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# Validation of a 3D Eulerian Spray Model Incorporating Nozzle Flow Effects Coupled with Engine Analysis

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# Contents

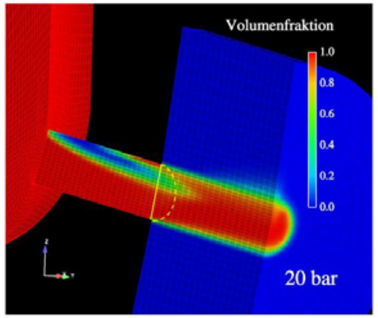
# 1. Motivation

**Objective:** Support for combustion design via 3D simulation tools
→ Analysis and prediction of new combustion concepts (i.e. LTC, HCCI)

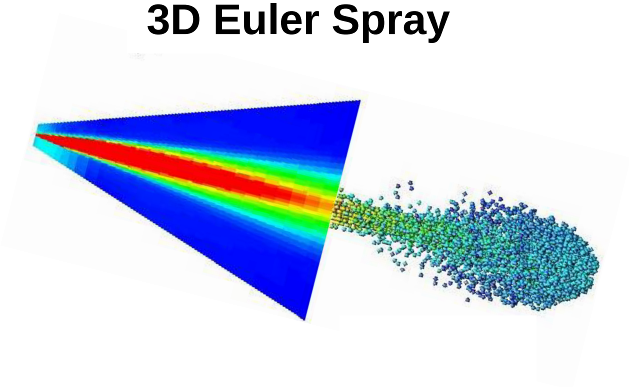
**Requirement:** Integrated simulation tool which is capable to reproduce the sensitivities of combustion design parameters

**Method:** Coupling of models for 3D-nozzle flow, nozzle resolved primary break-up model, mixture formation, turbulent combustion and emissions formation

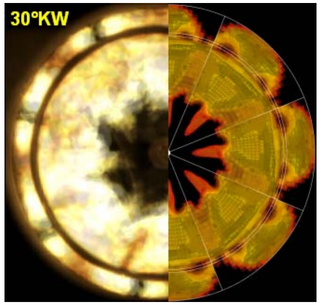
**Nozzle Flow**




**3D Euler Spray**



**Engine**




The project was developed under the **NICE B1 EU-Project**
- AVL provided the Eulerian Spray modeling and coupling routines

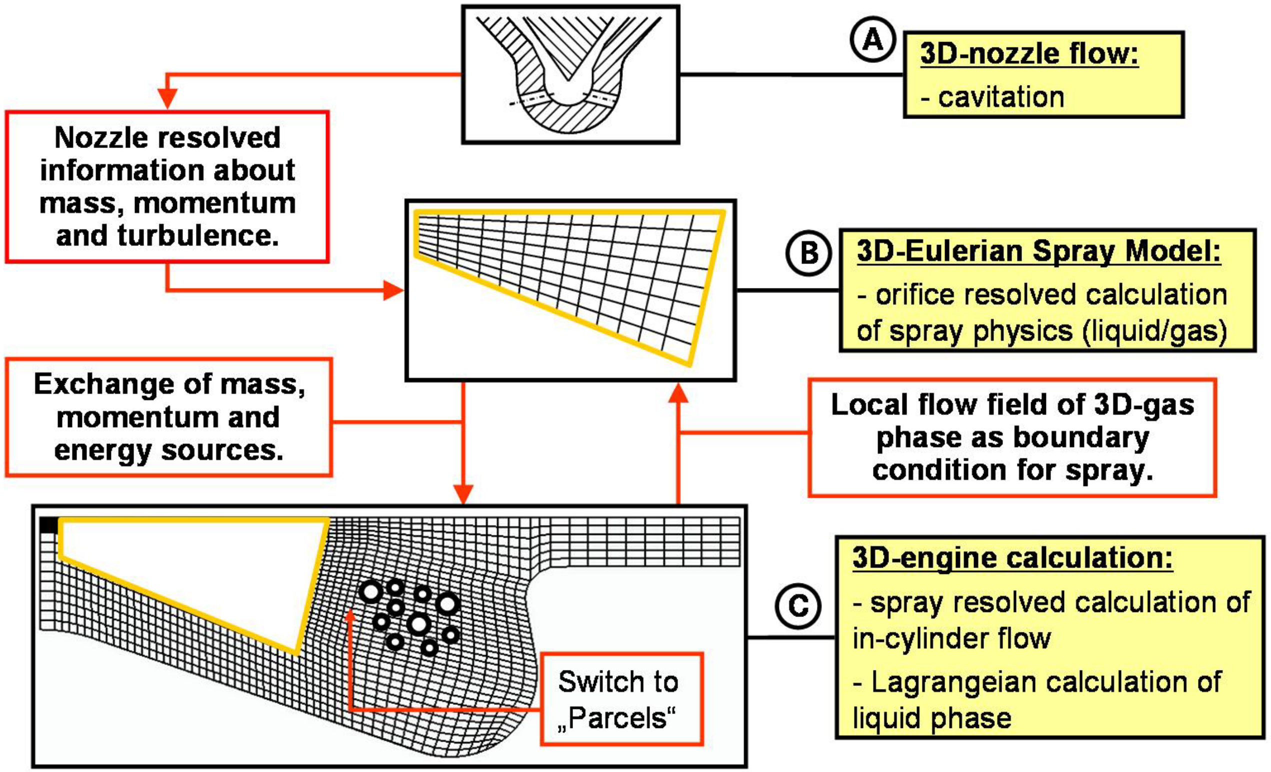
# 1. Concept

- The Diesel high-pressure direct injection could be divided into 3 different processes, which need distinct simulation approaches:

**A. *Nozzle flow***
(multiphase solver with cavitation model)

**B. *3D Eulerian Spray***
(multiphase solver with droplet class and related spray models)

**C. *Engine***
(single phase solver with DDM droplets and combustion models)



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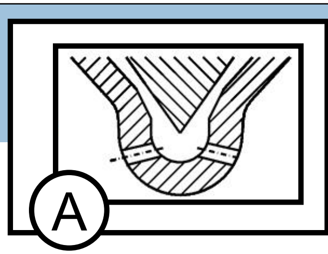
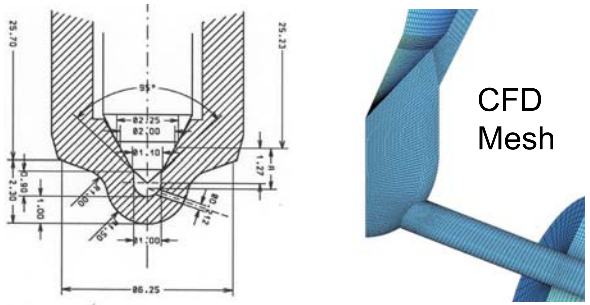
# 2. Nozzle flow simulation

