FRIEDRICH-SCHILLER-
UNIVERSITÄT
JENA

Group 1 – 18.04.2024

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Lens Design I (SS' 24)

Seminar 1

Exercise 1-1: “Stair-mirror-setup” (Homework)

A system with a stair mirror pair, which decenters an incoming collimated ray bundle.

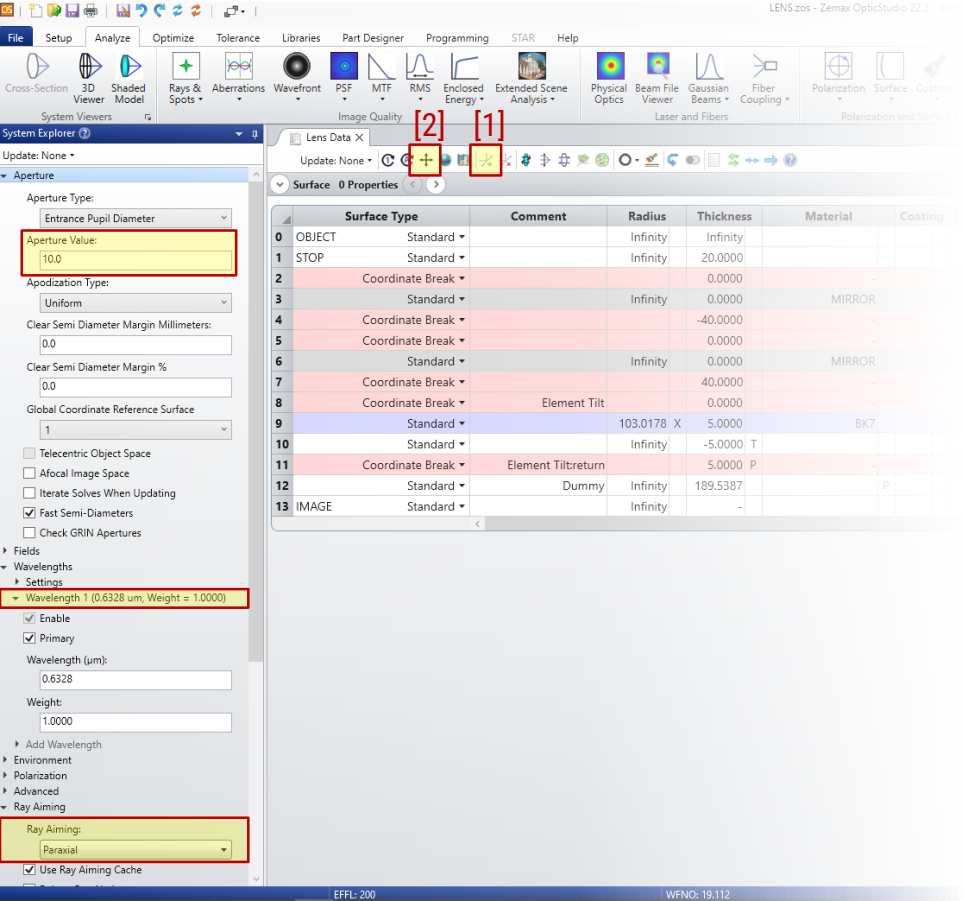
- Beam diameter = 10 mm;
- Beam decentration = 40 mm in the -Y direction;
- Beam wavelength (λ) = 632.8 nm.

After this pair of mirrors, a decentered main objective lens with focal length **f = 200 mm** made of **BK7** is located **25 mm below the optical axis** and focusses the beam.

Questions / Tasks:

a. Setup the system.
b. Generate layout drawings in 3D as well as “Shaded Model”.
c. Check the beam cross section on the second mirror, what is the size of the pattern?
d. Determine the optimal sensor plane location. Check the spot of the focused beam. Discuss the shape of this pattern.

Solution 1-1: A (Setup)

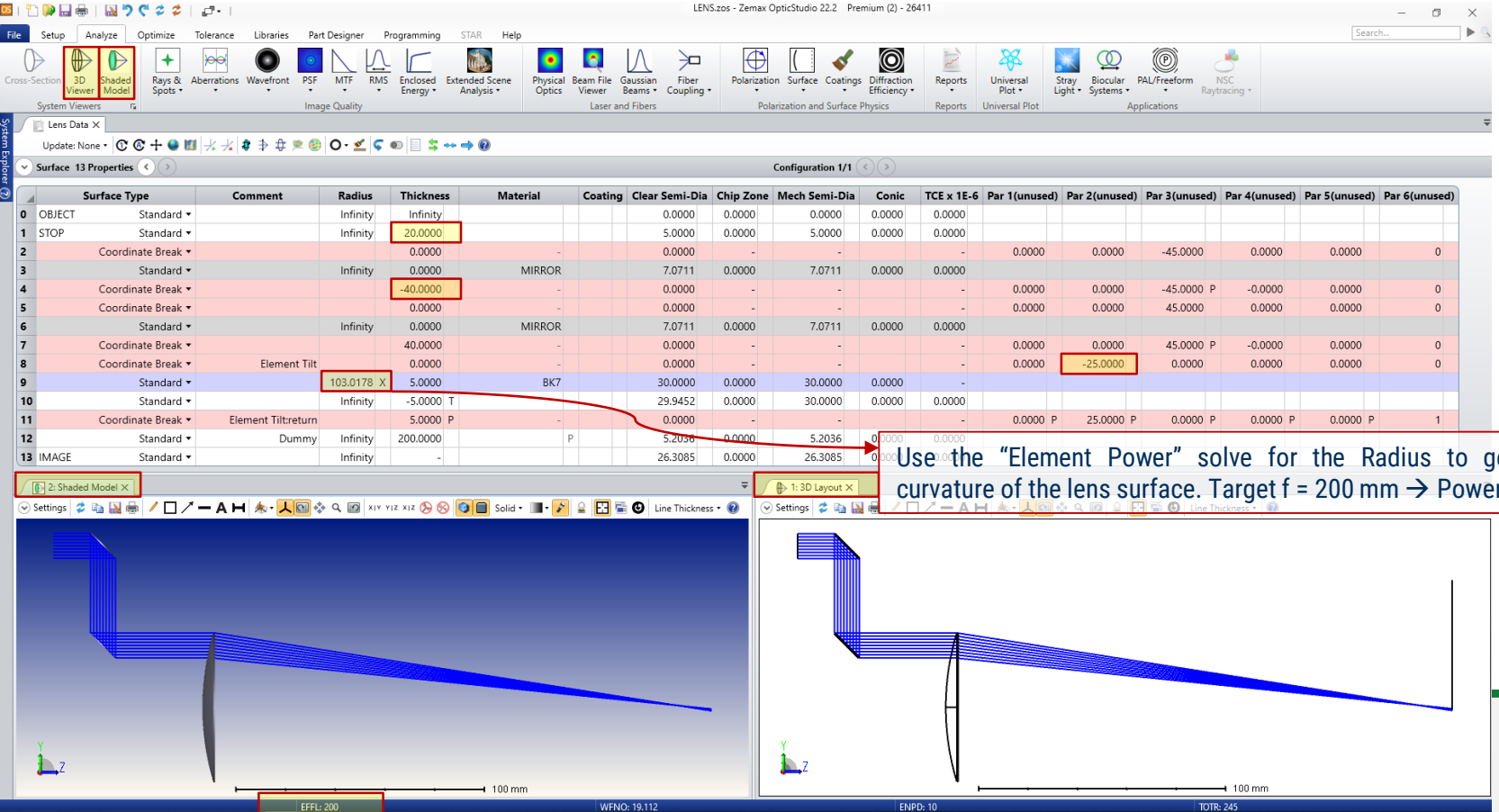


Aperture value – 10 mm
Wavelength – 0.6328 µm

Use paraxial ray-aiming for correct rays' propagation!

For adding folding mirrors use "Add Fold Mirror" [1]
For decentering the lens use "Tilt/Decenter Elements" [2]

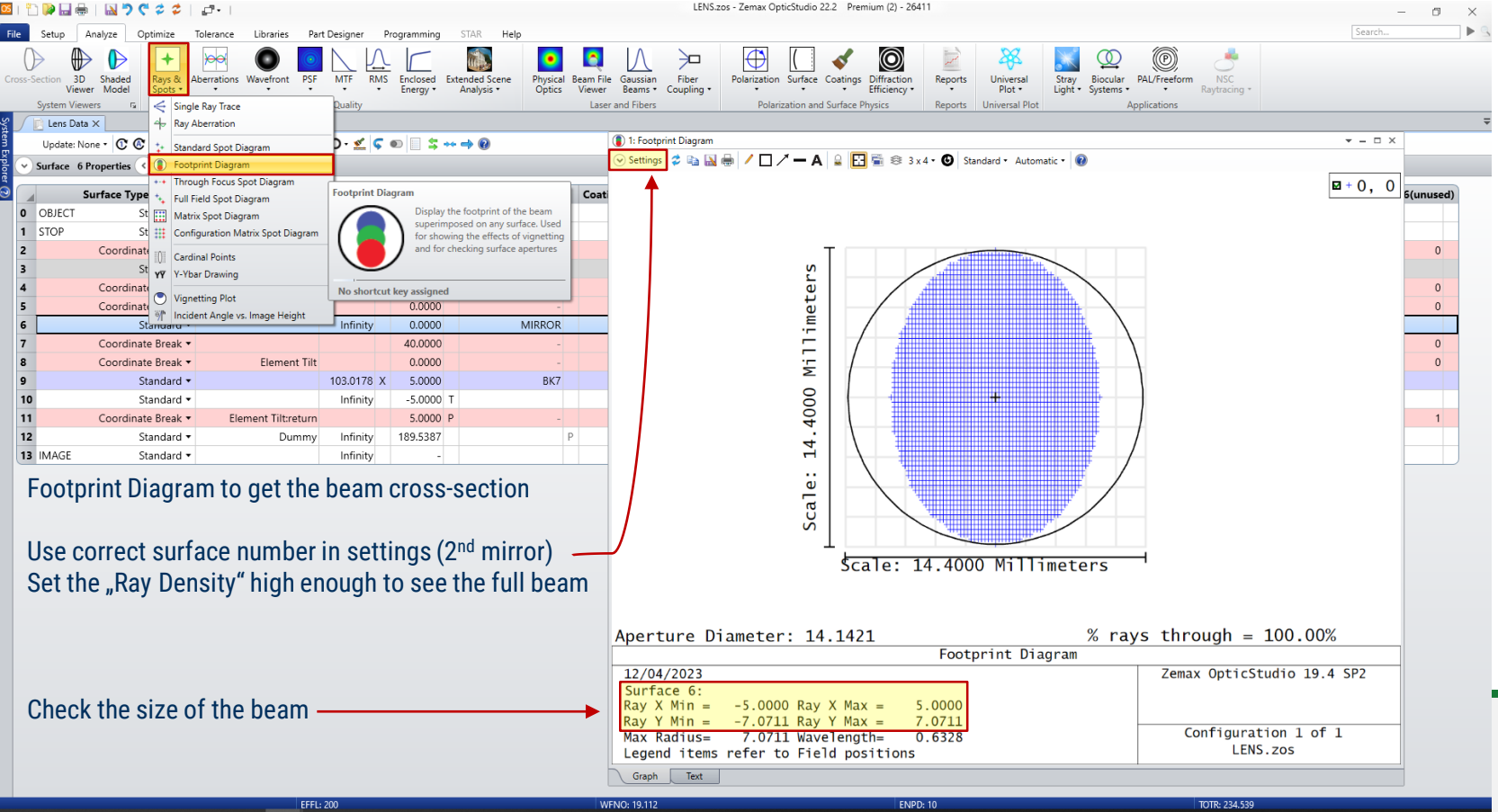
Solution 1-1: A-B (Setup & Layouts)



