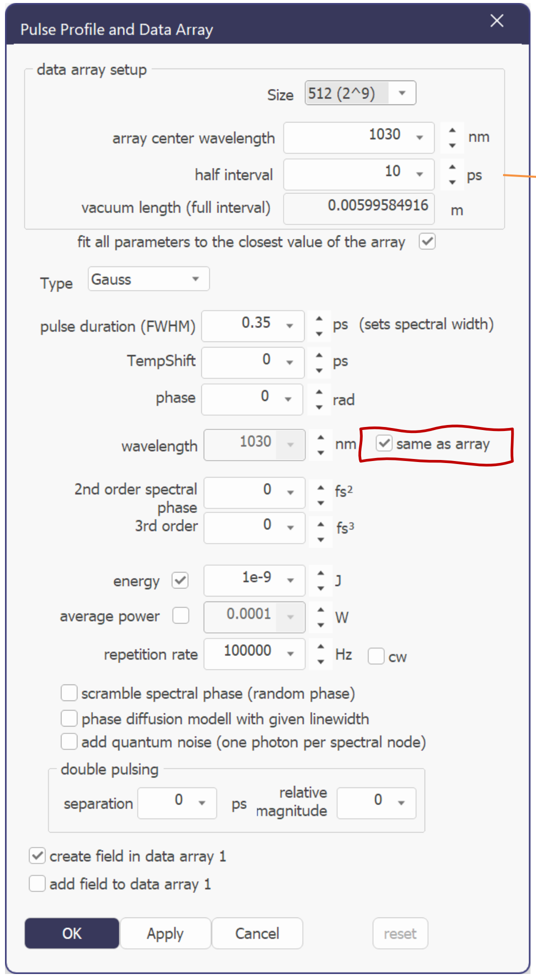
Tutorial 2 – Supercontinuum, Parameter Variation, Export

- A simple nonlinear propagation
- Supercontinuum generation
  - create the field
  - choose parameters
  - put result to memory
  - repeat with higher accuracy
  - check measurements
- (first) Parameter Variation
  - noise and coherence
- Export propagation data
- Dispersion and retarded time frame

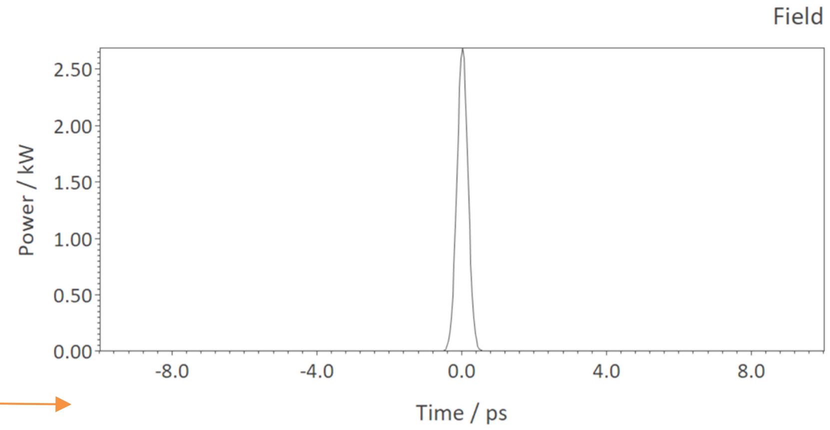
Tutorial 2

- A simple nonlinear propagation
  - Setting up the data array

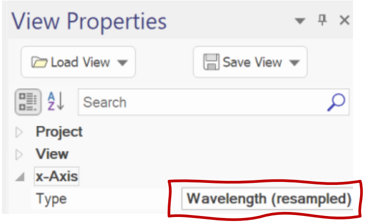
Create New

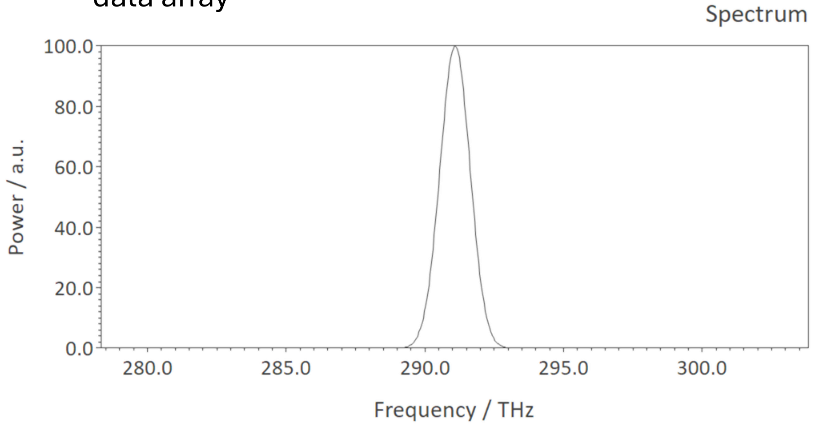


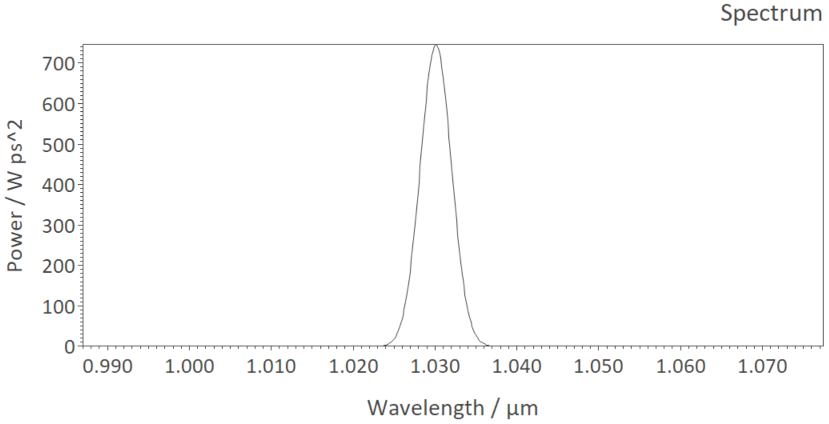
- from -10 ps .. 10 ps, 512 datapoints



- In the frequency domain, the axis is given by the Nyquist theorem
- the wavelength axis can be chosen but will only interpolate to the linear wavelength, the datapoint height (energy content per nm) is not adapted
- If the center array wavelength is set to be the same as array, the spectral center wavelength (default), the spectrum appears in the center of the data array

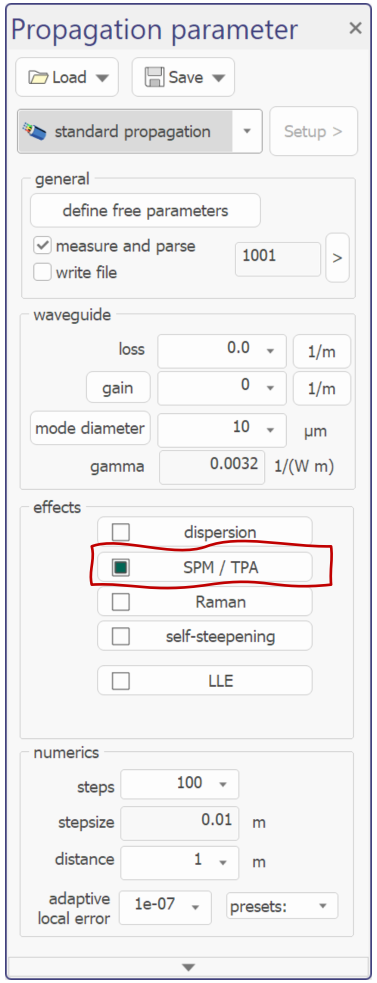




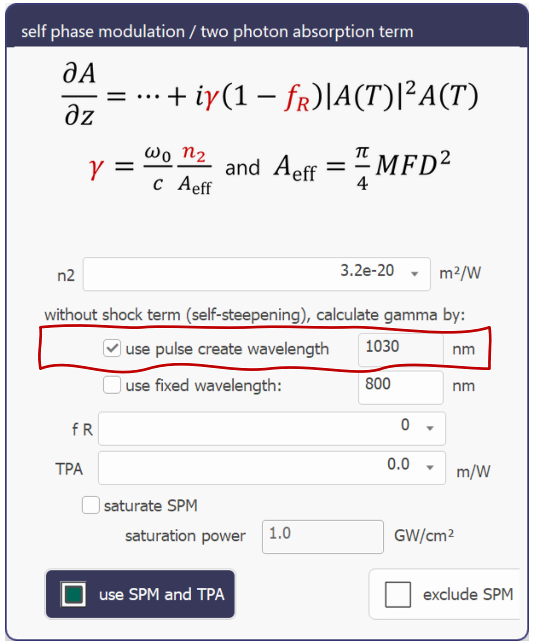


Tutorial 2

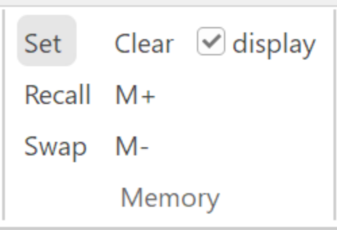
- A simple nonlinear propagation
  - Parameter for the propagation (SPM only , no shock term)

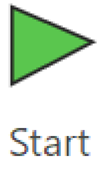


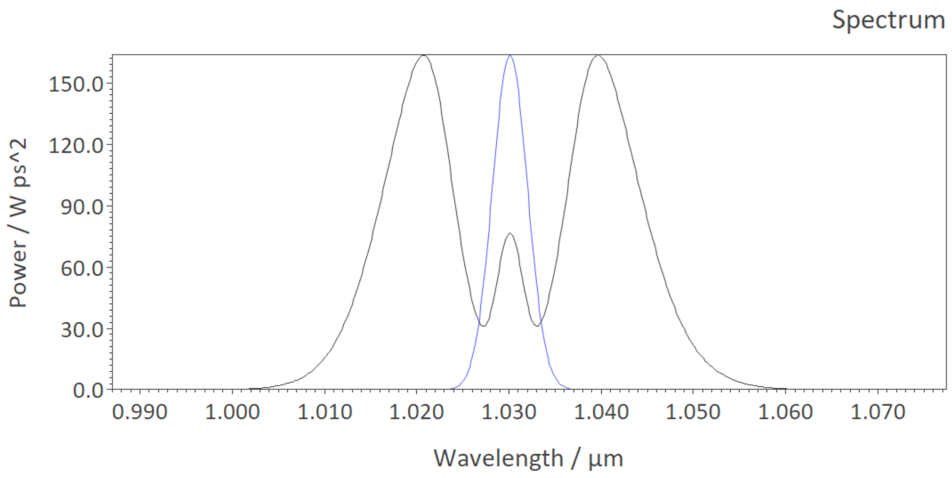
- Check that all effects except SPM is switched off
- Check the SPM dialog for correct settings
  - We set the array center to the spectral center, so this has to apply for the calculation of γ (see next slide)



- Prior to starting, select "Set" within the Main->Memory section.
- Once the propagation begins, you will be able to view the outcome alongside the original field (memory) for comparison.

