PAUL SCHERRER INSTITUT

PSI

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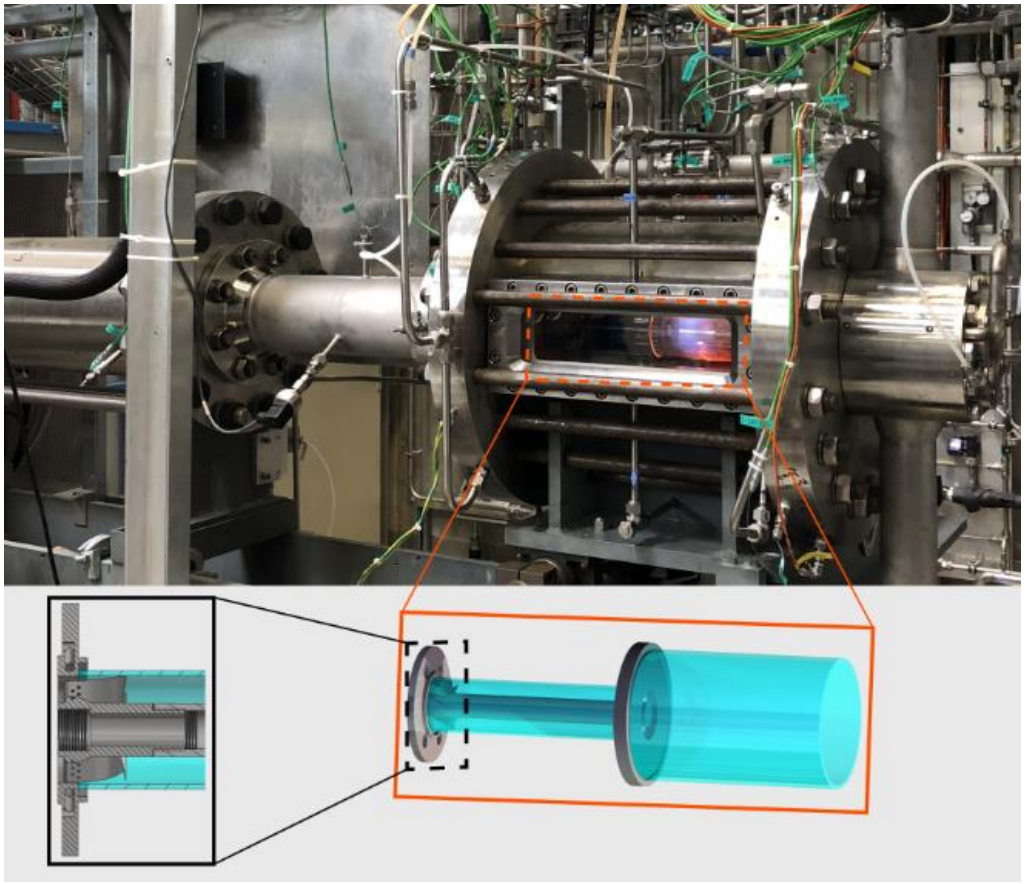
Combustion of CH4/H2 Mixtures in Gas Turbines – Effect of Mixing on Risk of Flashback

