BEYOND PILE-UP LIMITS IN TIME CORRELATED SINGLE PHOTON COUNTNG: A NEW APPROACH

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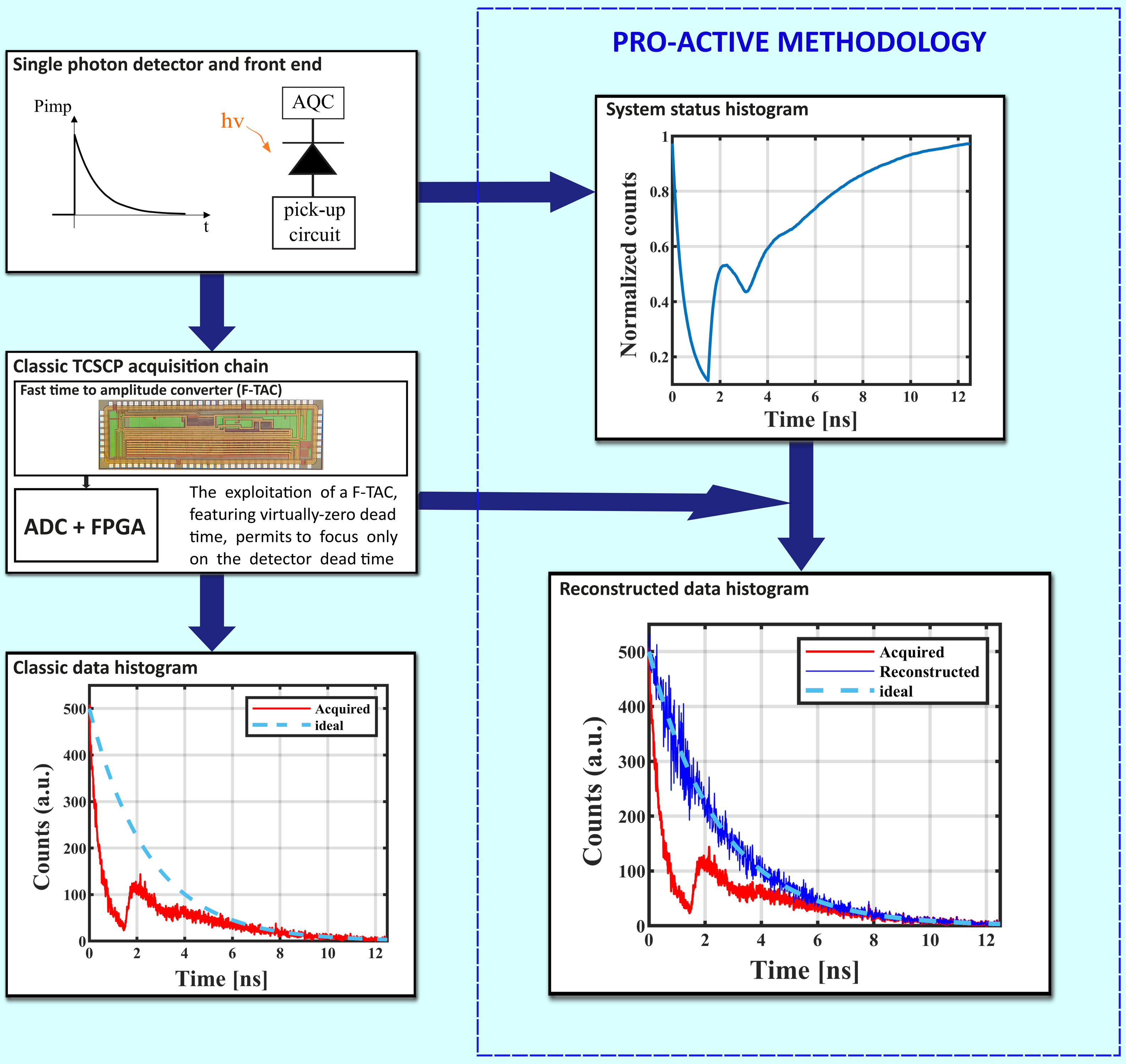
ABSTRACT

The Time Correlated Single Photon Counting (TCSPC) technique has gained a prominent role in the analysis of fast and faint optical signals. Nonetheless, it has been historically considered an intrinsically slow technique due to its repetitive nature combined with a strict constraint on the maximum detector count rate to avoid distortion. Indeed, classic TCSPC theory states that low (preferably negligible) distortion can be achieved only by limiting the single-photon detector count rate down to few percent (typically 1-5%) of the laser excitation rate[1]. In 2017, we demonstrated an alternative path to avoid distortion in TCSPC based on matching the detector dead time to the excitation period. This approach still limits the speed, preventing the exploitation of the fastest single photon detectors, e.g. Single Photon Avalanche Diodes with a dead time of a few nanoseconds. In this work, we present the experimental validation of a novel TCSPC methodology [2] showing how it is possible to remove all constraints (power, dead time, etc). and still get a negligible level of distortion. This approach opens the way to unprecedented speed in TCSPC measurements

