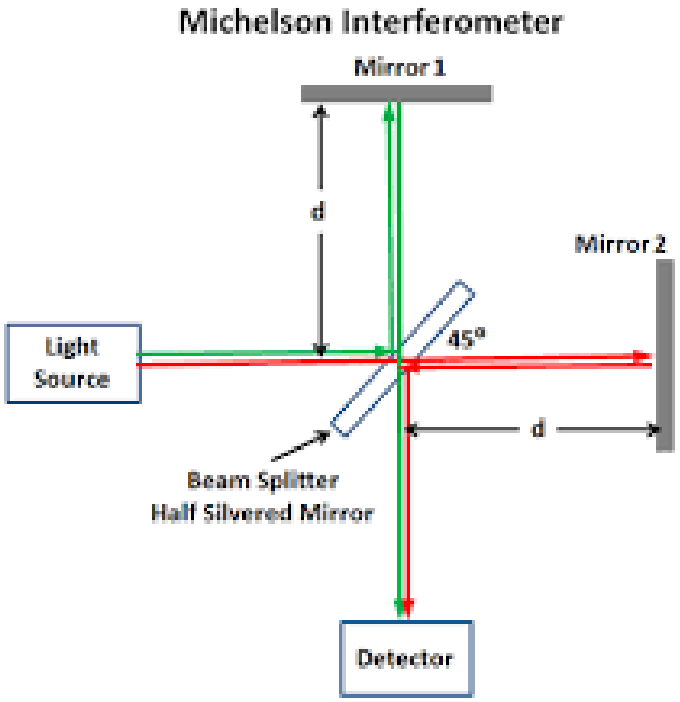
Measuring small beam sizes with Synchrotron Radiation Interferometry (SRI)

Task: To measure the virtual focus of the laser beam

Introduction to Interferometer

The method had come to accelerator physics from astrophysics and the basic idea of it is measuring of wave front spatial coherence. The well-known name of the interferometer is a *Michelson Interferometer*.

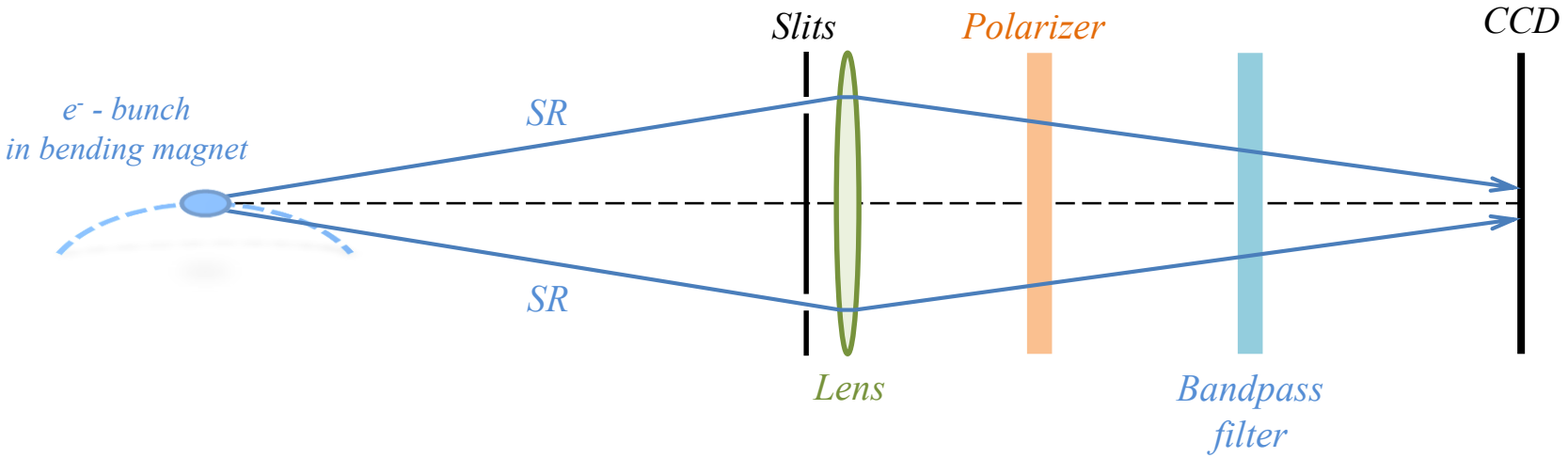
The idea had been translated and adopted for accelerator physics by T. Mitsuhashi. (*see. "Beam Profile and Size Measurements by SR Interferometer", T. Mitsuhashi et.al, Proc. of PAC 1999*). Nowadays the technique is widely used on many circular machines all over the world.



