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► **To cite this version:**

Pradip Xavier, Alexis Vandael, G. Godard, Bruno Renou, Gilles Cabot, et al.. Investigation of Thermoacoustic Oscillations in a Trapped Vortex Combustor. 7th European Combustion Meeting, Mar 2015, Budapest, Hungary. hal-02129415

**HAL Id: hal-02129415**

**<https://hal.science/hal-02129415>**

Submitted on 5 Aug 2023

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# INVESTIGATION OF THERMO-ACOUSTIC OSCILLATIONS IN A TRAPPED VORTEX MODEL COMBUSTOR

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## Context and Objectives

- Reduction of **pollutant emissions** in aero-engines.
- Development of **lean combustion** technologies.
- Improvement of **flame stabilization**.

Development of **disruptive concepts** for the combustor architecture:

**Trapped vortex combustor (TVC): flow passing above an active cavity**

Few data on **anomalous operating conditions** (combustion instabilities)

**Goals of this work:**

- Investigate mechanisms of **thermo-acoustic oscillations**
- Consequences on the **flame stabilization** in a TVC

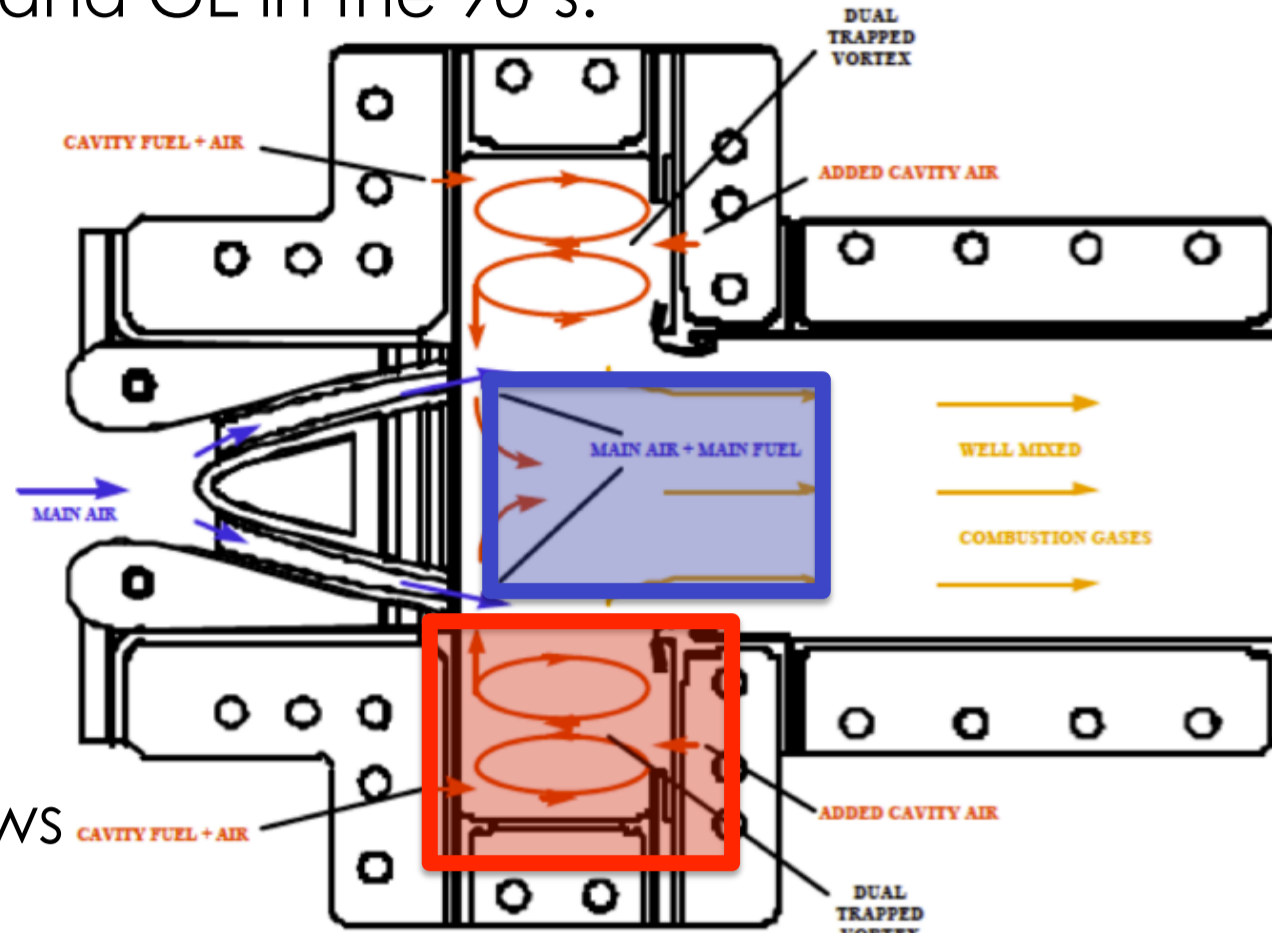
## TVC concept

Developed by US Air Force and GE in the 90's.

