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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 **anormal operating conditions** (combustion instabilities)

Goals of this work:

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

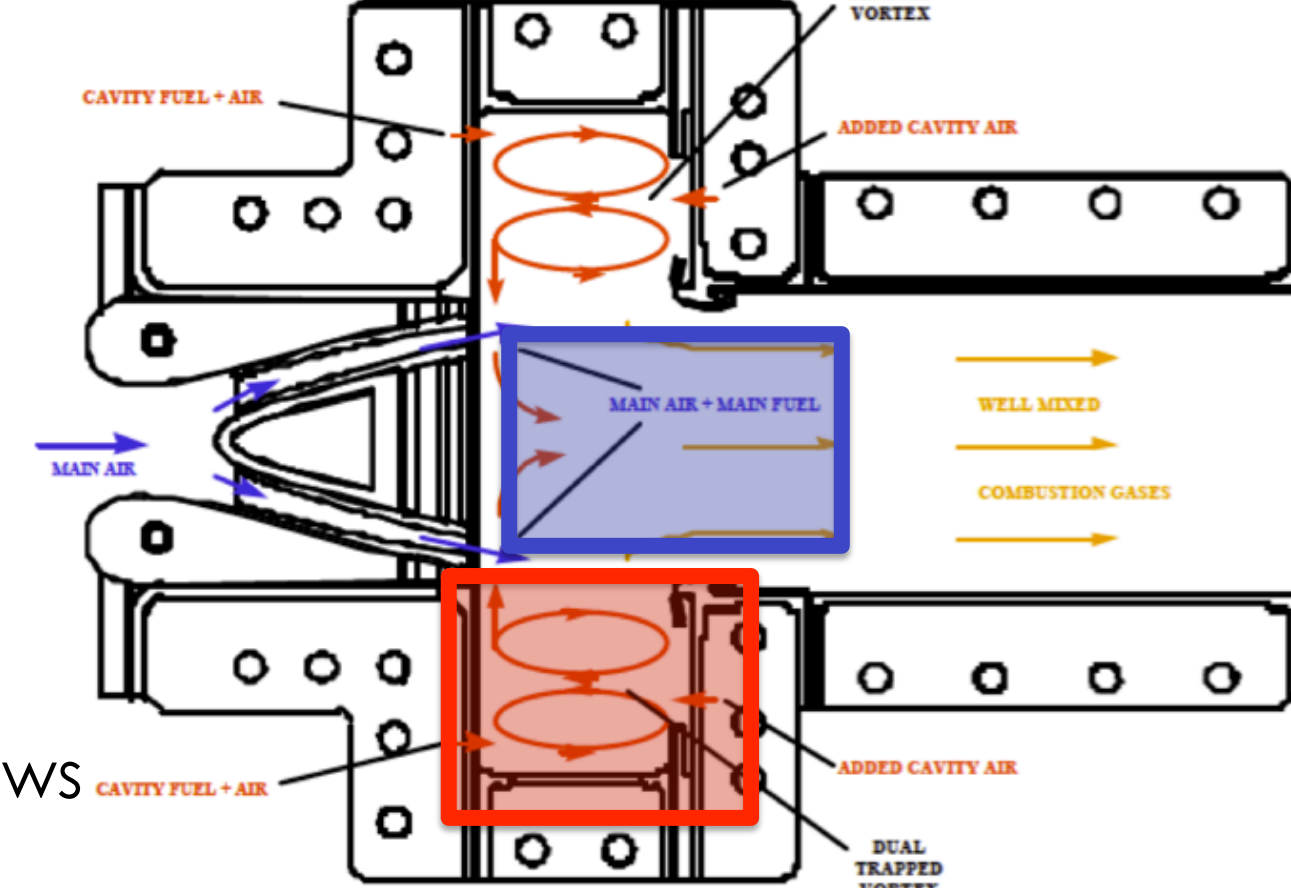
TVC concept

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

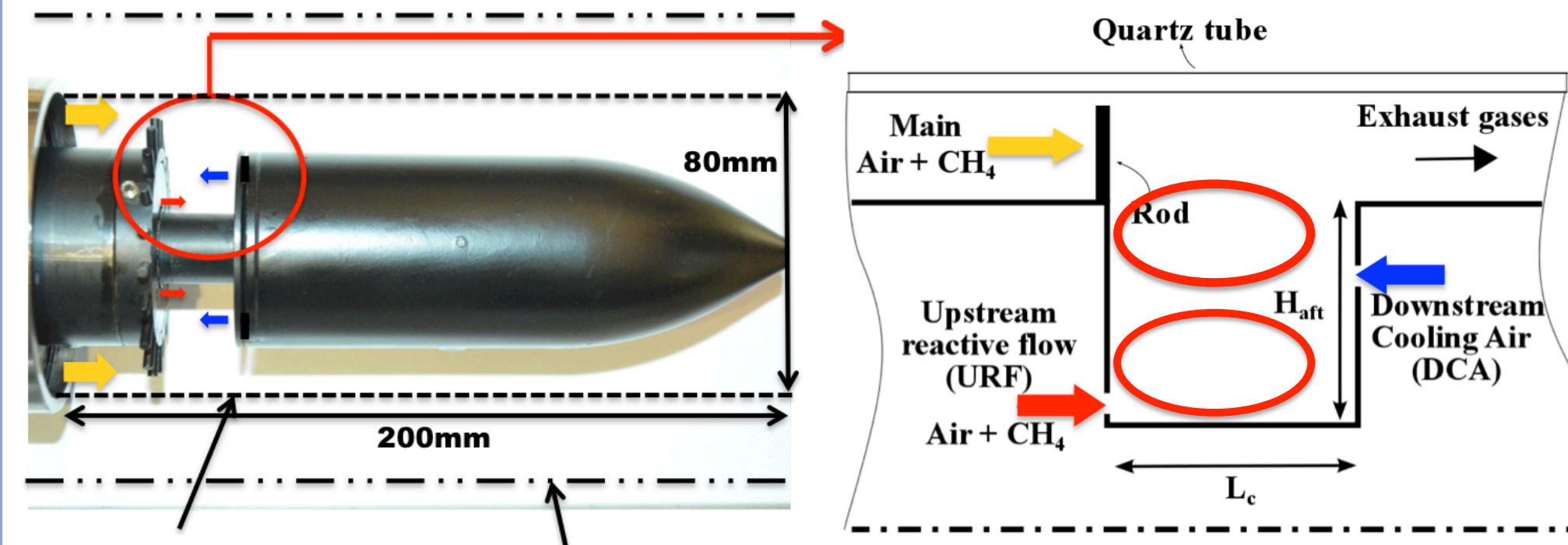
Cavity based flame-holder

Ignition and stabilization of
