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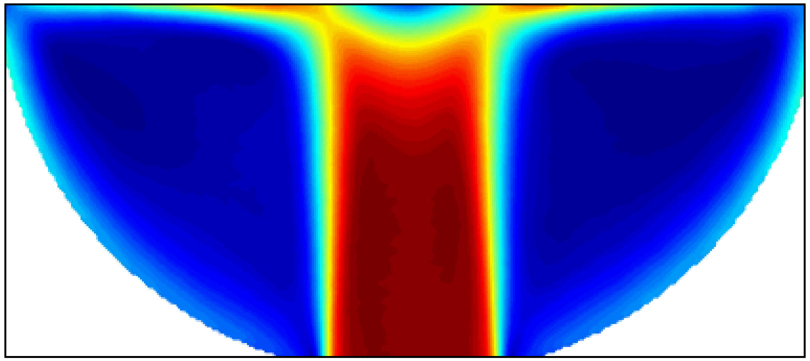

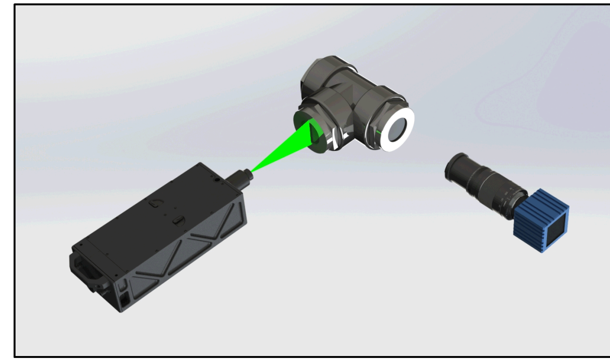

Printed Circuit Heat Exchanger Flow Distribution Measurements

Blake Lance

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Printed Circuit Heat Exchangers (PCHEs) are critical to sCO2 Brayton cycles

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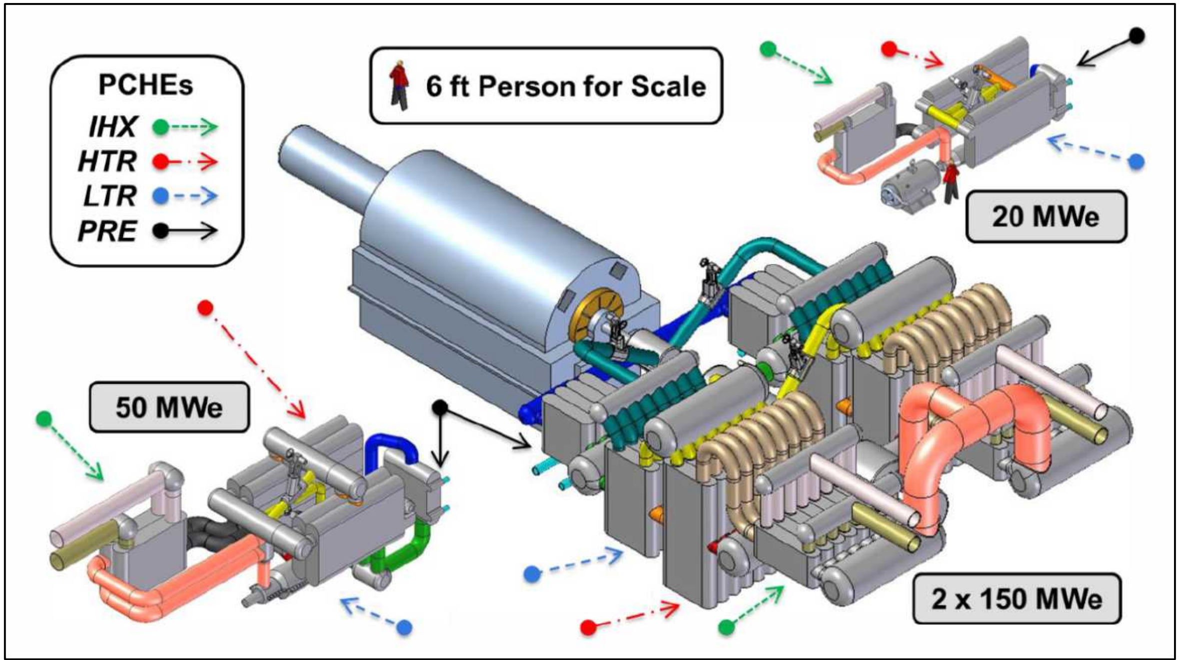
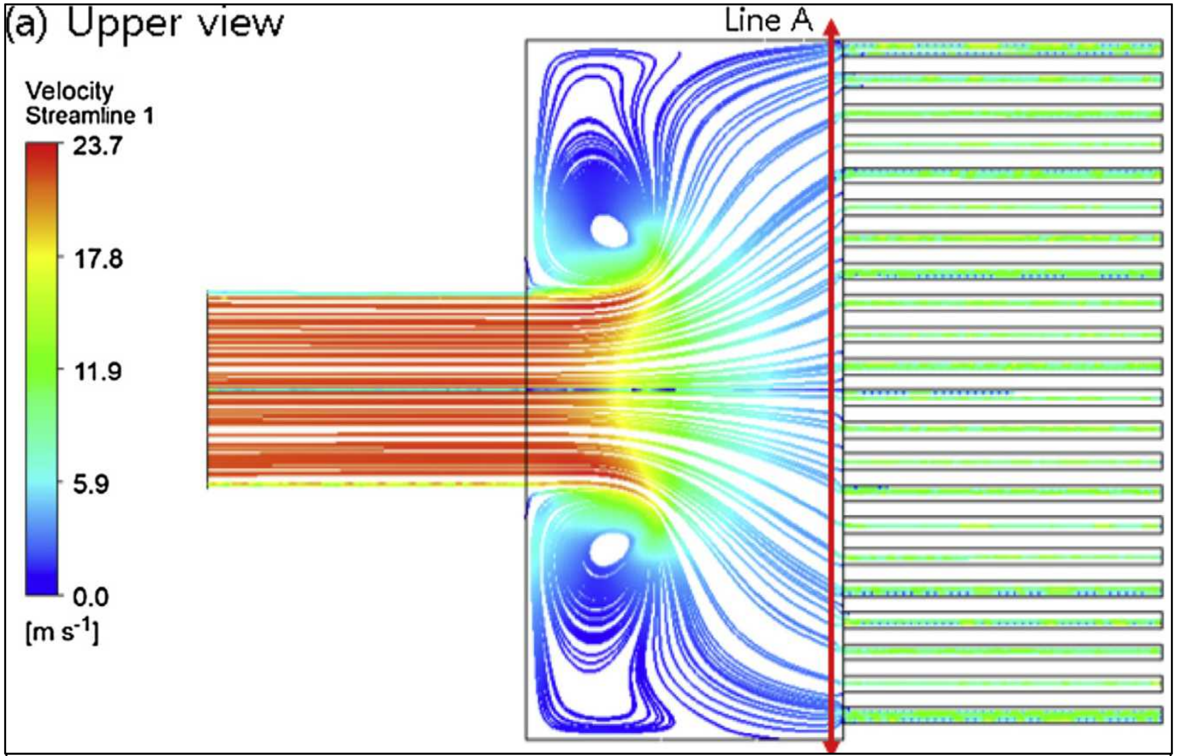
- Reduced size and cost compared with traditional heat exchangers for high pressures
- sCO_2 cycles rely on high levels of recuperation
- PCHEs comprise about 35% of the cycle component costs



Gibbs, J.P., Hejzlar, P., Driscoll, M.J., "Applicability of Supercritical CO2 Power Conversion Systems to GEN IV Reactors," Center for Advanced Nuclear Energy Systems MIT Department of Nuclear Science and Engineering, Cambridge, MA, Topical Report MIT-GFR-037, Sep. 2006.

