A Sensor for the Smallest Signals

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Nicolò Crescini explains a study in the field of quantum technologies published in Nature Communications

In the quest to explore the quantum world, one challenge has long stood out: **detecting single microwave photons**. These elusive particles, with energies measured in mere yoctojoules, are notoriously difficult to capture. Yet their significance extends far beyond scientific curiosity—they hold the key to advancing quantum technologies, exploring dark matter, and understanding the fundamental rules of quantum physics.

"Our recent research, published in Nature Communications, marks a breakthrough in this domain. By harnessing the unique properties of superconducting Josephson junctions, we developed a sensor capable of detecting these low-energy photons with remarkable efficiency and exceptionally low noise, positioning it among the most sensitive detectors ever built", says **Nicolò Crescini**, researcher and Science Ambassador at FBK.

The Experiment and the Sensor

Detecting the faintest signals requires meticulously controlled conditions. Our **experiment** was conducted in a **dilution refrigerator operating just 0.01°C above absolute zero**, within an environment shielded from external electromagnetic disturbances.

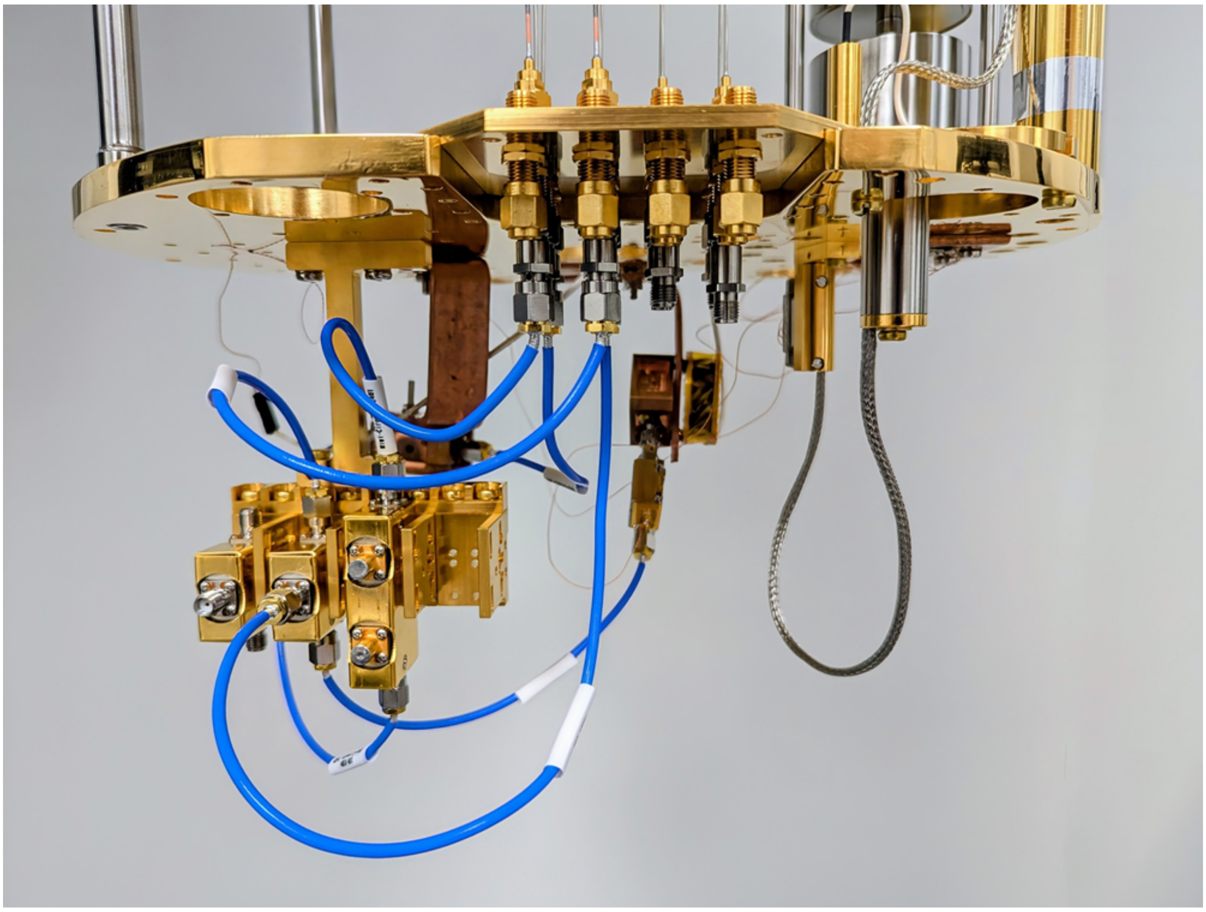

Figure 1: The coldest stage of a dilution refrigerator recently installed in FBK, which reaches a base temperature below 10 millikelvin, with microwave electronics components mounted.

At the heart of the setup was a custom-designed **microwave cavity**, a familiar tool for a physicist, used in an innovative way. This cavity not only confined the microwave photons but also enabled precise control over their generation and delivery to the sensor. By gently heating the cavity by just a few milli-degrees, we produced single **thermal photons**—weak signals with emission rates of only a few quanta per second.

Our **sensor**, a **Josephphson junction** integrated into an impedance-matching circuit, successfully detected these photons. When a photon struck the junction, it triggered a measurable switch to a resistive state—a definitive “click” that signaled photon detection. With an efficiency exceeding 40% and a dark count rate as low as 0.1 Hz, the device surpassed expectations, making it the most sensitive detector to date.

