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Laser ignition of methane jets in homogenous and isotropic turbulence

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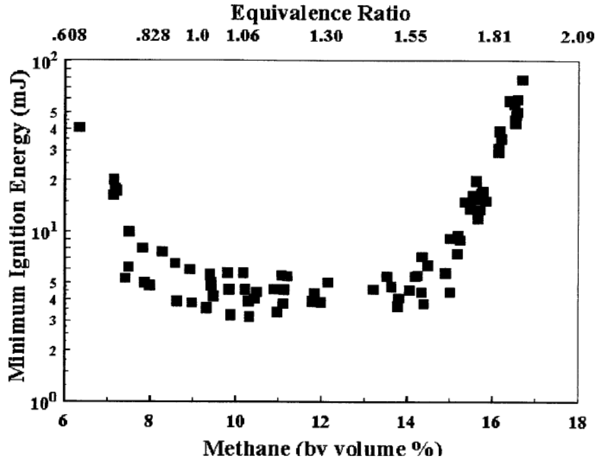
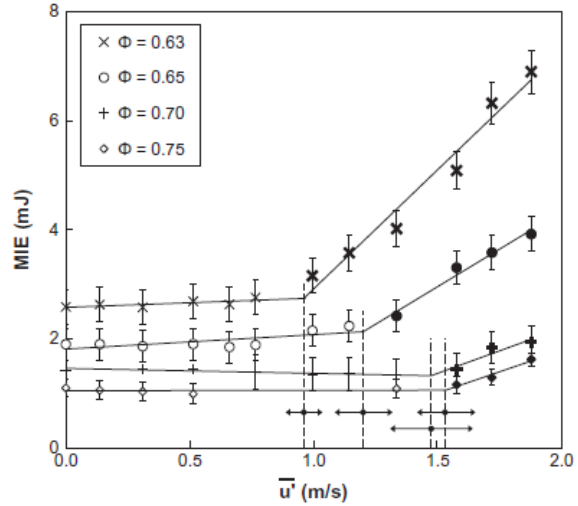
Motivation

- Minimum ignition energy (MIE) is an important parameter for ignition studies
  - Great dependence on local mixture fraction and flow conditions
  - ‘U’ shape relationship between MIE and equivalence ratio
- Few investigation into the influence of turbulence on laser ignition
  - In turbulent premixed methane/air flow, the MIE was found to increase with turbulent intensity
  - A transition in the increase was observed

