# RayLIX

## (Rayleigh Scattering, Laser Induced Incandescence, Laser Extinction)

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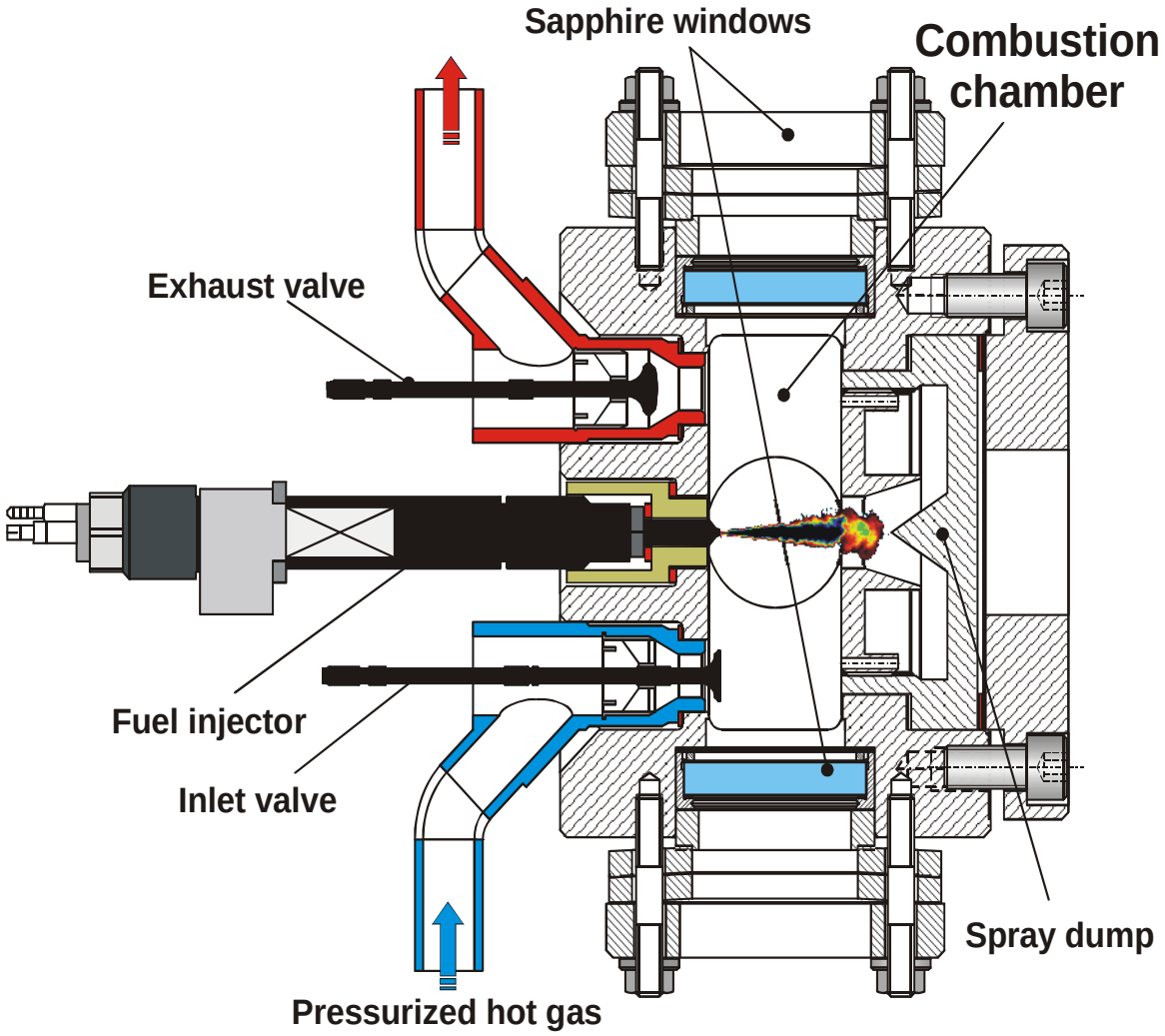
# *Hoch*Temperatur-*Druck*Zelle (*HTDZ*)




**Full optical access: design for 4 sapphire windows**

**Pre-combustion technique → higher end gas temperature**

*Pilot injection:*

- **100-1020 bar** injection pressure
- **2-80 bar** air pressure
- **760 K** air temperature

*Main injection*

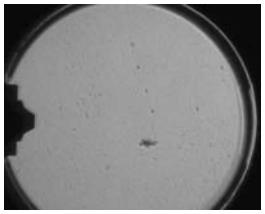
- **860 K** air temperature

# Applied techniques

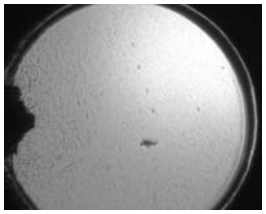
- ***Shadowgraphy:*** **density, extinction**
  - dense regions of spray, penetration depth and dispersion
- ***Laser scattering:*** **~$d^6$, bias to larger particles**
  - gas/vapor/liquid phases, particles
- ***Emission imaging:*** **VIS-UV**
  - chemiluminescence, flame structure, thermal soot emission
- ***Laser induced incandescence (LII):*** **~$d^3$**
  - soot volume fraction
- ***Time-resolved LII:*** **transient thermal radiation**
  - ensemble averaged particle diameter

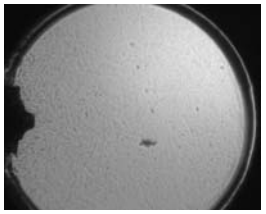
# Pilot Injection (1)

