ISTITUTO MOTORI
Consiglio Nazionale delle Ricerche

Droplets size and Velocity Measurements in a Diesel Spray from a Common Rail Injection System

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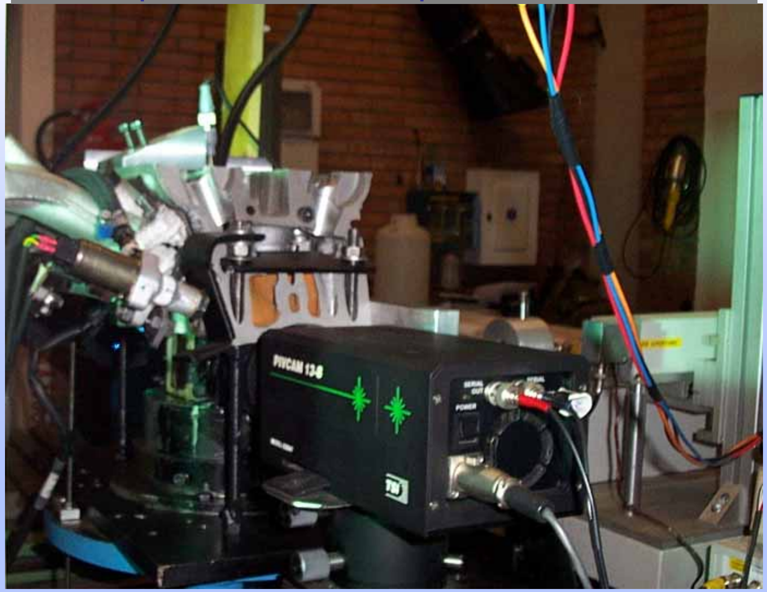
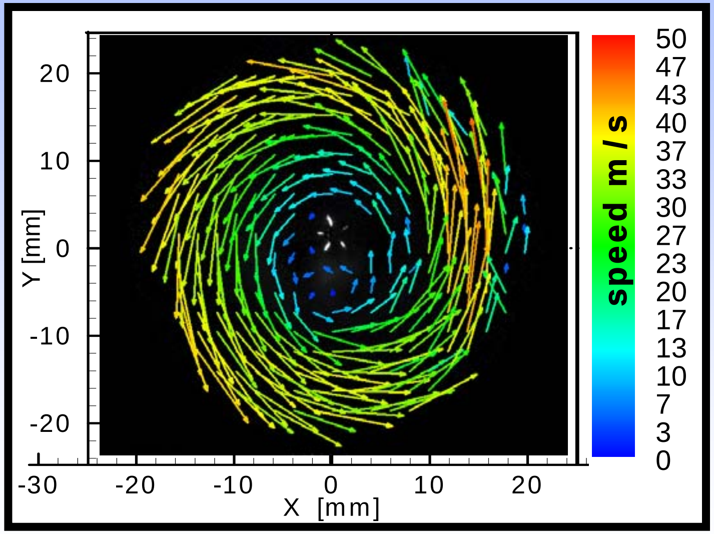
PRESENTATION OUTLINE

PIV Experimental Setup at Istituto Motori





Investigation of Diesel jet from a common rail injection system for engines applications

- Motivation and target of investigation
- Experimental setup for PDA Tests
- Discussion of Size and Velocity Results
- Conclusions and Future Work

MOTIVATION AND TARGET OF SPRAY INVESTIGATION

The fundamental mechanism of atomization has been under extensive experimental and theoretical study for many years and reviews have been provided by many researchers that also have developed different sub-models to compute the diesel spray combustion in internal combustion engines.

In spite of the importance of atomization of diesel jet for engines the mechanism still needs deeper understanding because of the difficulty to provide the necessary drop size, velocity and trajectory data at the injector nozzle exit for the modeling of the spray. The atomization also has a strong influence on the spray vaporization rates because it increases the total surface area of liquid fuel.

The application of optical diagnostics (PIV, PDA, 2D Image, LIF) can provide velocity distributions, droplets size, fuel trajectories and spray morphology, as well vapor distribution to supply the experimental database for air motion, turbulence and for advanced spray modeling development.

MOTIVATION AND TARGET OF SPRAY INVESTIGATION

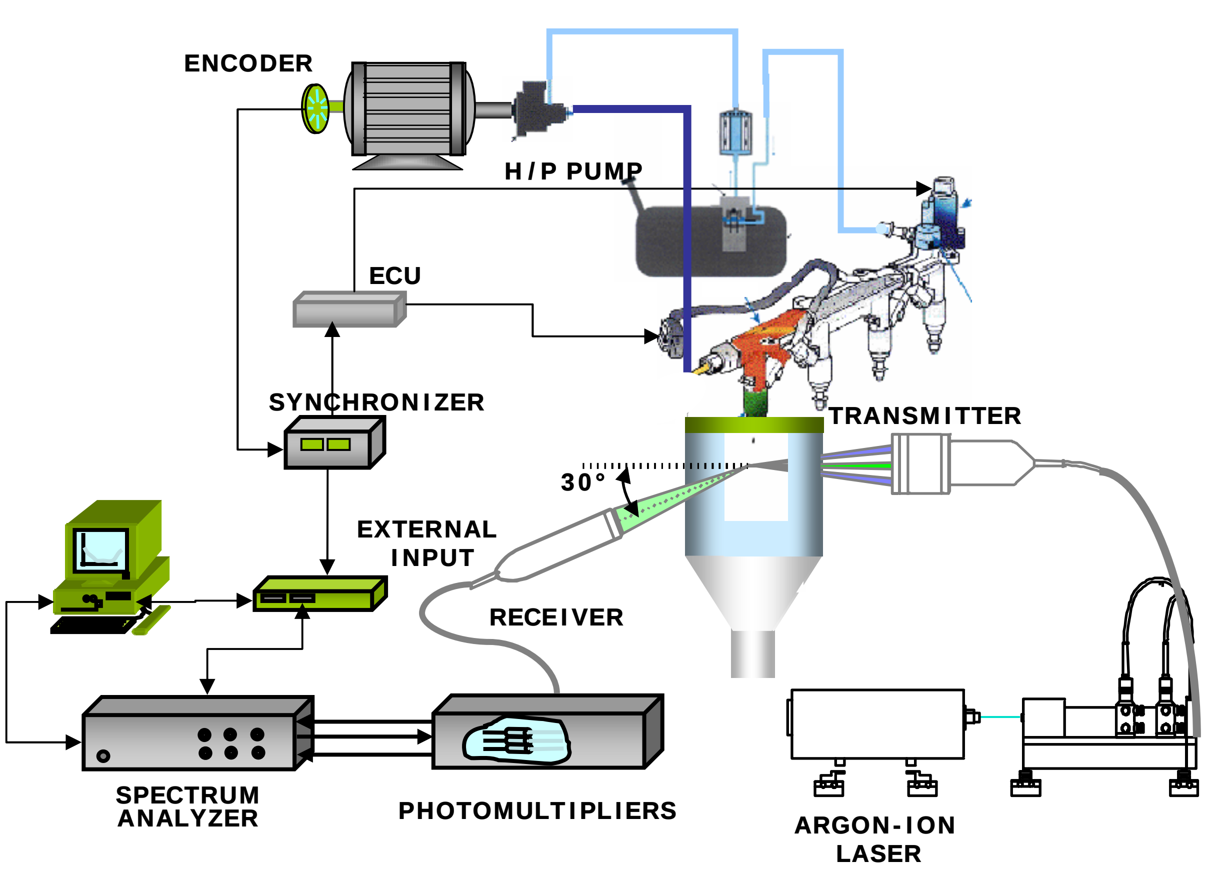
The aim of this work is to characterize the structure of a fuel spray generated by a common rail injection system for light duty diesel engines, able to manage multiple injection strategies.

- Applying the Phase Doppler Anemometry technique, liquid droplets size and axial velocity distribution has been estimated for a triple injection strategy spraying the fuel in an optically accessible vessel at ambient temperature and atmospheric pressure under quiescent conditions.

The common rail injection system has been equipped by:

- electro-hydraulic controlled injector
- micro-sac nozzle
- 5 hole, 0.13 mm diameter
- 150° spray angle
- flow rate of 270 cm^3/30s@10 MPa.

EXPERIMENTAL SET-UP & OPERATIVE CONDITIONS



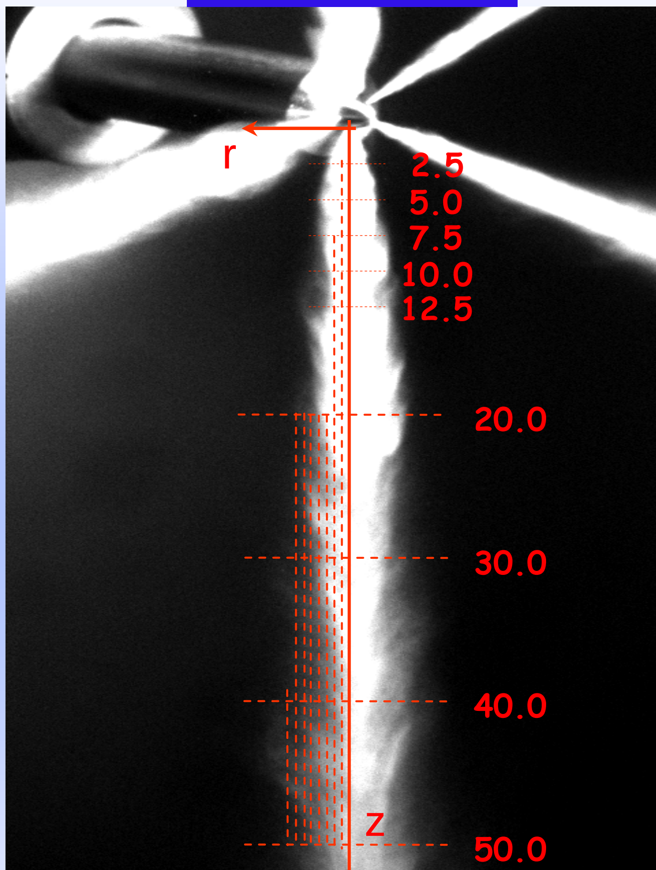
A two channel phase Doppler analyzer system is used to acquire, simultaneously, droplets size and the axial component of droplets velocity

PDA System:

- Argon-ion laser operating at 514.5 nm.
- A 310 mm focal length transmitting optics with a beam separation of 65mm
- A modular collecting optics working in forward scattering mode at an off-axis of 30°.
- A synchro-unit device, driven by an optical encoder connected to the pump shaft, to trigger the ECU of the injection system and the PDA processor
- Tests have been taken over 300 injection cycles with a time resolution of 20 μs.

