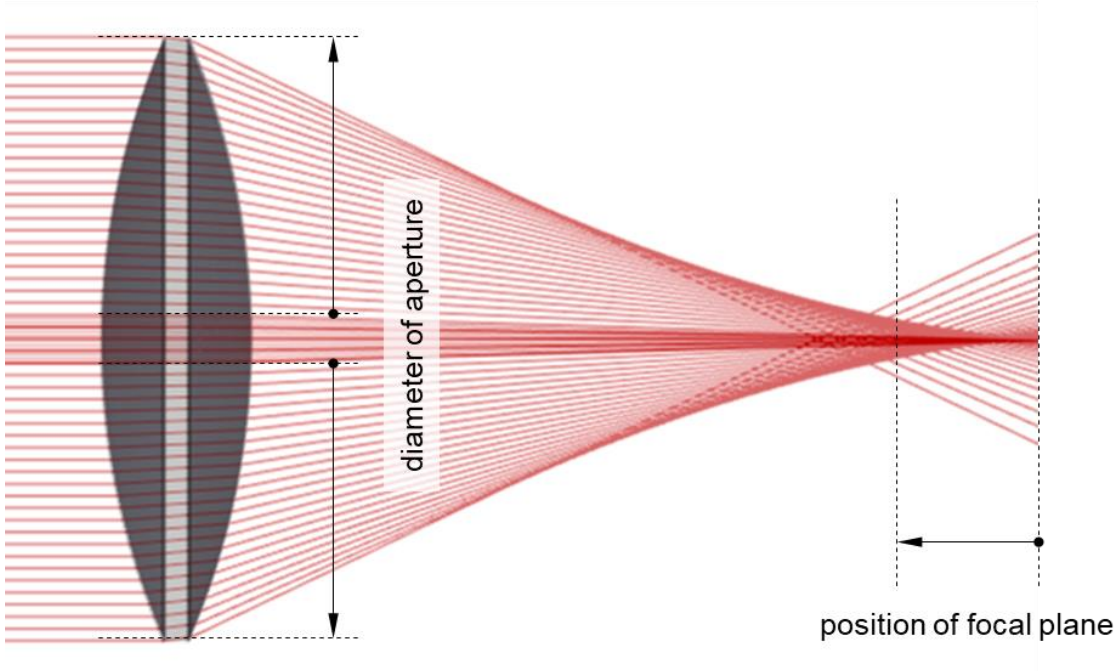
Analysis of Focal Plane Position as a Function of Numerical Aperture

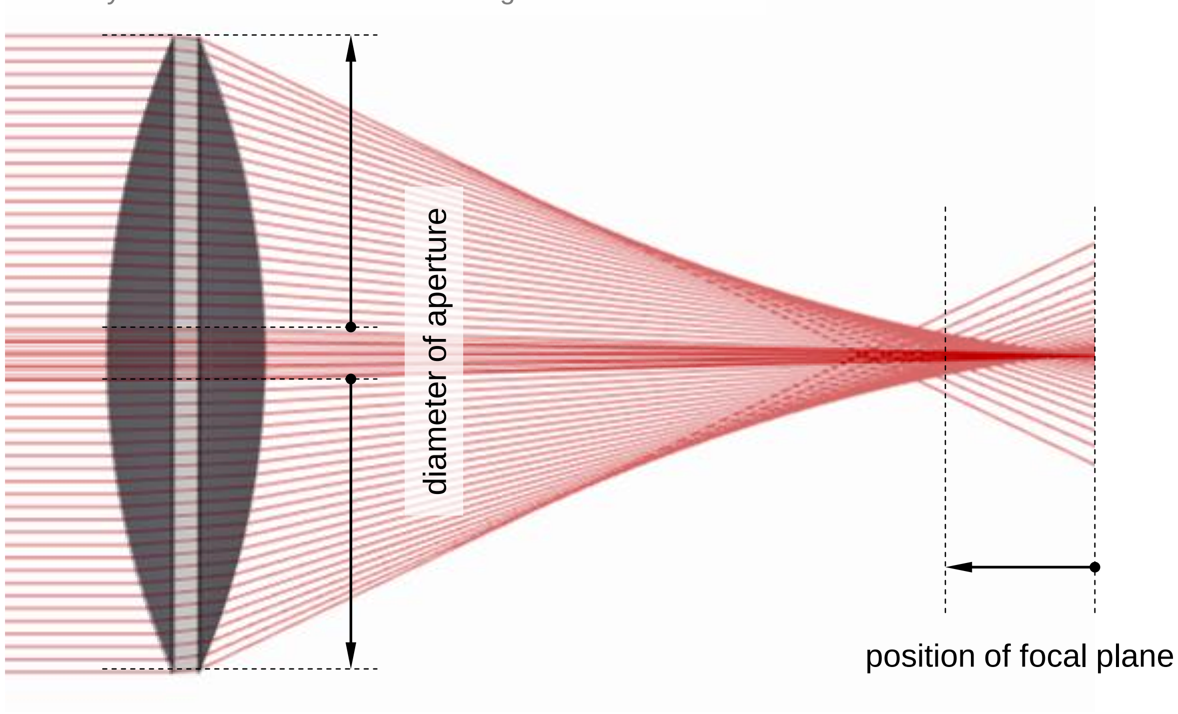
Abstract



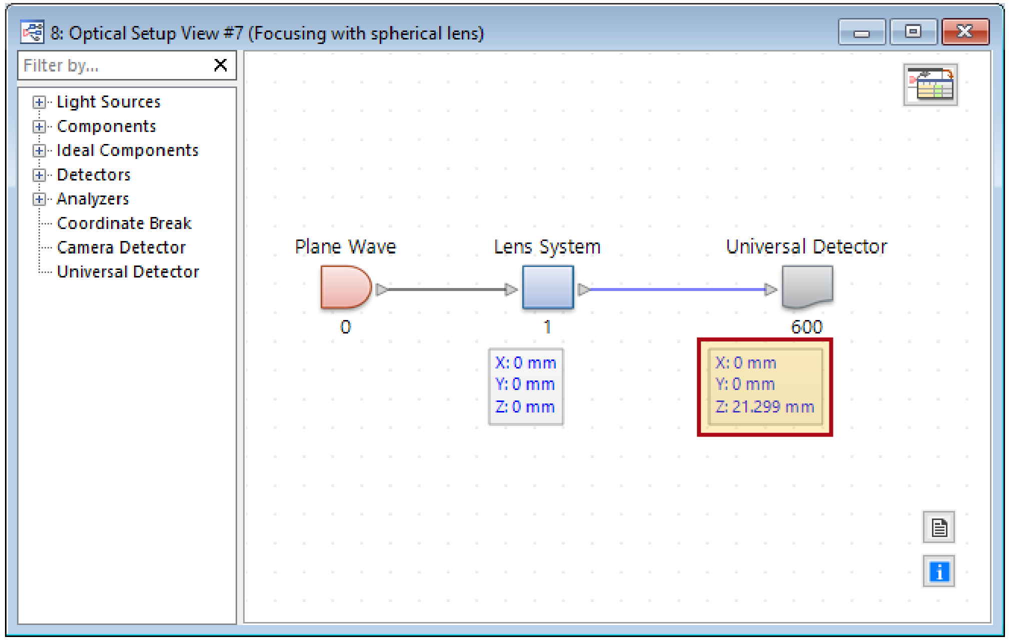
The focal length of a lens system may at first seem like a straightforward, immutable parameter of the component or lens system. There are, however, several aspects of the specific configuration in which a given lens is used which can affect the position of the focal plane: for instance, the fuller with light the aperture of the lens is, the higher the chance that aberrations may cause the focus to shift, compared with a more paraxial setup using the same lens. But then again, diffraction in systems with low F number will also displace the focus longitudinally with respect to the geometric prediction. In this use case, we use some programming in VirtualLab Fusion to ensure that our detector is always placed at the geometric focus of the lens system, and analyze how varying different parameters of the system can affect the position of the focal plane.

Task Description

Note: ray color does not match wavelength.