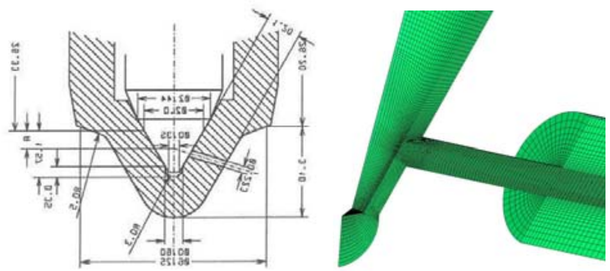



## Nozzle types examples

Sac hole



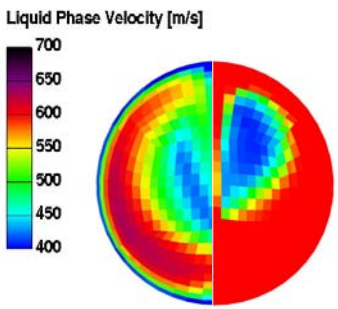

VCO

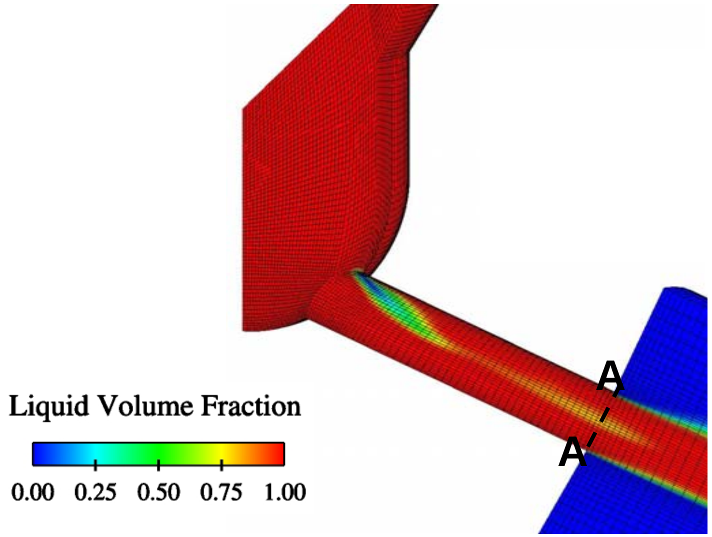


## Simulation settings

- 3-phases simulation: liquid, vapour and air;
- Cavitation model;
- Moving mesh;
- Unsteady boundary conditions.

Nozzle orifice A-A

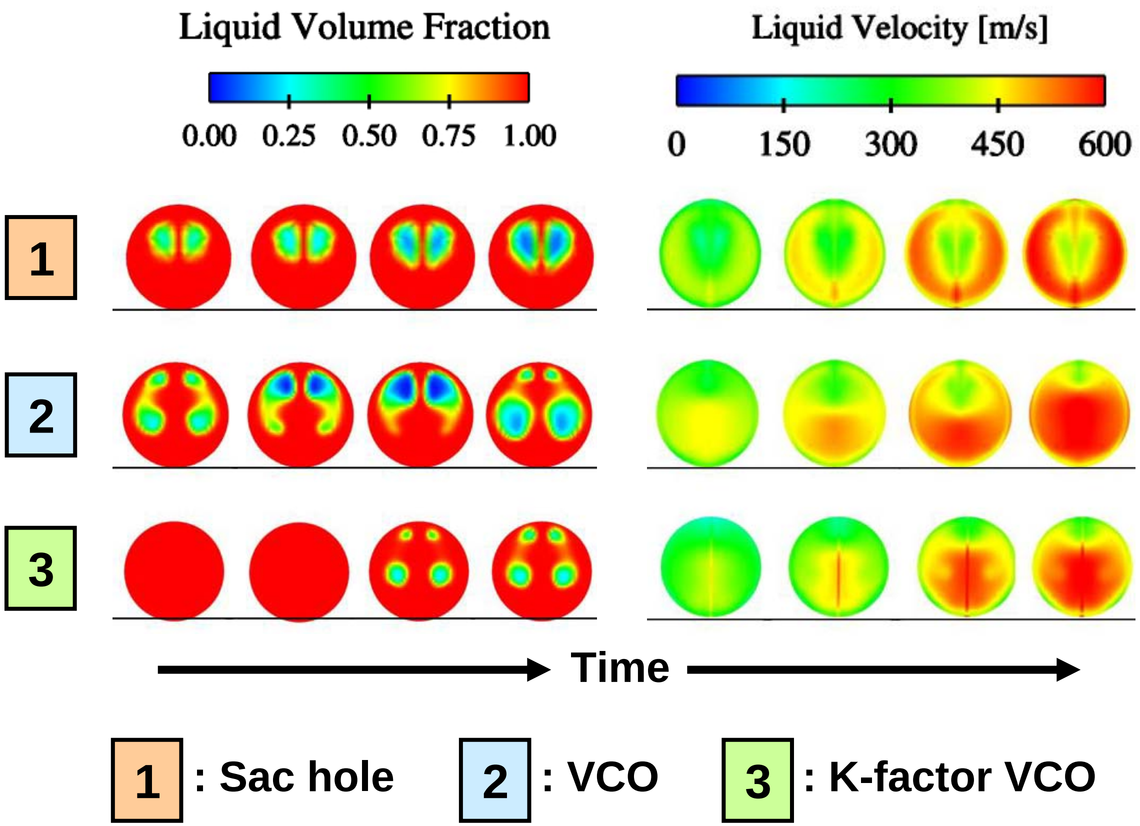


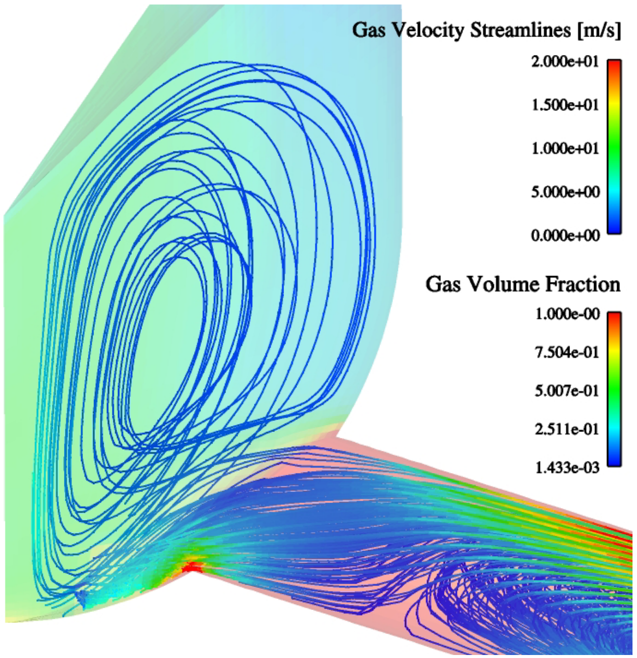
# 2. Nozzle flow simulation

- Each **nozzle type** produces **different cavitation, turbulence** and **flow fields**, which could strongly affect the spray.

**Example**: Nozzle outlet field (sac hole, VCO and K-factor VCO nozzles).




Hole erosion problems in sac hole nozzles: gas back flow at needle closure

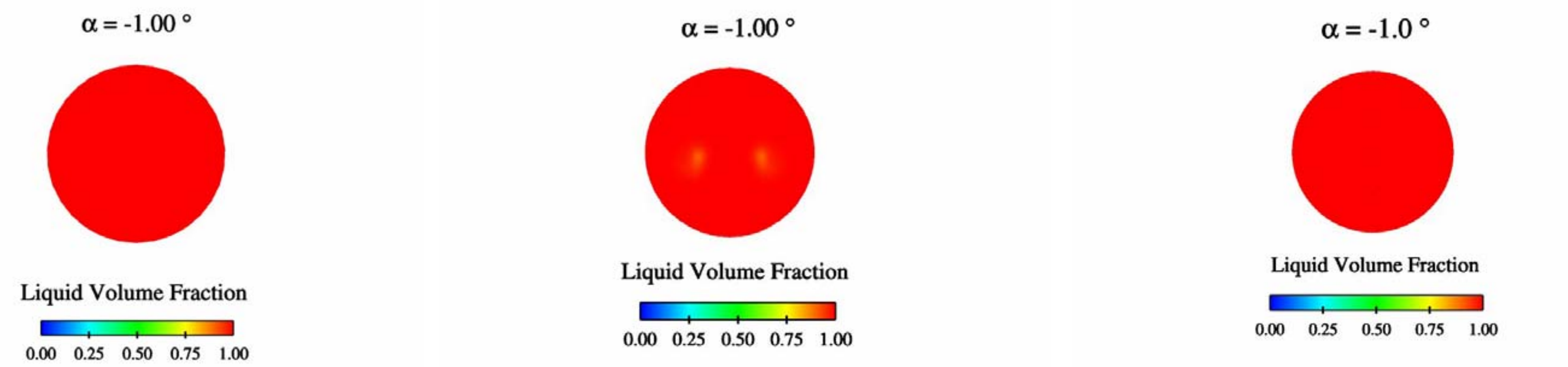


# 2. Nozzle flow simulation

- Each **nozzle type** has not only different flow properties, but presents also different **stability** behavior.

