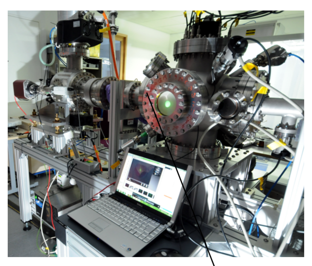
Beam Characterisation Using Laser Self-Mixing

A. Alexandrova, C.P. Welsch
Cockcroft Institute, Warrington, WA4 4AD, United Kingdom
University of Liverpool, Department of Physics, Liverpool, L69 7ZE, United Kingdom.

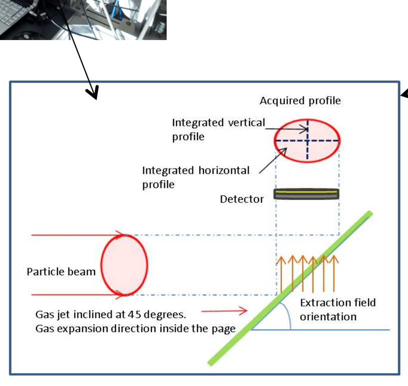
Abstract

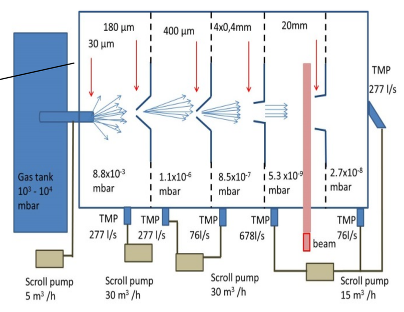
Non-destructive beam diagnostics are highly desirable for essentially any accelerator or storage ring. This concerns the characterization of the primary beam itself, but also for example of atom and molecular jets that are crossed with the primary beam as experimental targets or for diagnostics purposes. A laser feedback interferometer based on the optical self-mixing effect provides a low-cost, robust, compact and non-invasive sensor for velocity, displacement and density measurements of various targets. This poster presents results from theoretical and experimental studies into the factors influencing the performance and accuracy of this sensor. Parameters that have been assessed include the target velocity, the size of scattering particles, their density, type and scattering properties.

The Task: Gas-Jets



Gas targets are important for a number of accelerator-based applications. Detailed information about the gas jet is important for its optimization and the quality of the beam profile that can be measured with it.

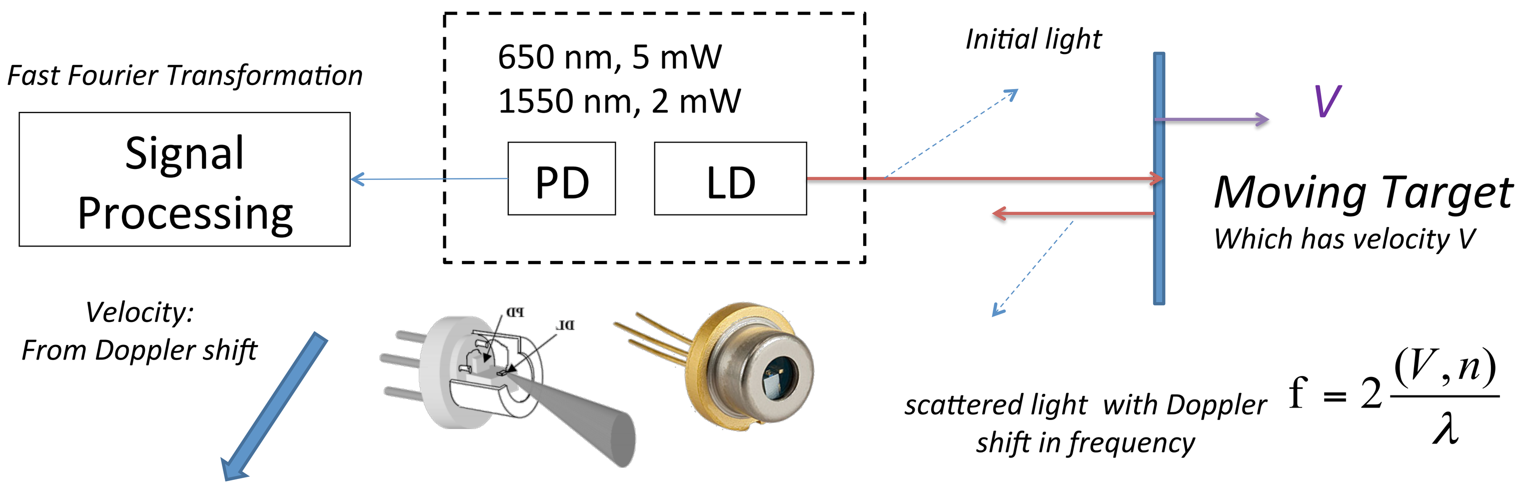




in-detail characterization of the gas jet:
- *Gas: Ar, N_2, He*
- *Velocities: 100-2000 m/s*
- *Density:* $10^9 - 10^{12}$ particles/cm^3
- compact and cheap

