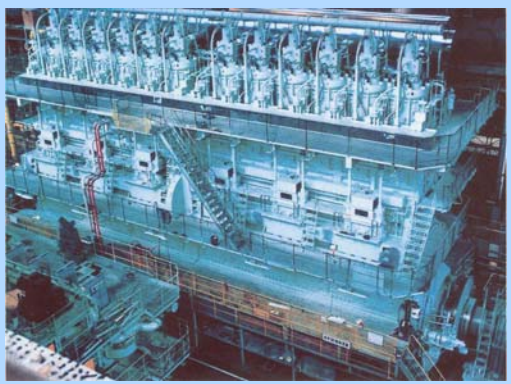
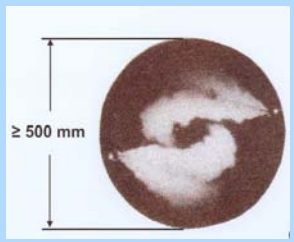
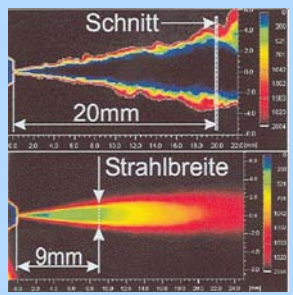
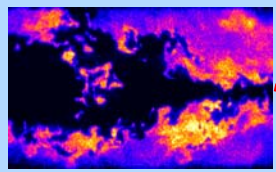
Low Emission Combustion Technologies for High Efficiency Energy Converters



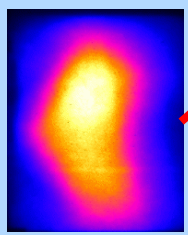




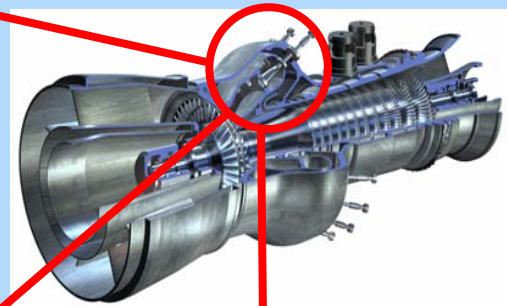
spray & soot diagnostics



turbulent premixed flames



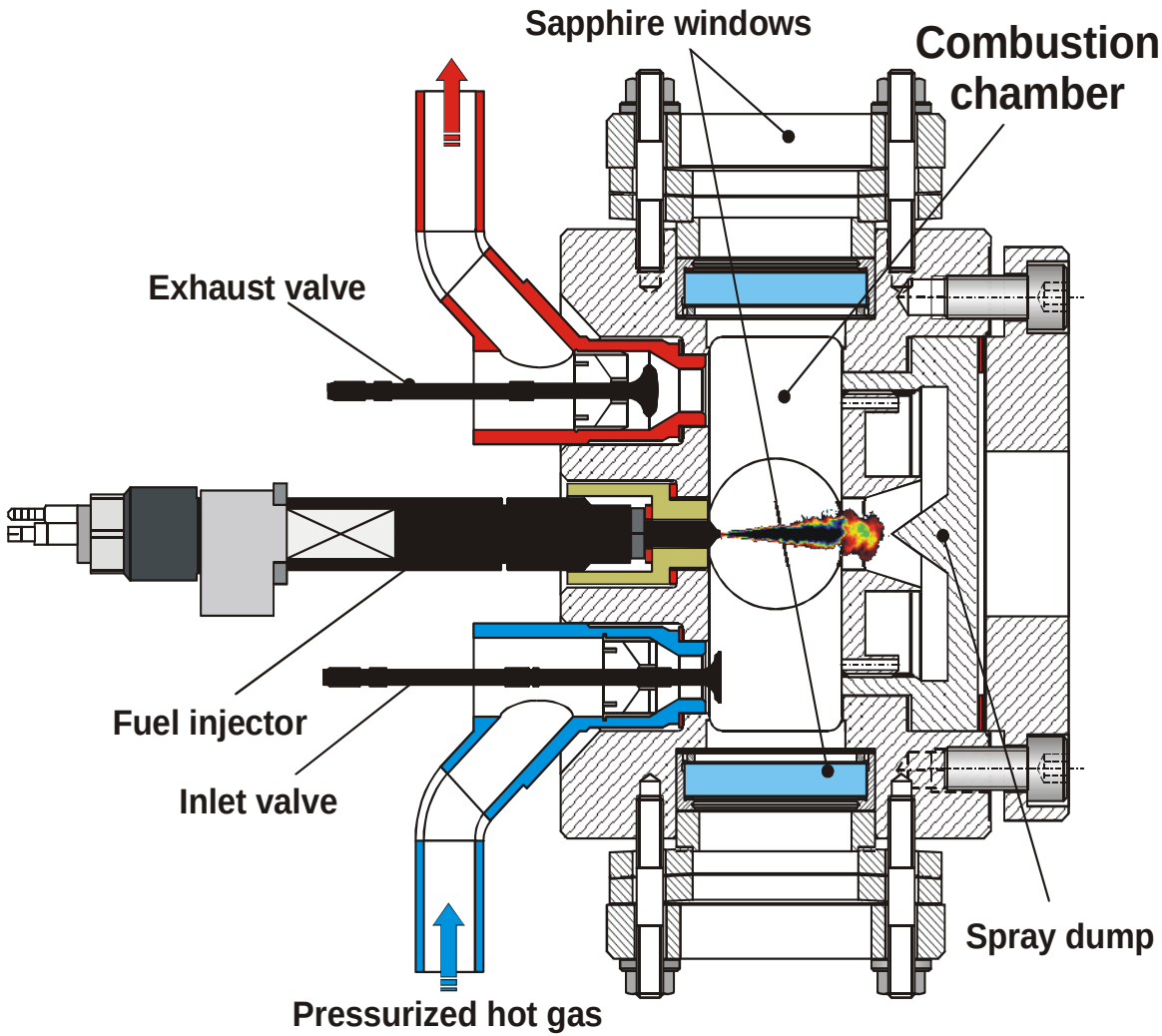
combustion diagnostics



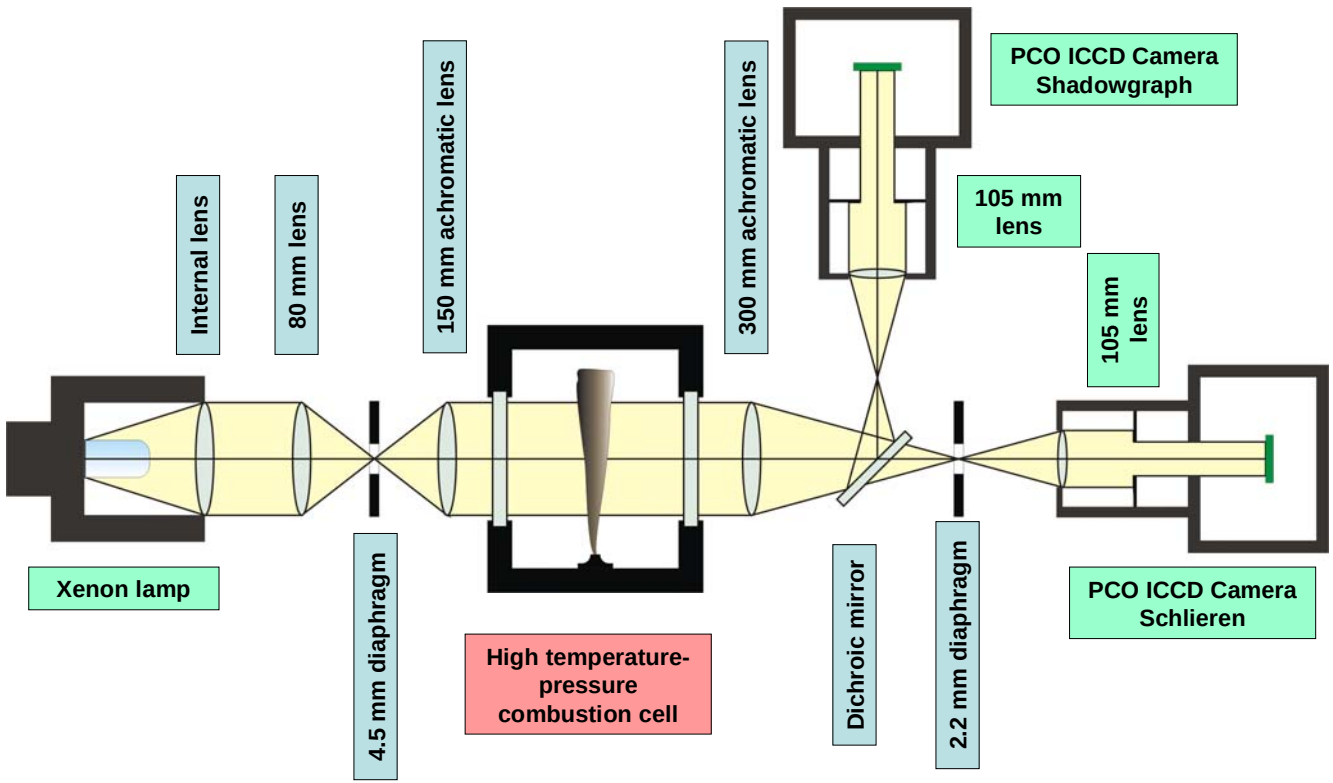
catalytic combustion

Focus: interaction of physical/chemical processes

*Hoch*Temperatur-*Druck*Zelle (*HTDZ*)



