Eulerian-Eulerian and Eulerian-Lagrangian LES of Diesel sprays

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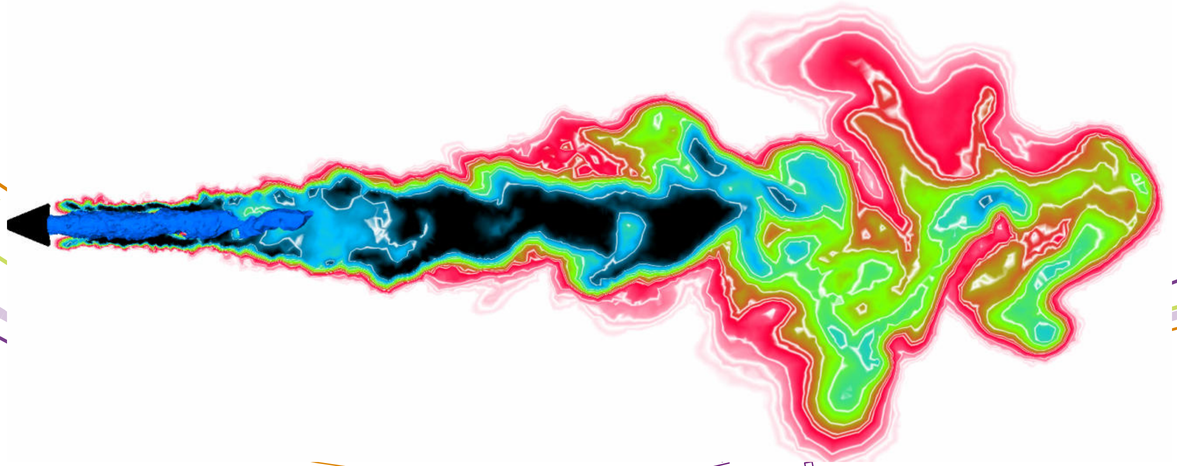


Context : Paving the way for a smooth energy transition

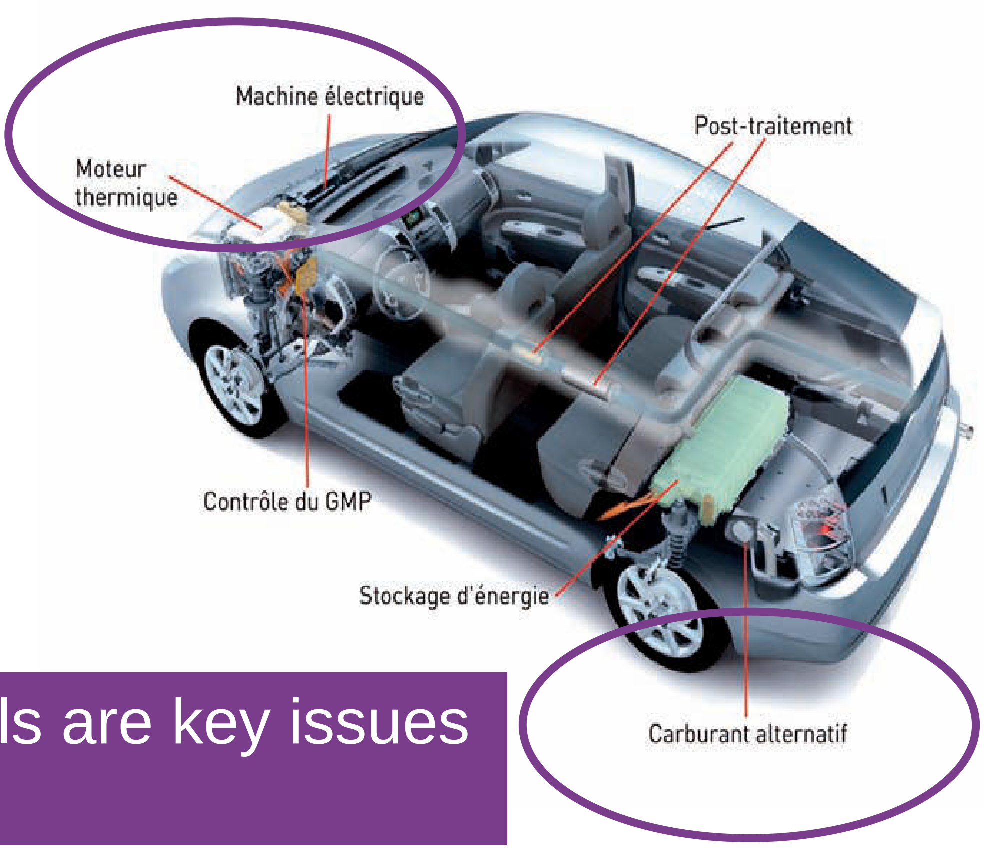
- Growing world energy demand,
  the gradual peaking of oil production,
  environmental imperatives :
  these are the factors that will shape
  the energy landscape of tomorrow.

- In such a context, it is essential that we develop new solutions to gradually take over from these energy sources while simultaneously inventing technologies to optimize oil and gas use.

Fuel-efficient vehicles

- R & D efforts is particularly intense

  in the field of
  - *hybridization of vehicles*
  - *and alternative fuels development*

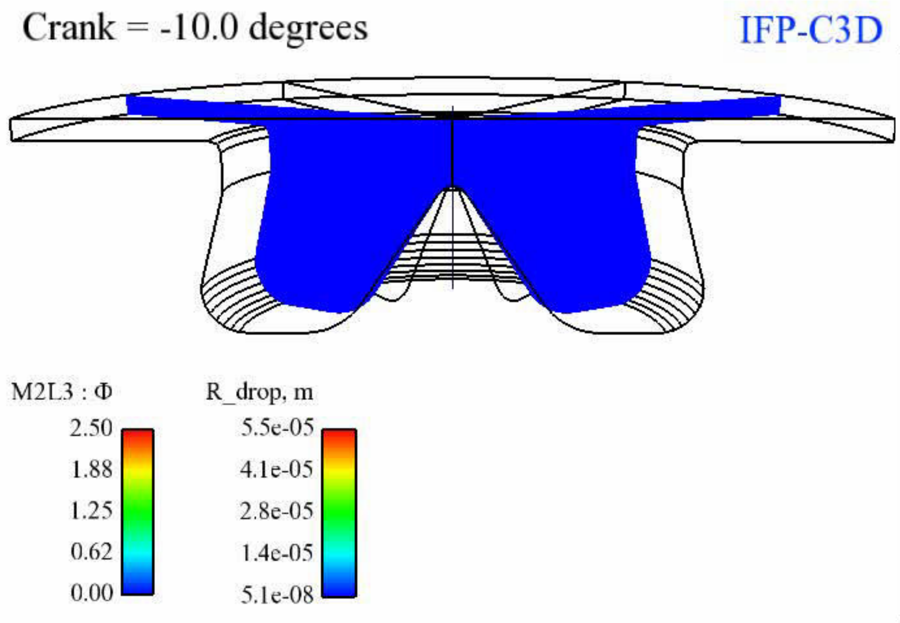


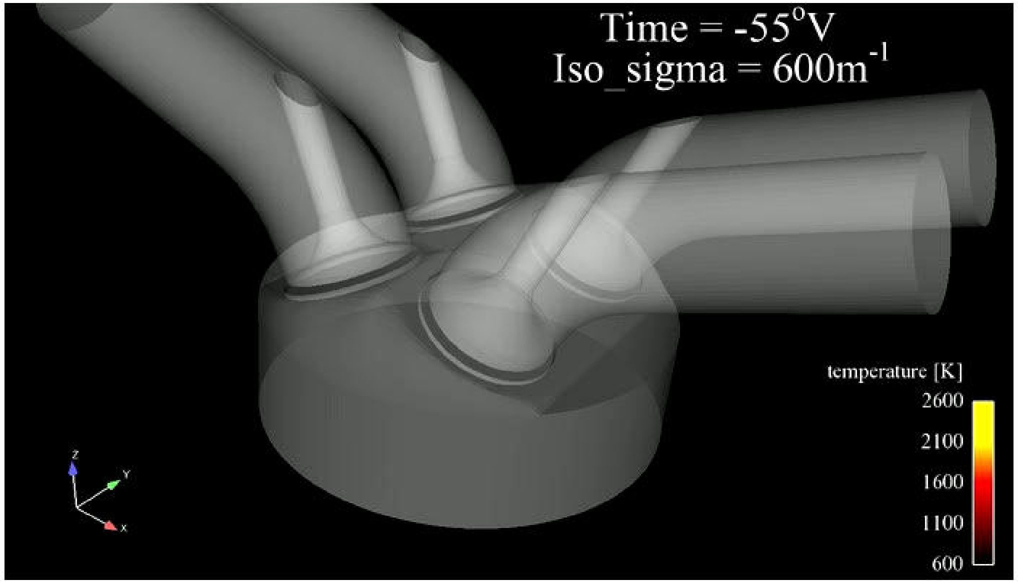
Modeling & Simulation Tools are key issues for Fuel-efficient vehicles

