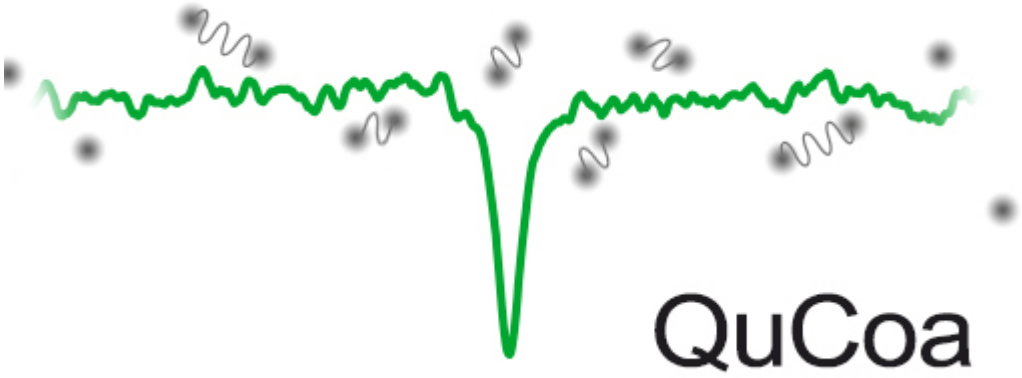
QuCoa

Quantum Correlation
Analysis Software

PicoQuant



Installation Manual and Technical Data

Version 1.4

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1. Introduction

1.1. QuCoa in a Nutshell

The QuCoa software package is an integrated solution for data acquisition and analysis using PicoQuant's TCSPC electronics. It is mainly targeted at all research areas that rely on coincidence detection such as Hanbury-Brown-Twiss setups to study single photon sources ($g^{(2)}$ / antibunching), quantum key distributions (QKD), or the study of entanglement using Hong-Ou Mandel setups, to name only a few.

Of pivotal importance are the Time–Tagged Time–Resolved (TTTR) measurement mode (and especially the T2 time tagging mode) of the MultiHarp, TimeHarp, PicoHarp and HydraHarp TCSPC devices, which allow the performance of vastly different measurement tasks based on one single data format, yet without any sacrifice of information available from each single photon. The T2 data of all supported sources are stored in the same PicoQuant Unified Tag File Format, which allows all measurement data to be handled in a standardised yet flexible way.

Based on the powerful T2 data collection and by application of STUPSLANG, our underlying scripting engine, users can perform an unlimited number of analysis steps without losing track of the interdependence and origin of their measurement and analysis data. Results can be obtained through a set of analysis tools, such as intensity time trace, coincidence analysis, antibunching.

2. Getting Started

2.1. Requirements

The QuCoa software is suitable for PCs running the Windows 7 x64, 8 x64 or 10 x64 OS. It demands a reasonable performance of the PC. For routine work, a machine with x64 quad–core CPU, incl. SSE2 and Intel 64 or AMD64 extension with at least 2.2 GHz CPU clock and a minimum of 4 GB RAM is necessary. For improved performance in data acquisition or during complex analysis tasks a CPU with more cores and more RAM (e.g. 16 GB) is recommended.

The software takes approximately 100 MB, however, not including the storage space for data files. To use the software efficiently, a full HD screen resolution is needed. For daily work, a screen resolution of at least 1680 × 1050 pixels is recommended. Even better is a dual display set–up.

The QuCoa package is protected by a HASP protection module (dongle) that must be connected to the USB port of the PC during operation. In order to recognize its presence and to use the HASP protection module, a software driver is automatically installed with the QuCoa software package.

