DE LA RECHERCHE À L'INDUSTRIE

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FRONTAL AND TILTED PDV PROBES FOR MEASURING VELOCITY HISTORY OF LASER-SHOCK INDUCED CALIBRATED PARTICLES

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GOAL OF THIS STUDY

- Characterization of particles ejected from shock loaded metallic plate :
  - Studied for years (1980…) by different laboratories,
  - density, size and velocity distributions, shape…
  - HE, gun, laser experimentation,
  - Different diagnostics available.

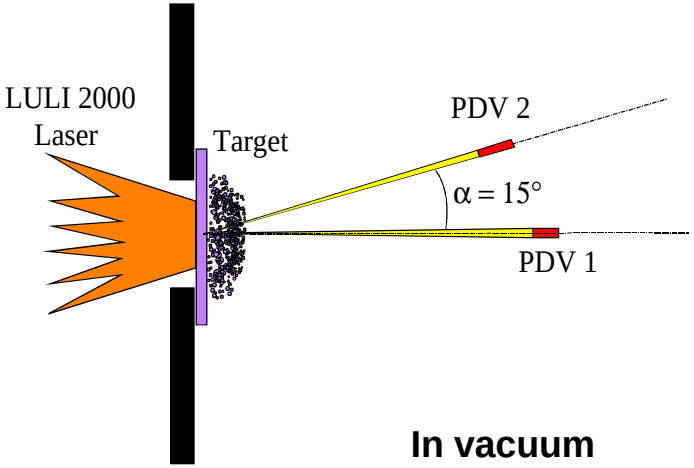
- PDV is an excellent tool to continue this study ➔ we use it since 2007, but in 2011, at the beginning of a new Ph.D. work (Gabriel Prudhomme), choice of simplifying first experiments :
  - calibrated particles (a few µm),
  - low power laser shock (then later, high power laser),
  - shots in ambient air.

- Presentation of some results

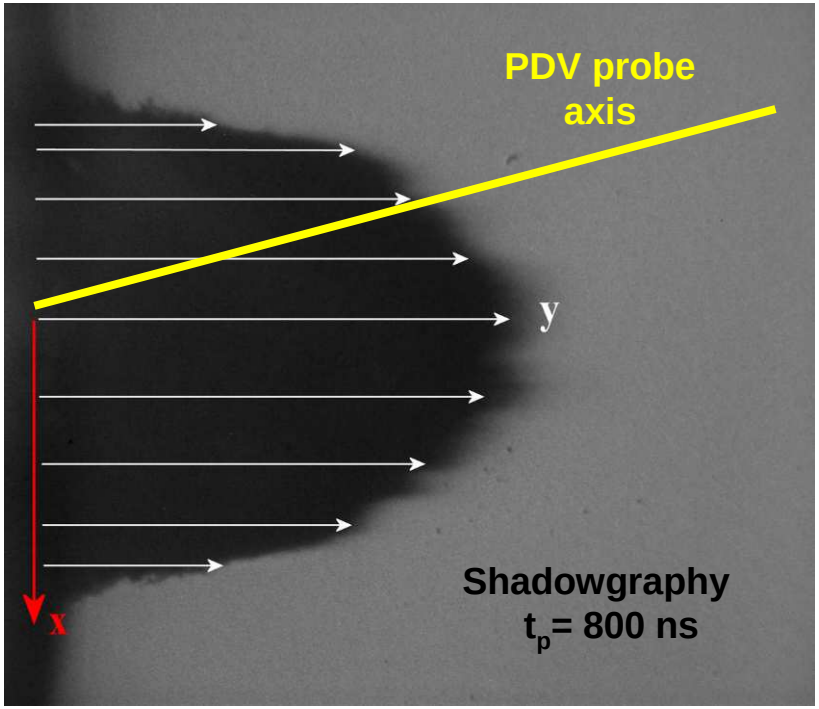
AVAILABLE SHOCK GENERATION MEANS TO STUDY CALIBRATED PARTICLE CLOUDS

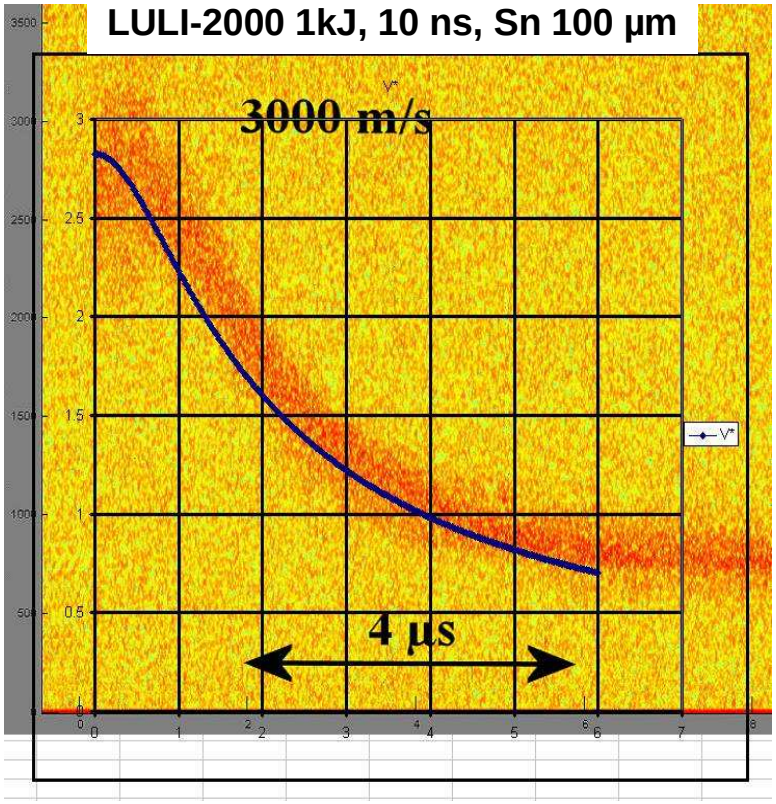
- HE shock
  - High pressure (a few GPa),
  - Plane shock wave over several cm,
  - Setup destroyed.
- Gun shock
  - High pressure (a few GPa),
  - Perfect plane shock wave (except tilt) over several cm,
  - Most of guns are horizontal,
  - Setup destroyed.
- Laser shock
  - Easy to achieve,
  - No probe destruction,
  - High shot rate (depending on the laser),
  - Little target diameter (several mm),
  - 2D effects (laser beam power shape and little spot size) but target behavior close to axisymetrical one,
  - Low pressure (of course depending on the laser power) inducing low velocities.

