Institute of
Applied Physics
Friedrich-Schiller-Universität Jena

Optical Design with Zemax

Lecture 1: Introduction

2012-10-16

Herbert Gross

1 Introduction
Overview

- Time: Tuesday, 8.00 – 9.30
- Location: Computerpool, Helmholtzweg 4
- Web page on IAP homepage under ‚learning/materials‘ provides slides and exercises Zemax files
- Contents (type of the lecture):

  Not: pure Zemax handling

  But: - optical design with Zemax as tool
  - understanding of simulation opportunities and limits
  - learning by doing
  - mix of theory/principles, presented examples and own exercises
  - questions and dialog welcome
- The content is adapted and is changed depending on progress
- Seminar: Exercises and solution of given problems

  time: Tuesday, 12.00 -13.30

  Computerpool, Helmholtzweg 4

  starting date: 2012-10-23
- Shift of some dates could be possible

1 Introduction
Preliminary time schedule

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1	16.10.	Introduction	Introduction, Zemax interface, menues, file handling, preferences, Editors, updates, windows, Coordinate systems and notations, System description, Component reversal, system insertion, scaling, 3D geometry, aperture, field, wavelength
2	23.10.	Properties of optical systems I	Diameters, stop and pupil, vignetting, Layouts, Materials, Glass catalogs, Raytrace, Ray fans and sampling, Footprints
3	30.10.	Properties of optical systems II	Types of surfaces, Aspheres, Gratings and diffractive surfaces, Gradient media, Cardinal elements, Lens properties, Imaging, magnification, paraxial approximation and modelling
4	06.11.	Aberrations I	Representation of geometrical aberrations, Spot diagram, Transverse aberration diagrams, Aberration expansions, Primary aberrations,
5	13.11.	Aberrations II	Wave aberrations, Zernike polynomials, Point spread function, Optical transfer function
6	20.11.	Optimization I	Principles of nonlinear optimization, Optimization in optical design, Global optimization methods, Solves and pickups, variables, Sensitivity of variables in optical systems
7	27.11.	Optimization II	Systematic methods and optimization process, Starting points, Optimization in Zemax
8	04.12	Imaging	Fundamentals of Fourier optics, Physical optical image formation, Imaging in Zemax
9	11.12.	Illumination	Introduction in illumination, Simple photometry of optical systems, Non-sequential raytrace, Illumination in Zemax
10	18.12.	Advanced handling I	Telecentricity, infinity object distance and afocal image, Local/global coordinates, Add fold mirror, Scale system, Make double pass, Vignetting, Diameter types, Ray aiming, Material index fit
11	08.01.	Advanced handling II	Report graphics, Universal plot, Slider, Visual optimization, IO of data, Multiconfiguration, Fiber coupling, Macro language, Lens catalogs
12	15.01.	Correction I	Symmetry principle, Lens bending, Correcting spherical aberration, Coma, stop position, Astigmatism, Field flattening, Chromatical correction, Retrofocus and telephoto setup, Design method
13	22.01.	Correction II	Field lenses, Stop position influence, Aspheres and higher orders, Principles of glass selection, Sensitivity of a system correction, Microscopic objective lens, Zoom system
14	29.01.	Physical optical modelling I	Gaussian beams, POP propagation, polarization raytrace, polarization transmission, polarization aberrations
15	05.02.	Physical optical modelling II	coatings, representations, transmission and phase effects, ghost imaging, general straylight with BRDF

Literature on optical design

1. Kingslake — Lens design fundamentals, SPIE Press, 2010
2. Mouroulis / McDonald — Geometrical Optics and Optical Design, Oxford, 1997
3. Fischer / Tadic-Galeb — Optical System Design, McGraw Hill, 2000
4. Malacara / Malacara — Handbook of Lens Design, Dekker, 1994
5. Laikin — Lens Design, Dekker, 2007
6. W. Smith — Modern Optical Engineering, Graw Hill, 2000
7. W. Smith — Modern lens design, McGraw Hill, 2005
8. Geary — Lens Design with practical Examples, Willmann-Bell, 2002
9. Gross (Ed.) — Handbook of optical systems, Vol 1-5, Wiley, 2005
10. Shannon — The art and science of optical design, Cambridge Univ. Press, 1997
11. G. Smith — Practical computer-aided lens design, Willman Bell, 1998

1. Introduction
2. Zemax interface, menues, file handling, preferences
3. Editors, updates, windows
4. Coordinate systems and notations
5. System description
6. Component reversal, system insertion, scaling
7. Solves and pickups, variables
8. 3D geometry
9. Aperture, field, wavelength

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- There are 4 types of windows in Zemax:

1. Editors for data input:
   lens data, extra data, multiconfiguration, tolerances
2. Output windows for graphical representation of results
   Here mostly setting-windowss are supported to optimize the layout
3. Text windows for output in ASCII numerical numbers (can be exported)
4. Dialog boxes for data input, error reports and more

- There are several files associates with Zemax

1. Data files (.ZMX)
2. Session files (.SES) for system settings (can be de-activated)
3. Glass catalogs, lens catalogs, coating catalogs, BRDF catalogs, macros, images, POP data, refractive index files,...

