532-nm
Photonic Doppler Velocimetry

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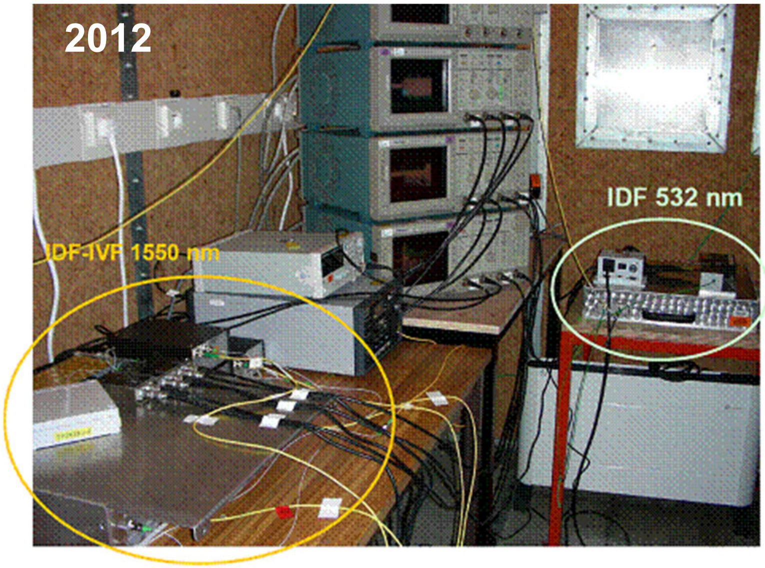
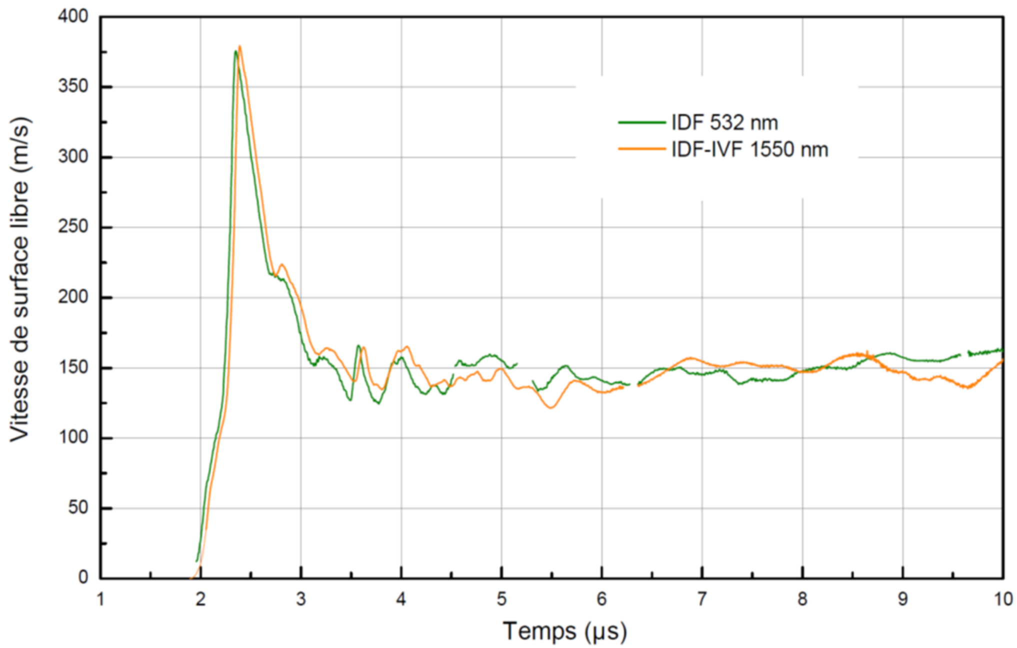
When did it start in Gramat ?

- First attempt in 2011 : low efficiency due to bad laser coupling using the VISAR laser (Coherent VERDI)
- Second attempt in 2012 using a fibered Oxxius laser (100 mW)

→ Successful measurement in real condition in a high-pulsed-power generator (result never published)



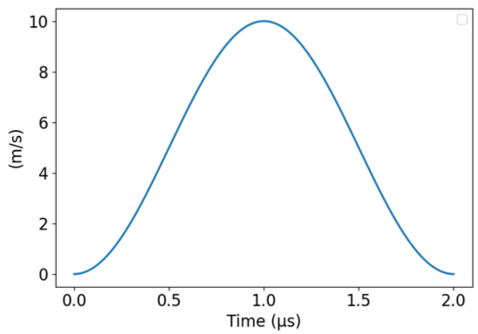


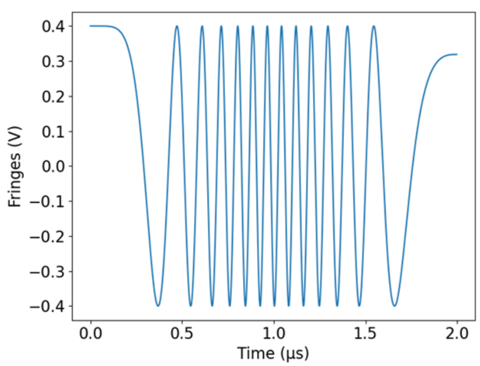
Why a 532-nm PDV system?

