Simultaneous planar measurements of fluid and particle velocities in particle-laden flows: proof-of-concept

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Introduction:

Simultaneous measurement of gas- and particle- phase velocities is of vital importance to advance understanding of the complex interactions between the two phases in particle-laden flows. The conventional velocity measuring method, namely particle image velocimetry (PIV), suffers from the signal cross-interference between phases as their implemented scattering signals share the same wavelength and occur at the same time as the excitation laser. Although laser-induced fluorescence (LIF) and phosphorescence (LIP) are well-known to the family of phosphor thermometry, no study has demonstrated their capability of optical discrimination to allow their simultaneous velocity measurements in a particle-laden flow.

Research background:

- Optical discrimination technique will be used to simultaneously measure gas and particle velocities;
- These measurements will advance current understanding of particle-fluid interactions, including phenomena such as air entrainment and particle clustering;
- New understanding will be used to improve design and operation of relevant industrial system including Sandia's G3P3 falling particle receiver.

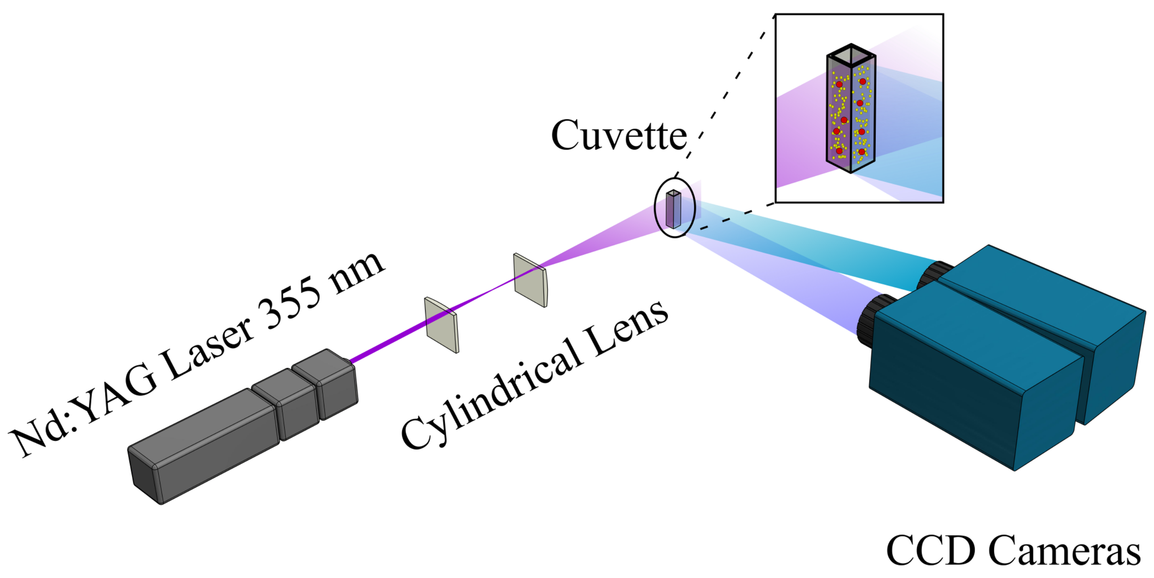

Figure 1: Measurements of LIP and LIF from 4 μm BAM:Eu^{2+} tracers and 250 μm PMMA particles within a water cuvette.

Detection channels	No. 1	No. 2
Objective signals	BAM:Eu^{2+} LIP	PMMA LIF
CCD cameras	PCO. 2000 (1)	PCO. 2000 (2)
Lens	Tamron 70-200 F/2.8	Cerco UV 100 F/2.8
Filters	LP 409 Semrock	BP 390 (BP18) Semrock
Exposure time (ns)	1000	1000
Delay to laser (ns)	+50	-950

Table 1: Imaging arrangement for separately capturing LIP and LIF.