EXPERIMENTAL SET-UP & OPERATIVE CONDITIONS

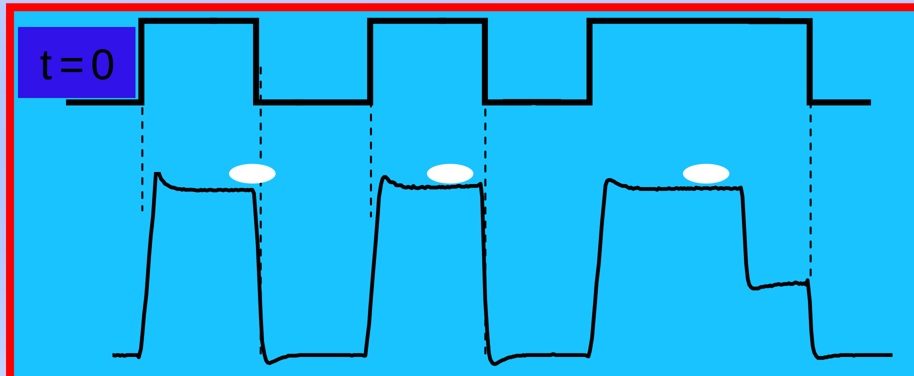
PDA Test grid

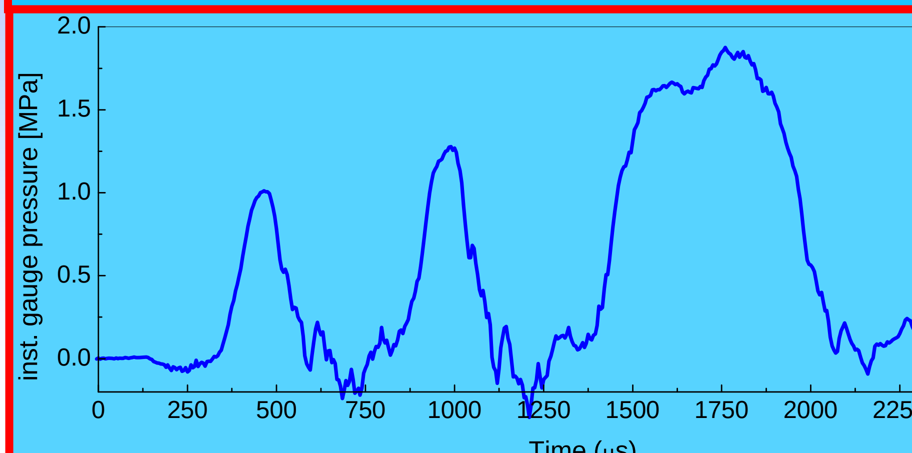


PDA Measurements:

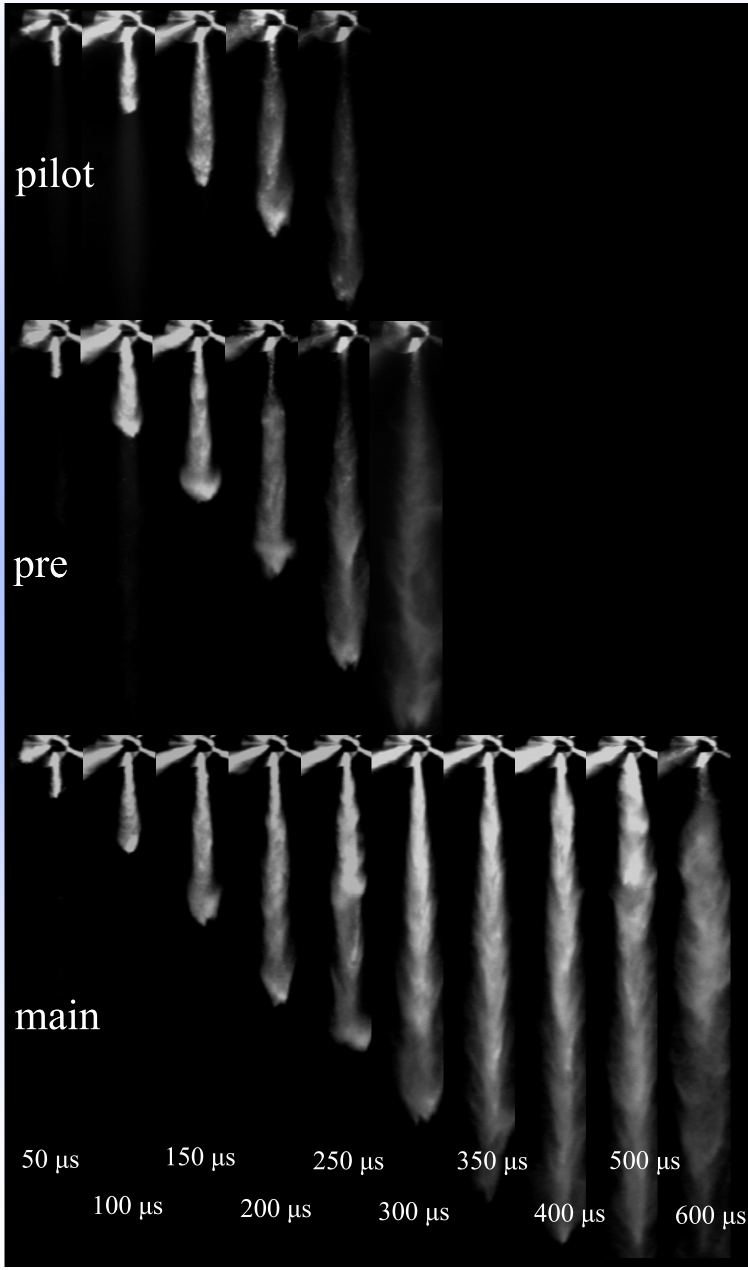
- Different locations from the nozzle and along the spray axis up to the border
- The radial step was $\Delta r = 0.5$ mm

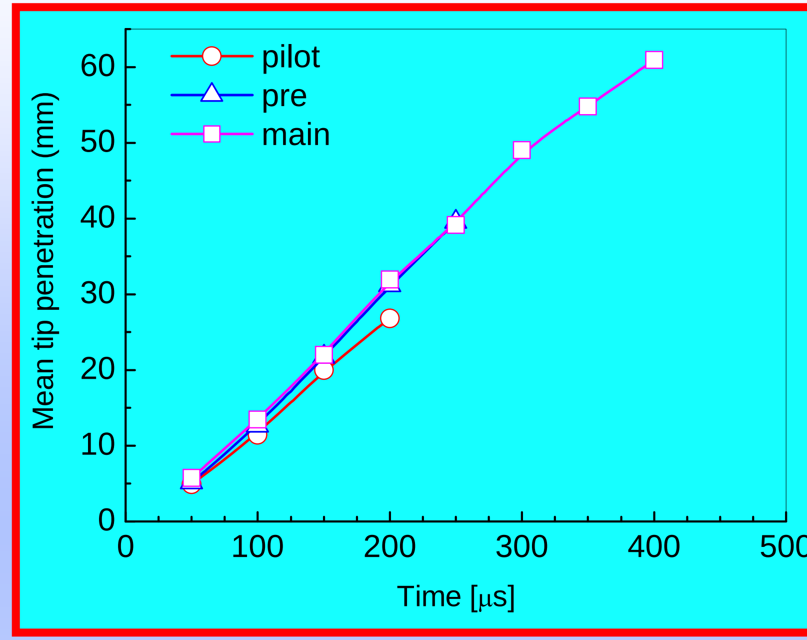
INJECTION STRATEGY				
Pinj=71 [MPa]	**Pilot [μs]**	**Pre [μs]**	**Main [μs]**	**Dwell [μs]**
dt [μs]	270	275	515	230
Injected fuel [mg/str]	1.65	2.06	8.51	
	Total fuel 12.22 mg			





