Q4 2024

QUANTUM VIBES

A newsletter on
Indian Quantum Technology Activities

Indian Army and C-DAC collaborate to Establish Centre of Excellence for Defence Technologies

DST announces Eight StartUps for Support Under National Quantum Mission and the National Mission on Interdisciplinary Cyber-Physical Systems

INSIDE THE MINDS

WITH
Dr. Saptarishi Chaudhuri
RRI Bangalore

Fighting Noise before Error Correction

Dr. Ritajit Majumdar
IBM Quantum

High brightness Entangled Photon Source using SAGNAC Interferometer

Mr. Sricharan Narasimha
CDAC, Bengaluru

Editor's Note

Stepping into the Q4, 2024 edition of Quantum Vibes, our eighth issue delving into the ever-evolving world of quantum technologies. In this edition, we present groundbreaking insights and developments that are shaping the trajectory of quantum science, while offering a platform to learn from thought leaders and innovators in the field.

This edition features an expert insight by Dr. Ritajit Majumdar from IBM Quantum, titled *Fighting Noise Before Error Correction*. Dr. Majumdar explores innovative techniques to mitigate quantum noise, a critical challenge in quantum computing, highlighting strategies that can enhance the performance and reliability of quantum systems.

In the Quantum Tutorial section, Mr. Sricharan Narasimha from CDAC Bangalore provides a comprehensive guide on *High Brightness Entangled Photon Source Using SAGNAC Interferometer*. This tutorial sheds light on the intricacies of generating entangled photon pairs with high efficiency, a fundamental component in quantum communication and networking.

The *Inside the Minds* section features an engaging conversation with Dr. Saptarishi Chaudhuri from the Raman Research Institute (RRI) Bangalore. Dr. Chaudhuri shares his perspectives on the current trends and future directions of quantum research, providing valuable insights into his groundbreaking work and the broader quantum landscape.

Under Quantum Currents, we bring you the latest updates shaping the quantum ecosystem in India: *C-DAC's collaboration with the Indian Army to establish a Center of Excellence for Defence Technologies*, showcasing the application of quantum advancements in national security; the Department of Science and Technology's (DST) announcement of new startups supported under the National Quantum Mission (NQM), highlighting the thriving entrepreneurial spirit in the quantum domain; and a landmark initiative by DST and AICTE introducing an undergraduate course in quantum technologies to nurture the next generation of quantum scientists and engineers.

With these cutting-edge developments and insights, this edition reflects the vibrancy and potential of the quantum revolution. We invite you to immerse yourself in the world of quantum innovation, exploration, and collaboration. Together, let us continue to embrace the frontiers of quantum science and redefine the future of technology and communication in the new year. Wishing you all a Happy New Year!

Happy Reading !

