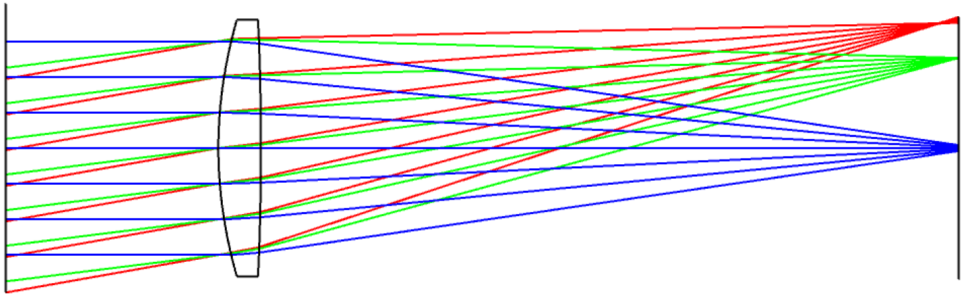
FRIEDRICH-SCHILLER-
UNIVERSITÄT
JENA

Group 1 – 20.10.2023
Group 2 – 27.10.2023
Group 3 – 30.10.2023
Group 4 – 23.10.2023

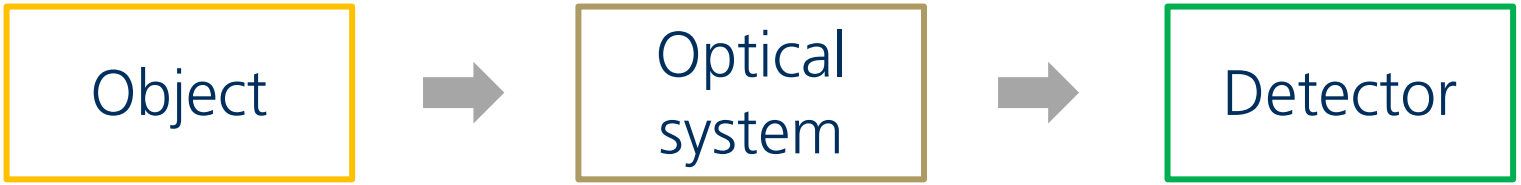


João Pedro Berti Ligabo
Dmitrii Stefanidi

Introduction to Optical Modelling (WS'23/24)

Seminar 1

General scheme of optical system



Sun
Tree
Laser
LED

Lens
Objective
Mirror system

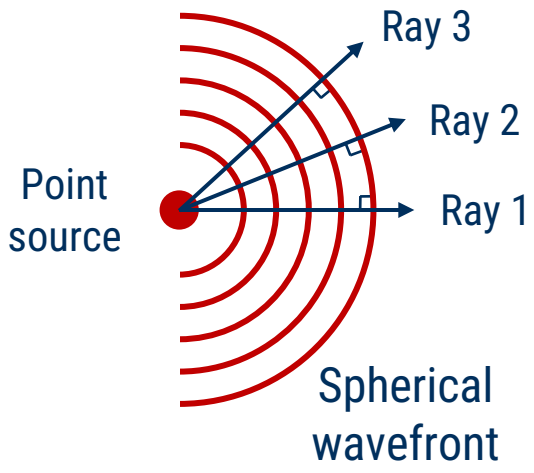
Eye
Camera sensor
Screen

Zemax shortcuts

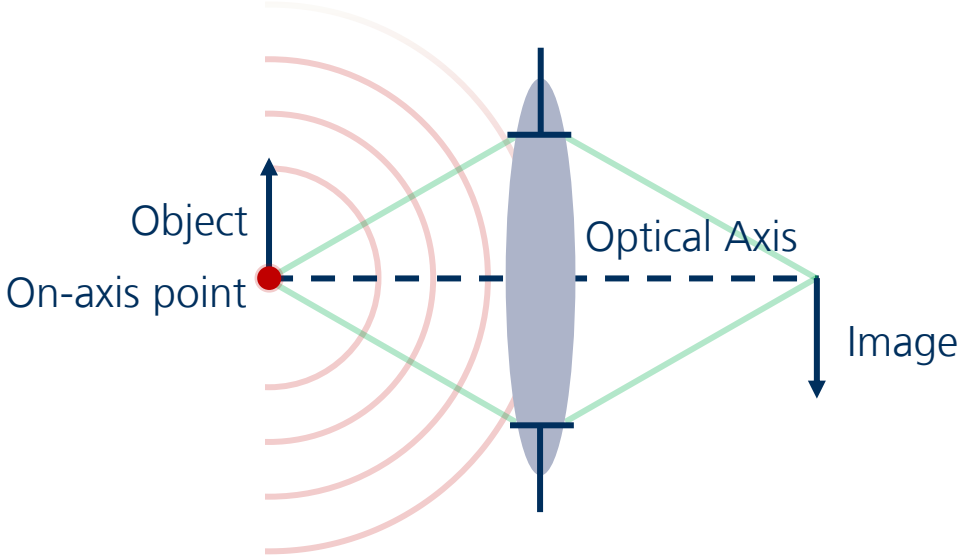
Function	English keyboard	German keyboard
• To insert a surface	“Insert”	“Einfg”
• To delete a surface	“Delete”	“Entf”
• To undo	F3 / Fn + F3	
• To make a variable	Ctrl + Z	Strg + Y

Ray-optics principles

Definition of ray

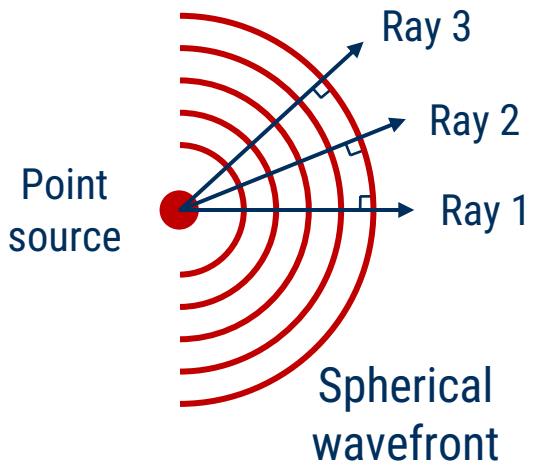


Rays in optical system

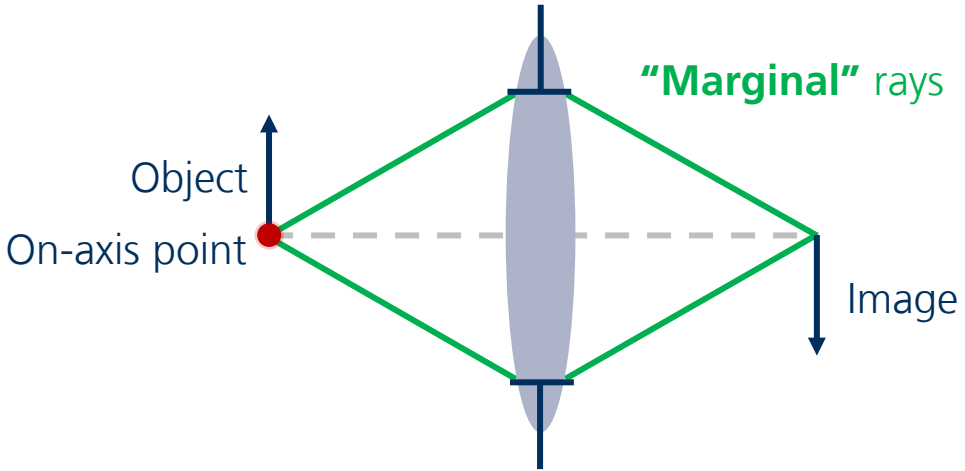


Ray-optics principles

Definition of ray

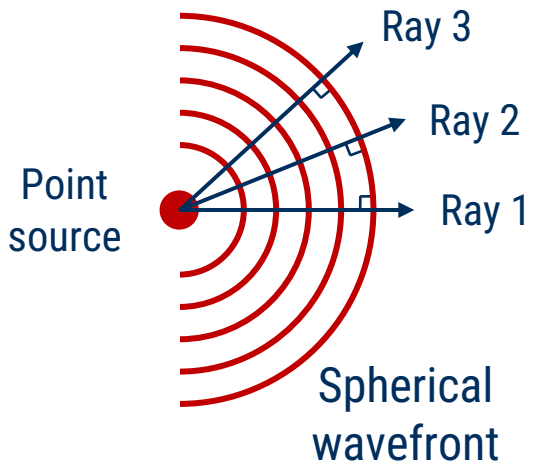


Rays in optical system

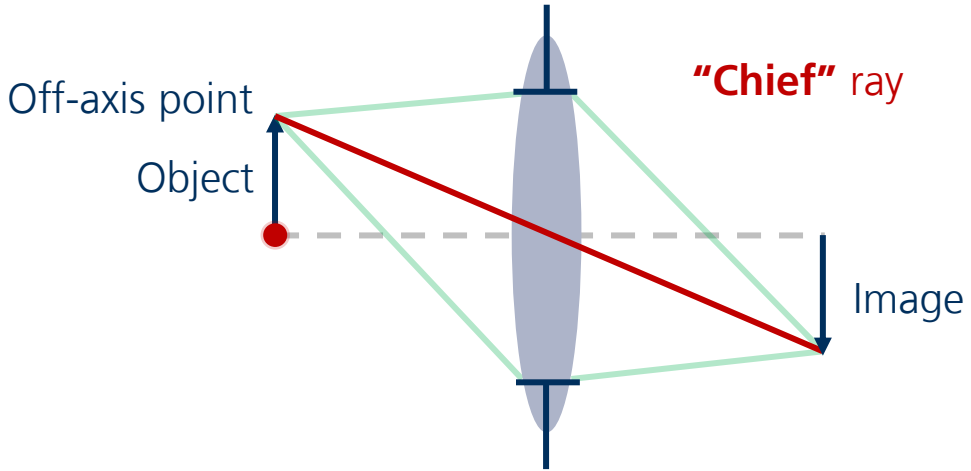


Ray-optics principles

Definition of ray

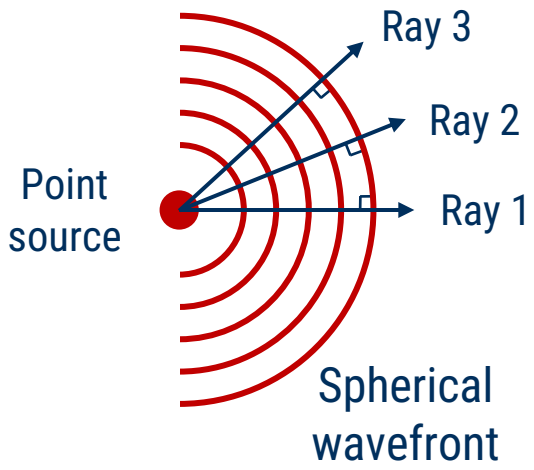


Rays in optical system

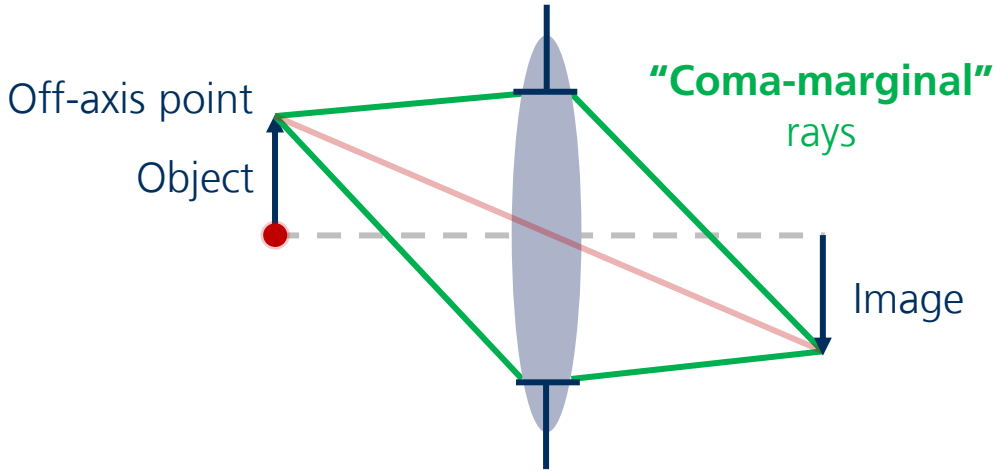


Ray-optics principles

Definition of ray

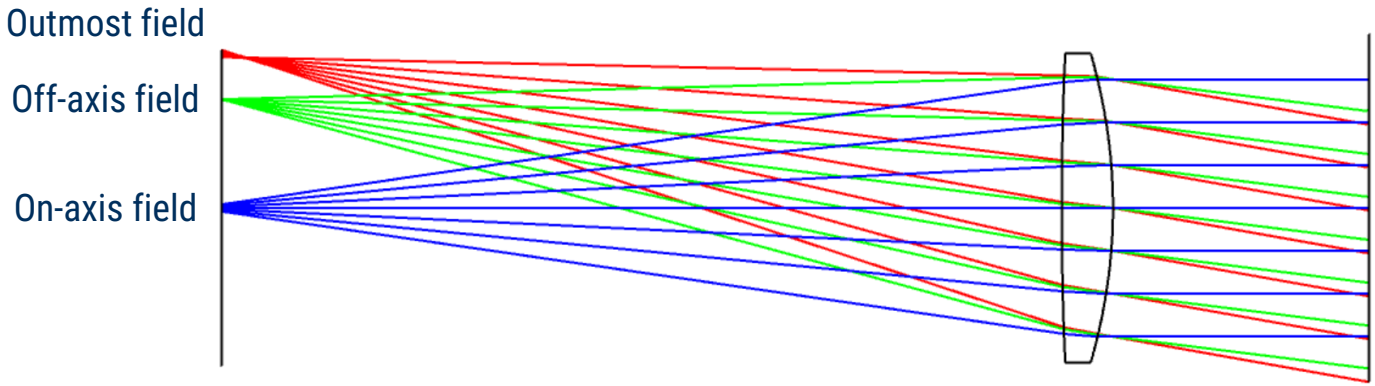


Rays in optical system



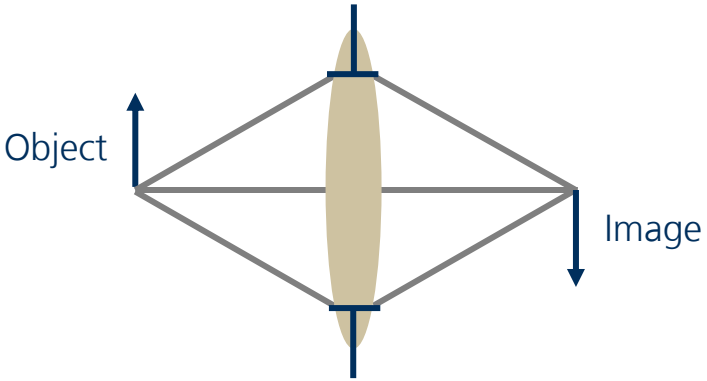
Ray-optics principles

Example of object decomposition



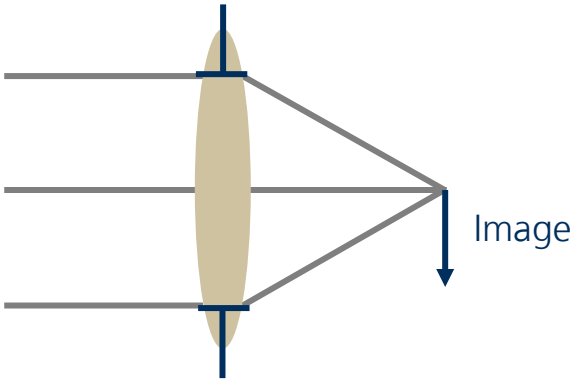
Distance to object

Object near optical system



Examples:
Microscope, projection system, etc.

Object at infinity



Examples:
Telescope, photo camera, etc.

Modelling of a **paraxial** lens

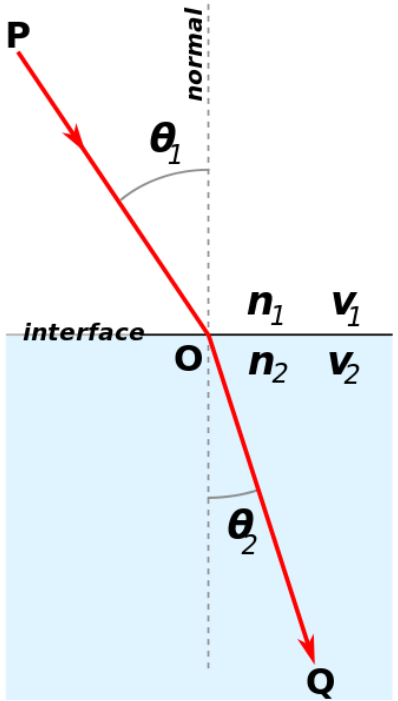
Law of refraction (Snell's law):

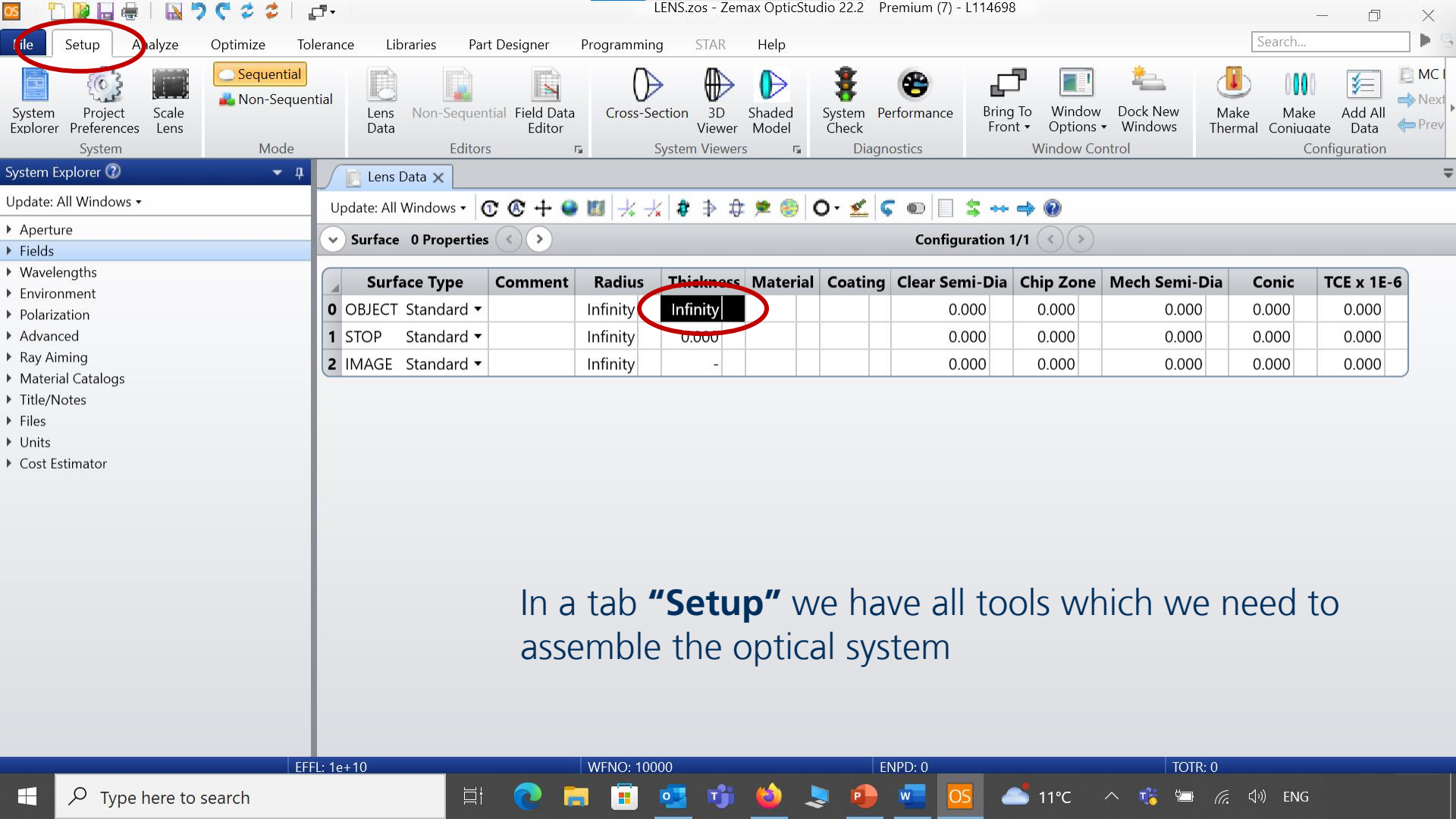
$$n_1 * sin\theta_1 = n_2 * sin\theta_2$$

Paraxial approximation:

$$sin\theta = \theta$$

Paraxial = no aberrations → **Ideal**




LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
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Lens Data
Update: All Windows
Surface 0 Properties
Configuration 1/1
Surface Type | Comment | Radius | Thickness | Material | Coating | Clear Semi-Dia | Chip Zone | Mech Semi-Dia | Conic | TCE x 1E-6
0 OBJECT Standard | Infinity | Infinity | 0.000 | 0.000 | 0.000 | 0.000 | 0.000
1 STOP Standard | Infinity | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000
2 IMAGE Standard | Infinity | - | 0.000 | 0.000 | 0.000 | 0.000 | 0.000
In a tab “Setup” we have all tools which we need to assemble the optical system
EFFL: 1e+10
WFNO: 10000
ENPD: 0
TOTR: 0
Type here to search
11°C
ENG

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

System Explorer | Project Preferences | Scale Lens — System
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Lens Data | Non-Sequential | Field Data Editor — Editors
Cross-Section | 3D Viewer | Shaded Model — System Viewers
System Check | Performance — Diagnostics
Bring To Front | Window Options | Dock New Windows — Window Control
Make Thermal | Make Conjugate | Add All Data — Configuration

System Explorer

Update: All Windows

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- Wavelengths
- Environment
- Polarization
- Advanced
- Ray Aiming
- Material Catalogs
- Title/Notes
- Files
- Units
- Cost Estimator

Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

	Surface Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	Infinity			0.000	0.000	0.000	0.000	0.000
1		Standard	dummy	Infinity	20.000			0.000	0.000	0.000	0.000	0.000
2	STOP	Standard		Infinity	0.000			0.000	0.000	0.000	0.000	0.000
3	IMAGE	Standard		Infinity	-			0.000	0.000	0.000	0.000	0.000

Dummy surface → Doesn't have any optical function.
We use it to make rays coming from infinity visible

dummy | EFFL: 1e+10 | WFNO: 10000 | ENPD: 0 | TOTR: 20

Type here to search 11°C ENG

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

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Cross-Section | 3D Viewer | Shaded Model — System Viewers
System Check | Performance — Diagnostics
Bring To Front | Window Options | Dock New Windows — Window Control
Make Thermal | Make Conjugate | Add All Data — Configuration

System Explorer

Update: All Windows

Aperture

Aperture Type:
Entrance Pupil Diameter

Aperture Value:
20.0

Apodization Type:
Uniform

Clear Semi Diameter Margin Millimeters:
0.0

Clear Semi Diameter Margin %
0.0

Global Coordinate Reference Surface
2

- [ ] Telecentric Object Space
- [ ] Afocal Image Space
- [ ] Iterate Solves When Updating
- [x] Fast Semi-Diameters
- [ ] Check GRIN Apertures

Fields
Wavelengths

Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000	0.000	0.000	0.000	0.000
1	Standard	dummy	Infinity	20.000			10.000	0.000	10.000	0.000	0.000
2	STOP Standard		Infinity	0.000			10.000	0.000	10.000	0.000	0.000
3	IMAGE Standard		Infinity	-			10.000	0.000	10.000	0.000	0.000

Aperture diameter → Roughly speaking, defines the diameter of the light beam which will go through the optical system

EFFL: 1e+10 | WFNO: 10000 | ENPD: 20 | TOTR: 20

Type here to search 11°C ENG

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

System Explorer | Project Preferences | Scale Lens — System
Sequential | Non-Sequential — Mode
Lens Data | Non-Sequential | Field Data Editor — Editors
Cross-Section | 3D Viewer | Shaded Model — System Viewers
System Check | Performance — Diagnostics
Bring To Front | Window Options | Dock New Windows — Window Control
Make Thermal | Make Conjugate | Add All Data — Configuration

System Explorer

Update: All Windows

Aperture

Aperture Type: Entrance Pupil Diameter

Aperture Value: 20.0

Apodization Type: Uniform

Clear Semi Diameter Margin Millimeters: 0.0

Clear Semi Diameter Margin %: 0.0

Global Coordinate Reference Surface: 2

- [ ] Telecentric Object Space
- [ ] Afocal Image Space
- [ ] Iterate Solves When Updating
- [x] Fast Semi-Diameters
- [ ] Check GRIN Apertures

Fields

Wavelengths

Lens Data

Update: All Windows

Surface 2 Properties Configuration 1/1

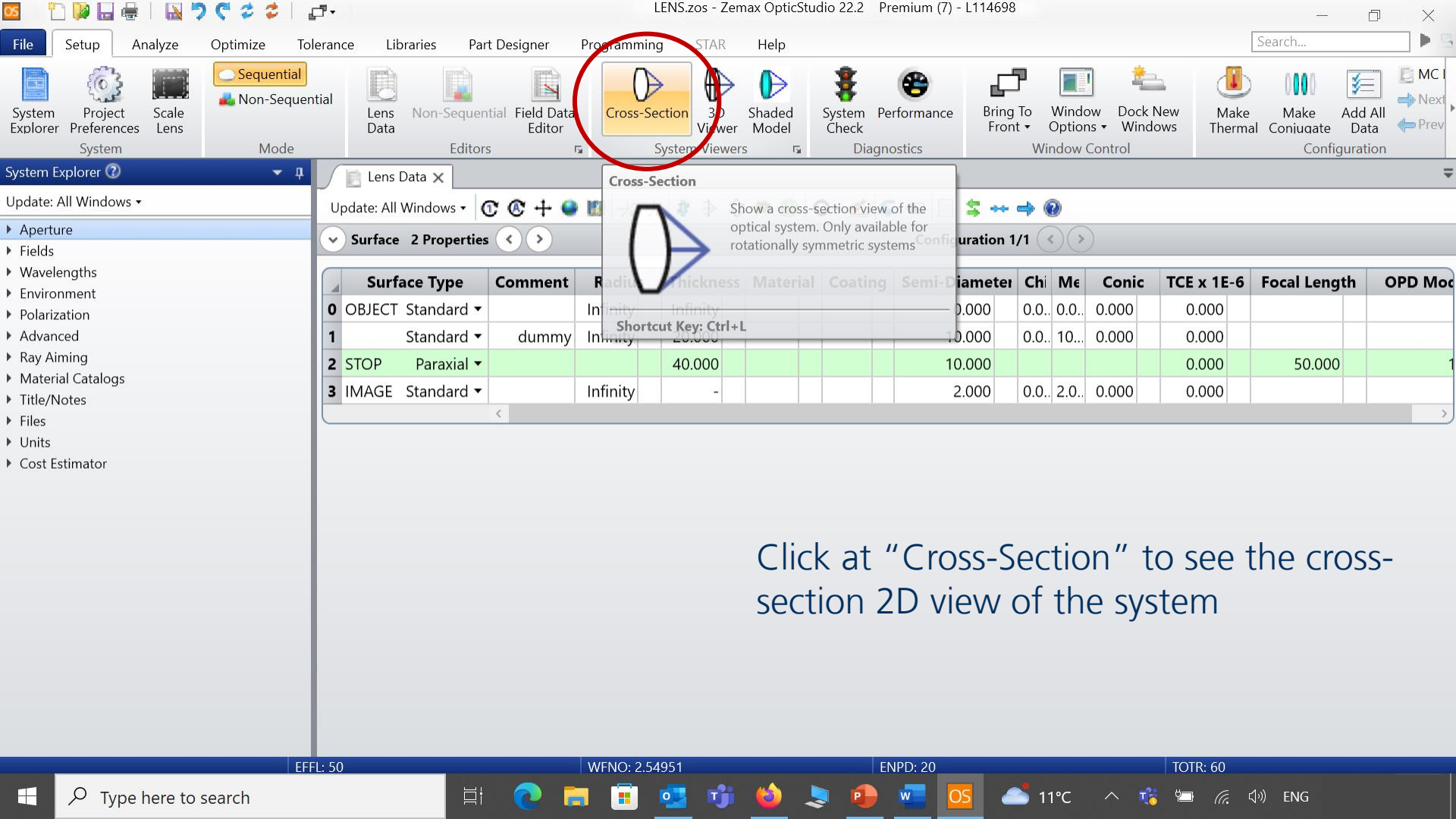
	Surface Type	Comment	Radius	Thickness	Material	Coating	Semi-Diameter	Chi	Me	Conic	TCE x 1E-6	Focal Length	OPD M
0	OBJECT Standard		Infinity	Infinity			0.000	0.0..	0.0..	0.000	0.000		
1	Standard	dummy	Infinity	20.000			10.000	0.0..	10...	0.000	0.000		
2	STOP Paraxial			40.000			10.000				0.000	50.000	
3	IMAGE Standard		Infinity	-			2.000	0.0..	2.0..	0.000	0.000		

Paraxial lens → Ideal lens, which refracts the rays without any aberrations. Always flat (doesn't have curvature), has a defined focal length.

