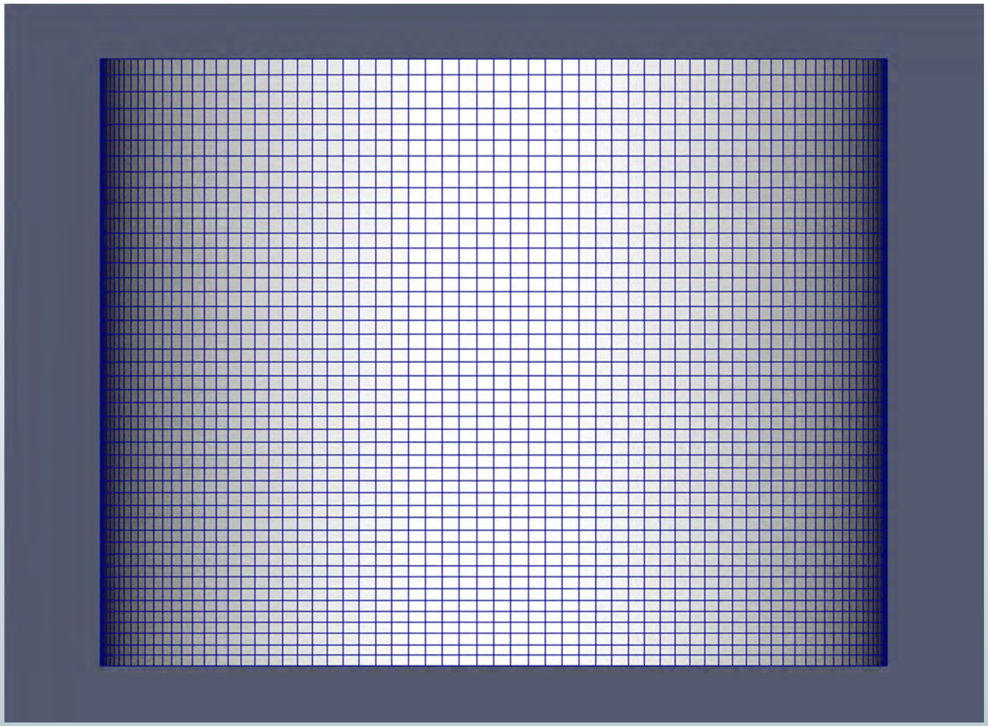
Spray bench vessel conditions

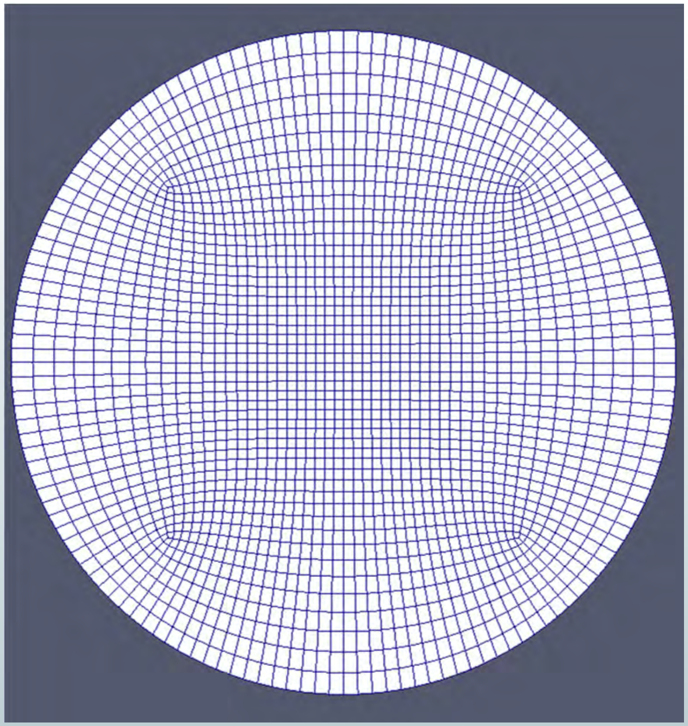
- Injection pressure 50, 100 and 150 bar
- Vessel back-pressure 1 bar
- Vessel temperature 298 K
- Fluid temperature (n-heptane) 298 K

Computational domain

- Fluid n-heptane
- T_{fluid} 298 K
- T_{vessel} 298 K

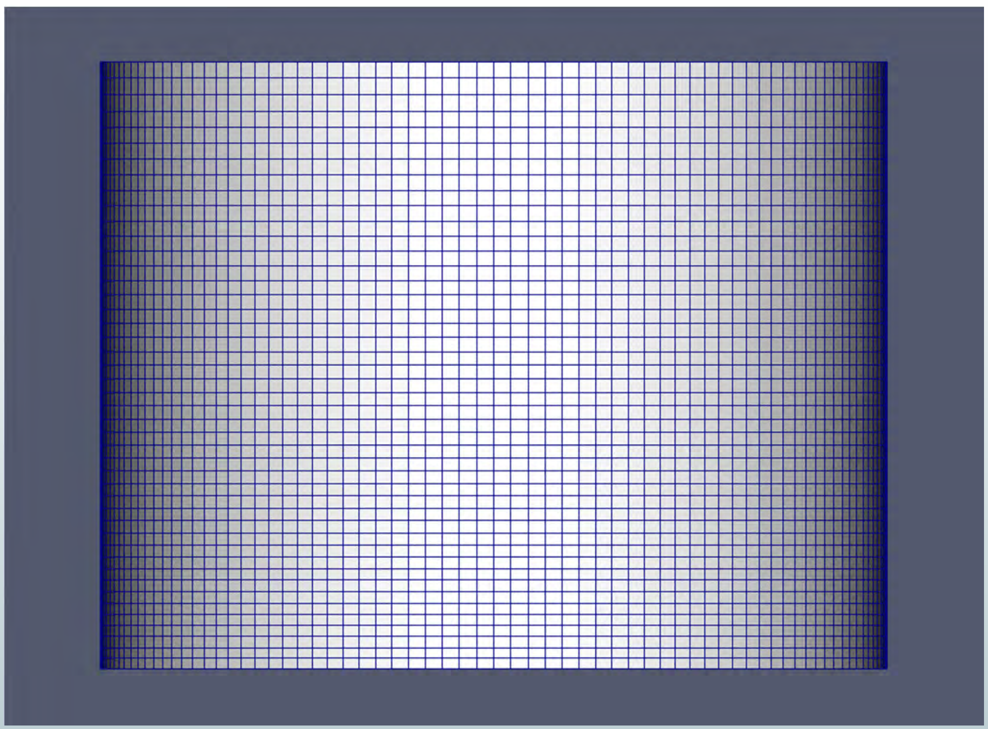
- Computational Vessel : L=65 mm, D=80 mm
- 100000 cells
- Mean cell dimension 1 mm

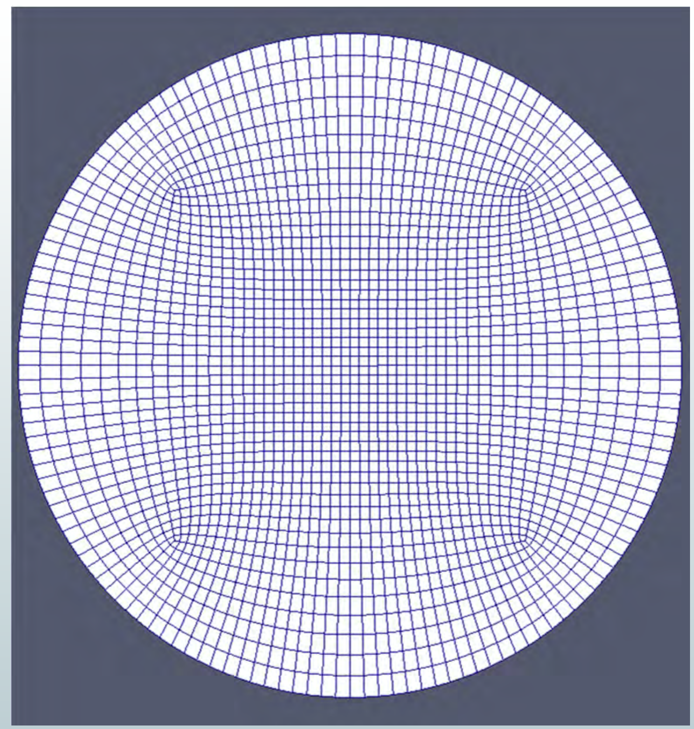




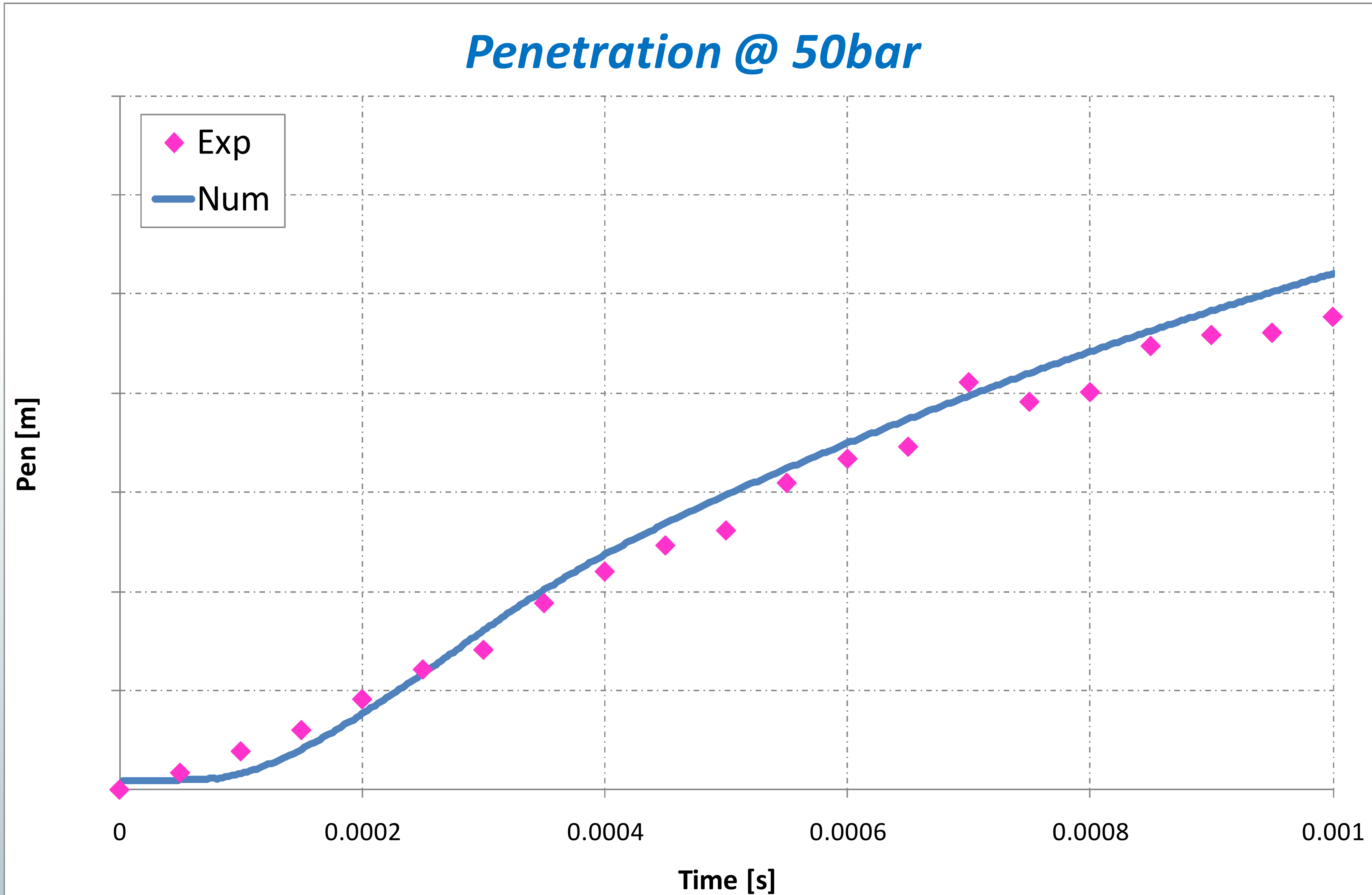
Computational domain

- Fluid n-heptane
- T_{fluid} 298 K
- T_{vessel} 298 K
- Injector vertically oriented
- Break-up model KHRT
- Coalescence model off

