Laboratory Session on Pepperpot Emittance Measurements

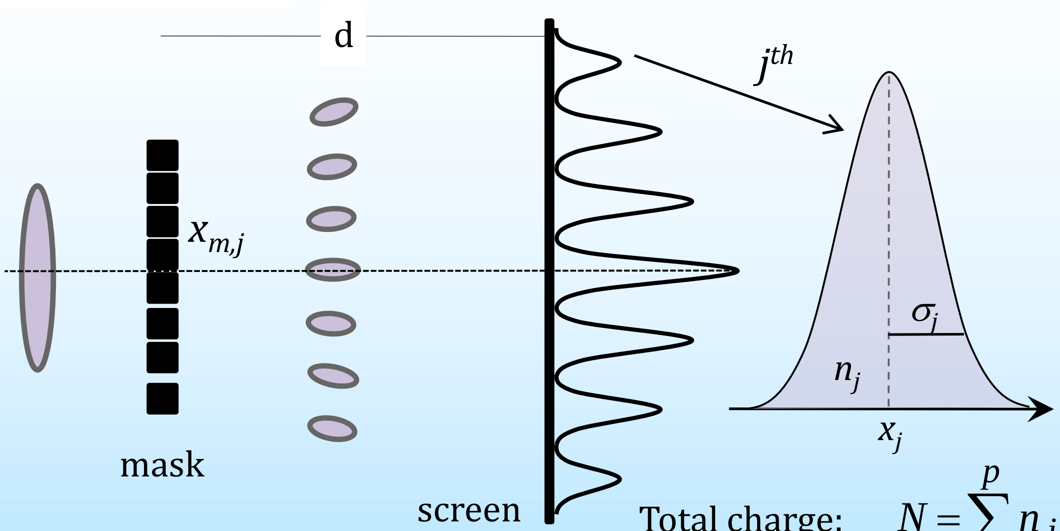
Ref 1: **Emittance Formula for Slits and Pepper-pot Measurement, Min Zhang, FERMILAB·TM-1988**

Your tasks in green frames

Pepperpot/slits emittance measurement

More at the end of this presentation

University of Strathclyde Glasgow



Total charge: $N = \sum_j n_j$

$$\varepsilon_{rms} = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}$$

$$\langle x^2 \rangle = \frac{1}{N^2} \sum_{j=1}^{p} n_j (x_{mj} - \bar{x})^2$$

$$\langle x'^2 \rangle = \frac{1}{N^2} \sum_{j=1}^{p} n_j \left[\left(\frac{\sigma_j}{d} \right)^2 + (x_{mj} - \bar{x})^2 \right]$$

$$\langle xx' \rangle^2 = \frac{1}{N^2} \left[\sum_{j=1}^{p} n_j x_j \overline{x'_j} - N \bar{x} \bar{x}' \right]^2$$

In all beamlets:

Mean position:

$$\bar{x} = 1/N \sum_j n_j x_{m,j} = \langle x \rangle$$

Mean divergence:

$$\bar{x}' = 1/N \sum_j n_j \bar{x}'_j = \langle x' \rangle$$

In j^{th} beamlet:

Mean divergence:

$$\bar{x}'_j = 1/n_j \Sigma x'_{ij}$$

rms divergence:

$$\sigma_{j,x'} = \frac{\sigma_j}{d}$$

with

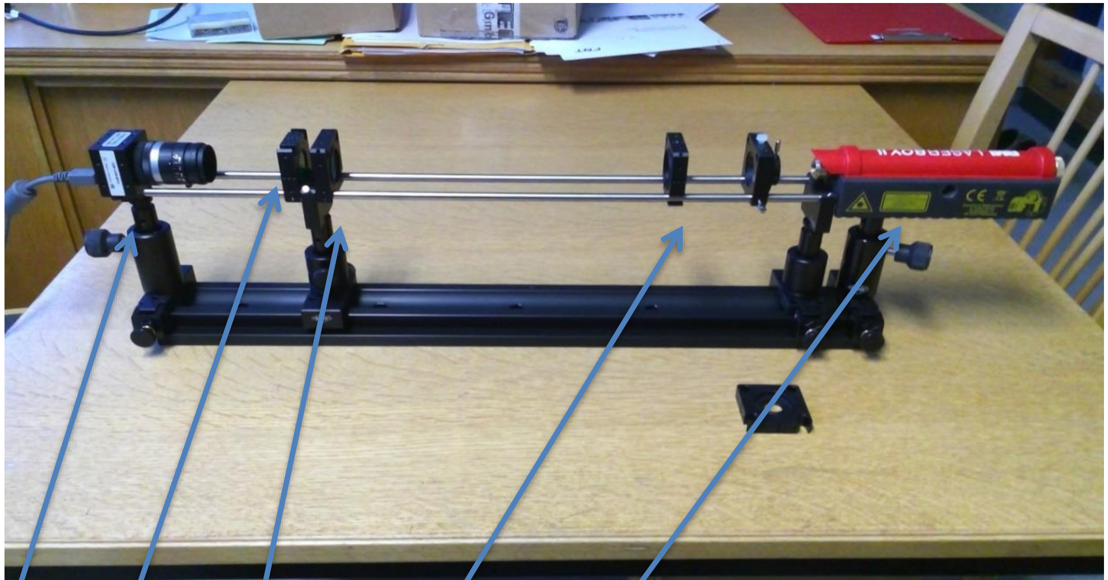
$$\sigma_j \equiv \sqrt{\frac{1}{n_j} \sum_{i=1}^{n_j} (X_{ji} - \bar{X}_j)^2},$$