Fast acceleration reaching a “low velocity” providing only few interference fringes

HPP Ramp compression experiment

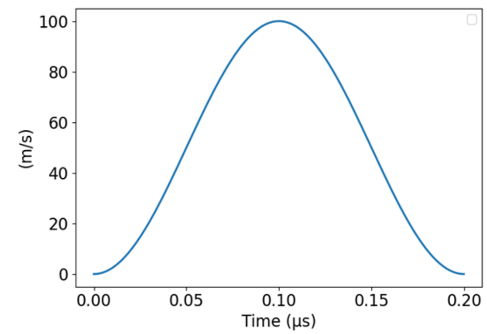
10 m/s
in 1 µs

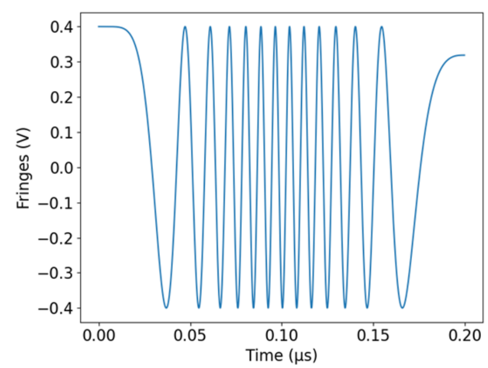




Laser shock experiment

100 m/s
in 100 ns





@ 1550 nm

(Homodyne PDV)

$$f_{Doppler} = \frac{2 \cdot v(t)}{\lambda}$$

Higher velocity and *temporal* resolutions

1550 nm *vs.* 532 nm

Fiber components :

Wavelength (nm)	1550	532
Mode diameter (µm)	10.4	4.2
Effective surface (µm²)	84.9	13.9
Optical losses dB/m	0.0002	0.03
Numerical Aperture	0.14	0.12
Connector losses (dB)	0.05	~1.0
Recommended maximum optical power (mW) ~500 kW/cm²	450	70

Bandwidth : $f_{Doppler} = \frac{2 \cdot v(t)}{\lambda}$

Wavelength (nm)	1550	532
$f_{Doppler}$ at 5'000 m/s (GHz)	6.45	18.8

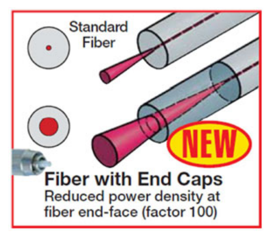
Photoreceiver :

Wavelength (nm)	1550	532
Diode gain (A/W)	0.9	~0.2

Final power ratio: > 20

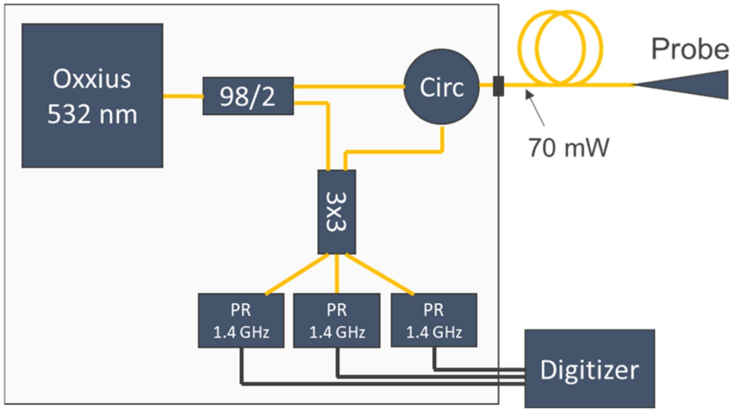
Solutions :

- Fiber splicing
- ? Multimode fibers ?
- Laser coupling with end-caps
- New photoreceiver Thorlabs : 25 GHz and high amplification



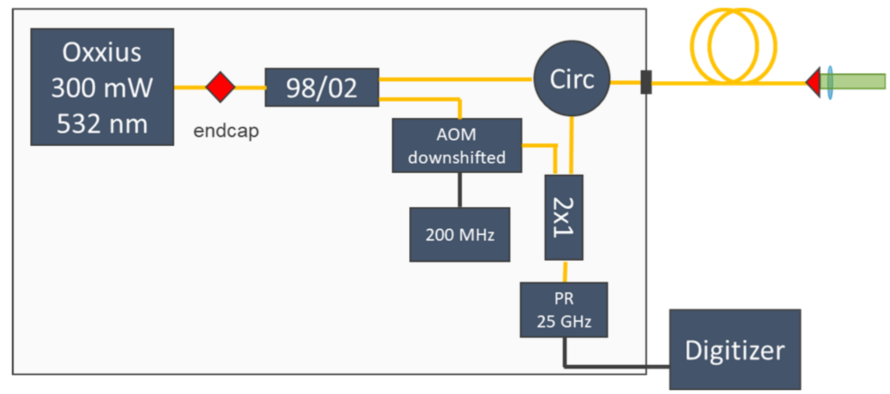
532-nm Photonic Doppler Velocimetry systems

Homodyne Green Triature



- Fibers spliced inside
- Simple connector at the output
- Signal processing:
  - STFT → velocity
  - Phases analysis → displacement
- Bandwidth: 1.4 GHz @-3dB
- Max. velocity: 500 m/s in practice

25 GHz Green PDV



- Fibers spliced inside
- Simple connector at the output
- Signal processing: STFT
- Frequency shift: 200 MHz
- Th. bandwidth: 25 GHz @-3dB
- Th. max. velocity: 6700 m/s

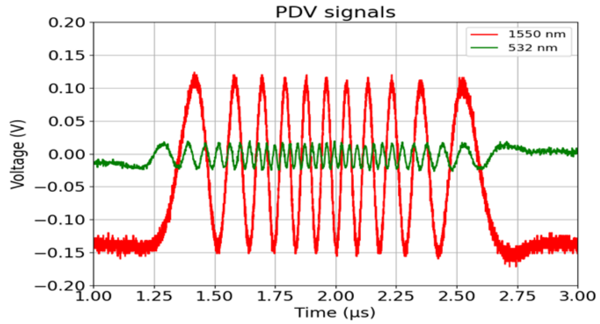
Fast acceleration reaching a “low velocity”