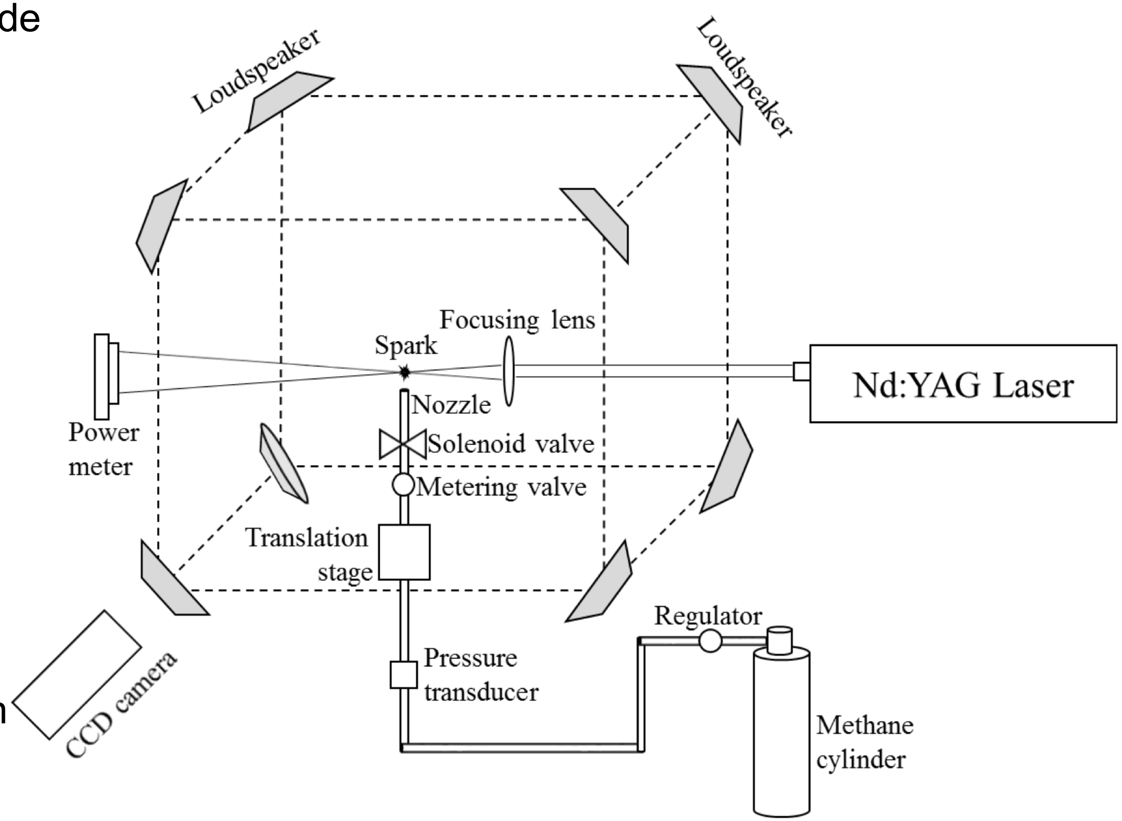




T.X. Phuoc et al., Combust Flame 119 (1999) 203-216
C. Cardin et al., Combust Flame 160 (2013) 1414-1427
C. Cardin et al., Comptes Rendus Mécanique 341 (2013) 191-200

Experimental Setup

1. Region of air, 40 x 40 x 40 mm^3 in size, is made turbulent
   - Use "box of turbulence" facility
   - Creates homogenous and isotropic turbulence (HIT)
   - Characterize turbulence using PIV
2. Pulsed methane jet ejected into HIT environment
   - Nozzle: 2 mm inner diameter, 0.6 mm lip thickness
   - Controlled by a solenoid valve, 100 ms injection duration
   - Re_{jet} = 160 (U_{jet} = 1.34 m/s)
3. Laser induced spark ignition inside HIT region
   - 532nm Nd:YAG laser, 5 ns pulse width
   - 50 mm focal length converging lens
4. Ignition results recorded by a CCD camera
   - Ignition attempted 300 times for each experimental condition at a rate of 1 Hz



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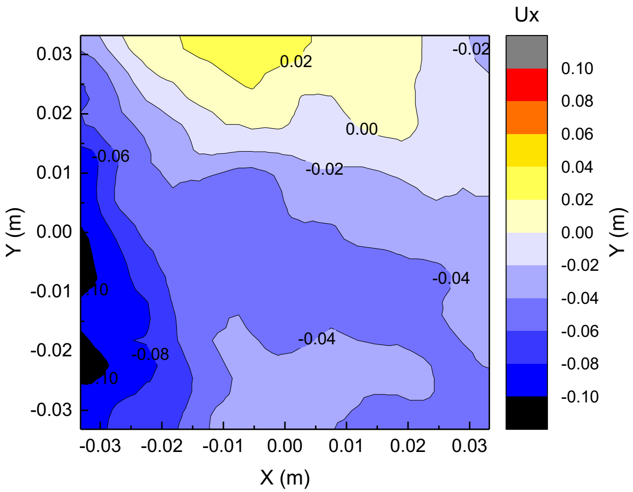
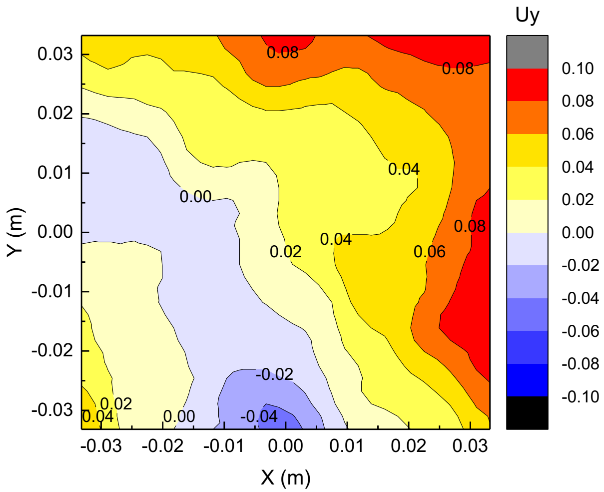
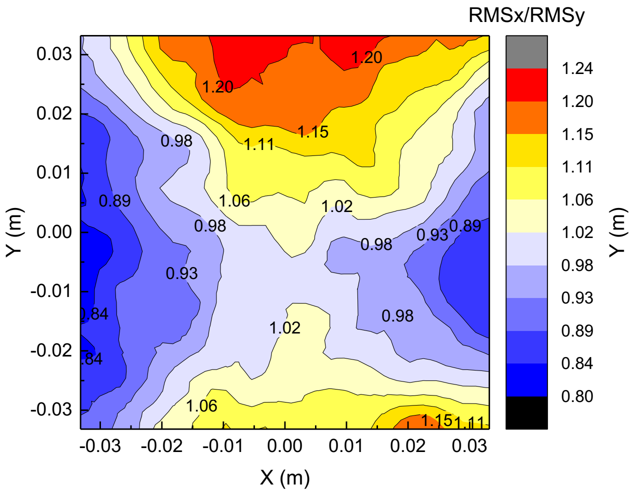
PIV Characterization