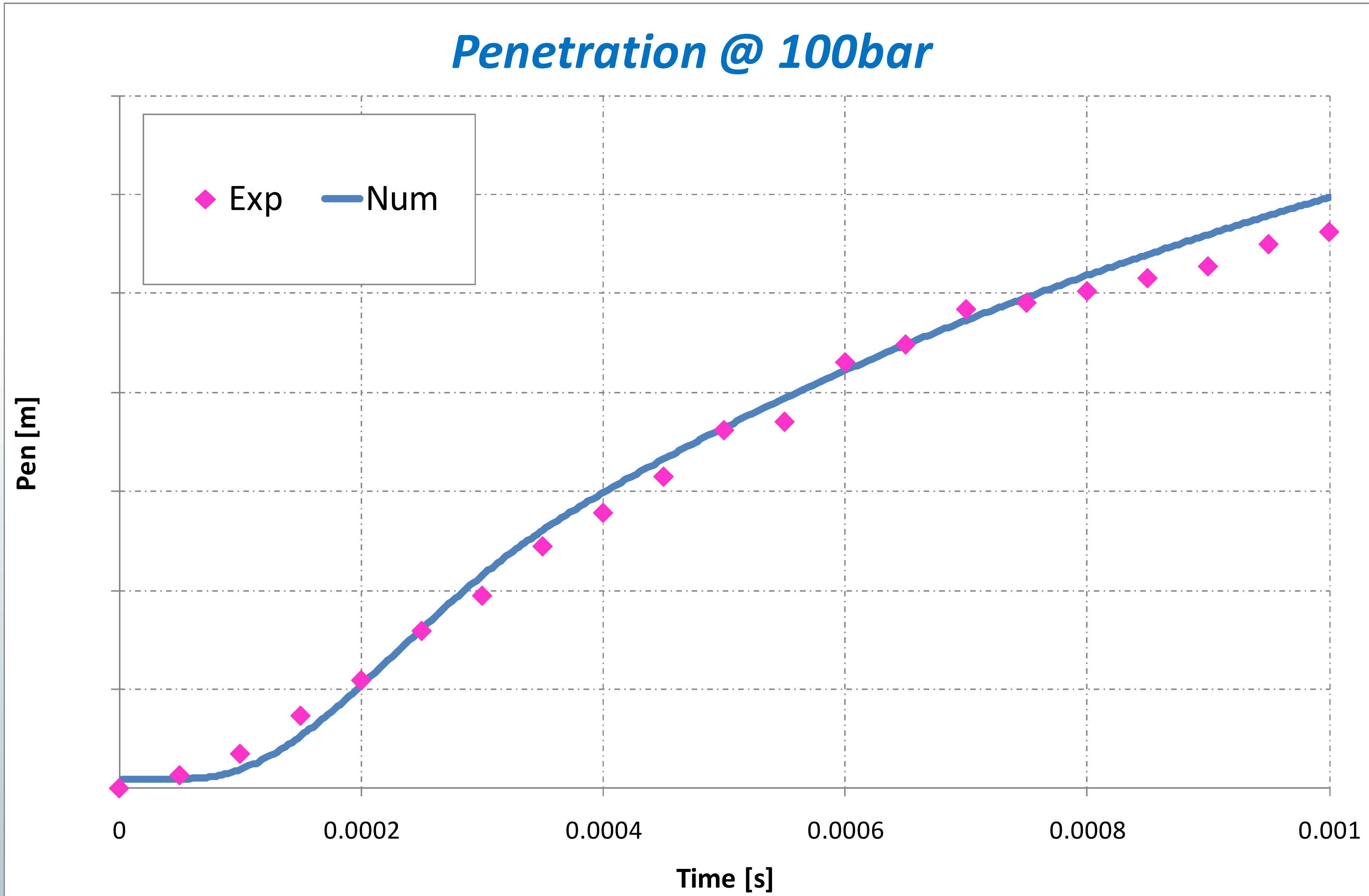




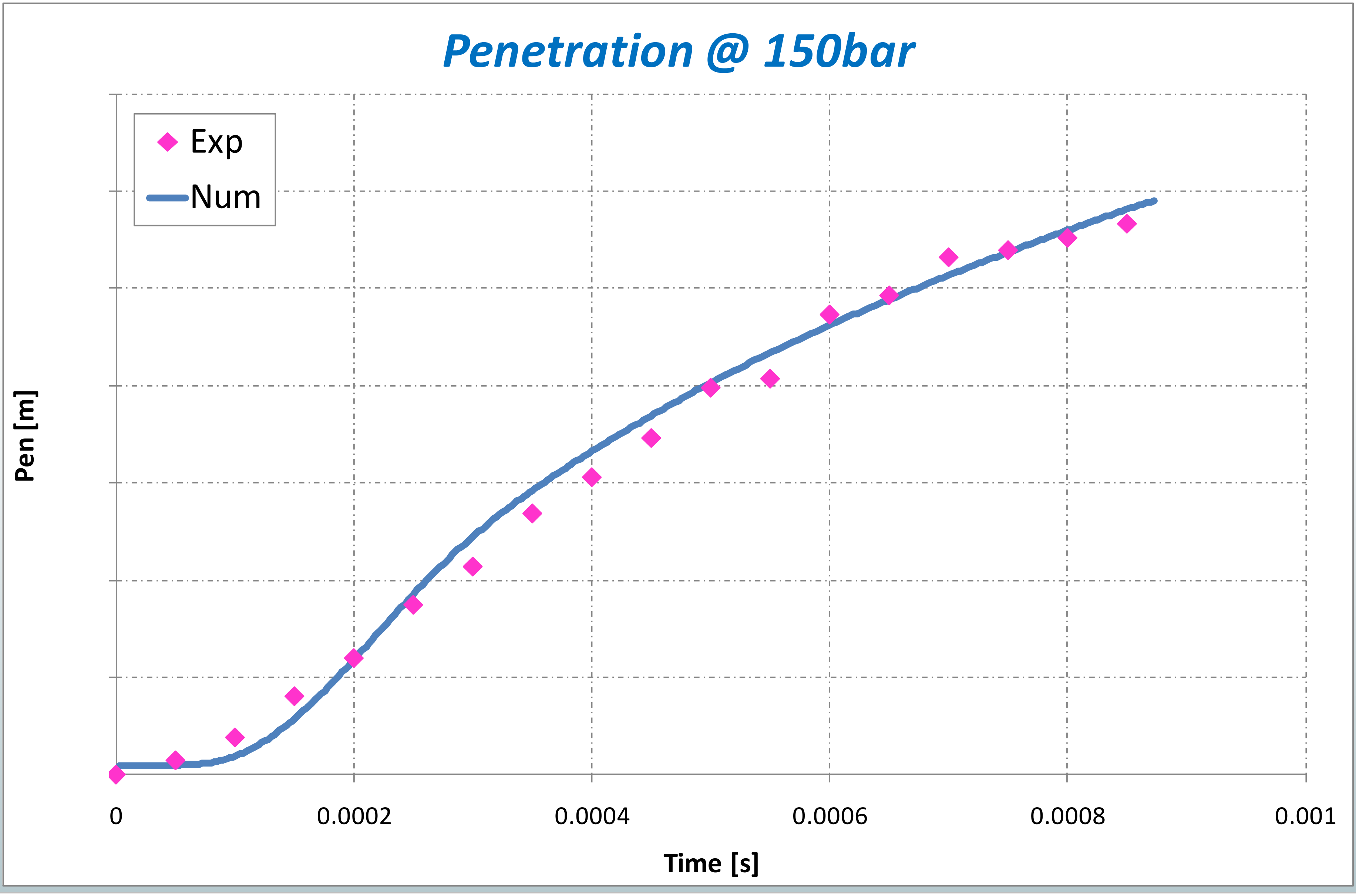
Jet penetration



Jet penetration



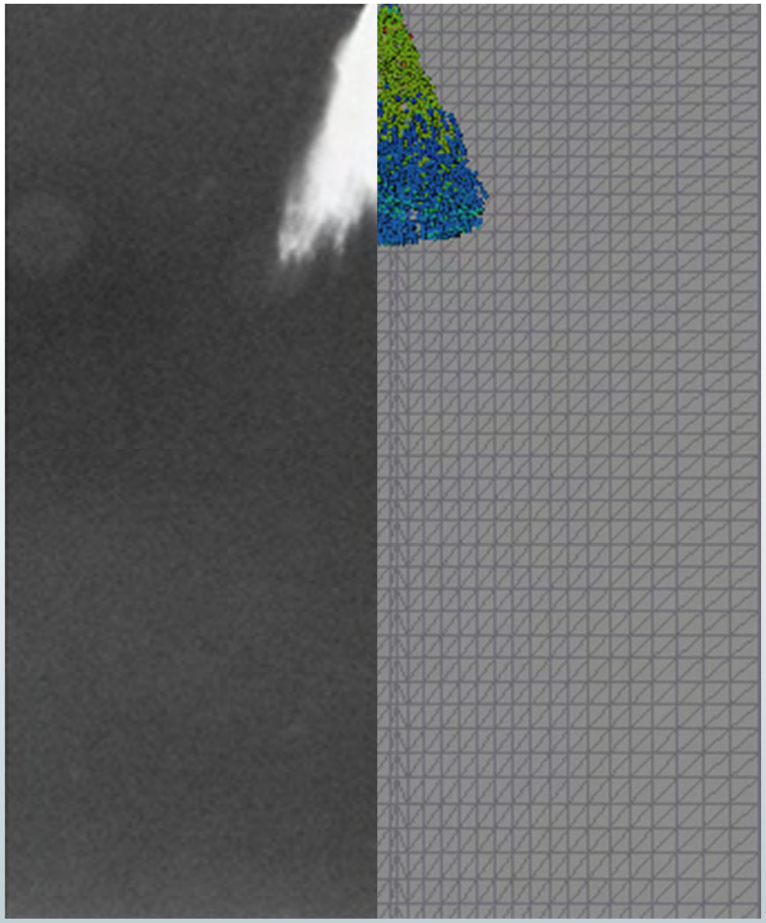
Jet penetration



Spray morphology

morphology @100bar

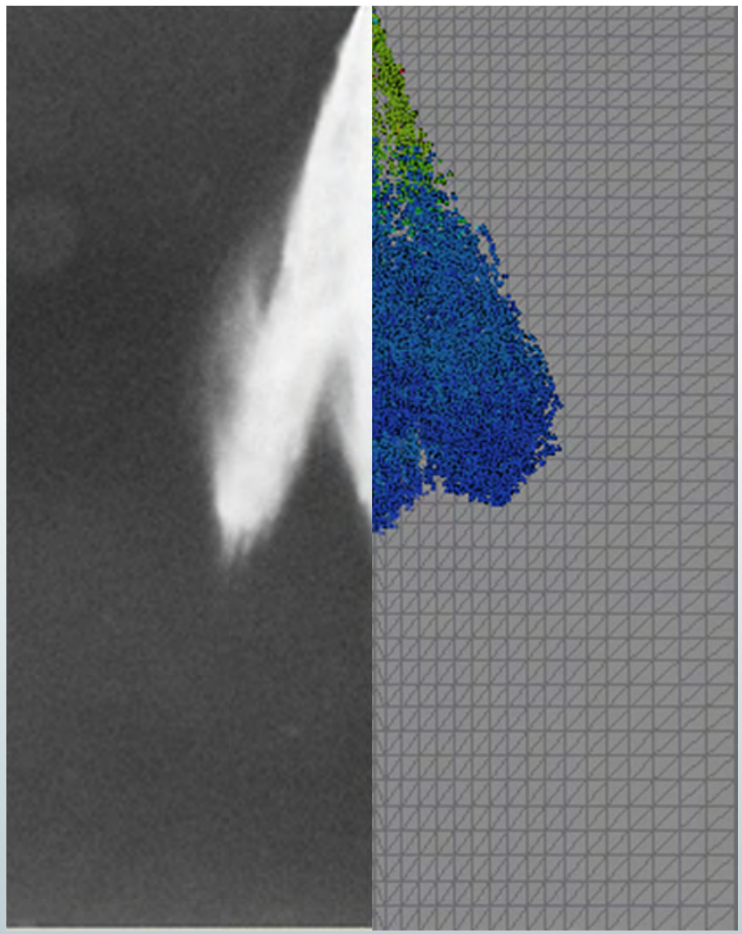
0.2ms



Spray morphology

morphology @100bar