Column **"thickness"** defines the distance which goes **after** this surface, not the thickness of paraxial lens!

EFFL: 50 WFNO: 2.54951 ENPD: 20 TOTR: 60

Type here to search 11°C ENG



Click at “Cross-Section” to see the cross-section 2D view of the system

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Sequential | Non-Sequential — Mode
Lens Data | Make Thermal | Make Conjugate | Add All Data — Configuration

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- Units
- Cost Estimator

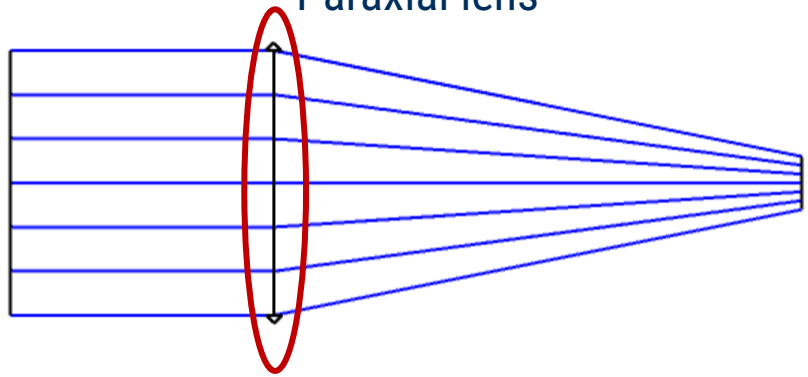
Lens Data
Update: All Windo
Surface 2 Pro

	Surface Ty		TCE x 1E-6	Focal Length	OPD Mod
0	OBJECT	Stanc	0.000		
1		Stanc	0.000		
2	STOP	Para	0.000	50.000	1
3	IMAGE	Stanc	0.000		

1: Layout

Settings | Line Thickness

H = 38.934391, V = 19.924243



Layout

11/3/2022
Total Axial Length: 60.00000 mm

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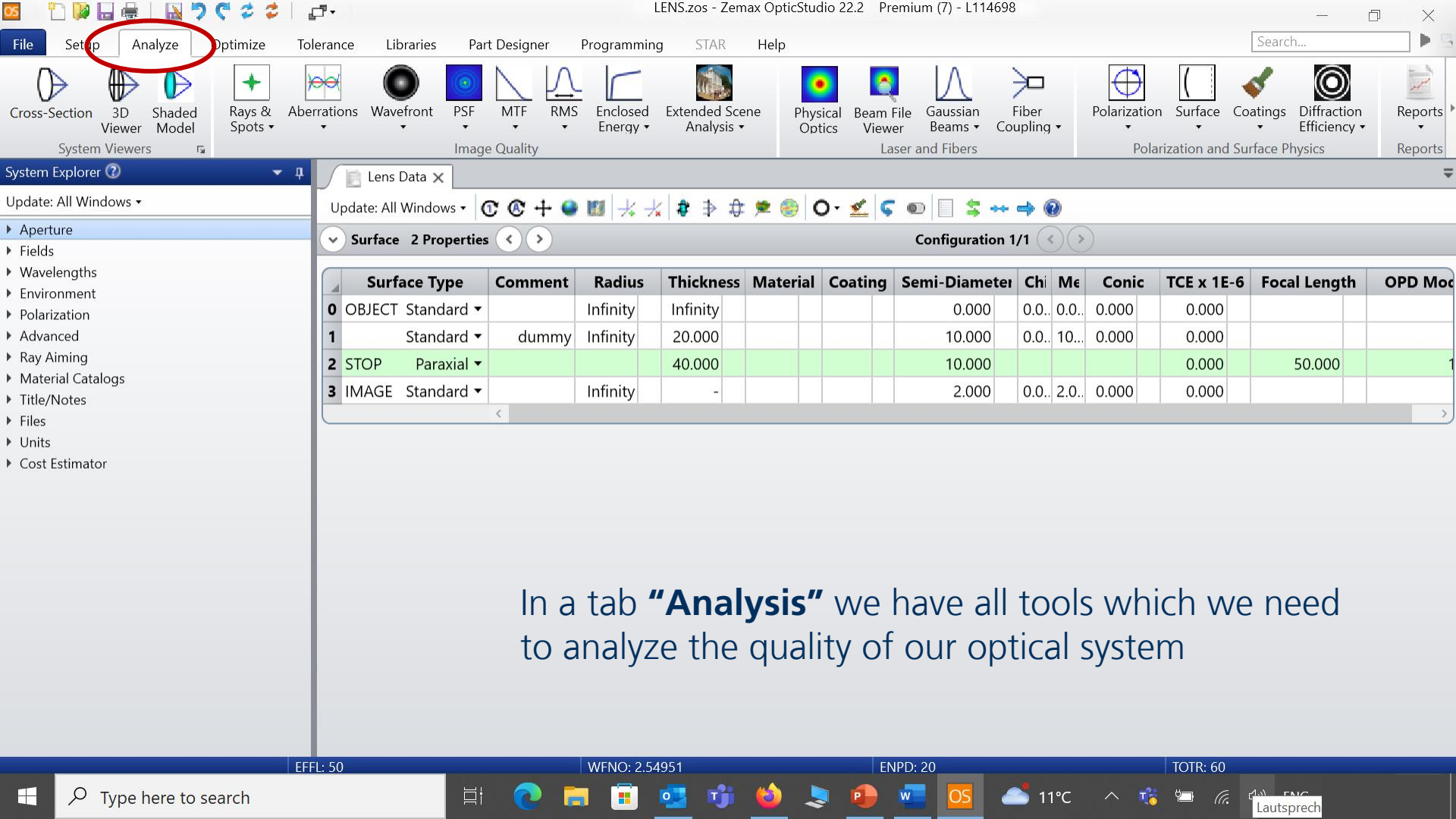
LENS.zos
Configuration 1 of 1

EFFL: 50 | WFNO: 2.54951 | ENPD: 20 | TOTR: 60

Type here to search

11°C ENG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Thickness
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Coating
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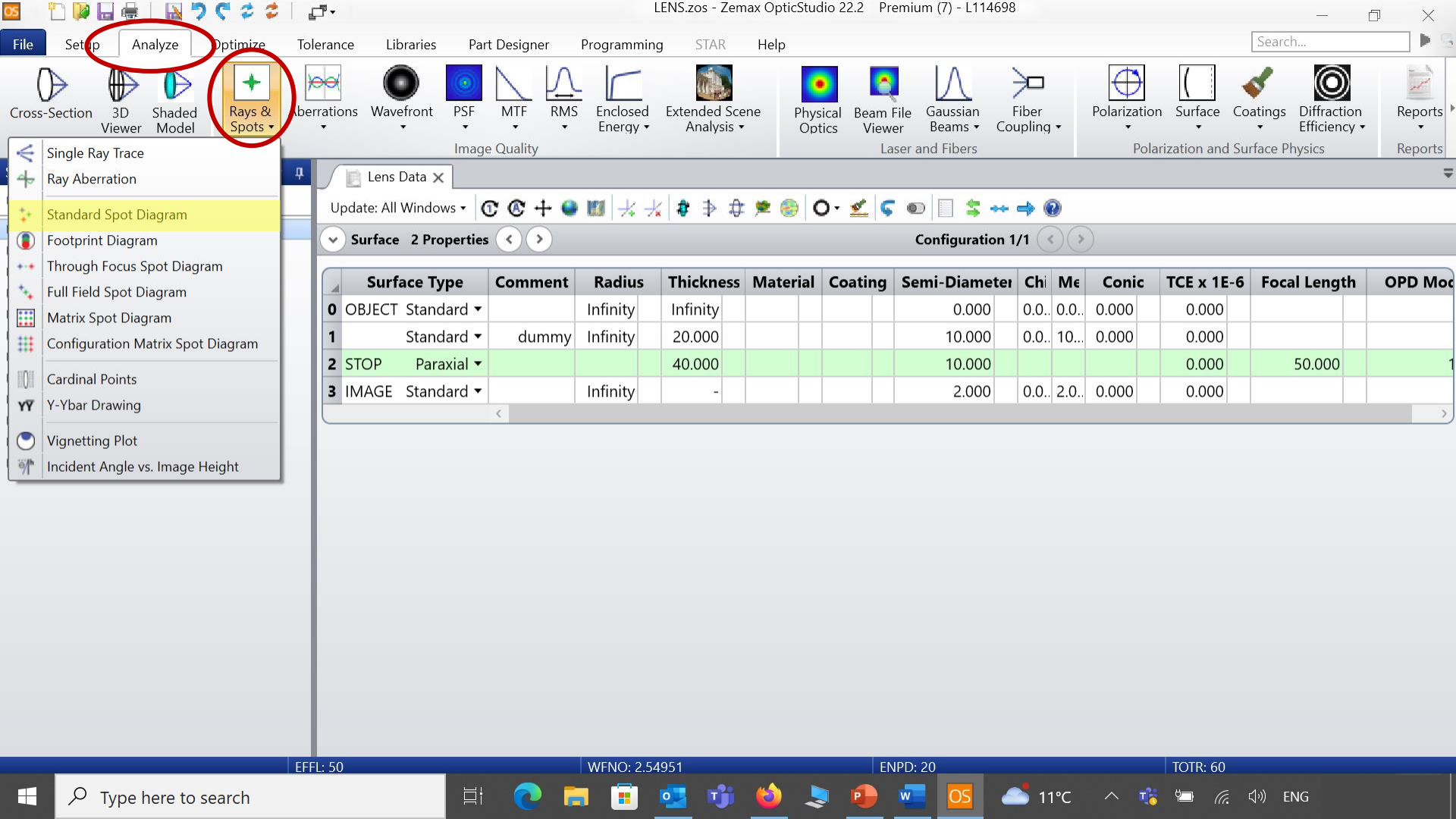
Chi
Me
Conic
TCE x 1E-6
Focal Length
OPD Mod
0 OBJECT Standard Infinity Infinity 0.000 0.0.. 0.0.. 0.000 0.000
1 Standard dummy Infinity 20.000 10.000 0.0.. 10... 0.000 0.000
2 STOP Paraxial 40.000 10.000 0.000 50.000
3 IMAGE Standard Infinity - 2.000 0.0.. 2.0.. 0.000 0.000
In a tab “Analysis” we have all tools which we need to analyze the quality of our optical system
EFFL: 50
WFNO: 2.54951
ENPD: 20
TOTR: 60
Type here to search
11°C
Lautsprech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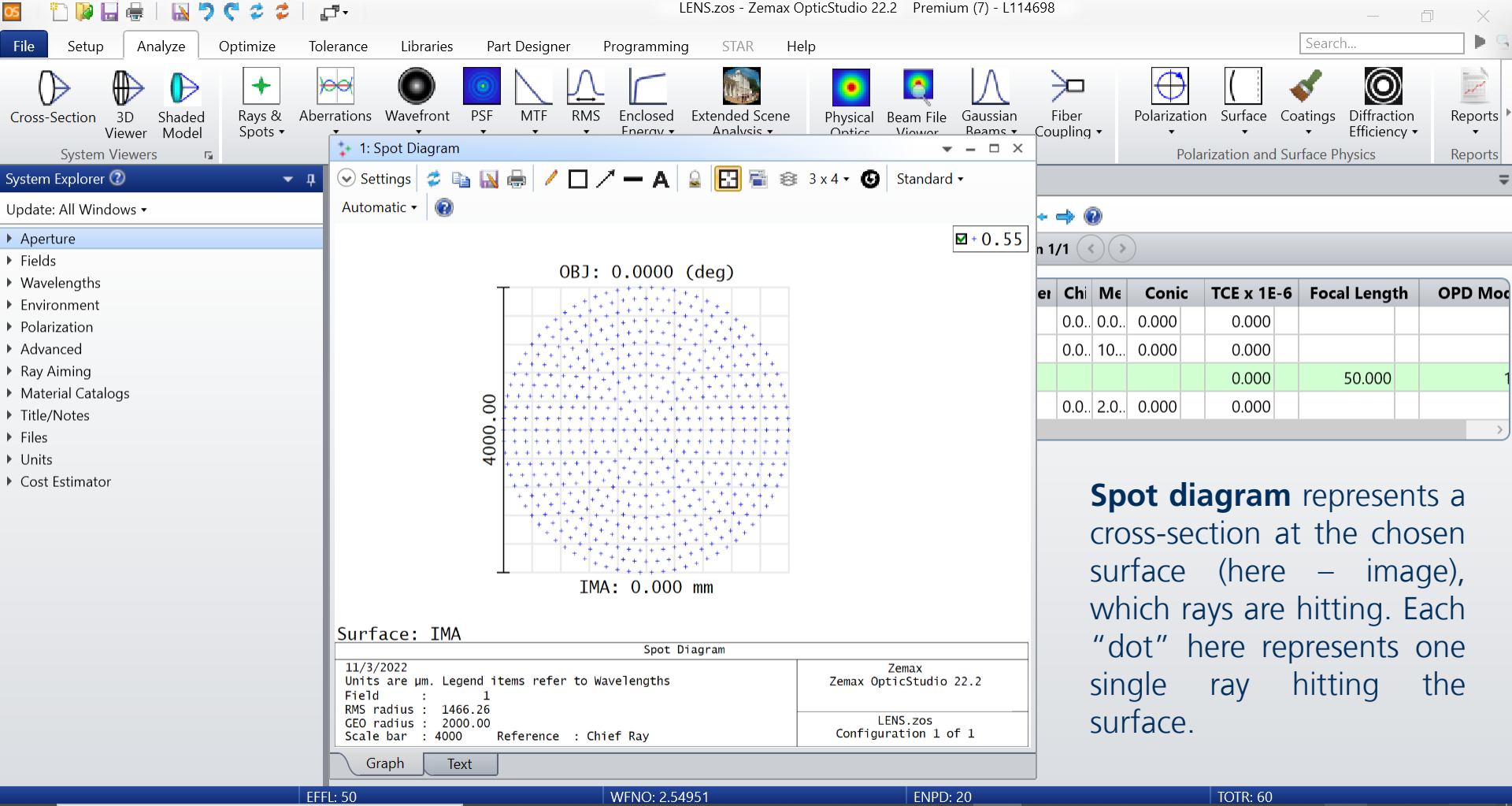
Focal Length
OPD Mod
0 OBJECT Standard Infinity Infinity 0.000 0.0.. 0.0.. 0.000 0.000
1 Standard dummy Infinity 20.000 10.000 0.0.. 10... 0.000 0.000
2 STOP Paraxial 40.000 10.000 0.000 50.000
3 IMAGE Standard Infinity - 2.000 0.0.. 2.0.. 0.000 0.000
EFFL: 50
WFNO: 2.54951
ENPD: 20
TOTR: 60
Type here to search
11°C
ENG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1: Spot Diagram
Settings
3 x 4
Standard
Automatic
0.55
OBJ: 0.0000 (deg)
4000.00
IMA: 0.000 mm
Surface: IMA
Spot Diagram
11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 1466.26
GEO radius : 2000.00
Scale bar : 4000 Reference : Chief Ray
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n 1/1
Chi
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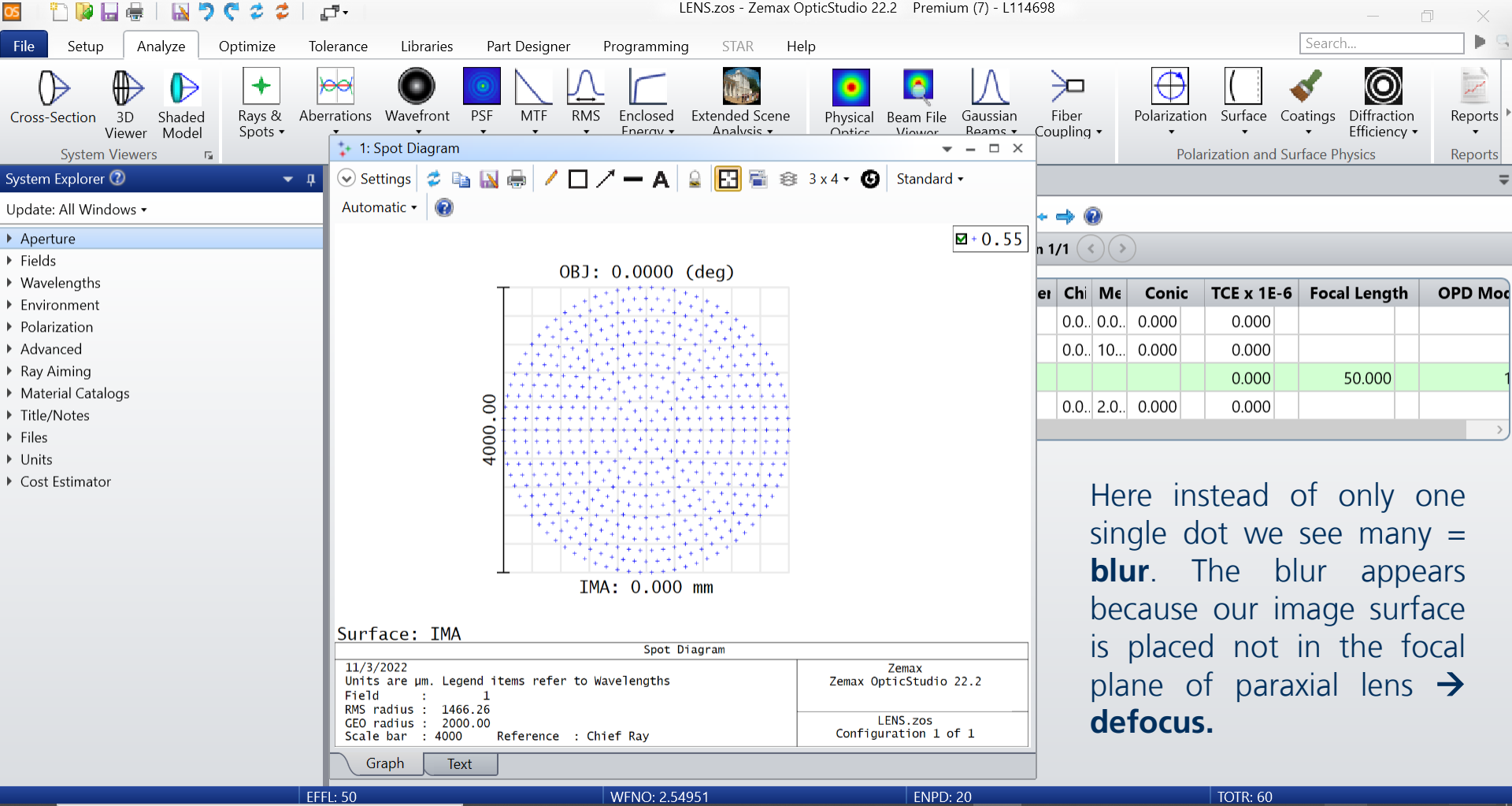
TCE x 1E-6
Focal Length
OPD Mod
0.0.. 0.0.. 0.000 0.000
0.0.. 10... 0.000 0.000
0.000 50.000
0.0.. 2.0.. 0.000 0.000
Spot diagram represents a cross-section at the chosen surface (here – image), which rays are hitting. Each "dot" here represents one single ray hitting the surface.
EFFL: 50
WFNO: 2.54951
ENPD: 20
TOTR: 60
Type here to search
11°C
ENG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Reports
1: Spot Diagram
Settings
3 x 4
Standard
Automatic
0.55
OBJ: 0.0000 (deg)
4000.00
IMA: 0.000 mm
Surface: IMA
Spot Diagram
11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 1466.26
GEO radius : 2000.00
Scale bar : 4000 Reference : Chief Ray
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Zemax OpticStudio 22.2
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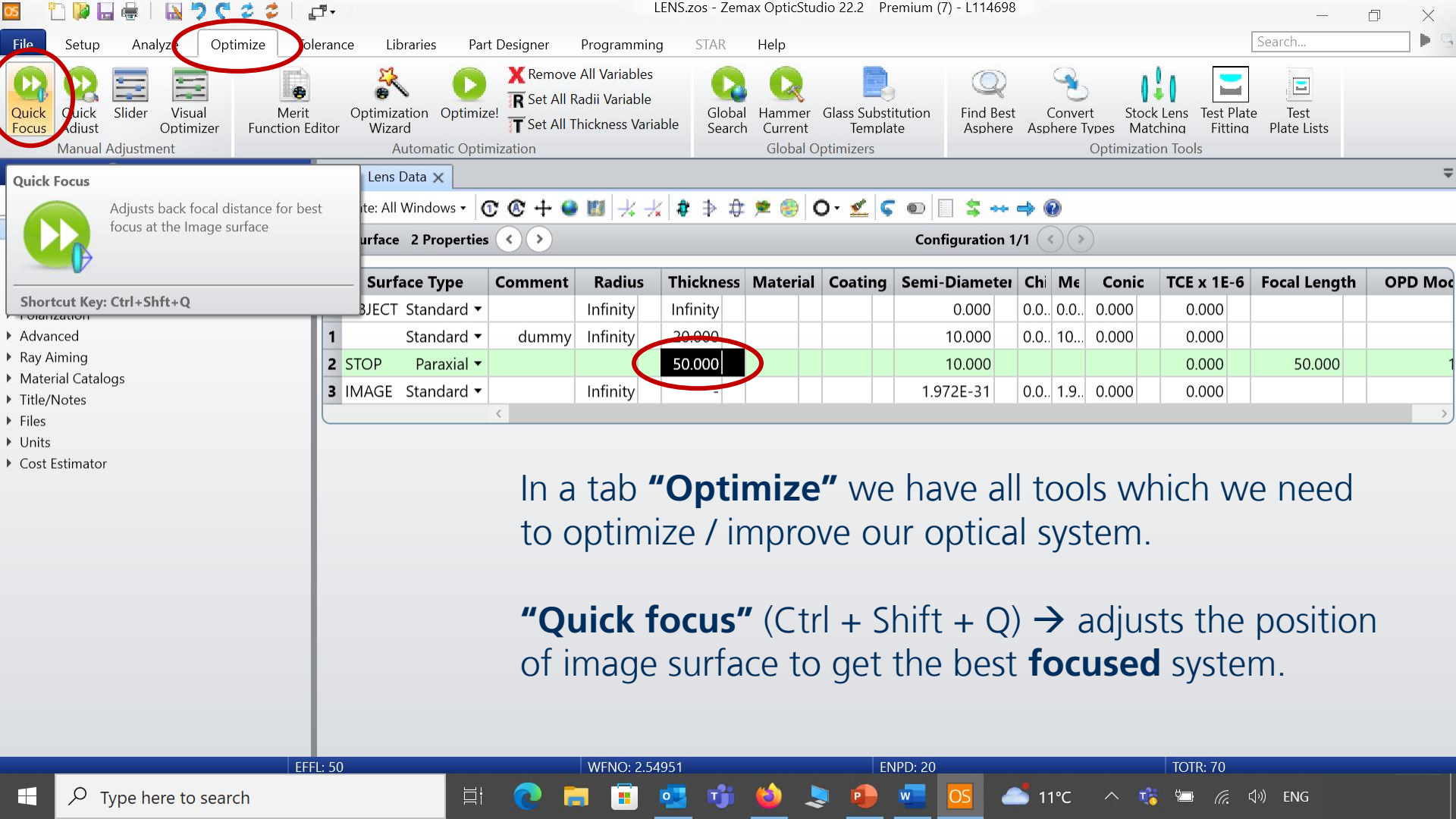
n 1/1
Chi
Me
Conic
TCE x 1E-6
Focal Length
OPD Mod
0.0.. 0.0.. 0.000 0.000
0.0.. 10... 0.000 0.000
0.000 50.000
0.0.. 2.0.. 0.000 0.000
Here instead of only one single dot we see many = **blur**. The blur appears because our image surface is placed not in the focal plane of paraxial lens → **defocus.**
EFFL: 50
WFNO: 2.54951
ENPD: 20
TOTR: 60
Type here to search
11°C
ENG



In a tab **"Optimize"** we have all tools which we need to optimize / improve our optical system.