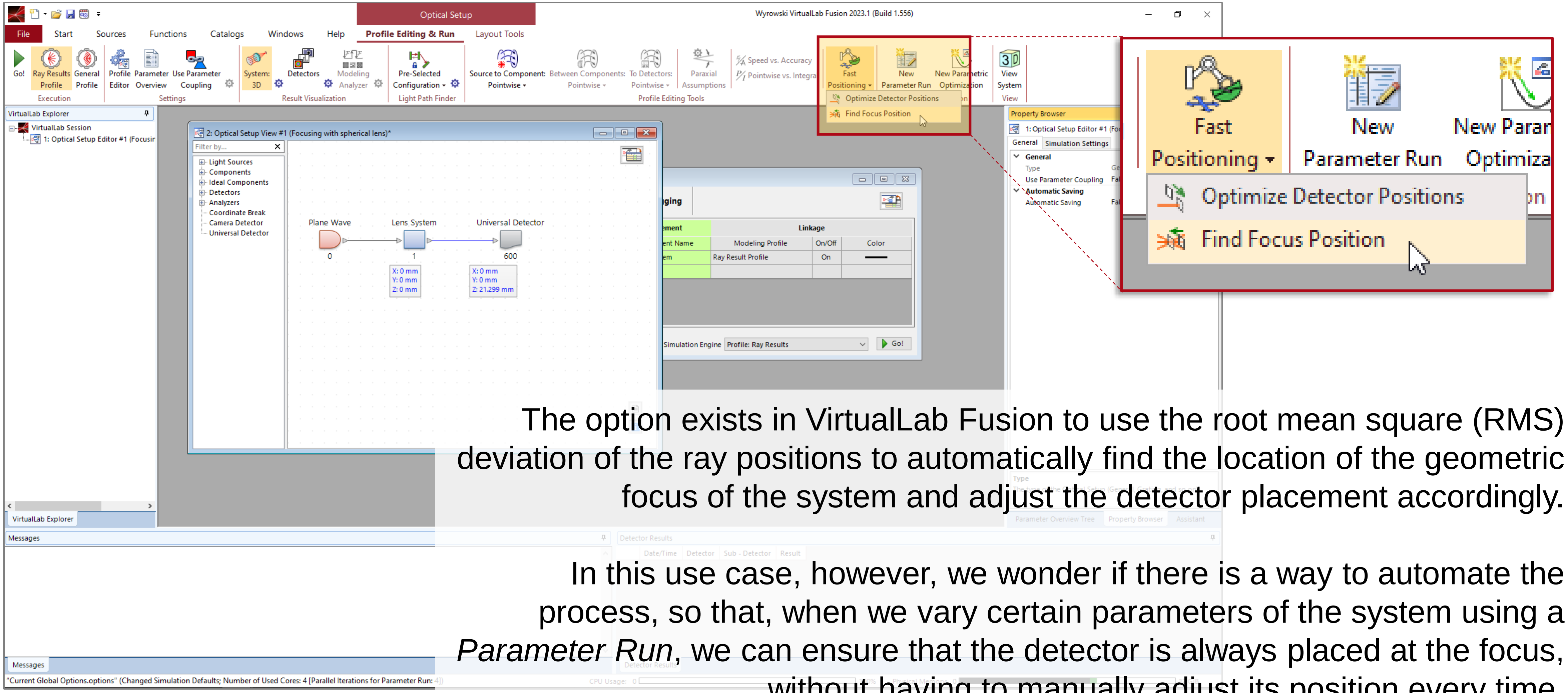


Task: Are there tools in VirtualLab Fusion to ensure that the detector is always automatically placed at the geometric focus, so that we can investigate the effect of the numerical aperture on focus position and spot size?



With a spherical lens, the spherical aberration can cause the geometric focus to shift as the numerical aperture (NA) of the setup increases.

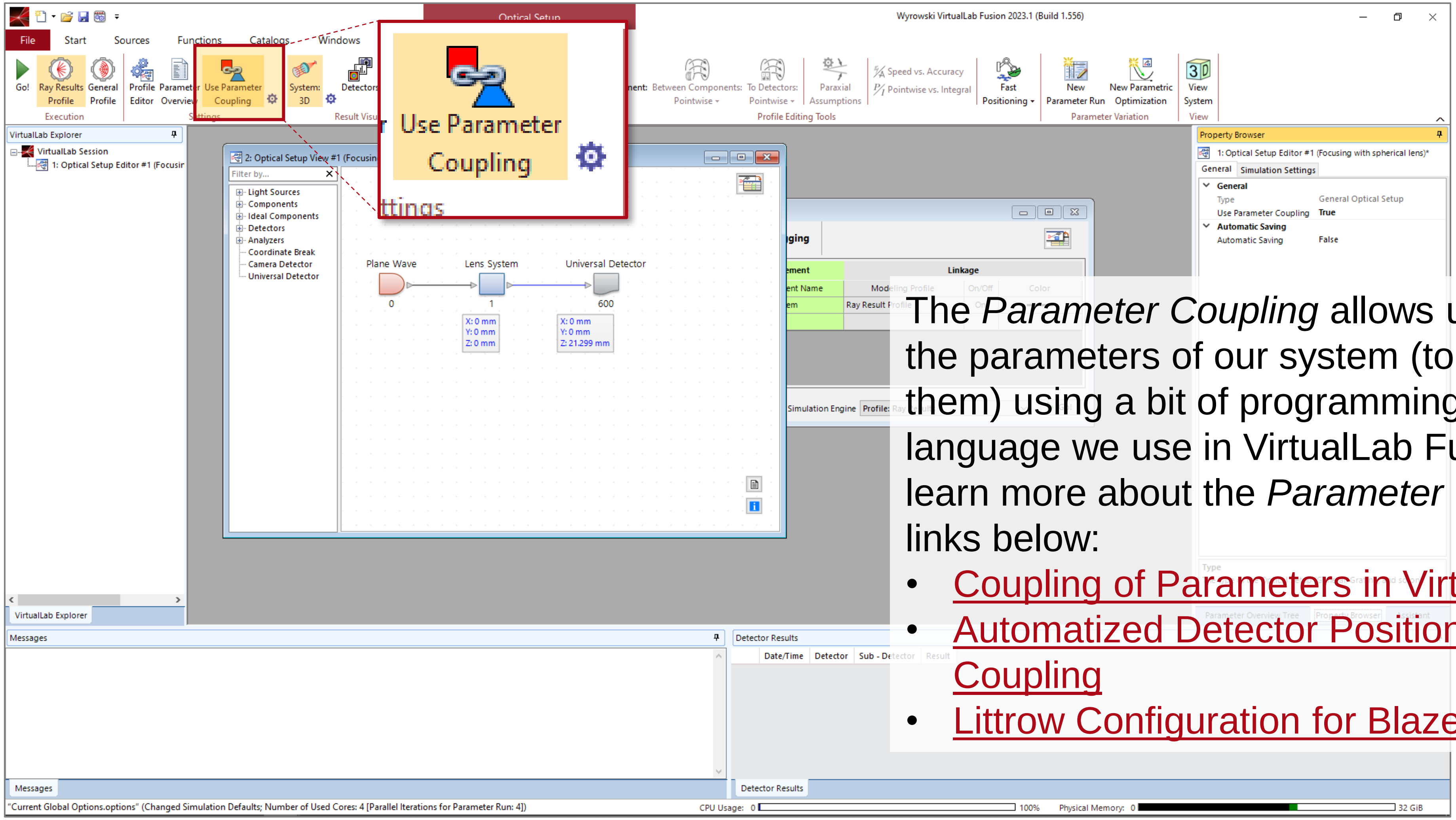
Setting Up: Find Focus Position



The option exists in VirtualLab Fusion to use the root mean square (RMS) deviation of the ray positions to automatically find the location of the geometric focus of the system and adjust the detector placement accordingly.

In this use case, however, we wonder if there is a way to automate the process, so that, when we vary certain parameters of the system using a *Parameter Run*, we can ensure that the detector is always placed at the focus, without having to manually adjust its position every time.