TILTED PROBING: PRESENTED AT PREVIOUS PDV WS (Livermore - 2011)



In vacuum



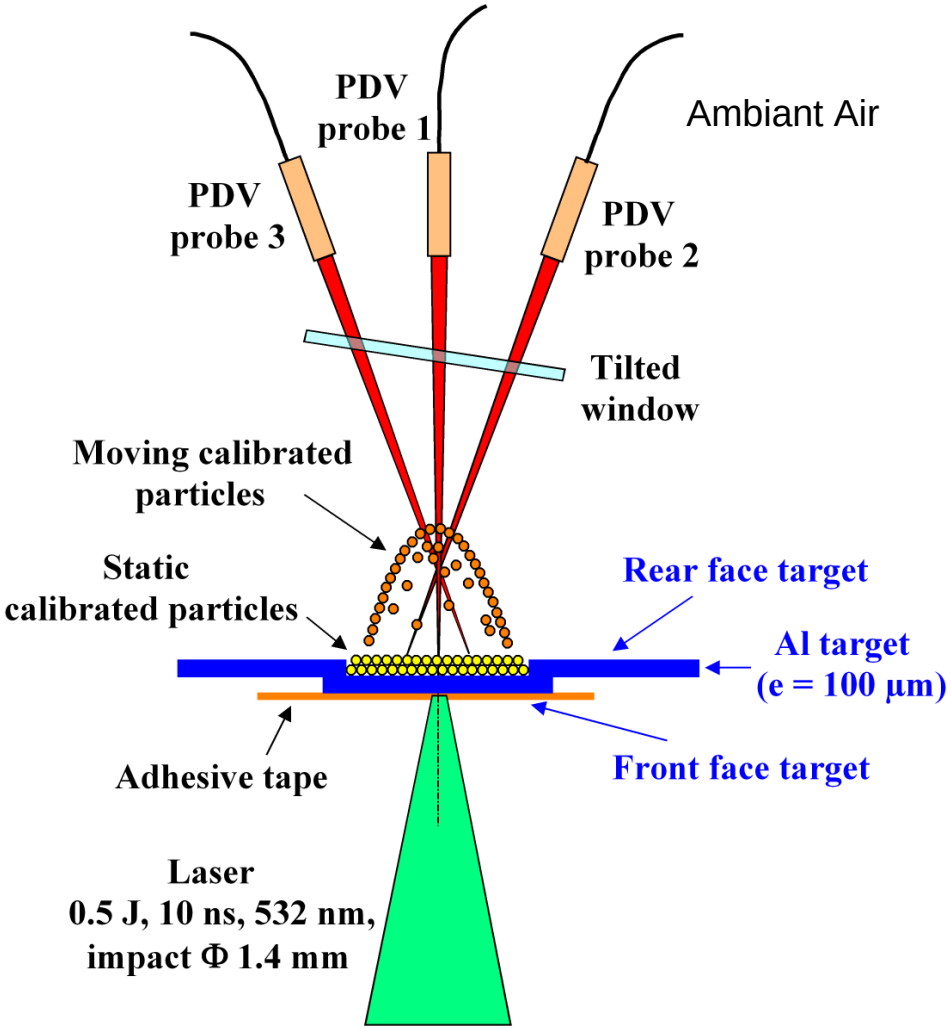


Simple model : Hypothesis

- **parallel velocities // oy**
- **all edge particles start at the same time (t=0 ns)**
- **y(x,t) is considered as a parabola**
- **vacuum, no particle deceleration**

SETUP

- After one HE shot we were confident in launching isolated calibrated particles, initially laid on a plate free surface.
- Record the velocity history (cloud, individual particles) by PDV : deceleration to try and determine initial velocity and diameter.
- Experiments realized at the PIMM laboratory, *Arts et Métiers ParisTech (2012).*

