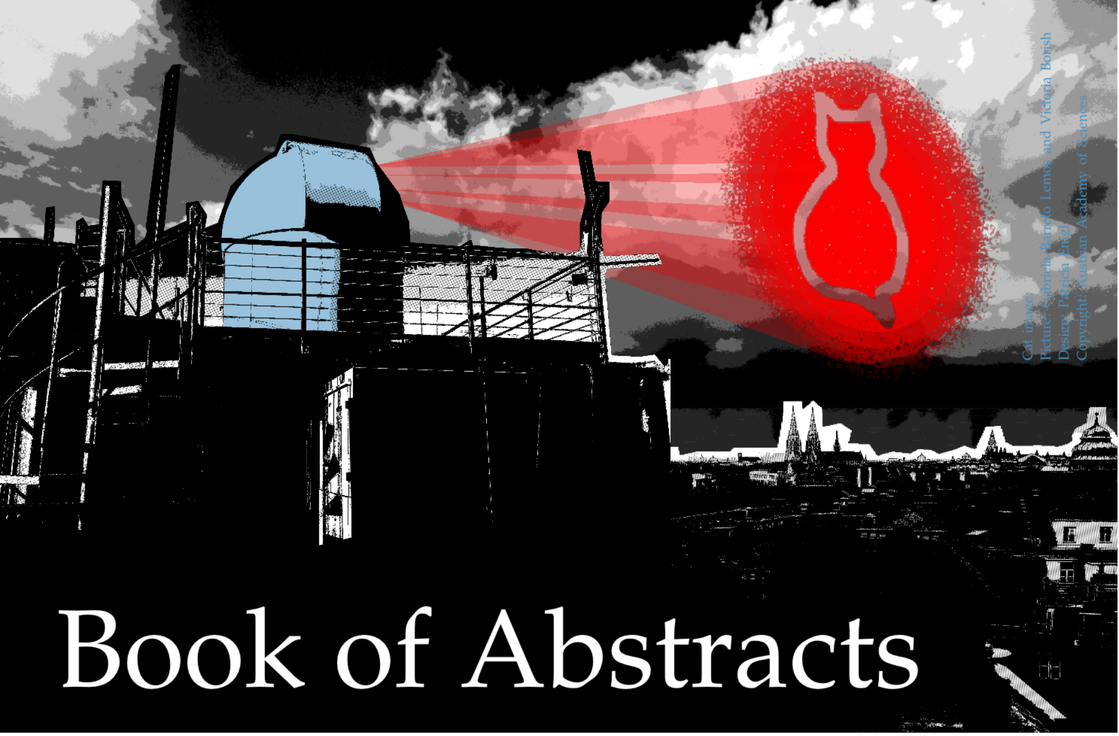

Book of Abstracts

Contributed Talks

International Conference for
Young Quantum Information Scientists (YQIS) and
Summer School of the Vienna Doctoral Program on
Complex Quantum Systems (CoQuS)

University of Vienna, Austria

September 17–21, 2018

Contents

Monday, Sep. 17

Bidirectional Dense Coding and Teleportation in Butterfly network

Nitica Sakharwade

Perimeter Institute of Theoretical Physics
31 Caroline Street North, N2L 2Y5 Waterloo, Canada

Non-local correlations via entangled states have been known to be resources for two-party communication tasks such as teleportation and dense-coding. We are interested in optimizing many such two-party communication tasks in a quantum network of many parties akin to the role the internet played in classical communication tasks. Specifically, we choose the simplest non-trivial communication task of two communication tasks simultaneously achieved between two-parties, Alice and Bob, and find optimal protocols for bidirectional teleportation and bidirectional dense coding by embedding them in the butterfly network and using a classical network coding protocol. Surprisingly, we find that a one-qubit channel (or two-cbit channel) along with pre-shared entanglement is sufficient for bidirectional teleportation (or dense-coding). We also find a general boundary rule that prescribes which parties require pre-shared entanglement for a given set of two-party tasks on a quantum network.

These results have implications for post-quantum theories like the indefinite causal theories.

