HETERODYNE VELOCIMETRY AND DETONICS EXPERIMENTS

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OVERVIEW

- **APPARATUS CONFIGURATIONS**
  - 1 or 2 lasers
  - 1 or 2 optical fibers
- **HARDWARE**
- **SOFTWARE & PROCESSING**
- **EXPERIMENTS**
  - Tin particles velocity
  - Laser shock driven experiments
  - Embedded fibers in nitromethane
- **CONCLUSION**

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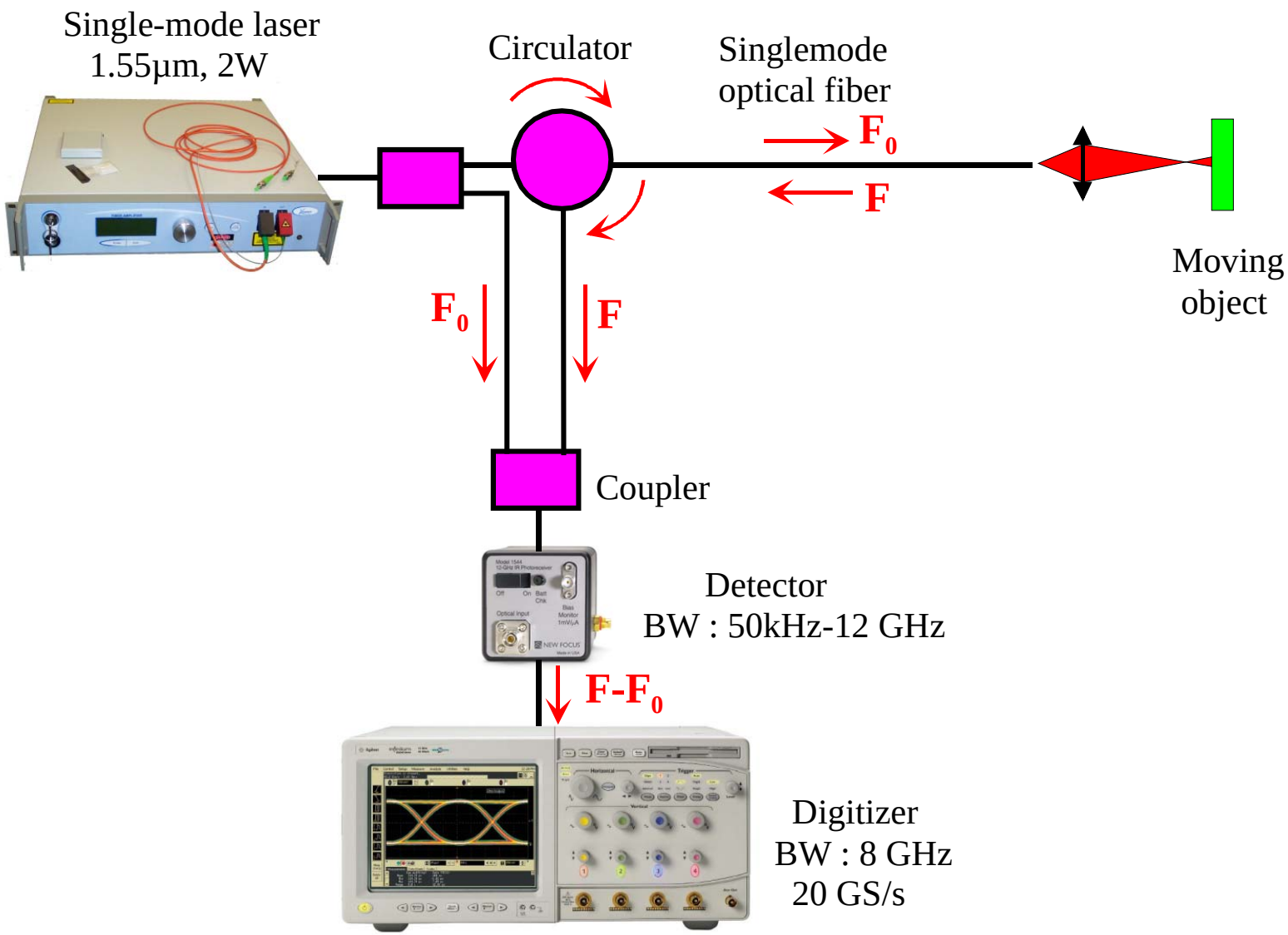
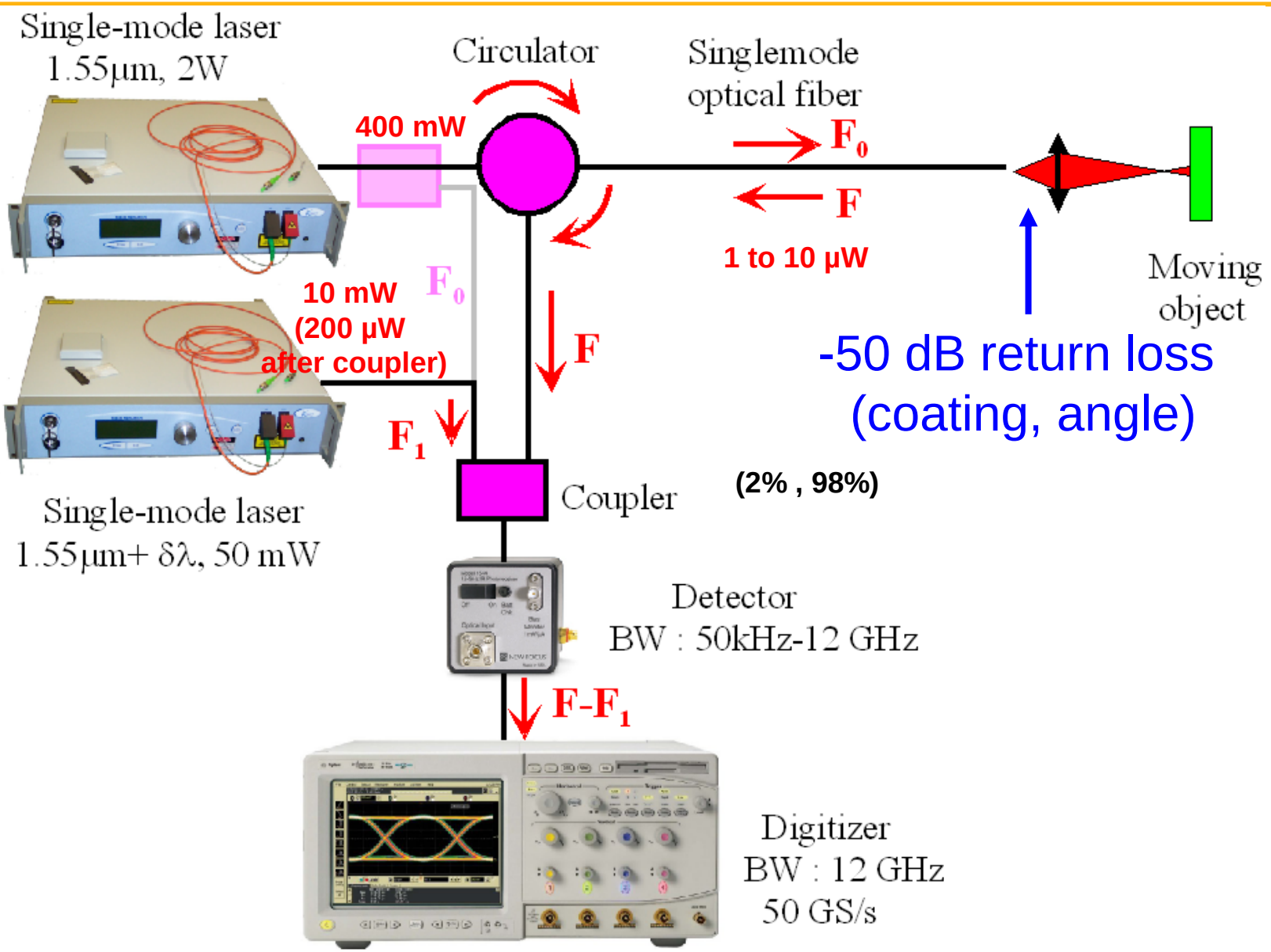
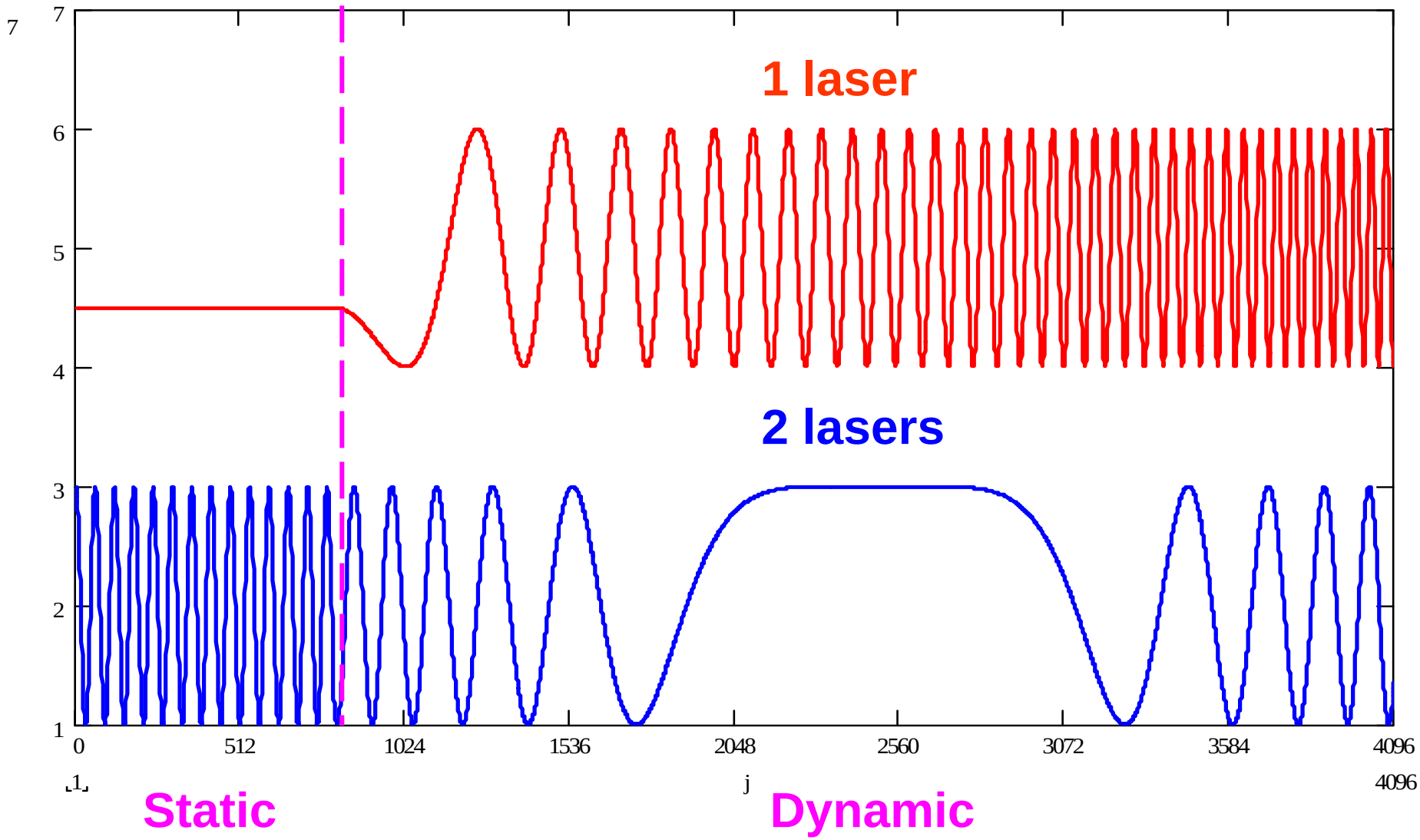
PDV : single setup with one optical fiber



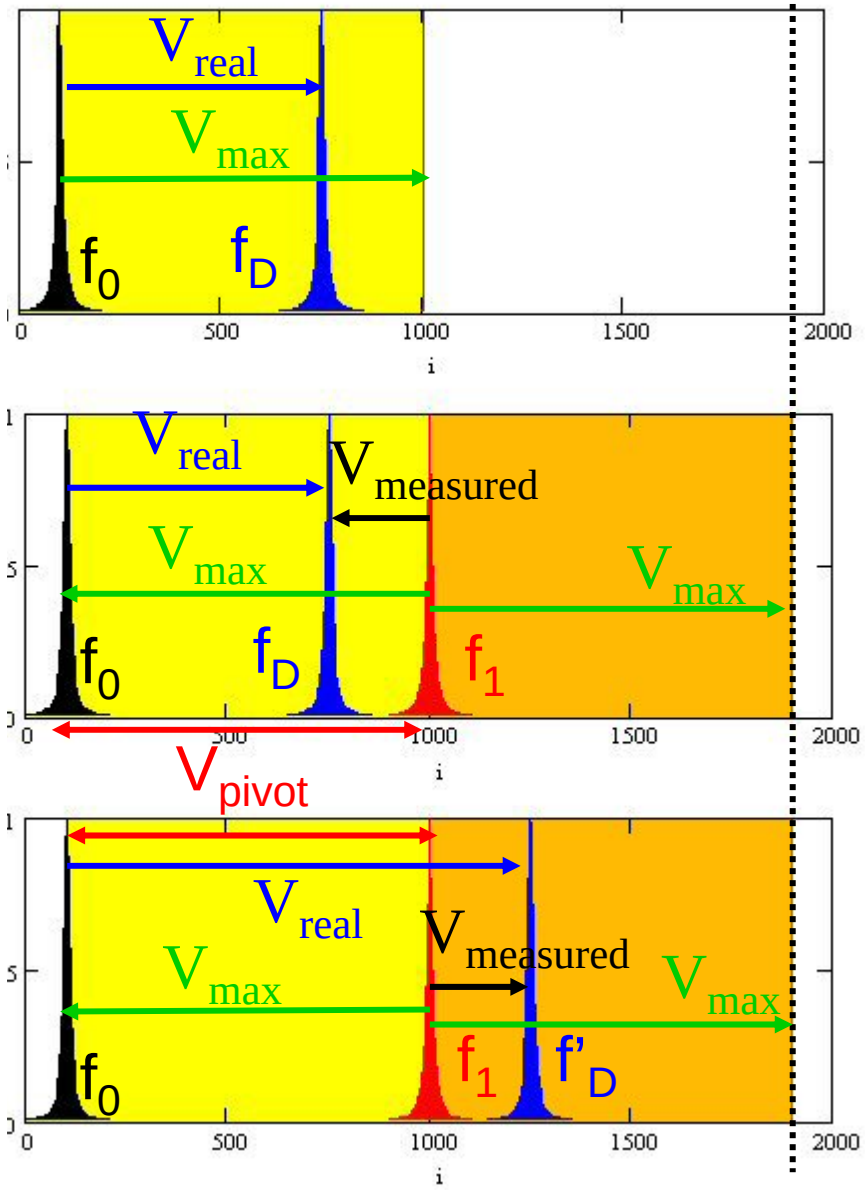
PDV : single or two-laser setups with a single optical fiber



PDV : Static adjustment easier with 2 spectrally-shifted lasers



PDV setup with 2 spectrally-shifted lasers : velocity range x2



- **1 laser : frequency f_0**

$$f_D := f_0 \cdot \left(1 + 2 \cdot \frac{V}{C}\right) \qquad \Delta f := f_D - f_0$$

- **1 single solution**

$$V = \frac{\lambda_0}{2} \Delta f$$

- **laser N°0 : frequency f_0**
- **laser N°1 : frequency f_1**
- **Bandwith is doubled**

2 solutions

(only 1 is physical)

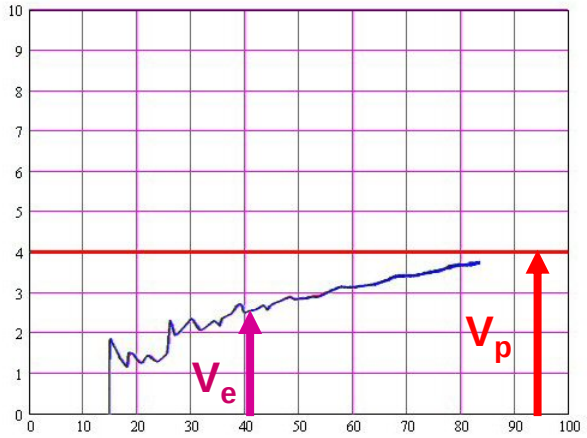
$$V_{real} = V_{pivot} \pm V_{measured}$$

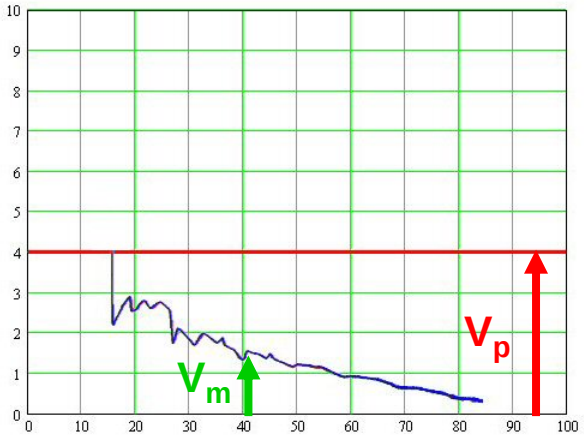
$$V_{measured} = |V_{real} - V_{pivot}|$$

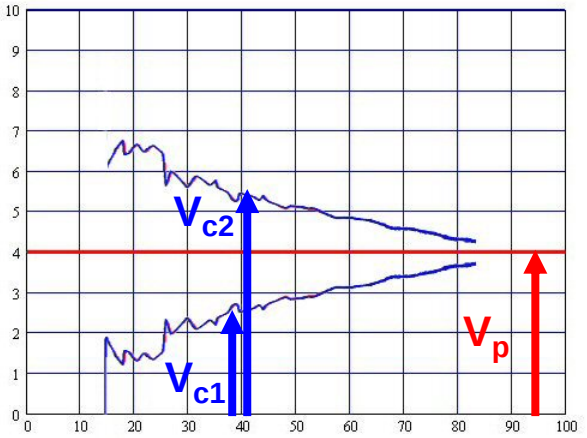
PDV setup with 2 spectrally-shifted lasers : velocity solutions

