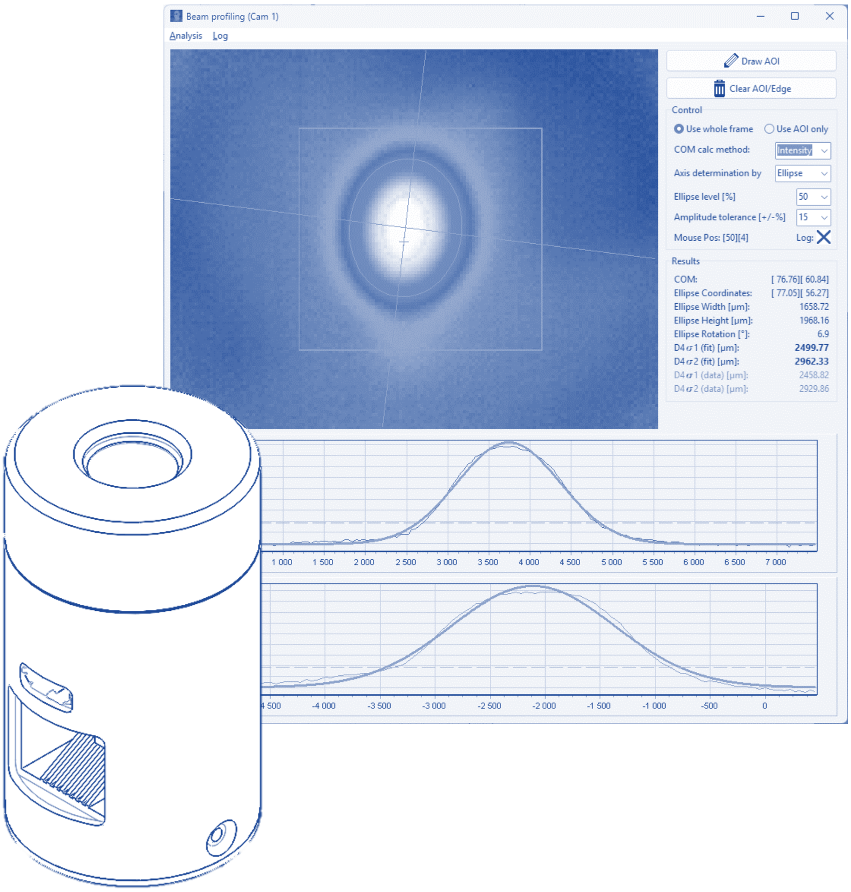

Beam Profiler Operating Manual

for Heimann Sensor ArraySoft v2

Author: B. Forg

Revision 0
11.04.2025

Content

1 Introduction

1.1 Preconditions

This software is implemented as a plugin in Heimann Sensor ArraySoft v2. ArraySoft is designed to visualize the data stream of Heimann's low-cost thermopile array modules with interface types of UDP or USB. The BeamProfiler module is enabled in a special release of the ArraySoft v2. Heimann provides thermopile arrays with different sizes and resolutions (hence different possible framerates), which can be configured with different planar filter materials, like CaF2, Ge, HRFZ-Si, Sapphire, BaF2 and even filter material provided by the customer, enabling beam analysis from the NIR to the FIR.

A beam profiler module supplied by Heimann Sensor is required and needs to be connected to the computer in use, according to the instructions in the ArraySoft manual. Furthermore, the ArraySoft release with beam profiler needs to be installed. The correct installer can be identified by the suffix "wBP" (for with Beam Profiler), i.e. "SetupHTPAdGUIv2_34_wBP.exe".

1.2 Purpose

This software is designed for analysing a live stream of infrared images provided by a Heimann Sensor HTPAd module. It will analyse 2D intensity profiles of laser beams and determine beam-specific parameters, such as the beam width. The algorithms used implement the recommended ISO standards.

2 Getting Started and General Considerations

For obtaining accurate results, the following properties should be considered:

1. Heimann Sensor's beam profiler modules usually come with a precalibrated setting, so that streaming in "T mode" is possible (refer to the HTPAd GUI manual). This calibration primarily minimizes pixel drift caused by changes in ambient temperature and compensates pixel sensitivity differences. However, small offsets might remain as a residue. Furthermore, offsets to the pixel output voltage may arise from the setup, e.g. when an object with different temperature than the sensor temperature might be in the FOV of the sensor. Since the sensor has a planar filter and no lens, this is usually negligible, but working with so-called dark offsets might yield better results. This can be done via:
    a. Switching the source off
    b. Run the module in V mode
    c. Press the button "Rec Th", make sure checkbox "Subtract Thermals" is set
    d. Now each subsequent frame will subtract the dark offsets
    e. Switch the light source on again

2. An optical attenuator might be necessary, start with the lowest power setting you can achieve. Coherent light may produce interference fringes caused by every reflective surface in the beam path. These will be visible in the image. These reflections can be avoided by picking different optical coatings depending on the laser wavelength or by simply slightly tilting the surface in respect to the beam.

3. Saturation: Always check the saturation level of the beam. Run the device in V mode. If you have configured the module using 16 bit ADC values, the maximum reading will be $2^{16} - 1$. However, keep in mind, that the operational amplifiers in the HTPAd are not rail-to-rail, so staying approximate 8% below the maximum reading is advised.

4. Sensor size: Make sure the FPA is larger than your beam size.

5. Resolution: While smaller pixels generally have a worse SNR, they might yield more information about the beam, especially for small beam profiles. In most cases, the incident power can easily be increased to compensate for the SNR.

3 Operation

After installing the ArraySoft with Beam Profiler (wBP), the program needs to be started, the camera connected and the stream should be running either in T mode or in V mode. Refer to the manual of ArraySoft to get instructions regarding these points.