Experimental results:

- The intensity of PMMA LIF is solely strong in the spectral region between 360 nm and 395 nm with a short lifetime on the magnitude of several nanoseconds (Figure 2);
- The intensity of BAM:Eu^{2+} LIP is solely strong in the spectral region between 400 nm and 520 nm after 50 ns delay of the laser pulse (Figure 2), with a lifetime of 1 μs, relatively "short" to the fluid time-scales;
- Background noises are below 100 counts (Figure 3.a~d & Figure 4); Solely corresponding signals are captured by the responsible camera when seeding only one type of particles (Figure 3.a ~ d & Figure 4);
- The signal-to-noise ratio is larger than 23 (Figure 3 & Figure 4).

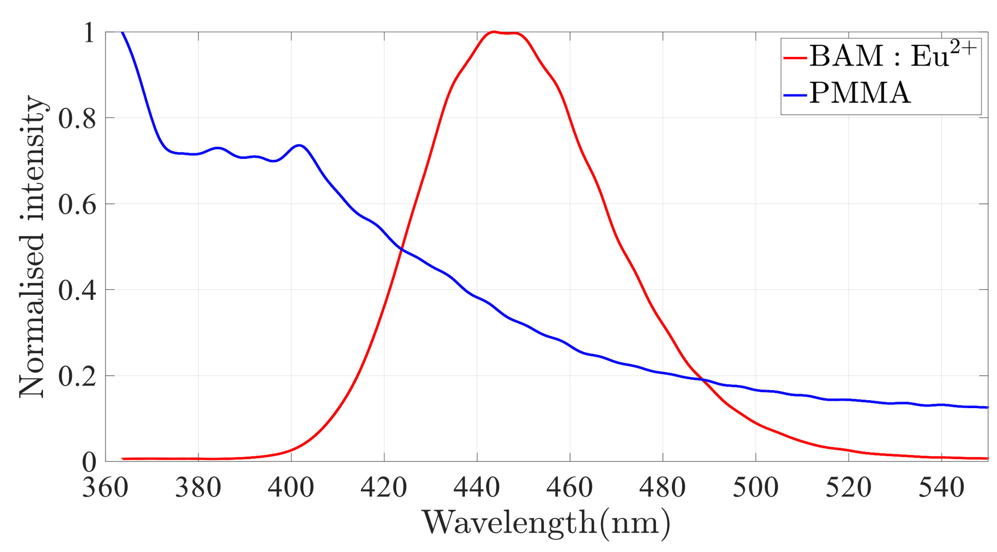

Figure 2: Laser-induced emission spectra of BAM:Eu^{2+} tracers and PMMA particles (355 nm), respectively normalised by their peak values. The emitted spectrum of BAM:Eu^{2+} was recorded after 50 ns delay of the laser pulse, while the PMMA emitting signals were recorded without delay.

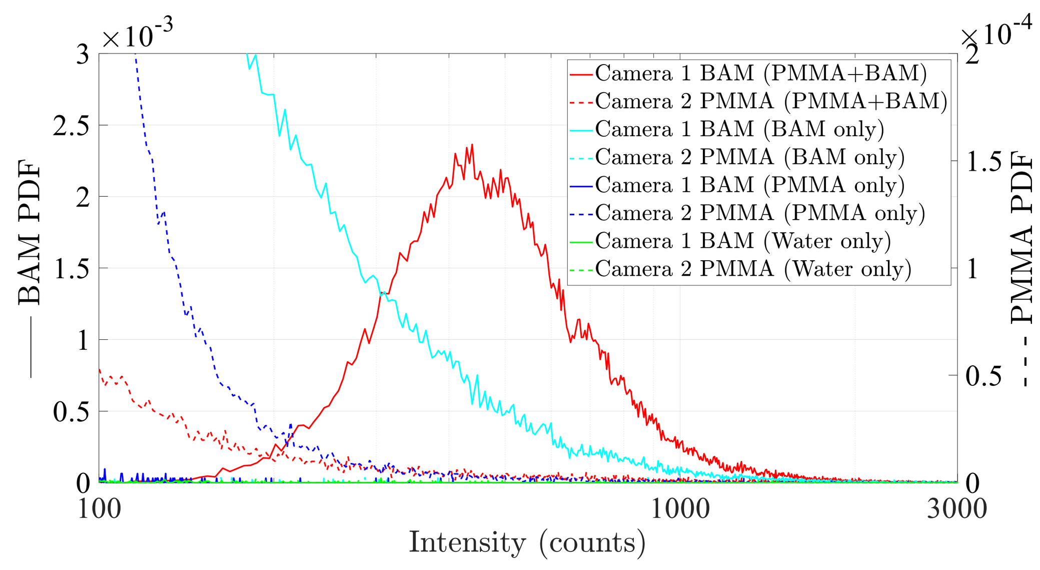

Figure 4: Intensity distribution (PDF) of signals captured by both cameras. Each PDF graph was normalized to achieve the area below each line to be 1.

