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The effect of hydrogen enrichment in strong dilution

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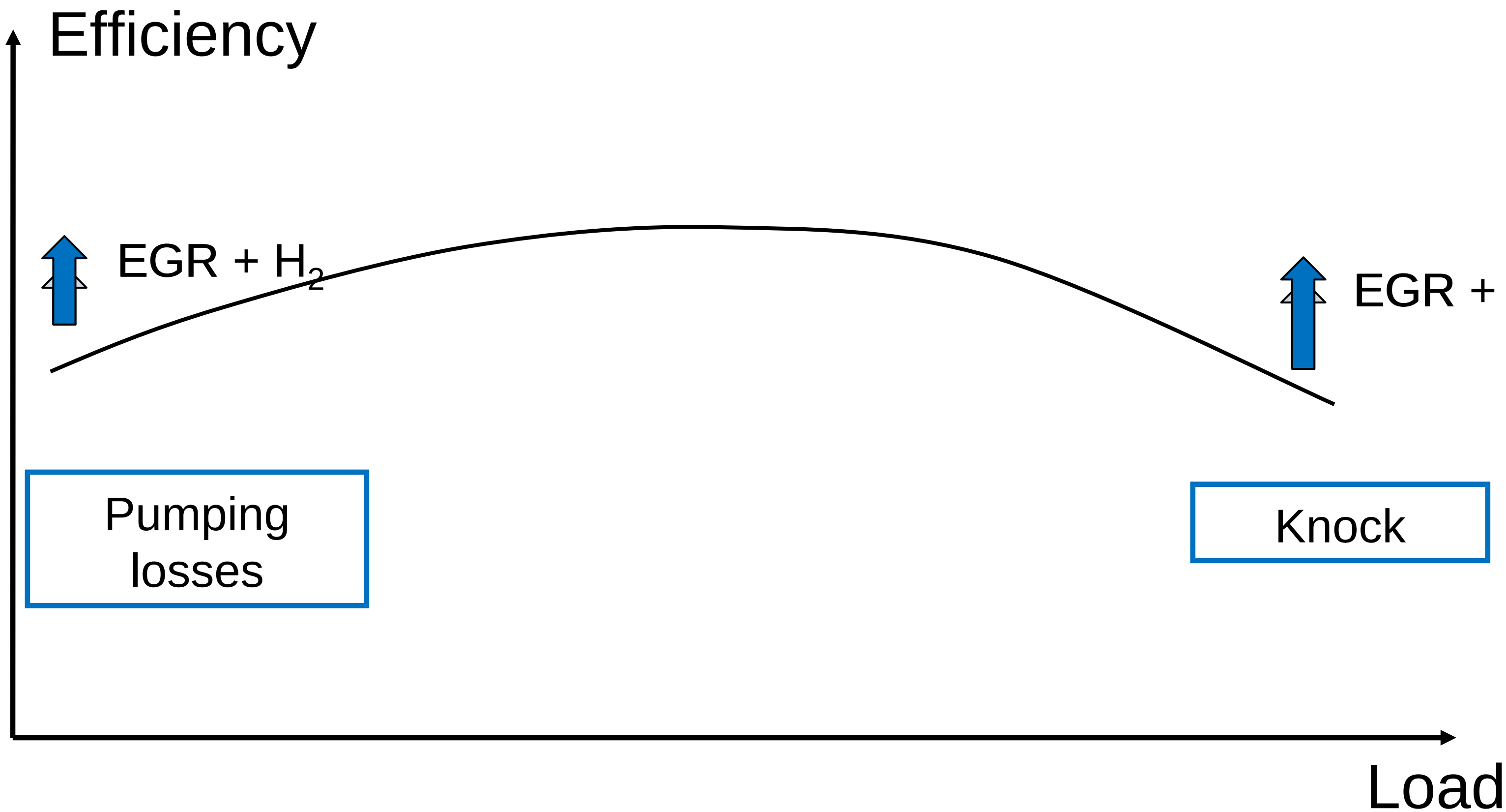
Problematic



- ✓ Hydrogen has an elevated RON (130).

  As a minor blending component, hydrogen seems to raise overall knock resistance.

Hydrogen production

- ✓ As hydrogen quantities are relatively small, the best solution could be an on-board production.

  This can be achieved by a reformer.

- ✓ However, the gain in efficiency has to conter-balance the energy needed for hydrogen production.

  Low load conditions are not favorable for the thermic of the reformer.