Flow maldistribution in PCHEs reduces effectiveness

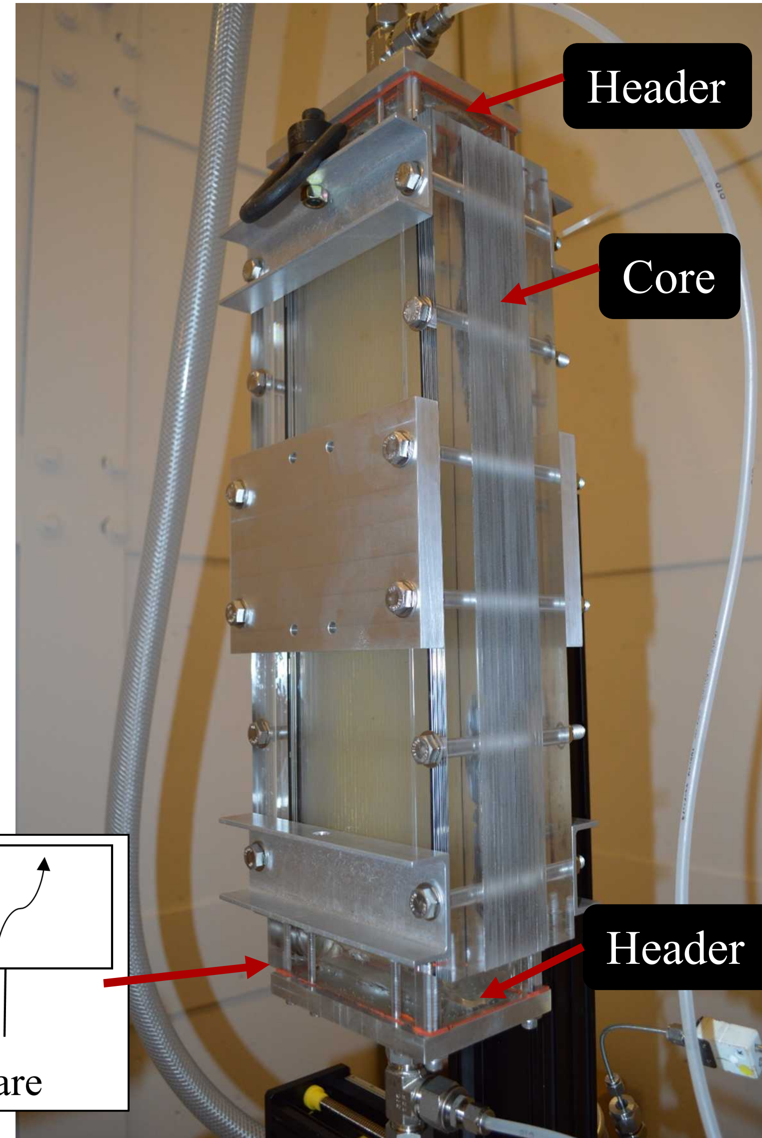
- Flow maldistribution can have a significant impact on compact heat exchanger effectiveness with reductions of 5-15%
- Others have predicted flow maldistribution with computational fluid dynamics (CFD)
- No experimental data are known for this issue

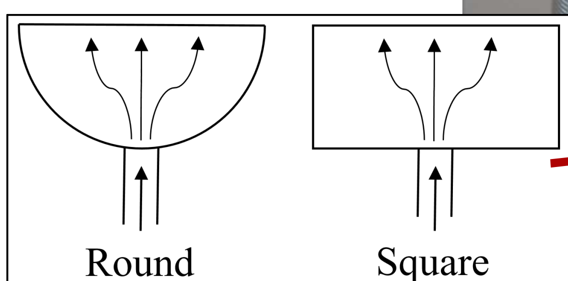


Baek, S., Lee, C., and Jeong, S., 2014, "Effect of Flow Maldistribution and Axial Conduction on Compact Microchannel Heat Exchanger," Cryogenics, 60, pp. 49-61.

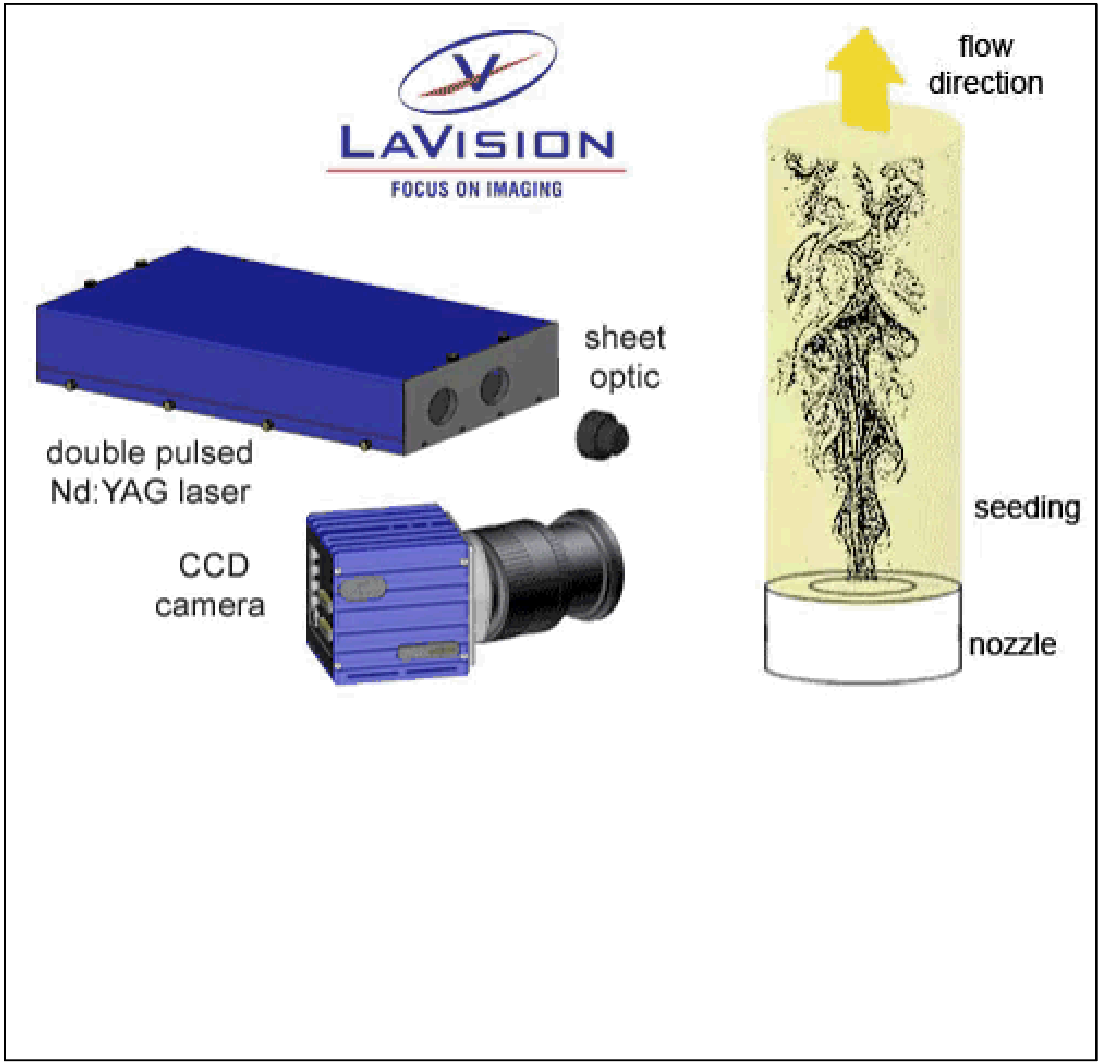
Measurements of compact heat exchanger flow distribution