Simultaneous Shadowgraph and Schlieren



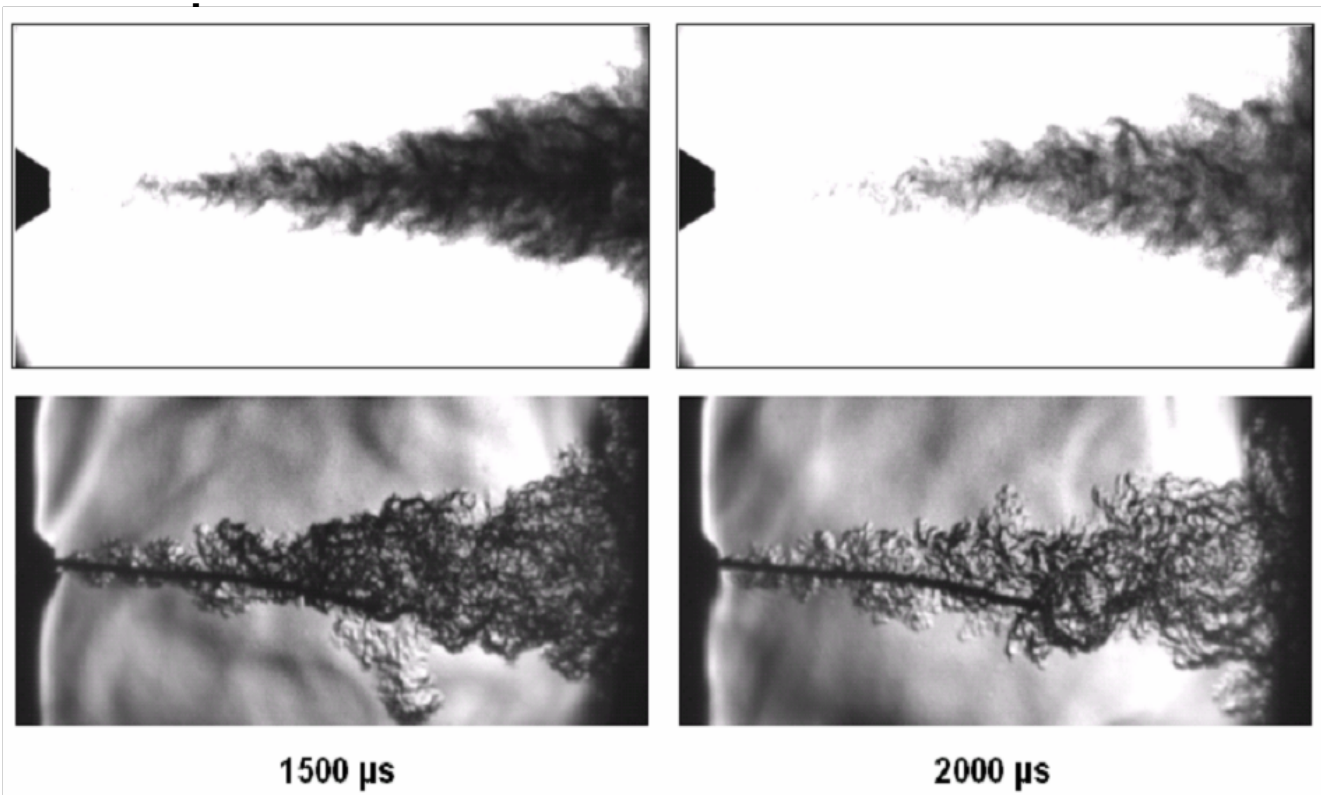
Temperature	T = 440 °C
Pressure	p = 40 bar
Injection pressure	p_{Inj} = 500bar

Inlet valve closed	0 ms
Start Pilot Injection	465 ms
Start Main Injection	500 ms

Comparison between Shadowgraphy and Schlieren

Shadowgraphy: mainly liquid phase visible
Schlieren: higher sensitivity to refractive index changes → evaporated fuel also visible

p_{Cell}=40 bar , T_{Cell}=750 K , $t_{injection}$=1.2 ms mit 500

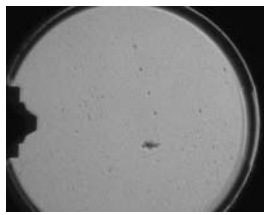


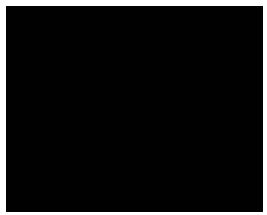
Shadowgraphy
(PhD thesis B. Schneider, 2003)

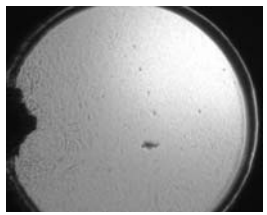
Schlieren
recent measurements at the ETHZ LAV
(A. Escher & R. Margari)

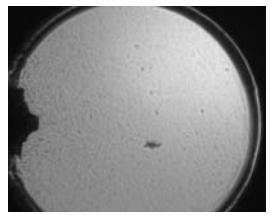
Pilot Injection (1)

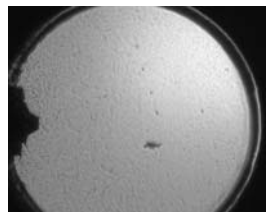
Shadowgraph


Without Injection

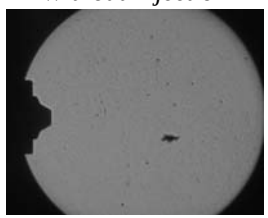

465.0 ms

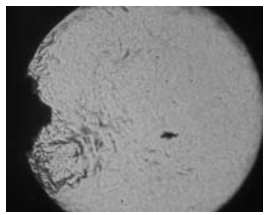

465.5 ms

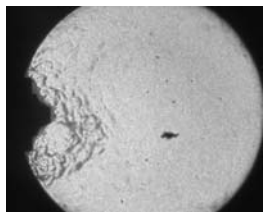

465.6 ms

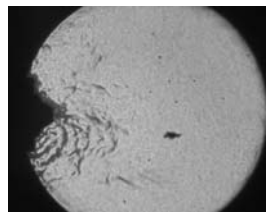

465.7 ms

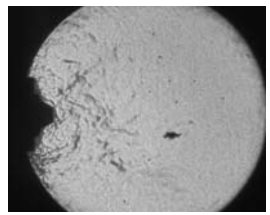
Schlieren



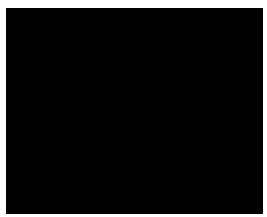


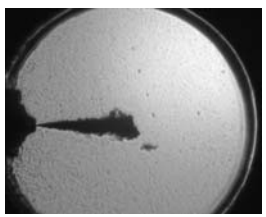


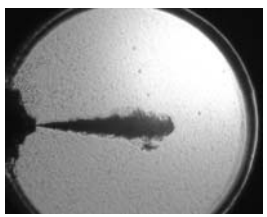


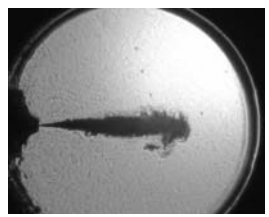


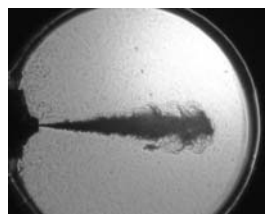
Shadowgraph


465.8 ms

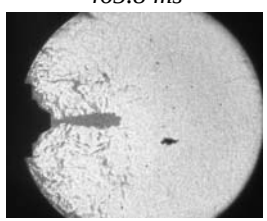

465.9 ms

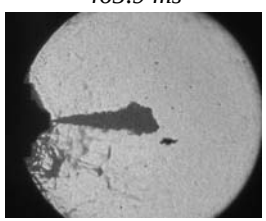

466.0 ms

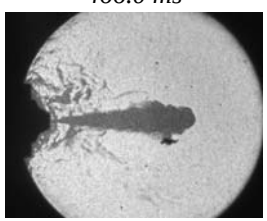

466.1 ms


466.2 ms

Schlieren

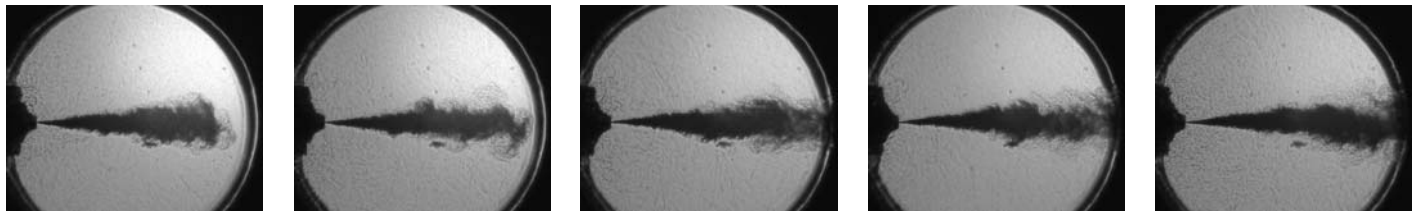






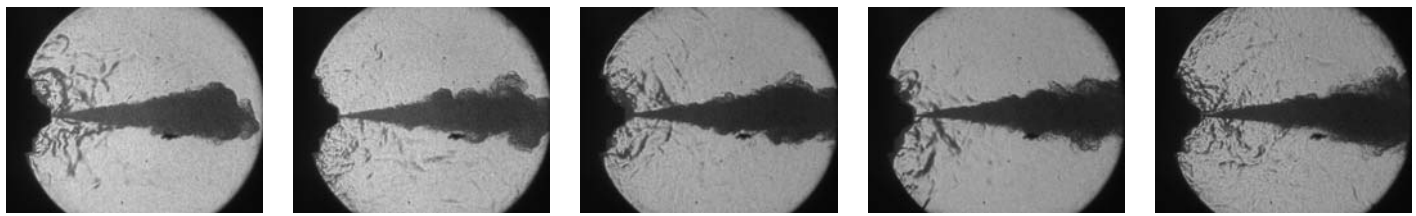
Pilot Injection (2)

