Focusing of fs Pulses

Tutorial_41.01_fs_pulse_focal_region.pdf

Related Tutorials: 33.01 (recommended to study before)

Related Scenarios: 98.01

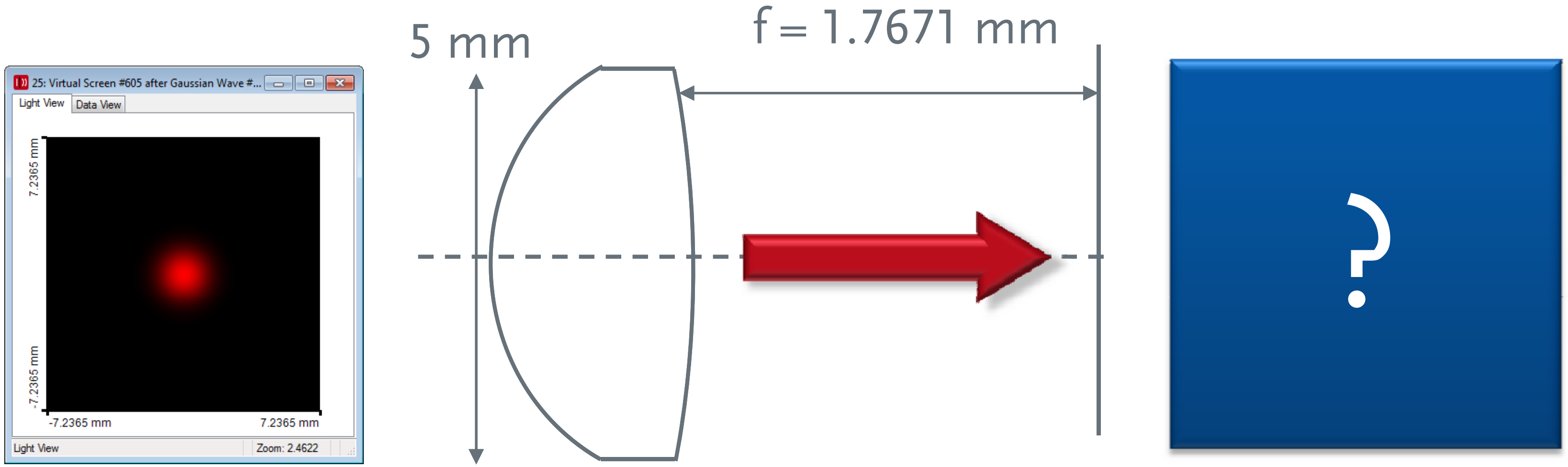
System description

Description of system to be modeled

Simulation with VirtualLab™: Example

- Example considers fs pulse propagation into focal region
- Sample file: Tutorial_41.01_VLF1_fs-pulse_focal_region.lpd
- File contains monochromatic source of wavelength 800 nm
- Pulse information to be introduced by user

Basic Setup for Harmonic Field Component



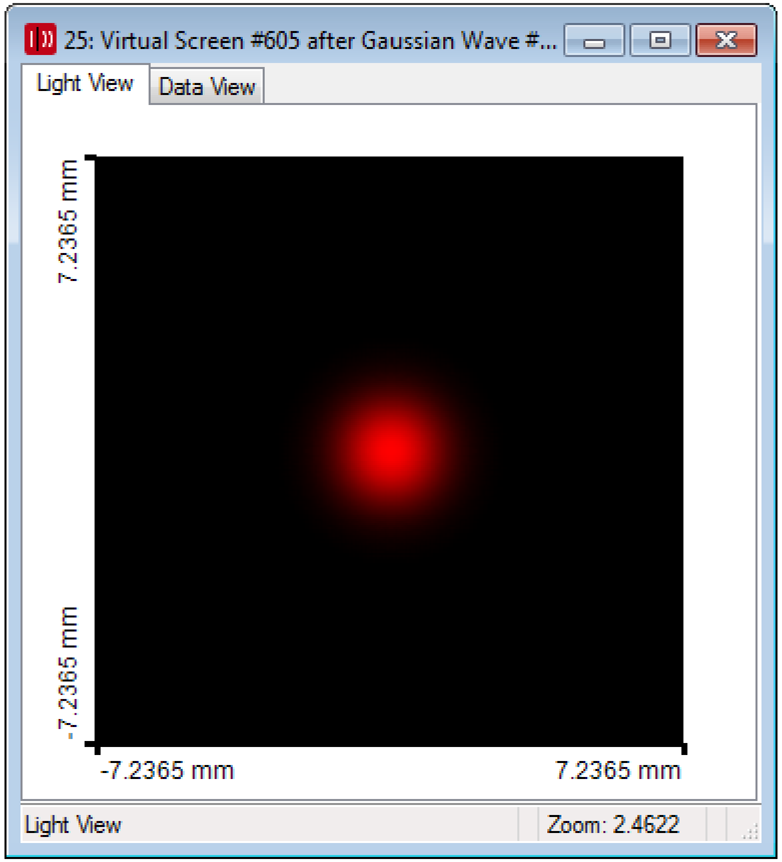
Laser beam

Aspherical lens

Focal plane

NA=0.68

Input Beam



- Polarization: linearly polarized in x-direction
- Beam diameter ($1/e^2$): 5 mm
- Wavelength: 800 nm

- Pulse specification
  - Carrier wavelength: 800 nm
  - Pulse FWHM: 5 fs

Lens Specification

Lens Parameters

Surface 1

- Radius: 2.75 mm
- Conical constant: -0.613916
- A4: 588919
- A6: -17660200000
- A8: 1.01025E+16
- A10: -3.91487E+21

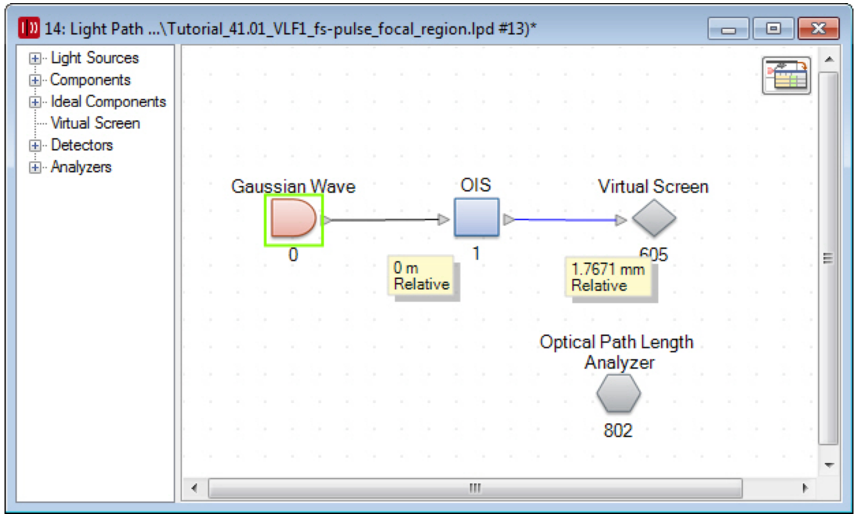
Surface 2

- Radius: -3.18854 mm
- Conical constant: -12.66386
- A4: 12458340
- A6: -3711945000000
- A8: 5.122391E+17
- A10: -3.108578E+22

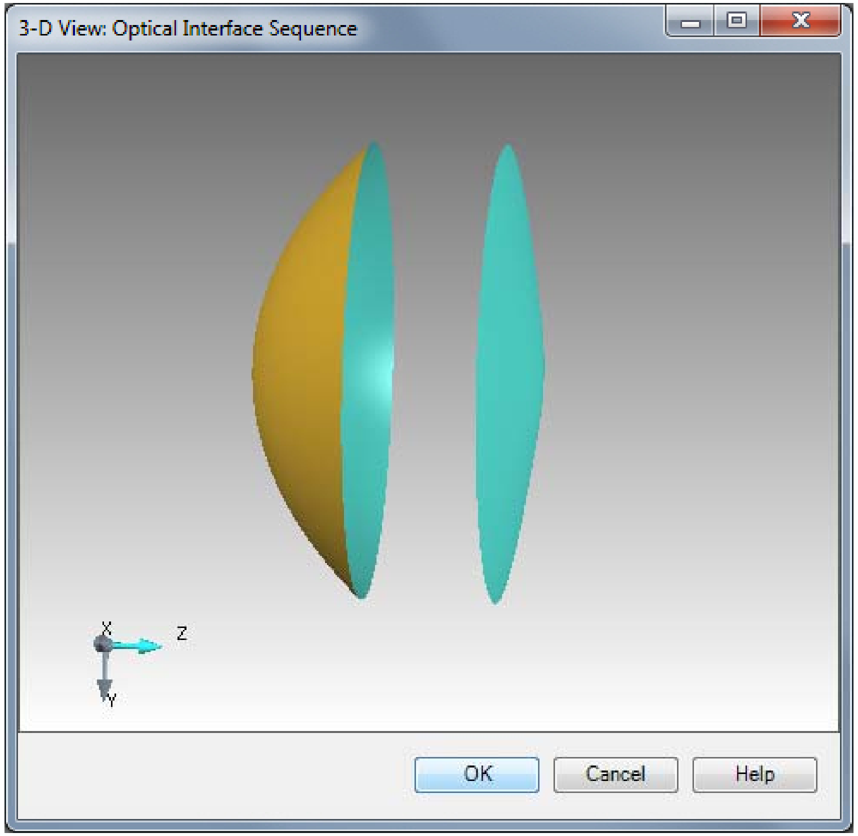
Center Thickness: 3.15 mm
Glass: Corning C0550

System

LPD file

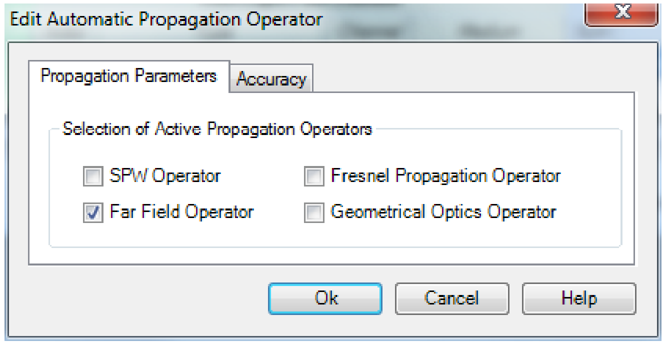


3D View of OIS



Comments on LPD

- The propagation from OIS to screen is chosen to be automatic, though for this task the far field to waist operator could be used too.
- The Automatic Operator is edited as follows:



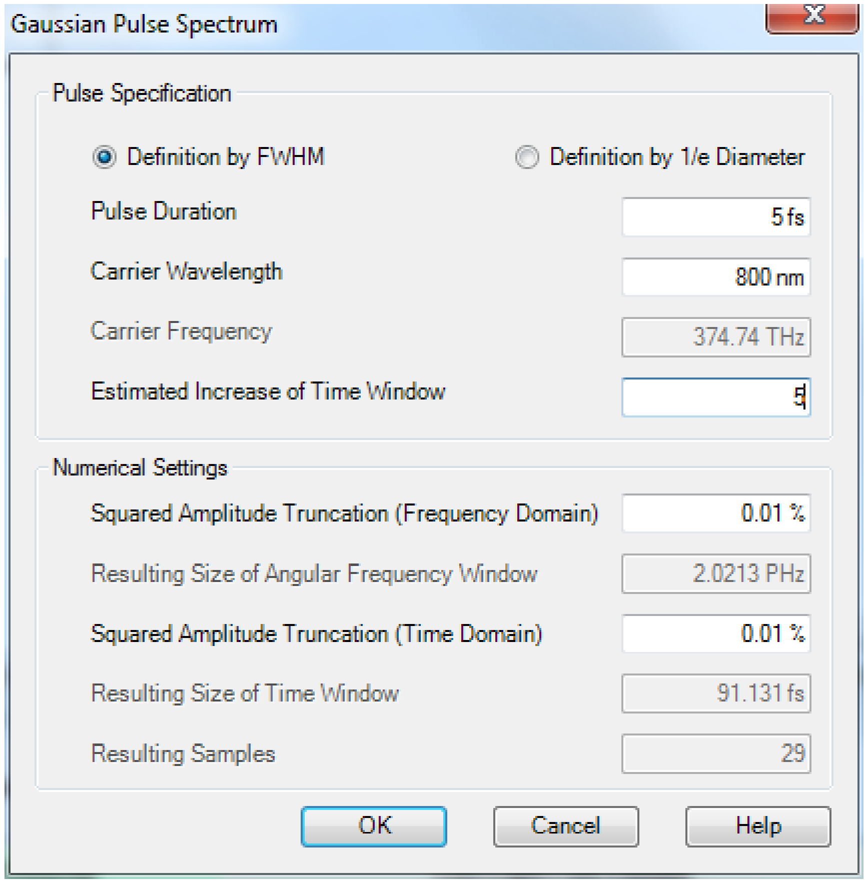
- In this modus the automatic operator uses always the far field operator but optimizes the sampling by a smart preprocessing step.
- Recommendation: Before you start pulse modeling, test the monochromatic setup.

Pulse Specification

Specification of envelope spectrum and insertion in source

Pulse Specification

- Introduce the pulse as described in Tutorial_33.01

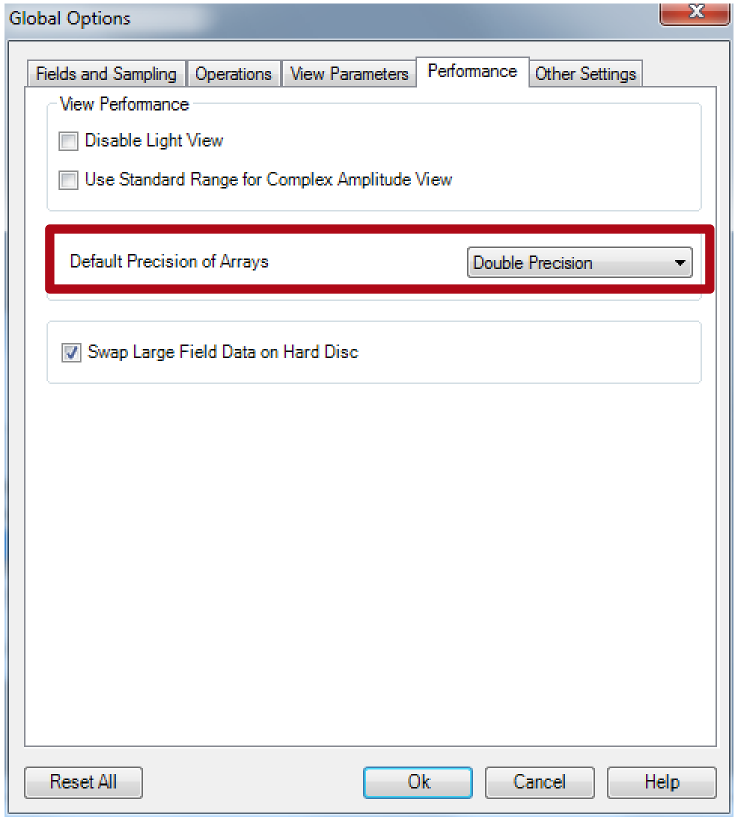


Comment on Pulse Specification

- A factor of 5 to 10 is a good first choice for the estimated increase of the time window.
- Use *a priori* information about the resulting pulse duration in the target plane if available.
- In what follows we show how to select a suitable time window factor by a few trials.

Important Reminder!

Makes sure, that for pulse modeling you have chosen Double Precision BEFORE pulse specification!

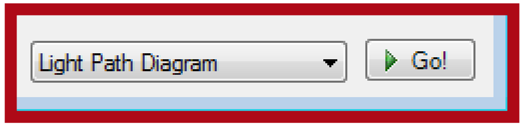


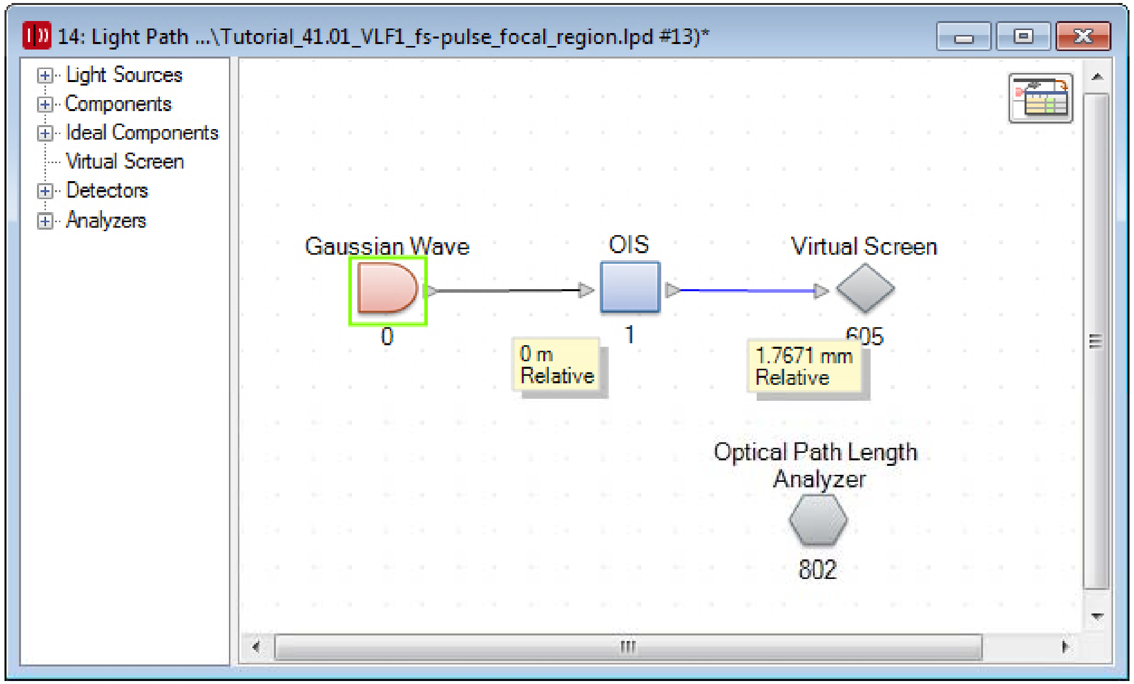
Modeling Pulse in Focal Region

Evaluation of pulse at arbitrary locations in focal plane

Simulation with VirtualLab™: Example

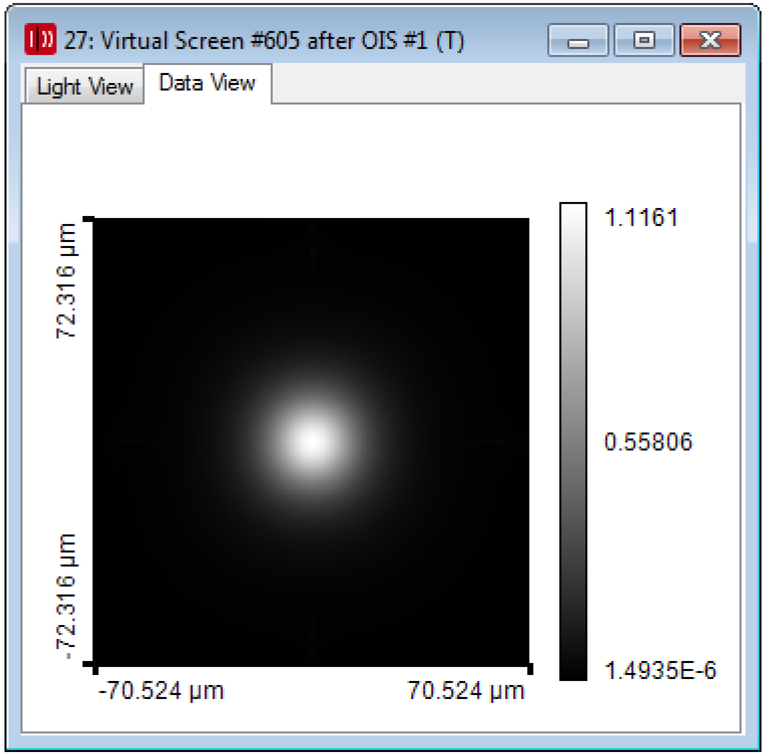
- Run LPD





Simulation with VirtualLab™: Example

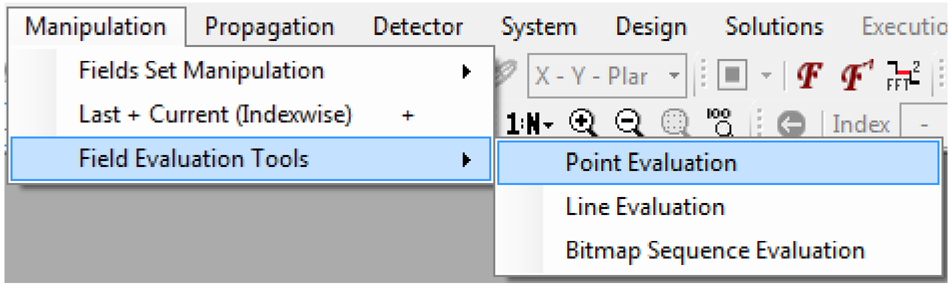
- Resulting Harmonic Field Set (HFS)

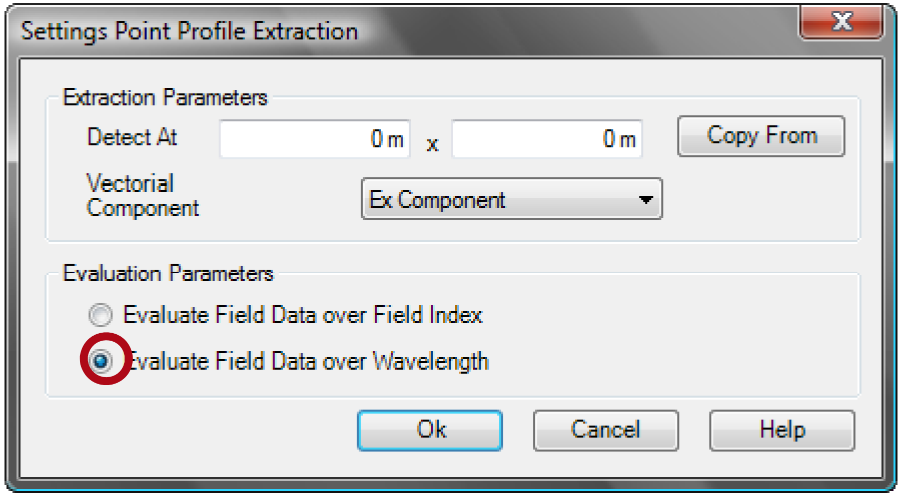


$$\tilde{U}_{\mathrm{c}}(r \in \bar{\Omega}_{\mathrm{out}}, \omega) = \tilde{U}_{\mathrm{e}}(r \in \bar{\Omega}_{\mathrm{out}}, \omega - \bar{\omega})\, e^{i\omega\hat{t}}$$

