Structure and Dynamics of Fuel Jets Injected into a High-Temperature Subsonic Crossflow: High- Data-Rate Laser Diagnostic Investigation under Steady and Oscillatory Conditions

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Outline of the Presentation

- Research Objectives
- Gas Turbine Combustion Facilities
- Laser Systems for High-Data-Rate Measurements: 5-10 kHz OH PLIF, 5-10 kHz PIV, 5-10 kHz CARS Measurements
- Planned Research
- Summary

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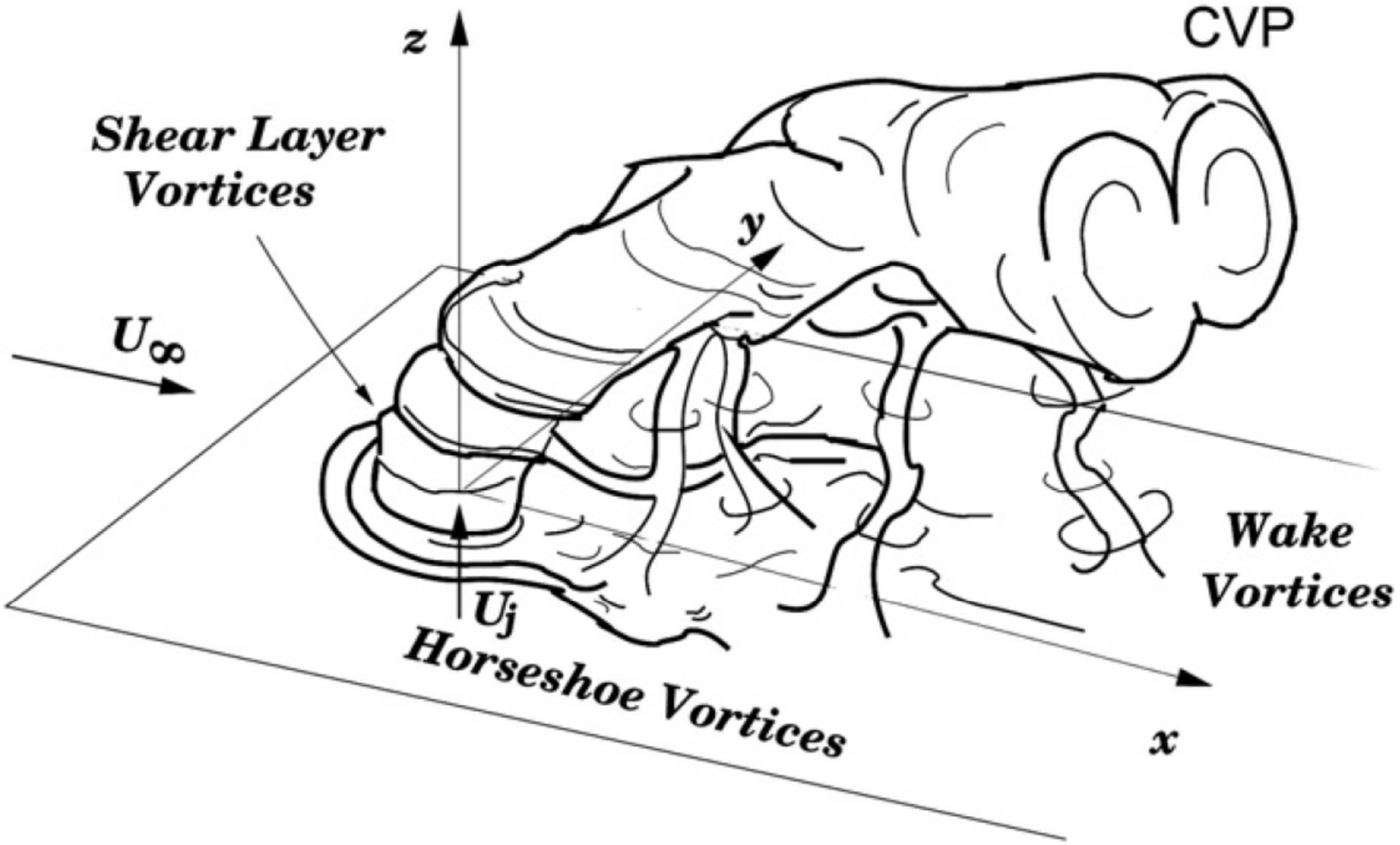
Research Objectives

- **Reacting Jet in Crossflow (RJIC) is a flow field that is of fundamental interest and practical importance.**
- **Primary objective is to investigate the structure and dynamics of reacting jet injected into a subsonic, high-pressure crossflow.**
- **High-pressure RJIC flow field will be investigated using advanced high-data-rate (5-10 kHz) laser diagnostic methods.**

Research Objectives

- Numerical simulation of the RJIC flow field is challenging but tractable. Development of benchmark quality data set for comparison with numerical models will be very valuable.
- Mixing and flameholding are issues of critical importance for understanding the generation of pollutant species as a result of the RJIC.
- Effect of the RJIC on combustion instabilities will also be investigated in the later stages of the project.

Research Objectives



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Research Tasks

- **Task 1: Finalization of Project Management Plan.**
- **Task 2: Modification and fabrication of test rig hardware.**
- **Task 3.1: Development of detailed test matrix for experiments. Jet parameters (fuel composition, momentum flux ratio, veloctiy ratio…), pressure, vitiated or non-vitiated co-flow.**

Research Tasks

- **Task 3.2: Development of techniques and apparatus for high-pressure, high-data-rate PIV measurements**
- **Task 3.3: High-data-rate PIV measurements.**
- **Task 4: High-data-rate OH PLIF measurements.**
- **Task 5: Simultaneous high-data-rate PIV and OH PLIF measurements.**

Research Tasks

- **Task 6: Measurements under conditions with significant combustion instabilities.**
- **Task 7: Development and demonstration of high-data-rate temperature measurements using femtosecond CARS..**

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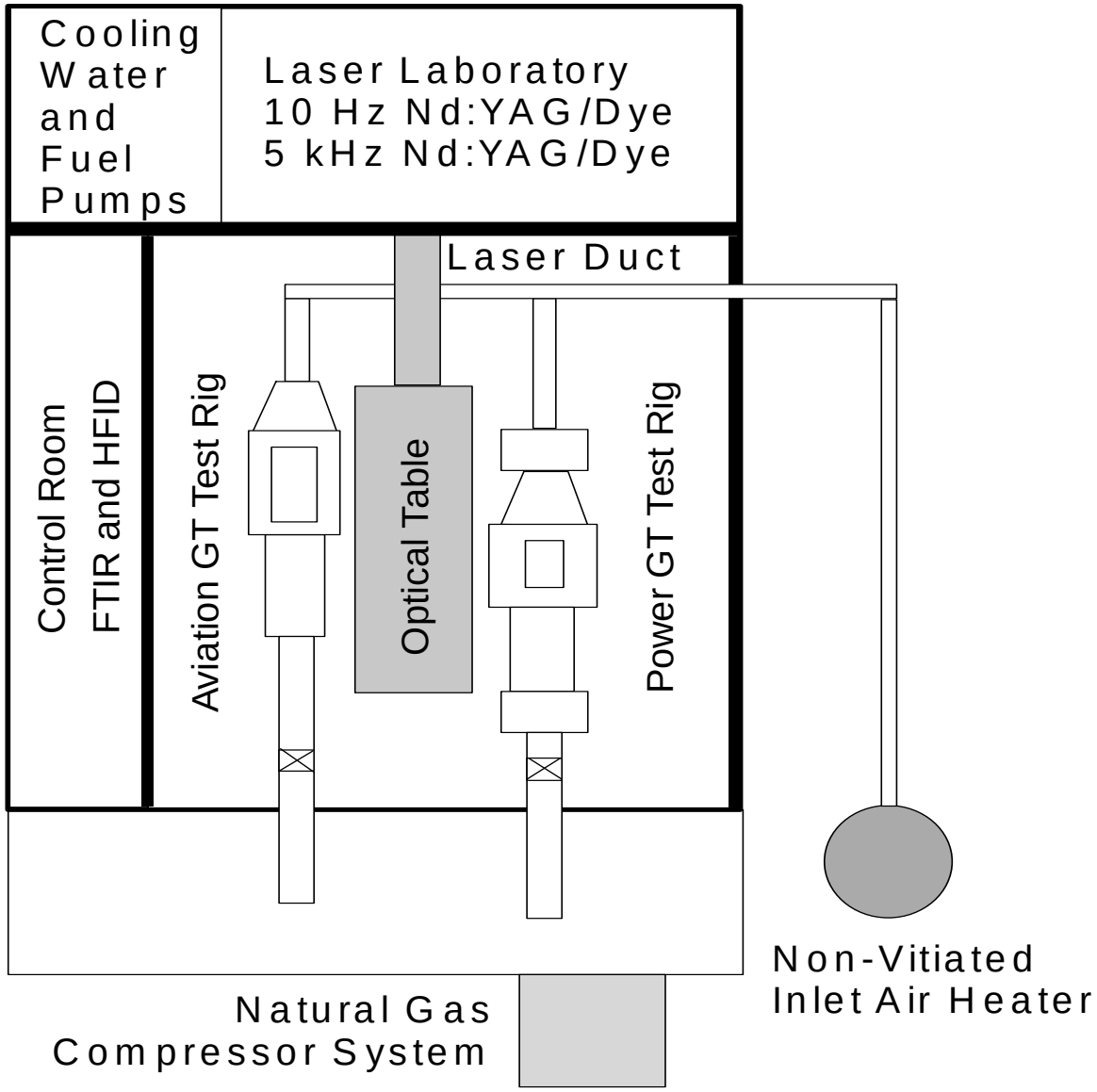
Purdue Gas Turbine Combustion Facility (GTCF)



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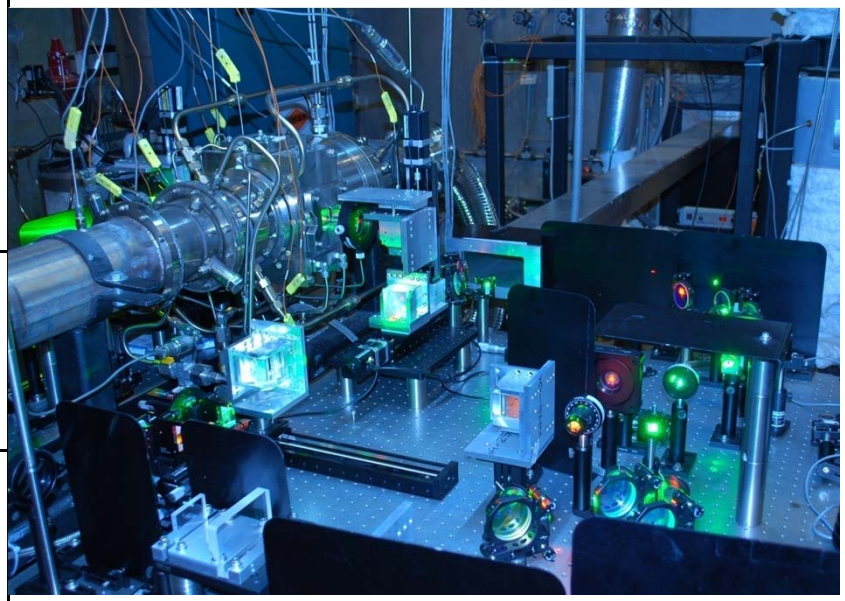
Purdue Gas Turbine Combustion Facility (GTCF)

High Pressure Lab System	Maximum Flow Capacity	Max Operating Condition
Natural Gas Heated High Pressure Air	9 lbm/sec	700 psi / 540 deg C 1000 deg F
Electric Heated Air or Nitrogen	1 lbm/sec	600 psi / 600 deg C
Nitrogen	2 to 5 lbm/sec	1,500 psi
Liquid Aviation Fuel (Kerosene)	1 lbm/sec/tank (2 tanks)	1,500 psi
Natural Gas	1 lbm/sec	3500 psi



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Natural Gas Compressor System

