peaXXus_sq_D30

(L96-18-30-B)

afocal beam splitting systems in multiple spots

Manual

September 20, 2022

Fig. 1 Outlook of the **peaXXus_1.8_sq_D30_1070**.

peaXXus_sq_D30_1070

1. Specifications

Items		Values		
Description		Beam splitter in multiple spots: - peak intensity in central spot - 3 x 3 square matrix of resulting spots - variable balance of spots energy portions - lossless		
Number of foci		9		
Splitting angle, mrad	Model	peaXXus_1.8	peaXXus_1.25	peaXXus_0.9
	Square full ***side***	1.84	1.22	0.92
	Square full ***diagonal***	2.60	1.72	1.30
Input		Collimated beam		
Clear Aperture		30 mm		
Laser		TEM_{00} and multimode, any M^2		
Spectral band		1065 – 1075 nm, transmission >96% 640 – 670 nm, transmission >40%		
		Other spectral bands within the range 300 – 2500 nm are available by request		
Angular field of view (FOV)		± 3°		
Recommended power by ***water*** cooling		average power up to 6 kW power density up to 200 kW/cm^2 with 2 ms pulse width		
Recommended power by ***air*** cooling		average power up to 300 W power density up to 200 kW/cm^2 with 2 ms pulse width		
Mounting		external threads M47x0.75 at entrance and exit		
Water cooling		- Coating of water cooling channel: Al oxide - water flow - minimum 2 liter/min - maximum 6 liter/min - pressure drop at 2 liter/min <1 bar - maximum water pressure 5 bar - water cooling channel connector Camozzi 8522 6-1/8 or similar - Hose diameters: inner 4 mm, outer 6 mm - water quality: deionised/ distilled water - water temperature 15-30°C - Recommended usage of NALCO water biocide inhibitors: 20 ml NALCO 7330 + 20 ml NALCO 460-RS200 per 10 liters of water - The temperature inside the water cooling circuit must be set in such a way that condensation cannot form on the optics		
Diameter		71 mm		
Length		135.5 mm		

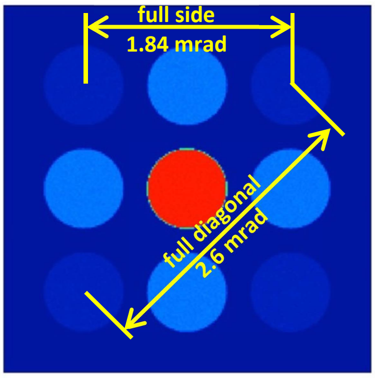


Fig. 2 The peaXXus-spot layout,
numerical data are given for the **peaXXus_1.8_sq_D30_1070**.

2. Description

Afocal optical devices peaXXus_sq_D30_1070, hereinafter referred to as *peaXXus*, are intended to split a collimated or low divergent laser beam into 9 beamlets which, by further focusing using a lens, form a multiple spot pattern, hereinafter called as a *peaXXus*-spot:

- 3 x 3 square matrix of resulting spots,
- as a rule, peak intensity in central spot,
  although "0" intensity of the central spot can be provided as well,
- operation with multimode or single mode lasers, any M^2,
- variable distribution of energy portions at separate spots by rotating the Adjustment Rings,
- theoretically lossless operation,
- minimized thermal focus shift due to optics implementation from crystalline quartz with high thermal conductivity, details in

  On the selection of materials for high-power laser optics with reduced thermal lensing, SPIE PW 2022
  http://adloptica.com/pub/spie_pw2022_selection_materials_with_reduced_thermal_lensing.pdf , https://doi.org/10.1117/12.2607931 ,

  On the selection of materials for high-power laser optics based on analysis of focus shift and aberration induced by thermal gradient
  http://www.adloptica.com/pub/on_selection_materials_high_power_laser_optics.pdf , http://dx.doi.org/10.1117/1.OE.60.11.115105

The *peaXXus* optics are developed for use with modern multi-kW CW or QCW lasers for welding copper and aluminium; most often using multimode fiber lasers or fiber-coupled lasers. The optical design also allows operation with free space lasers, ultra-short pulse lasers for parallel processing, for example in various application of micromachining such as drilling, scribing, etc.

Originally developed for near-IR lasers, the optical design can be adapted to lasers of near-UV, visible, IR spectra.

Implementation examples of optical systems with *peaXXus* are presented in Figs. 3, 4.

Applications:

- Welding, preferably copper, aluminium
- Cladding
- Cutting
- Parallel processing in micromachining, for example, drilling, scribing

Fig. 3 Typical optical layout with *peaXXus*:
- divergent laser beam of a fiber laser or a fiber-coupled laser is transformed by a collimator into a low divergent (collimated) beam at the *peaXXus* input,
- the beam is split by the *peaXXus* in several beamlets,
- by focusing using a lens, the peaXXus-spot, as the 3x3 square matrix, is formed in the lens focal plane.

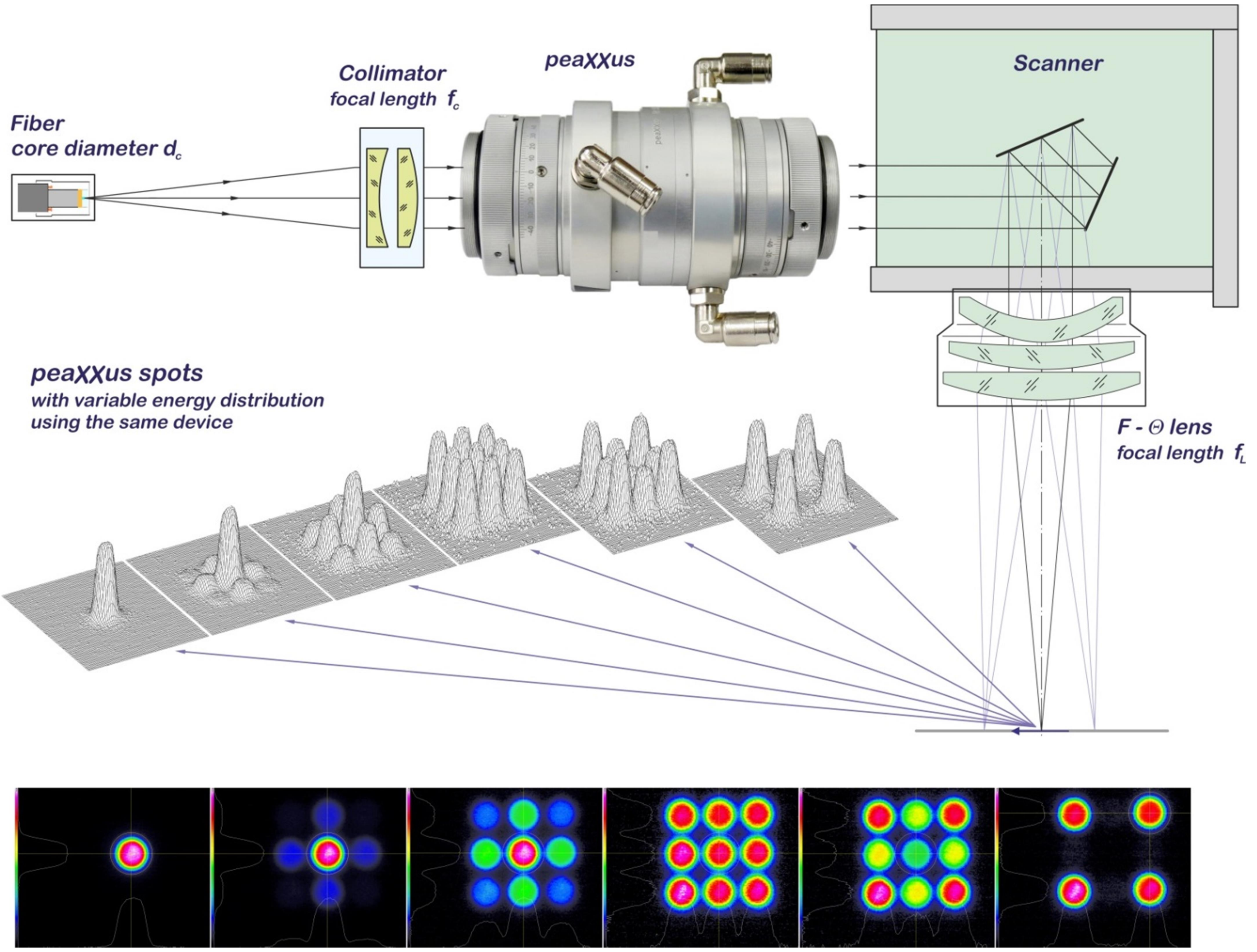


Fig. 4 Implementation of an optical system with *peaXXus* and scanner:

- the *peaXXus* should be installed in front of the scanner,
- low divergent beam after a collimator or a free space laser at the *peaXXus* input,
- F-Θ lens is focusing the output beamlets to create the peaXXus-spot in the working plane;
- by scanning, the peaXXus-spot moves in the working field of the F-Θ lens.

