Velocity measurements using self-mixing technique in laser diodes

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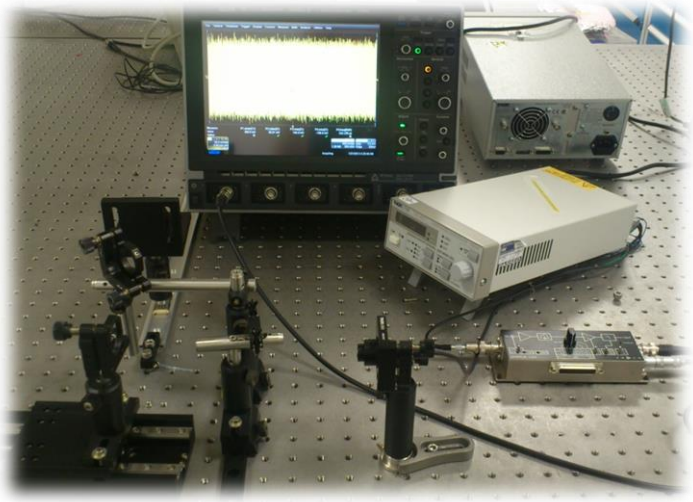
Laser Applications at Accelerators Conference 2015
25-27 March 2015, Mallorca

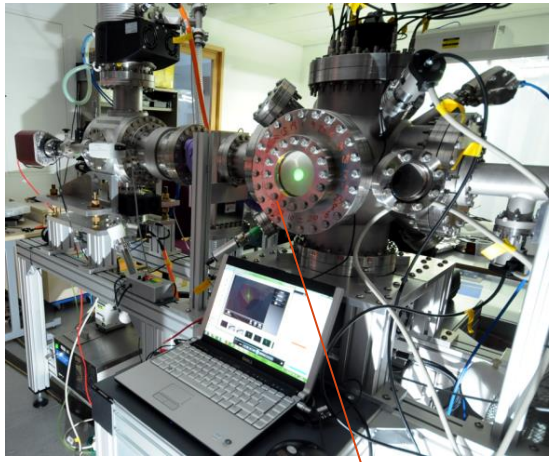
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191.

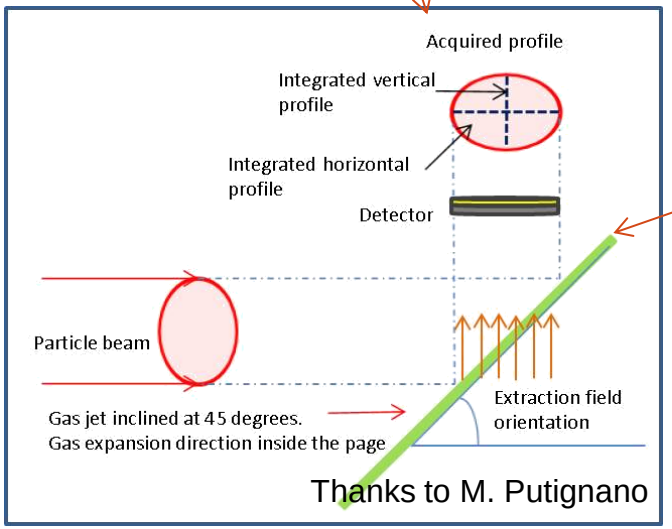
Outline

- 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





Details: workshop presentation by Dr. H. Zhang

Distribution of velocities in gas jet:

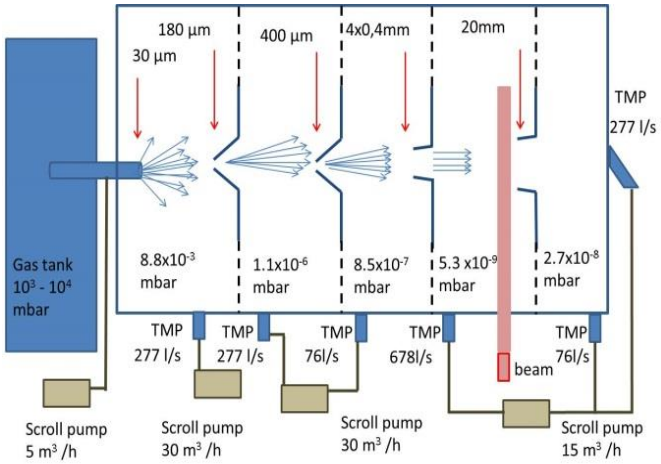
-in-detail characterization of the gas jet,

Gas: Ar, N_2, He

Velocities: 100-2000 m/s

Density: 10^{10} – 10^{15} mol/m^3

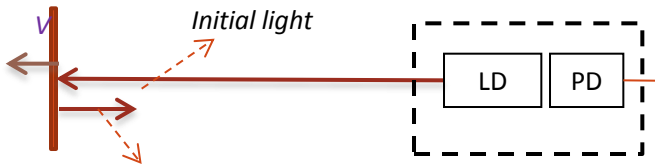
- compact and cheap



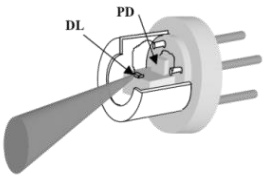
Other possible measuring techniques

Mechanical, Acoustic, Optical

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

From Doppler shift

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

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

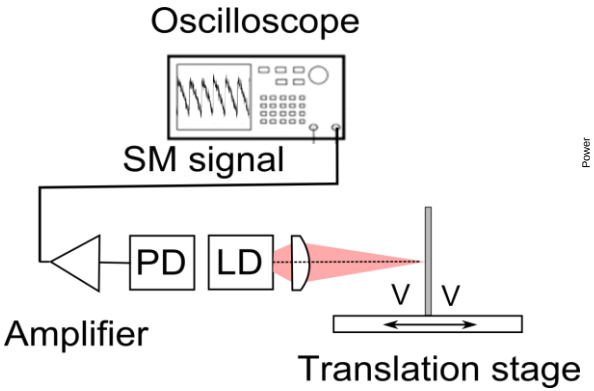
Details: workshop presentation by Prof. G. Scamarcio

Moving Targets

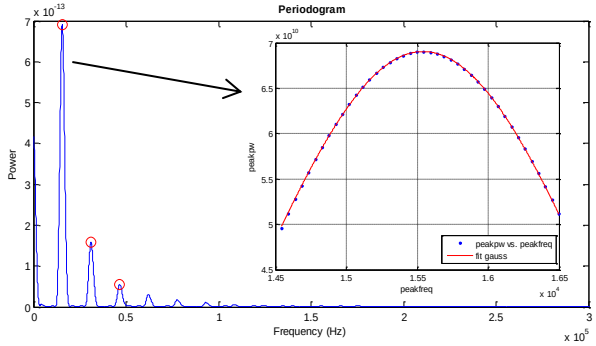
- *Solid target: mirror*
- *Solid target: white paper*
- *Fluids: milk*
- *Fluids: colloidal suspension*

- *Jets*

Self-mixing Technique

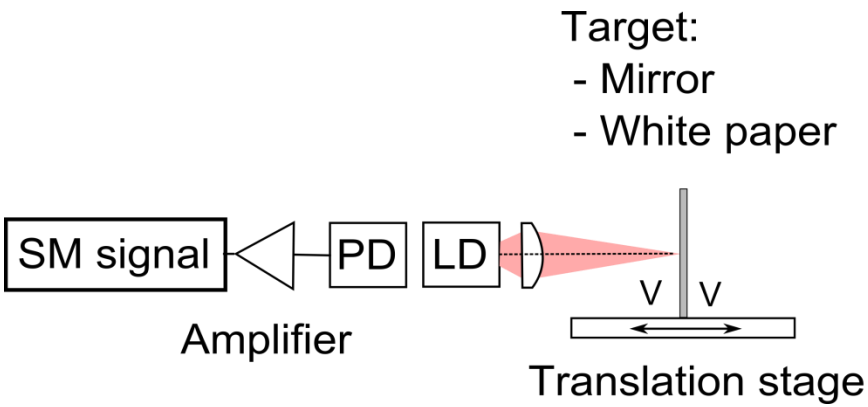


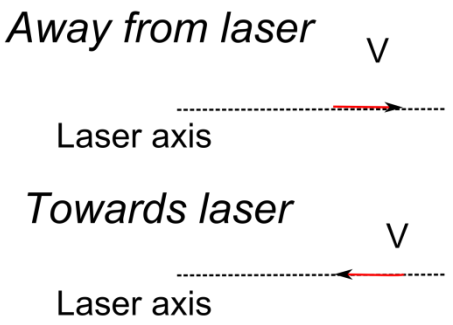
Signal Processing: FFT



Fd 15.542 kHz
Velocity 5.05 mm/sec

1. Translation stage





Why?