3D numerical Tools

RANS computation of a Diesel engine

LES computation of a gasoline engine





IFP-C3D

AVBP

The main models

- Two-phase flow models
  - Injection model (including the effects of the transient cavitating flow inside de nozzle)
  - Primary and secondary breakup models
  - Phase change models (vaporization, boiling, ...)
  - Spray-wall interaction models (liquid film, splashing, ...)
- Mixture preparation models
  - Gas turbulence model
  - Turbulent dispersion model
  - Two-way coupling models
- Combustion models
  - Ignition and auto-ignition models
  - Flame propagation models
  - Pollutants models

AVBP two-phase flow models

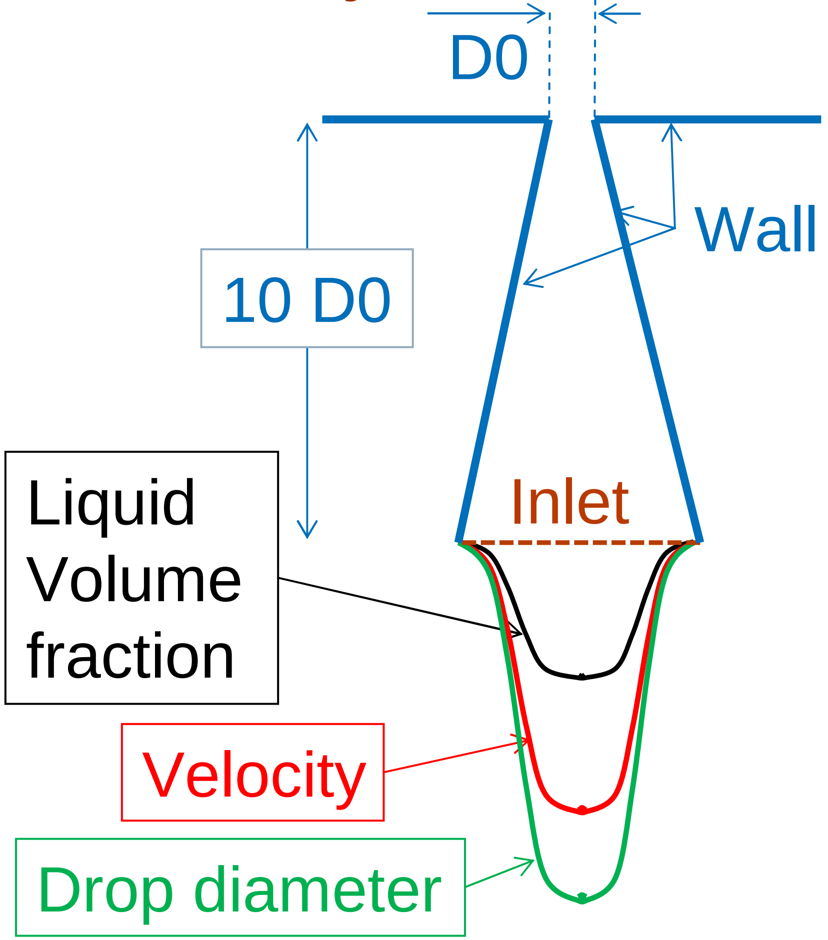
- Gas
  - Mass, Momentum & total enthalpy conservation equations
  - Dynamic Smagorinsky model for SGS turbulence
- Liquid (assumed as a dispersed phase in the gas)
  - The Euler-Euler mesoscopic model (*Février & al. ,JFM 2005*)
    - Monodisperse formulation including the equations of liquid volume fraction, Number density of droplets, Momentum & enthalpy + RUM - energy equation (including elastic collisions)
  - The Euler-Lagrange model
    - Position, radius, velocity & Temperature equations for each droplet or parcel

Aim of the presentation

- Apply the EE and EL approaches to LES of Diesel sprays
- Compare the EE and EL results to available experiments
- Answer to some FAQ about EE and EL LES such as :
  - How can we specify liquid injection boundary conditions (BC) in LES ?
  - What is the relative cost of EE/EL LES ?
  - What are the main advantages/drawbacks of the EE & EL approaches ?

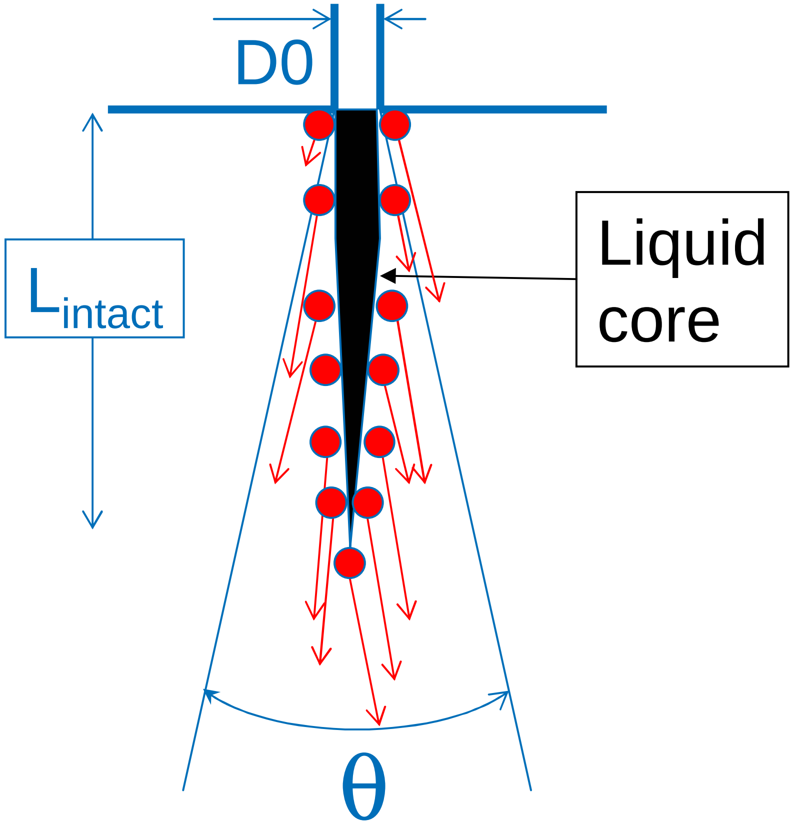
Injection models (single-hole injector case)

*EE injection model**



(*) Martinez et al, FUEL- 2010

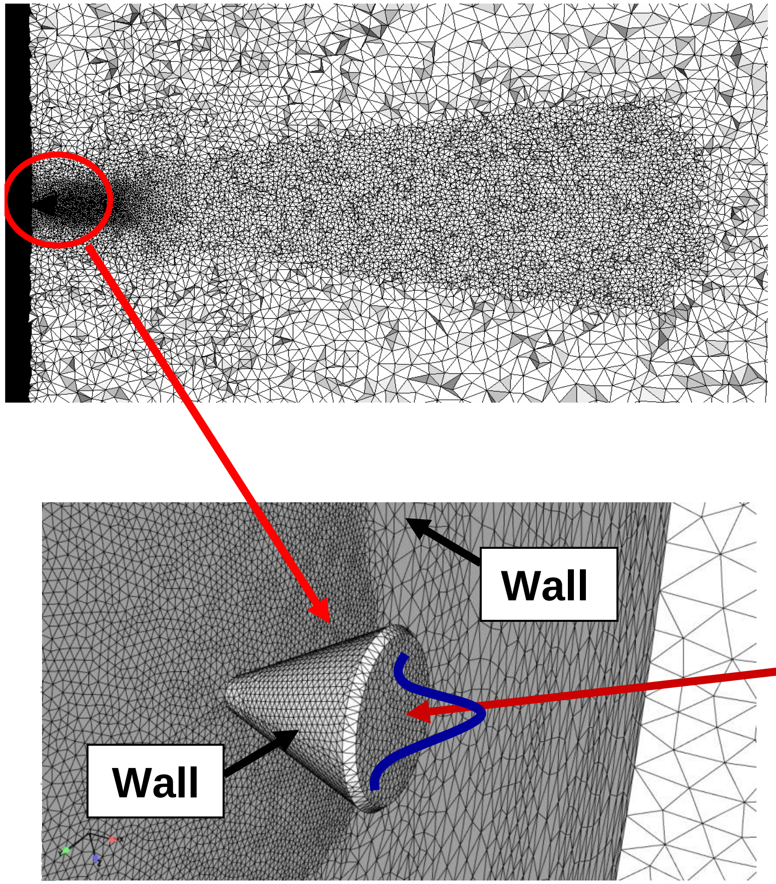
EL injection model



Initial drop Velocity is a function of the specified injection rate, cone angle θ and V_{rms}

