Alignment optimization and overlap function estimation in stepper-motor controlled lidars

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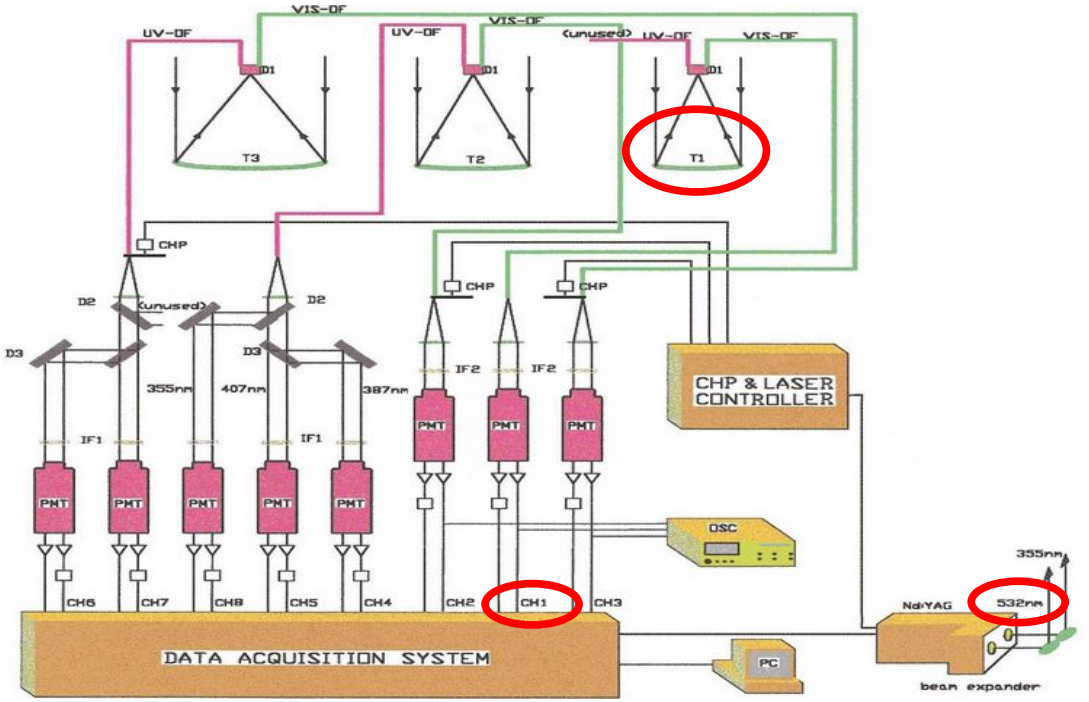
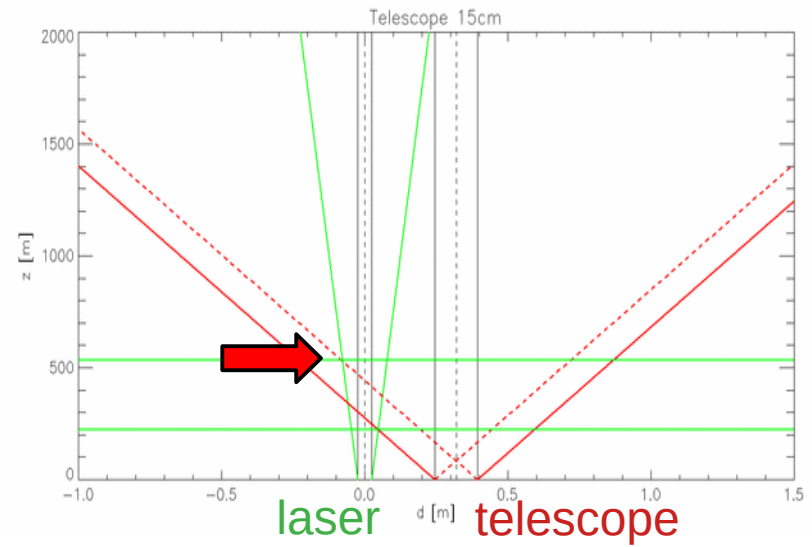
LIDAR SYSTEM: Tor Vergata “9-eyes” RMR lidar

Multi telescope – multi wavelength system,
mapping procedure applied to a single telescope-wavelength combination:
- CH01: 532 nm, 15 cm near range telescope
- CH02: 532 nm, 30 cm middle range telescope (used only for signal normalization)

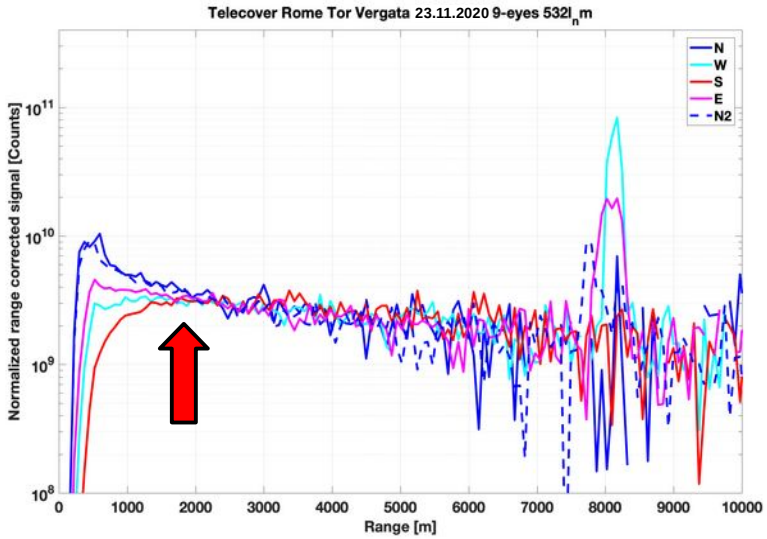


	355	387	407	532
15 cm				1
30 cm	8	5	4	2
9x50 cm		7	6	3

PROBLEM:
discrepancies between expected full overlap height and telecover results *
difficulties with manual alignment, a better alignment procedure is needed



?