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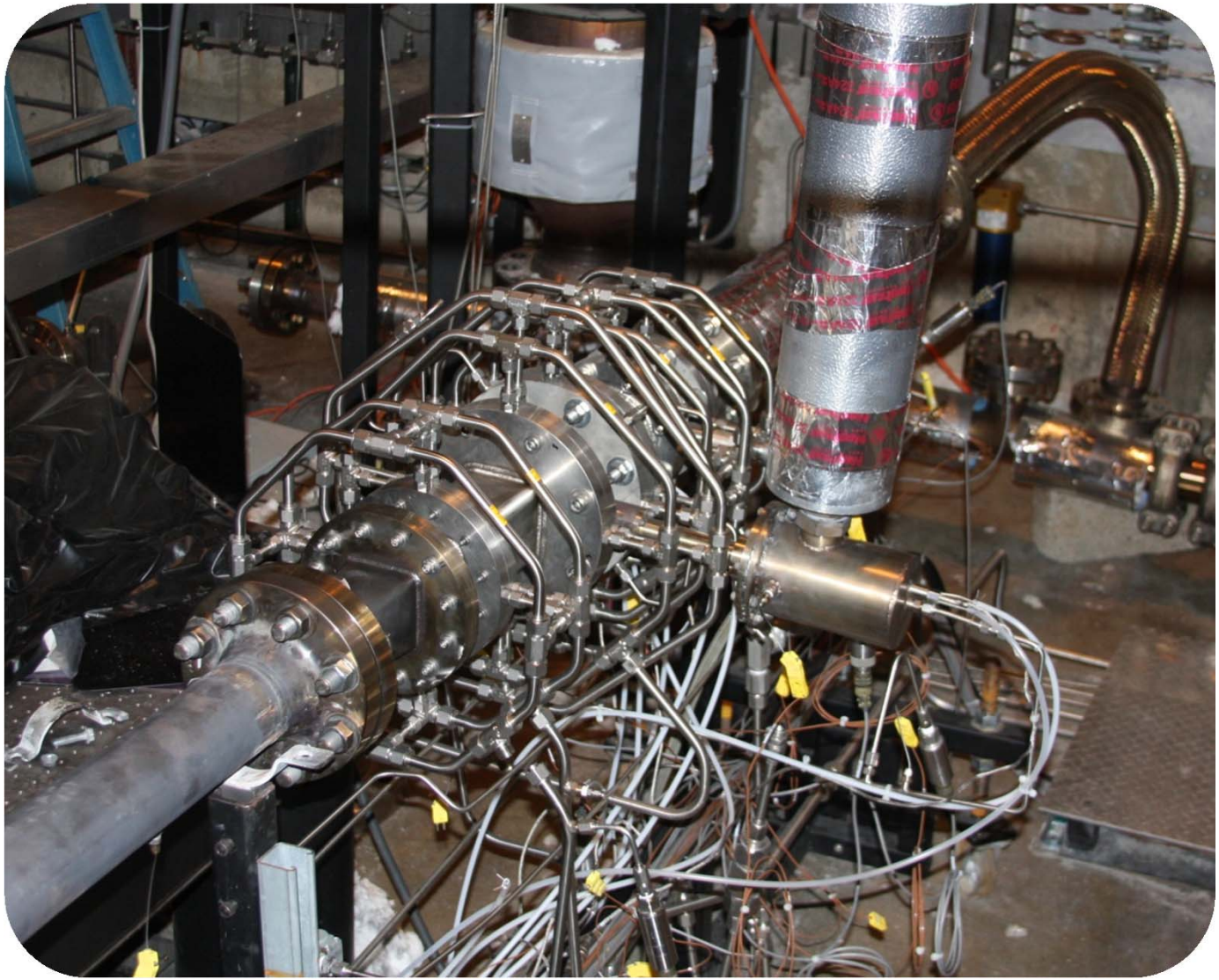
High-Pressure RJIC Test Rig



Test rig developed with funding from Siemens.

Emissions measured with FTIR system.

Window assembly for optical access.

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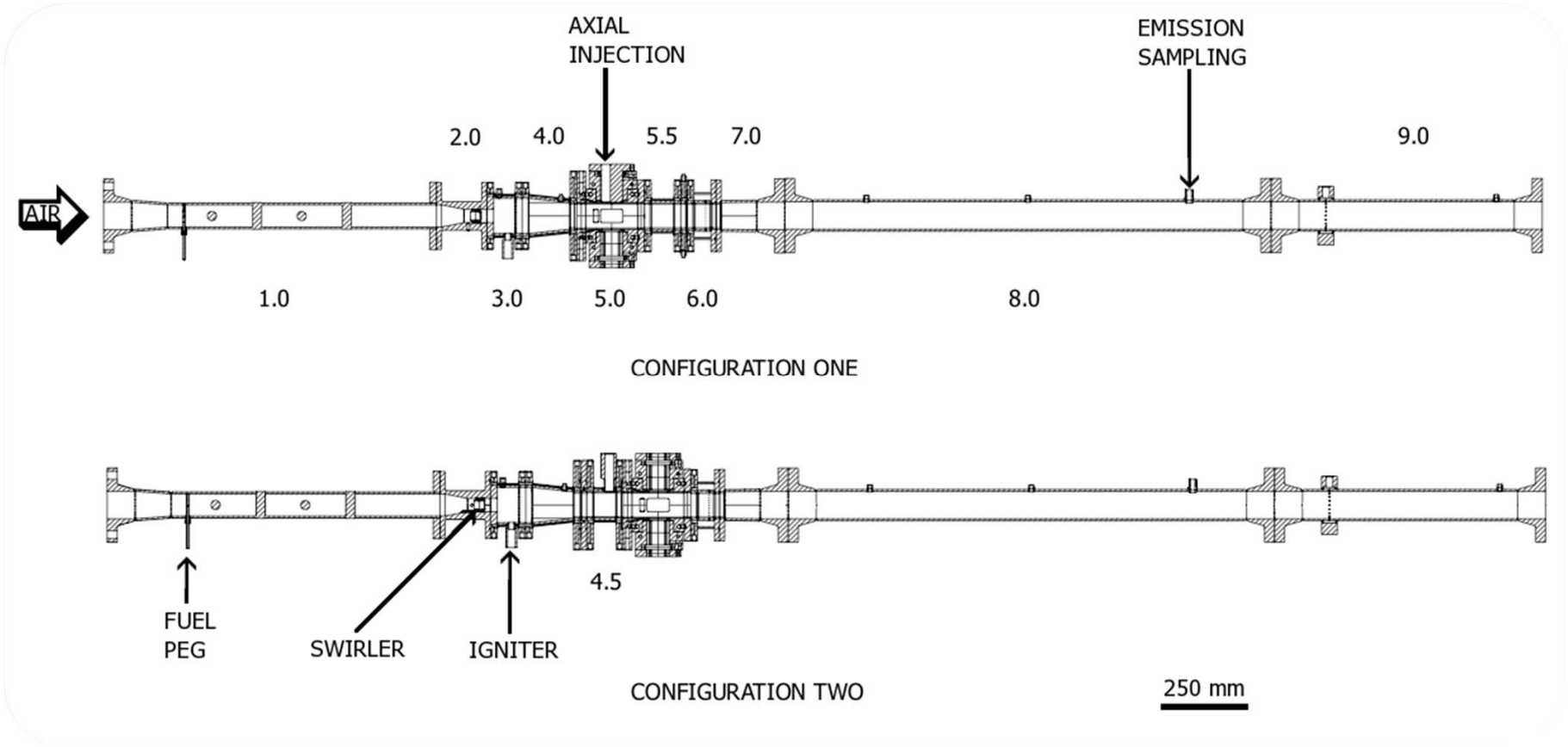
High-Pressure RJIC Test Rig



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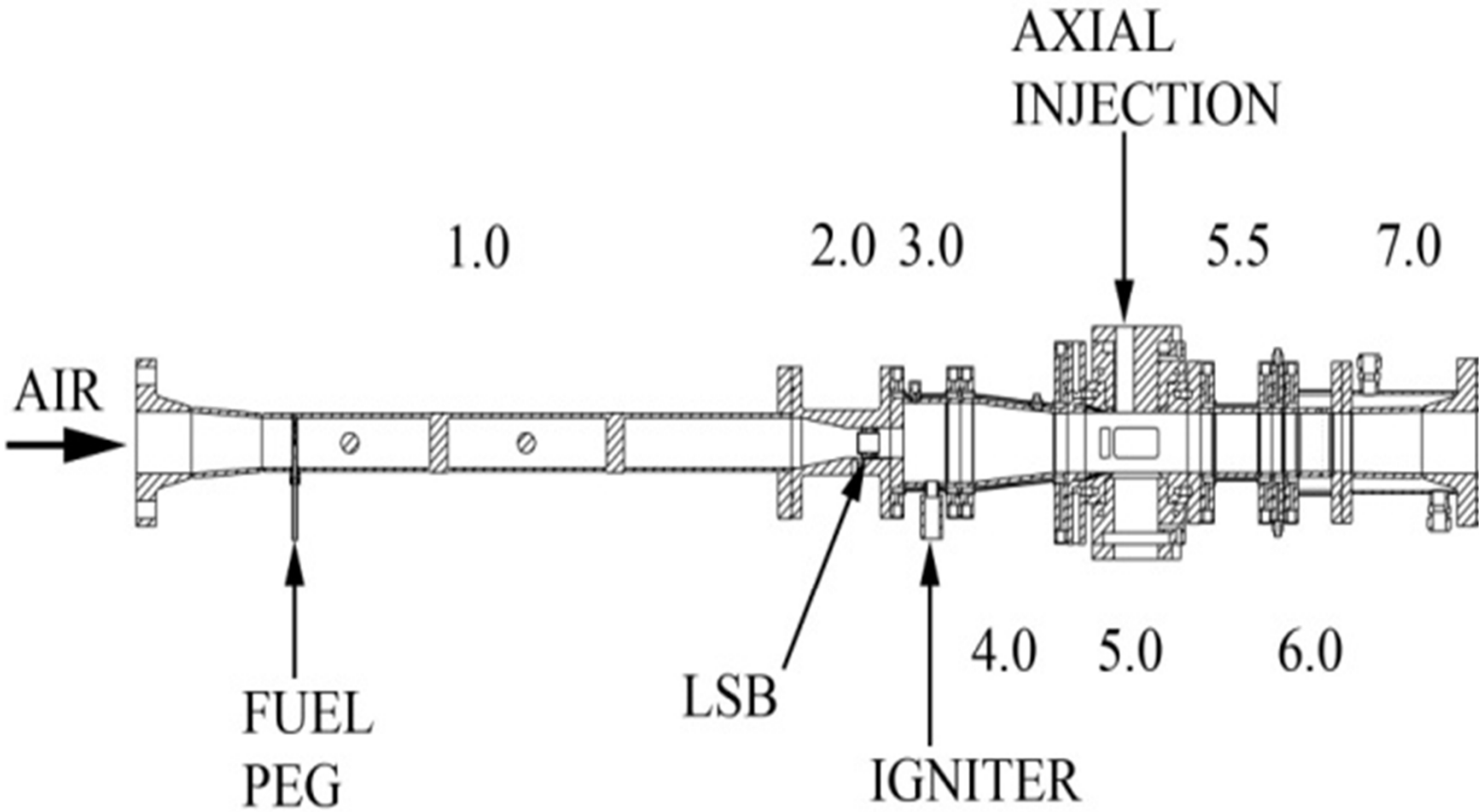
High-Pressure RJIC Test Rig



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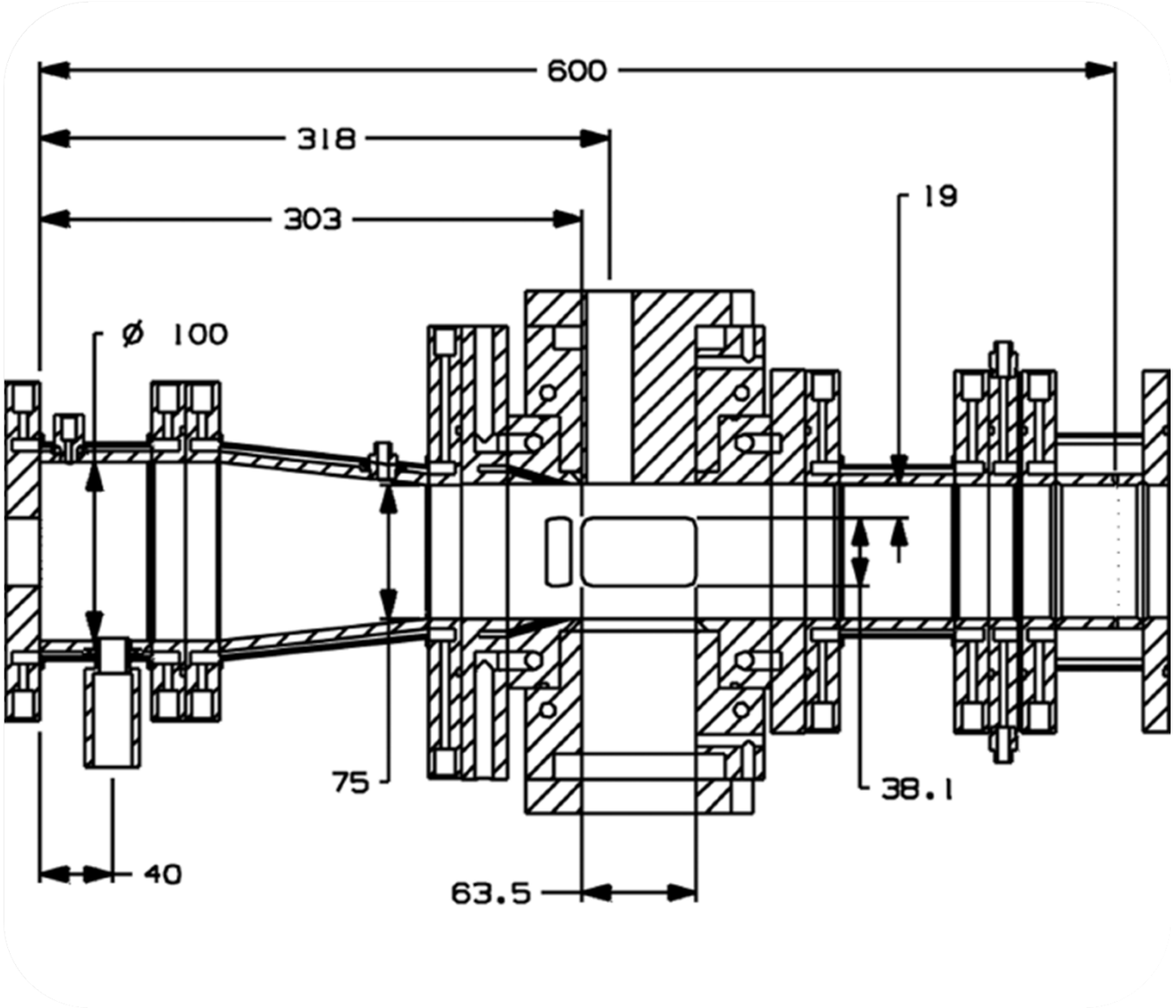
High-Pressure RJIC Test Rig: Current Configuration



