Diode Laser Self-Mixing Velocimetry

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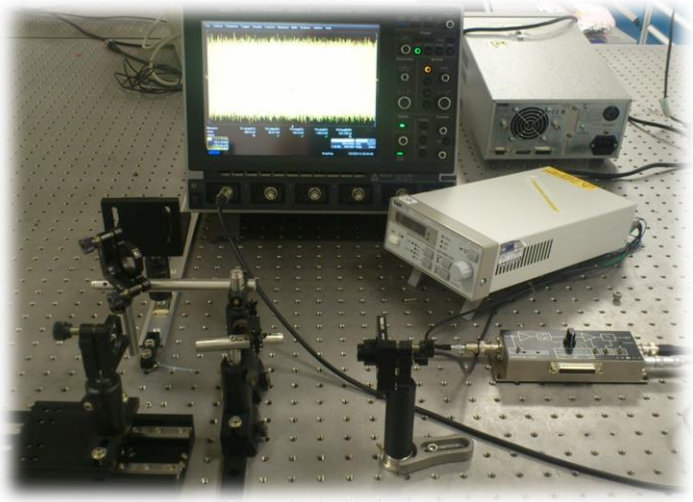
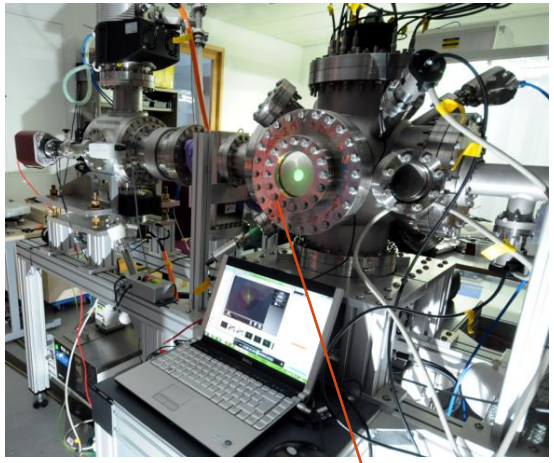
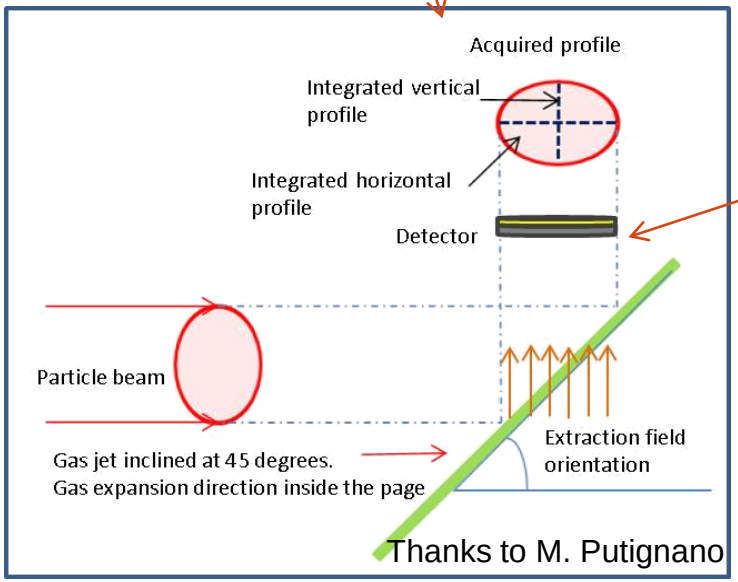
Outline

- Motivation: Velocimetry for gas-jet set-up
- Principal of the technique: self-mixing
- Targets of different nature
  - Solid target
  - Rotating disk
  - Fluids
- Results



Motivation: Gas-Jet Set-up





Distribution of velocities in gas jet:

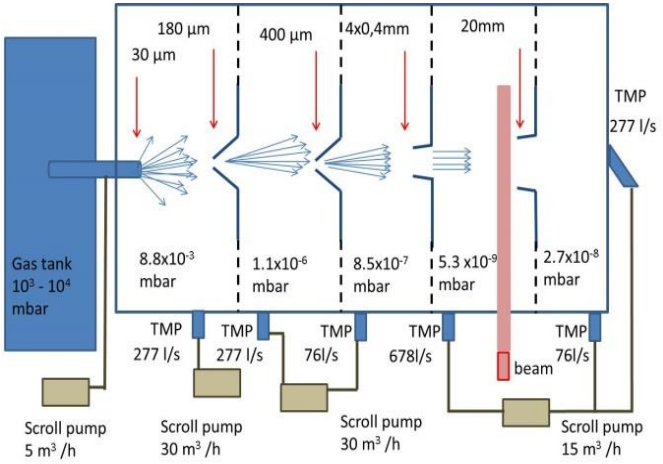
-in-detail characterization of the gas jet,

Gas: Ar, N_2, He

Velocities: 100-2000 m/s

Density: 10^{10} – 10^{15} mol/m^3

- compact and cheap



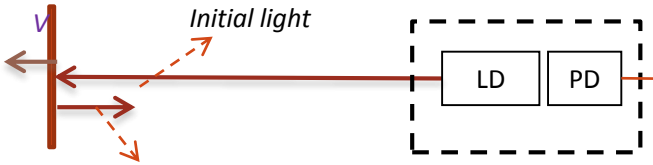
Other possible measuring techniques

Mechanical, Acoustic, Optical

Gas Jet characterisation methods

- **Mechanical**
  - x Intrusive – errors
  - **Constant Temperature Anemometry (CTA)**
  - **Hot-wire Anemometry (HWA)**
- **Optical**
  - ✓ Precise
  - ✓ Non-invasive
  - ✓ **Particle Image Velocimetry**
  - ✓ **Laser Doppler Velocimetry**
  - ✓ **Spectrally resolved Rayleigh scattering**
  - ✓ **Interferometry**
  - ✓ **Absorption sensors**

Self-mixing technique



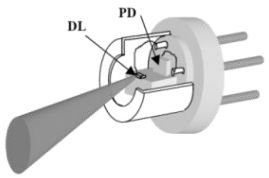
650 nm, 5 mW
1550 nm, 1 mW

Signal Processing → Estimated Velocity

Moving Target Which has velocity V

scattered light with Doppler shift in frequency

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



Fast Fourier Transformation + additional algorithms

$$P = P_0(1 + mF(2\pi\nu_F\tau_D))$$

From Doppler shift

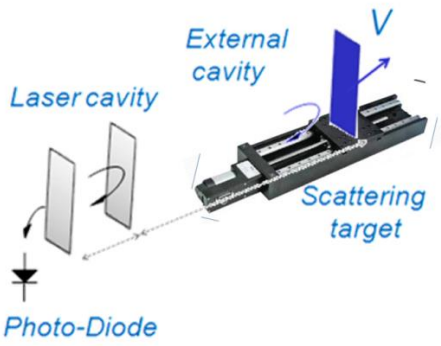
$$f = 2\frac{(V,n)}{\lambda}$$

Moving Targets

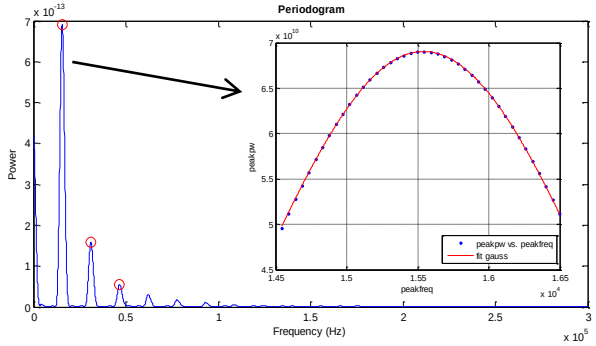
- *Solid target: mirror*
- *Solid target: white paper*
- *Fluids: milk*
- *Fluids: colloidal suspension*