Initial drop diameter is sampled in a Rosin-Rammler pdf

Typical 3D Mesh and BC



Grid characteristics	
Number of cells (tetrahedrons)	1.8 million
Characteristic cell size in the injection zone close to the nozzle	30 µm

EE injector model assumption :

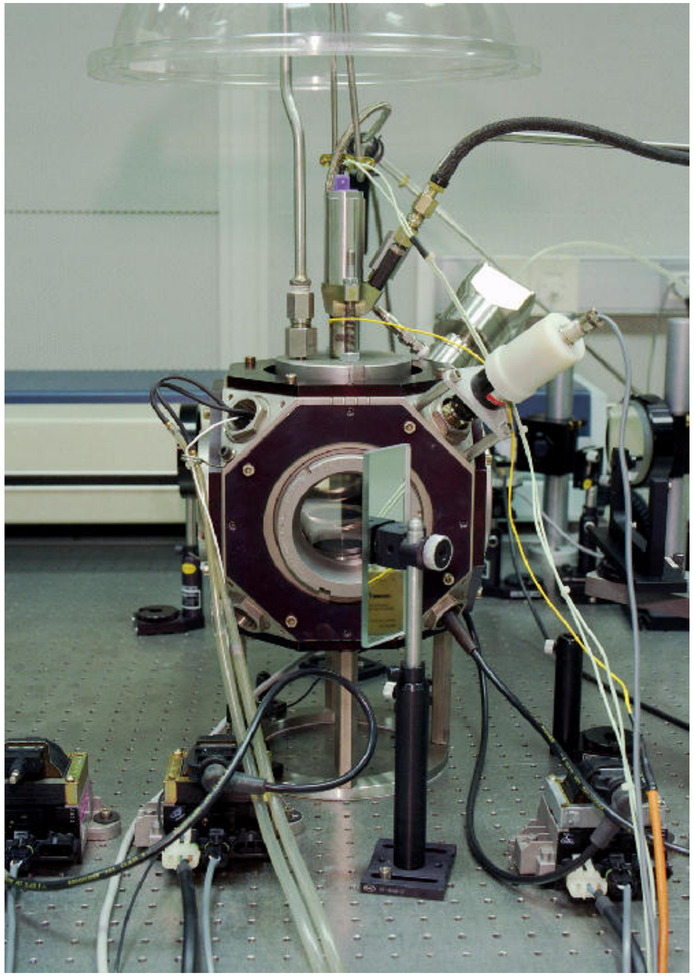
The meshed cone has a negligible effect on the gas entrainment induced by the liquid jet.

Experimental Diesel engine like conditions

- Operating conditions:

Common-rail system Ganser Injector with a single-hole Nozzle diameter (D0) : 200 µm	
Injection pressure (Pinj) : 40, 80, 150 MPa	
Back density : 25 kg/m3	
Non Vaporizing spray (Tgas = 400 K)	Vaporizing spray (Tgas = 800 K)

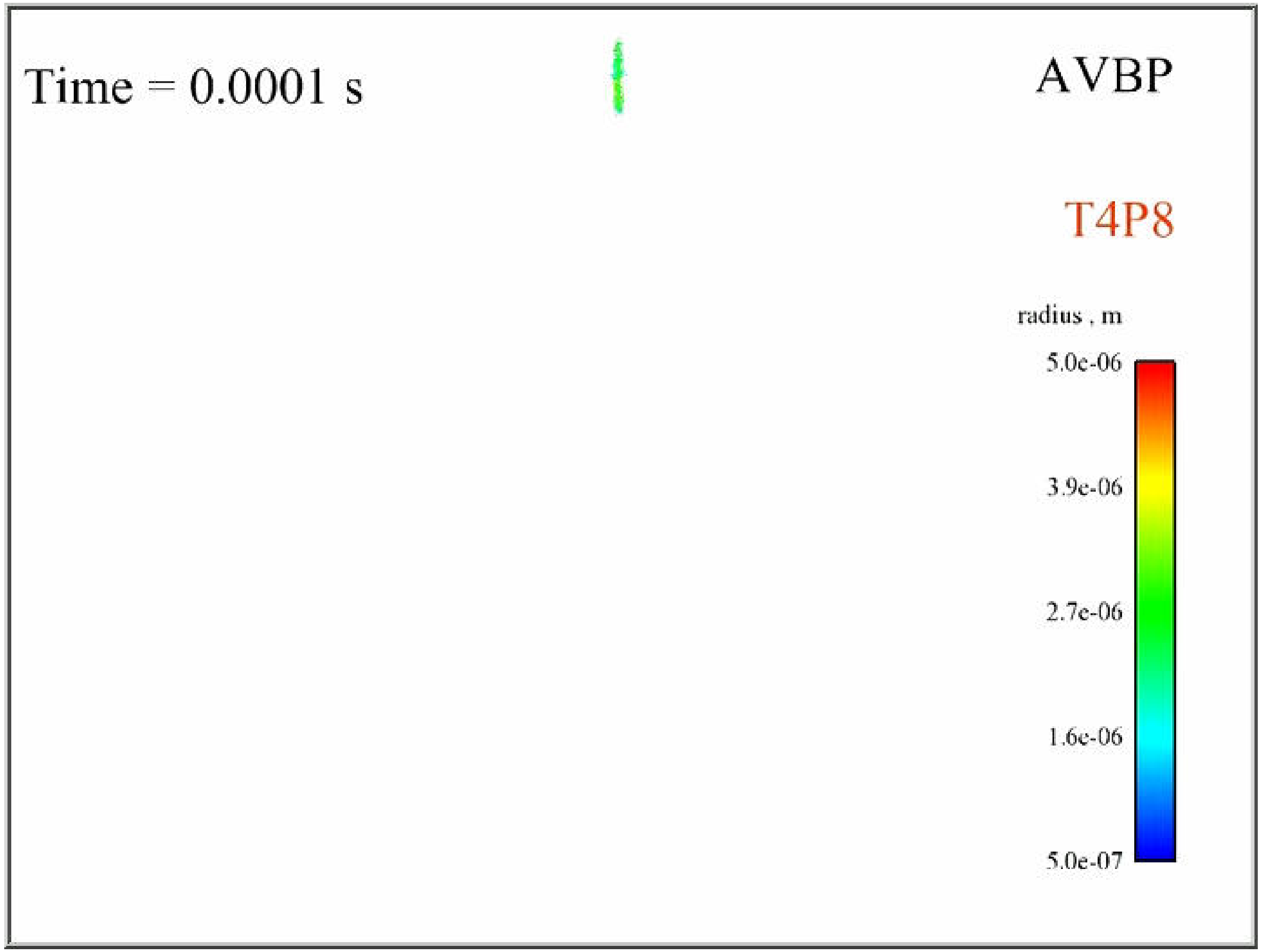
- Available data base :
  - Mie scattering images (cold cases)
  - PLIF images (vapor density distribution)
  - Liquid and vapor penetrations

