Quantitative measurements of fuel spatial densities from GDI sprays through optical and x-ray based techniques

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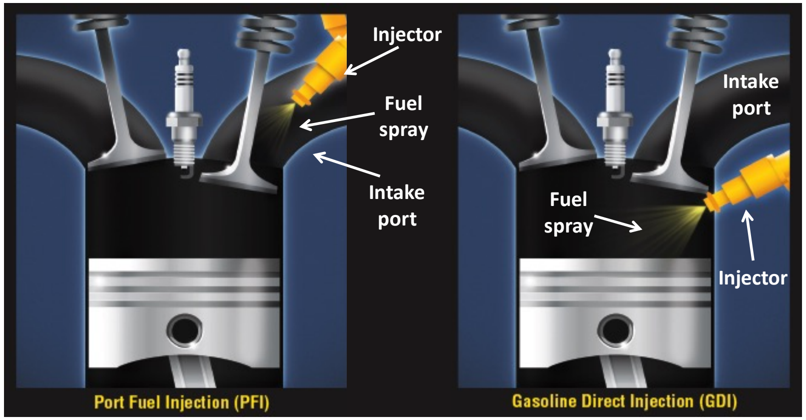
INTRODUCTION

New Spark Ignition engines promise higher combustion efficiency and exhaust emission reduction

How to reduce fuel consumption and CO_2 emission?

Through stratified lean combustion (up to 25% less consumption)

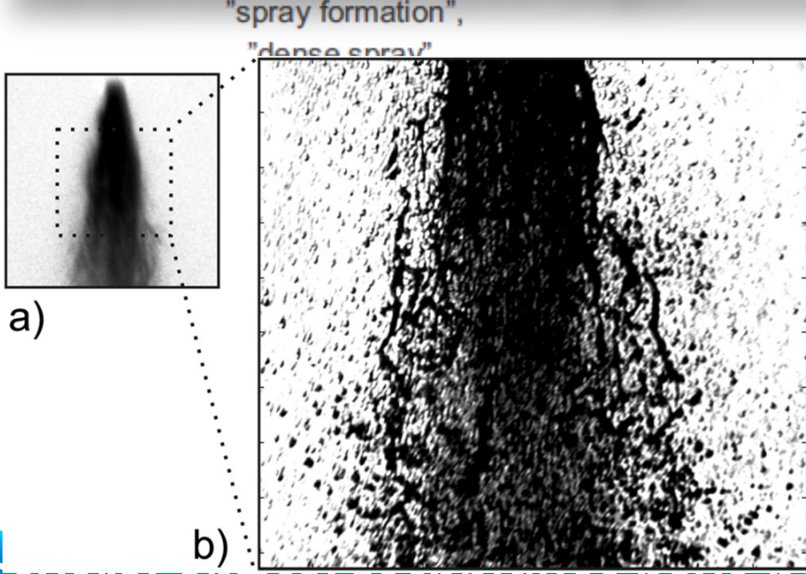


Controlling the charge formation by mans of injection

INTRODUCTION

How a high pressure sp

main jet geometric parameters:
tip penetration, cone angle



M. Linn
dense
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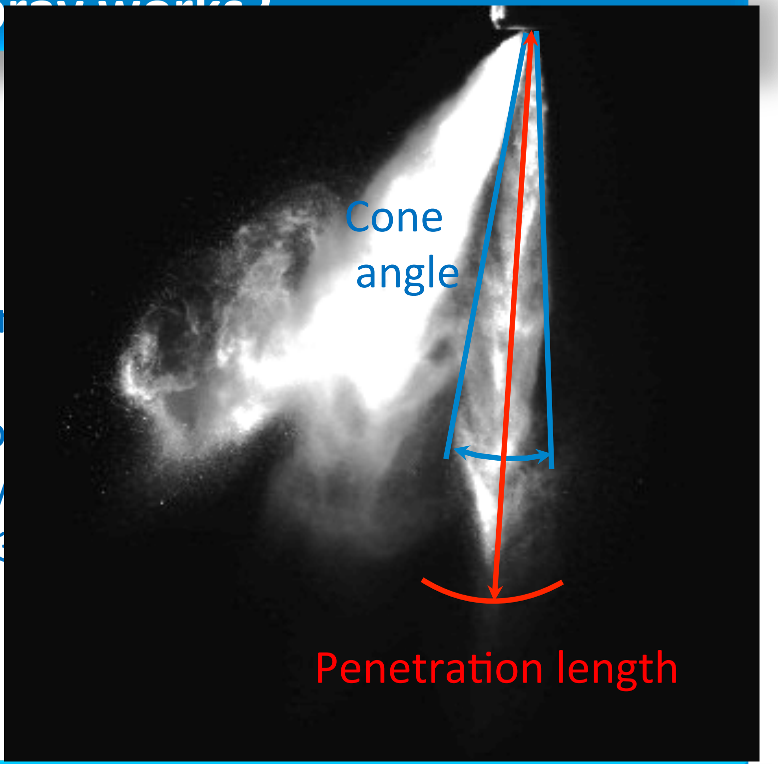
Energy
39: 40