Shadowgraph

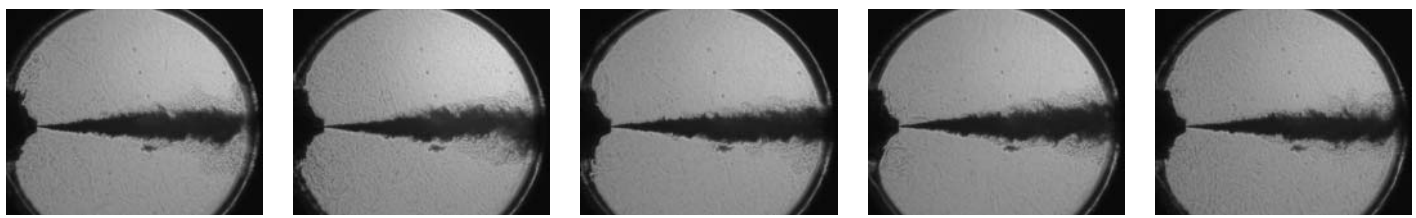


466.3 ms *466.4 ms* *466.5 ms* *466.6 ms* *466.7 ms*

Schlieren

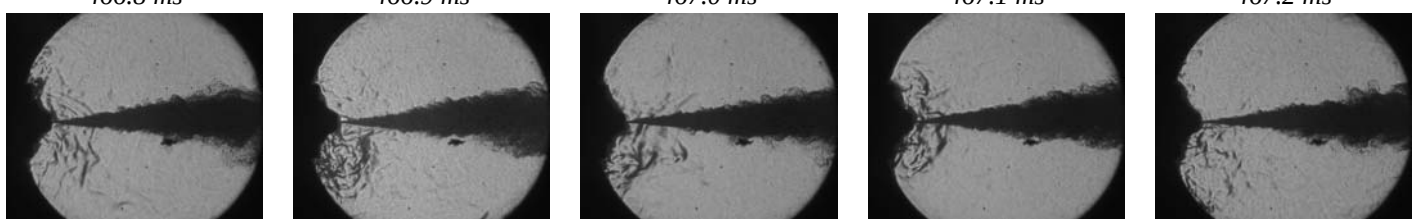


Shadowgraph



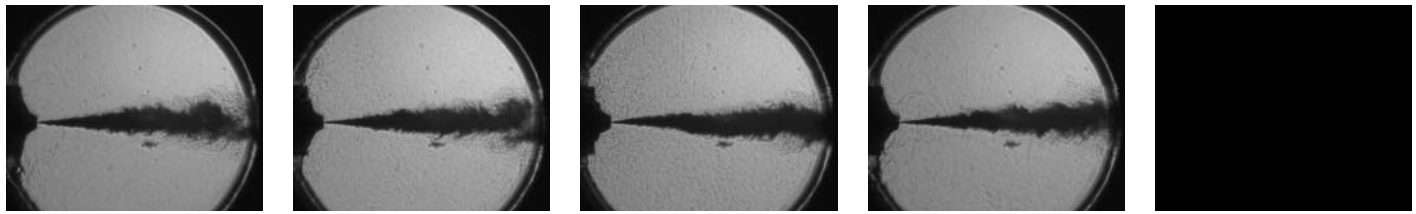
466.8 ms *466.9 ms* *467.0 ms* *467.1 ms* *467.2 ms*

Schlieren



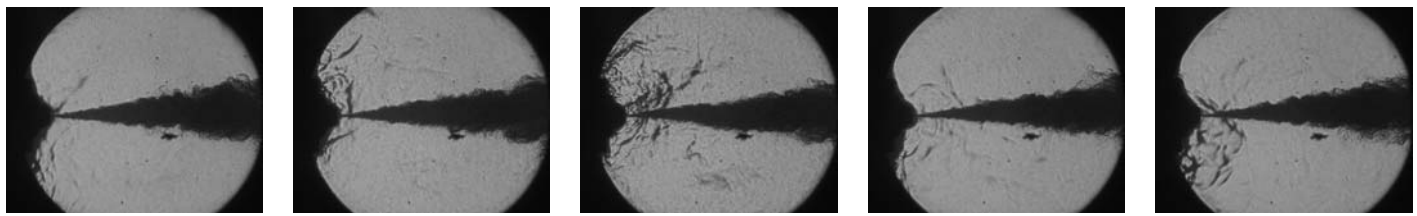
Pilot Injection (3)

Shadowgraph

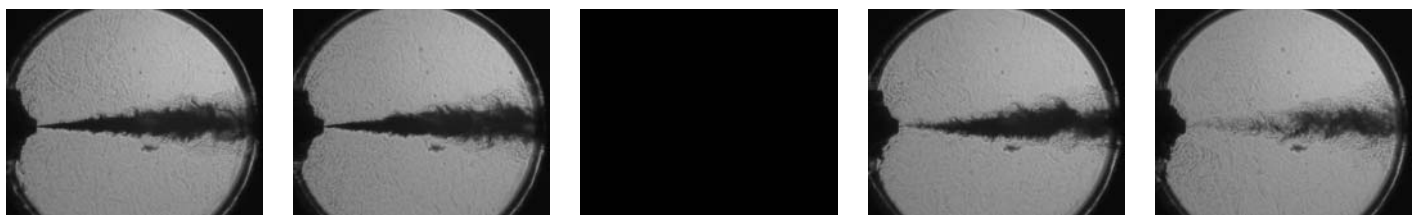


467.3 ms | 467.4 ms | 467.5 ms | 468.5 ms | 469.5 ms

Schlieren

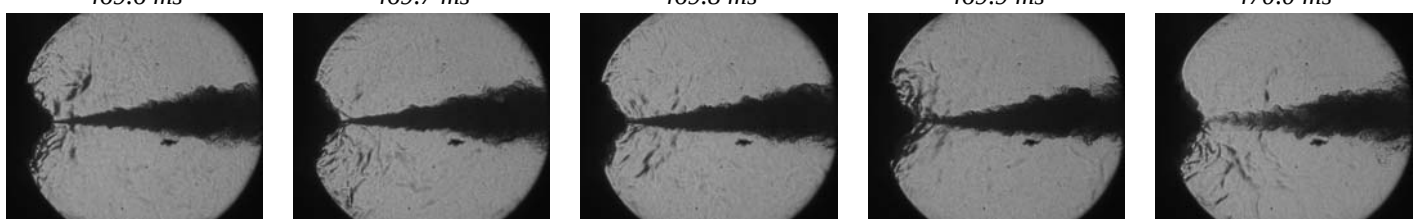


Shadowgraph



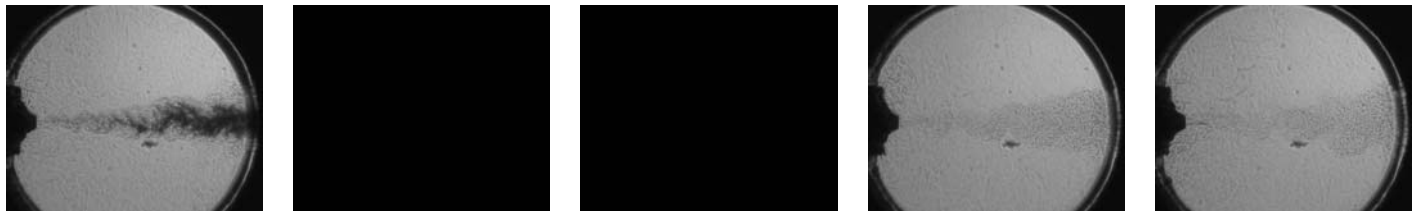
469.6 ms | 469.7 ms | 469.8 ms | 469.9 ms | 470.0 ms

Schlieren



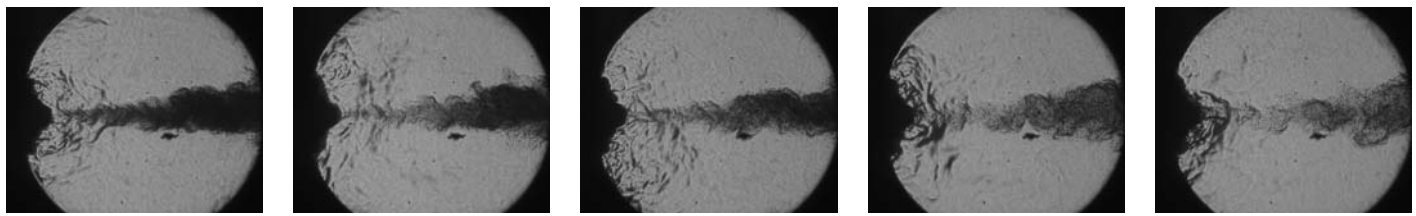
Pilot Injection (4)

Shadowgraph

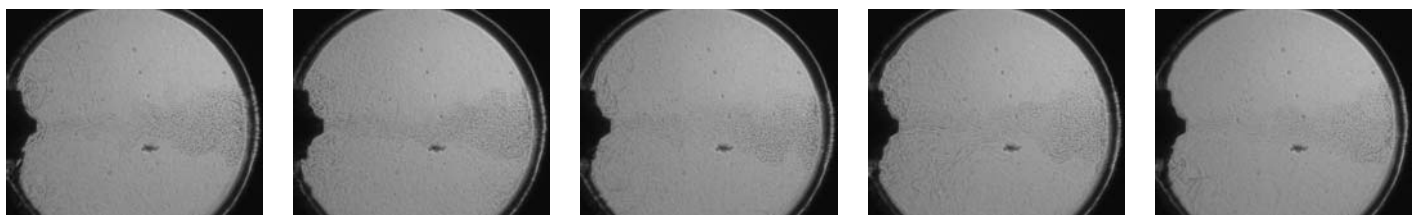


470.1 ms *470.2 ms* *470.3 ms* *470.4 ms* *470.5 ms*

Schlieren

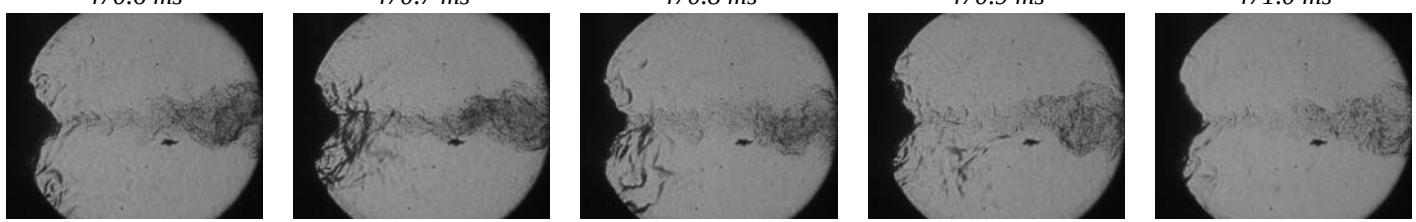


Shadowgraph



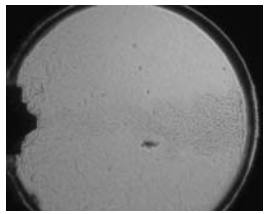
470.6 ms *470.7 ms* *470.8 ms* *470.9 ms* *471.0 ms*

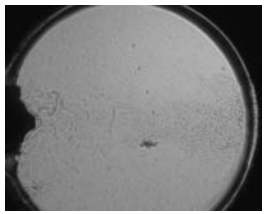
Schlieren

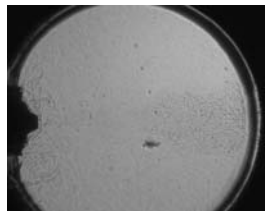


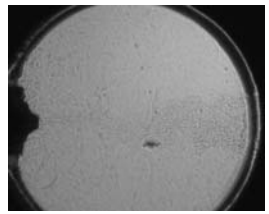
Pilot Injection (5)

