Laminar burning velocities and ignition delay times of ethanol

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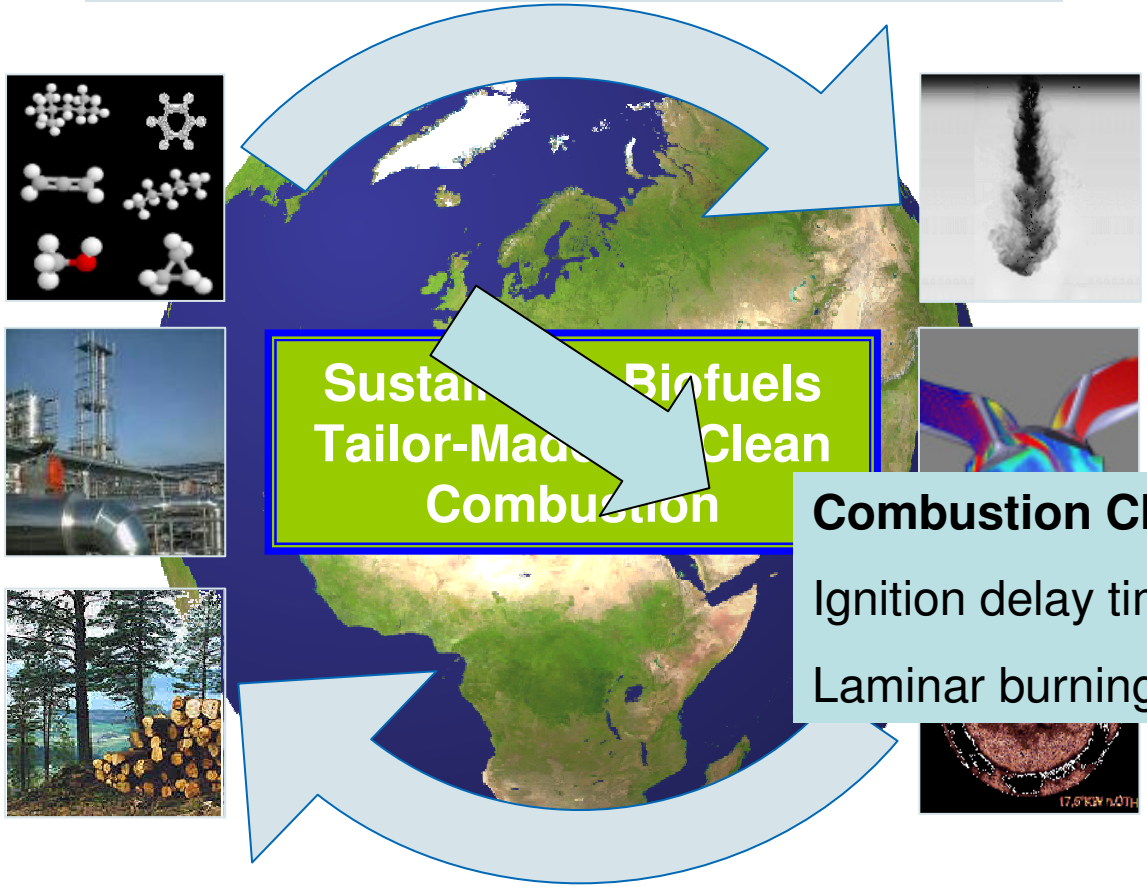
Overview

- **Introduction**
- **Laminar burning velocities**
  - Test facility
  - Data analysis
  - Results
- **Ignition delay times**
  - Test facility
  - Data analysis
  - Results
- **Summary**
- **Outlook**

Introduction

TMFB
Tailor-Made Fuels from Biomass

Novel Synthesis and Production Routes



Fuels from Biomass

Combustion Engine

Combustion Characteristics:

Ignition delay time

Laminar burning velocity

Model-Based Specification of Combustion Characteristics

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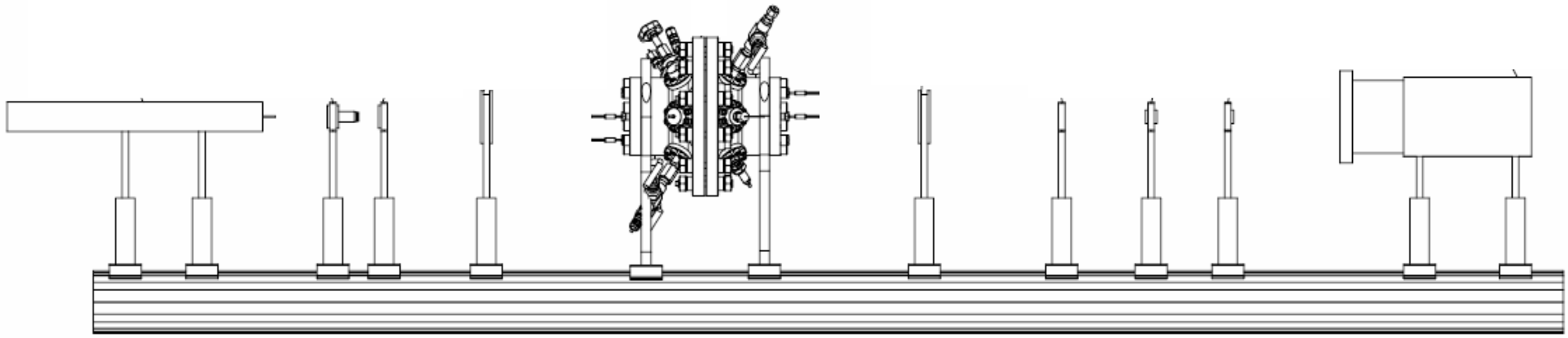
Laminar burning velocities

Laminar burning velocities
Experimental setup



Light source:
HeNe-Laser

Spherical pressure vessel with 100 mm inner diameter,

Windows: 50 mm diameter

High speed CCD-camera
384x384 Pixel at 5 kHZ

Laminar burning velocities
Physical Properties / Test Matrix

- **Investigated fuels**:
  - iso-octane
  - Ethanol
- **Oxidizer:**
  Technical Air
  (20.5% O_2, 79.5% N_2)
- **Equivalence ratio:**
  $\Phi = 0.8 – 1.2$
- **Initial test conditions:**
  - Pressure: 10 bar
  - Temperature: 373 K

	i-Octane (C_8H_{18})	Ethanol (C_2H_5OH)
Density, 20°C [kg/m³]	688	790
Boiling Point [°C]	99.3	78.5
Heating Value [MJ/kg]	44.13	26.8
RON	100	111.4
MON	100	94
Oxygen [%wt]	-	34.7
RVP [bar]	0.52	0.18

Laminar burning velocities
Extrapolation to zero stretch

Burnt gas flame speed:

$$s_b = \frac{dr_b}{dt}$$

Stretch:

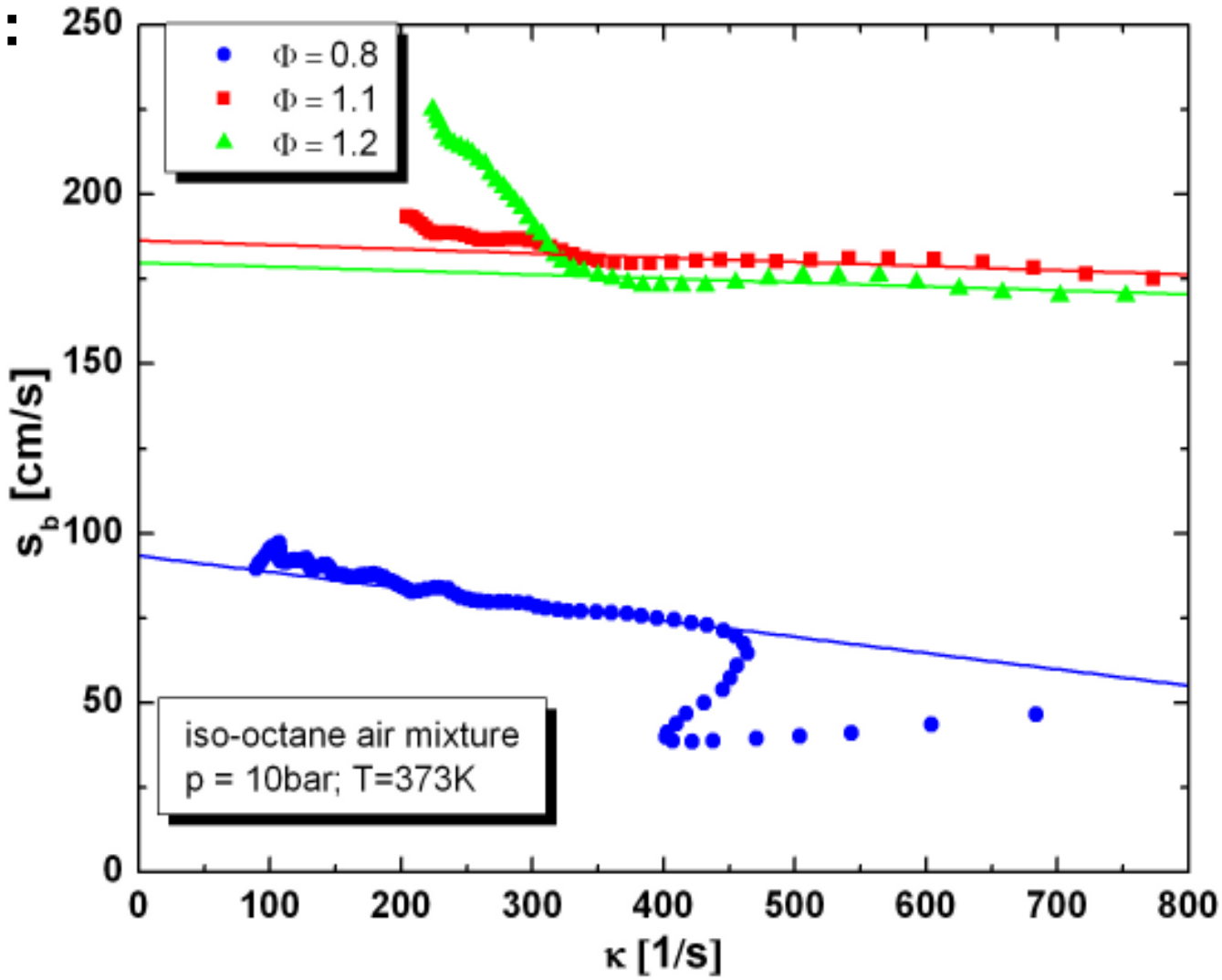
$$\kappa = \frac{1}{A} \cdot \frac{dA}{dt} = \frac{2}{r_b} \cdot \frac{dr_b}{dt}$$

Relationship:

$$s_{b0} - s_b = L_b \cdot \kappa$$

Continuity law:

$$s_L = s_{b0} \cdot \left(\frac{\rho_b}{\rho_u} \right)$$



Laminar burning velocities
Simualtion and Approximation

- **Differential equations for laminar burning velocity (s_L):**

$$\rho_u s_L c_p \frac{dT}{dx} = \frac{d}{dx}(\lambda \frac{dT}{dx}) - \sum_{i=1}^{n} c_{p,i} j_i \frac{dT}{dx} - \sum_{i=1}^{n} h_i \dot{m}_i$$

$$\rho_u s_L \frac{dY_i}{dx} = -\frac{dj_i}{dx} + \dot{m}_i$$

→ The set of equations is solved using **Cantera**

- **Approximation formulas for laminar burning velocity (s_L):**
  - iso-octane: Müller et al.
  - ethanol: Röhl et al.

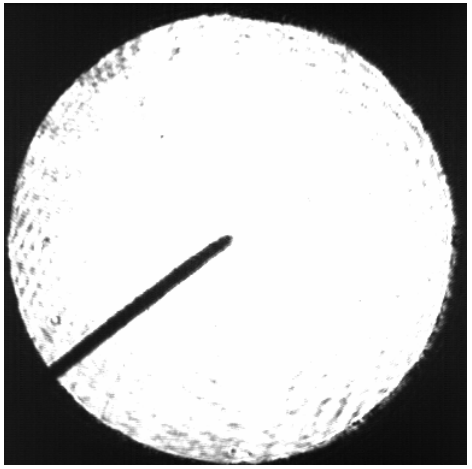
- **Mechanisms and numerical results:**

	i-octane		ethanol	
Mechanism	literature	present	literature	present
Jerzembeck et. al, CS	X		X	
Röhl et al., ECM				X
San Diego Mechanism				X

