



Become a femtosecond laser professional.

Installation and User Guide

femtoPro Version 0.6.0

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Contents

1	Installation	2
1.1	Requirements	2
1.2	Installation Instructions	2
2	Controls	4
2.1	Locomotion	4
2.2	Field of View	5
2.3	Basic Interactions	5
2.4	Special Interactions with Optical Elements	7
3	Getting Started with femtoPro	9
3.1	Laptop	9
3.2	Folder	13
3.3	Whiteboards	14
3.4	Lab Equipment	14
4	Credits and Support	16

1 Installation

1.1 Requirements

You need the following to install and run femtoPro:

- **Virtual-reality (VR) headset.** femtoPro is available for Oculus/Meta Quest*, Oculus/Meta Quest 2, Meta Quest 3*, Pico Neo 3 Pro or Pico Neo 3 Pro Eye*. However, due to limited resources, only marked VR devices (*) are tested in detail.
- **Personal computer (PC)** running Windows. Required for installation process. Direct download onto VR headset is currently not possible.
- **USB cable.** Required for femtoPro installation from PC to VR device. Afterwards femtoPro runs independently on VR devices as a "standalone application".
- **Only required for Oculus/Meta VR headsets (not for Pico VR headsets): Mobile device** with Android or iOS and installed Oculus/Meta Quest Mobile app. Required for initial setup of the VR headset and for activating the developer mode.
- **Only required for Oculus/Meta VR headset (not for Pico VR headset): Meta or Facebook account.** Required to "couple and activate" the VR headset.
- **Only required for Oculus/Meta VR headset (not for Pico VR headset): Developer account.** Must be applied for and set up with Oculus/Meta before femtoPro installation, if not already available (see below). Required for then being able to activate the developer mode of the VR headset for the femtoPro installation.

1.2 Installation Instructions

1.) Activate VR headset

Note: This procedure only needs to be done once on any VR headset.

Follow the user manual of your VR headset to set up and activate the VR headset. For Oculus/Meta VR headsets only, this process requires setting up an additional account and installing and running the Oculus/Meta Quest app on a mobile device.

2.) Only for Oculus/Meta VR headsets: Register developer account

Note: This procedure only needs to be done once for any person wanting to install femtoPro on an Oculus/Meta VR headset.

If you do not already have a developer account, you have to obtain one via the following procedure:

- a. Go to the Oculus Developer Site at <https://developer.oculus.com/sign-up/> and click **Register**.
- b. Choose between **Sign Up With a Facebook Account** or **Create an Account with E-Mail-Address**.
- c. Enter your personal information and create your account.

3.) Download and unzip femtoPro

- a. If not already done, visit <https://www.uni-wuerzburg.de/en/femtopro/download>, fill out and submit the request form for a femtoPro license.
- b. You will receive an automatically generated confirmation mail of your request.
- c. After processing, you will receive an e-mail containing a password-protected download link. Click on that link, enter the password you received in the same e-mail and download the zip file.
- d. Unzip the content of the zip file into any directory on your PC hard drive.

4.) Enable developer mode and allow USB debugging

- a. Turn on the VR headset.
- b. Connect VR headset and PC using the USB cable.
- c. Give the necessary permissions, i.e., enable the developer mode and allow USB debugging on your VR headset, by performing the following steps that depend on the VR headset type:

Pico Neo 3 Pro and Pico Neo 3 Pro Eye

- a. Go to **Settings** and open the tab **General**.
- b. In the **General** tab, select **About** and click **Software Version** ten times. Then, the **Developer** menu will appear on the bottom left.
- c. Enable **USB debugging** in the **Developer** menu.

Oculus/Meta Quest and Oculus/Meta Quest 2

- a. Enable **Bluetooth** and **WLAN** on your **mobile device**.
- b. Open the **Oculus/Meta Quest Mobile App** on your mobile device. Go to the **Menu** panel and select **Devices** and make sure that your Oculus/Meta Quest is displayed as “connected”. If not, restart your VR headset. Then select **Developer Mode**, which is listed below **Headset Settings**, and enable the Developer Mode (or Debug Mode) if it is not already enabled.
- c. **Connect** your VR headset to your computer via **USB with a suitable cable**.
- d. Make sure that your VR headset is displayed in the file explorer of your personal computer. If not, disconnect your VR headset and reconnect it. Put on your VR headset and click **Allow** on the **Allow access to data** prompt.
- e. Confirm the **Enable USB Debugging** prompt on your VR headset. It may occur that this prompt is displayed a second time a few seconds after confirming the first prompt. In that case, confirm again.

Meta Quest 3

- a. Enable **Bluetooth** and **WLAN** on your mobile device and the VR headset.
- b. Open the **Meta Quest App** on your mobile device. Select your connected Meta Quest 3.

- c. Select **Headset Settings** and then **Developer Mode** (or Debug Mode) and enable it.
- d. Confirm the **Enable USB Debugging** prompt on your VR headset. It may occur that this prompt is displayed a second time a few seconds after confirming the first prompt. In that case, confirm again. If the prompt does not appear, choose it from the list of notifications by selecting the notification bell in the menu bar.

