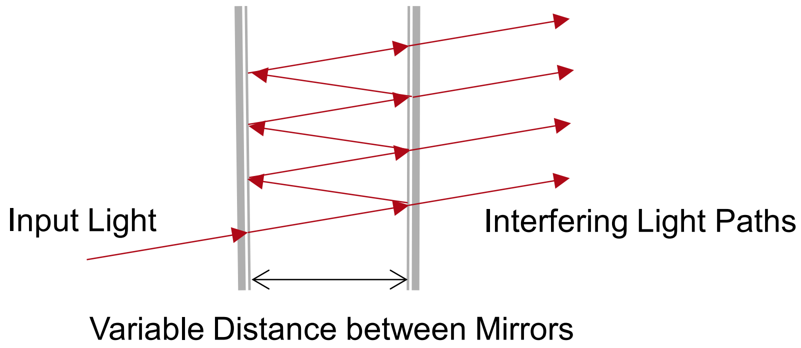
Educational Tutorial: Fabry-Pérot Interferometer

This Educational Tutorial requires no prior knowledge of VirtualLab Fusion and can be completed using the trial version of the software within two hours.

Introduction



- A Fabry-Pérot interferometer (FPI) is an optical device that employs multiple-beam interference to analyze light with exceptional precision. In its simplest configuration, it consists of two parallel, partially reflective mirrors, with the spacing between them either fixed or adjustable over small distances.
- When light enters the cavity, it partially reflects back and forth between the mirrors, creating multiple light paths that interfere with each other. Only specific wavelengths experience constructive interference, producing sharp transmission peaks. Key features include:
- Free Spectral Range (FSR): The spacing between transmission peaks.
- Finesse: The sharpness of these peaks, representing the resolution
- FPIs are extensively used in spectroscopy, laser tuning, and optical communications due to their ability to scan and isolate specific wavelengths.
- In this tutorial, we will configure an idealized Fabry-Pérot interferometer composed of two flat surfaces with mathematically defined reflectivities. A plane wave will be used as the light source, and we will record the amount of light transmitted through the interferometer.
- We will use a fixed wavelength and observe the transmission as a function of the distance between the mirrors. This analysis will be carried out for three different reflectivities.

Simulation Workflow in this Tutorial

1. Build the optical setup and perform a ray-tracing simulation. This quick simulation verifies the system's behavior and ensures that no obvious errors are present.

2. Evaluate electromagnetic fields using pointwise propagation, neglecting diffraction effects. This method remains computationally efficient.

3. Configure the detector to measure radiant flux, determining how much light passes through the interferometer. Normalize to power to simplify analysis.

4. Add partially reflecting coatings and enable non-sequential field propagation. The interferometer relies on the interference of multiple light paths.

5. Verify that the simulation converges and achieves acceptable precision. This ensures that results are reliable before proceeding further.

6. Evaluate whether diffraction must be included in the simulation to obtain accurate results. Prefer simulations without diffraction, as they are computationally faster.

7. Test the feasibility of using the paraxial approximation as another method to simplify and accelerate the simulation.

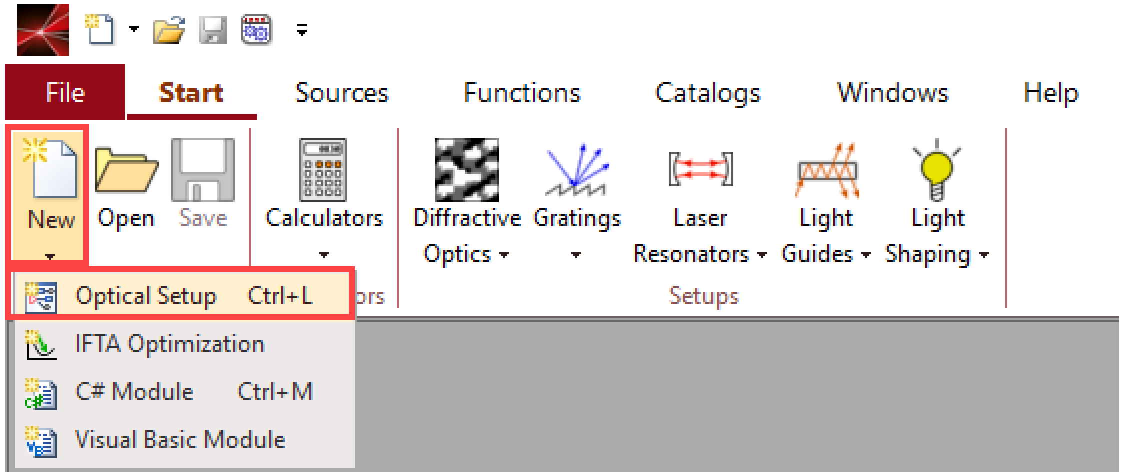
8. Lower the detector resolution to accelerate the simulation, reduce memory usage, and verify its validity.

9. Vary the length of the Fabry–Pérot Interferometer (FPI) to observe its effect on the transmission.

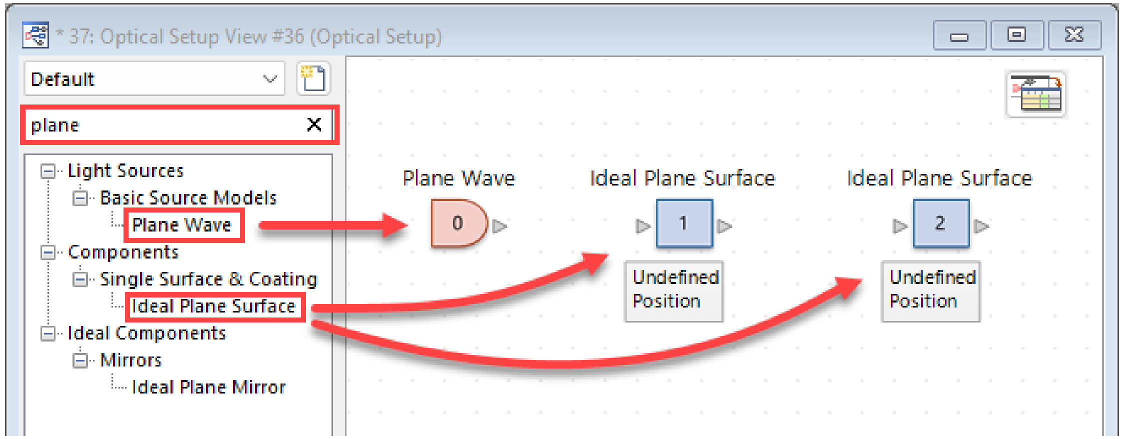
10. Simulate with increasing reflectivities. Higher reflectivity improves FPI resolution but also increases simulation time, as more light paths must be included.