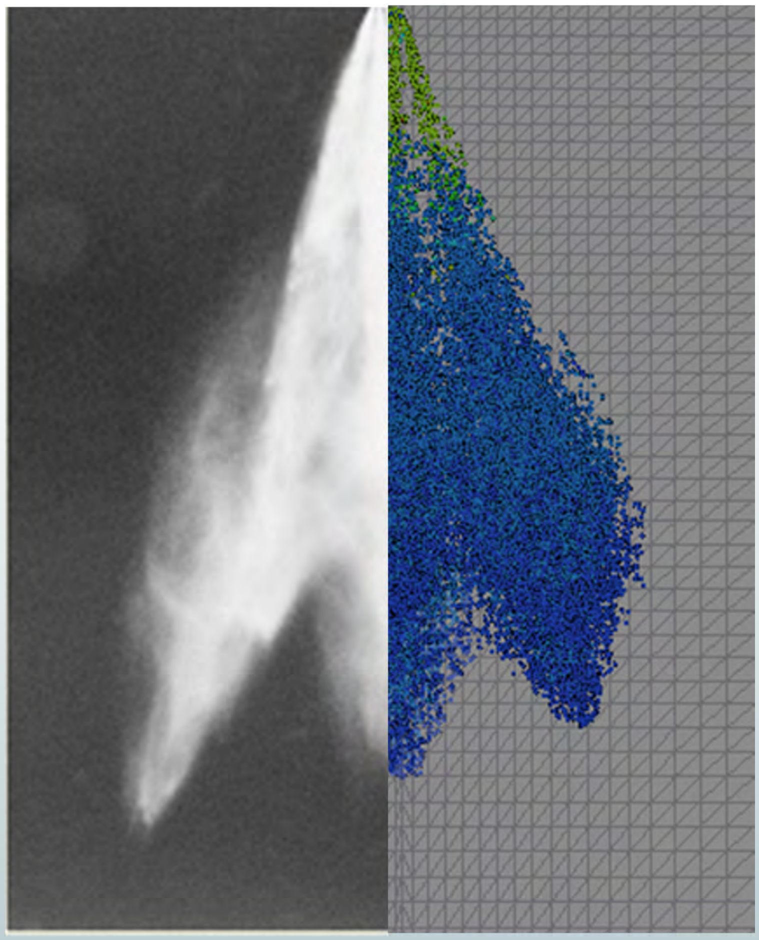
0.4ms



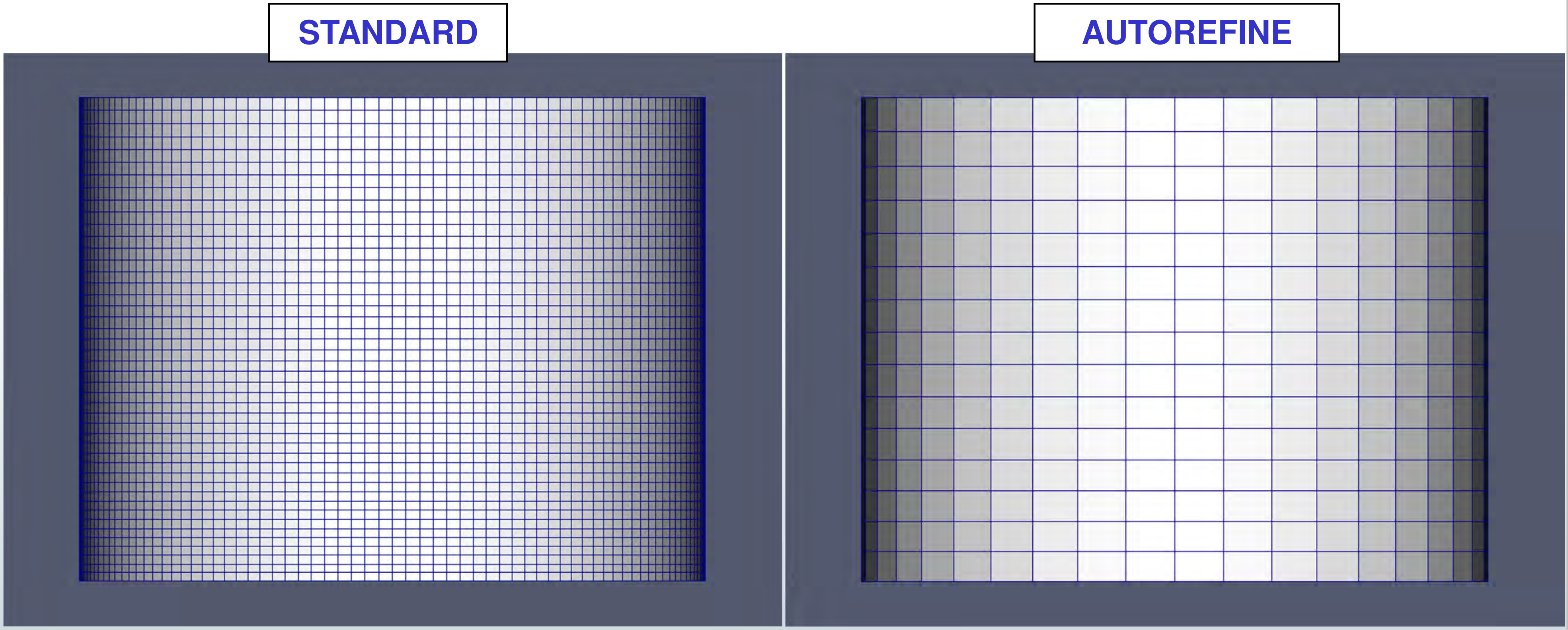
Spray morphology

morphology @100bar

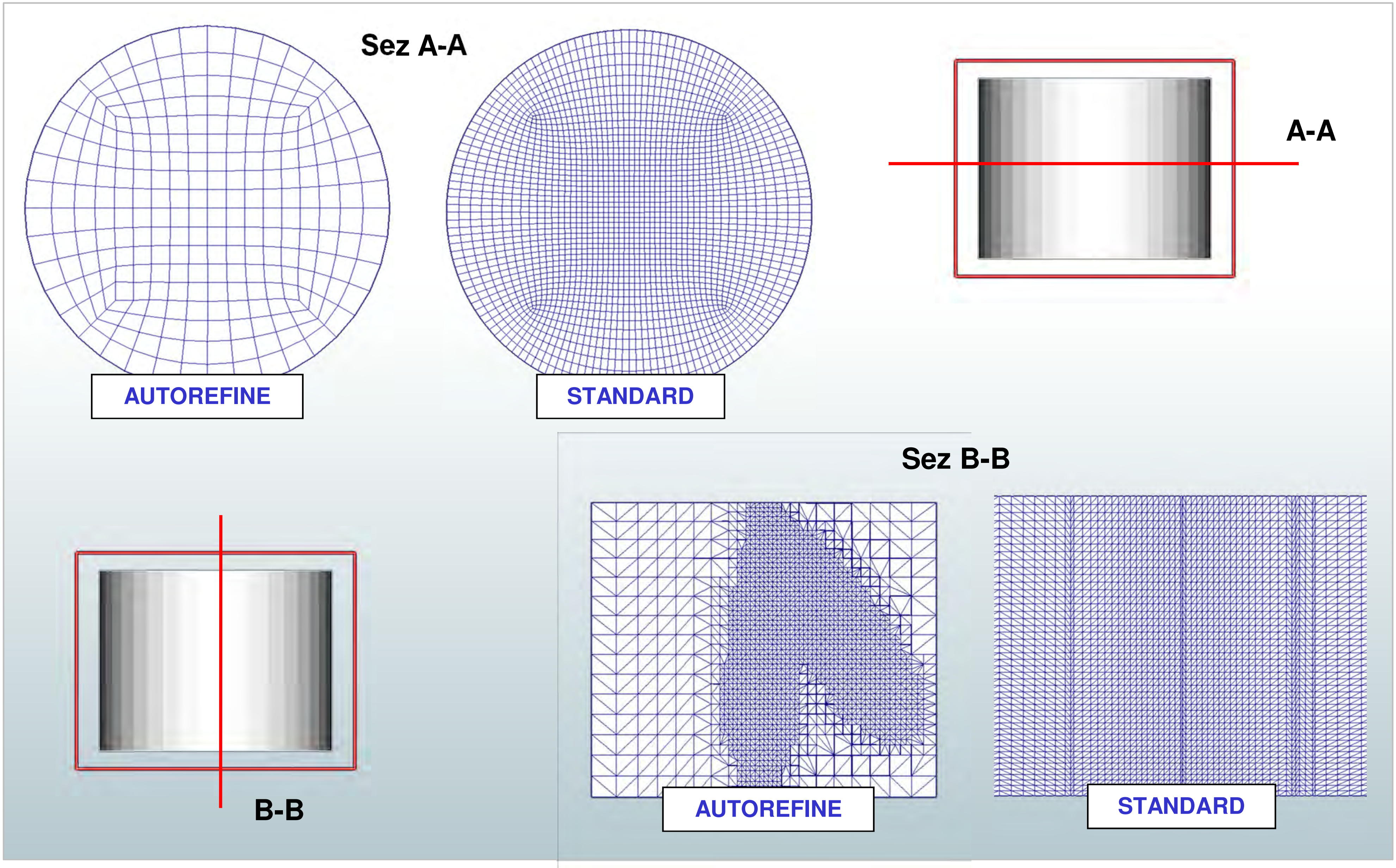
0.6ms



Simulation with autorefinement (Polimi Lib-ICE)



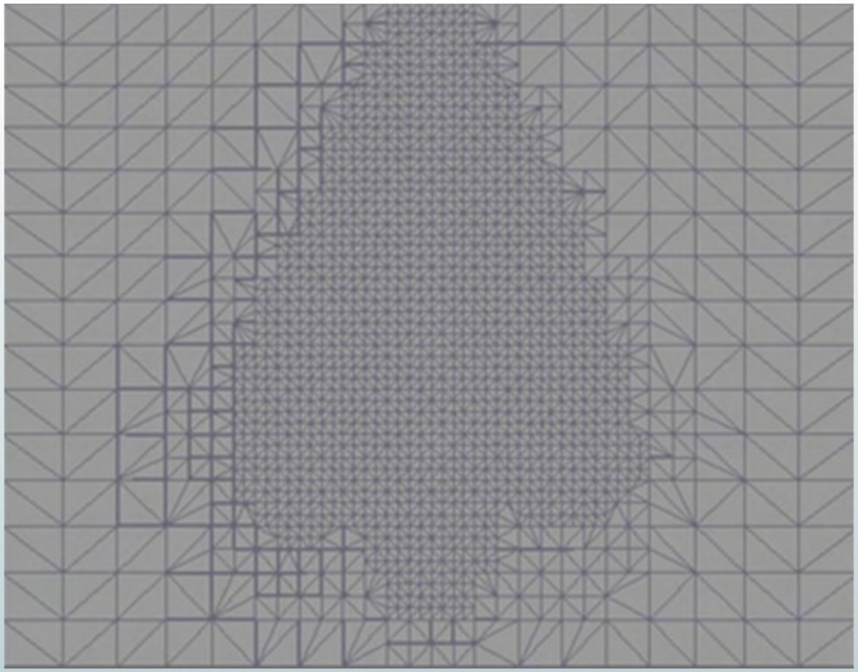
Simulation with autorefinement (Polimi Lib-ICE)



