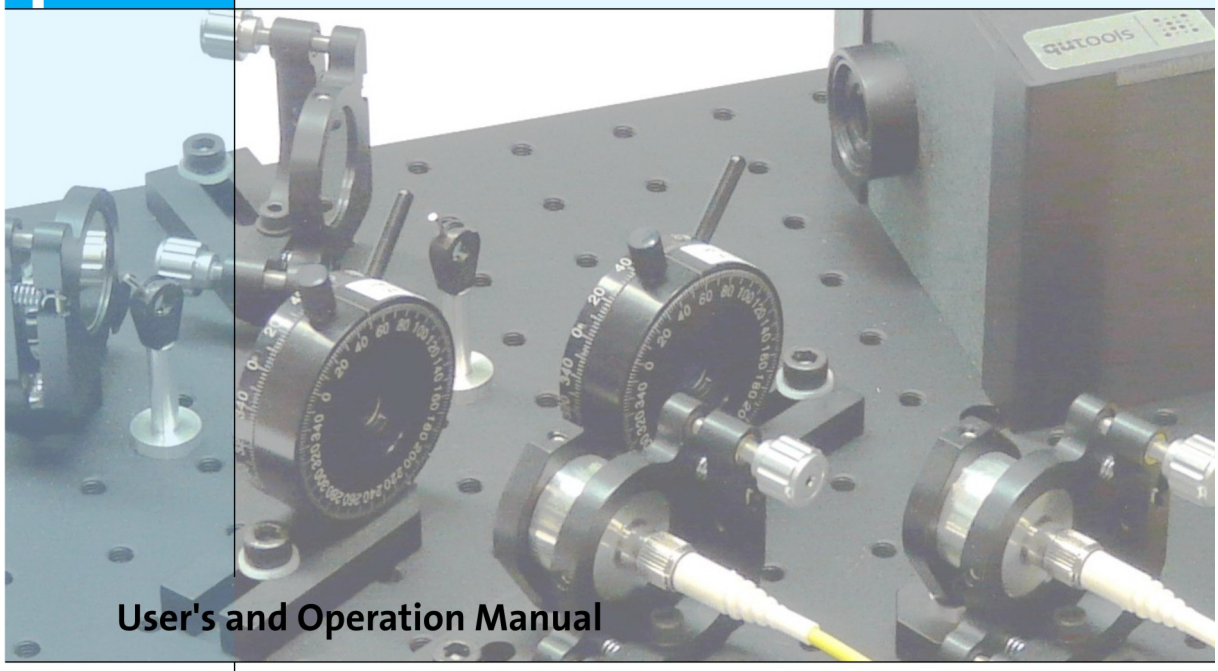
quED

Control and Read-out Unit



quCR Manual Version 3.2 (October 16, 2019)

Contents

1 Introduction

This manual describes the controller of qutools' quED - entanglement demonstrator. It features a laser diode controller, a coincidence counter and a twin APD[1] photon counting module. The laser diode controller regulates the temperature of the laser diode and the current flowing through it. The counter module displays the single and coincidence count rates of the signals coming from the APD module.

[1] APD: Avalanche Photo Diode. When working in the so-called Geiger mode, these devices can be used to register single photons with a rather high efficiency.

1.1 General Warnings

Before starting to use the controller, please read the instruction manual carefully. Make sure that you are familiar with and have obeyed all necessary safety precautions, especially with respect to laser safety and electrostatic discharges (ESD). Please consult the document *quED User's and Operation Manual* for this purpose.

- Do not connect this controller to anything but the optics part of the quED system.
- Do not open the case of the controller and do not unnecessarily remove the APD module.
- Never remove or install the APD module while the controller is running.
- Always turn the laser diode current down before switching it off.
- Always switch off the laser diode before turning off the controller.

1.2 Installation

For the installation and connection of the quED controller, please refer to the *quED User's and Operation Manual* delivered with the system.

1.3 Power

To switch on the system, please make sure that a suitable power cord is plugged into the socket (see figure 2 (11)) and supplied with 100..230 V, 50..60 Hz AC. Then, switch on the key switch (see figure 1 (1)). Please note that even when the key switch is in the off position, the controller may still consume some power. To ensure that the controller is switched of completely, please unplug the power cord from the controller socket.

2 Front Panel

The front panel (see Fig. 1) consists of only a few elements:

- **P**ower switch (1): The power key switch in the left lower corner turns the main power of the controller on or off. Make sure you always switch off the laser (see below) before you switch off the main power.

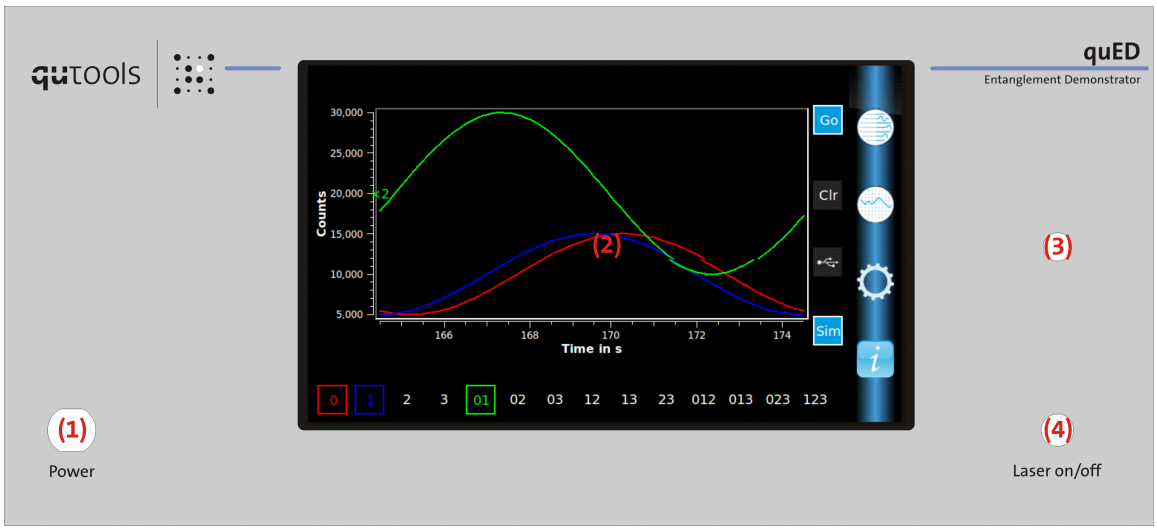


Figure 1: The front panel of the quED controller. Power key switch (1), touch panel (2), rotary encoder (3), laser on/off switch (4).

- **T**ouch panel (2): Most of the functionality is accessible through the touch panel. See section 5 for more information.
- **R**otary encoder (3) (middle, right): Use the rotary encoder to increase or decrease values shown on the touch panel. Note that a press on the rotary encoder while manipulating a data field brings you back to the default value.
- **L**aser on/off switch (4): The laser switch in the right lower corner switches the laser on and off. When it is switched on, it glows red.

Warning: Before switching on the laser, make sure that you are familiar with laser safety regulations and that it is safe to switch on the laser.

Always turn off the laser using this button before switching off the controller completely! Before switching of the laser, turn down the current.

3 Back Panel

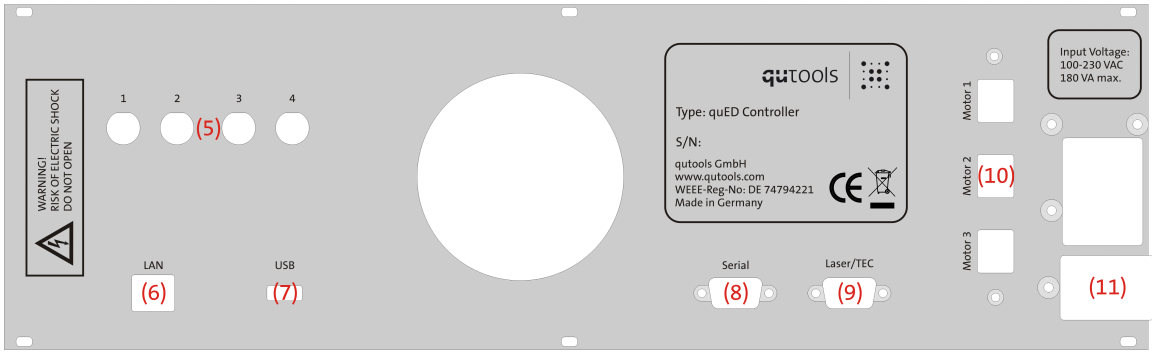


Figure 2: The back panel of the quED controller. Additional APD signal outputs (5), LAN socket (6), USB host socket (7), Serial port connector (8), Laser/TEC connector (9), Stepper motor connectors (10), Mains power connector (11)

The back panel (see Fig. 2) consists of the following connectors (from left to right, top to bottom):

- **A**dditional APD signal outputs (optional) (5): These BNC connectors output the TTL signals from the APDs. Since they are passing through an FPGA, their timing can be slightly altered.
- **L**AN (6): Not used in user mode.
- **U**SB (7): Type A USB host connector. Can be used to connect a USB memory stick or e.g. the external stepper motor driver (optional).
- **S**erial (8): Serial connector. Not used in user mode.
- **L**aser/TEC (9): Connect the cable here that is plugged to the laser head at the other end. Be careful with electrostatic discharges (see quED manual). The pinout is as follows:

#	Name	Potential
1	Fan -	N.C.
2	Peltier +	
3	Peltier -	
4		N.C.
5	Thermistor 1	GND
6	Fan +	N.C.
7	Laserdiode -	GND
8	Laserdiode +	var.
9	Thermistor 2	

- **M**otor 1 to 3 (10): Stepper motor driver connectors (optional). Connect the stepper motors (optional) here. Only use this with suitable stepper motors from qutools.

