Results and limitations of PDV measurement at 830 nm

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Institute for Shock Physics
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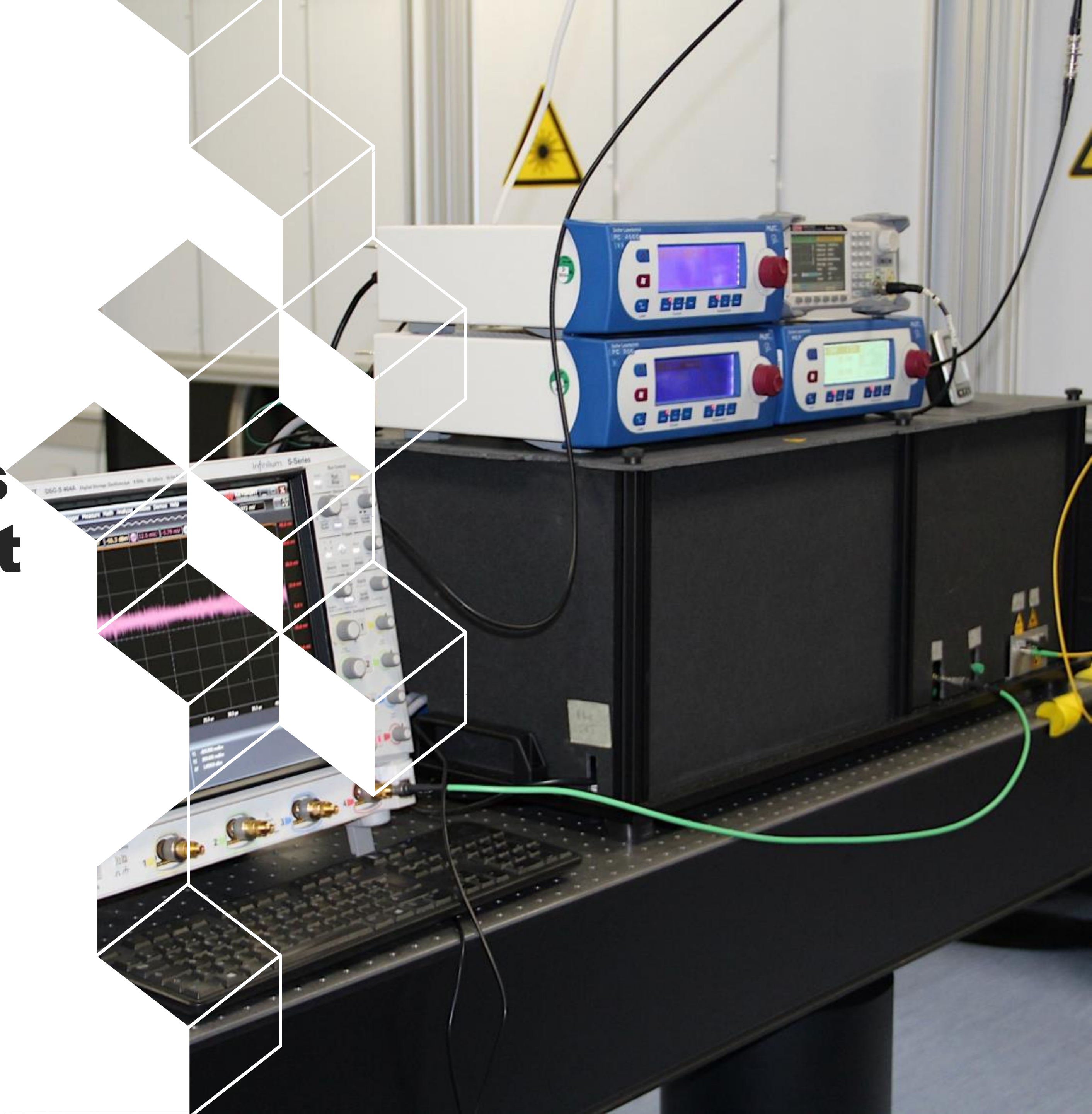