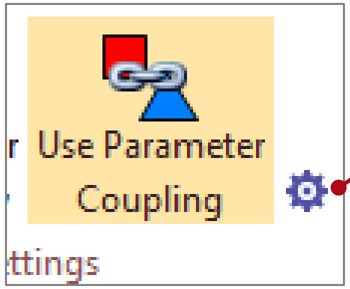
Setting Up: Automating the Process (*Parameter Coupling*)



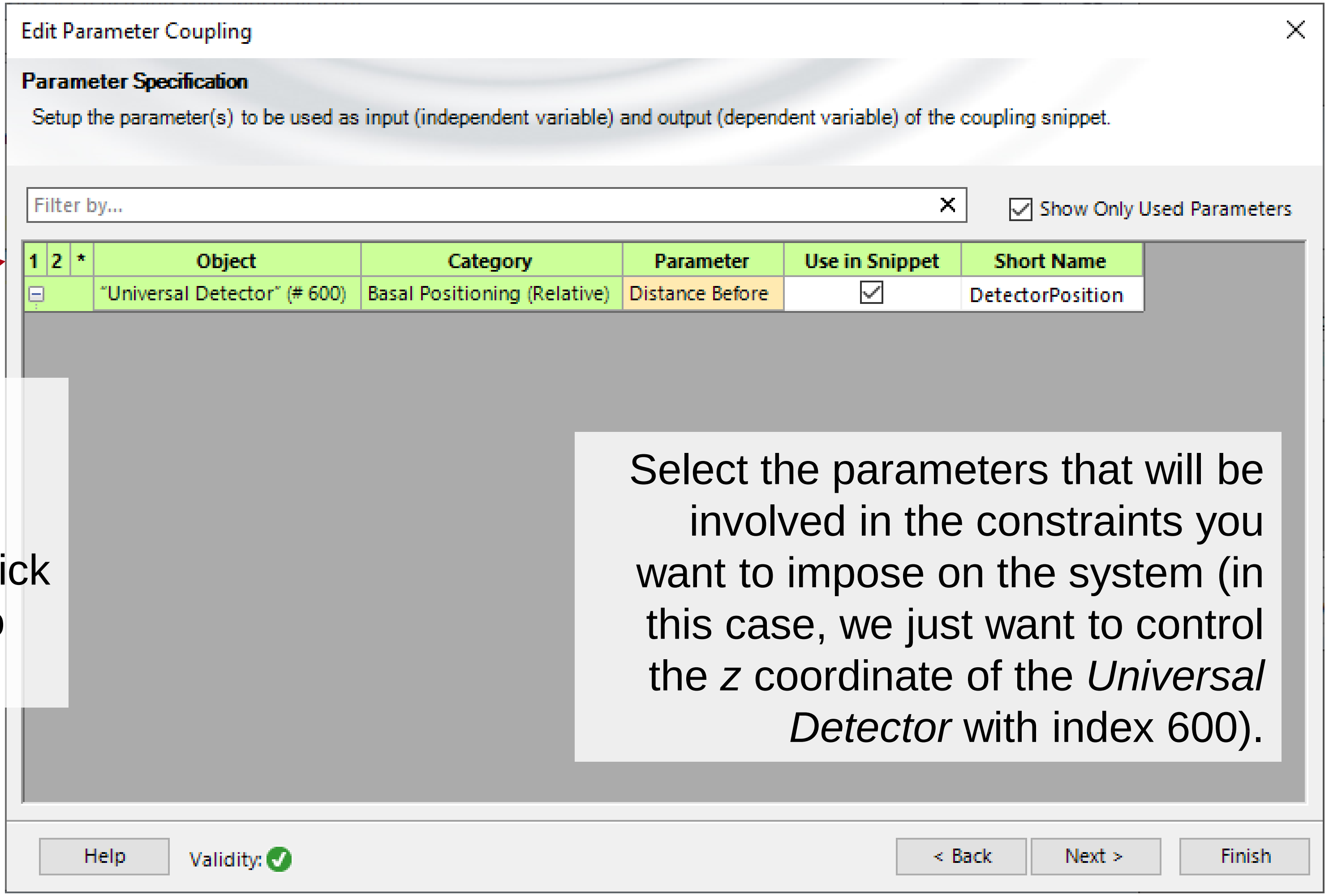
The *Parameter Coupling* allows us to apply constraints on the parameters of our system (to establish links between them) using a bit of programming. The programming language we use in VirtualLab Fusion is C#. You can learn more about the *Parameter Coupling* through the links below:

- Coupling of Parameters in VirtualLab Fusion
- Automatized Detector Positioning with Parameter Coupling
- Littrow Configuration for Blazed Gratings

Setting Up: Automating the Process (*Parameter Coupling*)



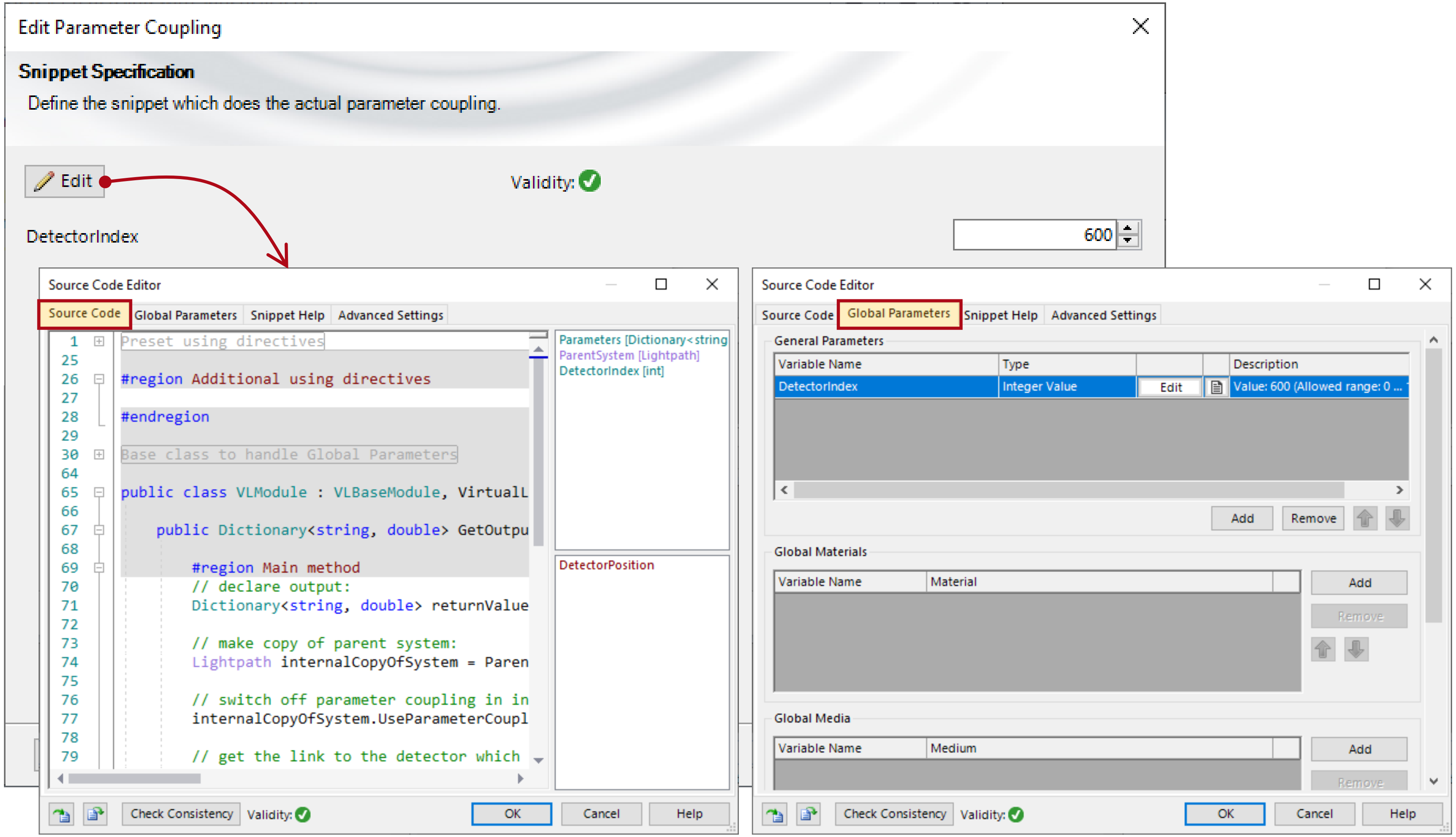
Activate the *Parameter Coupling* (it will be highlighted in yellow when it is active) and click on the cogwheel icon to set it up.