"Quick focus" (Ctrl + Shift + Q) → adjusts the position of image surface to get the best **focused** system.

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Polarization | Surface | Coatings | Diffraction Efficiency — Polarization and Surface Physics
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1: Spot Diagram

Settings | 3 x 4 | Thickest | Automatic | 0.55

OBJ: 0.0000 (deg)

0.02

IMA: 0.000 mm

Surface: IMA

Spot Diagram	
11/3/2022 Units are µm. Legend items refer to Wavelengths Field : 1 RMS radius : 0.000 GEO radius : 0.000 Scale bar : 0.02 Reference : Chief Ray	Zemax Zemax OpticStudio 22.2 LENS.zos Configuration 1 of 1

Graph | Text

n 1/1

ter	Chi	Me	Conic	TCE x 1E-6	Focal Length	OPD Mod
	0.0..	0.0..	0.000	0.000		
	0.0..	10...	0.000	0.000		
				0.000	50.000	1
	0.0..	1.9..	0.000	0.000		

Now, since we are **in the focus** of the paraxial lens → we see **infinitesimally small spot** instead of blur

EFF

TOTR: 70

Type here to search

11°C ENG

Modelling of a **standard bi-convex** lens

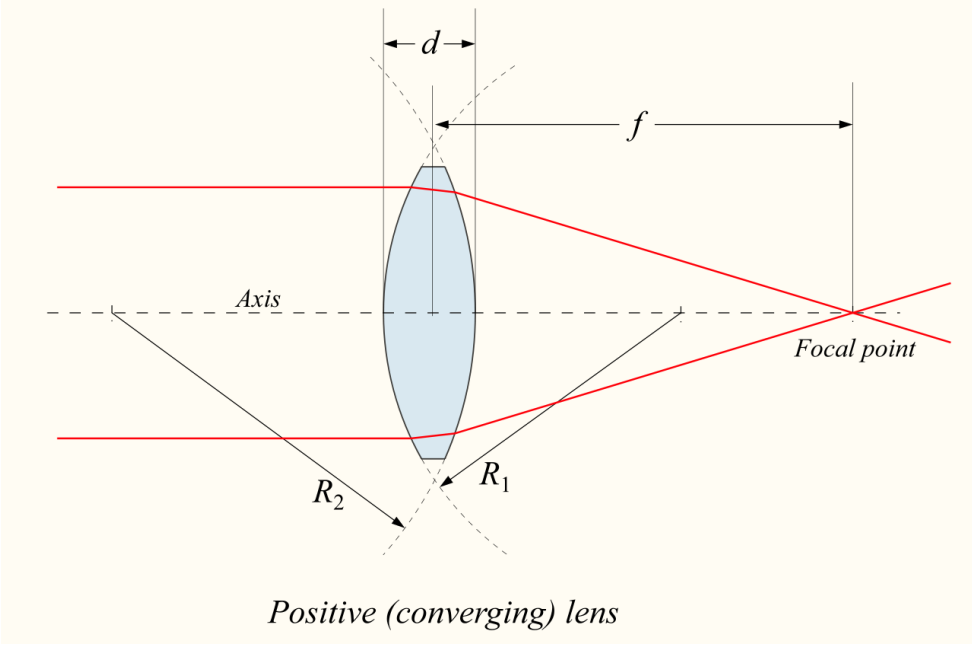
Lens maker formulas:

Thin lens approximation (d << R1, R2):

$$\frac{1}{f} \approx (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Thick lens approximation:

$$\frac{1}{f} \approx (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right)$$



Modelling of a **standard bi-convex** lens

We want to model a symmetric bi-convex **thin** lens => R1= -R2

- Aperture diameter = 20 mm (same as before)
- Object at infinity (same as before)
- Dummy surface with 20 mm after (same as before)
- Material → n = 1.5
- Lens thickness → d = 3 mm
- Distance to image = 50 mm
- R1 = R2 = 50 mm

$$\frac{1}{f} \approx (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \rightarrow \frac{1}{f} = 0.5 * \frac{2}{R_1} \rightarrow f = R_1 = R_2 = 50\,mm$$

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Lens Data

Update: All Windows

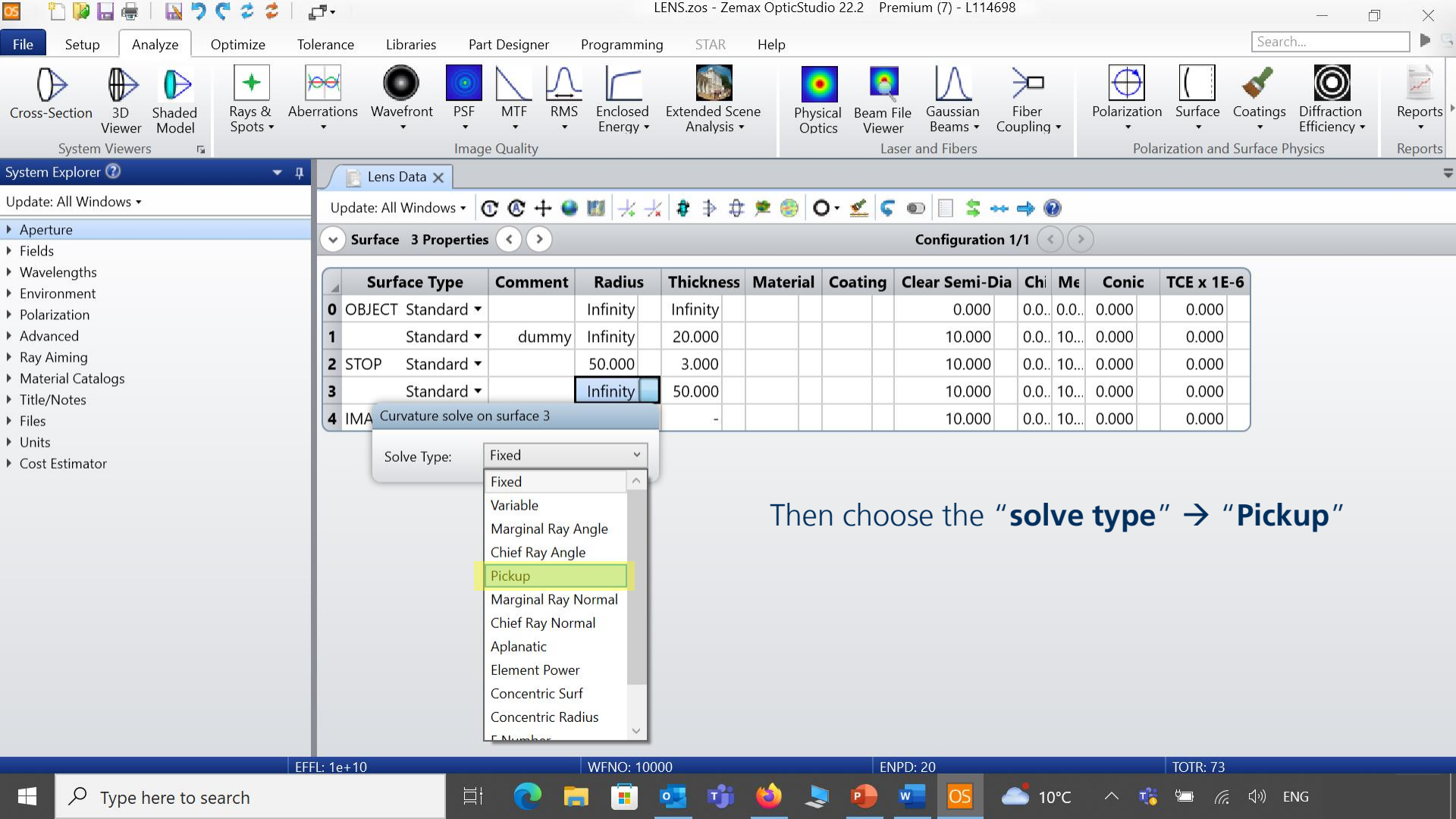
Surface 3 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity	20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000	3.000			10.000	0.0..	10...	0.000	0.000
3	Standard		Infinity	50.000			10.000	0.0..	10...	0.000	0.000
4	IMAGE Standard		Infinity				10.000	0.0..	10...	0.000	0.000

Click here

EFFL: 1e+10 WFNO: 10000 ENPD: 20 TOTR: 73

Type here to search 10°C ENG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Surface 3 Properties
Configuration 1/1
Surface Type Comment Radius Thickness Material Coating Clear Semi-Dia Chi Me Conic TCE x 1E-6
0 OBJECT Standard Infinity Infinity 0.000 0.0.. 0.0.. 0.000 0.000
1 Standard dummy Infinity 20.000 10.000 0.0.. 10... 0.000 0.000
2 STOP Standard 50.000 3.000 10.000 0.0.. 10... 0.000 0.000
3 Standard Infinity 50.000 10.000 0.0.. 10... 0.000 0.000
4 IMA - 10.000 0.0.. 10... 0.000 0.000
Curvature solve on surface 3
Solve Type: Fixed
Fixed
Variable
Marginal Ray Angle
Chief Ray Angle
Pickup
Marginal Ray Normal
Chief Ray Normal
Aplanatic
Element Power
Concentric Surf
Concentric Radius
Then choose the "solve type" → "Pickup"
EFFL: 1e+10
WFNO: 10000
ENPD: 20
TOTR: 73
Type here to search
10°C
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Lens Data

Update: All Windows

Surface 3 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity	20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000	3.000			10.000	0.0..	10...	0.000	0.000
3	Standard		Infinity P	50.000			10.000	0.0..	10...	0.000	0.000
4	IMA			-			10.000	0.0..	10...	0.000	0.000

Curvature solve on surface 3

Solve Type: Pickup
From Surface: 2
Scale Factor: -1
From Column: Current

"Pickup" function helps to easier control and "link" the parameters of different surfaces. In our case we need to make a symmetrical lens, which means that radius of surface #3 should be the same, but negative value of the radius of surface #2.

EFFL: 1e+10 | WFNO: 10000 | ENPD: 20 | TOTR: 73

Type here to search 10°C ENG

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Lens Data

Update: All Windows

Surface 3 Properties Configuration 1/1

	Surface Type	Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity		Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity		20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000		3.000			10.000	0.0..	10...	0.000	0.000
3	Standard		-50.000	P	50.000			10.000	0.0..	10...	0.000	0.000
4	IMAGE Standard		Infinity		-			10.000	0.0..	10...	0.000	0.000

Now the radius of surface #3 will be always picked-up with a negative sign from the radius of surface #2. You can try to change radius of surface #2 and see what happens (not shown here).

EFFL: 1e+10 | WFNO: 10000 | ENPD: 20 | TOTR: 73

Type here to search 10°C ENG

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Cross-Section

Show a cross-section view of the optical system. Only available for rotationally symmetric systems

Shortcut Key: Ctrl+L

- Ray Aiming
- Material Catalogs
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- Files
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- Cost Estimator

1: Layout

Settings | Line Thickness

20 mm

Layout

11/3/2022
Total Axial Length: 73.00000 mm

Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

1/1

Chi	Me	Conic	TCE x 1E-6
0.0..	0.0..	0.000	0.000
0.0..	10...	0.000	0.000
0.0..	10...	0.000	0.000
0.0..	10...	0.000	0.000
0.0..	10...	0.000	0.000

At the Cross-section view we don't see any refraction → because we haven't defined a **material** of the lens yet.

EFFL: 1e+10 | WFNO: 10000 | ENPD: 20 | TOTR: 73

Type here to search 10°C ENG

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IS Scatter Catalog | ABg Scatter Catalog | Scatter Function Viewer | Scatter Polar Plot — Scattering

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Update: All Windows

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Lens Data

Update: All Windows

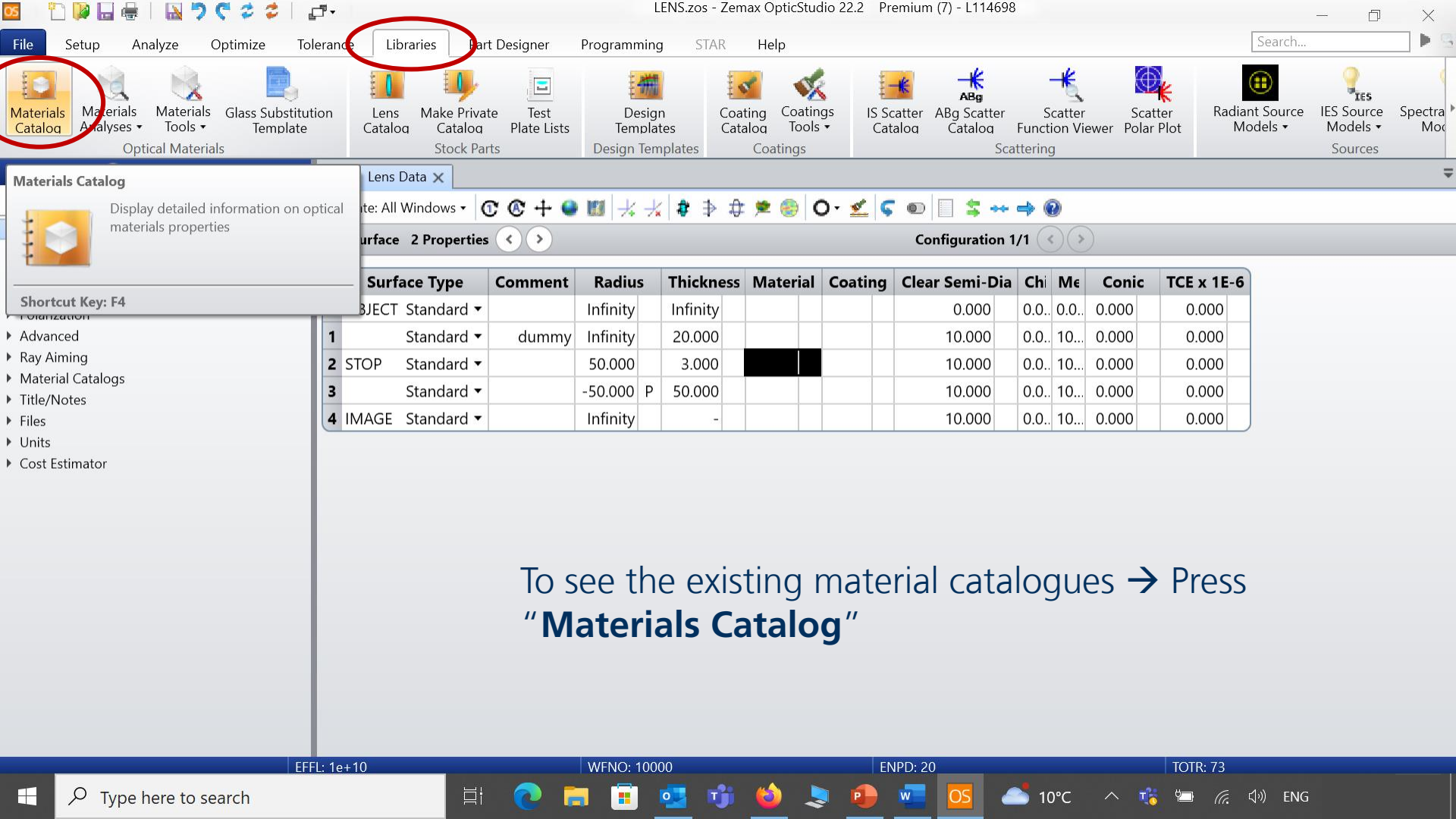
Surface 2 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity		Infinity			0.000	0.0..	0.0..	0.000	0.000
1		Standard	dummy	Infinity		20.000			10.000	0.0..	10...	0.000	0.000
2	STOP	Standard		50.000		3.000			10.000	0.0..	10...	0.000	0.000
3		Standard		-50.000	P	50.000			10.000	0.0..	10...	0.000	0.000
4	IMAGE	Standard		Infinity		-			10.000	0.0..	10...	0.000	0.000

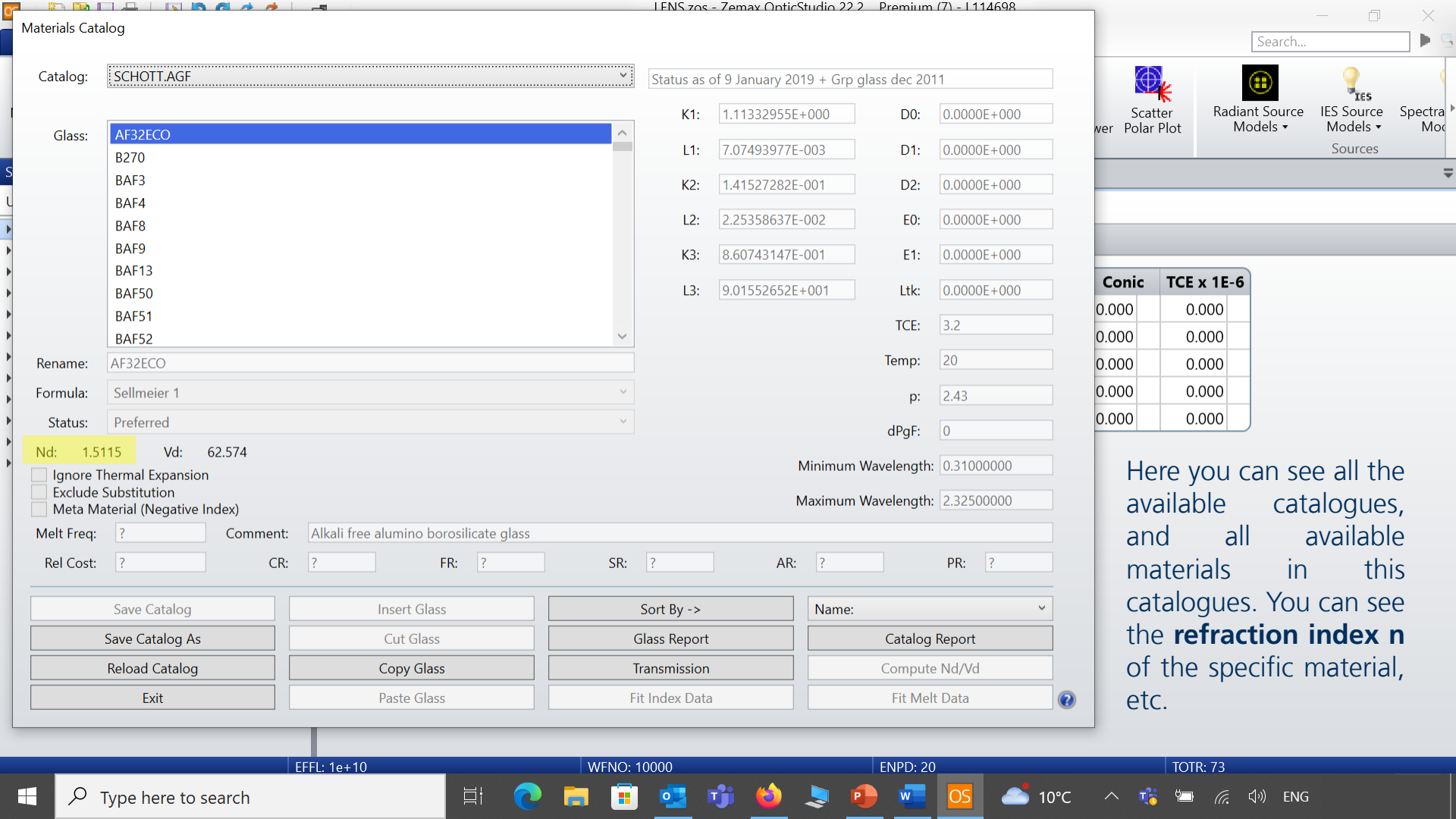
In a tab **“Libraries”** we have different catalogues of the optical materials, coatings, design templates, etc.

EFFL: 1e+10 WFNO: 10000 ENPD: 20 TOTR: 73

Type here to search 10°C ENG



To see the existing material catalogues → Press "**Materials Catalog**"



Here you can see all the available catalogues, and all available materials in this catalogues. You can see the **refraction index n** of the specific material, etc.

LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698

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Search...

Materials Catalog | Materials Analyses | Materials Tools | Glass Substitution Template — Optical Materials
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Surface 2 Properties Configuration 1/1

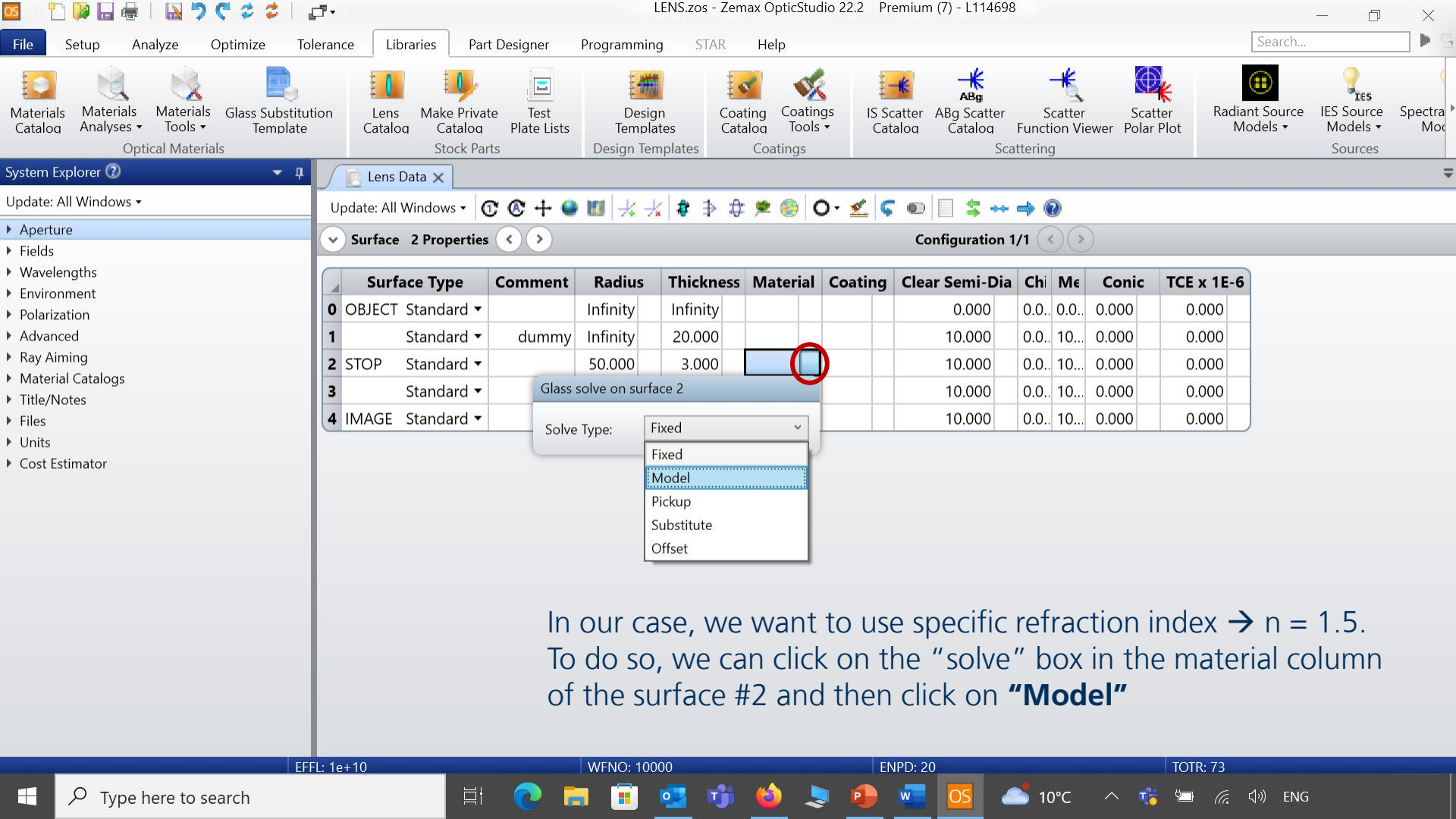
	Surface Type	Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity		Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity		20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000		3.000	BK7		10.000	0.0..	10...	0.000	-
3	Standard		-50.000	P	50.000			9.931	0.0..	10...	0.000	0.000
4	IMAGE Standard		Infinity		-			1.249	0.0..	1.2..	0.000	0.000

To define the material, which comes **after the chosen surface until the next one**, we need to type the name of the material exactly as it's written in the catalogue. Example is given here for one of the most common glass material → BK7