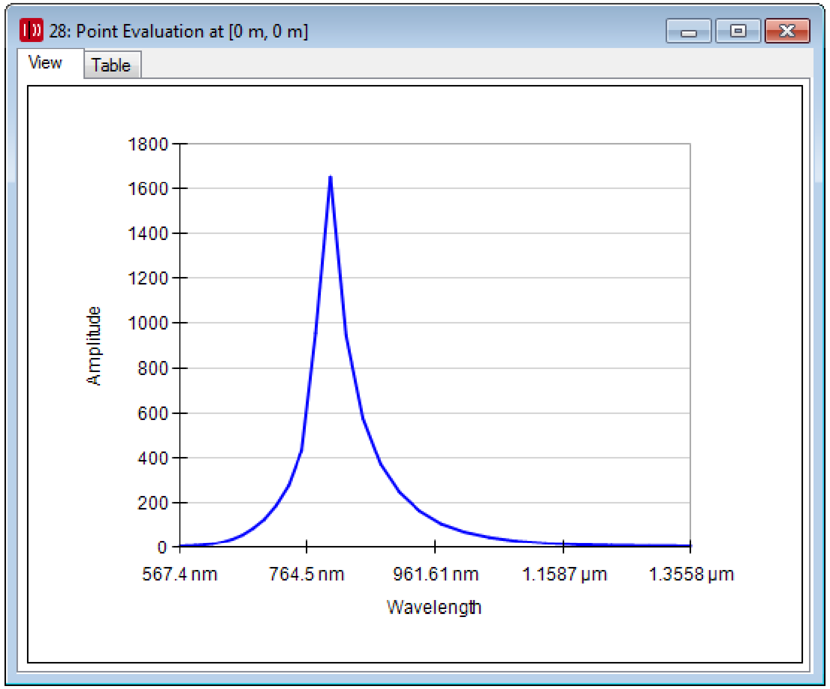
Field Evaluation Tools

- VirtualLab™ 4.5 allows investigation of pulse in time domain by *Field Evaluation Tools*





Simulation with VirtualLab™: Example

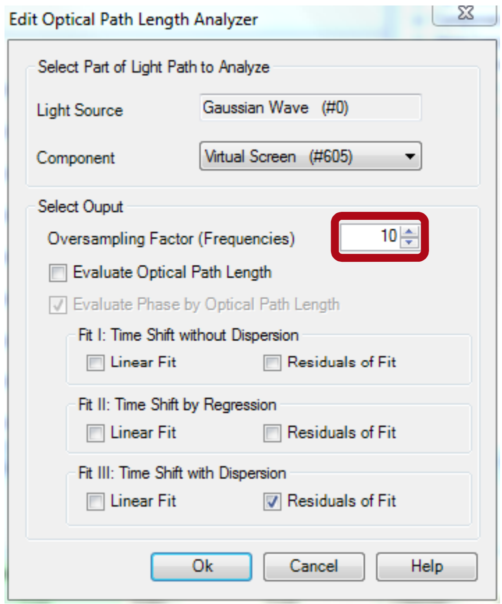


Note: If you do not see this result, double click on the diagram window to Initialize the zoom in the diagram.

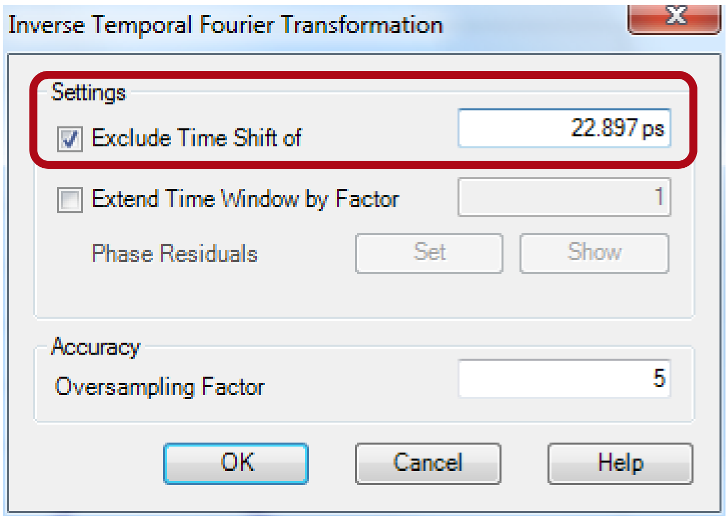
$$\tilde{U}_{\mathrm{c}}(0,0,z_{\mathrm{out}},\omega) = \tilde{U}_{\mathrm{e}}(0,0,z_{\mathrm{out}},\omega-\bar{\omega})\, e^{i\omega\hat{t}}$$

Simulation with VirtualLab™: Example

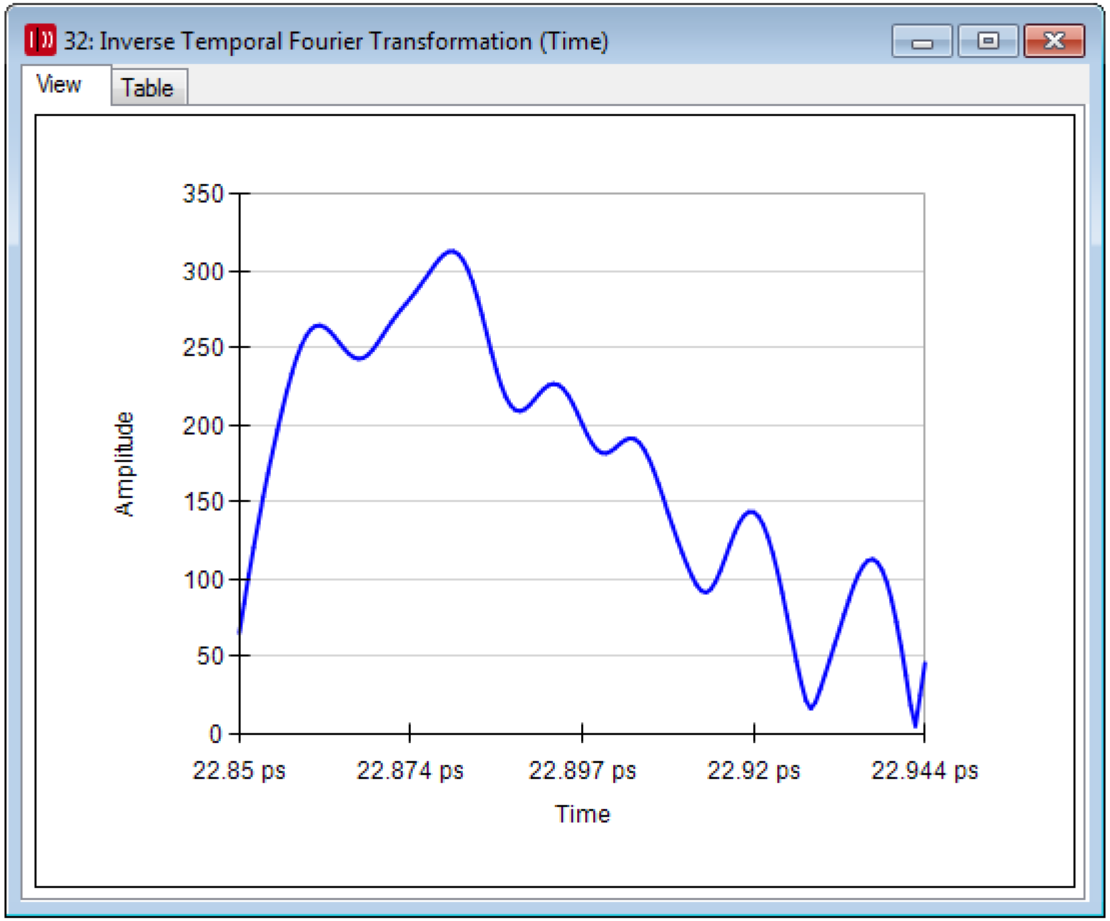
- Next run the OPL analyzer to get the time shift and the phase residual for smart inclusion of material dispersion.
- You need to initialize the OPL analyzer first by open the dialog.



Simulation with VirtualLab™: Example



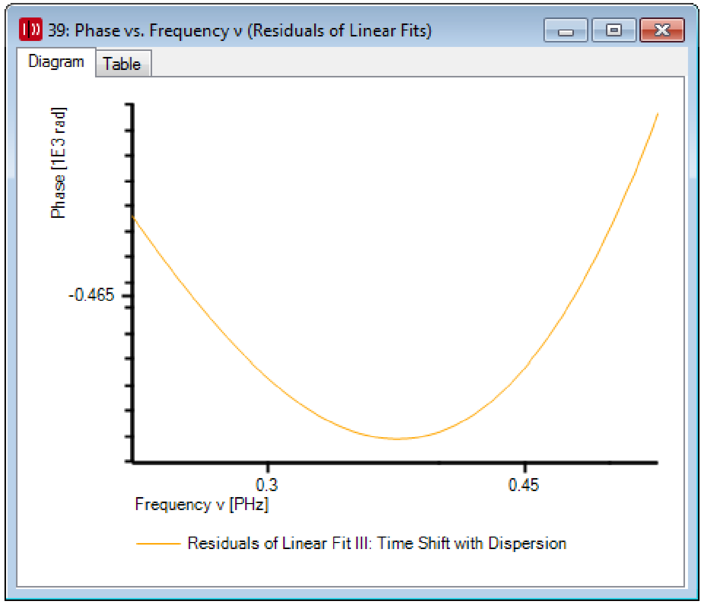
Simulation with VirtualLab™: Example



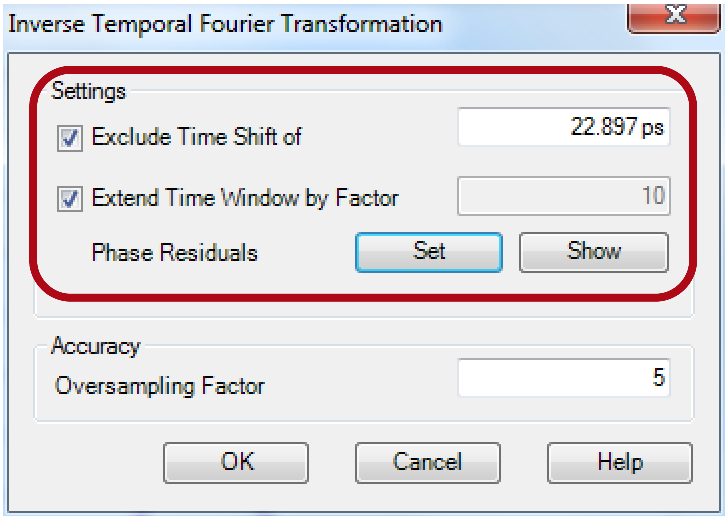
$$U_{\mathrm{e}}(0, 0, z_{\mathrm{out}}, t - \hat{t})$$

