Workshop 2016, 26 – 30 Januari

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RASDIF: THE LATEST RESULTS ON THE DEVELOPMENT OF AN ALIGNMENT

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- To achieve **ultra-low emittances** and a **nanometer beam size** beam based alignment is required;
- In order to have stable beams CLIC has to be **pre-aligned**.

Table 1: CLIC alignment requirements, defined in a sliding window of 200 m.

CLIC Component	Alignment precision
Main linac components	14 – 17 µm
Main linac reference point	10 µm
Beam delivery system	10 µm

- Both short and long range alignment:
  - Each component will be aligned with respect to its neighbors;
  - Overall alignment of sections of 200 m that partially overlap.

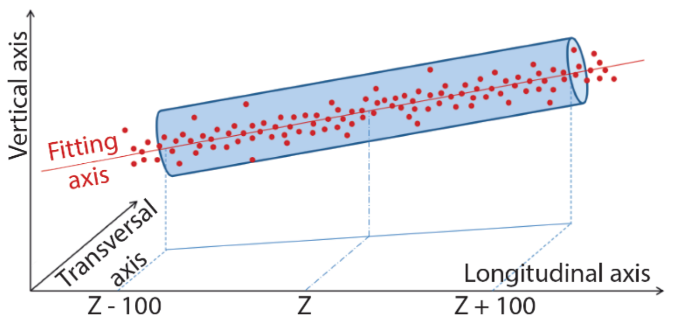


Fig. 1: Alignment requirements of CLIC. The cylinder represents the sliding window with a diameter of 10 µm.

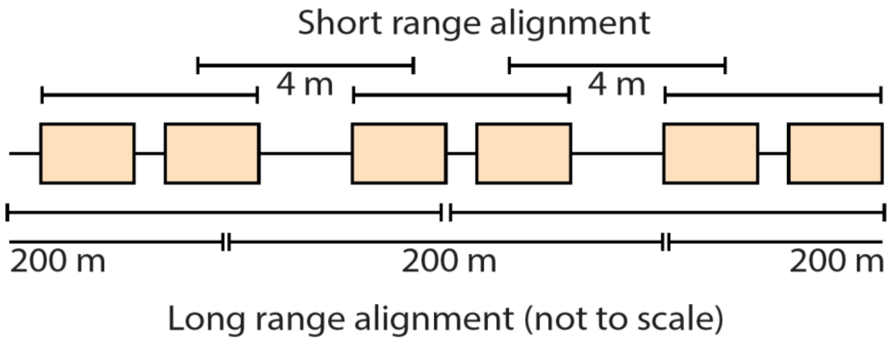


Fig. 2: Alignment scheme for CLIC. The blocks represent CLIC components

Rasdif: Red Alignment System Diffraction

- Rasdif: A three point optical alignment system;
- Designed for **long range alignment**, objects can be up to several hundreds of meters apart;
- A **monochromatic divergent light** source, a diffraction plate and a CCD sensor;
- Diffraction pattern is detected by CCD sensor, computer calculates the position of the image;
    - When one of the three points translates in a direction, the image translates in the same direction.

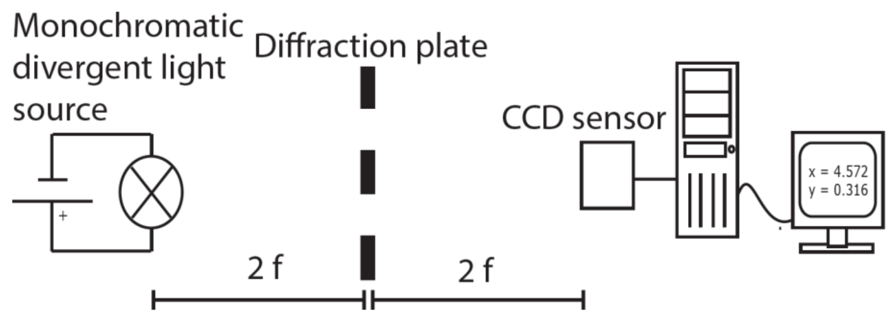


Fig. 3: Schematic drawing of a Rasdif system.