Select the parameters that will be involved in the constraints you want to impose on the system (in this case, we just want to control the *z* coordinate of the *Universal Detector* with index 600).

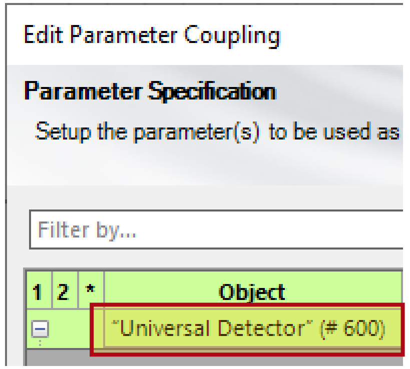
Setting Up: Automating the Process (*Parameter Coupling*)

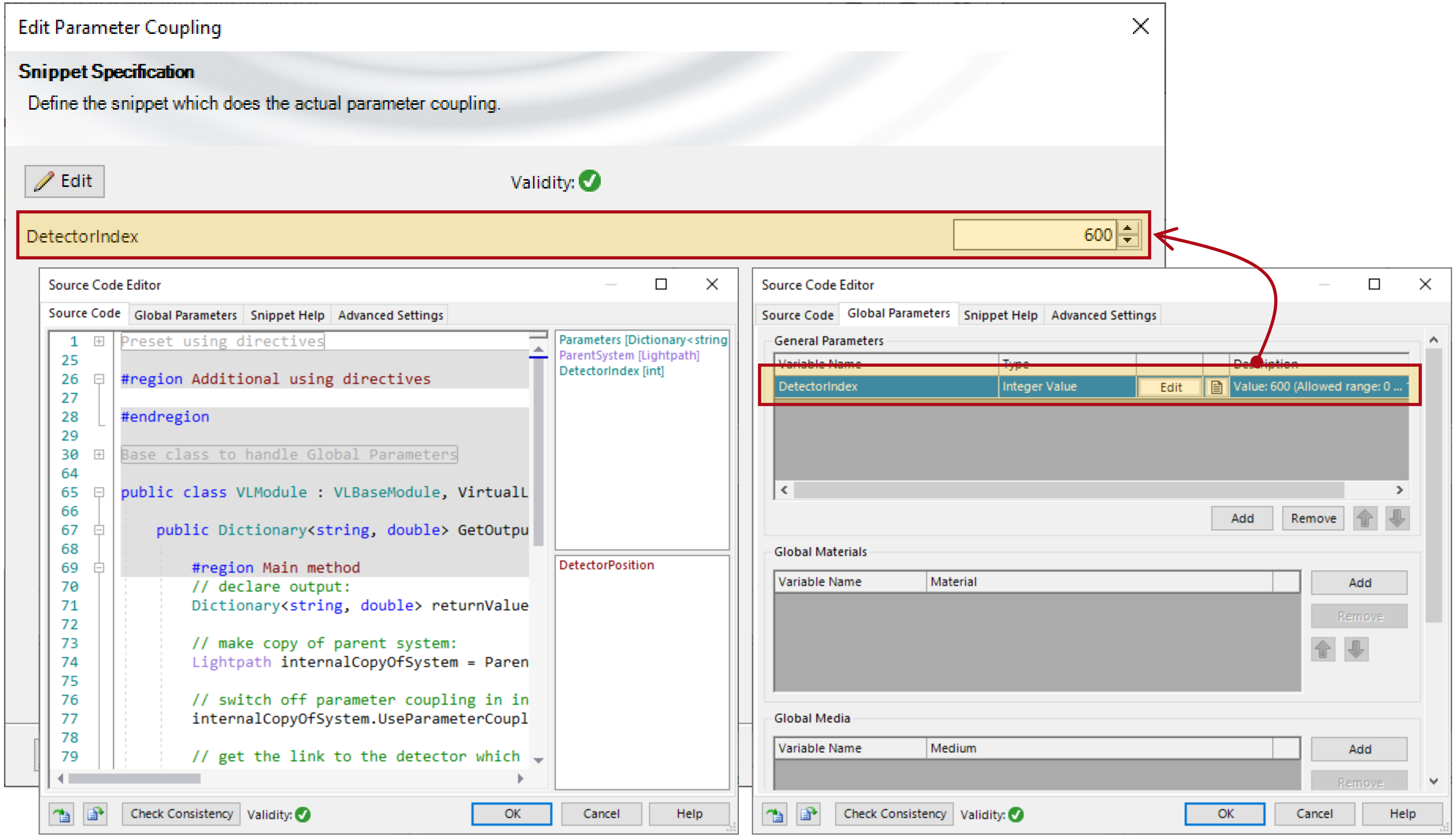
Edit the *Snippet* to implement the desired constraints. You can define additional parameters for your systems in the *Global Parameters* tab of the *Snippet*.



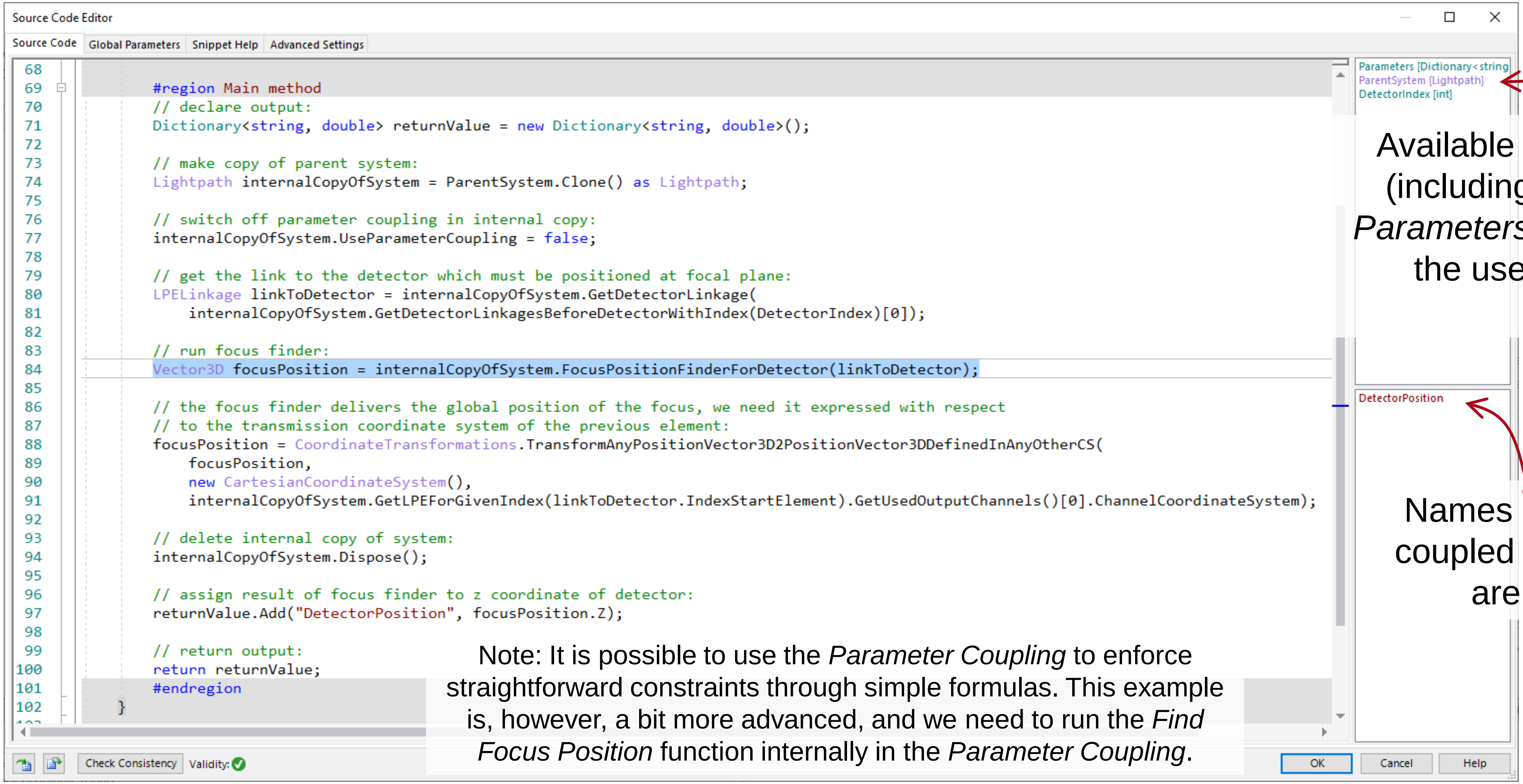
Setting Up: Automating the Process (*Parameter Coupling*)