Experimental velocities **Measured velocities (TFR)** **Retrieved velocities**

Example 1





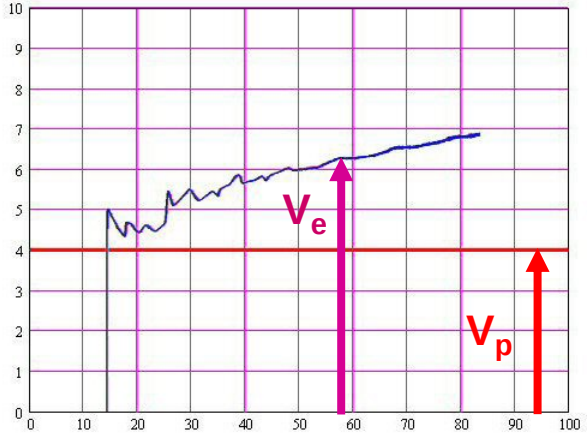


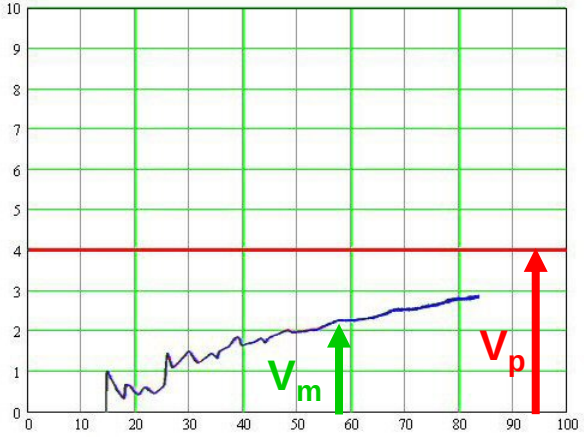
$V_p = (F_1 - F_0).\ \lambda/2$
$V_m = (F_D - F_0).\ \lambda/2$
$V_e = (F_D - F_0).\ \lambda/2 = (F_D - F_1).\lambda/2 + (F_1 - F_0).\ \lambda/2$
$V_e = V_m + V_p$

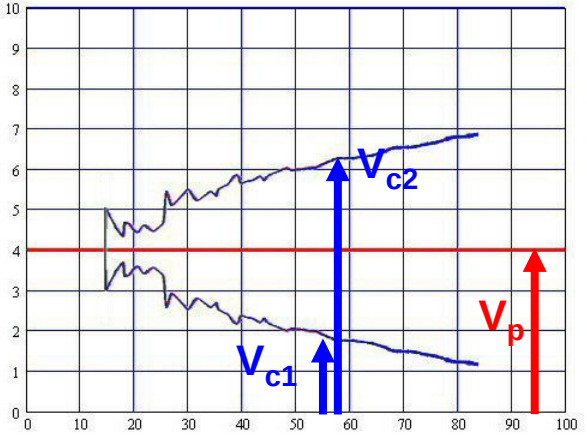
$V_m = |V_p - V_e|$

$V_c = V_p \pm V_m$

Example 2



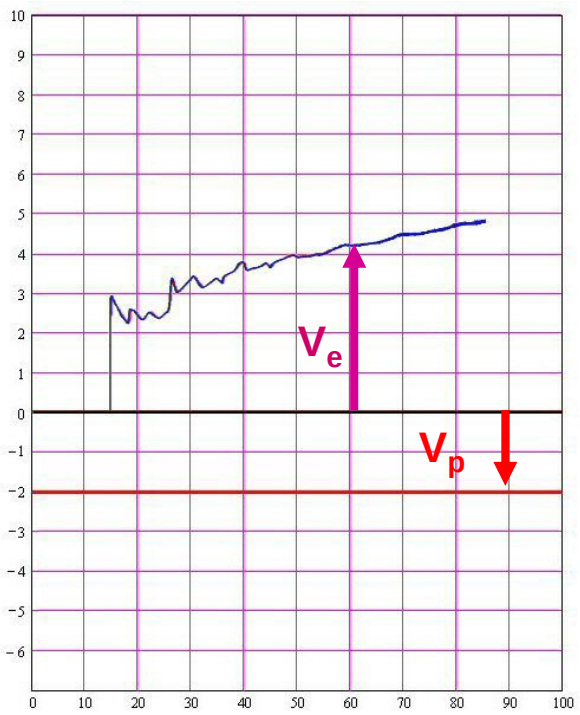


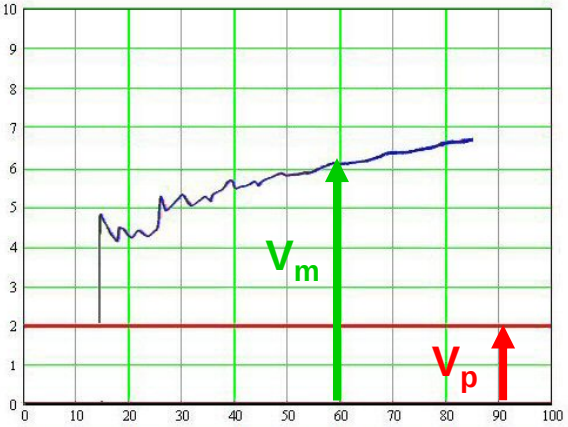


PDV setup with 2 spectrally-shifted lasers : velocity solutions with a wrong shift way

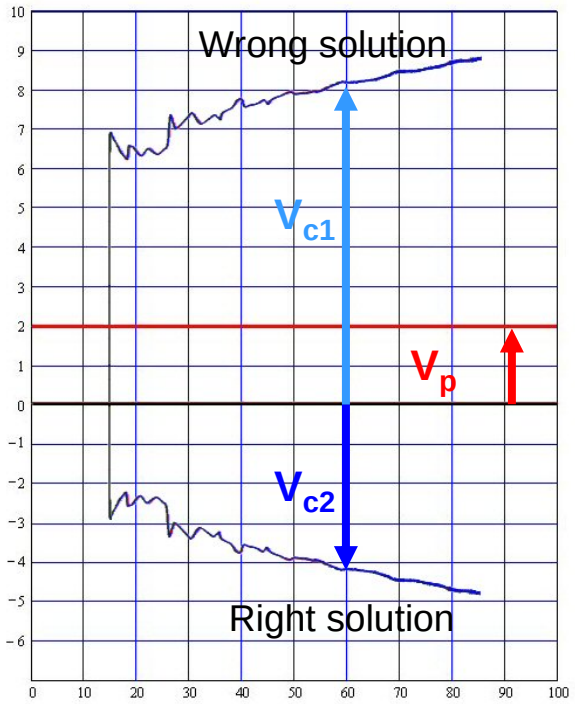
Experimental velocities **Measured velocities (TFR)** **Calculated velocities**

Example 3



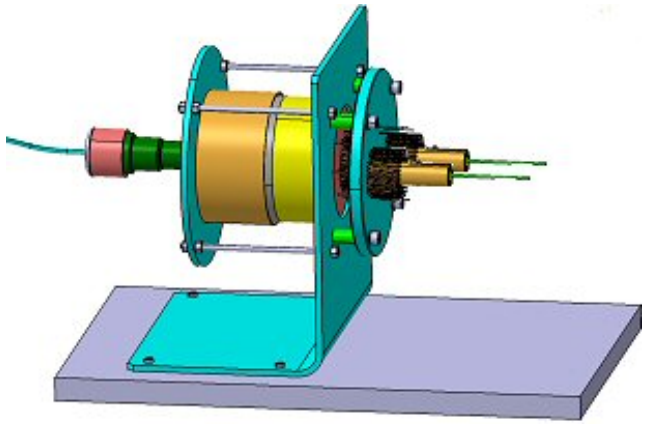


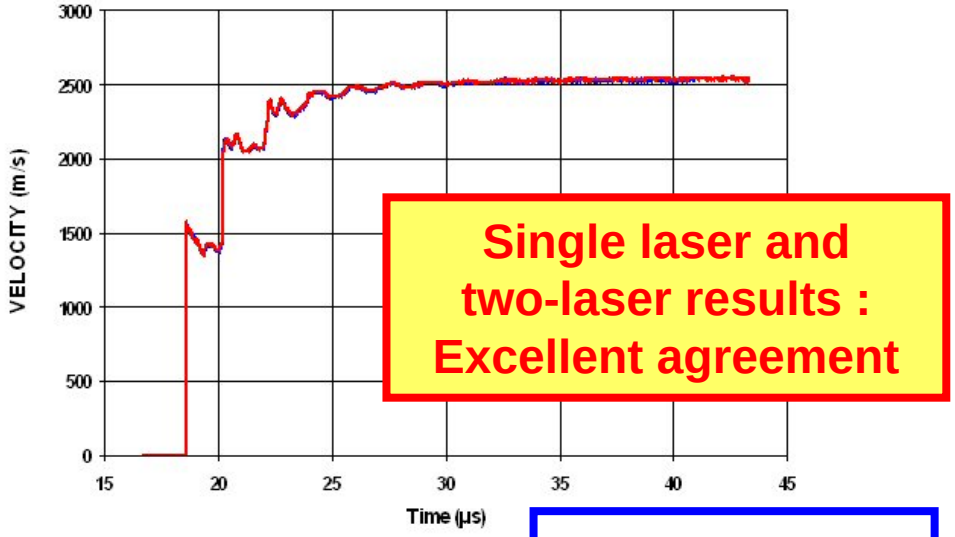
$V_m = |V_p - V_e|$



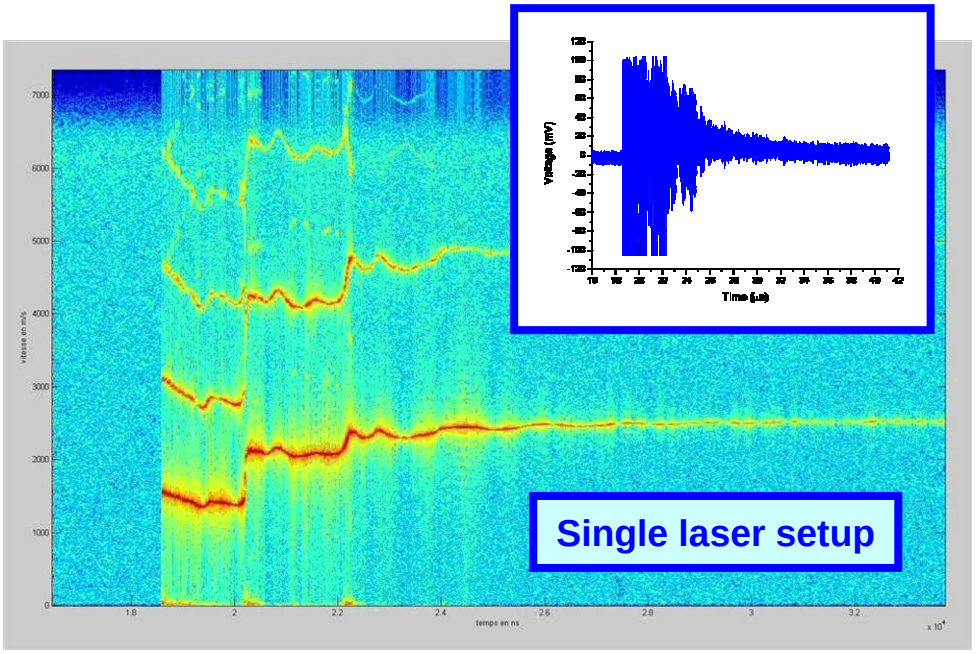
$V_c = V_p \pm V_m$

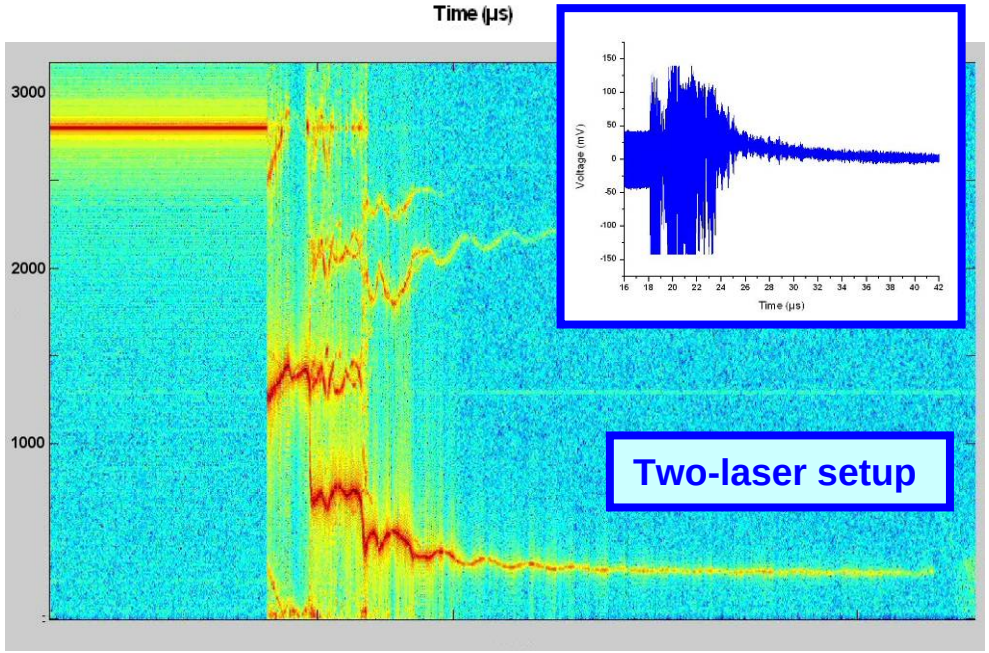
FREE SURFACE VELOCITY OF Ta PLATE. H.E. PWG





Single laser and two-laser results : Excellent agreement





Aliasing on 2-laser setup makes the signal slightly more complex

PDV with two spectrally-shifted lasers

- **Bandwith x2 → velocity range x2**
- **Higher velocity measurement (10, 20 km/s….)**
- **Frequency beat is useful**
  - For static level adjustments (easier for operator)
  - To measure photometry level and evolution (static/dynamic)
- **No folding of negative velocity (example later)**
- **Processing : two possible solutions, only one is physical**

$$V_{experimental} = |V_{measured} \pm V_{pivot}|$$

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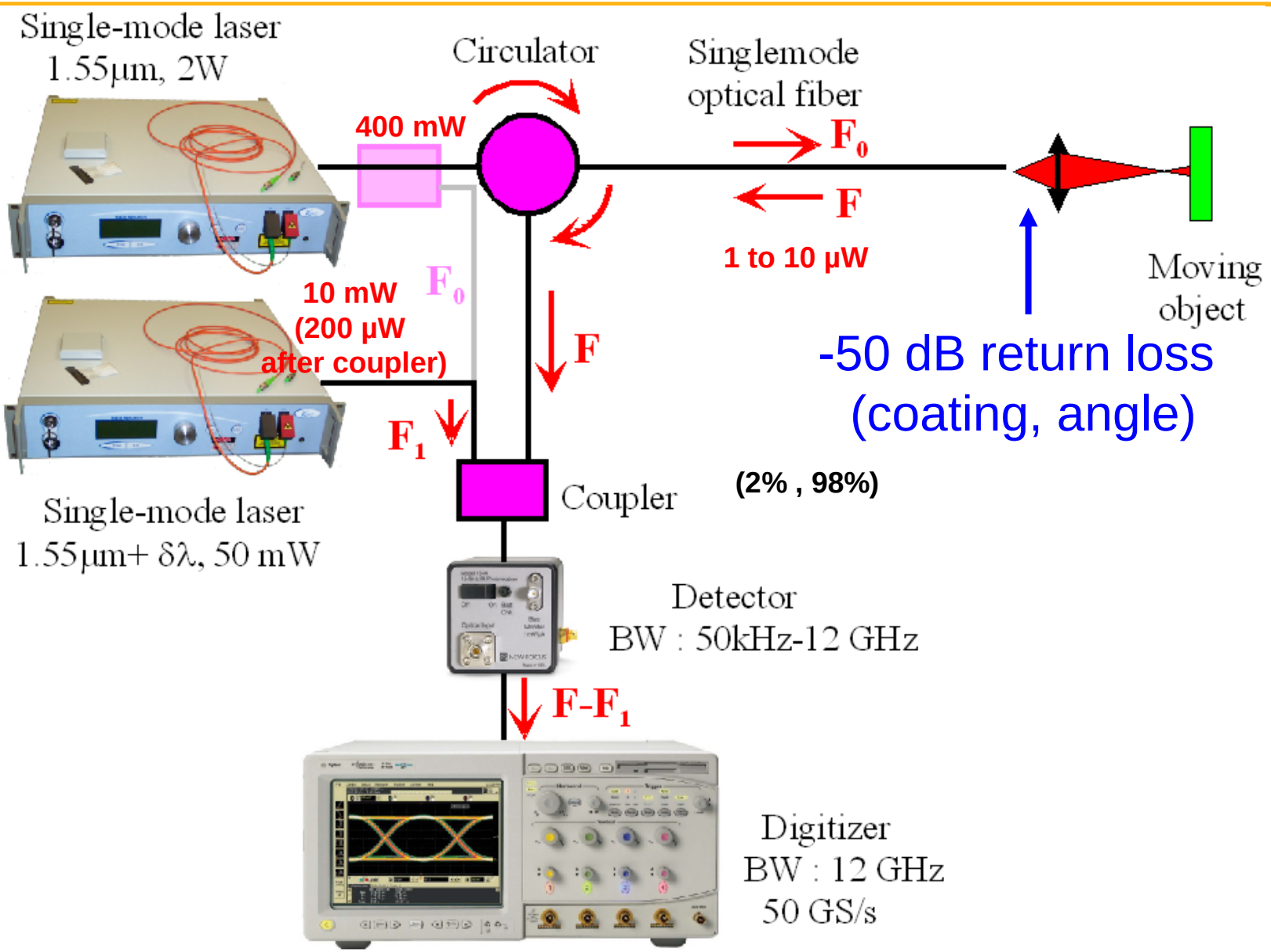
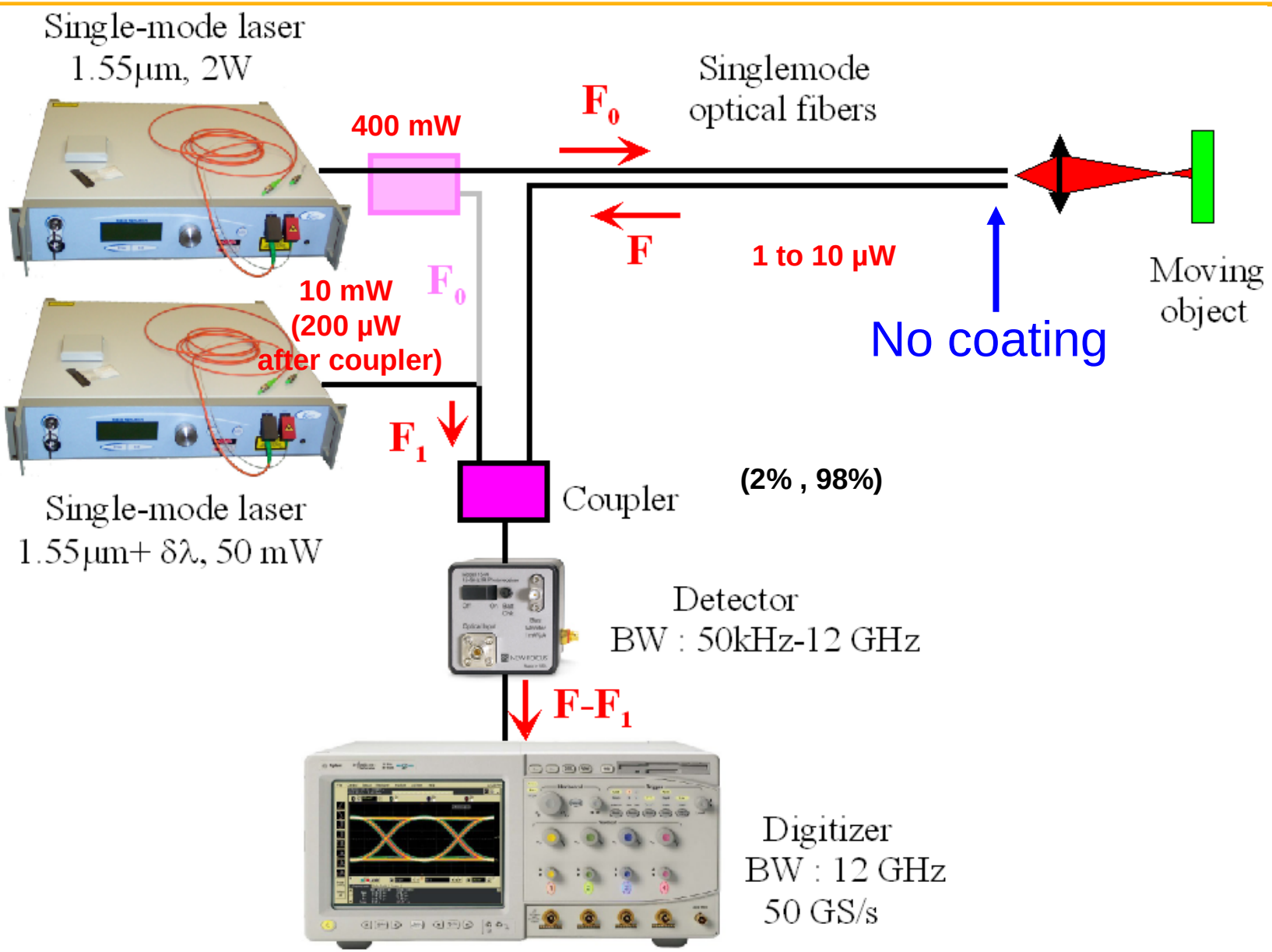
PDV : single or two-laser setups with a single optical fiber



