lecture 5

Multi-Element Propagation

lecture 5

Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

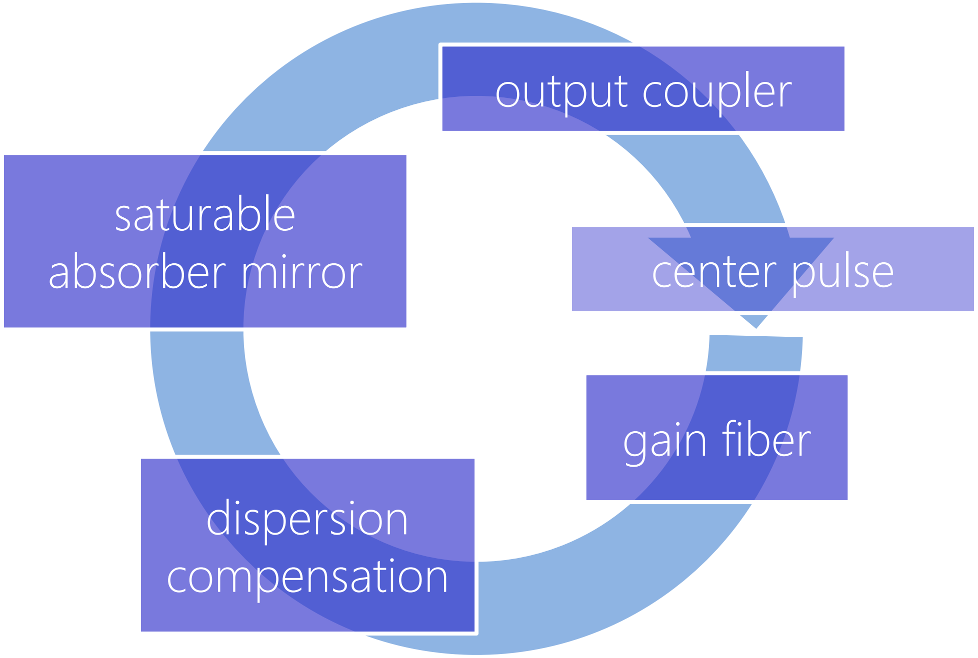
The layout of a typical short pulse oscillator (not only fiber laser) is shown in the image containing several elements in a ring cavity format (loop).

Each Element is modelled by an element typically based on the NLSE:

$$iA_z + \frac{g}{2}A + i\beta_2 A_{tt} = i\gamma |A|^2 A$$

Other elements, like the saturable absorber mirror is modelled by a fast saturable reflectivity/transmission according to:

$$R = R_{unsat} + R_{sat} \cdot \left(1 - \frac{1}{1 + P / P_{sat}}\right)$$



Each element setup is explained in the following >>

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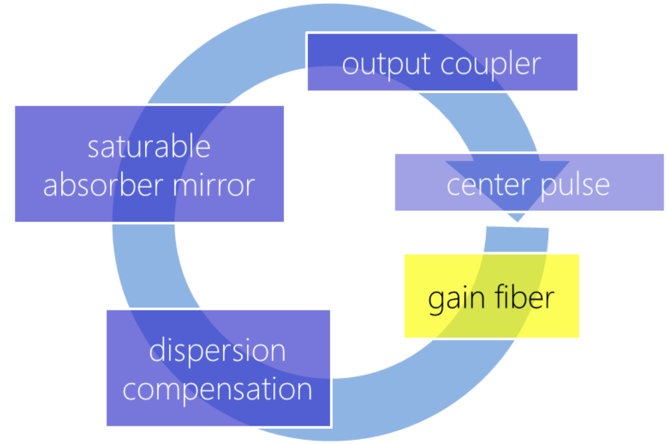
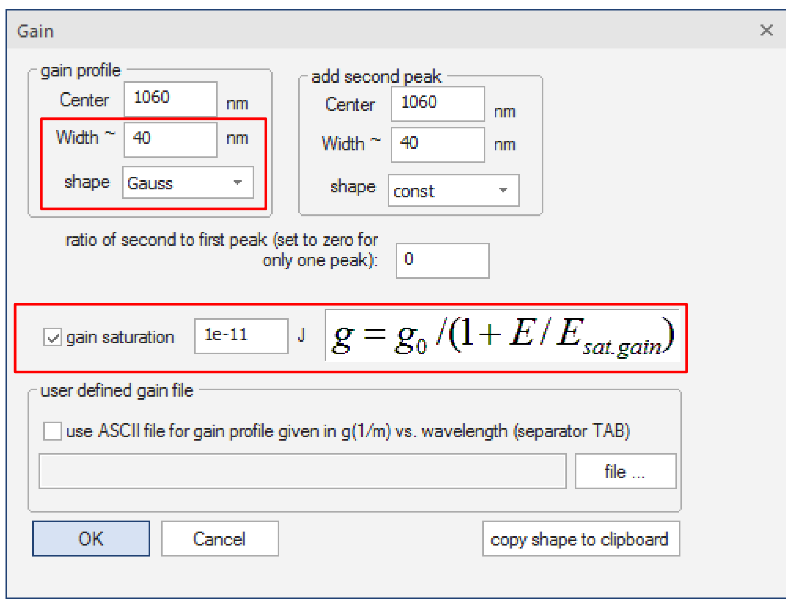
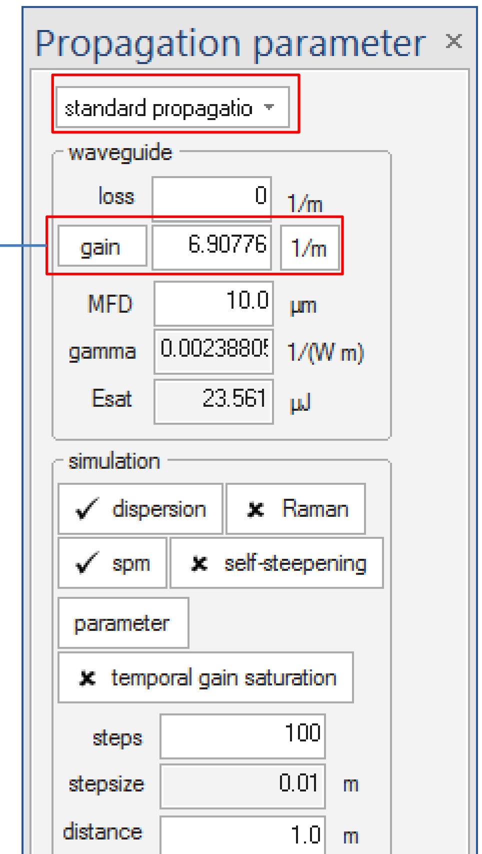


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Set up the gain fiber as a standard propagation with saturable gain





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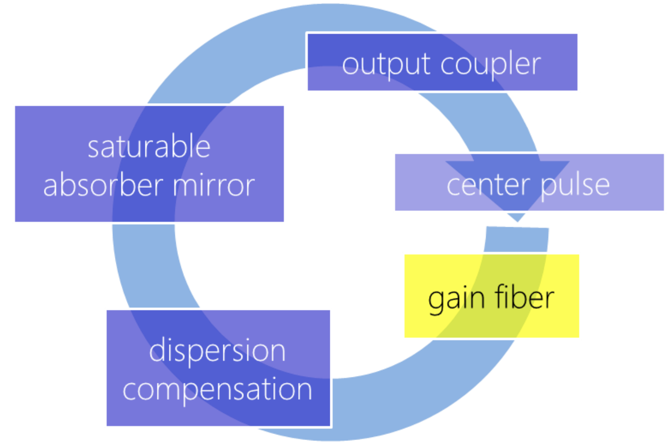
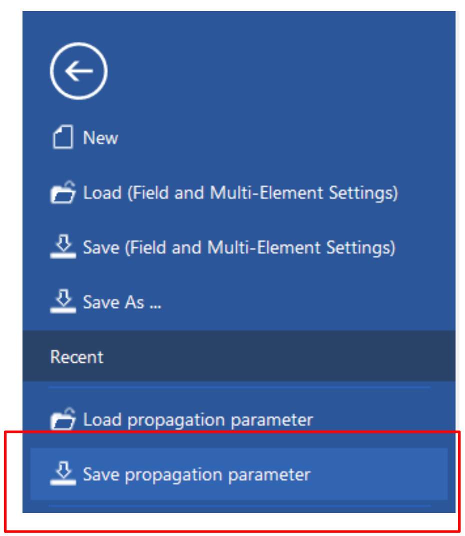


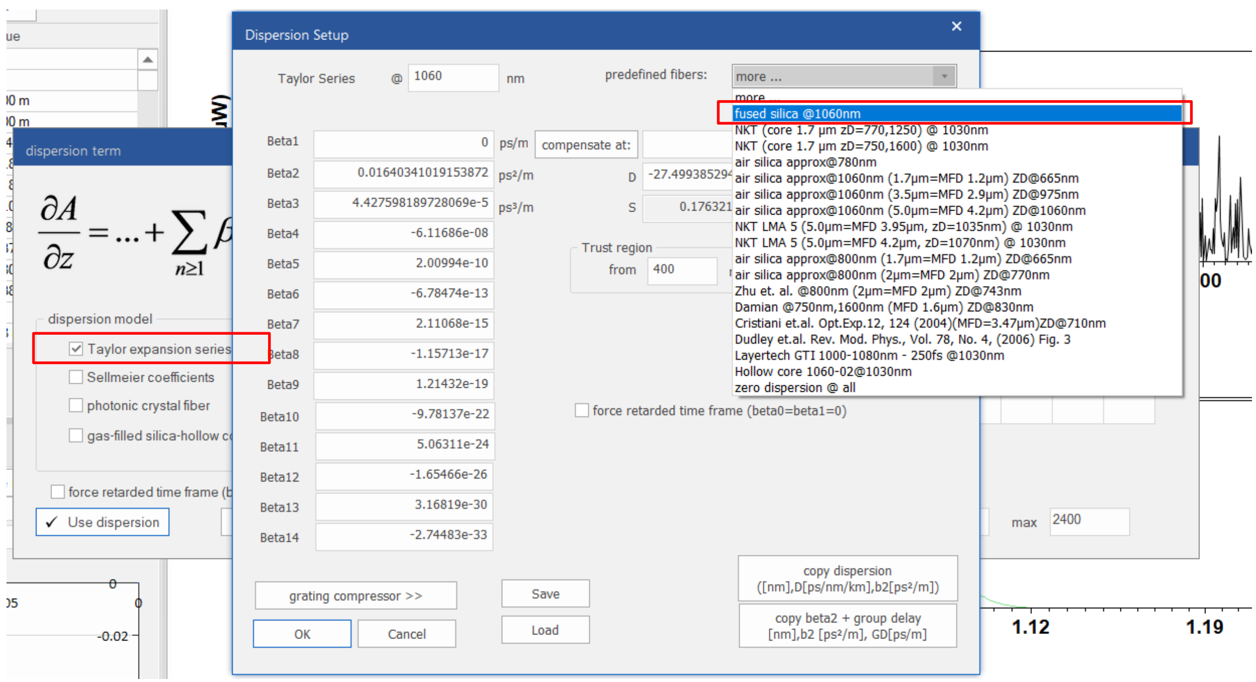
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Set the dispersion of that amplifier fiber to fused silica (e.g. predefined with its Taylor series at 1060 nm)

save as fiber.ppf





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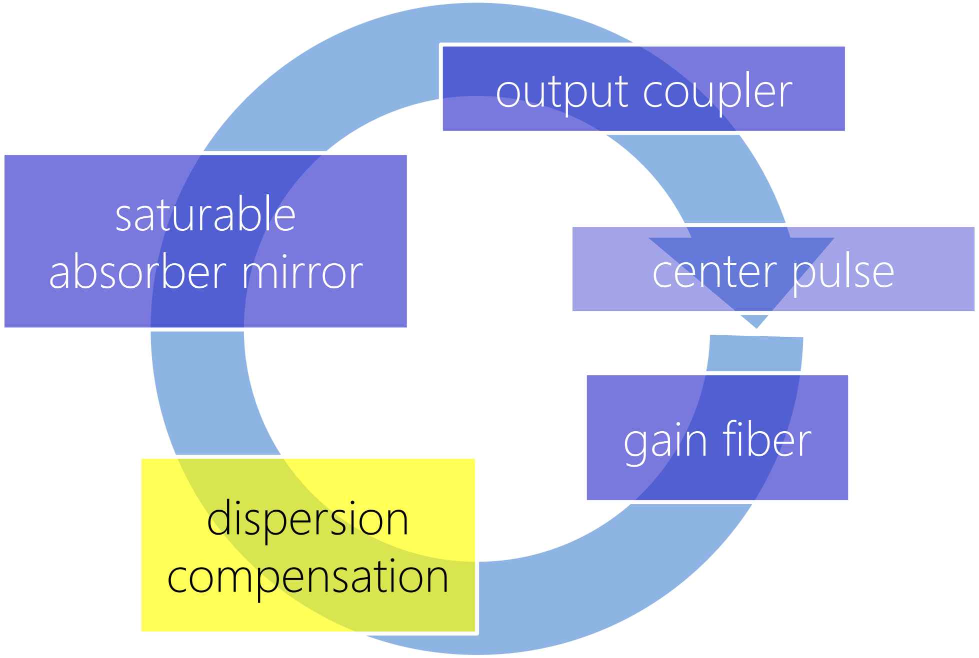

Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

For the dispersion compensation, we only set second order dispersion.

Before, set the gain to zero, switch off SPM etc. Only dispersion need to be set.

As it is a linear step, a single step is enough, see next slide.

