Numerical and Experimental Study of Hydrogen Combustion at High Pressures

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Subtask 3.1 C

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Overview of Presentation

- Introduction
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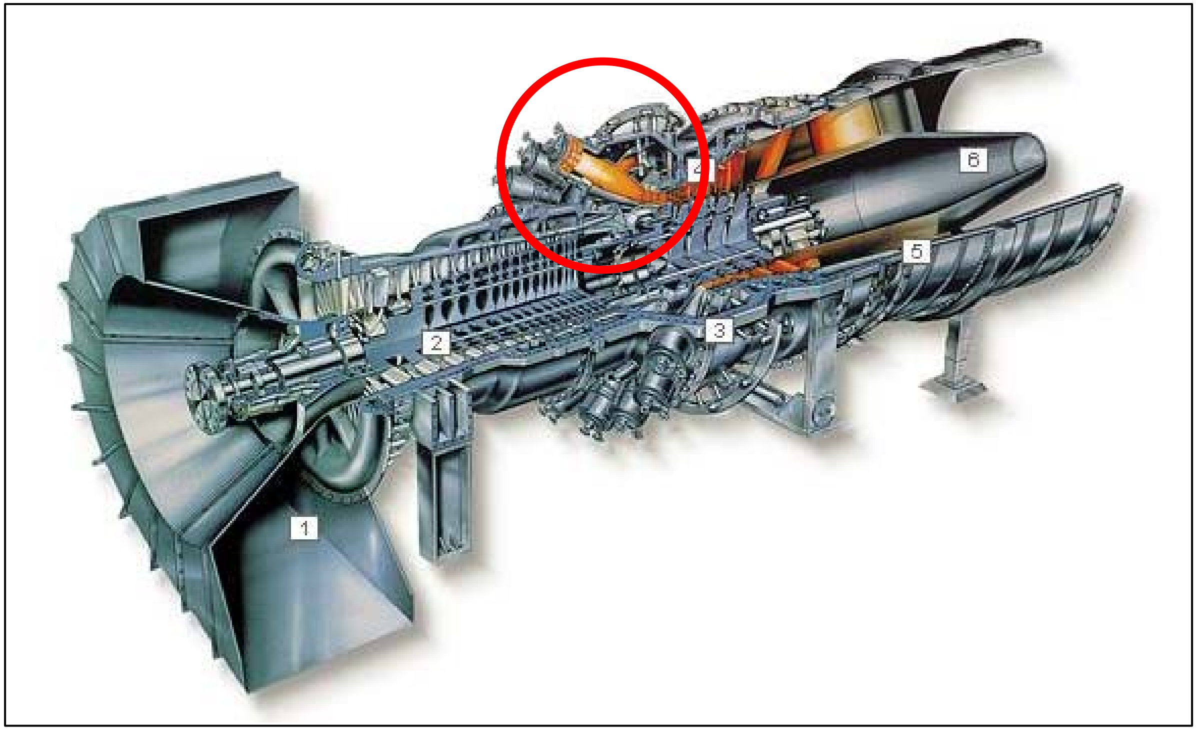
  - H_2+N_2 Fuel & TNF
- Previous Work
- Validation Case Parameters
- Experimental Results & CFD
  - Flame zone size and position (CL)
  - OH relative concentration (PLIF)
- Conclusions and Further Work

Introduction



Graphics: Siemens

Power generation with pre-combustion CO_2-capture:

-part of work package 2.3 'H2-rich combustion' of the EU research project ENCAP (ENhanced CAPture)
-among partners: SINTEF, DLR, ALSTOM, SIEMENS, RWE, VATTENFALL, STATOIL

Motivation

Hydrogen Non-premixed Combustion at Elevated Pressures:

- Premixed H_2-combustion requires very high burner velocities to avoid flashback, this implies large pressure losses in GT-operation
- Little experimental data available for hydrogen combustion under GT-conditions (high pressures), this work provides experimental data for validation of CFD-models

Nitrogen-dilution of the Hydrogen Fuel:

- Reduces reactivity of hydrogen (increase its ignition delay time) for safe operation and avoids burner damage
- Reduces flame temperature and NO_x-formation level
- To be preferred over steam because **a)** steam causes higher metal temperatures of the hot-gas components and **b)** steam increases the cost of operation and ownership, and **c)** within the context of the ENCAP project, N2 is available from IGCC plant

Previous Work

Hydrogen combustion chemistry benchmarking for pure H_2/O_2 kinetics (Strohle et al. C&F 2006):

- no hydrocarbons considered
- N_2 treated as inert (NO_x chemistry not included)
- N_2 acts as a third body
- high pressure conditions

DLR GT-model burner tested for (Weigand et al. C&F 2006):

- Methane fuel
- Atmospheric conditions

All present measurements performed by Rainer Lückerath of DLR in Stuttgart (scheduled for publication).

Relevant H_2-Co ms

Selected for validation against experimental data at high pressures (Strohle et al. C&F 2006)

Group	Authors	Reactions	Pressure
GRI-Mech	[1.2] Frenklach et al. (1995) [2.11] Bowman et al. (1999) [3.0] Smith et al. (2002)	58	1-2 atm
Dryer	Yetter et al. (1991) Kim et al. (1994) Mueller et al. (1999) Li et al. (2004)	38	0.3-2.2 atm 1-9.6 atm 0.3-15.7 atm 0.3-87 atm
Ó Conaire	Ó Conaire et al. (2004)	42	0.05-87 atm
Warnatz	Baulch et al. (1991) Warnatz (2004)	38	
Leeds	Hughes et al. (2001)	46	

H_2/O_2 Turbulent Combustion Modeling

SPIDER (SINTEF):

- EDC combustion model and detailed chemical kinetics solver already present
- H_2-combustion implemented comparing several detailed mechanisms (Li, GRI-Mech, Warnatz…)

