High-Fidelity PNR with Parallel SNSPDs

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Photon number resolution (PNR) is the ability of a detector to distinguish the number of photons in a light pulse rather than simply detecting their presence. In quantum science, the requirement is generally even more stringent: the goal is to correctly guess the number of photons from the signal derived from the detector. The better the guessing probability, the higher the fidelity of the PNR measurement. This capability is crucial for quantum optics, photonic quantum computing, quantum communication, and all applications where a single-shot measurement of the number of photons is needed. PNR can be achieved using different analysis strategies depending on the detector used (e.g., TES, SNSPDs, HPD, SiPMs, …). We present the result of combining the time-tagging technology of Swabian Instruments with ID Quantique (IDQ) PNR SNSPD technology to realize PNR detection with outstanding fidelity.

EXPERIMENTAL SETUP

To reach high-fidelity PNR detection, IDQ has developed a unique Parallel-SNSPD (P-SNSPD) design with an interleaved array of 8 to 28 SNSPD pixels connected in parallel on-chip [1]. This arrangement allows all pixels to be read out with a single coaxial cable. This design encodes the photon-number information in the amplitude and width of the electrical pulse generated. Leveraging a unique capability of Swabian Instruments' Time Taggers, one can simultaneously record both the rising and falling edges of a pulse with just a single input channel. Using this information, measuring the pulse width and inferring the number of photons contributing to the signal with high fidelity becomes straightforward.

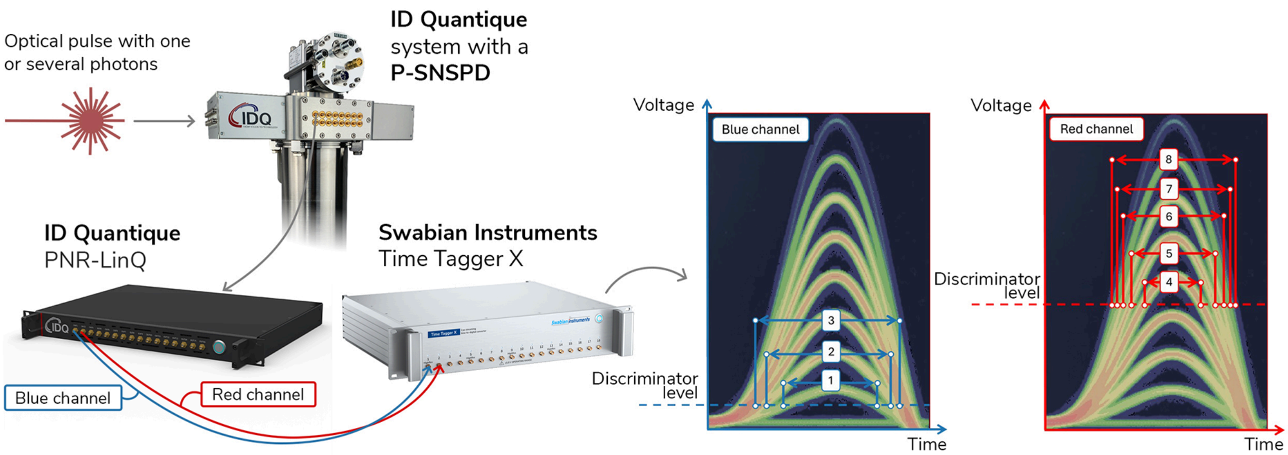

Figure 1 - Photon Number Resolving (PNR) detection setup: IDQ's P-SNSPDs, IDQ's PNR-LinQ, and Swabian Instruments' Time Tagger X (TTX). The graphs display the pulse widths measurement for each possible pulse amplitude (corresponding to 1 to 8 clicks on the P-SNSPD) using two TTX channels.

Figure 1 illustrates the measurement setup. An optical pulse is directed onto a P-SNSPD, and the electrical pulse generated by the P-SNSPD is displayed on the right-hand side. While all possible electrical pulse amplitudes are represented (up to eight different pulses are shown), only one pulse is realized for each detection. The distribution of these amplitudes closely follows the statistics of the photon number. The goal of the setup is to identify which pulse was detected and to time-tag the event, both with the highest possible accuracy.

The ID Quantique PNR-LinQ can be configured to create the number of copies necessary for each application, as one copy might not be enough to identify up to 8 photons with high fidelity. In the example depicted in Fig. 1, two copies are created: one for the Blue channel and another for the Red channel. It is important to note that the voltage amplitudes from the splitter are adjusted to meet the Swabian Instruments' Time Tagger X (TTX) pulse requirements, ensuring full compatibility.

