

# Multi-scalar and velocity measurements in a turbulent bluff-body flame using spectral fitting of Spontaneous Raman Scattering and PIV



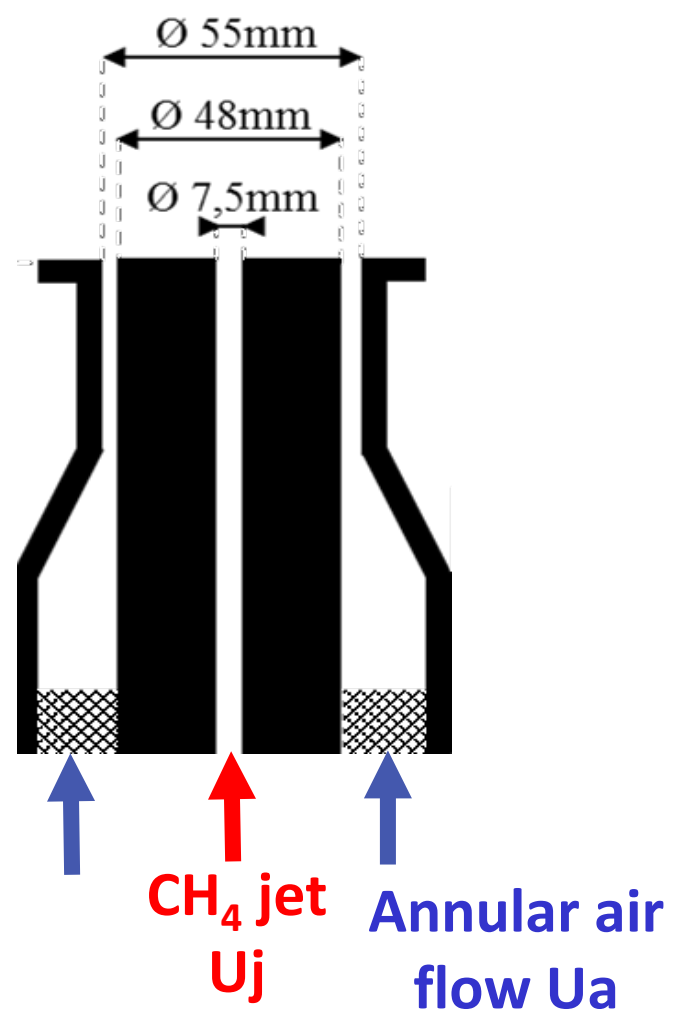
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## Introduction

- Improvement of energy efficiency and adaptability of industrial burners → operating conditions close to flame stability limit
- Bluff-Body burner → convenient configuration to ensure turbulent flame stabilization, but intermittent physical phenomena not yet fully understood
- Objective:** experimental investigation of the turbulent flame features stabilized in the shear and mixing layers in the recirculation zone at the exit of a canonical bluff-body burner by measurements of velocity fields by PIV associated to temperature and multi-species density numbers obtained by Spontaneous Raman Scattering (SRS)

## The Bluff-body burner



### Non-premixed geometry

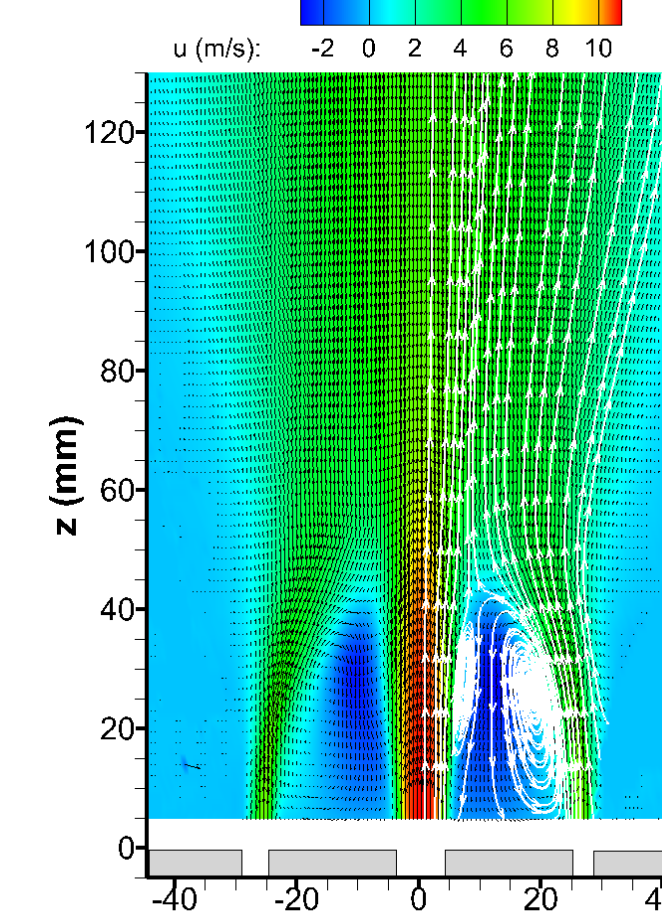
- Central methane jet
- Annular air flow
- Large blocking ratio:  
 $RB = Db/Da = 0.83$

