A Timeline of Quantum Technologies

Technologies which apply quantum mechanical effects have a wide range of possible applications within our modern society. They provide avenues to both outperform classical systems and provide new use-cases entirely. These quantum mechanical systems are inherently delicate and susceptible to external noise sources. This leads to difficult and unique engineering challenges that require the development of novel hardware, software and fundamental theories.

In this timeline we explore some of the historically significant events within quantum technologies, separated into five key sections: fundamental theory, quantum computation, quantum metrology, quantum communications and experimental realisations. Events occuring at the University of Bristol are marked with the university crest. A world map showing governmental investment in the multi-disciplinary field of quantum technologies is also included. This is just a small insight into the wide range of accomplishments within the field, and we encourage you to investigate further.

Scan the QR code to find additional linked content and references.

Fundamental Theory

The advent of quantum mechanics at the end of the 19th century led to a fundamental change in our understanding of the nature of reality. Quantum theory is inherently probabilistic, resulting in seemingly counter intuitive behavior. Whilst the philosophical meaning of this theory is still debated, it has become one of the world's best tested theories. Our understanding of quantum mechanics has provided a deeper insight into a multitude of fields within physics. It has become indispensable in the other scientific disciplines such as chemistry and biology, whilst also influencing the fields of mathematics and computer science.

Quantum Metrology

Metrology – the science of measurement – strives to continually create ever more accurate and precise measurements. However, quantum mechanics sets fundamental limits on the total amount of information it is possible to know about a system. For example, the Heisenberg uncertainty principle sets restrictions on the theoretical measurement uncertainty on a pair of conjugate variables. In addition, as we measure more precisely the discrete and probabilistic nature of reality imposes constraints on the scope of measurements. Quantum metrology looks to push the precision of our measurement devices beyond these standard limits.

Experimental Realisations

Whilst the theory underpinning quantum mechanics has led to the promise of revolutionary technologies there are many challenges in bringing these to fruition. There has been a large push to develop the hardware required for useful quantum devices, leading to a multitude of candidates for the building blocks of quantum computers - qubits. There is currently no clear winner, with platforms being developed using superconductors, trapped ions and photonics to name a few.

Quantum Computation

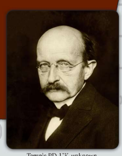
Quantum computers process information stored within quantum mechanical systems, encoding the information in qubits, or quantum bits. Unlike classical bits, qubits can be in a combination of being in 0 and 1 and can be entangled with other qubits where the state of one is correlated with the state of the other. By utilising these properties, quantum algorithms have been shown to provide computational speed ups over some of our best-known classical algorithms. This includes the efficient simulation of quantum systems, the factorisation of large numbers and solutions to linear equations.

Quantum Communications

Quantum communication is the application of quantum theory to communication networks. The most investigated aspect of this field is quantum key distribution (QKD), which involves securely establishing a secret string of random numbers with which a message may be encoded. By utilising the laws of quantum mechanics, two parties can theoretically communicate without any risk of eavesdropping. The field was established in 1984 and has rapidly expanded with a veritable zoo of protocols being developed. Physical realisations have been demonstrated which allow QKD to be performed with enough speed and ease that it is now used commercially. Current work explores increasing the speed of QKD, proving the security of QKD protocols and performing it during the day and between satellites in low earth orbit.

Quantisation of Light 1895

The continuous nature of energy was challenged by the UV catastrophe, whereby classical theories failed to explain experimental observations of the black body radiation spectrum from stars. Planck managed to resolve this failure by quantising black body energy into discrete packets.



Temple PD-UK-unknown.

The Photoelectric Effect 1905

The photoelectric effect is a phenomenon whereby light incidenct upon a metal must be above a threshold frequency in order to eject electrons from the metal - irrespective of the light's intensity. Whilst this couldn't be explained using classical theories, Einstein used Planck's concept of energy quantisation to explain these experimental observations. He theorised that light is comprised of discrete packets, later named photons, with energy dependent on frequency. Einstein's discovery later earned him the Nobel Prize in Physics.

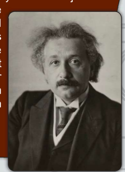


Image Credit: Walter Benington, for Elliott & Fry, vintage print, 18 May 1928.