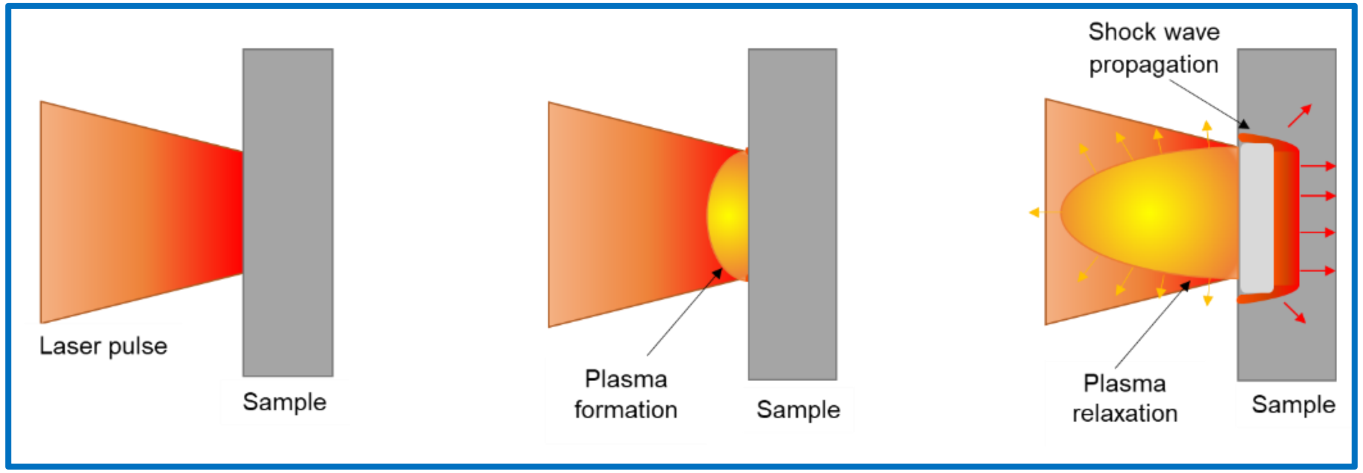
Summary

1. What is possible to detect at 830 nm ?
2. Power limitation at 830 nm
3. How to improve SNR ?
4. Conclusion

1. What is possible to detect at 830 nm ?

GCLT : Générateur Choc Laser Transportable

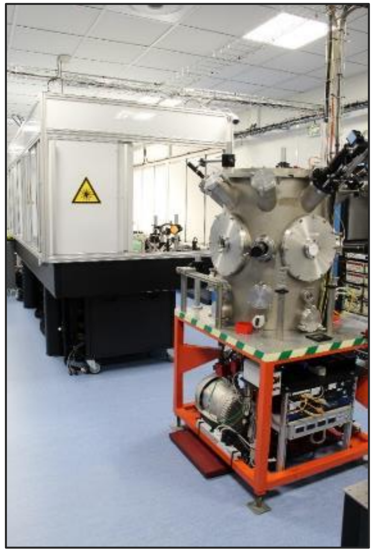
How to generate shock waves with laser power ?



Production of a shock wave in a sample

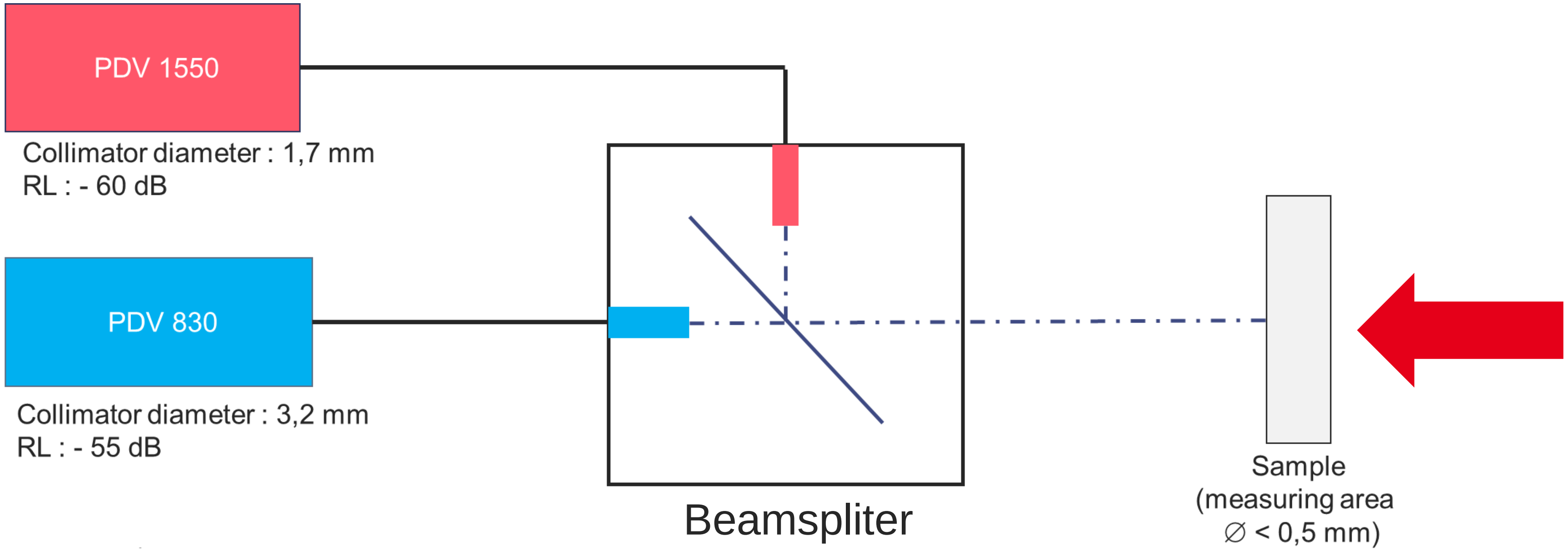
Main characteristics :

- λ : 1053 nm
- 4 ns > Pulse width > 100 ns
- Energy max :
  - 60 J (4 ns)
  - 150 J (100 ns)
- 0.1 mm > Spot size > 5 mm
- 7 GW/cm² > Power > 190 TW/cm²

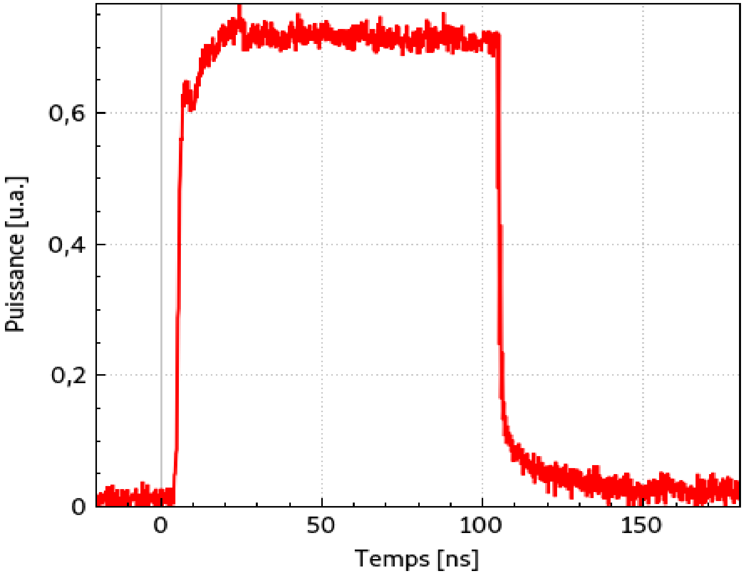


Acknowledgements: GCLT team (B. Jodar, T. Géral, E. Barraud)

Experimental set up



Beamspliter
T = 90% at 830 nm
R = 90% at 1550 nm



Pulse laser GCLT (“top hat” profile)

We observe same point of interest at same time with 2 collimators probes (each one has a different wavelength)

Observing elastic precursor on Al foil

Experimental set up:

Energy on sample: 76.6 J

Pulse width: 100 ns

Spot diameter: 2.5 mm

Intensity: 15.66 GW/cm²

Sample: Aluminum foil

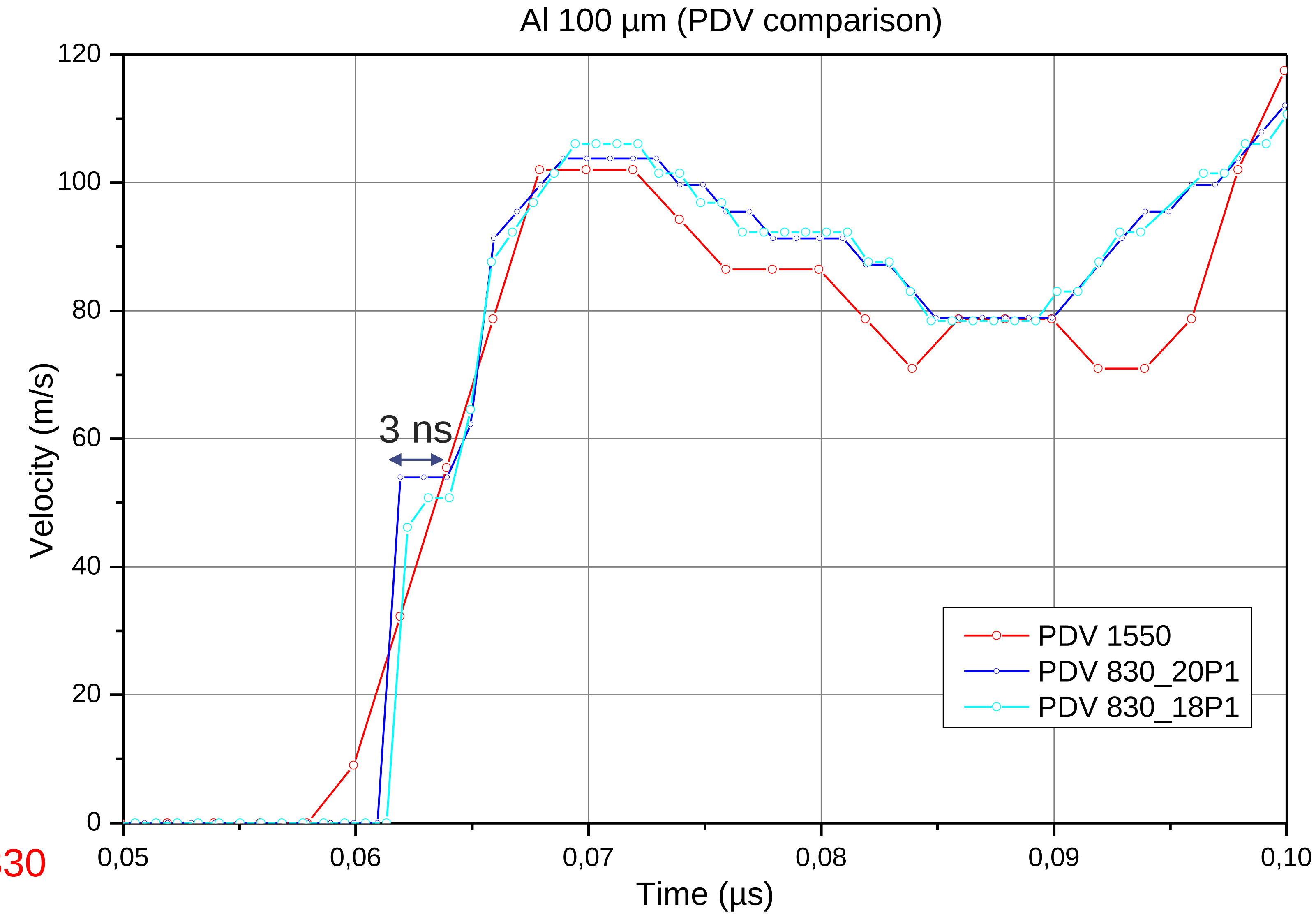
Thickness: 100 µm

Analysis set up:

STFT: Blackman-Harris window

Samples: 400 (20 ns) or 360 (18 ns)

Step: 20 (1 ns, 95% overlap)



We can see the best resolution for PDV830

Physical Phenomena

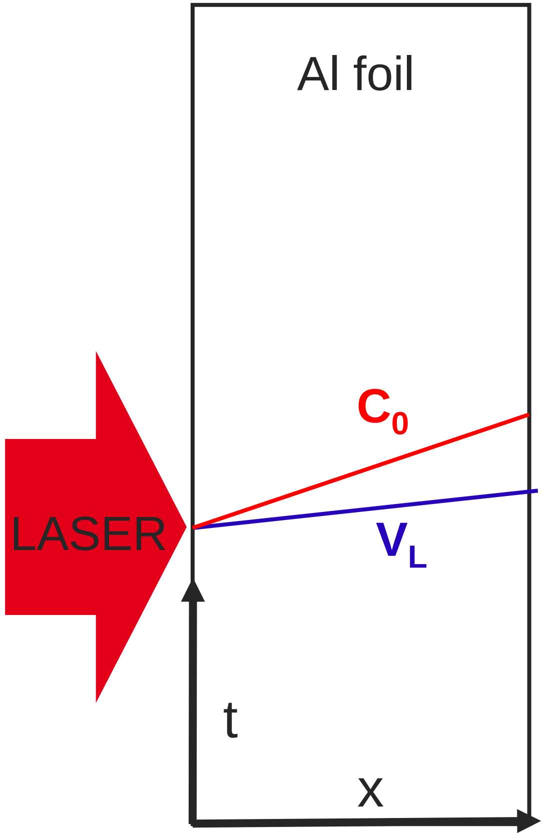
Shock on sample produce 2 types of velocity wave :