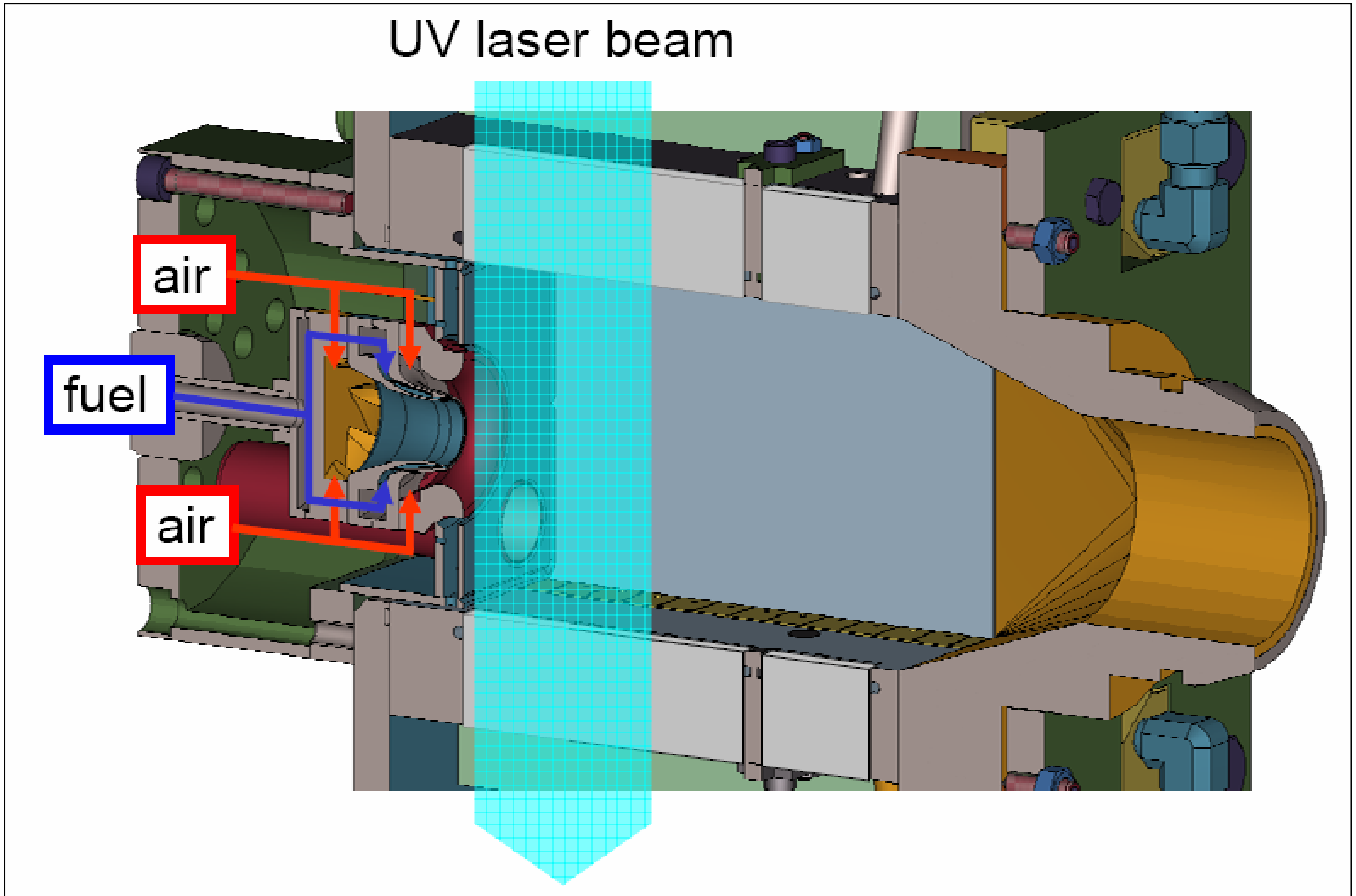
FLUENT (for ALSTOM):

- EDC combustion model present
- No external stiff-equations solver implemented (use built-in solver)
- H_2-combustion implemented in a 11-step reduced mechanism

CFX (for SIEMENS):

- EDC combustion model implemented
- Detailed chemical kinetics solver implemented as user library (including LIMEX and ChemKin)
- H_2-combustion implemented in a 11-step reduced mechanism

Case Configuration (1)



Graphics: DLR (Rainer Lückerath)

- Two co-rotating swirl generators for the air supply
- One annular multi-channel ring injector in between the swirled flows
- Maximum thermal power up to 1.3 MW
- CL and PLIF of flame @ 5, 10, 20 bars

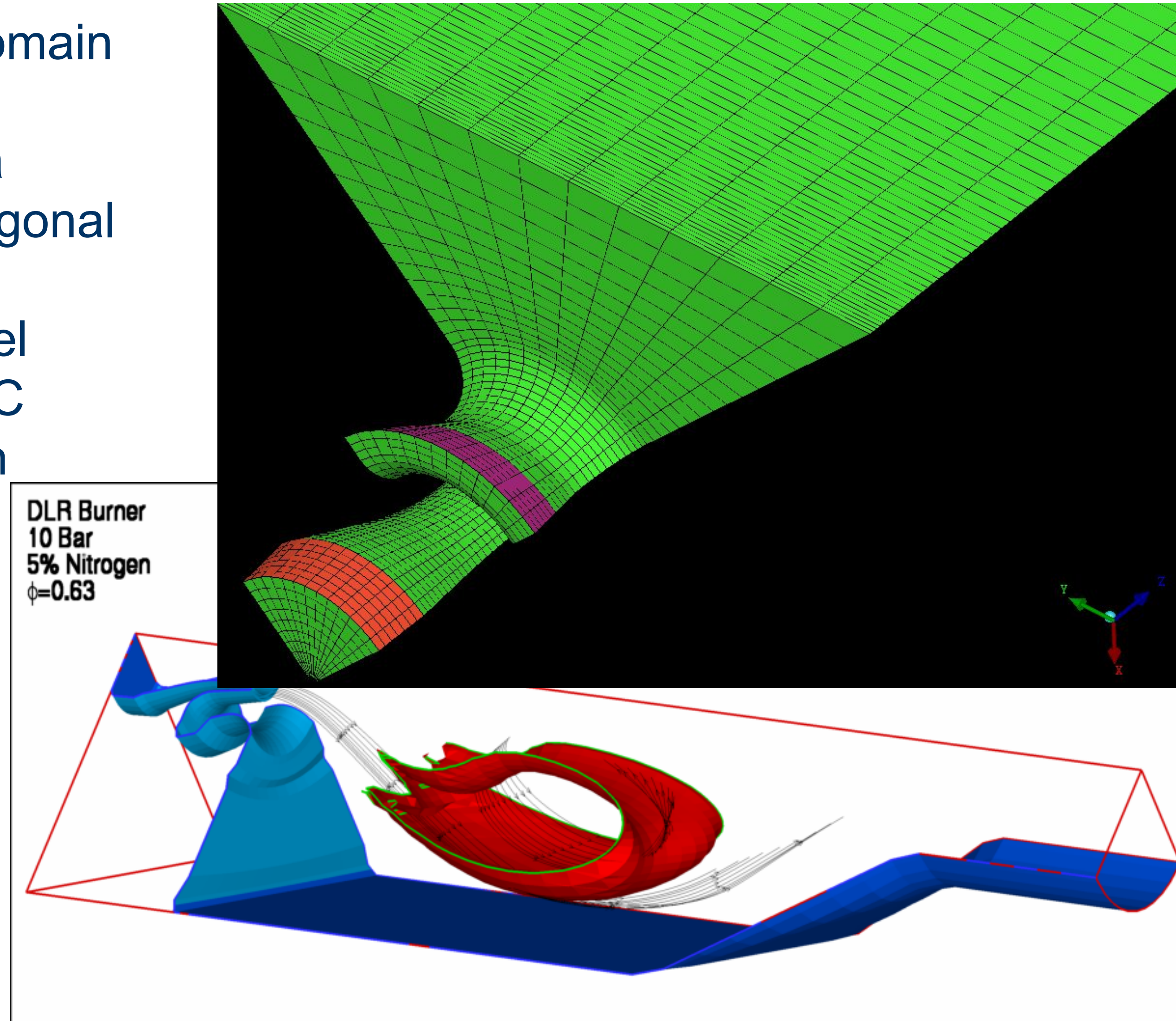
Case Configuration (2)

Gas supply!