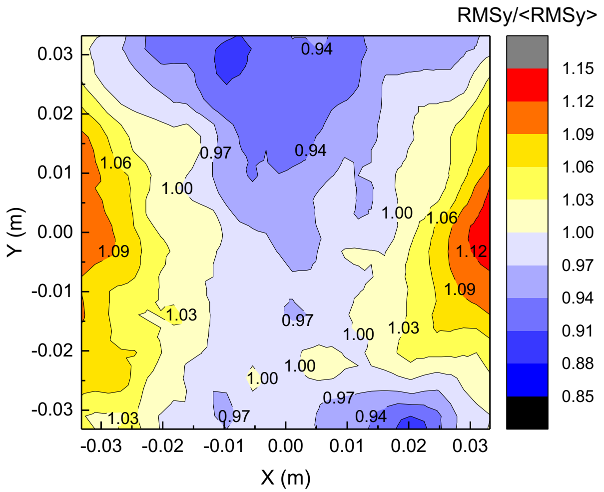
Mean velocity at x direction



Mean velocity at y direction



Isotropy

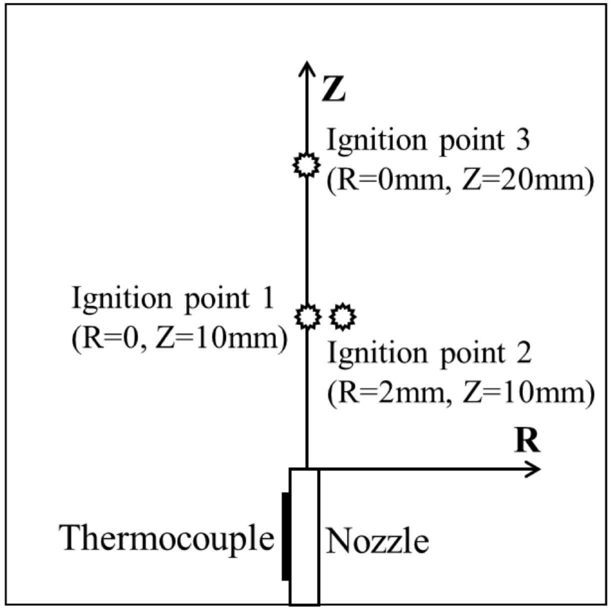


Homogeneity

Example flow field in ‘box of turbulence’ (Re_λ = 195, u’ = 0.38 m/s), characterized using PIV

- Near zero mean flow
- Great level of isotropy and homogeneity; inhomogeneity and anisotropy remain below 10%

