Autocorrelator with *pulse*Link Driver

*pulse*Check USB

User Manual

A·P·E Angewandte Physik & Elektronik GmbH
www.ape-berlin.de   service@ape-berlin.de
Plauener Str. 163 - 165 Haus N 13053 Berlin Germany
Phone +49 30 986 011 30 Fax +49 30 986 011 333

IMPORTANT – READ CAREFULLY BEFORE USE – KEEP FOR FUTURE REFERENCE

This user manual contains user information for the *pulse*Check USB. Read this manual carefully before operating the *pulse*Check USB, particularly Section 1 on safety instructions. The *pulse*Check USB is only to be used as described in this manual. Differing use may endanger safety and voids warranty.

CAUTION - USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION EXPOSURE

Symbols Used in this Manual and on the Measuring System

This symbol is intended to emphasize the presence of important operating instructions.

This symbol is intended to alert the operator to the danger of exposure to hazardous visible or invisible laser radiation.

This symbol is intended to alert the operator to the presence of dangerous voltage within the product’s enclosure that may be of sufficient magnitude to constitute a risk of electrical shock and to indicate possible risk of equipment damage.

Warranty

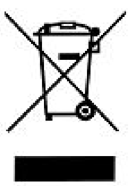
The warranty conditions are specified in the sales contract.

Any unauthorized modification (opening included) of the ***pulse*Check USB** system components or software will result in invalidity of the guarantee and service contract.

Disposal

The ***pulse*Check USB** fulfills the European Directive 2011/65/EU for reduction of hazardous substances in electrical and electronic equipment (RoHS).

All electrical and electronic products must be disposed separately from the standard municipal waste system. Proper disposal of your old appliance prevents potential negative consequences for the environment and human health.



Some components of your ***pulse*Check USB** system marked with the crossed out wheeled bin symbol are covered by the European Directive 2002/96/EC on waste of electrical and electronic equipment (WEEE) of the European Parliament and the Council of January 27, 2001. These items must be disposed via designated collection facilities appointed by government or local authorities. For more information about disposal of your old product, please contact A·P·E GmbH.

Contents

1. Safety Instructions

The European Community requirements for product safety are specified in the "Low Voltage Directive" (2006/95/EC). The "Low Voltage Directive" requires that electronic products comply with the standard EN 61010-1:2010 "Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use". Compliance of this product is certified by the CE mark.

1.1. Optical Safety

Since the *pulse*Check USB is intended to measure the duration of laser pulses all safety instructions relevant to the class of your laser have to be observed!

Laser light, because of its special properties, poses safety hazards not associated with light from conventional sources. The safe use of lasers requires that all laser users, and everyone near the laser system, are aware of the dangers involved. The safe use of the laser depends upon the user being familiar with the instrument and the properties of coherent, intense beams of light.

The greatest concern when using a laser is eye safety. In addition to the main beam, there are often many smaller beams present at various angles near the laser system. These beams are formed by specular reflections of the main beam at polished surfaces such as lenses or beam splitters. Although weaker than the main beam, such beams may still be sufficiently intense to cause eye damage.

Direct eye contact with the output beam from the laser can cause serious damage and possible blindness.

Laser beams can be powerful enough to burn skin, clothing or paint. They can ignite volatile substances such as alcohol, gasoline, ether and other solvents, and can damage light-sensitive elements in video cameras, photomultipliers and photodiodes. The laser beam can ignite substances in its path, even at some distance. The beam may also cause damage if contacted indirectly from reflective surfaces. For these reasons and others, the user is advised to follow the precautions below:

1. Observe all safety precautions given by the manufacturer of your laser.
2. All alignment procedures described herein shall only be done by qualified users who are familiar with laser safety practices and who are aware of the dangers involved.
3. Never look directly into the laser light source or at scattered laser light from any reflective surface. Never sight down the beam into the source.
4. Maintain experimental setups at low heights to prevent inadvertent beam-eye encounter at eye level.
5. As a precaution against accidental exposure to the laser beam or its reflection, those using the system have to wear laser safety glasses as required by the wavelength being generated.

Laser safety glasses can present a hazard as well as a benefit; while they protect the eye from potentially damaging exposure, they block light at the laser wavelengths, which prevents the operator from seeing the beam. Therefore, use extreme caution even when using safety glasses.

6. Avoid direct exposure to the laser light. The intensity of the beam can possibly cause flesh burns or ignite clothing.
7. Extreme care must be taken during alignment procedures with the free laser beam. Always start alignment with a beam attenuated to a level that allows for save handling.

Caution! When opening the optical head top cover a laser beam might emerge in upward direction if the input beam to the unit is not properly blocked nor the laser switched OFF.

1.2. Electrical Safety

The ***pulse*Check USB** uses DC voltages in the controller and in the optical head. All units are designed to be operated with protective covers in place.
The device complies with protection Class III / EN 61140:2007, degree of ingress protection IP20, according to EN 60529:2010.

For the connection of the controller and the optical head only the delivered cable may be applied. It is only allowed to run the *pulse*Check USB with the delivered mains adapter.

Use only the *pulse*Link controller and the optical head that have been delivered together. The units are electronically fitted to one another. Connection of other units might cause damage of the delay drive and electronic components.

Users are not recommended to open the *pulse*Link controller housing. Opening the housing is only allowed for trained service personal. In case it is necessary to open the housing for service purposes the device has to be disconnected from the power supply.

It is only allowed for the user to open the top cover of the optical head housing as described in the Paragraph 3.6.2 to exchange the detector unit. In this, the device has to be switched OFF and disconnected from the power supply.

Caution! High voltages can occur at the photomultiplier detector unit and its power supply.

1.3. Electromagnetic Compatibility

The European requirements for Electromagnetic Compliance (EMC) are specified in the EMC Directive (published in 2004/108/EC). Conformance (EMC) is achieved through compliance with the harmonized standards EN 61000. Compliance of the ***pulse*Check USB** autocorrelator system with the (EMC) requirements are certified by the CE mark.

2. Description and Specifications

2.1. Description and Intended Use

The ***pulse*Check USB** autocorrelator is a flexible device used to measure the pulse duration of a variety of laser systems emitting trains of femtosecond (fs) and picosecond (ps) pulses. It is designed for operation under laboratory conditions, that is, in closed, dry, and low-dust rooms at installation on an optical table or a similar stable vibration-free base.

The combination of the ***pulse*Check** optical head and the ***pulse*Link** USB Controller enables operation and measurement from a personal computer based on the comfortable and powerful ***pulse*Link** autocorrelator software.

The following main features are implemented with the ***pulse*Link** controller and its autocorrelator software:

- Fast USB 2.0 full speed interface to PC
- High resolution data acquisition (16 bit)
- High speed real time measurement
- Trigger function for a broad variety of trigger signals
- Wavelength calibrated tuning of the phase matching angle

The autocorrelator ***pulse*Check USB** is based on the principle of scanning autocorrelation. It consists of three components:

1. ***pulse*Check USB** optical head
2. ***pulse*Link** controller unit
3. Control Software

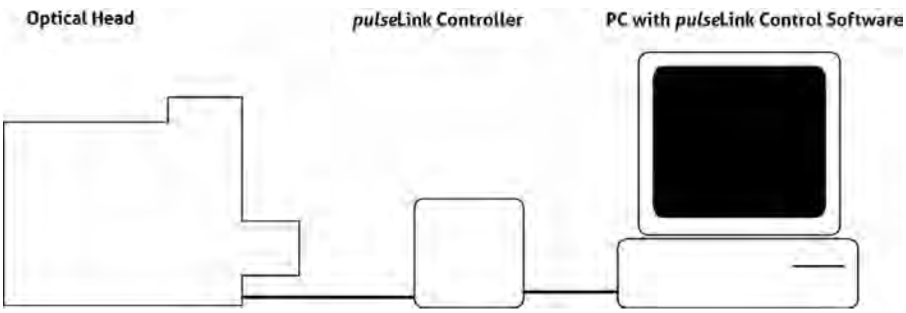


Figure 2.1.: ***pulse*Check USB** system

The Control Software runs on a computer with the Windows operating system (the computer is not included in the delivery).

The optical head comprises a Michelson interferometer, the delay unit, the interaction unit (SHG unit) and the detector module. The Controller Unit comprises the necessary drivers, amplifiers and the power supply. It acts as interlink between the optical head and a computer. Figure 2.2 shows the ***pulse*Check** optical head and the ***pulse*Link** controller unit. User interaction and control of the system is done on the computer with ***pulse*Link** Software.

Figure 2.2.: ***pulse*Check** optical head (left) and ***pulse*Link** controller (right)

2.2. Specifications

2.2.1. Optical Parameters

Version	**15**	**50**	**150**
Max. scan range	15 ps	50 ps	150 ps
Delay resolution	< 0.5 fs	1 fs	< 1 fs
Min. pulse width	50 fs	50 fs	50 fs
Max. pulse width	3.5 ps	12 ps	35 ps
Scan frequency (approx.)	10 Hz	10 Hz	7.5 Hz
Freerun trigger	5 ... 10 Hz	5 ... 10 Hz	5 ... 7,5 Hz
Linearity distortions	< 10 %		
Input polarization	E horizontal (polarization rotator optional)		
Standard wavelength ranges	VIS 1 420 ... 550 nm VIS 2 540 ... 750 nm NIR 700 ... 1100 nm IR 1000 ... 1600 nm (other ranges optional)		
Sensitivity (P_{AV} * P_{PEAK})	$< 10^{-4}$ W^2 (PMT), 1 W^2 (PD) (PMT: HighSensitivity $< 10^{-6}$ W^2 optional)		
Input beam height	75 mm (FC fiber connector optional)		

2.2.2. Electrical Parameters

Power adapter	input Output	100 … 240 VAC, 0.8 … 0.4 A, 47 … 63 Hz 12 VDC, 2.5 A
Trigger Input		TTL, 10 Hz … 50 kHz
Outputs (optional)	delay AC intensity	0 … 10 V analog 0 … 10 V analog
Communication interface		USB 2.0 full speed

2.2.3. Mechanical Parameters

Sizes (L x W x H)	optical head	see outline drawings
	***pulse*Link controller**	
	with feet	157 mm x 80 mm x 145 mm
	without feet	157 mm x 33 mm x 140 mm
Weights	optical head	5.4 kg (15 / 50 version) 7.3 kg (150 version)
	***pulse*Link controller**	0.9 kg

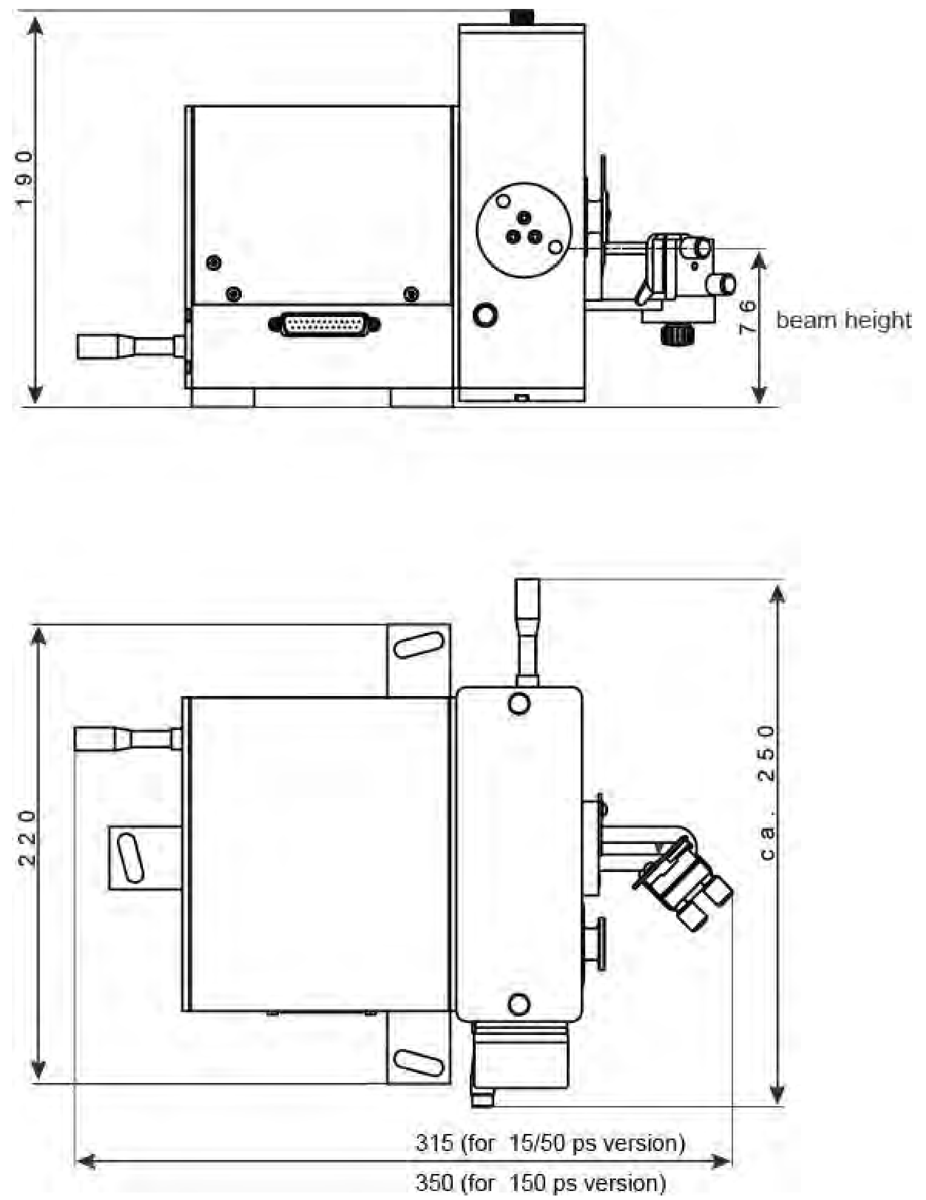


Figure 2.3.: Optical Head outline drawing (in mm)

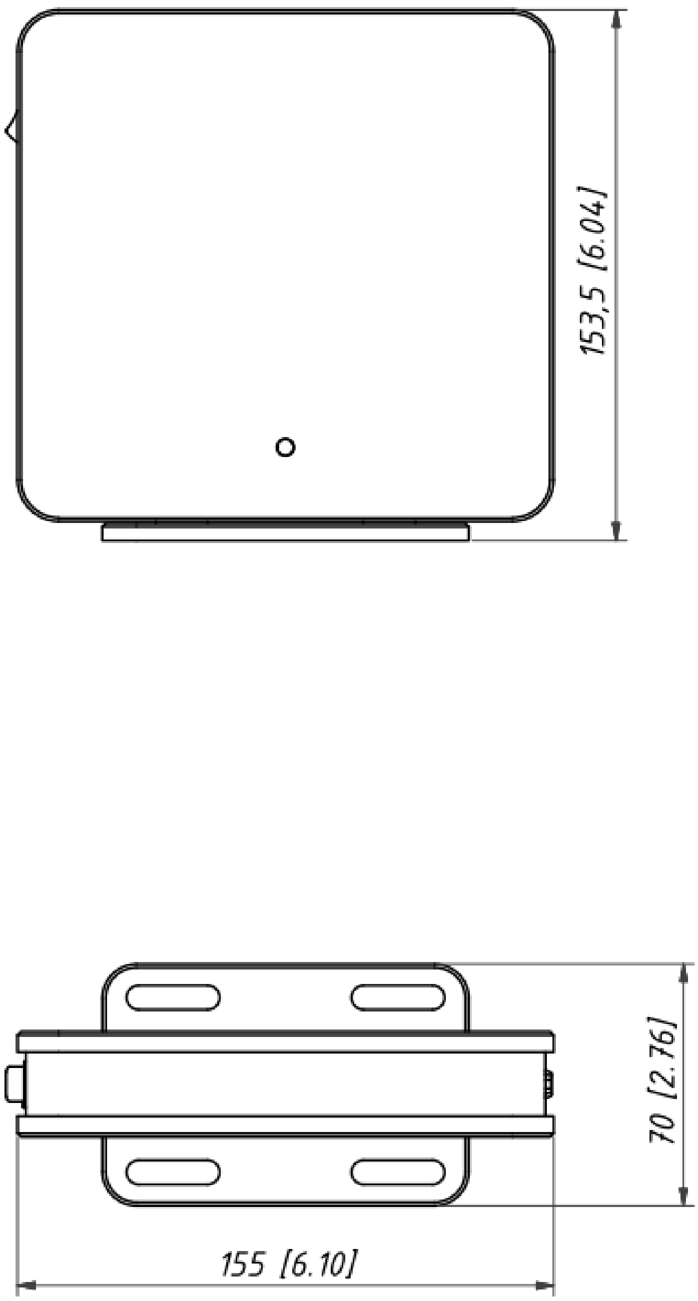


Figure 2.4.: ***pulse*Link** Controller outline drawing

2.3. System Requirements for *pulse*Link Control Software

The control computer should have at least the following configuration:

- Windows 7 /(Windows XP (SP2))[1] or higher
- 500 MB hard disc space
- Pentium IV or equivalent processor

[1]Windows is a registered trademark of Microsoft Corporation in the United States and other countries.

- 2 GB of RAM
- Screen resolution of 1024 x 768 pixels

2.4. Environmental Requirements

The *pulse*Check USB is intended for operation in indoor, dry and dust reduced rooms. It has to be firmly installed on an optical table or on a similar solid, vibration-free board.

During storage, transport, for the installation and during operation, the ambient conditions must be observed. Ensure reasonable transport conditions, free of major shocks, jolt or fall; protect against frost. Use original packing material for relocation. Before unpacking the device wait for at least six hours to allow for acclimatization of all components.

Ambient temperature during transportation:	- 30 ... + 50 °C
Relative humidity during transportation:	10 % ... 80 %, no condensation
Ambient temperature during operation:	+ 18 ... + 27 °C
Relative humidity during operation:	< 60 %, no condensation

3. Installation

3.1. Inspection of Delivery

On receipt of the ***pulse*Check USB** autocorrelator system:

1. Inspect the packing crate for signs of rough handling or damage directly at arrival. If you discover any irregularities:
   - Take photographs of the condition of the package, the labels and the inside of the box, if necessary.
   - List all defects on the shipping documents and let the delivery company countersign.
   - Inform your ***pulse*Check** vendor immediately.
2. Use safe lifting practices.
3. Before unpacking the ***pulse*Check USB** wait at least six hours to allow for acclimatization of all components.
4. Retain the packaging for future use.

3.2. Contents of Delivery

Figure 3.1.: Contents of Delivery

	Item	Amount
1	***pulse*****Check** optical head	1
2	***pulse*****Link** controller unit	1
3	USB drive with ***pulse*****Link** Control Software & explaining videos	1
4	12-VDC power adapter	1
5	Box with SHG crystal module (may contain more than one crystal module depending on purchase)	1
	Cables:	
6	25-pin Sub-D connection cable ***pulse*****Link** controller to ***pulse*****Check** optical head	1
7	USB cable type A-B	1
8	Trigger input cable	1
	Other:	
9	Test report	1
10	Certificate of Calibration	1
11	This ***pulse*****Check USB** user manual	1
12	Optics Set list (if appropriate)	1

3.3. System Controls and Indicators

Figure 3.2.: ***pulse*****Link** controller controls and connectors

1	POWER	power switch
2	AUX	auxiliary connector
3	TRIGGER IN	trigger input
4	DC IN	DC power connector (connect to 12-VDC power adapter)
5	USB	USB connector (connect to PC)
6	OPTICS	25-pin Sub-D connector (connect to optics head)

The ***pulse*****Link** has a status LED that indicates its status as listed in the table below:

LED	status pulseLink condition / status
OFF	***pulse*Link** off
RED	Hardware selftest after powering on (approx. 1...2 sec)
RED	(blinking) Optical head not connected or wrong optical head
YELLOW	***pulse*Link** is performing a selftest, connection with Control Software not (yet) established
GREEN	Optical head detected and connection with Control Software established
CYAN	Service only: Bootloader activated (approx. 1 sec)

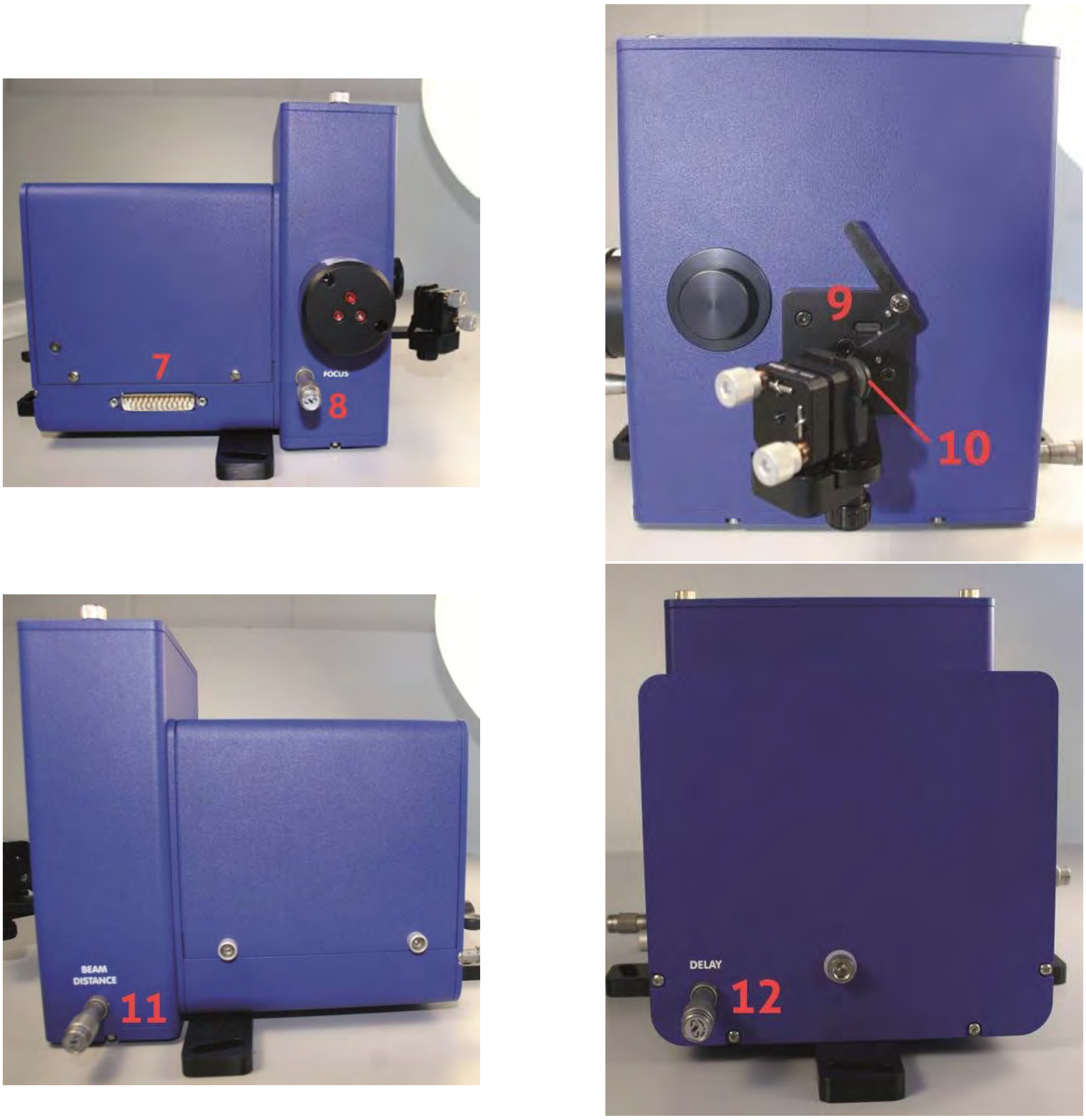


Figure 3.3.: ***pulse*Check** Optical Head

7 25-pin Sub-D connector (connect to ***pulse*Link controller**)

8 Focus alignment screw

9 Beam input with alignment aperture

10 Input mirror with beam aperture

11 Beam distance adjustment screw

12 Manual delay adjustment screw (***pulse*Check** 15 and 50 versions only)

3.4. Installation of the *pulse*Link Control Software

To control the ***pulse*Check USB** via the ***pulse*Link** controller it is necessary to use the delivered ***pulse*Link** Control Software. Before starting an autocorrelation measurement, please, install the ***pulse*Link** Control Software on your computer. For requirements to the computer refer to Section 2.3.