Build a Setup

- Start VirtualLab Fusion
- Select *New* > *Optical Setup*

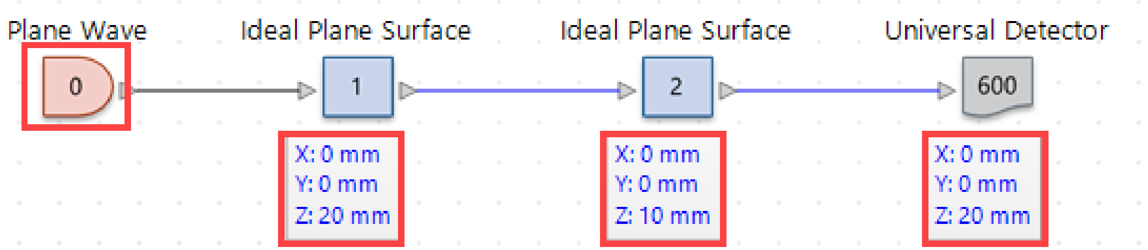


- In the *Optical Setup View* filter by plane
- Drag and drop one *Plane Wave*
- Drag and drop two *Ideal Plane Surfaces*
- Undo the filter function by clicking on the cross
- From the bottom of the list drag and drop one *Universal Detector* into the setup

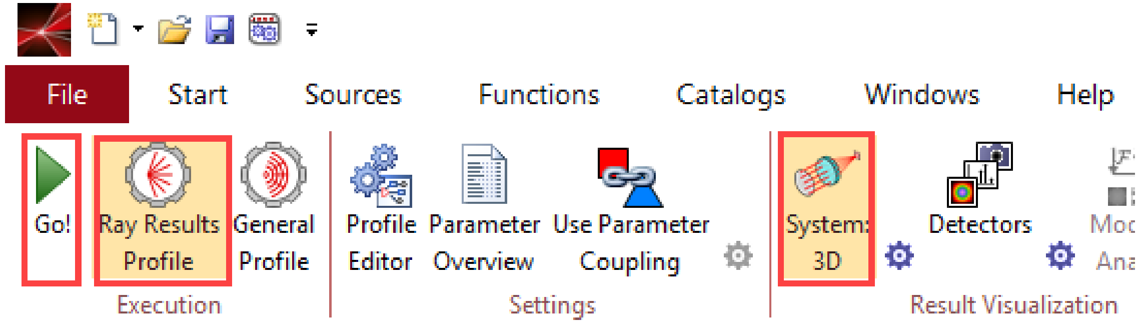


Position Elements, Perform Ray Tracing

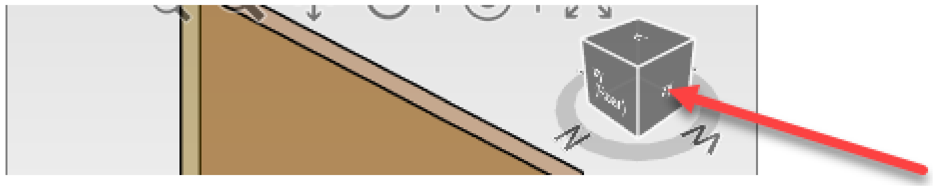
- Use the mouse to connect the elements
- Double click on the *Plane Wave* icon, select the tab *Spectral Parameters* and set the wavelength to 500 nm
- Click on the boxes below the other three elements and set the z values to 20, 10, and 20 mm. Tip: The position is with respect to the previous element



- Select *Ray Results Profile* and *System: 3D*
- Press *Go!*

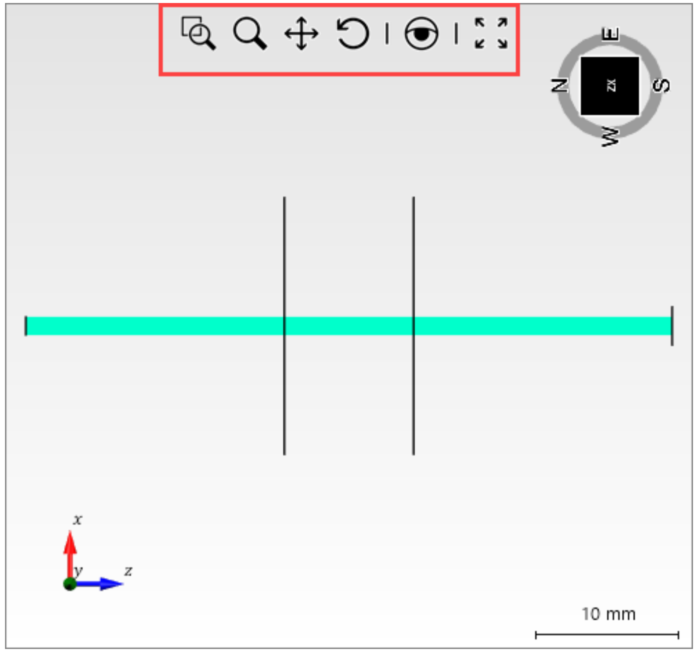


- Locate the black cube in the result window
- Click on the *zy* plane to change the perspective

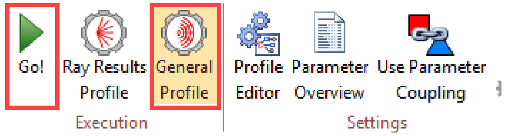


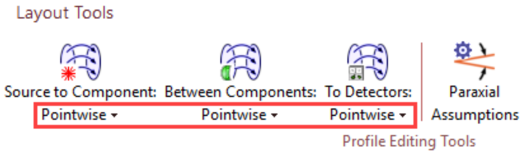
Result windows

- Verify the result window now looks like this
- Try out the tools at the top
- Right click on the result window and investigate the available tools
- Using the mouse, toggle between the result window and the setup window. Observe how the ribbon at the top adjusts based on the selected window. **Tip:** Keep this feature in mind if you cannot find a specific function

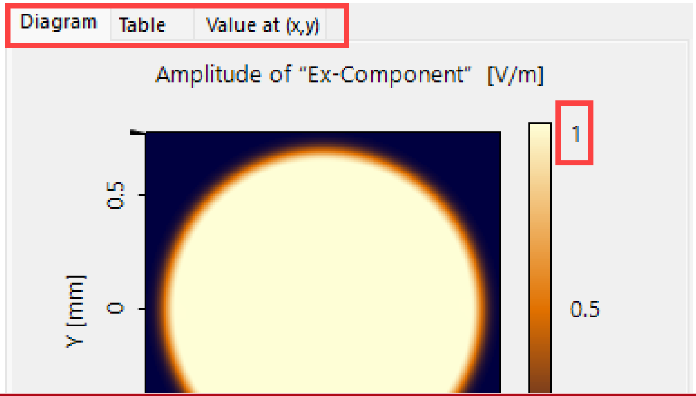


- Select the *General Profile*
- Note that all propagation is *Pointwise*
- Press *Go!*



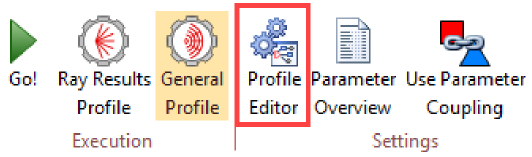


- Observe that the Ex-component is normalized to 1 V/m
- Observe the soft edge of the plane wave, reducing diffraction effects.
- Investigate the tabs *Table* and *Value at (x,y)*