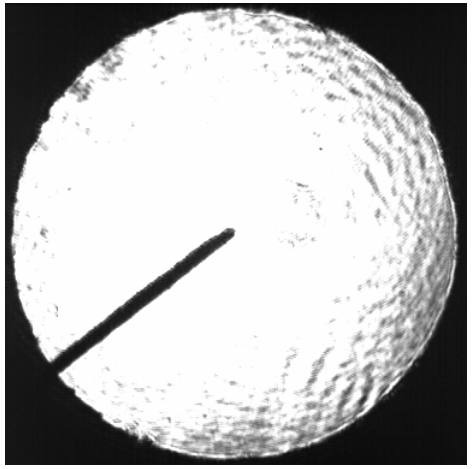
Laminar burning velocities

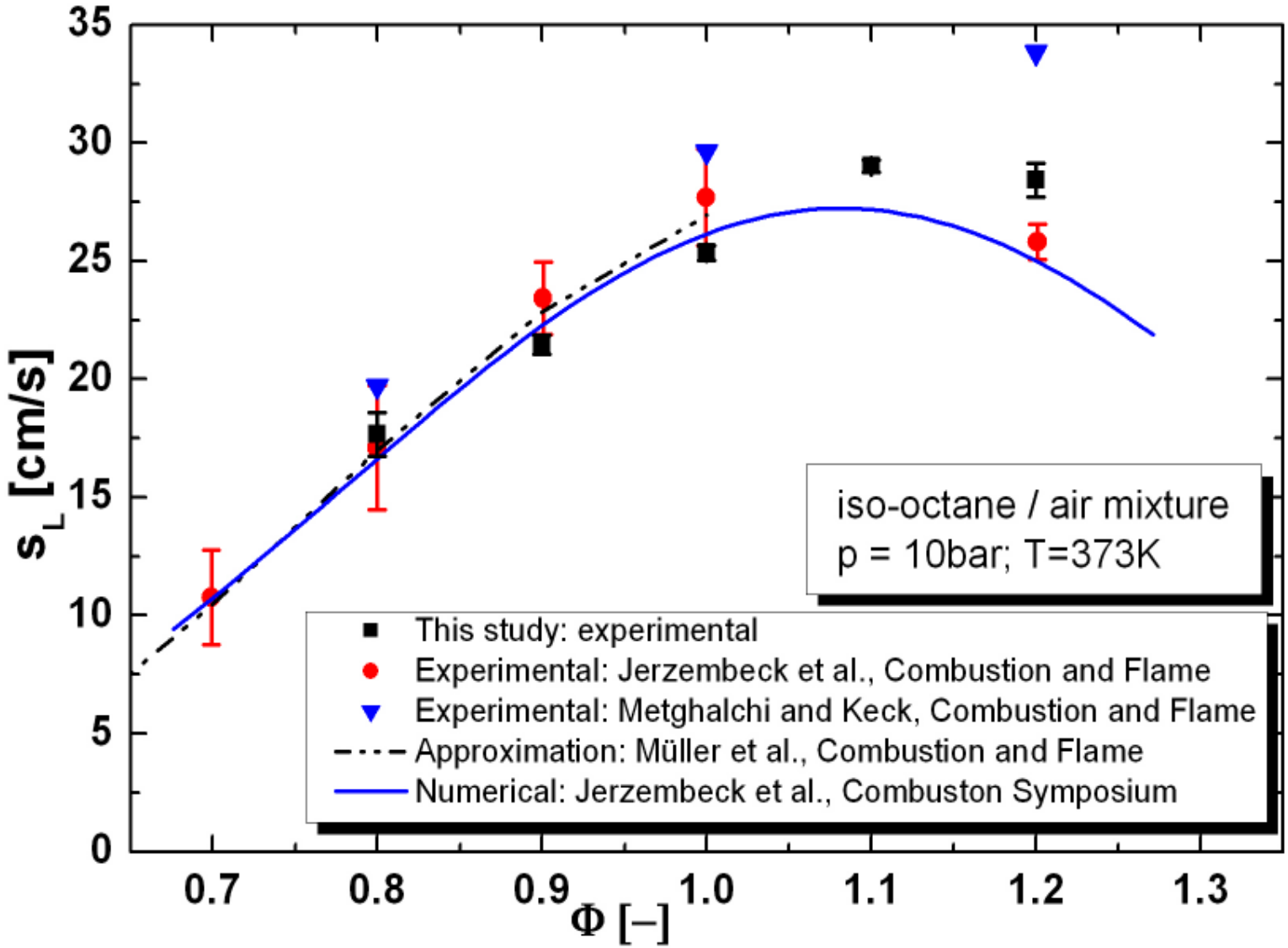
Results iso-Octane / Air

Φ = 0.8



Φ = 1.1





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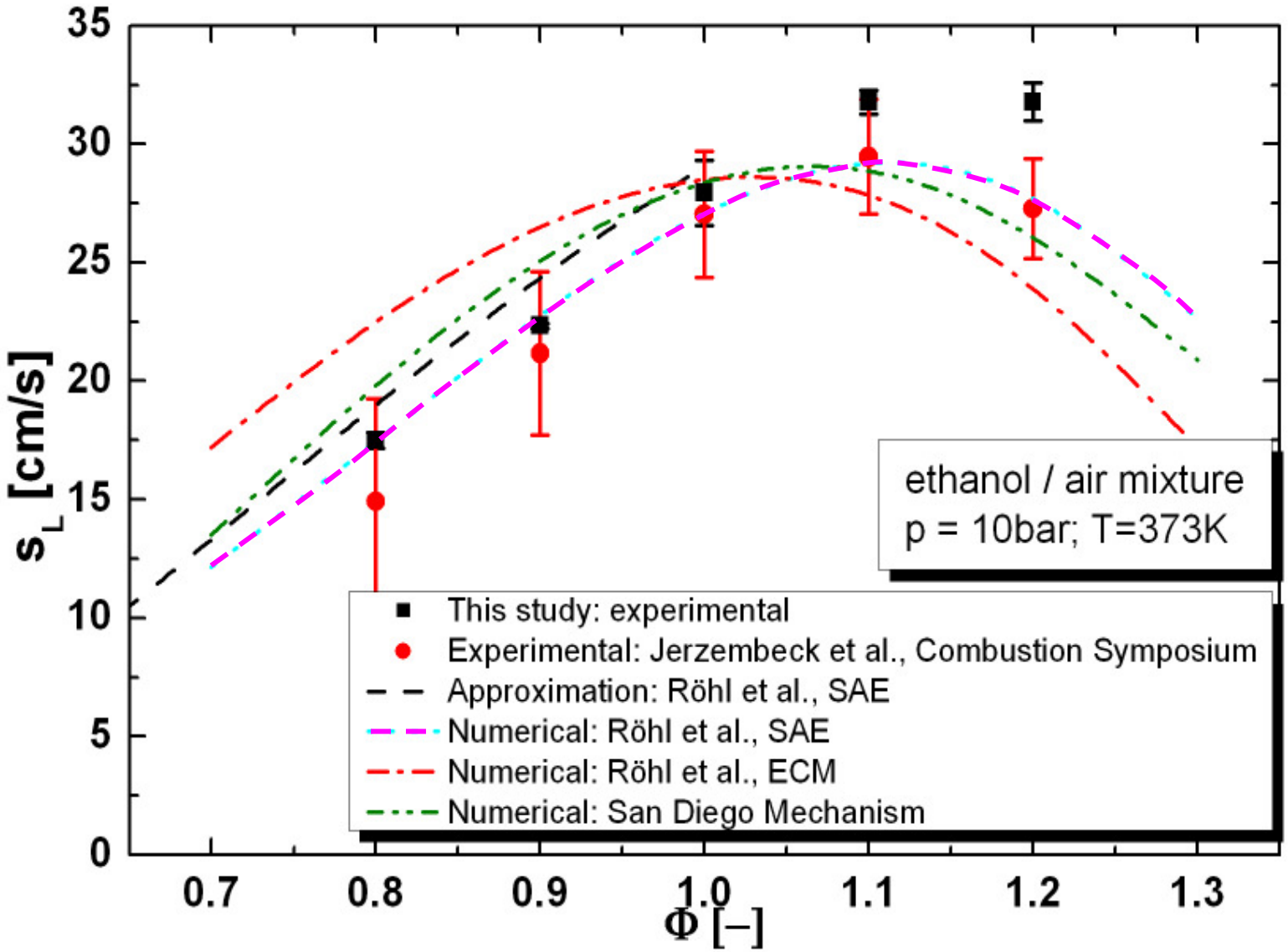
Laminar burning velocities
Results Ethanol / Air



