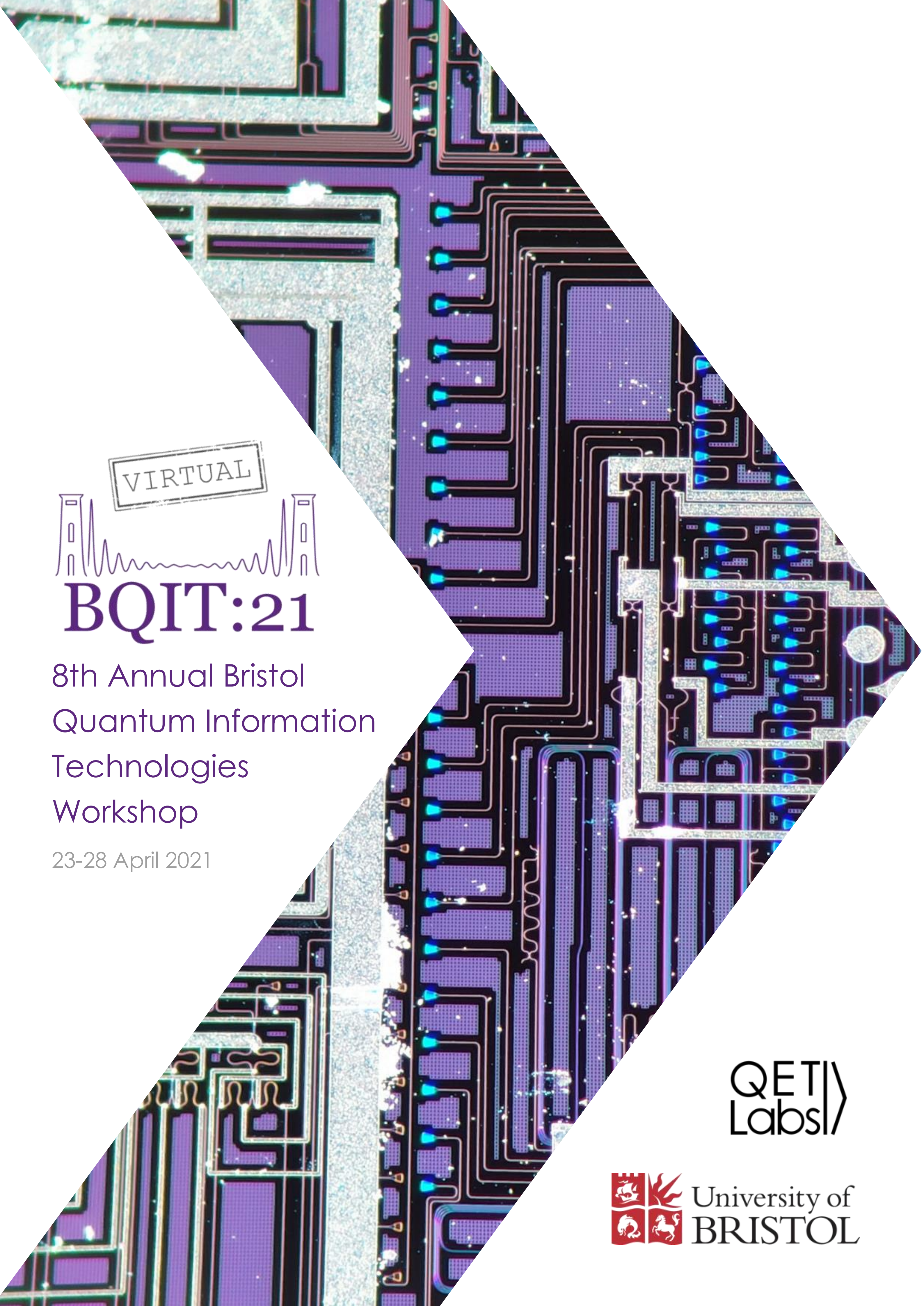
VIRTUAL

BQIT:21

8th Annual Bristol Quantum Information Technologies Workshop

23-28 April 2021



QET Labs

University of BRISTOL

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PROGRAMME COVER IMAGE: STEFANO PAESANI & STEFANO SIGNORINI - "SILICON QUANTUM PHOTONIC CHIP WITH SOURCES OF ULTRA-PURE SINGLE PHOTONS"

CODE OF CONDUCT

The BQIT team is dedicated to providing a harassment-free online conference experience for everyone. We do not tolerate harassment of workshop participants in any form. Workshop participants violating these rules may be sanctioned or expelled from Virtual BQIT:21 at the discretion of the workshop organisers. Our full Code of Conduct can be viewed on pages 38-39 of this programme and on our website: **bristol.ac.uk/bqit.**

WELCOME TO BQIT:21

The BQIT:21 team welcomes you to the eighth Bristol Quantum Information Technologies workshop.

Our understanding of the world has rarely been as shaken as with the adoption of quantum mechanics. The unprecedented elegance and precision of the theory validate a departure from conventional human intuition. Quantum information emerged from studies on the foundations of quantum mechanics and has evolved gradually to offer a disruptive approach to conventional information technologies, with applications in computing and simulations, communications and cryptography and also metrology, sensing and imaging. The BQIT workshop offers a platform for research communications poised to reform multiple disciplines to their ultimate physical limits and the development of the community that makes such outcomes possible.

Last year was the first time in our workshop's history that we had gone fully virtual, rather than meeting as a traditional, face-to-face workshop in BQIT's home of Bristol, UK. The global circumstances that continue to impact us all professionally and personally have forced BQIT once again to be delivered as an all-virtual workshop for 2021 (in perspective, a small price to pay). After many lessons learned and valuable feedback from last year's BQIT:20 attendees and organisers, we have organised this year's workshop keeping in mind the benefits of what it means to 'go online'. The access this creates to colleagues across the world who would otherwise be unable to join us, as well as being able to make the workshop free for all attendees due to the lower costs involved in delivering an online workshop, means that we can welcome three times as many attendees to BQIT than previous years. We can continue to connect with each other's research through our virtual poster sessions, whose access is available throughout the workshop, and benefit from written Q&A sessions with our presenters, allowing all attendees the equal chance to have their voices heard. We recognise the extra energy required to stay connected and motivated during these difficult times, and are hugely encouraged to see so many of you willing to continue to connect with us on an online platform.

2021 has several noteworthy quantum-information-themed anniversaries: In 1981, C.M. Caves proposed using the concept of squeezing for metrology applications. In the same year the first experimental verification of Bell's inequalities was announced by A. Aspect, P. Grangier and G. Roger. Ten years later, in 1991, A. Ekert proposed using Bell's theorem for quantum cryptography. It was only two decades ago when R. Raussendorf and H. Briegel revolutionised the field of quantum computing with their measurement-based architecture, and at the same time E. Knill, R. Laflamme and G. Milburn revealed that linear optical elements can be used efficiently for quantum computation. We would like to celebrate those historical milestones with a special tutorial day at BQIT:21 delivered by some of the original authors in the field.

This year we are offering our BQIT:21 attendees digital merchandise, available through the following links:

- Free license to watch the feature-length documentary film *Picture a Scientist*, "chronicling the groundswell of researchers who are writing a new chapter for women scientists." Available to view until 11 April 2022. Link will be sent to all attendees.
- Invitation to read our graphic novel 'The Light Keys', through the QET Labs website: https://www.bristol.ac.uk/physics/research/quantum/engagement/light-keys/

It is our hope that you have a productive and enjoyable time while you engage and interact with BQIT:21, and to everyone that has helped take BQIT:21 online, thank you!

Holly Caskie and Jorge Barreto, on behalf of the BQIT board and organisation team

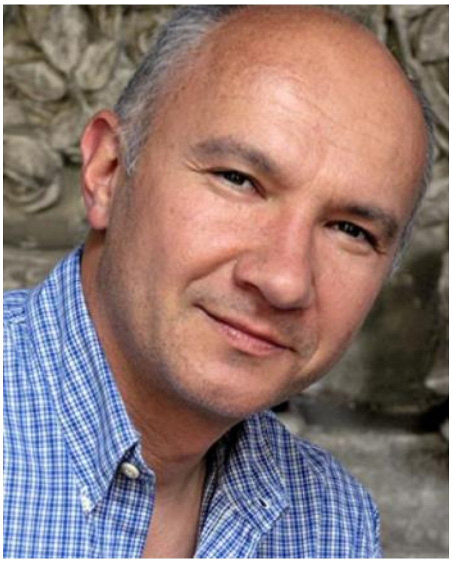
TUTORIAL SESSION

FRIDAY

APRIL 23

TIME	EVENT	LENGTH
09.00	Paul Skrzypczyk (University of Bristol) *Welcome*	10 min
Session One: chaired by Jorge Barreto (University of Bristol)		
09.10	Artur Ekert (University of Oxford) *Quantum Cryptography*	120 min
11.30	Networking on Gathertown - all attendees welcome to join!	120 min
Session Two: chaired by Stefano Valle (University of Bristol)		
13.30	Fabio Sciarrino (Sapienza Università di Roma) *Integrated Optics*	120 min
Session Three: chaired by Pieter Kok (University of Sheffield)		
16.00	Robert Raussendorf (University of British Columbia) *Measurement-Based Quantum Computation*	120 min
18.00 TUTORIAL DAY CLOSE - EVENING NETWORKING		
18.30	Evening networking on Gathertown - all attendees welcome to join!	120 min

TUTORIAL ABSTRACTS



Artur Ekert

University of Oxford

Quantum Cryptography

Quantum Cryptography allows for quantum phenomena, such as superposition and entanglement, to be used to perform cryptographic tasks.

