Redefining Measurement

# Use Case: Quantum Information Science

## Two and Four-Fold joint spectral measurements in real time using ID281 SNSPD detectors coupled with ID900 TCSPC electronics

**Customer:** University of Oregon

**Research Field:** Quantum science and engineering

**Country:** USA

| Customer Need | Solution | Results |
|---|---|---|
| Two and Four-Fold joint spectral measurements in real time | ID281 SNSPD with >85% Quantum Efficiency paired with the ID900 Programmable Time Tagger | Unprecedented resolution, efficiency, and quasi-real time measurement |

### Customer Need

Prior to acquiring the system, we developed time-of-flight spectrometers (TOFS) which utilize chromatic dispersion to map optical frequency to time of arrival. Through this process, the wavelength of a single-photon can be accurately measured over a certain range and the accuracy of this measurement is only limited by the temporal resolution of the detection.

We previously used SPAD-based detectors featuring 40 picosecond timing jitter and 12% quantum efficiency in order to maintain a relatively low dark count rate, combined with a time tagger. Due to the low quantum efficiency that these detectors offer, several dozens of minutes were necessary to gather enough data points. Also, the spectral coincidences were computed in post processing, where billions of data points were run through an algorithm to extract a few thousand coincidences.

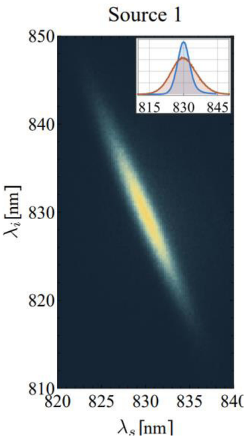
## Solution

After having tested the ID281 superconducting nanowire single-photon detection (SNSPD) system from ID Quantique, we confirmed quickly that it ticked all the boxes in our wish list. Most importantly, the system has a quite high detection efficiency, very low dark and low timing jitter. This allows us to perform high sensitivity measurements at the single-photon level with a high timing accuracy. The cryogenic system and the integrated helium compressor operate in a closed cycle. The system is also capable of running automatically and continuously with only a short measurement interruption of less than one hour every 24 hours, greatly improving the ease-of-use.

The provided ID900 time tagger also exceeded expectations. The instrument is FPGA based and allows for many operations to be conducted on board, which to our knowledge, no other company currently offers.

## Results

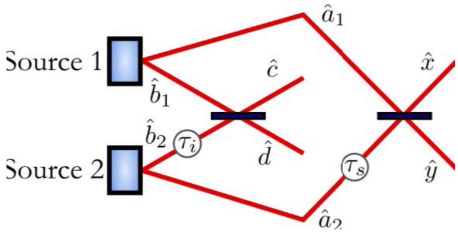
After upgrading our equipment with the SNSPD and time tagger from IDQ, our setup was massively improved. First of all, the actual quantum efficiency made the SNSPD ideal for coincidence experiments. Moreover, learning how to utilize the time tagger opened up countless possibilities that weren’t even considered before. The ability to compute the coincidences directly on the FPGA board enabled us to consider only the events that were indeed coincidences, dividing the amount of data to analyze by several orders of magnitude. As a result, obtaining a joint spectrum is now possible in quasi real-time: sufficient data is gathered in less than one second. The following image[1,2] shows a joint spectrum intensity (JSI) acquired with the experimental setup. While this method has been used for several years, the equipment acquired from IDQ makes the measurement likely state-of-the-art in terms of efficiency.



> *After upgrading our equipment with the SNSPD and time tagger from IDQ, our setup was massively improved. First of all, the actual quantum efficiency made the SNSPD ideal for coincidence experiments. Moreover, learning how to utilize the time tagger opened up countless possibilities that weren’t even considered before.*
>
> Dr. Valérian Thiel
> Postdoctoral Researcher at University of Oregon

### Four-fold measurements

When counting photons, the probability of a detection scales inversely with the power of the number of detectors. A four-fold detection is therefore 16 times less likely to occur than a single event, hence the need for detectors with high quantum efficiency. In the past, we performed an entanglement swapping experiment whereby four photons would interfere, and the entanglement between two of them is transferred to photons that didn’t share any entanglement. One photon from each source, called idlers, are combined, and when a coincidence is detected, it projects the two outer photons, called signal, into an entangled state.