SPRAY IMAGING AND TIP PENETRATION RESULTS

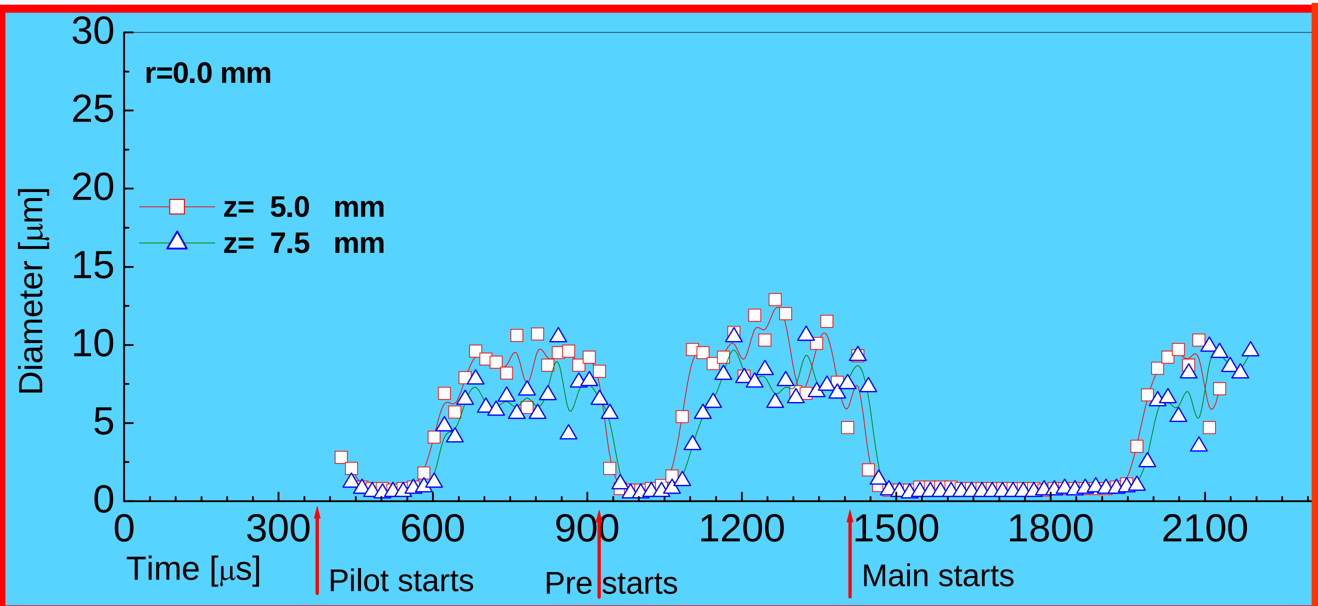


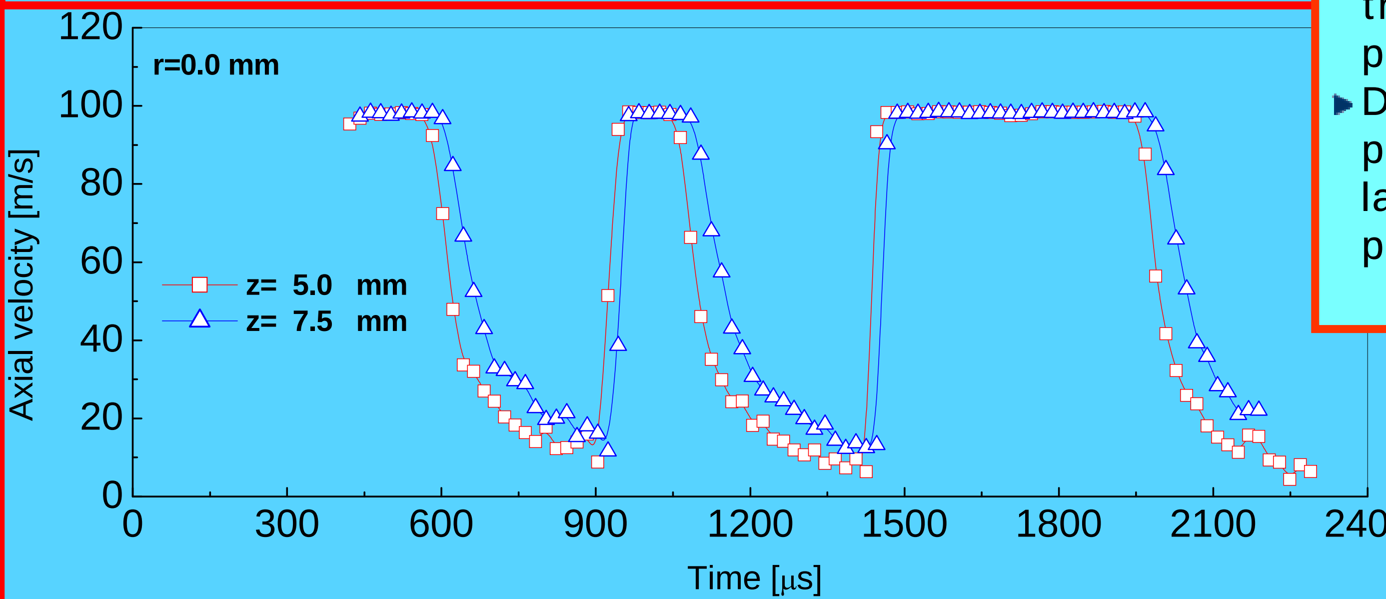


INJECTION STRATEGY				
Pinj = 71 [MPa]	**Pilot [µs]**	**Pre [µs]**	**Main [µs]**	**Dwell [µs]**
dt [µs]	270	275	515	230
Injected fuel [mg/str]	**1.65**	**2.06**	8.51	
	Total fuel 12.22 mg			

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Droplets size and velocity at the spray axis [R=0 mm]



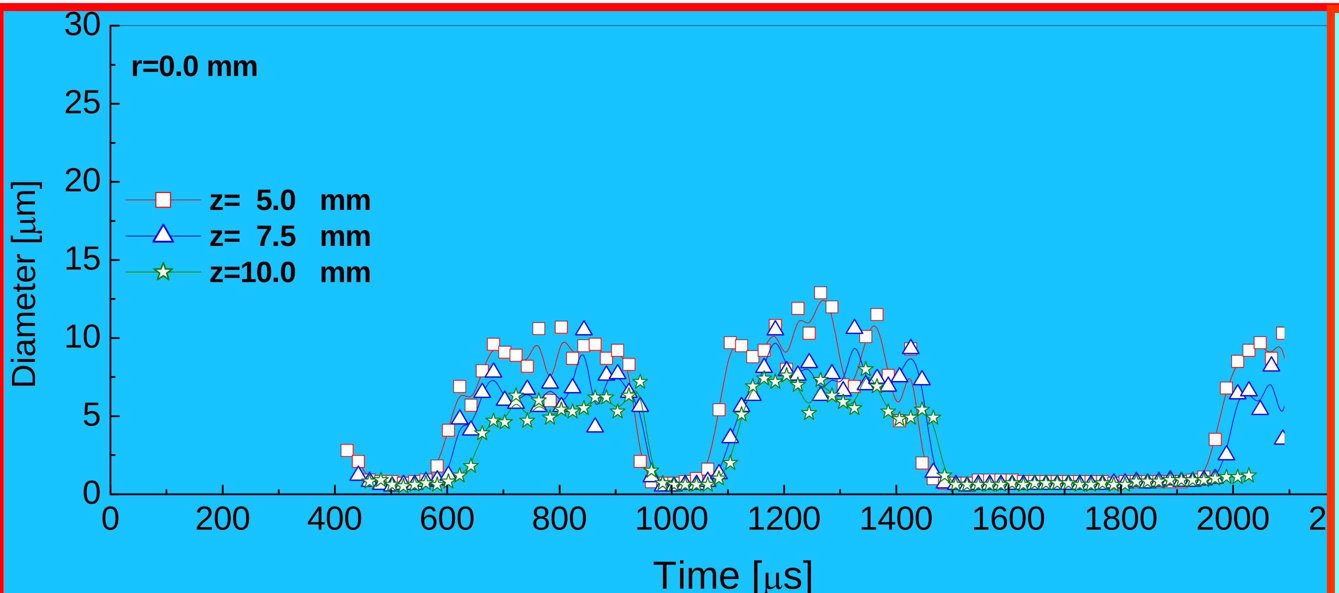


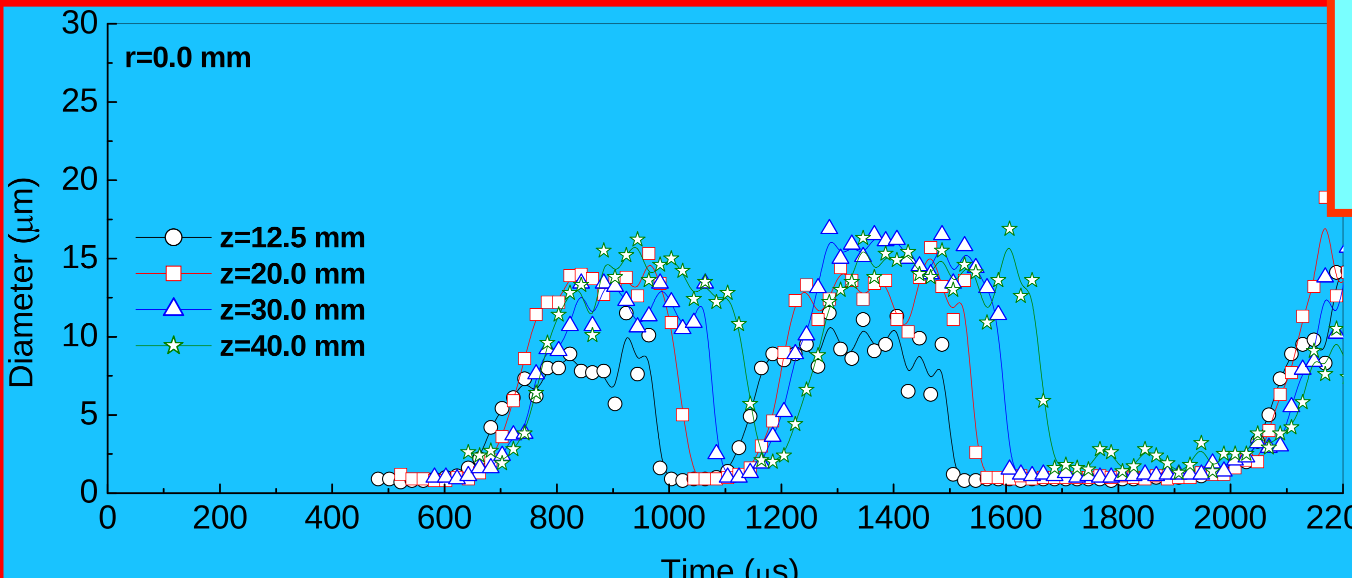
Main results:

- At 5 mm from the nozzle the jet is already atomized with small droplets of about 1-2 micron that travels up to 100 m/s
- Profiles of diameter and axial velocity have a flat behavior during the needle steady phase and a rapid increase of the axial velocity during the transient needle opening phase.
- During the transient phase of the needle lift larger droplets are produced.

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Near and far field droplets size at the spray axis [R=0 mm]