Graphics: DLR (Rainer Lückerath)

Case Configuration (3)

- •¼ of the physical domain is simulated
- •FV CFD-solver on a structured non-orthogonal mesh
- •k-e turbulence model coupled with the EDC turbulent combustion model
- •11-step reduced hydrogen chemistry



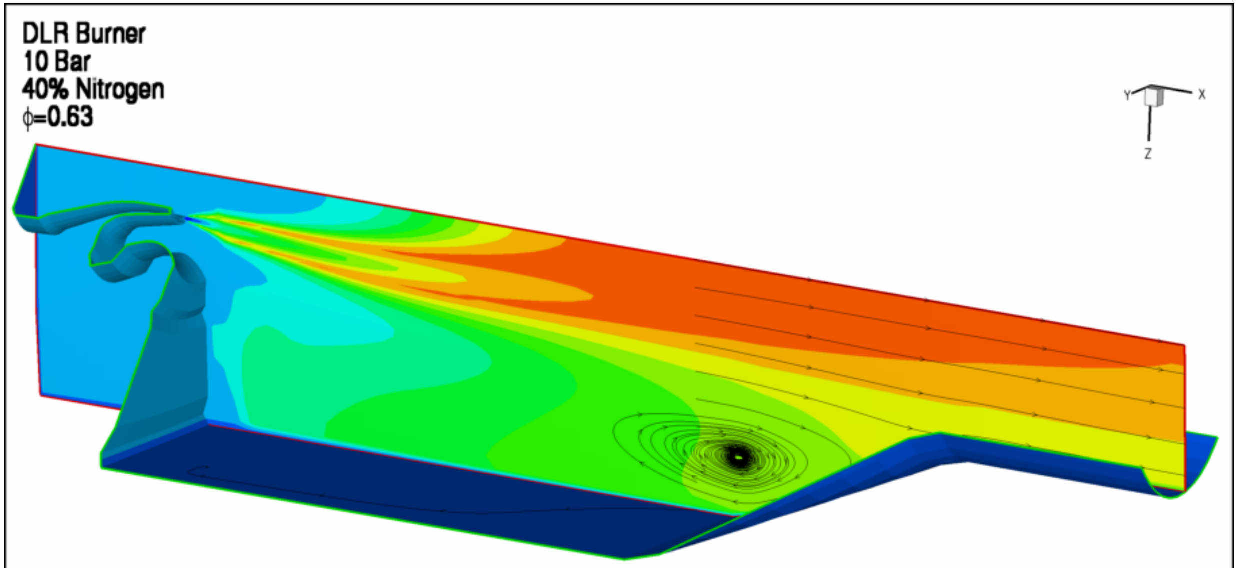
Flame Dependency on Dilution Level (1)

H_2=60% , N_2=40%

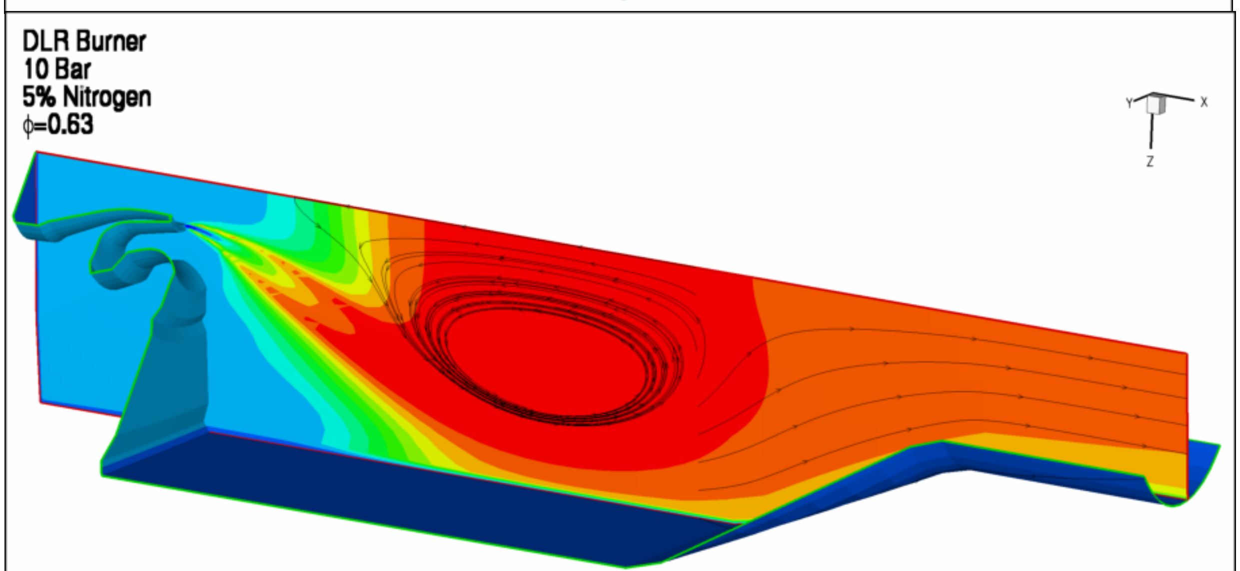
H_2=95% , N_2=5%

Graphics: DLR (Rainer Lückerath)

Flame Dependency on Dilution Level (2)