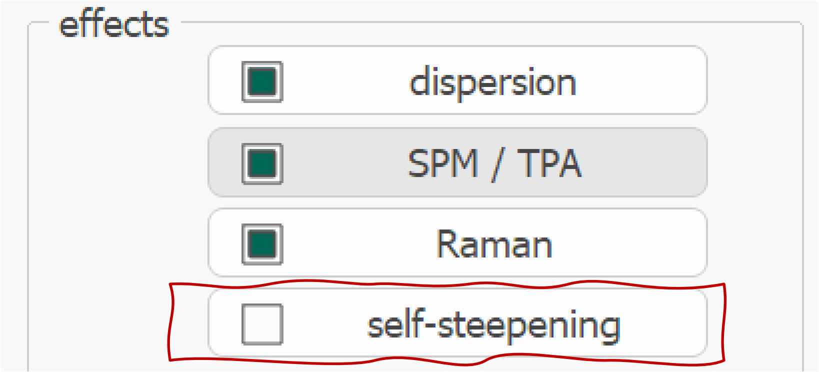






Tutorial 2

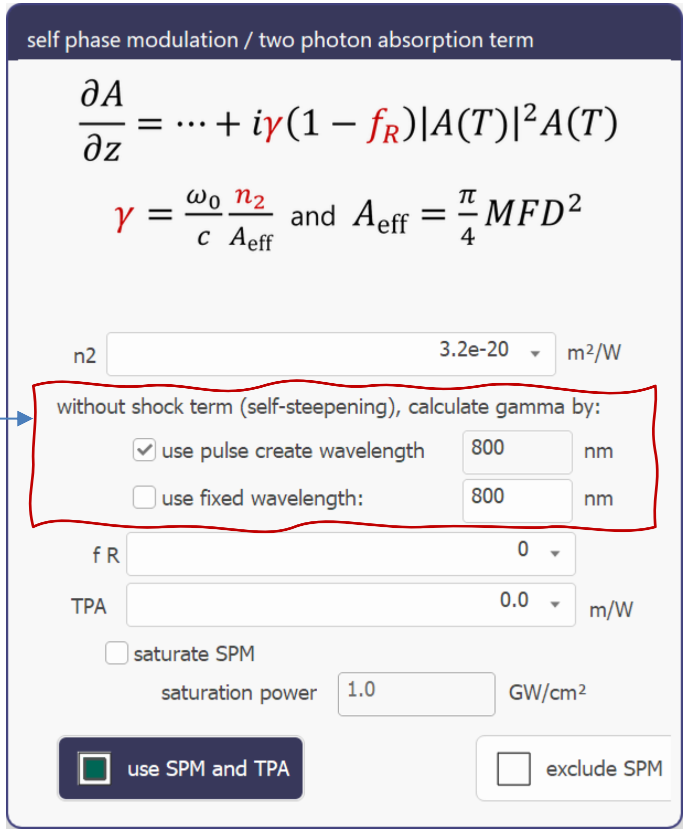
- A simple nonlinear propagation
  - Parameter for the propagation



When using a field whose center wavelength differs from the array center:

The **„No Shock“ Paradox:** if you choose *not* to include „self-steepening” (the shock term) in the numerical solution of the simplified nonlinear Schrödinger equation, you must specify the frequency of your field. This is necessary because *fiberdesk* allows fields to be set away from the array center ($\omega_0 \neq \omega_C$).

This adjustment is made within the SPM dialog:

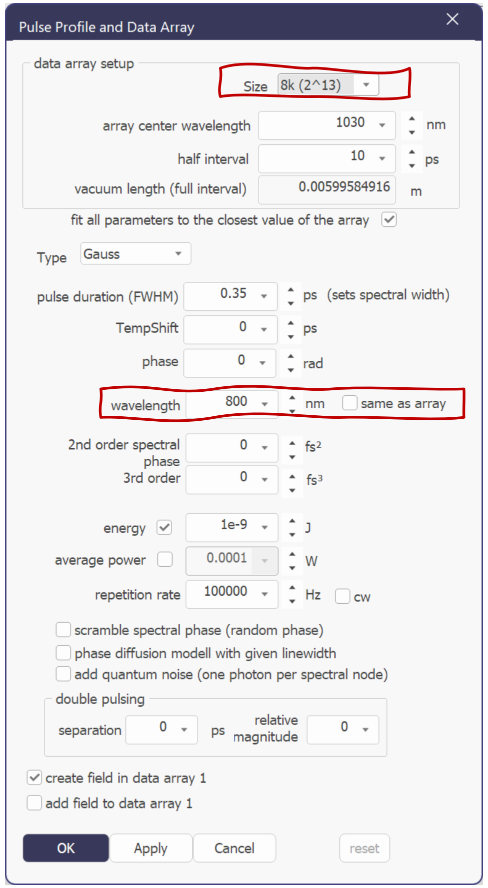


Typically, it can be aligned with the wavelength set in the dialog when creating a new field. However, if you import a field from an external source, you may need to define it using a different (fixed) wavelength.

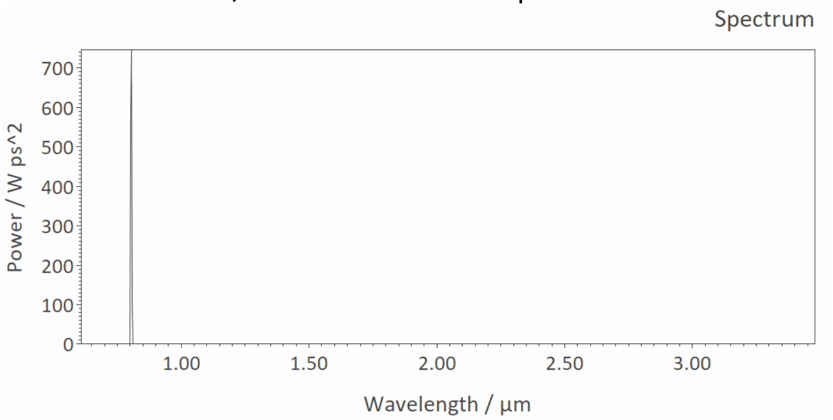
However, if you are using the shock term (self-steepening switched on), this spectral grid shift does not change the result and no setup is required.

Tutorial 2

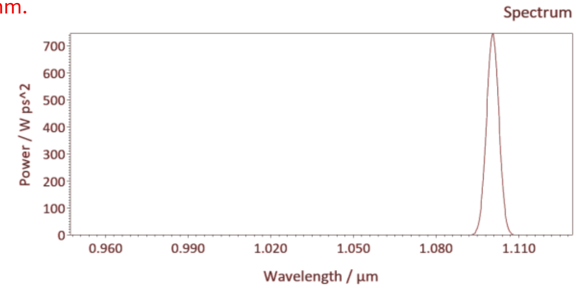
- A simple nonlinear propagation
  - Parameter for the propagation (SPM only, no shock term)



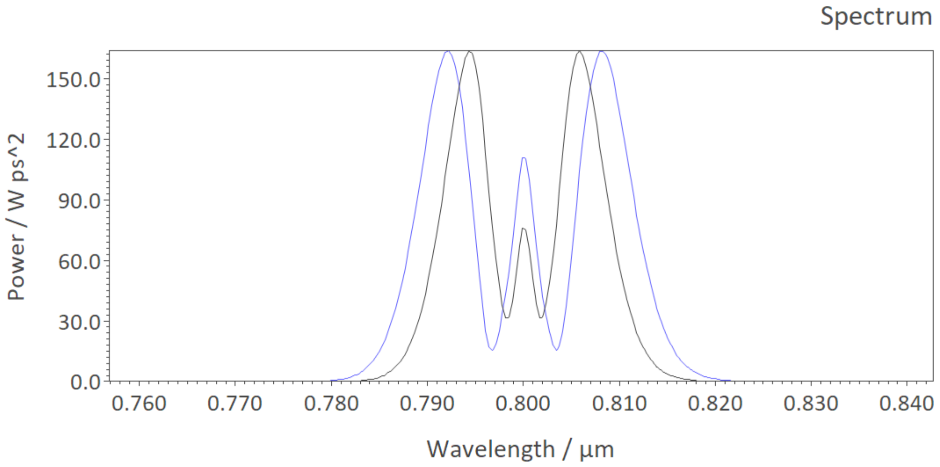
- When using a pulse that is not centered on the array, ensure that the spectral range is covered with sufficient resolution. In this case, the pulse spectrum is at 800 nm while the array center is at 1030 nm, with all other parameters remaining unchanged. To adequately cover the spectrum down to 800 nm, the number of data points must be increased to 8k.