- Mains Power Connector (11): Use a certified cattle plug to connect the quED controller to a power socket. The input voltage has to be in the range between 100 and 230 V AC, 50 to 60 Hz and can draw up to 180 W.

4 Twin APD Module

On the right-hand side of the controller there is the twin APD module. It works as a two-channel single photon counter. It is a vital part of the quED system and should be handled carefully. When no optical fibers are attached to the inputs the protective caps should always be used to cover them. Please be careful not to expose the APD inputs to very bright light. Normal room light intensities should be no problem, however.

Warning: Never remove or install the APD module while the controller is running. It will get damaged.

Status LEDs The two LEDs display the internal status of the APD module:

Power LED	Temp LED	Meaning
on	flashing	Internal temperature (i.e. the temperature of the APDs themselves) out of bounds (e.g. during start-up), trying to reach desired value.
constantly on or off	constantly on or off	Everything is O.K.
flashing	off	Module is booting
flashing		Module has registered a problem. See troubleshooting.

Tip: High Background Count Rate It sometimes happens that there is a high background count rate in one or both APDs. Often this results from stray light coming in through the fiber connection at the front panel. If you encounter this problem, please try to cover the fiber connections e.g. with some black tissue and/or switch off unnecessary light sources.

Troubleshooting When the two LEDs of the APD module are flashing, it has encountered a problem. There may be different reasons for that, e.g. the desired temperature was not reached after 10 minutes. We suggest to do the following:

1. Leave the controller switched on (if the APDs are overheated, they can cool down sooner, because the fan stays on).
2. Have a look at the ambient temperature in the room. Is it very warm? If so, try to get it cooler.
3. Is something blocking the ventilation of the controller? Make sure that is not the case.
4. Wait at least 30 minutes to let the APD module cool down.
5. Restart the system, observing how the LEDs of the APD module are behaving.
6. If they still report a problem, call qutools support.

The most probable cause for this behavior is that the APD module is overheated. This can happen when the ambient temperature is too high (> 25 °C) or when the ventilation slots are blocked. Please make sure that the ventilation openings beneath, at the back and at the front of the controller are kept clear.

5 Touch Panel

The quED controller features an integrated embedded computer with a touch panel. You can control the laser diode driver, the integrated counting module and the stepper motors (optional) with it.

5.1 Touch Panel Software Overview

The touch panel software is composed of four different modules

1. quLD: The laser diode driver module
2. quCNT: The counter module
3. quMotor: The stepper motor module (optional)
4. quInfo: The information and administration module.

Every module consists of different tabs, which provide information and accomplish different tasks.

Each of those four modules can be selected via the sidebar . The sidebar is always visible on the right most side of the touch panel. You can cycle through the different tabs of each module by repeatedly touching its module button. Alternatively you can cycle back and forth with a horizontal swipe gesture on the main display.

However, you may not see all those buttons if your version of the controller doesn't contain all the hardware modules (e.g. the stepper motor driver).

The larger, left part of the screen is the module screen, where the contents of the different modules are displayed. Also some tabs of the modules are only available if the software is running in the "expert" mode (see section 5.5.1).

5.2 The quLD Module

The quLD module has two different tabs:

1. User Parameters
2. Settings[1]

5.2.1 User Parameters

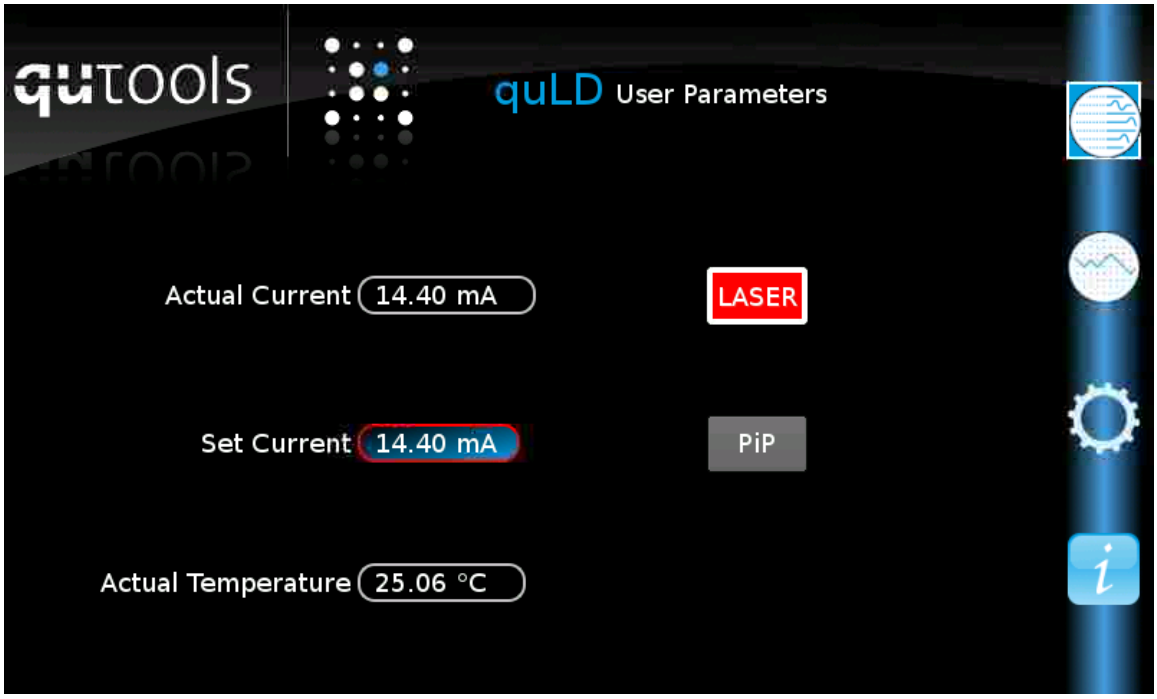


Figure 3: The first tab of the quLD module: User Parameters.

This tab informs you about the current running through, and the temperature of the laser diode.

After selecting the "Set Current" line edit via the touch screen you can change the value of the parameter using the rotary encoder on the front panel. The "LASER" button, on the top right side, indicates whether the laser emission is turned on or off (see figure 3). The data fields "Actual Current" and "Actual Temperature" display the respective values measured by the controller. They should be close to the corresponding "Set" values.

Please note the red warning triangle which might appear in the sidebar. This warning indicates that at least one of the parameters doesn't fit the desired value. This can also be the case when the laser is switched off, but the value "Set Current" is non-zero.

Additionally one can enable a Picture in Picture (PiP) mode by clicking on the "PiP" button. This mode comes in very handy if you want to monitor or change the laser diode

[1] only available in "expert" mode

current while you are working in another module (see figure 4). By clicking the "PiP" button once more you can disable this mode again.