Ignition Conditions

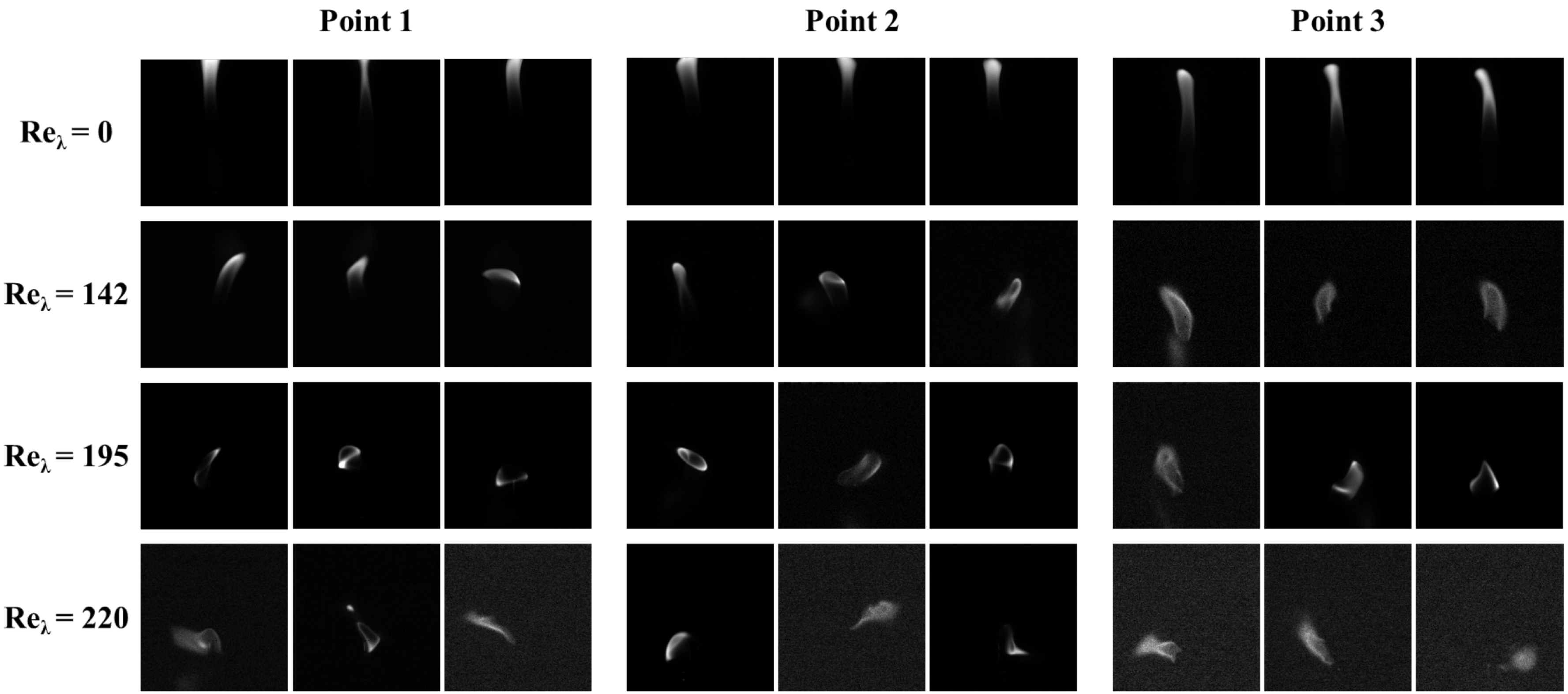


Nozzle inner diameter: 2 mm

1. Several ignition characteristics measured at three locations
   - Flame distribution
   - Ignition probability
   - Absorbed energy (E_3) , calculated from the difference between the laser incident energy (E_1) and transmitted energy (E_2)
   - Minimum ignition energy (MIE)
   - Nozzle temperature monitored using a thermocouple

2. Repeat measurements at different levels of turbulence in the surrounding air
   - Re_λ = 0, 142, 195, 220

Results – Flame Distribution



Some examples of the flame luminosity distribution

- When Re_{λ}=0, the flame always shows at the top centre of the image and develops in a rather axisymmetric way
- The position and shape of the flame becomes more unpredictable with increasing Re_{λ}