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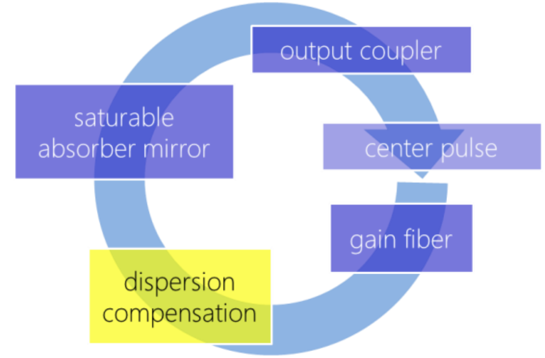
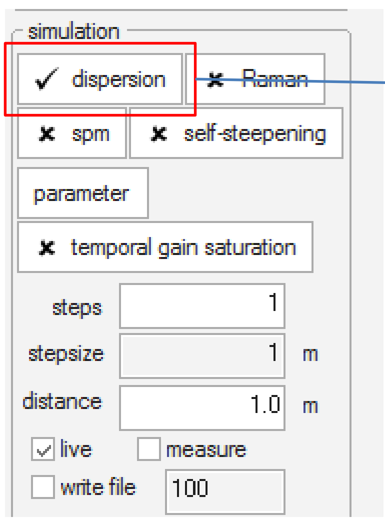
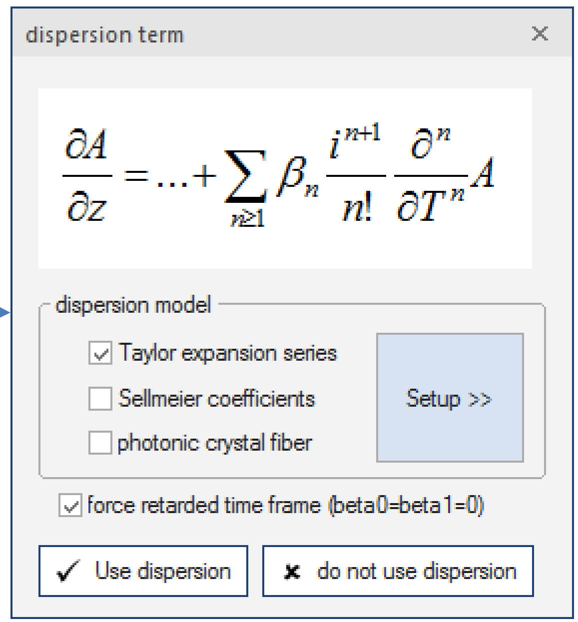
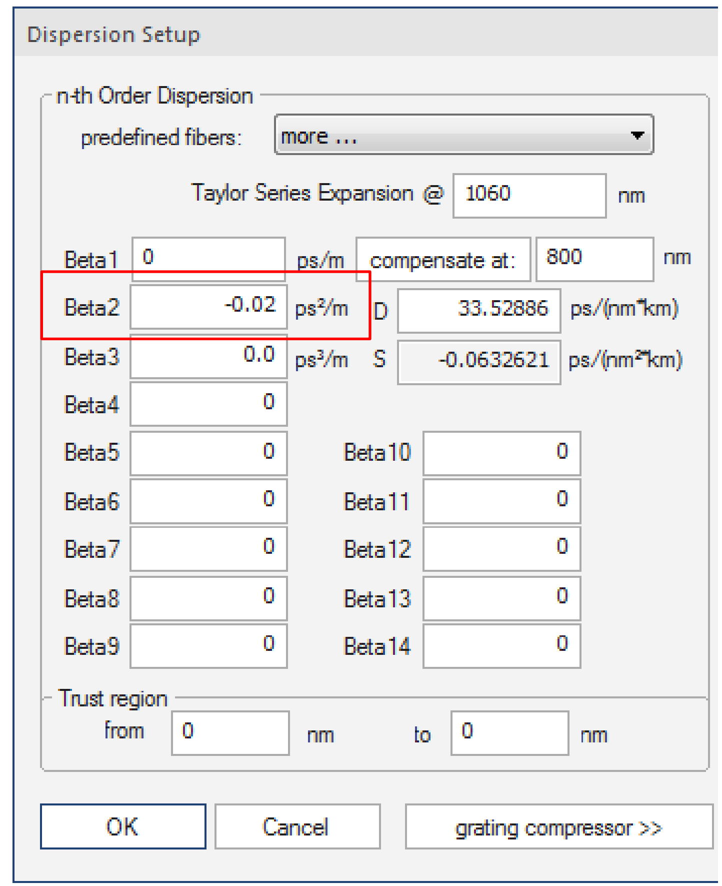


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers







save as dc.ppf

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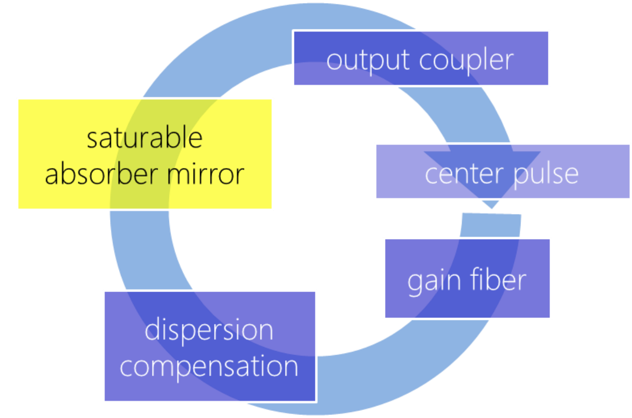
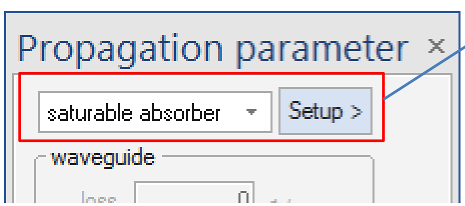


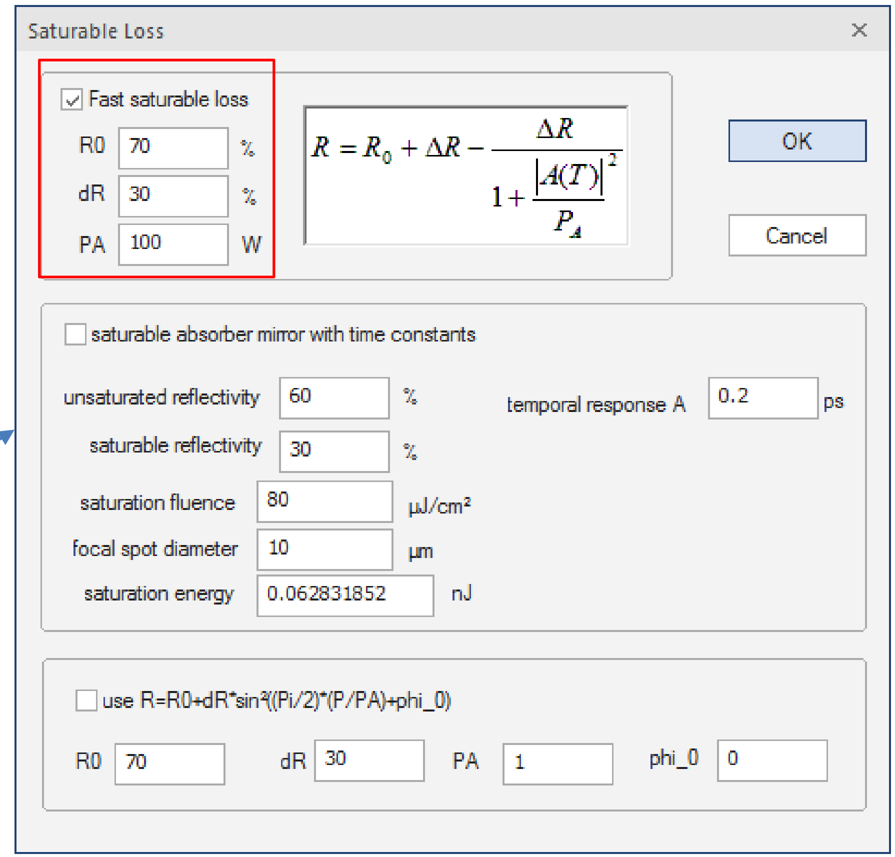
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

The saturable absorber is a different model, select „saturable absorber“ on top of the propagation parameter dialog.

Then, set it up with the parameters on the right.





save as SA.ppf

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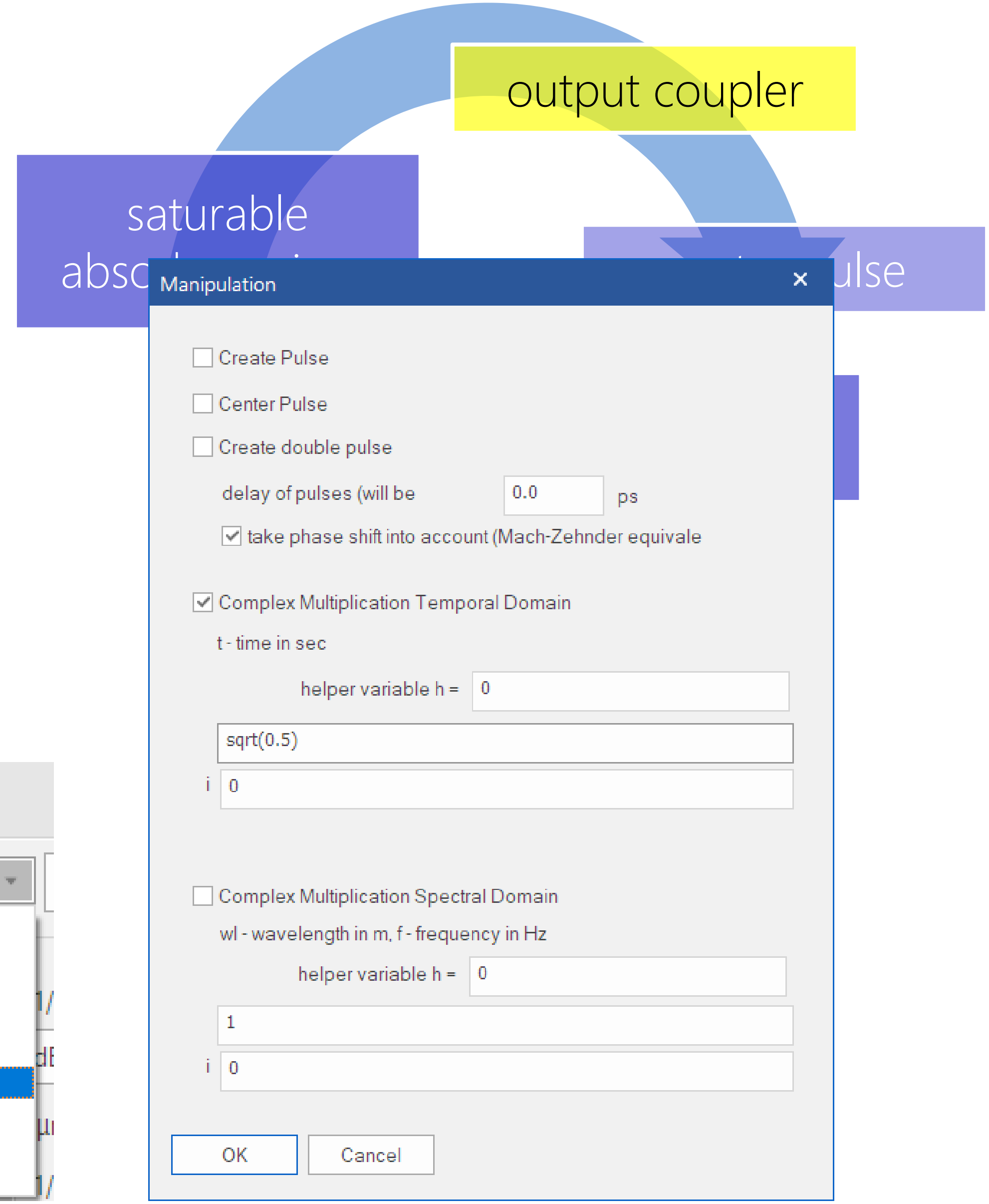
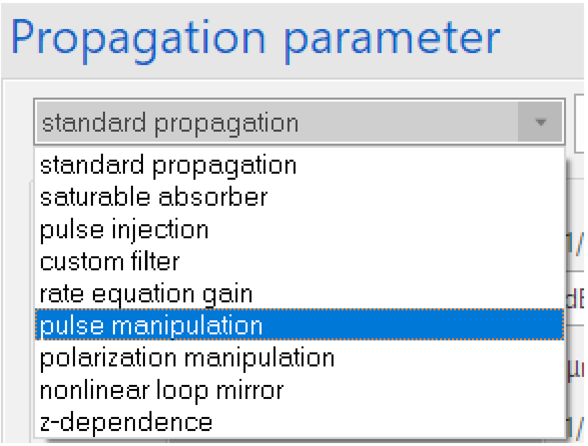
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Outcoupling:

50% means complex multiplication with sqrt(0.5)





save as OC.ppf

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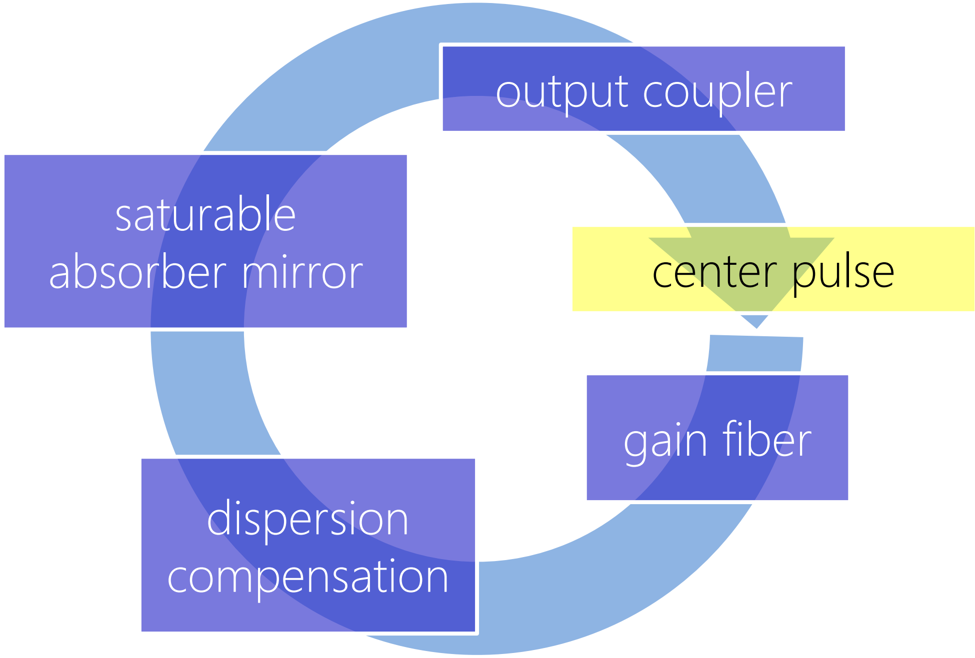
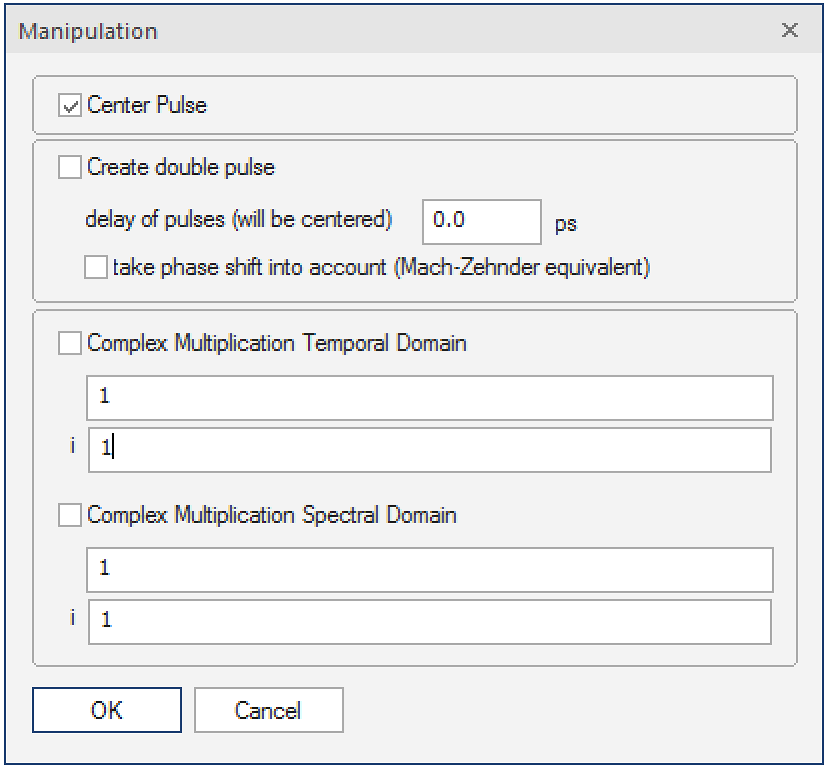
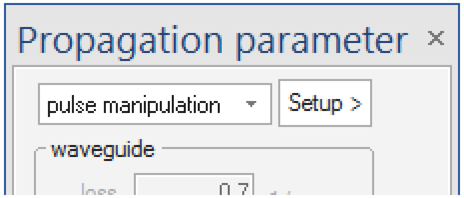