a lean-fuel flow

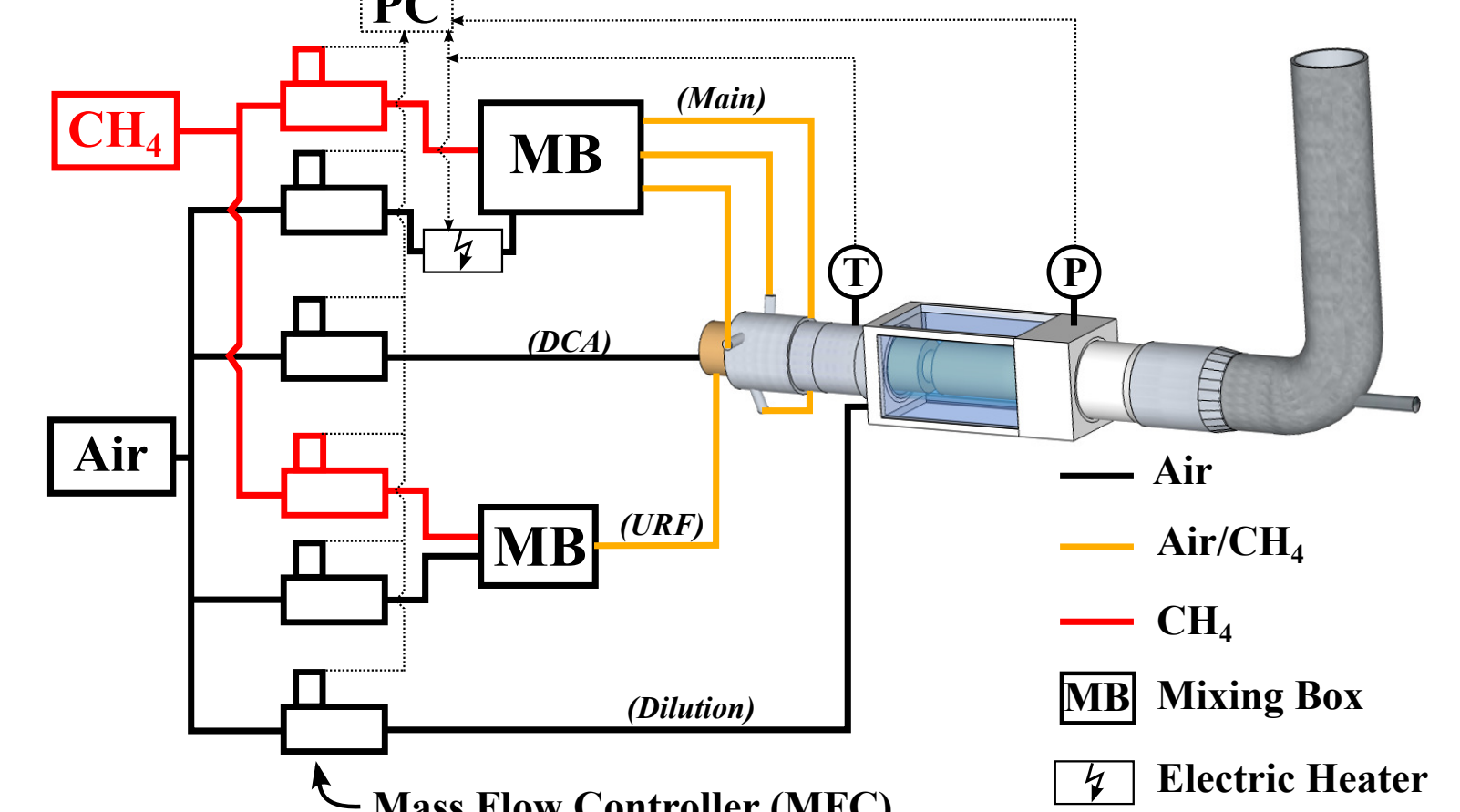
- Pilot region confinement
- High-speed mainstream flows
- Low-NOx technology
- Flexible (RQL, staged)



TVC burner and experimental setup



- Annular geometry with full optical access
- Fueled with CH₄
- Injection systems: slots
- Acoustic conditions: choked



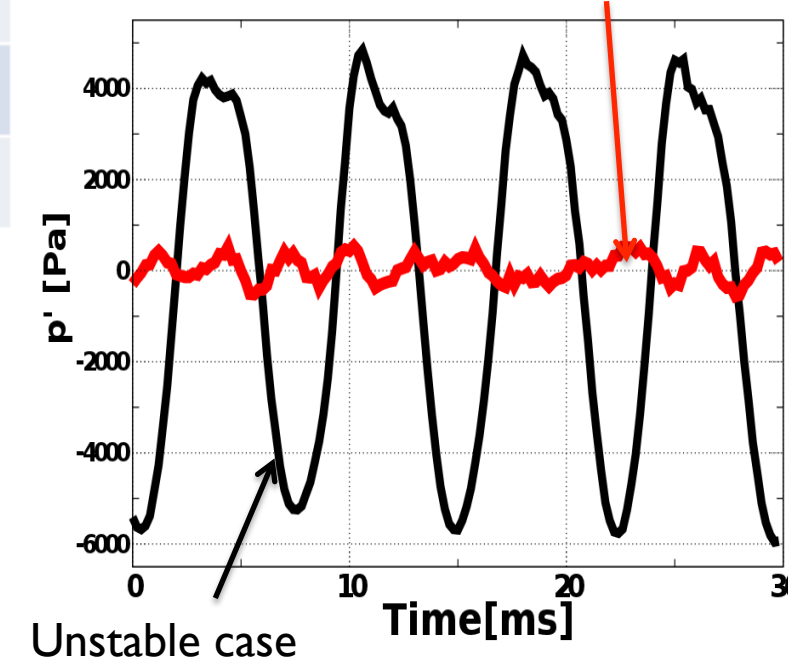
- 6 independant mass flow controllers
- Premixed feeding lines