- We are performing the first known measurements of flow distribution in compact heat exchangers
- An acrylic prototype was made for use in water
- An optical system called Particle Image Velocimetry (PIV) was used to measure flow fields



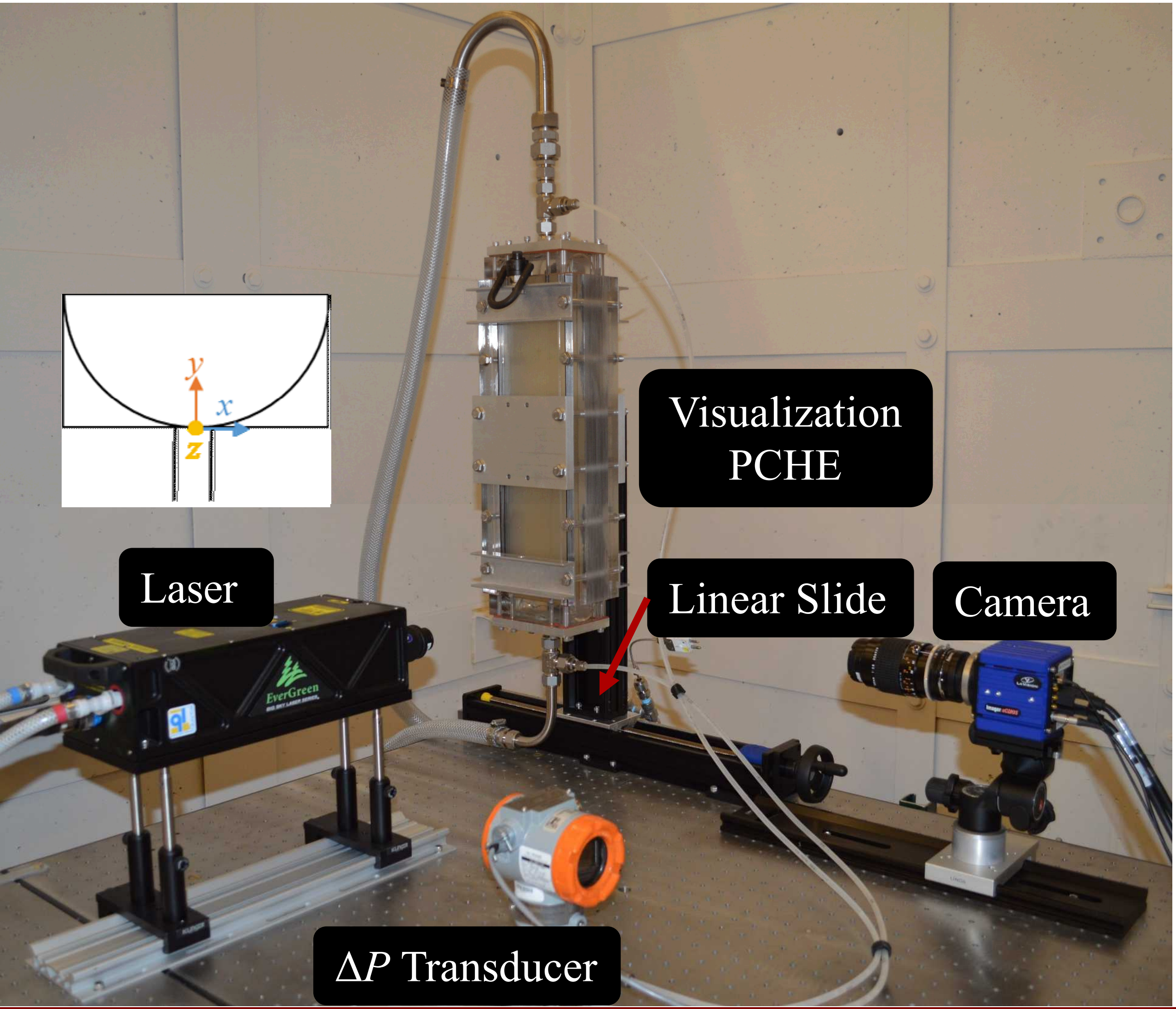


Particle Image Velocimetry (PIV) allows flow fields to be measured optically



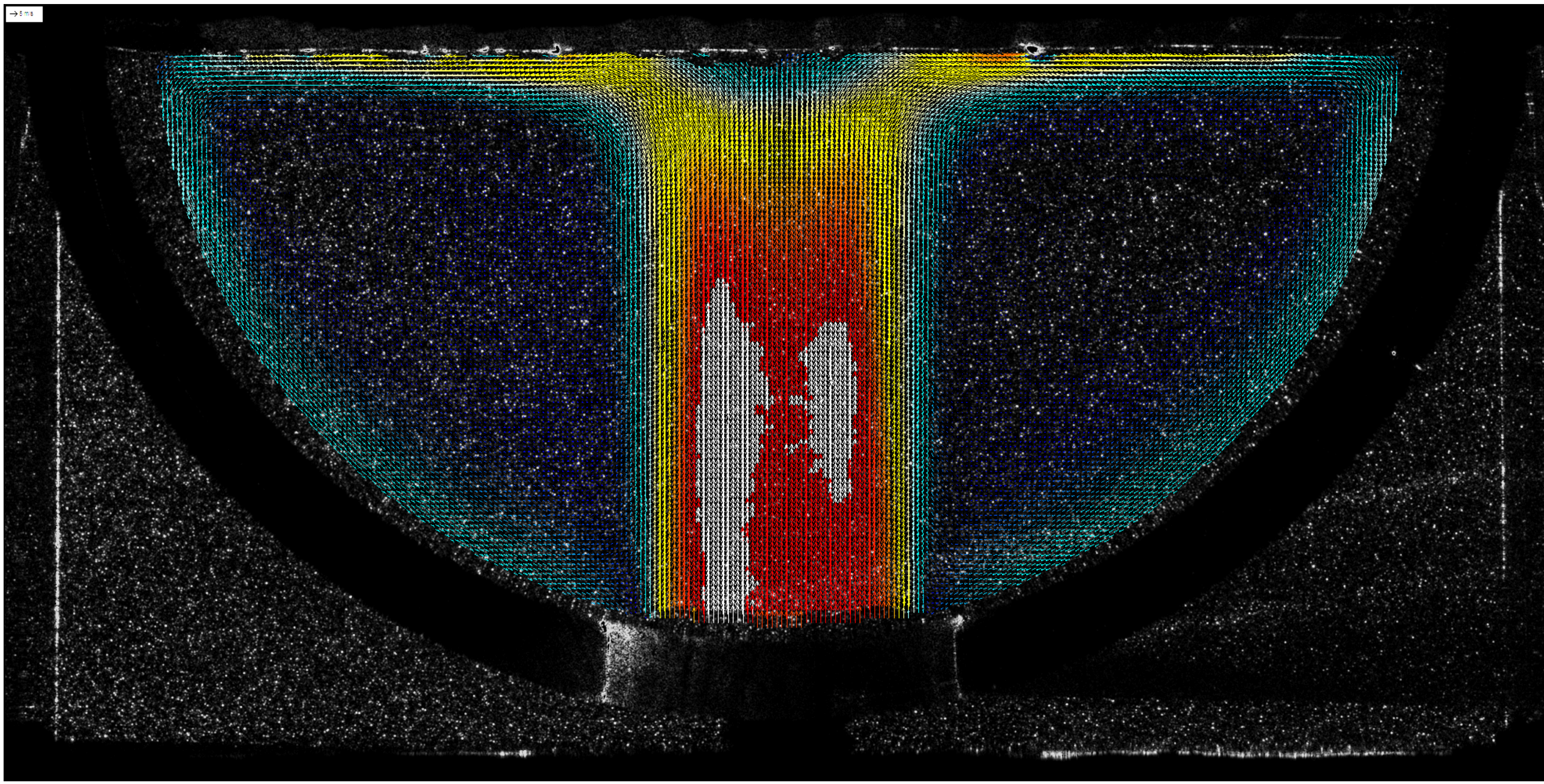
LaVision, http://www.lavision.de/en/techniques/piv.php