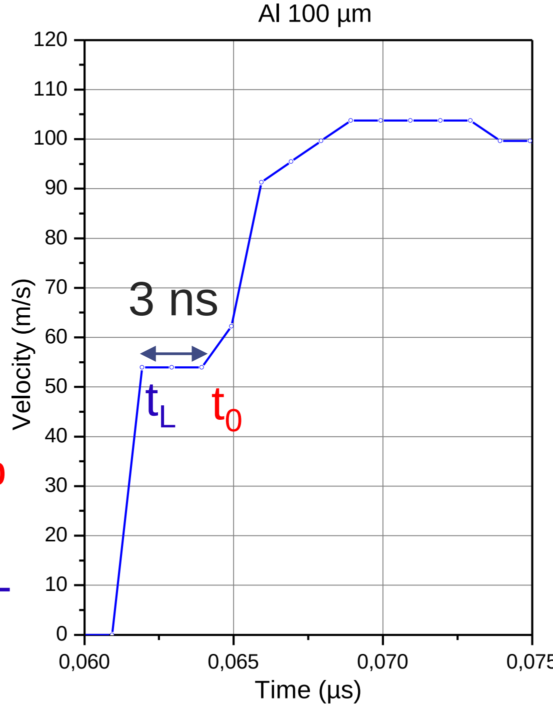
- Longitudinal wave (sound wave) : $\mathbf{V_L}$
- Transverse (shear) wave : $\mathbf{V_T}$

We have a following relation between 2 velocity:

$$C_0 = \sqrt{V_L^2 - \frac{4}{3}V_T^2}$$

C_0 : Bulk velocity





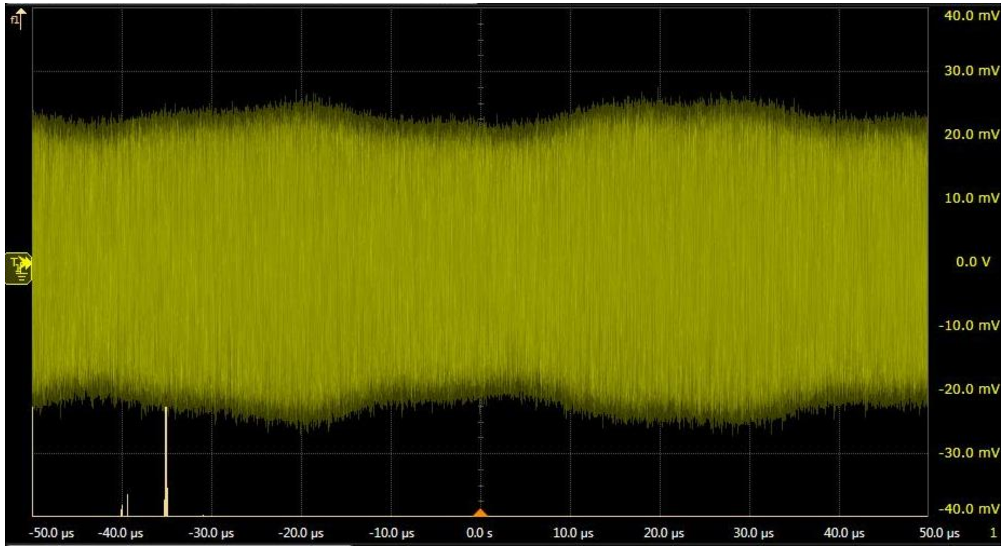
<u>Aluminum data:</u>
$\mathbf{V_L}$: 6.42 mm/µs
$\mathbf{V_T}$: 3.04 mm/µs
$\mathbf{C_0}$: 5.33 mm/µs

We have measured a delay (t_0-t_L) of about 3 ns and calculated with relation 3.2 ns.
This delay corresponds to a elastic deformation.