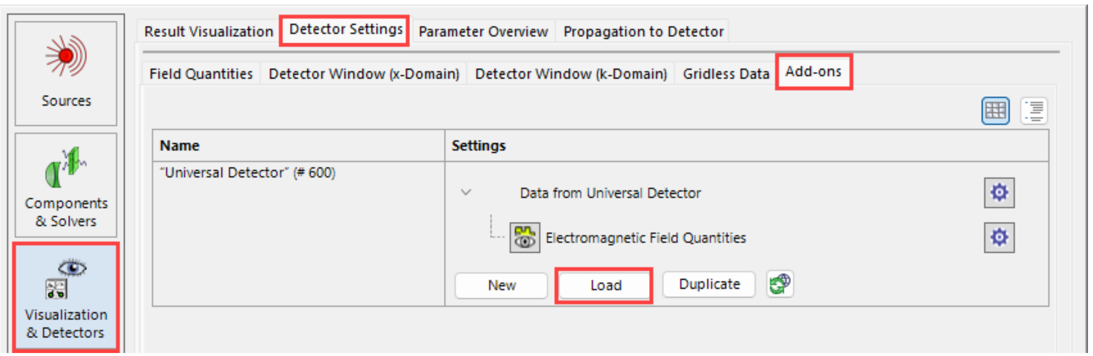


Activate the Radiant Flux Detector Add-On

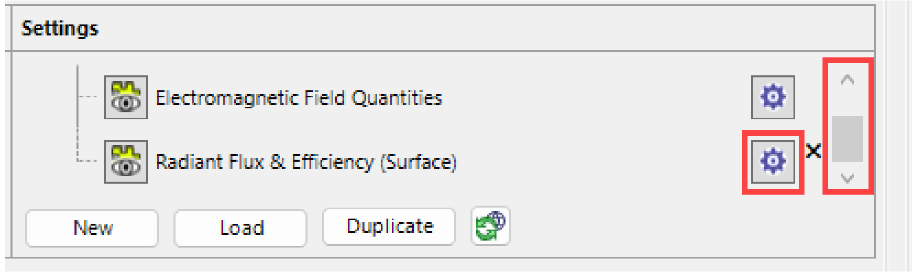
- Open the *Profile Editor*



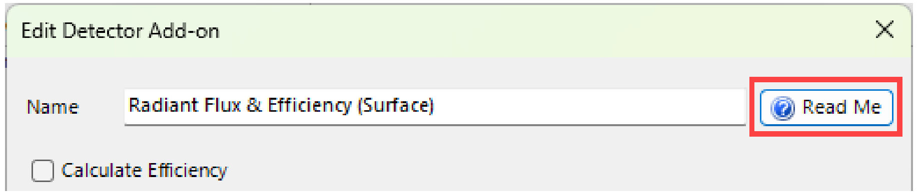
- Select *Visualization & Detectors*
- Select *Detector Settings*
- Select *Add-ons*
- Select *Load*
- From *Radiometry*, select *Radiant Flux & Efficiency (Surface)* and press *OK*



- Use the slide bar on the right to scroll down
- Click on the cog wheel

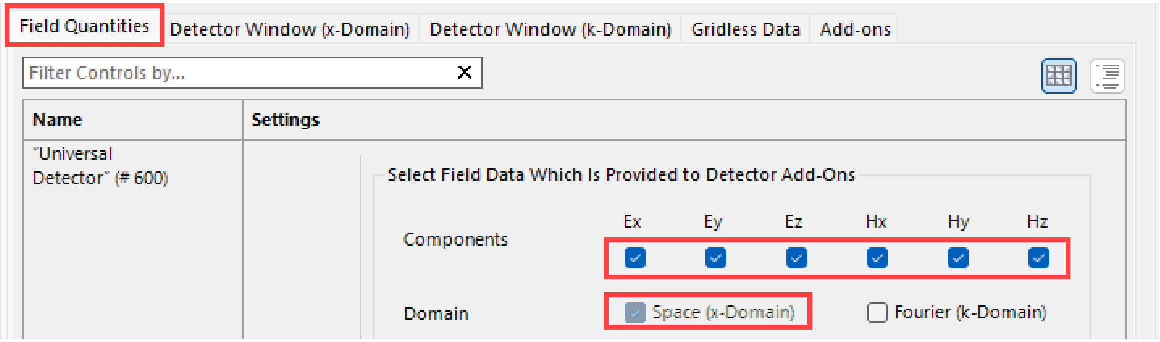


- Click on *Read Me*
- Verify that the Add-on requires all six components of the electromagnetic field in the x-domain as input

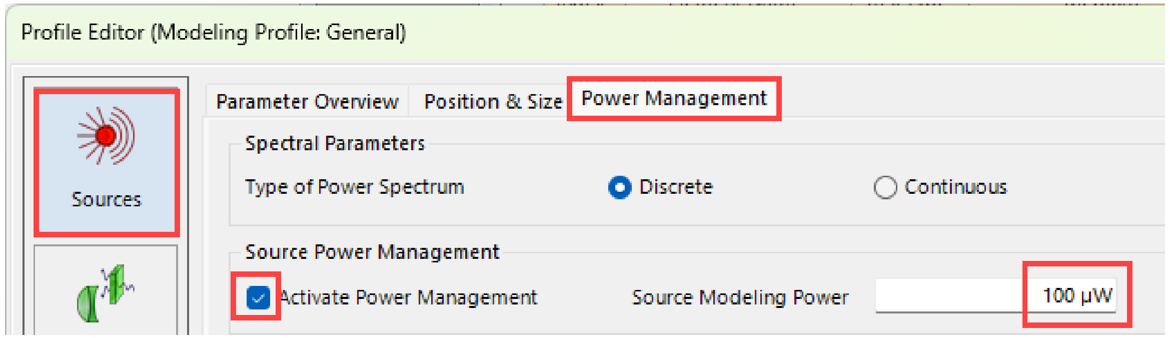


Normalize the Source Power, Set the Air Pressure

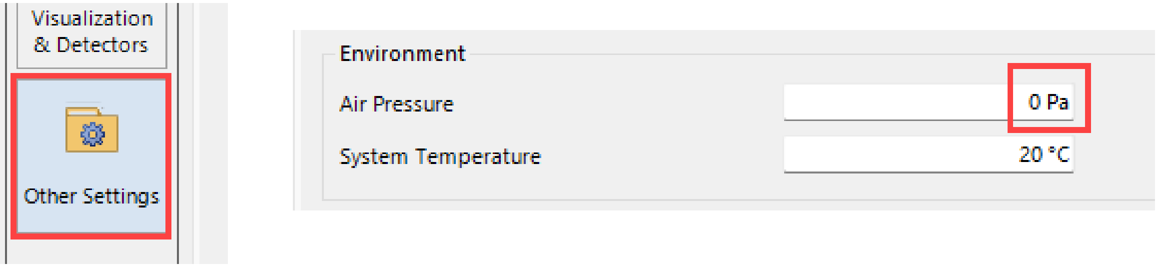
- Switch to the tab *Field Quantities*
- Observe that the x-domain is selected
- Tick all six field components



- Switch to *Sources*
- Select the tab *Power Management*
- Tick the box *Activate Power Management*
- Set the Power to 100 μW
- On keyboards without μ simply type uW
- Tip: In *Parameter Overview* it is possible to edit the *Relative Edge Width* of the *Plane Wave* source