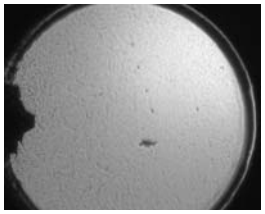
Shadowgraph


*Without Injection*

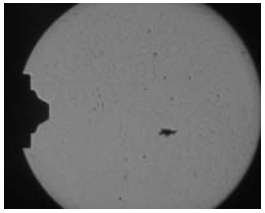

*465.0 ms*

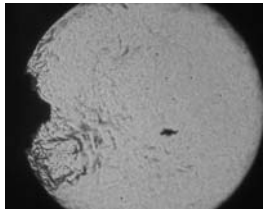

*465.5 ms*

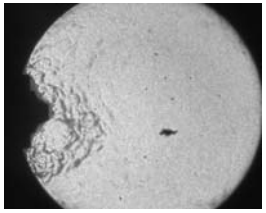

*465.6 ms*

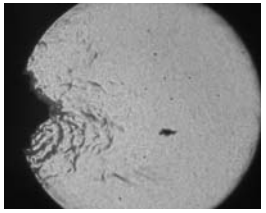

*465.7 ms*

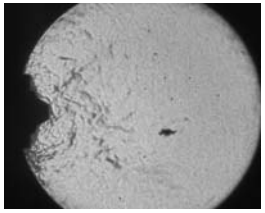
Schlieren





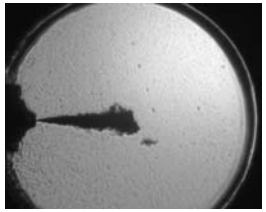


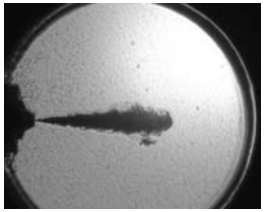


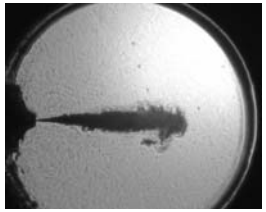


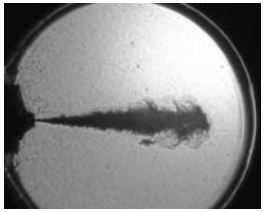
Shadowgraph


*465.8 ms*

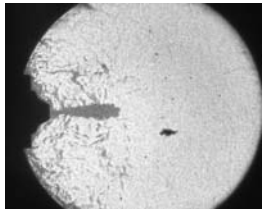

*465.9 ms*

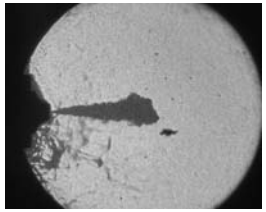

