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## Weak flame in a micro flow reactor with controlled temperature profile for the investigation of ignition characteristics in lean PRF/TRF/air mixtures

### Objective

#### Background

- Ultra lean gasoline combustion allows for higher thermal efficiency
- Ignition characteristics and mechanisms are not well validated in ultra lean condition
- Important to avoid engine knocking

#### Challenges

- Ultra lean combustion usually only possible in high temperature/pressure region
- Common approaches are not steady state (RCM, Shock tube)

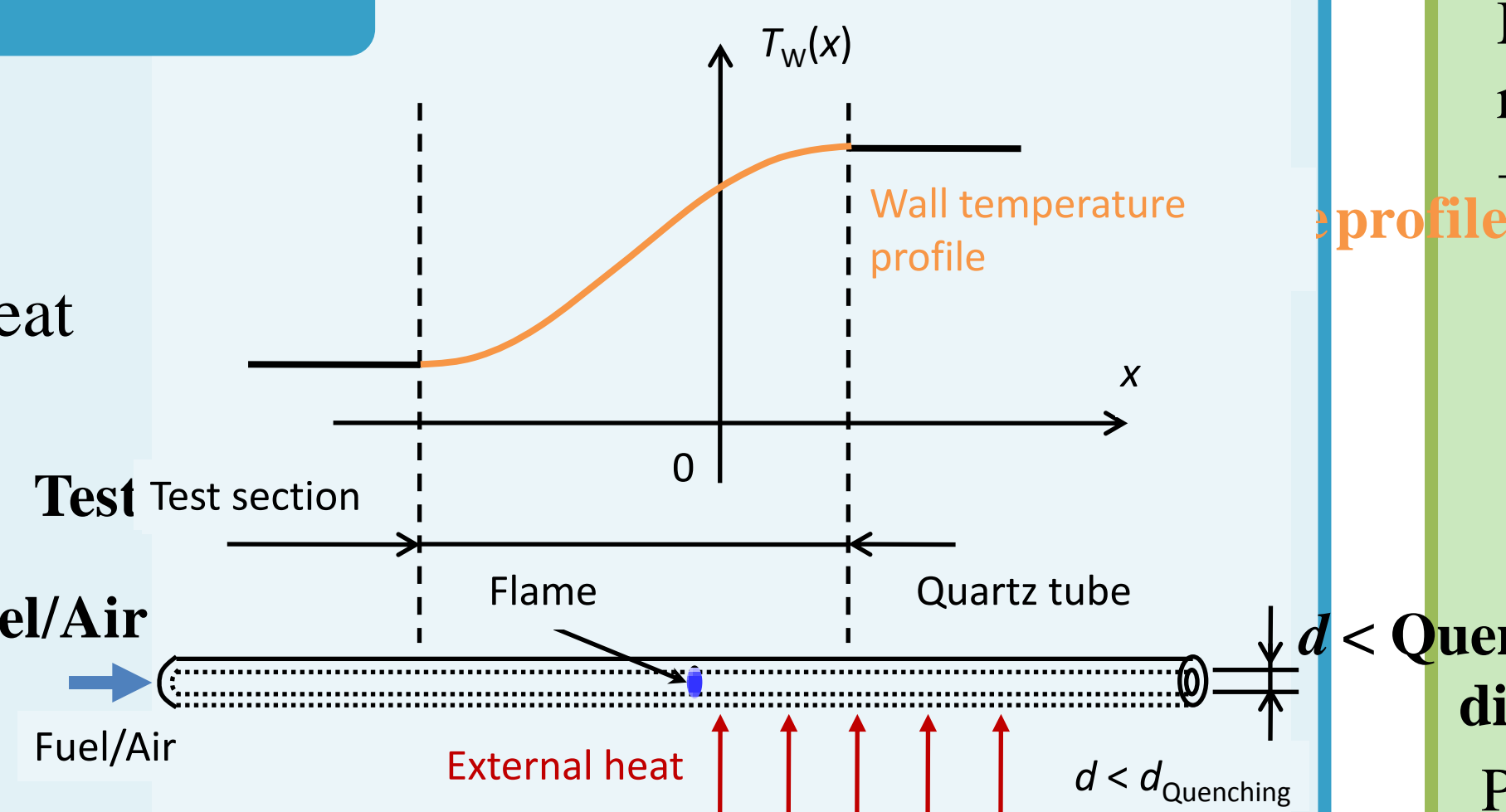
#### Solution

- Investigation by micro flow reactor with controlled temperature profile
- Allows for investigation at atmospheric and elevated pressures and temperatures
- Enables steady state investigation