3. Calculation of parameters of the compound peaXXus-spot

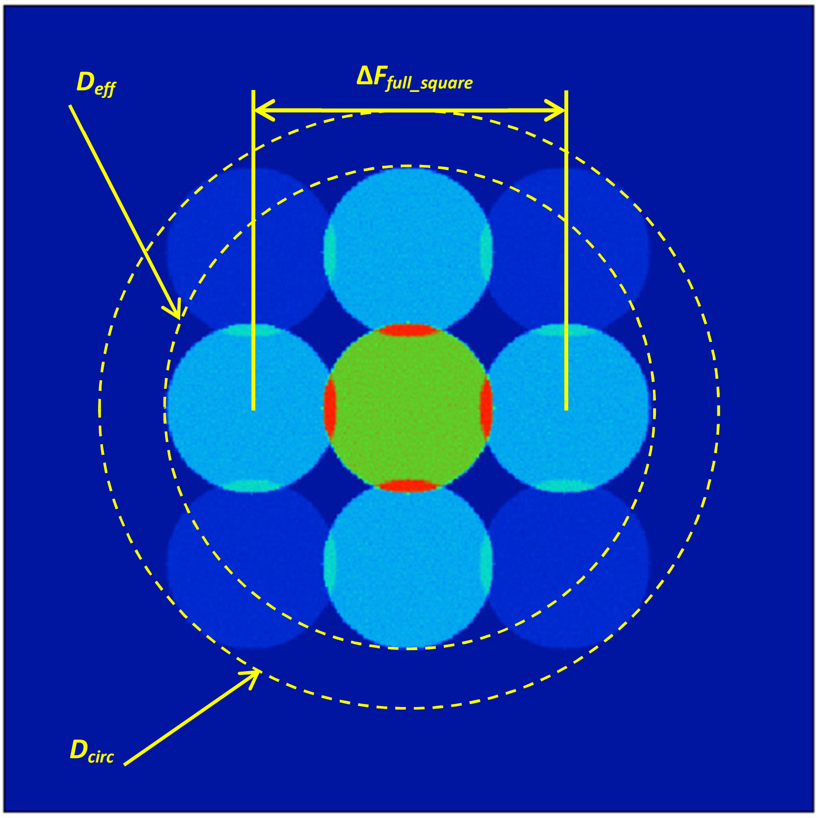


Fig. 5 Compound *peaXXus*-spot.

$$D_{eff} = f_{F-\Theta} \cdot \left(\alpha + \frac{d_{fiber}}{f_{col}} \right)$$

$$D_{circ} = f_{F-\Theta} \cdot \left(\alpha \cdot \sqrt{2} + \frac{d_{fiber}}{f_{col}} \right)$$

$$d_{spot} = \frac{f_{F-\Theta}}{f_{col}} \cdot d_{fiber}$$

$$\Delta F_{full\_square} = f_{F-\Theta} \cdot \alpha$$

where

$f_{F\text{-}\Theta}$ is focal length of F-theta lens,
f_{col} is focal length of collimator,
α is splitting angle, square side full,
d_{fiber} is fiber core diameter,
D_{eff} is effective diameter of peaXXus-spot,
D_{circ} is circumscribed circle diameter of peaXXus-spot,
ΔF_{full_square} is distance between spots, square side, full.

α = $1.84 \cdot 10^{-3}$ rad in peaXXus 1.8_sq_D30_1070

$1.22 \cdot 10^{-3}$ rad in peaXXus 1.25_sq_D30_1070

$0.92 \cdot 10^{-3}$ rad in peaXXus 0.9_sq_D30_1070

In Figure 4: $f_{col} = f_c$ $f_{F\text{-}\Theta} = f_L$

4. Controls and Adjustments

The controls and adjustment means are presented in Fig. 6:

- Mounting using external threads M47x0.75 at entrance and exit,
- By mounting to apply O-rings 45x1.5,
- Adjustment Rings:
    - at entrance and exit sides, rotatable,
    - rotation range ± 45°,
    - supplied with Angular Scales;
- as a rule to be rotated at the same angle,
- position to be fixed by the Fixation screws,
- Fixation: M4 allen screws locate at Adjustment Rings nearby the "0" mark on the Angular Scales,
- Indexes in form of triangle marks are scribed on rings mounted on main case.

Excel-program "Calculations for peaXXus – SQUARE.xlsx" is used to simulate energy distribution between spots of a *peaXXus*-spot. Theoretical and experimental distributions of different *peaXXus*-spots are presented in Sections 5 and 6.

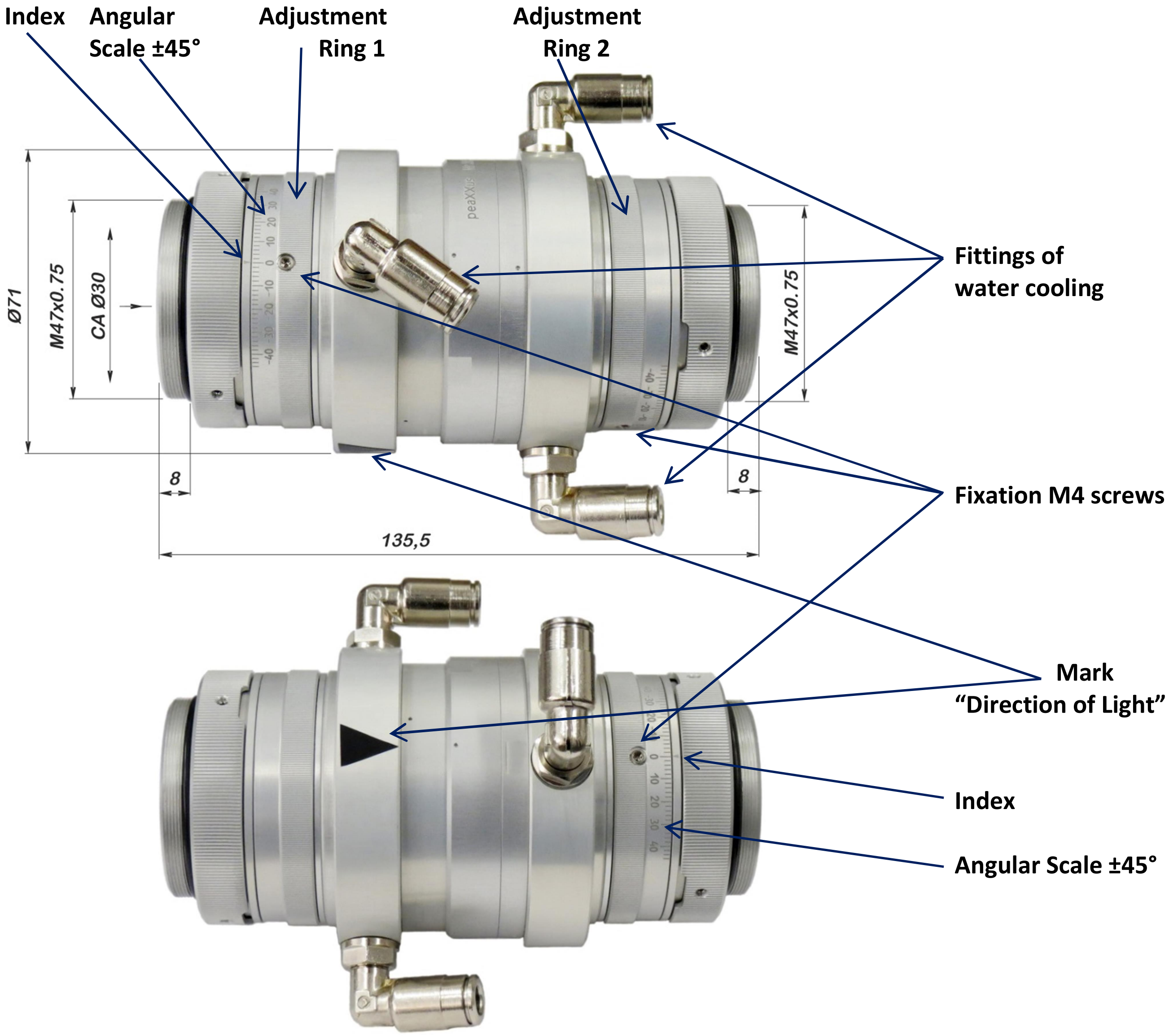


Fig. 6 Controls and adjustment means of the *peaXXus*.