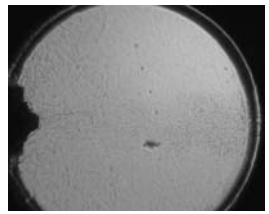
Shadowgraph


471.1 ms

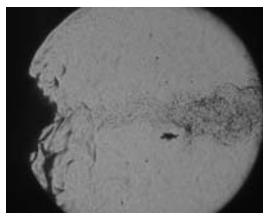

471.2 ms

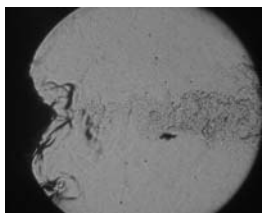

471.3 ms

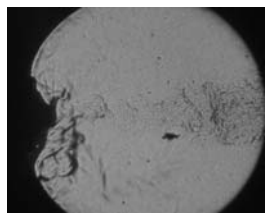

471.4 ms

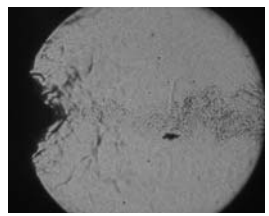

471.5 ms

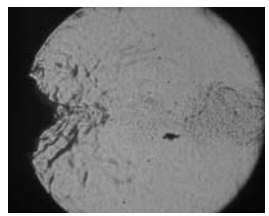
Schlieren



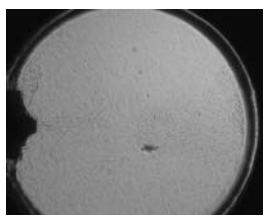


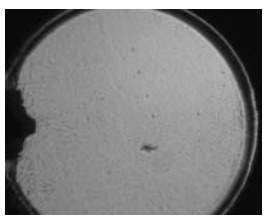


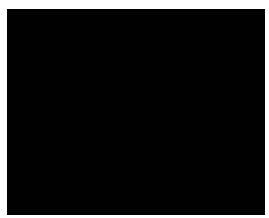


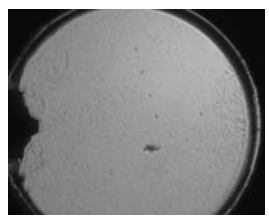


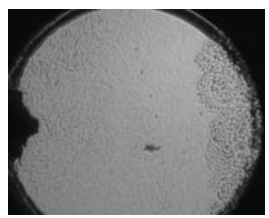
Shadowgraph


472.5 ms

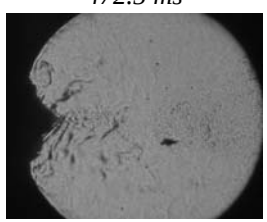

473.5 ms

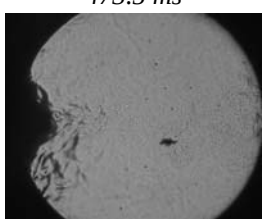

474.5 ms

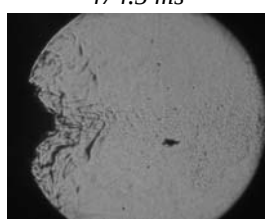

475.0 ms

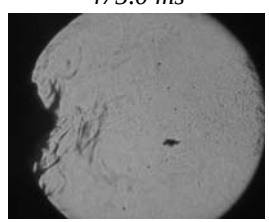

475.5 ms

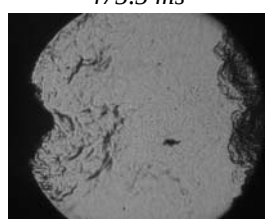
Schlieren





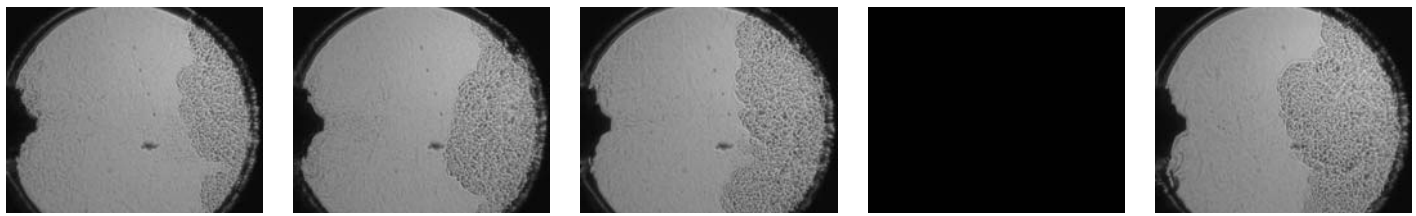






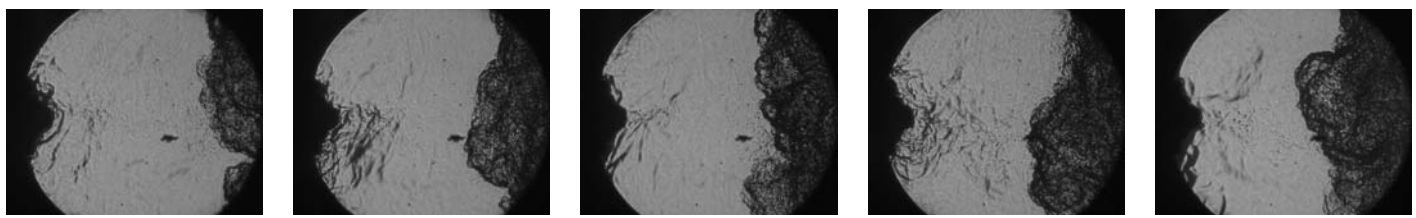
Pilot Injection (6)

Shadowgraph



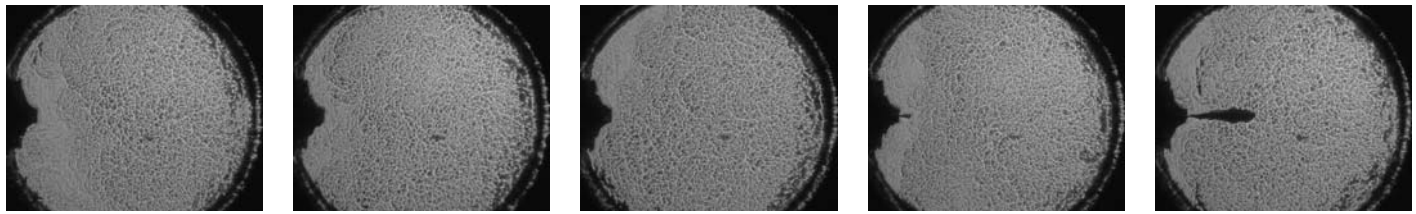
476.0 ms *476.5 ms* *477.0 ms* *477.5 ms* *478.0 ms*

Schlieren



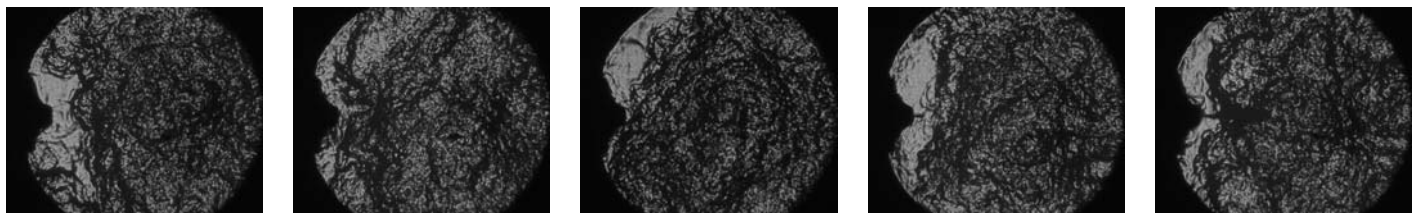
Main Injection (1)

Shadowgraph

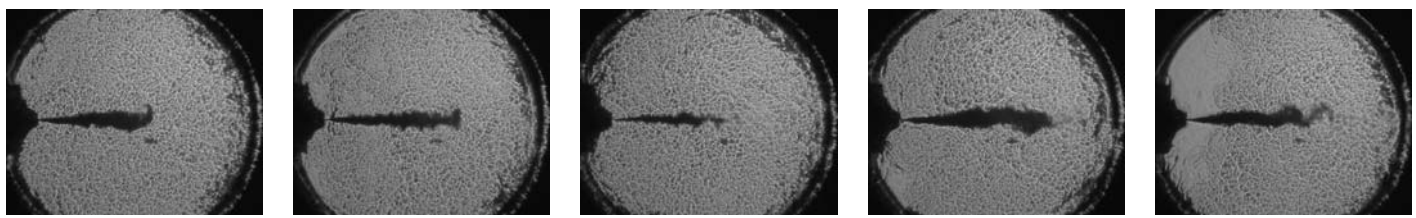


500.0 ms *500.5 ms* *500.6 ms* *500.7 ms* *500.8 ms*

Schlieren

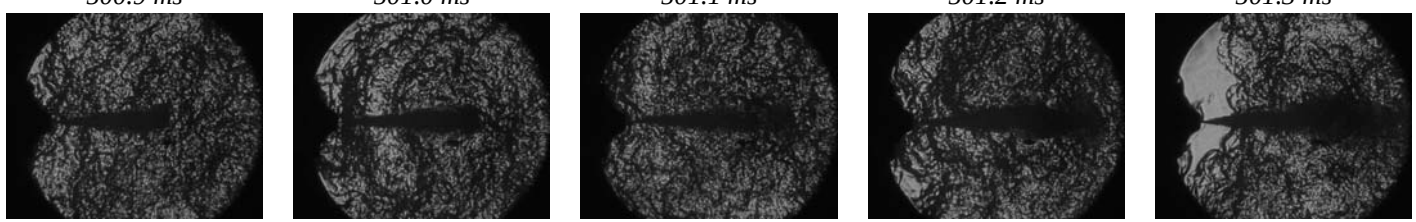


Shadowgraph



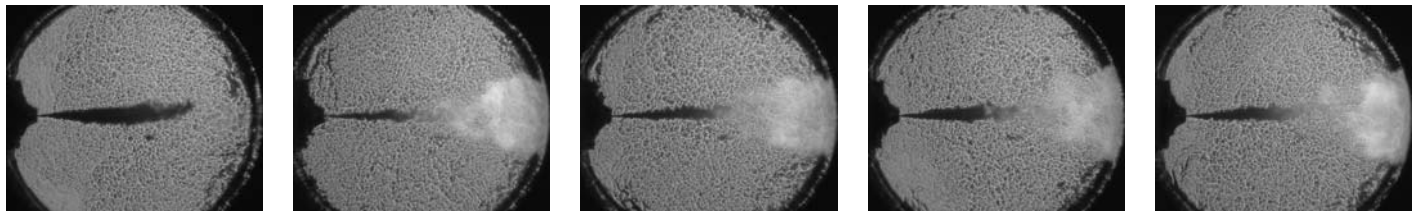
500.9 ms *501.0 ms* *501.1 ms* *501.2 ms* *501.3 ms*