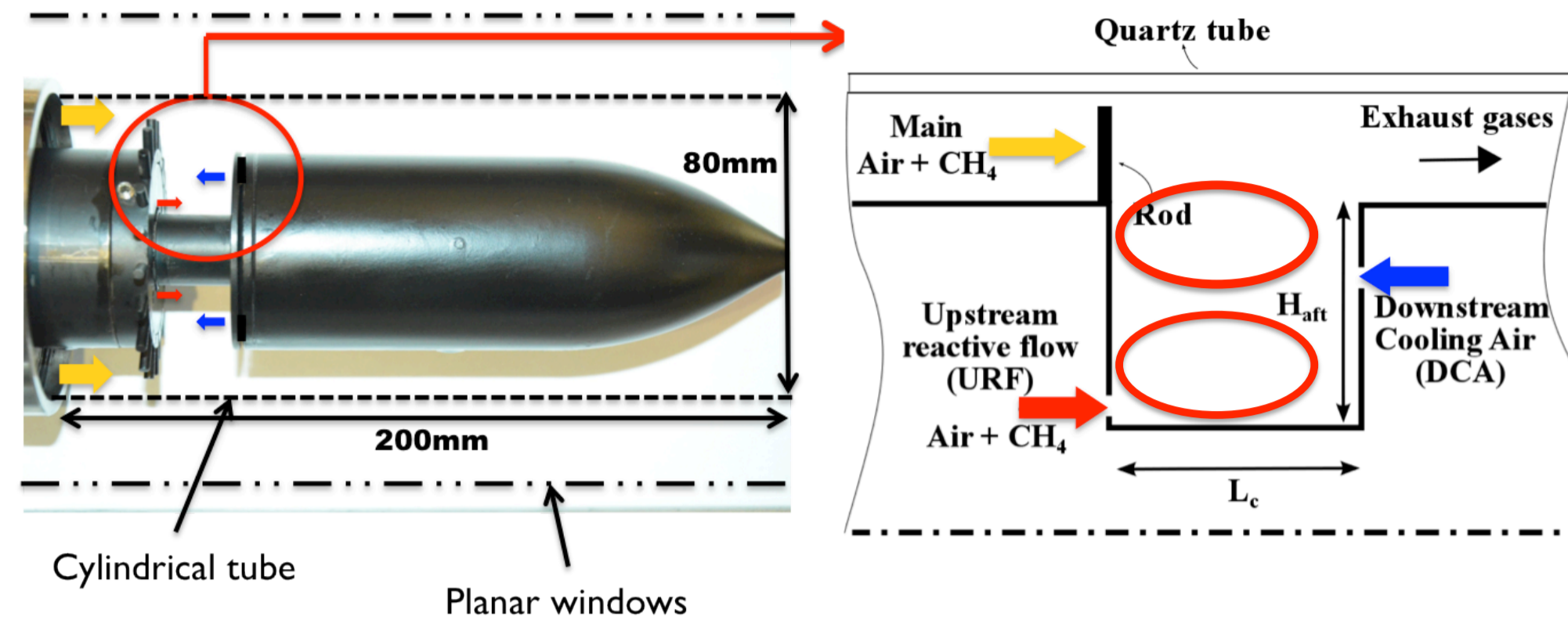
### Cavity based flame-holder

Ignition and stabilization of a **lean-fuel flow**

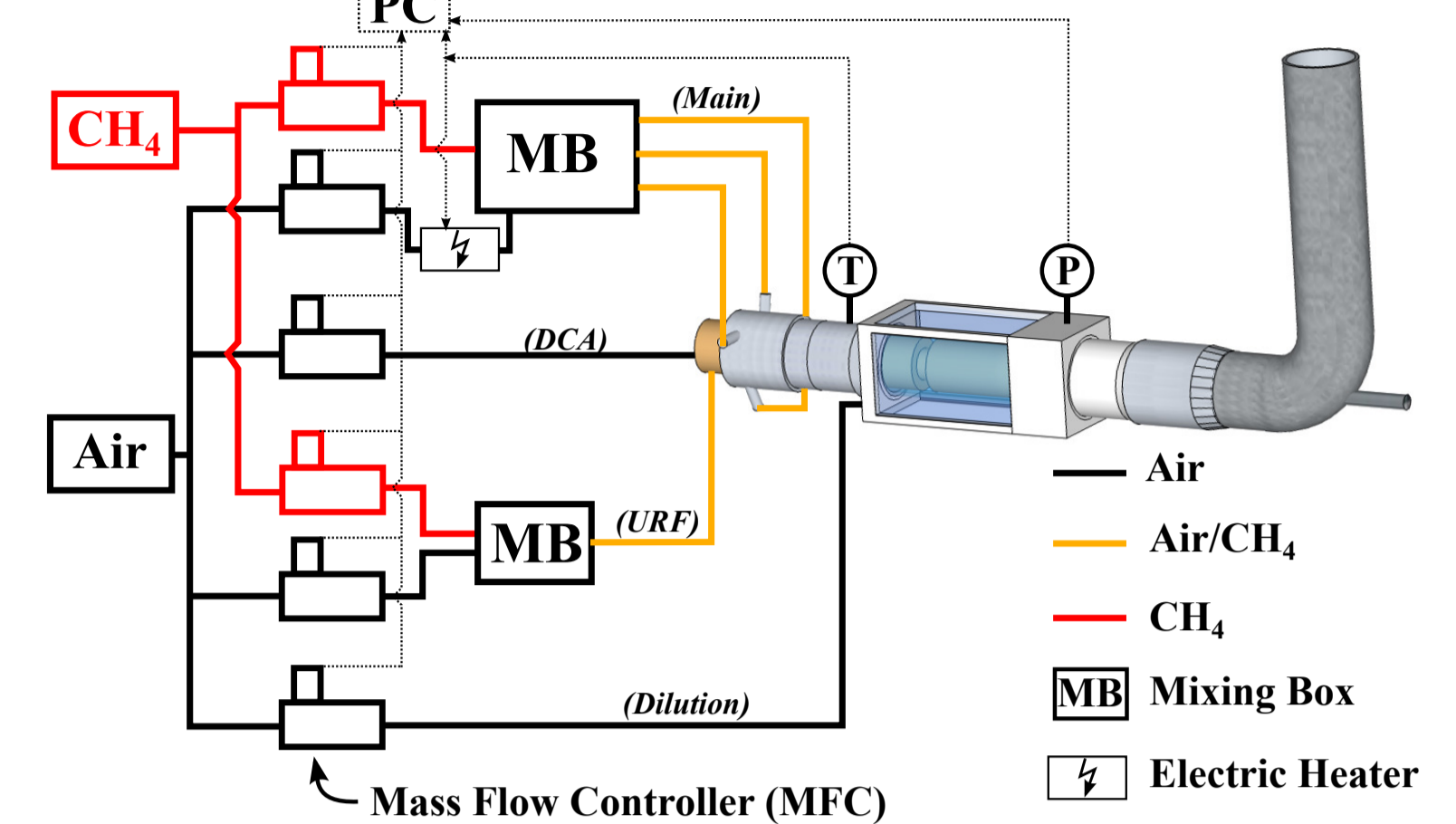
- Pilot region confinement
- High-speed mainstream flows
- Low-NOx technology
- Flexible (RQL, staged)



## TVC burner and experimental setup



- Annular geometry with full optical access
- Fueled with  $\text{CH}_4$
- Injection systems: slots
- Acoustic conditions: choked



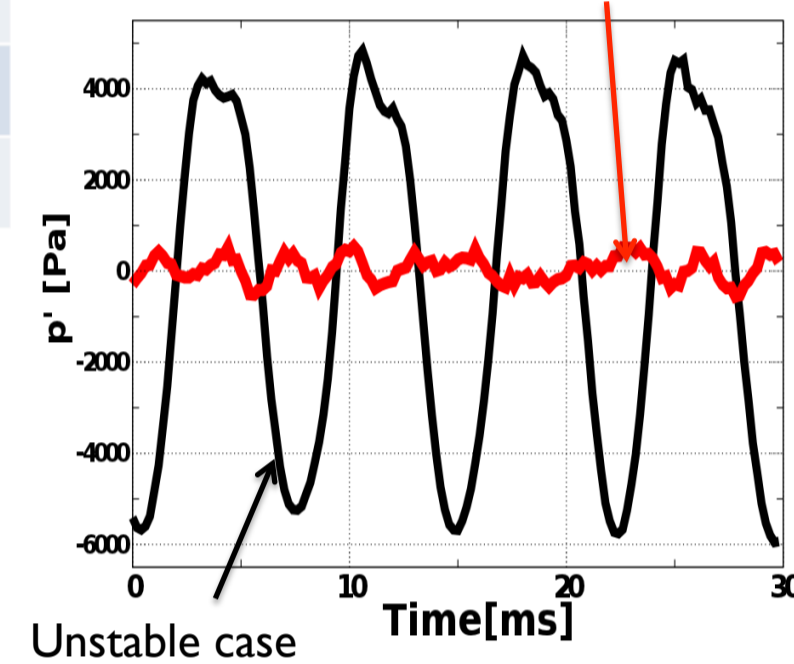
- 6 independent mass flow controllers
- Premixed feeding lines

## Operating conditions [3]

Region	Air	Fuel	$\Phi$
Main [g/s]	21.50	1.0	0.8
Bulk speed [m/s]	5.0		
URF [g/s]	0.7	0.12	3.0
Bulk speed [m/s]	6.0		
DCA [g/s]	1.0	0.0	-
Bulk speed [m/s]	3.6		