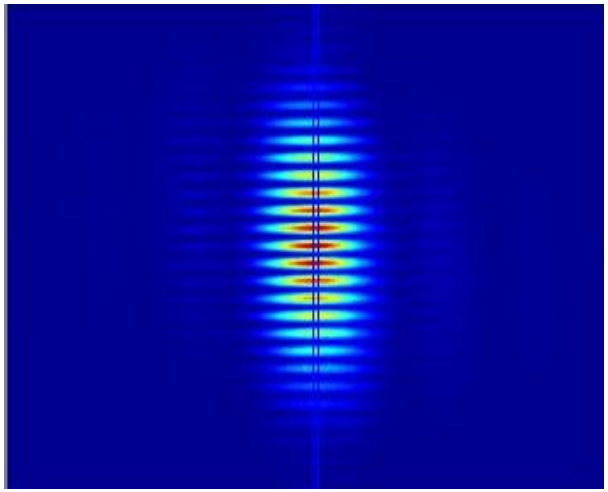
Picture at the detector

Introduction

The interferometer looks different from the Michelson one though.



The main idea is to measure somehow the spatial coherence of a wavefront. In the case of accelerator wavefront of synchrotron radiation (SR). There is a scheme of the interferometer above: the electron bunch passes through the bending magnet and radiates SR; the radiation passes through the slits and focused in the CCD plane by the lens; in addition there are polorizer and bandpass filter to get certain wavelength and polarization. Such way we cut two "identical" parts of the SR and make them interfere in the CCD plane. The picture we get in the case one may see at the right.



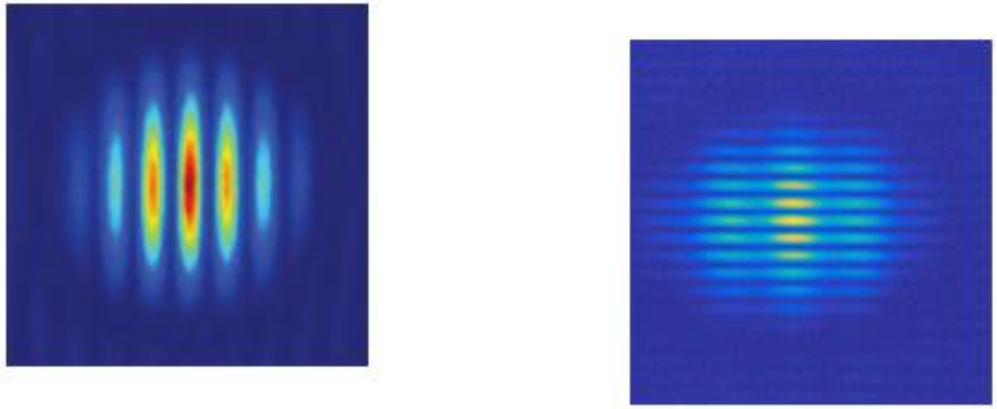
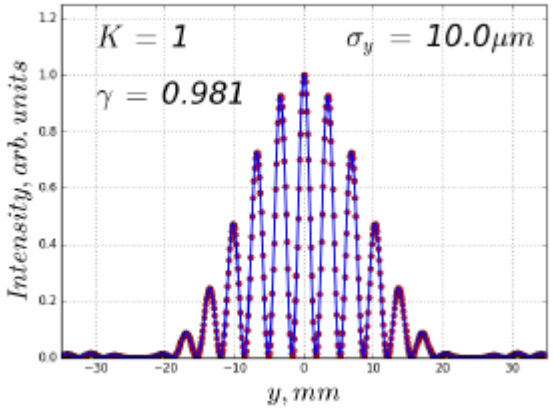


Figure 3: Measured 1-D (left) and 2-D (right) interferogram.