Proceed as follows:

1. Insert the delivered USB drive with the software and start "setup.exe".
2. Follow the instructions during installation of the software.

3.5. Cable Connection

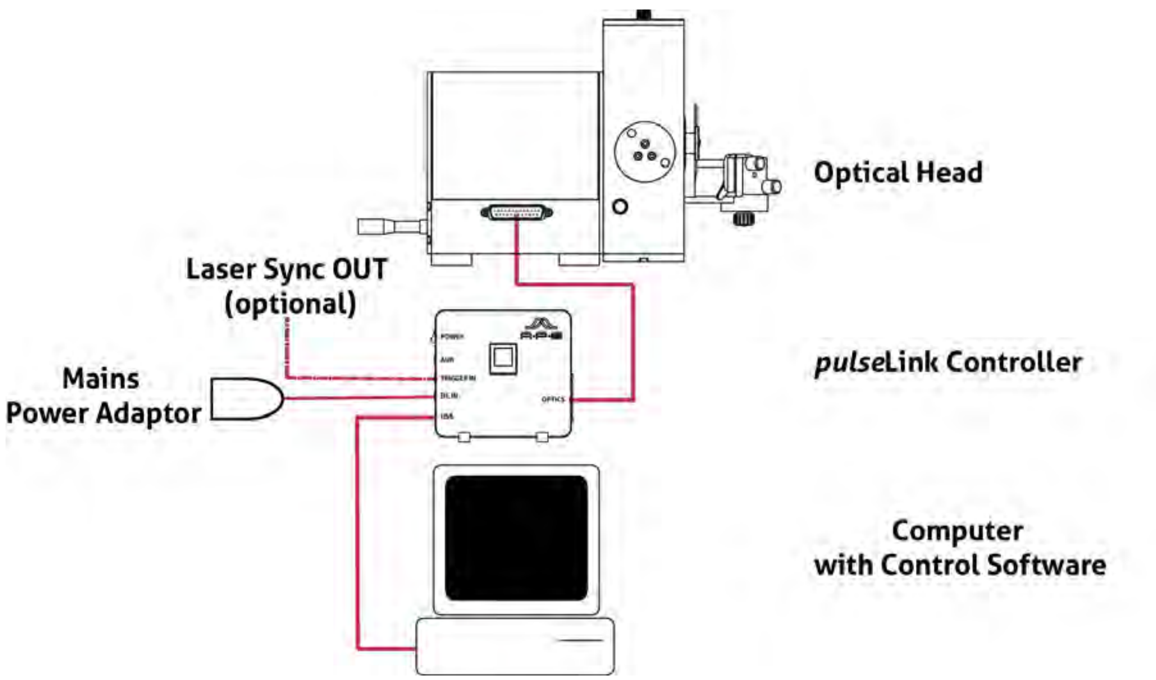


Figure 3.4.: Connection scheme

1. Connect the ***pulse*Check** optical head with the ***pulse*Link** controller ("OPTICS" port) using the delivered 25-pin Sub-D connection cable.

2. To avoid possible damage of the device:

Only connect an Optical Head to a *pulse*Link controller with the identical serial number!

3. Connect the ***pulse*Link** controller ("USB" port) with your computer using the delivered USB cable.
4. Connect the delivered AC/DC power adapter with the ***pulse*Link** controller ("DC IN" port) and the mains wall plug.
5. For measuring a low repetition rate laser system (> 10 Hz < 50 kHz) use the delivered trigger cable to connect the ***pulse*Link** controller ("TRIGGER IN" port) with the trigger source (usually the synchronization trigger output of your laser).

3.6. Installation of the Optical Head

If you have purchased more than one Optics Set make sure that the one fitting your laser wavelength range is mounted. If the suitable Optics Set is not already mounted, install the desired Optics Set as described below in the Paragraphs 3.6.1 "Mounting / Exchange of the SHG Crystal" and 3.6.2 "Exchange of the Detector Unit". The SHG crystal is packed separately and must be installed in any case before first measurement.

The optical head is secured by a transportation screw. After unpacking the ***pulse*Check** parts please remove screw (1) and replace with cover pin (2) (see Figure 3.5 and 3.6).

Attention! Before any further transportation the transportation screw has to be attached to the optical head again.

Attention! Autocorrelators with a 150 ps scan range do not have a transportation screw!

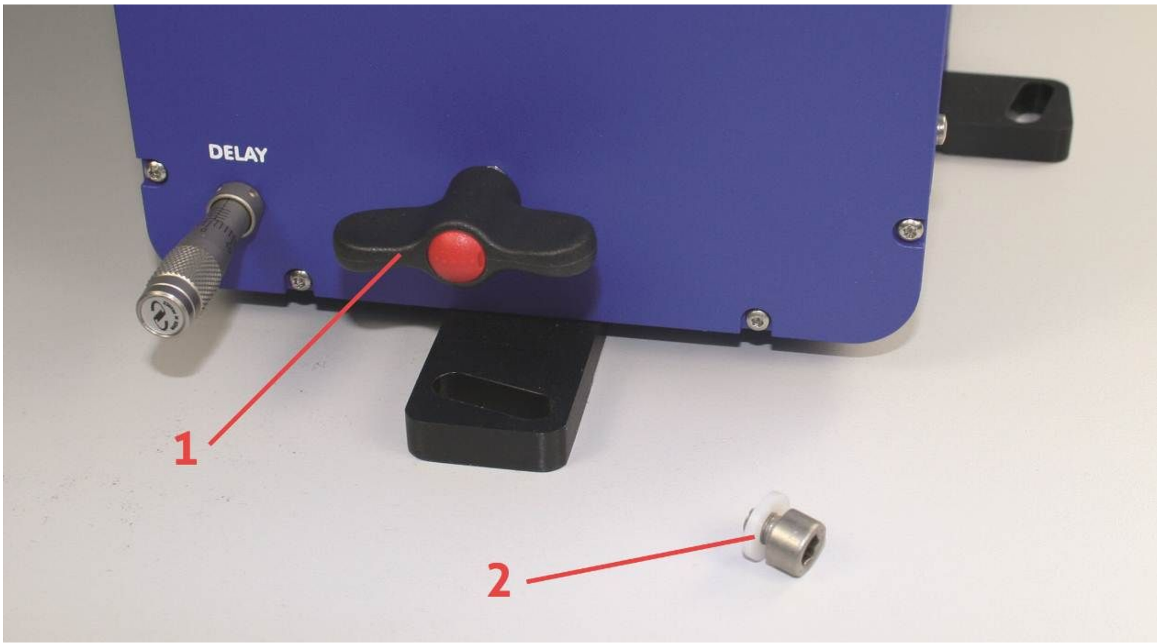


Figure 3.5.: Transportation screw (1) installed (for transportation), not included with ***pulse*Check USB** 150!

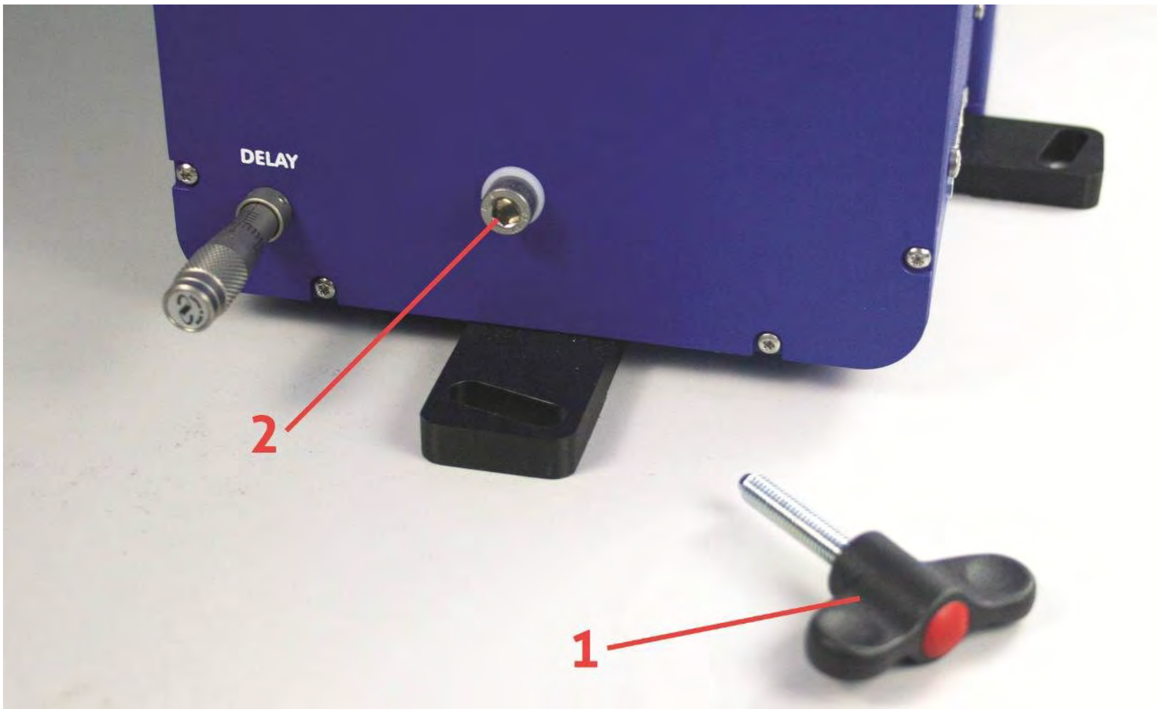


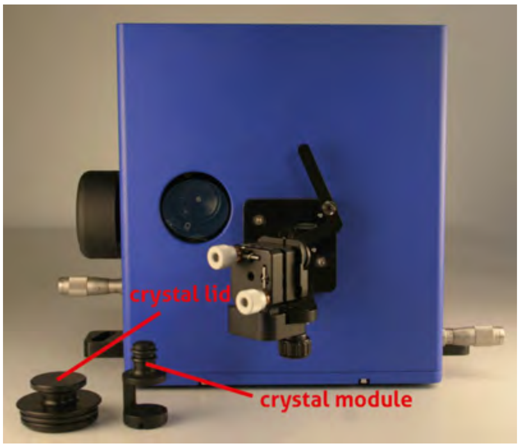
Figure 3.6.: Cover pin (2) installed (for operation), not included with ***pulse*Check USB** 150!

3.6.1. **Mounting / Exchange of the SHG Crystal**

At delivery of the ***pulse*Check** autocorrelator the crystal module (crystal and holder) is not installed in the optical head, but comes in a separate box to protect it from damage. It has to be installed before first operation. It may also be necessary to exchange the crystal module, if you need to work in a different wavelength range.

To install or exchange the crystal module proceed as follows:

1. Block or switch off the laser beam.
2. Switch off controller.
3. Open crystal lid (pull) (see Figure 3.7).
4. In order to exchange the crystal module, pull it out (as the crystal module is delivered separately, this is not necessary if the crystal module is mounted for the first time).
5. Insert new crystal module (ensure slot on crystal module fits into pin of container) (see Figure 3.8).
6. Close crystal lid.
7. Start controller and set the correct crystal in the "Enter lambda" window (see Paragraph 4.2.2). If the crystal is not yet calibrated with the unit (new or replacement crystal) execute angle calibration (see Paragraph 4.3.4).



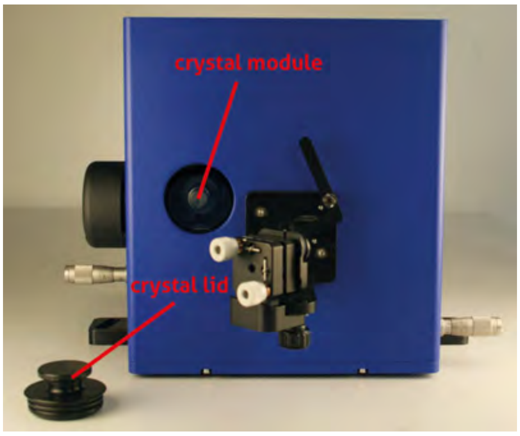


Figure 3.7.: Optical Head and crystal module (left - removed; right - installed)

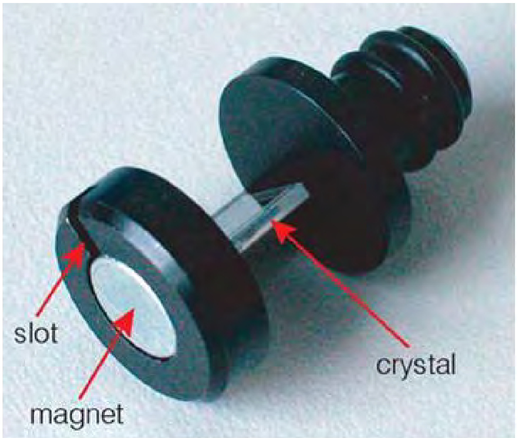


Figure 3.8.: Crystal module

3.6.2. **Exchange of the Detector Unit**

If you have more than one Optics Set, make sure that the correct detector unit is installed according to the laser to be measured. Check with the Optics Set list. Change the detector unit, if necessary, according to the instructions in this Paragraph.

CAUTION! A laser beam may emerge in an upward direction when opening the optical head top cover, if the unit is not properly blocked nor the laser switched off.

Caution! Do not expose the PMT of the detector module to intense light!

Caution! High voltages can occur at the PMT detector module and its power supply if electrical power is not properly switched OFF.

1. Switch OFF the laser or block the input laser beam.
2. Switch OFF the ***pulse*****Link** controller and disconnect it from the power supply.
3. Remove top cover of the optical head (knurled screws).

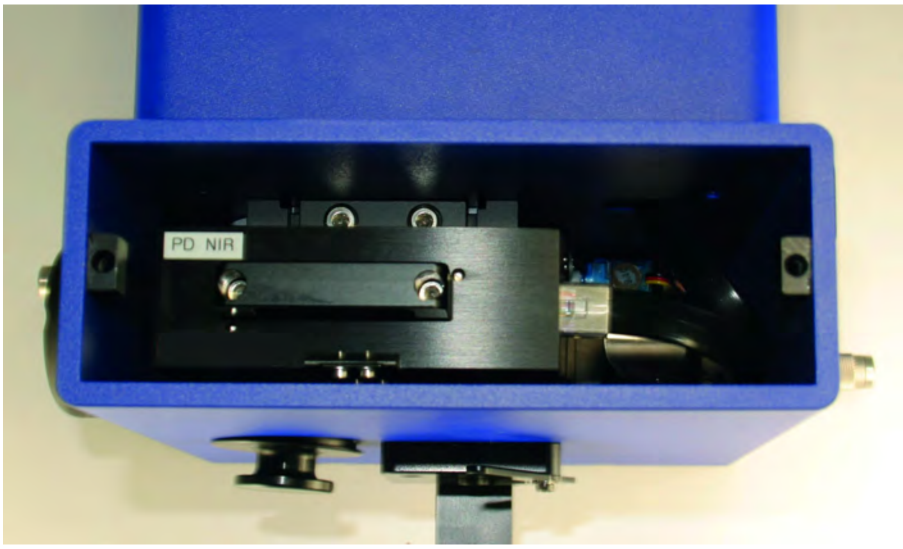


Figure 3.9.: Optical Head with removed top cover, detector module installed

4. Remove the detector module (hook off bracket and pull up detector block).
5. Unplug the electrical connector.

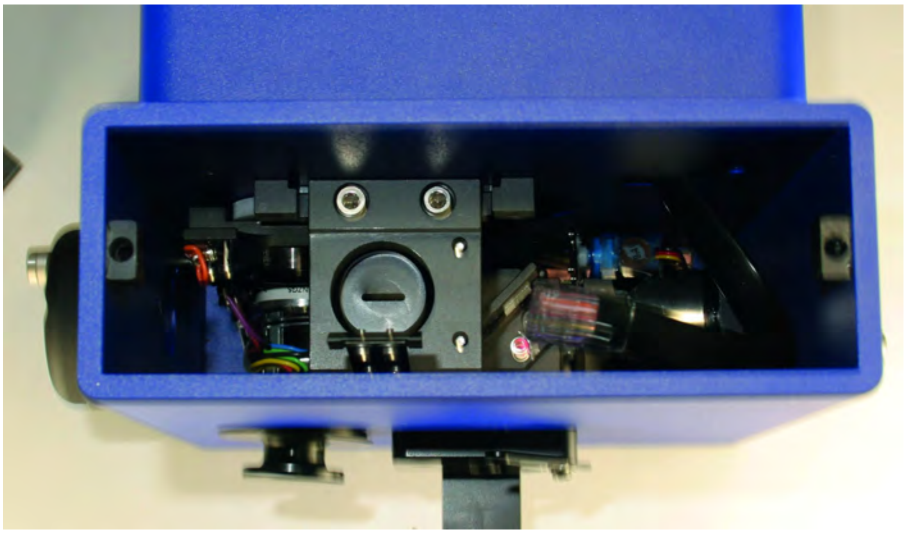


Figure 3.10.: Optical Head with open top cover, detector unit removed

Figure 3.11.: Photodiode detector module

6. If using a PMT detector, disconnect the current PMT from power supply, and exchange with the PMT suitable for the respective wavelength range.

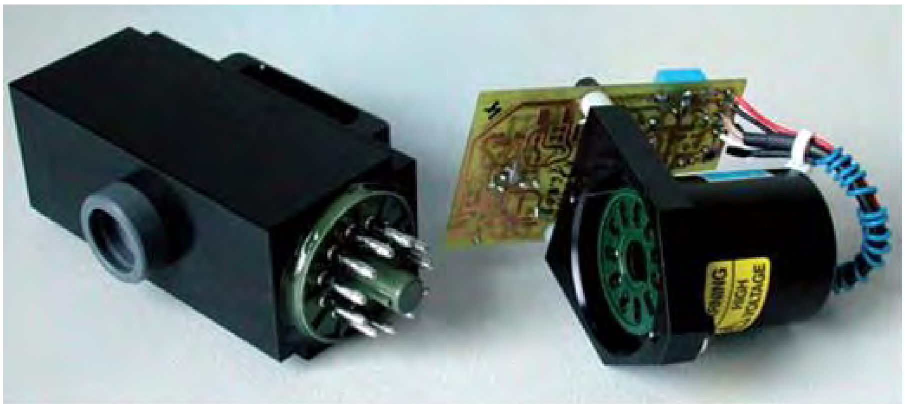


Figure 3.12.: PMT detector module consisting of PMT (with housing) and power supply

7. Plug in the connector of the new detector module and insert the module into the autocorrelator till the bracket snaps in.
8. Re-mount top cover.

3.6.3. Exchange of the Optical Filter

Depending on the optics set and laser parameters it may be necessary to change the filter on the detector (consult “Optics Sets” document for details). To do that simply unscrew the (grey) mount with the filter and replace it with the necessary filter.

4. Alignment and Measurement

After you have connected all components of the system and installed the ***pulse*Link** Control Software you are ready to start alignment and the first measurement. Proceed as follows:

1. Fasten the optical head on your optical table at a place where you can comfortably direct the laser beam to be measured onto the input mirror and handle the control elements. It should be possible to watch the display of your computer at the same time. The input mirror assembly can be mounted in two configurations allowing for different beam input directions (see Figure 4.1). To change the configuration loose the bottom thumb screw of the mirror assembly (see Figure 4.2).