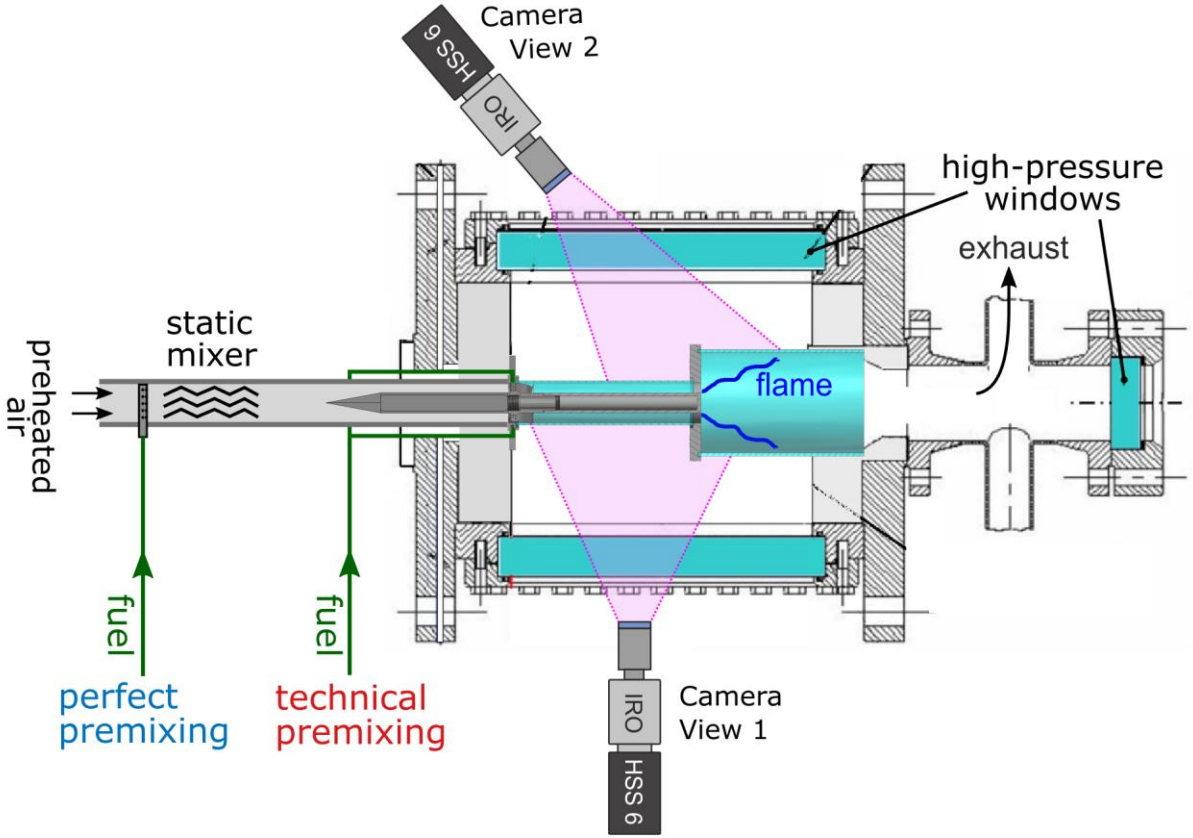
10th International Gas Turbine Conference - ETN – 13.10.2021

High-pressure test rig



- Pressure:
  1 bar - 7.5 bar
- Preheat temperature:
  200°C and 300°C
- Inlet velocities:
  15 - 40 m/s
- Fuel:
  H_2-CH_4 mixtures with
  50% - 100% H_2
- Swirl number:
  0.7
- Oil cooling/heating to control center body wall temperature