The PIV system provides optical measurements in planes

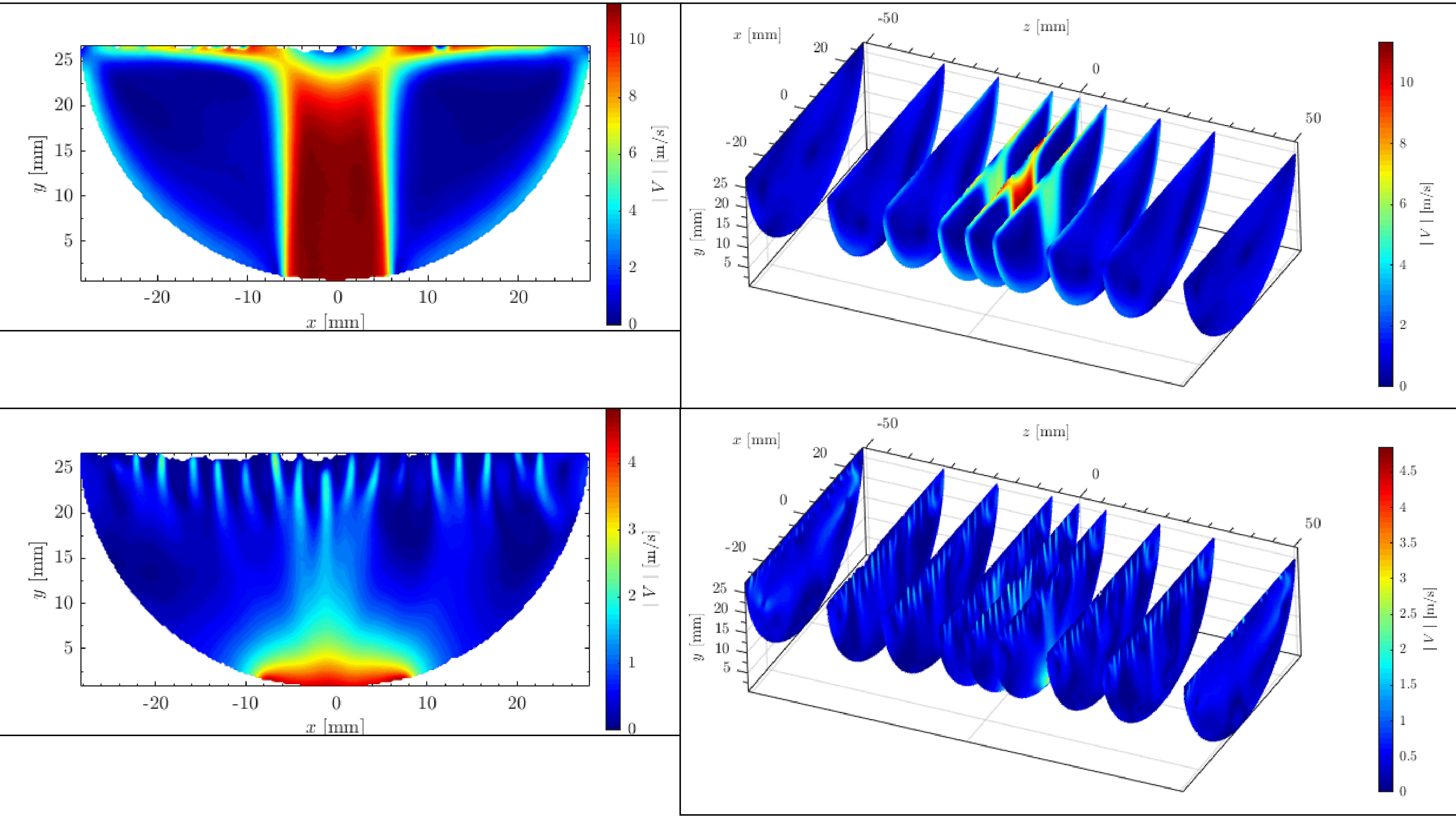


- The PIV system includes a laser, camera, timing unit, and computer
- Flow planes are measured in the lower header that is translated in *z* to map out the volume

The particle and vector fields show the geometry and data



The velocity magnitude plots show non-uniform flow distribution for Round geometry



The velocity magnitude plots show non-uniform flow distribution for Square geometry

