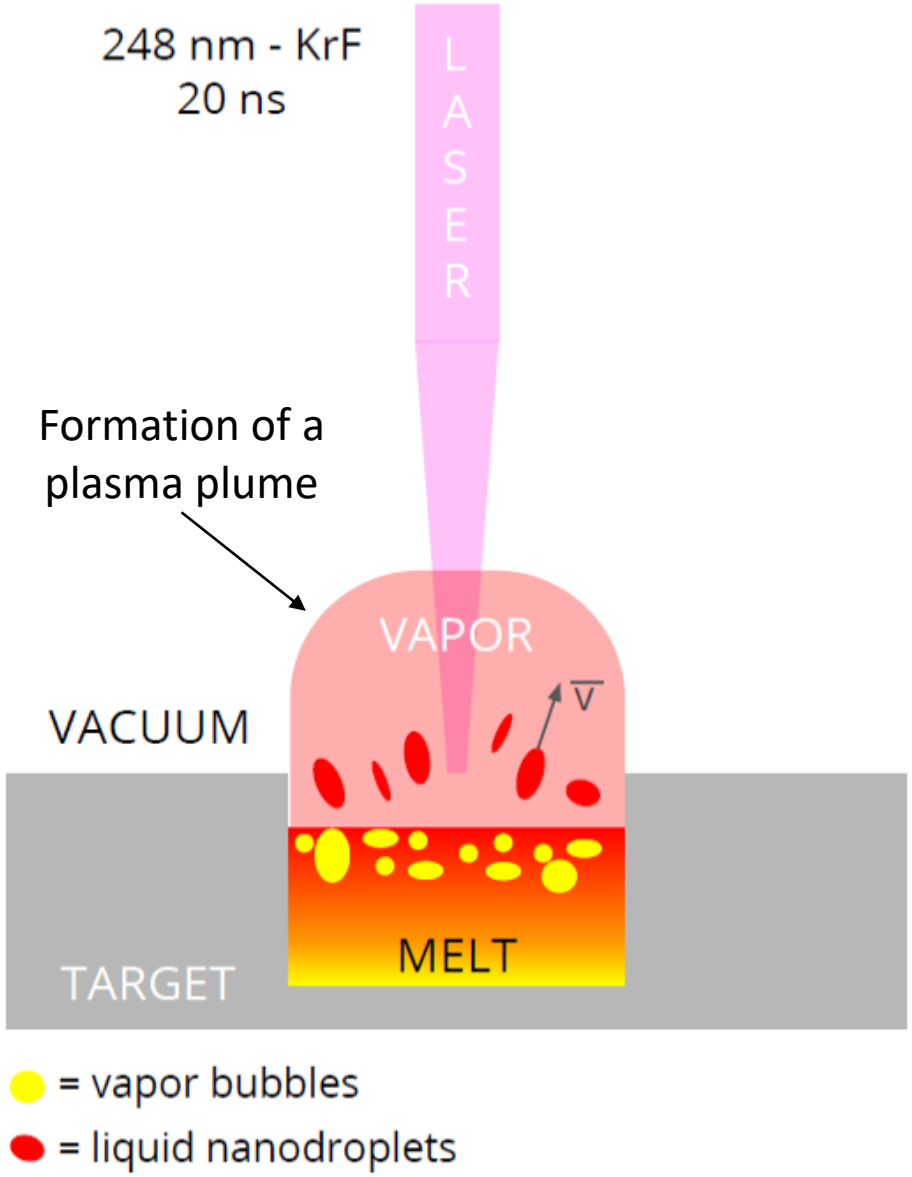
Laser ablation propulsion

PhD workshop, 02/12/20

Pietro Battocchio

Laser Ablation



An **intense (GW/cm²)** and **short (ns)** laser pulse irradiates the target material

Some mass is removed from irradiated area

Metals
Ejection of vapor and liquid nanodroplets

Polymers
Ejection of decomposition products: gas and chain fragments

Ablation mechanisms

Two mass removal mechanisms are involved:

1. **Fast vaporization** or **decomposition** of the material

2. **Phase explosion**

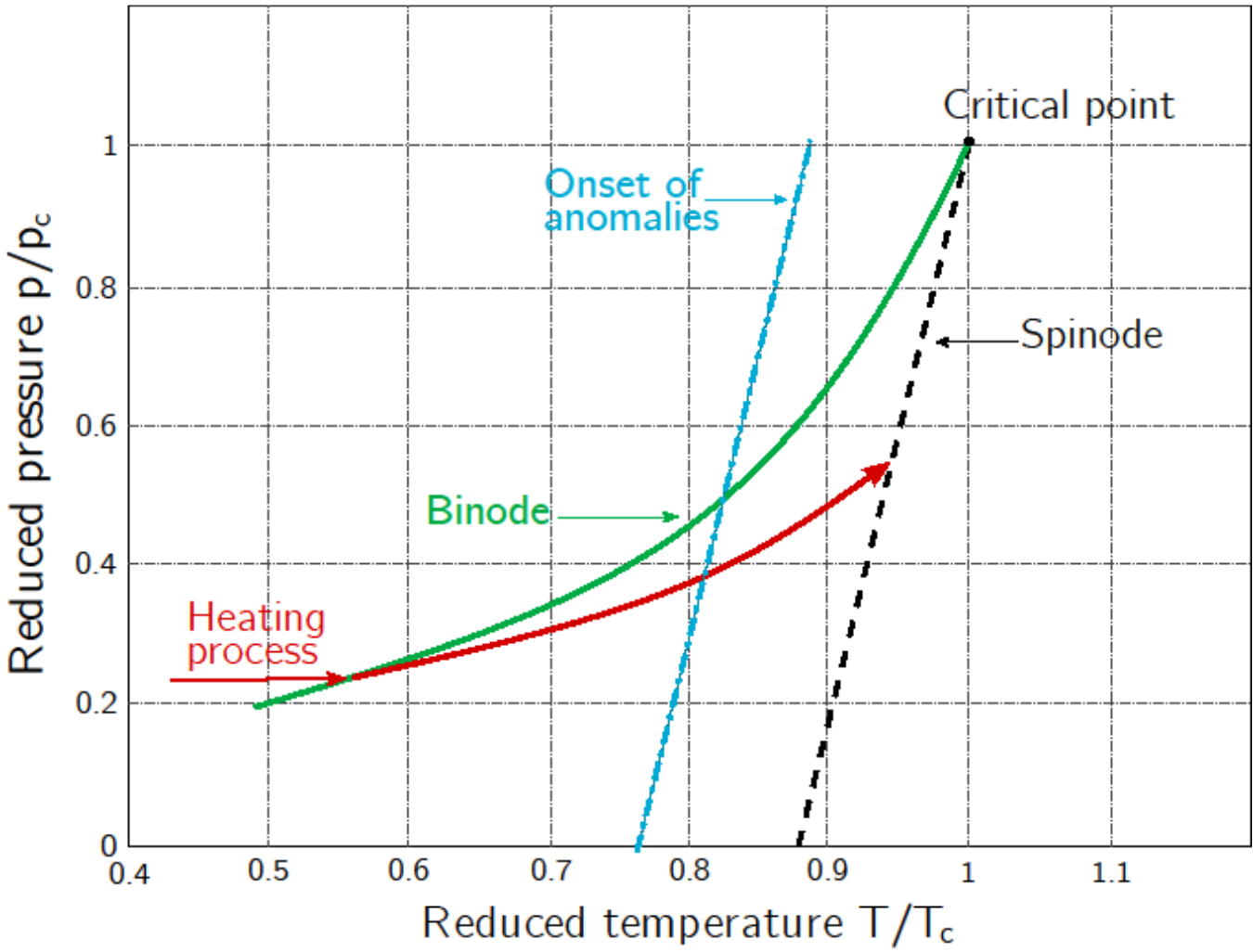
As T ~ T_c (critical temperature), extreme thermodynamic conditions

↓

Homogeneous nucleation of vapour bubbles

↓

Ejection of liquid nanodroplets



Laser ablation propulsion

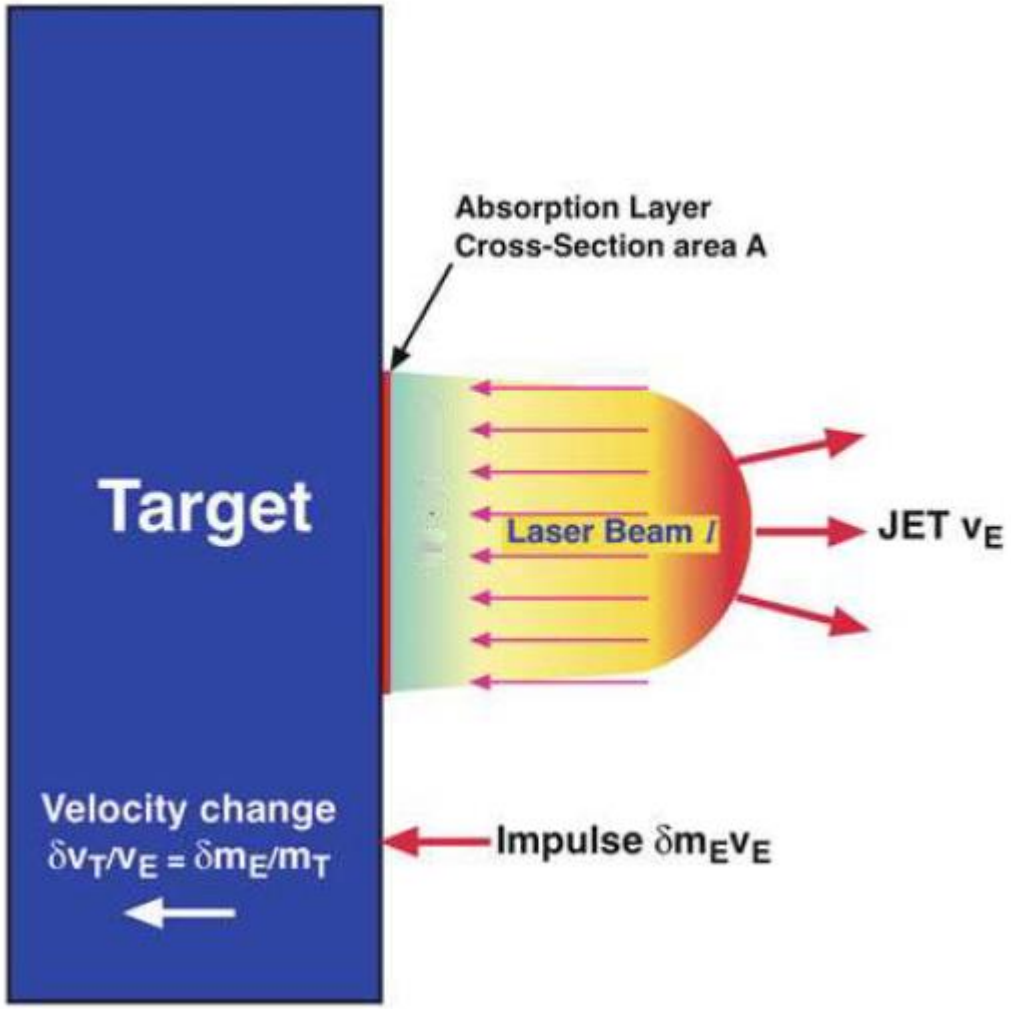
Small ejected mass (μg) leaves the material at **very high exhaust velocity** (km/s)