**Flow field at nozzle orifice**

**1 : Sac hole** **2 : VCO** **3 : K-factor VCO**



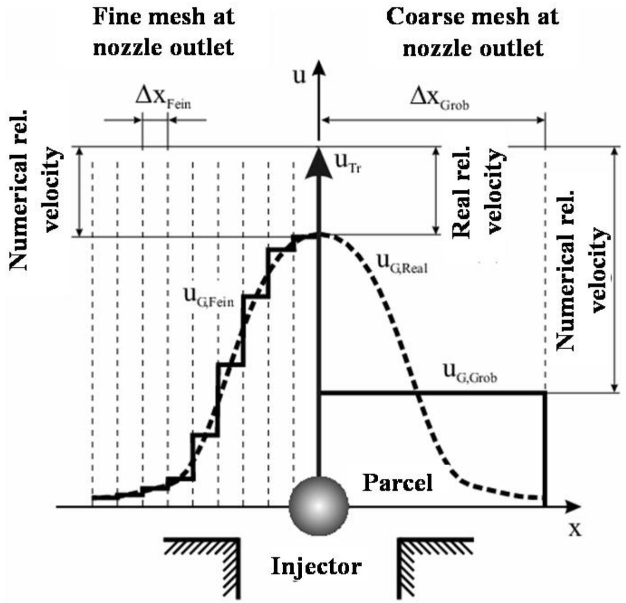

**The spray formation is influenced by the behavior of the internal nozzle flow.**

# 3. Why a 3D Eulerian Spray?

## Statistical convergence vs. spatial resolution

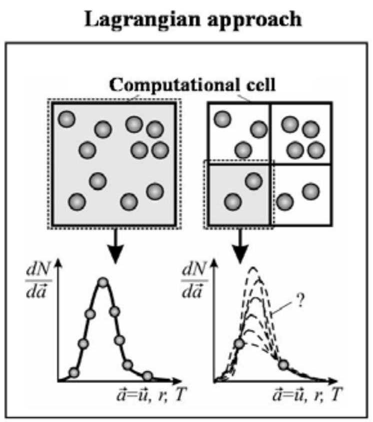
Coarse mesh at nozzle outlet
→ The relative velocity between droplets and gas is overestimated

- Incorrect solution of exchange processes
- Underrated turbulent production and viscosity

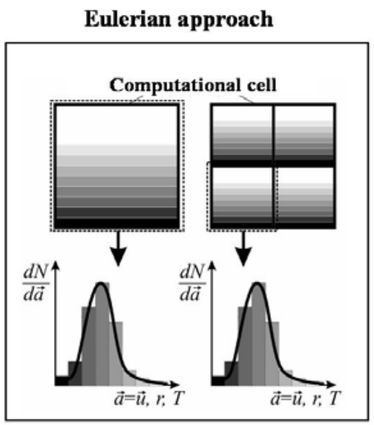



*(Source: A. Hermann, DaimlerChrysler Research)*

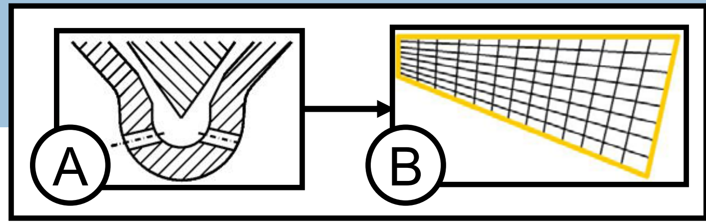
In the **Euler/Lagrange approach** the droplets-PDF is resolved by means of discrete "parcels" → statistical convergence with high droplets number per cell.




In the **Euler/Euler approach** the number of droplets classes is independent from cell dimension → the PDF is always consistently resolved.



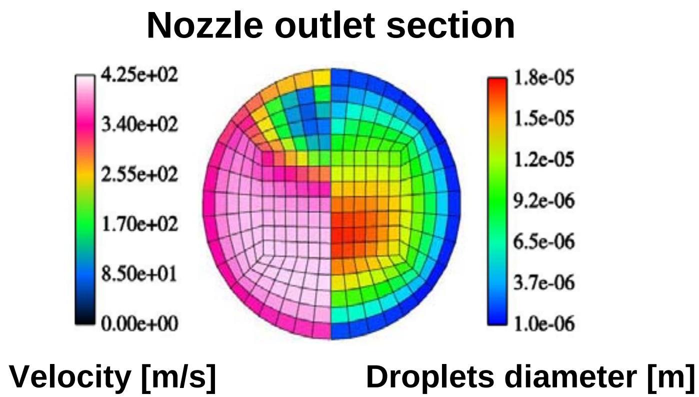
# 4. Coupling Nozzle - Spray

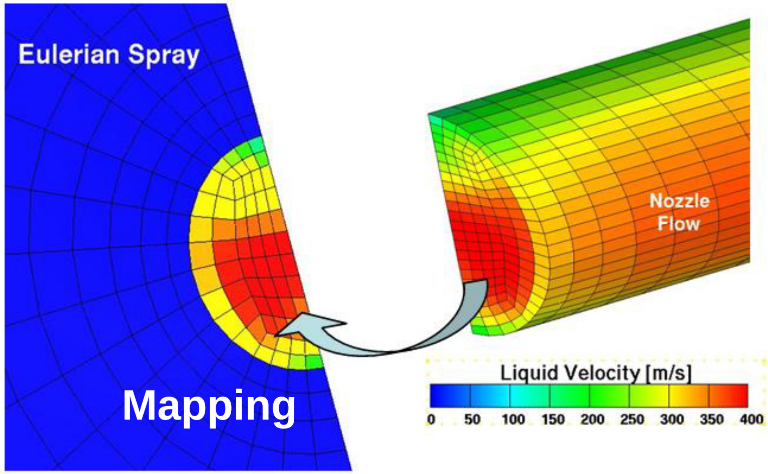


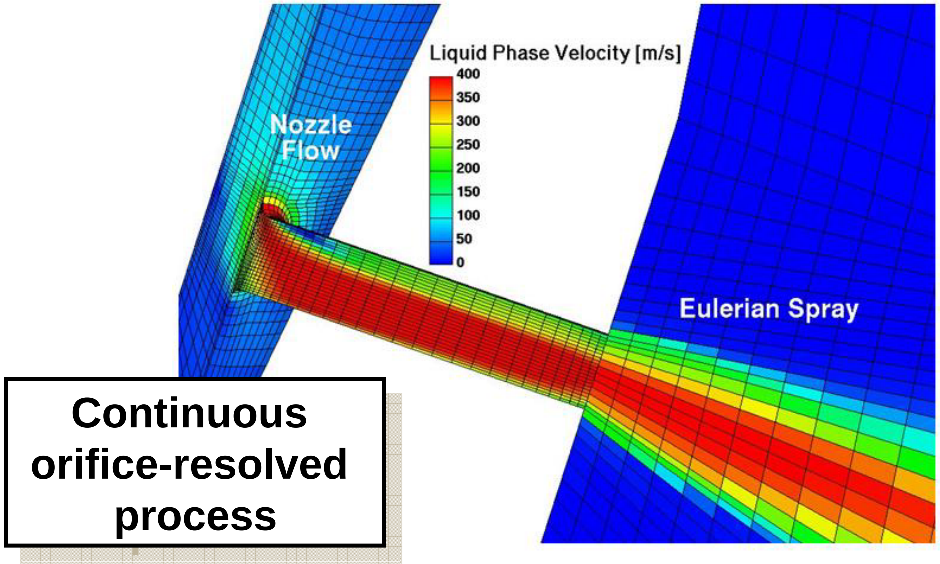

- Local values at nozzle orifice are extracted:
  - Velocity [m/s];
  - Dissipation rate (ε) [$m^2/s^3$];
  - Turbulence kinetic energy (k) [$m^2/s^2$]
- Definition of primary break-up criterion to initialize the droplet class diameters.