- Note: If the data array is not set correctly, the spectral position may "fold" back into the spectral range, causing the peak to show up at an incorrect wavelength. In this example, with a size of 1k, the 800 nm peak appears around 1100 nm.



- By repeating the nonlinear propagation as previously done, demonstrate the importance of selecting the appropriate setup in the SPM dialog for calculating γ.



(black result – correct)

fixed wavelength 1060 nm (blue – wrong)

Tutorial 2 – Supercontinuum, Parameter Variation, Export

- A simple nonlinear propagation

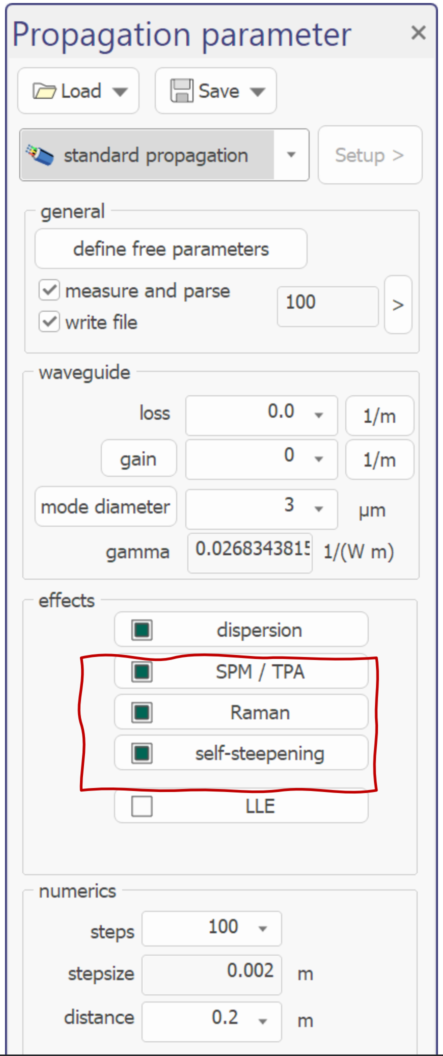
- Supercontinuum generation
  - create the field
  - choose parameters
  - put result to memory
  - repeat with higher accuracy
  - check measurements
- (first) Parameter Variation
  - noise and coherence

- Export propagation data

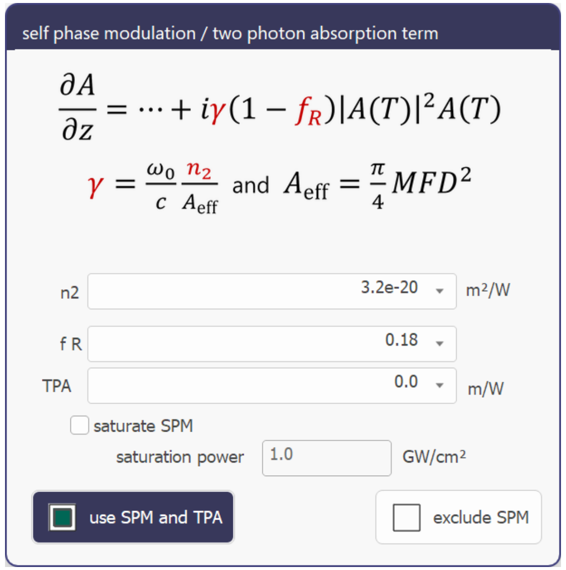
- Dispersion and retarded time frame

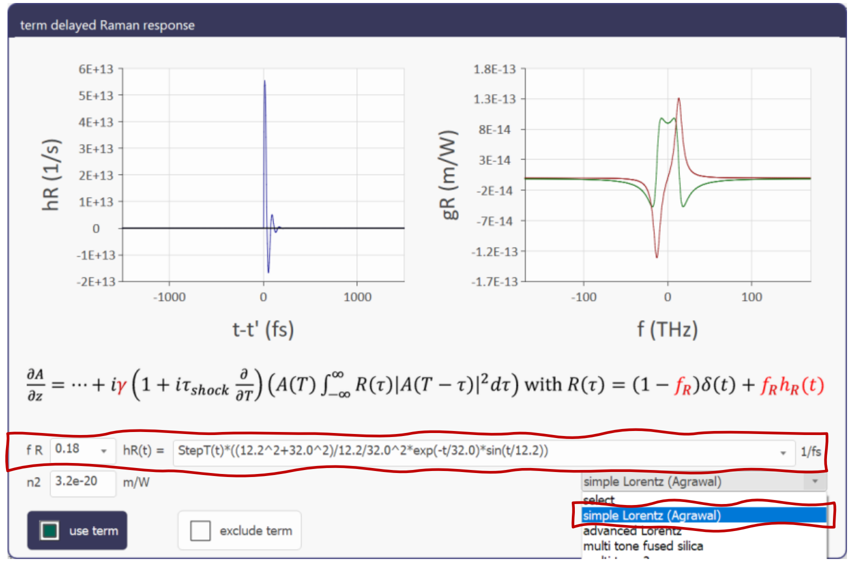
Tutorial 2

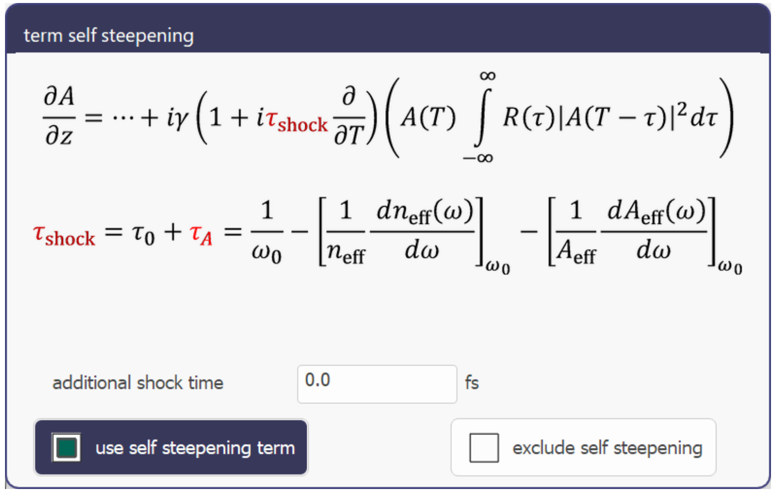
- Supercontinuum generation



- switch on all nonlinear effects:
- Click on „Raman“ and choose a simple Lorentz as the response function $h_{R,}$ and fR=0.18
- Click on „self-steepening“ to check, there is no shock term (tau = 0.0)
- Check the “SPM” for the right settings