Schlieren



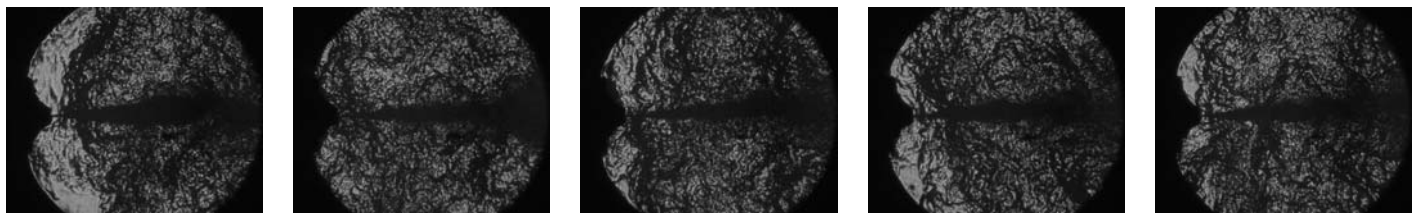
Main Injection (2)

Shadowgraph

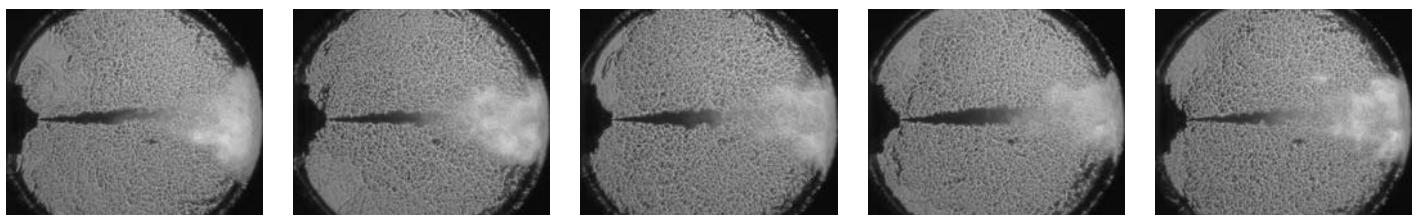


501.4 ms | 501.5 ms | 501.6 ms | 501.7 ms | 501.8 ms

Schlieren

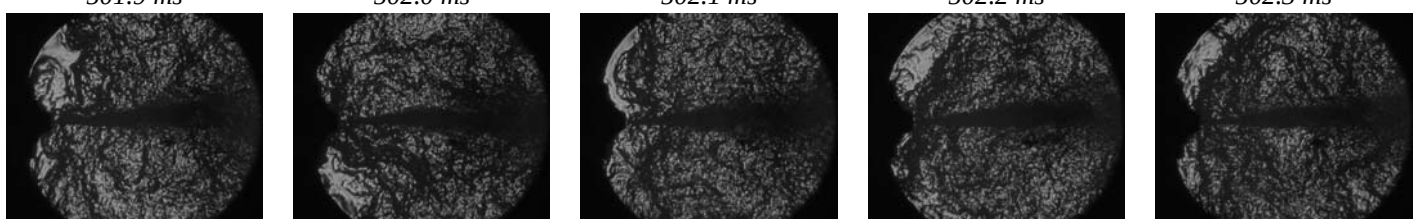


Shadowgraph



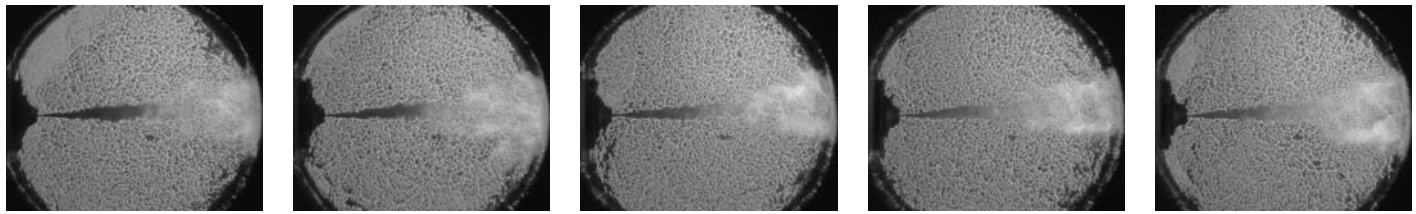
501.9 ms | 502.0 ms | 502.1 ms | 502.2 ms | 502.3 ms

Schlieren



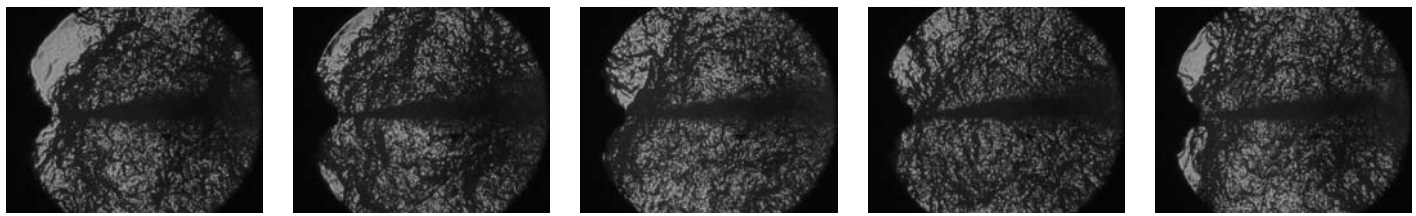
Main Injection (3)