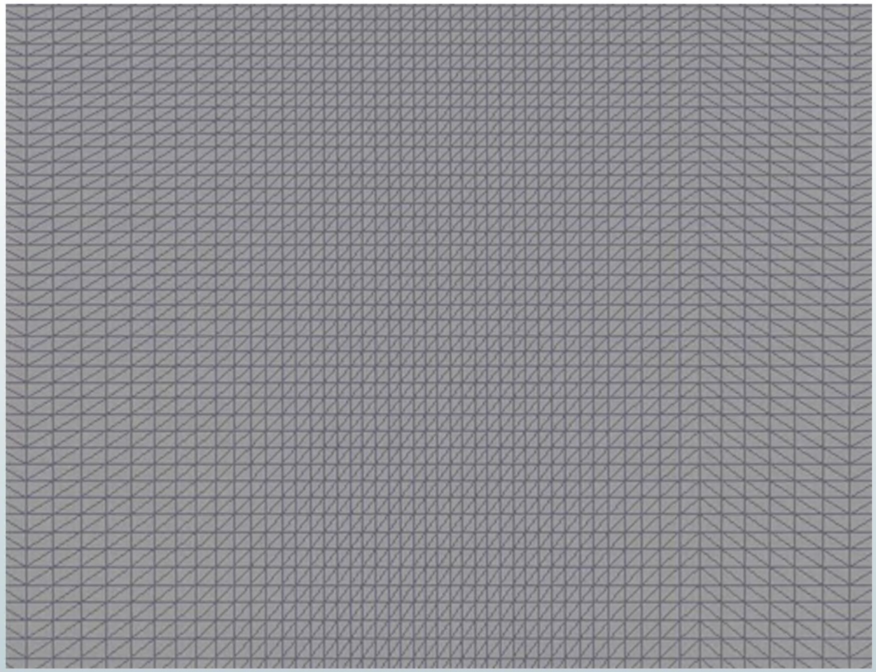
Simulation with autorefinement (Polimi Lib-ICE)

base vs autorefine: grid modification

autorefine



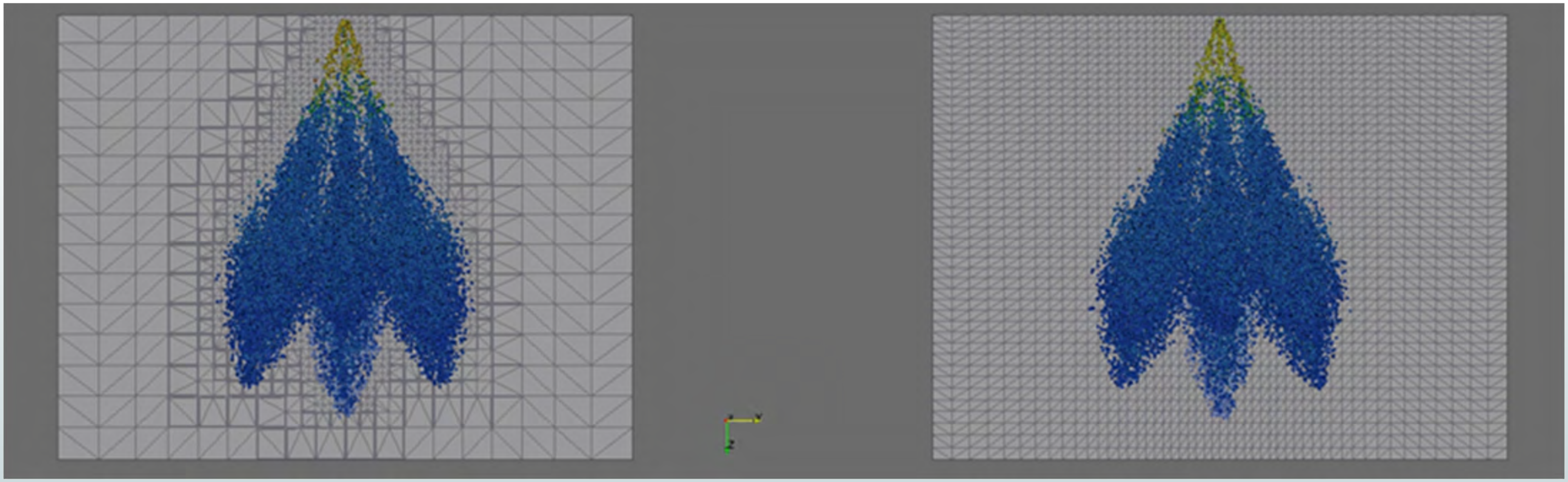
base grid



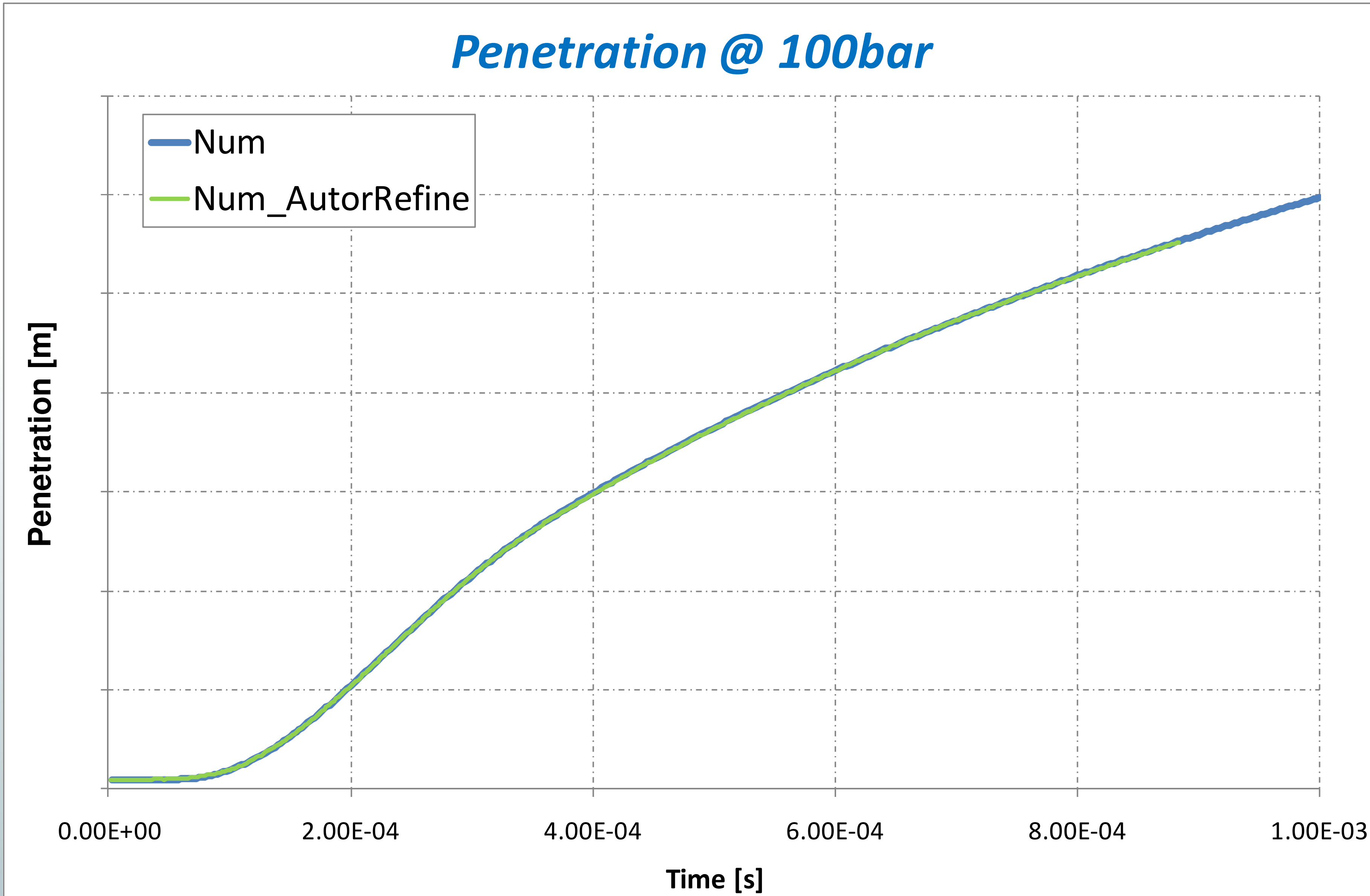
Simulation with autorefinement (Polimi Lib-ICE)

base vs autorefine: morphology @50bar

autorefine | **base grid**

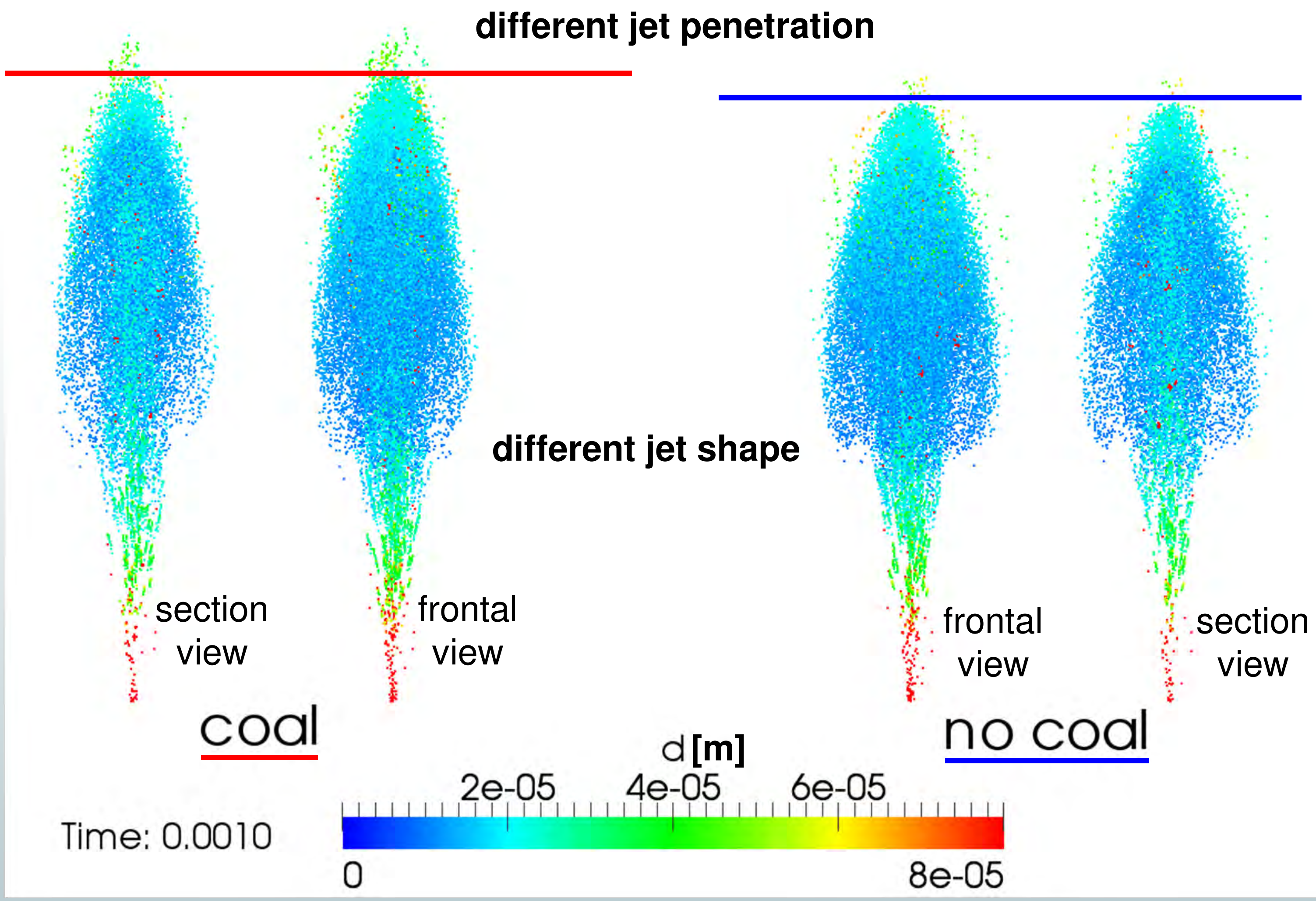


Simulation with autorefinement (Polimi Lib-ICE)