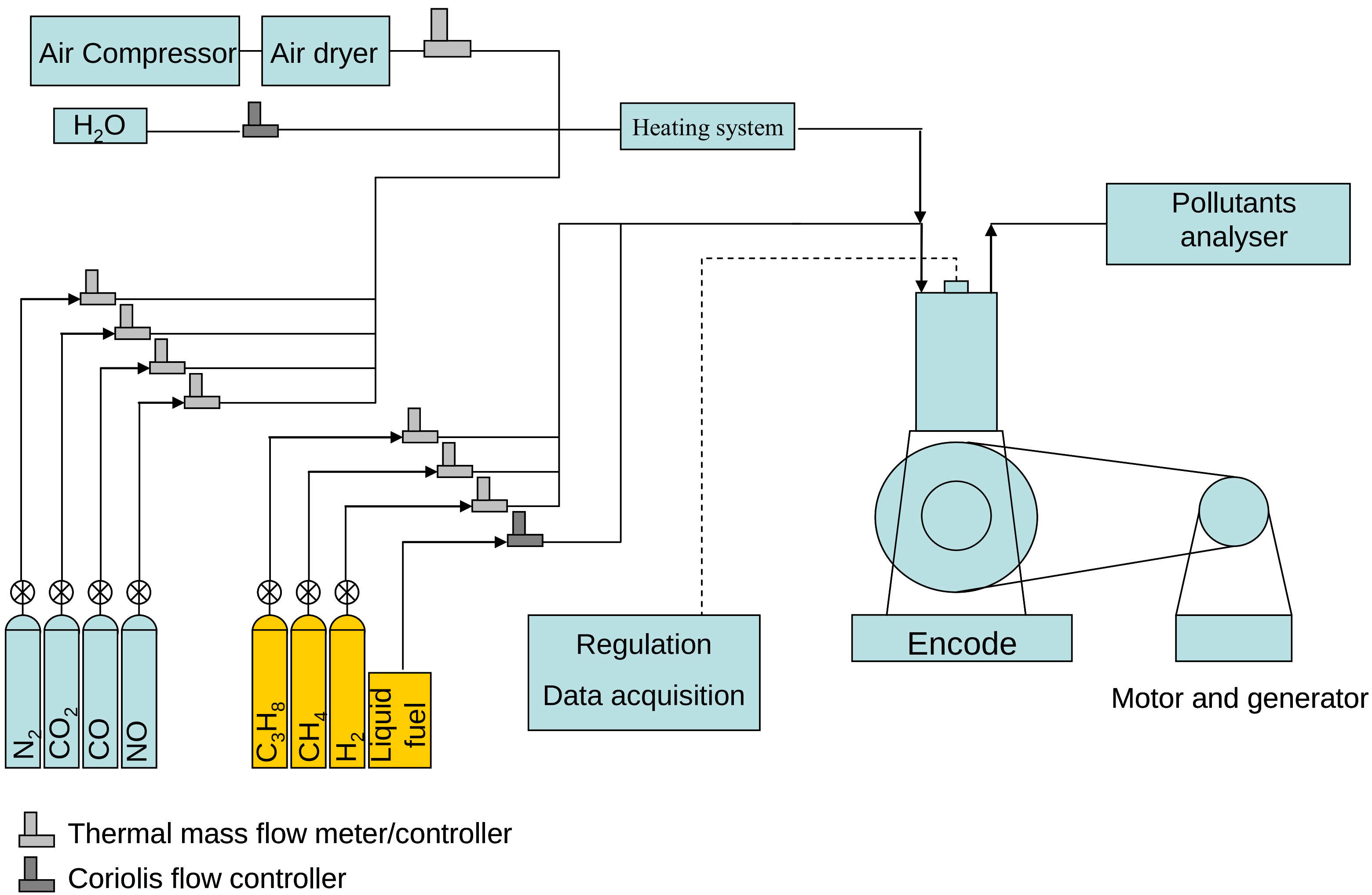
Hydrogen addition effect on the stability

- ✓ For low load conditions, EGR addition is limited by the engine stability.
- ✓ The first step is to show the benefic effect of hydrogen addition on the flame stability.
- ✓ Experiments were performed for low load conditions in a metal engine.

Engine specifications

Engine type	4 valves / cylinder
Displacement volume	499 cm^3
Bore	88 mm
Stroke	82 mm
Compression ratio	9,5
Connecting rod	137 mm

Experimental set-up



Experimental conditions

- ✓ 2 IMEP (2.8 and 4.0 bars)
- ✓ 4 EGR rates (0 – 10 – 15 – 20)
- ✓ 2 hydrogen blendings in the EGR (0 and 15% in vol.)