Droplets diameter

$$d \approx l_{turb} = C_1 \cdot C_\mu \cdot \frac{k^{1.5}}{\varepsilon}$$



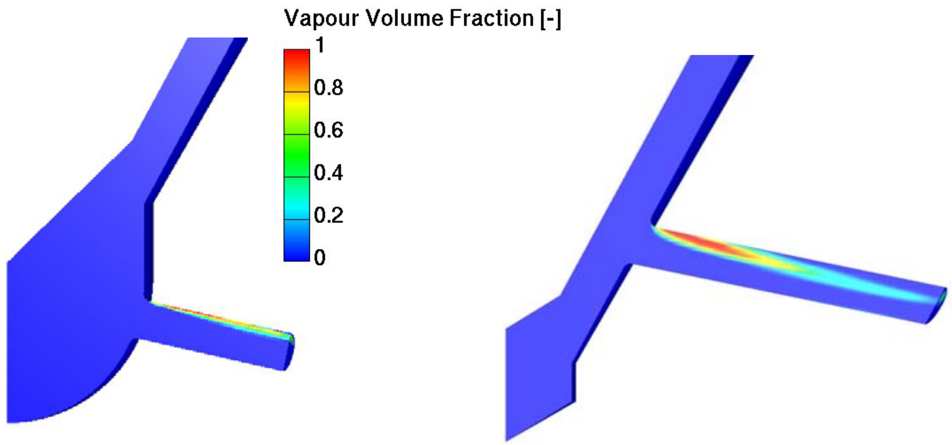



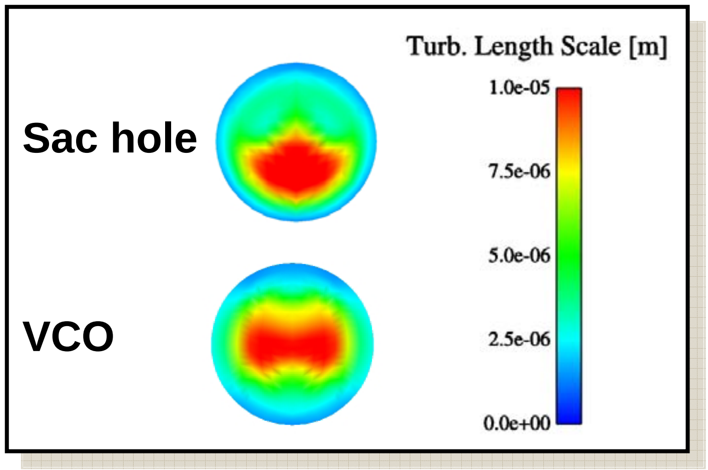
# 4. Coupling Nozzle - Spray: validation

- The nozzle flow simulations show different cavitation fields.
- 3D integral mass flows provide good agreement with the 1D hydraulic simulation → Hole rounding have been adjusted (20 μm for sac hole and 30 μm for VCO).
- Turbulence field at nozzle orifice is asymmetric for the VCO type → break-up process has to be affected.