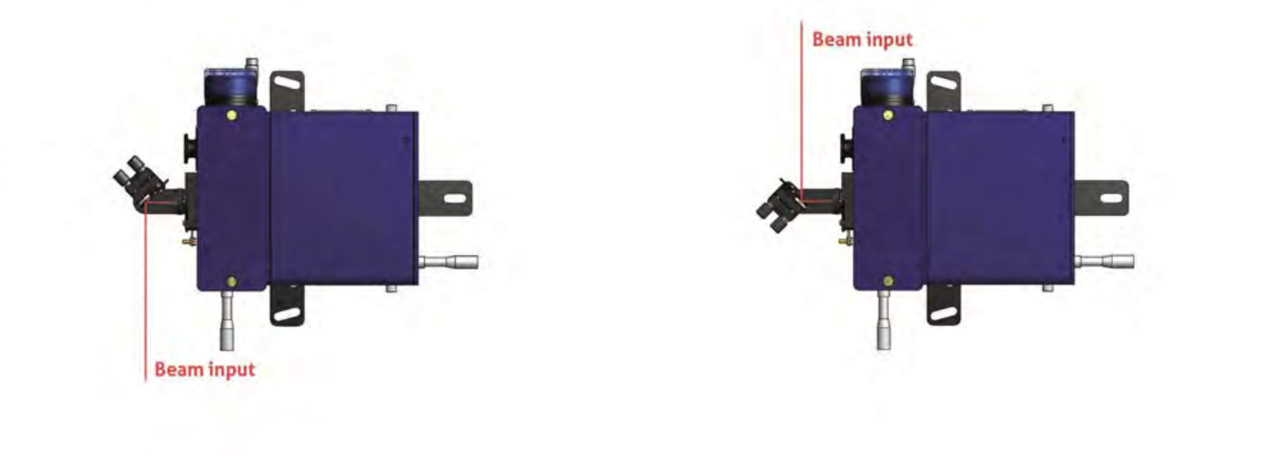


Figure 4.1.: Beam input: The input mirror assembly can be flipped to allow for beam input from either side.

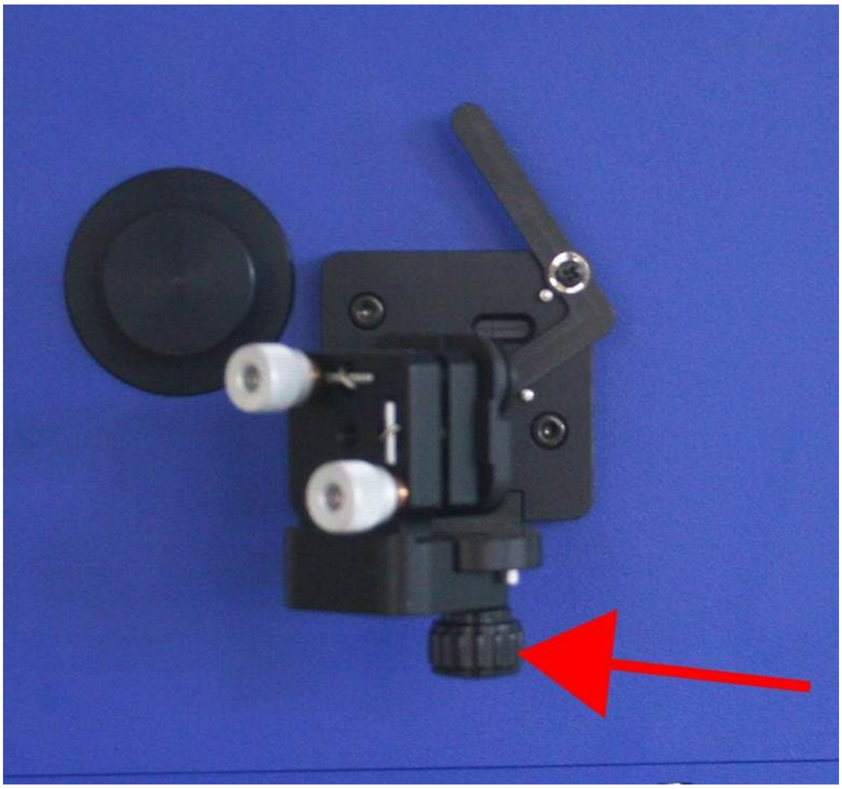


Figure 4.2.: Input mirror assembly: Loosen bottom screw to flip between configurations.

2. Switch the system ON at the POWER switch of the ***pulse*Link** controller.
3. Start the ***pulse*Link** Control Software from the start menu of the computer ("pulselink.exe"). The measurement (main) window will open. For details of the controls and functional regions of the measurement window see Paragraph 4.3.1 "Measurement Window and its Controls".

4.1. Communication Setup

By starting the A·P·E ***pulse*Link** Control Software it automatically tries to initiate communication to the ***pulse*Link** controller. If communication is properly established the info window displays the status "Connected" (see Figure 4.3).
Additionally a green LED on the ***pulse*Link** indicates an established connection.

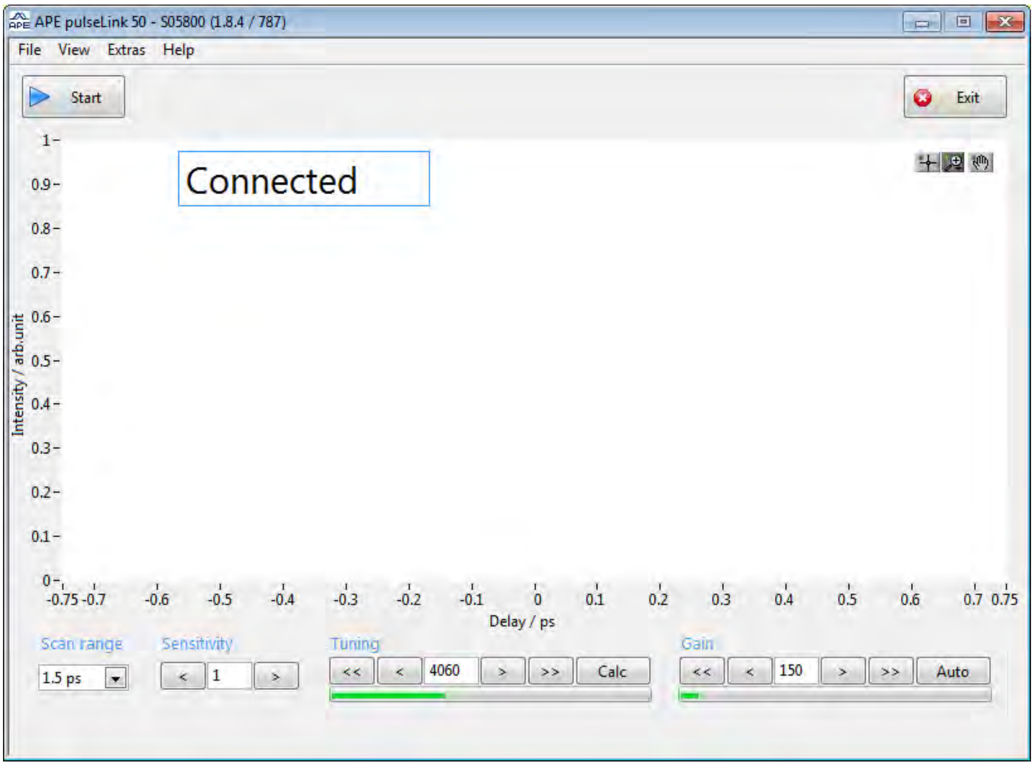


Figure 4.3.: ***pulse*Link** Control Software is correctly connected

If the ***pulse*Link** is not properly connected the info window shows the status "Not connected". In this case check the cable connections and make sure the ***pulse*Link** is switched ON. After that, initiate communication to the ***pulse*Link** controller by selecting "File/Connect..." from the menu bar (see Figure 4.4).

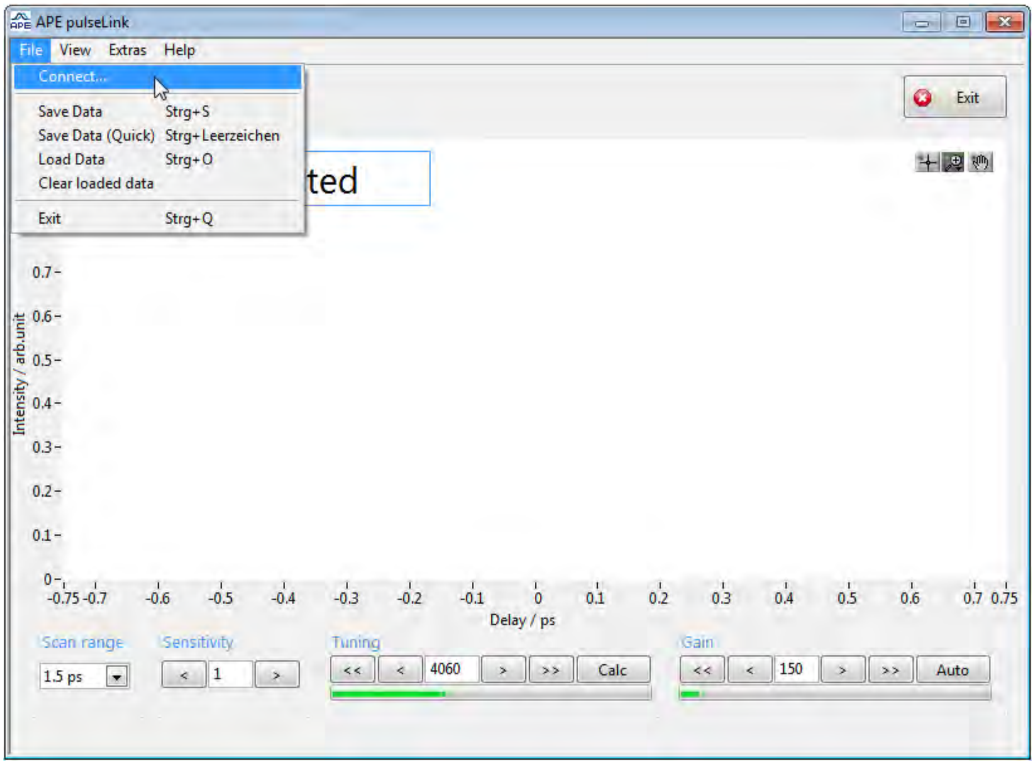


Figure 4.4.: Connect ***pulse*Link** Control Software via the menu bar

Before you proceed with the next steps, the communication must be established and the status "Connected" must be displayed in the info window as shown in Figure 4.3.

4.2. Starting a Measurement

1. With established communication (see Section 4.1), press the "Start" button to get the scanner motor running (see Figure 4.5).

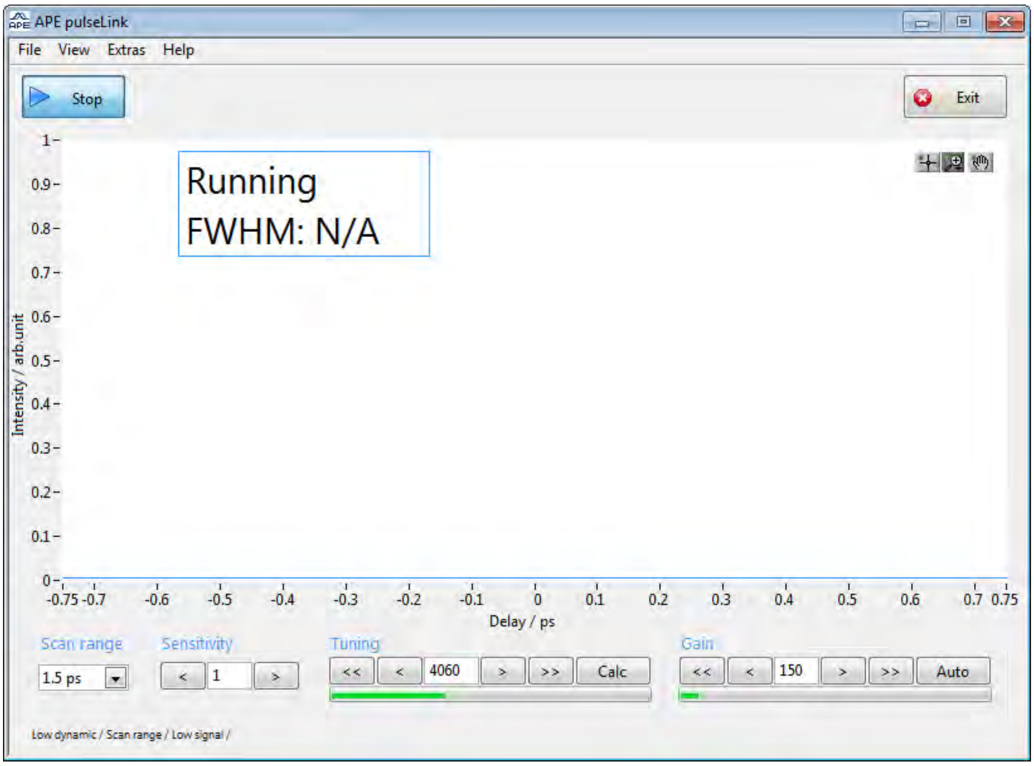


Figure 4.5.: By pressing the "Start" button the linear scanner motor starts running

2. Select the largest "Scan range" and the lowest gain, and the lowest sensitivity (***pulse*Link** Control Software: "Correlator settings").

4.2.1. Alignment of the Input Beam

3. Use appropriate optics (e.g., glass plate, beam splitter) to direct a part of the laser beam to be measured to the center of the input mirror of the optical head (depending on the beam diameter you either close or open the beam aperture; see Figure 4.6); make sure that the input polarization is **horizontal** and the divergence is small. The beam diameter should be at least 1 ... 2 mm. Although the sensitivity is much higher, for most configurations the average input power can be up to 1 W without danger of damaging the system. **However, if it is not stated explicitly for your device, the maximum power should not exceed 1 W for oscillators with a rep. rate of approx. 70 MHz or 10 μJ for amplied systems with rep. rates in the kHz range, whichever results in lower value!** Once you have found an autocorrelation signal the input power usually must be reduced to avoid overload.

Figure 4.6.: Beam aperture: closed for 3 mm beam diameter, open for 6 mm beam diameter

4. Flip alignment aperture in front of the input aperture into alignment position (see Figure 4.7).

Figure 4.7.: Alignment aperture - adjustment position

5. Align the input mirror to have the beam enter the device through the input aperture.
6. Further adjust the input mirror to adjust the back reflection spot on the cross-hairs at the alignment window. If there are two back reflection spots (non-collinear case) turn the "BEAM DISTANCE" screw to the collinear position (see test report) in order to find the signal more easily. The two back reflection spots now should be united (see Figure 4.8).

Figure 4.8.: Reflection spots on alignment window: left – non-collinear case, right - collinear case)

7. If the wavelength of the laser is above the visible spectrum (IR) it is recommended to use an IR-viewer to observe the back reflection.
8. Bring the alignment aperture back into the measurement position (see Figure 4.9).

Figure 4.9.: Alignment aperture - measurement position

9. Check if the "FOCUS" alignment knob at the optical head (see Figure 3.3, item 8) is at center position as given in the test report, and correct if necessary.
10. Check if the "DELAY" screw at the optical head (see Figure 3.3, item 12) is at the "zero" position as given in the test report (this is usually not the micrometer position "0.00"), and correct if necessary.
11. Make sure that the correct tuning angle is set (see Section 4.2.2).
12. Slowly increase "gain" until a clear noise of the autocorrelation function (ACF) graph is shown, if necessary also increase "sensitivity".

4.2.2. Tuning / Phase Matching

"Tuning" is the procedure of adjusting the angle of the SHG crystal to achieve phase matching necessary for the detector to register a signal. With standard crystals this procedure is automated relying on calibration:
Press the "calc" button to open the "Enter lambda" window (see Figure 4.10).

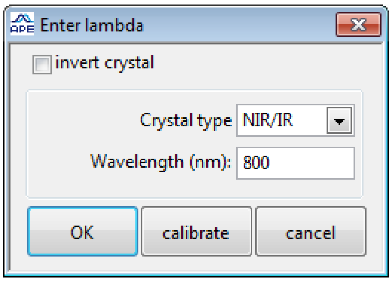


Figure 4.10.: "Enter lambda" window

Select the "Crystal type" that is installed in the ***pulse*Check** optics, type the center wavelength of the pulse that is to be measured in the "Wavelength (nm)" box and press "OK" button. The crystal is tuned automatically to the correct phase matching angle. An autocorrelation signal should appear in the measurement window.
Change the tuning manually by a few steps up or down with the arrow buttons to check if the signal can be further optimized.
Figure 4.11 shows an example autocorrelation signal under collinear alignment conditions.

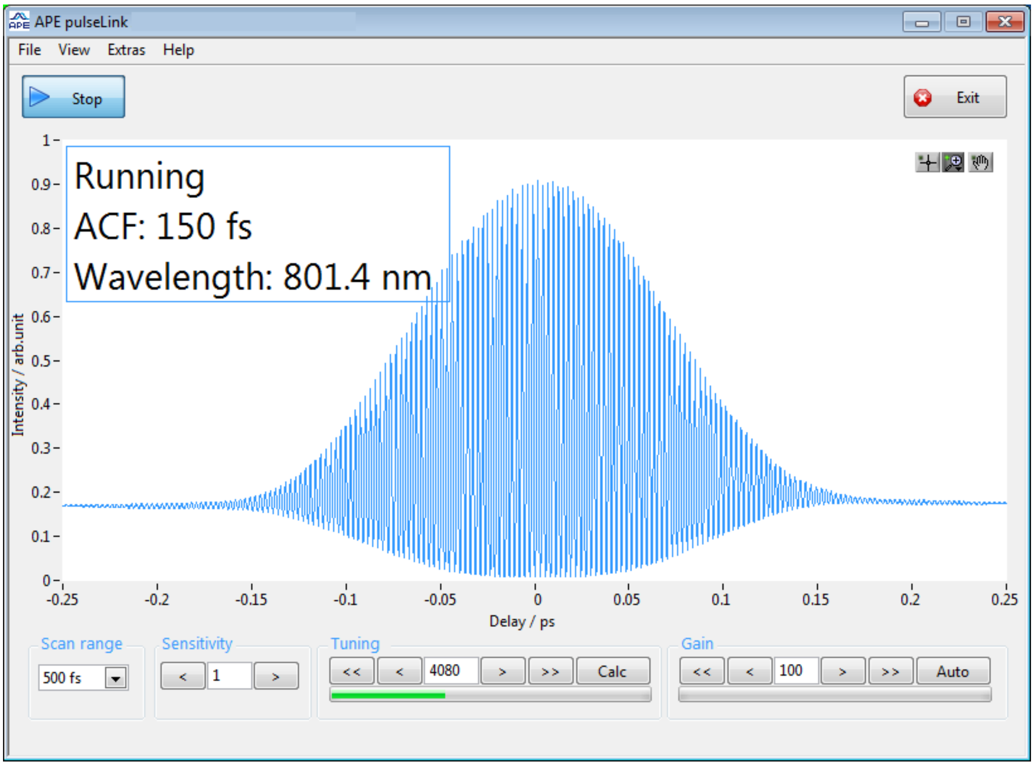
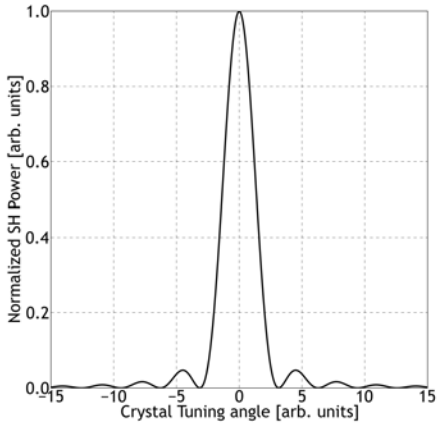


Figure 4.11.: Autocorrelation measurement with collinear alignment

In case no autocorrelation signal is detected (i.e. with a new crystal) adjust the phase matching angle manually. Use the arrow buttons in the autocorrelator settings "tuning" section of the measurement window for manual tuning and maximize an appearing autocorrelation signal with these arrow buttons. Make sure that the crystal is not tuned to first, second or higher order phase matching. To do this tune the crystal away from the maximum intensity and observe the display if a second or higher maximum appears. If none or smaller maxima appear the previous crystal tune setting with the highest intensity is the 0.th order. After reaching the maximum signal intensity you should correct for the wavelength calibration of the crystal tuning as described in Section 4.4.



4.2.3. **Change of Wavelength Range (Crystal and Detector Exchange)**

The wavelength range the autocorrelator can be used for depends on the phase matching angle of the crystal (crystal type and cut angle), and on the wavelength range of the detector. The detector has to be insensitive to the fundamental wavelength of the laser and highly sensitive to its SHG signal. Therefore the useful range of the detector is necessarily smaller than one octave and is determined by the detector itself and a blocking filter (optional). Accordingly, the detector unit including a filter as well as the crystal (which together constitute an optics set) have to be exchanged when another wavelength range is required. Refer to Paragraphs 3.6.1 and 3.6.2, respectively, for exchange of these components. A complete list of Optics Sets and their appropriate wavelength ranges is found in the "Optics Set list" that comes with the autocorrelator i.e. if the device was purchased with more than one Optics Set.

4.2.4. **Searching for Signal Using "Zero" Scan Range**

12. If you do not succeed in getting an ACF signal (i.e. in trigger mode) set "Scan range" to "Zero" and use the "tuning" arrow buttons until you observe a clear angle sensitive maximum of the noise background signal on the ACF graph.
13. Repeat input alignment.

4.2.5. **Checking Alignment with the Beam Shutters**

14. Check beam alignment using the internal beam shutters. To do so, open the "Settings" window (double click into the measurement window or select "Settings" from the "Extras" drop down menu of the menu bar) and locate the "shutter control" section on the "Main" tab. (see Figure 4.12).

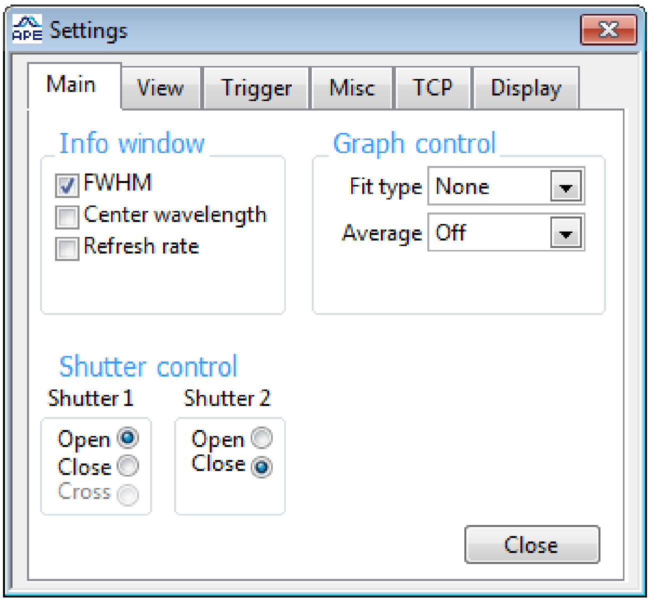


Figure 4.12.: "Main" tab of the "Settings" window with "shutter control"

15. First close either of the shutters. The background signal should go down to approximately half intensity (provided you have set the "BEAM DISTANCE" screw to the collinear position). Repeat this step with the other shutter.
16. Close both shutters simultaneously. The signal should go down to zero (see Figure 4.13).