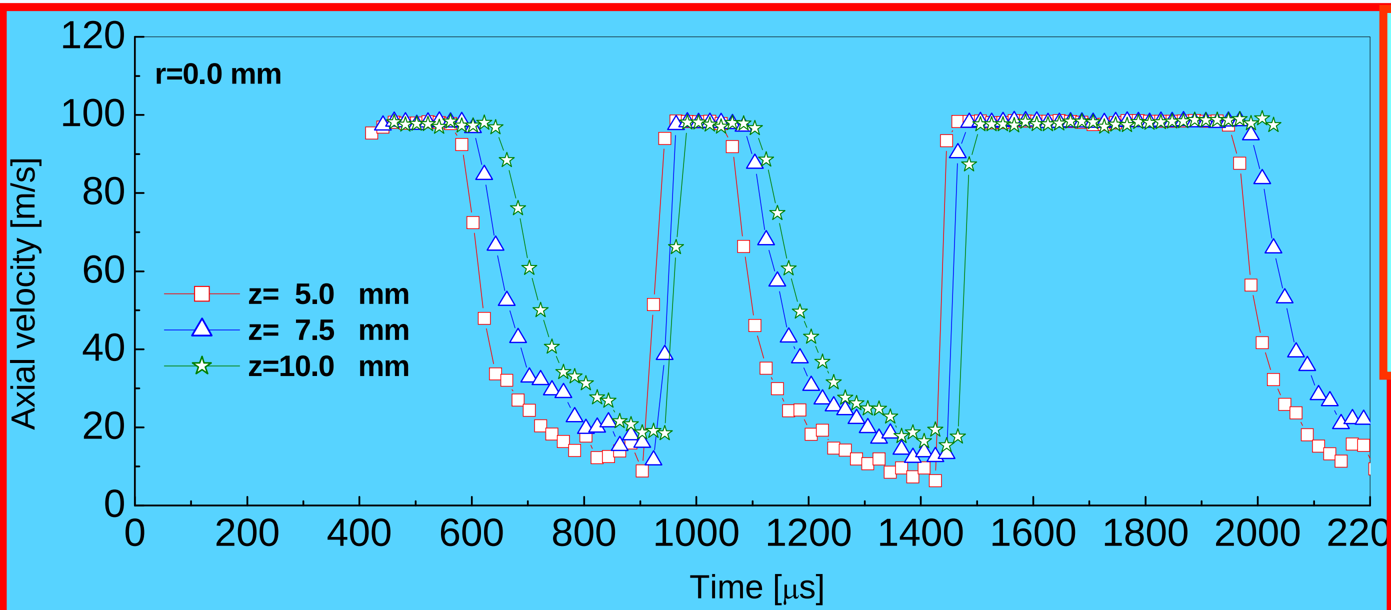


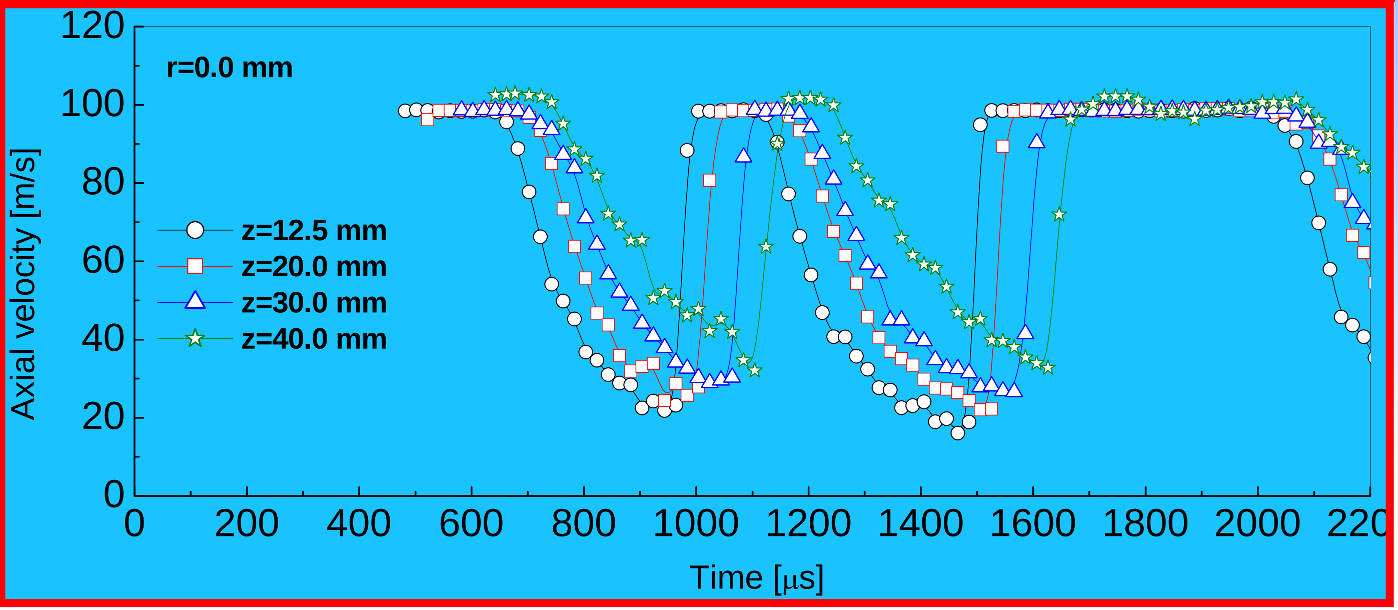
Main results:

- Along the spray axis, in the near field region (up to 10 mm from the nozzle), the droplets diameter shows a slight decreasing trend. This behavior may be due to the occurrence of the atomization process that is still proceeding.
- Moving away from the nozzle the bigger droplets disappear so confirming that they are confined at the spray border

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Axial velocity at the spray axis [R=0 mm]



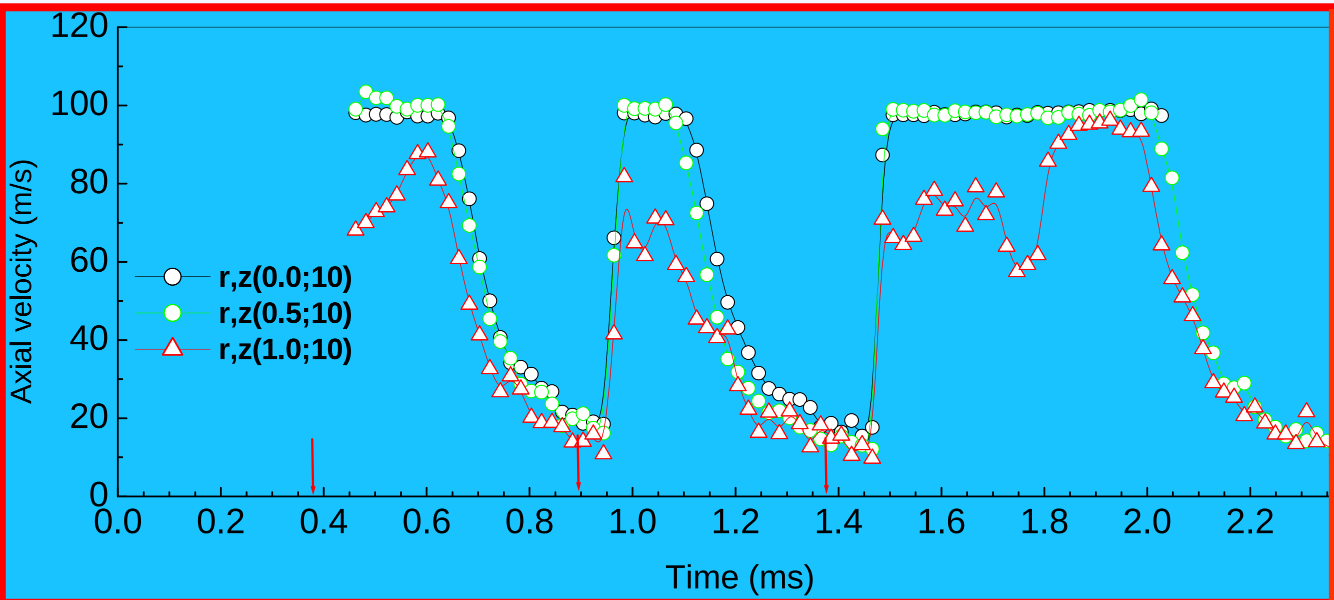


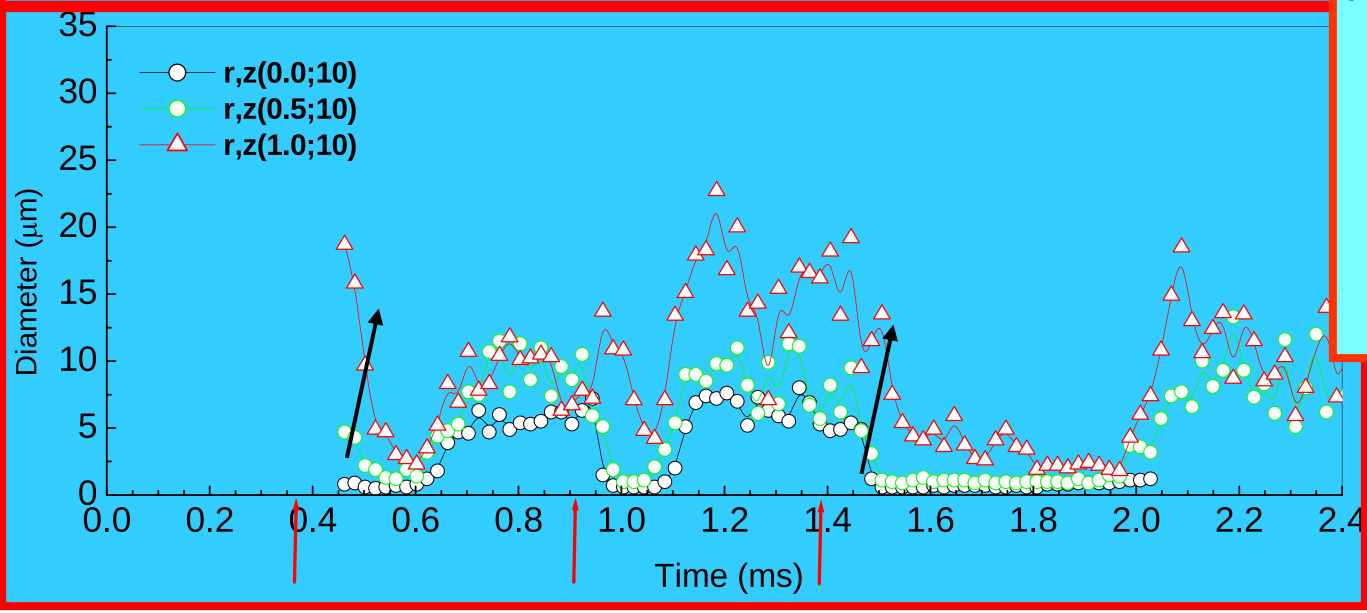
Main results:

- Along the spray axis the axial velocity shows an uniform field both in the near as well in the far field of the spray.

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=10 mm from the nozzle



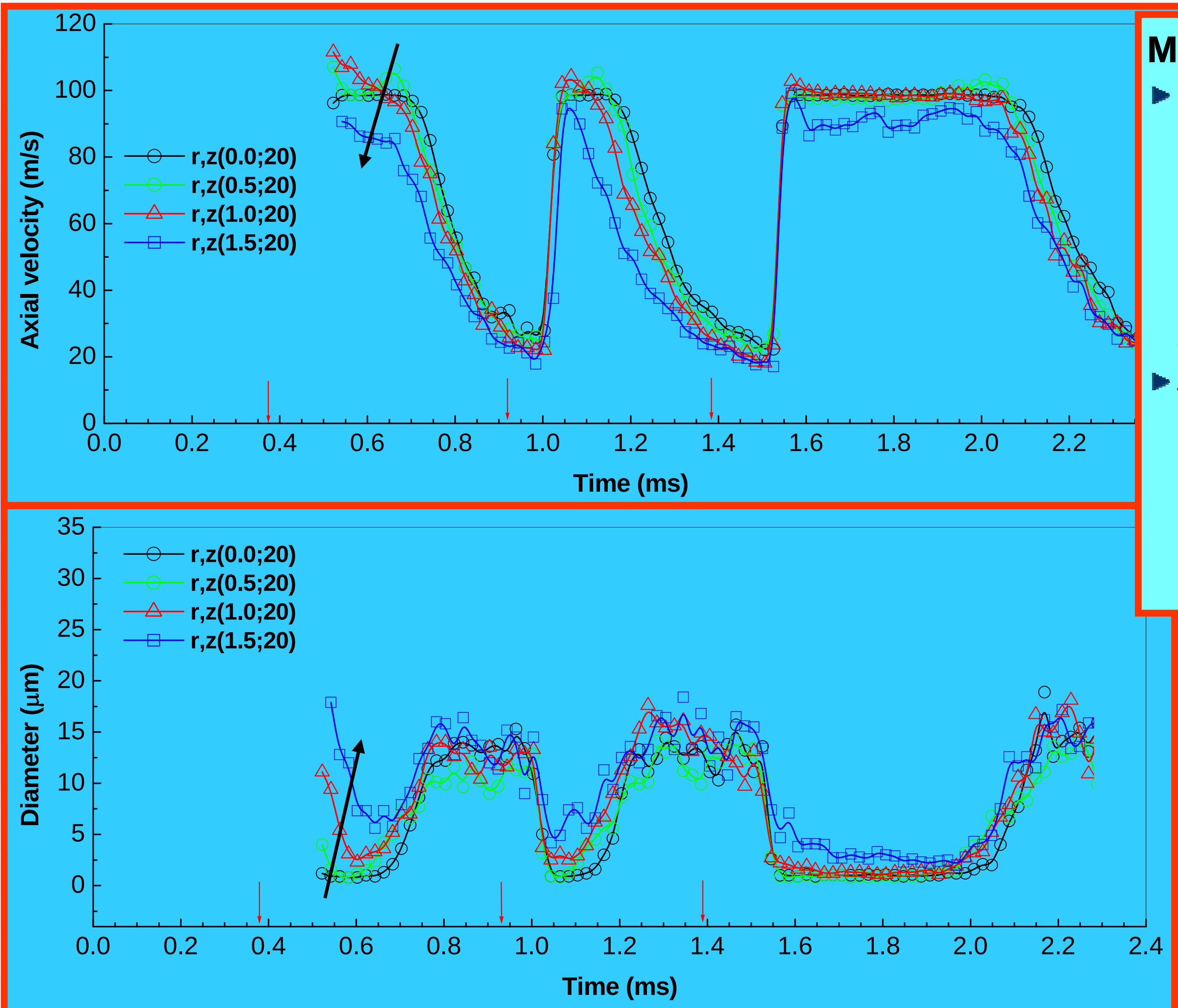


Main results:

- Locations farther from the spray axis give bigger droplets during the transient needle lift phase with mean diameter up to 20 microns at r=1mm
- This behavior is confirmed for the pilot, the pre, as well the main injection.
- During the opening transient stage of pilot injection the larger droplets travel at lower axial velocity pushed to the spray periphery by the jet momentum

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=20 mm from the nozzle

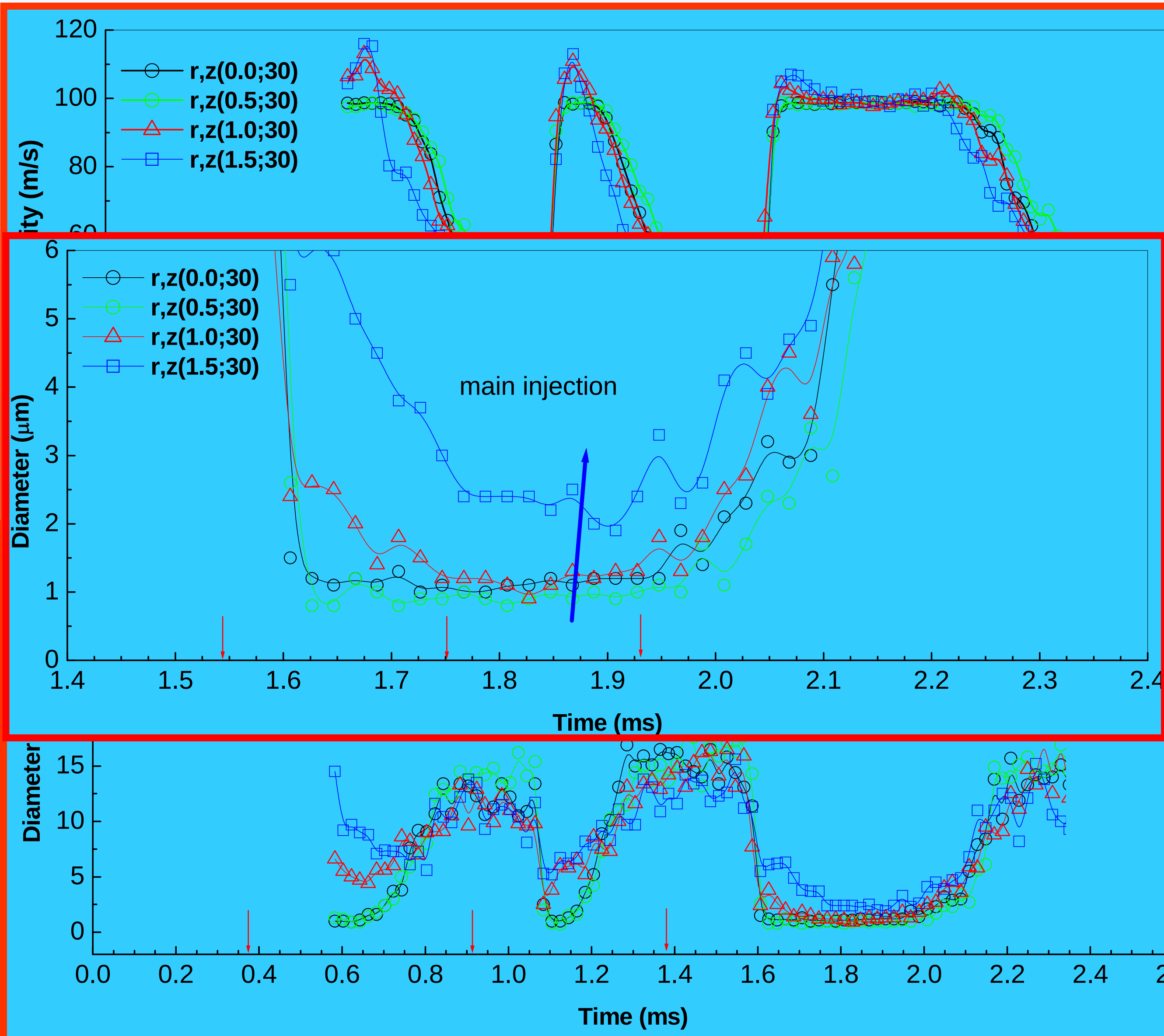


Main results:

- Same trend as that observed at 10 mm from the nozzle with bigger droplets during the transient needle lift phase increasing along the spray axis
- An opposite trend was observed for the axial velocity that shows the highest values close to the spray axis.

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=30 mm from the nozzle

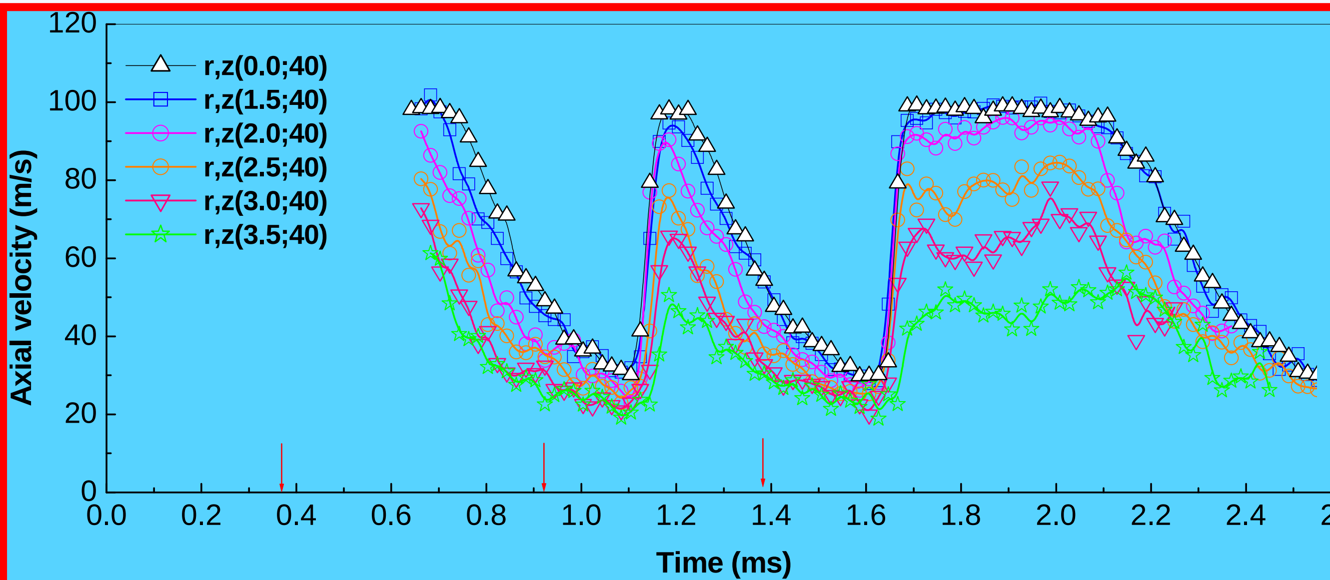


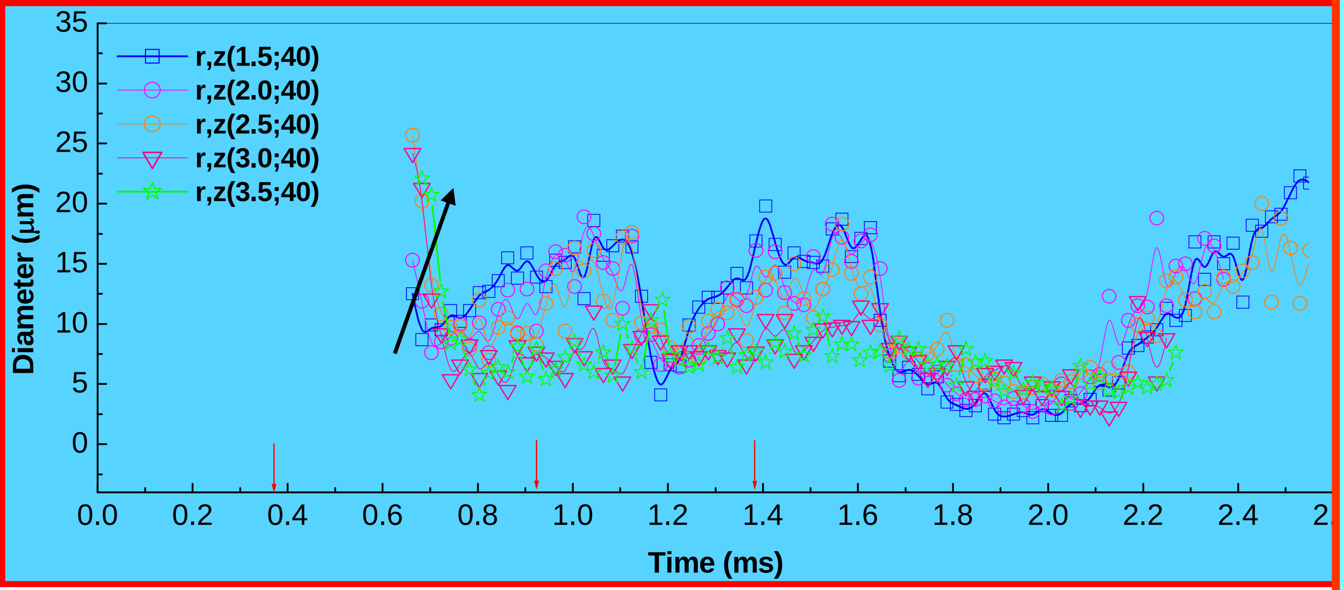
Main results:

- Locations at higher distances from the nozzle produces the same behavior for droplets diameter and axial velocity
- Droplets diameter collected during the steady state stage of the mean injection exhibits an increasing trend along the spray axis ranging from about 1 micron to 2.5 micron.
- Droplets size results also give the same trend as that observed at 10 mm from the nozzle, with bigger droplets produced during the transient needle lift phase with an increasing trend along the spray axis

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=40 mm from the nozzle



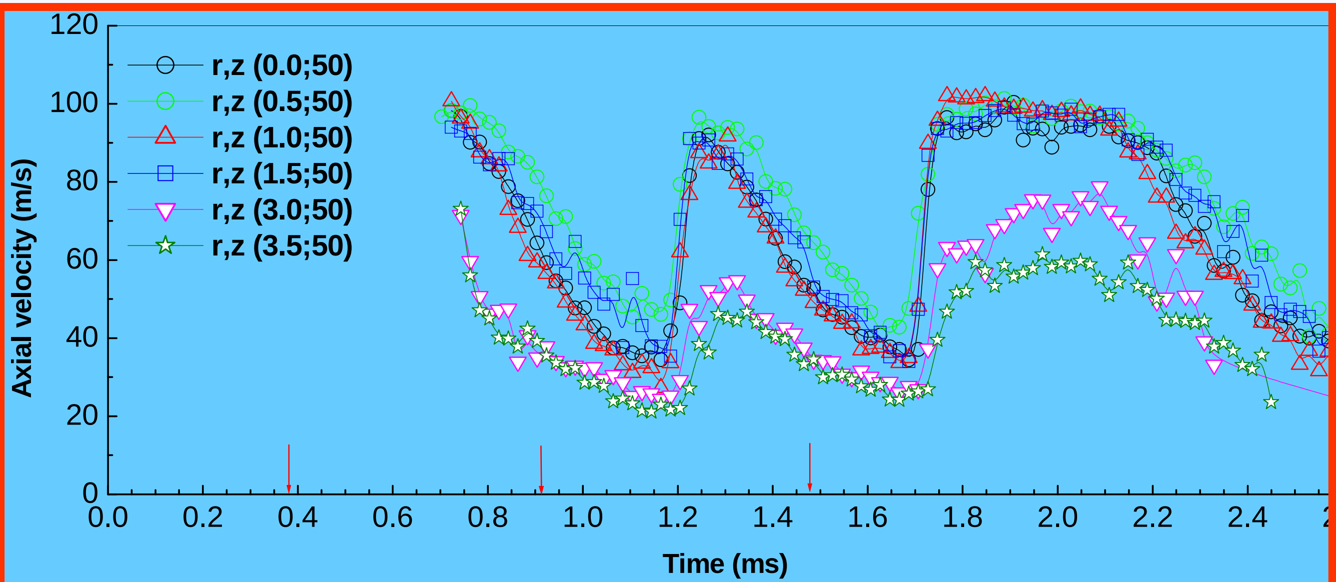


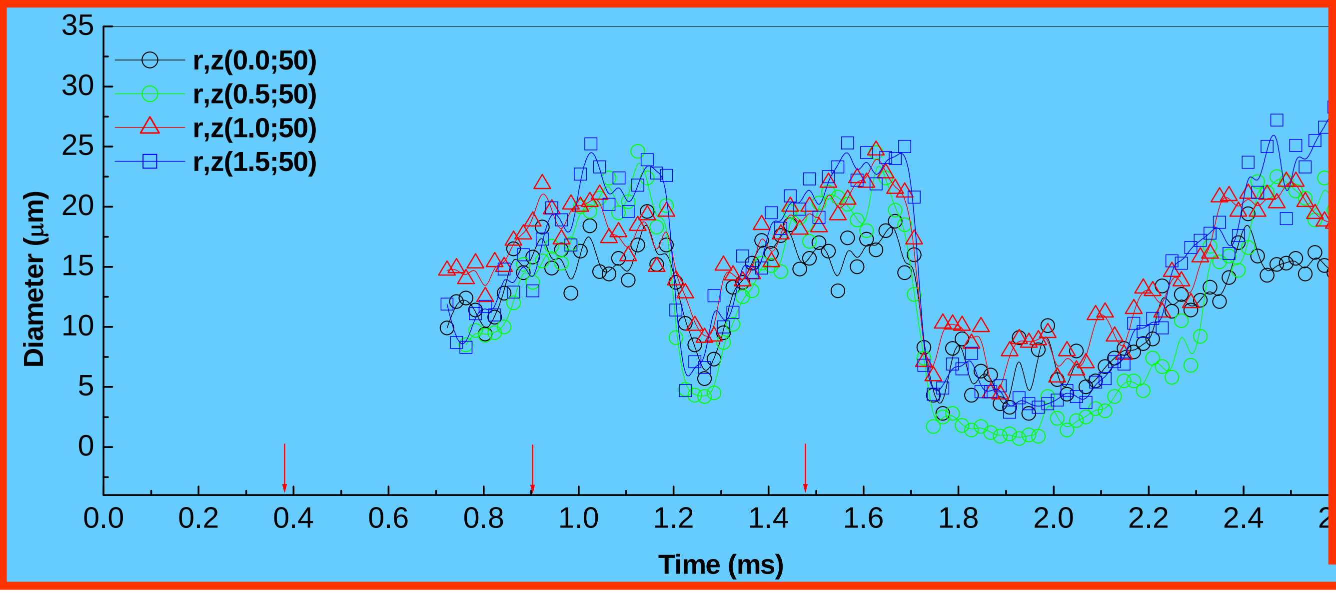
Main results:

- Locations at higher distances from the nozzle produces the same behavior for droplets diameter and axial velocity although a higher fluctuation of the diameter profiles is observed
- Droplets diameter, collected during the steady state stage of the mean injection, exhibits an increasing trend along the spray axis ranging from about 4 micron to 7 micron.
- The axial velocity profile starts to reduce its value with a more rapid trend along the spray axis also during the steady state part of injection

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=50 mm from the nozzle



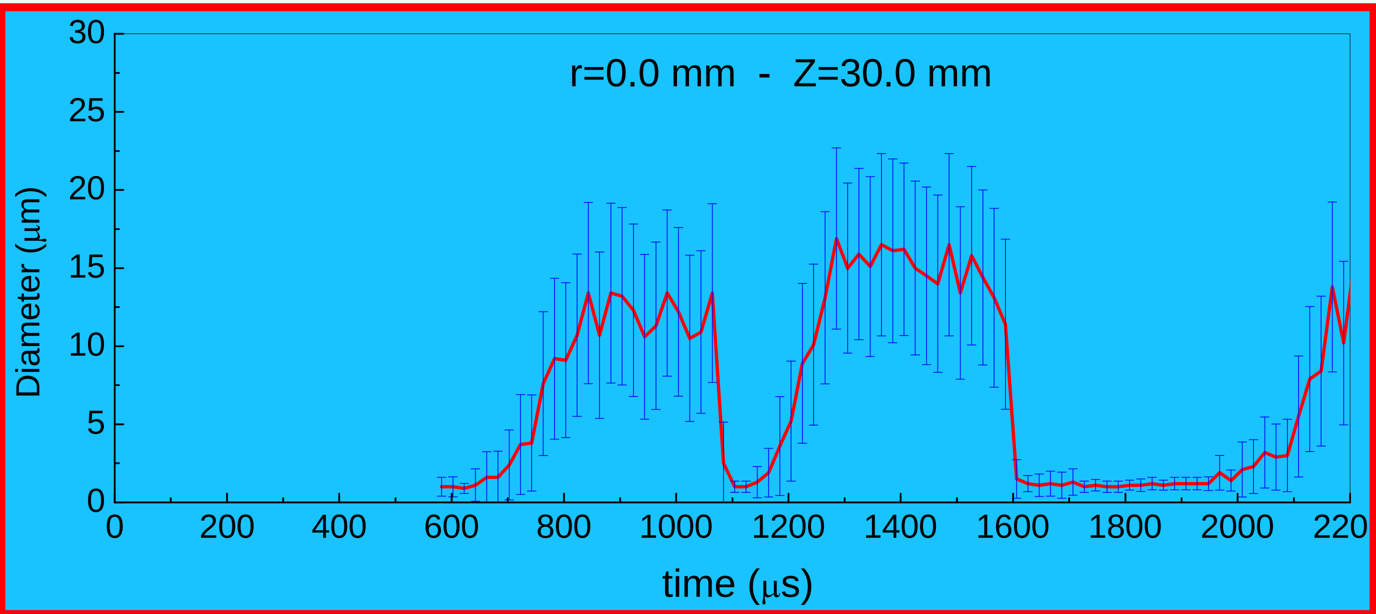


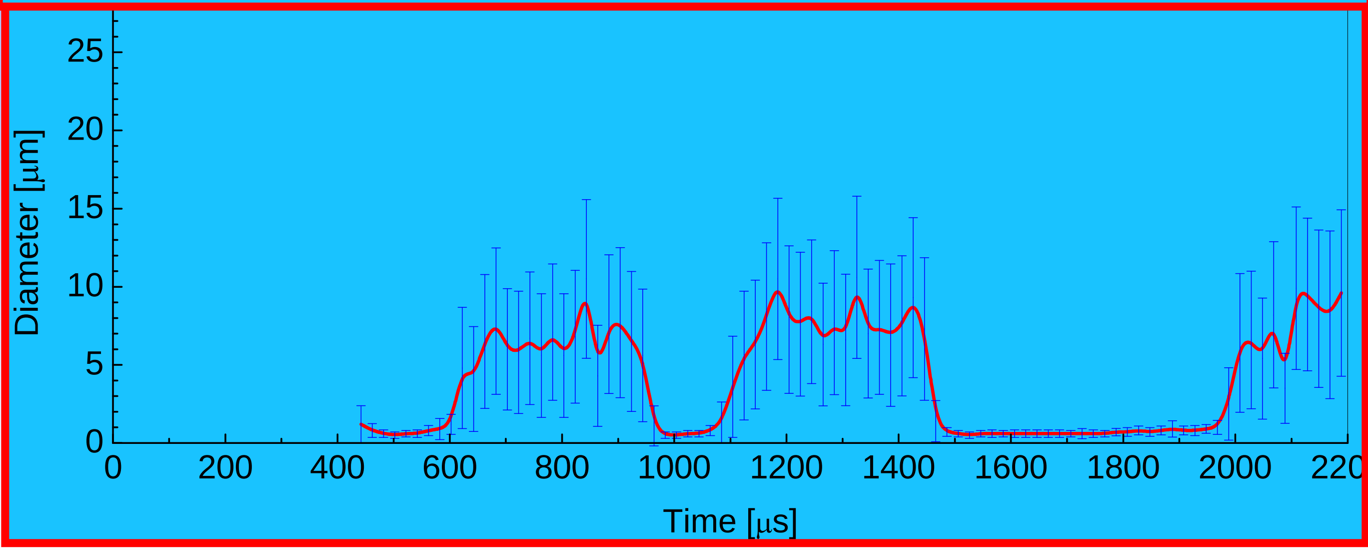
Main results:

- Locations at higher distances from the nozzle produces the same behavior for droplets diameter and axial velocity although a higher fluctuation of the droplets size profiles is observed
- Droplets size diameter collected during the steady state stage of the mean injection exhibits an increasing trend along the spray axis ranging from about 2 micron to about 10 micron.
- The axial velocity profile starts to assume a decreasing trend along the radial location also during the steady state part of injection

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

R=0.0 mm Z=7.5 mm





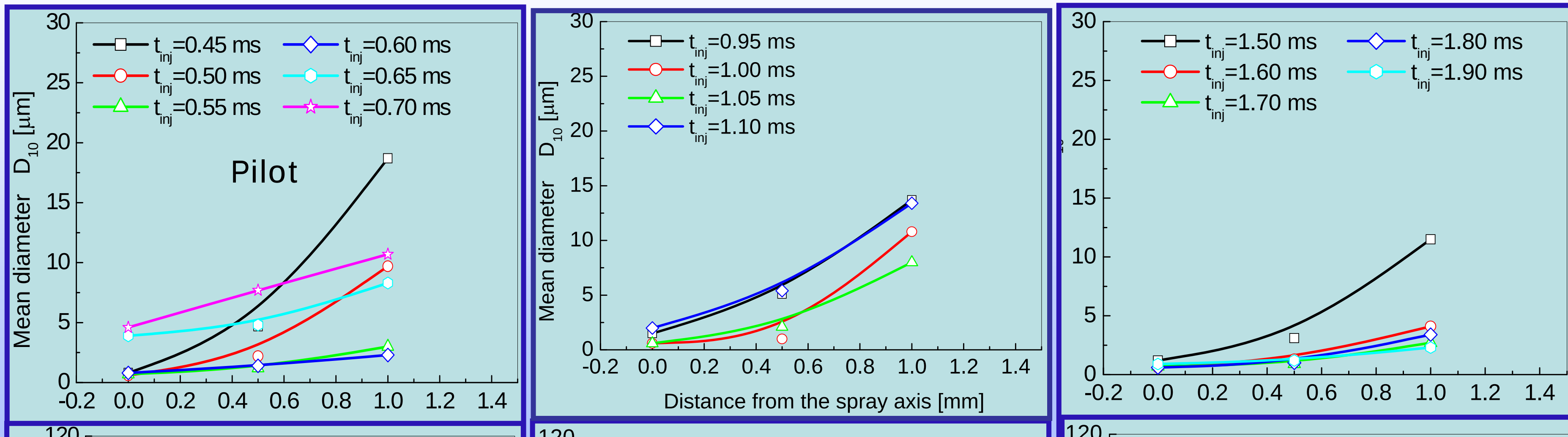
ata scattering:

Data collection has shown a very narrow dispersion during the steady-state stage of injection

During the transient working phase of the nozzle a wide scattering of date has been provided

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=10 mm from the nozzle

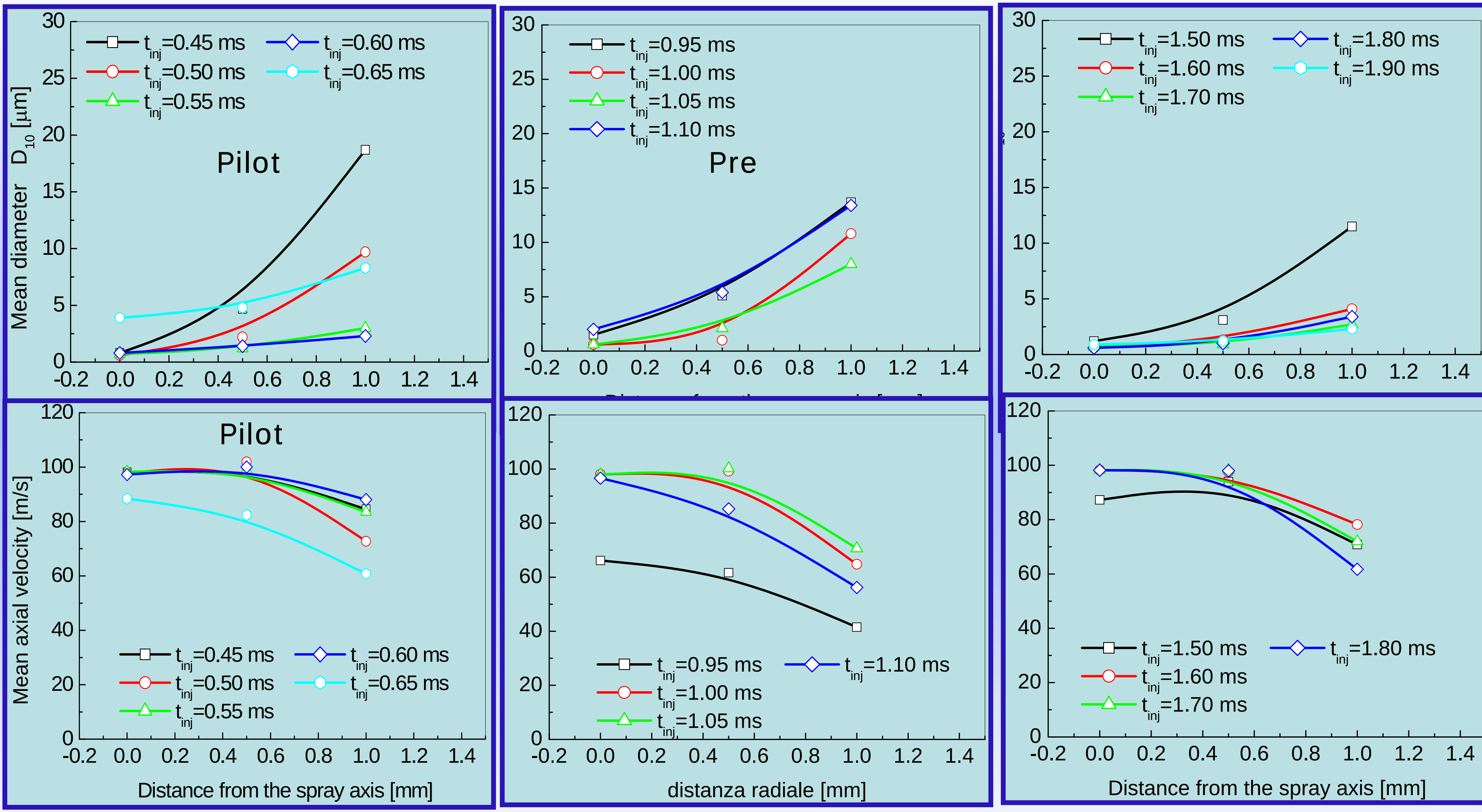


The droplets diameter in the near field shows increasing values along the spray axis with a fast slop during the early stage of the process. Following outward the spray, the droplets diameter increases rapidly up to a maximum value of 20 µm during the transient needle opening and closure phase

The plot relative to the main injection points out an uniform jet structure during the steady state phase with a diameter profile almost constant if compared to the non-stationary period.

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

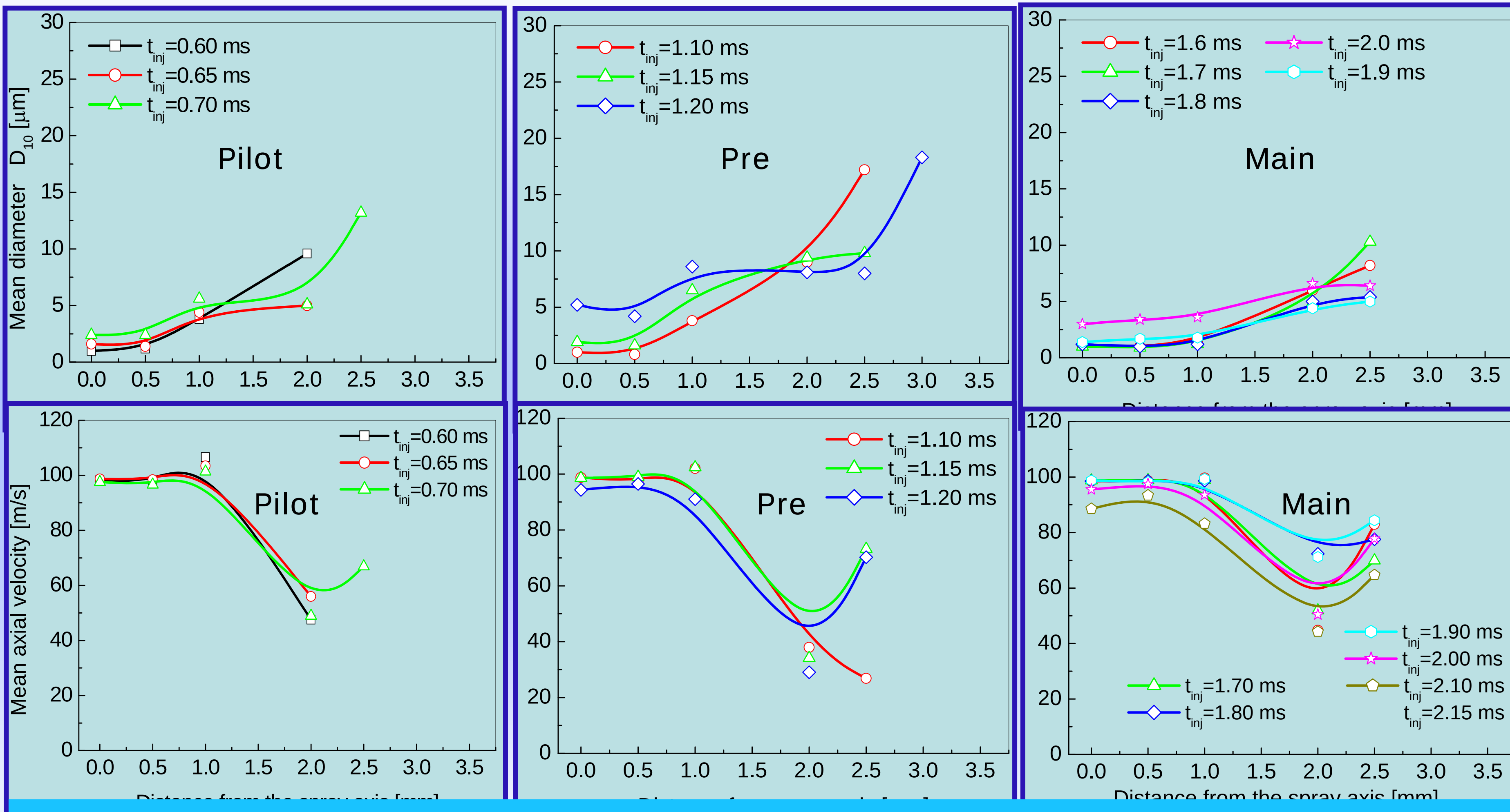
Z=10 mm from the nozzle



Velocity profiles have an opposite trend to the droplets size profiles with lower values located at the spray periphery

SPRAY CHARACTERIZATION: SIZE & VELOCITY RESULTS

Z=30 mm from the nozzle



The droplets diameter in the far field also shows an increasing trend along the spray axis with a slower slop compared to the near field one. The plot relative to the main injection points out a more uniform jet structure during the steady state phase with a diameter profile almost constant compared to the instationarity period.