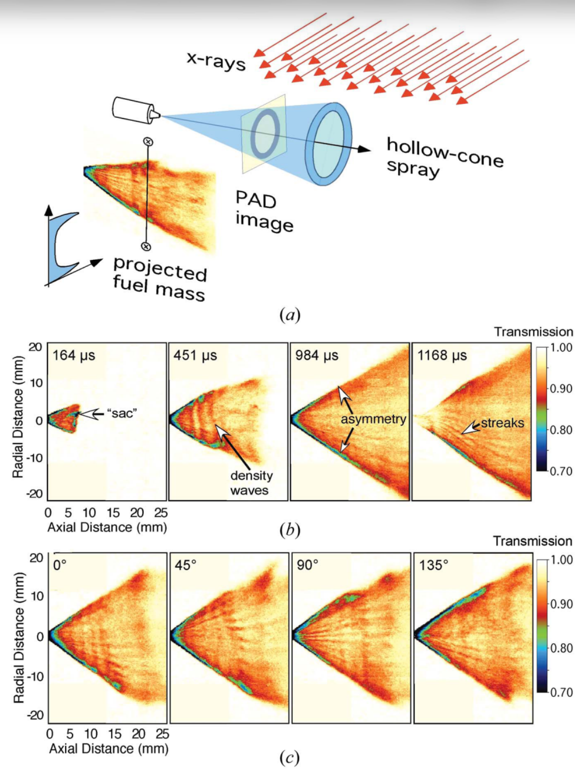


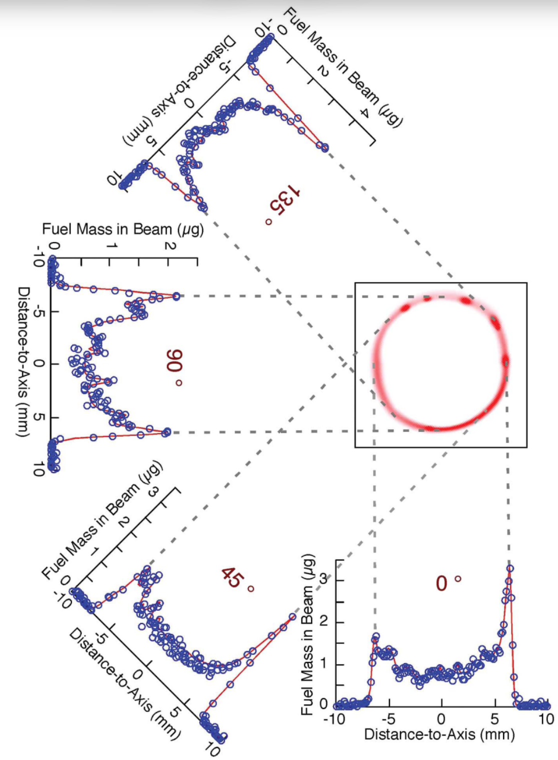
Several optical techniques have been applied for characterizing the fuel

measurements about the internal structure of the spray results quite complicated, especially in the dense region close the nozzle

INTRODUCTION

Techniques based on X-radiation have been applied to estimate the fuel distribution into high-density regions of fuel sprays.





X-radiography of hollow-cone direct injection fuel spray

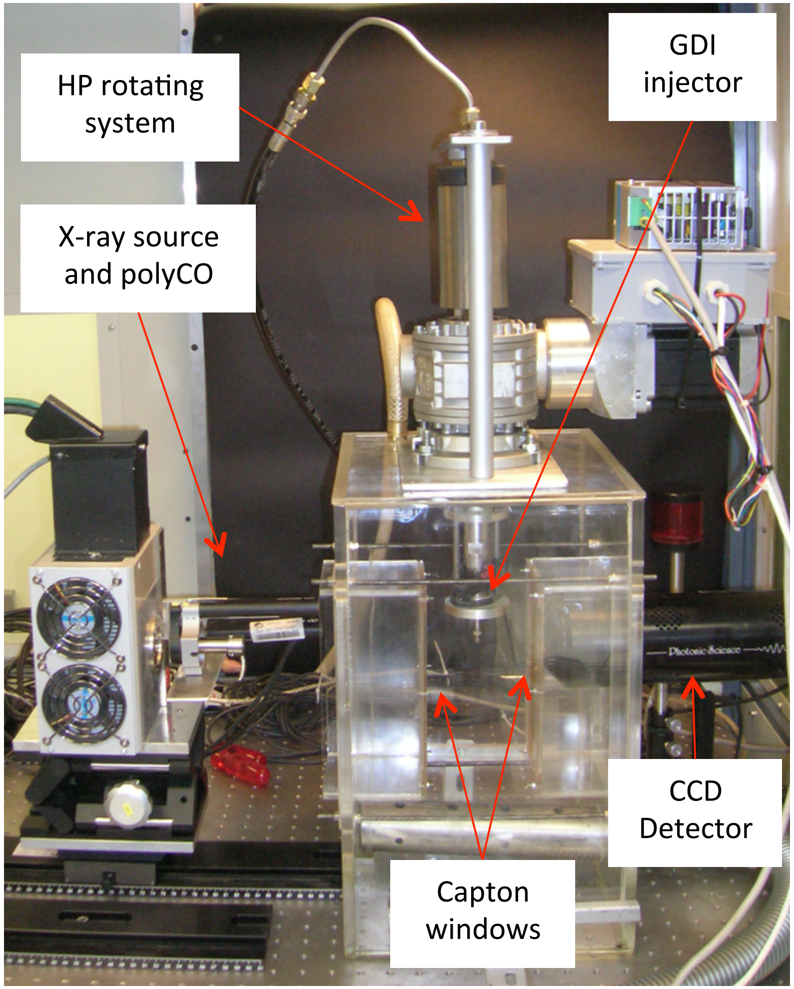
Computed fuel mass distribution by fitting the experimental data with mass reconstruction models

Wang, J., X-ray vision of fuel sprays, Journal of synchrotron radiation, 12: 197-207 (2005).

EXPERIMENTAL SET-UP 1/2

A Cu Kα X-ray source at ~ 8.0 keV coupled with a polycapillary halflens focuses the radiation on a selected spray region .
A CCD detector for X-radiation collects the emerging signal

A 6-hole GDI injector is coupled to the high pressure pump by a specially designed rotating device able to work up to 50 MPa with an angular step [?][?][?][?] 1°