Momentum conservation

$$m_{target}\Delta v_{target} = m_{ejected}v_{exhaust} \sim \mu N\ s$$

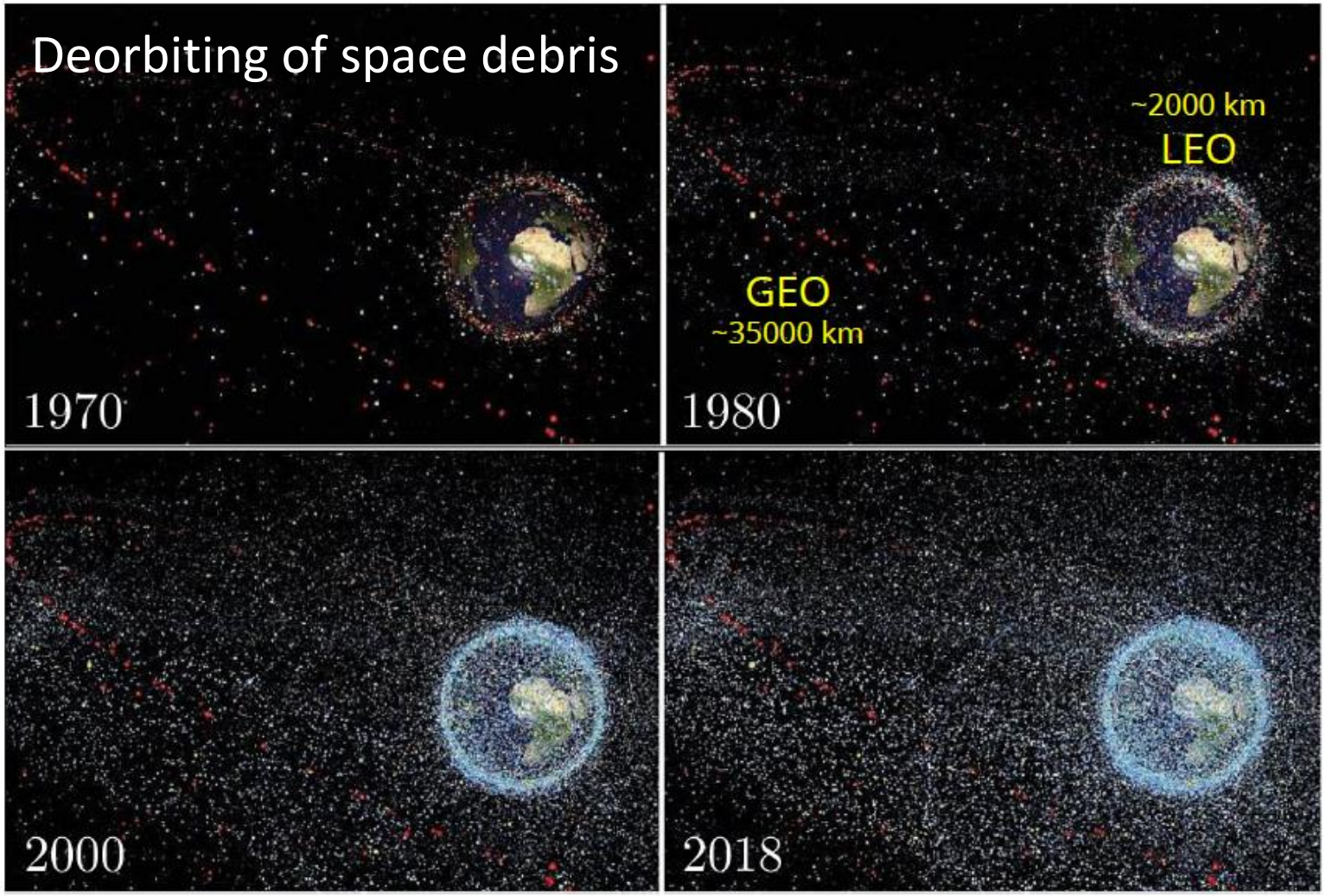
Thrust generation on target material

Laser ablation can be exploited as a **propulsion system**



Applications of laser ablation propulsion

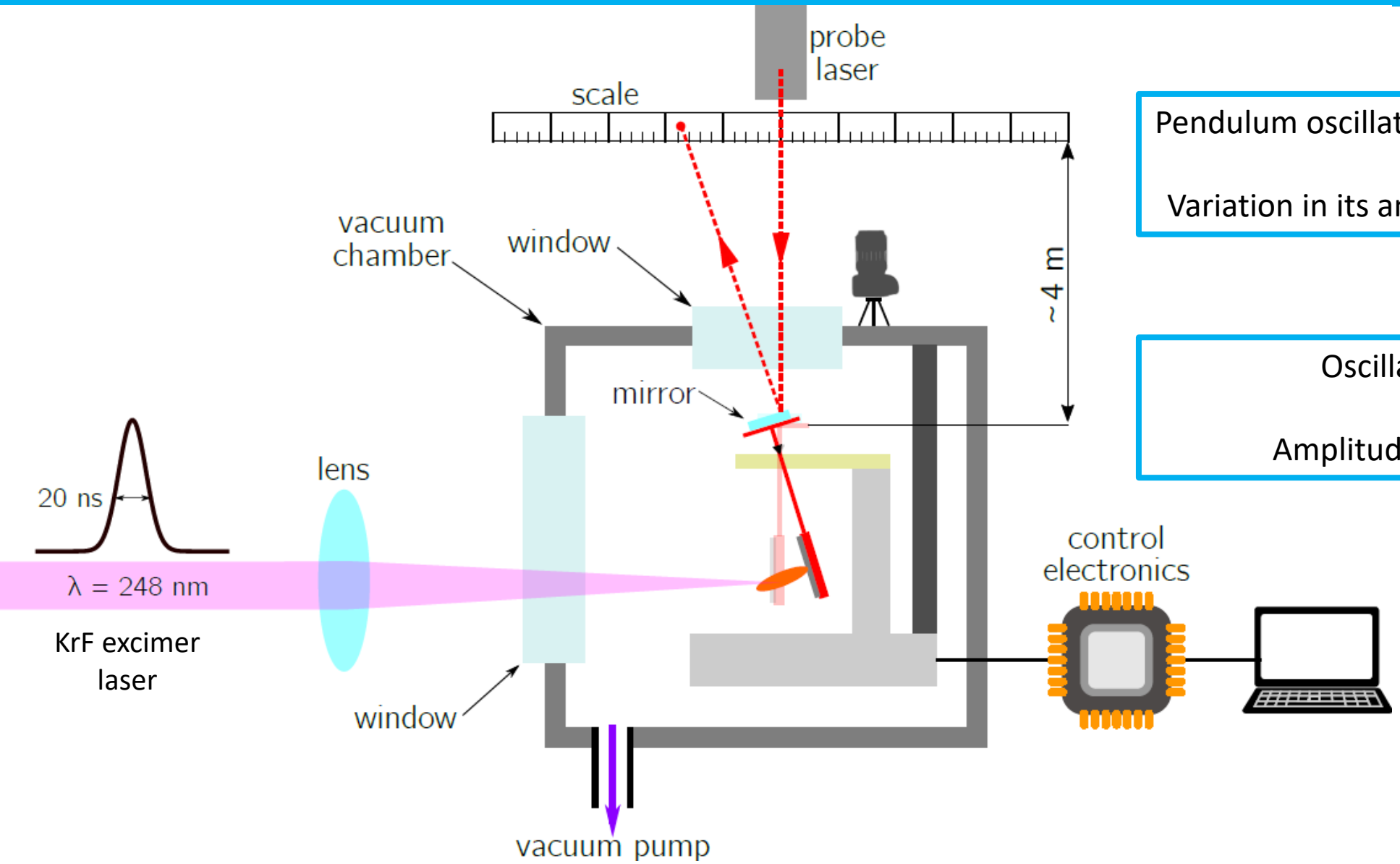
Two main applications in the space field:



Power storage (laser) far from fuel (target material on board)

Solution to mass and power limitation

Experimental apparatus for impulse measurements



Pendulum oscillates before and after impulse

↓

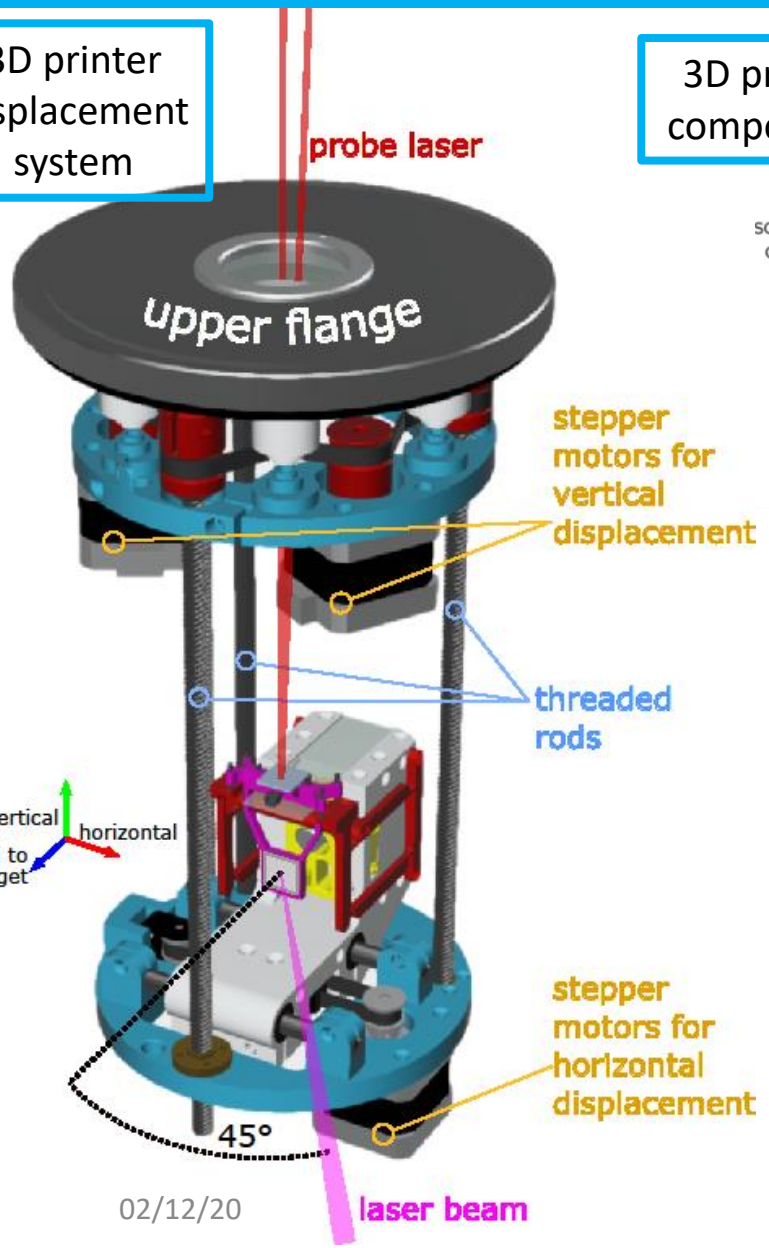
Variation in its angular velocity is measured

