

## **Title: Single- and entangled photon sources for quantum metrology**

### **Abstract**

Optical quantum enhanced metrology and sub-shot noise metrology have become increasingly relevant in recent years. However, the associated measurement techniques are not yet commonly put into practice at NMIs, mostly because the available relevant sources, i.e. highly efficient single-photon sources and sources of entangled photons, are not reliable or commercially available. Significant advancements have been made in engineering these sources, but if they are to be used in metrological applications, further development is needed. Proposals addressing this SRT should aim at the development of bright entangled photon sources based on different application-oriented platforms and at the exploitation of high-purity single-photon sources, to demonstrate the quantum advantage achievable using these sources for specific measurements.

### **Keywords**

Entangled-photon source, single-photon source, quantum metrology, entanglement, sub-shot noise

### **Background to the Metrological Challenges**

Quantum technologies are amongst the most relevant topics with respect to innovation and advanced technologies. For this reason, several programmes and initiatives have been started and are currently under way, e.g. the European Quantum-Flagship, Quant-ERA, ITN Networks, German Quantum Technology initiatives, and the UK Quantum Technologies programme. Furthermore, the European Metrology Network for Quantum Technologies (EMN-Q) has been established.

In the previous projects EMRP EXL02 SIQUTE and EMPIR 17FUN06 SIQUEST significant progress has been made in the development of single-photon sources for metrological applications. Within EXL02 SIQUTE, optical quantum technology at the single-photon level became customary at NMIs. Specifically, for the first time a single-photon source was realised, which was absolutely calibrated with respect to its absolute optical radiant flux and spectral power distribution, and traceable to the corresponding national standards via an unbroken traceability chain. Recently, a molecule-based single-photon source was exploited as a source for a direct calibration of a single-photon avalanche detector against a classical Si-photodiode. In that work, the photon flux was traceably measured to be up to  $1.32 \times 10^6$  photons per second, with a purity indicated by a second-order autocorrelation function at zero time delay below 0.1. Within 17FUN06 SIQUEST, the intensity squeezing from a single-emitter single-photon source was measured for the first time. It was shown that a photon was detected with a probability around 70 %, after the source has been triggered. This demonstration represents an important step towards the ideal and deterministic single photon source where every trigger pulse leads to a photon emission event.

Specific quantum correlations of two mode squeezed vacuum have demonstrated to be a fundamental resource for overcoming classical limits of measurements, and it has been experimentally shown that shot noise limit can be beaten in imaging by exploiting the specific photon number entanglement of twin beams. Therefore, measurements based on sources of entangled photons and on highly efficient single-photon sources provide the opportunity to achieve measurement results below the shot-noise limit. Furthermore, by using such light sources, quantum and sub-diffraction imaging will become possible and there will be minimum effect on the tested objects due to ultra-low light levels.

However, metrological applications based on photon sources have not yet been implemented at NMIs because single-photon and entangled-photon sources, with the improved performance parameters, are not readily available and there is not an infrastructure for their traceable characterisation.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of single- and entangled photon sources.

The specific objectives are

1. To assess single-photon sources and entangled-photon sources in traceable quantum enhanced measurements (e.g. quantum calibration at the single-photon level, sub-shot noise measurements, quantum imaging, sub-diffraction imaging and quantum illumination), to overcome classical measurement limits (e.g. noise);
2. To specify the performance parameters of single-photon and entangled-photon sources required to carry out different quantum enhanced measurements;
3. To develop novel validated methods for the fabrication of single-photon sources and to optimise the sources for highest purity ( $g^{(2)}(t=0)$  close to 0), brightness (photon rate  $> 5 \times 10^6$  photons per second) and indistinguishability (Hong-Ou Mandel visibility  $> 95\%$ ), according to the performance parameters specified in Objective 2;
4. To develop the European metrology infrastructure required for the traceable characterisation of entangled-photon and single-photon sources, i.e. detectors (including photon-number resolving detectors), amplifiers, single-photon spectroradiometers, as well as standardised quantum-optical setups for characterisation (in particular, entanglement tomography);
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the EMN Quantum, measurement supply chain, standards developing organisations (e.g. CEN and ISO) and end users (in the fields of quantum technology and nano-photonics).

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP EXL02 SIQUTE and EMPIR 17FUN06 SIQUST projects and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % of the total EU Contribution across all selected projects in this TP.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the quantum technology and nano-photonics sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards

- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

### **Time-scale**

The project should be of up to 3 years duration.