High-pressure test rig: Technical vs. perfect premixing



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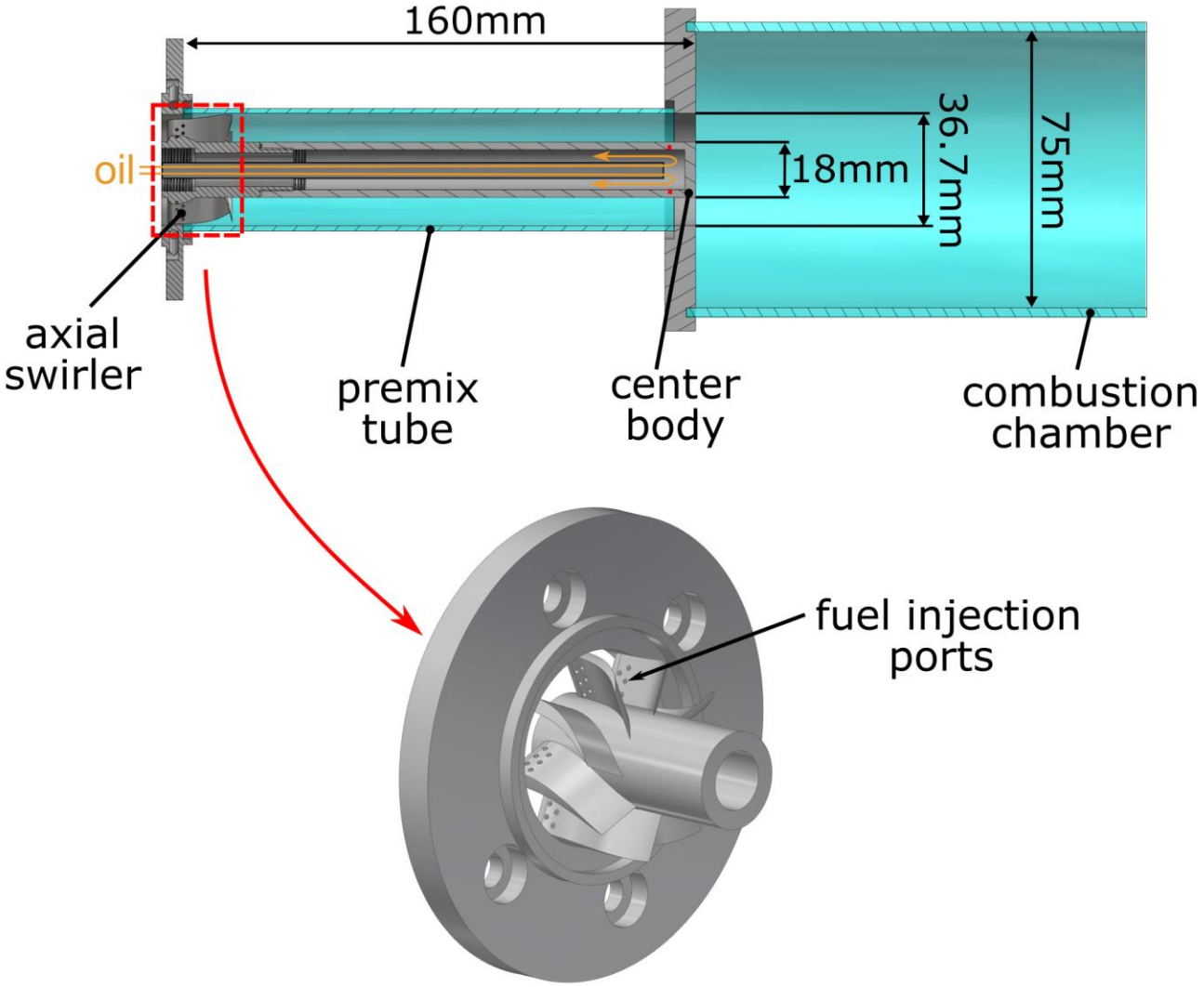
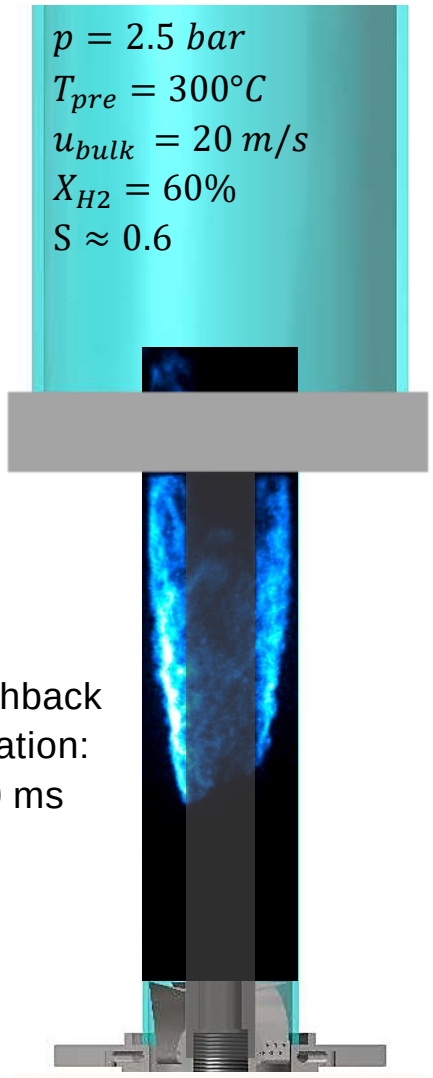
Swirl burner