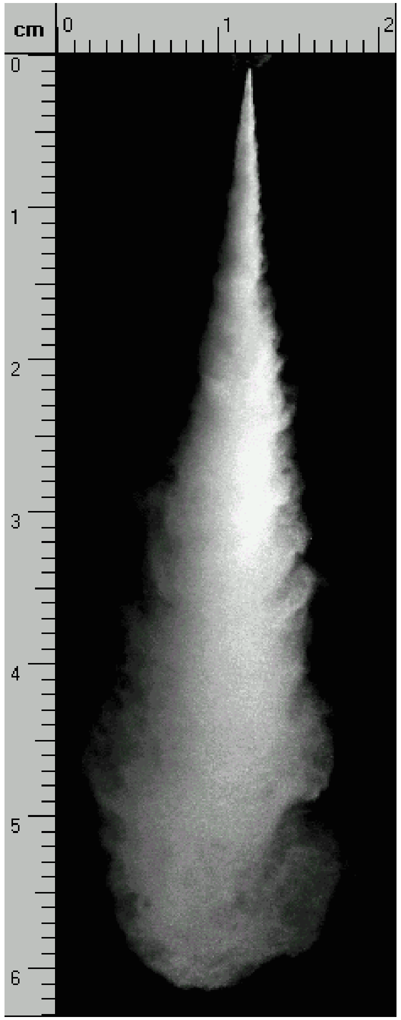


Computational conditions (1)

Nozzle diameter (D0) : 200 µm	
Fuel : n-dodecane (Tliq = 363 K)	
Back gas density : 25 kg/m^3	
Non Vaporizing case (T4P8)	Vaporizing case (T8P4)
Tgas = 400 K	Tgas = 800 K
Pinj = 80 MPa	Pinj = 40 MPa
Injected mass = 14 mg	Injected mass = 9.8 mg
Cone angle = 15 degrees	
Initial RMS velocity = 0.2*Vinj	
SMD = 5 µm	
Liquid core length = 10 D0	
Discharge coefficient = 0.9	
Total number of injected parcels (only for EL LES) = 300000 / 2 ms	

T4P8 Non-vaporizing case (1)
EL Computation (Tgas = 400K, Pinj = 80MPa)