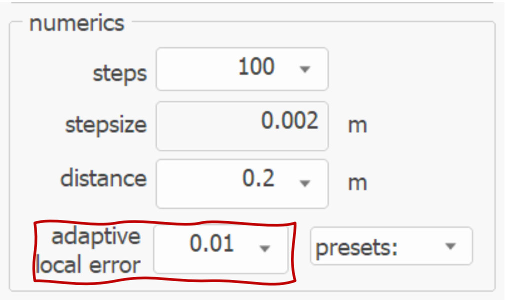




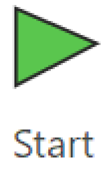


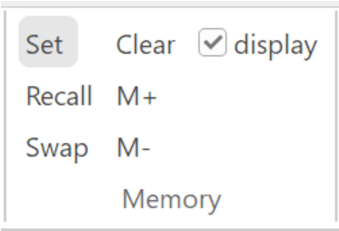
Tutorial 2

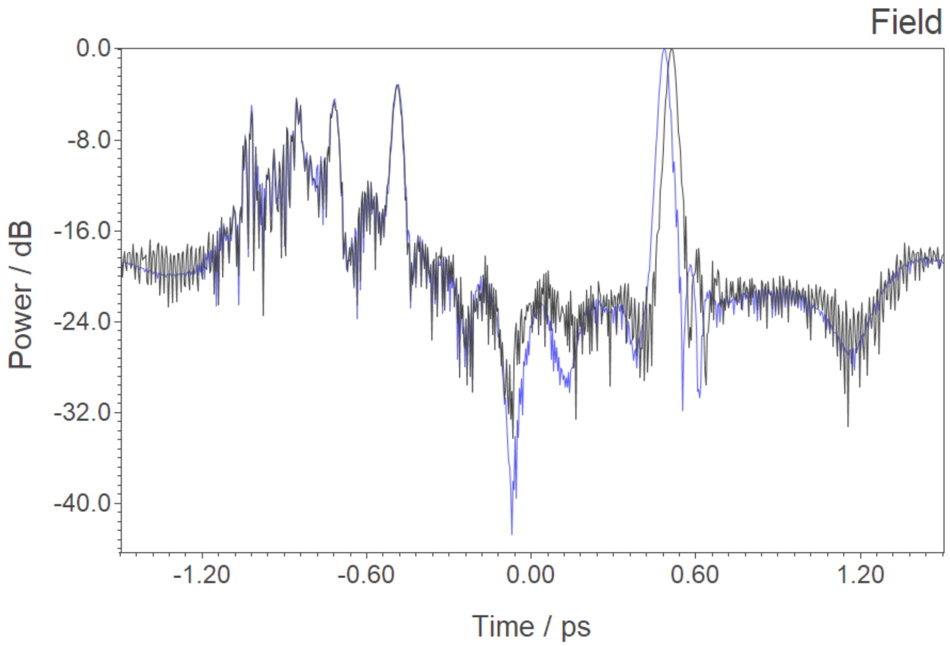
- Supercontinuum generation

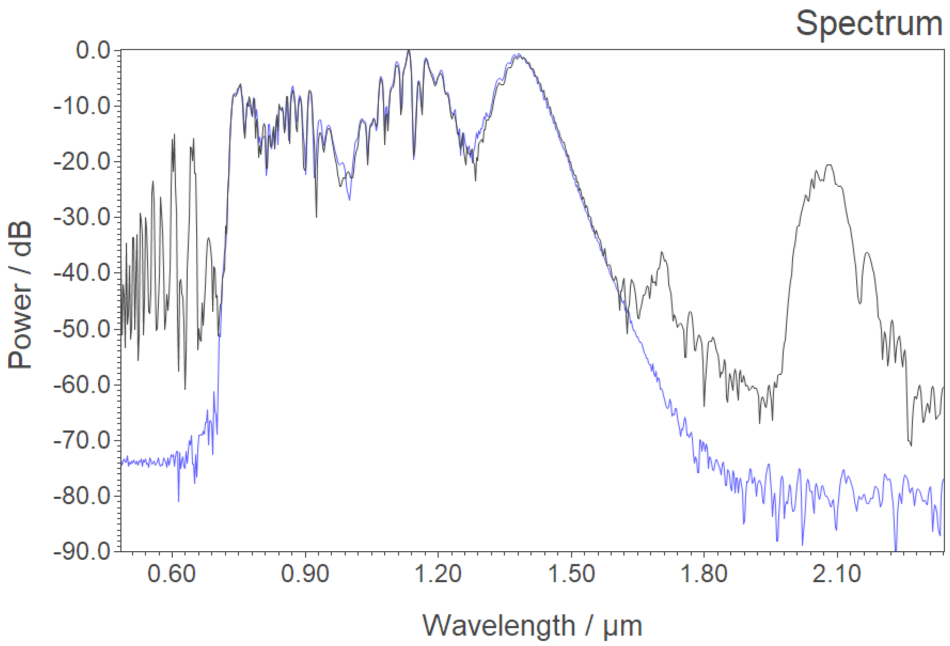


- Start the simulation with 0.01 adaptive local error
- save the result to memory result via „memory“>„set“ (black)
- Rerun with the adaptive local error set to “exact” 1e-07 (blue)
- Below, the accuracy can be compared (some spectral/temporal components were numerical artefacts in the 0.01 simulation)



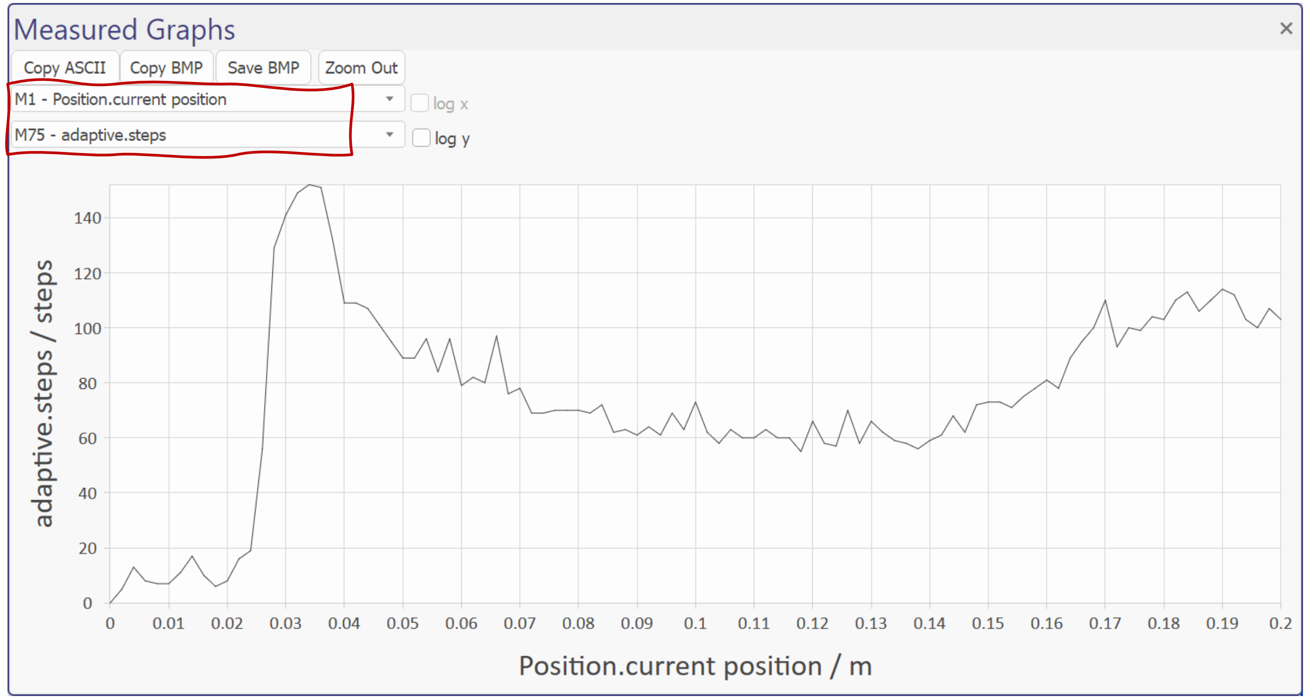






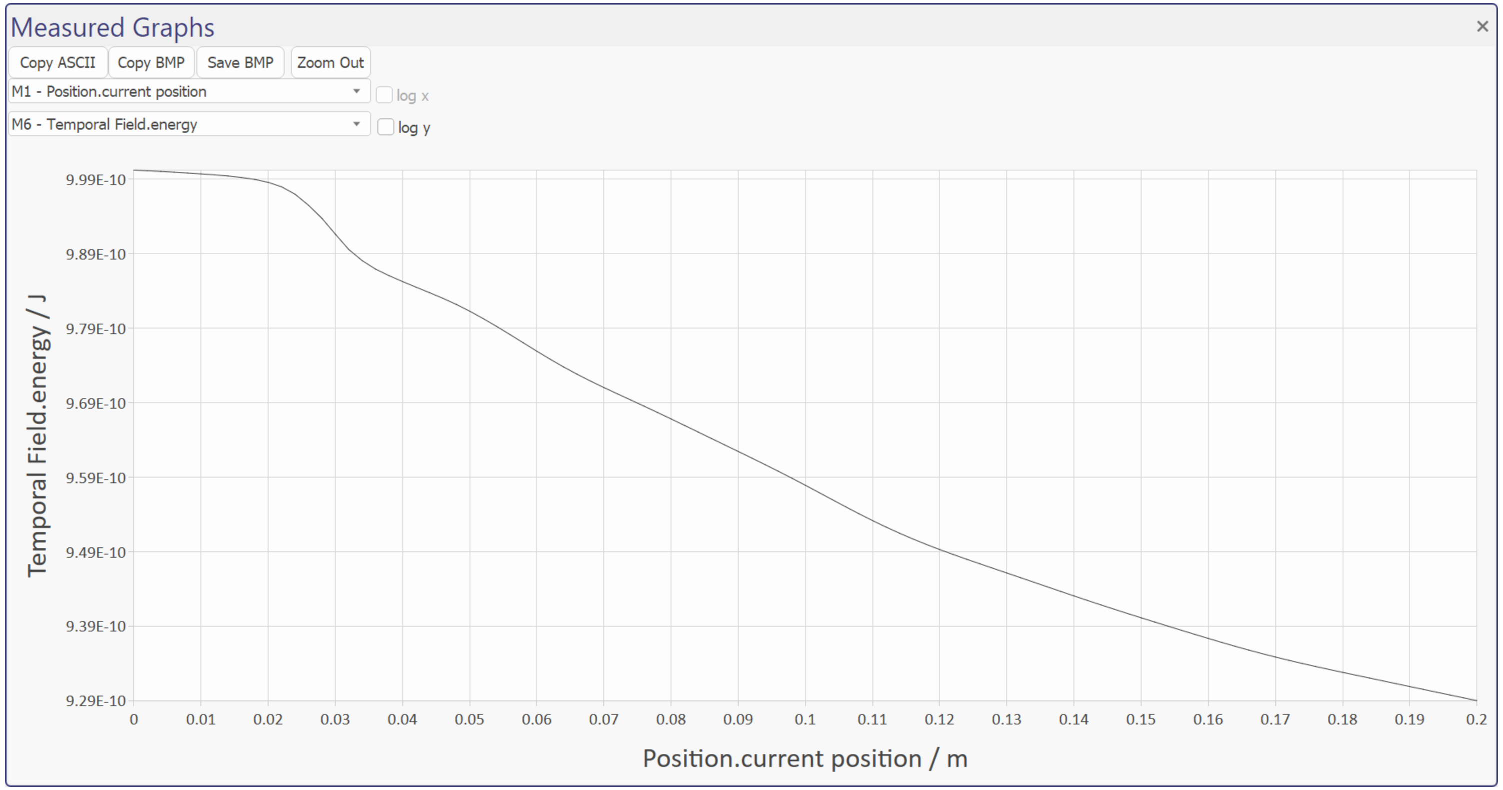
Tutorial 2

- Supercontinuum generation
  - The adaptive algorithm is bounded by the local error set and increases the number of steps (smaller steps) accordingly.
  - If you rerun the propagation with the option „measure and parse“ switched on, it can be analysed in the measurement graph. Here is an example of the number of adaptive steps used to arrive at the current position.