### Principle

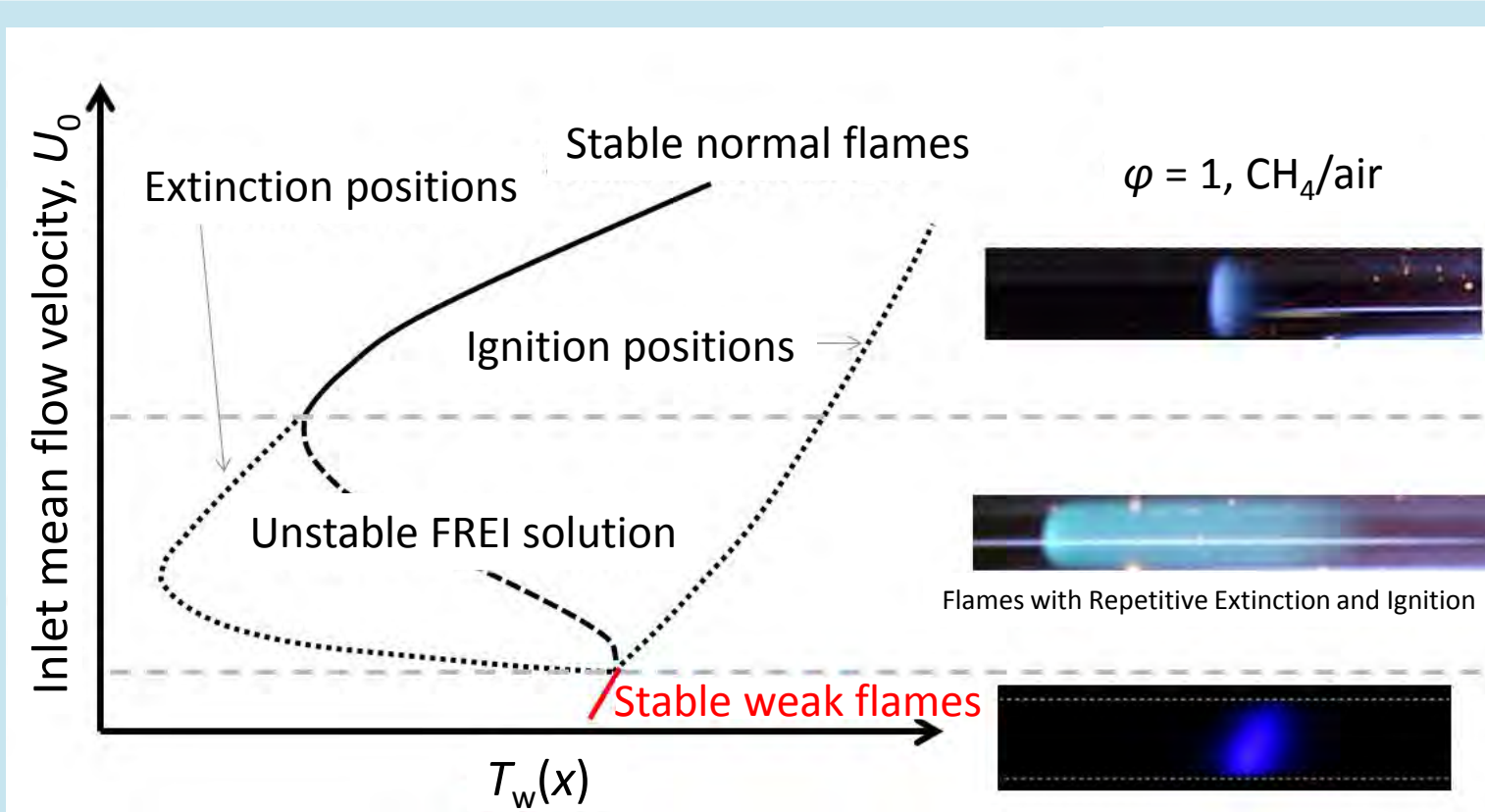
#### Micro flow reactor with controlled temperature profile [1][2]