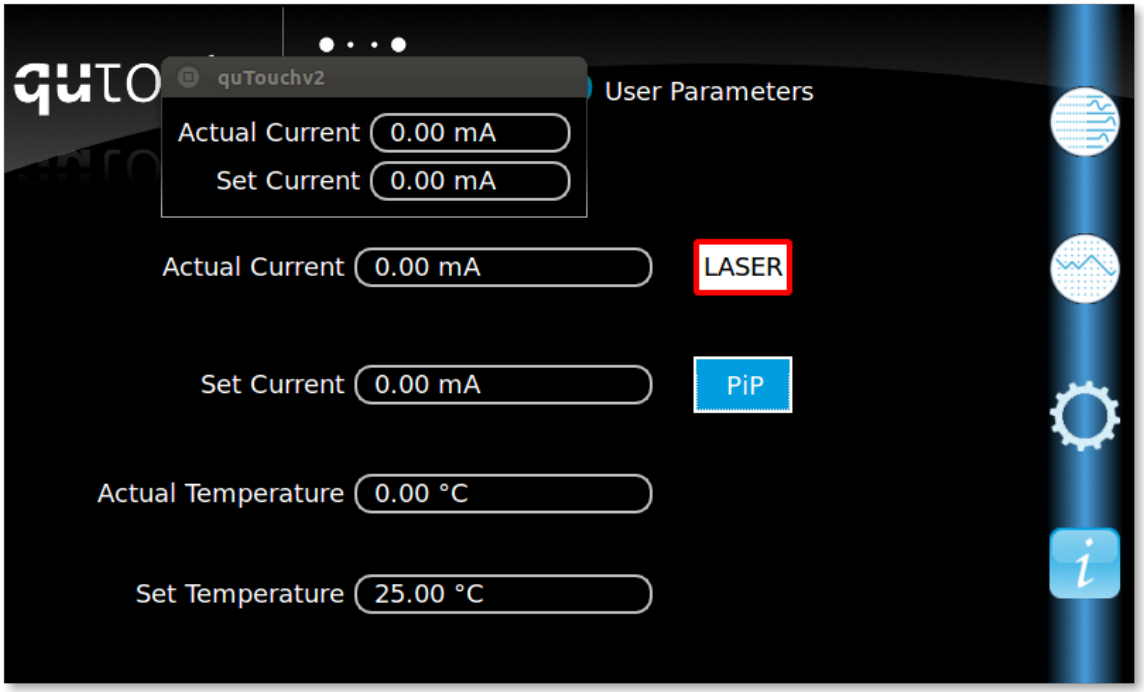


Figure 4: The first tab of the quLD module with enabled picture in picture mode.

5.2.2 Settings

The settings tab is shown in figure 5. Here you can set various options which should not be changed by an unauthorized user, such as maximum and minimum of the laser diode set values. Additionaly you can change the rate of the proportional and integral part of the temperature feedback loop.

After setting those values you can either save them to the EEProm of the quLD hardware or discard them by loading the saved values from there.

Warning: Do not change the preset maximum and minimum values unless you are absolutely sure this is necessary and safe to do. Wrong parameters can lead to a complete failure of the quED.

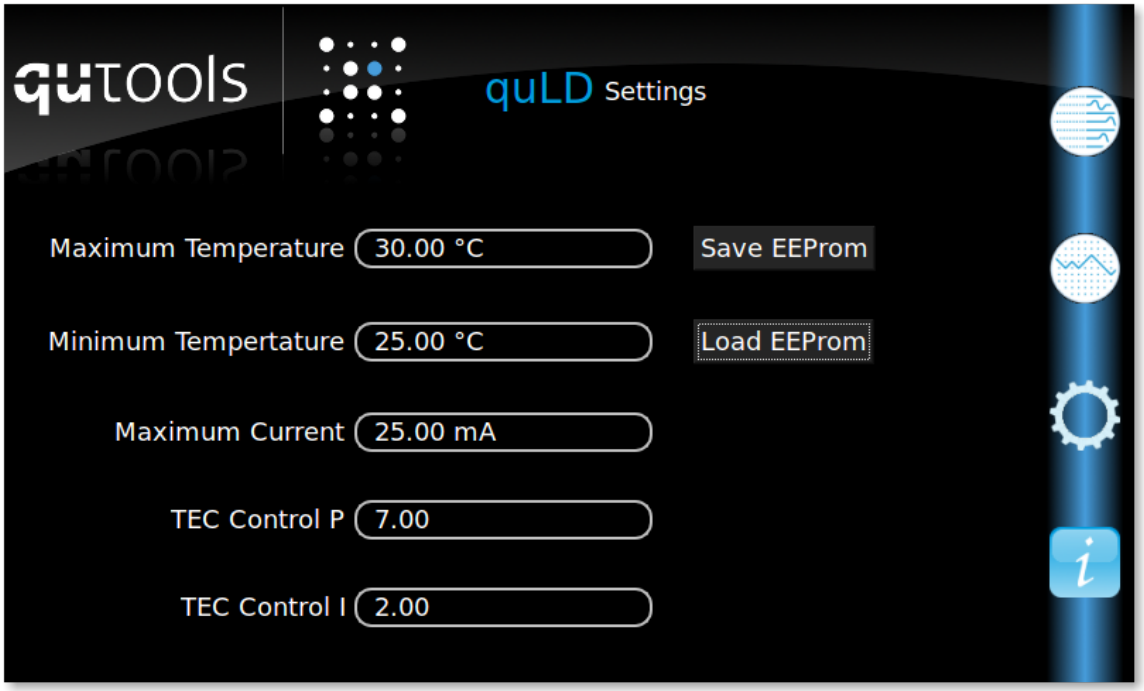


Figure 5: The second tab of the quLD module.

5.3 The quCNT Module

The second button on the sidebar belongs to the quCNT counter module. The first two tabs of this module are displaying the current rates of the different avalanche photo diode (APD) channels and their coincidences. The first one shows them as plain numbers and the second one as a time dependent plot. The third tab provides different display setting for those tabs. Subsequent tabs are only displayed depending on the installed hardware options. Among them are taps to help you perform a measurement of the bell inequality, to register a Hong-Ou-Mandel dip or to generate random numbers.

The first three tabs are named

1. Rates
2. Graph
3. Multipliers and Settings

5.3.1 Rates

The Rates tab displays the different count rates and the integration time of each APD channel and their coincidences (see figure 6). The bar at the bottom can be used to select the rates that are shown. There is the possibility to restrict the selectable channels using the quInfo module in “expert” mode (see sections 5.5.1 and 5.5.4).

A single shot of the rates can be triggered by pressing the “SiS” button. The “Go” button will be deactivated and become grey. For the free-running mode activate the “Go” button

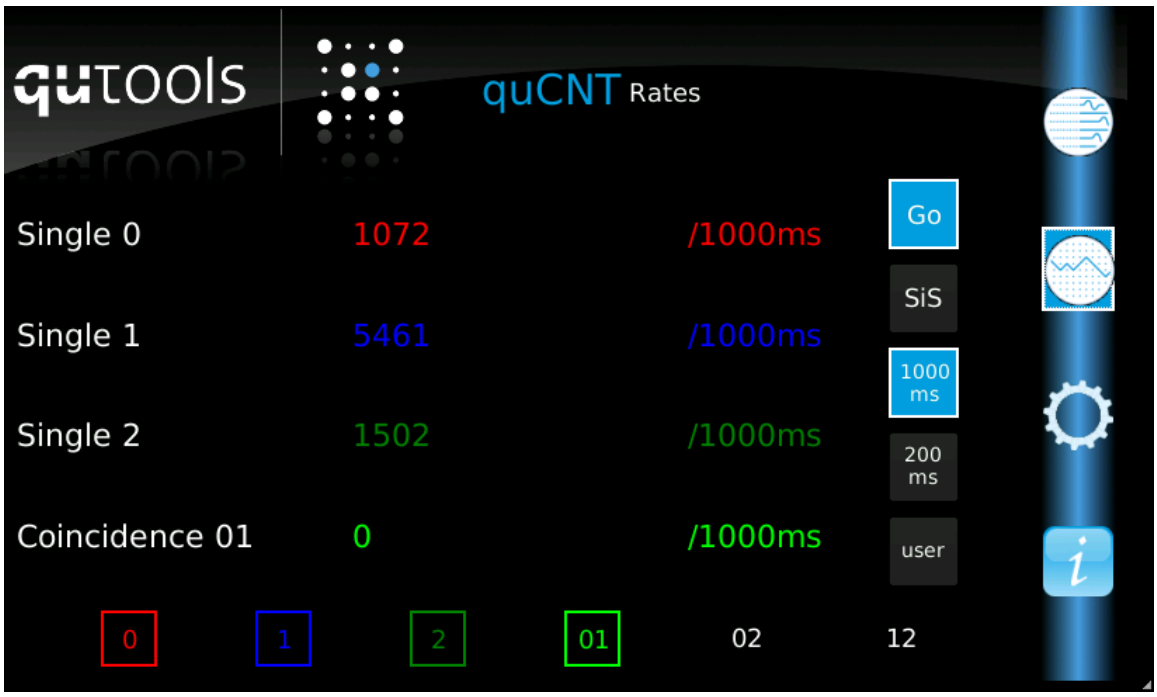


Figure 6: The first tab of the quCNT module with the different rates displayed.

again. The "user" button refers to the integration time set in the "multipliers and settings" tab.