Solution: Self-Mixing Laser Diode

Small portion of light is reflected from the study object and returned into the laser cavity. It is then mixed with the original wave inside the laser.



$$f = 2\frac{(V,n)}{\lambda}$$

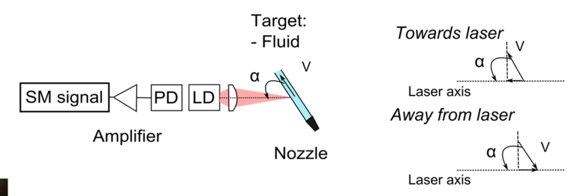
Calculated level of the expected backscattered signal from the gas-jets is :
- ***Based on the parameters of gas-jet: -240 dB***
- ***SM minimum level: -90 dB***
- ***Needed: seeding with at least 10 nm diameter particles***

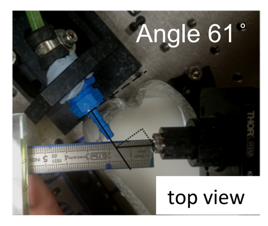
Possible seeders

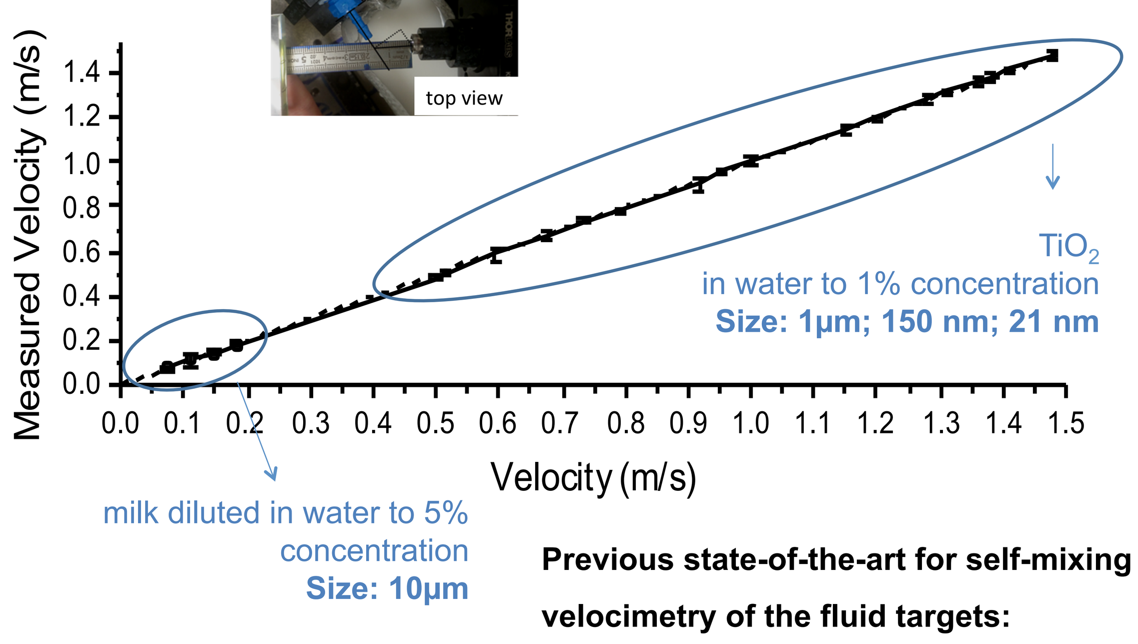
Type	Material	D for liquid flows, µm	D for gas flows, µm
Solid	Polystyrene	10-100	0.5-10
	Alumina Al_2O_3	2-7	0.2-5
	Titania TiO_2		0.1-5
	Carbon dioxide CO_2		5-15
	Glass spheres	10-100	0.2-3
	Granules (synthetic coatings)	10-500	10-50
Liquid	Different oils	50-500	0.5-10
	Diethylhexylsebacate		0.5-1.5
	Helium-filled soap bubbles		1000-3000
Gases	Oxygen bubbles	50-1000	

The experiments were performed with following ***seeders***:
- Milk: 5 µm;
- Titanium dioxide TiO_2: 1 µm; 150nm; 21 nm.
- Aluminium Oxide: 13 nm
- Silica: 200 nm.