TWO DIMENSIONAL SYNCHROTRON RADIATION INTERFEROMETRY AT PETRA III

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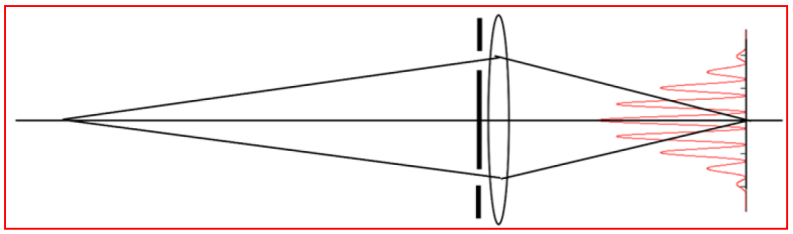
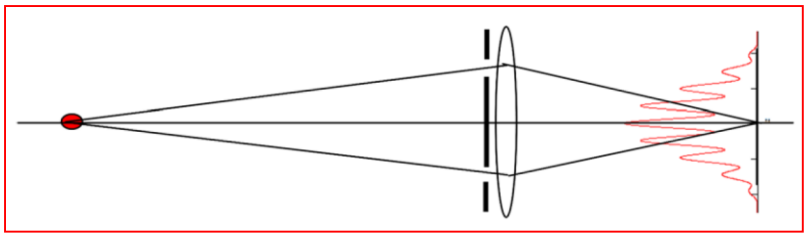
Introduction

Now we're getting to the point how we may get emittance/size from the measurements. There are two pictures below: the left one is the case when we have ***ideal point source*** (one electron); the bottom one is the case when we have ***finite size source*** (electron bunch). One may see that in the first case minimums of the interference are modulated down to zero, while the second case minimums are at some level. That is exactly what we measure.





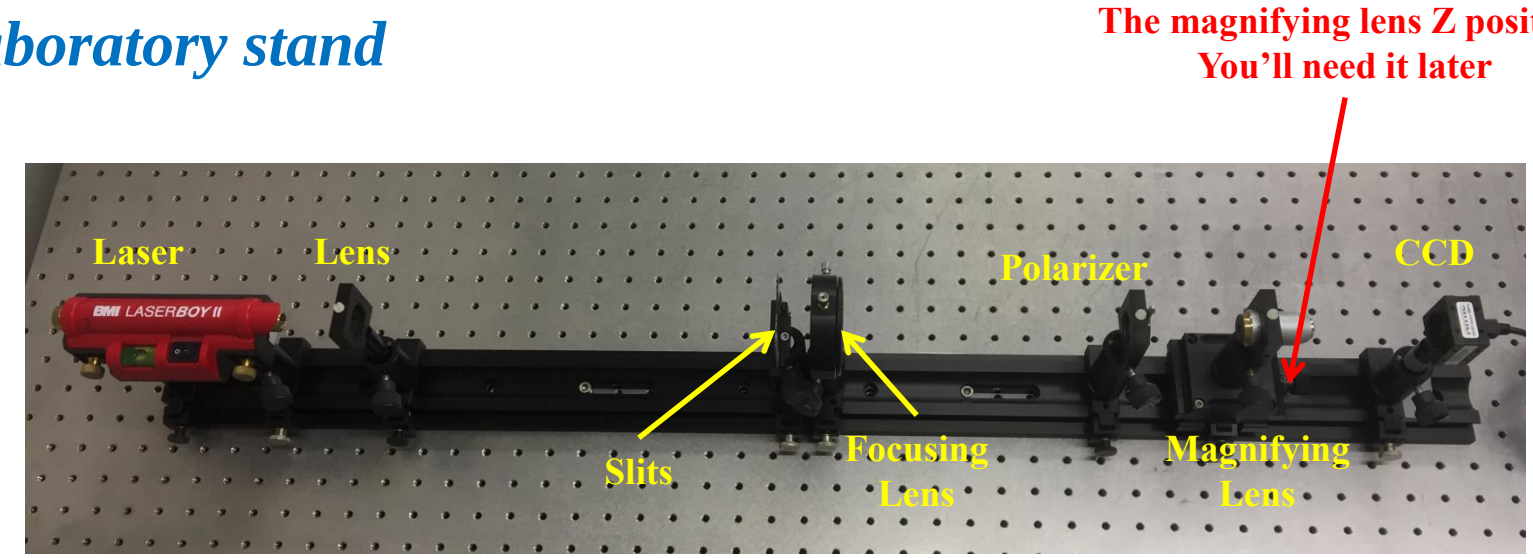
To measure this one should just fit the interference patter by the formula:

$$I(y) = I_0 \left[J_1\left(\frac{2\pi a y}{\lambda_0 R}\right) \Big/ \left(\frac{2\pi a y}{\lambda_0 R}\right) \right]^2 \left[1 + |\gamma| \cos\left(\frac{2\pi D\, y}{\lambda_0 R} + \phi\right) \right]$$

where a – half slit size, λ_0 – wavelength of SR, D – distance between slits, R – distance source–slits, γ – degree of spatial coherence. Getting the parameter γ from the fit one can recalculate it to the beam size (see formula below), and then the beam size to emittance if one knows beta-function, dispersion and energy spread:

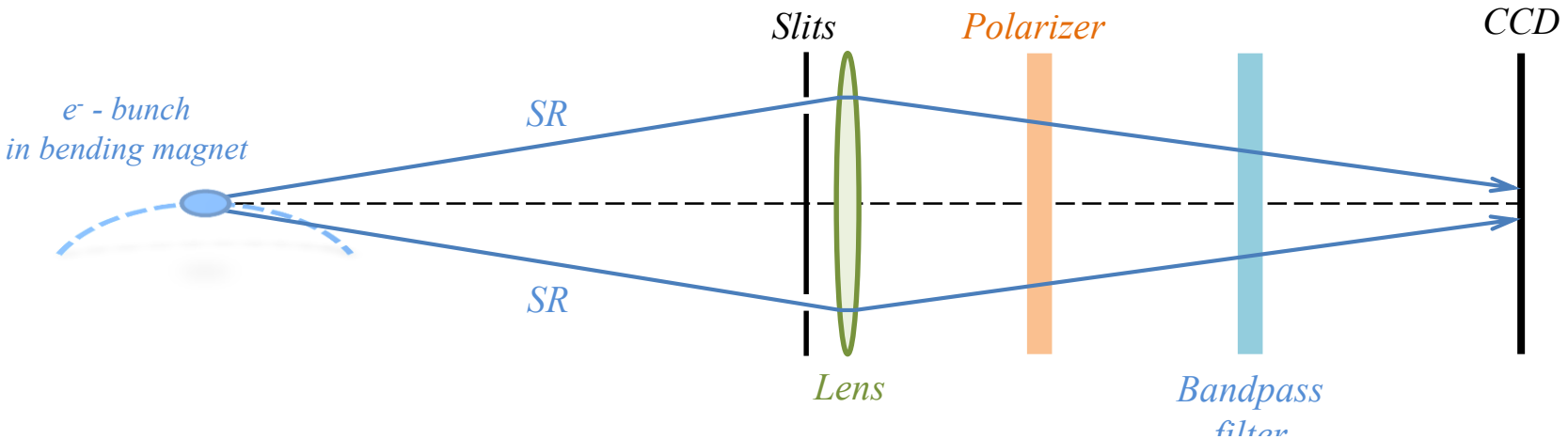
$$\sigma_y = \frac{\lambda R}{\pi D} \sqrt{\frac{1}{2} \log\left(\frac{1}{\gamma}\right)}.$$