Tutorial 2

- Supercontinuum generation
  - Measurements also allows for more detailed analysis
  - **Example**: supercontinuum generation energy drop due to intra-pulse Raman shift of the soliton, once it is „created“ at ~ 0.025 m



Tutorial 2 – Supercontinuum, Parameter Variation, Export

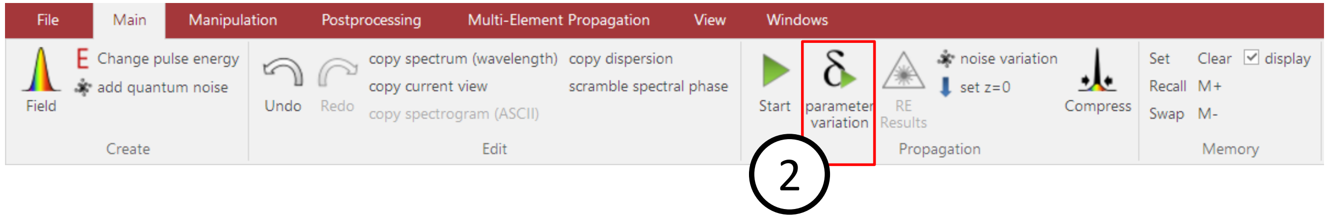
- A simple nonlinear propagation

- Supercontinuum generation
  - create the field
  - choose parameters
  - put result to memory
  - repeat with higher accuracy
  - check measurements
- (first) Parameter Variation
  - noise and coherence

- Export propagation data

- Dispersion and retarded time frame

Tutorial 2

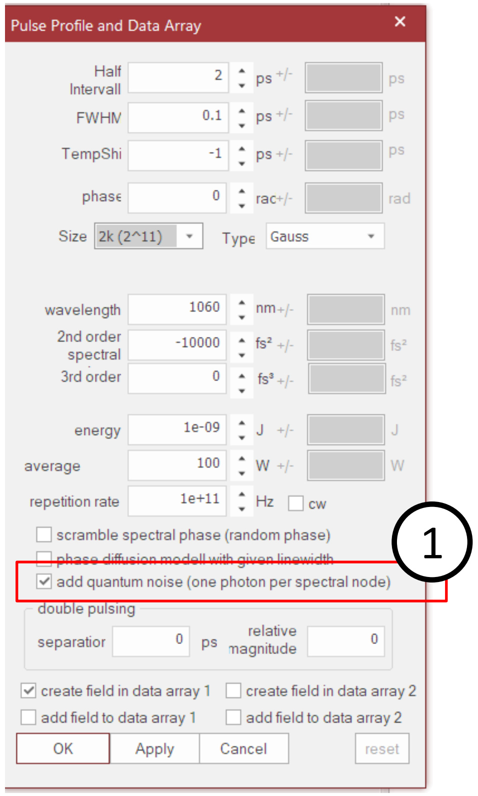


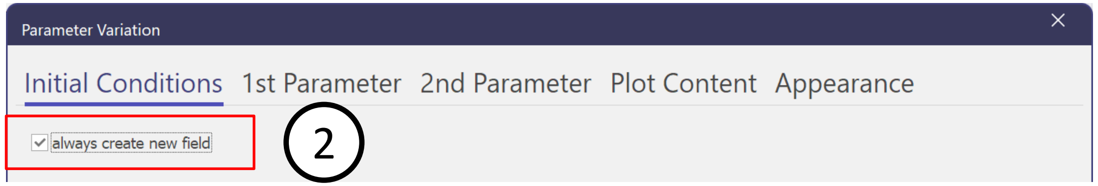
noise and coherence:

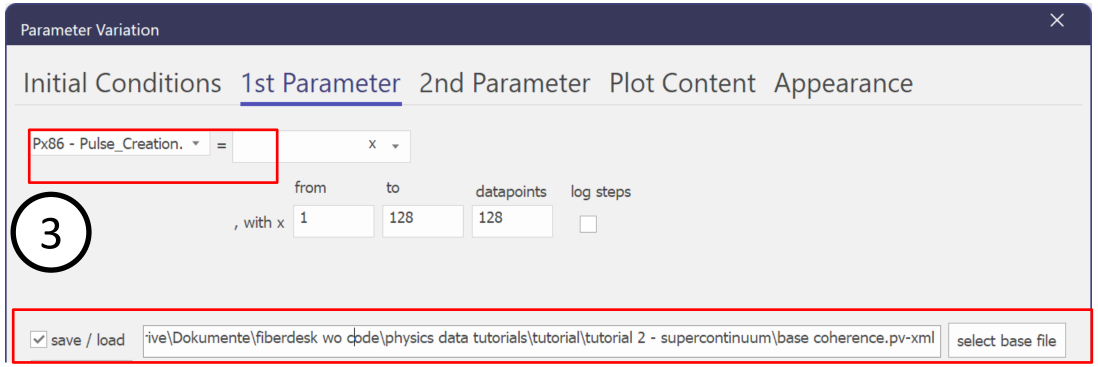
(1) same starting pulse as before via „Create Pulse Dialog“, check „quantum noise added“,

(2) then use „propagation“>“parameter variation“ dialog with „always create new field“ and

(3) „Pulse_Creation_iterator“ as the first parameter to vary (with this, actually nothing is varied, but the pulse recreated)







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

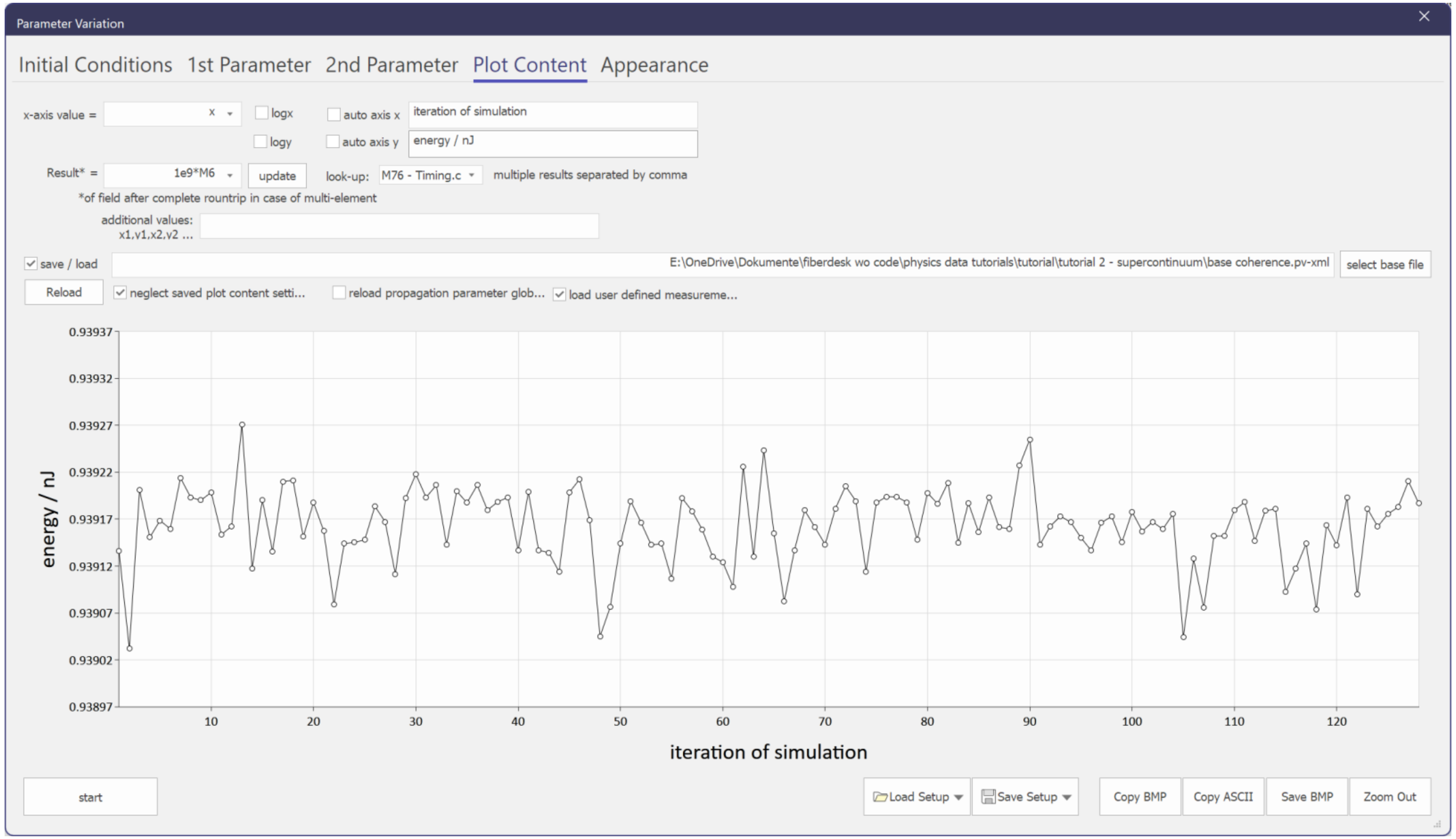
Tutorial 2

noise and coherence:

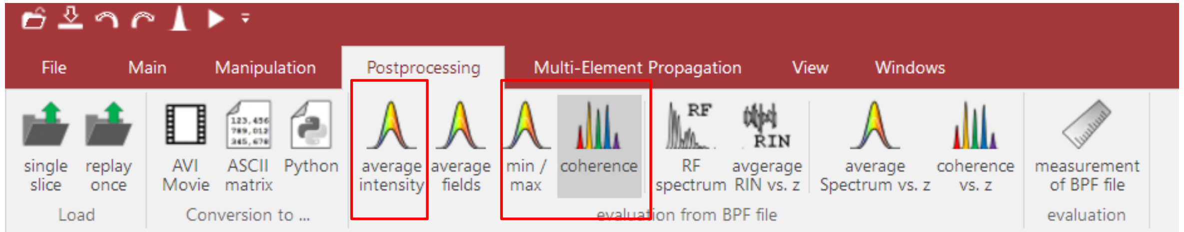
After starting the parameter variation, the simulations start.

The result of a measurement after the propagation can be plotted directly.

Here the energy is shown for example exhibiting noise, because each pulse is recreated with novel quantum noise feautres.