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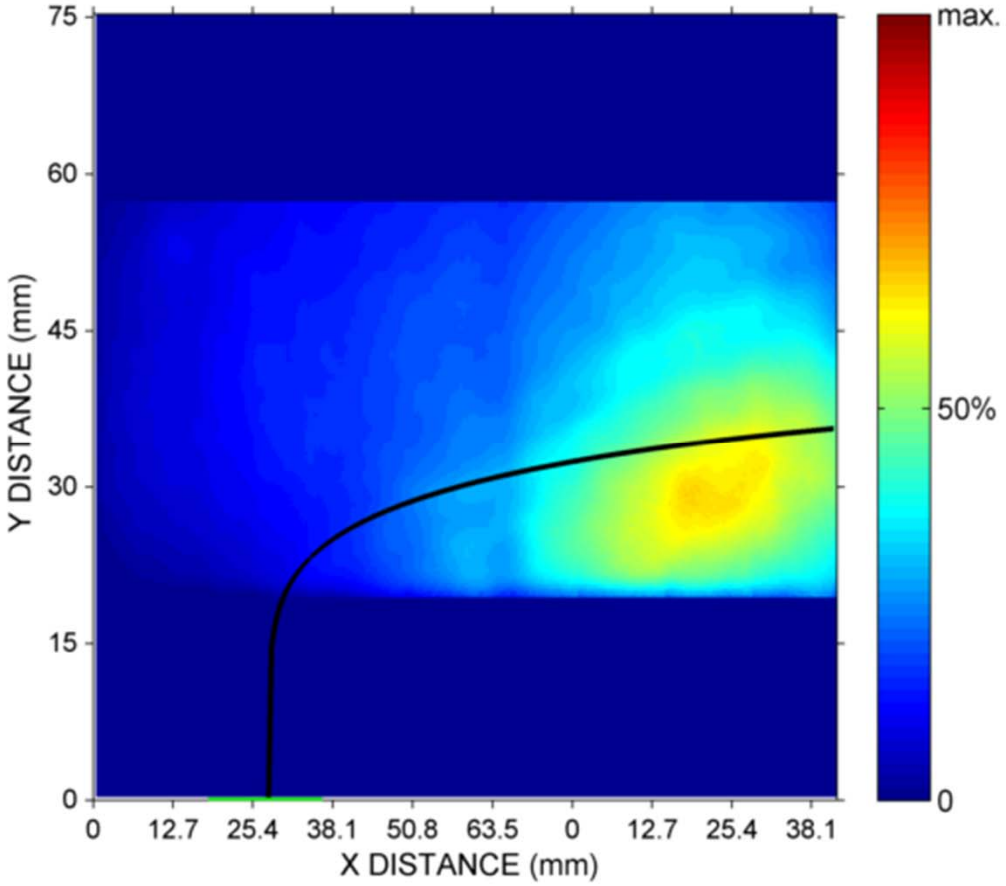
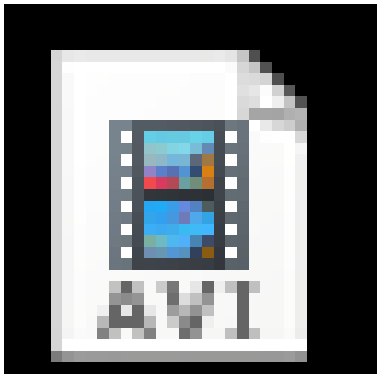
10 Hz OH PLIF Images of Hydrogen Jet Injection





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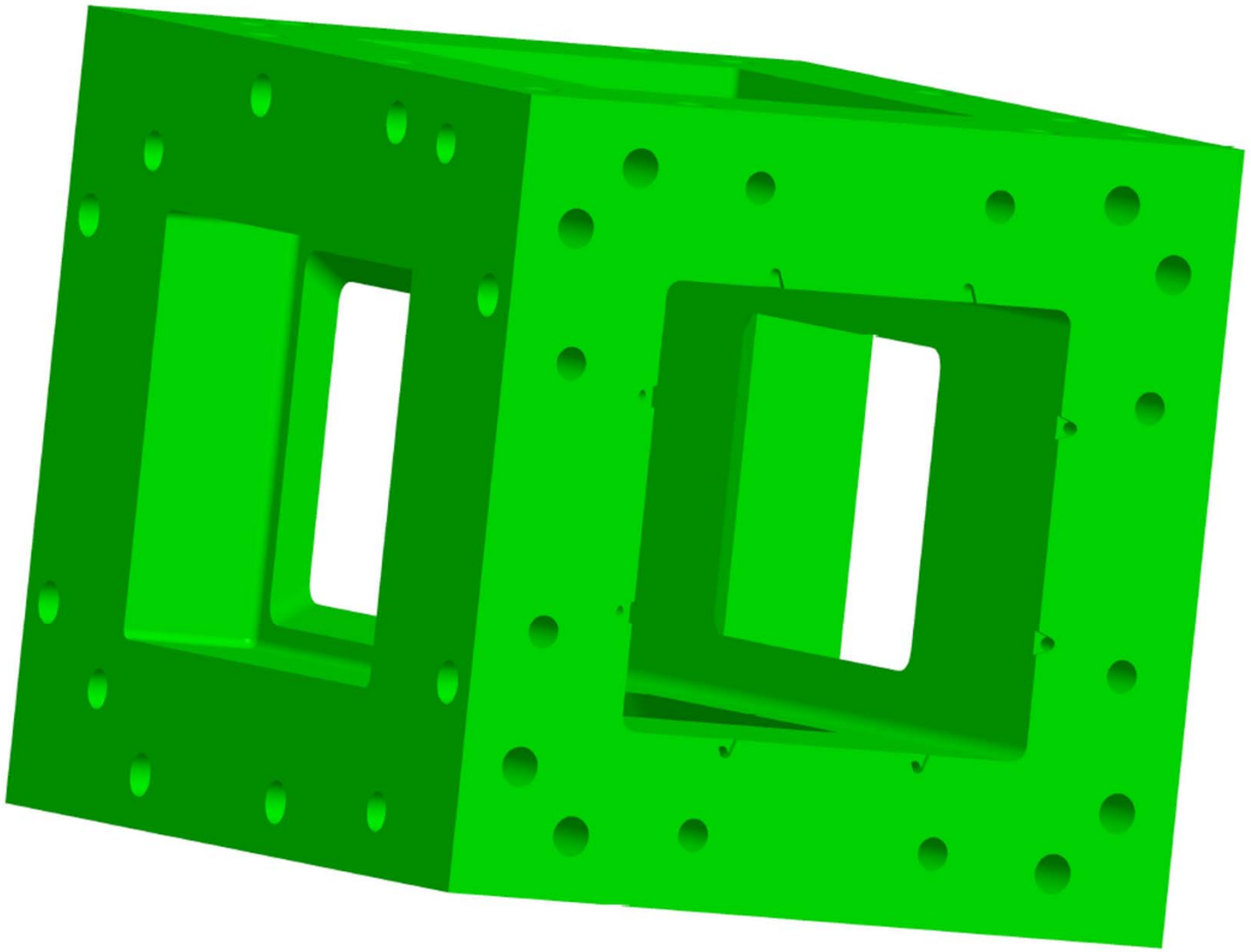
Modified Combustor Window Assembly

- Cross section increased from 3"x3“ to 4.2"x4.2". The modified CWA is fabricated from Hastelloy-X instead of stainless steel. Brazing has been eliminated.
- Thermal barrier coatings are being applied to the window assembly inner surfaces.
- Window film cooling incorporated through inserts in the test rig flow passage.

Modified Combustor Window Assembly



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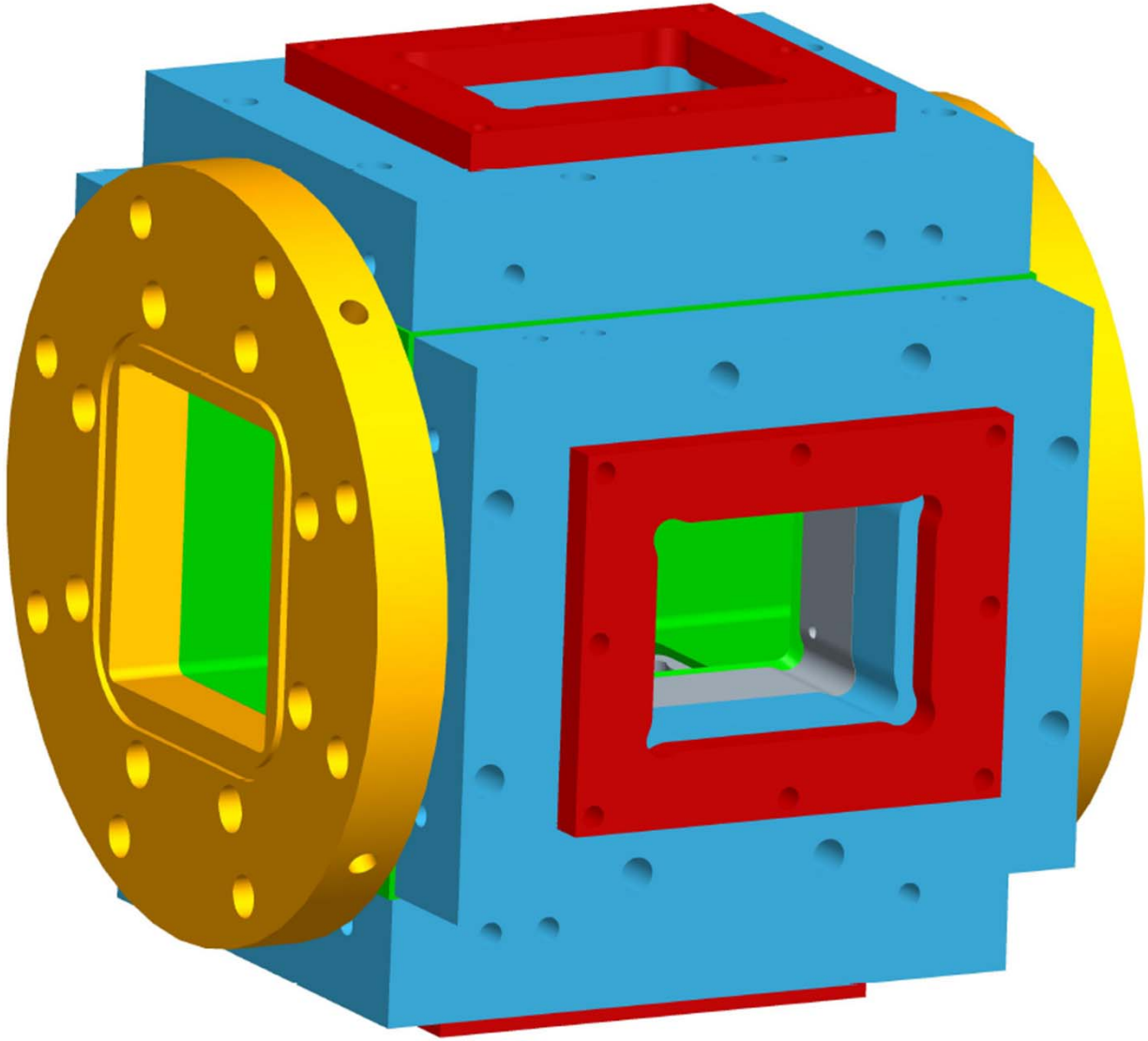
Modified Combustor Window Assembly