Wave Particle Duality 1924

De Broglie proposed that matter should show wave-like behaviour, similar to the particle-like behaviour of electromagnetic waves. These matter waves have wavelength inversely proportional to momentum. He was awarded the 1927 Nobel Prize in Physics for his work.

Quantum Wave Mechanics 1925

Schrödinger, building on the work of de Broglie, published his famous equation describing the evolution of a wave function. The wave function describes the properties of an isolated quantum system and provides the probability of obtaining a specific outcome when an observable is measured. The Schrödinger equation laid the foundation for the wave theory of quantum mechanics and earned Schrödinger the 1933 Nobel Prize in Physics.

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = \hat{H}(t)\Psi(\mathbf{r},t)$$

Uncertainty Principle 1927

In quantum mechanics variables have intrinsic uncertainty depending upon the quantum state. Heisenberg showed that the uncertainties of position and momentum are fundamentally constrained.

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

Quantum Tunnelling 1927

Hund discovered the phenomenon of quantum tunnelling where quantum particles can pass through classically impenetrable barriers.

Dirac Notation 1928

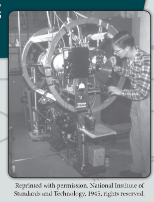
Dirac developed a new notation for quantum mechanics which has since become the standard.

EPR Paradox 1935

Einstein–Podolsky–Rosen (EPR) proposed a thought experiment that they believed showed that quantum mechanics is an incomplete theory. They argued that measurements made on a pair of distantly entangled particles could violate the uncertainty principle, and therefore the foundations of quantum mechanics, if the theory of relativity was upheld.

First Atomic Clock 1949

Traditional clocks relying on the natural oscillation frequency of quartz crystals are highly dependent on temperature, accruing significant errors. A search for more accurate devices led to the concept of timekeeping by measuring the frequency of atomic transitions, a highly stable parameter. NIST developed the first atomic clock using vibrations of molecular ammonia, with its derivatives used in GPS satellites.



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Bell's Inequality 1964

Bell demonstrated that no local hidden variable theory could reproduce all the predictions of quantum mechanics. Local hidden variable theories require that measurement outcomes are predetermined via some probability distribution upon creation of a system. Bell derived an inequality that if violated suggested that no local hidden variable theory could describe quantum mechanics, suggesting quantum mechanics is a non-local theory.

First SQUID 1964

SQUID's, superconducting quantum interference devices, were first invented by Jaklevic *et al.* by placing two Josephson junctions on a closed loop. SQUID magnetometers are highly sensitive and are capable of detecting a single magnetic flux quantum.

No Cloning Theorem 1970

The no cloning theorem proved that perfect copies of unknown quantum states cannot be made. Initially developed by Park, it was later generalised in 1982 by work from Wootters and Zurek in addition to independent work from Dieks, at which point the theorem gained its name. This forms the basis of security for many quantum communication experiments. It also prevents the use of classical error correcting codes being directly applicable to quantum computers.

First Bell Violation 1982

Aspect et al. demonstrated the first violation of Bell's inequality using polarisation entangled photons, giving the first evidence of the non-local nature of reality. However, sceptics identified certain loopholes which would avoid this conclusion.

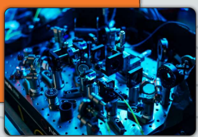


Image Credit: Siddarth Joshi, QET Labs, University of Bristol

BB84 Protocol 1984

Bennett and Brassard developed the first QKD scheme which is provably secure. The scheme involves preparing qubits in one of four states before sending them to another party. Due to the no cloning theorem, the states may not be read by an eavesdropper without disturbing them. The two parties may detect such an eavesdropper by the disturbance of the states. The data encoded in the sent qubits form the encryption/decryption key. The message is sent over public classical channel using the one-time pad protocol. BB84 is the basis of the most common QKD protocol.

Hong Ou Mandel Interference 1987

Hong, Ou, and Mandel demonstrated that two indistinguishable photons entering the two input ports of a beam splitter interfere and both emerge from the same output port. This result is integral to many fields of quantum physics but was initially proposed to measure small timing intervals for metrology.