The most famous example of quantum cryptography is quantum key distribution, in which two parties securely generate a shared key.

Quantum cryptography is fascinating as it allows for various tasks to be performed in a secure manner, which are conjectured to be impossible using classical cryptography.

This tutorial will cover the basic aspects of quantum cryptography, including a historical overview of key developments.

Fabio Sciarrino

Sapienza Università di Roma

Integrated Optics

Quantum technologies are an emerging range of devices that are capable of controlling quantum properties such as superposition and entanglement, in order to outperform ordinary classical devices.

The technology of integrated quantum photonics enables the generation, processing and detection of quantum states of light.

The complexity of this powerful technology has progressed rapidly over recent years, with state-of-the art devices being programmable and containing 100s or 1000s of components.

This tutorial will cover the basics of integrated quantum photonics, including an overview of how the technology has developed.

Robert Raussendorf

University of British Columbia

Measurement-Based Quantum Computation

Quantum computation allows for information to be processed in completely novel ways, by harnessing non-classical features of quantum mechanics, such as entanglement.

There are numerous models of quantum computers, all of which are equivalent in their power, but are conceptually and practically distinct.

Measurement-based quantum computation is a fascinating model, where information is processed by performing measurements on a highly entangled initial state.

This tutorial will introduce the basic aspects of measurement-based quantum computation, including the historical developments of the field.

DAY ONE AGENDA

MONDAY
APRIL 26

TIME	EVENT	LENGTH
09.00	Jorge Barreto (University of Bristol) *Welcome and opening of the workshop*	10 min
Session One: chaired by Paul Skrzypczyk (University of Bristol)		
09.10	Eric Cavalcanti (Griffith University) *What's ahead for Wigner's friend?*	15 min (+ 5 min questions)
09.30	Antonio Acin (ICFO) *Bell nonlocality is not sufficient for the security of standard device-independent quantum key distribution protocols*	15 min (+ 5 min questions)
09.50	Ramón Ramos (ICFO) *Measurement of the time spent by a tunnelling atom within the barrier region*	15 min (+ 5 min questions)
10.10	Sarah Croke (University of Glasgow) *Quantum matched filtering for Gravitational Wave Astronomy*	15 min (+ 5 min questions)
10.30	Andres Ducuara (University of Bristol) *Multiobject operational tasks for convex quantum resource theories of state-measurement pairs*	15 min (+ 5 min questions)
10.50	Vatshal Srivastav (Heriot-Watt University) *Genuine High-Dimensional Quantum Steering*	10 min
11.00	Sponsor demo: Angstrom Engineering	10 min

11.30	Networking on Gathertown - all attendees welcome to join!	60 min

Session Two: chaired by Caterina Vigliar (University of Bristol)

12.30	Philip Dolan (NPL) *Photon statistics of single photon sources*	15 min (+ 5 min questions)
12.50	Peter Lodahl (Niels Bohr Institute) *Single-photon quantum hardware: towards scalable photonic quantum technology with a quantum advantage*	15 min (+ 5 min questions)
13.10	Joe Smith (University of Bristol) *Hybridising NV centres with silicon nitride photonics for high efficiency sources of indistinguishable photons at 200 K*	15 min (+ 5 min questions)
13.30	Marco Liscidini (University of Pavia) *Parametric fluorescence in linearly uncoupled resonators*	15 min (+ 5 min questions)
13.50	Kartik Srinivasan (NIST & University of Maryland) *Connecting widely separated optical frequencies using chip-integrated nonlinear microresonators*	15 min (+ 5 min questions)
14.10	Duarte Magano (Instituto de Telecomunicações, Instituto Superior Técnico) *Investigating Quantum Speedup for Track Reconstruction: Classical and Quantum Computational Complexity Analysis*	10 min
14.20	Sponsor demo: IDQ	10 min

Session Three: chaired by Ross Donaldson (Heriot Watt University)

15.00	Aurora Maccarone (Heriot-Watt University) *Underwater single-photon depth imaging*	15 min (+ 5 min questions)
15.20	Elke Neu-Ruffing (University of Kaiserslautern) *Diamond Nano-Quantum Sensors*	15 min (+ 5 min questions)
15.40	Fred Daum (Raytheon) *Bayesian quantum radar with full polarization and hyperentanglement of non-Gaussian photons*	15 min (+ 5 min questions)
16.00	Agustina Gabriela Magnoni (Laboratorio de Óptica Cuántica, DEILAP UNIDEF (CITEDEF-CONICET)) *Impact of Skipper-CCD technology on Quantum Microscopy*	10 min
16.10	Sponsor demo:	10 min

LIGENTEC

16.20 DAY ONE CLOSE - POSTER SESSION 1 BEGINS

16.20	Poster session 1 and evening networking on Gathertown - all attendees welcome to join!	120 min

DAY ONE ABSTRACTS

Eric Cavalcanti

Griffith University

What's ahead for Wigner's friend?

In this talk I will review and discuss a recent no-go theorem on an extended version of the Wigner's friend paradox [1]. In that work, we showed that a set of meta-physical assumptions we called "Local Friendliness" lead to certain inequalities that can be in principle violated by quantum correlations. We demonstrated this violation in a "proof of principle" experiment.

In this talk I will briefly review that result, clarifying how the Local Friendliness inequalities are derived from a strict subset of the assumptions of Bell's theorem, and therefore how their violation puts strictly stronger constraints on physical theories.

I will then discuss what a fully convincing experiment may look like, some of the implications of this result for quantum foundations, and future research directions.

[1] Bong et al, Nature Physics 16, 1199 (2020)

Antonio Acin

ICFO

Bell nonlocality is not sufficient for the security of standard device-independent quantum key distribution protocols

Device-independent quantum key distribution is a secure quantum cryptographic paradigm that allows two honest users to establish a secret key, while putting minimal trust in their devices. Most of the existing protocols have the following structure: first, a bipartite nonlocal quantum state is distributed between the honest users, who perform local projective measurements to establish nonlocal correlations. Then, they announce the implemented measurements and extract a secure key by post-processing their measurement outcomes. We show that no protocol of this form allows for establishing a secret key when implemented on certain entangled nonlocal states, namely on a range of entangled two-qubit Werner states. To prove this result, we introduce a technique for upper -bounding the asymptotic key rate of device-independent quantum key distribution protocols, based on a simple eavesdropping attack. Our results imply that either different tools -- such as different reconciliation techniques or non -projective measurements -- are needed for device-independent quantum key distribution in the large-noise regime, or Bell nonlocality is not sufficient for this task.

Ramón Ramos

ICFO

Measurement of the time spent by a tunnelling atom within the barrier region

Tunnelling is one of the phenomena at the heart of quantum mechanics. Despite its central role in physics, the duration of this process has been debated since the development of quantum theory without a definite answer.

We study the tunnelling of a Bose-Einstein condensate in a single collision configuration through a thin optical barrier. As the atoms tunnel, each of their spins acts as a 'clock' to record the time spent in the barrier region.

Our experiment achieves a long-sought tunnelling time measurement with a clear interpretation, demonstrating a non-zero tunnelling time.

Sarah Croke

University of Glasgow

Quantum matched filtering for Gravitational Wave Astronomy

Matched filtering is a signal processing technique used to maximize the signal-to-noise ratio by correlating signal templates with detector data. It is central for detecting the extraordinarily weak signals in the field of gravitational wave astronomy. In cases where the signal is too weak and the template bank is too extensive, the matched filtering process can become computationally unfeasible.

In this talk I will analyse the potential of Grover's algorithm to speed up match filtering for gravitational wave detection, where even a polynomial speed -up could make previously intractable searches possible. I will present an example of simulated quantum matched filtering applied to the detection of the first gravitational wave signal to demonstrate the algorithm's potential application in data analysis.

Andres Ducuara

University of Bristol

Multiobject operational tasks for convex quantum resource theories of state-measurement pairs

The prevalent modus operandi within the framework of quantum resource theories has been to characterize and harness the resources within single objects, in what we can call single-object quantum resource theories. One can wonder, however, whether the resources contained within multiple different types of objects, now in a multiobject quantum resource theory, can simultaneously be exploited for the benefit of an operational task.

In this work, we introduce examples of such multiobject operational tasks in the form of subchannel discrimination and subchannel exclusion games, in which the player harnesses the resources contained within the composite object of a state-measurement pair. We prove that for any state-measurement pair in which either of them is resourceful, there exist discrimination and exclusion games for which such a pair outperforms any possible free state-measurement pair. These results hold for arbitrary convex resources of states, and arbitrary convex resources of measurements where the set of free measurements is closed under classical post-processing.

Furthermore, we prove that the advantage in these multiobject operational tasks is determined, in a multiplicative manner, by the resource quantifiers of: generalized robustness of resource of both state and measurement for discrimination games and weight of resource of both state and measurement for exclusion games.

Vatshal Srivastav

Heriot-Watt University

Genuine High-Dimensional Quantum Steering

High-dimensional quantum entanglement can give rise to stronger forms of nonlocal correlations compared to qubit systems. Beyond being of fundamental interest, this offers significant advantages for quantum information processing. However, the problem of certifying these stronger correlations remains a critical challenge, particularly in an experimental setting.