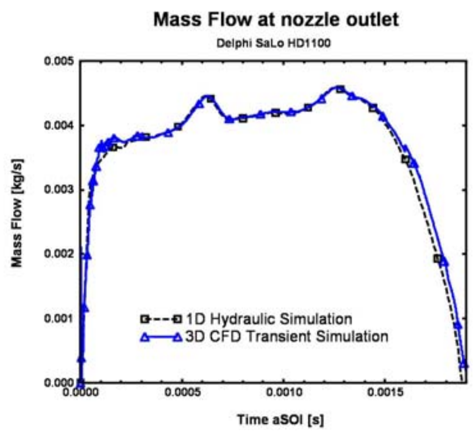
**Sac hole nozzle** **VCO nozzle**

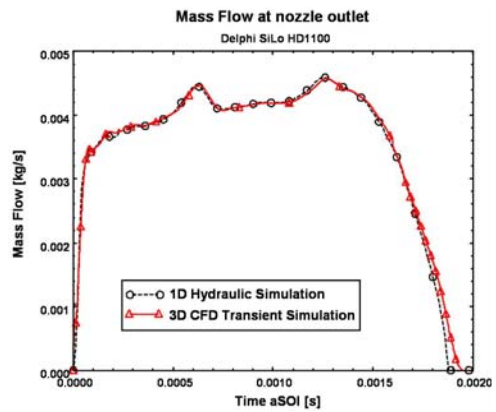



**t = 1ms**




**Mass flow at nozzle outlet**

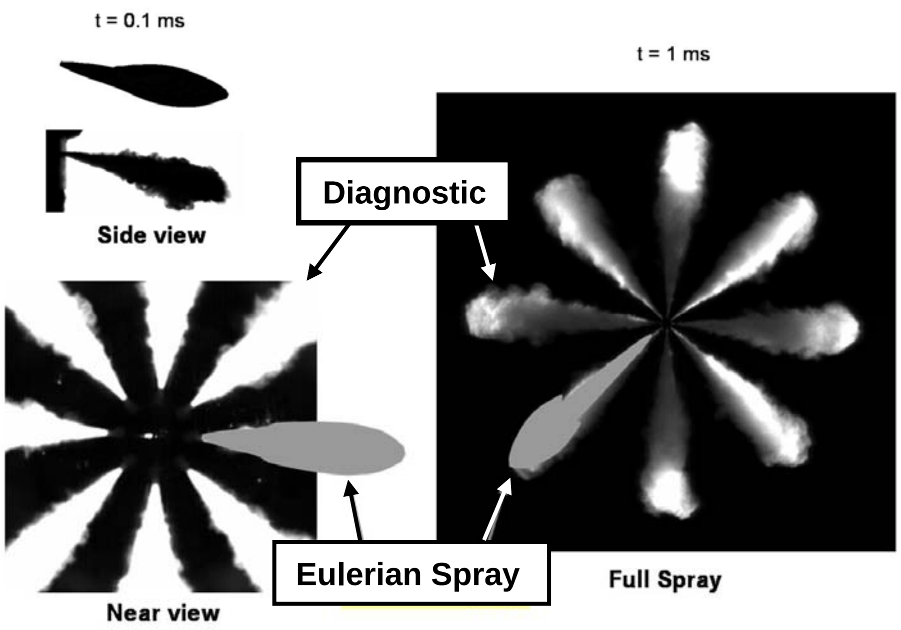


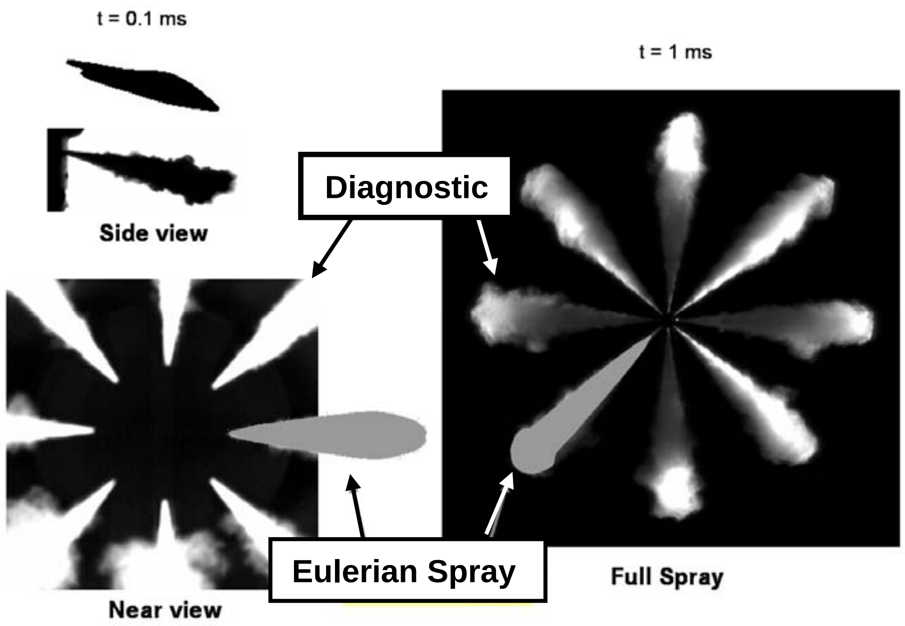
# 4. Coupling Nozzle - Spray: validation

## Eulerian spray validation

### Sac hole nozzle

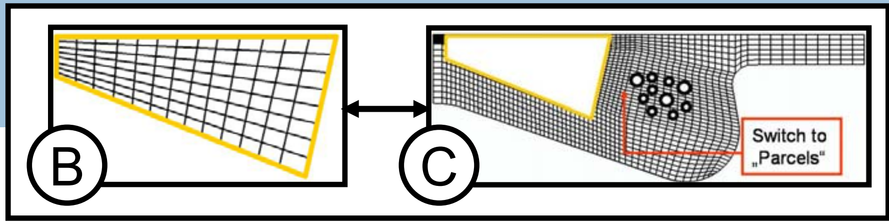


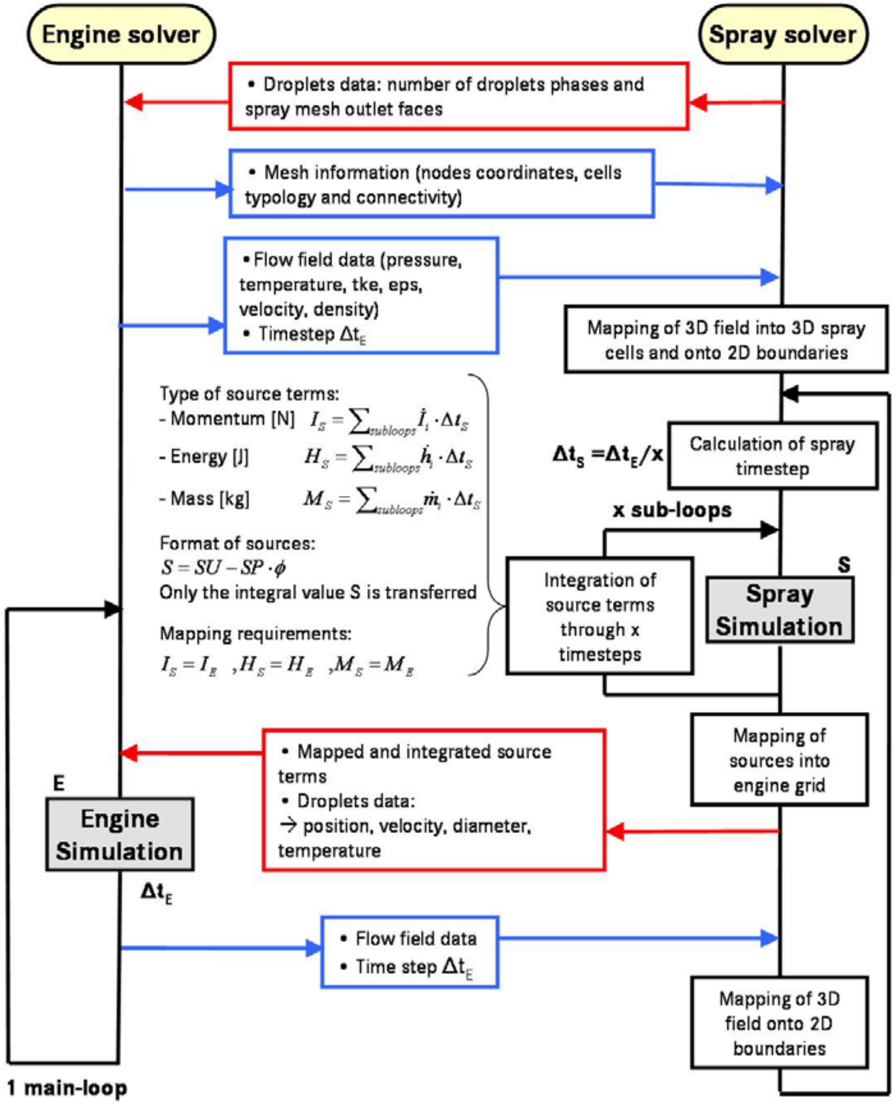

### VCO nozzle




**Nozzle flow simulations** are **coupled** to the multiphase spray boundaries via primary break-up → the **Eulerian spray** simulations provides **good results** in the prediction of spray formation.

# 5. Coupling Spray - Engine




**Code coupling interface**

- Based on the ACCI coupling interface (embedded in Fire v8)
- „Real-time“ coupling between the CFD-codes
- Client/Server TCP-IP protocol for data exchange

**Performed tasks**

A. 3D-volume mapping between the meshes

B. Boundary conditions transfer from engine to spray

C. Source terms transfer from spray to engine

D. Initialization of DDM parcels in the engine mesh out of the Eulerian grid

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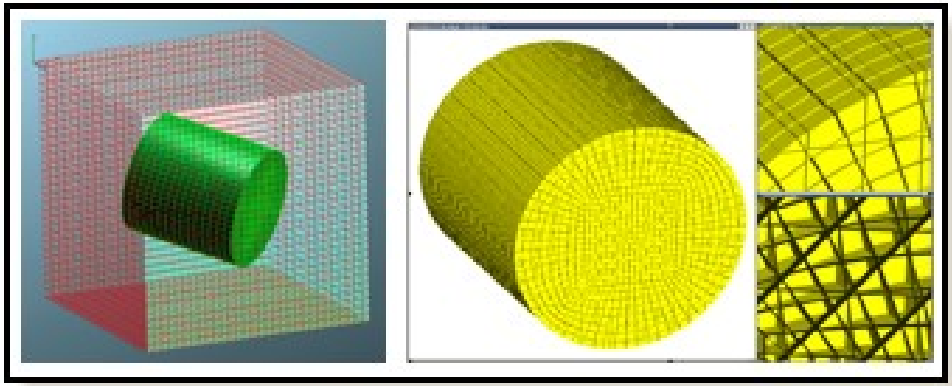
# 5. Coupling Spray - Engine: mapping