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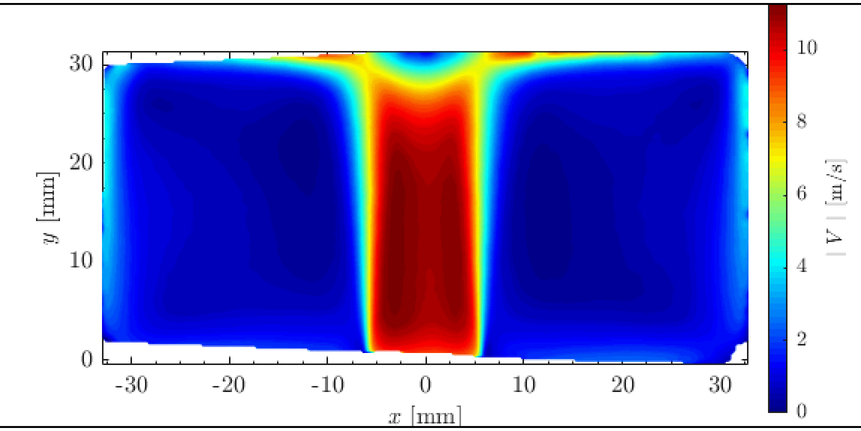
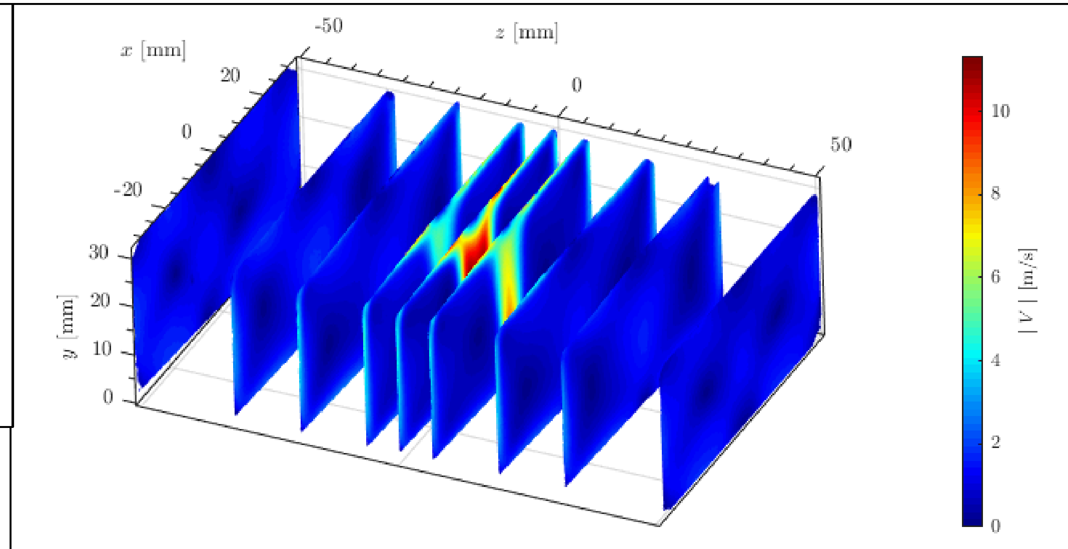
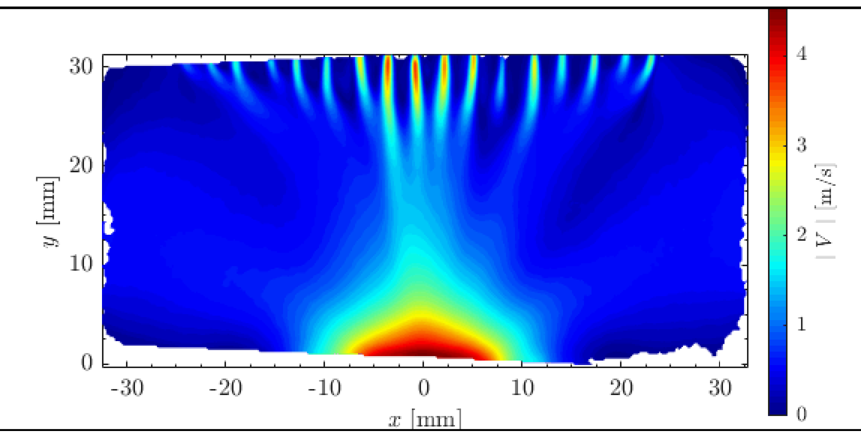
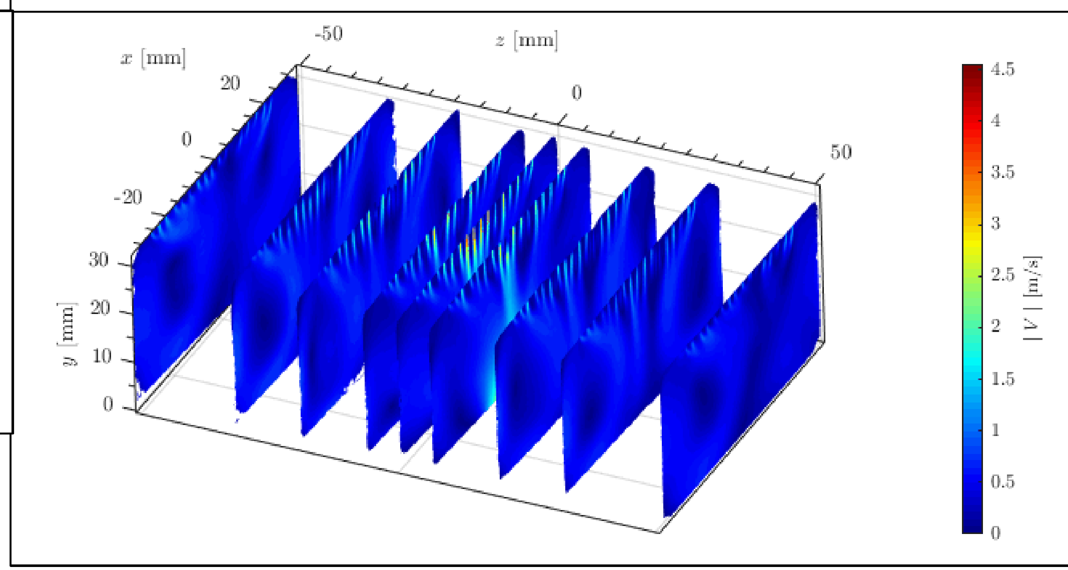
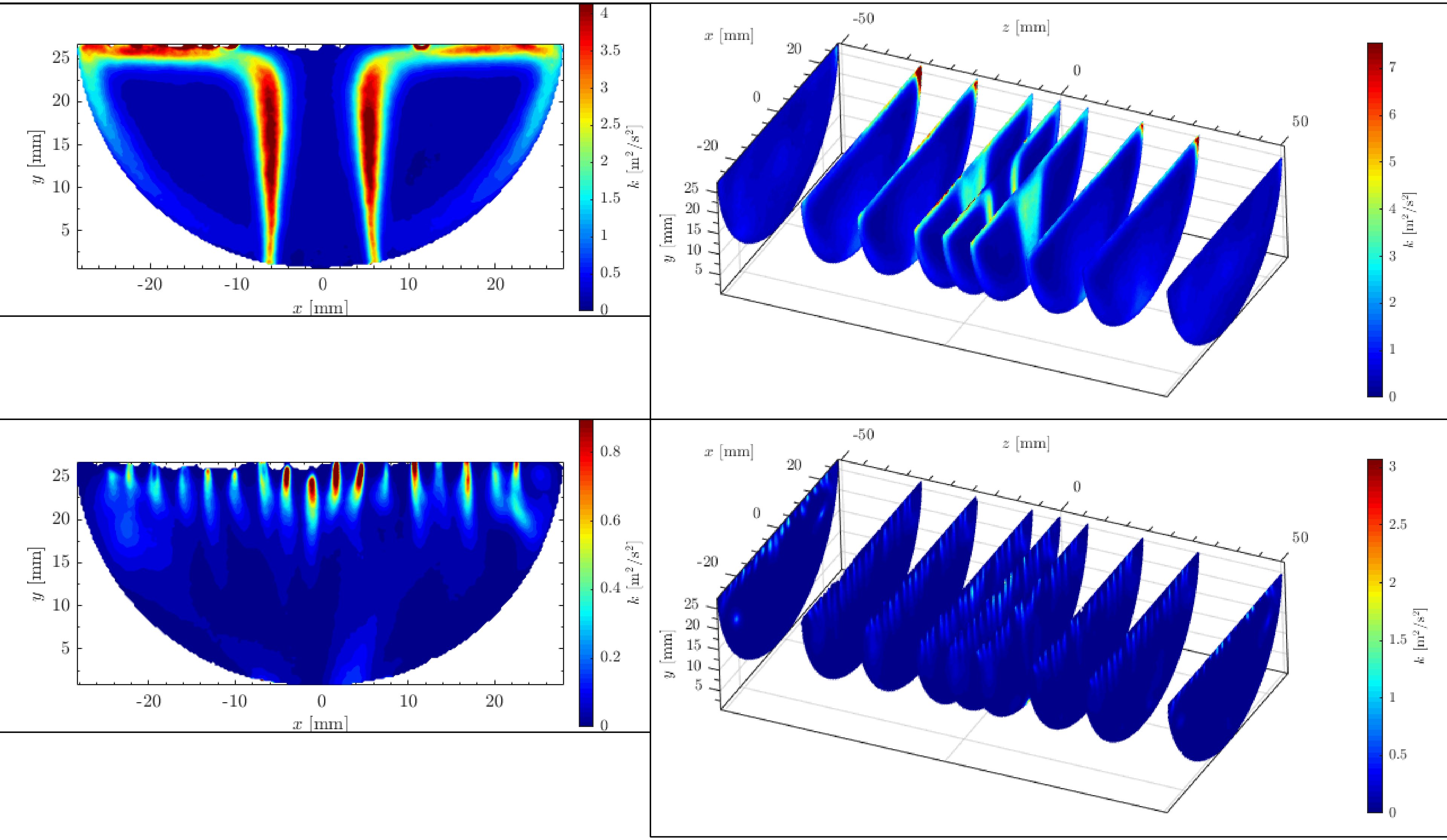






