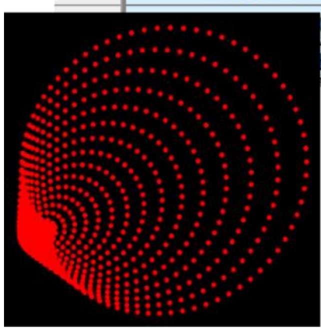
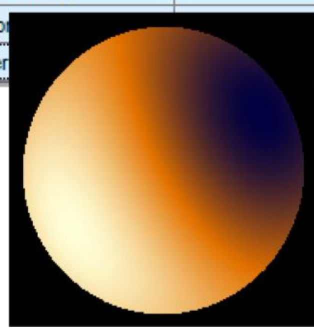
Wave Aberration Detectors

Abstract

	Sub - Detector	Result
10	Maximum Radius	9.778214 mm
9	Piston [λ]	130746.66
8	Magnitude of Distortion [λ]	-27.544493
7	Angle of Distortion [λ]	202.50177°
6	Field Curvature [λ]	-158.71186
5	Magnitude of Astigmatism [λ]	120.43849
4	Angle of Astigmatism [λ]	-63.585916°
3	Magnitude of Coma [λ]	142.59892
[illegible]	[illegible] Co[illegible]	26.409933°
[illegible]	[illegible] ber[illegible]	-30.515483

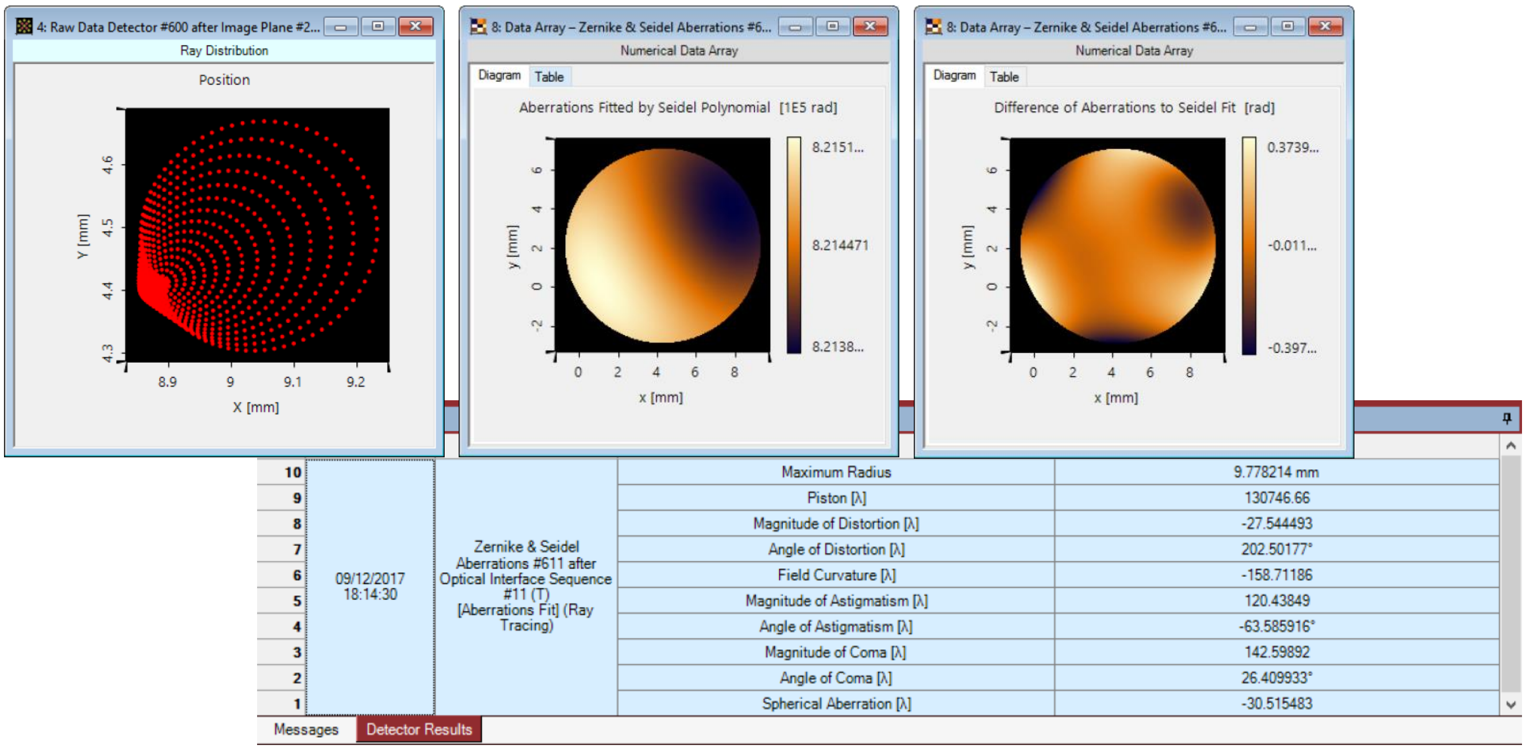




In lens design, the aberration information in the lens system is important for the optimization process. In VirtualLab Fusion, detectors for different kinds of wave aberration representation are provided. User can choose to fit the wave aberration as general polynomial, also as Zernike and Seidel polynomial. VirtualLab Fusion allows the calculation of these polynomials by ray tracing and field tracing simulation.

Modeling Task

- how to detect the aberration information with different kind of polynomial fitting (general polynomial, Zernike and Seidel polynomial)