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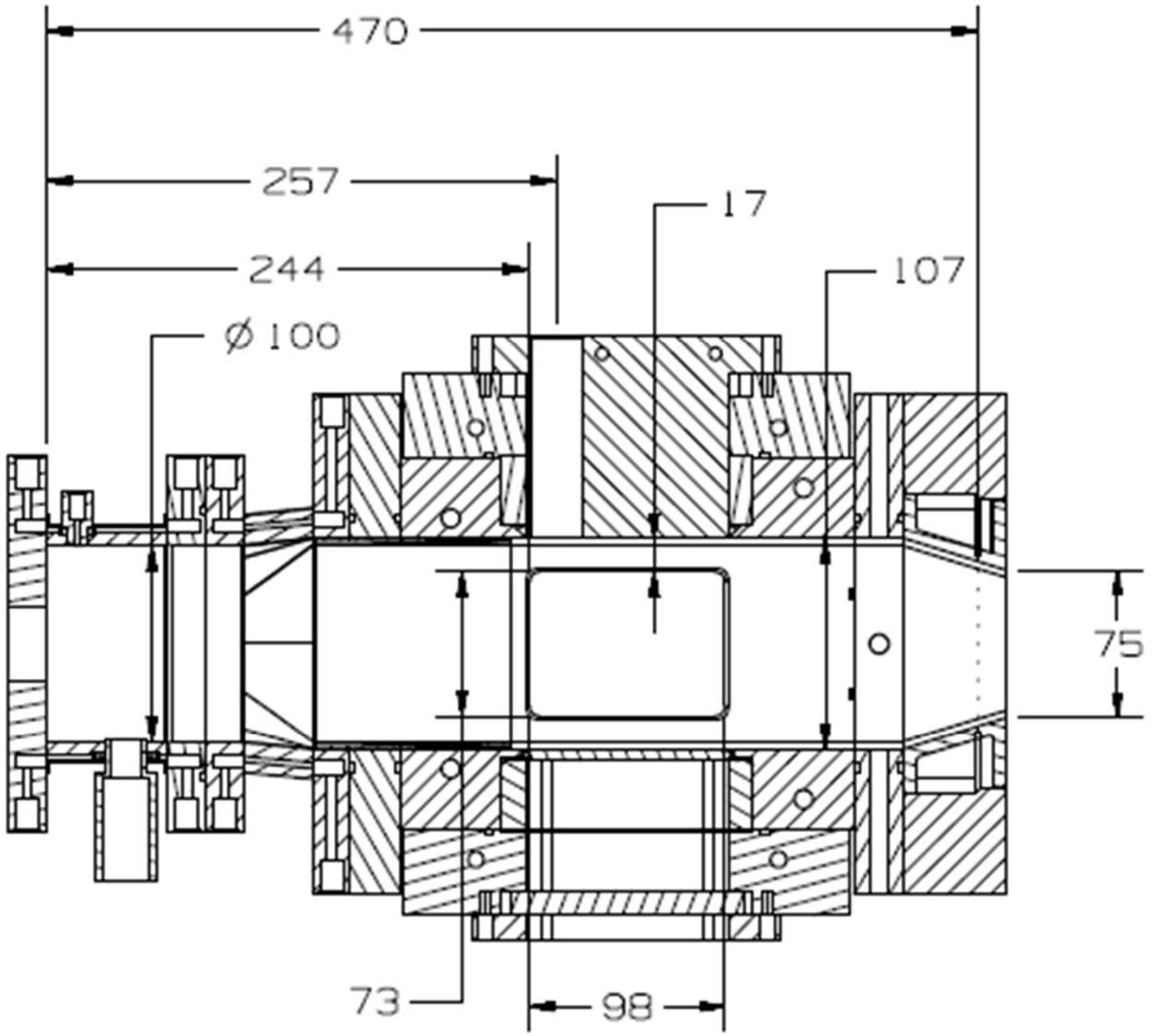
High-Pressure RJIC Test Rig: Future Configuration



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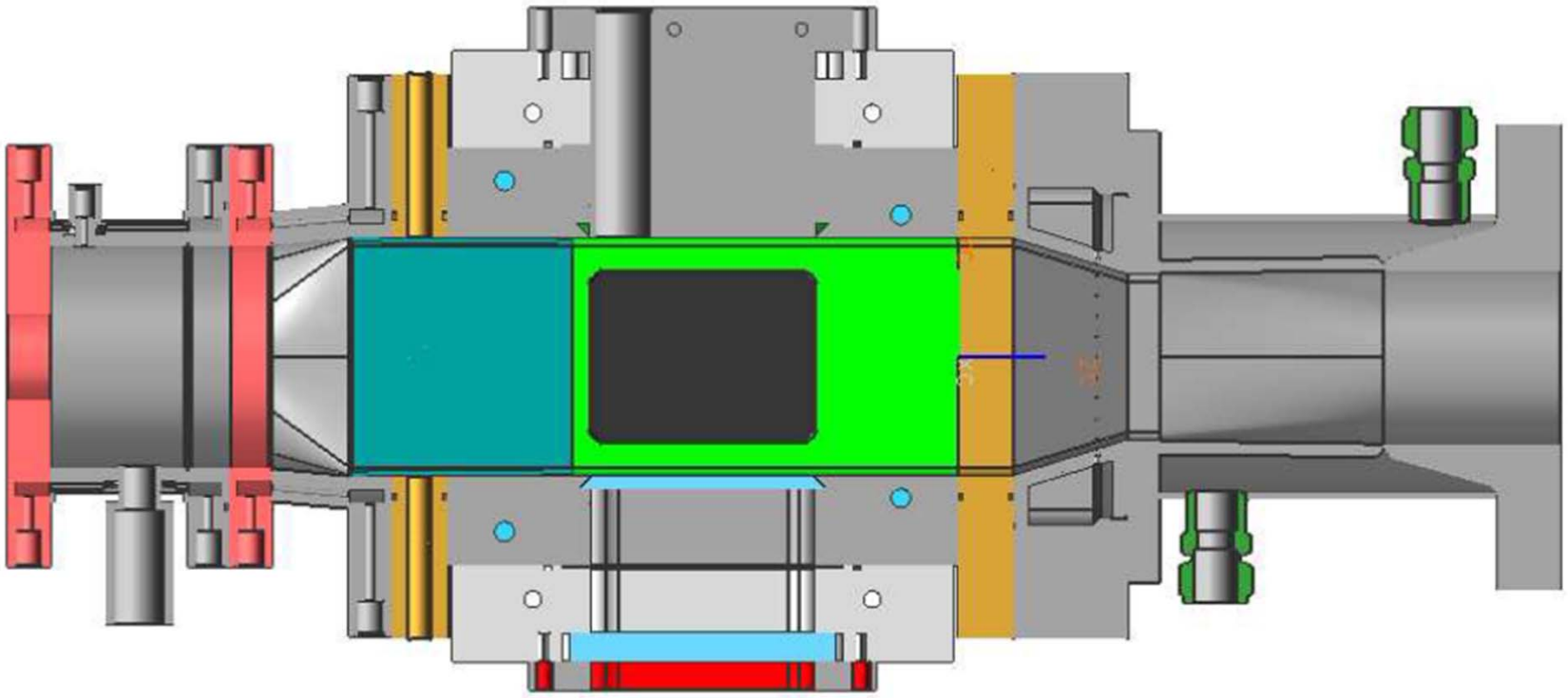

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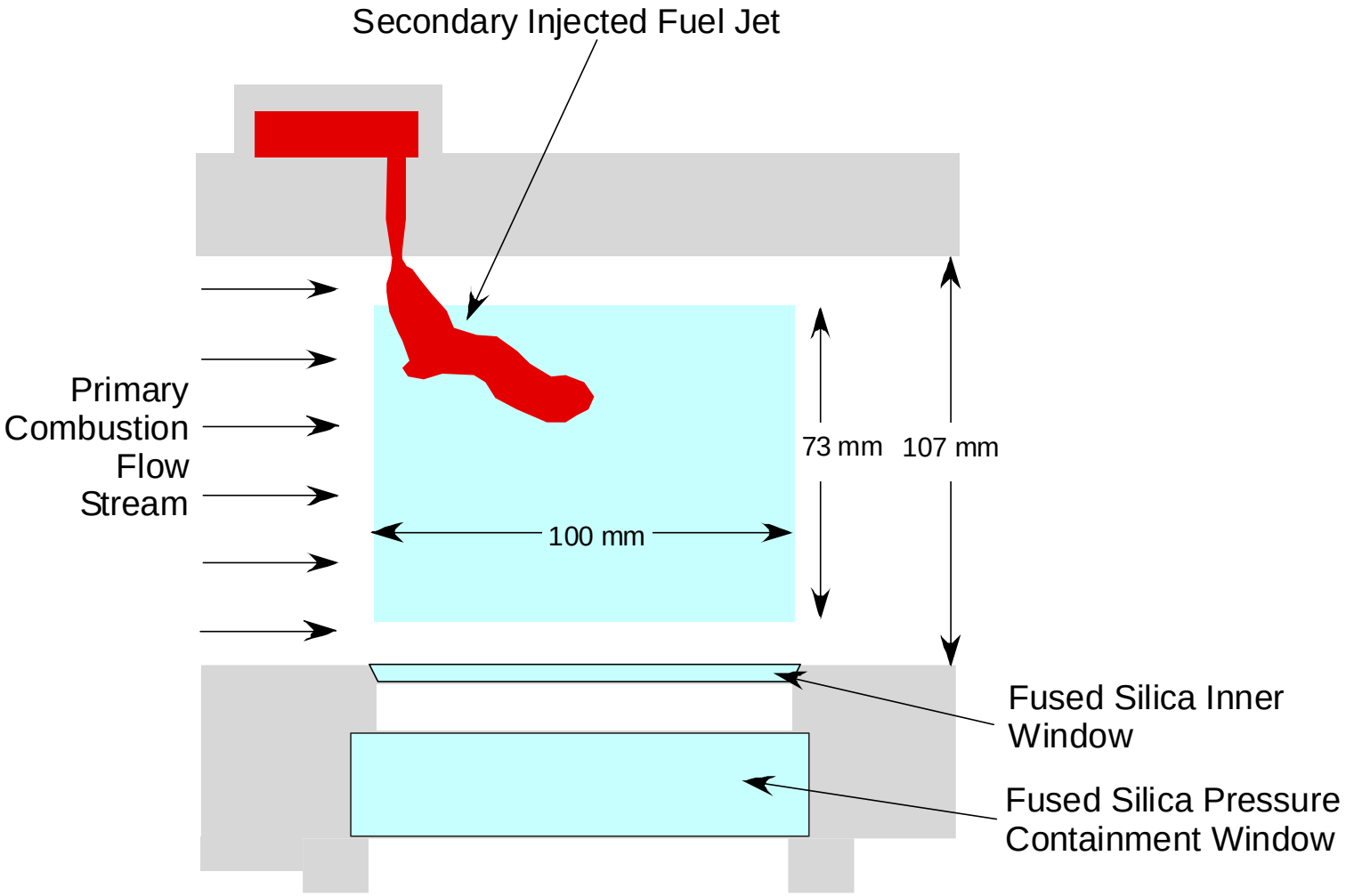

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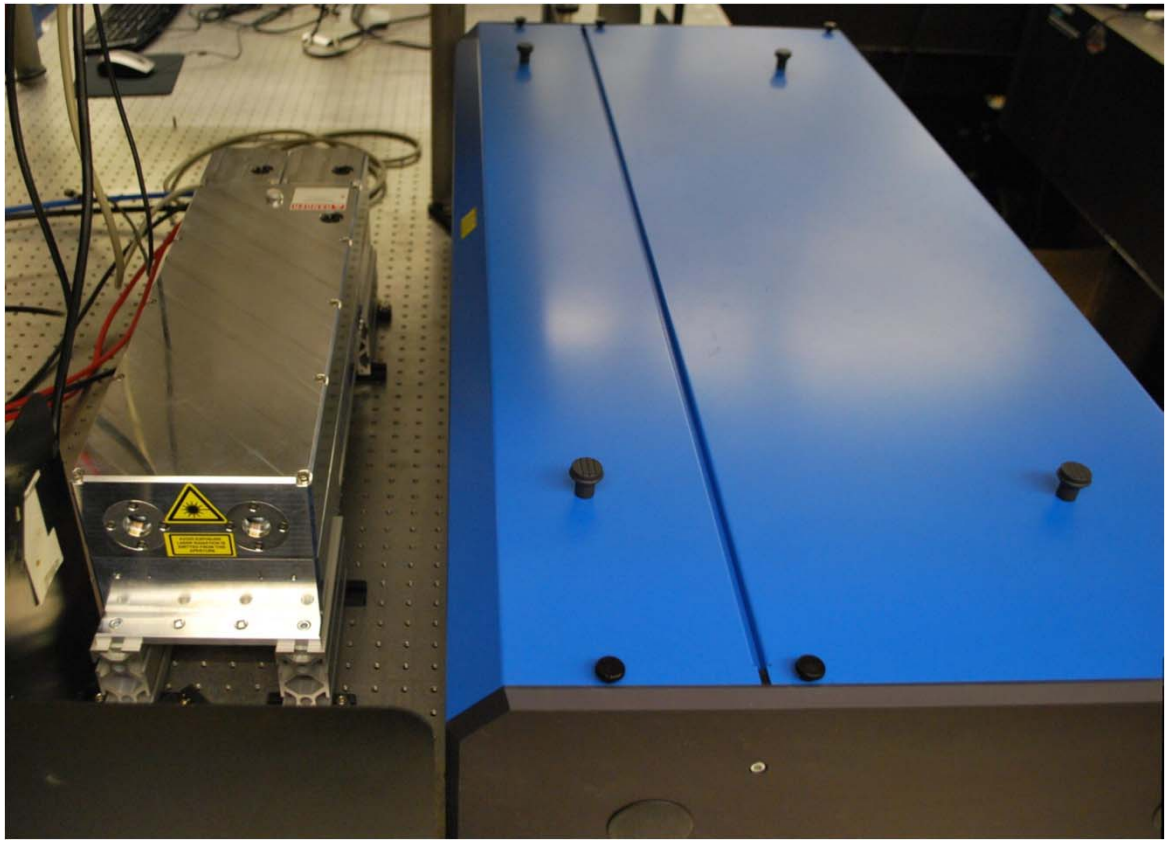
High-Repetition-Rate Diagnostic Techniques

- 10 kHz PIV – dual-head Edgewave laser
- 10 kHz OH PLIF – Credo dye laser pumped by the Edgewave laser
- Femtosecond CARS – ~~1 kHz~~ 5 kHz measurements in turbulent flames have been demonstrated. New Coherent ultrafast laser system with repetition rate of up to 10 kHz, > 10 W average power has been installed.