- *Jets*

Self-mixing Technique

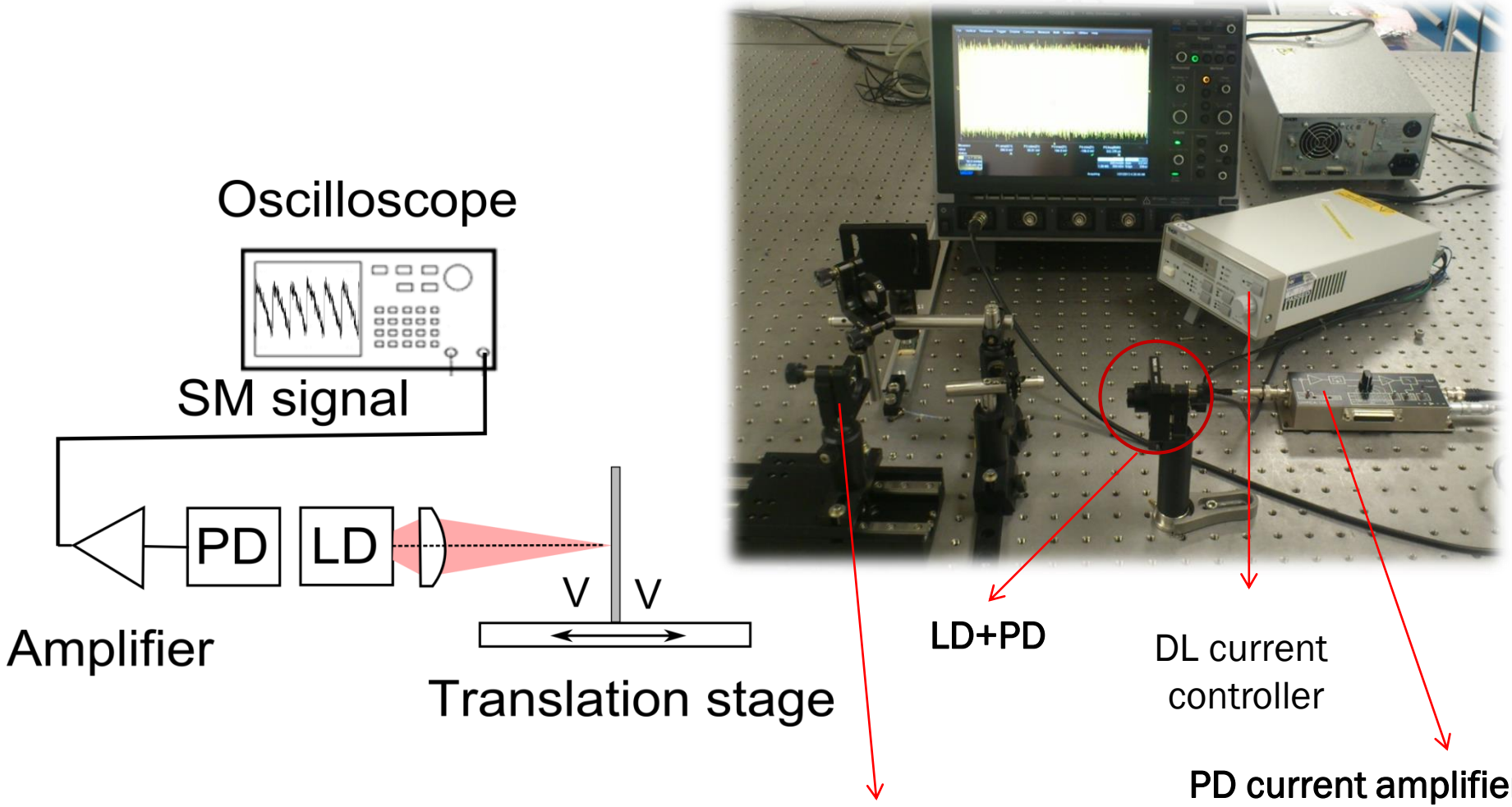


Signal Processing: FFT

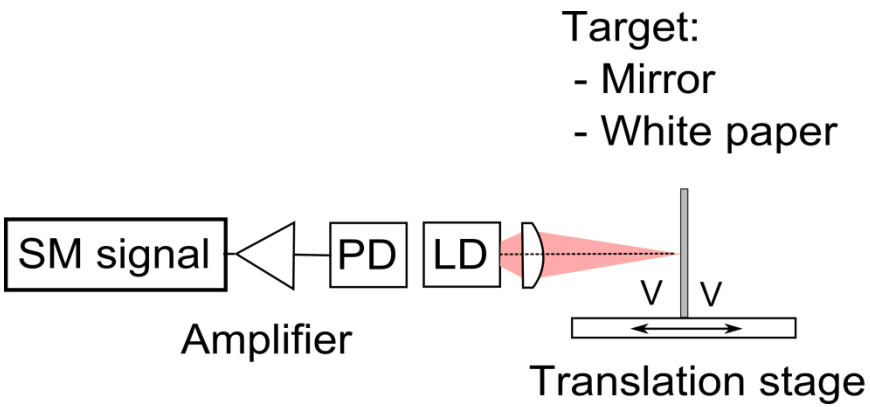


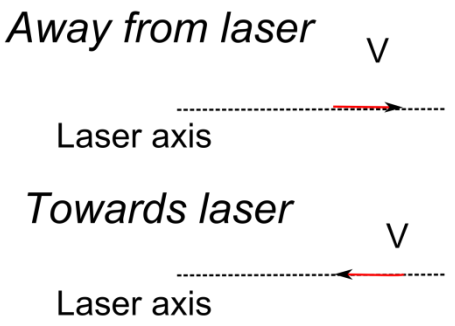
Fd 15.542 kHz
Velocity 5.05 mm/sec

Experiments – set-up



1. Translation stage





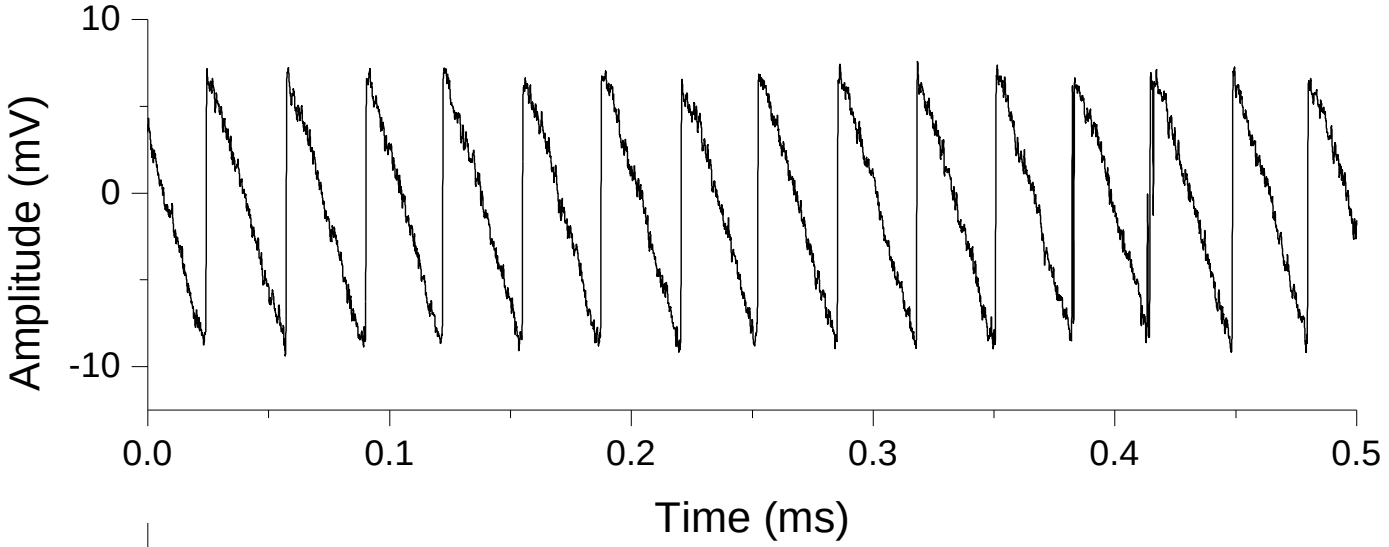
Why?

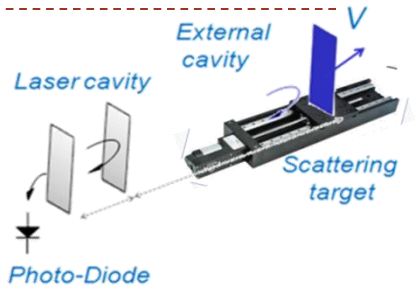
- Study the technique
- Precise reference velocity
- Easier to change from mirror to white paper