PDV : single or two-laser setups with two optical fibers



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Subcontracted PDV cabinet

Digitizer
DPO 71254
(12 GHz, 50 GS/s)

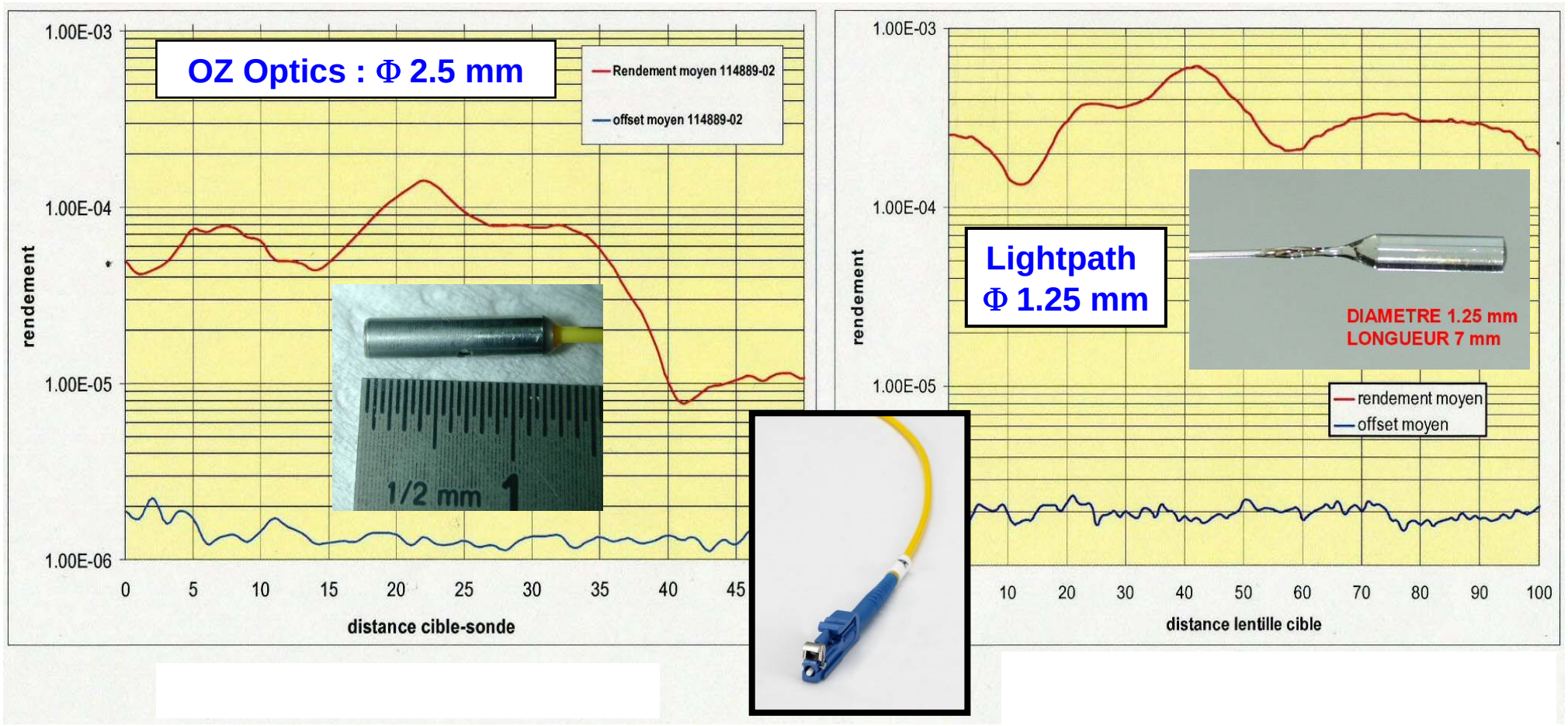
Detector unit

Tunable laser

Main laser

PDV PROBES : « OZ optics » and « LIGHTPATH »

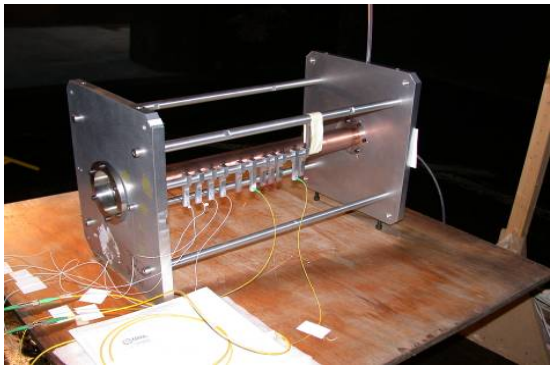
- Efficiency law : level and probing depth range
- Return loss (-40 to -60 dB)
- Size

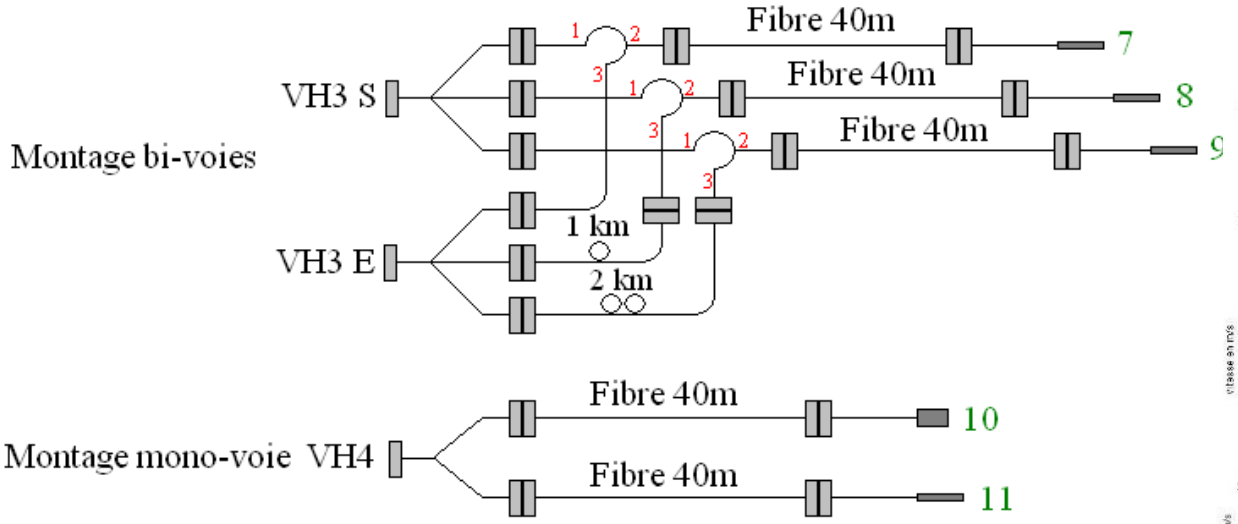


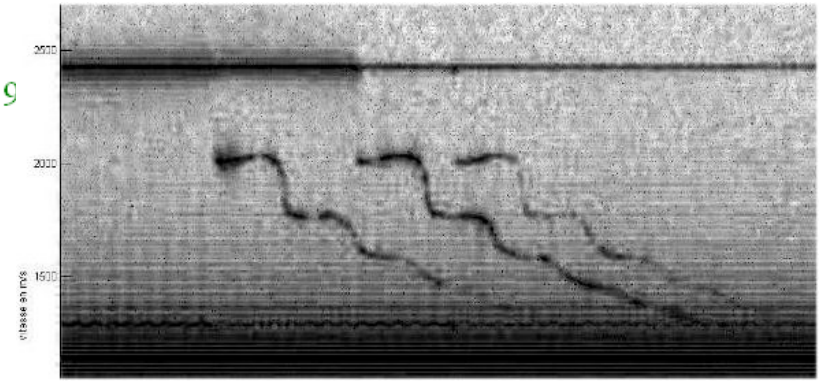
E2000 connector

MULTIPLEXING

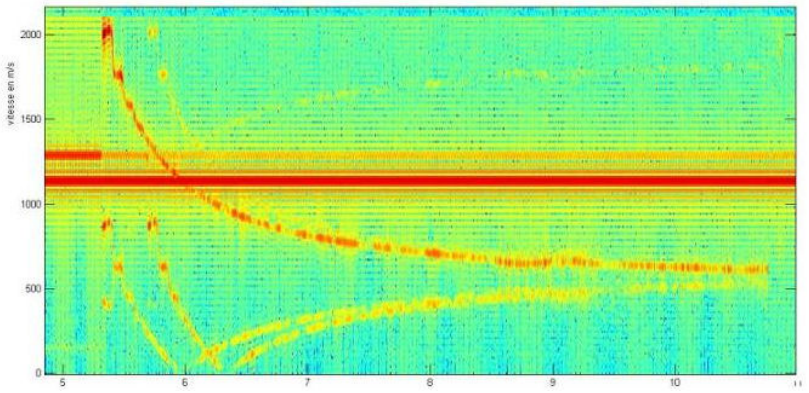
- **Copper cylinder experiment:**
  - 2 channels setup with couplers and circulators.
  - Single channel setup with couplers.







Delay lines



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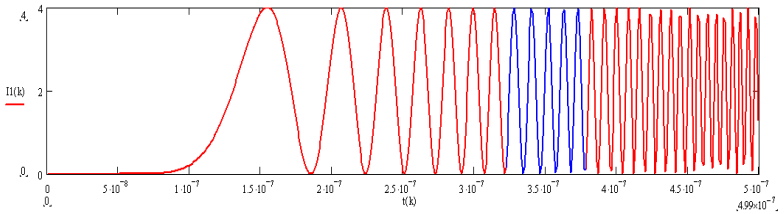
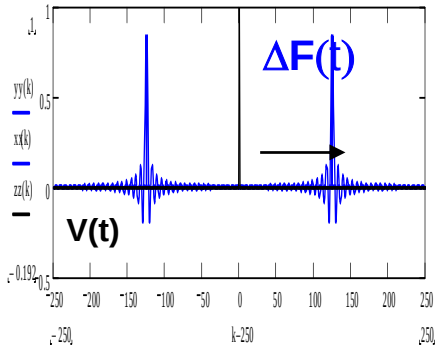
PDV Signal Processing

Short Term Fourier Transorm algorithm (FFT as implemented in Matlab). Mostly with 50 ns (1000-2000 pts) windowing and 10 ns step. Satisfying enough for most experiments

$$|S_x(\tau,\nu)|^2 = \int x(\tau)h(\tau-t)^*\, x(u)^* h(u-t)\, e^{-j2\pi\nu(\tau-u)} d\tau\, du$$

$$I(t) = 1 + \cos\left(2\cdot\frac{2\cdot\pi}{\lambda_0}\cdot\int_0^t v(u)\,du\right)$$





$$V(t) = \Delta F(t)\cdot\frac{\lambda_0}{2}$$

PDV Signal Processing

Uncertainties are spread over :

Signal dependent

A few 10^{-4} m/s each

- *Drift*

$$Biais\left(\hat{f}_i(l)\right) \approx \frac{\phi^{(3)}(lT).h^2}{80.\pi}$$

Difficult to evaluate

- *Variance*

$$Var\left(\hat{f}_i(l)\right) \approx \frac{6\sigma^2 T}{4\pi^2|A|^2 h^3}$$

Evaluable through momentum algorithm (under gaussian white centered noise assumption)

Sampling / Processing dependent

Typically 5-15 m/s

- *Quantization*

$$\Delta\nu = \frac{1}{2 \cdot \delta t \cdot N \cdot padding}$$

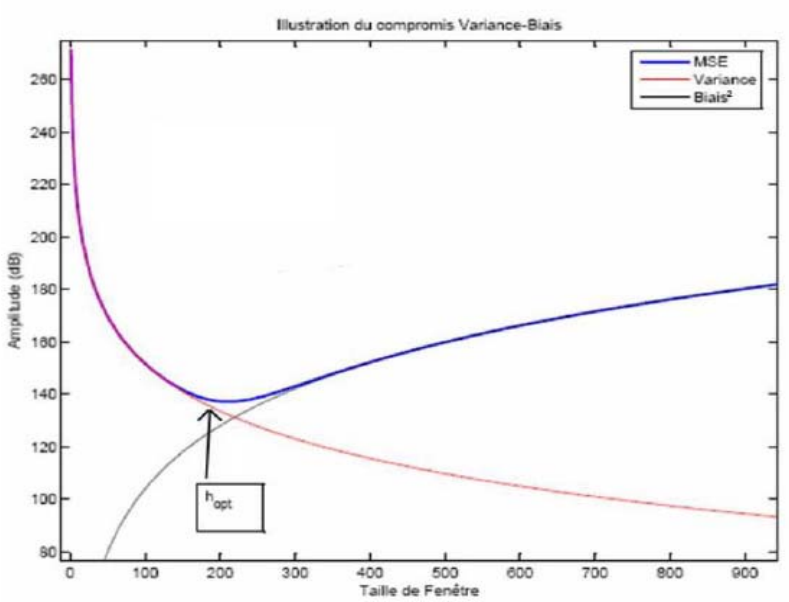
PDV Signal Processing

Collaboration with a DSP team (Supelec) brought us to develop an algorithm with adaptative window.
Currently under development (latest modifications allow efficient processing, even with multi-frequency contents). To be further tested and implemented.

The size of the window is chosen such as to minimize bias and variance (chosen through an interval of confidence algorithm) :

- Thus, bias and variance are made negligeable wrt quantization : in this case, zero-padding lowers down uncertainties

- Not applicable to rapid changes in velocities



PDV Signal Processing

- Easier Graphical User Interface for ‘daily’ processing of PDV signals

  - Better visualisation

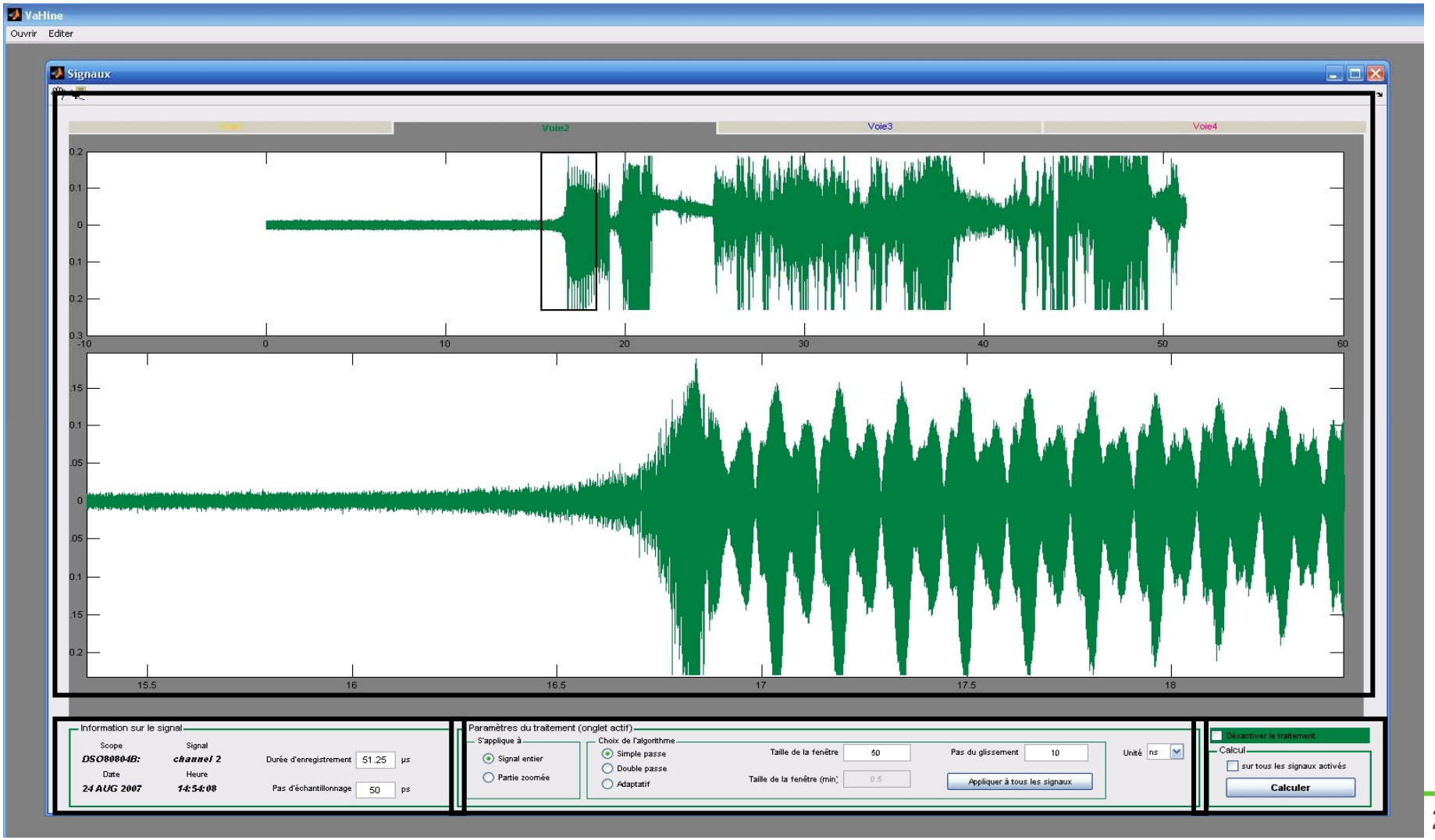
  - Automatic selection of the velocity curve on the spectrogram…

