Optical Diagnostics in a Swirl Stabilized Flame and the High Pressure Combustion Rig in Lund

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Lund University

Outline

- Imaging Studies of Swirl-Stabilized Premixed Flames
- Optical measurements on a LPP4 module
- Outlook

Swirl burner

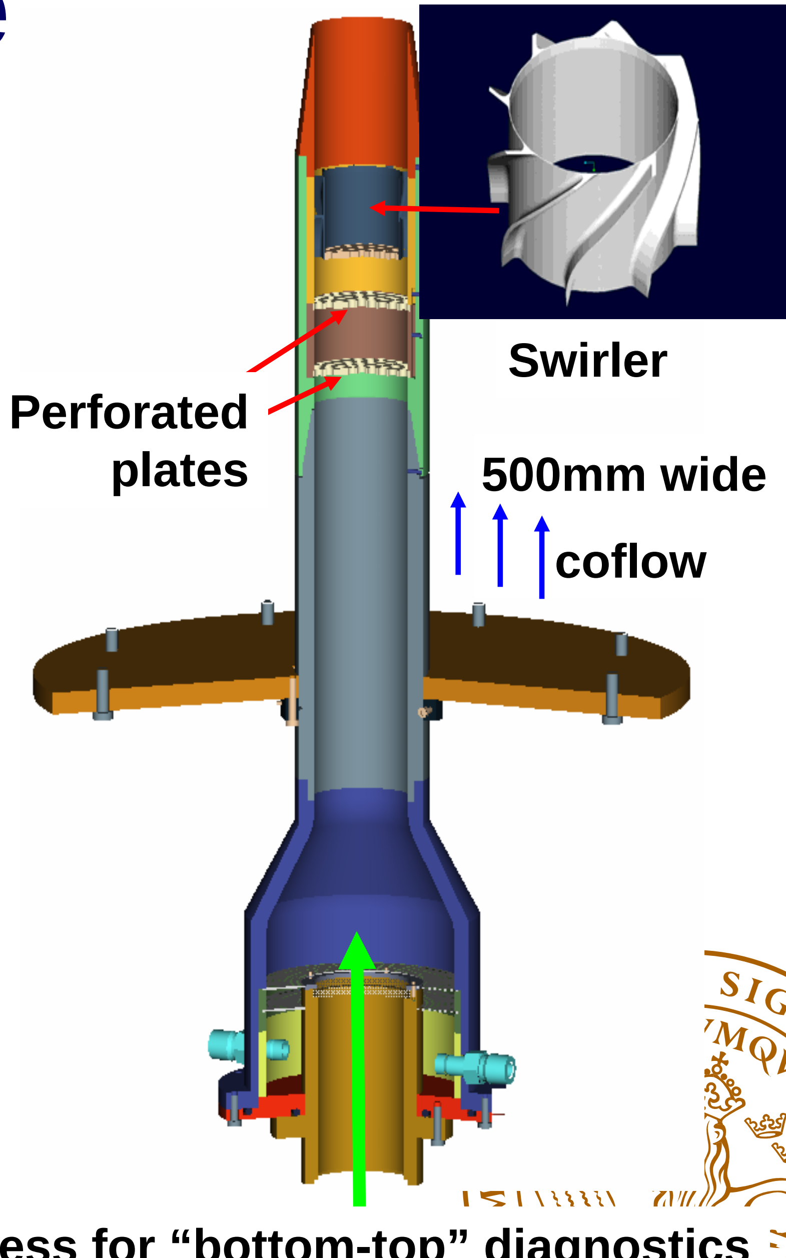
Starting Point

→ Need for well studied premixed benchmark flames of different complexity

- Rising complexity
- Flame series
  - Variation of Reynolds number
  - "From stable to unstable" flames (extinction/re-ignition, flash back,…)
- Comprehensive data set
  - Inlet and boundary conditions
  - Flow field
  - Scalar field
  - LES validation: "more than statistical moments at single points"
    - Gradients
    - Correlations
    - …