Importance of Smart Material Inclusion

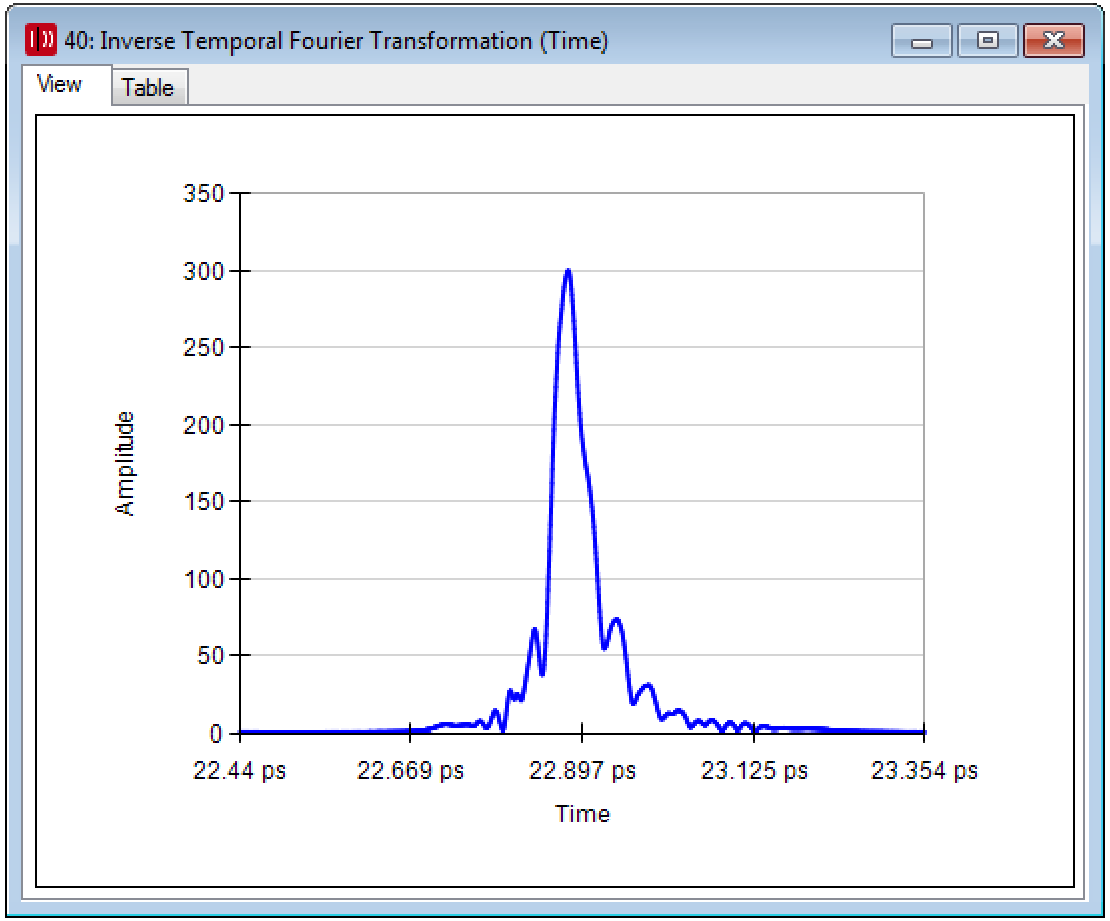
- Obviously, this result suffers from too low sampling in frequency domain and the resulting aliasing in time domain.
- The major reason is caused by material dispersion.
- That is included next.



Simulation with VirtualLab™: Example



Simulation with VirtualLab™: Example

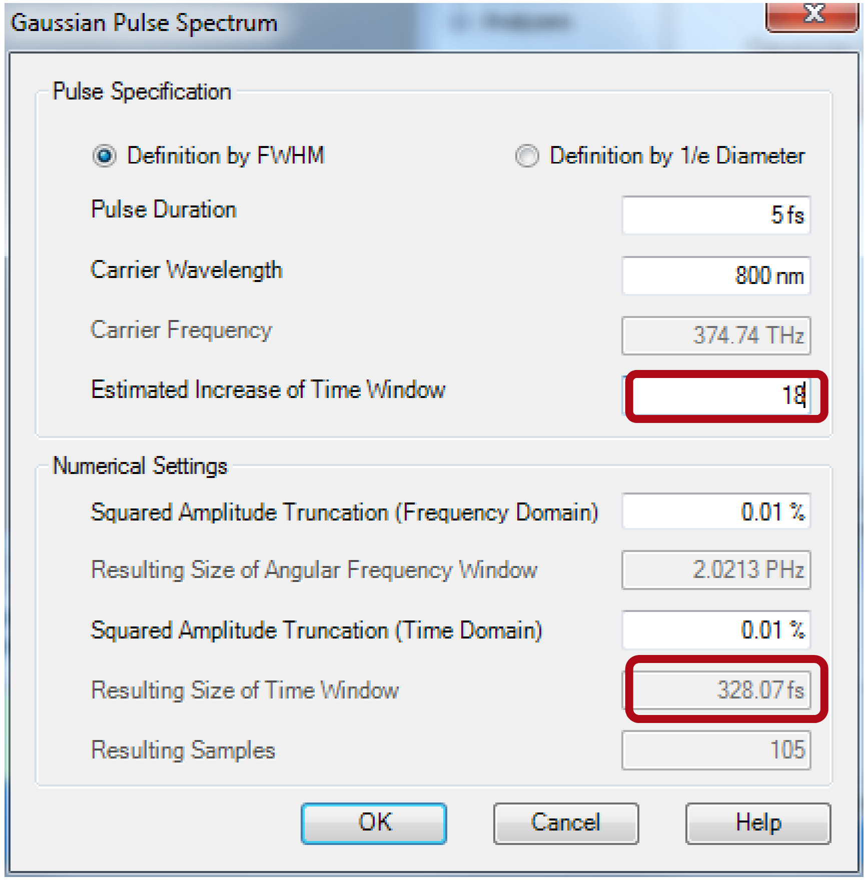


$$U_e(0, 0, z_{out}, t - \hat{t})$$

Importance of Smart Material Inclusion

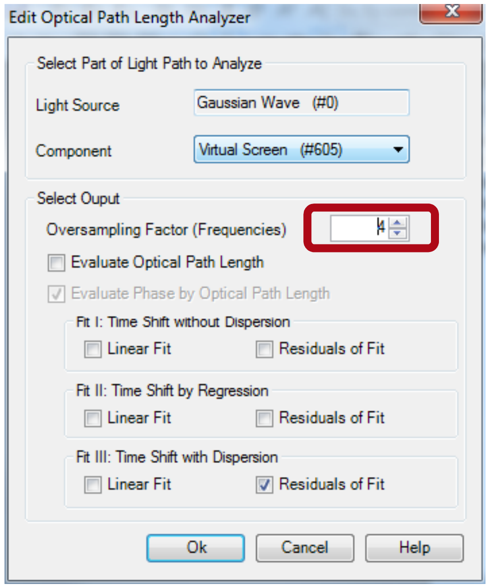
- Now a pulse shape can be considered. However, it is not yet ensured, that all fluctuations in time are of physical nature.
- Though the increase of the time window by material dispersion is most dominant, also angular dispersion causes an increase.
- From the result we conclude, that the pulse is mainly located inside a time window of about 300 fs.
- Thus, we increase the initial time window to about 300 fs.

New Pulse Specification



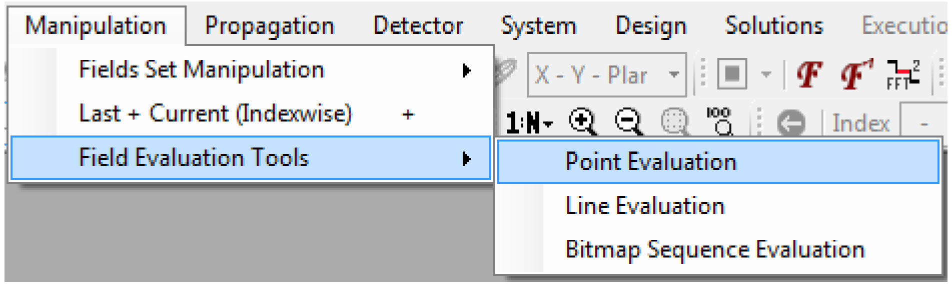
Initial Time Window and Material Dispersion

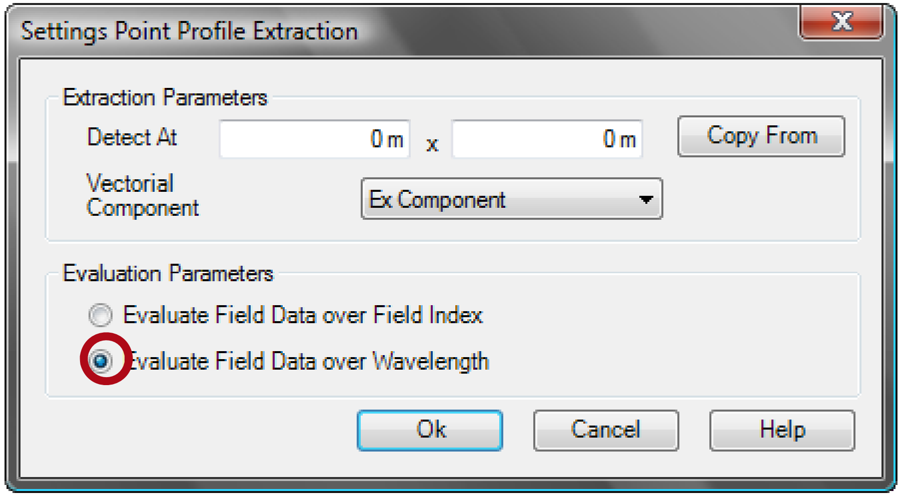
- According to the new specification now we simulate with 105 harmonic fields, which takes more time.
- Because of the increase of the initial window we optionally reduce the factor for the smart inclusion to 4, that is:



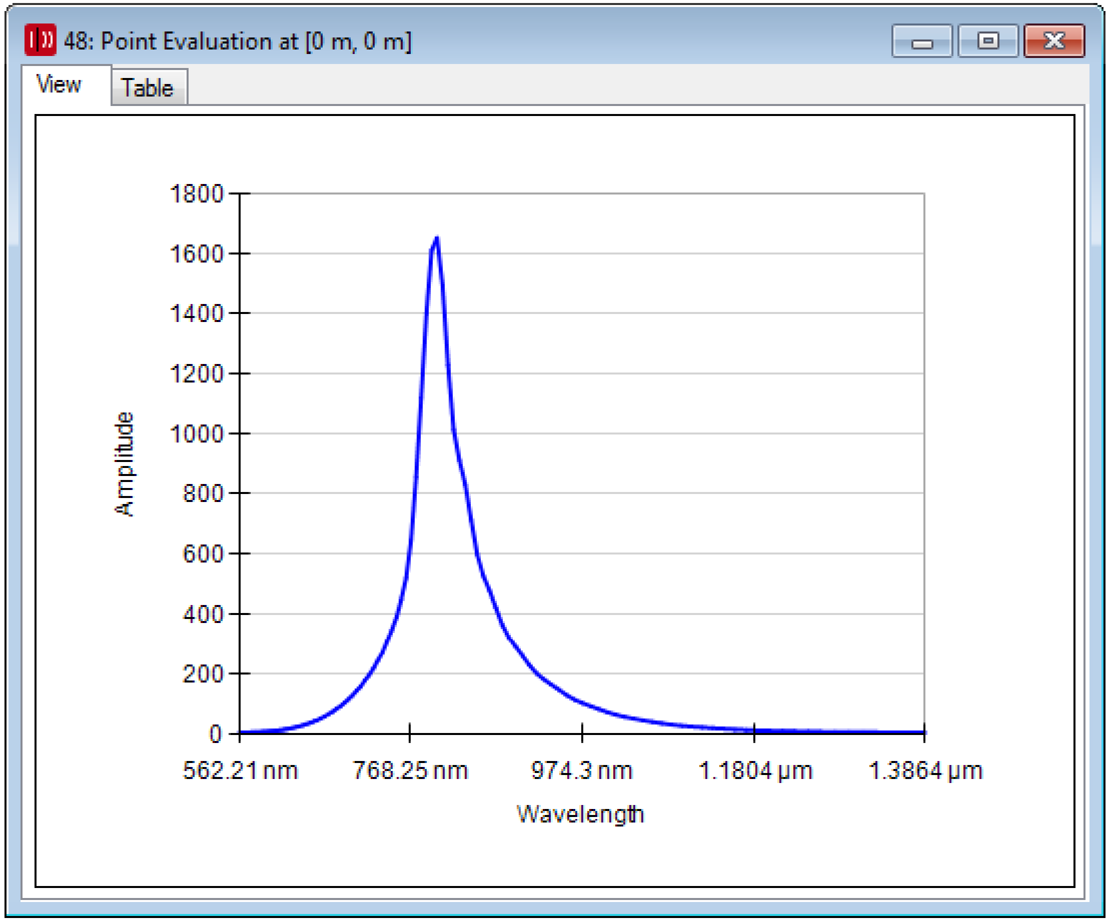
Field Evaluation Tools

- VirtualLab™ 4.5 allows investigation of pulse in time domain by *Field Evaluation Tools*





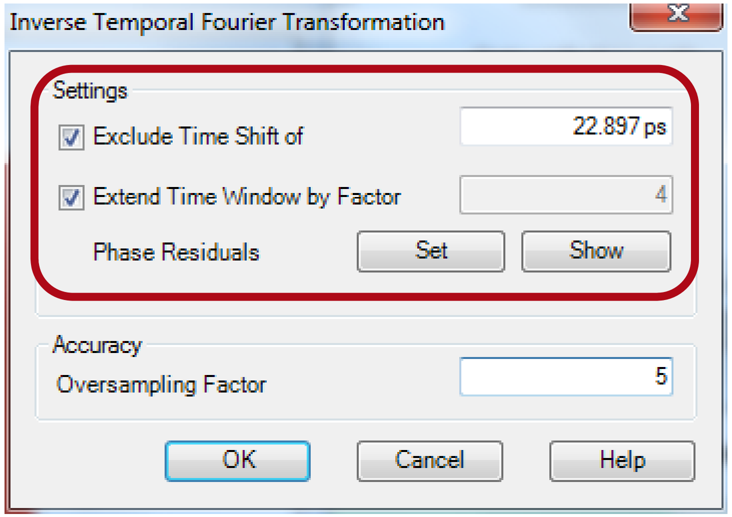
Envelope Spectrum



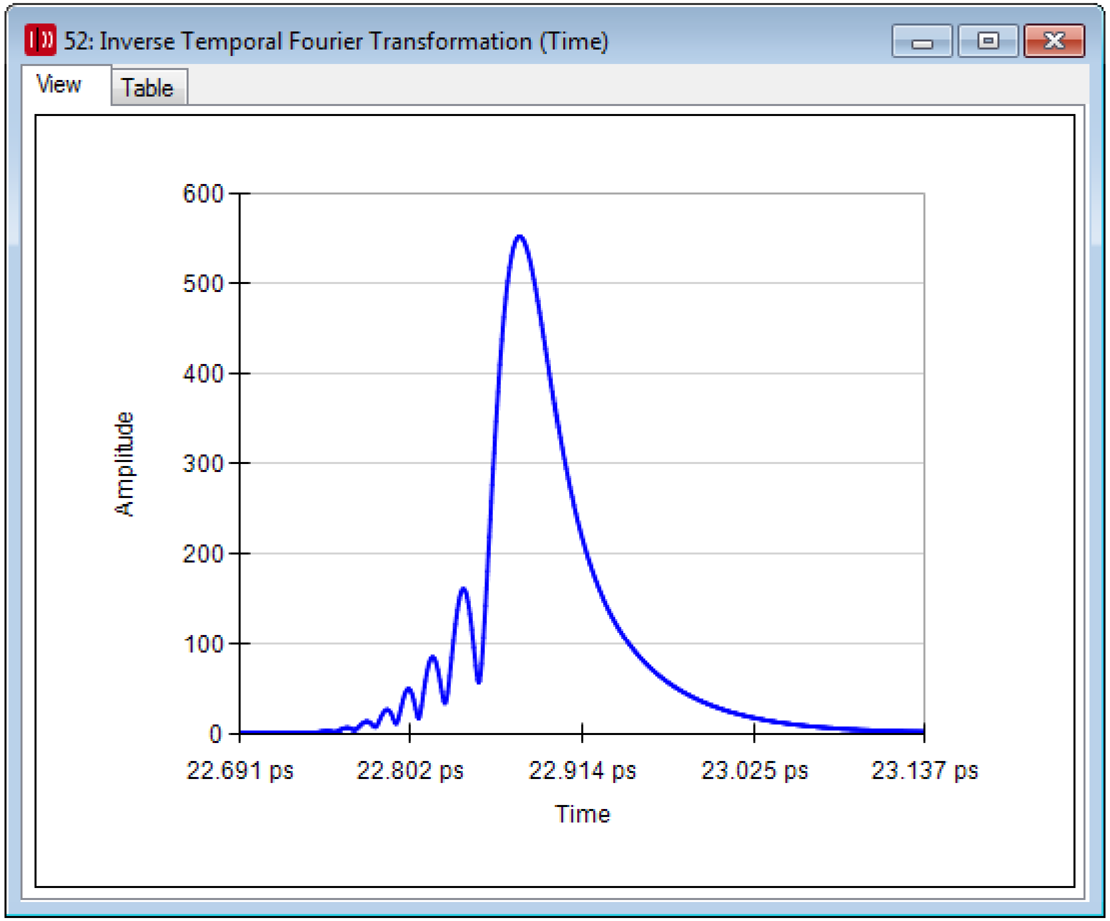
$$\tilde{U}_{\mathrm{c}}(0,0,z_{\mathrm{out}},\omega) = \tilde{U}_{\mathrm{e}}(0,0,z_{\mathrm{out}},\omega-\bar{\omega})\,e^{\mathrm{i}\omega\hat{t}}$$

Transformation into Time Domain

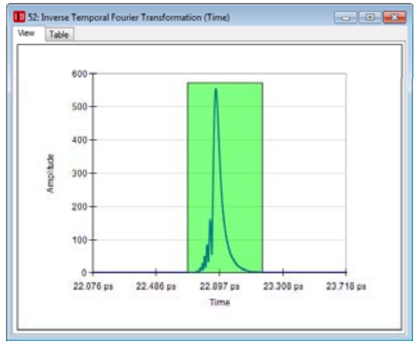
- Run OPL Analyzer to obtain
  - Time shift (not changed by new pulse specification)
  - Phase residual by material dispersion
- Perform Transformation:



Pulse in Focal Region: x-Component



$$U_{\mathrm{e}}(0, 0, z_{\mathrm{out}}, t - \hat{t})$$



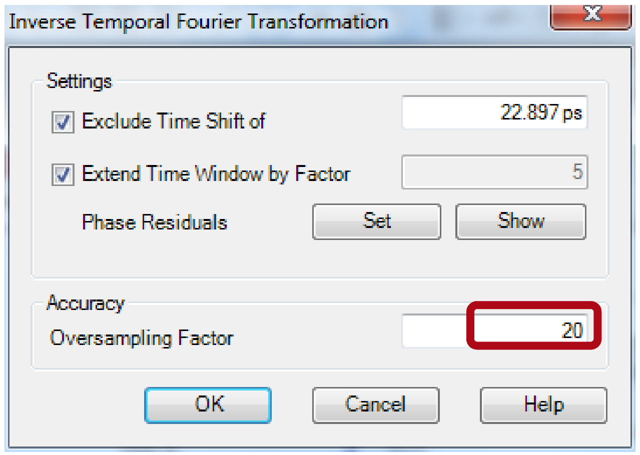
Zoomed by diagram tool: Just press left mouse button and mark the area in which you like to zoom.