Note: the surface with a defined material is highlighted by blue color

EFFL: 48.7129 WFNO: 2.33485 ENPD: 20 TOTR: 73

Type here to search 10°C ENG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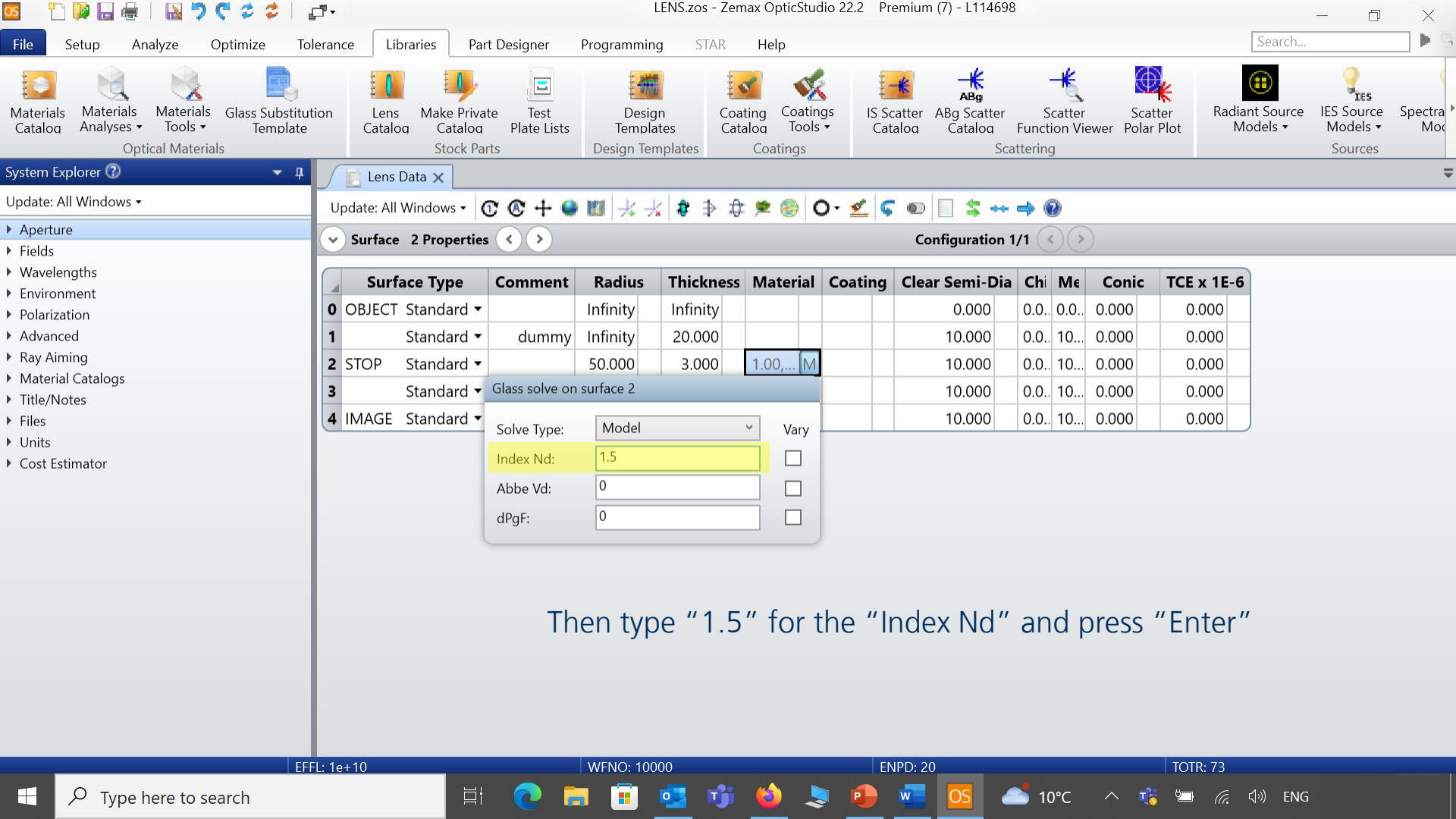
Surface 2 Properties
Configuration 1/1
Surface Type | Comment | Radius | Thickness | Material | Coating | Clear Semi-Dia | Chi | Me | Conic | TCE x 1E-6
0 OBJECT Standard | Infinity | Infinity | 0.000 | 0.0.. | 0.0.. | 0.000 | 0.000
1 Standard | dummy | Infinity | 20.000 | 10.000 | 0.0.. | 10... | 0.000 | 0.000
2 STOP Standard | 50.000 | 3.000 | 10.000 | 0.0.. | 10... | 0.000 | 0.000
3 Standard | 10.000 | 0.0.. | 10... | 0.000 | 0.000
4 IMAGE Standard | 10.000 | 0.0.. | 10... | 0.000 | 0.000
Glass solve on surface 2
Solve Type: Fixed
Fixed
Model
Pickup
Substitute
Offset
In our case, we want to use specific refraction index → n = 1.5.
To do so, we can click on the "solve" box in the material column
of the surface #2 and then click on **"Model"**
EFFL: 1e+10
WFNO: 10000
ENPD: 20
TOTR: 73
Type here to search
10°C
ENG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Surface Type
Comment
Radius
Thickness
Material
Coating
Clear Semi-Dia
Chi
Me
Conic
TCE x 1E-6
0 OBJECT Standard Infinity Infinity 0.000 0.0.. 0.0.. 0.000 0.000
1 Standard dummy Infinity 20.000 10.000 0.0.. 10... 0.000 0.000
2 STOP Standard 50.000 3.000 1.00,... M 10.000 0.0.. 10... 0.000 0.000
3 Standard 10.000 0.0.. 10... 0.000 0.000
4 IMAGE Standard 10.000 0.0.. 10... 0.000 0.000
Glass solve on surface 2
Solve Type: Model
Vary
Index Nd: 1.5
Abbe Vd: 0
dPgF: 0
Then type “1.5” for the “Index Nd” and press “Enter”
EFFL: 1e+10
WFNO: 10000
ENPD: 20
TOTR: 73
Type here to search
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Lens Data

Update: All Windows

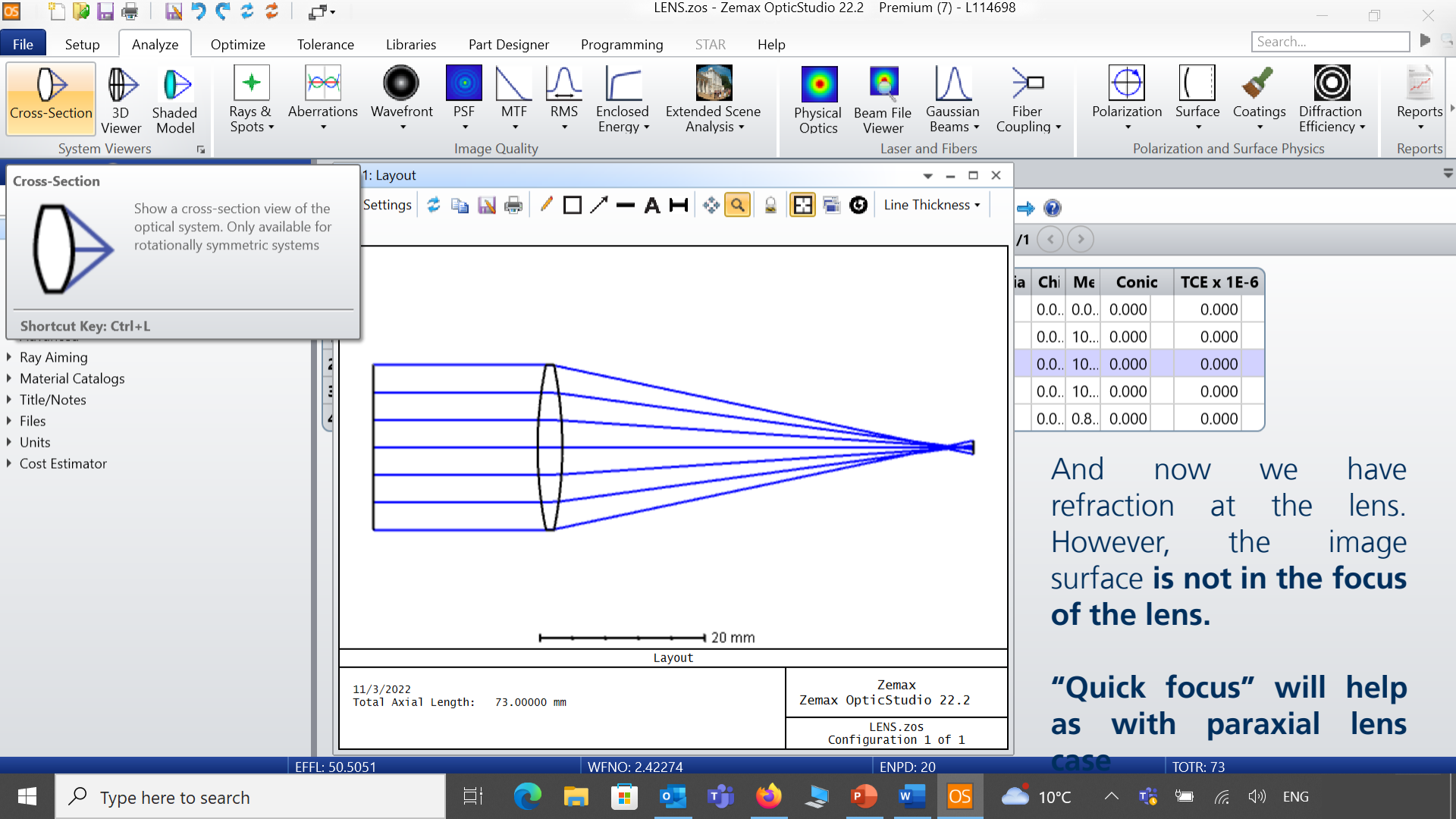
Surface 3 Properties Configuration 1/1

	Surface Type	Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity		Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity		20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000		3.000	1.50,0.0 M		10.000	0.0..	10...	0.000	0.000
3	Standard		-50.000	P	50.000	[redacted]		9.933	0.0..	10...	0.000	0.000
4	IMAGE Standard		Infinity		-			0.823	0.0..	0.8..	0.000	0.000

Now we have a lens, modelled according to our specification (slide 22)

EFFL: 50.5051 WFNO: 2.42274 ENPD: 20 TOTR: 73

Type here to search 10°C ENG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Cross-Section
Show a cross-section view of the optical system. Only available for rotationally symmetric systems
Shortcut Key: Ctrl+L
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1: Layout
Settings
Line Thickness
20 mm
Layout
11/3/2022
Total Axial Length: 73.00000 mm
Zemax
Zemax OpticStudio 22.2
LENS.zos
Configuration 1 of 1
Chi
Me
Conic
TCE x 1E-6
0.0.. 0.0.. 0.000 0.000
0.0.. 10... 0.000 0.000
0.0.. 10... 0.000 0.000
0.0.. 10... 0.000 0.000
0.0.. 0.8.. 0.000 0.000
And now we have refraction at the lens. However, the image surface **is not in the focus of the lens.**
"Quick focus" will help as with paraxial lens case
EFFL: 50.5051
WFNO: 2.42274
ENPD: 20
TOTR: 73
Type here to search
10°C
ENG

LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698

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Lens Data

Update: All Windows

Surface 3 Properties Configuration 1/1

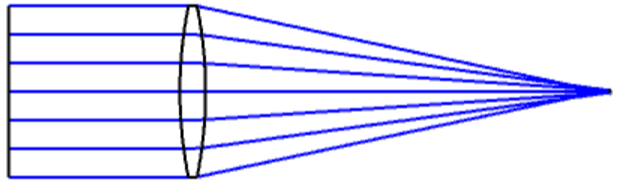
	Surface Type	Comment	Radius	Thickness	Material	Coating	Cl
0	OBJECT Standard		Infinity	Infinity			
1	Standard	dummy	Infinity	20.000			
2	STOP Standard		50.000	3.000	1.50,0.0 M		
3	Standard		-50.000 P	47.239			
4	IMAGE Standard		Infinity	-			

Now the system is focused.
At the lower part of the screen, you can see a value “EFFL”, which is ~50.5 mm in this case.
This is a paraxial focal length of our lens.
But the Image is at ~47.2 mm. **Why – explained later in the slides.**

1: Layout

Settings

Line Thickness



20 mm

Layout

11/3/2022
Total Axial Length: 70.23869 mm

Zemax
Zemax OpticStudio 22.2

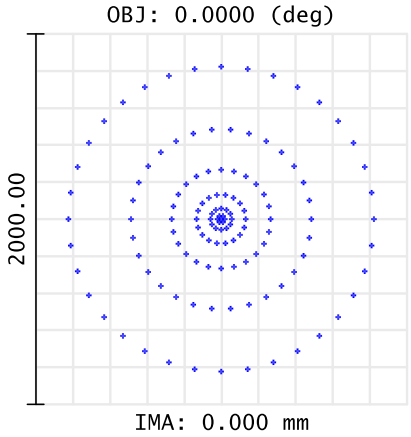
LENS.zos
Configuration 1 of 1

EFFL: 50.5051 | WFNO: 2.42274 | ENPD: 20 | TOTR: 70.2387

Type here to search

10°C ENG

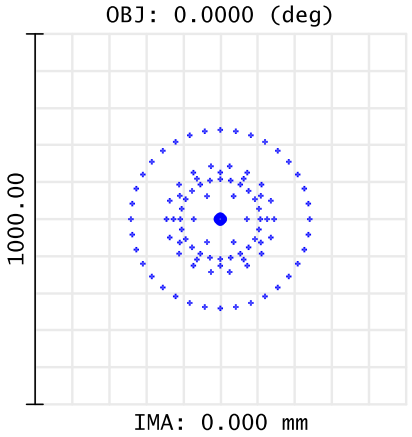
We can also compare the spot diagrams of defocused (left) and focused systems (right). As you can see, the blur of focused system is much (~3.3 times) smaller. **But still, the right blur is not just a spot.**



Surface: IMA

Spot Diagram

11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 514.009
GEO radius : 823.383
Scale bar : 2000 Reference : Chief Ray



Surface: IMA

Spot Diagram

11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 152.999
GEO radius : 240.971
Scale bar : 1000 Reference : Chief Ray

Aberrations

Problems:

1. Focal length of the lens ≠ distance from lens to focused imaged
2. Not perfect spot with real lens

Reason → **Aberrations:**

$\frac{1}{f} \approx (n-1)(\frac{1}{R_1} - \frac{1}{R_2})$ → Paraxial calculation, **which doesn't include aberrations!**

Aberrations

$\frac{1}{f} \approx (n-1)(\frac{1}{R_1} - \frac{1}{R_2})$ → is based on paraxial simplification of Refraction law:

$n_1 * sin\theta_1 = n_2 * sin\theta_2 \approx n_1 * \theta_1 = n_2 * \theta_2$

which is not true in real systems (Taylor's decomposition of sine):

$$sin\theta \approx \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} + \frac{\theta^7}{7!} \ldots$$

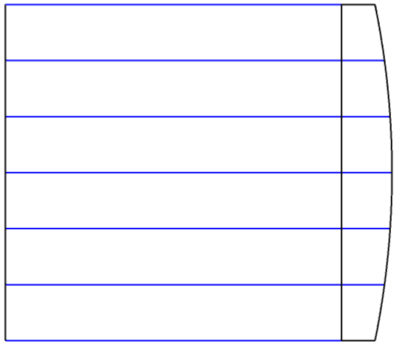
Aberrations!

Modelling of a **standard plano-convex** lens

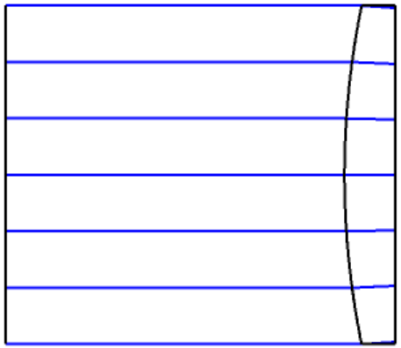
Lens parameters are same as in previous case (slide 23), but now one of the surfaces of the lens is flat.

Question → which case would be better in terms of aberrations?

Parallel rays enter flat surface



Or parallel rays enter curved surface



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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Polarization | Surface | Coatings | Diffraction Efficiency — Polarization and Surface Physics
Reports — Reports

System Explorer

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- Units
- Cost Estimator

Lens Data

Update: All Windows

Surface 3 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity	20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		50.000	3.000	1.50,0.0 M		10.000	0.0..	10...	0.000	0.000
3	Standard		-50.000 P	47.239			9.933	0.0..	10...	0.000	0.000
4	IMA			-			0.241	0.0..	0.2..	0.000	0.000

Curvature solve on surface 3

Solve Type: Pickup

From Surface:

Scale Factor:

From Column:

- Fixed
- Variable
- Marginal Ray Angle
- Chief Ray Angle
- Pickup
- Marginal Ray Normal
- Chief Ray Normal
- Aplanatic
- Element Power
- Concentric Surf
- Concentric Radius

To make plano-convex lens, we need to remove Pickup from surface 3 → click on solve box and choose **"Fixed"**

1: Layout

by -1 | EFFL: 50.5051 | WFNO: 2.42274 | ENPD: 20 | TOTR: 70.2387

Type here to search 10°C ENG

Lens Data

Update: All Windows

Surface 2 Properties — Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chi	Me	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000	0.0..	0.0..	0.000	0.000
1	Standard	dummy	Infinity	20.000			10.000	0.0..	10...	0.000	0.000
2	STOP Standard		0	3.000	1.50,0.0 M		10.000	0.0..	10...	0.000	0.000
3	Standard		-50.000	96.941			10.000	0.0..	10...	0.000	0.000
4	IMAGE Standard		Infinity	-			0.158	0.0..	0.1..	0.000	0.000

Then we can make the surface #2 to be flat. To do so, just type in the "radius" column "0". The radius will become "Infinity" in this case.

Afterwards, use the Quick Focus tool to get the correct distance to the image!

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1: Layout

Settings | Line Thickness

50 mm

2: Spot Diagram

Settings | 3 x 4 | Standard | Automatic

0.55

OBJ: 0.0000 (deg)

400.00

IMA: 0.000 mm

The blur in this case has RMS radius ~100 micron

Surface: IMA

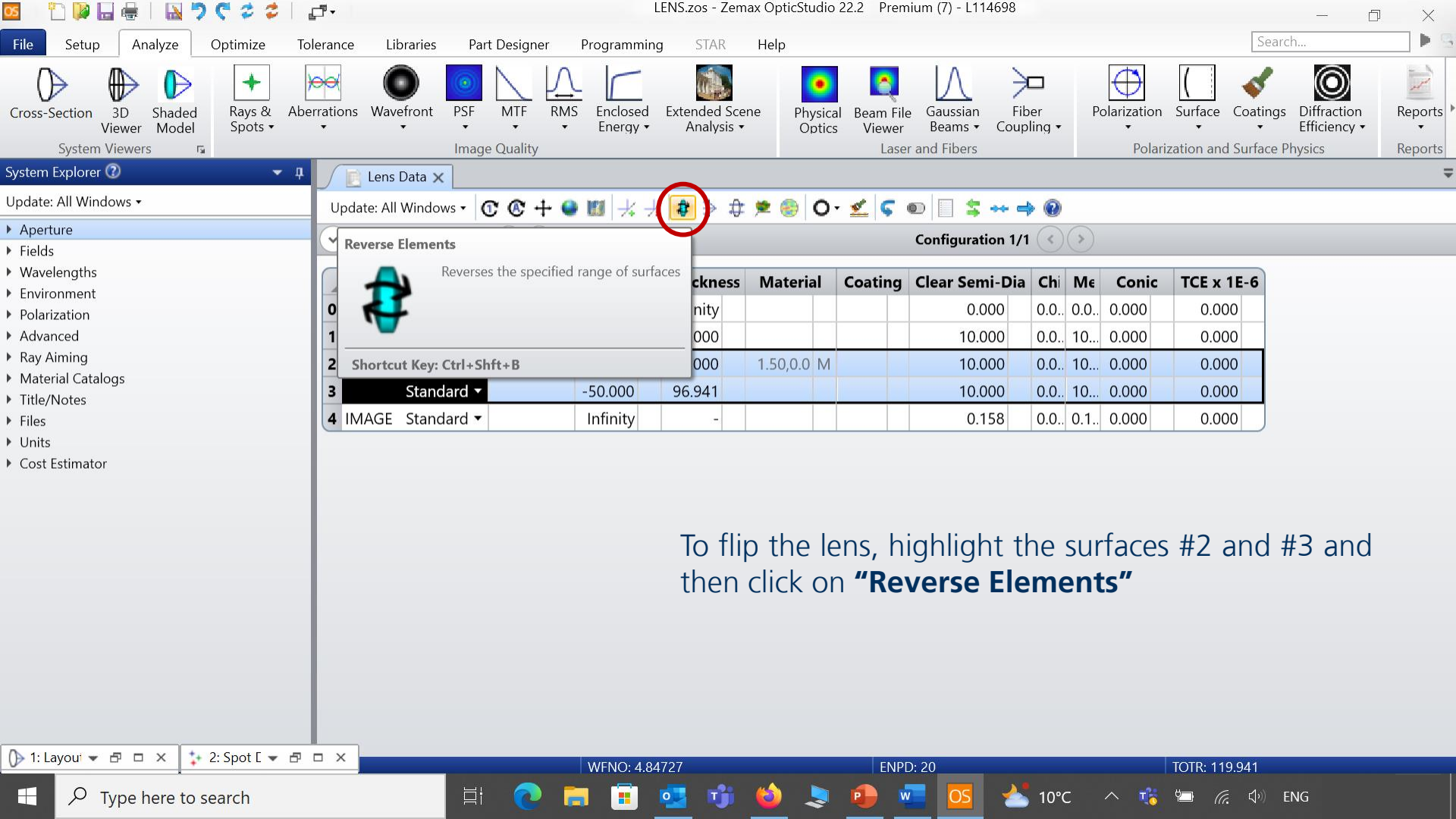
Spot Diagram	
11/3/2022 Units are µm. Legend items refer to Wavelengths Field : 1 RMS radius : 100.893 GEO radius : 157.911 Scale bar : 400 Reference : Chief Ray	Zemax Zemax OpticStudio 22.2 LENS.zos Configuration 1 of 1

Graph | Text

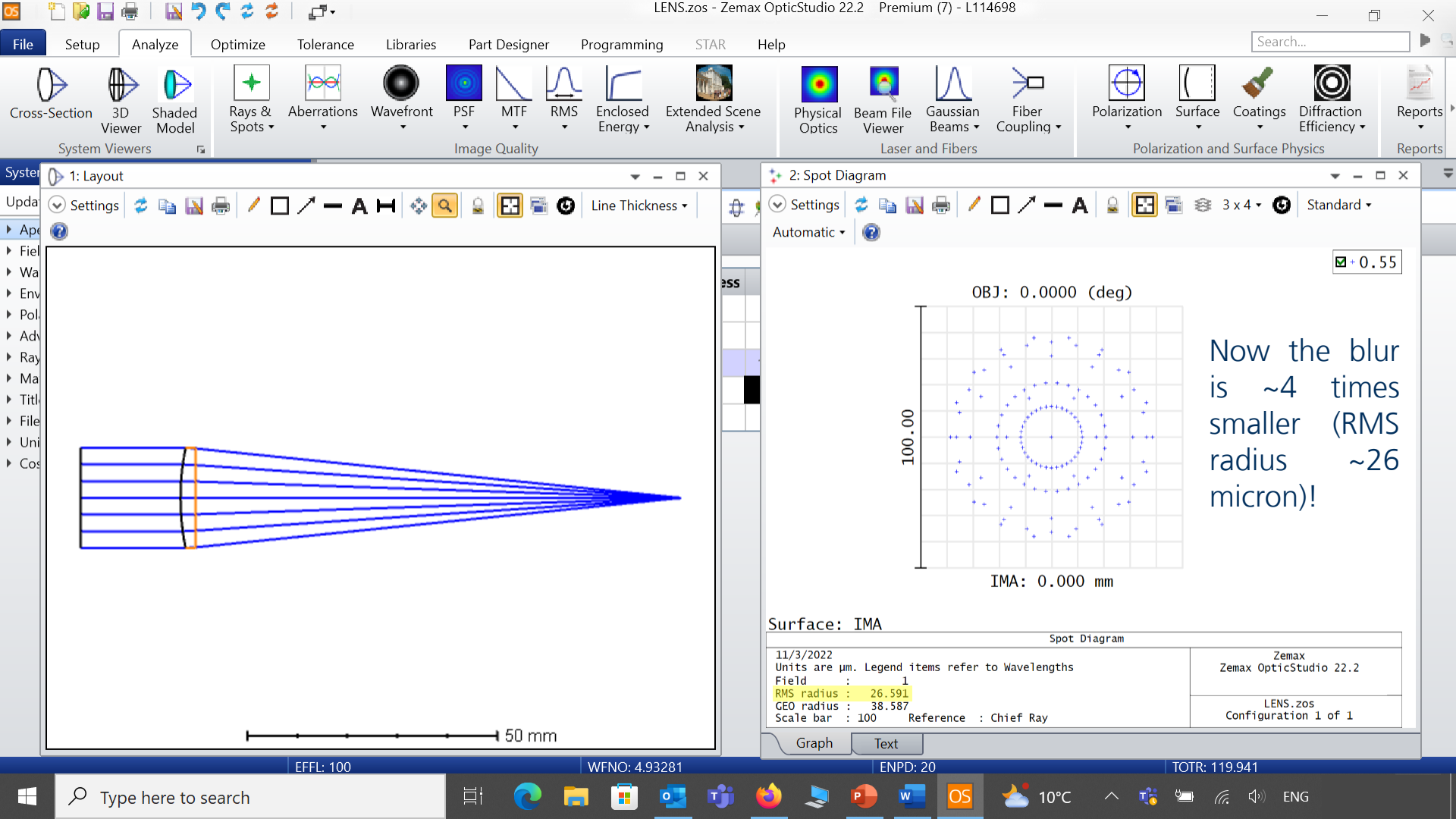
EFFL: 100 | WFNO: 4.84727 | ENPD: 20 | TOTR: 119.941

Type here to search

10°C ENG



To flip the lens, highlight the surfaces #2 and #3 and then click on **"Reverse Elements"**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Polarization Surface Coatings Diffraction Efficiency
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Polarization and Surface Physics
Reports
1: Layout
Settings
Line Thickness
50 mm
2: Spot Diagram
Settings
3 x 4
Standard
Automatic
0.55
OBJ: 0.0000 (deg)
100.00
IMA: 0.000 mm
Now the blur is ~4 times smaller (RMS radius ~26 micron)!
Surface: IMA
Spot Diagram
11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 26.591
GEO radius : 38.587
Scale bar : 100 Reference : Chief Ray
Zemax
Zemax OpticStudio 22.2
LENS.zos
Configuration 1 of 1
Graph
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EFFL: 100
WFNO: 4.93281
ENPD: 20
TOTR: 119.941
Type here to search
10°C
ENG

Modelling of a **standard plano-convex** lens

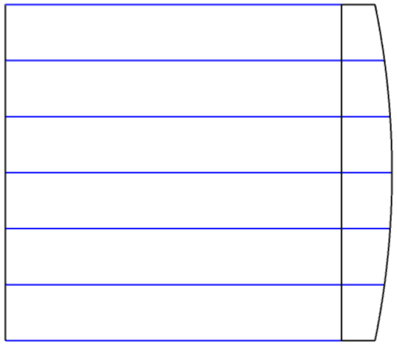
Why is that so?