5.) Install femtoPro

- a. Confirm that the VR headset is connected to PC via USB cable (see previous step).
- b. Make sure that only one VR headset is connected to the PC and that no other android devices (such as smartphones) are connected as well.
- c. Execute the **femtoPro Installer** executable on the PC by double-click.
- d. Click **Install**.
- e. The installation process will take a few seconds. Once installation is finished, it will be displayed: “femtoPro has been successfully installed to your VR device! Please start femtoPro from within your VR headset.”

6.) Start femtoPro

- a. Turn on the VR headset.
- b. Put on the VR headset.
- c. Start femtoPro by selecting it from the App panel, depending on the VR headset type:

Oculus/Meta VR headset

- a. Go to **Apps** in the Main Menu and select **Unknown Sources** from the dropdown menu in the top right corner. If the dropdown menu does not appear, type “femtoPro” in the search bar to make it visible.
- b. Select femtoPro.

Pico VR headset

- a. Select femtoPro directly from the **Library** menu. If femtoPro does not appear, first select “**Unkown**” in the left panel.

2 Controls

The following sections provide a quick overview of the femtoPro controls using pictures of the Pico Neo 2 VR headset and controller. Other supported VR headsets use analogous buttons.

2.1 Locomotion

For moving around the VR lab, you may walk through your real-world room, and the movement is mapped into VR. Alternatively, you can also move via **teleportation**. Push and hold a **thumbstick forward** to reveal the teleport cursor as shown in Fig. 1. After selecting your destination with the cursor by tilting your hand into an appropriate angle, release the thumbstick again to perform the teleportation.

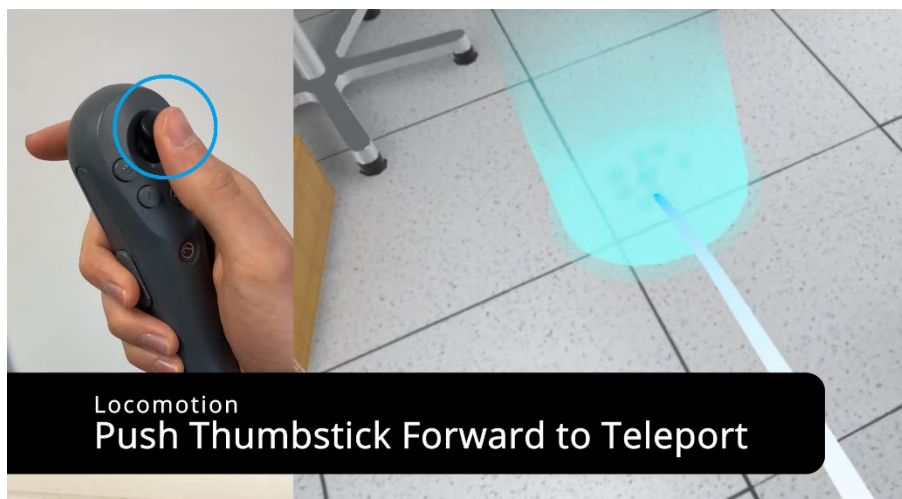


Figure 1. Move in the virtual lab via teleportation using the thumbstick.

2.2 Field of View

Tilt your head or turn around in your real-world room to modify your viewing direction in VR. Alternatively, push the **thumbstick** to the **left** or the **right** to initiate a **view rotation** by 45°.

2.3 Basic Interactions

To **grab** objects like mirrors, lenses, irises, spectrometers, and powermeters, approach the bottom part of the element with your virtual hand and once the bottom part is highlighted in light blue, press and **hold the grip button**, which is usually attached on the side of the controller (Fig. 2). Objects like the alignment card, the ruler, the delay stage, the folder, and the laptop can be grabbed anywhere.



Figure 2. Interact with a mirror using the grip button.

With the **trigger button**, which is usually located on the front of the controller, you perform a pinch gesture with which you can interact with the top part of optical elements in order to adjust coarse rotation and height. Approach the top part of the optical element and hold the trigger button as soon as the top part is highlighted in light blue. Then, while holding the trigger button, a red circle

appears. To **adjust the height** of an optical element, now move the controller up and down. Rotating the top part works as follows. While holding the trigger button, the radius of the red circle can be changed by pulling back the interacting hand. After leaving a region of minimum radius, the circle will turn light blue. The radius of this light blue circle then dictates the sensitivity for rotating the top part. To **align coarse rotation** of an optical element, move the controller to the left and to the right along the indicated circle while holding the trigger button (Fig. 3).



Figure 3. Interact with a mirror using the trigger button.

The **trigger button** is also used to interact with **user interfaces (UI)** like those on the laptop (Section 3.1) or the folder (Section 3.2). Once you approach the laptop display with a virtual hand, a light blue **pointer** will appear with which you can navigate on the UI. Selecting UI elements is performed with the trigger button (Fig. 4).

