

4. Recommended alignment procedure:

4.1 Introduction

The described below procedure presents an example of alignment of beam shapers π Shaper and *Focal- π Shaper (F- π Shaper)* with using the standard π Shaper Mount and auxiliary tools: “Aligner” and “1 meter Lens”.

Important: Usually by installing a beam shaper in certain equipment it is recommended to align the optical system of that equipment without the beam shaper and then to install the beam shaper and align it by checking the measured input and output intensity profiles

The basic approach implies several stages:

- to provide a proper alignment of the *Aligner* with using a camera-based beam profiler,
- to install a beam shaper and correct its alignment by checking the output beam profile at the beam shaper exit,
- in case of *F- π Shaper* to install the 1 meter lens and correct the alignment by checking the resulting beam profile in zone of focal plane.

The below considered example was carried out

- with using laser of $\lambda = 532$ nm,
- the beam was expanded with using a zoom beam-expander $2^x - 10^x$,
- initial laser beam is elliptic, aspect ratio 1:0.9,
- camera-based beam profiler was used, see figure on right.

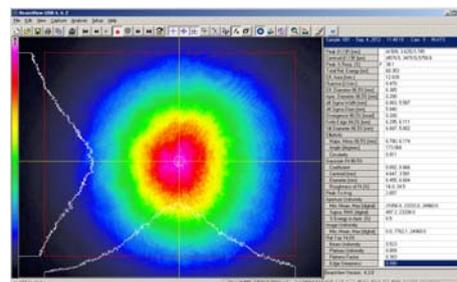
The below description presents stepwise procedure that is illustrated with photos and screenshots from beam profiler. There are provided also comments and recommended actions.



Initial beam

The beam after the zoom beam expander, at the Beam Shaper entrance:

- $1/e^2$ diameter ~ 6.4 mm,
- Ellipticity characterized by aspect ratio 1:0.9, larger vertical section.



Aligner

Aligner presents a tube with mounting thread M27x1 in its central part, this thread is identical to one used at most of π Shaper / *Focal- π Shaper* systems.

The tube ends are precisely machined with respect to the thread and are used for mounting with tough tolerance replaceable apertures:

- at entrance – aperture of 2 mm diameter,
- at exit - apertures of diameters
 - 3 mm,
 - 2 mm,
 - 1 mm.



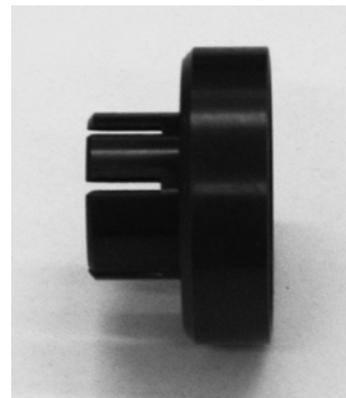
1 meter Lens

This is a convex-plano lens with focal length ~ 1000 mm mounted in a special holder compatible with exit mechanics of the *Focal- π Shaper*. The lens is used for purposes of alignment only.

Since the operational principle of the *Focal- π Shaper* implies using a diffraction limited lens after it that 1 meter lens is a convenient tool replacing a normal lens (for example F- Θ lens) on alignment stage and providing relatively big laser spots (typically several hundreds of microns) that can be caught by state-of-the-art camera-based beam profilers.

Thus the same beam profile measuring instrument can be used to catch the intensity distributions before and after the *Focal- π Shaper* as well as in zone of focal plane.

After aligning the *Focal- π Shaper* with respect to the laser that 1 meter lens has to be replaced back to the normal lens.