5. Theoretical *peaXXus*-spots by de-focusing

This chapter presents results of computer simulation of the *peaXXus*-spot when de-focusing of the focusing lens.

Conditions:

- Optical layout according to Figs.3,4,
- Beam shaper *peaXXus*_1.8_sq_D30_1070,
- Settings of the Adjustment rings -17,5° / 17,5°,
- Theoretical profiles calculated using Zemax software,
- Intensity ratio in focal plane: “Central Spot” : “Side Spot” : “Corner Spot” $1 : \frac{1}{4} : \frac{1}{17}$
- There are presented the *peaXXus*-spot Top views and 3D-views.

Flat-top

- Collimator f'_{Col} = 140 mm
- Lens $f'_{F-\Theta}$ = 306 mm
- Blue square in diagrams – 1 x 1 mm²
- Multimode fiber-coupled laser,
- Divergence full angle 0.2 rad
- Fiber core diameter: **100** µm
- full beam diameter after collimator ~28 mm
- profile at fiber end – **flat-top**, see right

Magnification $\beta = - f'_{F-\Theta} / f'_{Col} = -2{,}19^{x}$
=> Spot diameter ~**220** µm

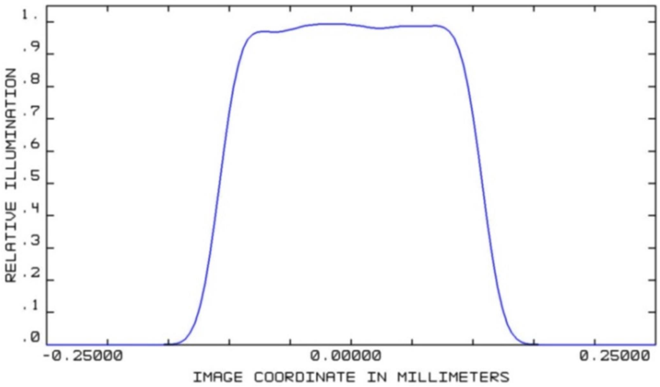
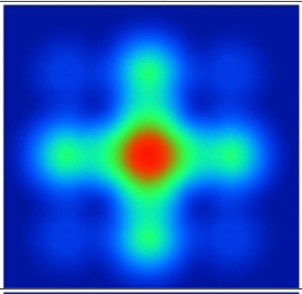
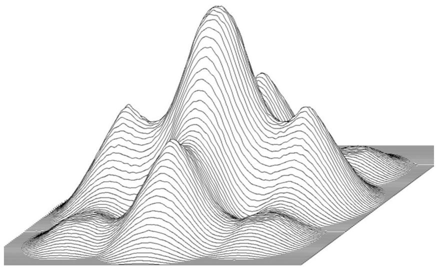
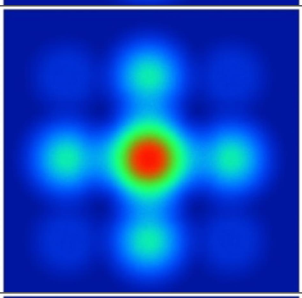
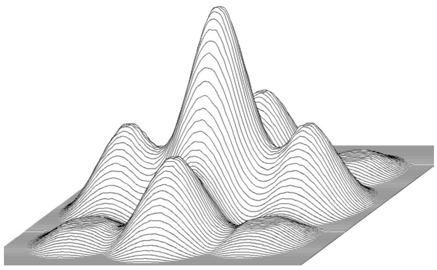
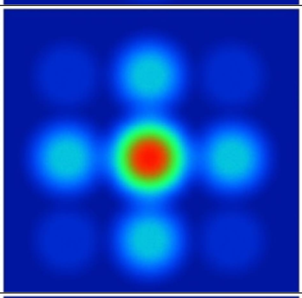
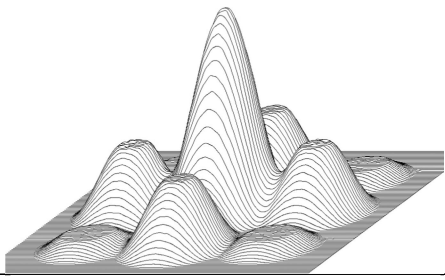
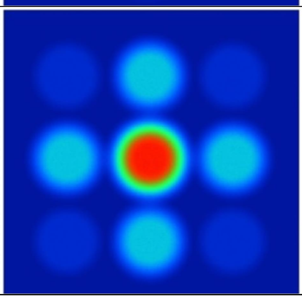
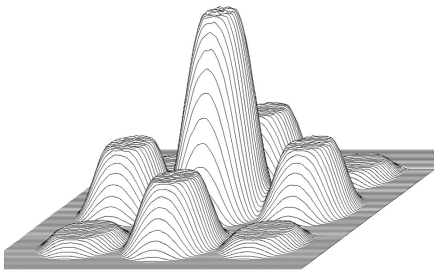
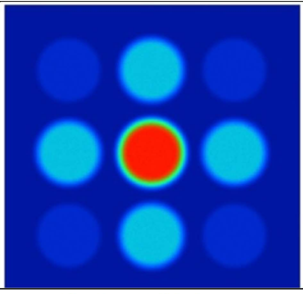
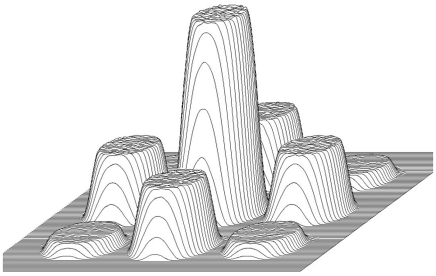
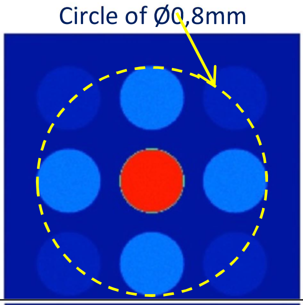
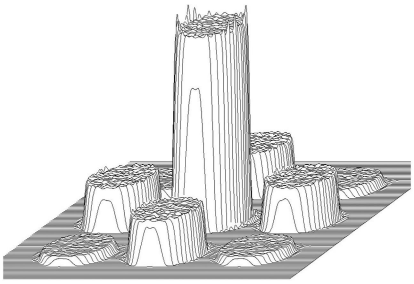
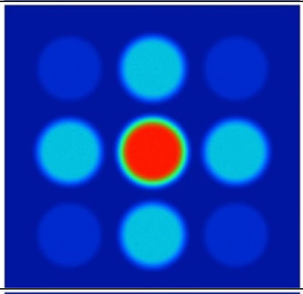
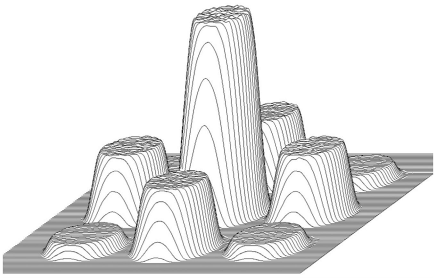
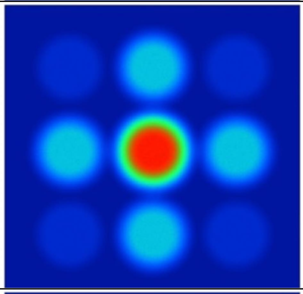
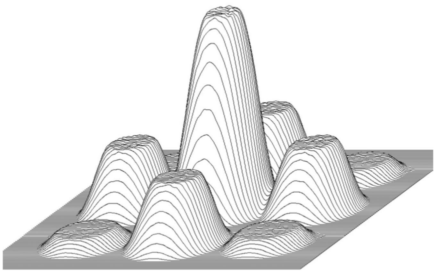
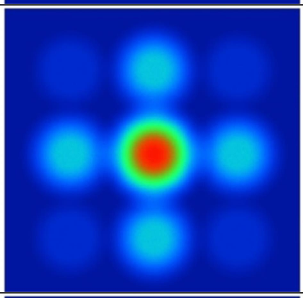
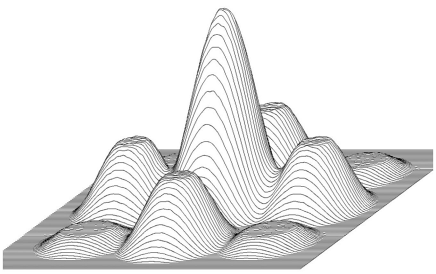
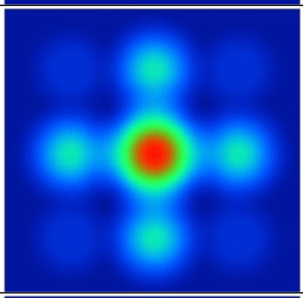
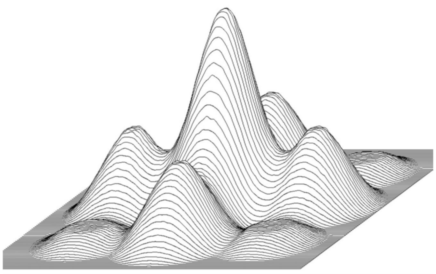
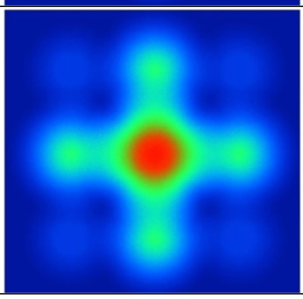
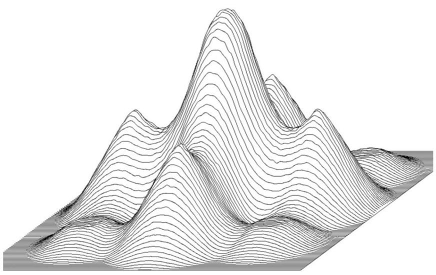