2.2. Feature Overview

Data Acquisition	**Features**
TCSPC–Based	PicoHarp 300 & 330 by import or direct measurement HydraHarp 400 by import or direct measurement TimeHarp 260 by import or direct measurement MultiHarp 150 & 160 by import or direct measurement
Suppported numbers of detectors	1 to 16
Supported number of markers for coincidence counting	up to 4
Measurement modes	Antibunching, Coincidence correlation, Coincidence counting
Measurement previews	Coincidence correlation trace ($g^{(2)}$ / Antibunching), Coincidence counting, Intensity time trace, TCSPC histogram Parallel calculation and display of up to 4 different previews

Analysis	**Features**
General Features	Binning Least–Squares Fitting, MLE fitting, Bootstrap error analysis GUI themes
Coincidence correlation	Antibunching curve calculation pulsed excitation: estimation of pulse rate, G(0) and G(∞) cw excitation: estimation of G(0) and G(∞) Antibunching Fitting Global Analysis Reconvolution with Gaussian Confidence Intervall Estimation Model for cw-excitation with and without shelving state Model for pulsed excitaton, single lifetime parameter
Coincidence counting	freely definable coincidence criterion, combination of detection channels and markers using logical filters (AND, OR, NOT) in a user-defined time gate

2.3. Installation Procedure

The software is supplied pre–installed and on DVD, together with a copy protection module (HASP). On the installation DVD you will find the following files and directories:

QuCoa_Setup.exe	self–extracting installation file
Readme.txt	installation notes
WhatsNew.txt	QuCoa change history
LSM_Remote_Control	Remote Control setup and developer documentation
Samples.sptw	Workspace with example data
Developer	Developer information for QuCoa
FileDemos	Demos for implementing reading of ptu files
HASP	drivers for hardware protection module

Install the software by running QuCoa_Setup.exe and follow the instructions of the installer program. The drivers for the TCSPC electronics can be found on its respective Install DVD or CD and need to be installed as a part of installing the TCSPC device. **The QuCoa software does not install any drivers, except the drivers for the HASP copy protection module.**

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3. Quick Start Guide

This section aims to provide a short primer on how to carry out an antibunching or coincidence correlation measurement and analyze the collected data with the QuCoa software package. All steps will be only briefly outlined here. Detailed explanations of concepts and options can be found in the QuCoa on-line help, which can be accessed from the *Help* menu or by pressing the **F1** key.

This guide assumes that the QuCoa software is installed and its associated hardware (one TCSPC unit such as a TimeHarp, PicoHarp, or HydraHarp as well as up to 8 single photon sensitive detectors) has been integrated into the experimental set-up.