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers



- Center pulse in the time domain, helps to converge the pulse, as changes are measured in the time domain
- Can be combined with OC.ppf in a single element



save as center.ppf

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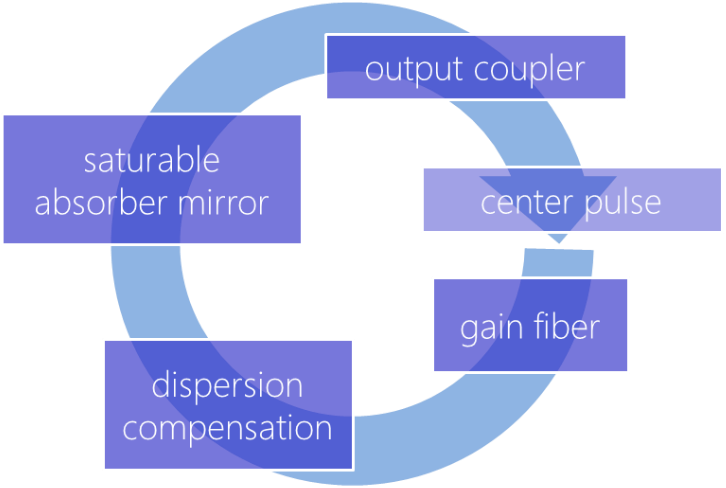
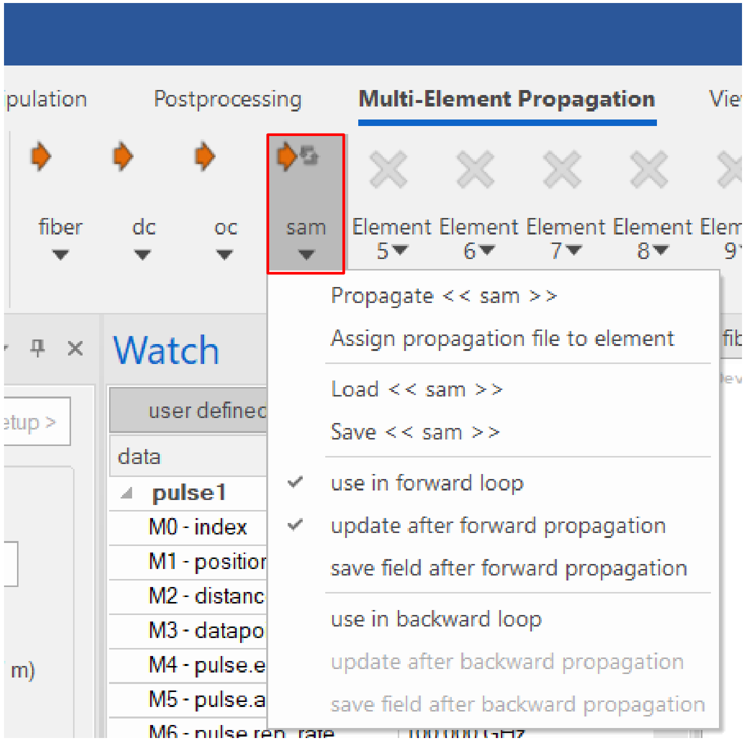
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers



- assign all files to elements in the right order of the cavity
- Select „use in forward loop" for all elements
- Select the last one to be updated after each loop to see convergence live during simulation
- Icons on top change according to selected status



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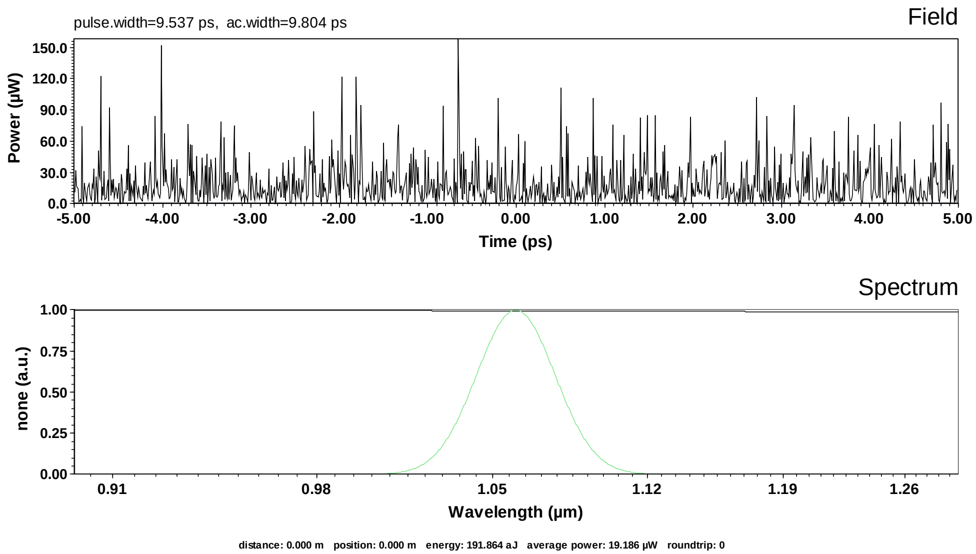
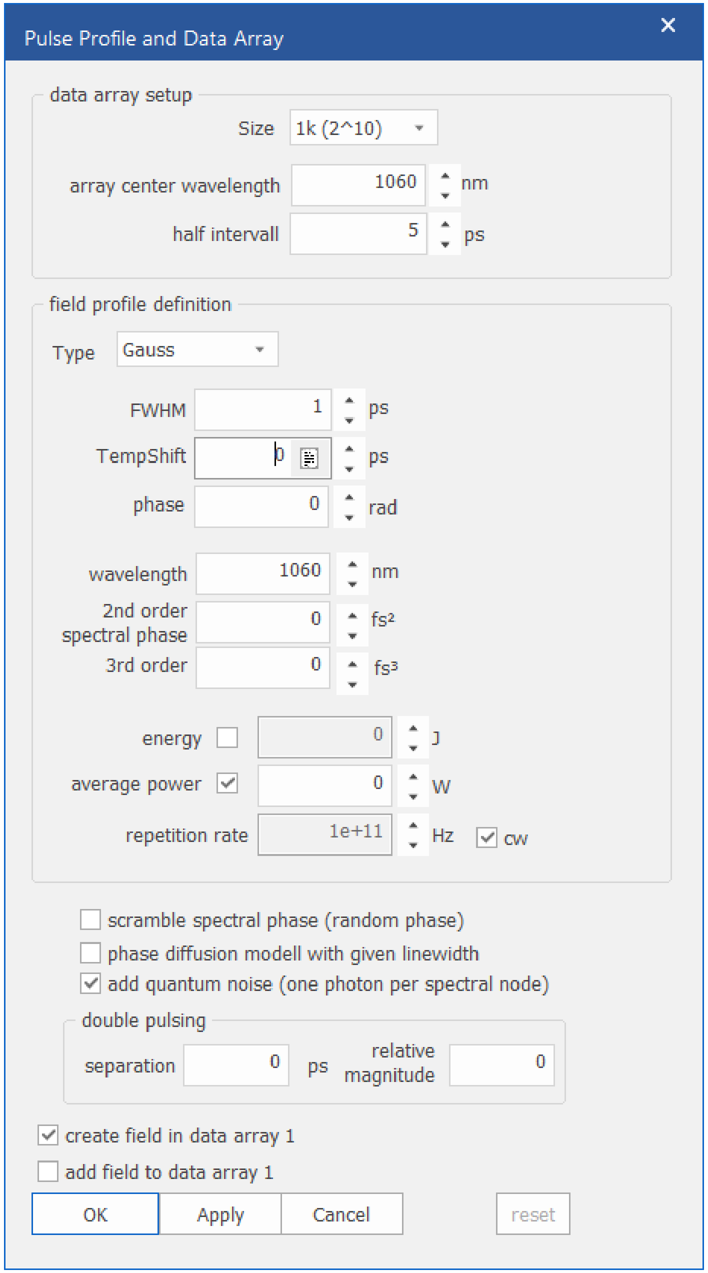
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

(1) create initial pulse, e.g. quantum noise

(green spectrum is the gain spectrum from „fiber.ppf“





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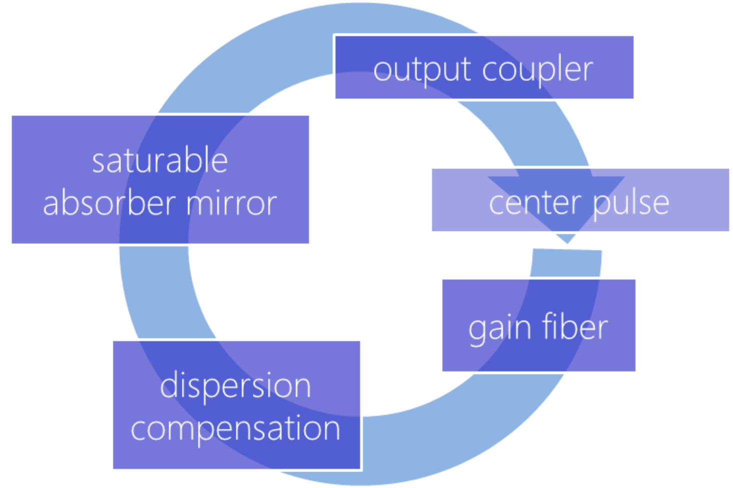
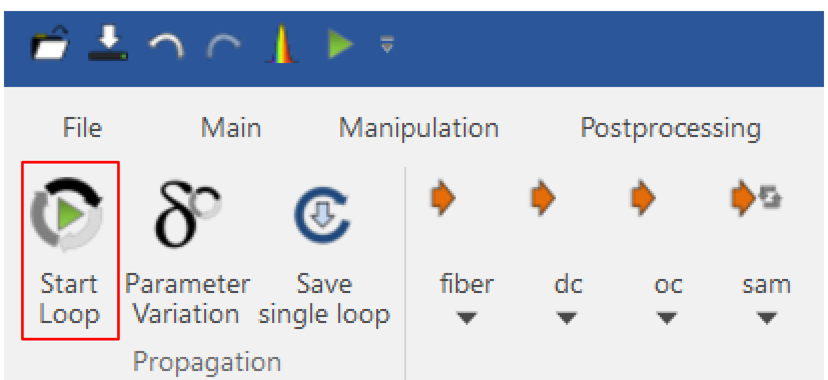
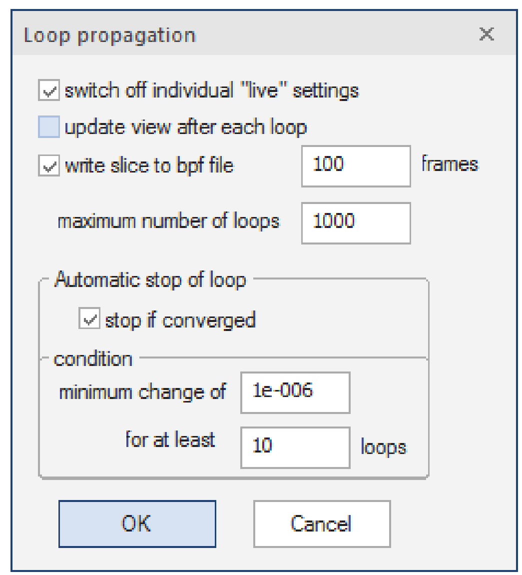


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

(1) start loop (switch on „write slice … „ for later postprocessing)