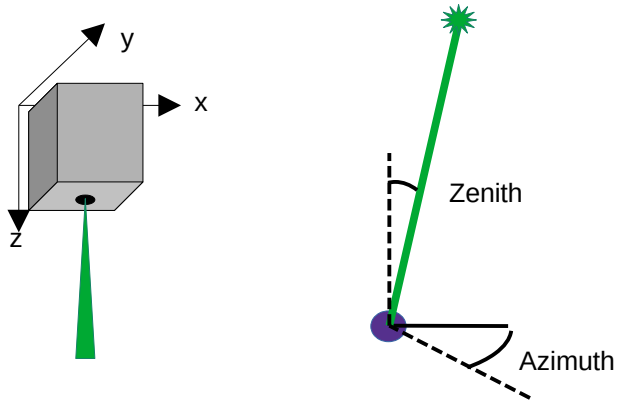


~ 500 m

> 1500 m

** ref.: "EARLINET lidar quality assurance tools" - Freudenthaler et al. - 2018*

SOLUTION:
take advantage of the capability of the lidar system to control with stepper motors the position of the receiving block and the orientation of the laser beam

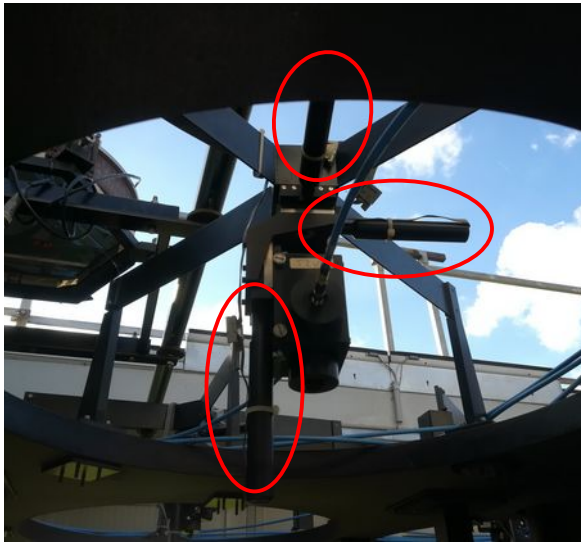


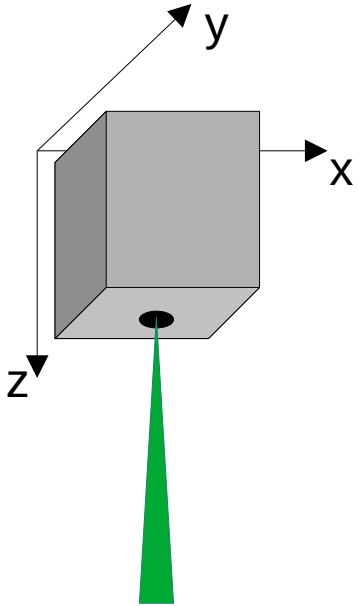
- Telescope *mapping*: diagnosis and alignment
- Laser *mapping*: overlap function estimation

Telescope *mapping*

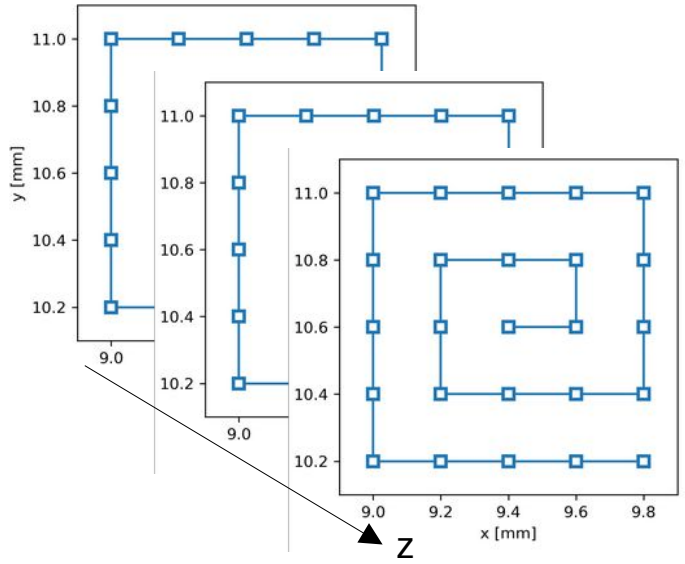
Goal: analyze the signal moving the receiving block in X, Y, Z
problem diagnosis and optimization of the alignment

receiving block with stepper-motors





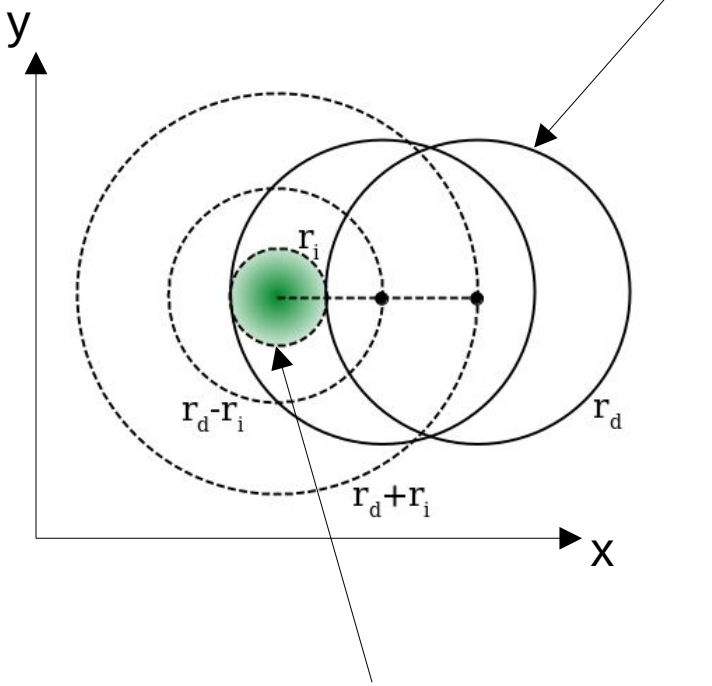
mapping geometry:
3D scan of the volume around the focal point