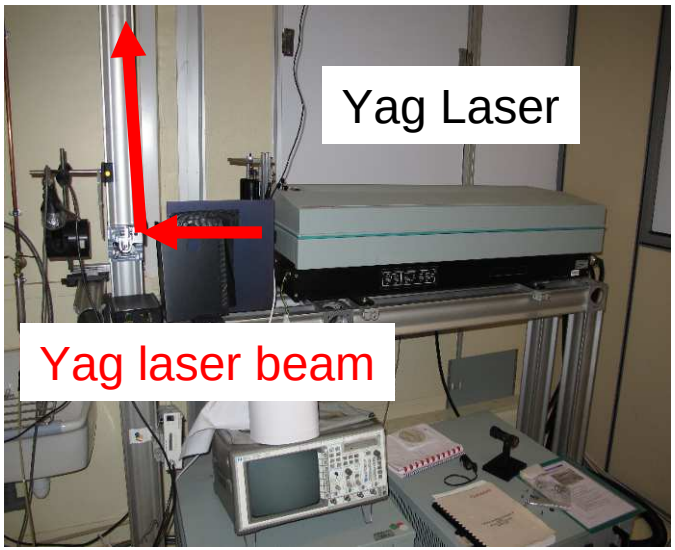


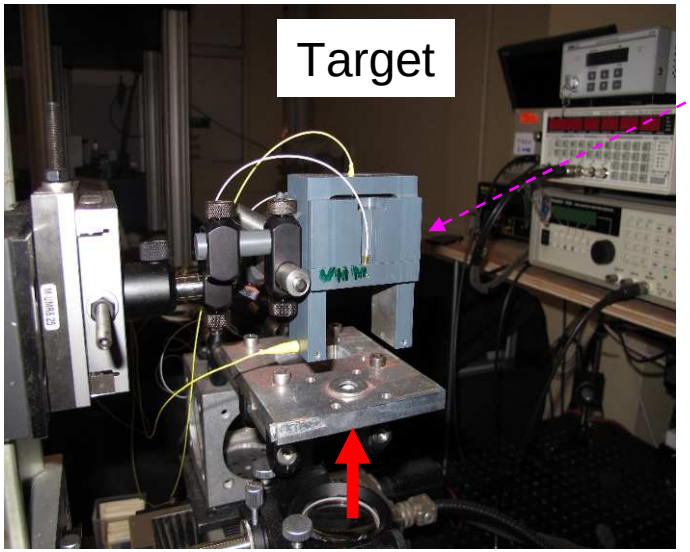
TARGET PREPARATION

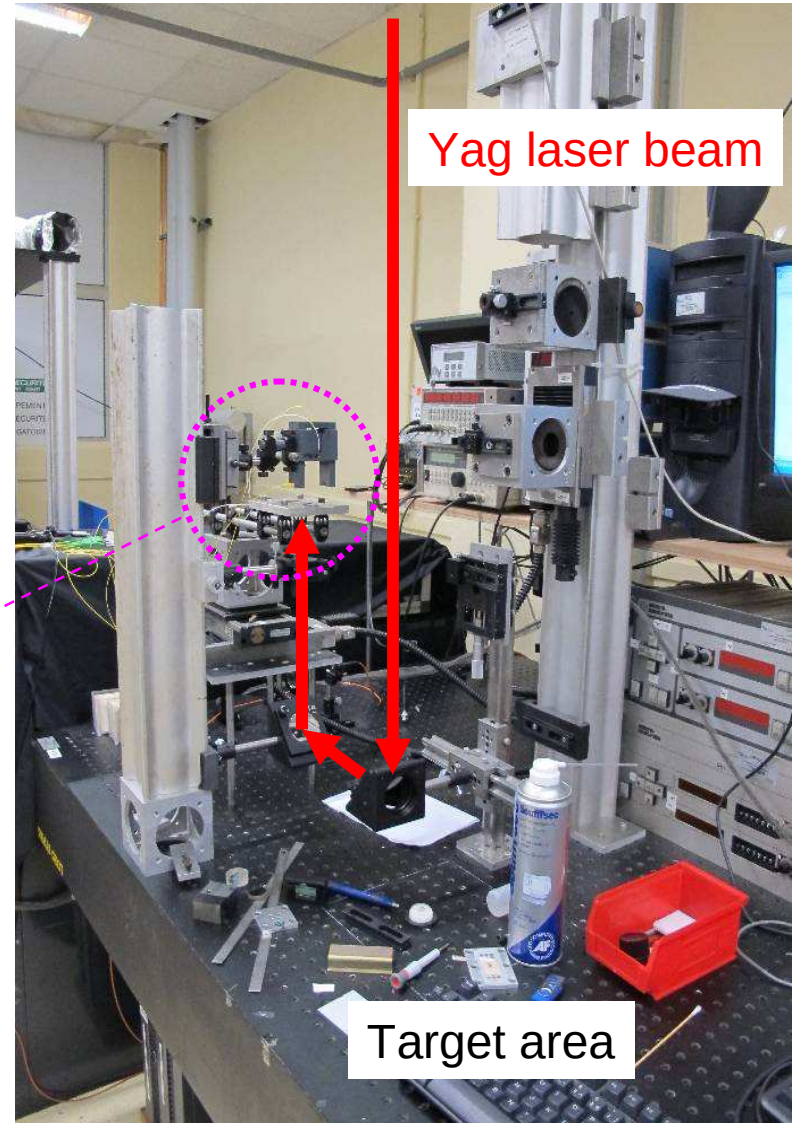
- Targets :
  - thin 10 mm square aluminum plates: 100 µm thickness,
  - stamped in their middle (Φ 5 mm) to receive calibrated powder.

- Powder :
  - single simple element (Al, Cu..),
  - calibrated sizes (Alfa Aesar, GmbH),
  - assumed composed of spherical particles,
  - same amount per shot (weighted).