SM fluids measurements with seeders







Previous state-of-the-art for self-mixing velocimetry of the fluid targets:
maximum measured velocity is 0.1 m/s

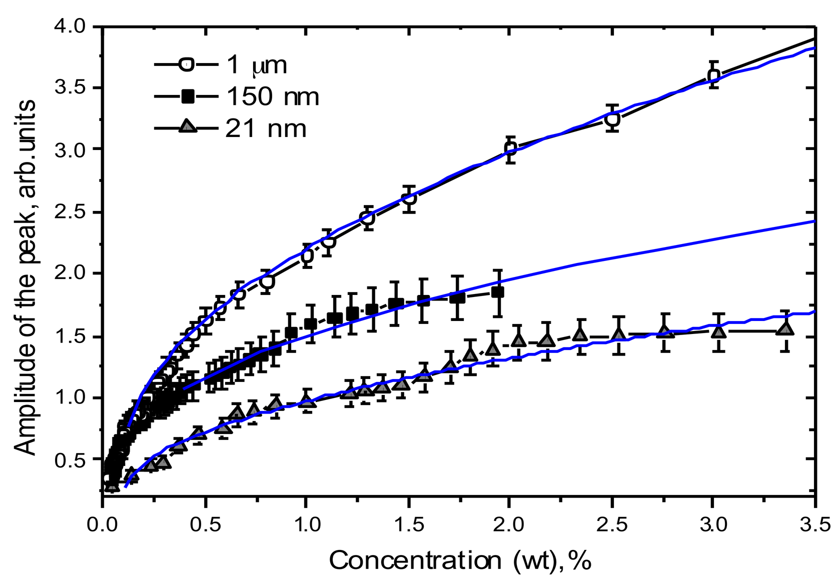
Parameters affecting SM signal:

Scattered off the rotating disc light:

$$I(\omega) = I_0 \frac{1}{A}\frac{N}{V\sin a / w_0}\exp\left(-\frac{(\omega-(\omega_0+kV\cos a))^2}{2(V\sin a)^2 / w_0^2}\right)$$

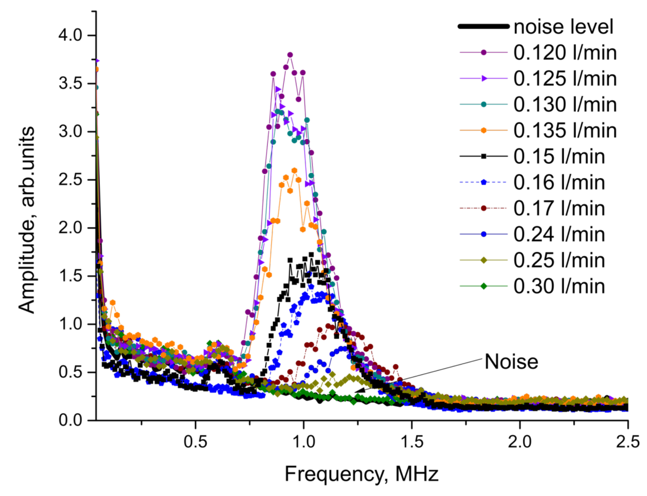
The variation of the concentration

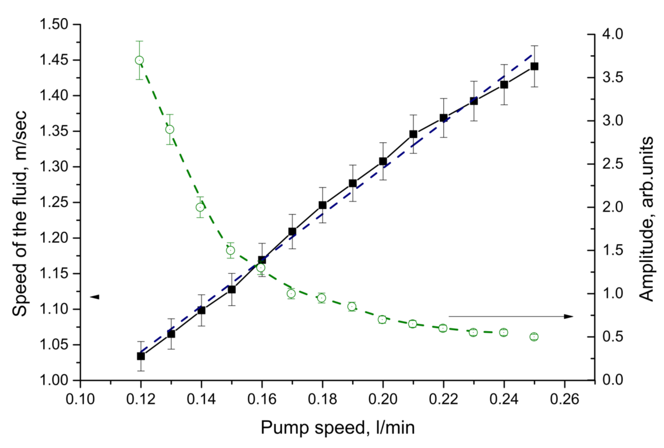
The experimental influence of the concentration of TiO2 seeders in the flow of water on the spectrum of the self-mixing signal with a fixed flow velocity (at 1.3 m/s). The amplitude of the spectrum peak decreases steadily with decreasing concentration..