If running in V mode, make sure to follow the dark offset compensation procedure described in 2. After connecting the module, a new slot in the GUI appears, the beam profiler can be started in the following dialogue:

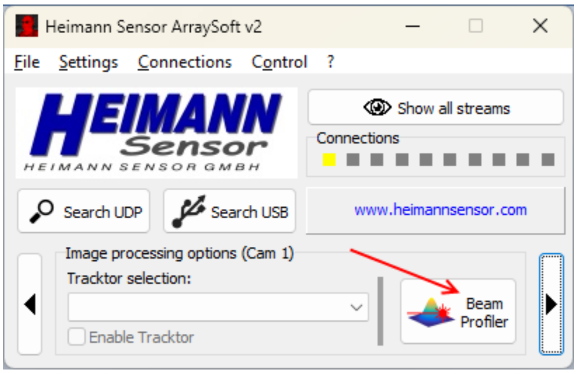

Figure 1 Starting the plugin

3.1 General

Generally, almost every setting applied to the slot of the device will be applied to the beam profiler data. This is of special interest for filter settings like Frame Stacking, IIR, FIR. These settings can be used to denoise the image and improve the SNR.

Keep in mind: Applied filters with a spatial component might alter the measurement result! Filters with spatial component are AWA and Median. Make sure, that these <u>are not enabled</u> in the corresponding slot.

Actually, the mirror options of the slot will not be applied to image of the beam profiler. Also, interpolation will not be applied, since this does not yield better results.

If the device is used in voltage mode, it is possible to disable the source, build a mean dark frame by pressing "Rec Th" (see Manual of the ArraySoftv2) and subtract the recorded dark frame from each consecutive frame. The source can be switched on again and influence due to the setup should be eliminated.

3.2 Main Control Frame

The main control frame is used to setup the basic parameters of the beam analysis, such as area of interest (AOI), axis, axis orientation and the center of mass (COM). Appearance:

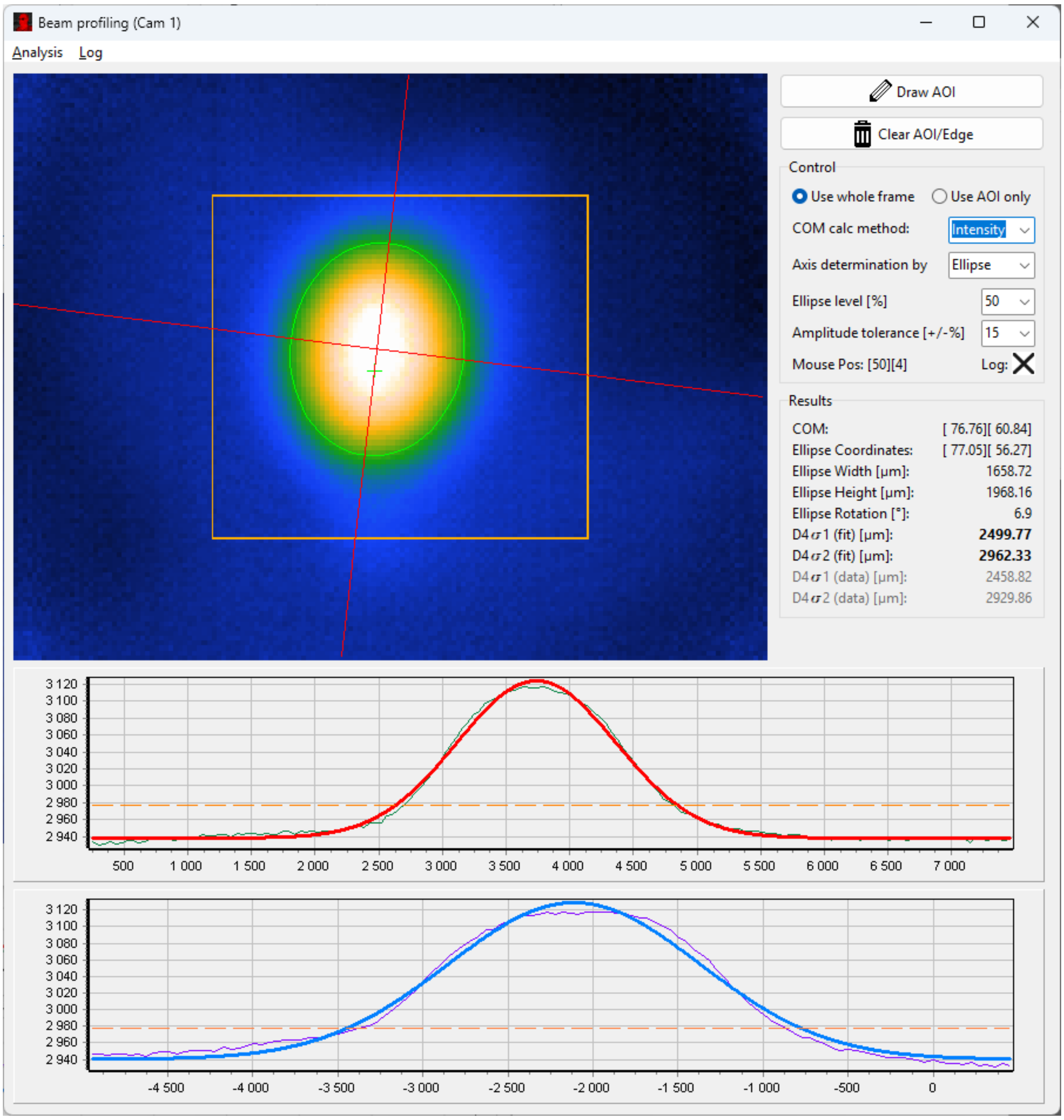

Figure 2 Main Control Frame

The image shows the actual data streamed by the module. The false color scheme can be changed via the color selection in the according slot of the GUI. Furthermore, the basic parameters are shown. The COM is represented by a small lime colored cross. The actual used axis displayed as two red lines, they are always orthogonal to each other. If another orientation is of interest, it is necessary to set it manually.

For an explanation of the control elements refer to 3.4.