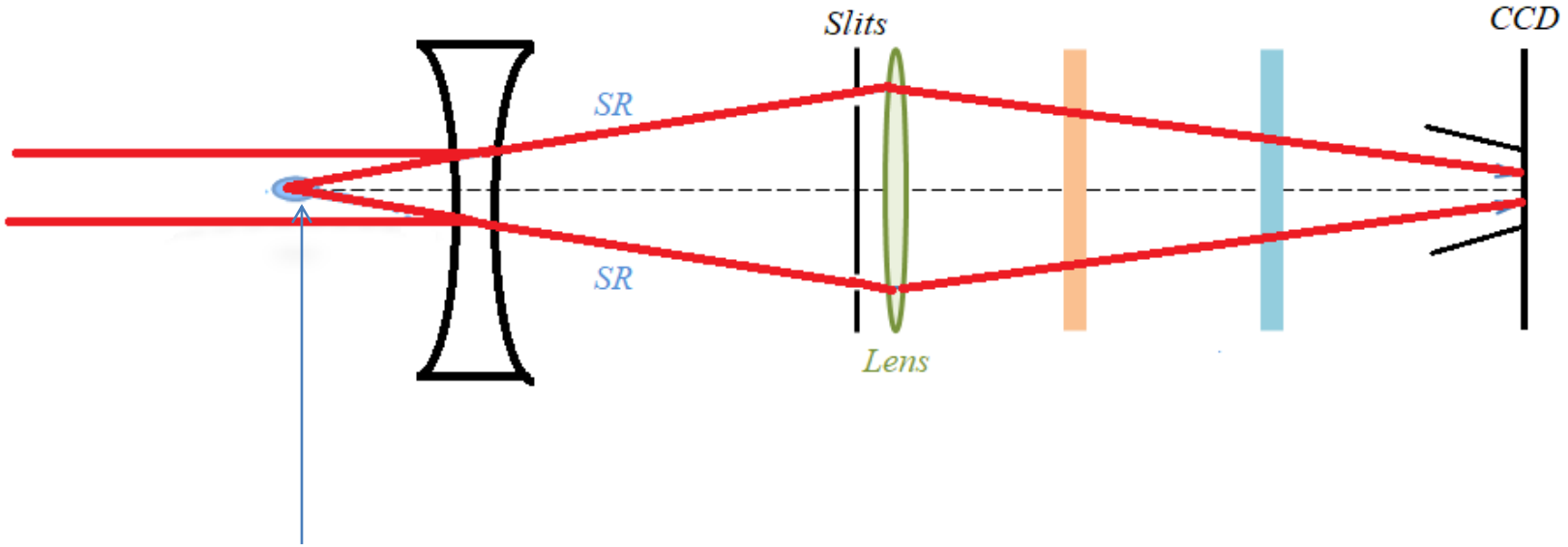
Laboratory stand



The whole setup introduced above is a stand simulating Interferometer for beam size measurements. Here one can see:

1. Laser. It simulates SR coming from the beam.
2. First lens after the laser makes the light to diverge.
3. Slits – you could see them on the previous slide.
4. Focusing lens – gather SR together to make them interfere.
5. Polarizer
6. Magnifying lens – the light gathers exactly in the lens to be, it means that the lens is in the image plane; the lens makes our future image magnified.
7. CCD – here we finally get the picture.



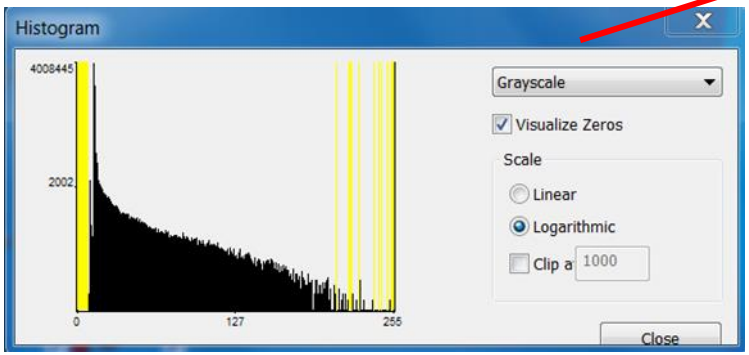


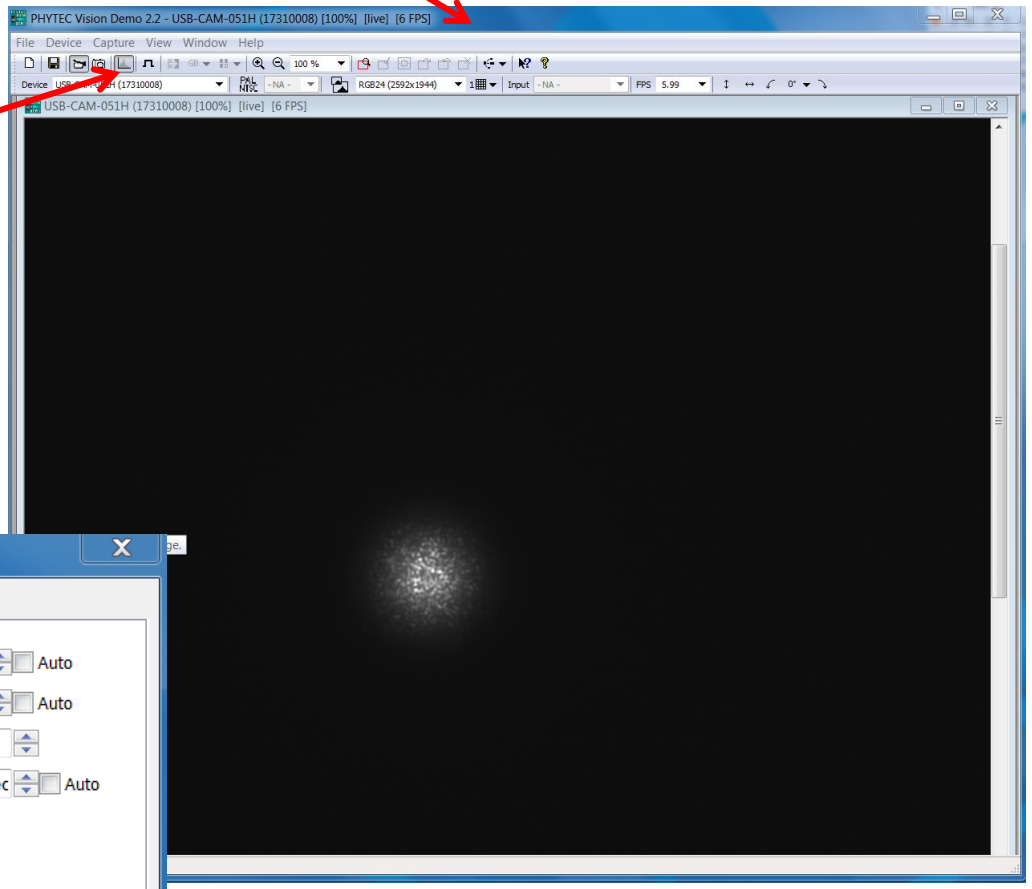
We are measuring this spot size!!!!!!