Comments

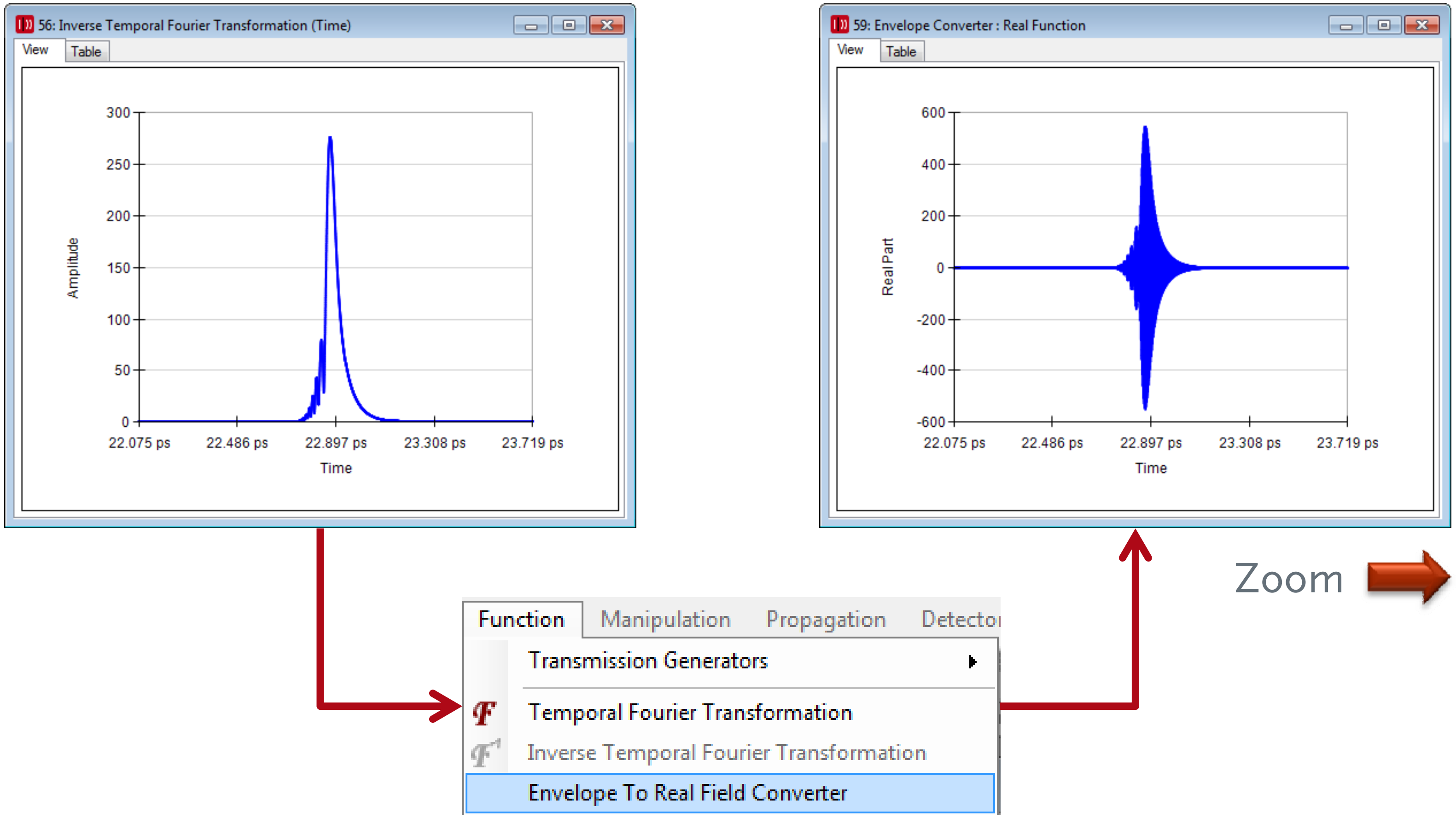
- Right side of pulse is smooth, which indicates that there are no numerical artifacts anymore.
- Therefore, the side lobes on the left side have physical meaning.
- Of course it is possible to further increase the initial time window to check, if the result is stable. We did it and found no further modification of the result.
- Next we consider another feature for pulse evaluation.

Further Features: Real Field Converter

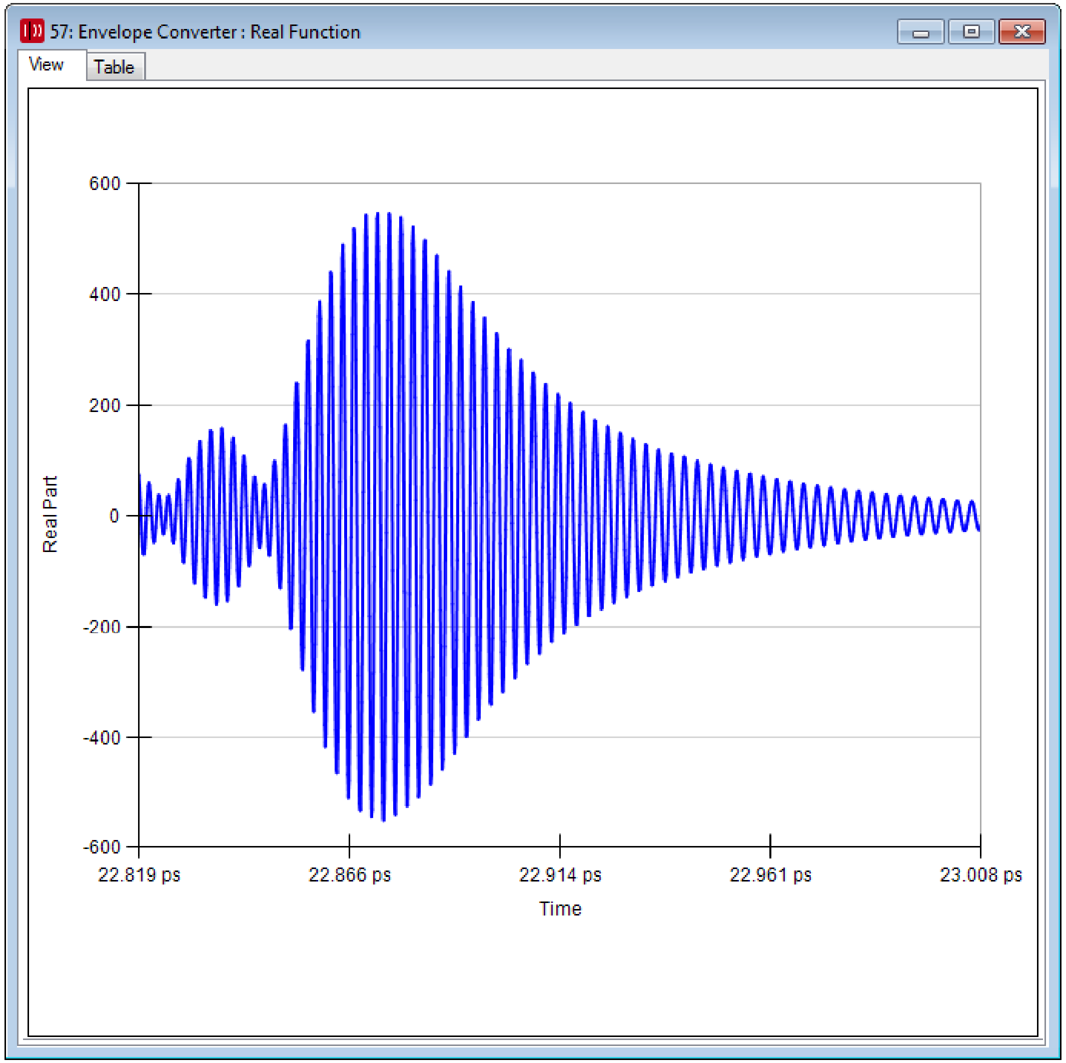
- The pulse simulations in VirtualLab™ are based on the envelope function. It is always possible to use the Envelope to Real Field Converter to obtain the pulse with its frequency carrier.
- Because of high carrier frequencies it is recommended to introduce a high oversampling in the time domain by:



Envelope to Real Field Converter

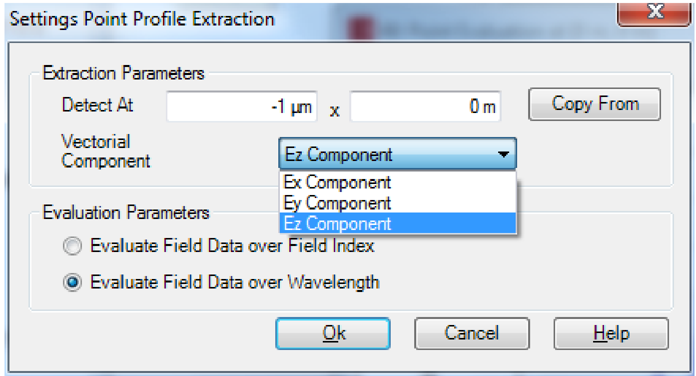


Pulse Shape with Carrier



Further Features: Vectorial Modeling

- Pulse simulations in VirtualLab™ are done on base of an electromagnetic and therefore vectorial pulse description.
- That gives access to the y- and z- component of the pulse field. Selection via:



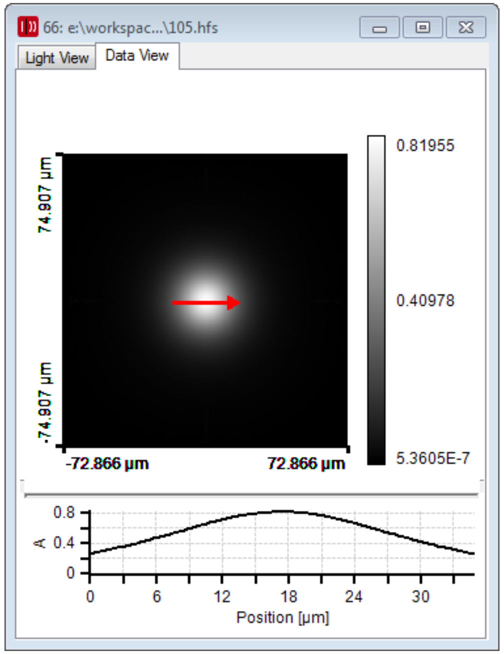
- z-component calculation on demand. Takes some extra time. Try it! (z-component zero at (0,0))!

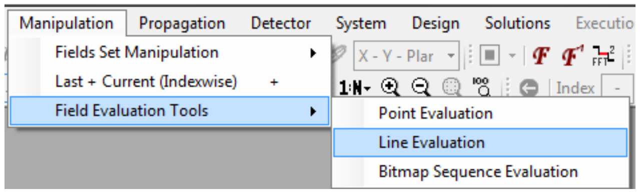
Modeling Pulse in Focal Region

Evaluation of pulse on arbitrary line in focal plane

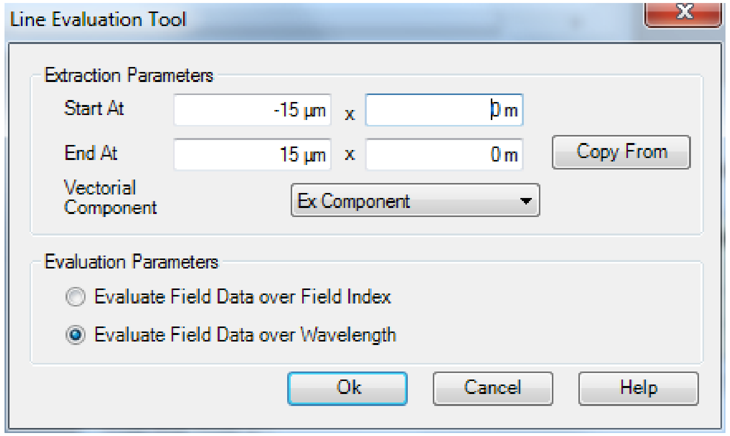
Line Evaluation Tool

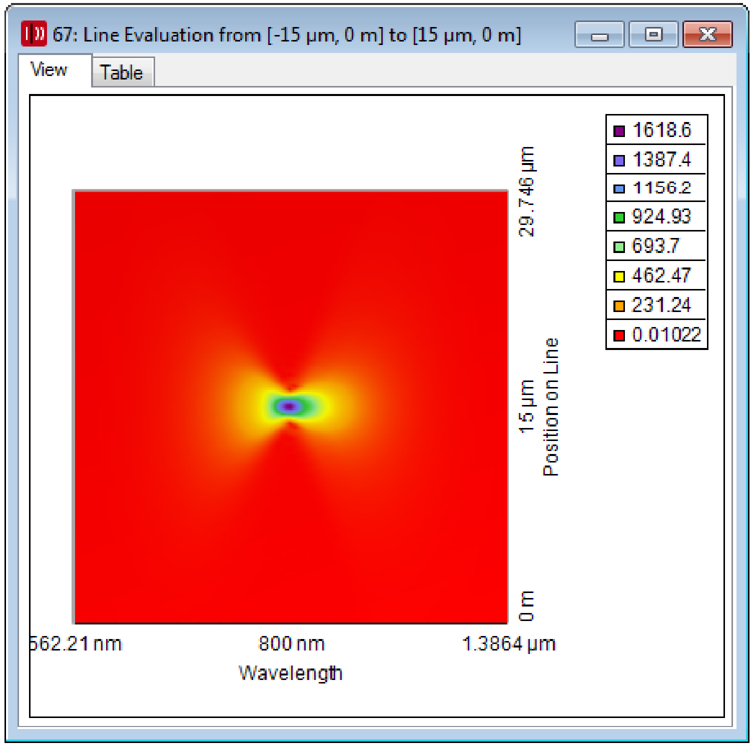
- Instead of *Point Evaluation* the *Line Evaluation* can be used to obtain the envelope spectrum along a line in the focal plane.