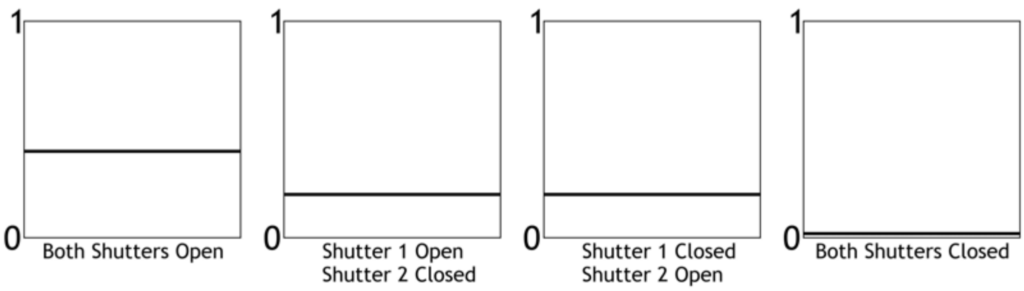


Figure 4.13.: Shutter related signal behavior in "Zero" scan mode (collinear interaction)

17. If the behavior of the signal is different, check beam alignment.
18. Select the largest "scan range" from the correlator settings section of the measurement window. You now should see an autocorrelation function (ACF).
19. Maximize the autocorrelation signal with the "sensitivity" and "gain" controls. For the latter an automated gain function can be used by pressing the "auto" button.

20. In case of overload (cut ACF peak) "GAIN" and / or input power have to be reduced.
21. When you now operate the beam shutters the signal should behave as shown in Figure 4.14.

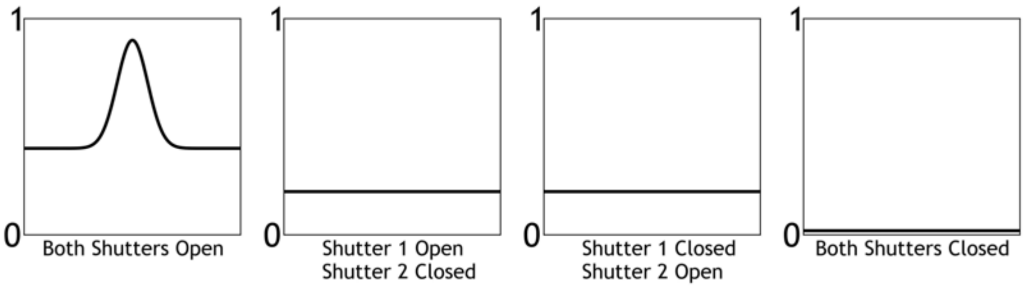
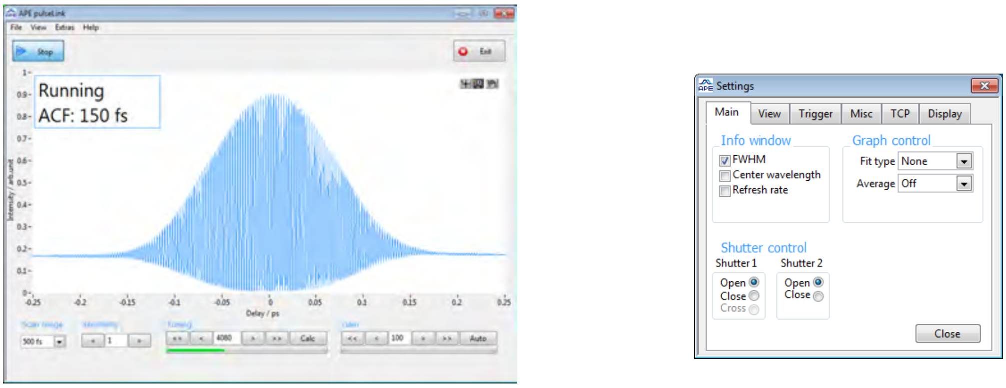
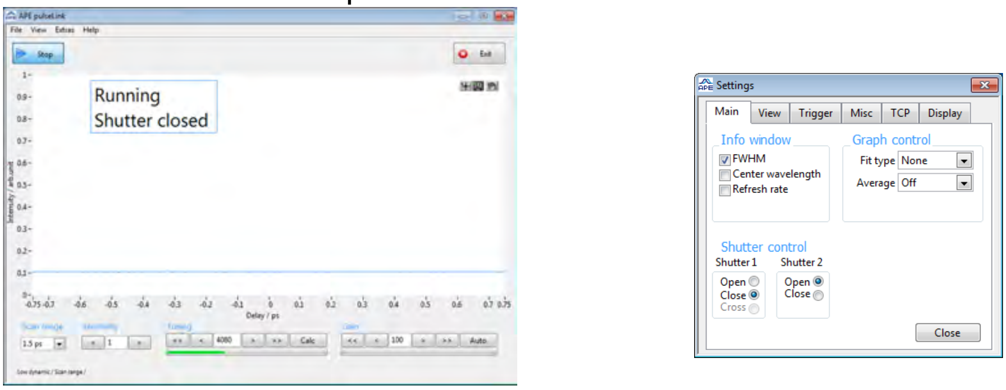


Figure 4.14.: Shutter related signal behavior in non-"Zero" scan mode (collinear interaction)



Both Shutters Open



Shutter 1 Closed

Shutter 2 Closed

Both Shutters Closed

Figure 4.15.: Example of shutter related signal behavior with ACF in non-"Zero" scan range (collinear interaction)

4.2.6. Alignment Optimization

22. Reduce "scan range" until it fits the pulses to be measured (one third to one fifth of scan range). See Section 4.8 "Error Sources of an Autocorrelation Measurement" for correct choice of scan range.
23. Maximize the autocorrelation signal by adjusting the input beam into the ***pulse*Check** optical unit. Always check alignment with the beam shutters (see Paragraph 4.2.5 "Checking Alignment with the Beam Shutters").
24. Maximize ACF signal with the focus alignment micrometer at the optical head (adaption to beam divergence).

4.2.7. Background-Free (Non-Collinear) Autocorrelation

To adjust for background-free autocorrelation proceed as follows:

- Increase the beam distance to the micrometer value stated in the test report for non-collinear interaction (i.e. >3.5); optionally check the spot distance in control window the moving spot has to be on the right hand side of the static one (see Figure 4.8 left).
- At the same time the SHG signal should be continuously optimized using focus screw, tuning and gain.
- Check beam alignment with the shutters (see Paragraph 4.2.5). In this non-collinear case, however, closing either of the shutters should cause the SHG signal to go completely down to zero level.

  If this is not the case, check and correct beam alignment:
  - Beam position at input mirror and cross-hairs on alignment window
  - Focus adjustment
  - Tuning (phase matching)

For more information on collinear and non-collinear autocorrelation please see Section 5.4

4.2.8. Autocorrelator with Fiber Input Connector (Optional)

The fiber connector and the input mirror (free space beam - refer to Paragraph 4.2.1) modules are exchangeable. Unscrew the fixing screws of the mounted input module and exchange modules. Use the pins for correct positioning of the respective module.

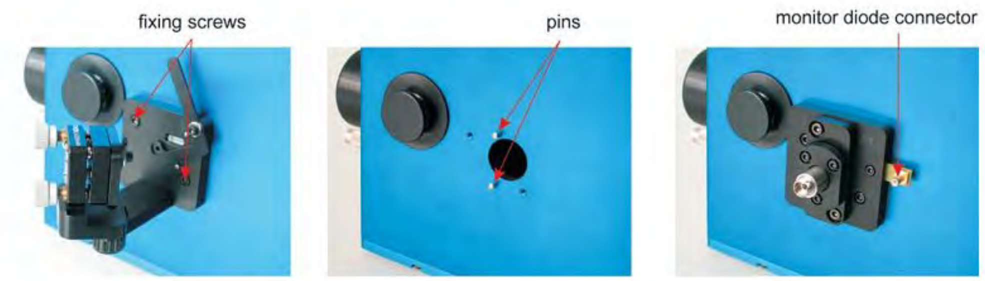


Figure 4.16.: Exchange of input mirror and fiber input

At the fiber input module the control window is replaced by a monitor diode located at the back reflection of the interferometer. This monitor diode has a polarizer on top to detect the light intensity with the "correct" polarization (E horizontal) only.

When connecting the monitor diode to an oscilloscope with the supplied cable one can display the intensity of the incoming light. To get the best autocorrelation efficiency you have to maximize the diode signal (fiber coupling, fiber bending for optimal polarization). Use 50 Ohms input impedance at the oscilloscope input.

4.2.9. Autocorrelator with FROG Upgrade (Optional)

The FROG Option enables the ***pulse*Check USB** to measure the spectral and temporal bandwidth and phase with just a few adjustments to the ***pulse*Check USB** autocorrelator. The FROG Option consists of:

- One or several FROG crystals
- A plane FROG mirror
- The separate FROG measurement and retrieval software

To measure a FROG (Frequency-resolved Optical Gating) trace a specially selected SHG crystal acts as a tunable spectral filter inside the autocorrelator. The selected wavelength can be changed via tuning the crystal angle. With each step a different fraction of the pulse spectrum is partially converted to its second harmonic and the resulting autocorrelation is recorded. To achieve a high enough spectral resolution allowing to adequately resolve a laser pulse, the so called mix acceptance bandwidth of the crystal must be appropriately narrow. This is achieved by a relatively high crystal length. At the same time the stretching of the pulse width should be as minimal as possible. This effect occurs due to chromatic dispersion in the crystal and is stronger for shorter pulses.
These two conditions set limitations to the parameters for which a given FROG crystal allows a viable measurement. If the parameters of the laser pulse are outside of these boundaries the result will be an insufficient resolution or an artificially broadened pulse width. In either case the result of the measurement is distorted. Therefore it is critical to choose the right crystal for the given laser parameters. If the FROG option came with several crystals, please refer to the “Optics Set” sheet provided with the FROG Option to decide which crystal is appropriate.
The second optical component of the FROG Option is the FROG mirror. This mirror, contrary to the autocorrelation or AC mirror, does not focus the beam into the crystal, but redirects it into the crystal. As a result the whole crystal length is equally (in terms of light intensity) used to generate the second harmonic signal which in turn is necessary to achieve a narrow mix acceptance bandwidth (s. above). Furthermore, to ensure that the beams from both interferometer arms interact evenly over the whole crystal length, a FROG measurement must be done in collinear mode (s. ***pulse*Check USB** manual).

4.2.9.1. FROG crystal and mirror installation

The ***pulse*Check USB** with FROG Option comes with a mirror mount adapter (see Figure 4.17) and two mirrors labeled “AC MIRROR” and “FROG MIRROR”. To change the mirror (i.e. from AC to FROG) unfix the screws as indicated in Figure 4.17 and remove the mirror mount. To facilitate the orientation while installing a mirror the adapter has two pins and a black triangle/arrow mark. After switching to the FROG mirror fasten it with the two fixing screws.

Figure 4.17.: Mirror adapter ring with and without FROG mirror.

Next open the crystal retainer lid as pictured in Figure 4.18. Carefully insert the appropriate FROG crystal into the retainer until the magnetic holder snaps in. Note that the crystal holder has a notch/slot that matches a pin in the crystal retainer. Both must be properly oriented and matched for the crystal holder to snap in.

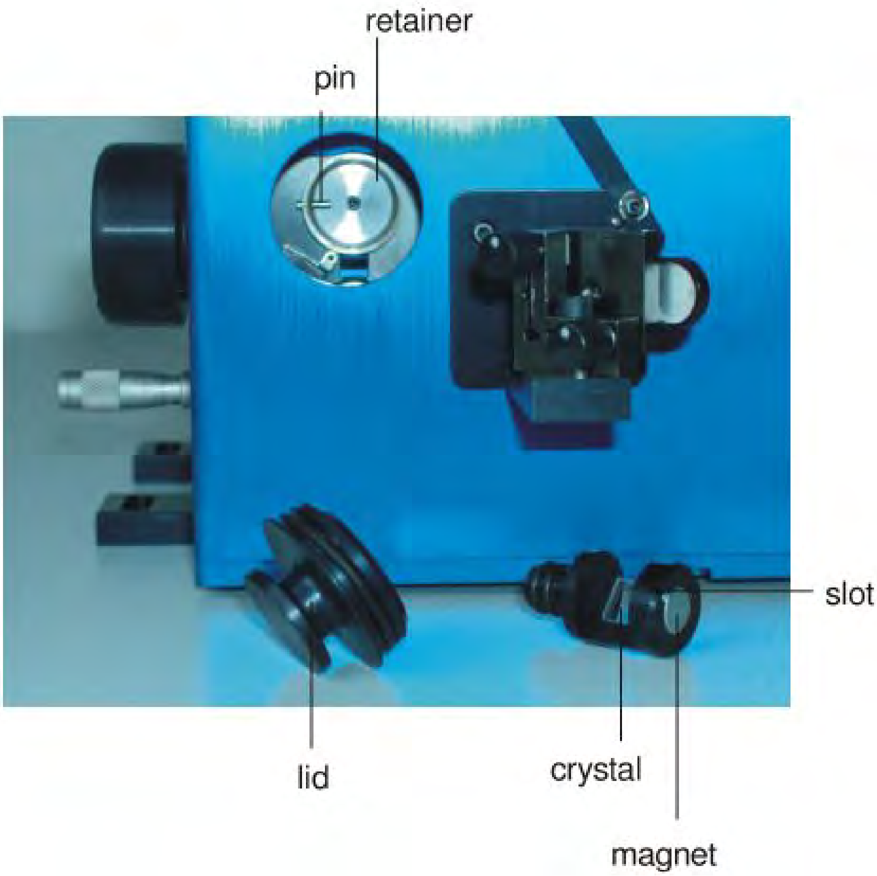


Figure 4.18.: Open crystal mount.

4.2.9.2. **Final measurement preparation**

After the installation of the FROG crystal and mirror, the laser beam has to be coupled into the autocorrelator as described in the ***pulse*Check USB** manual. Additionally the beam distance ("BEAM DISTANCE" screw) of the ***pulse*Check USB** must be set to collinear mode for correct FROG operation. Now the FROG crystal can be tuned i.e. phase matched to the laser wavelength (***pulse*Link** Software - tuning) to get an autocorrelation function (ACF).
Finally, if you observe an autocorrelation signal, optimize all parameters such as scan range, sensitivity and gain to get a well saturated ACF. The above steps should be done with the ACF filter turned off (***pulse*Link** software). To make sure the beam alignment is correct and that no portions of the beam are obstructed open and close the shutters. The ACF should behave as shown in Figure 4.19

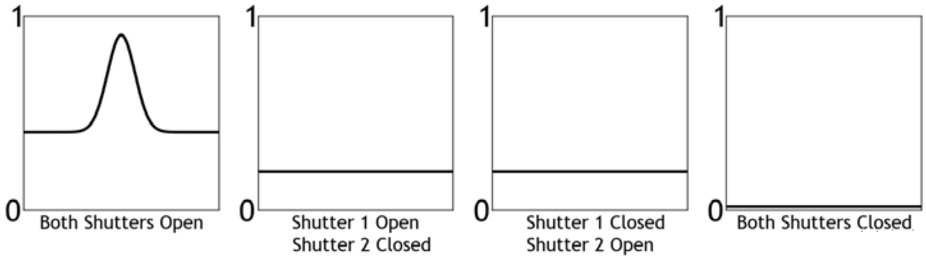


Figure 4.19.: Signal at different shutter positions.

4.3. **Measurement and Display Configuration in Detail**

The A·P·E ***pulse*Link** Control Software offers different display configurations.

4.3.1. **Measurement Window and its Controls**

Figure 4.20 shows the measurement window of the A·P·E ***pulse*Link** Control Software that is displayed when you start the software (in this particular case with no ***pulse*Check** optical head connected).

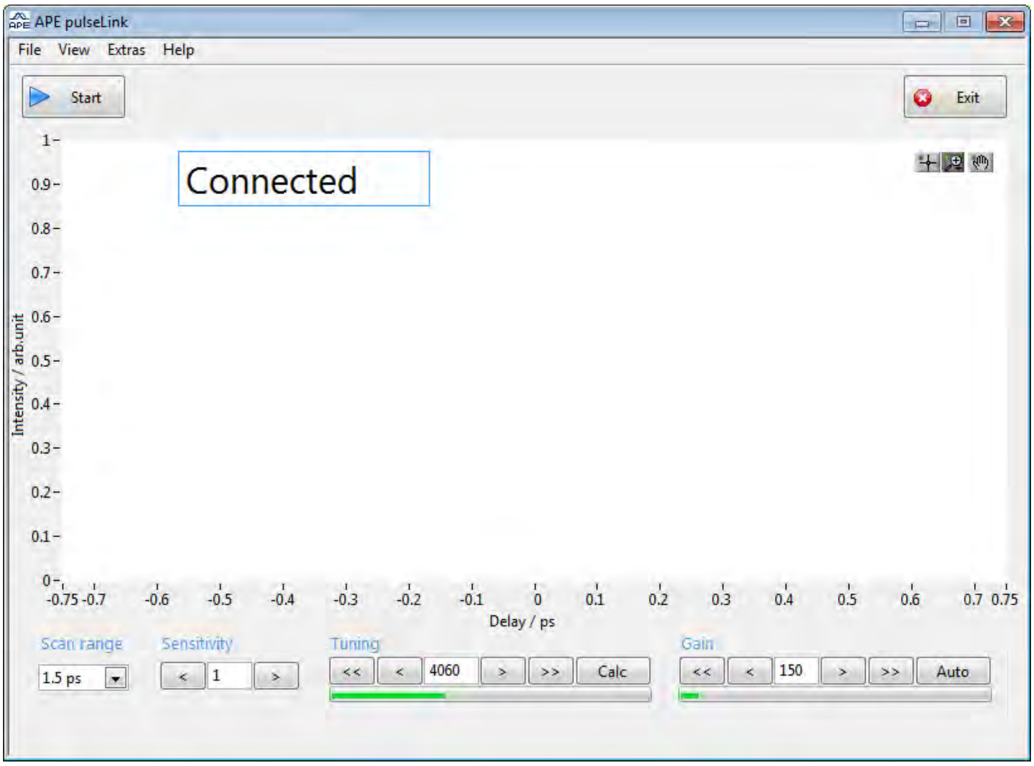


Figure 4.20.: Measurement window of the A·P·E ***pulse*Link** Control Software prior to the connection to the ***pulse*Link** controller unit

The following controls and functional regions are available in the measurement window:

Start / Stop Button: Starts or stops the scanner motor and the measurement

Info window: Configurable, movable window that displays the status of the device and information about the current measurement.(Change the content and the size by a right mouse button click into the Info window. To move the window, drag and drop it with the left mouse button.)

Correlator settings: Software controlled change of autocorrelation measurement parameters:

- **"Scan range":** Change of the time window of the autocorrelation measurement
- **"Sensitivity":** Change the detector sensitivity for different signal power levels
- **"Tuning":** Turns the angle of the non-linear crystal to increase SHG signal by phase matching
- **"Gain":** Change the detector gain to increase or decrease the measured autocorrelation amplitude

Measurement details: Error information of the measurement and hints for improvement of the signal

4.3.2. The "View" Drop Down Menu

Open the "View" drop down menu in the menu bar to select the following options:

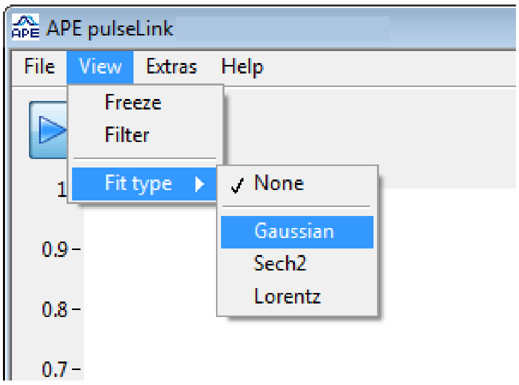


Figure 4.21.: "View" drop down menu

"**Freeze**": Stops the measurement update to show a snap-shot of an autocorrelation function

"**Filter**": Activate / de-activate a low-pass filter function to suppress fringes or noise substructure on the autocorrelation trace (see Figure 4.22).