Table 4.1

		ΔF = -5 mm (before Image)
		ΔF = -4 mm (before Image)
		ΔF = -3 mm (before Image)
		ΔF = -2 mm (before Image)

		ΔF = -1 mm (before Image)
		0 (Image in focal plane of focusing lens)
		ΔF = +1 mm (after Image)
		ΔF = +2 mm (after Image)
		ΔF = +3 mm (after Image)
		ΔF = +4 mm (after Image)
		ΔF = +5 mm (after Image)

Gauss

- Collimator f'_{Col} = 140 mm
- Lens $f'_{F\text{-}\Theta}$ = 306 mm
- Blue square in diagrams – 1 x 1 mm²
- Multimode fiber-coupled laser,
- Divergence full angle 0.2 rad
- Fiber core diameter: **100** µm
- full beam diameter after collimator ~28 mm
- profile at fiber end – **flat-top**, see right

Magnification $\beta = - f'_{F\text{-}\Theta} / f'_{Col} = -2{,}19^{x}$
=> Spot diameter ~**220** µm

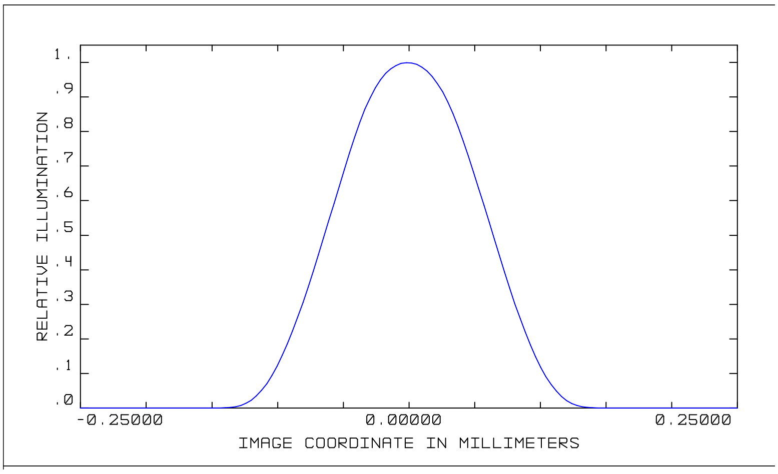
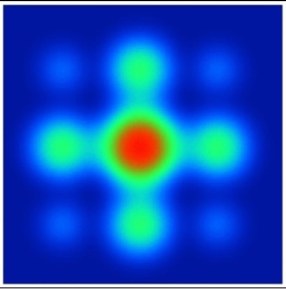
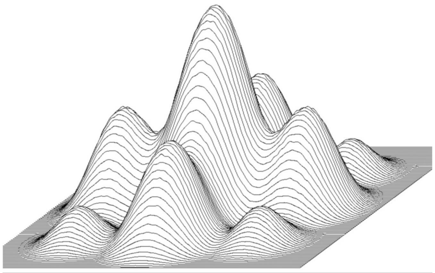
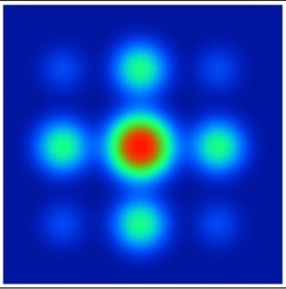
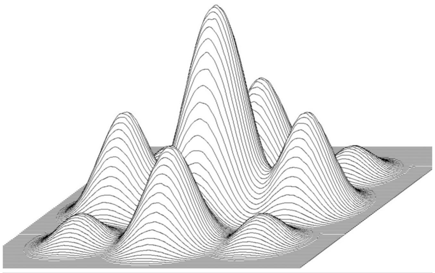
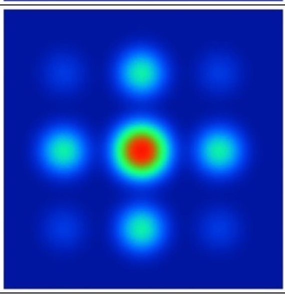
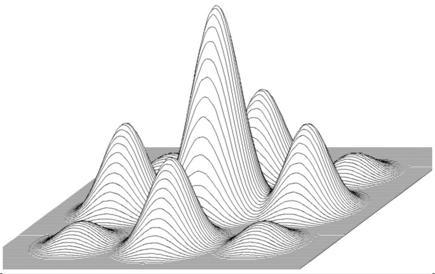
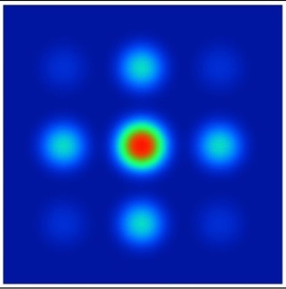
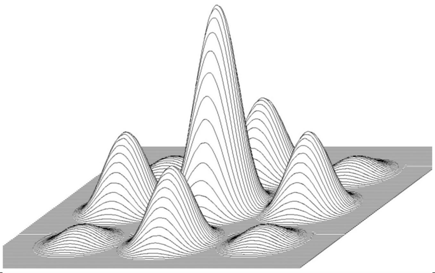
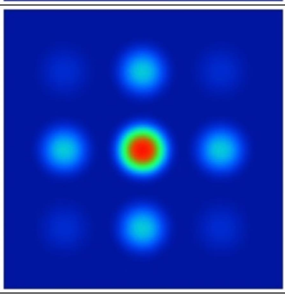
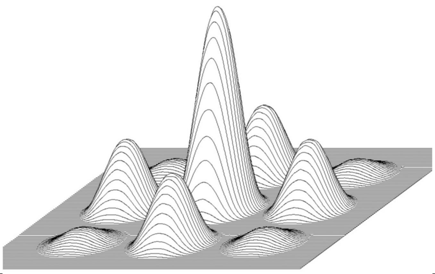
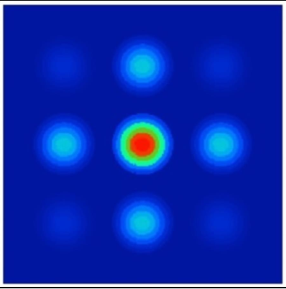
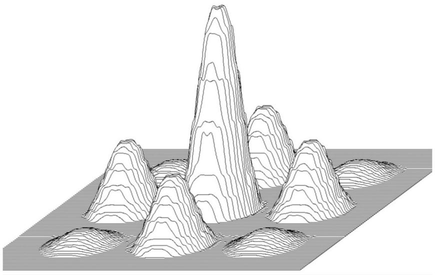
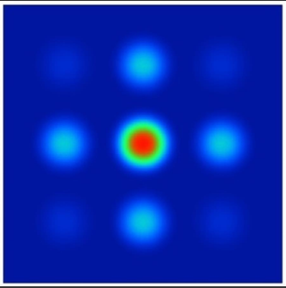
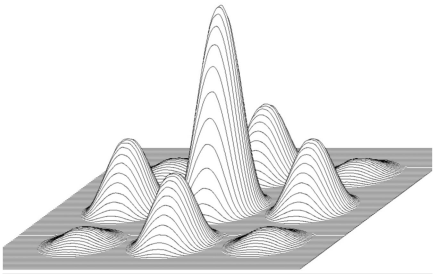
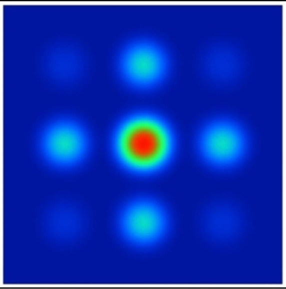
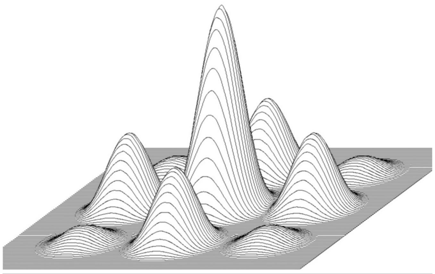
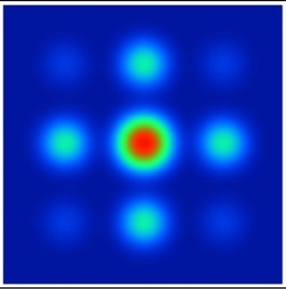
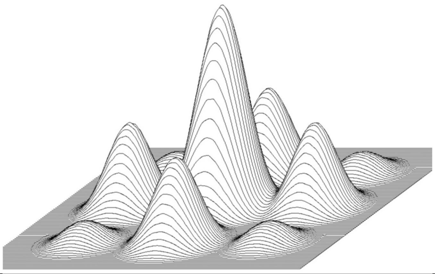