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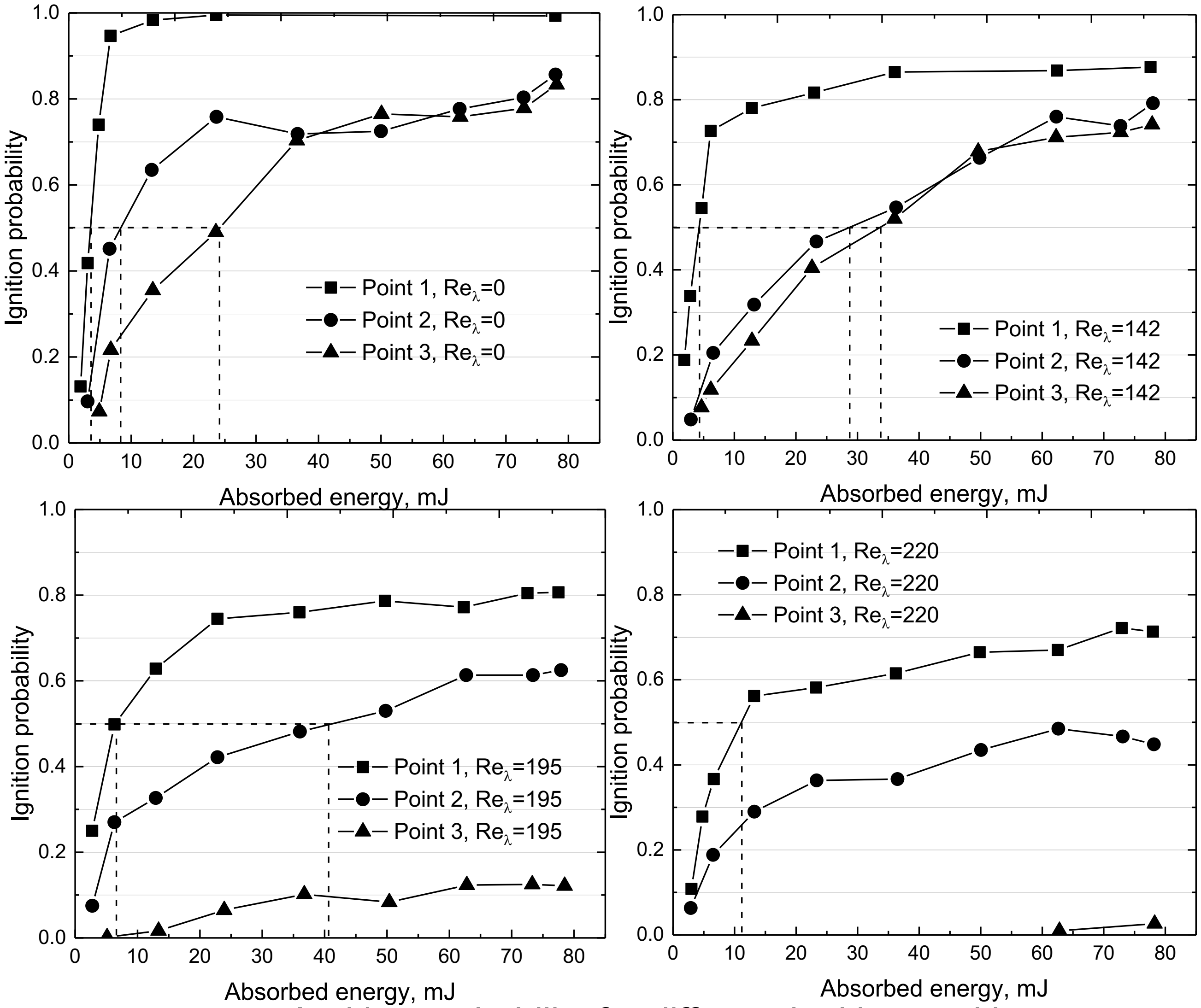
Results – Influence of Ignition Location



Ignition probability for different ignition positions for various levels of surrounding air turbulence

- MIE is defined as the absorbed energy[1] corresponding to a ignition probability of 50%, as shown in the figures
- MIE is in the order of Point 1 < Point 2 < Point 3 for all levels of turbulence
- For Point 3 at Re_λ=195 & 220 and Point 2 at Re_λ=220, MIE cannot be determined since the ignition probability never reaches 50%. However, it is reasonable to assume that MIE of point 3 should be much higher than point 2 at these cases due to the much lower ignition probability at point 3 than point 2

[1]Absorbed energy (E_3) is calculated from the difference between incident energy (E_1) and transmitted energy (E_2)