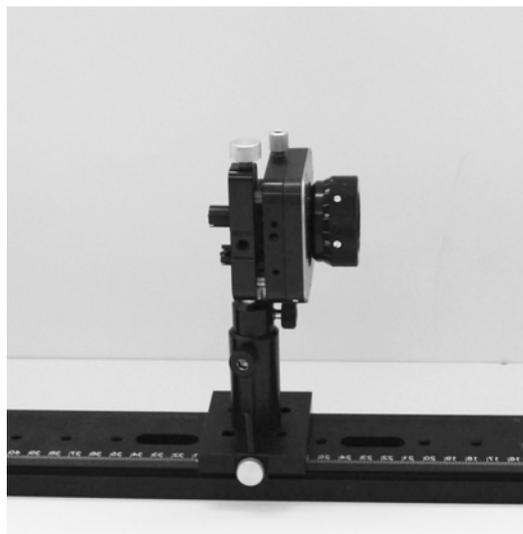


π Shaper Mount

This is a 5- or 4-axis Mount providing alignment in 2 lateral shift X/Y and 2 tilts around X/Y.

This device is usually recommended to be applied while delivery of π Shaper or Focal- π Shaper.

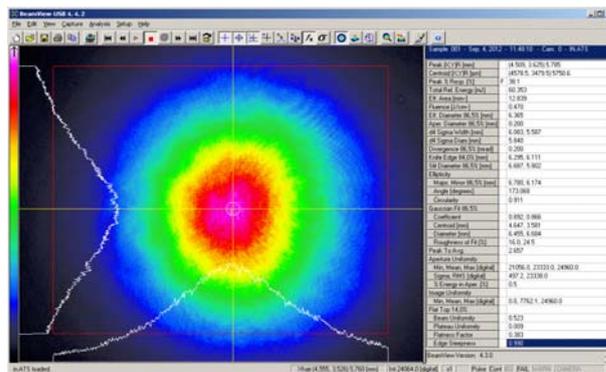
It is possible also to use other opto-mechanical devices providing similar functionality of alignment.



4.2 Alignment procedure for the Aligner

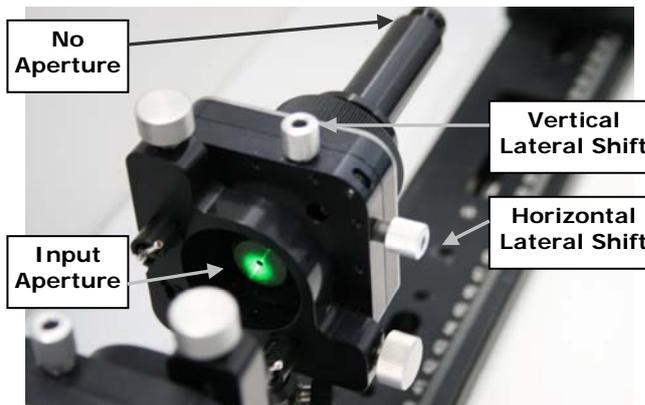
Action:

- to install the Laser and the Beam Expander,
- to install the camera-based beam profiler,
- to put the crosshair of beam profiler in center of the laser spot, this will ease further procedure.



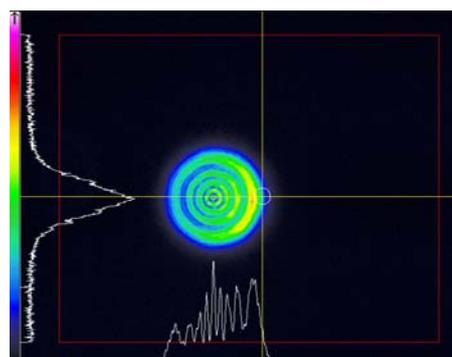
Action: to install the Aligner in the π Shaper Mount :

- entrance aperture of 2 mm diameter,
- **NO** aperture at the exit.



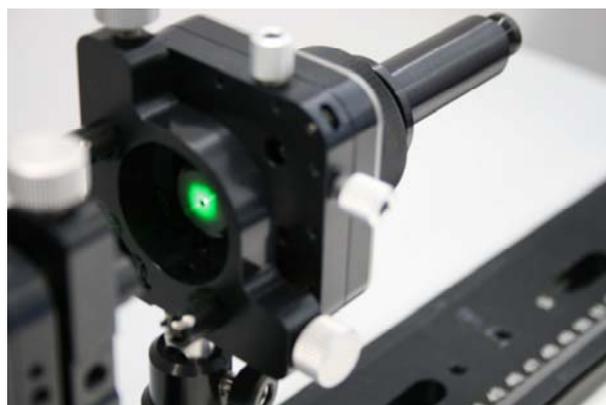
Apertures, mm	
In	Out
2	-

Comment:
The Aligner is misaligned in horizontal direction



Action: to do lateral shifting in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

