quTAG

Time-to-Digital Converter

Manual V1.4

Contents

1. Introduction

The quTAG is a time-to-digital converter that measures electric signals and marks them with time tags. This stream of time tags can be used in various and versatile applications – from measurements in the picosecond range up to days. The universal time tagging method allows correlation measurements (cross-correlation, auto-correlation), lifetime measurements (start-(multi)stop) and many more possibilities within one measurement. The saved stream of time tags contains all information needed to reconstruct every measurement and analysis performed.

2. Safety and Maintenance

2.1 Legend

	Caution	General risk of danger.
	Warning	An instruction which draws attention to the risk of injury or death.
	Warning	Risk of electric shock. High voltages present.

2.2 General Instructions

The equipment, as described herein, is designed for use by personnel properly trained in the use and handling of mains powered electrical equipment. Only personnel trained in the servicing and maintenance of this equipment should remove its covers or attempt any repairs or adjustments. If malfunction is suspected, immediately return the part to the vendor for repair or replacement. There are no user-serviceable parts inside the electronics. Modified or opened electronics cannot be covered by the warranty anymore. Take special care if connecting products from other manufacturers. Follow the General Accident Prevention Rules.

If this equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired. Do not operate the instrument outside its rated supply voltages or environmental range. In particular, excessive moisture may impair safety.

For laboratory use only. This unit is intended for operation from a normal, single phase supply, in the temperature range 5° to 40°C, 20% to 80% RH.

2.3 Environmental Conditions

Warning. Operation outside the following environmental limits may adversely affect operator safety:

- Indoor use only
- Maximum altitude 2000 m
- Temperature range 5°C to 40°C
- Maximum humidity less than 80% RH (non-condensing) at 31°C
- To ensure reliable operation the unit should not be exposed to corrosive agents or excessive moisture, heat or dust. If the unit has been stored at a low temperature or in an environment of high humidity, it must be allowed to reach ambient conditions before being powered up.

2.4 Electrical Installation

The unit must be connected only to an earthed fused supply of 100 to 240V (Japan, USA and Europe).

Use only power supply cables supplied by the manufacturer, other cables may not be rated to the same current. The unit is shipped with appropriate power cables for use in Europe. When shipped to other territories the appropriate power plug must be fitted by the user.

Never connect any cabling to the electronics when contacts are exposed!

Avoid short-cuts.

Prevent electrical shock from electronic. To prevent electrical shock do not remove the cover of the control unit. Unplug power cord and all other electrical connections and consult qualified service personnel when servicing or cleaning. Operate only under dry conditions and at room temperature conditions.

2.5 Preventive Maintenance

The equipment contains no user serviceable parts. There is a risk of severe electrical shock if the equipment is operated with the covers removed. Only personnel authorized by the vendor and trained in the maintenance of this equipment should remove its covers or attempt any repairs or adjustments. Maintenance is limited to safety testing and cleaning as described in the following sections.

2.6 Safety Testing

Safety testing in accordance with local regulations, should be performed on a regular basis, (typically once per year for an instrument in daily use).

Caution. The instrument contains a power supply filter. Insulation testing of the power supply connector should be performed using a DC voltage.

2.7 Cleaning

Disconnect the power supply before cleaning the unit. Never attempt to clean the quTAG by immersion into any liquid. Never allow water to get inside the case. The quTAG parts are sensitive to any kind of liquid. Do not use any type of abrasive pad, scouring powder, or solvent, e.g. alcohol or benzene. Please note that all parts of quTAG are cleaned in our production facility.

3 Technical Information

The key features of the quTAG device are:

- High timing resolution (bin size 1 ps)
- High event rates
- USB3.0 interface
- Easy-to-use

The device can be used for a variety of Applications:

- Time correlated single photon counting (TCSPC)
- Fluorescence lifetime imaging
- Quantum information experiments
- LIDAR
- High energy/accelerator physics
- High precision time measurements

Channels	4
Bin width	1 ps
Input pulse high level	-3.3 V ... 3.3 V
Input pulse width	300 ps
Input pulse separation	40 ns
Input Impedance	50 Ω

4 Technical Specifications

Time to digital converters

Digital resolution	1 ps
Timing jitter, RMS	< 10 ps , < 4.2 ps (jitter upgrade)
Timing jitter, FWHM	< 25 ps , < 9.9ps (jitter upgrade)
Max. event rate per channel	25 Mcps 200 MHz periodic (with divider)
Sustained throughput rate	100 Mcps (USB3.0)
Delay range	-100 ... +100 ns
Delay resolution	1 ps
Min. pulse to pulse separation	40 ns
Differential non-linearity	<1%
Max. acquisition time without overflow	13 days

Input Channels

Number of channels	1 start, 4 stop (model dependent)
Input connector	SMA
Signal levels (threshold comparator)	-3 ... +3V e.g. LVTTL, NIM
Threshold level resolution	1.46 mV
Max. input level	± 3.3V
Edge	Rising, falling
Min. input pulse width	300 ps
Termination	50 Ohms
Divider	On start input (model dependent)

Clock Input (model dependent)

Frequency	10 MHz (model dependent)
Signal levels (threshold)	-5 ... +5V
Signal form	Sinusoidal, square wave
Termination	50 Ohms
Input connector	SMA

Synchronization (model dependent)

Number of synchronizable quTAGs	4
Number of synchronized stop channels	16

Operation

Interface	USB3.0
Operating system	Windows, Linux
Power consumption	< 50W at 100 to 230 VAC, 50-60 Hz

5 Variants and Options

The quTAG is available in the basic and the standard variant. The variants differ in the availability of optional features that can also be installed individually. For the procedure of installation refer to section 7.4 .

Option	Meaning
3 Channels	3 stop channels are available.
4 Channels	4 stop channels are available.
Start as Ch. 5	The start input may be used as 5th stop channel, allowing the device to have 5 completely equal input channels.
Markers *	4 GPIO-Inputs can be used as data markers. The markers are included in the timeline to help sorting timestamps. See sections 6.2 and 8.1 .
Ext. Clock	The device may be synchronized to an external clock signal.
Device Synchronization	Up to four devices may be synchronized allowing to use all 16 stop channels at the same time.
Filters	Filters timestamp events that are not needed for the application. This filtering happens inside the device and therefore saves bandwidth on the USB connection. See section 8.2 for more details.
HBT	Enables correlation measurement software, see section 8.6 for details.
Lifetime	Enables lifetime measurement software, see section 8.7 for details.
Jitter Upgrade *	This feature allows to reduce the time tag jitter to < 6.4 ps RMS on all four input channels, or < 4.2 ps RMS for two pairs of combined channels. For optimal jitter results, recalibration with external signals might be necessary. See section 8.8 for details.

* not available in basic variant

6 Hardware Description

6.1 Rear side

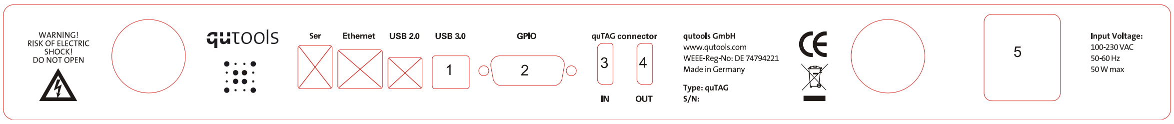


Figure 1: Rear side of the quTAG

1: USB3.0 connection

2: GPIO connection, used for Marker inputs

3: Synchronization input

4: Synchronization output

5: AC power input and power switch

Note: The "Ser", "Ethernet" and "USB 2.0" connectors are reserved for future use and will not work.