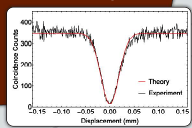
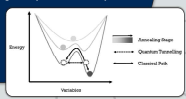


Image Credit: Alex Clark, QET Labs, University of Bristol

Quantum Annealing 1988

A form of quantum computation was proposed for finding a global minimum of a function using quantum tunnelling. By slowly varying a Hamiltonian in the time dependent Schrödinger equation, the system evolves into the solution represented by the smallest eigenvalue with high probability.



Atom Interferometry 1991

Within an optical interferometer light is split into two independent arms, before being recombined. Any phase difference acquired between the arms creates an interference pattern. Within the proposed atom interferometer light is replaced by atoms, utilising the wave-like behaviour of matter. An individual atom is put in a superposition of states which are then spatially separated into two arms and manipulated using laser pulses. A relative phase change acquired between the arms creates an interference pattern which is detected when the atomic state is measured. This technique can be employed to create high precision measurement devices.

Image Credit: ESA–G. Porter CC BY-SA 3.0 IGO

E91 Protocol 1991

Ekert introduced a QKD protocol with its security derived from the properties of entanglement. A source shares a pair of entangled particles between two parties, with each party performing a measurement on their particle in a random basis from a given set. When the measurements bases coincide, a secure shared key can be created between the parties.

Quantum Teleportation Theorised 1993

Bennett *et al.* published a paper proposing quantum teleportation. The scheme consists of two parties who share a maximally entangled pair. By making local measurements on their half of the pair, and using classical communication, the state of one qubit can be projected between the two parties.

First Josephson Junction 1963

Josephson junctions were experimentally realised by Anderson *et al.* These quantum devices are macroscopic superconducting junctions and would form the basis of superconducting qubits.

First Quantum Dot 1981

First realised by Ekimov, quantum dots are layers of semiconducting materials and can be thought of as artificial atoms. Quantum dots are particularly useful as single photon sources or qubits where the properties may be designed in manufacturing.

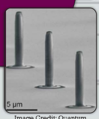


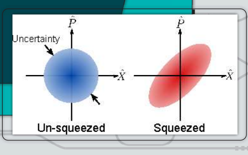
Image Credit: Quantum Dot Group, QET Labs, University of Bristol

Quantum Computation Proposed 1980

Quantum computers were theorised by Benioff, providing the first theoretical quantum mechanical framework of a reversible Turing machine. Feynman proposed the use of these quantum computers to efficiently simulate quantum systems, avoiding the exponential resource requirements when using classical computers. Lloyd subsequently confirmed that quantum computers can efficiently simulate any local quantum system. Extending this, Deutsch later showed that quantum computers can simulate any physical process.

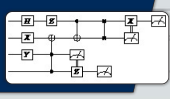
First Demonstration of Squeezed Light 1985

Slusher *et al.* generated squeezed light for the first time by harnessing the non-linear process of four wave mixing. Due to the Heisenberg uncertainty principle, it is impossible to know two conjugate variables precisely. By squeezing the light, the uncertainty in one of these can be decreased at the expense of increasing the uncertainty of the other variable. They reduced the noise fluctuation in one of the variables of the light below the shot noise limit - the limit of precision placed on classical light. Techniques like this would go on to form the basis of ultra-sensitive quantum measurements with applications in metrology and computing.



Circuit Based Quantum Computing 1989

Yao formulated a type of quantum computation, analogous to classical computation, whereby initialisation, logical gates, and measurements are sequentially applied to the qubits to implement a specific algorithm. This model is universal - it can run any quantum algorithm.



First QKD Implementation 1989

The first physical implementation of QKD was achieved by Bennett and Brassard using the BB84 scheme. A 403-bit string was shared over a distance of 30 cm, which after privacy amplification - a distillation stage to protect against eavesdropping - was reduced to only 175 bits of secret key.

Deutsch's Algorithm 1985

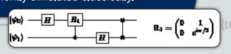
The first quantum algorithm that achieved a proveable speed up over classical counterparts was developed by Deutsch. The algorithm would determine if a two-bit function was balanced or constant with probabilistic success using only one call to the function. This was an improvement over the best classical algorithm which requires two calls. A constant function returns the same value for all inputs whilst balanced functions return one of two values, each for half the possible inputs.

Deutsch-Jozsa Algorithm 1992

A generalisation of Deutsch's algorithm was proposed which gave the first provable exponential quantum speedup over any possible deterministic classical algorithm, in terms of the number of queries to the input.