### operating conditions

- central methane jet velocity:  
 $U_j = 10.5 \text{ m/s}$
- annular air velocity:  
 $U_a = 5.0 \text{ m/s}$



PIV axial velocity field and mean streamlines



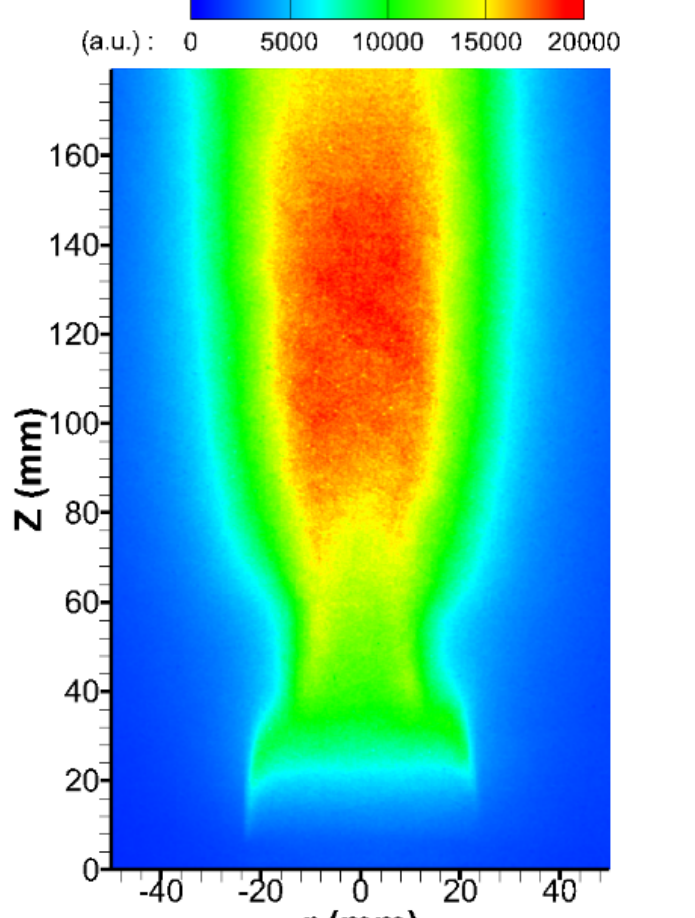
### Flow aerodynamics

- recirculation zone (RZ) with inner centrifugal  $\text{CH}_4$  vortex and outer centripetal air vortex
- RZ pierced by the central methane jet

### Flame structure

- Stabilisation in the recirculation zone
- Jet-like flame in continuity from the top of the recirculation zone

