# lecture 2

## Details on nonlinear propagation


- Supercontinuum generation .. Page 2
  - create a pulse
  - choose parameters
  - press start
  - put result to memory
  - repeat with higher accuracy
  - check measurements
  - noise and coherence

- Export propagation data .. Page 11

- Dispersion and retarded time frame .. Page 15




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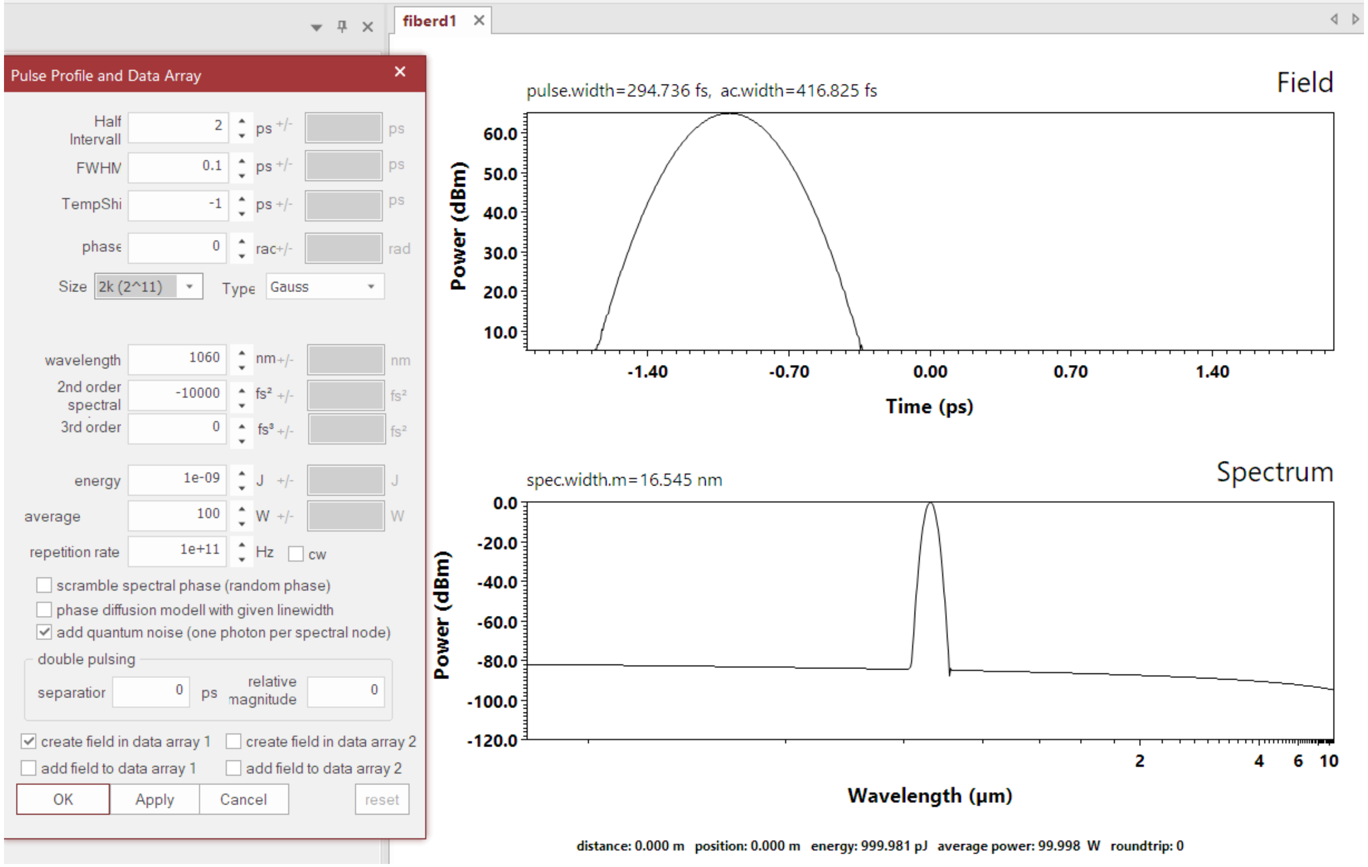
**Create a pulse with the following data:**

Gaussian pulse with 100 fs duration, temporal windows +/-2 ps, 2k datapoints, temporal shift: -1 ps, energy 1 nJ *(repetition rate and corresponding average power are not of importance here, the energy in the field determines the intensity and thus, nonlinear interaction)*, central wavelength of pulse and of data array center: 1060 nm, added quantum noise (one photon per spectral bin)





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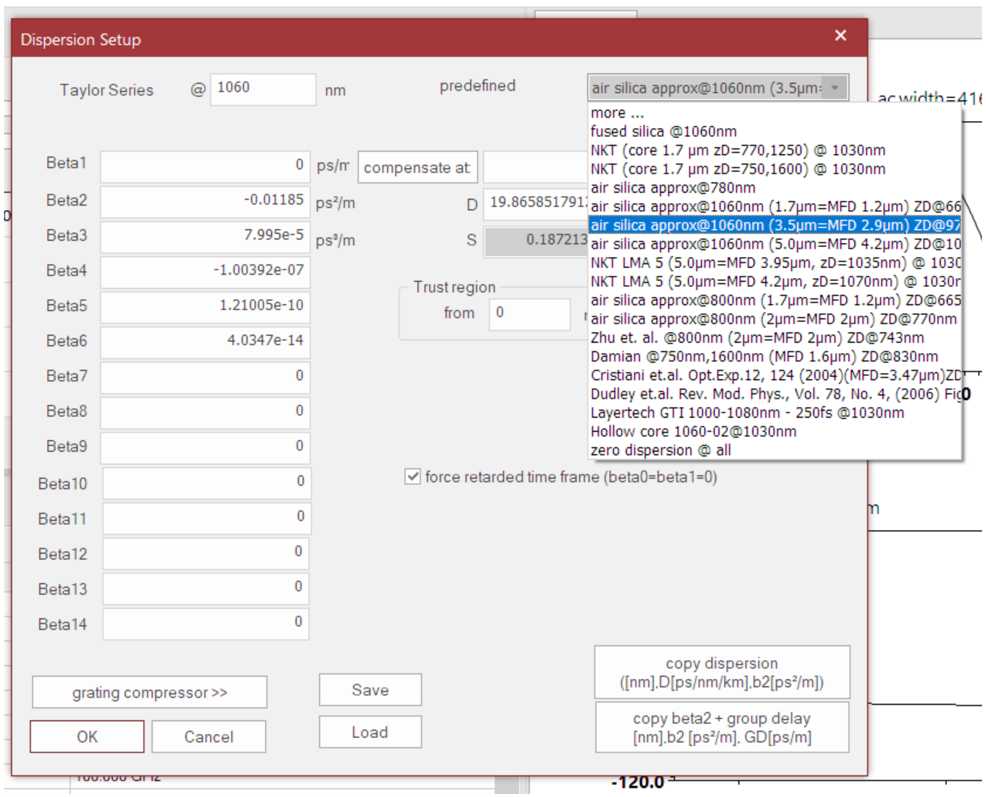
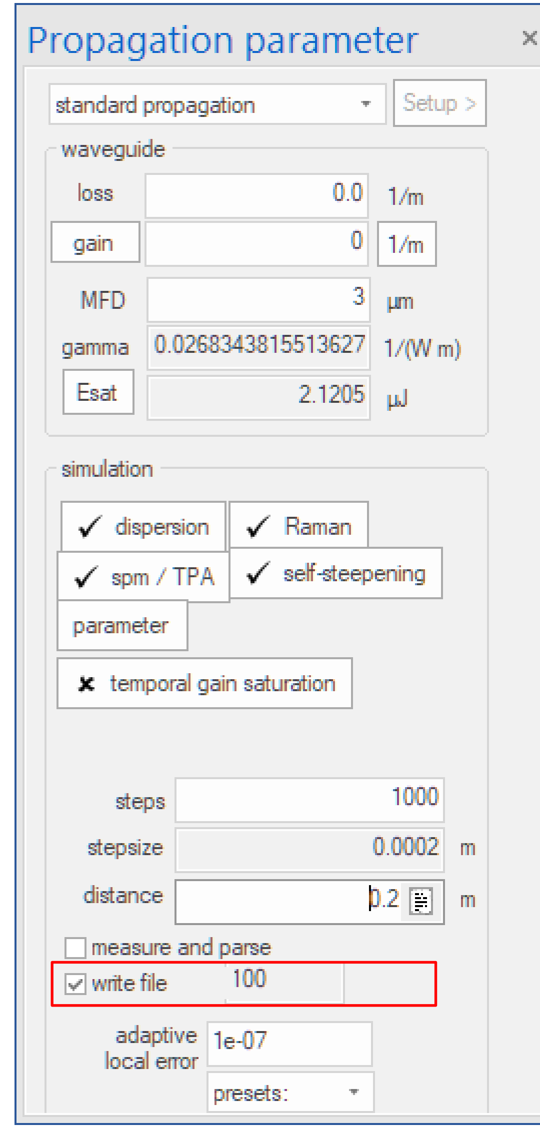
fiber is: NKT-ZD-975 with ~3 µm MFD, dispersion preselected. Length is 0.2 m and 100 steps. Switch on „write file“ to save the propagation to a file for later post-processing.