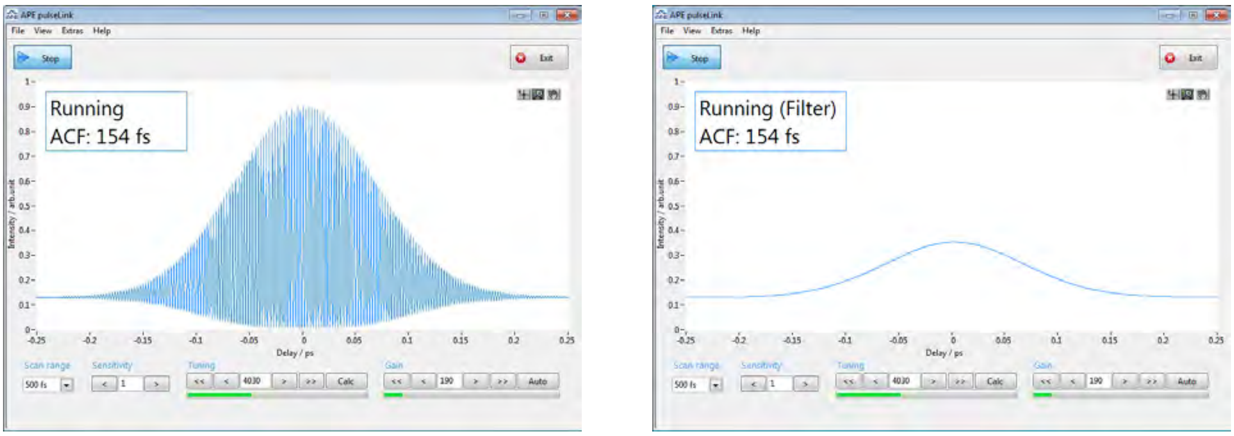


Figure 4.22.: Collinear autocorrelation measurement before (left) and after (right) suppression of the interference fringe structure by the activated filter

4.3.3. Wavelength Retrieval from Fringe-Resolved Autocorrelation Function

In case of a collinear autocorrelation measurement with deactivated filter function, the software is able to retrieve the approximate center wavelength of the laser pulse from the interference pattern modulation of the autocorrelation signal. This wavelength can be displayed in the info window (see Figure 4.23) by setting the check mark at EXTRAS > SETTINGS > MAIN > INFO WINDOW > CENTER WAVELENGTH (see Paragraph 4.3.4). For a correct evaluation of the center wavelength the fringe structure of the collinear autocorrelation measurement has to be correctly resolved over the full range of the autocorrelation function. Therefore, it is necessary to choose a high data resolution in combination with a narrow scan range that still allows for a complete autocorrelation measurement. Figure 4.23 displays a fringe-resolved, interferometric autocorrelation measurement. Due to the large scan range aliasing effects can lead to additional modulation artifacts of the envelope of the autocorrelation function. However, this does not affect the wavelength evaluation. In case of a narrow scan range an autocorrelation function with high temporal resolution can be measured without data aliasing effects. The effect of aliasing and possible data distortion is also dependent on the measured wavelength. Combinations of certain wavelengths and scan ranges may lead to a more or less distorted measurement. For an overview distortion-free combinations of scan ranges and wavelengths please refer to Figure 5.1.

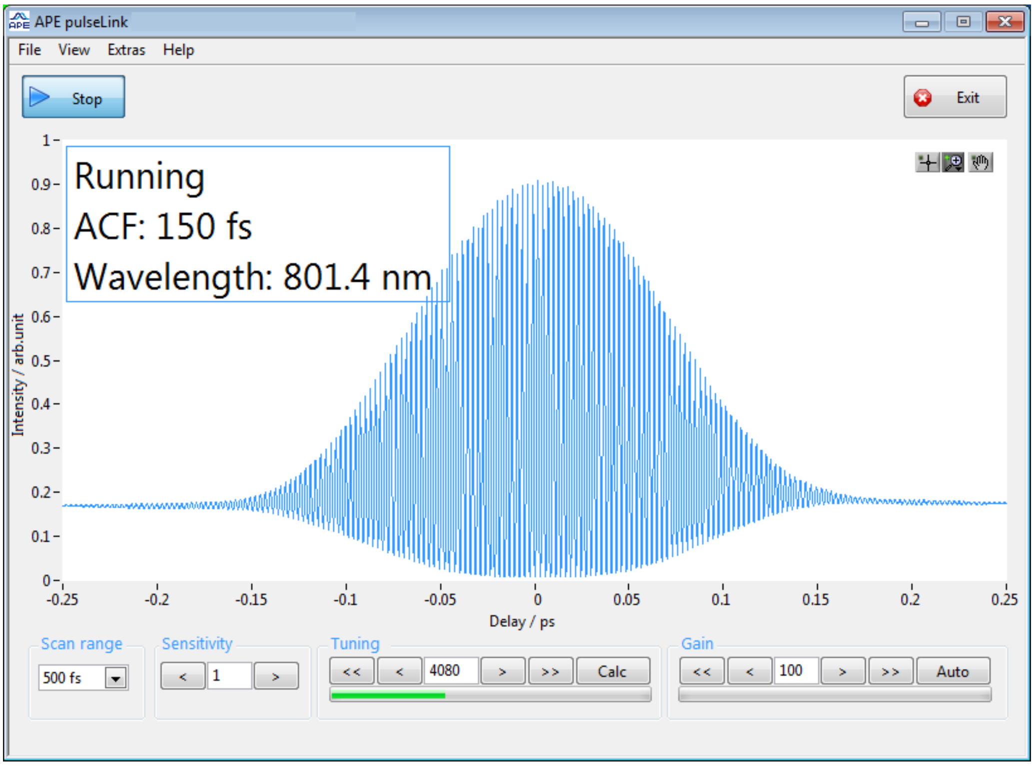
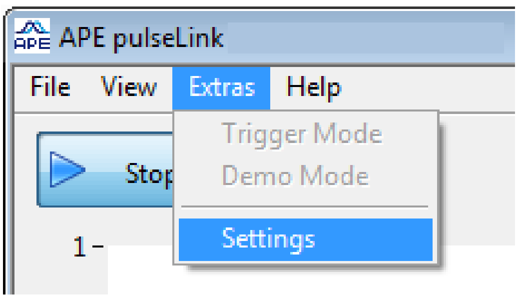


Figure 4.23.: Collinear autocorrelation measurement with center wavelength information retrieved from the fringe pattern

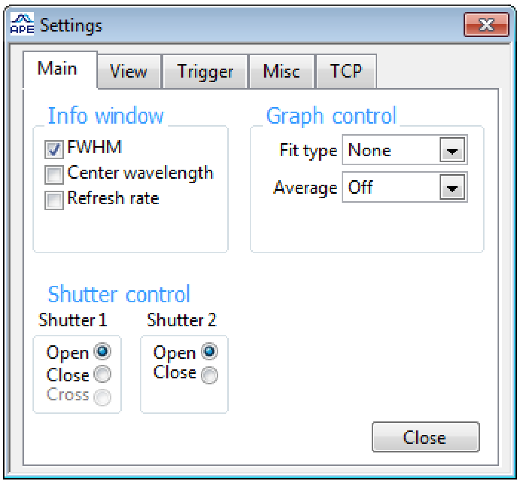
4.3.4. **Setting Window**

Most of the software and autocorrelator options can be chosen in the "Settings" menu. To activate the "Settings" menu, double click into the measurement window or select EXTRAS > SETTINGS from the menu bar.



"Main" Tab

The "Main" tab of the "Settings" menu is split in three subsections:



Info window The contents of the Info window can be configured here.

FWHM: Set a check mark to display the Full Width at Half Maximum of the function that is selected as "Fit Type" in the "graph control" subsection.

Center Wavelength: Set a check mark to display the center wavelength of the laser pulse. In case the modulation structure of the interferometric autocorrelation function is not sufficiently resolved the FWHM value will stay empty. See Paragraph 4.3.3 for details.

Refresh rate: Set a check mark to display the update rate of the measurement in Hz.

Graph control The graph displayed in the measurement window can be configured by the user.

Resolution: The number of data points in averaged or triggered mode can be reduced to save acquisition time

Fit type: The user can choose between displaying the autocorrelation measurement data (ACF) only, or additional curve fits of the measurement (e.g., Gaussian, Sech^2, Lorentzian)

Average: The number of autocorrelation scans for measurement averaging can be changed.

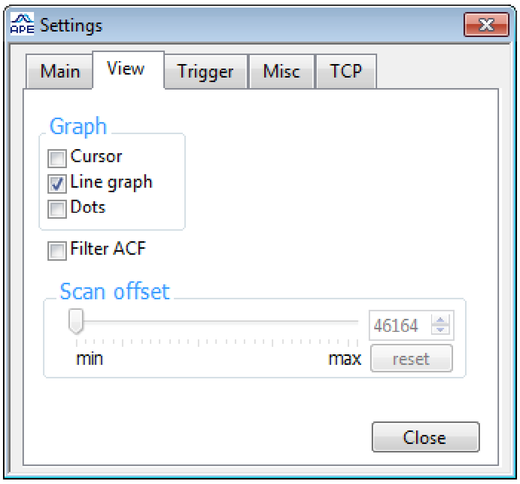
Shutter control The state/position of the two internal beam shutters in the ***pulse*Check** optical head can be switched from here. To check for the detection of a proper autocorrelation signal it is sometimes necessary to block the two interferometer arms in the ***pulse*Check** optics independently:

- to check if the autocorrelation signal exists only if both interferometer beams are unblocked, and vanishes if one of the beams is blocked
- to check if the contribution from both beams is approximately equal (i.e. approximately equal SHG background level from each interferometer beam in case of a collinear beam alignment).

Also refer to Paragraph 4.2.5 for the use of the beam shutters.

"View" Tab

Additional graphical options affecting the display of the measurement curve can be selected in the "View" tab:



Cursor: Set a check mark to show pairs of movable horizontal and vertical cursors. At half the distance between the two horizontal cursors an additional red horizontal line is displayed. The temporal separation between the two vertical cursors is displayed as a "Delta cursor" value in the info window.

Line graph: Set a check mark to connect the measurement points of the graph with lines.

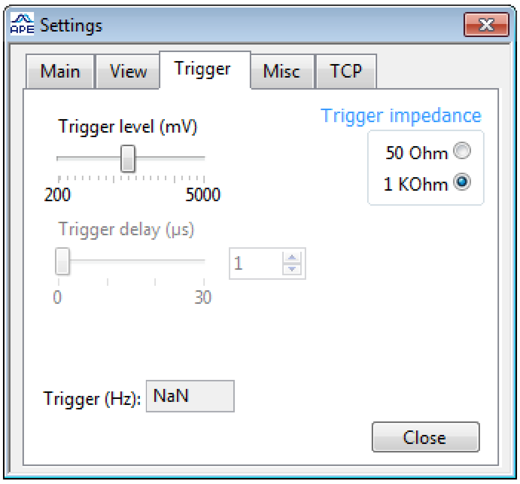
Dots: Set a check mark to highlight the measurement points of the graph as dots.

Filter ACF: Set a check mark to activate a filter function to suppress fringe or noise substructure on the autocorrelation function (refer to the "Filter" option in the "View" drop down menu of the menu bar).

Scan offset: This setting is active in combination with autocorrelators that have a 150 ps scan range. Instead of a delay screw the digital scan offset can be changed here to center the autocorrelation on the display if necessary.

"Trigger" Tab

In case the repetition rate of the laser under test is below 50 kHz the ***pulse*Link** has to be triggered with a synchronization signal with the same timing as the laser repetition rate in order to reconstruct a proper autocorrelation trace of the pulse train. The "Trigger" tab allows for setting electronic parameters to assure a proper application of the incoming trigger signal.



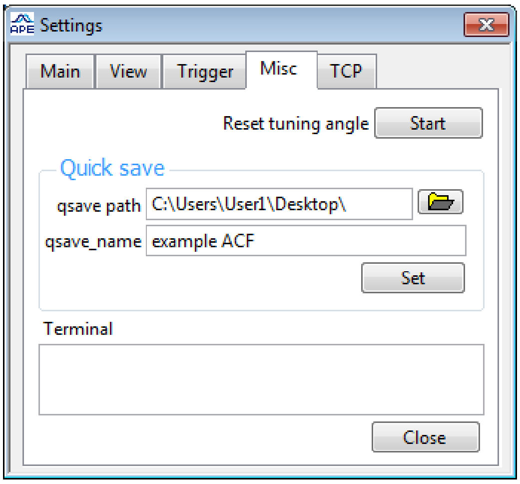
Trigger level (mV): The voltage level for the detection of an incoming trigger signal can be set. Change this value if a trigger signal is not recognized by the ***pulse*Link** . If possible the trigger level can be checked with an oscilloscope.

Trigger delay (μs): A temporal delay between the trigger pulse and the intensity measurement of the autocorrelator's detector can be set for proper synchronization. Changing this value may impare the strength of the signal dramatically if the trigger and pulse are not synchronized properly.

Trigger impedance (Ω): The appropriate input impedance for the trigger signal has to be set.

Frequency display: Display a frequency when a trigger input signal is recognized as valid. Use this to check for the expected trigger frequency. Adjust trigger level if necessary.

"Misc" Tab

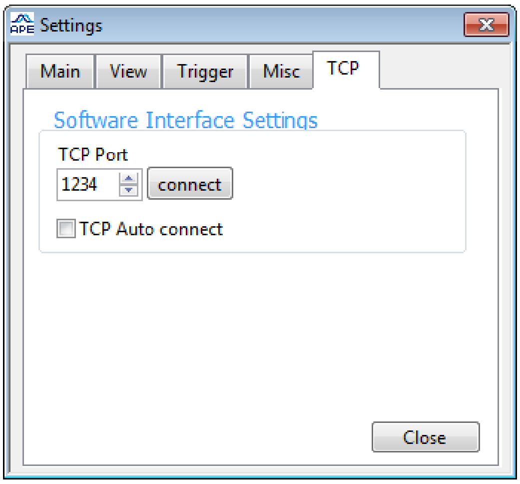


The "Reset tuning angle" option is only needed for a first setup of the ***pulse*Link** , after a system failure and if automatic tuning becomes imprecise.

Reset tuning angle: This procedure calibrates the crystal tuning motor position. During the calibration procedure the motor turns from its minimum position to its maximum position to recalibrate the position read out. Such a calibration becomes necessary if the memory of the motor position is lost, e.g., due to computer crash or at first installation of the system. It is also advisable to do this calibration procedure from time to time to ensure a proper wavelength calibrated crystal tuning. Press the "Start" button to start crystal calibration.

"TCP" Tab

For automatic or remote measurements via the A·P·E Software Interface the TCP/IP port has to be set in the TCP/IP tab:

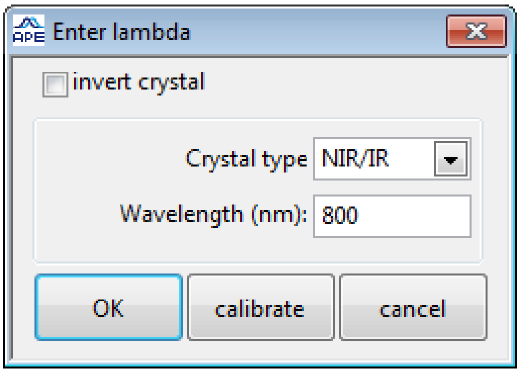


After setting a port number press “connect” for the ***pulse*Link** software to be ready to receive remote commands.
Important note: TCP/IP communication with the pulseLink is only possible via the software. The software must run on the local PC during remote communication. To avoid conflicts with standard TCP/IP ports (e.g. port 80 for HTTP) it is recommended to use port numbers between 50000 and 64000.

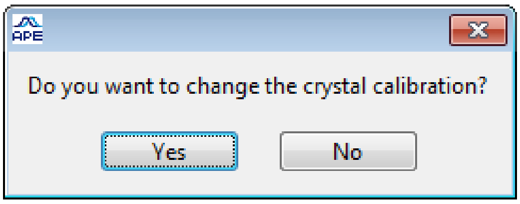
4.4. Wavelength Calibration

The ***pulse*Check USB** comes factory calibrated with respect to the phase matching angle of the non-linear crystal. This allows for automatic tuning according to the laser wavelength. However, in some cases a wavelength calibration procedure has to be done manually (i.e. with new non-linear crystals). Proceed as follows:

1. Use the arrow buttons in the "tuning" section of the measurement window to initially find an autocorrelation signal and to maximize it.
2. Press the tuning "Calc" button to open the "Enter lambda" window:



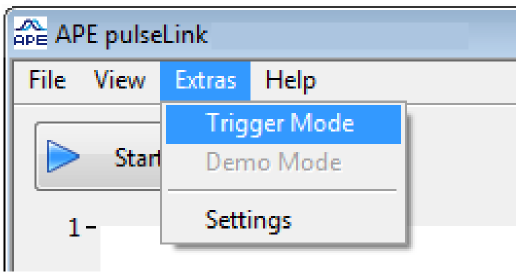
3. Choose the "Crystal type" currently installed in the ***pulse*****Check** optical head (**Please note** no calibration is available for MIR or cross correlation crystals). For the correct crystal type, please refer to the label on the crystal module.
4. Type the center wavelength of the laser pulse in the "Wavelength (nm)" box.
5. Press the "calibrate" button. A new window opens to confirm the action:



6. Choose "Yes" to save the new wavelength calibration of the phase matching tuning.
7. Try to get an autocorrelation signal with another laser wavelength when typing this wavelength into the "Wavelength (nm)" box and this time pressing the "OK" button. If this fails, check the "invert crystal" box and repeat the procedure starting at 4.

4.5. Triggered Measurement

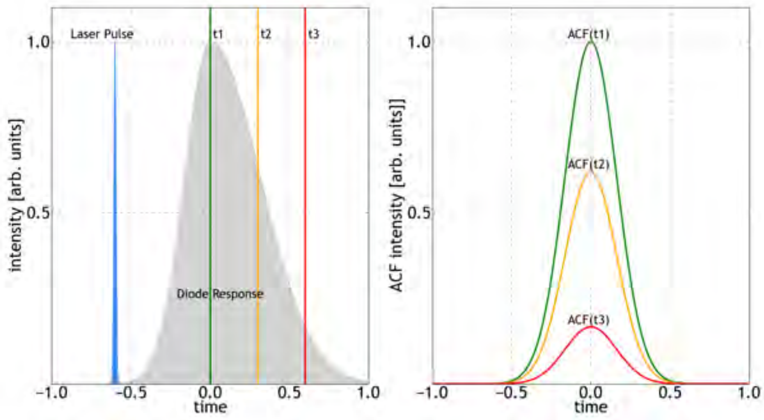
Apply a trigger signal to the ***pulse*****Link** in case the repetition rate of the laser is between 10 Hz and 50 kHz . Use the delivered trigger cable to connect the ***pulse*****Link** electronics ("TRIGGER IN" port) with the trigger source. The ***pulse*****Link** software detects a trigger signal automatically and prompts the user to switch to trigger mode. If no trigger is detected try to change the trigger level to a lower value (see Section 4.3.4). For manually switching to trigger mode select EXTRAS > TRIGGER MODE from menu bar:



Open the "Trigger" tab in the settings menu and set the "Trigger level", the "Trigger delay", and the "Trigger impedance" to the appropriate values (refer to Paragraph 4.3.4). Use an oscilloscope to specify your trigger signal, if necessary.

In trigger mode each trigger pulse initiates an SHG intensity measurement for the respective delay position. With increasing number of trigger pulses more and more data points are measured and form an autocorrelation trace.

In trigger mode the resolution can be changed (EXTRAS > SETTINGS > TRIGGER > RESOLUTION). A lower resolution gives a faster reconstruction of the autocorrelation trace, but is less accurate.



4.6. Changing the Trigger Frequency during Operation

If the trigger frequency of the laser (or other source) changes while in trigger mode a warning pops up to alert the user. The trigger mode automatically turns of. To measure with the changed trigger frequency one must switch trigger mode back on manually.

4.7. FROG Measurement (Optional Upgrade)

In order to take a FROG measurement two programs are necessary: The ***pulse*****Link** control software and the FROG measurement and retrieval software. The ***pulse*****Link** control software operates the autocorrelator whereas the FROG measurement and retrieval software records a FROG trace and calculates the resulting spectral and temporal phase.

Important Note: Both programs must be installed prior to operating FROG. It is important that both programs are installed with the same Windows User and have read/write permission.

The ***pulse*****Link** control software can operate separately on its own (see ***pulse*****Check USB** manual). In contrast, the FROG measurement and retrieval software depends on the ***pulse*****Link** control software in order to tune the crystal and to record the FROG trace. For this purpose the FROG software communicates locally with the ***pulse*****Link** software via the (A·P·E) Software Interface using the TCP/IP protocol.
After installation start the ***pulse*****Link** software as well as the FROG software. In the ***pulse*****Link** software select: Extras → TCP then select “EnableTCP”. If the port number is different from 51019 change it to 51019 to enable the FROG software to connect (see Figure 4.24). Optionally check the option “Autoconnect” to keep this setting at the next program start.

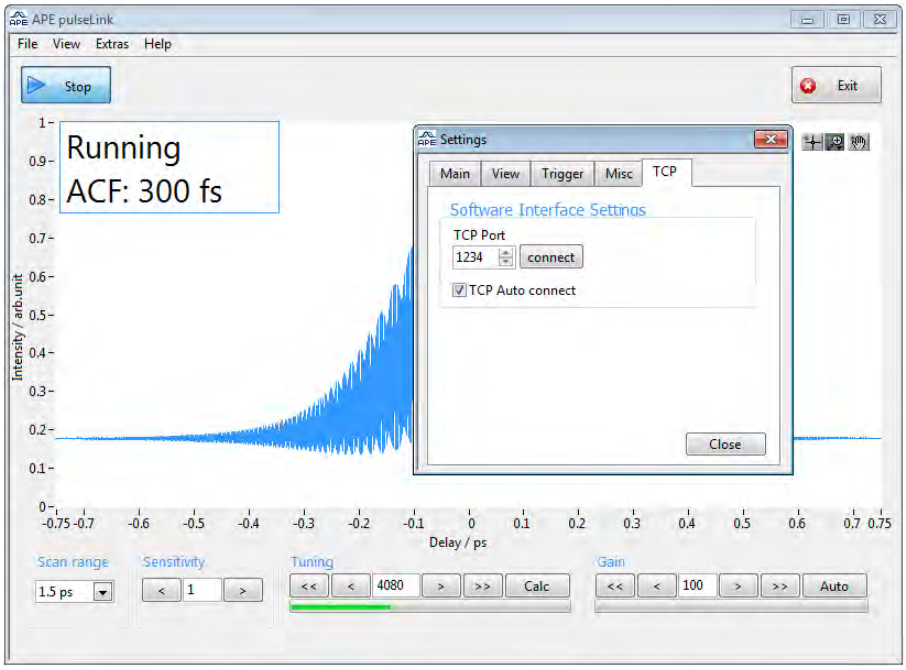


Figure 4.24.: Software interface Settings tab.

After the TCP port is enabled the FROG software connects automatically to the ***pulse*Link** software as pictured in Figure 4.25. The FROG window title shows the following information: FROG Connected to: pulseLink S0xxx (SW Version / FW Version) @ localhost.