which is the rms spot size of j-th beamlet on screen.

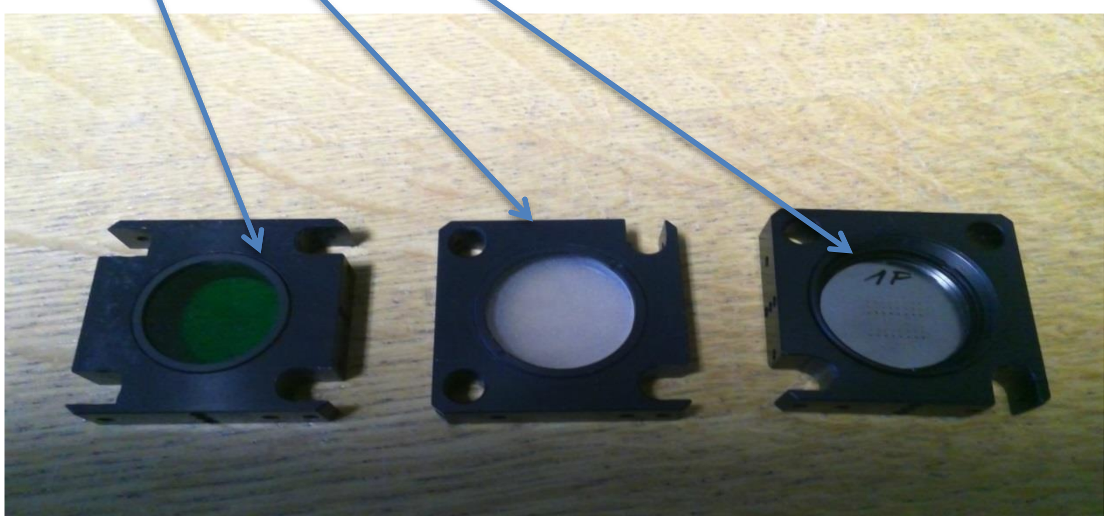
p = number of slits, $x_{m,j}$ = j-th slit position, N = all particles behind the slits

n_j = number of particles passing through slit (weight of spot intensity)