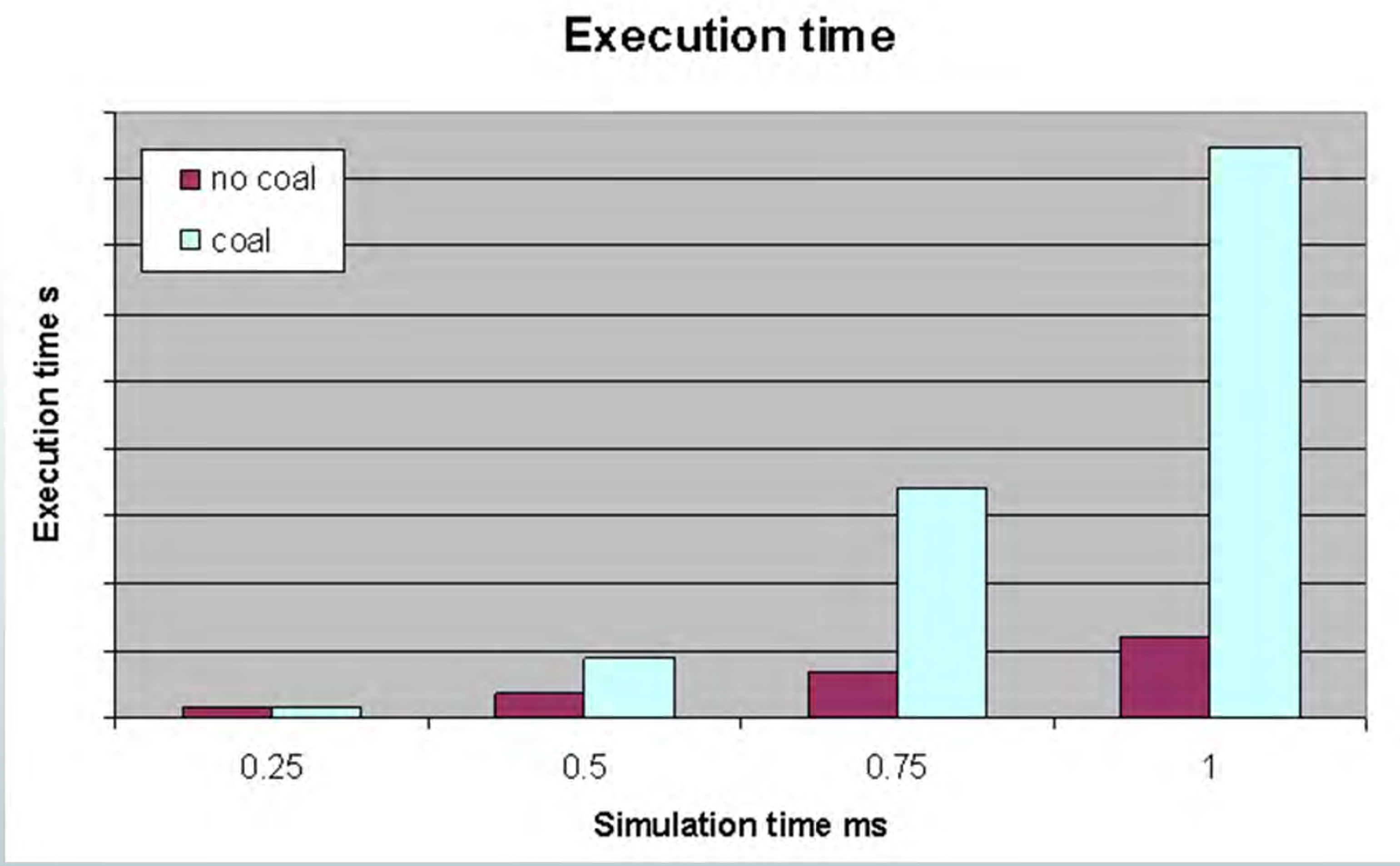
Coalescence model

Single hole injector: solver with coalescence model (Nordin traiectory)



Coalescence model

Coalescence model: execution time



- GDI engine: mixture formation
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- **Injectors comparison**
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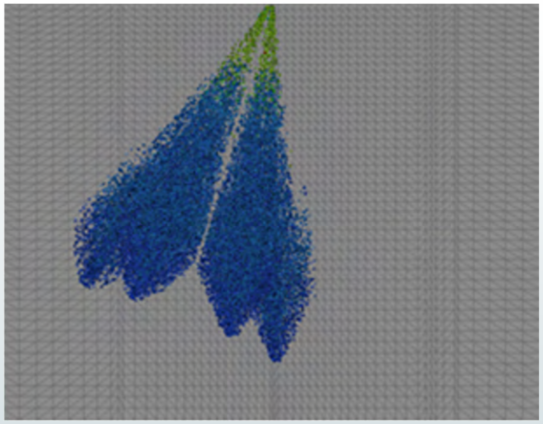
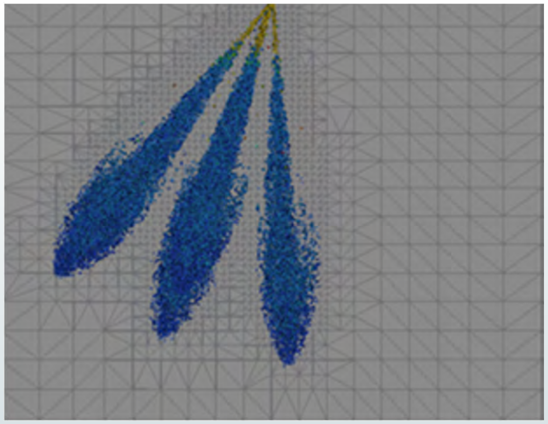
Injectors comparison

morphology @150bar

injector 1 | LATERAL VIEW | injector 2





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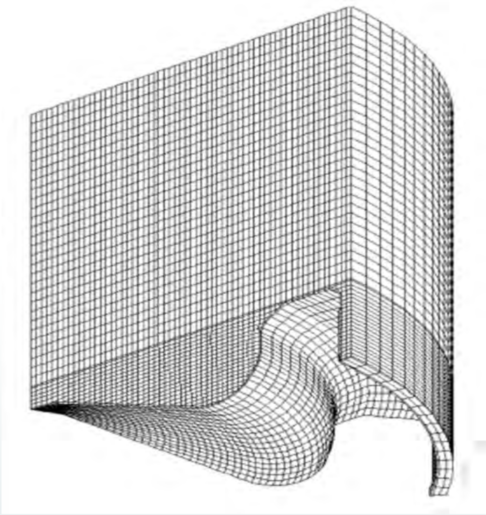
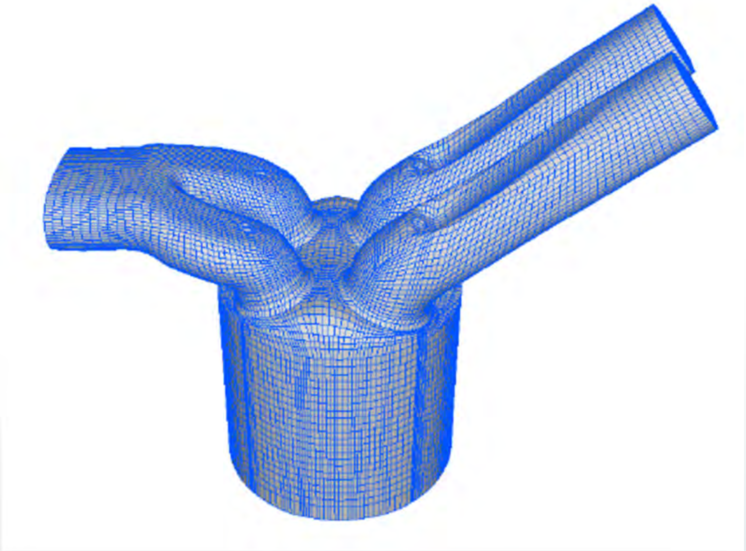
Engine simulation approach: geometry

Diesel



- Usually only a sector of the domain (symmetric domain)
- Valve closed cycle
- No valves motion

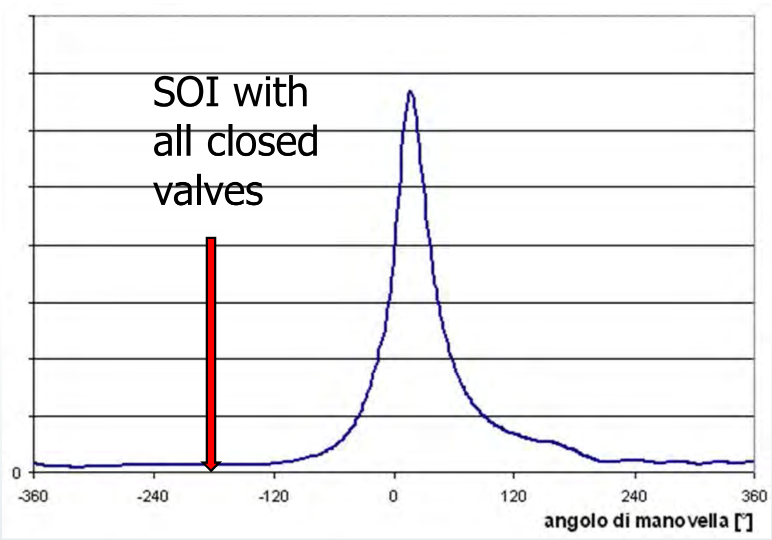
GDI



- Complete engine cycle
- Intake and exhaust ducts in fluid domain
- Valves motion

Engine simulation approach: grid management

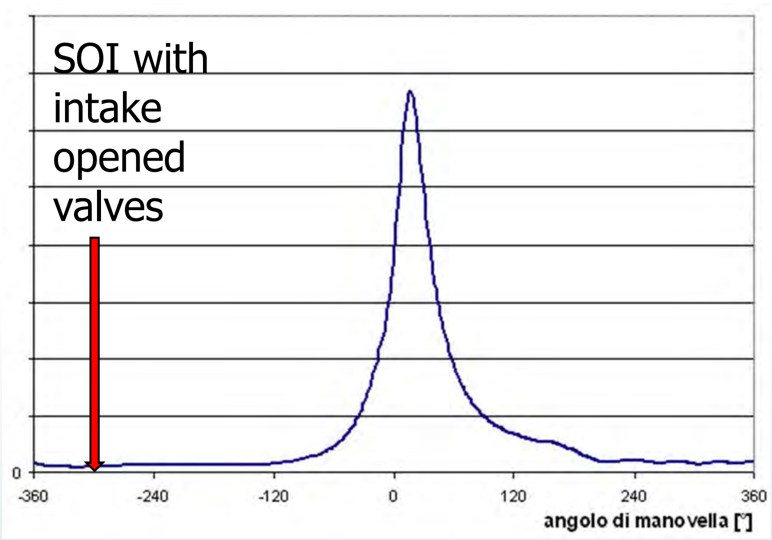
Diesel



- Injection with intake valves closed
- Simulation of compression only

GRID MOTION→ layering

GDI



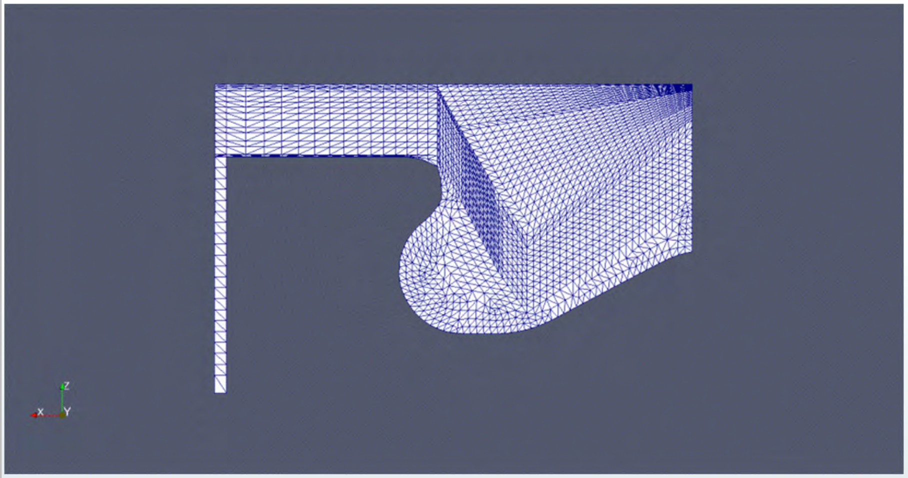
- Injection with intake opened valve
- Simulation of the complete intake cycle