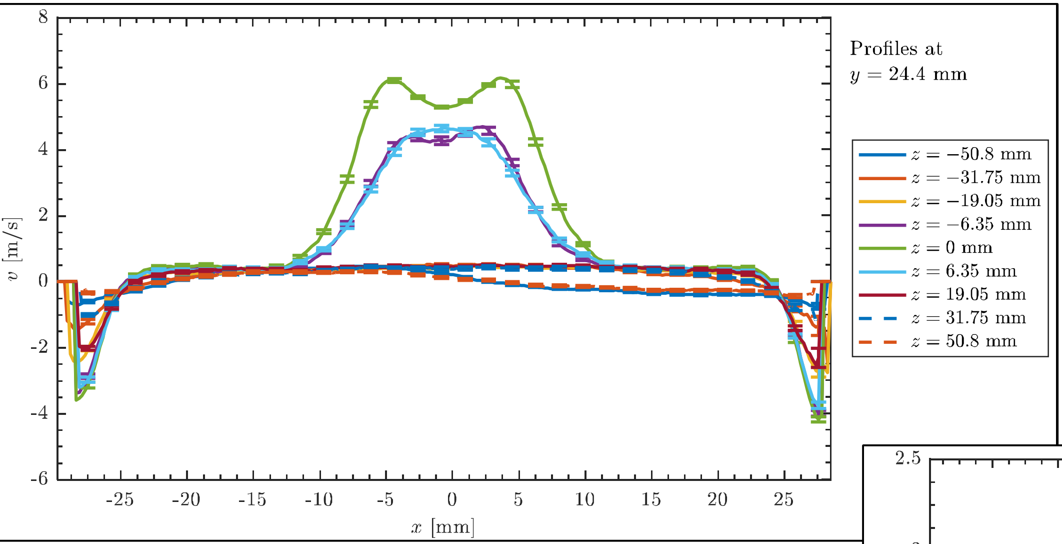


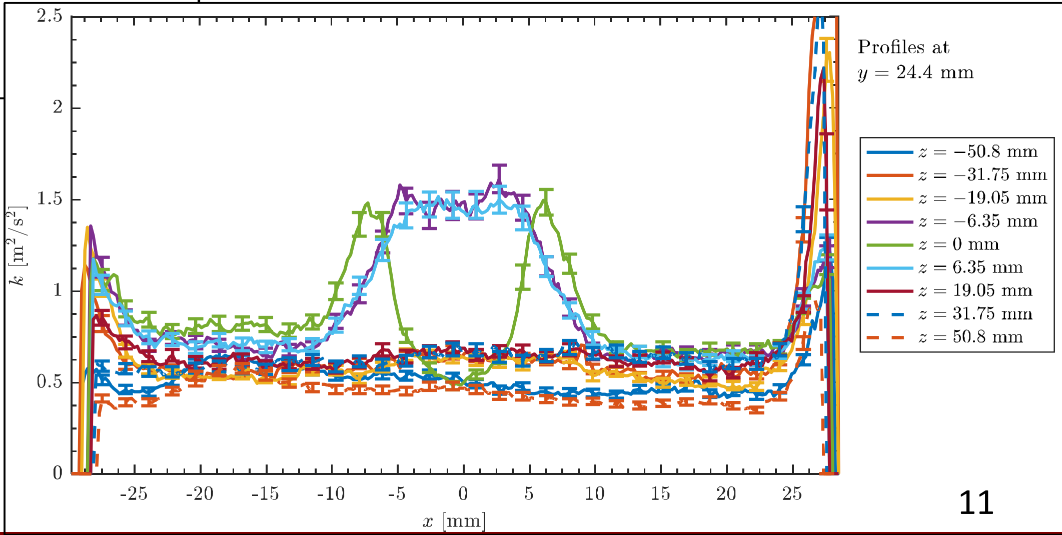
The turbulent kinetic energy was also measured and can be a very useful CFD validation quantity