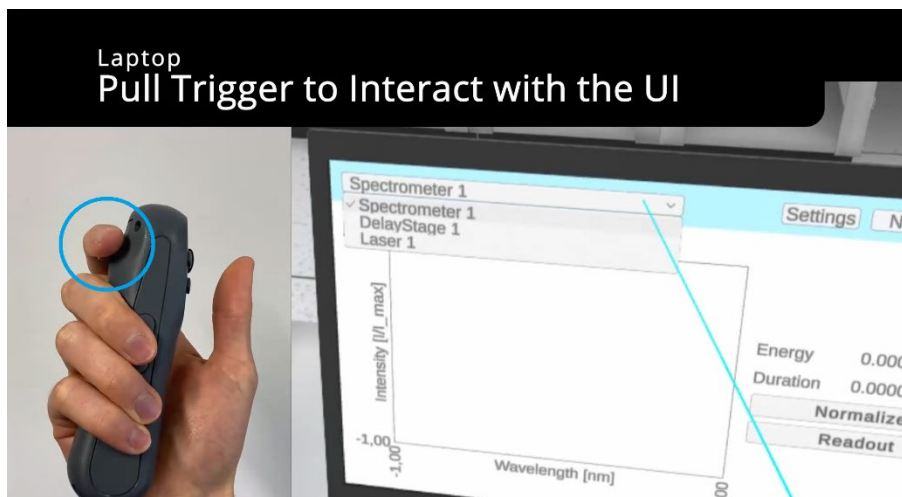


Figure 4. Interact with a user interface (UI) using the trigger button. UI elements can be selected by a light blue pointer.

2.4 Special Interactions with Optical Elements

In addition to the interactions described above, you can also interact with the brass-colored alignment screws of an optical element such as a mirror (Fig. 5) in order to fine-tune its alignment. The top screw is used to tilt the mirror forward (backward) which effectively causes the propagation path of a reflected laser beam to incline downward (upward). In a similar sense, the bottom screw controls the mirror tilt to the left and right such that the reflected laser beam can be moved within the horizontal plane. To **adjust an alignment screw**, approach it such that the screw is centered between the virtual thumb and index finger, and press and hold the trigger button as soon as the screw is highlighted. Then, **while holding the trigger button, perform a circular motion with the controller in your hand** to turn the screw (Fig. 5).

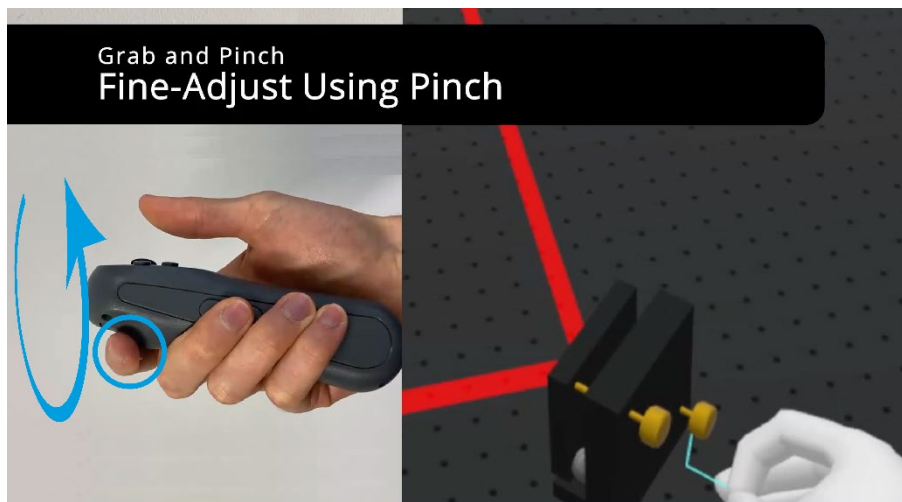


Figure 5. Fine-adjust the alignment of mirrors by performing a circular motion with the controller while holding a brass-colored screw with the trigger button.

There are also such brass-colored screws on the lens holder, which can be turned in an analogous fashion (Fig. 6). However, on the lens holder, the screws have a different purpose. The screw on the side controls the lateral position of the lens inside the holder whereas the screw at the top is responsible for moving the lens up and down within the holder.