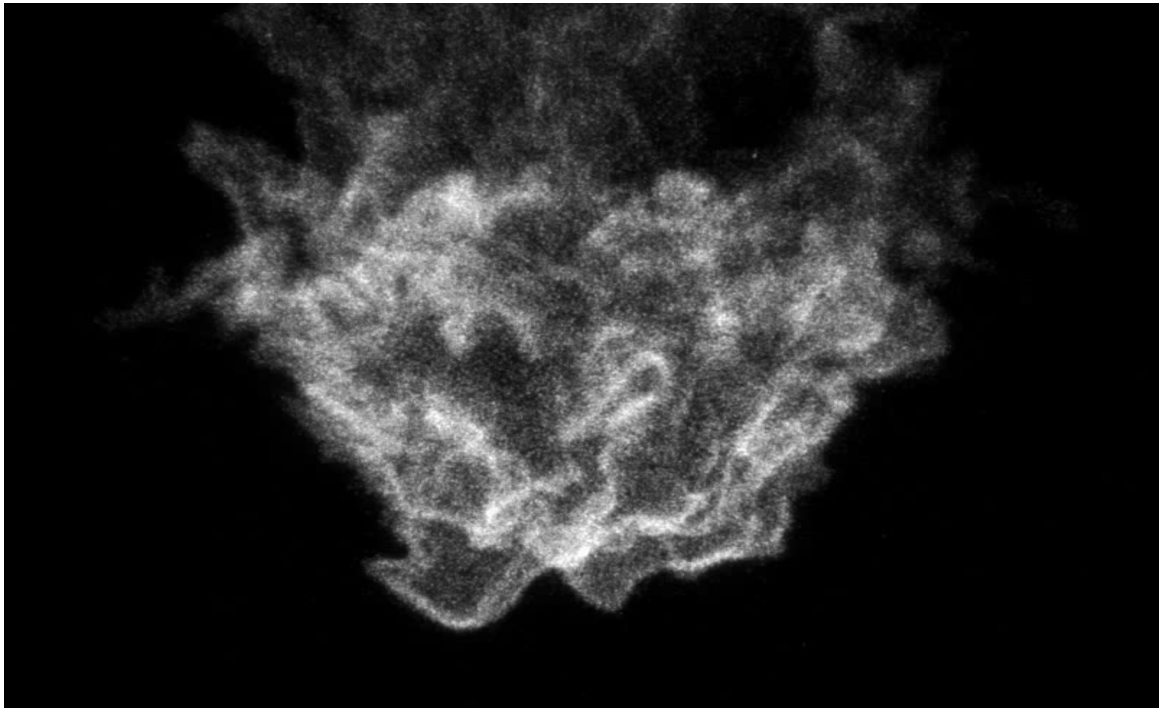
Low Swirl Flame

- Original design by R.K. Cheng
- Nozzle diameter 50mm
- Access for laser beam along burner axis → no beam steering
- Operating conditions
  - premixed CH_4 /air
  - Φ=0.62, Re=20080, 27 kW (LSF1)
  - Φ=0.62, Re=30125, 40 kW (LSF3)
  - classified in the thin reaction zone based on LDV auto-correlation measurements
  - Swirl number S=0.63 based on LDV velocity profiles at nozzle exit (2mm)



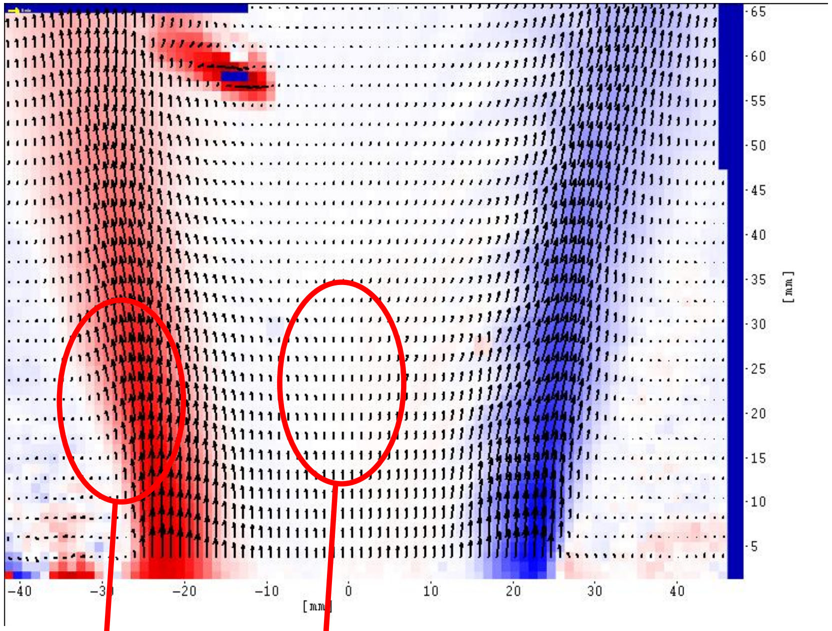
Visual Impressions

- High speed chemiluminescence
  - 7200 fps, Phantom v7.1



LSF3 – 3D PIV

- Centerline
  - Free of swirl
  - Axial component slows down
  - Mean stagnation point at x=61mm
- Outer parts
  - Symmetric swirl
  - PIV in horizontal planes shows some remaining flow structures of the eight-fold vanes

