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Equivalence ratio and velocity measurements in combustion using laser-induced plasma

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flex plant

Outline

- 1. Background
- 2. Laser-induced plasma evolution
- 3. Laser induced breakdown spectroscopy (LIBS)
- 4. Laser induced plasma image velocimetry (LIPIV)
- 5. Equivalence ratio and velocity measurement in swirl burner.
- 6. Conclusions

1. Motivations

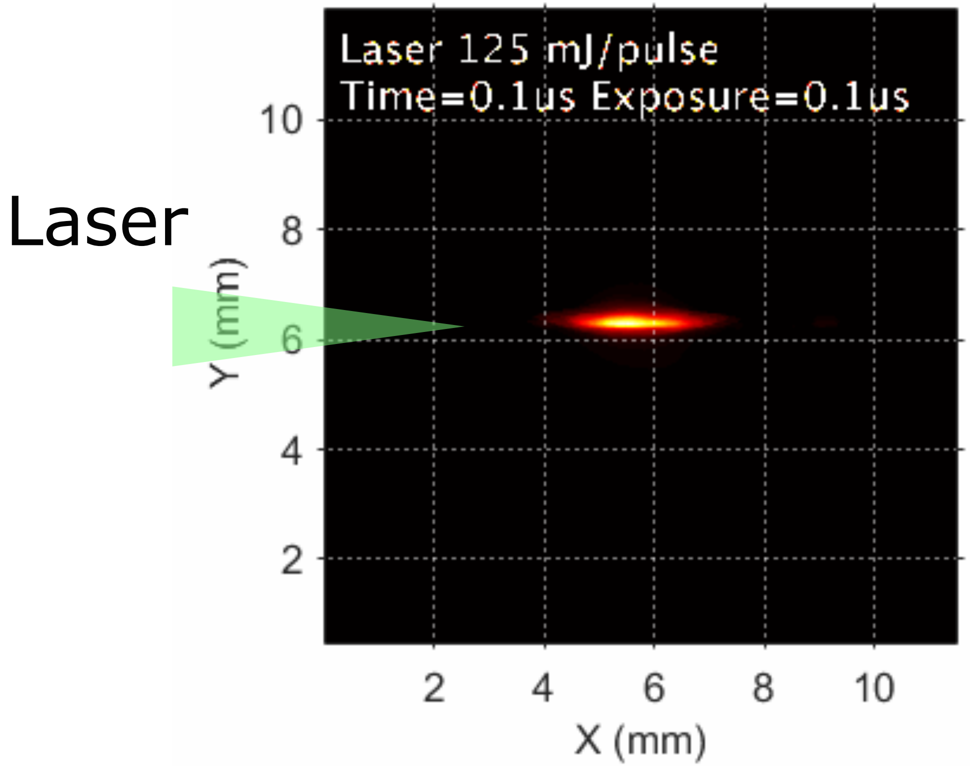
Develop advanced sensors for:

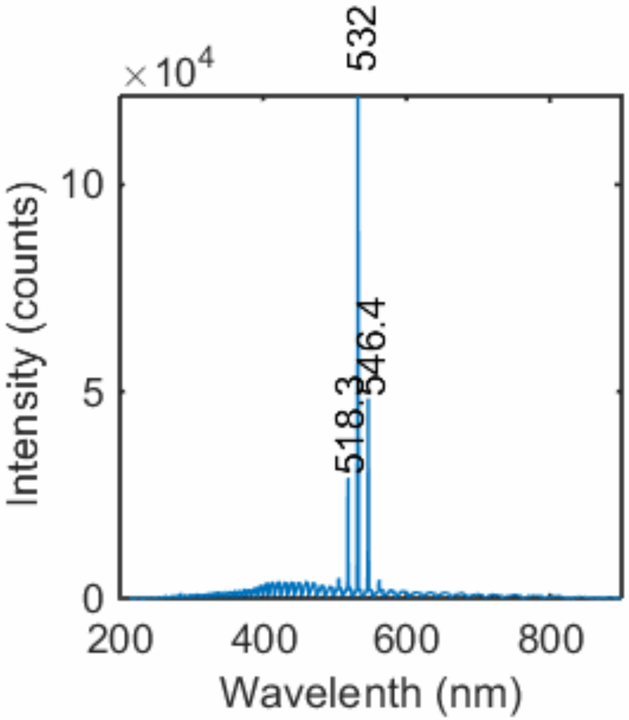
1. Local air-fuel ratio in reacting and non-reacting flows

2. Online monitoring of components of fuel blends and Wobbe index

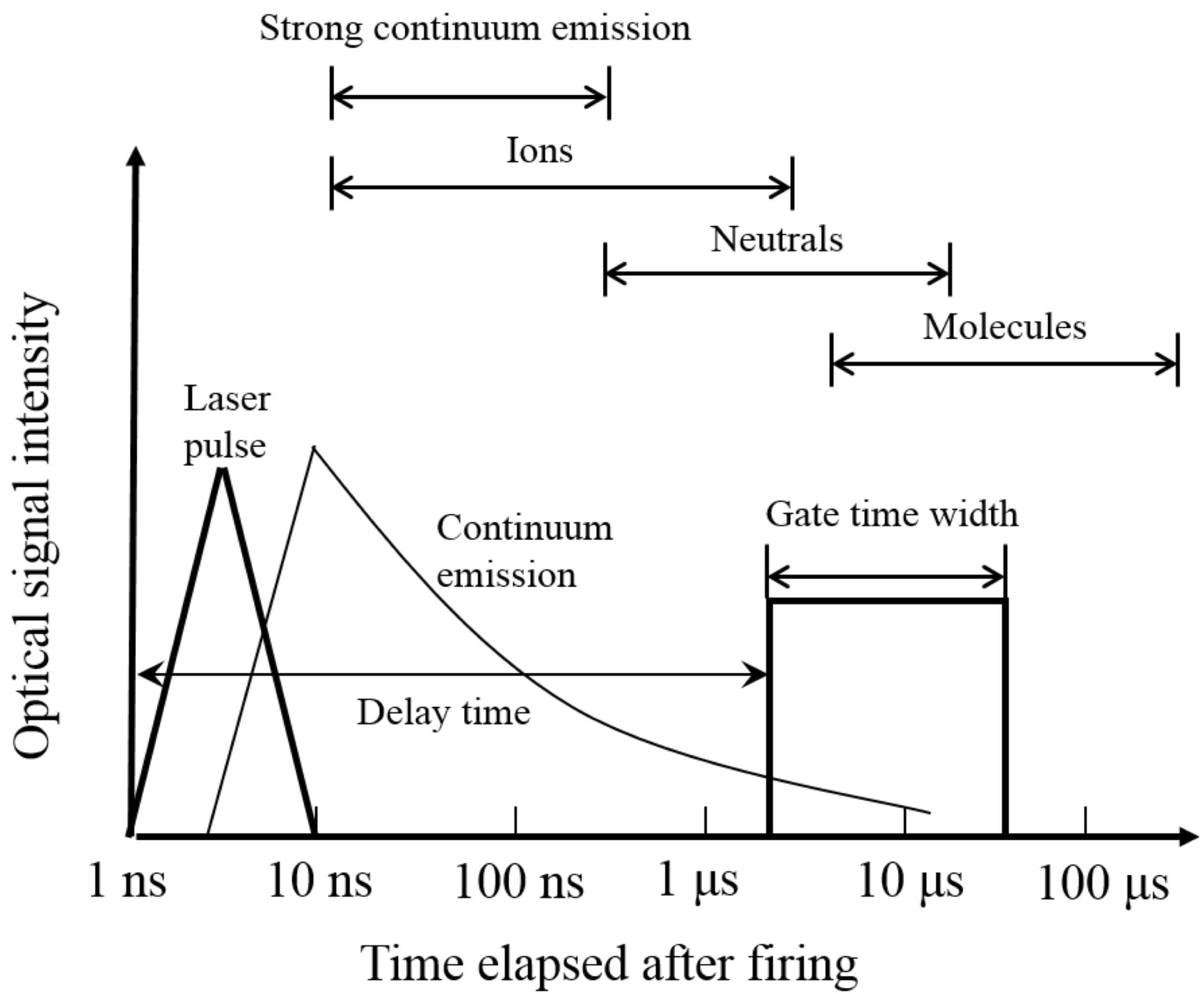
3. Velocity measurements in reacting and non-reacting flows without the introduction of ‘seeding’ particles

2. Plasma image and spectrum in quiescent air





2. Laser induced plasma timing diagram



2. Laser induced plasma emissions

$$I_{ij} = F C^{s} A_{ij} \frac{g_i e^{-E_i/kT}}{U^{s}(T)}$$

$$I \propto C^{s}$$

where C^s is the concentration of the emitting species in the plasma. The experimental parameter F takes into account the optical efficiency of the collection system.