Oscillation angle ~ 1°

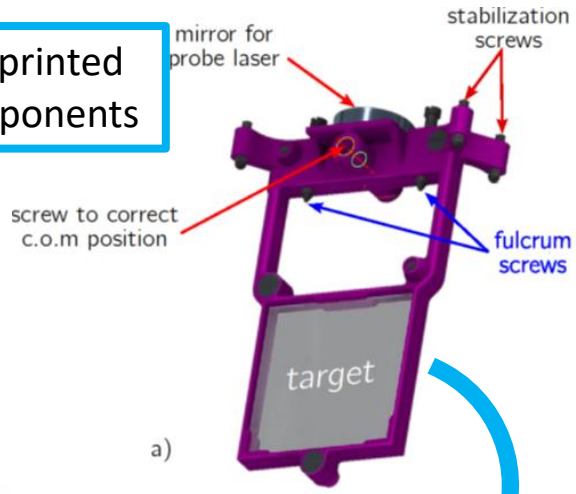
Amplitude on scale ~ 10 cm

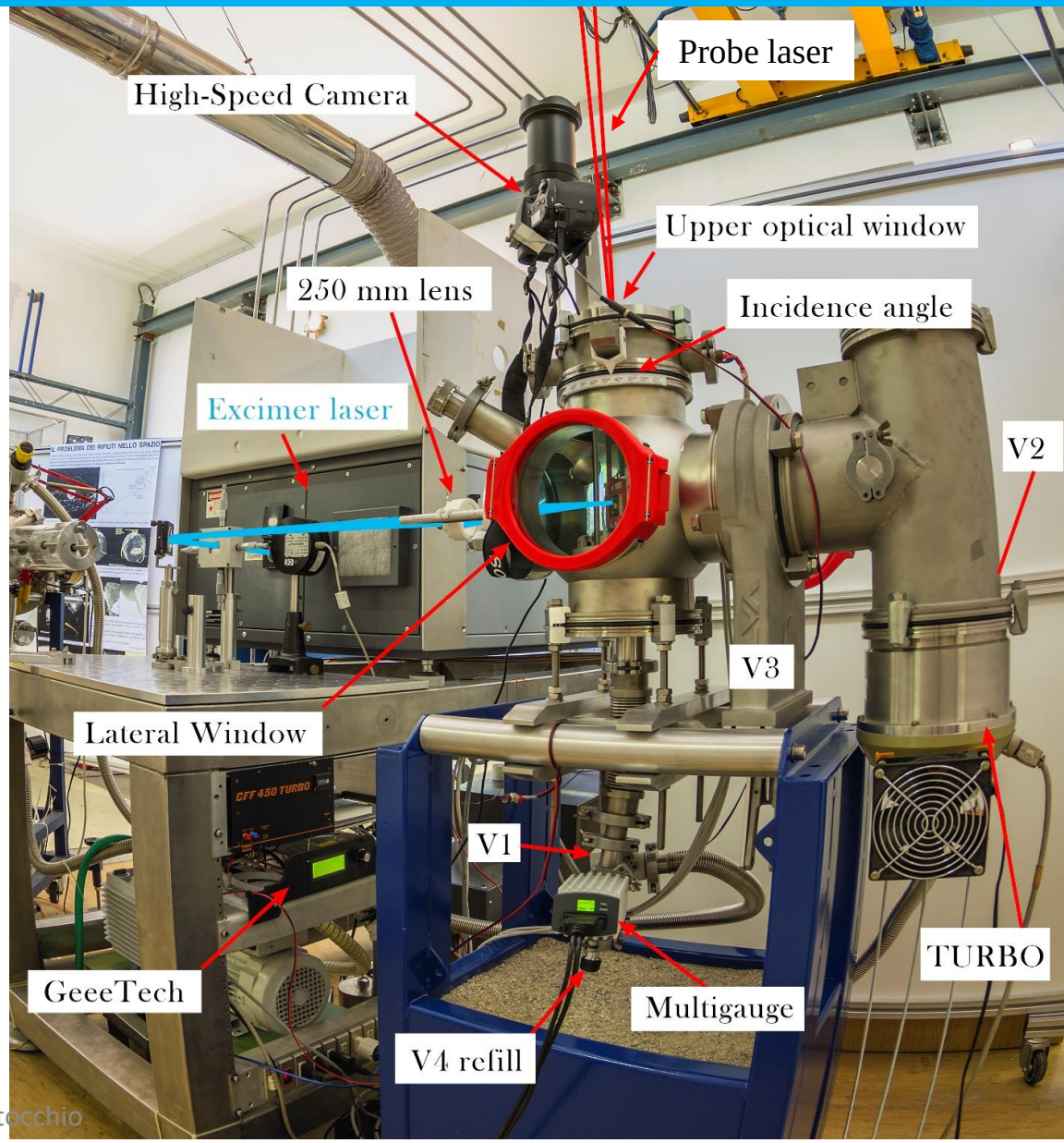
Experimental apparatus for impulse measurements