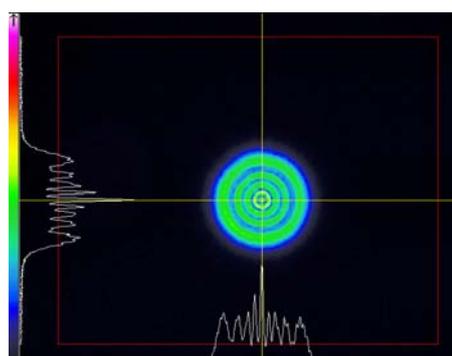
Important: Use lateral shifts (X/Y) only when ONLY entrance aperture is installed!



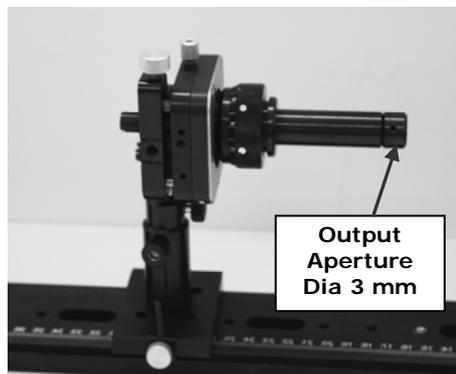
The knobs of lateral shifts are marked in above photo; the resulting spot is shown in right photo and next screenshot.

Apertures, mm	
In	Out
2	-

Comments:
The entrance aperture of the Aligner is aligned in vertical and horizontal directions. Diffraction pattern is symmetric. The center of rings coincides with the crosshair.

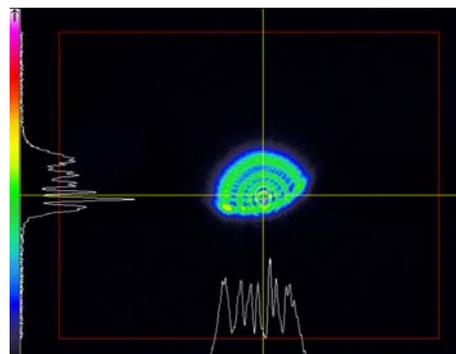


Action: to install the Output Aperture of 3 mm diameter.



Apertures, mm	
In	Out
2	3

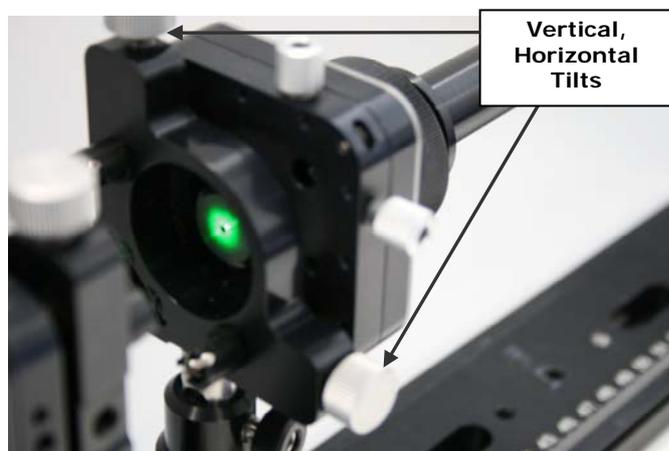
Comment:
There exists angular misalignment in vertical direction



Action: to do tilt in vertical direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

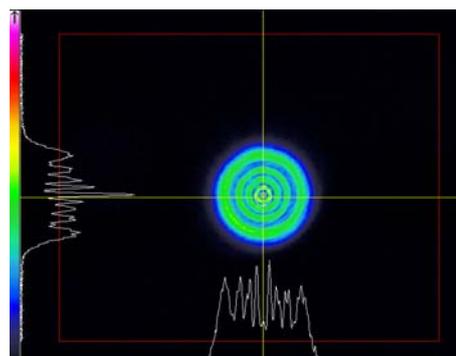
Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

The knobs of tilts around X/Y are marked in the right photo.