- Quartz tube heated by an external heat source (H<sub>2</sub>/air flame)
- Diameter smaller than quenching diameter
- Gas phase temperature is governed by wall temperature



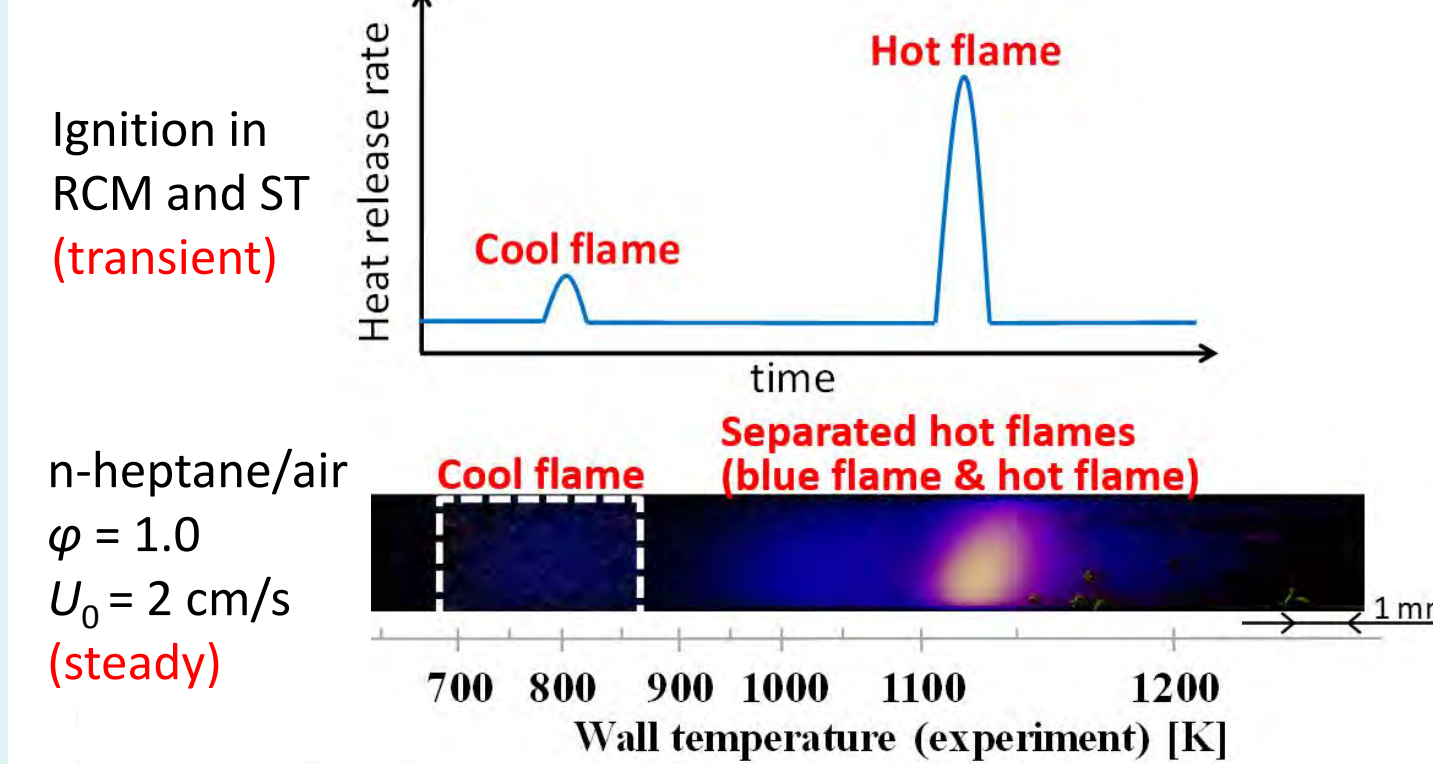
#### Flame responses to velocity [1][2]

- Three flame branches exist
- Unstable branch connecting normal flame and weak flame
- Weak flame occurs at low velocities
- Applicable for investigation on ultra lean preheated premixed flame by normal flame