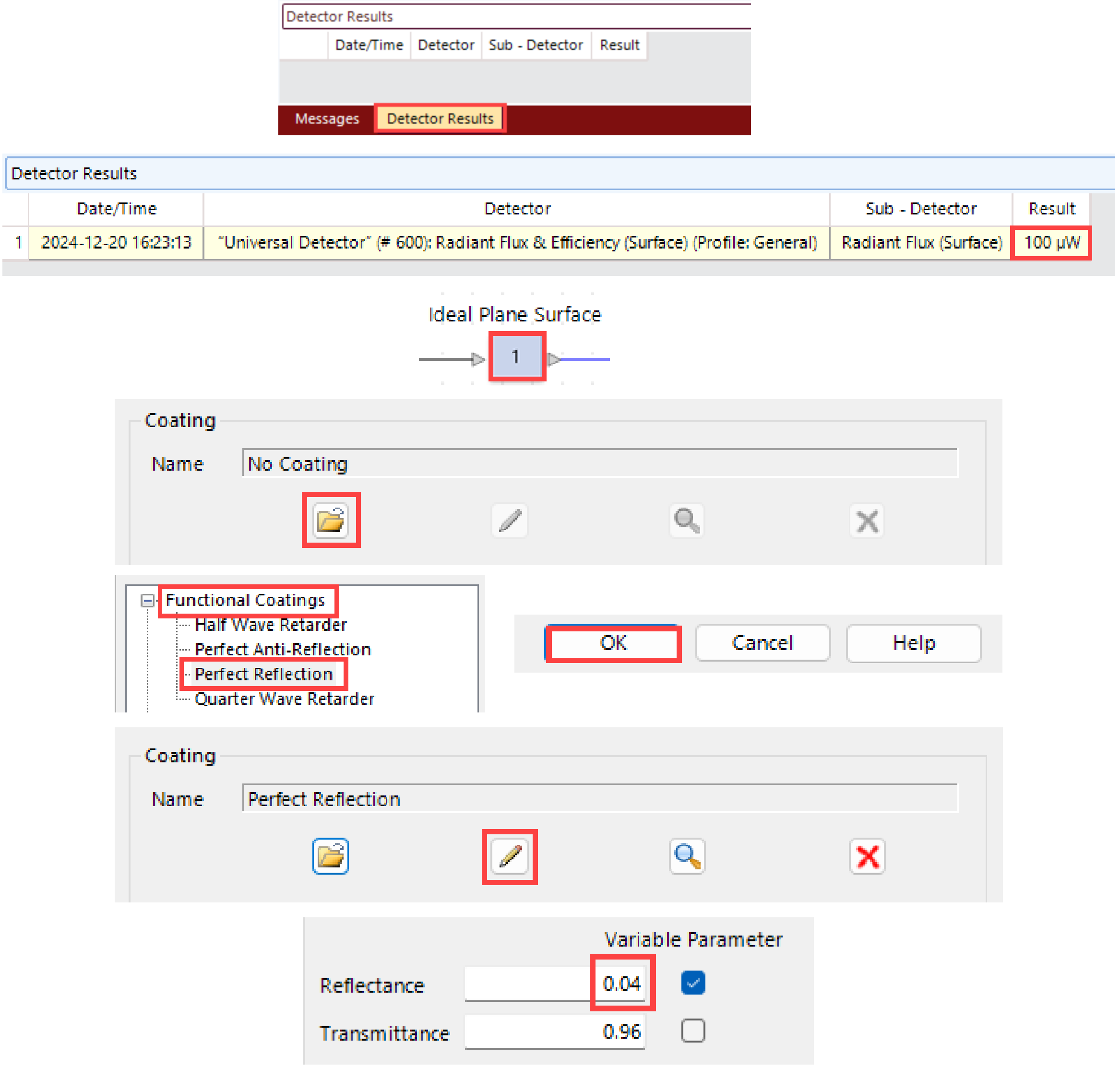


- Switch to *Other Settings*
- For demonstration purposes, set the air pressure to zero such that the wavelength equals the vacuum wavelength of 500 nm. Alternatively select *Vacuum* as the *Homogenous Medium* behind every element
- Close the *Profile Editor* by pressing *OK*



Add Coatings

- In the *General Profile*, click *Go!*
- Locate the *Detector Results* window (normally at the bottom of the VLF master window, together with the *Messages* window)
- Verify that the *Radiant Flux* equals 100 µW
- Double-click on the icon of the first *Ideal Plane Surface*
- Click on the load icon in the coating panel
- From *Functional Coatings*, select *Perfect Reflection*
- Press *OK*
- Click on the edit icon in the coating panel
- Set the *Reflectance* to 0.04 (uncoated glass), press *OK*
- Add the same coating to the second *Ideal Plane Surface*



Set the Light Path, Check the Convergence

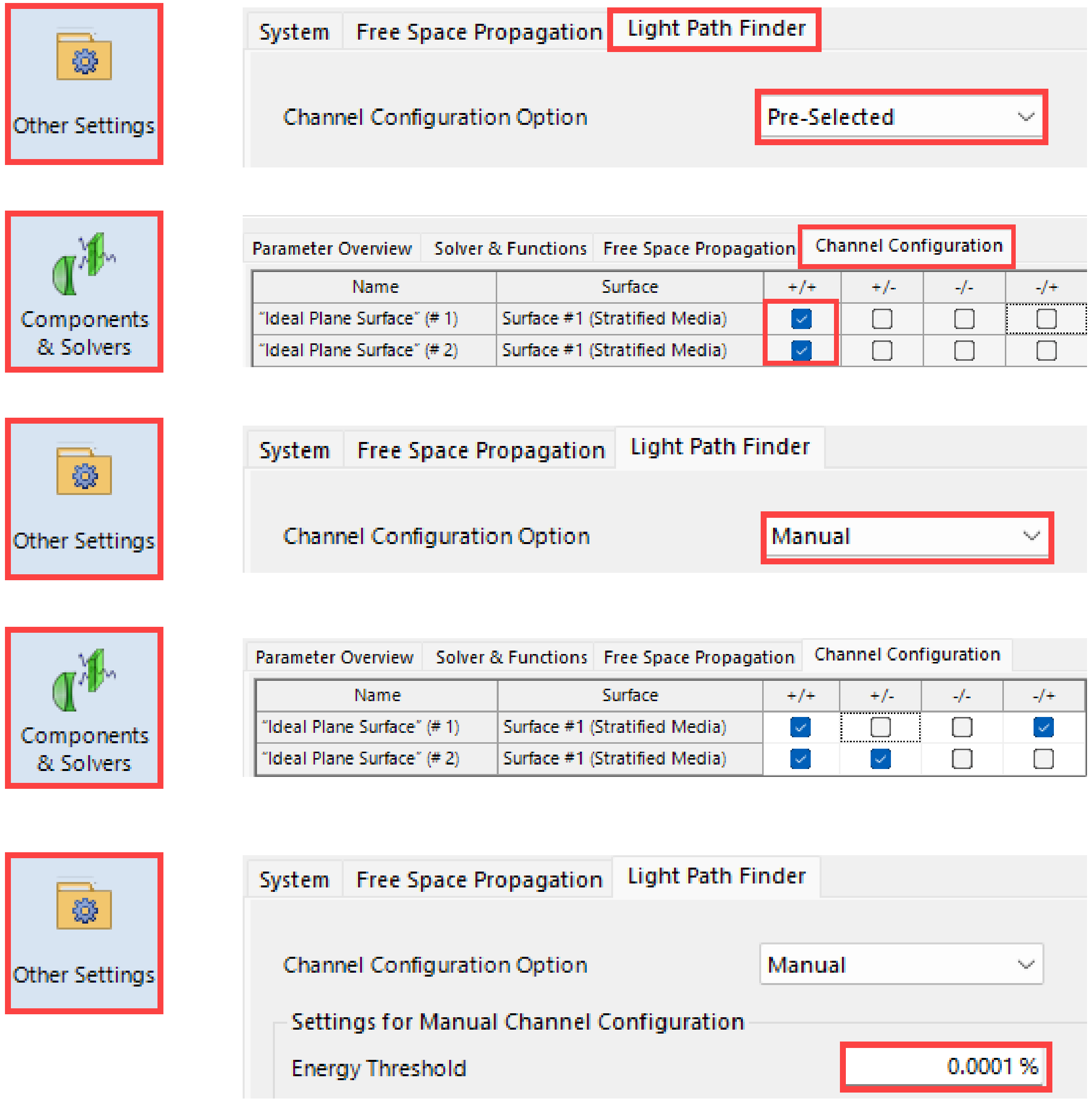
- In the *General Profile*, click *Go!*
- Verify that the *Radiant Flux* equals 92.16 µW
- Open the *Profile Editor*, select *Other Settings* and *Light Path Finder*