EXPERIMENTAL SET-UP 2/2

Polycapillary Lens

POLYCAPILLARY SEMI-LENS

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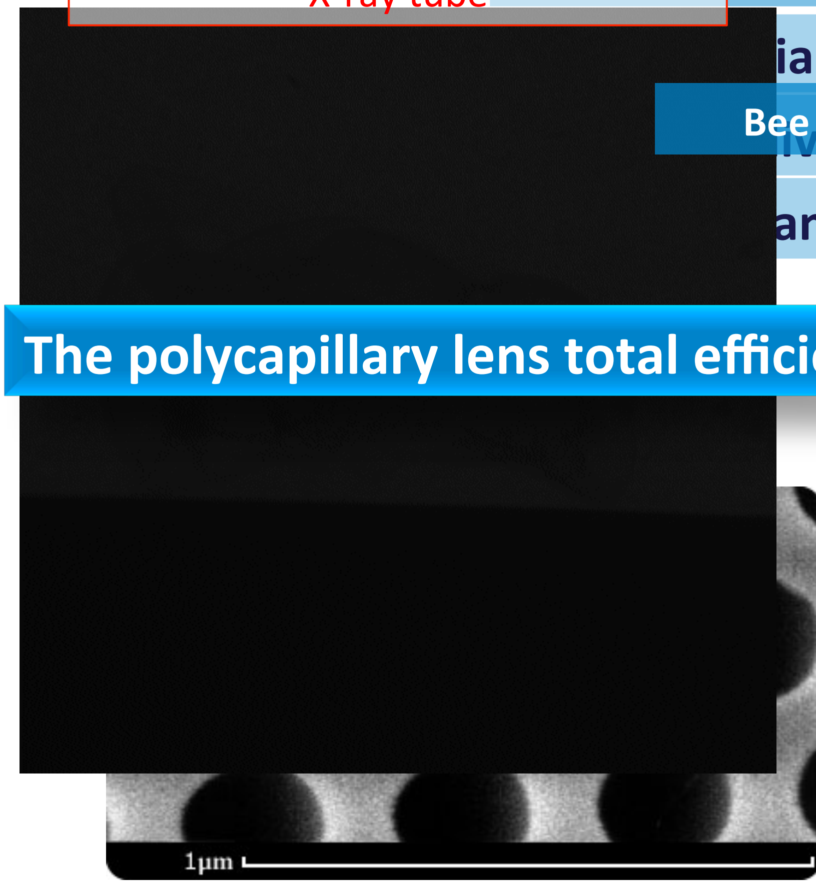
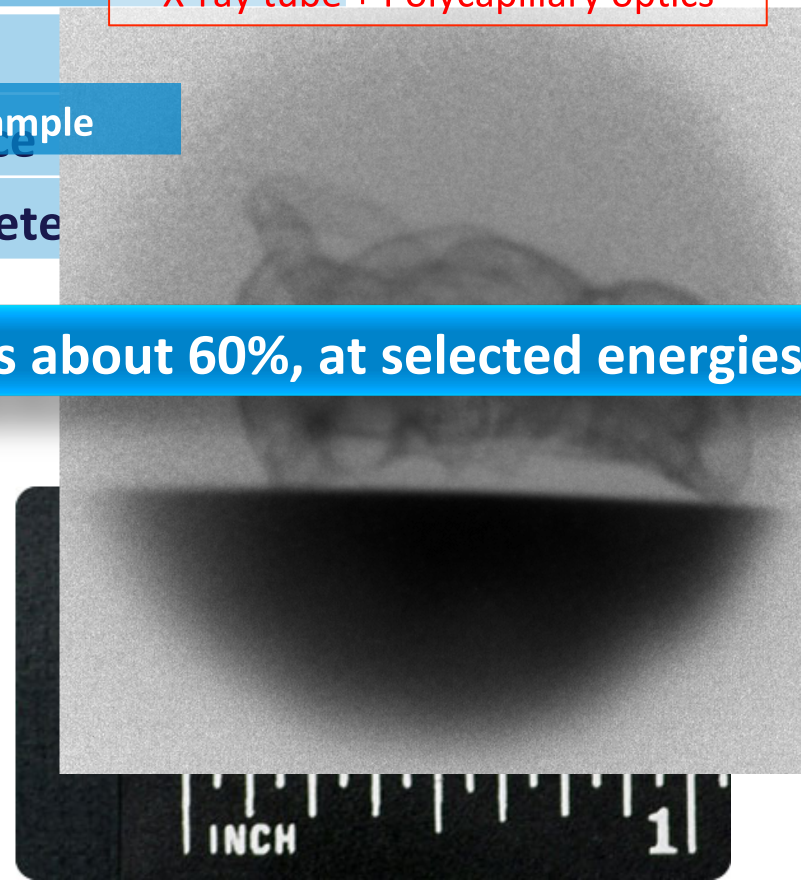
an diamete

X-ray tube



Bee Head Sample

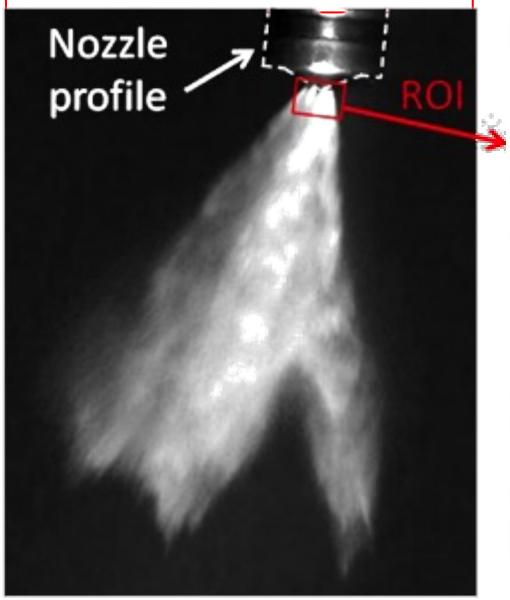
X-ray tube + Polycapillary optics



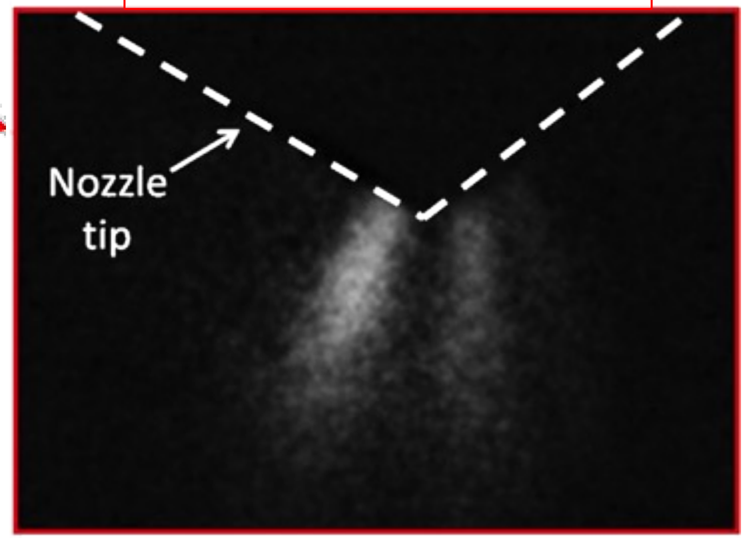
The polycapillary lens total efficiency is about 60%, at selected energies.

IMAGE ACQUISITION 1/3

MIE SCATTERING



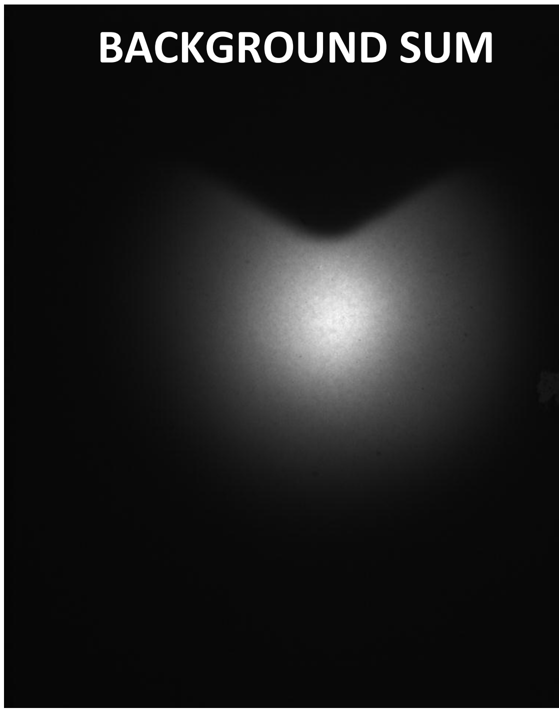
X-RAY ABSORPTION (I_0/I)