5.3.2 Graph

This tab of the quCNT module visualizes the count rates of the APD channels as a plot against time (figure 7). The values on the y-axis always indicate detections per second, regardless of the selected integration time.

Besides the bar at the bottom, with same functionality as described in section 5.3.1, the Graph tab includes four new buttons. The "Go" button is used to start and stop the plot. The Clear ("Clr") button is used to erase the data in the plot. The "autorange" button toggles autoranging of the y-axis and, finally, The button with the USB symbol ( ) is used for saving the plot data to a usb flash drive.

Because coincidence rates are usually much lower than single event rates, each of the rates can be multiplied by an integer as described in section 5.3.3. This factor is also shown in the plot as can be seen in figure 7 (in this example a green "x 2" close to the y axis).

5.3.3 Multipliers and Settings

As shown in figure 8 the "Multipliers and Settings" tab consists of various line edits which can be used to change the multiplier of a rate. This factor is then applied to the count

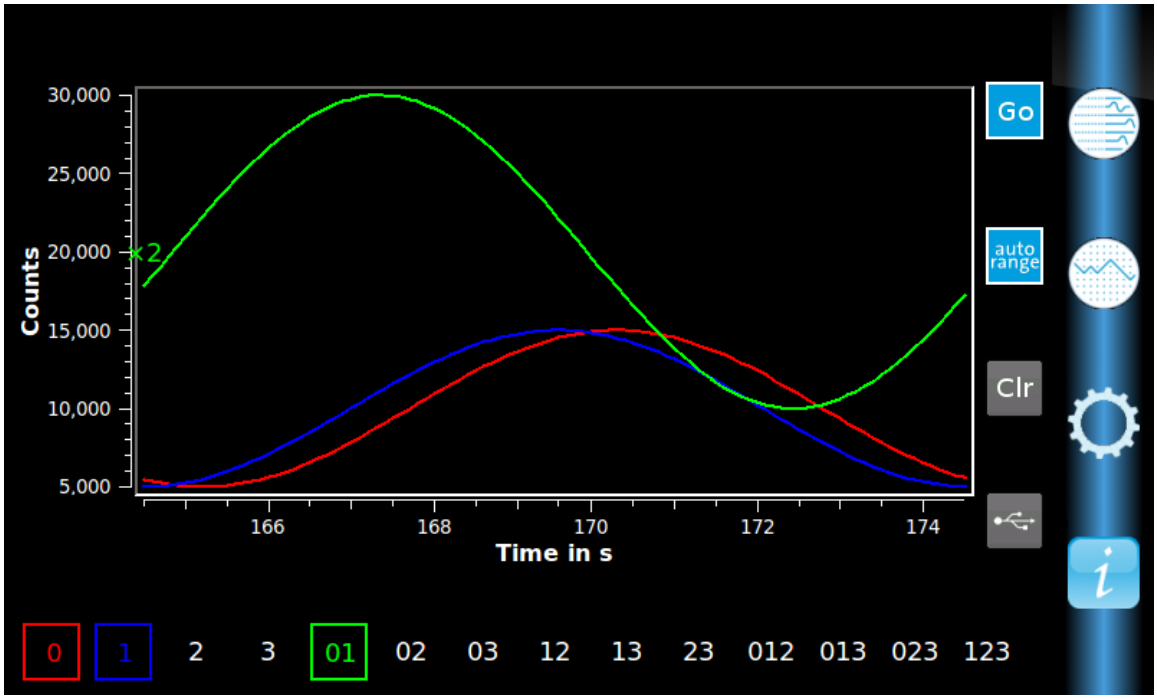


Figure 7: The second tab of the quCNT module with the different rates depicted in a graph.

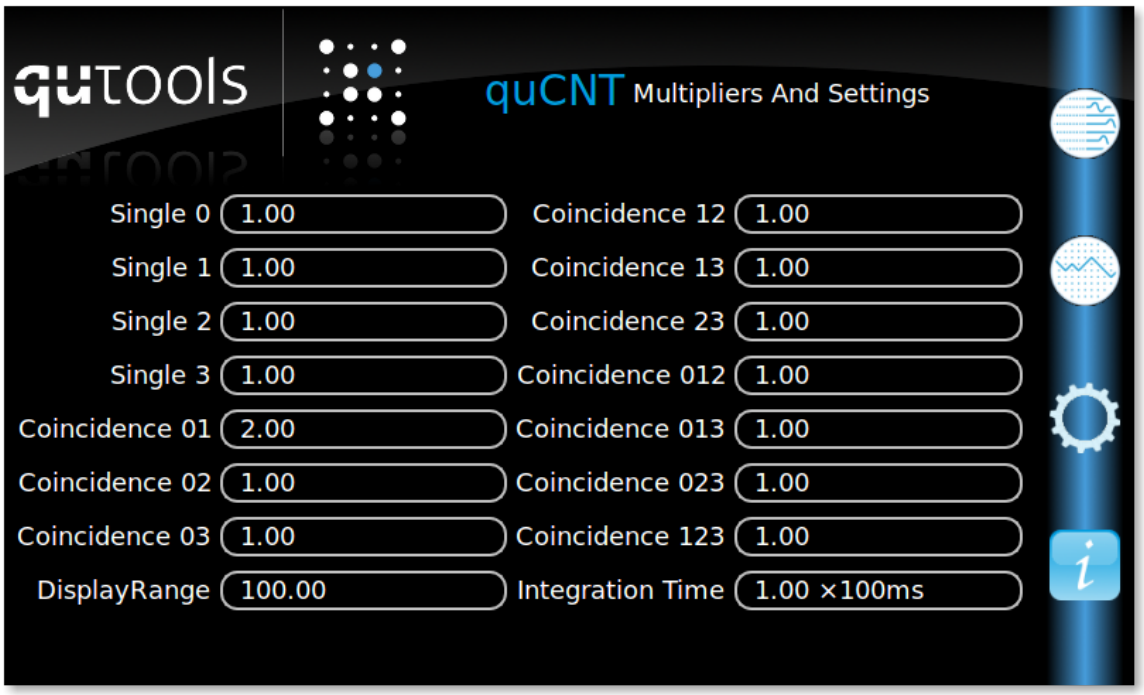


Figure 8: The third tab of the quCNT module with the various multipliers and settings

rates before plotting them in the Graph tab. In the lowest line of this tab you can set the number of data points in the Graph tab (display range) and the user integration time, which will effect both, the Rates and the Graph tab.

5.3.4 RNG

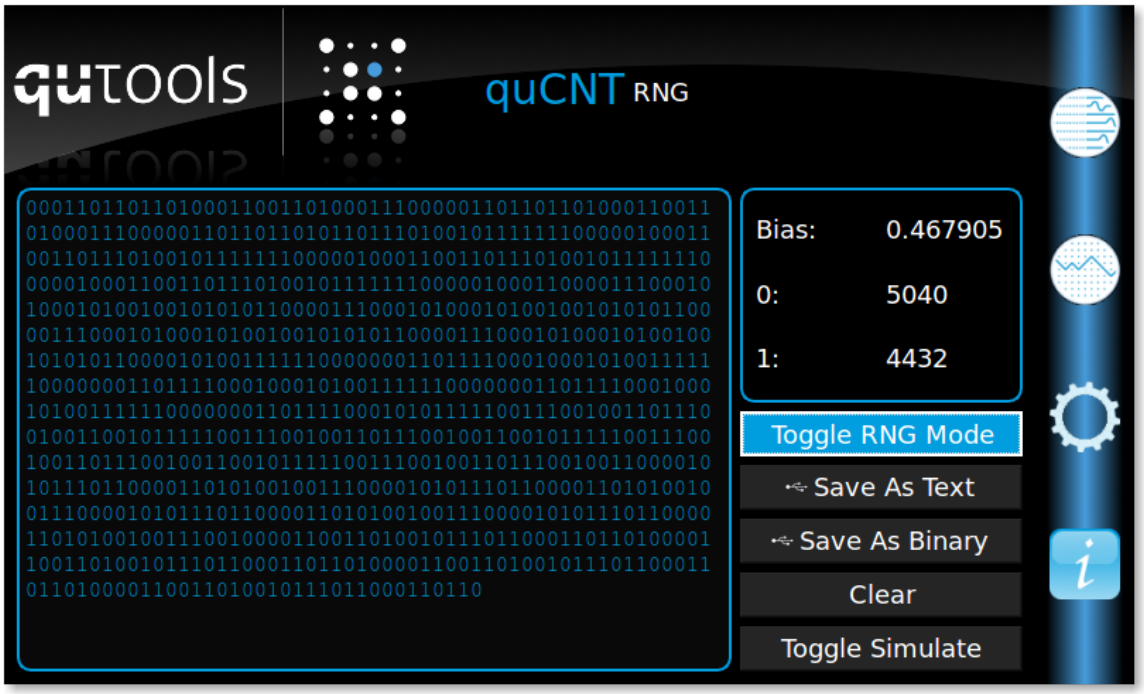


Figure 9: The RNG tab of the quCNT module.