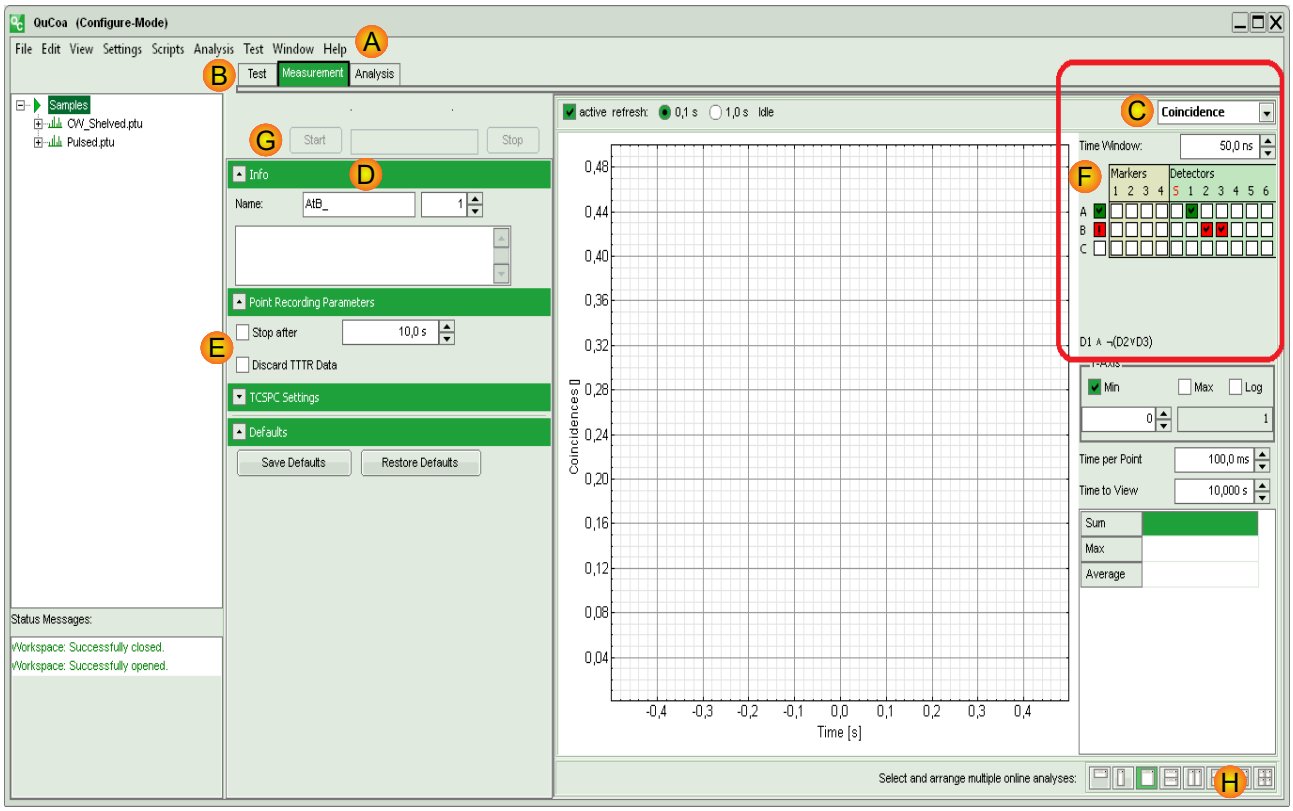

Fig. 1: Main GUI window of the QuCoa software.

3.1. Setting the System up for a Measurement

- Turn on and initialize your experimental set up; including the TCSPC unit and all detectors.
- Insert your sample and ensure that the desired feature is located in the observation spot.
- Start the QuCoa software.
- From the main menu bar (A) select ***Settings*** → ***Hardware Settings***:
  - Check that the QuCoa software has established a connection with the TCSPC unit. If more than one TCSPC unit is present, the right one can be selected from the ***TCSPC*** selection box and pressing the ***Init TCSPC*** button.
- In the QuCoa software, open or create a workspace (***File*** → ***Create Workspace*** or ***File*** → ***Open Workspace***).

3.2. Optimizing parameters

- Click on the "***Test***" tab in the CuQoa main window to enter the *Test* working mode (B).

NOTE: While in *Test* working mode, no data will be saved. The tools available in this mode are intended for measurement set-up and instrument adjustment.

- Adjust the settings of the CFD, the Zero Cross and the Delays of the TCSPC Module in the "***TCSPC Settings***" panel (if necessary)
- Select the desired online preview panel (e.g., ***Time Trace*** to monitor and adjust the detector count rate or ***TCSPC Histogram*** to check usage of histogramming channels). Please note that only one preview panel can be active at any time in *Test* working mode.
- Once all parameters have been adjusted to your linking, switch to *Measurement* working mode by clicking on the "***Measurement***" tab in the CuQoa main window.

3.3. Starting the measurement

- Once in the *Measurement* working mode, enter a sample name in the text box labeled "***Name***" under the ***Info*** tab (D).
- You can optionally enter an extended sample description in the large text box below.
- In tab ***Point Recording Parameters***, you can enable a time limit for the measurement by ticking the "***Stop afte***r" check box and set the duration by means of the spin box next to it (E).
- Tick the "***Discard TTTR Data***" check box, if you do not wish to save any raw data (E).
  NOTE: For longer measurements, e.g., 20 min or more, the raw data file can become quite large (in the order of several GB). By discarding the raw data, only the results of the *online* analysis will be saved. Please note that without raw T2 data, the *offline* analysis will not be possible!
- **NOTE:** the resolution settings in the "**TCSPC Settings**" panel will not have any influence on your data. It only has an influence in the Test mode during histogramming.
- Choose the number of parallel online analysis procedures using the icons on the lower right (H). Up to 4 parallel operating analysis procedures are possible.
- For each on-line analysis select the desired experiment type (***Antibunching*** or ***Coincidence or Time-Trace***) from the drop down box in the top right corner of the main window (C).
- Set-up the counting conditions for your experiment:
  - In the case of an ***Antibunching*** experiment, select the two channels to be cross-correlated by ticking their corresponding check boxes in the right part of the main window (F). The selected boxes will turn green and display a check mark to indicate that they have been selected. Then define the maximum time for the correlation and the sampling points. In most cases, these can also be left at their default values-
  - In ***Coincidence*** mode, the activity pattern for a coincidence can be defined as a logical combination of detector and maker signals. The combination is set-up by ticking the desired detector or marker check boxes in the grid shown in the right part of the GUI (F).
    - The time interval in which the defined coincidence pattern needs to occur (so that it is counted as a coincidence) can be set by the spin box "***Time Window***"
    - If more than one box is checked in a row, the corresponding detectors / markers will be combined by the boolean operator OR.
    - Clicking the check box in front of a row will change the logical combination from AND (green box with check mark) to AND NOT (red box with exclamation mark).
    - Activating the check box of a row will also add a new empty row to the table.
    - Detector channels that are not displayed (usually channels > 6) can be access by moving the mouse cursor the right edge of the grid. The grid will then scroll to show these channels.
    - At least two detectors need to be active to define an activity pattern.
    - The boolean expression of the defined activity pattern is shown at the bottom of the grid. A verbose definition is displayed when hovering the mouse cursor over the boolean expression.
  - In ***CountRate Display*** up to two intensity time traces can be displayed. These either directly display one selected input channel or the sum of all channels.