Tutorial 2



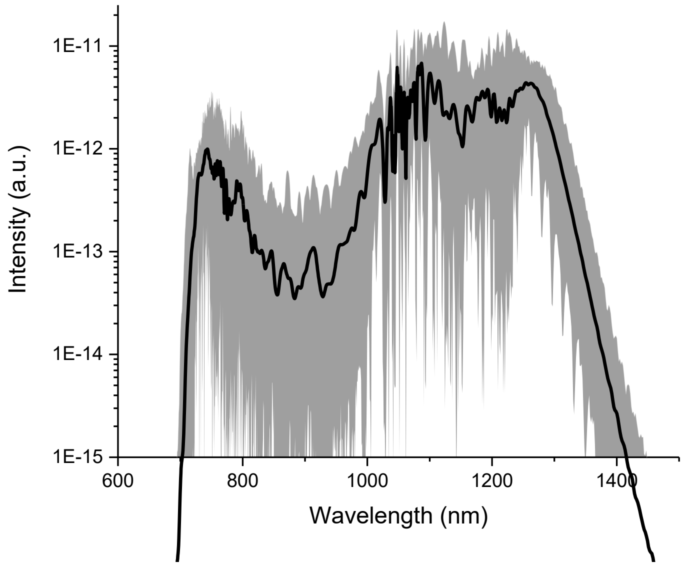
The saved files are now used for average spectrum and coherence calcualation via Postprocessing > coherence

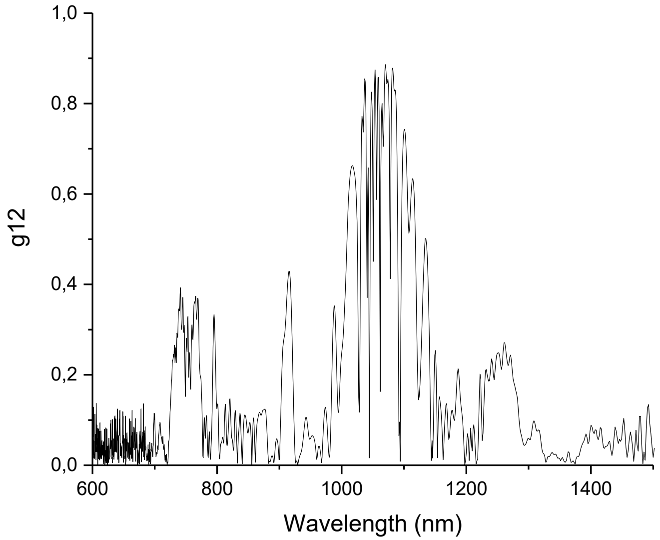
Postprocessing > average intensity

Postprocessing > min / max (intensity) for boundaries as displayed below

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

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





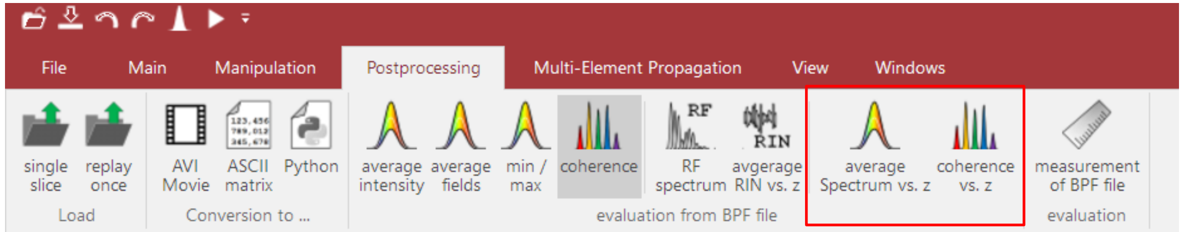
Tutorial 2

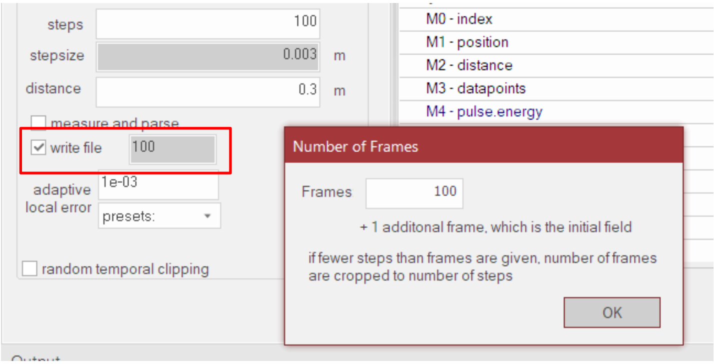
You can also average a series of simulations or calculate the coherence along z.

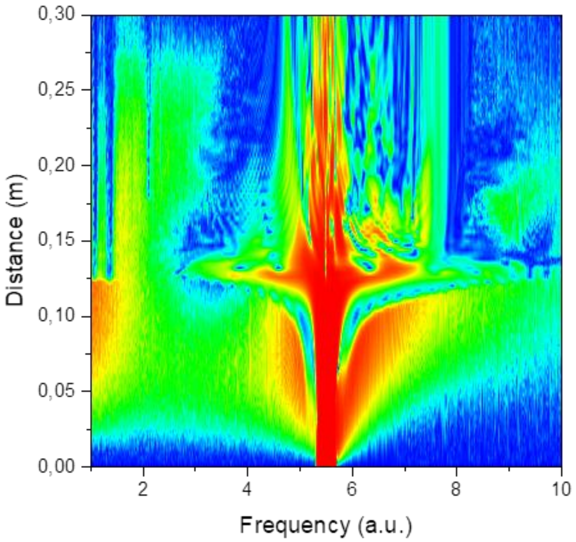
It requires to save the fields along z during parameter variation. To do so, enable „write file“ in the propagation parameter setup and run the parameter variation with „save to file“ switched-on again.

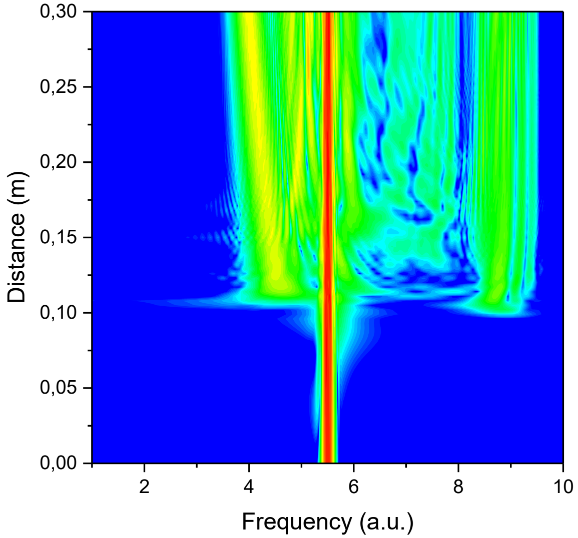
The results can be obtained by the Postprocessing items shown on top, which request you to select the base file for evaluation.

Only 1D parameter variation can be used.









Tutorial 2 – Supercontinuum, Parameter Variation, Export

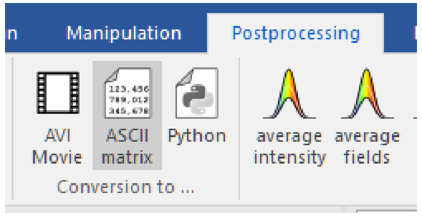
- A simple nonlinear propagation
- Supercontinuum generation
  - create the field
  - choose parameters
  - put result to memory
  - repeat with higher accuracy
  - check measurements
- (first) Parameter Variation
  - noise and coherence
- Export propagation data
- Dispersion and retarded time frame

Tutorial 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).

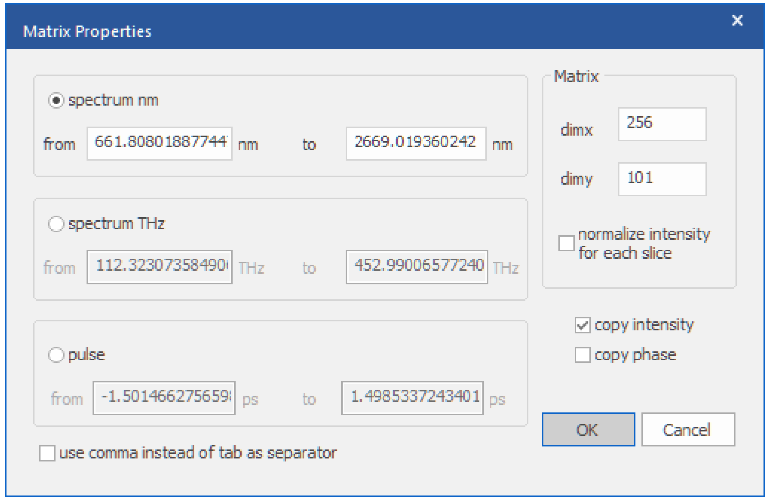
Then either use the python script to display what is saved in this propagation file (*.bpfx) or use the internal function to copy such data as ASCII to the clipboard and paste it, e.g. in Origin.

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



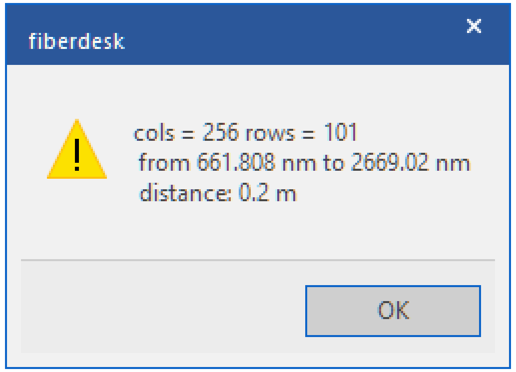
First, you will be asked for the BPF file, then choose the "comma/dot" convention.