GRID MOTION→ multiple mesh

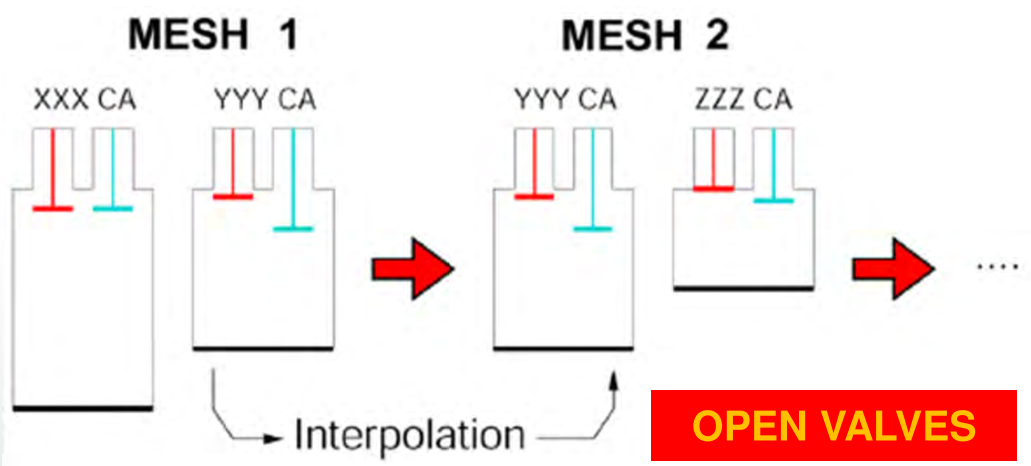
Engine simulation approach: grid management

Layering Vs MultipleMesh

Diesel



GDI



- To keep an optimum mesh size during piston and valve motion
- Definition of an arbitrary base surface, where layers of cells are added and removed.
- Removal and addition of cells layers handled automatically according to prescribed values of minimum layer thickness.
- No mass loss due to topological changes due to a consistent remapping strategy

- Each mesh is valid for a specified interval of simulation
- During each time step it is possible to:

→move the grid points using automatic mesh motion and/or predefined points motion (simple cases).

→ Change the mesh topology (dynamic mesh layering, sliding interface, attach-detach boundary, adaptive local mesh refinement)

- Mesh-to-Mesh interpolation by inverse, distance-weighted tecnique.

3D engine model

3D engine model of the exhaust, intake and compression strokes

- boundary conditions from 1D complete engine model
- turbulence model: RNG k-ε
- Bai-Gosman wall impingment model (Lib-ICE Polimi)

Point selected for presentation: 1500 rpm, bmep 15 bar

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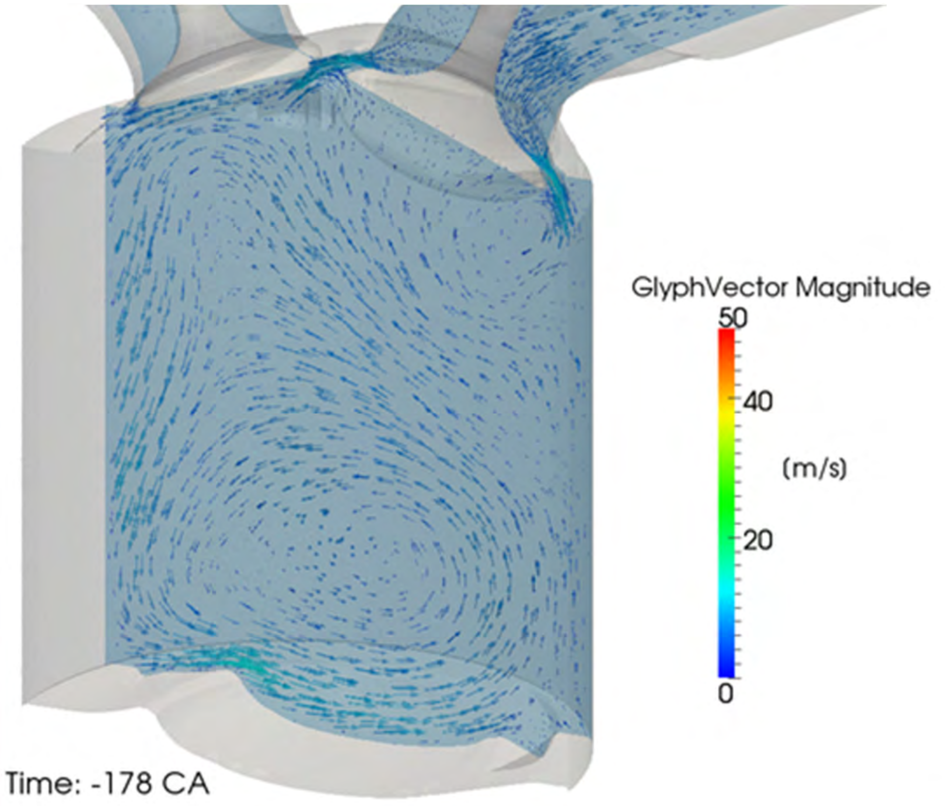
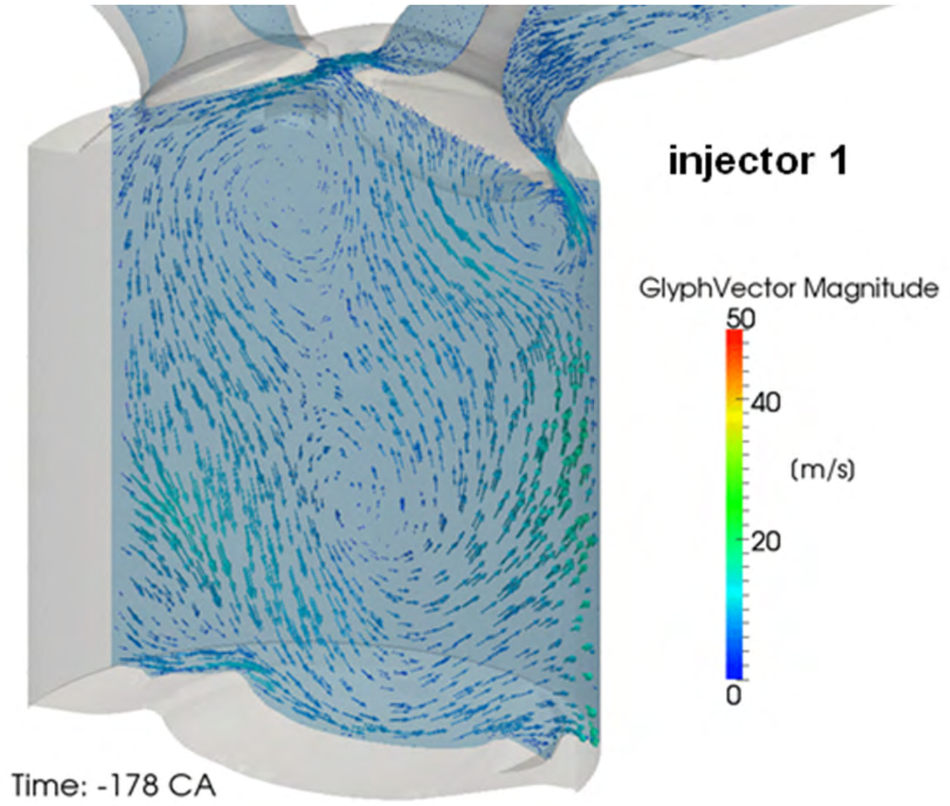
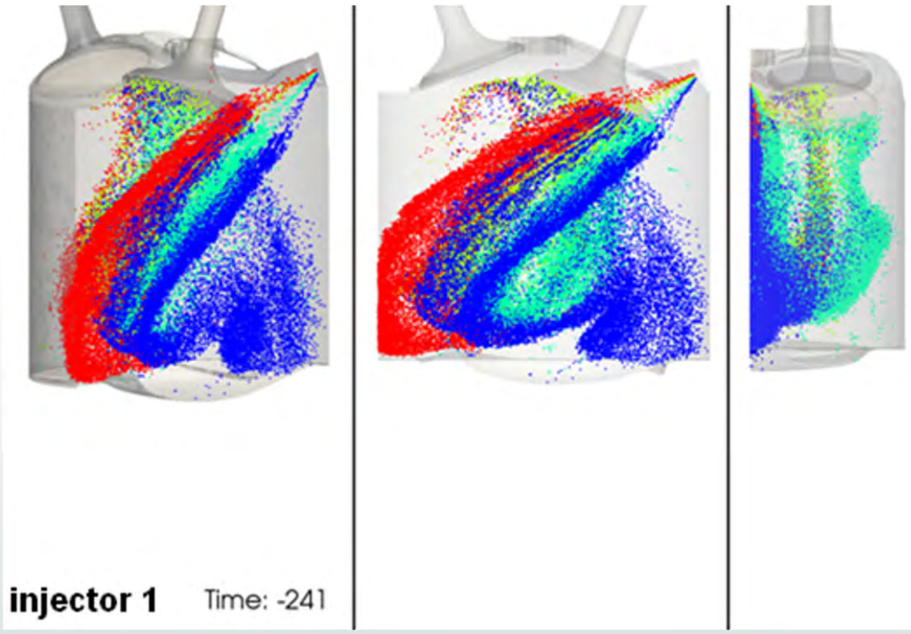
Velocity field with and w/o injection