Here we theoretically formalise and experimentally demonstrate a notion of genuine high-dimensional quantum steering. We show that high-dimensional entanglement combined with judiciously chosen local measurements can lead to a stronger form of steering, provably impossible to obtain via entanglement in lower dimensions. Exploiting the connection between steering and incompatibility of quantum measurements, we derive simple two-setting steering inequalities for certifying the presence of genuine high-dimensional steering. We report the experimental violation of these inequalities using macro-pixel photon-pair entanglement certifying genuine high-dimensional steering in dimensions up to n=15.

Our work paves the way for the characterisation and certification of nonlocal quantum correlations in high-dimensional systems.

Philip Dolan

NPL

Photon statistics of single photon sources

To support the development of a U.K. quantum technology industry, NPL has been developing techniques to perform accurate and precise measurements of key parameters of components used in quantum photonic systems. This resulted in the first standardised methods for quantifying the performance of quantum communications hardware and is important for security evaluation.

Attenuated coherent states are used in current hardware, but a single-photon source based on a single emitter could be more efficient. The emission from these single-photon sources is frequently characterised by the second-order correlation, g2(τ). A g2(0) < 0.5 indicates the channel consists of mostly single photons. Reported values of g2(0) never reach zero, as expected for a perfect single-photon source; these measurements cannot definitively ascribe the additional coincidences at τ = 0 to an uncorrelated background, or a second dimmer single-photon source. Higher order correlation functions provide additional discrimination between these contributions.

We have performed g3(τ) measurements on NV centres in nanodiamond. We have developed a model which predicts the form of the measured histograms and have found that it fits the data well. In one example these results show no three-fold coincidences detected over an 18-hour period. This allows to ascribe what fraction of the additional coincidences at g2(0) are due to a second single-photon source.

This technique has immediate applicability for optimising single-photon sources, which can enable a range of photonic quantum technologies.

Peter Lodahl

Niels Bohr Institute

Single-photon quantum hardware: towards scalable photonic quantum technology with a quantum advantage

Quantum dots embedded in photonic nanostructures offer a highly efficient and coherent deterministic photon-emitter interface [1]. It constitutes an on-demand single-photon source for quantum-information applications, enables single-photon nonlinear, optics and the constructing of deterministic quantum gates for photons [2]. We review recent experimental progress, and demonstrate that the current technology can be scaled up to reach quantum advantage [3] with the demonstration of near-transform -limited emitters in high-cooperativity planar nanophotonic waveguides [4]. The coherent control of a single spin in the quantum dot [5, 6] offers additional opportunities of generating advanced multi-photon entangled states [7]. We discuss potential applications of these novel deterministic photonic hardware in quantum computing and quantum communication [8], e.g., for constructing a resource efficient one-way quantum repeater [9].

References

[1] Lodahl et al., Rev. Mod. Phys. 87, 347 (2015). [2] Lodahl, Quantum Science and Technology 3, 013001 (2018). [3] Uppu et al., Science Advances 6, eabc8268 (2020). [4] Pedersen et al., ACS Photonics (2020). [5] Javadi et al., Nature Nanotechnology 13, 398 (2018). [6] Appel et al., Phys. Rev. Lett. 126, 013602 (2021). [7] Tiurev et al., Arxiv: 2007.09295. [8] Uppu et al., Arxiv: 2103.01110. [9] Borregaard et al., Phys. Rev. X 10, 021071 (2020).

Joe Smith

University of Bristol

Hybridising NV centres with silicon nitride photonics for high efficiency sources of indistinguishable photons at 200 K

Solid state atom-like systems have great promise for building quantum networks at scale but are burdened by phonon sidebands and broadening due to surface charges. Nevertheless, coupling to a small mode volume cavity would allow high rates of extraction from even highly dephased emitters. Recently, low-noise silicon nitride has been demonstrated as platform compatible with single spin and single photon manipulation [1]. We consider the nitrogen vacancy centre in diamond, a system understood to have a poor quantum optics interface with highly distinguishable photons, and design a silicon nitride cavity that allows 99 % efficient extraction of photons at 200 K with an indistinguishability of > 50 %, improvable by external filtering. We analyse our design using FDTD simulations, and treat optical emission using a cavity QED master equation valid at and beyond strong coupling and which includes both ZPL broadening and sideband emission [2]. The design is compact (< 10 um), and owing to its planar geometry, can be fabricated using standard silicon processes. Our work therefore points towards scalable fabrication of non-cryogenic atom-like efficient sources of indistinguishable photons.

[1] JA Smith, J Monroy-Ruz, JG Rarity, KC Balram. "Single photon emission and single spin coherence of a nitrogen vacancy centre encapsulated in silicon nitride" Appl. Phys. Lett. 116, 134001 (2020). [2] JA Smith, C Clear, KC Balram, DPS McCutcheon, JG Rarity. "NV centre coupled to an ultrasmall mode volume cavity: a high efficiency source of indistinguishable photons at 200 K" accepted for publication in Physical Review Applied (2021)

Marco Liscidini

University of Pavia

Parametric fluorescence in linearly uncoupled resonators

Integrated micro- and nanostructures allow for the efficient generation of photon pairs via parametric fluorescence thanks to the enhancement of the light-matter interaction associated with the spatial and temporal light confinement.

These systems grant an unprecedented control over the properties of the generated non-classical light, as their spectral properties can be designed to enhance or suppress specific nonlinear processes.

An interesting case is that of structures composed of resonant elements that are linearly independent but are coupled through the nonlinear interaction.

In this case one is able to control the spectral position of one or more resonances independently, resulting in a great flexibility and resilience.

In this talk I will provide some examples connected with the generation of photon pairs by spontaneous four-wave mixing or spontaneous parametric down conversion.

Kartik Srinivasan

University of Kaiserlautern

Connecting widely separated optical frequencies using chip-integrated nonlinear microresonators

Nonlinear nanophotonic technologies can enable an unprecedented ability to connect regions of the optical spectrum together.

In this talk, I will discuss our laboratory's efforts in developing nonlinear photonic resonators in the silicon nitride platform for both quantum and classical photonic links.

I will review the basic design and engineering principles behind these devices, and discuss their application in quantum frequency conversion of single photons, visible-telecom entangled photon pair generation, the generation of visible laser light from near-infrared pump sources, and the use of nonlinear resonators in optical atomic clocks.

Duarte Magano

Instituto de Telecomunicações, Instituto Superior Técnico

Investigating Quantum Speedup for Track Reconstruction: Classical and Quantum Computational Complexity Analysis

To investigate the fundamental nature of matter and its interactions, particles are accelerated to very high energies and collided within detectors, producing a multitude of other particles that are scattered in all directions. These particles leave signals of their passage while traversing the detector. The problem of track reconstruction is to recover the original trajectories from these signals. This represents a very demanding data analysis problem, and it will become even more so as the luminosity of the next generation accelerators keeps increasing. Approaches to track reconstruction based on quantum information technologies have recently been put forward. In order to access the potential for a quantum speedup for this problem, we start by elaborating a computational complexity analysis of a standard tracking algorithm, the Combinatorial Track Finder. First, we find that it is possible to improve the classical complexity of the original algorithm. We further show that we can use quantum search algorithms to reach a lower quantum computational complexity. To the best of our knowledge, this is the first computational complexity-level demonstration of a quantum advantage for a state-of-the-art track reconstruction method. Work developed in collaboration with A.Ambainis, P.Bargassa, M.Dimitrijevs, A.Glos, M.Kālis, A.Kumar, A.Locāns, Y.Omar, S.Pratapsi, G.Quinta, A.Rivošs, J.Seixas

Aurora Maccarone

Heriot Watt University

Underwater single-photon depth imaging

Time-correlated single-photon counting (TCSPC) has been established as the preferred detection approach for high performance lidar and depth profiling due to its excellent surface to surface resolution and high optical sensitivity.

This presentation will show the results of laboratory-based experiments obtained using different optical transceiver configurations. Particular attention will be given to underwater depth imaging using an individual commercially available silicon single photon avalanche diode (Si-SPAD) detectors, and prototypes of Si-SPAD detector arrays fabricated in complementary metal-oxide semiconductor (CMOS) or in custom fabrication technology.

Depth and intensity profiles of stationary and moving targets were obtained under several underwater scattering conditions. The spatial resolution of each system was investigated in order to provide an estimation of the image degradation as the level of scattering increased. Data were analyzed using a pixel-wise cross-correlation approach, however additional bespoke image processing approaches will be discussed.

Elke Neu-Ruffing

University of Kaiserslautern

Diamond Nano-Quantum Sensors

Individual quantum systems are extremely sensitive sensors e.g., for magnetic fields. Such quantum sensors harness quantum mechanics for ultimate sensitivity and versatility. Simultaneously, they are atomically small quantum systems and boost spatial resolution in imaging.

We employ point defects in diamond crystals, so called nitrogen vacancy (NV) color centers, as nanoscale sensors. Electrons bound to such defects provide highly controllable spins and create bright luminescence that enables us to use even individual color centers as sensors and to read out their spins. Efficient sensor devices rely on sophisticated nanofabrication and a high level of control of the diamond material system.

Applications of the sensors include e.g. material science where magnetic nanostructures are characterized to life science were currents in living organisms are detected.