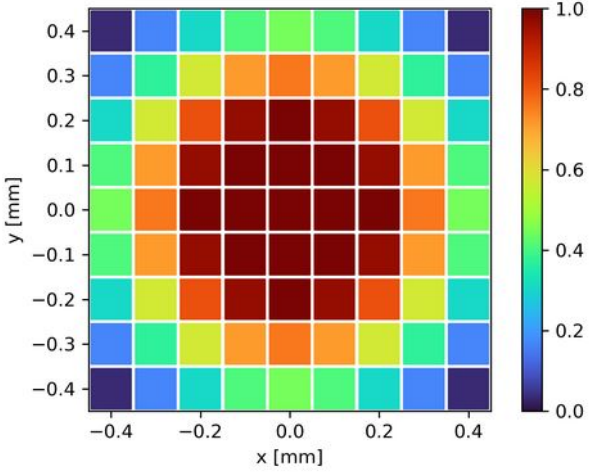
EXPECTED SIGNAL INTENSITY:

$r < r_d - r_i$: maximum signal
$r > r_d + r_i$: background

moving the diaphragm (radius r_d) in x and y



simulated output



misaligned optics example

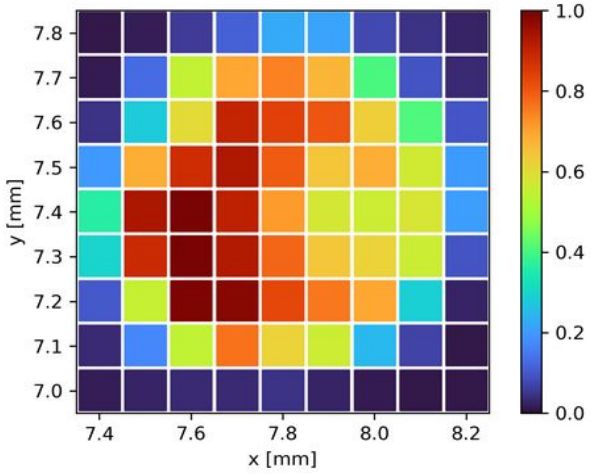
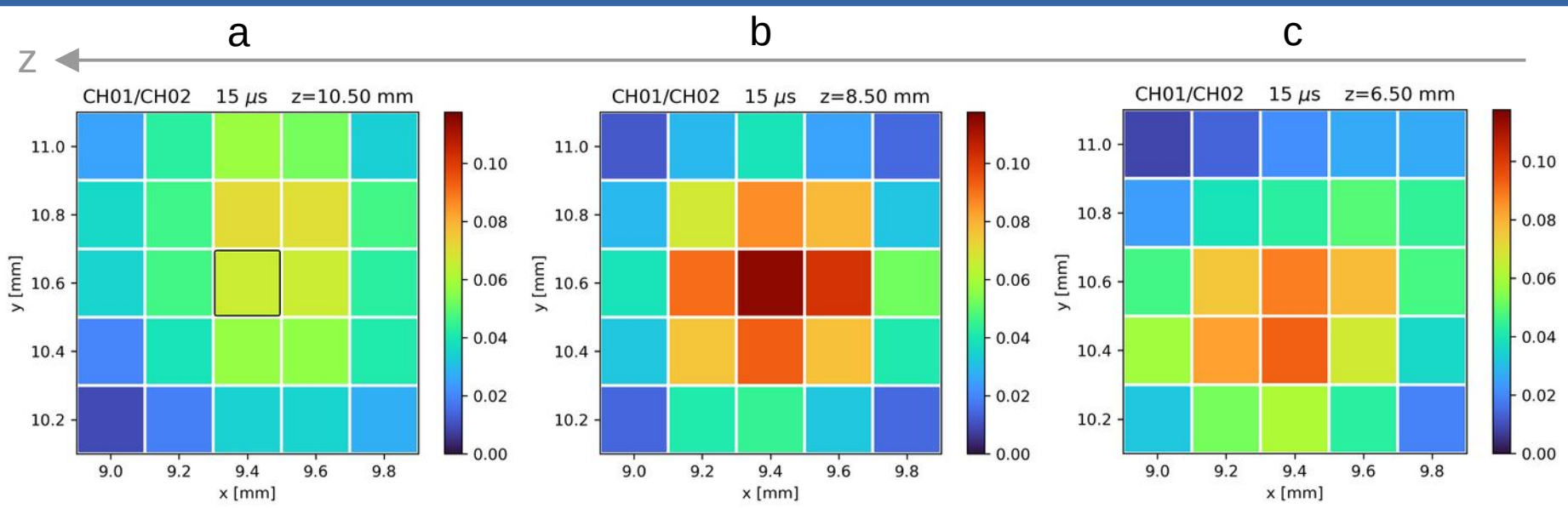
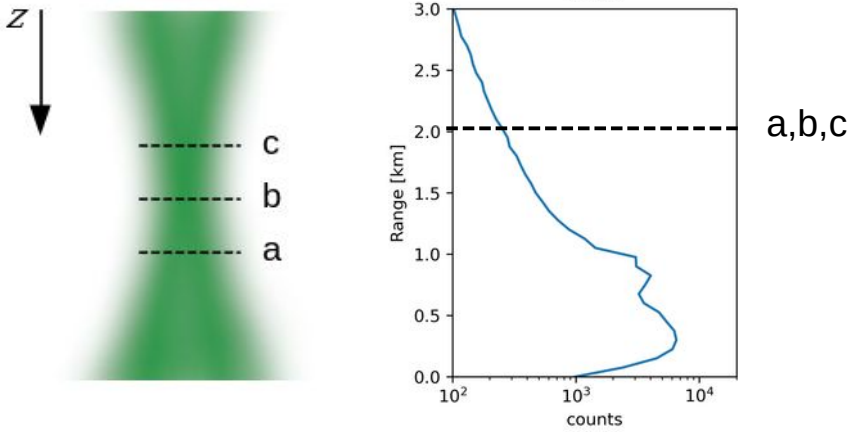
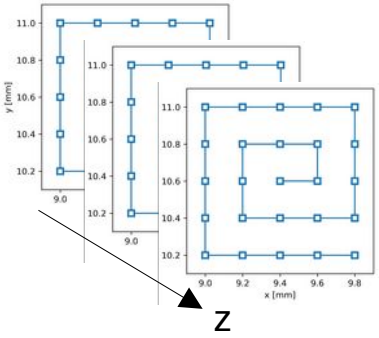