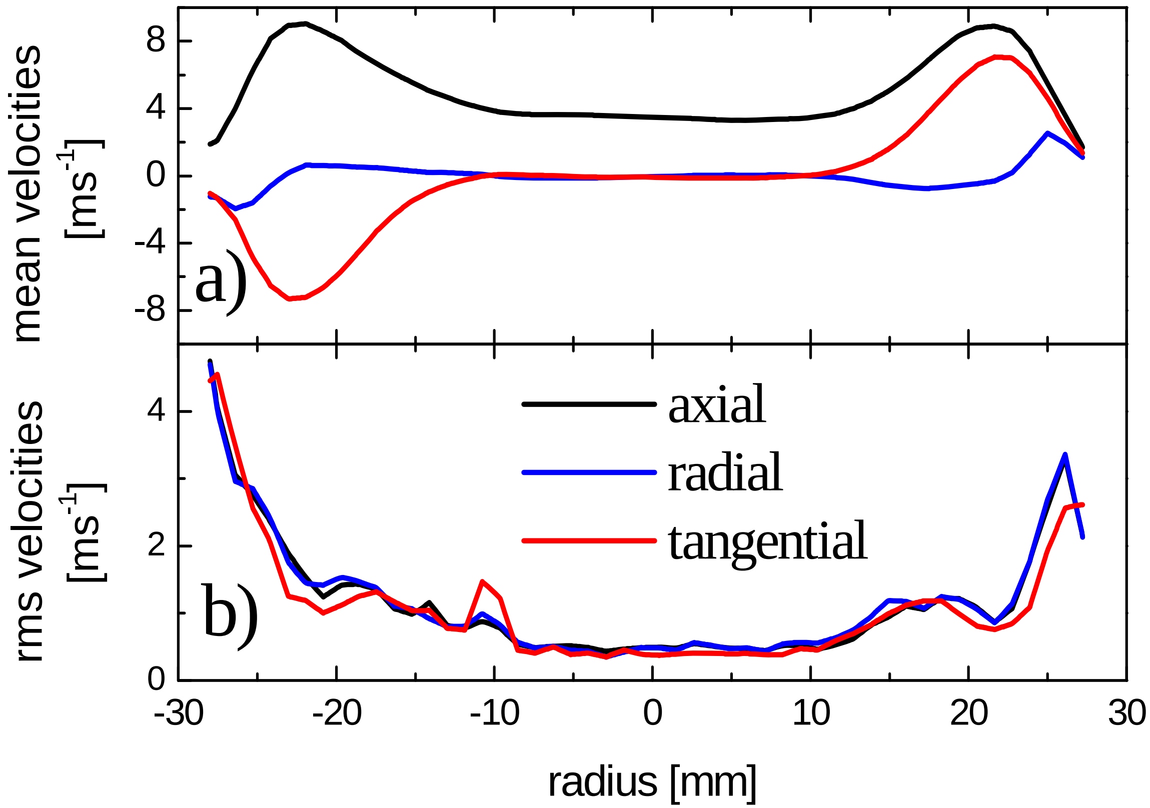


Premixed flame

Sheared stratified swirled premixed flame

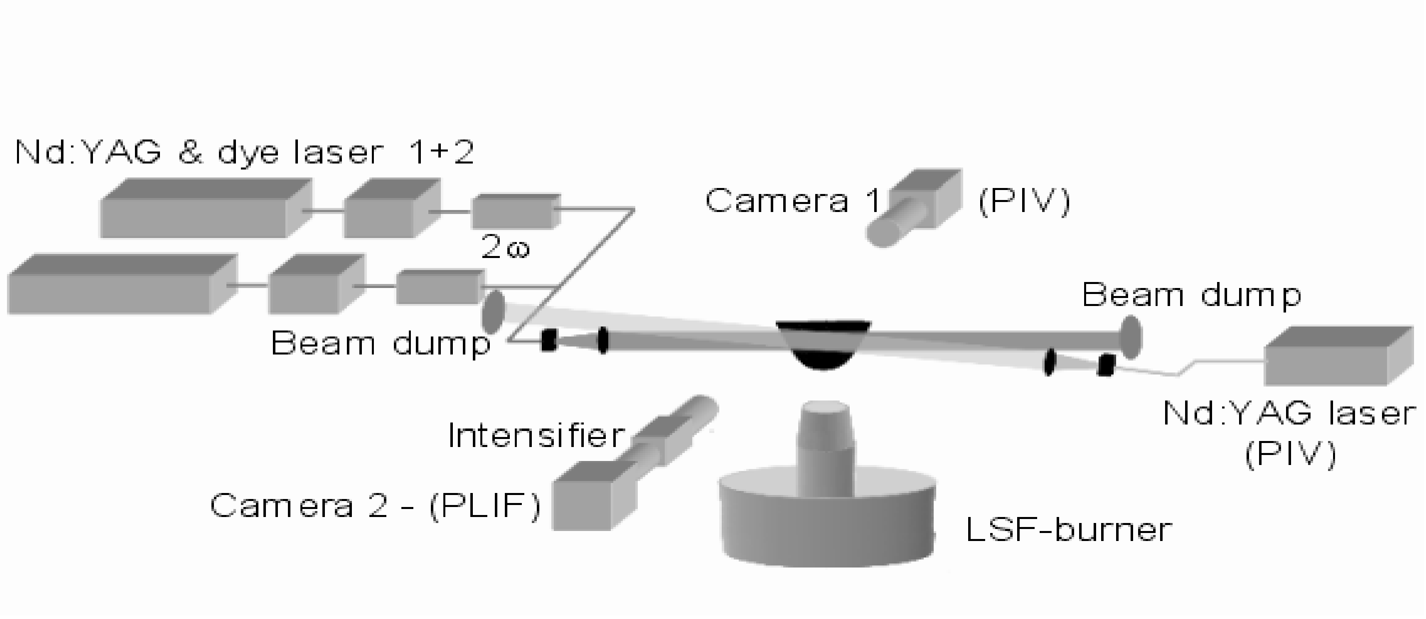
LSF – Exit Profiles Nozzle

- **Fairly symmetric**
- **Lowest turbulence levels at centerline**



PIV – sequential OH PLIF

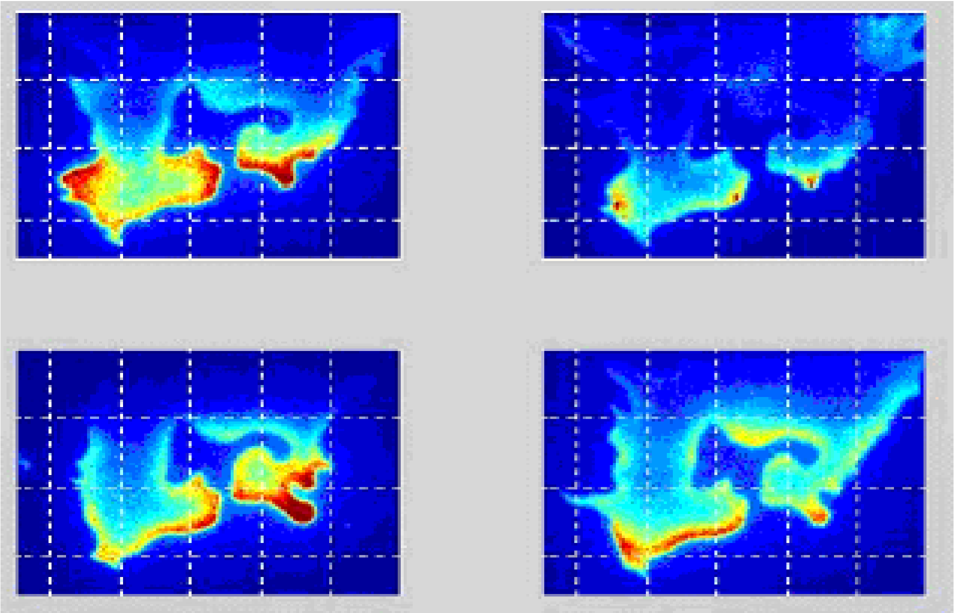
- **Set-up**



- **Simultaneous flow and scalar field measurement**
  - **Scalar fluxes**
  - **Flame-vortex interaction,…**