Signal
- How to receive

V =0.01 – 10.00 cm/s

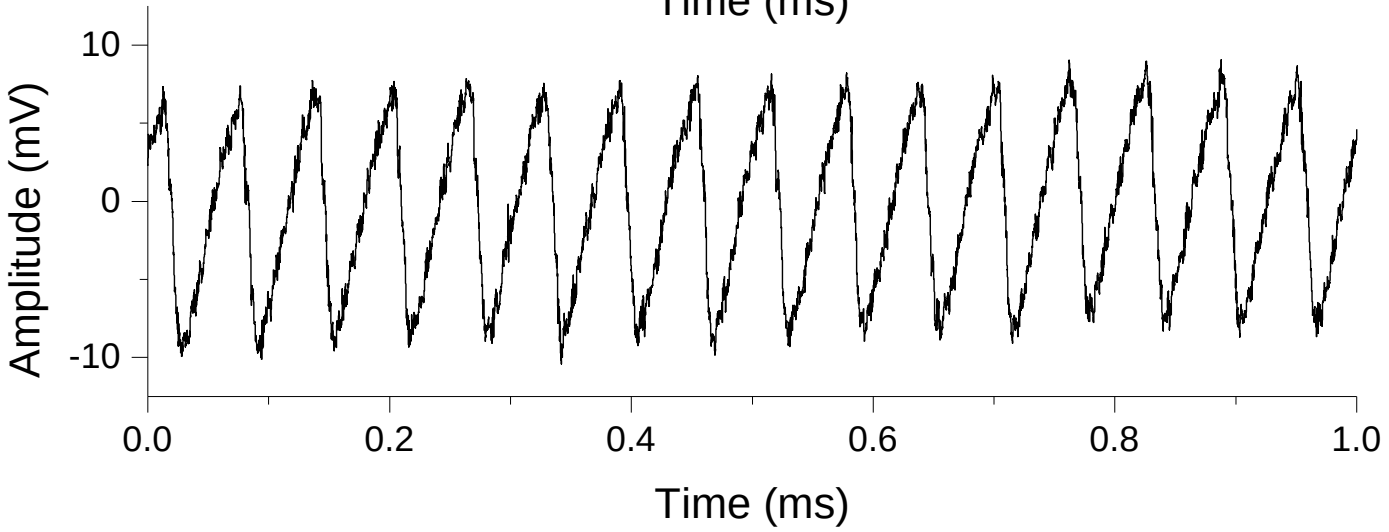
Examples of the signal





a mirror as target
5.0 mm/s

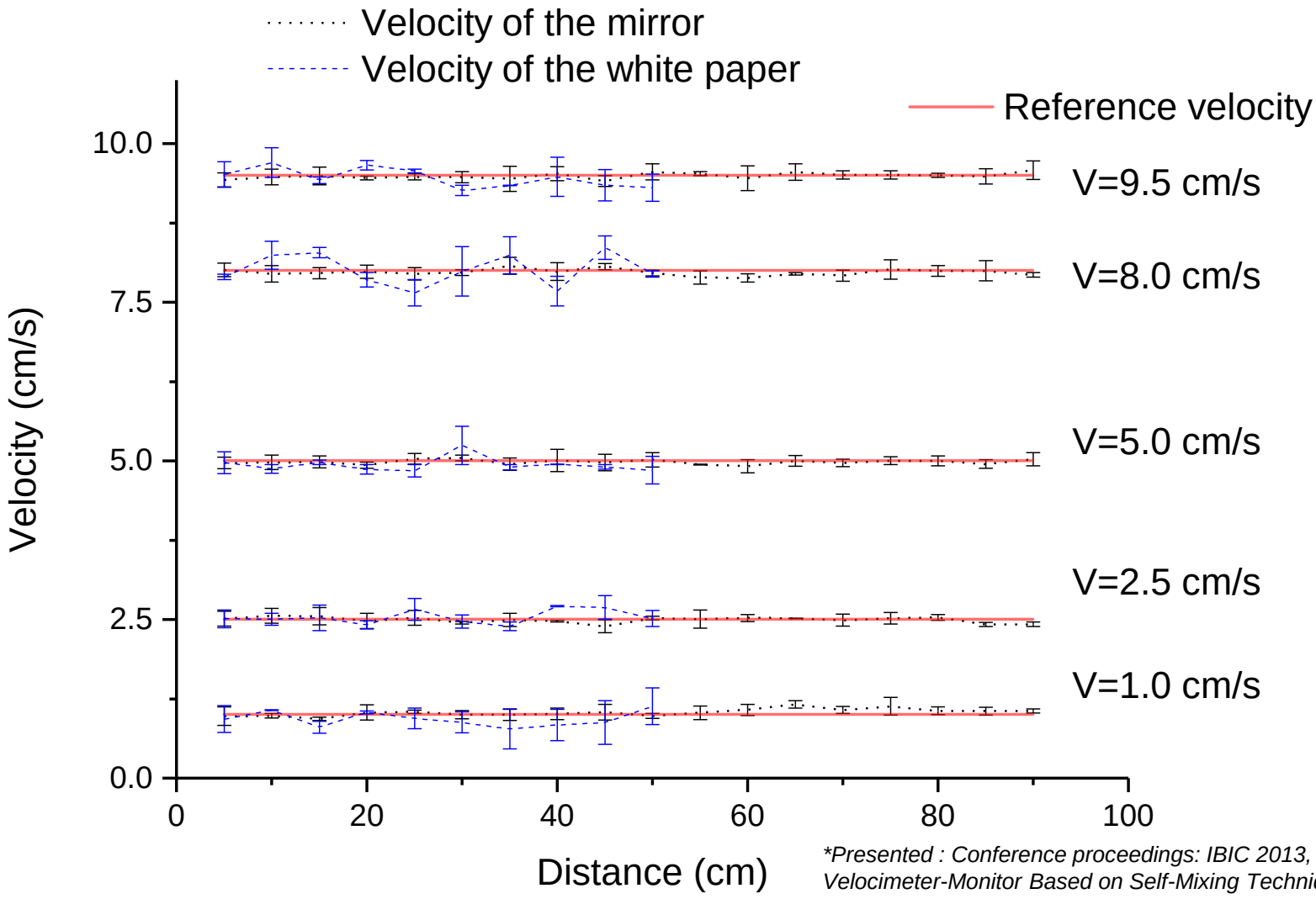
forward movement



white paper as target
5.2 mm/s

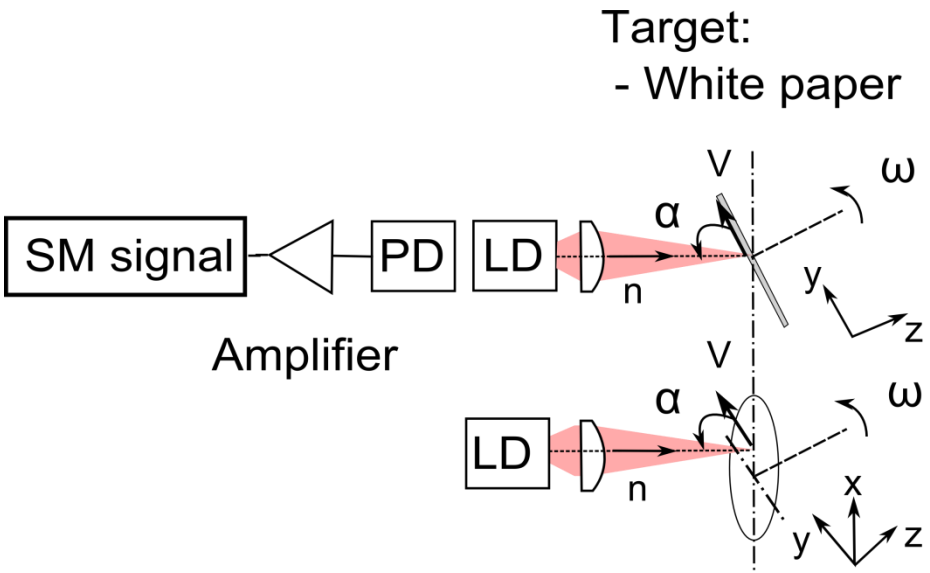
away from the laser movement

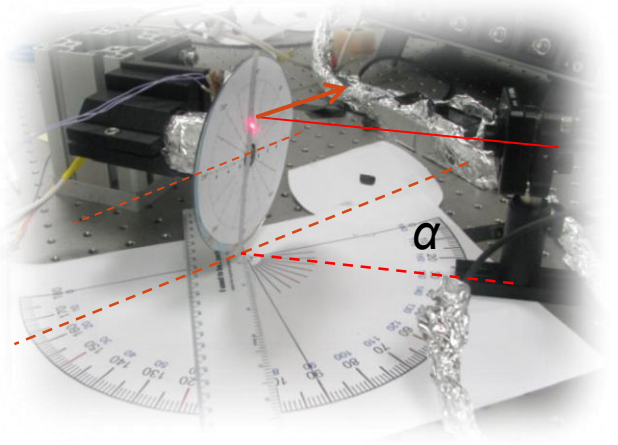
Accuracy: solid targets



*Presented : Conference proceedings: IBIC 2013, Laser Diode Velocimeter-Monitor Based on Self-Mixing Technique

2. Rotating disc





Why?

- Study the limitation: how fast
- Study angle variation
- White paper, and the distance is fixed

$$\mathrm{V} = V(\sin\beta, \cos\beta, 0)$$

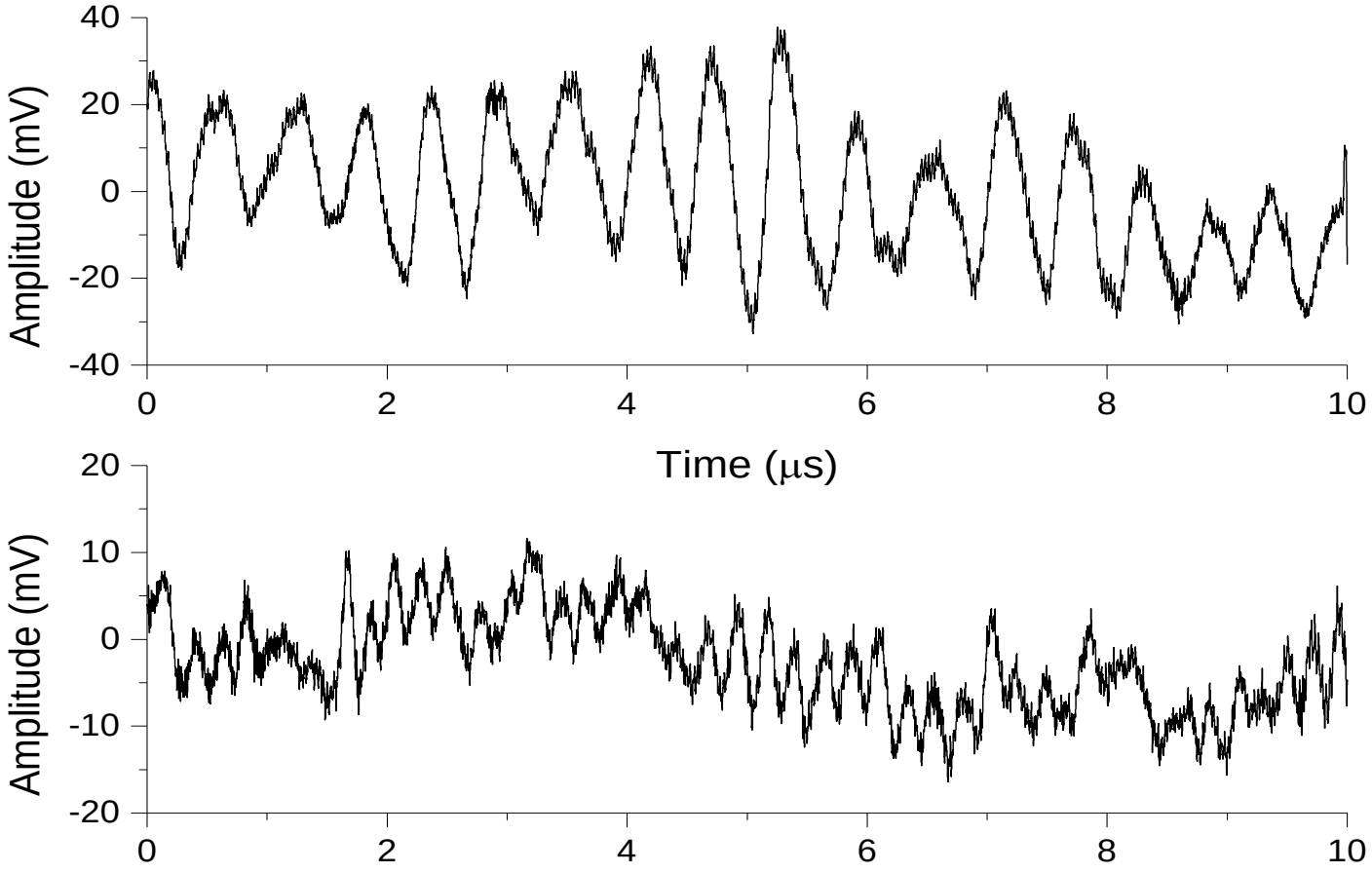
$$\vec{\mathrm{n}} = (0, \cos\alpha, \cos\alpha)$$

$$\mathrm{f} = \frac{2\omega \mathrm{R}\cos\alpha\cos\beta}{\lambda}$$

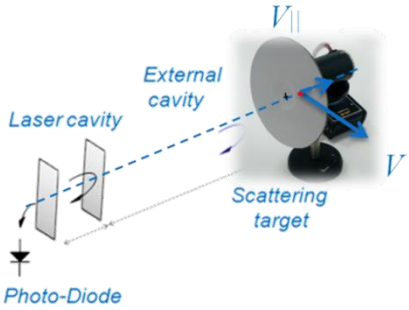
Variation:

- *R*
- *ω*
- *α*

Rotating disc: signal



Velocity 4.6 m/s

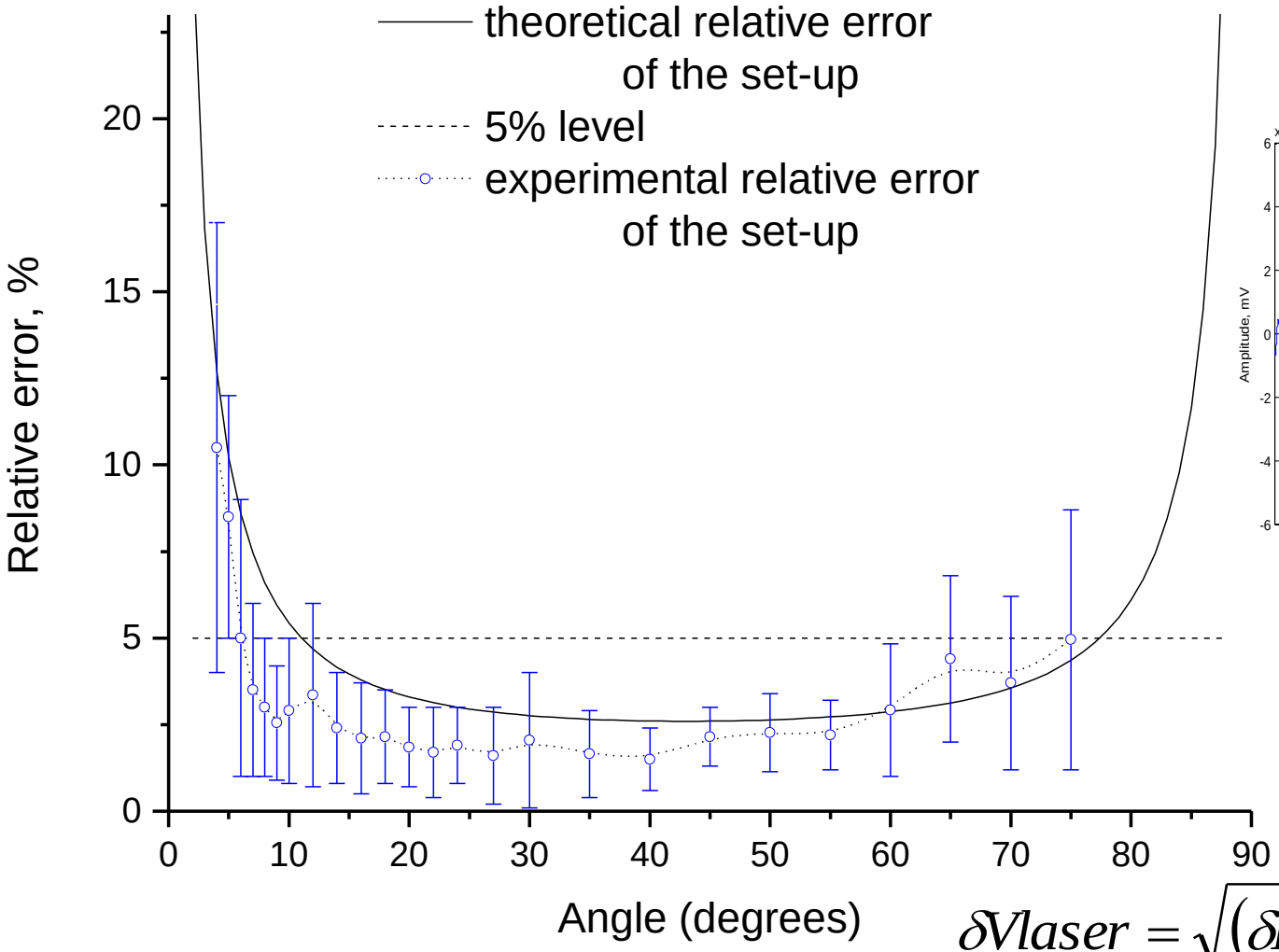


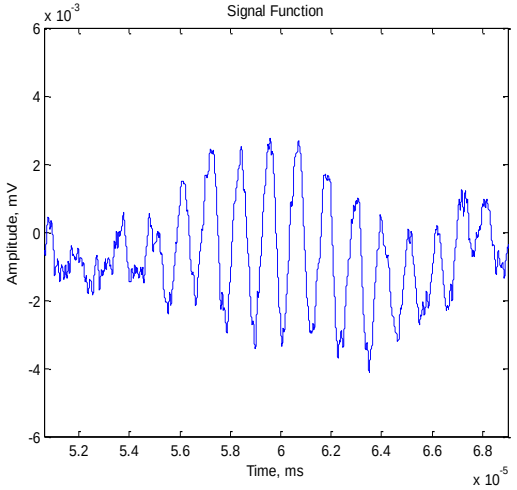
Velocity15.3 m/s

Here presented signal: the angle between the target and laser axis was 83°

*Presented: Proc. SPIE 9141, Optical Sensing and Detection III, 91412C (May 15, 2014) Self-mixing diode laser interferometry for velocity measurements of different targets