- There are in general two working modes of Zemax

1. Sequential raytrace (or partial non-sequencial)
2. Non-sequential

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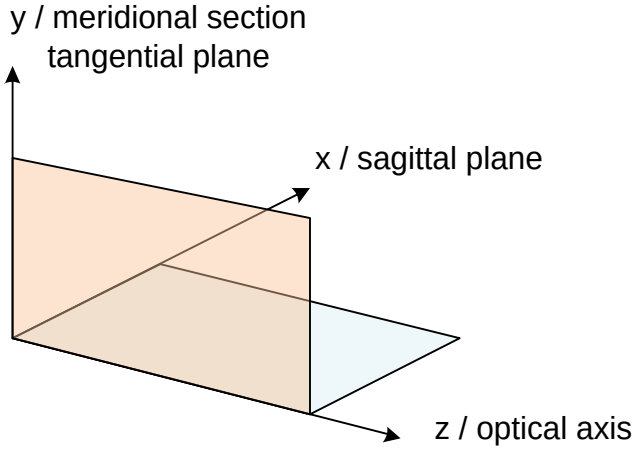
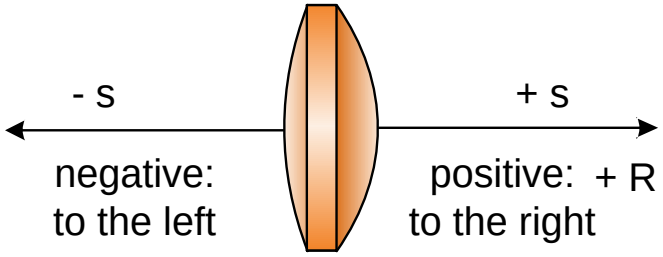
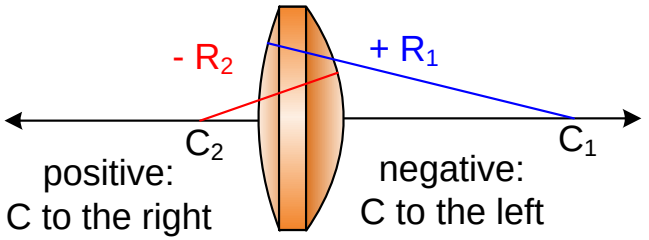
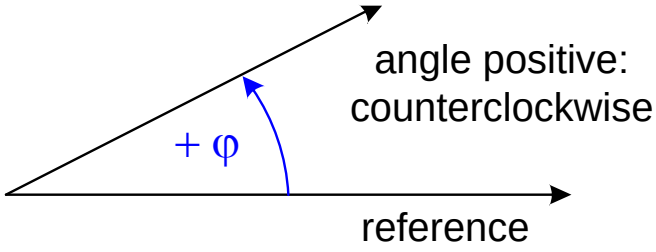
- Coordinate systems
  2D sections: y-z shown



- Sign of lengths, radii, angles:







- Interface surfaces
  - mathematical modelled surfaces
  - planes, spheres, aspheres, conics, free shaped surfaces,…
- Size of components
  - thickness and distances along the axis
  - transversal size,circular diameter, complicated contours
- Geometry of the setup
  - special case: rotational symmetry
  - general case: 3D, tilt angles, offsets and decentrations, needs vectorial approach
- Materials
  - refractive indices for all used wavelengths
  - other properties: absorption, birefringence, nonlinear coefficients, index gradients,…
- Special surfaces
  - gratings, diffractive elements
  - arrays, scattering surfaces