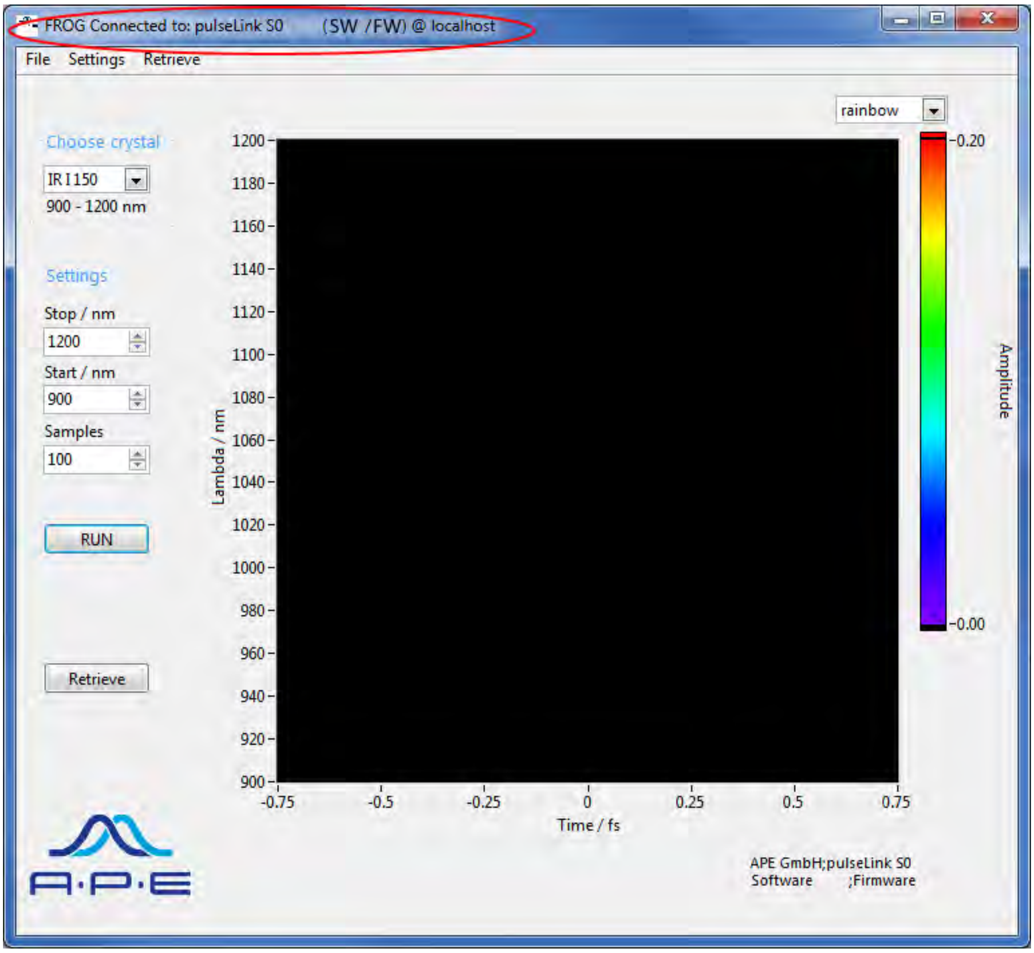


Figure 4.25.: FROG Software connected to ***pulse*Link** software.

Note: The TCP/IP communication is strictly done locally on the operating PC (IP 127.0.0.1 i.e. localhost). Nevertheless, it might be necessary to adjust the local firewall or other network restrictions to allow the connection between the two programs.

Note: Though the "Settings" menu of the FROG Software contains "TCP/IP Settings" this options is not available yet.

Once the connection between the two programs is established the system is ready to take a FROG measurement.

4.7.1. Recording a FROG trace

The FROG Option comes with one or several FROG crystals (depending on your order). For each crystal the software has calibration data that enables it to tune the crystal to a given wavelength to achieve phase-matching. The crystal type has to be selected (see Figure 4.25 "Choose crystal") according to the crystal that was installed for the current measurement. After selecting the crystal the "Start" and "Stop" settings are fixed automatically based on the wavelength range that can be measured with this crystal type. Additionally the wavelength range of the selected crystal is displayed below the drop down menu.

These settings, i.e. “Start”, “Stop” and “Samples” must be set individually to run the measurement.

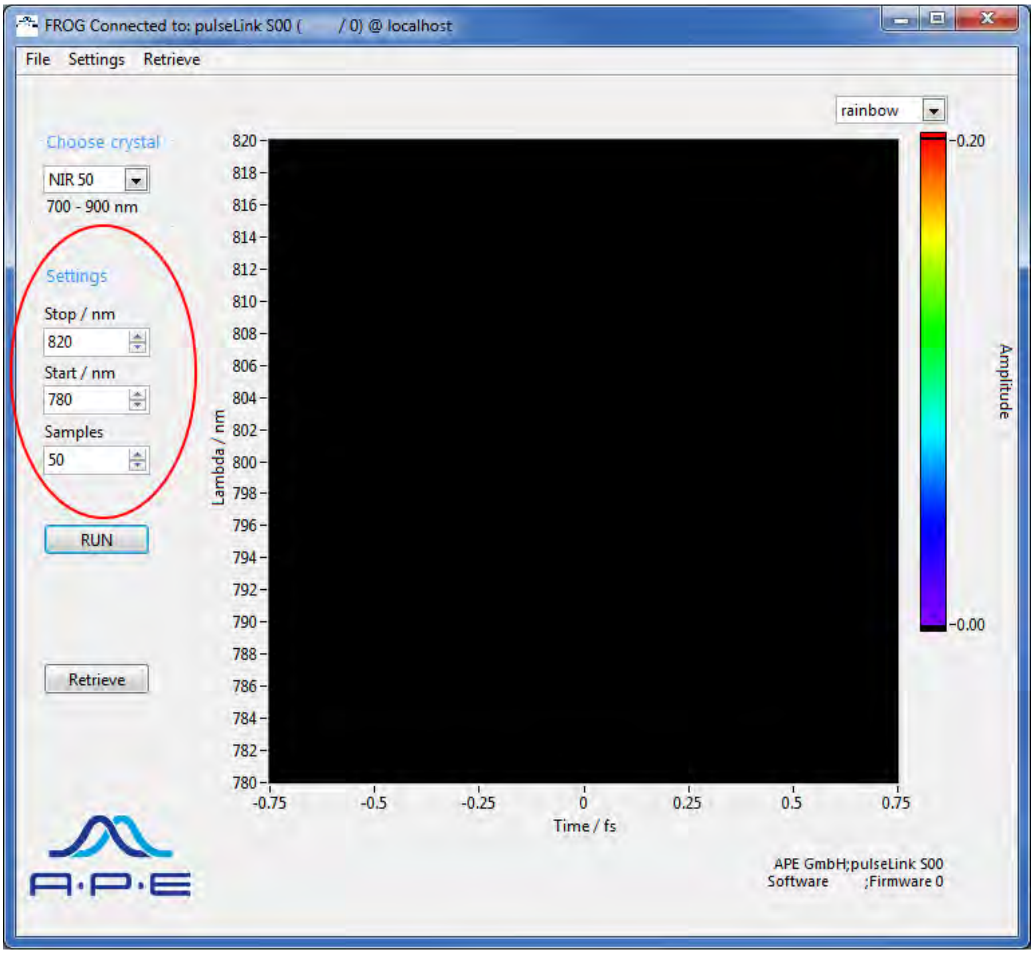


Figure 4.26.: FROG set to measure 40 nm (±20 nm) around 800 nm with 50 samples.

After loading the appropriate crystal the calibration can be fine-tuned to compensate for small deviations of the optical alignment and coupling of the laser and the ***pulse*****Check USB** . This is done by selecting “Settings” → “Calibrate Crystal”. In order for the calibration to be correct the following steps must be taken.

- The central wavelength of the given laser must be measured or must be known.
- Optimize the ACF at the ***pulse*****Check USB** as described in the manual.
- Most importantly tune the crystal to maximize the ACF (optimal phase-matching).
- In the FROG software select “Calibrate Crystal” and enter the wavelength from step 1. Now click the “calibrate” button. See also Figure 4.27.
- In the case that the software tunes the crystal away from achieving phase-matching, check the “invert crystal” box.

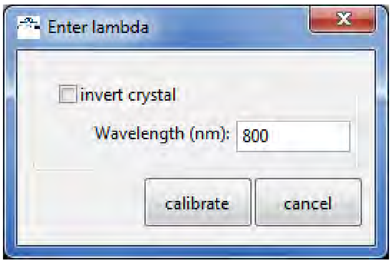


Figure 4.27.: FROG crystal calibration dialog.

Note: The calibration is only necessary if after recording the FROG trace the maximum intensity of the trace is not centered at the wavelength of the given laser.

It is important to choose meaningful values. “Start”, “Stop” should be chosen such that the whole FROG trace fits into the display window. To find the right values, repeat the measurement with different values if necessary. The number of “Samples” defines the resolution of the trace in terms of the wavelength. Setting a too small value may result in loss of information. On the other hand if “Samples” is set to high for the given crystal to resolve each individual step the FROG software will automatically ignore certain steps. While a too high value will not alter the measurement the result will be an unnecessarily long measurement time.
After choosing appropriate “Start”, “Stop” and “Samples” values press the “RUN” button to start recording the FROG trace. During the measurement the software tunes the crystal stepwise according to the previously set values and records the ACF at each step. This process is pictured exemplarily in Figure 4.28.

Figure 4.28.: Progression of the FROG trace recording.

Note: The software automatically adjusts the color scale of the FROG trace display between the minimum and maximum intensity value. Therefore the color will change several times during the measurement until the whole trace is recorded.

Note: During the FROG measurement the ***pulse*****Link** software displays the filtered collinear autocorrelation.

After recording a satisfying FROG trace press the "Retrieve" button to open the FROG retrieval window to calculate the spectral and temporal phase.

4.7.2. Retrieving Spectral and Temporal Phase

A FROG trace can be retrieved iteratively directly after recording ("Retrieve" Button) the trace or using a saved FROG trace ("Retrieve" → "Open retrieval") after opening the FROG retrieval window. The FROG retrieval window with a FROG trace is pictured in Figure 4.29.

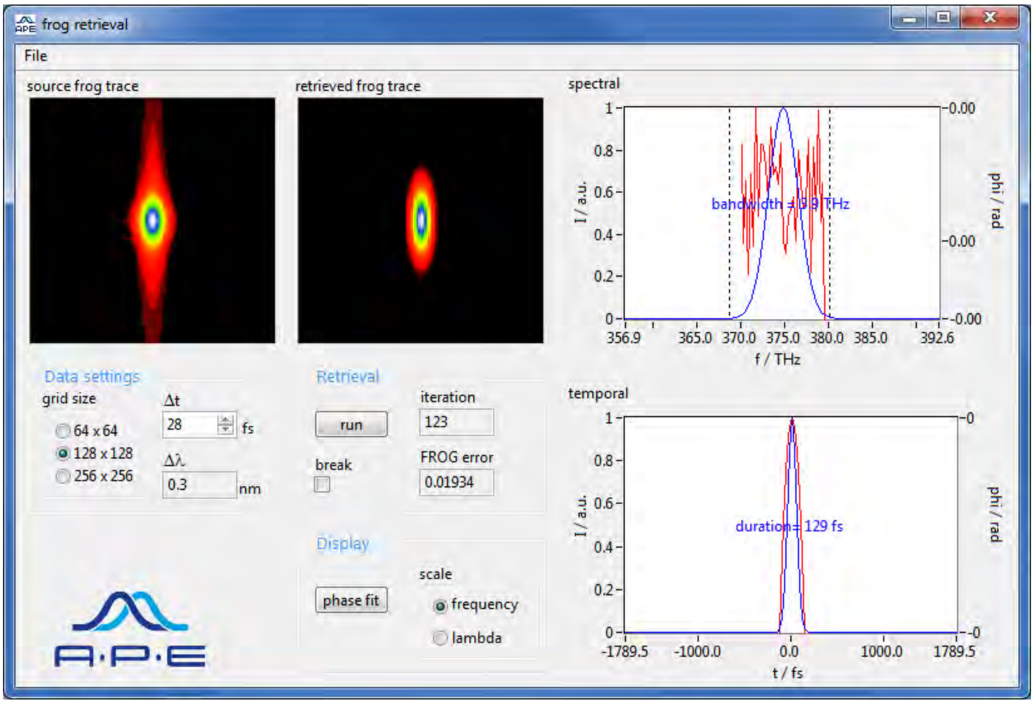


Figure 4.29.: FROG retrieval window with recorded data.

The raw measurement data is displayed in the "source frog trace" window. In it the time and frequency axes (not displayed) are automatically rescaled to fulfill the relationship between time and frequency that is defined by the Fourier transformation. Therefore the trace may appear different as in the FROG measurement window.
Additionally the software will automatically optimize all start parameters for the retrieval algorithm. Thus, in most cases no additional user input is necessary. Run the retrieval algorithm by pressing the "run" button in the "Retrieval" control field. Nevertheless, the parameters "grid size" and temporal resolution Δt can be set manually to optimize the algorithm individually.
The "grid size" control allows selecting three different data array sizes where the 256 x 256 size is for more complex pulses and the 64 x 64 for simple pulses close to the Fourier transform limit. The standard grid size is 128 x 128.

A very crucial parameter of the algorithm is the temporal resolution Δt. This value has to be set very carefully, because the accuracy of the retrieval is strongly affected by this setting. As already mentioned, the time and frequency domains are linked via the Fourier transformation. Therefore the resolution of time and frequency are connected reciprocally. By changing the time resolution the wavelength must change accordingly. Therefore the "source FROG trace" is adjusted to visualize the set Δt value. As a rule of thumb the resolution should be adjusted to obtain a round shape for the FROG trace which in this case is a simplification for nearly transform limited pulses. Figure 3.7 shows an example of a too high value for Δt, a too low value and the correct Δt. Figure 3.7 demonstrates that a too high Δt leads to an artificially broad spectrum and an artificially short pulse. The same is true for a too low Δt, only with a reversed relationship between spectrum and pulse width.

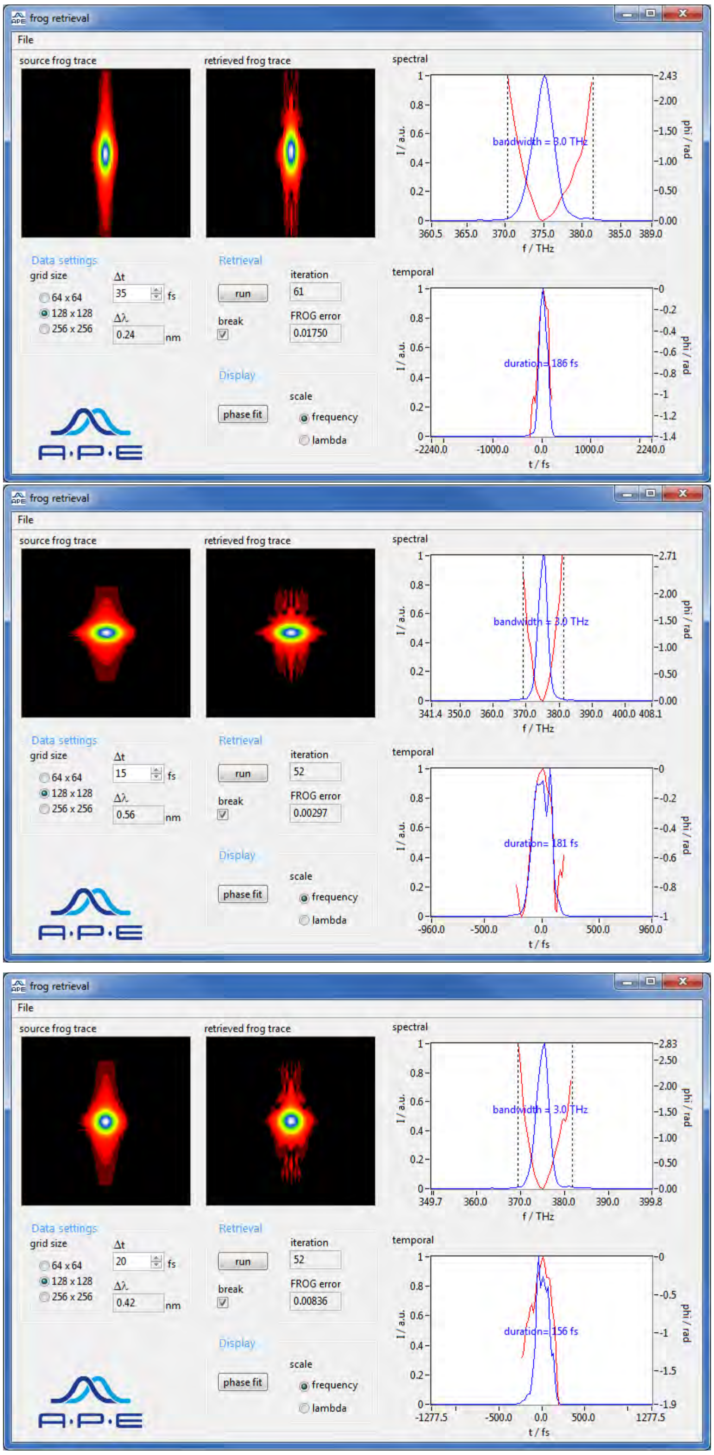


Figure 4.30.: Top: Δt set too high and broadened spectrum and shortened pulse width. Middle: Δt set too low and shortened spectrum and broadened pulse width. Bottom: ideal value of Δt.

After a successful retrieval the raw and the retrieved data can be saved via the “File” menu.
Additional FROG retrieval functions are:

- **“break”** stops the retrieval algorithm automatically if the difference between the raw data and the FROG fit reaches a certain minimal value for ten consecutive iterations.

- **"phase fit"** fits the retrieved spectral phase (frequency domain) and displays the fitted chirp. The user can move the cursors in the spectral view to limit the fit range left and right of the spectrum. This is necessary when data artefacts create a false phase shape or the program does not set the cursors correctly. An example of the cursor function is pictured in Figure 4.31.
- **"scale"** changes the axis of the spectral window between wavelength and frequency scale.

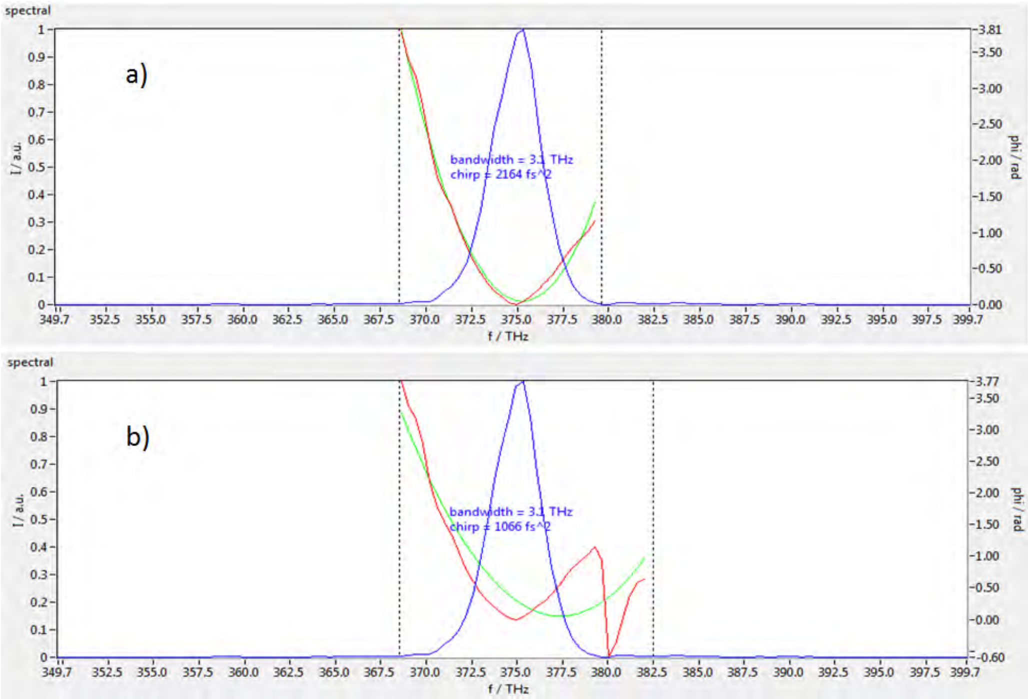


Figure 4.31.: a) Cursors set correctly to the base of the spectrum and fit (green) matching the data (red), b) cursors set too far where the fit is not able to match the data.

4.8. Error Sources of an Autocorrelation Measurement

The A·P·E ***pulse*****Link** Control Software detects several error sources of the signal that could lead to imprecise evaluation of the laser pulse duration. If such a limitation of the measurement is detected the FWHM duration indicator in the info window is colored red and the critical parameter is displayed in the measurement details section in the lower left corner of the measurement window.

The following critical parameters are displayed if detected by the software:

- Scan range too small: If the chosen scan range is too small with respect to the detected width of the autocorrelation trace, a part of the measured autocorrelation might be clipped. The software needs to detect the whole ACF (i.e. maximum and minimum) to determine the FWHM of the SCF correctly. If the ACF is too broad for the scan range / measurement window the calculated FWHM value may be incorrect. Without a robust determination of the signal offset the evaluation of the half of maximum intensity to determine the FWHM value is not possible with the necessary precision (see Figure 4.32).

Action: Increase the scan range.