Operating conditions [3]

Region	Air	Fuel	Φ
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		

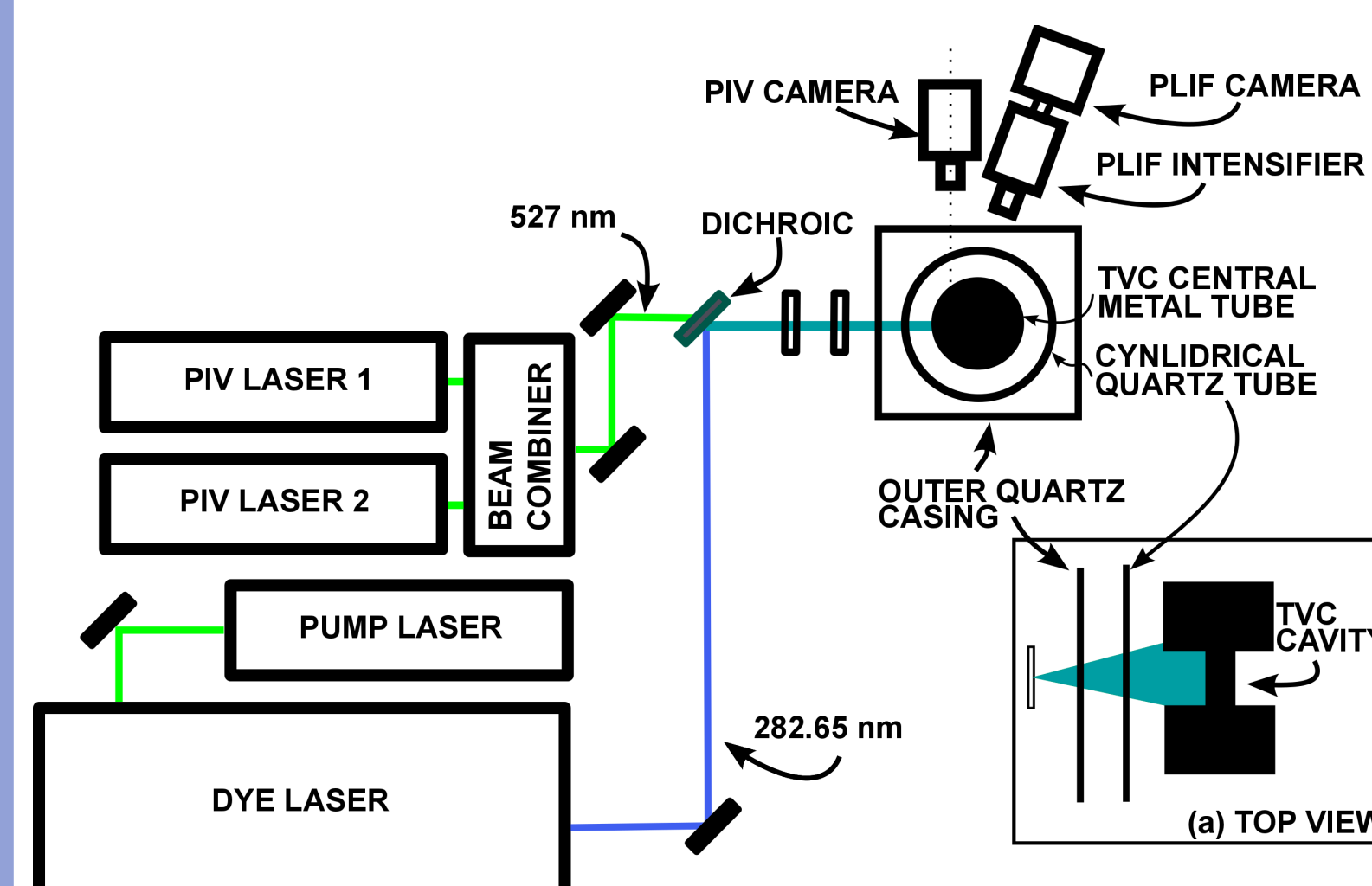
$\Phi_{glob} = 0.83$
 $P_{glob} = 60kW$
 $P_{ch} = 1.7 \text{ bar}$

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 ZrO₂ seeding for each injection w/ fluidized beds