## A. 3D-volume mapping

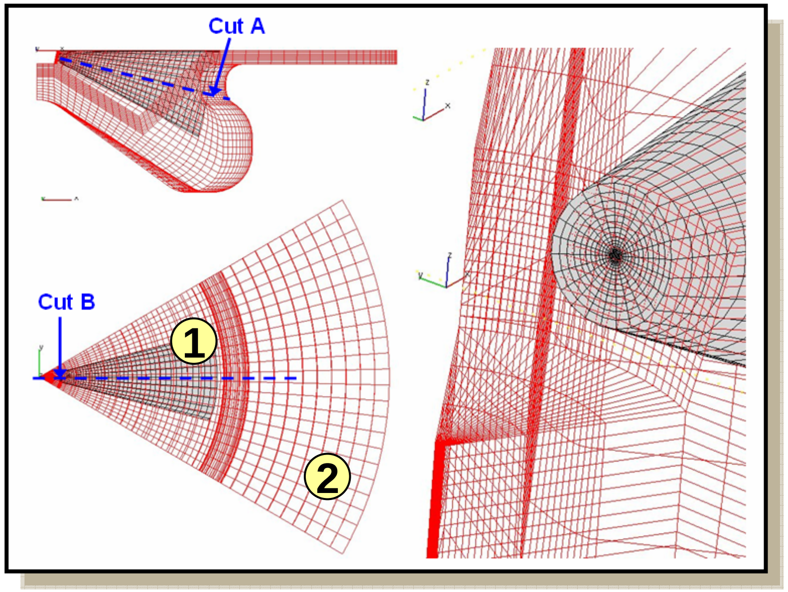
→ The ACCI coupling interface calculates the volume intersection between the computational cells.



## Test case definition

Passenger car engine (DC)

- Full load;
- Continuous injection;
- Two different levels of swirl (0.0 and 2.9).



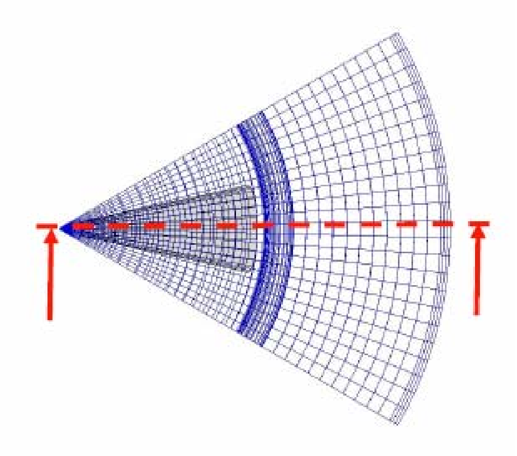

① **Eulerian spray mesh**

② **Engine sector mesh**

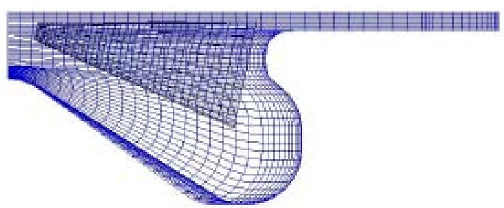
# 5. Coupling Spray - Engine: boundaries

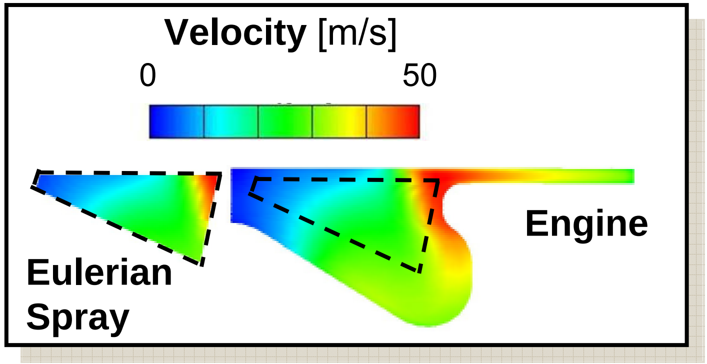
## B. Boundary conditions transfer from engine to spray

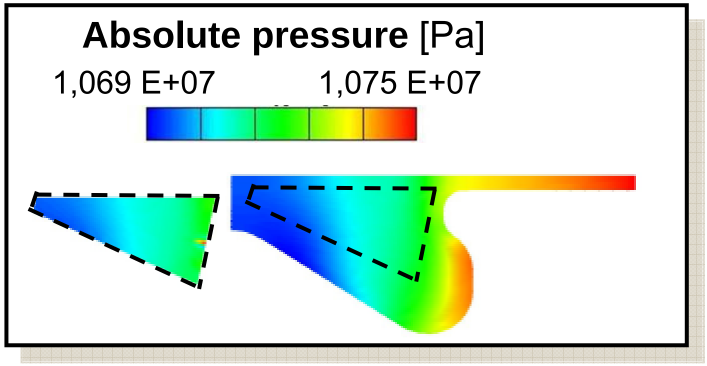
Gas coupling in Compression run for a passenger car engine (DC)

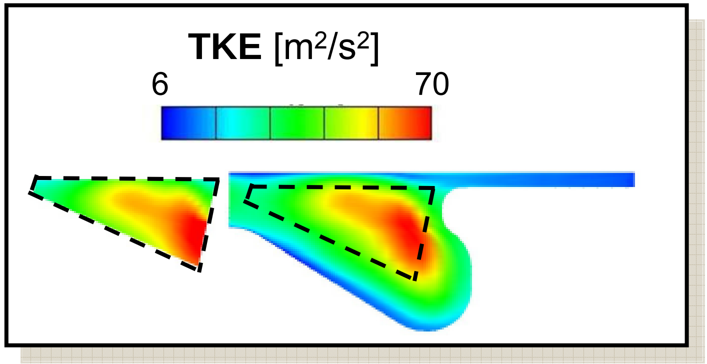


**At TDC**






Gas flow field is correctly transferred from engine to spray code →

The Eulerian Spray mesh can reproduce the flow effects of the engine domain (i.e. swirl, tumble, …).

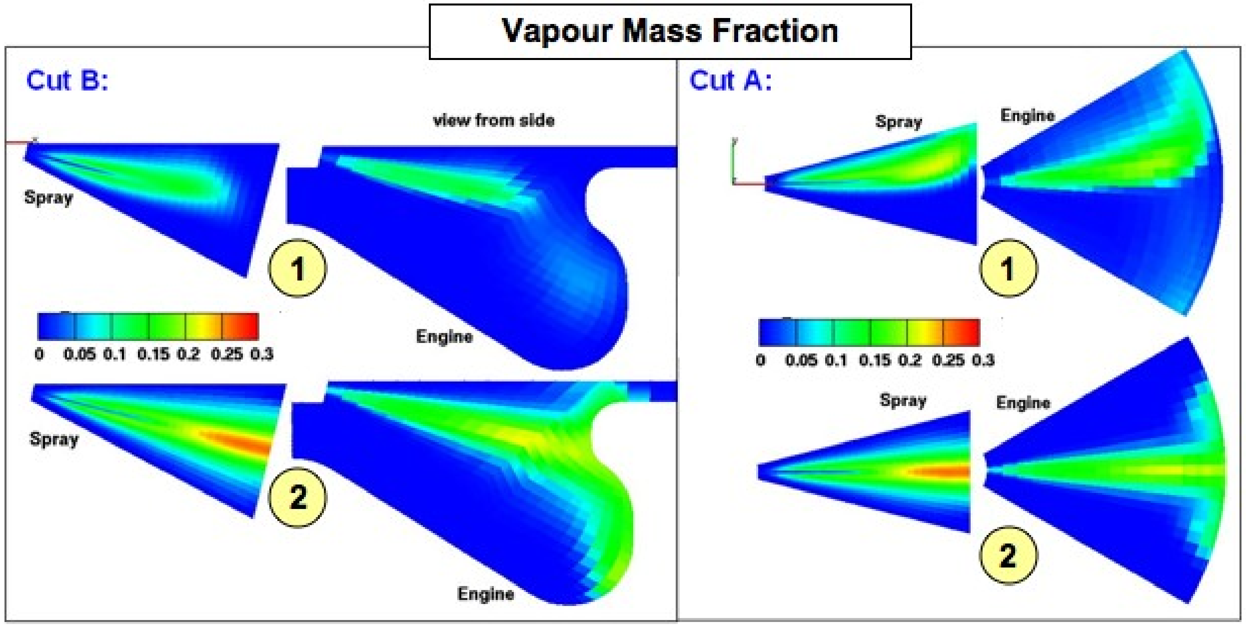
# 5. Coupling Spray - Engine: source terms

## C. Source terms transfer from spray to engine

### Transferred data

- Eulerian spray → Engine code
  - Source terms (momentum, mass, energy)
  - DDM droplets
- Engine code → Eulerian spray
  - Boundaries (p, T, k, ε, v)

→ Simulation of the **mixture formation** with the 3D Eulerian model in the region nearby the nozzle orifice.