Quantum Fourier Transform 1994

The quantum Fourier transform, formulated by Coppersmith, is a critical algorithm underpinning the speedups of many quantum algorithms. Requiring a polynomial number of operations to complete, the quantum Fourier transform provides an exponential speedup over the classical Fourier transform when performing operations in superpositions. Despite the possible speedups, it was shown by researchers at the Universities of Oxford and Bristol that there are some cases when the quantum Fourier transform and its variants can be efficiently simulated classically.



Shor's Algorithm 1994

A quantum algorithm for prime factoring was formulated by Shor, providing an exponential speedup compared to the most efficient known classical algorithm, the general number sieve. This algorithm relies on speedups from the quantum Fourier transform and modular exponentiation. Shor's algorithm has implications for classical encryption methods that rely on a public-key encryption scheme, whereby security is derived from the classical complexity of prime number factoring. Shor's paper kickstarted research into building a fault tolerant quantum computer and the field of post-quantum cryptography.

First Quantum Error Correcting Codes 1995

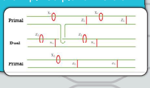
Quantum computers are highly susceptible to noise, meaning qubits need protection against errors. The laws of quantum mechanics prevent the use of classical error correction protocols, requiring quantum compatible protocols. Shor and Steane independently formulated the first quantum error correcting codes. Shor's code encoded one logical qubit across nine physical qubits, protecting against arbitrary errors on one qubit. Steane's more general formulation provided the same protection with only seven qubits using a Hamming code.

Quantum Phase Estimation 1995

A quantum algorithm which harnesses the quantum Fourier transform was proposed by Kitaev to estimate the phase of a quantum state and is widely utilised as a quantum subroutine.

Topological Computing 1997

Kitaev proposed a method of fault tolerant quantum computation using topological features, with high resilience against errors, by distributing qubits across a toroid. In later work with Bravyi, they developed a simplified planar version known as the surface code, which became one of the most predominant error correction schemes.



First entanglement distribution 1997

Entanglement distribution is a critical component for quantum networks, allowing for distributed quantum computation as well as quantum communication protocols. This was first experimentally demonstrated by Bouwmeester *et al.* in free-space using polarisation entangled photons.

First Implementation of a Quantum Algorithm 1998

A two-qubit NMR quantum computer successfully solved Deutsch's problem, marking the first quantum algorithm demonstrated on a physical system. NMR computers, where information is encoded into nuclear spins of atoms, would later be superseded by platforms including superconducting and trapped ion qubits.

Quantum Gravimeter 1998

A design for an atomic interferometer used to measure acceleration due to gravity was proposed, with a theoretical precision higher than the best available classical gravimeters.

Quantum Teleportation Demonstrated 1998

Quantum teleportation, with information encoded within the degrees of freedom of photons, was demonstrated for the first time by two groups lead by Popsecu and Zeilinger.

Ion Trap in Semiconductor Chip 2006

Ionised Cadmium atoms were trapped floating over the surface of a microelectronic chip, by Hensinger *et al.* Manufactured in the same way as computer chips, they provide a compact and scalable way to build a quantum computer. Wires in the chip generate electric fields which attract or repel the ion to provide spatial confinement, allowing it to be cooled and controlled using lasers. Before this, ions were trapped in bulky traps that were too large to use for a quantum computer.

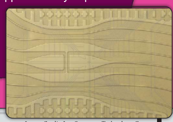


Image Credit: Ion Quantum Technology Group, University of Sussex

Proof Entanglement Is Needed 2002

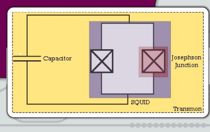
Jozsa and Linden proved the necessity of multi particle entanglement in order to achieve exponential quantum-computational speedup. This is explained by systems with only a small amount of entanglement being efficient to simulate classically. They ultimately say that entanglement should not be treated as the only key to quantum speed-up as large-scale entanglement may be efficiently simulated in some circumstances.

Entanglement-Based Quantum Communication Over 144 km 2007

QKD was performed over 144 km between the islands of Tenerife and La Palma by Ursin and Rarity *et al.* using polarisation entangled photons. This was an order of magnitude improvement over existing free-space quantum communication experiments, demonstrating an essential step in realising long range free-space quantum communication.