We discuss recent advances in sensor devices as well as novel approaches to NV based sensing using near field energy transfer (FRET).

Fred Daum

Raytheon

Bayesian quantum radar with full polarization and hyperentanglement of non-Gaussian photons

We show that the optimal quantum radar has 12 dB better effective signal-to-noise ratio compared with the corresponding optimal classical radar, assuming full polarization antennas with hyperentanglement of photons at low photon flux per mode. The photon states are non-Gaussian, and we hyperentangle M-tuples of photons rather than the boring old pairs of photons. Full polarization means that the radar transmits two orthogonal polarizations simultaneously and also receives two polarizations simultaneously. We use the Belavkin-Zakai equation rather than the boring old Schrödinger equation, because the latter does not model macroscopic noisy measurements of quantum systems.

We also compute the minimum cost for the optimal quantum radar at X-Band, which is 20 orders of magnitude more than for the corresponding optimal classical radar today. With the most optimistic assumptions this cost ratio can be reduced to only 15 orders of magnitude in the future.

We speculate that further improvements in quantum radar are possible by exploiting non-Gaussian states of photons, hyperentanglement of more than pairs of photons, more advanced protocols for entanglement beyond the so-called "quantum illumination," more advanced technology, more clever ideas and new physics yet to be discovered using Bayesian quantum field theory.

Agustina Gabriela Magnoni

Laboratorio de Óptica Cuántica, DEILAP UNIDEF (CITEDEF-CONICET)

Impact of Skipper-CCD technology on Quantum Microscopy

The field of Quantum Microscopy (QM) promises highly efficient imaging for low absorption samples and microscopy at the single photon level. The recently developed Skipper-CCD detector technology is able to measure the charge in each pixel, repeatedly, in a non-destructive way. As a result, the readout noise can be reduced as much as desired. It allows the precise counting of the number of electrons in each pixel ranging from empty pixel to more than 1900 electrons. In addition, they account for very high quantum efficiency (above 90% in the visible range), extremely low dark current (less than 1 electron per pixel per day), and high resolution (pixel size of 15 microns by 15 microns).

The use of Skipper-CCD detectors opens the possibilities for multiple applications within this field. In particular, they are expected to provide comparable resolution and Noise Reduction Factor to state-of-the-art setups for QM, with a dramatically/drastically reduced photon count per pixel.

The same advantage can be expressed as an order of magnitude increase in resolution for the same number of photons per pixel. This presents a valuable impact of QM applications in biology and chemistry, when avoiding damage of the sample is required. The status and plans for the implementation of Skipper-CCD in this field will be presented.

DAY TWO AGENDA

TUESDAY

APRIL 27

TIME	EVENT	LENGTH
Session Four: chaired by Carmen Palacios Berraquero (NuQuantum)		
09.00	Dominic Horsman (Universite Grenoble Alpes) *"Ungluing your LEGO": lattice surgery and the ZX calculus*	15 min (+ 5 min questions)
09.20	Niccolo Somaschi (Quandela) *Modular Optical Quantum Computing*	15 min (+ 5 min questions)
09.40	Stefano Valle (University of Bristol) *Cryogenic HBAR: a route toward efficient transduction from microwave to optical frequency*	15 min (+ 5 min questions)
10.00	Vindhiya Prakash (ICFO) *HOM interference between **distinguishable** photons?*	15 min (+ 5 min questions)
10.20	Ankur Khurana (University of Bristol) *Integrated phononic-photonic circuits on GaAs as a platform for microwave to optical signal transduction*	15 min (+ 5 min questions)
10.40	Sara El Gaily (Budapest University of Technology and Economics) *Constrained Quantum Optimization Strategy*	10 min
10.50	Sponsor demo: University of BRISTOL Quantum Technologies Innovation Centre	10 min
11.30	Networking on Gathertown - all attendees welcome to join!	60 min

EDI PANEL

Session Five: chaired by Naomi Solomons (University of Bristol)

12.30	**EDI panel: The impact of the COVID-19 pandemic on STEM**	120 min
	Caroline Clark (KETS)	
	Lia Li (UCL)	
	Winston Morgan (University of East London)	
	Jo O'Leary (UKRI)	
	David Palmer (University of Kent/Mind Bexley)	
	Send questions at www.slido.com using the event code #678981	

Caroline Clark

KETS

A mechanical engineer by background, Caroline is co-founder and Chief Operating Officer at KETS Quantum Security, a Bristol based quantum communications start-up. Caroline has experience of working across many sectors including academia, consulting, research and development, and innovation funding. Caroline is passionate about people and has a particular interest in how we inspire, develop and educate young people.

Lia Li

UCL

Lia is an expert in optical and quantum technologies, with a decade -long track record in building lasers and optical devices at Imperial College, BAE Systems and University College London. She is the inventor of optical technologies, having worked with lasers throughout her decade long career, and completing a PhD in experimental quantum physics in 2016. In 2017 she successfully demonstrated outdoor operation of a battery powered optical accelerometer undergoing +/-60g shocks, made for Dstl. Lia is a member of the UCL Race Equality Steering Group, having previously run the UCL Women in Physics group. She recently worked with Dr Erinma Ochu MBE, Dr Hope Bretscher, and Prof Rachel Oliver to write an article titled 'Racism, equity and inclusion in research funding' for Science in Parliament, the journal for the Parliamentary and Scientific Committee (https://osf.io/preprints/pgv3x/). Lia is also the Founder and CEO of optical sensing start-up Zero Point Motion.

Winston Morgan

University of East London

Winston is a Reader in Toxicology and Clinical Biochemistry and also Director of Impact and Innovation in the school of Health Sport and Bioscience at University of East London. In addition to his work as a research active scientist, he is also involved in research and scholarly activity into factors particularly race which determines societal outcomes in higher education, medicine and wider society. Over the last year he has written or contributed to numerous articles and given presentations, appeared in the media on the impact COVID-19 on Blakpeople, on vaccine hesitancy (agency) and using his knowledge of Toxicology to explain the safety of the new COVID-19 vaccines. Media contributions include the Guardian, The Times, The Independent, the Standard, Metro, Sky news, The Conversation, YouTube, NPR in the USA, Channel 4, and on numerous occasions on BBC TV and radio nationally and locally. Many of his articles focus on the intersection of race, education, ethnicity, genetics, medicine and medical racism in societal outcomes.

Jo O'Leary

UKRI

Jo is the Head of Equality, Diversity and Inclusion in the Strategy Directorate at UK Research and Innovation. Jo started in this role in August 2020 having previously been Head of Funding Delivery for the Biotechnology and Bioscience Research Council. Jo and her team work closely with teams across UK Research and Innovation on the development of our EDI programme and policies, which includes work on tackling bullying and harassment, and with stakeholders across the research and innovation sector.

David Palmer

University of Kent/Mind Bexley

David Palmer is the CEO of Mind Bexley, an honorary research fellow at the University of Kent, and editor of the Journal of Mental Health and Well-being. He has been at Mind for over 12 years, drawing on his own lived experiences and empathy to support those who experience poor mental health, and those that care for them. He set up Café Revival in Whitstable, and also Bexleyheath, which function as wellbeing hubs that people can use as a safe space to share their experiences.

Session Six: chaired by Siddarth Joshi (University of Bristol)

15.00	Eleni Diamanti (CNRS & Sorbonne University) *Demonstrating quantum advantage with practical photonic systems*	15 min (+ 5 min questions)
15.20	Stefanie Barz (University of Stuttgart) *Protocols in quantum networks: communication and beyond*	15 min (+ 5 min questions)
15.40	Antia Lamas Linares (AWS) *Right in time: Entanglement distribution for accurate and safe clock synchronization*	15 min (+ 5 min questions)
16.00	Beatrice Da Lio (Copenhagen University) *Path-encoded high-dimensional quantum states distribution towards QKD applications*	15 min (+ 5 min questions)
16.20	Naomi Solomons (University of Bristol) *Scalable authentication and optimal flooding in a quantum network*	15 min (+ 5 min questions)
16.40	Elliott Hastings (University of Bristol) *Field Demonstration Of A Mobile Optical Ground Station For CubeSat Quantum Key Distribution*	10 min
16.50	Sponsor demo: QuiX	10 min

17.00 DAY TWO CLOSE

17.30	Evening networking on Gathertown - all attendees welcome to join!	120 min

Dominic Horsman

Universite Grenoble Alpes

"Ungluing your LEGO": lattice surgery and the ZX calculus

Lattice surgery is the method of choice for operations in proposed fault-tolerant architectures using the surface code. In this talk I will show how it also gives an independent computational model for quantum computing. The 'splitting' and 'merging' of logical qubits are the new computational primitives, rather than gates such as a CNOT. By "ungluing the LEGO" of the gate model, much more efficient procedures can be implemented. This has been shown in optimisation work by Google and others, and in the recent first experimental demonstration of lattice surgery.

This computational model has a natural language in the ZX calculus. I will show how using this diagrammatic language gives a computational model that can represent parts of QC that have not previously had an efficient language. In particular, I will show how certain linear optical and network procedures are the exact analogues of lattice surgery operations. This gives them a proper, natural, computational model for the first time, and opens new possibilities for computing within these systems.