10	09/12/2017 18:14:30	Zernike & Seidel Aberrations #611 after Optical Interface Sequence #11 (T) [Aberrations Fit] (Ray Tracing)	Maximum Radius	9.778214 mm
9			Piston [λ]	130746.66
8			Magnitude of Distortion [λ]	-27.544493
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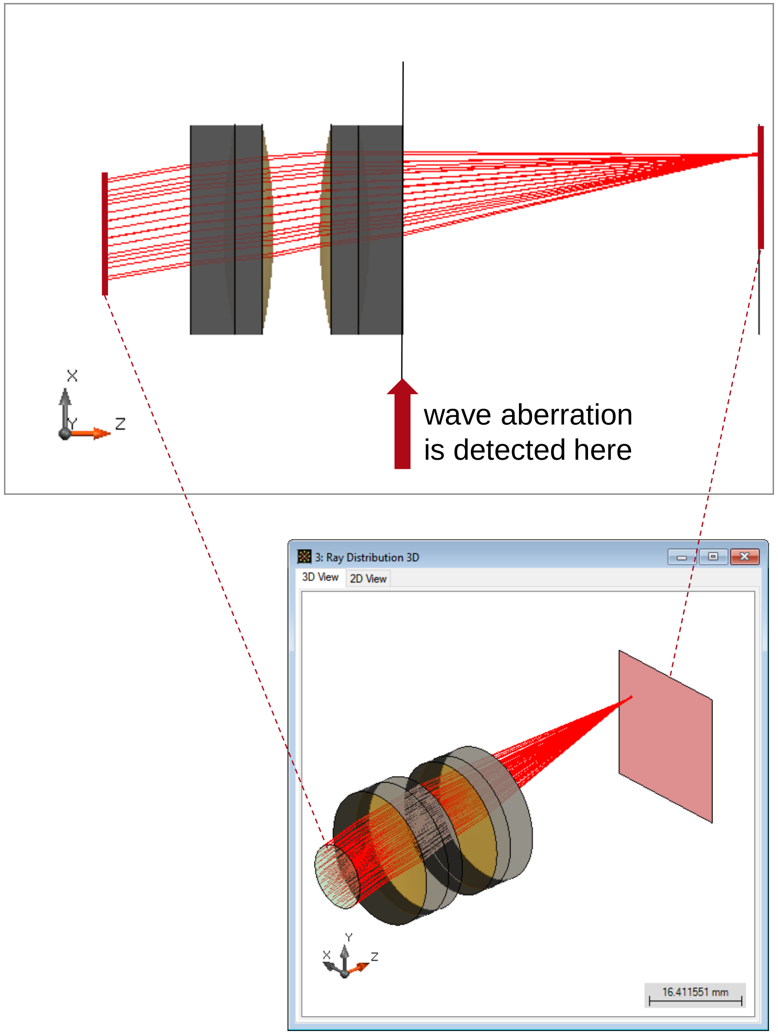
4			Angle of Astigmatism [λ]	-63.585916°
3			Magnitude of Coma [λ]	142.59892
2			Angle of Coma [λ]	26.409933°
1			Spherical Aberration [λ]	-30.515483

System Configuration

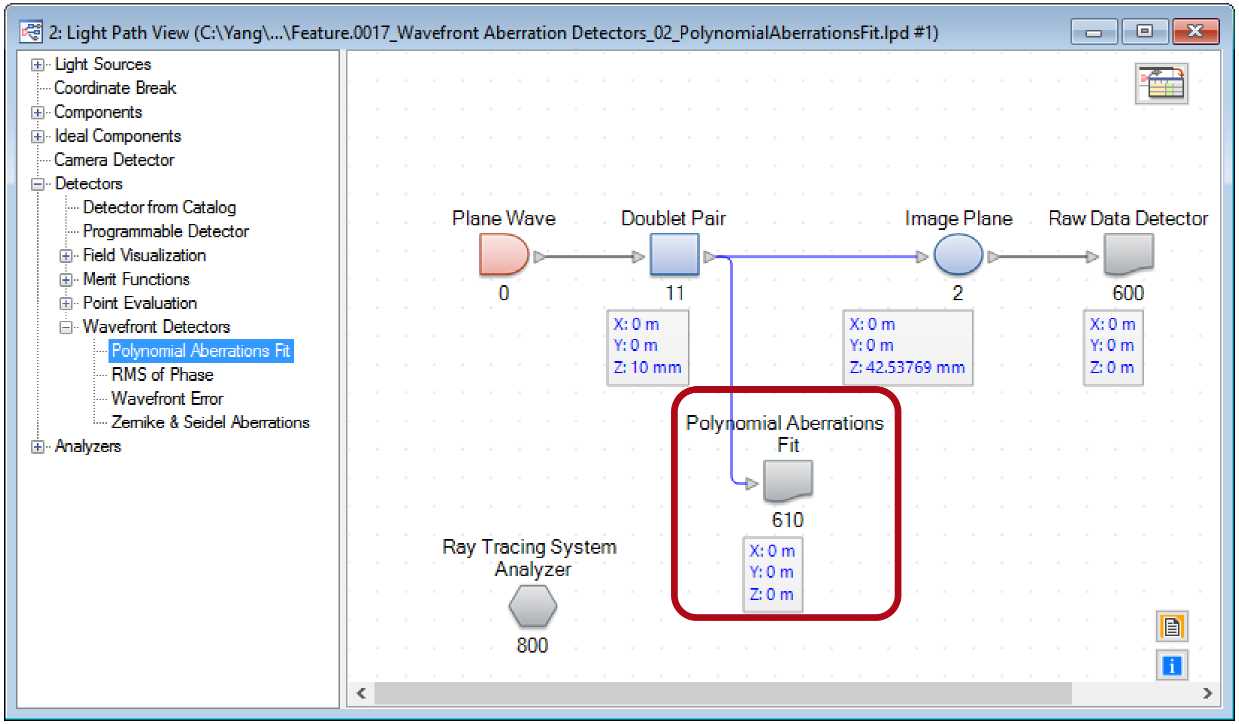
- To illustrate the usage of the wave aberration detectors, an doublet pair lens system is used as an example.
- In the simulation, the source is an off-axis plane wave which propagates with 10° to the x-axis and 5° to y-axis.
- We detect the aberration information right behind the second doublet.
- The 3D ray tracing figures are shown here for visualization.



Detector: Polynomial Aberrations Fit

Detector: Polynomial Aberrations Fit

- A *Polynomial Aberrations Fit* detector is set right behind the doublet lens component.