3.3 Ellipse Calculation

It is possible to select the data of pixels in a certain intensity region to fit an ellipse to these data points. For data selection two parameters can be set:

- The average relative intensity level (ComboBox Ellipse level) for setting the base of the amplitude
- Amplitude tolerance [+/-]

The concept is shown in the Figure 3. The selection "Ellipse level" is represented by the darker plane, the amplitude tolerance is shown by the two lighter planes below and above the main amplitude level planes. All data points, which are in between the two lighter planes, are marked with a green circle. These are the points, which will be used for the ellipse generation. Ellipse height and width will be determined and displayed. The two main axes of the ellipse can be used as axis for the beam intersection. The ellipse height and width depends of course strongly on the set limits for amplitude level and tolerance, therefore these values can be used only as a rough estimate, but do not represent any ISO conform value. If 50 % for the amplitude level is selected, ellipse height and width are equal to the half power beam width **(HPBW)**.

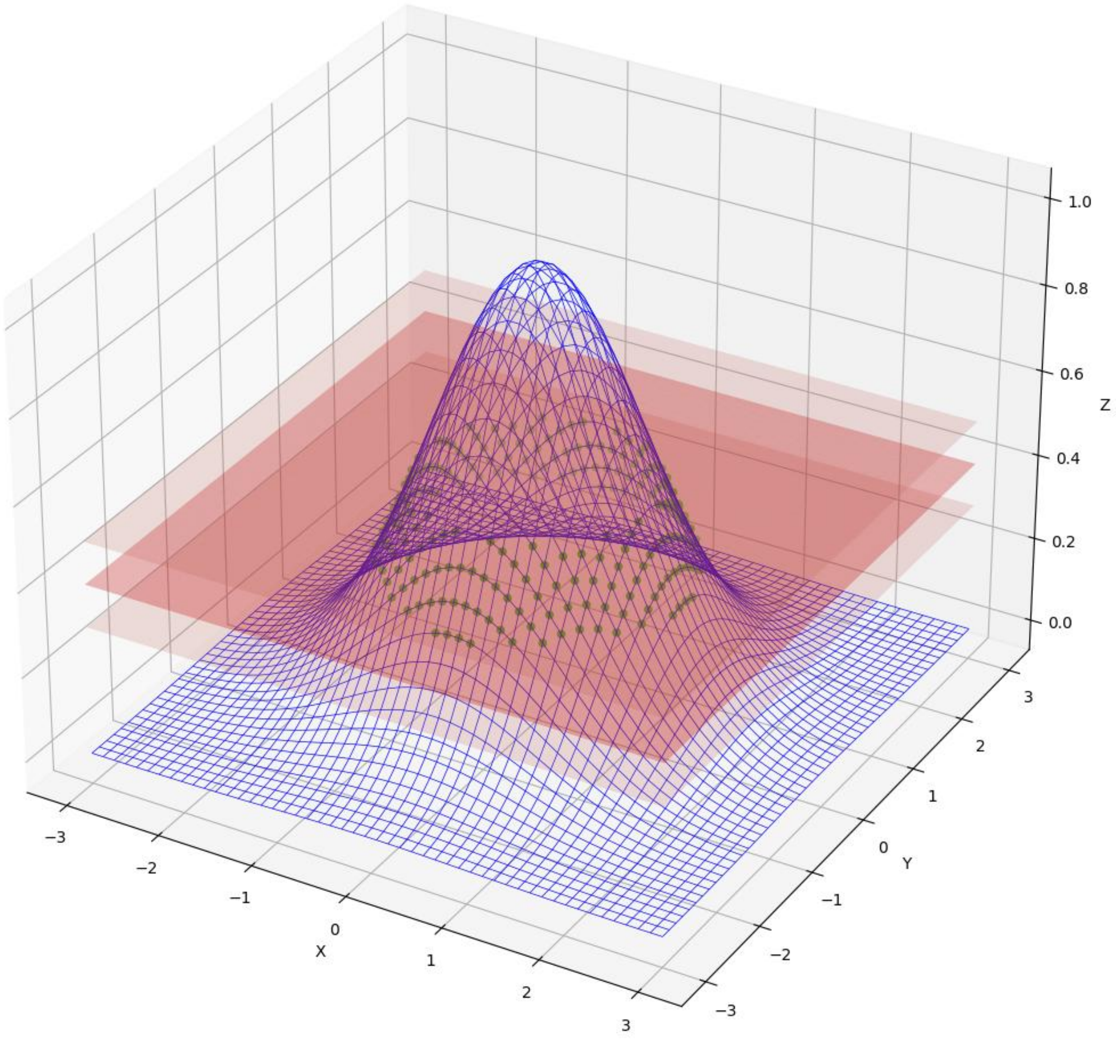

Figure 3 Intensity planes and highlighted input data for ellipse generation

3.4 Main Frame Control Elements

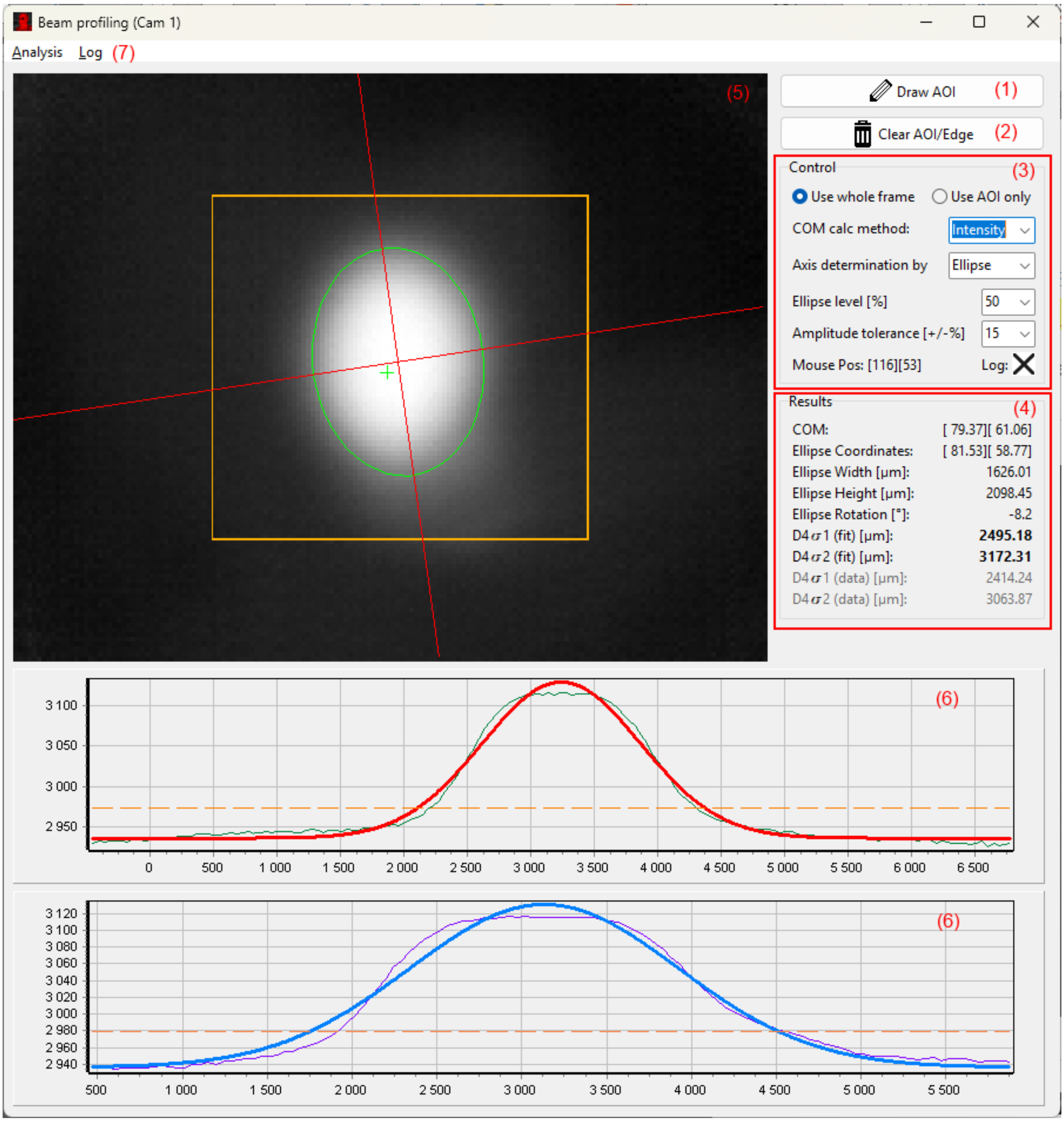

Figure 4 Main frame

Button Draw AOI / Draw edge / Set COM (1): Toggles the drawing mode between "Draw AOI" / "Draw Edge" and "Set COM":

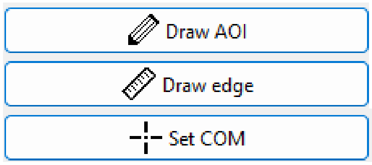

Figure 5 Modes of operation of Button (1)

"Draw AOI" allows to draw a rectangle into the main frame. Only pixels within this rectangle will be considered during analysis if the Radiobutton "Use AOI only" is selected.

"Draw edge" allows to select the first axis. The second axis will be generated through the COM and the orthogonal intersection. The edge will be only adopted, if in the axis selection box (5) "User" is specified.

"Set COM" allows the user to set the COM coordinates manually. This can be used to determine the intersection between first and second axis. "COM calc method" (4) needs to be set to "User" in this case.

Button Clear AOI/Edge (2): Clears all previously set parameters.

Group Control (3): Different settings and indicators for controlling the profiler. For a detailed description refer to 3.4.1.