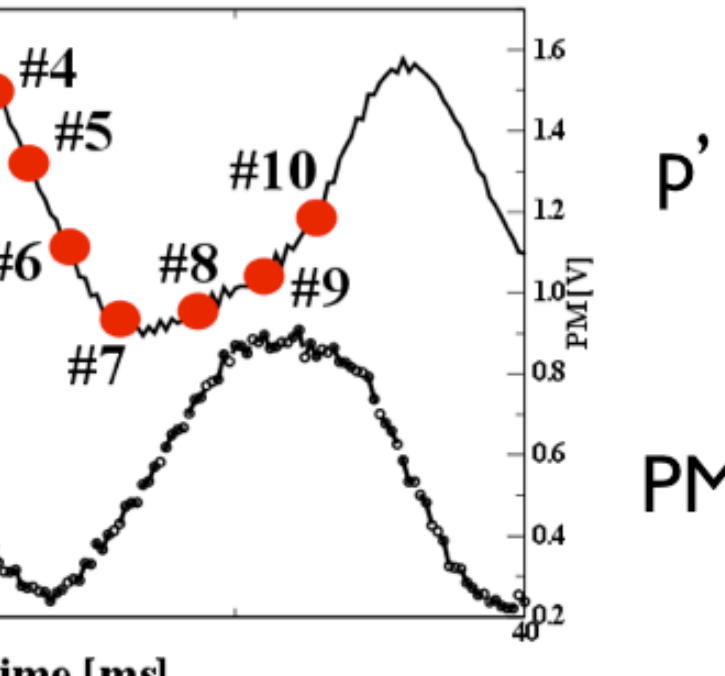
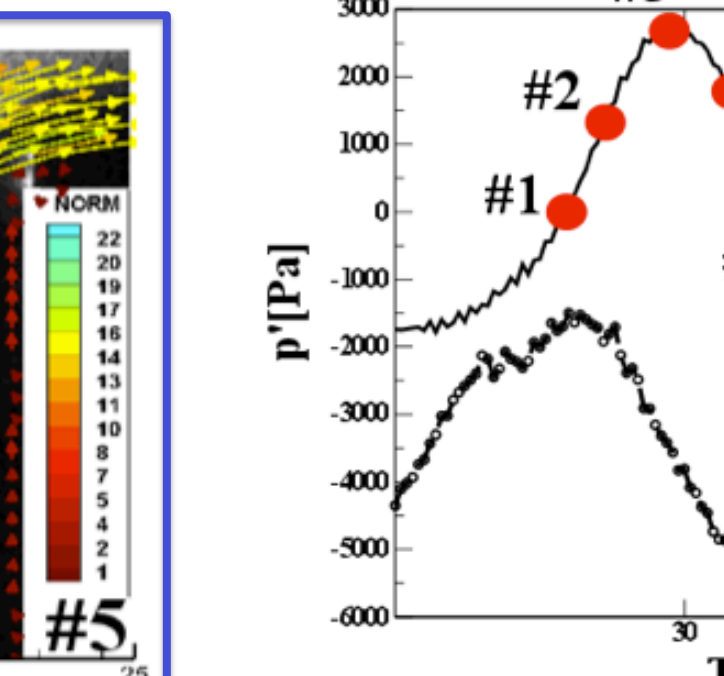
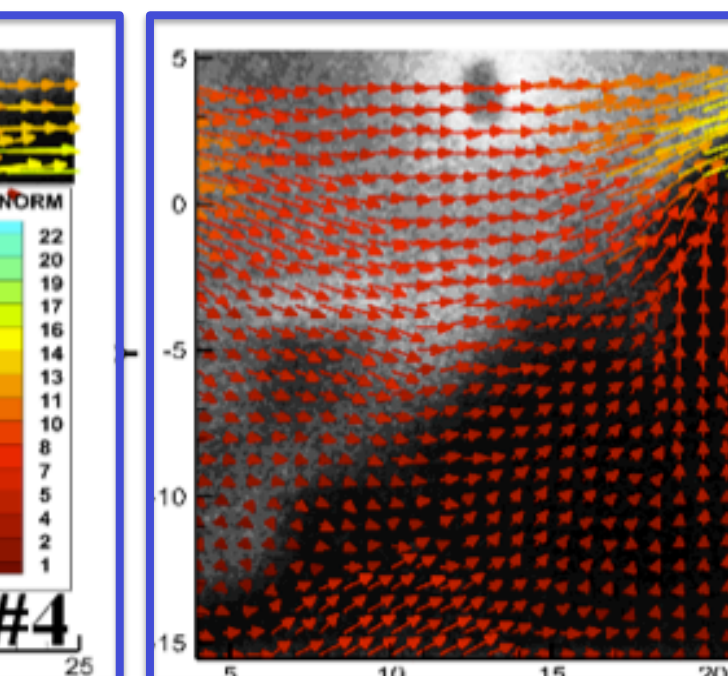
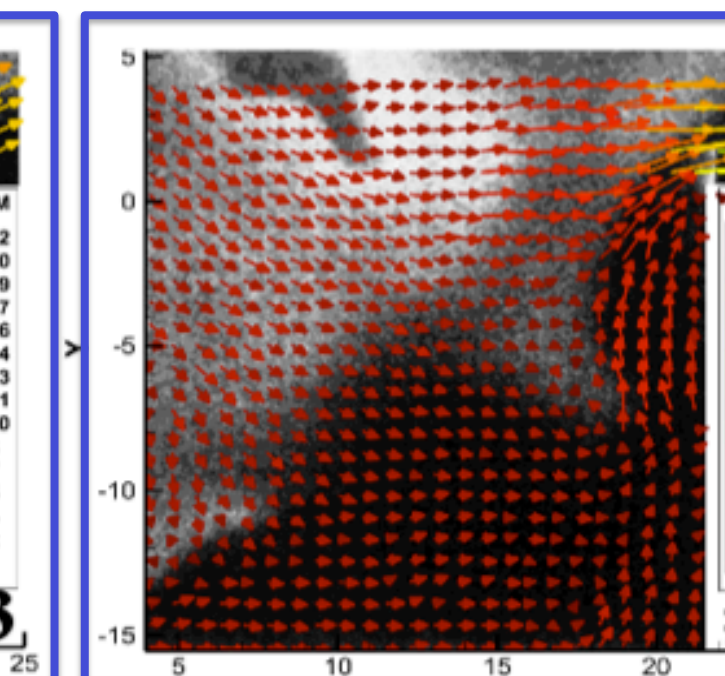