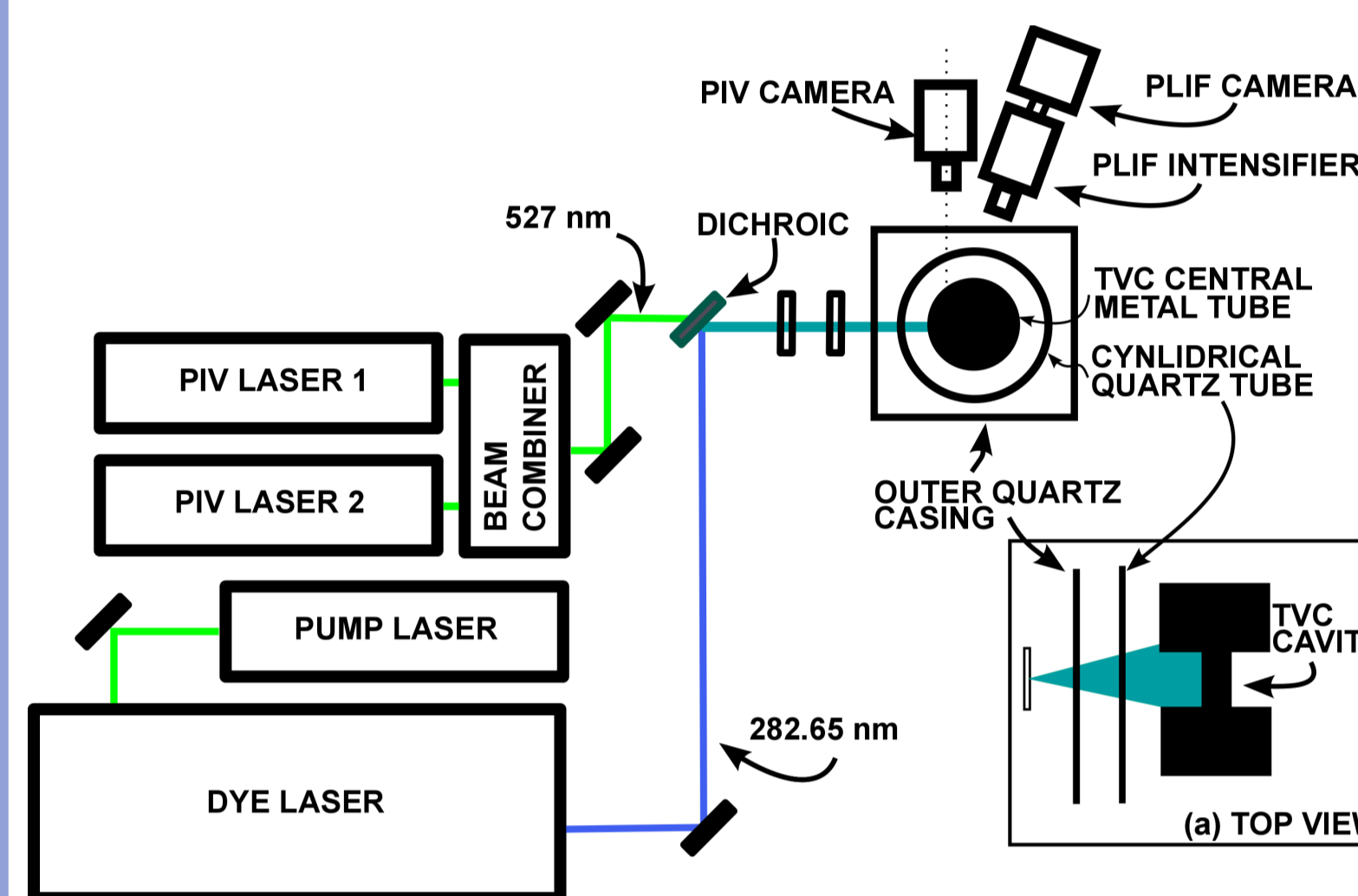
$\Phi_{\text{glob}} = 0.83$   
 $P_{\text{glob}} = 60\text{ kW}$   
 $P_{\text{ch}} = 1.7\text{ bar}$

Stable case



The combustor can exhibit large and self-sustained pressure oscillations for some operating conditions.

## Optical diagnostics



## Coupled high-speed laser diagnostics

### High-speed PIV @ 2.5KHz

- Pump laser: 2x30W Nd:YLF Darwin Dual @ 2.5kHz
- Collection system: Phantom V10, Nikon lens f/2.8 105mm
- Output energy: 12mJ / shot @ 2.5kHz
- Solid  $\text{ZrO}_2$  seeding for each injection w/ fluidized beds

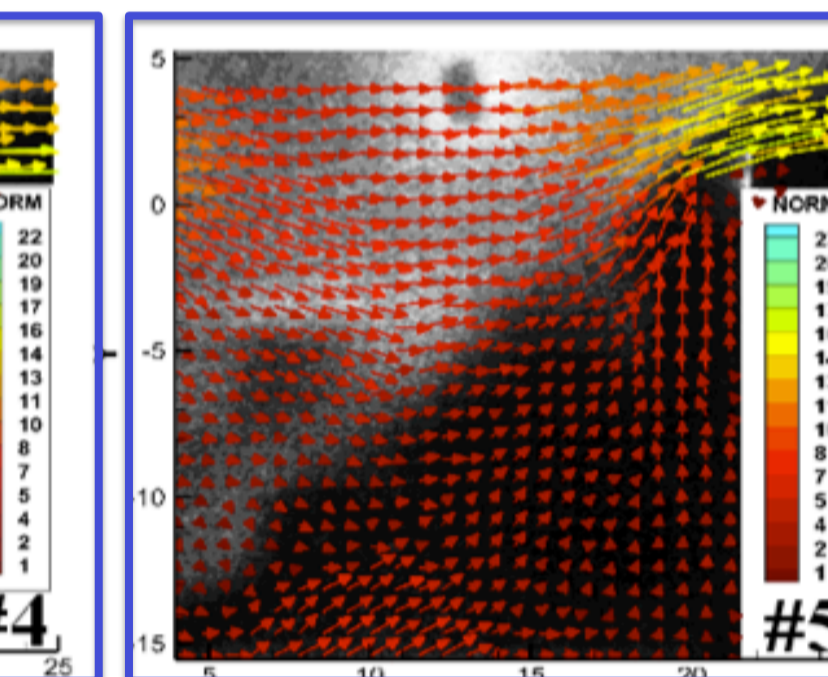
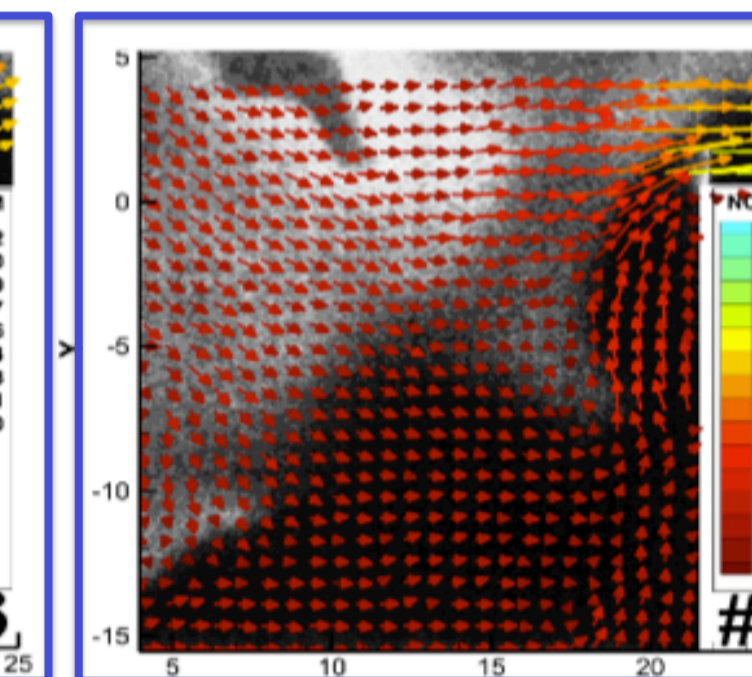
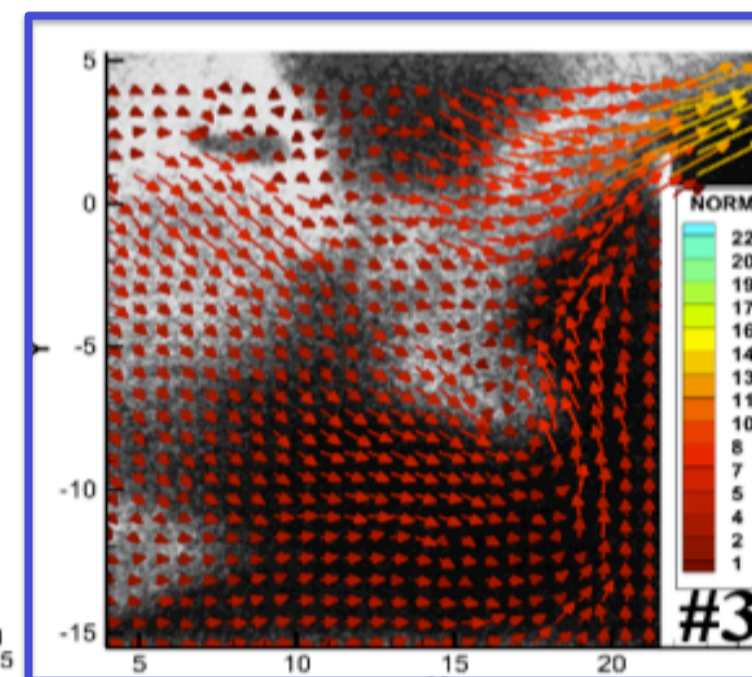
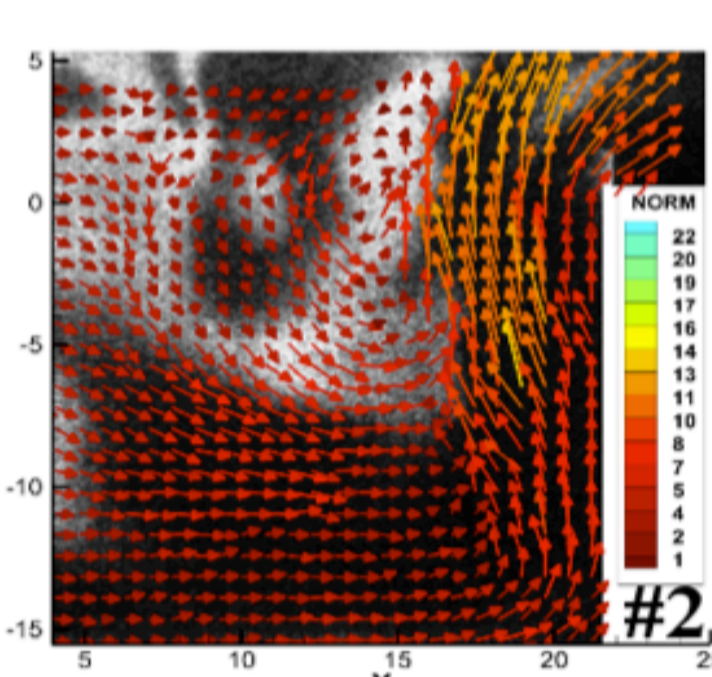
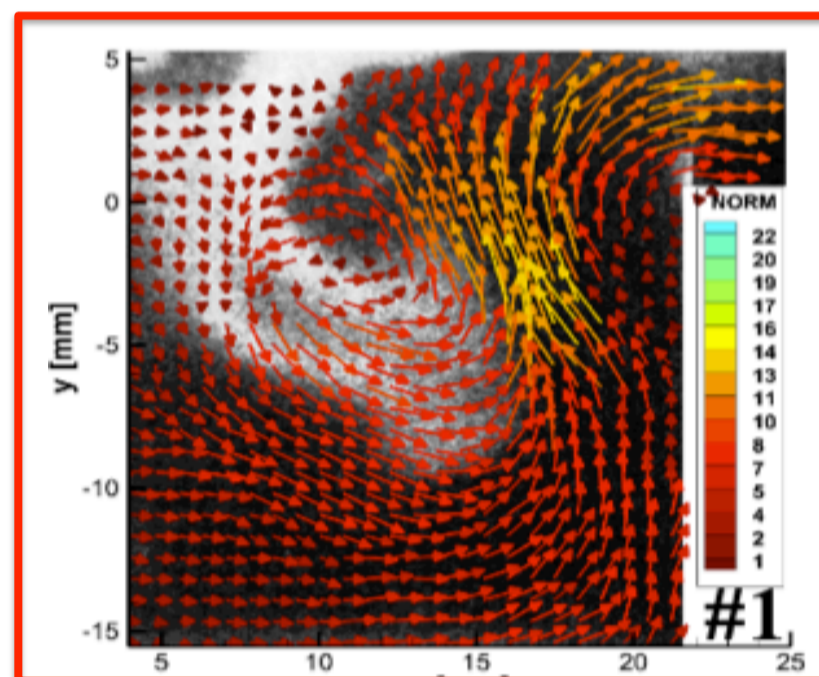
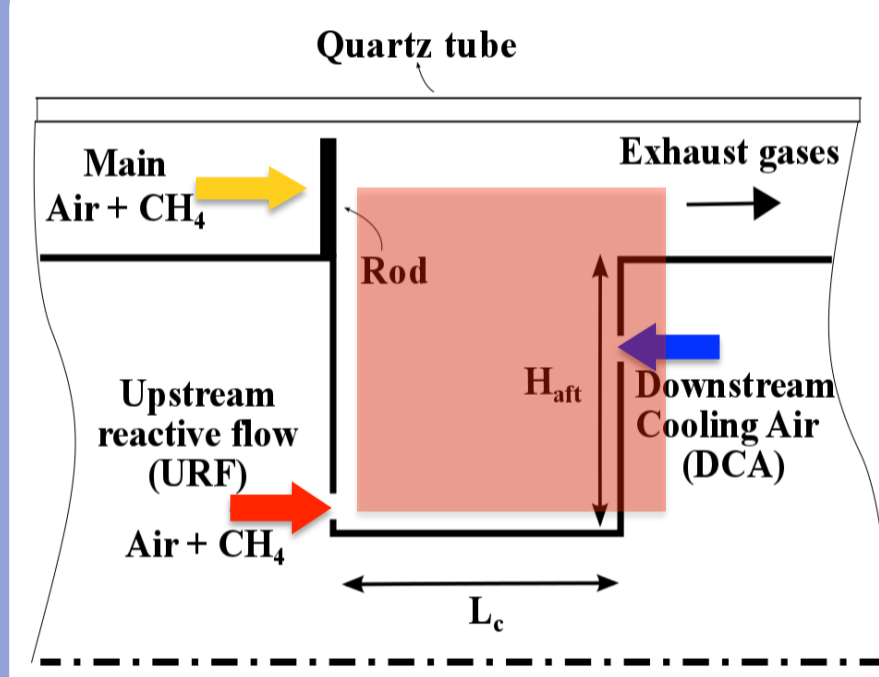
Dynamic pressure sensor Kistler 7061B