Accuracy and precision of the system





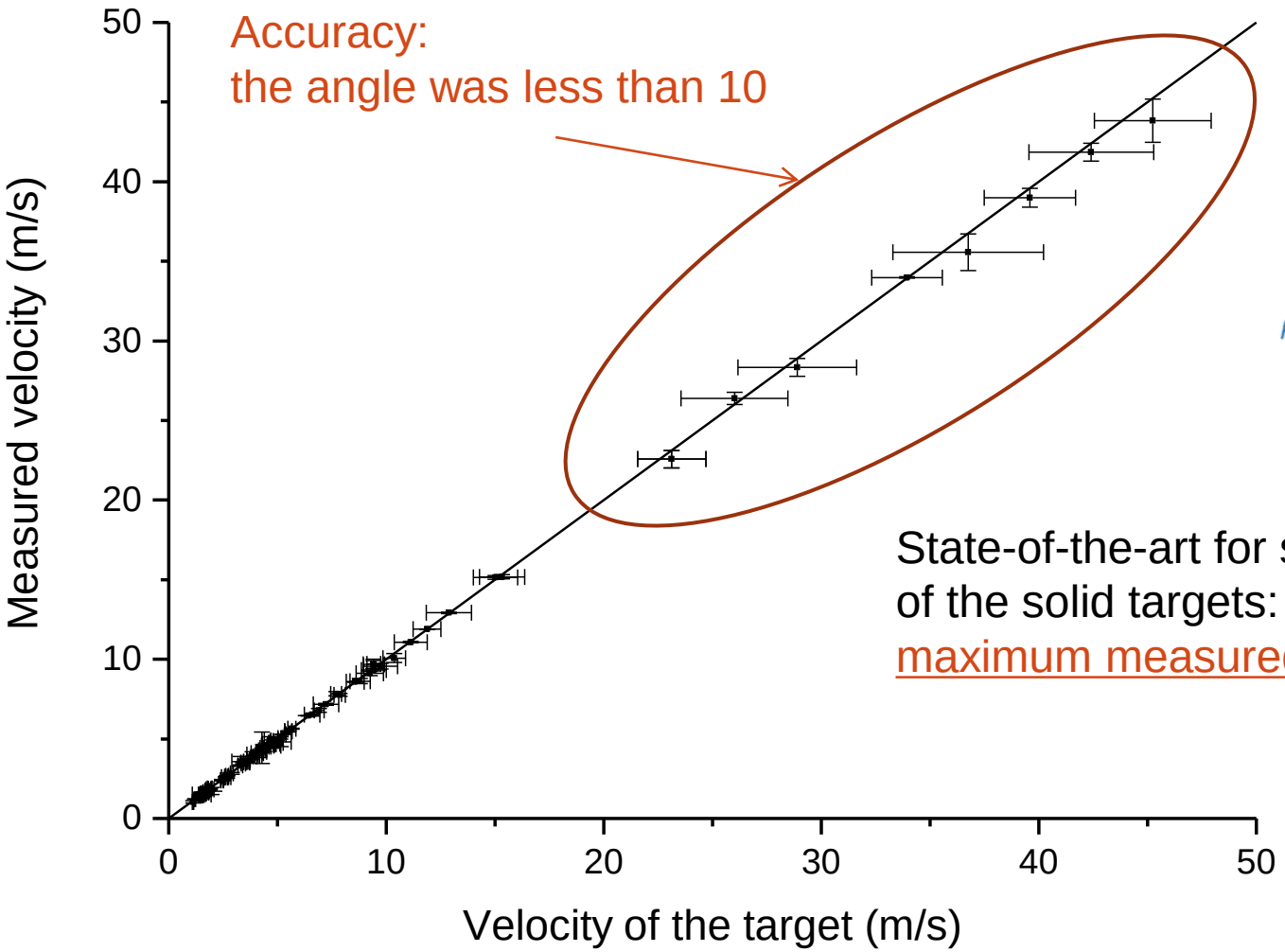
$$\delta\nu = \Delta\nu/\nu$$

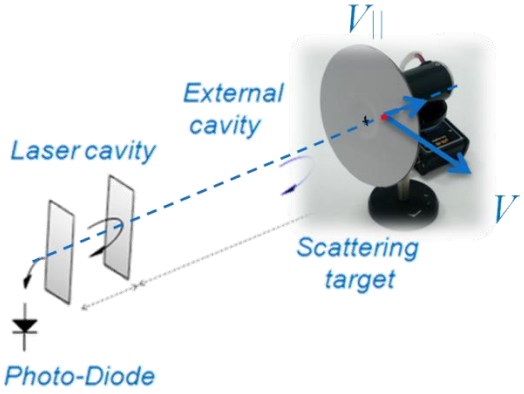
$$\delta\alpha = \cot(\alpha)\Delta\alpha$$

$$\delta R = \Delta R/R$$

$$\delta Vlaser = \sqrt{(\delta R)^2 + (\delta\nu)^2 + (\delta\alpha)^2}$$

Benchmarking

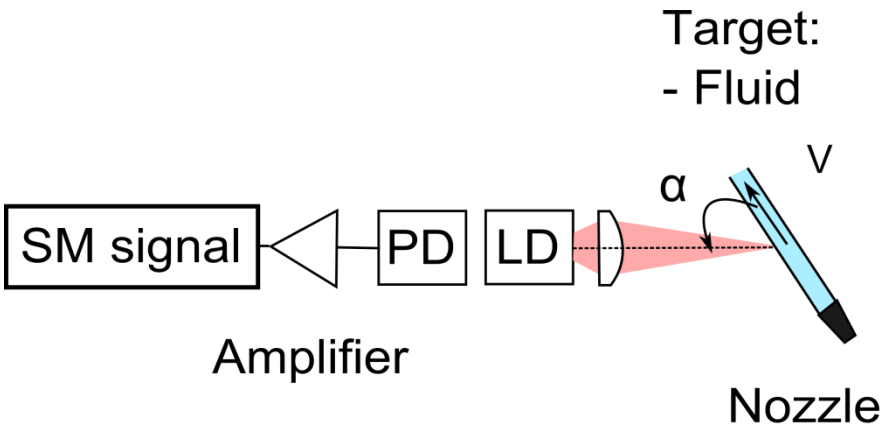


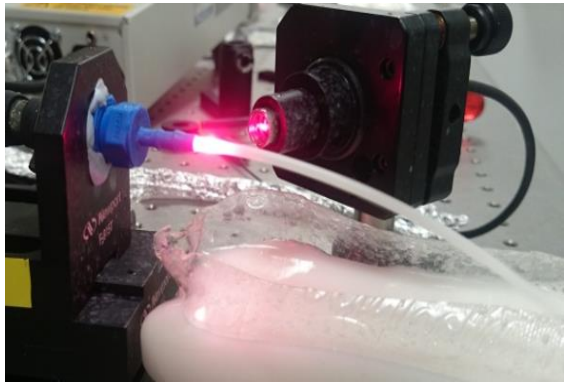


State-of-the-art for self-mixing velocimetry of the solid targets:
maximum measured velocity is 25 m/s

**Results are presented: Journal article: Optical Engineering: Laser Diode Self-mixing Interferometry for Velocity Measurements*

3. Fluids





Why?

- New scattering process – on particles
- Study SM technique on fluids
- Seeders? Laser? Geometry? How fast?