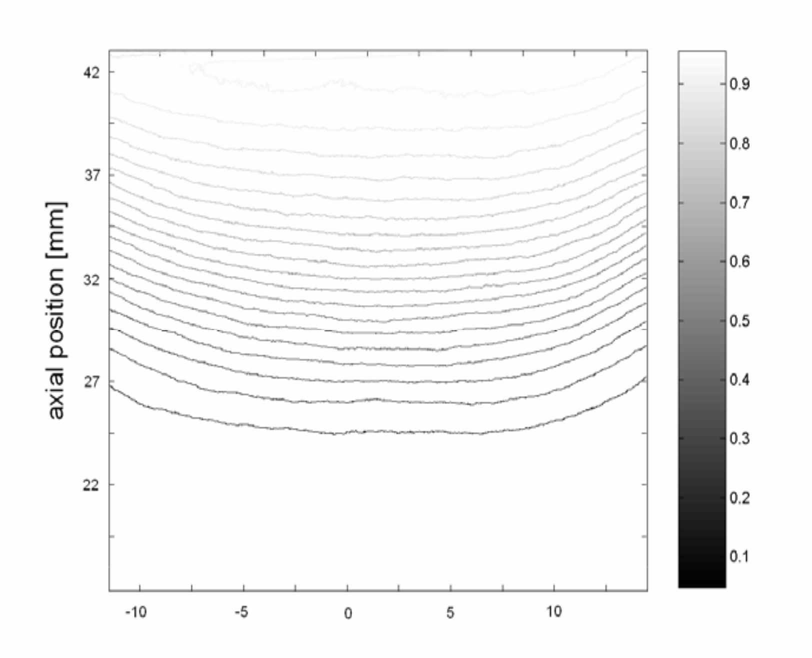
Multi-exposure OH PLIF

- 4 sequential images
- Time separation of 400µs

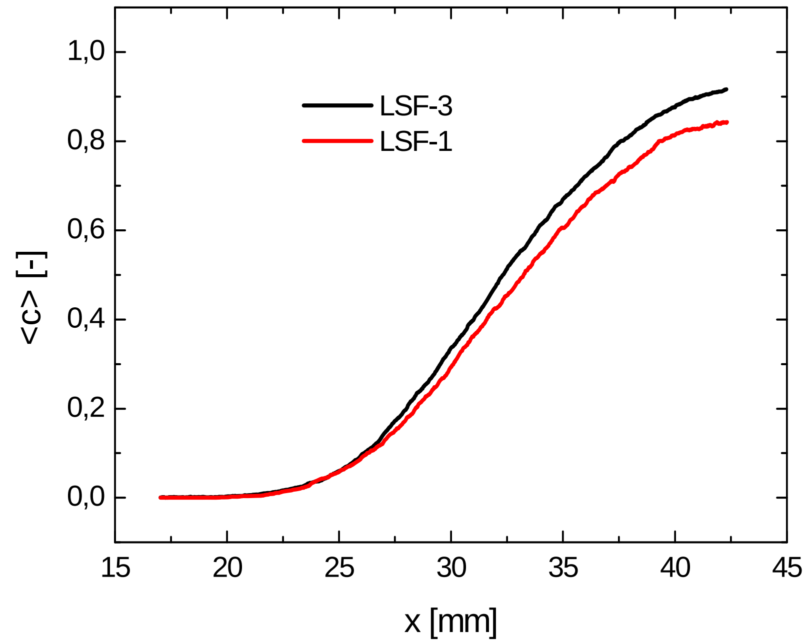


Mean Reaction Progress

2D field



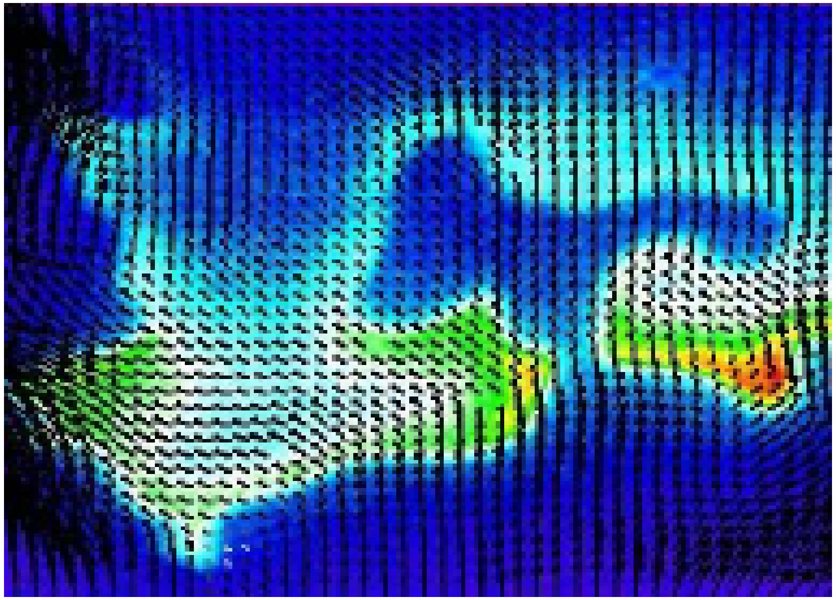
Centerline profile



- **<c>=0.5 at x=33mm, slightly dependent on Re**
- **Width of flame brush ~17mm**

Conditional Velocities

- Use of simultaneous PIV/OH PLIF images
- Condition velocity on distance from OH front



Conditional Velocities – Results

	LOCATION	$\bar{u}_b \left[m\,s^{-1}\right]$	$u'_{b,rms} \left[m\,s^{-1}\right]$	$\bar{u}_u \left[m\,s^{-1}\right]$	$u'_{u,rms} \left[m\,s^{-1}\right]$	$u''c'' \left[m\,s^{-1}\right]$
LSF1	cl	0.52	0.37	0.41	0.36	0.013
LSF1	6mm from cl	0.56	0.43	0.43	0.42	0.017
LSF1	12mmfrom cl	0.48	0.57	0.38	0.53	0.013
LSF3	cl	0.52	0.46	0.53	0.47	-0.001
LSF3	6mm from cl	0.45	0.56	0.46	0.57	-0.001
LSF3	12mmfrom cl	0.50	0.77	0.47	0.88	0.003

- **LSF1**
  - $\bar{u}_b > \bar{u}_u$ **thermal expansion dominates**
  - **Counter-gradient diffusion (positive scalar flux)**