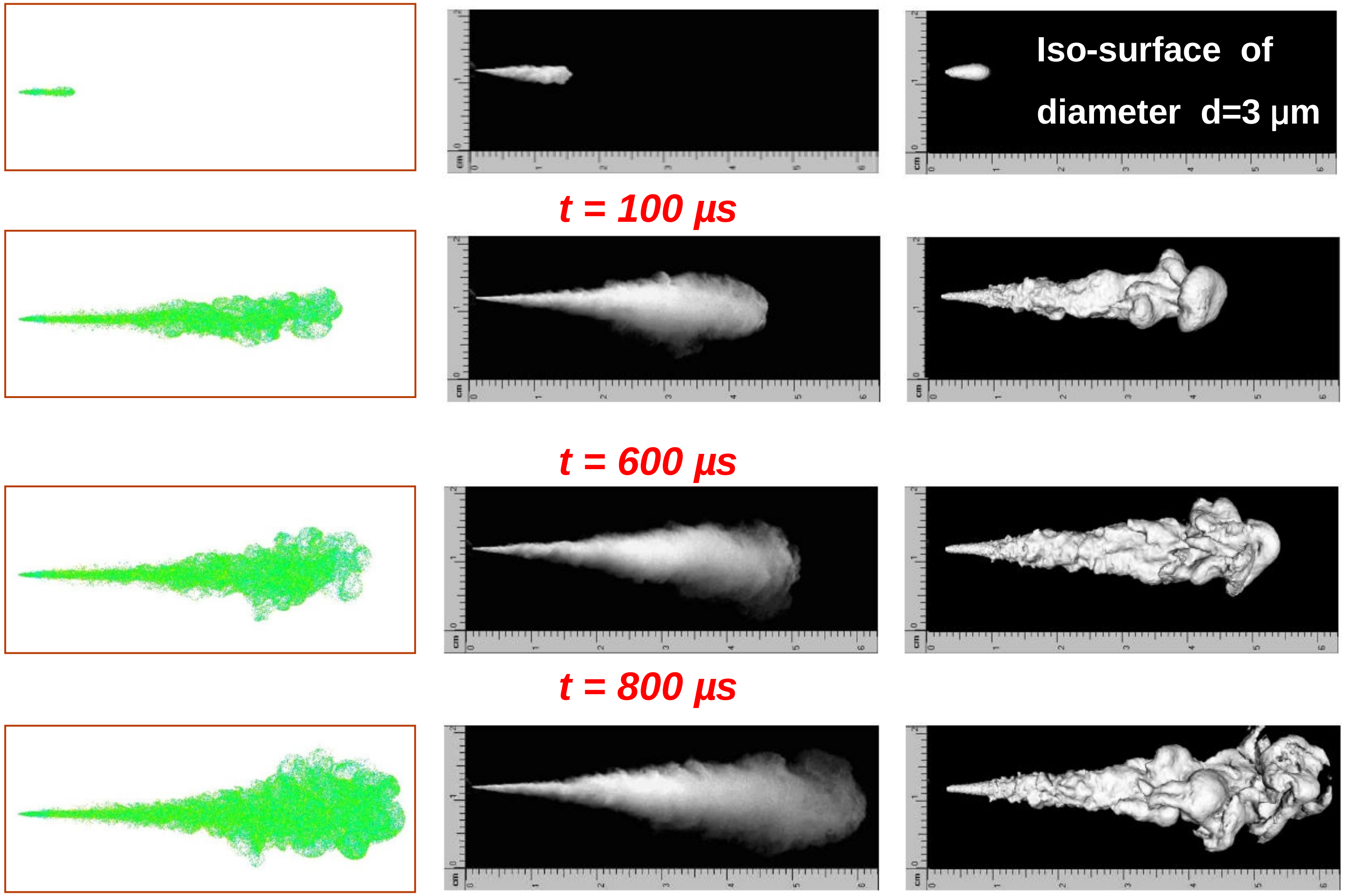




1.1 ms

T4P8 Non-vaporizing case (2)
Tgas = 400K, Pinj = 80MPa

LES - EL ***Experiments*** ***LES - EE***



Iso-surface of diameter d=3 μm

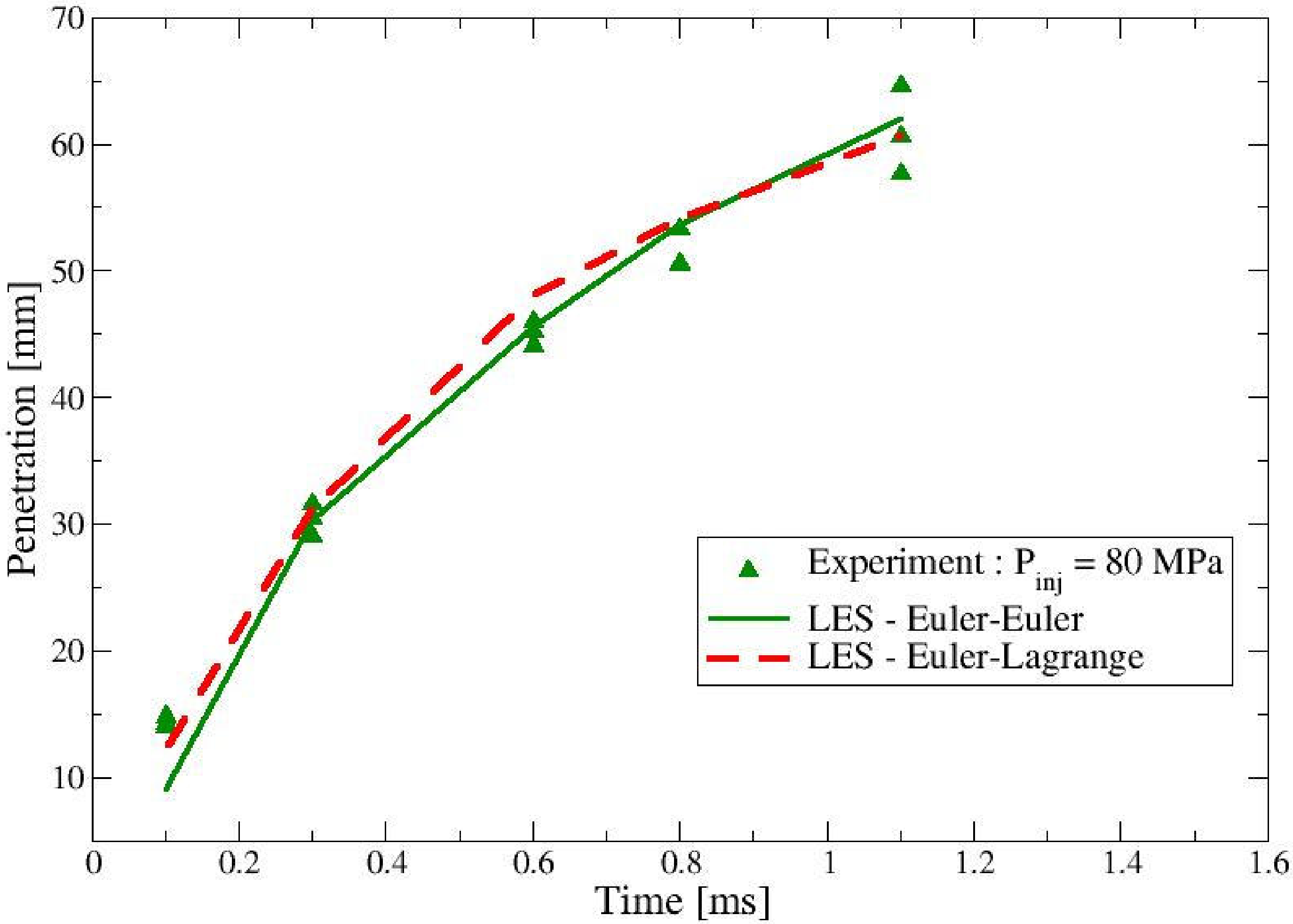
t = 100 μs

t = 600 μs

t = 800 μs

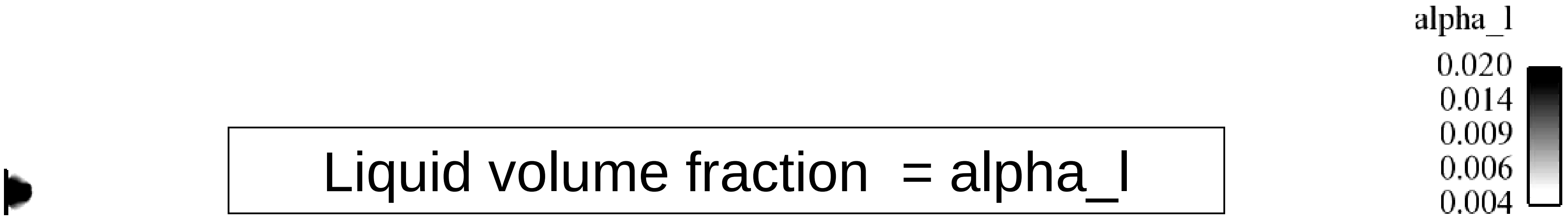
t = 1100 μs

Non-vaporizing cases (Tgas = 400K)
EE vs. EL liquid penetrations

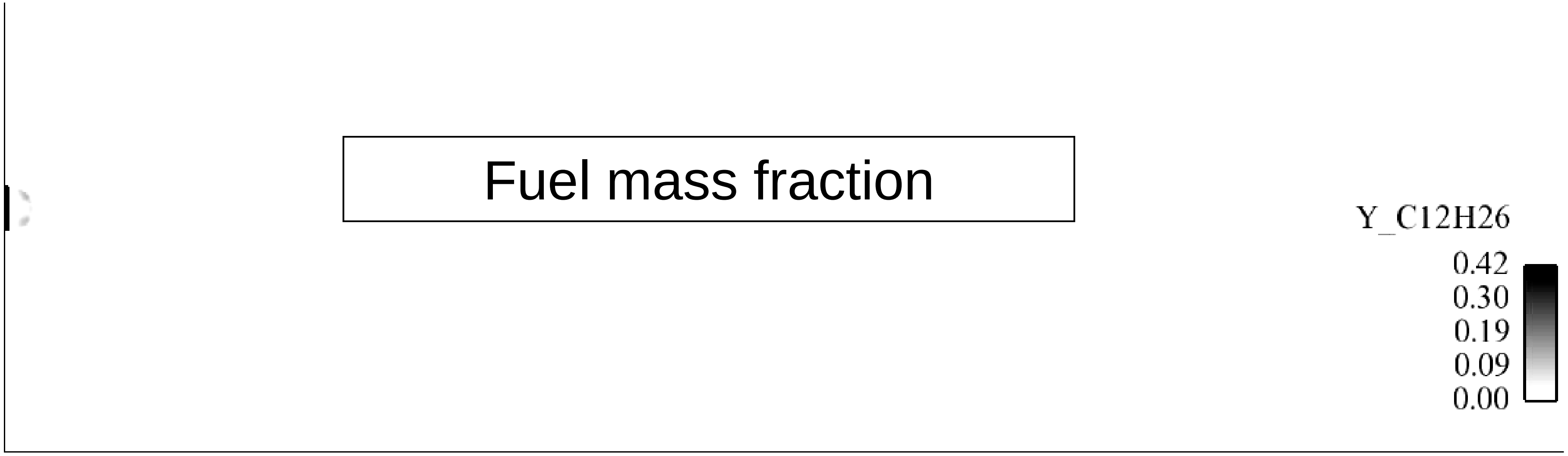


Vaporizing case (Tgas=800K,Pinj = 40MPa)

EE computation



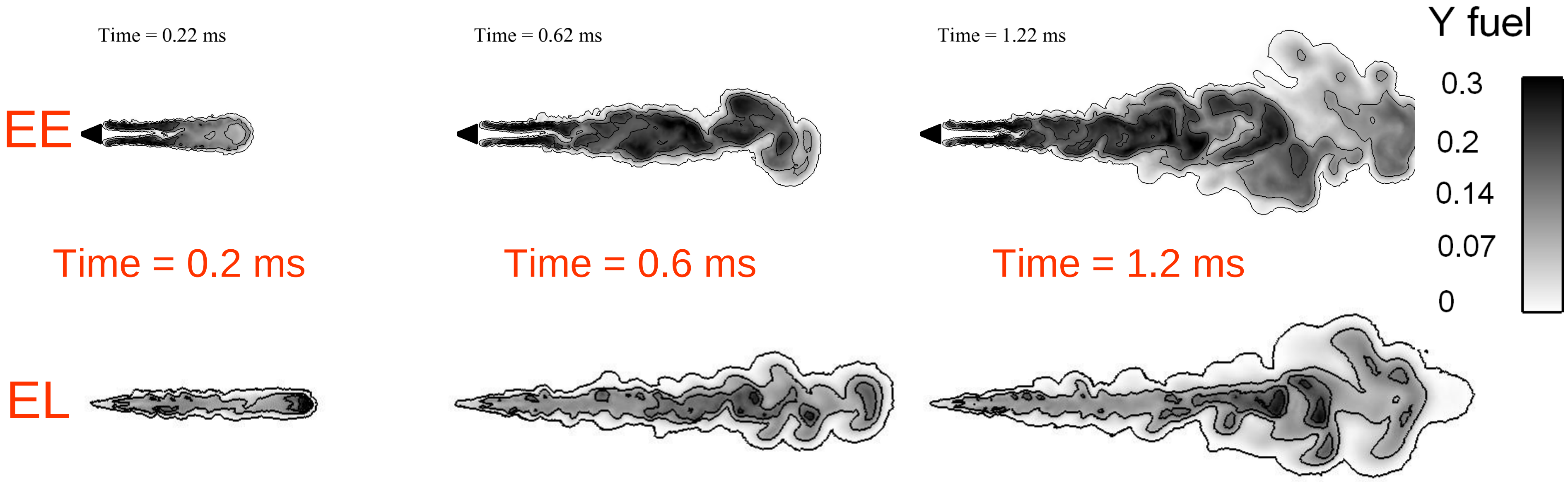
Liquid volume fraction = alpha_l



Fuel mass fraction

Vaporizing case (Tgas=800K,Pinj = 40MPa)