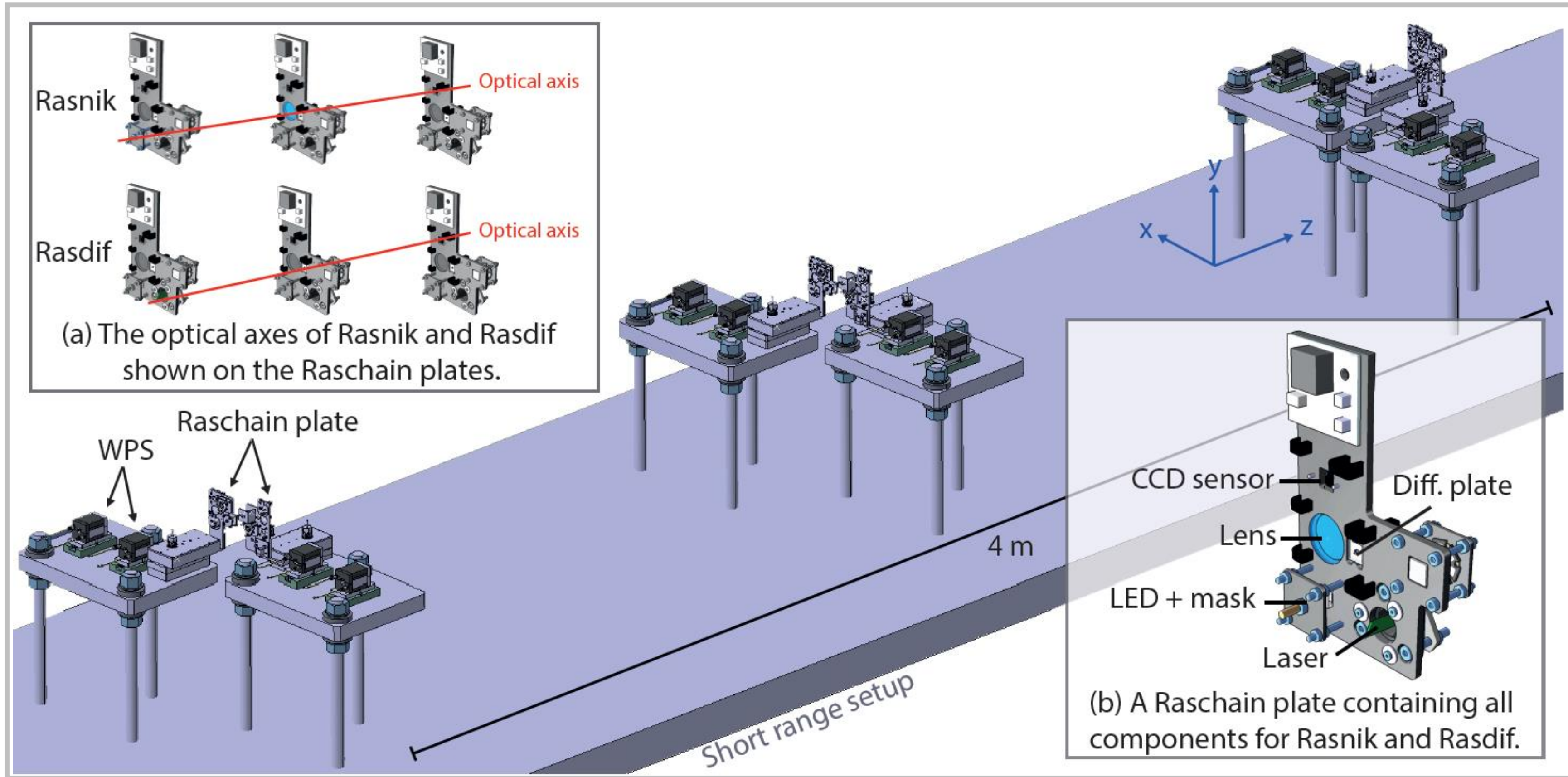


Fig. 4: Short range setup to test two Rasdif systems. Two Rasnik systems and 12 WPS sensors are added for comparison.