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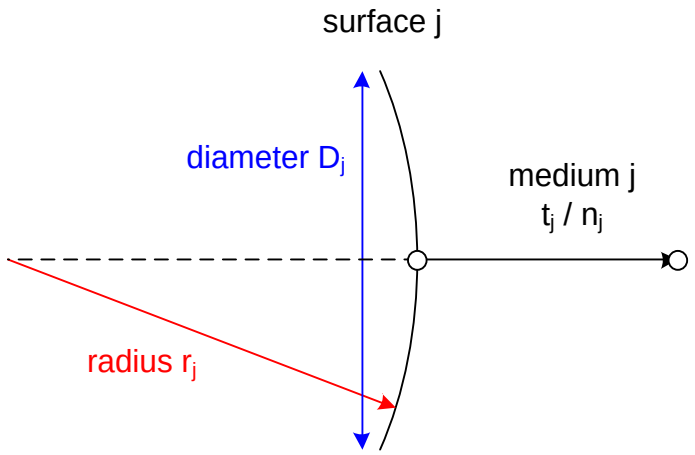
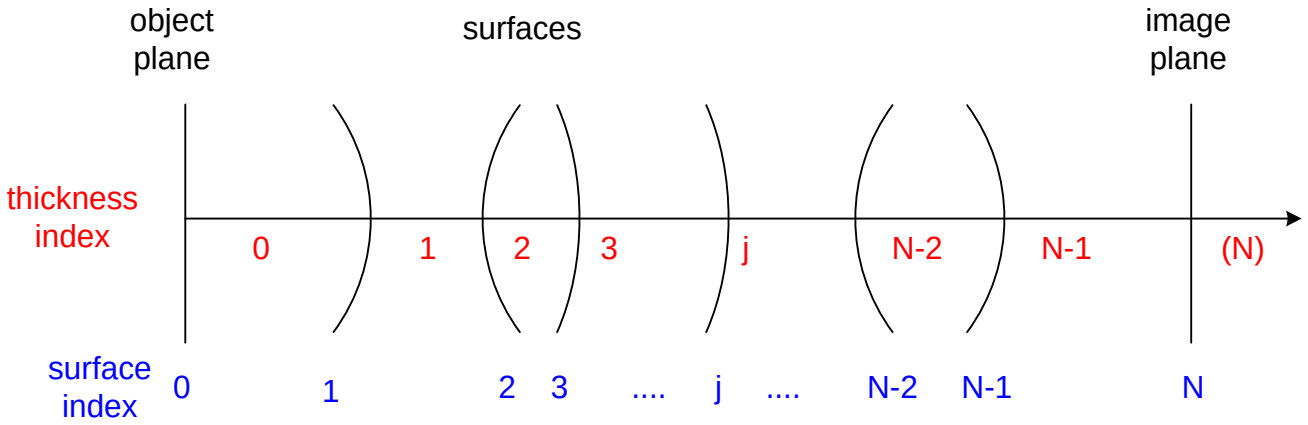
- Single step:
  - surface and transition
  - parameters: radius, diameter, thickness, refractive index, aspherical constants, conic parameter, decenter, tilt,...



- Complete system:
  - sequence of surfaces
  - object has index 0
  - image has index N
  - tN does not exist

- Ray path has fixed sequence
  0-1-2-...-(N-1)-N



1 Introduction
System data tables

1: Prescription Data

Update Settings Print Window

```
System/Prescription Data

File : C:\Users\gross\Documents\ZEMAX\UNDO\UND00001.ZMX
Title: F-Achromat 40x0.65
Date : 12.07.2012


GENERAL LENS DATA:

Surfaces               :              18
Stop                   :              13
System Aperture        : Object Space NA = 0.75
Glass Catalogs         : SCHOTT
Ray Aiming             : Off
Apodization            : Uniform, factor =   0.00000E+000
Temperature (C)        :    2.00000E+001
Pressure (ATM)         :    1.00000E+000
Adjust Index Data To Environment  : Off
Effective Focal Length :          19.837 (in air at system temperature and pressure)
Effective Focal Length :          19.837 (in image space)
Back Focal Length      :       -780.1608
Total Track            :        367.6294
Image Space F/#        :        17.61264
Paraxial Working F/#   :        17.80135
Working F/#            :        26.98113
Image Space NA         :      0.02807668
Object Space NA        :            0.75
Stop Radius            :       -4.618535
Paraxial Image Height  :        12.29257
Paraxial Magnification :       -40.36967
Entrance Pupil Diameter :       1.126294
Entrance Pupil Position :      -0.4966489
Exit Pupil Diameter    :        22.61643
Exit Pupil Position    :       -402.8808
Field Type             : Object height in Millimeters
Maximum Radial Field   :          0.3045
Primary Wavelength     :        0.546074 µm
Lens Units             :   Millimeters
Angular Magnification  :     -0.04980756

Fields          : 3
Field Type             : Object height in Millimeters
 #        X-Value        Y-Value        Weight
 1       0.000000       0.000000       1.000000
 2       0.000000       0.220000       1.000000
 3       0.000000       0.304500       1.000000
```

Prescription Data Settings

☑ General Data	☑ Global Vertex
☑ Surface Data	☑ COC Point
☑ Surface Detail	☑ Element Volume
☑ Edge Thickness	☑ F/ Numbers
☑ Multi-Config Data	☑ Cardinal Points
☑ Solves/Variables	☑ POP Settings
☑ Index/TCE Data	☑ Files Used

OK Cancel Save Load Reset Help

Menu:

reports / prescription data

1 Introduction
System data tables

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SURFACE DATA SUMMARY:

surface data

Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment
OBJ	STANDARD	Infinity	0		0.609	0	
1	STANDARD	Infinity	0.17	K5	4	0	
2	STANDARD	Infinity	0.4493669		4	0	
3	STANDARD	-1.7783	2.58	LASFN31	2	0	
4	STANDARD	-2.6993	0.15		4	0	
5	STANDARD	-31.851	1.93	PSK53A	6	0	
6	STANDARD	-4.5316	0.07		6	0	
7	STANDARD	-170.31	1	SF1	8	0	
8	STANDARD	5.7049	3.94	FK51	8	0	
9	STANDARD	-6.6834	14.27		8	0	
10	STANDARD	51.955	1.19	LAK31	8	0	
11	STANDARD	7.1821	2.98	FK51	8	0	
12	STANDARD	-30.287	19.77		8	0	
STO	STANDARD	Infinity	96		6.2	0	
14	STANDARD	147.49	6	BAF3	40	0	
15	STANDARD	-273.84	35		40	0	
16	STANDARD	Infinity	161.2	BK7	40	0	
17	STANDARD	Infinity	20.93		40	0	
IMA	STANDARD	Infinity			27.97122	0	