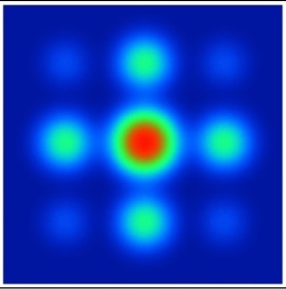
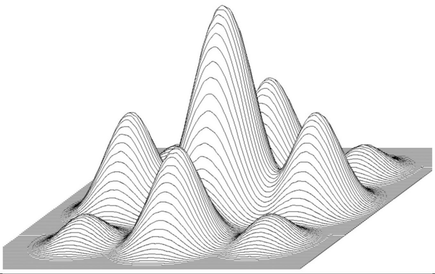
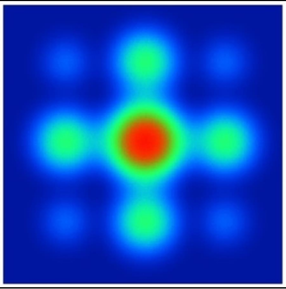
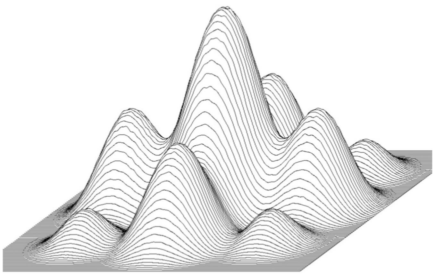


Table 4.2

		ΔF = -5 mm (before Image)
		ΔF = -4 mm (before Image)
		ΔF = -3 mm (before Image)
		ΔF = -2 mm (before Image)
		ΔF = -1 mm (before Image)

		0 (Image in focal plane of focusing lens)
		ΔF = +1 mm (after Image)
		ΔF = +2 mm (after Image)
		ΔF = +3 mm (after Image)
		ΔF = +4 mm (after Image)
		ΔF = +5 mm (after Image)

6. Experimental *peaXXus*-spots by different settings

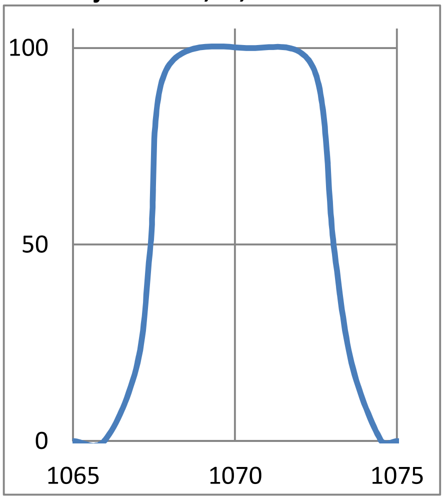
This chapter presents measurements of characteristic *peaXXus*-spots under different settings of the Adjustment Rings.

Characteristic peaXXus-spots

Conditions:

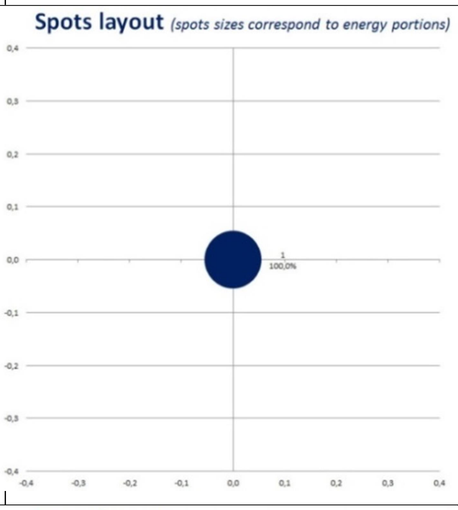
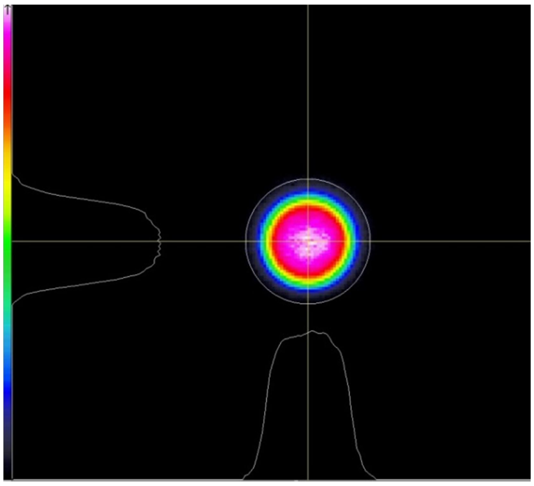
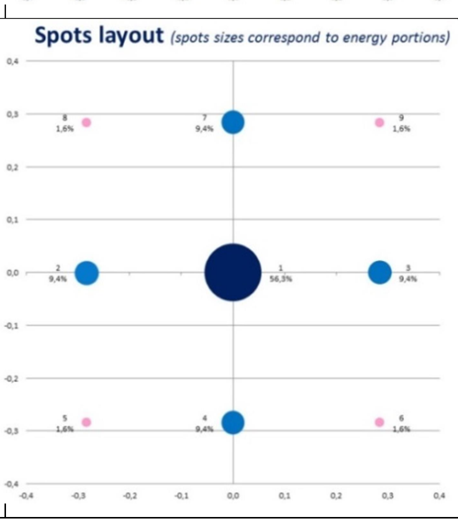
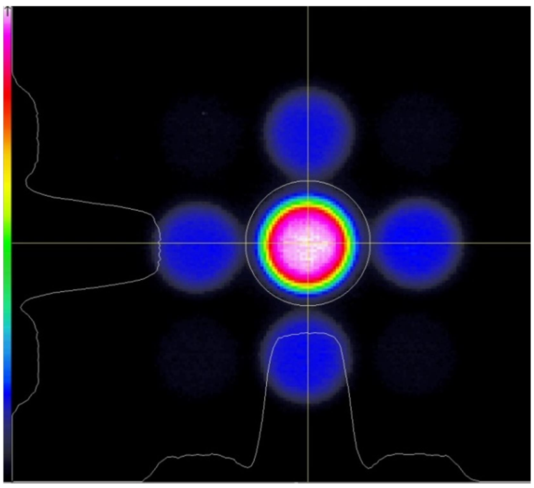
- Beam shaper *peaXXus*_1.8_sq_D30_1070,
- Equal angular settings at both Adjustment rings,
- Theoretical profiles calculated using Excel-program
  "Calculations for peaXXus – SQUARE.xlsx",
- Intensity ratio is given for
  "Central Spot" : "Side Spot" : "Corner Spot",
- Experimental profiles measured using the beam profiler
  LaserCam-HR / BeamView software,
- Collimator of f'_{Col} = 140 mm,
- Focusing lens of f'_{Lens} = 300 mm,
- Light source – spectral lamp of spectral band 1067.4-1073nm (FWHM), λ_C=1070.3 nm, Δλ=5.6 nm (FWHM), through multi-mode fiber of 105µm core diameter.