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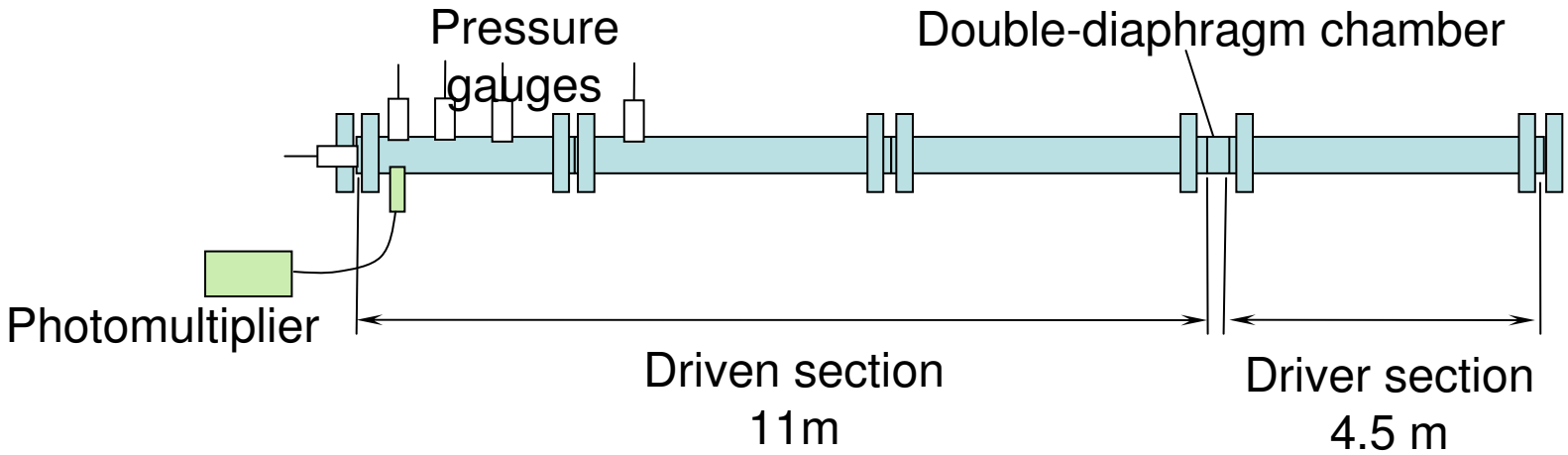
Ignition delay times

Ignition delay times
Experimental setup



Technical data:
Total length: 15.5 m
Inner diameter: 142 mm
Maximum temperature: 200 °C
Maximum working pressure: 200 bar
Material: steel

Investigated fuels:
Methane (CH_4) for validation, Ethanol (C_2H_5OH)

Oxidizer:
Technical Air (20.5% O_2, 79.5% N_2)

Conditions:
Φ = 1.0, 13 - 23 bar, 850 - 1700 K

Ignition delay times
Data analysis

Desired result: Ignition delay time at known conditions (pressure and temperature)

- **Pressure** can directly been measured in experiment

- Direct **temperature** determination is very difficult in experiment
  ⇨ Calculation of temperature

- **Ignition delay time** can be deduced from pressure and UV-sensor signals

Ignition delay times
Data analysis

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Determination of temperature

Determination of shock speed from pressure measurements

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Calculation of condition behind reflected shock including real gas behavior by shock tube simulation program (KASIMIR)

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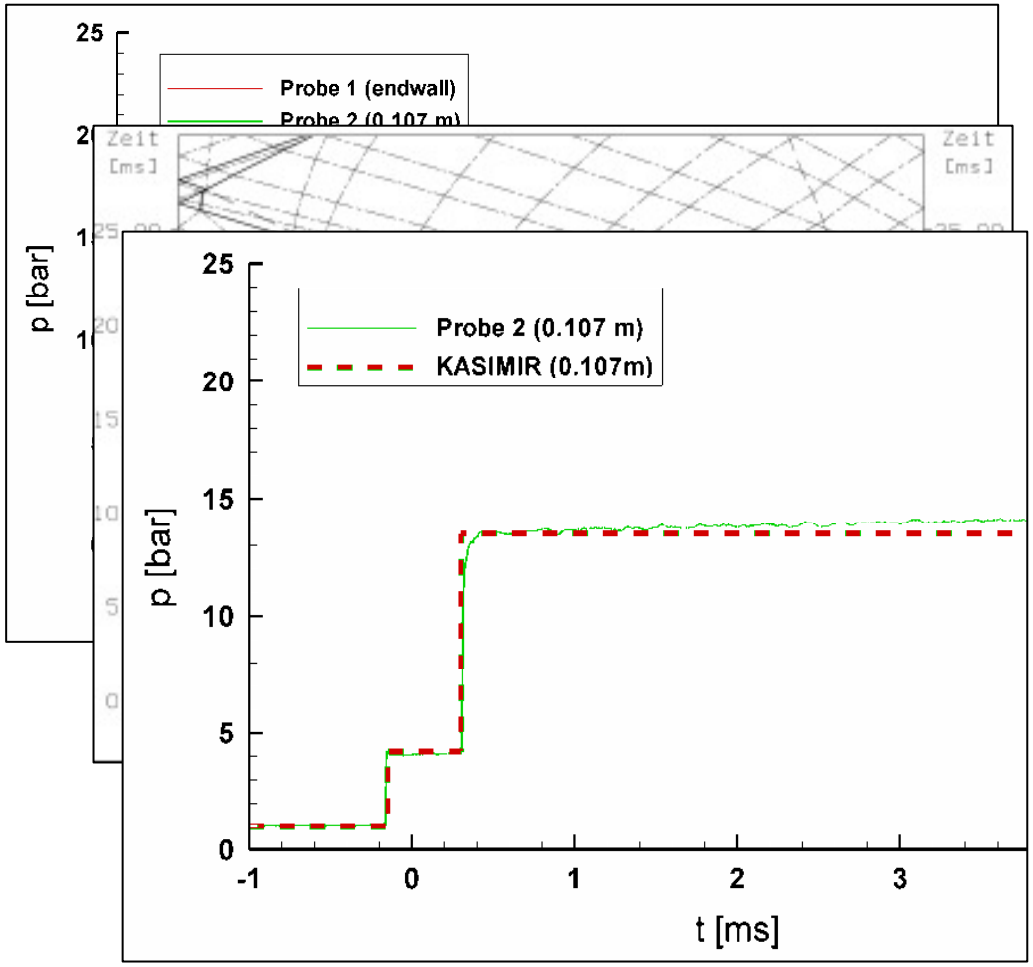
Comparison between calculated and measured pressures