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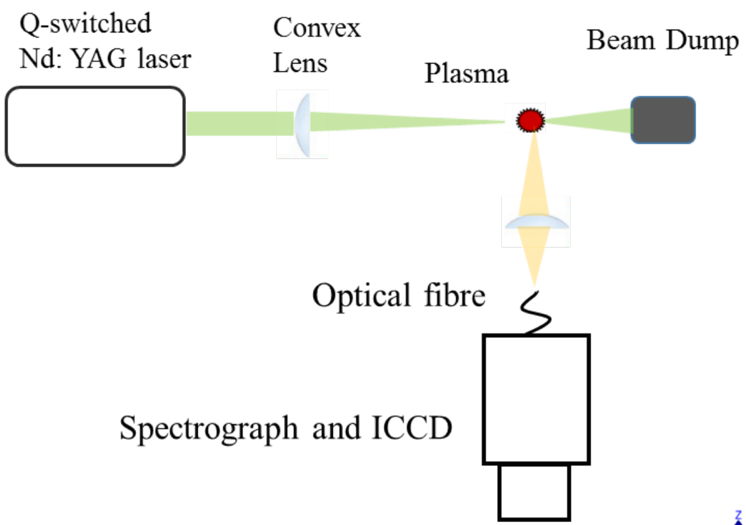
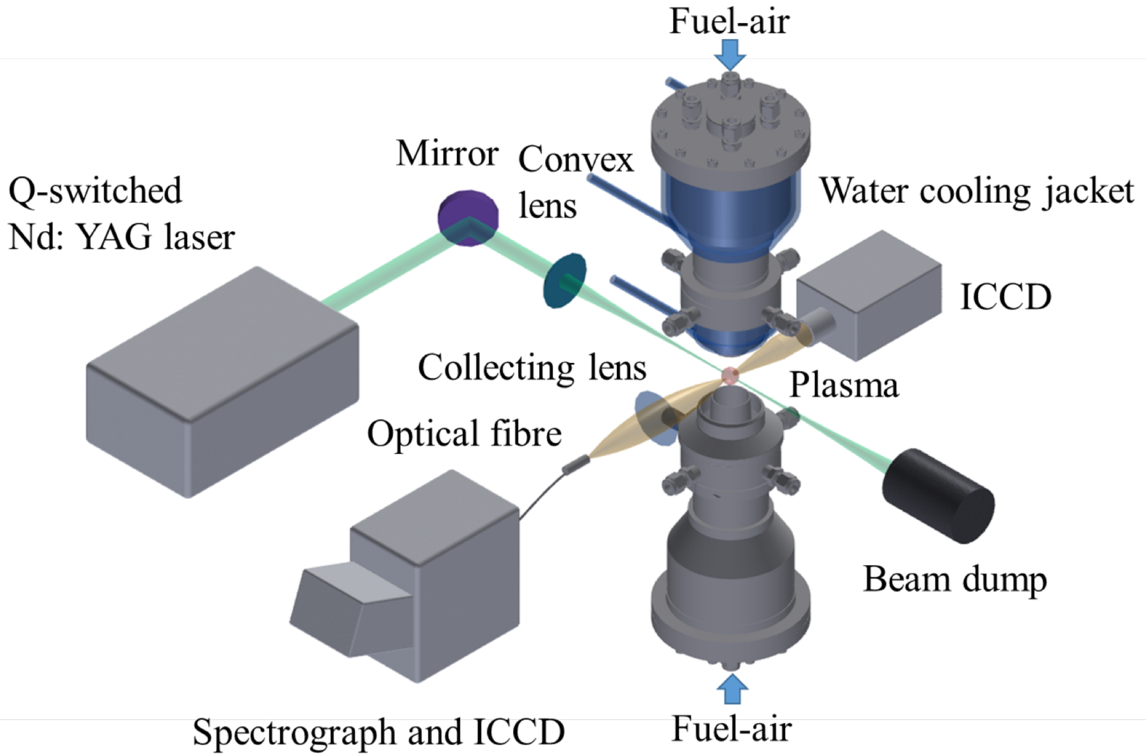
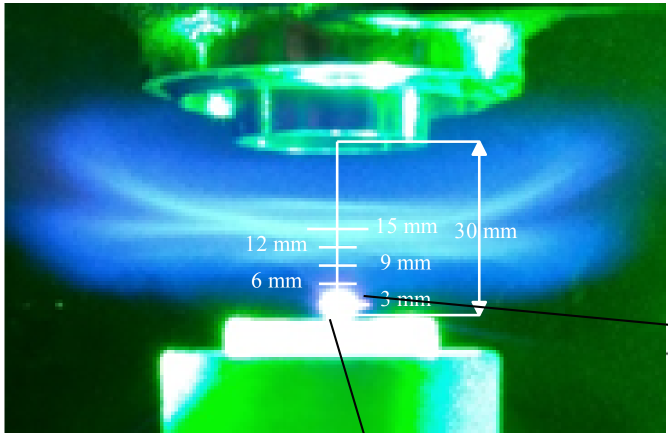
3. LIBS setup





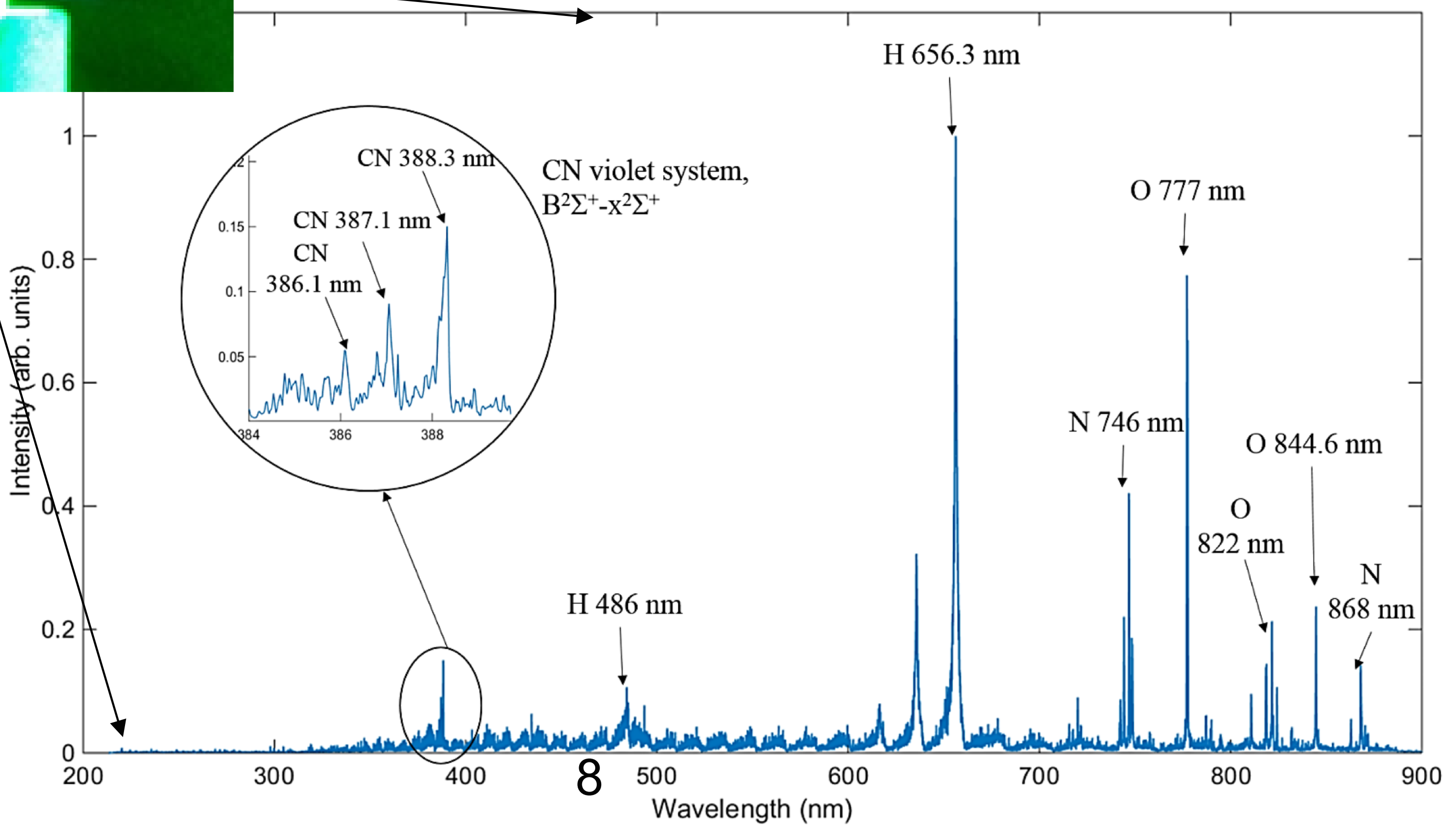
Name	Parameters
Nd: YAG Laser	532 nm, 8 ns pulse widths, 10 Hz, 30~408 mJ /pulse, Surelite III
Laser beam focused lens	Focal length 300 mm
Collection lens	25.4 mm diameter, 35 mm focal length
Fiber optic	Edmund 1000 μm diameter, 180 -1150 nm
ICCD	Andor DH534
Spectrograph	Andor's Mechelle ME5000 (200-975 nm), Spectral resolution ($\lambda/\Delta\lambda$)=4000
Calibration lamp	Xenon lamp and Mercury lamp