This tab of the quCNT module can be used as a random number generator if at least three different APDs (channels 0, 1, and 2) are installed in your hardware. You can toggle the RNG mode by pressing the respective button as seen in figure 9. A coincidence event between APD 0 and APD 1 is then interpreted as a zero bit and a coincidence event between APD 0 and 2 as a one bit.

Warning: For the time the RNG mode of the quCNT module is enabled, there will be no new count rates displayed in the first or second tab of this module.

The other buttons shown in figure 9 are used for saving the random data either as an ASCII string or as binary data to a USB flash drive. The "Clear" button is used to delete the gathered random bits.

The section above the buttons shows the number of registered ones and zeros in the random string as well as their bias (proportion of ones with respect to all events). The most recently fetched bits are displayed on the left hand side of the screen.

5.3.5 Entanglement Visibility

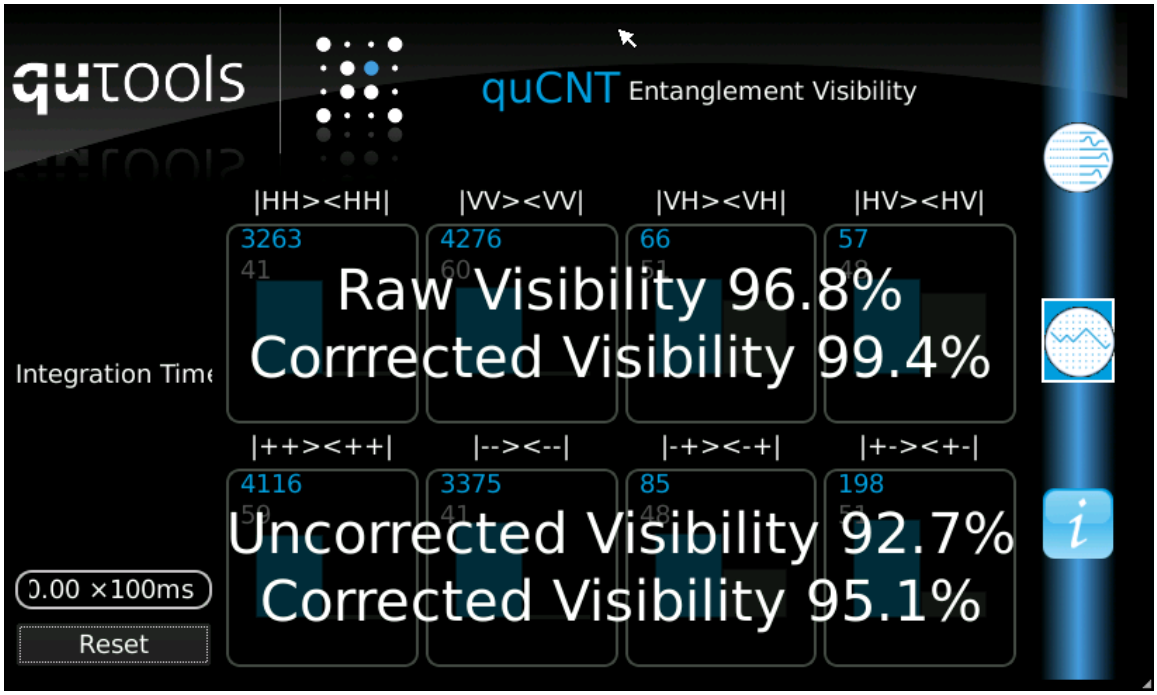


Figure 10: Tab for measurement of the two-photon correlation visibility

The Entanglement of the quED two-photon output state can be analyzed by a measurement of the visibility of the two-photon correlations in mutually unbiased bases. If the polarizers in front of the detectors are mounted in motorized stages and attached to the quMotor driver, this tab can do the visibility measurement completely automatically. Alternatively, without motorized stages, the user can trigger a single correlation measurement by a click on the according box after setting the polarizers manually. The Visibility will be displayed once all measurements in a row are done. Note that the laser has to be enabled manually prior to this measurement.

5.3.6 Correlation Curves

This tab enables measurements of the correlation of the two output photon polarizations. For the given integration time, angular interval and number of steps, the number of

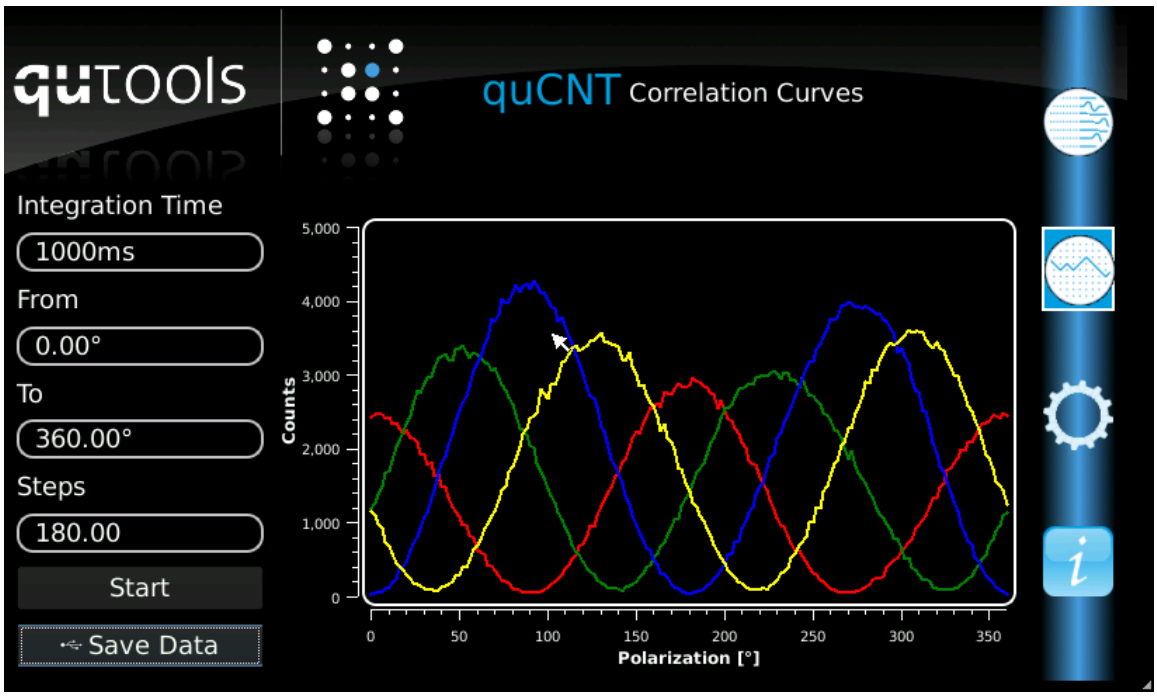


Figure 11: Tab for measurement of correlation curves

coincidences is registered with the first polarizer in the orientation 'H', '+45', 'V' and '-45' automatically. The data can subsequently be stored on an attached USB drive.

5.3.7 CHSH Measurement

In order to evaluate the CHSH inequality, the coincidence rates for 16 polarizer settings have to be measured. Again, if the polarizers are mounted in motorized stages this can be done completely automatically in this tab. Without motorized stages the tab assists the user in the CHSH measurement: Simply adjust the polarizers for each of the 16 settings and click the according tab do trigger the coincidence measurement.

Once all measurements are completed, the CHSH inequality is evaluated and the result is displayed together with an error information. Note that the laser has to be enabled manually prior to this measurement.

5.3.8 Houng-Ou-Mandel effect

This tab shows up if a motor controller is present when starting the quCR. It enables an automatic measurement of Houg-Ou-Mandel effect with an optional motoized qu2PI setup.

Please note that the qu2PI motor has to be connected to the third channel of the motor-driver and that only coincidences of APD channel 0 and 1 are registered.