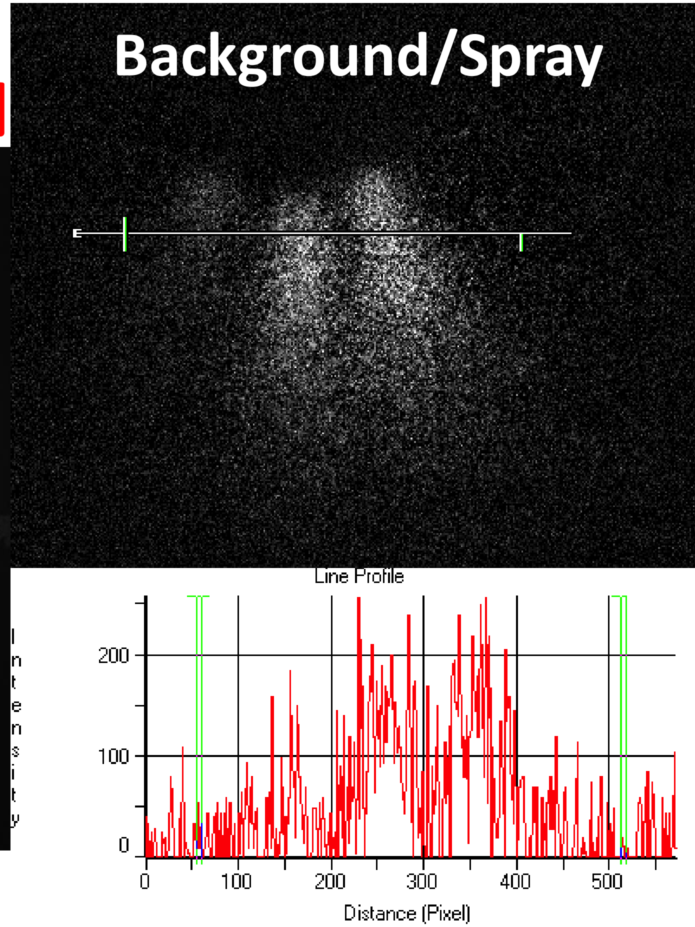


Field of View

IMAGE ACQUISITION 2/3

BACKGROUN **E GDI FUEL SPRAY**





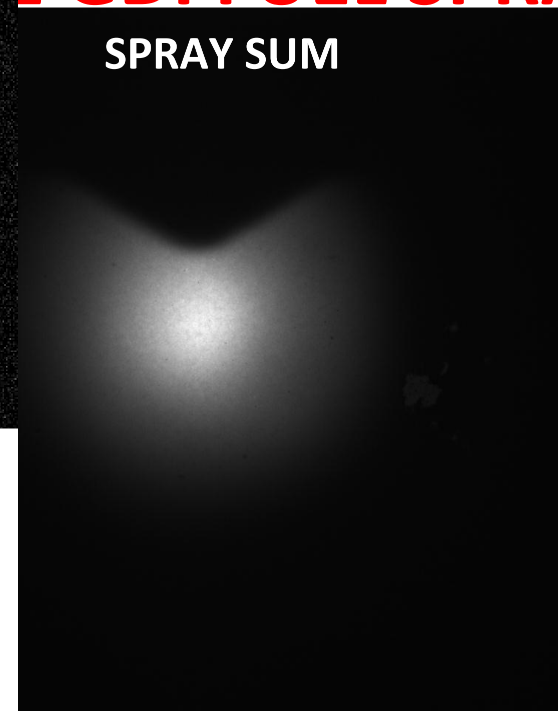
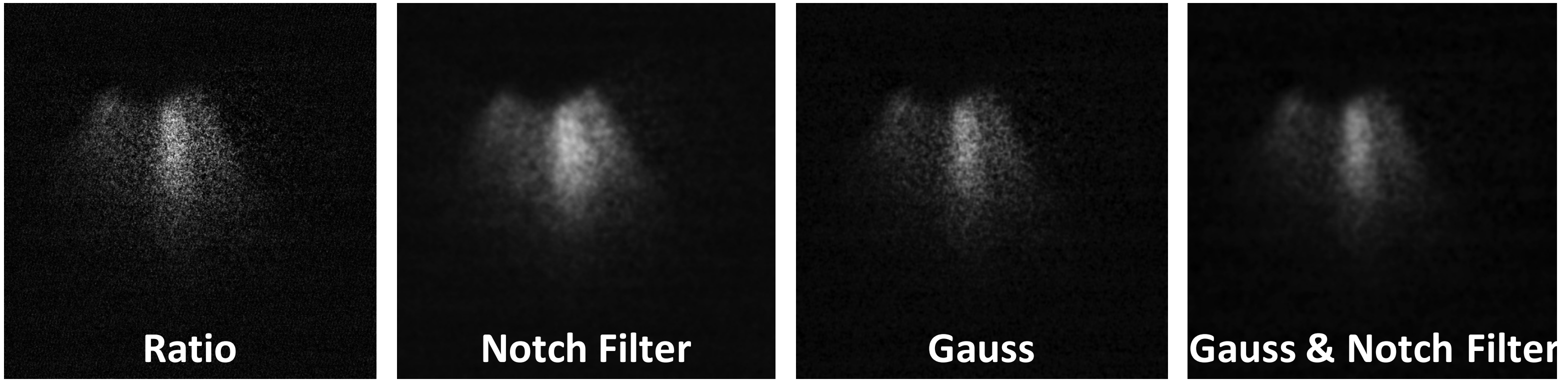
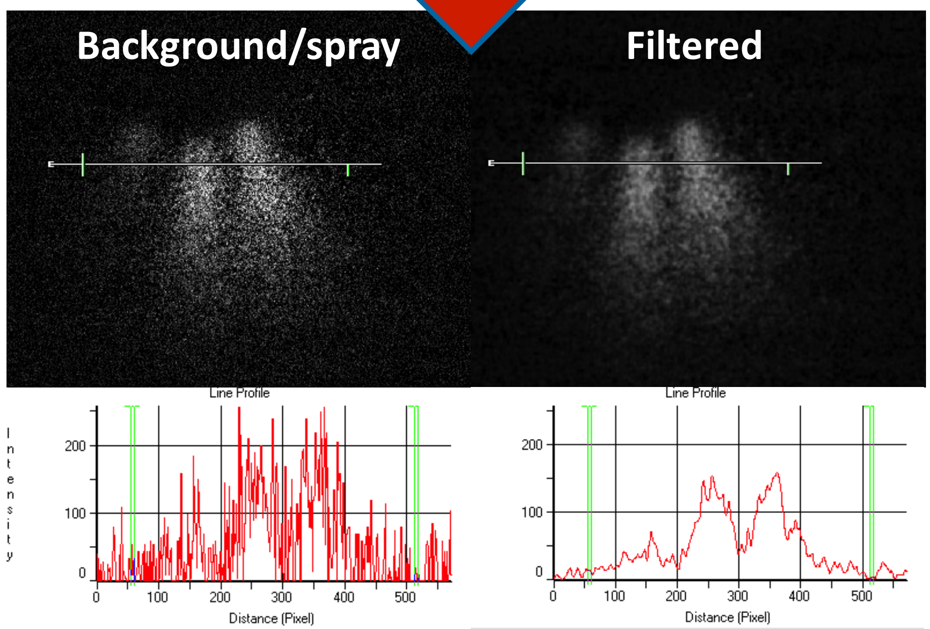
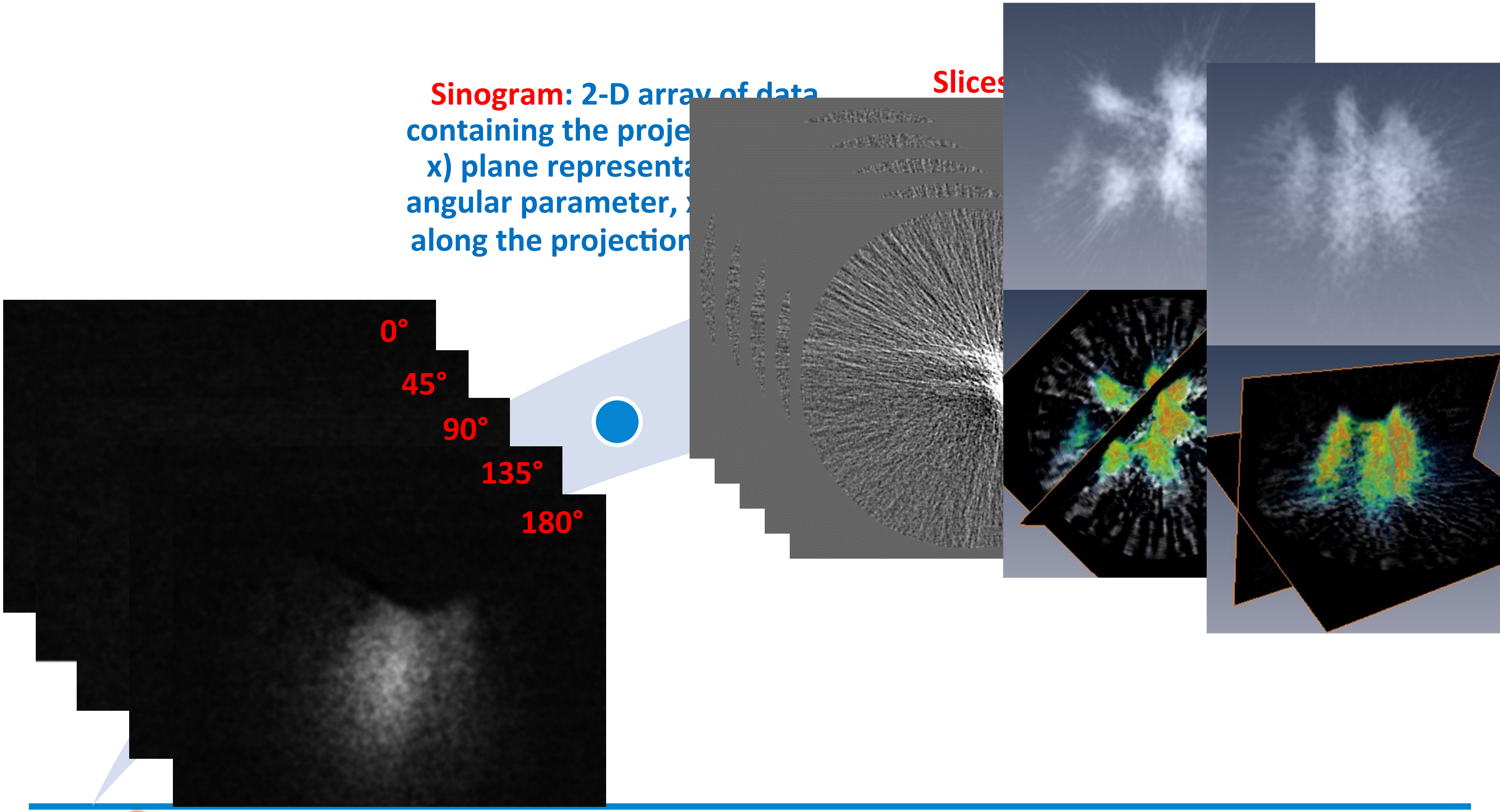