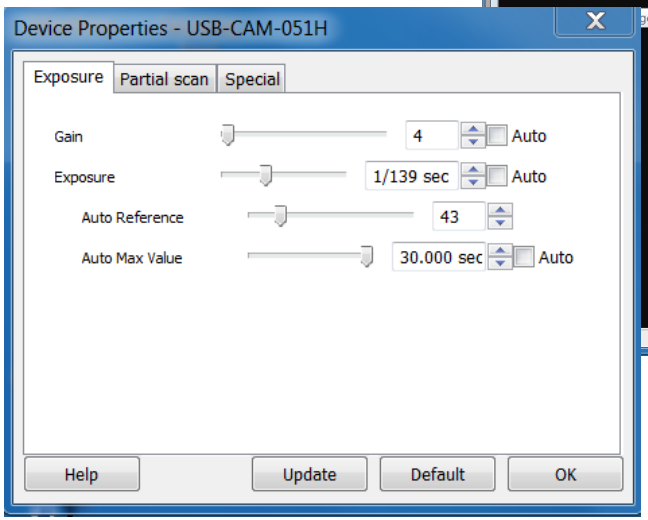
CCD readout

To get the picture from the camera you have to use *PHYTEC Vision Demo* program.

Always check that the camera isn't saturated by getting the histogram.







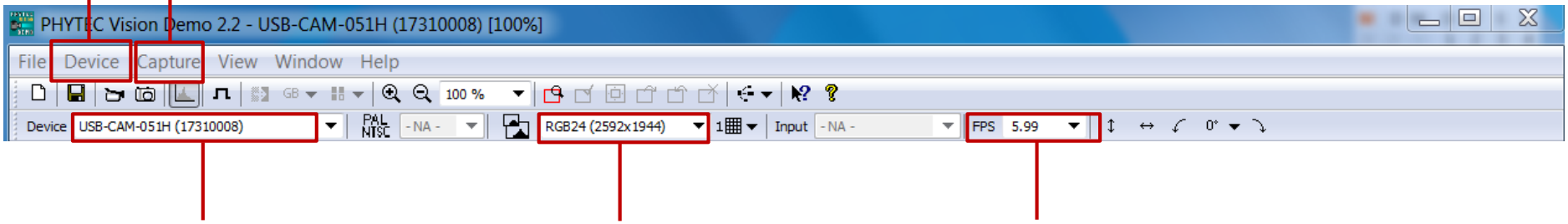
If the camera is saturated, go to the Properties of the camera and decrease exposure time

CCD readout

Start/Stop acquisition → Device → Live (Shortcut: Ctrl + L)

CCD control parameters → Device → Properties

Save image → Capture → Save Image (Shortcut: Ctrl + U): *save images as JPEG*



CCD type

readout format (RGB, 2592 x 1944 pixel)

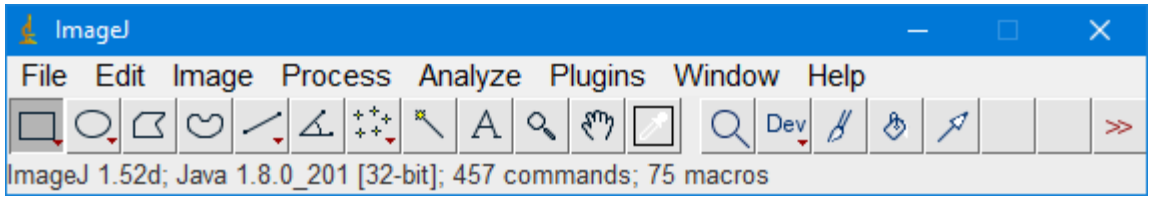
readout rate (5.99 frames per second)