Here, we need to know the position of which detector the *Parameter Coupling* needs to use for the focus finding, so we define a global parameter of type *int* called *DetectorIndex*. This **must** coincide with the index of the detector whose position we previously selected for coupling.





Setting Up: Automating the Process (*Parameter Coupling*)



Available parameters (including the *Global Parameters* defined by the user) are listed here.

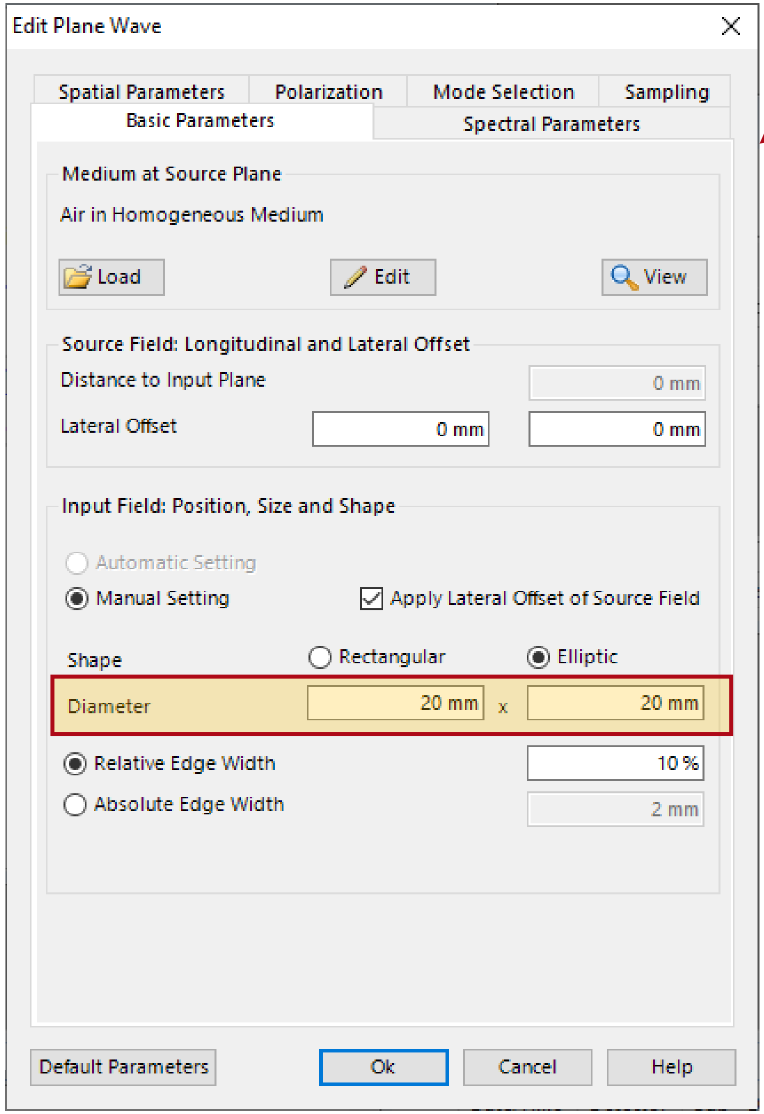
Names assigned to coupled parameters are listed here.

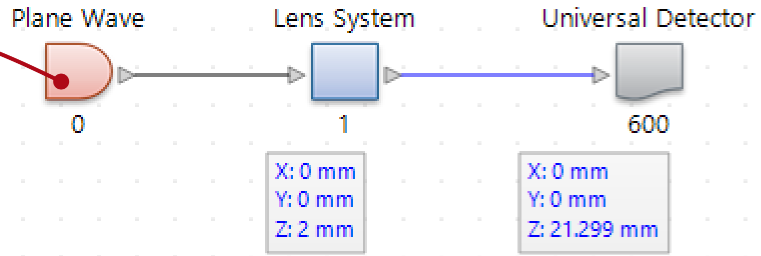
Note: It is possible to use the *Parameter Coupling* to enforce straightforward constraints through simple formulas. This example is, however, a bit more advanced, and we need to run the *Find Focus Position* function internally in the *Parameter Coupling*.

Putting the System to Use

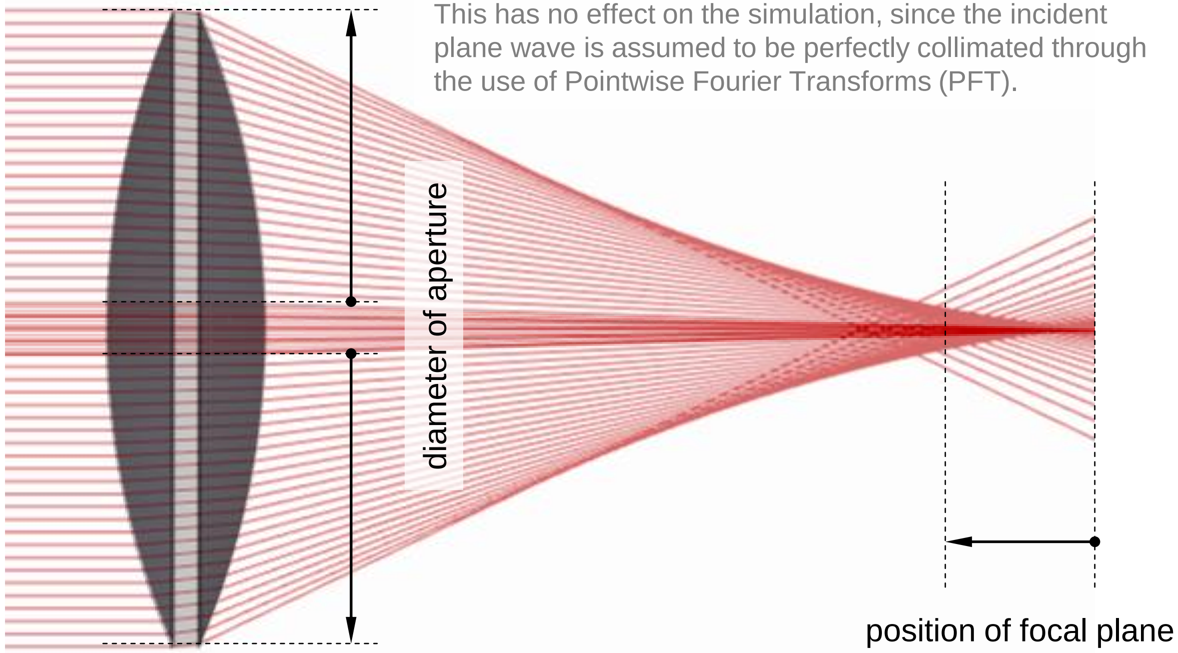
We are going to use a *Parameter Run* to vary the value of the source aperture diameter from 500 µm to 20 mm (the full aperture of the spherical lens).

The *Parameter Coupling* will remain active throughout and ensure that the detector is always placed at the z position where the RMS deviation of the ray positions is at its smallest (geometric focus).