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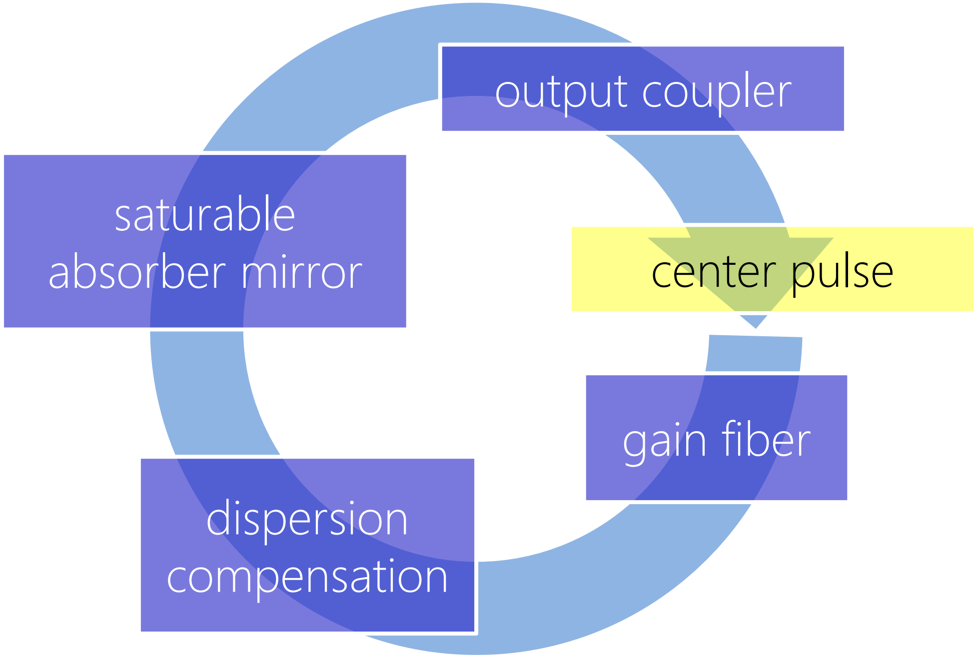
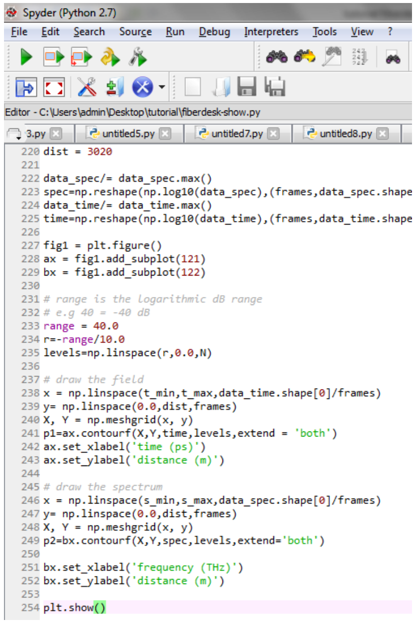
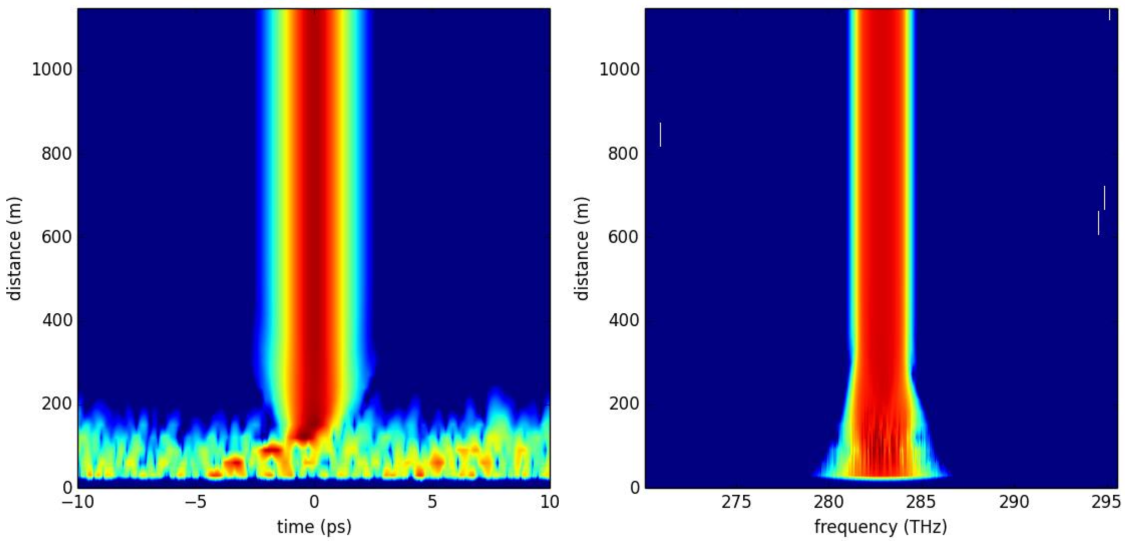


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Download the python script from the homepage to process BPF files.





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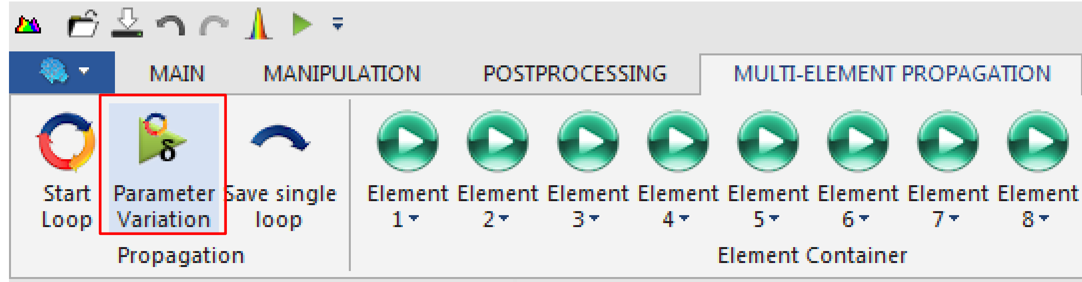
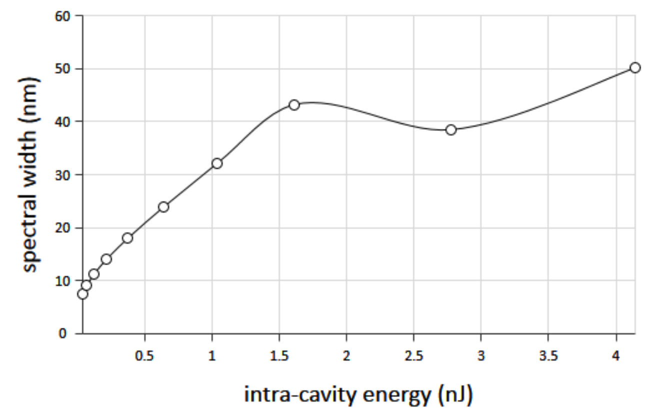


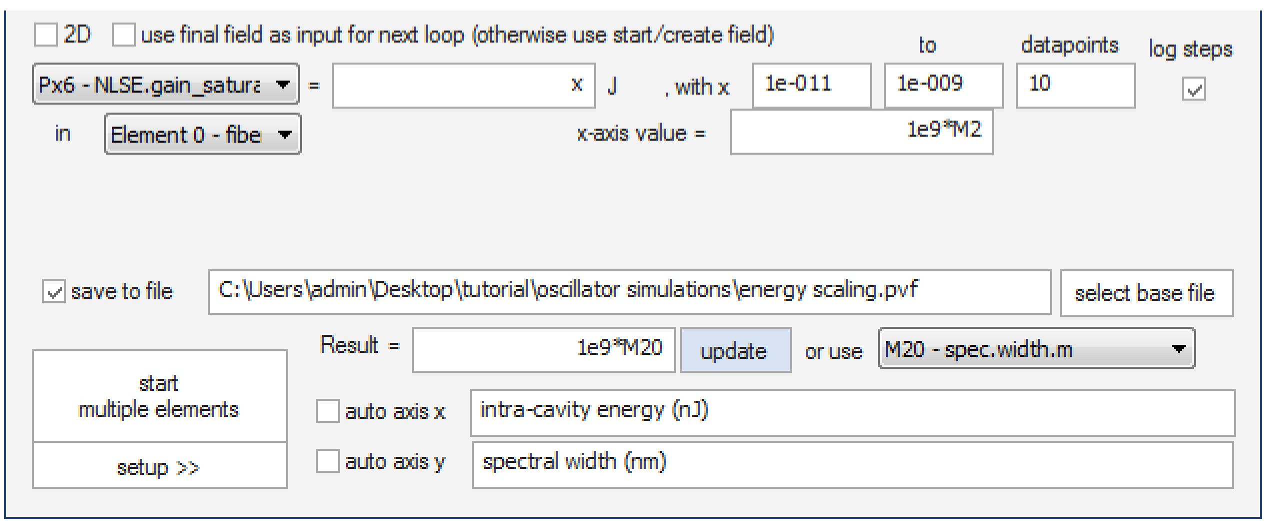
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers



Multi-element > Parameter variation

we change the gain saturation to increase the energy (remark: intracavity energy!)



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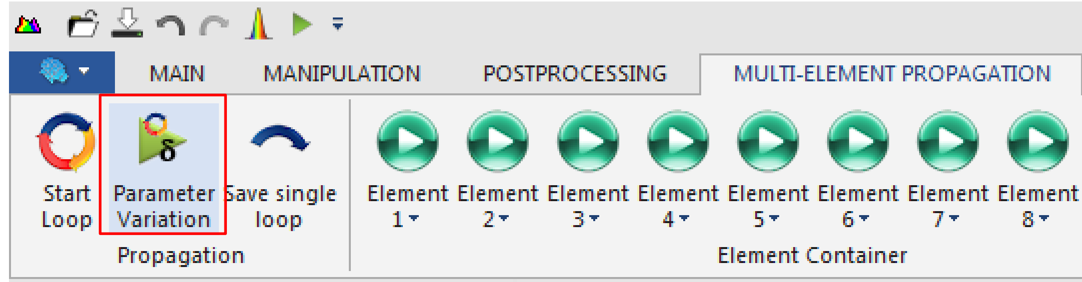
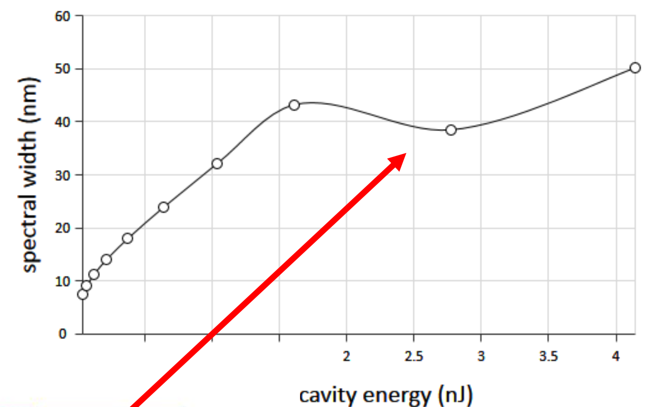


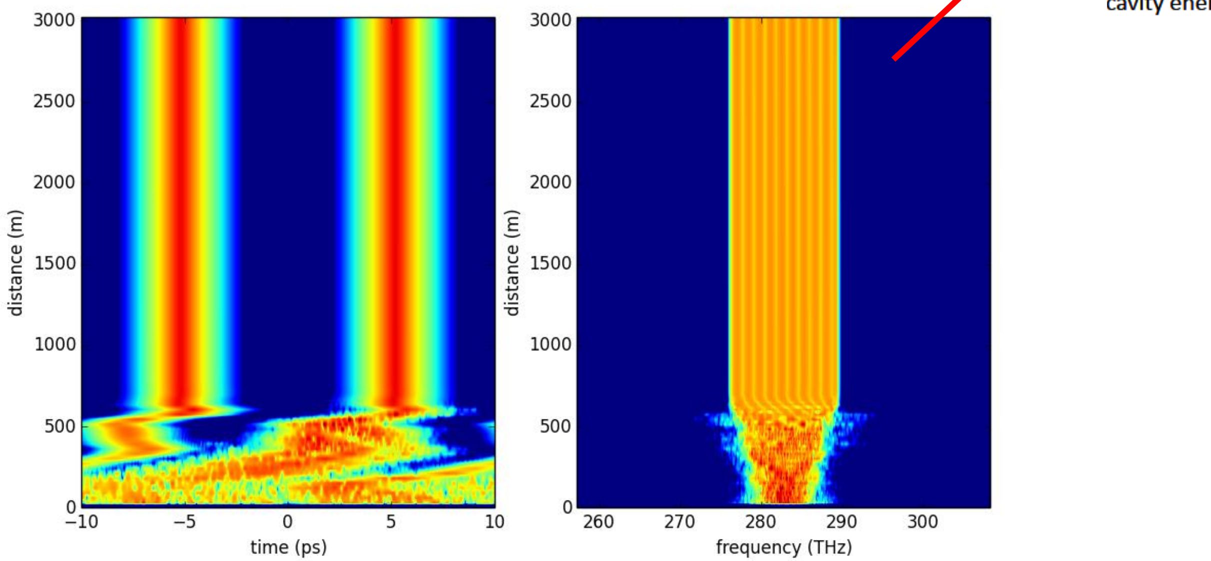
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Multi-element > Parameter variation

we change the gain saturation to increase the energy (remark: intracavity energy!)





fiberdesk
nonlinear pulse propagation

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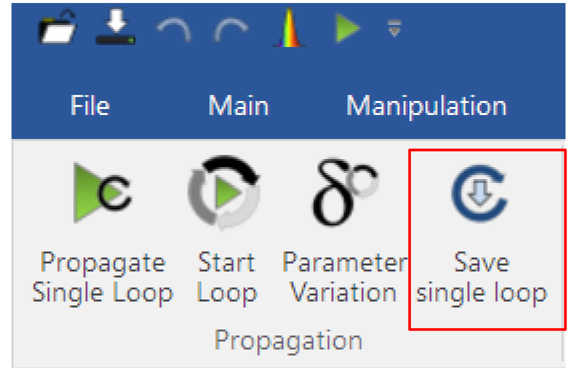
Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