Make sure the cooling fans are not obstructed. Otherwise the quTAG may be damaged due to overheating.

6.2 Marker Inputs

In addition to the 4+1 channel input, the device features marker inputs that insert marker timestamps in the timeline. They can be connected e.g. to some pixel clock or line clock in order to help sorting the timestamps. The GPIO Connector is used for those inputs:

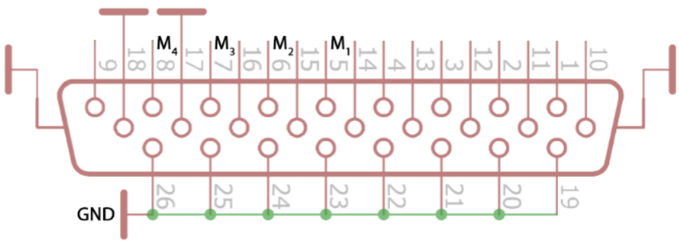


Figure 2: D-Sub connector at the back panel

Marker inputs 1...4 reside on pins 5...8; pins 17...26 are used for ground.

Marker Inputs	4
Input pulse width	Min 10 ns
Input pulse level	Low -0.5 ... 0.8 V High 2.0 ... 5.5 V
Input Impedance	470 Ohm
Frequency	10 MHz
Digital resolution	5 ns
Timing Jitter	2 – 5 ns

6.3 Front side

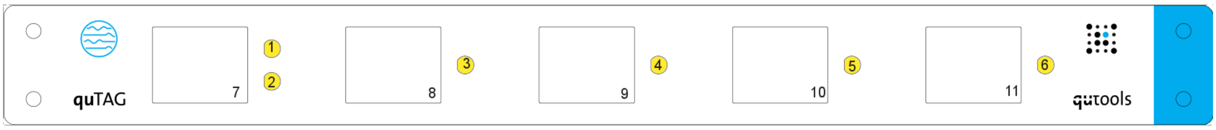
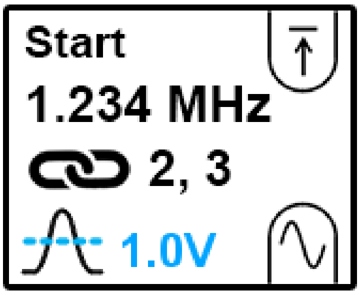


Figure 3: Front side of the quTAG

1:	Start input connector
2:	Clock input connector
3...6:	Stop input connectors 1...4
7:	Start channel display
8...11:	Stop channel 1...4 displays

6.4 Displays on the front panel



Single tap on the left display to toggle on and off the illumination of all displays within the device.

Start	Channel mode (start/stop) and channel number.
1.234 MHz	Displaying the counts per second.
 **2, 3**	Shows coincidences with other channels within the device.

	Threshold with rising / falling edge. The threshold level is displayed next to it.
	External Clock connected / Clock not connected
	Synchronization: connected as slave device / error in connection
	Synchronization: connected as master device / error in connection
	Filter (see section 8.2 for details) active on that channel

6.5 Synchronization

If more than four stop channels are required for a measurement, up to four quTAGs can be synchronized – provided the "Sync" option (see section 5) is activated. To synchronize devices, turn off their power and connect them using the provided cables as shown in figure 4.

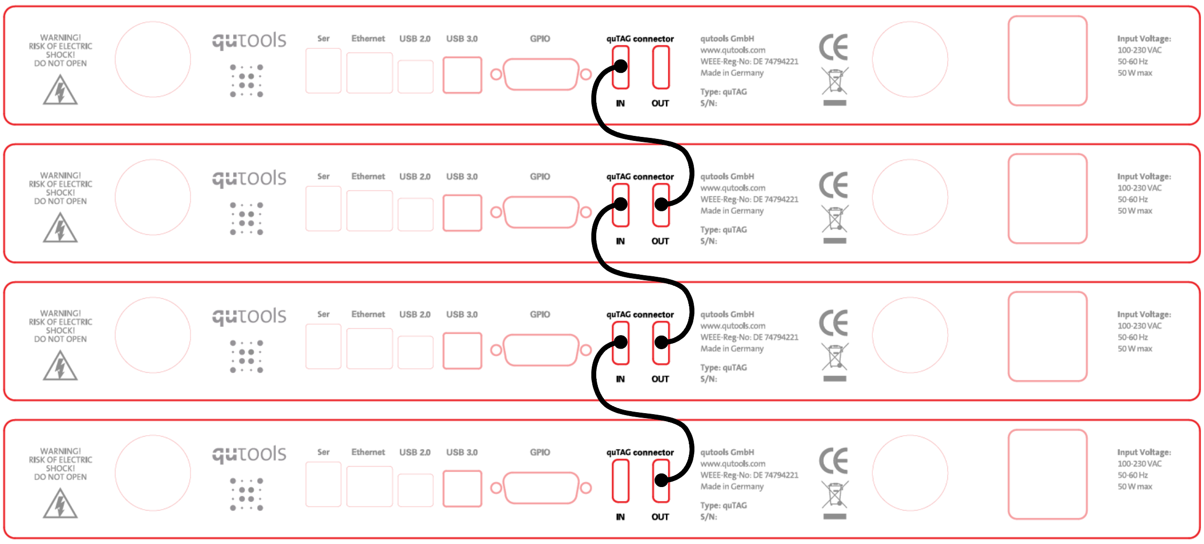


Figure 4: Diagram showing cable configuration for synchronizing quTAGs with bottom device as master

We recommend putting the devices on top of each other. For each pair of neighboring devices, the quTAG "OUT" connector of the bottom device is connected to the "IN" connector of the top device using the provided cables. After the devices are turned on, you can obverse the changed channel numbers on the front displays.

Please note that all devices must have the "Sync on Power on" setting enabled (see section 8.1). When the devices are switched on, the synchronization setup will be started within the device. The left display will show the number of this device in the chain and all found devices. When the link to the next device is established, the arrow turns green and the device is ready. Please tap on the left display when all devices are found.

A hotplugging of devices is not possible. Please make sure that all devices that need to be synchronized are switched on and found during the described setup.

For alignment and initial measurements with synchronized devices Daisy can be used. After startup a dialog will appear which allows you to choose which device will be connected.

Multiple instances of Daisy can be run to work with different synchronized devices. For measurements using Timestamps from all synchronized devices the Tarec tool must be used, see section 9.1 .

6.6 First Setup

- Supply power to the quTAG via the AC power input and turn it on using the power switch.
- Connect the quTAG to a PC using the USB 3.0 connector. An USB 2.0 cable can be used, but limits the transfer rate.
- The clock input hasn't to be connected in most cases. It is used only to synchronize the device with an external clock source of about 10 MHz.
- "Payload" signals are connected to the start and the stop input connectors.

7 Software Installation and Configuration

7.1 Software Installation

The quTAG software can be installed on Windows 7, 8, 8.1, and 10, 32- and 64 Bit. The Linux version requires a x86-64 Bit distribution with libc 2.19 or newer.

On Windows, using the installer `Daisy@QUTAG-Vx.y.z.exe`	Start the installer program and follow the instructions. Drivers and necessary libraries will be installed automatically.
On Windows, using the zip archive `QUTAG_Vx.y.z.zip`	Extract the zip archive to a directory of your choice. Install the device driver in the `usbdriver` directory using dpinst32.exe or dpinst64.exe, whatever conforms to your Windows version.
On Linux, using the tgz archive `QUTAG_Vx.y.z.tgz`	Extract the archive to a directory of your choice. Follow the instructions in `install/readme.linux.txt`.

