OPTICAL DESIGN OF A **MINIATURISED LASER ALTIMETER** IMPLEMENTING **SINGLE-PHOTON COUNTING** DETECTION FOR **TOPOGRAPHIC MAPPING** USING **SMALL SATELLITES**

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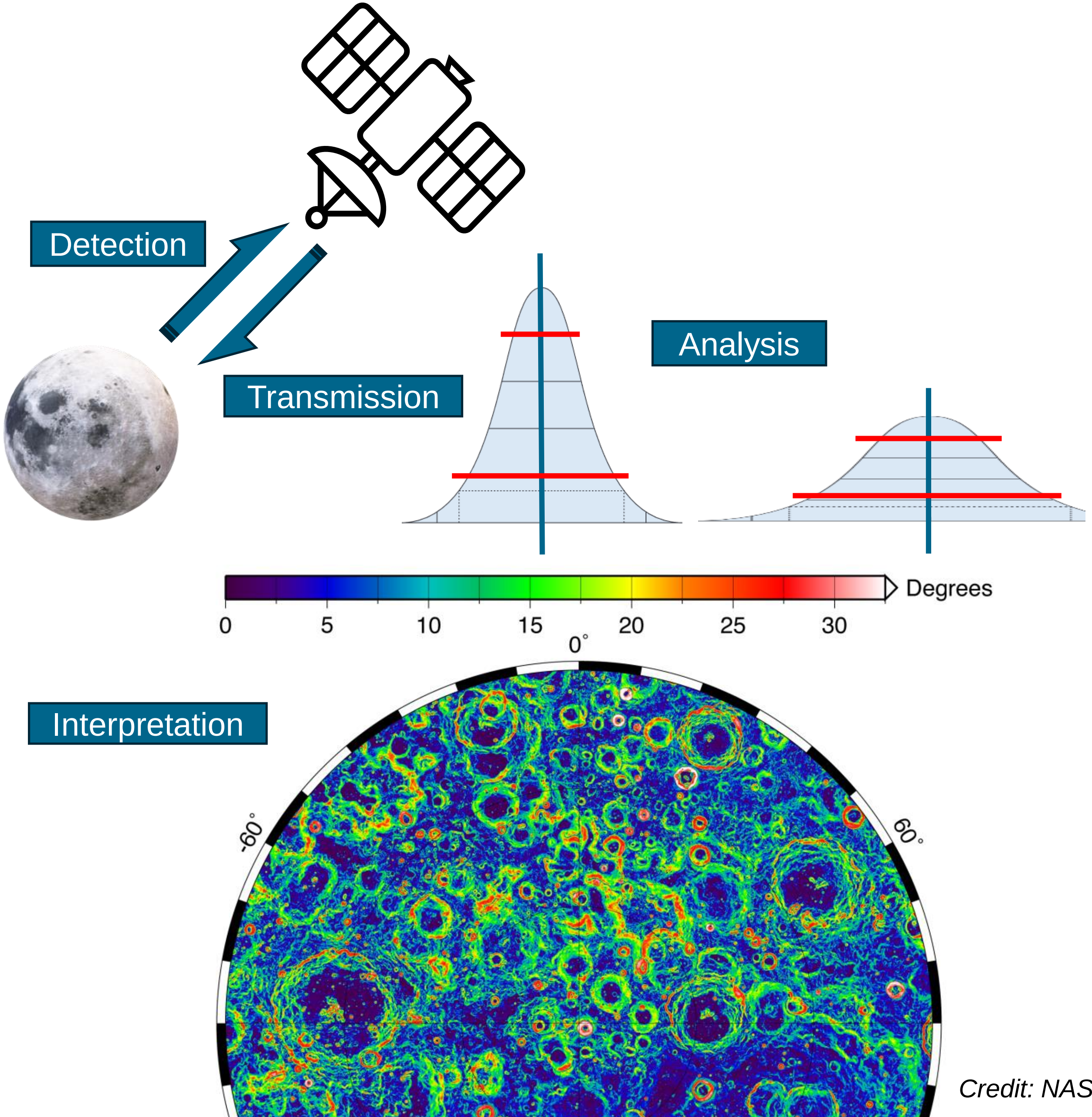
Measurement principle of laser altimeters



Credit: NASA, LOLA

Transmission and Detection

- Sending the **laser pulse** to the target
- Capturing the returning pulse with a **telescope**

Analysis

- **Identification** (threshold crossing) and **evaluation** (time of flight, pulse spread, pulse intensity)

Interpretation

- Global maps for altitude, terrain slope and roughness, and albedo

A widespread tool in space applications

Main applications:

Earth Observation

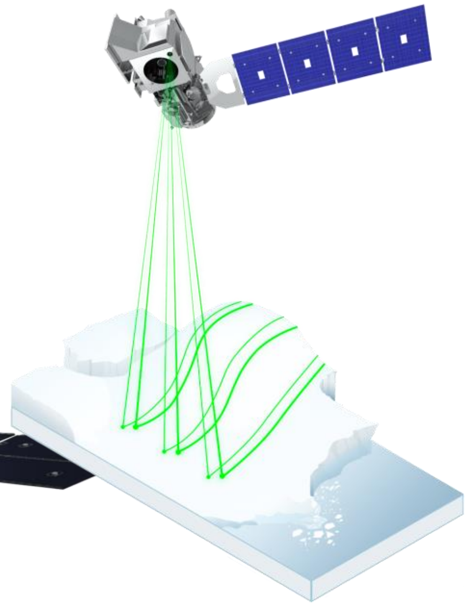
- Atmospheric and climate change monitoring

Navigation & Landing

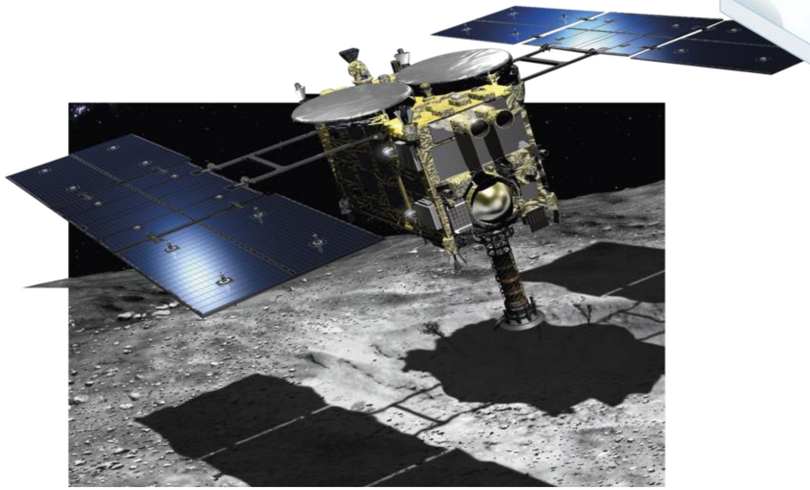
- Scanning and approaching small asteroids