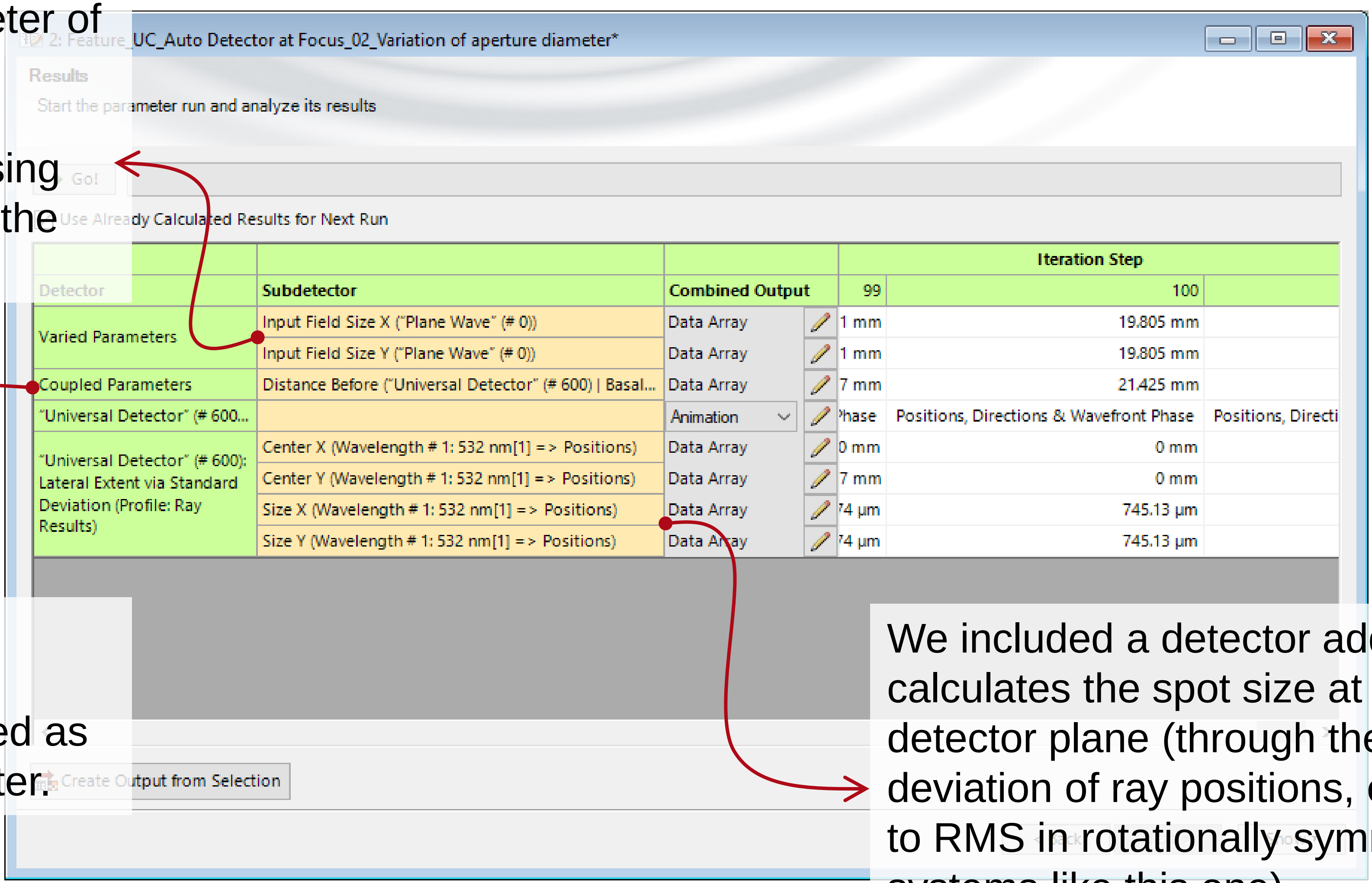


Note: we just added some distance between the source and the lens for aesthetic purposes in the 3D visualization. This has no effect on the simulation, since the incident plane wave is assumed to be perfectly collimated through the use of Pointwise Fourier Transforms (PFT).



Effect of Numerical Aperture on Geometric Focus Position

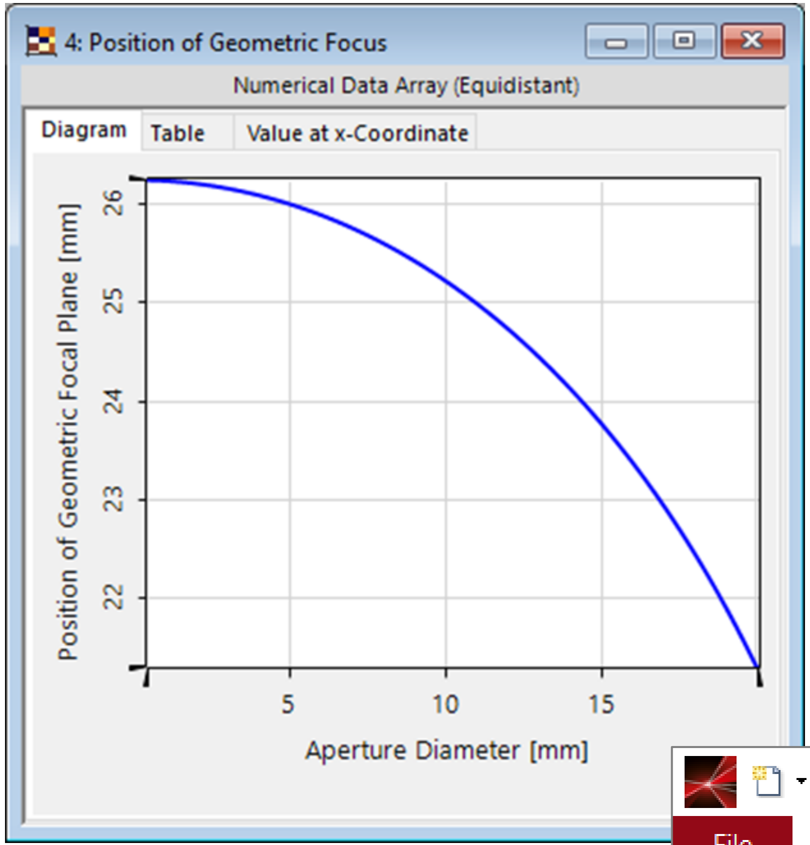
We vary the diameter of the aperture of the source in x and y simultaneously (using *Standard* mode in the *Parameter Run*).



The value of the z coordinate of the detector is delivered as a coupled parameter.

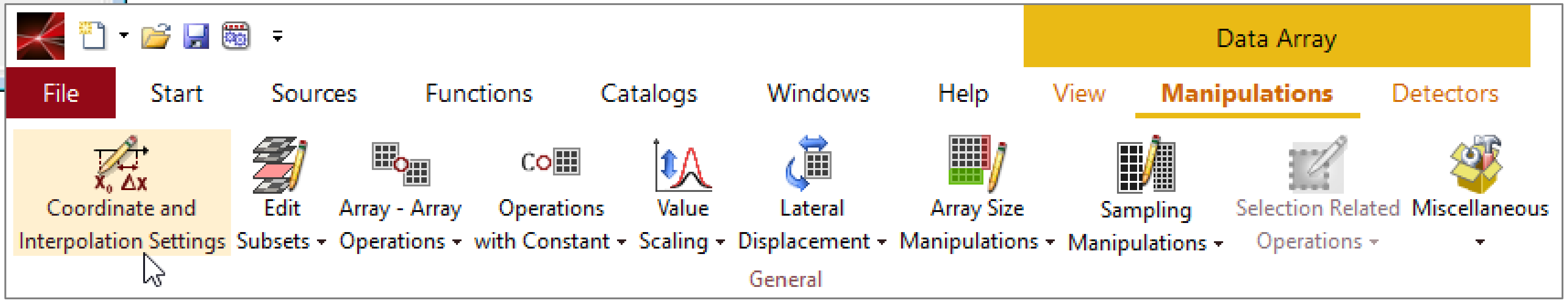
We included a detector add-on that calculates the spot size at the detector plane (through the standard deviation of ray positions, equivalent to RMS in rotationally symmetric systems like this one).