Two-way communication with a single quantum particle

Flavio del Santo

Faculty of Physics, University of Vienna
Boltzmanngasse 5, 1090 Vienna, Austria

Communication, when restricted to a) limited resources (i.e. a single information carrier) and b) finite speed of propagation (bounded by the speed of light), is fundamentally limited for classical systems. Quantum systems, however, can violate this limitation. I will show that communication bounded to the exchange of a single quantum particle in superposition of different spatial locations can result in "two-way signaling", a task that is impossible in classical physics. Starting from an easy bipartite 'quantum game', I then generalize the protocol to an arbitrary number of parties and show that while classically the probability of success is asymptotically decreasing as the number of parties grows, quantum superposition enables the players to accomplish the task always with certainty. Moreover, I will report on the recent experimental demonstration of these proposed theoretical findings, and on the practical applications for cryptography.

Composable security in relativistic quantum cryptography

Vilasini Venkatesh

University of York
Heslington, York YO10 5DD, United Kingdom

Relativistic protocols have been proposed to overcome certain impossibility results in classical and quantum cryptography. However, composing specific relativistic bit commitment protocols to construct other cryptographic resources is known to be insecure. To make general statements about such constructions, a composable framework for modelling cryptographic security in Minkowski space is required. Here, we propose such a framework and show that (1) fair and unbiased coin flipping can be constructed from a channel with delay resource (which we introduce in the paper) (2) Biased coin flipping, bit commitment and channel with delay through any classical, quantum and/or relativistic protocol are all impossible without further assumptions (3) It is impossible to securely increase the "commitment time" of a channel with delay even if one is given n channels with delay to start with. Results (1) and (3) imply in particular the non-composability of existing relativistic bit commitment and coin flipping protocols.

Q^3Sat: Quantum Communications Uplink to a 3U CubeSat - Feasibility & Design

Sebastian Neumann

IQOQI Vienna
Boltzmanngasse 3, 1090 Vienna, Austria

Satellites are the most efficient way to achieve global scale quantum communication (Q.Com) because unavoidable losses restrict fiber based Q.Com to a few hundred kilometers. We demonstrate the feasibility of establishing a Q.Com uplink with a 3U CubeSat, measuring only 10x10x34 cm^3, using commercial off-the-shelf components, the majority of which have space heritage. We demonstrate how to leverage the latest advancements in nano-satellite body-pointing to show that our 4 kg CubeSat can generate a quantum-secure key, which has so far only been shown by a much larger 600 kg satellite mission. A comprehensive link budget and simulation was performed to calculate the secure key rates. We discuss design choices and trade-offs to maximize the key rate while minimizing the cost and development needed. Our detailed design and feasibility study can be readily used as a template for global scale Q.Com.

Tuesday, Sep. 18

Optimal EPR steering inequalities from generalized entropic uncertainty relations

Tamás Kriváchy

University of Geneva
24 rue du Général-Dufour, 1211 Genève 4, Geneva, Switzerland

We establish a general connection between entropic uncertainty relations, EPR steering, and joint measurability. Specifically, we show how to derive steering inequalities starting from a broad class of entropic uncertainty relations. This allows us to construct steering inequalities based on Renyi entropy, which are optimal in many scenarios. Considering steering tests where Alice performs two noisy measurements, our inequalities exactly recover the noise threshold for steerability. This is the case for qubit 2-outcome measurement, as well as for mutually unbiased bases in any dimension, using here min- and max-entropy. This shows that easy-to-evaluate quantities such as entropy can optimally witness steering, despite the fact that they are coarse-grained representations of the underlying statistics.

Self-testing quantum states and measurements in the prepare-and-measure scenario

Armin Tavakoli

University of Geneva
Chemin de Pinchat 22, 1227 Geneva, Switzerland

The goal of self-testing is to characterise an a priori unknown quantum system based solely on measurement statistics, i.e. using an uncharacterised measurement device. Here we develop self-testing methods for quantum prepare-and-measure experiments, thus not necessarily relying on entanglement and/or violation of a Bell inequality. We present noise-robust techniques for self-testing sets of quantum states and measurements, assuming an upper bound on the Hilbert space dimension. We discuss in detail the case of a $2 \rightarrow 1$ random access code with qubits, for which we provide analytically optimal self-tests. The simplicity and noise robustness of our methods should make them directly applicable to experiments.