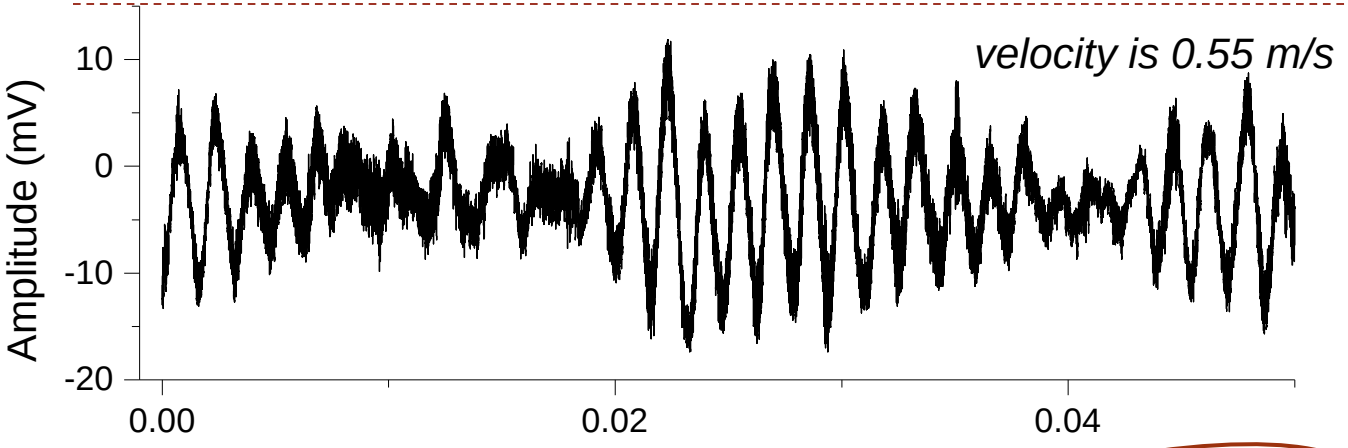
Rayleigh - Mie

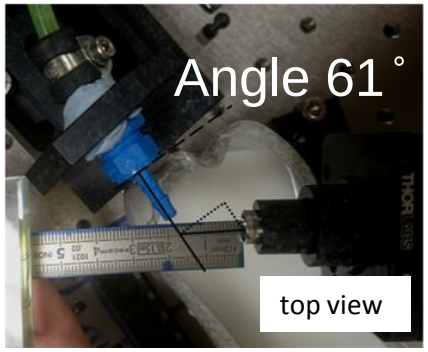
$R<<\lambda$ $R>>\lambda$

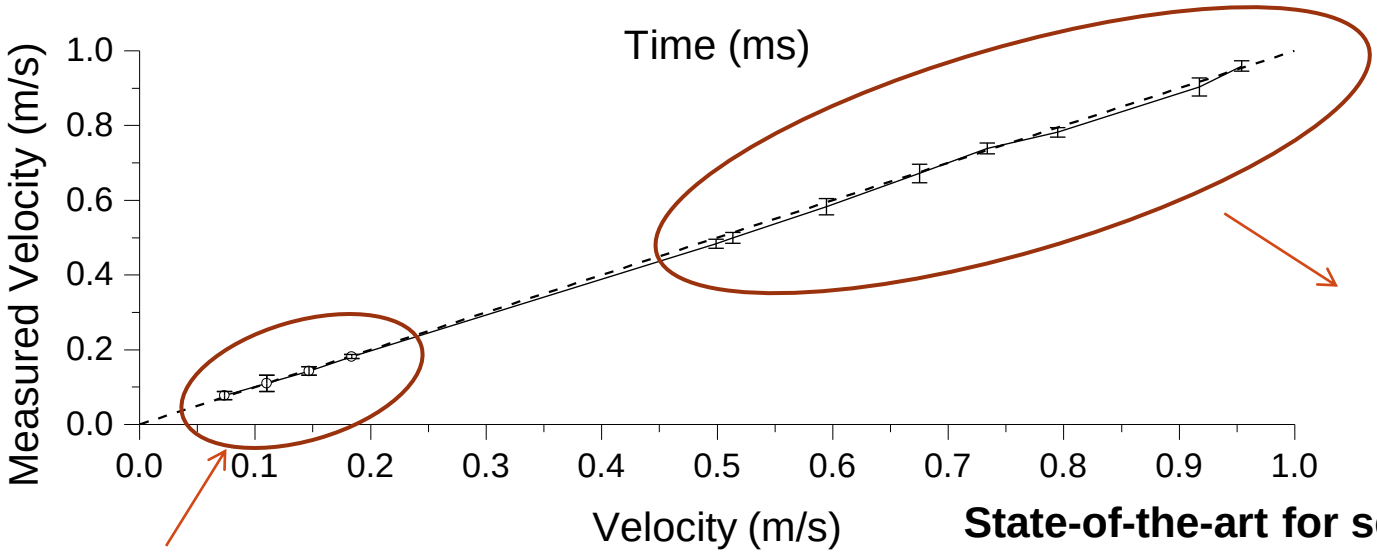
TiO2?

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

Fluids: signal and benchmarking







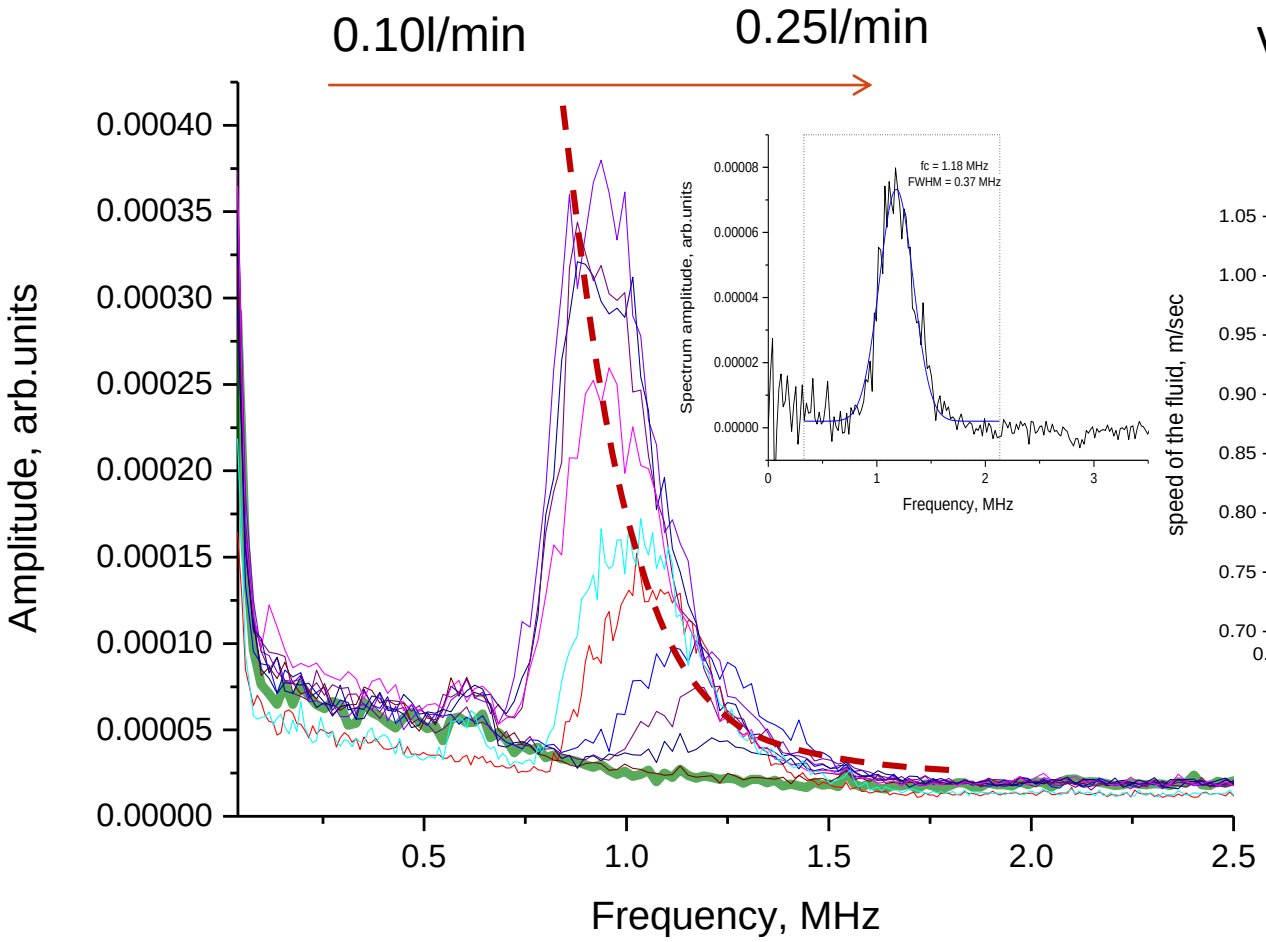
colloidal suspension diluted in water to 1% concentration
Size: 1µm

milk diluted in water to 5% concentration
Size: 10µm

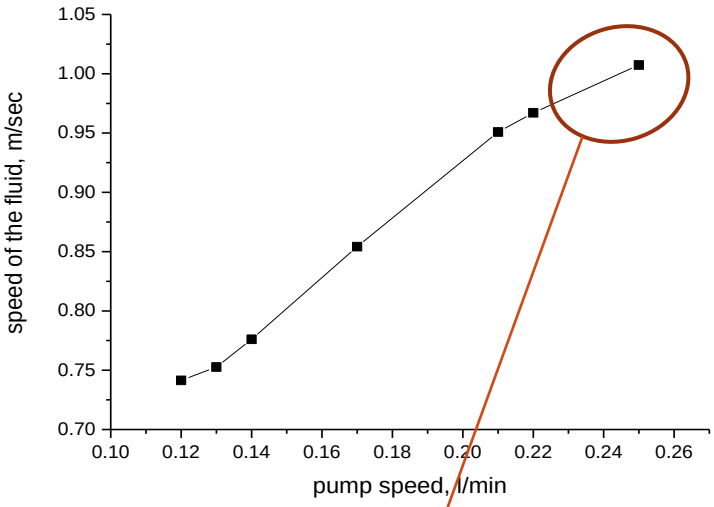
State-of-the-art for self-mixing velocimetry of the fluid targets:
maximum measured velocity is 0.1 m/s

Fluids: FFT

Concentration is fixed. Velocity increases



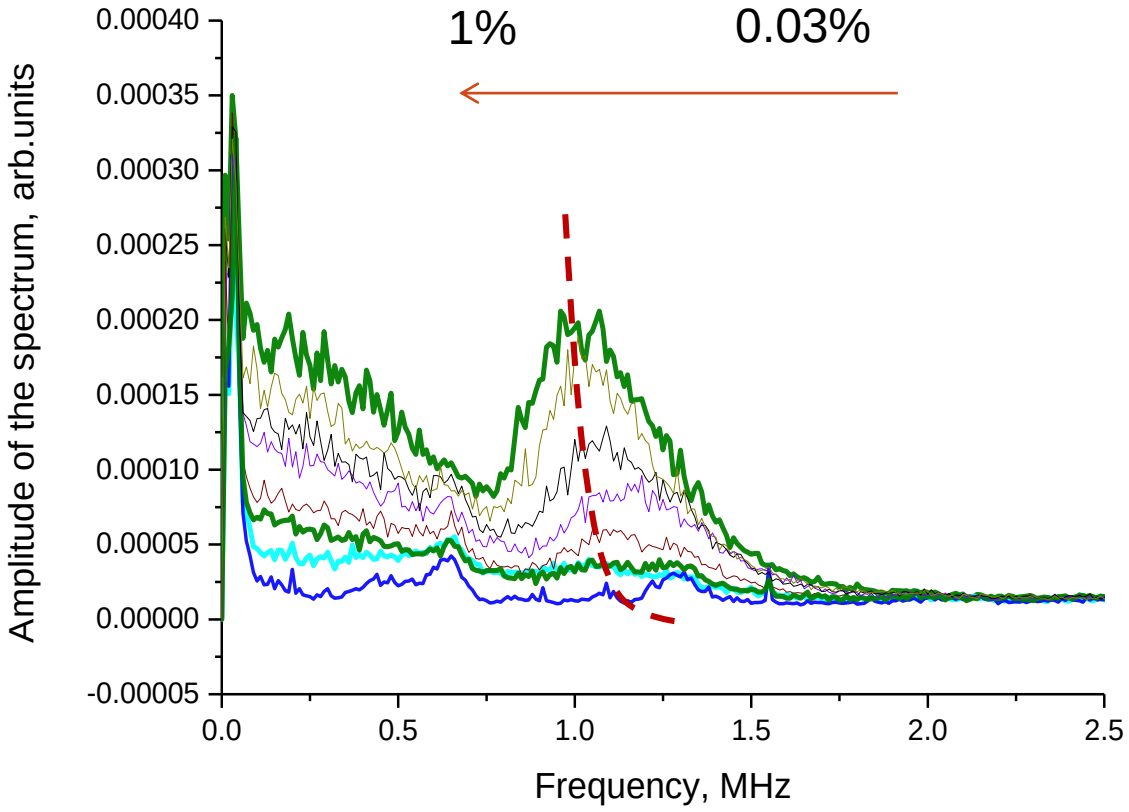
Velocity of the fluid depending on the pump rate