3. LIBS in a premixed methane-air flame



Setting	Values
Number of shots	50
Laser energy	125 mJ ± 5 mJ
ICCD delay time	1 μs
ICCD gate time	5 μs
Strain rate	120 /s
Equivalence ratio	1.0

A typical methane-air spectrum in the flames



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3. Correlation curves

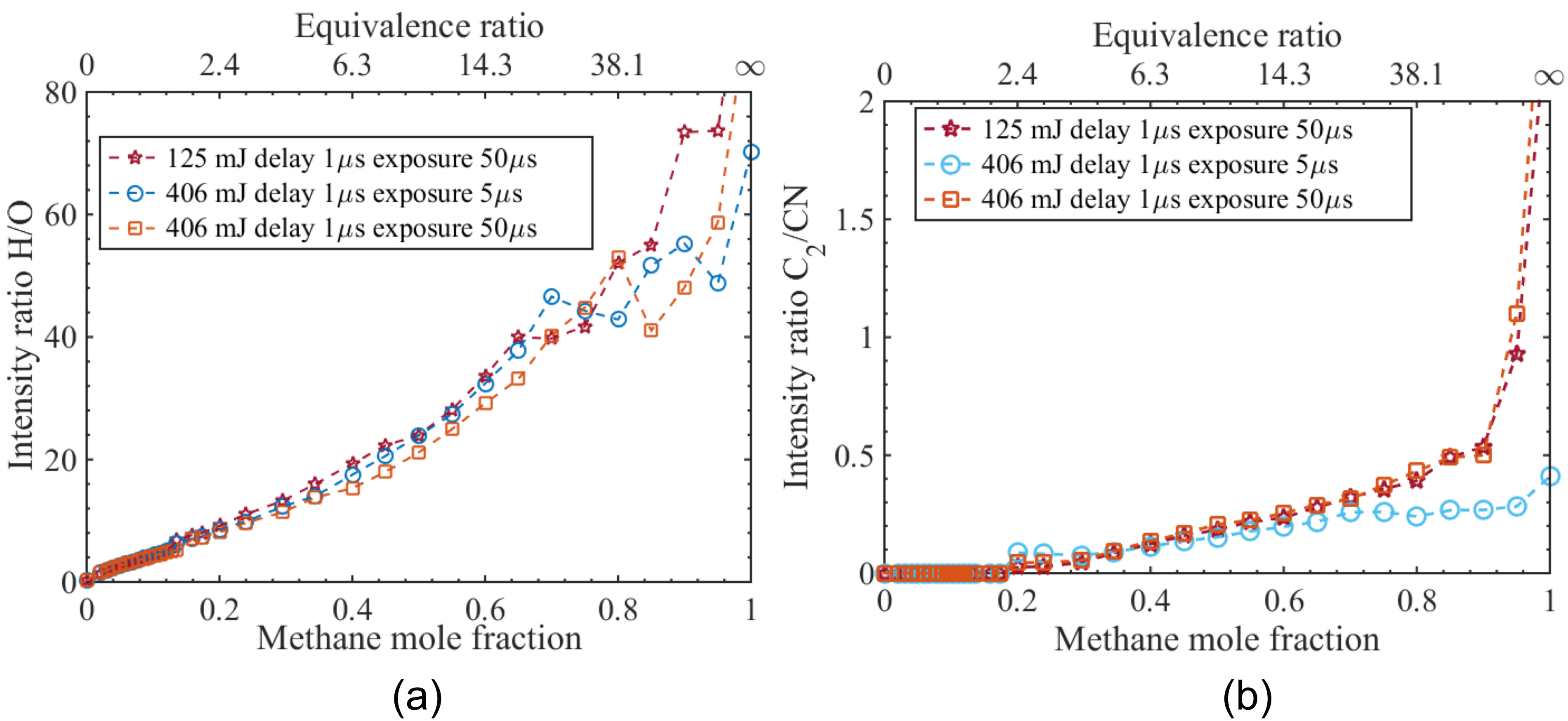
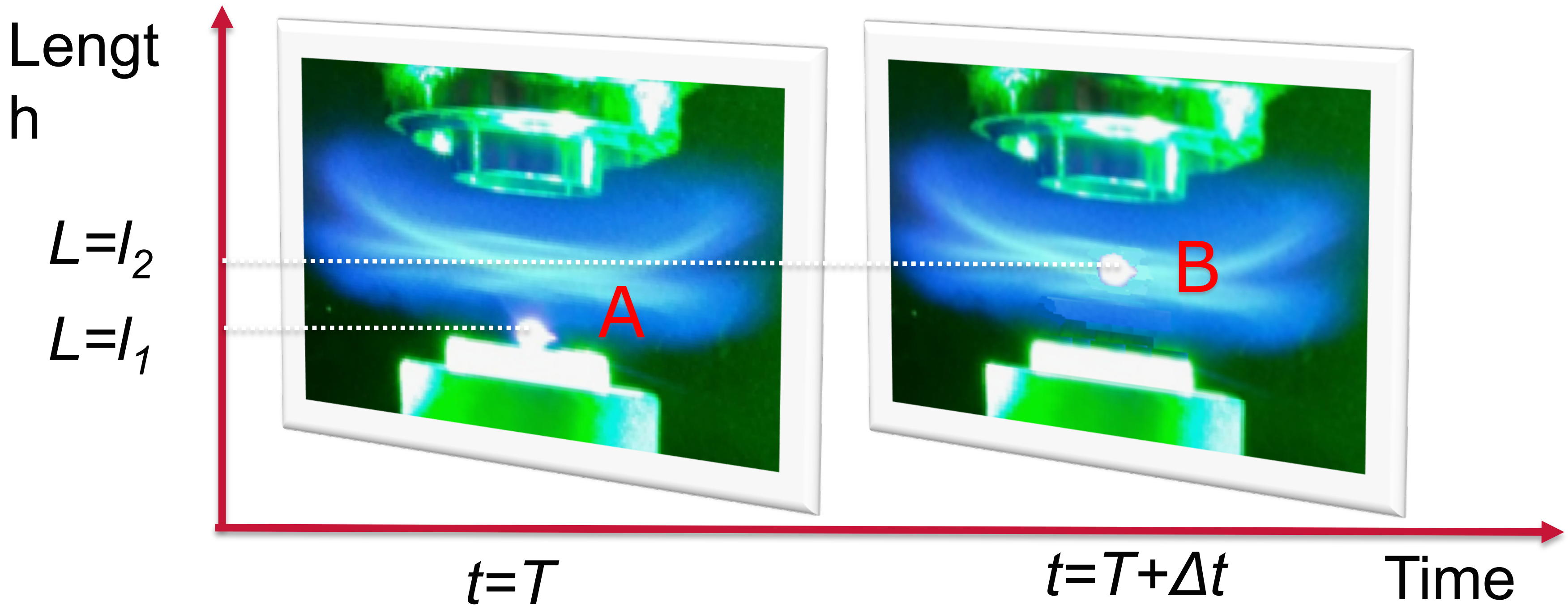


Figure Correlation of the equivalence ratio with the intensity ratio H/O (a) and C_2/CN (b) of LIBS spectra