Catalytic Quantum Randomness

Paul Boes

Fachbereich Physik - AG Eisert - Freie Universität Berlin
Arnimallee 14, 14195 Berlin, Germany

Randomness is a defining element of mixing processes in nature and an essential ingredient to many protocols in quantum information. In this work, we investigate how much randomness is required to transform a given quantum state into another one. We provide a complete answer to these questions, by identifying provably optimal protocols for both classical and quantum sources of randomness, based on a dephasing construction. Building upon these results, we discuss applications in both equilibration and quantum information theory: We discuss the smallest possible measurement device, capturing the smallest equilibrating environment allowed by quantum mechanics, and introduce a novel type construction for a cryptographic private quantum channel. We complement the exact analysis with a discussion of approximate protocols based on quantum expanders deriving from discrete Weyl systems.

The boundaries and twist defects of the color code and their applications to topological quantum computation

Markus Kesselring

FU Berlin
Arnimallee 14, 14195 Berlin, Germany

Making use of the condensed matter perspective of topological phases of matter, we discover new features realizable in the promising and well studied error correction code called “color code”. These features are new boundaries and twist defects. After categorizing and studying the interplay between these features, we discuss how they might be used for quantum information processing. In the talk, I can offer a basic introduction to topological error correction based on the example of the color code.

Inadequacy of modal logic in quantum settings

Nuriya Nurgalieva

Institute for Theoretical Physics, ETH Zurich
Wolfgang-Pauli-Strasse 27, 8093 Zurich, Switzerland

We explore the extent to which the principles of classical modal logic can be applied to fully quantum settings. Modal logic models our reasoning in multi-agent problems, and allows us to solve puzzles like the muddy children paradox. The Frauchiger-Renner thought experiment highlighted fundamental problems in applying classical reasoning when quantum agents are involved; we take it as a guiding example to test the axioms of classical modal logic. In doing so, we find a problem in the original formulation of the Frauchiger-Renner theorem: a missing assumption about unitarity of evolution is necessary to derive a contradiction and prove the theorem. Adding this assumption clarifies how different interpretations of quantum theory fit in, i.e., which properties they violate. Finally, we show that most of the axioms of classical modal logic break down in quantum settings, and make suggestions to generalize them.

Many-particle interference to test Born's rule

Marc-Oliver Pleinert

Institut für Optik, Information und Photonik,
Friedrich-Alexander-Universität Erlangen-Nürnberg
Staudtstr. 1, 91058 Erlangen, Germany

Born's rule, one of the cornerstones of quantum mechanics, predicts that quantum interference can be traced back to pairs of quantum paths. In slit experiments involving single-particle interference, Born's rule thus excludes any third-order interference terms. Deviations can be quantified via the Sorkin parameter, which has been measured in several systems in recent years. We extend these ideas to many-particle interference, which exhibit more diverse characteristics allowing for far more nonzero higher-order interference defined correspondingly. We further introduce a family of many-particle Sorkin parameters being more sensitive to deviations from Born's rule than their single-particle analogs. The introduced parameters are thus perfectly suited for a more precise test of Born's rule and thus quantum mechanics.

Wednesday, Sep. 19

The pair-flip model: a very entangled translationally invariant spin chain

Libor Caha

Research Center for Quantum Information Institute of Physics, Slovak Academy of Sciences
Dúbravská cesta 9, 84511 Bratislava, Slovakia

How much entanglement can there be in the ground state of a simple qudit spin chain with a reasonable energy gap? We introduce the pair-flip model, a family of spin chains with nearest neighbor, translationally invariant, frustration-free interactions, with a very entangled ground state and an inverse-polynomial spectral gap. For a ground state in a particular invariant subspace, the entanglement entropy scales as $\sqrt{N}$ for qutrits (and higher qudits), and as $\log N$ for qubits. Moreover, we conjecture that this particular ground state can be made unique by adding a small translationally-invariant perturbation while retaining its entropy scaling.

Generalized Probabilistic Description of Noninteracting Identical Particles

Marcin Karczewski

Adam Mickiewicz University in Poznań
Wieniawskiego 1, 61-712 Poznań, Poland

This talk aims to present the operational description of identical noninteracting particles in multiports developed in Phys. Rev. Lett. 120, 080401. In particular, I will try to explain the bunching probabilities of photons without reffering to the quantum formalism. Instead, we will see their emergence as a result of some simple, physically motivated restrictions.