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

Signal
- How to receive

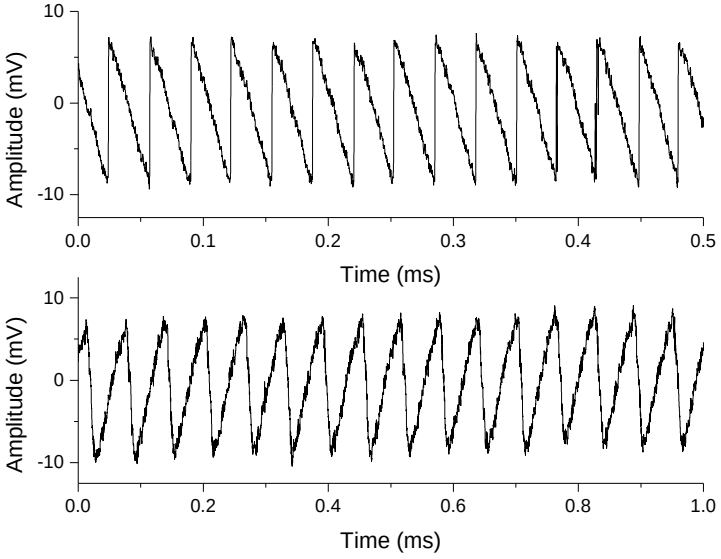
V =0.01 – 10.00 cm/s

Accuracy: solid targets

Examples of the signal

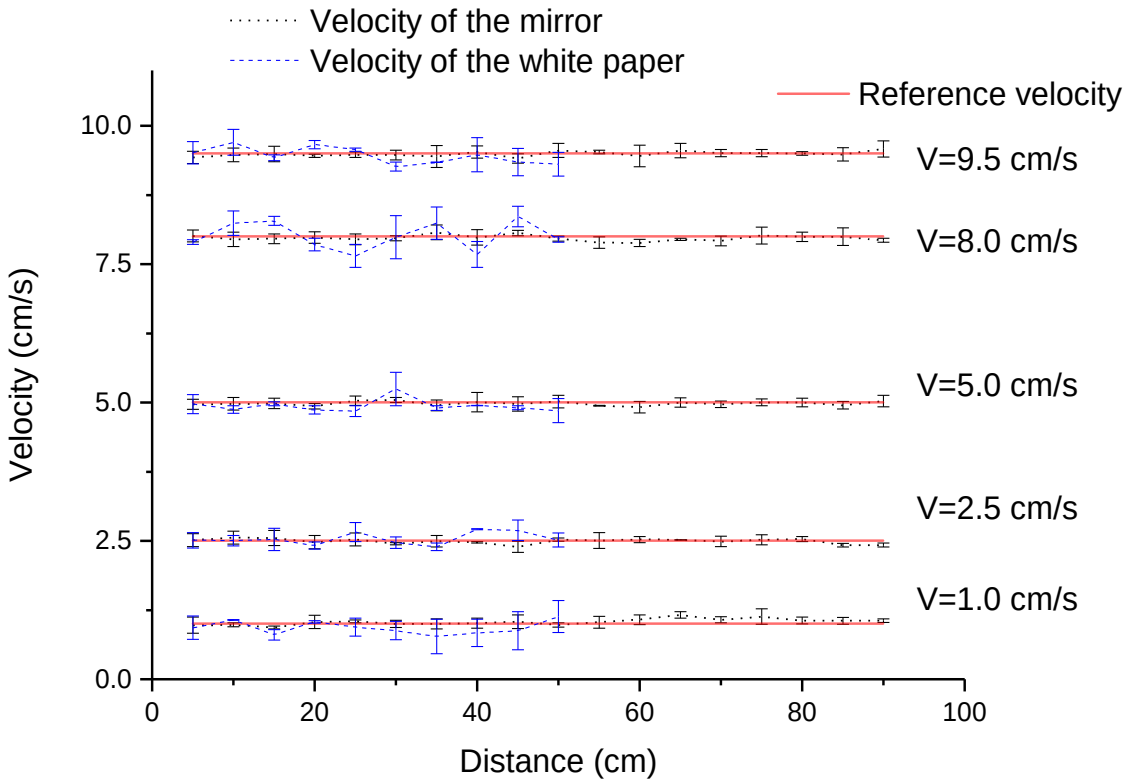
a mirror as target 5.0 mm/s

forward movement



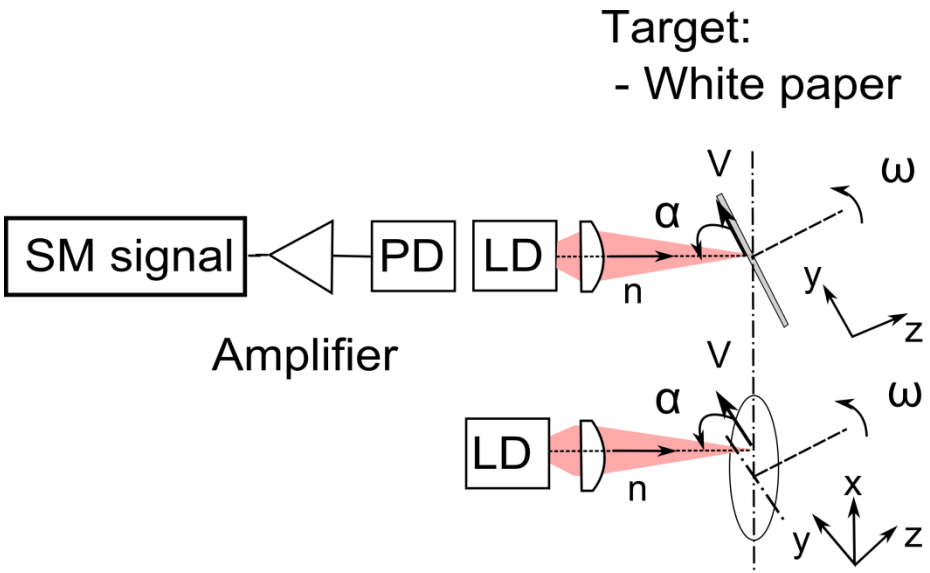
white paper as target 5.2 mm/s

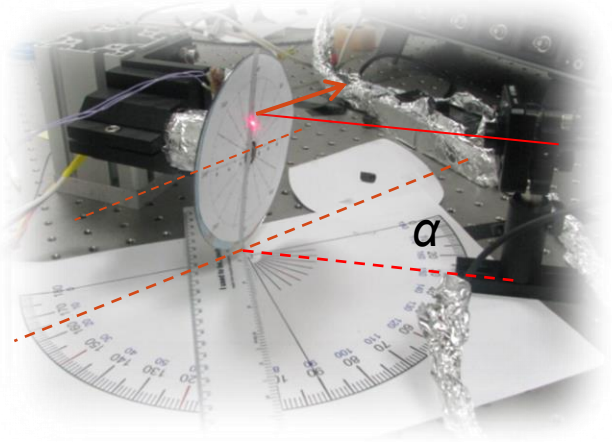
away from the laser movement