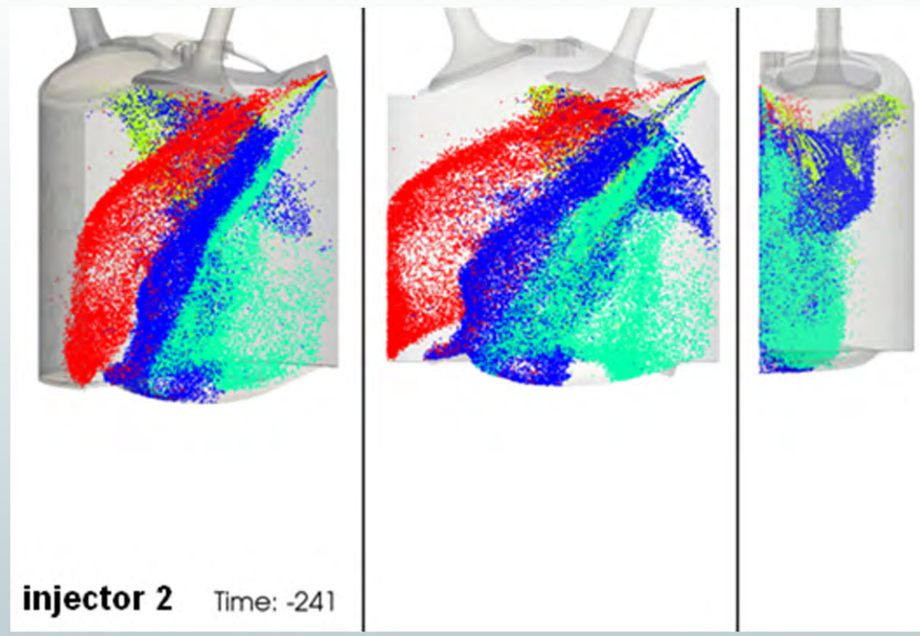




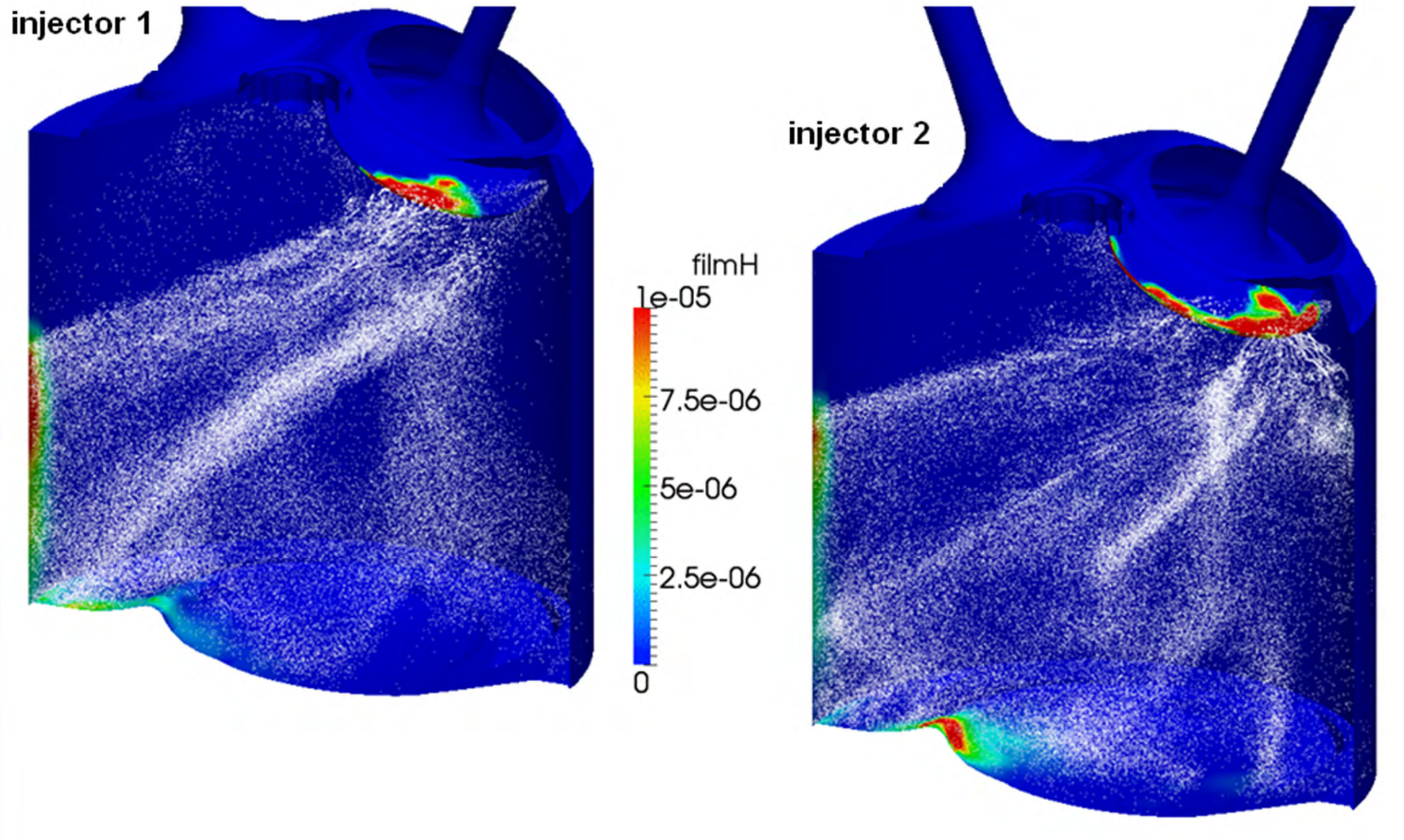
w/o Injection **with Injection**

Spray analysis and wall impingement
Jet fuel tracers method.

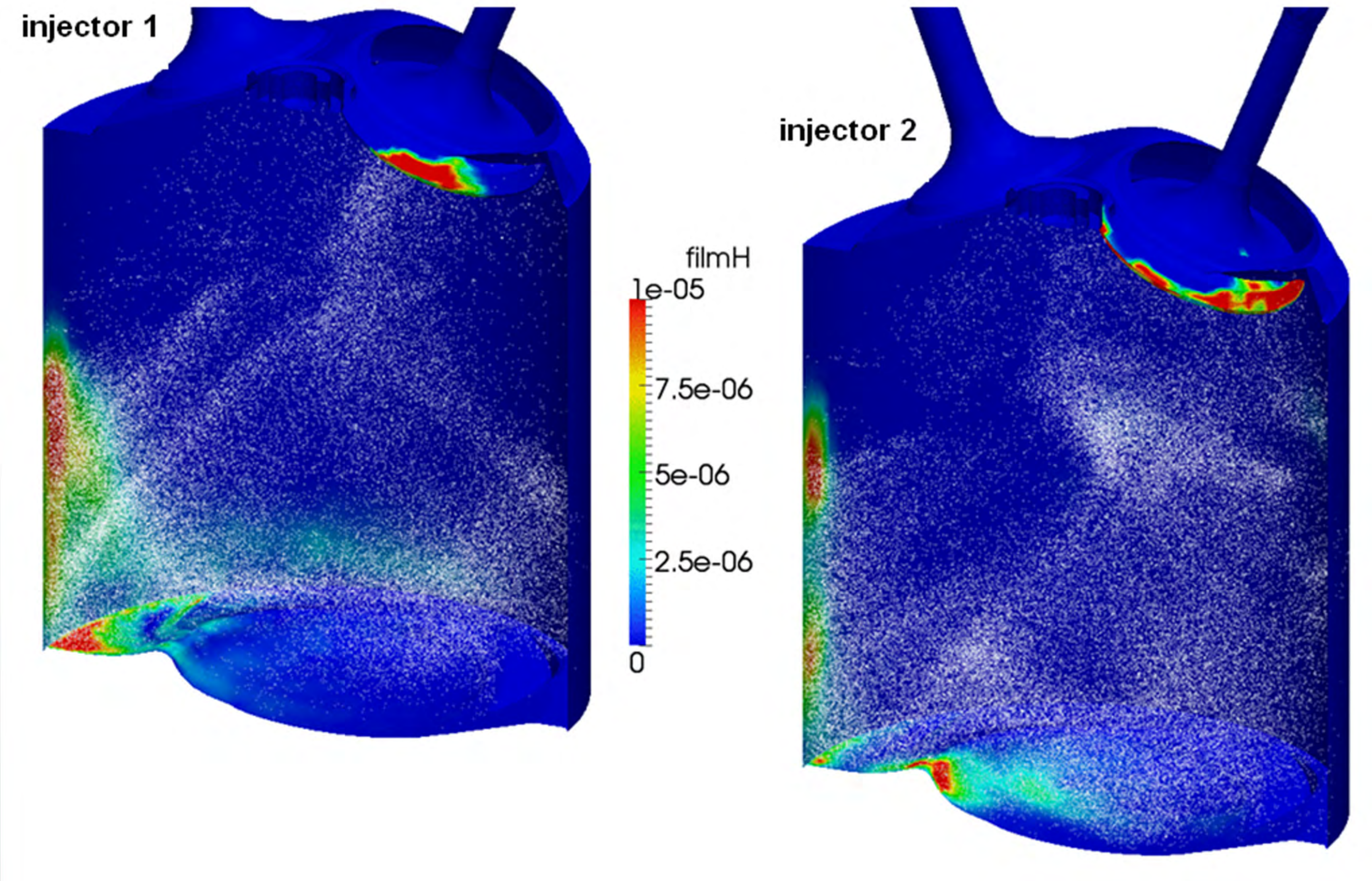




Spray simulation engine test point condition
Injector spray and wall impingement comparison



Spray simulation engine test point condition
Injector spray and wall impingement comparison