$\text{OH}^*$  chemiluminescence average image



## Setup of Spontaneous Raman Spectroscopy

### Nd:YAG laser Agilite Continuum

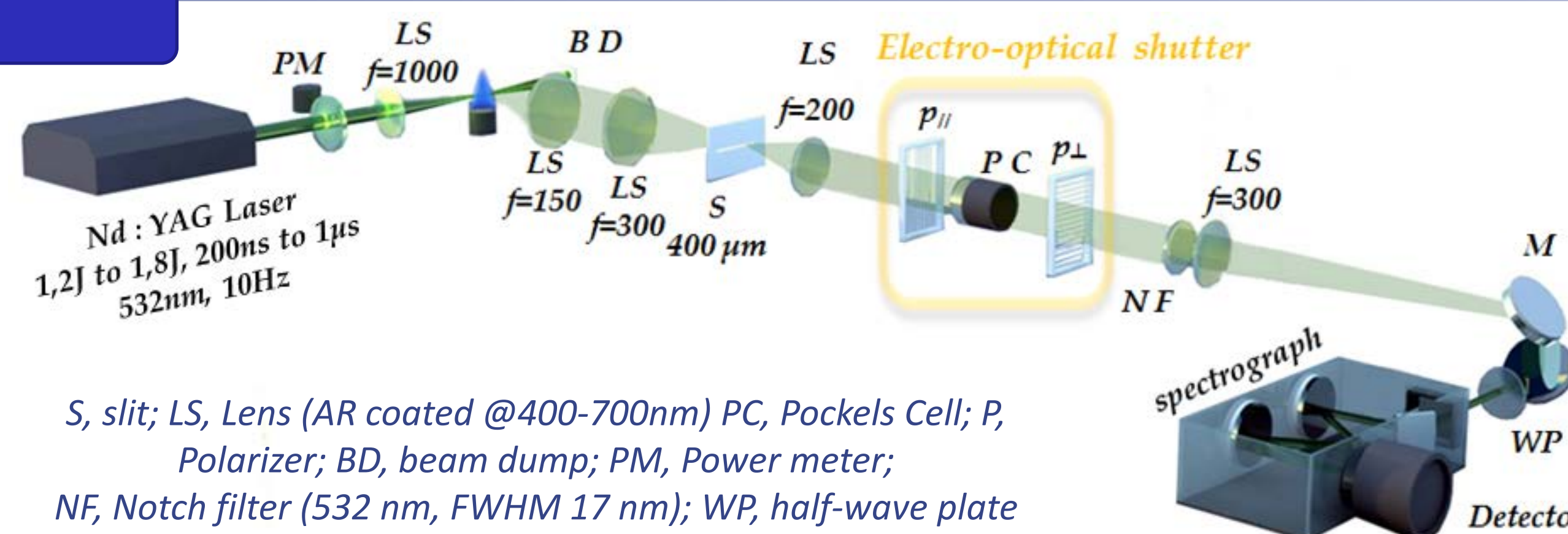
- 1.8 J top-hat pulse @ 10 Hz
- Long pulse duration adjustable from 200 ns till 1  $\mu\text{s}$

### spectrograph IsoPlane SCT 320 (Princeton Inst.)

- 600 grooves/mm grating
- spectral resolution = 0.67 nm

### full-frame back-illuminated CCD camera

- Pixis 400B, Princeton Instruments
- 1340 x 400 pixels, pixel size 20  $\mu\text{m}$ , NF = 1



S, slit; LS, Lens (AR coated @400-700nm) PC, Pockels Cell; P, Polarizer; BD, beam dump; PM, Power meter; NF, Notch filter (532 nm, FWHM 17 nm); WP, half-wave plate

### background light emission suppression

- Notch filter (OD=6 @ 532nm)
- Gated collection with a fast electro-optical shutter composed of a Pockels Cell Shutter

### 1D measurements

- 8 simultaneous probe volumes
- spatial resolution : 170 x 330  $\mu\text{m}$
- This work**