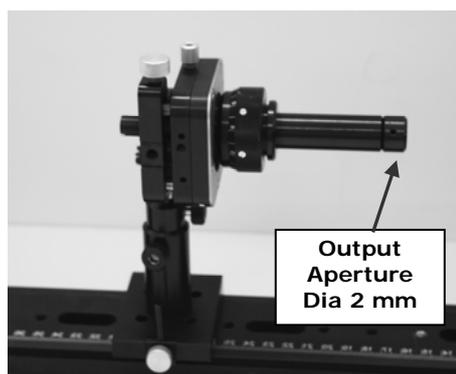


Apertures, mm	
In	Out
2	3

Comments:
Full beam after input 2mm aperture passes through the output 3 mm aperture.
Diffraction pattern is symmetric.
The center of rings coincides with the crosshair.

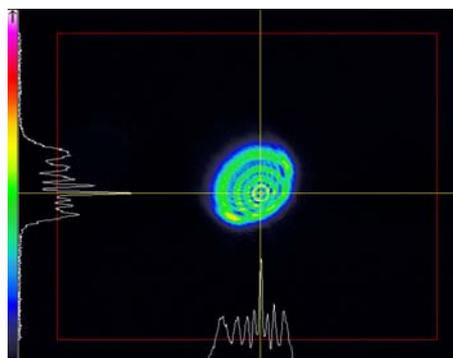


Action: to install the Output Aperture of 2 mm diameter.



Apertures, mm	
In	Out
2	2

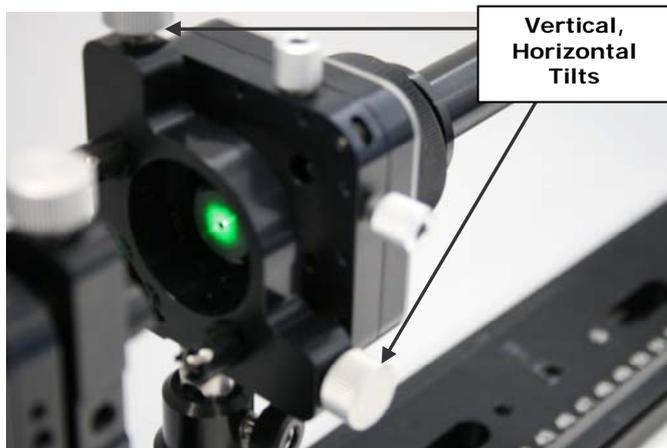
Comment:
There exists angular misalignment in horizontal and vertical directions.



Action: to do tilt in horizontal and vertical directions with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

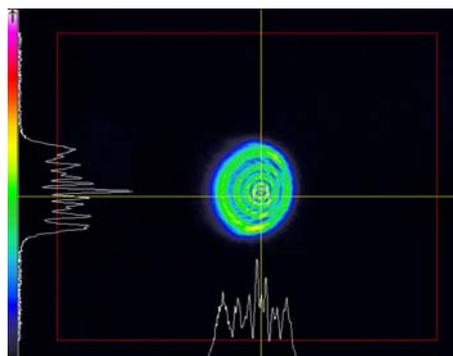
The knobs of tilts around X/Y are marked in the right photo.



Apertures, mm	
In	Out
2	2

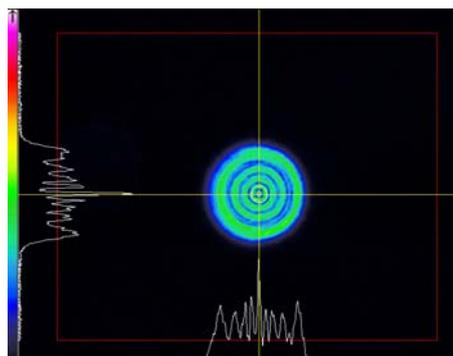
Comments:
Angular misalignment is almost eliminated in vertical direction but still strong in horizontal direction.