High-Repetition-Rate Laser System



Edgewave Diode-Pumped Solid State Nd:YAG Laser: 5 kHz Rep Rate, Dual-Head, 6 mJ/Pulse at 532 nm, 7 nsec Pulses

Sirah Credo Dye Laser
5 kHz Rep Rate, 500 μJ/Pulse at 283 nm (2.5 W average power in UV)

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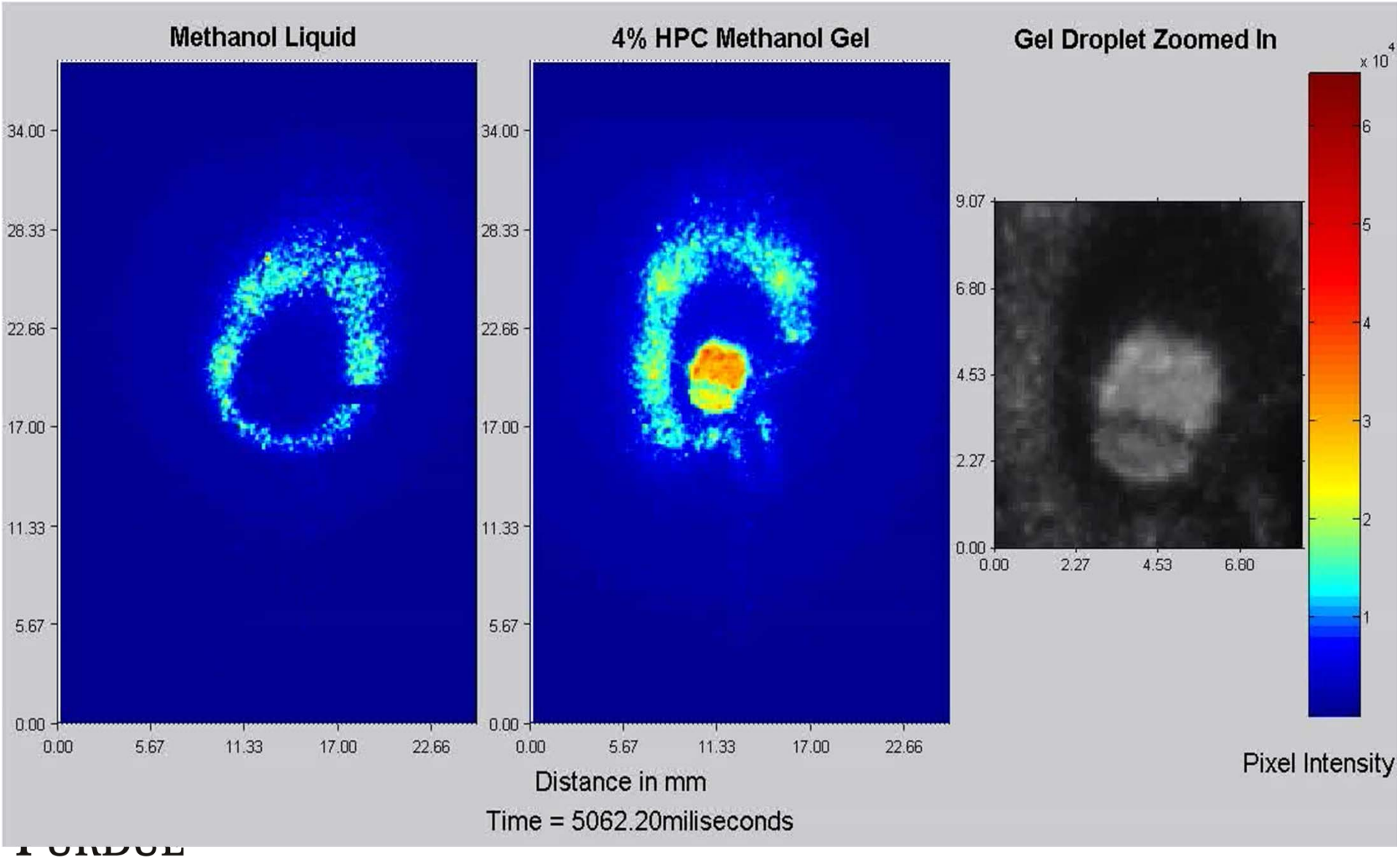
5 kHz OH PLIF of Liquid Methanol and Gelled Methanol/HPC Droplets



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5 kHz OH PLIF of Shear Layer Combustion for a Hydrogen Nonpremixed Jet Flame

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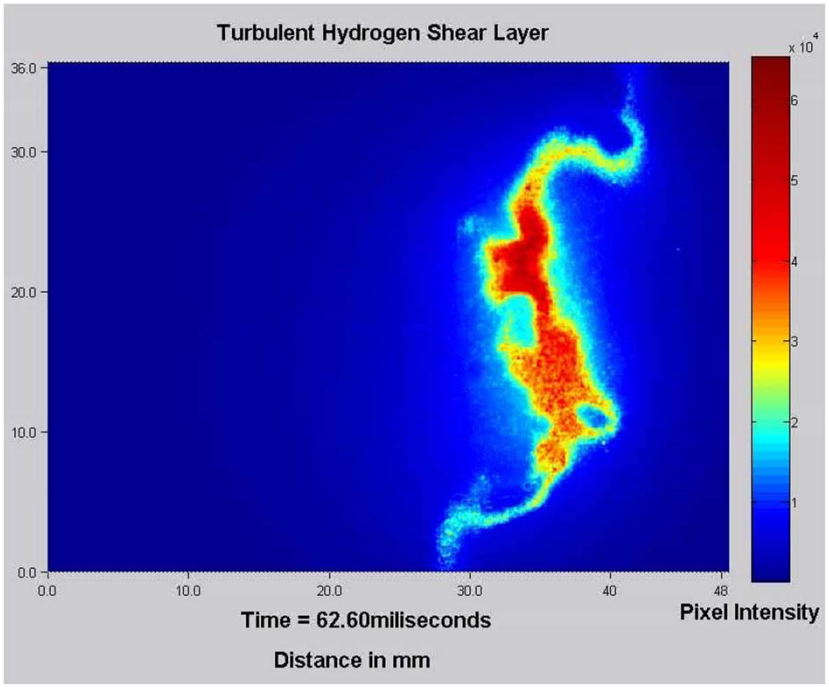