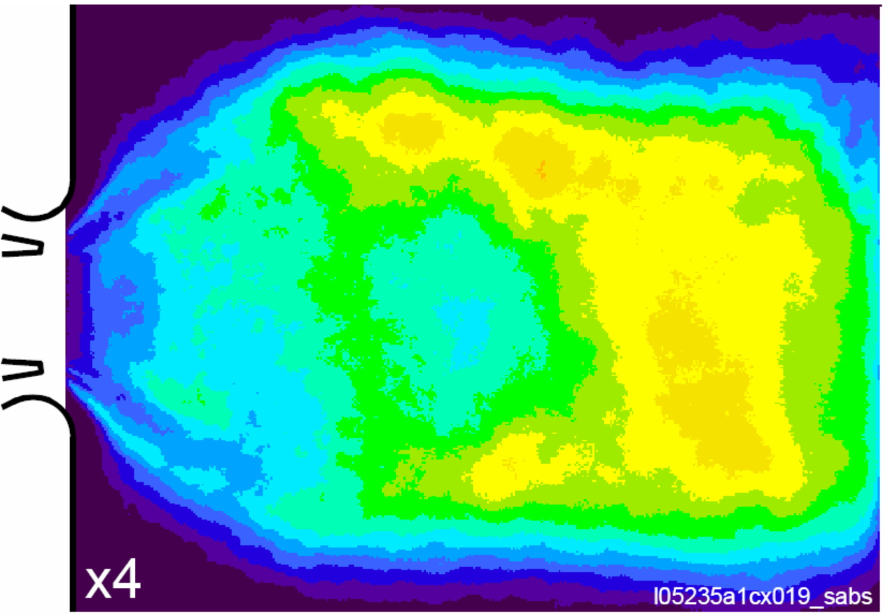


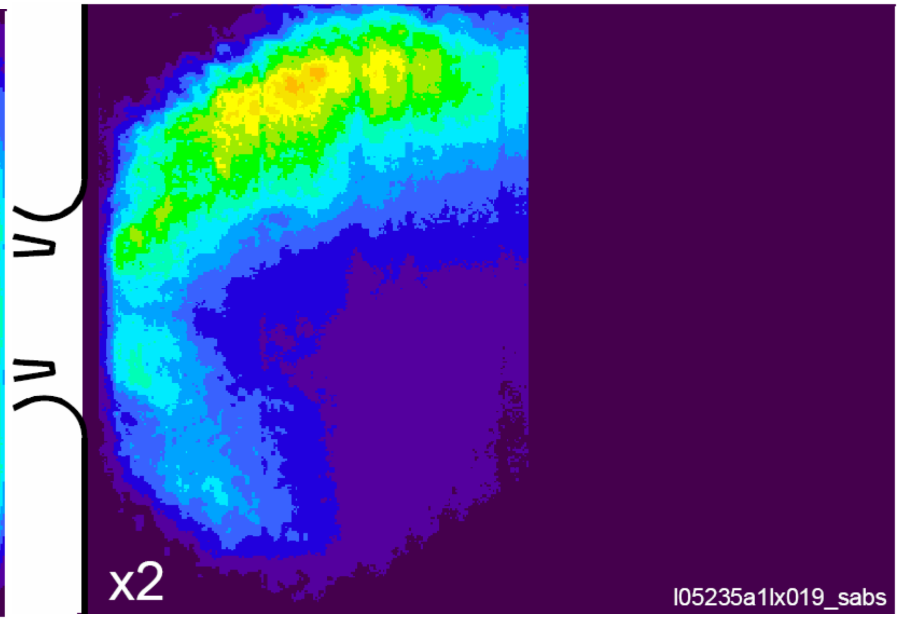
H_2=60% , N_2=40%