### High-speed OH-PLIF @ 10kHz

- Pump laser: 100W 527nm Edge Wave @ 10kHz
- Tunable dye laser Sirah CREDO operating with Rhodamine 6G
- Collection system: Photron Fastcam SA1.1, IRO intensifier, UV Halle lens f/2.8 100mm
- Output energy: 420  $\mu\text{J}$  / shot @ 10kHz

Photo Multiplier Tube Hamamatsu 6780-20 +  $\text{CH}^*$  filter

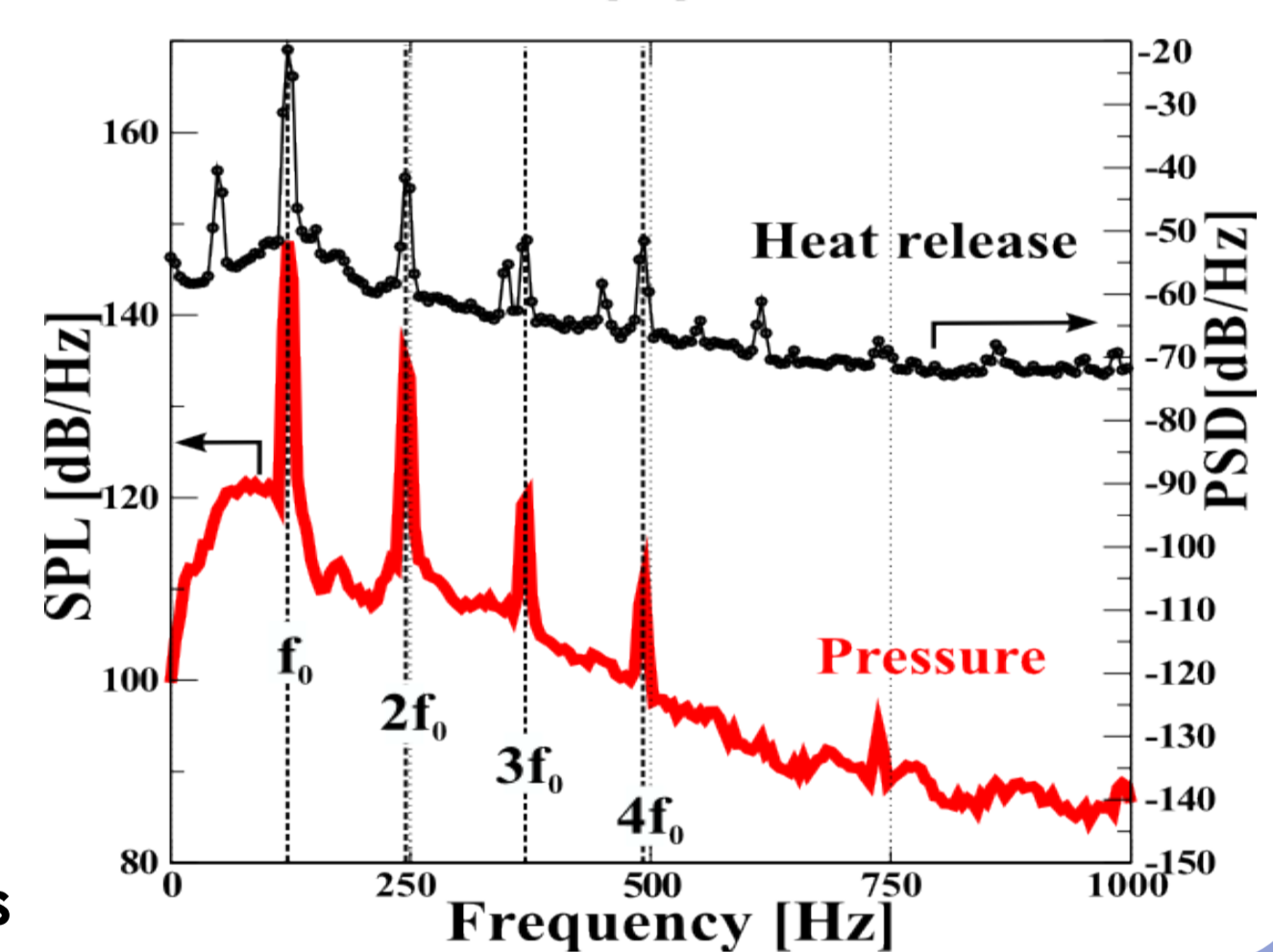
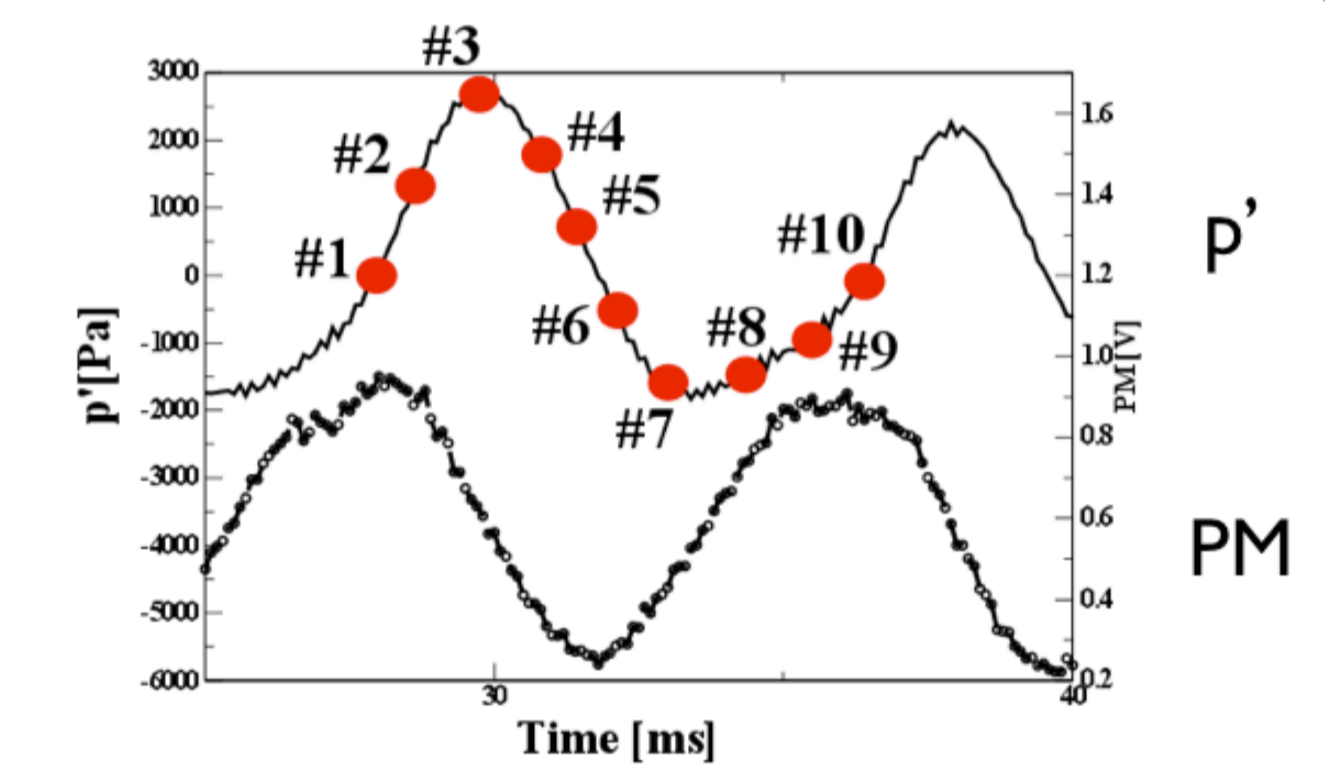
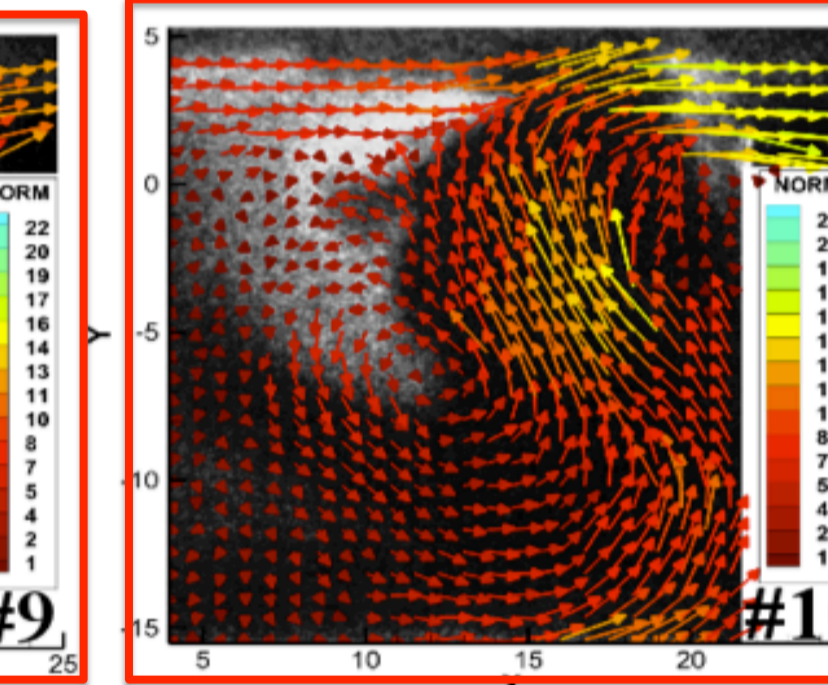
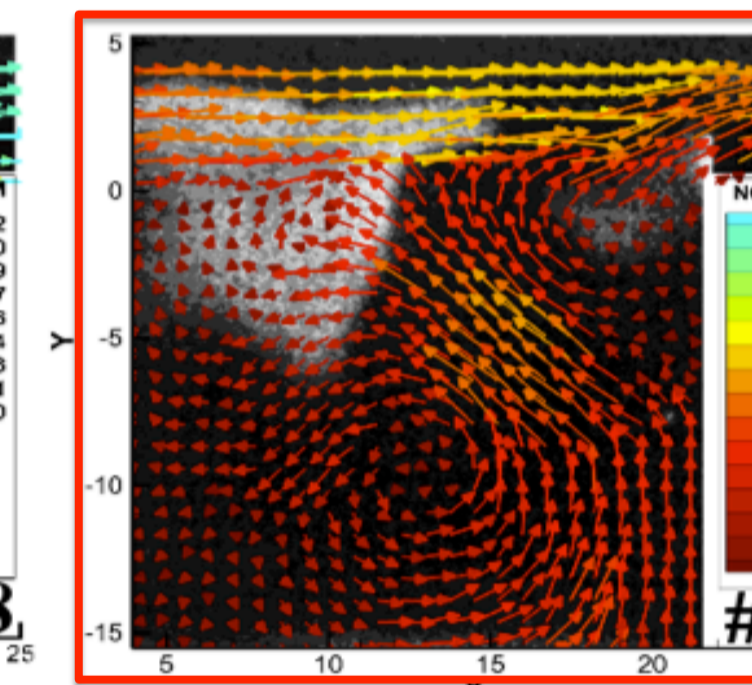
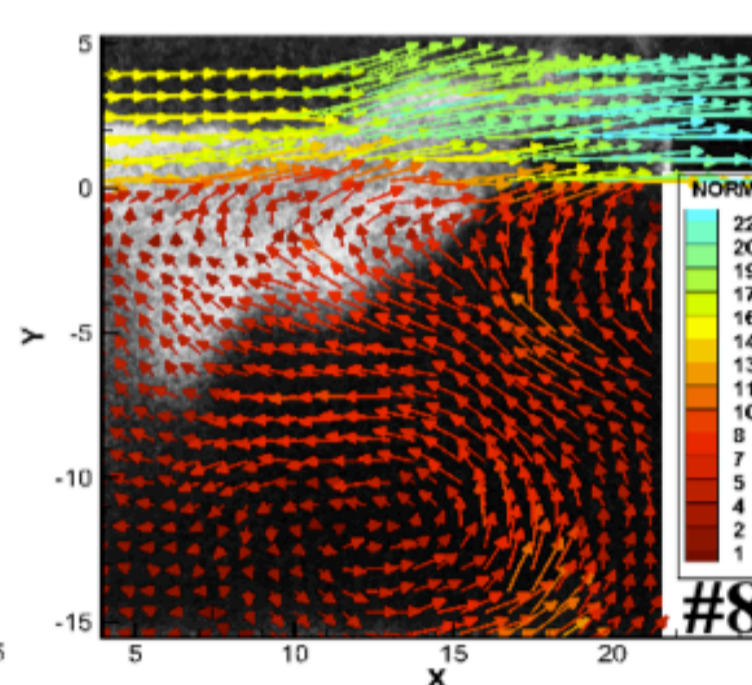
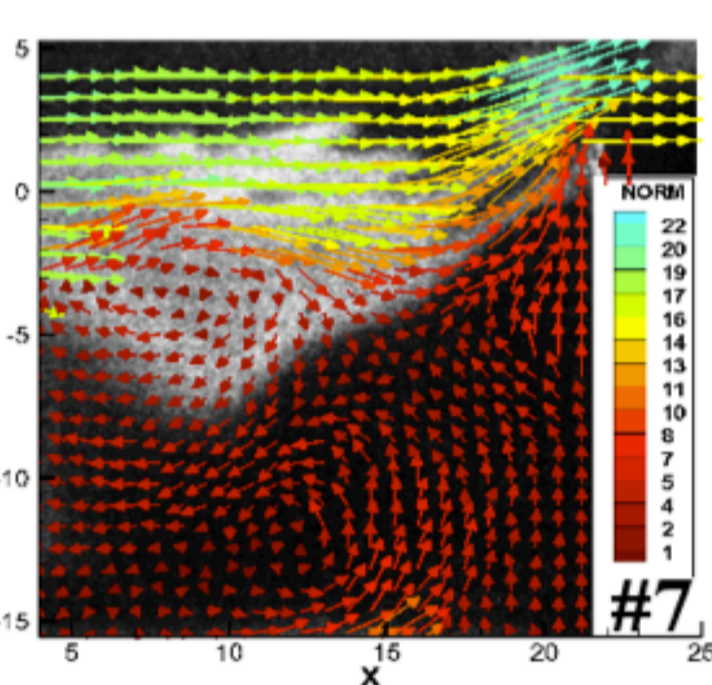
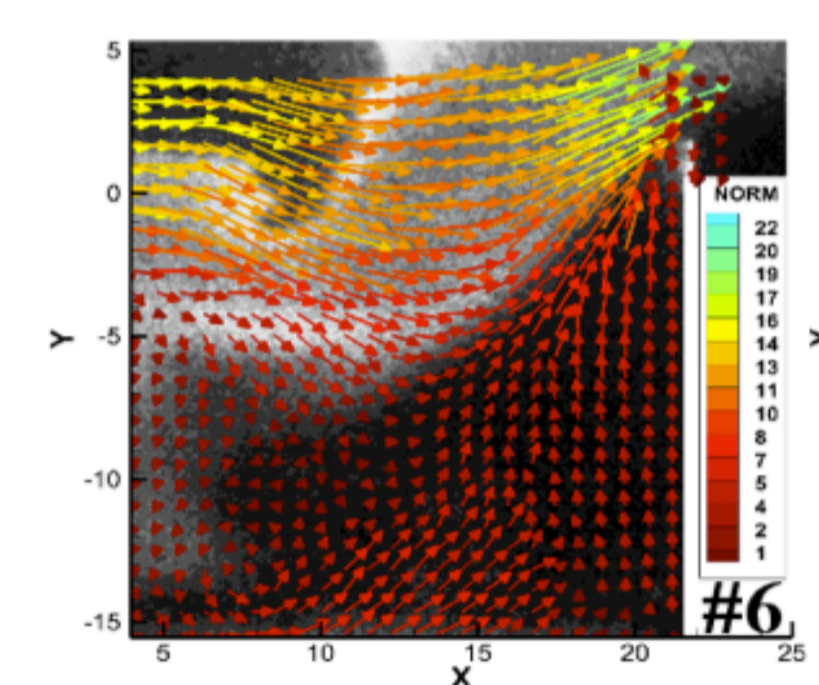
## Combustion instability cycle