**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

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

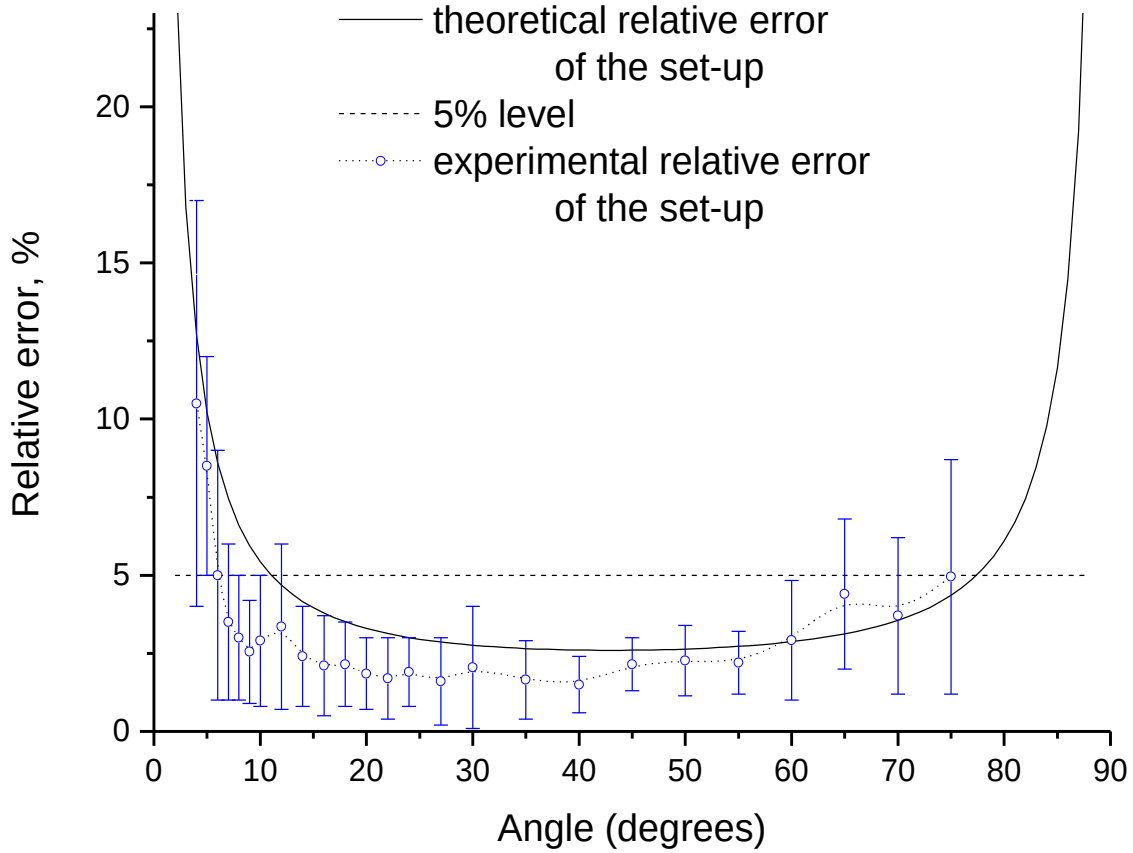
$$\vec{\mathrm{n}} = (0, \cos\alpha, \cos\alpha)$$

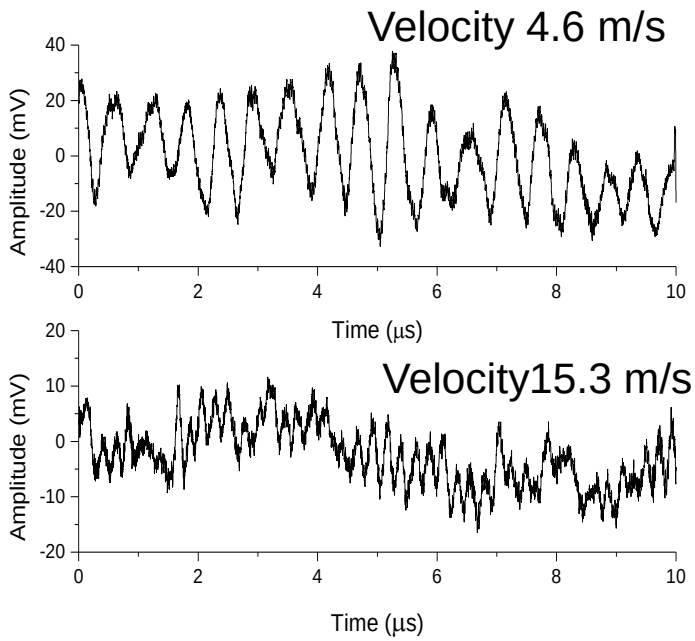
$$\mathrm{f} = \frac{2\omega \mathrm{R} \cos\alpha \cos\beta}{\lambda}$$

Variation:

- *R*
- *ω*
- *α*

Rotating disc: example of the signal, accuracy and precision





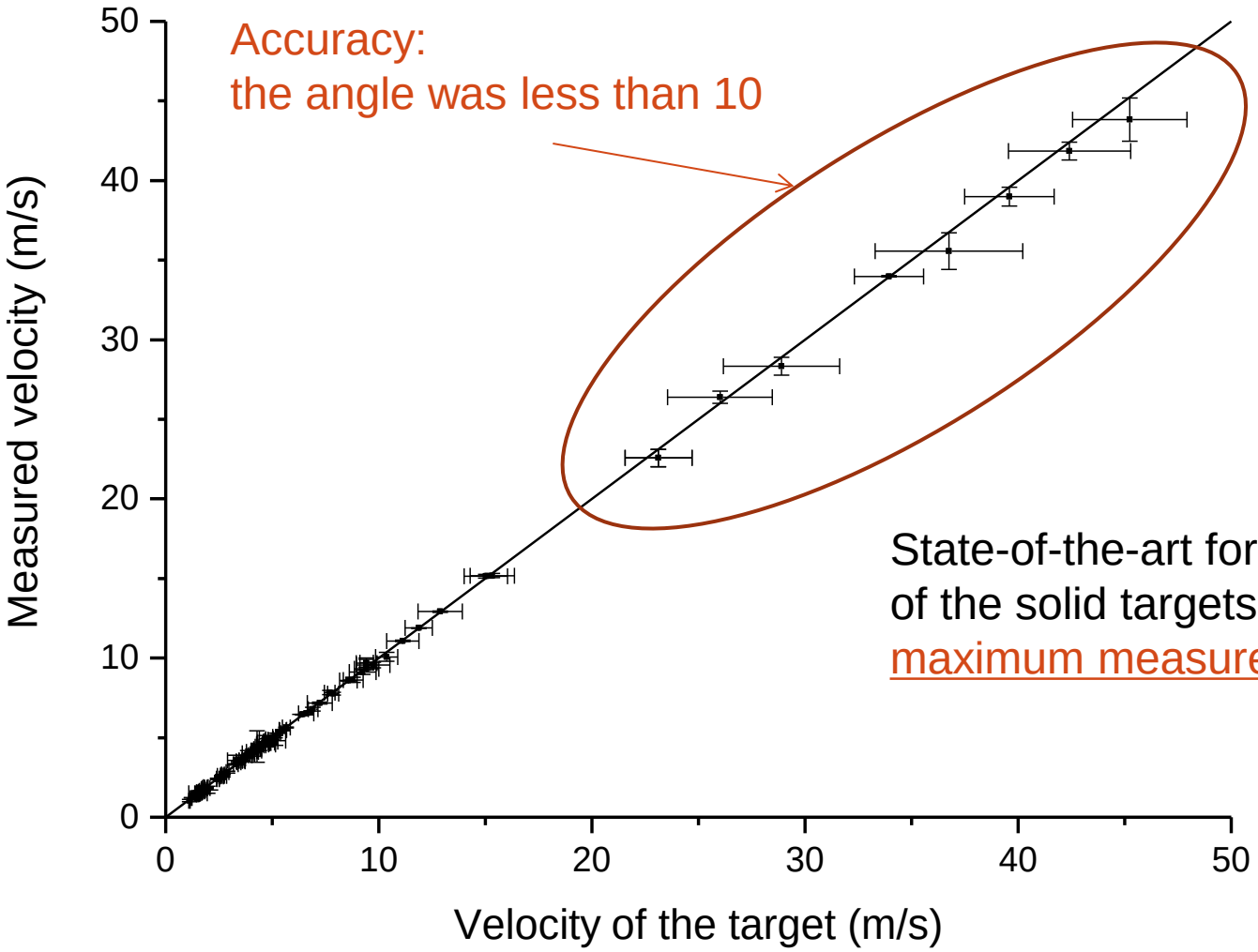
Here presented signal: the angle between the target and laser axis was 7°