IMAGE ACQUISITION 3/3





TOMOGRAPHY – BASE CONCEPT



3D RECONSTRUCTION

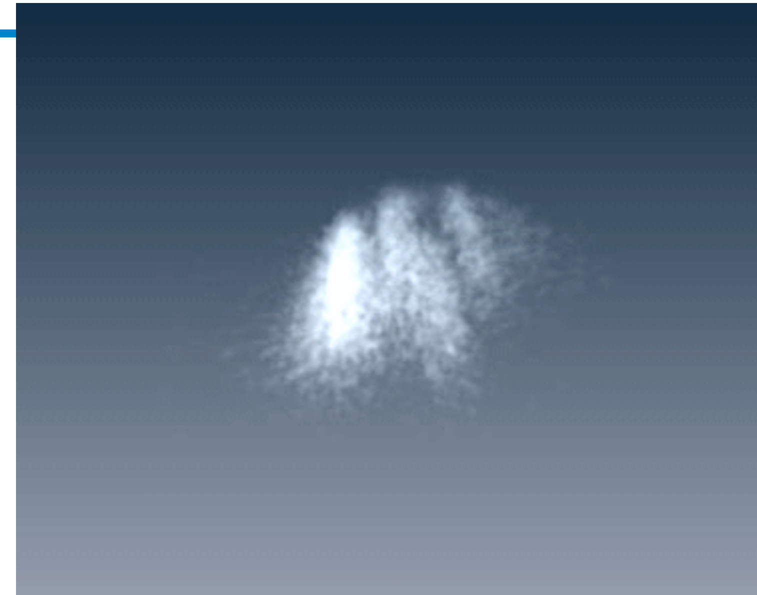
The absorption is linked to the sample local density ρ by the well known Lambert Beer law :

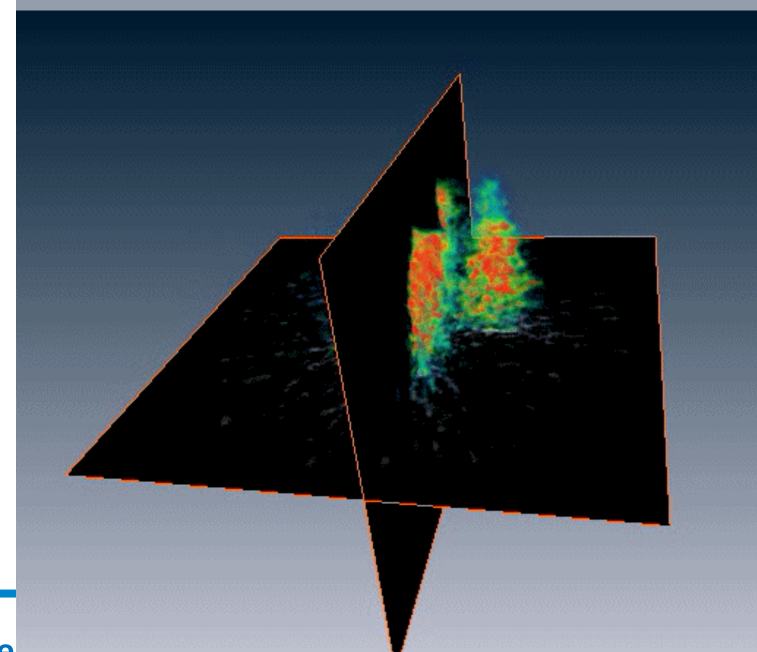
$$I/I_0 = e^{-\mu_l \rho l}$$

where μ_l is the linear absorption coefficient and l is the crossed spray length. The previous equation can also be written as:

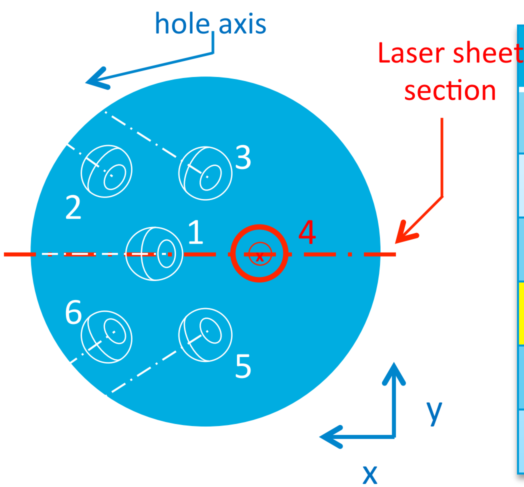
$$I/I_0 = e^{-\mu_M M}$$

where μ_M is the mass absorption coefficient. Considering the single cross section, M represents the fuel mass m related to the spray cross section area A.

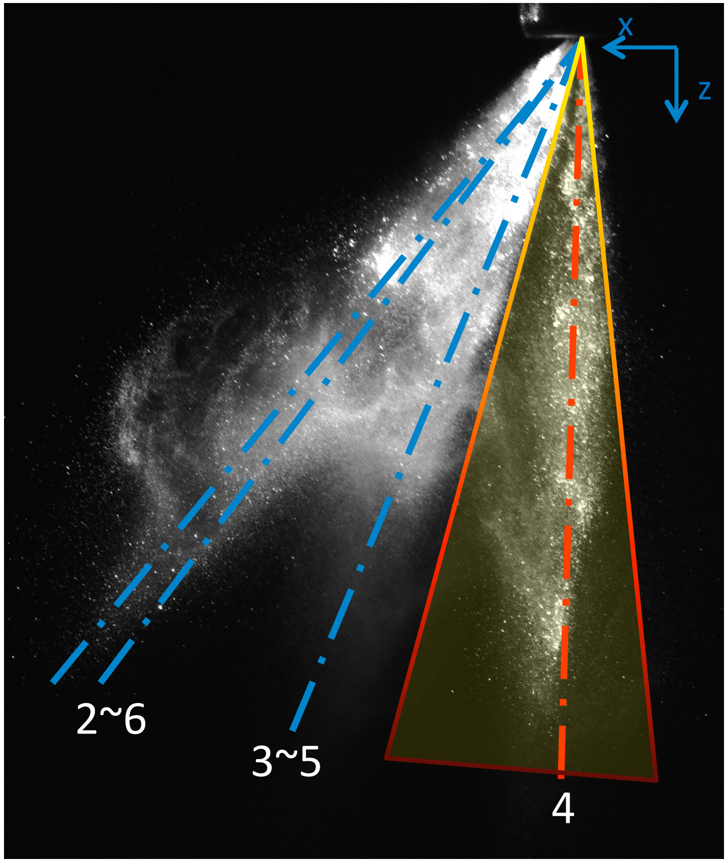




3D RECONSTRUCTION

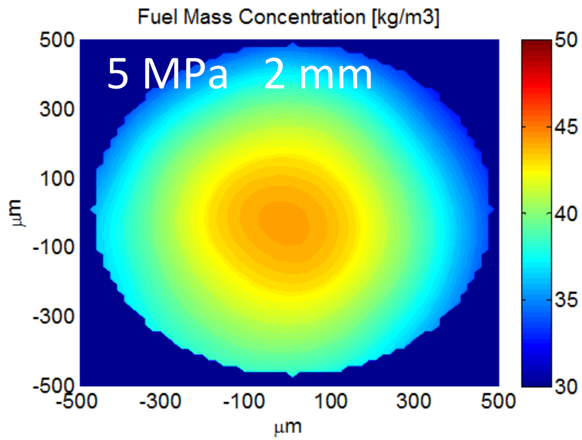


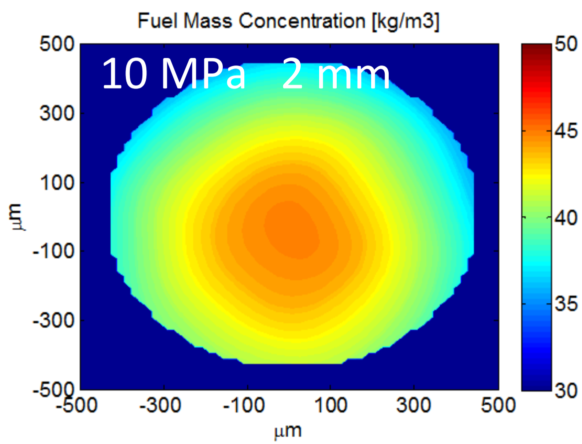
Hole	xz [°]	yz [°]
1	54.8	0.0
2	49.9	-27.7
3	21.8	-11.6
4	3.1	0.0
5	21.8	11.6
6	49.9	27.7



The jets don't have any symmetry. The jet 4 has just a little inclination respect to nozzle axis and it is confined always in the beam spot.

CROSS SECTION MEASUREMENTS





Fuel Mass per Volume Unit

$=m_{fuel}/V_{voxel}$

Void Fraction

(V_a/V_{voxel})

$$\vartheta = 1-\iiint f\cdot(4/3)\pi r^3 dr d\vec{v} dT_d$$

ϑ = Void Fraction

r = droplet radius

$\vec{v}$ = droplet velocity

T_d = droplet temperature

"For a regular arrangement of spherical droplets with a spacing equal to their diameter…it can be shown that the void fraction becomes θ≈0.92 [60]. Consequently, it is often assumed that a spray behaves as a thick spray if the void fraction is less than about 0.9. O'Rourke [60] also considered an additional spray regime located between the intact core and the thick spray, termed churning flow, for void fractions less than 0.5."

Stiesch, Gunnar. Modeling engine spray and combustion processes. Springer Science & Business Media, 2013.