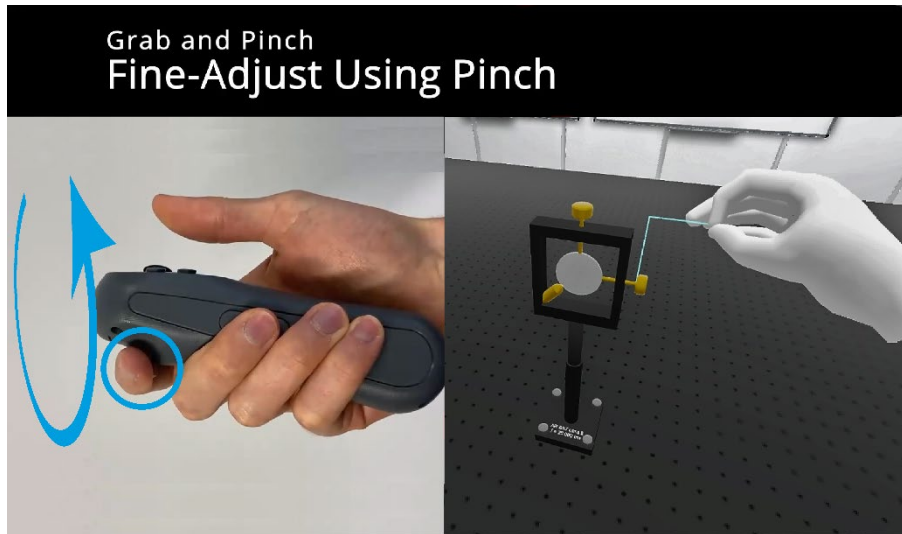


Figure 6. Aligning the position of lenses within the lens holder. Similar to mirrors, the brass-colored screw on lens holders can be turned by performing a circular motion of the controller while holding a brass-colored screw with the trigger button.

Irises feature a gray handle which is attached to the top. With this handle, the diameter of the iris aperture can be adjusted. To interact with the handle, approach it such that the handle is centered between the virtual thumb and index finger and press and hold the trigger as soon as the handle is highlighted in light blue. Then, **move the controller along the perimeter of the iris to adjust the size of the aperture** (Fig. 7).

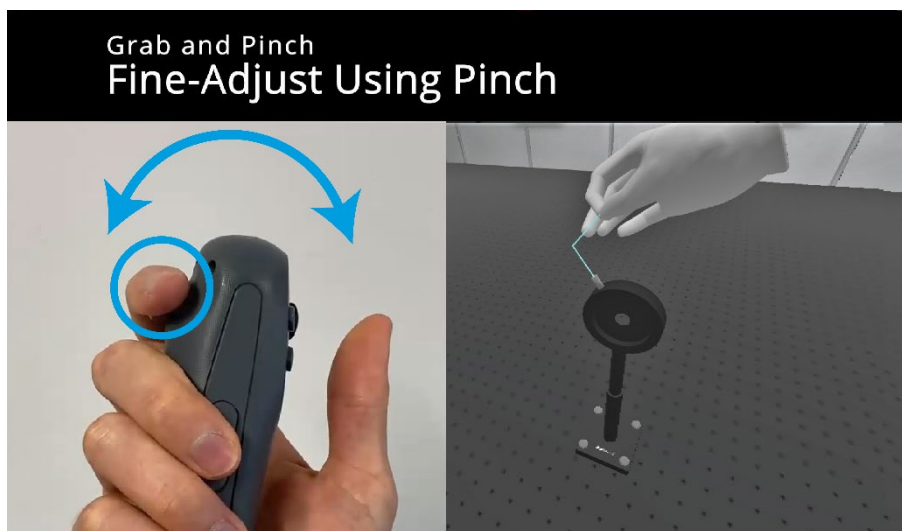


Figure 7. Adjusting the size of iris apertures. By holding the gray handle attached to the iris with the trigger button and moving the controller along the perimeter of the iris, the diameter of the aperture can be changed.

In a real laser lab, metallic clamps are used to attach optical elements to the laser table. In femtoPro, these clamps are abstracted as gray screws, which are attached to the bottom of an optical element. This is intended as a means of laser safety, as it is very likely that you might accidentally knock over optical elements, just as in a real laser lab. In contrast to the alignment screws, however, these gray screws do not have to be turned. Select and hold one of the **gray screws** with the **trigger button** and

then **move your controller downward** to lock the optical element on the table (Fig. 8). Likewise, unlocking an optical element is achieved by moving the controller upward while holding a gray screw with the trigger button.



Figure 8. Lock down optical elements by pushing down a gray screw on the base plate with the trigger button.

3 Getting Started with femtoPro

Welcome in your personal femtosecond laser lab! In Fig. 9, you may already notice the large, bulky table in the middle. This is the place where you are going to set up your first experiments with femtosecond lasers in VR. Below, you find further information about some important objects in the laser lab.

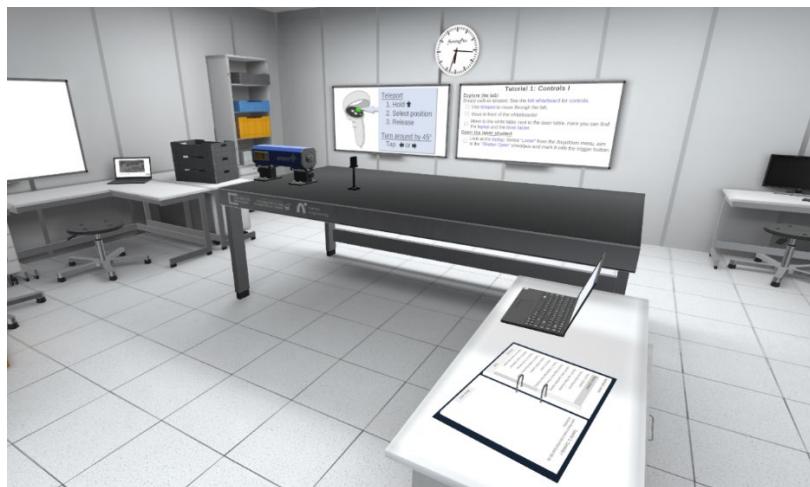


Figure 9. View into the virtual femtosecond laser lab.