The following software will now reside in the installation directory:

`daisy(.exe)`	"Data Analysis and Imaging System" – the main control software for the quTAG. See chapter 8 .
`nhflash(.exe)`	The firmware update tool. See section 7.2 .
`tarec(.exe)`	A record & merge tool for synchronized devices. See section 9.1 .
`tdccli(.exe)`	A command line tool for simple tasks. See section 9.3 .
`userlib`	The directory contains the custom programming library, with HTML documentation and LabView wrapper VIs. See section 9.2 .
`usbdriver`	USB driver packet for Windows 32 and 64 Bit.
`firmware`	Firmware for the device.

When using the Windows installer, also start menu entries for the programs are created.

7.2 Firmware Update

Attention: Naturally, firmware updates are a delicate process and can potentially harm the device if done incorrectly. Please read and follow the instructions carefully.

A firmware update is generally necessary when a new software version is installed. If the control software is warning about an outdated firmware or if you are unsure if the firmware currently running is up to date, execute the following procedure:

1. Turn on the device. If any quTAG software is still running, close it.
2. Start `nhflash(.exe)`. After some time, the indicator turns green. Proceed only if the tool display "Firmware: outdated".
3. Press "Flash". Make absolutely sure the device is not shut down or disconnected during this step! The flash process takes several minutes and may seem to hang without progress for up to 3 minutes. After the update is completed successfully, the indicator stops flashing and the text next to it shows "Update complete".
4. Close the firmware update utility.
5. Turn the quTAG device off and on again.

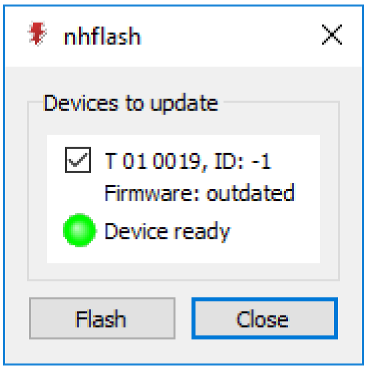


Figure 5: The firmware update tool nhflash

7.3 Hardware ID

The Hardware ID is a (positive) number stored in the device so that it can be used to distinguish between multiple quTAG that are connected to the same PC. If the Daisy software detects more than one device, it asks the user to select a device using the Hardware IDs and serial numbers. Also the DLL uses the ID to identify a device. If device discrimination is an issue, individual IDs should be programmed.

To assign a device ID start Daisy.exe, locate "id.ngc" in the installation folder with the file manager and drag it into the program window (or open the program menu using ctrl+F9 and select file/ load panel). Enter an individual ID and press "Save". Close the program window and restart the device.

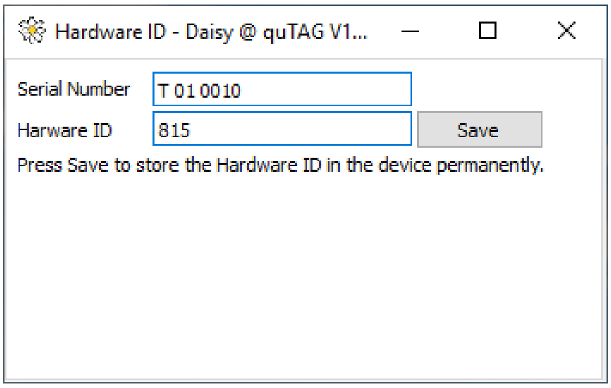


Figure 6: Programming the Hardware ID

7.4 Option Upgrade

As stated in chapter 5 the number of axes and some features of quTAG are optional. Options and axes may be upgraded (or downgraded) on-site by entering a device specific key. The serial number of the quTAG is required when ordering an upgrade key.

To inspect the active options or to install a new one start Daisy. In the file manager, locate "feature.ngc" in the installation folder and drag it into the program window (or open the program menu using ctrl+F9 and select file/load panel). Enter the key obtained from the vendor and press Enter. Close the program window and restart the device.

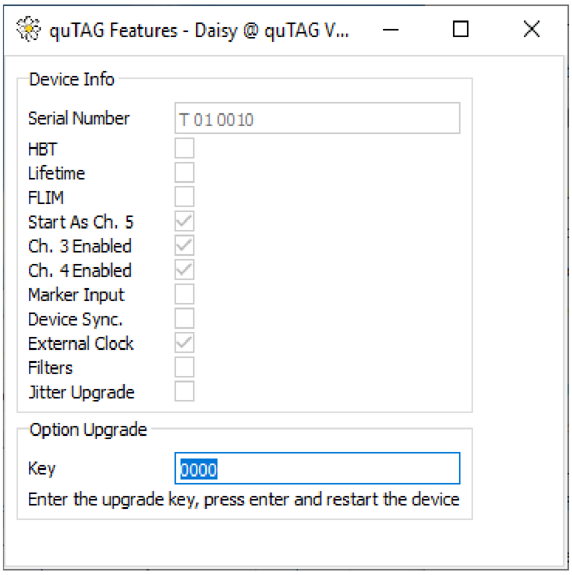


Figure 7: Option upgrade

8 Daisy Software

The Daisy GUI is started by `daisy.exe`. It provides several functions which allow the full control of the device. The user interface consists of several tabs for different tasks. All tabs and all graphs can be decoupled from the main window by double-clicking it.

Note that some features depend on installed options (see chapter 5). If they are not available for your device, they are typically invisible in the software.

8.1 Detector Parameter Settings

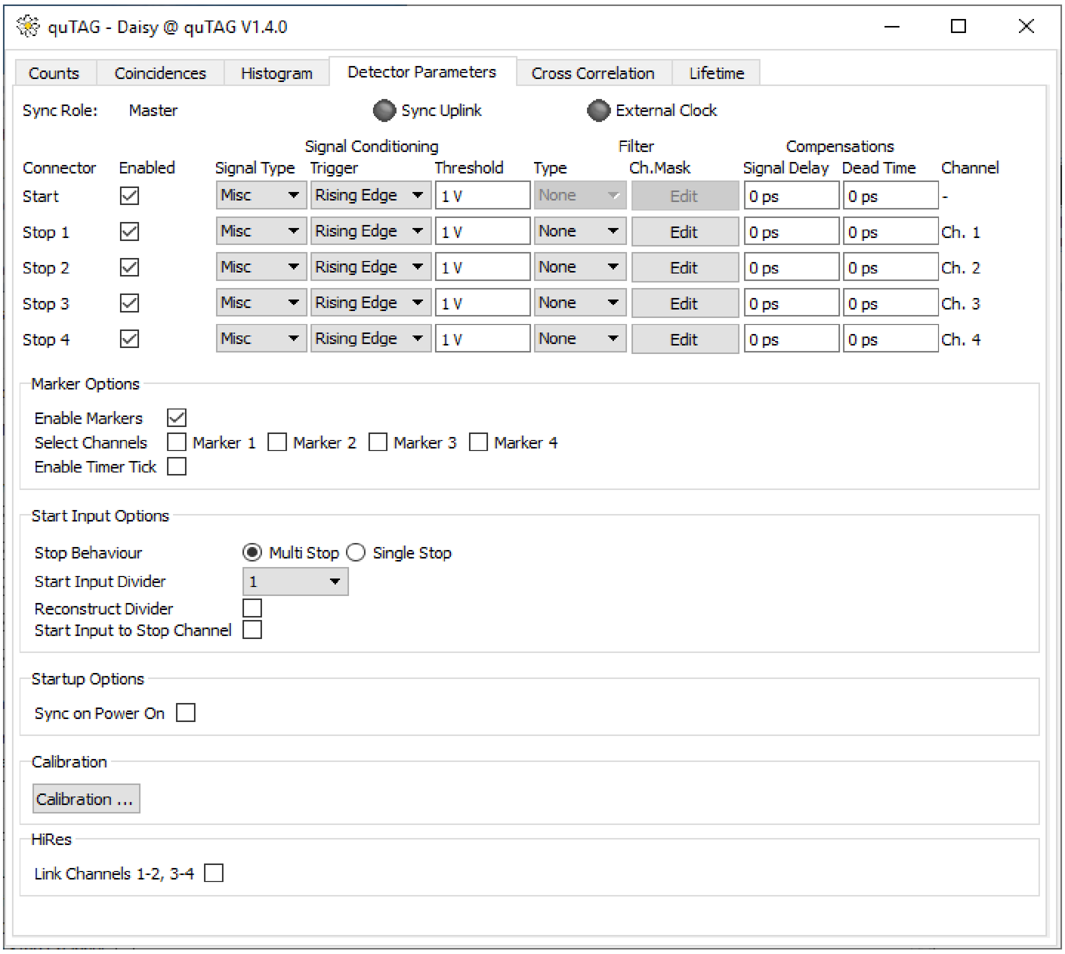
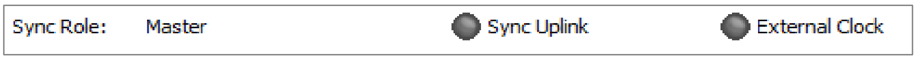


