# Entanglement Distribution in Quantum Networks (SYED)

jointly organised by
the Quantum Information Division (QI) and
the Semiconductor Physics Division (HL)

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Scalable quantum networks, i.e., links between quantum nodes that are capable of storing and processing quantum information, promise advantages in many applications such as secure quantum communication, networks of distributed quantum sensors and connecting quantum computers. A common prerequisite is the ability to create and distribute entangled states as resource for establishing such a network. This symposium reviews some recent developments in the field of entanglement generation and distribution in quantum networks with solid state and photonic qubit systems, both from an experimental and conceptual perspective.

# Overview of Invited Talks and Sessions

(Lecture hall H1)

## Invited Talks

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|---|---|---|---|---|
| SYED 1.1 | Wed | 9:30–10:00 | H1 | **A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson |
| SYED 1.2 | Wed | 10:00–10:30 | H1 | **Quantum key distribution with highly entangled photons from GaAs quantum dots** — •Armando Rastelli, Santanu Manna, Saimon Covre da Silva, Gabriel Undeutsch, Christian Schimpf |
| SYED 1.3 | Wed | 10:30–11:00 | H1 | **Entanglement distribution with minimal memory requirements using time-bin photonic qudits** — •Johannes Borregaard |
| SYED 1.4 | Wed | 11:15–11:45 | H1 | **Quantum photonics: interference beyond HOM and quantum networks** — •Stefanie Barz |
| SYED 1.5 | Wed | 11:45–12:15 | H1 | **Photonic cluster-state generation for memory-free quantum repeaters** — •Tobias Huber |

## Sessions

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| SYED 1.1–1.5 | Wed | 9:30–12:15 | H1 | **Entanglement Distribution in Quantum Networks** |

# SYED 1: Entanglement Distribution in Quantum Networks

Time: Wednesday 9:30–12:15 Location: H1

**Invited Talk** SYED 1.1 Wed 9:30 H1

**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson — QuTech and Kavli Institute of Nanoscience Delft, Delft University of Technology, The Netherlands

Future quantum networks may harness the unique features of entanglement in a range of exciting applications, such as quantum computation and simulation, secure communication, enhanced metrology for astronomy and time-keeping as well as fundamental investigations. To fulfill these promises, a strong worldwide effort is ongoing to gain precise control over the full quantum dynamics of multi-particle nodes and to wire them up using quantum-photonic channels.

We report on the realization of a three-node entanglement-based quantum network based on diamond NV centers and demonstrate several quantum network protocols without post-selection: the distribution of genuine multipartite entangled states across the three nodes, entanglement swapping through an intermediary node [1], and qubit teleportation between non-neighbouring nodes [2]. Moreover, we will discuss future challenges and prospects for quantum networks, including increasing the distance between nodes to metropolitan scales [3] and the role of next-generation integrated devices.

[1] M. Pompili, S.L.N. Hermans, S. Baier et al., Science 372, 259 (2021).

[2] S.L.N. Hermans, M. Pompili et al., Nature 605, 663 (2022).

[3] Arian Stolk, Kian L. van der Enden et al., arXiv: 2202.00036 (2021).

**Invited Talk** SYED 1.2 Wed 10:00 H1

**Quantum key distribution with highly entangled photons from GaAs quantum dots** — •Armando Rastelli, Santanu Manna, Saimon Covre da Silva, Gabriel Undeutsch, and Christian Schimpf — Institute of Semiconductor and Solid State Physics, Johannes Kepler Universität Linz, Linz, Austria

Entanglement is one of the most peculiar phenomena in quantum science and a key resource for quantum technologies. More than two decades after the initial proposal [1], semiconductor quantum dots (QDs) are now beginning to outperform other sources for the generation of entangled photon pairs. Among different material systems, QDs in the (Al)GaAs platform have demonstrated the highest degree of polarization entanglement to date together with other appealing features for quantum science and technology [2]. In this talk, we will discuss the properties of GaAs QDs obtained by the droplet etching method and present recent results relevant to their application in quantum communication, i.e. entanglement-based quantum key distribution [3,4], quantum teleportation and entanglement swapping.

References [1] O. Benson et al., Phys. Rev. Lett. 84, 2513*2516 (2000). [2] S. F. C. da Silva et al., Appl. Phys. Lett. 119, 120502 (2021). [3] C. Schimpf et al., Adv. Photonics 3, (2021). [4] C. Schimpf et al., Sci. Adv. 7, eabe8905 (2021).

**Invited Talk** SYED 1.3 Wed 10:30 H1

**Entanglement distribution with minimal memory requirements using time-bin photonic qudits** — •Johannes Borregaard — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ, Delft, The Netherlands

Generating multiple entangled qubit pairs between distributed nodes is a prerequisite for a future quantum internet. To achieve a practicable generation rate, standard protocols based on photonic qubits require multi-qubit quantum memories with long coherence times, which remains a significant experimental challenge. In this talk, I will discuss a novel protocol based on time-bin photonic qudits that allow for the simultaneous generation of multiple entangled pairs between two distributed qubit registers. By adopting the qudit protocol, the required memory time is independent of the transmission loss between the nodes in contrast to standard qubit approaches. Consequently, a significant boost of the capabilities of near-term quantum communication hardware can be achieved paving the way for a practical quantum internet.

**15 min. break**

**Invited Talk** SYED 1.4 Wed 11:15 H1

**Quantum photonics: interference beyond HOM and quantum networks** — •Stefanie Barz — Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany — Center for Integrated Quantum Science and Technology (IQST), University of Stuttgart, Germany

In the first part of my talk, I will talk about recent experiments on quantum interference. I will show the impact of distinguishability and mixedness - two fundamental properties of quantum states - on quantum interference. I will demonstrate that these two properties can influence the interference of multiple particles in very different ways, leading to effects that cannot be observed in the interference of two particles alone. In the second part of my talk, I will report on our recent work in quantum networks. I will talk about a crucial component of a photonic quantum network: Bell-state measurements and report on an experimental demonstration of a scheme that allows obtaining a success probability of more than 50%. Finally, I will show the implementation of a novel protocol for networked key exchange using cluster states as a resource.

**Invited Talk** SYED 1.5 Wed 11:45 H1

**Photonic cluster-state generation for memory-free quantum repeaters** — •Tobias Huber — Lehrstuhl für Technische Physik, University of Würzburg, Würzburg, Germany

Many different hardware implementations show very promising results towards implementing quantum repeater nodes based on local memories [1]. While defects in diamond are currently the frontrunners, due to already demonstrated 3-node networks [2] and the possibility to enter the quantum repeater advantage regime (when comparing to direct links, considering losses at the given wavelength) [3], semiconductor quantum dots offer an intriguing alternative. Semiconductor quantum dots have the advantages of easy fabrication which leads to high device efficiencies. Furthermore, protocols for deterministic generation of linear photonic-cluster states do exist and have been already demonstrated experimentally [4]. With only moderate resource overhead a quantum repeater graph state can be fused from linear cluster states, opening the pathway towards memory-less 3rd generation quantum repeaters.

In this talk I will present our recent advances in device design and cluster-state generation with semiconductor quantum dots.

[1] van Loock et al. Adv. Quantum Technol. 3, 1900141 (2020)

[2] Pompili et al. Science 372, 259-264 (2021)

[3] Bhaskar et al. Nature 580, 60-64 (2020)

[4] Schwartz et al. Science 354, 434 (2016)