image (radius r_i) in the diaphragm plane



fixed observing range, different z positions





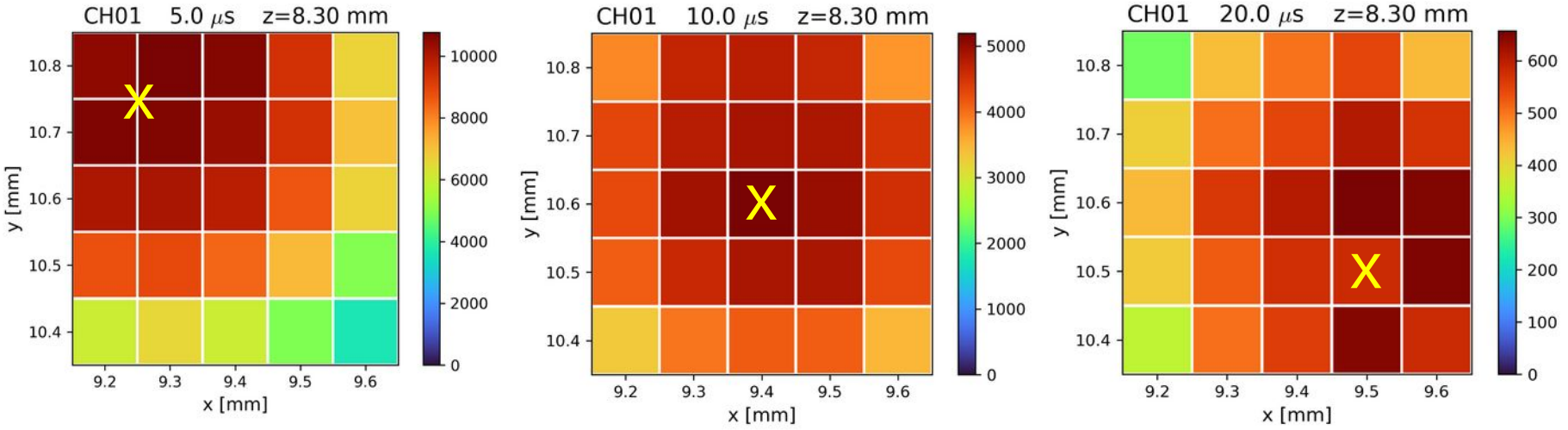
30s acquisitions
each plane takes ~15 min

normalized signal: CH01/CH02
in order to minimize atmospheric / laser power variability

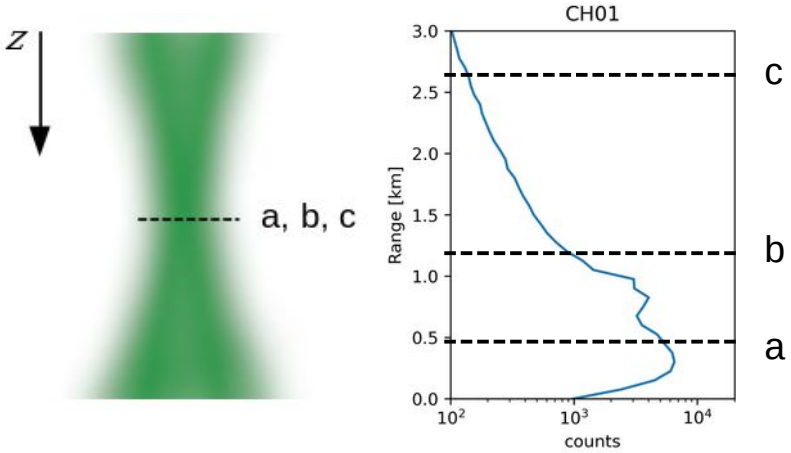
symmetric image but part of the signal is lost:
in the starting Z position (a) the system is out of focus