→ analysis of the core of the RZ at  $z = 12 \text{ mm}$

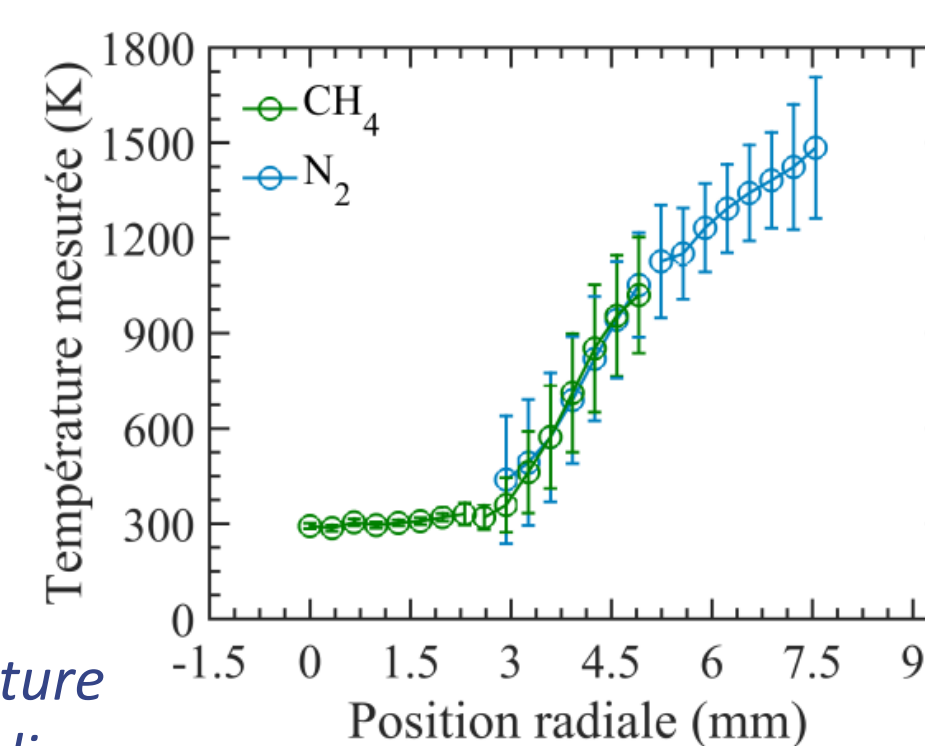
## Spectral fitting of SRS spectra for Instantaneous measurements of temperature and multi-species concentrations

### Simultaneous single-shot measurements of $\text{CH}_4$ , $\text{O}_2$ , $\text{N}_2$ , $\text{CO}$ , $\text{CO}_2$ and $\text{H}_2\text{O}$ concentrations

- Spectral fitting method with apparatus function convolution
- $\text{H}_2\text{O}$  SRS spectra modelisation suitable up to at least 2000K
- minimization of  $\text{CO}_2$  SRS spectra on new borders for higher precision
- $\text{CH}_4$  SRS spectra modelisation (600,000 lines) up to 1500K