Scope of work and flashback type

OH* imaging at 5 kHz



flashback duration: 100 ms

Novel aspects of current project

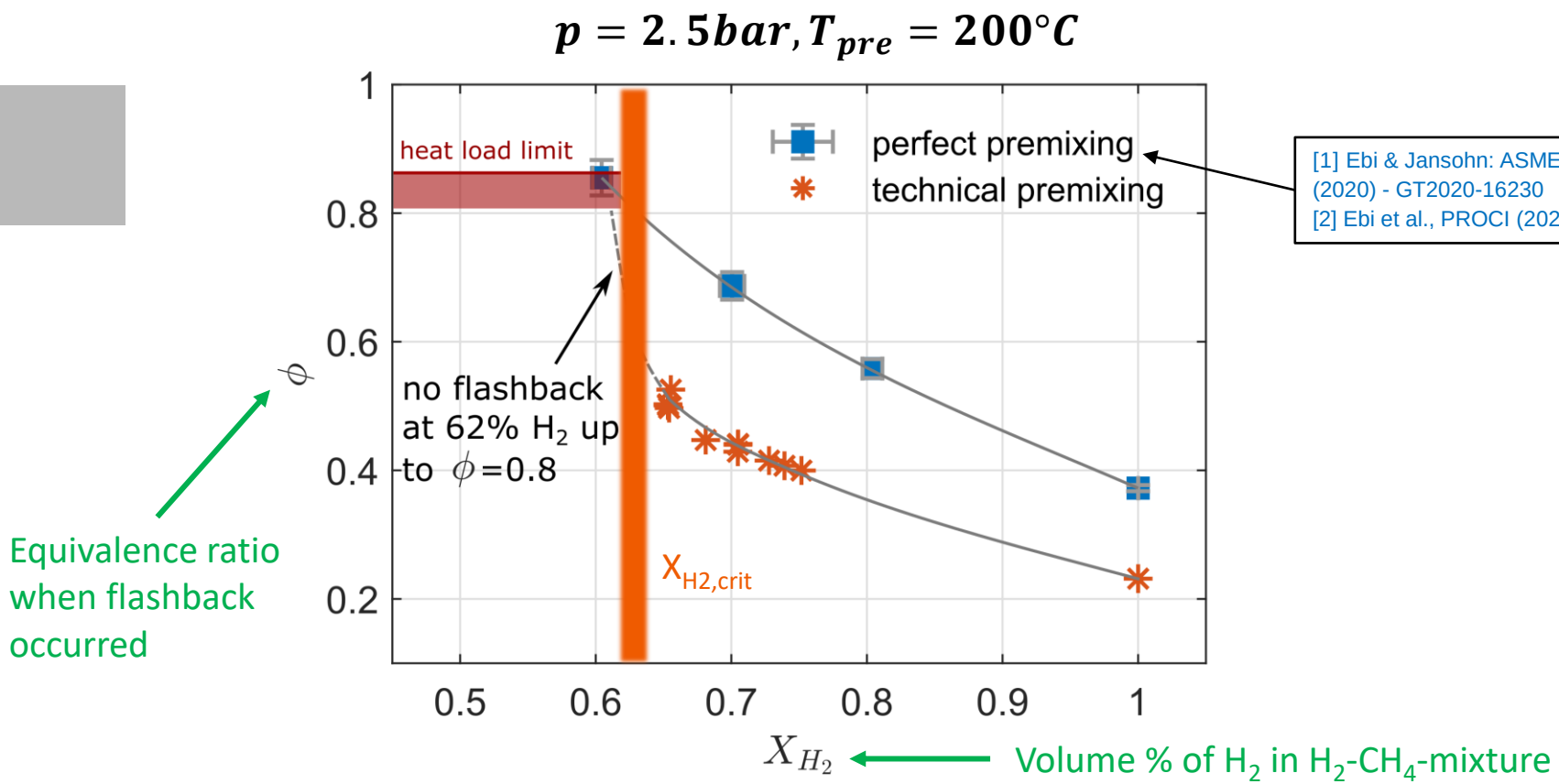
- Systematic investigation of H_2-CH_4-mixtures
- Swirl flame boundary layer flashback at elevated pressure and preheat temperature with optically accessible premix section
- Controlled thermal boundary condition on center body

General observations

- Flashback along center body wall
- Flame already creeps into premix section prior to flashback [1-3]
- "Flashback": equivalence ratio at which flame propagates all the way up to the swirler