4. Laser-induced plasma image velocimetry

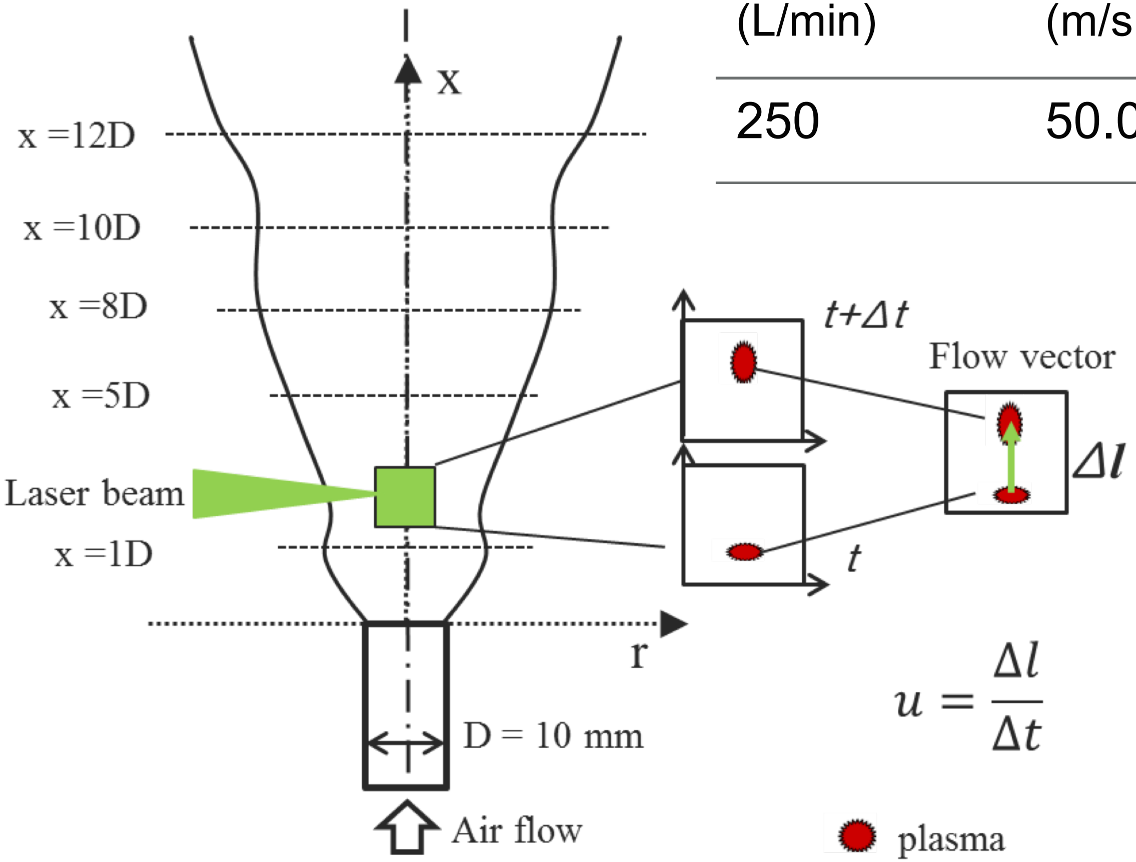


Velocity from A to B:

$$V = \frac{l_2 - l_1}{\Delta t}$$

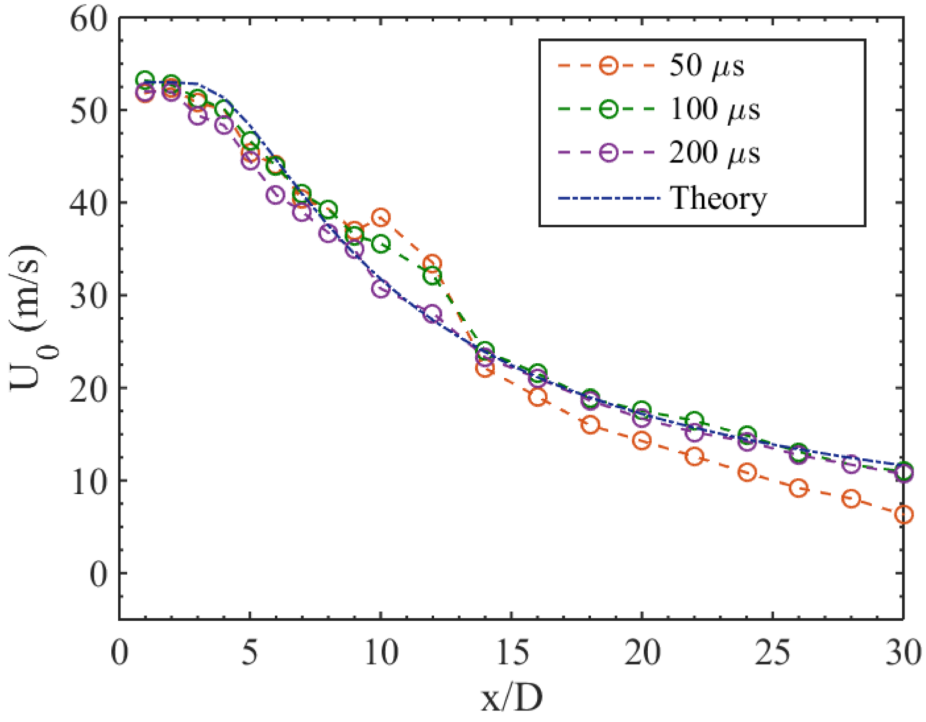
4. LIPIV measurement in turbulent jet;

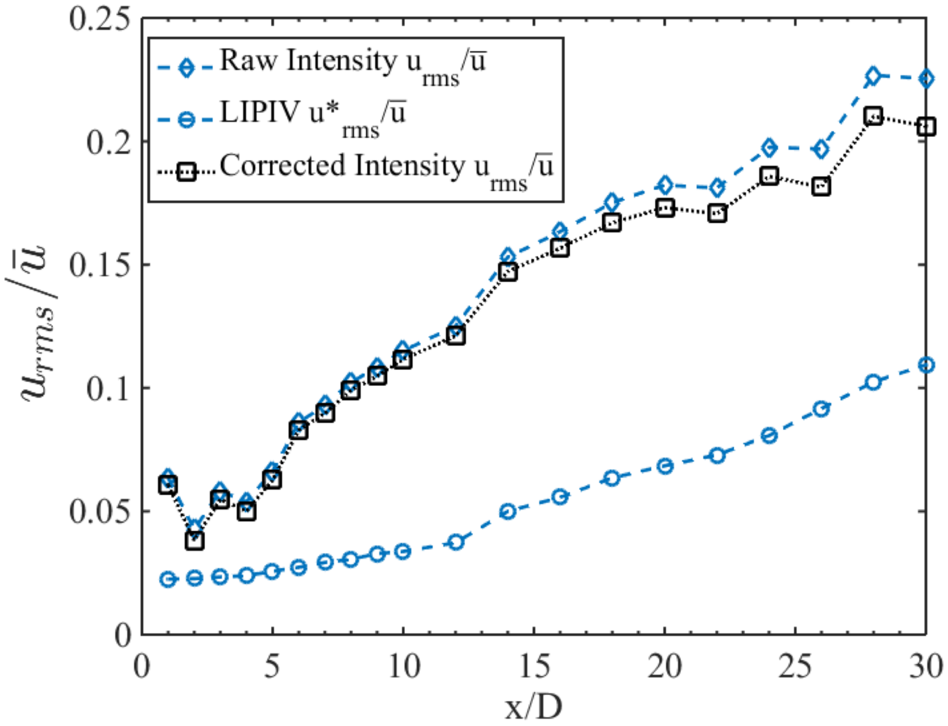
Flow rate (L/min)	Exit Velocity (m/s)	Reynolds number
250	50.06	3.38×10^4