	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	Par 1(unused)	Par 2(unused)	Par 3(unused)	Par 4(unused)	Par 5(unused)	Par 6(unused)
0	OBJECT Standard		Infinity	Infinity			0.0000	0.0000	0.0000	0.0000	0.0000						
1	STOP Standard		Infinity	20.0000			5.0000	0.0000	5.0000	0.0000	0.0000						
2	Coordinate Break			0.0000	-		0.0000	-	-		-	0.0000	0.0000	-45.0000	0.0000	0.0000	0
3	Standard		Infinity	0.0000	MIRROR		7.0711	0.0000	7.0711	0.0000	0.0000						
4	Coordinate Break			-40.0000	-		0.0000	-	-		-	0.0000	0.0000	-45.0000 P	-0.0000	0.0000	0
5	Coordinate Break			0.0000	-		0.0000	-	-		-	0.0000	0.0000	45.0000	0.0000	0.0000	0
6	Standard		Infinity	0.0000	MIRROR		7.0711	0.0000	7.0711	0.0000	0.0000						
7	Coordinate Break			40.0000	-		0.0000	-	-		-	0.0000	0.0000	45.0000 P	-0.0000	0.0000	0
8	Coordinate Break	Element Tilt		0.0000	-		0.0000	-	-		-	0.0000	-25.0000	0.0000	0.0000	0.0000	0
9	Standard		103.0178 X	5.0000	BK7		30.0000	0.0000	30.0000	0.0000	-						
10	Standard		Infinity	-5.0000 T			29.9452	0.0000	30.0000	0.0000	0.0000						
11	Coordinate Break	Element Tilt:return		5.0000 P	-		0.0000	-	-		-	0.0000 P	25.0000 P	0.0000 P	0.0000 P	0.0000 P	1
12	Standard	Dummy	Infinity	200.0000		P	5.2036	0.0000	5.2036	0.0000	0.0000						
13	IMAGE Standard		Infinity	-			26.3085	0.0000	26.3085	0.0000	0.0000						

Use the "Element Power" solve for the Radius to get the correct curvature of the lens surface. Target f = 200 mm → Power = 0.005

Solution 1-1: C (Beam cross-section)

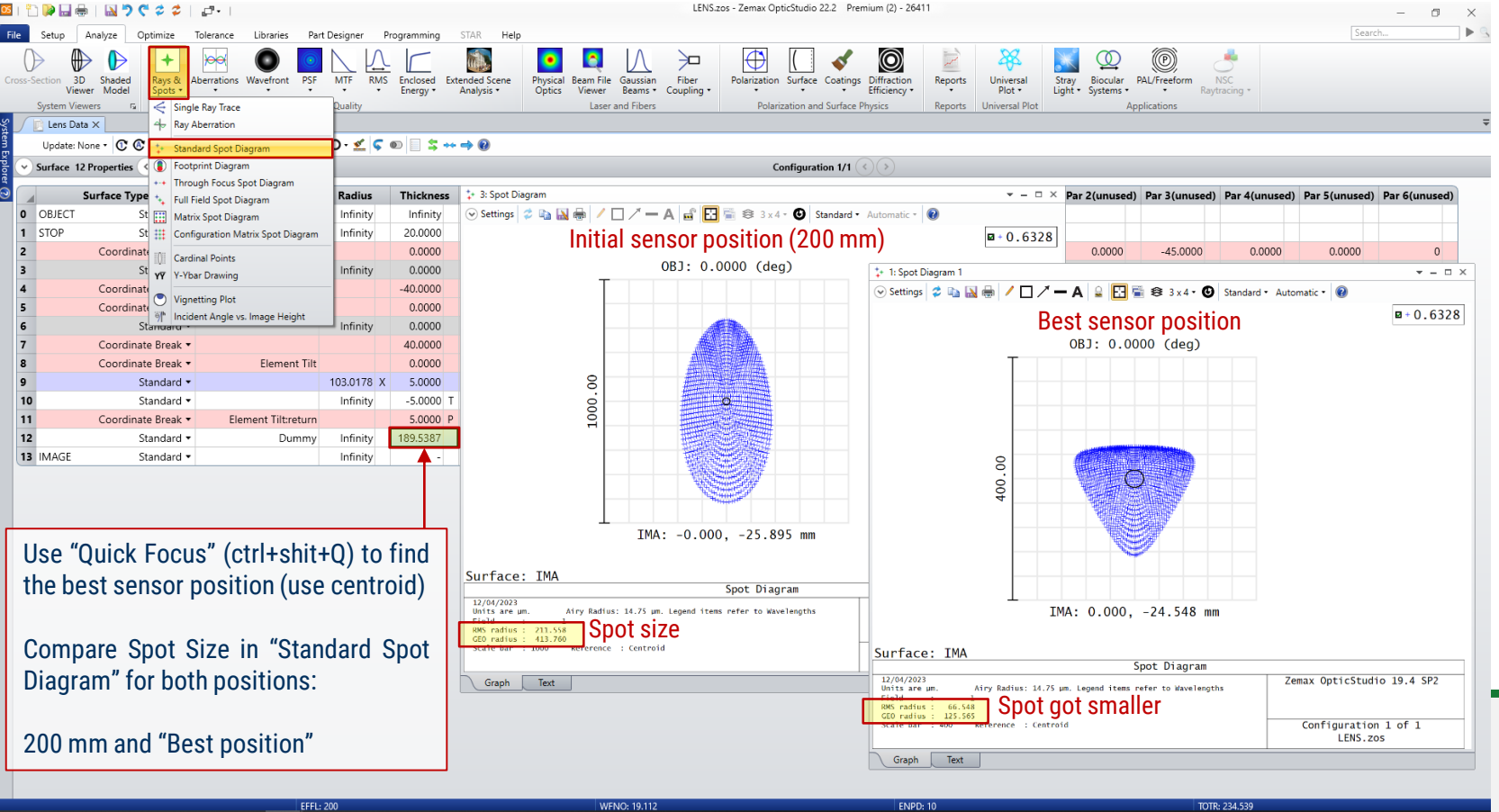


Footprint Diagram to get the beam cross-section

Use correct surface number in settings (2nd mirror)
Set the „Ray Density“ high enough to see the full beam

Check the size of the beam

Solution 1-1: D (Best sensor position)



Exercise 1-2: “Symmetrical 4F-system”

A telecentric 4F imaging system with two identical plano-convex lenses:

- Lenses’ material = BK7;
- Lenses’ thickness (d) = 10 mm;
- Approximate lenses’ focal length (f) = 100 mm;
- Object space NA = 0.2;
- Object diameter = 10 mm;
- Beam wavelength (λ) = 546.1 nm.

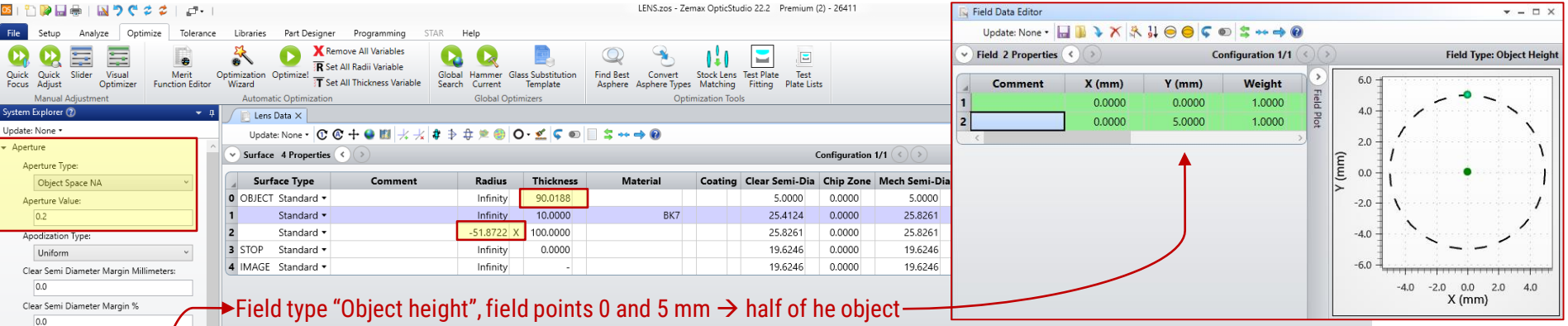
Questions / Tasks:

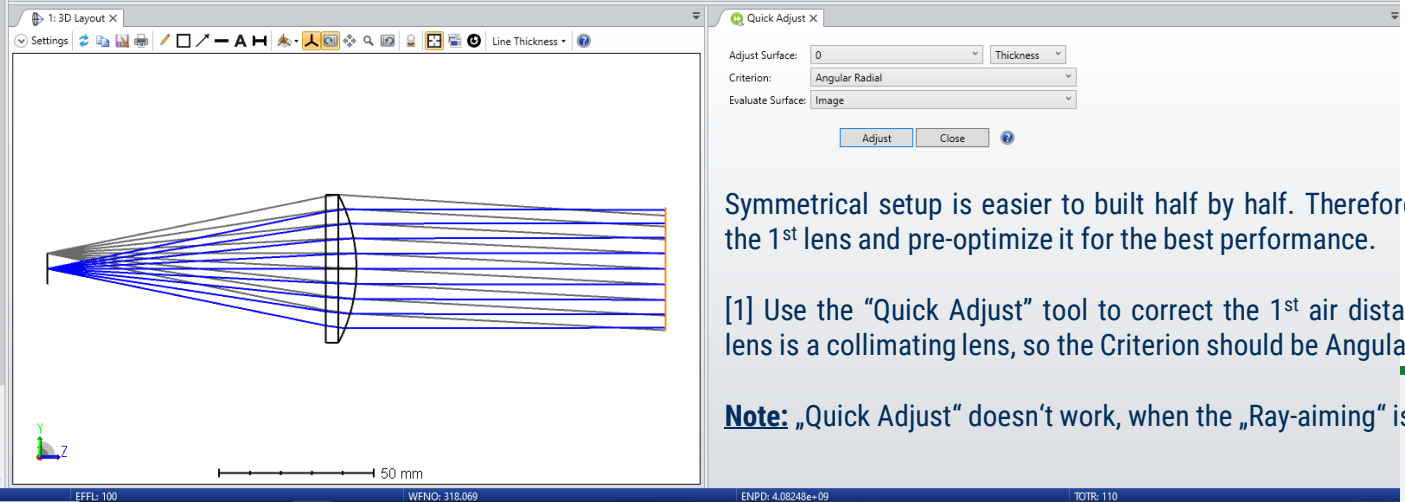
a. First, for perfectly symmetrical setup, determine the layout and the spot diagram of the system.

b. Optimize the image location. Why is the spot size improved?

c. If the starting aperture is decreased, the system becomes more and more close to diffraction limited. What is the value of the NA to get a diffraction limited system on axis? Take in mind here, that a re-focusing might be necessary due to the lowered spherical aberrations, which depends on the aperture.