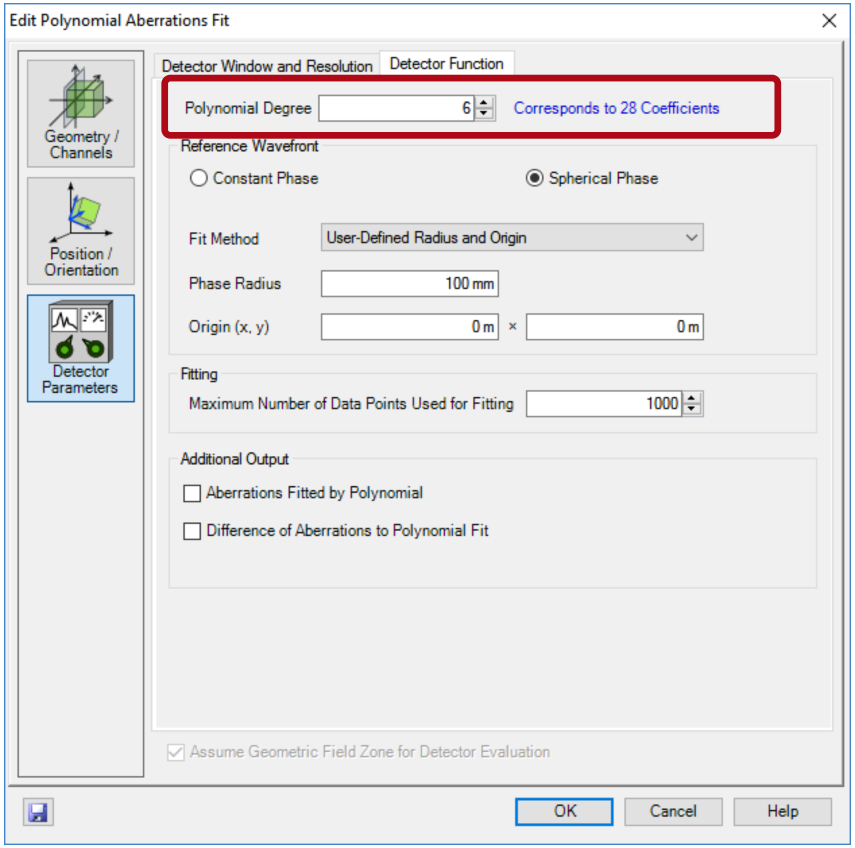


Detector Configuration

- The detector performs a least squares polynomial fit to the wavefront of the incident ray or field information with selectable degree of the polynomial (between 1 and 12, inclusively), and defines the aberration by subtracting a reference wavefront phase.
- The polynomial is a 2D function with respect to the coordinate of the detector plane,

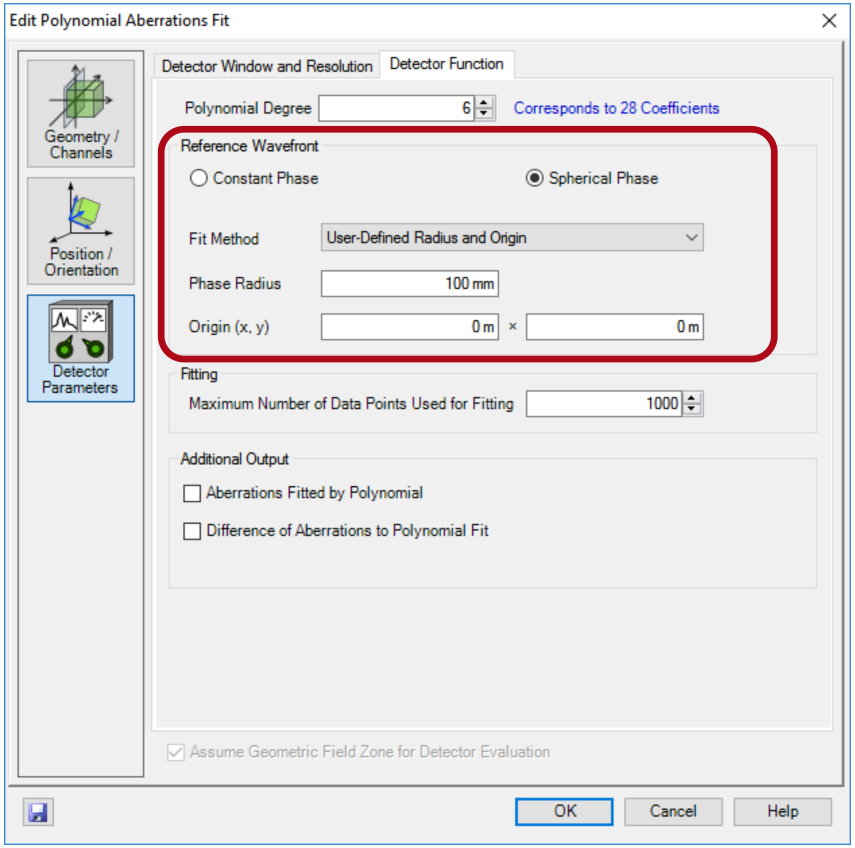
$$P(x,y) = \sum_{m=0}^{M} \sum_{n=0}^{N} x^m y^n .$$

- The polynomila degree is define as $M + N$.



Detector Configuration

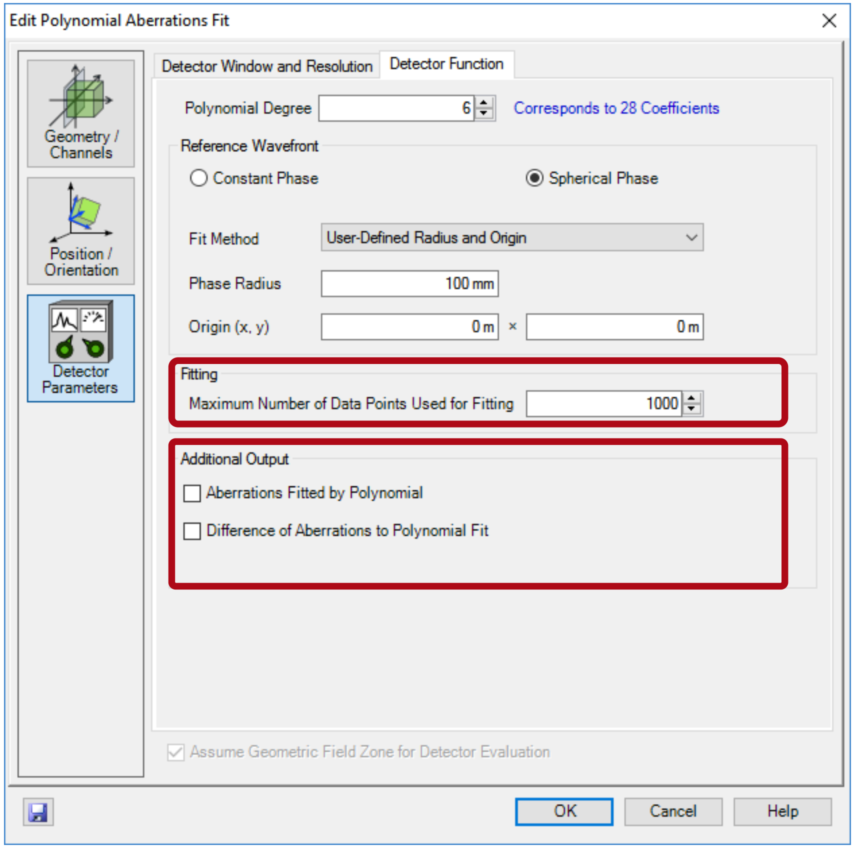
- The *Reference Wavefront* can be set as *Constant Phase* or *Spherical Phase* by the user.
- The constant phase is defined as the average wavefront phase of the incident field at the detector plane.
- The spherical phase is defined either by the user or by optimal fitting. If the fitted absolute value of the phase radius is larger than 100 meters, a constant phase is used internally.*



* Please refer to the Feature UseCase „ Wavefront Error Detector“ for more detail.