*466.0 ms*

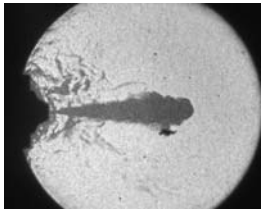

*466.1 ms*


*466.2 ms*

Schlieren





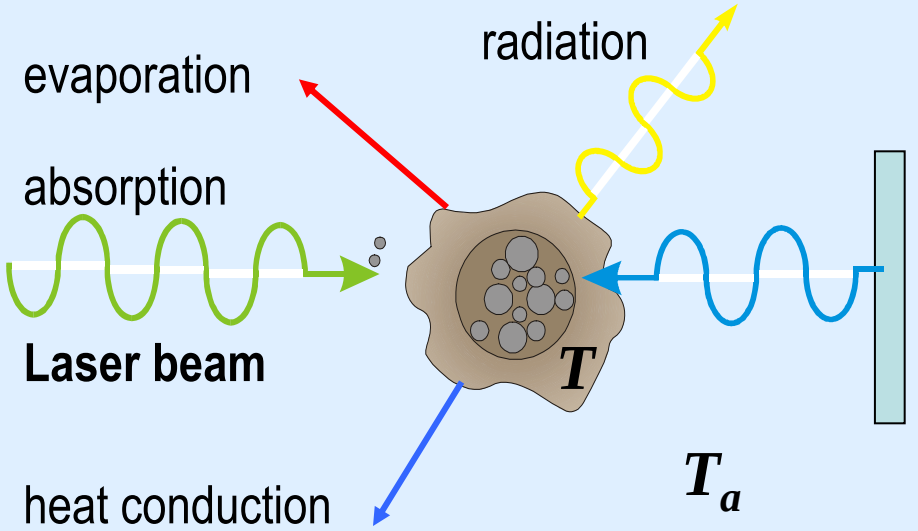


# Time resolved laser-induced incandescence (TIRE-LII)

## *in-situ particle sizing*

***Mass balance***

$$\frac{dM_s}{dt} \propto C_{abs} q \frac{W_v}{\Delta H_v}$$

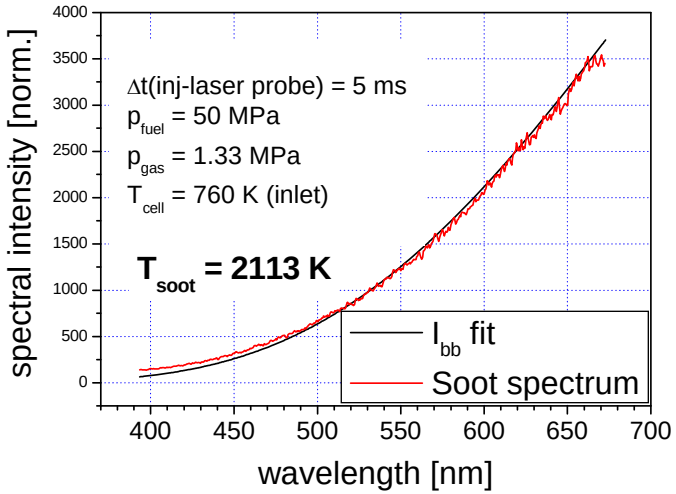


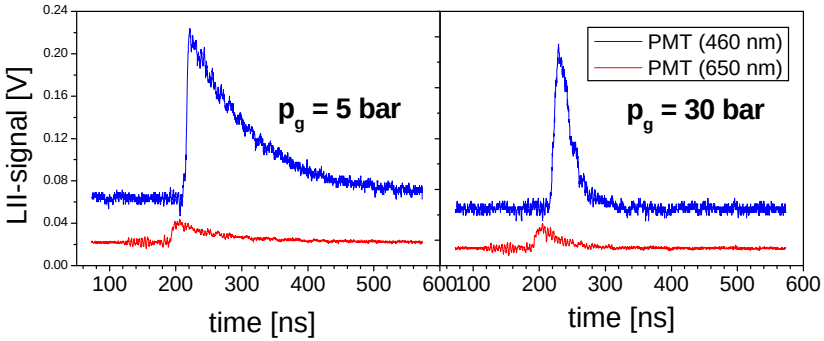

***Energy balance***

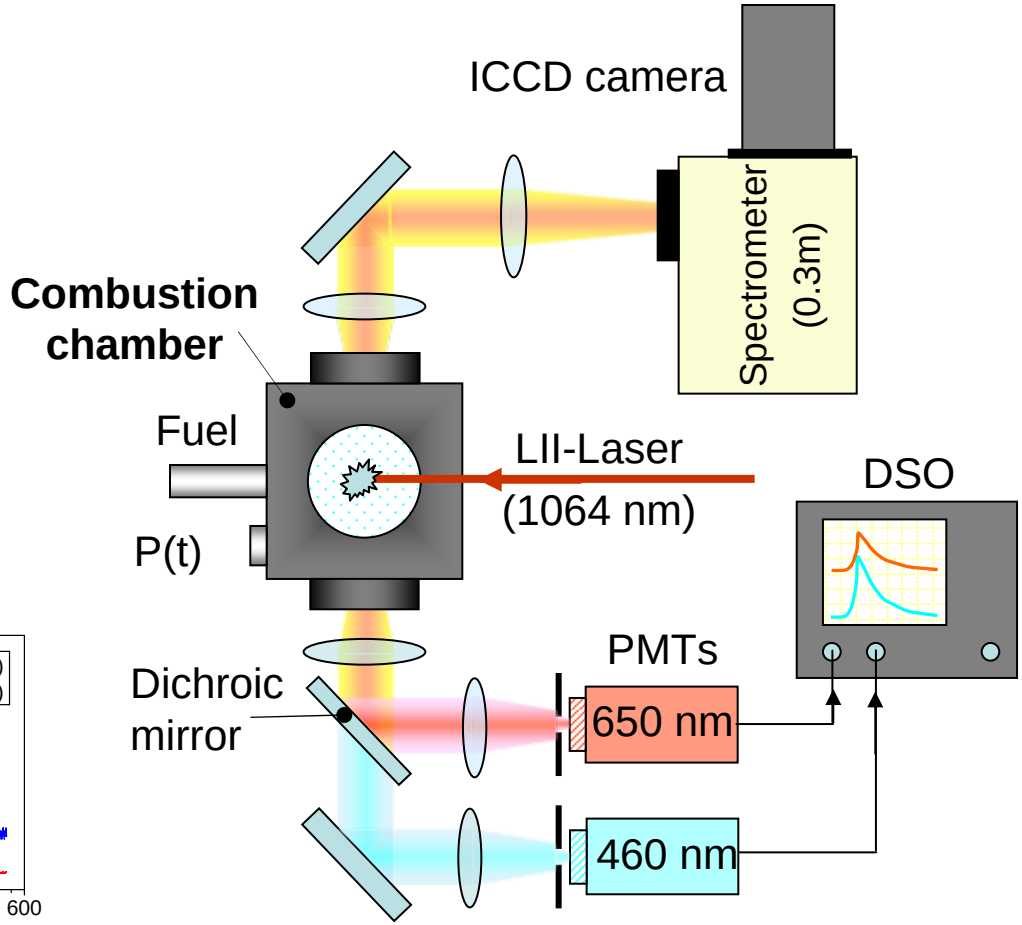
$$r^3 \rho_s C_{p,s} \frac{dT}{dt} \propto C_{abs} I_{laser} - \frac{T - T_a}{\lambda_{gas}} r^2 - \sigma_{SB} r^2 (T^4 - T_a^4) - \Delta H_v \rho_v U_v r^2$$