Solution 1-2: A (1st half of a setup)



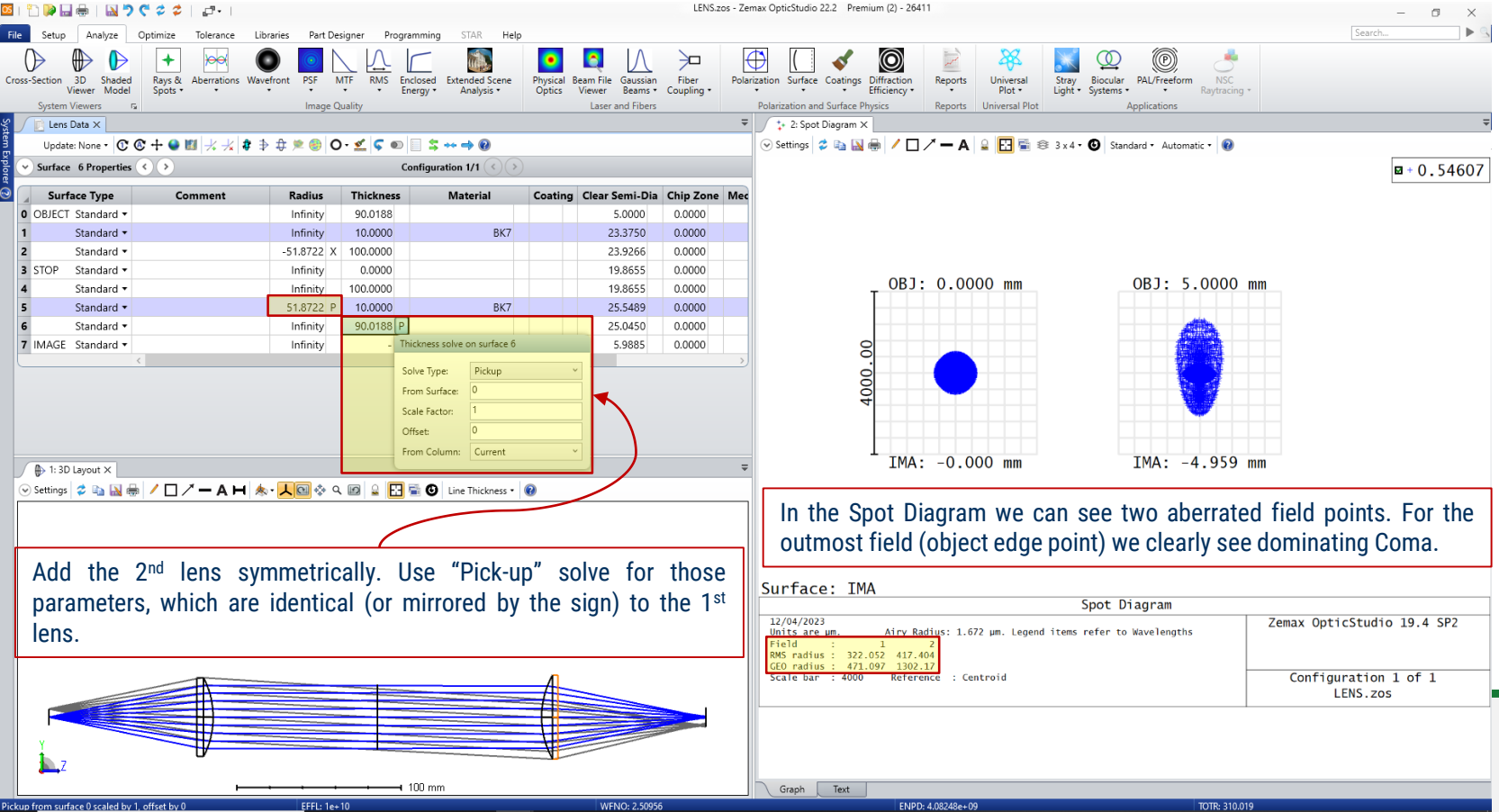


Symmetrical setup is easier to built half by half. Therefore, we define the 1st lens and pre-optimize it for the best performance.

[1] Use the "Quick Adjust" tool to correct the 1st air distance. The 1st lens is a collimating lens, so the Criterion should be Angular!

Note: „Quick Adjust" doesn't work, when the „Ray-aiming" is on!

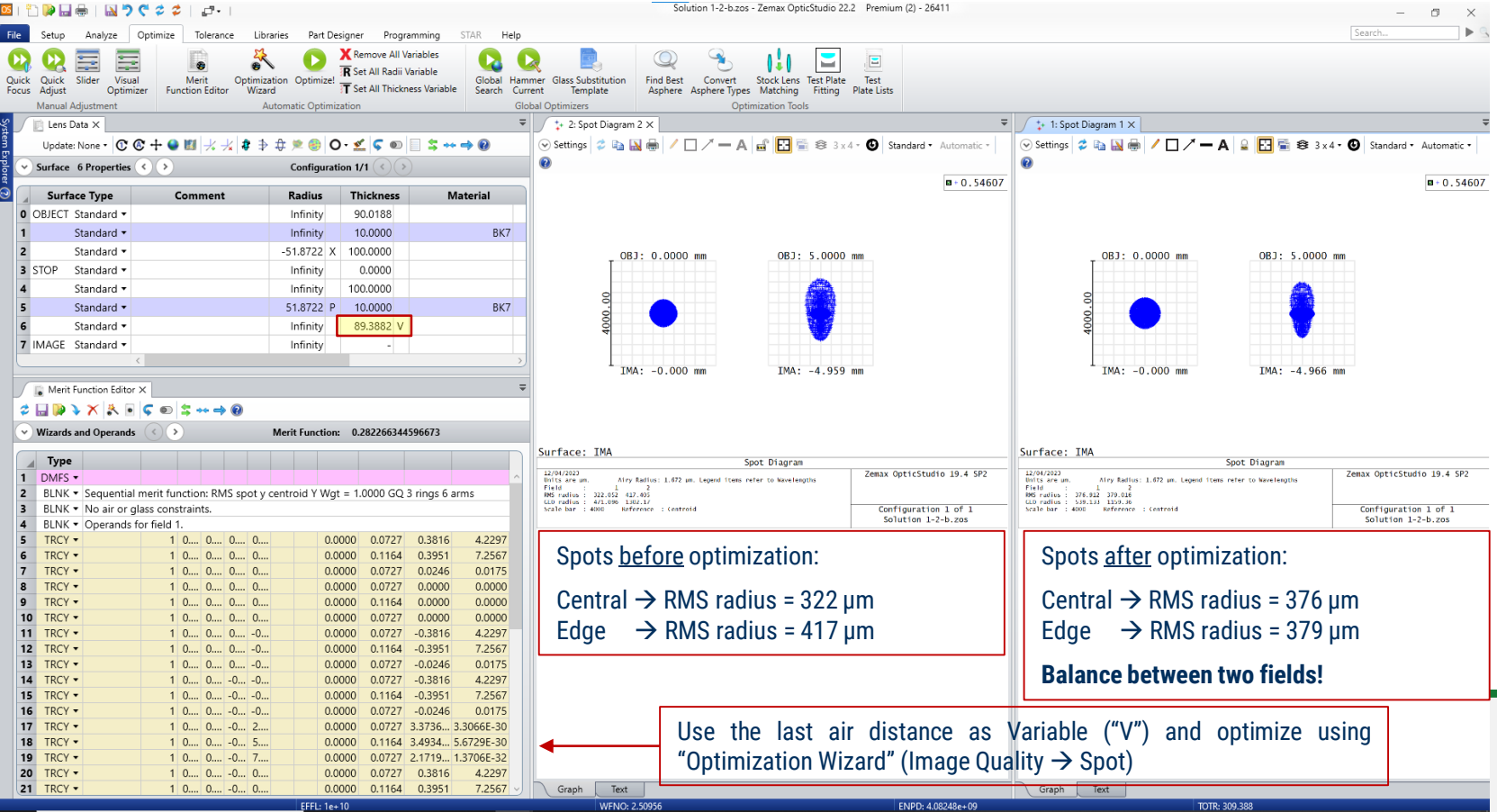
Solution 1-2: A (Full setup)



Add the 2nd lens symmetrically. Use “Pick-up” solve for those parameters, which are identical (or mirrored by the sign) to the 1st lens.

In the Spot Diagram we can see two aberrated field points. For the outmost field (object edge point) we clearly see dominating Coma.

Solution 1-2: B (Optimization)



Spots before optimization:

Central → RMS radius = 322 µm
Edge → RMS radius = 417 µm

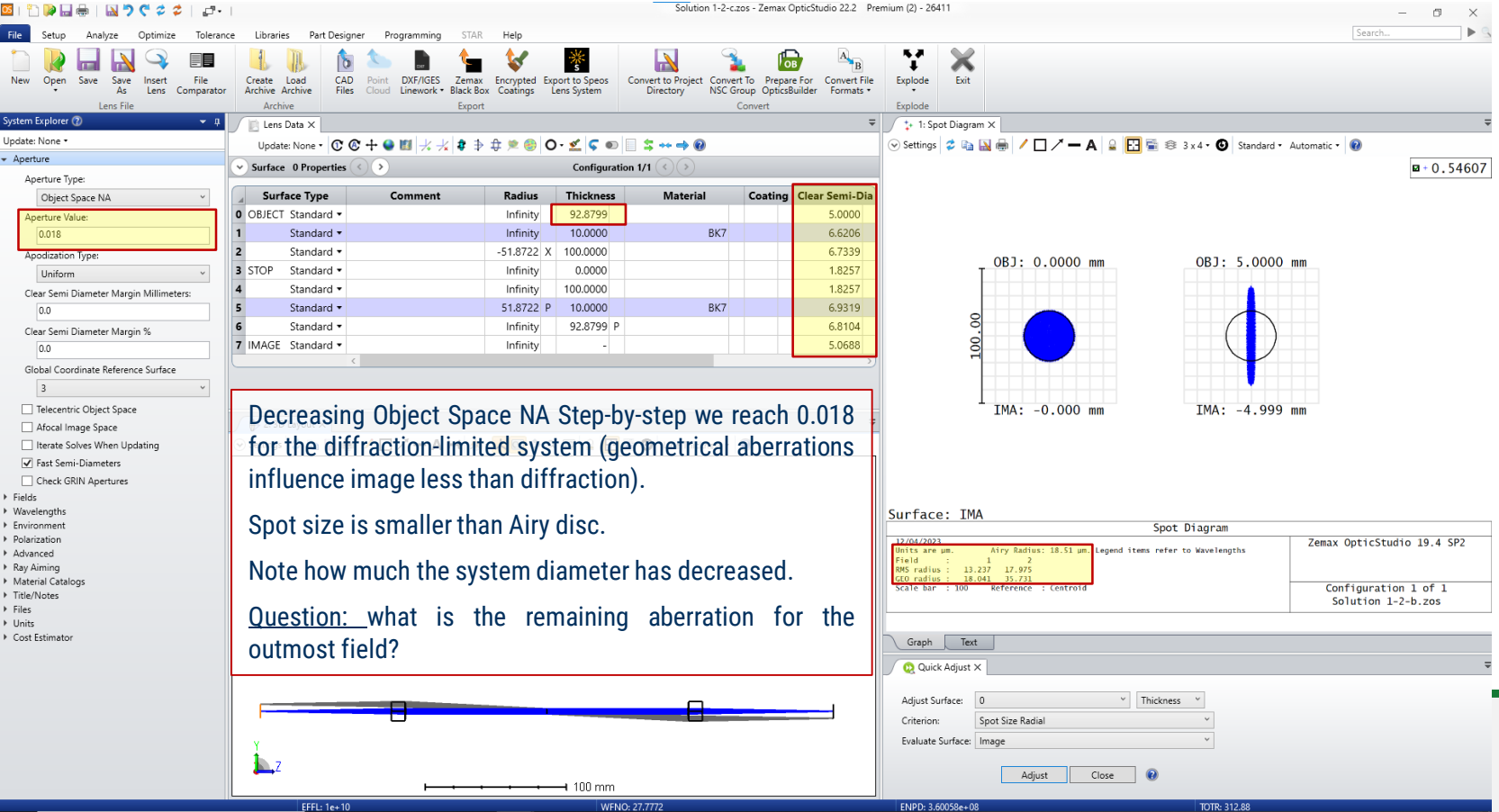
Spots after optimization:

Central → RMS radius = 376 µm
Edge → RMS radius = 379 µm

Balance between two fields!