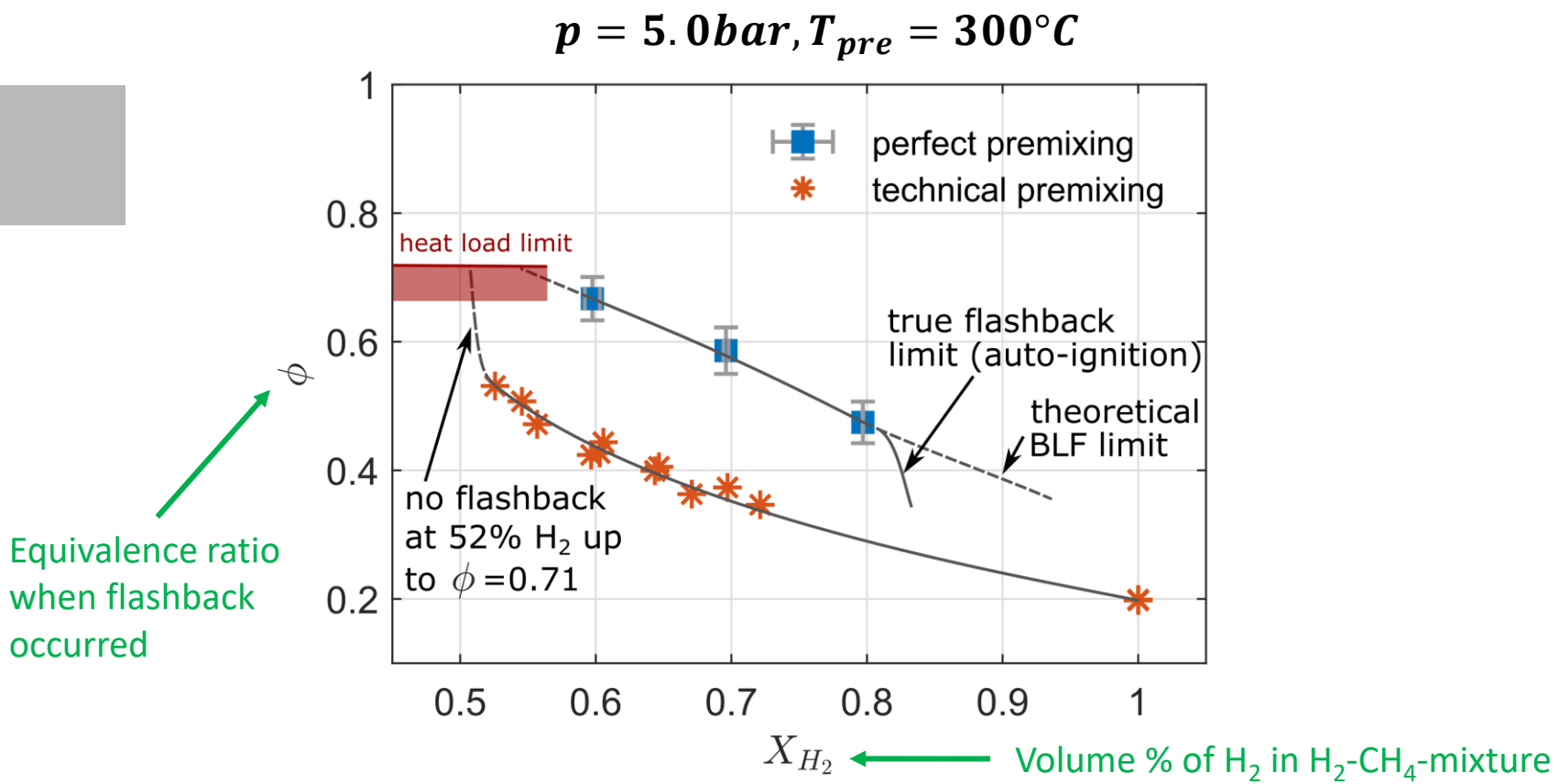
[1] Nauert et al. (2007). *Experiments in Fluids*, *43*(1), 89–100
[2] Ebi & Clemens (2016). *Combustion and Flame*, *168*, 39–52
[3] Schneider & Steinberg (2020). *J Propulsion and Power*, *36*(6), 940–949

Effect of H_2 content on flashback limit



- Well-known strong increase in flashback propensity with increase in H_2 content
- Technical premixing hardly effects flashback limit below critical X_{H2} (here: ~ 60%)
- **Hydrogen-rich flames react strongly to unmixedness above a** critical X_{H2}