Figure 8: Input parameter settings in Daisy

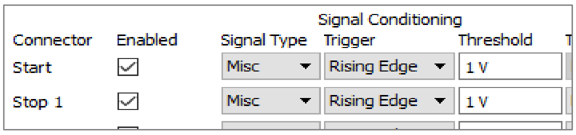
Input parameter settings like the trigger level and rising/falling edge detection can be configured in the "Detector Parameters" tab shown in figure 8. After a restart of the device, all channels are by default configured to detect the rising edge of input signals at a trigger level of 1 V, which is suitable for LVTTL signals.

Please note that these settings are saved in the device and therefore persistent between software restart. Only a restart of the device will reset all settings to their default values.



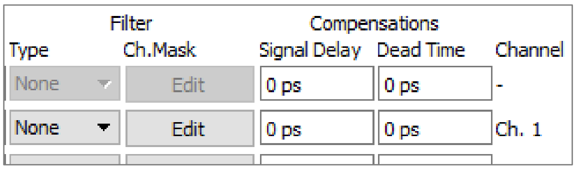
The "Sync Role" indicates the role of the device. The device will be marked as "Master" when it's the only device or the first device in synchronization mode. "Slave 1" will be the second device with channels 6-10 and so on.

The "Sync Uplink" indicator turns green if the device is connected as a Master to a synchronized device and the synchronization is established without errors. The "External Clock" indicator turns green if an external clock is connected and locked. The external clock can be received from the clock input on the front panel or from a master device.



The checkboxes next to "Enabled" can disable individual inputs. If a channel is disabled, no events will be detected on this channel and the events will not be processed.

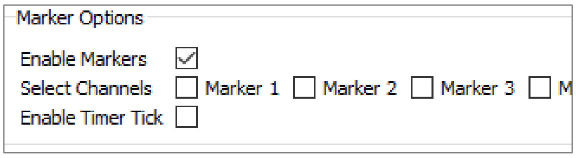
The trigger level and rising/falling edge detection of each input can be configured with the inputs under "Signal Conditioning". Presets for the common LVTTL and NIM signal standards can be chosen under "Signal Type".



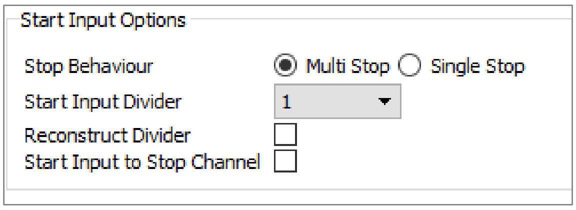
In the filter section, different filters can be defined for each channel. Events that are filtered will not be transferred to the PC but they will continue to contribute to count rates and correlations. "None" means that all events are processed and filtering is not active. There are three types of filter currently available (see section 8.2). The channel mask is a parameter of some filter types that can be edited by pressing "Edit".

The "Signal Delay" setting can be used to compensate runtime differences between -100 ns and 100 ns for each input.

The setting in "Dead Time" enforces dead time after each generated timestamp. After an event has been detected on a specific channel, subsequent events on the same channel are ignored during the "Dead Time". The setting can be used to replace the natural dead time of the device of about 40ns by an exactly defined time span. Values below the natural dead time have no effect.



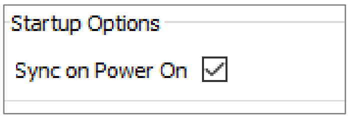
The marker channels can be enabled globally and individually. The device internally generates a timer tick every millisecond for timing purposes. Markers and timer ticks can't be observed in the GUI itself but only in stored data. They show up as channels 100-103 (markers) and 104 (timer tick).



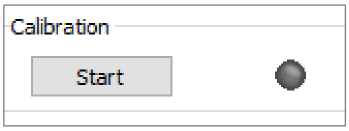
In the next section, some options related to the start channel can be configured. When using the Single Stop mode, only the first event after one start channel event of each stop channel will be transferred to the PC, all others will be suppressed. The multi stop mode will process all events.

The "Divider" setting configures the input divider on the start input. Setting of n > 1 cause only every n-th input pulse to be measured, allowing event rates above 25 MHz. The "Reconstruct" checkbox selects whether events "lost" due to the divider should be reconstructed assuming a periodic input signal. This feature is implemented in the PC software and may cause considerable consumption of CPU time.

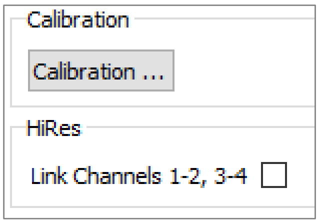
The start channel can be used as an additional stop channel which can be enabled in "Start Input to Stop Channel". This will disable the Start-Stop mode and all timetags detected on the start input will be inserted in the time tag stream with channel number 5. The divider settings will then be applied to channel 5, reconstruction doesn't work in this case. If the feature is not selected, every event detected on the start input resets the internal clock. That means that all time tags are now to be interpreted as time differences to the last start event.



The Startup Option "Sync on Power on" must be enabled in order to use synchronization. When disabled, the device will not search for synchronized devices. This may speed up the boot process and is useful when the synchronization is not used (see chapter 9 for details on synchronization).



In order to achieve constant measurement resolution, an internal calibration process has to be performed from time to time. It may need to be redone when the temperature of the device or the environment have changed. In the standard mode (no "Jitter Upgrade", see section 5), the process doesn't require user support and is run each time Daisy is started. It can be retriggered by clicking "Start" in the calibration part.