Topographic Mapping

- Global map of rocky bodies



Credit: NASA, ICESat-2



Credit: DLR, Hayabusa 2

Credit: DLR, GALA

A widespread tool in space applications

Main applications:

Earth Observation

- Atmospheric and climate change monitoring

Navigation & Landing

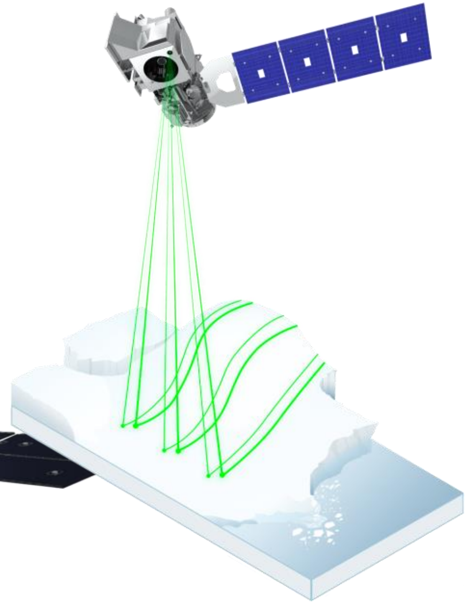
- Scanning and approaching small asteroids

Topographic Mapping

- Global map of rocky bodies

State-of-the-art technology:
BELA: BepiColombo Laser Altimeter
GALA: Ganymede Laser Altimeter

But why they cannot directly fit in microsatellites?



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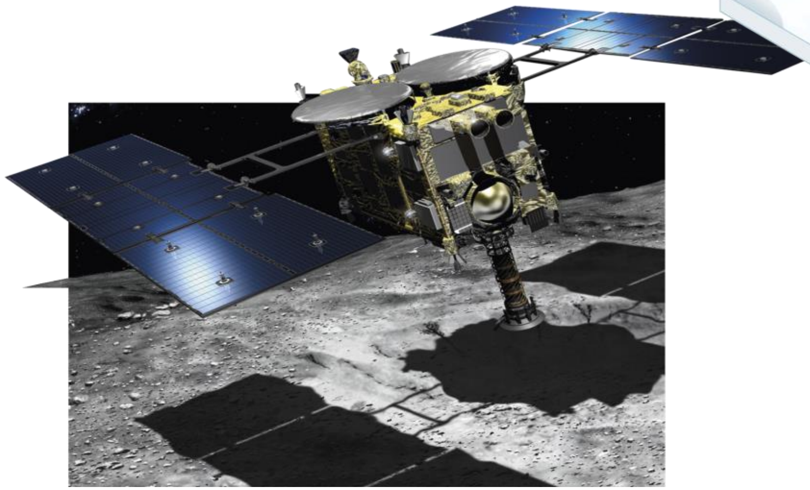


Credit: DLR, Hayabusa 2

Credit: DLR, GALA

Classic approach downsides

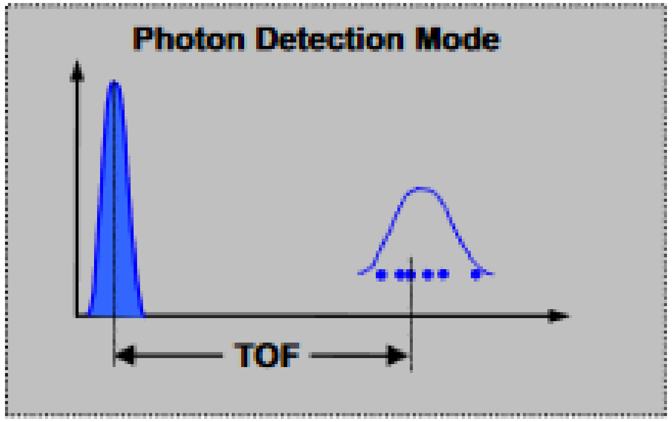
1. Detection approach

Waveform processing and analysis

1. Telescope size
2. Laser power consumption
3. Data handling system

SOLUTION

Single Photon Counting



Zhou et al. 2017

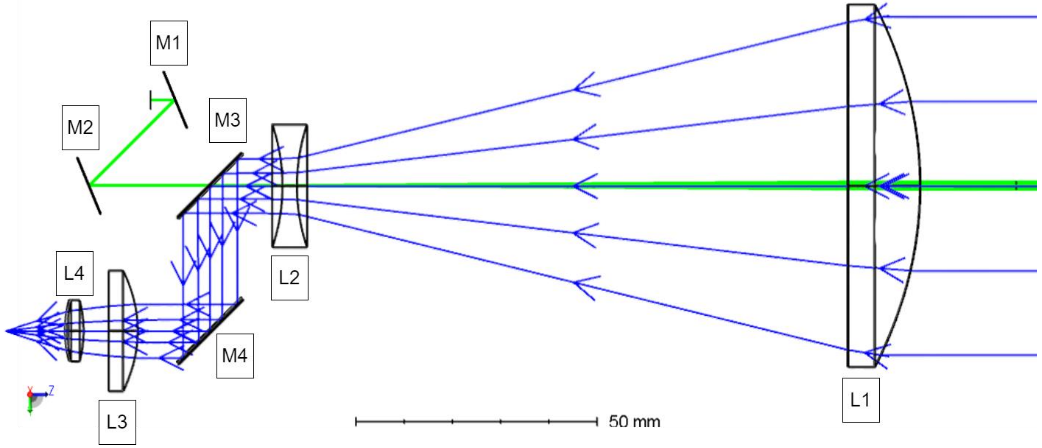
2. Optical Design

Transmitter-Receiver differentiation

1. Two optical systems
2. Volume allocation

SOLUTION

Transceiver Optics



Mission Proposal

SER3NE mission

- ESA **OSIP** call
- Selected for **Pre-Phase A** studies
- New Laser Altimeter (**NLA**) from the **SER3NE** mission proposal
- **Enhance the precision** of lunar topographic data
- Characterisation of **future landing sites**
- **6-12 U CubeSat**