Group Results (4): Several measurement results shown numerical. For a detailed description refer to 3.4.2.

Main Image (5): The main image shows following elements:

- AOI size and location (orange rectangle)
- Main axis which will be used for analysis (red lines)
- Ellipse size and location (lime colored ellipse)
- COM (lime colored cross)

The false color visualization will follow the selected color scheme in the according slot. Color schemes can also be created by the user. Please refer to the manual of the HTPAd GUI for more information.

Plots (6): Shows the raw data for the given axis (thin line) and the function fitted to this data (thick line).

Menu (7): For a detailed description of the menu and its entries refer to section 3.4.3.

3.4.1 Control

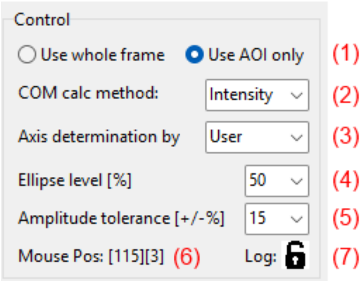

Figure 6 Elements of the control group

Selection whole Frame/AOI (1): Selection if the data of the whole frame or only the AOI is used as input data for the analysis.

COM calc method (2): Selection of the center of mass calculation algorithm:

- User: COM is selected by toggling Button Draw AOI / Draw edge / Set COM (1) to "Set COM" and clicking into the image
- Intensity: The intensity-weighted center of mass of the 2D image (either AOI or whole frame) is used
- Intensity^2: Same as "Intensity", but the squared intensity-weighted center of mass

Axis determination by (3): Selection of the method of axis determination:

- Ellipse: The axes are the main axes of the generated ellipse, see Ellipse Calculation for detailed information
- User: The primary axis drawn by the user. The secondary axis is automatically generated as orthogonal intersection to the primary axis and intersection with COM
- COM: A vertical and horizontal axis with intersection in COM

Ellipse level (4): Ellipse level allows to set the middle virtual intensity plane (darker color in Figure 3), either based on the data of the whole image or the selected AOI, if any. The ellipse level can be determined in 10 % steps, ranging from 10 to 90 % between zero and the maximum intensity in the image/AOI. It is also possible to type into the box. Ellipse levels >99 % and <1 % are not allowed, signified by red font color. Refer to Ellipse Calculation and the subsequent explanation for more information regarding the ellipse calculation.