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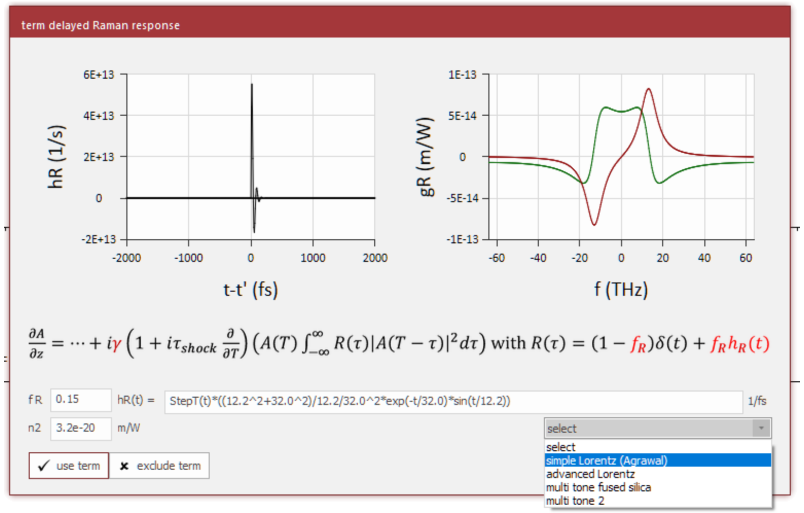
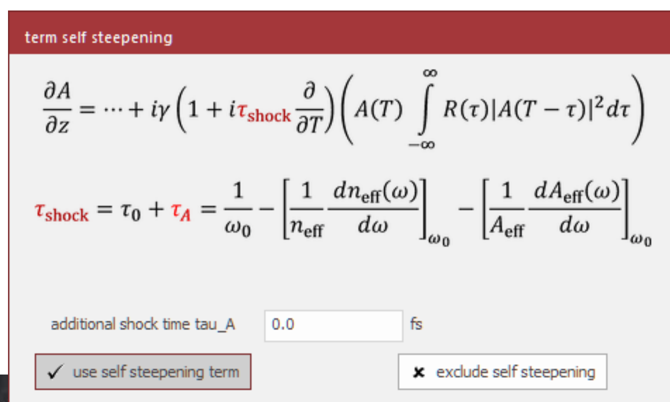
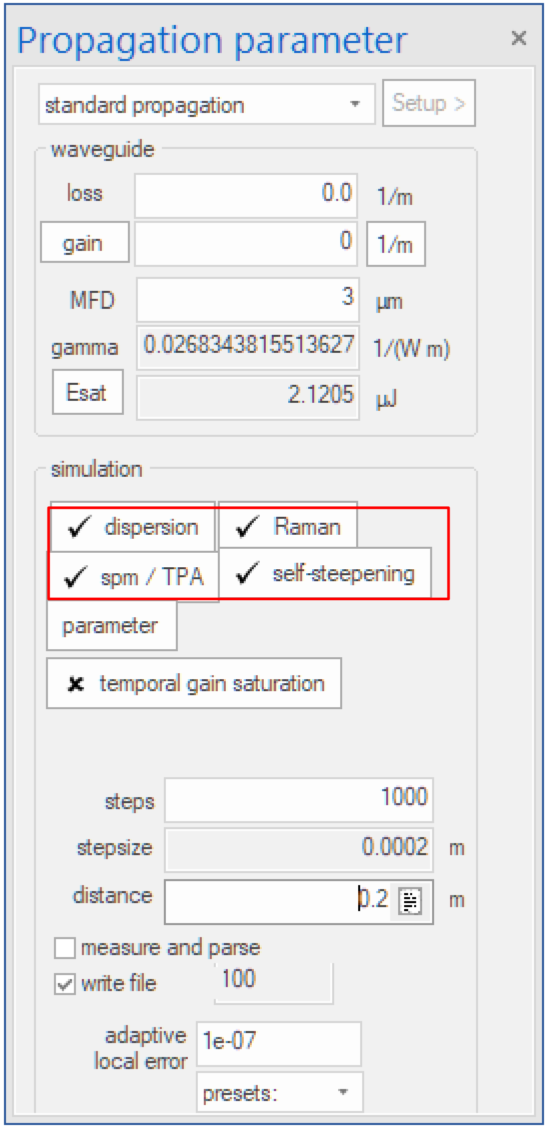
Additionally, switch on all nonlinear effects
Raman response function is simple Lorentz




self-steepening without shock term





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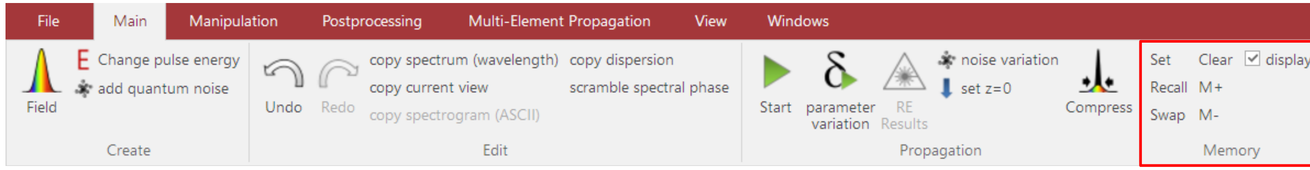
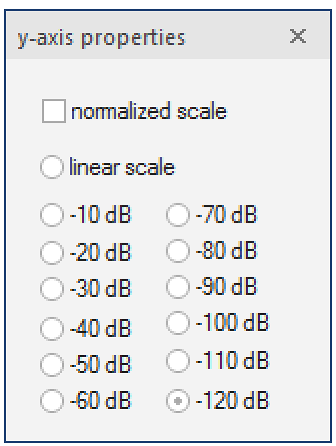
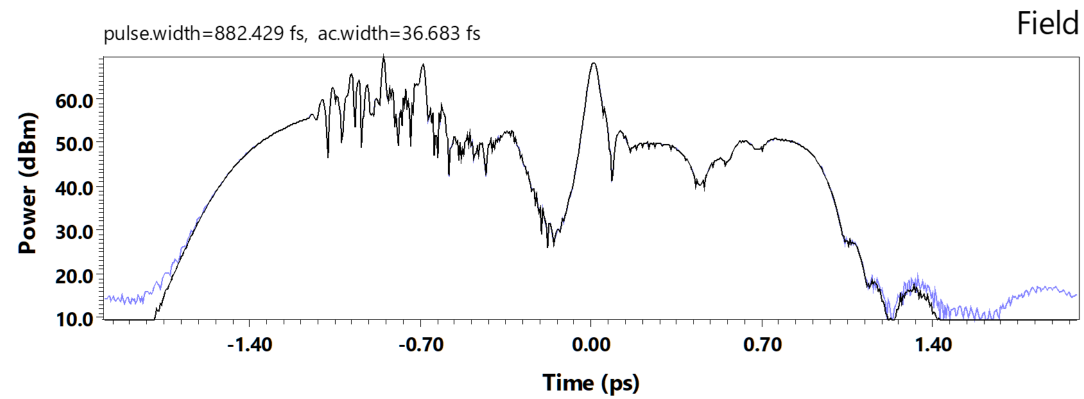
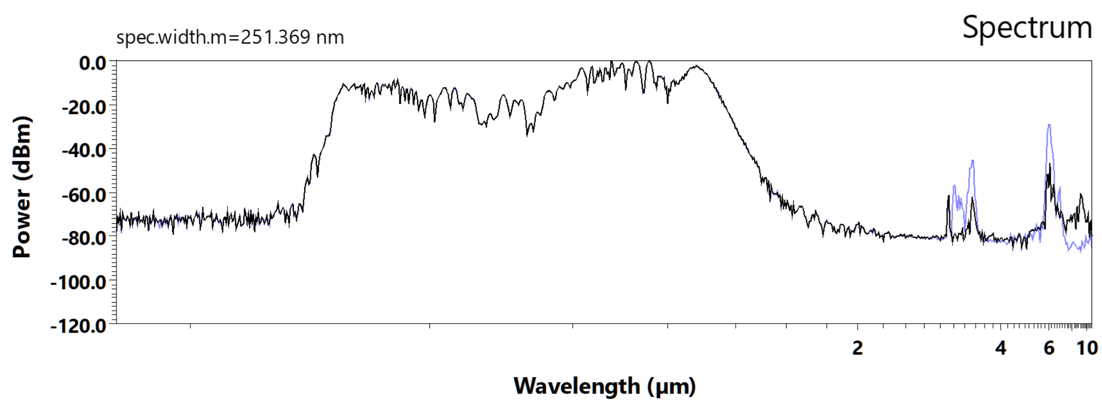



propagate 0.2 m, 100 steps, firstly with 0.01 adaptive local error, save result via „memory“>„set“, then **Undo** to return to initial field, change the adaptive local error to 0.0001, re-run and compare on log scale (numerical errors reduced).