Uncertainty on time-mean velocity and turbulent kinetic energy were calculated

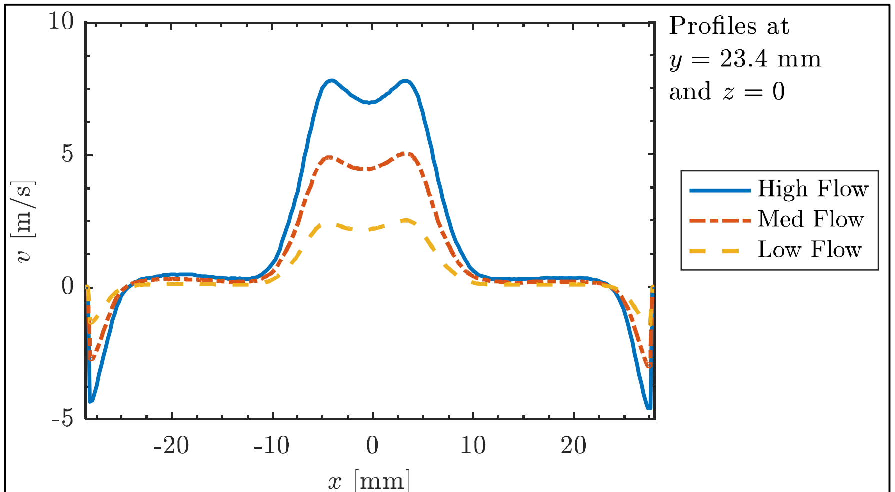
- Experimental uncertainty estimates are essential to validation activities

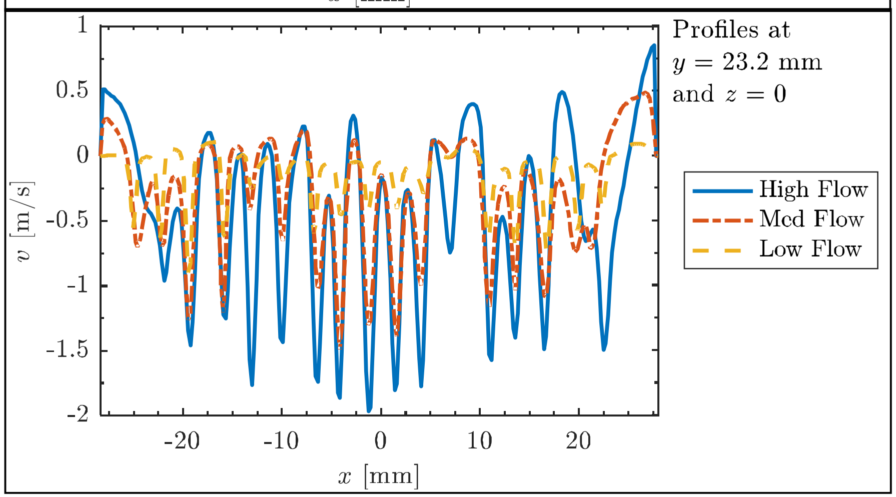




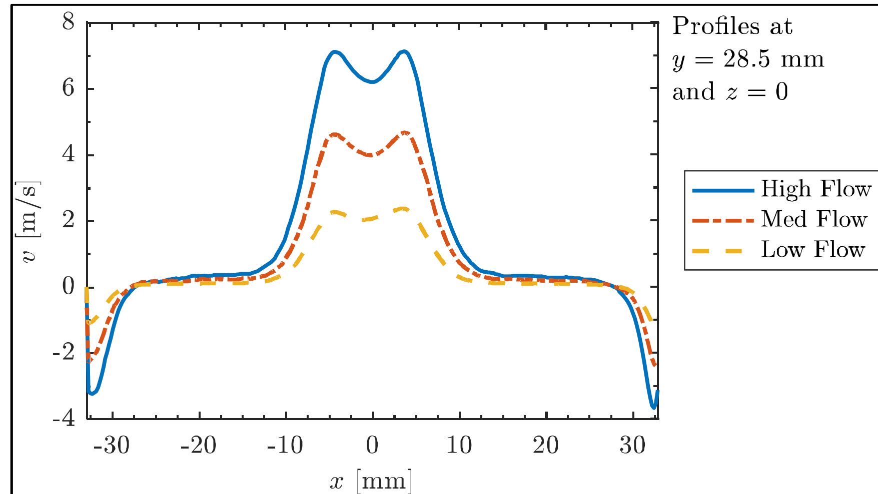
The results show self-similar velocity profiles with different flow rates as expected

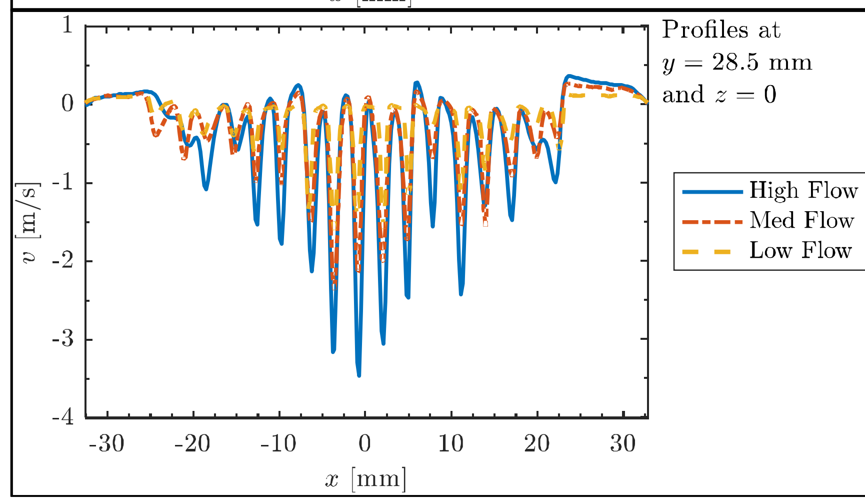
Round





Square





The Coefficient of Variation (CoV) is a measure of flow maldistribution

$$\text{CoV} = \frac{\text{standard deviation } (\sigma)}{\text{average } (\mu)} = \frac{\sqrt{\sum_{i=1}^{N}(\dot{m}_i - \bar{\dot{m}})^2 / N}}{\bar{\dot{m}}}$$

- We measured velocity, not mass flow, but they are synonymous for incompressible water with constant area.