Action: to do tilt in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

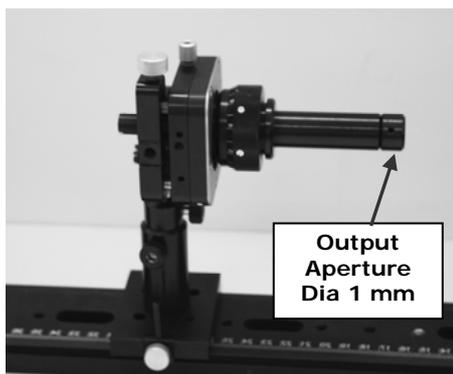


Apertures, mm	
In	Out
2	2

Comments:
The beam after input 2mm aperture passes through the output 2 mm aperture.
Diffraction pattern is symmetric.
The center of rings coincides with the crosshair.



Action: to install the Output Aperture of 1 mm diameter.



Apertures, mm	
In	Out
2	1

Comment:

There exists angular misalignment in horizontal direction.

Action: to do tilt in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

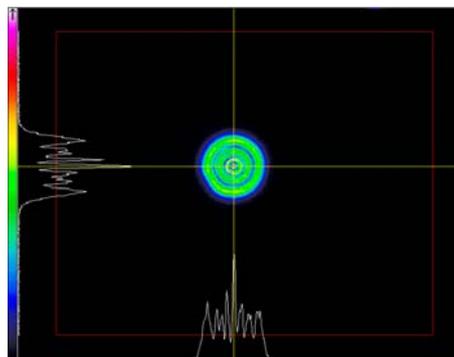
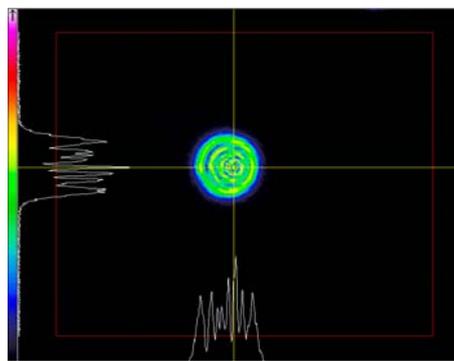
Apertures, mm	
In	Out
2	1

Comments:

The Aligner is aligned.

Diffraction pattern is symmetric.

The center of rings coincides with the crosshair.



4.3 Alignment procedure for the Focal- π Shaper

Aligning of the Aligner means the Mount is close to the optimum position and the Focal- π Shaper can be installed. Because of production tolerances there might be necessary to tune the position of the Focal- π Shaper.

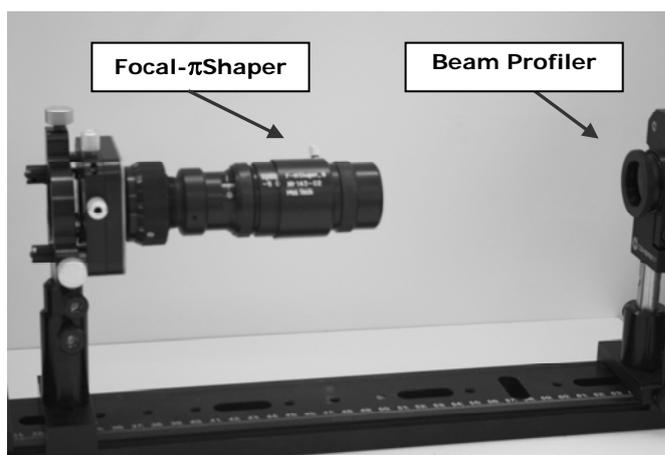
Action: to install the Focal- π Shaper and camera-based beam profiler.

Typical view of beam profile pattern is shown in next figure.

Important:

The output intensity profile *SHOULDN'T BE* Flattop!
It should have central laser spot and several rings, so similar to Airy disk distribution.