Transmon Qubit Invented 2007

A new type of superconducting qubit with a lower sensitivity to noise than previous designs was invented. The transmon would go on to form the basis of the first quantum computer to show a quantum advantage.



Controlled-NOT Gate Implemented on Superconducting Qubits 2007

Controlled-NOT gates were demonstrated on superconducting flux qubits by Plantenberg *et al.*

Grover's Algorithm 1996

Grover devised a quantum algorithm that provides a quadratic speedup compared to the best classical algorithm for unstructured search problems. Grover's algorithm can also be used to speed up classical unstructured search problems in the case where the solution can be checked efficiently.

Entanglement Concentration 1996

Popescu, with collaborators, demonstrated that partially entangled qubit pairs may be transformed into a smaller number of maximally entangled pairs. This process uses only local operations and classical communication, and was shown to asymptotically conserve the degree of entanglement in the system. Notably the process can be reversed to generate any partially entangled state using only standard singlet states.

First Superconducting Qubit 1999

The first superconducting qubit was built by Nakamura et al. This was a charge qubit where the basis states are represented by the absence or presence of electron pairs in the Josephson junction.

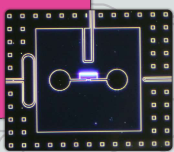


Image Credit: Andersen Lab of QuTech

Linear Optical Quantum Computation 2001

Knill, Laflamme and Milburn (KLM) devised a scheme for quantum computation requiring only linear optical components such as directional couplers and phase shifters, with the necessary non-linearity induced by projective measurements and ancilla photons. This avoids the challenge of implementing nonlinear interactions, providing a theoretically scalable pathway to optical quantum computation, at the expense of practically achievable determinism.

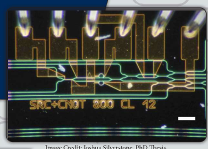


Image Credit: Joshua Silverstone, PhD Thesis, University of Bristol.

Quantum Computation & Quantum Information 2000

Michael Nielsen and Isaac Chuang, sometimes affectionately labelled 'Mike and Ike', first published "Quantum Computation and Quantum Information". This textbook has been held as a go-to resource for all in the field.

First Entanglement Based QKD Implementation 2000

Using polarisation entangled photon pairs, secret keys of up to 800 bits per second were generated between two users 360m apart. This was a direct implementation of E91, and a 43 kbit image was subsequently transmitted between the users using the secret key as the seed for a hashing function used to extend the key from 0.8 to 43 kbits.

BB84 Decoy State Protocol 2003

The decoy state protocol was proposed to overcome photon number-splitting attacks against BB84. These occur when an eavesdropper measures some of the signal when more than one photon is present, compromising security. This protocol is highly favoured due to true single photon sources being unavailable.

All Optical Controlled-NOT Gate 2003

The CNOT gate, a two-qubit entangling gate that is critical for quantum computing, was demonstrated for the first-time using photonics. O'Brien *et al.* used a probabilistic scheme, similar to that proposed by KLM, to create this gate with a success probability of 1/9. This proved the feasibility of photonics as a platform for quantum computing.

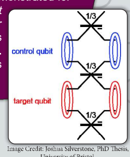


Image Credit: Joshua Silverstone, PhD Thesis, University of Bristol.

Measurement-Based Quantum Computing 2003

Raussendorf and Briegel devised a form of universal quantum computation known as measurement-based quantum computing. Information is processed by performing single qubit measurements on a highly entangled system known as a cluster state. This scheme is ideal for photonics, providing a more resource efficient and practically achievable alternative than the traditional KLM scheme.

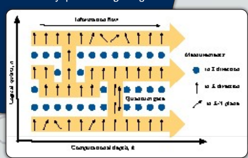


Image Credit: Mercedes Gimeno-Segovia, Pete Shadbolt, Dan E. Browne, Terry Rudolph, Public domain, via Wikimedia Commons

HHL Algorithm 2008

Harrow, Hassidim and Lloyd proposed an efficient quantum algorithm for solving large systems of linear equations. Their algorithm requires the input and output to be given as quantum states. The HHL algorithm has since been used as a subroutine in many other quantum algorithms, such as for solving differential equations, and in quantum machine learning.