DR. S.D. SUDARSAN
Editor

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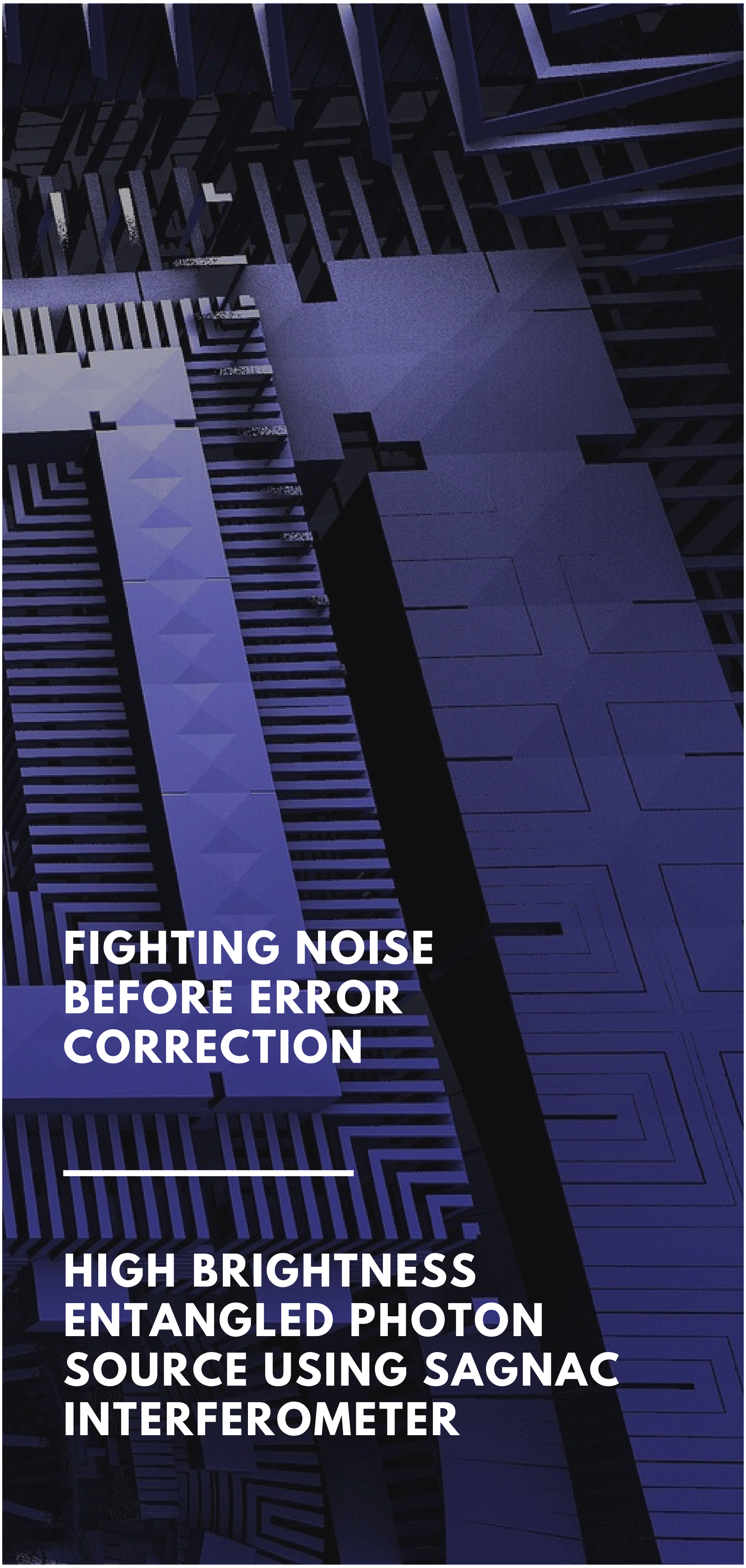


FIGHTING NOISE BEFORE ERROR CORRECTION

HIGH BRIGHTNESS ENTANGLED PHOTON SOURCE USING SAGNAC INTERFEROMETER

FIGHTING NOISE BEFORE ERROR CORRECTION

Dr. Ritajit Majumdar

INTRODUCTION

If you peek into the characterization of the quantum devices available today, you will find that most of them characterize some sort of noise which affects the system. For example, a qubit prepared in the state |1⟩ has a natural tendency to release the excess energy spontaneously and decay to the state |0⟩. Similarly, each quantum gates are affected by noise, making the operations imperfect. Even the state preparation and the readout of qubits are not perfect. So, how to perform reliable quantum computation when all its components are imperfect? A natural solution is to be able to incorporate error correction, which will detect the presence of error, correct it, and restore the system to the noiseless state. A plethora of research is ongoing in this direction [1, 2, 3]. However, an error corrected commercial quantum computer is still a few years away. So, how do we fight with noise in the meantime? The answer lies in quantum error mitigation.

Several applications of importance, where quantum computers are expected to be useful, rely on calculating the expectation value of an observable. An observable is any quantity that can be measured. For example, we may want to measure the ground state energy of a molecular system, the magnetization of some Ising chain, some property of a graph, or even the accuracy of a machine learning model. We obtain the solution to the problem by encoding it into a quantum state, executing the quantum circuit multiple times to obtain a probability distribution of bitstrings, and then classically calculating the expectation value of the observable from this distribution. Due to the presence of noise, the estimation of the expectation value can be erroneous. Quantum error mitigation provides a more accurate estimate of the expectation value by running multiple versions of the original quantum circuit and performing some classical postprocessing on the obtained outcomes.

ZERO NOISE EXTRAPOLATION (ZNE)

In this article we shall discuss one of the simplest, yet one of the most profound, error mitigation techniques called Zero Noise Extrapolation (ZNE). To understand this technique, let us first recall that any quantum gate U is a unitary operator. Therefore, there exists an inverse gate $U^\dagger$ such that $UU^\dagger = U^\dagger U = I$. Thus, a quantum circuit remains functionally equivalent if we replace a gate U in the circuit by $U(U^\dagger U)^\lambda$, for some $\lambda \geq 0$. Such a method, where a gate U is replaced by $U(U^\dagger U)^\lambda$, is called folding and λ is called the noise factor. We show an example of folding in Fig 1 where each gate is folded into 3 functionally equivalent gates.