internal energy | absorption | heat cond. | radiation | evaporation

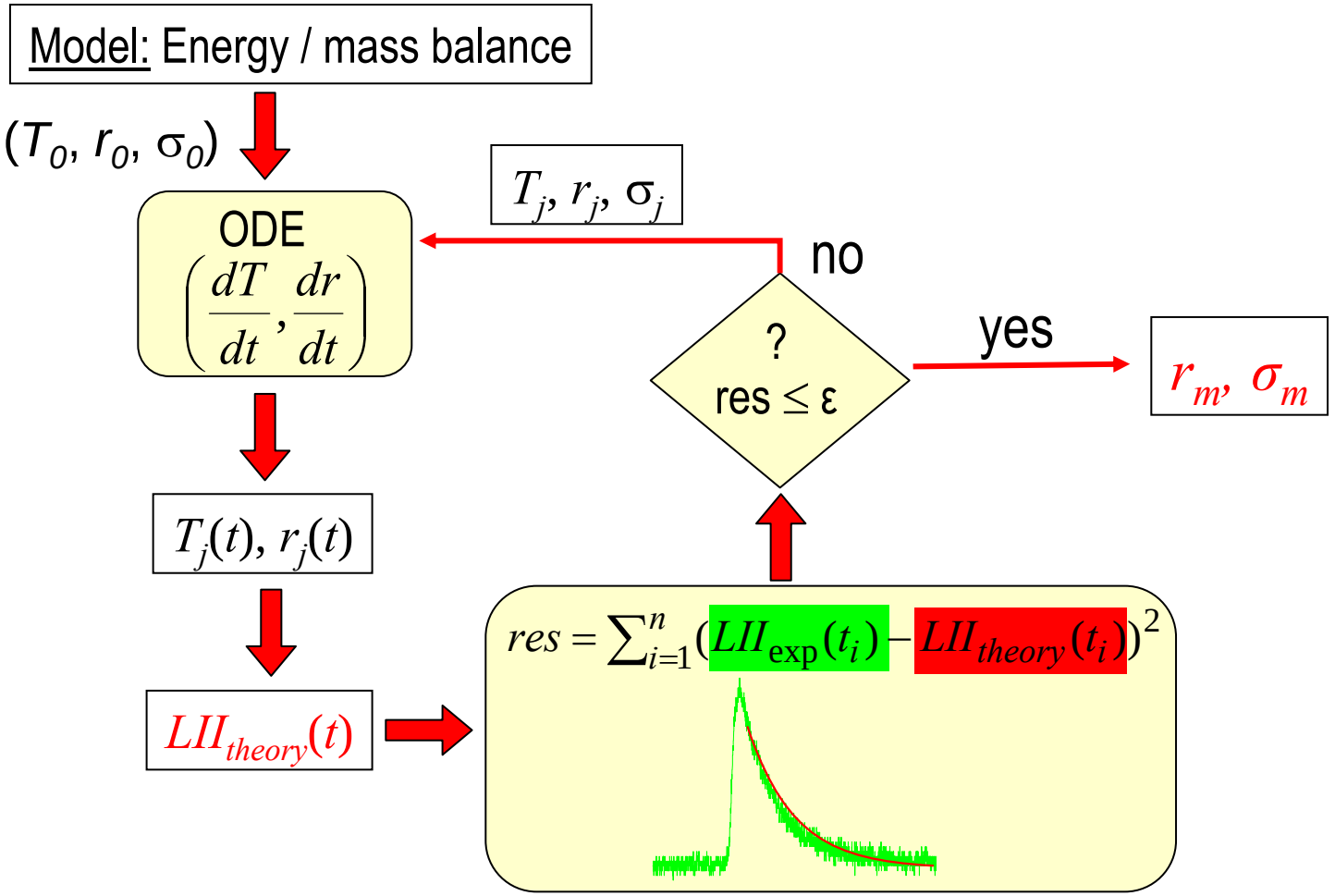
# 2-λ Time-Resolved LII



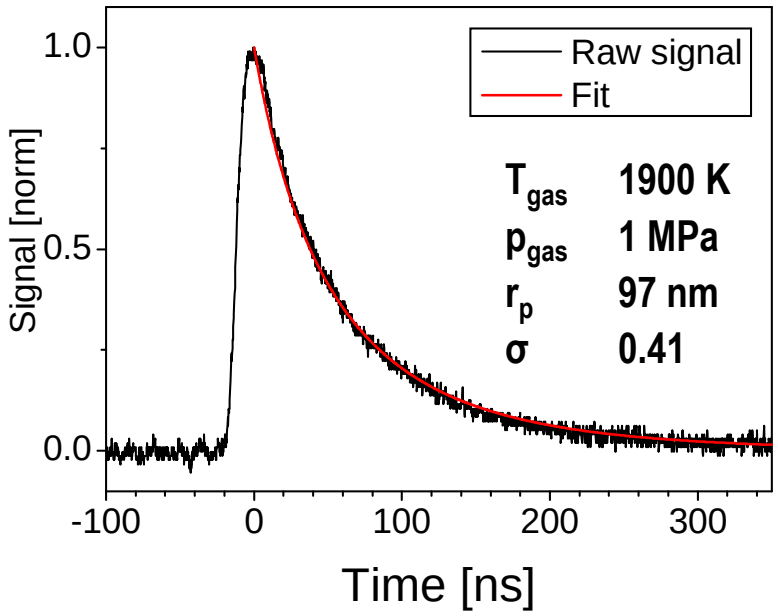



# LSQ Curve Fit Procedure

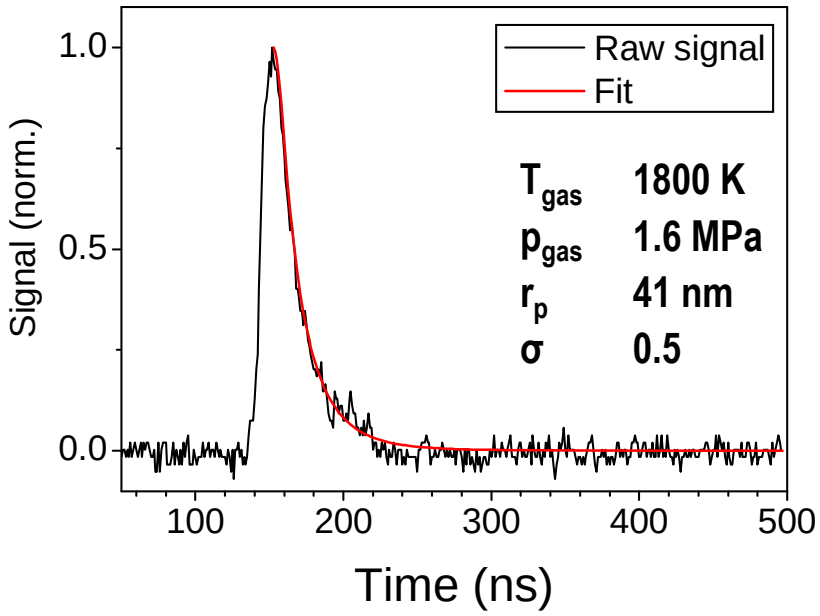


# TR-LII Measurements

## *PSI-HTDZ*




## *DAF Heavy-Duty Engine* *



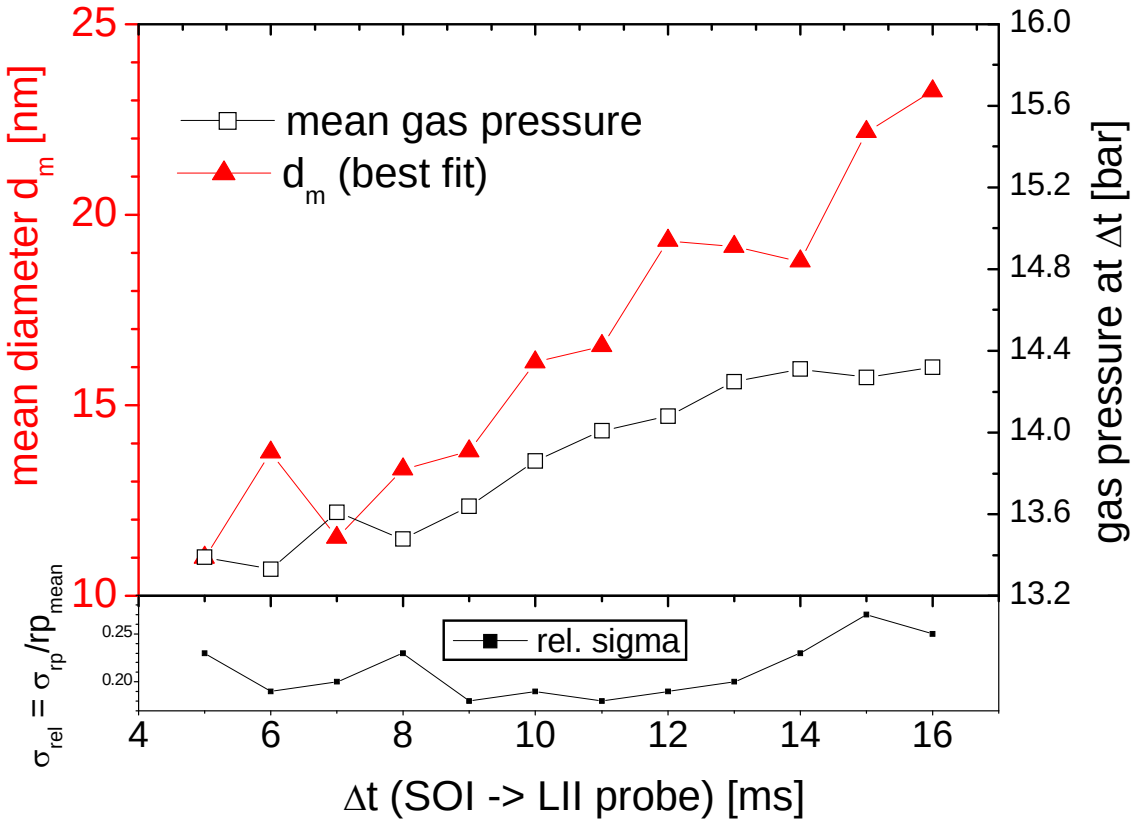

** B. Bougie et. al., University of Nijmegen, NL*

# Single-pulse TIRE LII signal