Use the last air distance as Variable ("V") and optimize using "Optimization Wizard" (Image Quality → Spot)

Solution 1-2: B (Optimization)



Exercise 1-3: “Apertures, stops and vignetting”

Load the achromat **AAP-125.0-25.4** from the lens catalogue **(CVI Melles Griot, f = 125mm)**. Set the diameter of the **entrance pupil to 20 mm** and the **wavelength to 546.1 nm**. Display the wavefront of the achromat for the **field points 0°, 3° and 5°** with different stops and apertures:

a. With the stop surface at 1st surface of the system;

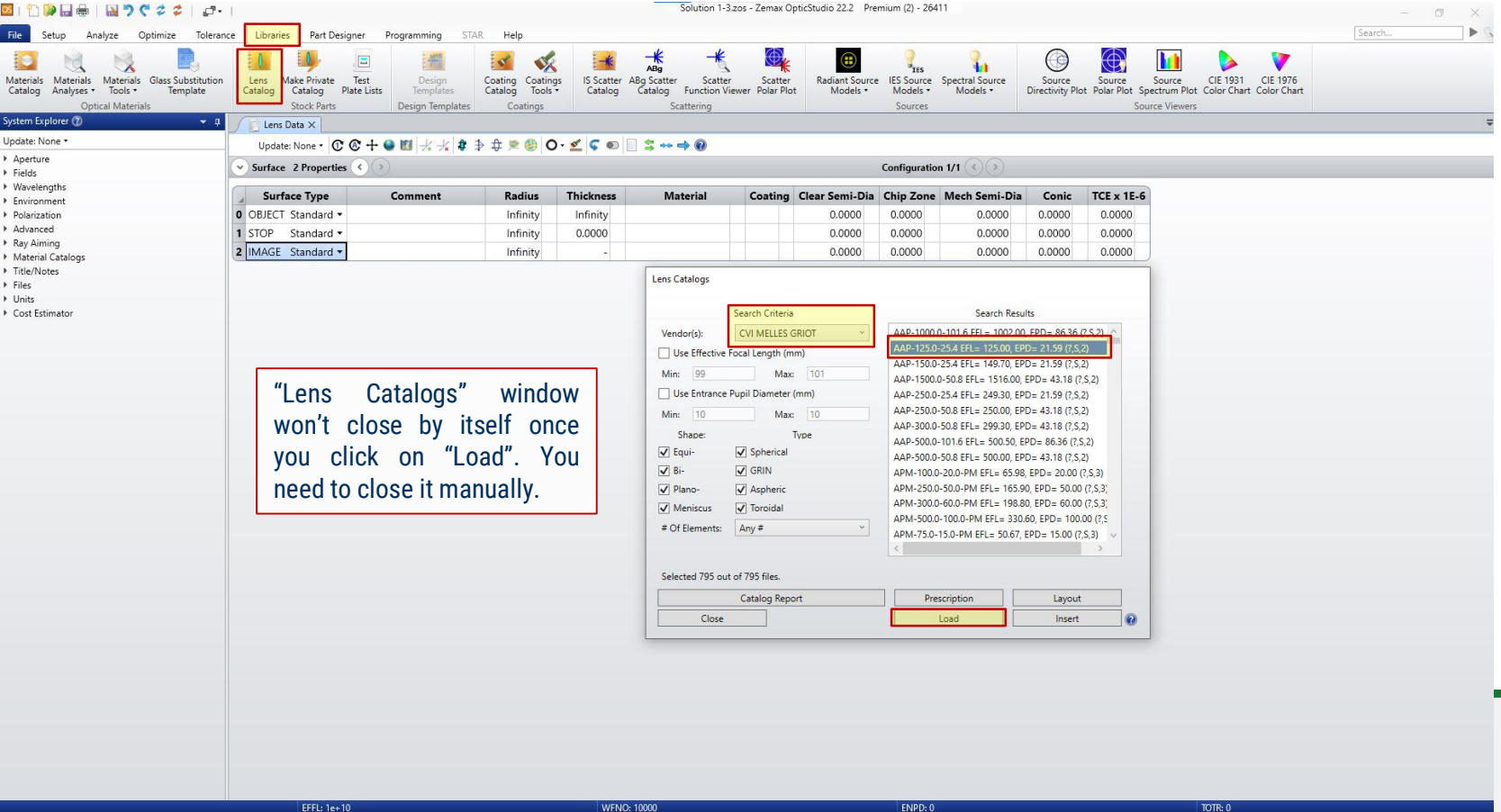
b. With the stop surface at the front focal plane (for finding the position of the focal plane, use Analysis → Rays and Spots → Cardinal Points);

c. With adjusted entrance pupils using System Data → Fields → Settings → Set Vignetting;

d. Insert a circular central obscuration with 6 mm radius at the 1st surface of the achromat and recalculate the wavefront with and without vignetting factors;

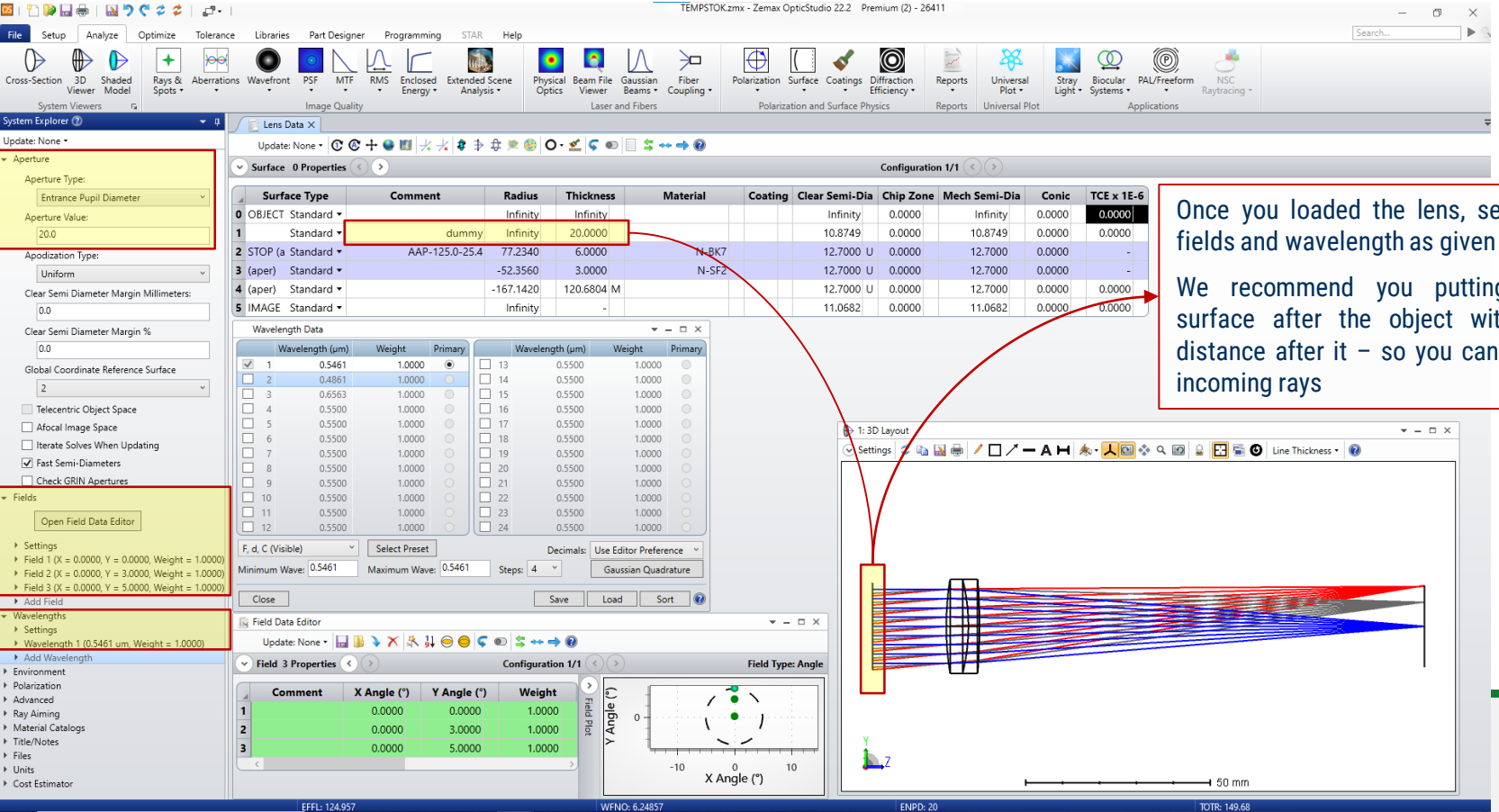
e. Clear all vignetting, then calculate the ray intersection coordinates (REAY) at the last surface for the upper marginal ray and the chief ray of field 5° in the merit function editor. Interpret the result.

Solution 1-3: Loading the lens



"Lens Catalogs" window won't close by itself once you click on "Load". You need to close it manually.

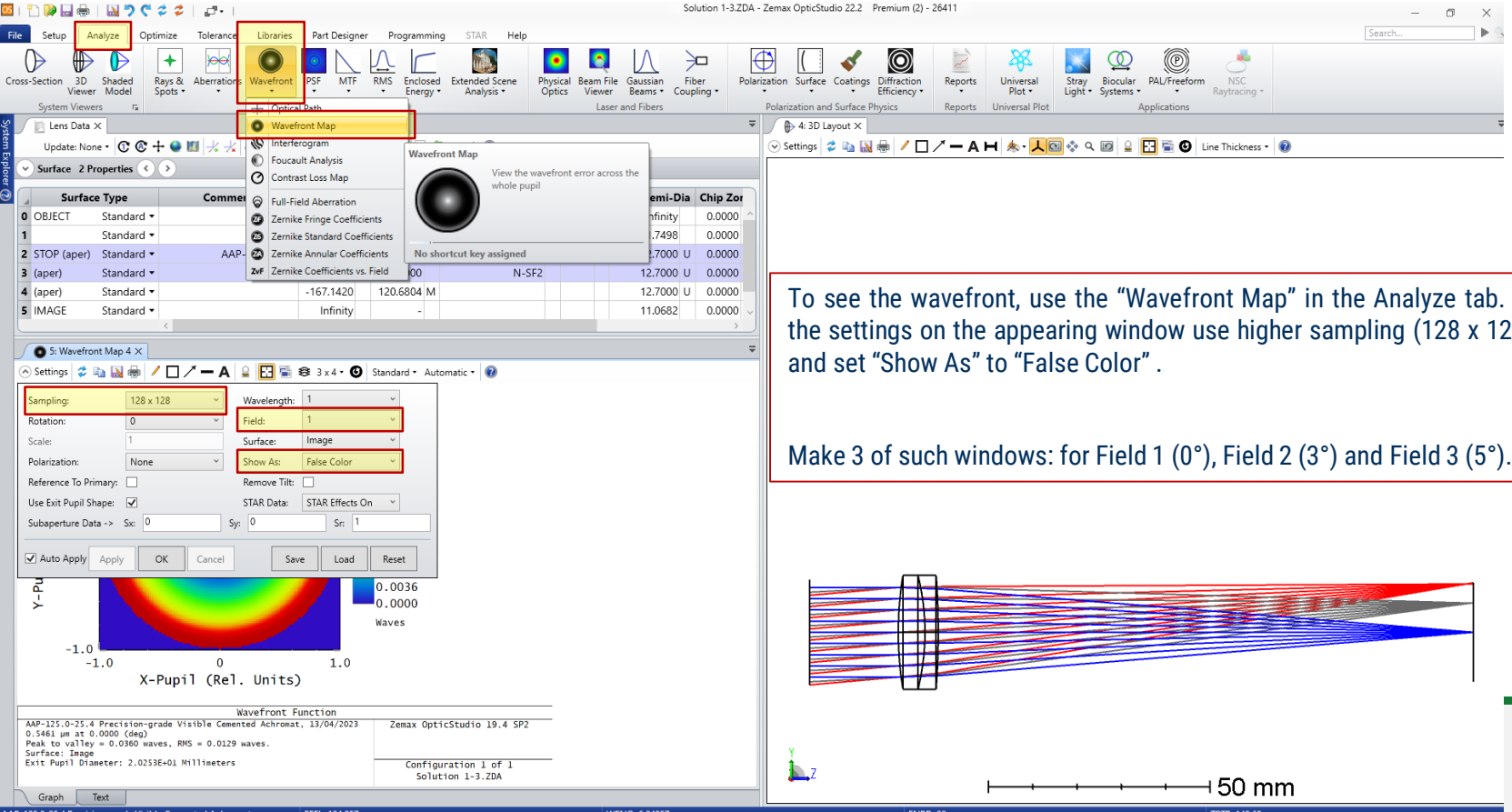
Solution 1-3: Loading the lens



Once you loaded the lens, set the aperture, fields and wavelength as given in the task.