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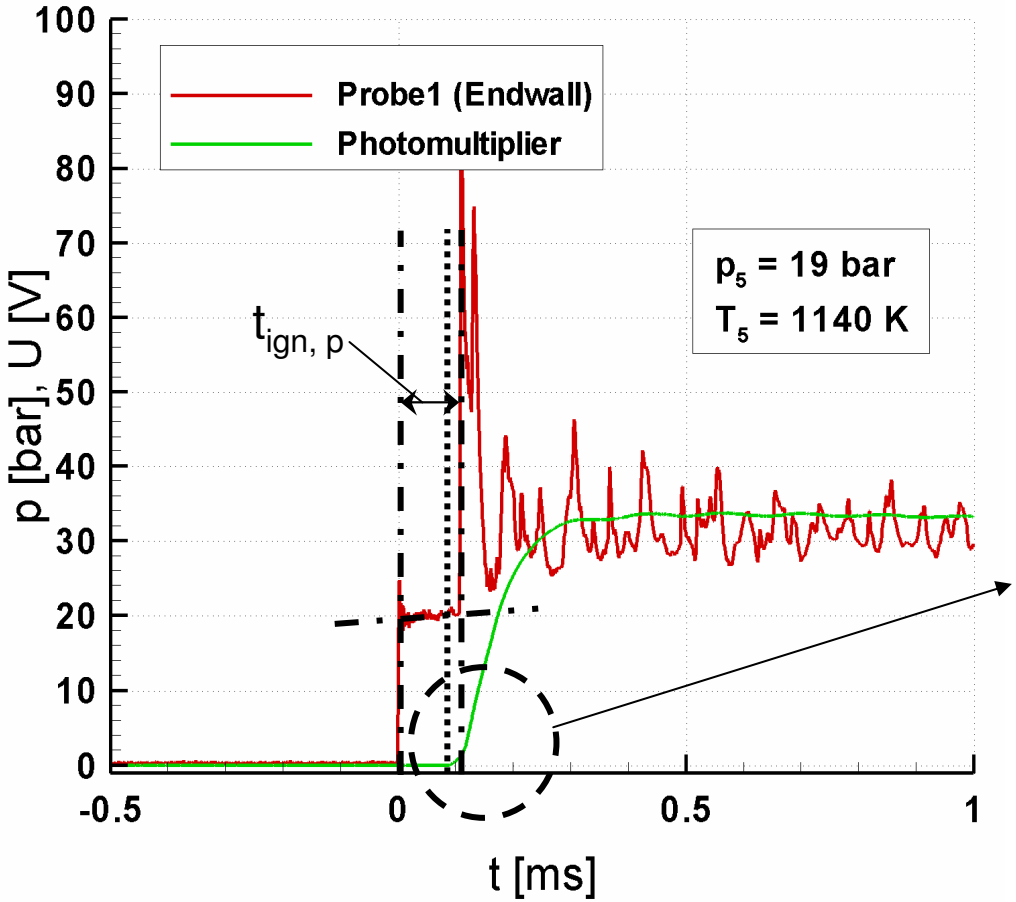
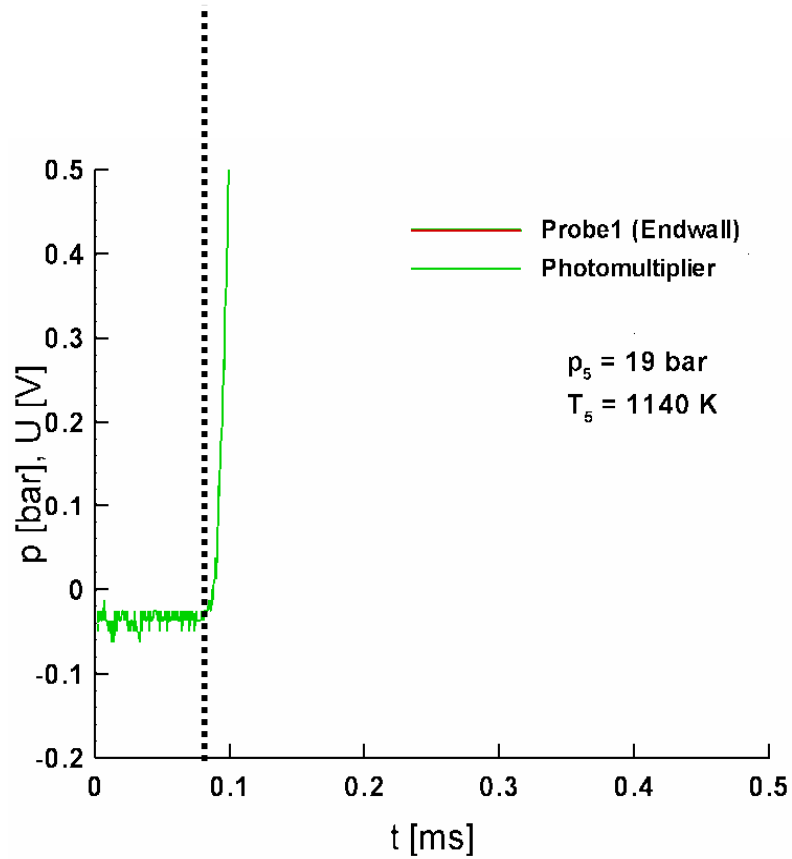
Determination of ignition delay time