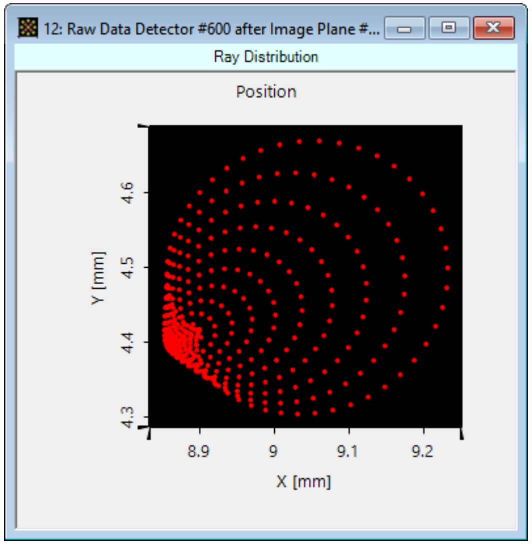
Detector Configuration

- A maximum number of the data points can be set by the user. For avoiding time consuming, by default only 1000 random data points with non-zero amplitude are extracted for the fitting.
- The fitted polynomial can be displayed in a data array if *Aberration Fitted by Polynomial* is checked.
- The fitting error can also be output in a data array by checking the option *Difference of Aberrations to Polynomial Fit*.

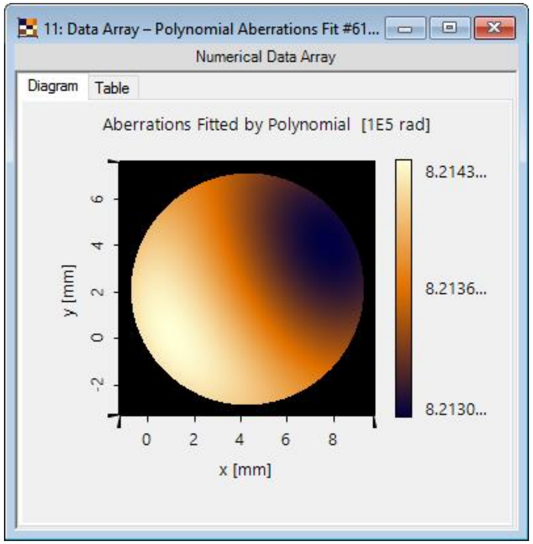


Detector Results

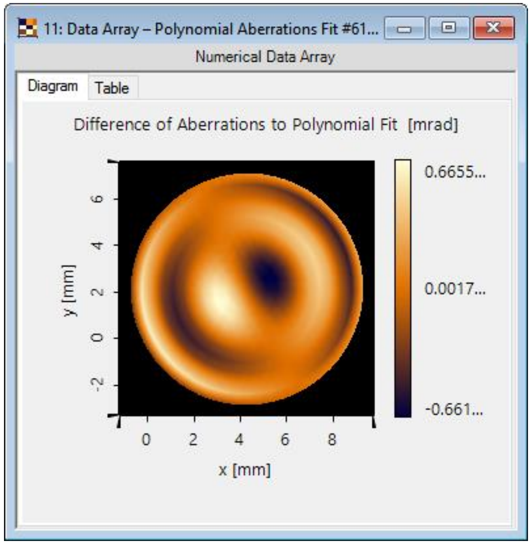
- The result can be obtained either by performing ray tracing or field tracing 2nd generation.
- In the simulation here, the Reference Wavefront is chosen as Spherical Phase with optimal fit by VirtualLab Fustion. The results are shown below.



dot diagram (image plane)



aberrations (detector plane)



fitting error

Detector Results

- All the coefficients of the polynomial as well as the radius and the origin of the reference spherical phase are logged in the detector results window.

Detector Results

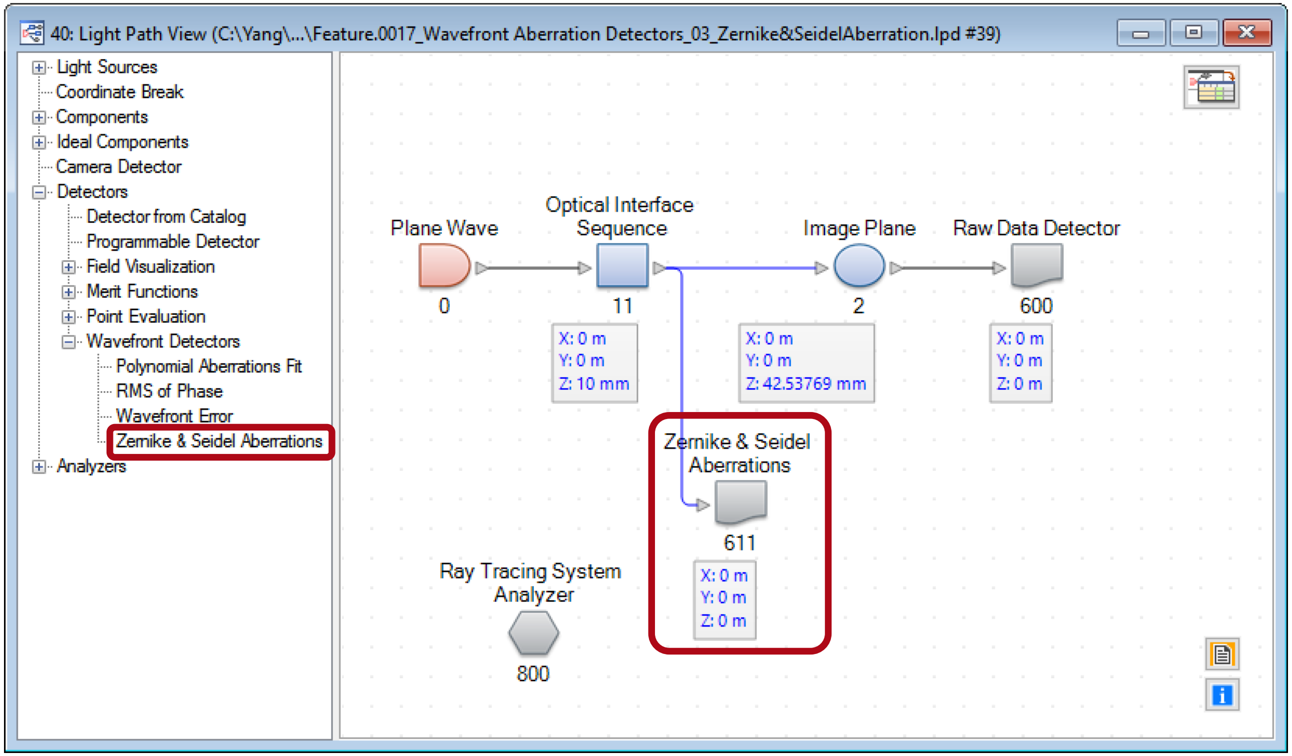
	Date/Time	Detector	Sub - Detector	Result
31			Fitted Phase Radius	-41.346786 mm
30			Fitted Origin X	8.8496203 mm
29			Fitted Origin Y	4.3971935 mm
28			(x^0; y^0) [λ]	130745.23
27			(x^1; y^0) [λ]	0
26			(x^0; y^1) [λ]	0
25			(x^2; y^0) [λ]	-1411570.9
24			(x^1; y^1) [λ]	-999032.52
23			(x^0; y^2) [λ]	-653971.64
22			(x^3; y^0) [λ]	1.4009897E+08
21			(x^2; y^1) [λ]	68990519
20			(x^1; y^2) [λ]	1.402425E+08
19			(x^0; y^3) [λ]	69785685
18			(x^4; y^0) [λ]	-3.9939177E+09
17			(x^3; y^1) [λ]	-4.048304E+08
16	09/09/2017 16:27:52	Polynomial Aberrations Fit #610 after Doublet Pair #11 (T) [Aberrations Fit] (Field Tracing 2nd Generation)	(x^2; y^2) [λ]	-7.697014E+09
15			(x^1; y^3) [λ]	-3.7800592E+08
14			(x^0; y^4) [λ]	-3.695554E+09
13			(x^5; y^0) [λ]	4.3821549E+10
12			(x^4; y^1) [λ]	2.6323073E+10
11			(x^3; y^2) [λ]	8.6333063E+10
10			(x^2; y^3) [λ]	4.6421479E+10
9			(x^1; y^4) [λ]	4.2638189E+10
8			(x^0; y^5) [λ]	1.995787E+10
7			(x^6; y^0) [λ]	-7.9806652E+11
6			(x^5; y^1) [λ]	-3.1518382E+11
5			(x^4; y^2) [λ]	-2.1420068E+12
4			(x^3; y^3) [λ]	-6.504889E+11
3			(x^2; y^4) [λ]	-1.8951113E+12
2			(x^1; y^5) [λ]	-3.3539863E+11
1			(x^0; y^6) [λ]	-5.5140743E+11