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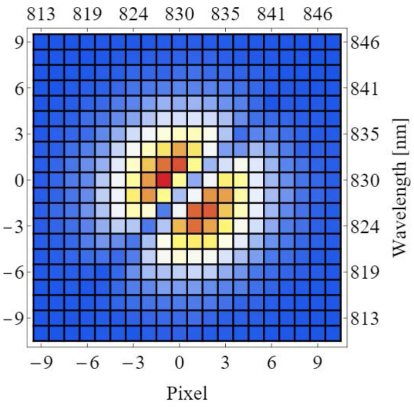
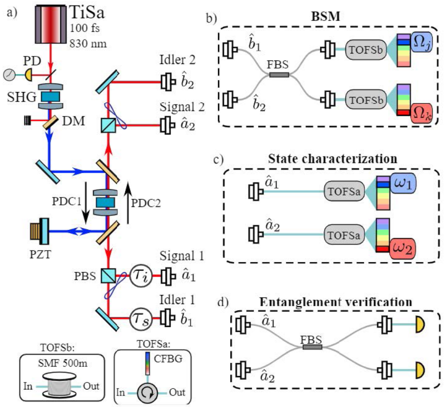
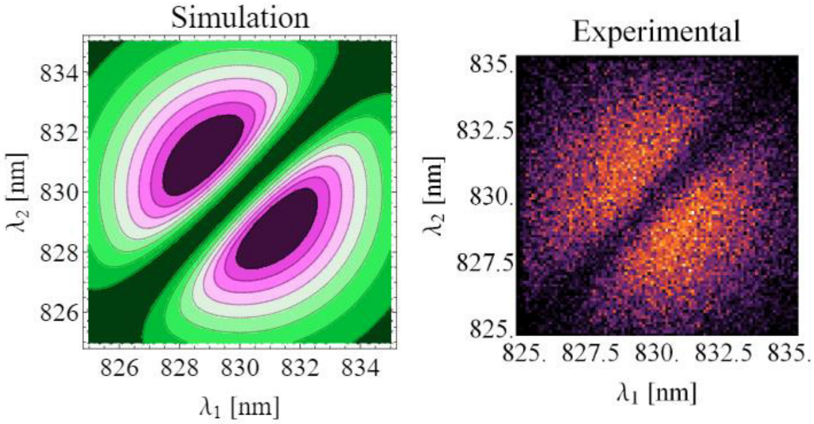
[1] https://arxiv.org/pdf/2102.03485.pdf
[2] https://arxiv.org/pdf/2104.05655.pdf

This measurement requires four-fold coincidences. Earlier, this was achieved with single-photon avalanche diodes and two TOFS to achieve spectral resolution. The upgrade to the ID281 and ID900 enabled us to greatly decrease the acquisition time by a factor of 5. Moreover, thanks to the ID900, we were able to interface four TOFS and compute four-fold spectral coincidences, which is to our knowledge one of the first demonstration of such a feature. The count rate is quite low but still above a few Hertz, which enables an experiment that wouldn't be achievable without the high efficiency of an SNSPD.





In the above figure[1][2], on the right is the experimental setup with the different measurement configurations. Every detector here is an SNSPD of the ID281 system. On the left is a two-fold coincidence map between independent single-photons that undergo Hong Ou Mandel interferences. It shows the coarse spectral resolution achieved with the SNSPD and TOFS, where one spectral bin is about 2 nm wide. These measurements are achieved simultaneously thanks to the equipment used in the experiment.



The above plot is the simulated and experimental JSI of the signals state that is heralded by a coincidence on the two idler photons. The ID900 is operated in high resolution mode in this case. This is the most lossy experiment (over 99%), but the count rate is still macroscopic, yielding over 50 000 four-fold spectral coincidences over a nightly measurement. This would be unreachable with lower resolution detectors, or even with another type of time-tagger that does not compute coincidences on board. We have noticed that upgrading our algorithm, inherited from an older time tagger where coincidences are computed in post processing, virtually removed any dead time in our measurement. It used to be that 50% of an acquisition would be spent on computing the coincidences, while the ID900 automatically filters them out on the built-in FPGA board.

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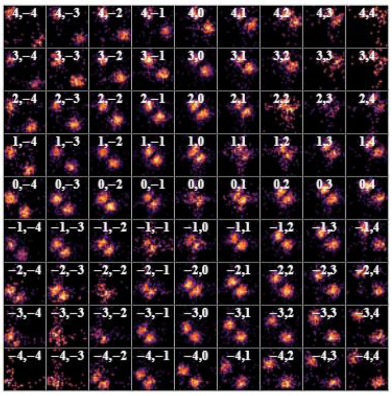
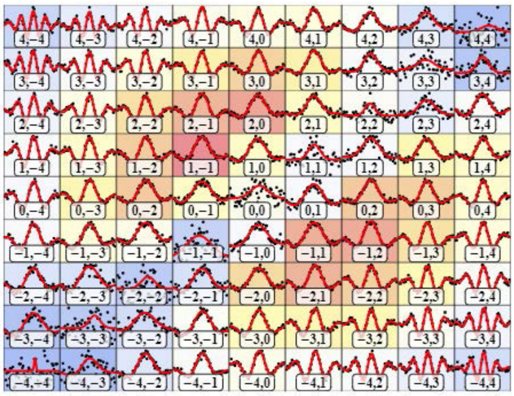
[1] https://arxiv.org/pdf/2102.03485.pdf

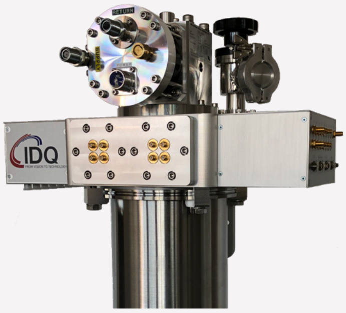
[2] https://arxiv.org/pdf/2104.05655.pdf





On the left is shown the different heralded JSI depending on which bin is heralded at the idler stage. They show multiple heralded Bell states, all acquired simultaneously. On the right is a procedure where the heralded signal-photons are combined and their delay is scanned in a HOM-type experiment. Rather than a usual HOM dip, we see interferences at a frequency which depends on which frequency bin is heralded (on the left). This experiment was achieved before with only a few counts per second, whereas the upgrade allowed us to see count rates exceeding 100 Hz.

## MEET THE PRODUCTS



ID281 Superconducting Nanowire

ID900 Time Controller Series

For more information:

- Heralding multiple photonic pulsed Bell-pairs via frequency-resolved entanglement
- Spectrally-resolved four-photon interference of time-frequency entangled photons