Niccolo Somaschi

Quandela

Modular Optical Quantum Computing

Recent breakthroughs in quantum photonics towards the realization of large optical quantum computing (QC) platforms were achieved following both a "full integration" approach [1] or based on an interconnected modular-like platform [2,3]. Either way, each architecture is based on well identified fundamental blocks which independent performances contribute to drive the full platform computation capacity.

These building blocks, forming the hardware side, consist in quantum light sources, active routers, processors/ interferometers and detectors; independently of the computational scheme (linear optical QC or measurement-based QC) one can extract the required performance thresholds of each component which allow to scale up, or not, the computing platform.

Besides, these same building blocks are also required in diverse applications, ranging from quantum communication and networks to quantum metrology, encompassing the full spectrum of quantum technologies enabled by light.

At Quandela we work on building these fundamental optoelectronics modules which permit to realize reconfigurable quantum computing platforms in an efficient and scalable way. The modules consist in quantum light sources with emission efficiencies above 30%, interconnected via optical fibers to active demultiplexers (transmission >70% / line), frequency converters and subsequently, to integrated circuits and high-performance detectors. All these components are designed to guarantee plug-and-play operation and reconfigurability, permitting their efficient implementation and adaptability to different quantum technologies and applications.

[1] J. M. Arazzola et al., "Quantum circuits with many photons on a programmable nanophotonic chip", Nature 591, 54–60 (2021) [2] H. S. Zhong et al. "Quantum computational advantage using photons", Science, DOI: 10.1126/ (2020) [3] H. Wang et al. "Boson Sampling with 20 Input Photons and a 60-Mode Interferometer in a 10e14 Dimensional Hilbert Space" Phys. Rev. Lett. 123, 250503 (2019)

Stefano Valle

University of Bristol

Cryogenic HBAR: a route toward efficient transduction from microwave to optical frequency

The interface between superconducting qubits with lights can be achieved by an efficient transduction of signals from the microwave to the optical frequency exploiting the optomechanical interaction in nanoscale devices [1][2]. The efficiency is negatively affected by the poor phonons injection efficiency from the transducer and difficulties to maintain single mode operation in the mechanical mode. We propose an alternate route for efficient microwave-to -optical transduction at cryogenic temperatures by using HBAR resonator compatible at cryogenic temperature where optical and mechanical field is enhanced by the acousto-optic cavity [2]. The limited efficiency g0 is compensated by the large number of cavity phonon (N) which can be injected into a single acoustic mode, and the efficiency is proportional to g0N, revealing an alternative route to an efficient transduction microwave-to-optical. One of the benefits of HBAR is the heating effect from the laser is negligible at cryogenic temperature, which is a limiting factor in other nanoscale optomechanical devices. We report the first acousto-optic transduction at cryogenic temperature (10K) using a HBAR modulator showing the potential of this (bulk) HBAR approach towards quantum transduction. The quantum transduction regime can be obtained by significantly improving the efficiency working on two fronts: improving the optical and mechanical quality factors by novel cavity design and improving g0 by exploiting the elasto-optic effect (Stimulated Brillouin scattering).

[1] K. C. Balram, M. I. Davanço, et al. (2017). ``Acousto-optic modulation and optoacoustic gating in piezo-optomechanical circuits". Physical review applied, 7(2), 024008.

[2] V.J. Gokhale, B.P. Downey, D.S. Katzer, et al. ``Epitaxial bulk acoustic wave resonators as highly coherent multi-phonon sources for quantum acoustodynamics." Nat Commun 11, 2314 (2020).

[3] S. Valle and K. C. Balram, "High-frequency, resonant acousto-optic modulators fabricated in a MEMS foundry platform," Opt. Lett. 44, 3777 -3780 (2019)

Vindhiya Prakash

ICFO

HOM interference between distinguishable photons?

It is possible, in fact. I will present recent experimental results that demonstrate the "non-degenerate HOM effect," that occurs within the time-envelope of photon pairs that meet at a beam splitter.[1].

The coincidence rate shows an oscillation in time at the difference frequencies, both for same-path and different-path output events. This proves to be a useful tool to map the difference frequency spectrum in a two-photon state, with frequency resolution impossible to achieve with existing techniques. Hence, it is well suited to characterise narrow-band photon pairs for applications involving quantum light-matter interactions.

We also demonstrate the closely -related "time-domain Ghosh-Mandel effect." For both experiments, we use a cavity enhanced-SPDC source, resonant to the D1 line in cold atomic Rubidium [2]. The source allows for independent control over the central frequency of each photon in the pair and allows to pick and choose which hyperfine transition each photon is resonant to, with MHz resolution. We map the frequency content with the interference effects.

[1] V. Prakash, A. Sierant, and M.W. Mitchell https://arxiv.org/abs/2101.03144

[2] V. Prakash, L. C. Bianchet, M. T. Cuairan, P. Gomez, N. Bruno, and M. W. Mitchell, Opt. Express 27, 38463 (2019). https://doi.org/10.1364/OE.382474

Ankur Khurana

University of Bristol

Integrated phononic-photonic circuits on GaAs as a platform for microwave to optical signal transduction

Efficient conversion between microwave and optical frequency signals plays an important role in classical and quantum information processing. Recent advances in superconducting devices for quantum technologies have put significant constraints on conversion frequency, power and efficiency between phononic and photonic domains. Here, we demonstrate an acousto-optic modulator (AOM) for conversion of microwave signals up to 2.5 GHz to optical signals in the telecom wavelength range. The modulator is fabricated on a suspended Gallium Arsenide (GaAs) integrated photonic circuit platform, where an unsuspended interdigital transducer (IDT) drives surface acoustic waves to modulate the light travelling in a suspended photonic micro-ring resonator. Despite having smaller piezoelectric coefficients compared to Lithium Niobate (LN) and Aluminium Nitride (AlN), GaAs shows significantly higher optomechanical coupling strength due to its higher refractive index and photoelastic coefficients. Simulations suggest that photoelastic effect alone for GaAs AOMs leads to higher change in refractive index per phonon compared to LN AOMs, where both photoelastic and electro-optic effects contribute almost equally [1]. It has been shown in [2] that the optical losses and Q values for this platform can be significantly better. We are working towards improving the optical Q by surface passivation and improving the acoustic Q by moving towards contour mode IDT geometry. [1] Linbo Shao, Mengjie Yu, Smarak Maity, Neil Sinclair, Lu Zheng, Cleaven Chia, Amirhassan Shams-Ansari, Cheng Wang, Mian Zhang, Keji Lai, et al. Microwave-to-optical conversion using lithium niobate thin-film acoustic resonators. Optica, 6(12):1498–1505, 2019. [2] Pisu Jiang and Krishna C Balram. Suspended gallium arsenide platform for building large scale photonic integrated circuits: passive devices. Optics express, 28(8):12262–12271, 2020.

Sara El Gaily

Budapest University of Technology and Economics

Constrained Quantum Optimization Strategy

We proposed a new constrained quantum optimization algorithm (CQOA) inspired by the quantum extreme value Searching algorithm (QEVSA) [1]. The QEVSA finds the extreme value (minimum or maximum) of an unconstraint goal function. It combines the well-known binary searching algorithm and the quantum existence testing [QET] which is a special case of a quantum counting algorithm. if one is interested in finding the extreme value of a constraint goal function, an extension of the functionalities of the QEVSA is required, in other words, a new extended version of the QET is needed, we name it constraint quantum relation testing (CQRT). The QET exploits the power of the quantum phase estimation (QPE) [2] for computing the necessary qubits for classical and quantum certainty of the physical implementation. Therefore, involving the constraint and the index relation which determines the type of the optimization (minimum or maximum) in the QET does not modify the working mechanism of the QPE. Consequently, the optimum number of qubits necessary for the CQRT is similar to the QET function i.e., the computational complexities of QET and CQRT are equal. The CQOA merges the binary search algorithm and the CQRT function.

[1] S. Imre, "Quantum Existence Testing and Its Application for Finding Extreme Values in Unsorted Databases" IEEE Transactions on Computers, Vol: 56, Issue: 5, May 2007.

[2] Imre, S.; Balázs, F.: Quantum computing and communications: An engineering approach (Wiley, Chichester, UK) 2005

Eleni Diamanti

CNRS & Sorbonne University

Demonstrating quantum advantage with practical photonic systems

The goal of demonstrating a quantum advantage for useful applications with currently available technology is an important challenge in quantum information science.

In this talk, we discuss examples of such rigorous demonstration of advantage in security and efficiency due to the use of quantum resources for cryptographic and communication complexity protocols. This requires devising novel protocols amenable to experimental implementations, which involve encoding in properties of coherent states of light, linear optic circuits and single-photon detection.

We further discuss the extension of our results in quantum communication complexity to the efficient verification of NP-complete problems with limited information.

Stefanie Barz

University of Stuttgart

Protocols in quantum networks: communication and beyond

In this talk I will discuss applications of quantum networks going beyond quantum key distribution.

I will show that quantum networks can be used to perform distributed computing, both classical and quantum. Furthermore, I will present a recent experiment that shows quantum communication in a multipartite network and allows – besides security in the communication – keeping the identities of the participating parties secure.

I will conclude with a discussion of experimental challenges in realizing advanced networked quantum protocols.

Antia Lamas Linares

AWS

Right in time: Entanglement distribution for accurate and safe clock synchronization

Entanglement distribution is a fundamental component of quantum networks, often in the context of quantum key distribution. It is less well known that entanglement distribution can help with a very different problem: time distribution.