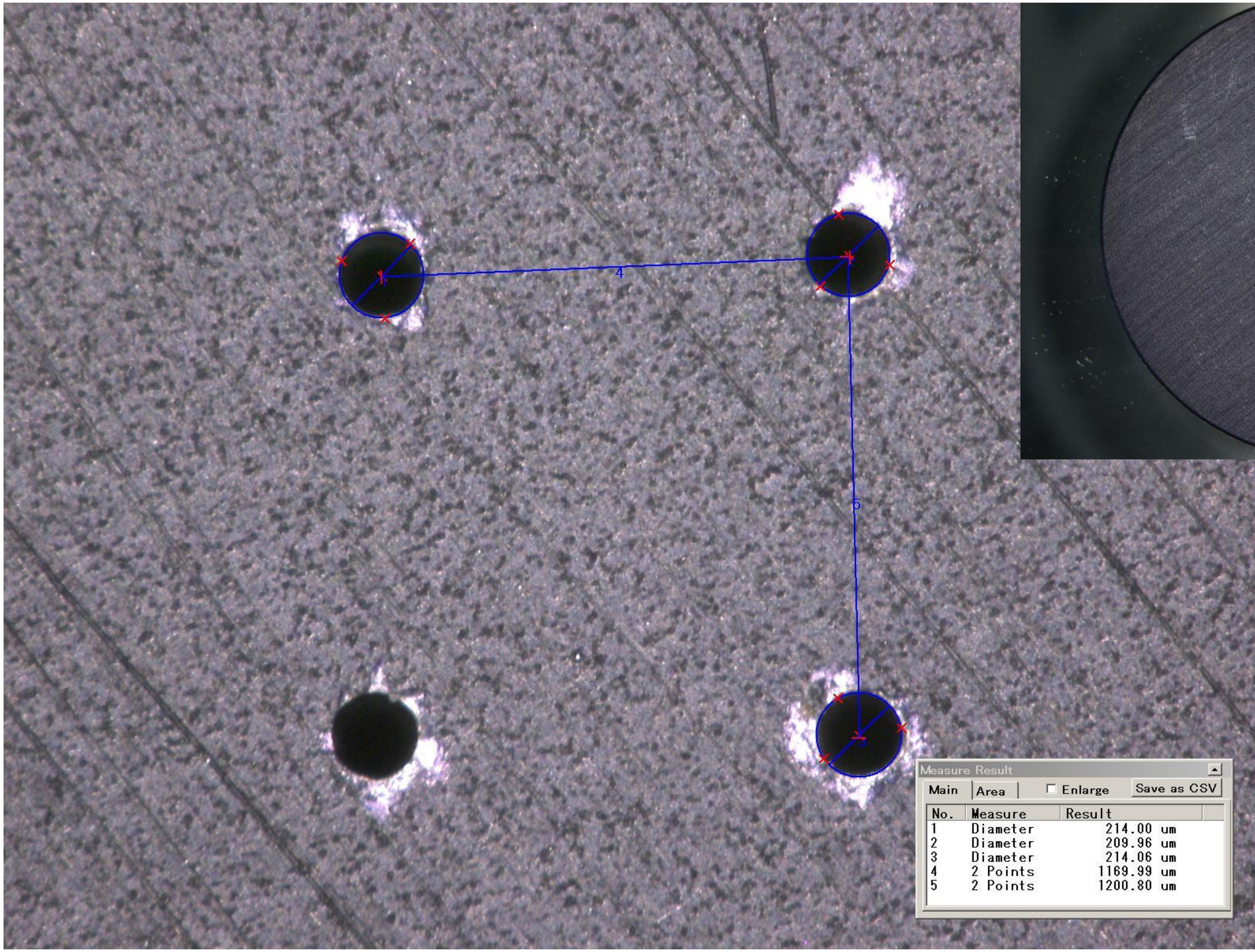
Pepperpot Emittance Measurement

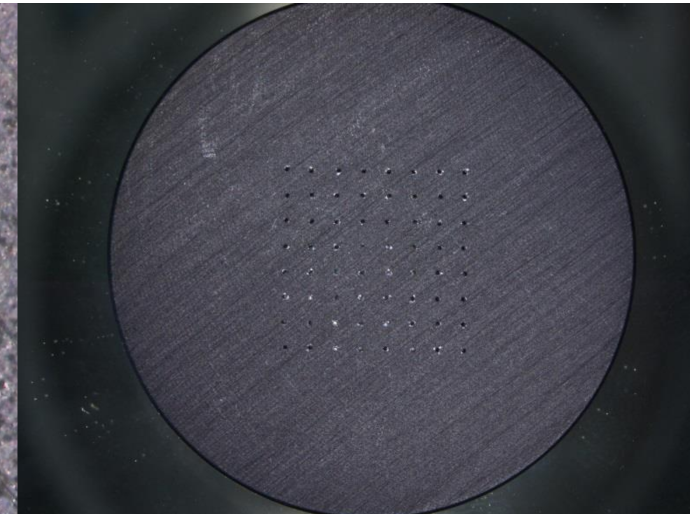


Optical bench with: Camera, ~~Filter~~, Screen, Pepperpot plate, Laser, Data acquisition (CCD readout), Data analyzation (ImageJ), Evaluation program (Excel)



Pepperpot Emittance Measurement





There are 8 rows with 8 holes each. The holes have a diameter of 210 μm. The horizontal distance is 1170 μm in each row.

Peppercot Measurement

Only the evaluation of the horizontal phase plane is implemented but… on an optical system horizontal and vertical phase space is symmetric.