Shadowgraph

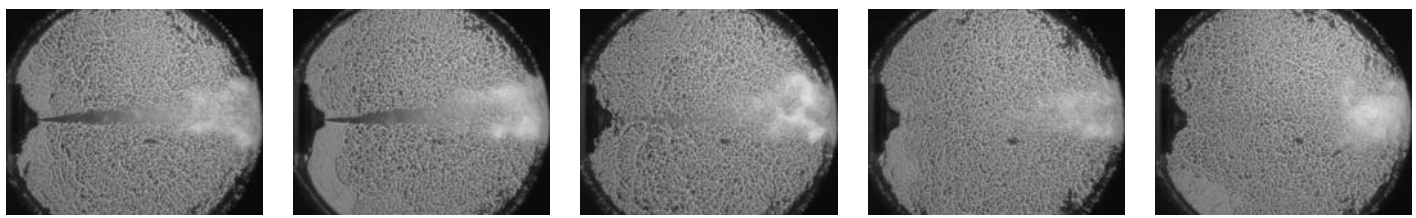


502.4 ms *502.5 ms* *503.5 ms* *504.5 ms* *504.6 ms*

Schlieren

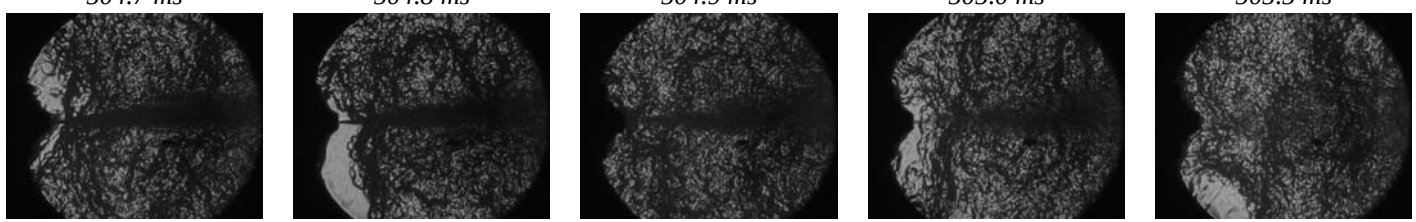


Shadowgraph

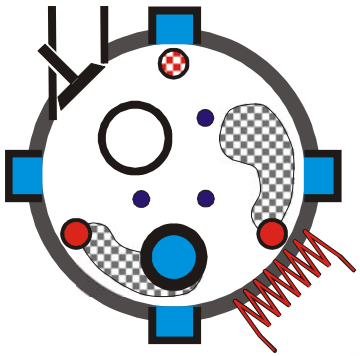


504.7 ms *504.8 ms* *504.9 ms* *505.0 ms* *505.5 ms*

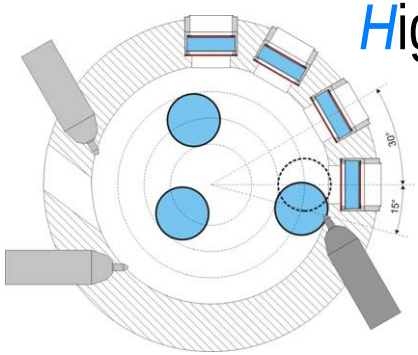
Schlieren



kick-off meeting

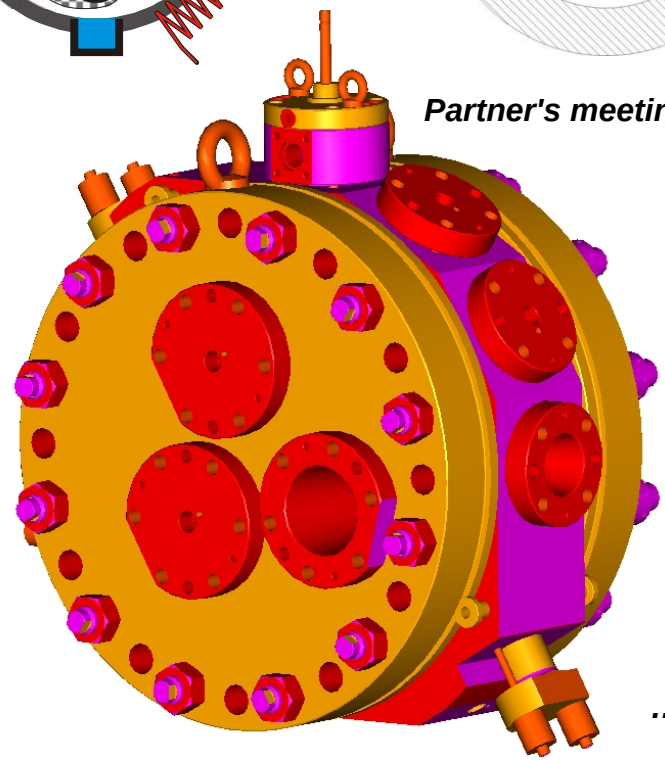


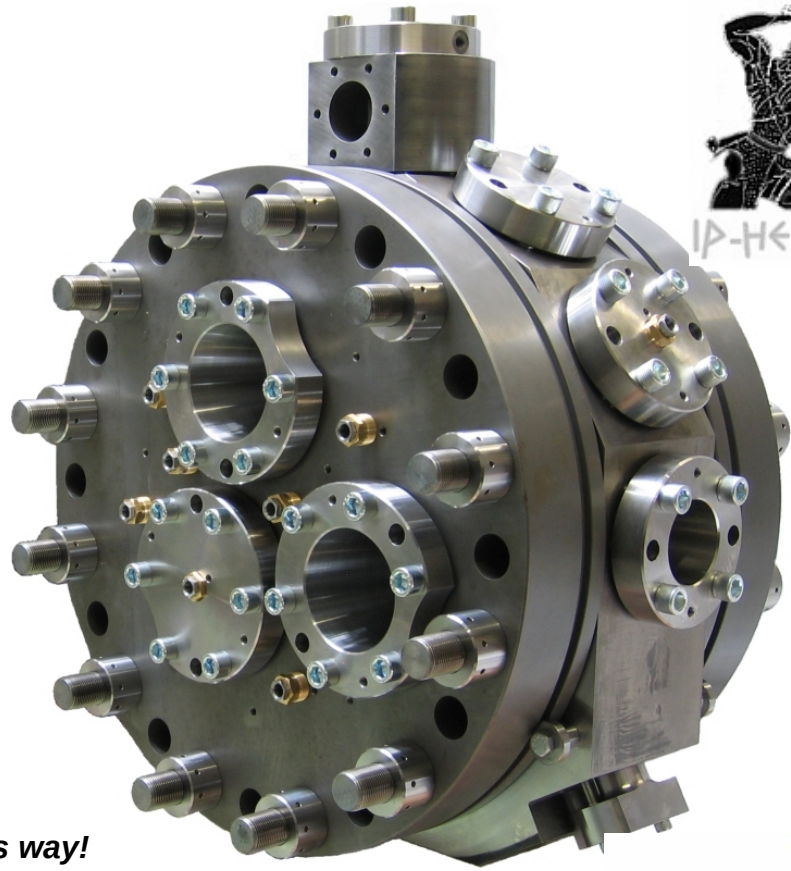
Partner's forum Helsinki



*H*igh *E*fficiency Engine *R*&D on *C*ombustion with *U*ltra-*L*ow *E*missions for *S*hips

Partner's meeting PSI

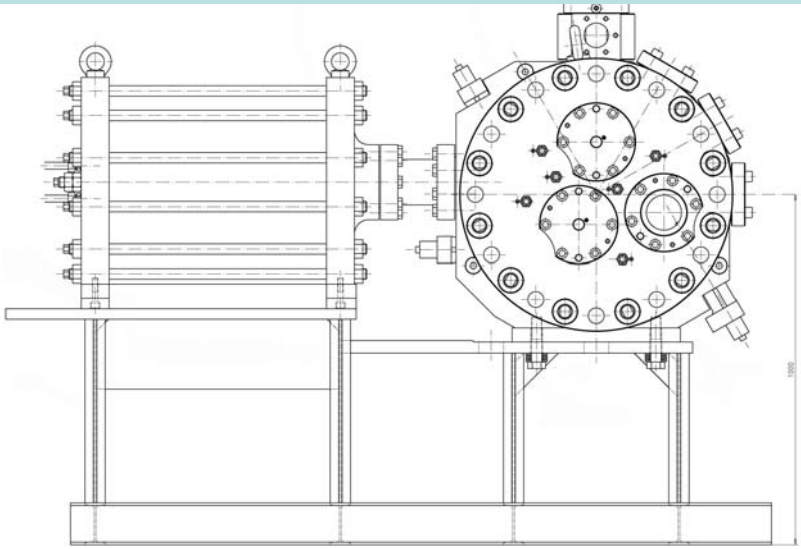


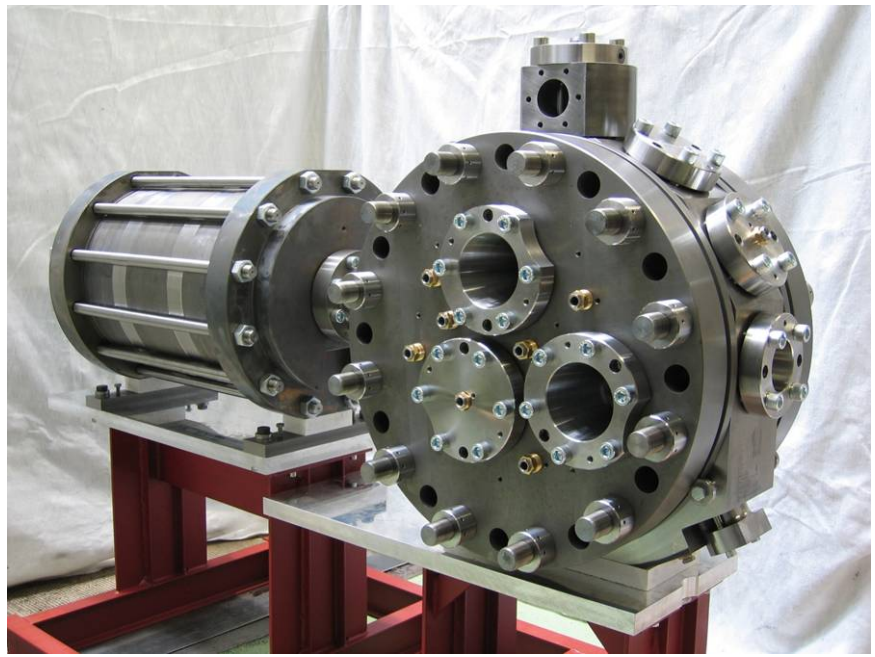


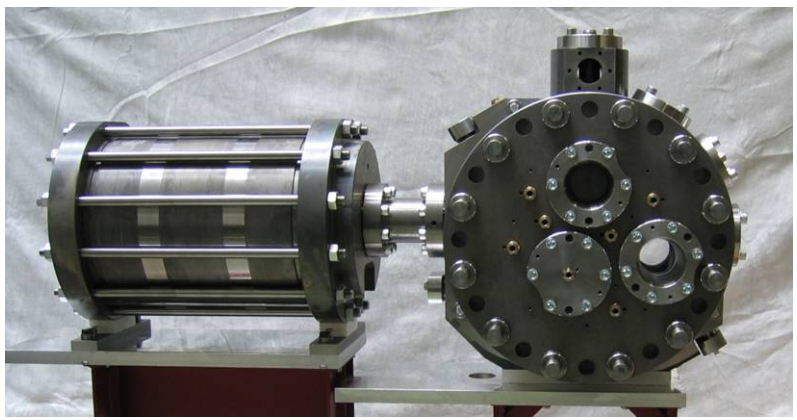
… it's on its way!