Four input fields control the measurement:

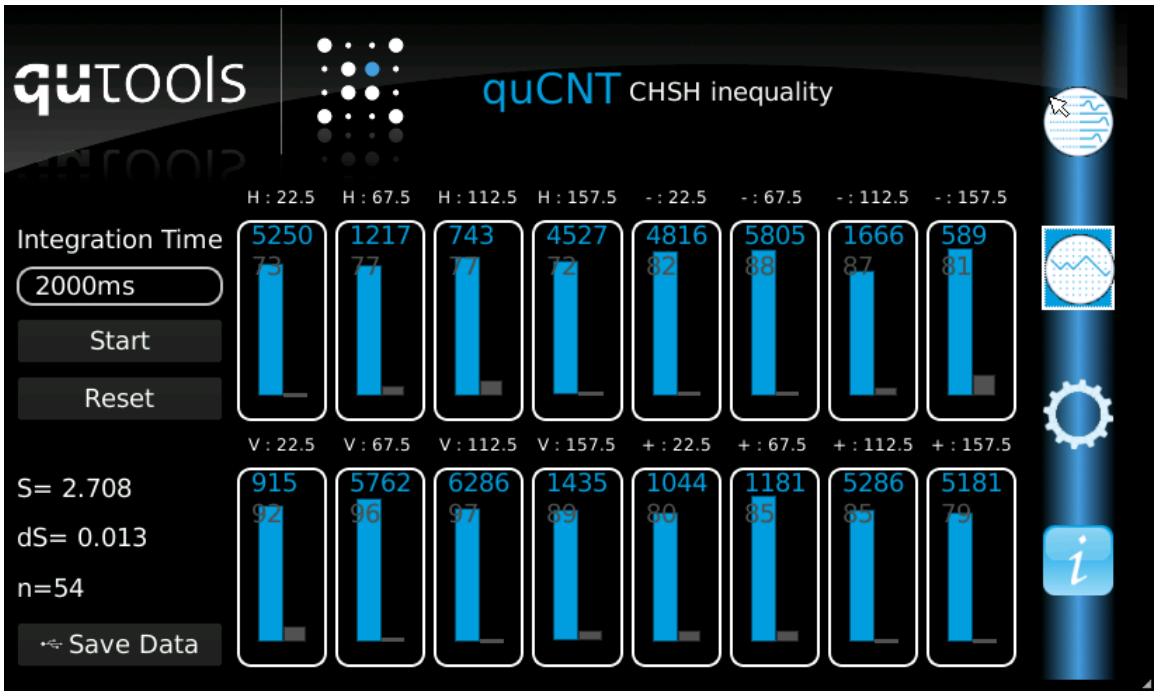


Figure 12: Tab for measurement of the CHSH inequality

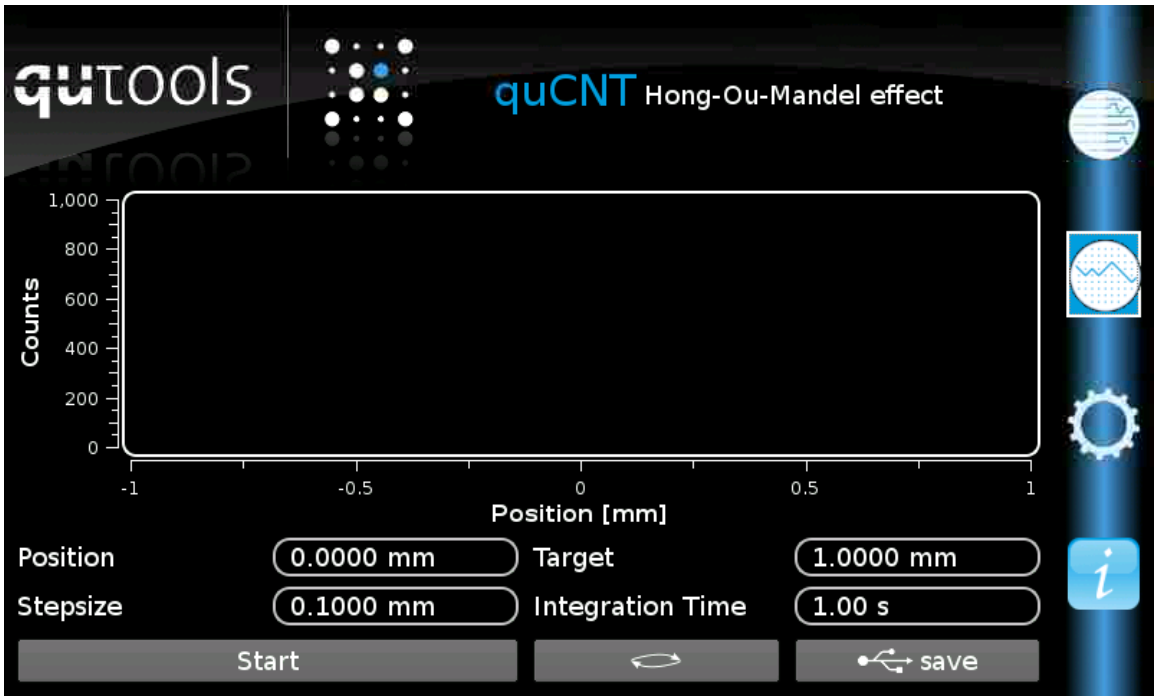


Figure 13: Tab for measurement of the Houg-Ou-Mandel effect.

Position: This field displays the actual position of the linear actuator. You can also manipulate the value. Please understand that this simply shifts the scale. It is usually best to manuall set the position of the actuator to a defined position (perhaps a marking) and then set the position field to zero.

Target: This field indicates the target position of a measurement scan. Once started, the actuator will move in steps of "Stepsize" towards this target position.

Stepsize: The measurement scan will be done in steps of the size indicated here. This parameter can only be manipulated in multiples of the stepper motor stepsize which is 1/3200 mm. The display changes accordingly when the stepsize field has focus.

Integration Time: This sets the integration time per measurement point.

The measurement scan is started with the "Start" button. Once the scan is completed, the state of the arrow button determines how the target position is updated:

The position where the last scan started from becomes the new target position. Useful to scan across the HOM-dip back and forth.

The target is incremented by the length of the last scan. Useful to search for the HOM-dip by scanning 1 mm, then the next and so on.

The data acquired can be stored on an attached flash drive with the USB () button.

5.4 The quMotor Module

The quMotor module is controlled with this tab which is only displayed when the motor driver option is installed: the Motor Positions tab is shown in figure 14.

5.4.1 Motor Positions

In the "Motor Positions" tab you can change the absolute position of the motors in the range from -400° to 400°. This is done by selecting the position field and adjusting the value using the rotary encoder.

The angular positions are relative to the magnetic hardware references of the motors[2]. In case these angles are not valid anymore – i.e. after the motors had been blocked or moved by hand – valid positions can be obtained using the "Go to Zero" button.

To account for the angle between the magnetic reference of the motor and the installed optical element, an offset value can be stored. For this purpose a button "make Zero" is displayed in "expert" mode. When pressed, the motor measures the angle between its current position and the magnetic reference and stores this value as a the new offset. In this way, even a manually set position can be stored as the new zero position. A second

[2]The hardware reference is realized with a hall sensor and a small magnet on the circumference of the large wheel.

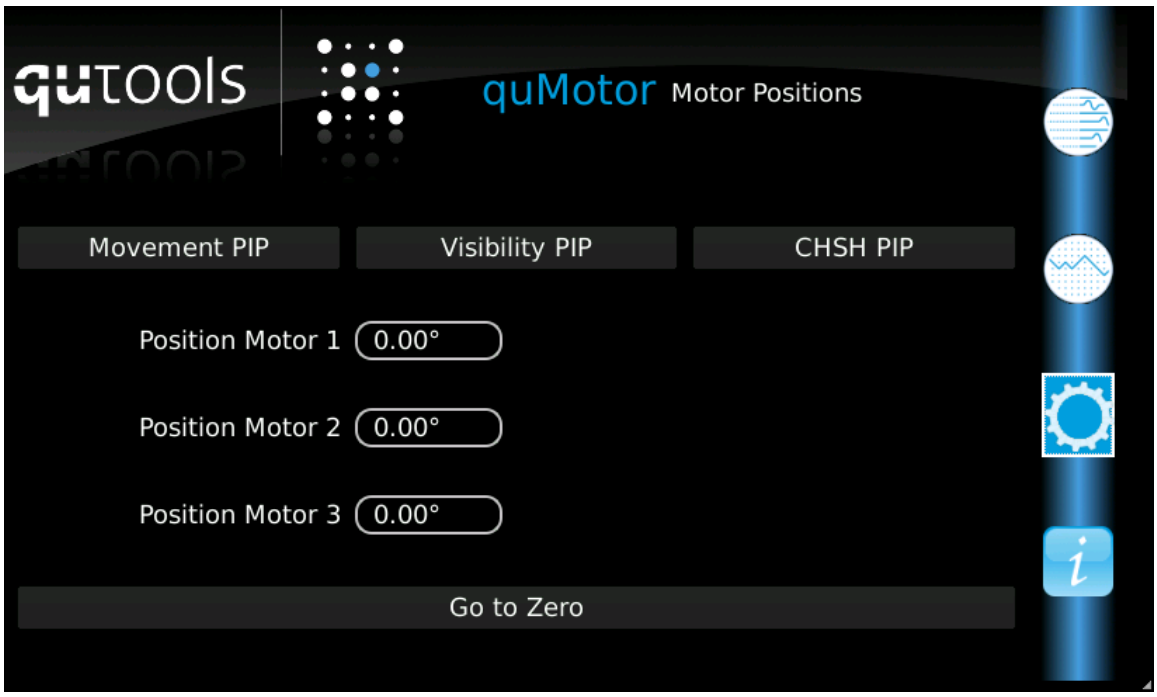


Figure 14: The only tab of the quMotor module.