Modelling of a **standard plano-convex** lens

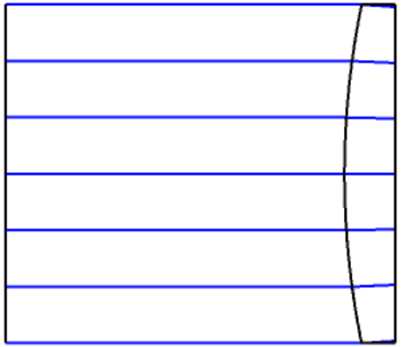
$$sin\theta \approx \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} + \frac{\theta^7}{7!} \dots$$

Aberrations are not linear w.r.t. angle of refraction!

One strong refraction



Two weaker refractions

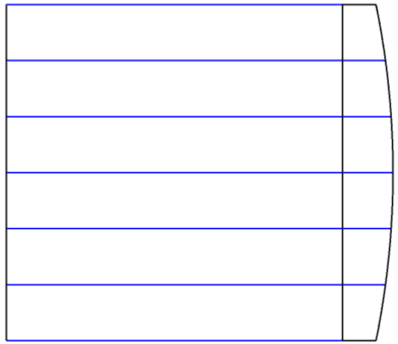


Modelling of a **standard plano-convex** lens

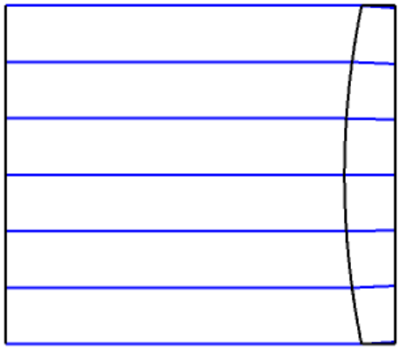
$$sin\theta \approx \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} + \frac{\theta^7}{7!} \dots$$

Aberrations are not linear w.r.t. angle of refraction!

One strong refraction, θ_1



Two weaker refractions, $\theta_2 + \theta_3$, $\theta_2 \approx \theta_3 \approx \frac{1}{2}\theta_1$



Modelling of a **standard plano-convex** lens

$$sin\theta \approx \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} + \frac{\theta^7}{7!} \dots$$

$$\frac{\theta_1^3}{3!} \; is \sim 4 \; times \; higher \; than \; \frac{\left(\frac{1}{2}\theta_1\right)^3}{3!} + \frac{\left(\frac{1}{2}\theta_1\right)^3}{3!}$$

Optimization of standard lens

- 1:1 imaging
- Object distance = 100
- Aperture diameter = 20
- Start with planoconvex lens (radius = 25, thickness = 3), material N-BK7
- Radii → variable
- Image distance = 100

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Lens Data

Update: All Windows

Surface 0 Properties

Configuration 1/1

	Surface Type		Comment	Radius	Thickness	Material	Coatin	Clear Semi-Di	Chip Z	Mech Se	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	100.000			0.000	0.0...	0.000	0.000	0.000
1	STOP	Standard		Infinity	3.000	N-BK7		10.000	0.0...	10.0...	0.000	-
2		Standard		-25.000	100.000			10.058	0.0...	10.0...	0.000	0.000
3	IMAGE	Standard		Infinity	-			3.404	0.0...	3.404	0.000	0.000

EFFL: 48.2139 | WFNO: 3.82537 | ENPD: 20 | TOTR: 103

Type here to search

9°C

ENG

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

Cross-Section | 3D Viewer | Shaded Model | Rays & Spots | Aberrations | Wavefront | PSF | MTF | RMS | Enclosed Energy | Extended Scene Analysis | Physical Optics | Beam File Viewer | Gaussian Beams | Fiber Coupling | Polarization | Surface | Coatings | Diffraction Efficiency | Reports

1: Layout

Settings | Line Thickness

System not optimized yet → very big blur (~2.2 mm)

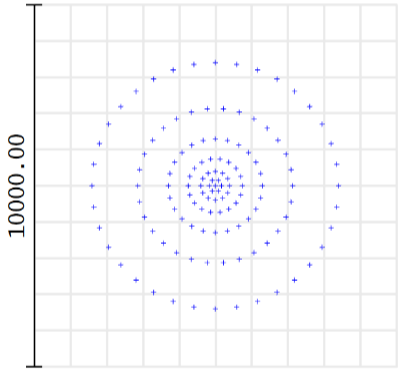
50 mm

2: Spot Diagram

Settings | 3 x 4 | Standard | Automatic

0.55

OBJ: 0.0000 (deg)



IMA: 0.000 mm

Surface: IMA

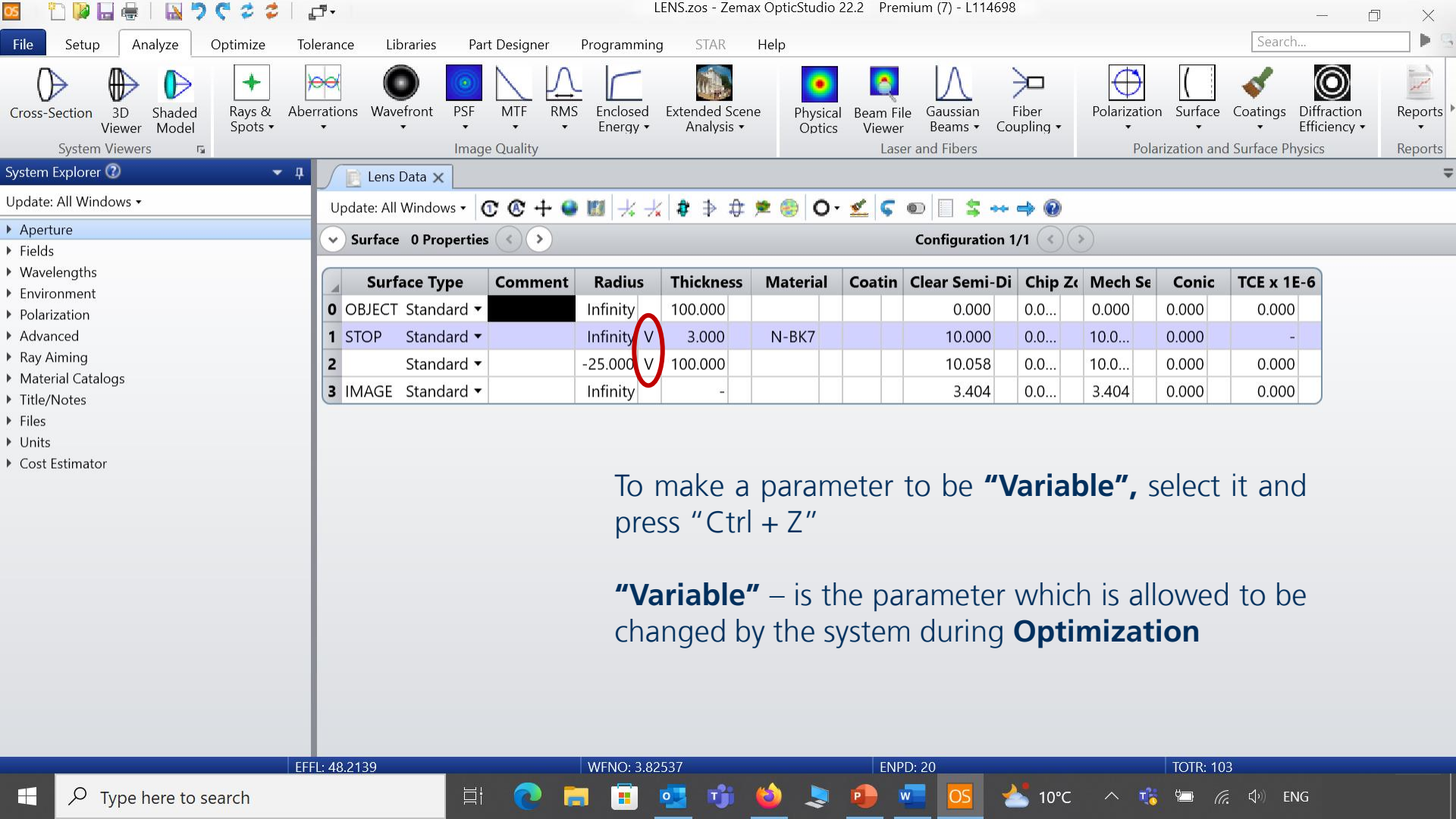
Spot Diagram

11/3/2022 Units are µm. Legend items refer to Wavelengths Field : 1 RMS radius : 2185.55 GEO radius : 3404.00 Scale bar : 1e+04 Reference : Chief Ray	Zemax Zemax OpticStudio 22.2 LENS.zos Configuration 1 of 1

Graph | Text

Type here to search

ENG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Surface Type
Comment
Radius
Thickness
Material
Coatin
Clear Semi-Di
Chip Z
Mech Se
Conic
TCE x 1E-6
0 OBJECT Standard Infinity 100.000 0.000 0.0... 0.000 0.000 0.000
1 STOP Standard Infinity V 3.000 N-BK7 10.000 0.0... 10.0... 0.000 -
2 Standard -25.000 V 100.000 10.058 0.0... 10.0... 0.000 0.000
3 IMAGE Standard Infinity - 3.404 0.0... 3.404 0.000 0.000
To make a parameter to be "Variable", select it and press "Ctrl + Z"
"Variable" – is the parameter which is allowed to be changed by the system during Optimization
EFFL: 48.2139
WFNO: 3.82537
ENPD: 20
TOTR: 103
Type here to search
10°C
ENG

Optimization…

…is an automatized process of searching for the minimum value of the **Merit Function (MF)**

Merit Function (MF) – roughly speaking is a function, which represents all the aberrations we want to correct in the optical system during optimization.

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

Quick Focus | Quick Adjust | Slider | Visual Optimizer — Manual Adjustment

Merit Function Editor | Optimization Wizard | Optimize! | Remove All Variables | Set All Radii Variable | Set All Thickness Variable — Automatic Optimization

Global Search | Hammer Current | Glass Substitution Template — Global Optimizers

Find Best Asphere | Convert Asphere Types | Stock Lens Matching | Test Plate Fitting | Test Plate Lists — Optimization Tools

System Explorer

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Optimization Wizard

Set up the merit function with the most common requirements. Can be edited subsequently

No shortcut key assigned

Configuration 1/1

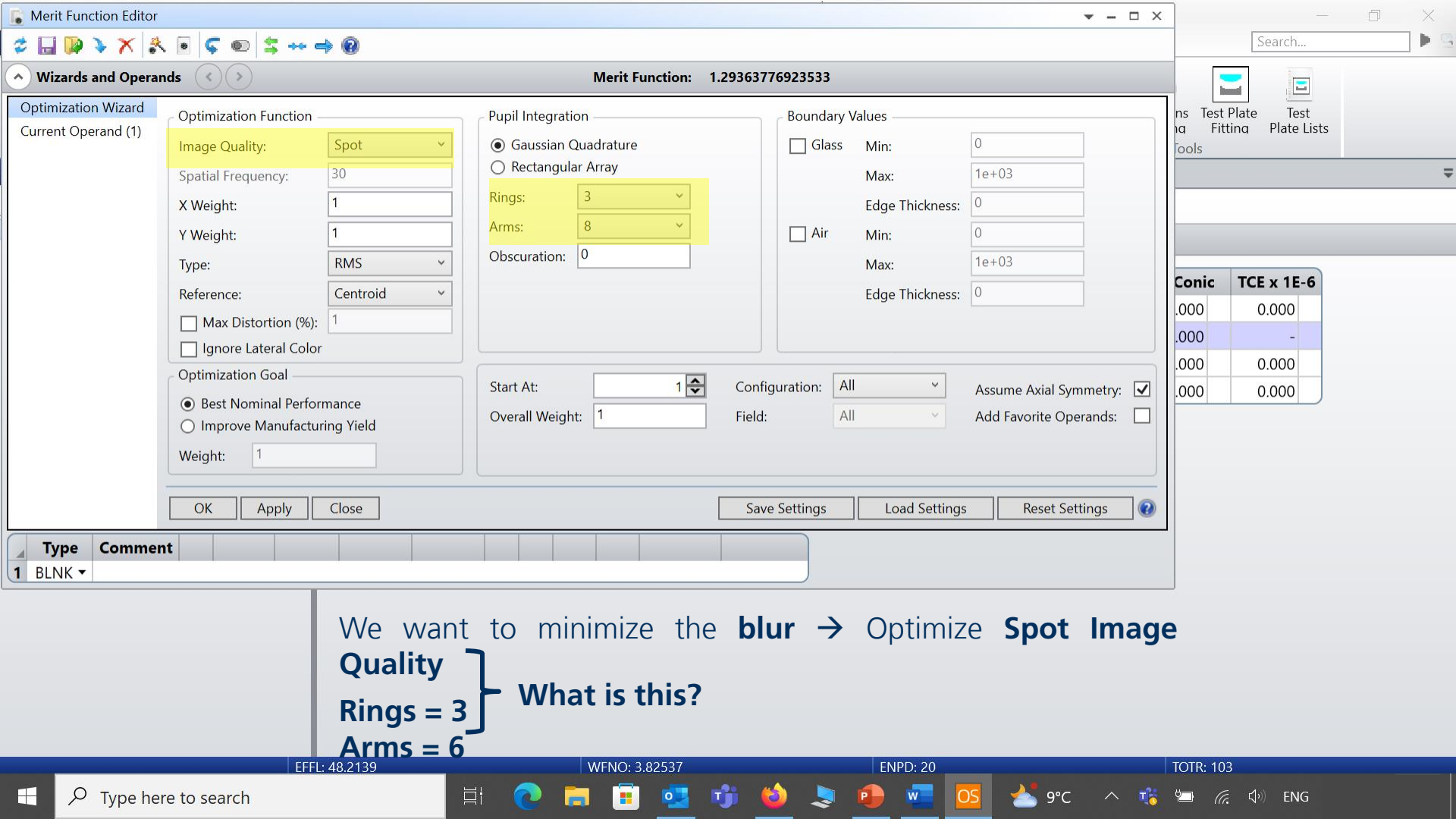
						kness	Material	Coatin	Clear Semi-Di	Chip Z	Mech Se	Conic	TCE x 1E-6
0						000			0.000	0.0...	0.000	0.000	0.000
1	STOP	Standard		Infinity	V	3.000	N-BK7		10.000	0.0...	10.0...	0.000	-
2		Standard		-25.000	V	100.000			10.058	0.0...	10.0...	0.000	0.000
3	IMAGE	Standard		Infinity		-			3.404	0.0...	3.404	0.000	0.000

To optimize our system, we can use **“Optimization Wizard”** in the tab **“Optimize”**

Optimization Wizard is a quick tool, which defines a **“Default Merit Function”**

EFFL: 48.2139 | WFNO: 3.82537 | ENPD: 20 | TOTR: 103

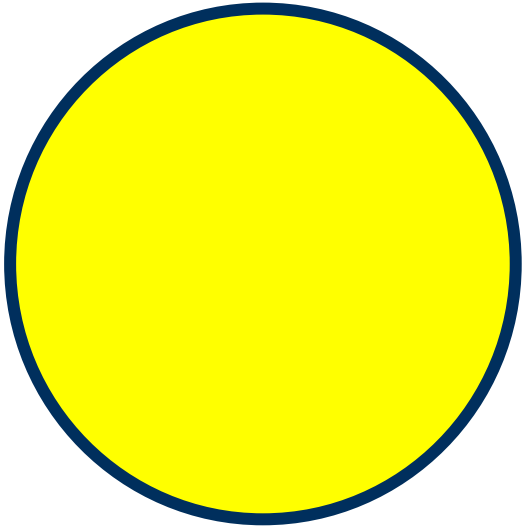
Type here to search 9°C ENG


Merit Function Editor
Wizards and Operands
Merit Function: 1.29363776923533
Optimization Wizard
Current Operand (1)
Optimization Function
Image Quality: Spot
Spatial Frequency: 30
X Weight: 1
Y Weight: 1
Type: RMS
Reference: Centroid
Max Distortion (%): 1
Ignore Lateral Color
Pupil Integration
Gaussian Quadrature
Rectangular Array
Rings: 3
Arms: 8
Obscuration: 0
Boundary Values
Glass
Min: 0
Max: 1e+03
Edge Thickness: 0
Air
Min: 0
Max: 1e+03
Edge Thickness: 0
Optimization Goal
Best Nominal Performance
Improve Manufacturing Yield
Weight: 1
Start At: 1
Overall Weight: 1
Configuration: All
Field: All
Assume Axial Symmetry:
Add Favorite Operands:
OK
Apply
Close
Save Settings
Load Settings
Reset Settings
Type
Comment
1 BLNK
Test Plate Fitting
Test Plate Lists
Tools
Conic
TCE x 1E-6
.000
0.000
.000
-
.000
0.000
.000
0.000
We want to minimize the blur → Optimize Spot Image Quality
Rings = 3
Arms = 6
What is this?
EFFL: 48.2139
WFNO: 3.82537
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG

Pupil integration

If we look at the aperture of the optical system in a front view:

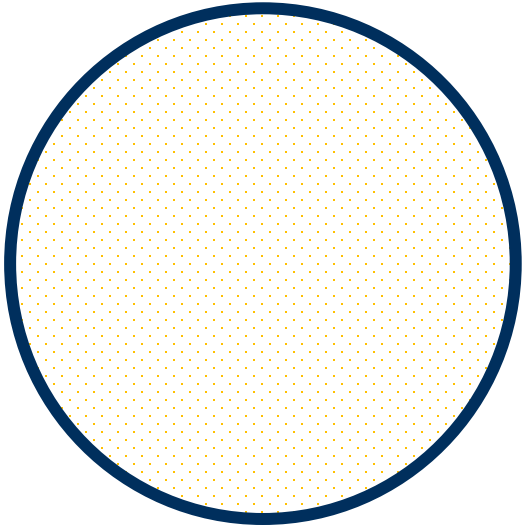
In reality we would see a circle, filled with light → infinite number of rays.



Pupil integration

If we look at the aperture of the optical system in a front view:

To simplify computational task, we restrict ourselves to finite number of rays.



Pupil integration

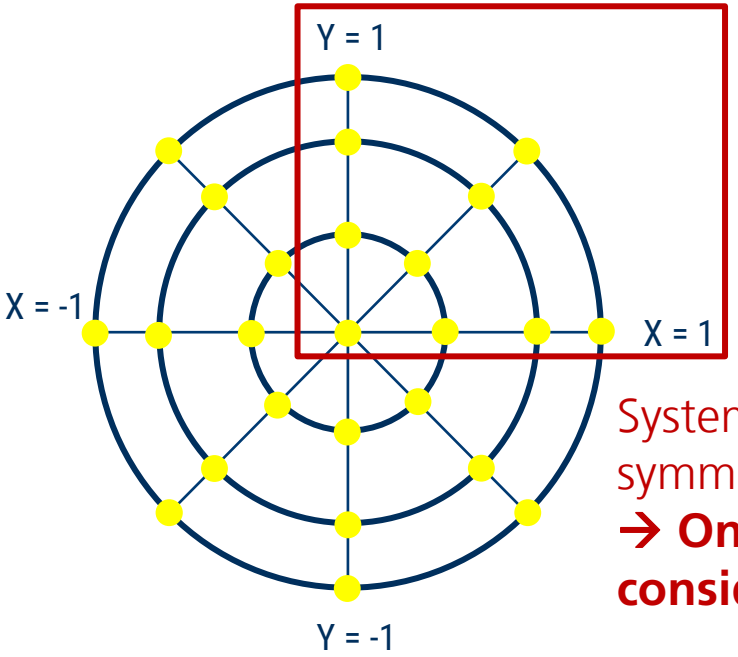
If we look at the aperture of the optical system in a front view:

For optimization we define specific rays, which will be considered during optimization.

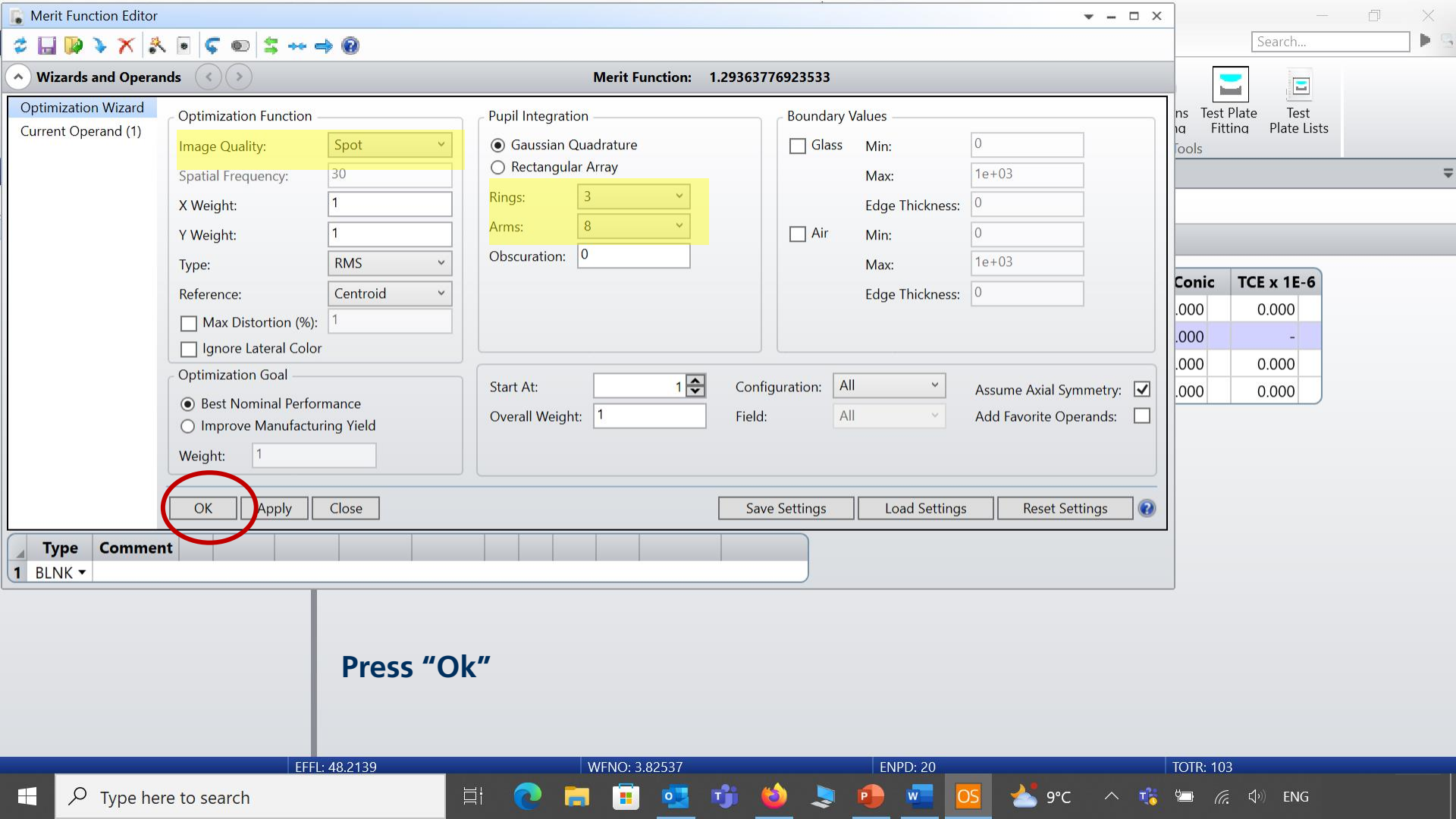
Coordinates of those rays are given by intersection of “Rings” and “Arms” defined by “Optimization Wizard”.

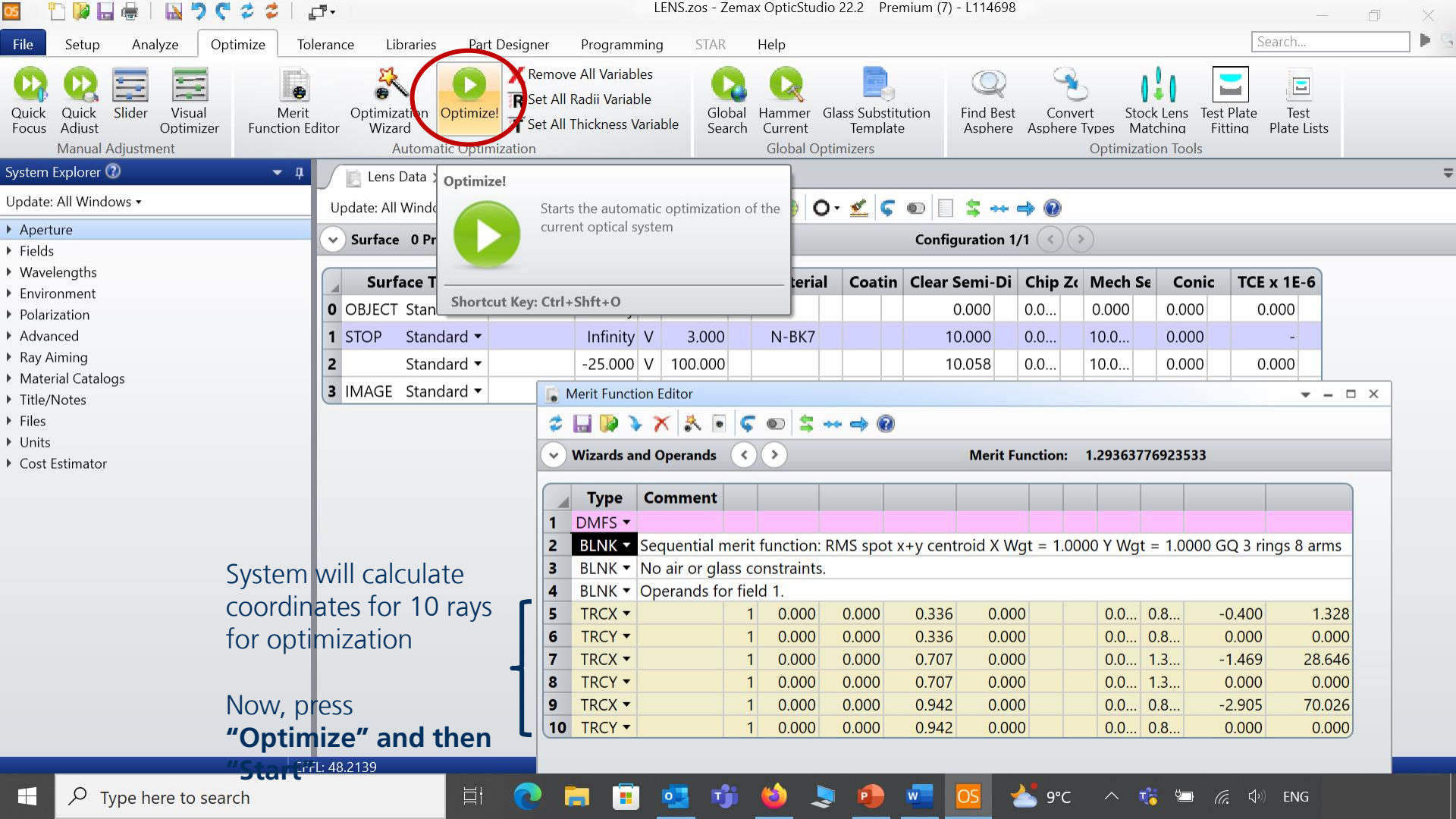
Rings represent normalized pupil radii!