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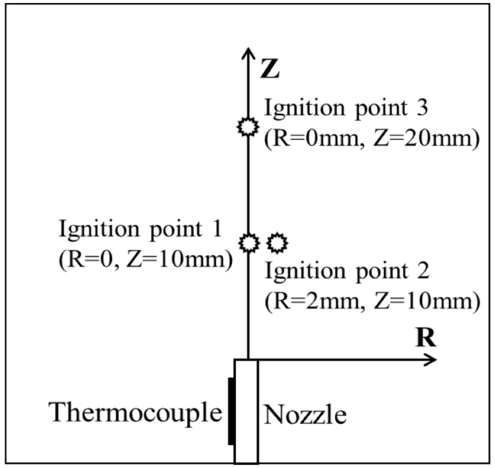
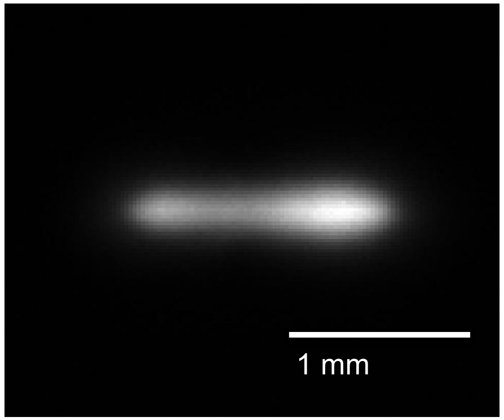
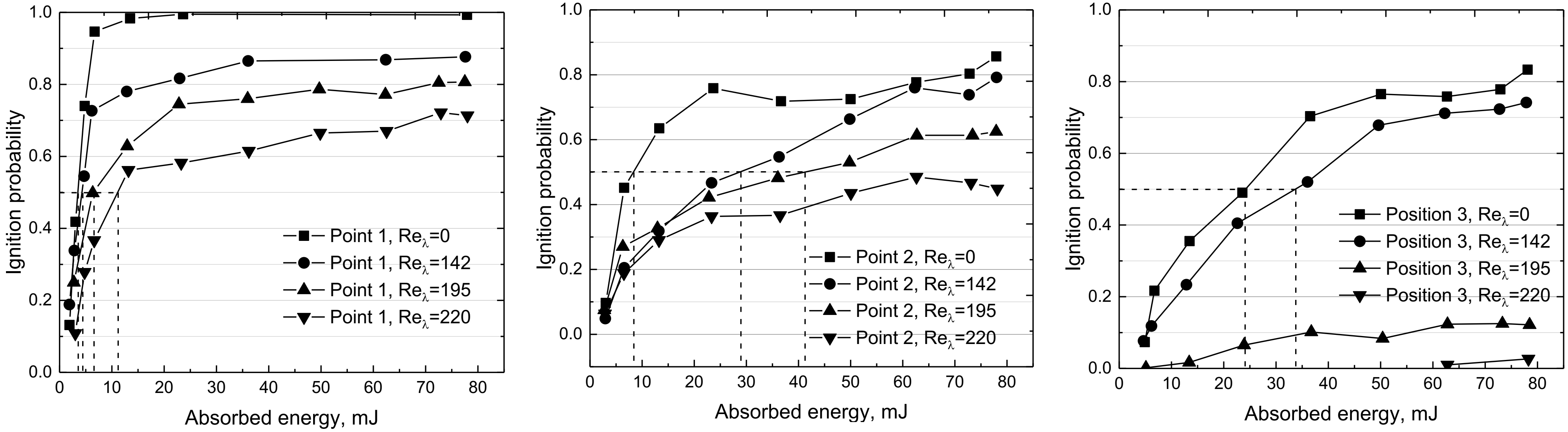
Results – Influence of Ignition Location





- Mixture fraction at Point 1 is expected to be higher than stoichiometric, while the mixture at Point 2 should be near stoichiometric
- The possible reason that Point 1 has lower MIE is the finite size of the plasma (about 1 mm long in the direction of the laser beam at 0.5 μs after the laser was fired)
- Plasma at Point 1 might expand to ignite the more flammable mixture near the jet/air mixing layer, leading to low MIE (jet width at this axial distance is about 4 to 6 mm)
- For the plasma at Point 2, about half of it expands in the air side of the mixing layer, of which the energy has no contribution to the ignition, leading to high MIE
- The effect of plasma size at Point 3 is less significant due to the larger jet width (about 10 mm) at this axial distance

Results – Influence of Turbulence



Ignition probability at various levels of surrounding turbulence at different ignition locations

- MIE increases with turbulent intensity at all three ignition locations
- This may be attributed to the increasing scalar dissipation rate introduced at the ignition location by the surrounding air turbulence

Summary and Future Work

- The position and distribution of the ignited flame become increasingly unpredictable with increasing Re_λ
- MIE is in the order of Point 1 < Point 2 < Point 3 for all levels of turbulence. The discrepancy between the MIE results and the local mixture fraction at these points might be caused by the finite size of the plasma, which has a more significant influence at locations near the nozzle tip
- MIE increases with turbulent intensity at all three ignition locations
- Future work includes MIE measurements for more ignition locations and turbulent intensities. The local mixture fraction will also be measured to investigate its correlation with the MIE results