In this talk I will describe a protocol for time distribution and clock synchronization that allows synchronization on the order of ps, is extremely robust against losses and is resilient against spoofing attacks, which are problematic in, for example, time distribution via GPS satellites.

Beatrice Da Lio

Copenhagen University

Path-encoded high-dimensional quantum states distribution towards QKD applications

Quantum key distribution (QKD) protocols based on high-dimensional quantum states have shown the route to increase the key rate generation while benefiting of enhanced error tolerance, thus overcoming the limitations of two-dimensional QKD protocols.

Nonetheless, the reliable transmission through fiber links of high-dimensional quantum states remains an open challenge that must be addressed to boost their application.

In this talk, I will present our recent demonstration of the reliable transmission, over a 2 km long multicore fiber, of path-encoded high-dimensional quantum states. Leveraging on a phase-locked loop system, a stable interferometric detection is guaranteed, allowing for low error rates and the generation of 6.3 Mbit/s of secret key rate.

Naomi Solomons

University of Bristol

Scalable authentication and optimal flooding in a quantum network

The global interest in quantum networks stems from the security guaranteed by the laws of physics. Deploying quantum networks means facing the challenges of scaling up the physical hardware and, more importantly, of scaling up all other network layers and optimally utilising network resources.

Here we consider two related protocols, their experimental demonstrations on an 8-user quantum network test-bed, and discuss their usefulness.

First, an authentication transfer protocol to manage a fundamental limitation of quantum communication – the need for a pre-shared key between every pair of users linked together on the quantum network. By temporarily trusting some intermediary nodes for a short period of time (<35 min in our network), we can generate and distribute these initial authentication keys with a very high level of security.

Second, when end users quantify their trust in intermediary nodes, our flooding protocol can be used to improve both end-to-end communication speeds and increase security against malicious nodes.

Elliott Hastings

University of Bristol

Field Demonstration Of A Mobile Optical Ground Station For CubeSat Quantum Key Distribution

Satellite-based quantum key distribution enables quantum-secured communication on a global scale. There are international efforts underway to build and launch satellites capable of Quantum Key Distribution ('QKD') e.g. the QUARC, QEYSSat, Micius and SpooQy-1 missions.

These QKD satellites work with a network of Optical Ground Stations (OGSs) to receive optical signals and distribute cryptographic keys to end users. However, OGSs near metropolitan centres are often subject to high levels of light pollution and suffer from restricted clear lines of sight to the satellite. Further, static ground stations are severely limited by local meteorological conditions.

A mobile OGS is not subject to these restrictions and can be used to distribute keys flexibly. This may be useful when performing site surveys in order to derive realistic data on expected key rates and meteorological/geographic conditions. We present our progress towards field-demonstrations of QKD using our mobile OGS to receive both a beacon signal and quantum signal. This OGS is designed to work with our industry lead 6U and research focused 12 U QKD CubeSats.

DAY THREE AGENDA
WEDNESDAY APRIL 28

TIME	EVENT	LENGTH
Session Seven: chaired by Jonathan Matthews (University of Bristol)		
09.00	Pieter Kok (University of Sheffield) *Commemorative Talk for Jon Dowling*	45 min

Pieter Kok

University of Sheffield

From High Noon to Boson Sampling — Commemorative Talk for Jon Dowling

Jonathan Dowling was a driving force in the optical quantum information community. His work introduced new fundamental concepts and helped experimentalists implement the abstract ideas from quantum information theory.

In this commemorative talk I will use Jon's work over the past two-and-a-bit decades to give a highly subjective sketch of the history of the field and Jon's role in it. I will conclude with Jon's most recent work on photonic quantum data locking.

Due to the nature of the anecdotes about Jon, this talk has a PG-13 rating.

10.00	Poster session 2 continued and networking on Gathertown - all attendees welcome to join!	120 min

Session Eight: chaired by Giacomo Ferranti (University of Bristol)

12.30	Han-Sen Zhong (University of Science and Technology of China) *Photon-based quantum advantage*	15 min (+ 5 min questions)
12.50	Ulrik Lund Andersen (DTU) *Implementing gates in a continuous variable optical cluster state*	15 min (+ 5 min questions)
13.10	Valentina Parigi (Sorbonne University) *Non-Gaussian Continuous Variables quantum networks*	15 min (+ 5 min questions)
13.30	Oliver Thomas (University of Bristol) *A General Framework for Multimode Gaussian Quantum Optics and Photo-detection*	15 min (+ 5 min questions)
13.50	Nicolás Quesada (Xanadu) *Quantum Computational Supremacy via High-Dimensional Gaussian Boson Sampling*	15 min (+ 5 min questions)
14.10	Joe Randall (TU Delft) *Quantum simulation of a discrete time crystal using solid-state spins in diamond*	10 min
14.20	Sponsor demo The European Physical Journal EPJ Quantum Technology	10 min

Session Nine: chaired by Molly Thomas (University of Bristol)

15.00	Sponsor demo Zurich Instruments	10 min
15.10	Samuel Gyger (KTH Stockholm) *Reconfigurable photonics with on-chip single-photon detectors*	10 min
15.20	Caterina Vigliar (University of Bristol) *Error-protected measurement-based quantum computing on an eight-qubit silicon photonics processor*	15 min (+ 5 min questions)
15.40	Kevin Weatherill (Durham University) *Rydberg Quantum Technologies*	15 min (+ 5 min questions)
16.00	Patty Lee (Honeywell Quantum Solutions) *High Performance Commercial Trapped Ion Quantum Computers*	15 min (+ 5 min questions)
16.20	Galan Moody (UC Santa Barbara) *Heterogeneous III-V/Silicon Quantum Photonics*	15 min (+ 5 min questions)
16.40	Wolfram Pernice (WWU Muenster) *Hybrid integrated quantum photonic technologies*	15 min (+ 5 min questions)
17.00	Jonathan Matthews (University of Bristol) *Workshop close*	10 min

17.10 DAY THREE CLOSE

17.30	Workshop virtual celebrations and networking on Gathertown - all attendees welcome to join!	120 min

DAY THREE ABSTRACTS

Han-Sen Zhong

University of Science and Technology of China

Photon-based quantum advantage

Quantum computing is a promised method to solve some computational tasks that are intractable for classical computing. Boson Sampling is one of the candidates to demonstrate quantum computational advantage. In our recent experiment, we realize quantum computational advantage in a Gaussian Boson Sampling (GBS) experiment.

We inject 25 two-mode squeezed states into a 100-mode ultralow-loss interferometer with full connectivity and random matrix, and sample the output distribution using 100 single photon detectors.

We have ruled out some plausible hypotheses, including thermal states, distinguishable photons, and uniform distribution. We observe coincidence event with up to 76 clicks. This GBS machine can sample 14 orders of magnitude faster than classical supercomputer.

Ulrik Lund Andersen

DTU

Implementing gates in a continuous variable optical cluster state

Continuous variable measurement-based quantum computation (MBQC) shows great potential for scalable quantum information processing. It has in recent years witnessed an increasing interest due to the simplicity in generating the foundational states – the cluster states – deterministically and in a scalable manner (1,2). There are still numerous steps to be taken towards realizing universal quantum computation but one of the critical steps is the realization of single and two-mode gates.

In MBQC, quantum gates are implemented through simple Gaussian measurements of the cluster state: High-efficiency homodyne detection suffices to realize a complete gate set in the two-dimensional subspace of the Gottesman-Kitaev-Preskill (GKP) qubits. GKP qubits are of particular interest as they allow for the implementation of non-Clifford gates via Gaussian transformation and they are error-correctable by Gaussian transformations (3).

Here we present the execution of a complete set of measurement-based Gaussian single- and two-mode gates in a large two-dimensional cluster state (4). The fully programmable gates are also combined into a small-scaled circuit, demonstrating the programmability and flexibility of the setup. These demonstrations are critical steps towards realizing a universal quantum processor based on continuous variables.

(1) Larsen et al, Science 366, 369 (2019) (2) Warit et al, Science 366, 373 (2019) (3) Larsen et al, arxiv:2101.03014 (4) Larsen et al, arxiv:2010.14422

Valentina Parigi

Sorbonne University

Non-Gaussian Continuous Variables quantum networks

Large multipartite Continuous Variables (CV) quantum states are easy to characterize as far as the measurement statistics of quadratures is Gaussian.

Although they are essential resources for CV quantum technologies, non-Gaussian statistics is required for reaching a quantum computational advantage.

Non-Gaussianity can be induced via local operations. When the number of involved optical mode and non-Gaussian operations are large enough, these systems are hard to benchmark in theory, to test experimentally, and they can even be hard to sample.

I will speak about experimental challenges on producing such states, theoretical benchmarks based on complex network theory [1] and machine learning technique for experimental detection of Wigner negativity [2].