- Observe that the *Channel Configuration* is set to *Pre-Selected*
- In *Components & Solvers*, select *Channel Configuration*
- Observe that only the +/+ channels (forward transmission) are selected
- In the *Light Path Finder* switch to *Manual*

- Edit the *Channel Configuration* and enable the modeling of light bouncing between the two surfaces. Press *OK*

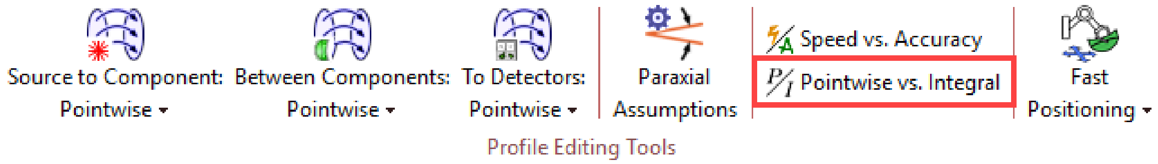
- Run the simulation and observe the *Radiant Flux*

- Open again the *Light Path Finder* and set the *Energy Threshold* to 0.0001%
- Repeat the simulation and observe the *Radiant Flux*

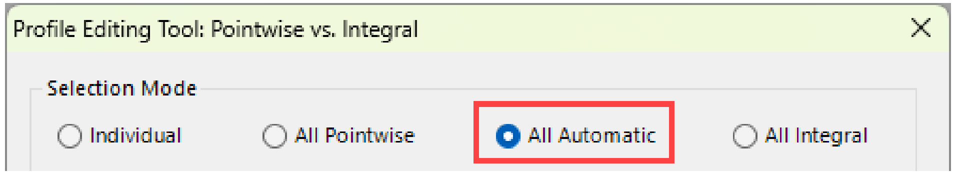


Verify Pointwise vs. Integral and Paraxial Assumptions

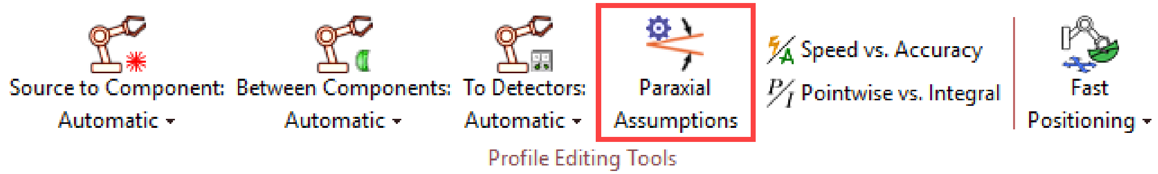
- Select *Pointwise vs. Integral*



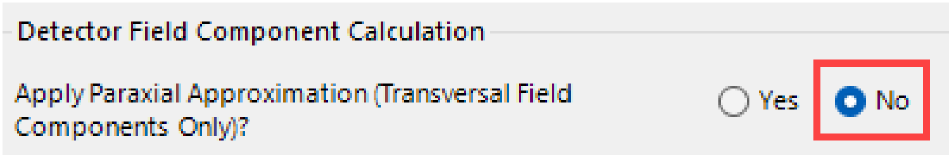
- Change to *All Automatic*, enabling diffraction
- Run the simulation
- Compare the *Radiant Flux* with the previous value



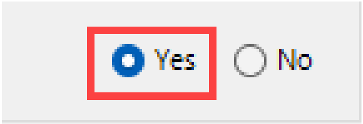
- Select *Paraxial Assumptions*

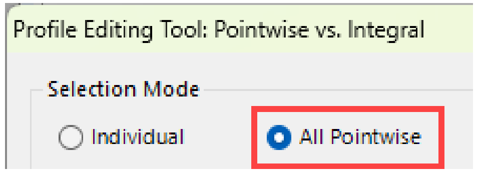


- Switch off the *Paraxial Approximation* by selecting *No*
- Run the simulation
- Compare the *Radiant Flux* with the previous value



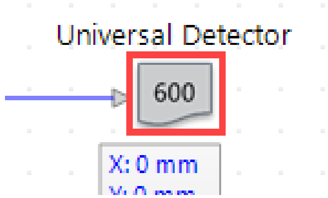
- Switch the *Paraxial Approximation* back on again
- Set *Pointwise vs. Integral* to *All Pointwise* to switch diffraction off





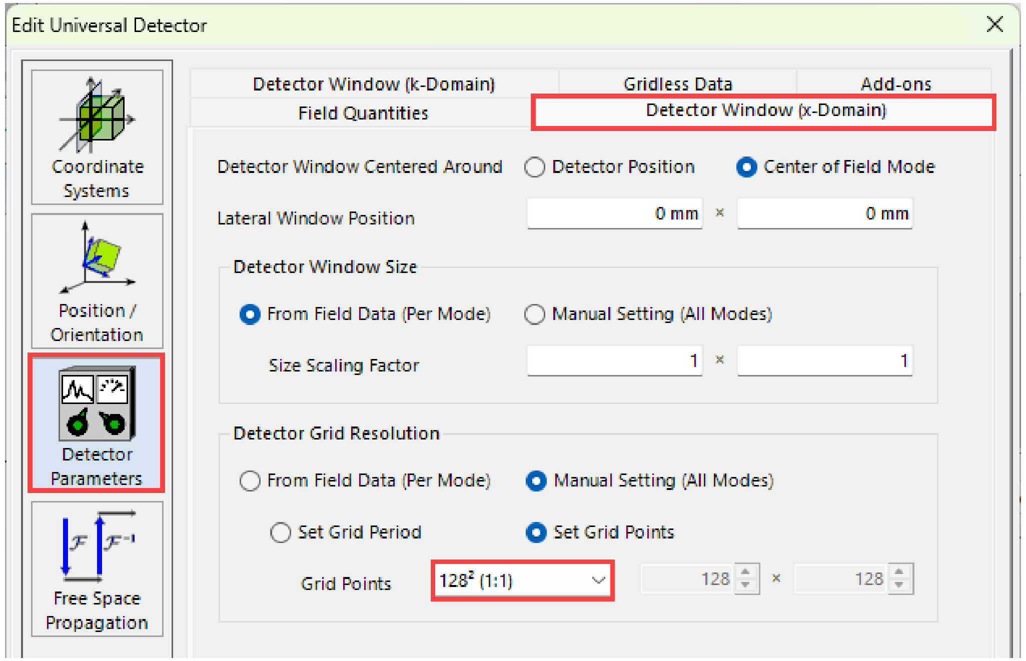
Lower Detector Resolution, Reduce Memory Usage

- Double click on the icon of the *Universal Detector*



- Under *Detector Parameters*, select the *Detector Window (x-Domain)* tab
- Set the number of *Grid Points* to the lowest value
- Click *OK* and run the simulation
- Compare the *Radiant Flux* with the previous value to verify the validity of using a lower resolution