  - …and direct export to a .xls file

  - Designed to be expandable (modules) and compilable as a standalone crossplatform application

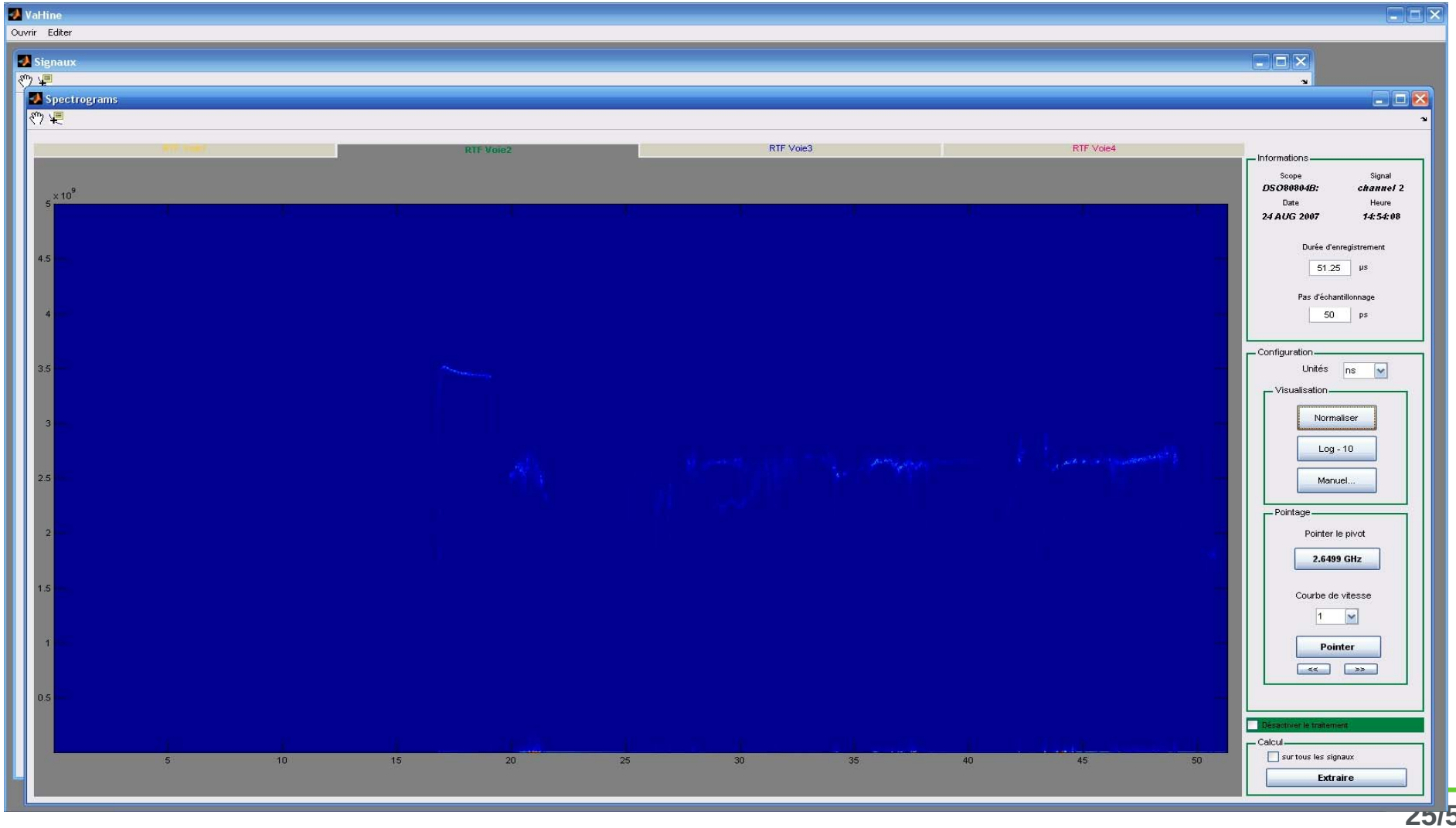
PDV Signal Processing

Software : signal interface



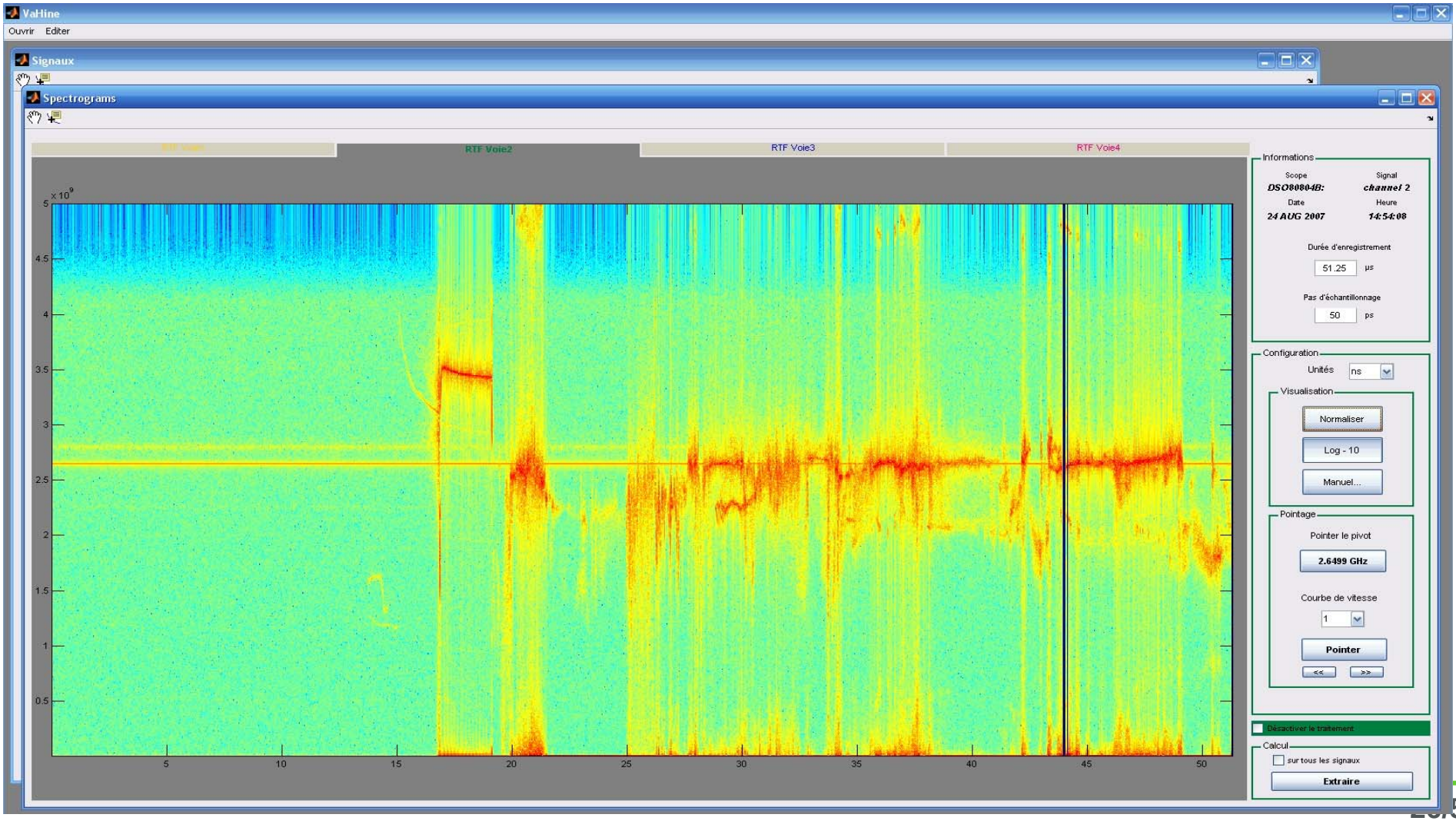
PDV Signal Processing

<u>Software :</u> spectrogram interface – linear scaling



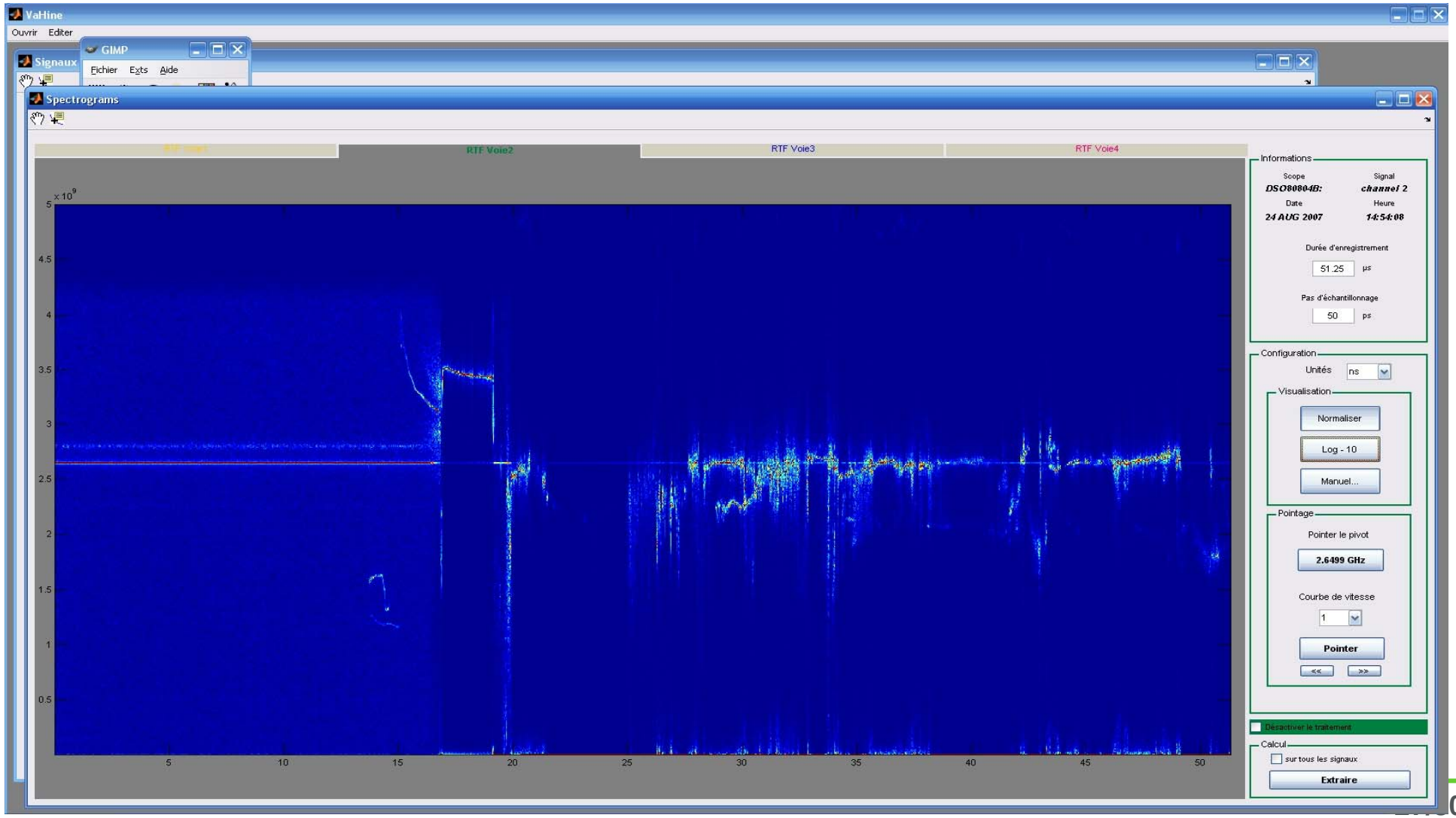
PDV Signal Processing

<u>Software :</u> spectrogram interface – Log10 scaling



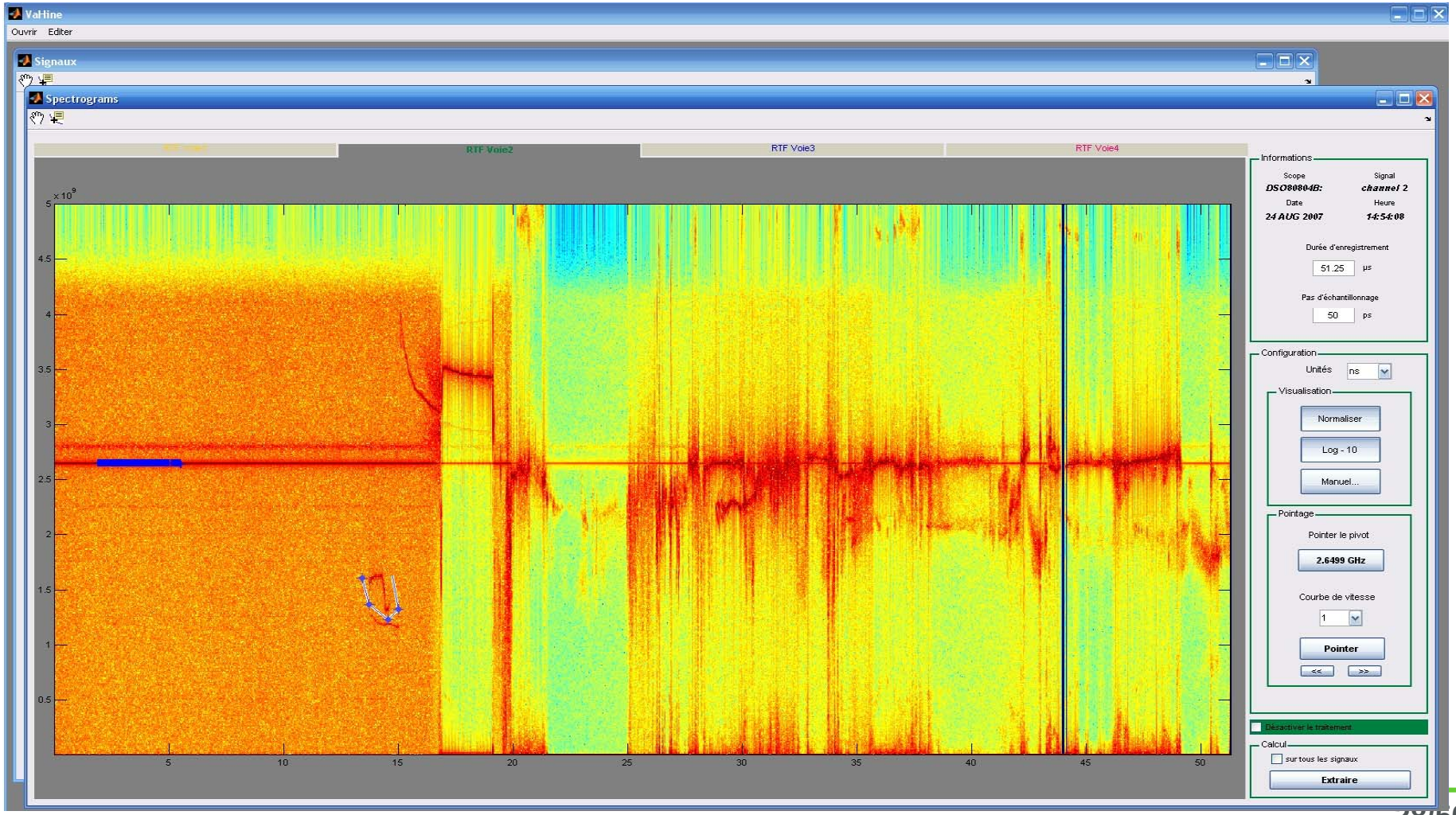
PDV Signal Processing

Software : spectrogram interface – column-normalized scaling



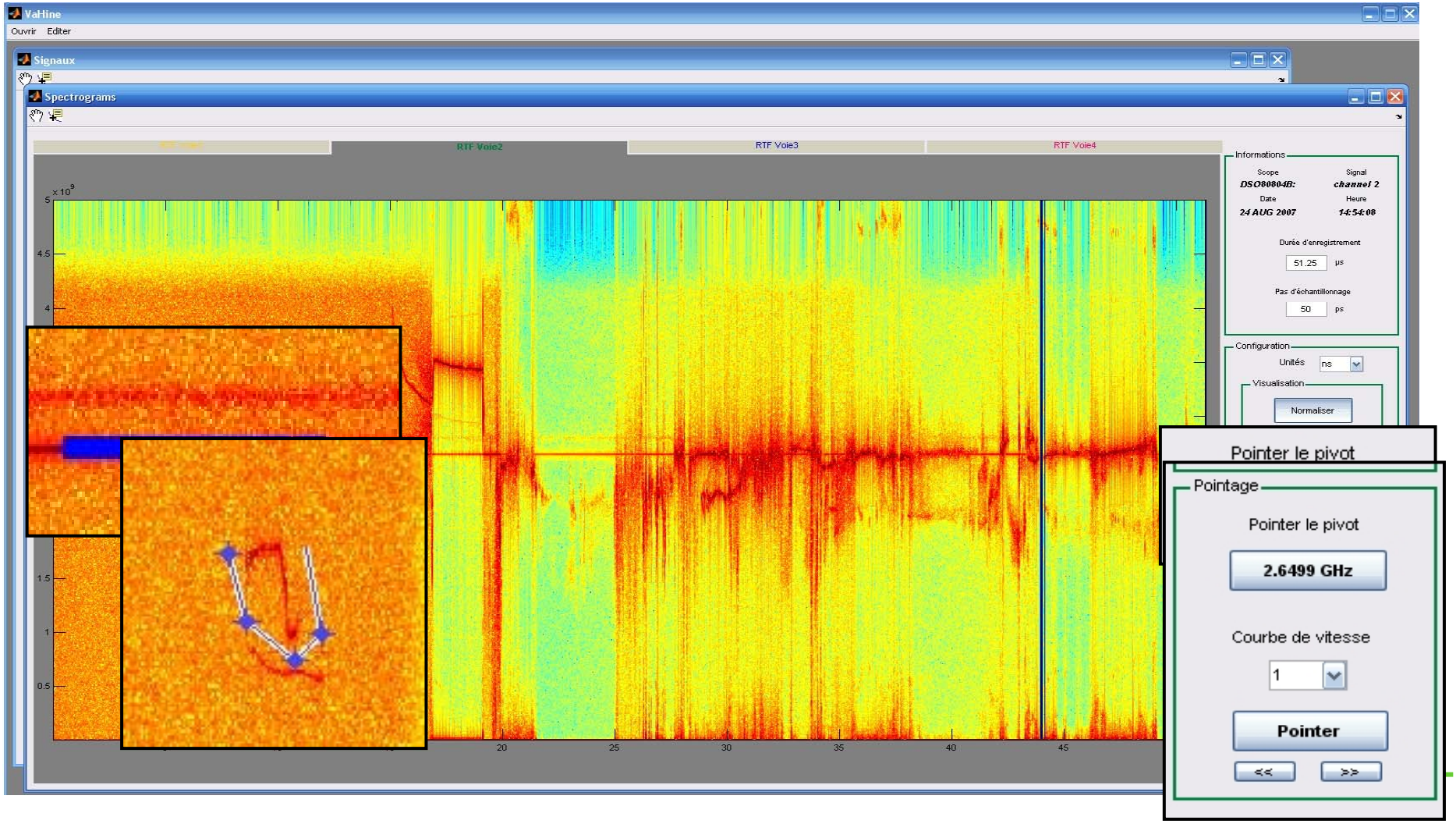
PDV Signal Processing

<u>Software :</u> spectrogram interface – column-normalized and Log10 scaling



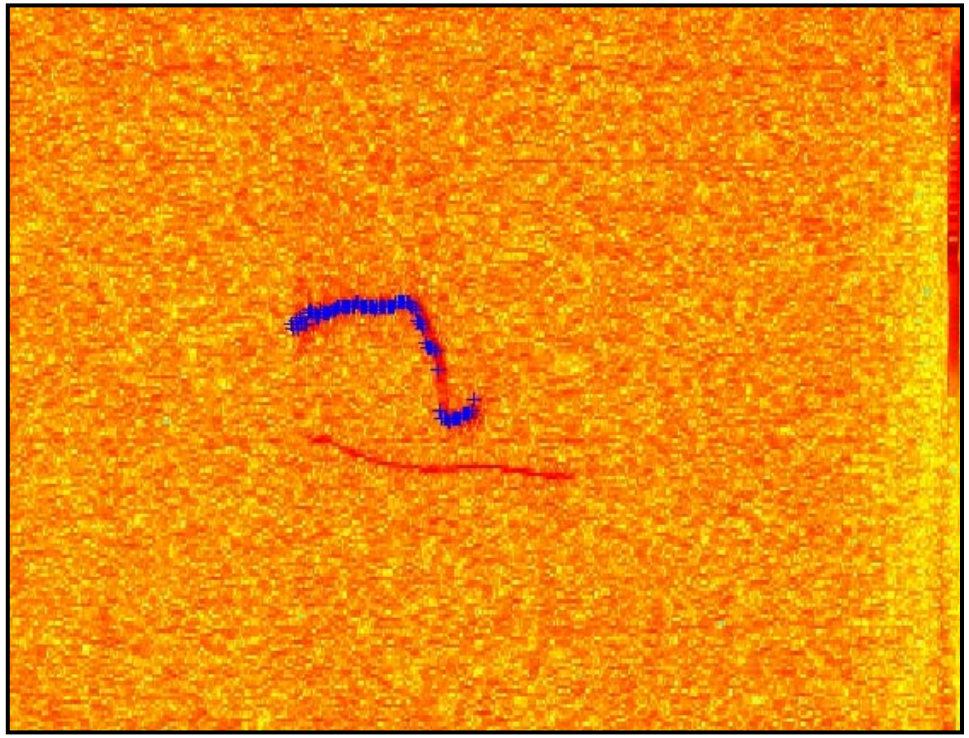
PDV Signal Processing

Software : *interactive tracking* of the *velocity*



PDV Signal Processing

Software : *interactive tracking* of the *velocity*