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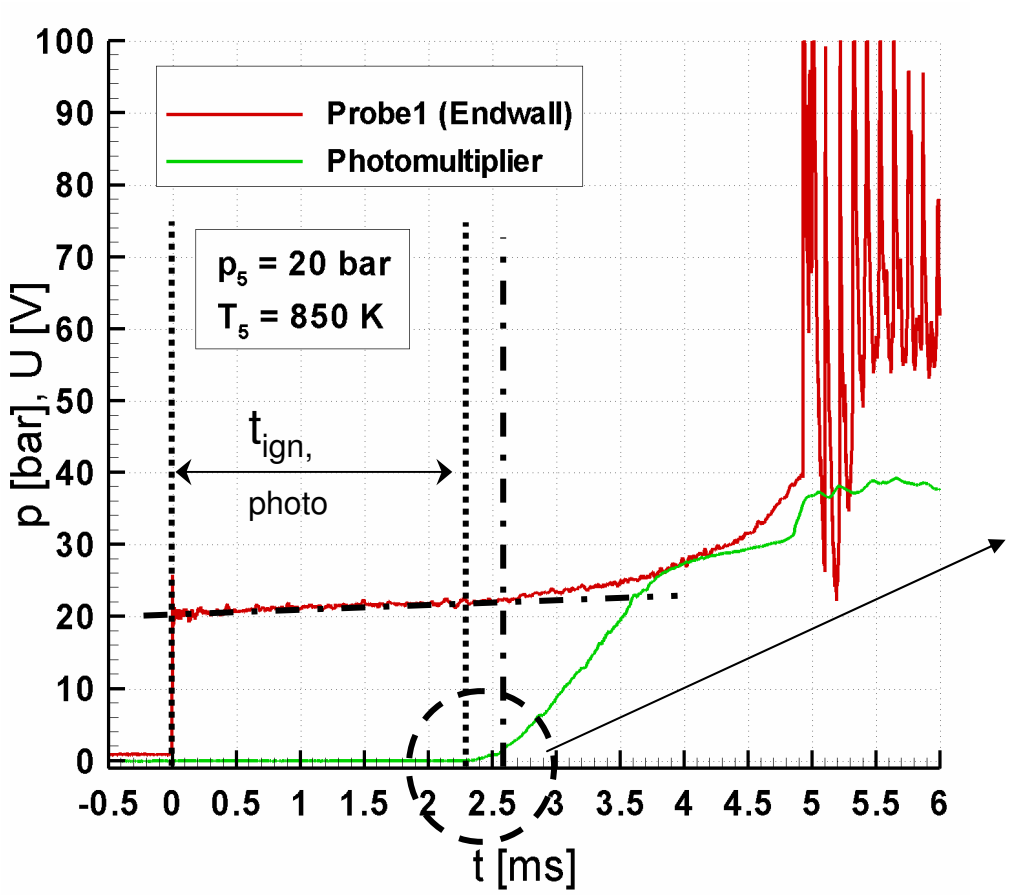
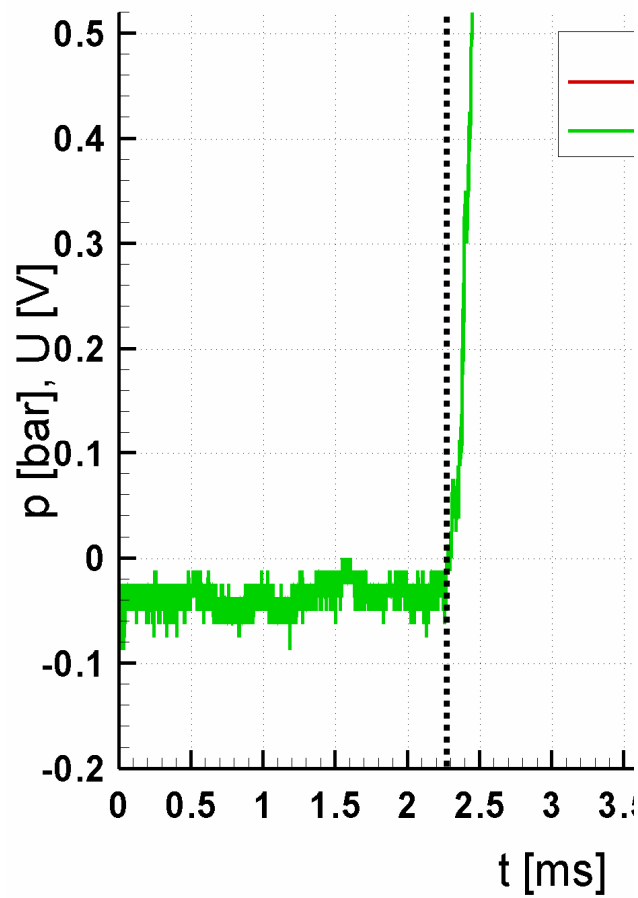
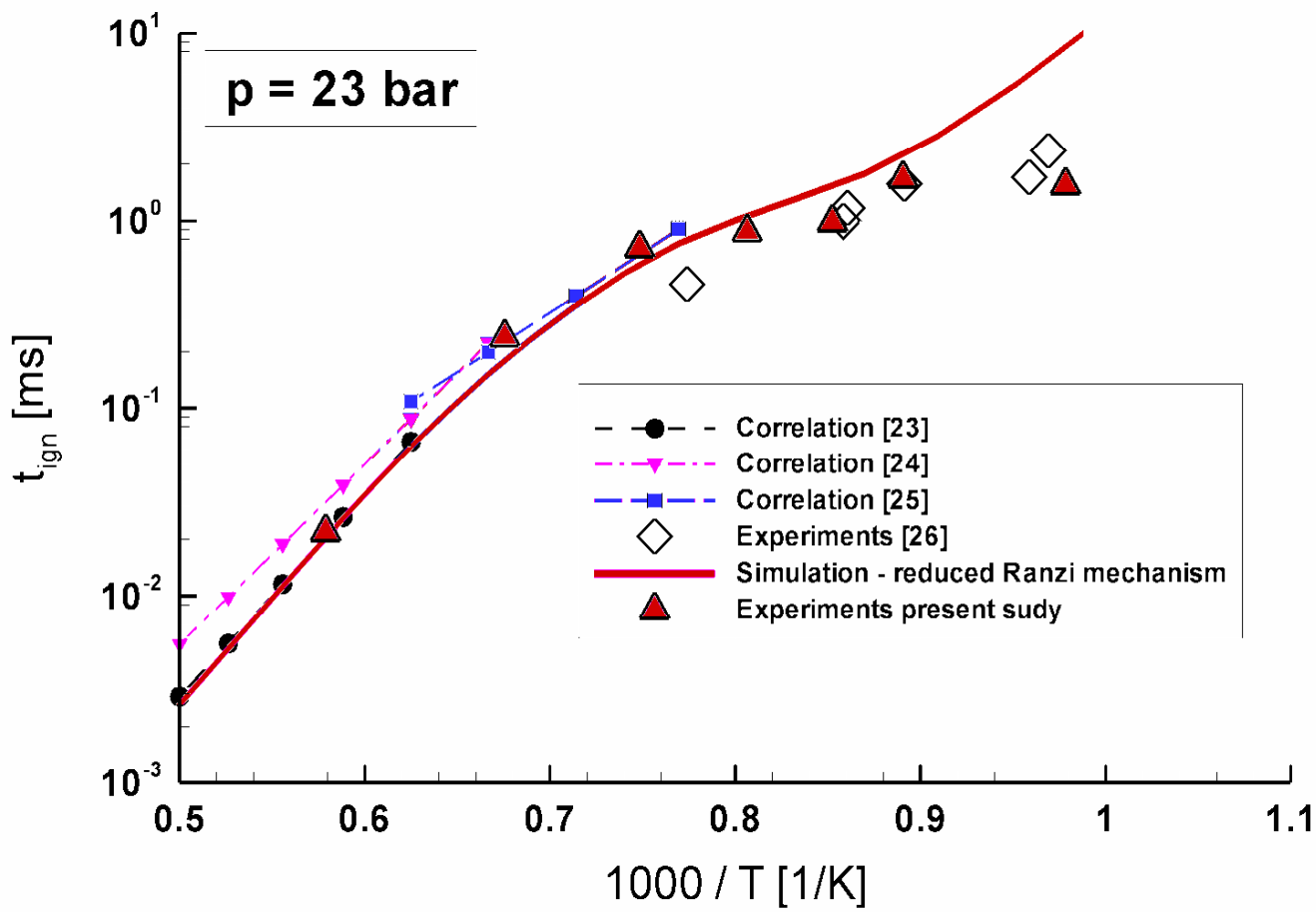