double-click y-axis for logarithmic setup

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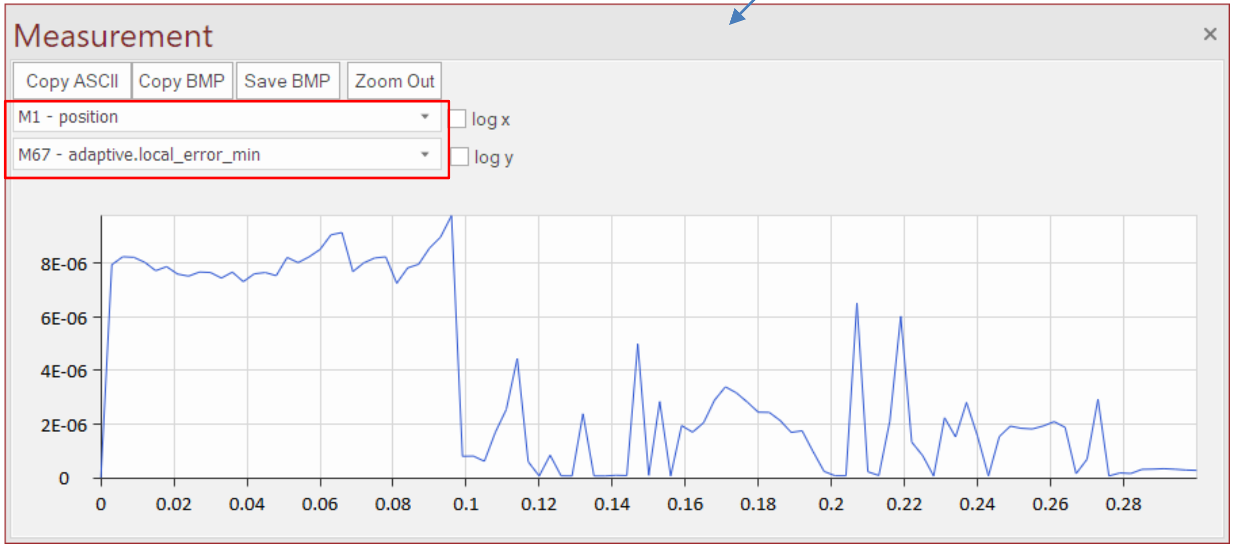
The adaptive algorithm is bounded by the local error set.

If you rerun the propagation with the option „measure and parse“ switched on, it can be analysed in the measurement graph





**Example**: supercontinuum generation with local error <1e-5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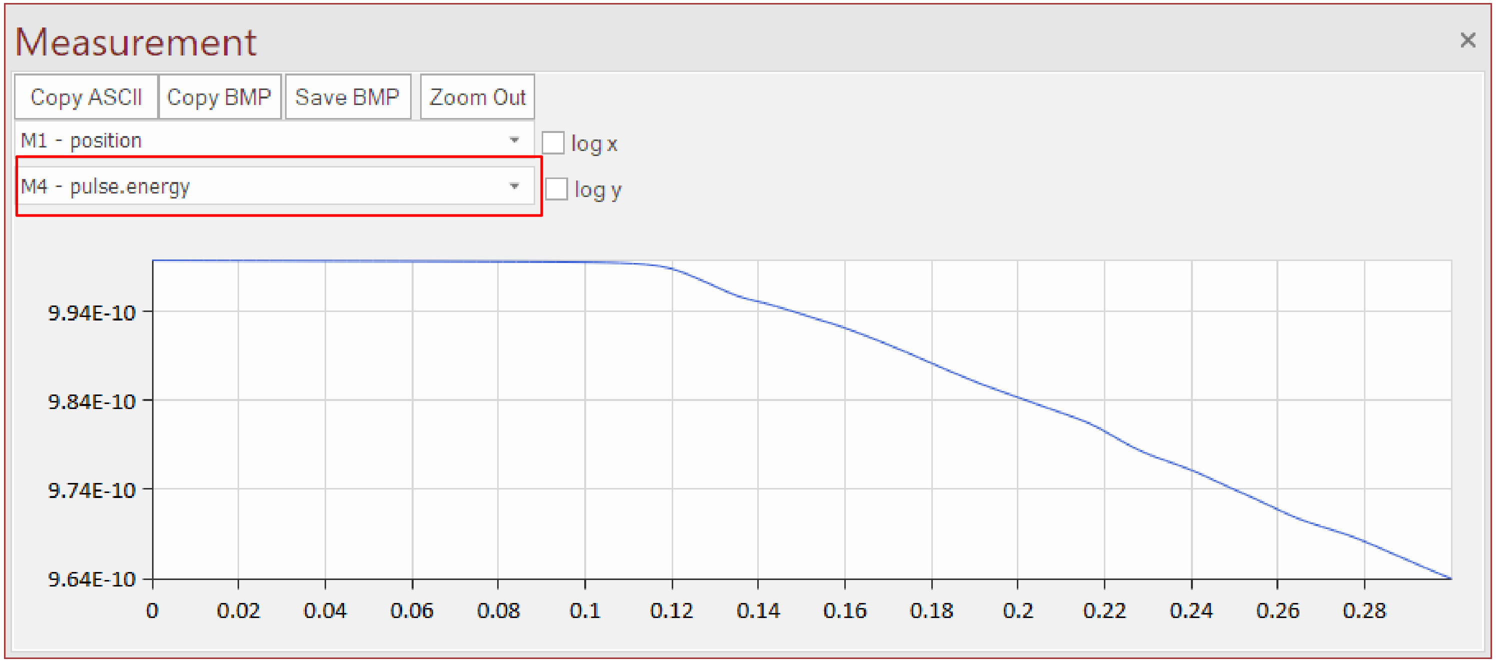
Measurements also allow for more detailed analysis:




**Example**: supercontinuum generation energy drop due to intrapulse Raman shift of the soliton, once it is „created"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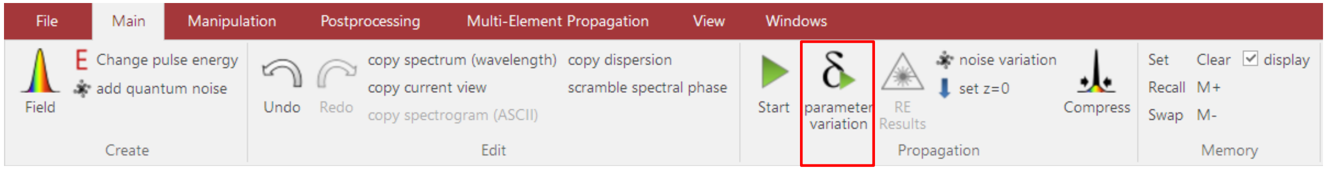
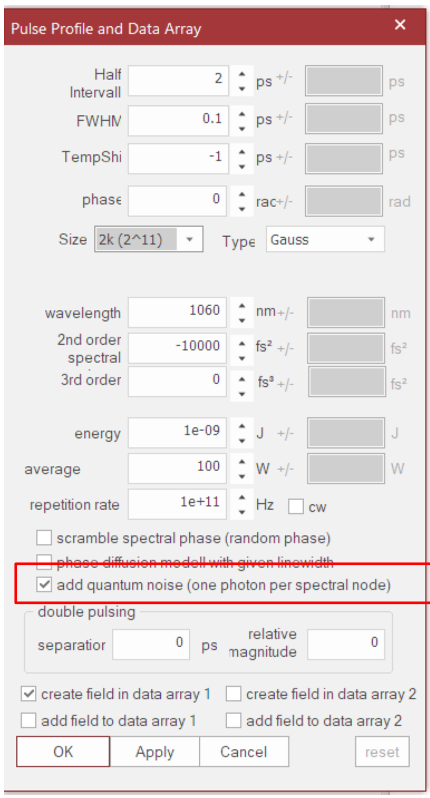
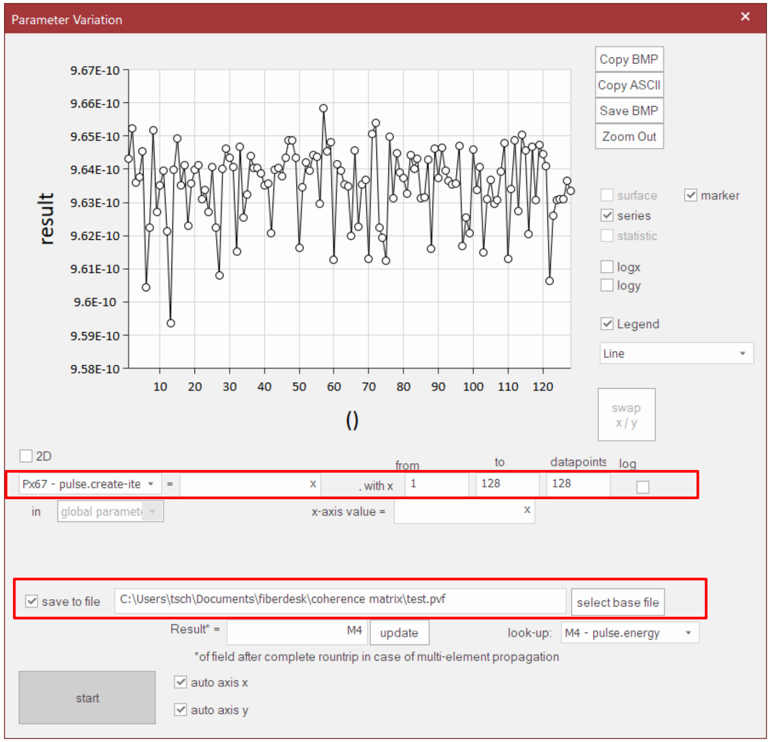