Messages | Detector Results

Detector: Zernike & Seidel Aberrations

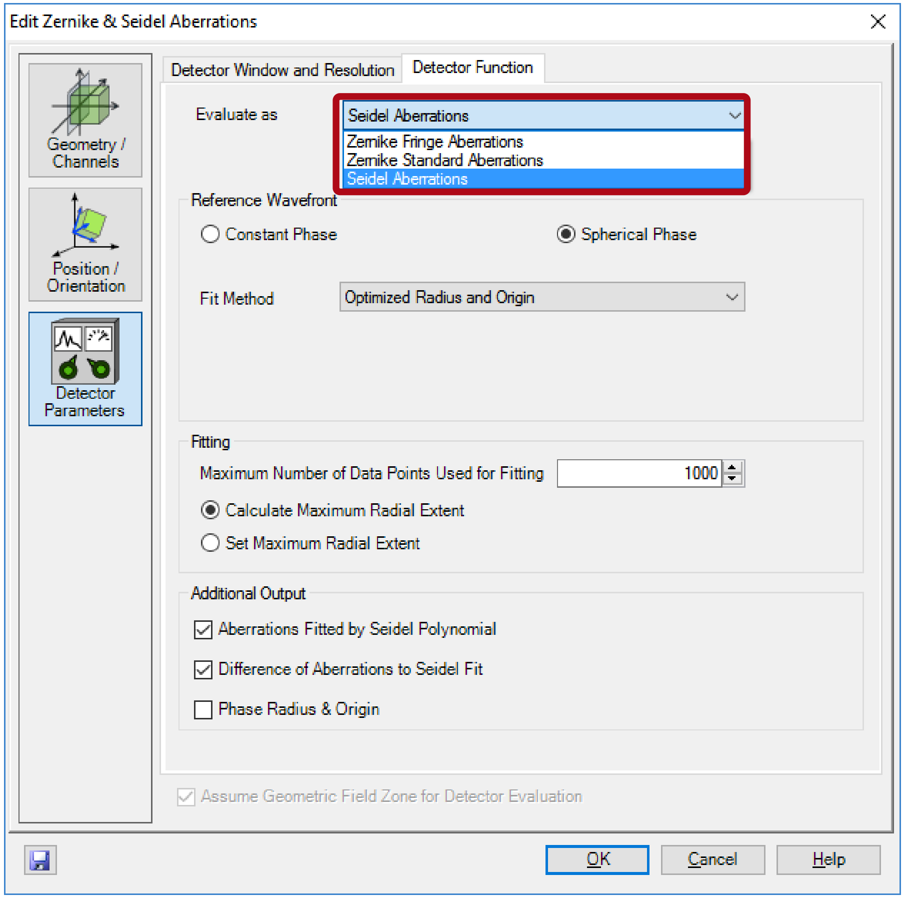
Detector: Zernike & Seidel Aberrations

- To calculate the aberration as Zernike or Seidel polynomial, a *Zernike & Seidel Aberrations* detector is set right behind the Optical Interface Sequence component.



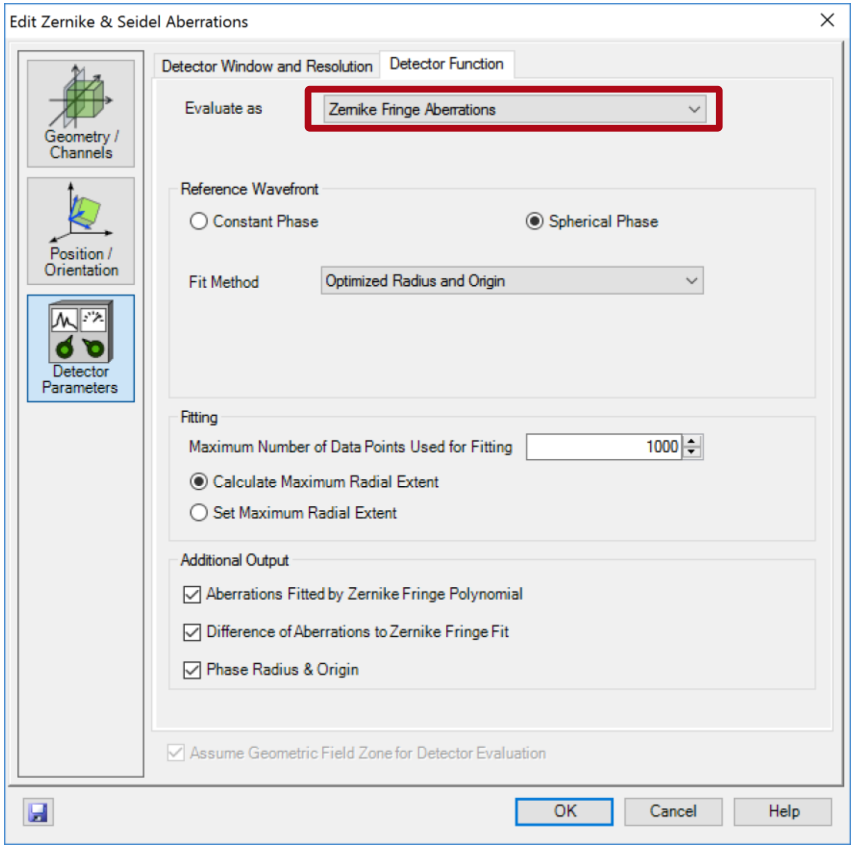
Detector: Zernike & Seidel Aberrations

- The detector contains three kinds of aberration representations: Zernike fringe, Zernike standard, and Seidel aberrations.
- Zernike polynomials are defined in standard form: $Z_n^m(\rho,\theta) = N_n^m R_n^m(\rho)\Theta_m(\theta)$ with the nomalization constant N_n^m, the radial polynomial $R_n^m(\rho)$ and an azimuthal component $\Theta_m(\theta)$. m is the azimuthal order and n is the radial order.