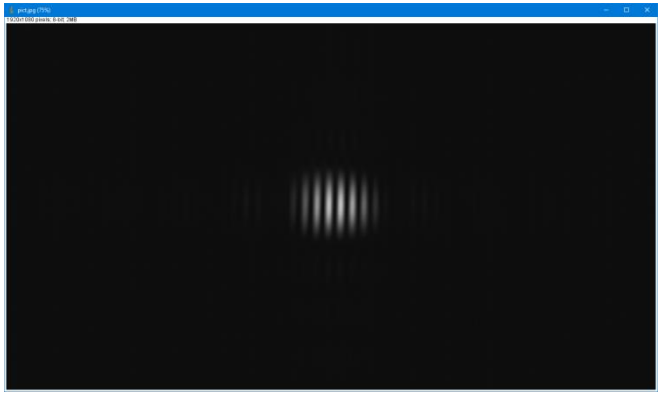
Summarizing all above. Basically with the program one has to get a picture which will be later treated. For that you need to be connected to a camera (check it). Then press "Capture" and "Save Image". Save the image as you wish. That is all.

Image treatment (ImageJ program)

1

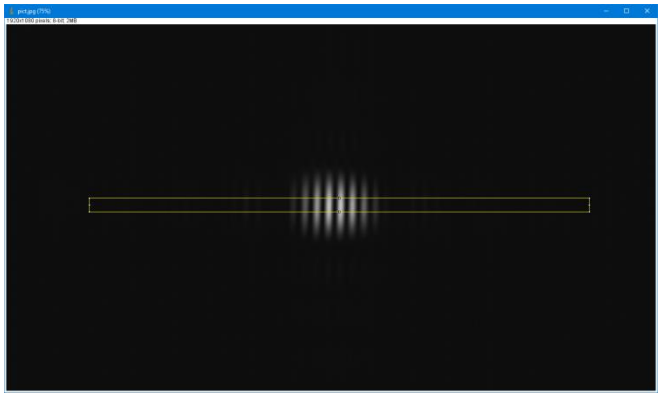
That how it looks. This program we need to get 1d set of data from the image we saved.
Now press “File”, then “Open…” and open your picture. Below is what you get

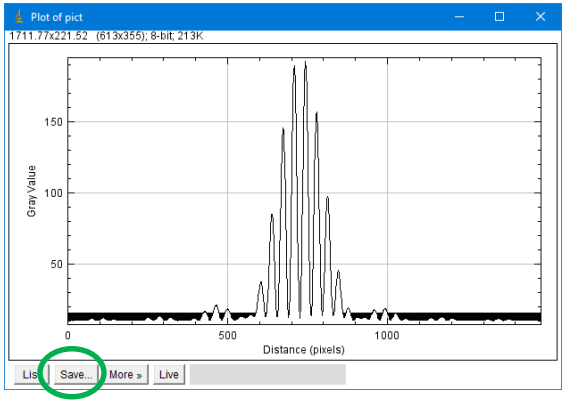




2

Now grab the box in the center as shown on the right picture. After that go to “Analyze” and “Plot Profile”. You’ll get the plot below.