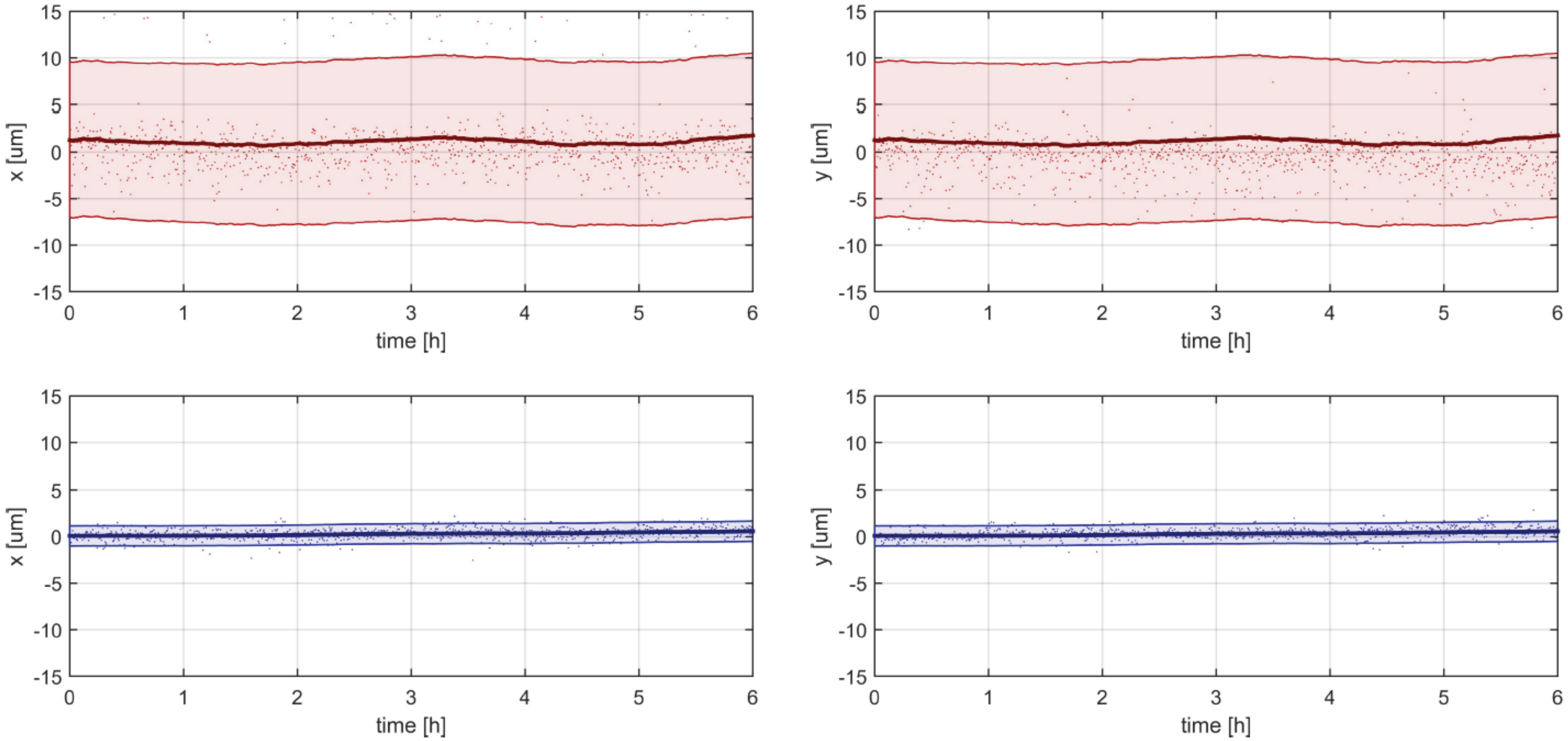
- A setup was designed in which Rasdif could be installed on support plates;
- **Other alignment sensors** were added for verification of the Rasdif results;
- Data was taken when the support plates were **misaligned purposely** and when the setup was untouched.