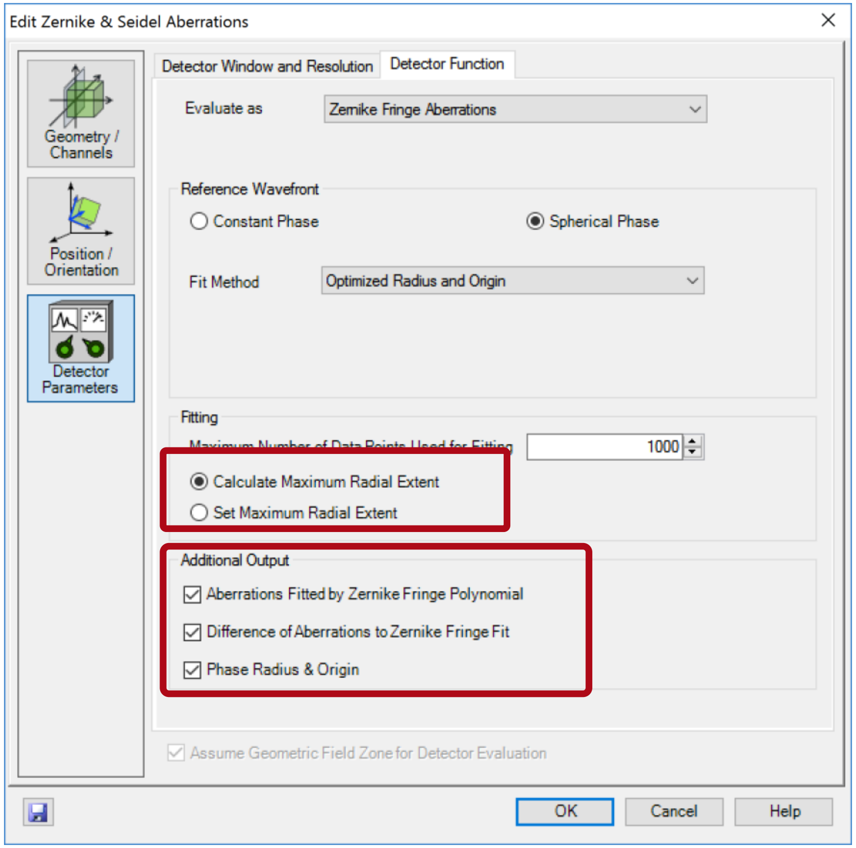
Zernike Fringe Aberrations

- Zernike fringe aberrations are a commonly used subset of 37 Zernike polynomials, with a different indexing from the Zernike standard one.
- For Zernike fringe aberrations the normalization constant N_n^m always equals 1.



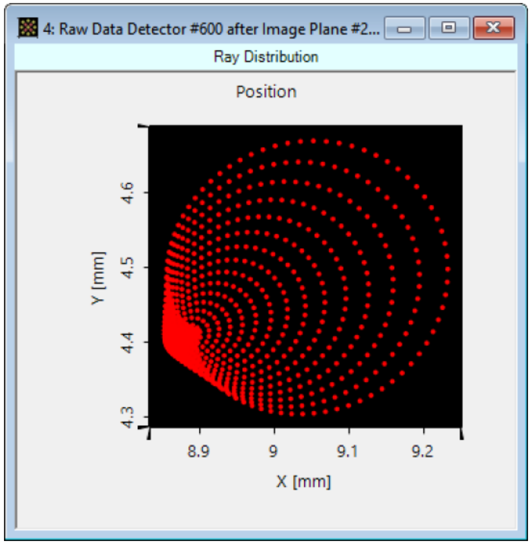
Ouput Configuration

- The maximum radial extent for the polynomial can be set manually, or by default calculated as the smallest centered circle containing all data points with non-zero amplitude.
- By making a check, additional output such as *Aberration Fitting by Zernike Fringe Polynomial*, and *Difference of Aberration to Zernike Fringe Fit* could be displayed as DataArray.
- *Phase Radius & Origin* also be shown if optimal radius and oringin is chosen for spherical phase reference wavefront.

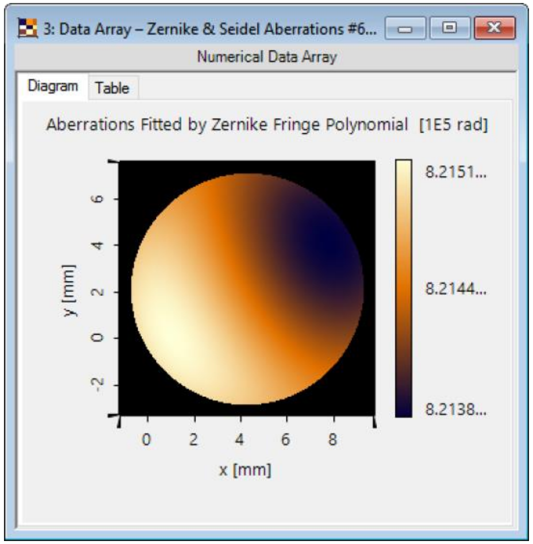


Detector Result

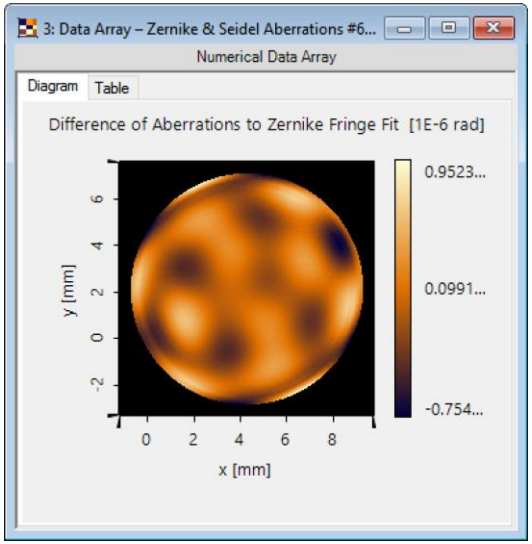
- After doing ray tracing, the dot diagram at the image plane, the fitted Zernike aberrations, and the fitting error are shown below.



dot diagram (image plane)



aberrations
(detector plane)



fitting error

Detector Result

All the 37 coefficients of the Zernike fringe polynomial are logged in the detector results, with the name of different kind of aberrations. The coefficients are in the unit of input wavelength (λ).