$$u = \frac{\Delta l}{\Delta t}$$

4. Centreline velocity distribution





Variation of mean velocity and turbulent intensities along the jet centreline

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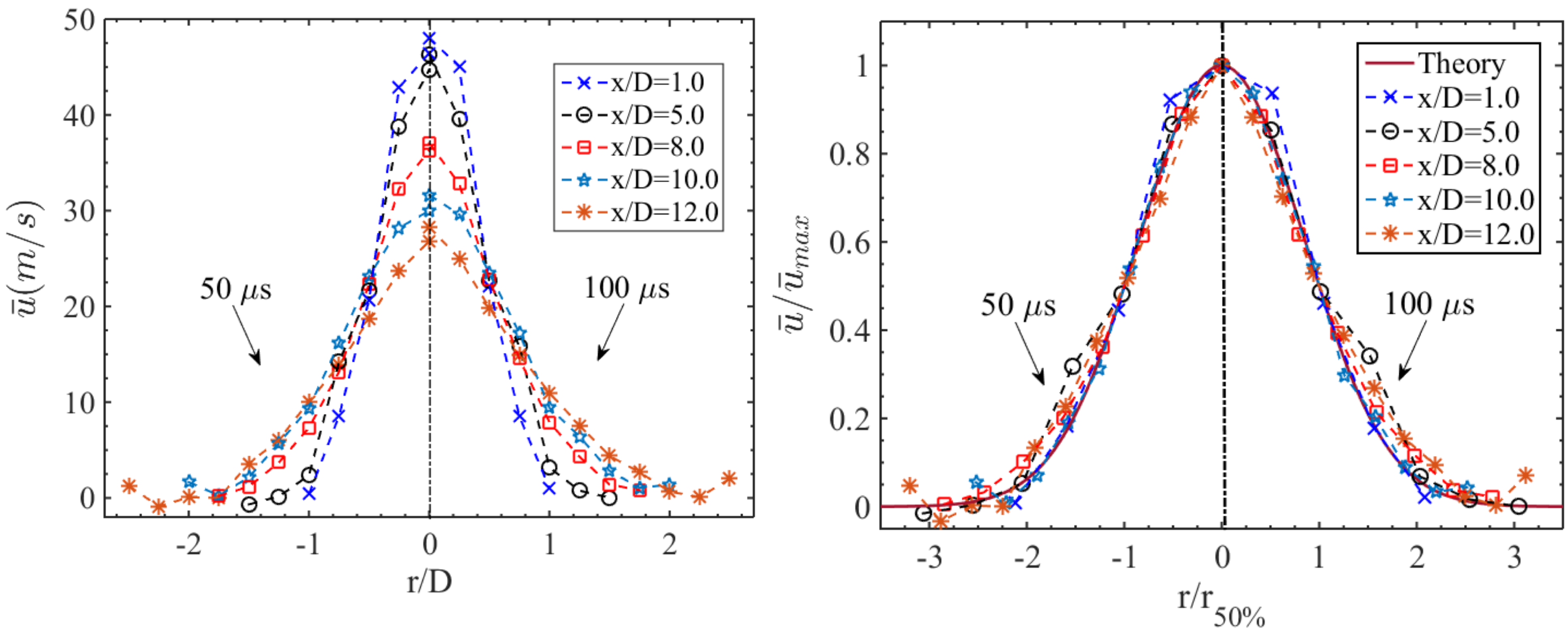
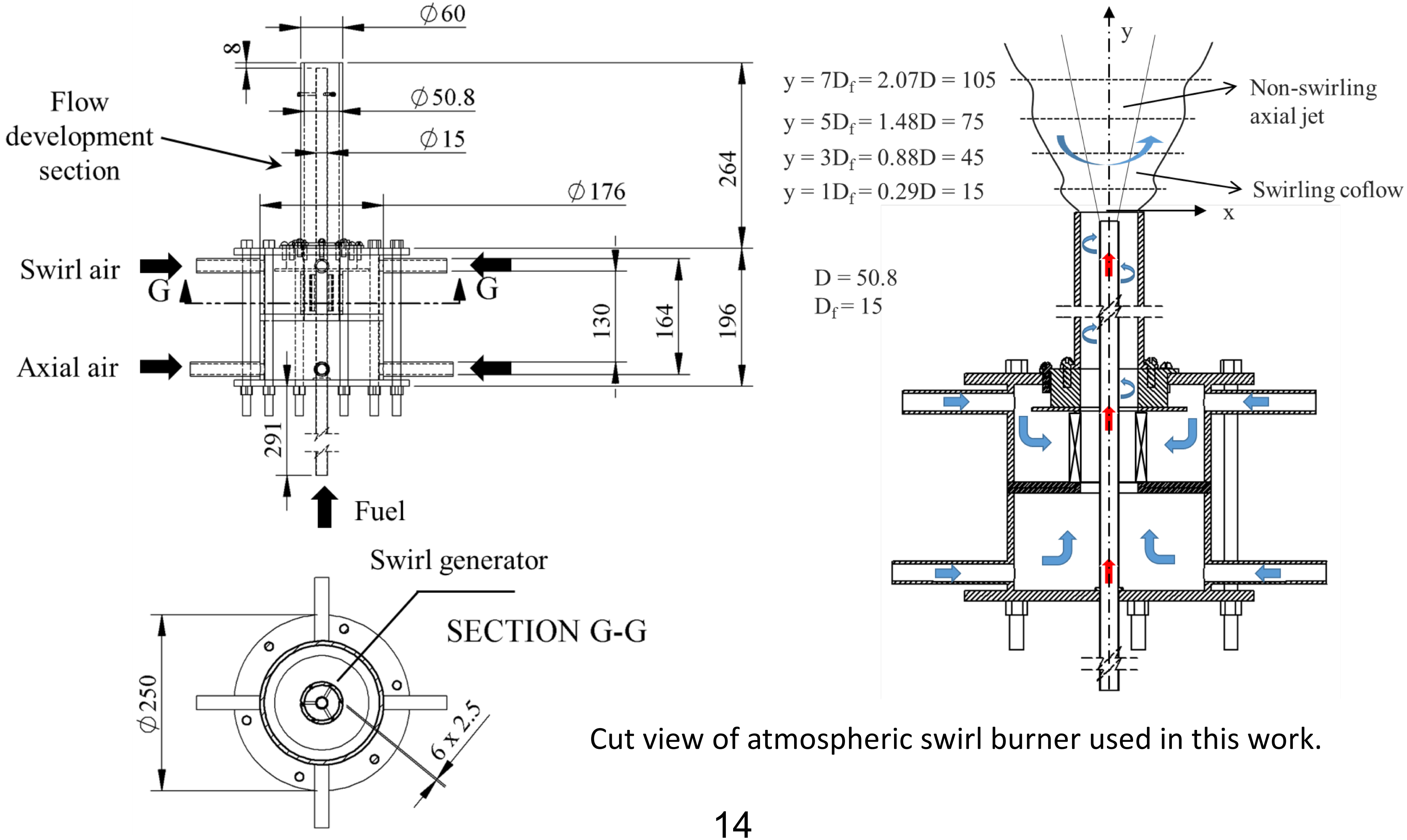
4. Radial profile and self similar 50 μs V.S. 100 μs



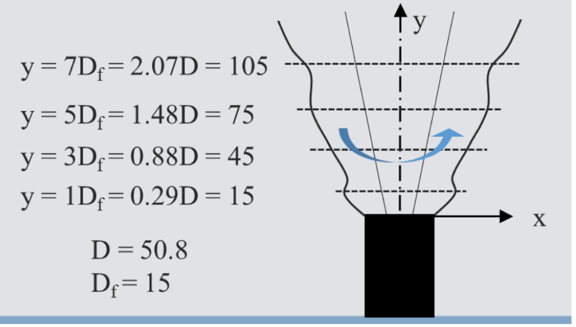
Axial profiles of mean velocity and normalized mean velocity at various heights