#1,9,10: strong flow ejection from the cavity to the mainstream  
→ **important interaction between the cavity & the main channel**

#3,4,5: No flow topology in the combustor  
→ **pressure effects on the injection systems**

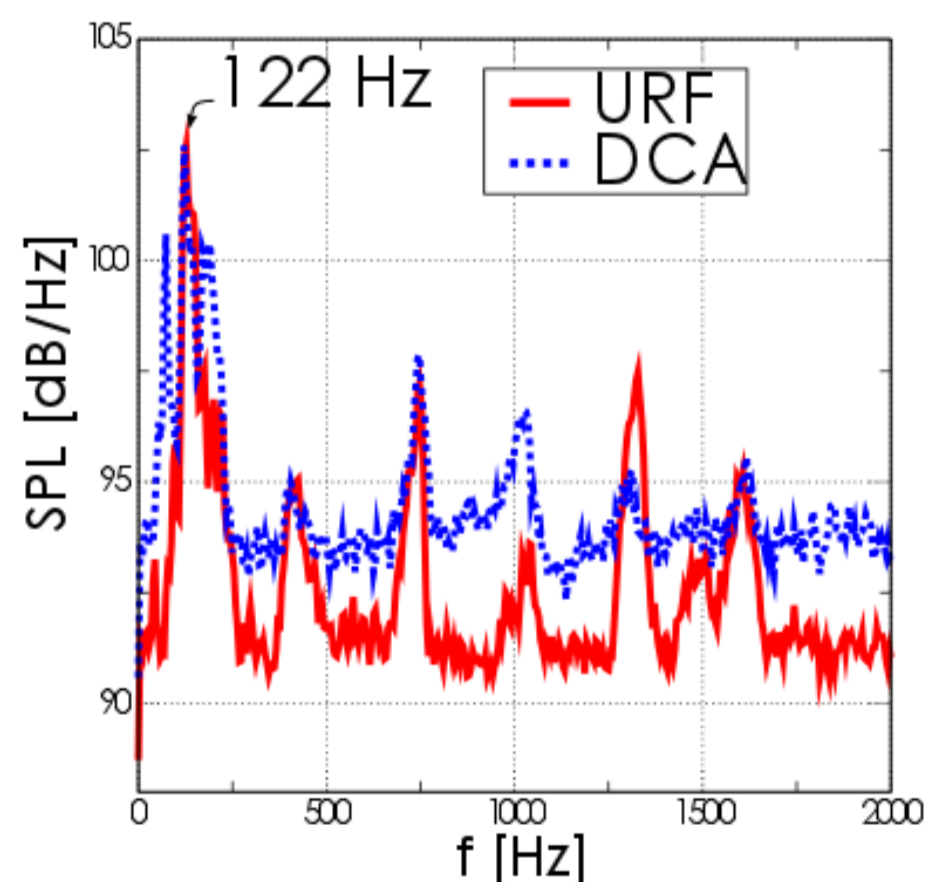
#7,8: vortices in the cavity, burned gases in the shear layer  
→ « **ideal flow topology** »