- The blue dots are the ones that are actually exported in the '*.xls*' file

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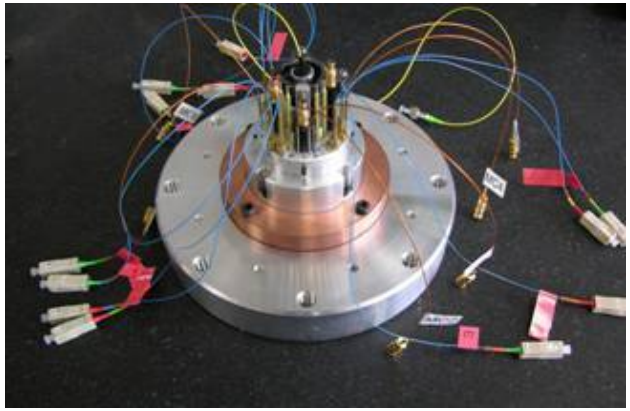
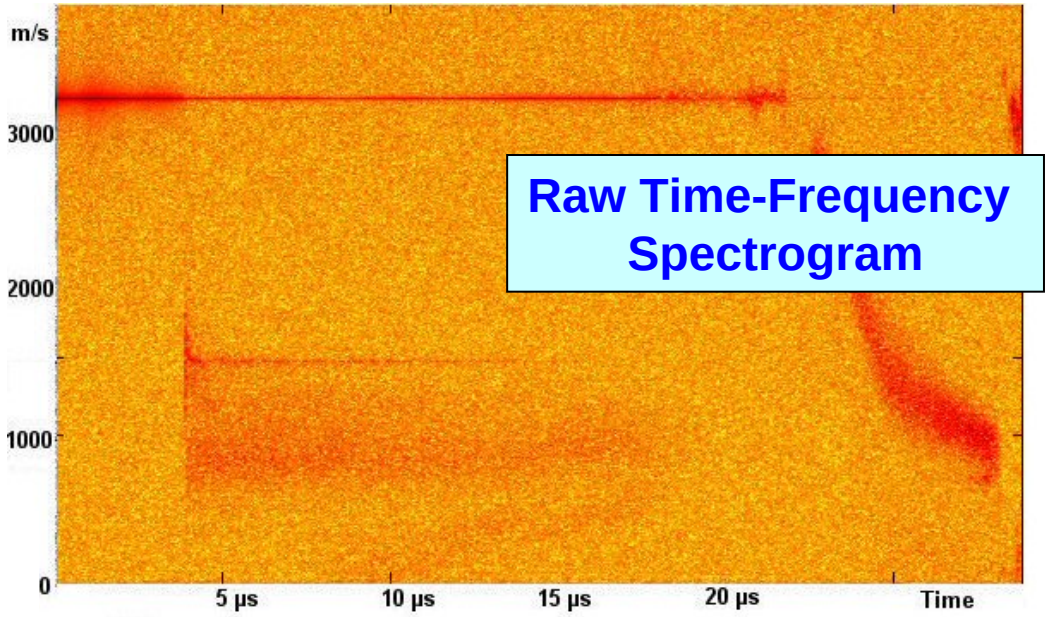
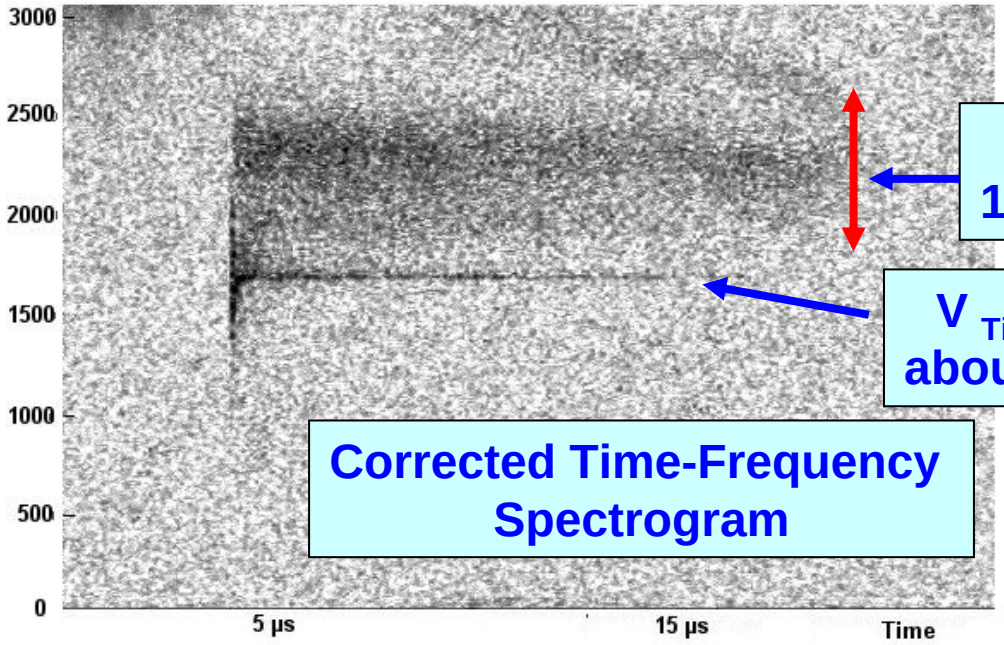
GUN EXPERIMENT ON TIN : PARTICLE VELOCITY





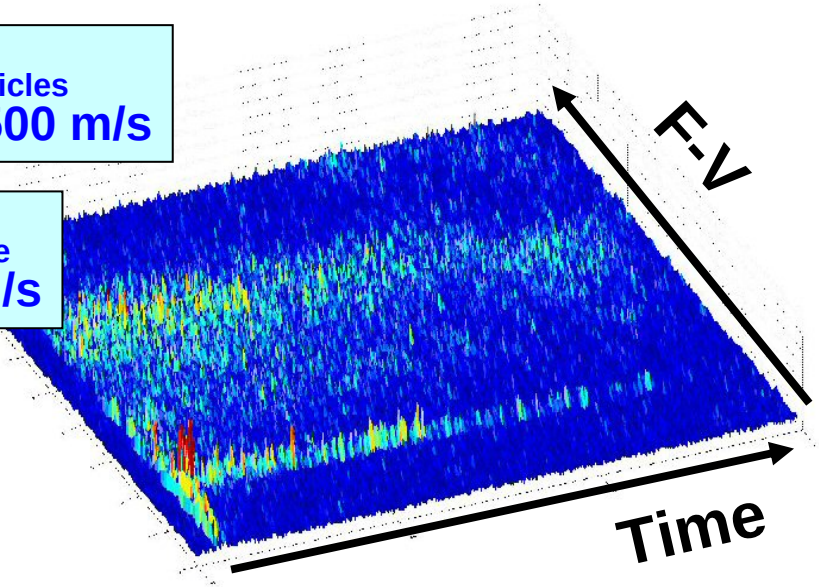
Raw Time-Frequency Spectrogram



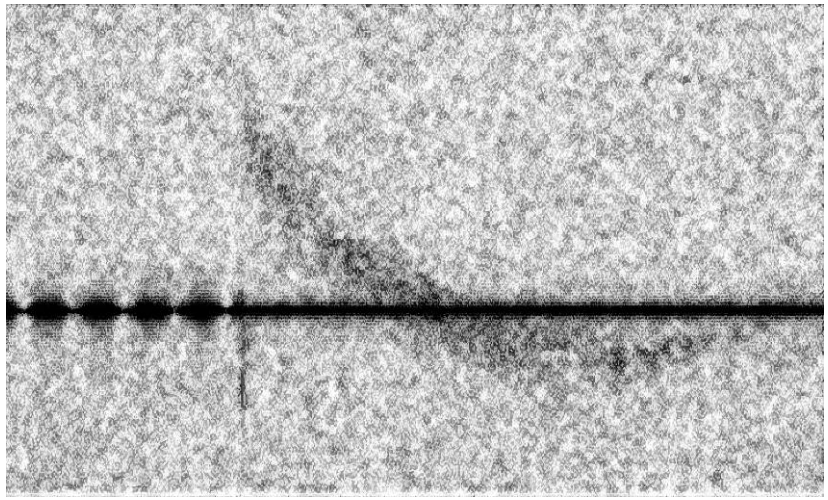
V Tin articles 1800 to 2500 m/s

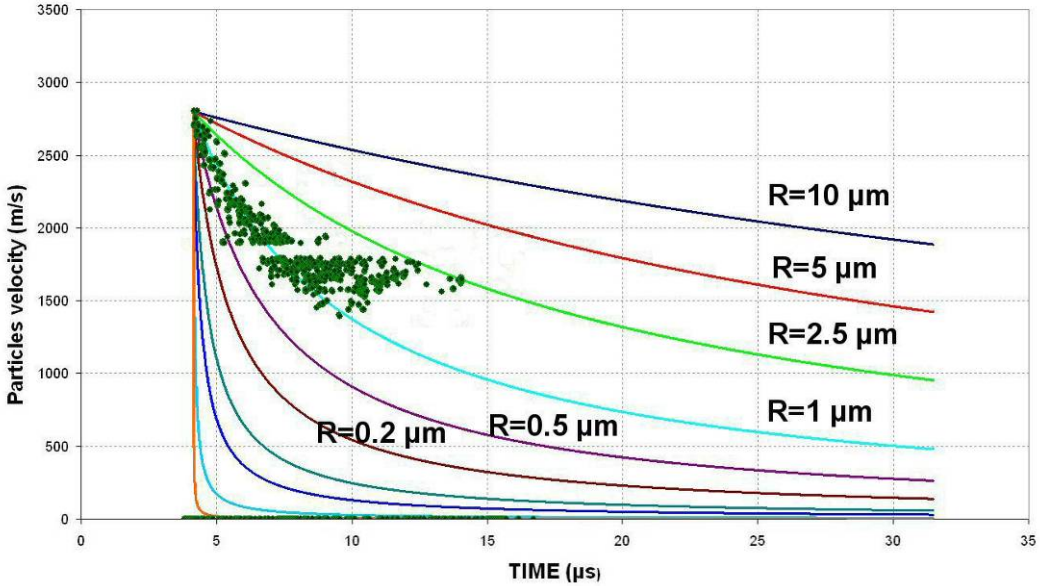
V Tin free surface about 1700 m/s

Corrected Time-Frequency Spectrogram



GUN EXPERIMENT ON TIN : PARTICLE SIZE





- No vacuum (air atmospheric pressure)
- Model with only drag force : braking
- C_d = 0.45
- Size range : 0.4 to 5 µm

- Better model : with ablation

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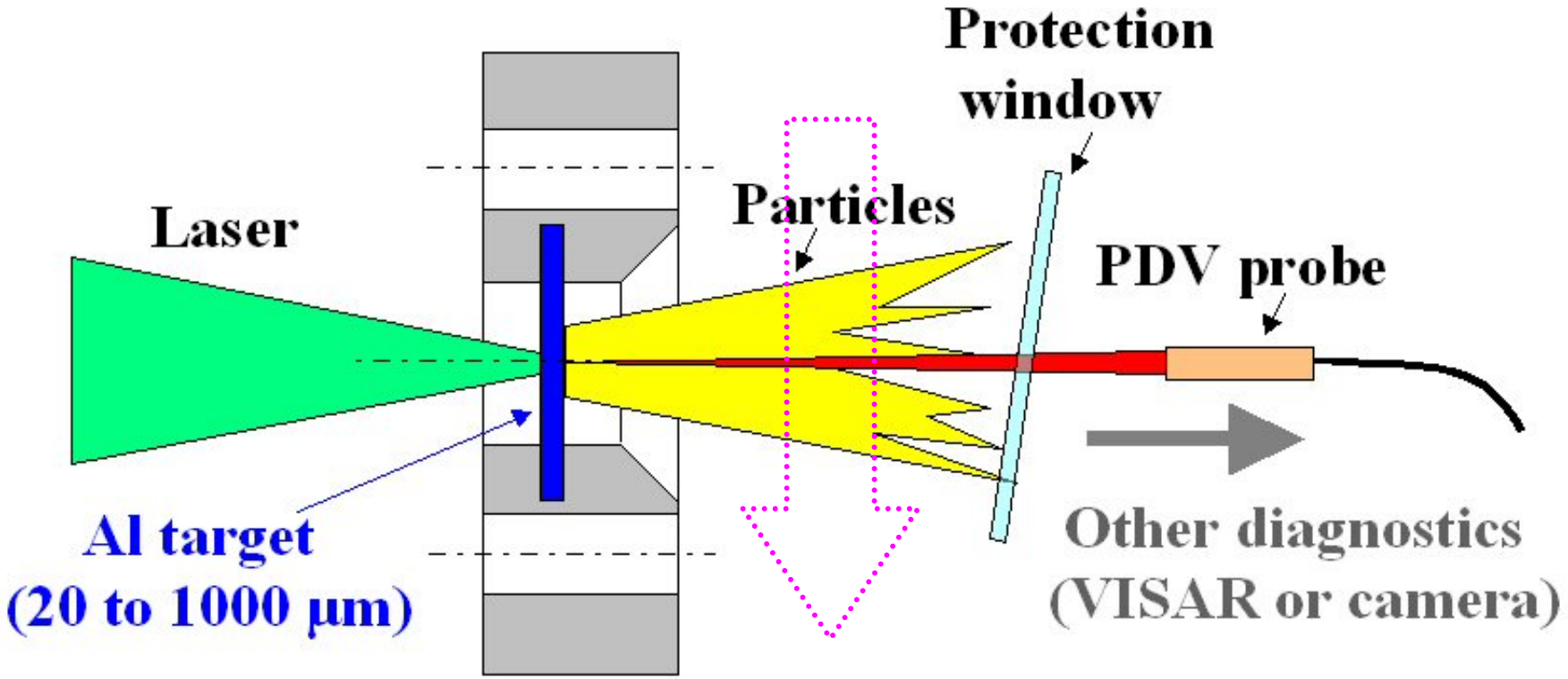
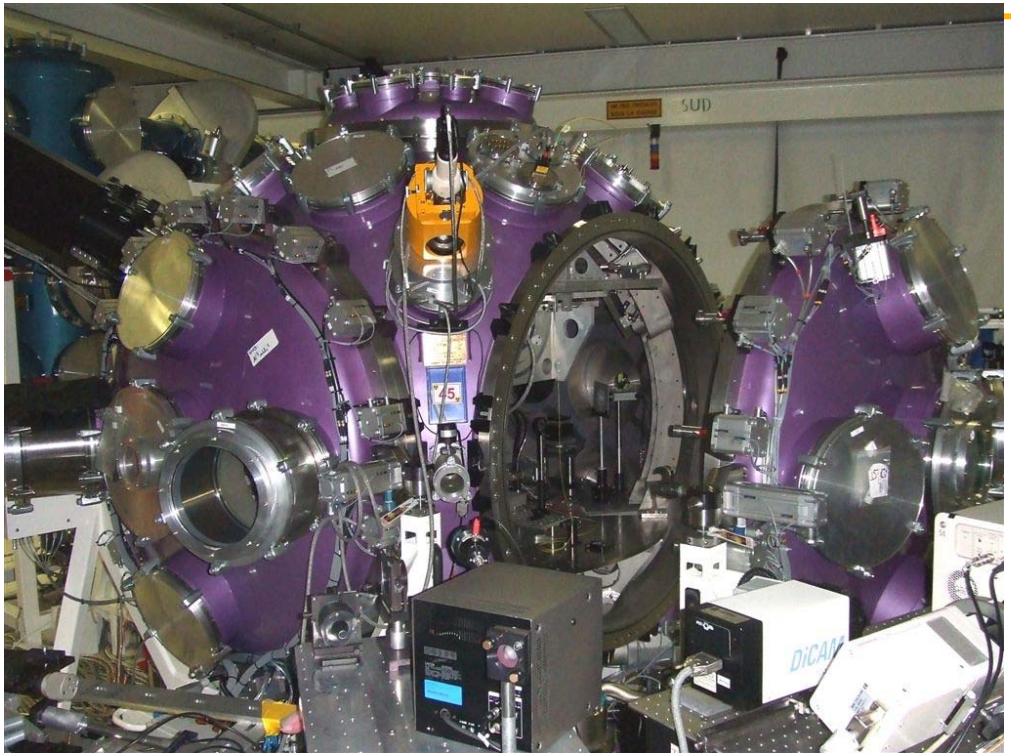
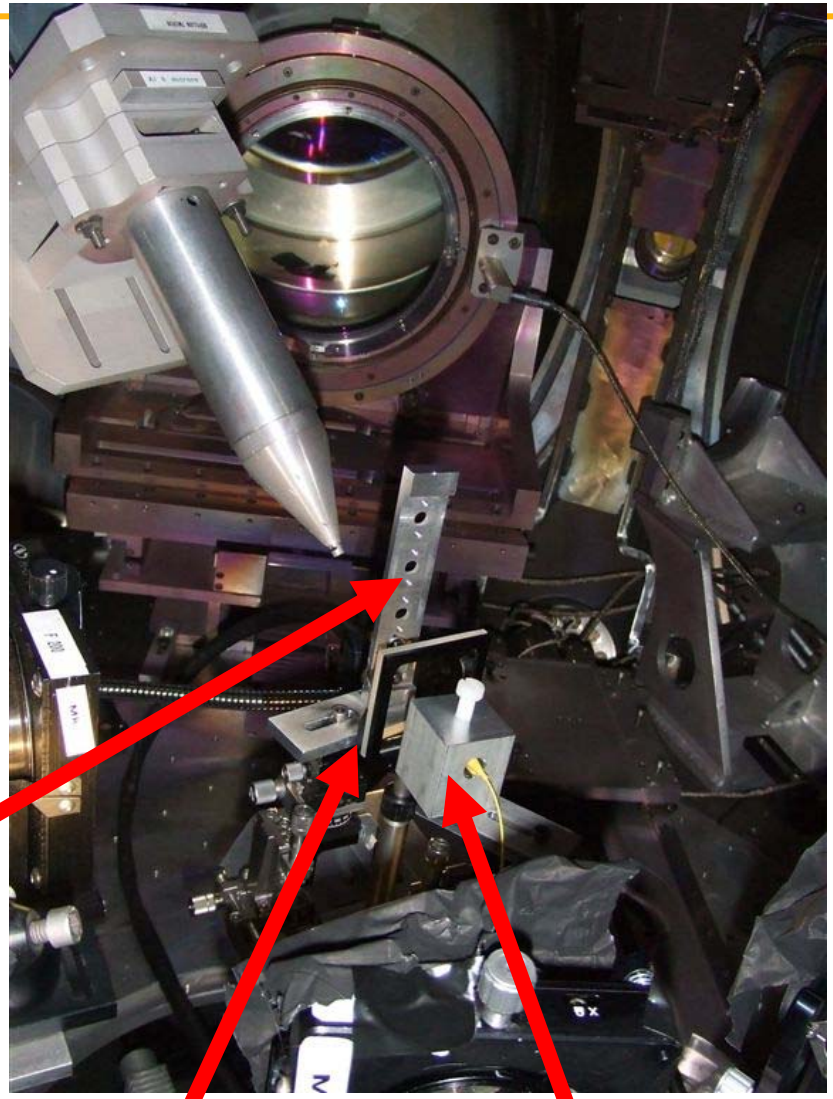
LULI EXPERIMENTAL SETUP