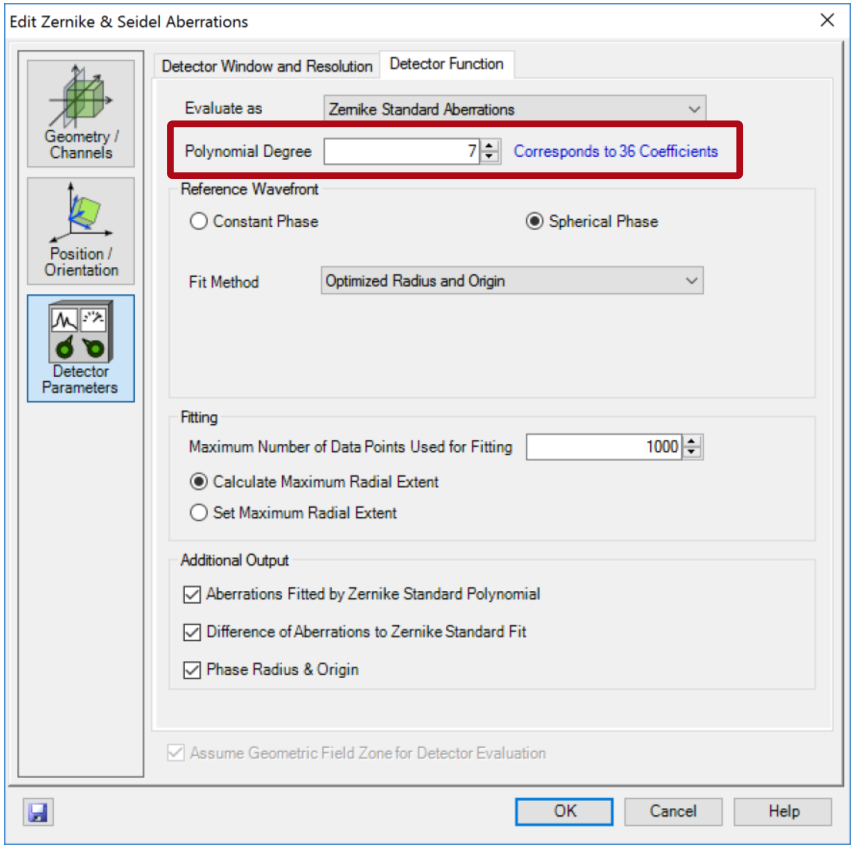
Detector Results

	Date/Time	Detector	Sub - Detector	Result
38			Maximum Radius	9.778214 mm
37			Piston [λ]	130684.4
36			Tilt X [λ]	117.117
35			Tilt Y [λ]	56.059367
34			Defocus [λ]	-69.019253
33			Astigmatism X [λ]	-38.614877
32			Astigmatism Y [λ]	-50.912077
31			Coma X [λ]	47.464477
30			Coma Y [λ]	23.567491
29			Spherical [λ]	-6.8973466
28			Trefoil X [λ]	0.14734645
27			Trefoil Y [λ]	0.76040507
26			Secondary Astigmatism X [λ]	-0.99252412
25			Secondary Astigmatism Y [λ]	-1.305145
24			Secondary Coma X [λ]	1.0668305
23			Secondary Coma Y [λ]	0.52915274
22			Secondary Spherical [λ]	-0.19508189
21			Tetrafoil X [λ]	0.050389718
20	09/12/2017 17:55:53	Zernike & Seidel Aberrations #611 after Optical Interface Sequence #11 (T) [Aberrations Fit] (Ray Tracing)	Tetrafoil Y [λ]	-0.18071858
19			Secondary Trefoil X [λ]	0.044070209
18			Secondary Trefoil Y [λ]	0.23055435
17			Tertiary Astigmatism X [λ]	-0.10668932
16			Tertiary Astigmatism Y [λ]	-0.14047122
15			Tertiary Coma X [λ]	0.066913947
14			Tertiary Coma Y [λ]	0.033202563
13			Tertiary Spherical [λ]	-0.008338117
12			Pentafoil X [λ]	-0.004515323
11			Pentafoil Y [λ]	0.0050310042
10			Secondary Tetrafoil X [λ]	0.0029121215
9			Secondary Tetrafoil Y [λ]	-0.010471116
8			Tertiary Trefoil X [λ]	0.0019318578
7			Tertiary Trefoil Y [λ]	0.010090064
6			Quaternary Astigmatism X [λ]	-0.0034157892
5			Quaternary Astigmatism Y [λ]	-0.0044961865
4			Quaternary Coma X [λ]	0.0014962155
3			Quaternary Coma Y [λ]	0
2			Quaternary Spherical [λ]	0
1			Quinary Spherical [λ]	0

Messages | Detector Results

Zernike Standard Aberrations

- For the Zernike standard aberrations, the polynomial degree can be set by the user, whereas the number should be between 0 to 20.



Detector Result

The polynomial degree is set as 7. After ray tracing or field tracing, the coefficients of the Zernike standard polynomial are shown, with different indexing from the fringe ones.