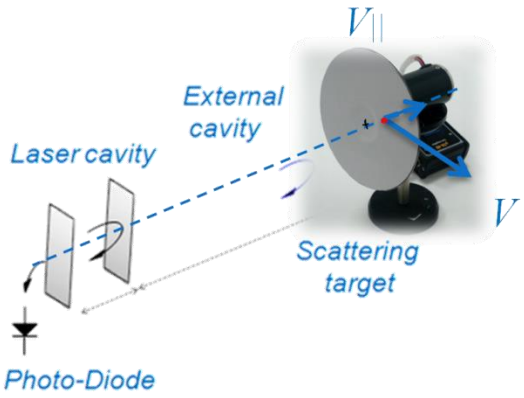
$$\delta Vlaser = \sqrt{(\delta R)^2 + (\delta \nu)^2 + (\delta \alpha)^2}$$

$$\delta \nu = \Delta \nu / \nu$$
$$\delta \alpha = \cot(\alpha) \Delta \alpha$$
$$\delta R = \Delta R / R$$

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

Benchmarking

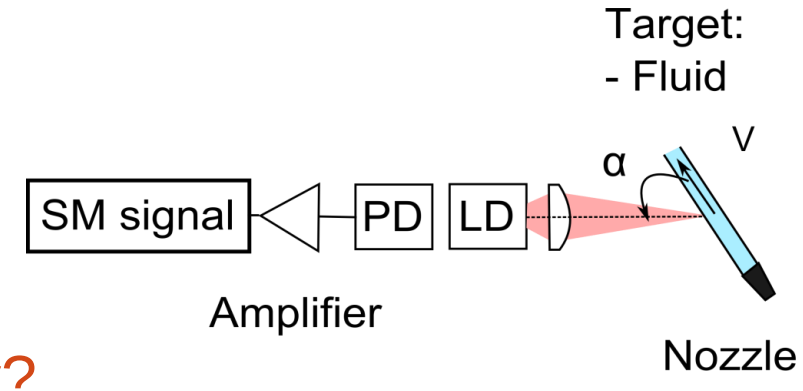


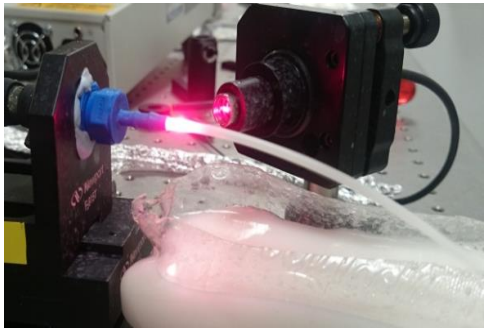


State-of-the-art for self-mixing velocimetry of the solid targets:
maximum measured velocity is 25 m/s

**Results are presented: Journal article: Optical Engineering: submitted fro review: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?

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

TiO2?

Seeding material for liquid flows

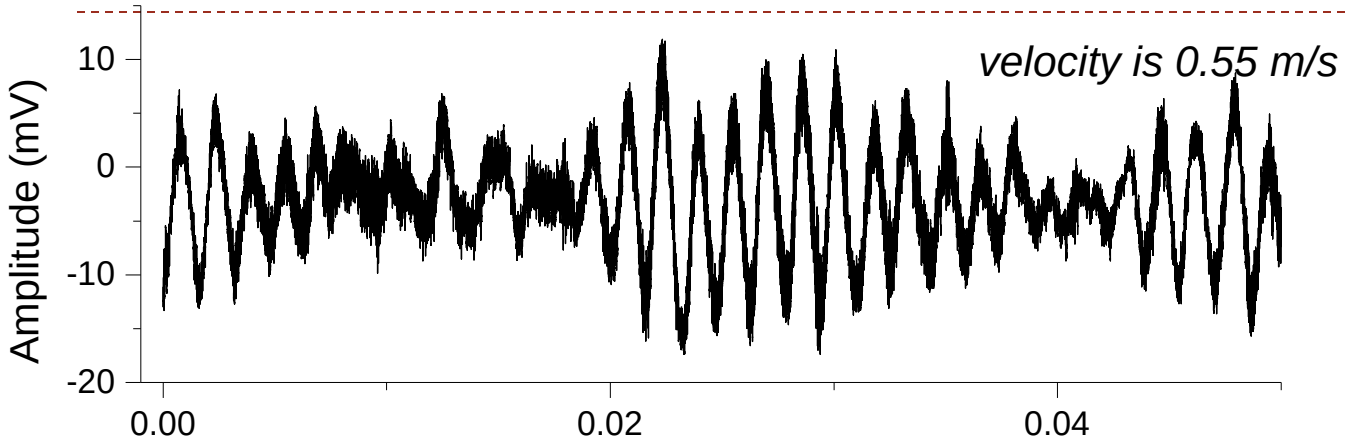
Type	Material	Mean diameter in μm
Solid	Polystyrene	10 – 100
	Aluminum flakes	2 – 7
	Hollow glass spheres	10 – 100
	Granules for synthetic coatings	10 – 500
Liquid	Different oils	50 – 500
Gaseous	Oxygen bubbles	50 – 1000

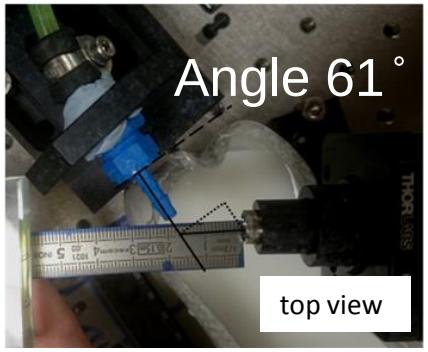
Seeding material for gas flows

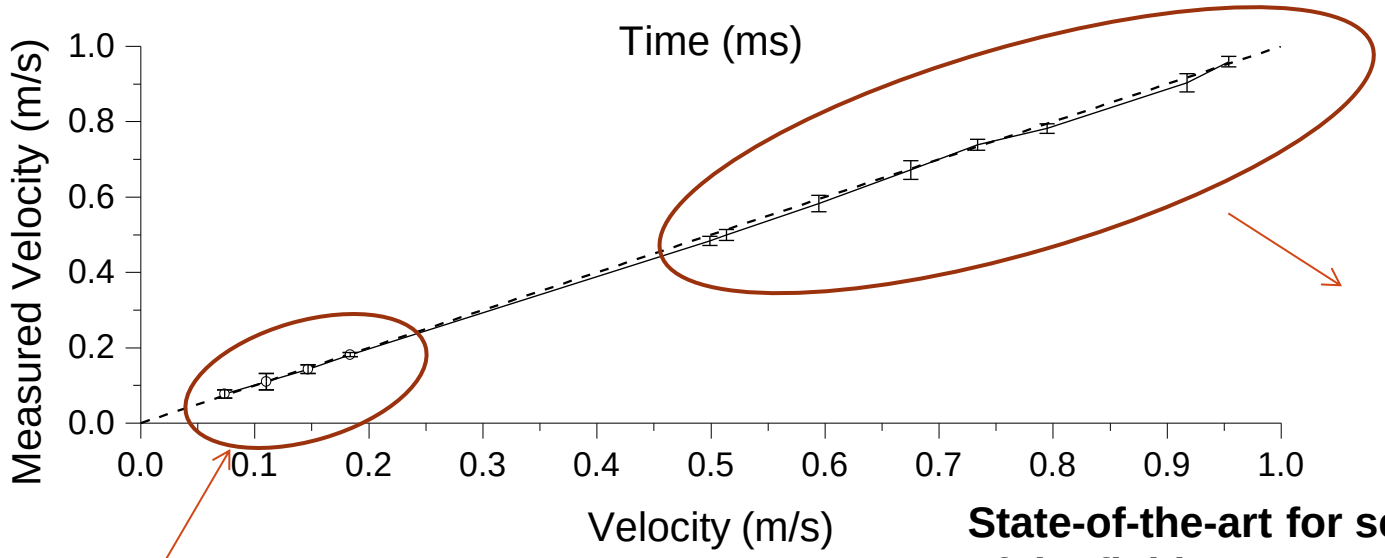
Type	Material	Mean diameter in μm
Solid	Polystyrene	0.5 – 10
	Alumina Al_2O_3	0.2 – 5
	Titania TiO_2	0.1 – 5
	Glass micro-spheres	0.2 – 3
	Glass micro-balloons	30 – 100
	Granules for synthetic coatings	10 – 50
	Dioctylphathalate	1 – 10
	Smoke	< 1
Liquid	Different oils	0.5 – 10
	Di-ethyl-hexyl-sebacate (DEHS)	0.5 – 1.5
	Helium-filled soap bubbles	1000 – 3000

* Tables are adapted from Raffel, M., Willert, C. E., Wereley, S. T. & Kompenhans, J., *Particle Image Velocimetry: A Practical Guide* (Springer, 2007).