Spray/Combustion Chamber

Spray/Combustion Chamber Facility



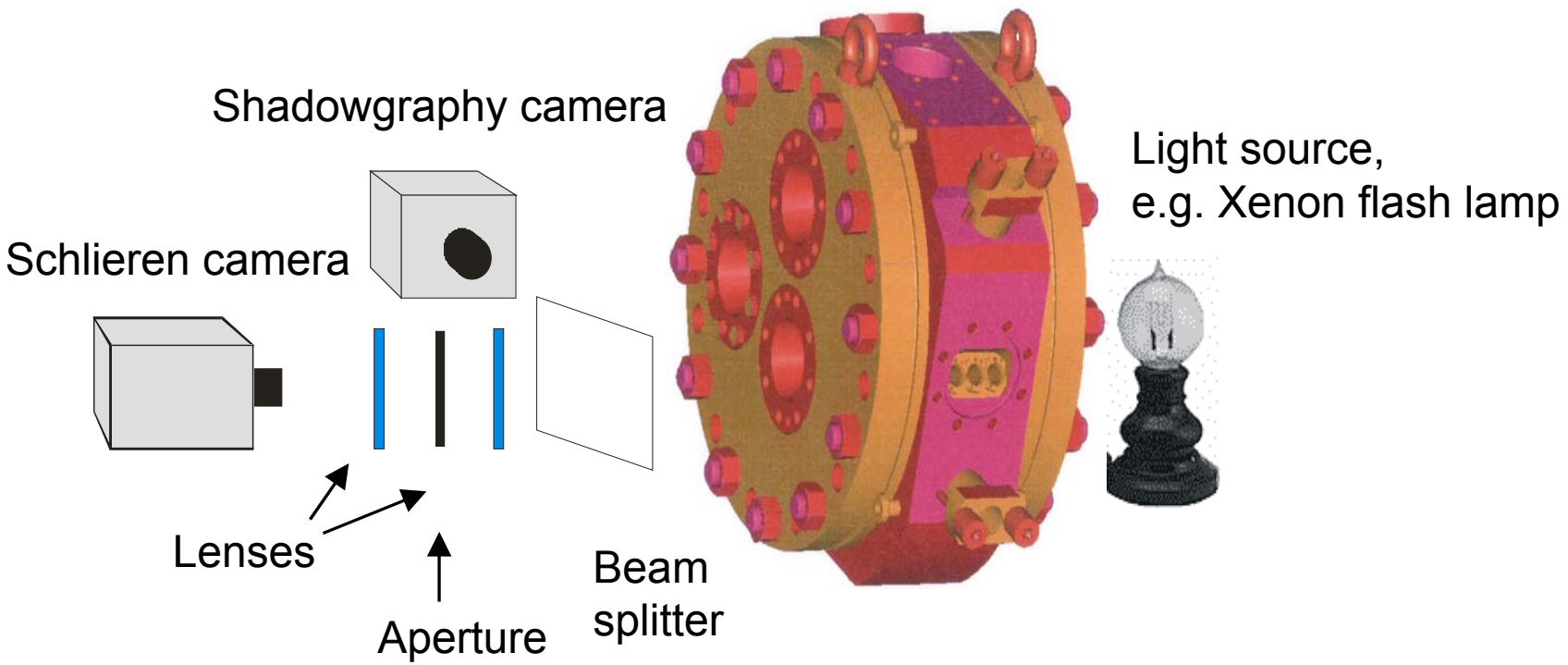




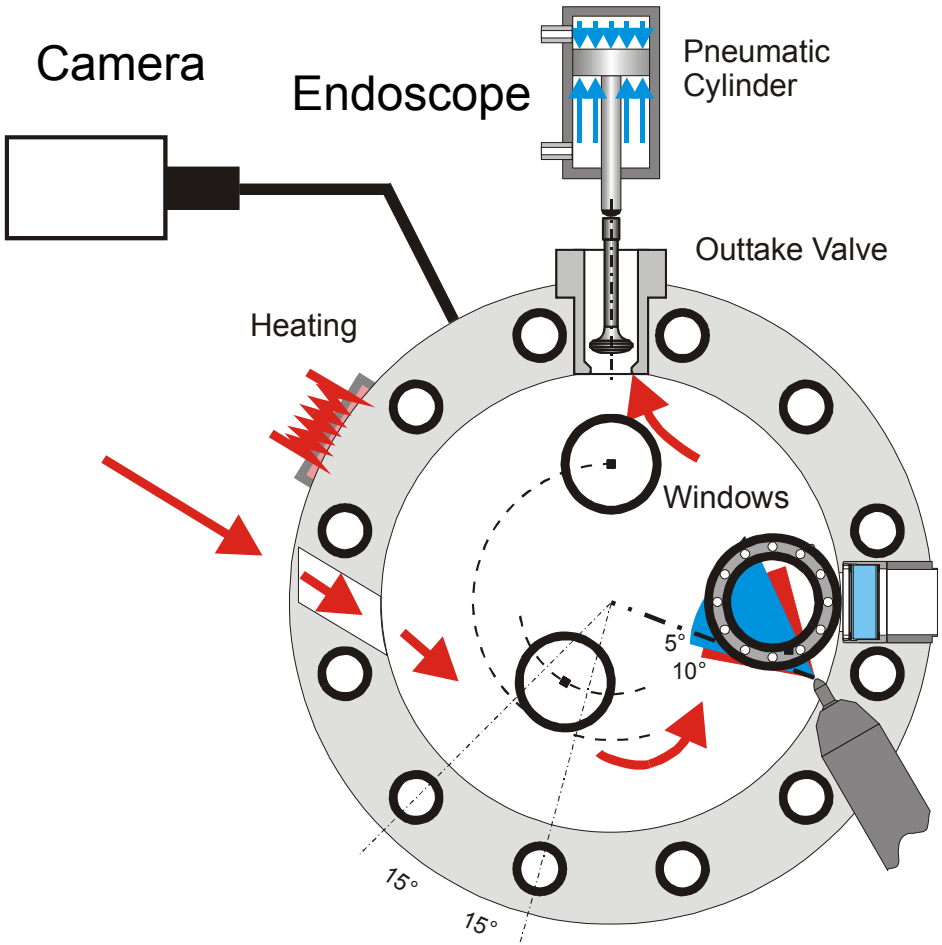
Shadowgraphy and Schlieren at Wärtsilä's test rig

Shadography without aperture or knife edge → visualizes light ray displacements in image plane

Schlieren visualizes $\partial n/\partial y$



What can we measure with Shadowgraphy and Schlieren?



Parameters:

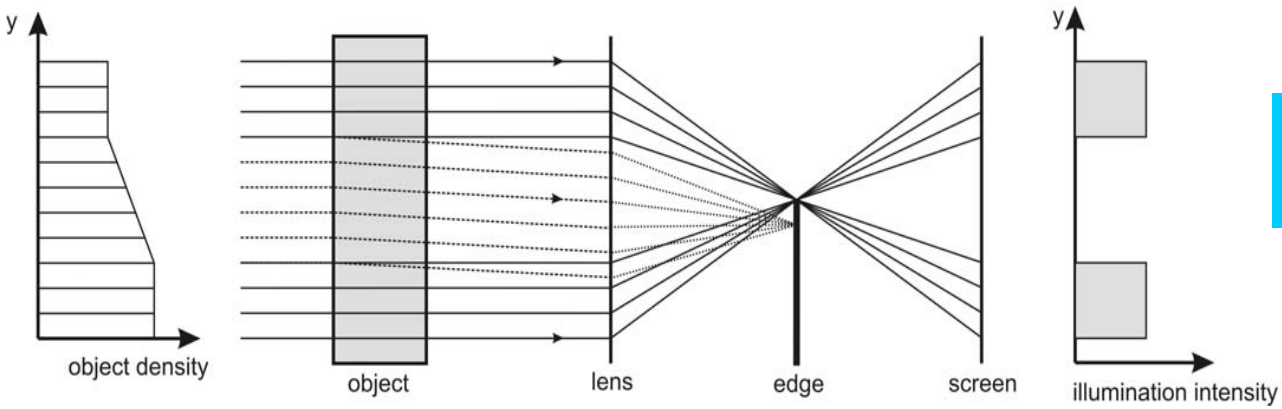
- Spray angle, penetration depth
- distinction between liquid/gaseous phase

(simultaneous shadowgraphy and schlieren)

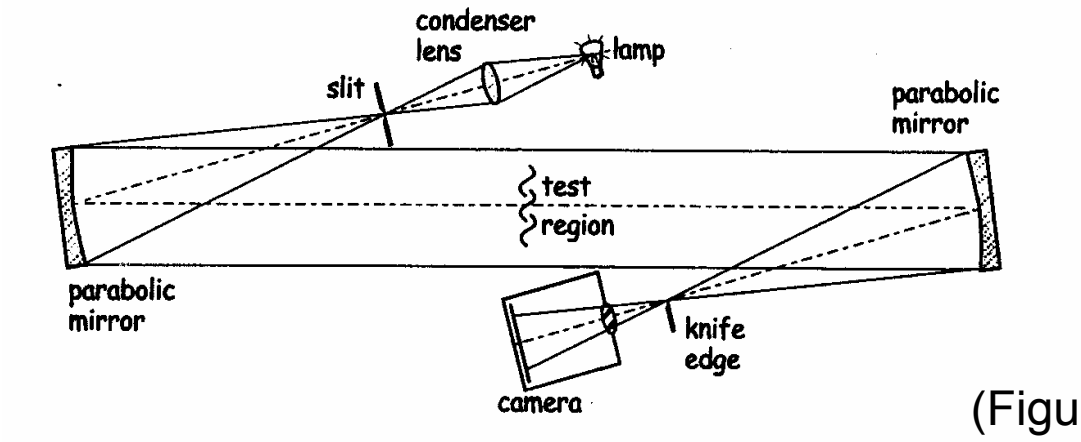
Issues:

- Limited field of view through windows
  → use endoscope

Principle of shadowgraphy and schlieren



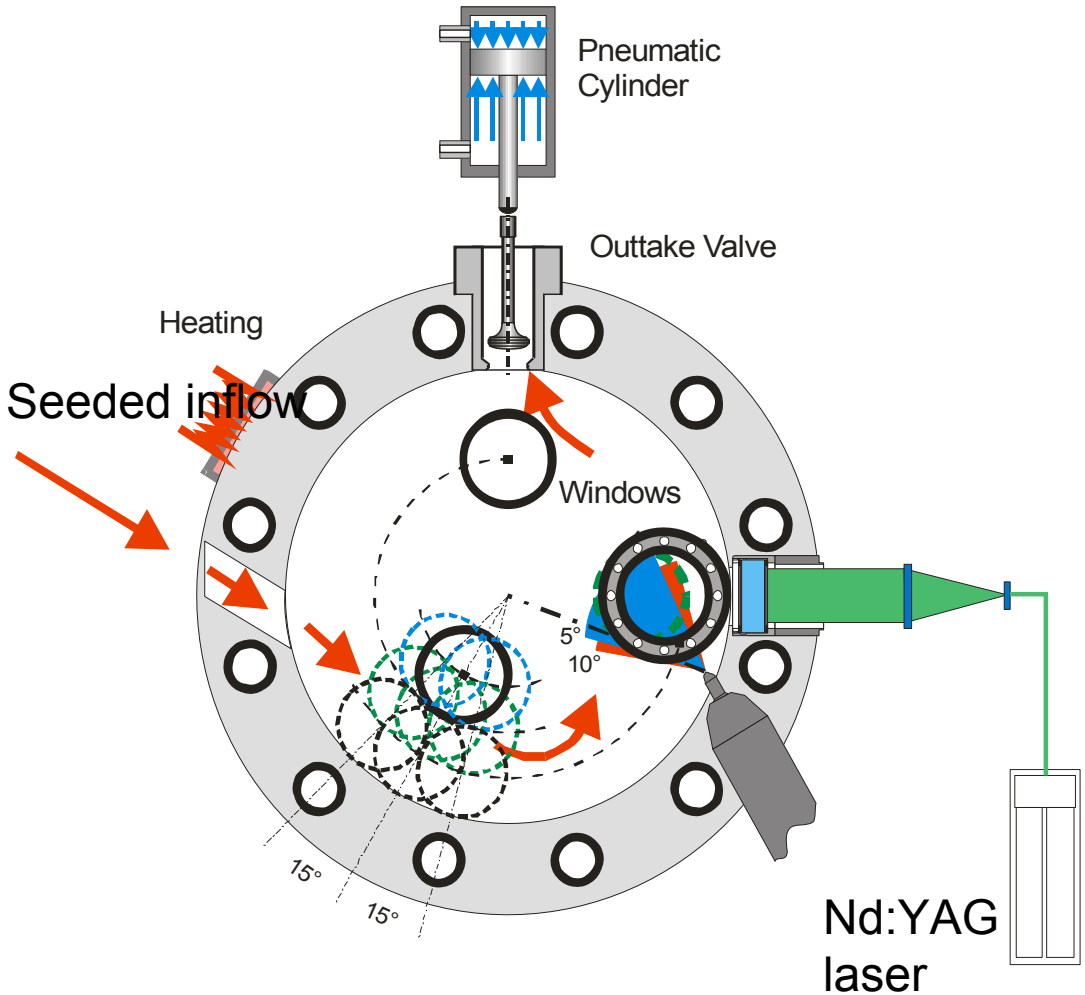
Schlieren visualizes
$\partial n / \partial y$



Shadography without aperture or knife edge → visualizes light ray displacements in image plane

(Figure from: Settles, 2001)

What can we measure with PIV ?