### SRS thermometry

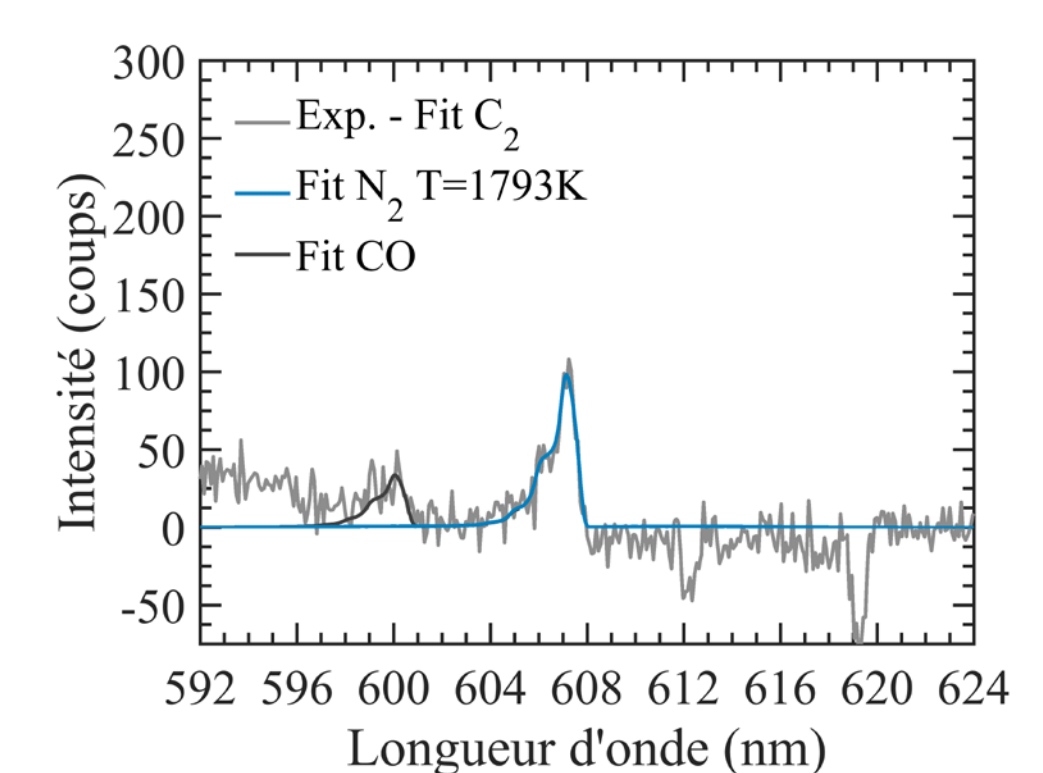
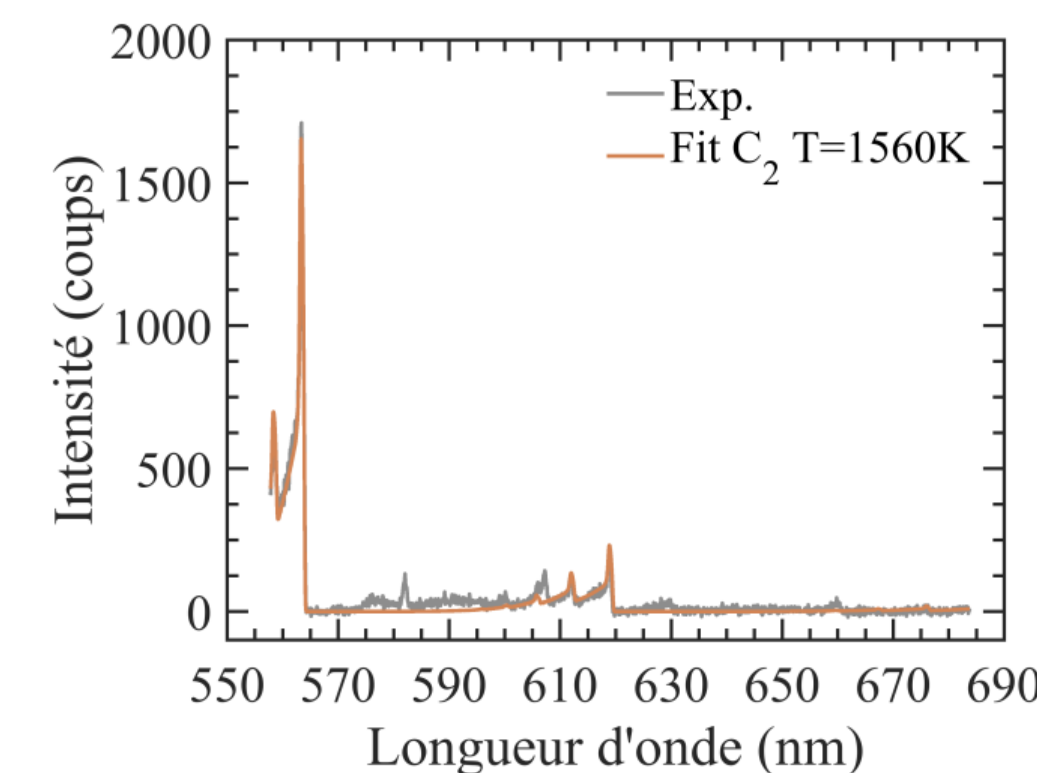
- Spectral fitting of  $\text{N}_2$  and/or  $\text{CH}_4$  SRS spectra