Fluids: signal and benchmarking







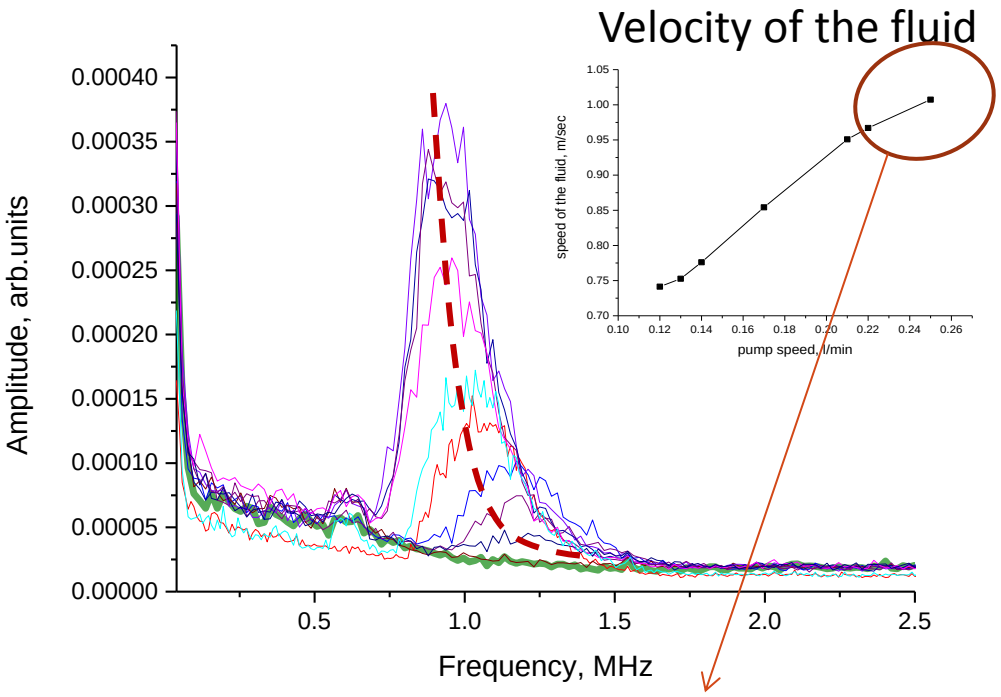
TiO_2 colloidal suspension diluted in water up to 0.01% concentration

milk diluted in water to 5% concentration

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

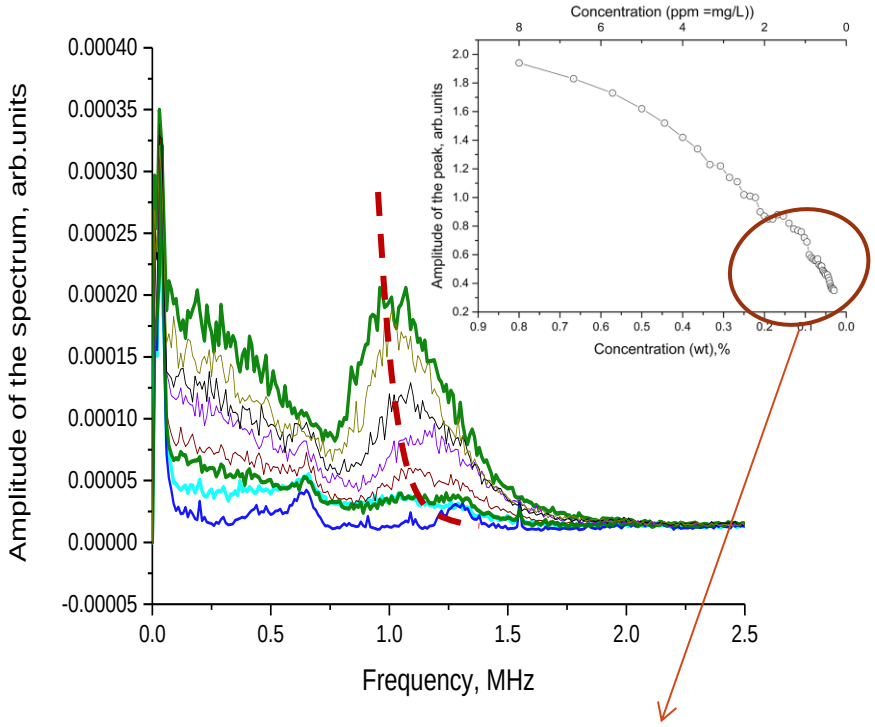
Fluids: FFT

Concentration is fixed
Velocity increases



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

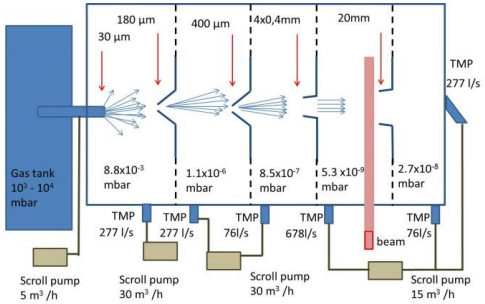
Velocity is fixed
Concentration decreases



Minimal concentration was 0.01 %
of the seeders in water

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



Seeding material for gases

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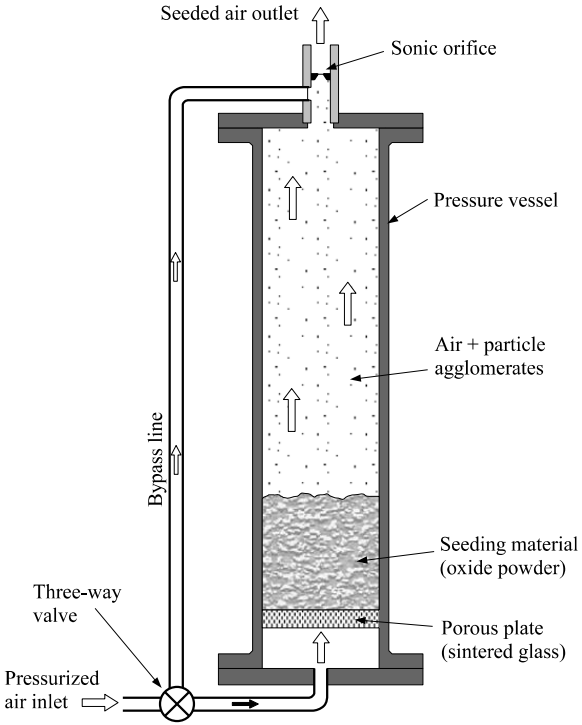


* Table and the bottom right picture are adapted from Raffel, M., Willert, C. E., Wereley, S. T. & Kompenhans, J., *Particle Image Velocimetry: A Practical Guide* (Springer, 2007).

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!

Thank You
for Your attention!