THEORY AND SIMULATIONS

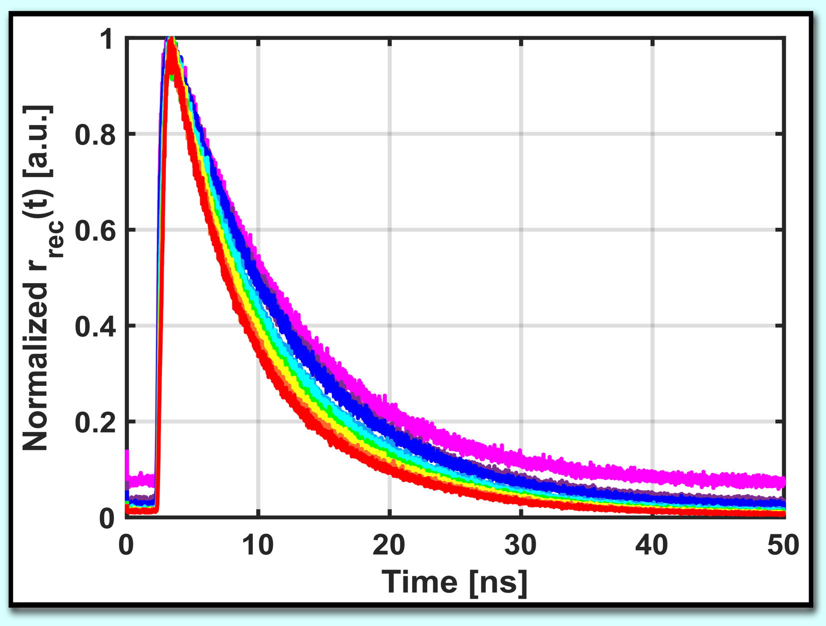


The idea of TCSPC is reconstructing a light signal starting from the probability density function (pdf) of the photons over time. The signal reaching the photodetector has a certain pdf Pimp(t) while the pdf recorded by the system can be called Prec(t). In general, there is a difference between Pimp(t) and Prec(t) which can be summarized by the following formula:

$$Prec(t) = a(t) * Pimp(t)$$

where a(t) accounts for the efficiency of the system and for the dead time. While efficiency does not impair the signal shape, dead time is the main cause of signal distortion at high rates. Acquiring the shape of a(t) during each measurement permits to eliminate the distortion with no need of a priori knowledge of the signal features.

EXPERIMENTAL VALIDATION



Pile-up distorted data histogram: a single exponential decay with tau=10ns has been acquired with an average number of photons per period (P) from 0.02 to 1.76. Pile-up distortion is clearly visible as it reduces the measured time constant with respect to the real one. The pink curve is the undistorted reference obtained respecting the classic power limit.

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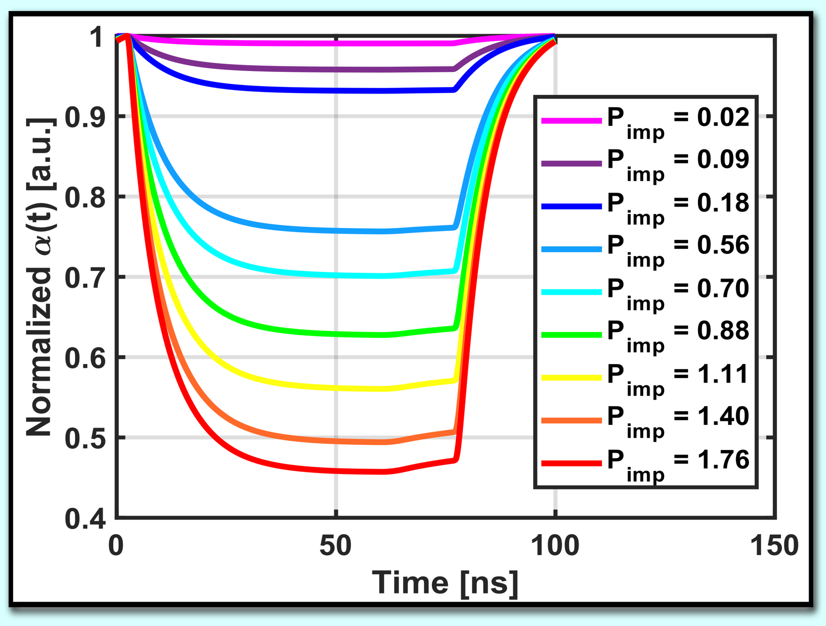

System status histogram: every time a photon is acquired, the system becomes unavailable for a time interval called dead time. The histogram derived from the occured dead time intervals reconstructs the time-varying probability that the system was active and thus able to record a photon during the measurement.