We recommend you putting a "dummy" surface after the object with 20 mm air distance after it – so you can better see the incoming rays

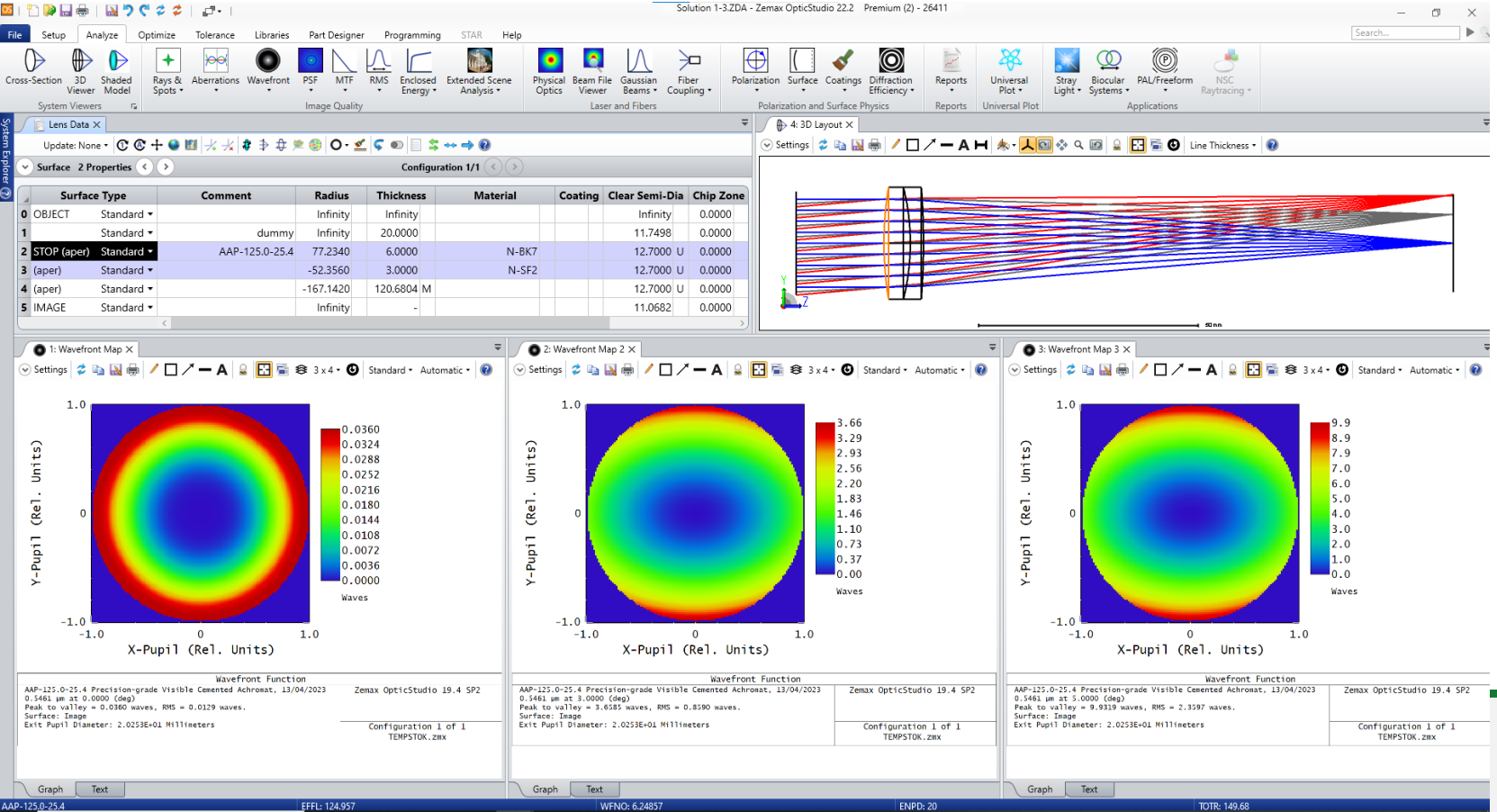
Solution 1-3: A (STOP at the 1st surface)



To see the wavefront, use the "Wavefront Map" in the Analyze tab. In the settings on the appearing window use higher sampling (128 x 128) and set "Show As" to "False Color" .

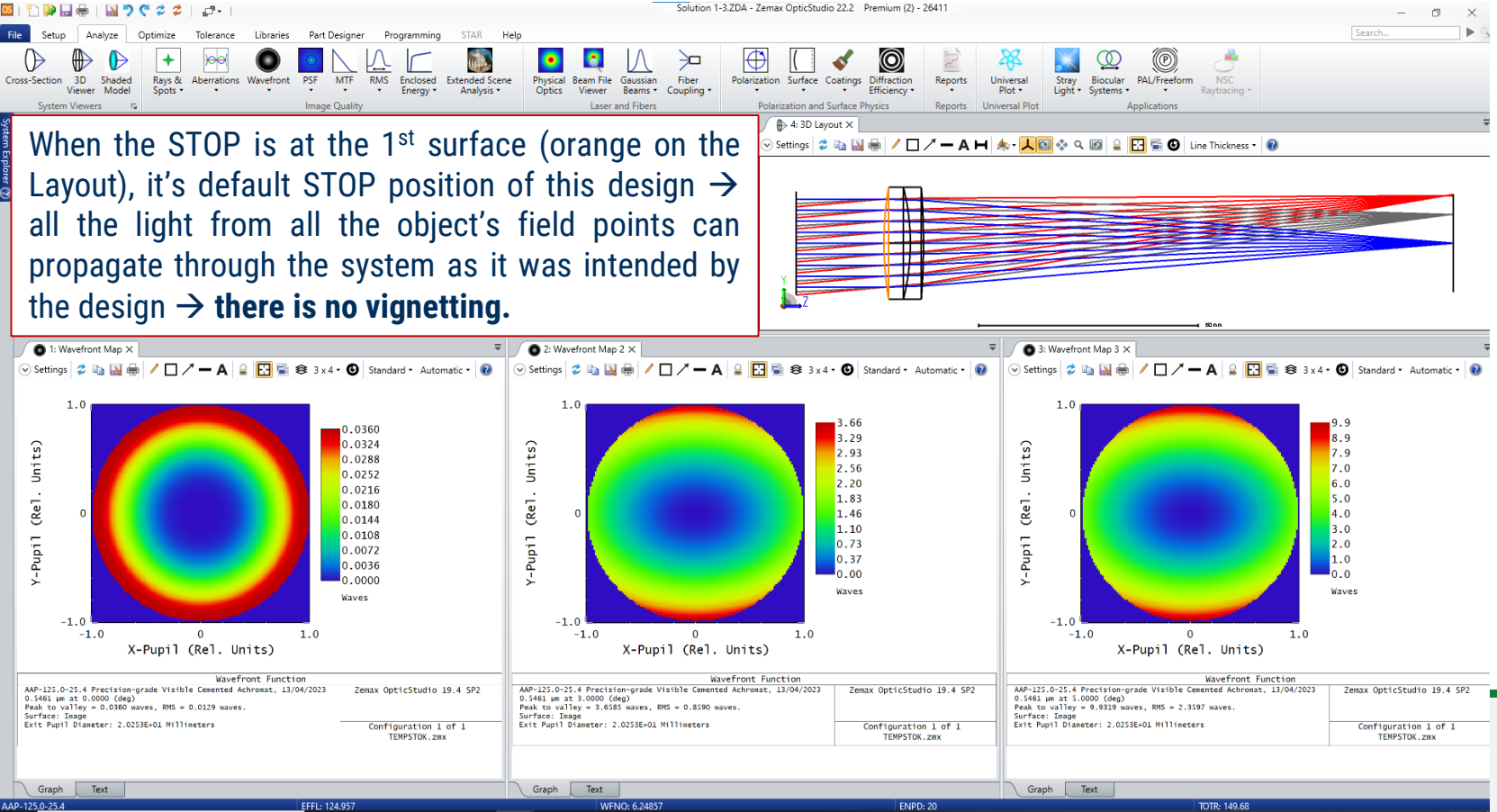
Make 3 of such windows: for Field 1 (0°), Field 2 (3°) and Field 3 (5°).

Solution 1-3: A (STOP at the 1st surface)

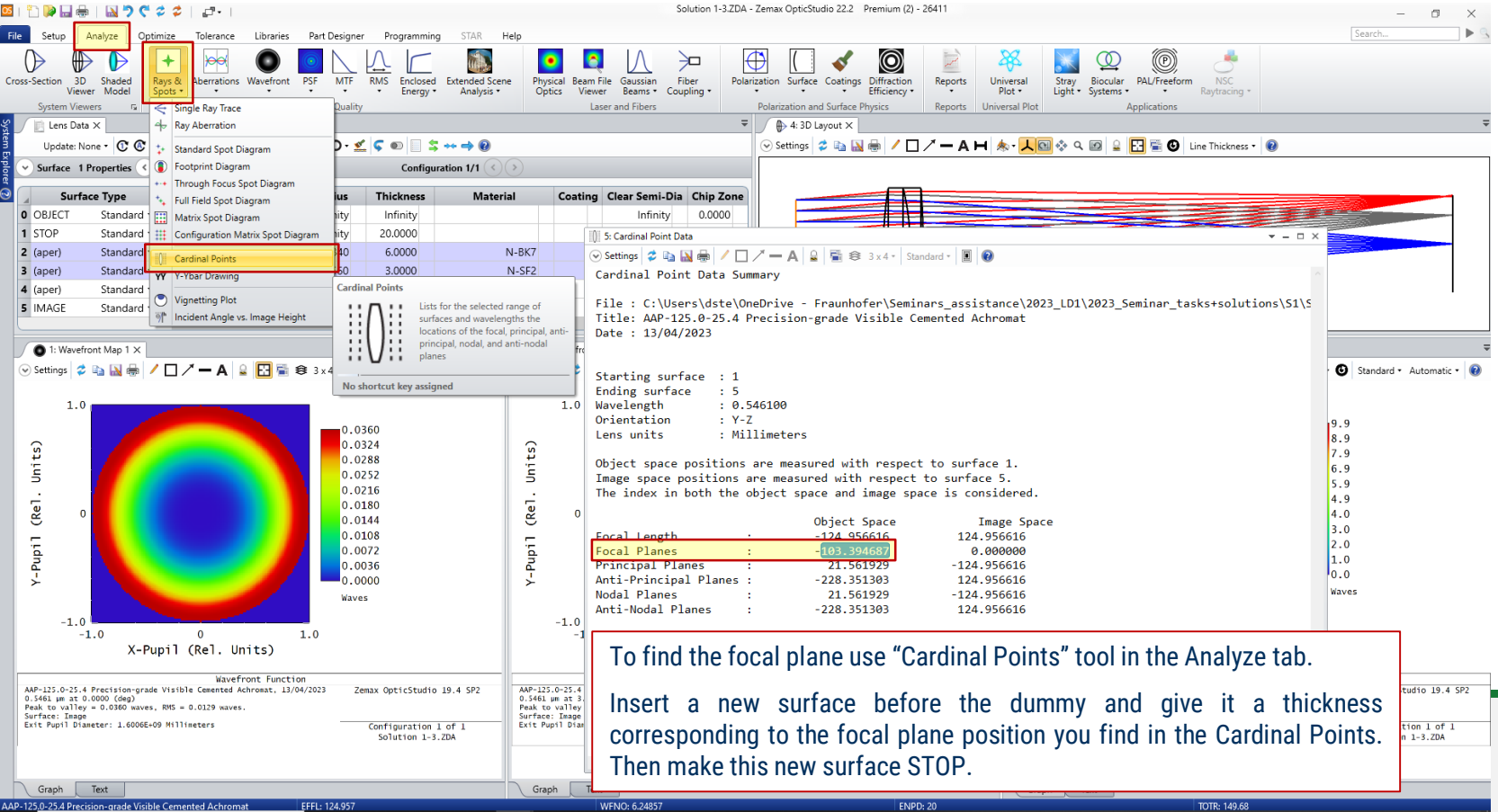


Solution 1-3: A (STOP at the 1st surface)