Optical Design 1

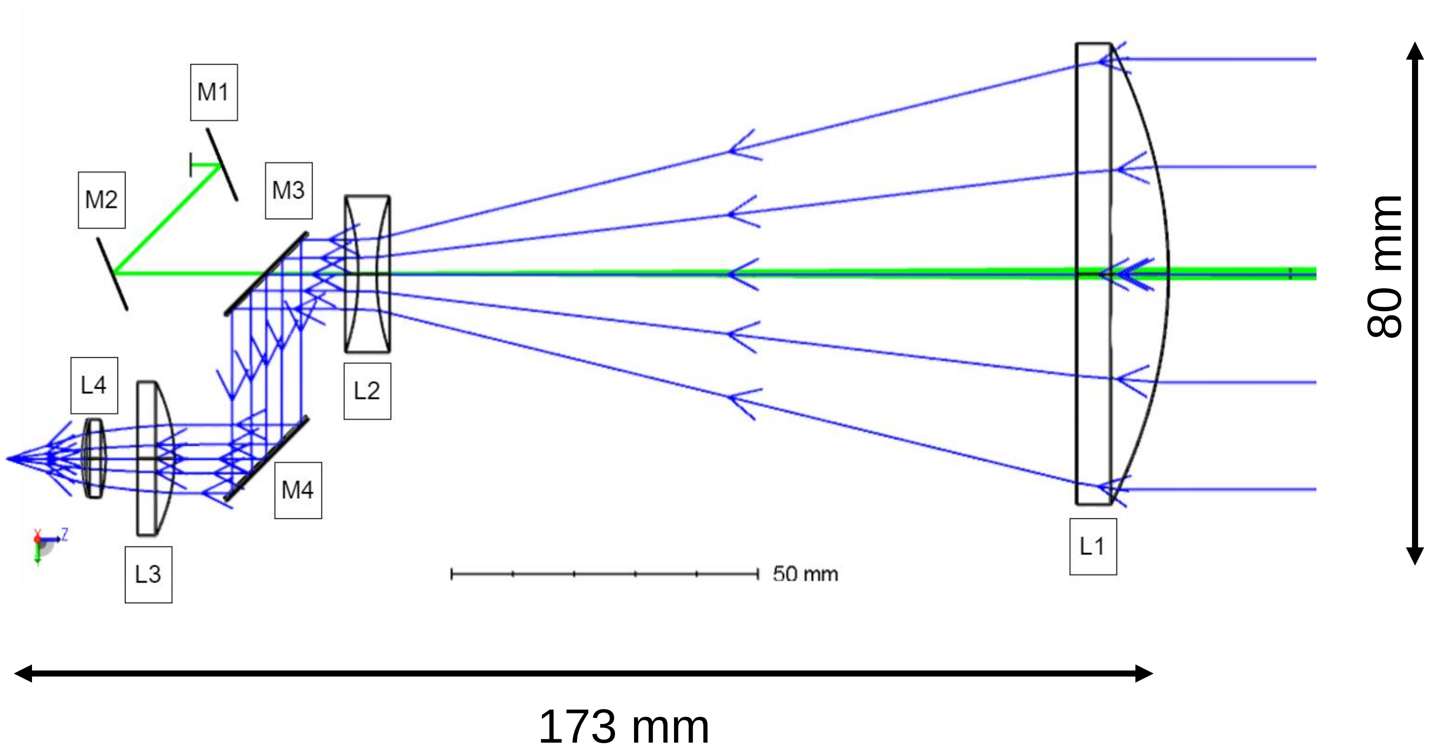
Overview

- **Commercial Off-The-Shelf** mirrors and lenses
- Shared **borehole mirror**
- Transceiver optics