Steps to be performed:

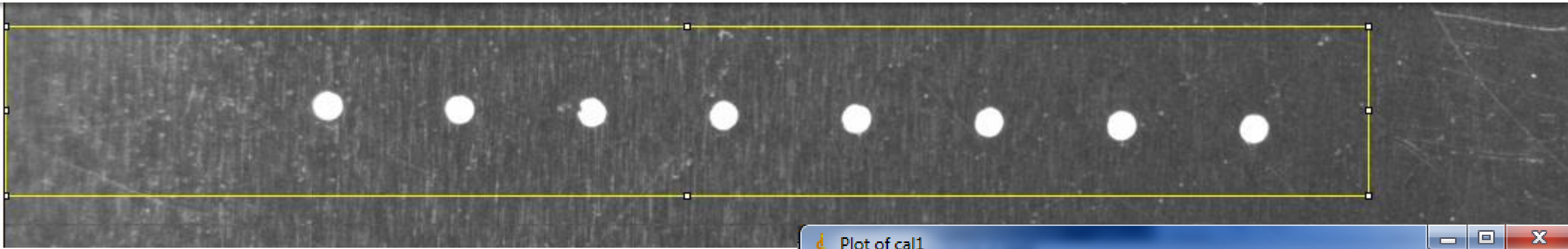
1. We will use a series of horizontal holes calculating the projection of the image to the horizontal axis. Therefore …
   Make sure all 8 holes are visible, almost aligned and are on a horizontal line (use 2048x1536 resolution)
2. Measure the distance between the holes (in pixels) and calculate the scaling factor s [pixels/mm]
   To do this: Replace the screen with the pepperpot plate. After this measurement keep the distance screen-camera constant.
   Save the image as an .jpg file
3. Take the pepperpot image on the screen (make sure the camera focuses on the screen), save it and calculate the emittance.

In more details: Your tasks in green frames

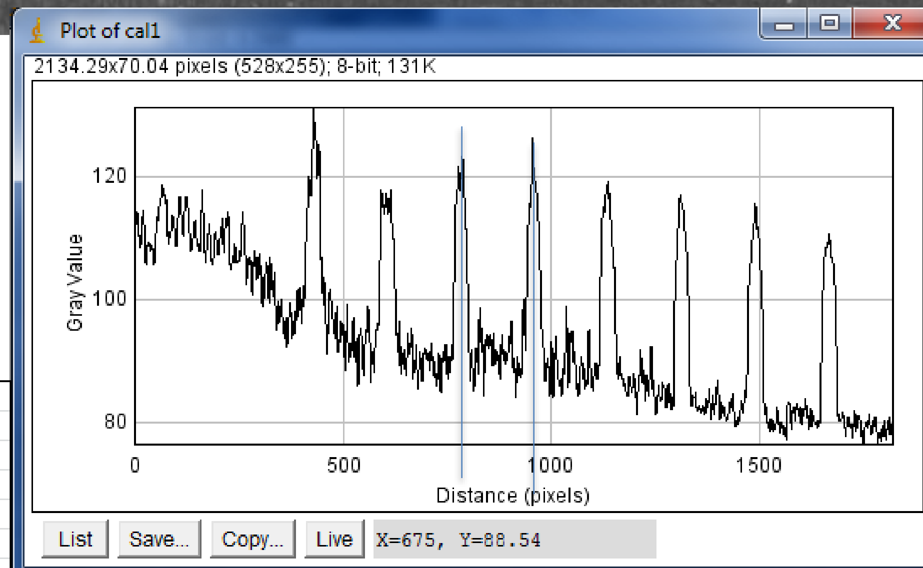
Camera Calibration

Check: Do not saturate (255)

- To 1) and 2): **<u>Camera Calibration!:</u>** Replace the screen with the pepperpot plate. The distance of the holes (1.170 mm) is known and can be used for calibration. Focus the camera and take a picture of all 8 holes in the middle of the picture and measure the distance in pixels. Hint: Use a white paper to illuminate the holes from the back. Keep the filter in.



Use ImageJ to open the picture , define an ROI (up to the left side =0!!!) and measure the distance between 2 holes. Enter this number into the pre-pepared Excel sheet “Pepperpot_calc.xlsx” at c1 and c2. The calibration will be calculated automatically (yellow field).