A correlation measure detecting almost all non-Markovian evolutions

Dario de Santis

ICFO - The Institute of Photonic Sciences
Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain

Given a quantifier for the information encoded in an open quantum system, in general it is not clear if, for any non-Markovian evolution, it is possible to observe a characteristic behavior of the studied quantity that witnesses this regime of evolution. Therefore, the potential of several physical quantities to witness non-Markovian dynamics have been studied. We investigate the ability of correlation measures to witness non-Markovian evolutions. It is shown that the mutual information and any entanglement measure between the system and an ancilla do not witness all non-Markovian dynamics. We introduce a new correlation measure and we prove that, in an enlarged setting with two ancillary systems, this measure detects almost all non-Markovian dynamics, except possibly a zero-measure set of dynamics that is non-bijective in finite time-intervals. We provide different initial states detecting the non-Markovian regime. They are all separable and some are arbitrarily close to a product state.

Non-demolition quantum thermometry of BECs in the sub-nK domain

Mohammad Mehboudi

ICFO
Mediterranean Technology Park, Avinguda Carl Friedrich Gauss 3, 08860 Casteldefels, Barcelona, Spain

We introduce a novel minimally-disturbing method for sub-nK thermometry in a Bose-Einstein condensate (BEC). Our technique is based on the Bose-polaron model; namely, an impurity embedded in the BEC acts as the thermometer. We propose to detect temperature fluctuations from measurements of the position and momentum of the impurity. Crucially, these cause minimal back-action on the BEC and hence, realize a non-demolition temperature measurement. Following the paradigm of the emerging field of *quantum thermometry*, we combine tools from quantum parameter estimation and the theory of open quantum systems to solve the problem in full generality. We thus avoid *any* simplification, such as demanding thermalization of the impurity atoms, or imposing weak dissipative interactions with the BEC. Our method is illustrated with realistic experimental parameters common in many labs, thus showing that it can compete with state-of-the-art *destructive* techniques, even when the estimates are built from the outcomes of accessible (sub-optimal) quadrature measurements.

Ultra-strong spin-motion coupling with cold atoms in a nanofiber-based trap

Yijian Meng

Atominstitut, TU Vienna
Stadionallee 2, 1020 Vienna Austria

The Quantum Rabi Model (QRM) constitutes the most fundamental description of the light-matter interaction. Recently, a cold-atom based implementation of the quantum Rabi model (QRM) was proposed in which the atom's quantized motion and its spin correspond to the light and the emitter, respectively [arXiv: 1706.07781]. We present the first experimental evidence for coherent ultra-strong coupling with this approach, enabling a systematic study of the QRM in extreme parameter regimes.

Partial Thermalizations Allow for Optimal Thermodynamic Processes

Elisa Bäumer

Institute for Theoretical Physics, ETH Zurich
Wolfgang-Pauli-Str. 27, 8093 Zurich, Switzerland

Thermalization processes are ubiquitous in macroscopic thermodynamics, being at the core of optimal processes such as a Carnot engine. However, when dealing with small quantum systems, energy exchanges do not always lead to thermalization, but rather to partial thermalization, where the system becomes closer to a thermal state while not reaching it. In fact, partial thermalizations happen to characterize a large set of interactions between small systems. In our work, we show that optimal thermodynamic processes can still be constructed by means of such partial thermalizations. At the fundamental level, this shows that optimal thermodynamic processes are much more common than previously expected in small quantum systems. Furthermore, this result also has implications at the experimental level, by simplifying the task of constructing optimal thermodynamic processes for small engines.

Thursday, Sep. 20

Device-Independent Witnesses of Entanglement Depth from two-body correlators

Albert Aloy

ICFO
Mediterranean Technology Park, Avinguda Carl Friedrich Gauss 3, 8860 Casteldefels (Barcelona), Spain

We present a method to derive device independent witnesses of entanglement depth (DIWED). Such DIWEDs certify how strongly entangled a quantum many-body system is without relying on assumptions on the system or the measurement. To derive such witnesses, as their building blocks we consider Bell Inequalities that are constrained by symmetry and that involve only one-and two-body correlation functions and construct methods to derive their corresponding entanglement depth bounds. Such choice of building blocks allows to derive DIWEDs on a computationally tractable way and to measure them on experiments by accessing only total spin components and their second moments.