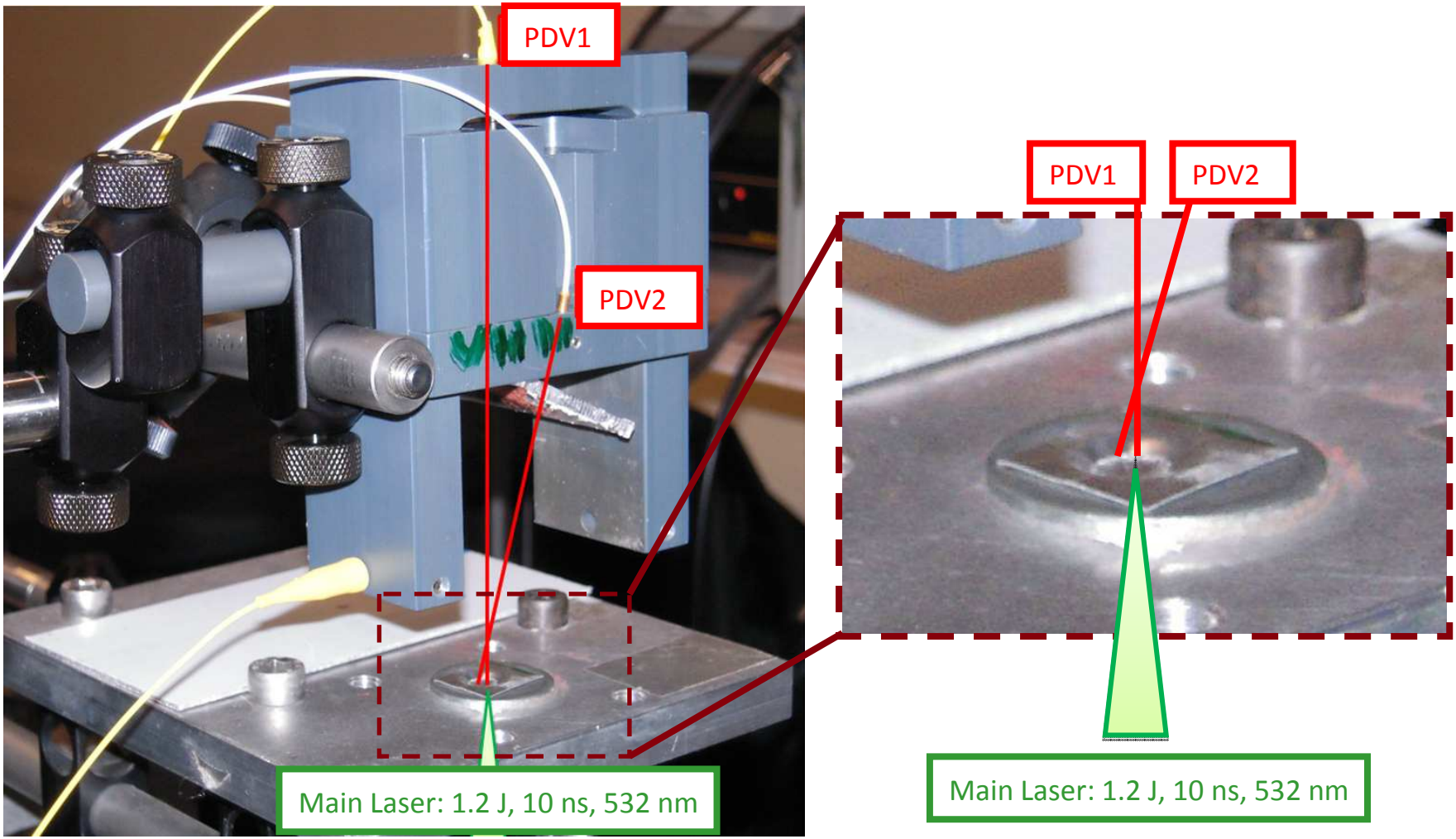
EXPERIMENTAL SETUP



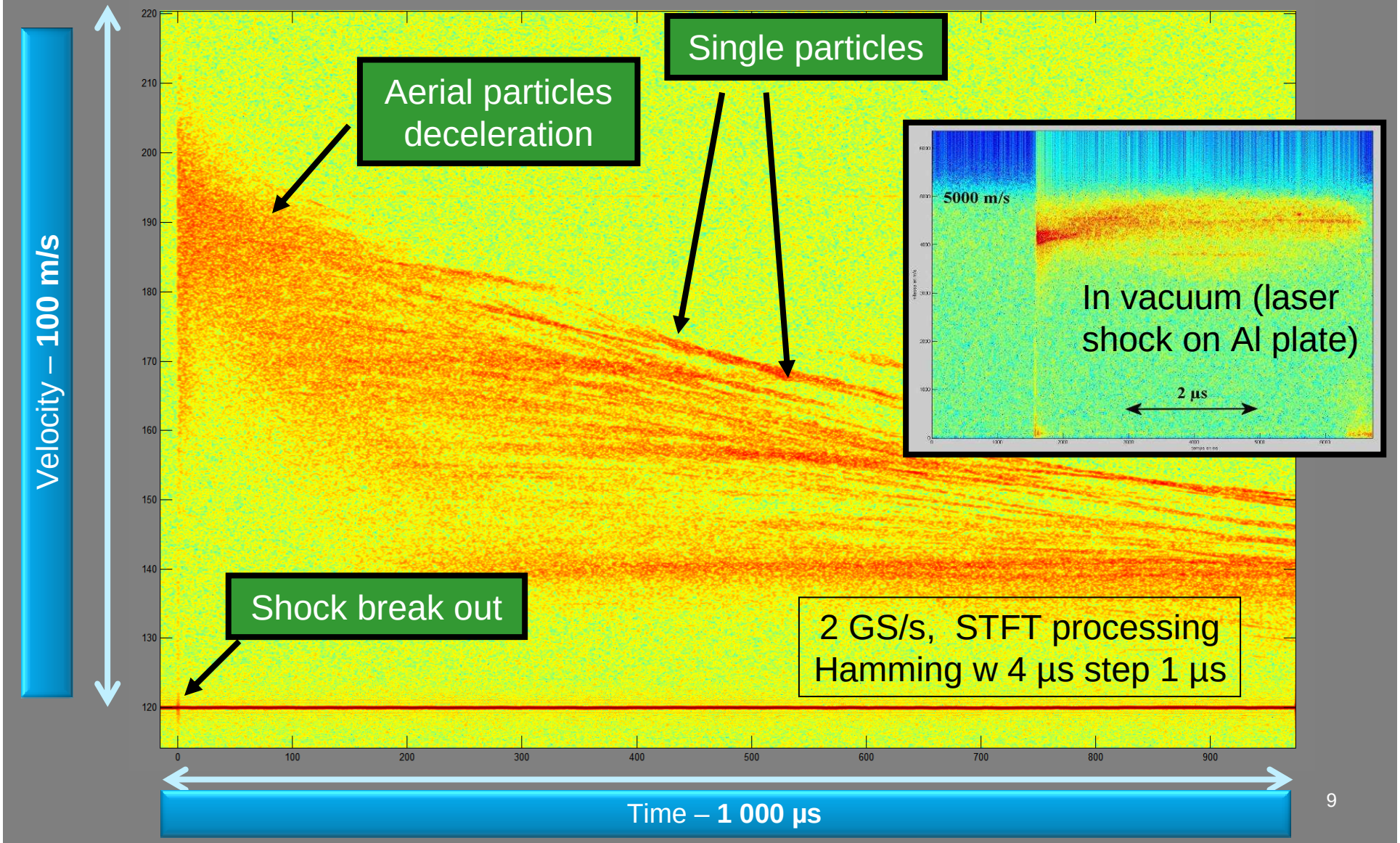




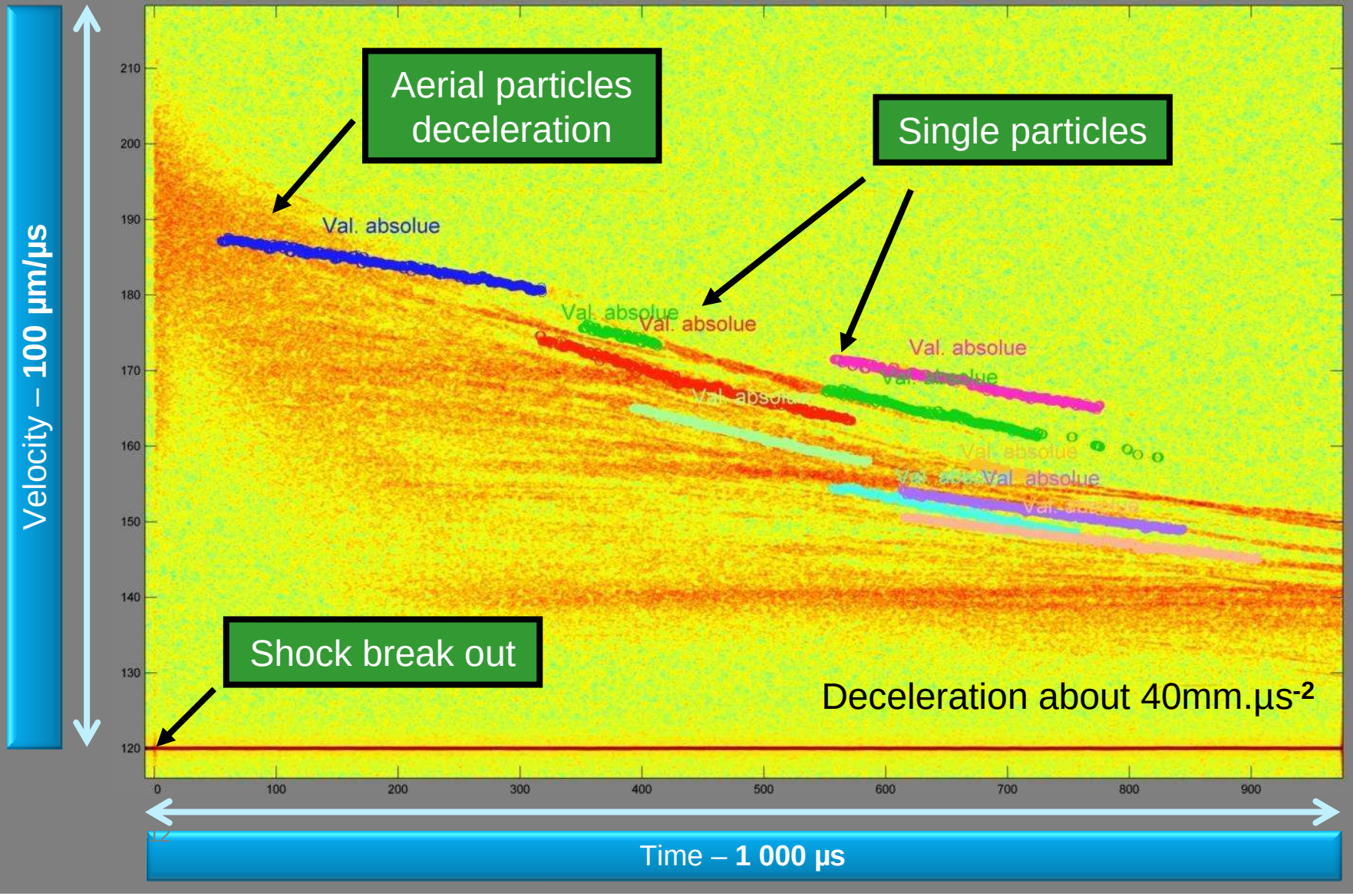
EXPERIMENTAL SETUP (ZOOM)



PDV SPECTROGRAM : PARTICLES BRAKING IN AIR
SHOT 24, Cu 10 µm, 21.9 mg, PDV1 (Frontal)