CROSS SECTION MEASUREMENTS

The tests were performed at ambient pressure and temperature, hence the fuel droplet density is known:

$$\rho_{fuel} = 719.7\ kg/m^3$$

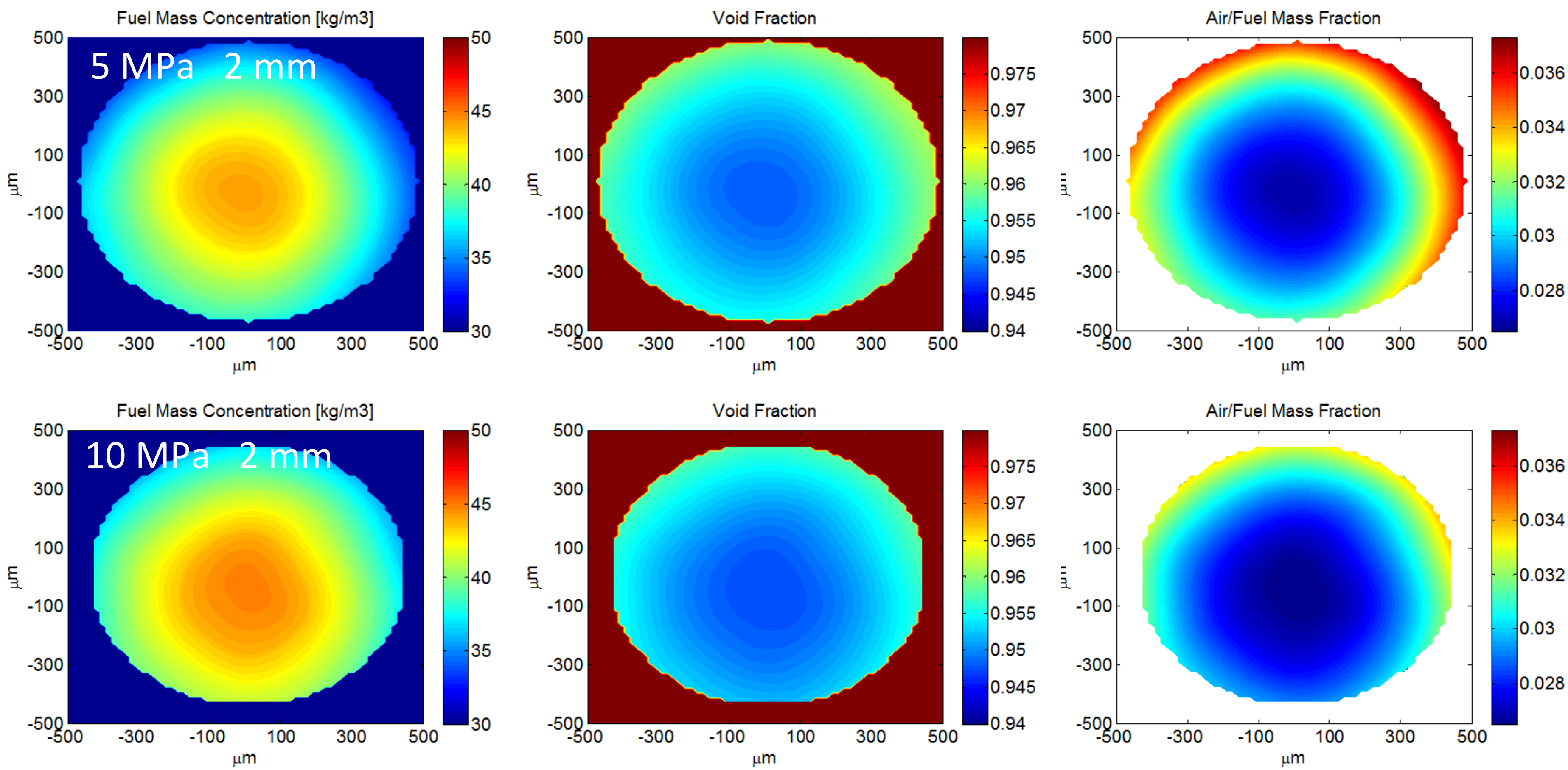
The ratio between the fuel density and voxel density (measured one) is linked to the air and fuel volumes through the following relationship:

$$\rho_{fuel}/\rho_{voxel} = V_{voxel}/V_{fuel} = (V_{air}+V_{fuel})/ V_{fuel}$$

This equation can be easely rewritten to obtaint he void fraction:

$$V_{air}/V_{fuel} = (\rho_{fuel}/\rho_{voxel})-1$$

CROSS SECTION MEASUREMENTS

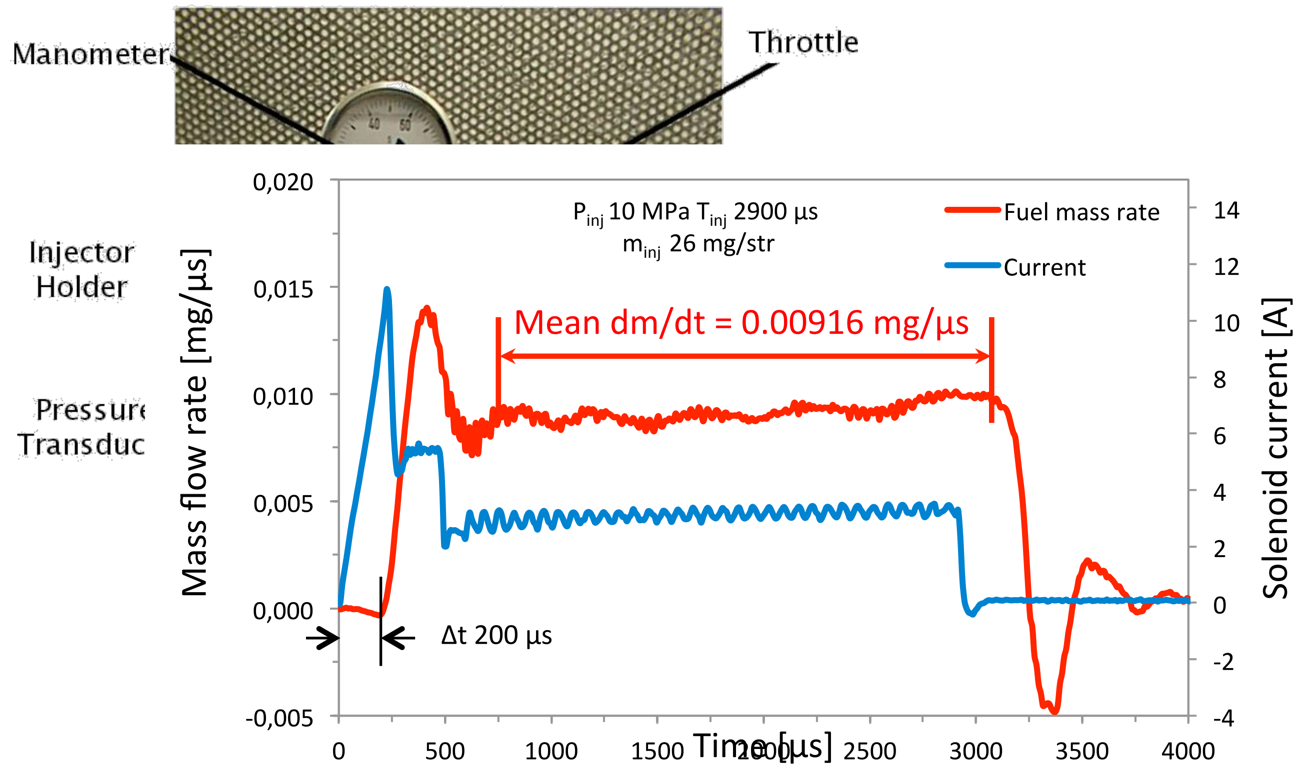


Fuel Mass per Volume Unit $=m_{fuel}/V_{voxel}$

Void Fraction $=V_{air}/V_{voxel}$

Mass Fraction $=m_{air}/m_{fuel}$

MASS FRACTION VALIDATION



Instantaneous fuel injection rate measurements were performed through Bosch tube principle

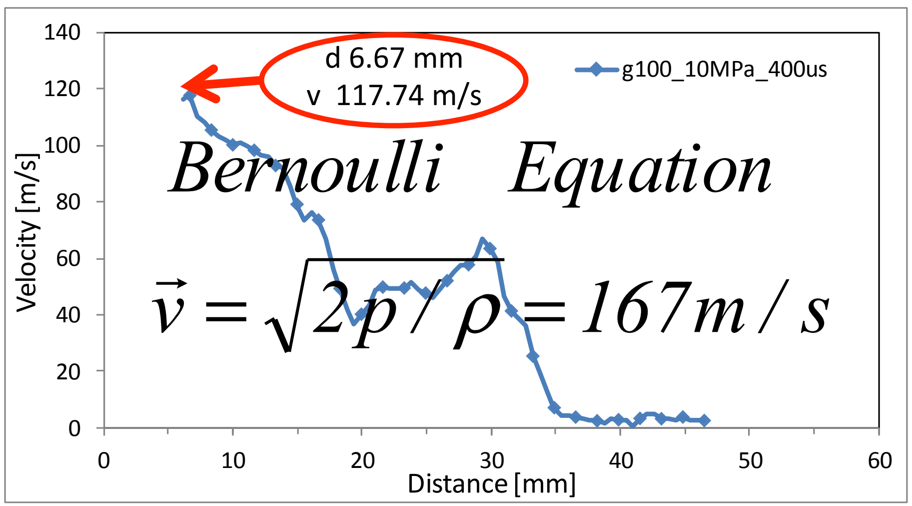
MASS FRACTION VALIDATION

$$dm/dt = \rho \pi r^2 \vec{v} = \mathbf{0.00915}\,kg/s < 0.00916\,kg/s$$

$\rho = density$

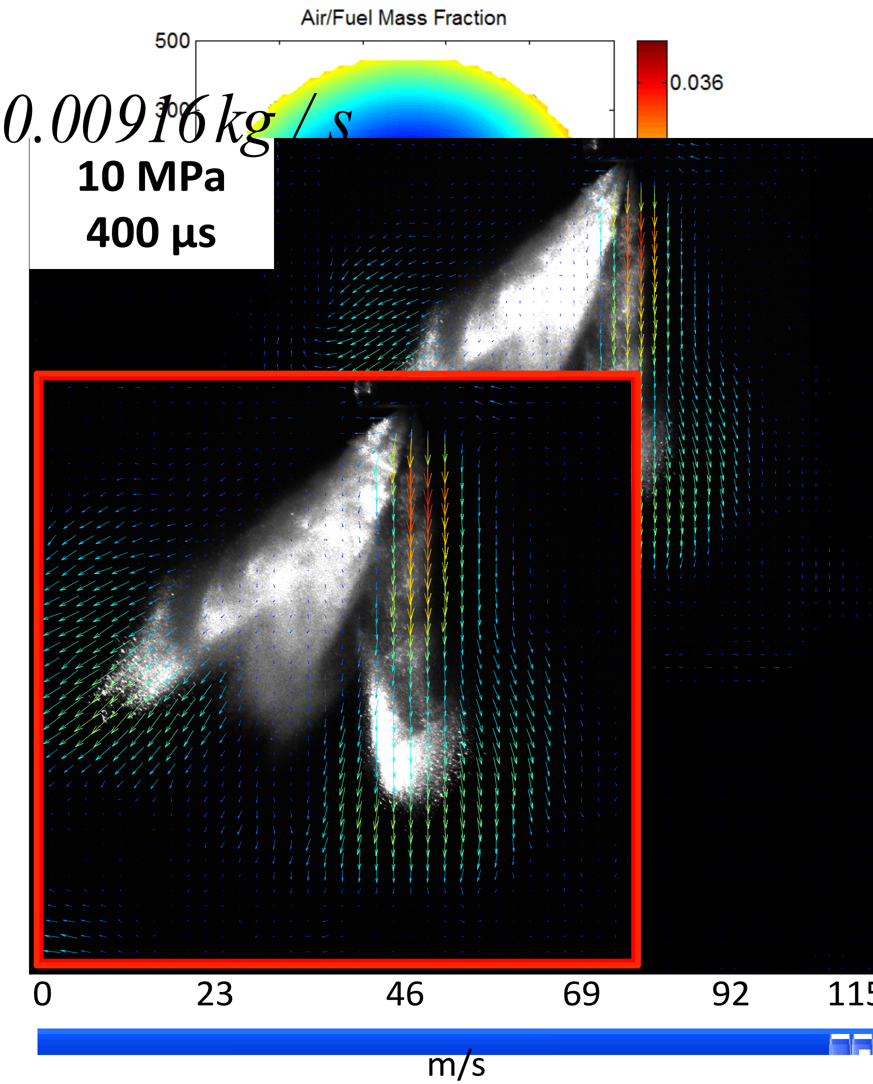
$r = section \quad radius$

$\vec{v} = jet \quad speed$



Bernoulli Equation

$$\vec{v} = \sqrt{2p/\rho} = 167\,m/s$$



CONCLUSION

X-ray tomography has been applied to investigate the inner structure of a gasoline spray delivered by a 6-hole Gasoline Direct Injection system. The experimental set-up is based on a Cu Kα X-ray tube coupled with a polycapillary halflens, that allowed to obtain a high intensity quasi parallel beam (lens total efficiency ~60%).

The technique has provided a detailed reconstruction of the spray structure in the region close to the nozzle allowing quantitative 3D measurements of fuel mass and local air-fuel distribution

The single-jet fuel mass-rate was obtained and compared with the injection rate one measured by the injection Gauge Rate System working on the Bosch tube principle. The comparison demonstrates the accuracy of x-ray tomography desktop facility as a reliable diagnostic tool

THANK YOU FOR YOUR ATTENTION