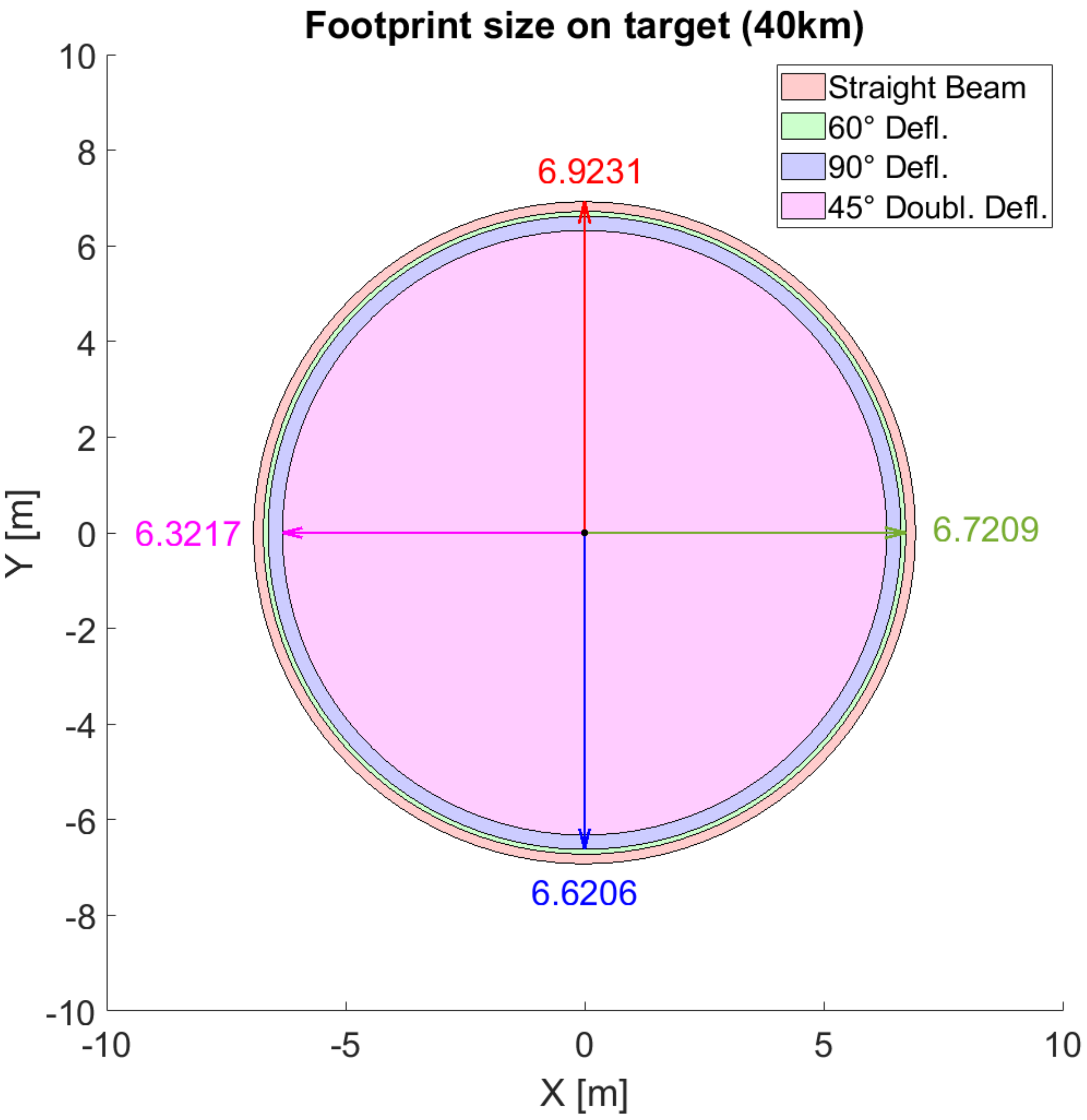
Trade-off analysis

- Zemax **optical simulations** to assess performance:

1. **Volume constraints** (2 U)
2. **Optical performance** (footprint size, easiness of alignment, misalignment budget, transmittance losses, thermal stability)
3. **Laser cross-coupling** to detector



Optical Design 2

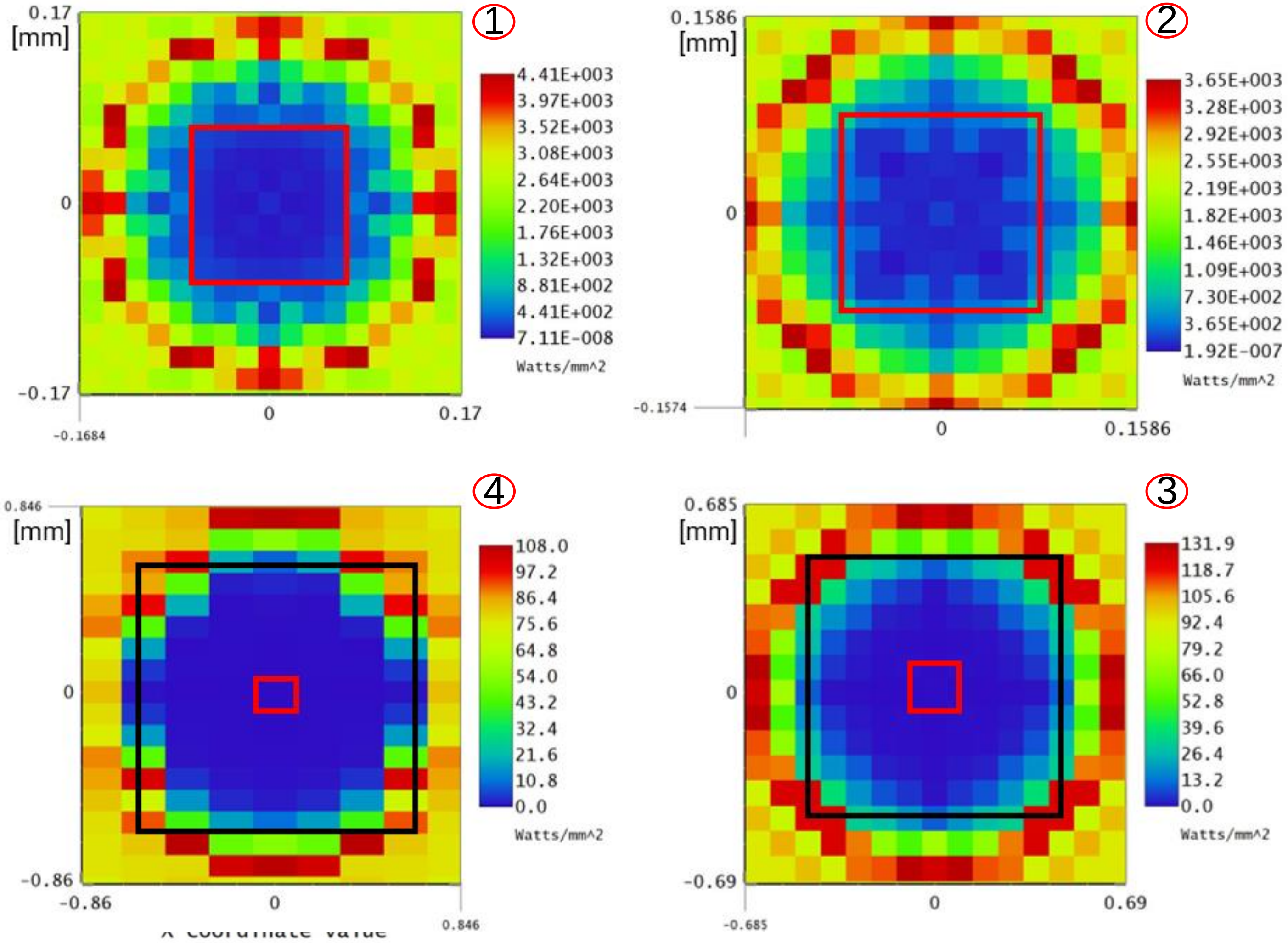


Misalignment

- The capability of the candidate to provide a footprint size **as close as possible to the nominal case**
- Not shorter: to allow for **misalignment margins**
- Not too large: to avoid **energy dissipation**

Criterion	Direct Beam	60° Deflection	90° Deflection	45° Doubl. Defl.	Weight
Misalignment	5	7	8	10	9