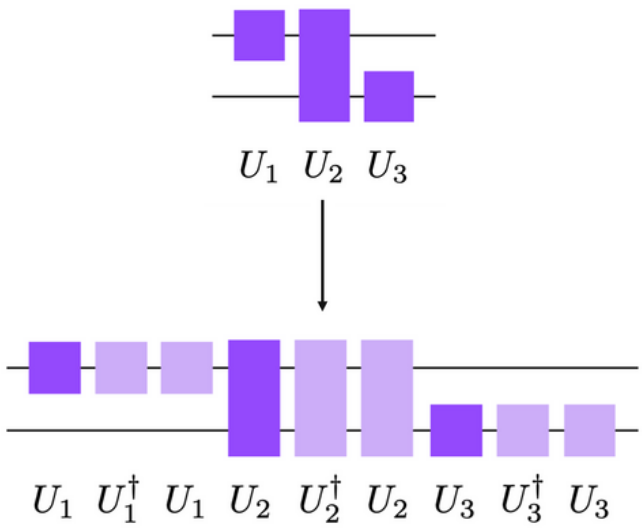


Figure 1: Folding each gate of a quantum circuit with 3 functionally equivalent gates

However, each quantum gate has some associated noise. Therefore, although $U(U^\dagger U)^\lambda$ is functionally equivalent to U, the former will incur more noise due to the presence of more gates. Thus, apparently folding is a foolish idea both in terms of resource (more gates are used than necessary) as well as noise. Nevertheless, ZNE constructs such folded circuits for multiple values of λ, and calculates the expectation value of the required observable for each of them. Naturally, the obtained expectation value deviates from the ideal outcome more and more with increasing λ. Fig 2 shows an example where the expectation values $E(\lambda_1)$, $E(\lambda_2)$, $E(\lambda_3)$ calculated by executing three folded circuits with some noise factors λ_1, λ_2, λ_3.

Now comes the final classical postprocessing step. $E(\lambda_1)$, $E(\lambda_2)$, $E(\lambda_3)$ give an estimate of the expectation values at different noise levels. Next, we fit a curve through these points and extrapolate it to $\lambda = 0$. The extrapolated value E^* gives an estimate of the noiseless expectation value. In other words, E^* gives an estimate of what the expectation value would have been if there were no noise in the system.

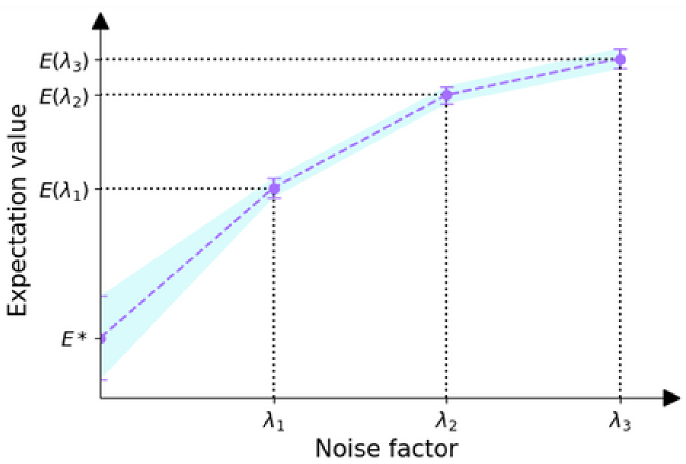


Figure 2: Fitting the expectation values at various noise factors and extrapolating it to the zero-noise limit

A common misconception is that ZNE and other error mitigation methods reduce quantum device noise. In reality, the noise stays the same. These methods use extra quantum (running circuits for different values) and classical (curve fitting and extrapolation) resources to estimate the expectation value for the noiseless scenario.

PARTIAL FOLDING

Could you identify a possible limitation of the ZNE method discussed so far? The quantum utility paper from IBM [5] recently executed a circuit with more than 100 qubits and 3000 2-qubit gates. The 2-qubit depth of this circuit was around 60. Imagine that you have selected noise factors (1, 3, 5) for this circuit. What will happen if you use a noise factor of 5 on this circuit? The 2-qubit depth will become 300. At such a depth, the noise overwhelms, and it is difficult to obtain any meaningful signal from the computation. One or more of the expectation values obtained from the folded circuit will be garbage values. Hence, the extrapolation will also fail! So how do we use ZNE for bigger and deeper circuits? The solution is partial folding.

The overall procedure for ZNE with partial folding is exactly similar to what we have seen till now. Except that, in this method, we provide fractional values to λ. Take an example, where $\lambda = 1.2$. This implies that two out of ten gates from the circuit will be selected randomly, and each of these two gates will be folded as in Fig. 1. This method restricts the increase in depth due to folding and makes ZNE applicable for deep circuits as the one used in the quantum utility paper.