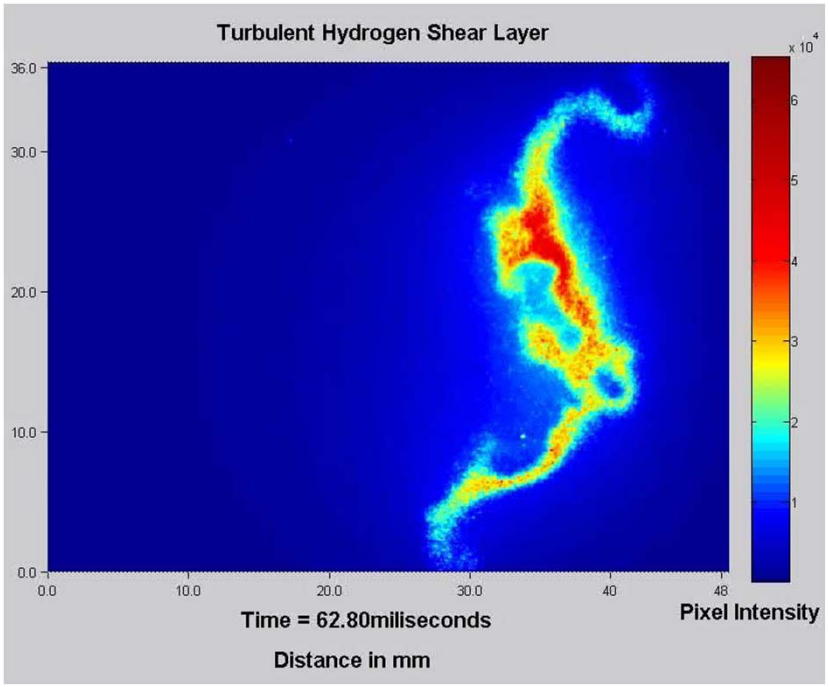

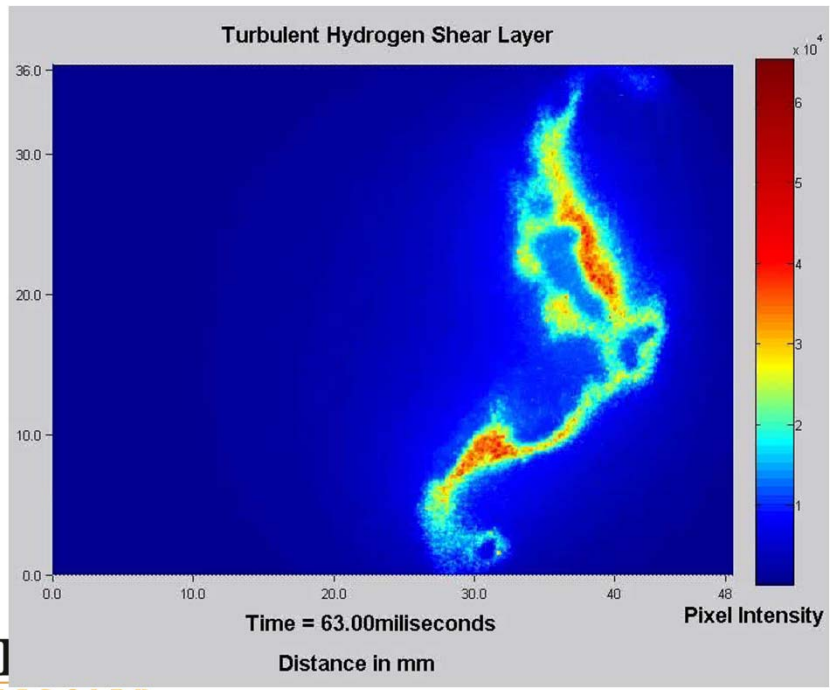

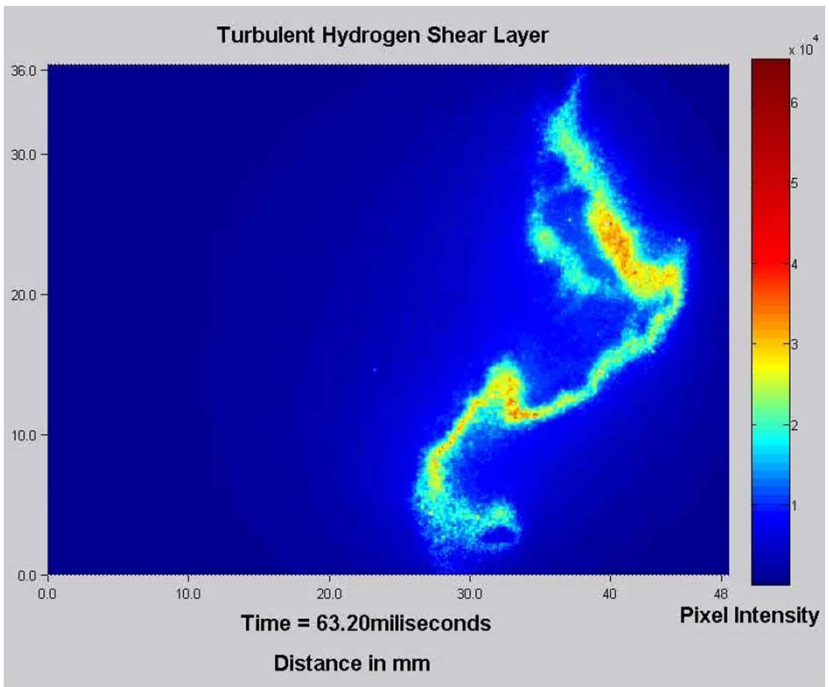

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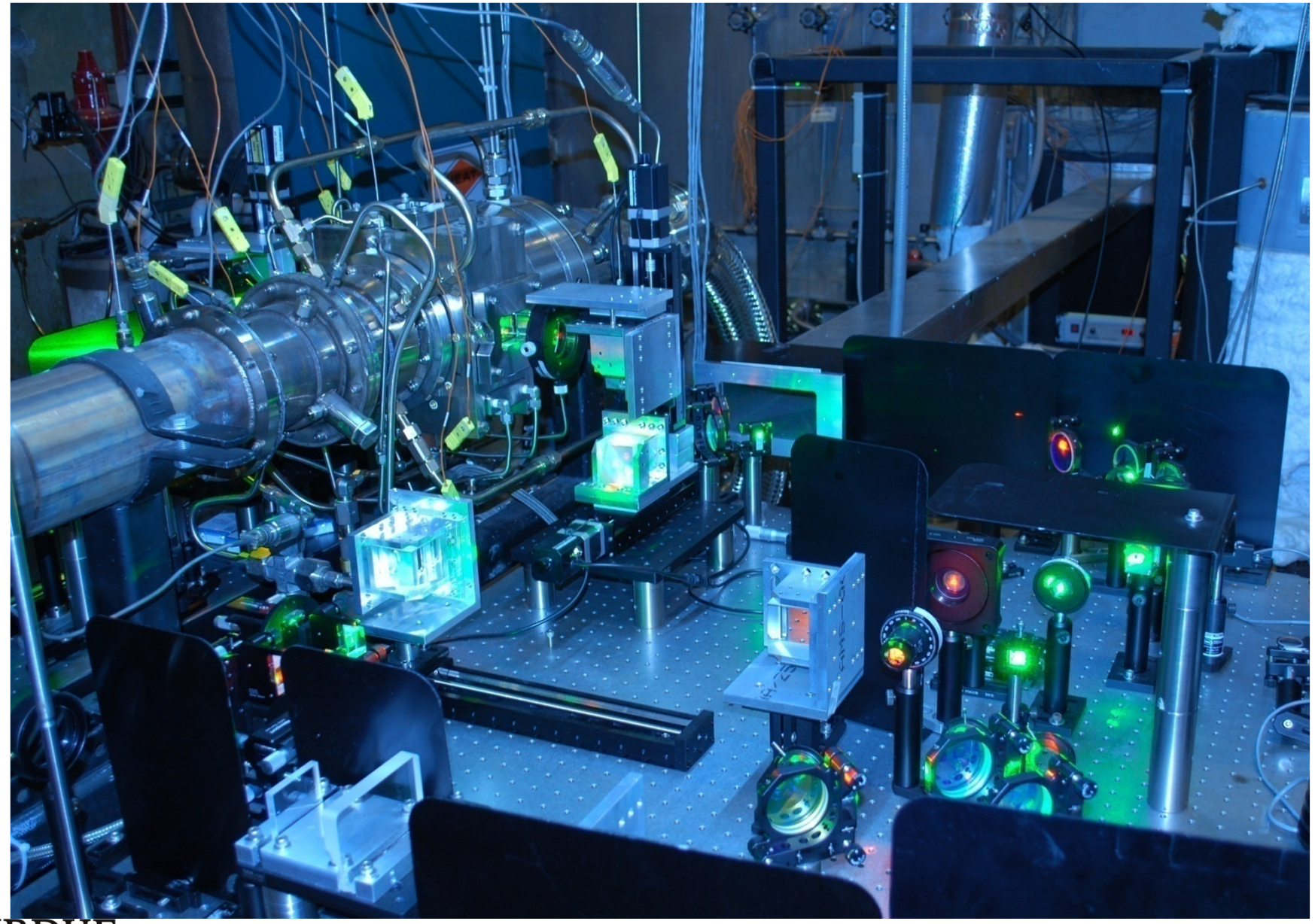
5 kHz PLIF and PIV in Flames and Combustors

- 5 kHz OH PLIF imaging had been performed in laboratory jet flames to demonstrate the system
- 5 kHz OH PLIF imaging has proven to be a powerful tool for droplet and propellant combustion studies
- 5-10 kHz OH PLIF and 10 kHz PIV will be performed in the RJIC experiments

Optical System near GTCF



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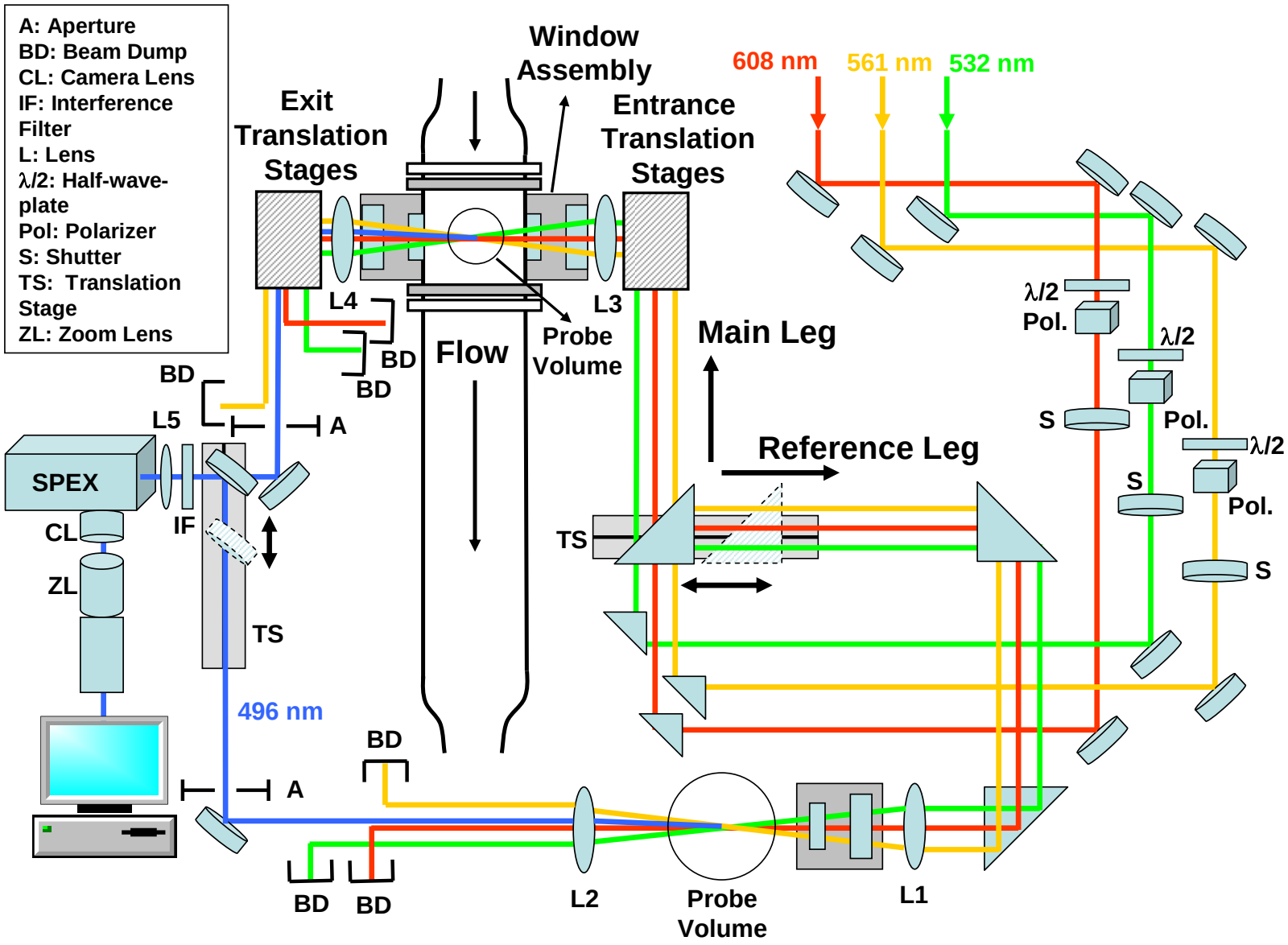
CARS System for GTCF Measurements



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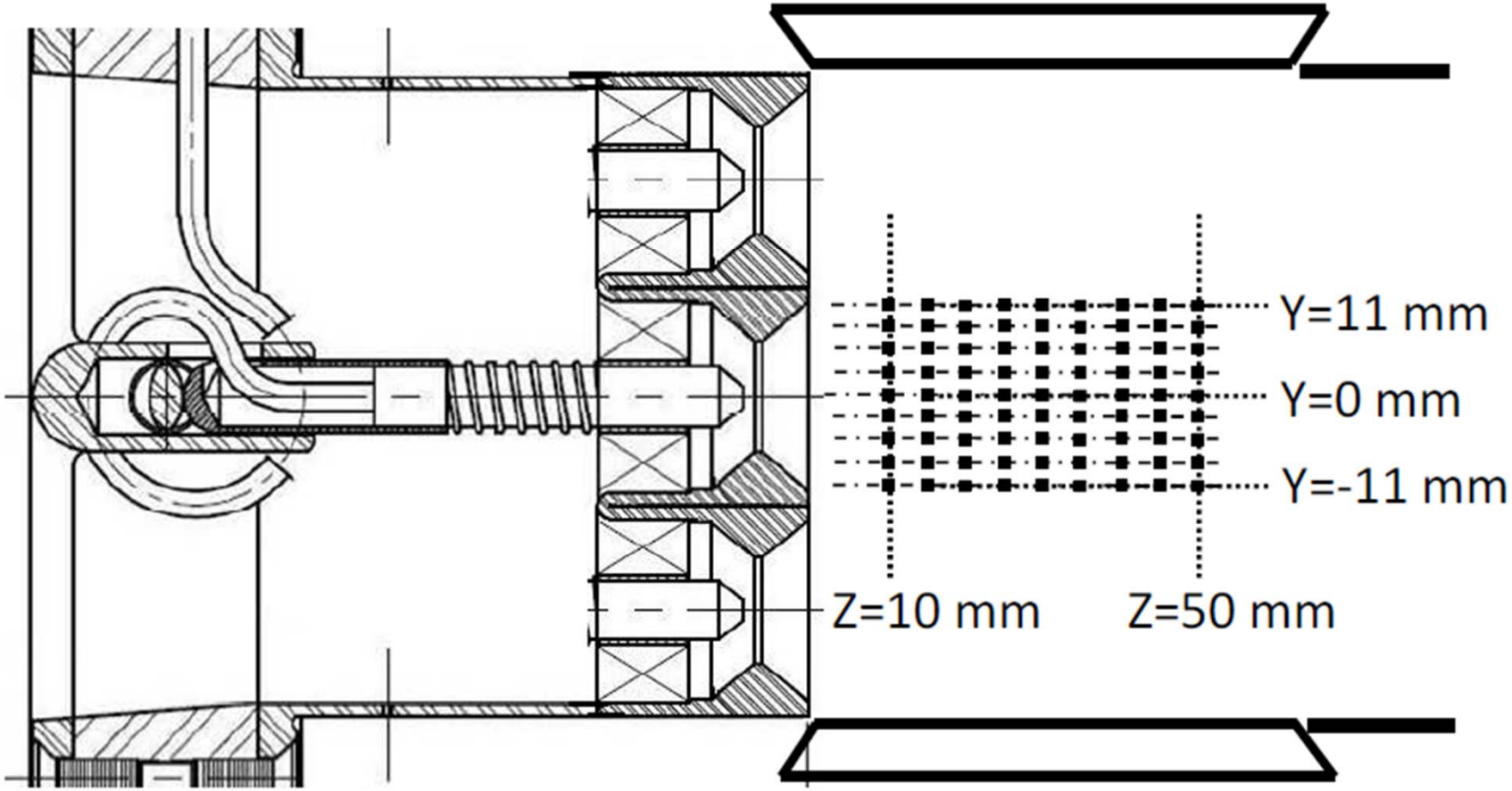
CARS: Coherent Anti-Stokes Raman Scattering

Measurement Grid for DP-CARS



M. P. Thariyan, A. H. Bhuiyan, S. E. Meyer, S. V. Naik, J. P. Gore, and R. P. Lucht, "Dual-Pump Coherent Anti-Stokes Raman Scattering (DP-CARS) System for Temperature and Species Measurements in an Optically-Accessible High-Pressure Gas Turbine Combustor Facility," *Measurement Science and Technology* **22**, Article Number 015301 (2011).