evaluation

**Ensemble mean particle diameter during high pressure spray combustion**

Varied:

Laser probe delay after time of fuel injection



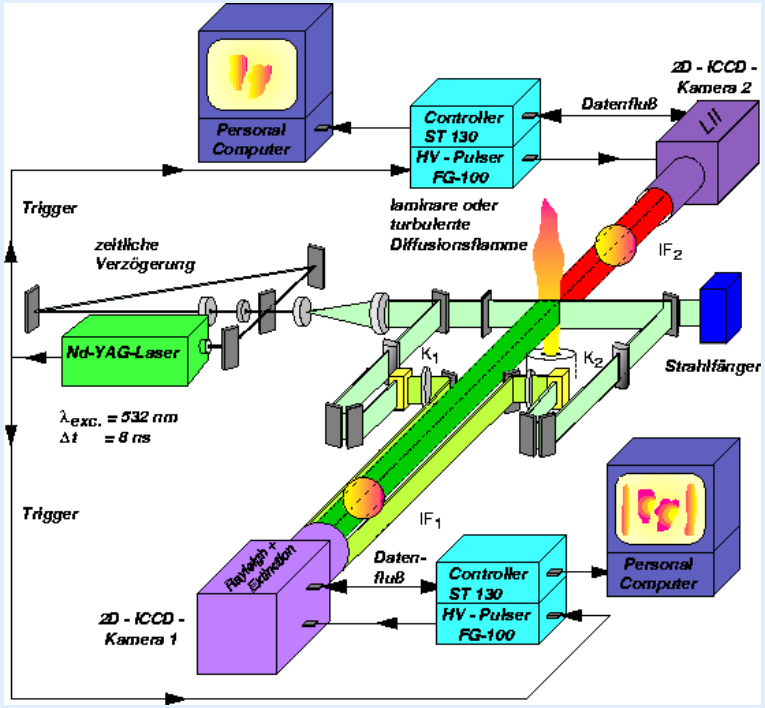
# Quantitative 2-D Soot Measurement by RayLIX

- Simultaneous use of
  - *Rayleigh Scattering* (particle diameter, particle number density)
  - *Laser-Induced Incandescence* (particle diameter, soot volume fraction)
  - *Laser Extinction* (laser absorption)