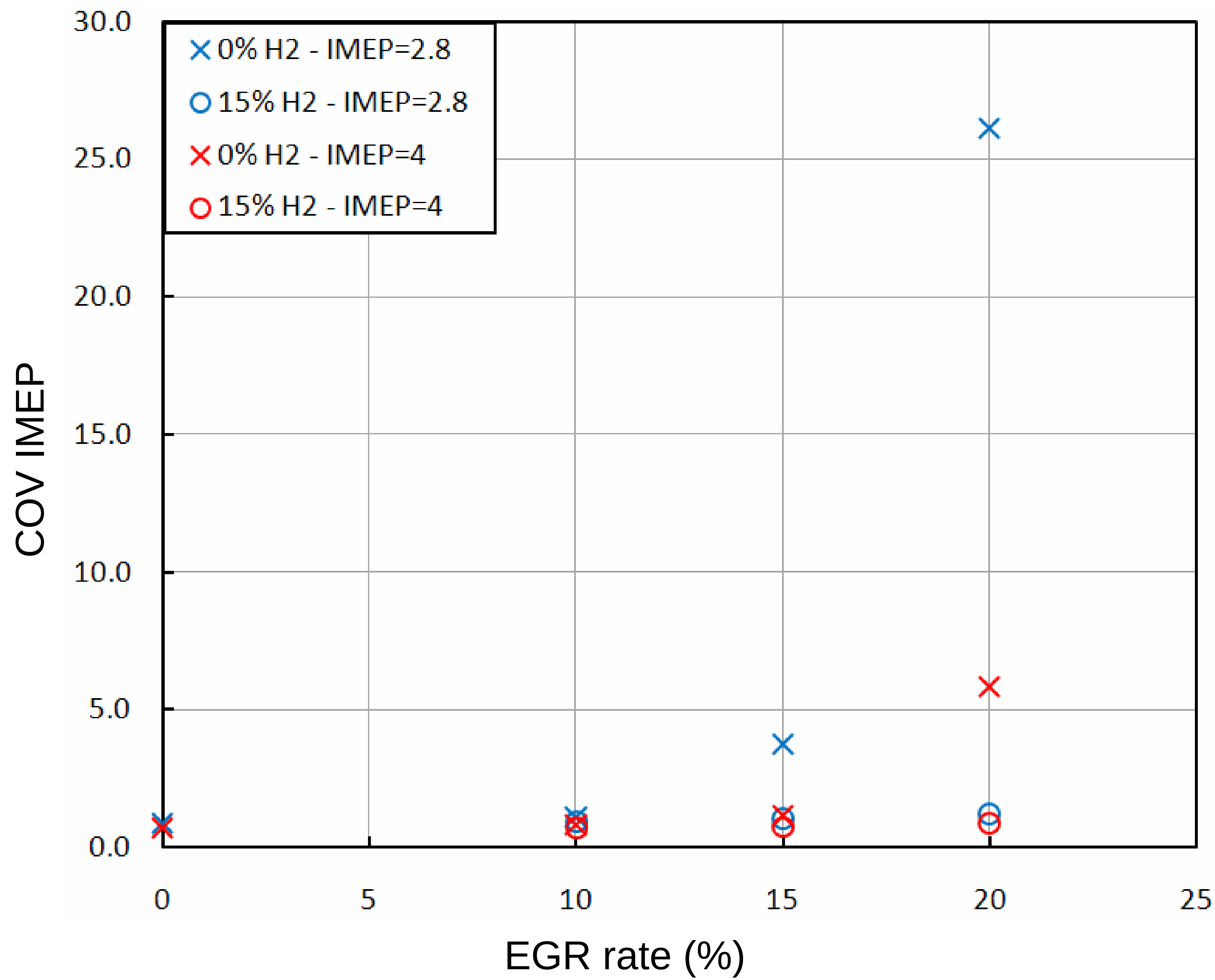
$$IMEP = \frac{\oint PdV}{Vc}[bar]$$

$$COV_{IMEP} = \frac{\sigma_{IMEP}}{IMEP}[\%]$$

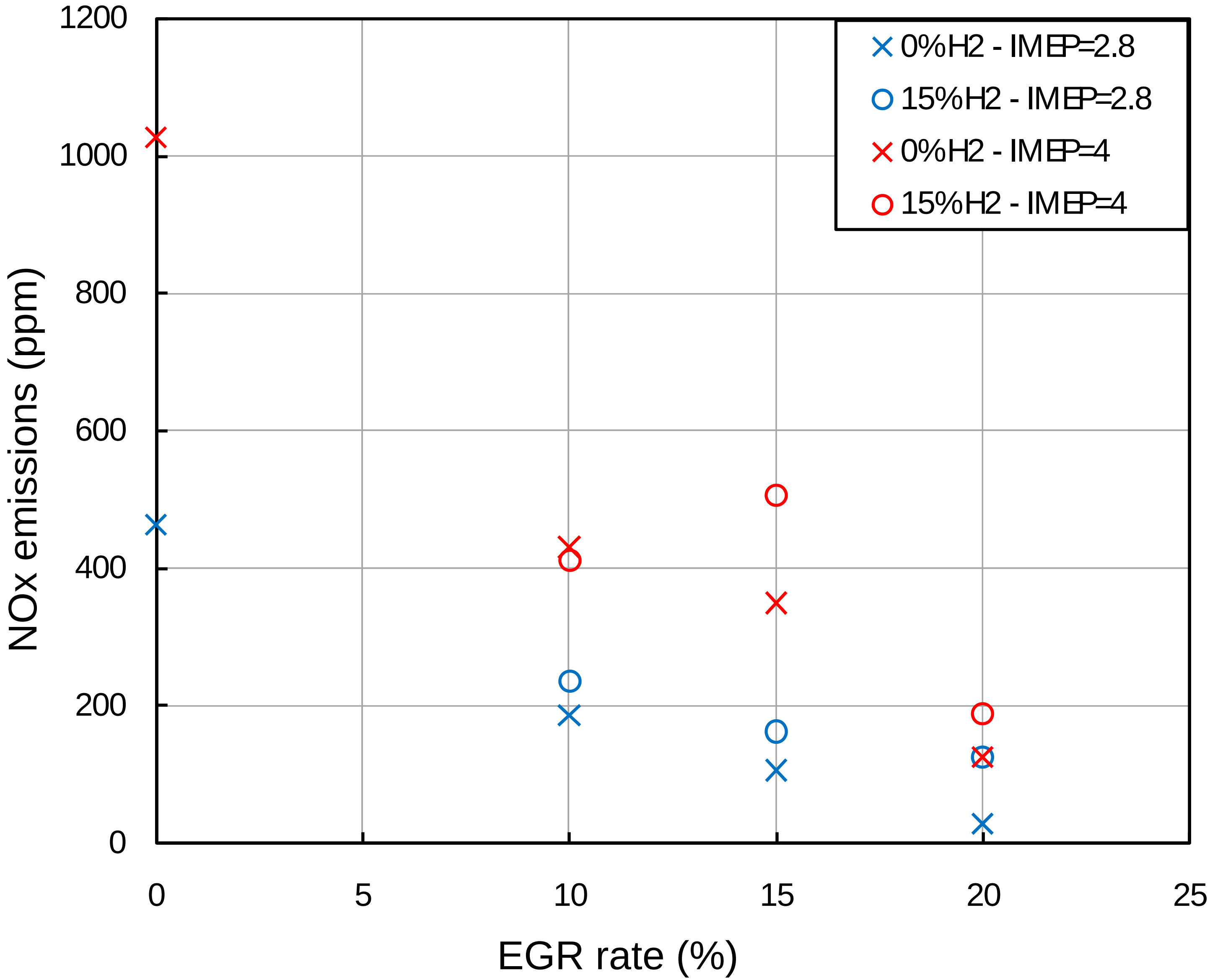
σ_{IMEP} is the standard deviation of the indicated mean effective pressure

Ignition timing and intake pressure were optimised to find the maximum of the Indicated Mean Effective Pressure.