For Calibration (pixels/mm)						
dist. Of holes:	1.202	mm		dist. Pepperpot-Screen L =	188	mm
c1=	425	pixel				
c2=	673	pixel				
cal:	206.3227953	pixel/mm				

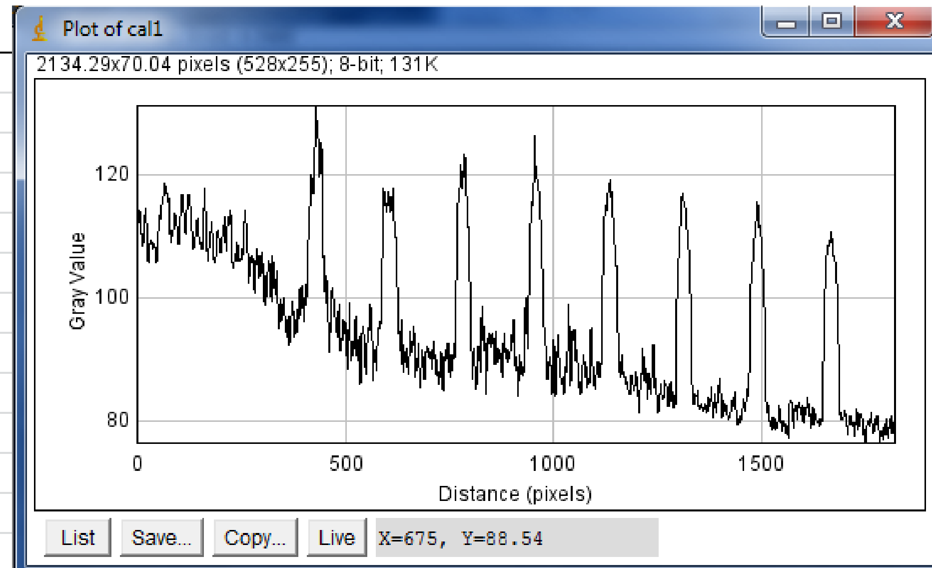
Camera Calibration

Check: Do not saturate (255)

- Use the picture also to define the positions of the holes:

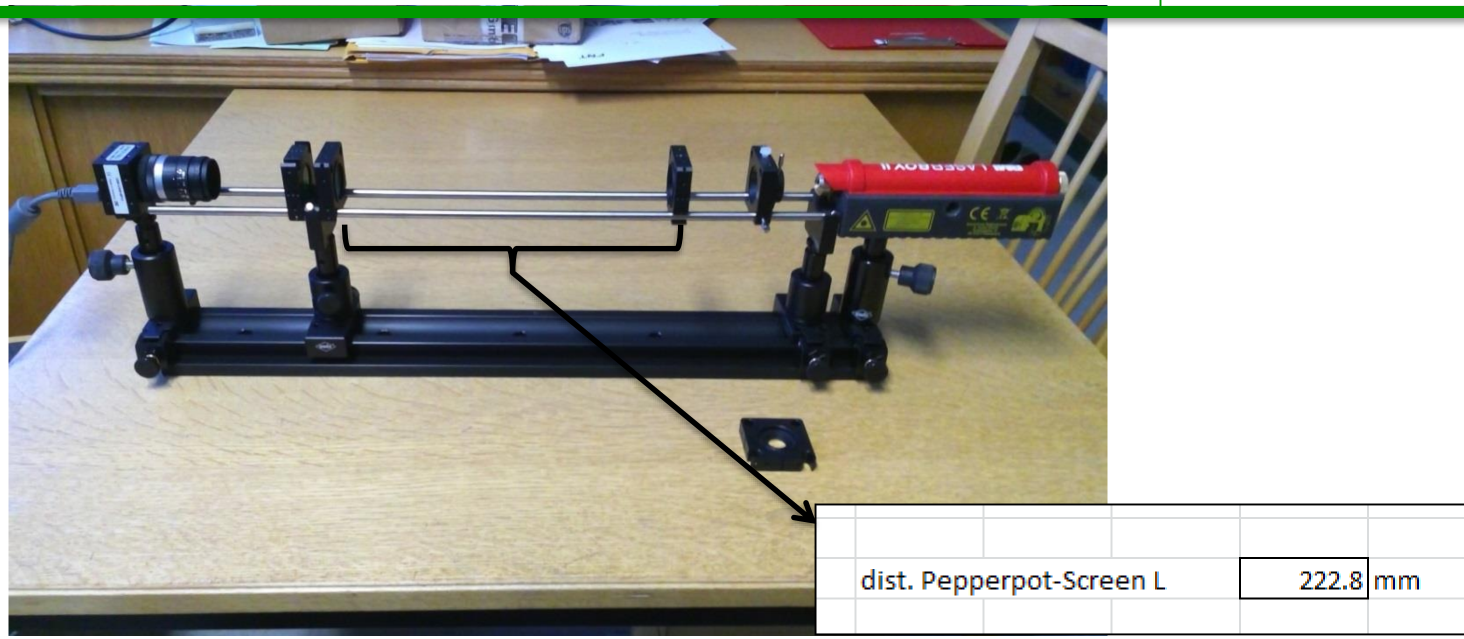
Measure the x coordinate in Pixels of the center of each hole. Enter this number into the Excel sheet at xs1 to xs8.