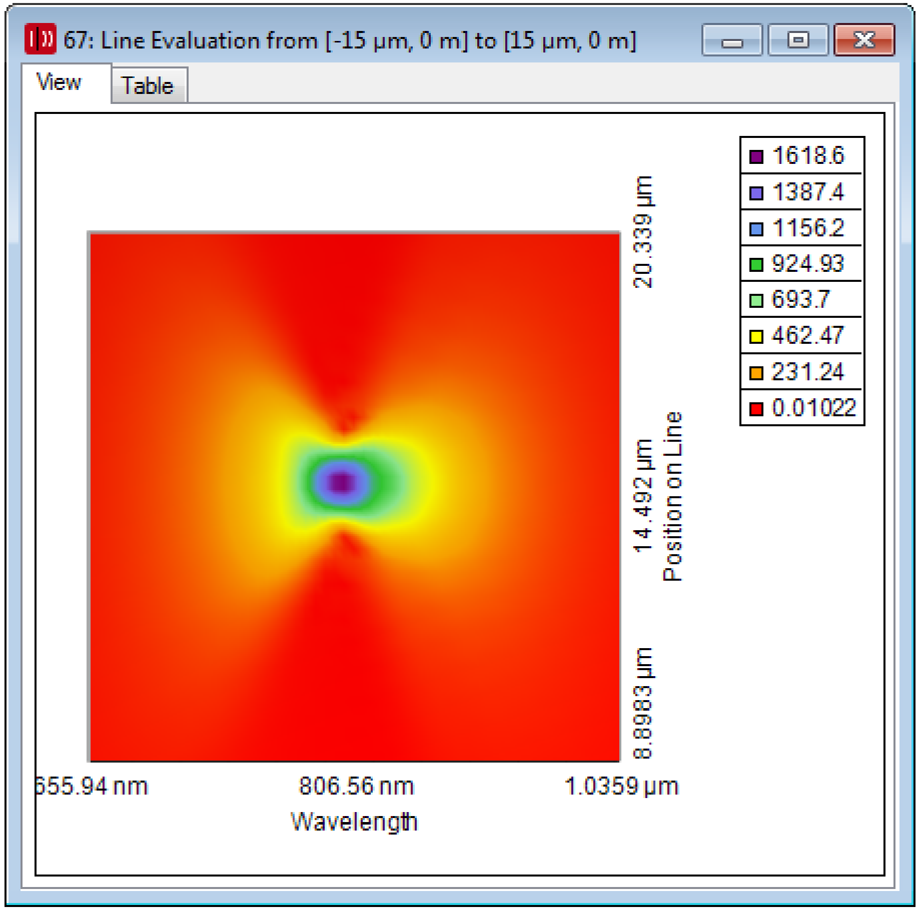
Line Evaluation Tool





Zoom

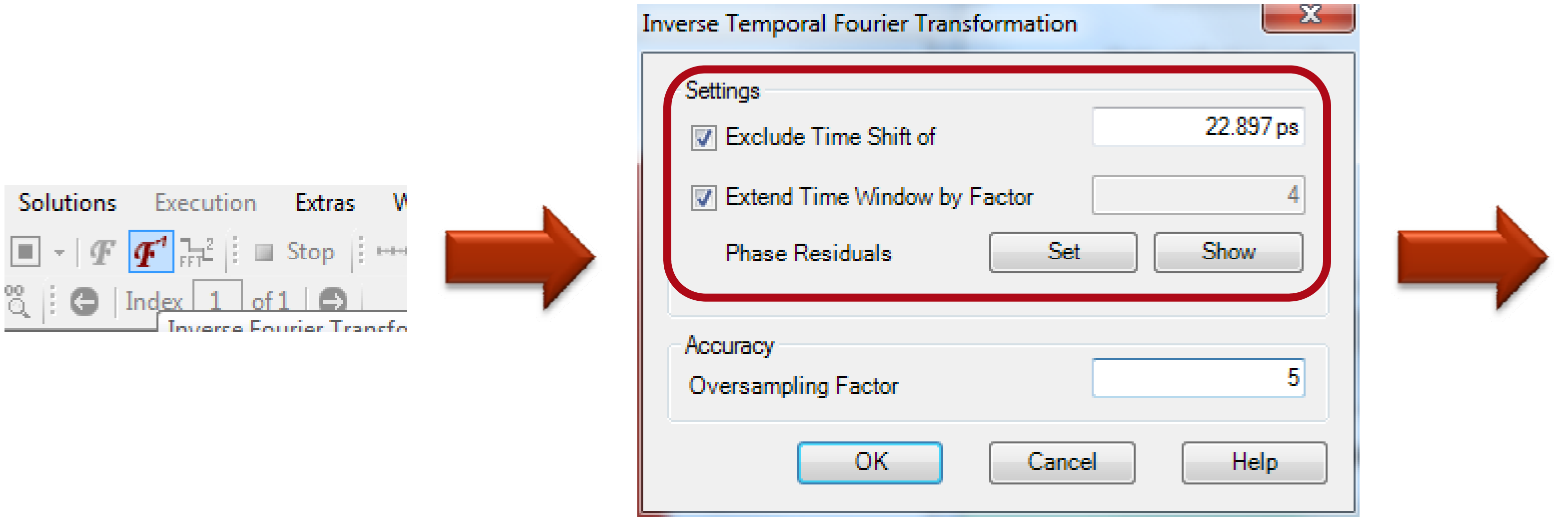
Envelope Spectrum along Line



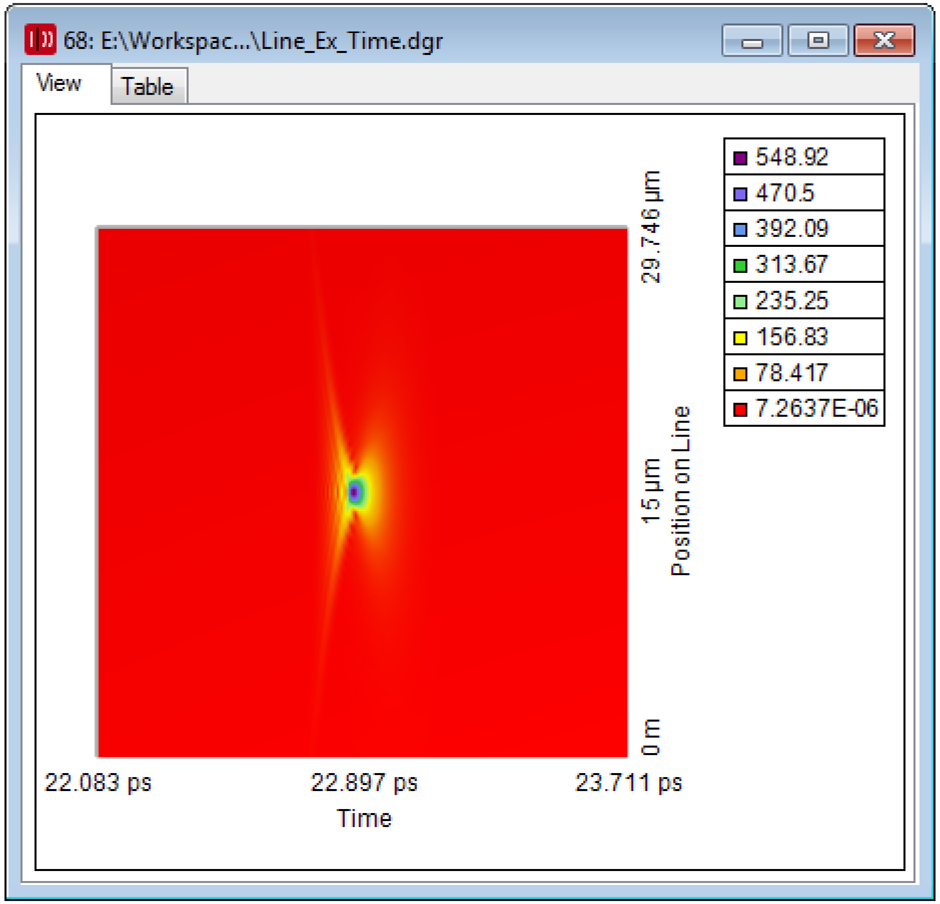
$$\tilde{U}_{\mathrm{c}}(\boldsymbol{r} \in \mathrm{Line}, \omega) = \tilde{U}_{\mathrm{e}}(\boldsymbol{r} \in \mathrm{Line}, \omega - \bar{\omega})\, e^{\mathrm{i}\omega\hat{t}}$$

Transformation into Time Domain

- Identical inverse FT as before (decrease the oversampling factor only, to reduce cpu time)



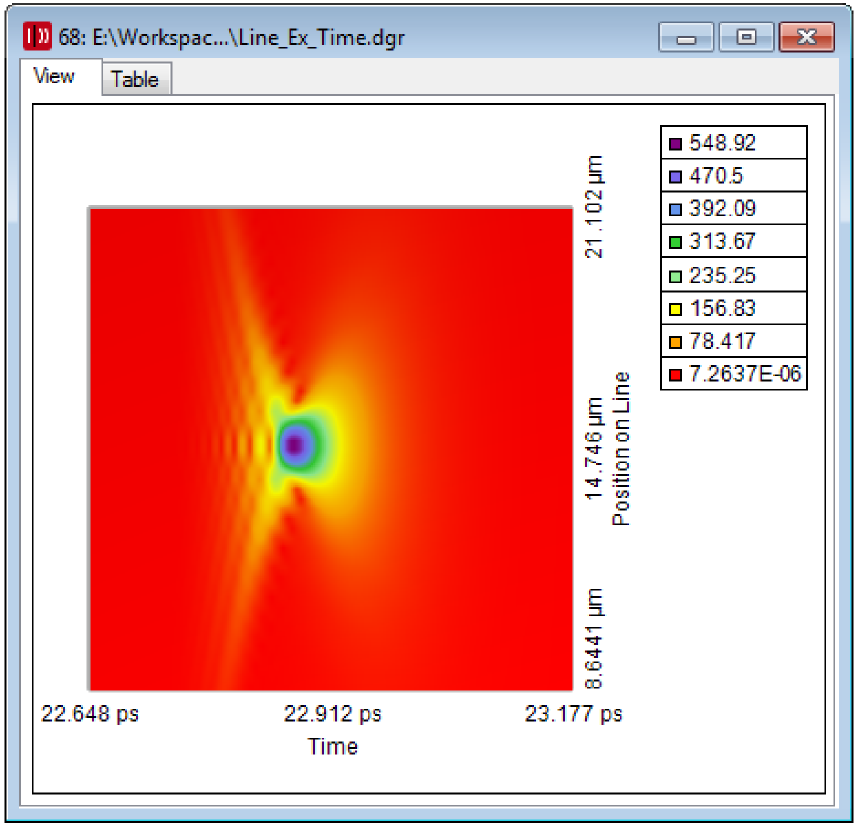
x-Component of Envelope Function on Line