3D printer displacement system

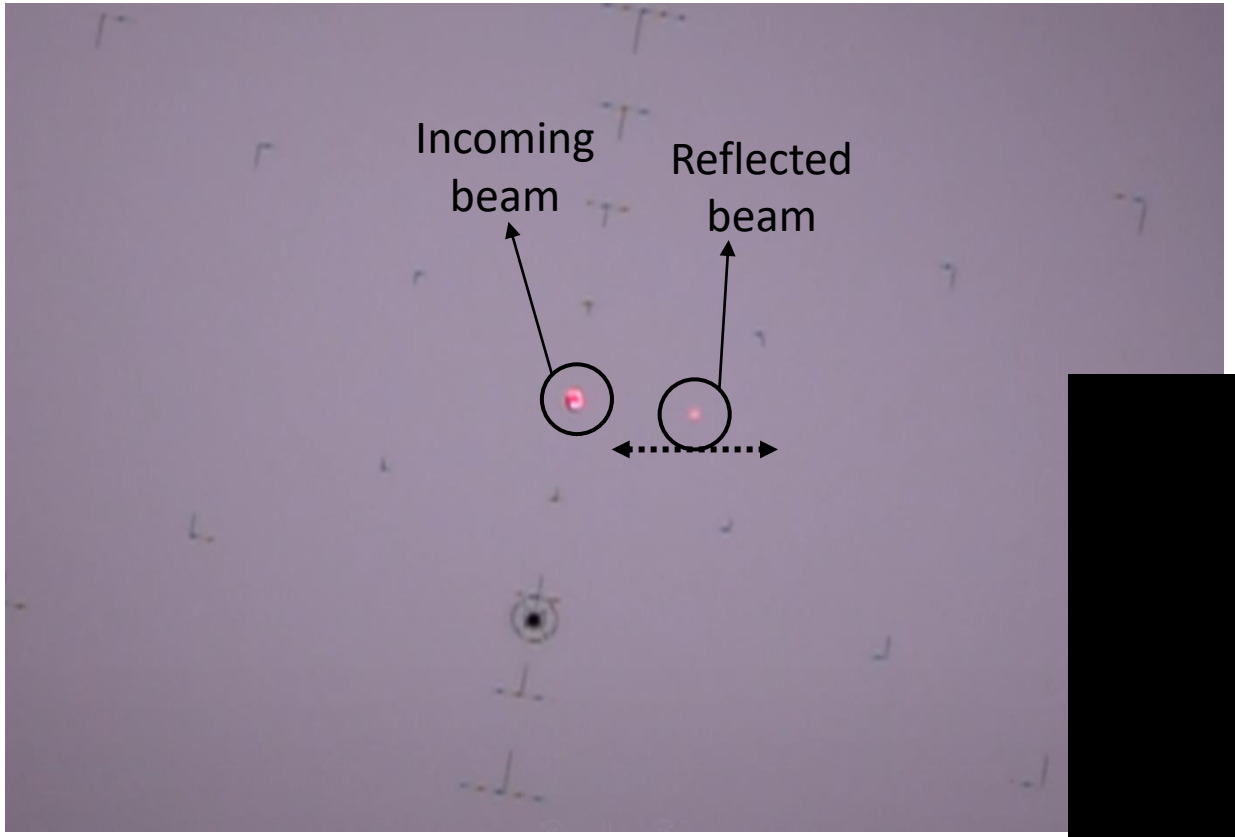


3D printed components





Impulse measurement: data analysis



High speed (1000 fps) video of reflected probe laser

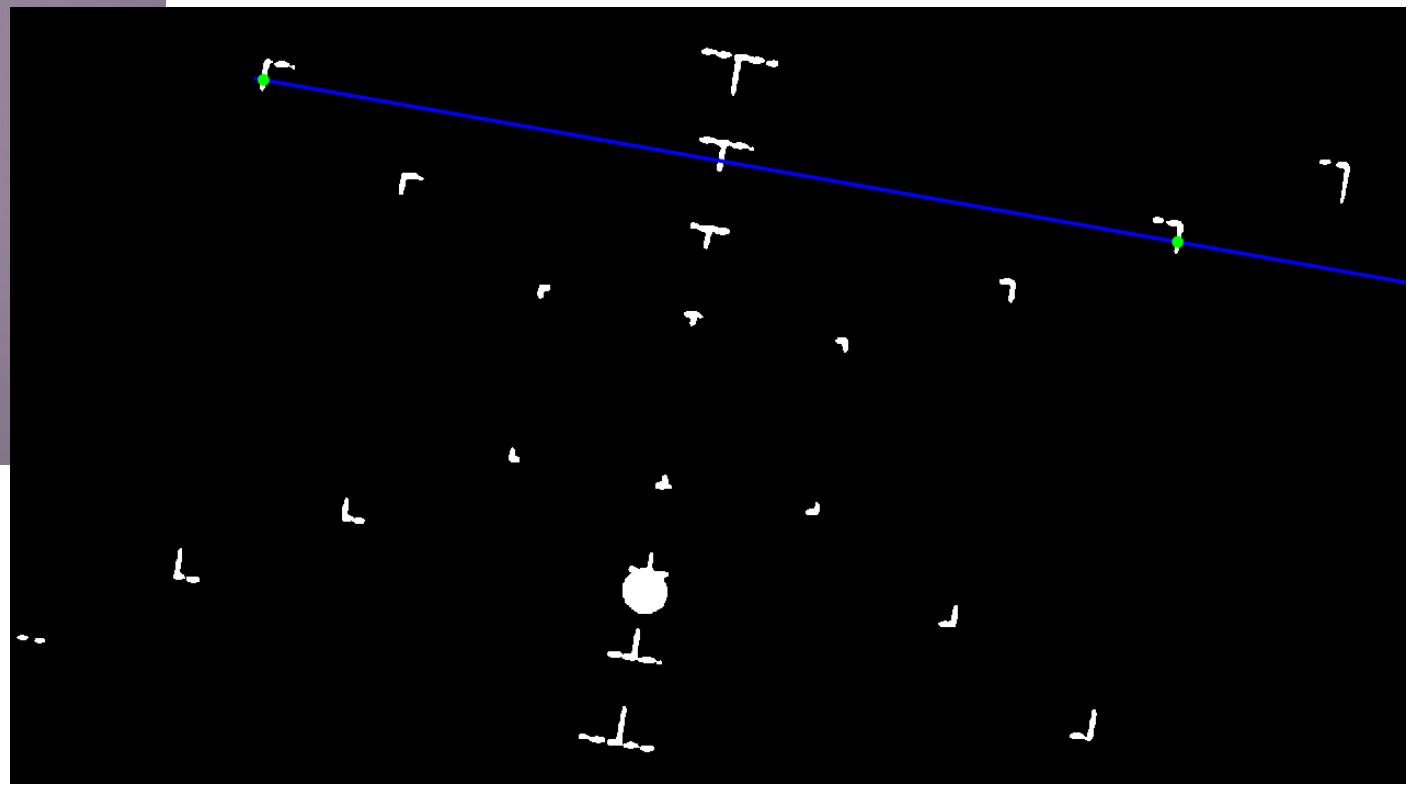


Image analysis: scale calibration