Optical Design 3



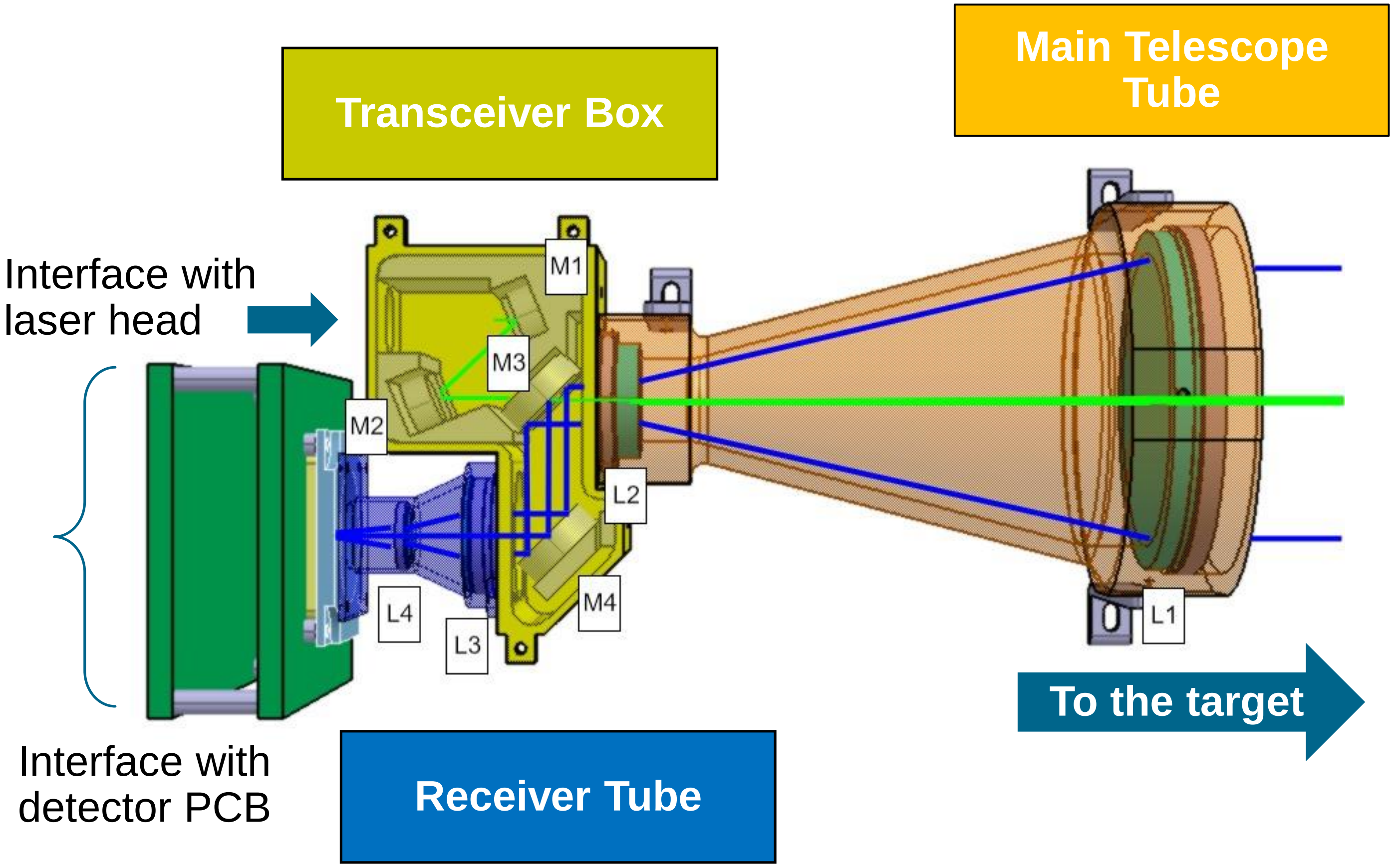
Straylight

- The capability of the candidate to limit the **energy density level** reflected internally to the detector
- Back reflection of **both telescope lenses**, comparing their size with the nominal and **limit** position of the detector

	Direct Beam	60° Deflection	90° Deflection	45° Doubl. Defl.	Weight
Straylight	4 (1)	5 (2)	7 (3)	10 (4)	9

Test Campaign 1

- **Modular** CAD design to accommodate optics
- **Three** different sections:



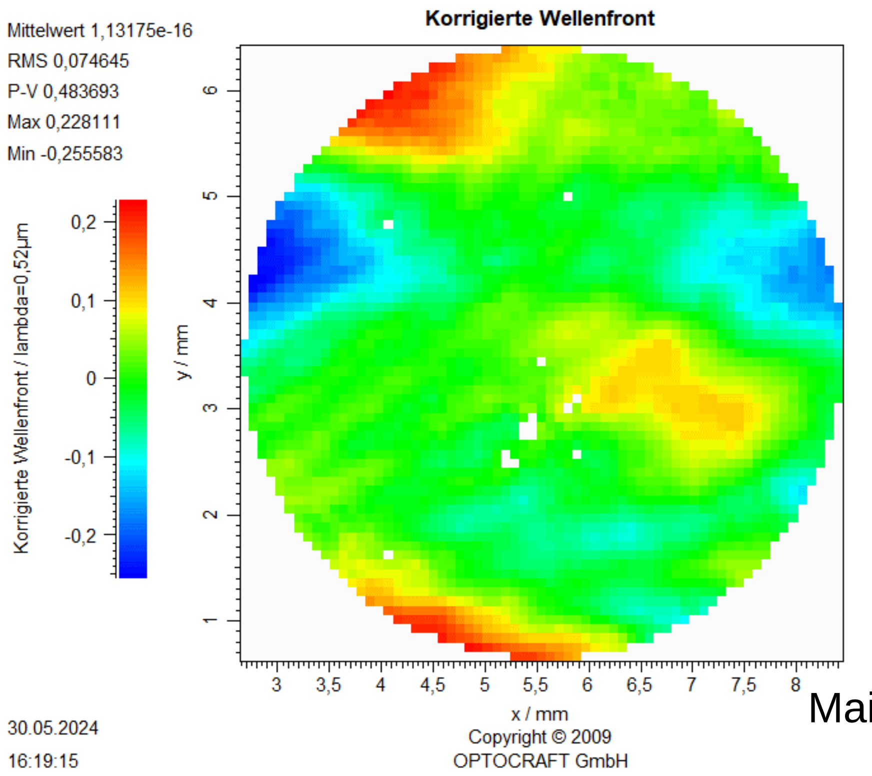
Mounted prototype on test bench

PCB: Printed Circuit Board

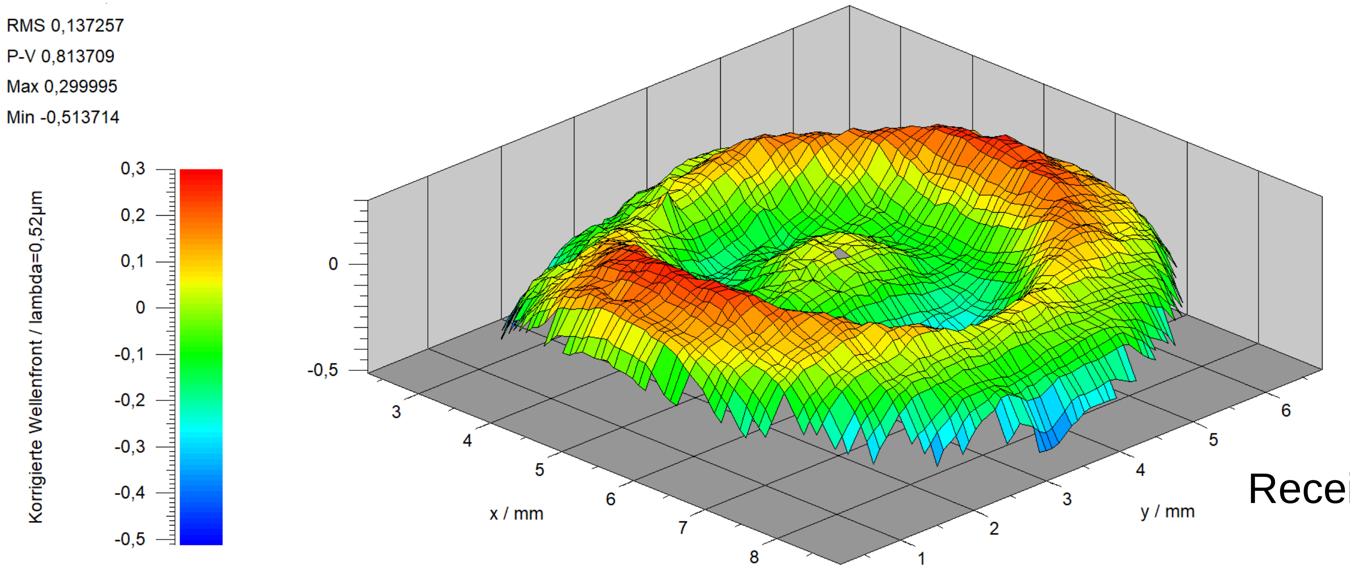
Test Campaign 2

Baseline Performance

- **Induced aberrations** in starting and returning signals
- The main telescope tube is assumable as **aberration-free** (Strehl Ratio ~ 0.8)
- The Receiver distorts the wavefront within an **acceptable limit** (Strehl Ratio ~ 0.5)