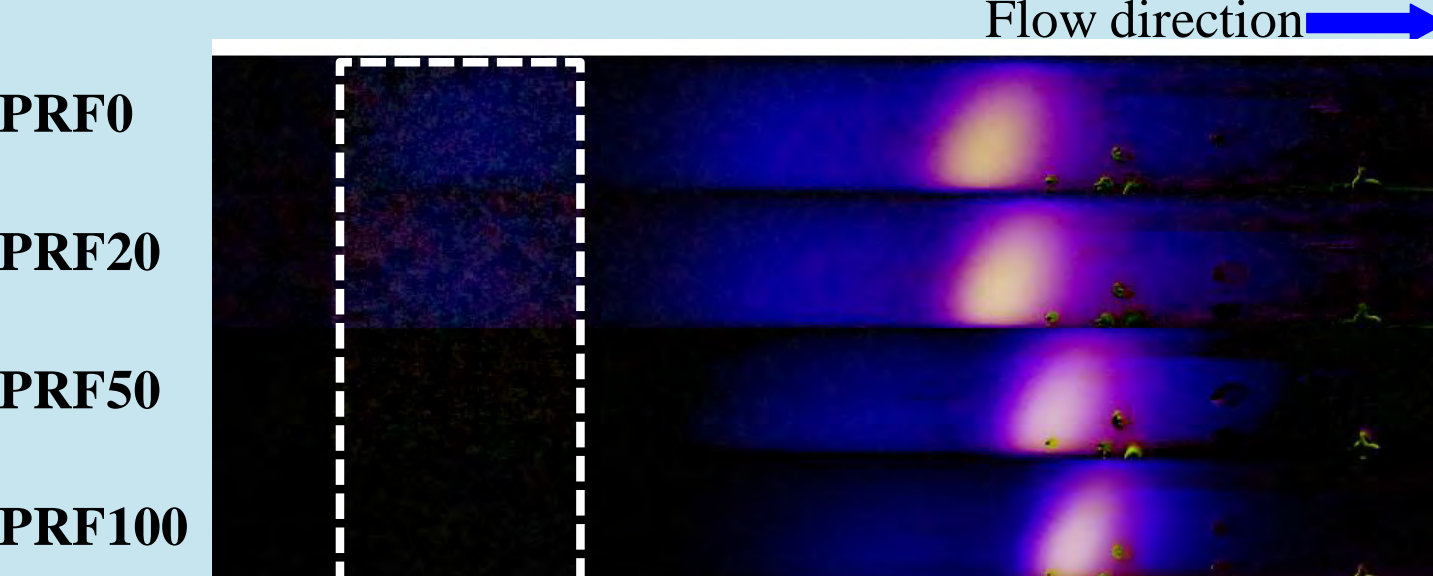
#### Weak flame in MFR [3][4]

- Separation of reaction zones
- Transformation from timescale to time independent length/temperature scale
- Applicable for investigation about ignition characteristics



#### Flame structure and octane number [4]

- Octane number has influence on flame pattern
- For low octane number low temperature oxidation occurs



MFR can be utilized for characterization of ignition properties

### References

- [1] K. Maruta, T. Kataoka, N. Kim, S. Minaev, R. Fursenko, *Proc. Combust. Inst.*, 30 (2005), 2429-2436.
- [2] S. Minaev, K. Maruta, R. Fursenko, *Combustion Theory and Modelling*, Vol. 11 No. 2 (2007), 187-203.
- [3] A. Yamamoto, H. Oshibe, H. Nakamura, T. Tezuka, S. Hasegawa, K. Maruta, *Proc. Combust. Inst.*, 33 (2011), 3259-3266.
- [4] M. Hori, A. Yamamoto, H. Nakamura, T. Tezuka, S. Hasegawa, K. Maruta, *Combust. Flame*, 159 (2012), 959-967.
- [5] R.J. Kee, et al., Sandia National Laboratories Report (1985), No. SAND85-8240.