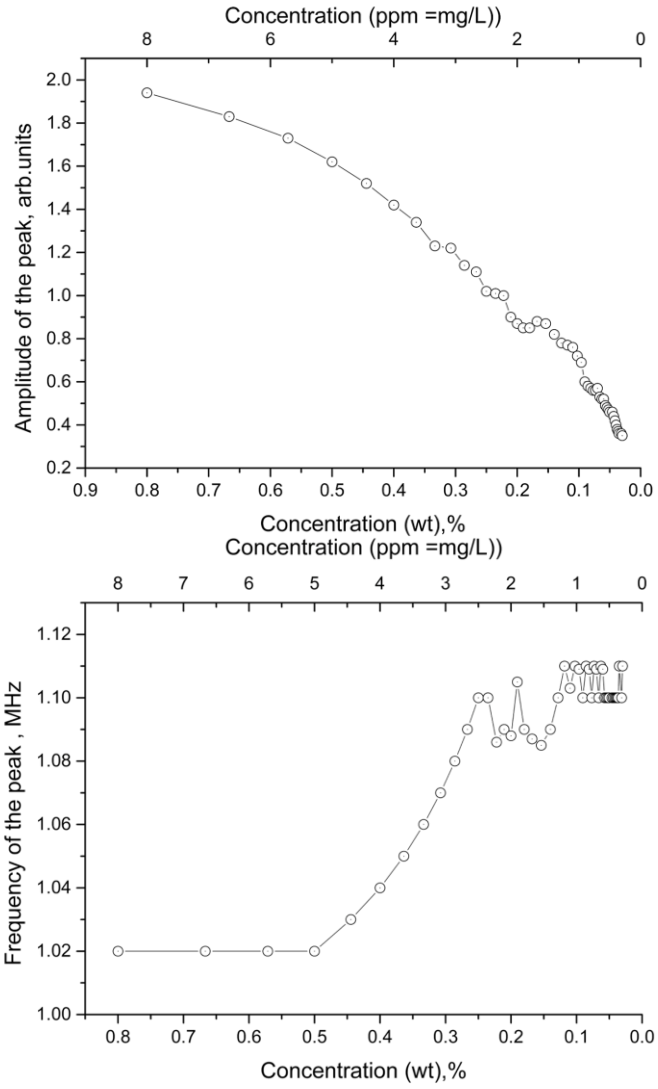


Velocity of 1.02 m/s
Size of the seeders 1 µm

Fluids: FFT

Velocity is fixed. Concentration decreases.

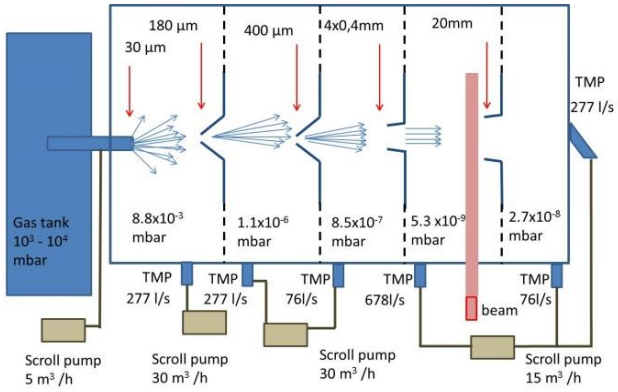


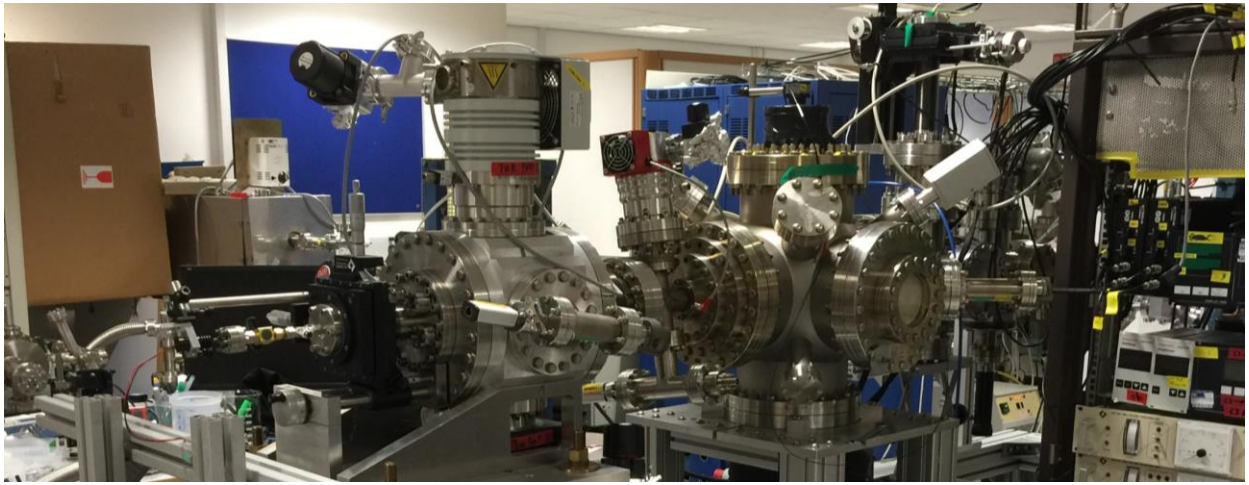


Frequency is 1.01 MHZ

Gas-jet set-up: next step

- 1. building into the existing set-up
- 2. seeding the gas-jet with particles which allows having the acceptable for SM level of scattered light





Results

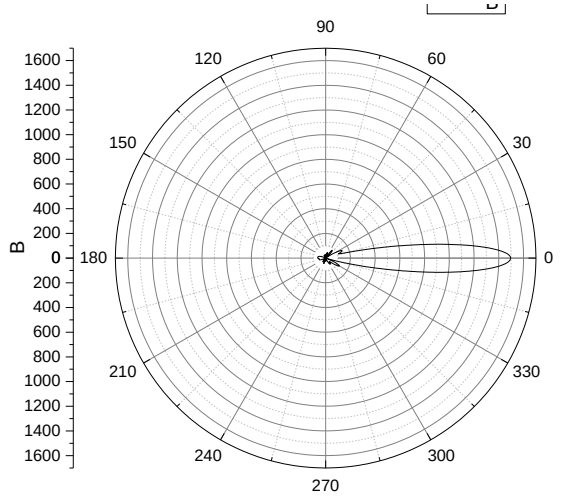
- ✓ Range of velocity
  - *measured up to 50 m/s for solid target (in papers: up to 25 m/s)*
  - *measured up to 1 m/s for fluids (in papers: up to 0.1 m/s)*

- ✓ Relative error depends on the angle between laser and target's velocity vector
  - *the relative error of 3-4% in the range of 11 ˚-77 ˚degrees theoretically and in the range of 10 ˚-70 ˚experimentally*

- ✓ Seeding for liquids experiments and studying different concentration of the fluids

- ✓ Limitation reasons: electronics, laser properties, level of scattered light

Thank You
for Your attention!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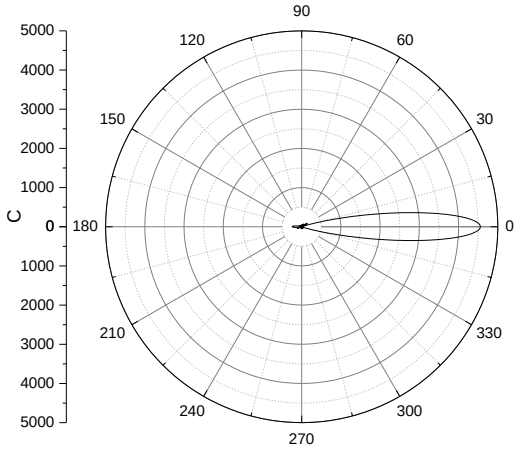
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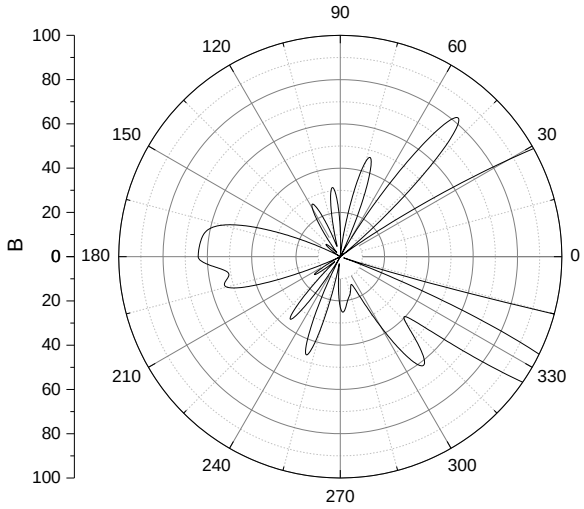
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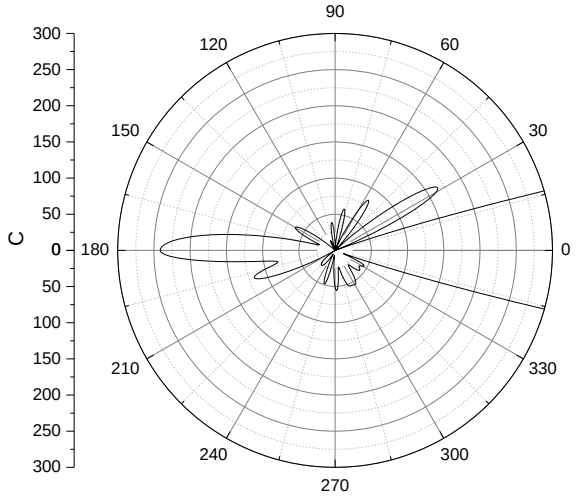
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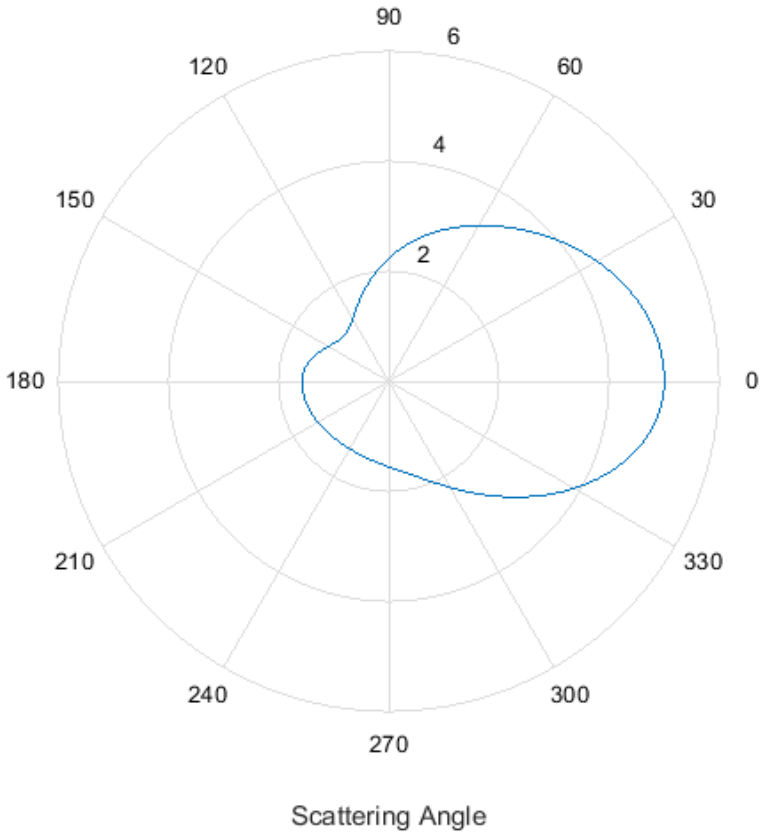
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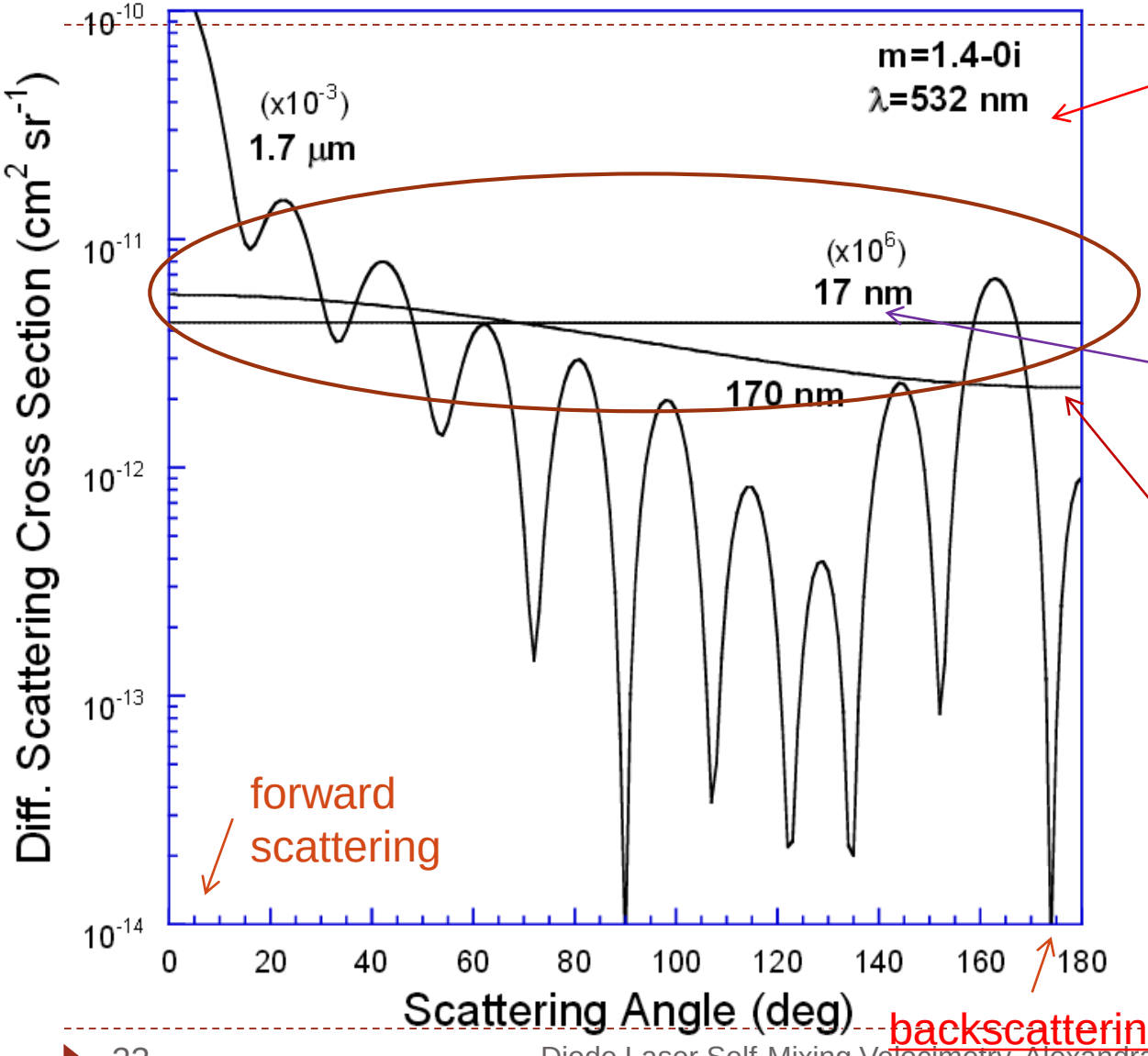
Scattering Angle