a b c

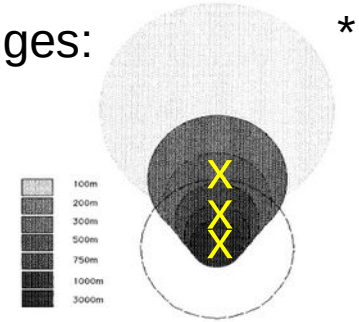
Range



different observing range, fixed z position

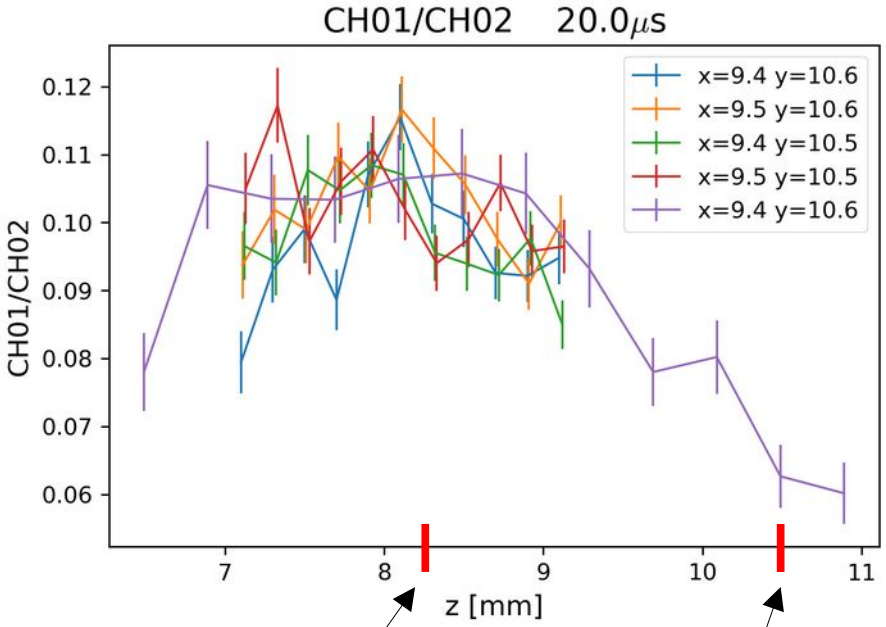


the image shifts at different ranges: *



X and Y selection:
trade-off between high and low range

** ref: "Analysis of the receiver response for a noncoaxial lidar system with fiber-optic output" – Chourdakis et al. - 2002*



optimized position

non-optimized position: signal lost due to defocusing

Finding the optimal Z:

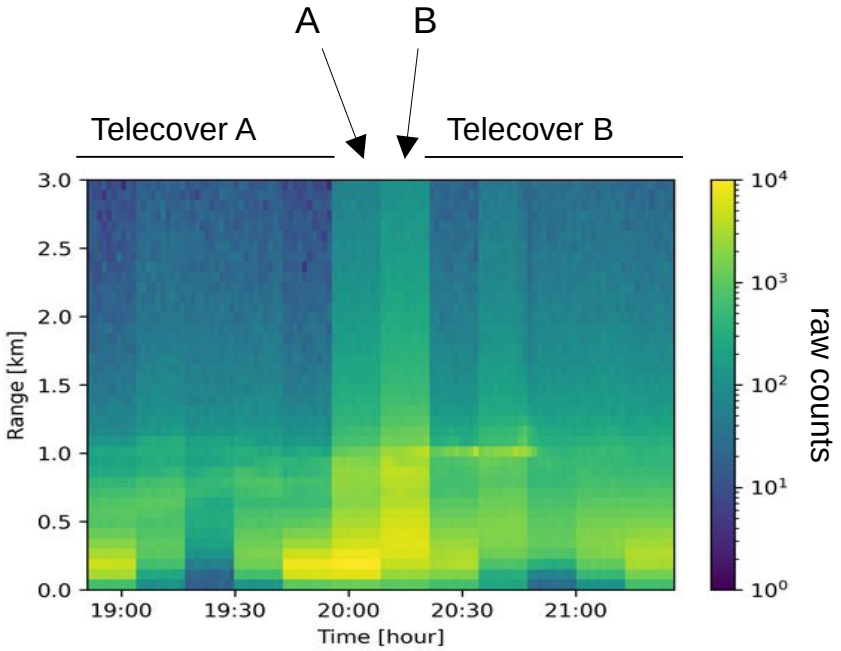
normalized signal for X and Y around the chosen position as a function of Z

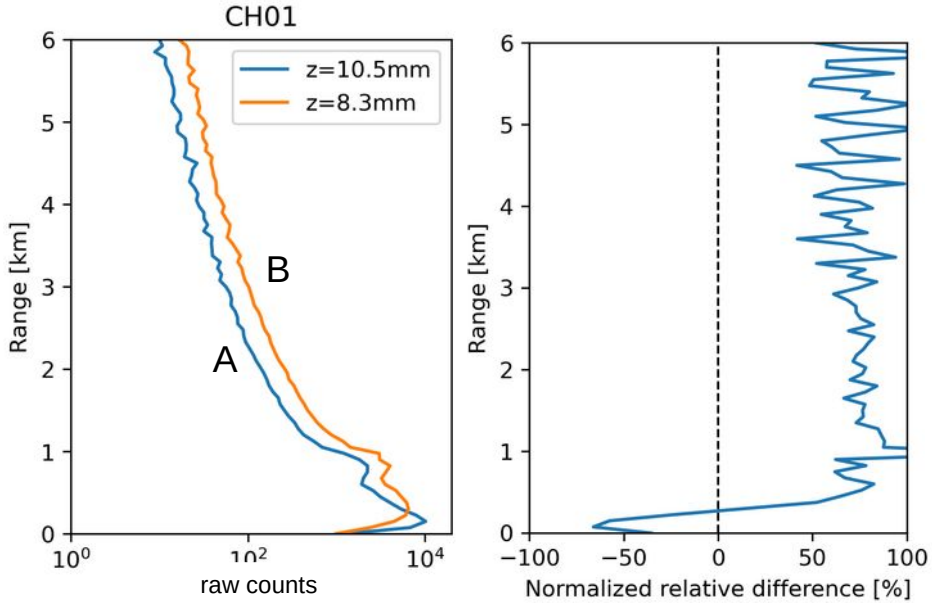
the normalization with a second channel (CH02: 532 nm, 30 cm telescope) permits longer sessions or comparisons between the different *mapping* sessions