Short range misalignment results

- Rasdif measures more than **twice** as much displacement as Rasnik does;
- Since Rasdif and Rasnik are almost in the same location, **rotations** of the plate **can not** explain the large difference;
- The same effect was found when the sensors were installed on the Two Beam Modules in B169;
- The cause of this is not yet understood.

Table 2: Results of misaligning the support plates while data was taken with Rasdif and Rasnik.

Sensor	Δx_1	Δy_1	Δx_2	Δy_2	Δx_3	Δy_3	Δx_4	Δy_4	Δx_5	Δy_5
	mm	mm	mm	mm	mm	mm	mm	mm	mm	Mm
Rasdif	-2.556	-1.502	2.556	1.505	0.684	0.919	0.255	-1.459	-2.787	2.553
Rasnik	-1.067	-0.186	1.067	0.186	0.275	0.498	0.091	-0.731	-1.347	1.291



- For Rasdif (top) the noise is also twice as big as for Rasnik;
- Both sensors are equally stable, no drift is observed.

- In the **ideal case**: Rasdif noise is only determined by the noise of the CCD sensor;
- Rasdif noise in this limit **(Cramer-Rao Lower Bound (CRLB))** is in the order of nanometers;
- In the **real situation**: there is a **medium** between the three components of Rasdif (i.e. air);
- Air **density fluctuations** cause for the light to be **refracted** which increases the Rasdif noise;
- Shielding might reduce the noise caused by air fluctuations, shielding studies will be performed to prove this hypothesis.

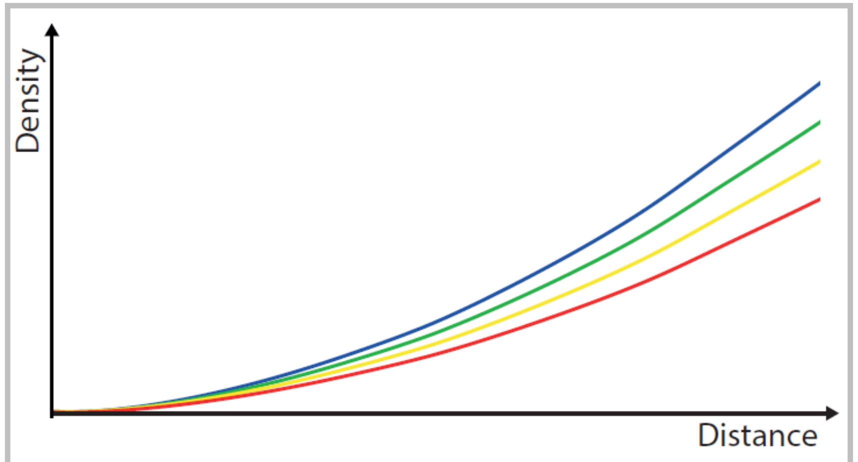


Fig. 5: The effect that air density has on the refraction of light.

Long range alignment with Rasdif

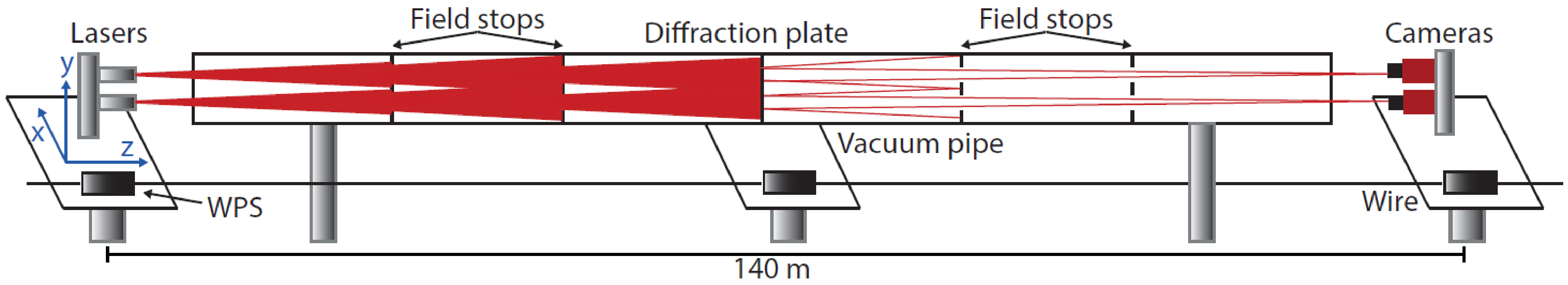


Fig. 6: Setup to test Rasdif systems for long range alignment.