2. Power limitation at 830 nm

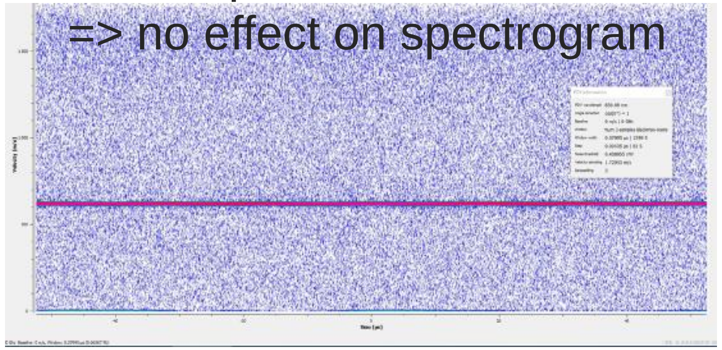
Power effect on optical fiber

L = 3 m



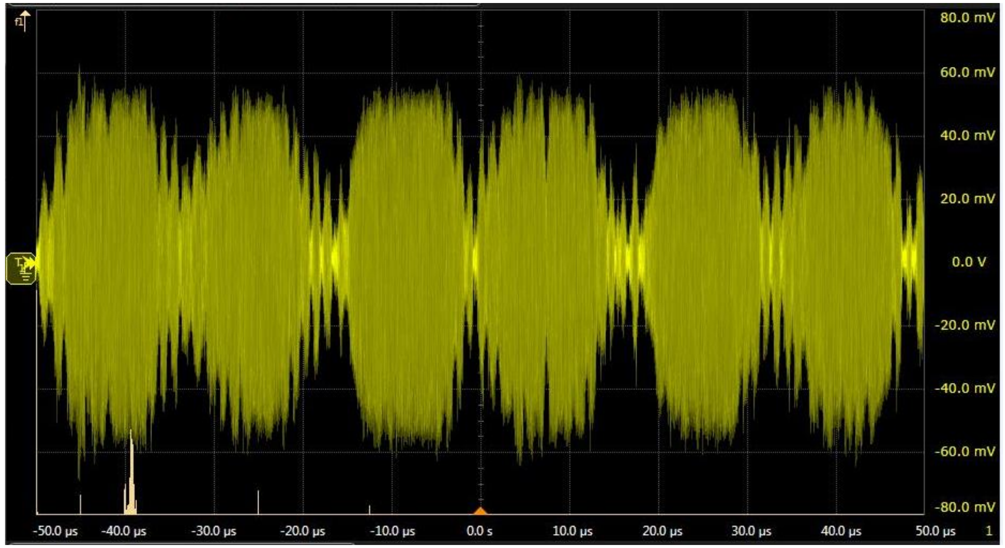
Little power modulation

=> no effect on spectrogram



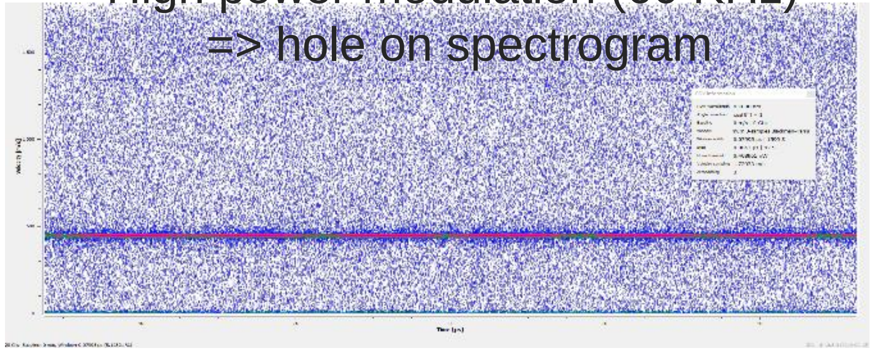
P_l = 84 mW

L = 63 m



High power modulation (60 KHz)

=> hole on spectrogram



What is it ?

High-power Laser creates nonlinear effects in the optical fiber and limits its capacity to carry energy.

Main effect is Stimulated Brillouin Scattering (SBS) => due to interaction between light and acoustic waves in the fiber (intense light create a periodic refractive index grating in the fiber core).

This effect is a function of optical fiber index and fiber length.

Optical fiber	index	Wavelength	Speed of sound	Brillouin frequency shift	Power limit (theoretical)
G652 (SMF28e)	1.4682	1550 nm	5.96 km/s	11.3 GHz (V = 8.9 km/s)	2 W for 100 m
Hi780	1.4491	830 nm	5.76 km/s	20.1 GHz (V = 8.35 km/s)	0.43 W for 60 m

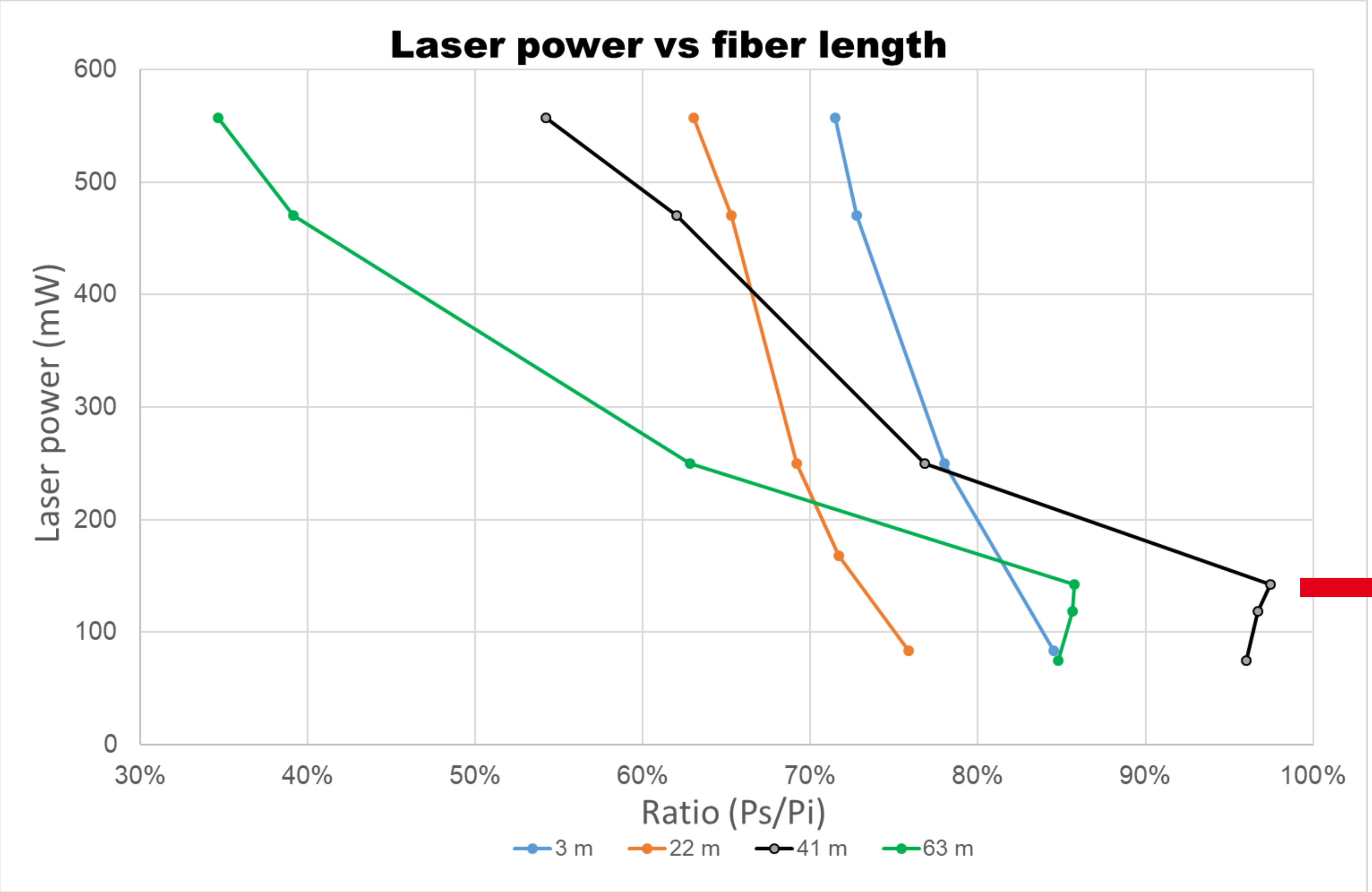
$$P_{limit} = \frac{21.A_{eff}}{g_B.L_{eff}}$$

with

A_{eff}: *Effective mode area (m²)*
g_B: *Brillouin gain coefficient (m/W)*
L_{eff}: *Effective length of the fiber (m)*

Excessive SBS can lead to signal distortion, power loss and reduced system performance

Study power limit at 830 nm



We observe that power limit is lower than 430 mW (theoretical power limit of SBS) and we think that other phenomena are at play such as Stimulated Raman Scattering (SRS) or Kerr effect.