index data

Surf	Glass	Temp	Pres	0.479991	0.546074	0.643847
0		20.00	1.00	1.00000000	1.00000000	1.00000000
1	K5	20.00	1.00	1.52909921	1.52458303	1.52024098
2		20.00	1.00	1.00000000	1.00000000	1.00000000
3	LASFN31	20.00	1.00	1.89702493	1.88577397	1.87529361
4		20.00	1.00	1.00000000	1.00000000	1.00000000
5	PSK53A	20.00	1.00	1.62749149	1.62247133	1.61764048
6		20.00	1.00	1.00000000	1.00000000	1.00000000
7	SF1	20.00	1.00	1.73609961	1.72310488	1.71141216
8	FK51	20.00	1.00	1.49088232	1.48793656	1.48507869
9		20.00	1.00	1.00000000	1.00000000	1.00000000
10	LAK31	20.00	1.00	1.70601121	1.69967699	1.69356322
11	FK51	20.00	1.00	1.49088232	1.48793656	1.48507869
12		20.00	1.00	1.00000000	1.00000000	1.00000000
13		20.00	1.00	1.00000000	1.00000000	1.00000000
14	BAF3	20.00	1.00	1.59220573	1.58564993	1.57952233
15		20.00	1.00	1.00000000	1.00000000	1.00000000
16	BK7	20.00	1.00	1.52282924	1.51872197	1.51471931
17		20.00	1.00	1.00000000	1.00000000	1.00000000
18		20.00	1.00	1.00000000	1.00000000	1.00000000

GLOBAL VERTEX COORDINATES, ORI 3D geometry data !/OFFSET MATRICES:

Reference Surface: 1

Surf	R11	R12	R13	X
	R21	R22	R23	Y
	R31	R32	R33	Z
1	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	1.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.0000000000	1.0000000000	0.000000000E+000
2	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9961946981	-0.0871557427	0.000000000E+000
	0.0000000000	0.0871557427	0.9961946981	2.200000000E+002
3	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9961946981	-0.0871557427	0.000000000E+000
	0.0000000000	0.0871557427	0.9961946981	2.200000000E+002
4	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9848077530	-0.1736481777	0.000000000E+000
	0.0000000000	0.1736481777	0.9848077530	2.200000000E+002
5	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9848077530	-0.1736481777	1.736481777E+001
	0.0000000000	0.1736481777	0.9848077530	1.215192247E+002
6	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9961946981	-0.0871557427	3.472963553E+001
	0.0000000000	0.0871557427	0.9961946981	2.303844940E+001
7	1.0000000000	0.0000000000	0.0000000000	0.000000000E+000
	0.0000000000	0.9961946981	-0.0871557427	3.472963553E+001
	0.0000000000	0.0871557427	0.9961946981	2.303844940E+001

- Necessary data for system calculation:

1. system surfaces with parameters (radius)
2. distances with parameters (length, material)
3. stop surface
4. wavelength(s)
5. aperture
6. field point(s)

- Optional inputs:

1. finite diameters
2. vignetting factors
3. decenter and tilt
4. coordinate reference
5. weighting factors
6. multi configurations
7. ...

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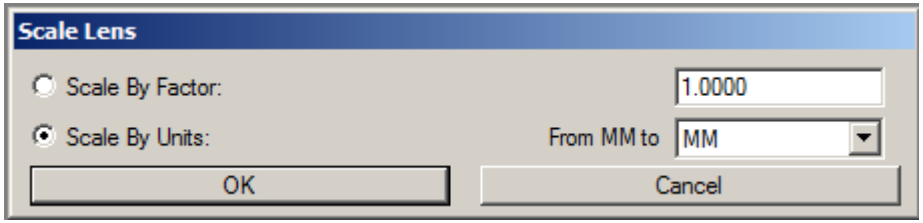
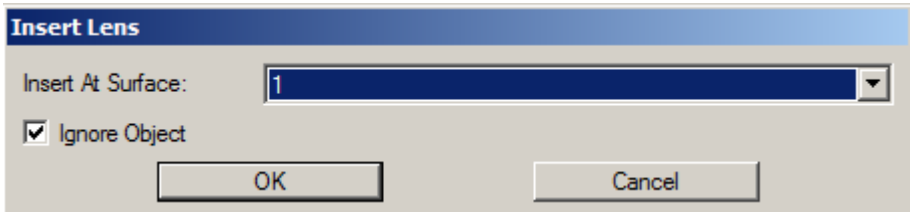
- Useful commands for system changes:

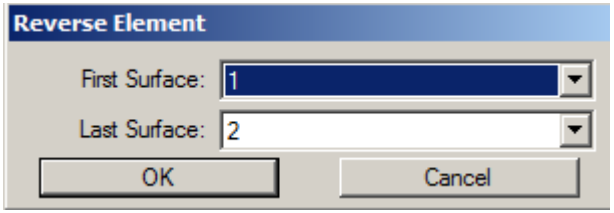
1. Scaling (e.g. patents)



2. Insert system
   with other system file
   File - Insert Lens



2. Reverse system



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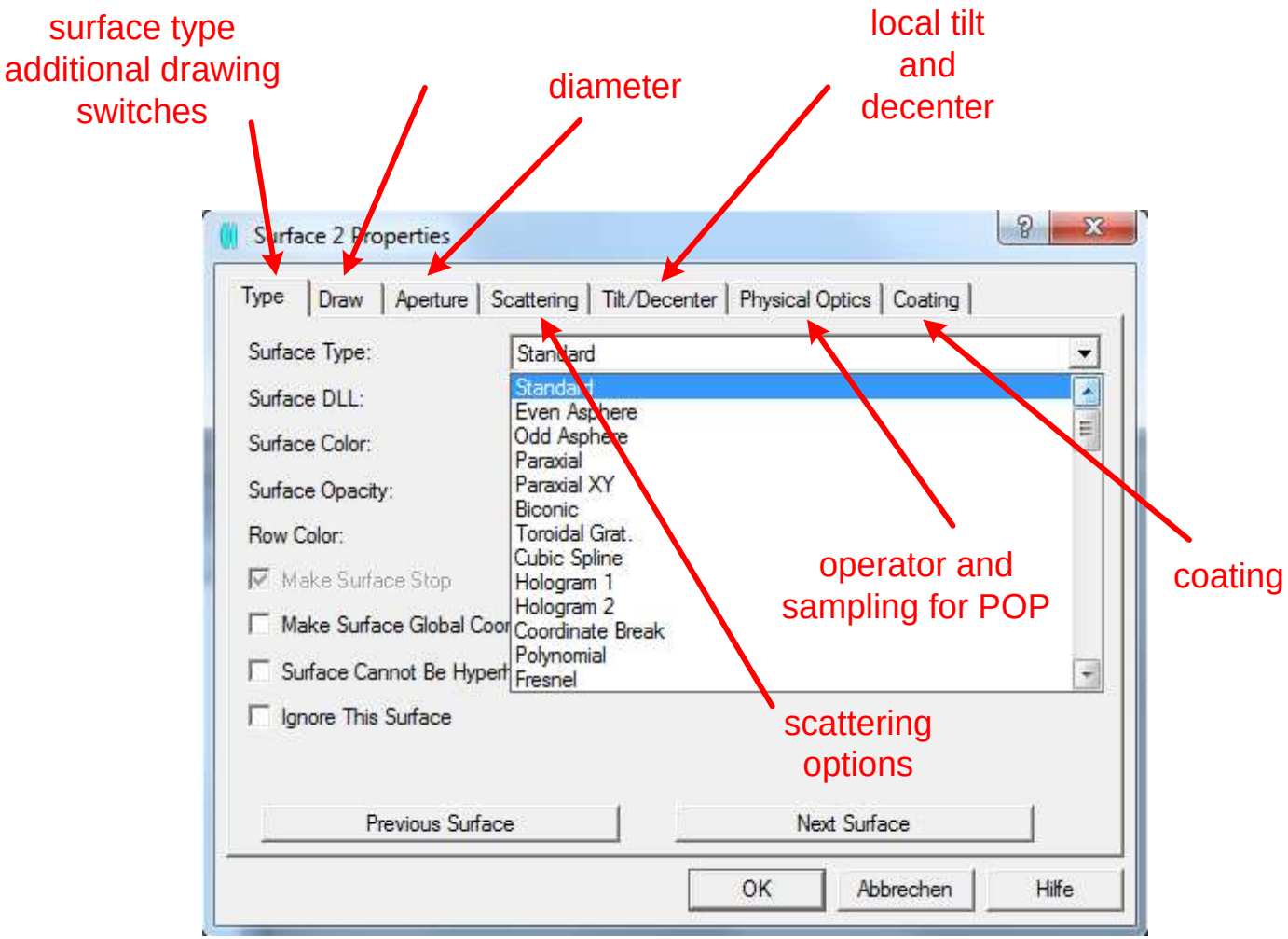
- Setting of surface properties



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- Value of the parameter dependents on other requirement
- Pickup of radius/thickness: linear dependence on other system parameter
- Determined to have fixed: - marginal ray height
  - chief ray angle
  - marginal ray normal
  - chief ray normal
  - aplanatic surface
  - element power
  - concentric surface
  - concentric radius
  - F number
  - marginal ray height
  - chief ray height
  - edge thickness
  - optical path difference
  - position
  - compensator
  - center of curvature
  - pupil position

Solves

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- Examples for solves:

1. last radius forces given image aperture
2. get symmetry of system parts
3. multiple used system parts
4. moving lenses with constant system length
5. bending of a lens with constant focal length
6. non-negative edge thickness of a lens
7. bending angle of a mirror (i'=i)
8. decenter/tilt of a component with return