Pressure spectrum shows several spikes: 122 Hz, 244Hz, ...  
→ **Periodic motion with nonlinearities**

## Burner acoustics

### Impulse response test



Cavity feeding lines subject to an important acoustic activity  
→ **Pressure blockage leads to a flow-rate oscillations**

### Analytical model

- 1D model (planar waves)
- choked-plenum conditions

Set of resonant frequencies:

$$f_n = (2n + 1)\bar{c}/4L$$

The experimental frequency is retrieved for:

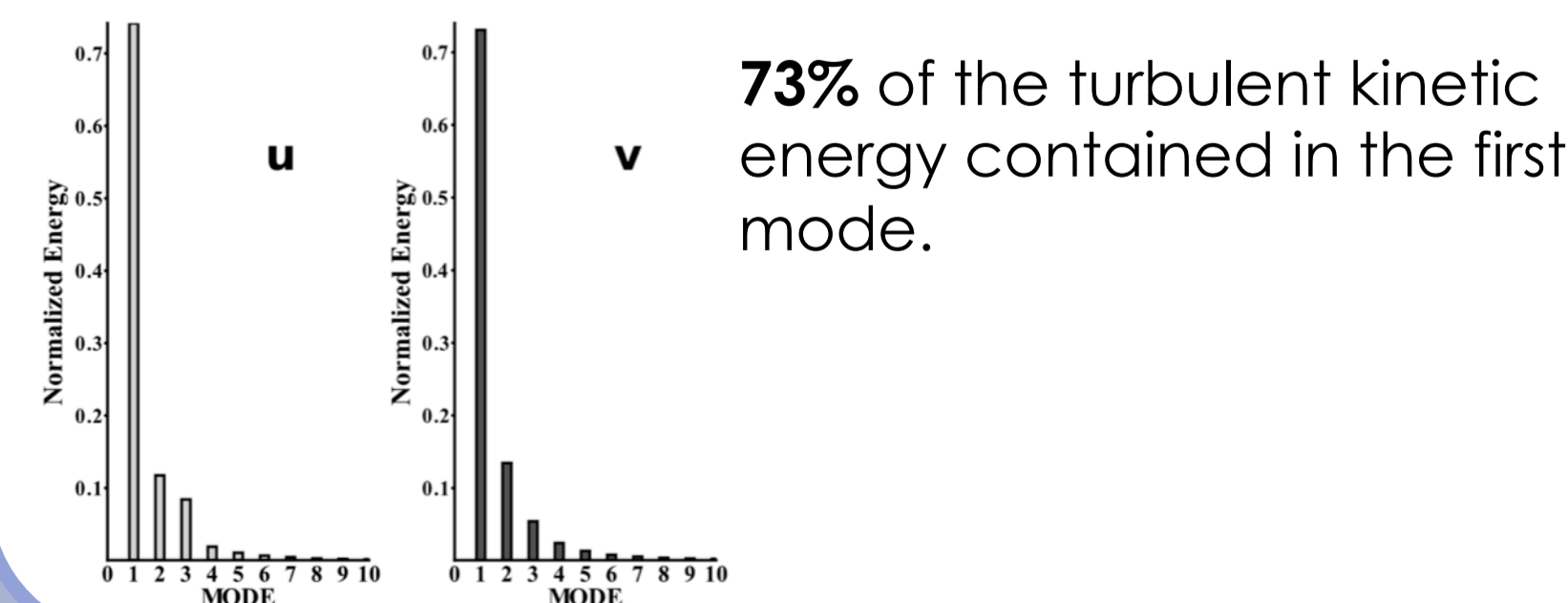
$$f_5 = 119\text{ Hz}$$

## Flow Dynamics

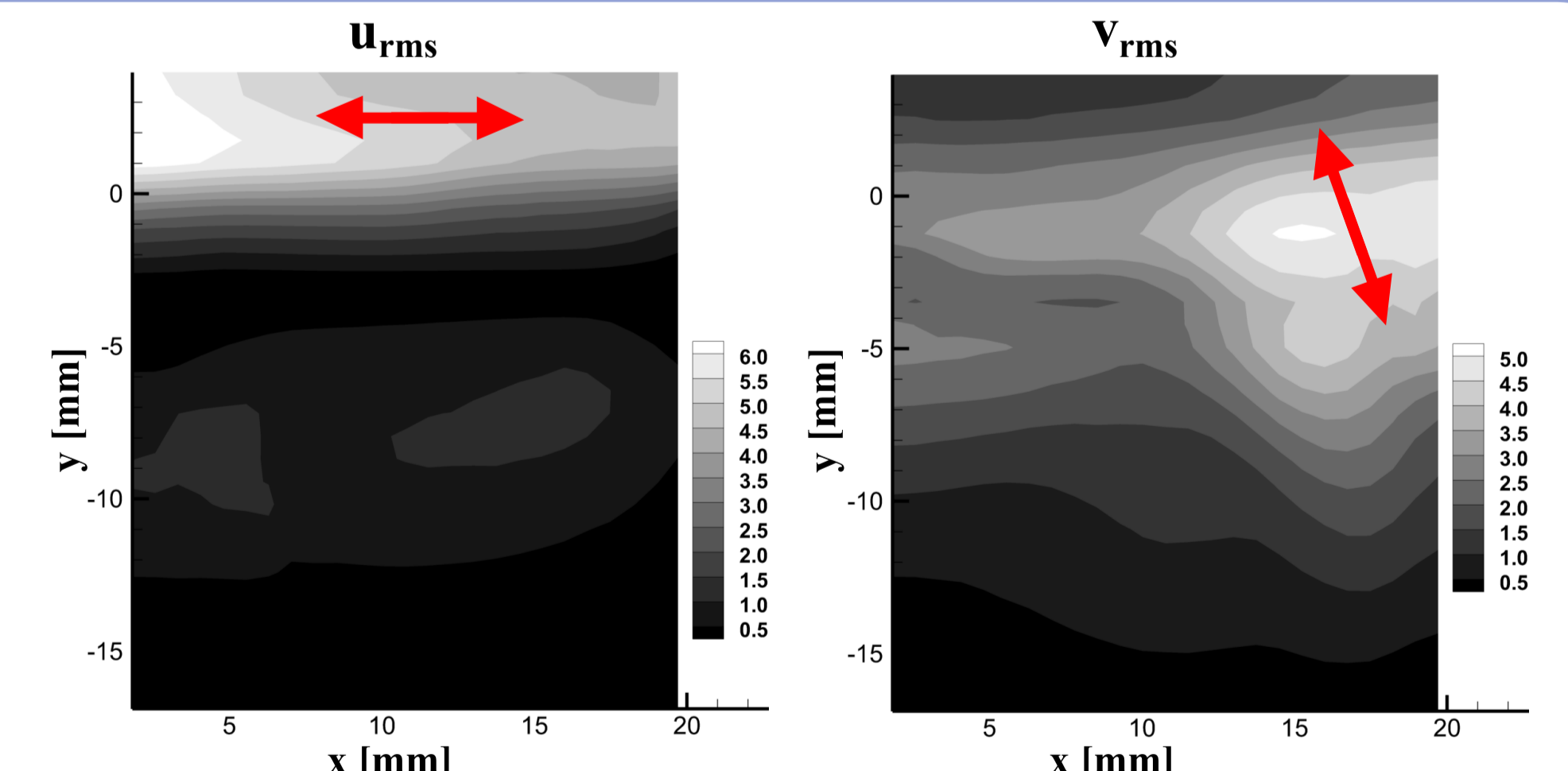
Effects of pressure fluctuations on the flow unsteadiness (i.e., coherent structures).