Amplitude tolerance (5): Sets the distance of the virtual intensity planes, which mark the lower and upper thresholds for ellipse input data determination. The distance can be set in 5 % steps, ranging from 5 to 25 %. If a combination of (6) and (7) is selected, which would result in a level lower 0 % or higher than 100 %, the minimum will be set to 0, respective 100 %. It is also possible to type into the box, amplitude tolerance levels >35 % and <1 % are not allowed, signified by red font color. Regarding ellipse calculation, refer to Ellipse Calculation and the subsequent explanation.

Mouse Pos (6): This shows the actual coordinate of the mouse cursor in pixels

Log (7): Shows the current status of the log file: Closed / not opened, Opened, Recording, Pause, Successfully closed. After successfully closing a log file, the status will return to the black X again.

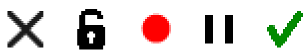

Figure 7 Possible states of the log indicator (Closed / not opened, Opened, Recording, Pause, Successfully closed)

3.4.2 Group Results

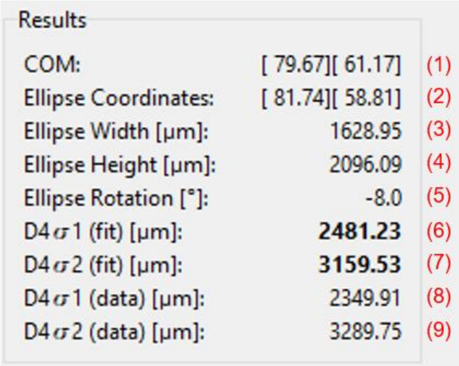

Figure 7 Visual representation of the results

COM (1): Shows the x and y coordinates of the center of mass in pixels.

Ellipse coordinates (2): Shows the x and y coordinates of the center of the ellipse in pixel.

Ellipse Width [µm] (3): Shows the calculated width of the ellipse in µm.

Ellipse Height [µm] (4): Shows the calculated height of the ellipse in µm.

Ellipse Rotation [°] (5): Shows the rotation of the ellipse in degrees.

D4σ1 (fit) (6): Shows the current $D4\sigma$ of the fitted function on the primary axis.

D4σ2 (fit) (7): Shows the current $D4\sigma$ of the fitted function on the secondary axis.

D4σ1 (data) (8): Shows the current $D4\sigma$ of the raw data on the primary axis.

D4σ2 (data) (9): Shows the current $D4\sigma$ of the raw data on the secondary axis.

D4 σ1/2(data) represents the standard deviation along the x-axis of the data. If the AOI does not fit well to the “tails” of the Gaussian distribution a large error is the result. Also, a suboptimal background correction may have a significant impact. This value should only be used under certain circumstances. For higher modes than TEM_{00} the return value is not correct.

3.4.3 Menu Items

The menu structure can be described by the following architecture:

- Analysis
    - Settings
    - Amplitude (t)
- Log
    - Specify file
    - Start logging / Pause logging
    - Stop logging
    - Raw data logging

Analysis→Settings: Shows the settings window of the Analyzer. For a detailed description see 5.

Analysis→Amplitude (t): Opens a window with time dependent pixel data of the image. It can be selected which percentile of the data will be drawn.

Log→Specify file: Specify the location of the log file. If the file already exists, the user will be asked, if the data should be appended. If not, the file will be cleared from remnant data. If the file does not exist, it will be created.

Log→Start logging / Pause logging: Starts or pauses the recording of the log data to the specified log file.

Log→Stop logging: Closes the log file permanently.

Log→Raw data logging: Toggles between enabling and disabling raw data logging. If enabled the raw data of the axis will be included into the log. This will enlarge the size of the log file significantly. This option is switchable during recording.

Logfile: The structure of the log file is pretty self-explanatory. A header is provided with the corresponding column values. Separator is "\t". Both axis data is printed row-wise consecutively.

HEIMANN Sensor GmbH
Maria-Reiche-Str. 1
D-01109 Dresden / Germany

Contact / Customer Support
Phone 49 (0) 6123 60 50 30
Fax 49 (0) 6123 60 50 39

Internet
www.heimannsensor.com
mail: info@heimannsensor.com

4 Methods

$D4\sigma$ is specified in the ISO standards 11145 or 11146 as a measure for the width of the beam. In the ISO 11145 the standard deviation σ along the corresponding axis is calculated to obtain $4\sigma = 4 \cdot \sigma$. For a Gaussian beam these values correspond to the waist of the Gaussian function, $D4\sigma = 2 \cdot w$.

The 1D data is given by the axis selection done in the main panel. The data will be analyzed by one of the following methods: Super-Gauss, Hermite-Gauss, Laguerre-Gauss and the Knife-Edge-Method.

4.1 Super-Gauss

The algorithm will fit a Super-Gaussian function of the following form:

$$A = exp\left(-2\left(\frac{x - x_0}{w}\right)^{2m}\right) + B$$

Where x_0 is the center position, A is the amplitude, B the offset, w the waist of the profile and m the order of the Super-Gaussian. For $m = 1$ this function is identical to the Hermite Gaussian of the order 0.