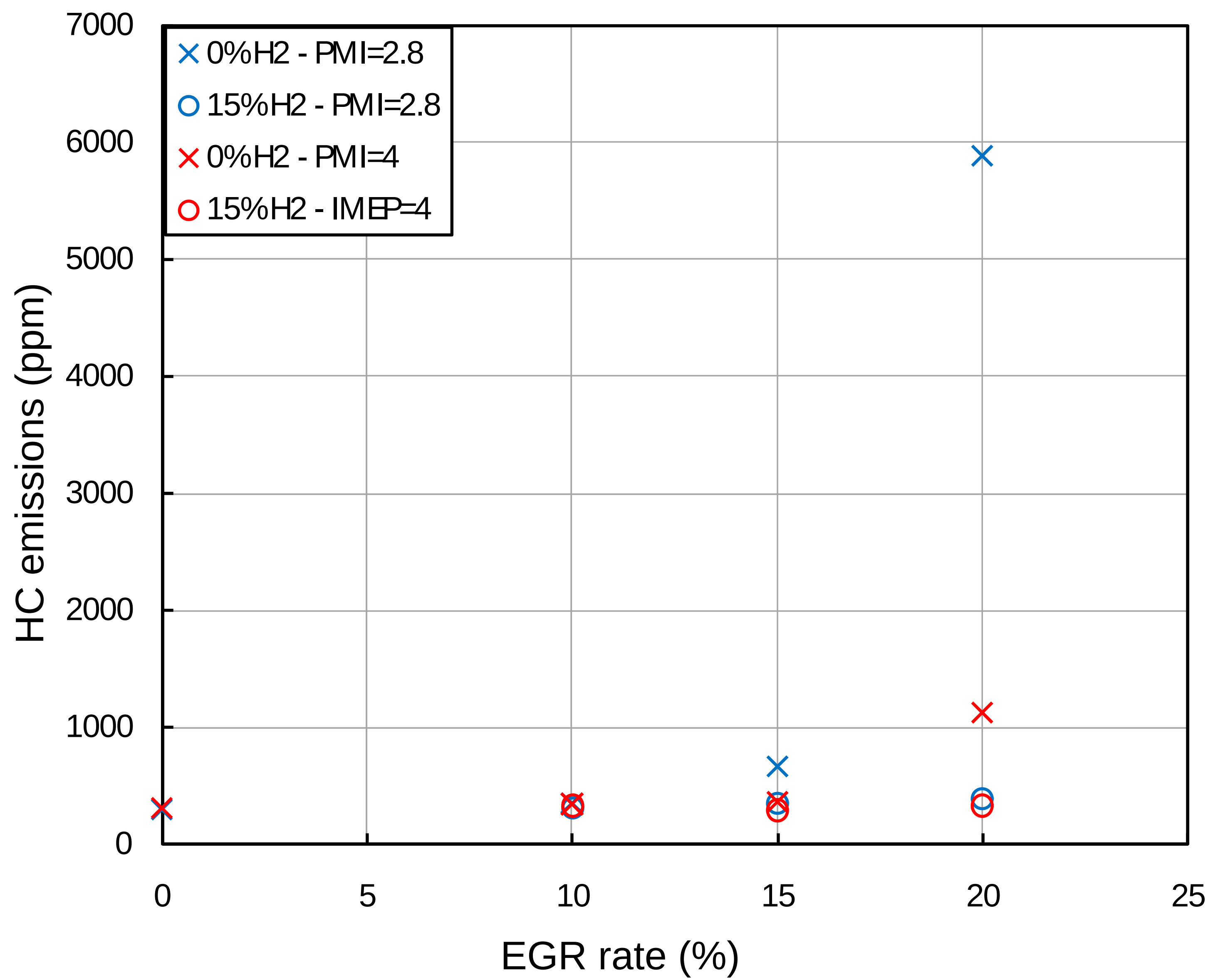
Experimental results - Stability



Experimental results – N0x emisisons



Experimental results – HC emissions



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Conclusions on this first study

- ✓ EGR rate is limited by engine stability.
- ✓ Engine stability can be increased for low load conditions by hydrogen addition.
- ✓ This improvement is directly linked to the enhancement of the turbulent burning velocity.
- ✓
- ✓ This information will be measured experimentally.
- ✓ If we consider a flamelet approach, the turbulent burning velocity is linked to the turbulent flame surface and also to the laminar burning velocity.

Laminar study

- ✓ Propagation limits for different CH_4-H_2-N_2-air mixtures

- ✓ Determination of laminar burning velocities for different N_2 dilution amounts (from 0 - 30%) and for different hydrogen additions (from 0 – 30%).

Experimental conditions:

Pini=0.1 MPa – Tini=300 K – ER=1

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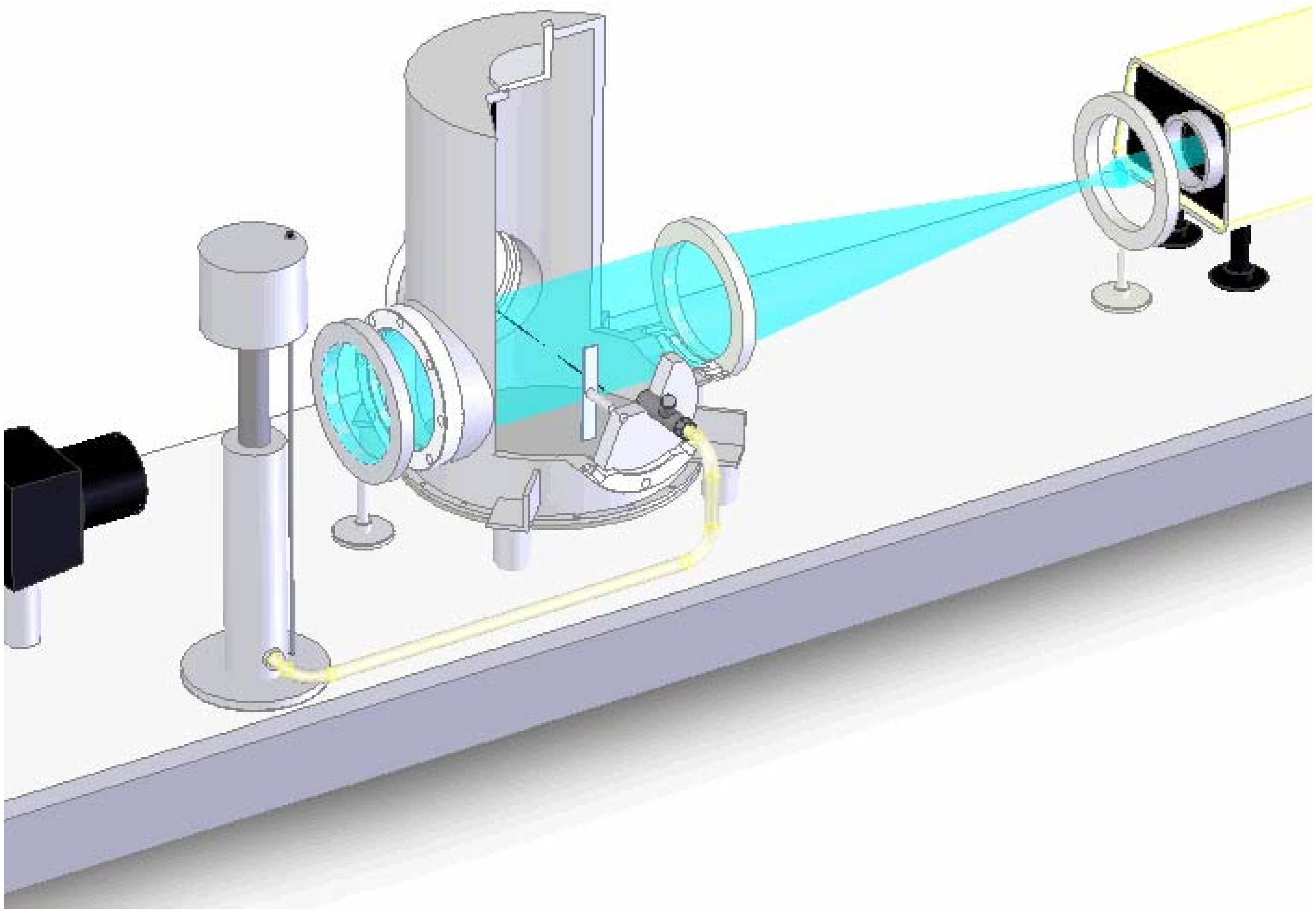
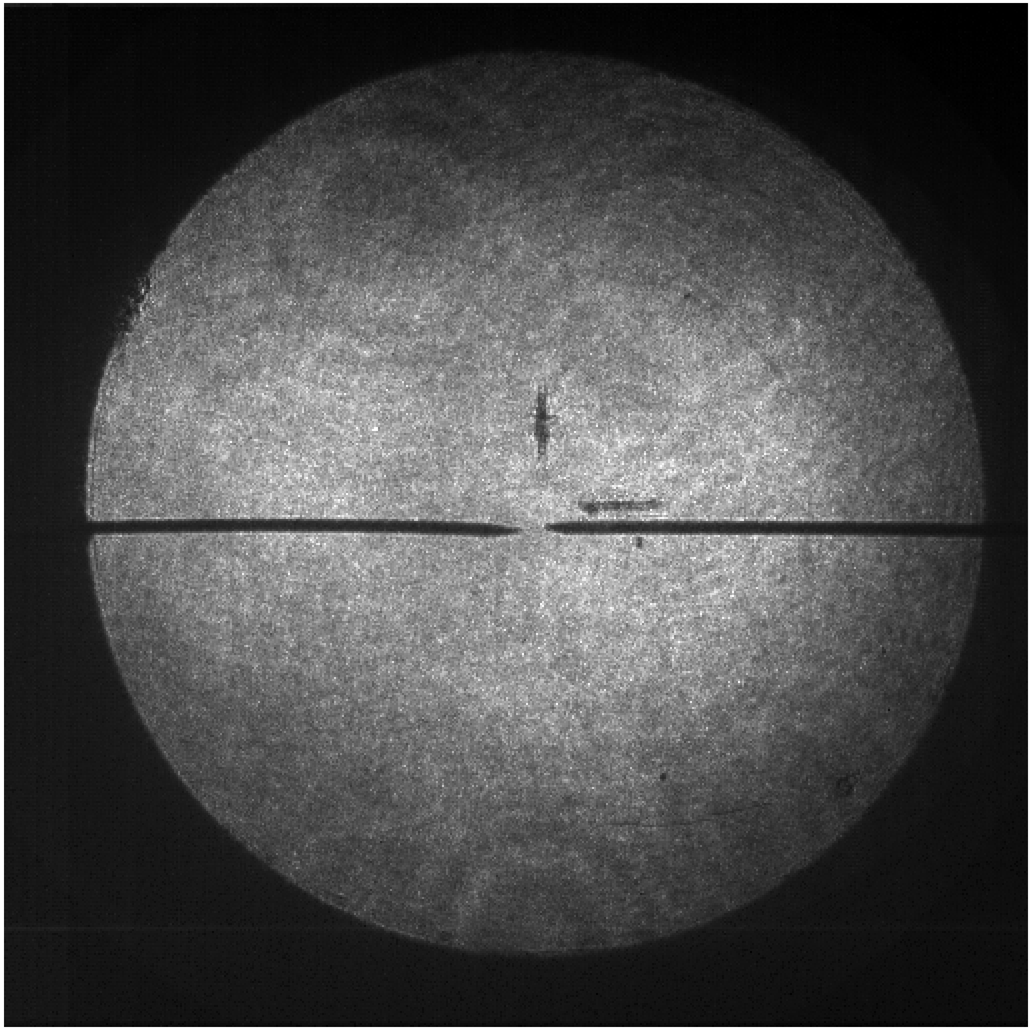
Experimental device