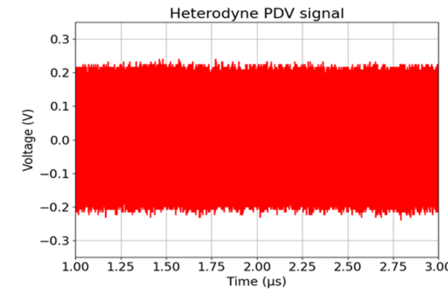
75-ns STFT window in all cases

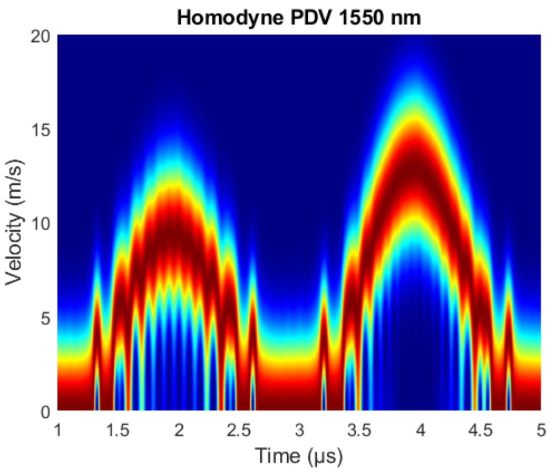
Homodyne PDV @ 1550 nm

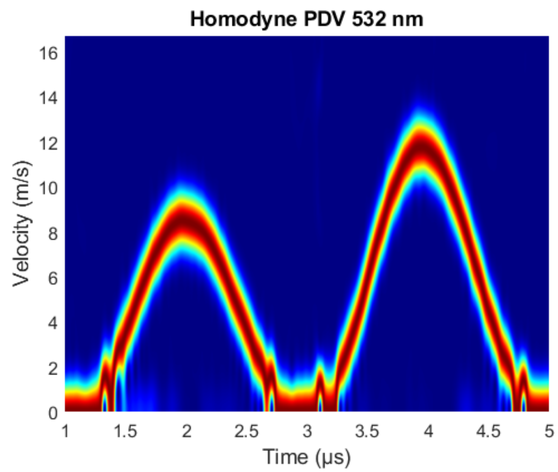
Homodyne PDV @ 532 nm

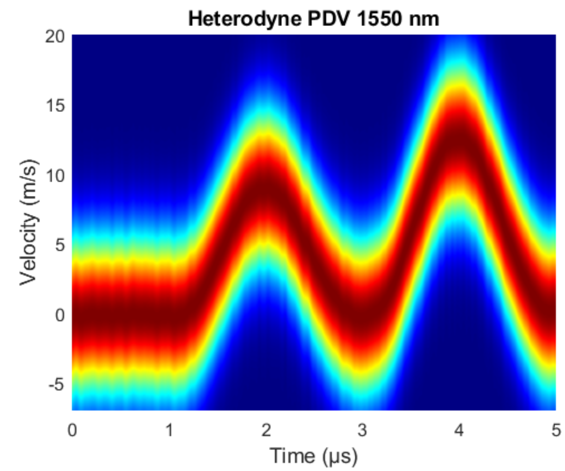
Heterodyne PDV @ 1550 nm











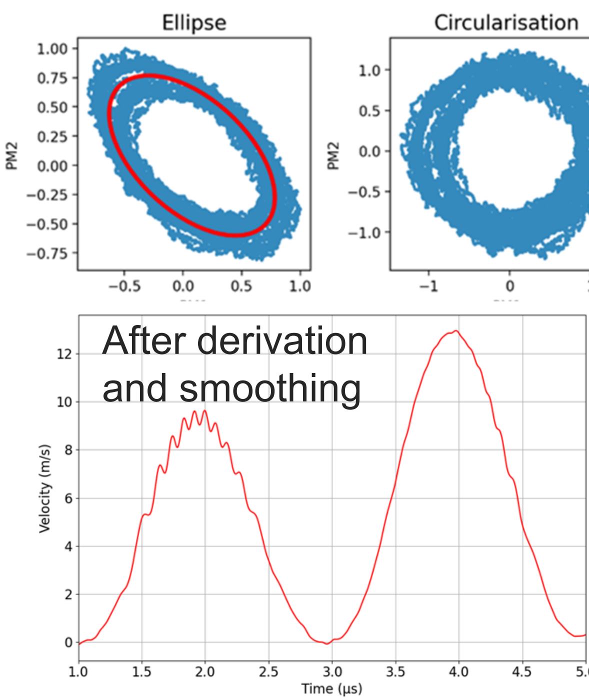
- Minimum velocity: ~8 m/s
- Small ripples on the first peak

- Minimum velocity: ~3 m/s
- Thin spectrogram trace / No ripple

- Full velocity range
- Thick spectrogram trace

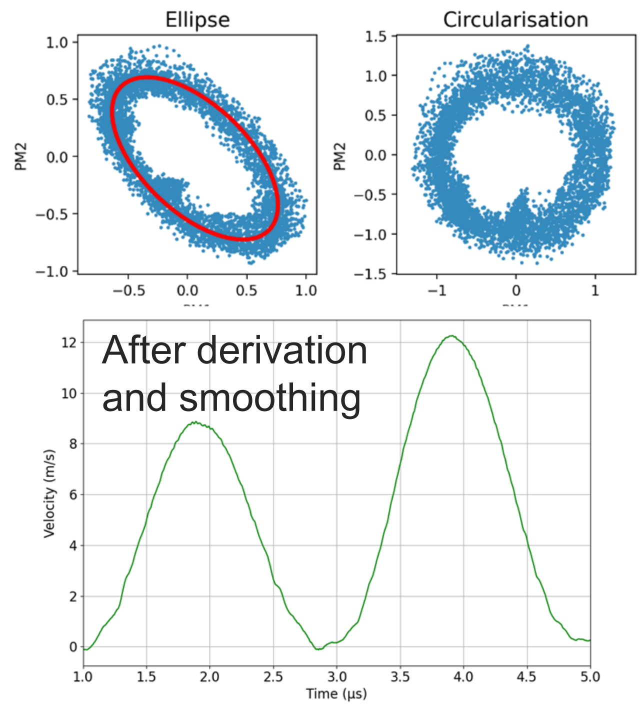
Using 2 phases analysis

Homodyne PDV @ 1550 nm



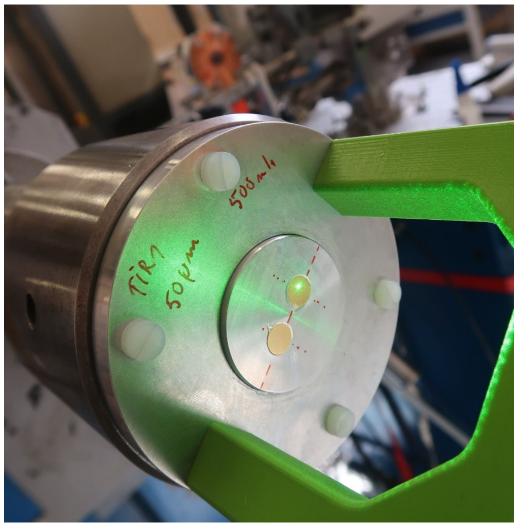
- Full velocity range
- Ripples on the first peak