Transverse
Shadowgraphy
(3cameras)

LULI 2000 LASER : EXPERIMENTAL CHAMBER





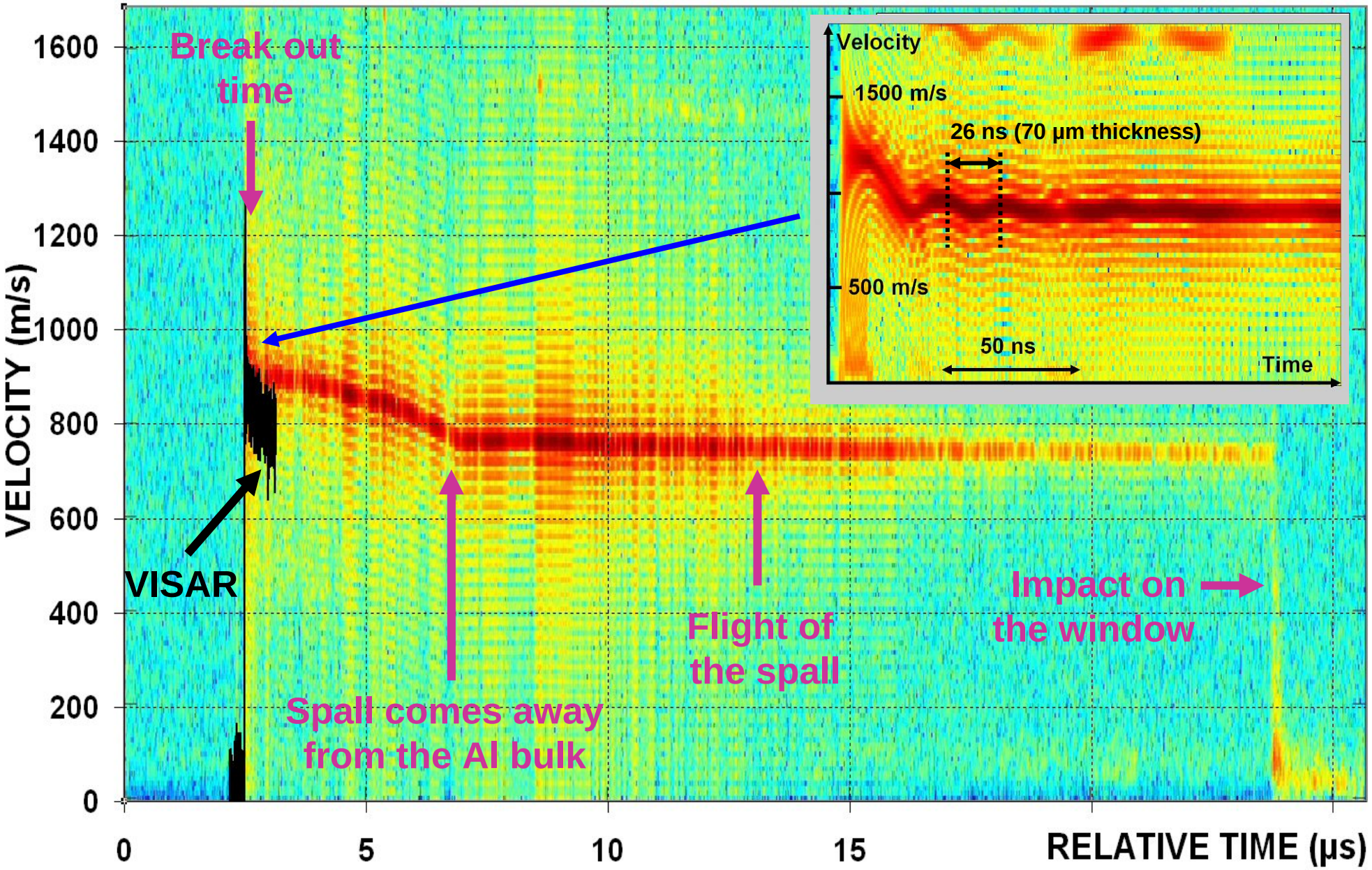
- **LULI 2000**
  - λ = 1057 nm
  - E = 790 J
  - Pulse duration = 2 or 3 ns
  - Target spot diameter : 3 or 4 mm
  - Irradiance = 2 to 5 TW/cm²
  - Vacuum = 10^{-5} mbar

LULI PDV SHOT PROGRAM (12 ns shots , 22 fs shots)

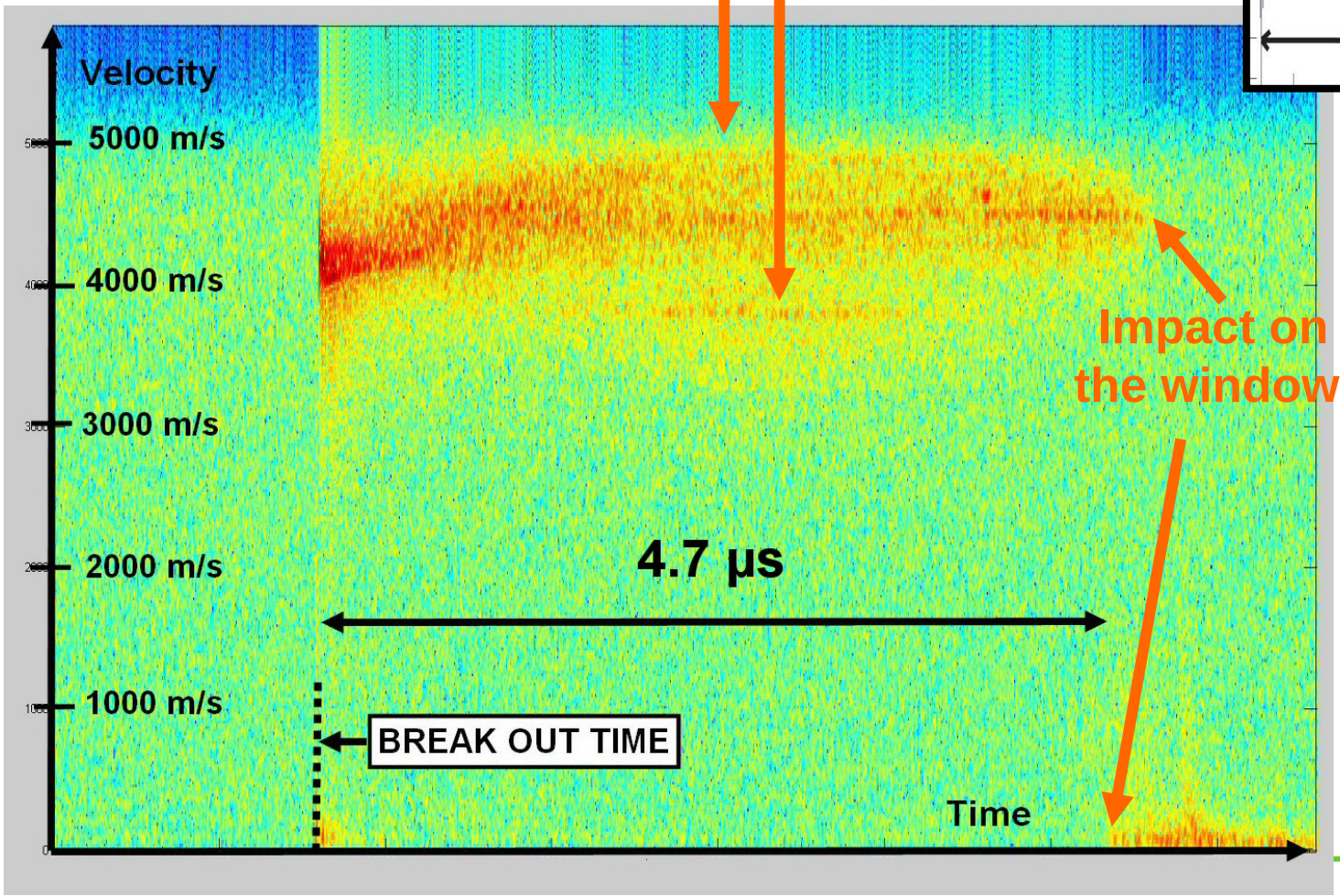
Shot	Target		Laser (λ = 1057 nm)			Target (defocus)		Diagnostics
	Material	Thickness		Pulse	Energy	Spot Φ	Irradiance	
T15 ns	Al	200 µm	LULI200	2.2 ns	790 J	3 mm	5 TW/cm²	PDV Shadowgraphy
T20 ns	Al	1000 µm	LULI200	3.1 ns	794 J	4 mm	2 TW/cm²	PDV VISAR
T19 fs	Al	20 µm	100TW	300 fs	16 J	2 mm	1.7 PW/cm²	PDV Shadowgraphy
T22 fs	Al	20 µm	100TW	300 fs	33 J	2 mm	3.5 PW/cm²	PDV Shadowgraphy

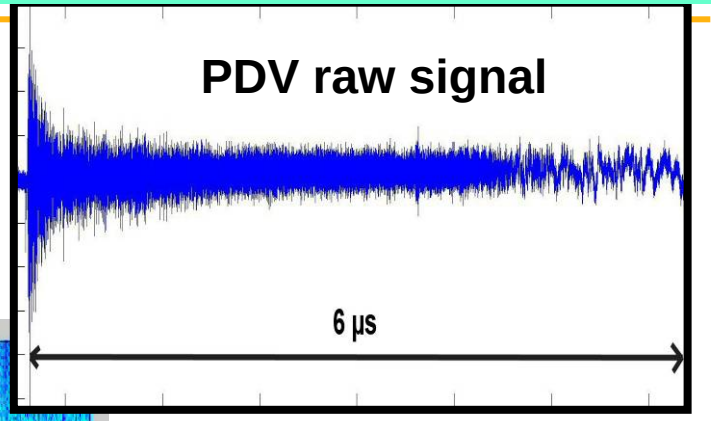
Single laser configuration
OZ probe, Φ 2.5 mm

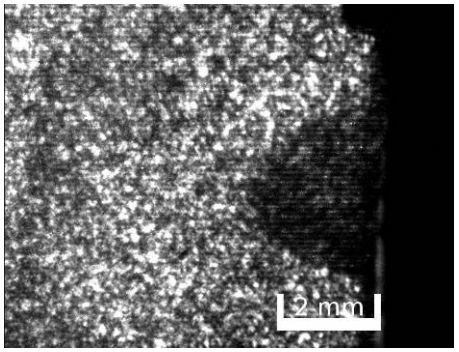
SHOT T20 ns : 1 mm, 2 TW/cm², 3.1 ns → Spall created



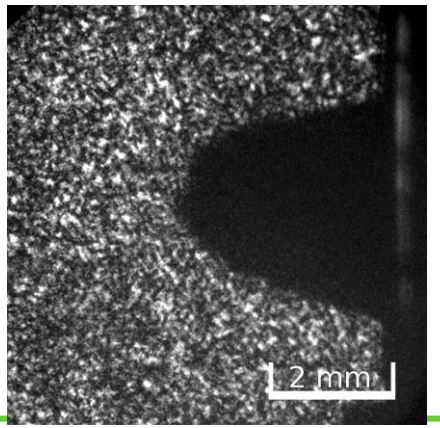
SHOT T15 ns : 200 μm, 5 TW/cm², 2.2 ns → Particles created







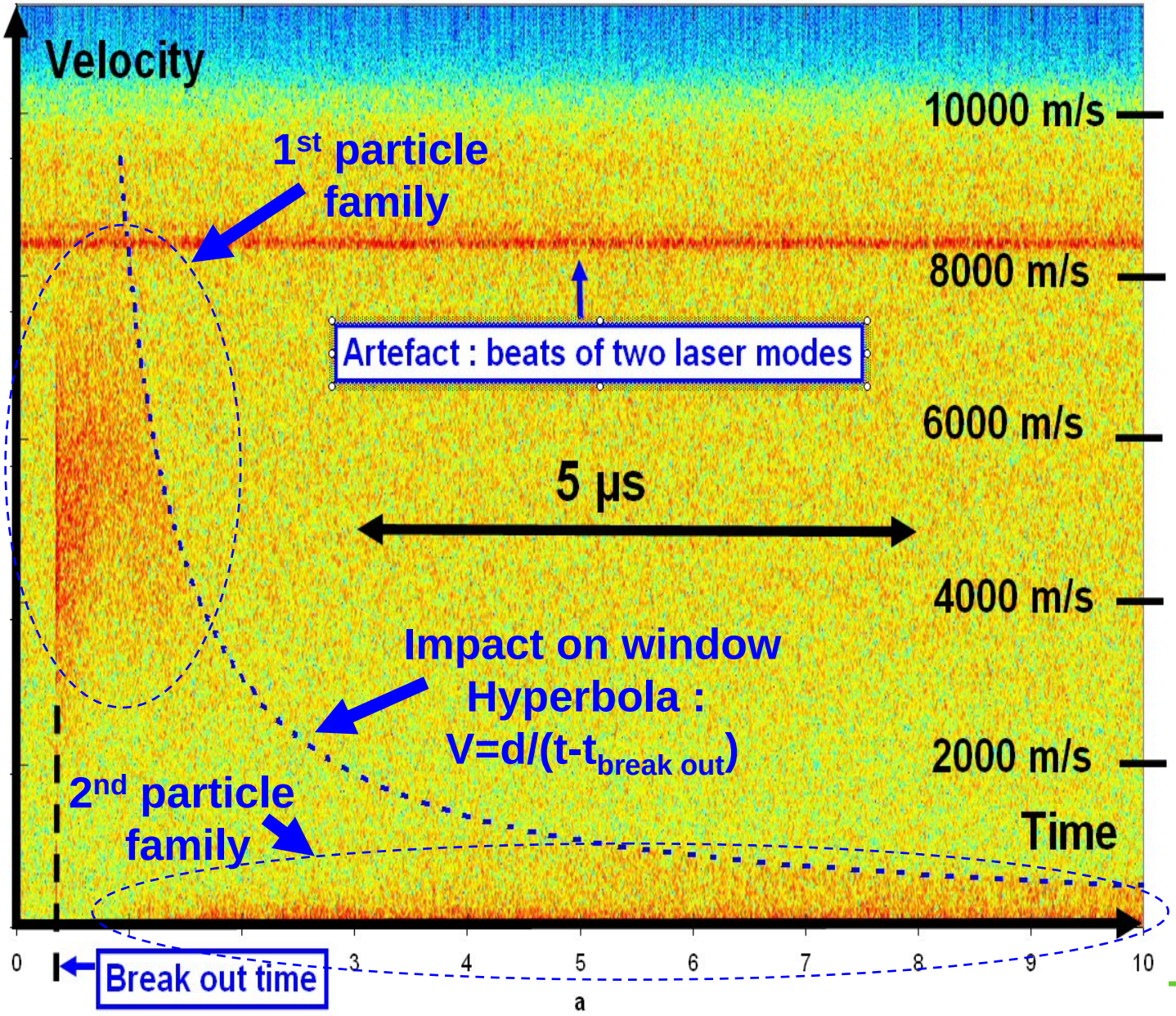
T = 250 ns

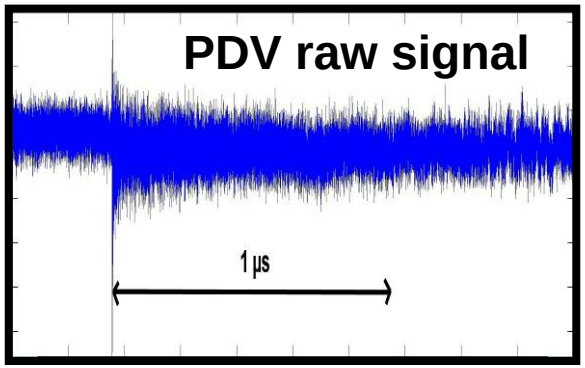


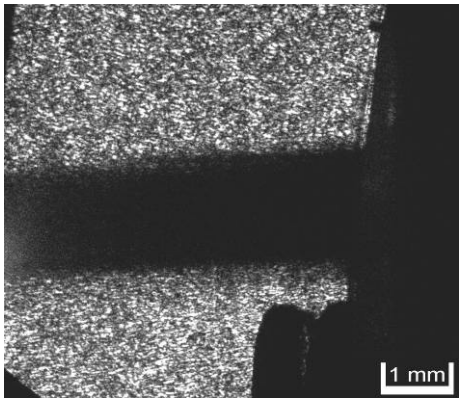
T = 500 ns

Shadowgraphy (50 ns)