- Tip: The *Edit Universal Detector* window appears differently when the *Ray Results Profile* is active



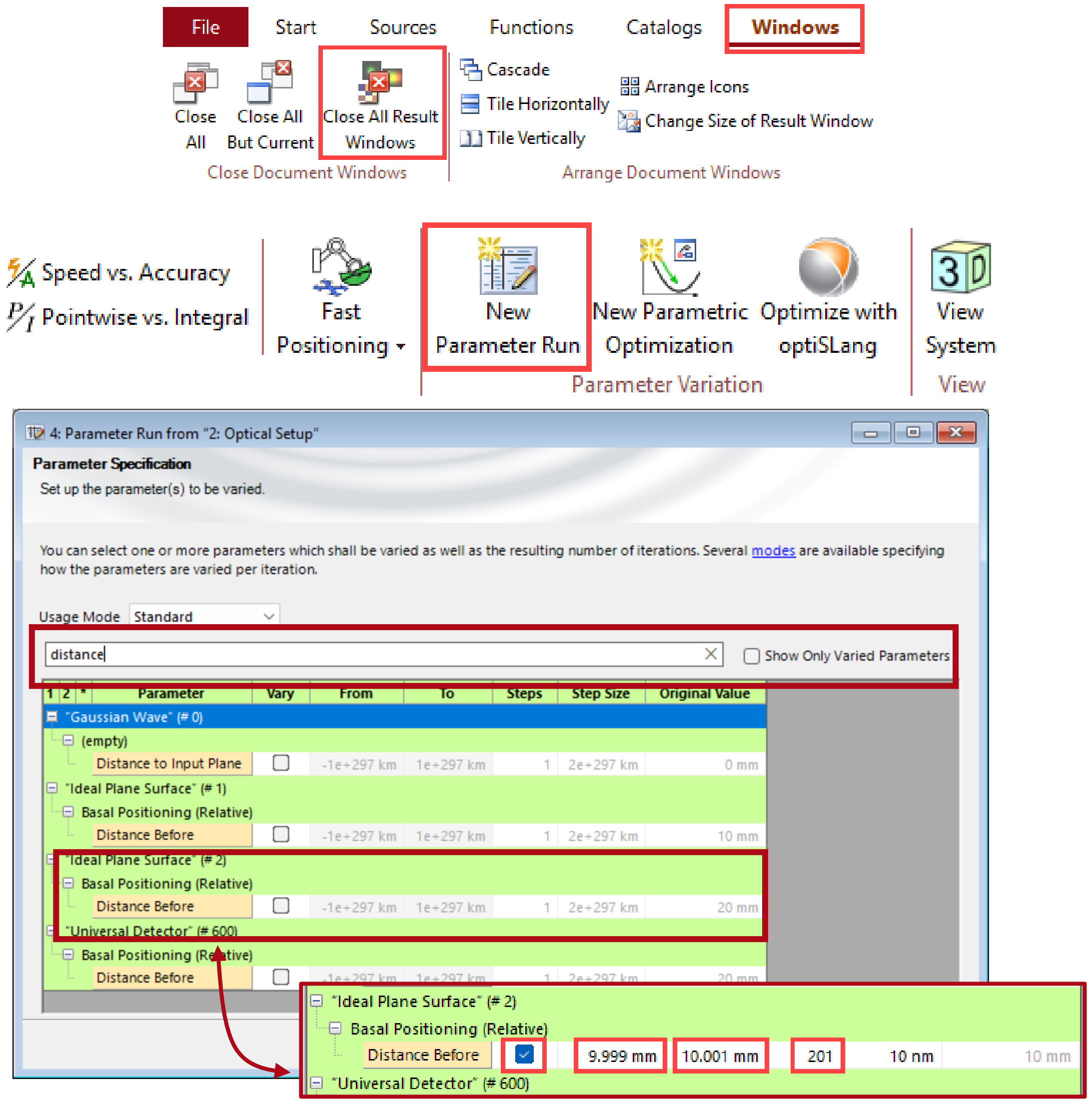
Vary the Distance Between the Mirrors

- Clean up the work space by clicking *Close All Result Windows* in the Windows ribbon
- To clean up the *Detector Results* window, right-click on it and select *Clear Detector Results* from the menu

- Ensure that the *General Profile* is active
- Select *New Parameter Run*
- Click *Next*

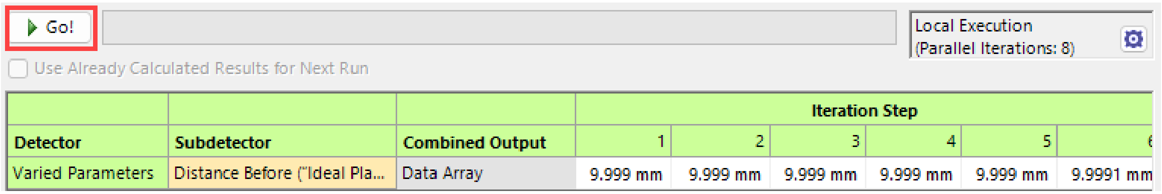
- In the filter function start typing *distance*
- Observe that *dis* suffices
- Locate the value *10 mm*
- The corresponding parameter will be varied

- Tick the appropriate checkbox
- Enter *From 9.999 mm*, *To 10.001 mm* and *Steps 201*
- Observe that *Step Size* automatically updates to 10 nm

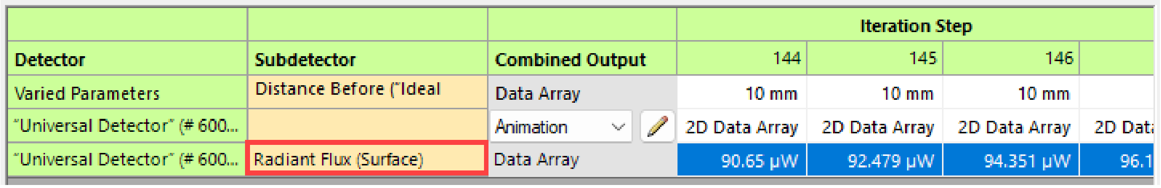


Execute the Parameter Run

- Click *Next* three times
- Press *Go!*
- Let the simulation finish



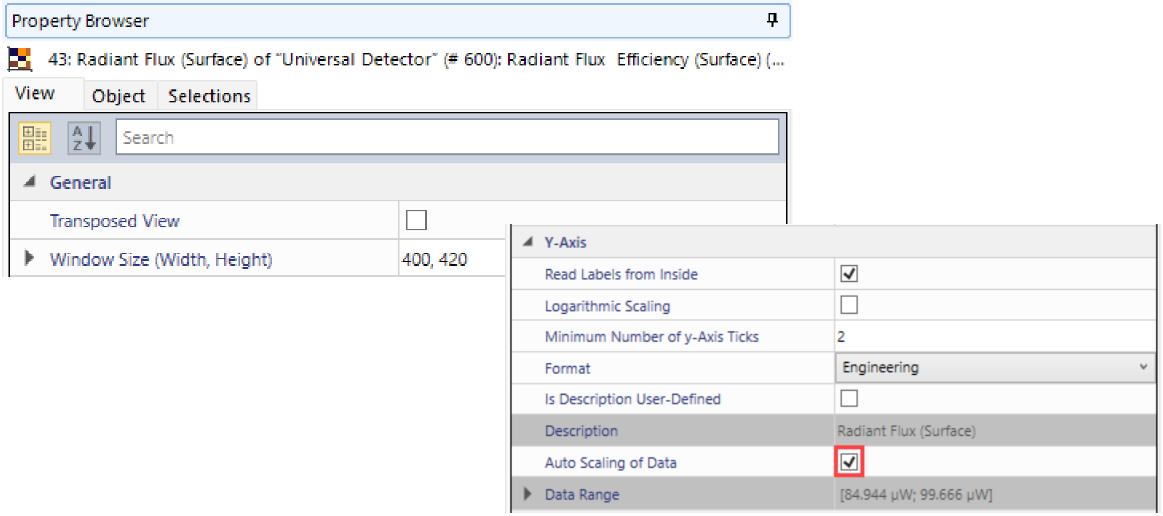
- Click on *Radiant Flux* to select the row