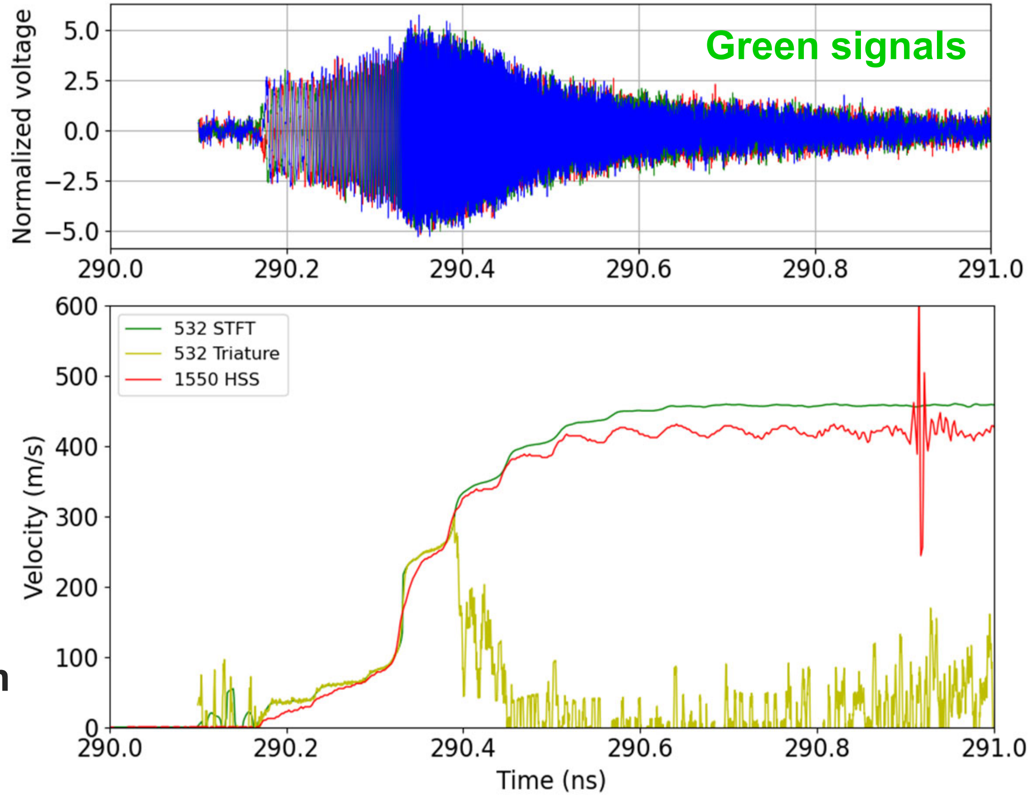
Homodyne PDV @ 532 nm



- Full velocity range
- No ripple observed

Shock plate experiment: Al – Al + 100 µm Au





Non-optimized setup :

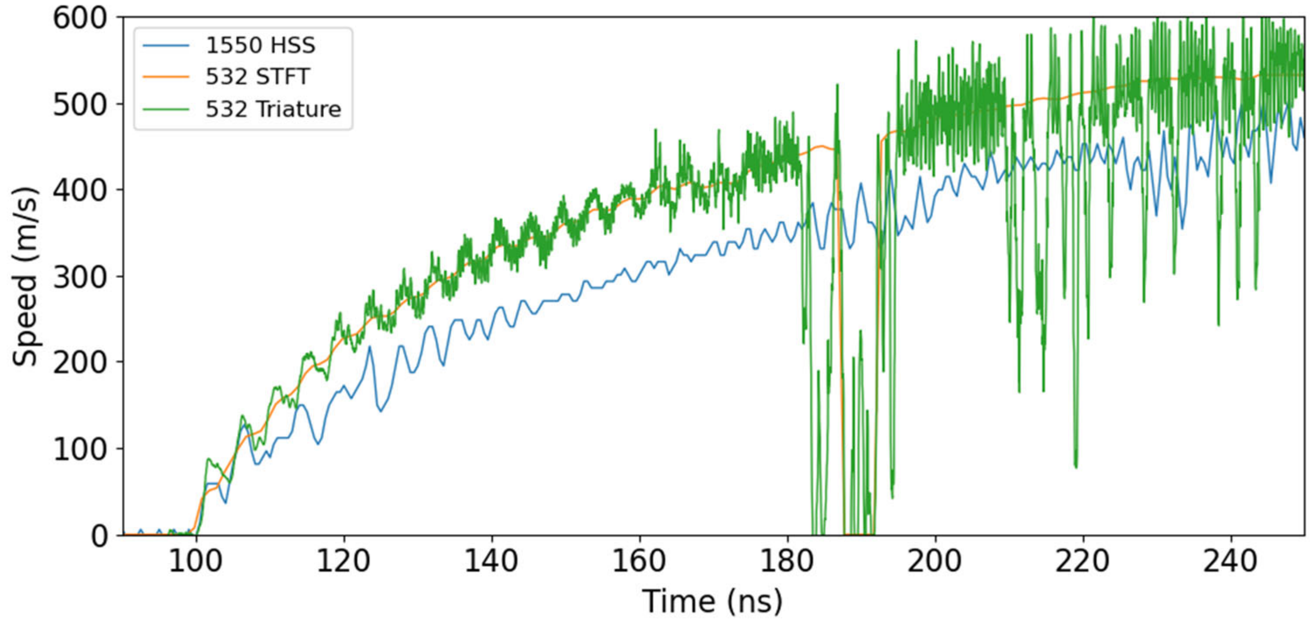
- **Working distance off**
- **Frequency sampling too low @ 532 nm**