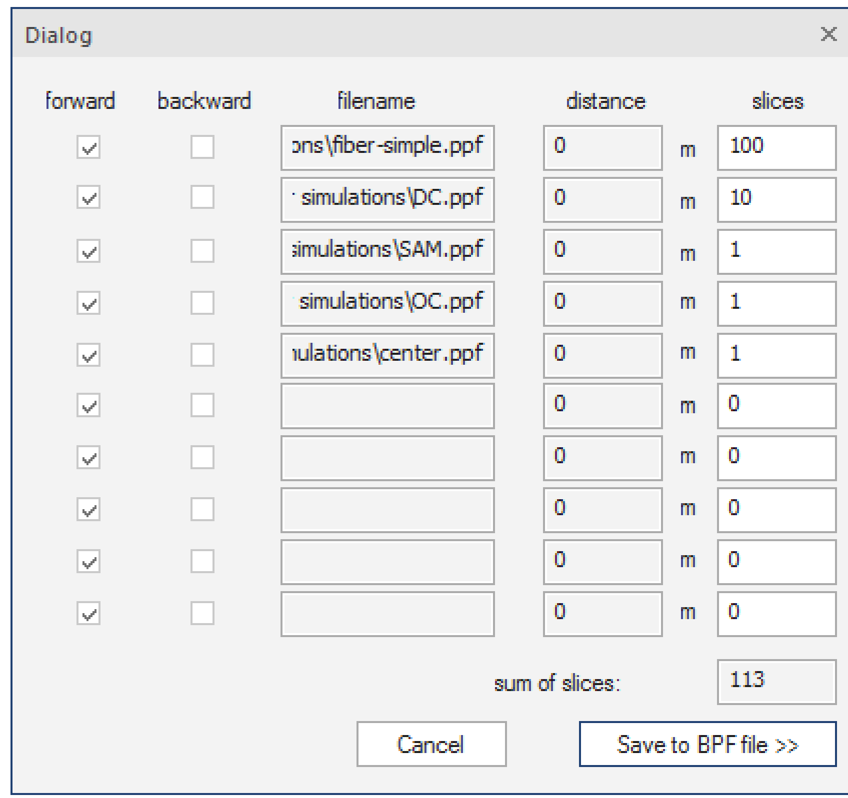


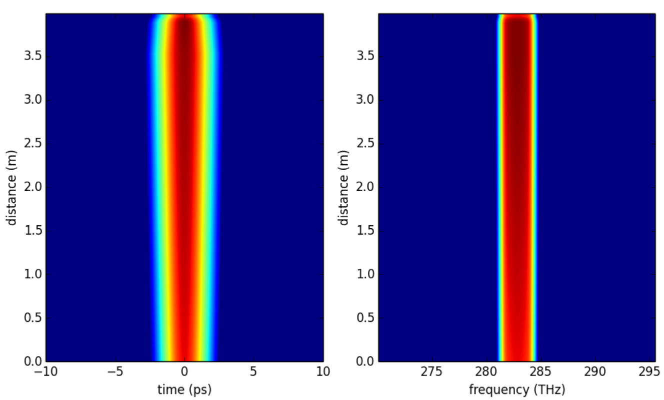
Intracavity evolution

(1) select stable solution from saved file

(2) specify slices to be saved

(3) post-process





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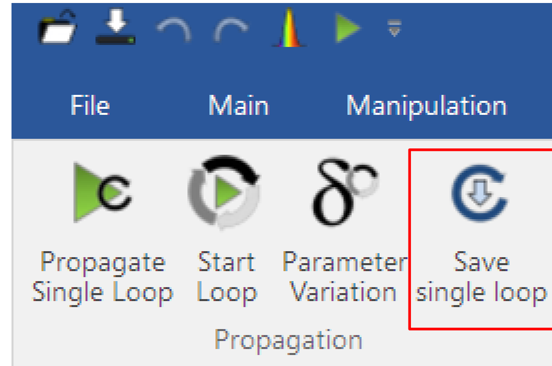
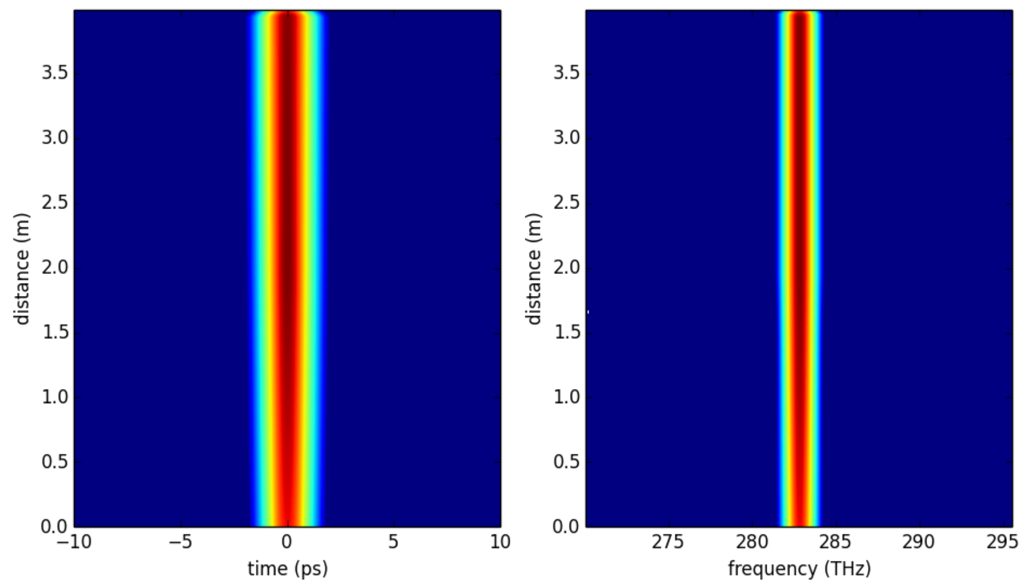
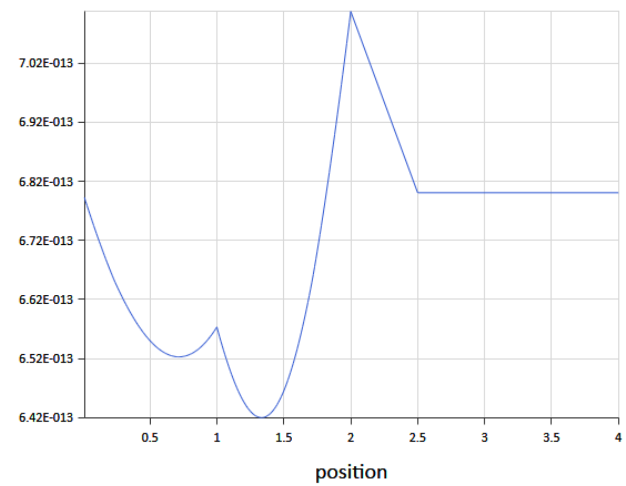


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

soliton solution: beta2@DC = -0.06 ps^2





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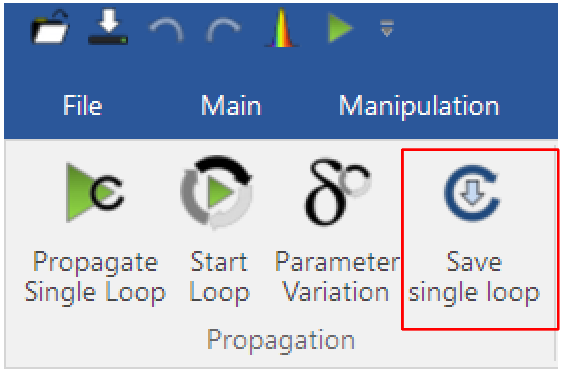
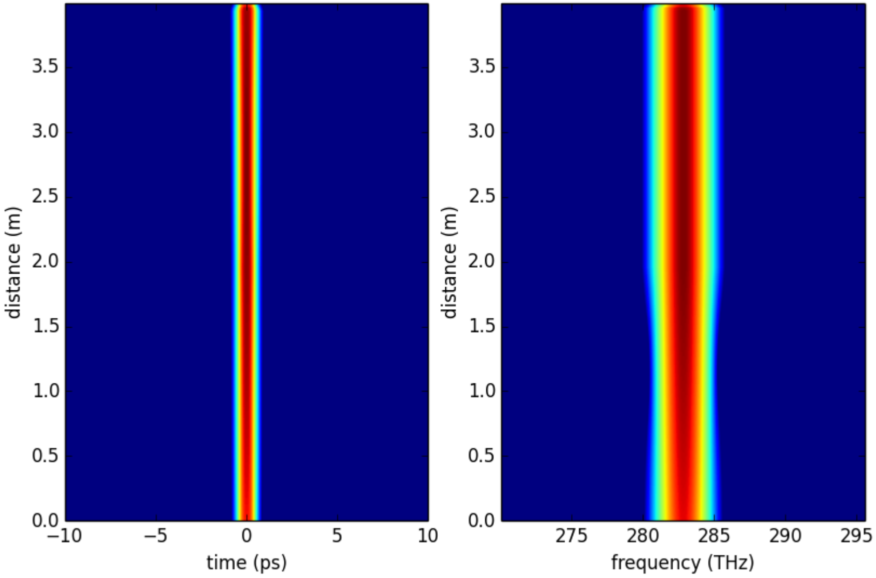
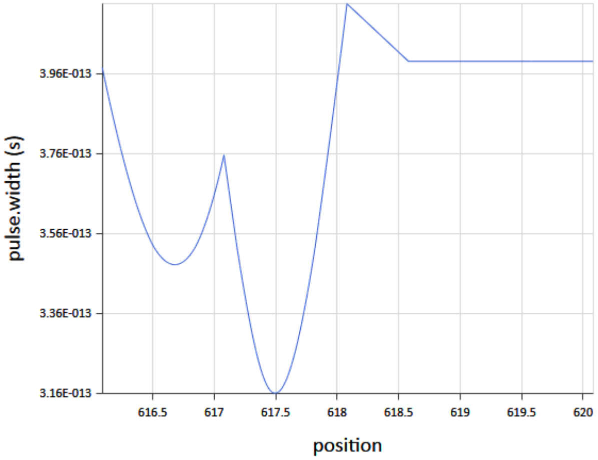


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

soliton solution: beta2@DC = -0.04 ps^2





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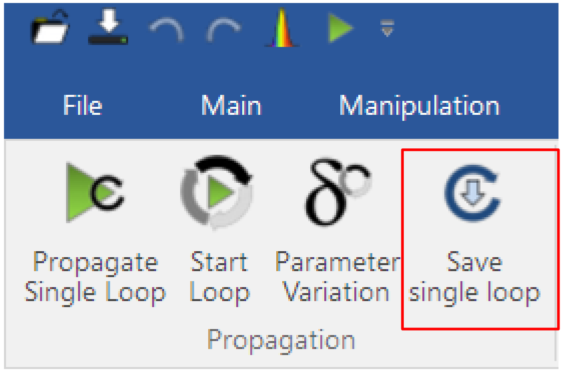
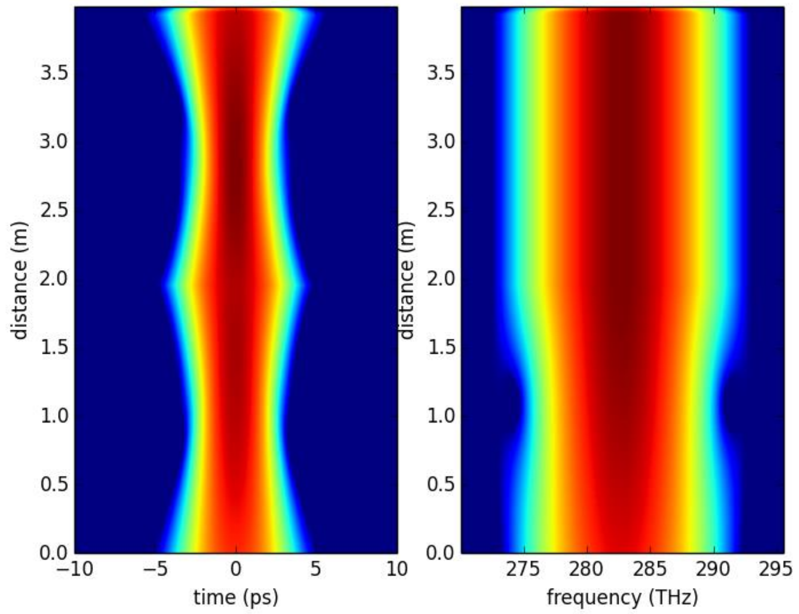
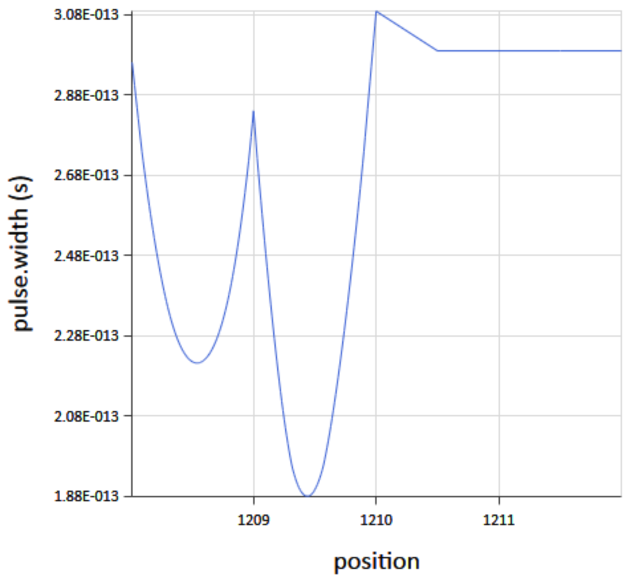


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

toward stretched pulse: beta2@DC = -0.03 ps^2





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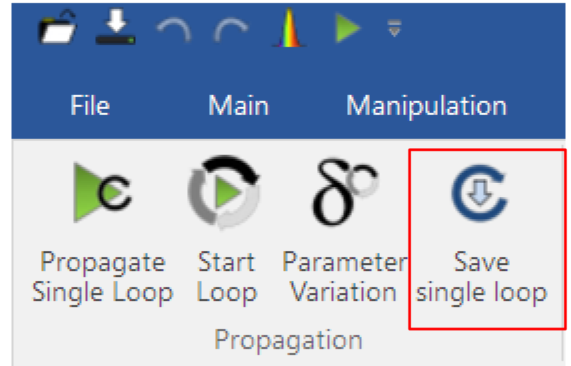
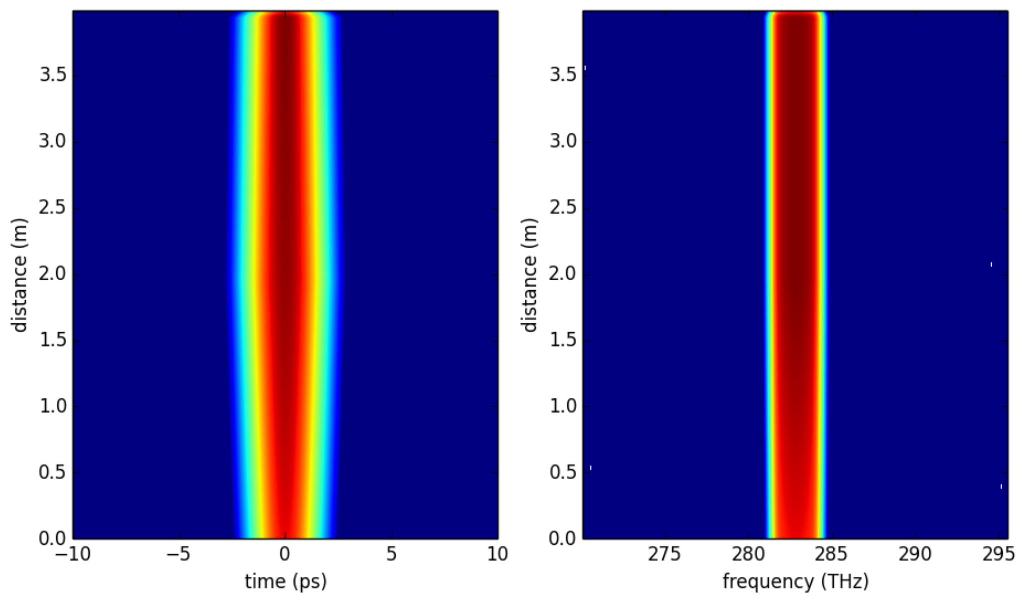
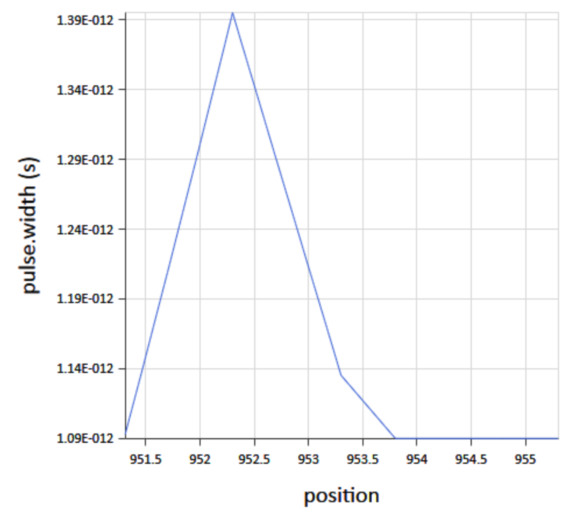