- The measurement can now be started by pressing the "***Start***" button above the ***Info*** tab (G).
- Stopping the measurement can be achieved by pressing the "**Stop**" (G) button or it will stop automatically if a stop time has been defined.
- During the measurement, the pre-defined online-analysis procedures will be calculated and automatically updated.

3.4. Data Analysis

- Data analysis can be performed either online (in *Test* and *Measurement* working mode) or offline (by opening a saved TTTR data file).
- In the online mode, all data from activated analyses are written to the hard drive. Up to four online previews can be running simultaneously.
- To perform an offline analysis, select the saved TTTR data from the workspace and then click on the ***Analysis*** (B) tab in the main window.
  - Select the desired analysis method from either the ***Time Trace***, ***TCSPC***, ***Antibunching*** or ***Coincidence*** tab.
  - Refer to the online help of the software for additional details on the fitting procedures
  - Results of the analysis can be saved or exported by clicking the the corresponding buttons in the ***File*** tab.

4. Technical Data / Specifications

Data Acquisition

TCSPC devices:
for direct measurements.....PicoHarp 300&330, HydraHarp 400, TimeHarp 260, MultiHarp 150&160
Supported number of detectors .....1 to 16
Supported number of markers .....up to 4
for coincidence counting
Measurement modes:
for direct measurements.....TTTR: t2, (test measurements: t3)
Measurement previews .....Coincidence correlation trace ($g^{(2)}$ / Antibunching), Coincidence
.....counting, Intensity time trace, TCSPC histogram
.....Parallel calculation and display of up to 4 different previews

Analysis

Supported methods.....Antibunching, coincidence, intensity time traces, lifetime fitting

TCSPC Fitting

Models.....1 to 5 exponentials, iterative re-convolution
Optimization.....least squares, MLE, Marquardt-Levenberg, Monte Carlo,
.....Global analysis
Error test / assessment.....χ^2, distribution weighted residuals
Error analysis.....Bootstrap

Coincidence Correlation Fitting

Models.....cw-excitation with and without shelving state,
.....pulsed excitation with lifetime parameter
Optimization.....least squares, Marquardt-Levenberg, Monte Carlo,
.....Global analysis
Error test / assessment.....χ^2, distribution weighted residuals
Error analysis.....Bootstrap

Coincidence Counting

Correlation scheme.....Combination of detection channels and markers using logical filters (AND, OR, NOT) in user-defined time gates

User Interface

Graphical user interface.....Windows™ GUI, menu or mouse driven, STUPSLANG scripted
Preferences.....saved in factory / user settings data files

Supported Data Formats

Input for analyzes.....`ptu` and `pqres` files: PicoQuant Unified Tag File Format
Output.....`pqres` files: PicoQuant Unified Tag File Format; ASCII file export

Operating Environment

PC requirements:
CPU.....with SSE2 and EMT64 or AMD64 extension;
.....quad-core or better recommended