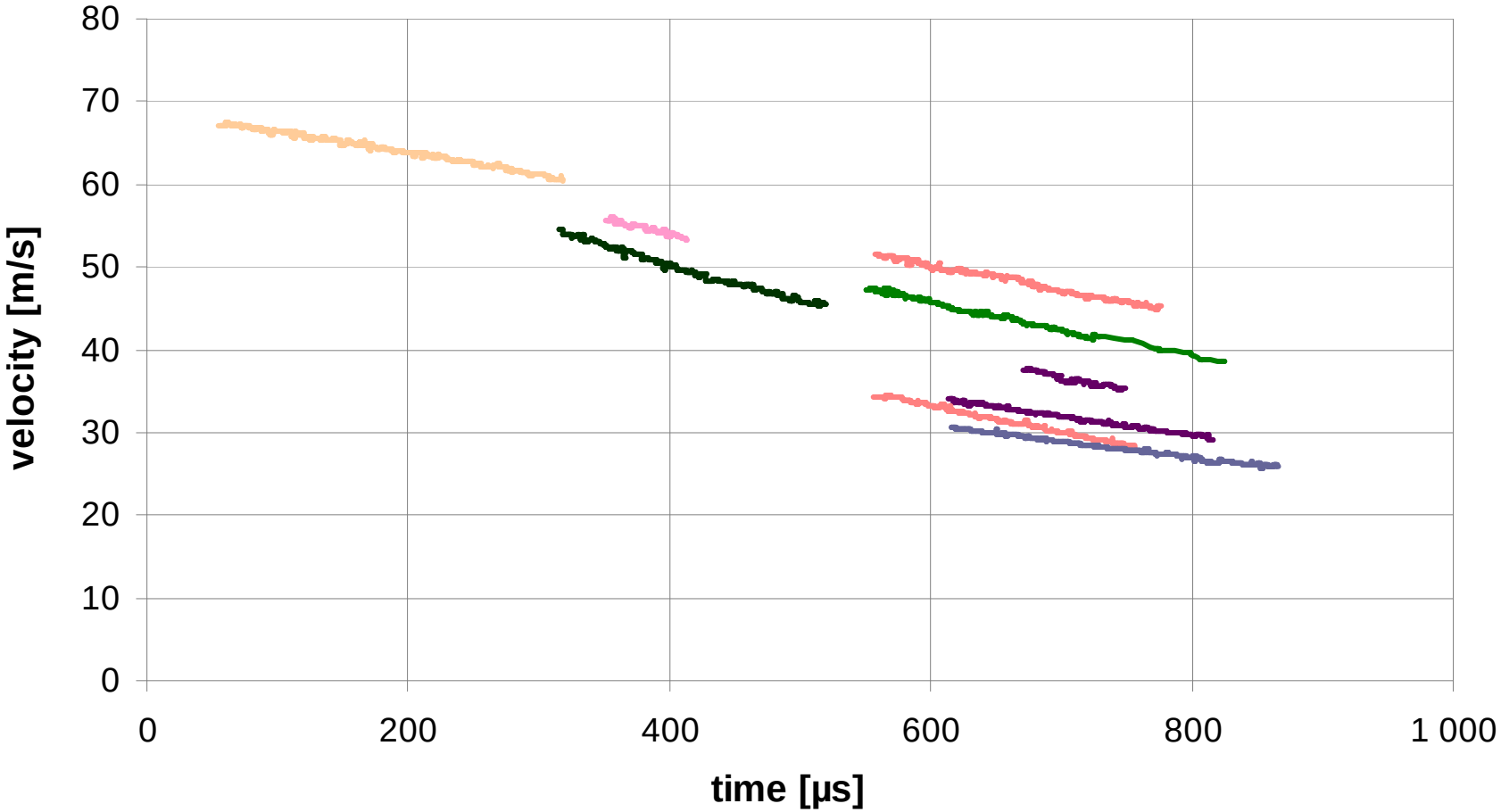


PDV SPECTROGRAM : TRAJECTORY EXTRACTION
SHOT 24, Cu 10 µm, 21.9 mg, PDV1 (Frontal)



EXTRACTED TRAJECTORIES
SHOT 24, Cu 10 µm, 21.9 mg, PDV1 (Frontal)

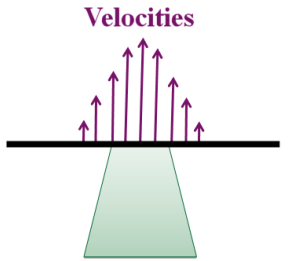
9 trajectories of the time-velocity spectrogram.



SIMPLIFIED ANALYTICAL MODEL: MOVEMENT EQUATION. DRAG FORCE ON SPHERICAL PARTICLES, WITH INTERMEDIATE REYNOLDS NUMBER.

Hypothesis:

- identical and spherical particles,
- particles independent on each other,
- velocities perpendicular to the static surface,
- (quasi) same initial moving time (less than 1 µs),
- no air shock wave,
- no ablation.



$$m.\frac{dv}{dt} = -\frac{C_D.A.\rho_{air}.(v-u_{gas}).|v-u_{gas}|}{2}$$

$$Re = \frac{\rho_{gas}.|v-u_{gas}|.d_p}{\mu_{gas}}$$

$$u_{gas} = 0$$

$$C_D = \frac{24}{Re} + \frac{4}{Re^{1/3}} \quad \text{if} \quad Re \le 1000$$

$$C_D = 0.424 \quad \text{if} \quad Re \ge 1000$$

$$v(t) = \frac{1}{\left[\left(v_0{}^{-2/3} + C\right)e^{2/3 B(t-t_0)} - C\right]^{3/2}}$$

$$B = \frac{18\,\mu_{gaz}}{\rho_{metal}\,d_p{}^2} \qquad C = \frac{\rho_{gaz}}{6}\left(\frac{d_p}{\mu_{gaz}}\right)^{2/3}$$

Non-linear optimization problem

$$\frac{1}{v(t)} = \frac{1}{v_0} + K.(t-t_0) \qquad K = \frac{0.318}{d_p}.\frac{\rho_{gas}}{\rho_{metal}}$$

- *t, v(t)*: Experimental data (angle corrected if tilted PDV axis)
- *B,C*: Intermediate variables
- V_0, d_p: Adjustement variables (initial velocity, diameter)
- t_0, μ_{gas}, ρ_{metal}, ρ_{gas}: parameters (break-out time, dynamic viscosity, densities)

EXTRACTED TRAJECTORIES AND MODEL SOLUTIONS
SHOT 24, Cu 10 µm, 21.9 mg, PDV1 (Frontal)