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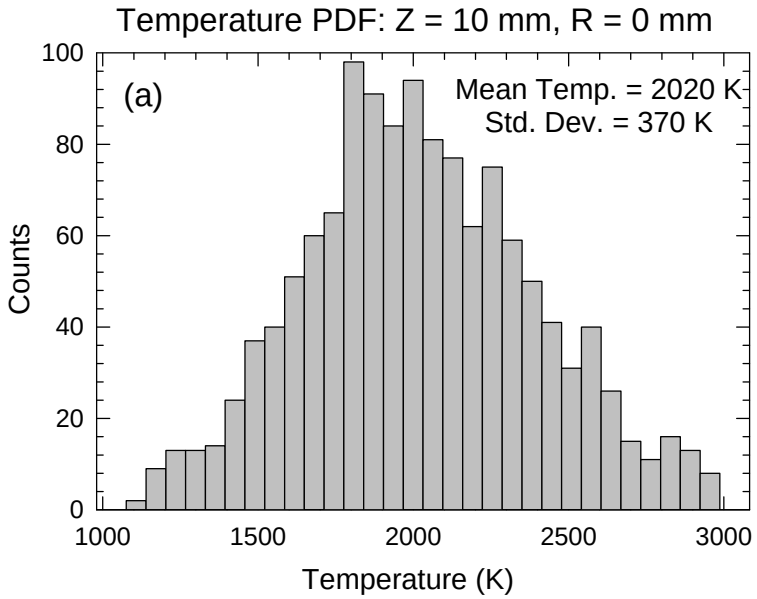
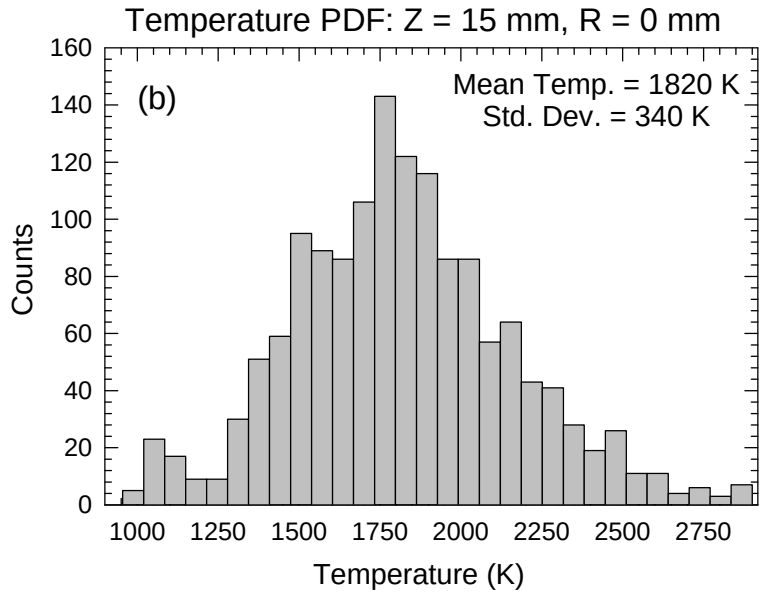
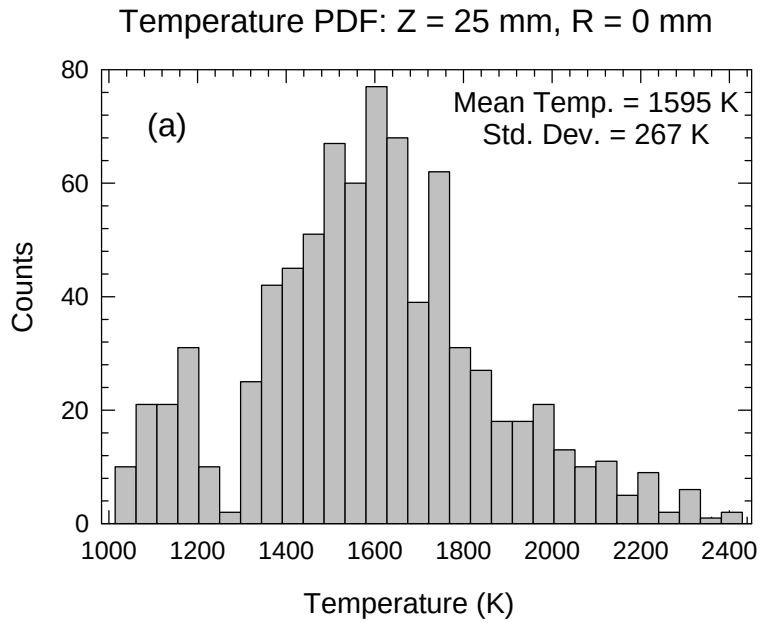
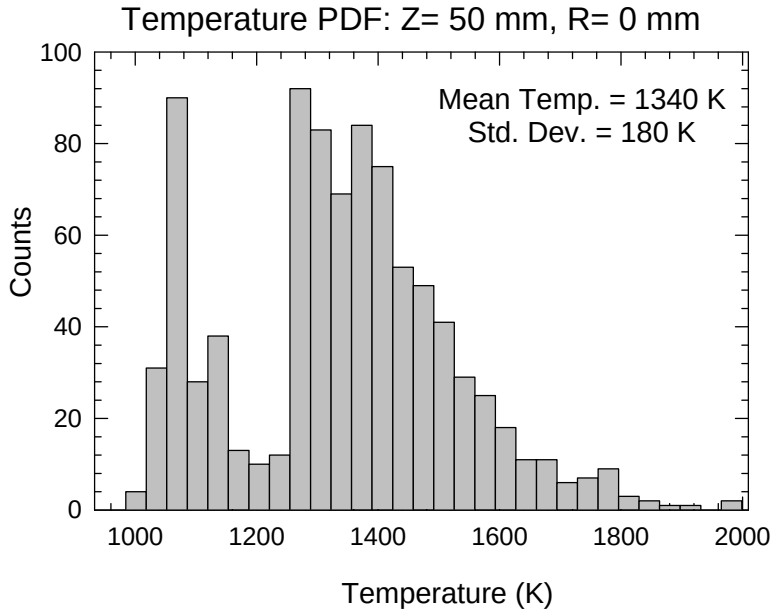
Temp PDFs Along Centerline

Combustor Pressure: 104 psia, Equivalence Ratio: 0.4









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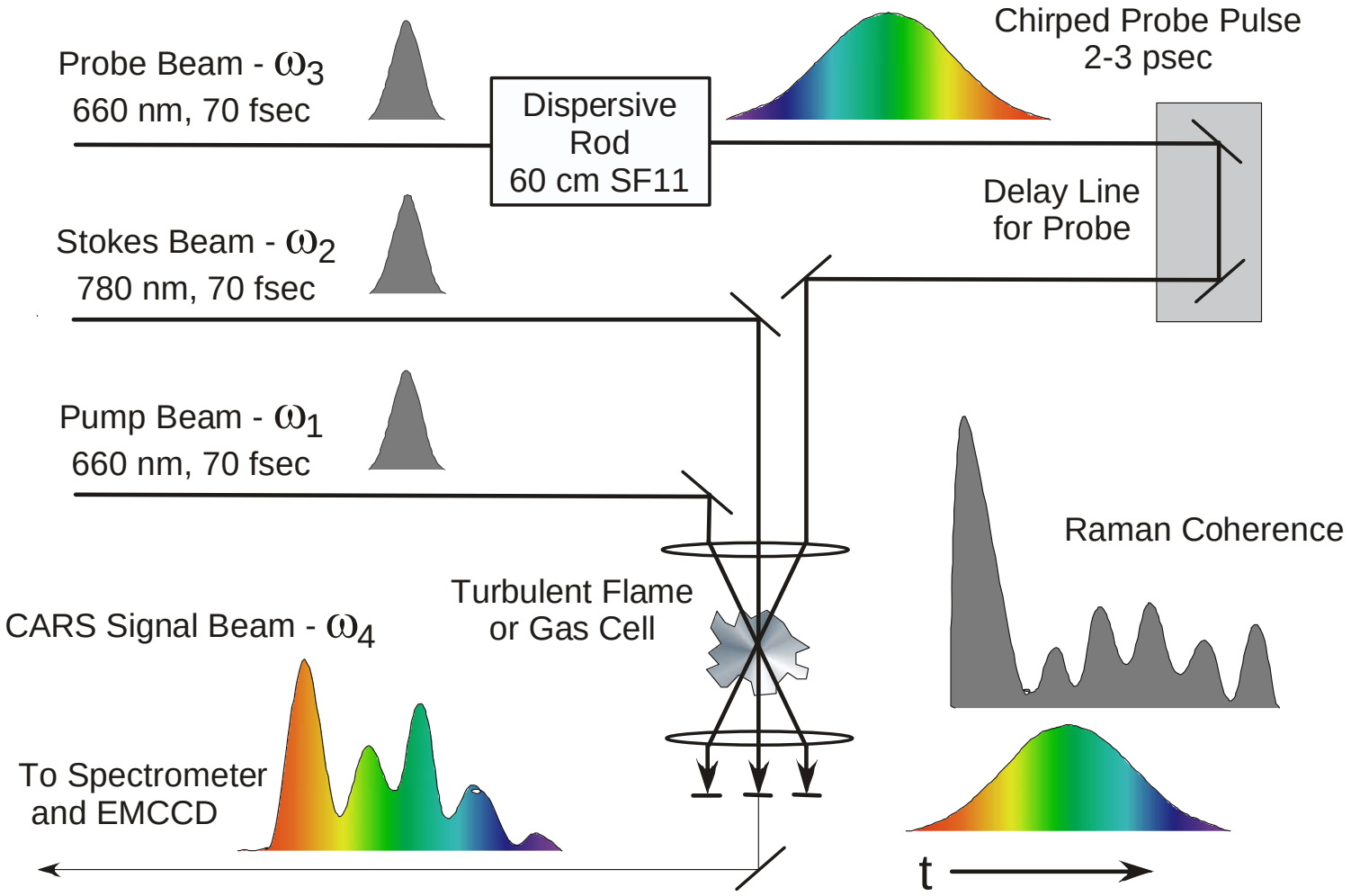
Optical System for Single-Pulse fs CARS with Chirped Probe Pulse



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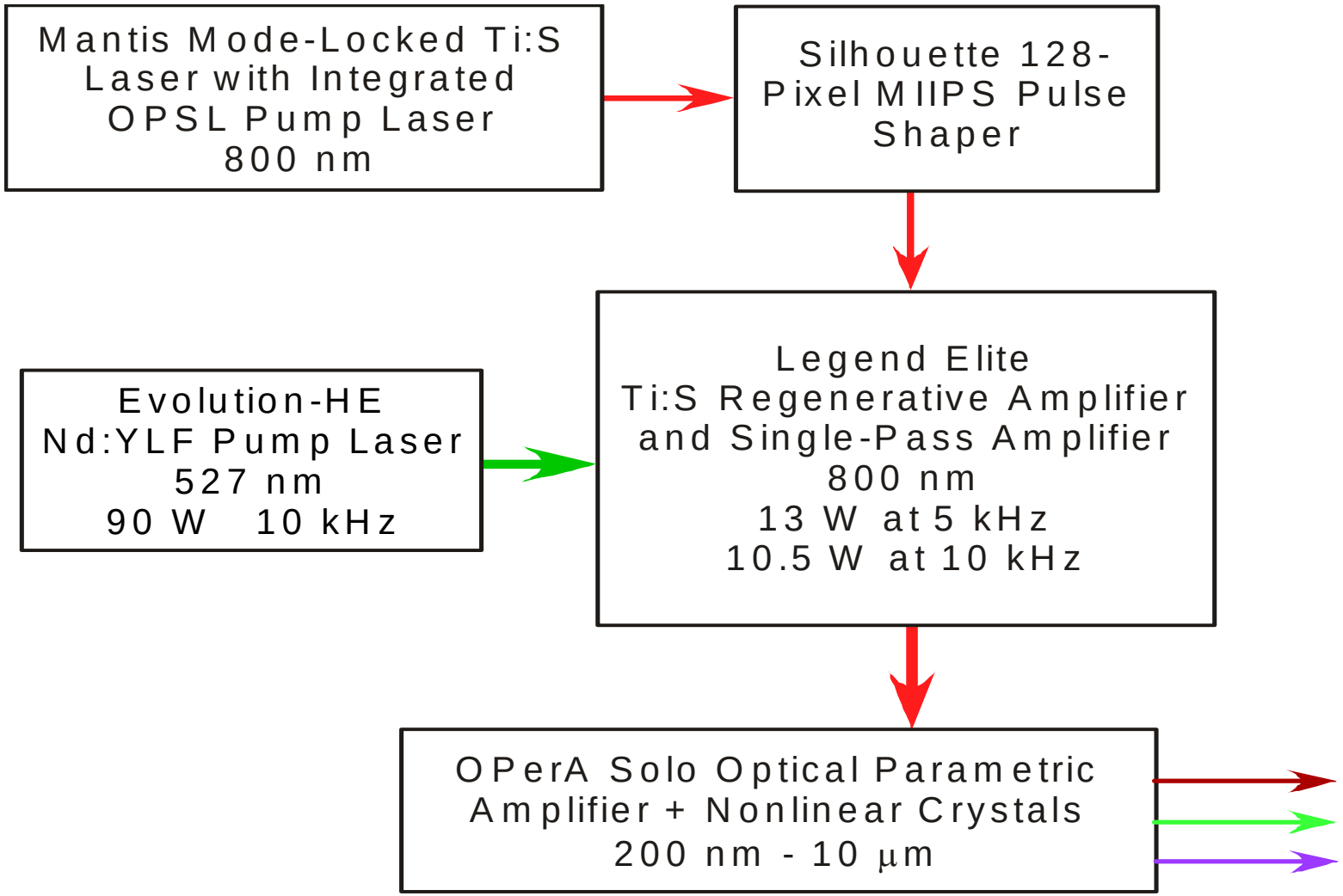
Ultrafast Laser System for fs CARS