3.1 Laptop

The laptop on the side table next to the laser table (Fig. 10) is used to control devices like the laser and delay stages. Moreover, it is used to display the output of powermeters and spectrometers. You

can interact with the laptop user interface by approaching the display with your virtual hand until a light blue pointer occurs (see also Fig. 4).



Figure 10. The laptop. Use it to control devices, to display device output signals, and to quit the program.

You can also grab the laptop and put it somewhere else. Exiting femtoPro is also done via the laptop. To quit the program, select **Settings** in the upper right corner, and then click **Quit Program** at the bottom.

Devices like the powermeter can be selected by the dropdown menu at the top left. Once selected, a new panel with data plotting and acquisition options will appear. The **powermeter UI** panel, which is relevant for tutorial 6, for example, is exemplarily shown in Fig. 11.

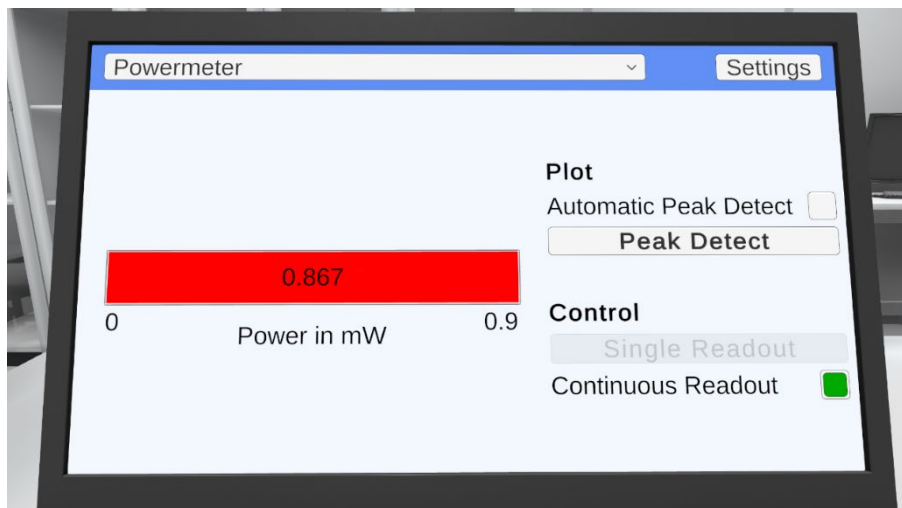


Figure 11. The powermeter UI. The power of the beam, which is currently incident on the detector, is displayed as a red bar on the left. Plotting and acquisition options are displayed on the right.

The power bar on the left side shows the currently detected power. On the right side under **Plot**, the maximum value of the power bar, the “peak value” can be set manually by clicking **Peak Detect**. The

currently detected power then serves as the maximum value for the power bar. This peak value can also be set automatically by enabling **Automatic Peak Detect**.

The power readout can be set under **Control**. By clicking **Single Readout** (while having Continuous Readout disabled), the power is only measured once. Enabling **Continuous Readout** leads to a continuous measurement of the laser power.

Spectrometers feature a separate UI. Once a spectrometer has been selected from the dropdown menu at the top left, the active UI panel will change to the **spectrometer UI** panel, which is shown in Fig. 12.