4.2 Hermite-Gauss

The algorithm will fit a Hermite-Gaussian function of the following form to the measured profile:

$$y = A \cdot H_m\left(\sqrt{2}\left(\frac{x - x_0}{w}\right)\right)^2 \cdot exp\left(-2\left(\frac{x - x_0}{w}\right)^2\right) + B$$

Where x_0 is the center position, A is the amplitude, B the offset, w the waist of the profile and H_m is the Hermite polynomial of the order m. The calculated waist w can be used to determine the beam size. For an ideal Gaussian beam with the transversal electromagnetic mode TEM_{00} the value $2w$ is equal to its $\frac{1}{e^2}$ diameter. For Gaussian beams of any order w describes the envelope of the transverse intensity distribution and is related to the divergence of the beam. The first six physicist's Hermite polynomials are:

$$H_0(x) = 1$$

$$H_1(x) = 2x$$

$$H_2(x) = 4x^2 - 2$$

$$H_3(x) = 8x^3 - 12x$$

$$H_4(x) = 16x^4 - 48x^2 + 12$$

$$H_5(x) = 32x^5 - 160x^3 + 120x$$

4.3 Laguerre-Gauss

The algorithm will fit a Laguerre-Gaussian function of the following form to the measured profile:

$$y = A \cdot \left(\sqrt{2}\left(\frac{x - x_0}{w}\right)\right)^{2|\alpha|} \cdot L_m^\alpha \left(2\left(\frac{x - x_0}{w}\right)\right)^2 \cdot exp\left(-2\left(\frac{x - x_0}{w}\right)^2\right) + B$$

Where x_0 is the center position, A is the amplitude, B the offset, w the waist of the profile and L_m^α is the **generalized** Laguerre polynomial of the degree m.
Refer to https://en.wikipedia.org/wiki/Laguerre_polynomials for the exact polynomials.

4.4 Knife-Edge Method

The Knife-Edge Method involves moving a sharp edge (such as a razor blade) through the laser beam, while measuring the transmitted power. As the knife-edge progressively blocks the beam, the power measured by a photodetector decreases. By analyzing this power reduction as a function of the knife-edge position, the beam's spatial intensity profile can be determined. This is the physical principle, which can be virtualized by software. The algorithm virtually moves a boundary along the axis and integrates the remaining signal. The result is normalized and shown in the plot in dependency of the edge position. The error function can be used to express the integral for an ideal Gaussian beam by $\frac{1}{2}P\left(1 + \text{erf}\left(\sqrt{2}\frac{(x-x_0)}{w}\right)\right)$. Where x_0 is the center position, P is the integrated total intensity and w is the waist. Different values can be used to determine the beam size:

- 10/90: The distance between two positions, where the remaining total intensity corresponds to 10 and 90 % of the maximal value.
- 16/84: The distance between two positions, where the remaining total intensity corresponds to 16 and 84 % of the maximal value. For a Gaussian beam this value is equal to w. (precise these values are 0.15866 and 0.84134).

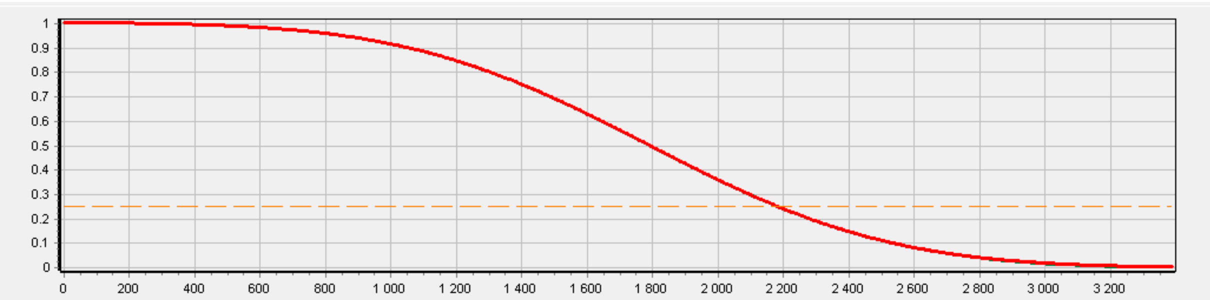

Figure 8 Error function fit of the Knife-Edge-Method

5 Analyzer Settings

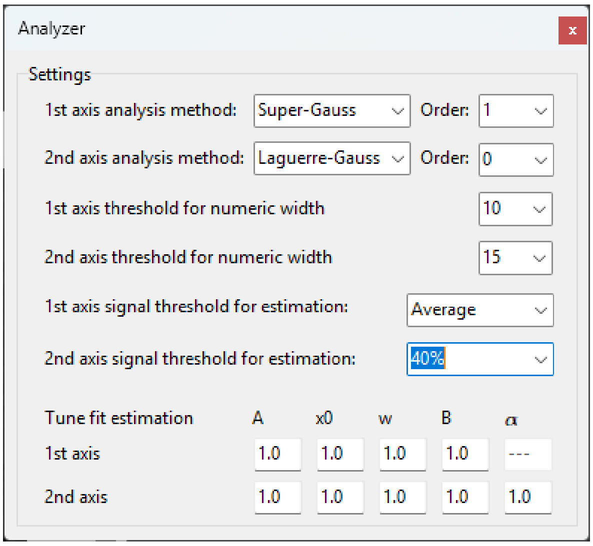

Figure 9 Settings of the analyzer

This window can be opened via the menu. The analysis method and the corresponding order are selectable in this dialogue. Furthermore, different parameters can be fine tuned, if the fit does not find the best estimation for the start values automatically.

1st/2nd analysis method: Selection of Super-Gauss, Hermite-Gauss, Laguerre-Gauss or Knife-Edge-Method for the corresponding axis.

Order: The order of the fit or, in case of Knife-Edge, the distance between two points.