For Calibration (pixels/mm)			
dist. Of holes:		1.170	mm
	c1=	425	pixel
	c2=	673	pixel
	cal:	206.3227953	pixel/mm
Center Position of hole images of Pepperpot:			
	xs1	460	pixel
	xs2	702	pixel
	xs3	950	pixel
	xs4	1192	pixel
	xs5	1428	pixel
	xs6	1670	pixel
	xs7	1906	pixel
	xs8	2160	pixel

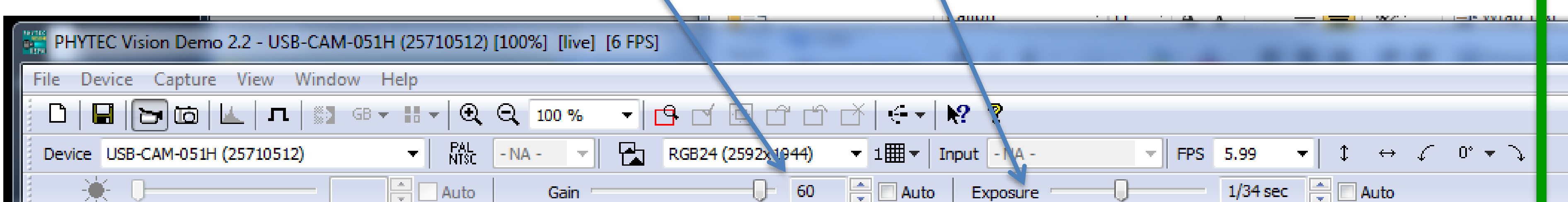


Camera Calibration

Check: Do not saturate (255)

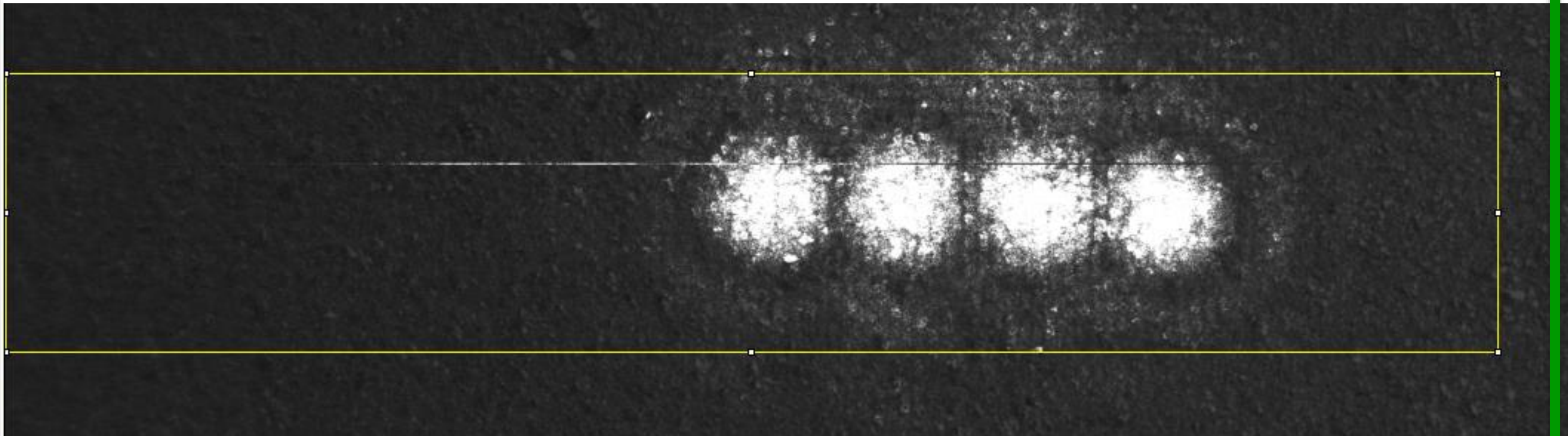


Now put the screen at the **exact location** of the pepperpot (keep camera focus, etc.) and put the pepperpot between the aperture and screen, so that the images of the holes **do not overlap**. Measure the distance L between pepperpot and screen and enter it at L in the Excel sheet. Switch on the laser. Ensure that the one of the rows used for calibration is now illuminated (at least 4 holes should be visible) by the laser and projected on the screen. Ensure that no saturation exist, in case adjust gain and/or exposure time of the camera. Save the picture, that is your measurement!