CONCLUSIONS

An experimental investigation of the fuel spray characteristics, generated by a common rail injection system for light duty diesel engines, in terms of droplets size and axial component of velocity has been carried out by applying the Phase Doppler Anemometry technique.
Tests have been performed in an optically accessible vessel at ambient temperature and atmospheric pressure setting a multiple injection for a medium load running conditions of an automotive diesel engine.
Time resolved size and velocity data have been obtained at different locations within the spray investigating a grid points on a plane across the jet axis of one of the five jets.
The main results can be summarized as follows:

- The central region of the spray shows a mean diameter profile with a decreasing trend during the transient needle opening phase, a flat zone characterized by droplets diameter of few microns (1 to 7 microns) during the steady-state stage and an increasing trend during the non-stationary needle closure phase.
- During the transient needle opening the diameter profiles show a decreasing trend with an early production of large droplets, up to 25 microns, located mainly around the spray periphery and traveling at a lower axial velocity.

CONCLUSIONS

- Close to the jet axis, time-resolved axial velocity profiles show maximum values of about 100 m/s with a flat zone during the steady state part of the pilot, pre and main injections. Lower values, with more fluctuating profiles, have been observed moving toward the spray periphery because of the interaction with the air that produces wide fluctuations

- During the steady state part of each injection, the jet shows an uniform velocity field with a good atomization level in the central region of the spray both in the near and far field. Droplets diameter ranges between 1÷7µm presenting higher values in the far field (up to 40 mm from the nozzle). Moving farther from the nozzle (Z=50 mm) bigger droplets have been found also during the steady period of the main injection that might be due to a coalescence process

- The spray periphery, instead, is characterized by bigger droplets, up to 25-30µm formed mainly during the transient opening phase of the needle with high velocity gradients due to its interaction with the surrounding air.

FUTURE WORK

The next step of this investigation will be focused on:

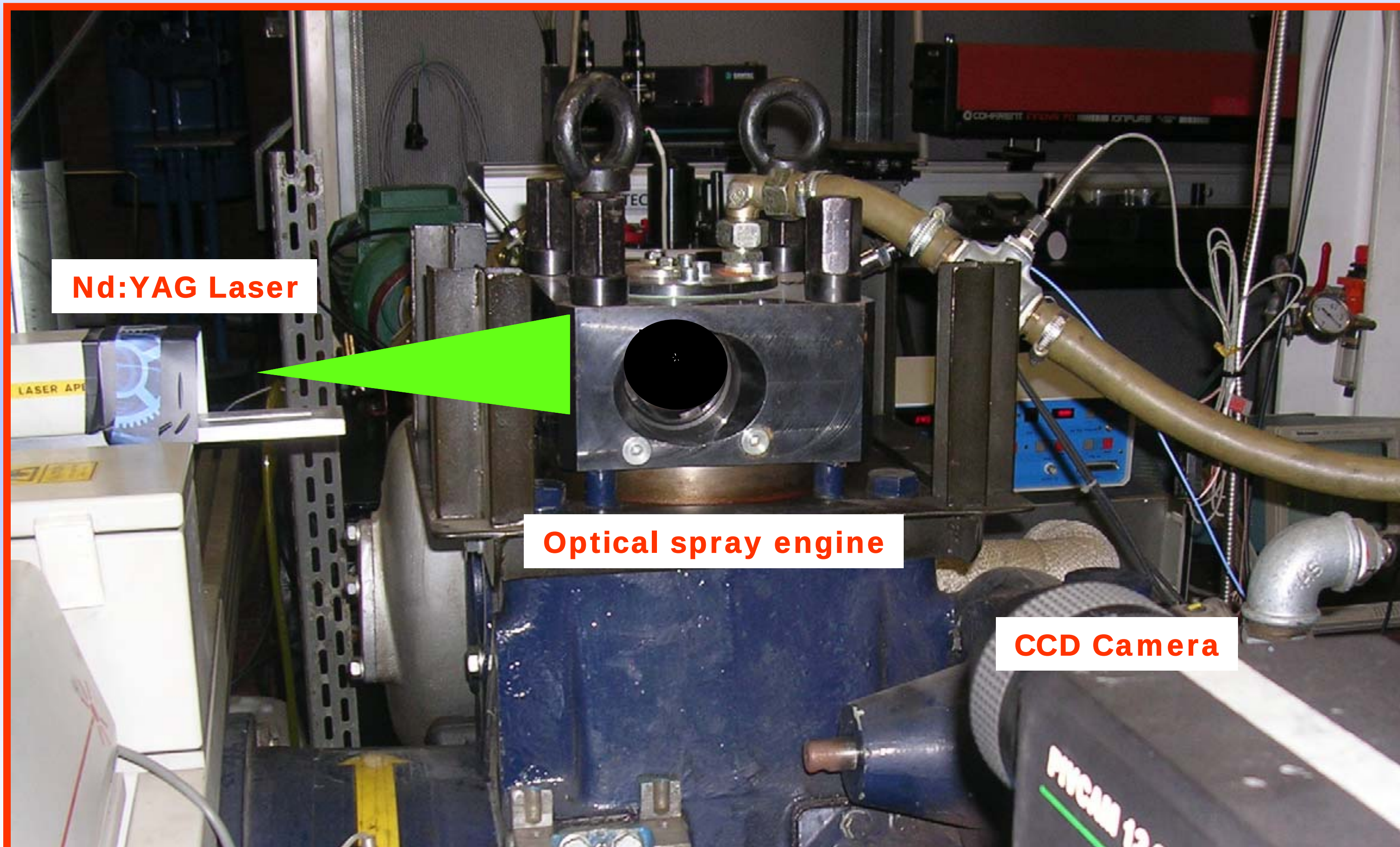
- the influence of operating conditions on droplets size and velocity distribution at different injections strategies;

- the analysis of the droplets size distribution during the ignition delay spraying the fuel inside the combustion chamber of an optically accessible prototype 2-stroke diesel engine able to reproduce gas density and temperature values of a real engine under quiescent/swirl air flow conditions.

- mixture formation with visualization and PIV

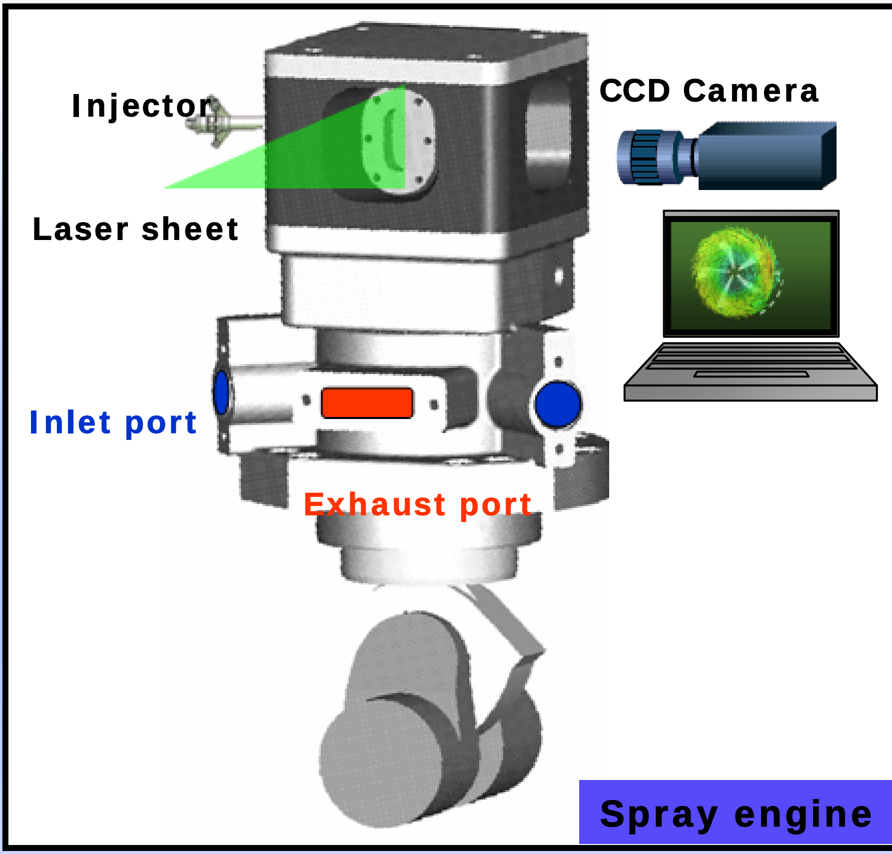
SPRAY CHARACTERIZATION UNDER ENGINE CONDITIONS

The analysis of the droplets size distribution during the ignition delay will be performed spraying the fuel inside the combustion chamber of an optically accessible prototype 2-stroke engine to reproduce gas density and temperature values of a real engine under quiescent/swirled flow conditions.



PDA & PIV for size and velocity vector distribution of fuel droplets under evaporating conditions

FUTURE WORK UNDER ENGINE REALISTIC CONDITIONS



ENGINE SPECIFICATIONS	
Single cylinder 2-stroke, loop-scavenged	
Bore	150 mm
Stroke	170 mm
Displacement	3000 cm^3
Combustion chamber	Quiescent/Swirled
Compression ratio	10.1:1
Intake air pressure	0.217 MPa

INJECTION STRATEGIES

		Pilot	Pre	Main	dw_1 [μs]	dw_2 [μs]	Injection Pressure [MPa]
Low Load	Solenoid exciting time [μs]	375	375	480	200	240	28.0
	Fuel injected [mg/str]	0.66	1.15	1.5			
Medium Load	Solenoid exciting time [μs]	270	275	515	230	230	71.0
	Fuel injected [mg/str]	1.65	2.06	8.51			
High Load	Solenoid exciting time [μs]	-	-	685	-	-	140.0
	Fuel injected [mg/str]	-	-	26.7			

TEST CONDITIONS

Non evaporative conditions		Evaporative conditions	
Gas density [kg/m^3]	Gas temperature [K]	Gas density [kg/m^3]	Gas temperature [K]
12.50	294	12.50	716
16.15	294	16.15	785
20.62	294	20.62	**950**

Table 2 – Experimental conditions for non evaporating and evaporating sprays.