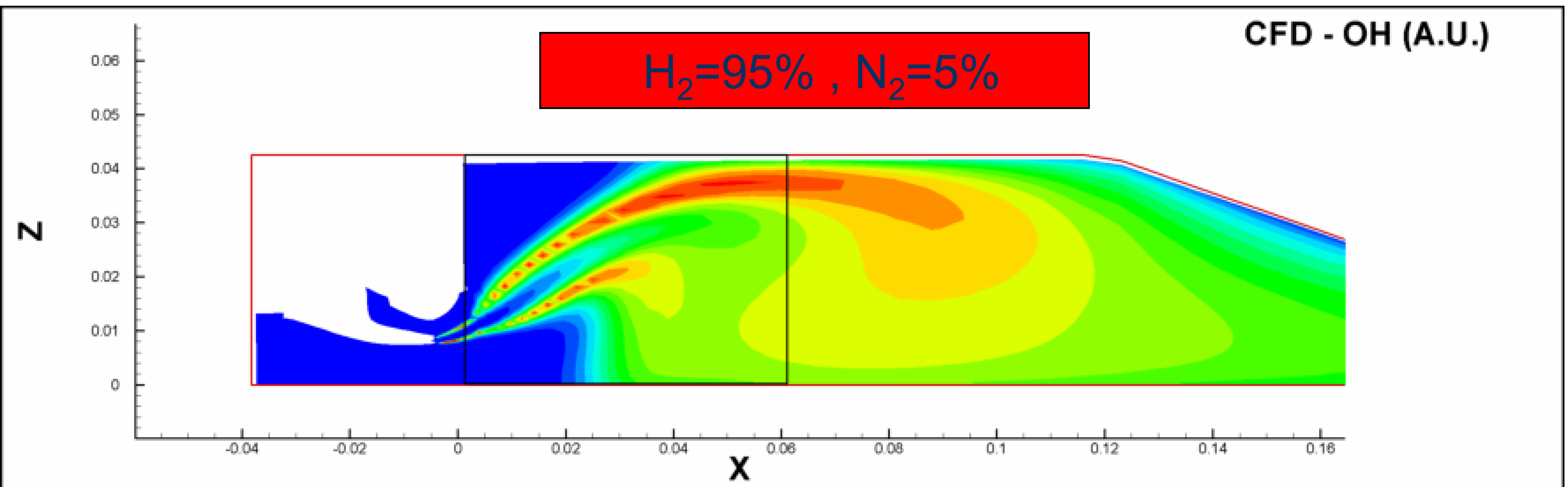


H_2=95% , N_2=5%

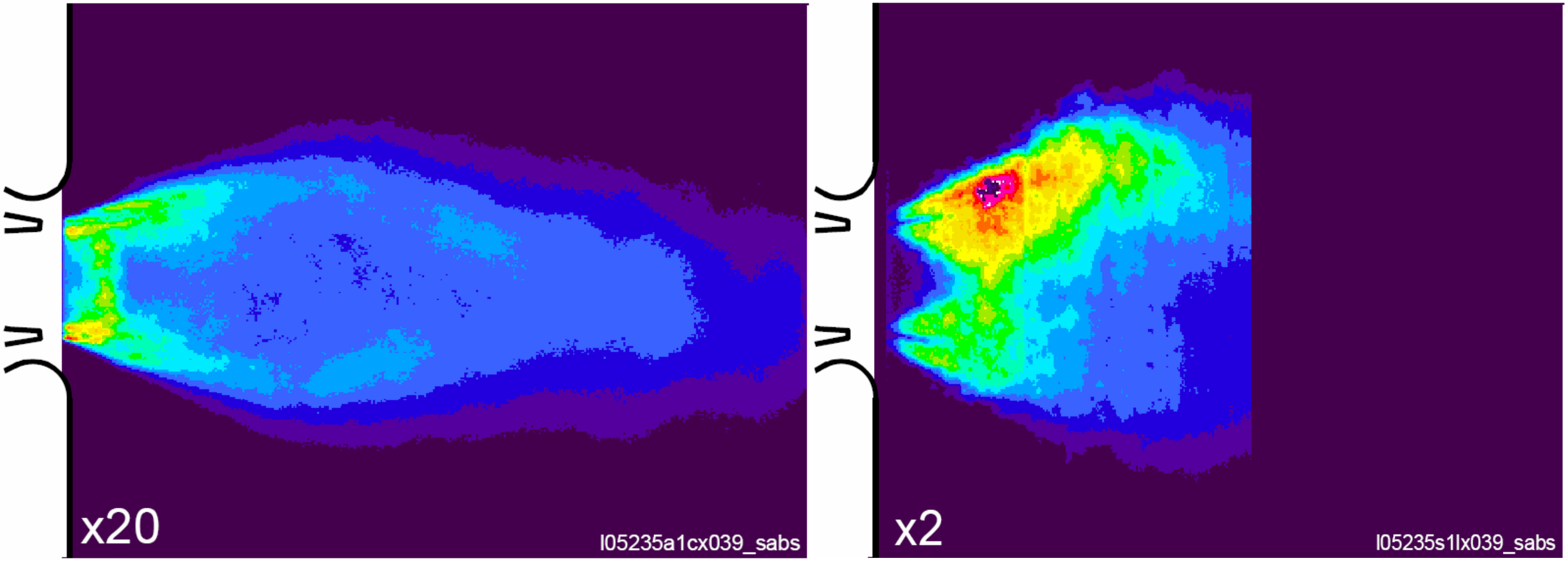
Flame Dependency on Dilution Level (3)