Transmission of filter used by adjustment, %, Δλ=5.6nm



Rotating of both Adjustment rings counter-clockwise when looking from the entrance side, i.e. in the direction of light propagation:
Ring_1 negative values, Ring_2 positive values.

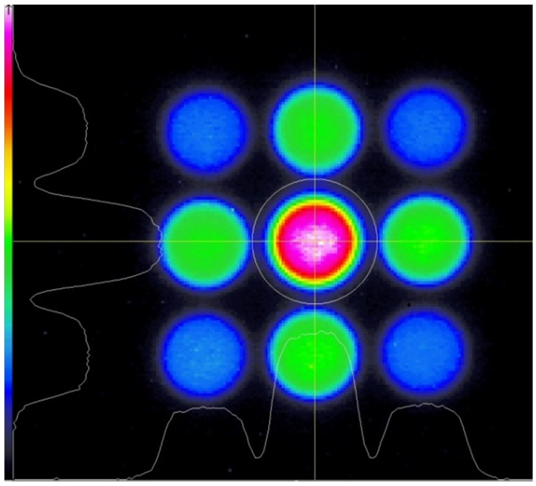
Table 5.1

<table>
<tr><th>Ring_1 / Ring_2</th><th>Theoretical profiles</th><th>Measured profiles</th></tr>
<tr><td>0° / 0°
Only central spot
Intensity ratio
$1 : 0 : 0$</td><td>
</td><td></td></tr>
<tr><td>-15° / 15°
Intensity ratio
$1 : \frac{1}{6} : \frac{1}{36}$</td><td>
</td><td></td></tr>
</table>

-22,5° / 22,5°

Intensity ratio

$$1 : \frac{1}{2} : \frac{1}{4}$$

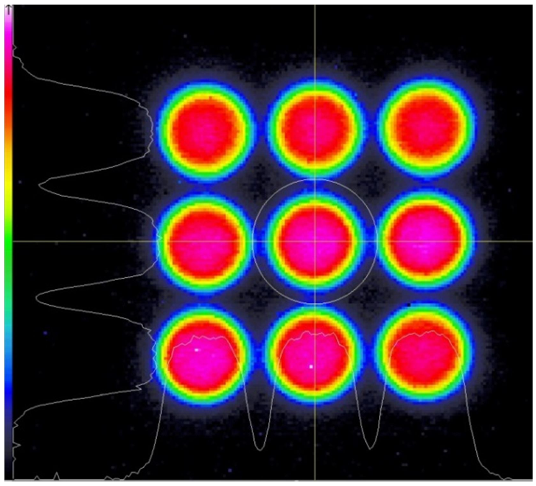


-27,5° / 27,5°

Even intensity of all 9 spots

Intensity ratio

$$1 : 1 : 1$$

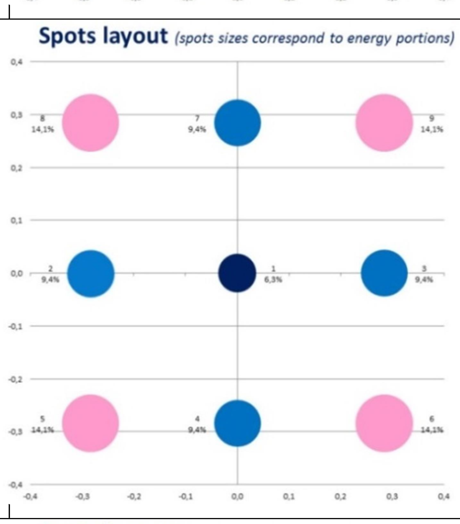


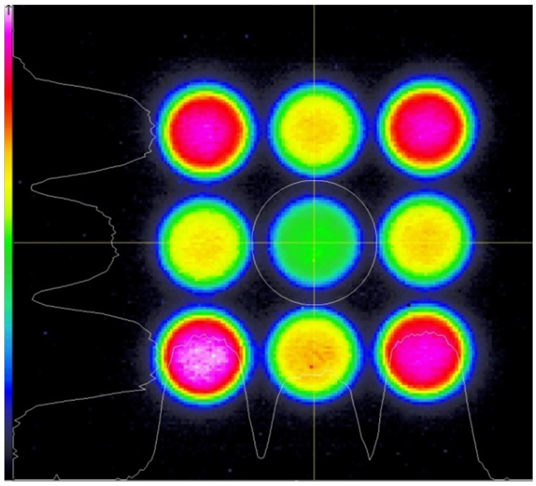
-30° / 30°

Analogous to Donut

Intensity ratio

$$\frac{1}{2.25} : \frac{1}{1.5} : 1$$



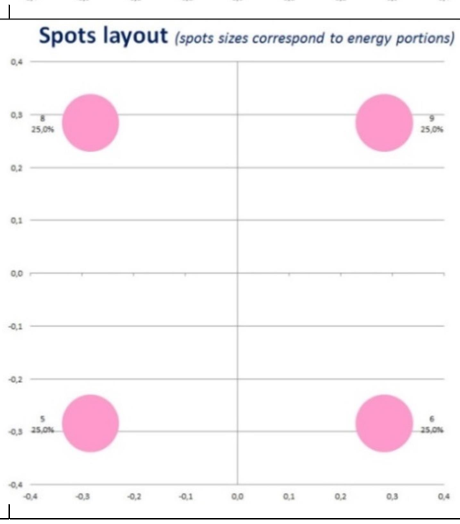


-45° / 45°

Only corner spots

Intensity ratio

$$0 : 0 : 1$$



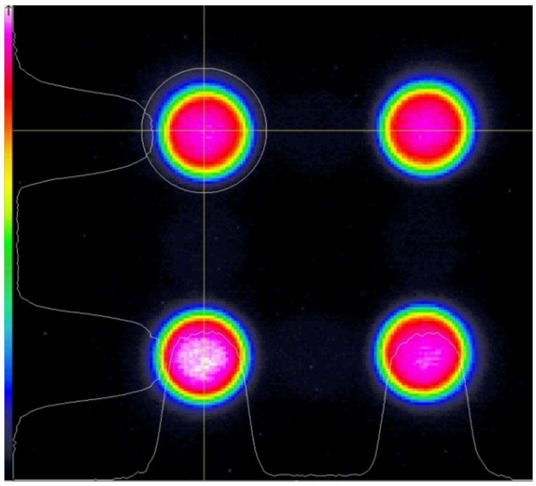


Table 5.2

peaXXus-spots
under various settings
of the Adjustment Rings

Conditions are the same like for the above presented “Characteristic *peaXXus*-spots”