IMPLEMENTING ZNE USING QISKIT

Using ZNE with Qiskit [6] is extremely simple. For this article, we consider an example of a 10-qubit Ising model with nearest neighbor interaction and study its time evolution for t = 0.2 over 2 trotter steps. The corresponding circuit is shown in Fig. 3. Let us consider the observable to be the average of the weight-1 Z-type operator on all qubits $M_Z = \frac{1}{N}\sum_i Z_i$, N being the number of qubits (10 for this case). Since this is a small system, the ideal expectation value can be calculated numerically and is known to be 0.88. Now, we apply ZNE and compute the expectation value on a 127 qubit IBM Quantum device.

We will use the Estimator primitive from IBM Qiskit Runtime to compute the expectation value. The specifics of Zero-Noise Extrapolation (ZNE) can be configured using the EstimatorOptions class.

```python
from qiskit_ibm_runtime import QiskitRuntimeService
service = QiskitRuntimeService(channel='ibm_quantum', token=<YOUR API TOKEN>)

backend = service.backend(<NAME OF BACKEND>)
```

```python
from qiskit_ibm_runtime import EstimatorV2, EstimatorOptions

options = EstimatorOptions()
options.resilience.zne.noise_factors = [1,3,5]
options.resilience.zne.extrapolator = ['linear', 'exponential']

estimator = EstimatorV2(mode=backend, options=options)
```

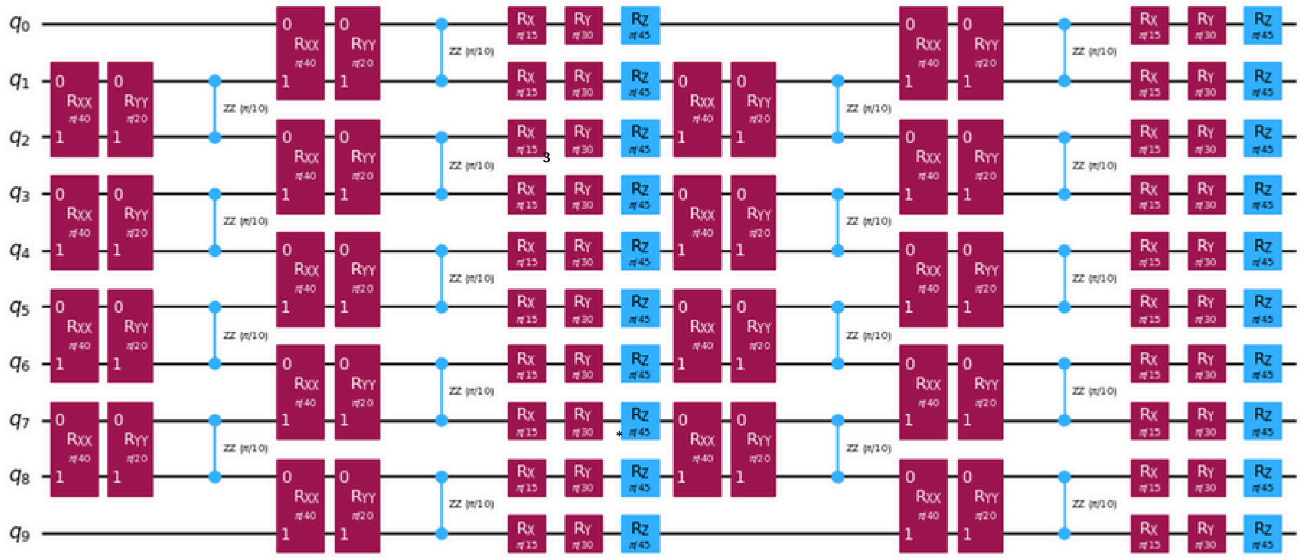


Figure 3: The circuit for time evolution of a nearest neighbour Ising model Hamiltonian with t = 0.2 and 2 trotter steps

Here, we first selected our backend, and then explicitly stated the noise factors and the extrapolators to be used. In this example, Qiskit Runtime will run the folded circuits with λ = 1, 3, 5, calculate the expectation values for each one of them, and then attempt to fit these values with both linear and exponential curves, and extrapolate to λ = 0. It will return that result for which the standard deviation of the extrapolated value is minimum.

You can provide any values in the noise factors, including fractional values for partial folding. You can provide other curves to be tried for fitting or can provide a single curve as well.