Projected Entangled Pair States with Continuous Virtual Symmetries

Henrik Dreyer

Max-Planck Institute of Quantum Optics
Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Which properties can a quantum system possess from a macroscopic perspective? The classification of phases lies at the heart of many-body physics, both from a fundamental and a technological point of view. Quantum information science, with its conception of entanglement patterns - has brought about the greatest paradigm shift in this field, since the invention of spontaneous symmetry breaking. The two disciplines are usually bridged via the tensor network formalism. In this talk, I will give a brief historical account of the interplay between many-body physics and quantum information. Then, I will present recent results on tensor networks with continuous symmetries and show how they open up a new chapter in the study of many-body quantum phases. The talk is based on https://arxiv.org/abs/1805.03659

Multipartite state generation in quantum networks with optimal scaling

Julius Wallnöfer

Institute for Theoretical Physics, University of Innsbruck
Technikerstrasse 21a, A-6020 Innsbruck, Austria

We introduce a repeater scheme to efficiently distribute multipartite entangled states in a quantum network with optimal scaling. The scheme allows to generate graph states such as 2D and 3D cluster states of growing size or GHZ states over arbitrary distances, with a constant overhead per node/channel that is independent of the distance. The approach is genuine multipartite, and is based on the measurement-based implementation of multipartite hashing, an entanglement purification protocol that operates on a large ensemble together with local merging/connection of elementary building blocks. We analyze the performance of the scheme in a setting where local or global storage is limited, and compare it to bipartite and hybrid approaches that are based on the distribution of entangled pairs. We find that the multipartite approach offers a storage advantage, which results in higher efficiency and better performance in certain parameter regimes. We generalize our approach to arbitrary network topologies and different target graph states.

Testing the reality of the quantum state under free-choice relaxation

Giorgos Eftaxias

Quantum Engineering Centre for Doctoral Training
Tyndall Avenue, BS8 1FD Bristol, United Kingdom

In a previous work, R. Colbeck and R. Renner constructed a theorem concluded to the non-epistemic character of the quantum state within the framework of an underlying physical state (See “A system’s wave function is uniquely determined by its underlying physical state”). A core assumption behind their proof was that the inputs used for a chained Bell test were free-choices. In this work we relax this assumption and we test the robustness of the theorem’s conclusion. We allow the inputs to be correlated with the underlying variables and through a randomness amplification technique we show that there exist conditions under which the theorem’s conclusion still holds.

Under what conditions two elementary quantum particles behave like a single object?

Zakarya Lasmar

Faculty of Physics, Adam Mickiewicz University
Umultowska 85, 61-614, Poznan, Poland

We consider an evolution of two elementary quantum particles and ask the question: under what conditions such system behaves as a single object? It is intuitive to assume, and was experimentally confirmed, that if the attraction between the elementary objects is stronger than any other force acting on them the whole system behaves as one. However, recent insight from the quantum information theory suggests that in bipartite systems it is not attraction per se that is responsible for the composite nature, but the entanglement between the parts. Since entanglement can be present between the subsystems that interacted in the past, but do not interact anymore, it is natural to ask when such an entangled pair behaves as a single object. We study three situations: free evolution, interference in a Mach-Zehnder-like setup, and Bloch-oscillations on a lattice due to a linear potential. In addition, we also examine how thermalization affects the stability of the system. We show that some kind of interaction is necessary whenever a desired composite behaviour of the system demands that the dynamics of one elementary object depends on the presence of the other object, which is a form of signalling. Finally, we discuss the problem of compositeness in non-trivial evolutions for which an interaction may not be necessary.

Friday, Sep. 21

How Spacetime Structure Affects Field Entanglement

Alexander Smith

Physics & Astronomy Department, Dartmouth College
6127 Wilder Laboratory, 03755 Hanover, USA

Physically motivated detector models, such as the Unruh-DeWitt detector, provide an operational way to probe the properties of quantum fields on curved spacetimes. In this talk we will review such detectors, identifying the specific measurement model a collection of them define in terms of POVM elements acting on the field Hilbert space. In particular, we will see how this measurement model depends upon the detectors' trajectories and internal structure. Then we will examine a generalization of the entanglement harvesting protocol in curved spacetimes, in which entanglement is extracted from the field and transferred to a pair of detectors. We will then use this protocol to probe the entanglement structure of the vacuum, examining how this structure is affected by global spacetime topology, spacetime curvature, and the presence of black hole horizons.