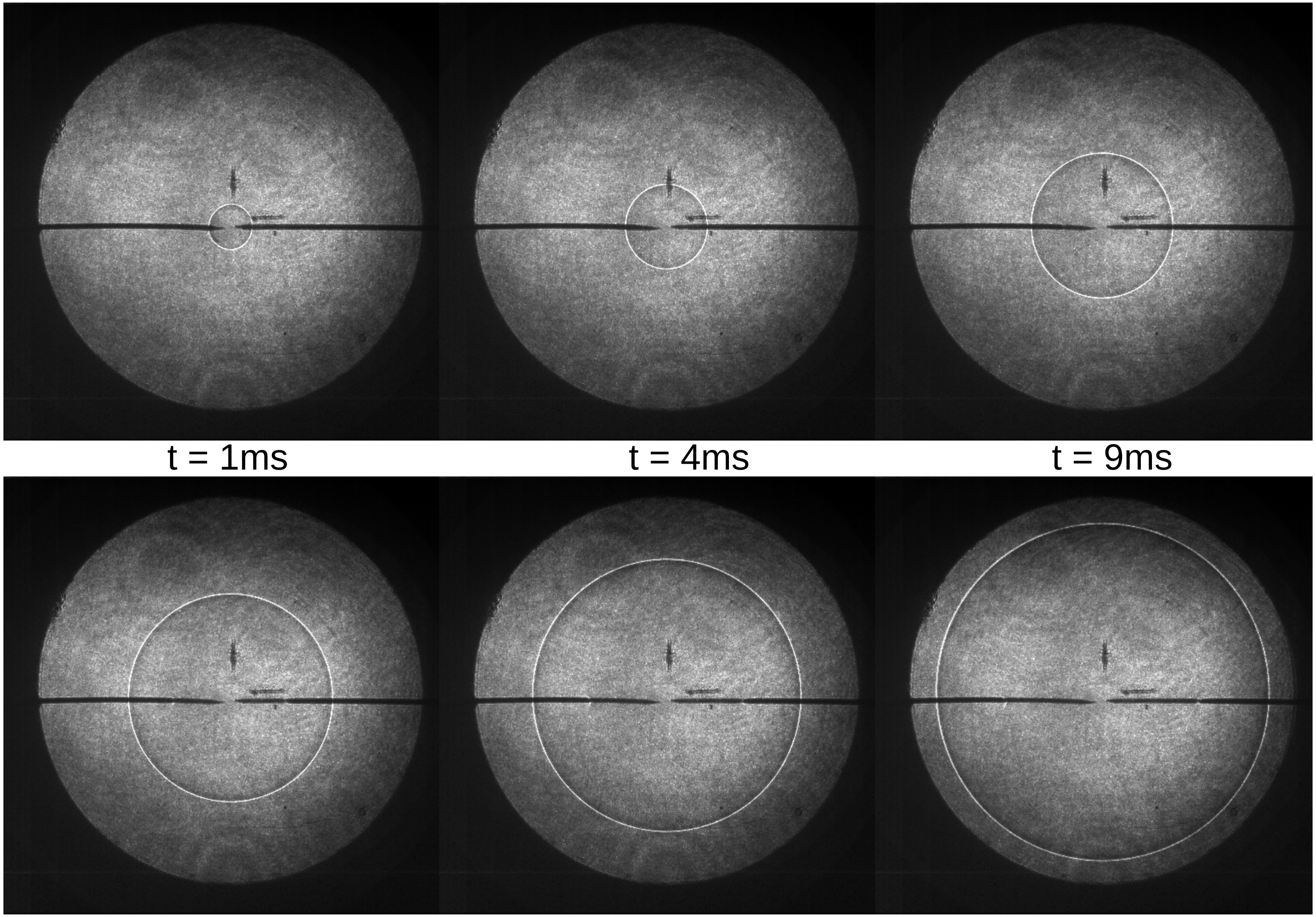


Laminar results extraction

✓ High speed recording of flame front temporel evolution



Laminar results extraction


t = 1ms t = 4ms t = 9ms

t = 14ms t = 19ms t = 24ms

Methane-air mixture with 20%H_2 addition and 20%N_2 dilution

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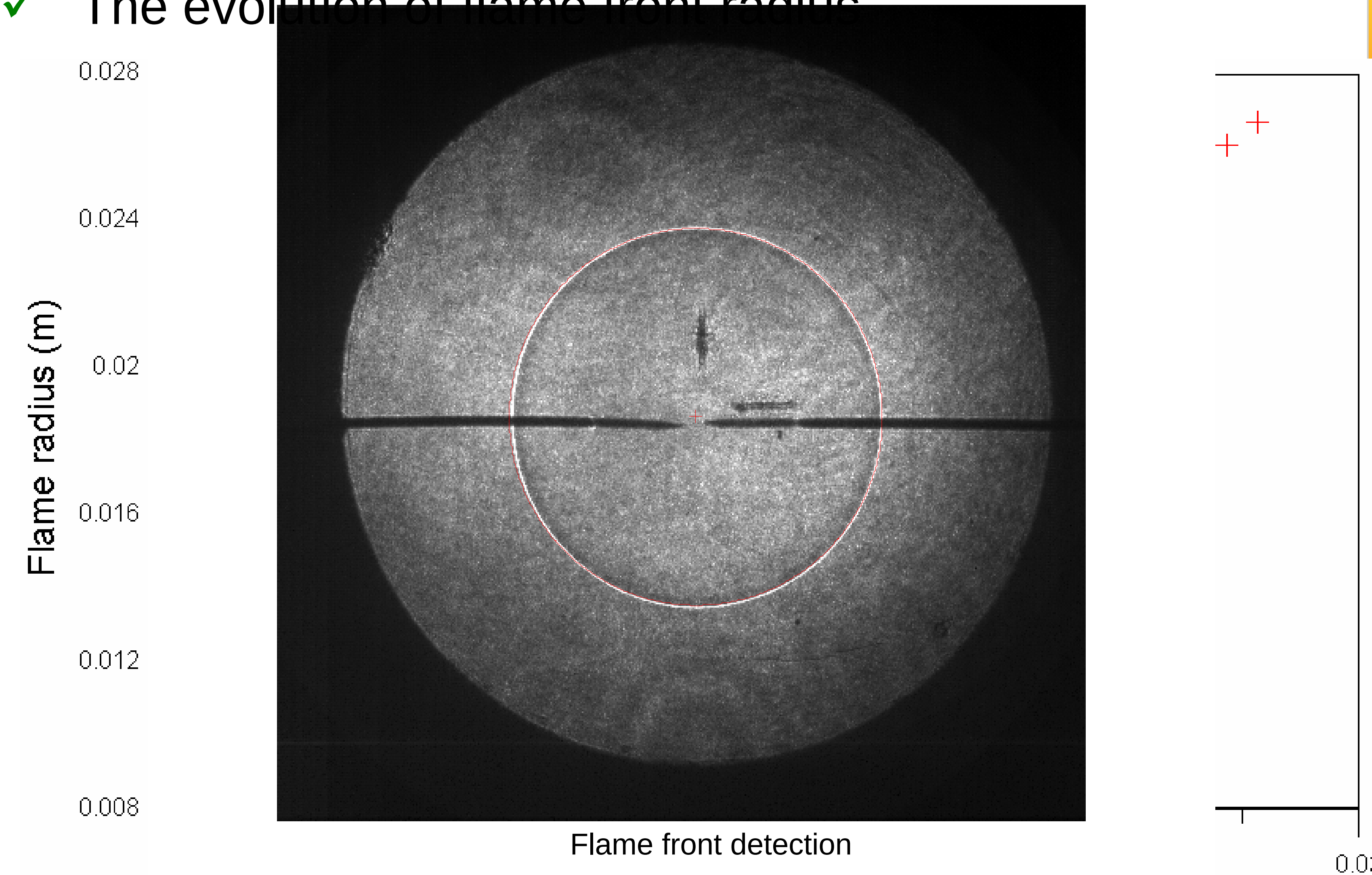
Laminar results extraction