Impulse measurement: data analysis

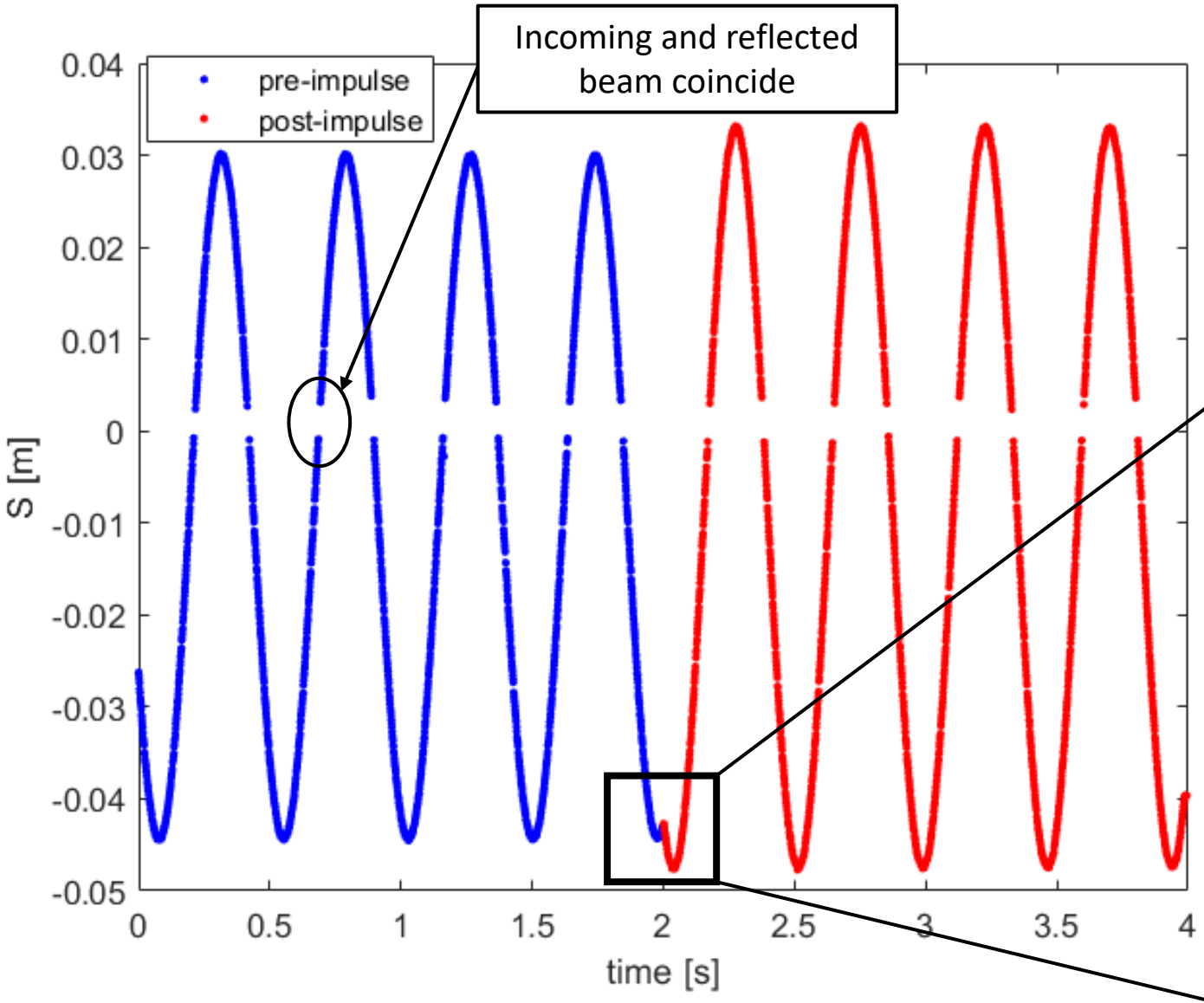
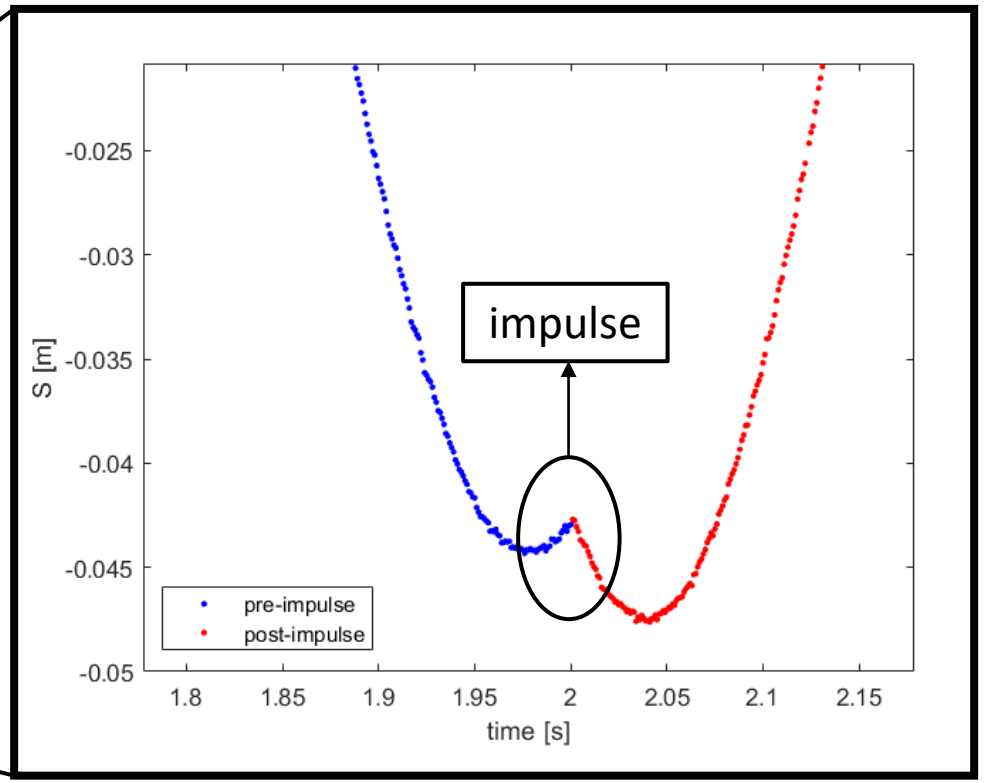


Image analysis: traking the motion of reflected probe laser



Impulse measurement: data analysis

Displacement of reflected spot S(t)