Nanophotonic near-field levitated optomechanics

Lorenzo Magrini

Faculty of Physics, University of Vienna
Boltzmanngasse 5, 1090 Vienna, Austria

Optical control of trapped dielectric objects provides a remarkably simple, yet versatile platform for studying a plethora of intriguing problems in single molecule biophysics, thermodynamics, sensing or fundamental physics. Realizing full quantum control of trapped nanoparticles will enable new insights into quantum-enhanced precision metrology as well as into fundamental aspects of quantum physics. One of the major challenges is to efficiently transduce and manipulate the particle motion at the quantum level. Here we present a nanophotonic platform suited to solve this problem. By optically trapping a 150 nm dielectric particle in the vicinity of the near field of a photonic crystal cavity, at a distance of 310 nm from its surface, we achieve strong, tunable single-photon optomechanical coupling of up to g0/2pi = 9 kHz, three orders of magnitude larger than previously reported for levitated cavity optomechanical systems. In addition, efficient collection and guiding of light through our nanophotonic structure results in a per-photon displacement sensitivity that is increased by two orders of magnitude when compared to state-of-the-art far-field detection. The demonstrated performance shows a promising route for quantum optical control of levitated nanoparticles.

A resource theory of entanglement with a multipartite maximally entangled state

Patricia Contreras-Tejada

Complutense University of Madrid
Avda. Séneca 2, Ciudad Universitaria, 28040 Madrid, Spain

Entanglement theory is a resource theory for parties constrained to LOCC manipulation. However, recent results have shown that this theory suffers from severe limitations in the multipartite regime. We study an alternative theory by considering as free operations the largest set that still induces a well-defined resource theory of entanglement and obtain a maximally GME state of n qudits.

Experimental resource-efficient entanglement detection

Valeria Saggio[1] and Aleksandra Dimić[2]

[1] *Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria*
[2] *Faculty of Physics, University of Belgrade, Studentski Trg 12-16, 11000 Belgrade, Serbia*

The conventional entanglement detection schemes assume an idealized situation where an infinite number of copies of a quantum system is available. Therefore, repeated measurements can be performed in order to extract the mean values of desired quantities, such as entanglement witnesses. In practice, the procedure boils down to collecting "sufficiently large" statistics from a large ensemble of equally prepared copies of the entangled state. However, due to various technical and fundamental challenges, many practical situations involve only a limited number of instances of a given quantum resource, especially when dealing with large-scale entangled quantum systems. In such a situation, the standard detection methods are questionable because of insufficient experimental data and consequently large experimental errors. Therefore, our aim is to develop a scheme for the probabilistic verification of quantum resources. The main idea is to merge the method of random sampling and quantum information processing together, to design a practically feasible framework. Random sampling is an important technique in statistical analysis which consists of selecting of a small part of population in order to learn certain global properties at low cost. From our point of view, the verification method should not rely on criteria that implicitly assumes an ideal situation of an infinite number of repetitions. For example, rather than saying: "The state is entangled if $\langle W \rangle > 1/2$", we should ask: "What is the probability that the measurement (of W) returns the outcome satisfying $\langle W \rangle > 1/2$?" Thus, rather then focusing on a large ensemble of independent and identically distributed copies of a quantum resource in question, we want to perform a single experimental run and use the probability of success for the quantum system to perform certain information tasks as the central quantity for verification of the presence/absence of the quantum resource (e.g. the state was entangled/separable). We show that for a variety of large quantum states even a single copy suffices to detect entanglement with a high probability by using local measurements. For example, a single copy of a 16-qubit k-producible state or one copy of 24-qubit linear cluster state suffices to verify entanglement with more than 95% confidence. Our method is applicable to many important classes of states, such as cluster states or ground states of local Hamiltonians in general. Moreover, we go further showing that this method can be used to translate any entanglement witness to this probabilistic framework. In this way, entanglement detection can be easily carried out in a resource-efficient way, meaning that only a reduced number of copies of a quantum system leads to reliable entanglement verification. To benchmark our theoretical findings, we report the experimental entanglement verification in a photonic six-qubit cluster state generated using three photon-pair sources at telecom wavelength. We find that entanglement can be certified with at least 99.74% confidence by using only around 20 copies of the state. This novel method entails a significant reduction of resources and provides an easy tool to certify the presence of entanglement in large-scale systems, promising a great impact in future experiments where an efficient and resource-saving approach will be essential for entanglement verification problems in multi-qubit states.