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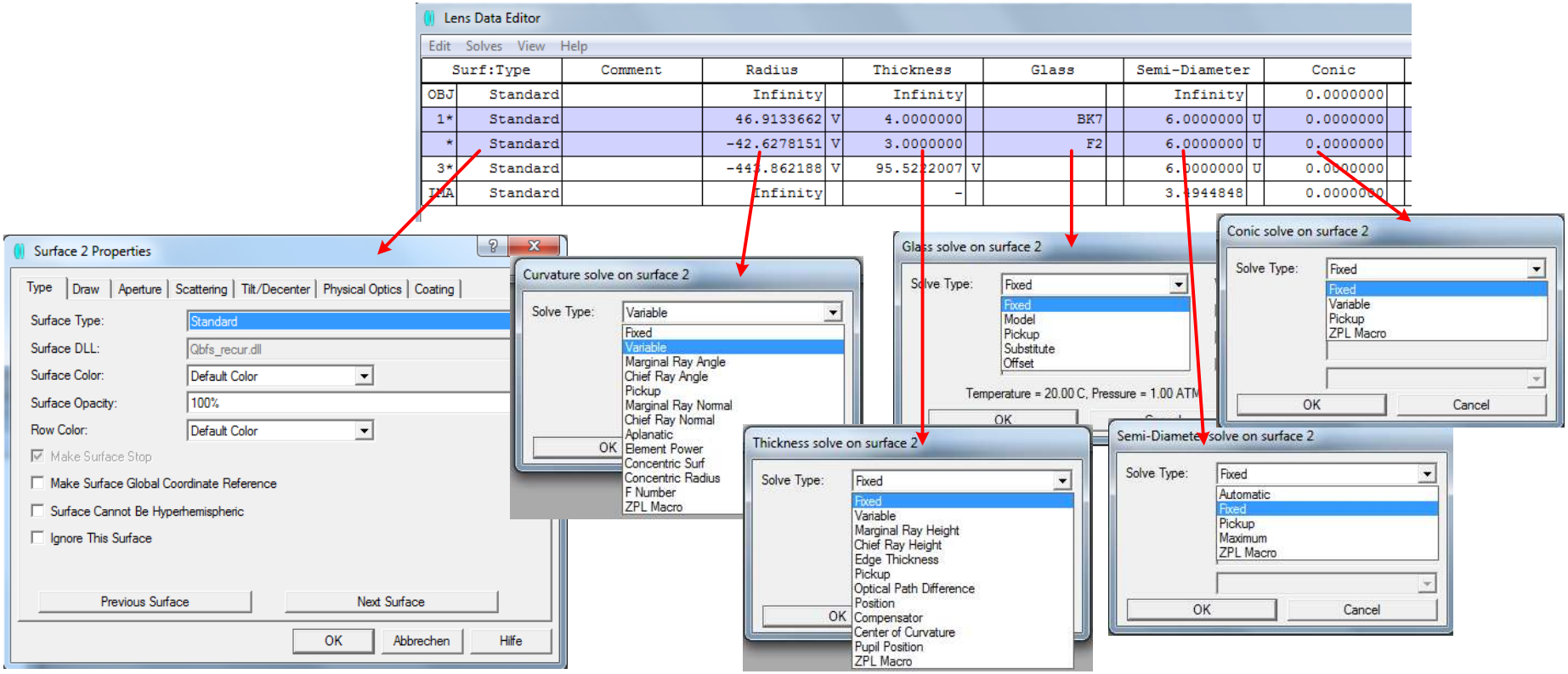
- Open different menus with a right-mouse-click in the corresponding editor cell
- Solves can be chosen individually
- Individual data for every surface in this menu



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- General input of tilt and decenter:
  Coordinate break surface
- Change of coordinate system with lateral translation and 3 rotations angles
- Direct listing in lens editor
- Not shown in layout drawing

Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius		Thickness	Glass
OBJ	Standard		Infinity		20.0000000	
1	Coordinate ..				5.0000000	-
2	Standard		100.0000000		5.0000000	BK7
STO	Standard		-100.0000000	V	10.0000000	
4	Standard		50.0000000		5.0000000	SF6
5	Standard		-40.0000000		50.0000000	
IMA	Standard		Infinity		-	

Decenter X	Decenter Y	Tilt About X	Tilt About Y	Tilt About Z
0.0000000	5.0000000	0.0000000	0.0000000	0.0000000