- To test Rasdif systems for long range a 140 m setup was build;
- Two Rasdif systems were installed on top of each other on support plates, **a vacuum tube** was installed around the optical axis of both;
- **Other alignment sensors** were added on the support plates to allow for the verification of the results;
- **Linearity tests** were conducted by moving the lasers with well know steps;
- The middle support plate was **misaligned deliberately** to test Rasdif, measurements where also taken when the setup was **untouched**.

- During the linearity test problems with the top Rasdif appeared that could not be solved quickly. Therefore there are only results from the bottom Rasdif:

$$x_0 = (0.93 \pm 0.01)\ x_{mm,0}$$
$$y_0 = (0.94 \pm 0.02)\ y_{mm,0}$$

- Rasdif was found to be **linear** with a slope not equal to one;

- This is expected when the distance between the CCD and the diffraction plate is not equal to the distance between the diffraction plate and the light source.

- Another cause is when Virtual Point of Departure (VPD) of the light does not overlap with the actual laser position.

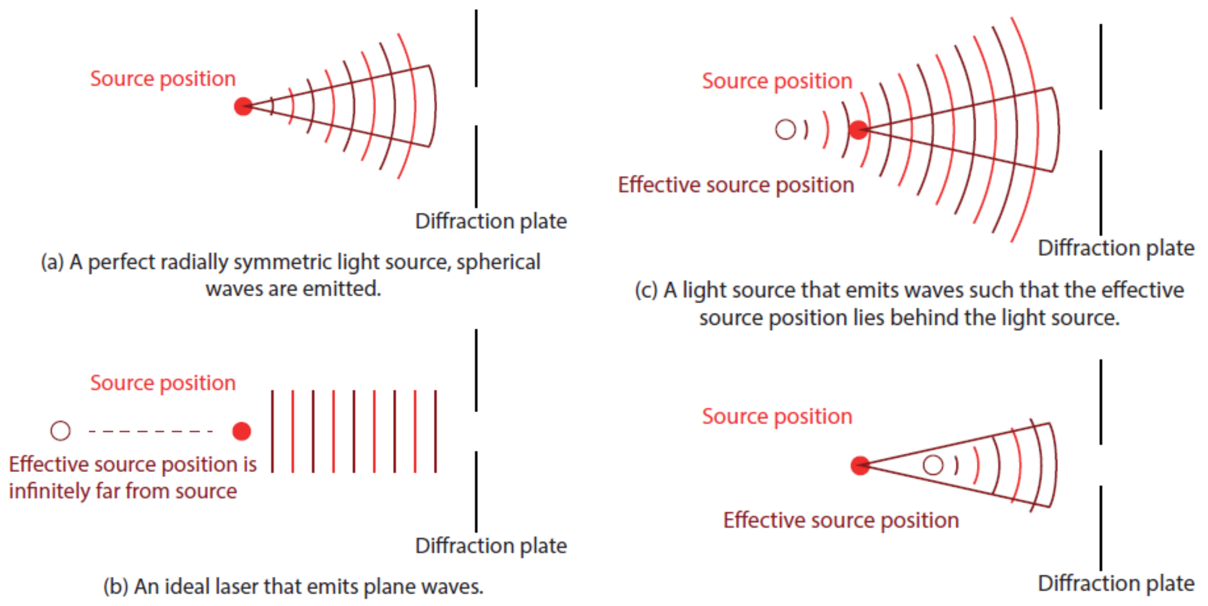


Fig. 7: The shape of waves of different kind of light sources.