noise and coherence: same starting pulse as before via „Create Pulse Dialog“, check „quantum noise added“, then use „propagation“>“parameter variation“ dialog with iterating pulse creation




By choosing „save to file“ and selecting a base file, the parameter variation is saved and all results are store in a BPF file name „..., all x.bpf“. This can be used for evaluation, see next slide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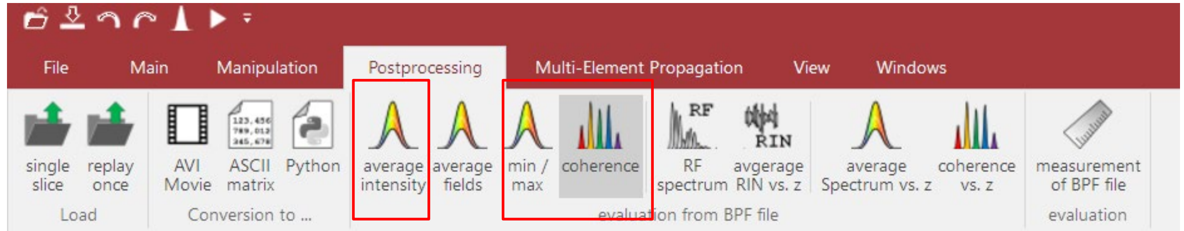


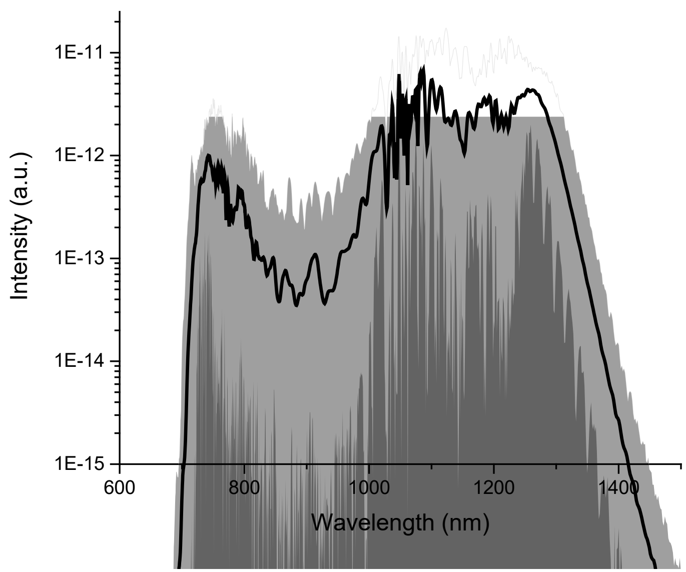

the saved files are now used for average spectrum and coherence calcualation via Postprocessing > coherence

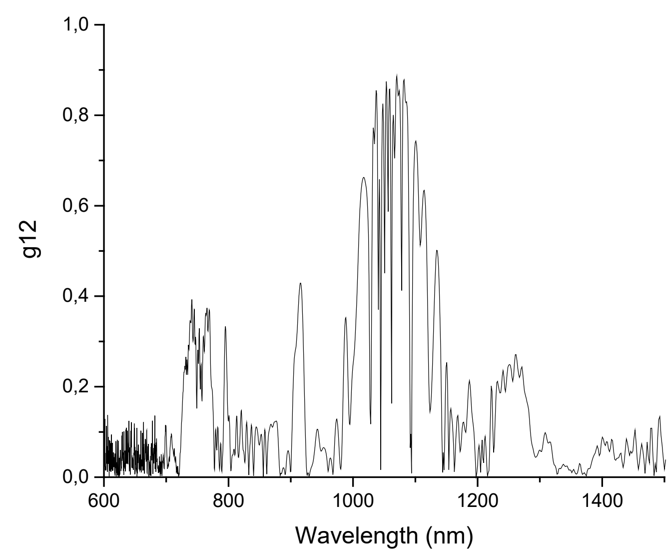
Postprocessing > average intensity

Postprocessing > min / max

$$\left|g_{12}(\lambda)\right| = \left|\frac{\left\langle E_1^*(\lambda)E_2(\lambda)\right\rangle}{\sqrt{\left\langle\left|E_1(\lambda)\right|^2\right\rangle\left\langle\left|E_2(\lambda)\right|^2\right\rangle}}\right|$$

past both results to clipboard and display in e.g. in Origin .





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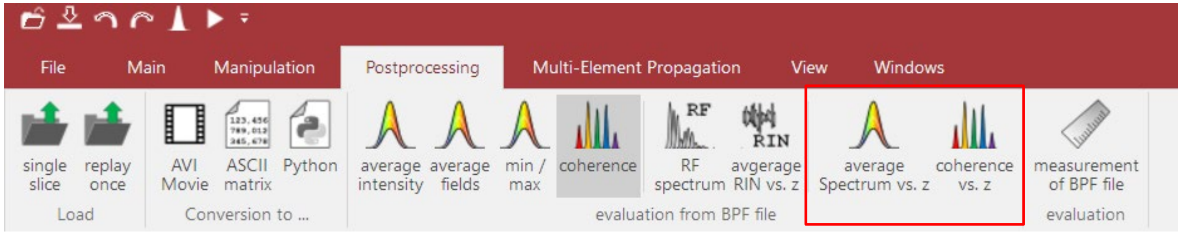
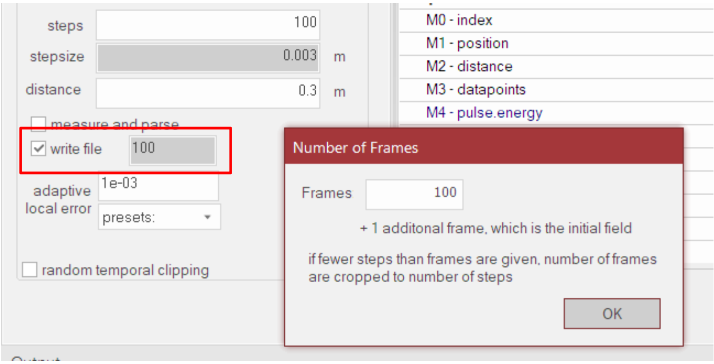
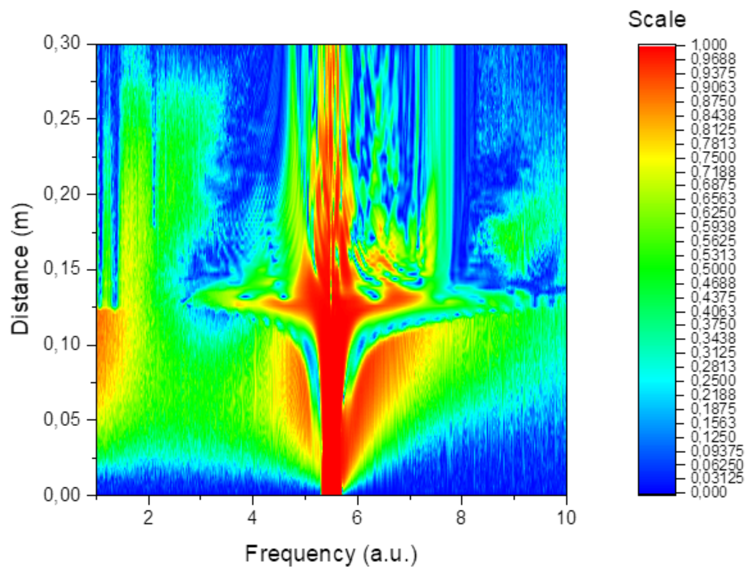
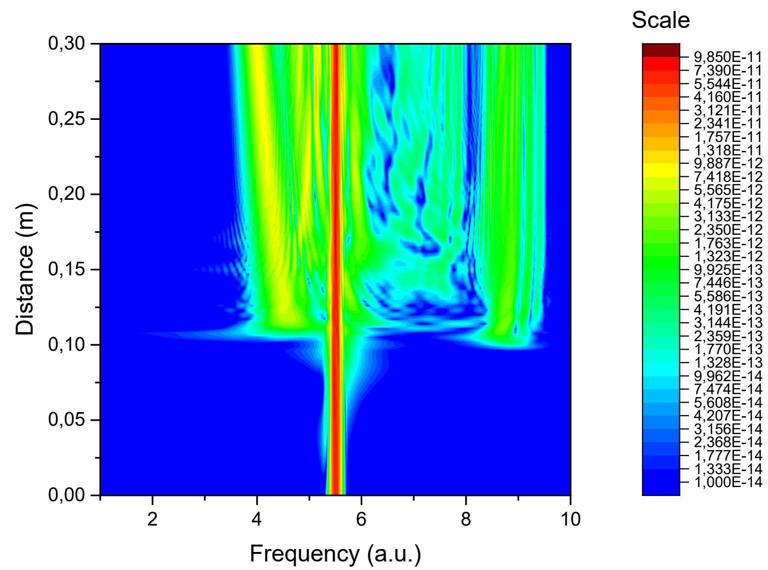