- **LSF3**
  - $\bar{u}_b \approx \bar{u}_u$
  - **Crossover to gradient diffusion (negative scalar flux)**

Conclusions

- **Data sets for different turbulent premixed target flames under construction**
  - **Inlet conditions**
  - **Flow field (mean, fluctuations, correlations, vorticity,…)**
  - **Scalar field (reaction progress, temperature, thermo-kinetic state and secondary air entrainment via Raman/Rayleigh,…)**
  - **Combined flow-scalar diagnostics (conditional flow statistics, scalar fluxes, local turbulent flame speed,…)**
  - **Stable and flash back**
  - **High and low swirl regions**
  - **Technically relevant geometries**

- **Contributors:**
  - **P. Petersson, C. Brackman, H. Seyfried, J. Olofsson, M. Aldén, M.A. Linne,** Division of Combustion Physics, Lund University
  - **A. Nauert, Andreas Dreizler,** Fachgebiet Energie- und Kraftwerkstechnik, Fachbereich Maschinenbau, TU Darmstadt
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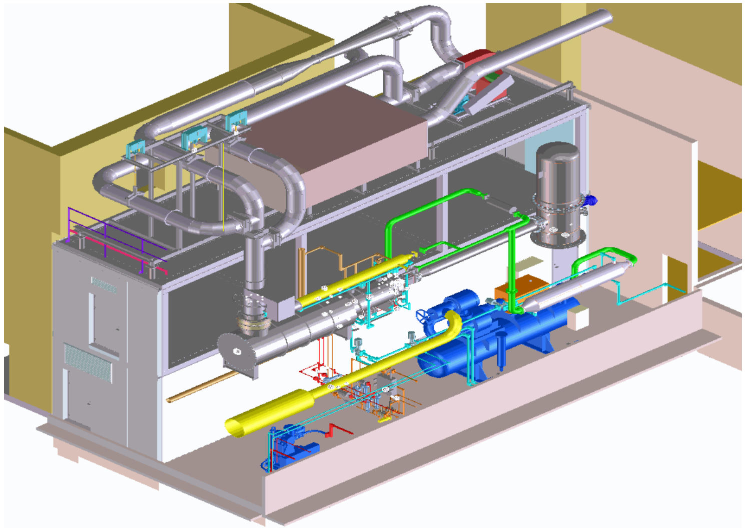
High Pressure Rig