Proper orthogonal decomposition (POD)[4]:

$$\mathbf{u} = [u(t), v(t)] \approx \sum_{k=1}^K a_k(t) \Phi_k(\mathbf{x})$$



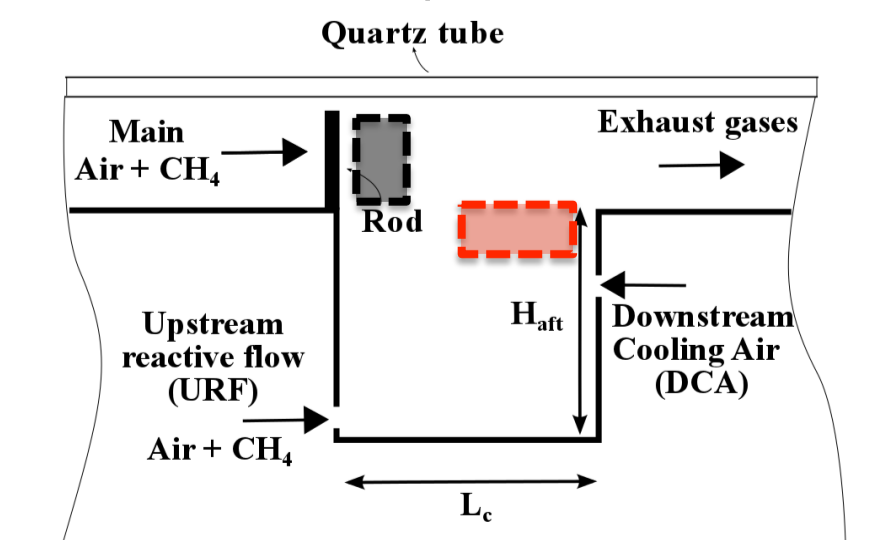
73% of the turbulent kinetic energy contained in the first mode.



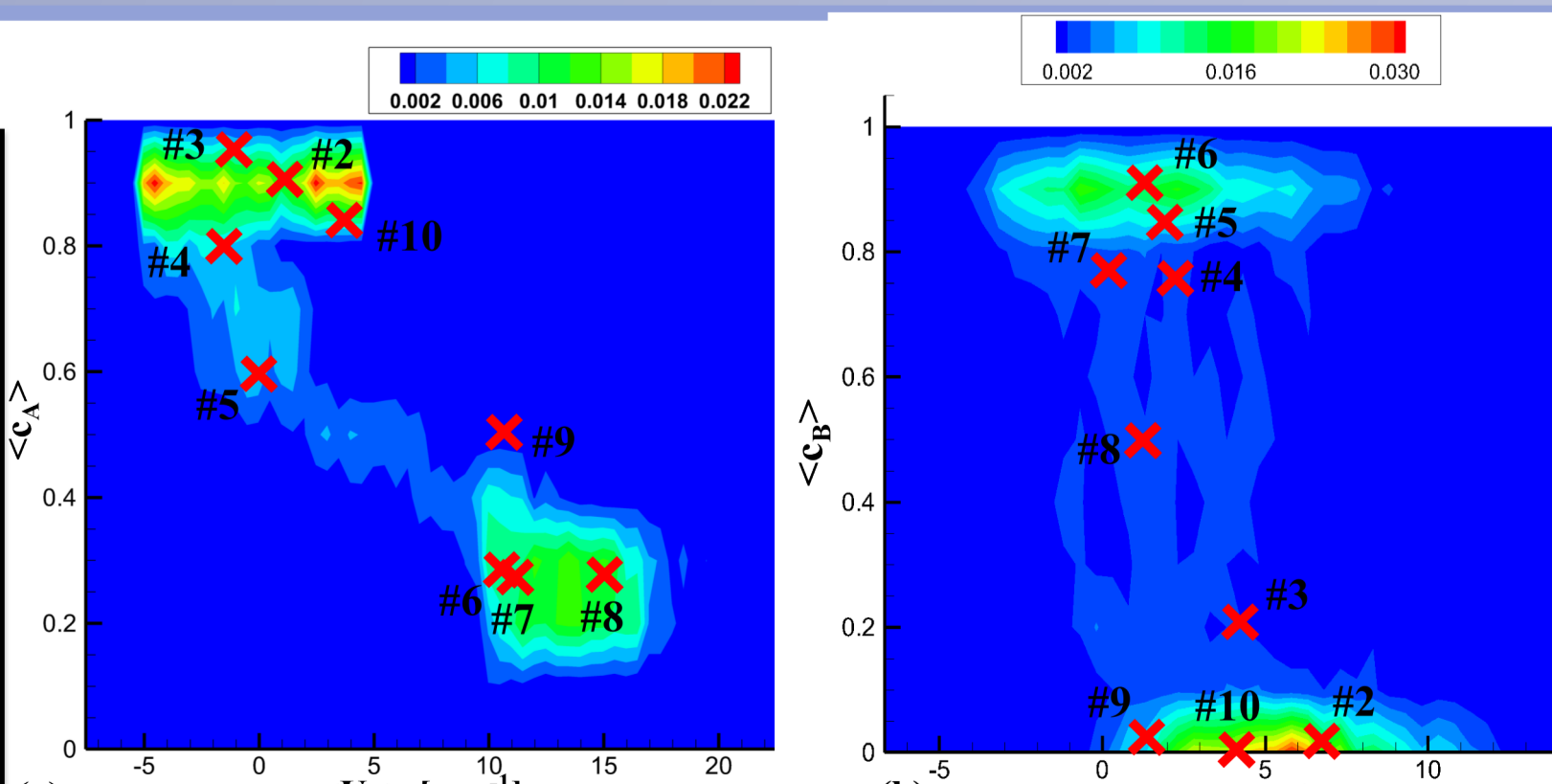
- large fluctuations in the mainstream ad next to the cavity trailing edge.
- Strong interactions leads to important flow oscillations

## Combustion Dynamics

Effects of pressure and flow fluctuations on the combustion process



Statistical joint analysis (pdfs) with 1) flow (velocities) and 2) combustion (variable progress  $\mathbf{c}$ )



Bimodal distribution

opposite combustion and aerodynamics

Alternation between these two spikes

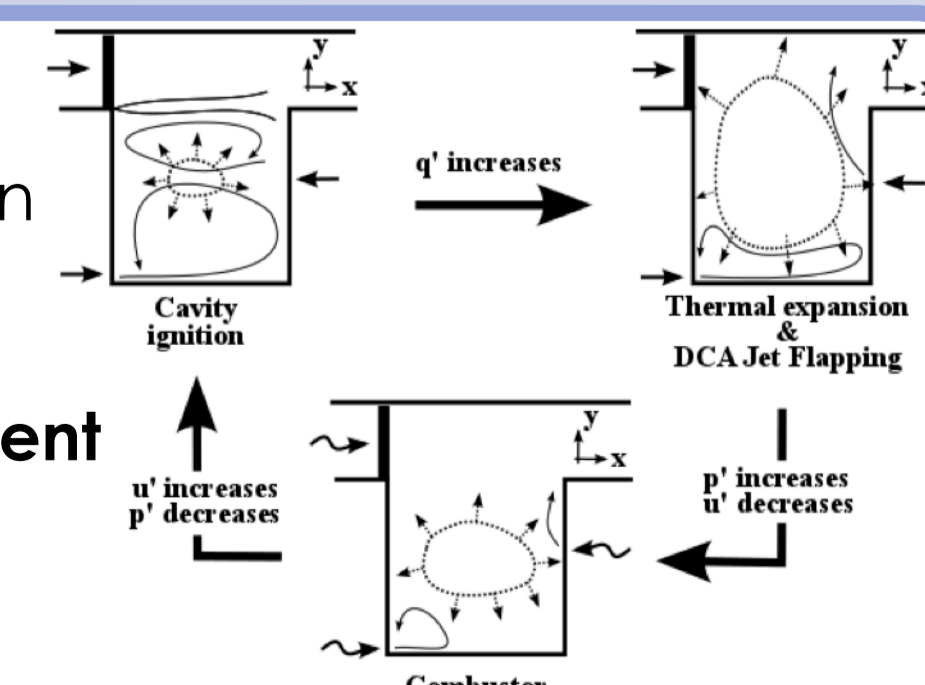
Pulsed combustion regime

→ **No possibilities to obtain efficient mass transfers and stabilize a flame**

## Conclusions

Scenario of combustion instabilities in a TVC.

**Injection strategy + cavity confinement** need to be optimized in order to obtain a stable combustion



## References

- [1] Hsu et al., JPP (14), 1998
- [2] Roquemore et al., AIAA (0483), 2001
- [3] Burguburu et al., Proc. ASME (68451), 2012
- [4] Lumley et al., Atmospheric turbulence and radio wave propagation, 1967