Z selection:
center of the plateau where all the signal passes through the diaphragm

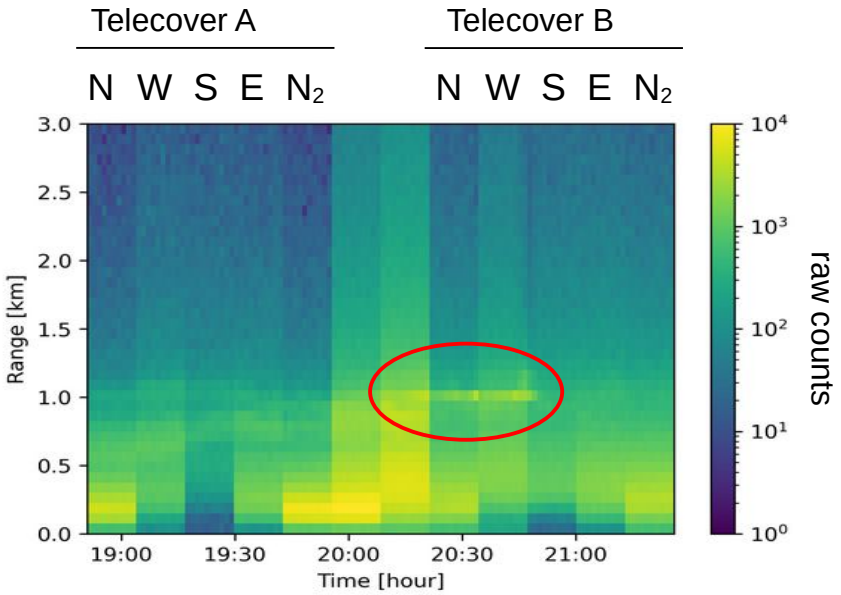
Alignment validation

Profile comparison (02-02-2021) between position A (non-optimized) and B (optimized):
- higher signal at all levels
- lower values well below the full overlap height

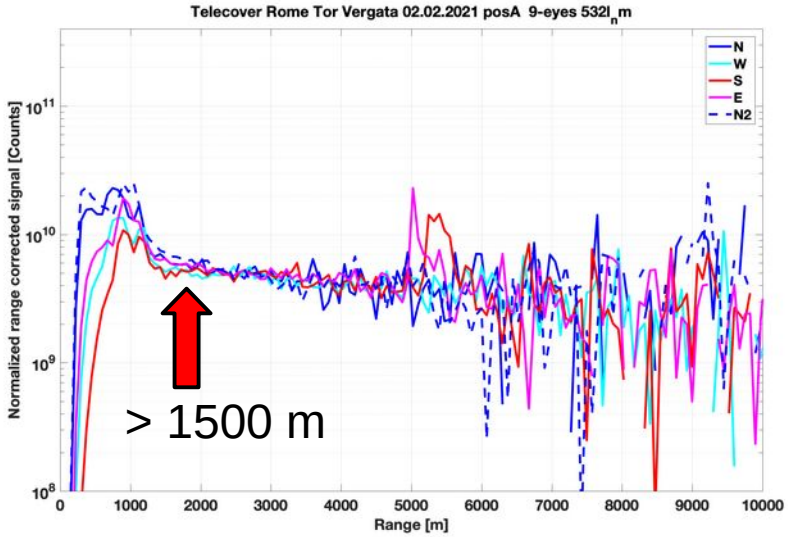




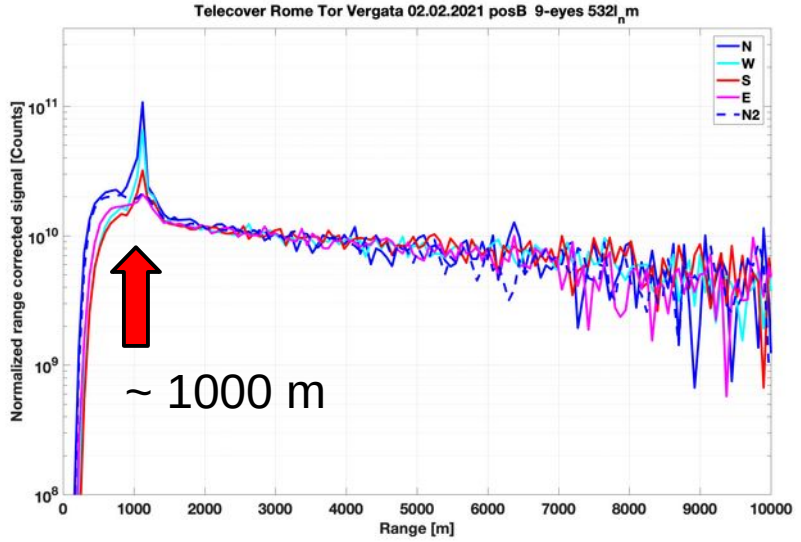
Telecover test (02-02-2021):
- higher signal and less noise
- lower overlap height (1000 m or less, atmospheric variability in the lower range)