- Air flow: 1.3 kg/s
- Preheated 650 K
- 16 bar
- various fuels (liquid and gas) at same pressures
- Combustion parameter evaluation
- Vaporisation studies
- Mixing studies
- Laser diagnostic measurements (CARS, LIF/MIE, LDV, PIV)
- Oscillation studies.

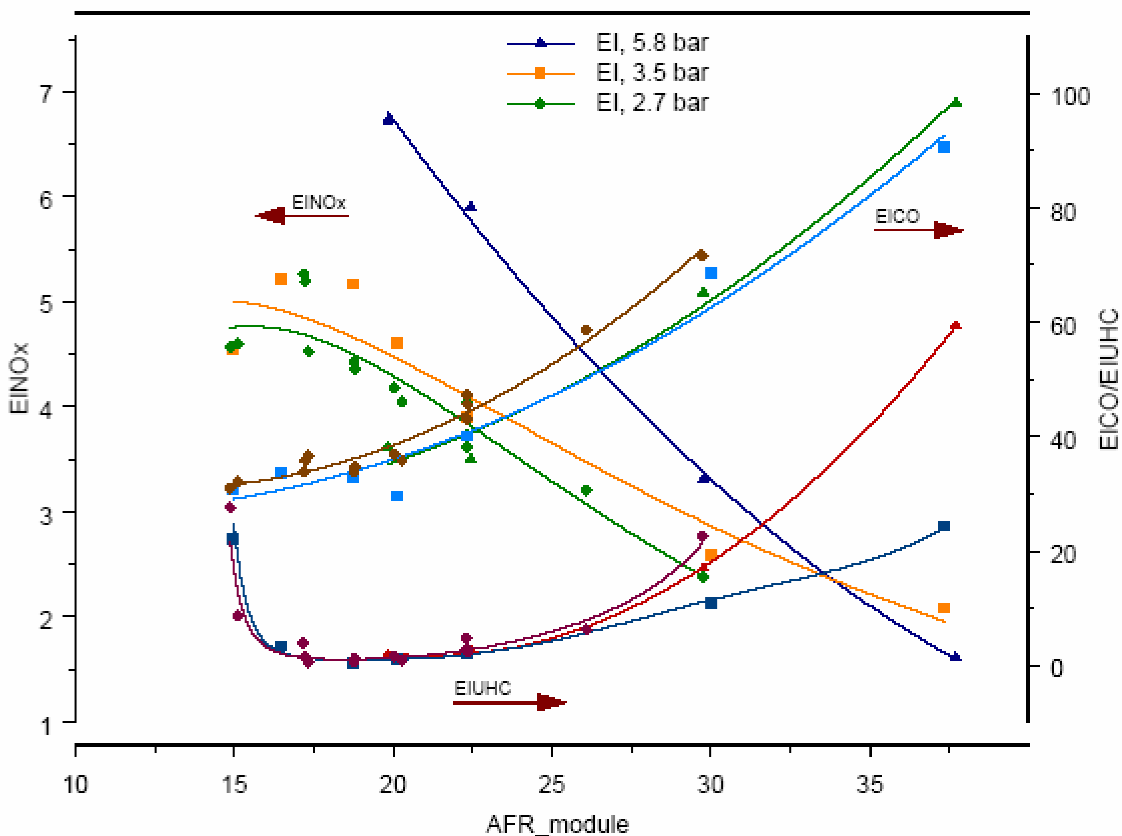
LTH High-Pressure Rig

Established flame, Jet A in LP(P)4-Phase I , pilot only

Chamber, with windows