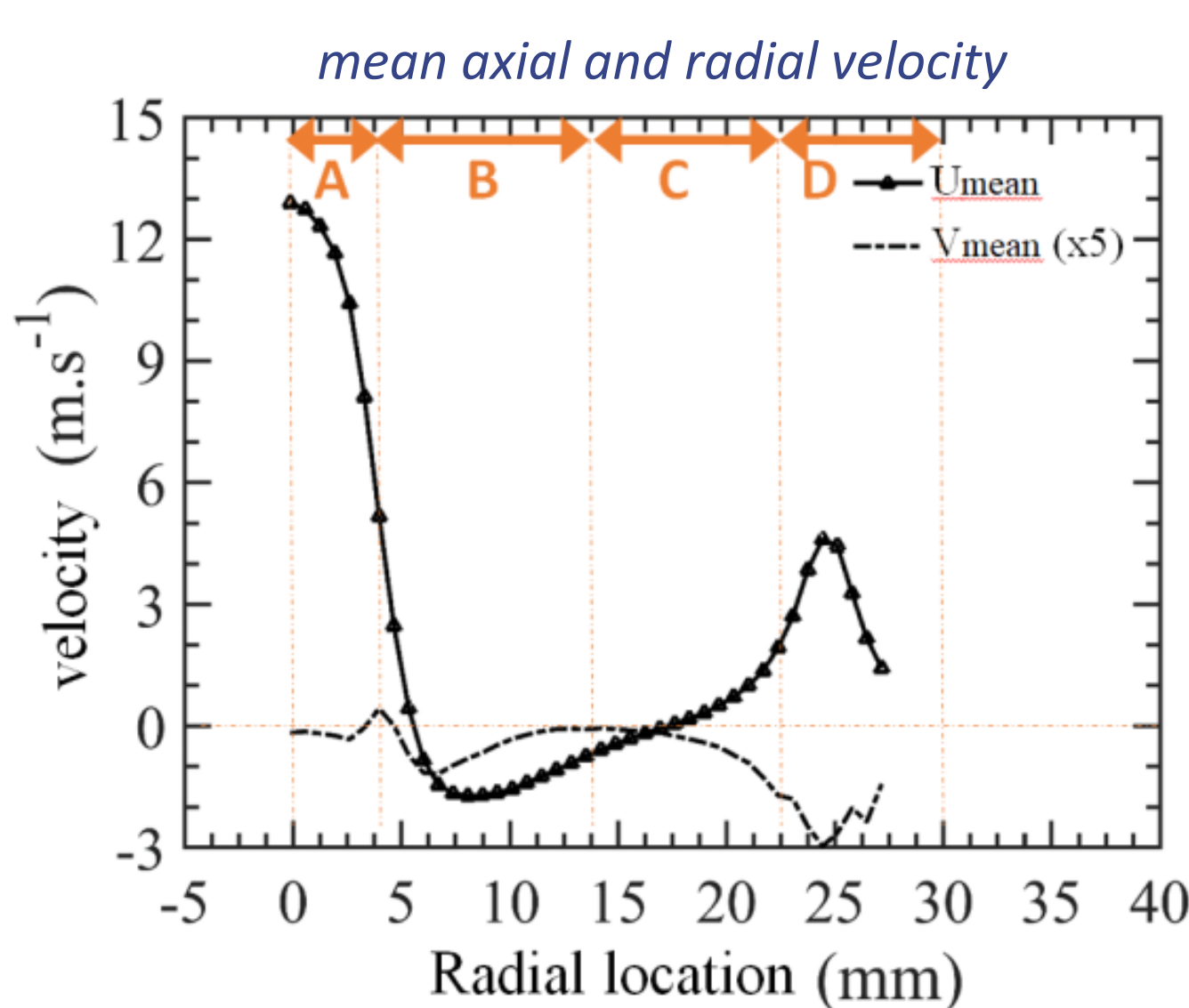
radial profiles of temperature close to the  $\text{CH}_4$  jet centerline

### Correction of $\text{C}_2$ interference

- $\text{C}_2$  LIF synthetic spectra fitted on 555-565 nm range
- Subtraction on single-shot SRS spectra to enable  $\text{N}_2$  and  $\text{CO}$  spectral fitting