button "find Ref" displayed in "expert" mode can be used to test the calibration routine of the motor driver. However, the angular position values then do not respect the stored offset value anymore.

To facilitate measurements one of three PIP windows can be enabled:

Measurement PIP: allows to change the angular position of the motors to arbitrary values

Visibility PIP: offers hotkeys for the eight angular combinations necessary to measure the visibility of an output state

CHSH PIP: offers hotkeys for the 16 angular combinations necessary to measure the violation of a CHSH inequality

5.5 The quInfo Module

The quInfo module is used for different administrative tasks. However most of the tabs in this module are only available in the "expert" mode:

1. Change Mode
2. Info and USB Update[1]
3. Change Expert Pass phrase[1]
4. Rates Configuration[1].

[1] only available in "expert" mode

5.5.1 Change Mode

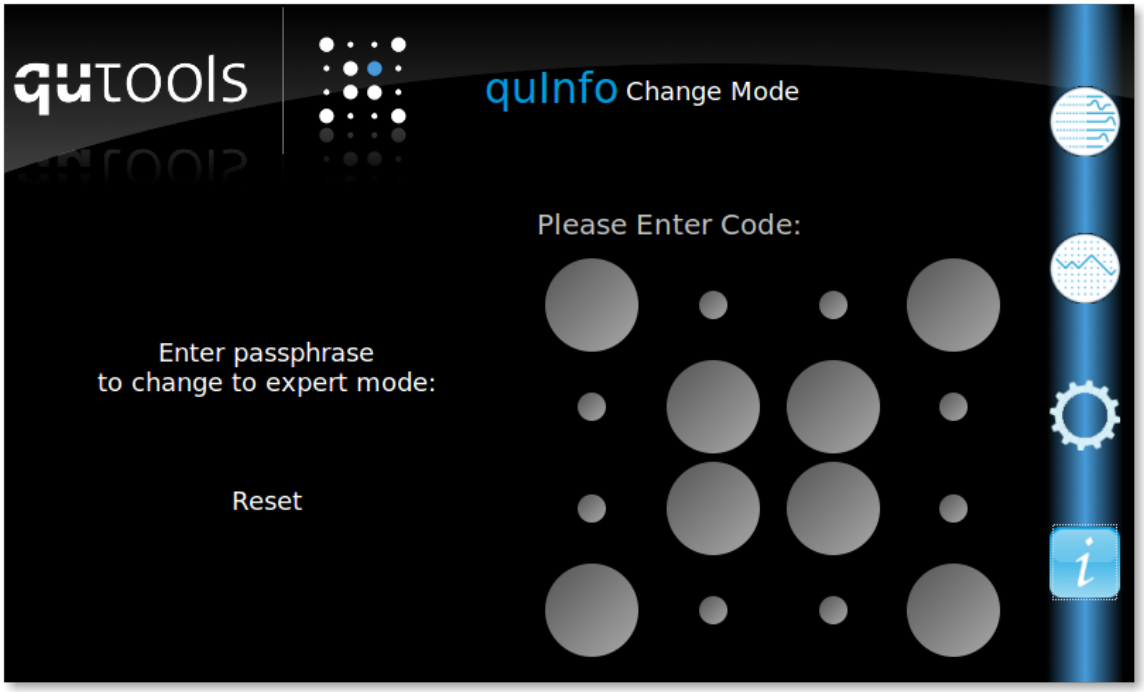


Figure 15: The tab used for switching to the "expert" mode.

Warning: The "expert mode" should only be used when absolutely necessary. While in this mode, the user has approach to parameters which might cause permanent damage to the laser diode.

This tab, shown in figure 15, is used to change to the "expert" mode. Here all circles on the right hand side can be clicked once to compose the proper pass phrase. If you pressed a wrong circle, you can retry by pressing the "Reset" button on the left. After you successfully entered the pass phrase, the quInfo Module immediately switches to the Info and USB Update tab described in section 5.5.2. The Change Mode tab itself, will change like displayed in figure 16 and is then used for switching back to the standard mode.

5.5.2 Info and USB Update

This tab provides you with some additional information such as the current software revision and the startup time. It also shows the current IP address(es) of the device (see figure 17). Please use the "refresh" button to update the IP display when necessary.

Figure 16: The tab used for switching to the standard mode.

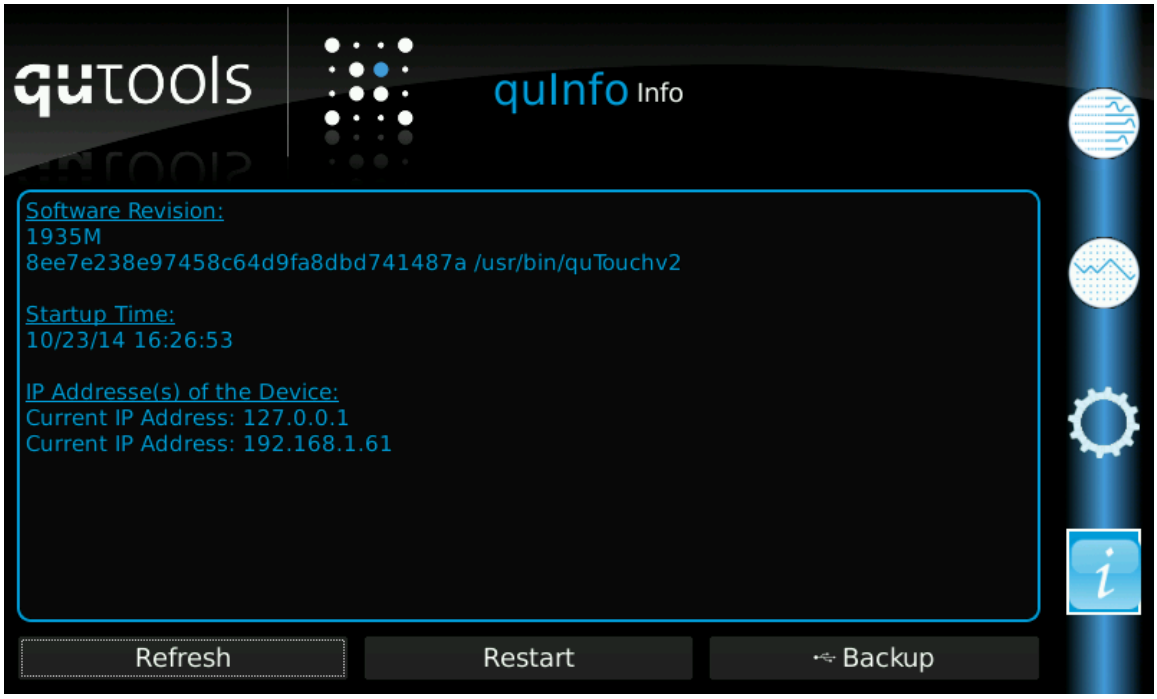


Figure 17: The Info and USB Update tab.

Backup: In addition you can backup the software in this tab to a USB flash drive. Simply plug in the flash drive and give it some time to be mounted automatically. Then hit the "Backup" button. This will copy the currently installed version of the quTouchv2 software to the flash drive. Please ensure that the backup was successfully written by looking into the stick from a computer.