When the STOP is at the 1st surface (orange on the Layout), it's default STOP position of this design → all the light from all the object's field points can propagate through the system as it was intended by the design → **there is no vignetting.**



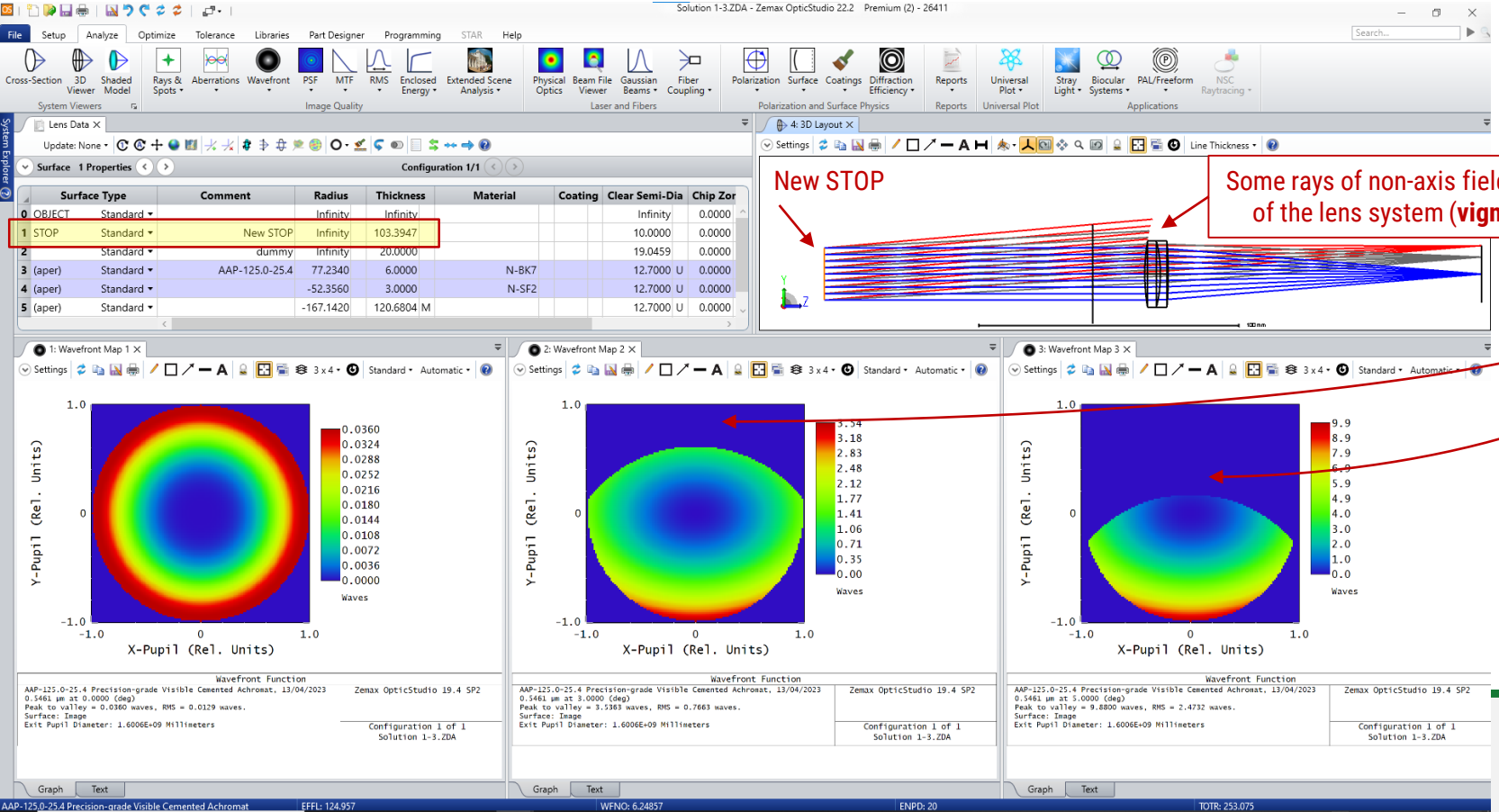
Solution 1-3: B (STOP at the focal plane)



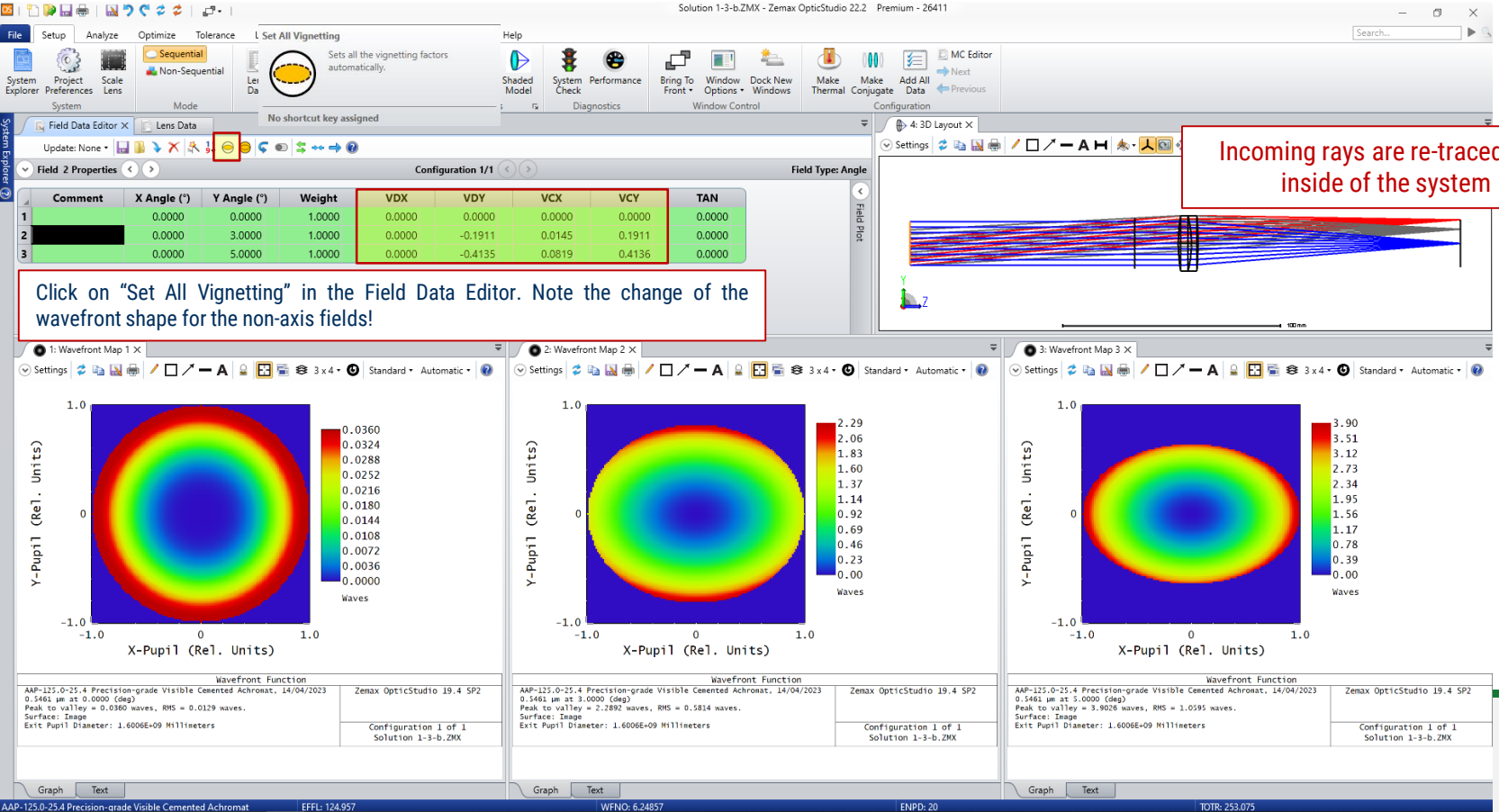
To find the focal plane use “Cardinal Points” tool in the Analyze tab.

Insert a new surface before the dummy and give it a thickness corresponding to the focal plane position you find in the Cardinal Points. Then make this new surface STOP.