→ difficult to compare the systems

Laser shock experiment on a thin iron layer

Energy: 82 J in 100 fs
Spot size: 2.5 mm
Intensity: ~ 16.8 GW/cm²
Iron film: 12.5 µm

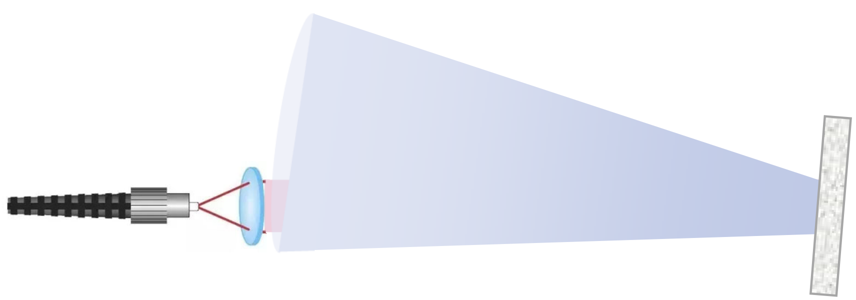
HSS frequency shift : ~ -1.2 GHz

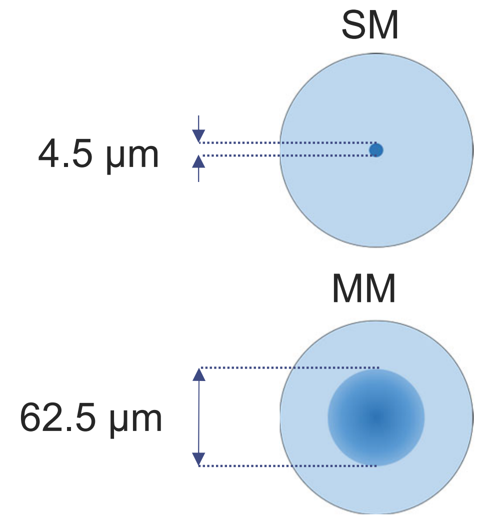


- Two different experiments → not exactly the same velocity profile,
- @ 532 nm, the triature processing provides a better time resolution,
- The triangular shape is physical according to our EOS,
- @1550 nm, the probing wasn't optimum, better results should be obtained, also by increasing the frequency shift to -3 GHz.

What about multimode fibers ?

- Single mode fibers have a very small core diameter
- On-field constrains:
  - Probes not always in a kinetic mount
  - Possible tilting during the measurement
  - Bad surface quality => high diffusion
  - @532 nm limited laser input power





Can we get lower alignment constrains, larger interference fringes and reduce the lasing power if we use 62.5 µm multi-modes fibers ?

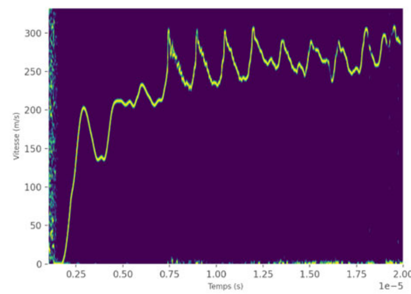
Despite the interference contrast reduction!

High pulse power generator experiment up to 300 m/s

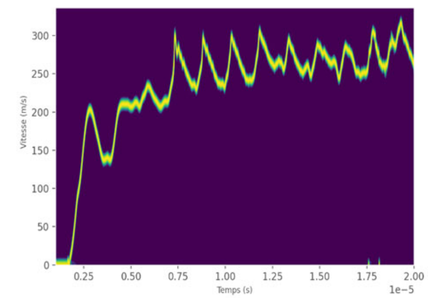
Probes: focusers with a 20-mm WD

@ 1550 nm (SM) on the top side
@ 532 nm (MM and SM) on the lower side

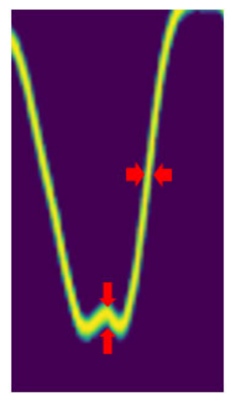
Alignment times:
- SM 1550 nm: ~ 5 min
- SM 532 nm: ~ 60 min
- MM 532 nm: ~2 min