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

similariton: beta2@DC = -0.02 ps^2





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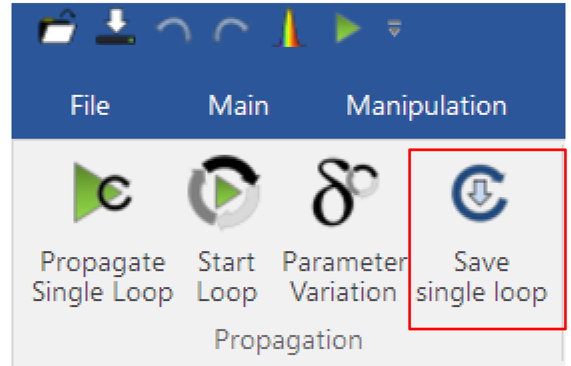
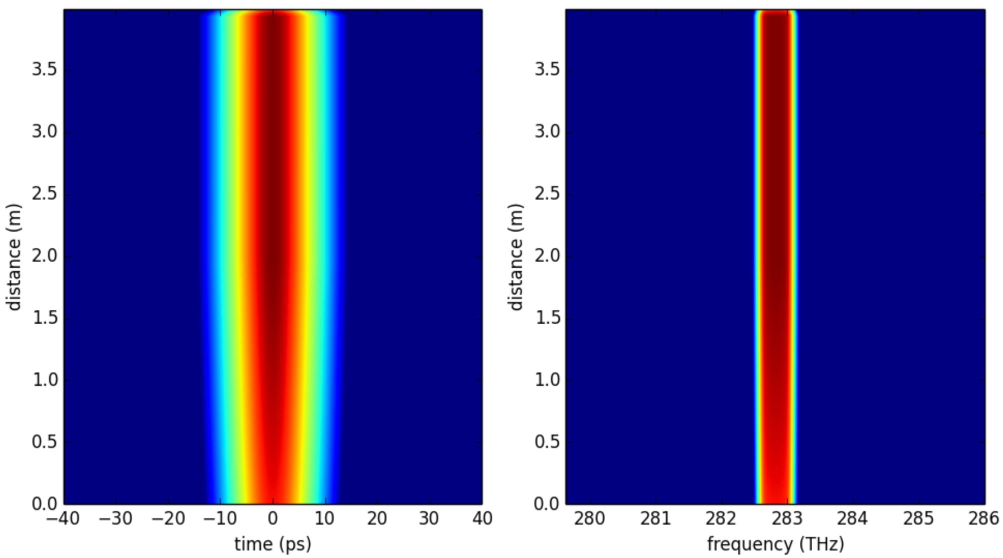
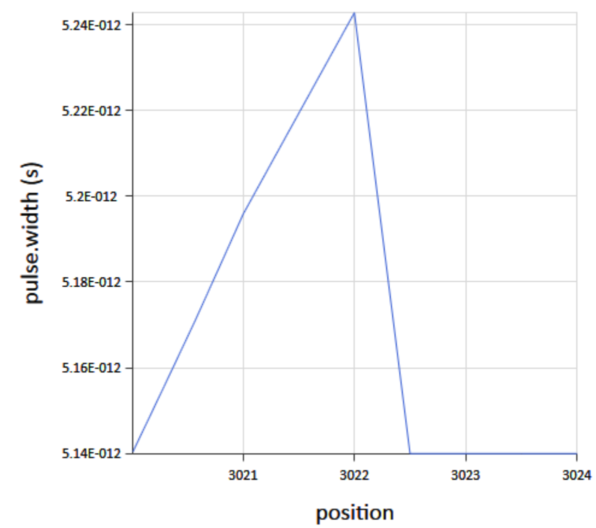


Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

chirped pulse oscillator: beta2@DC = +0.02 ps^2





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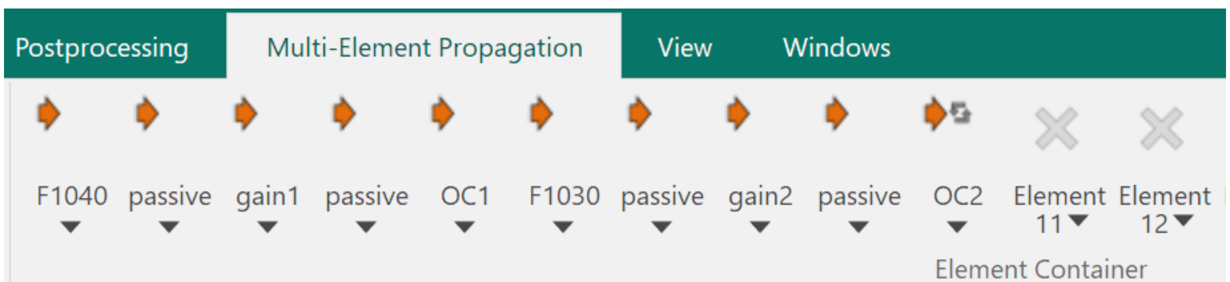
Part 2: Mamyshev Oscillator

See Z. Liu, Z. Ziegler, L. G. Wright, and F. W. Wise. “Megawatt peak power from a Mamyshev oscillator.” Optica **4**, 649 (2017).

The model of the Mamychev oscillator is using the following elements:



It uses two separated filters at 1030 nm and 1040 nm as well as passive and active fibers in between. The gain fibers are different after the filter. An output coupler is used at the end.

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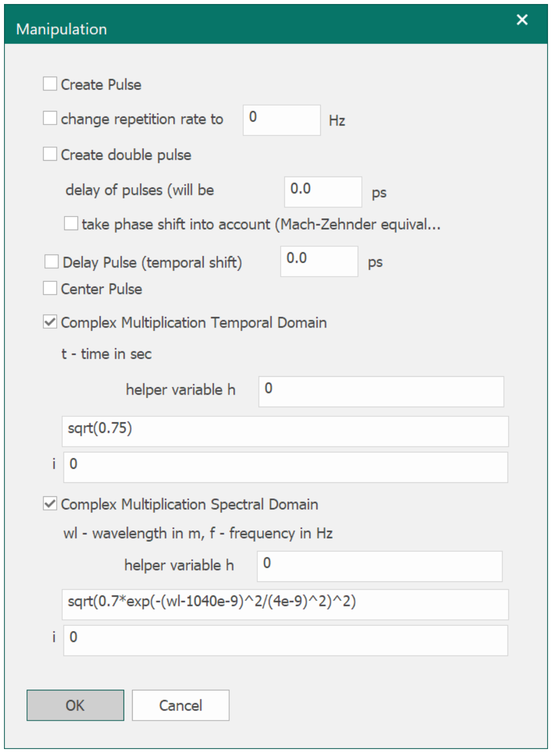
The filters are defined as follows:

Pulse manipulation propagation

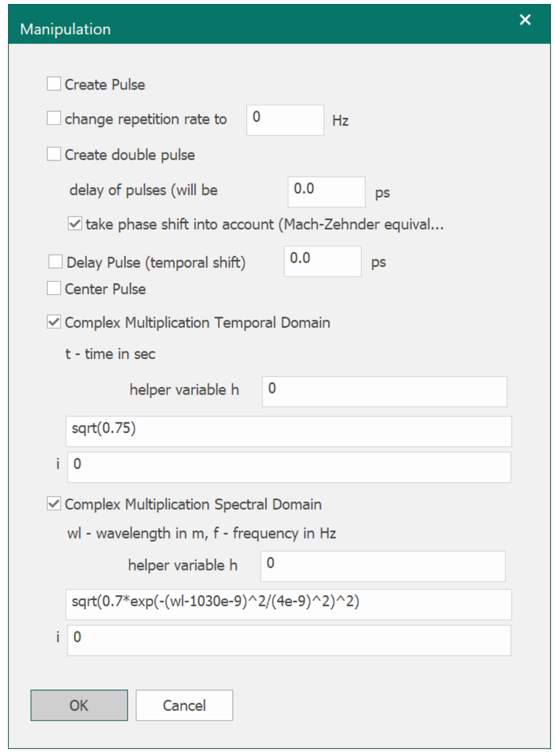
Saved as: 1040.ppf



Contains a general loss of 25 % and a filter transmission of 70%. The width ($1/e^2$) is 4 nm centered at 1040 nm.

Pulse manipulation propagation

Saved as: 1030.ppf



Similar, but centered at 1030 nm.

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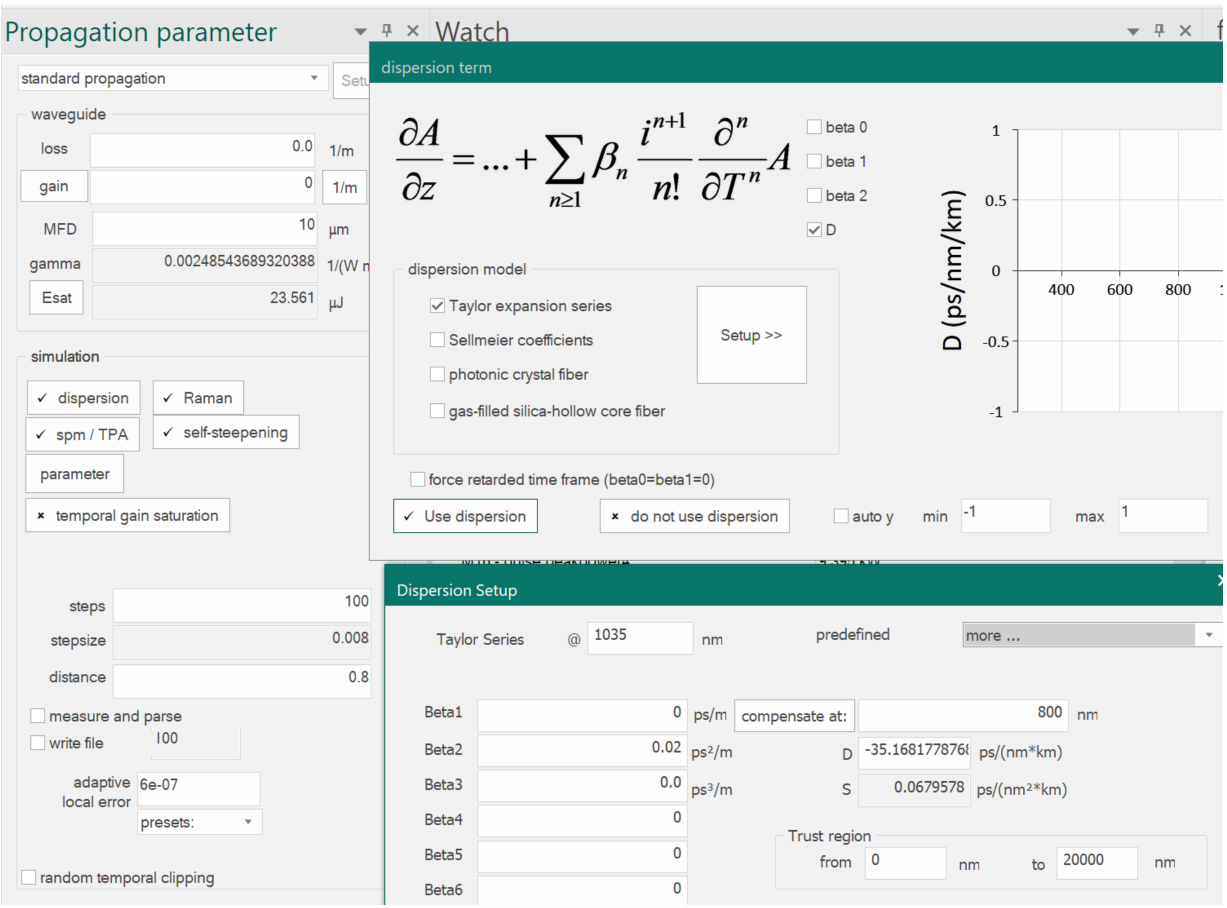
The passive fiber is defined as a standard propagation. The dispersion is only second order at 1035 nm.

standard propagation
Saved as: passive.ppf



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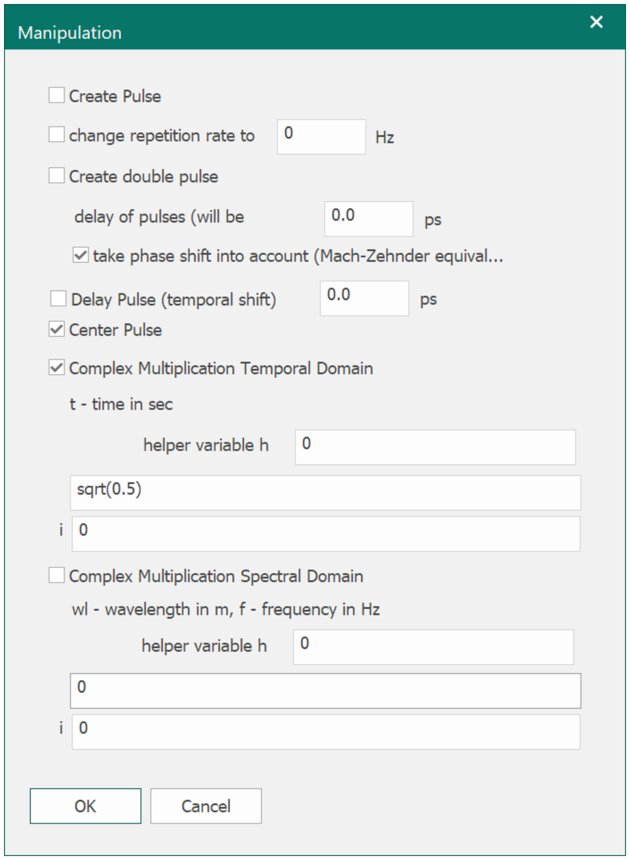
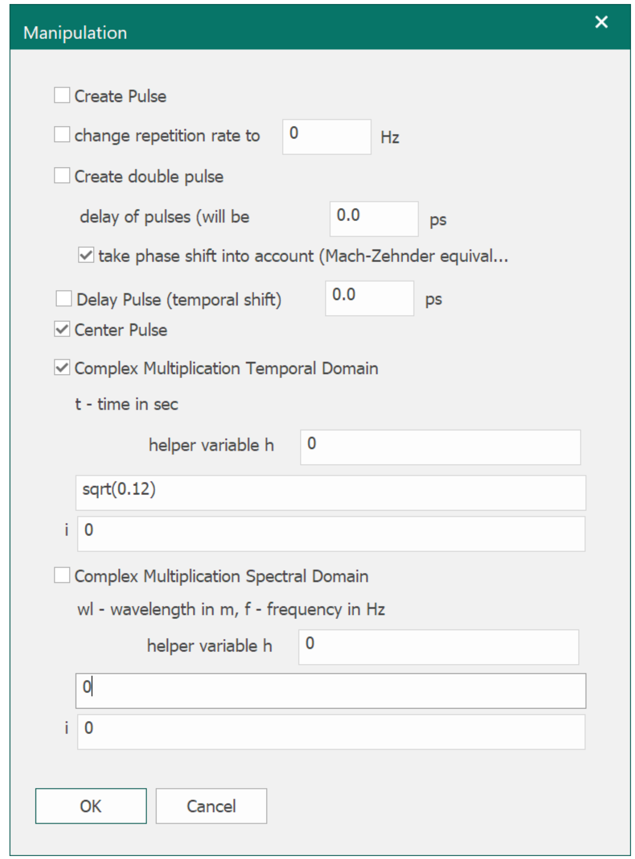
The output coupler is again defined as a pulse manipulation:

Pulse manipulation propagation
Saved as: OC1.ppf



50% Transmission.