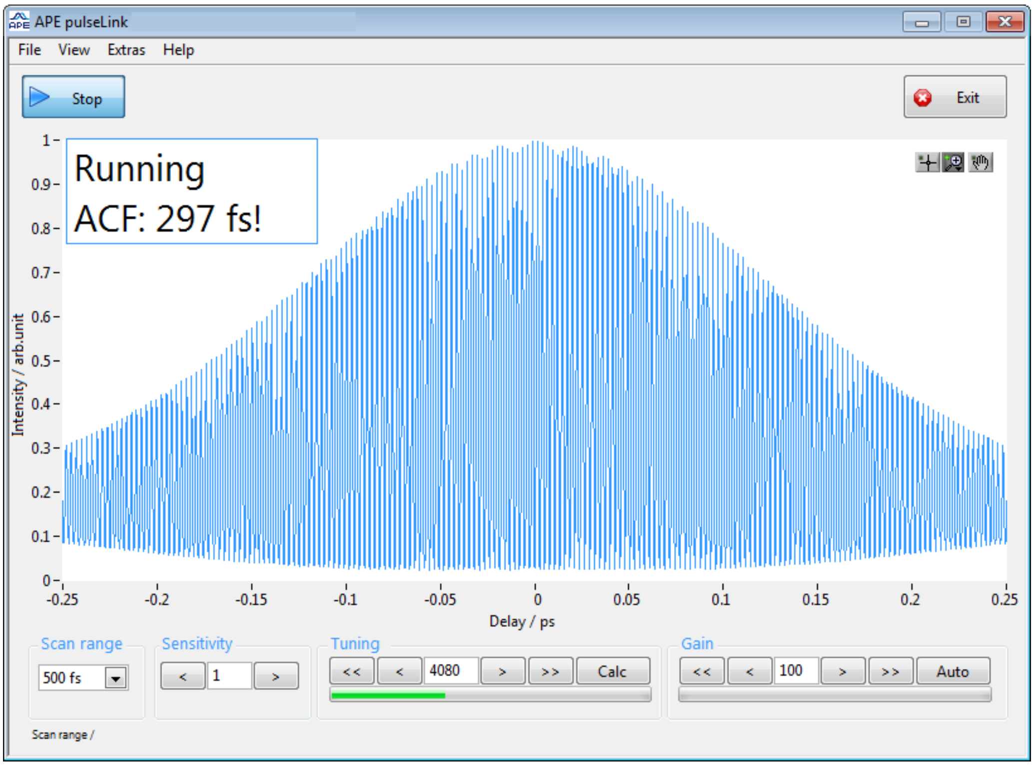


Figure 4.32.: The ACF indicator shows an exclamation mark and the info line shows a "Scan range/" error because the chosen scan range is too small for the detected width of the autocorrelation trace.

- Scan range too large: If the chosen scan range is too large with respect to the detected width of the autocorrelation trace, the data resolution is too low for a precise determination of the FWHM value (see Figure 4.33). Also this leads to an unnecessary high error of the FWHM value.

Action: Decrease the scan range.

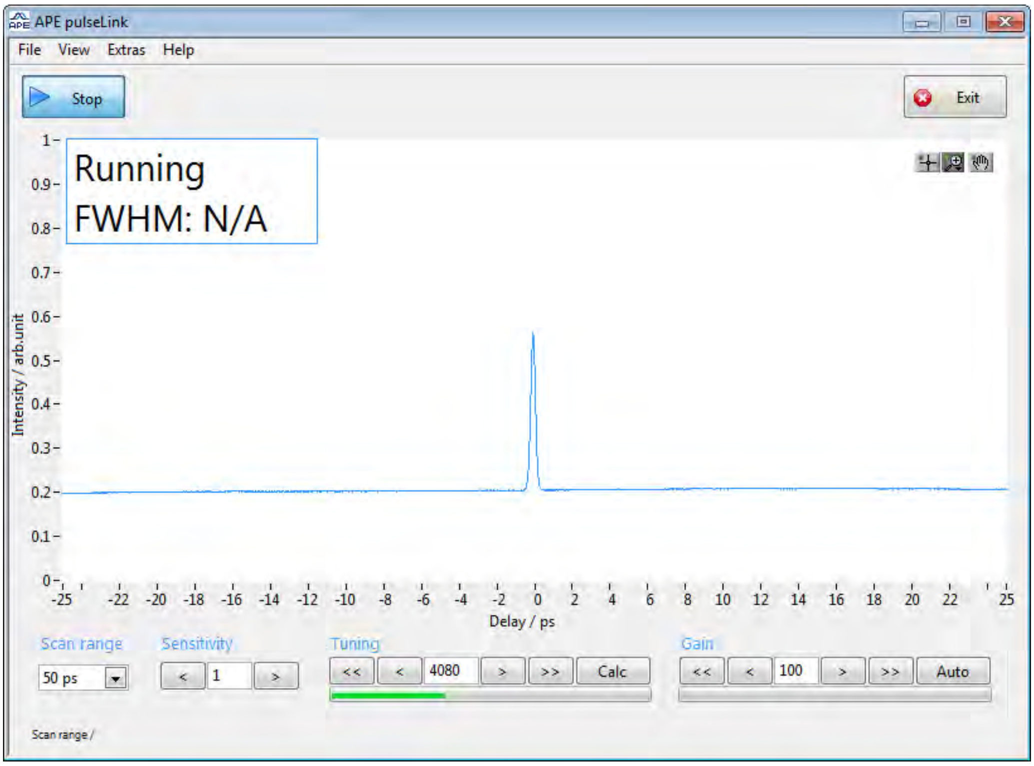


Figure 4.33.: The FWHM indicator shows N/A and the info line shows a "Scan range/" error to emphasize that the chosen scan range is too large for the detected width of the autocorrelation trace .

- Clipping: An intense autocorrelation signal can lead to detector overload which results in clipping of the measurement trace (see Figure 4.34).

Action: Decrease the gain, turn down the sensitivity or decrease the power of the input laser beam.

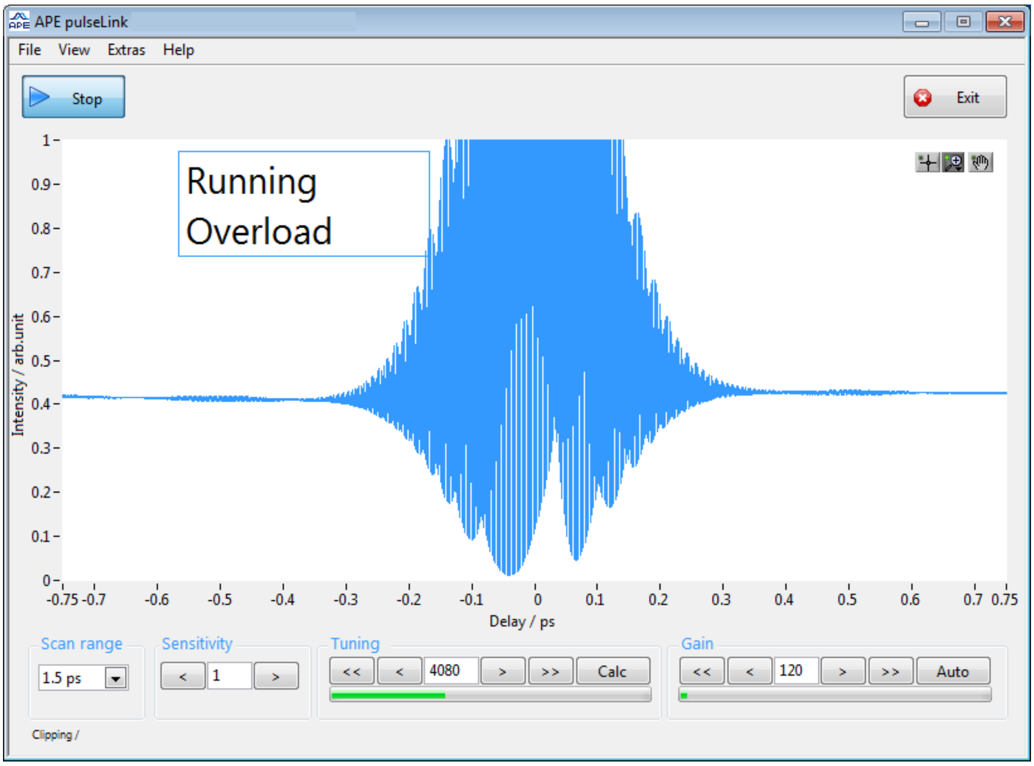


Figure 4.34.: The FWHM indicator is replaced by an "Overload" message and the info line shows a "Clipping/" error to emphasize that the intensity of the autocorrelation signal is too high.

- Low dynamic / low signal: A weak autocorrelation signal uses only a minor part of the given dynamic range. This can lead to an erroneous measurement of the FWHM value due to the low signal-noise ratio (see Figure 4.35).

Action: Increase the gain, the sensitivity, or the power of the input laser beam. Also check fo

Figure 4.35.: The ACF indicator shows an exclamation mark and the info line shows a "Low dynamic/Low signal/" error to emphasize that the intensity of the autocorrelation signal is too weak.

- <u>Asymmetric signal:</u> An SHG autocorrelation function is always symmetric by definition. If the measured autocorrelation trace deviates too much from symmetry the info line shows an "asymmetric" error message (see Figure 4.36).

Action: Adjust the delay screw or optimize the beam alignment into the *pulse*Check optical head.

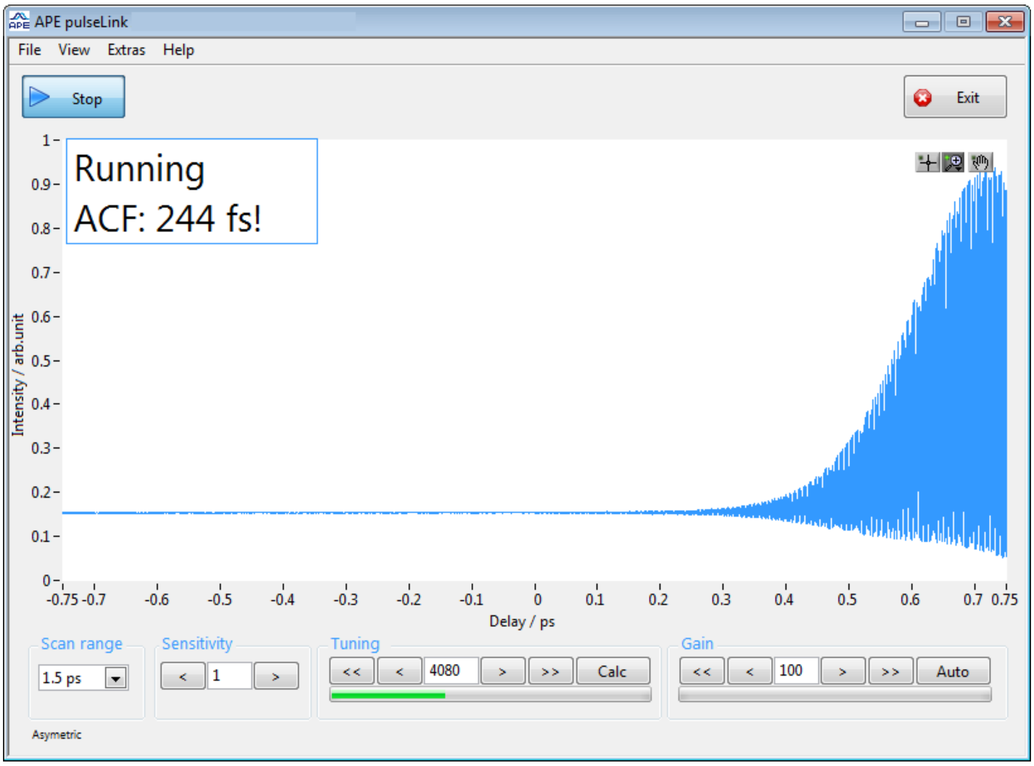


Figure 4.36.: Example of an asymmetric signal due to a large delay offset.

4.9. Fundamental Overload

At very extreme wavelengths and input power levels the ACF in collinear case can be superposed up to being completely covered by a background signal resulting from the fundamental wave. This can be avoided by using the non-collinear interaction or deploying special filters and detectors. They can be ordered at your ***pulse*****Check USB** vendor.

4.10. Troubleshooting

Error characteristics		Possible reason	Check and removal
No SHG Signal		wrong polarization direction	check with polarization rotator; introduce a polarization rotator in the input beam
		wrong alignment	check beam position at input aperture; check back reflection at control window; check "FOCUS" position; check phase matching
		no input pulses or pulses too long	check with an independent method (fast photodiode, spectral width etc.)
		input power too small	compare with sensitivity specifications
		delay zero position outside of scan range	check at wider scan ranges; check and correct for delay "zero" position (see test report)
No clear ACF		wrong scan range	check at wider scan ranges
		no input pulses or pulses too long	check with an independent method (fast photodiode, spectral width etc.)
SHG Signal w / o ACF peak	non-collinear case	wrong alignment of beam on detector	check with shutters (i.e. if the signal level reacts to each of the shutters); realign input beam in horizontal direction only
	collinear case	wrong "FOCUS" position	check and correct for "FOCUS" position
		Delay zero position outside of scan range	check at wider scan ranges; check and correct for delay "0" position (see test report)

5. Important Additional Hints

5.1. "Zero" Scan

In "Zero" scan the delay drive is stopped at the zero position. The zero position is the position of the retro reflectors where there is no delay between the pulses in the interferometer. Thus this is the position of the highest intensity of the SCF.

5.2. Low Pass Filter

This switchable filter suppresses high frequency noise from the detector and also the interference fringes in the collinear case. For the measurement in triggered mode it is automatically switched off.

5.3. Collinear and Background-Free (Non-Collinear) Autocorrelation Function

These interaction types can be chosen by turning the "BEAM DISTANCE" screw at the optical head to the appropriate position. The beam distance of the interacting beams from the two interferometer arms can be changed between 0 ... 6 mm (check at the alignment window next to the input aperture - the moving spot has to be at the right side of the fix spot). When changing the beam distance, the focusing, the sensitivity, and the phase matching angle tuning should be optimized accordingly. It is recommended to proceed in small steps, so that the ACF never disappears entirely.

5.4. Interference Modulation

If exactly aligned in the collinear case, the ACF is modulated by the fundamental beam interference fringes in the interferometer (sinusoidal modulation - fringe resolved ACF). They can either be suppressed by the low pass filter (simple intensity ACF) or displayed without filtering and used for retrieval of the center wavelength of the laser pulses (see Paragraph 4.3.3). The more the beams are changing from being collinear to non-collinear the more these interferences are spatially averaged and the less they modulate the AC signal. In the triggered mode, where the low pass filter is not active, and in "ZERO SCAN" the fringes simulate strong amplitude fluctuations of the signal, that make it difficult to align for optimal phase matching. That is why it is useful to increase the beam distance slightly to measure a nearly collinear ACF without interferences.

To allow for optimal triggered measurements (i.e. low repetition systems) optical detectors for the ***pulse*Link** comprised of photodiodes (PD) contain an additional electronic low pass filter. Since the intensity of the interference fringes varies with a relatively high frequency at the photodiode the filter will dampen and thereby distort the collinear fringe signal for some scan ranges in combination with certain wavelengths. To see at which wavelengths and at which scan ranges the filter takes effect see Figure 5.1. The filter not only affects the signal intensity of the fringe resolved autocorrelation but may also distort it. Thus it is advised to make fringe resolved measurements only in the region marked as distortion-free in Figure 5.1 .

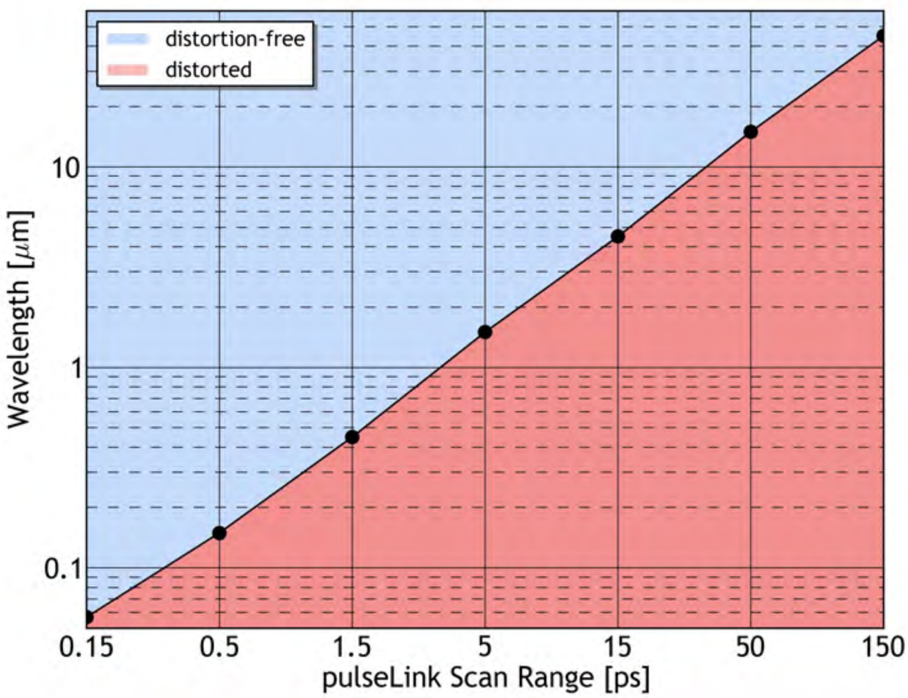


Figure 5.1.: Effect of the low pass filter depending on wavelength and scanrange

5.5. Signal Level

The sensitivity range is very wide in order to adapt the autocorrelator to different power input levels. This might cause a high noise level at high gain and a loss of linearity at low gain because of the PMTs physics in particular. Therefore it is advisable to adapt the input level to an operation with moderate gain values for most exact measurements. The operation in triggered mode with very short pulses at low repetition rates is most critical. In this case, the detector can be overloaded at high input levels with low gain causing a suppression of the ACF peak. To prevent this it is strictly recommended to operate this mode with photodiode (PD) detectors only.

5.6. Rotation of the Plane of Polarization

The required input polarization of the ***pulse*Check** autocorrelator is horizontal (E-field; see specifications Paragraph 2.2.1). If the laser beam is vertically polarized, the plane of polarization has to be rotated.

5.6.1. Rotation with $\lambda/2$-Plate Polarization Rotator

By positioning a $\lambda/2$ plate in the input beam and tilting the plate by an angle of α the polarization is rotated by 2α. The effect of polarization rotation can be very wavelength sensitive.

5.6.2. Rotation with Periscope

Two mirrors mounted at a 45° angle to the input beam and steering it in different planes flip the plane of polarization by 90° (see Figure 5.2). This method is very efficient and wavelength independent. Such a polarization rotator can be ordered at your ***pulse*Check USB** vendor.

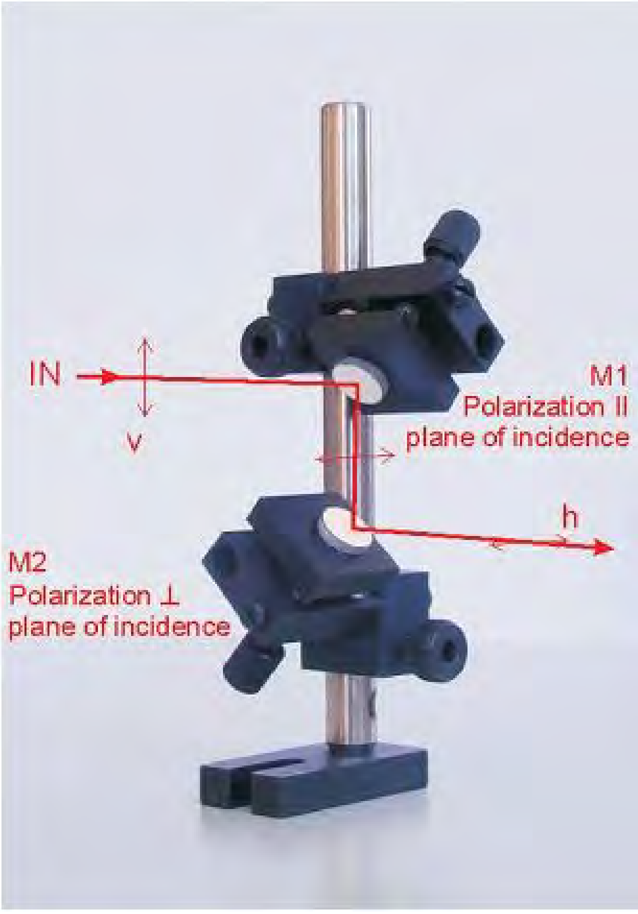


Figure 5.2.: Polarization rotator (periscope type)

At very extreme wavelengths and input power levels the ACF in collinear case can be superposed up to being completely covered by a background signal resulting from the fundamental wave. This can be avoided by using the non-collinear interaction or deploying special filters and detectors. They can be ordered at your ***pulse*Check USB** vendor.

6. Maintenance

6.1. Cleaning

Do not use any aggressive solvents to clean the *pulse*Check autocorrelator components! Switch the laser OFF or block the input beam, switch the *pulse*Link OFF and unplug the mains power adapter from the wall power socket for cleaning!

Use a soft lint-free dry or only slightly moist cloth to clean the covers of the ***pulse*Check USB** components.

Use dry methanol and lens cleaning tissue applying common optics cleaning techniques for cleaning the input mirror.

6.2. Storage of SHG Crystal

The SHG crystals are slightly hygroscopic. Store crystals that are not in use in an airtight box along with silica gel. If you do not use the autocorrelator for a long time it is recommended to remove the crystal (see Paragraph 3.6.1 for removal / mounting of the SHG crystal) from the ***pulse*Check** optical head and to store it in an airtight box along with silica gel.

6.3. Technical Support

For technical questions or problems within Germany, please contact:

A·P·E Angewandte Physik & Elektronik GmbH
Plauener Straße 163 - 165, Haus N
D - 13053 Berlin
tel +49 30 98601130
fax +49 30 986011333
ape@ape-berlin.de
http://www.ape-berlin.com

To contact our international distributors, please have a look at our website:

http://www.ape-berlin.com

A. TCP/IP Command Set

This section provides a complete overview of the remote control commands of the ***pulse*****Check USB** . The command structure of the ***pulse*****Check USB** is mostly in agreement with the SCPI-standard. However, A·P·E does not state compliance nor conformance to the standard, since some standard commands are not yet implemented in the present version. Detailed information about the SCPI is found at: www.ivifoundation.org

For comprehensive usage and code examples in familiar programming languages such as C++, C#, LabVIEW, Python, Matlab, and Ruby, please go to our webpage:

http://www.ape-berlin.de/en/software-interface-tcpip/

IMPORTANT NOTICE:
In order to remotly control the *pulse*Link the *pulse*Link sotware must run and a TCP/IP port must be set in the software. Do not attempt to send TCP/IP commands to the controller via USB!