Results

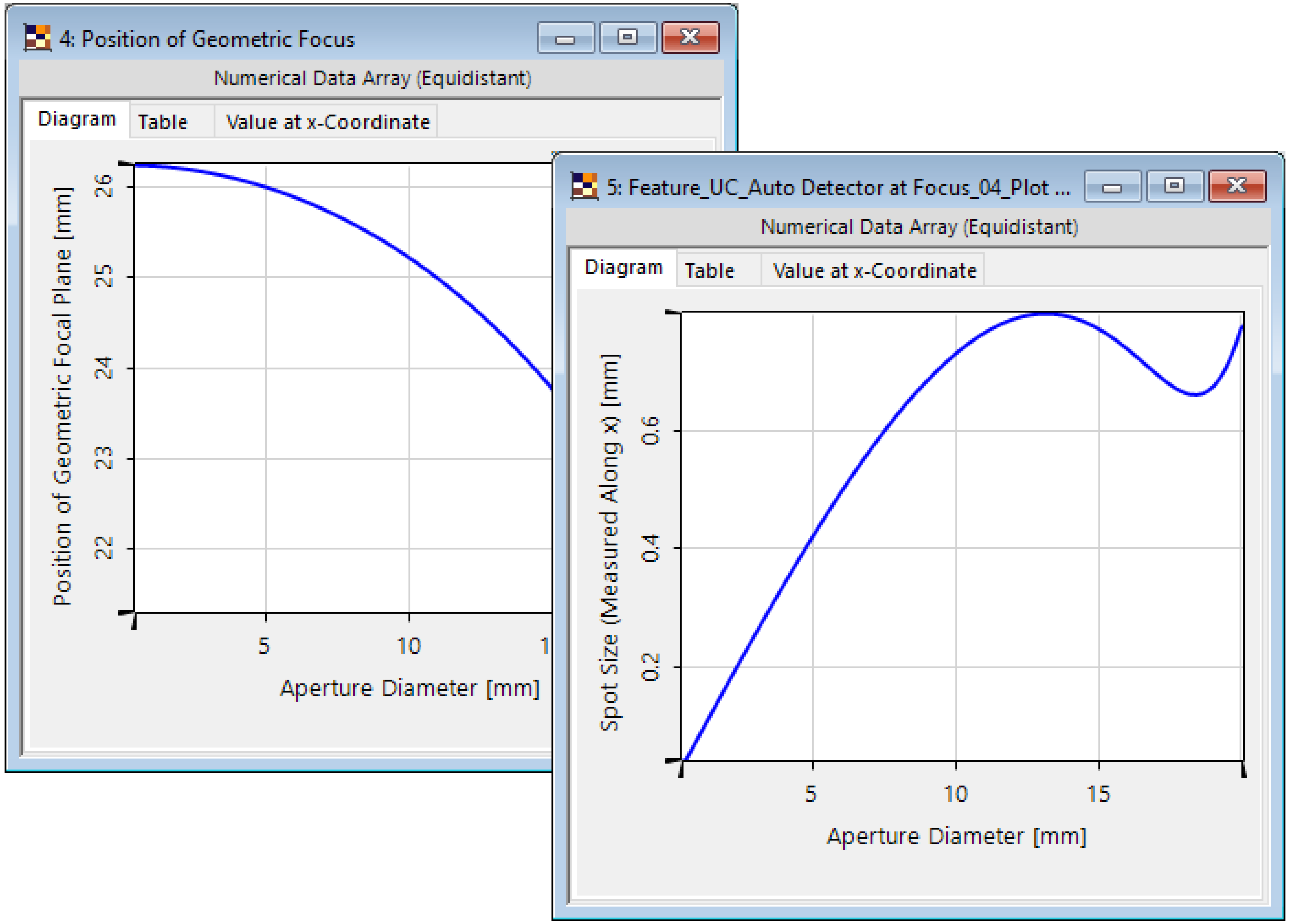


This graph plots the position along the optical axis of the geometric focal plane measured relative to the last vertex of the spherical lens, where the detector is automatically positioned thanks to the *Parameter Coupling*.

We used the *Coordinate and Interpolation Settings* (in the *Manipulations* tab) to configure the abscissa, and changed the label of the y axis through the *Property Browser*.



Results

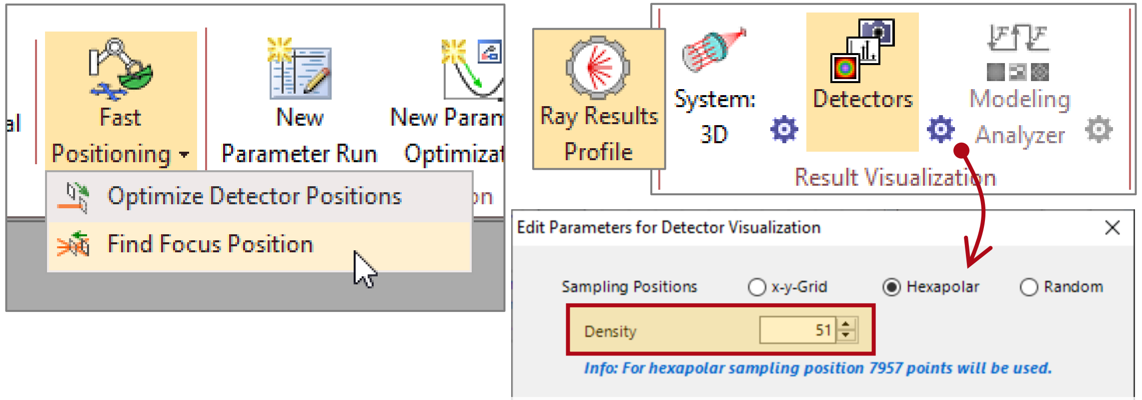


This graph plots the spot size diameter calculated as the standard deviation of the ray positions in the dot diagram at the detector plane.

Please note that the position of the detector plane is different for each of the points in this curve, and coincides with the position at which the spot size is minimum for a given value of the aperture diameter of the source.

We once again adjusted the plot using the *Coordinate and Interpolation Settings* and the *Property Browser*.