Main Telescope Tube

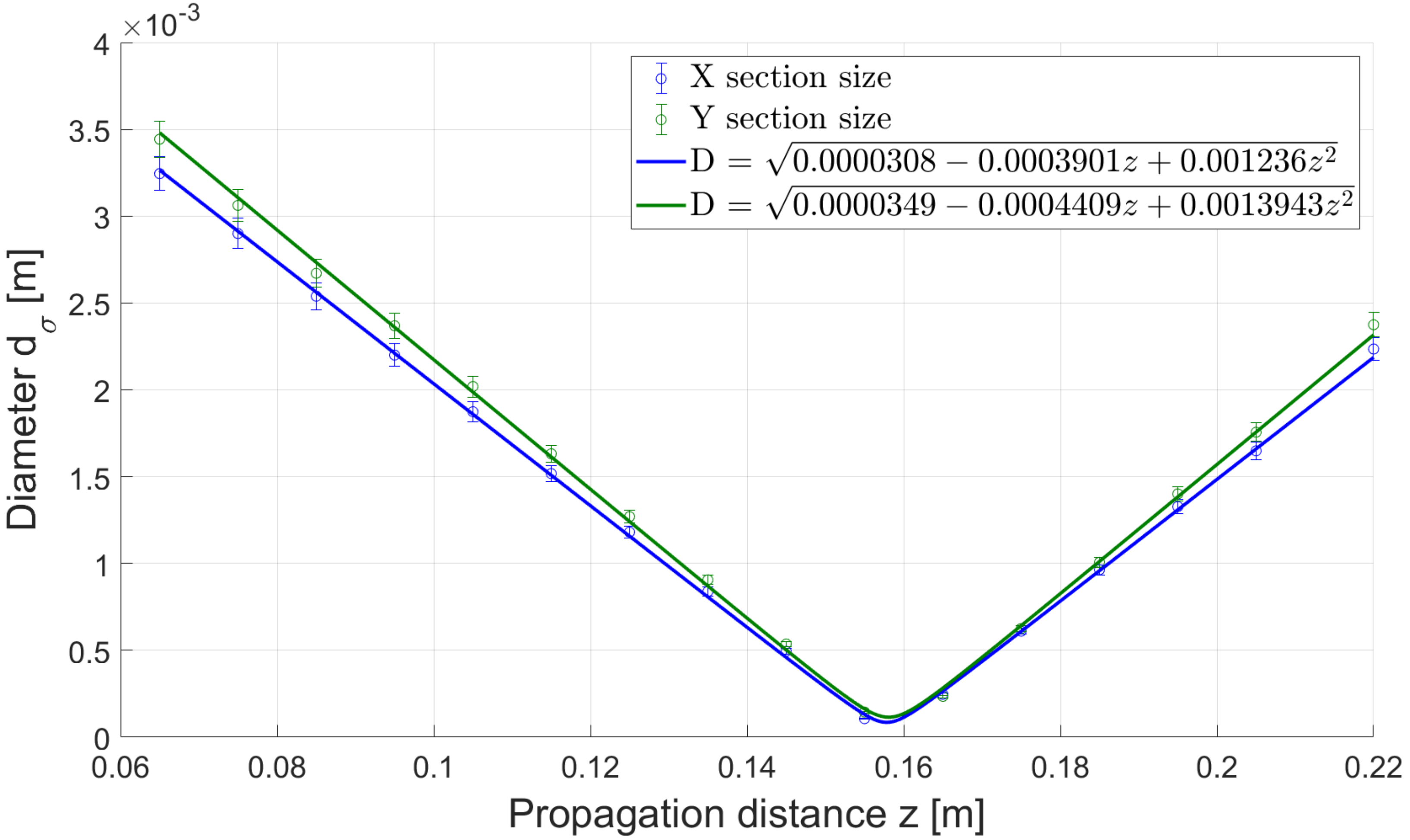


Receiver

Test Campaign 2

Baseline Performance

- **Expansion quality** of the main telescope tube
- The divergence of the exiting beam, interpolated by hyperbolic fitting, is **predictable** using Zemax simulations

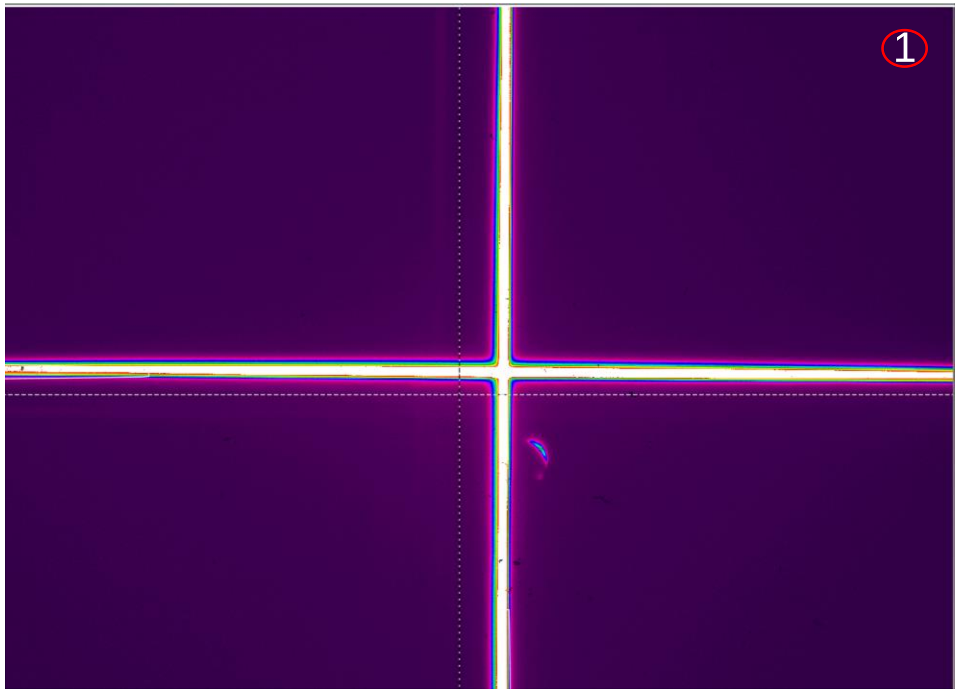


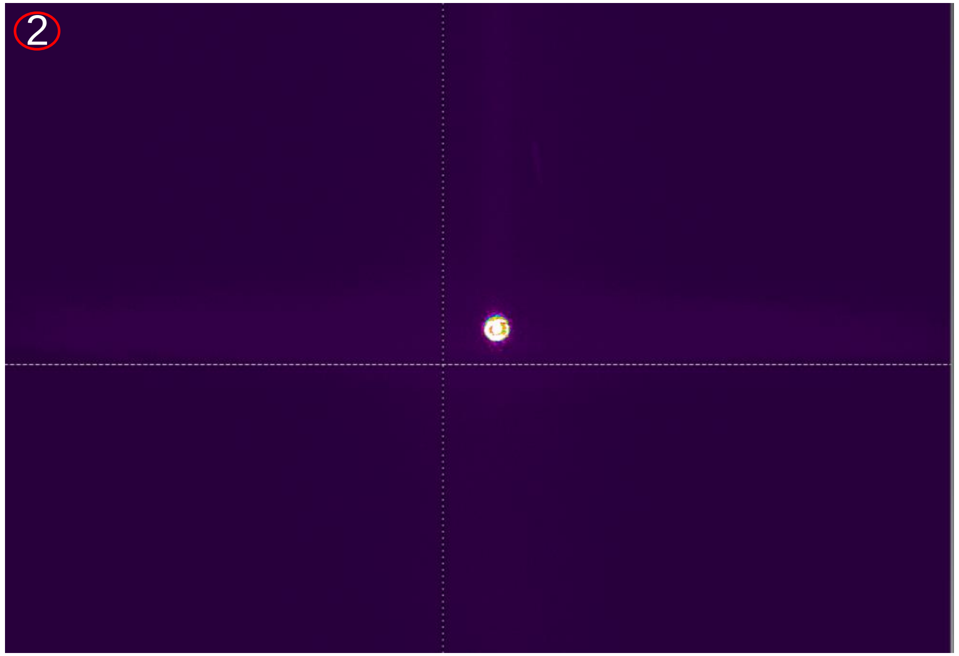
Test Campaign 3

Alignment procedure

- Use of **autocollimator** to adjust orientation
- Three control surfaces:

1. **Telescope lens**
2. **Laser source**
3. **Detector**

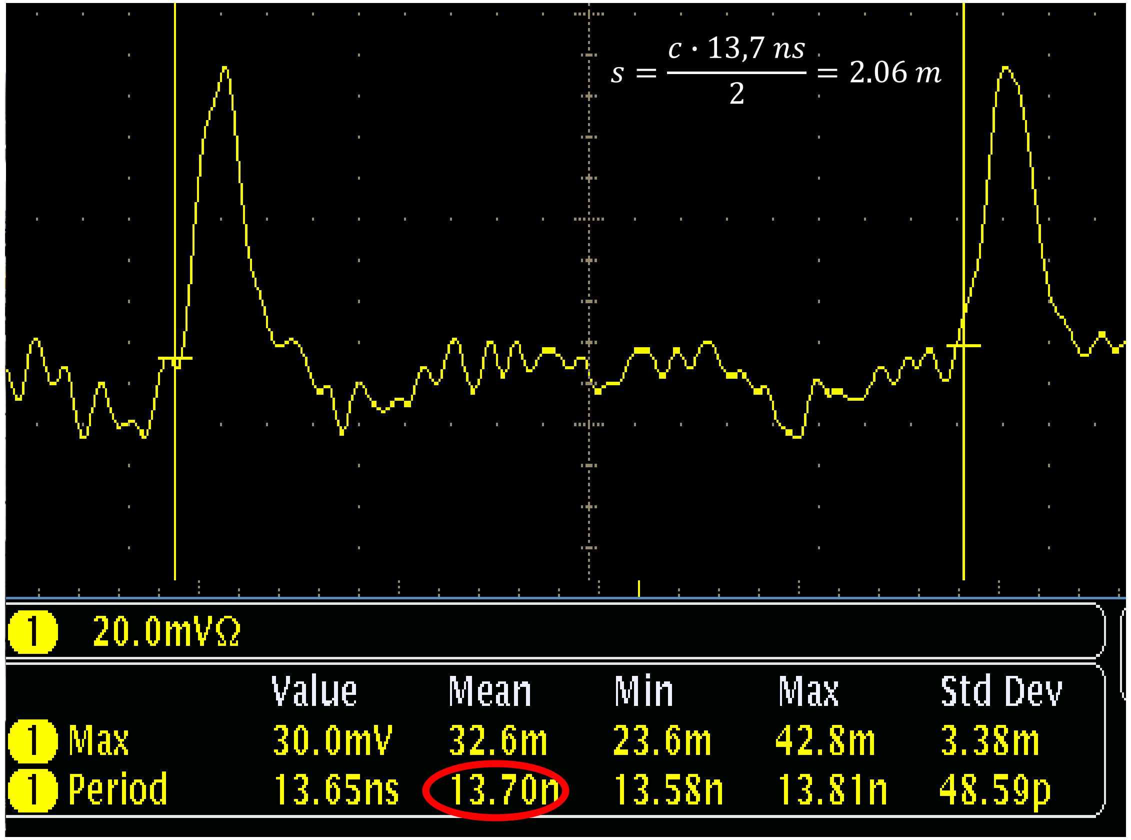


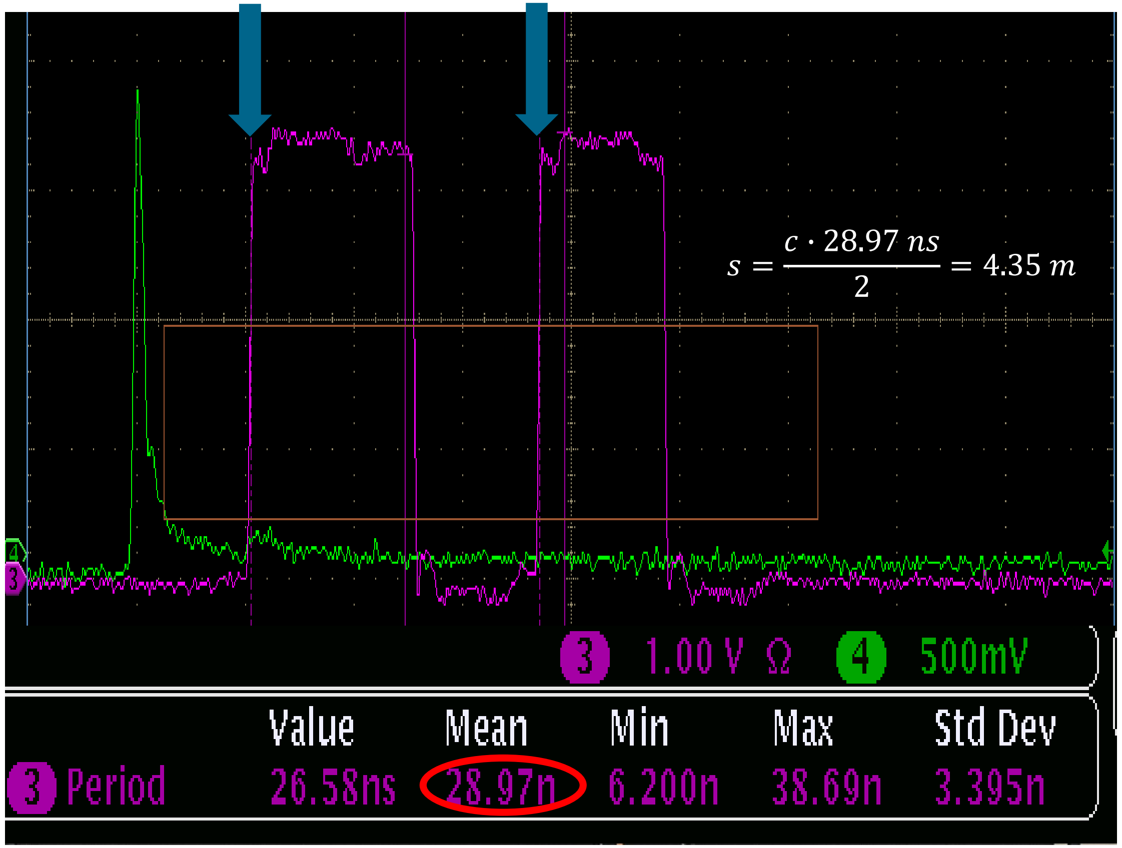


Test Campaign 4

Ranging Measurements

- **Timing measurements** with single-pixel APD and SPAD
- The SPAD range is higher to deal with the **dead time** of the detector





APD: Avalanche Photodiode | SPAD: Single Photon Avalanche Diode

Conclusions and Recommendations

Research Outcomes

- **Single photon detection** and **transceiver optics** can drive the miniaturisation of topographic laser altimeters
- **Optical design** optimising the performance required by the **SER3NE mission proposal**
- Manufacturing a prototype, verification of the **baseline optical performance** and feasibility of **ranging measurements**

Future Work

- Implementation of **SPAD array** with coincident detection
- Measurements in relevant environment → **Flight campaign** in November
- **Electronics** development for subsystems