- The effect of the VPD not overlapping with the light position is calculated as:

$$tan(\theta) = \frac{d_{ap}}{z} = \frac{d_{sz}}{l_{ap-sz} + z}$$

- The result is a function for the distance between the laser position and the VPD, *z*, which shows **asymptotic behavior**;

$$tan(\theta) = \frac{d_{ap}}{z} = \frac{d_{sz}}{l_{ap-sz} - z}$$

- *z* is **minimal** when the spot size becomes infinitely large and the laser aperture infinitely small;

- This results in waves that appear like **plane waves** on the diffraction plate.

$$z = \frac{d_{ap} \cdot l_{ap-sz}}{d_{sz} \pm d_{ap}}$$

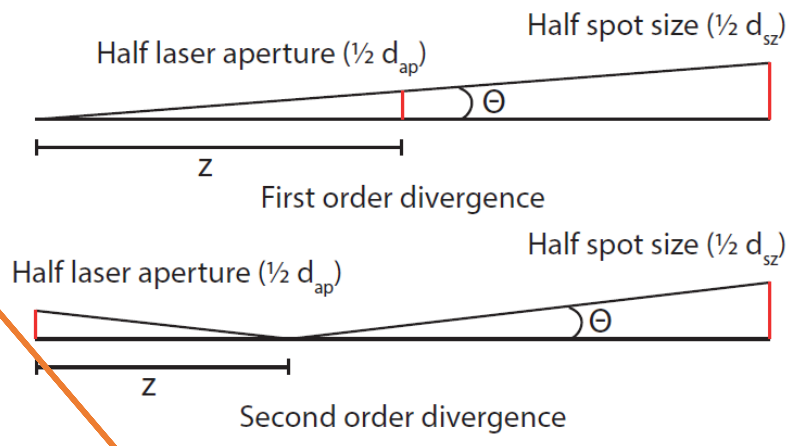


Fig. 8: First and second order divergence from the VPD.

Slope of Rasdif: $$S = \frac{l_{ap-sz}}{l_{ap-sz} + z}$$

- Using the results of the data from WPS1/2, HLS and tilt meter the expected displacement of Rasdif was calculated;
- There is a small uncertainty in the expected value because only two of the three rotations of the plate were measured;
- Rasdif measurements agree with the expected value with an accuracy of 10 µm.