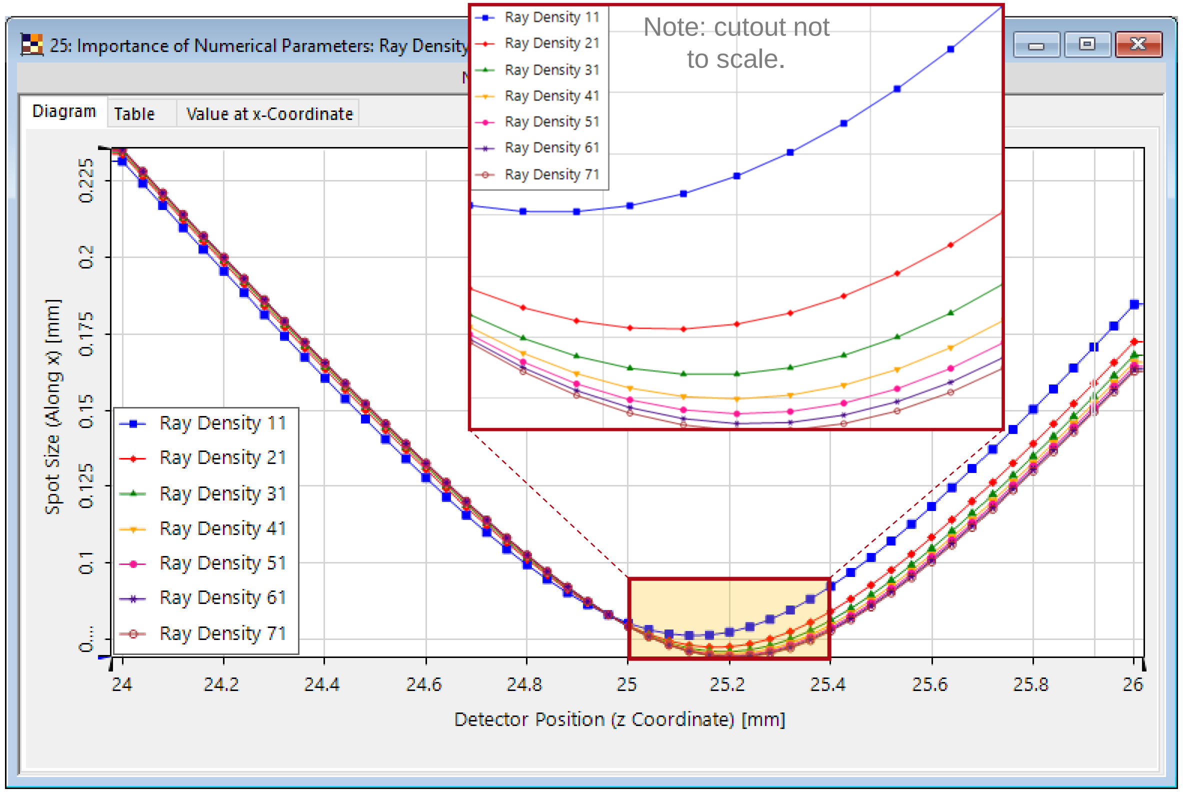
Appendix: Understanding Your Tools



The focus finder will use the *Ray Results Profile* for its internal calculation, with whatever settings are active at a given point in time.

This means that the number of ray samples configured in the *Ray Results Profile* (either *System 3D* or *Detectors*, whichever one is active) can affect the RMS calculation and consequently also the position selected by the focus finder.

The detector add-on will use whatever profile is selected for its measurement (*Ray Results* or *General*).

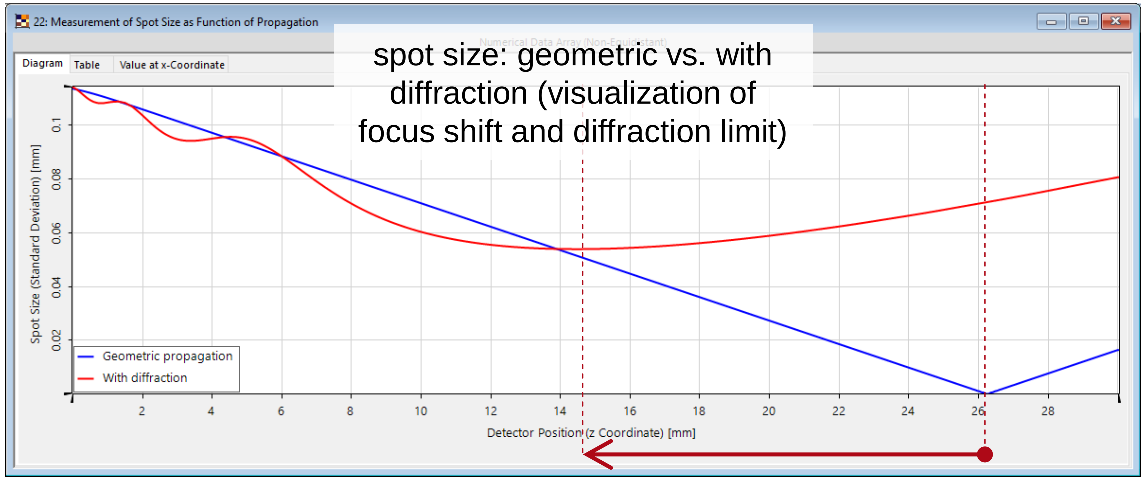


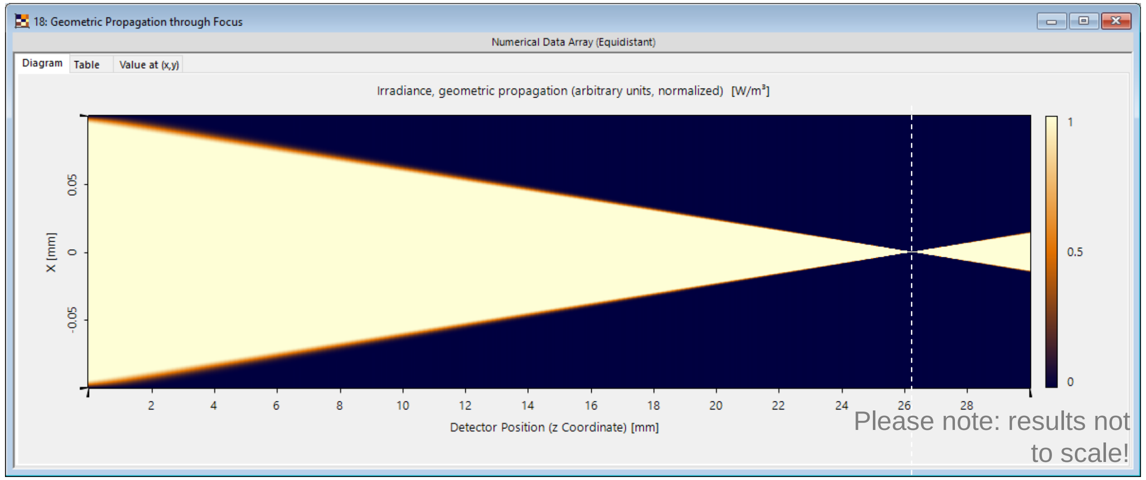
See plotted above the standard-deviation spot size as a function of detector position, for different values of ray density. Convergence of the minimum can be observed. The *Parameter Coupling* was deactivated to obtain these results.

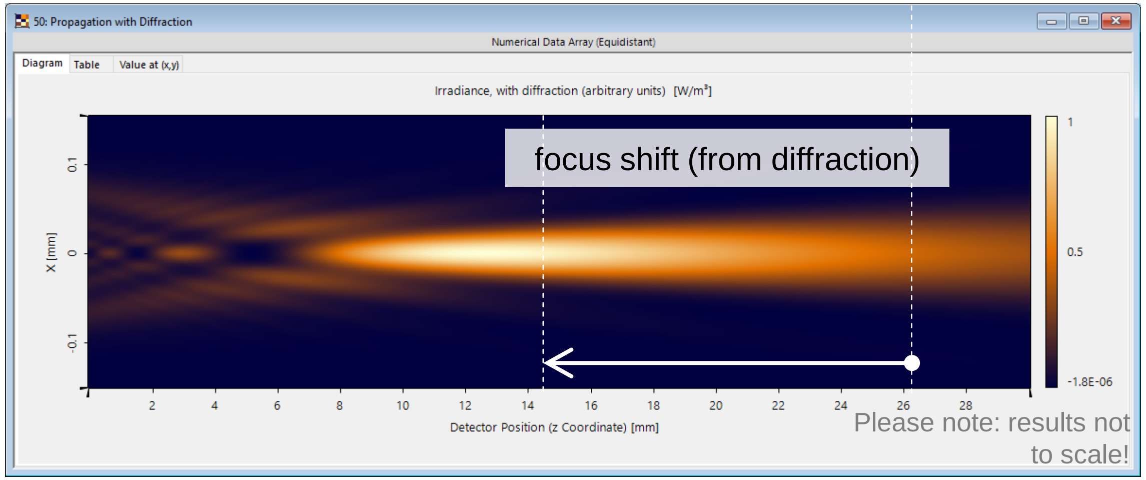
Appendix: The Role of Diffraction (200 µm Aperture)

It is well-known (especially in the case of Gaussian beams, for which there is an analytic solution, although it holds true in general) that, in paraxial systems, the presence of diffraction causes a longitudinal shift in the focus position with respect to the geometric prediction.

We have set up an extreme case (aperture 200 µm) to illustrate this with the setup we have been working with throughout this example. The *Parameter Coupling* was deactivated to obtain these results.







Learn more about simulating diffraction here:
[Free Space Propagation Settings]

Document Information

title	Analysis of Focal Plane Position as a Function of Numerical Aperture
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further reading	• Coupling of Parameters in VirtualLab Fusion • Automatized Detector Positioning with Parameter Coupling • Littrow Configuration for Blazed Gratings • Free Space Propagation Settings • Pinhole Modeling in a Low-Fresnel-Number System