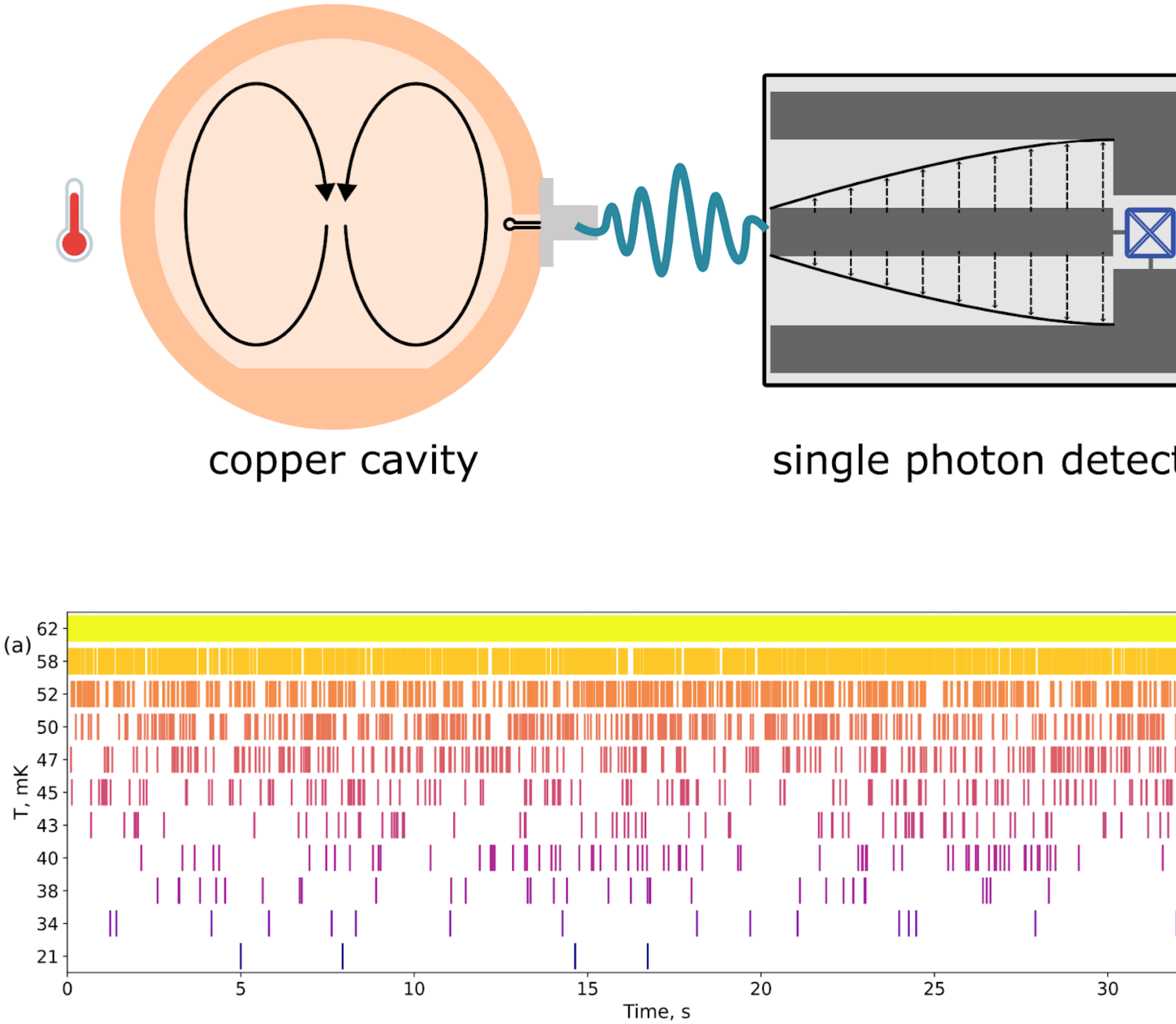

Figure 2: Top – Schematic drawing of the experimental setup, with the microwave cavity of the left and the
detector on the right.
Bottom – Time trace of the recorded clicks of the detector as a function of the cavity temperature: every ve
line indicates the detection of a microwave photon.

One of the most exciting aspects of this work was the ability to observe the quantum nature of the detected photons. By varying the cavity temperature, we confirmed the photons' **super-Poissonian** arrival statistics—a quantum correlation between one photon and the next—a hallmark of their thermal origin and a fascinating glimpse into quantum chaos.

Implications and Future Directions

This achievement opens the door to a host of applications. From quantum computing and secure communication to dark matter searches, the potential of single-photon detection is immense. For instance, haloscopes used in axion research could benefit significantly from this technology, overcoming the limitations of quantum amplifiers.

Looking ahead, we aim to refine the sensor design for even greater sensitivity and broader applicability. By pushing the boundaries of microwave photon detection, we hope to uncover new physics and transform the tools available for quantum technologies. All in all, we look forward to using this sensor for more.

Eventually, this achievement highlights the importance of international collaboration, with contributions from teams in Russia, Italy, and Sweden. It underscores the value of open and cooperative research in driving progress and overcoming scientific challenges.

For those interested in the full details of our findings, the paper is available here.

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