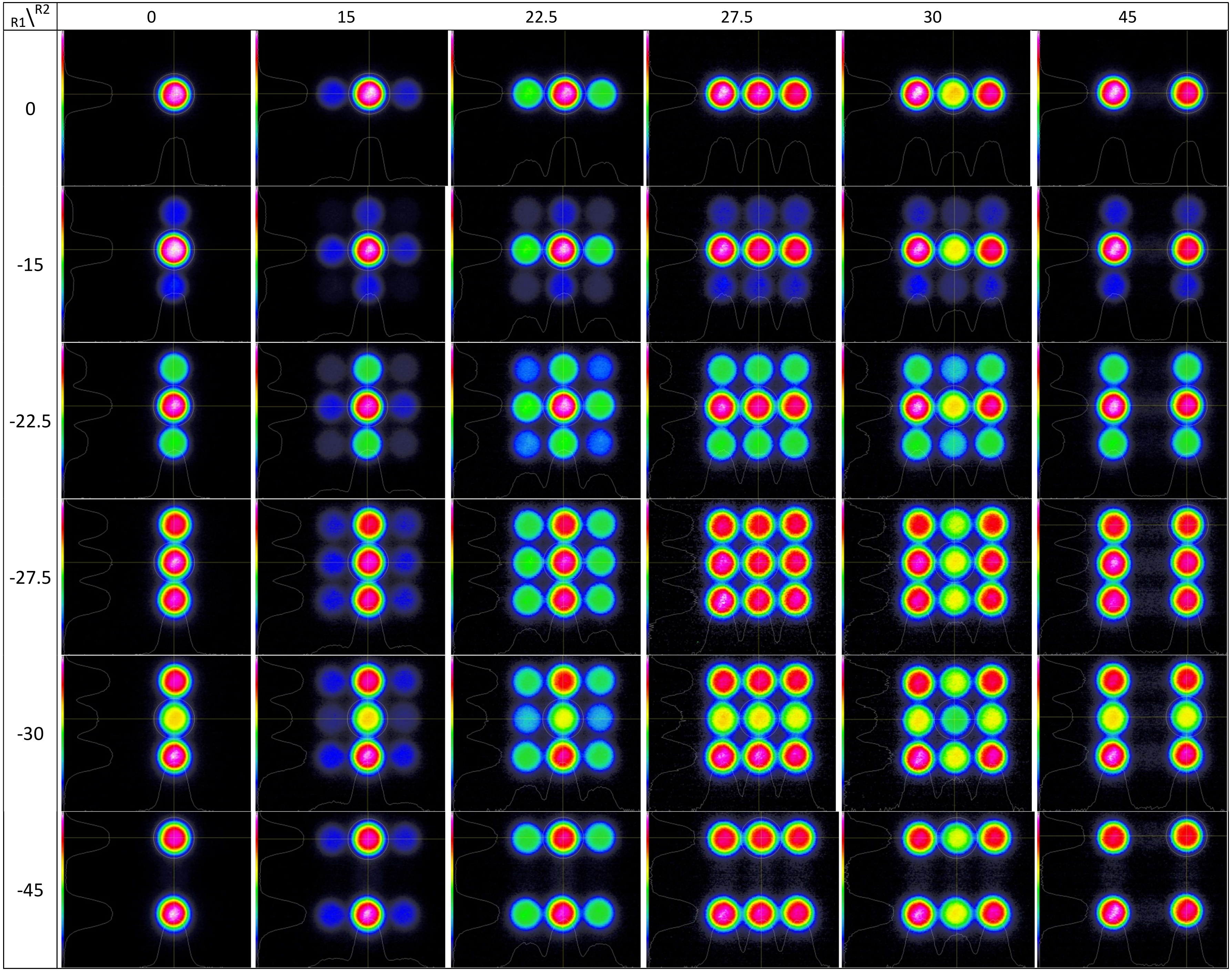
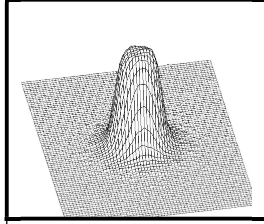
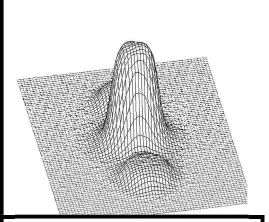
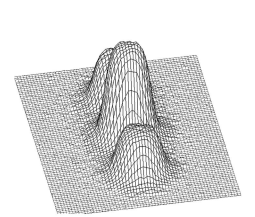
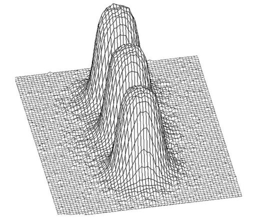
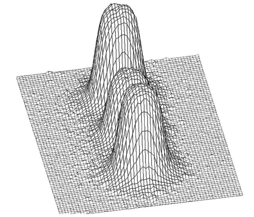
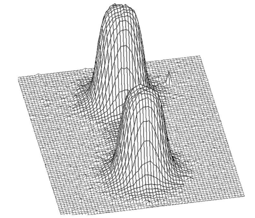
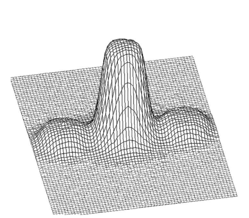
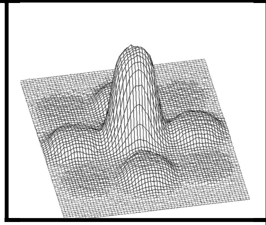
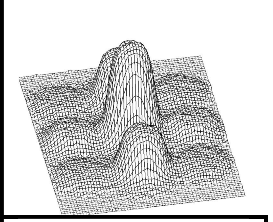
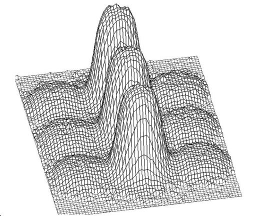
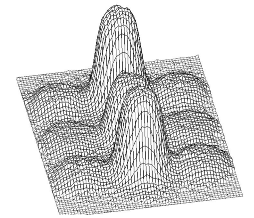
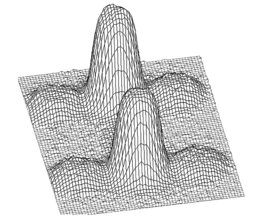
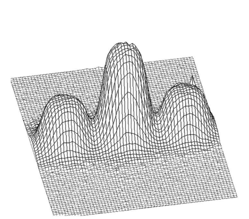
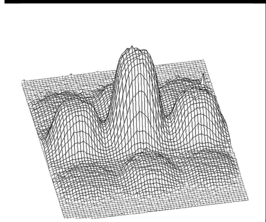
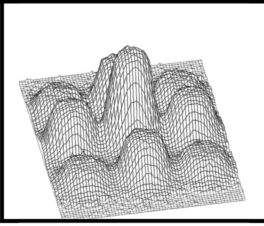
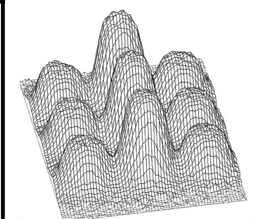
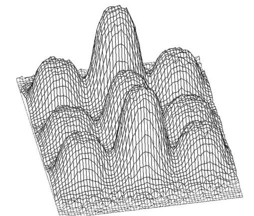
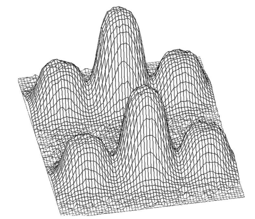
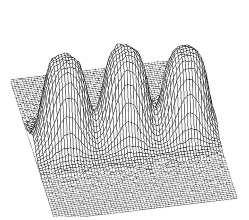
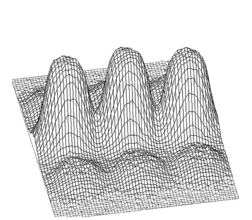
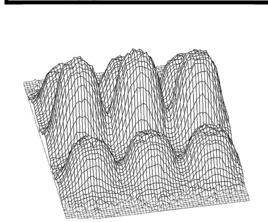
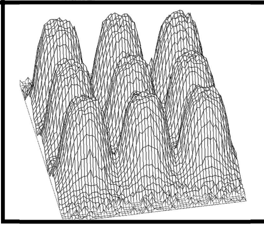
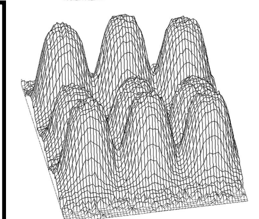
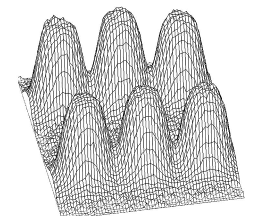
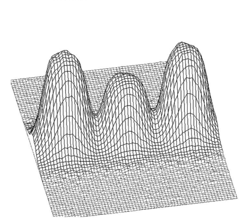
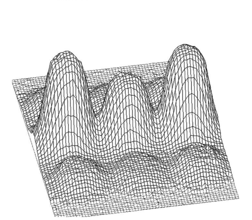
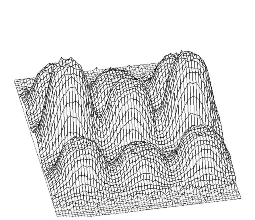
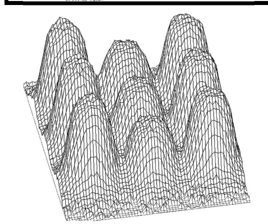
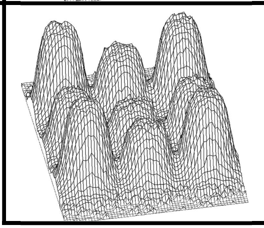
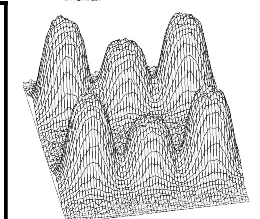
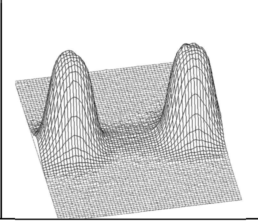
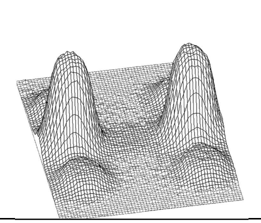
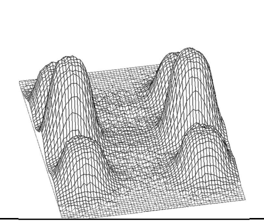
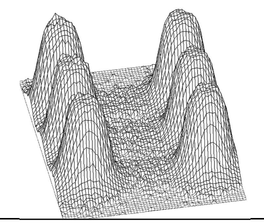
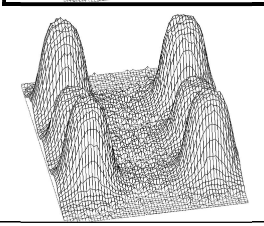
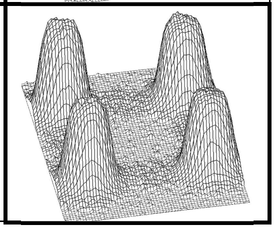


