European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-f03**
Version: 1.0

Title: Entangled photon sources for improved quantum metrology

Abstract

Entangled photons are key for quantum metrology and have the potential to be used in a wide range of applications, e.g., quantum microscopy, quantum illumination, optical phase measurement and quantum communication. However, for entangled photon sources to be of practical use in quantum enhanced measurements, further work is required. Proposals addressing this SRT should develop and characterise bright and efficient entangled photon sources, develop metrology infrastructure and demonstrate the quantum advantage of entangled-photon sources in specific fields of metrology.

Keywords

Entanglement, entangled photon sources, quantum metrology, quantum enhanced measurements, quantum advantage, quantum sensing

Background to the Metrological Challenges

The use of entangled photon sources for quantum metrology is an important area of current research in National Metrology Institutes (NMIs) and probable future use in many scientific and industrial applications. Quantum metrology has the potential to provide more precise and accurate measurements compared to classical metrology techniques, making it a valuable tool in different applications and fields e.g. optics, engineering, medicine etc. This potential has been acknowledged by CEN/CENELEC, which included the importance of further work on quantum technologies, in particular entangled-photon sources, in their standardisation roadmap [1].

The state of the art for entangled photon sources has advanced in recent years, resulting in increased brightness, efficiency, and photon pair rates. The fidelity to one of the maximally entangled Bell states, a measure of the quality of entanglement, has also been improved, leading to stronger correlations between entangled photons. These advancements have enabled using entangled photon sources in a wider range of applications, including communication. However, these advancements are still not sufficient to classical metrology accuracy and precision. There has also been progress in the development of metrology infrastructure for the traceable characterisation of entangled photon sources, but this is not yet able to ensure that their quality and performance are consistent across different applications and users.

Within the EMPIR project 20FUN05 SEQUME, performance parameters for entangled photon sources were derived, an assessment of entangled-photon sources was carried out and a development of metrology infrastructure for entangled photon sources was started.

For entangled photon sources to reach their full potential, it is crucial to develop bright and efficient entangled photon sources with high entanglement fidelity, as the brightness and efficiency of entangled photon sources directly impact the measurement precision and accuracy of measurements in new fields of quantum technologies, the so-called quantum technology 2.0. Additionally, for the sources to be of practical use in quantum metrology and communication, they must be traceably characterised. Therefore, it is required to develop a robust metrology infrastructure for the traceable characterisation of entangled-photon sources, aiming at improving consistency, reliability, and accuracy in quantum technology measurements.

NMIs are responsible for establishing and maintaining national measurement standards, and the use of entangled photons can greatly improve the accuracy and precision of these standards. By exploiting entangled photon sources, European NMIs will advance the field of metrology. Also, the demonstration of quantum advantage for specific fields of metrology is crucial for advancing the practical use of quantum technologies. In this context, quantum advantage refers to the superiority of quantum-based systems over classical systems.

To show quantum advantage in metrology, it is necessary to prove lower uncertainties and higher resolution in specific measurements compared to classical methods.

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 development of metrology capability in entangled photon sources for improved quantum metrology.

The specific objectives are to:

1. Develop bright and efficient entangled photon sources based on different platforms, including on-demand sources, as well as sources based on spontaneous parametric down-conversion, with a fidelity > 98 %;
2. Develop the necessary metrology infrastructure and perform the traceable characterisation of entangled-photon sources. This should include the development of i) detectors (cryogenic and room temperature), ii) single-photon spectroradiometers, iii) analysis and detection techniques, such as polarisation analysis and systems for enhanced collection rates, and iv) standardised quantum-optical setups for characterisation and validation of the sources. Additionally, novel methods should be developed for quantum entanglement witness, Bell states measurements, entanglement protection and noise sensing (specifically entanglement tomography with respect to quantum metrology and quantum communication);
3. Demonstrate quantum advantage of entangled-photon sources and hyper-entangled states of light, by achieving lower uncertainties, higher sensitivities and/or higher resolution as compared to classical measurements. The quantum advantage should be proved in fields like: i) super-resolution and sub-shot-noise imaging metrology, ii) spectroscopy and microscopy, and iii) multiphoton entangled states for the enhancement of interferometric measurements (super phase resolution);
4. Facilitate the take up of the technology and measurement infrastructure developed in the project by the EMN Quantum, measurement supply chain, research organisations, standards developing organisations (e.g. CEN/CENELEC) and end users (in the fields of quantum technology and nano-photonics). This should include the implementation of entangled photon sources in measurement setups and the creation of services based on entangled photon sources (e.g., in quantum microscopy, quantum illumination, optical phase measurements, and quantum communication) at NMIs.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. 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, including other European Partnerships, 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 EMPIR project 20FUN05 SEQUME and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€ and has defined an upper limit of 2.5 M€ for this project.

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

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

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,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the quantum technology sector.

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 the Partnership 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.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] 005_CEN SECT-FGQT Quantum metrology, https://metpart.eu/nrm-call-2023