A



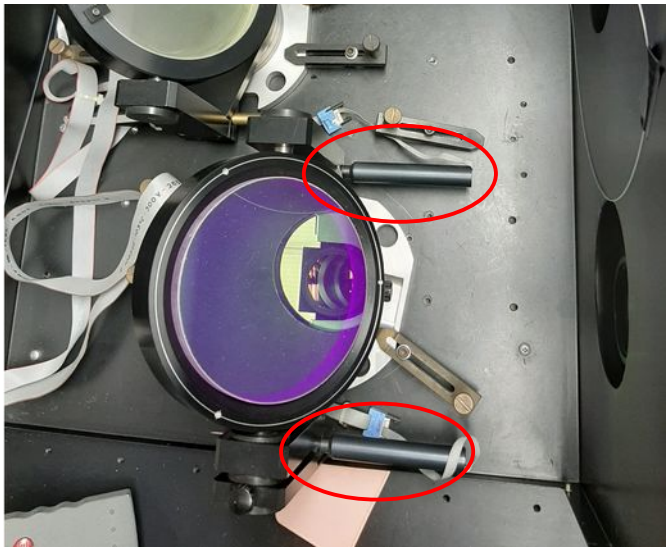
B

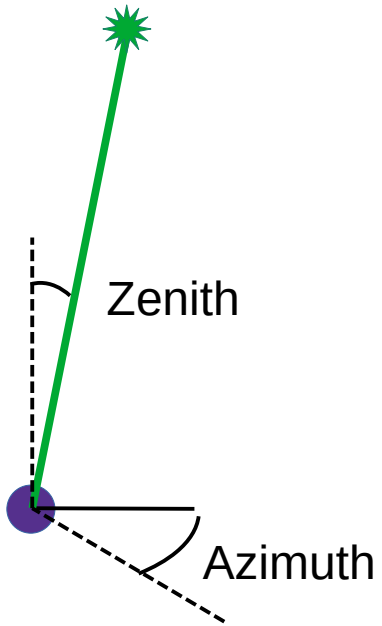


Laser *mapping*

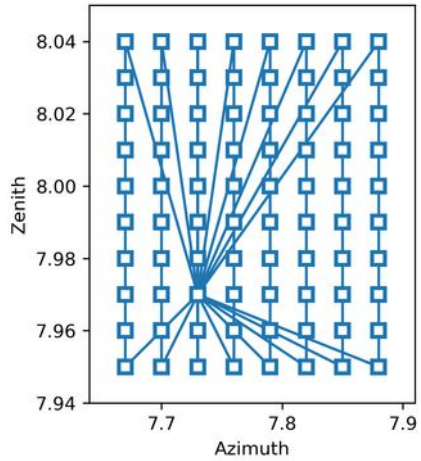
Goal: overlap function estimation

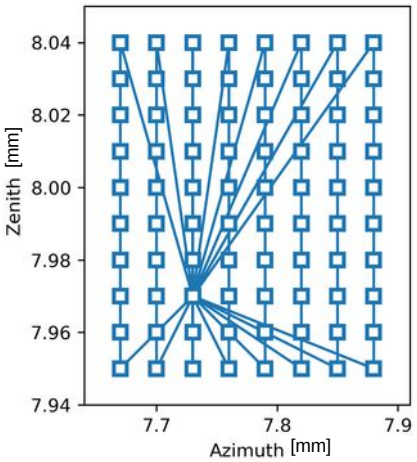
laser beam mirror with stepper-motors



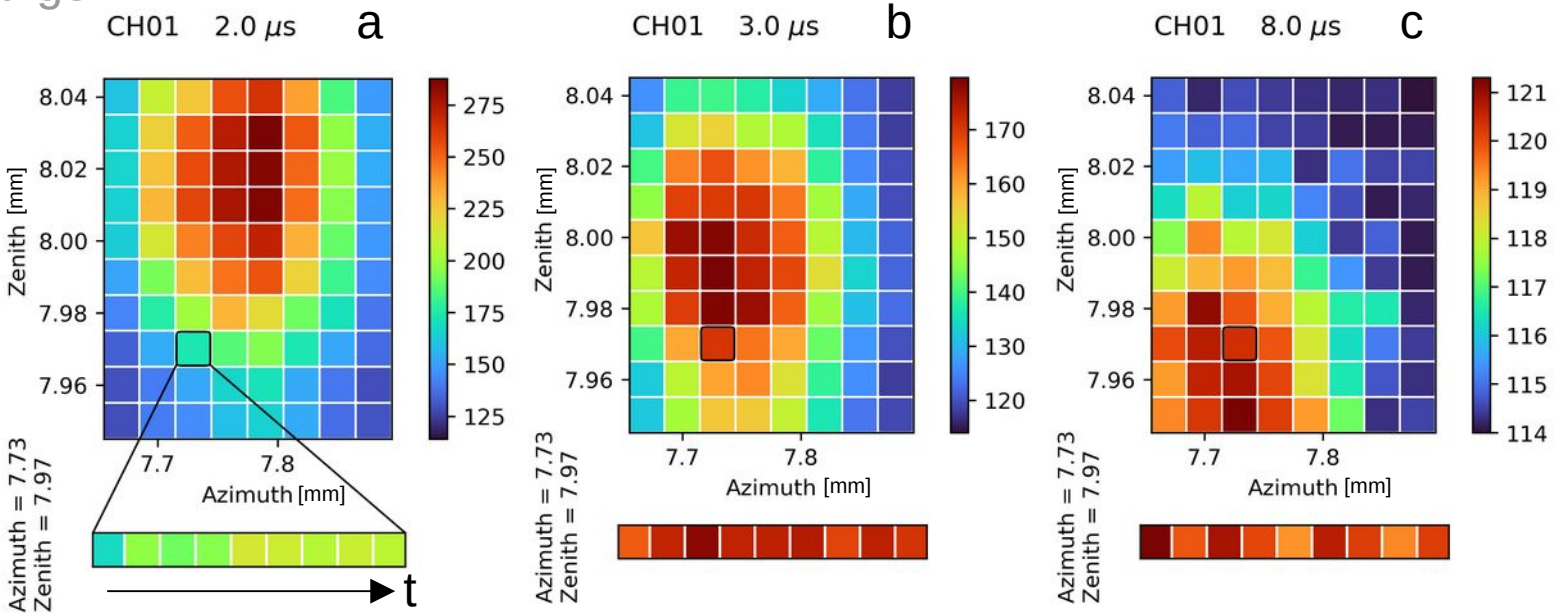


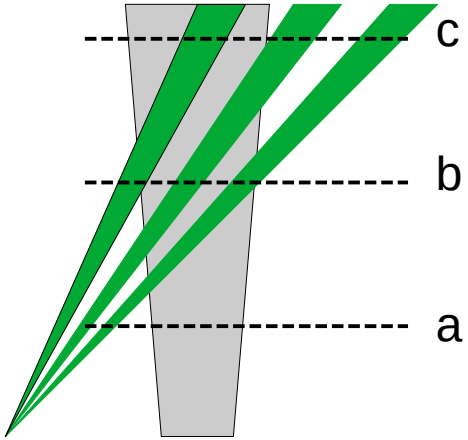
mapping geometry:
scan in zenith and azimuth





Range

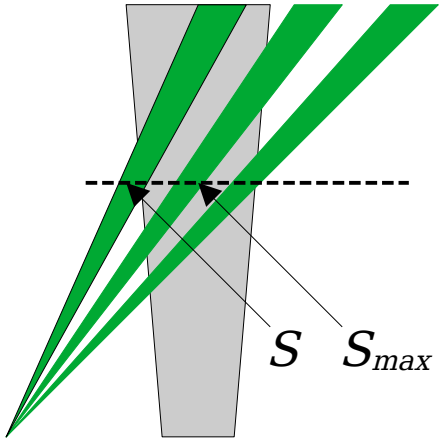


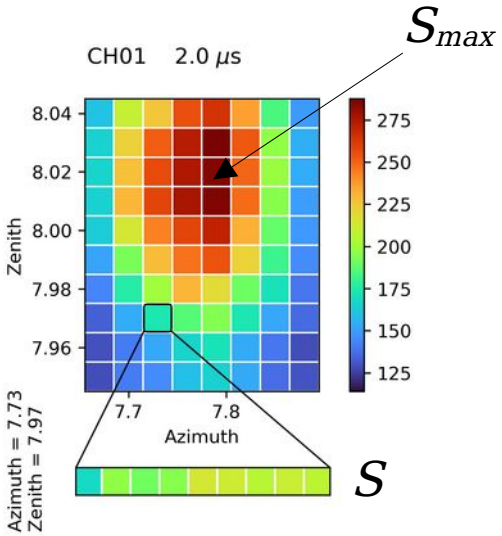


Mapping geometry: a measurement with the beam in the "routine" acquisition position is taken every zenith swipe in order to minimize variability (atmosphere and laser power)

the image shifts in the lower range (partial overlap region), we see both the signal that we would have in a "routine" acquisition and the maximum obtainable at each range

Overlap function estimation:





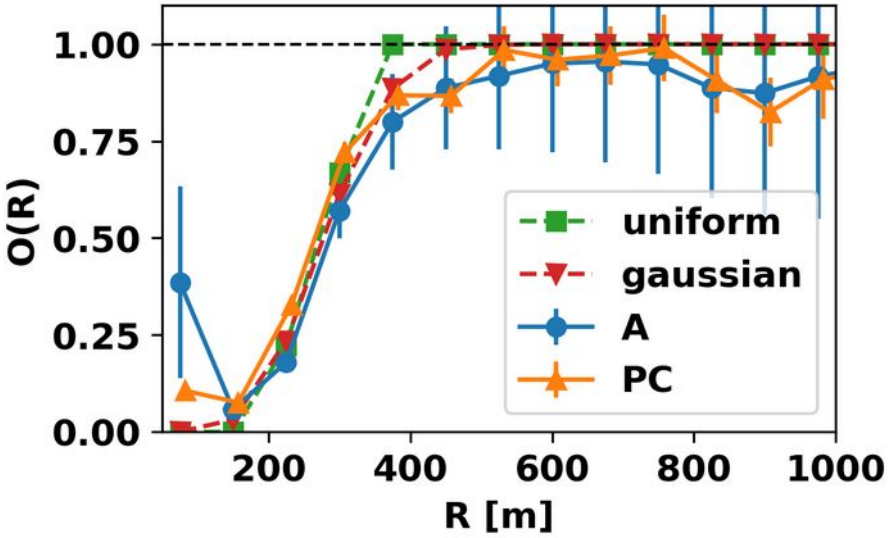
$$O(R) = \frac{S(R)}{S_{max}(R)}$$

S: signal in the “routine” position (affected by partial overlap)

S_{max}: maximum signal found at each observing Range
assuming a sufficiently small image completely inside the diaphragm,
this corresponds to all the signal available as if O(R)=1 (complete overlap)

Overlap function:
good agreement between data and model *

model assumptions:
- uniform/gaussian energy distribution
- diaphragm in the focal plane
- beam inclination (0.35 mrad)



* ref.: "Analytical function for lidar geometrical compression form-factor calculations" - Stelmaszczyk et al. - 2005
"Geometrical form factors for the lidar function" – Halldórsson and Langerholc - 1978

Conclusions

- Results:
  - characterization of the system emission-reception geometry
  - optimized alignment resulting in:
    > 50% signal increase in the profile
    lowering of the full overlap height
  - experimental estimate of the overlap function

- Reminder: consider out of focus images in the diaphragm plane as possible cause of low signal / high overlap

- The procedure will be extended to the whole system and the overlap estimation will be verified comparing overlap corrected middle range channels and the lower range channel

- Simplified versions of this procedure (e.g. scan on a single axis) could be applied also to non-motorized systems