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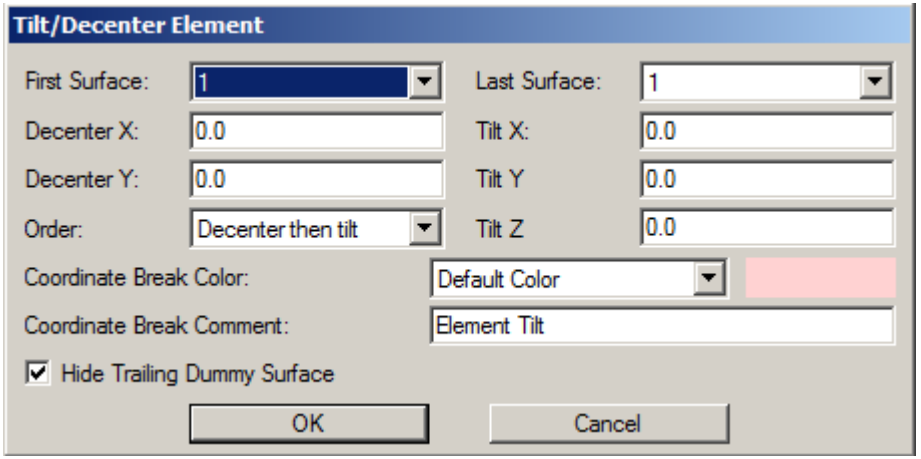
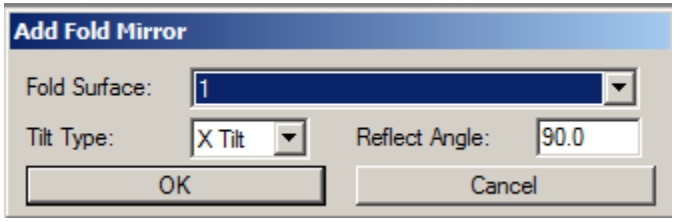
- Auxiliary menus:

1. Tilt/Decenter element



2. Folding mirror



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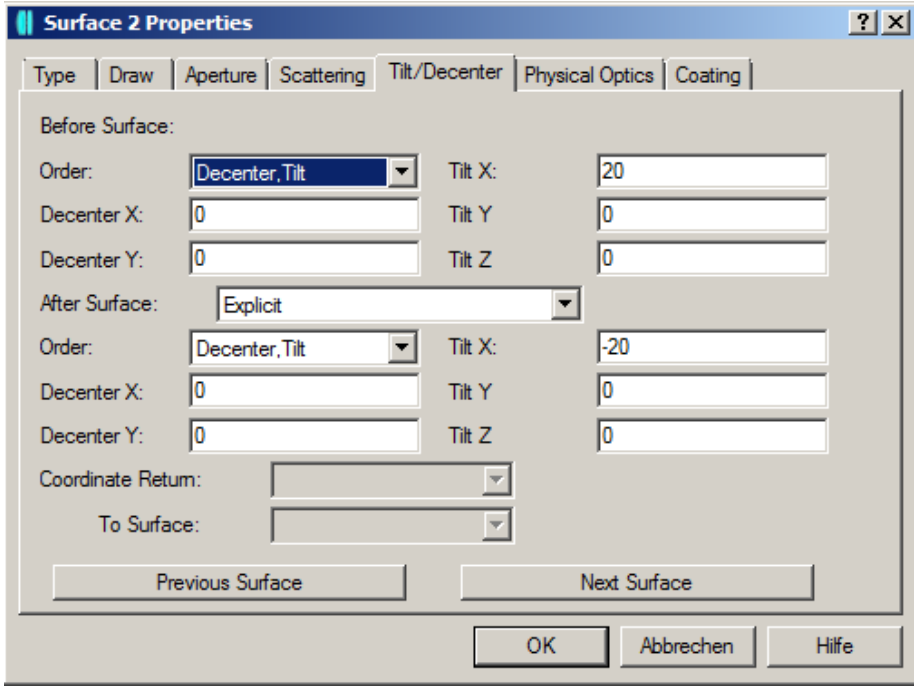
- Local tilt and decenter of a surface
  1. no direct visibility in lens editor
     only + near surface index
  2. input in surface properties
  3. with effect on following system surfaces



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- Imaging on axis: circular / rotational symmetry
  Only spherical aberration and chromatical aberrations