Pulse manipulation propagation
Saved as: OC2.ppf



12% Transmission. (88% out-coupling)

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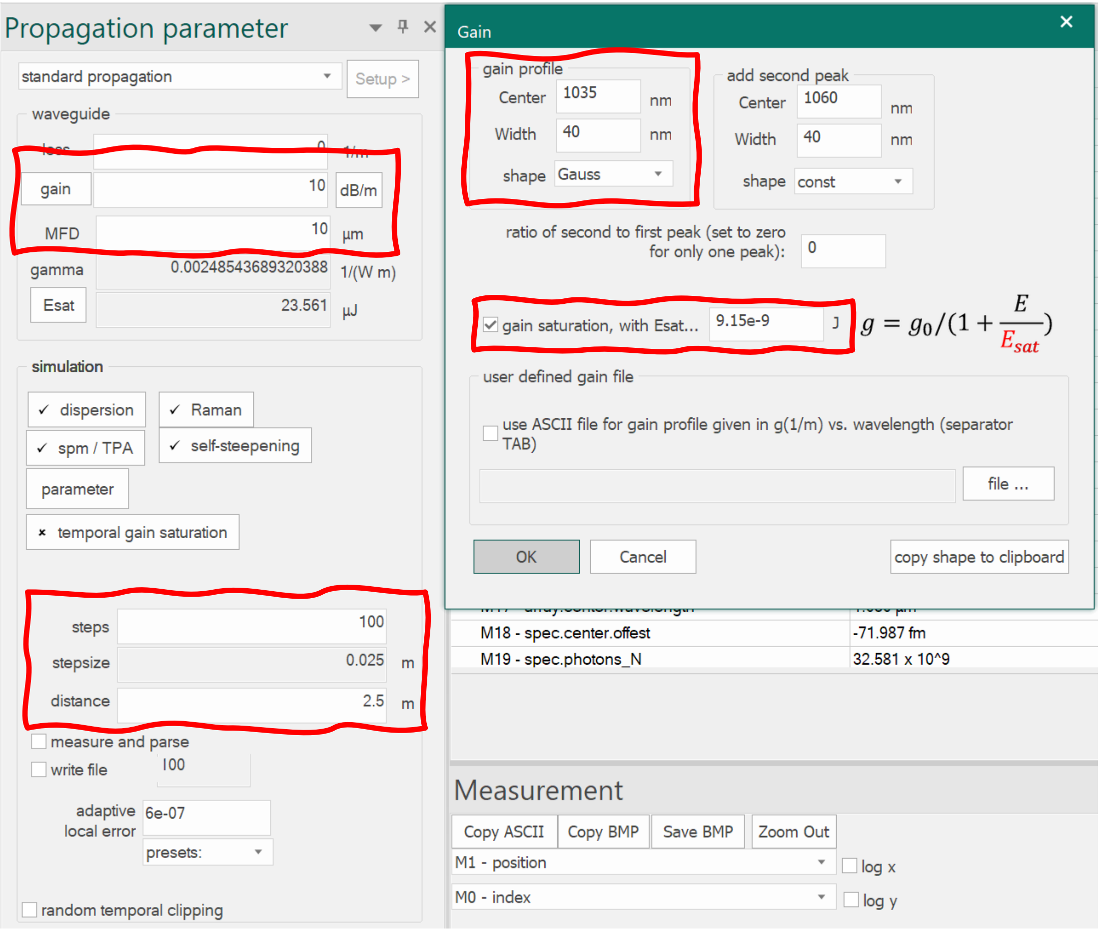
The first gain fiber is defined as a standard propagation:

Standard propagation

Saved as: gain1.ppf



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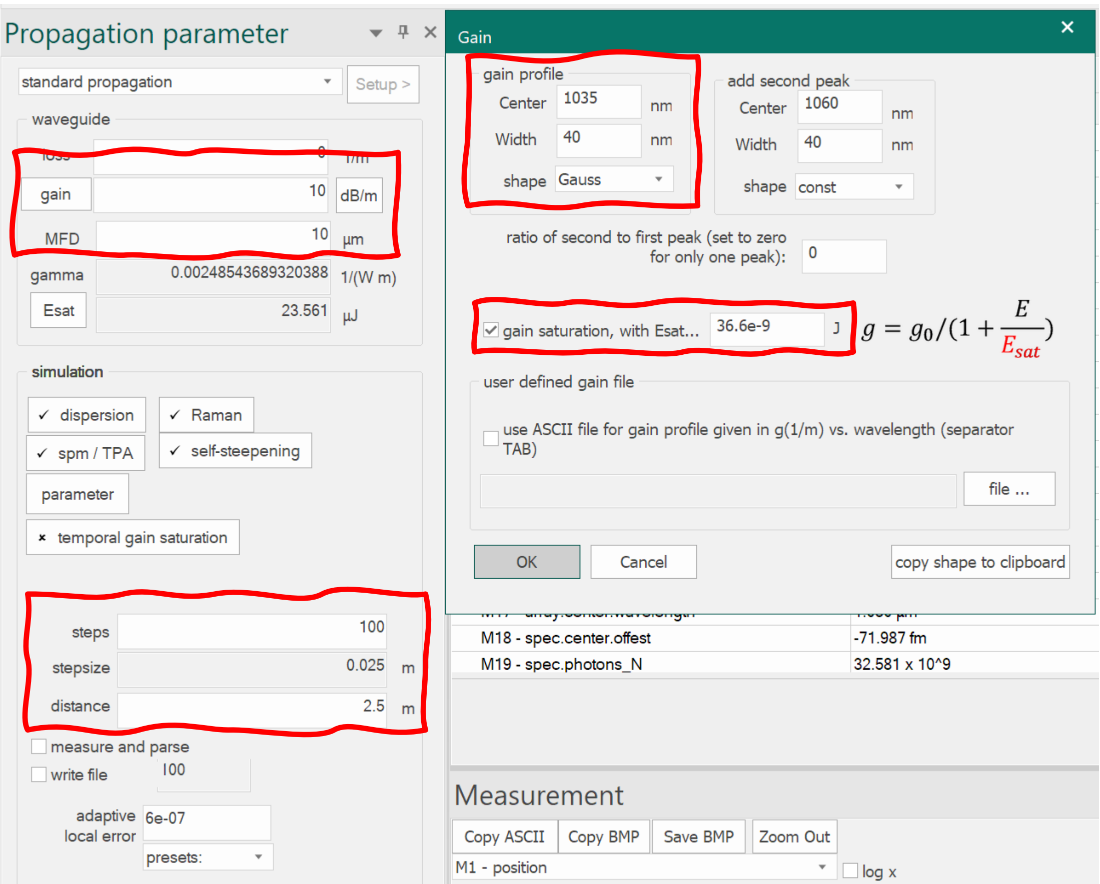
The second gain fiber is defined as a standard propagation:

Standard propagation
Saved as: gain2.ppf



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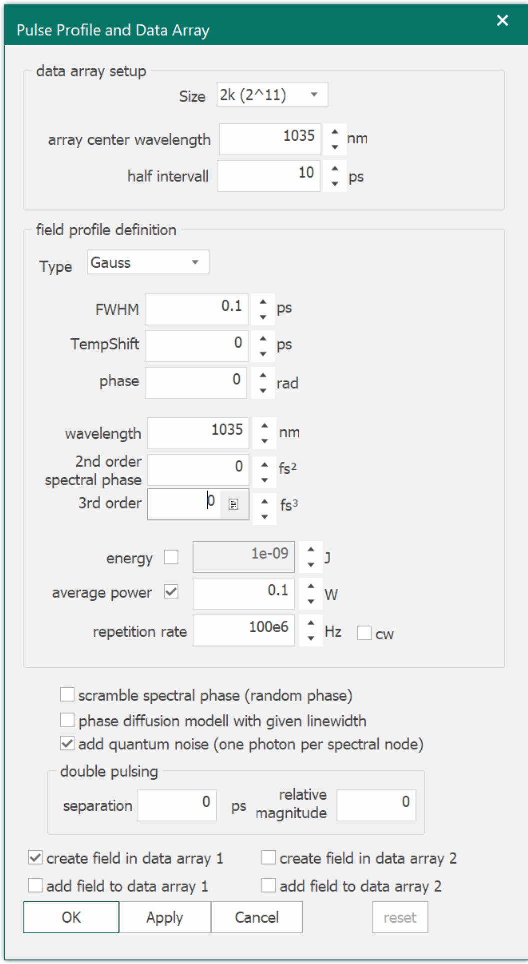
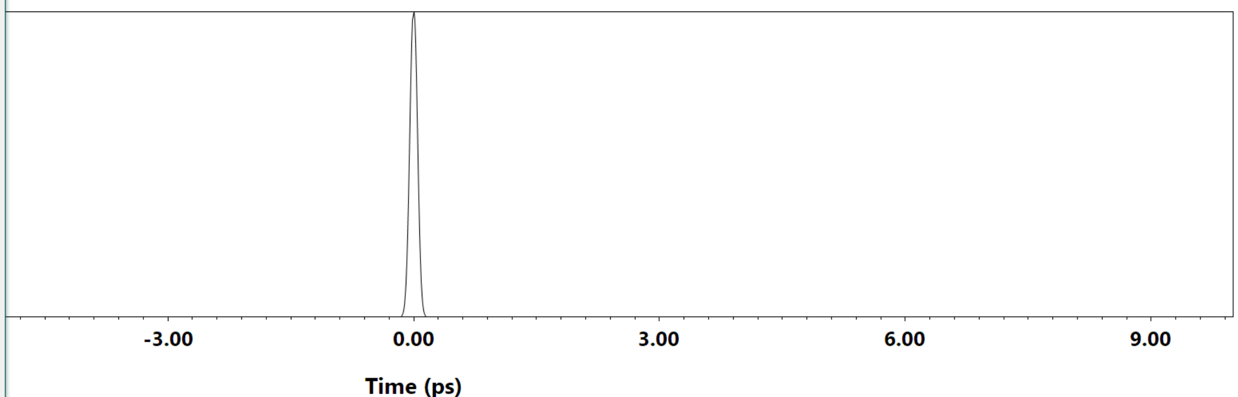
As most Mamychev oscillators are not self starting, we seed with a short pulse:

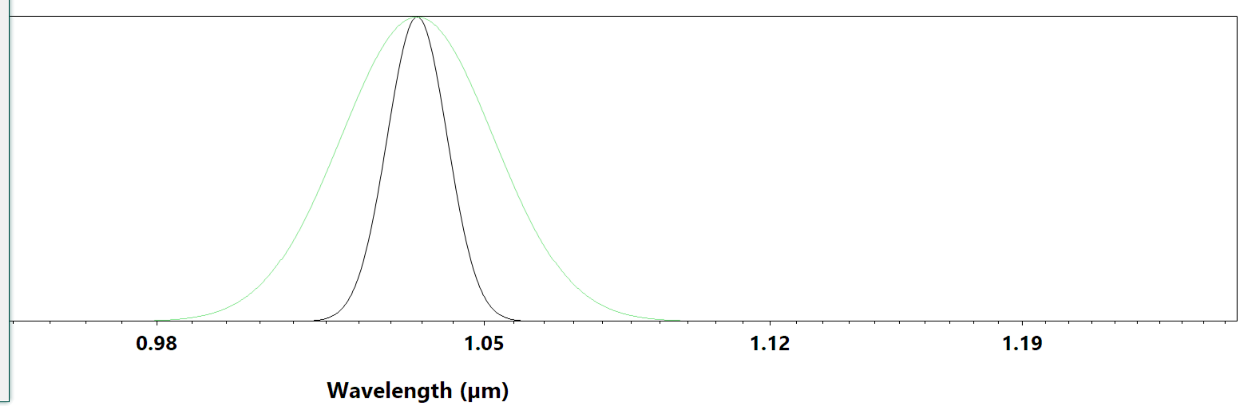
Create Pulse:



Field

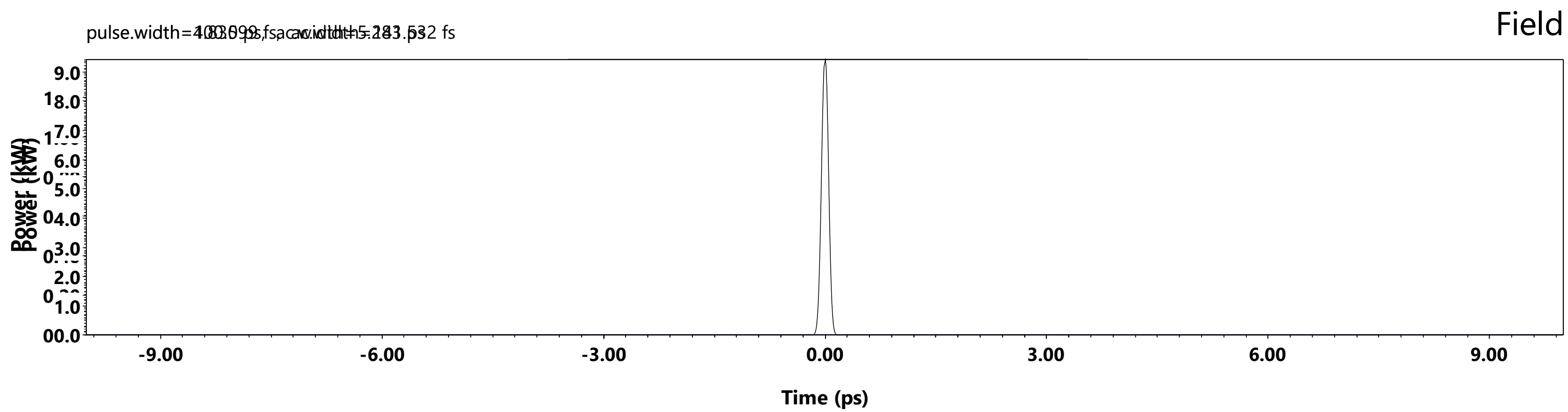


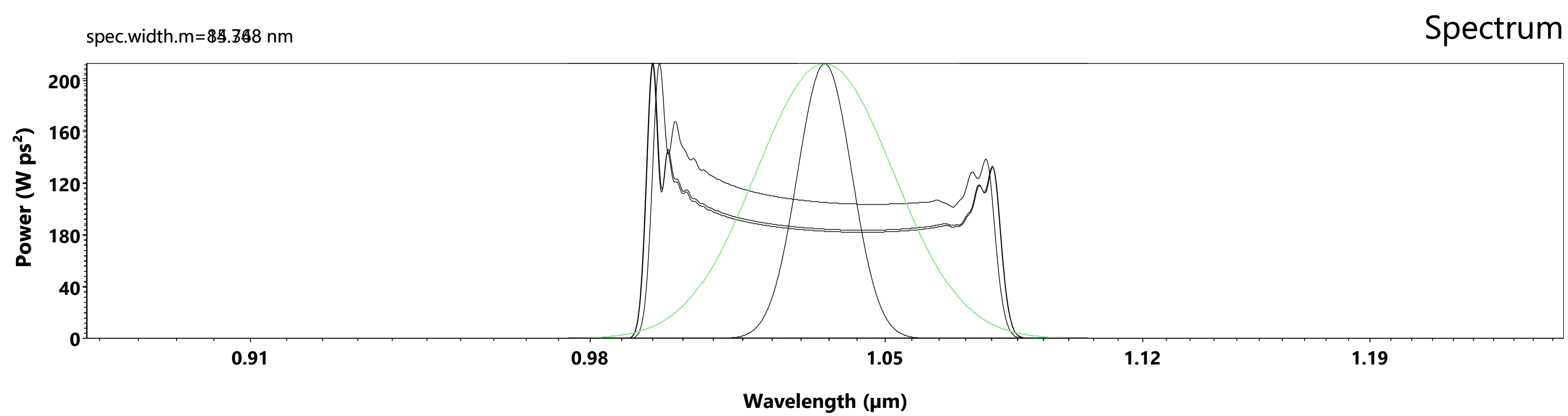
Spectrum



lecture 5

After some roundtrips, we see the pulse converging. However, after many roundtrips, the pulse might destabilize.





lecture 5

Part 3: Micro Comb Generator

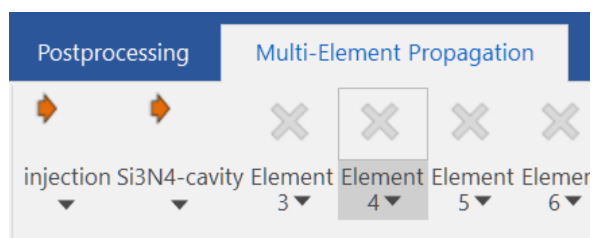
Alessia Pasquazi, Marco Peccianti, Luca Razzari, David J. Moss, Stéphane Coen, Miro Erkintalo, Yanne K. Chembo, Tobias Hansson, Stefan Wabnitz, Pascal Del'Haye, Xiaoxiao Xue, Andrew M. Weiner, Roberto Morandotti, Micro-combs: A novel generation of optical sources, Physics Reports, Volume 729, 2018, Pages 1-81.

Fiberdesk's multi element propagation can be used to simulate roundtrips in the micro-resonator. Please see section 5.1 of the reference for details. In principle, the first element simulates the in/outcoupling (boundary conditions) and the second element is the nonlinear propagation within the resonator.

$$E^{(m+1)}(0,\tau) = \sqrt{\theta}\,E_{\text{in}} + \sqrt{1-\theta}\,E^{(m)}(L,\tau)e^{i\phi_0},$$

$$\frac{\partial E(z,\tau)}{\partial z} = -\frac{\alpha_{\text{i}}}{2}E + i\sum_{k\geq 2}\frac{\beta_k}{k!}\left(i\frac{\partial}{\partial\tau}\right)^k E + i\gamma|E|^2 E$$

So, only two elements need to be defined:

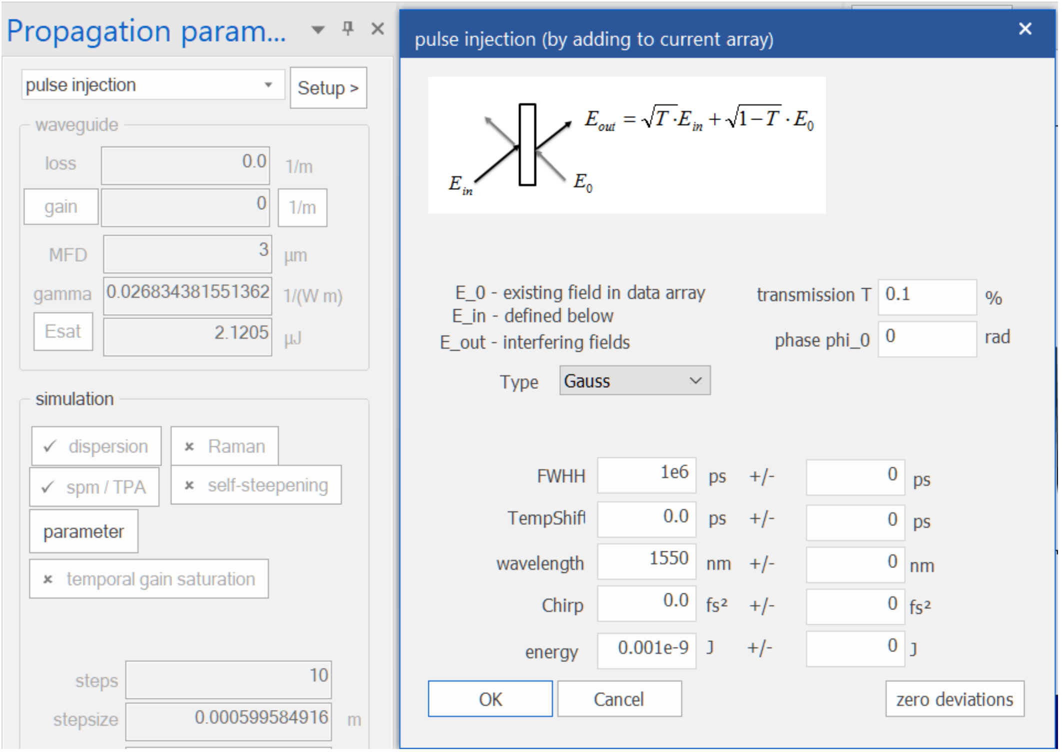


Please also note that the average propagation equation (LLE) can be used for simulating Micro Comb Generation but are intended for another tutorial.

lecture 5

The injection element is done using the “pulse injection” propagation.
As you can see, in the setup a low transmission (High Q Cavity) and long pulse duration (to simulate a cw injection) is given.

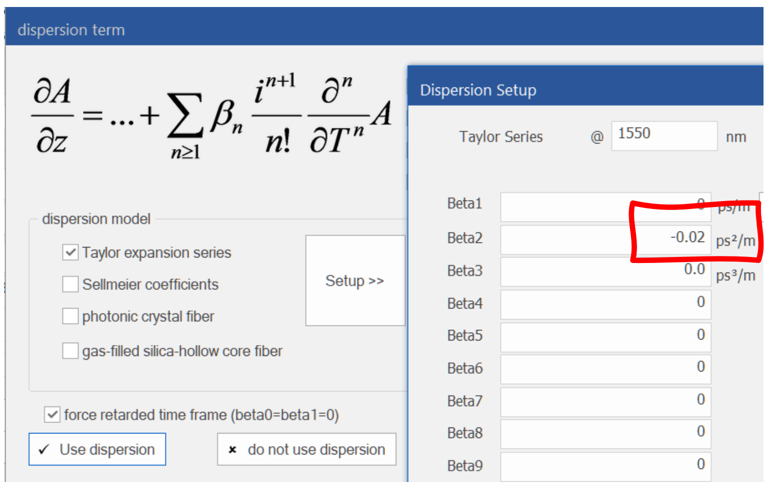
Save as injection.ppf

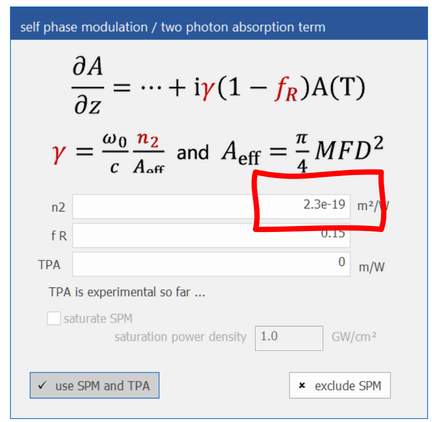


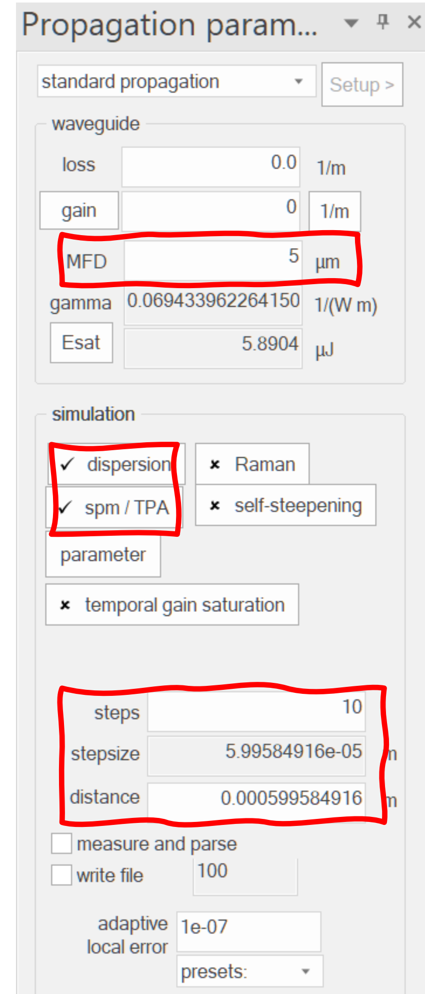
lecture 5

The ring itself is defined as a standard propagation with the dispersion of the material (including the waveguide dispersion), the nonlinearity and length.
The dispersion is a simple second order approx. only.

Save as Si3N4-cavity.ppf







lecture 5

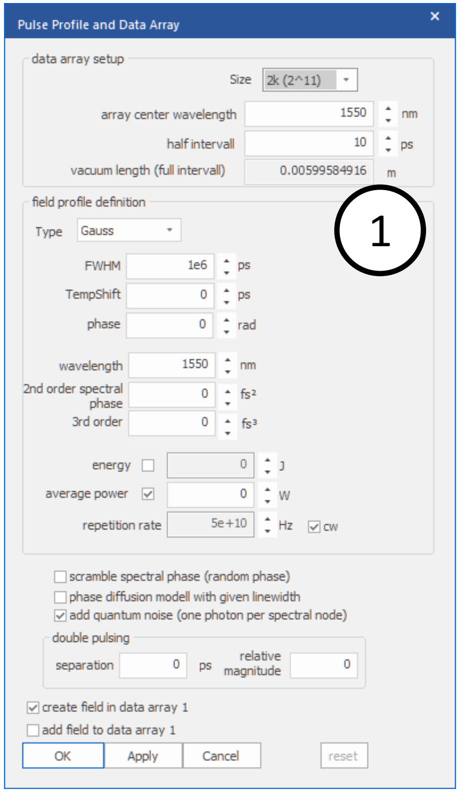
Starting the multi-element propagation. (Please make sure to have done the first steps of this tutorial to learn multi-element propagation.)

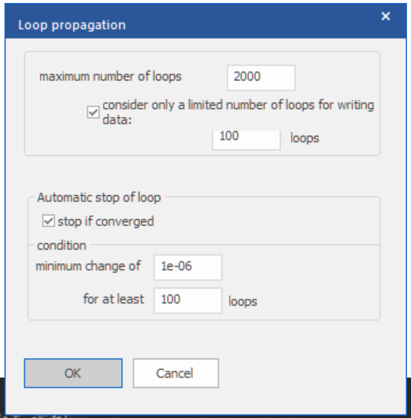
Quick reminder:

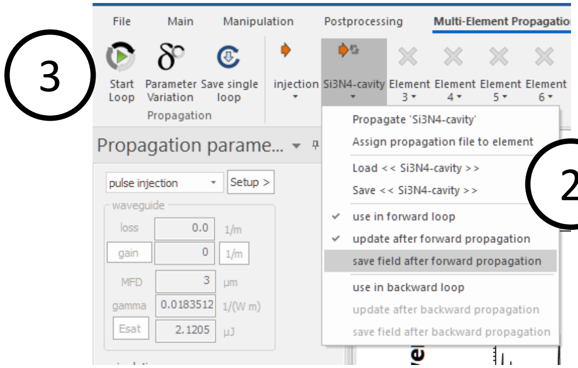
(1) Setup a field with a temporal window fixed to the length of the cavity (here ~60µm). This allows to draw a roundtrip map later on. We also only use quantum noise as the input come from the injected field.

(2) Assign the two propagations files to elements and use both in forward loop direction. Also, to see the chance after the propagation, switch on “update after forward propagation” of the second element. You might also save the field after forward propagation, in order to postprocess it later on, e.g. plot te graph on the next slide.

(3) Setup and start the loop.







lecture 5

Using the python script, you can draw the save file and get this roundtrip map. It shows the built-up of structures from the cw input. The parameters now need to be refined to enable the desired output.