3

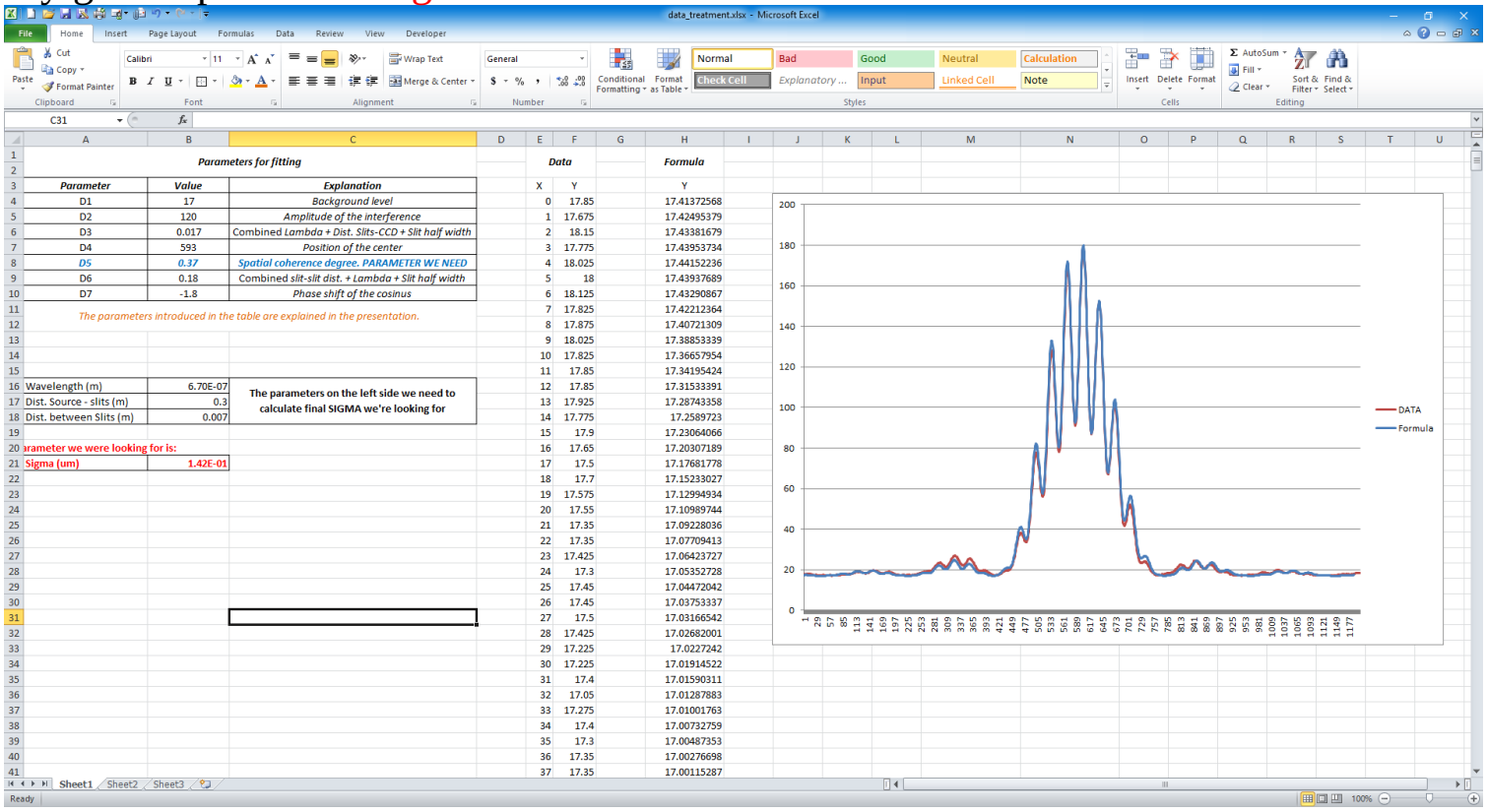
Now we just need to save the profile we’ve got. The small button “Save” in the bottom left corner will help you with this.

4

Now the data has been saved and we may treat it. Thus go to Excel treatment file!

Data treatment

- Below you may see a picture. The picture demonstrates how everything should look like finally. All that you have to do here is to open or implement your data and to adjust the parameters of the formula.
- To open your data click on the “X” under “Data” and go to “Data” menu above. Here press “Refresh” button, find you data saved from your picture and open it, copy it into the pre-pepared Excel sheet “Interferometer.xlsx”
- Now you see that the blue and red curves do not matches. **This you have to fix by playing around with the parameters in the “Parameters for fitting” table.** After you matched them you may get the parameter Sigma below.



Formula explanation

$$I(y) = I_0 \left[J_1 \left(\frac{2\pi a y}{\lambda_0 R} \right) / \left(\frac{2\pi a y}{\lambda_0 R} \right) \right]^2 \left[1 + |\gamma| \cos \left(\frac{2\pi D\, y}{\lambda_0 R} + \phi \right) \right]$$

This is the formula which you've already seen above. But the formula in the excel treatment file uses some *D1*, *D2*, *D3* … parameters. What are they?

D1 – is just a background which is added to the whole formula because in the real case we never get 0

D2 – is I_0

D3 – *2*pi*a/(lambda*R)*

D4 – is a center of the interferogram, it is a constant which is added to *y*

D5 – is exactly the spatial coherence degree which we need for the size calculation

D6 – 2*pi*D/(lambda*R)

D7 – is a phase of the *cos*