- Click on *Create Output from Selection*

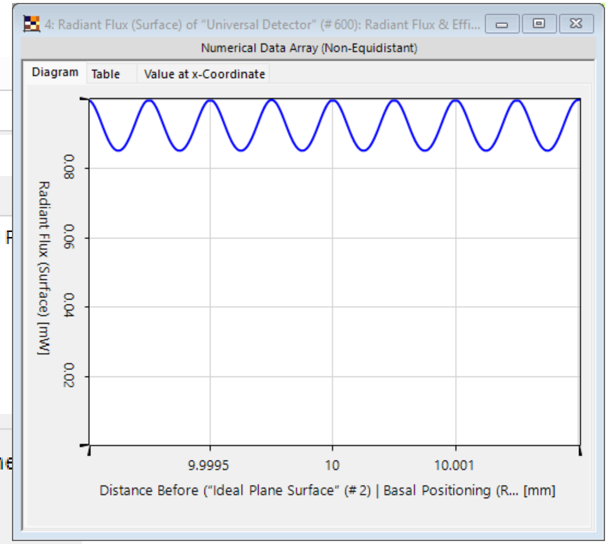
- With the *Result Window* selected, find the *Property Browser.*
- Tip: The *Property Browser* and the *Assistant* window are usually separate tabs within the same window located on the right side of the VLF Master window

- Locate the properties of the *Y-Axis*
- Uncheck the *Auto Scaling of Data*

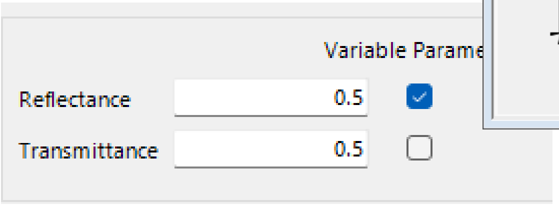


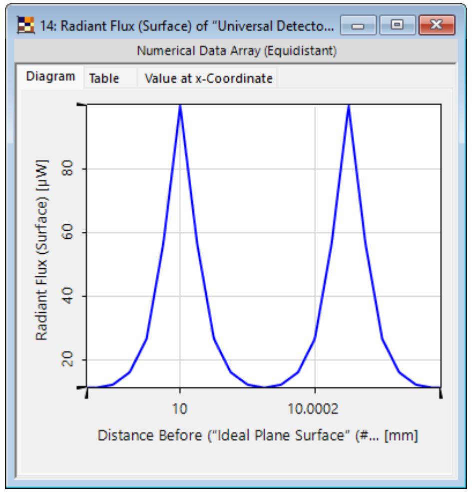
Optimize the Visualization of the Data

- Set the *Data Range* from 0 to 100 µW
- Tip: The *X-Axis Description* can be changed in its properties settings



- Click on the icon of the first *Ideal Plane Surface*
- Click *Edit Coating*
- Set the *Reflectance* to 0.5
- Do it for both Surfaces
- Run the simulation and observe the *Radiant Flux*
- In *Light Path Finder* set *Energy Threshold* to 1e-6 %
- Repeat the simulation and observe the *Radiant Flux*

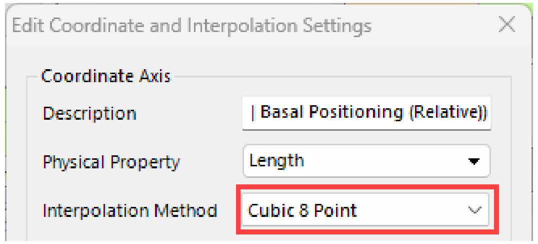


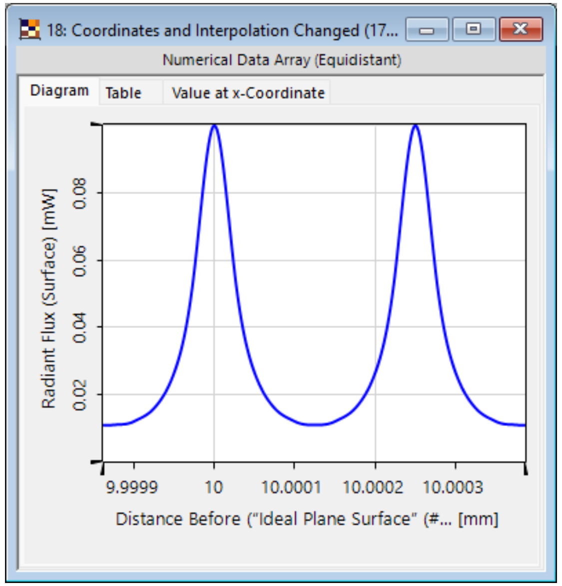


- Start a *New Parameter Run*
- *From* 9.999875 mm, *To* 10.000375 µm, *Step Size* 25 nm
- Execute the *Parameter Run* and generate a plot
- Ensure under *File/Global Options* that the *Number of Significant Digits* equals at least 10

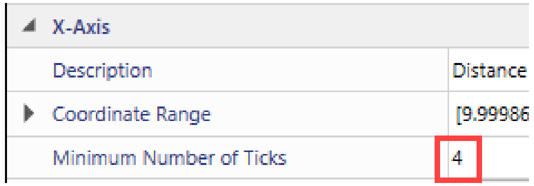
Visualization: Adjust the Interpolation

- Set the *Y-Axis Data Range* from 0 to 100 µW
- Under the *Manipulations* ribbon, select *Coordinate and Interpolations Settings*, and switch to *Cubic 8 Point*