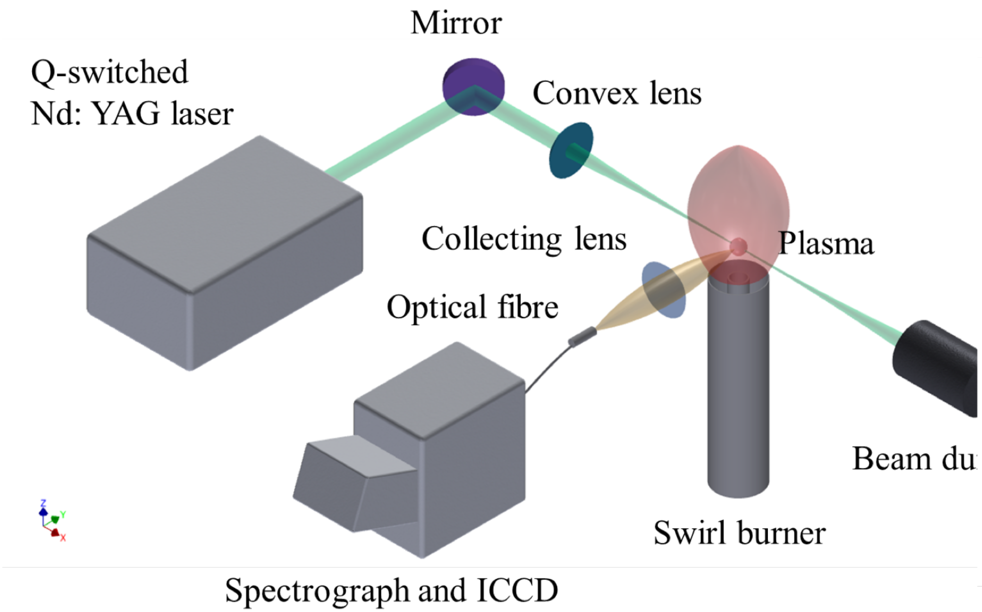
5. Swirl burner experiment

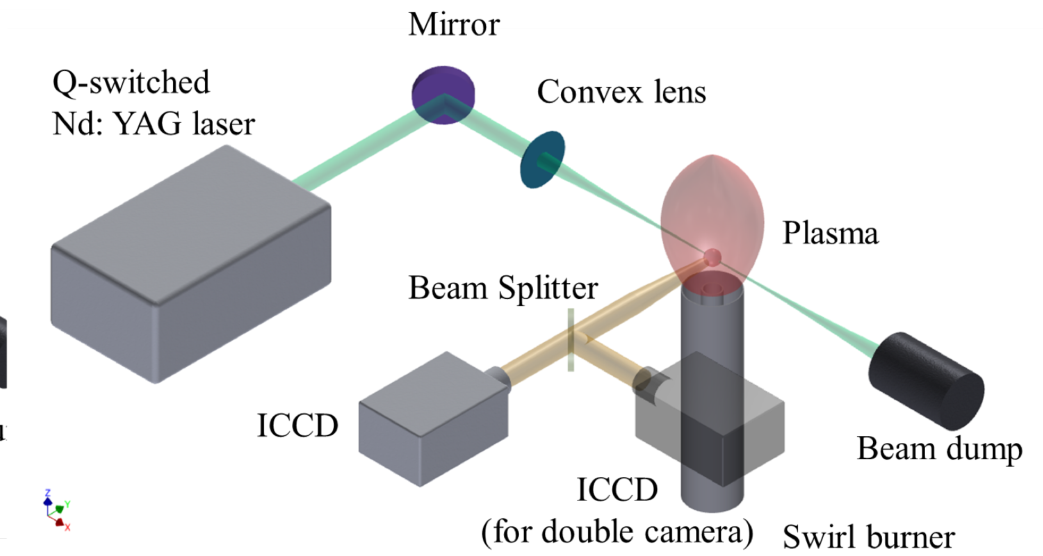


Cut view of atmospheric swirl burner used in this work.

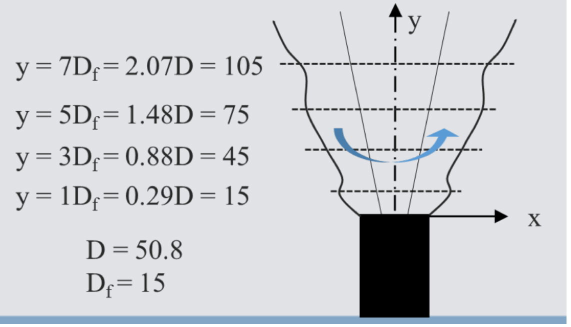
5. Swirl burner experiment





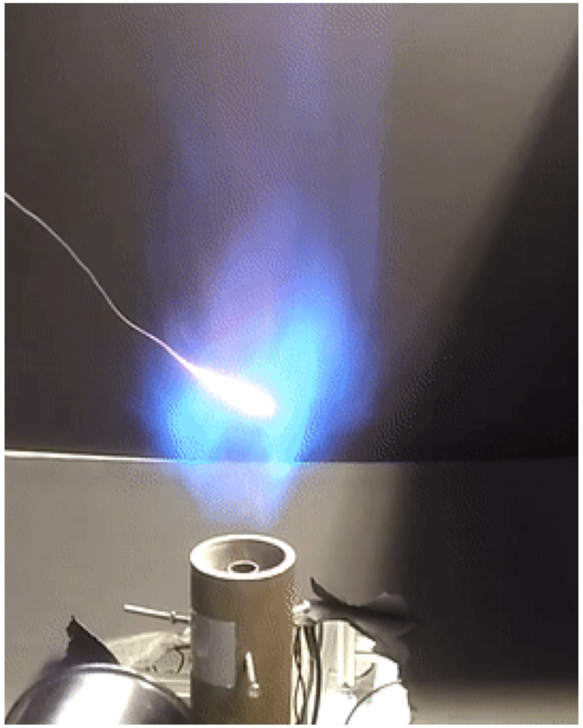


5. Operating conditions reacting



Swirl number	V_{axial} l/min	V_{swirl} l/min	V_{CH_4} l/min	u_{fuel} m/s	u_{air} m/s	Re_{air}	Re_{fuel}	Equivalence ratio
0.58	350	550	68	6.42	8.46	28662	5743	0.72

Slava using DLR fuel



Choose the condition of Keeping fuel momentum same as slava's

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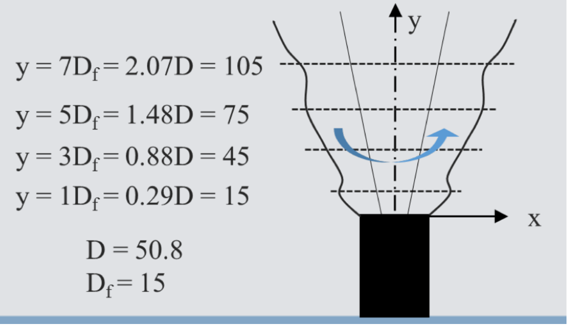
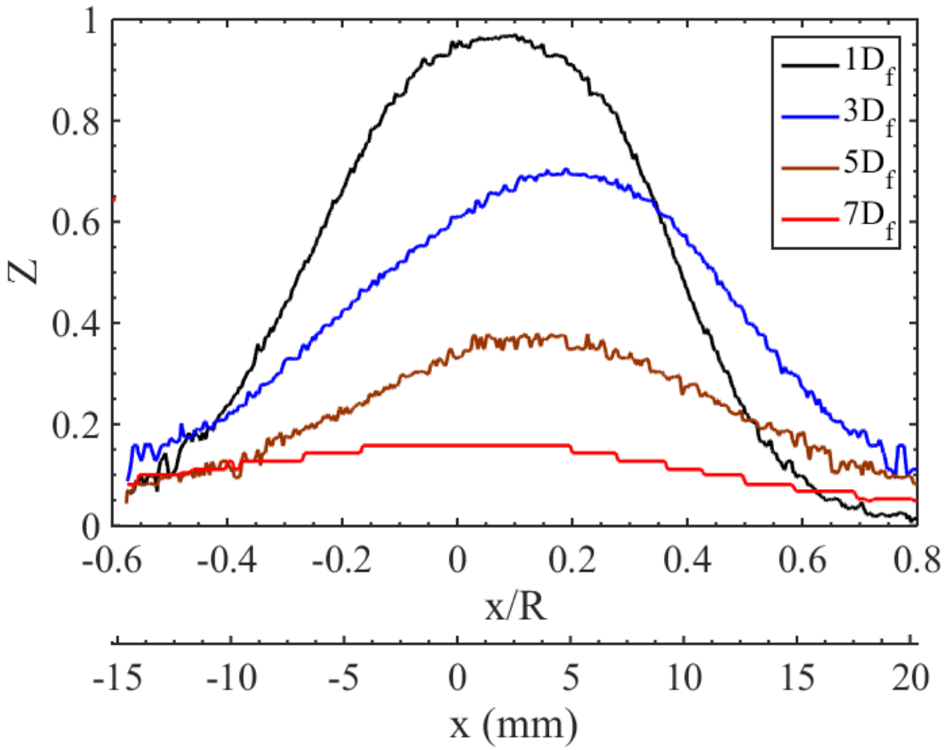
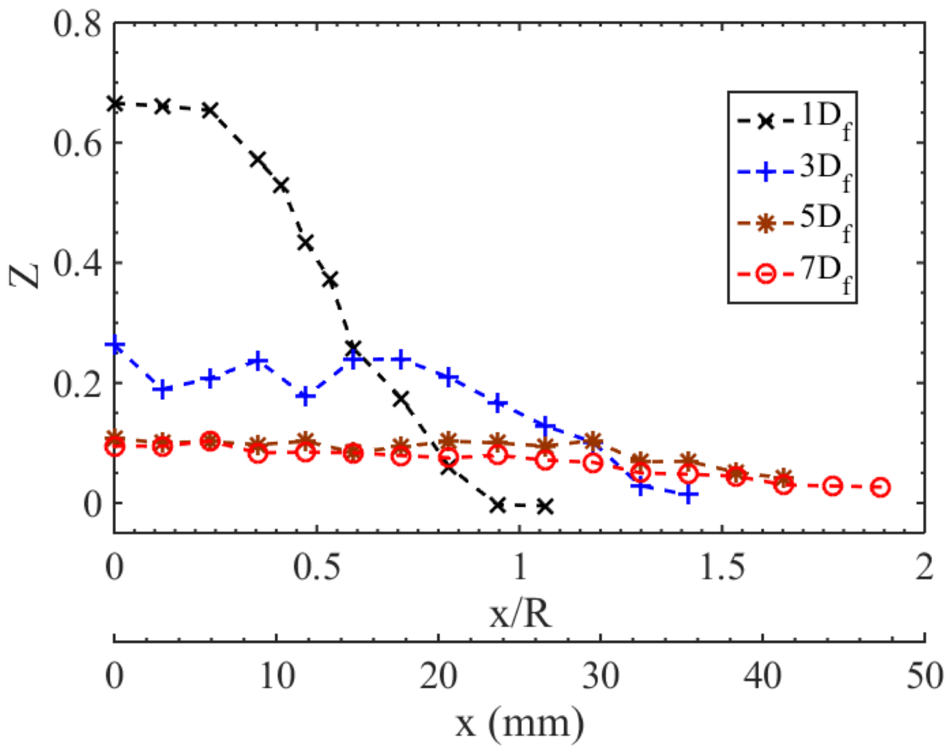
5. Mixture fraction results using LIBS