Table 5.3

<u>3D-views of the peaXXus-spots under various settings of the Adjustment Rings</u>

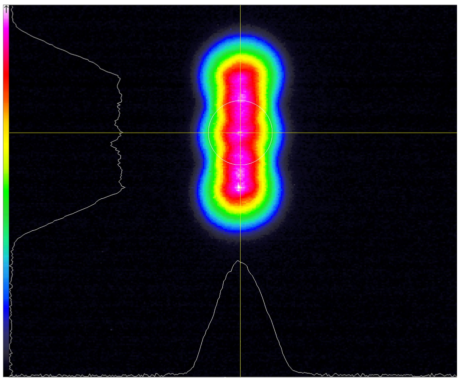
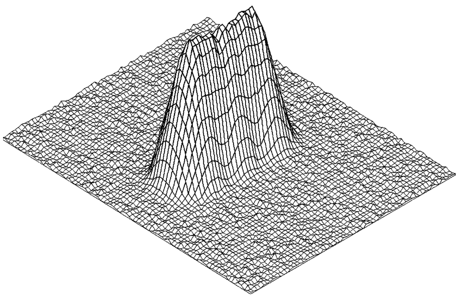
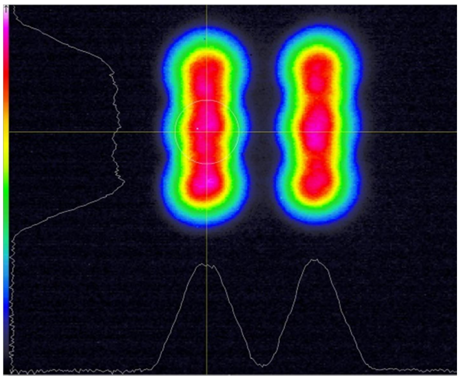
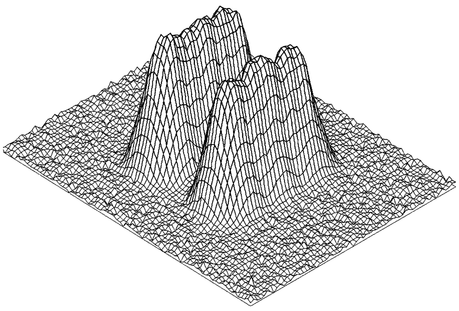
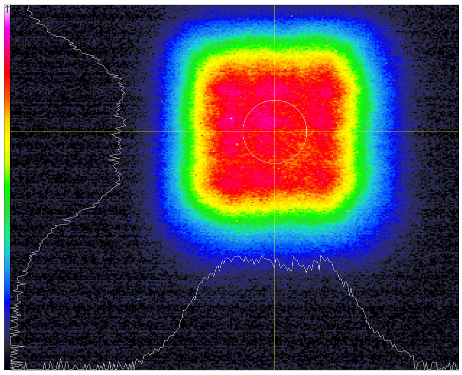
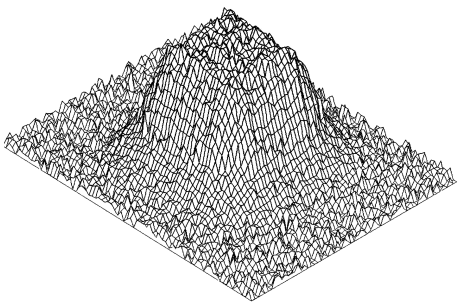
Conditions are the same like for the above presented "Characteristic *peaXXus*-spots"

R1 \ R2	0	15	22.5	27.5	30	45
0						
-15						
-22.5						
-27.5						
-30						
-45						

Characteristic peaXXus-spots by defocusing

Conditions are the same like for the above presented "Characteristic *peaXXus*-spots",
the working plane is defocused,
numerical data in table 5.4 are settings for Ring_1 / Ring_2, Fig.6.

Table 5.4

Line	Dual Line	Flat-top Square
-27.5 / 0	-27.5 / 45	-27.5 / 27.5
 	 	 

7. Data for communication with a supplier

By the communication with a supplier for evaluation of the optics alignment and performance, it is recommended to present, beforehand:

- Focal lengths of the
  - collimator,
  - focusing lens,
- Laser specifications:
  - Fiber core diameter,
  - Measured divergence of the laser beam emerging the fiber,
  - M^2 or BPP of the laser beam,
  - Central wavelength,
  - Spectral bandwidth (Emission Bandwidth),
  - Polarization State,
- for the *peaXXus* unit
  - Model,
  - Serial Number,
  - Settings of the Adjustment Rings,
- Measured intensity distributions in focal plane of the focusing lens,

  measurements using beam profilers, preferably PRIMES,

  with describing details of the measurement optical system, incl. mirrors, wedges, attenuators, neutral filters.

Data with material processing are considered **ONLY** when the above mentioned measured intensity distributions of the compound *peaXXus*–spots are presented.