2 states:
amplification
& attenuation

Other limitations

The coherence length (L_c) is important for PDV application.

It's represents the difference in optical path length from which waves will no longer interfere correctly.

The relationship between spectral linewidth (Δf) and coherence length (L_c) in fiber is define by relation:

$$L_c = c * \tau_c = \frac{c}{n * \Delta f}$$

At 830 nm with laser feature: Δf = 300 KHz, we estimate that maximum of optical fiber length is about 350 m for one laser (homodyne system) and **170 m** for 2 lasers (heterodyne system).

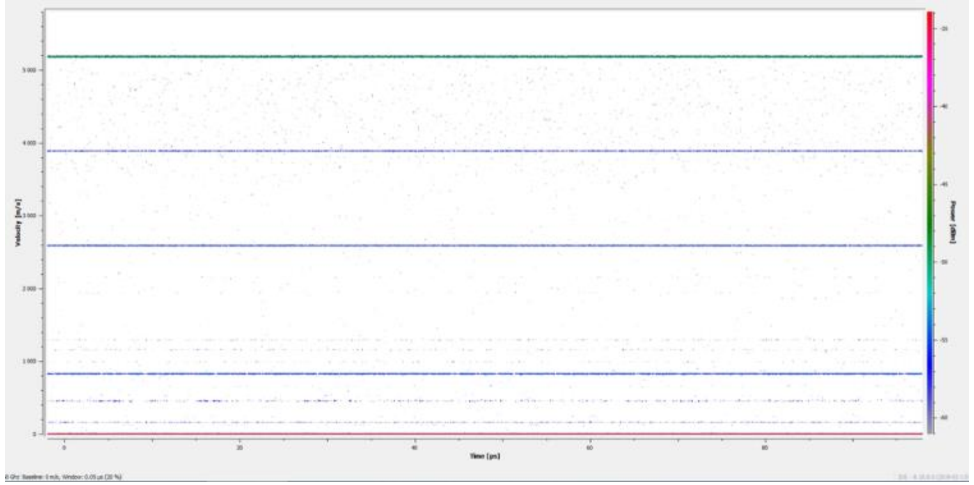
Spectral resolution of the laser determines the smallest detectable velocity difference: $\Delta v = \frac{\lambda}{2} \cdot \Delta f$

In our case, we estimate than velocity resolution is about **0.25 m/s** (Rayleigth criterion with Δf = 600 KHz).

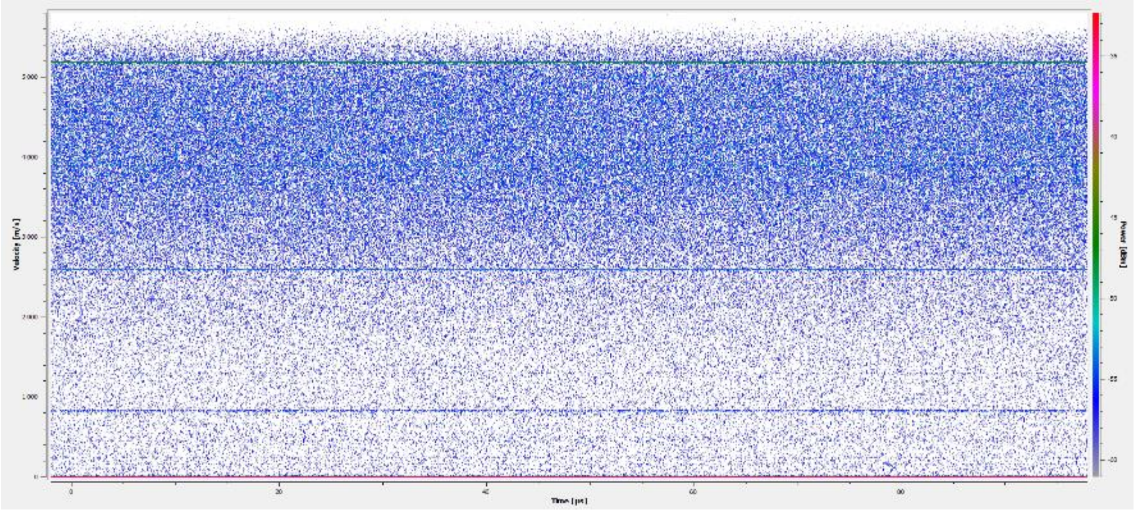
3. How to improve SNR ?