### Progress

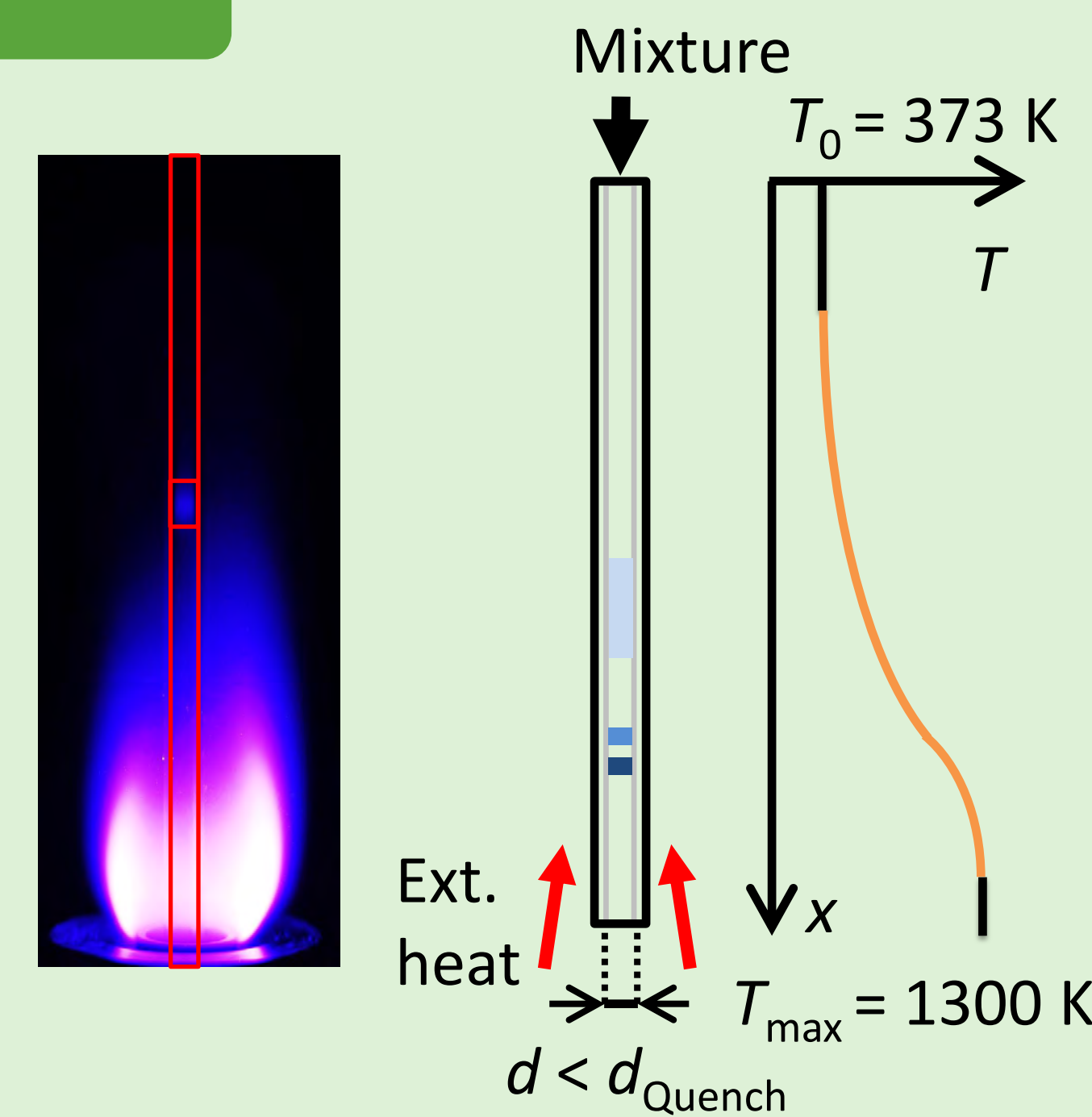
#### Experimental setup

- New vertical MFR with milder temperature gradient allows for more detailed analysis
- Mixing of fuel and air by partial pressure in heated tank
- Very stable and uniform conditions inside the MFR