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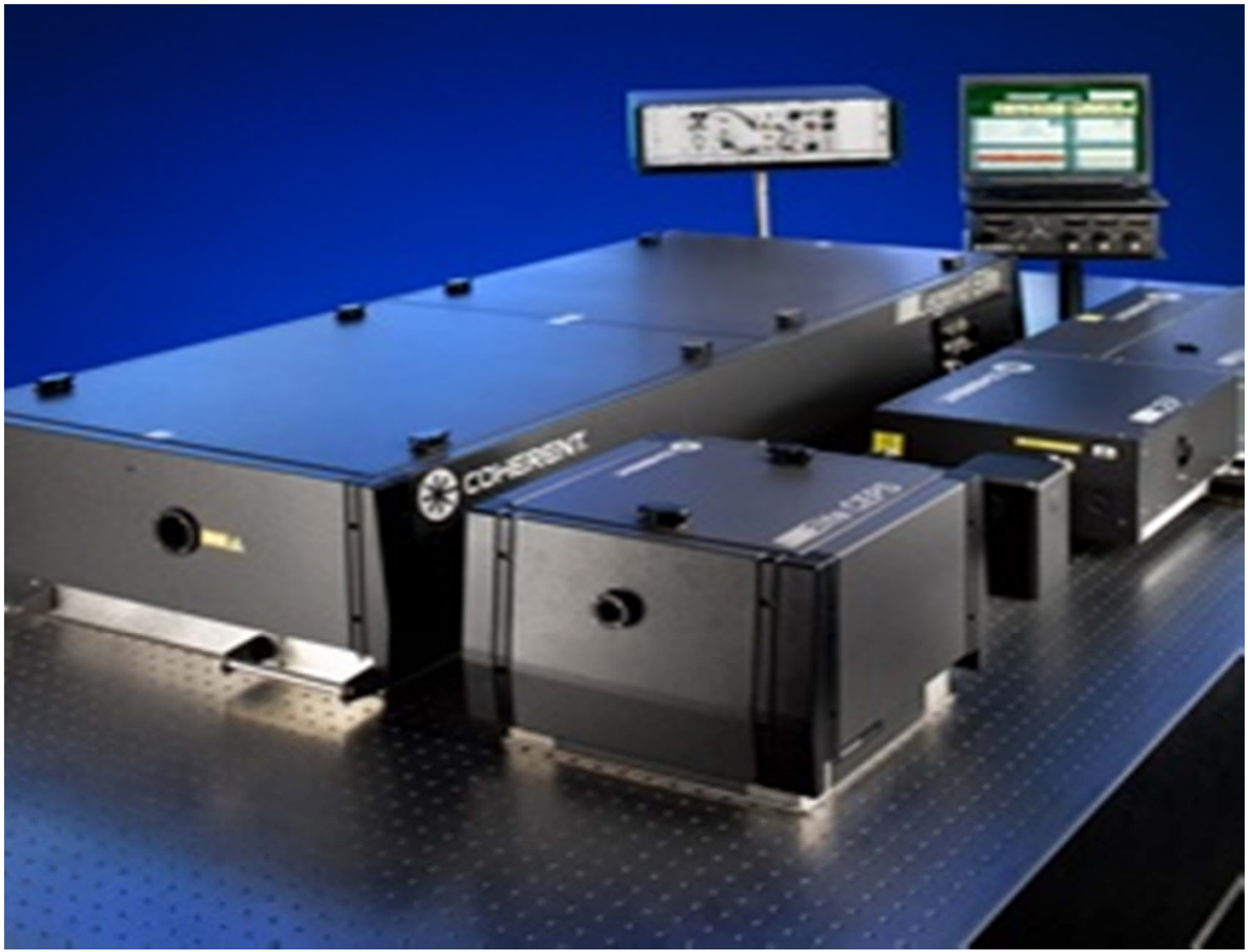
Ultrafast Laser System for fs CARS



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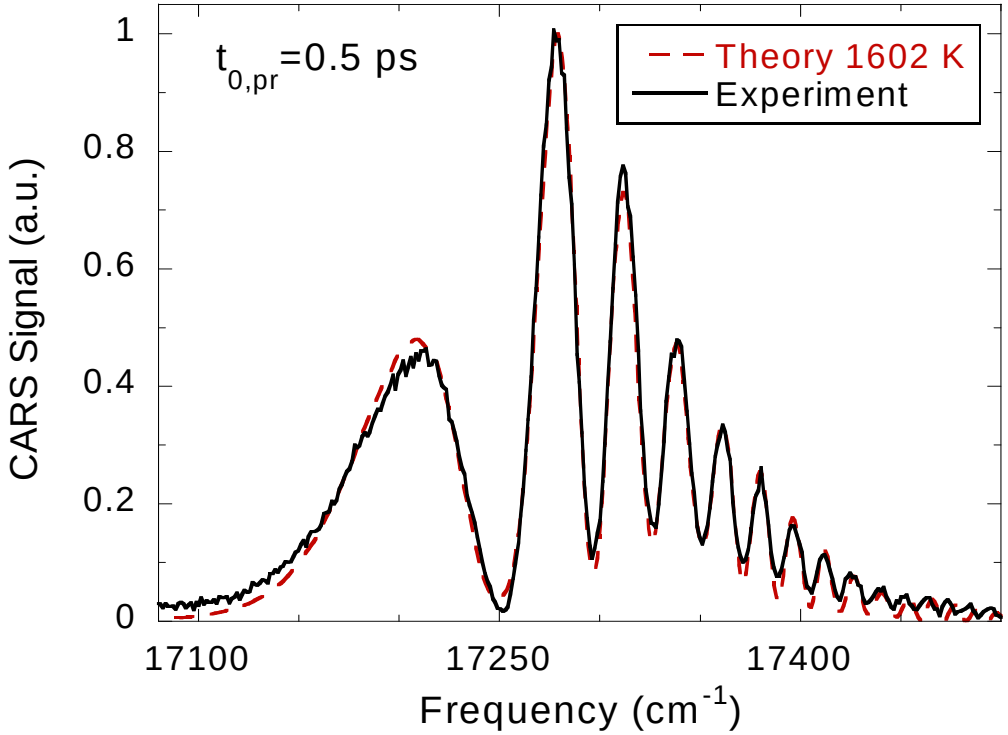
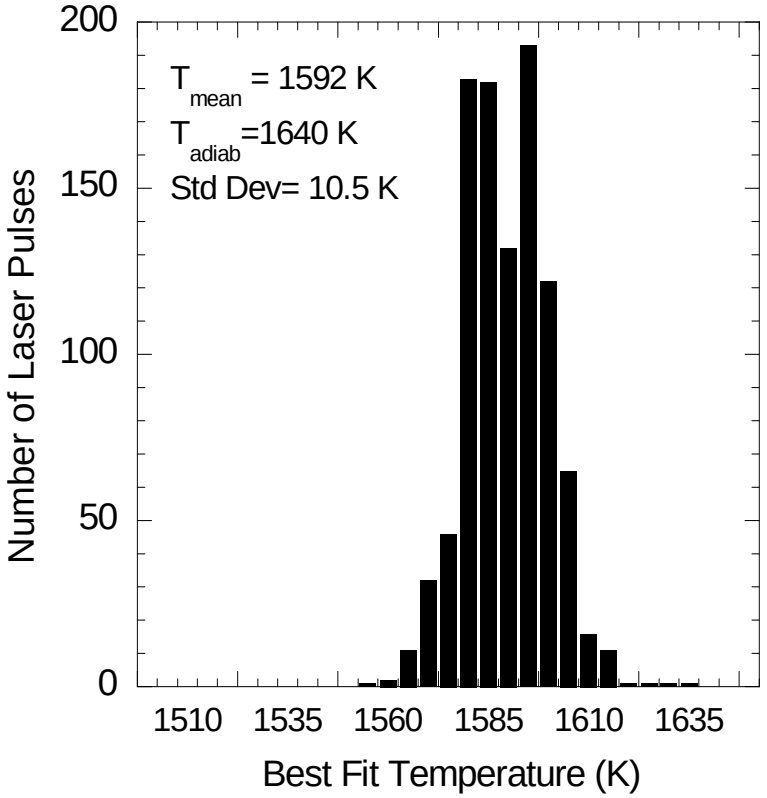
Temperature Histograms from Single-Shot fs CARS in Flames





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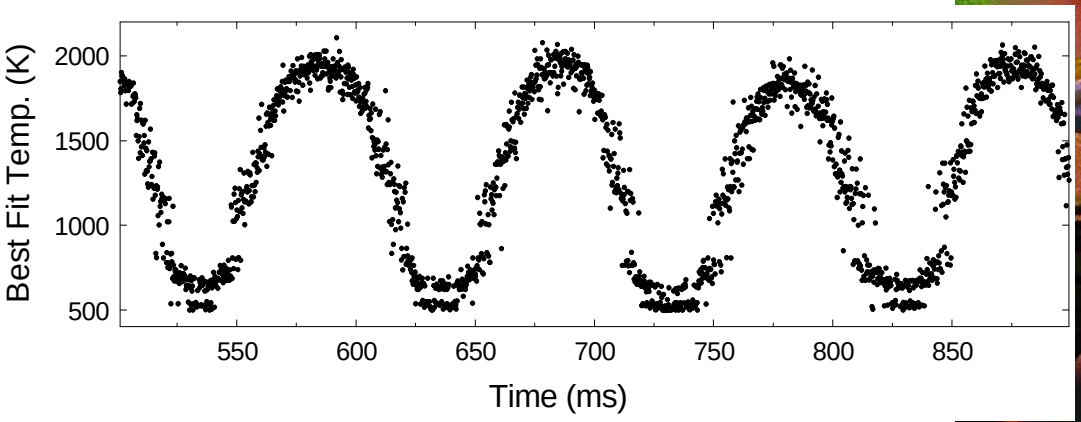
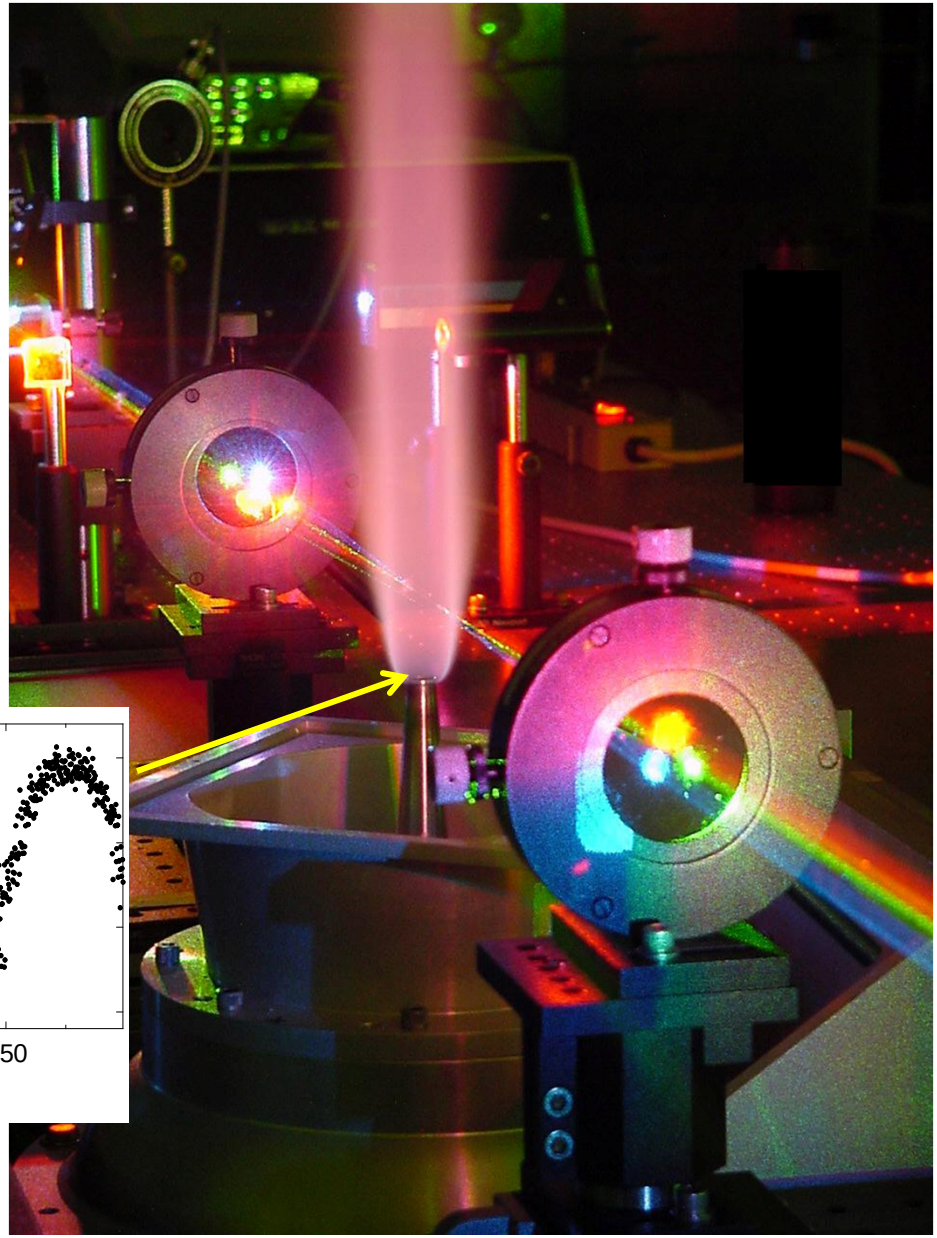
5 kHz Temperature Time Series from a Turbulent H_2/Air Diffusion Flame Near Nozzle





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Summary

- **Facilities for high-pressure gas turbine combustion are well suited for detailed RJIC studies at realistic pressure conditions.**
- **High-data-rate laser diagnostic measurements will provide new insights into the structure of the RJIC flow field including the flameholding region near the jet exit plane.**
- **Laser diagnostic facilities are state-of-the-art, new generation of high-data-rate systems coming on line.**

Acknowledgements

- PhD graduate students: Warren Lamont, Mario Roa, and Pratikash Panda.
- Managing Director of Zucrow Laboratories: Scott Meyer.
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