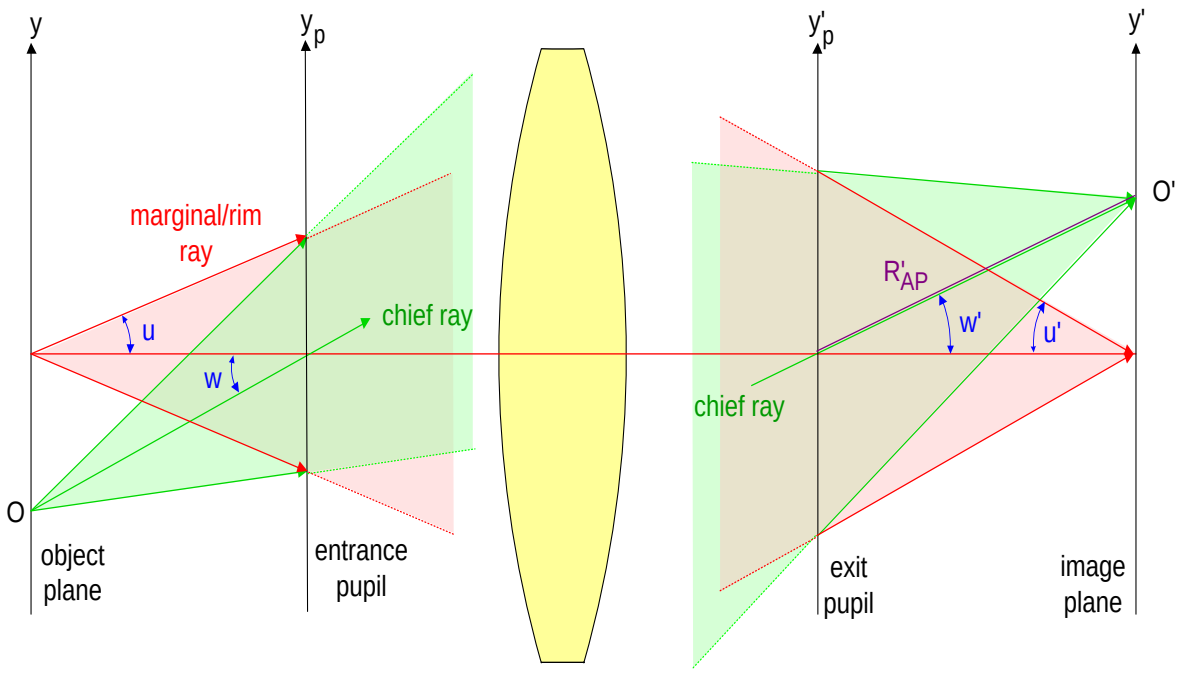
- Finite field size, object point off-axis:

  - chief ray as reference

  - skew ray bundels:
    coma and distortion

  - Vignetting, cone of ray bundle
    not circular symmetric

  - to distinguish:
    tangential and sagittal
    plane



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Quantitative measures of relative opening / size of accepted light cone

- Numerical aperture

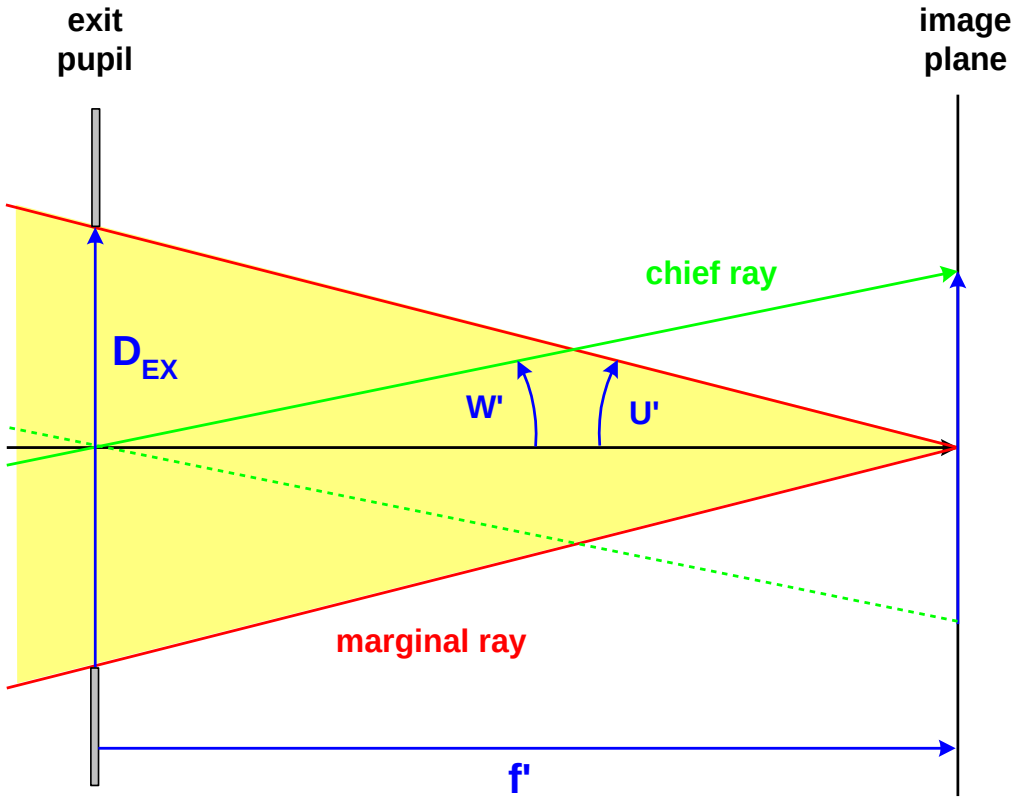
$$NA = n \cdot \sin u'$$

- F-number

$$F\# = \frac{f'}{D_{EX}}$$

- Approximation for small apertures:

$$F\# = \frac{1}{2 \cdot NA}$$



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- Helpful shortcuts:

1. F3 undo
2. F2 edit a cell in the editor
3. cntr A multiconfiguration toggle
4. cntr V variable toggle
5. F6 merit function editor
6. cntr U update
7. shift cntr Q quick focus

- Window options:
  1. several export options
  2. fixed aspect ratios
  3. clone
  4. adding comments or graphics