When proper alignment the centre of those rings to be in coincidence with the peak of central laser spot.



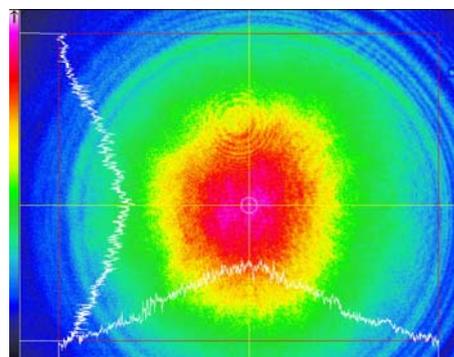
Comments:

- there exists certain misalignment in vertical and horizontal directions – the rings should be “raised” and shifted left.

Action: to do *lateral shifting* in vertical and horizontal directions with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

Important: Use lateral shifts (X/Y) only!

It is recommended also to locate the beam profiler at longer distance.



Important: When small input beam size the rings can be not good seen, then it is recommended either to enlarge temporally the input beam size for alignment purposes, or another way – scanning full range of lateral shifts on Mount in both directions to make the rings visible.

The right figure shows typical view of beam profile after F- π Shaper at 0.9 m distance.

Comments:

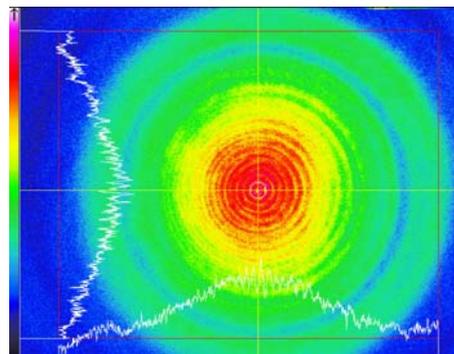
- the image demonstrates good symmetry.

Next step is analyzing the pattern near the focal plane of a lens.

For alignment purpose it is convenient to apply 1 meter lens:

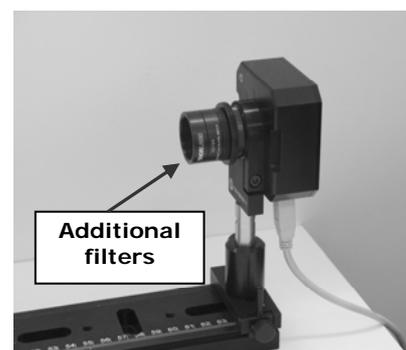
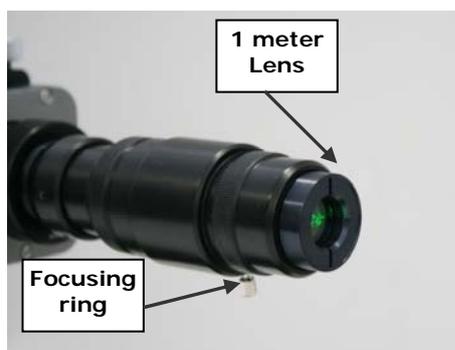
- negligible aberrations,
- relatively large spots, several hundreds of microns, that can be caught by the popular camera based beam profilers.

By finishing the alignment that 1 meter lens should be replaced by a working focusing lens.



Actions:

- to install the 1 meter lens at the Focal- π Shaper exit,
- to install additional neutral filters on the beam profiler, typically +2D, to prevent damaging of camera due to increased irradiance,
- to put the beam profiler after the F- π Shaper at distance approx. 1 meter,



- by rotating the focusing ring (see on right) to find the position of the beam waist, this will be a starting point for further adjustments,
- by rotating the focusing ring to shift the waist far from 1 meter lens, in order to analyze the profiles BEFORE the waist,
- to reach the profile looking as a donut, see the next picture.

Important: To move the waist far from the lens it is necessary to rotate focusing ring in direction of negative values on the scale engraved on the F- π Shaper case,
The rule: Negative values correspond to negative optical power, hence to shifting the profiles FROM the lens.