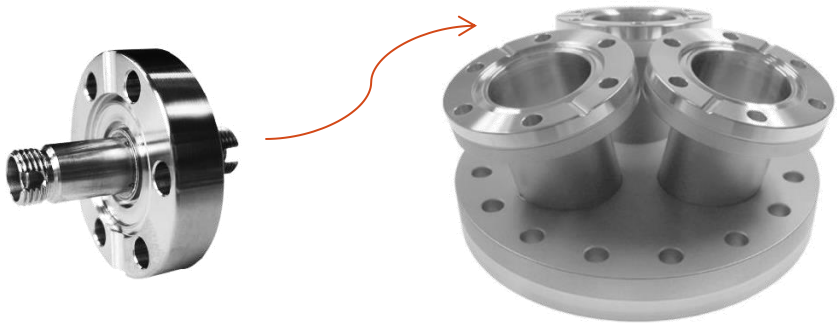
Results

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%

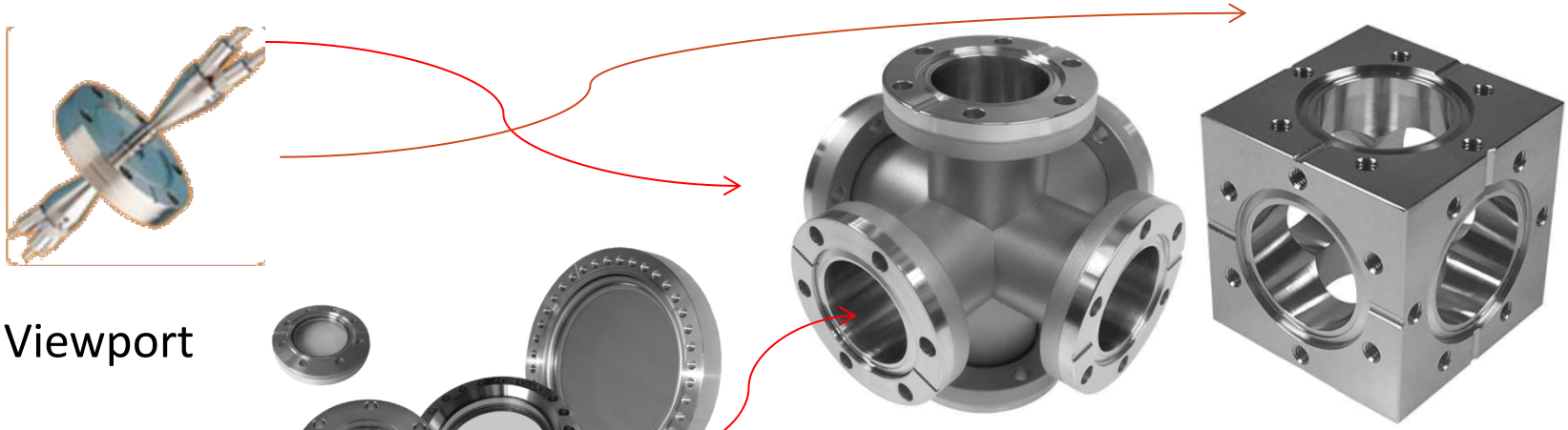
**Results are presented: Journal article: Optical Engineering: submitted fro review:Laser Diode Self-mixing Interferometry for Velocity Measurements*

Difficulties: delivery of the light to the gas jet

- Optical feedthrough
- - perpendicular



- - under the angle

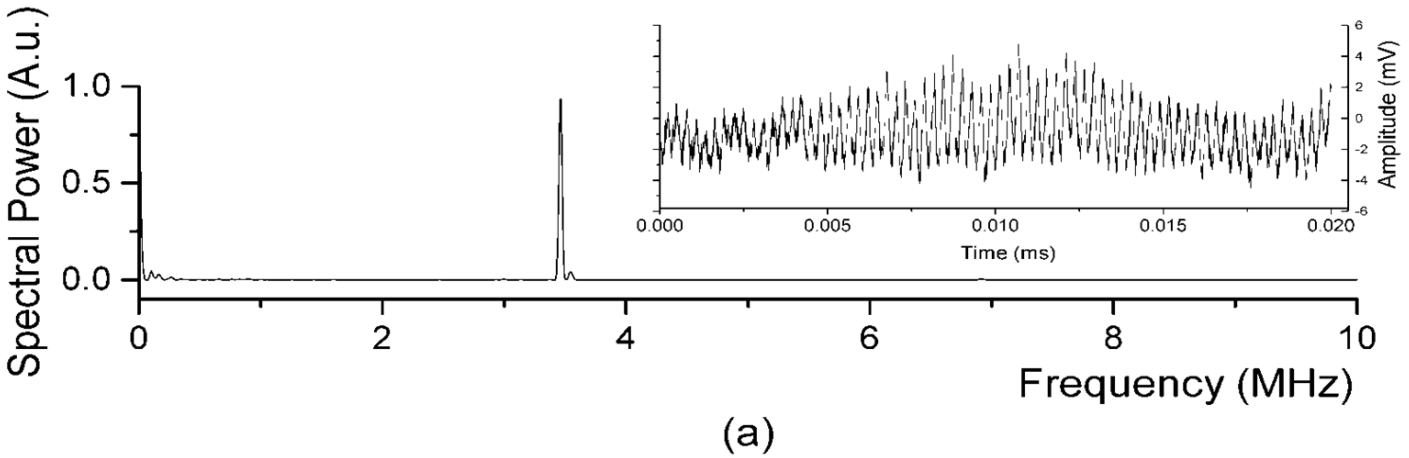


- Viewport

Rotating disc: signal and FFT

17.6 m/s, 51˚

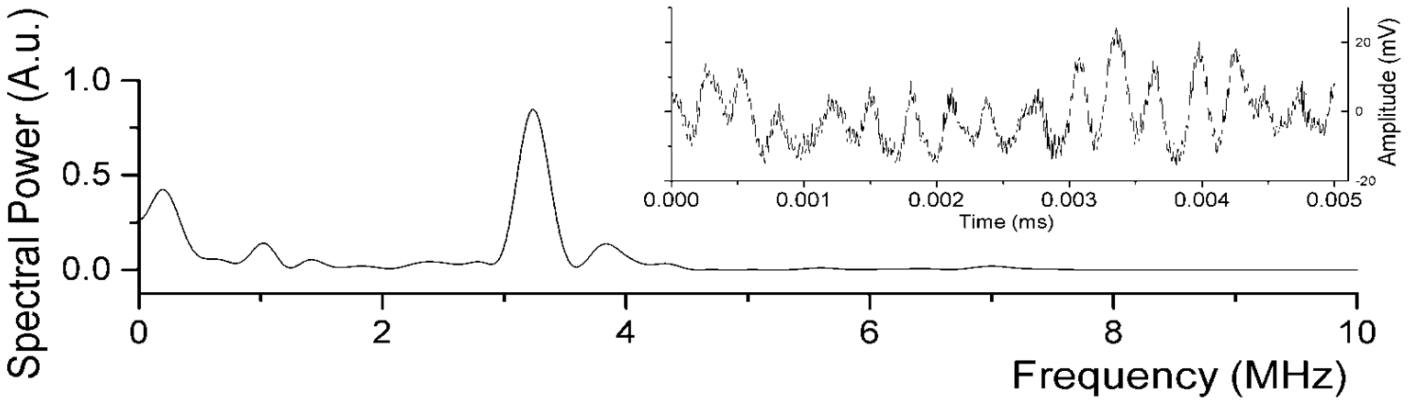
3.4 MHz



(a)