✓ The evolution of flame front radius



Flame front detection

Laminar results extraction

- ✓ The linear relation between laminar flame speed and stretch (Clavin) : $V_S = V_{S0} - L_b * K$

- ✓ Velocity evolution is obtained from radius evolution

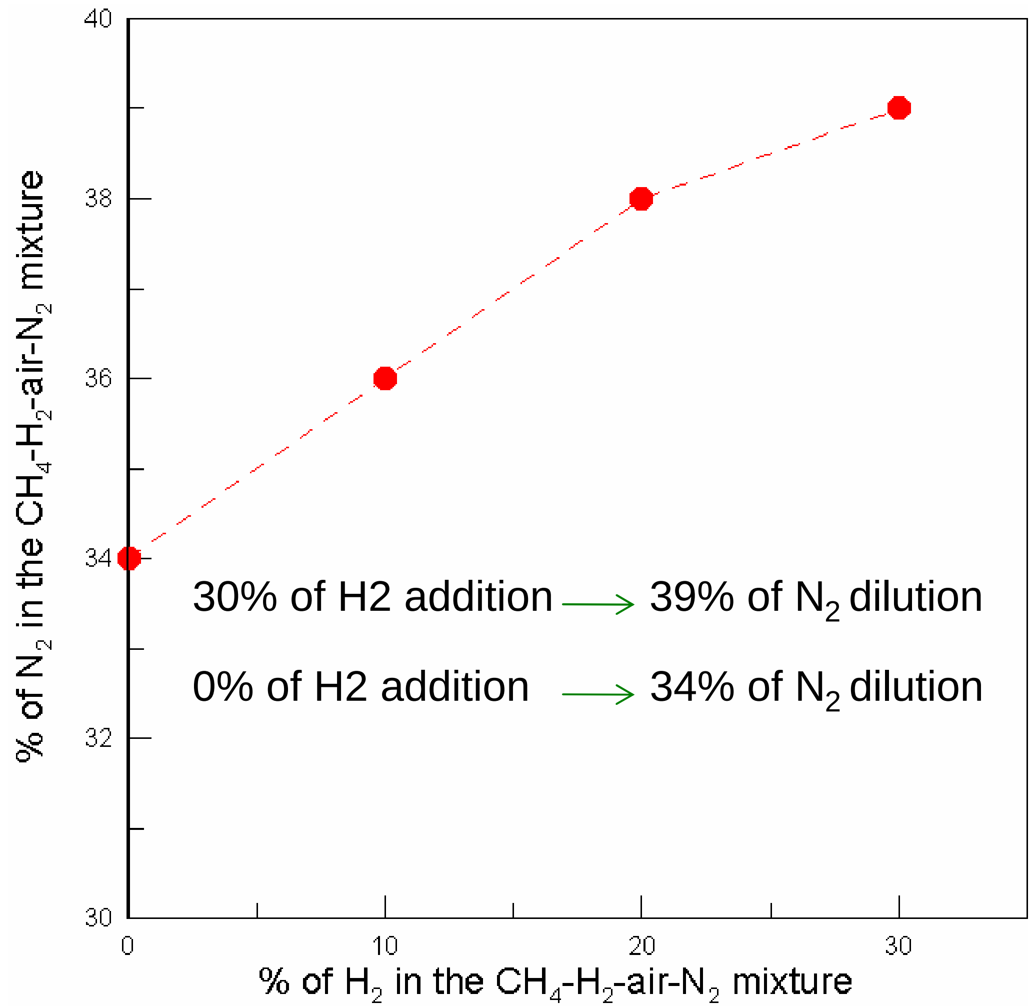
- ✓ Flame stretch evaluation: $K = \frac{1}{A} * \frac{dA}{dt} = \frac{1}{2r_f} \frac{dr_f}{dt}$