3 rings
8 arms
} 10 rays to be considered for optimization



System is symmetrical
→ **Only ¼ is considered**


Merit Function Editor
Wizards and Operands
Merit Function: 1.29363776923533
Optimization Wizard
Current Operand (1)
Optimization Function
Image Quality: Spot
Spatial Frequency: 30
X Weight: 1
Y Weight: 1
Type: RMS
Reference: Centroid
Max Distortion (%): 1
Ignore Lateral Color
Pupil Integration
Gaussian Quadrature
Rectangular Array
Rings: 3
Arms: 8
Obscuration: 0
Boundary Values
Glass
Min: 0
Max: 1e+03
Edge Thickness: 0
Air
Min: 0
Max: 1e+03
Edge Thickness: 0
Optimization Goal
Best Nominal Performance
Improve Manufacturing Yield
Weight: 1
Start At: 1
Overall Weight: 1
Configuration: All
Field: All
Assume Axial Symmetry:
Add Favorite Operands:
OK
Apply
Close
Save Settings
Load Settings
Reset Settings
Type
Comment
1 BLNK
Test Plate Fitting
Test Plate Lists
Tools
Conic
TCE x 1E-6
.000
0.000
.000
-
.000
0.000
.000
0.000
Press “Ok”
EFFL: 48.2139
WFNO: 3.82537
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG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Quick Adjust
Slider
Visual Optimizer
Manual Adjustment
Merit Function Editor
Optimization Wizard
Optimize!
Remove All Variables
Set All Radii Variable
Set All Thickness Variable
Automatic Optimization
Global Search
Hammer Current
Glass Substitution Template
Global Optimizers
Find Best Asphere
Convert Asphere Types
Stock Lens Matching
Test Plate Fitting
Test Plate Lists
Optimization Tools
System Explorer
Update: All Windows
Aperture
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Files
Units
Cost Estimator
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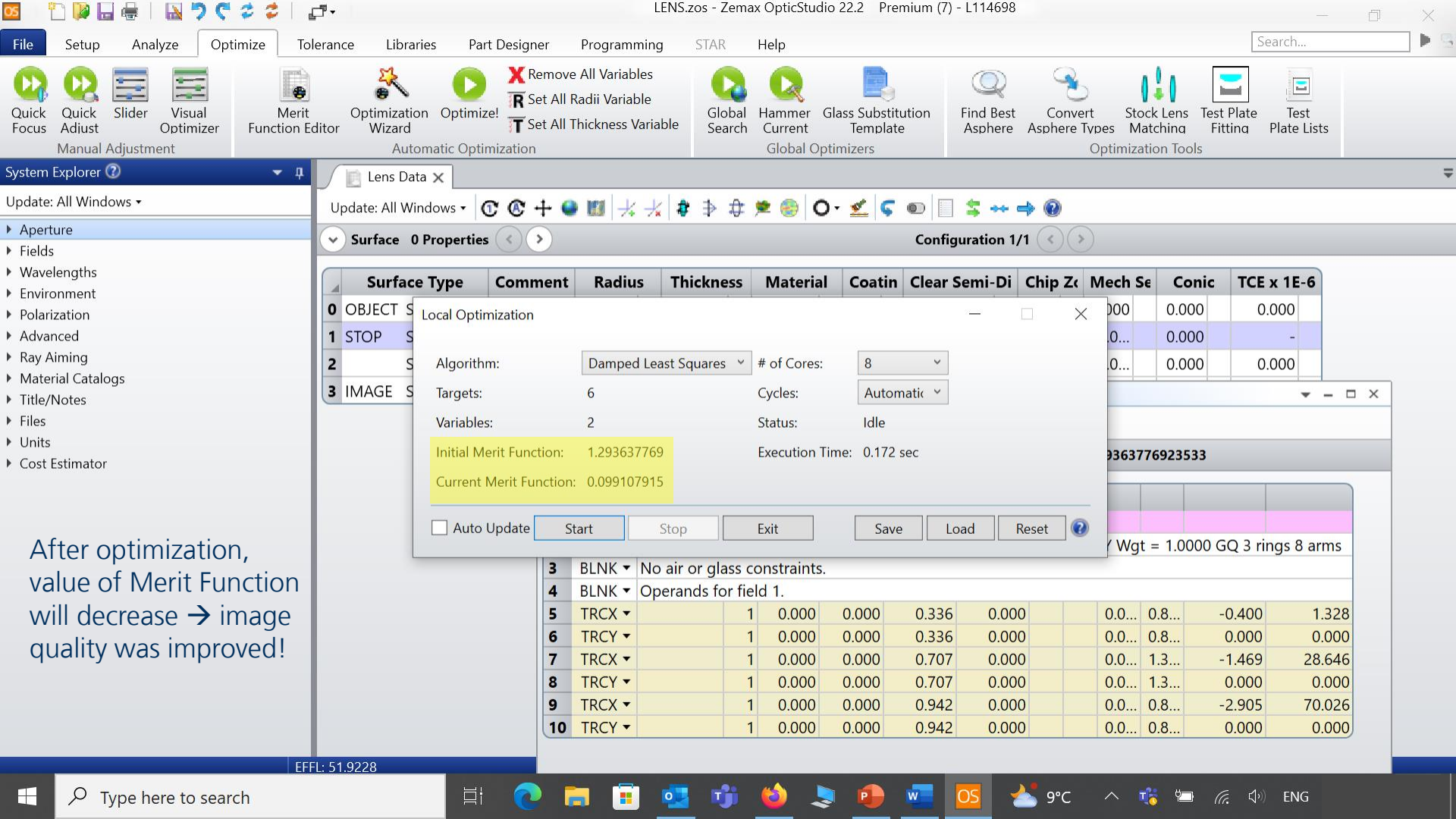
Optimize!
Starts the automatic optimization of the current optical system
Shortcut Key: Ctrl+Shft+O
Configuration 1/1
Surface T
Coatin
Clear Semi-Di
Chip Z
Mech Se
Conic
TCE x 1E-6
0 OBJECT Stan 0.000 0.0... 0.000 0.000 0.000
1 STOP Standard Infinity V 3.000 N-BK7 10.000 0.0... 10.0... 0.000 -
2 Standard -25.000 V 100.000 10.058 0.0... 10.0... 0.000 0.000
3 IMAGE Standard
Merit Function Editor
Wizards and Operands
Merit Function: 1.29363776923533
Type
Comment
1 DMFS
2 BLNK Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 8 arms
3 BLNK No air or glass constraints.
4 BLNK Operands for field 1.
5 TRCX 1 0.000 0.000 0.336 0.000 0.0... 0.8... -0.400 1.328
6 TRCY 1 0.000 0.000 0.336 0.000 0.0... 0.8... 0.000 0.000
7 TRCX 1 0.000 0.000 0.707 0.000 0.0... 1.3... -1.469 28.646
8 TRCY 1 0.000 0.000 0.707 0.000 0.0... 1.3... 0.000 0.000
9 TRCX 1 0.000 0.000 0.942 0.000 0.0... 0.8... -2.905 70.026
10 TRCY 1 0.000 0.000 0.942 0.000 0.0... 0.8... 0.000 0.000
System will calculate coordinates for 10 rays for optimization
Now, press
“Optimize” and then
“Start”
EFFL: 48.2139
Type here to search
9°C
ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help
Search...
Quick Focus
Quick Adjust
Slider
Visual Optimizer
Manual Adjustment
Merit Function Editor
Optimization Wizard
Optimize!
Remove All Variables
Set All Radii Variable
Set All Thickness Variable
Automatic Optimization
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Glass Substitution Template
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Lens Data
Surface 0 Properties
Configuration 1/1
Surface Type Comment Radius Thickness Material Coatin Clear Semi-Di Chip Z Mech Se Conic TCE x 1E-6
0 OBJECT 0.000 0.000
1 STOP 0.000 -
2 0.000 0.000
3 IMAGE
Local Optimization
Algorithm: Damped Least Squares
# of Cores: 8
Targets: 6
Cycles: Automatic
Variables: 2
Status: Idle
Initial Merit Function: 1.293637769
Current Merit Function: 0.099107915
Execution Time: 0.172 sec
Auto Update
Start
Stop
Exit
Save
Load
Reset
Wgt = 1.0000 GQ 3 rings 8 arms
3 BLNK No air or glass constraints.
4 BLNK Operands for field 1.
5 TRCX 1 0.000 0.000 0.336 0.000 0.0... 0.8... -0.400 1.328
6 TRCY 1 0.000 0.000 0.336 0.000 0.0... 0.8... 0.000 0.000
7 TRCX 1 0.000 0.000 0.707 0.000 0.0... 1.3... -1.469 28.646
8 TRCY 1 0.000 0.000 0.707 0.000 0.0... 1.3... 0.000 0.000
9 TRCX 1 0.000 0.000 0.942 0.000 0.0... 0.8... -2.905 70.026
10 TRCY 1 0.000 0.000 0.942 0.000 0.0... 0.8... 0.000 0.000
After optimization, value of Merit Function will decrease → image quality was improved!
EFFL: 51.9228
Type here to search
9°C
ENG

LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698

File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

Cross-Section | 3D Viewer | Shaded Model — System Viewers
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System Explorer

Update: All Windows

- Aperture
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- Material Catalogs
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- Units
- Cost Estimator

Optimized system with much less blur **(~0.2 mm)**

Before → ~2.2 mm

Lens Data

Update: All Windows

Surface 0 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness	Material	C
0	OBJECT	Standard		Infinity		100.000		
1	STOP	Standard		52.649	V	3.000	N-BK7	
2		Standard		-54.027	V	100.000		
3	IMAGE	Standard		Infinity		-		

2: Layout

Settings

Line Thickness

1: Spot Diagram

Settings 3 x 4

Standard Automatic 0.55

OBJ: 0.0000 (deg)

1000.00

IMA: 0.000 mm

Surface: IMA

Spot Diagram

11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 179.752
GEO radius : 278.977
Scale bar : 1000 Reference : Chief Ray

Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

Graph | Text

EFFL: 51.9228 WFNO: 4.93601 ENPD: 20 TOTR: 103

Type here to search 9°C ENG

Optimization constrains

We can use **constrains** for the geometrical parameters of the optical system, to keep it withing possible / manufacturable limits during optimization.

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Besides radii, we can also use **thickness of the lens as variable**

Lens Data

Update: All Windows

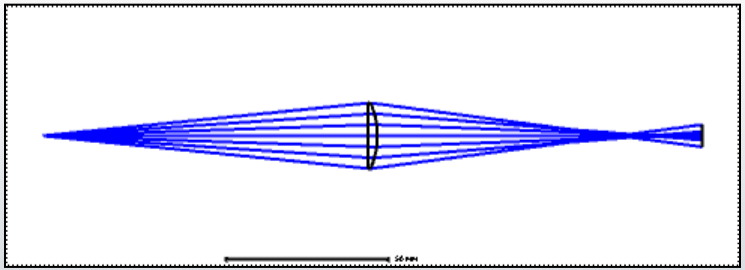
Surface 0 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness		Material
0	OBJECT	Standard		Infinity		100.000		
1	STOP	Standard		Infinity	V	3.000	V	N-BK7
2		Standard		-25.000	V	100.000		
3	IMAGE	Standard		Infinity		-		

2: Layout

Settings

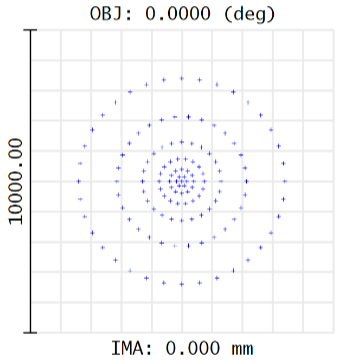
Line Thickness



1: Spot Diagram

Settings 3 x 4

Standard Automatic 0.55



Surface: IMA

Spot Diagram

11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 2185.55
GEO radius : 3404.00
Scale bar : 1e+04 Reference : Chief Ray

Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

Graph | Text

EFFL: 48.2139 WFNO: 3.82537 ENPD: 20 TOTR: 103

Type here to search 9°C ENG

LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698

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But, if we don't use constraints, the lens becomes **~1.2 m long after optimization**

Lens Data

Update: All Windows

Surface 0 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness		Material
0	OBJECT	Standard		Infinity		100.000		
1	STOP	Standard		53.223	V	1.174E+04	V	N-BK7
2		Standard		-53.597	V	100.000		
3	IMAGE	Standard		Infinity		-		

2: Layout

Settings

Line Thickness

1: Spot Diagram

Settings 3 x 4

Standard Automatic 0.55

OBJ: 0.0000 (deg)

1000.00

IMA: 0.000 mm

Surface: IMA

Spot Diagram

11/3/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 139.550
GEO radius : 214.900
Scale bar : 1000 Reference : Chief Ray

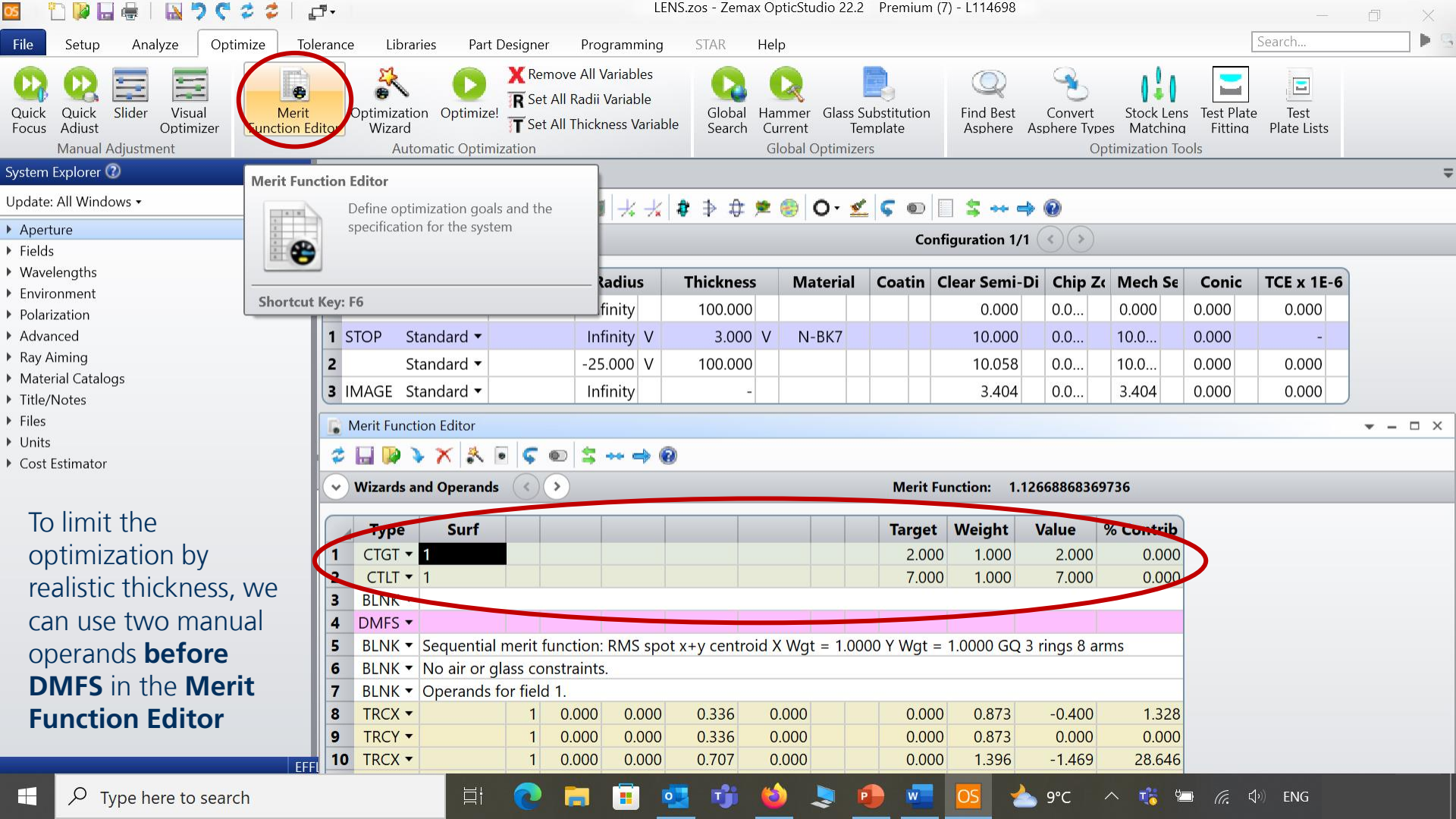
Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

Graph | Text

EFFL: -1.40967 WFNO: 29.0186 ENPD: 20 TOTR: 11841.8

Type here to search 9°C ENG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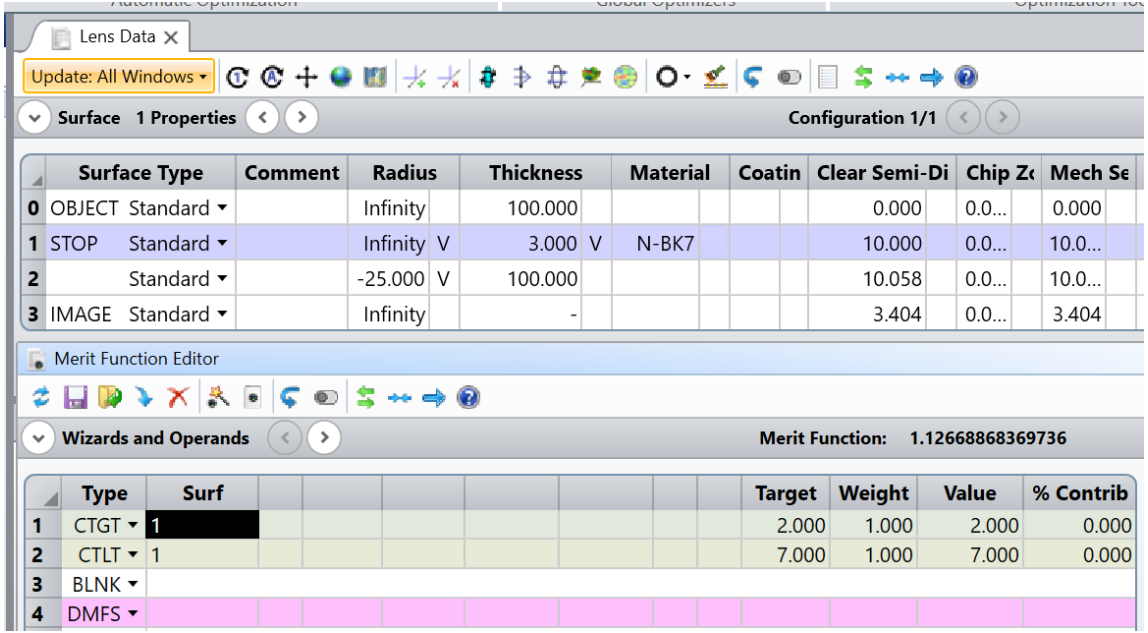
Merit Function Editor
Define optimization goals and the specification for the system
Shortcut Key: F6
Configuration 1/1
Radius
Thickness
Material
Coatin
Clear Semi-Di
Chip Zo
Mech Se
Conic
TCE x 1E-6
1 STOP Standard Infinity V 3.000 V N-BK7 10.000 0.0... 10.0... 0.000 -
2 Standard -25.000 V 100.000 10.058 0.0... 10.0... 0.000 0.000
3 IMAGE Standard Infinity - 3.404 0.0... 3.404 0.000 0.000
Merit Function Editor
Wizards and Operands
Merit Function: 1.12668868369736
Type
Surf
Target
Weight
Value
% Contrib
1 CTGT 1 2.000 1.000 2.000 0.000
2 CTLT 1 7.000 1.000 7.000 0.000
3 BLNK
4 DMFS
5 BLNK Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 8 arms
6 BLNK No air or glass constraints.
7 BLNK Operands for field 1.
8 TRCX 1 0.000 0.000 0.336 0.000 0.000 0.873 -0.400 1.328
9 TRCY 1 0.000 0.000 0.336 0.000 0.000 0.873 0.000 0.000
10 TRCX 1 0.000 0.000 0.707 0.000 0.000 1.396 -1.469 28.646
To limit the optimization by realistic thickness, we can use two manual operands before DMFS in the Merit Function Editor
Type here to search
9°C
ENG



- **"Surf"** – which surface should be limited;
- **"Target"** – the goal value for limitation;
- **"Weight"** – how important this limitation is (0 – ignored; 1 – highest importance);
- **"Value"** – current value of the parameter;
- **„% Contrib"** – contribution for optimization → How difficult would it be to fulfill this goal, w.r.t. to other operands.

"CTGT" = "Central Thickness Greater Then" → defines minimum for the thickness of surface 1;
"CTLT" = "Central Thickness Less Then" → defines maximum for the thickness of surface 1

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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System Explorer

Update: All Windows

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- Cost Estimator

If we optimize now, we will see, that thickness of the lens was held in the specified range

Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness		Material
0	OBJECT	Standard		Infinity		100.000		
1	STOP	Standard		52.063	V	7.000	V	N-BK7
2		Standard		-54.658	V	100.000		
3	IMAGE	Standard		Infinity		-		

2: Layout

Settings

Line Thickness

1: Spot Diagram

Settings 3 x 4

Standard Automatic 0.55

OBJ: 0.0000 (deg)

1000.00

IMA: 0.000 mm

Surface: IMA

Spot Diagram

11/4/2022
Units are µm. Legend items refer to Wavelengths
Field : 1
RMS radius : 179.552
GEO radius : 278.666
Scale bar : 1000 Reference : Chief Ray

Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

Graph | Text

EFFL: 52.6019 WFNO: 4.94081 ENPD: 20 TOTR: 107

Type here to search 9°C ENG

Seidel Diagram and Conic

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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

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Rays & Spots | Aberrations | Wavefront | PSF | MTF | RMS | Enclosed Energy | Extended Scene Analysis — Image Quality
Physical Optics | Beam File Viewer | Gaussian Beams | Fiber Coupling — Laser and Fibers
Polarization | Surface | Coatings | Diffraction Efficiency — Polarization and Surface Physics
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System Explorer

Update: All Windows

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Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

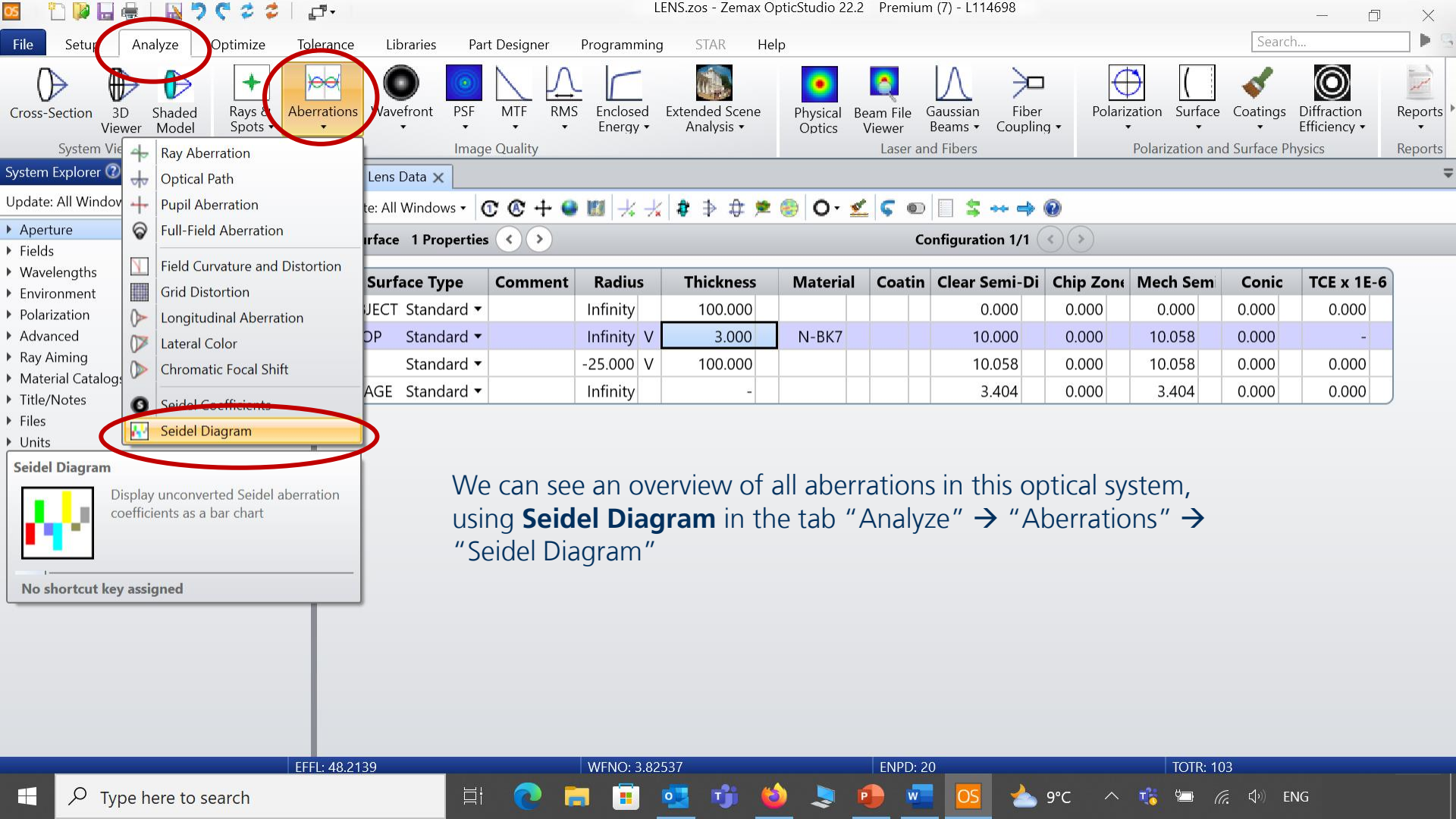
	Surface Type		Comment	Radius		Thickness	Material	Coatin	Clear Semi-Di	Chip Zone	Mech Sem	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity		100.000			0.000	0.000	0.000	0.000	0.000
1	STOP	Standard		Infinity	V	3.000	N-BK7		10.000	0.000	10.058	0.000	-
2		Standard		-25.000	V	100.000			10.058	0.000	10.058	0.000	0.000
3	IMAGE	Standard		Infinity		-			3.404	0.000	3.404	0.000	0.000

Now, please, go back to the case of not-optimized lens with a fixed thickness of 3 mm (thickness should not be variable).