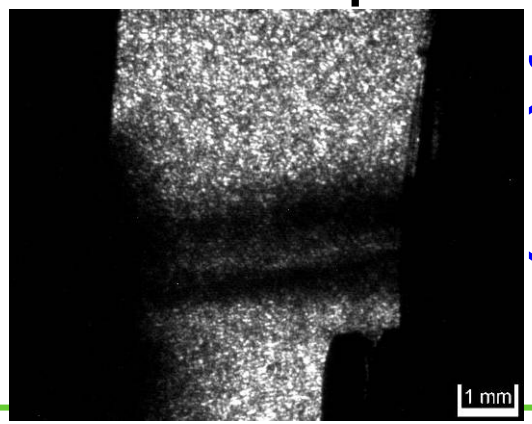
SHOT T19 fs : 20 μm, 1.7 PW/cm², 300 fs → Particles cloud







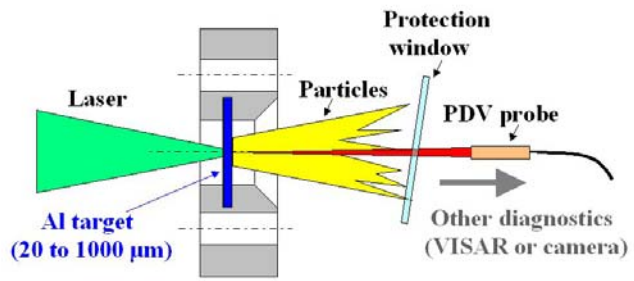
T = 1 µs

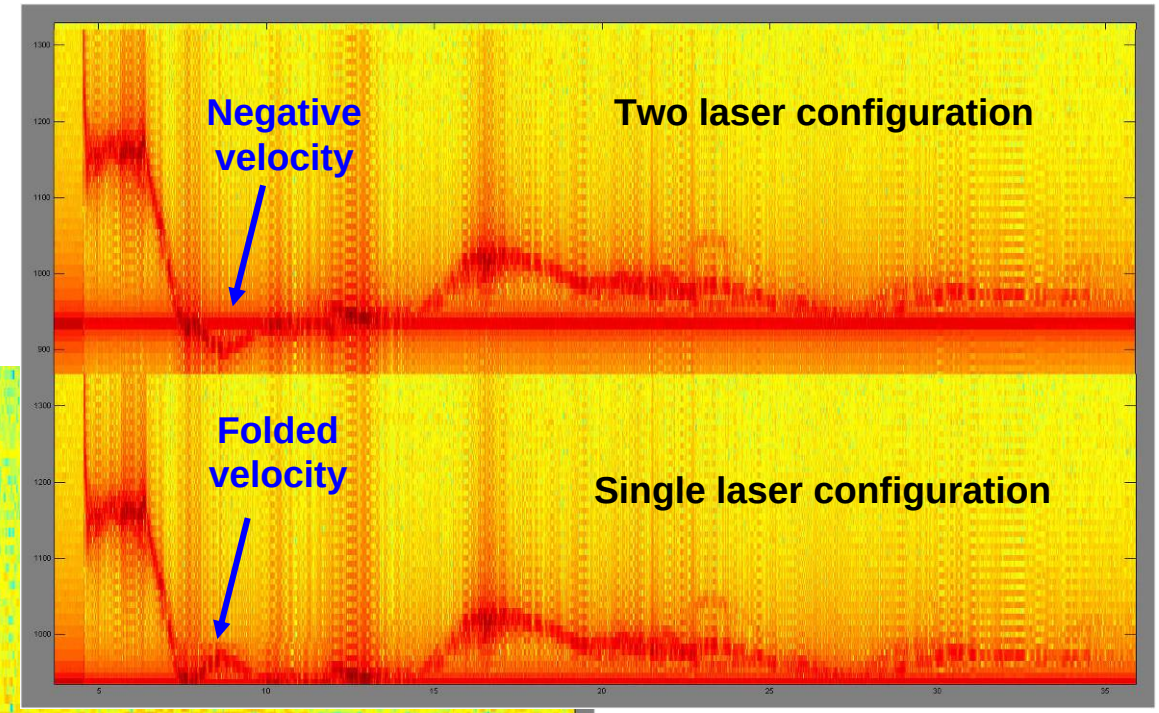


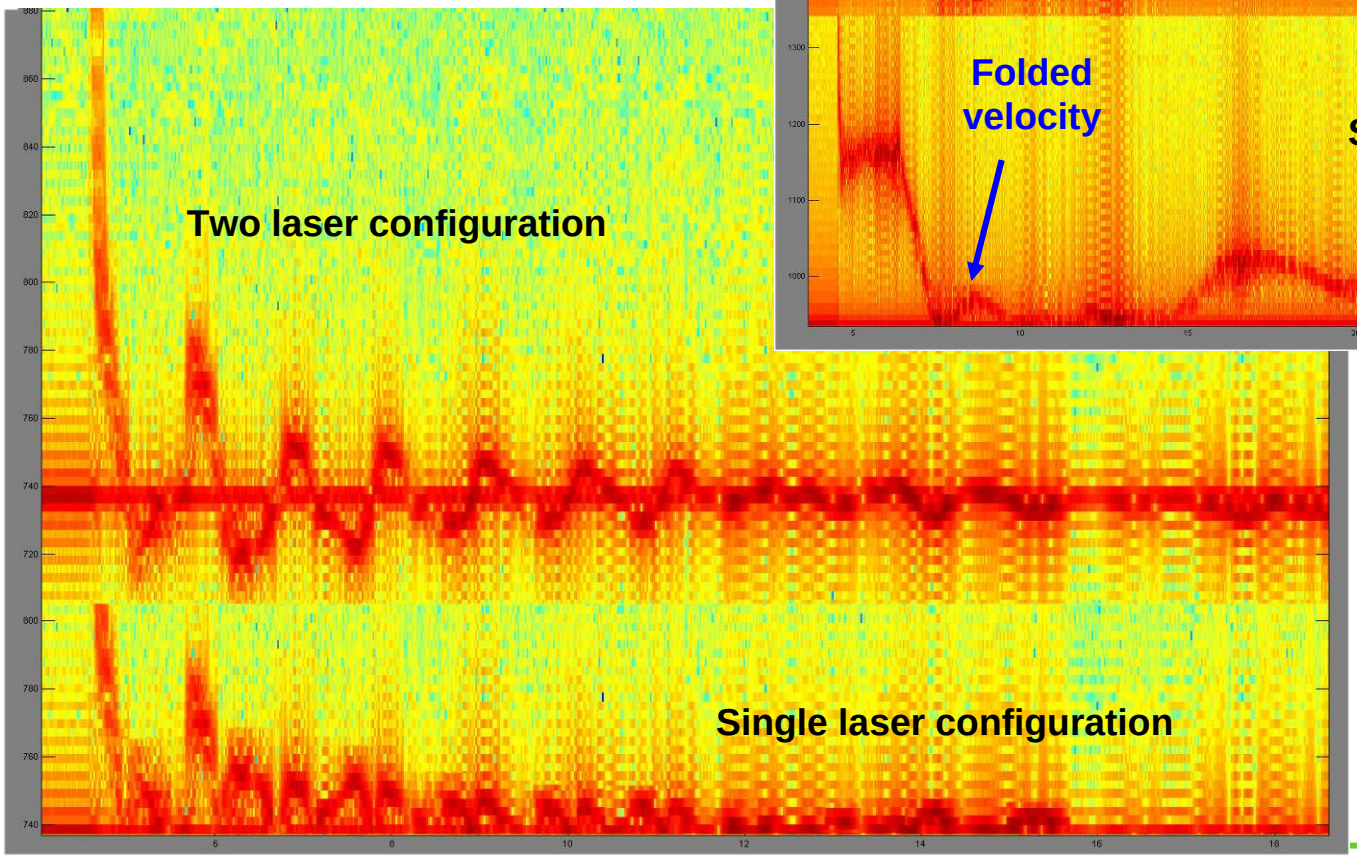
T = 3 µs

Shadowgraphy (50 ns)

PDV : Velocity sign accessible with 2 spectrally-shifted lasers



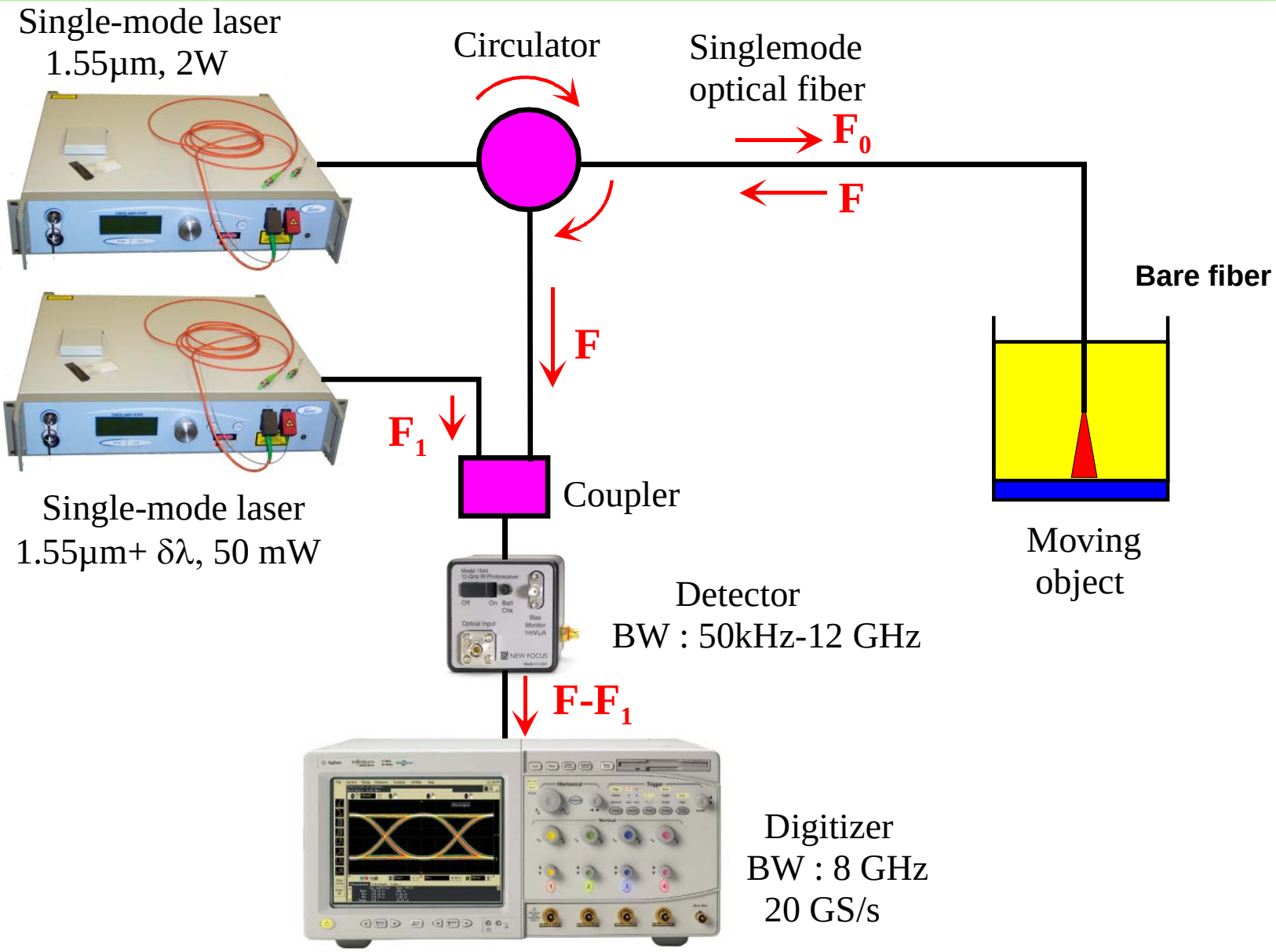




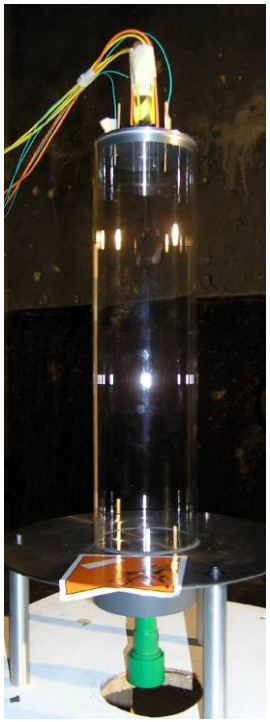
OVERVIEW

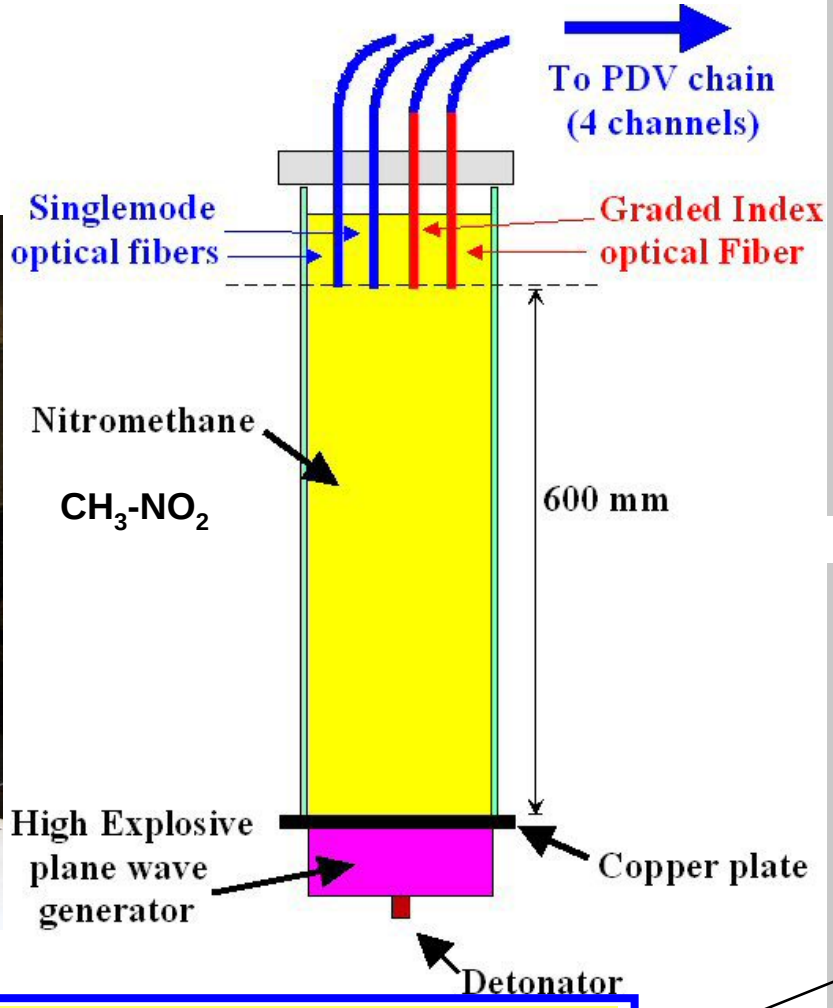
- APPARATUS CONFIGURATIONS
  - 1 or 2 lasers
  - 1 or 2 optical fibers
- HARDWARE
- SOFTWARE & PROCESSING
- **EXPERIMENTS**
  - Tin particles velocity
  - Laser shock driven experiments
  - Embedded fibers in nitromethane
- CONCLUSION

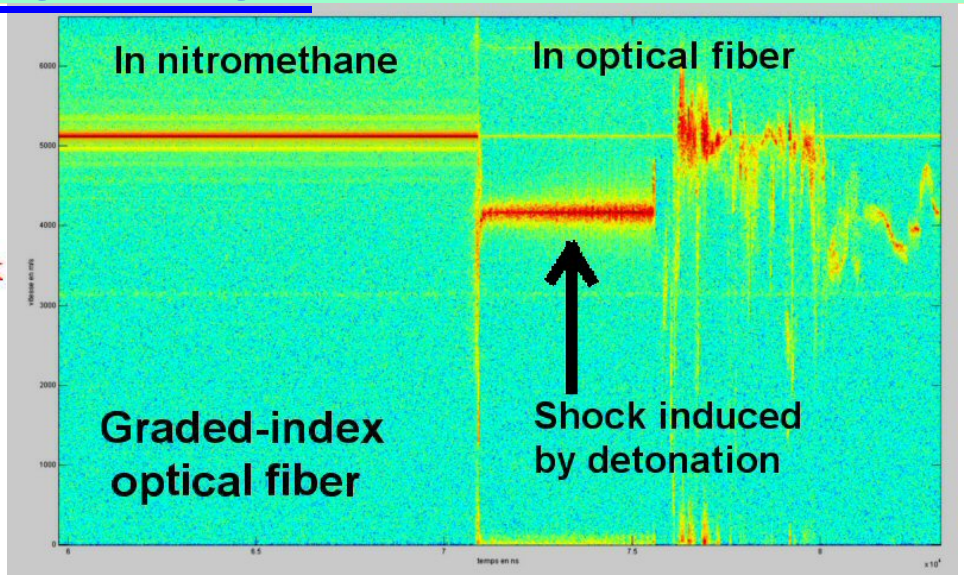
PDV SETUP FOR EMBEDDED FIBER IN NITROMETHANE