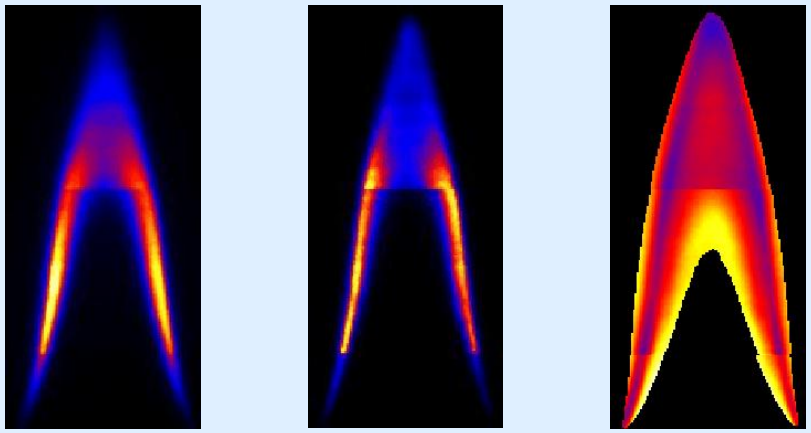
  to reduce the uncertainty of parameter estimations
  by the combination of independent techniques

# RAYLIX Applications (I)

## Laminar and turbulent diffusion flames




## Result for laminar diffusion flame

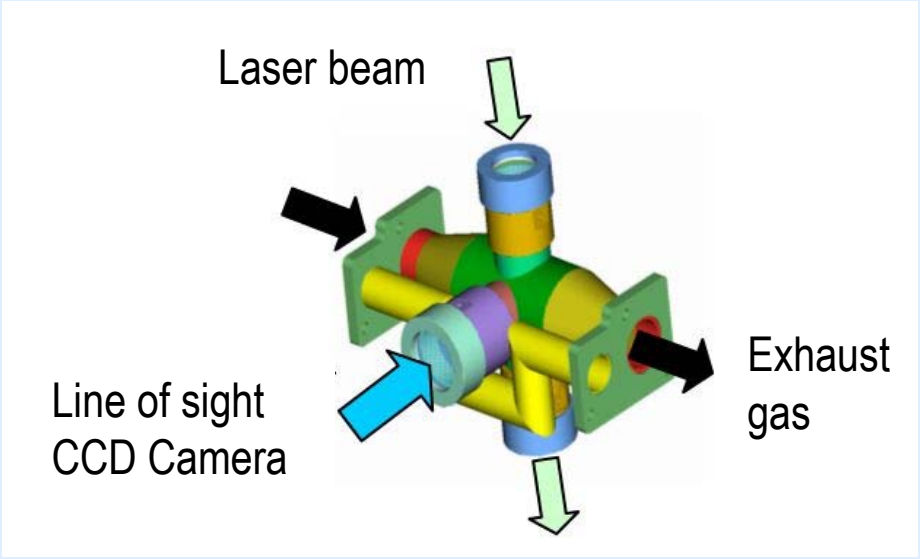


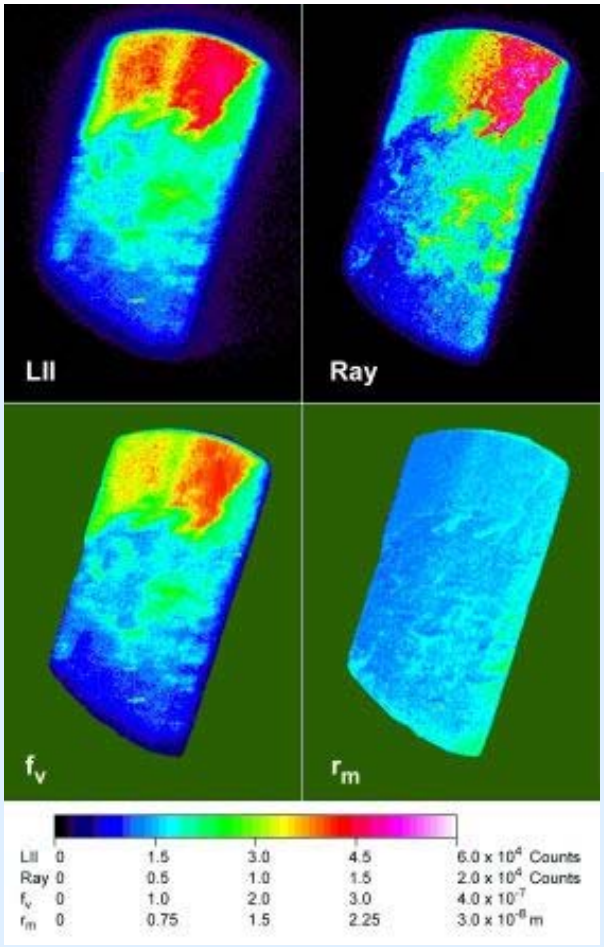
$f_v$ $N_v$ $R$

*R. Suntz et. al., University of Karlsruhe*

# RAYLIX Applications (II)

Exhaust of an Internal Combustion Engine