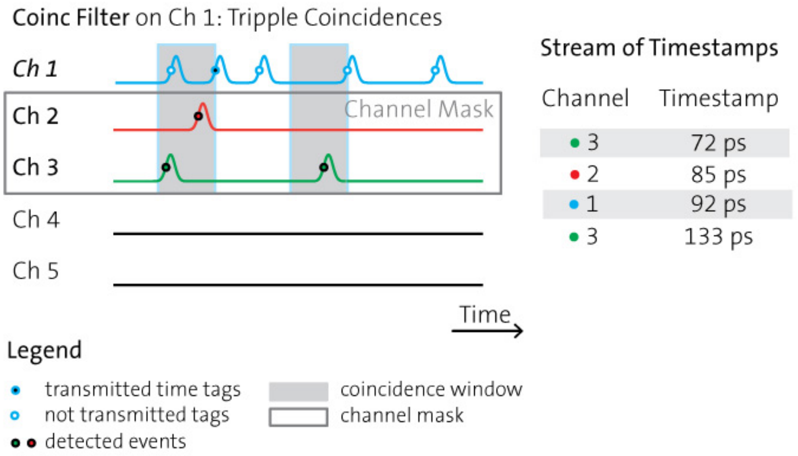


With the "Jitter Upgrade" in place, the process is more complex and is handled in a dialog that is opened by the "Calibration" button and will be discussed in detail in section 8.8 . In this case also channel linking is enabled. "Link Channels" links the signal evaluation circuitry of channel 2 and 4 to inputs 1 and 3 respectively. The device will evaluate inputs 1 and 3 twice and average the results internally. Inputs 2 and 4 will be inoperable.

8.2 Filters

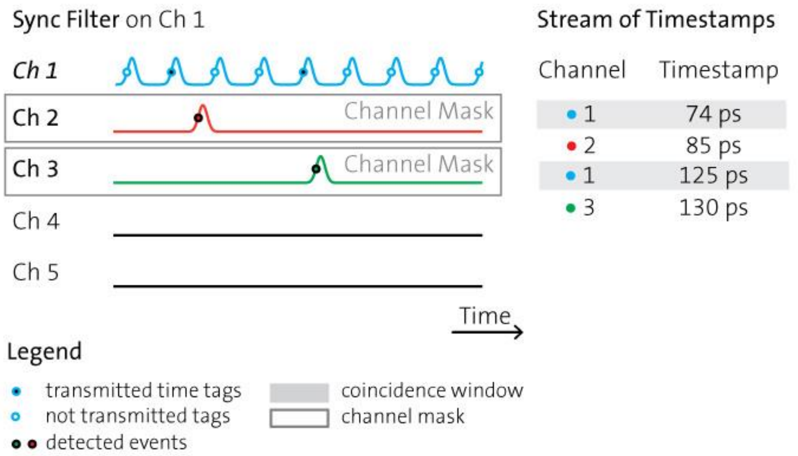
Mute This filter mutes the channel. This means that all events at this channel are processed internally and can be used for coincidence counting or other filters, but will not be transmitted to the PC.

Coinc The coincidence filter will only transmit the time tag to the PC if earlier events have been detected on each channel of the channel mask within the coincidence window (as defined in the "coincidence" tab).



The filter can also be applied symmetrically, e.g. to two channels, each one with the channel masks reversed. Hence, a huge variety of filtering options is available.

Sync The Sync filter will only transmit a time tag when a later event is detected at one of the channels of the "channel mask".



This filter is useful e.g. for a laser trigger signal when there is not a lot of detection signals. Trigger events not followed by a detection event are useless and will be suppressed.

None No filtering.

8.3 Counting

All single (each channel individually) counting rates (channel 1 to 5) are displayed in the "Counts" Tab shown in figure 9.

Figure 9: Counters tab of Daisy

The integration (or "exposure") time can be set to any ms value between 1 ms and 2^{16} -1 ms ≈ 65.5 s.

The count rates can be saved to a text file by pressing on the button next to "Save Counts". The button with two red dots will save the count rates continuously after every exposure time.

The raw time tags can be saved with the buttons next to "Save Time Tags". The used file format is determined by the file name and its suffix. "Textfiles" save the timetags in ASCII format which is easy to read and process, but also needs more hard disk space. "Binary" saves the time tags in a simple binary format with a header of 40 bytes (containing some information about the device, please ignore that in our own processing routine) and a 10 byte timestamp event, containing 8 bytes for the timestamp and 2 bytes for the channel number, stored in little endian (Intel) byte order. The binary format can be read back with functions of the custom programming library.

If configured, Marker events and time ticks are saved within the data stream as timestamps with channel numbers 100-103 and 104.

8.4 Coincidences

The coincidence time window can be set to any value between 0 ps and 2^{32}-1 ps ≈ 4.3 ms. The exposure time will be used from the Counts tab.

Two (or more) detection events will be counted as a coincident event if the difference of their time stamps is less or equal than the specified time window. The trend of a selected count rates can be displayed in the line graphs.