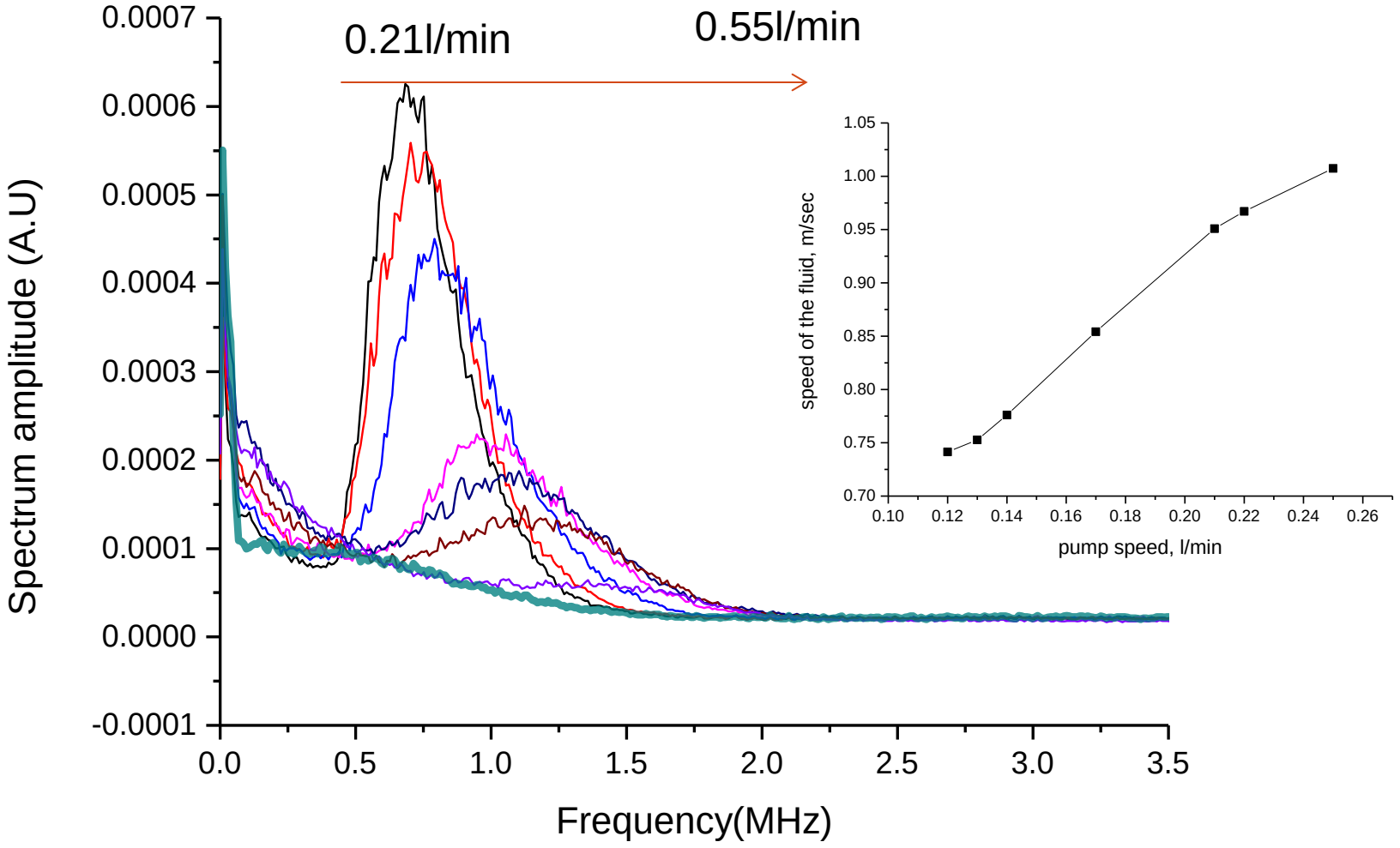
10.6 m/s, 9˚

3.23 MHz

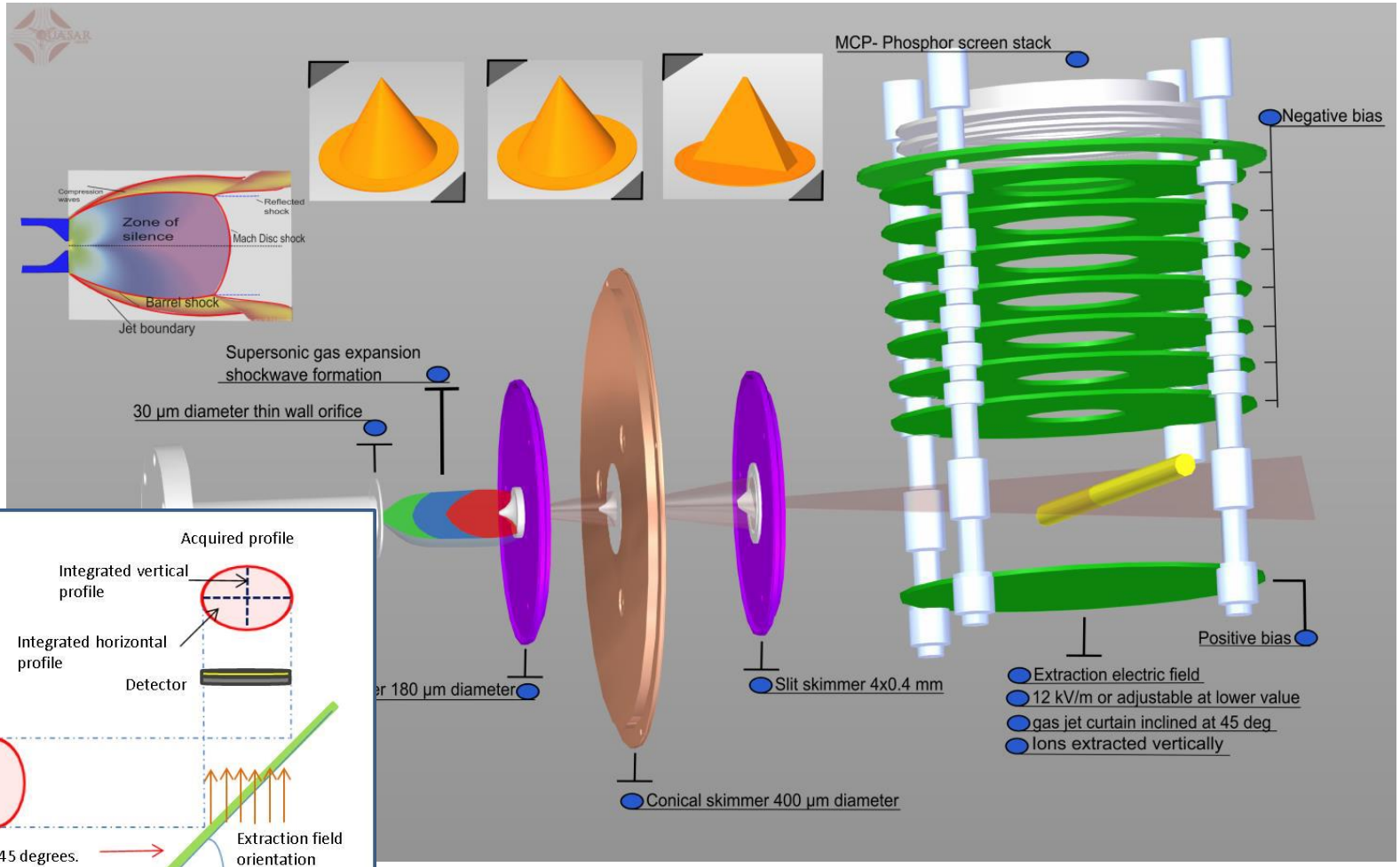


(b)

FFT: fluids

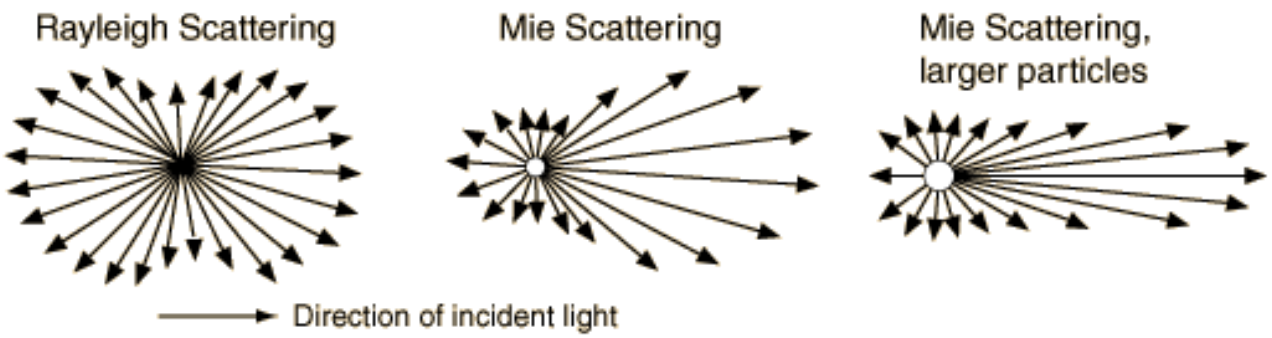

0.21l/min
0.55l/min
Spectrum amplitude (A.U)
Frequency(MHz)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
-0.0001
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
speed of the fluid, m/sec
pump speed, l/min
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26

Gas-Jet set-up



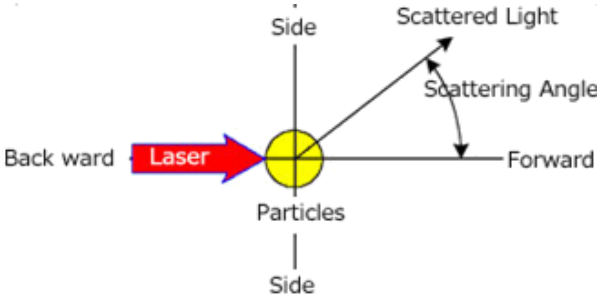
Thanks to M. Putignano;
// V. Tzoganis, et al. IPAC2013