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.



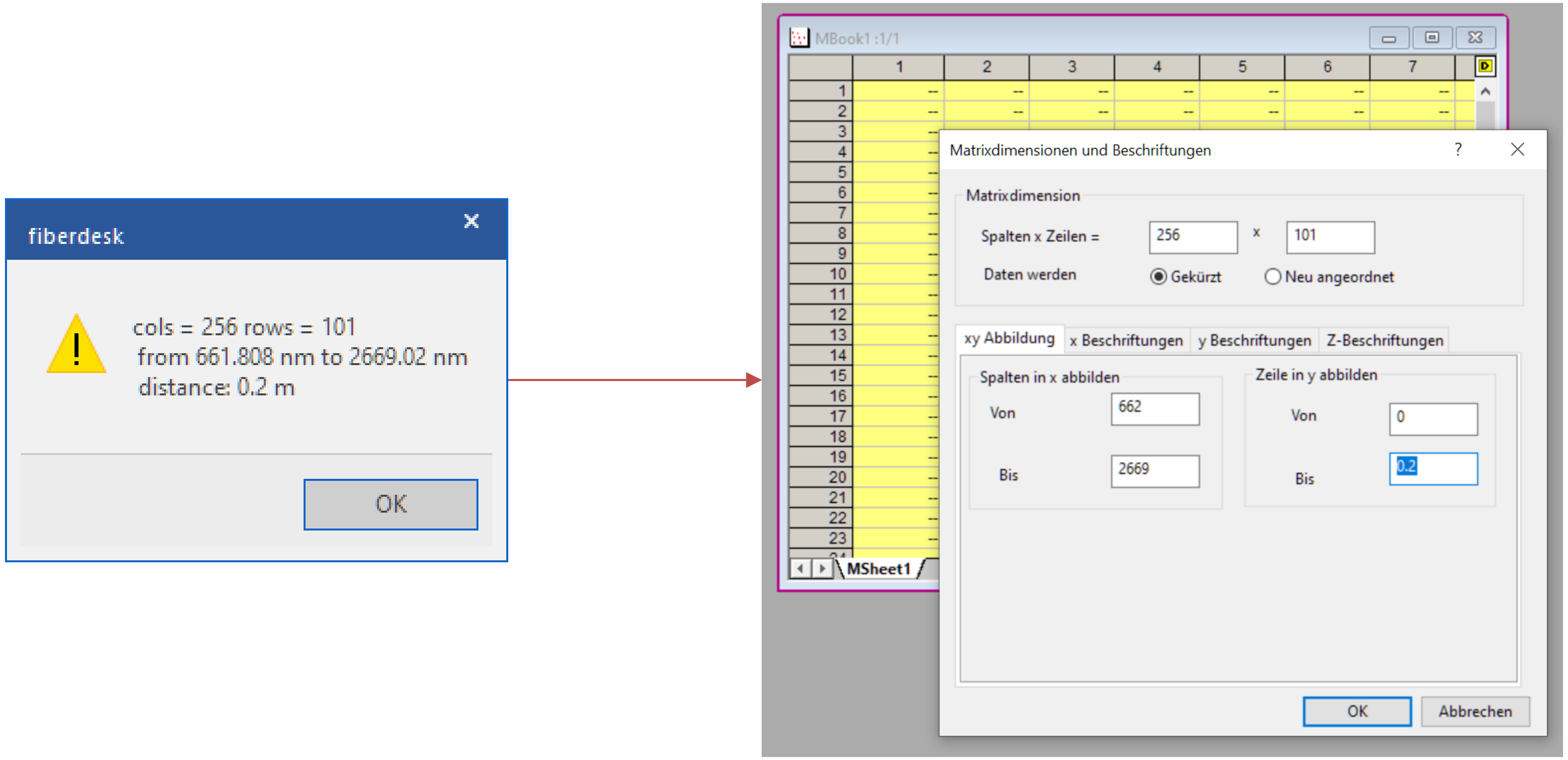
Once it is copied, the important information are shown.

You'll need those to set up your graph in Origin correctly.



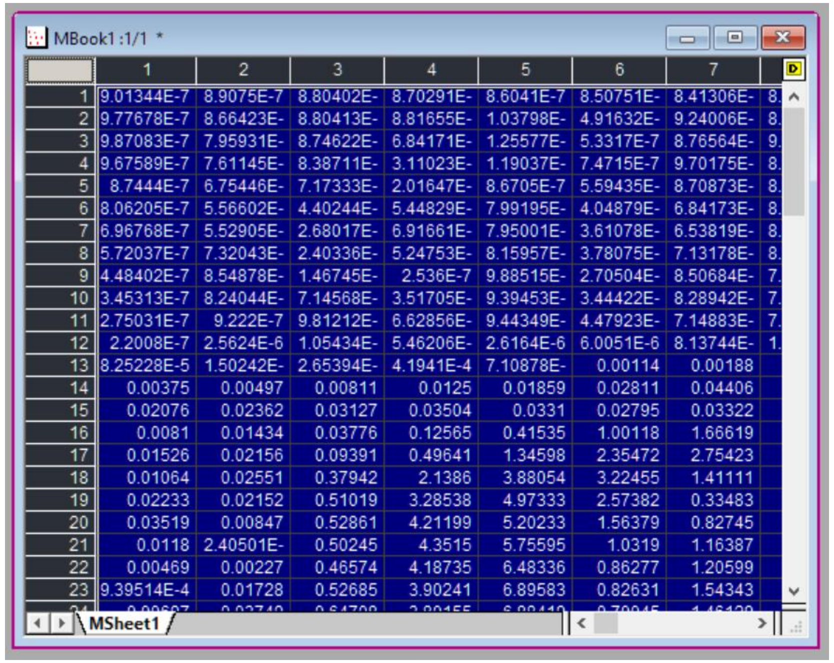
Tutorial 2

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



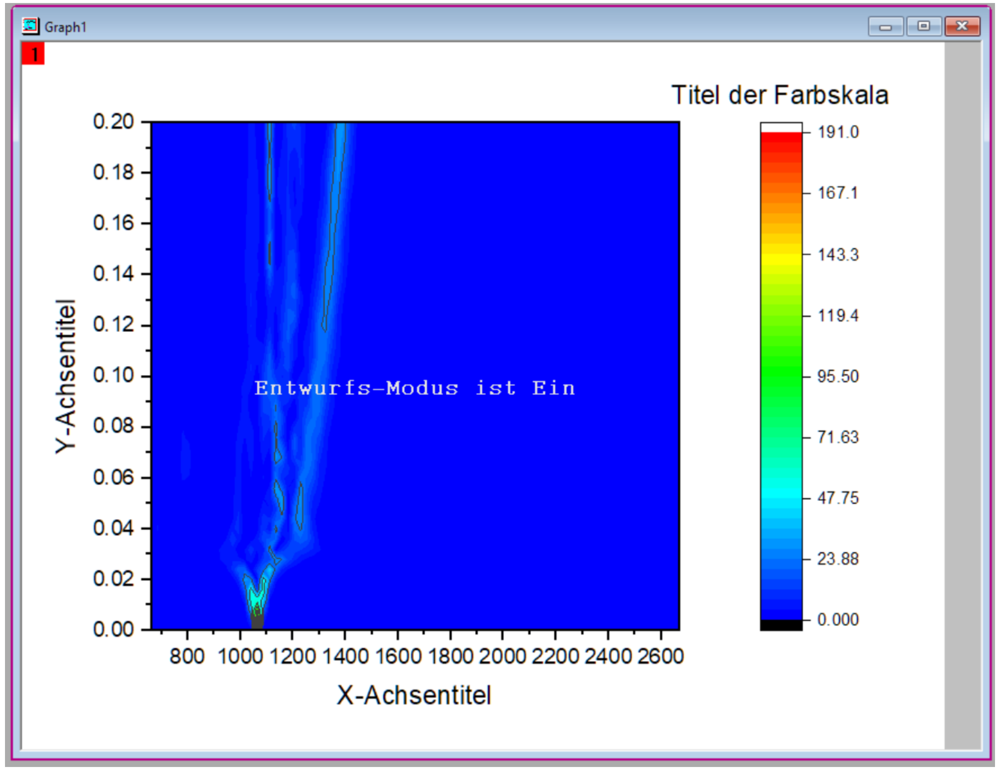
Tutorial 2

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.