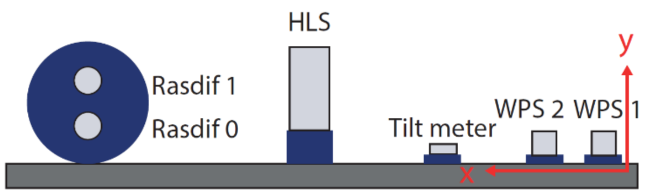
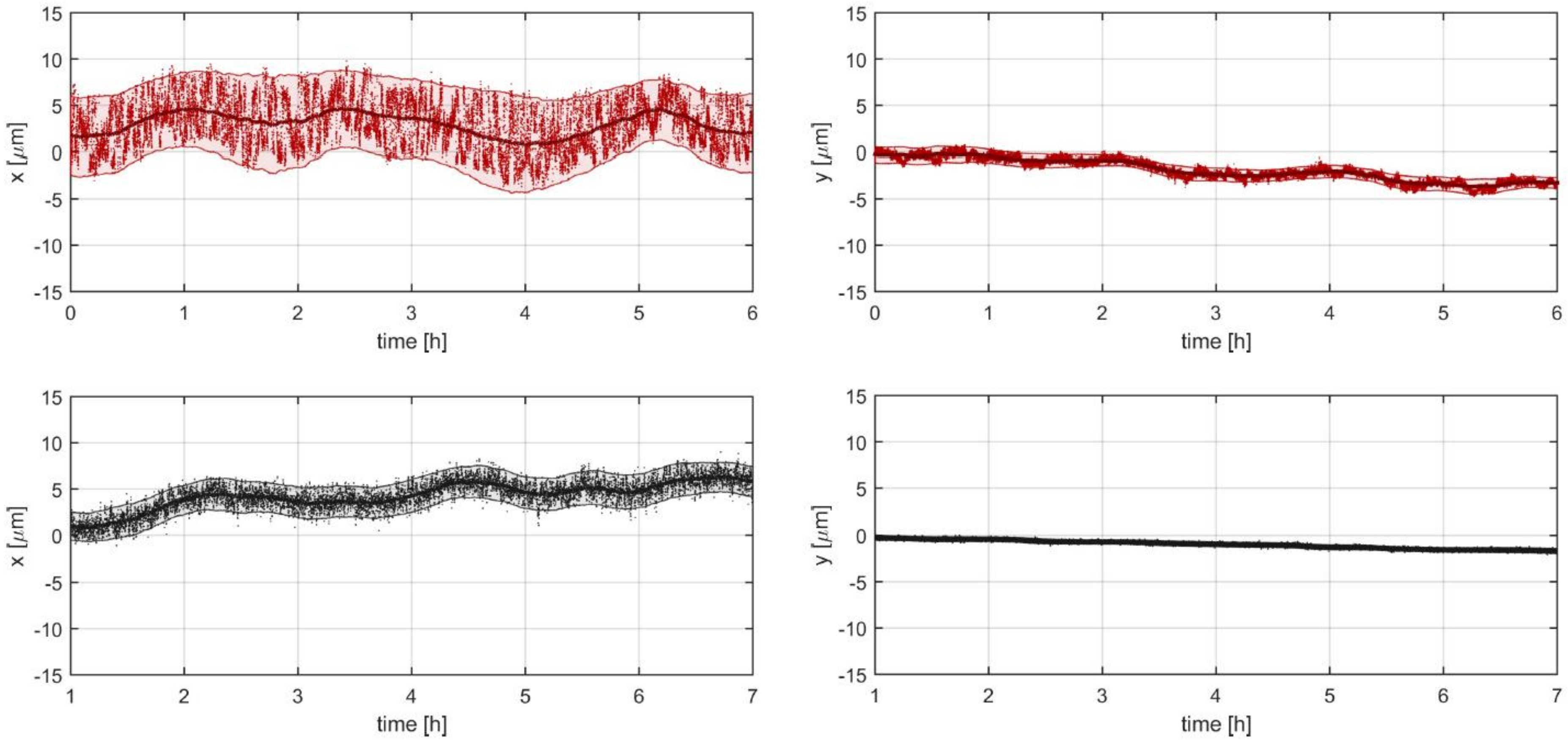


Fig. 9: Frontal view of the middle plate in the long range setup.

Table 3: Results of misaligning the middle support plate while the sensors were taking data.

Sensor	Δx_1	Δy_1	Δx_2	Δy_2	Δx_3	Δy_3
WPS 1	-0.079 mm	-0.008 mm	0.092 mm	-0.037 mm	-0.161 mm	0.355 mm
WPS 2	-0.081 mm	-0.007 mm	0.092 mm	-0.016 mm	-0.163 mm	0.361 mm
HLS		0.002 mm		0.007 mm		0.355 mm
Tilt meter	0.019 mrad	0.036 mrad	-0.137 mrad	-0.231 mrad	-0.084 mrad	-0.010 mrad
Expected Rasdif displacement	-0.080 mm	-0.006 mm	0.058 mm	0.092 mm	-0.161 mm	0.363 mm
Rasdif measurement	-0.080 mm	-0.001 mm	0.057 mm	0.084 mm	-0.150 mm	0.361 mm



- During long term measurements Rasdif (top) again agreed with WPS (bottom) within 10 µm.

- The Rasdif systems in the short range setup do **not agree** with the Rasnik sensors in the same setup:
  - The cause of this has to be investigated with additional measurements;
  - Precise monitoring of the plates is necessary to exclude that the plates are rotating;
- The Rasdif systems in the long range setup agree with the other sensors in the same setup with an accuracy of 10 μm;
- The error in the movement of the lasers has to be resolved to enable accurate linearity tests.