Effect of H_2 content on flashback limit

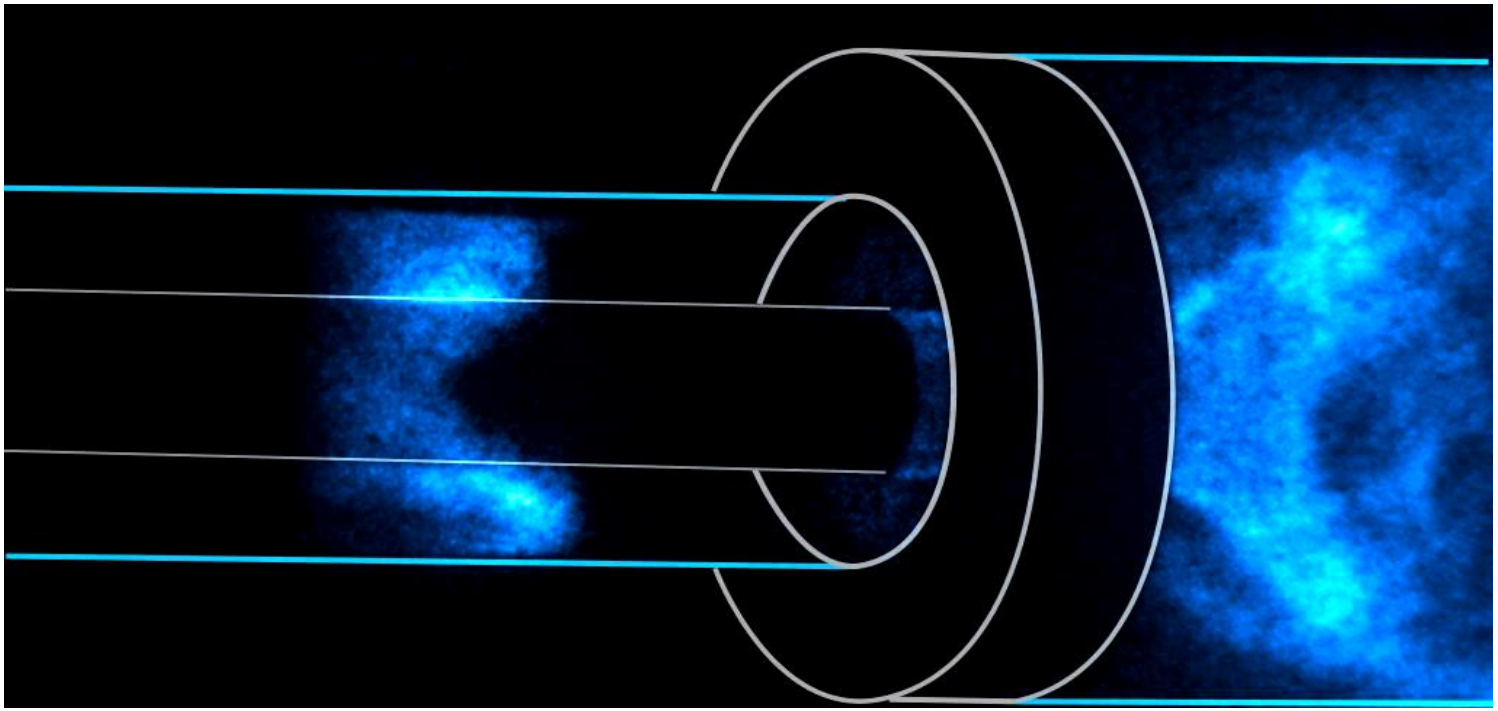


- Findings consistent at higher pressure and preheat temperature, but critical X_{H2} shifts down to ~ 50%
- Conditions for strong sensitivity to equivalence ratio stratification: Large hydrogen content ***and*** globally lean conditions

Flashback due to auto-ignition

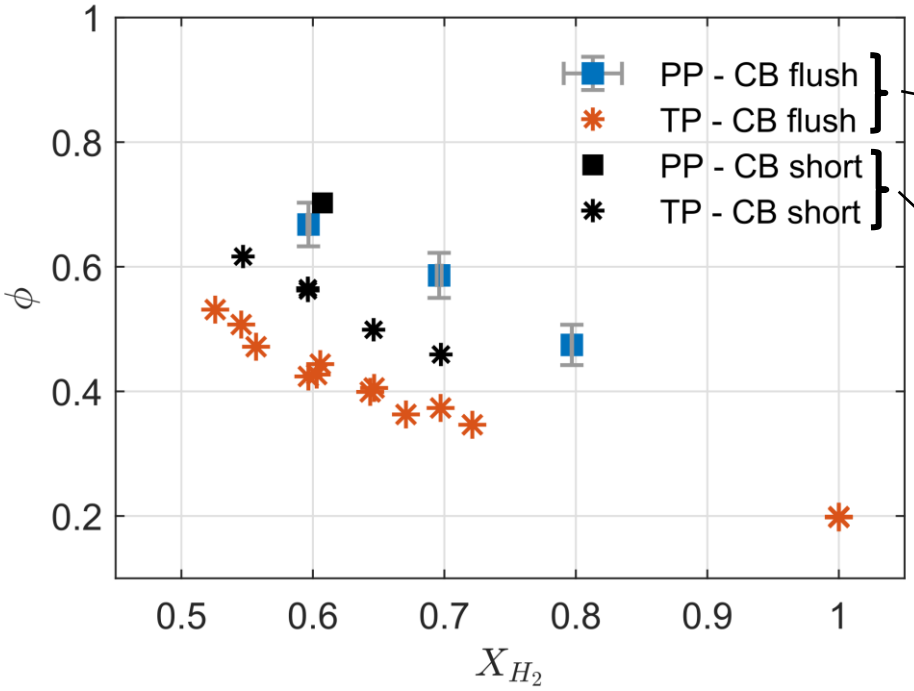
$$p = 5.0bar, T_{pre} = 300°C, X_{H2} = 70\%$$