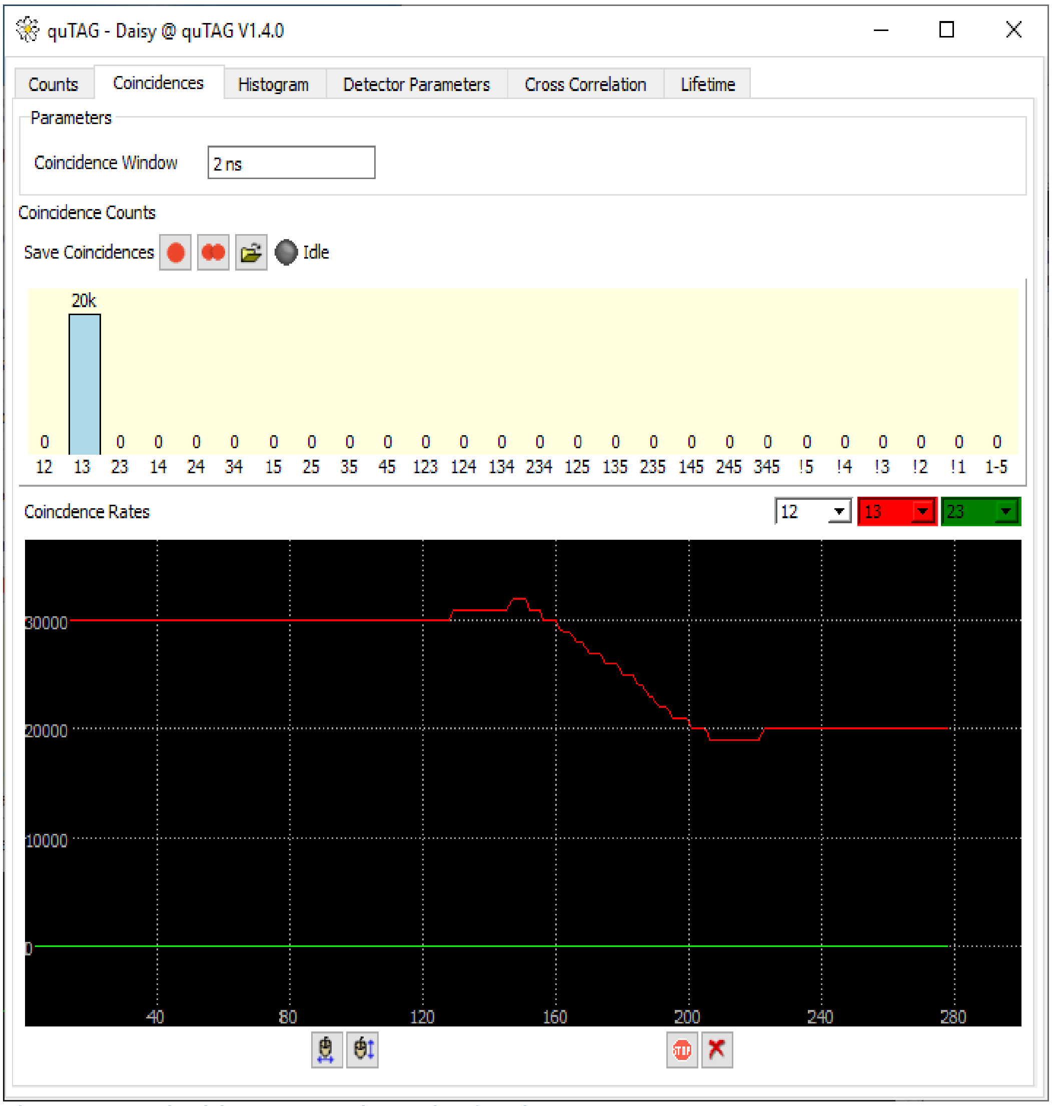


Figure 10: Coincidence counting tab of Daisy

8.5 Histograms

Timestamps histograms accessible in the "Time diffs" tab shown in figure 11. The histogram is calculated in the PC, therefore only timestamps transferred to the PC contribute to it. Timestamps filtered out or suppressed by the "single stop" feature don't show up here.

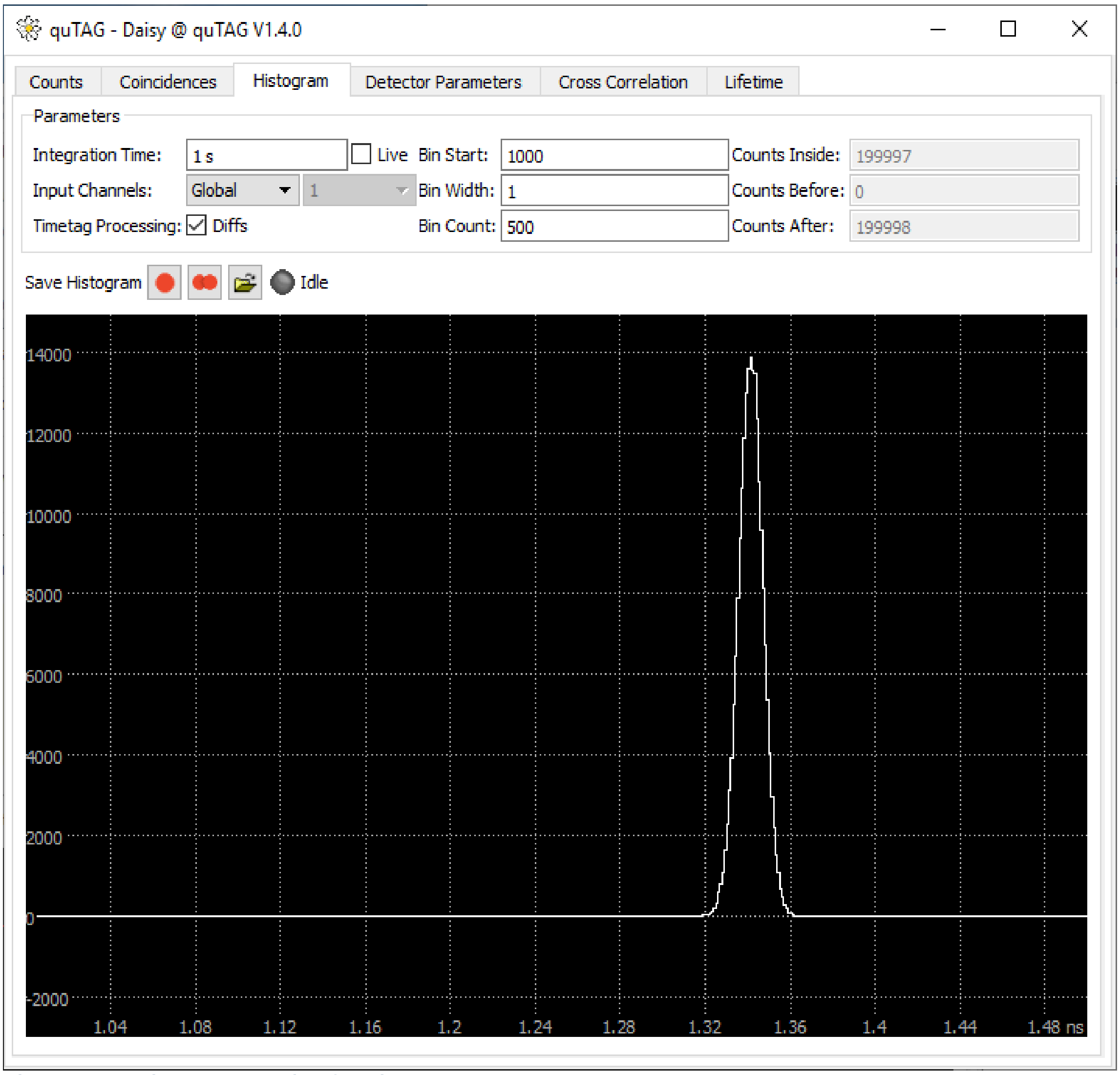


Figure 11: Histogram tab of Daisy

To configure the histogram measurement, the bin width, bin count and the value of the first bin can be configured under "Histogram Window". Note that negative values are not allowed for these settings. Which channels contribute to the measurement can be chosen in the "Histogram" drop-down menu. If "Global" is selected all Timestamps from all channels used are used as start and stop events. If a histogram from one channel using the start-stop mode is desired, use the same channel name for both inputs and deselect "diffs".

The integration time of each measurement is set at "Exp. Time". If "Live" is not selected, the finished histogram is displayed after every measurement (equals the exposure time), otherwise a "live view" of the running measurement is shown.

If "Diffs" is selected, the differences of consecutive Timestamps are added to the histogram. Use this setting if the time differences between events on different stop inputs are of interest. If "Diffs" is not selected the absolute value of individual timestamps are added to the histogram. Use this setting if the time between events on the start input and a stop input is of interest.

The data of the currently displayed histogram or of every finished measurement can be saved using the buttons next to "Save histogram".

8.6 Correlation Measurement: HBT

The HBT measurement and fit feature is accessible in the "Cross Correlation" tab shown in figure 12. This tab will only be visible if the "HBT" option (see chapter 5) is activated.