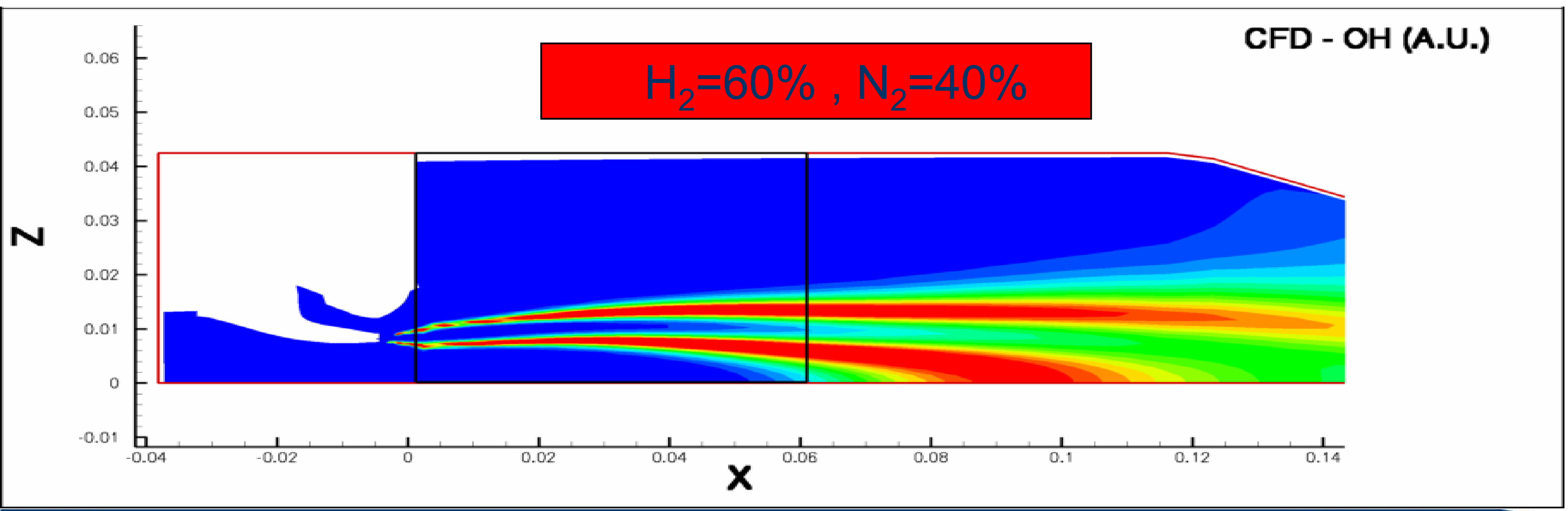




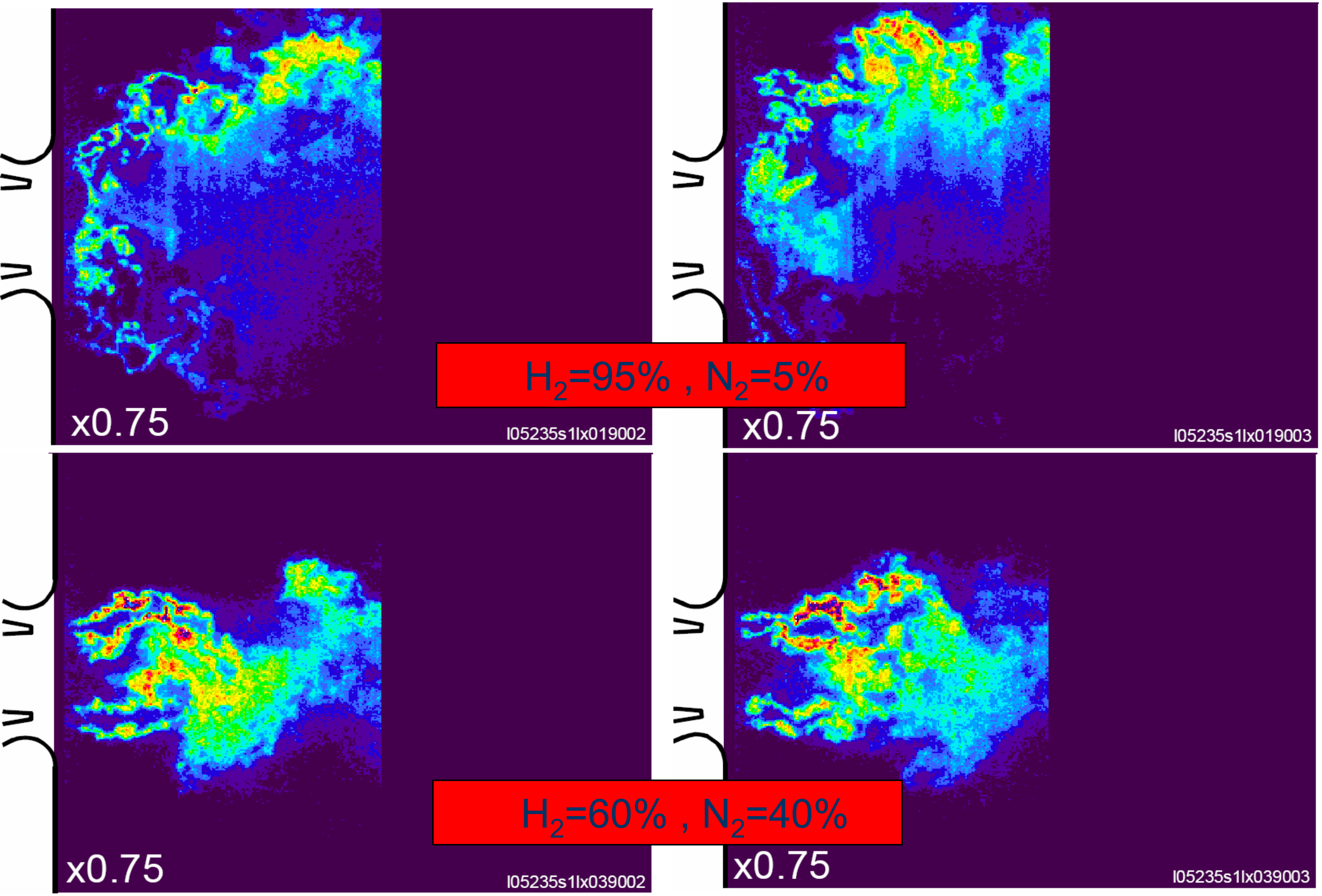


Flame Dependency on Dilution Level (4)





Flame Dependency on Dilution Level (5)

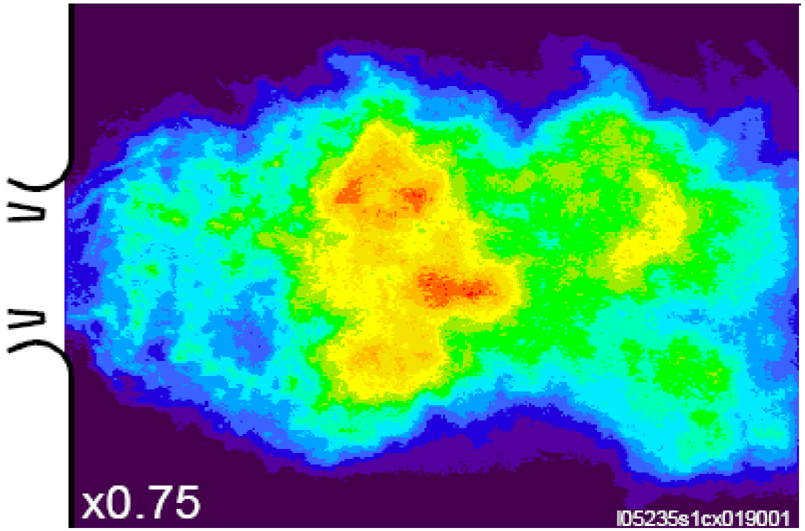


Flame Dependency on φ (1)