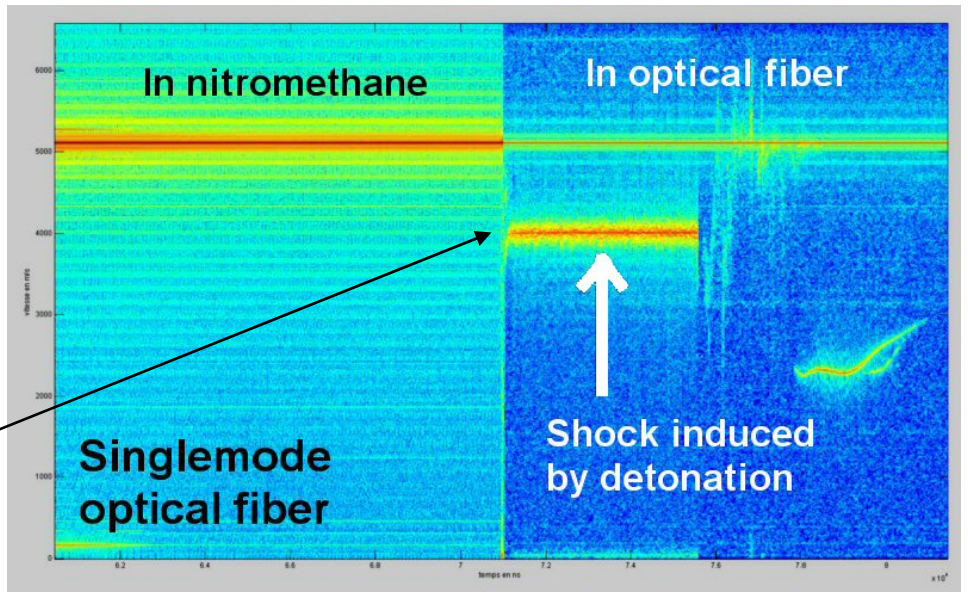


PDV AND EMBEDDED FIBER IN NITROMETHANE : STEADY DETONATION



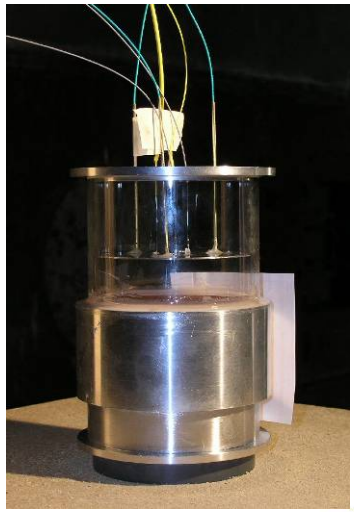


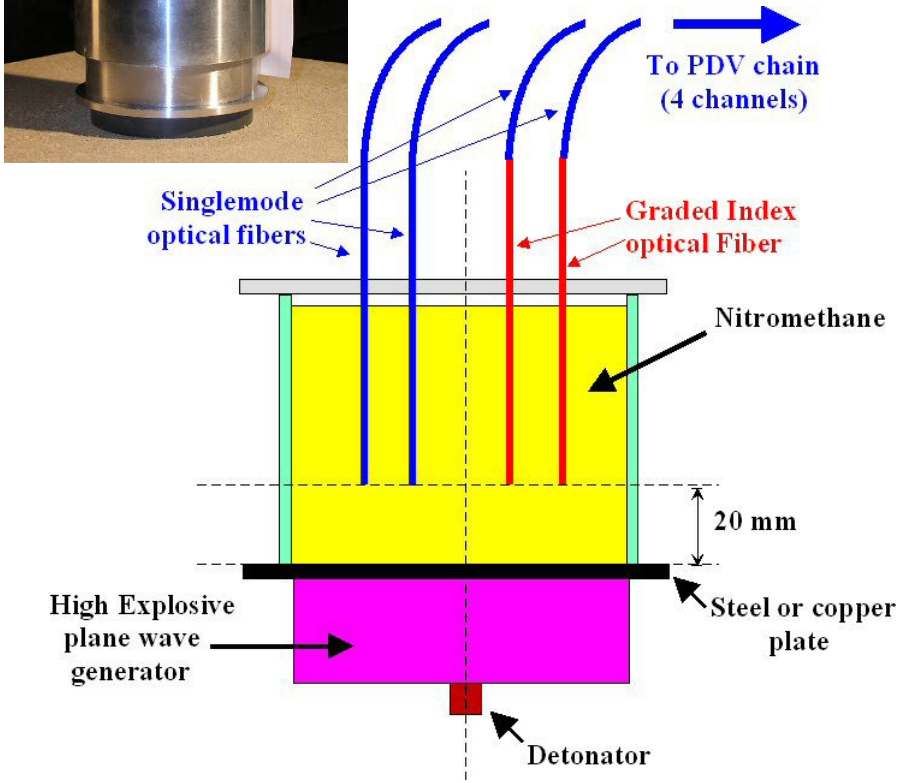


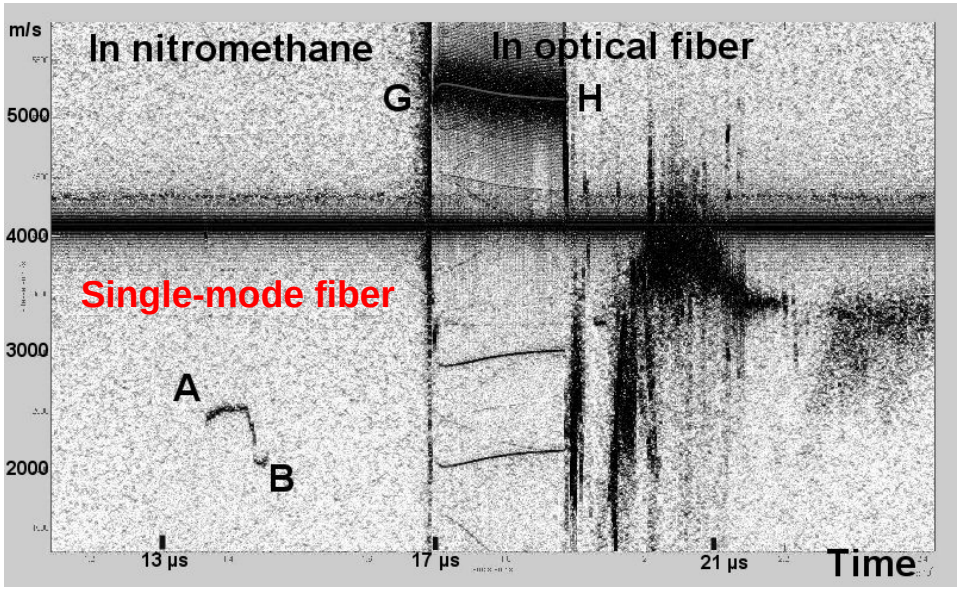


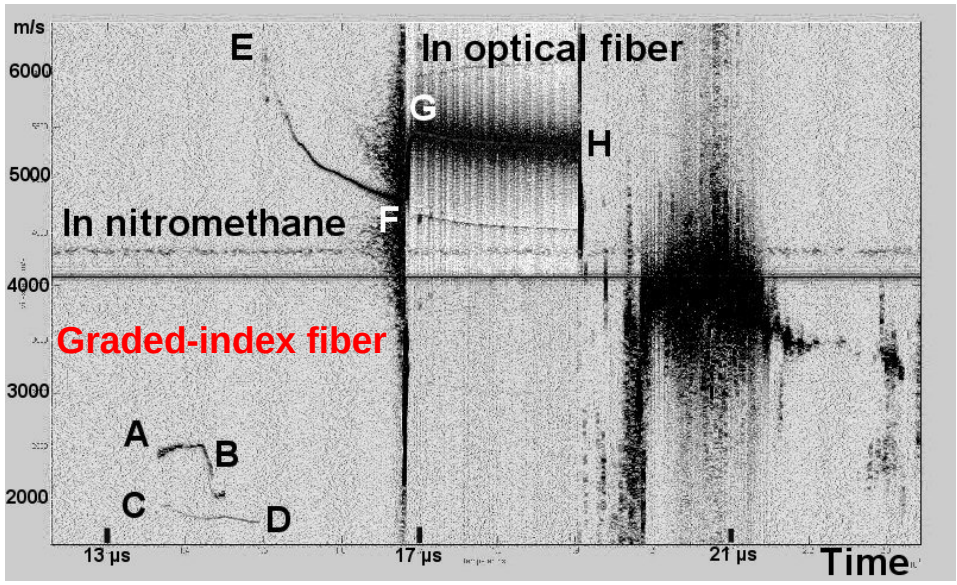
$$V_{real} = \frac{V_{pivot} + V_{measured}}{n_{silica}} = 6270 ms^{-1}$$

PDV AND EMBEDDED FIBER IN NITROMETHANE : NON STEADY DETONATION

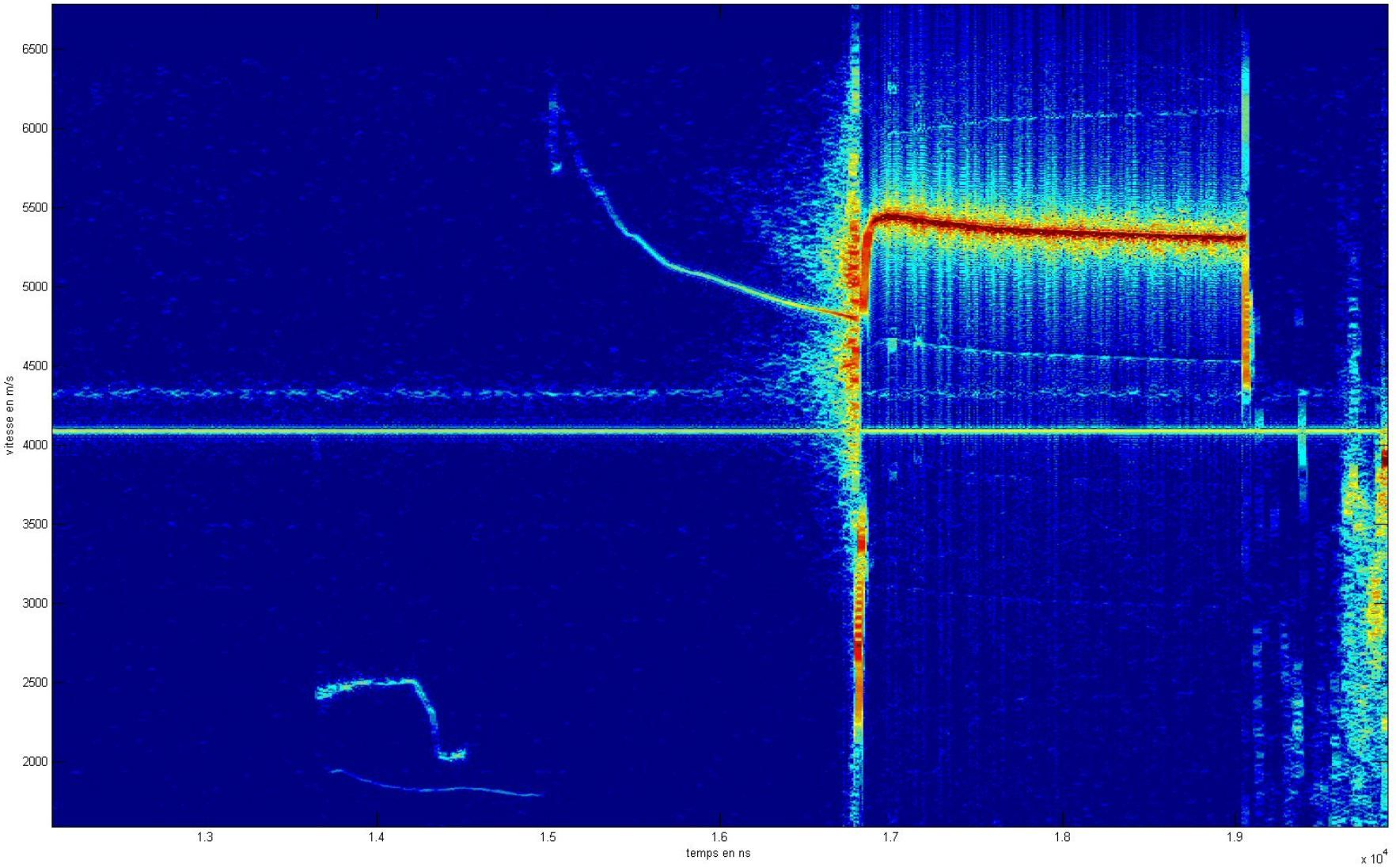




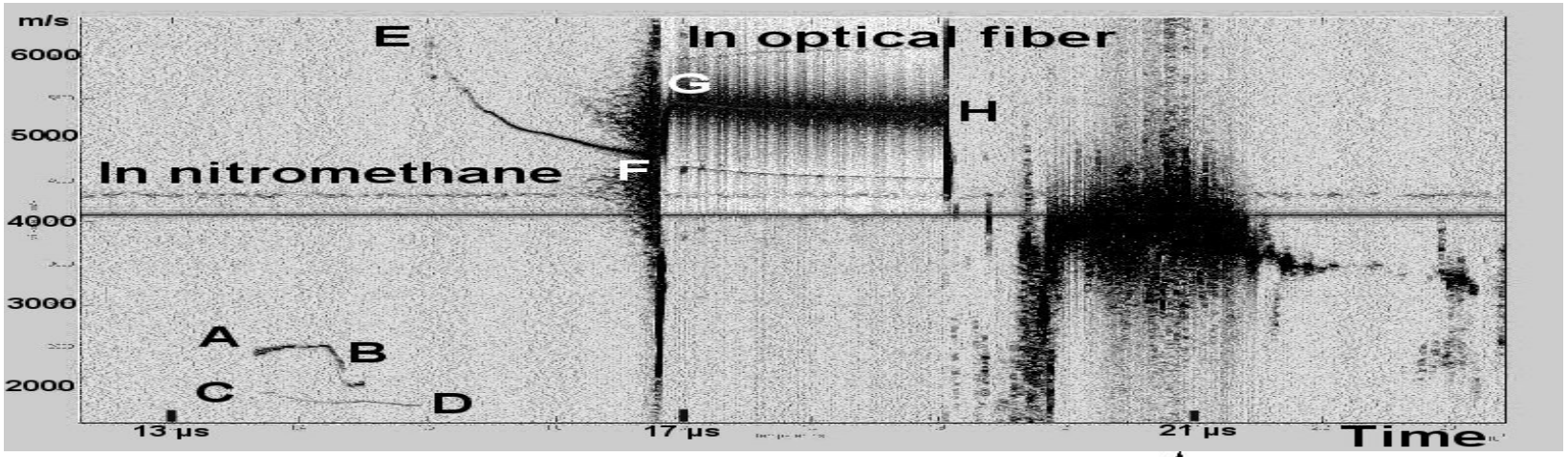


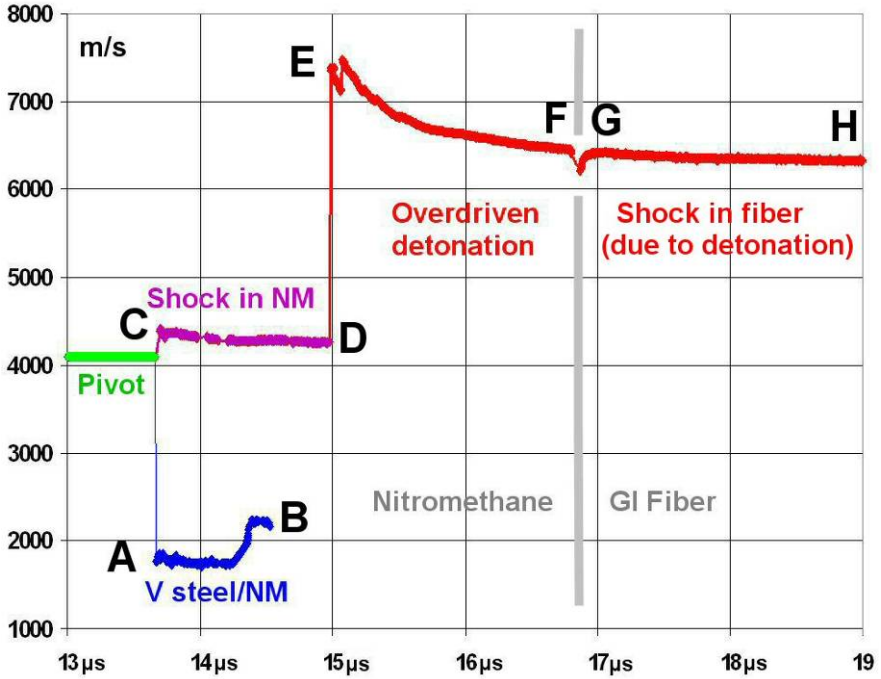


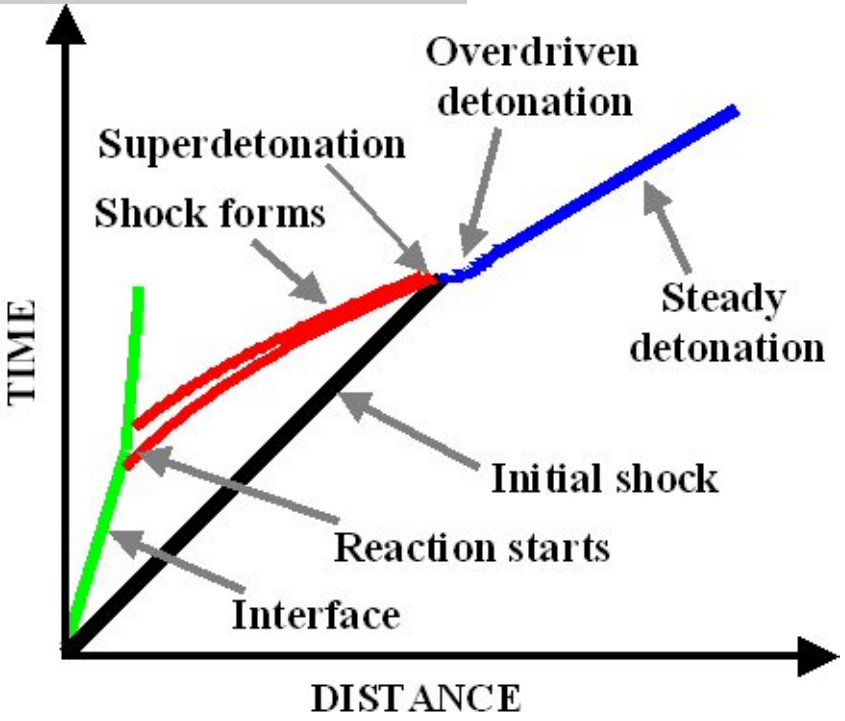
HV AND EMBEDDED FIBER IN NITROMETHANE : NON STEADY DETONATION



PDV AND EMBEDDED FIBER IN NITROMETHANE :
NON STEADY DETONATION : ANALYSIS







CONCLUSION

- **Photonic Doppler Velocimetry (PDV)** is a remarkable and versatile tool with many advantages in comparison to DLI and VISAR :
  - Low cost, fully fibered setup, small probe sizes & spot
  - Good accuracy (a few m/s), good photometric dynamics (more than 26 dB)
  - Long time record (5 to 100 μs)
  - Ability to record simultaneously many velocities (with one or two solutions)
  - Large velocity range (0 – 20 km/s with 2-laser setup)
  - New PDV equipments subcontracted (12 GHz BW, 50 GS/s sampling)

- **Future**
  - We plan to improve the number of probes
  - Raw signal information (20 ps sampling) not yet completely used
  - Particles (histogram, size)
  - Embedded fibers…

PUBLICATIONS

2006 :

P. MERCIER, J. BENIER, A. AZZOLINA, JM. LAGRANGE, D. PARTOUCHE
"Photonic Doppler Velocimetry in shock physics experiments“
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28th International Congress on High-Speed Imaging and Photonics. Canberra, Australia. 9-14 november (2008).

2009 :

P.MERCIER, J. BENIER, P.A. FRUGIER, A. SOLLIER, M. RABEC LE GLOAHEC, E. LESCOUTE, J.P. CUQ-LELANDAIS, E. GAY, T. DE RESSIEGUIER, L. BERTHE, M. BOUSTIE, M. NIVARD, A. CLAVERIE
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New Heterodyne Velocimetry and shock physics.
DYMAT 2009. Bruxelles, Belgique. 7-11 september (2009).

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