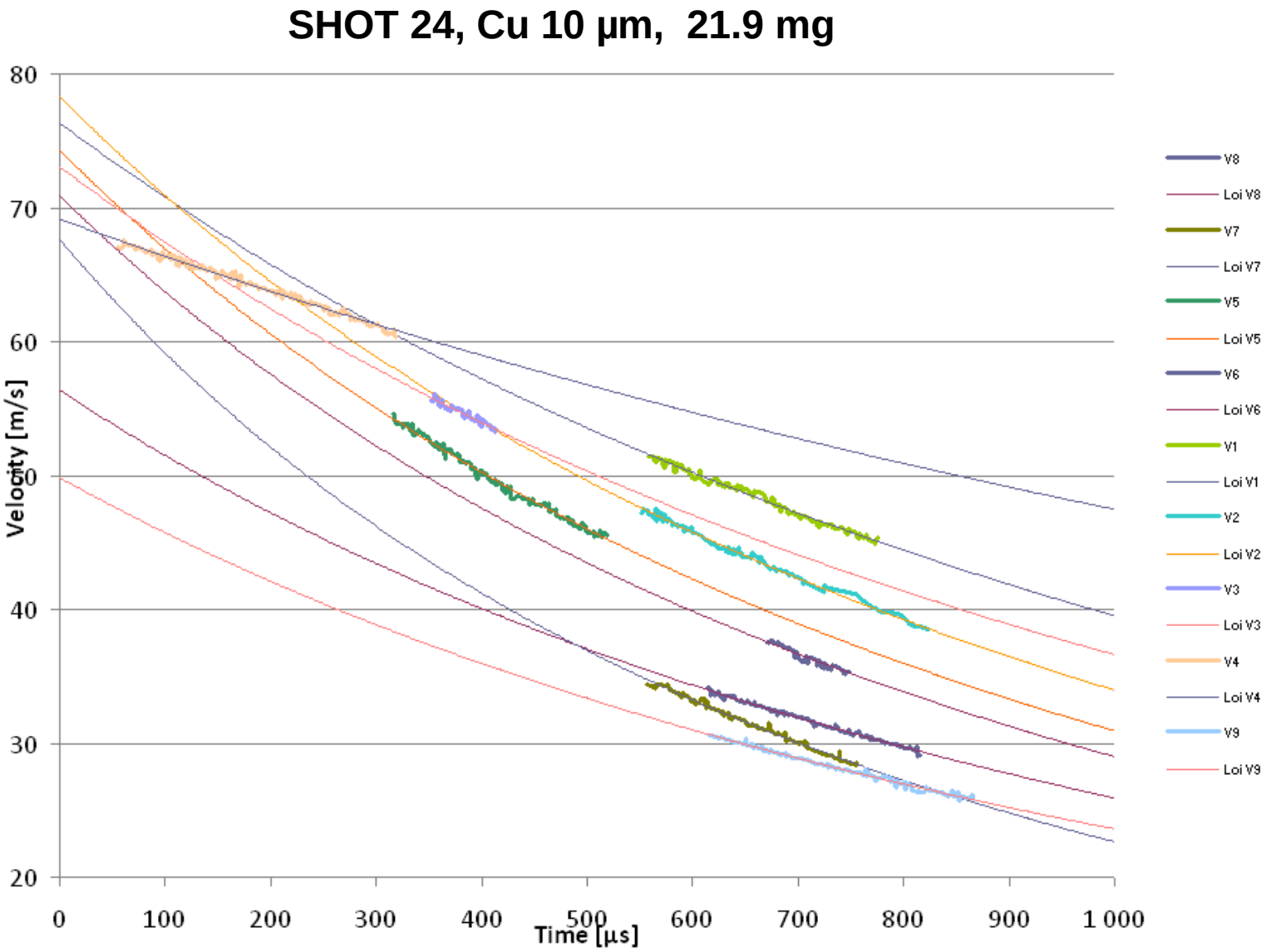
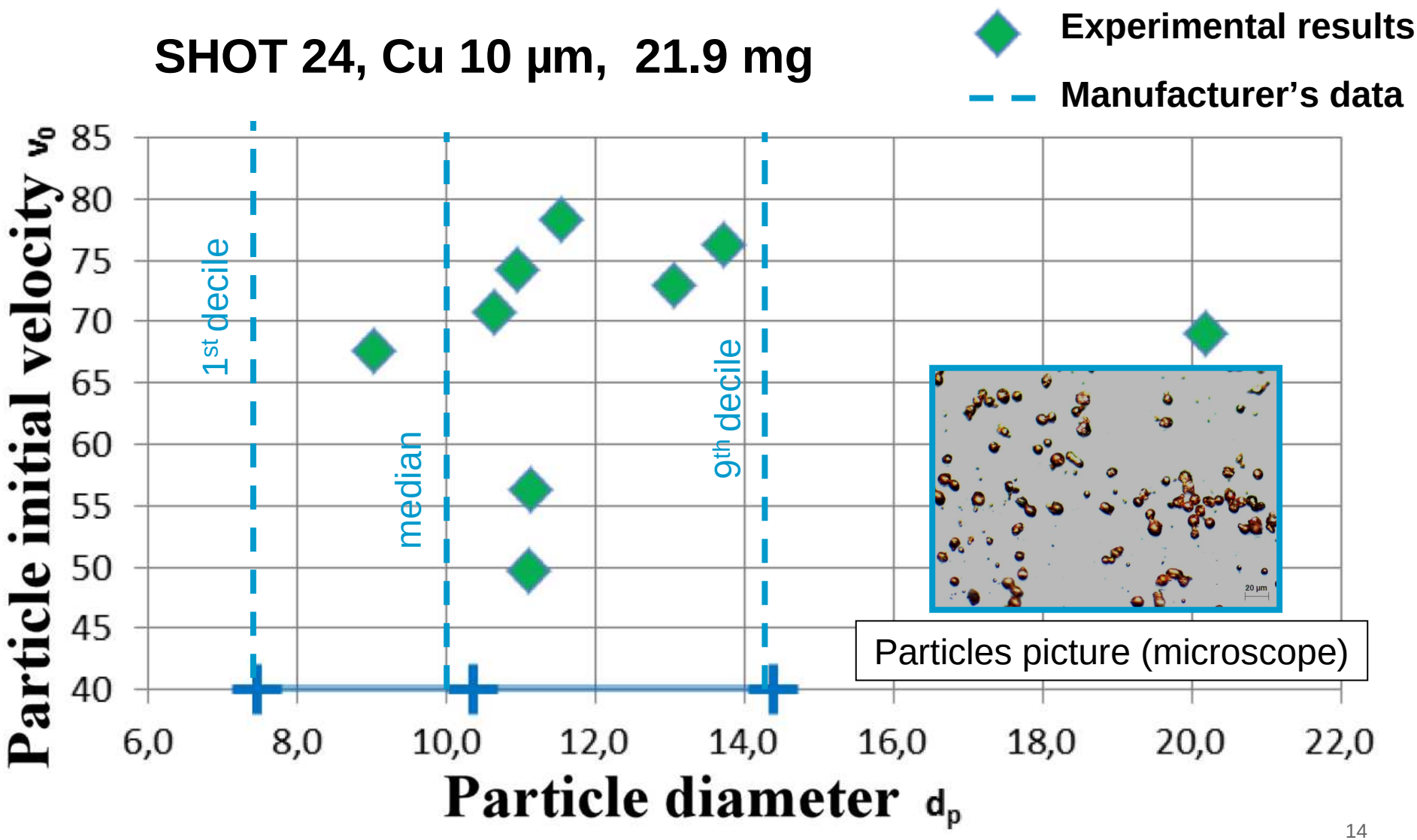
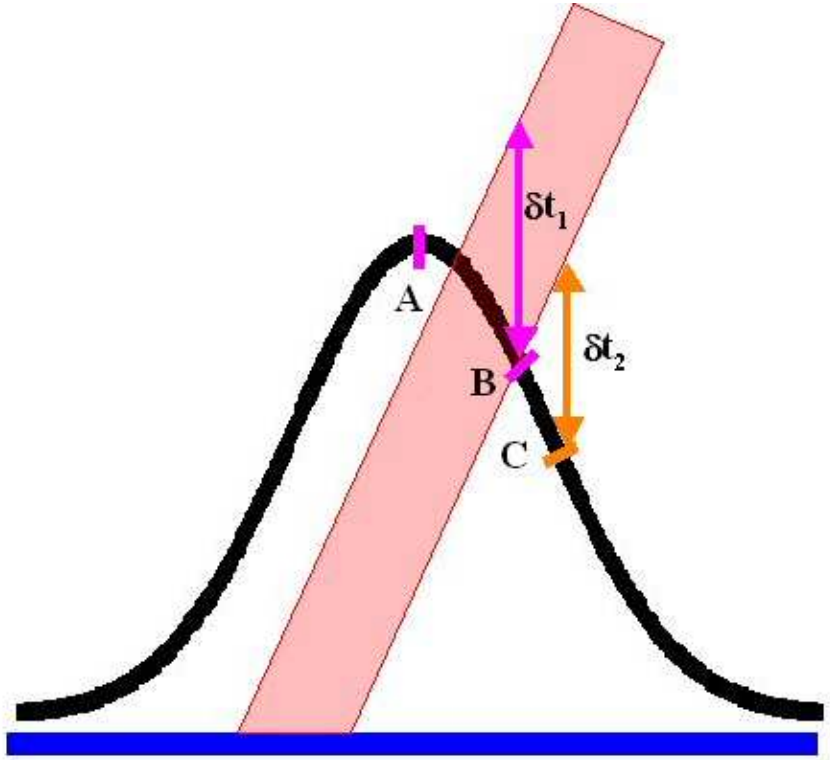