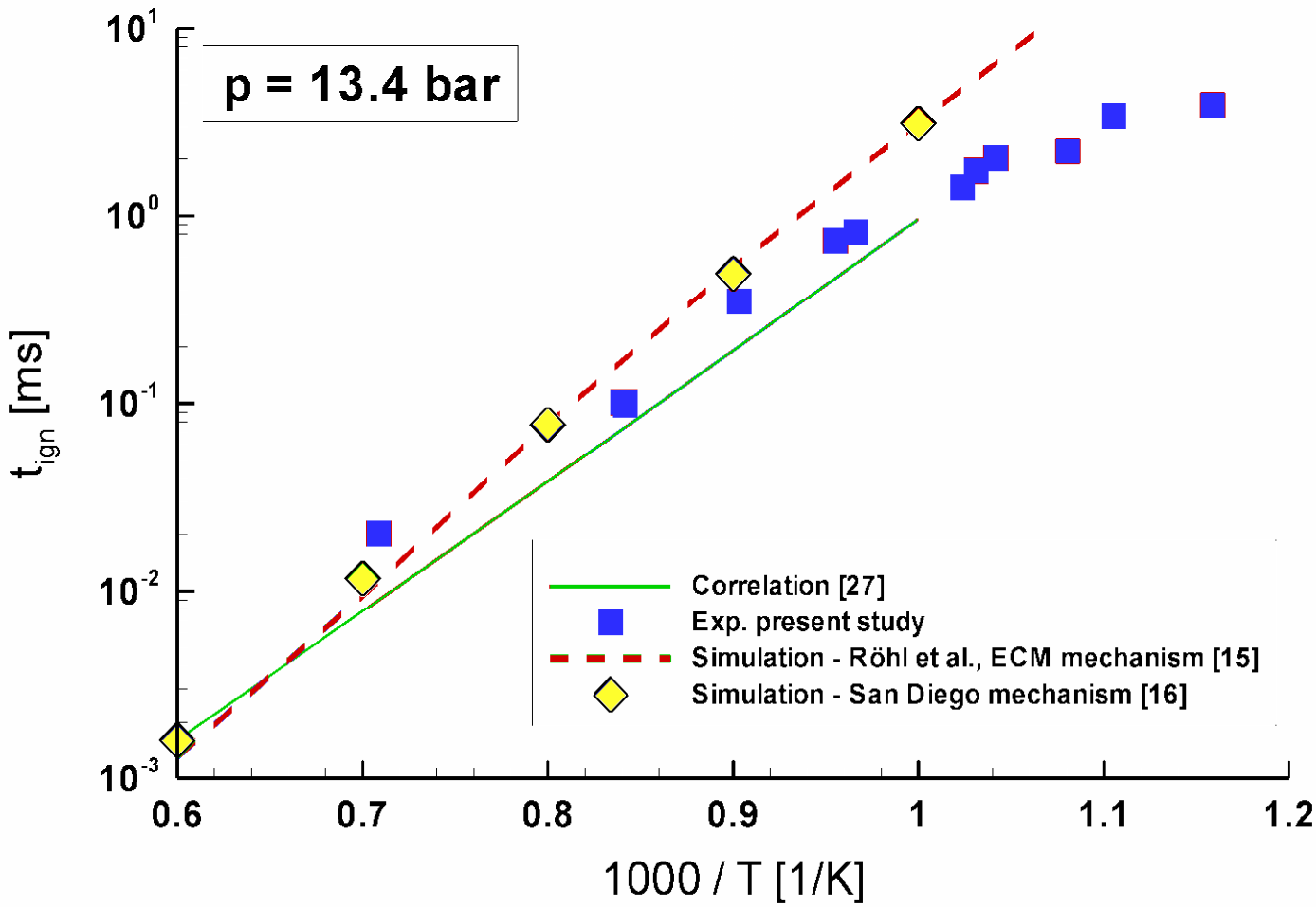
Ignition delay times
Results

Stoichiometric methane-air-mixture



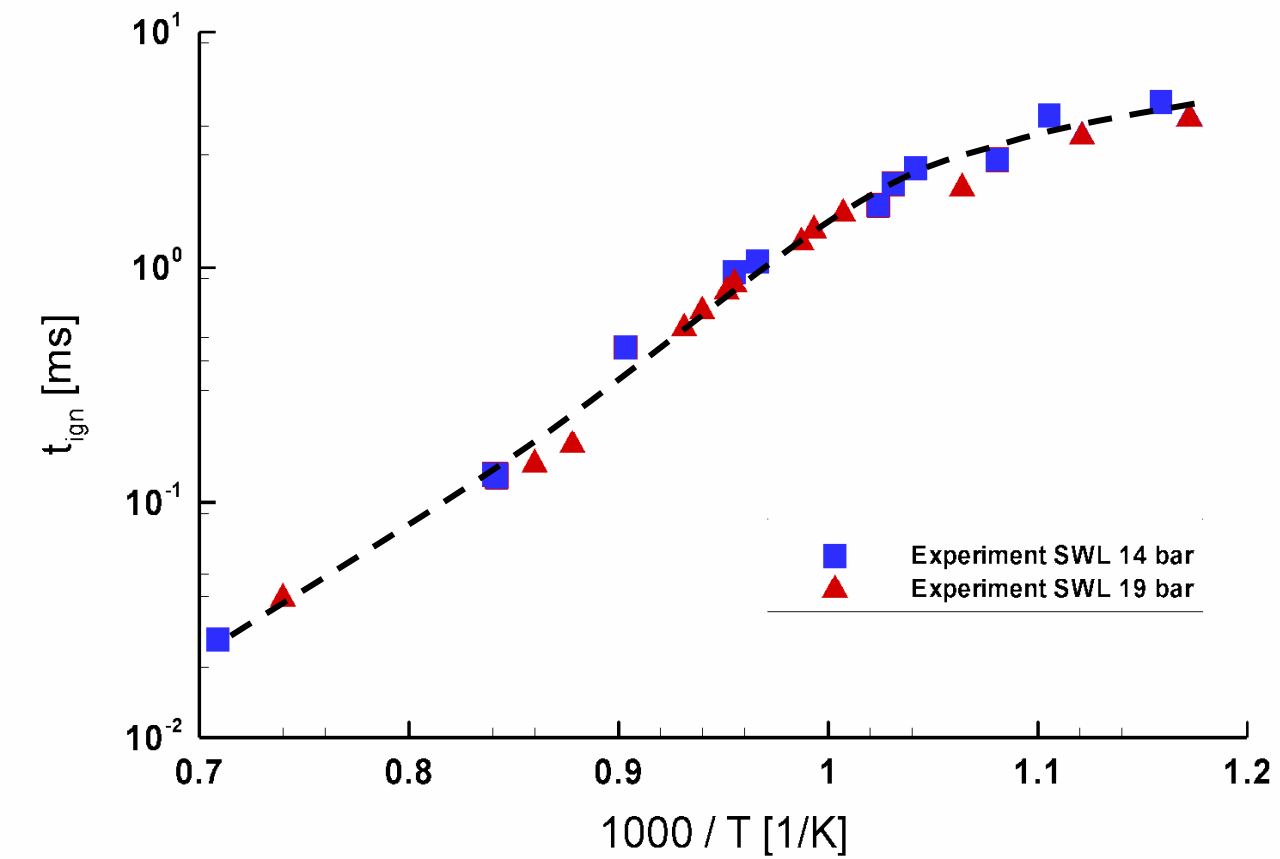
Ignition delay times
Results

Stoichiometric ethanol-air-mixture



Ignition delay times
Results

Stoichiometric ethanol-air-mixture



$$\tau = A \cdot p^x \cdot e^{(-B/T)}$$

$$\Rightarrow \tau_{ref} = \tau_{measured} \cdot \left(\frac{p_{ref}}{p_{measured}} \right)^x$$

x = 0.77
p_{ref} = 10 bar

Summary

Summary

Laminar burning velocities

- Conditions: 10 bar, 373 K
- Experiments with I-Octane show good agreement between recent experimental results and literature data
- The results with lean ethanol-air-mixtures coincide well with simulation data, but for rich mixtures the simulation predicts lower burning velocities

Ignition delay times

- Conditions: 13 – 23 bar, 850 – 1700 K