- ✓ Linear extrapolation to a zero stretch rate for the calculation of the unstretched laminar flame speed

- ✓ Correction linked to the expansion factor (density ratio $\frac{\rho_b}{\rho_u}$)

Results and discussion (1/2)

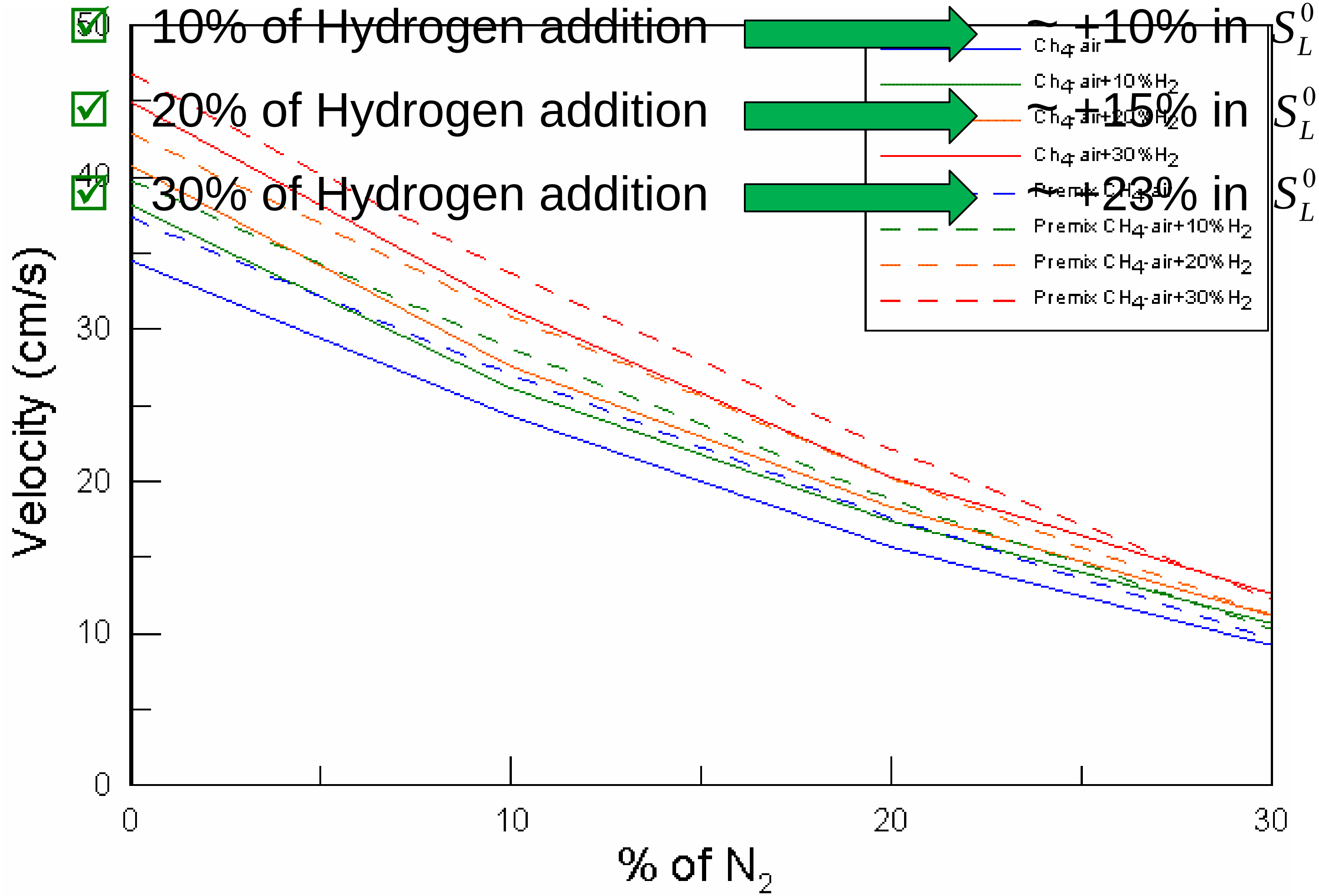
- ✓ Determination of the propagation limits
  - ☑ Using a visual criterion



Results and discussion (2/2)

✓ Laminar burning velocity

- ☑ 10% of Hydrogen addition → ~ +10% in S_L^0
- ☑ 20% of Hydrogen addition → ~ +15% in S_L^0
- ☑ 30% of Hydrogen addition → ~ +23% in S_L^0



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Laminar results - Conclusion

- ✓ Flammability limits are extended
  - ☑ 30% of Hydrogen addition → ~ +5% of N_2 dilution
- ✓ Laminar burning velocities are increased
  - ☑ 30% of Hydrogen addition → ~ +23% in u_{l0}

Perspectives

- Engine conditions:
  - ☑ A knock sensivity study when hydrogen is added.
    A two zones modelisation with detailed chemistry.
  - ☑ Stabilisation study for high load conditions.
  - ☑ Turbulent burning velocities and flame front structure in an engine with optical accesses.

- Laminar conditions
  - ☑ Iso-octane
  - ☑ High pressure (20 bars) and temperature (450 K) conditions.

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