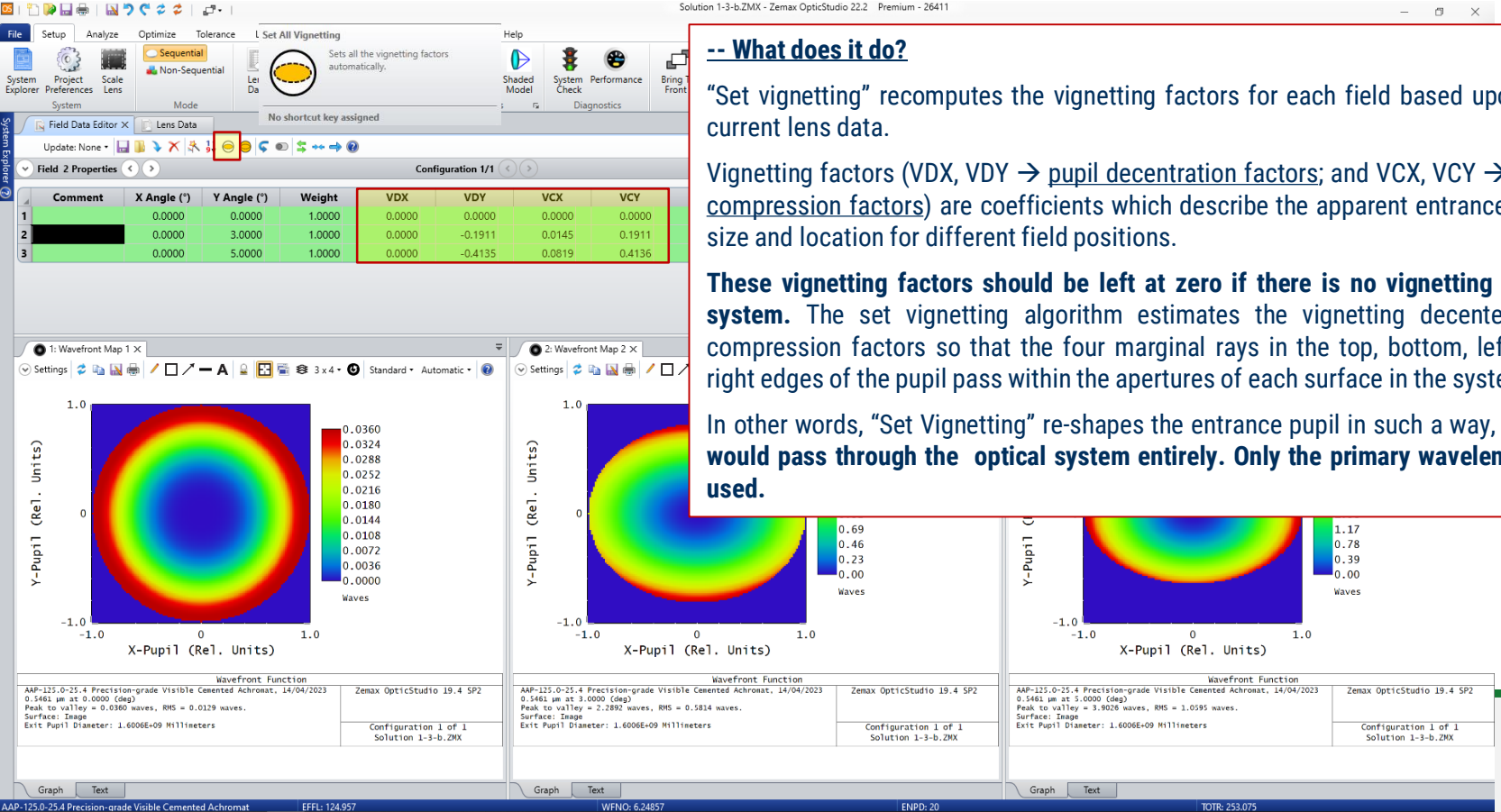
Solution 1-3: B (STOP at the focal plane)



Solution 1-3: C (Set vignetting)



Solution 1-3: C (Set vignetting)



-- What does it do?

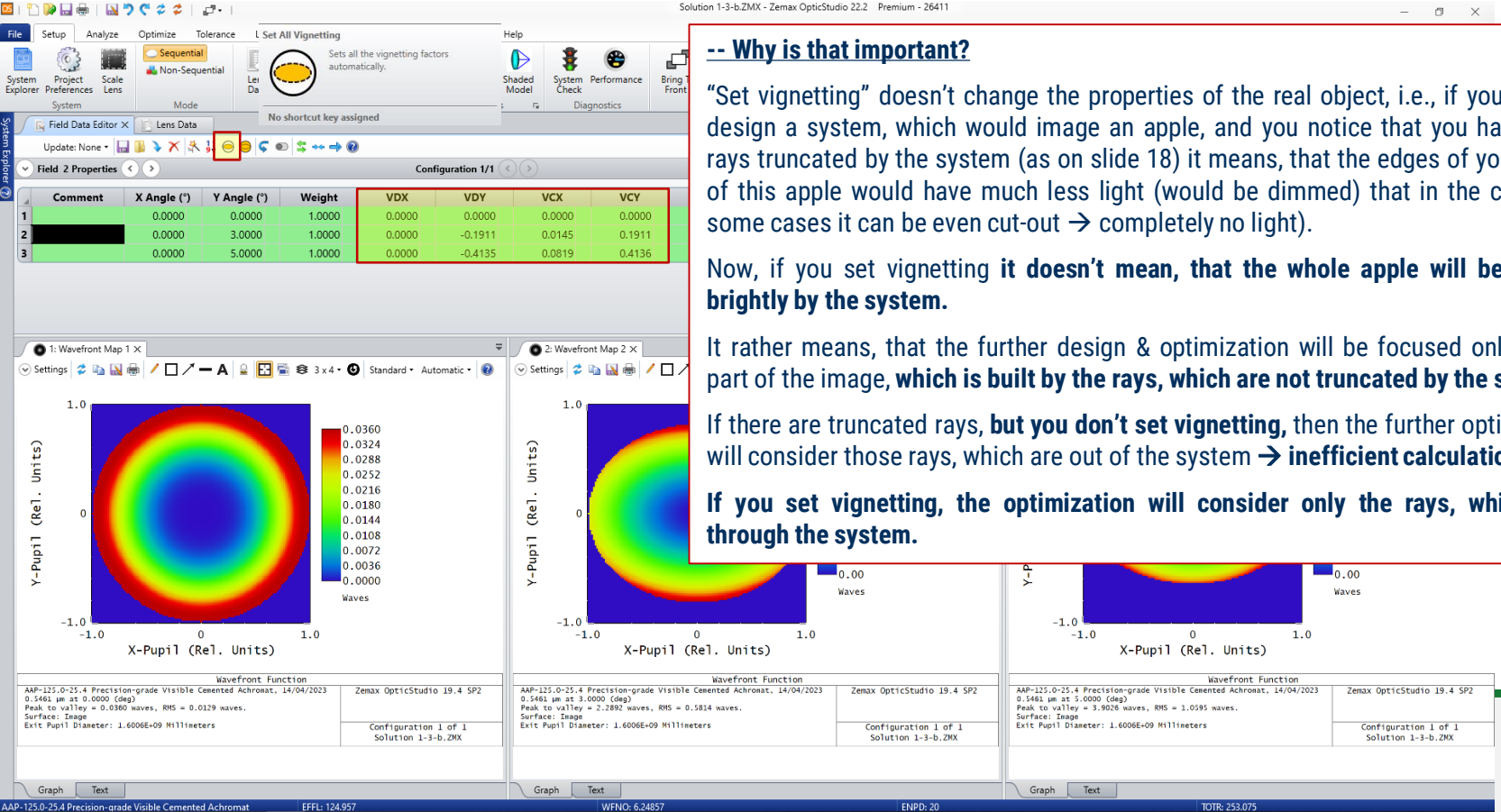
"Set vignetting" recomputes the vignetting factors for each field based upon the current lens data.

Vignetting factors (VDX, VDY → pupil decentration factors; and VCX, VCY → pupil compression factors) are coefficients which describe the apparent entrance pupil size and location for different field positions.

These vignetting factors should be left at zero if there is no vignetting in the system. The set vignetting algorithm estimates the vignetting decenter and compression factors so that the four marginal rays in the top, bottom, left, and right edges of the pupil pass within the apertures of each surface in the system.

In other words, "Set Vignetting" re-shapes the entrance pupil in such a way, that **it would pass through the optical system entirely. Only the primary wavelength is used.**

Solution 1-3: C (Set vignetting)



-- Why is that important?

"Set vignetting" doesn't change the properties of the real object, i.e., if you want to design a system, which would image an apple, and you notice that you have some rays truncated by the system (as on slide 18) it means, that the edges of your image of this apple would have much less light (would be dimmed) that in the center (in some cases it can be even cut-out → completely no light).

Now, if you set vignetting **it doesn't mean, that the whole apple will be imaged brightly by the system.**

It rather means, that the further design & optimization will be focused only on the part of the image, **which is built by the rays, which are not truncated by the system.**

If there are truncated rays, **but you don't set vignetting,** then the further optimization will consider those rays, which are out of the system → **inefficient calculation.**

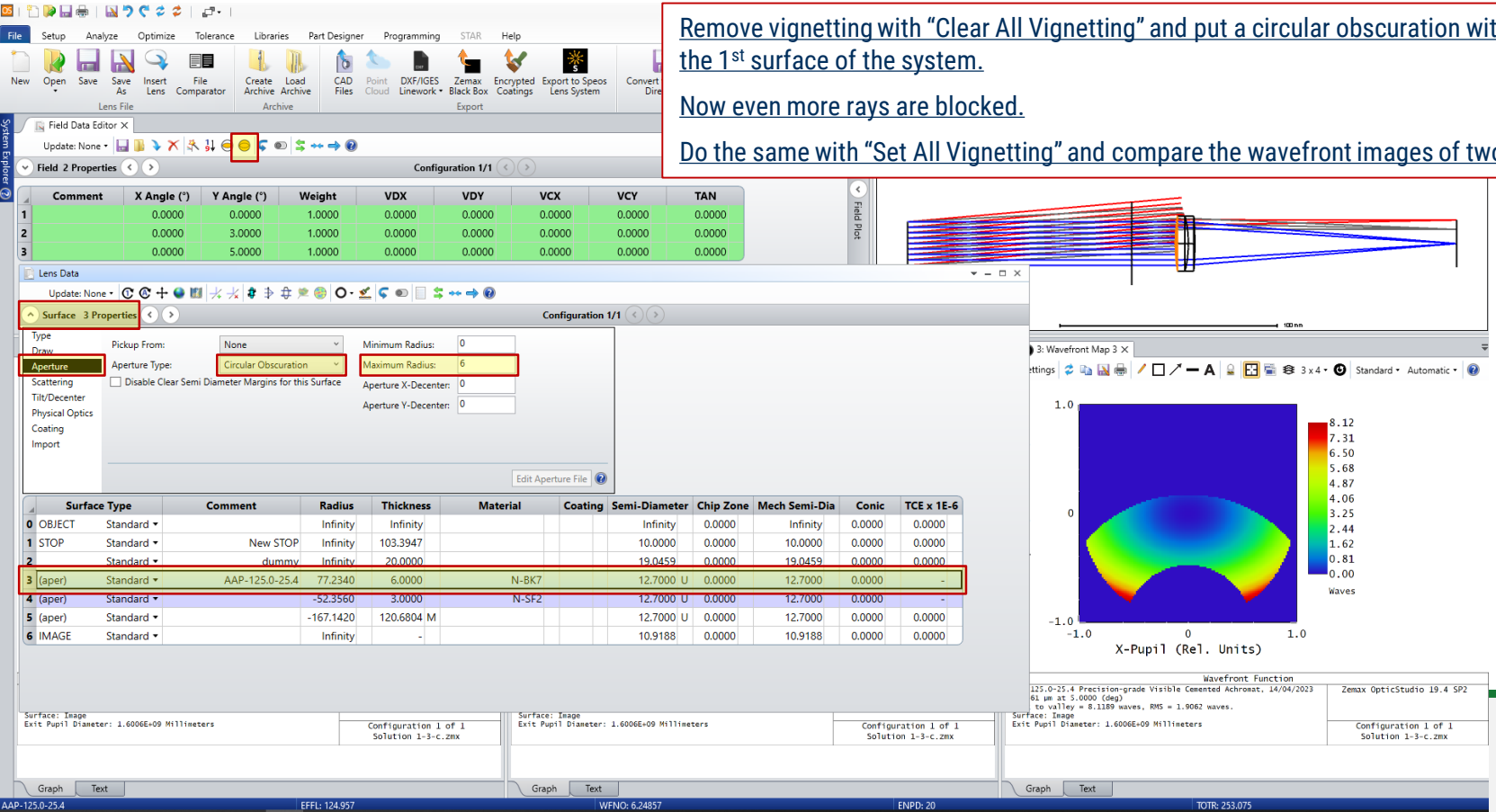
If you set vignetting, the optimization will consider only the rays, which pass through the system.

Solution 1-3: D (Obscuration)

Remove vignetting with “Clear All Vignetting” and put a circular obscuration with 6 mm radius at the 1st surface of the system.

Now even more rays are blocked.