- Experiments with Methane show good agreement between recent experimental results and literature data
- For ethanol approximately same ignition delay times in experiment and simulation in high temperature region
- At low temperatures lower ignition delay times than predicted from simulation

Outlook

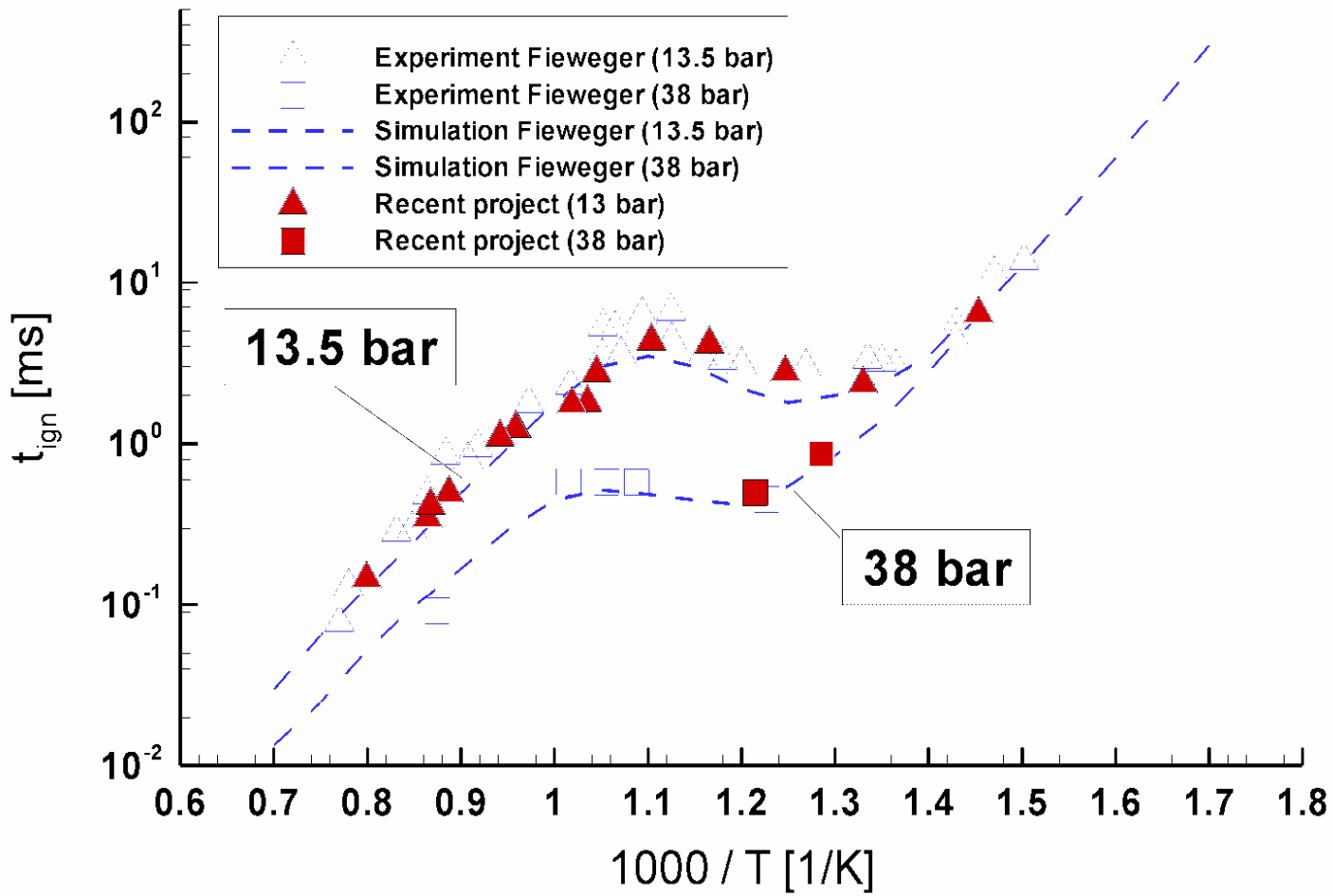
Outlook

Laminar burning velocities

- New conditions: up to 40 bar, 500 K
- New fuels like butanol, decanol and bio components derived from the platform components identified in the Cluster of Excellence

Ignition delay times

- New stainless steel shock tube with higher working pressure (950 bar @ 200 °C)
- High pressures (40 bar and more) and lower temperatures (down to 700 K)
- New fuels like butanol, decanol and bio components derived from the platform components identified in the Cluster of Excellence

Outlook

Validation experiments performed with new stainless steel shock tube (n-heptane)