The autocorrelator will execute the following commands:

***IDN?**

Get Device Identification
<idn> string
Device Information (APE GmbH, Devicename, Serialnumber, Software Version, Firmware Version)

Example:
```
*IDN?
```

***RST**

Perform Device Reset

Example:
```
*RST
```

*STB?

Get Status Byte

<stb> integer
SCPI Status Byte (8 Bit unsigned as decimal) Bit0: reserved Bit1: reserved Bit2: Error Bit3: reserved Bit4: MAV Bit5: ESB Bit6: RSQ/MSS Bit7: OPE

Example:

```
*STB?
```

*CLS

Clear Status Byte (STB)

Example:

```
*CLS
```

*ESE<value>

Set Event Status Enable Register

<value> integer, range: 0 ... 255
ESE Register Value

Example:

```
*ESE=127
```

*ESE?

Get Event Status Enable Register

<value> integer, range: 0 ... 255
ESE Register Value

Example:

```
*ESE?
```

*SRE<value>

Set Service Request Enable Register

<value> integer, range: 0 ... 255
SRE Register Value

Example:

```
*SRE=127
```

***SRE?**

Get Service Request Enable Register
<value> integer, range: 0 ... 255
SRE Register Value

Example:

```
*SRE?
```

***ESR?**

Get Event Status Register
<value> integer, range: 0 ... 255
ESE Register Value

Example:

```
*ESR?
```

***OPC?**

Get Operation Complete Status
<status> integer, range: 0 ... 255
OPC Stats Value (always "1", since multi-command interface is not available)

Example:

```
*OPC?
```

***OPER?**

Get Operation Status
<oper> integer
SCPI Opertation Status (16 Bit unsigned as decimal) Bit0: Disconnected, Bit1: VISA Connected, Bit2: Device Initialized, Bit3: Device ready, Bit4: Device busy, Bit5: Standby (Delaymotor off), Bit6: Data Error (AFC not valid), Bit7: Software Error, Bit8: Firmware Error (see *FRMW?), Bit9: Shutdown, Bit10: Service Mode active, Bit11: unused, Bit12: unused, Bit13: unused, Bit14: unused, Bit15: unused

Example:

```
*OPER?
```

***INIT?**

Get Device Initialization Status
<init> integer
SCPI INIT Status (8 Bit unsigned as decimal, upper 4 Bits are always "1") Bit0: unused, forced to "0", Bit1: unused, forced to "0", Bit2: Link Initialization OK, Bit3: Optic Initialization OK, Bit4: unused, forced to "1", Bit5: unused, forced to "1", Bit6: unused, forced to "1", Bit7: unused, forced to "1"

Example:
```
*INIT?
```

***BUSY?**

Get Device Busy Status
<busy> integer
SCPI BUSY Status (8 Bit unsigned as decimal, upper 4 Bits are always "0") Bit0: IDLE, Bit1: New data available, Bit2: Measurement running, Bit3: Curvefit running, Bit4: unused, Bit5: unused, Bit6: unused, Bit7: unused

Example:
```
*BUSY?
```

***ERR?**

Get Data Error Status
<errs> integer
SCPI DATA ERROR Status (8 Bit unsigned as decimal, Bit 7 is always "0") Bit0: Signal too low, Bit1: Signal too high, Bit2: No Peak found, Bit3: ACF is asymmetric, Bit4: Dynamic range too low, Bit5: Scanrange too low, Bit6: Negative offset, Bit7: unused

Example:
```
*ERR?
```

***FRMW?**

Get Firmware Status
<frmw> integer
SCPI Firmware Error Status (16 Bit unsigned as decimal, Bit12..15 are always "0") Bit0: Parser Error, Bit1: Parameter Error, Bit2: FRAM Error, Bit3: I2C-0 Error, Bit4: I2C-0 Error, Bit5: I2C Locked, Bit6: Configuration Error, Bit7: Optics Error, Bit8: Buffer Overflow, Bit9: DMA Error, Bit10: USB Error, Bit11: Data Timeout, Bit12: unused, Bit13: unused, Bit14: unused, Bit15: unused

Example:

```
*FRMW?
```

SYSTEM:DEVICE?
SYS:DEVICE?

Get Device Name
<name> string
Device Name

Example:

```
:system:device?
```

SYSTEM:SNUMBER?
SYS:SNUMBER?

Get Device Serial number
<snr> string
Device Serial Number (S00000 - S99999)

Example:

```
:system:snumber?
```

SYSTEM:SOFTWARE?
SYS:SOFTWARE?

Get Software Version
<version> string
Software Version

Example:

```
:system:software?
```

SYSTEM:HARDWARE?
SYS:HARDWARE?

Get Hardware Version
<version> string
Hardware Version

Example:

```
:system:hardware?
```

SYSTEM:FIRMWARE?
SYS:FIRMWARE?

Get Firmware Version
<version> string
Firmware Version

Example:
```
:system:firmware?
```

SYSTEM:MOTOR?
SYS:MOTOR?

Get Motor Type
<version> string
Motor Type

Example:
```
:system:motor?
```

STATUS:AVERAGE<number>

Set numer of measurements used for averaging
<number> integer, range: 0 ... 4
Number of Measurements 0: Averaging OFF, 1: 2 Measurements, 2: 4 Measurements, 3: 8 Measurements, 4: 16 Measurements

Example:
```
:status:average=1
```

STATUS:AVERAGE?

Get numer of measurements used for averaging
<number> integer, range: 0 ... 4
Number of Measurements 0: Averaging OFF, 1: 2 Measurements, 2: 4 Measurements, 3: 8 Measurements, 4: 16 Measurements

Example:
```
:status:average?
```

STATUS:RESOLUTION<setting>

Set numer of data points used for averaging
<setting> string
Number of samples used 0/200/very low, 1/500/low, 2/1000/medium, 3/1500/high, 4/2000/very high

Example:

```
:status:resolution=1
```

STATUS:RESOLUTION?

Get numer of data point used for averaging

<setting> string
Number of samples used 0/200/very low, 1/500/low, 2/1000/medium, 3/1500/high, 4/2000/very high

Example:

```
:status:resolution?
```

STATUS:FITTYPE<type>

Set type of curve fit to apply to measured ACF

<type> integer, range: 0 ... 3
Fittype 0/OFF/NONE: No Curvefitting performed, 1/GAUSSIAN: Fit Gaussian Model, 2/SECH2: Fit Sech2 Model, 3/LORENTZ: Fit Lorentz Model

Example:

```
:status:fittype=1
```

STATUS:FITTYPE?

Get type of calculated curve-fit

<type> integer, range: 0 ... 3
Fittype 0: No Curvefit performed, 1: Gaussian Model, 2: Sech2 Model, 3: Lorentz Model

Example:

```
:status:fittype?
```

STATUS:START?

Status of Measurement

<status> string
Status of measurement (1 = Measurement running, 0 = Measurement paused)

Example:

```
:status:start?
```

STATUS:FILTER<status>

Set Status of ACF Filtering
<status> string

Example:
```
:status:filter=1
```

STATUS:FILTER?

Get Status of ACF Filtering
<status> string
Status of ACF filtering (1 = filter active, 0 = filter not active)

Example:
```
:status:filter?
```

MOTOR:SCANRANGE<scanrange>
MOTOR:SCR<scanrange>

Set ScanRange
<scanrange> integer, unit: fs
Scanrange (Device configuration dependent) 0: Zeroscan, 150: 150 fs, 500: 500 fs, 1500: 1.5 ps, 5000: 5 ps, 15000: 15 ps, 50000: 50 ps, 150000: 150 ps

Example:
```
:motor:scanrange=15000
```

MOTOR:SCANRANGE?
MOTOR:SCR?

Get ScanRange
<scanrange> integer, unit: fs
Scanrange (Device configuration dependent) 0: Zeroscan, 150: 150 fs, 500: 500 fs, 1500: 1.5 ps, 5000: 5 ps, 15000: 15 ps, 50000: 50 ps, 150000: 150 ps

Example:
```
:motor:scanrange?
```

DETECTOR:GAIN<value>

Set Gain value
<value> integer, range: 300 ... 1000
Gain Value

Example:

```
:detector:gain=450
```

DETECTOR:GAIN?

Get Gain value
<value> integer, range: 300 ... 1000
Gain Value

Example:

```
:detector:gain?
```

DETECTOR:AUTOGAIN<number>
DETECTOR:AUG<number>

Activate Autogain Feature
<number> integer
Status of autogain feature

Example:

```
:detector:autogain=1
```

DETECTOR:AUTOGAIN?
DETECTOR:AUG?

Get Autogain status (0=OFF, 1=ON)
<number> integer
Status of autogain feature

Example:

```
:detector:autogain?
```

DETECTOR:SENSITIVITY<number>
DETECTOR:SEN<number>

Set Sensitivity
<number> integer
Detector Sensitivity 1: Low Sensitivity, 10: High Sensitivity, 100: (optional "HighSen"-Feature)

Example:

```
:detector:sensitivity=10
```

DETECTOR:SENSITIVITY?
DETECTOR:SEN?

Get Sensitivity
<number> integer
Detector Sensitivity 1: Low Sensitivity, 10: High Sensitivity, 100: (optional "HighSen"-Feature)

Example:
```
:detector:sensitivity?
```

TRIGGER:LEVEL?
TRIGGER:LVL?

Get Trigger Level
<level> integer, unit: mV, range: 200 ... 5000
Trigger Level

Example:
```
:trigger:level?
```

TRIGGER:DELAY?
TRIGGER:DEL?

Get Trigger Delay
<level> integer, unit: us, range: 1 ... 50
Trigger Delay

Example:
```
:trigger:delay?
```

TRIGGER:FREQUENCY?
TRIGGER:FRQ?

Get Trigger Frequency
<level> integer, unit: Hz
Trigger Frequency

Example:
```
:trigger:frequency?
```

TRIGGER:IMPEDANCE?
TRIGGER:IMP?

Get Trigger Impedance
<level> integer, unit: Ohms
Trigger Impedance

Example:

```
:trigger:impedance?
```

ACF:DATA?

Get ACF Data (raw, unfiltered data)
<acf> array of s in block data format
ACF Data as binary Block (little-endian byte order); The returned data holds an interleaved array of Double (IEEE754) Values with the following scheme [y0,x0,y1,x1,...,yN,xN], x = Delay (ps), y = Intensity (a.u.) | Please note: the binary Data must be unpacked before it can be used. Please also see our example codes for more info about that.

Example:

```
:acf:data?
```

ACF:DISPLAYED_ACF?
ACF:DACF?

Get ACF Data as shown on the applications graph control (with applied filter, AVG, etc.)
<dacf> array of s in block data format
Displayed ACF Data as binary Block (little-endian byte order); The returned data holds an interleaved array of Double (IEEE754) Values with the following scheme [y0,x0,y1,x1,...,yN,xN], x = Delay (ps), y = Intensity (a.u.) | Please note: the binary Data must be unpacked before it can be used. Please also see our example codes for more info about that.

Example:

```
:acf:displayed_acf?
```

ACF:MEANDATA?

Get ACF Mean Data
<mean> string
Mean Values separated by semicolons: "[AVG];[Xmax];[Xmin];[Ymax];[Ymin]"

Example:

```
:acf:meandata?
```

ACF:FWHM?

Get FWHM Value
<fwhm> double
FWHM Value

Example:

```
:acf:fwhm?
```

ACF:FITFWHM?

Get fitted FWHM Value
<fwhm> integer
Fitted FWHM Value

Example:

```
:acf:fitfwhm?
```

SHUTTER:FIX<parameter>

Set fix-shutter position
<parameter> boolean
Shutter position, 1=open, 0=close

Example:

```
:shutter:fix=0
```

SHUTTER:FIX?

Get fix-shutter position
<parameter> boolean
Shutter position, 1=open, 0=close

Example:

```
:shutter:fix?
```

SHUTTER:SCAN<parameter>

Set scan-shutter position
<parameter> boolean
Shutter position, 1=open, 0=close

Example:

```
:shutter:scan=0
```

SHUTTER:SCAN?

Get scan-shutter position
<parameter> boolean
Shutter position, 1=open, 0=close

Example:

```
:shutter:scan?
```

XTAL:TUNING<parameter>
XTAL:TUN<parameter>

Set crystal tuning position
<parameter> integer, range: 500 ... 11000
Crystal position

Example:

```
:xtal:tuning=5000
```

XTAL:TUNING?
XTAL:TUN?

Get crystal tuning position
<parameter> integer, range: 500 ... 11000
Crystal position

Example:

```
:xtal:tuning?
```

XTAL:LAMBDATUNE<parameter>
XTAL:LTU<parameter>

Set crystal tuning in nm
<parameter> integer
Crystal target position in nm

Example:

```
:xtal:lambdatune=800
```

XTAL:LAMBDATUNE?
XTAL:LTU?

Get crystal tuning position
<parameter> integer
Crystal position in a.u.

Example:

```
:xtal:lambdatune?
```

XTAL:MOVE?
XTAL:MOV?

Get status of crystal motor
<number> integer
crystal motor status (1 - motor running, 0 - motor stopped)

Example:

```
:xtal:mov?
```

XTAL:SETXTAL?
XTAL:SEX?

Get crystal type
<parameter> string
XTAl Type

Example:

```
:xtal:setxtal?
```

B. Fitting Functions

B.1. Gaussian

The mathematical description for a gaussian pulse is:

$$G(t) = e^{-t^2} \tag{B.1}$$

The autocorrelation of this pulse is given by the solution of the convolution integral

$$G_{ACF}(\tau) = \int_{-\infty}^{\infty} G(t)G(t-\tau)dt = \sqrt{\frac{\pi}{2}} e^{\frac{-\tau^2}{2}} \tag{B.2}$$

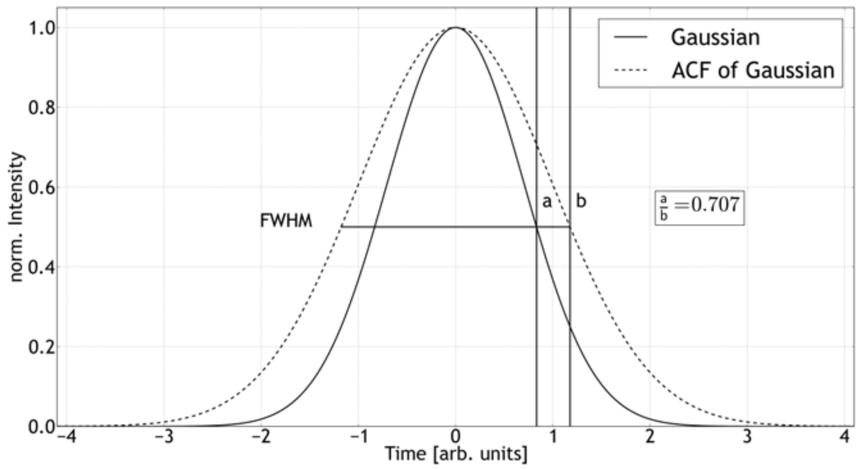


Figure B.1.: Gaussian function e^{-t^2} and its normalized autocorrelation $e^{\frac{-\tau^2}{2}}$ (dotted line)

Equating the normalized gaussian functions with $\frac{1}{2}$ gives the time value at half amplitude.

$$G(a) = \frac{1}{2} \qquad \Rightarrow a = \sqrt{\ln(2)} \tag{B.3}$$

$$G_{ACF}(b)\sqrt{\frac{2}{\pi}} = \frac{1}{2} \qquad \Rightarrow b = \sqrt{2\ln(2)} \tag{B.4}$$

The quotient of this time values supplies the transformation factor between the pulse width and the FWHM value of its autocorrelation function.

$$\frac{a}{b} = \frac{\sqrt{\ln(2)}}{\sqrt{2\ln(2)}} = 0.71 \tag{B.5}$$

B.2. Lorentzian

The mathematical description for a lorentzian pulse is:

$$L(t) = \frac{1}{1+t^2} \tag{B.6}$$

The autocorrelation of this pulse is given by the solution of the folding integral

$$L_{ACF}(\tau) = \int_{-\infty}^{\infty} L(t)L(t-\tau)dt = \frac{2\pi}{4+\tau^2} \tag{B.7}$$

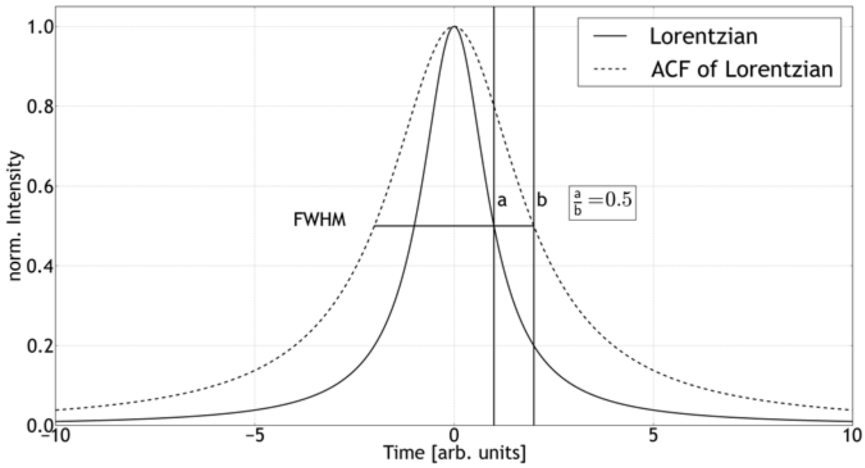


Figure B.2.: Lorentzian function $\frac{1}{1+t^2}$ and its normalized autocorrelation $\frac{4}{4+\tau^2}$ (dotted line)

Equating the normalized gaussian functions with $\frac{1}{2}$ gives the time value at half amplitude.

$$L(a) = \frac{1}{2} \qquad \Rightarrow a = 1 \tag{B.8}$$

$$L_{ACF}(b)\frac{2}{\pi} = \frac{1}{2} \qquad \Rightarrow b = 2 \tag{B.9}$$

The quotient of this time values supplies the transformation factor between the pulse width and the FWHM value of its autocorrelation function.

$$\frac{a}{b} = 0.5 \tag{B.10}$$

B.3. sech^2

The autocorrelation of the $S(t) = \text{sech}(t)^2$ pulse is given by the solution of its folding integral

$$S_{ACF}(\tau) = \int_{-\infty}^{\infty} S(t)S(t-\tau)dt = 4\text{csch}(\tau)^3(\tau\cosh(\tau) - \sinh(\tau)) \tag{B.11}$$

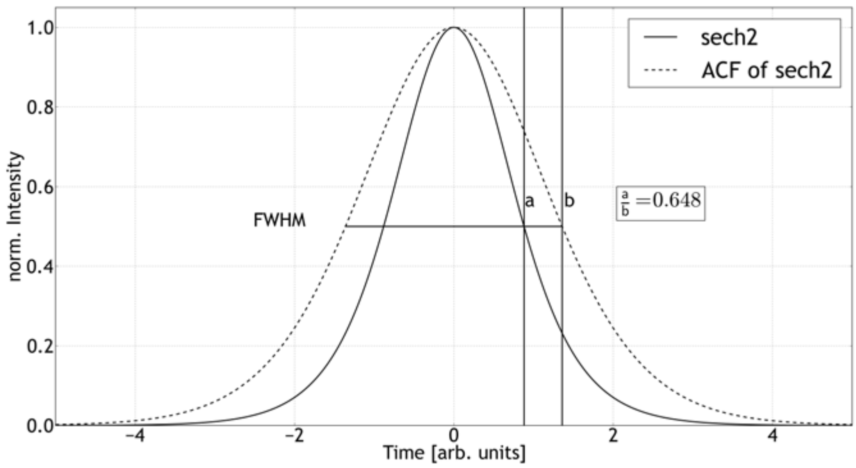


Figure B.3.: The function $\text{sech}(t)^2$ and its normalized autocorrelation $3\text{csch}(\tau)^3(\tau\cosh(\tau) - \sinh(\tau))$ (dotted line)

Equating the normalized functions with $\frac{1}{2}$ gives the time value at half amplitude.

$$S(a) = \frac{1}{2} \qquad \Rightarrow a = 0.881374 \tag{B.12}$$

$$L_{ACF}(b)\frac{3}{4} = \frac{1}{2} \qquad \Rightarrow b = 1.35979 \tag{B.13}$$

The quotient of this time values supplies the transformation factor between the pulse width and the FWHM value of its autocorrelation function.

$$\frac{a}{b} = 0.648 \tag{B.14}$$

A·P·E Angewandte Physik & Elektronik GmbH
Plauener Str. 163 – 165 | Haus N
13053 Berlin
Germany

Declaration of Conformity to EU RoHS

Products listed below that are manufactured by A·P·E Angewandte Physik & Elektronik GmbH are in compliance with Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (also known as "RoHS Recast"). In addition, this declaration of conformity is issued under the sole responsibility of A·P·E Angewandte Physik & Elektronik GmbH. Specifically, products manufactured do not contain the substances listed in the table below in concentrations greater than the listed maximum value.

Substance	**Maximum Limit (ppm)**
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000

Product Identification:
Product

Autocorrelator ***pulse*****Check USB** 15 (w/o Optics Set)
A·P·E Id: 130621

Autocorrelator ***pulse*****Check USB** 15 *short*Pulse (w/o Optics Set)
A·P·E Id: 130624

Autocorrelator ***pulse*****Check USB** 50 (w/o Optics Set)
A·P·E Id: 130626

Autocorrelator ***pulse*****Check USB** 50 *short*Pulse (w/o Optics Set)
A·P·E Id: 130627

Autocorrelator ***pulse*****Check USB** 150 (w/o Optics Set)
A·P·E Id: 130628

pulse**Check USB** 15 MIR (w/o Optics Set) Autocorrelator with ***pulse*****Link** Controller
A·P·E Id: 134127

***pulse*Check USB** 50 MIR (w/o Optics Set) Autocorrelator with ***pulse*Link** Controller
A·P·E Id: 134133

***pulse*Check USB** 150 MIR (w/o Optics Set) Autocorrelator with ***pulse*Link** Controller
A·P·E Id: 134134

Signature:

Name (printed): Dr. Bodo Richter
Title: CEO Technical Director

Telephone: +49 30 98601130
Email: ape@ape-berlin.de