Update: In case you want to update[3] or restore the quTouchv2 software, please follow these steps:

- Make a backup of the currently installed version as described Above.
- Copy the new version of quTouchv2 to the root directory of an empty flash drive. In case you want to restore an earlier backup, first rename it to "quTouchv2". If the update comes as a zip archive, please extract the content to the root directory of the drive and make sure the directory structure is maintained.
- Turn off the controller and plug in the prepared flash drive.
- Turn on the controller. The system should now start with the update process and run the quTouchv2 software directly from the flash drive. This is indicated by the message "evaluation-mode" in the top left corner of the display. For a more involved updates, in order to arrive at this state it might be necessary to turn the controller off and on again with the flash drive attached.
- You can now evaluate the software without any restrictions. Additionally, in the info tab, the md5 checksum of the running binary is displayed. Please compare it to the value provided with the update to verify the integrity of the binary.
- While in "evaluation mode" the info tab displays an "update" button. If you finally want to make the program version currently running from the flash drive permanent, hitting this button will copy the binary from the flash drive to the controller memory. A message requesting a reboot is displayed afterwards. Please remove the flash drive and hit "restart".

After this process, the new or restored version is installed permanently. Please remove the update files from the flash drive in order to avoid starting in evaluation mode in the future when using the drive with the controller.

5.5.3 Change Expert Passphrase

This tab is used for changing the expert mode pass phrase (see figure 18). It has to be composed of 4 distinct circles and the order in which they have been touched. The changed pass phrase will be saved immediately after you clicked the last (4th) circle of the pass phrase. The new pass phrase is valid after you restarted the application via the restart button described in section 5.5.2. In case you pressed an unwanted circle you can restart typing the new pass phrase by pressing the reset button. If your last circle was wrong just start typing a new pass phrase.

[3] You can find software updates in the download area of our website: http://www.qutools.com/download/list.php .

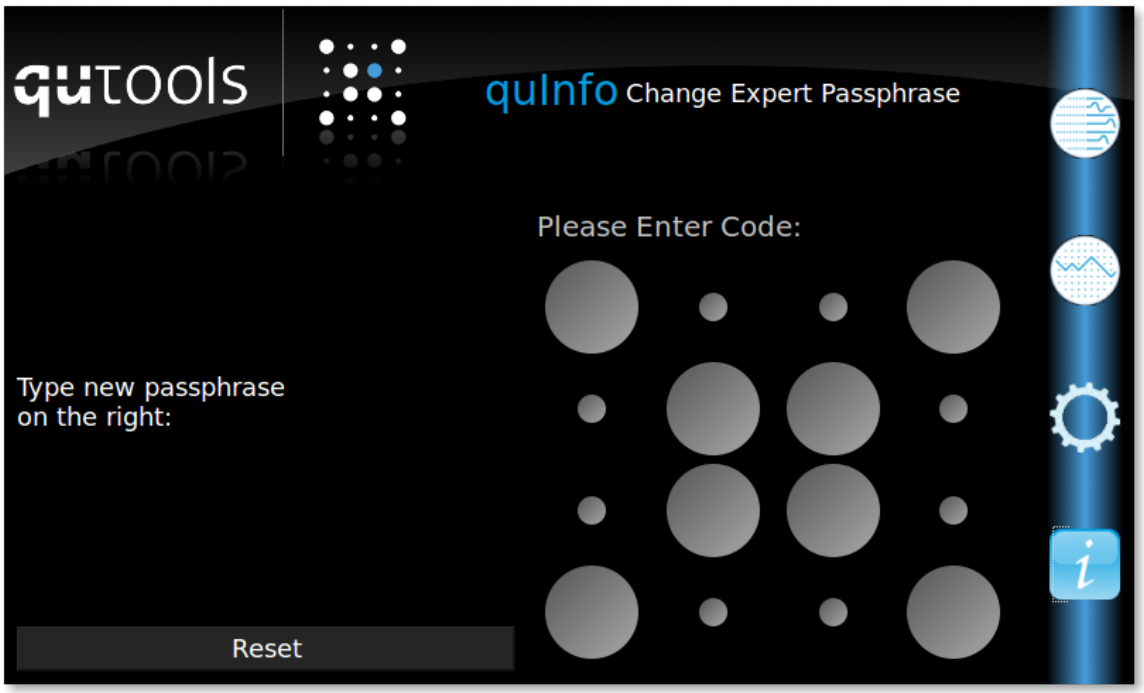


Figure 18: Change the Expert Passphrase tab.

5.5.4 Rates Configuration

This last tab (figure 19) is used for selecting those APD channels which can be chosen in the quCNT tabs described in sections 5.3.1 and 5.3.2. A checked box in the left column will show the respective button, an unchecked box will hide it, so you can't see it at all. The right column defines which of those buttons are enabled by default at the start-up of the application.

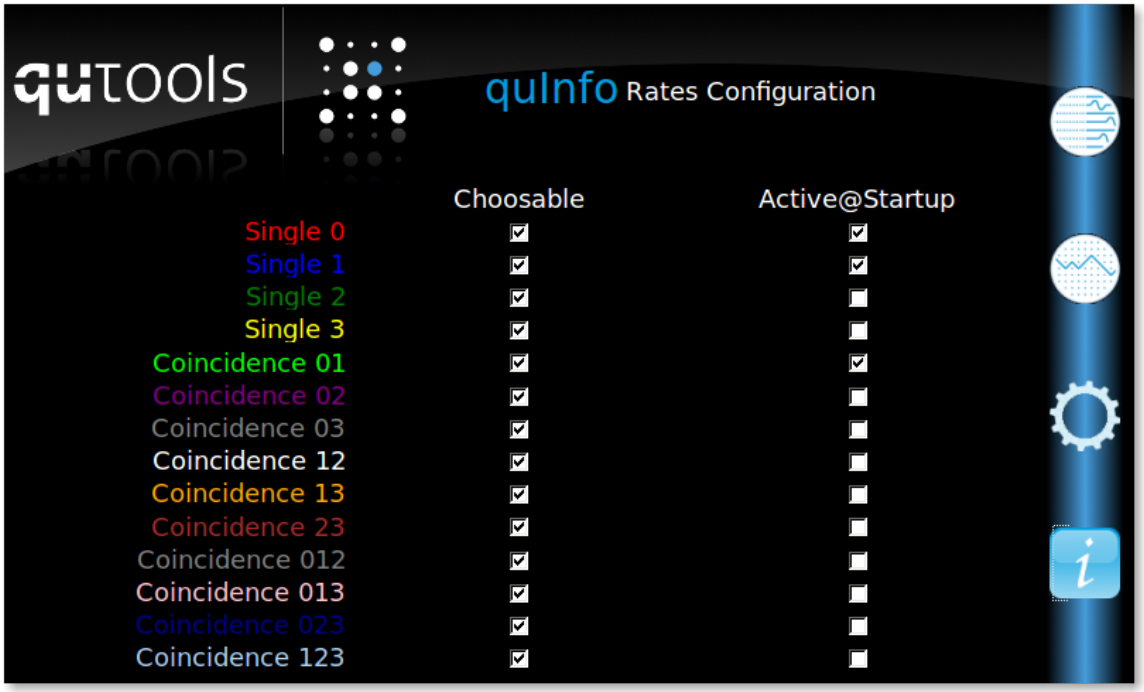


Figure 19: The Rates Configuration tab.

6 Controlling the quCR via Ethernet

Some functionalities of the quCR can also be used over the network. If the quCR is connected to a DHCP device (such as a router), the assigned IP address will show in the Info tab (see Sec. 5.5.2). With that, you can both open a VNC connection or control some functionalities of the quCR remotely by HTTP.

6.1 Open a VNC connection

To open a VNC connection (to, e.g., display the quCR screen on a big screen or beamer), type in the IP adress of the quCR into your VNC software (*VNC Viewer* for Windows is free and works fine). If prompted for a password, use **qut00lsMUNICH**. You will then get access to the screen of the quCR and all its functionalities.

6.2 HTTP Interface

The quCR can also be controlled via HTTP. For that, build the URL like this:

`http://<ipaddress>:8080/?action=<action>&param=<parameter><&value=<value>>`

Valid actions are "‘get"’ and "‘set"’, valid parameters are:

- "‘ild"’: Laser diode current (set and get)
- "‘pm1"’, "‘pm2"’: Motor positions 1 and 2 (set only, in degrees)
- "‘int"’: Integration time in ms (set and get)
- "‘cnt"’: Get Countrates (get only)
- "‘mref"’: recalibrate motor <value> (set only)

For example, you can get all countrates by requesting the URL

`http://192.168.1.23:8080/?action=get&param=cnt`

The motor position of the first motor could be set by

`http://192.168.1.23:8080/?action=set&param=pm1&value=22.5`

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