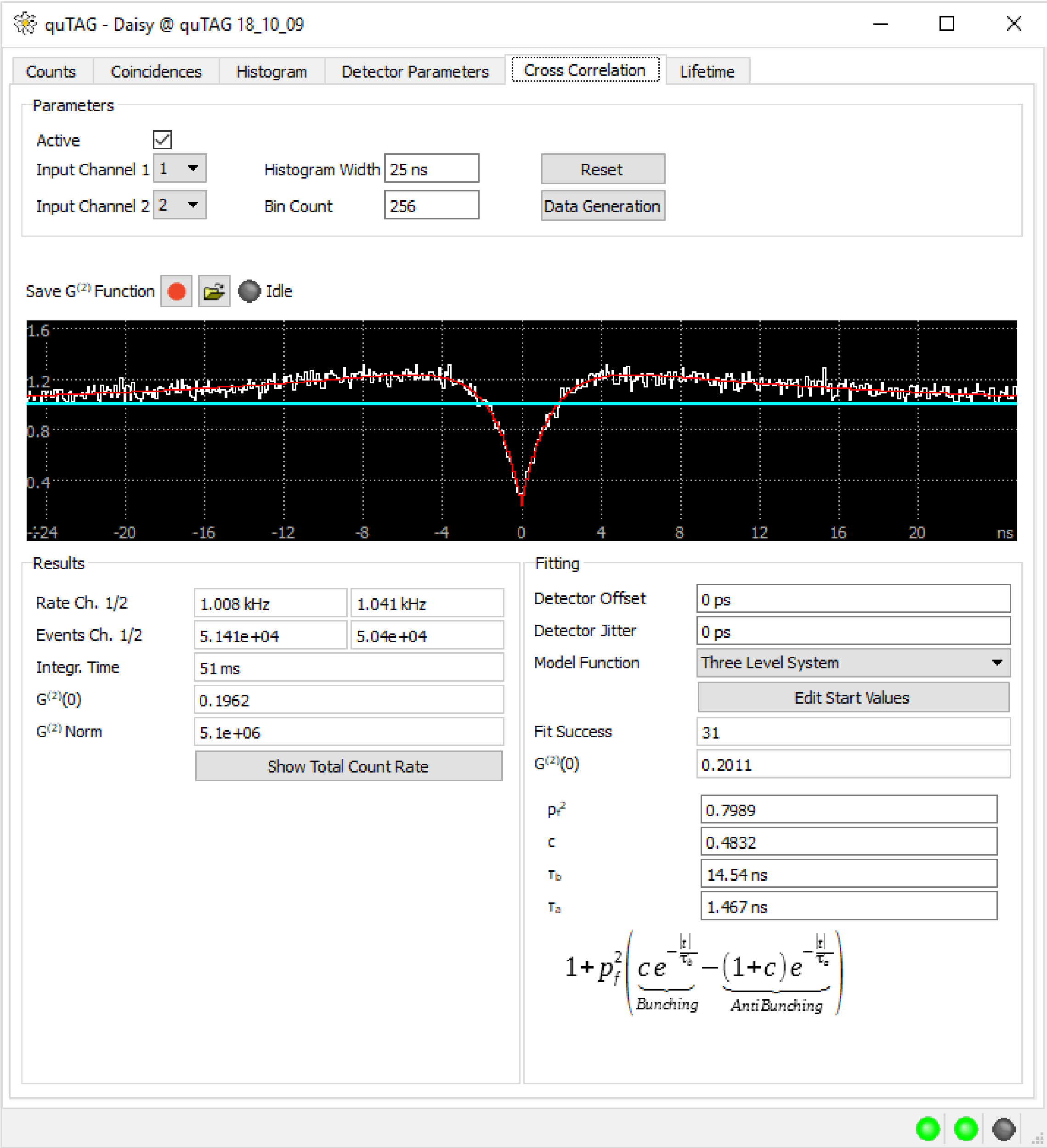


Figure 12: HBT measurement and fit tab of Daisy

The measurement is configured in the "Parameters" field. Here the histogram width, a bin count as well as the two input channels are selected. Select "active" to start collecting the correlation data.

The "Results" shows several parameters of the current measurement including the event rates, measurement time and the $g^{(2)}(0)$ value.

In the "Fitting" field a model function for the fit can be chosen. The result of the fit is displayed in the bottom field. The fit is only valid, if the number next to "Fit Success" is positive. If no fit can be found, please adjust the starting values using the "Edit Start Values" button.

The available models for the correlation function are shown below. With these, thermal photons, single photons (antibunching) and three-level-systems can be described.

Thermal $g_{th}^{(2)}(t) = Ae^{-\frac{t^2}{2c^2}} + B$

Antibunching $g_{ab}^{(2)}(t) = 1 - e^{-\frac{|t|}{\tau_a}}$

Three-Level-System $g_{tl}^{(2)}(t) = 1 + p_f^2\left(ce^{-\frac{|t|}{\tau_b}} - (1+c)e^{-\frac{|t|}{\tau_a}}\right)$

Additional fit models which take detector offsets and jitter into account are available. If they are used, the appropriate values for the detectors have to be entered in the "Detector Parameters" field.

The "Data Generation" dialog allows to demonstrate the functions with data generated by one of the model functions.

8.7 Lifetime Measurement

The lifetime measurement and fit feature is accessible in the "Lifetime" tab in the daisy software. This tab will only be visible if the "Lifetime" option (see chapter 5) is activated.

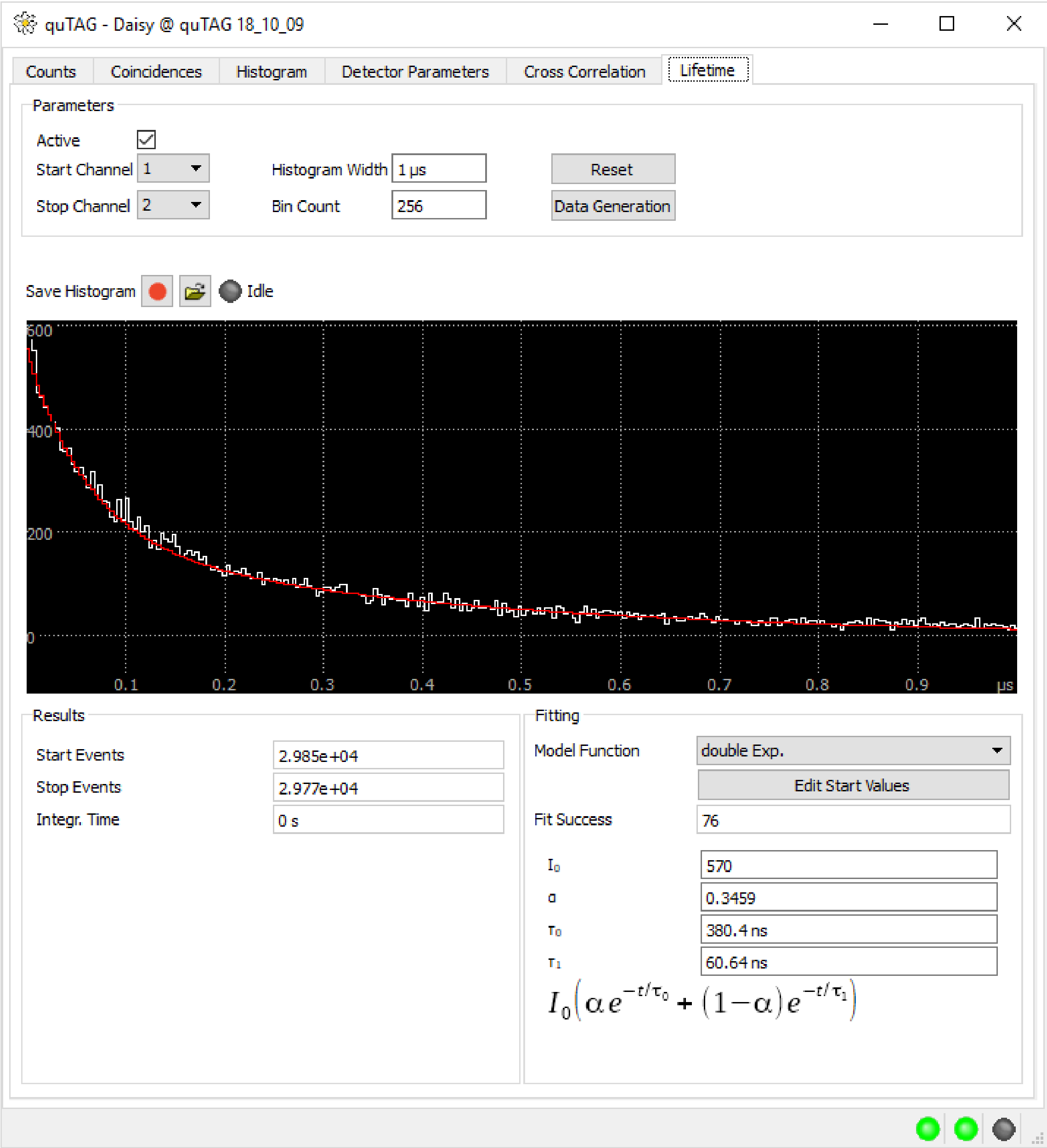


Figure 13: Lifetime measurement and fit tab in daisy software

The measurement is configured in the "Parameters" field. Here the histogram width, a bin count as well as the two input channels are selected. The lifetime histogram is calculated from the difference between the stop and the start channel. Select "active" to start collecting the lifetime data.