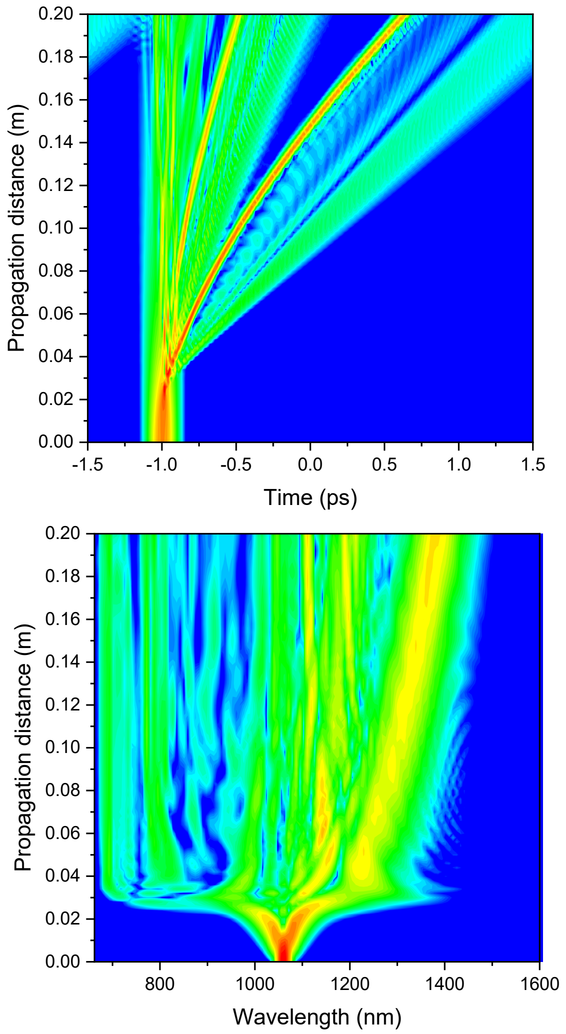


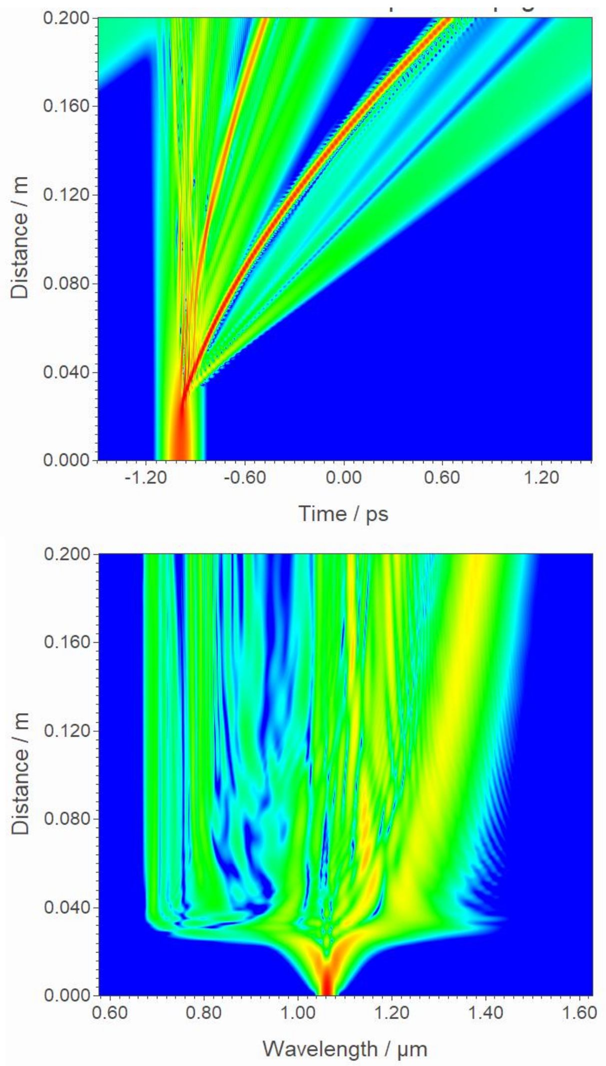
Lecture 2

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

Origin display

(differences due to different sampling)





fiberdesk display

Since fiberdesk 7 this feature in directly available in the software.

Tutorial 2 – Supercontinuum, Parameter Variation, Export

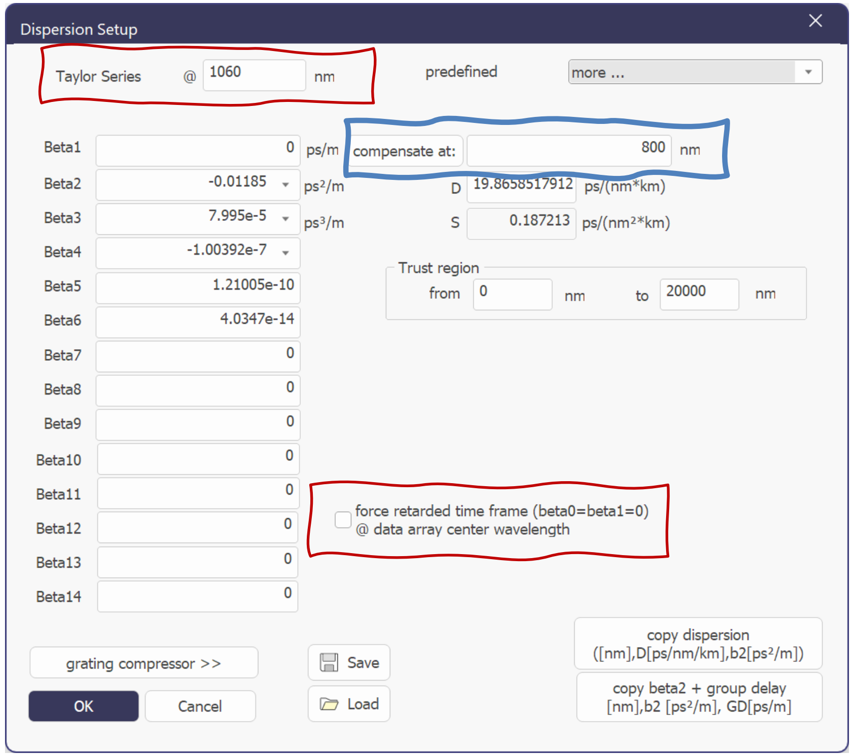
- A simple nonlinear propagation
- Supercontinuum generation
  - create the field
  - choose parameters
  - put result to memory
  - repeat with higher accuracy
  - check measurements
- (first) Parameter Variation
  - noise and coherence
- Export propagation data
- Dispersion and retarded time frame

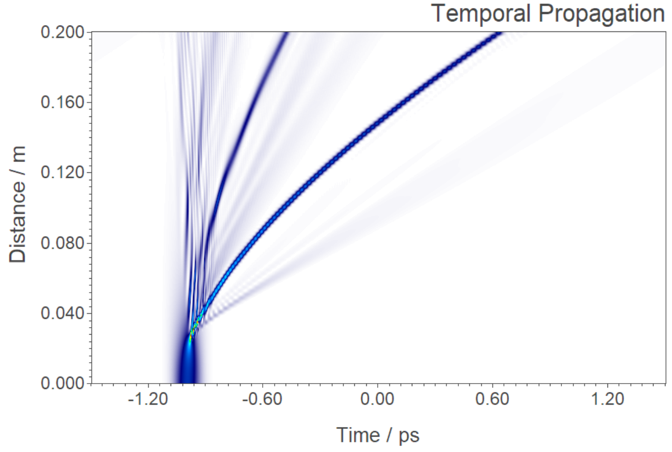
Tutorial 2 - dispersion and retarded time frame

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.

Here is the example of the supercontinuum generation again.

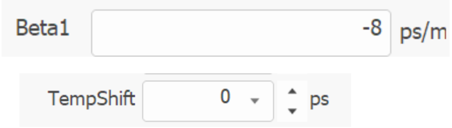
The option "force retarded time frame" is off in the dispersion settings, because the Taylor Series used for dispersion is actually calculated around the center wavelength of the pulse center $\lambda_{TS} = \lambda_P$ – so no surprise.

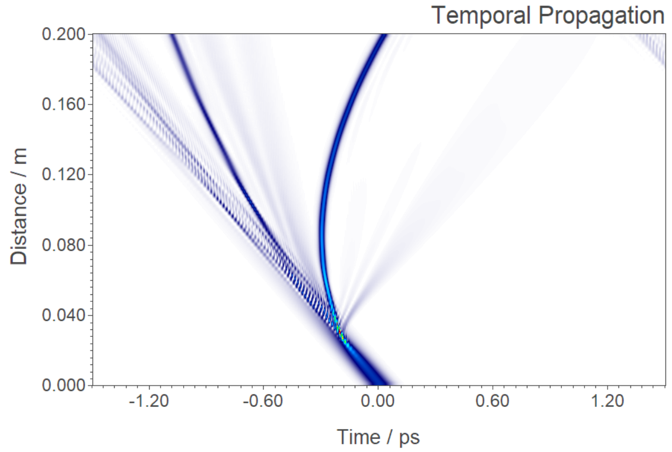




To move the temporal windows with a different group delay, you can generate that group delay at any wavelength by pressing „compensate at".

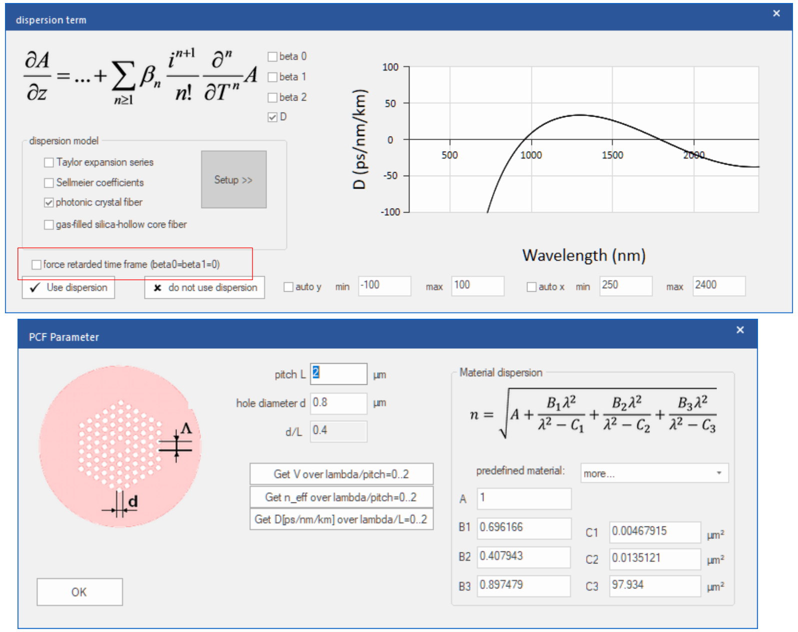
In our example the wavlength are generated and evolve not constant. But for instance, the first soliton ends the propagation at 0.6 ps. So it traveled 1.6 ps/0.2 m which is 8 ps/m. We also do not start the pulse at -1 ps. If compensating this, the evolution looks like the second graph.





Tutorial 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)