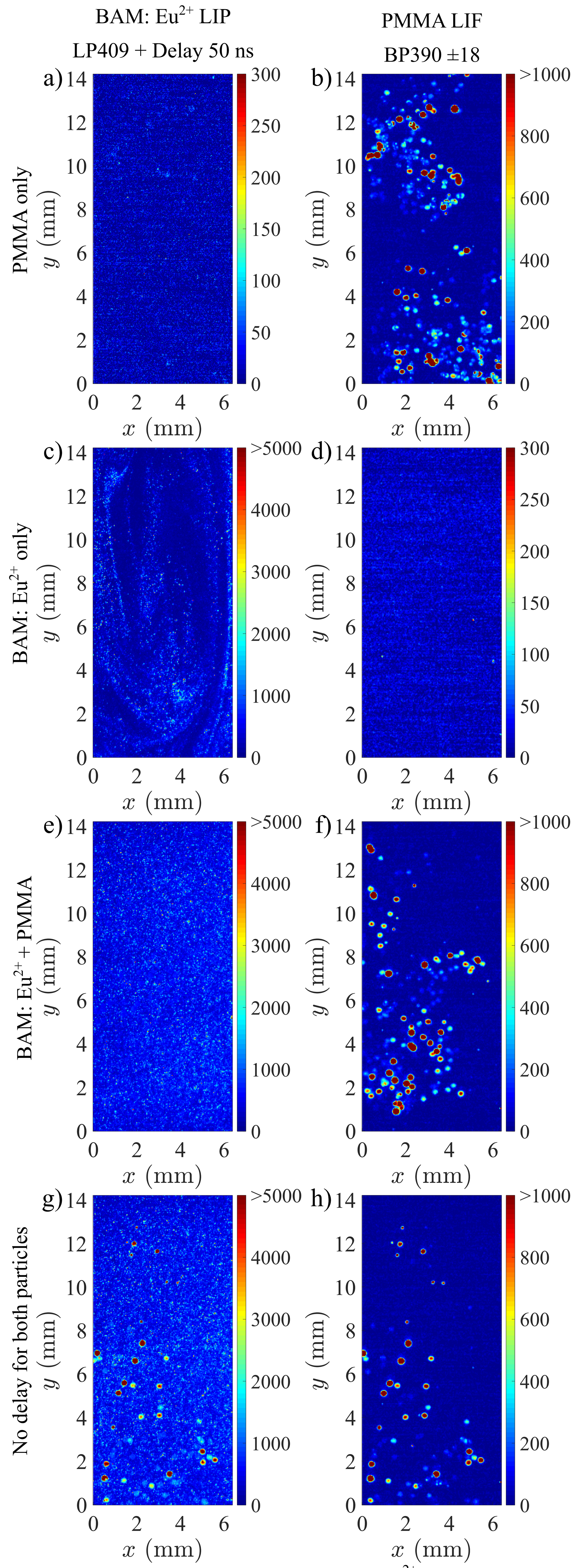

Figure 3: Simultaneous images of BAM:Eu^{2+} LIP and PMMA LIF.