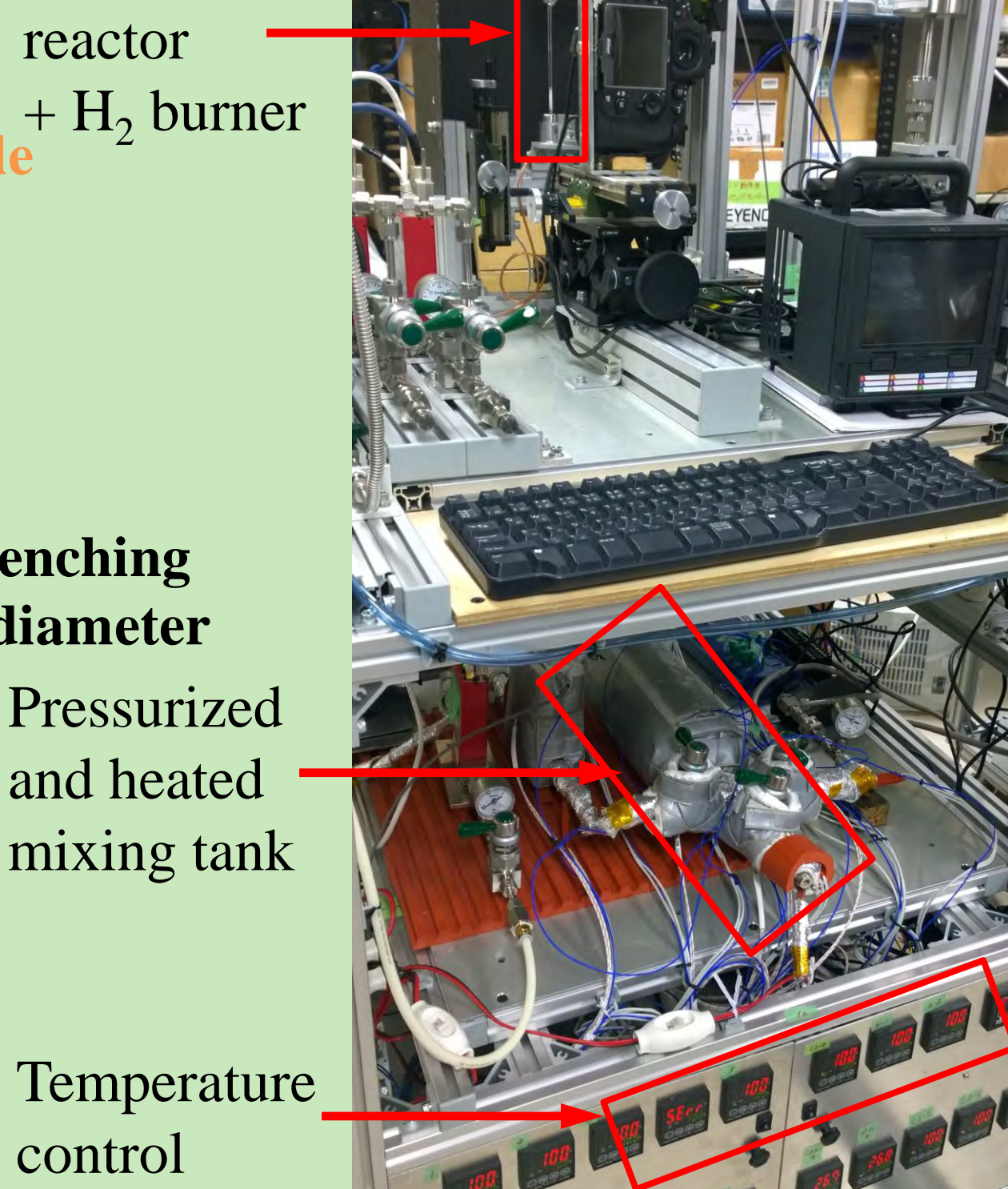
#### Numerical simulations

- PREMIX<sup>[5]</sup> based 1-D steady code<sup>[1]</sup>
- Detailed PRF reaction mechanisms
- Additional term for heat transfer to wall

$$\dot{M} \frac{dT}{dx} - \frac{1}{c_p} \frac{d}{dx} \left( \lambda A \frac{dT}{dx} \right) + \frac{A}{c_p} \sum_{k=1}^K \rho Y_k V_k c_{pk} \frac{dT}{dx} + \frac{A}{c_p} \sum_{k=1}^K \dot{\omega}_k h_k W_k - \frac{A}{c_p} \frac{4\lambda Nu}{d^2} (T_w - T) = 0$$