The "Results" shows several parameters of the current measurement, showing the event rates and the measurement time.

In the "Fitting" field a model function for the fit can be chosen. The result of the fit is displayed in the bottom field. The fit is only valid, if the number next to "Fit Success" is positive. If no fit can be found, please adjust the starting values using the "Edit Start Values" button.

The available models for the lifetime function are shown below:

Exponential fit $h_{exp}(t) \;=\; I_0 e^{-\frac{t}{\tau_0}}$

Double exponential fit $h_{de}(t) \;=\; I_0\left(\alpha e^{-t/\tau_0} + (1-\alpha)e^{-t/\tau_1}\right)$

Kohlrausch fit $h_k(t) \;=\; I_0 e^{(-t/\tau_0)^{\beta}}$

The "Data Generation" dialog allows to demonstrate the functions with data generated by one of the model functions.

8.8 Jitter Reduction: Calibration Procedure

The "Jitter Upgrade" option (see section 5) allows measurement with reduced jitter at < 6.4 ps RMS on all four input channels. To reduce the jitter even more (to < 4.2 ps RMS), two channels can be combined, leaving two stop-channels of one device for measurements. These jitter values belong to time differences, i.e. two-point measurements (start and stop). Assuming equal Gaussian distributions for start and stop, one obtains a single-point jitter of $\sigma/\sqrt{2}$: < 4.5 ps RMS (4 channels) and < 3.0 ps RMS (linked channels).

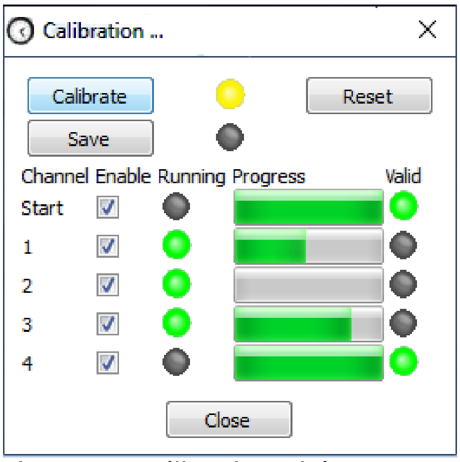


Figure 14: Calibration Dialog

For optimal jitter results, recalibration with external signals might be necessary. Figure 14 shows the calibration dialog that can be opened on the "Device Parameters" Tab (section 8.1). It controls a calibration procedure of the evaluation circuitry that is advisable from time to time. Running the procedure on an input channel requires 2 million events to be detected on that channel. It is recommended to connect the channel with a periodic signal of 50 – 500 kHz.

The channels can be calibrated all together at the same time, in groups or one after the other. Select the channels to be calibrated, press calibrate and wait until the indicator next to the calibrate button turns gray again. If all "Valid" indicators are green and the indicator next to "Calibrate" is gray, press "Save" to store the result in persistent memory and wait until the indicator next to "Save" returns to gray again. "Reset" aborts the calibration procedure.

9 Other Software Components

9.1 Tarec

Tarec (quTag Record & Merge Tool) is a tool for use with synchronized devices (see section 6.5). It connects to all available devices at the same time, records their time tag streams and merges them into a single timeline. Please close all instances of Daisy before starting Tarec. The Tarec GUI is shown in figure 15.

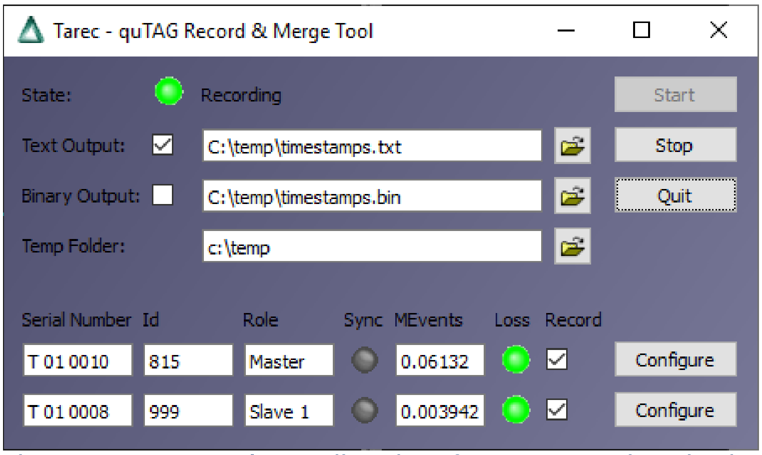


Figure 15: Tarec tool recording data from two synchronized quTAGs

The serial number, hardware ID and an approximate number of recorded events are shown on the bottom for each connected device. The "Config" buttons on each line can be used to configure the inputs of the devices similar to the "Detector Parameters" tab in daisy introduced in section 8.1 .

Whether a text or a binary output file is created and their filenames can be chosen next to "Text Output" and "Binary Output". Recording data is controlled using the "Start" and "Stop" buttons.

For performance reasons, Tarec works in two steps: In the first step (after Start has been pressed), the time tags are stored in temporary files per device. In the second step (after Stop has been pressed), that files are read back and the timestamps are merged into the target file(s). The state indicator turns yellow and shows "Saving". If tarec is closed in that state, the recorded data are lost.

In merging the data, the channel numbers are transformed: The master device keeps its original numbers (1-5 and 100-104) while for the slave devices 5*chain-position is added to every number.

9.2 quTAG custom software ("DLL")

The software packet provides a shared library (DLL or shared object) that allows to access the quTAG from custom software. The development kit is located in the subdirecory `userlib`:

`userlib\lib`	All required shared libraries and a proxy lib (Windows only). The libs must be made available for the program loader when running an application.
`userlib\inc`	A couple of header files for custom programming of the lib.
`userlib\doc`	Documentation of the functions in HTML format. It can be opened by the link `userlib\documentation.html`.
`userlib\src`	A simple example in C.
`userlib\labview11`	LabView VIs that wrap every single function together with some simple examples (Windows only).

9.3 Command Line Interface

The command line interface can be used for some simple tasks as a one-time readout of the count rates, writing time stamps to a file or saving histogram data. To use it, open a command prompt, go to the software directory and call tdccli(.exe). Use the parameter -h for additional information.

The CLI program also serves as an example DLL application. The source code is available in userlib\cli.

10 Revision History

Revision	Date	Changes
1.4	2019-04-15	Manual reorganization Specifications Extension Marker Inputs Options completed Procedures for Hardware ID and Option upgrade Jitter upgrade
1.2.2	2018-12-03	Show active filter on quTAG device displays
1.2.0	2018-10-22	Redesign of GUI Filter feature assessable from API and GUI Lifetime feature assessable from GUI Marker feature assessable from API and GUI minor bugfixes
1.0.0	2018-02-09	initial release