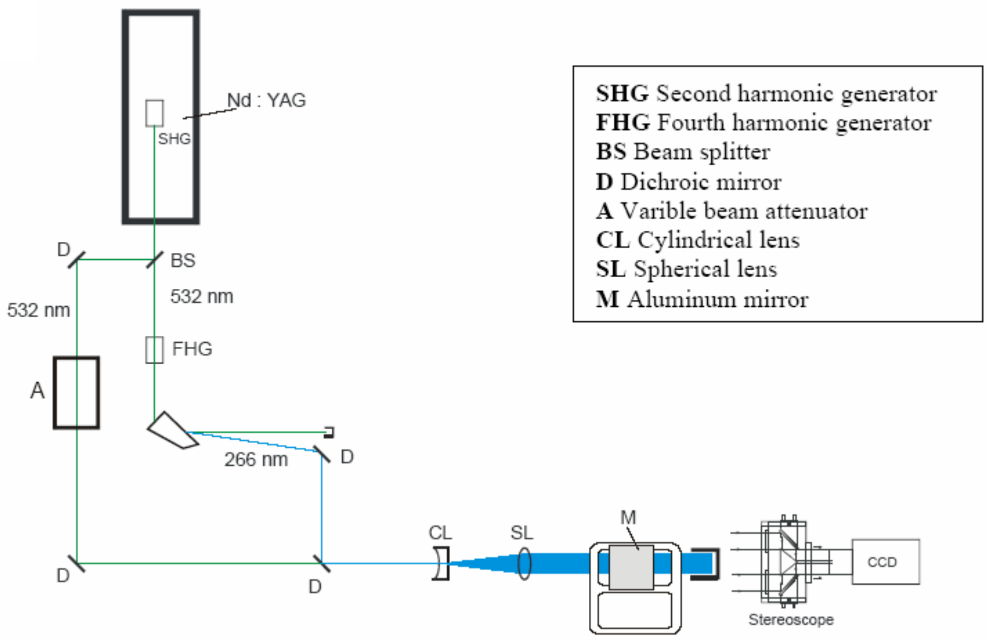
LP(P)4 Measurements

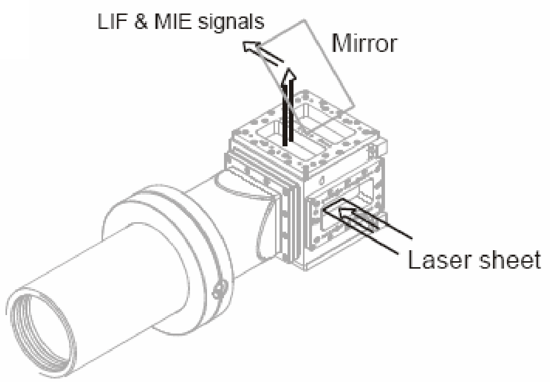
- **Test results - emission measurements at fixed inlet T = 530 K, 3 different pressures and various AFR**



LP(P)4 Measurements

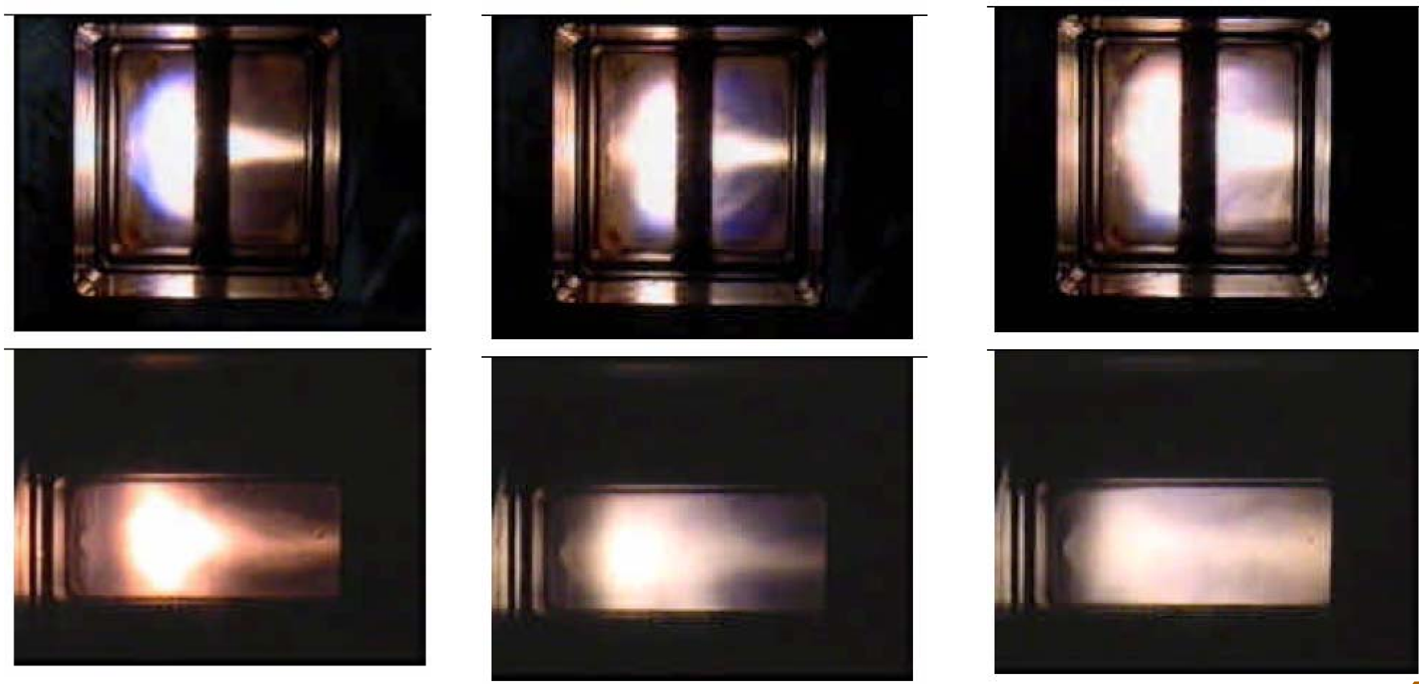
- **Planar laser imaging of fuel vapor (via laser induced fluorescence) and liquid (via Mie scattering)**