[1]Emergent complex quantum networks in continuous-variables non-Gaussian states M .Walschaers, N. Treps, B. Sundar, L.D. Carr, V. Parigi, arXiv:2012.15608

[2]Neural networks for detecting multimode wigner negativity V. Cimini, M. Barbieri, N. Treps, M. Walschaers, V. Parigi , Physical Review Letters 125, 160504 (2020)

Oliver Thomas

University of Bristol

A General Framework for Multimode Gaussian Quantum Optics and Photo-detection

The challenging requirements of large scale quantum information processing using parametric heralded single photon sources involves maximising the interference visibility whilst maintaining an acceptable photon generation rate [1]. By developing a general theoretical framework that allows us to include large numbers of spatial and spectral modes together with linear and non-linear optical elements, we investigate the combined effects of spectral and photon number impurity on the measured Hong–Ou–Mandel interference visibility of parametric photon sources, considering both threshold and number resolving detectors, together with the effects of spectral filtering. We find that for any degree of spectral impurity, increasing the photon generation rate necessarily decreases the interference visibility, even when using number resolving detection. While tight spectral filtering can be used to enforce spectral purity and increased interference visibility at low powers, we find that the induced photon number impurity results in a decreasing interference visibility and heralding efficiency with pump power, while the maximum generation rate is also reduced [2]. More generally this formalism could be readily applied to investigations into larger scale Gaussian boson sampling protocols [3] for which the effects of source errors is yet to be fully understood.

References

[1] S. Slussarenko, and G. J. Pryde. "Photonic quantum information processing: A concise review." Applied Physics Reviews 6.4 (2019).

[2] O. F. Thomas, W. McCutcheon, and D. P. S. McCutcheon, "A general framework for multimode Gaussian quantum optics and photodetection: application to Hong-Ou-Mandel interference with filtered heralded single photon sources." arXiv:2012.05991 (2020). [3] H. S. Zhong, et al. "Quantum computational advantage using photons." Science 370.6523 (2020): 1460-1463.

Nicolás Quesada

Xanadu

Quantum Computational Supremacy via High-Dimensional Gaussian Boson Sampling

Photonics is a promising platform for demonstrating quantum computational supremacy (QCS) by convincingly outperforming the most powerful classical supercomputers on a well-defined computational task. Despite this promise, existing photonics proposals and demonstrations face significant hurdles.

Experimentally, current implementations of Gaussian boson sampling lack programmability or have prohibitive loss rates. Theoretically, there is a comparative lack of rigorous evidence for the classical hardness of GBS.

In this work, we make significant progress in improving both the theoretical evidence and experimental prospects. On the theory side, we provide strong evidence for the hardness of Gaussian boson sampling, placing it on par with the strongest theoretical proposals for QCS. On the experimental side, we propose a new QCS architecture, high-dimensional Gaussian boson sampling, which is programmable and can be implemented with low loss rates using few optical components. We show that particular classical algorithms for simulating GBS are vastly outperformed by high-dimensional Gaussian boson sampling experiments at modest system sizes. This work thus opens the path to demonstrating QCS with programmable photonic processors.

Joe Randall

TU Delft

Quantum simulation of a discrete time crystal using solid-state spins in diamond

Interacting spins in diamond are a promising new platform for simulating many-body physics phenomena, due to their naturally realised spin-spin interactions combined with high -fidelity control and selective readout. Recently, we demonstrated the 3D imaging of a cluster of 27 interacting nuclear spins using a nitrogen-vacancy (NV) centre in diamond [1], as well as a fully connected 10-qubit register formed of 9 nuclear spins combined with the NV centre electron spin [2].

Building on these recent results, I will show how we can use this system to demonstrate a quantum simulation of a discrete time crystal (DTC) – a recently discovered out-of-equilibrium phase of matter that spontaneously breaks discrete time-translation symmetry in a periodically driven Floquet system [3].

Unlike previous experiments, our system simultaneously meets all of the requirements to realise the DTC phase that would persist to infinite time in the thermodynamic limit. Our results therefore provide signatures of a new out-of-equilibrium phase of matter and establish a novel programmable quantum simulator.

[1] M. H. Abobeih et al. Nature, 576, 411–415 (2019)

[2] C. E. Bradley, J. Randall et al. Phys. Rev. X 9, 031045 (2019)

[3] J. Randall et al. (in preparation)

Samuel Gyger

KTH Stockholm

Reconfigurable photonics with on-chip single-photon detectors

Integrated quantum photonics is a promising avenue for scaling up quantum optics beyond the proof of principle demonstrations. Such a future requires on-chip reconfigurable photonics were the integration with single-photon detectors remains a significant challenge. Heat as a standard method to tune photonic circuits makes superconducting detectors challenging.

This work shows the cointegration of microelectromechanical reconfiguration with on-chip superconducting single photon detectors (SSPD).

As a demonstration of principle, we perform high-extinction routing, high-dynamic range single-photon detection and power stabilization. This platform allows for heat-load free reconfiguration and all-integrated quantum optics experiments.

Caterina Vigliar

University of Bristol

Error-protected measurement -based quantum computing on an eight-qubit silicon photonics processor

Quantum computing machines have now entered a regime where tasks that were intractable on classical hardware can be solved. However, computational errors in such devices are still prohibitive for scaling to hundreds of good quality qubits. In photonics, towards the achievement of a scalable platform for fault-tolerant universal quantum computing the reconfigurable generation of large entangled states is needed. These states can provide a flexible architecture which can naturally embed error-correction and be therefore useful for real applications in error-full scenarios.

Here we propose and experimentally demonstrate a novel integrated silicon photonic architecture that both entangles multiple photons and encodes multiple physical qubits on individual photons to produce error-correctable logical qubits. We realise reprogrammable entangled states for measurement-based quantum computing and compare a wide range of quantum information processing tasks with and without error correction. Moreover, we show the effectiveness of error correction codes in quantum applications, such as the quantum phase estimation protocol, observing a significant success rate increase when running algorithms with error correction. We do it on an integrated silicon photonic platform which provides, fast-reconfigurable, high-precision, compact and mass-manufacturable circuitry, able to process tens of qubits. Our work represents a record for number of reconfigurable on-chip generated photonic qubits.

Our results show how quantum error correcting schemes can provide advantages not only for faulttolerant machines, but also for near-term applications on pre-fault-tolerant devicesimplemented with resource-efficient photonic architectures that can already dramatically improve the performance of quantum algorithms.

Kevin Weatherill

Durham University

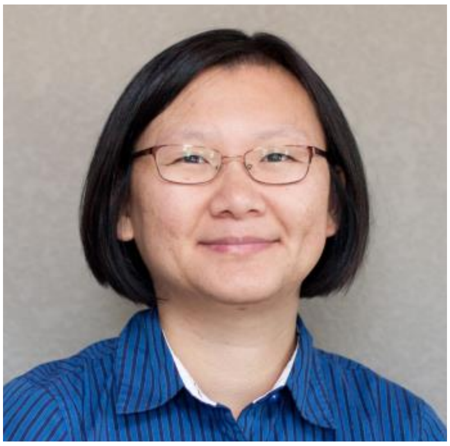
Rydberg Quantum Technologies

Rydberg atoms are highly excited atoms with exaggerated properties. In recent years, Rydberg atoms have emerged as a promising platform for numerous quantum technologies, ranging from quantum computation and simulation, single photon sources, RF communications and SI-traceable standards for electric fields.

In this talk, I will explain how the properties of Rydberg atoms make them advantageous for such applications and I will present the results from two recent experiments at Durham. (1) High speed terahertz imaging in thermal atoms that achieves frame rates that are orders of magnitude faster than other terahertz sensors. (2) Collectively encoded qubits in cold-atom ensembles that demonstrate coherence properties that are robust to atom loss and electric field noise.

(1) L. A. Downes et al. Physical Review X. 10, 011027 (2020)

(2) N. L. R. Spong et al. arXiv:2010.11794



Patty Lee

Honeywell Quantum Solutions

High Performance Commercial Trapped Ion Quantum Computers

Honeywell Quantum Solutions launched its first commercial trapped-ion quantum computer in 2020, designed around the quantum charge-coupled device (QCCD) architecture.

By applying fast transport operations to reorder and position ion qubits across multiple trapping zones simultaneously on the device, the QCCD architecture creates a fully-connected, high fidelity, and scalable quantum computer. These systems offer the unique capability of performing conditional quantum operations dependent on mid-circuit measurement outcomes, and qubits can be re-used in the same circuit after measurements.

This feature allows users to perform efficient quantum simulations and execute repeated cycles of quantum error correction.

Recently, the 10-qubit System Model H1 became the first quantum computer to pass the quantum volume 512 benchmark, the largest quantum volume ever measured on a commercial quantum computer.

Future generation systems will incorporate new technologies such as 2D trap architectures and integrated photonics, in order to scale the number of physical qubits and further increase system performance.

Galan Moody

UC Santa Barbara

Heterogeneous III-V/Silicon Quantum Photonics

In this presentation, I will highlight our recent progress on developing AlGaAs-on-insulator (AlGaAsOI) integrated photonic devices for ultra-efficient quantum light generation, manipulation, and detection. AlGaAsOI boasts several advantages for integrated quantum photonics, including the brightest chip-scale entangled-photon pair sources, negligible two-photon absorption in the telecommunications band, low-loss reconfigurable interferometers with high extinction, high-efficiency and low-noise waveguide-integrated single-photon detectors, and prospects for low VpL electro-optic modulators. Combined, these components offer exciting prospects for scalable, all-on-chip quantum photonic computing.

I will also present our recent work on the integration of III-V gain with silicon-on-insulator entangled-pair sources for turn-key quantum light generation.