You can also average a series of simulations or calculate the coherence along z.

It requires to save the fields along z during parameter variation. To do so, enable „write file“ in the propagation parameter setup and run the parameter variation with „save to file“ switched-on again. The results can be obtained by the Postprocessing items shown on top, which request you to select the base file for evaluation. Only 1D parameter variation can be used.

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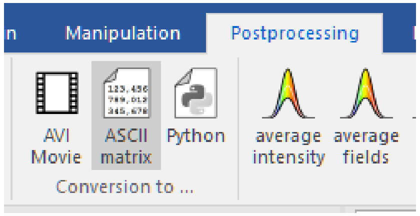
# lecture 2 – export propagation data

To make a propagation graph outside of fiberdesk, you **need to have your propagation saved to a file** (switch on „write file" in the propagation parameter windows and do the propagation afterwards).

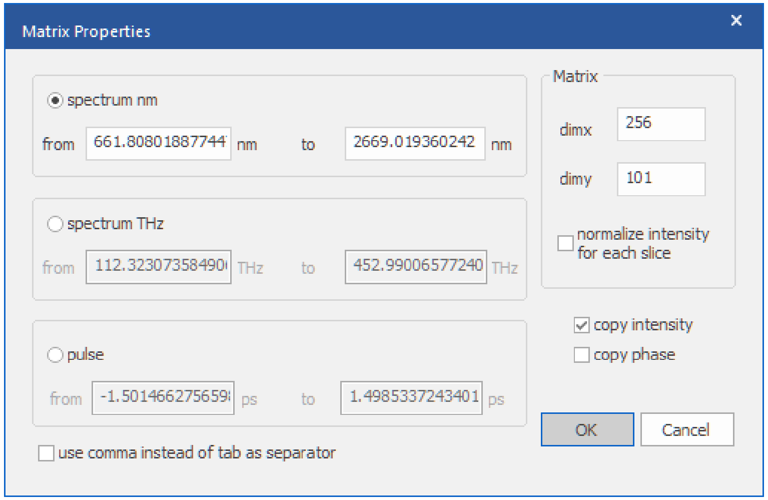
Then either use the python script to display what is saved in this propagation file (*.bpf) or use the internal function to copy such data as ASCII to the clipboard and paste it, e.g. in Origin.

To copy your data to the clipboard use the functions "Conversion to > ASCII matrix"

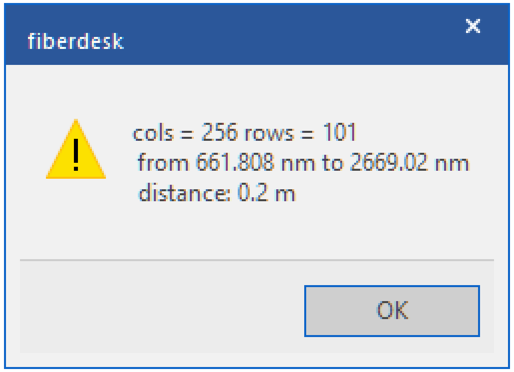



First, you will be asked for the BPF file, then choose the "comma/dot" convention.

In the following dialog, you can choose your setting. If you have selection a specific region already of the field, those values will be inserted by default.




Once it is copied, the important information are shown. You'll need those to set up your graph in Origin correctly.





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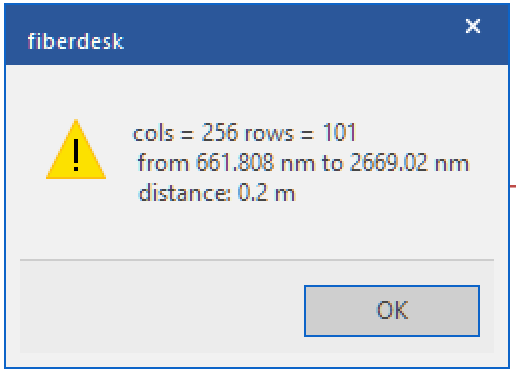
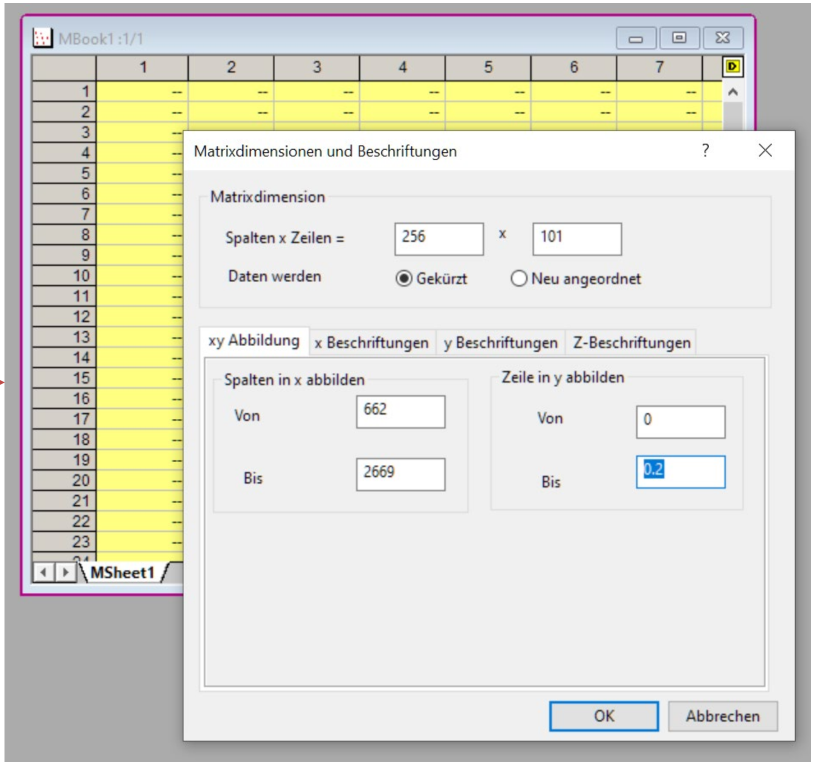
In Origin, create a matrix with the same dimensions as your data.