Noise analysis on spectrogram

Digitizer without detector

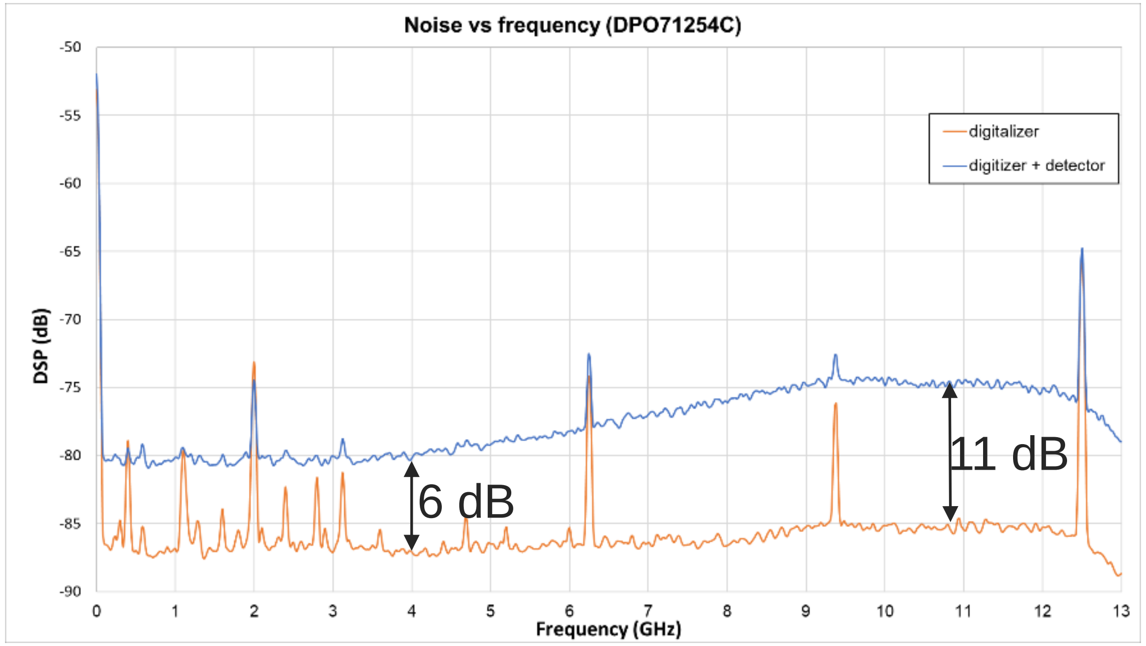


Digitizer with detector



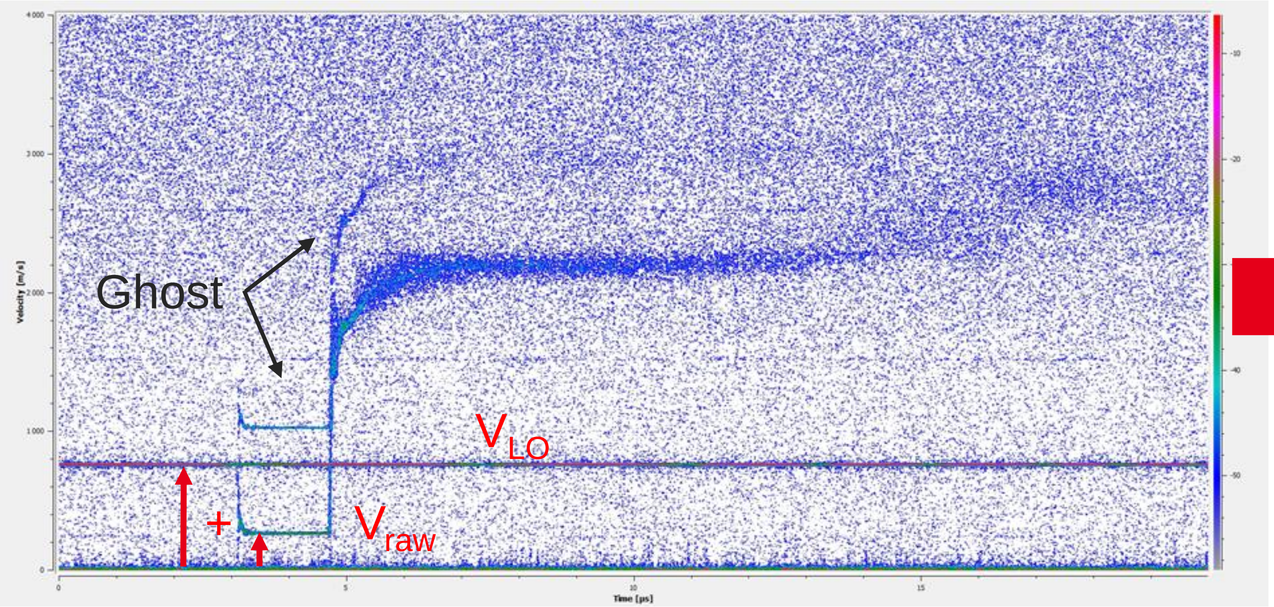
Study the noise response of digitizer (DPO71254C) and detector (NF1580) in function of frequency.

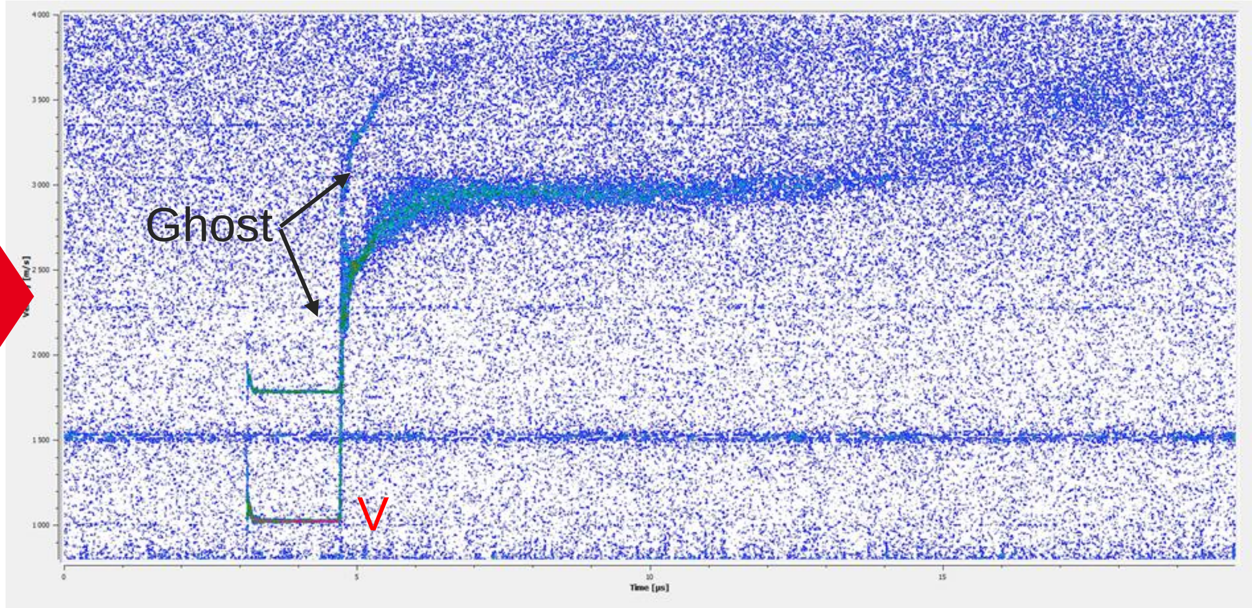
Noise difference : 6 dB for frequency < 4 GHz
max:11 dB