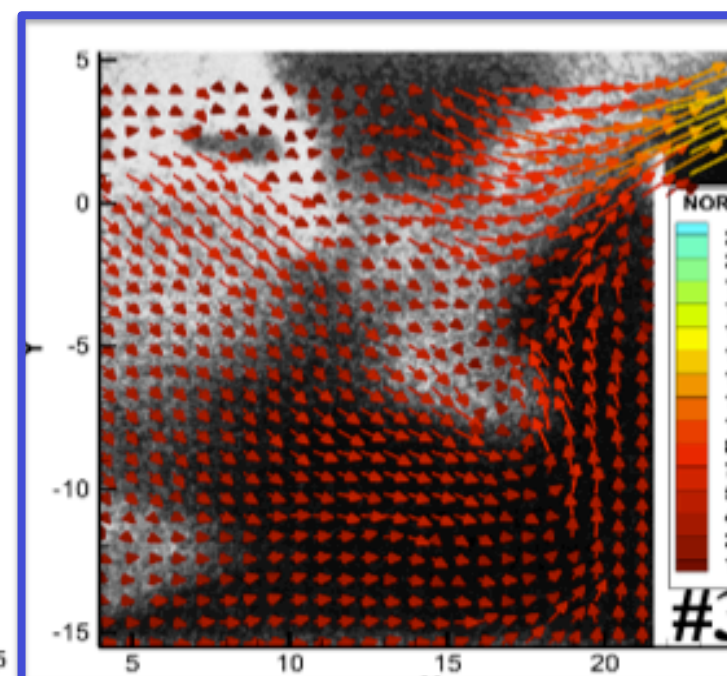
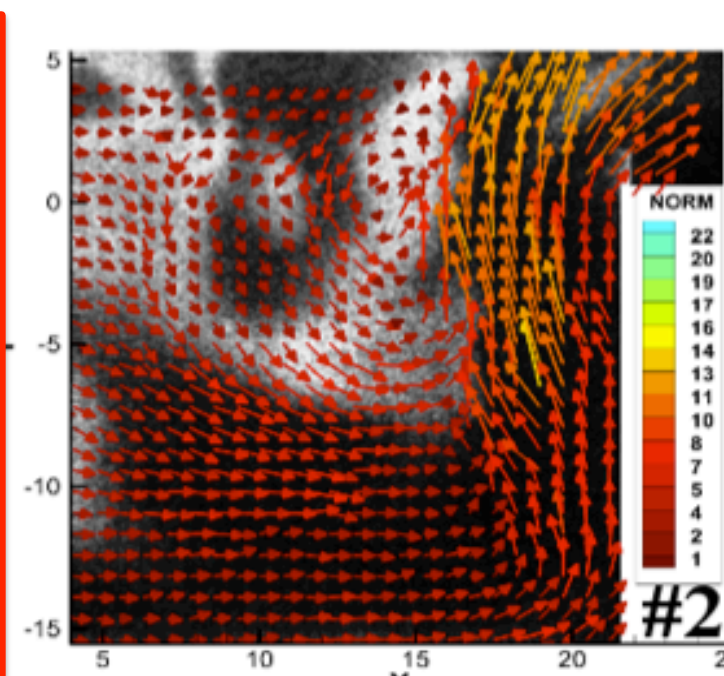
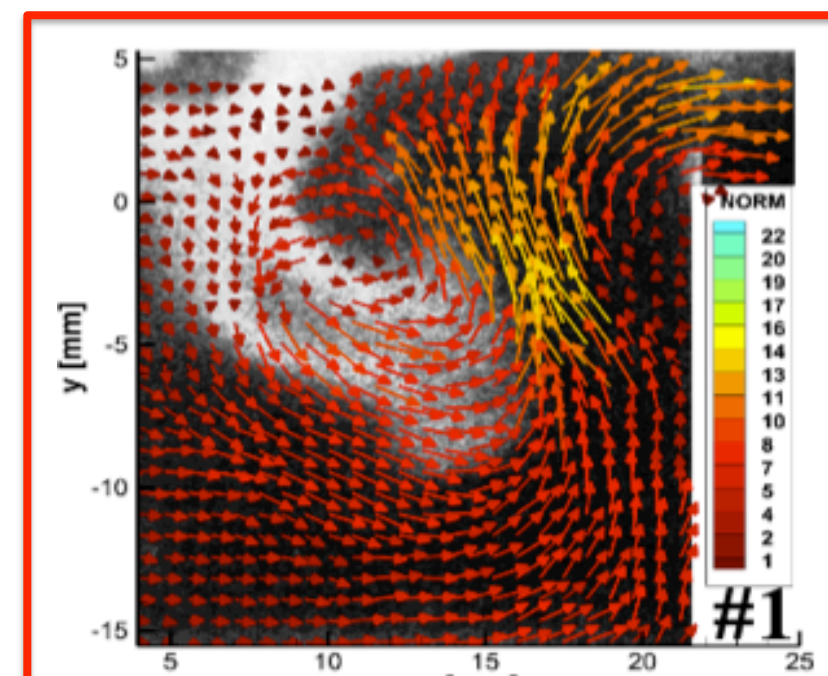
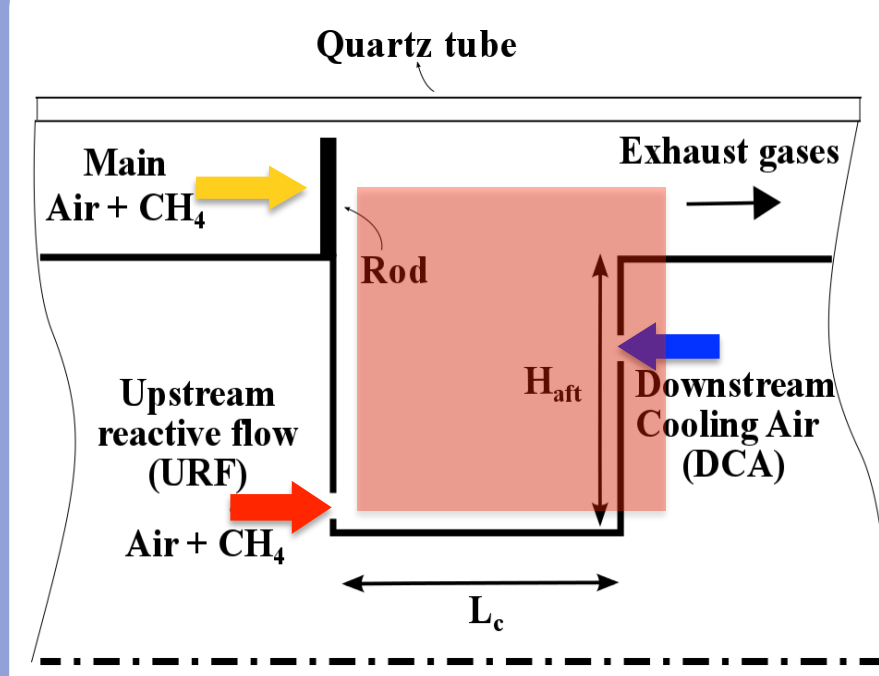
Dynamic pressure sensor Kistler 7061B