(1) **Swirling gas flow**

(2) **Non-swirling gas flow**

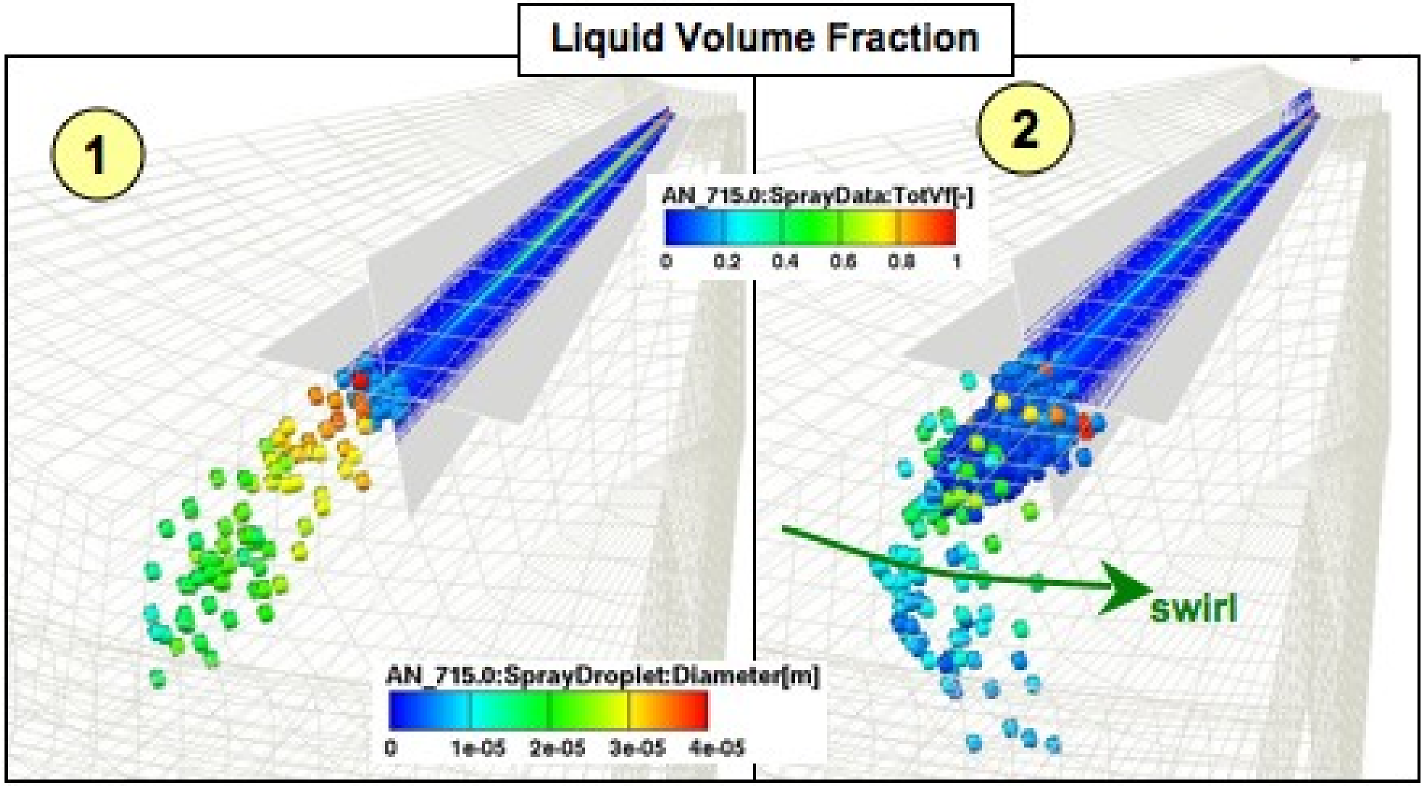
# 5. Coupling Spray - Engine: DDM parcels

## D. Initialization of DDM parcels out of the Eulerian grid

→ As the liquid phase reaches the outlet boundary of the Eulerian mesh, new DDM parcels are initialized in the engine mesh

① **Non-swirling gas flow**

② **Swirling gas flow**



# 5. Coupling Spray - Engine: test case

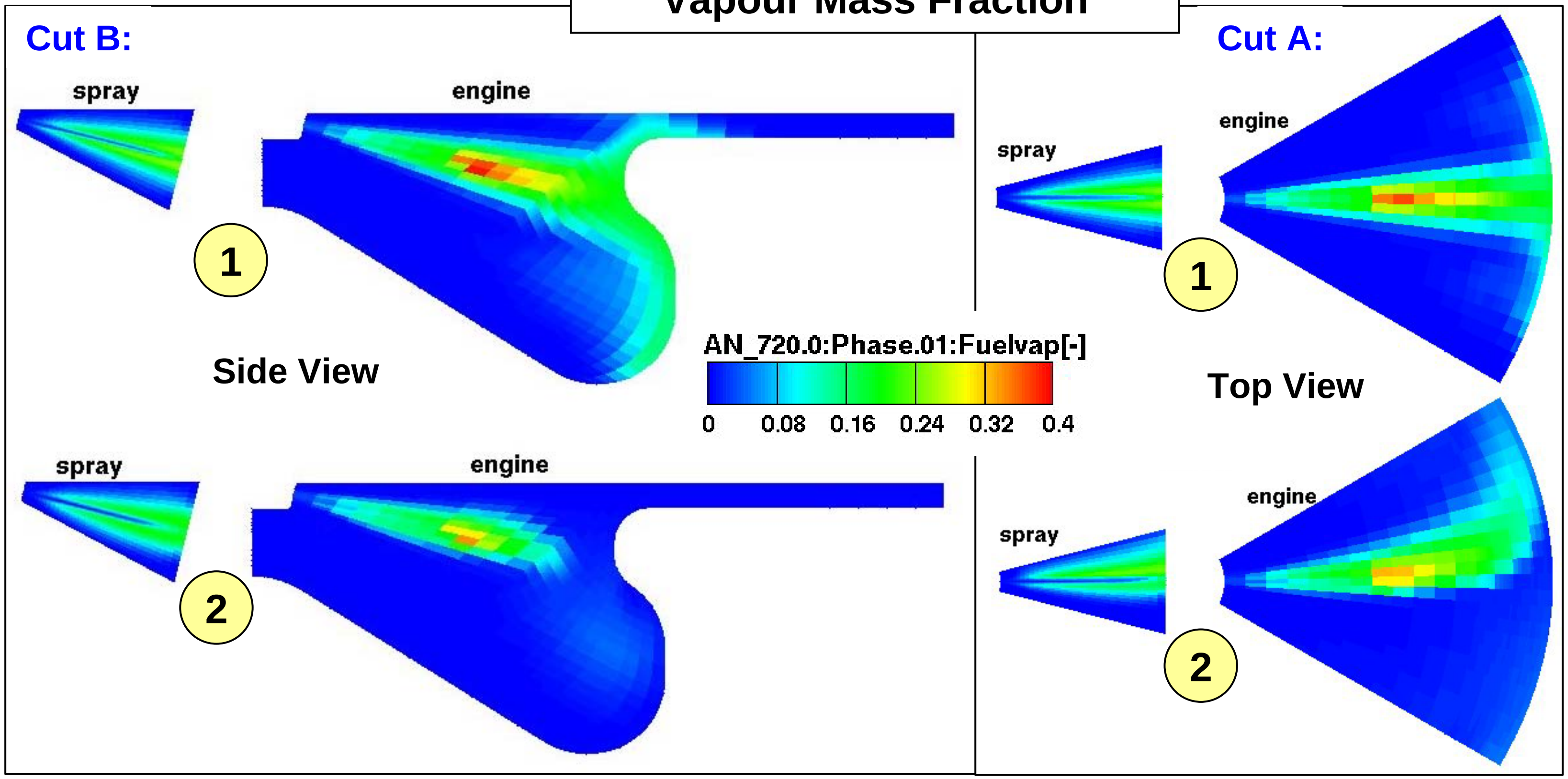
**Coupled Eulerian Spray / IC-engine Calculation**