LP(P)4 Measurements

- **Measurement points for imaging experiments** (normal photographs of the flowfield shown here) **:**



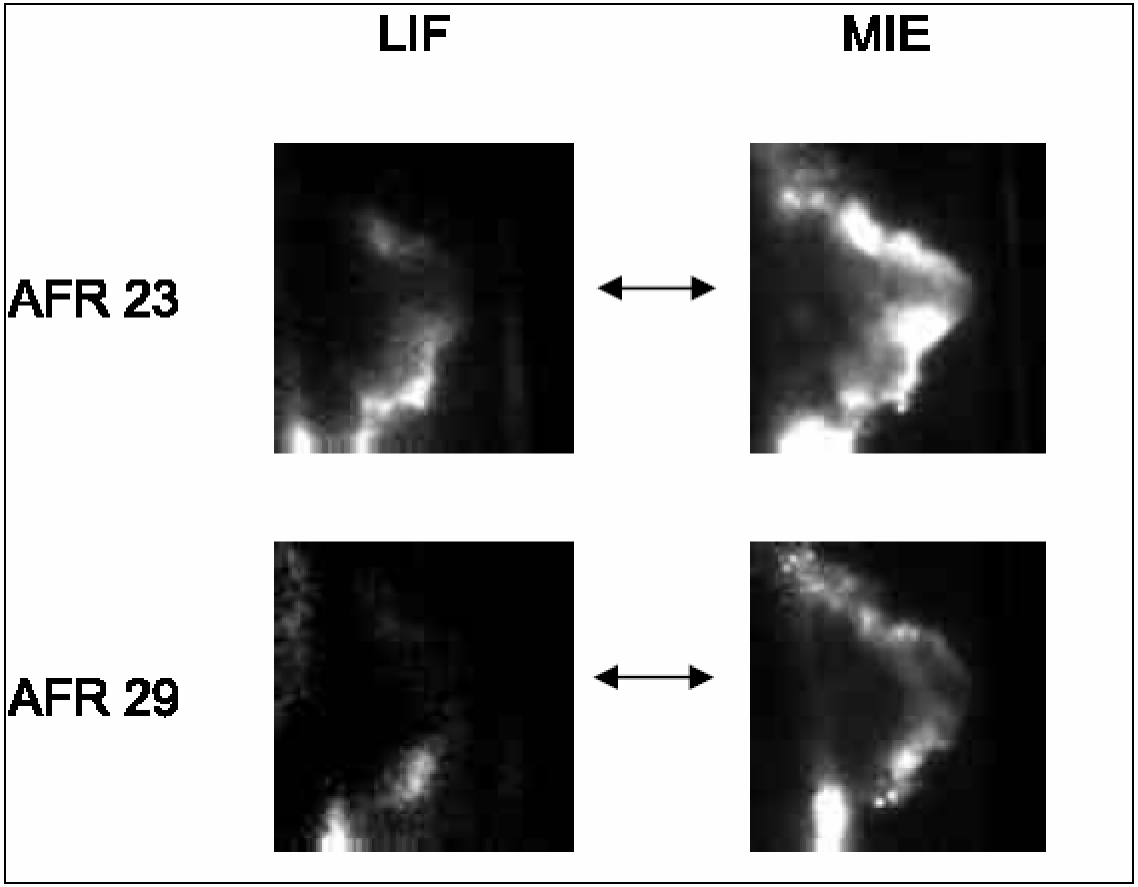
point 1
AFR 60

point 2
AFR 29

point 3
AFR 23

LP(P)4 Measurements

- Example imaging measurements



- **Contributors**
  - **M. Aldén, M. Linne, A. Lindholm, C. Brackmann, H. Seyfried,** Combustion Physics, Lund University
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  - **European union (LOPOCOTEP)**
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The Gas Turbine Project in CECOST

- Stability of burners for fuel flexible gas turbines
  - Laszlo Fuchs, LTH, SIEMENS
- Alternative fuel spray modelling and validation
  - Laszlo Fuchs, LTH , SIEMENS
- Flameless oxidation burner with piloting
  - Mark Linne, LTH , SIEMENS
- Flame temperature measurement for syngas application
  - Marcus Aldén, LTH , SIEMENS
- Fuel profile measurement for syngas application
  - Marcus Aldén, LTH , SIEMENS
- Optical diagnostics in a jet engine afterburner
  - Marcus Aldén, LTH , Volvo Aero
- Investigation of flames from biogas
  - Jens Klingmann, LTH , E.ON Sweden

The Modeling & Validation Project in CECOST

- Validation: experiments and laser diagnostics (swirl burner)
  - Mark Linne, Marcus Aldén, LTH
- Modeling: Flamelet and level-set based LES model (swirl burner)
  - Xue-Song Bai, LTH
- Modeling: LES flame-capturing model (swirl burner)
  - Lars-Erik Eriksson, CTH
- Validation: experiments and laser diagnostics (plane wall jets)
  - Joakim Bood, Marcus Aldén and Mark Linne, LTH
- Modeling: DNS model development (plane wall jets)
  - Arne Johansson, KTH
- Modeling: chemical kinetics development
  - Fabian Mauss, LTH