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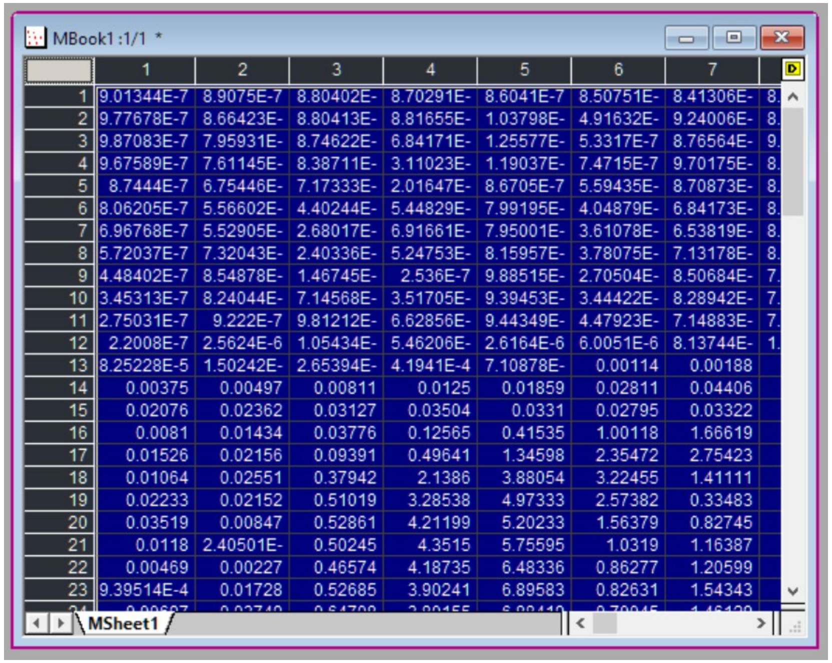
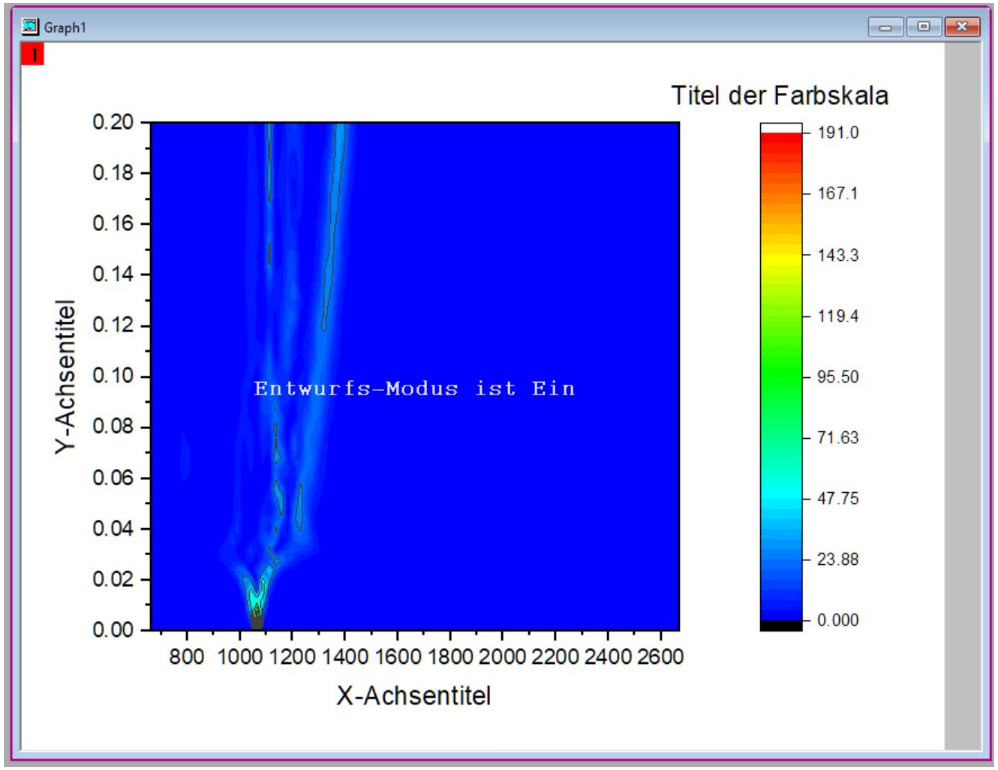
Then select the matrix content and paste then clipboard data into it.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| 1 | 9.01344E-7 | 8.9075E-7 | 8.80402E- | 8.70291E- | 8.6041E-7 | 8.50751E- | 8.41306E- | 8. |
| 2 | 9.77678E-7 | 8.66423E- | 8.80413E- | 8.81655E- | 1.03798E- | 4.91632E- | 9.24006E- | 8. |
| 3 | 9.87083E-7 | 7.95931E- | 8.74622E- | 6.84171E- | 1.25577E- | 5.3317E-7 | 8.76564E- | 9. |
| 4 | 9.67589E-7 | 7.61145E- | 8.38711E- | 3.11023E- | 1.19037E- | 7.4715E-7 | 9.70175E- | 8. |
| 5 | 8.7444E-7 | 6.75446E- | 7.17333E- | 2.01647E- | 8.6705E-7 | 5.59435E- | 8.70873E- | 8. |
| 6 | 8.06205E-7 | 5.56602E- | 4.40244E- | 5.44829E- | 7.99195E- | 4.04879E- | 6.84173E- | 8. |
| 7 | 6.96768E-7 | 5.52905E- | 2.68017E- | 6.91661E- | 7.95001E- | 3.61078E- | 6.53819E- | 8. |
| 8 | 5.72037E-7 | 7.32043E- | 2.40336E- | 5.24753E- | 8.15957E- | 3.78075E- | 7.13178E- | 8. |
| 9 | 4.48402E-7 | 8.54878E- | 1.46745E- | 2.536E-7 | 9.88515E- | 2.70504E- | 8.50684E- | 7. |
| 10 | 3.45313E-7 | 8.24044E- | 7.14568E- | 3.51705E- | 9.39453E- | 3.44422E- | 8.28942E- | 7. |
| 11 | 2.75031E-7 | 9.222E-7 | 9.81212E- | 6.62856E- | 9.44349E- | 4.47923E- | 7.14883E- | 7. |
| 12 | 2.2008E-7 | 2.5624E-6 | 1.05434E- | 5.46206E- | 2.6164E-6 | 6.0051E-6 | 8.13744E- | 1. |
| 13 | 8.25228E-5 | 1.50242E- | 2.65394E- | 4.1941E-4 | 7.10878E- | 0.00114 | 0.00188 | |
| 14 | 0.00375 | 0.00497 | 0.00811 | 0.0125 | 0.01859 | 0.02811 | 0.04406 | |
| 15 | 0.02076 | 0.02362 | 0.03127 | 0.03504 | 0.0331 | 0.02795 | 0.03322 | |
| 16 | 0.0081 | 0.01434 | 0.03776 | 0.12565 | 0.41535 | 1.00118 | 1.66619 | |
| 17 | 0.01526 | 0.02156 | 0.09391 | 0.49641 | 1.34598 | 2.35472 | 2.75423 | |
| 18 | 0.01064 | 0.02551 | 0.37942 | 2.1386 | 3.88054 | 3.22455 | 1.41111 | |
| 19 | 0.02233 | 0.02152 | 0.51019 | 3.28538 | 4.97333 | 2.57382 | 0.33483 | |
| 20 | 0.03519 | 0.00847 | 0.52861 | 4.21199 | 5.20233 | 1.56379 | 0.82745 | |
| 21 | 0.0118 | 2.40501E- | 0.50245 | 4.3515 | 5.75595 | 1.0319 | 1.16387 | |
| 22 | 0.00469 | 0.00227 | 0.46574 | 4.18735 | 6.48336 | 0.86277 | 1.20599 | |
| 23 | 9.39514E-4 | 0.01728 | 0.52685 | 3.90241 | 6.89583 | 0.82631 | 1.54343 | |

Let Origin draw a contour plot with the data and setup the appearance to your needs.





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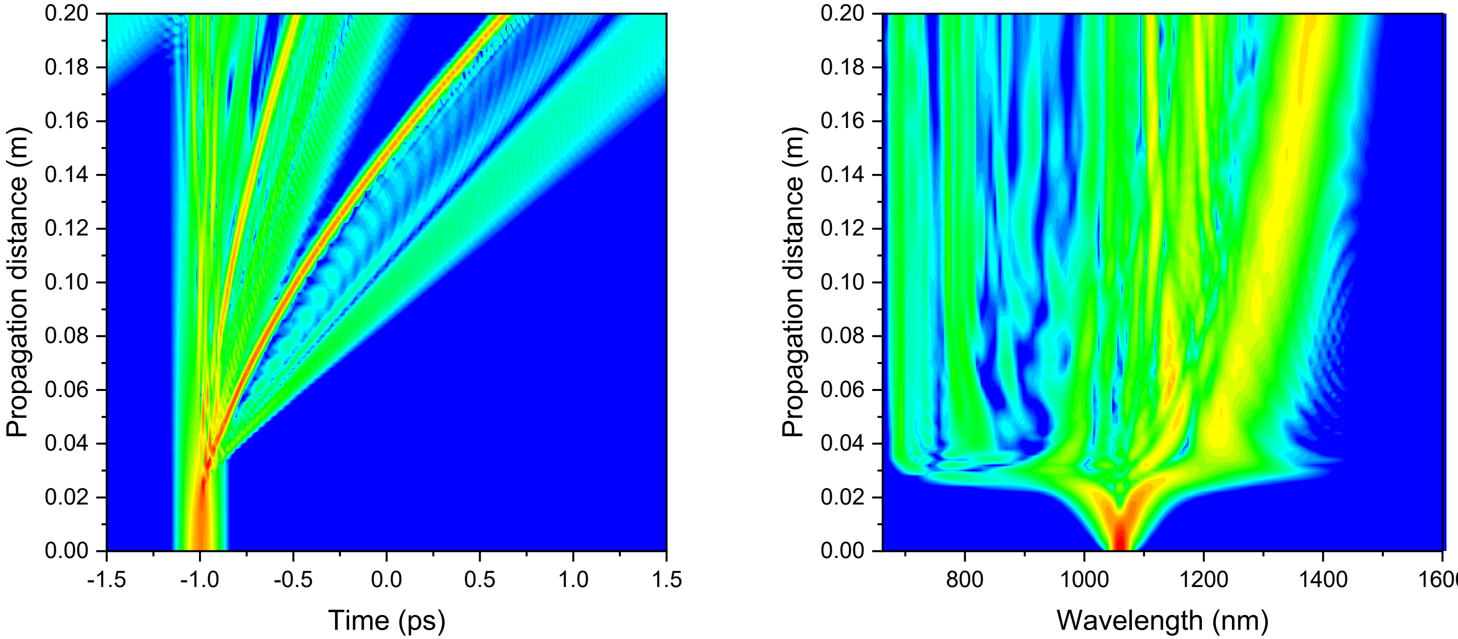
# Lecture 2