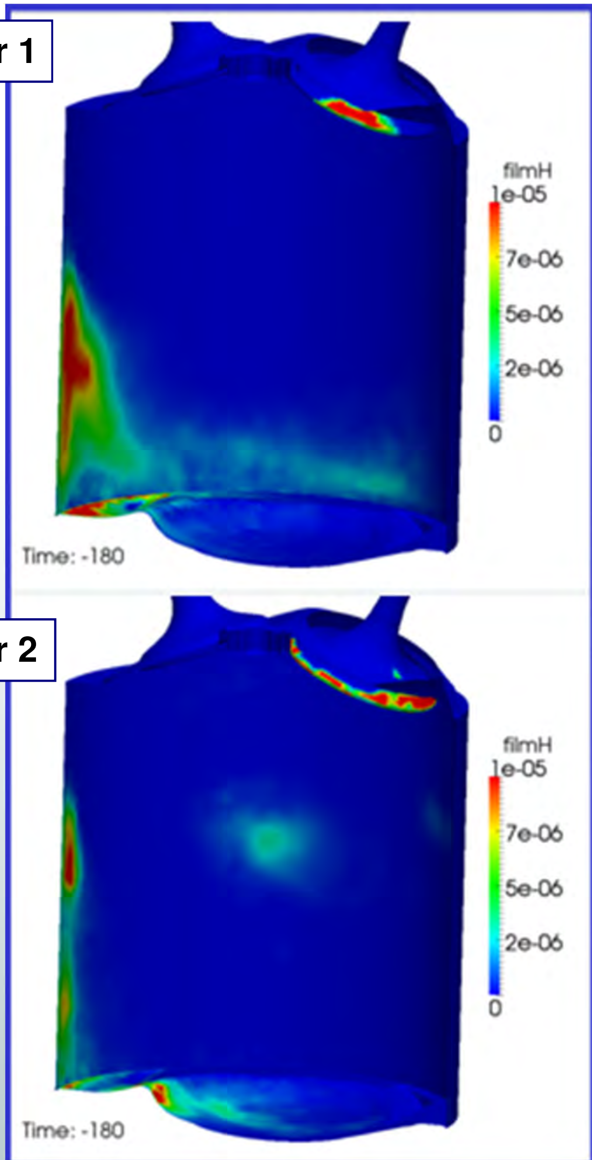


Wall impingement comparison

-180 deg

injector 1

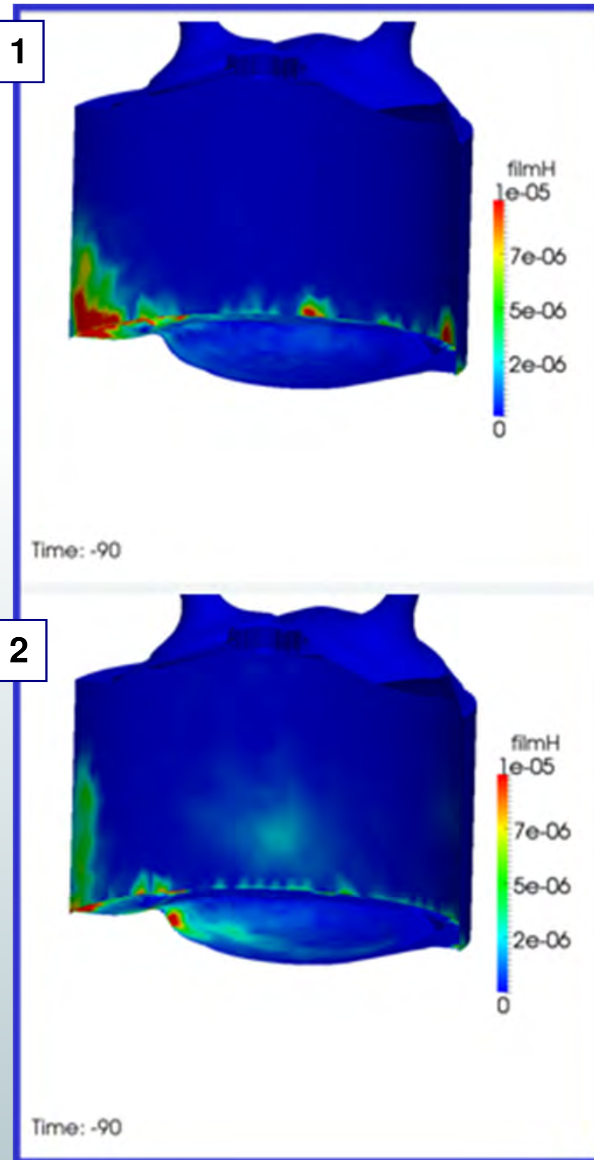
injector 2



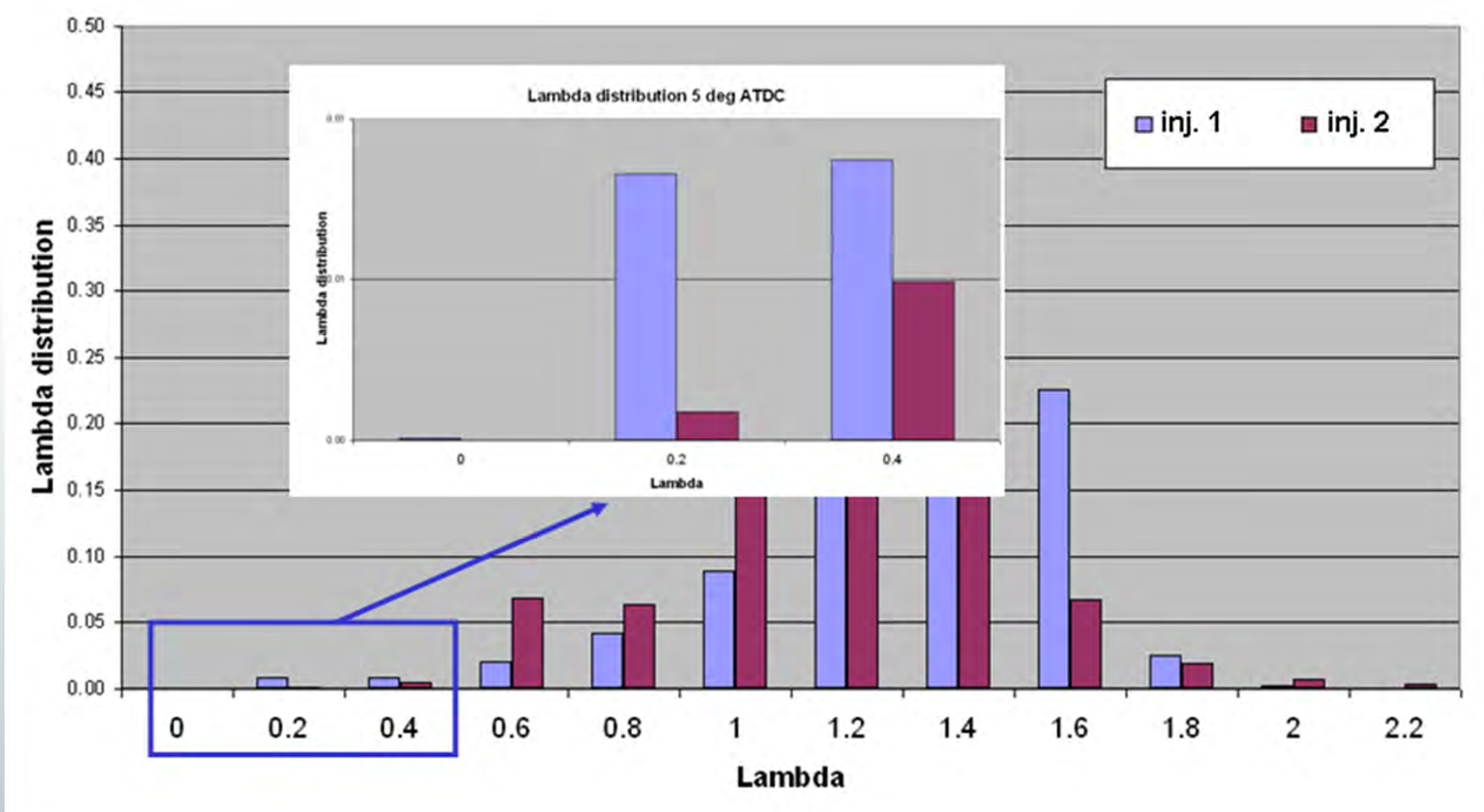
- 90 deg

injector 1

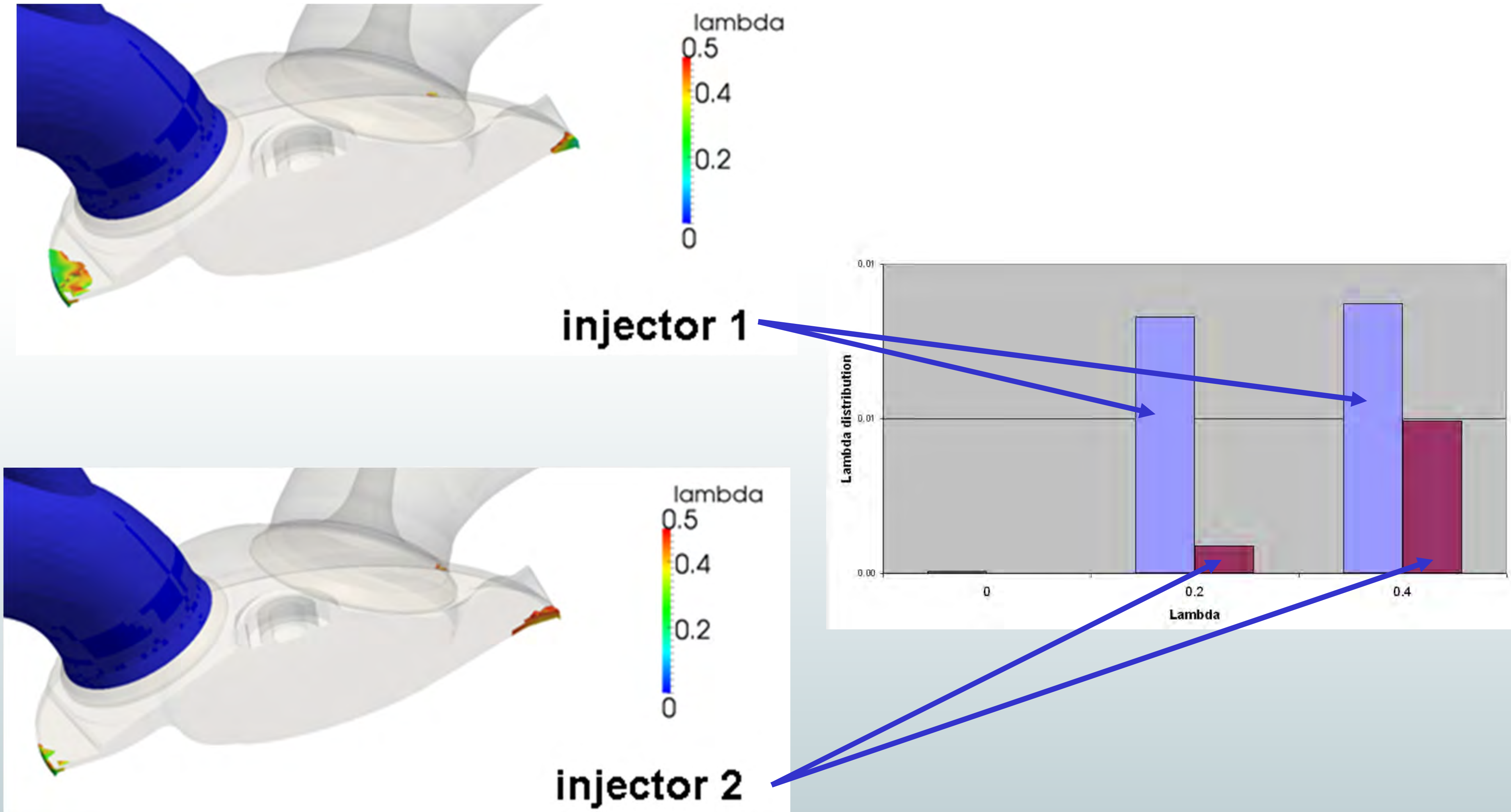
injector 2



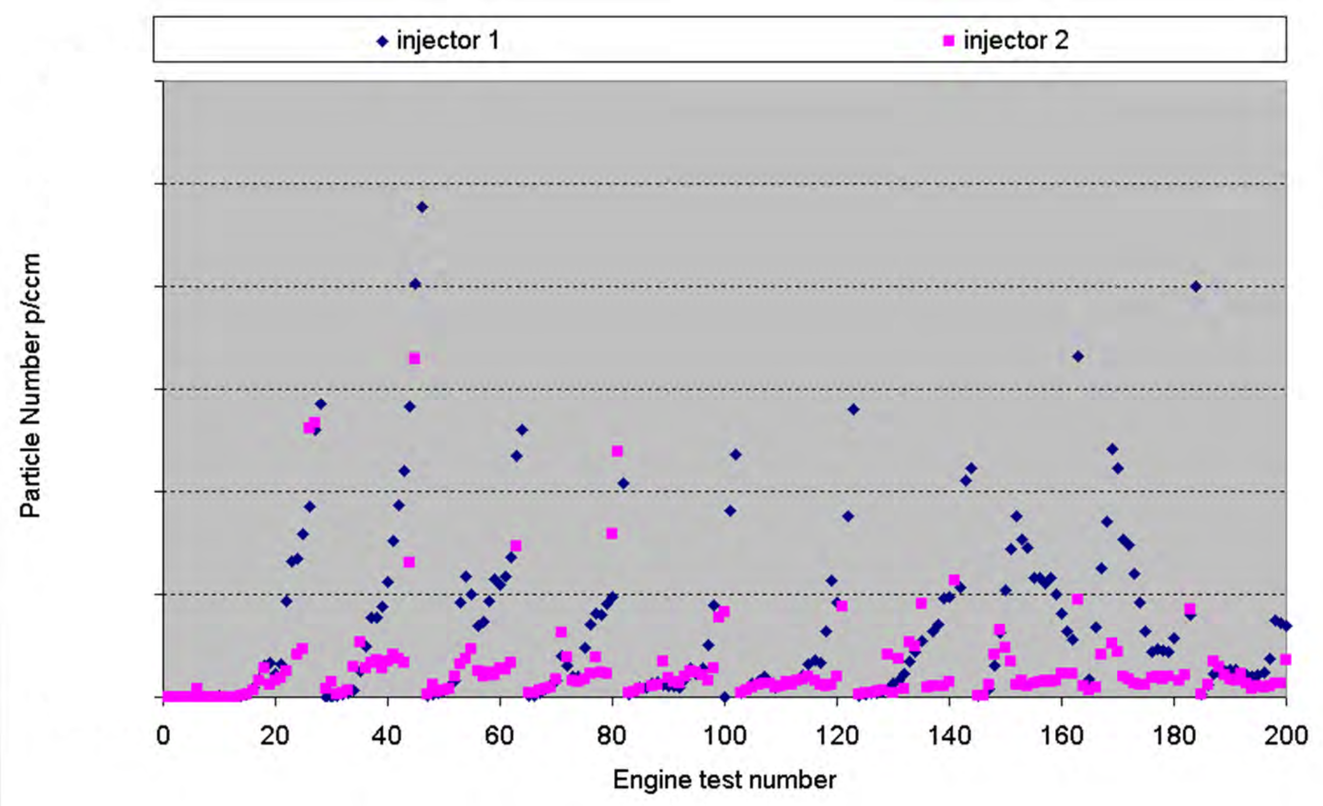
Lambda distribution @ spark
Injectors comparison



Lambda < 0.5 distribution @ spark
Injectors comparison : “**SOOT FORMATION ZONE** “



Particle measurements on engine bench
Injector performance comparison



Point 1500 rpm, imep 15 bar, Particle Number measurements:

- injector 1 ~ 1.5*10^7 p/ccm
- injector 2 ~ 4.6*10^6 p/ccm

Conclusion

- In-engine 3D simulation fundamental for the injection optimization
- 3D-1D model integration necessary for simulation
- OpenFOAM integrated by Lib-ICE useful for GDI engine simulation

Acknowledgments

Thanks to

- Tommaso Lucchini and Polimi ICE Group
- Federico Brusiani (DIEM-Unibo)

Thank you for the attention