1st/2nd axis signal threshold for numeric width: If the AOI does not fit well to the boundaries of the signal or there is a lot of background signal (poor dark frame correction), the numeric method by determination of the standard deviation of the x-axis yields poor results. This can be improved by introducing a level above, which x-data is used. The level is selectable by user and is shown by a dashed orange line in the according plot:

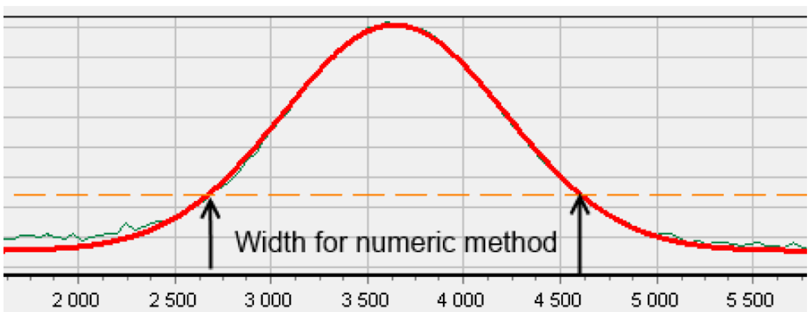

Figure 10 Selection of x-Axis width by threshold

1st/2nd axis signal threshold for estimation: This threshold is used for estimating the parameters x_0 and w as an input for the optimizer algorithm, which then determines the fit of the selected function. It works basically the same way as the threshold for the numeric width: It introduces a virtual level, all values above these level will be used for approximating the width and the center. The estimation does not need to be very precise for a good fit, but should be in the ballpark. In a few scenarios (especially for high TEM) it can make sense to set this level to another value as the average. Do this only if you experience trouble with the calculated fit to the data.

Tune fit estimation: For determining the fit, each parameter needs to have a starting value, which should be relatively close to the final real value. For high TEM it might be the case, that some of the starting values are not anticipated correctly. The values shown in the boxes are multipliers to the estimation. For Example: If the fitted curve is off, the most likely wrong starting value can, in most cases, be easily identified. In this case, it is possible to tweak the starting value by a factor, so that the optimizer finds a correct solution again. In the following example a wrong starting value was given for x_0:

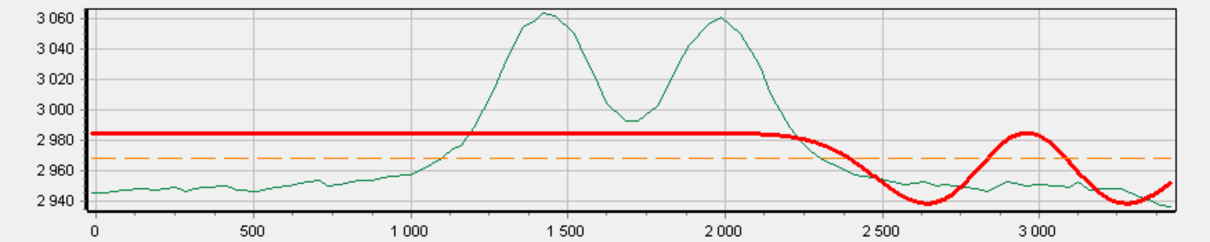

Figure 11 Mistuned starting value for the center

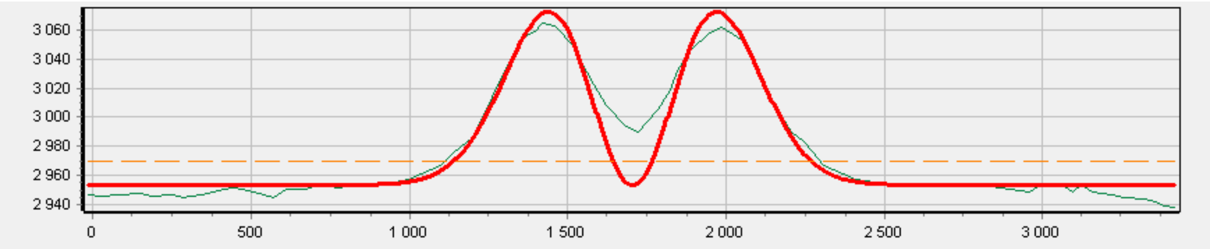

Figure 12 Correct starting value for the center

Higher modes setup: For higher TEM it is necessary to draw the axis and usually the COM manually. For doing so, set the COM calc method to “User”, set Axis determination also to “User”. Then, toggle through the options of Button (1), set the COM and afterwards draw the edge.