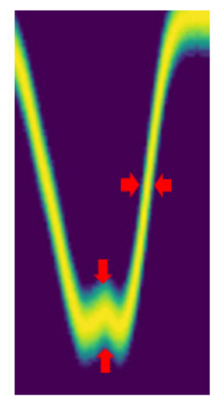


Singlemode
532 nm



Singlemode
1550 nm

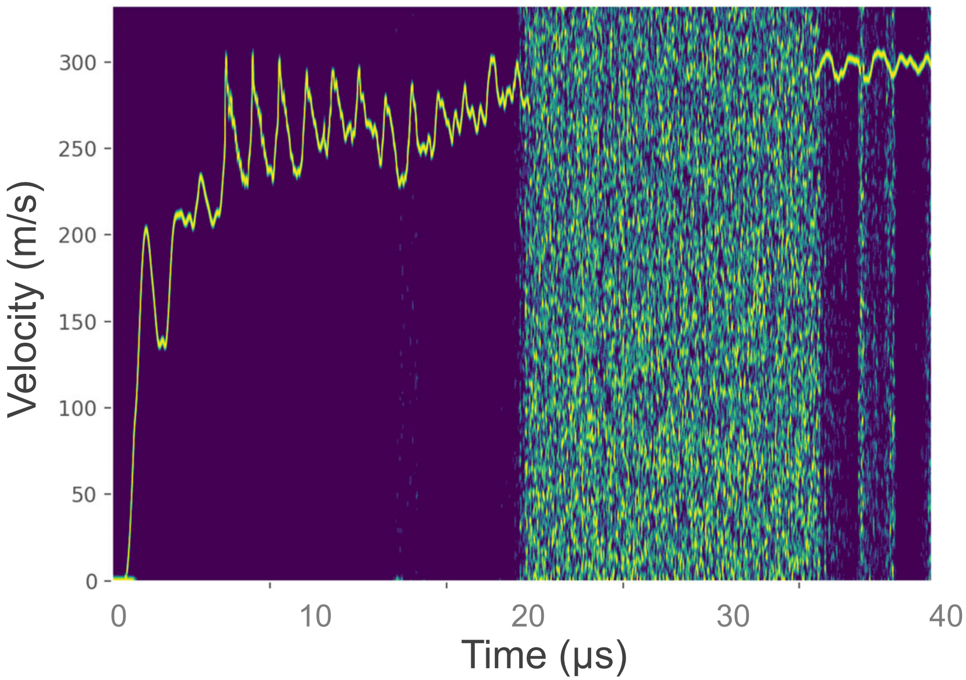




Higher temporal and velocity resolutions !

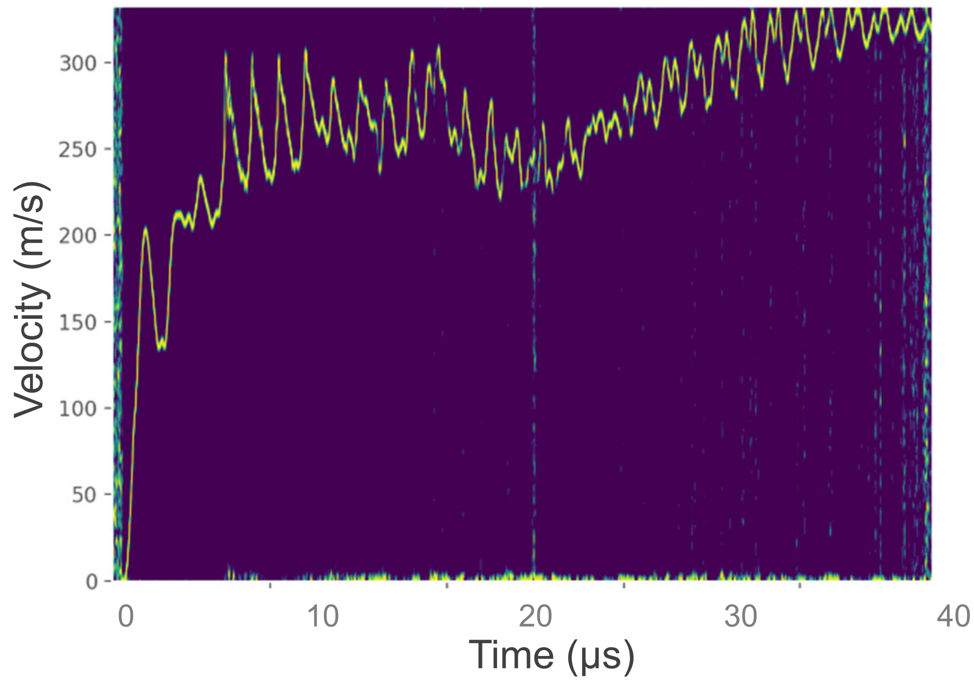
Singlemode vs. multimode at 532 nm

Singlemode



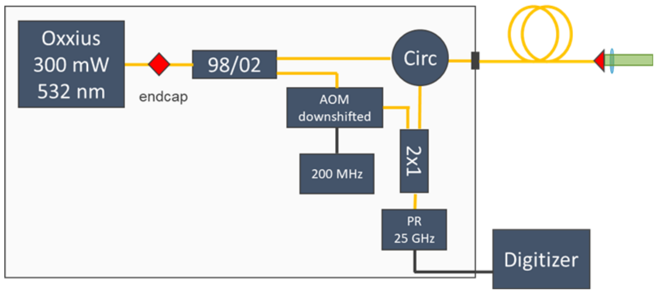
- Measurement OK
- Fringes RMS value: 37 mV
- Signal lost between 23 and 42 µs