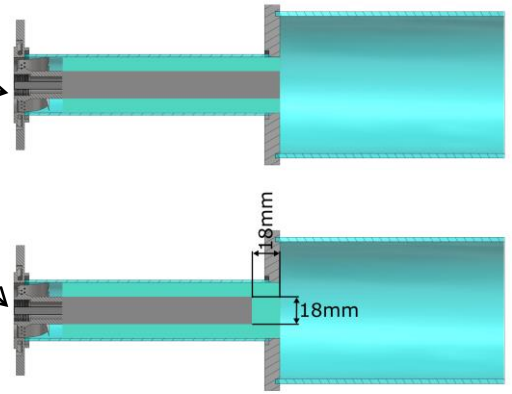
perfect premixing



Effect of recessed central fuel lance

$$p = 5.0bar, T_{pre} = 300°C$$

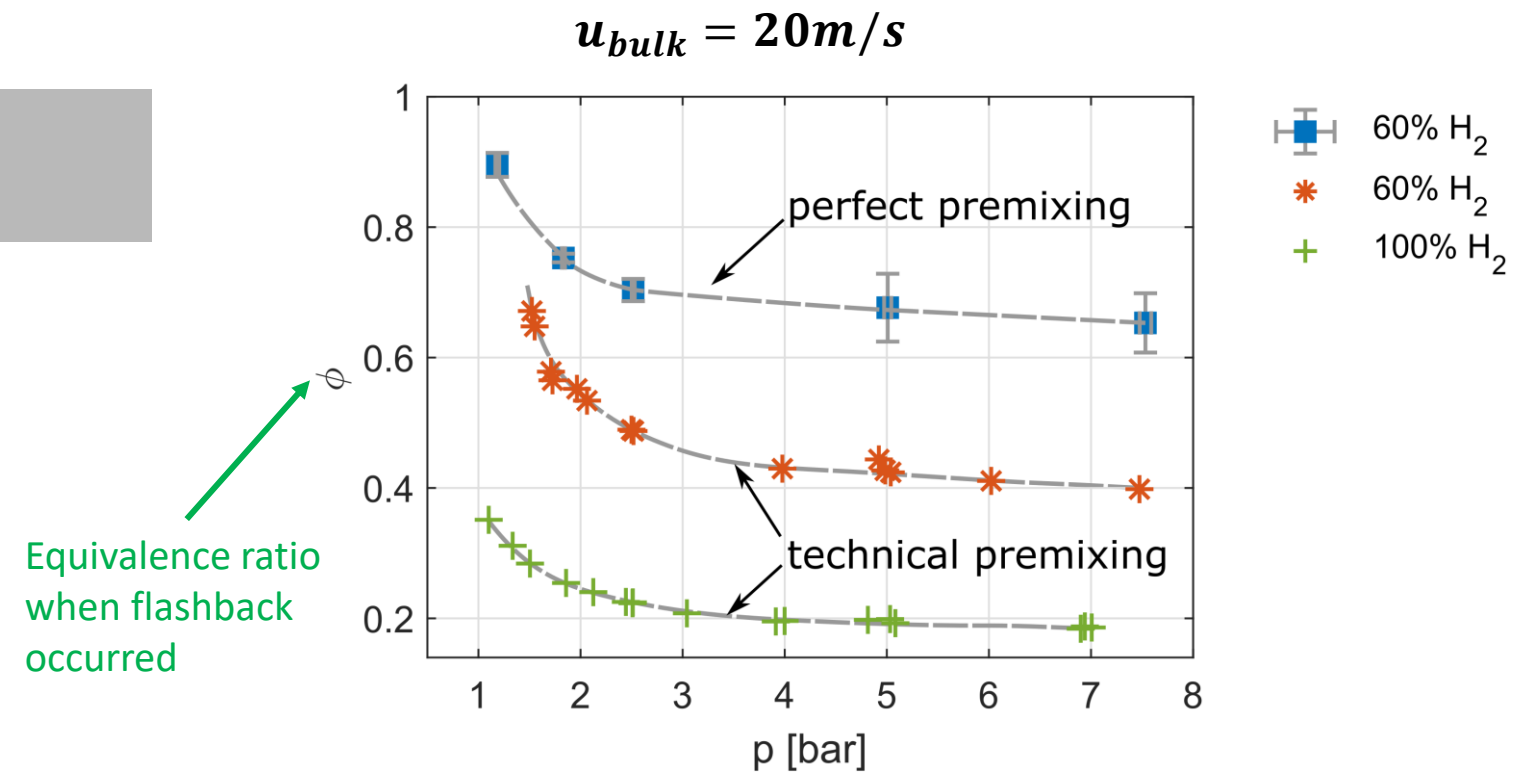




Equivalence ratio when flashback occurred

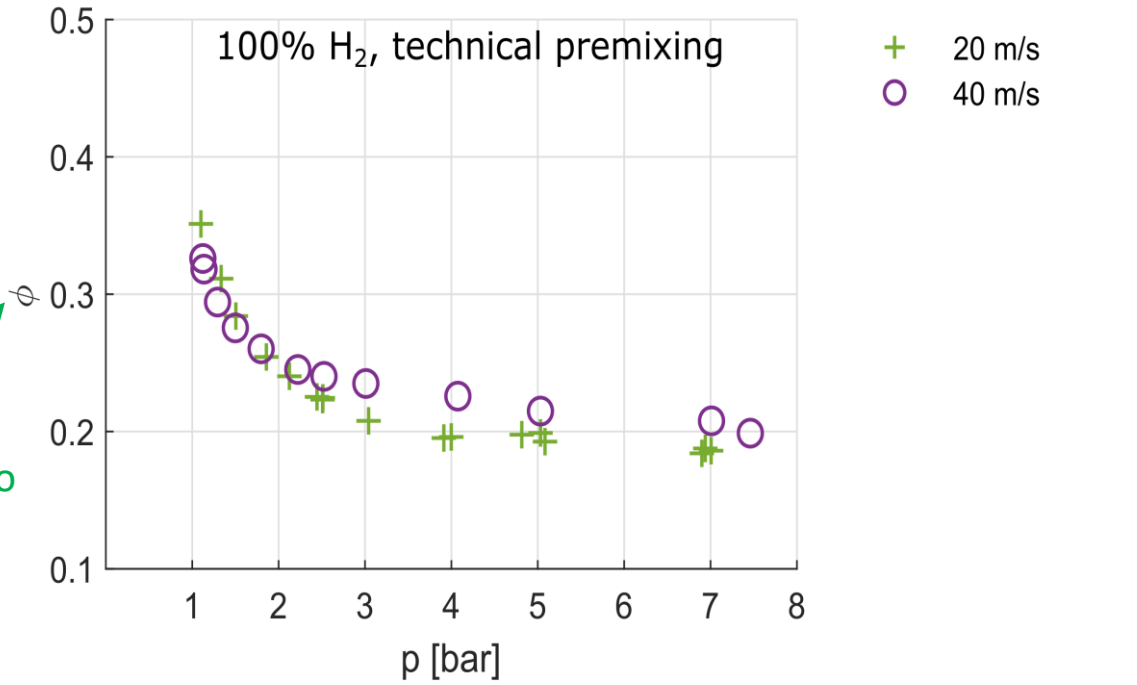
- Recessed center body decreases flashback risk
- Same effect of unmixedness (technical (TP) vs. perfect premixing (PP)) for recessed center body

Effect of pressure on flashback limit



- Flashback risk increases significantly up to about 3 bar
- No strong pressure effect beyond 3 bar (for flashback due to flame propagation in boundary layer)
- Remember that metal temperature is kept constant in these experiments to identify the fundamental flashback limit (i.e., decoupled from heat load effects etc.)

Effect of bulk flow on flashback limit



Equivalence ratio when flashback occurred

- Doubling the volume flow rate through burner (→ flow velocity in the premix section) hardly improved flashback margin for pure H_2 flames
- **H_2 makes flames significantly more resistant against extinction due to shear**

→**Very high shear required to prevent flashback** (micro mixer burner design essentially benefits from this)

Summary & Conclusions

- Technical premixed flames have some remaining unmixedness
- **Unmixedness strongly affected flashback limits for lean, hydrogen-rich flames above a critical H_2 volume fraction**
- Unmixedness hardly affected H_2-CH_4 flames with low H_2 content
- **Critical H_2 volume fraction depends on operating conditions** (here: 50 – 60% H_2 by volume in H_2-CH_4 mixture)
- Switching from CH_4 to Swiss natural gas had negligible effect on flashback limits → same conclusions hold for H_2-NG mixtures

Outlook

- Physics responsible for observed behavior
- Simple, but very good model to predict effect of H_2 on flashback limits
  – Extend this model to account for mixing effects
- Strong sensitivity to mixing also a chance for improvement of flashback margin: Tailor near-wall equivalence ratio

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