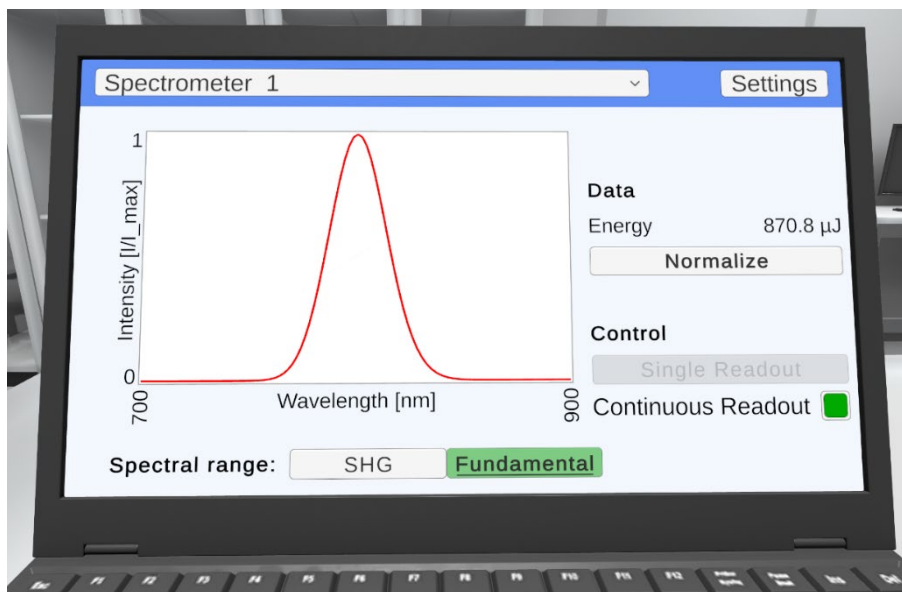


Figure 12. The spectrometer UI. The laser spectrum, which is currently incident on the detector, is displayed as a red line plot on the left. On the right, the energy of the incident pulse is displayed. There are also options for plotting and acquisition on the right and at the bottom.

The laser spectrum is displayed as a line plot (intensity vs wavelength in nm). This graph can be normalized to the maximum value by clicking the **Normalize** button. To adjust the spectral range of the wavelength axis, one can choose between **SHG** (second-harmonic generation) and **Fundamental**.

The delay stage UI has two main control panels: **Move** and **Scan**.

The **Move** panel (Fig. 13, top left) is used to quickly move the delay stage to a position corresponding to a certain temporal delay entered under **Target**. You can choose between, femtoseconds (fs), picoseconds (ps), and nanoseconds (ns) by the dropdown menu. By clicking inside the input field next to **Target**, a numpad will show up with which you enter a certain number manually. Alternatively, you can move the **Target** slider in the **Stage** panel (Fig. 13, top right). The **Stage** panel displays the status of the delay stage with all current values of Current, Zero as well as those of From and To, which are relevant for the **Scan** panel discussed below. After having set a target value, you can move the delay stage by clicking **Move To** in the **Move** panel.

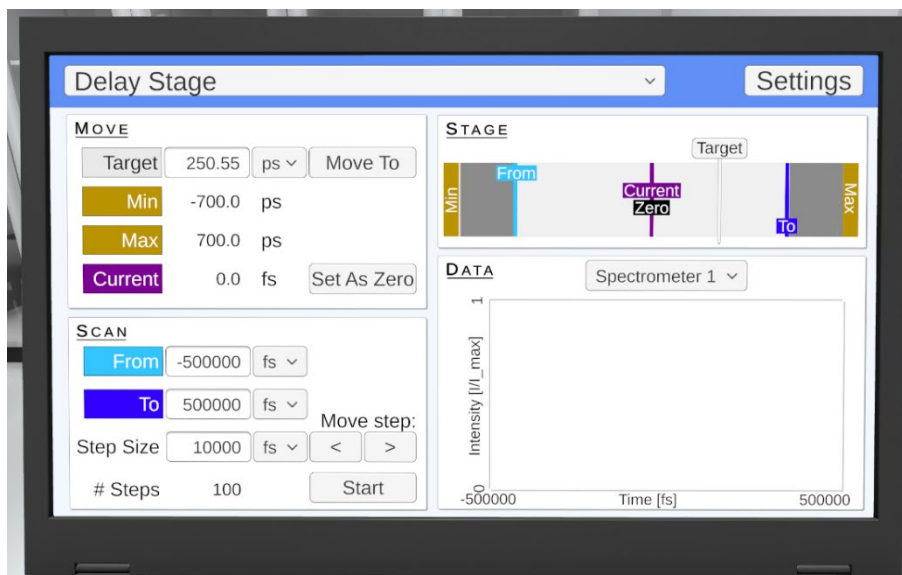


Figure 13. Control panels of the delay stage UI. The Move panel (top left) is used to quickly move the stage to a certain time delay via an input field. One can also move the stage via the Target slider in the Stage panel (top right). The Scan panel enables one to perform automatic scans or to do stepwise stage incrementation. In case an automated Scan is performed, measured data will show up in the Data panel.

In the **Move** panel, the delay corresponding to the current position of the stage is displayed at **Current** while the minimum and maximum possible delays are displayed under **Min** and **Max**, respectively. By clicking **Set As Zero**, you can set the current delay to the new time-zero value, which serves as a reference for scans carried out in the **Scan** panel.

The **Scan** panel (Fig. 13, bottom left and Fig. 14, bottom left) is used to manually step the stage in a pre-defined delay range with a preset increment. To conduct a scan, one must enter a start value (**From**), an end value (**To**), and a **Step Size**. The **From** and **To** values are referenced to the value that was set in the **Move** panel using **Set As Zero**. (If no value was selected, then the reference is 0.) Based on the parameter set, the number of scan points are displayed at **# Steps**.

After having entered values for **From**, **To**, and **Step Size**, a click on **Start** moves the delay stage to the position corresponding to the value of **From** and the stage subsequently performs an automatic scan. After starting a scan, the measured data will be displayed under **Data** in real time (Fig. 14, bottom right). In the example of Fig. 14, the integrated second harmonic spectrum received from a spectrometer is plotted against the scanned delay.