Shor's Algorithm Implemented on a Photonic Chip 2009

Researchers at the University of Bristol used photonic qubits to implement Shor's algorithm to factor fifteen. This was the first quantum algorithm performed on a photonic chip.

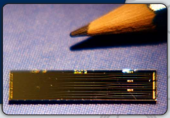


Image Credit: Alberto Politi, Centre for Quantum Photonics, University of Bristol

Quantum Thermal Equilibrium 2009

Linden, Popsecu, Short, and Winter proposed a mechanism by which quantum systems equilibrate when in contact with a thermal reservoir. This result was one of many contributions towards the effort to derive the laws of thermodynamics as an emergent property of quantum mechanics. This foundational area of research has the potential to underpin future quantum technologies such as nanoscale heat engines, refrigerators and batteries.

QKD Performed in Daylight 2010

BB84 QKD was performed for the first time in daylight conditions.

Real World Implementation Problems of QKD 2014

This black paper examined the reality of QKD security and questioned the claims of "security guaranteed by the laws of physics". QKD security is theoretically absolute, however, in reality it is much more subtle and open to side channel attacks. These attacks exploit flaws in hardware to sidestep the protocol security. For QKD to become viable, it is vital that any side channel which leak information must be closed to maintain security. Many papers claiming security have ignored these issues and as such have been subsequently refuted.

Variational Quantum Eigensolver 2014

A hybrid quantum-classical algorithm for finding the ground state energies of a Hamiltonian was developed. This is a key problem in quantum chemistry and is one of the most promising applications of near-term quantum computing. The scheme operates via classical optimisation updating the ansatz for a quantum algorithm. VQE was developed and demonstrated on a photonic chip at University of Bristol.

Imaging Without Detection 2014

A protocol was proposed to detect objects by measuring exclusively photons which do not interact with the object itself. This uses entangled photon states which interfere such that the single photon counts reveal the object's transmittance and phase profile. This provides a method to detect objects at wavelengths at which they are transparent.

Squeezed Light Used in LIGO 2018

Having successfully detected gravitational waves in 2016, the Laser Interferometer Gravitational Wave Observatory (LIGO) upgraded its setup to include squeezed light to enhance sensitivity. Gravitational waves, famously predicted by Einstein, are tiny ripples, many times smaller than a proton, in the fabric of space and time and are the consequence of interacting masses. LIGO splits a high-power laser between two perpendicular arms, 4 km long, where they bounce off mirrors before being recombined and the interference between the two beams is measured. When gravitational waves deform spacetime the lengths of these arms change leading to a change in the interference pattern. LIGO was sensitive enough that vacuum fluctuations were inserting noise into the interferometer, limiting the precision. This upgrade inserted a squeezed vacuum state to suppress this noise.

Courtesy Caltech/MIT/LIGO Laboratory

Quantum Volume Proposed 2017

Quantum volume was proposed as a hardware-agnostic metric for the performance of quantum computing devices. This metric assesses the amount of useful quantum computation performed by the device across space and time.

$$\log_2(V_Q) = \underset{n}{\operatorname{argmax}}(\min[n, d(n)])$$

QKD to an Orbiting Satellite 2017

The Chinese built Micius satellite performed QKD between itself and the earth. By propagating in space this overcame the distance restrictions imposed by fibre loss. The satellite later mediated a QKD connection between two ground-based parties. Satellite QKD is the only currently known scalable route to a truly global QKD network.

Boson Sampling Proposed 2011

Aaronson and Arkhipov proposed a method of proving quantum advantage by generating samples from a distribution that is classically hard to simulate. Whilst this is a non-universal method of quantum computation, it provided a useful benchmarking tool for the progression of quantum hardware beyond what was possible classically.

Measurement-Device-Independent QKD 2012

Measurement-device-independent QKD was proposed by Lo *et al.* By changing how the measurements are performed, measurement devices no longer need to be trusted, and can even be controlled by an adversary. Adversaries will not be able to gain information about the key established by the two users even when in control of the detectors.

QKD to a Moving Aircraft 2013

QKD was demonstrated to a moving platform (300kph) for the first time.

First Quantum Computer Available on the Cloud 2013

University of Bristol reveals an internet-facing two-qubit quantum computing circuit, accessible to the general public.

Two Qubit Gate in Silicon 2015

Two-qubit controlled-NOT gates were demonstrated in silicon. Qubits were formed from silicon spin states and interacted via the spin-spin exchange interaction.