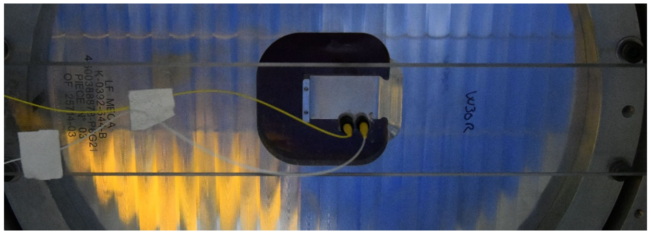
Multimode

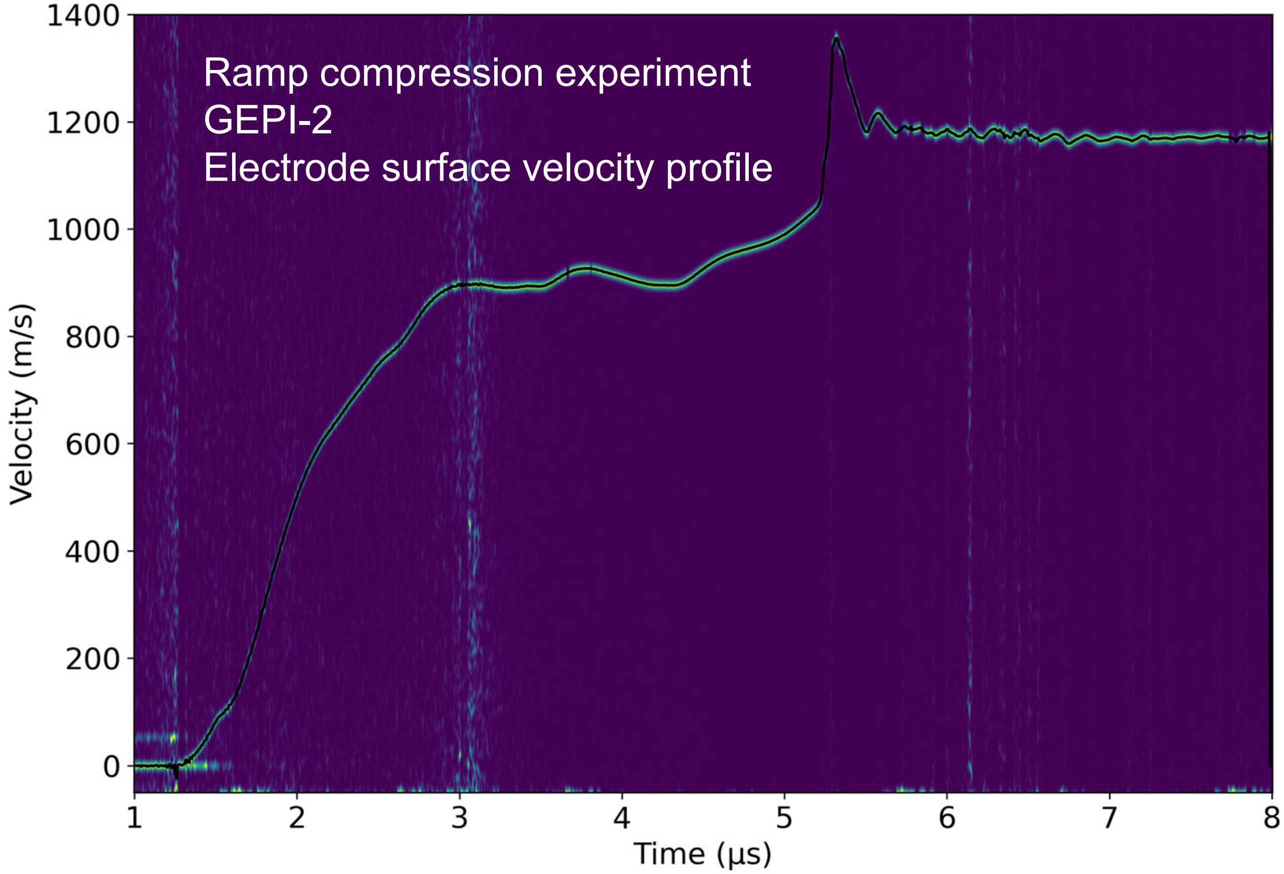


- Measurement OK
- Fringes RMS value: 190 mV
- Not any signal lost
- A bit more noise near 0 m/s

25 GHz Green PDV system







- Singlemode system, alignment still “demanding”,
- Velocity profile easily processed with the 200-MHz frequency shift,
- So far, the highest velocity measured is 1350 m/s.

Conclusion

- Green PDV remain more difficult to built and operate with singlemode fibers,
- Nowadays, high velocities > 5'000 m/s should be reachable,

- Green PDV clearly give 3 times better resolution on the velocity,
- Better time resolution is questionable, since a 1550 nm PDV with high frequency shift might have similar performances,
- Green PDV with triature phase analysis seems well suited for laser shock experiments,

- Multimode fibers degrade the interferences but could be interesting on fields when alignments are not guaranteed,

- 25 GHz Green PDV system : higher velocities and cloud of particles measurements are planned.

Thank you for your attention !

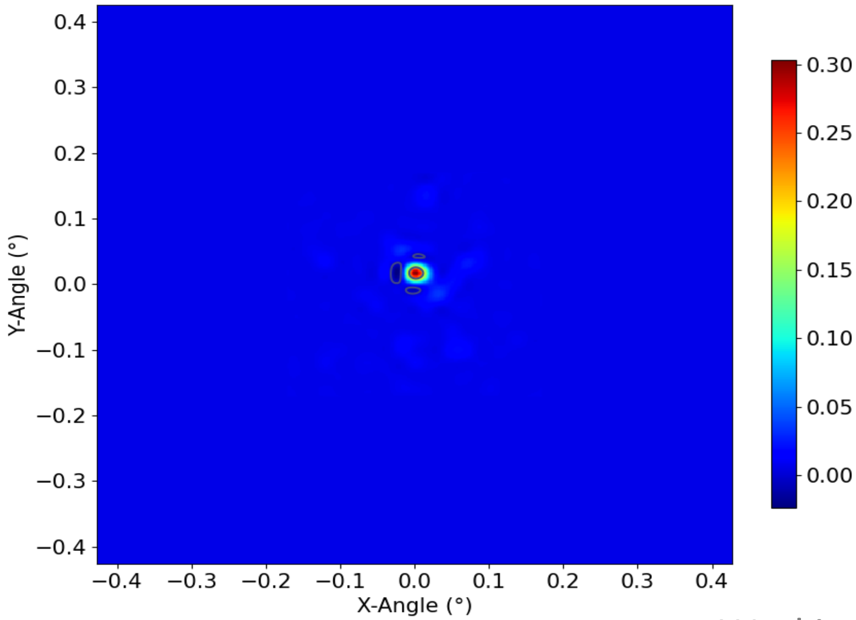
Y. Barbarin, P.-Y. Chanal, S. Bergey, G. Bourcier, J. Luc et G. Le Blanc "Vélocimétrie hétérodyne à 532 nm à basses vitesses« Journées Vélocimétrie Hétérodyne et Etude des Matériaux sous Choc (2022)

G. Le Blanc, S. Bergey, J. Vich, T. d'Almeida, M. Roudot, J. Luc, Y. Barbarin, "532-nm triature Photonic Doppler Velocimetry," Proc. SPIE 12016, Optical and Quantum Sensing and Precision Metrology II, 120160X (2022)