Scattering



1.7 mkm: Mie regime

Ripples: constructive and destructive interference along different path

17nm: Rayleigh regime

as the size of the scatterer increases, the more radiation is scattered in the foward direction

170 nm: departing from the Rayleigh Regime: some angular variation

http://plaza.ufl.edu/dwhahn/Rayleigh%20and%20Mie%20Light%20Scattering.pdf

Experiment: all

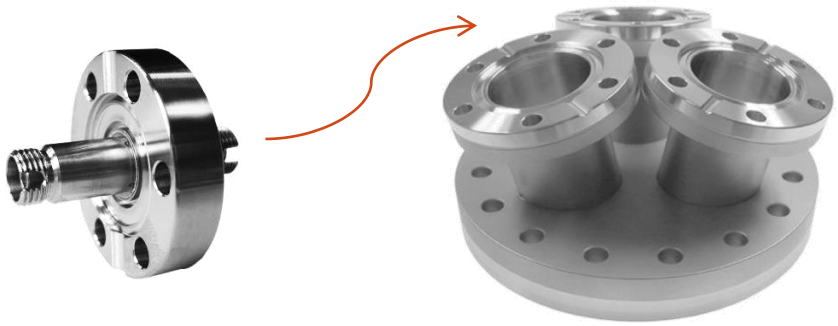
Results

Target	*Velocity*	*Error*
Mirror, n= 92% , White paper, n = 60%	Up to 0.1 m/s (limitation from the moving set-up)	Less than 1%
White paper on a disc, n = 60%	Up to 50 m/s (limitation from the electronic part)	Less than 5%
Fluid, milk diluted in water at a 5% concentration, n = 3.5%	Up to 0.2 m/s(limitation is under investigation)	Less than 5%
Fluid, colloidal suspension diluted in water at a 5% concentration, n = 4%	Up to 1 m/s (limitation is under investigation)	Less than 4%

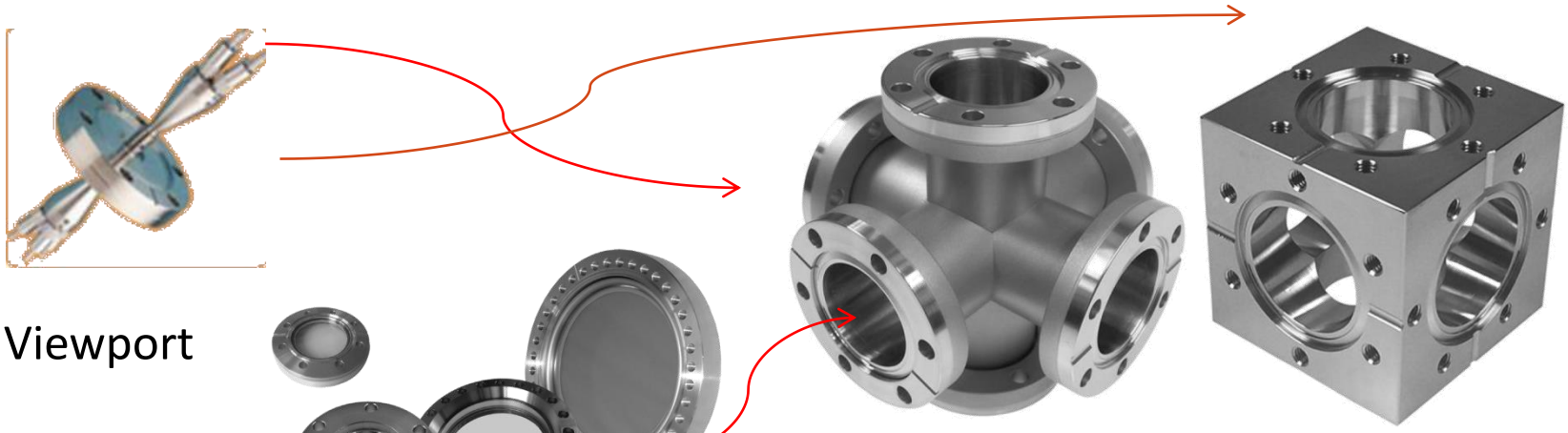
**Results are presented: Journal article: Optical Engineering: submitted fro review:Laser Diode Self-mixing Interferometry for Velocity Measurements*

Difficulties: delivery of the light to the gas jet

- Optical feedthrough
- - perpendicular



- - under the angle

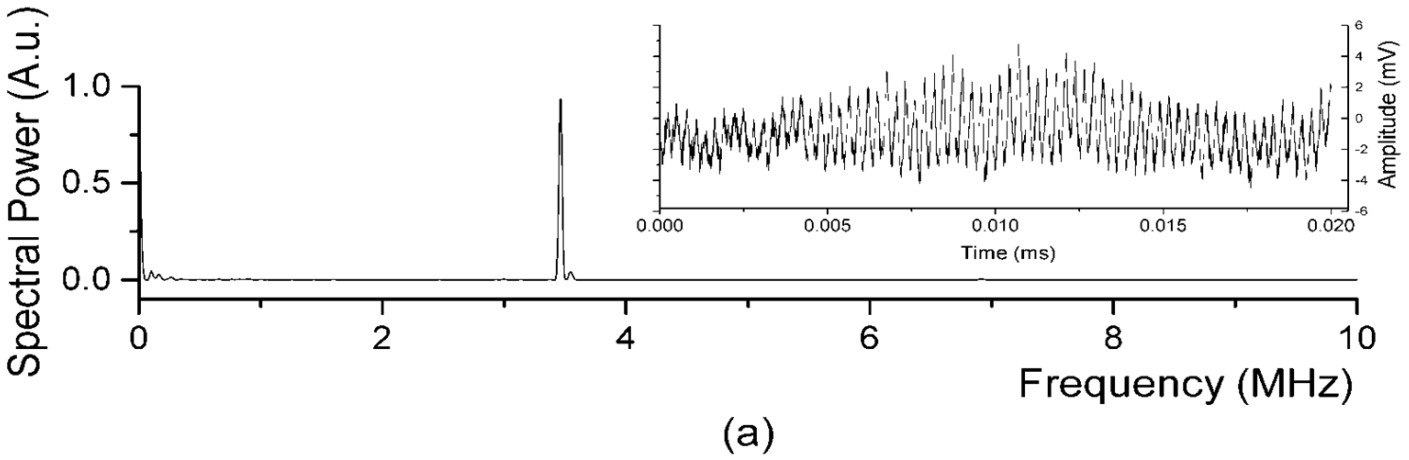


- Viewport

Rotating disc: signal and FFT

17.6 m/s, 51˚

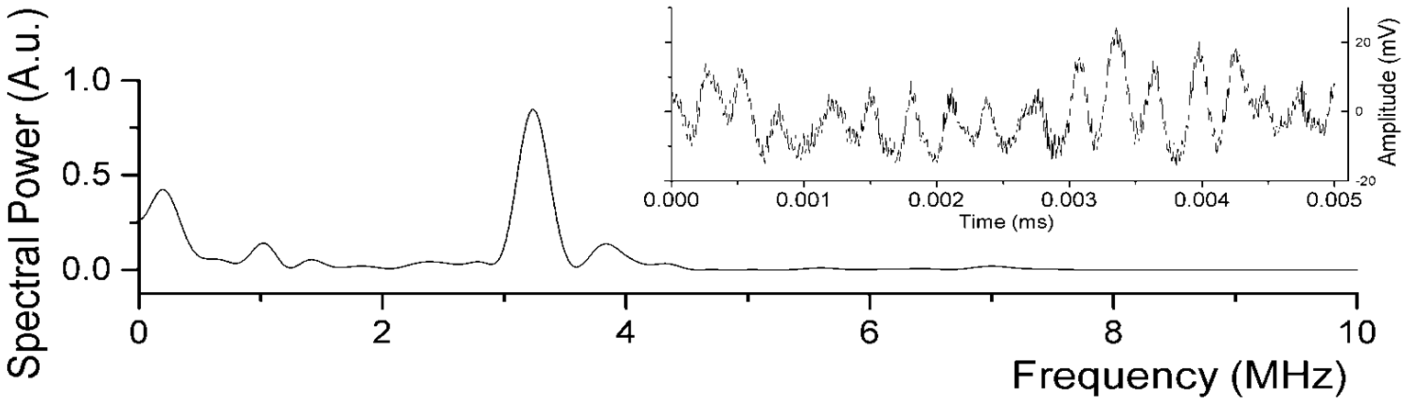
3.4 MHz



(a)