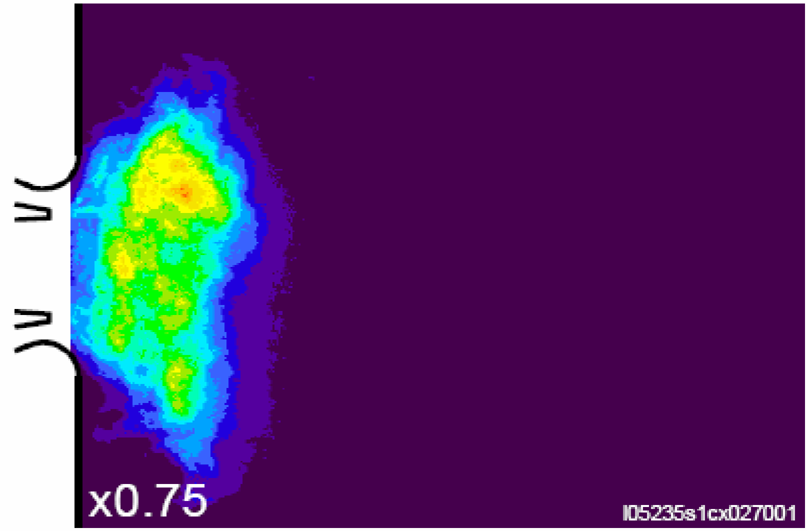
H_2=95% , N_2=5%

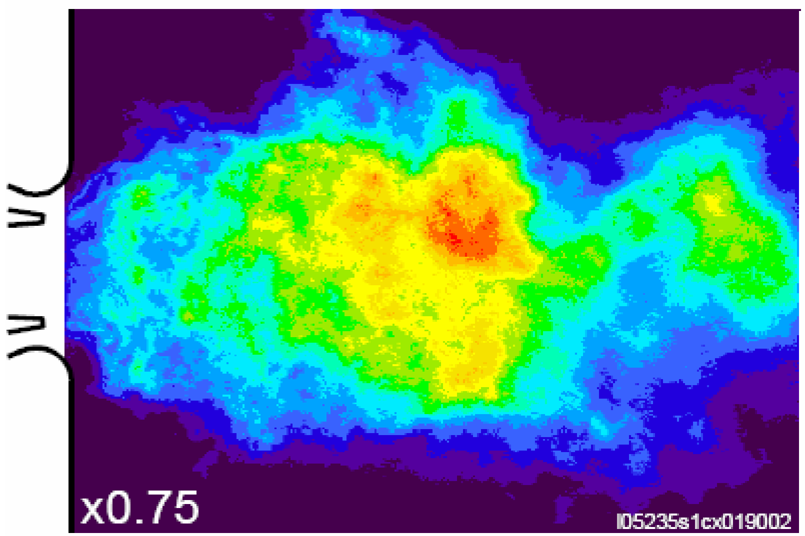
richer flame

leaner flame

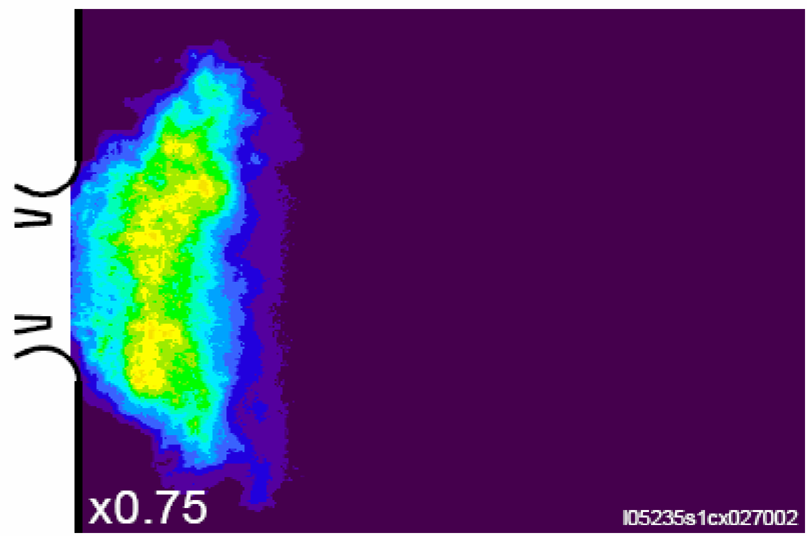


instantaneous





instantaneous

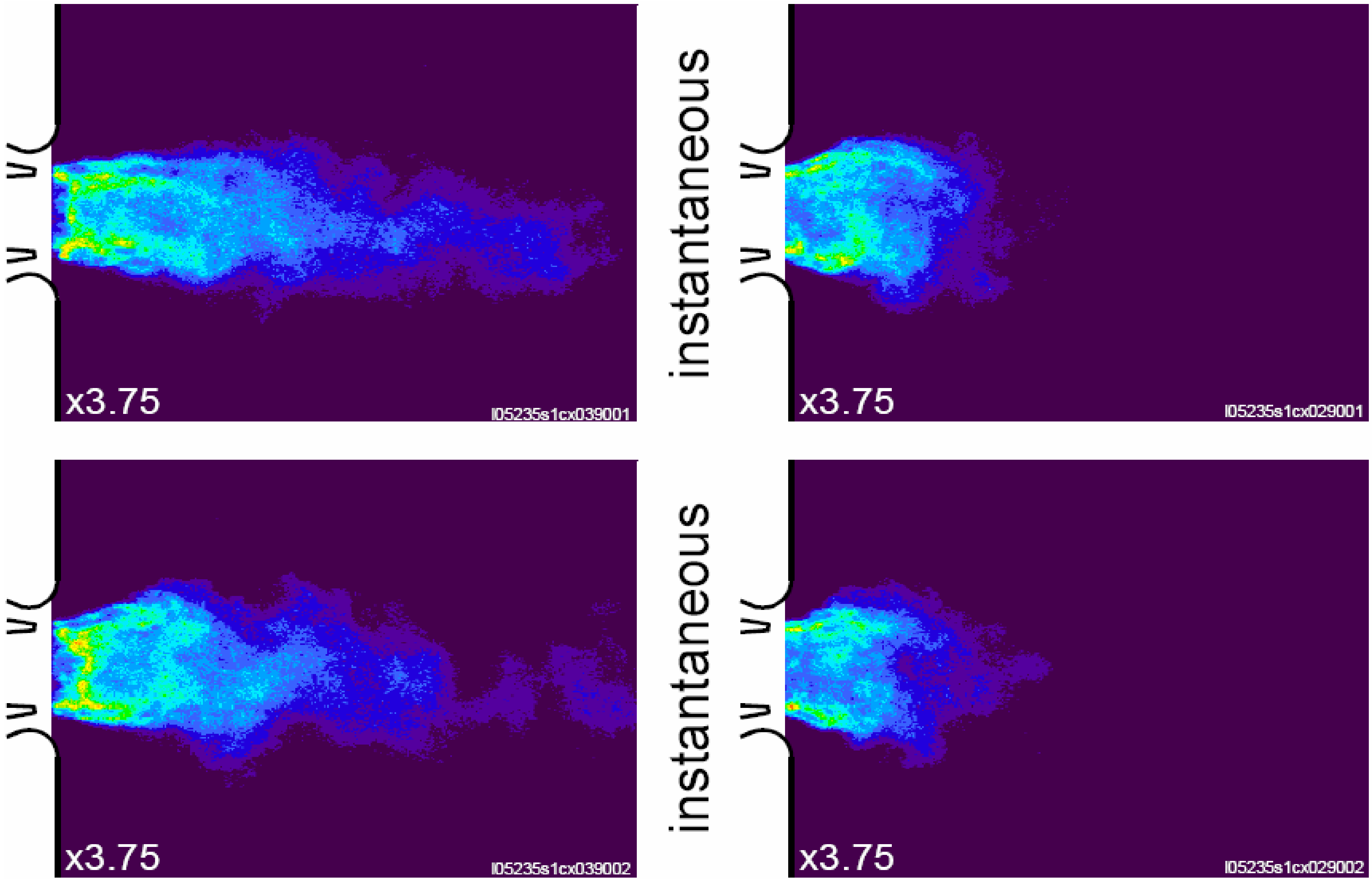


Flame Dependency on φ (2)