Image Credit: Poster by Mason Adshead

Loophole Free Bell Violation 2015

The first Bell test that claimed to close all possible loopholes was performed. This provided evidence that nature is not described by a local realistic theory.

Quantum Speedup of Monte Carlo Methods 2015

Montanaro proposed a quantum algorithm for Monte Carlo methods that provides a near-quadratic speed up over the best-known classical algorithm. Monte Carlo algorithms utilise randomness to estimate solutions to problems that are difficult to solve deterministically, with uses in fields from statistical mechanics to mathematical finance.

IBM Lauches Cloud Quantum Computing 2016

IBM delivers cloud access to a quantum computer starting with a five-qubit superconducting machine.

Boson Sampling Achieved with 14 Photons 2019

Wang *et al.* demonstrated boson sampling by detecting up to 14 photons from a 60-mode optical interferometer. This demonstrated a significant step towards a quantum advantage.

Quantum Advantage Achieved 2019

Google claimed to have achieved quantum advantage for the first time with their 53-qubit superconducting quantum processor - Sycamore. The team sampled the output state from the processor after applying a series of one and two-qubit gates. Whilst it took 200 seconds to get ~10^6 samples of this distribution, it was theorised to take the best classical algorithm 10,000 years. This claim was disputed by IBM who claimed to have a classical algorithm that could produce samples in only 2.5 days. This was confirmed by subsequent classical algorithms which have enabled faster sampling from the required distribution. Despite this, it represented a significant milestone on the route to competitive quantum technologies.

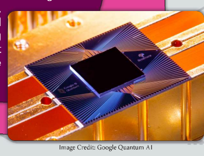
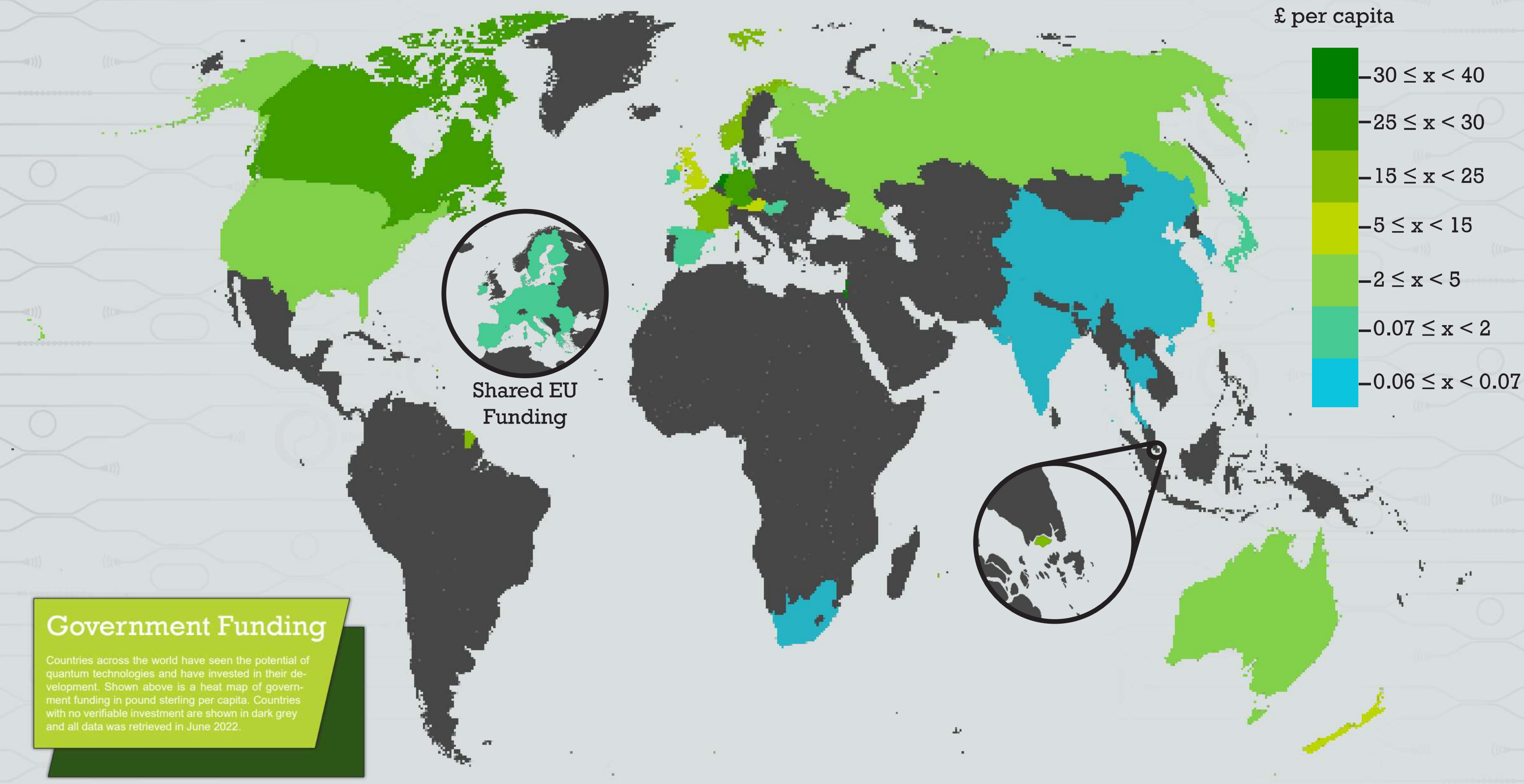