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: $\chi > 50$



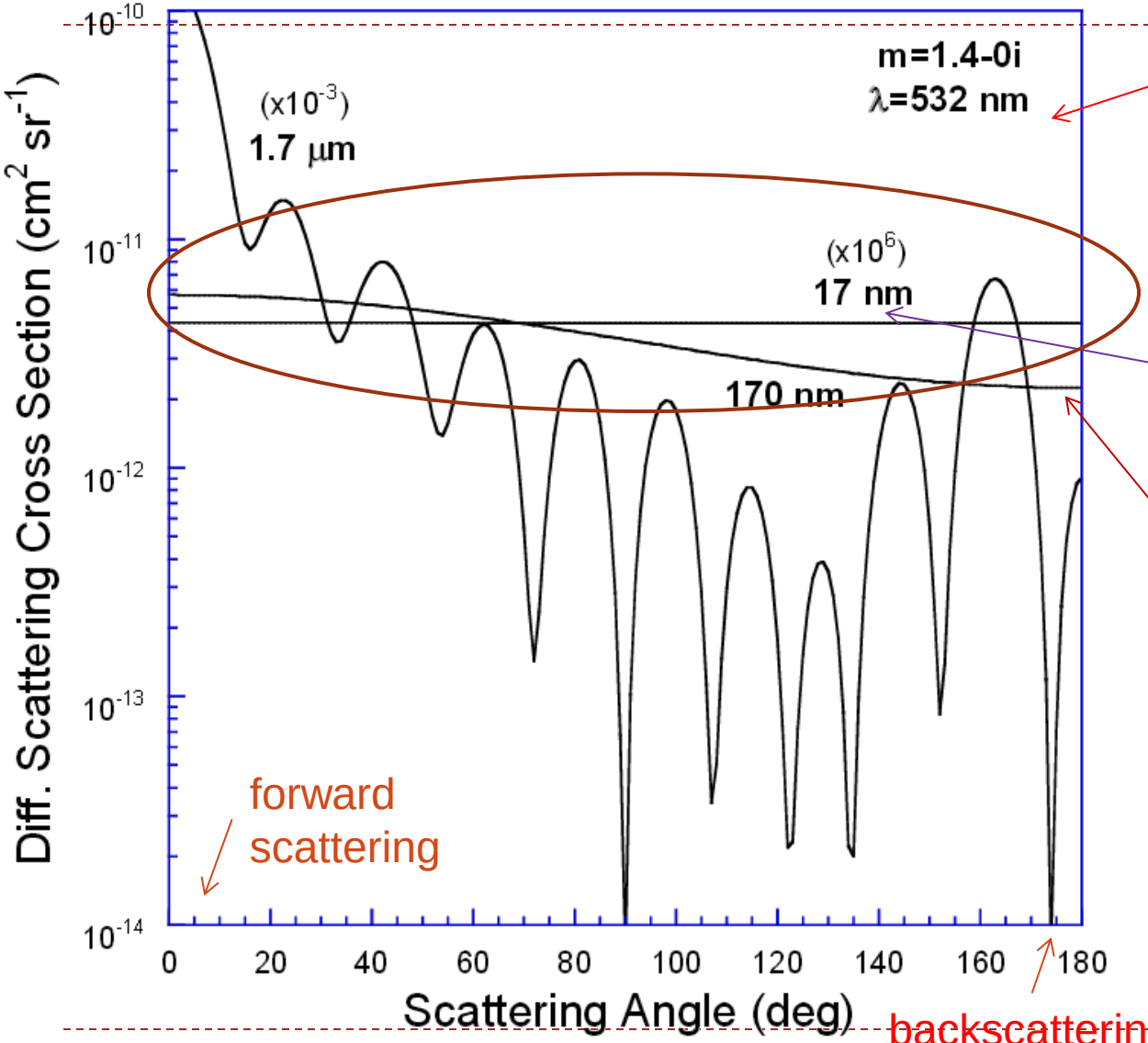
Scattering

- 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

Scattering



1.7 mkm: Mie regime

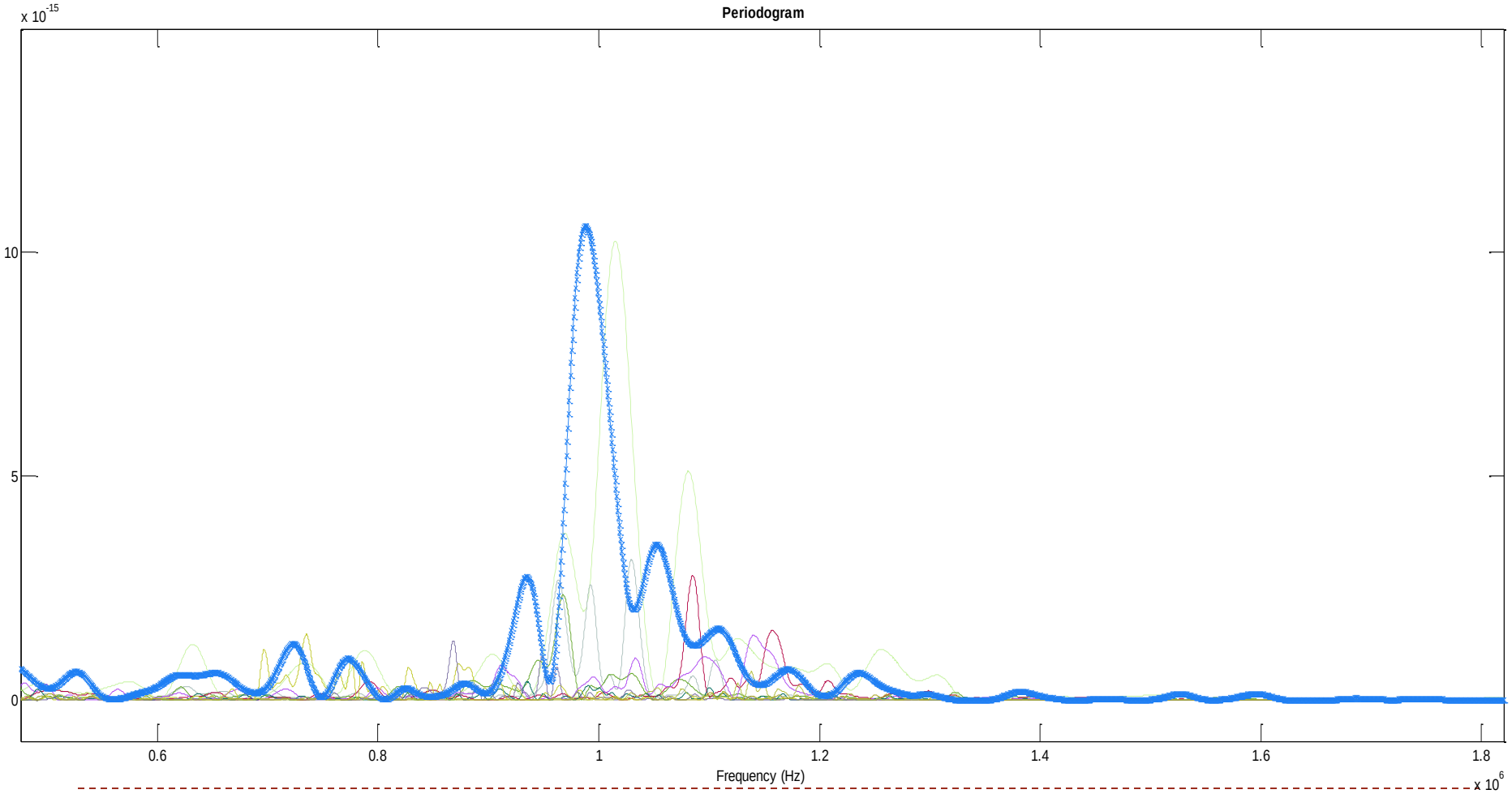
Ripples: constructive and destructive interference along different path

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


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