EE vs. EL results of vapor distribution

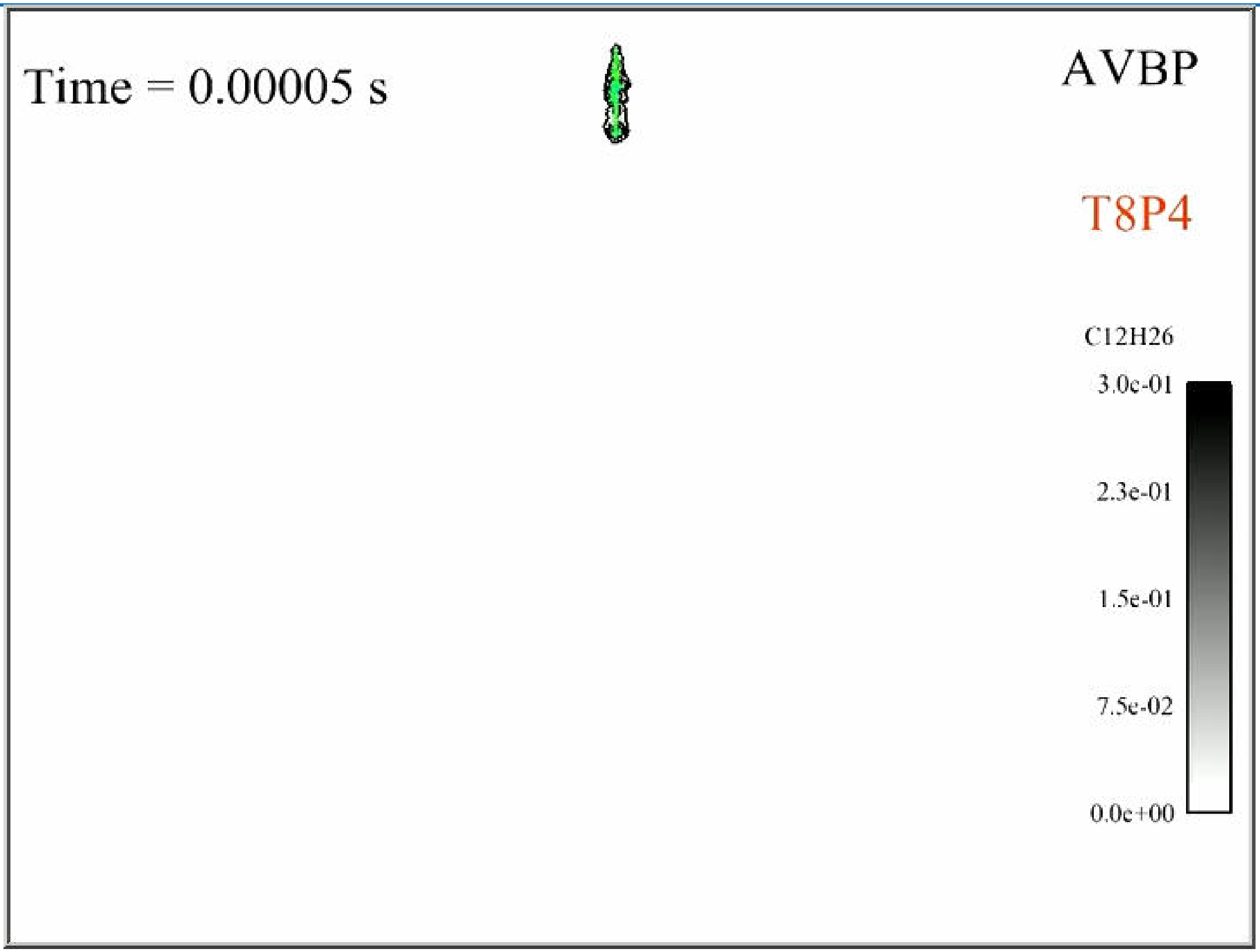


Iso-contours of mass fraction : 0.1 , 0.2, 0.3

- The vapor penetrations are similar but the vapor distribution seems to be very different.
- The initial shape of the spray is slightly modified by the EE injection model but this modification may affect the gas entrainment and the delay for the jet destabilization.

Vaporizing case (Tgas=800K,Pinj = 40MPa)

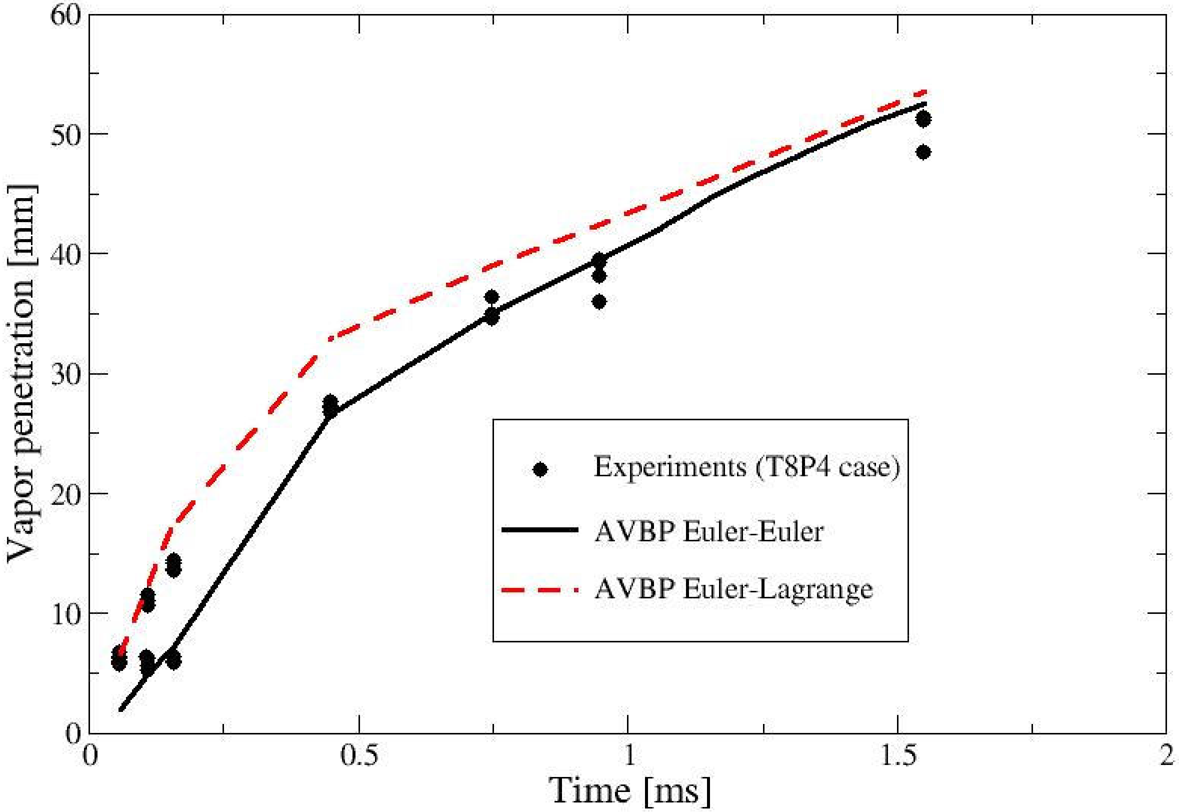
EL Computation -Vapor distribution and liquid spray



The detached clouds prevent the definition of precise liquid penetration.

Vaporizing case (Tgas=800K,Pinj = 40MPa)

EE vs EL Vapor penetrations



- Vapor penetrations are fairly well predicted for EE and EL computations
- The initial slope of the EL penetration better corresponds to the experiments but it is slightly overestimated.

EE vs. EL CPU time

	Non-evaporating case		Evaporating case	
model	EL	EE	EL	EE
CPU time (hr/ms/proc.)	3.7 (*0.3 M*) 10 (*1 M*)	5.5	5 (*0.3 M*) 11.8 (*1 M*)	6

Number of proc. (AMD 2.3 Ghz Barcelona) = 64

M : Million of parcels

Main advantages/drawbacks of the EE & EL approaches

- EE approach
  - + Same type of equations for liquid and gas phase
  - + Parallelism (Load balancing not an issue !)
  - +- Grid dependency (SGS models!)
  - - droplet crossing
  - - spray polydispersion (atomization, coalescence, ...)
  - - spray-wall interaction
- EL approach
  - + Well defined equations
  - + Easy to add more physics (atomization, collision, drag, ...)
  - + Wall interaction (bouncing, splashing)
  - - parallelism (load balancing !)
  - - grid dependency (seems to be less critical than in RANS)

Conclusions and future works (1)

- Different LES of non-vaporizing and vaporizing diesel sprays have been carried out using an Eulerian-Eulerian and Eulerian-Lagrangian approaches.