H_2=60% , N_2=40%

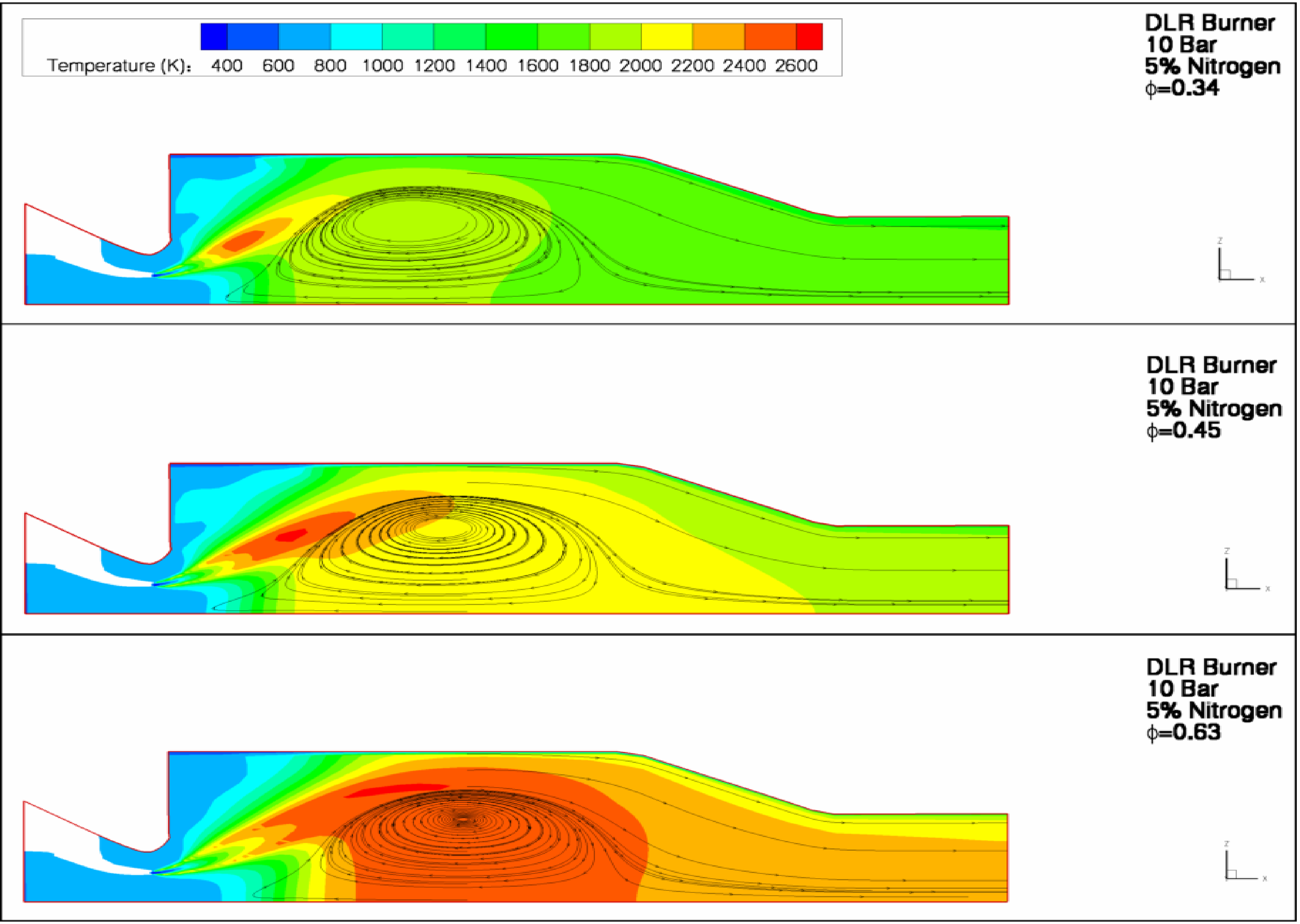
richer flame

leaner flame



Flame Dependency on φ (3)

H_2=95% , N_2=5%

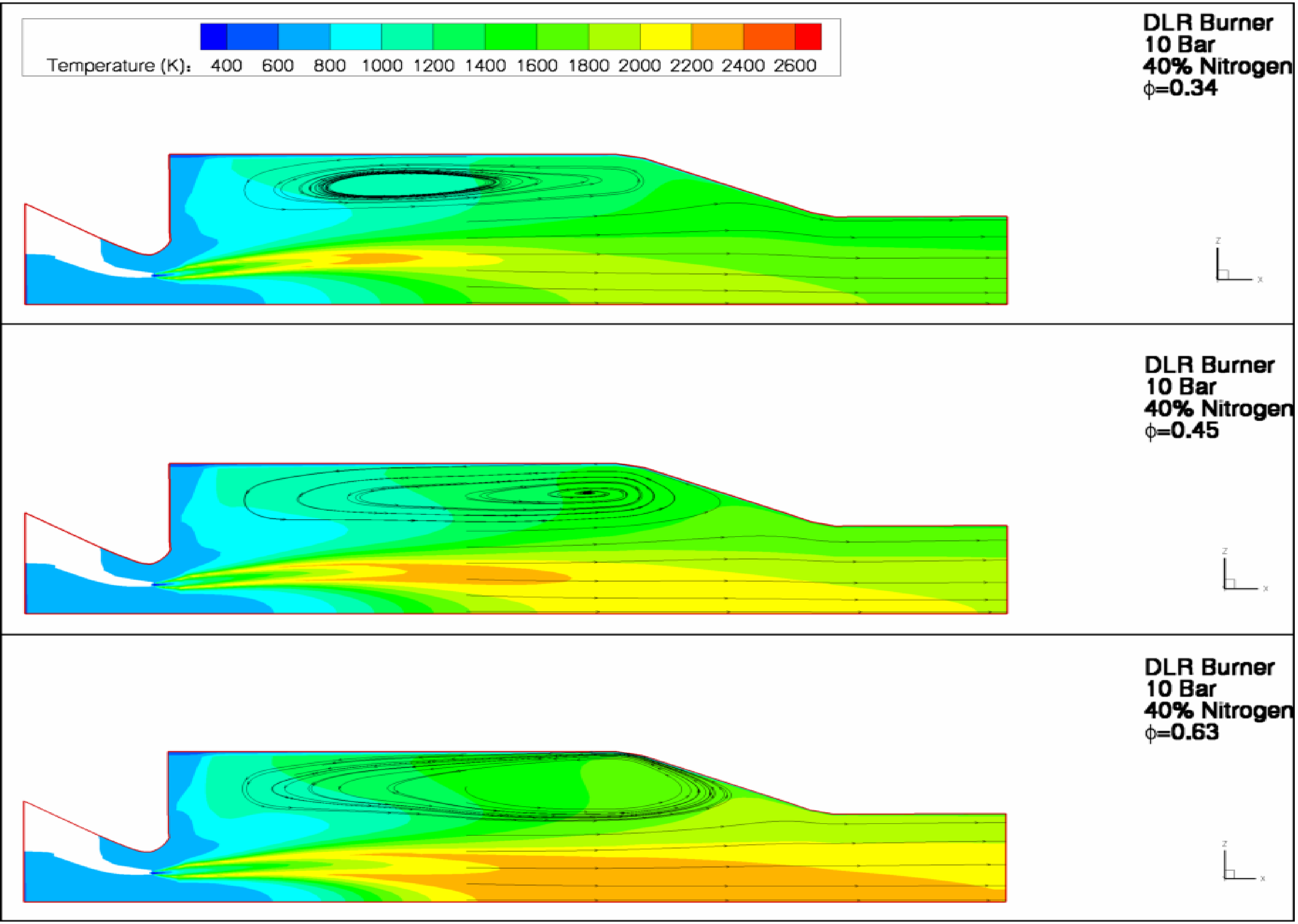


leaner flame

richer flame

Flame Dependency on φ (4)

H_2=60% , N_2=40%



leaner flame

richer flame

Conclusions and Further Work

- Flame shape, position and structure seems to be well captured by the CFD
- Flame is strongly dependent on the dilution level resulting in a classical swirl-flame for the 5%-dilution case (low fuel axial momentum) and in a jet-flame for the 40%-dilution case (high fuel axial momentum)
- No large effect of pressure on the flame shape and position is observed between 10 and 20 bars operating conditions
- No blow-off limit found even for very lean conditions (φ~0.3) both in experiments and simulations
- No significant pulsation or flame instability could be detected
- NO_x level between several hundred ppm (@ 15% O_2) for the 5%-dilution case and 6 ppm for the leanest 40%-dilution case
- Simulations with the 11-steps reaction mechanism gives significantly lower peak temperatures and thus NO formation compared to the infinitely fast chemistry assumption
- Glarborg model (simple data postprocessing) gives correct order of magnitude estimates for NO-formation rate
- CARS temperature measurements are the next task at DLR

Thank you for your attention!