The amplitude is identified by measuring the signal width at a certain trigger level using the Start-Stop measurement provided in the Swabian Instruments software package. In the example of Fig. 1, the pulse width of the Blue copy is measured with a discrimination level set to trigger on the amplitude of the 1st level of the P-SNSPD electrical pulse. The Red copy is measured with a discrimination level set on the amplitude of the 4th level.

Figure 1 shows the pulse's analysis on the right side. The TTX measures the time difference between each pulse's rising and falling edges. The Blue channel is used to identify the width of the first three levels (1 to 3), while the Red channel is used to identify the width of the fourth to eighth levels (4 to 8). The approximate widths measured for each case are shown and labeled.

RESULTS

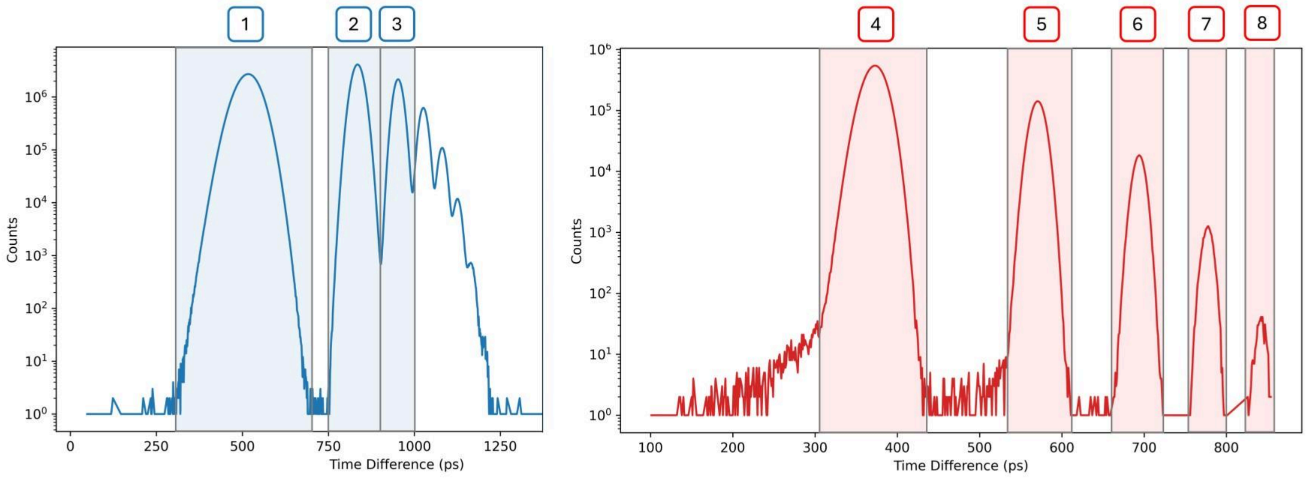

Figure 2 - Log-scale histogram of the events measured on the Blue channel (left) and on the Red channel (right). Bands show the regions corresponding to the widths of the different amplitude levels of the electrical pulses.

The measurement is repeated many times, and the distribution of the measured widths is shown in Fig. 2. The left panel shows the widths measured on the Blue channel, and the right panel shows the widths measured on the Red channel. The colored bands are used to indicate the widths used to identify the different levels. There is little to no overlap between the different bands, which suggests that assigning the correct amplitude can be performed with a high level of accuracy. This feature is fundamental to obtaining high-fidelity PNR measurements with P-SNSPDs.

CONCLUSION AND OUTLOOK

The approach presented here is an innovative, highly practical, and scalable solution for performing high-fidelity single-shot identification of the number of photons. It leverages the uniqueness of both Swabian Instruments' Time Tagger X and IDQ's P-SNSPD technologies.

This advancement in photon number resolving measurement is anticipated to significantly impact various applications. It enables PNR measurements at high detection rates, which could substantially enhance the scalability of photonic quantum computing and quantum communication. Furthermore, it will create opportunities for new applications that take full advantage of the possibilities offered by multiphoton detection.

REFERENCES

[1] Stasi, L., Taher, T., Resta, G. \I., Zbinden, H., Thew, R. and Bussieres, F., 2024. Enhanced Detection Rate and High Photon-Number Efficiencies with a Scalable Parallel SNSPD. ACS Photonics, 12(1), pp.320-329.