- Both approaches gave similar numerical results using dedicated injection models. However, the special grid used for the EE injector model may be difficult to generate in case of multi-hole injectors.

Conclusions and future works (2)

- The numerical results have been compared to available experiments. However, more validations are needed in the future.

- The EL model becomes slower than the EE model when the number of injected parcels is greater than ½-Million. This preliminary conclusion has to be checked especially when both EE and EL models would be more mature (including polydispersion and atomization models).

Innovating for energy

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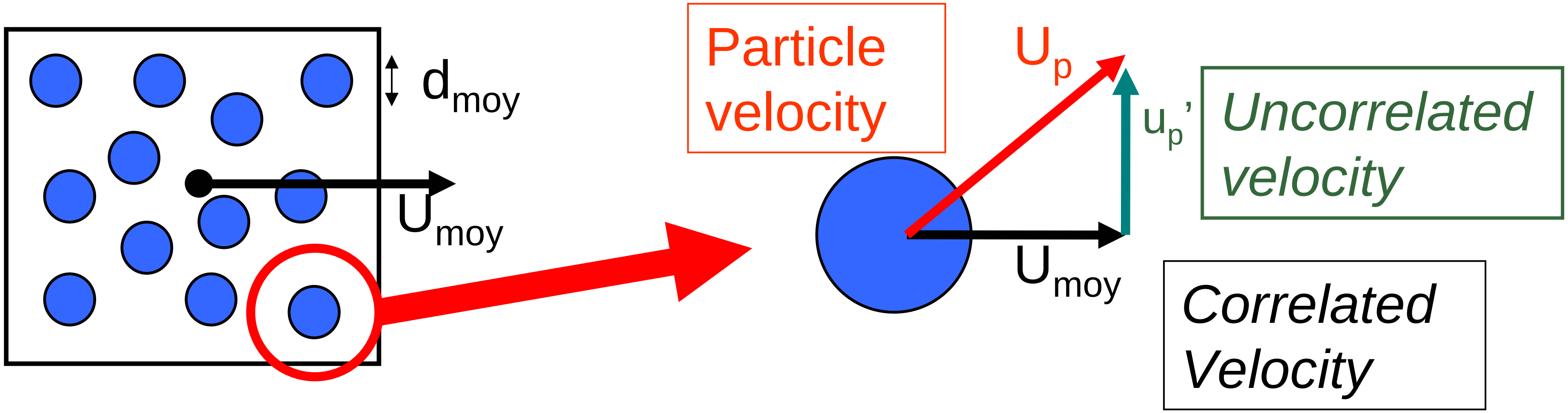
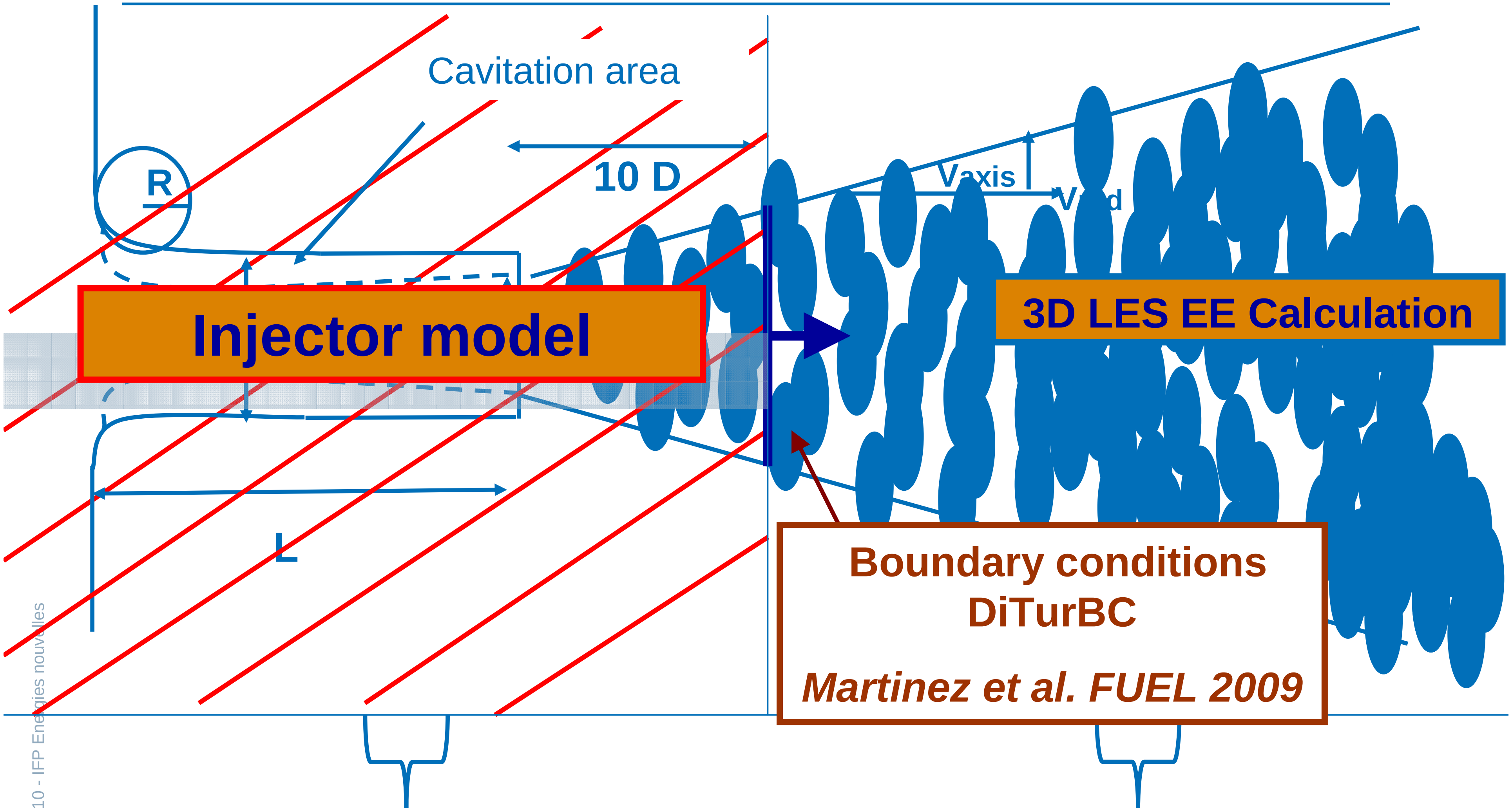
Correlated and Uncorrelated Motions



- **Stress tensor in liquid momentum equation**
- **Transport of Uncorrelated Energy**

- **Collision model inspired from kinetic theory :**
  - *Jenkins and Richman, Arch. Ratio. Mech. Anal.(1985)*
  - *Boëlle et al., ASME (1995)*
  - *Peirano and Leckner, Prog. in Ener. and Comb Sci. (1998)*
  - *Vié - ICLASS 2009*