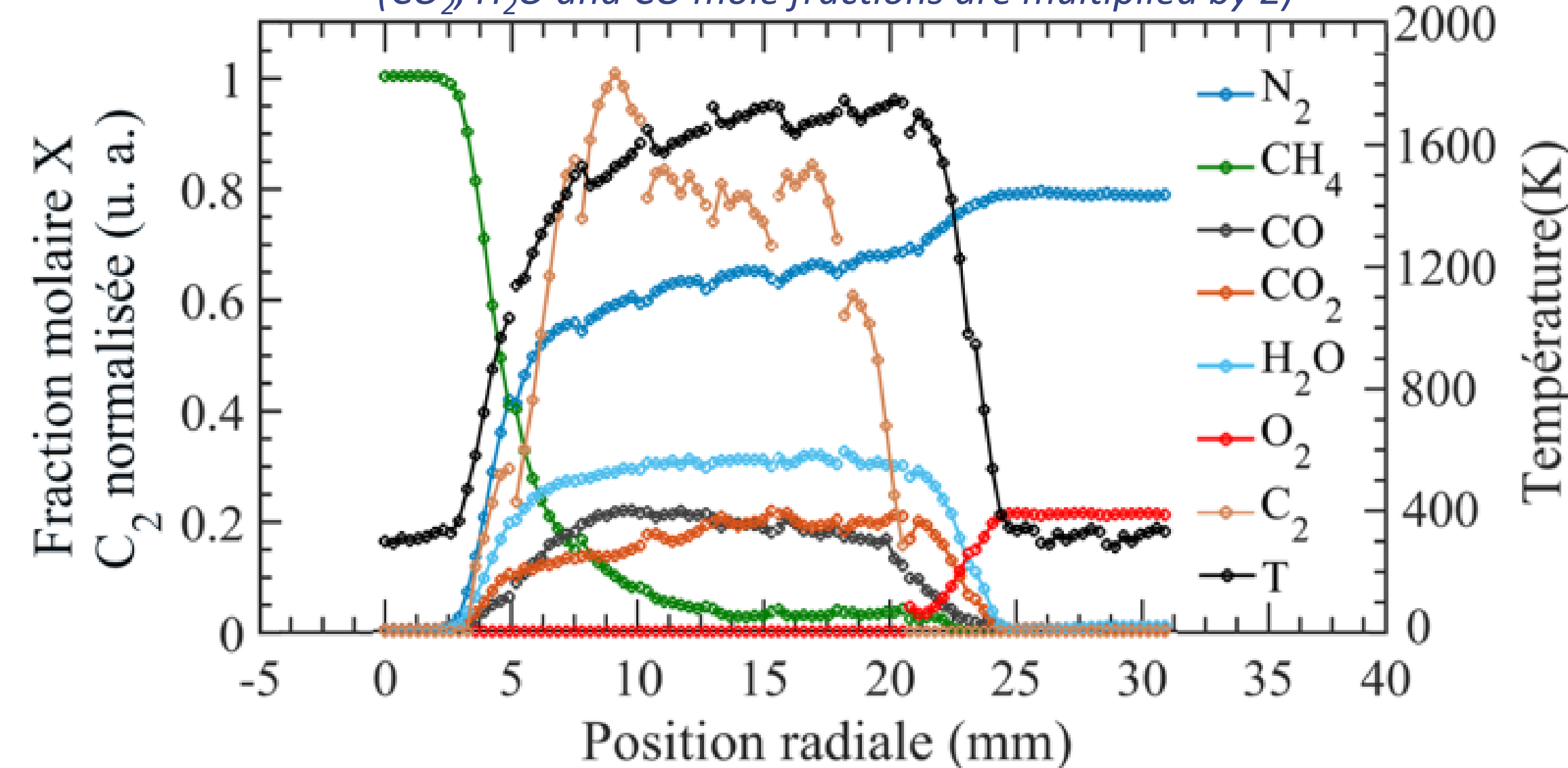
## Mean radial profiles at $z = 12 \text{ mm}$



### 4 separated regions in the recirculation zone:

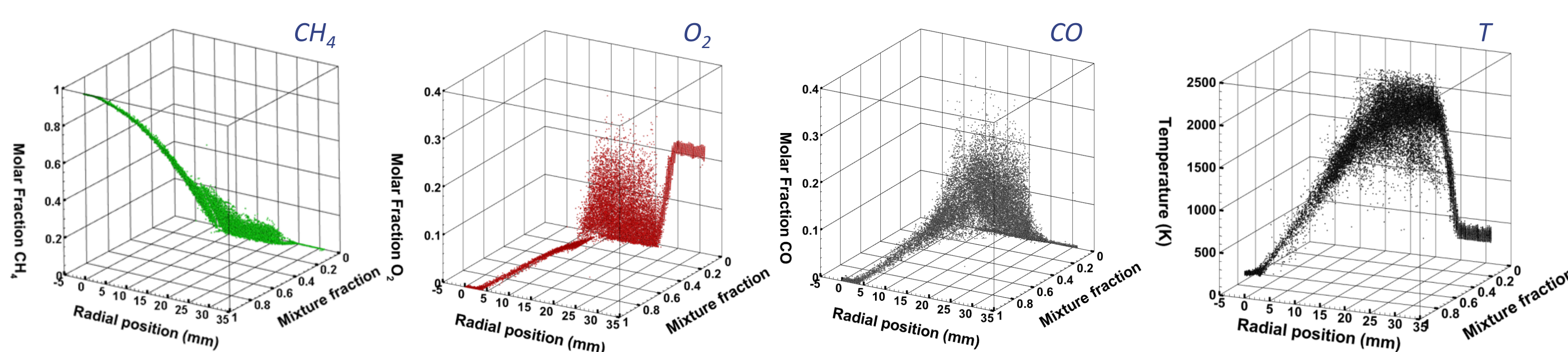
- A → central methane jet
- B → upstream mixing layer
- C → downstream recirculating burnt gases
- D → annular air flow