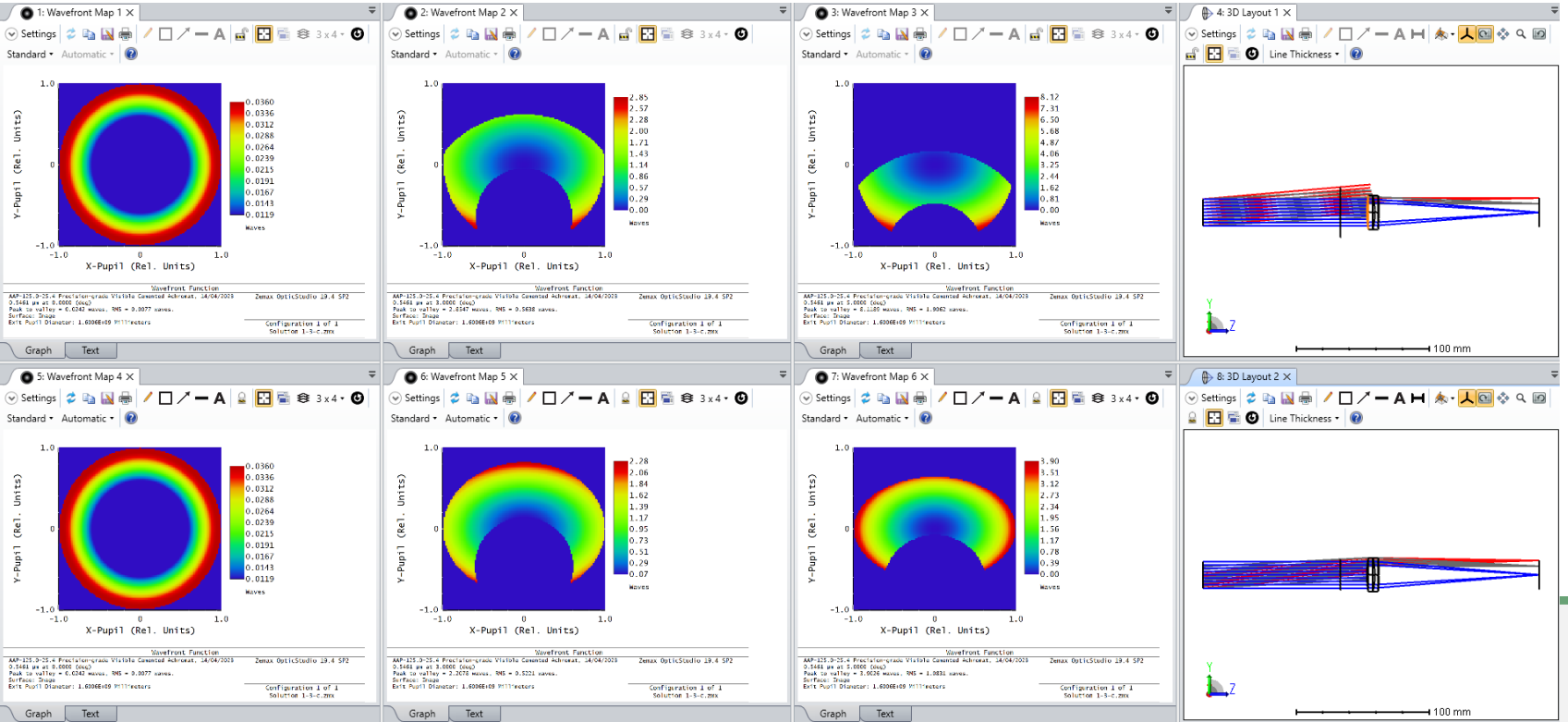
Do the same with “Set All Vignetting” and compare the wavefront images of two cases.



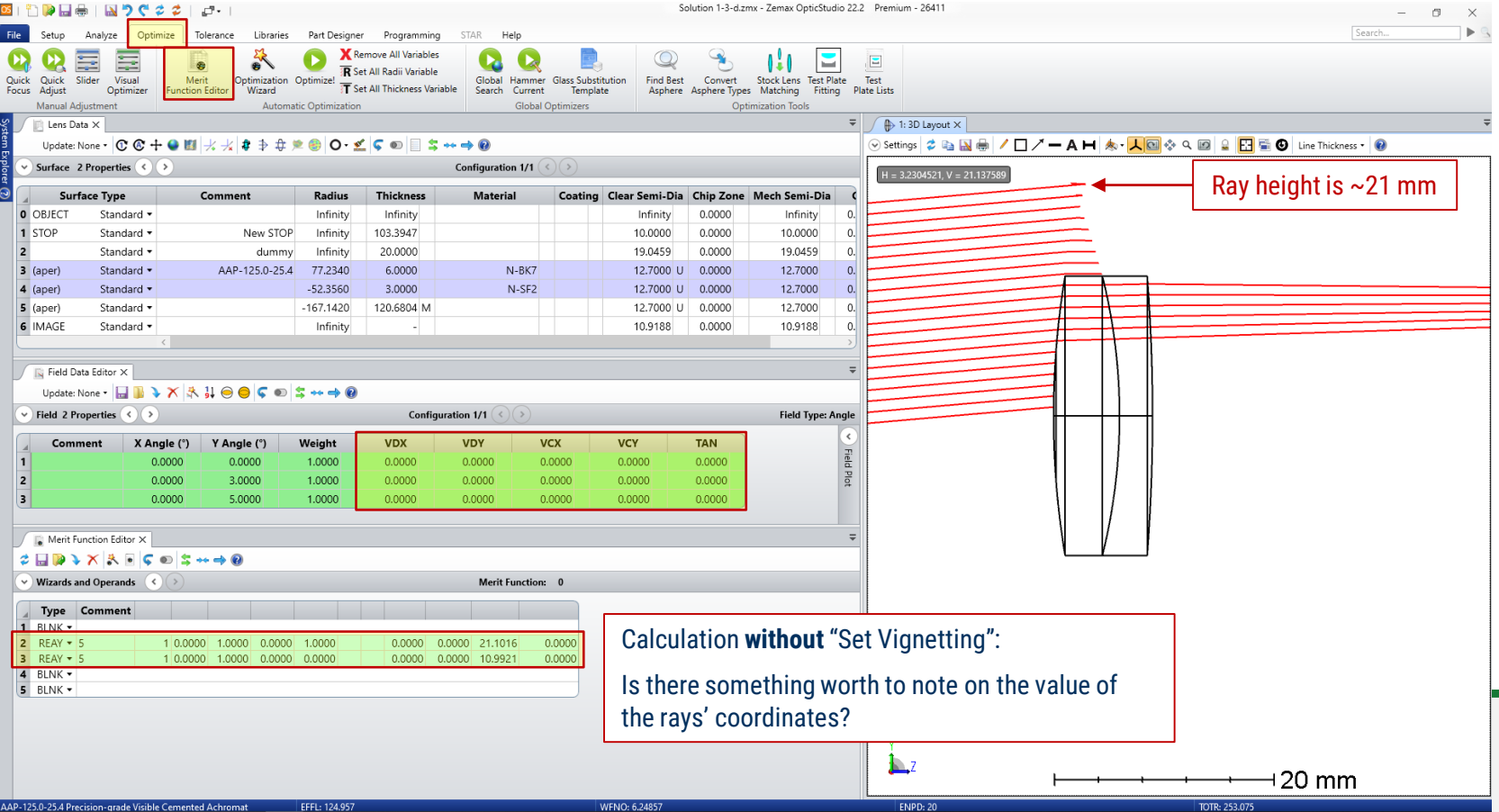
Solution 1-3: D (Obscuration → Result)

Top images → Without “Set Vignetting”

Bottom images → With “Set Vignetting”



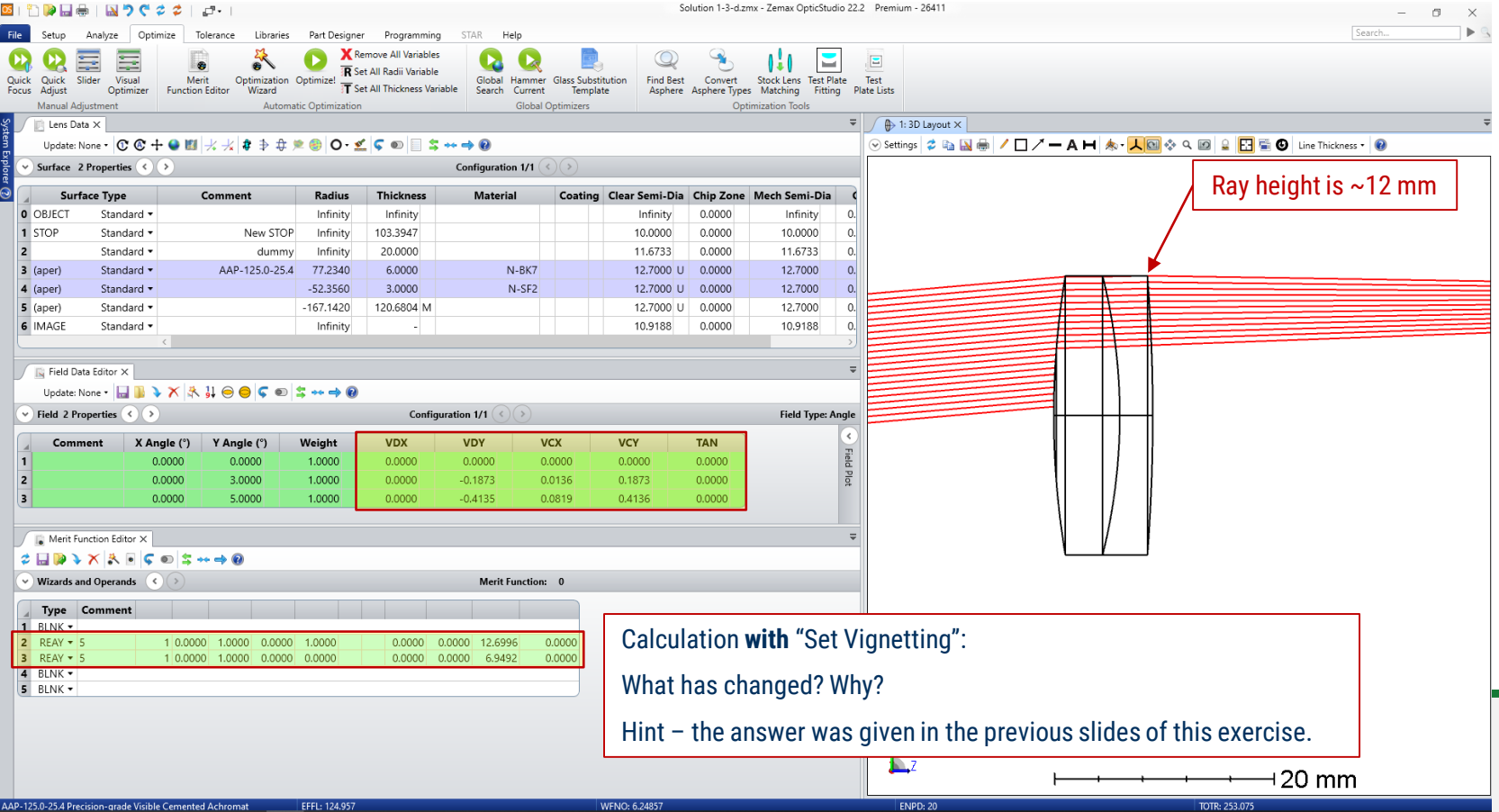
Solution 1-3: E (Ray coordinates)



Calculation **without** "Set Vignetting":

Is there something worth to note on the value of the rays' coordinates?

Solution 1-3: E (Ray coordinates)



Calculation **with** "Set Vignetting":

What has changed? Why?

Hint – the answer was given in the previous slides of this exercise.

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Thank you for attention!

End of Seminar 1