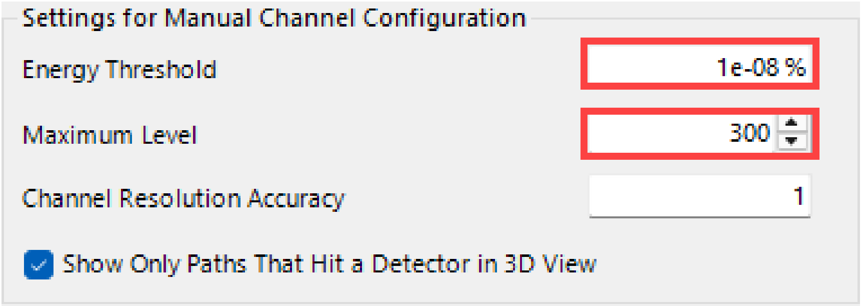




- In the *Property Browser*, set *Minimum Number of Ticks* to e.g. 4



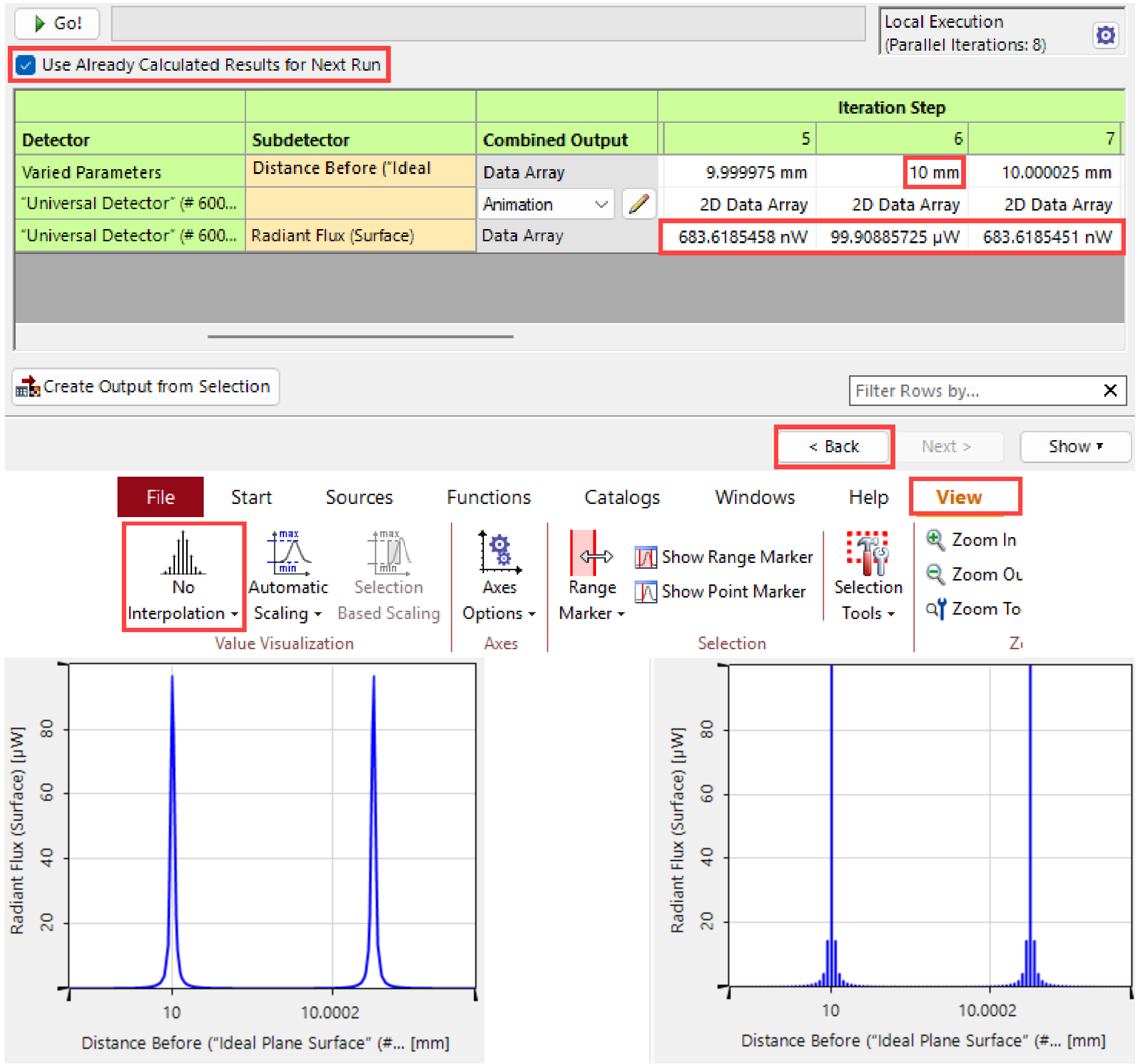
- Set the *Reflectance* to 0.95 for both Surfaces
- Run the simulation and observe the *Radiant Flux*
- In *Light Path Finder* set *Energy Threshold* to 1e-8 % and set the *Maximum Level* to 300
- Repeat the simulation and observe the *Radiant Flux*



Final Simulation

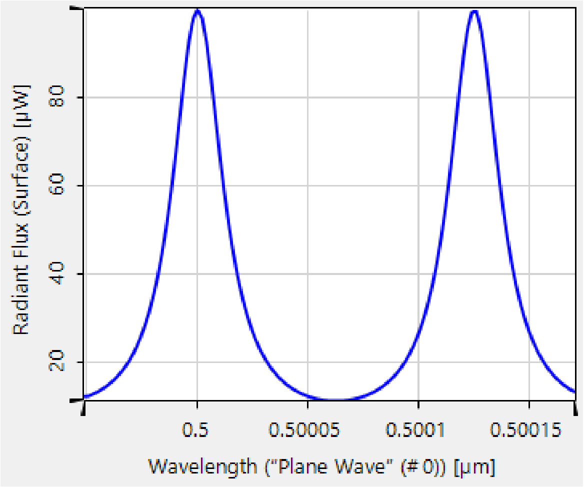
- Warning: The following parameter run may last several minutes. For a quicker but inaccurate simulation limit the number of light paths by setting the *Maximum Level* to 50. The effect is still visible

- Execute a *New Parameter Run* from 9.999875 mm to 10.000375 mm with *Step Size* 25 nm and generate a plot
- Observe the values around the peak at 10 mm
- Ensure the box *Use Already*… is checked
- Click *Back* several times and change the *Step Size* to 5 nm
- Click *Next* several times and press *Go!*
- Generate plot
- In the *View* tab, try out *No Interpolation* and *Pixelated Interpolation*
- Reselect *Interpolated View*
- Under *Manipulations* try out different *Interpolation Settings*

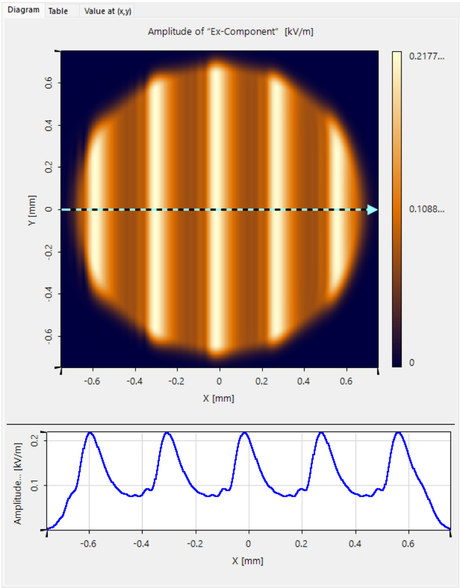


Ideas for Further Simulations

- For a fixed distance between the two mirrors, vary the wavelength of the source
- Repeat for a different distance and compare the results
- Tip: Always start with fast and inaccurate calculations and increase the accuracy once parameters are as desired



- Investigate the effect of misalignment
- Tilt the second mirror by e.g. 0.05°



Summary of Skills Acquired

Congratulations on completing this educational tutorial

Throughout this tutorial, you have acquired a range of valuable skills, including:

- Setting up an optical system
- Adding sources, components, and detectors
- Positioning elements and generating 3D views
- Switching between rays and electromagnetic fields
- Using a Detector Add-on and normalizing to power instead of amplitude
- Adding functional coatings and setting up the light path
- Utilizing Energy Threshold and Maximum Level for convergence testing
- Toggling between pointwise and integral Fourier transforms
- Enabling and disabling the Paraxial Approximation,
- Changing the detector resolution
- Executing a Parameter Run
- Adjusting the range of coordinate axes in plots
- Editing interpolation settings

Document Information

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