Methodology for EE Diesel injection



Injector model

3D LES EE Calculation

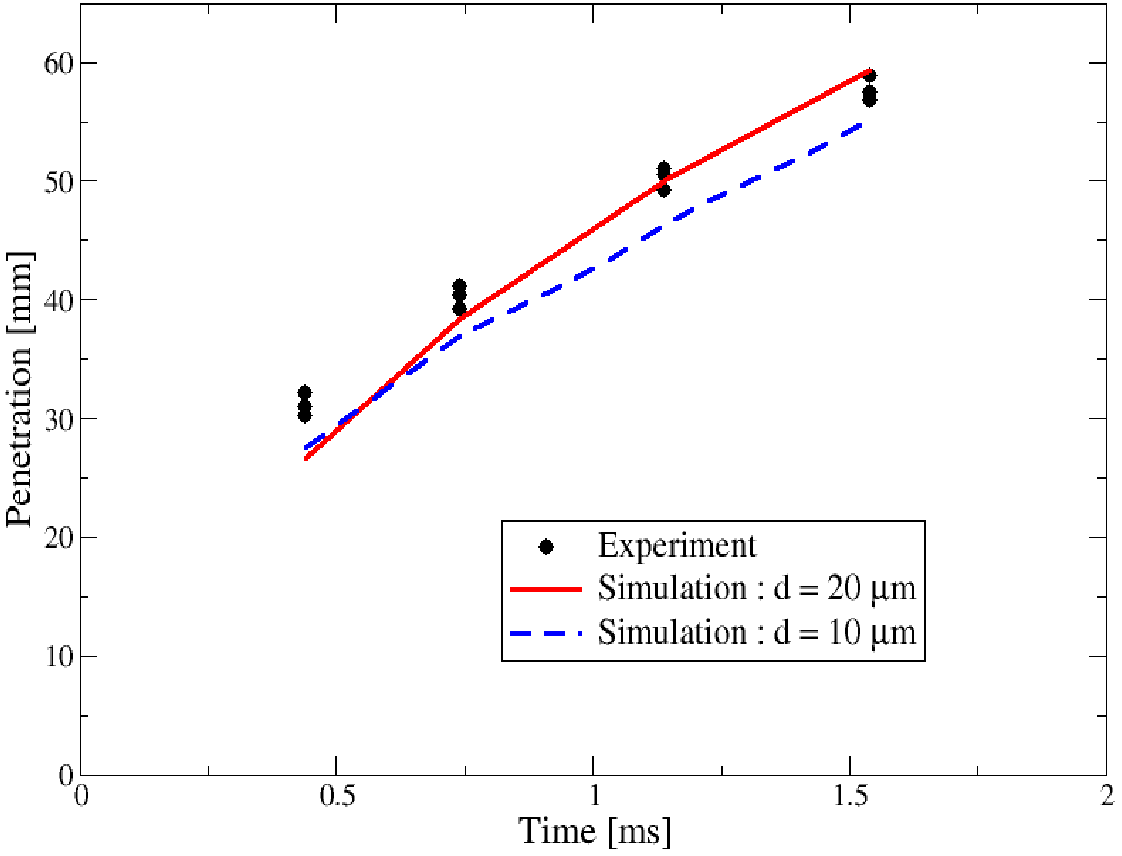
Boundary conditions
DiTurBC

Martinez et al. FUEL 2009

Near nozzle exit

Far from nozzle exit

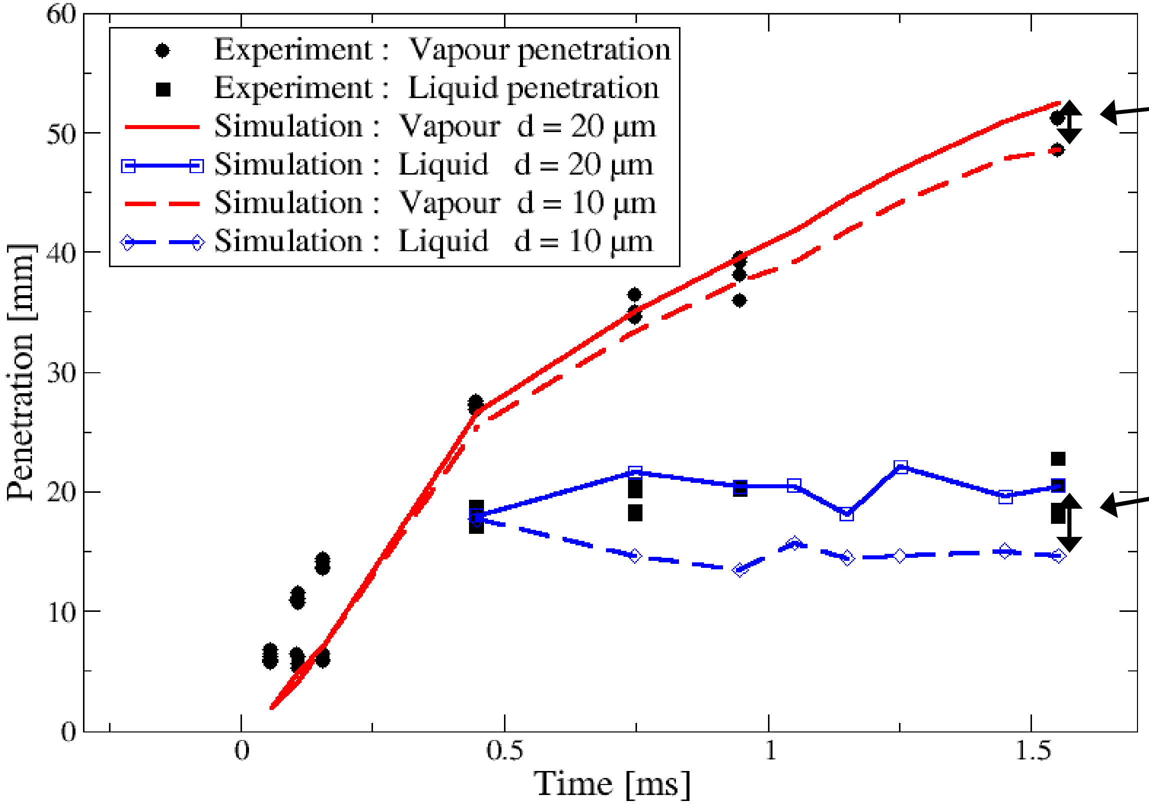
Non-vaporizing cases: Liquid penetration Pinj = 40 MPa



- **Very good results for all cases:**
  - **Same grid**
  - **Same numerical parameters**

Vaporizing case: liquid and vapour penetration – Influence of inlet droplet diameter

Pinj = 40 MPa T = 800 K



Weak influence of injected droplet diameter on gas penetration

Greater influence of injected droplets diameter on liquid penetration

- Maximum injected droplet diameter :

—— 20µm — — — 10µm

Grid dependency - Pinj = 40 MPa

Fine mesh

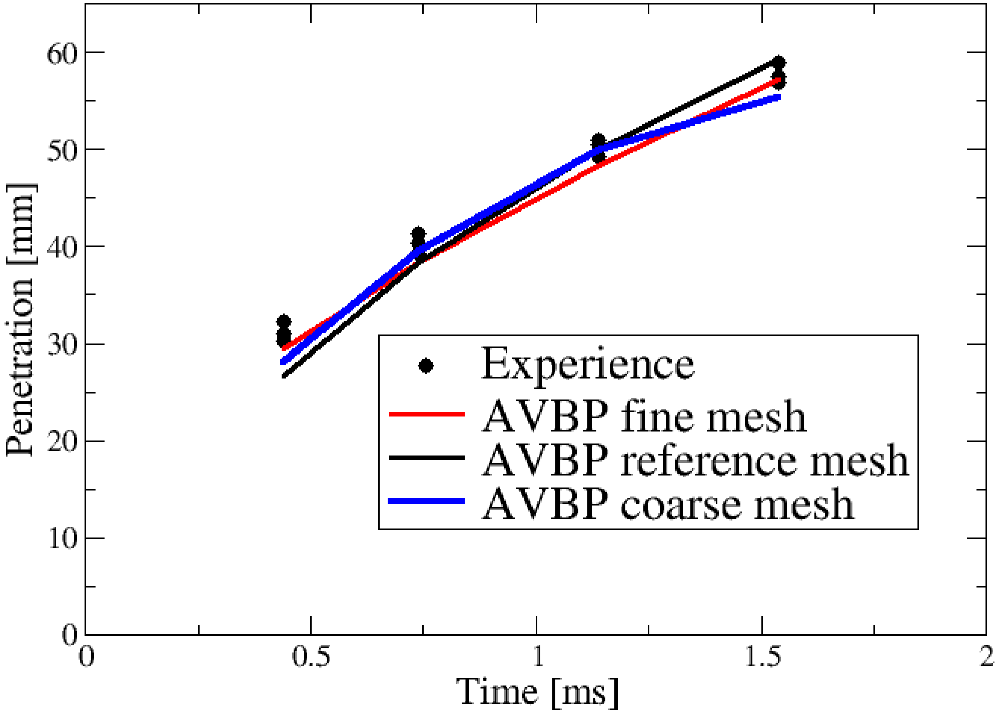
Delta= 0.7

Reference mesh

Delta= 1

Coarse mesh

Delta= 1.2



- **Weak grid dependency**

Delta: normalised characteristic edge length

Vaporizing case (Tgas=800K, Pinj = 80MPa) EL computation