Here is an example of a logarithmic intensity plot for the temporal and spectral propagation.





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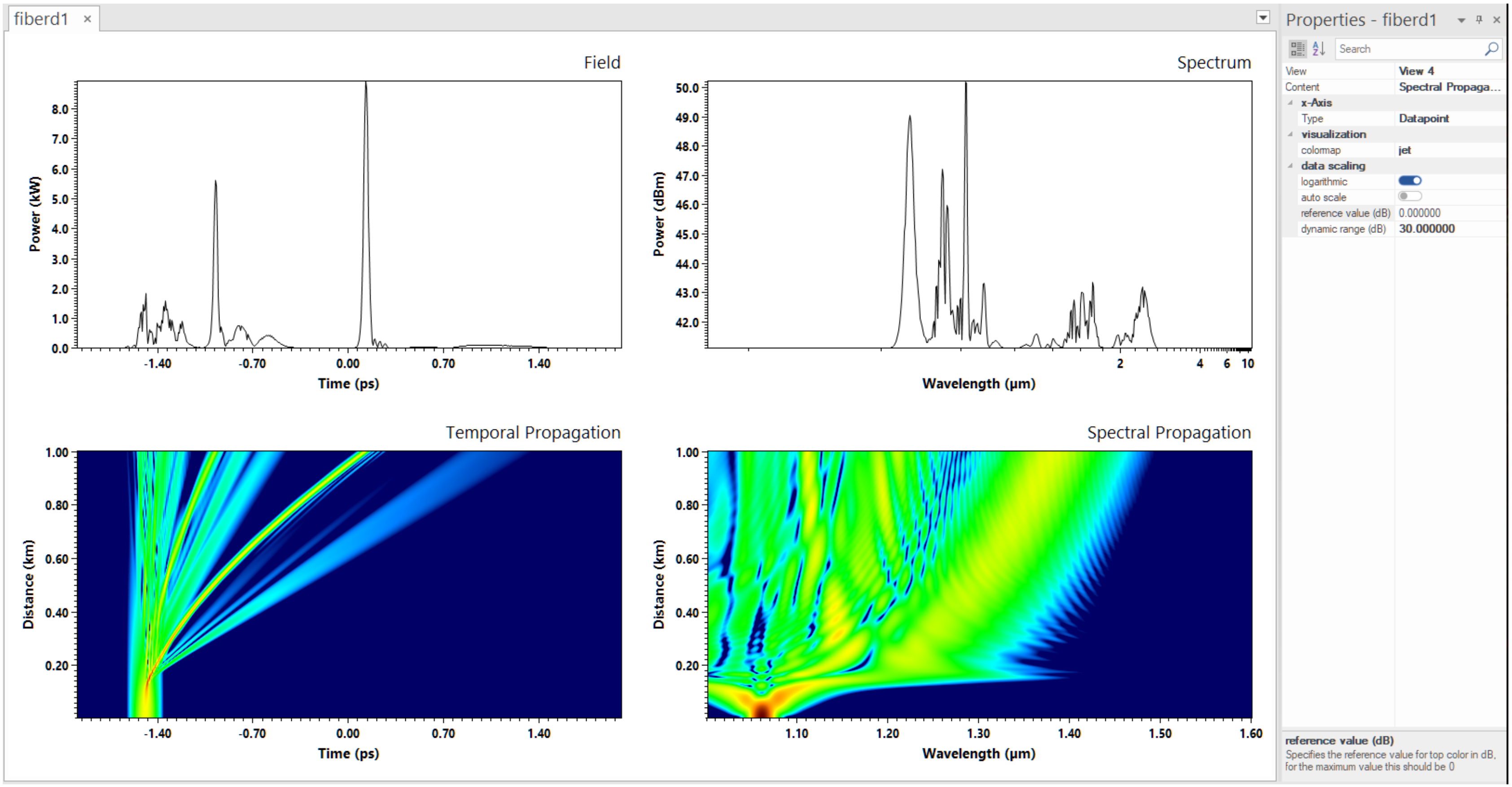
# Lecture 2

In a future release (2022) fiberdesk 7 will have this feature internally.





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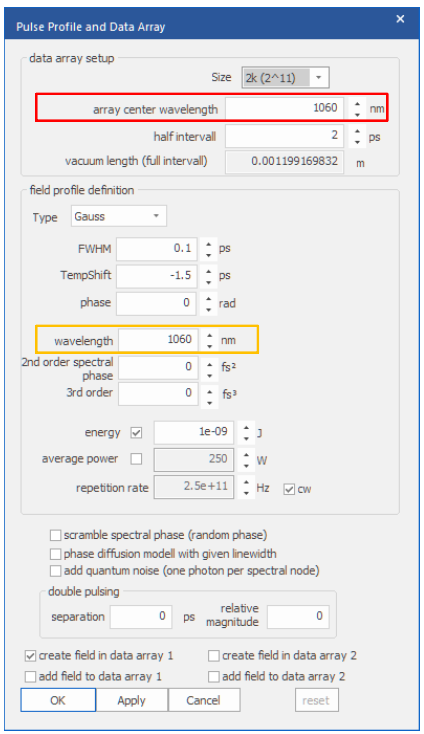
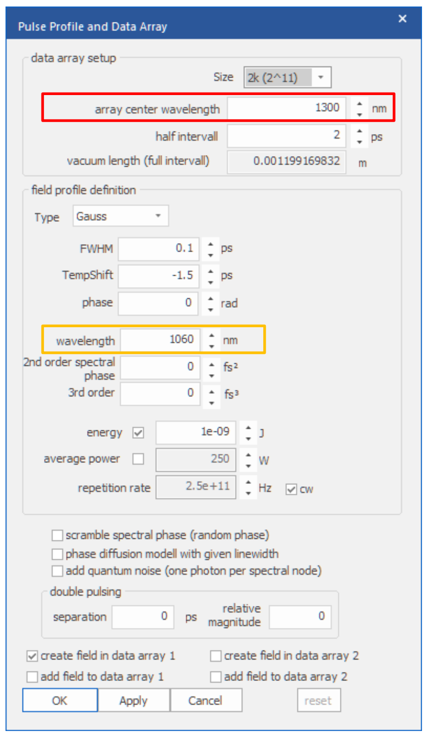
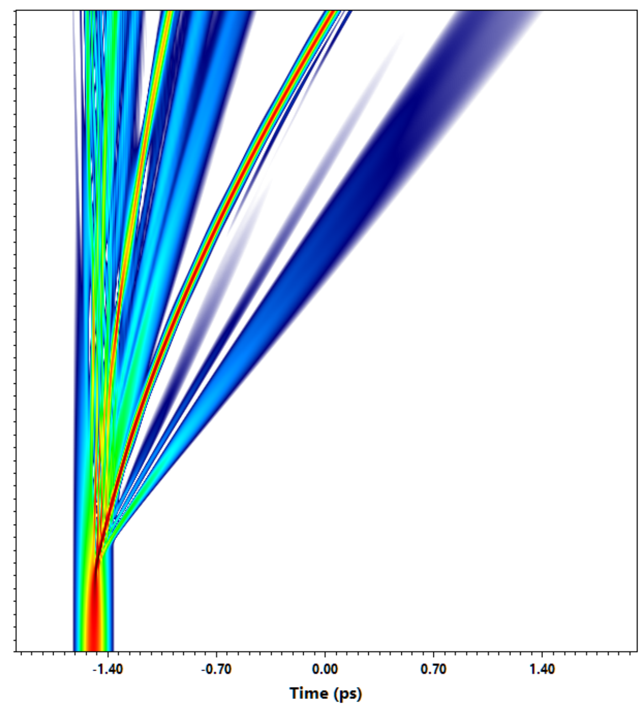
# Lecture 2 - dispersion and retarded time frame

**Background:** fiberdesk uses a complex data array for handling the field envelope A(T) numerically in a retarded time frame and uses the NLSE for propagation. Defining the pulse with a central wavelength $\lambda_P$ can be done with a data array center wavelength $\lambda_{DA}$ that differs from that central wavelength. Usually, you would require this options, but there are cases, where the wavelength extension during propagation makes it necessary to do so. In this case, nothing really changes during propagation.