*in-situ, on-line* measurement

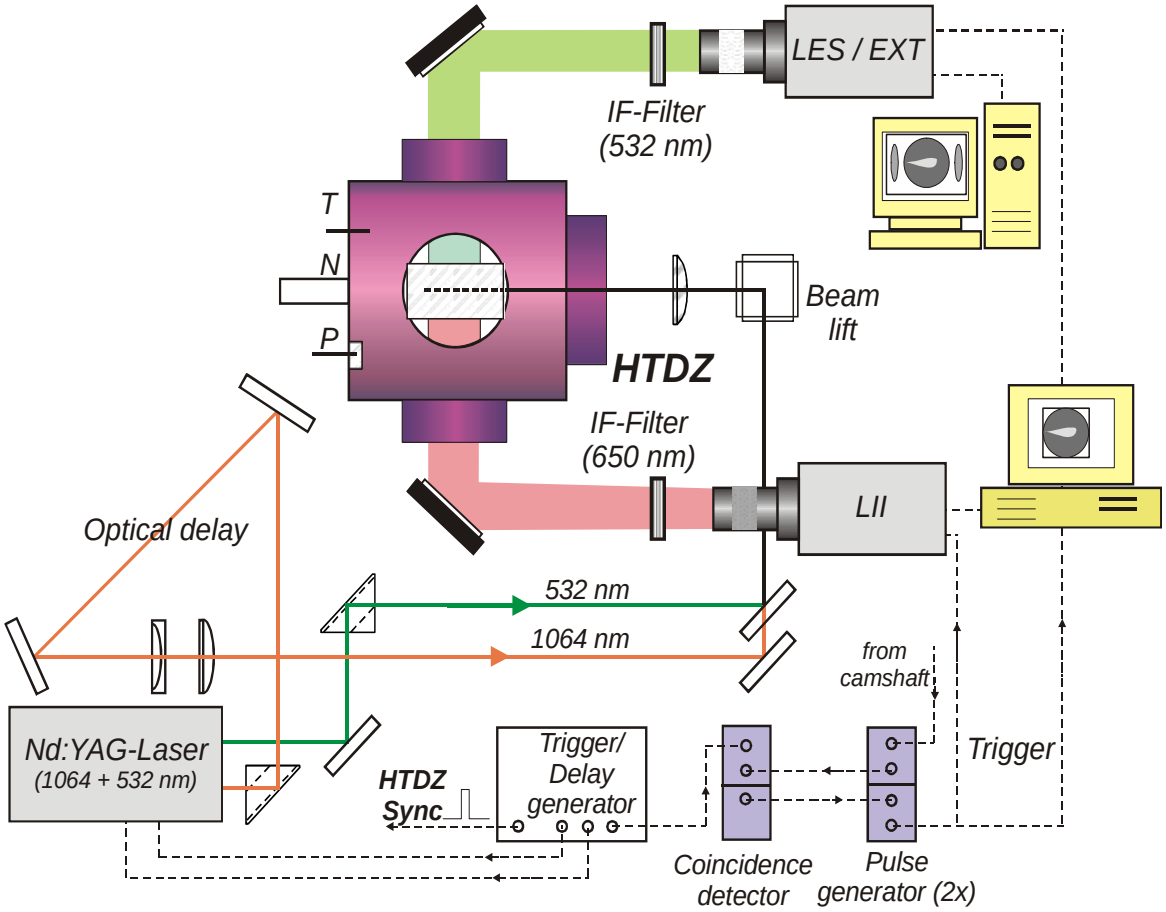
*U. Spicher et. al., University of Karlsruhe*

# "RAYLIX" simultaneous Rayleigh, LII & Extinction

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

$(f_v / N_v / r_m)$

- instantaneous
- imaging
- temporally resolved
- quantitative ?



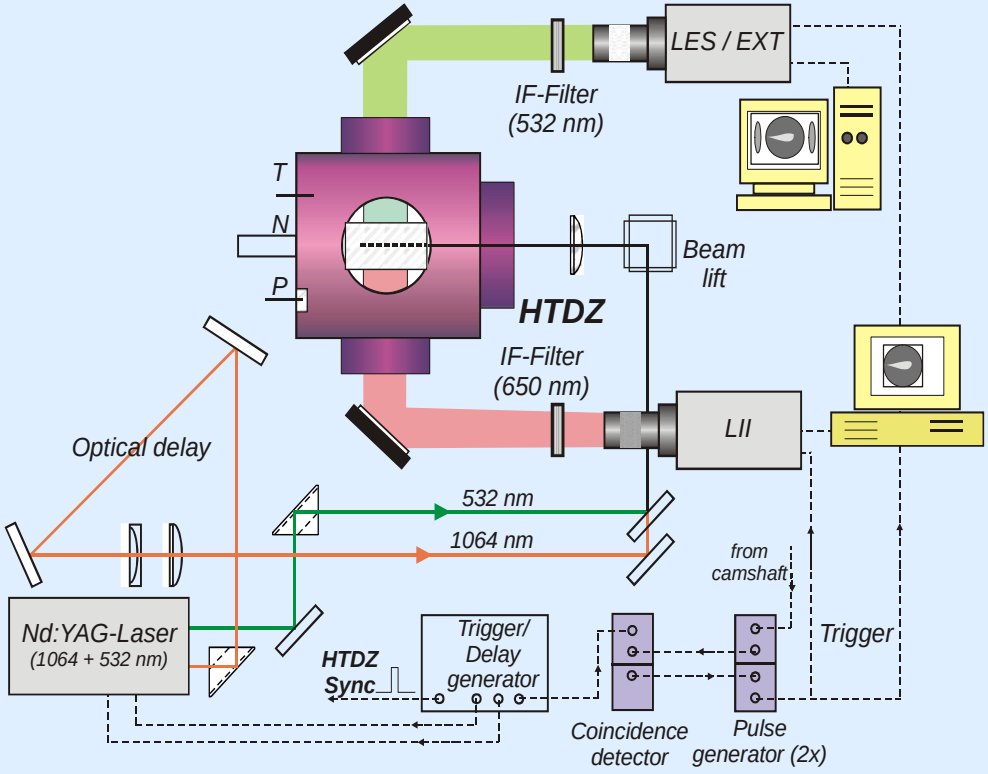
# Application of RAYLIX Technique at HTDZ

RAYLIX = Simulataneous Application of Rayleigh Scattering + LII + Laser Extinction