Wolfram Pernice

WWU Muenster

Hybrid integrated quantum photonic technologies

On-chip integration of single-photon detectors and reconfigurable optical circuits is a crucial step toward a fully scalable approach to quantum photonic technologies. By confining light inside lithographically patterned waveguides, single-photons can be actively routed and interfered in miniaturized reconfigurable optical networks, and their state can be read out with on-chip detectors.

Integration of these two key elements on a common platform enhances the scalability of quantum photonic devices by minimizing their footprint and eliminating the need of lossy interconnects between separated optical systems.

I will present recent progress on realizing cryo-compatible reconfigurable photonic circuits using hybrid integration. Our design is based on superconducting nanowire detectors for measuring single photon events combined with either electro-optomechanical or electro-optical phase shifters embedded in on-chip interferometers. These concepts enable the realization of programmable photonic circuits that feature low dissipation loss.

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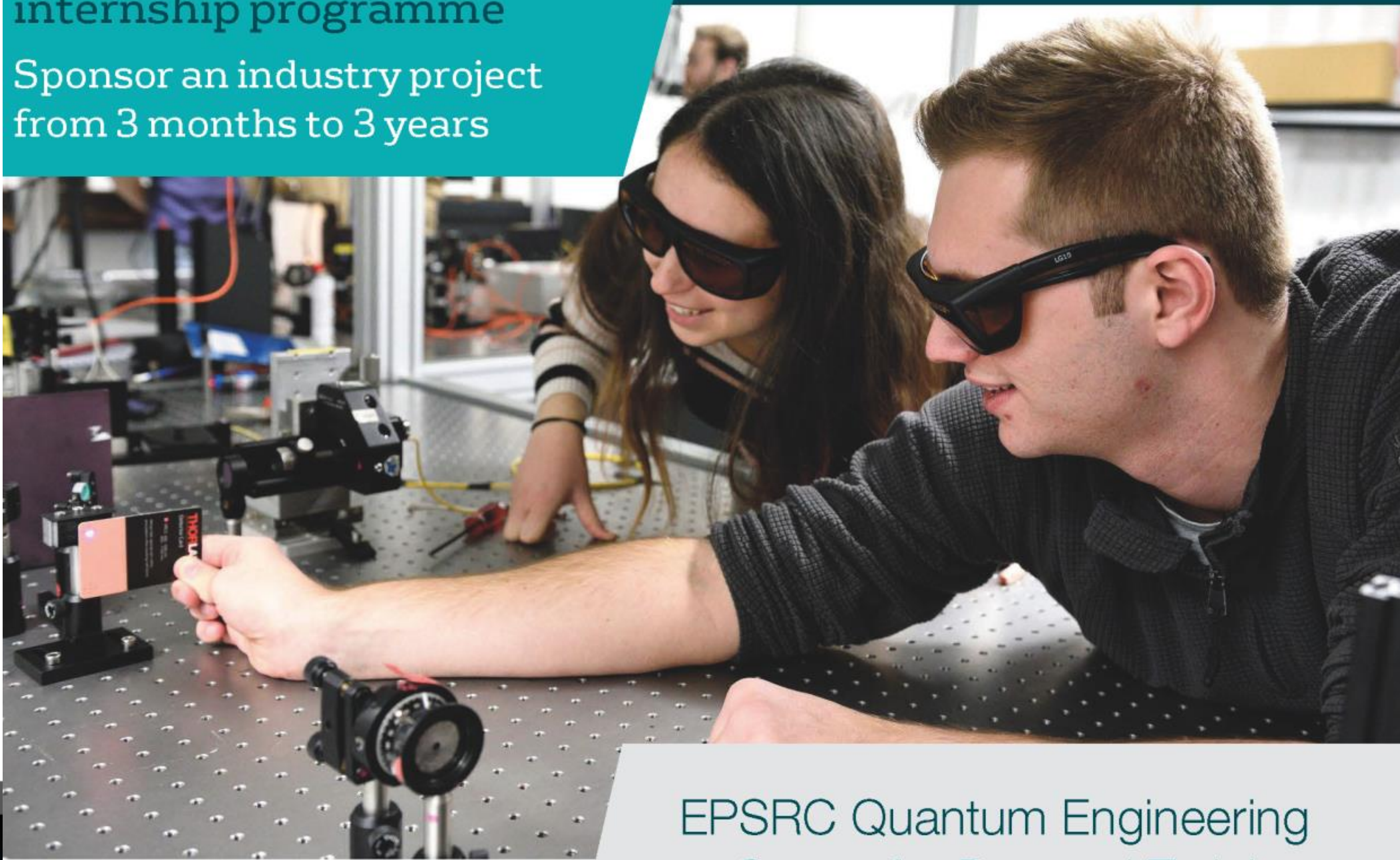

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01. Jeremy Adcock
Denmark Technical University
Dynamic quantum photonics

02. J. Eli Bourassa
Xanadu/University of Toronto
Blueprint for a Scalable Photonic Fault-Tolerant Quantum Computer

03. Luís Bugalho
Instituto Superior Técnico/ Instituto de Telecomunicações
Distributing Multipartite Entanglement over Noisy Quantum Networks

04. Elena Callus
The University of Sheffield
Maximal entanglement of spectrally distinct solid-state qubits by iteration

05. Adam Zaman Chaudhry
Lahore University of Management Sciences
Improving the estimation of environment parameters via initial probe-environment correlations

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CODE OF CONDUCT

BQIT:21 is a workshop intended for networking and collaboration in the quantum technology community. We value the engagement of each attendee and work to ensure all participants have an enjoyable and fulfilling experience. Accordingly, all attendees are expected to show respect and courtesy to other attendees throughout the workshop and at all workshop events. All attendees, speakers, sponsors and volunteers at BQIT:21 are required to agree with the following code of conduct. Organisers will enforce this code throughout the event. We expect cooperation from all participants to help ensure a safe environment for everybody. Thank you for helping make this a welcoming, friendly event for all.

THE SHORT VERSION

The BQIT team is dedicated to providing a harassment-free online conference experience for everyone, regardless of gender, gender identity and expression, age, sexual orientation, disability, physical appearance, body size, race, ethnicity, religion (or lack thereof), or technology choices. We do not tolerate harassment of workshop participants in any form. Sexual language and imagery is not appropriate for any workshop platform, including talks, panels, Twitter and other online media. Workshop participants violating these rules may be sanctioned or expelled from BQIT:21 at the discretion of the workshop organisers.

THE LONGER VERSION

Harassment includes, but is not limited to:

- Verbal comments that reinforce social structures of domination related to gender, gender identity and expression, sexual orientation, disability, physical appearance, body size, race, age, religion, or technology choices.
- Sexual images in public spaces.
- Deliberate intimidation, stalking, or following.
- Harassing photography or recording.
- Sustained disruption of talks or other events.
- Unwelcome sexual attention.
- Advocating for, or encouraging, any of the above behaviour.

Participants asked to stop any harassing behaviour are expected to comply immediately.

Sponsors are also subject to the anti-harassment policy. In particular, sponsors should not use sexualised images, activities, or other material.

If a participant engages in harassing behaviour, the workshop organisers may take any action they deem appropriate, including warning the offender or expulsion from BQIT:21.

WHO TO CONTACT

If someone makes you or anyone else feel unsafe or unwelcome, please contact our team as soon as possible through our email bqit-admin@bristol.ac.uk. Harassment and other code of conduct violations reduce the value of our event for everyone. We want you to be happy at our event. People like you make our event a better place.

The BQIT team will be happy to help participants contact local law enforcement or otherwise assist those experiencing harassment to feel safe for the duration of the workshop.

We expect participants to follow these rules on all workshop platforms and workshop-related online social events.

ATTENDEE PROCEDURE FOR INCIDENT HANDLING

1. The BQIT team will be prepared to handle the incident. All our staff are informed of the code of conduct policy and guide for handling harassment at the workshop.
2. Report the harassment incident to a BQIT team member through email at bqit-admin@bristol.ac.uk (this inbox will be frequently checked for the duration of the event). All reports are confidential. When taking a personal report, our staff will ensure this is confidential. They may involve other event staff to ensure your report is managed properly. During the reporting process, we'll ask you to tell us about what happened. This can be upsetting, but we'll handle it as respectfully as possible. You won't be asked to confront anyone and we won't tell anyone who you are.
3. We will only involve law enforcement or security at a victim's request. If you are not in the UK, please note that you can ask a member of the BQIT team to call the UK authorities on your behalf.

ATTRIBUTION

This Code of Conduct was adapted from confcodeofconduct.com and Geek Feminism Wiki.

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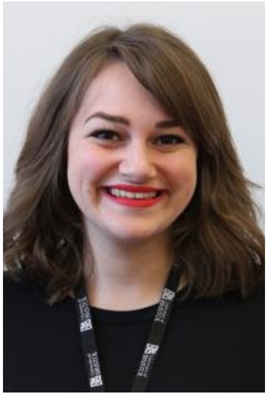

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THE BQIT TEAM WOULD LIKE TO THANK

Our speakers and panellists for their flexibility in going online to share their work and opinions on an expansive range of topics.

Our sponsors for supporting our evolution to a virtual event and helping to make BQIT a continued success.

Our phenomenal BQIT board, and Jaya and Ravi for their innovative ideas and diligent work throughout the year. Thank you for your support and enthusiasm during the whole process.

And finally, all of our Virtual BQIT:21 attendees for participating. Thank you for signing on, and we look forward to welcoming you to Bristol soon.

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