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 μJ / shot @ 10kHz

Photo Multiplier Tube Hamamatsu 6780-20 + 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**

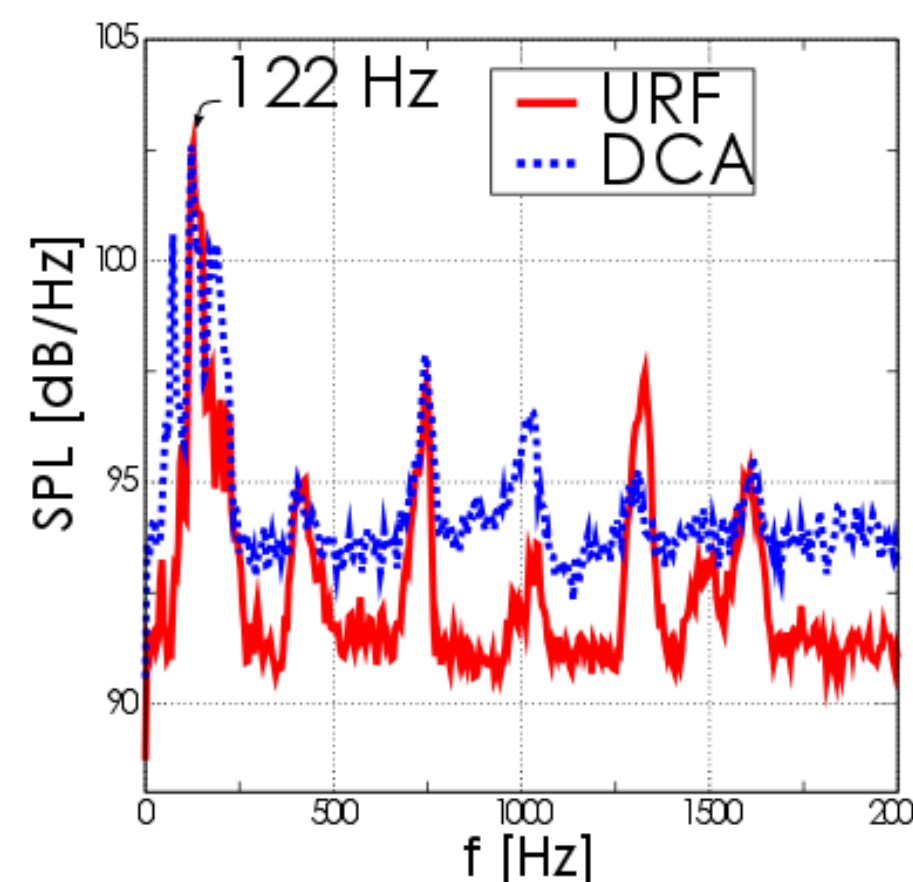
#3,4,5: No flow topology in the combustor
→ **pressure effects on the injection systems**

#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:

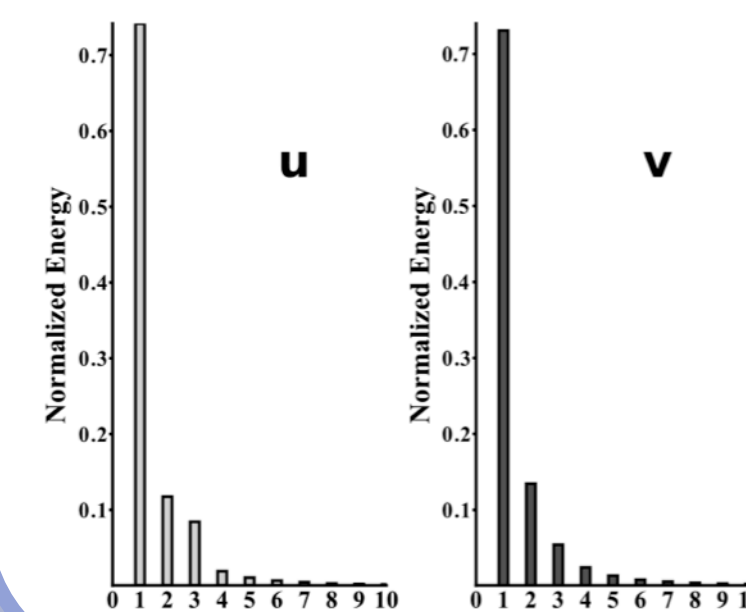
$$f_5 = 119Hz$$

Flow Dynamics

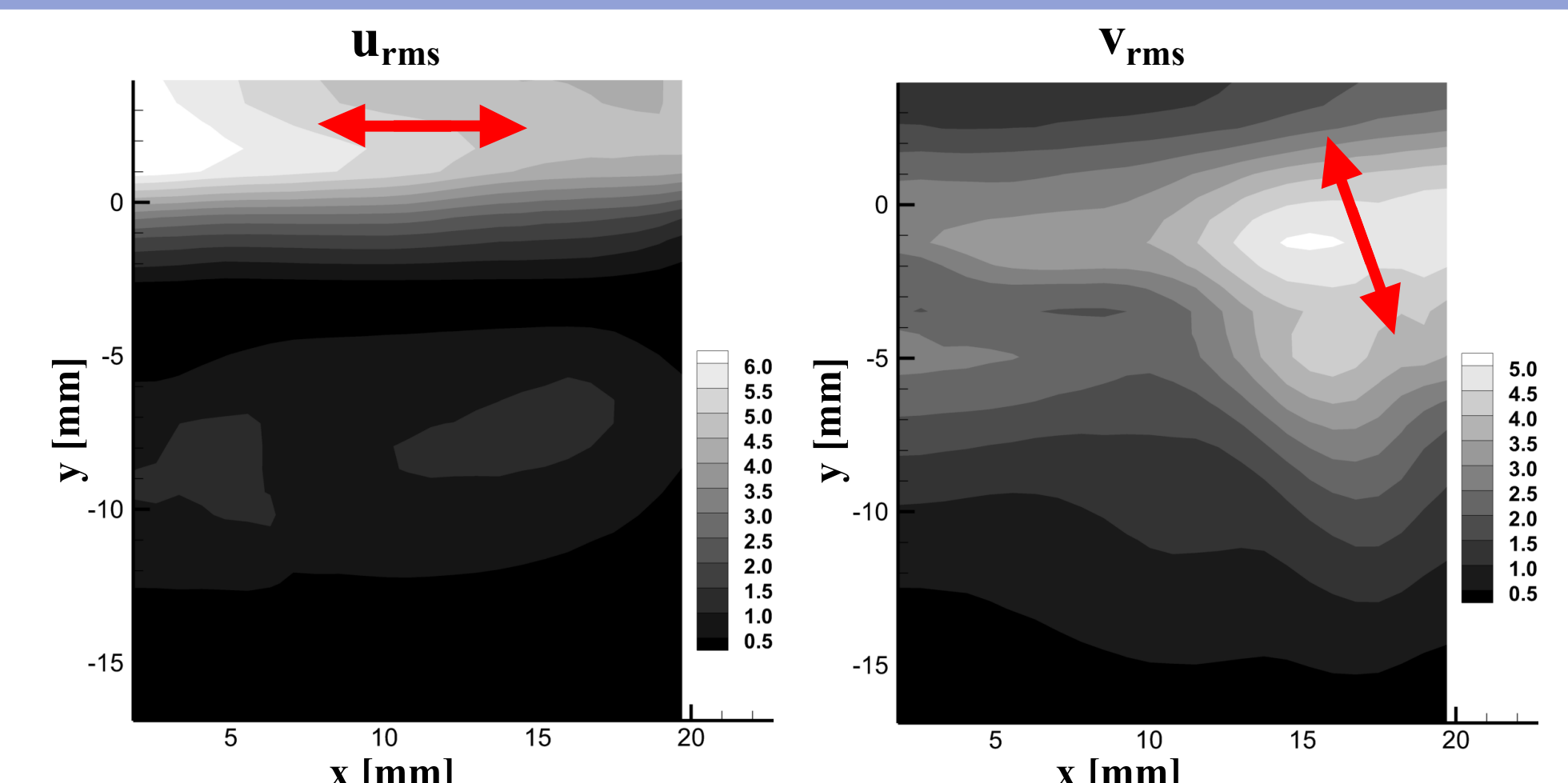
Effects of pressure fluctuations on the flow unsteadiness (i.e., coherent structures).

Proper orthogonal decomposition (POD)[4]:

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



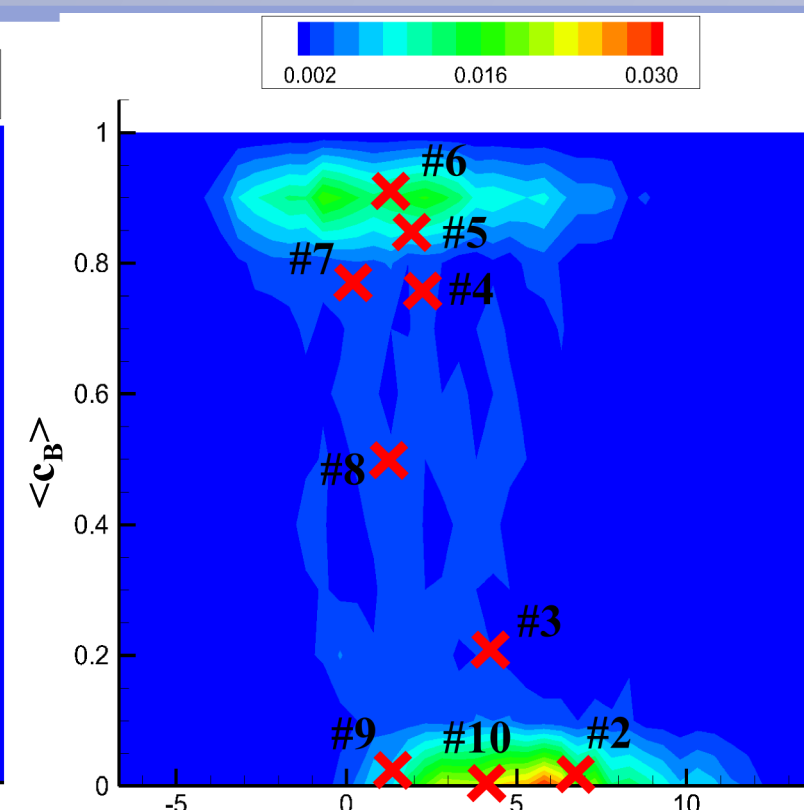
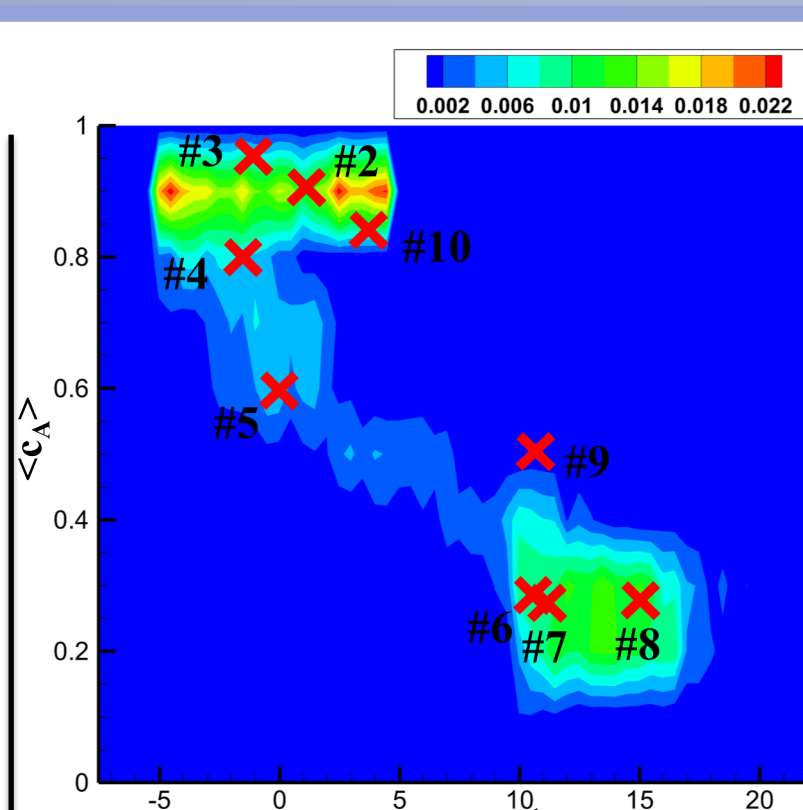
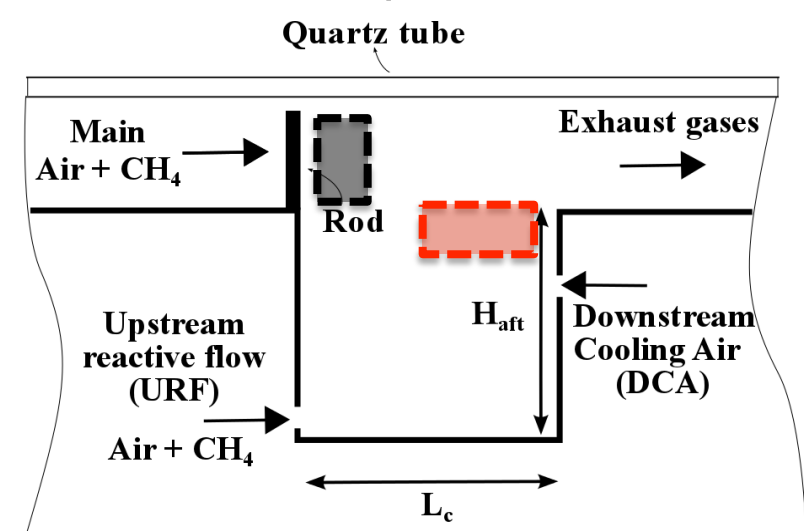
73% of the turbulent kinetic energy contained in the first mode.



- 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



Bimodal distribution
opposite combustion and aerodynamics
Alternation between these two spikes

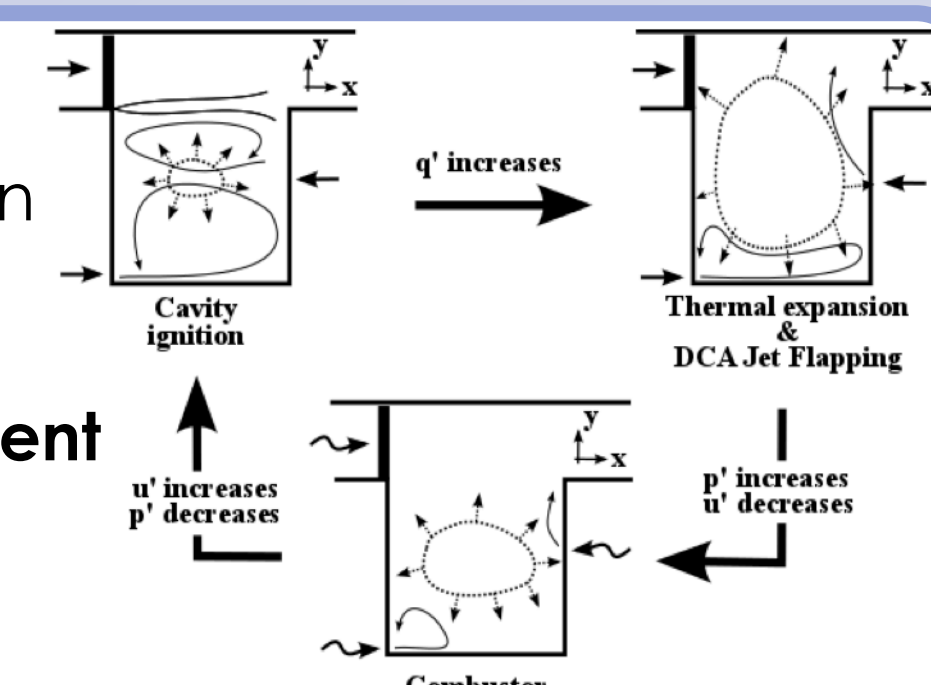
Pulsed combustion regime

→ **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] Roquemoire et al., AIAA (0483), 2001
- [3] Burguburu et al., Proc. ASME (68451), 2012
- [4] Lumley et al., Atmospheric turbulence and radio wave propagation, 1967