1: Spot D | 2: Seidel

39 | WFNO: 3.82537 | ENPD: 20 | TOTR: 103

Type here to search 9°C ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
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PSF
MTF
RMS
Enclosed Energy
Extended Scene Analysis
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Fiber Coupling
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Full-Field Aberration
Field Curvature and Distortion
Grid Distortion
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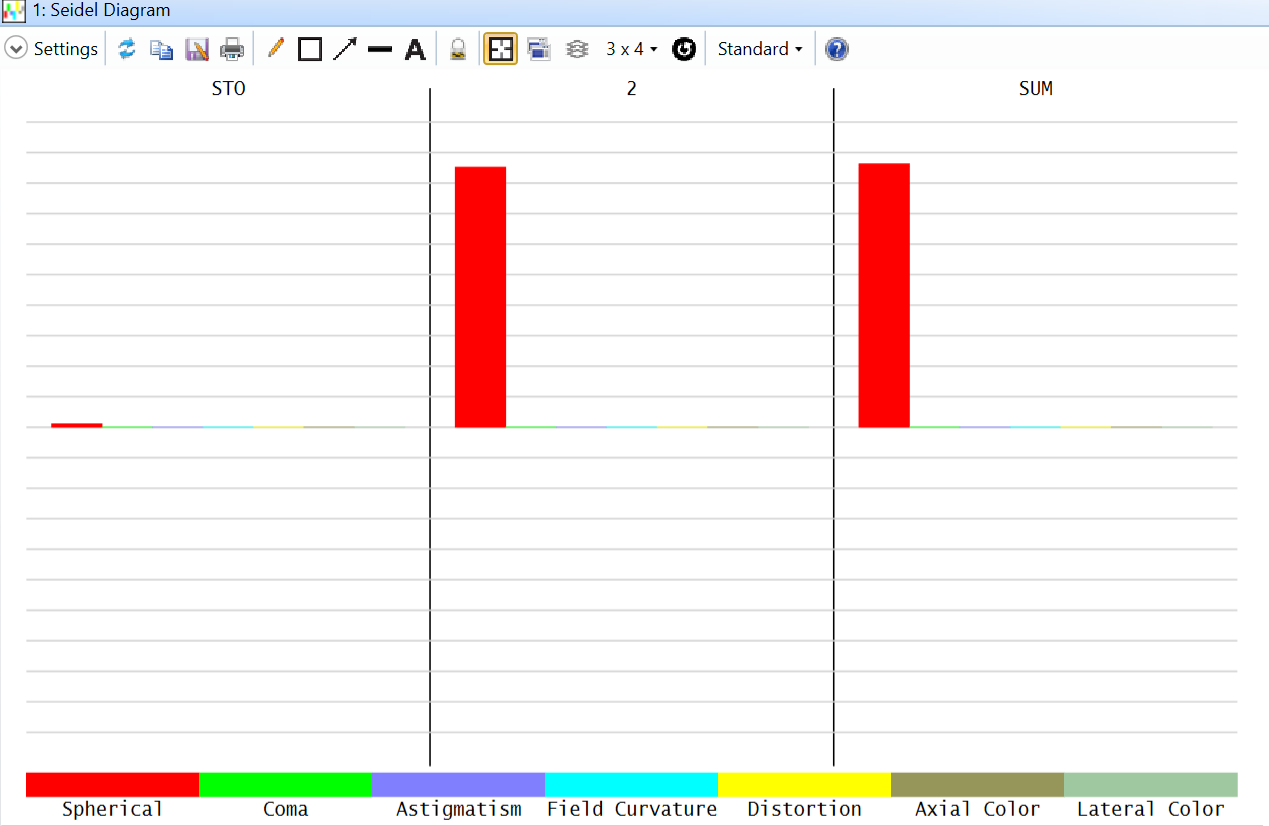
Thickness
Material
Coatin
Clear Semi-Di
Chip Zone
Mech Sem
Conic
TCE x 1E-6
UECT Standard Infinity 100.000 0.000 0.000 0.000 0.000
OP Standard Infinity V 3.000 N-BK7 10.000 0.000 10.058 0.000 -
Standard -25.000 V 100.000 10.058 0.000 10.058 0.000 0.000
AGE Standard Infinity - 3.404 0.000 3.404 0.000 0.000
Seidel Diagram
Display unconverted Seidel aberration coefficients as a bar chart
No shortcut key assigned
We can see an overview of all aberrations in this optical system, using Seidel Diagram in the tab "Analyze" → "Aberrations" → "Seidel Diagram"
EFFL: 48.2139
WFNO: 3.82537
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG



In this diagram you will see, that in this system the dominant is the **“Spherical aberration”**

Spherical aberration is caused by spherical profile of the surfaces of the lens

More about Spherical and other aberrations → Next seminars

But how can we optimize Spherical aberration?

→ Using Aspherical surfaces

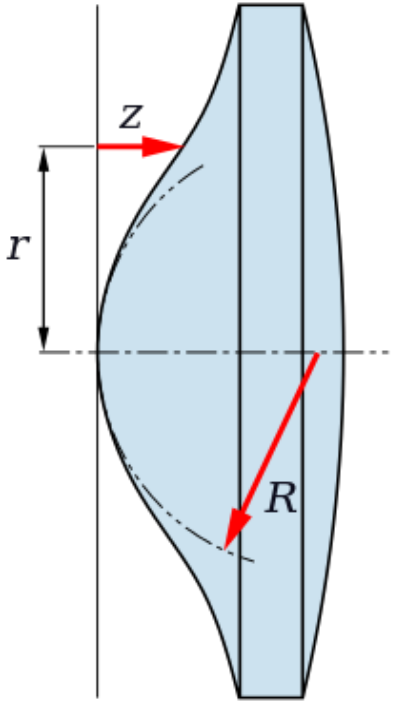
Conic → Aspheric surface

Aspheric surface → surface, which has not a form of a sphere, but of a **conic section.**

Conic formula:

$$z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2r^2}}$$

Conic constant "K"	Conic section
K < -1	Hyperbola
K = -1	Parabola
-1 < K < 0	Ellipse
K = 0	Sphere
K > 0	Ellipse



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File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

Quick Focus | Quick Adjust | Slider | Visual Optimizer — Manual Adjustment

Merit Function Editor | Optimization Wizard | Optimize! | Remove All Variables | Set All Radii Variable | Set All Thickness Variable — Automatic Optimization

Global Search | Hammer Current | Glass Substitution Template — Global Optimizers

Find Best Asphere | Convert Asphere Types | Stock Lens Matching | Test Plate Fitting | Test Plate Lists — Optimization Tools

System Explorer

Lens Data

Update: All Windows

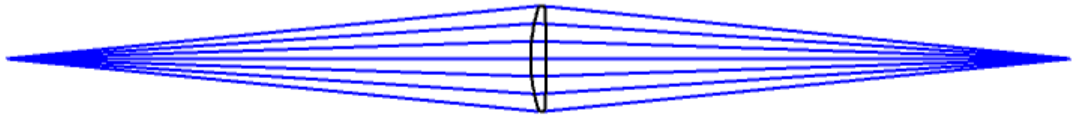
Surface 1 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Co	Clear Semi	Chi	Mech Sen	Conic	T
0	OBJECT Standard		Infinity	100.000			0.000	0.0..	0.000	0.000	
1	STOP Standard		31.133 V	3.000	N-BK7		10.000	0.0..	10.000	-1.434 V	
2	Standard		-159.234 V	100.000			9.952	0.0..	10.000	0.000	
3	IMAGE Standard		Infinity	-			1.270E-...	0.0..	1.270...	0.000	

1: Layout

Settings | Line Thickness

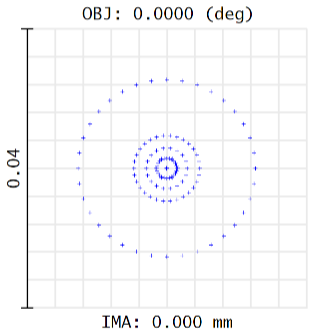
Use conic as variable for surface 1 and press Optimize!



Now the RMS spot radius is only 7 micron → No spherical aberration

2: Spot Diagram

Settings | Standard | Automatic | 3 x 4 | 0.55



Surface: IMA

Spot Diagram

11/4/2022
Units are μm. Legend items refer to Wavelengths
Field : 1
RMS radius : 0.007
GEO radius : 0.013
Scale bar : 0.04 Reference : Chief Ray

Zemax
Zemax OpticStudio 22.2

LENS.zos
Configuration 1 of 1

Graph | Text

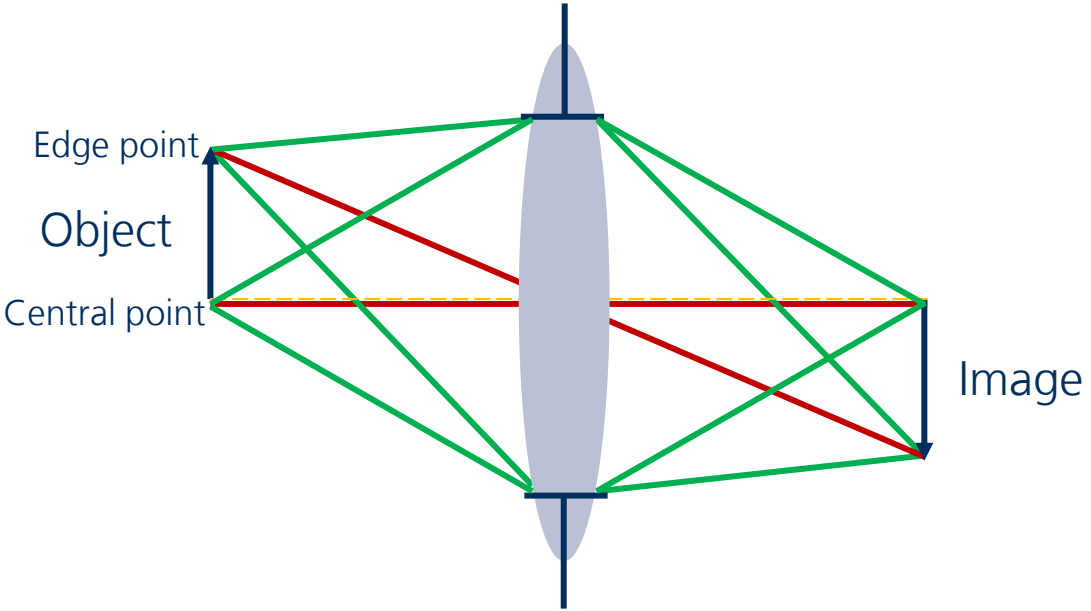
Variable | EFFL: 50.4944 | WFNO: 5.06444 | ENPD: 20 | TOTR: 103

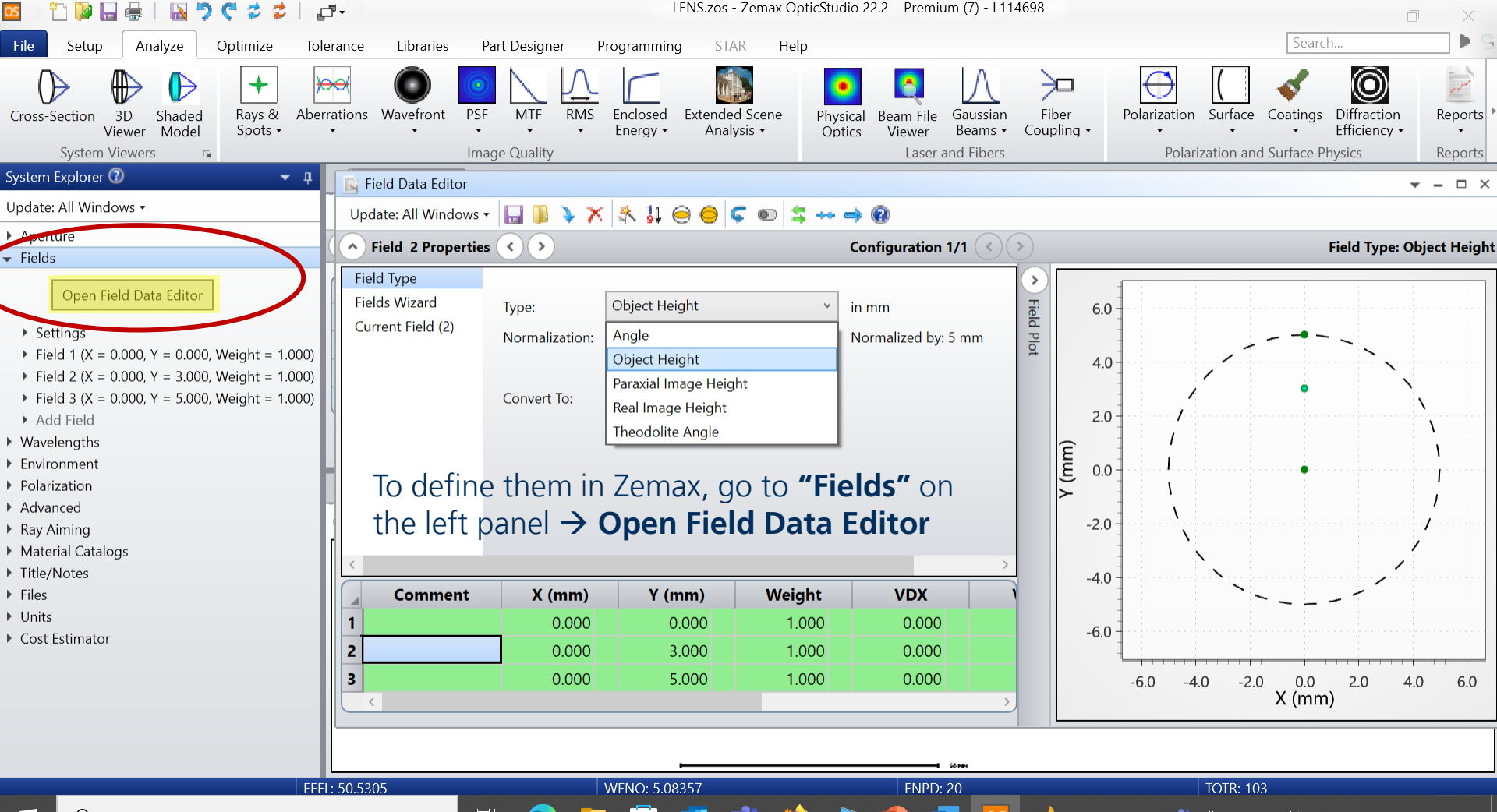
Type here to search 9°C ENG

Finite object → Field points

In all previous examples we have been using only **infinitesimally small point** as an object

Real objects (even laser) have **finite size** → Field points in Zemax

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Laser and Fibers
Polarization Surface Coatings Diffraction Efficiency
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Fields
Open Field Data Editor
Settings
Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)
Field 2 (X = 0.000, Y = 3.000, Weight = 1.000)
Field 3 (X = 0.000, Y = 5.000, Weight = 1.000)
Add Field
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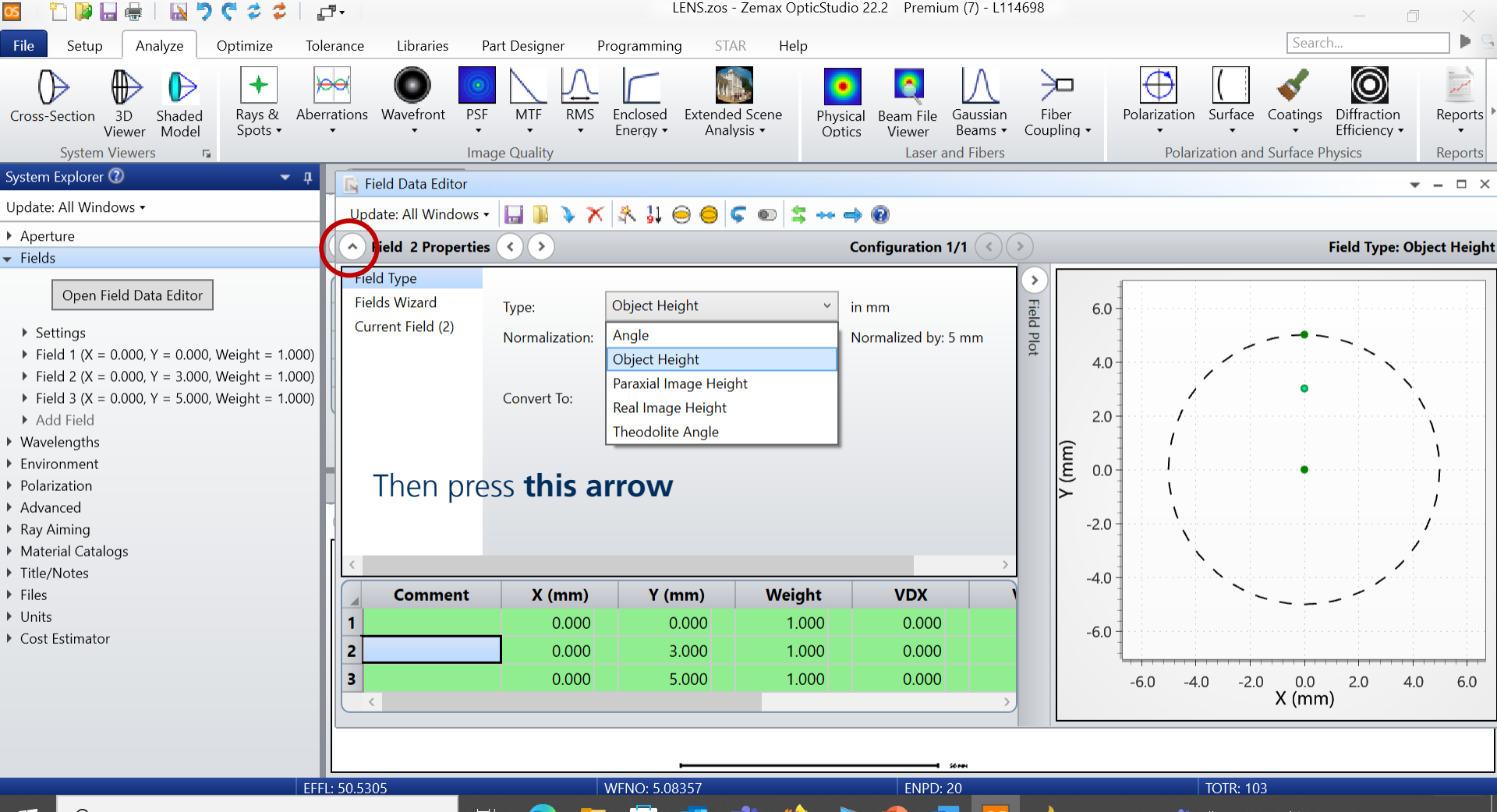
Field Type: Object Height
Field Type
Fields Wizard
Current Field (2)
Type: Object Height
in mm
Normalization:
Angle
Object Height
Paraxial Image Height
Real Image Height
Theodolite Angle
Normalized by: 5 mm
Convert To:
To define them in Zemax, go to "Fields" on the left panel → Open Field Data Editor
Field Plot
Comment X (mm) Y (mm) Weight VDX
1 0.000 0.000 1.000 0.000
2 0.000 3.000 1.000 0.000
3 0.000 5.000 1.000 0.000
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
Y (mm)
-6.0 -4.0 -2.0 0.0 2.0 4.0 6.0
X (mm)
EFFL: 50.5305
WFNO: 5.08357
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File
Setup
Analyze
Optimize
Tolerance
Libraries
Part Designer
Programming
STAR
Help
Search...
Cross-Section
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Aberrations
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RMS
Enclosed Energy
Extended Scene Analysis
Image Quality
Physical Optics
Beam File Viewer
Gaussian Beams
Fiber Coupling
Laser and Fibers
Polarization
Surface
Coatings
Diffraction Efficiency
Polarization and Surface Physics
Reports
System Explorer
Update: All Windows
Aperture
Fields
Open Field Data Editor
Settings
Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)
Field 2 (X = 0.000, Y = 3.000, Weight = 1.000)
Field 3 (X = 0.000, Y = 5.000, Weight = 1.000)
Add Field
Wavelengths
Environment
Polarization
Advanced
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Material Catalogs
Title/Notes
Files
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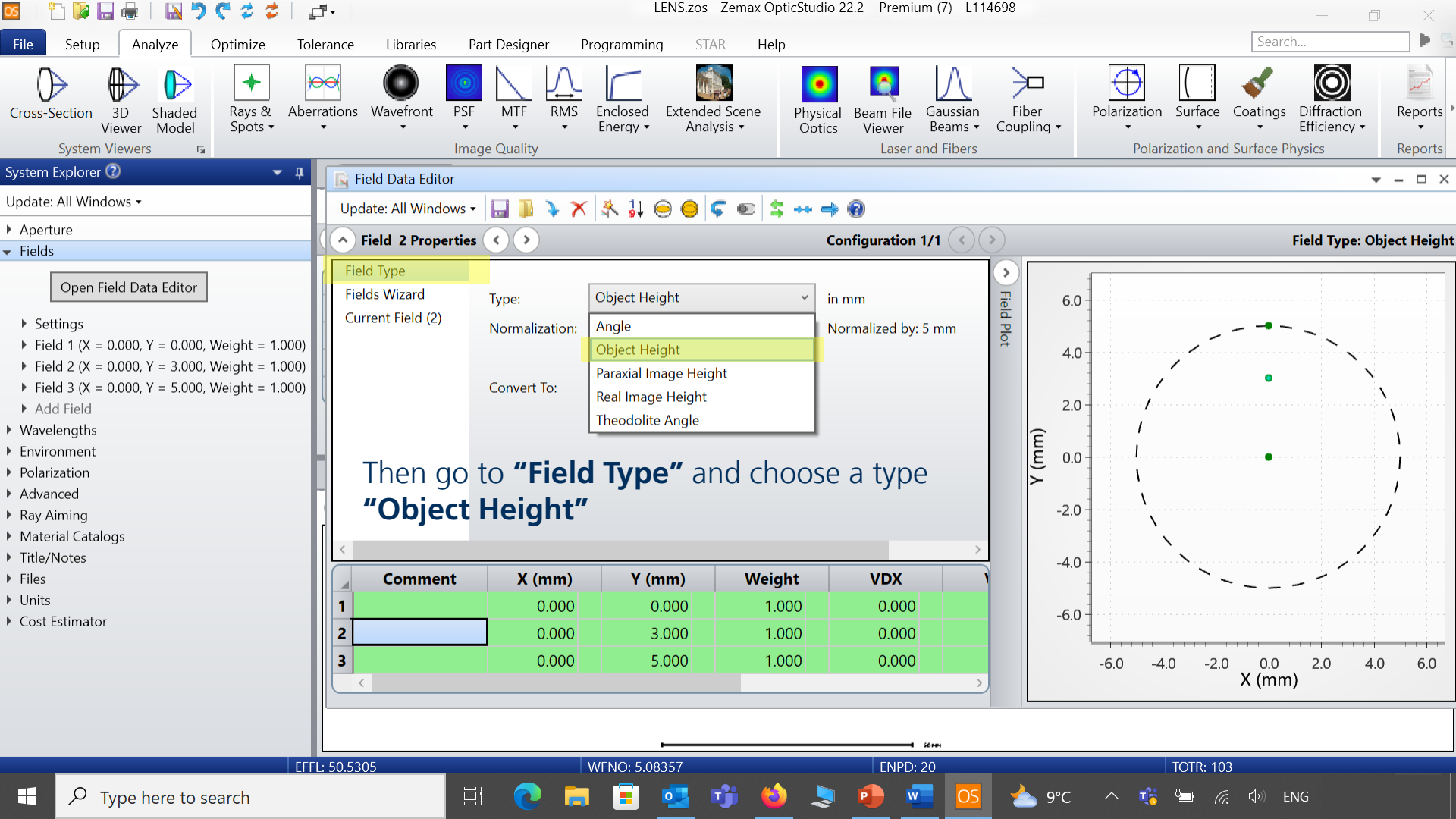
Cost Estimator
Field Data Editor
Update: All Windows
Field 2 Properties
Configuration 1/1
Field Type: Object Height
Field Type
Fields Wizard
Current Field (2)
Type:
Object Height
in mm
Normalization:
Angle
Object Height
Paraxial Image Height
Real Image Height
Theodolite Angle
Normalized by: 5 mm
Convert To:
Then press this arrow
Field Plot
Comment
X (mm)
Y (mm)
Weight
VDX
1 0.000 0.000 1.000 0.000
2 0.000 3.000 1.000 0.000
3 0.000 5.000 1.000 0.000
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
Y (mm)
X (mm)
EFFL: 50.5305
WFNO: 5.08357
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help
Search...
Cross-Section 3D Viewer Shaded Model
System Viewers
Rays & Spots Aberrations Wavefront PSF MTF RMS Enclosed Energy Extended Scene Analysis
Image Quality
Physical Optics Beam File Viewer Gaussian Beams Fiber Coupling
Laser and Fibers
Polarization Surface Coatings Diffraction Efficiency
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Reports
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Aperture
Fields
Open Field Data Editor
Settings
Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)
Field 2 (X = 0.000, Y = 3.000, Weight = 1.000)
Field 3 (X = 0.000, Y = 5.000, Weight = 1.000)
Add Field
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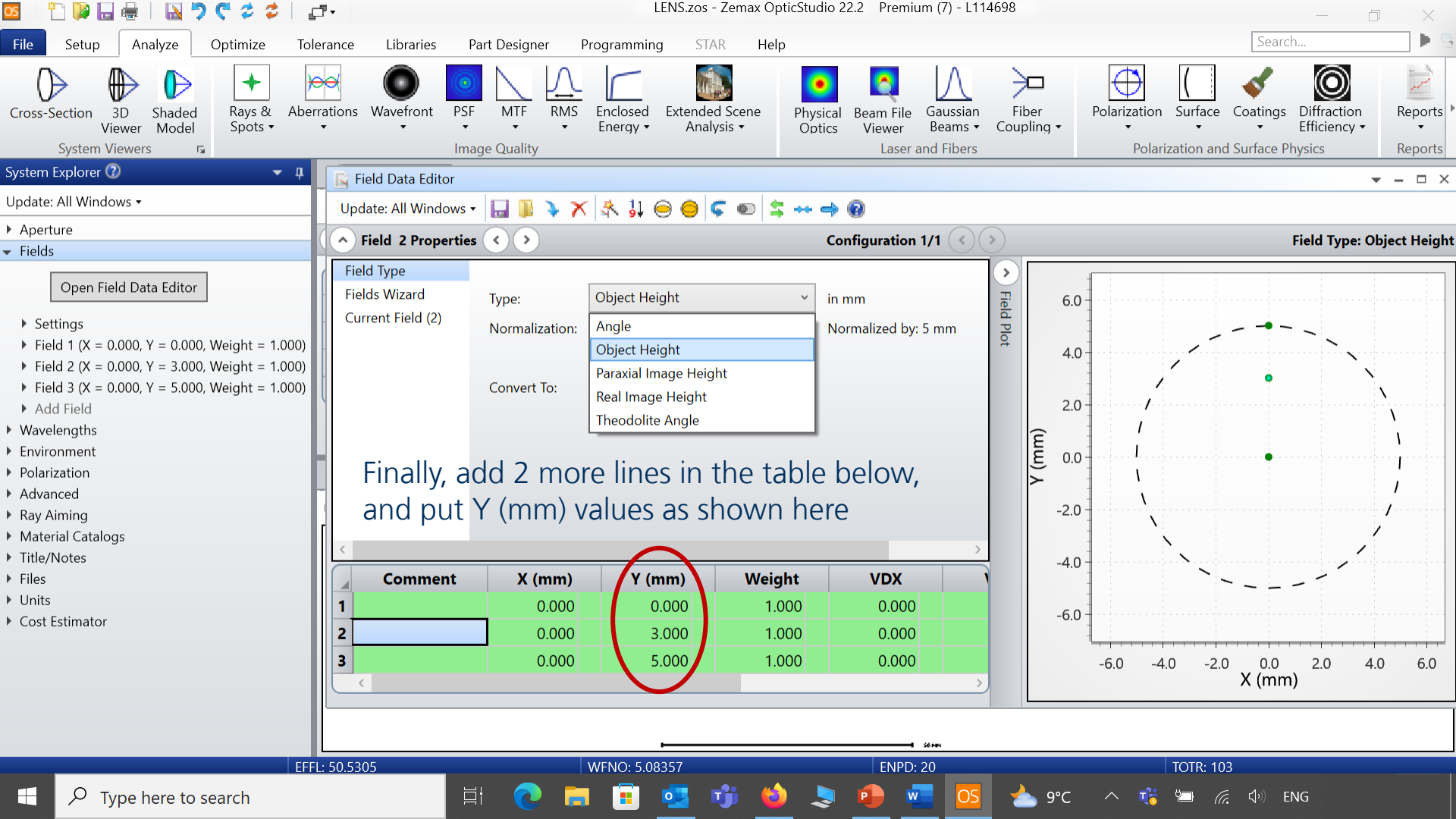
Cost Estimator
Field Data Editor
Update: All Windows
Field 2 Properties
Configuration 1/1
Field Type: Object Height
Field Type
Fields Wizard
Current Field (2)
Type: Object Height
in mm
Normalization: Angle
Object Height
Paraxial Image Height
Real Image Height
Theodolite Angle
Normalized by: 5 mm
Convert To:
Then go to "Field Type" and choose a type "Object Height"
Field Plot
Comment X (mm) Y (mm) Weight VDX
1 0.000 0.000 1.000 0.000
2 0.000 3.000 1.000 0.000
3 0.000 5.000 1.000 0.000
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
Y (mm)
-6.0 -4.0 -2.0 0.0 2.0 4.0 6.0
X (mm)
EFFL: 50.5305
WFNO: 5.08357
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help
Search...
Cross-Section 3D Viewer Shaded Model
System Viewers
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Physical Optics Beam File Viewer Gaussian Beams Fiber Coupling
Laser and Fibers
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Reports
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Open Field Data Editor
Settings
Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)
Field 2 (X = 0.000, Y = 3.000, Weight = 1.000)
Field 3 (X = 0.000, Y = 5.000, Weight = 1.000)
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Wavelengths
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Polarization
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Material Catalogs
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Field Data Editor
Update: All Windows
Field 2 Properties
Configuration 1/1
Field Type: Object Height
Field Type
Fields Wizard
Current Field (2)
Type: Object Height
in mm
Normalization:
Angle
Object Height
Paraxial Image Height
Real Image Height
Theodolite Angle
Normalized by: 5 mm
Convert To:
Finally, add 2 more lines in the table below, and put Y (mm) values as shown here
Field Plot
Comment X (mm) Y (mm) Weight VDX
1 0.000 0.000 1.000 0.000
2 0.000 3.000 1.000 0.000
3 0.000 5.000 1.000 0.000
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
Y (mm)
-6.0 -4.0 -2.0 0.0 2.0 4.0 6.0
X (mm)
EFFL: 50.5305
WFNO: 5.08357
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG

LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698

File | Setup | Analyze | Optimize | Tolerance | Libraries | Part Designer | Programming | STAR | Help

Search...

Quick Focus | Quick Adjust | Slider | Visual Optimizer — Manual Adjustment

Merit Function Editor | Optimization Wizard | Optimize! | Remove All Variables | Set All Radii Variable | Set All Thickness Variable — Automatic Optimization

Global Search | Hammer Current | Glass Substitution Template — Global Optimizers

Find Best Asphere | Convert Asphere Types | Stock Lens Matching | Test Plate Fitting | Test Plate Lists — Optimization Tools

System Explorer

Update: All Windows

- Aperture
- Fields

Open Field Data Editor

- Settings
- Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)
- Field 2 (X = 0.000, Y = 3.000, Weight = 1.000)
- Field 3 (X = 0.000, Y = 5.000, Weight = 1.000)
- Add Field
- Wavelengths
- Environment
- Polarization
- Advanced
- Ray Aiming
- Material Catalogs
- Title/Notes
- Files
- Units
- Cost Estimator

Lens Data

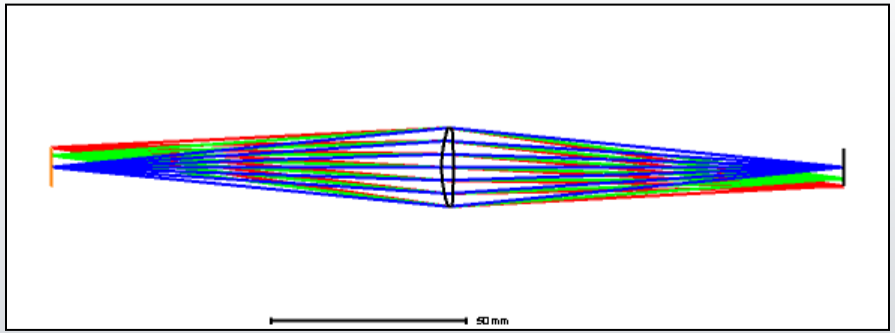
Update: All Windows

Surface 0 Properties Configuration 1/1

	Surface Type		Comment	Radius		Thickness	Material	Co	Clear Semi-Dia	Chi	Mech Sen	Conic		TCE x 1E-6
0	OBJECT	Standard		Infinity		100.000			5.000	0.0..	5.000	0.000		0.000
1	STOP	Standard		31.133	V	3.000	N-BK7		10.000	0.0..	10.000	-1.434	V	-
2		Standard		-159.234	V	100.000			9.985	0.0..	10.000	0.000		0.000
3	IMAGE	Standard		Infinity		-			4.845	0.0..	4.845	0.000		0.000

1: Layout

Settings | Line Thickness

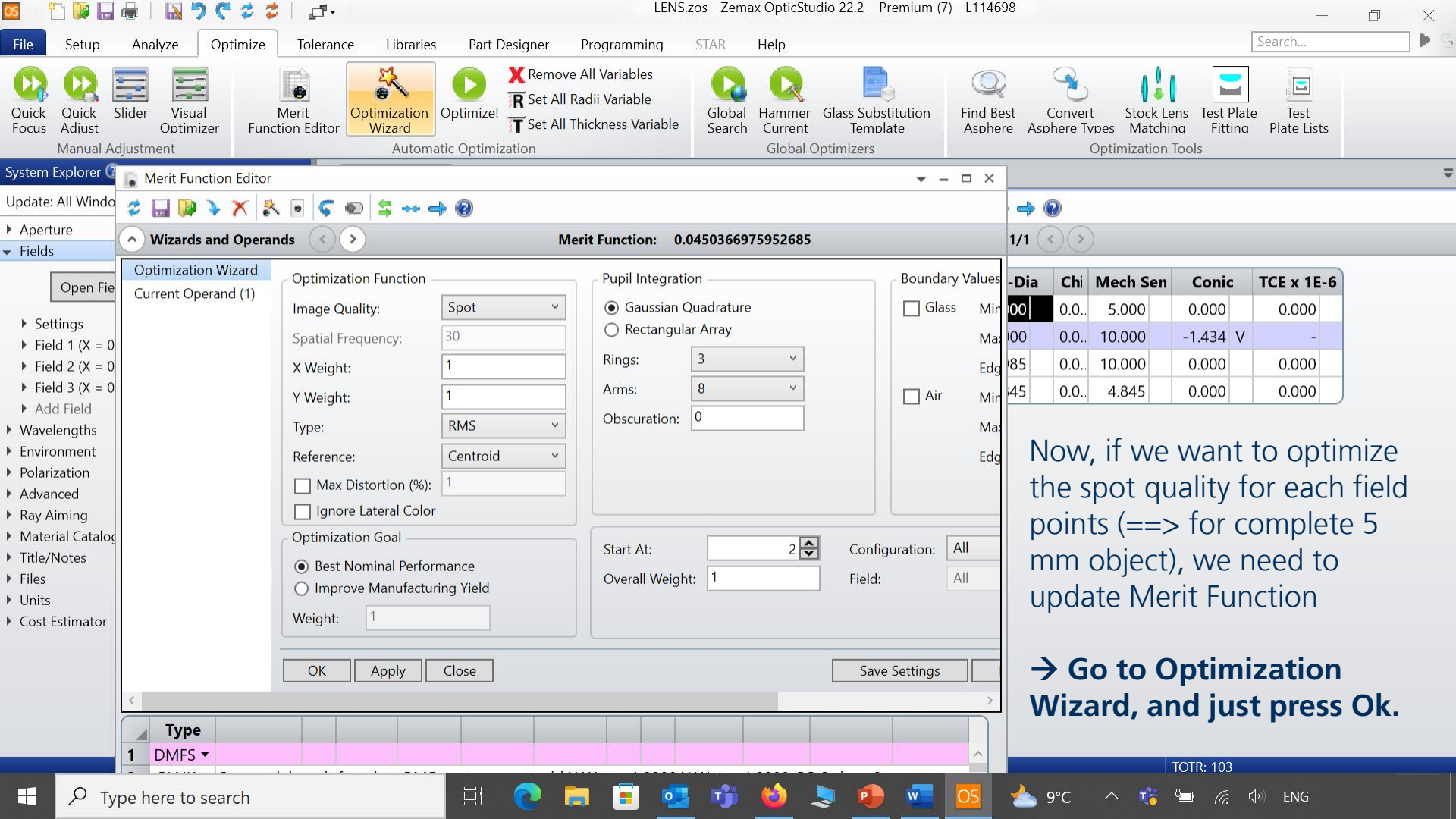


Then close Field Data Editor, and you'll see, that now you have an object, which has half-height of 5 mm

(Clear Semi-Dia value of surface 0)

EFFL: 50.4944 WFNO: 5.06444 ENPD: 20 TOTR: 103

Type here to search 9°C ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help
Quick Focus
Quick Adjust
Slider
Visual Optimizer
Manual Adjustment
Merit Function Editor
Optimization Wizard
Optimize!
Remove All Variables
Set All Radii Variable
Set All Thickness Variable
Automatic Optimization
Global Search
Hammer Current
Glass Substitution Template
Global Optimizers
Find Best Asphere
Convert Asphere Types
Stock Lens Matching
Test Plate Fitting
Test Plate Lists
Optimization Tools
System Explorer
Update: All Windo
Aperture
Fields
Open Fie
Settings
Field 1 (X = 0
Field 2 (X = 0
Field 3 (X = 0
Add Field
Wavelengths
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Material Catalog
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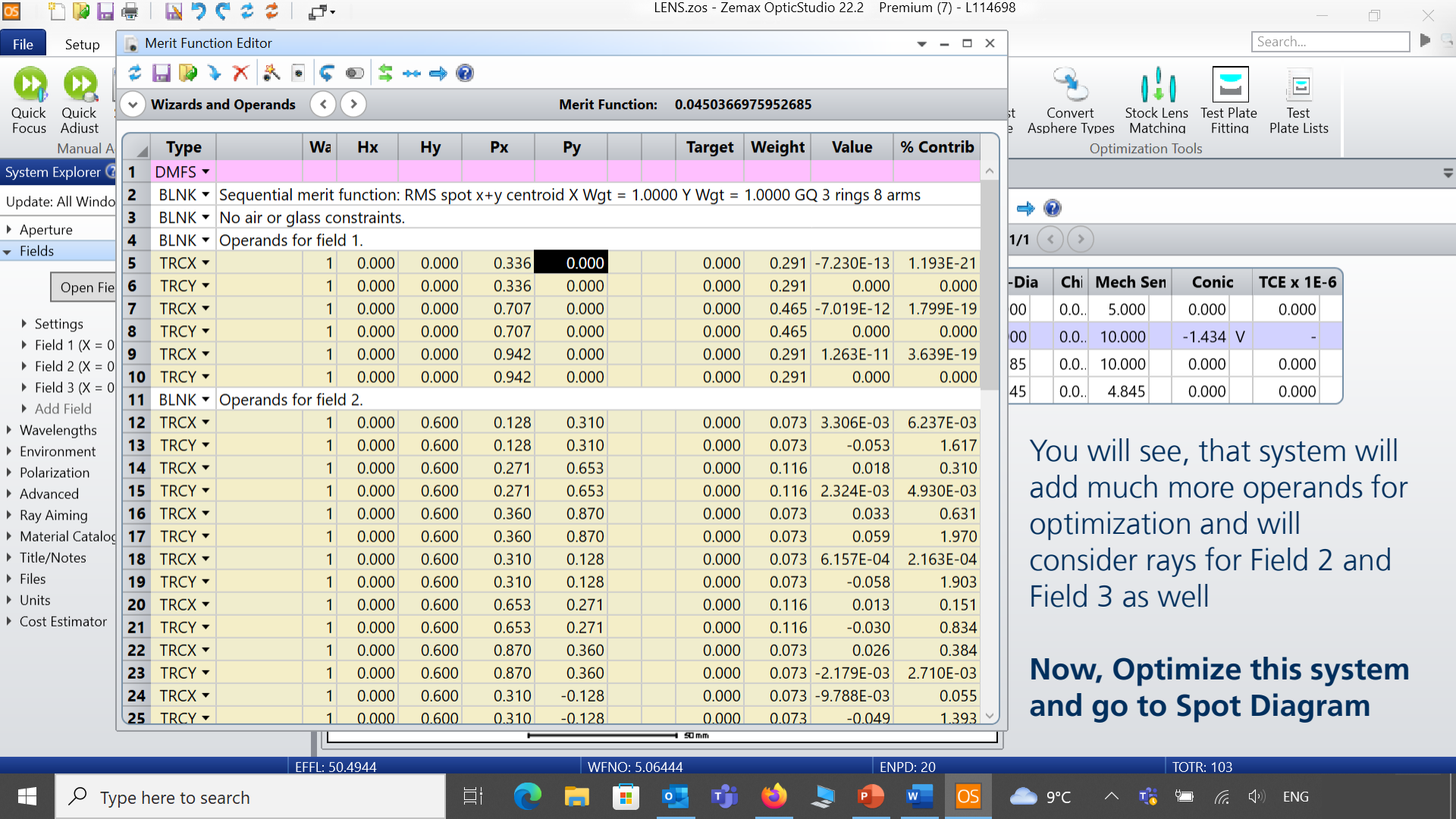
Units
Cost Estimator
Merit Function Editor
Wizards and Operands
Merit Function: 0.0450366975952685
1/1
Optimization Wizard
Current Operand (1)
Optimization Function
Image Quality: Spot
Spatial Frequency: 30
X Weight: 1
Y Weight: 1
Type: RMS
Reference: Centroid
Max Distortion (%): 1
Ignore Lateral Color
Pupil Integration
Gaussian Quadrature
Rectangular Array
Rings: 3
Arms: 8
Obscuration: 0
Boundary Values
Glass
Air
Optimization Goal
Best Nominal Performance
Improve Manufacturing Yield
Weight: 1
Start At: 2
Overall Weight: 1
Configuration: All
Field: All
OK
Apply
Close
Save Settings
Type
1 DMFS
-Dia Chi Mech Sen Conic TCE x 1E-6
00 0.0.. 5.000 0.000 0.000
00 0.0.. 10.000 -1.434 V -
85 0.0.. 10.000 0.000 0.000
45 0.0.. 4.845 0.000 0.000
Now, if we want to optimize the spot quality for each field points (==> for complete 5 mm object), we need to update Merit Function
→ Go to Optimization Wizard, and just press Ok.
TOTR: 103
Type here to search
9°C
ENG


LENS.zos - Zemax OpticStudio 22.2 Premium (7) - L114698
File
Setup
Merit Function Editor
Wizards and Operands
Merit Function: 0.0450366975952685
Quick Focus
Quick Adjust
Convert Asphere Types
Stock Lens Matching
Test Plate Fitting
Test Plate Lists
Optimization Tools
System Explorer
Aperture
Fields
Wavelengths
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Material Catalog
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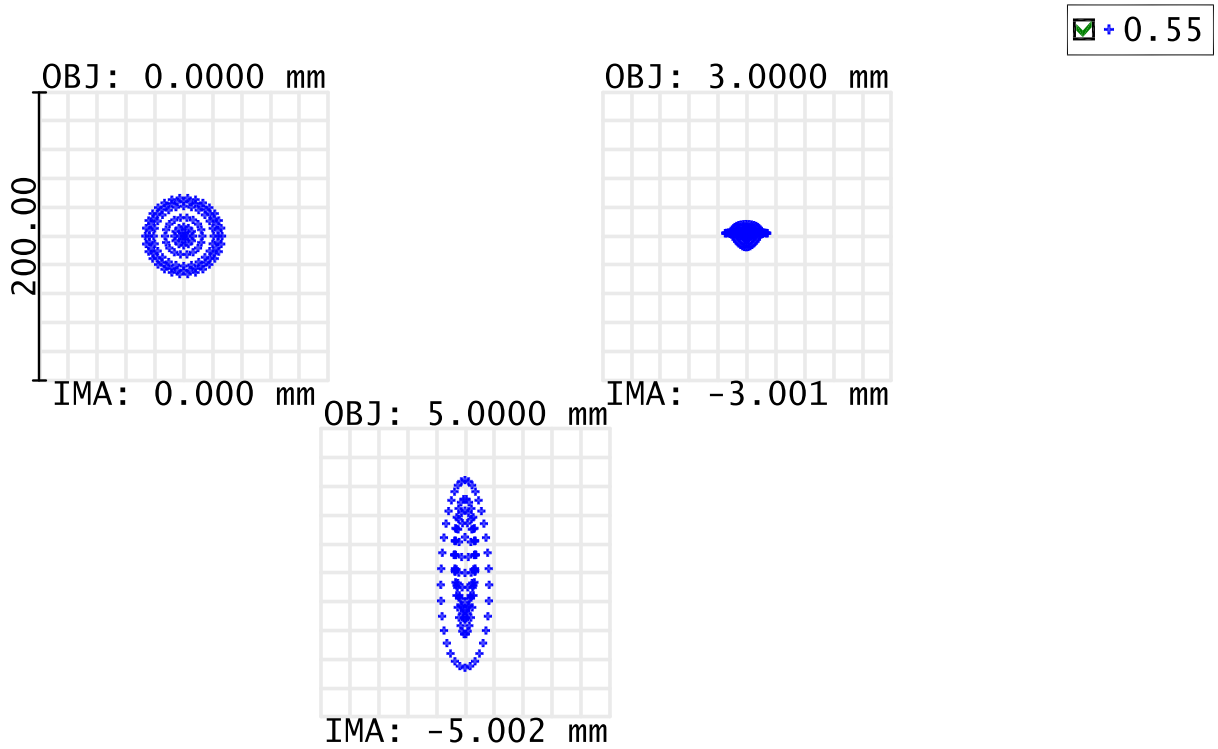
Units
Cost Estimator
Type | Wa | Hx | Hy | Px | Py | Target | Weight | Value | % Contrib
1 DMFS
2 BLNK Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 8 arms
3 BLNK No air or glass constraints.
4 BLNK Operands for field 1.
5 TRCX 1 0.000 0.000 0.336 0.000 0.000 0.291 -7.230E-13 1.193E-21
6 TRCY 1 0.000 0.000 0.336 0.000 0.000 0.291 0.000 0.000
7 TRCX 1 0.000 0.000 0.707 0.000 0.000 0.465 -7.019E-12 1.799E-19
8 TRCY 1 0.000 0.000 0.707 0.000 0.000 0.465 0.000 0.000
9 TRCX 1 0.000 0.000 0.942 0.000 0.000 0.291 1.263E-11 3.639E-19
10 TRCY 1 0.000 0.000 0.942 0.000 0.000 0.291 0.000 0.000
11 BLNK Operands for field 2.
12 TRCX 1 0.000 0.600 0.128 0.310 0.000 0.073 3.306E-03 6.237E-03
13 TRCY 1 0.000 0.600 0.128 0.310 0.000 0.073 -0.053 1.617
14 TRCX 1 0.000 0.600 0.271 0.653 0.000 0.116 0.018 0.310
15 TRCY 1 0.000 0.600 0.271 0.653 0.000 0.116 2.324E-03 4.930E-03
16 TRCX 1 0.000 0.600 0.360 0.870 0.000 0.073 0.033 0.631
17 TRCY 1 0.000 0.600 0.360 0.870 0.000 0.073 0.059 1.970
18 TRCX 1 0.000 0.600 0.310 0.128 0.000 0.073 6.157E-04 2.163E-04
19 TRCY 1 0.000 0.600 0.310 0.128 0.000 0.073 -0.058 1.903
20 TRCX 1 0.000 0.600 0.653 0.271 0.000 0.116 0.013 0.151
21 TRCY 1 0.000 0.600 0.653 0.271 0.000 0.116 -0.030 0.834
22 TRCX 1 0.000 0.600 0.870 0.360 0.000 0.073 0.026 0.384
23 TRCY 1 0.000 0.600 0.870 0.360 0.000 0.073 -2.179E-03 2.710E-03
24 TRCX 1 0.000 0.600 0.310 -0.128 0.000 0.073 -9.788E-03 0.055
25 TRCY 1 0.000 0.600 0.310 -0.128 0.000 0.073 -0.049 1.393
-Dia | Chi | Mech Sen | Conic | TCE x 1E-6
00 | 0.0.. | 5.000 | 0.000 | 0.000
00 | 0.0.. | 10.000 | -1.434 V | -
85 | 0.0.. | 10.000 | 0.000 | 0.000
45 | 0.0.. | 4.845 | 0.000 | 0.000
1/1
You will see, that system will add much more operands for optimization and will consider rays for Field 2 and Field 3 as well
Now, Optimize this system and go to Spot Diagram
EFFL: 50.4944
WFNO: 5.06444
ENPD: 20
TOTR: 103
Type here to search
9°C
ENG



Surface: IMA

Spot Diagram	
11/4/2022 Units are µm. Legend items refer to Wavelengths Field : 1 2 3 RMS radius : 20.991 8.124 33.964 GEO radius : 26.601 14.637 65.876 Scale bar : 200 Reference : Chief Ray	Zemax Zemax OpticStudio 22.2 LENS.zos Configuration 1 of 1

Here you will see 3 diagrams instead of only one → each for the given field point.

You'll notice, that the quality (RMS radius) now is not that small, as before, and it's also not same for different field points.

Reason → it's impossible to optimize everything just by one lens

→ **More components required**

You may also notice, that blur looks differently for different fields → **Different types of aberrations → Next seminars**

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Thank you for attention!

End of Seminar 1