Instead of performing an automatic scan, you can also move the stage stepwise by the **›** button which moves the delay stage one step forward or the **‹** button which moves the delay stage one step back.



Figure 14. Automatic scan carried out with the delay stage UI. The scan parameters (From, To, and Step Size) can be entered in the Scan panel (bottom left) and the scan can be started by Start. Acquired data is plotted in the Data panel. In the present example, an interferometric autocorrelation received from integrating the second harmonic of the output of a Michelson-type interferometer was measured (bottom right).

3.2 Folder

The folder, which is located next to the laptop, is used to navigate through the tutorial levels (Fig. 15). On the left page, you find a list of the available levels. You can navigate between these levels with the **Previous** and **Next** buttons. On the right page, you find level descriptions as well as a **Start level** button. Once you have started a level, the Start level button is replaced with a **Retry level** button, which allows you to restart the current level.

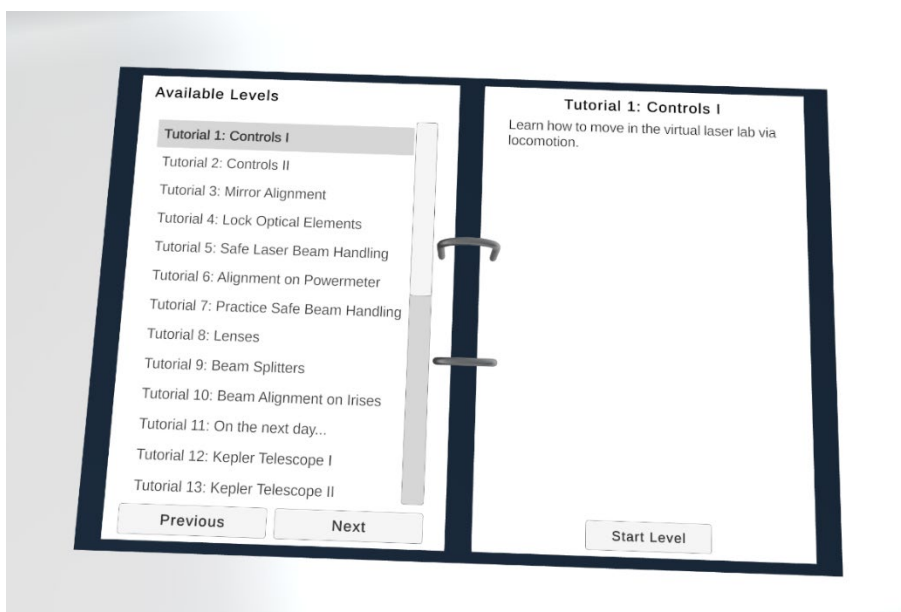


Figure 15. The folder. The left page displays a list of available levels while the right page shows the level descriptions.

3.3 Whiteboards

Whiteboards are used to display tasks and other useful information. There are two main whiteboards in the lab (Fig. 16). The right whiteboard shows your current tasks. The fulfillment of a task will be automatically detected and then indicated by a checkmark.

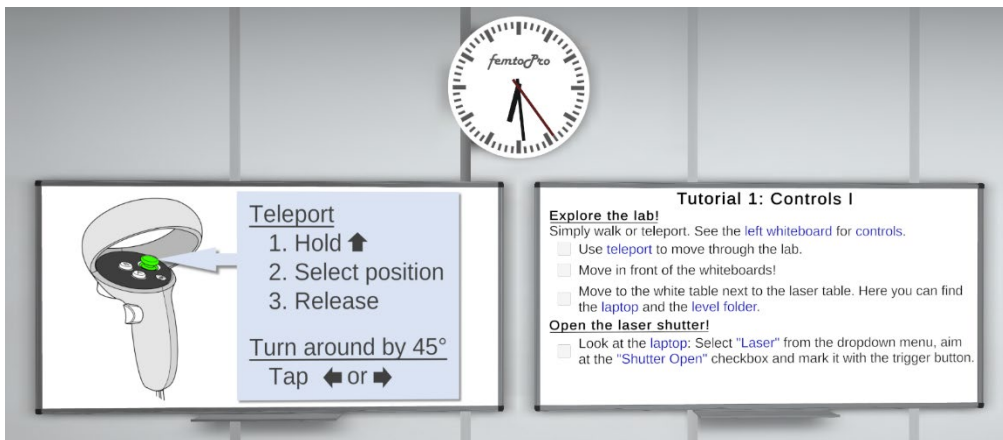


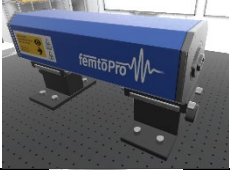

Figure 16. The Whiteboards. The left whiteboard displays information on controls, laser safety, and schematics of optical setups. The right whiteboard displays your current tasks.