Mass of the pendulum (m), c.o.m. position (d), arm (r)

Oscillation angle $\theta(t)$

Impulse instant t_{imp}

Period of oscillation T

Angular velocity before and after impulse

$$\omega(t) = \frac{\mathrm{d}\theta(t)}{\mathrm{d}t}$$

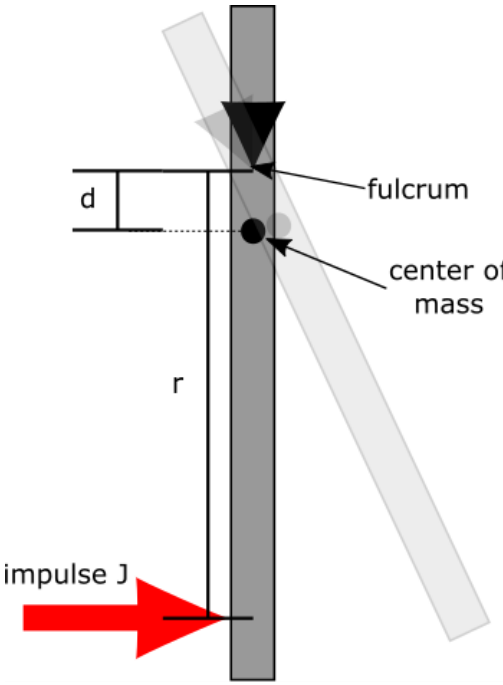
Moment of inertia I

Variation in angular velocity $\Delta\omega$ at t_{imp}

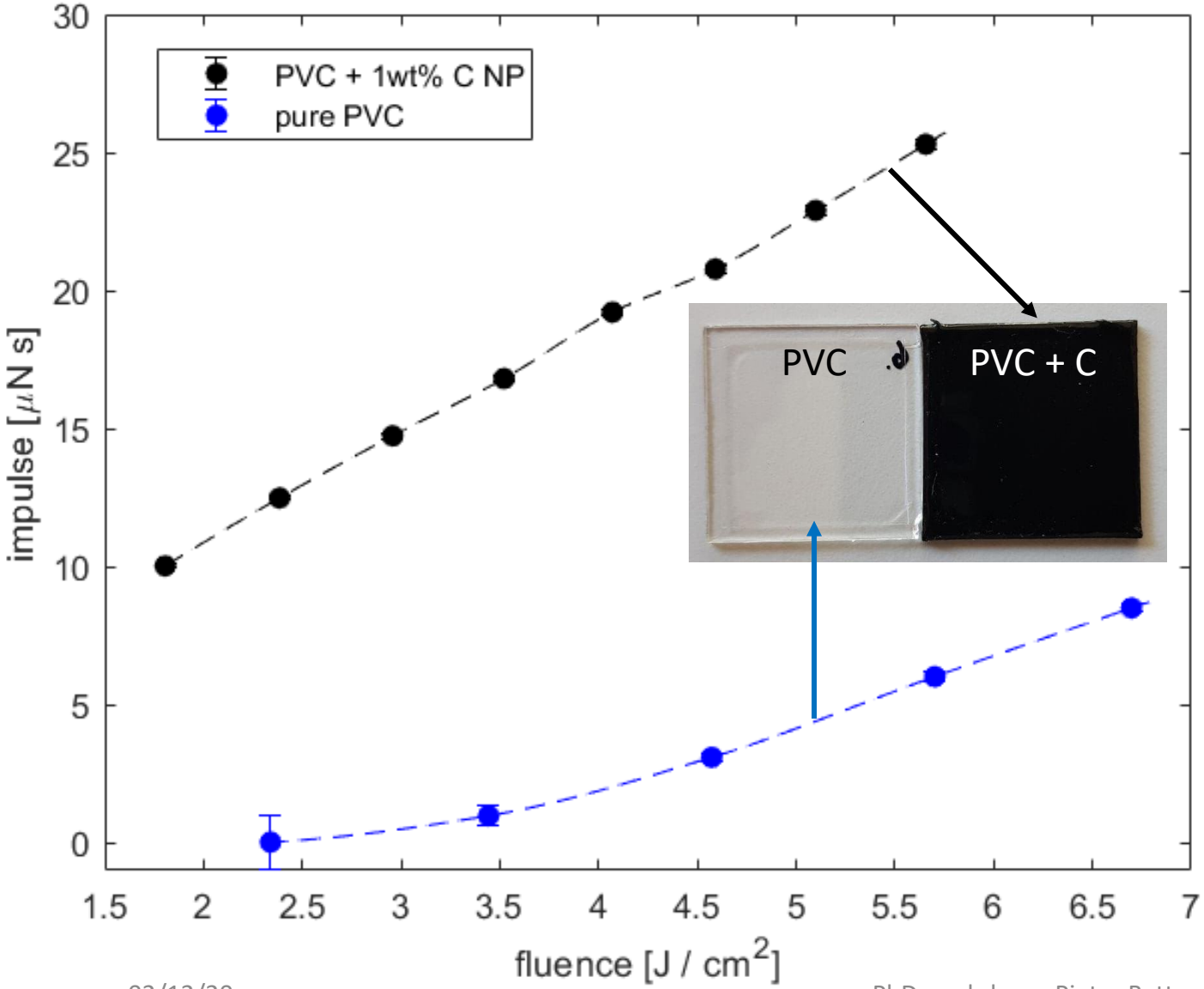
Generated impulse:

$$J = \frac{I\Delta\omega}{r}$$

Resolution: 50 nN s



Impulse measurments



Impulse measurements on poly (vinyl chloride) (PVC)

Materials can be designed to generate higher impulse

↓

Addition of carbon nanoparticles in PVC as absorbers of laser radiation

Future works

Tune polymer properties to understand their role in impulse generation

- Mix of PVC and PSS

Systematic study of propulsion performances of Aluminum

- Impulse generated at different laser incidence angles: role of plasma shielding
- Measure of ejected mass during impulse generation

Thank you!