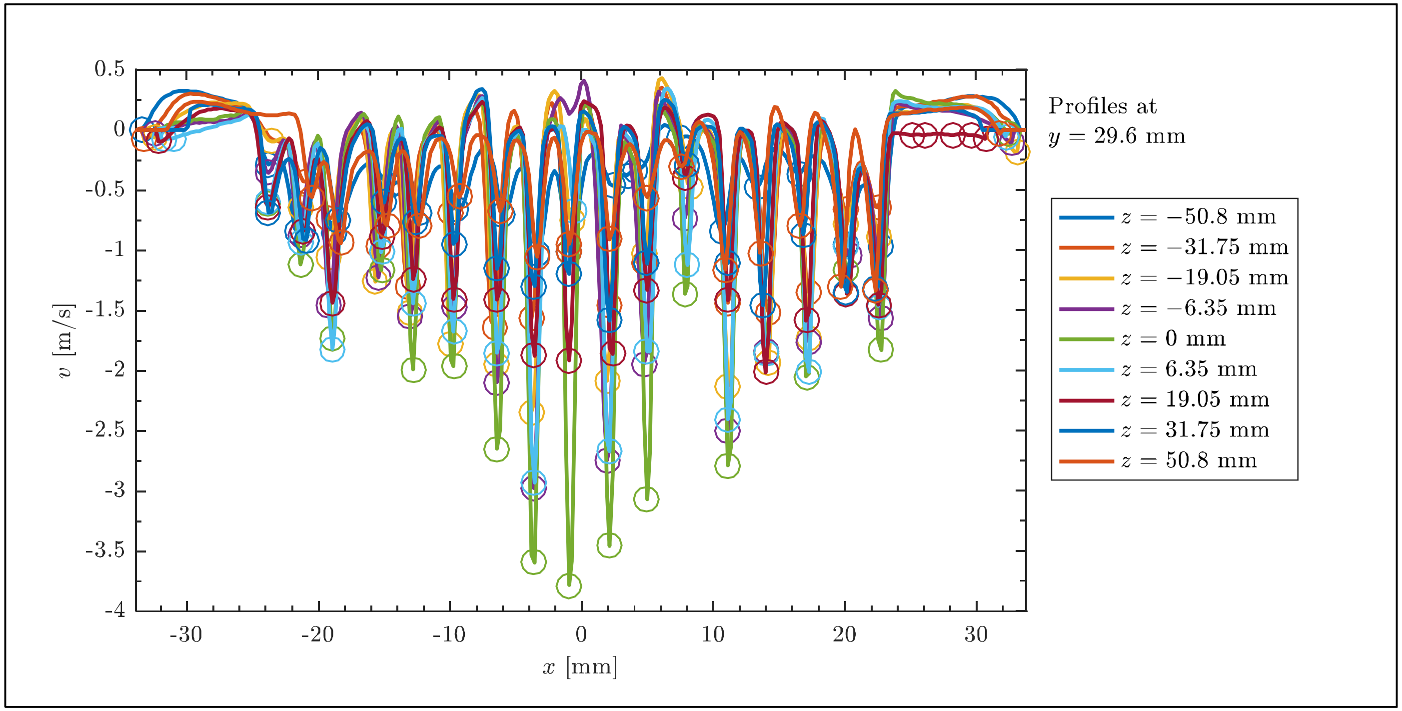
$\dot{m} = \rho V A$ $\quad\quad$ ρ =constant $\quad\quad$ A =constant

$$\text{CoV} = \frac{\sqrt{\sum_{i=1}^{N}(V_i - \bar{V})^2 / N}}{\bar{V}}$$

Baek, S., Lee, C., and Jeong, S., 2014, "Effect of Flow Maldistribution and Axial Conduction on Compact Microchannel Heat Exchanger," Cryogenics, 60, pp. 49-61.

Channel uniformity is assessed by measuring the velocity in outlet header

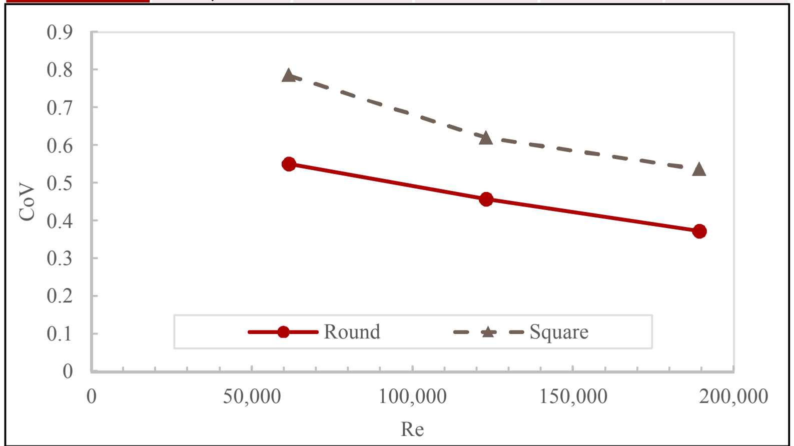
- Local velocity maxima are used for channel velocity (circles)
- The three center-most profiles have the largest velocity and show parabolic behavior
- The channel velocity changes by a factor of about 5 in space for this square header case

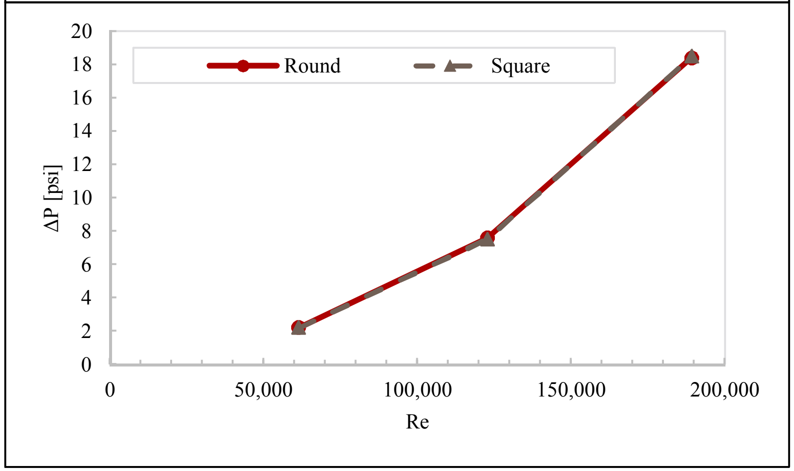


The CoV is larger for square headers but decreases with increasing jet Reynolds number

- CoV is much higher for the square geometry, suggesting the round headers guide the flow to be more uniform.
- CoV is lower for increasing Reynolds number based on the jet diameter.
- Comparing CoV to Baek et al., the effectiveness should be reduced by 5-8%.
- Pressure drop is a strong function of flow rate but not header geometry.
- sCO2 typically has large Reynolds numbers due to moderately high density with low dynamic viscosity.

		CoV		ΔP [psi]	
Q [gpm]	Re	Round	Square	Round	Square
18.5	189,000	0.373	0.537	18.4	18.5
12.0	123,000	0.457	0.621	7.58	7.52
6.0	61,400	0.550	0.786	2.20	2.20





Conclusions and future work

- Future work will include experiments in water with an oblique jet, z-side channels, and novel header geometries.
- Future simulations will include a validation study using the measured velocities in water. When confidence is gained, the simulation will be extended to sCO_2 and results analyzed.
- We will attempt PIV flow measurements in sCO_2 later this year.