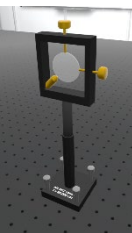




In the first levels, the left whiteboard displays images and explanations on how to use the controls. Note that the displayed images refer to the controllers of the Pico Neo 3 Pro Eye, which may deviate somewhat from those of other VR headsets, but the usage of buttons is analogous in all cases. From the fifth level on, the golden rules of laser safety or other level-relevant information such as schematics of experimental setups are displayed on the left whiteboard.

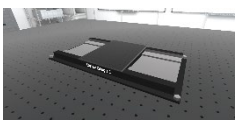
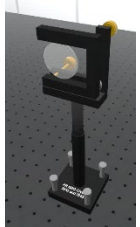
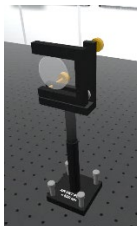
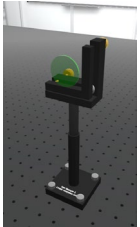
3.4 Lab Equipment

The following table lists the lab equipment, that is, optical elements and devices along with short descriptions of their function. More elements and functionalities are planned for future releases of femtoPro.

Table 1. List of lab equipment in femtoPro.

Element	Picture	Description
Laser		Generates pulses with 15–30 fs duration (full width at half maximum) centered at 800 nm, having an energy of 1 mJ and a beam waist of 5 mm.
Beam Blocker		Stops the laser beam. The millimeter grid is useful to estimate the beam radius. Height and rotation angle of the blocker can be adjusted.

Mirror		<p>Directs the beam into other directions. Mirrors are available as planar (“flat”) mirrors as well as convex and concave mirrors. Height and coarse rotation are adjustable. In addition, you can fine-align the direction of the reflected beam in the vertical plane and the horizontal plane with the upper and lower brass screws, respectively.</p>
Lens		<p>Focuses or defocuses the beam, depending on the sign of the focal length (positive: focusing, negative: defocusing). Height and rotation is adjustable. The brass screws control the position of the lens within the holder (top screw: vertical position, side screw: horizontal position).</p>
Iris		<p>Reduces the beam diameter and monitors alignment. Irises are useful in ensuring a reproducible beam path when used in pairs. While the height and rotation is adjustable, the diameter of the iris aperture can be changed by moving the gray handle using a pinch gesture.</p>
Beam Splitter		<p>Acts as a semi-reflective mirror. It can split one laser beam into two beams (one transmitted beam, one reflected beam), or recombine beams. Height, rotation, and fine-alignment is adjustable (similar to mirrors).</p>
Powermeter		<p>Measures the average optical power of an incident laser beam. In addition to the height and rotation, the diameter of the input aperture can be changed (like an iris). Looks similar to a spectrometer but uses a metallic-reflective detector housing. For several incident beams, interference is simulated taking into account the spatial beam properties, mutual beam overlap factors and angular mismatch.</p>
Spectrometer		<p>Measures the wavelength intensity spectrum of an incident laser beam. Height, rotation, and input aperture are adjustable (like an iris). Looks similar to a powermeter but uses a black detector housing. For several incident beams, spectral interference is simulated taking into account the spatial beam properties, mutual beam overlap factors and angular mismatch.</p>

Delay Stage		Moves optical elements that are attached to the stage. This is used to implement optical delay lines with which variable time delays between laser pulses can be created.
Nonlinear Crystal		Doubles the frequency of an input laser beam taking into account femtosecond pulse properties such as pulse shape. The underlying process is also called second-harmonic generation (SHG). If two laser beams with individual frequencies are spatiotemporally overlapped in the crystal, a new beam emerges in a third direction resulting from sum frequency generation (SFG).
Wavelength Filter		Blocks a part of the laser spectrum while being transparent for the other part. Wavelength filters are available as low-pass filters (transmission below a certain wavelength), high-pass filters, (transmission above a certain wavelength), or band-pass filters (transmission within a given wavelength interval).
Molecular Sample*		A solution of a molecule with individual optical properties. femtoPro simulates the first-order optical response using a Franck–Condon model. Molecular properties are parameterized and can be changed to investigate the effect of a certain property on the spectral response. Nonlinear third-order response is under development.

* Will be part of an upcoming update.

4 Credits and Support

Credits

femtoPro is developed at the Julius-Maximilians-University of Würzburg (Germany), in a cooperation between the research groups of Prof. Dr. Tobias Brixner (Chair for Physical Chemistry I, Institut für Physikalische und Theoretische Chemie) and Prof. Dr. Sebastian von Mammen (Games Engineering, Human-Computer Interaction, Institut für Informatik).

For more information, visit <https://www.femtopro.com>.

Support

If you have any questions, please first refer to <https://www.uni-wuerzburg.de/en/femtopro/faq>.

If your problem persists, if you would like to report bugs, suggest improvements, or submit other feedback (e.g., how you like femtoPro overall), contact us via e-mail: femtopro@uni-wuerzburg.de.