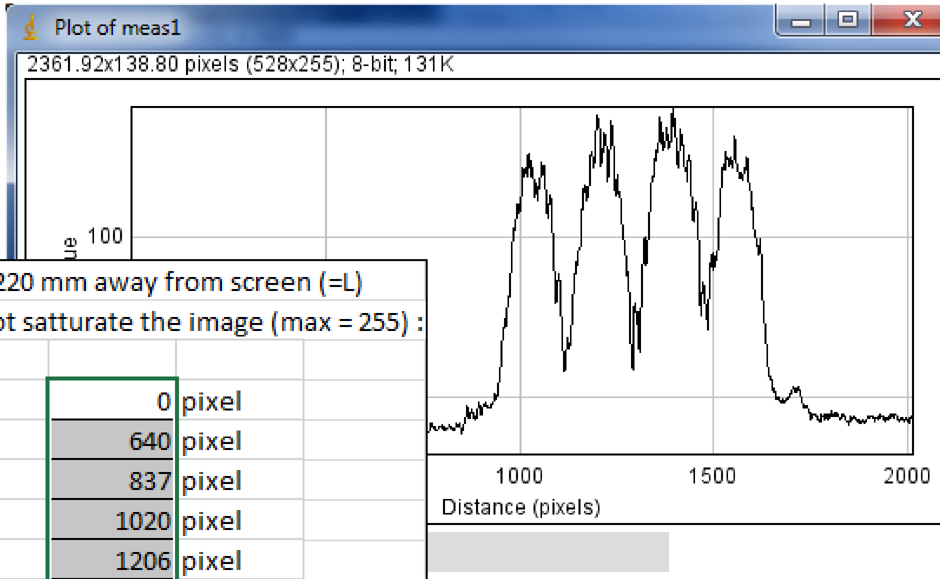


Experiment

Check: Do not saturate (255)



That is your measurement! Open the picture in ImageJ and define ROI like before (left border is 0). Plot the profile and measure the amplitude and the center position of each visible hole and enter it into Excel as n1-n8 and X1-X8, zeros for holes not visible.



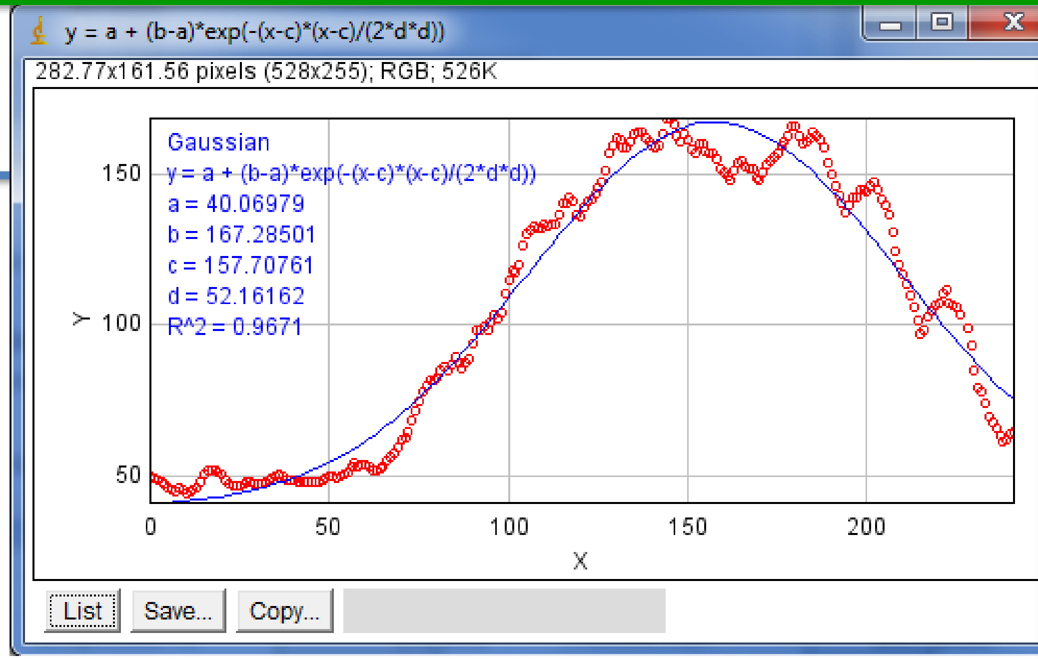
Now put screen on exact position of pepperpot and the pepperpot about 220 mm away from screen (=L)