Acetone PLIF mean Z v.s. Mean LIBS Z

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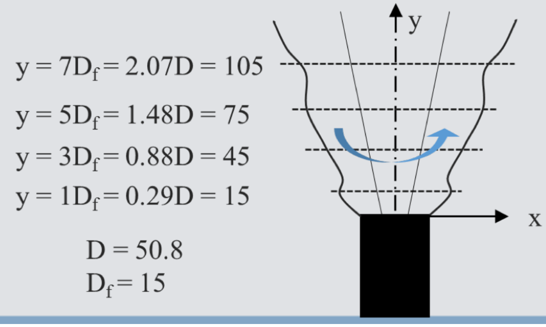
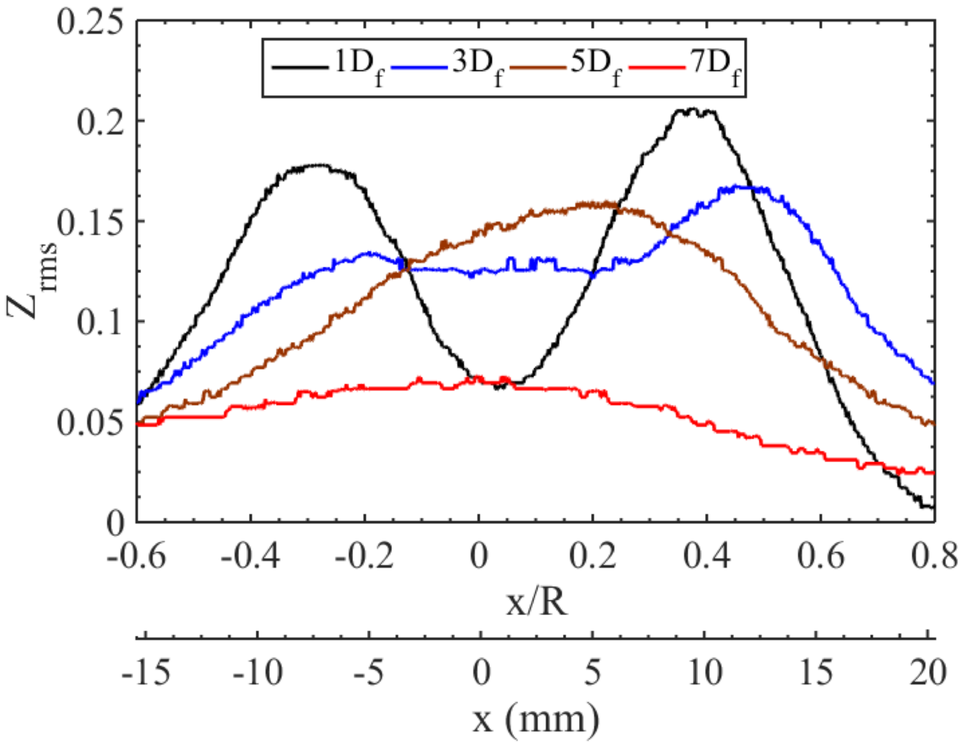
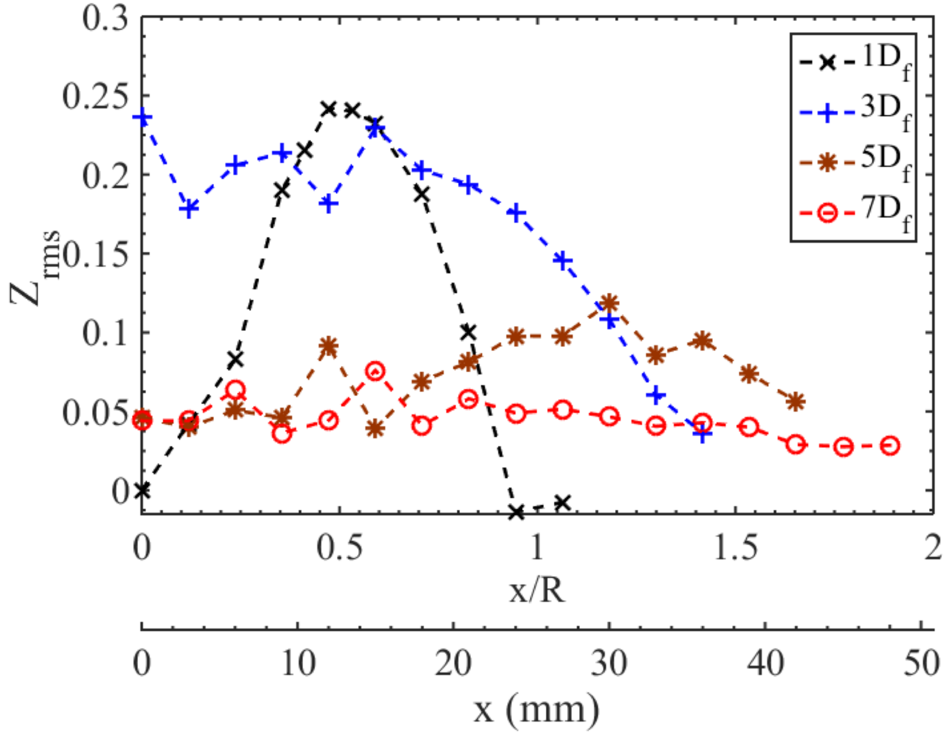
5. Mixture fraction profiles_rms







Acetone PLIF rms Z v.s. LIBS rms Z

5. Reacting flow velocity measurement

4 Issues

- High temperature ↓ plasma intensity

✓ Offset by ↑ the laser pulse energy

- Flame lights interference

✓ Adding filter and post-processing code

- **High fuel concentration quenches plasma**

  (shorter lifetime and deformation)