The variation of the velocity

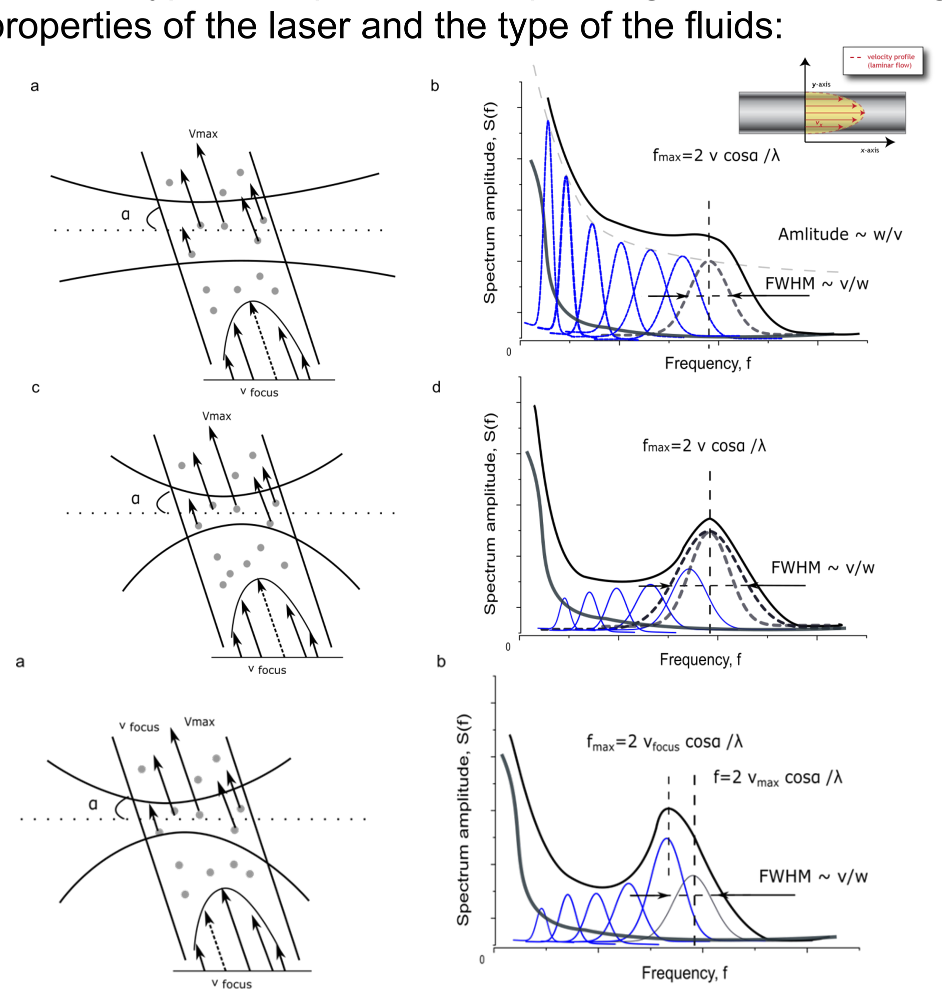
of the target directly influences on the value of the Doppler shift, the amplitude of the peak of the signal spectrum and its bandwidth. When the velocity was increased, the peak amplitude decreased and its full width at half maximum (FWHM) increased proportionally.





The shape of the spectrum

The resulting spectrum is the sum of the distribution of all velocities within the illuminated volume, which leads to a different types of spectrums depending on the focusing properties of the laser and the type of the fluids:



Conclusion

This study has been focussed on the optimisation of a SM sensor to measure the velocity of gas jet based beam profile monitors. A theoretical investigation into the spectrum expected for such a sensor has been presented together with a calculation of the expected level of backscattered signal from a gas jet. A range of different seeding materials added to a water flow was investigated, and such parameters as velocity, reflectivity, and concentration of the seeders in the fluid were under study. The laboratory experiments with TiO_2 with different diameters (1 µm, 150 nm, 21 nm) showed the dependence of the peak spectrum amplitude from the concentration of seeders with a minimum concentration of 0.03wt% still being possible to measure velocities with better than 3% accuracy.

LA³NET is funded by the European Commission under Grant Agreement Number GA-ITN-2011-289191

http://www.cockcroft.ac.uk
http://www.quasar-group.org
A.Alexandrova@liverpool.ac.uk

The Cockcroft Institute of Accelerator Science and Technology