CPU clock.....minimum 2.2 GHz; recommended ≥ 3 GHz
RAM.....minimum 4 GB; recommended: ≥ 16 GB
Disk space.....≥ 100 MB (program without data storage)
Display(s).....Single display: 1920 x 1080 pixel (full HD)
.....Dual display: 2 x 1680 x 1050 or higher
Operating System.....64bit Windows™ 10, 64bit Windows™ 11
Protection module / port.....HASP USB dongle

Retraction of Old Devices

Waste electrical products must not be disposed of with household waste. This equipment should be taken to your local recycling center for safe treatment.
WEEE–Reg.–No. DE 96457402

5. Support

5.1. Returning Products for Repair

Should you encounter serious problems that require sending the device in for inspection / repair, please contact us first at: support@picoquant.com and request an RMA number before shipping the device. Observe precautions against static discharge under all circumstances during handling, packaging and shipping. Use original or equally protective packaging material. Inappropriate packaging voids any warranty.

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7. Further Reading

7.1. PicoQuant Bibliography

PicoQuant maintains a database of publications mentioning PicoQuant devices. It can be found at our website www.picoquant.com/scientific/references. It is a valuable source if you would like to know which laboratories are using PicoQuant products or how broad the field of various applications is.

7.2. Download of Technical Notes / Application Notes

PicoQuant, along with our customers, continuously writes and publishes short documents about techniques, methods and applications that are possible with our hardware or software. The download section can be found at www.picoquant.com/scientific/technical-and-application-notes

7.3. Recommended Literature

Photon Counting	D. V. O'Connor, D. Phillips: **Time–Correlated Single Photon Counting** Academic Press, London, 1984; ISBN 0-12-524140-2 P. Kapusta: **Photon Counting with PicoQuant Devices Using Low Repetition Rate Excitation** Application Note, PicoQuant, 2006 M. Wahl: **Time Tagged Time–Resolved fluorescence data collection** Application Note, PicoQuant, 2004
Various Data Analysis Methods	A. Grinwald, I. Z. Steinberg: **On the Analysis of the Fluorescence Decay Kinetics by the Method of Least–Squares** Analytical Biochemistry, 1974, Vol. 59, p. 583-598
Fitting Parameter Precision	D. E. Koppel: **Statistical accuracy in fluorescence correlation spectroscopy** Physical Review A, 1974, 10, (6), 1938-1945 T. Wohland, R. Rigler, H. Vogel: **The standard deviation in fluorescence correlation spectroscopy** Biophysical Journal, 2001, 80, (6), 2987-2999 S. Saffarian, E. L. Elson: **Statistical Analysis of Fluorescence Correlation Spectroscopy: The Standard Deviation and Bias** Biophysical Journal, 2003, 84, (3), 2030-2042
Correlation Algorithms	S. Chopra, L. Mandel: **An electronic correlator for photoelectric correlation measurements** Review of Scientific Instruments, 1972, 43, (2), 1489-1491 D. Magatti, F. Ferri: **Multi–τ real–time software correlator for dynamic light scattering** Applied Optics, 2001, 40, (24), 4011-4021 D. Magatti, F. Ferri: **25 ns software correlator for photon and fluorescence correlation spectroscopy** Review of Scientific Instruments, 2003, 74, (2), 1135-1144

8. Appendix

8.1. Abbreviations

BNC	British Naval Connector or Bayonet Nut Connector or Bayonet Neill Concelman
CAN	Controller Area Network
CCD	Charge–Coupled Device
CFD	Constant Fraction Discriminator
cps	Counts per Second
FIFO	First In, First Out (buffer type)
FWHM	Full–Width at Half–Maximum
IO	Input / Output
IRF	Instrument Response Function
LED	Light Emitting Diode
PC	Personal Computer
PCI	Peripheral Component Interconnect
PIE	Pulsed Interleaved Excitation
PMT	Photomultiplier Tube
SMA	Sub–Miniature version A (connector type)
SMD	Single Molecule Detection
SPAD	Single Photon Avalanche Diode
STUPSLANG	**S**ymPho**T**ime **U**ser **P**rogramming **S**cript **LANG**uage
SYNC	Synchronisation (signal)
TCSPC	Time–Correlated Single Photon Counting
TTL	Transistor–Transistor Logic
TTTR	Time–Tagged Time–Resolved

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