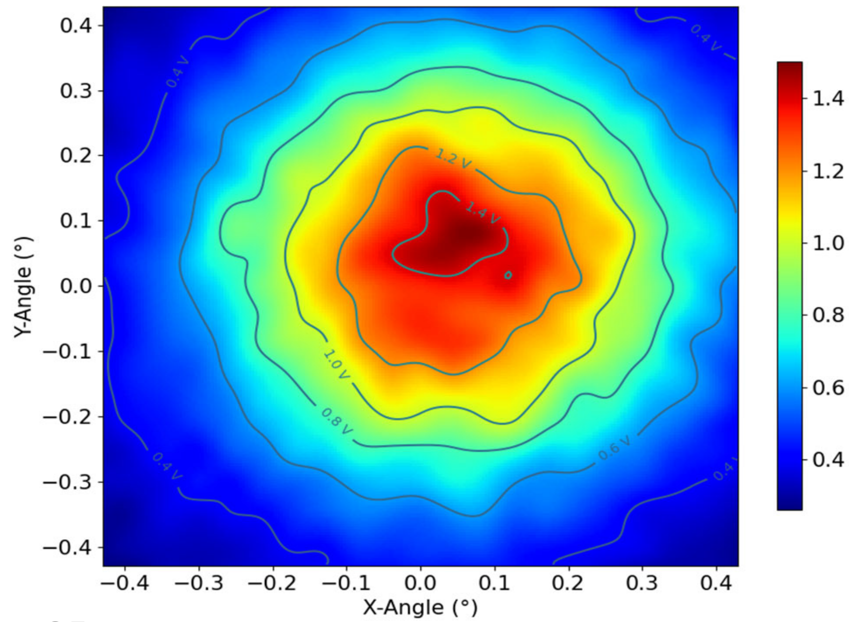
Y. Barbarin, G. Lefrère, G. Bourcier, D. Plouhinec, T. Paccou, G. Le Blanc, "Photonic Doppler velocimetry with 62.5 μm graded index multimode fiber at 1550 and 532 nm," Proc. SPIE 12428, Photonic Instrumentation Engineering X, 124280B (2023)

Light collection @ 532 nm without interferences

SM collimator



MM collimator



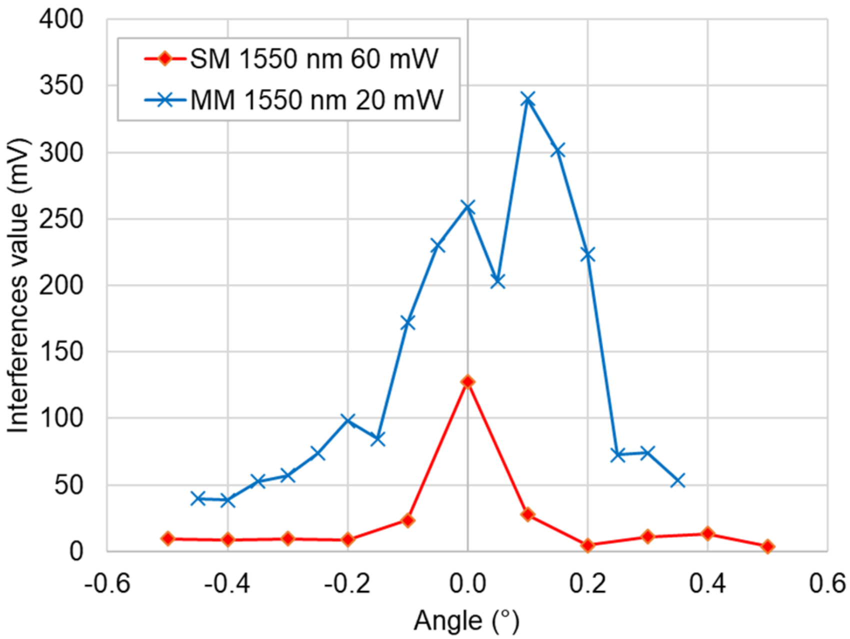
Working distance 25 mm
Aluminum target

- At the central position: 4.5 times more signal collected by the MM collimator
- Much greater tolerance angle !

Low speed experiments as a function of tilt angle

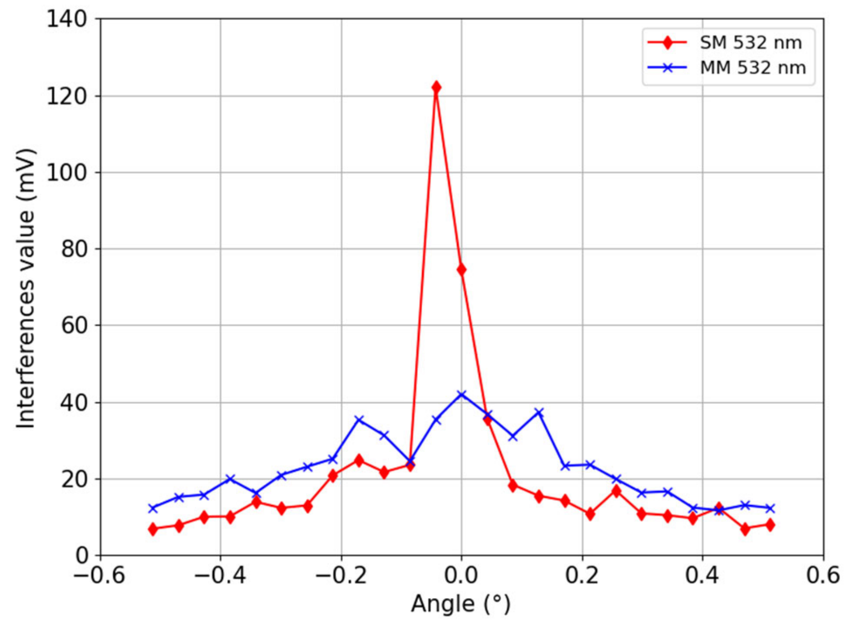
Aluminum target

@ 1550 nm



- Up to 6.5 times larger interference fringes with the same input power
- Tolerance angle increased from ± 0.1° up to ± 0.35°

@ 532 nm:



- The SM system provides ~3 times larger interference fringes but in a narrow angle range
- The MM system provide enough signal for the signal processing over a much larger angle range