Measure the intensity and center and RMS of each hole distribution (do not satturate the image (max = 255) :

offset	15					
Amplitude n1	15	0	bits	Position X1=	0	pixel
Amplitude n2	22	7	bits	Position X1=	640	pixel
Amplitude n3	122	107	bits	Position X1=	837	pixel
Amplitude n4	154	139	bits	Position X1=	1020	pixel
Amplitude n5	120	105	bits	Position X1=	1206	pixel
Amplitude n6	115	100	bits	Position X1=	1385	pixel
Amplitude n7	17	2	bits	Position X1=	1542	pixel
Amplitude n8	15	0	bits	Position X1=	0	pixel
Sum N =		460	bits			

Experiment

Now we need the width σ of each hole image. One can do it by hand (σ = FWHM/2.36) or can use the fitting algorithm of ImageJ: **See ImageJ Introduction.**
Enter each RMS value in the Excel table at RMS1-RMS8. Now Excel calculates <x>, <x'>, ,<x^2>, <x'$_2$>, ,<xx'> and with ε^2 = <x2><x'^{2}> - <xx'>^{2} the emittance. It follows the formalism of Ref 1.
The result should be a around some 10^{-6} rad.



Now put screen on exact position of pepperpot and the pepperpot about 220 mm away from screen (=L)
Measure the intensity, offset and center and RMS of each hole distribution (do not satturate the image (max = 255) :

offset	15							
Amplitude n1	15	0	bits	Position X1=	0	pixel	RMS1	0	pixel
Amplitude n2	22	7	bits	Position X1=	640	pixel	RMS2	70	pixel
Amplitude n3	122	107	bits	Position X1=	837	pixel	RMS3	48	pixel
Amplitude n4	154	139	bits	Position X1=	1020	pixel	RMS4	46	pixel
Amplitude n5	120	105	bits	Position X1=	1206	pixel	RMS5	44	pixel
Amplitude n6	115	100	bits	Position X1=	1385	pixel	RMS6	46	pixel
Amplitude n7	17	2	bits	Position X1=	1630	pixel	RMS7	56	pixel
Amplitude n8	15	0	bits	Position X1=	0	pixel	RMS8	0	pixel
Sum N =		460	bits						

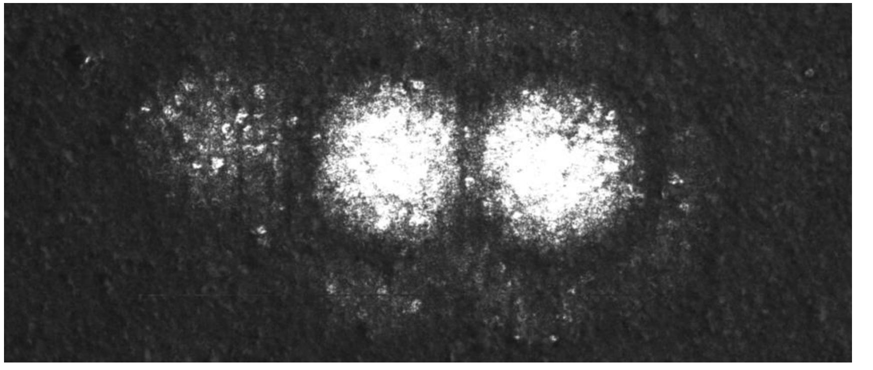
99					
100	<xx'> =	-0.00029563			
101					
102					
103	Emittance^2 =	9.16246E-07	Emittance =	0.000957	mm rad
104				9.57E-07	rad

$$\epsilon_x^2 = <x^2><x'^2> - <xx'>^2$$

Experiment

Check: Do not saturate (255)

Try to reduce the dimension of the Laser beam by closing the aperture. What happened to the emittance?



Amplitude n1	0	bits	Position X1=	0	pixel	RMS1	0	pixel
Amplitude n2	0	bits	Position X1=	0	pixel	RMS2	0	pixel
Amplitude n3	0	bits	Position X1=	0	pixel	RMS3	0	pixel
Amplitude n4	164	bits	Position X1=	1219	pixel	RMS4	32.2	pixel
Amplitude n5	165	bits	Position X1=	1460	pixel	RMS5	29.7	pixel
Amplitude n6	0	bits	Position X1=	0	pixel	RMS6	0	pixel
Amplitude n7	0	bits	Position X1=	0	pixel	RMS7	0	pixel
Amplitude n8	0	bits	Position X1=	0	pixel	RMS8	0	pixel
Sum N =	329	bits						