→ Ignition and combustion models are activated

① **Non-swirling gas flow**

② **Swirling gas flow**

**Vapour Mass Fraction**



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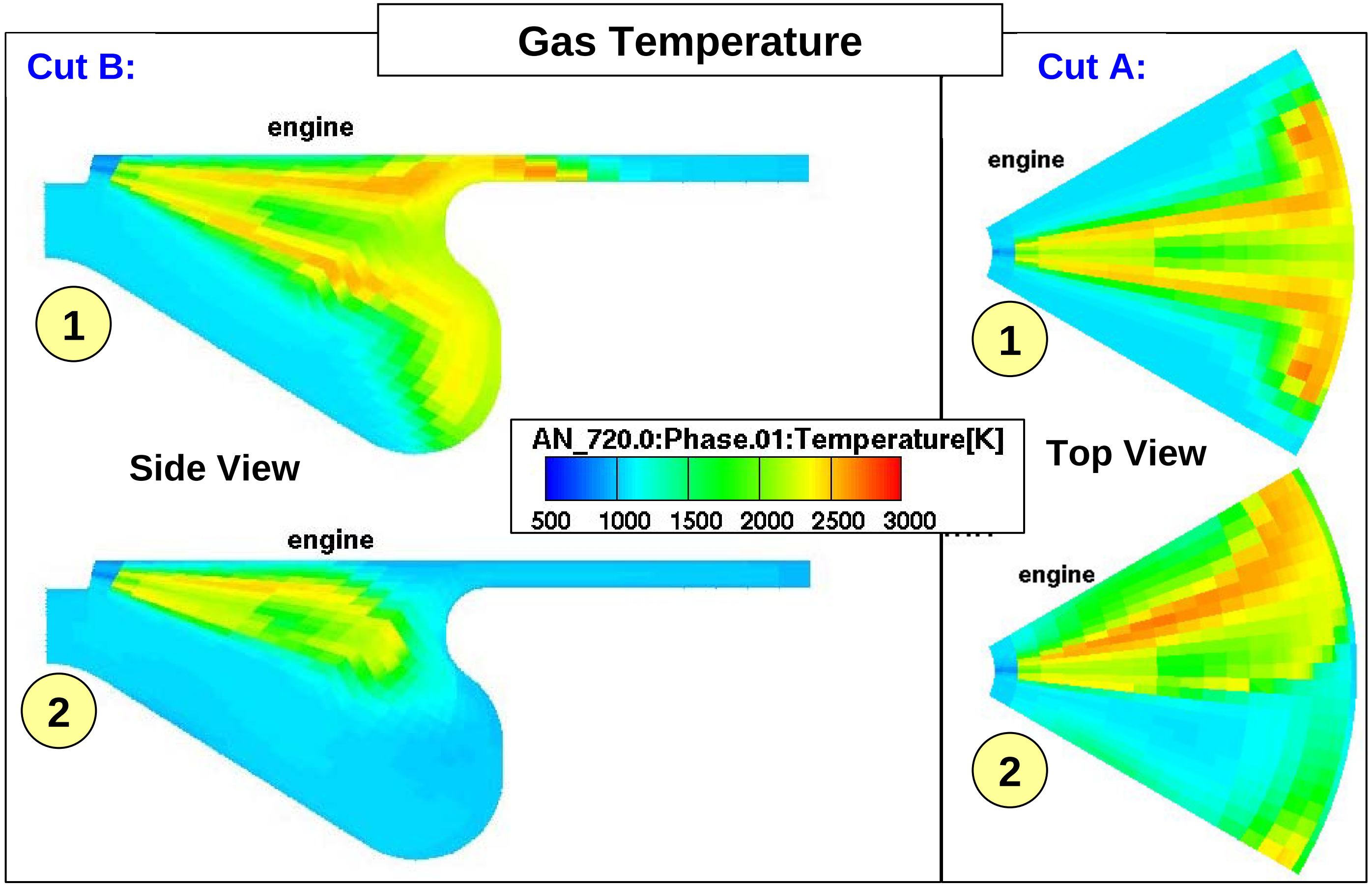
# 5. Coupling Spray - Engine

**Coupled Eulerian Spray / IC-engine Calculation**

1. Non-swirling gas flow
2. Swirling gas flow



# 6. Conclusions

1. A **new coupling concept** has been developed in order to comprehensively consider 3D nozzle flow, orifice resolved primary break-up and mixture formation in a real engine environment.

2. At the state of the art the spray simulation begins at nozzle orifice. In the current approach the **nozzle flow simulation** provides essential information for the spray initialization.

3. The **ACCI** coupling interface appeared capable to perform the required mapping and transfer operations between the engine and spray codes.

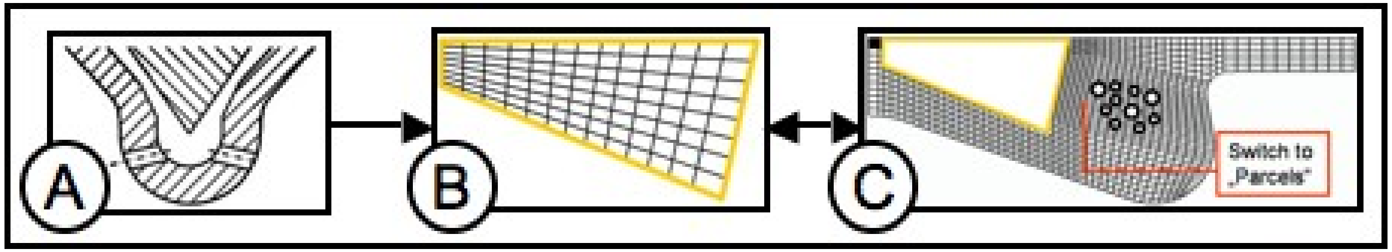
4. The **3D Eulerian spray model** has been validated on a cold chamber and coupled with engine combustion simulation.

# 6. Outlook

1. The coupling concept could provide **advantages** in the prediction of **mixture formation** process in the region nearby the nozzle orifice.

2. The method needs further **validation** in **engine environment** by means of pressure and heat release rate traces.

3. The effects of **different nozzle geometries** on combustion and emissions formation have already been analyzed. Results will be presented at the SAENA 2007 conference in Capri.



Thank you for the attention