Issues:

- snapshot every 15 min (test cycle is limiting factor)
- Characterization of the flow field of the entire cell is prohibitive (window locations to be chosen very carefully)

Parameters:

- tangential velocity profile, decay of swirl (S=f(t))
- time delay between interaction of fuel sprays

2-color TIRE LII + spectral measurements

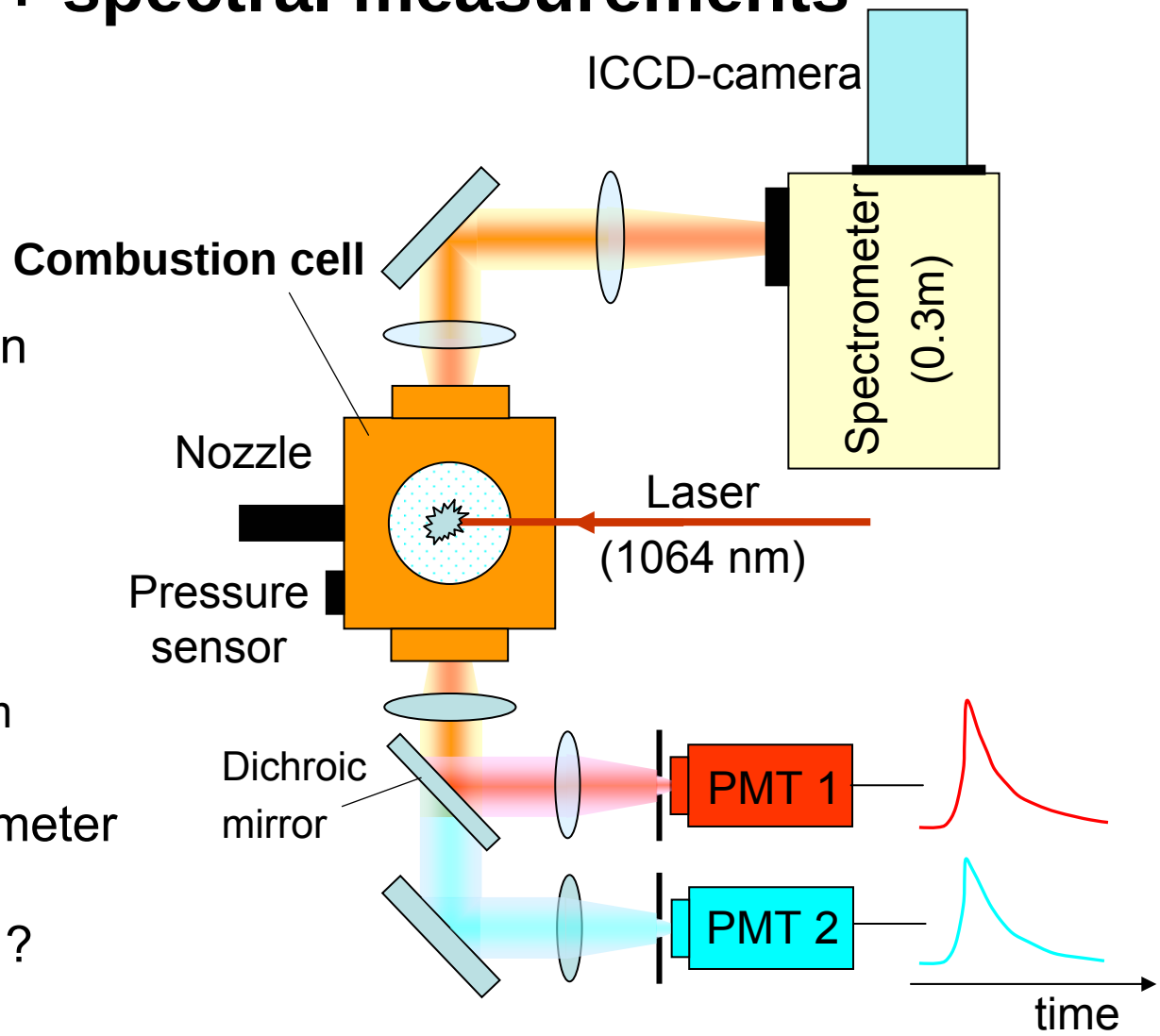
BB spectrum:

Temperature of
→ Laser-heated soot
→ Natural soot emission

2-color TIRE-LII:

Excitation @ 1064 nm
Detection @ 450 + 650 nm

→ Ensemble mean diameter
→ Laser heated particle temperature ?



Single-pulse TIRE LII signal evaluation

LSQ-fit of LII signal transients at high pressures:

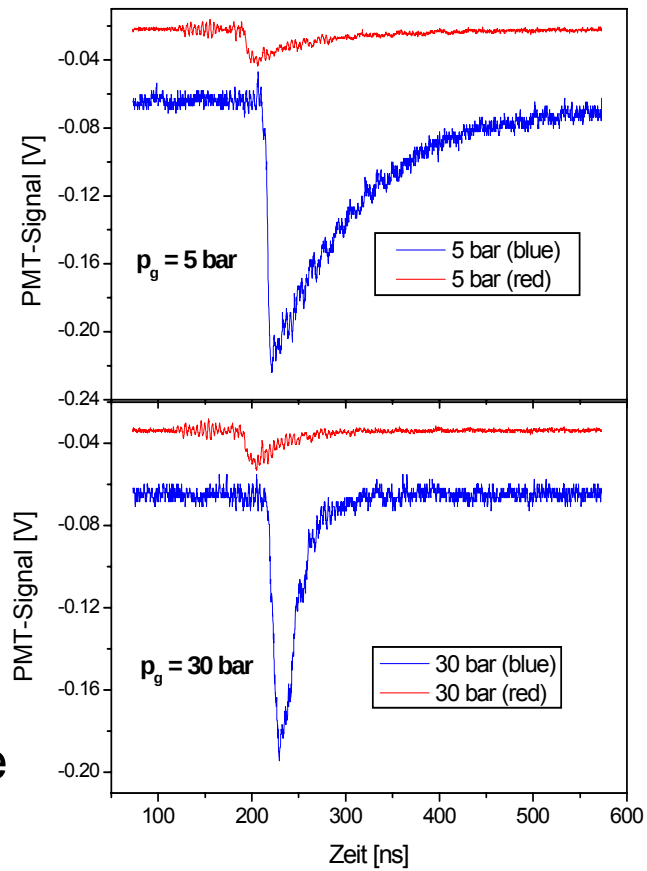
Method: Levenberg-Marquart

LII sub-model:
- „Kock“ et al.
- lognormal SDF
- spatially resolved intensity in probe beam volume

Known parameter: p_{gas}

Constrained fit parameters: T_{gas}, d_p

Fixed parameters: σ_g, laser fluence

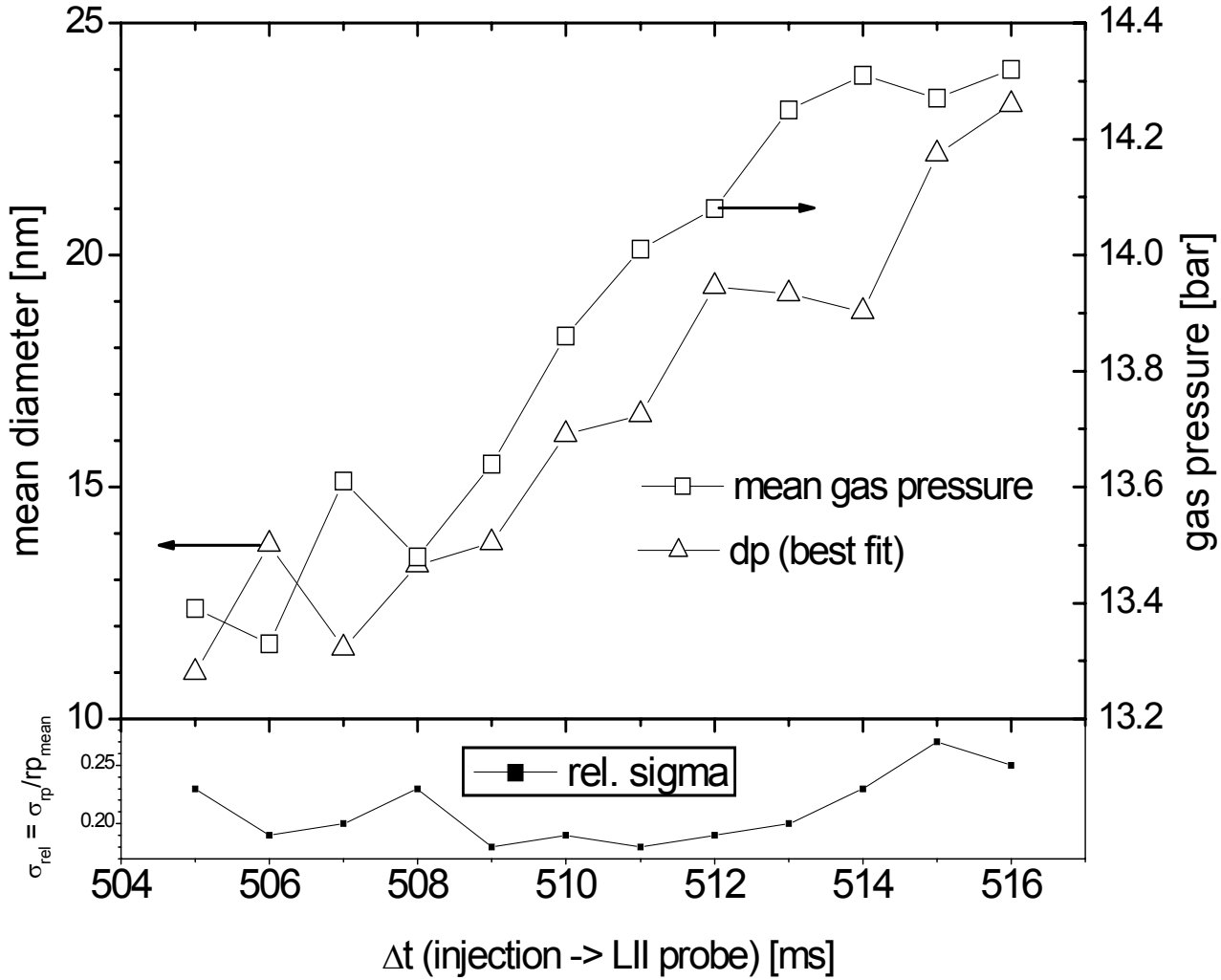


Single-pulse TIRE LII signal evaluation

Ensemble mean particle diameter during high pressure spray combustion

Varied:

Laser probe delay after time of fuel injection



"RAYLIX" simultaneous Rayleigh, LII & Extinction

(Suntz / Bockhorn et al.: PCCP **4**, 3780 (2002)):

$(f_v / N_v / r_m)$

- instantaneous
- imaging
- temporally resolved
- quantitative ?