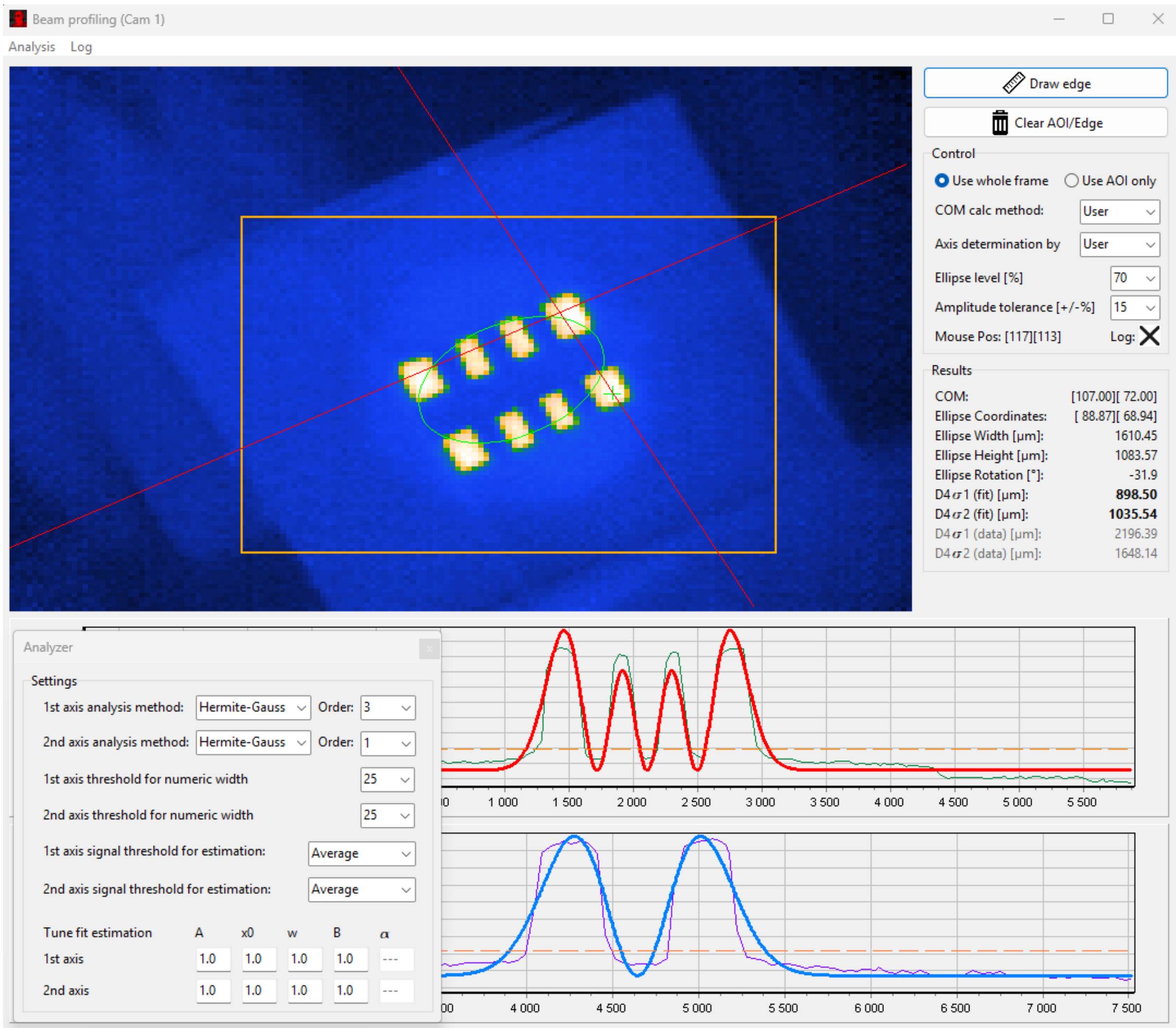

Figure 13 Setup of a Hermite TEM31 analysis

This is the setup for a Hermite TEM_{31} fit. This data was not generated by a laser, also a poor background correction was done, but it is sufficient to show the principle. COM and axis was selected by the user.

6 Amplitude vs Time

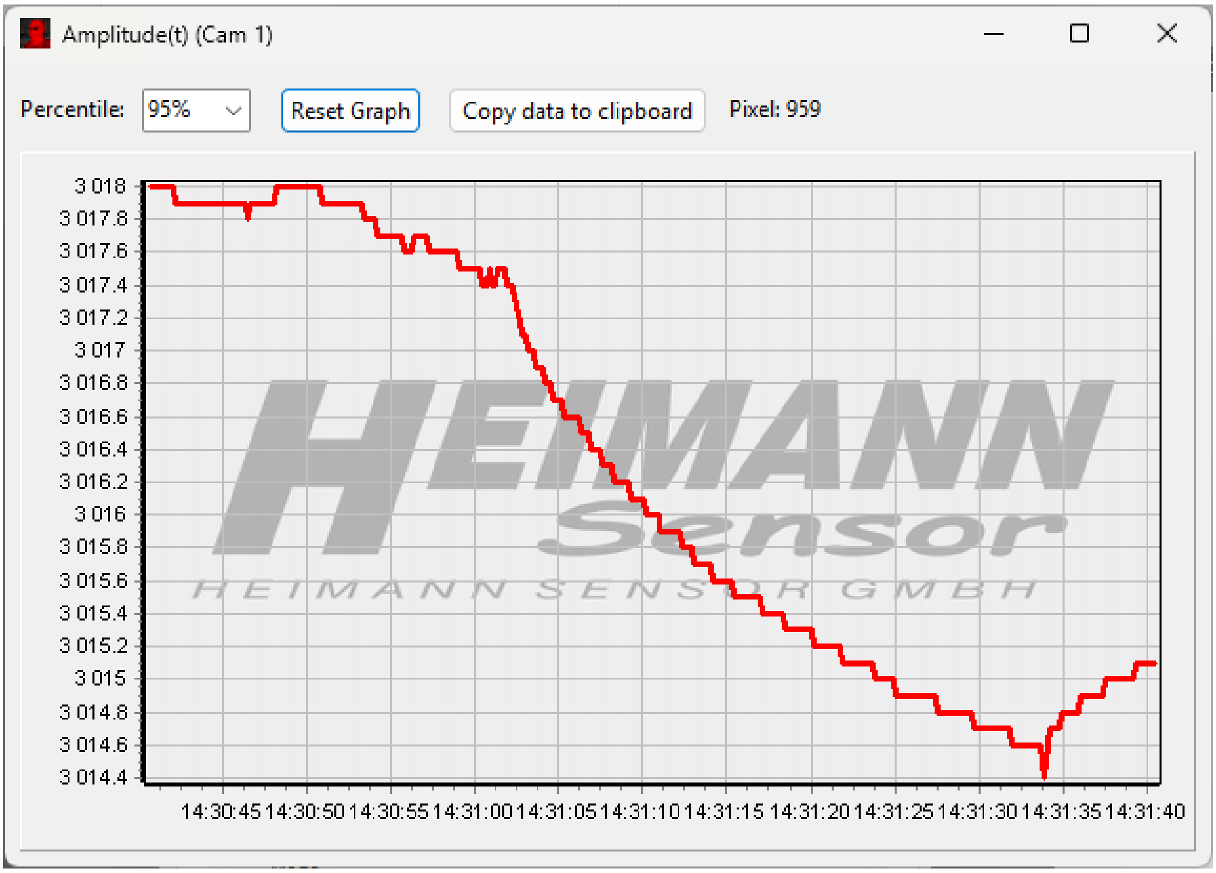

Figure 14 average maximum amplitude depending on time

This plot can show the average value of the pixels above the selected percentile. It is accessible via the menu Analysis→Amplitude(t)…

The data can be copied to the clipboard and pasted to any application by using CTRL+V. The label "Pixel" shows the amount of pixel, which are used to build the shown average of the (in this example 5 %) highest pixel values. Be aware, that sorting algorithms (which are needed to build the percentile value) can be very time consuming. This means, the performance (and respective the FPS) may drop. Also, if the plot stays open for a long time, a long graph needs to be drawn, which might also reduce the FPS of the system.