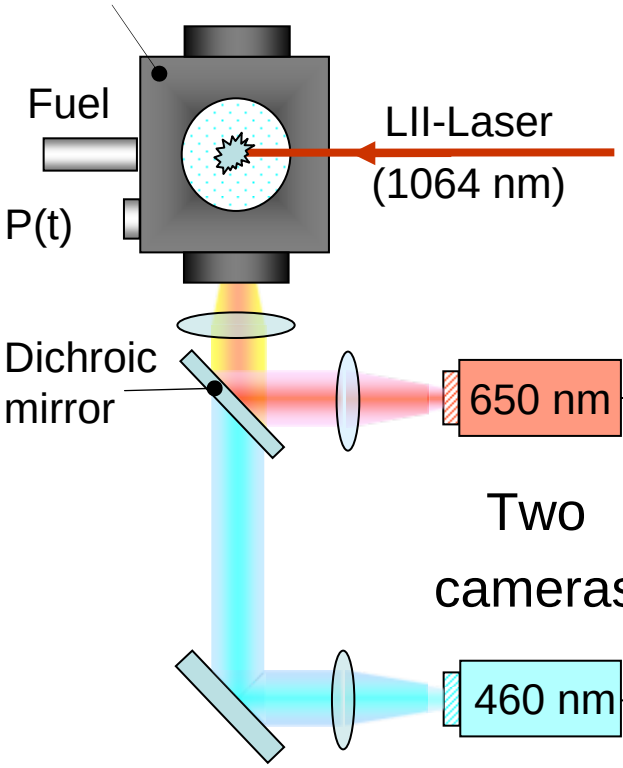
Suntz / Bockhorn et al.: PCCP **4**, 3780 (2002)

Determination of $f_v$, $N_v$, $r_m$

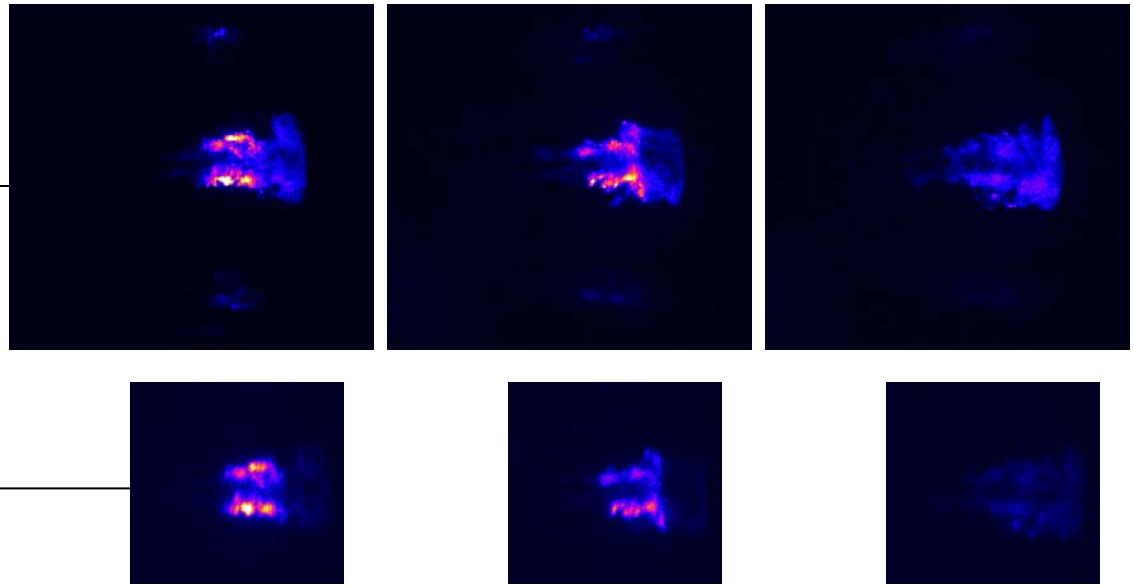
- instantaneously
- spatially resolved
- quantitative



# Novel LII setup with 2-d recording




Cell wall temperature: 350°C
Gas temperature (after pre-injection): 415°C
Pressure (after pre-injection): 40 bar

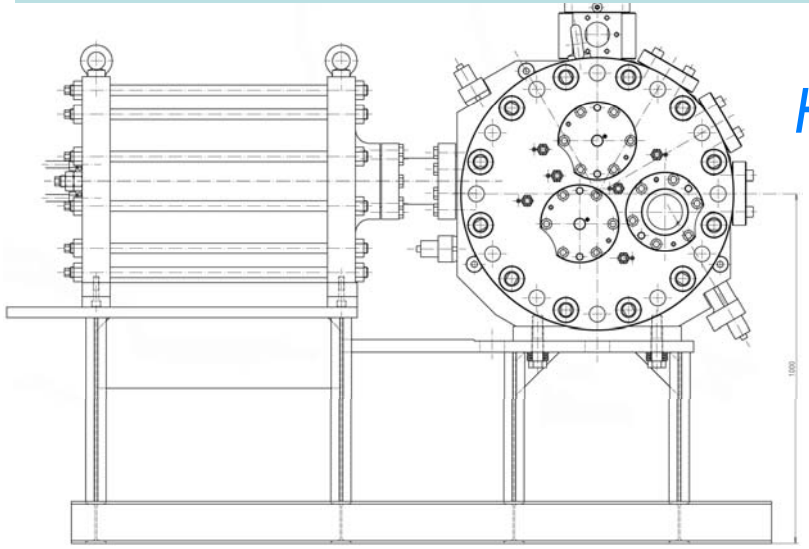


Time after laser pulse: 20 ns 40 ns 60 ns

# Summary

- RAYLIX is a combination of the techniques Rayleigh Scattering, Laser Extinction and Laser-Induced Incandescence to measure in-situ soot particle diameter, soot volume fraction and soot particle number density
- This combination allows to reduce the uncertainties and number of assumptions in the measurement of soot
- The application of this method has been started to be used on the PSI-HTDZ

# Spray/Combustion Chamber Facility



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