Main source of noise is detector

Shift local oscillator (LO)





Raw spectrogram
V_{LO} = +760 m/s (spectral folding)
V_{raw} = +268 m/s

After correction
$V = V_{raw} + V_{OL}$ = 1028 m/s

We used local oscillator to adapt frequency and choosing the best location on spectrogram to limit impact of noise and ghost signal (circulator leak) on the ROI (Region Of Interest).

Conclusion

- Best temporal resolution with PDV830 allows to detect elastic precursor on aluminum foil.

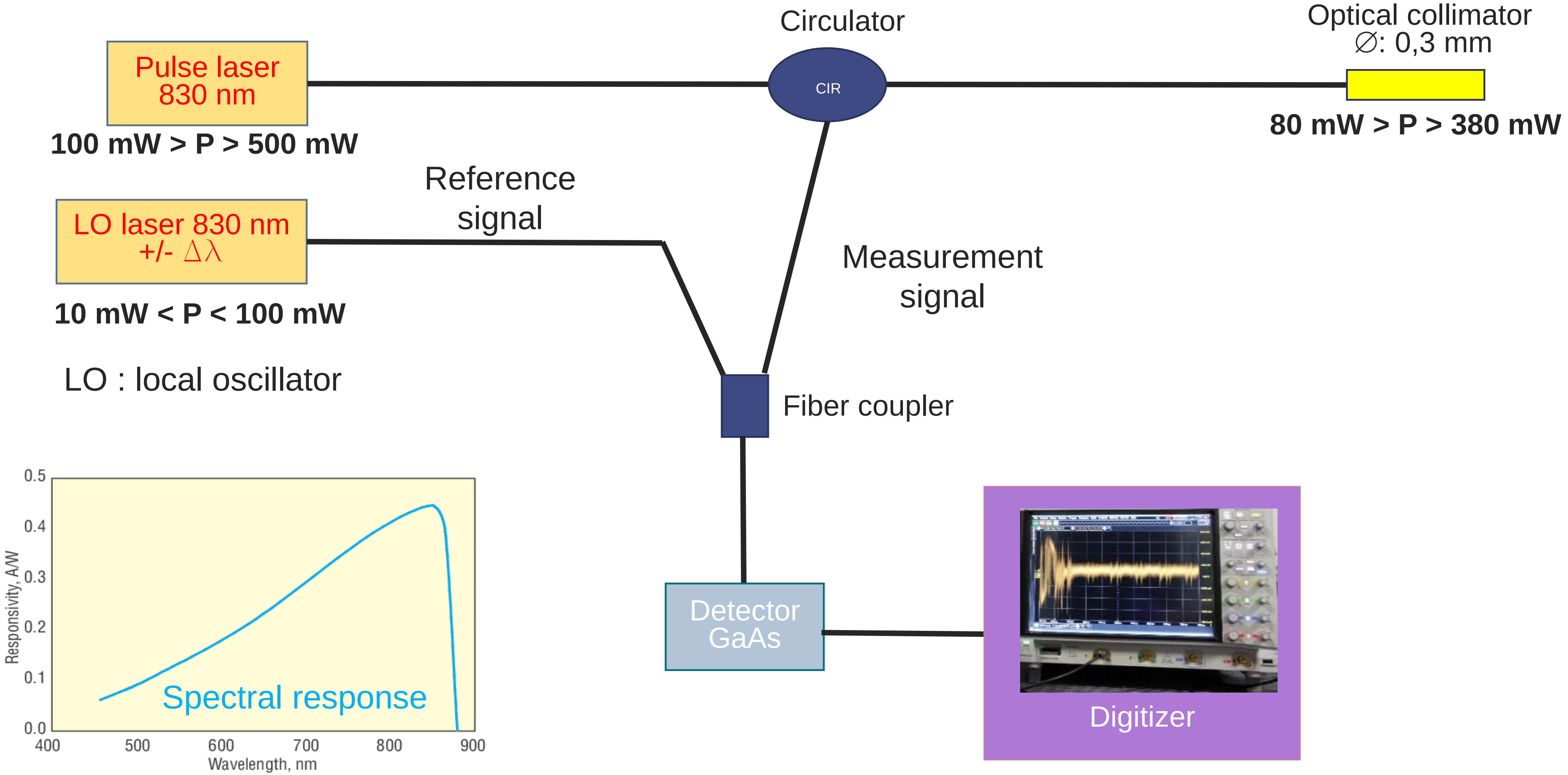
- Power limitation at 830 nm :

Unlike the PDV at 1550 nm, the signals of the PDV at 830 nm are more quickly disturbed by the power injected into the fiber (non linear effect) and this could limit the detection of the system.

- We presented a study on the SNR and we propose a method to limit its impact on the measurements.

Thank you for your attention

Optical design (Heterodyne with LO)



Interest of 830 nm

Limit of PDV diagnostic => STFT analysis

Measurement uncertainty => Gabor unequal : $\Delta f \cdot \Delta T \geq \frac{1}{4\pi}$ **and** $\Delta V \cdot \Delta T \geq \frac{\lambda}{8\pi}$

Wavelength (nm)	830	1550
Gabor limit (ns.m/s)	33	62
ΔT for ΔV = 10 m/s (ns)	3,3	6,2

➡ X 2

Wavelength (nm)	830	1550
Attenuation (dB/km)	4	0,2

➡ X 20

➡ **830 nm is a good compromise between attenuation in fiber (att. 9% for 100 m), availability of components and resolution (in time and velocity)**

STFT : Short-Time Fourier Transform