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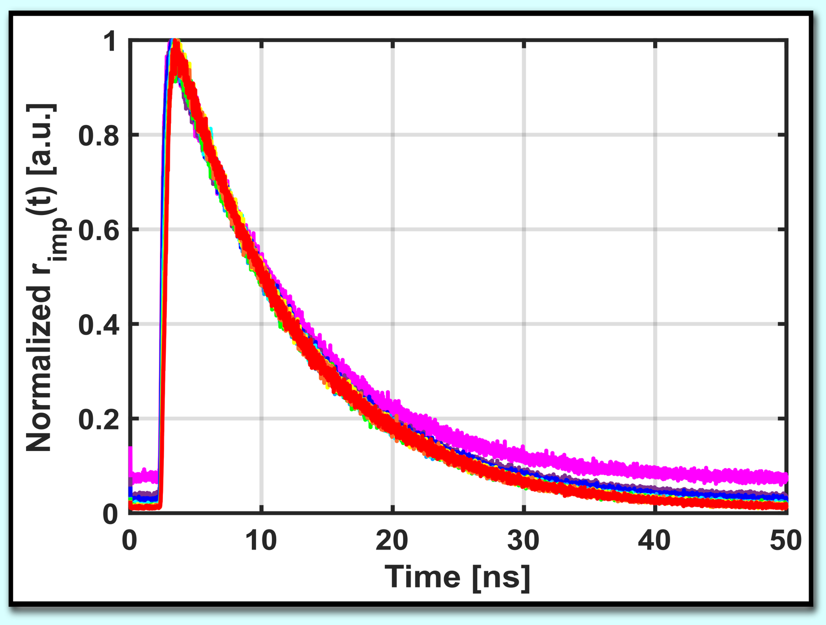
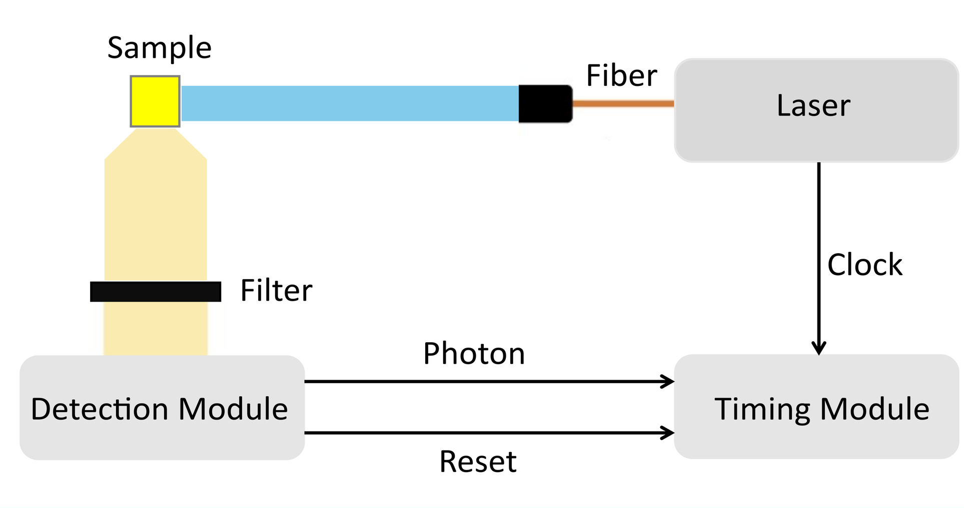


Final undistorted data histogram: the correct shape of the fluorescence signal was recovered by dividing the data histogram by the system-status histogram. This experiment validates the theory showing that all the curves, even with more than one impinging photon per period, lead to the same result obtained at a low excitation rate.

Setup of the experiment based on commercial modules



The setup consisted of:
- laser at 470nm (f=10MHz)
- fluorescent slide (tau=10ns)
- modified SPAD module
- time tagger

The detection module features a dead time of 80ns while the time tagger dead time is negligible.

REFERENCES

[1] Becker, Wolfgang, et al. "Advanced time-correlated single photon counting applications" Springer book, 2005.

[2] Rech, Ivan, et al. "Toward constraint-less Time-Correlated Single-Photon Counting measurements: a new method to remove pile-up distortion"IEEE Journal of Selected Topics in Quantum Electronics (2023).

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