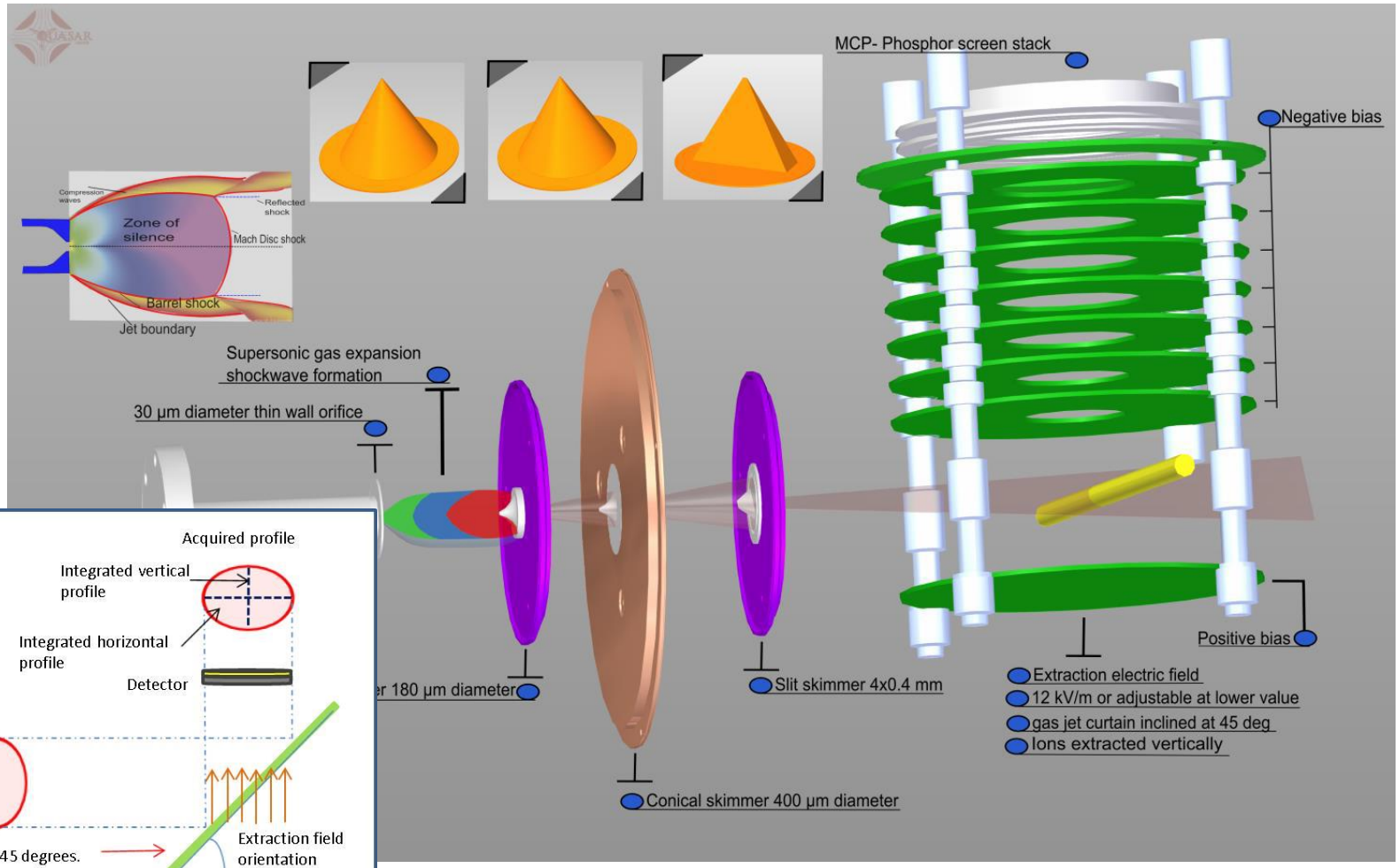
10.6 m/s, 9˚

3.23 MHz



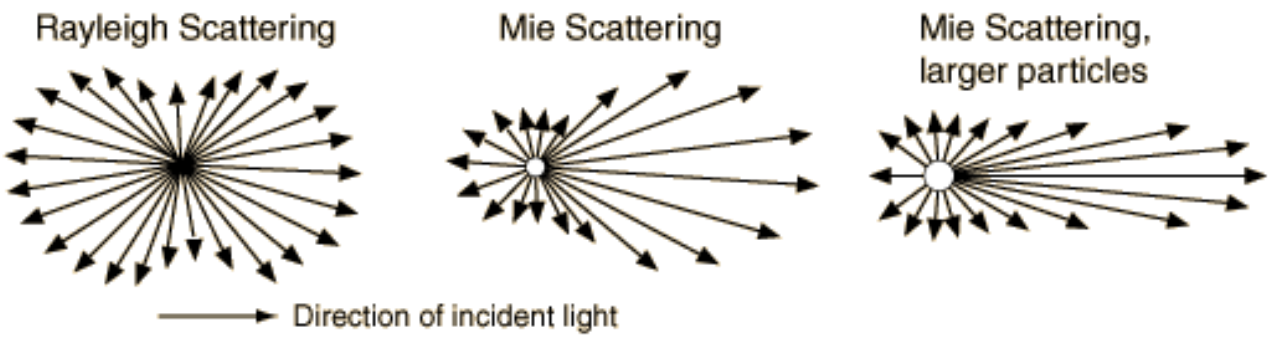
(b)

Gas-Jet set-up



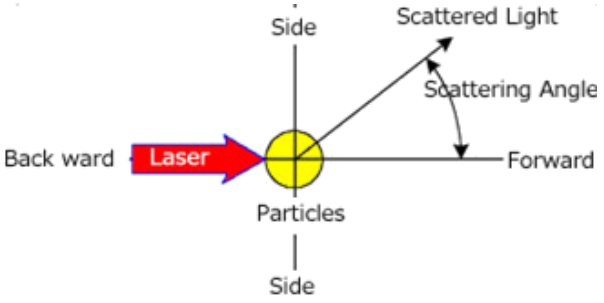
Thanks to M. Putignano;
// V. Tzoganis, et al. IPAC2013

Scattering



→ size parameter $\chi \equiv 2\pi r / \lambda$, where r = radius of the sphere

- Rayleigh scattering: $\chi < 0.1$
- Mie scattering: $0.1 < \chi < 50$
- Geometric (optics) scattering: $\chi > 50$

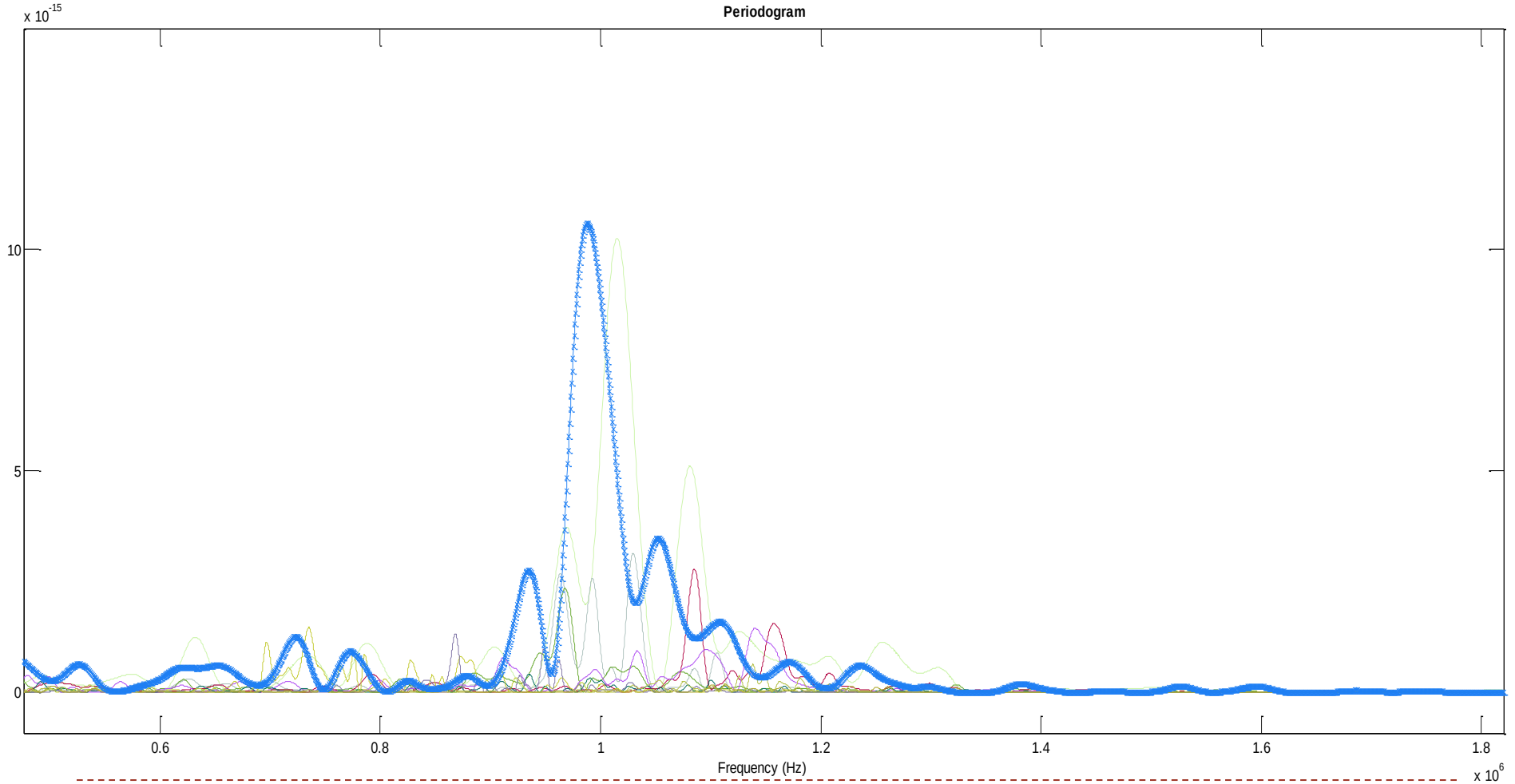


Scattering

- Mirror: reflection

- White paper: scattering in all direction, but it is not particles, it is a surface, so it is backscattering is prevalent

- Fluids: particles: pure scattering: Smaller size of seeders, bigger the backscattering cross-section


Periodogram
x 10^-15
10
5
0
0.6
0.8
1
1.2
1.4
1.6
1.8
Frequency (Hz)
x 10^6