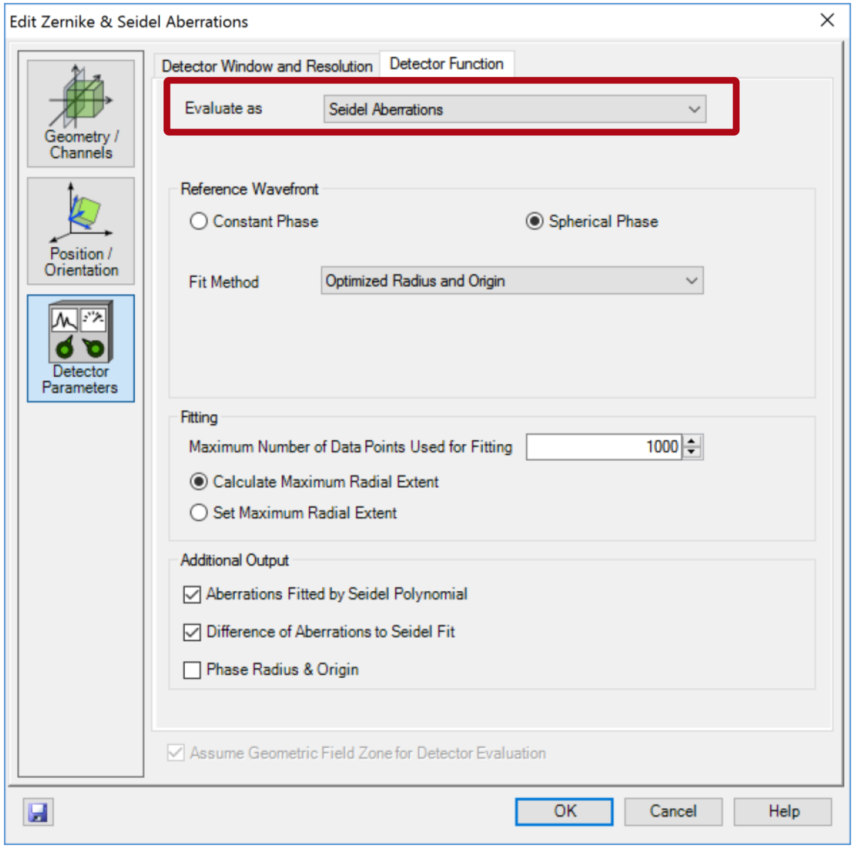
Detector Results

	Date/Time	Detector	Sub - Detector	Result
37	09/12/2017 17:58:04	Zernike & Seidel Aberrations #611 after Optical Interface Sequence #11 (T) [Aberrations Fit] (Ray Tracing)	Maximum Radius	9.778214 mm
36			Piston [λ]	130684.86
35			Tilt Y [λ]	27.733123
34			Tilt X [λ]	57.960782
33			Astigmatism Y [λ]	-20.463625
32			Defocus [λ]	-39.377047
31			Astigmatism X [λ]	-15.520492
30			Trefoil Y [λ]	0.1232597
29			Coma Y [λ]	8.1444932
28			Coma X [λ]	16.402567
27			Trefoil X [λ]	0.024230703
26			Tetrafoil Y [λ]	-0.027513958
25			Secondary Astigmatism Y [λ]	-0.28102449
24			Spherical [λ]	-2.8797612
23			Secondary Astigmatism X [λ]	-0.21381466
22			Tetrafoil X [λ]	0.0076871793
21			Pentafoil Y [λ]	0
20			Secondary Trefoil Y [λ]	0.031074619
19			Secondary Coma Y [λ]	0.098053152
18			Secondary Coma X [λ]	0.19771885
17			Secondary Trefoil X [λ]	0.0059308581
16			Pentafoil X [λ]	0
15			Hexafoil Y [λ]	0
14			Secondary Tetrafoil Y [λ]	0
13			Tertiary Astigmatism Y [λ]	-0.014724092
12			Secondary Spherical [λ]	-0.033252669
11			Tertiary Astigmatism X [λ]	-0.011179012
10			Secondary Tetrafoil X [λ]	0
9			Hexafoil X [λ]	0
8			Heptafoil Y [λ]	0
7			Secondary Pentafoil Y [λ]	0
6			Tertiary Trefoil Y [λ]	0
5			Tertiary Coma Y [λ]	0.0019003203
4			Tertiary Coma X [λ]	0.0038285168
3			Tertiary Trefoil X [λ]	0
2			Secondary Pentafoil X [λ]	0
1			Heptafoil X [λ]	0

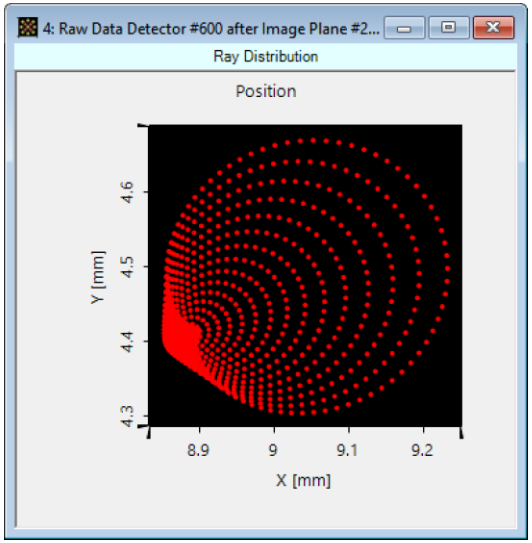
Messages | Detector Results

Seidel Aberrations

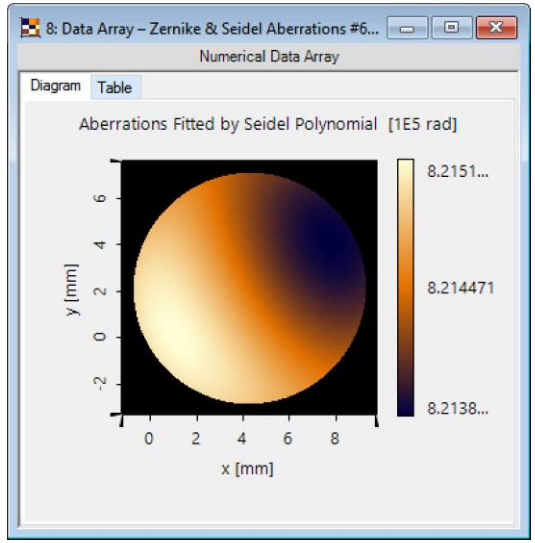
- The five primary monochromatic aberration is known as the Seidel aberrations.
- The Seidel polynomial formula is: $S(\rho,\theta) = M_P + M_D \cdot \rho\cos(\theta - \theta_D) + M_F \cdot \rho^2 + M_A \cdot \rho^2\cos^2(\theta - \theta_A) + M_C \cdot \cos(\theta - \theta_C) + M_S \cdot \rho^4$
- The $M_?$ and $\theta_?$ give the magnitude and the orientation angle of the corresponding Seidel aberrations.



Detector Result

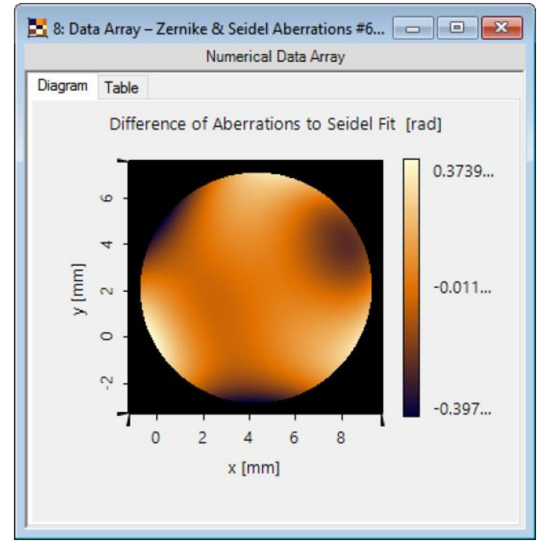


dot diagram (image plane)



aberrations

(detector plane)



fitting error

Detector Results

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3			Magnitude of Coma [λ]	142.59892
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1			Spherical Aberration [λ]	-30.515483

Messages | Detector Results

Document Information

title	Wave Aberration Detectors
version	1.0
VL version used for simulations	7.0.3.4
category	Feature Use Case