X shorter delay time between two images

- **Non-uniform temperature field deforms the plasma**

x get rid of the bad points

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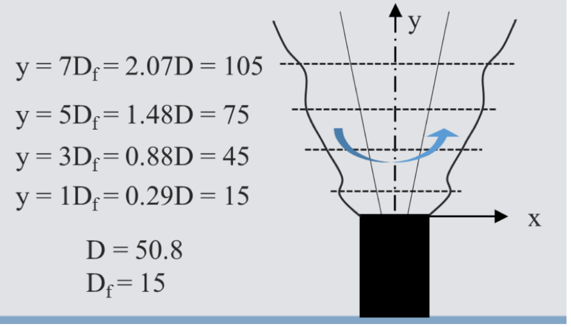
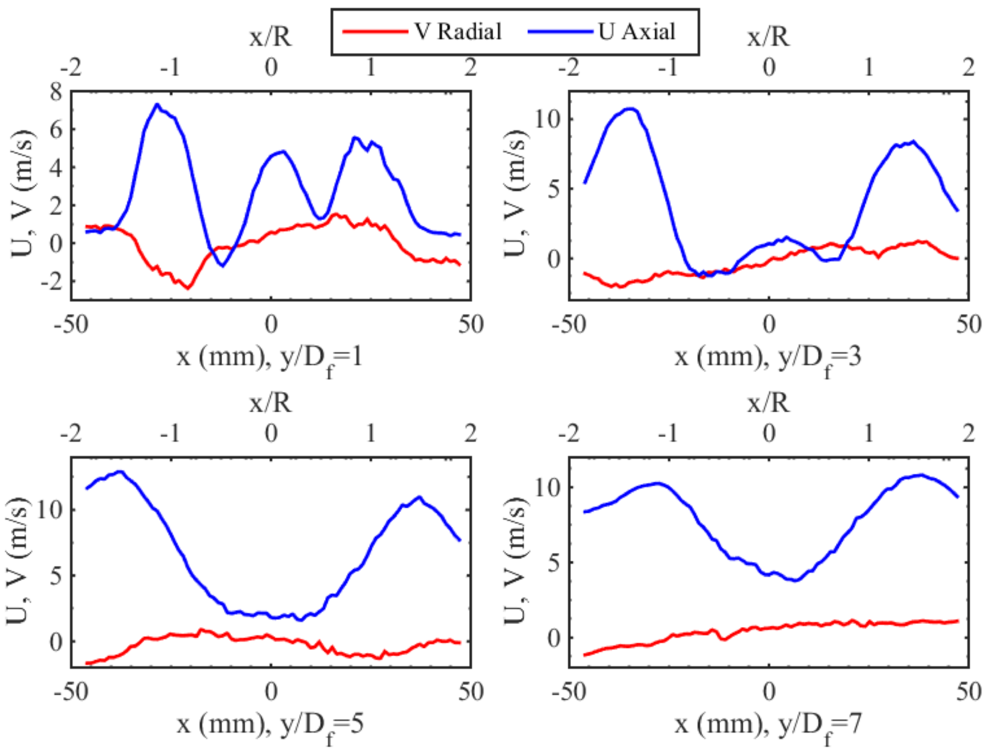
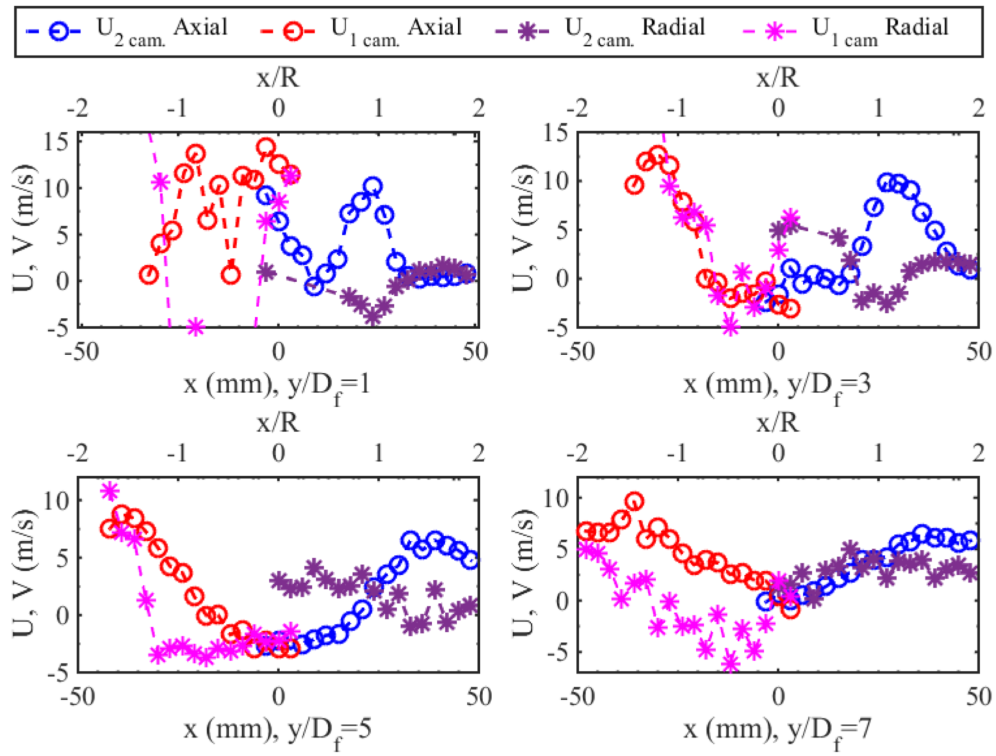
5. Reacting velocity profile







Mean PIV velocity v.s. Mean LIPIV velocity

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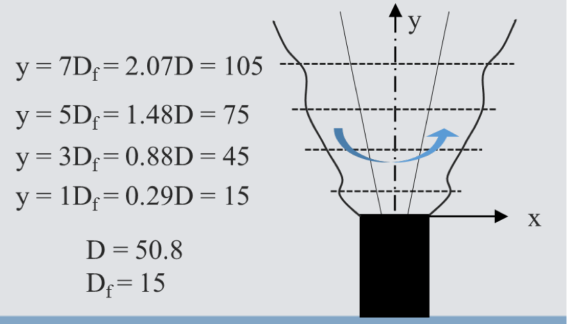
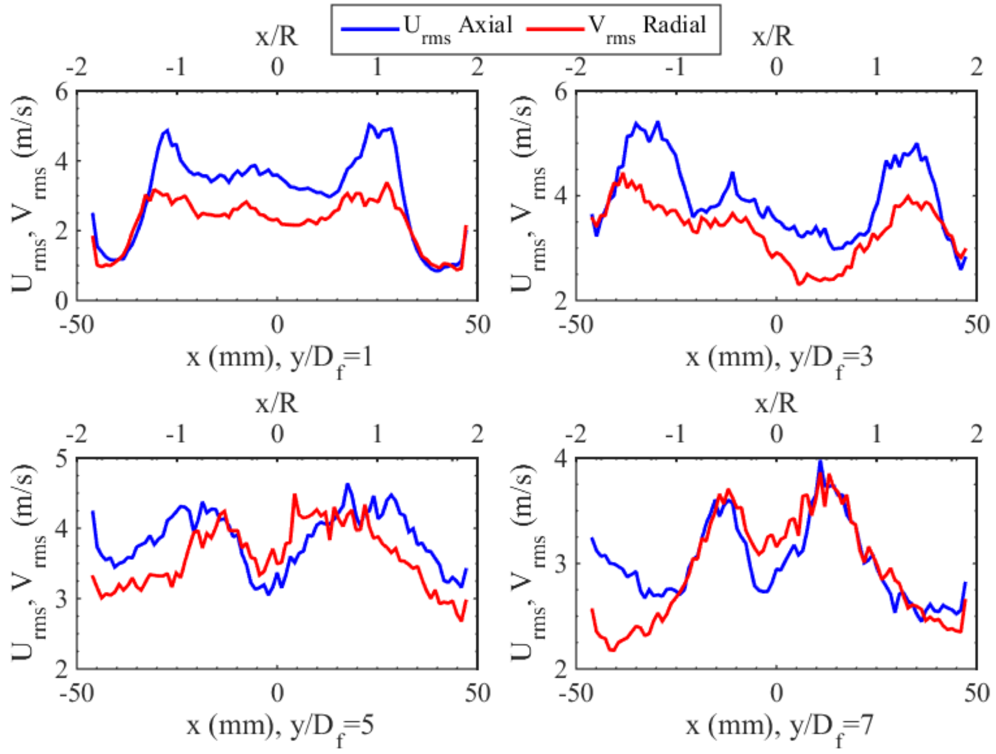
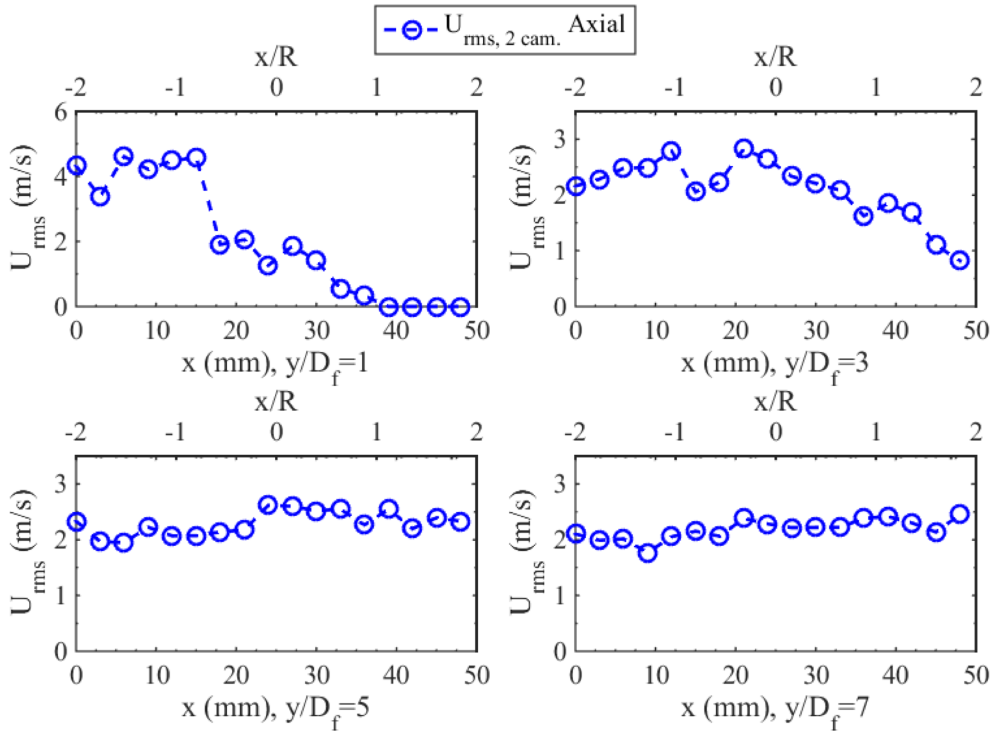
5. Reacting rms velocity







PIV rms velocity v.s. LIPIV rms velocity

6. Conclusions:

- The LIBS measurements in equivalence ratio is successful, with less than 10% uncertainty.
- LIPIV is accurate in non-reacting measurements using single or double cameras. Although the flames increased the uncertainty, double camera LIPIV still works with reasonable accuracy.
- The gas temperature using the laser induced plasma has the potential to be developed.

Thank you