average radial profiles of temperature and major species mole fraction ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$  and  $\text{CO}$  mole fractions are multiplied by 2)



### A complete characterisation of the Bluff-Body flame along a radial profile in the recirculation zone

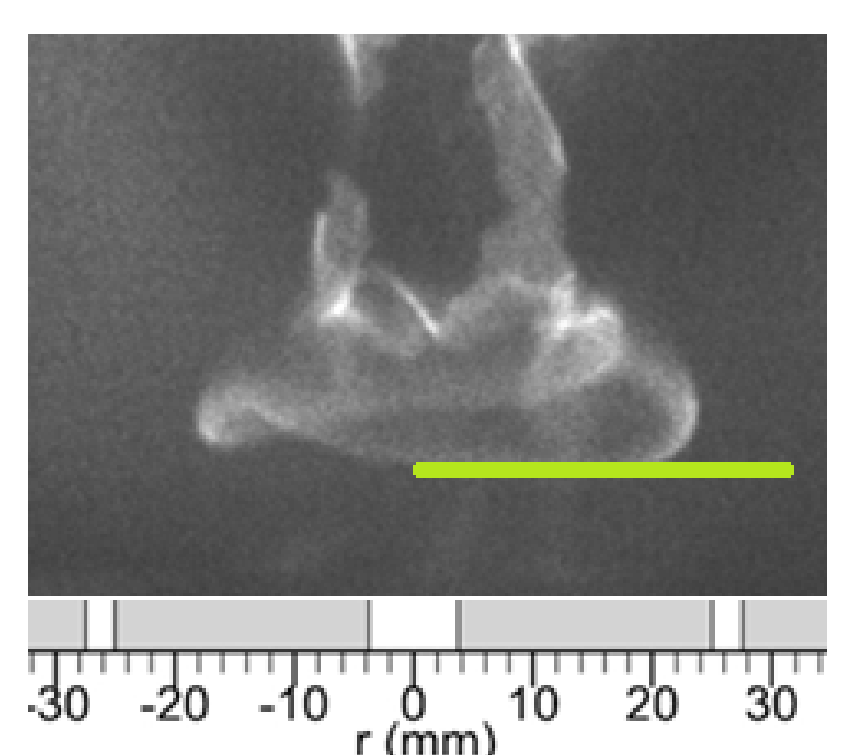
## 3D plots of instantaneous mole fraction vs. radial location and mixture fraction



### Premixed combustion regime in B-C regions at quasi constant mixture fraction (close to $Z_{st}$ )

### $\text{CO}$ flame in the inner mixing layer of the annular air flow (C-D regions) → base of the bluff-body flame

instantaneous image of high rate flame chemiluminescence



## Conclusions

- Temperature and multi-species concentrations measurements by SRS with a spectral fitting method
- Combined analysis of PIV and SRS results to describe the complexity of turbulent flame stabilised in the recirculation zone of the Bluff-Body burner
- Next future: complete map of SRS measurements from 12 to 90 mm downstream to the burner

## Acknowledgements

- This work is funded by the BIOENGINE project, co-financed by the European Union with the European regional development fund (ERDF) and by the Normandy Regional Council. This work is also supported by the PASTEC project (ANR-16-CE22-0005-02) with the financial support of ANR. The PhD fellowship of F. Guichard is supported by Normandy Regional Council.