Here is an example of the supercontinuum generation with an array centered at the pulse central wavelength and the other one, where it is not. Both produce the same result, if **"force retarded time frame" is** off in the dispersion settings. Especially the pulse stays in the co-moving (retarded) frame. This happens, because the Taylor Series used for dispersion is actually calculated around the center wavelength of the pulse center $\lambda_{TS} = \lambda_P$ – so no surprise.





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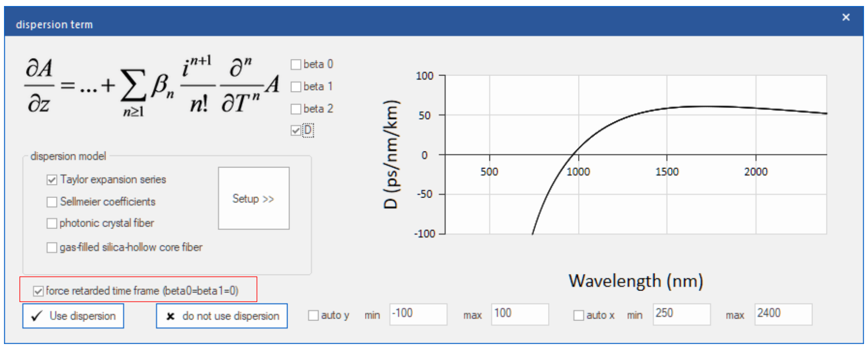
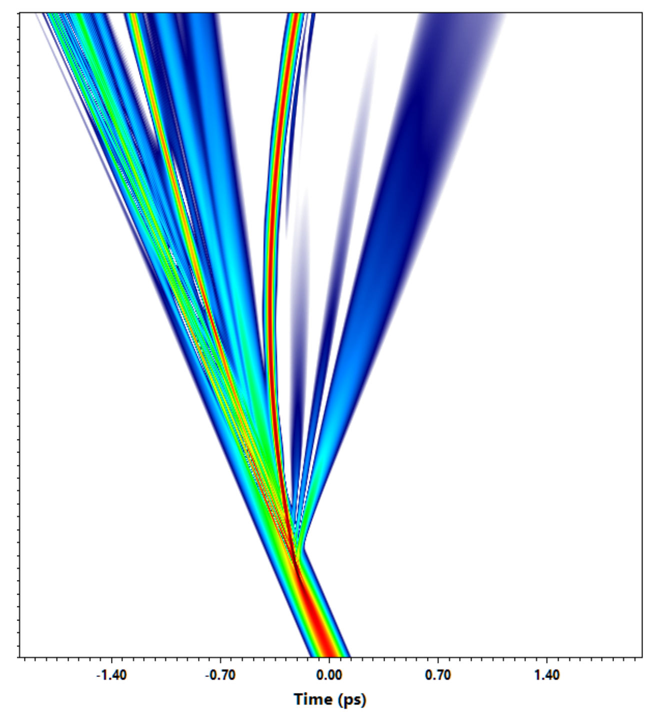
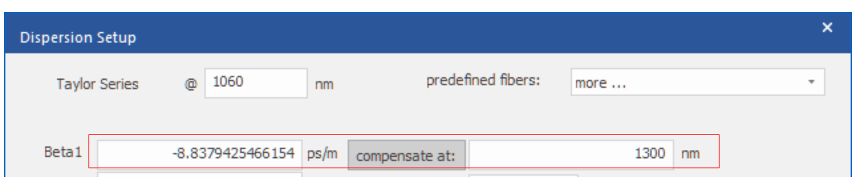
# Lecture 2 - dispersion and retarded time frame

If you repeat the simulation with the option “force retared time frame” switched ON in the dispersion dialog, fiberdesk subtracts the offset (beta0) and linear term (beta1, group delay) of the dispersion curve **at the array center**. This makes sense, if your pulse is also at the array center and both are not the same as the Taylor Series wavelength. However, for our example, where the array center is shifted to 1300 nm but both, Taylor Series and pulse center, are still at 1060 nm, the resulting group delay to 1300 nm is added and the temporal evolution is delayed by this amount, tilting the propagation. Nevertheless, the result of the envelope is of course the same (the initial pulse was temporally shifted to account for the delay, so that the propagation looks centered).




**Alternative:** If “force retared time frame” stays switched **off**, and you take the group delay directly into the value of beta 1, by pressing “compensate at” and a value of 1300 nm.

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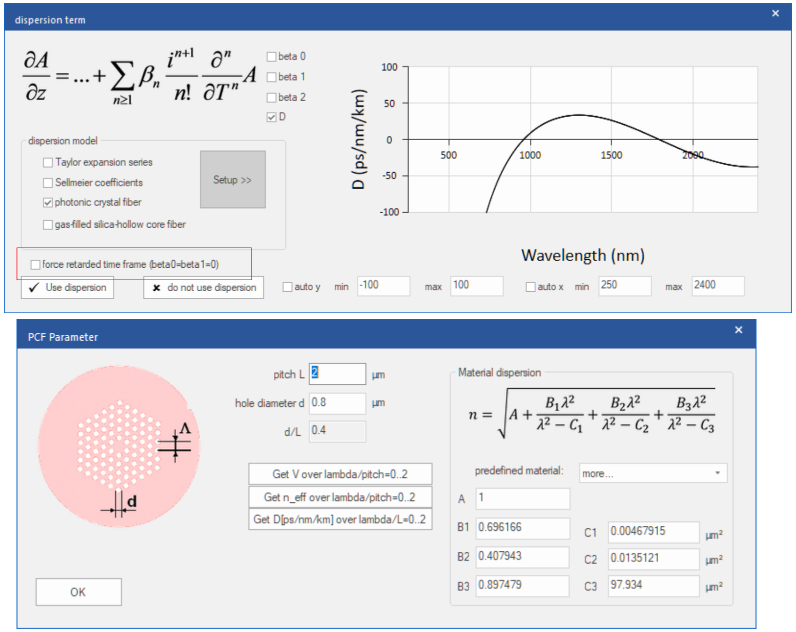
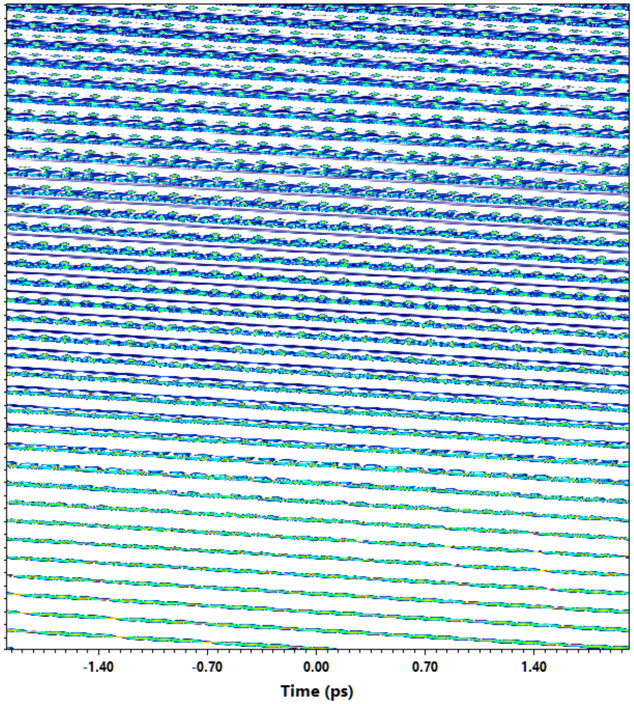
# Lecture 2 - dispersion and retarded time frame

For other dispersion definitions, like Sellmeier, PCF and gas-filled hollow core fibers, the dispersion is not defined with any wavelength reference like the Taylor-Series but uses the full propagation constant β (or equivalent the refractive index *n*). Thus, you should **switch on** “force retarded time frame” to eliminate any group delay that results from this definition. Again, this removing of the group delay is done at the array center wavelength, so be sure, if you defined your pulse at this array center or not. Here is an example, if it is not retarded - despite the fact that, of course, the result is still correct (not shown here)!




(setting achieves a similar dispersion as the Taylor series before)

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