DIAGRAM (v_0, d_P)
SHOT 24, Cu 10 µm, 21.9 mg, PDV1 (Frontal)

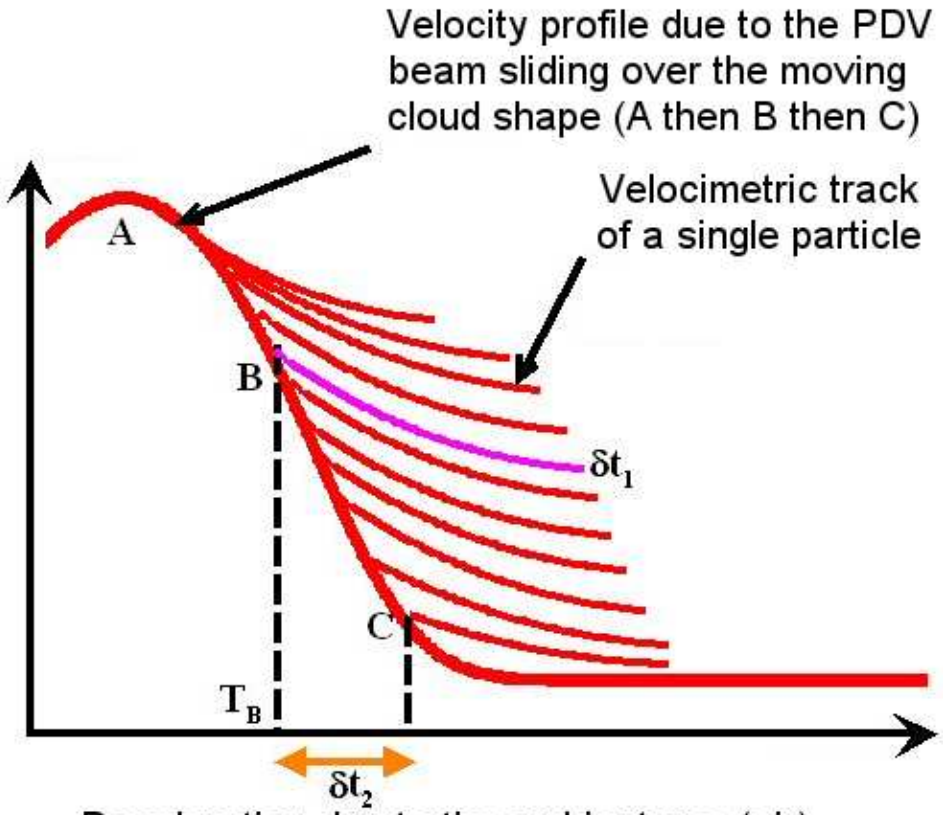


PARTICLE CLOUD AND TILTED PDV LASER BEAM

Tilted PDV laser beam

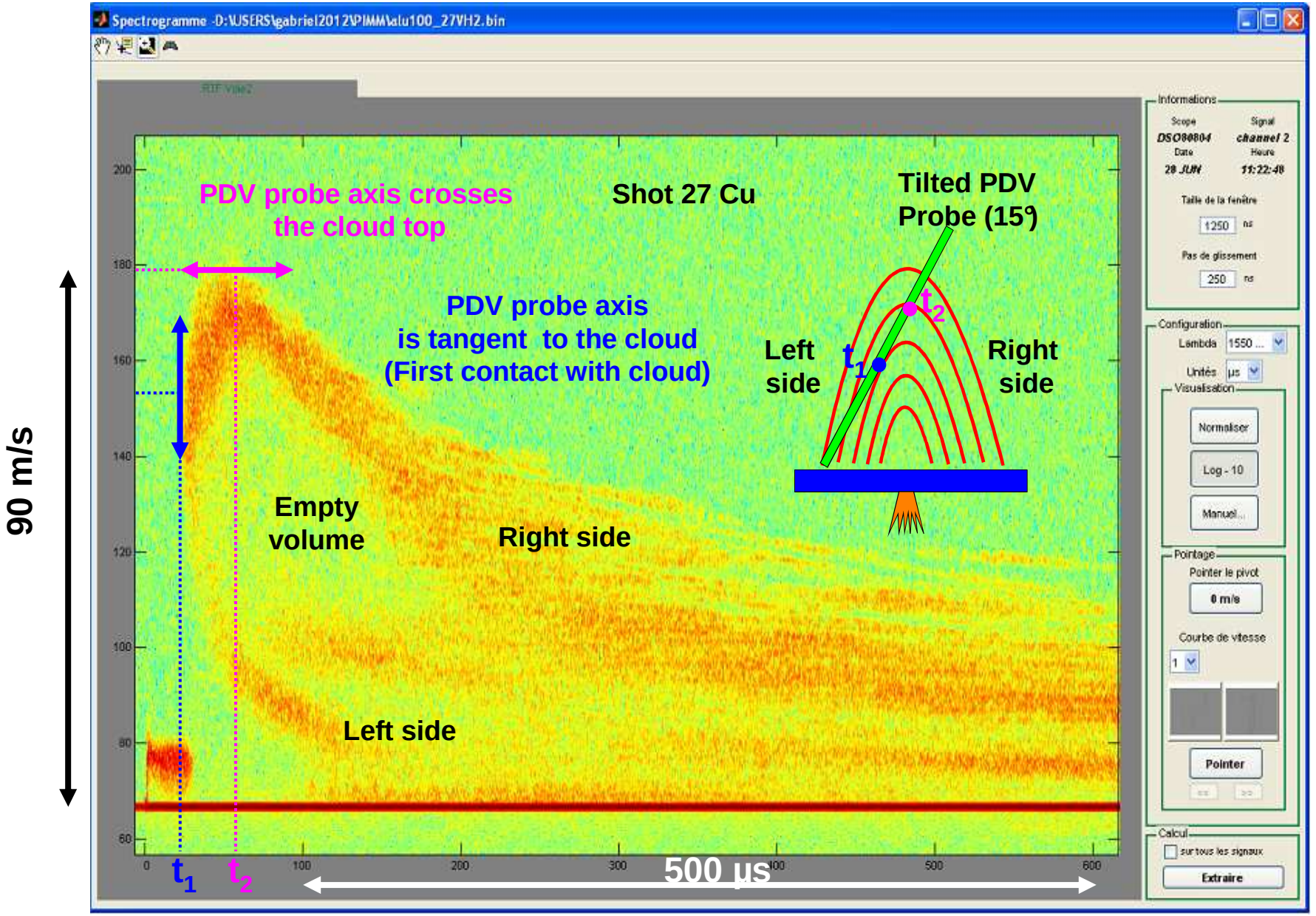


Particle cloud shape at T_B



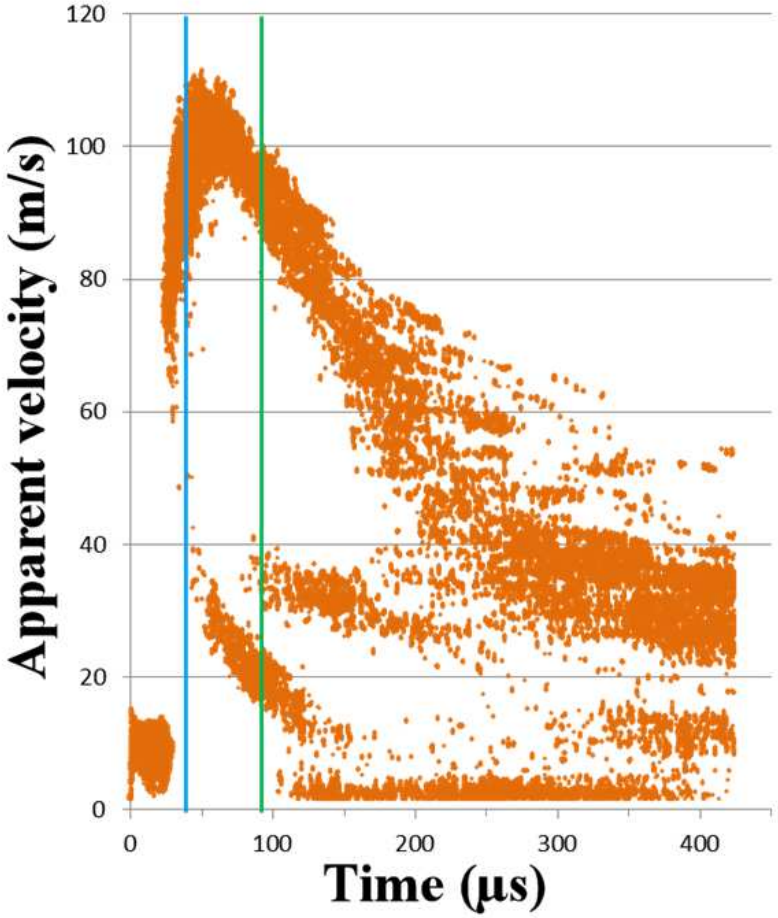
Deceleration due to the ambient gas (air)

CORRESPONDING SPECTROGRAM

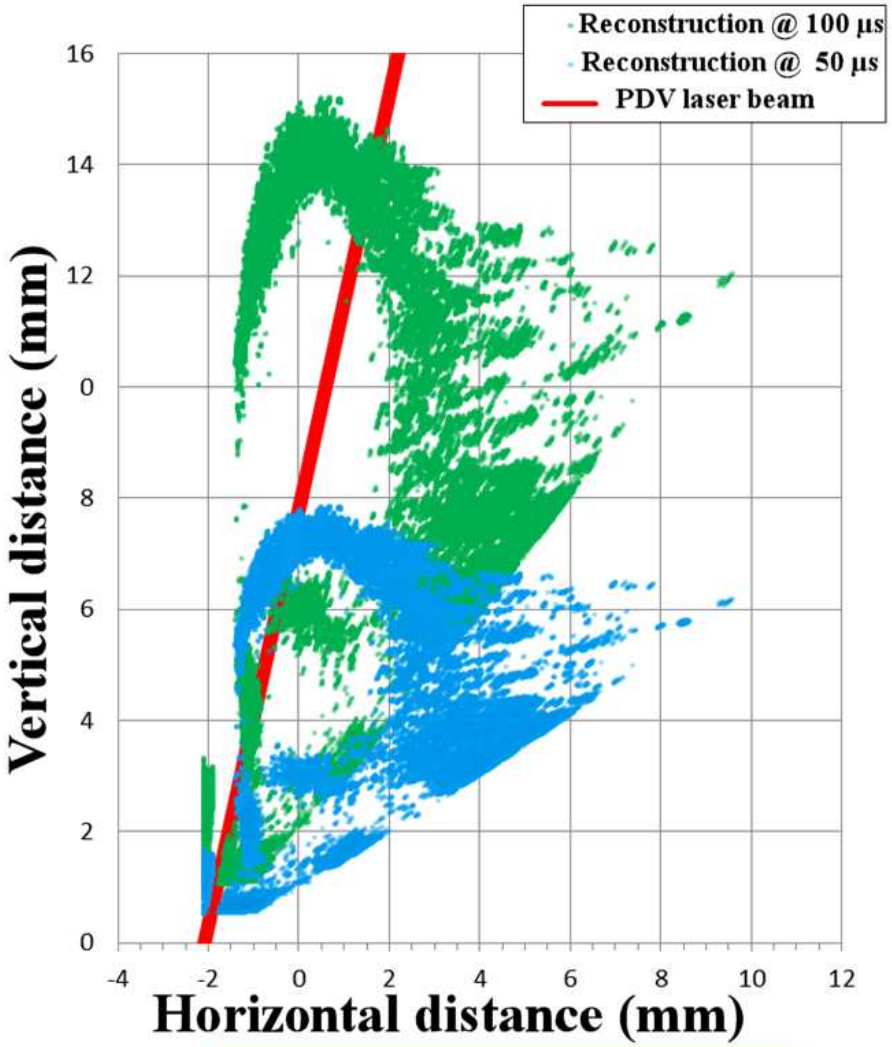


CLOUD GEOMETRICAL SHAPE RECONSTRUCTION FROM THE TILTED PDV PROBE SIGNAL

SHOT 27, Cu 10 µm, 11.6 mg



Spectrogram



Reconstruction *x*, *z*

CONCLUSION

- Particle launching demonstration with laser,
- Derive particle diameter (a few µm) thanks to a simplified model,
- Velocities are still low (100 m/s) compare to those observed in HE experimentations (a few km/s).

►HE shots scheduled with:
Calibrated particles,
Particle produced by a HE shock loaded plates.
►Model:
Shock wave in gas: (re-acceleration, …),
Ablation in gas,
…..

Thank you for your attention.