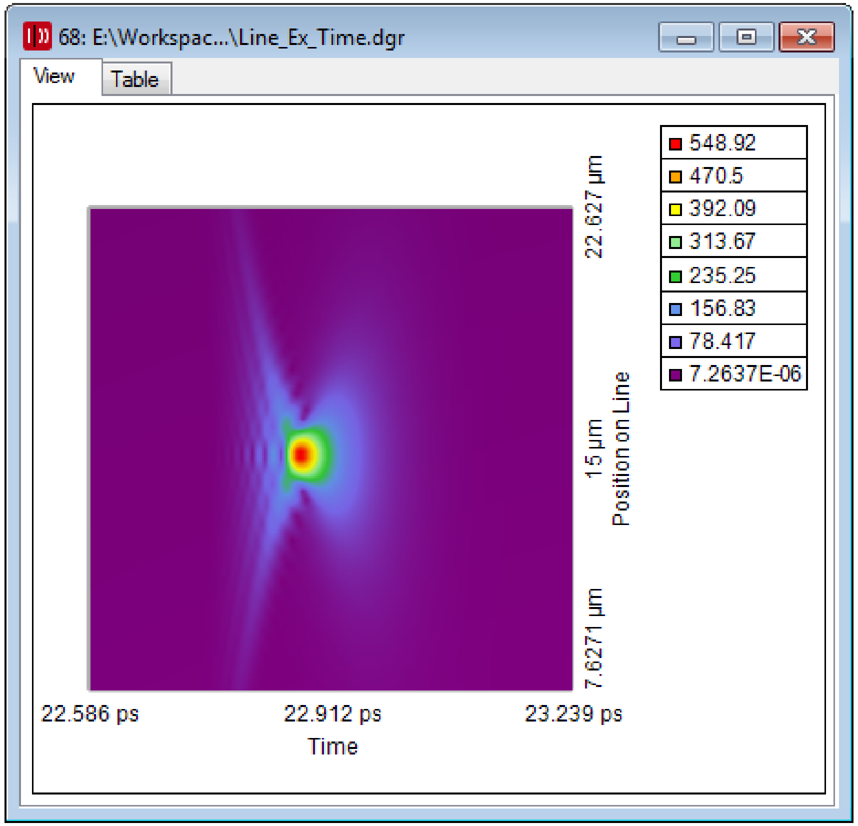
$$U_e(r \in \text{Line}, t - \hat{t})$$

x-Component of Envelope Function on Line

Zoomed function

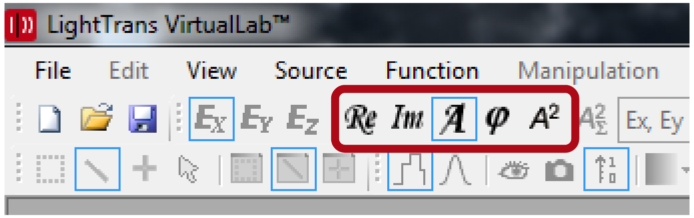


Inverse rainbow scheme (see property browser (F4))



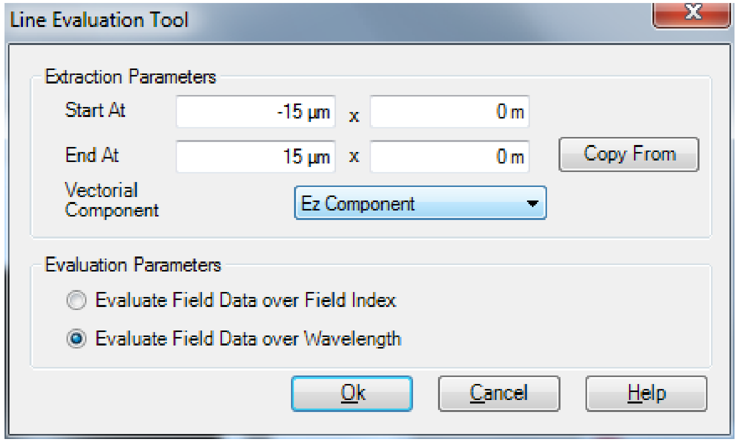
Comments

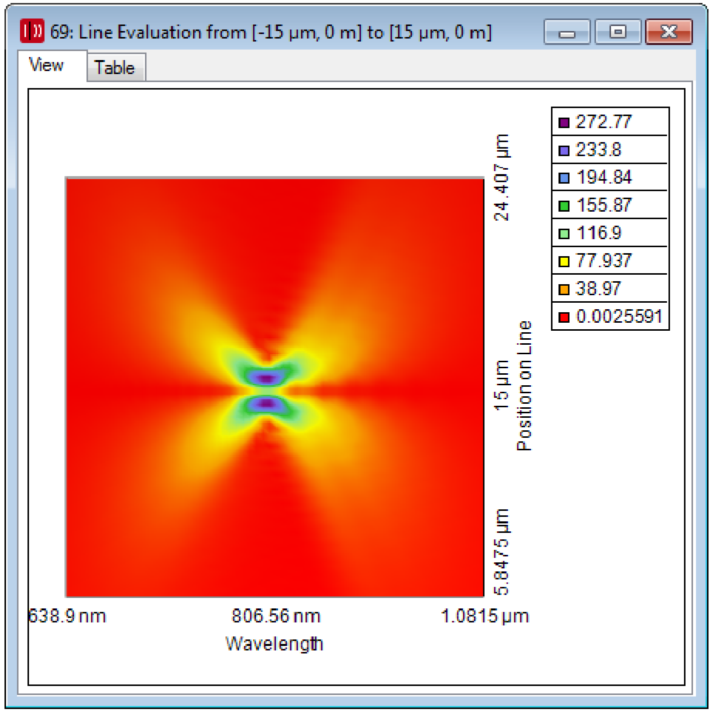
- Try also the choice different options of the field quantities:



- The results demonstrate, that the pulse simulation with VirtualLab™ include aberrations, diffraction and other wave-optical effects.
- Next we consider the vectorial nature of the simulations.

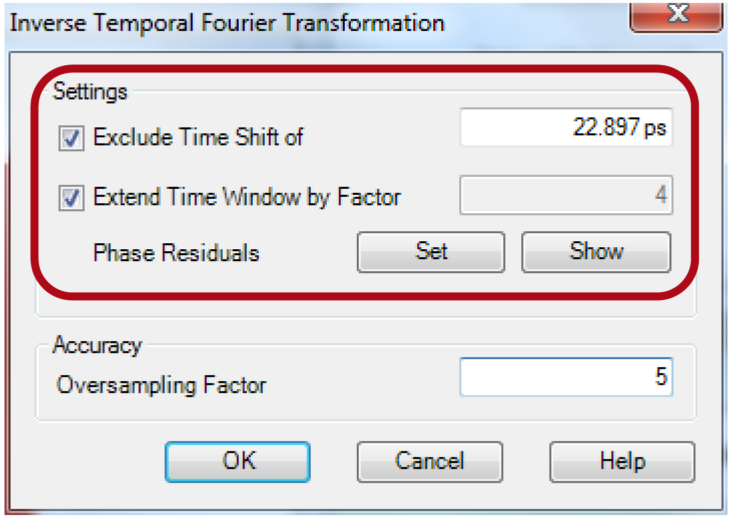
Line Evaluation Tool: z-Component



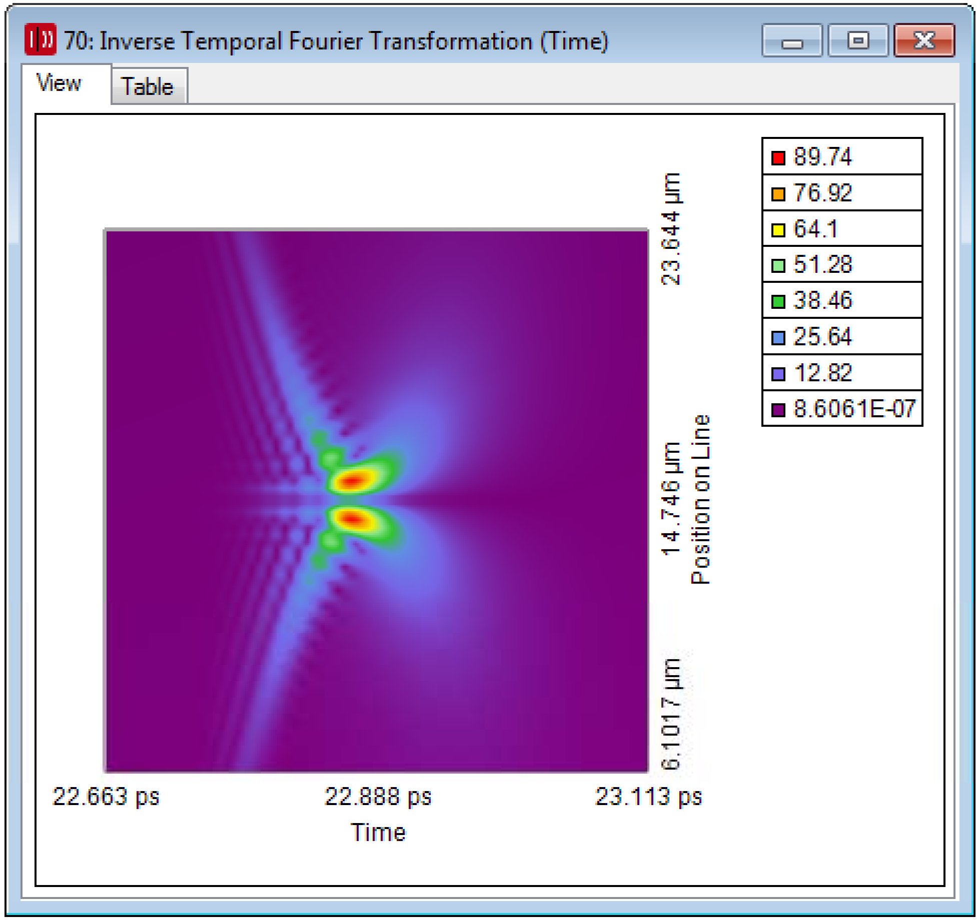


Transformation into Time Domain

- Identical inverse FT as before



z-Component of Envelope Function on Line



$$U_e(r \in \text{Line}, t - \hat{t})$$

Further Developments

- Pulse modeling in VirtualLab™ is based on tracing harmonic fields through optical systems.
- Steadily we add new techniques and components.
- Gratings and prisms are to be added in 2010 to allow modeling of pulse compression and extension.
- Please help us to develop the ultrashort pulse modeling features of VirtualLab™. Send us your suggestions and demands for new and improvements of existing features.
- Thank you for your interest in VirtualLab™.