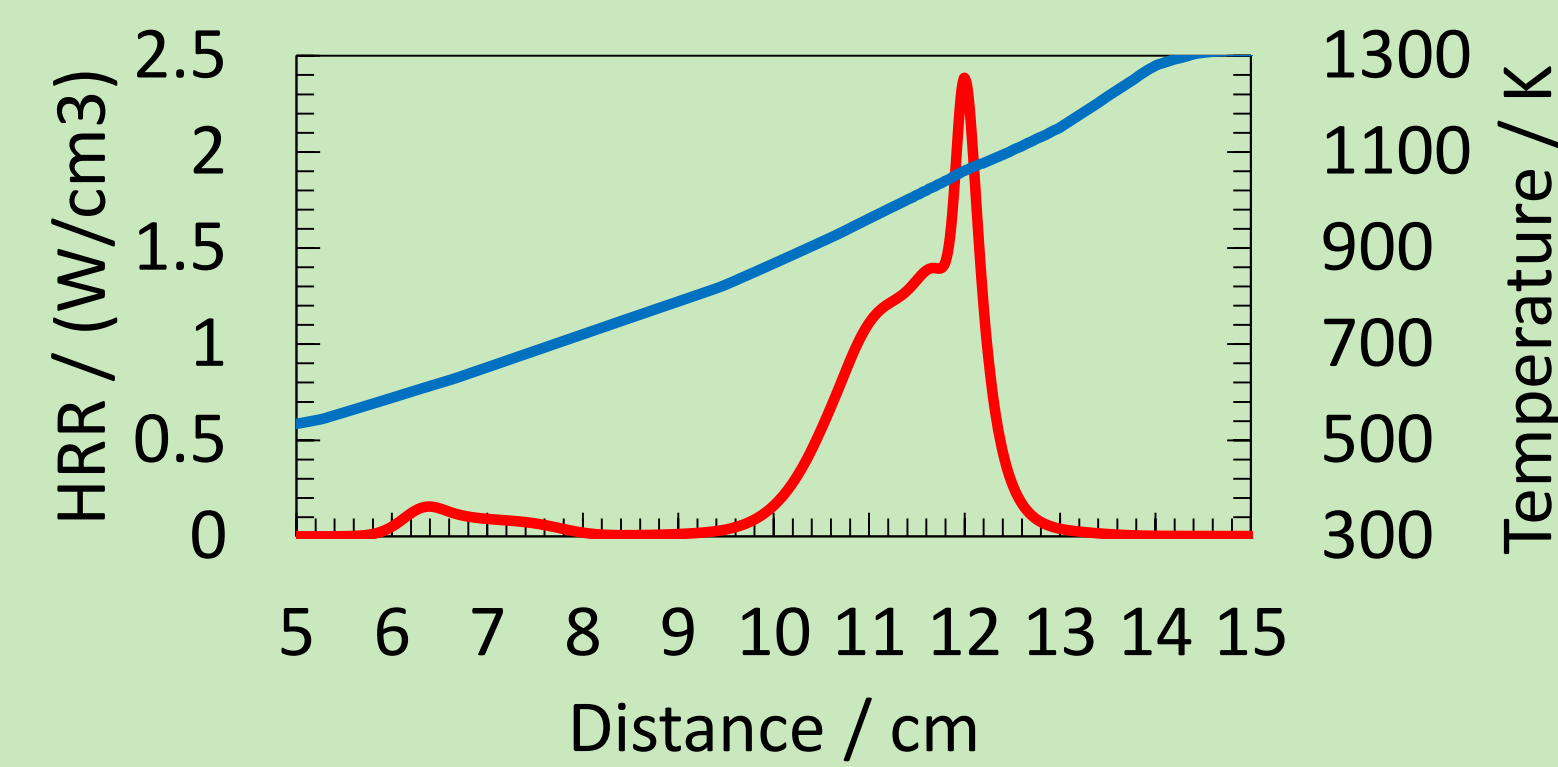


#### Micro flow reactor + H<sub>2</sub> burner



#### Obtained results

- Validity of new setup has been confirmed
- Separation of flames can be observed
- Some discrepancy between experiment and simulations which implies further modifications of kinetics



### Outlook

#### Lean combustion

- Ignition properties of various fuel mixtures including n-heptane, iso-octane (PRF) and toluene (TRF) will be conducted.
- Experiments will be done in atmospheric and elevated pressures.
- Mass spectroscopy will be employed for species measurement.
- Numerical simulations will help understand complex ignition properties in ultra lean condition.
- Innovative ignition property index can be developed from data.

#### Exhaust gas recirculation (EGR)

- Micro flow reactor with controlled temperature profile can be employed to investigate stable normal flame in EGR case

### Research Plan

2015	2016	2017
Experiments and simulations for PRF and TRF	Elevated pressure and species measurement by MS	Compilation of data and creation of index numbers