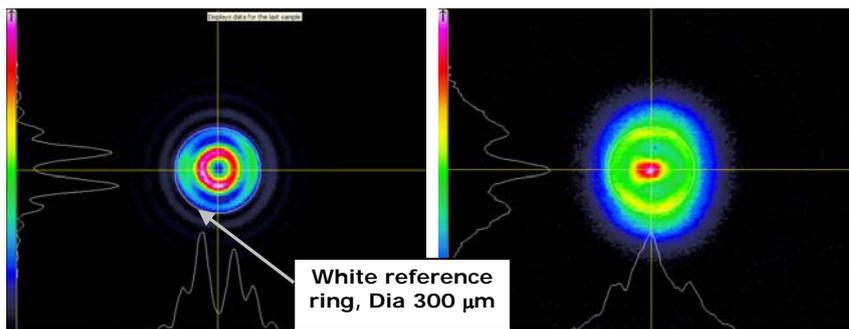
The right figure shows examples of profile.
 Spot diameter is about 300 μm .

Comments:

- there exists certain misalignment in horizontal direction.

Action:

- to do tilt in vertical direction with checking the spot with camera to provide symmetric diffraction pattern.



Important: It is convenient to use a reference ring like white ring of 300 μm diameter on the above and below pictures.

Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

Important: As a rule by aligning it is necessary to “move” the spot in direction of maximum intensity, in case of above pictures – to the left.

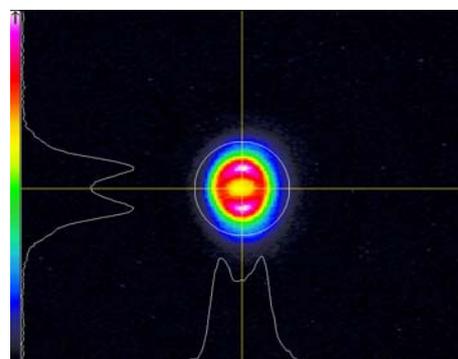
The right figure shows typical view of beam profile for the aligned F- π Shaper.

Comments:

- the image demonstrates good symmetry,
- the profile in vertical direction has deeper intensity in the centre due to ellipticity of initial laser beam.

To reach the flattop intensity it is necessary to adjust input beam diameter.

The optimum beam diameter depends on a profile of initial TEM₀₀ laser beam, typically for the Focal- π Shaper 9 the optimum $1/e^2$ diameter to be 4-4.5 mm.



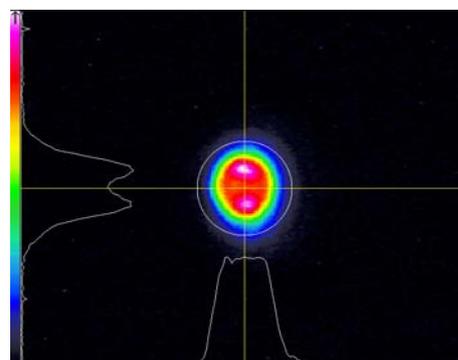
Action:

- to tune the input beam diameter by external zoom beam expander .

Example of resulting spot is shown in right figure.

Comments:

- the profile is flattop in horizontal direction,
- the image demonstrates good symmetry,
- the profile in vertical direction has deeper intensity in the centre due to ellipticity of initial laser beam.



Important: It is recommended to use a zoom beam expander ahead of the Focal- π Shaper in order to simplify the final procedure of adjusting the input beam diameter.

Important: The fine tuning of beam size internally can be done by rotating the magnification ring of the Focal- π Shaper;
 it is necessary to keep in mind that the range of size variation is limited by +/-15% only and by rotating the magnification ring there happens shift of the waist of resulting beam and it is necessary to compensate that shift by rotating the focusing ring.

After finishing the alignment of the Focal- π Shaper with respect to the laser it is necessary to remove the 1 meter lens and use a working focusing lens.

Important: The sequence of profiles created by focusing of a beam after the Focal- π Shaper will be repeated with the working lens as well, but the spot size will be changed *proportionally* to change focal length, while *distances along the optical axis* are changed in *square proportion*.