Image Credit: Google Quantum AI



Government Funding

Countries across the world have seen the potential of quantum technologies and have invested in their development. Shown above is a heat map of government funding in pound sterling per capita. Countries with no verifiable investment are shown in dark grey and all data was retrieved in June 2022.

8-User Quantum Network 2020

The University of Bristol developed an 8 user QKD network with all 28 possible pairings having connectivity.

Image Credit: Siddarth Joshi, QET Labs, University of Bristol

4600km Quantum Network 2020

By using two satellite-to-ground links along with 700 fibre based QKD links, a 4600km QKD network with full connectivity was demonstrated in China.

Quantum Advantage in Microscopy 2021

The stochastic nature of light poses limits to the achievable microscope sensitivity and resolution when operated at low intensities. However, quantum correlations were shown for the first time to provide a quantum advantage of 35% to the signal to noise ratio over the classical limit.

Boson Sampling Claimed to Achieve a Quantum Advantage 2020

Expanding on previous gaussian boson sampling experiments, Pan's group detected up to 76 photons in a 100-mode interferometer. They claimed that the best supercomputer would have taken 10^{14} times longer to generate samples from the same probability distribution. Whilst this marked the first-time boson sampling had been used to demonstrate quantum advantage, there was scrutiny from the surrounding community. Research from The University of Bristol suggested classical algorithms could in reality perform this calculation this in only a few months.

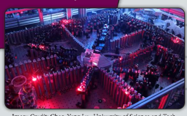


Image Credit: Chao-Yang Lu, University of Science and Technology of China

Trapped Ion Shuttling 2021

Ions were successfully shuttled between two modular chips, a huge step toward a scalable trapped ion quantum computer.

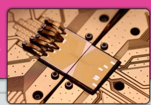


Image Credit: Ion Quantum Technology Group, University of Sussex

Fusion Based Quantum Computing 2021

PsiQuantum developed a universal form of fault tolerant quantum computation in which qubits are topologically encoded within a cluster state. The generation of this cluster state processes the information as well as facilitating error correction. Whilst created for use in PsiQuantum's photonic quantum processors, the paradigm is hardware agnostic.

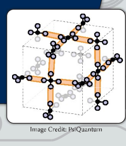


Image Credit: PsiQuantum

Quantum Advantage on a Programmable Processor 2022

Xanadu demonstrated quantum advantage through boson sampling on a programmable photonic quantum processor which was subsequently made available on the cloud. The result detected up to 219 photons across 216 modes.

Quantum Gravity Gradient Sensor 2022

A quantum gravity gradient sensor was shown to perform measurements faster than a traditional device in a field test. It was able to locate metre sized features in the gravitational field making gravity cartography a realistic proposal. However, the atom interferometry based setup was shown to operate with a similar uncertainty to traditional devices.

Designed and Researched by QE-CDT Cohort 8
2022

Centre for Doctoral Training in Quantum Engineering

QET Labs

University of Bristol

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