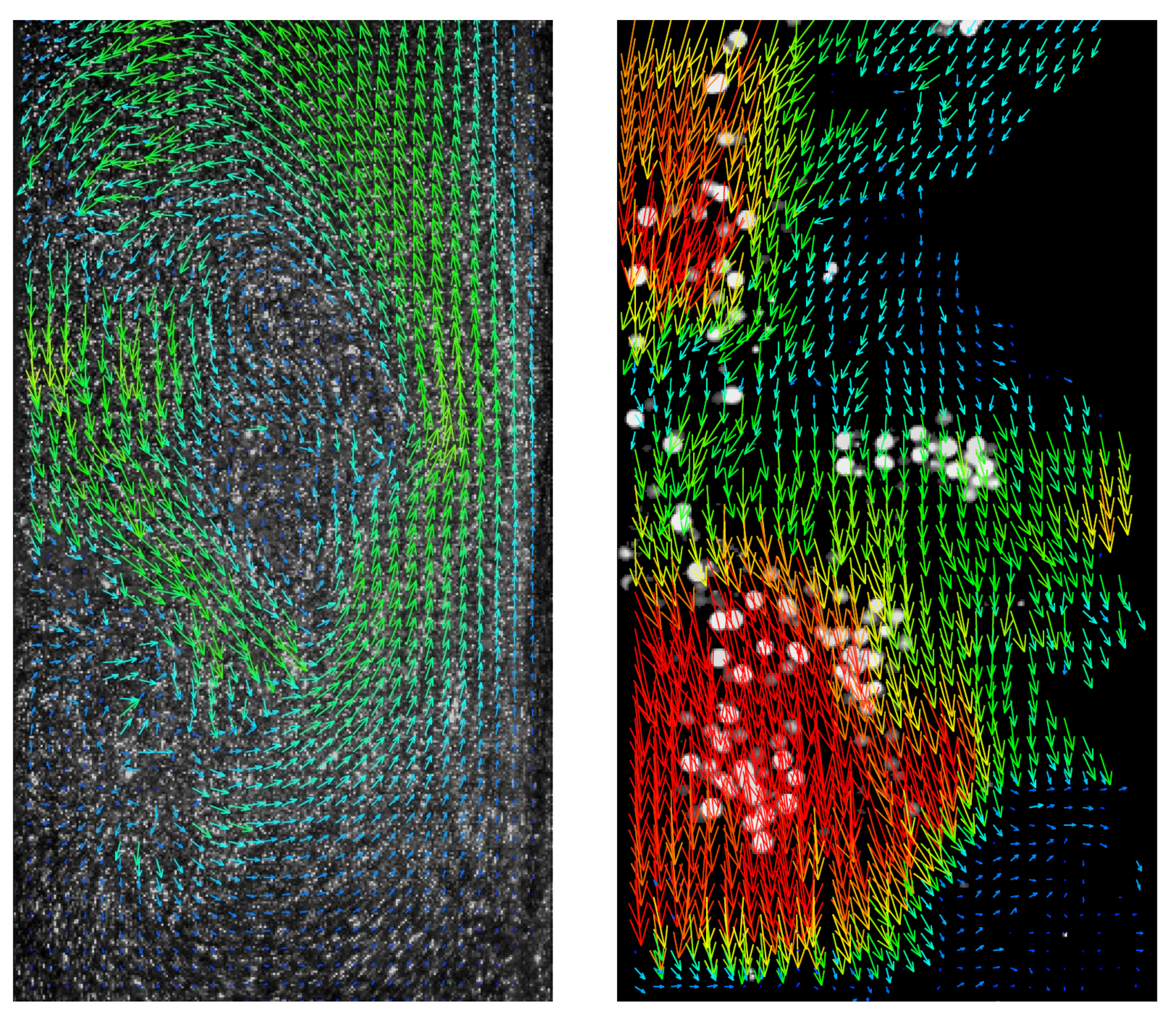

Figure 5: PIV images of BAM:Eu^{2+} tracers and PMMA particles within a water cuvette.

Conclusions:

- PMMA and BAM:Eu^{2+} forms a strong candidate pair for phase discrimination in particle-laden flows, together with optical filtering and camera triggering delay.
- Both PMMA LIF and BAM:Eu^{2+} LIP signals captured by non-intensified CCD cameras are sufficiently strong with low noises for their simultaneous velocity measurements.

Future work:

- Applying this phase discrimination technique in gas-particle flows to demonstrate its viability of particle and gas velocity measurements in a high velocity field.
- Applying this phase discrimination technique in particle curtain flows to demonstrate its viability of gas-phase velocity measurements in a particle-dense condition.

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