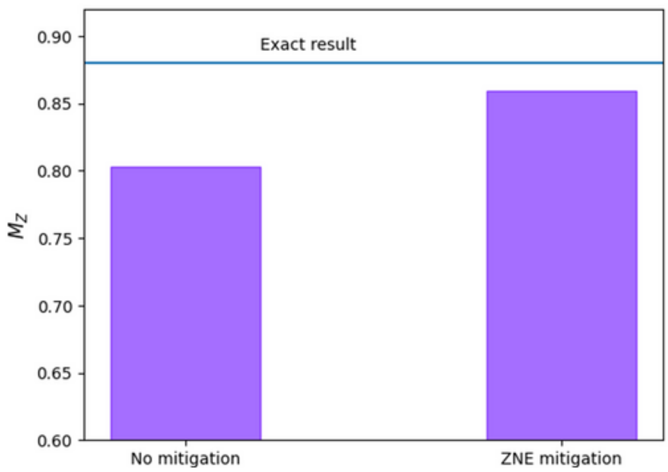
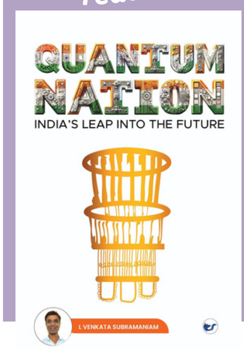


Figure 4: Expectation values obtained without and with ZNE mitigation

The values of noise factors and extrapolators shown in the code snippet above are the default values in Qiskit Runtime. If you want to use the default values, you can replace the explicit statements with *options.resilience_level = 2*. Fig 4 shows the results obtained with and without ZNE. The results clearly show the significant improvement offered by ZNE when executing on a noisy IBM Quantum device.

Must read



QUANTUM NATION *-By L Venkata Subramaniam, IBM Quantum India*

Imagine a universe where every star in the sky and every molecule in your coffee cup forms part of an immense quantum computer. This is not just a poetic metaphor; it's the reality that underpins our universe. Quantum Nation delves into this transformative voyage, exploring how India is positioning itself at the forefront of the quantum revolution. It's a story of innovation, vision, and the relentless pursuit of knowledge, set against the backdrop of a nation striving to redefine its future.

CONCLUSION

In this article, we provided insight into the Zero Noise Extrapolation (ZNE) error mitigation technique. We discussed its working principle and demonstrated some code snippets in Qiskit to apply it to IBM Quantum devices. Additionally, we showcased the significant improvement that ZNE provides using an example with the nearest-neighbor Ising model. You can ask that the outcome obtained in Fig 4 with ZNE is still not perfectly agreeing with the exact expectation value. This is because there are other types of noise which ZNE alone cannot mitigate. An example is the readout error. We refer readers to [7], where we discussed the entire pipeline of error mitigation and suppression techniques used in current quantum systems. This article points out the other techniques to be used together with ZNE to obtain the optimal result. In fact, the figures 1 and 2 are used from this paper. There is another version of ZNE called *Probabilistic Error Amplification [5]* where the noise in the system is first learnt via Sparse-tomography method, and then folding is done using this information. Using all these techniques in Qiskit is as simple as using ZNE, which we demonstrated earlier. More details on this can be found in the Qiskit documentation.

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DR. RITAJIT MAJUMDAR

Dr. Ritajit Majumdar is a Research Scientist at IBM Quantum, based at the IBM India Research Lab, where he focuses on enabling both internal and external researchers to achieve utility-scale outcomes using IBM Quantum technologies. He holds a PhD from the Indian Statistical Institute, where he also spent a significant period as a visiting scholar at the IBM Thomas J. Watson Research Center in New York under the prestigious Fulbright-Nehru Doctoral Research Fellowship. Prior to his doctoral studies, Dr. Majumdar served as an Assistant Professor at B. P. Poddar Institute of Management and Technology, affiliated with MAKAUT, and continued his academic engagement there as a visiting faculty member during his PhD tenure. He is a recipient of the Gold Medal from Calcutta University for his Master's degree and was honored with the esteemed DST Inspire Fellowship. In addition to his work at IBM, he is currently a guest faculty at the Department of Computer Science & Engineering at Calcutta University and is also offering a semester-long course on Quantum Computing and its Applications at the S. N. Bose National Centre for Basic Sciences.

HIGH BRIGHTNESS ENTANGLED PHOTON SOURCE USING SAGNAC INTERFEROMETER

Mr. Sricharan Narasimha

INTRODUCTION

Entangled photon sources are a natural extension to the existing single photon source in CDAC Bengaluru, but with the benefit of nonlocal correlations. They are of paramount significance in Photonics based Quantum computing and communications. There are various methods that can be employed to generate entangled photon pairs, but the major workhorse remains in generating polarization entangled photon pair via Spontaneous parametric down-conversion (SPDC) in second order ($X^{(2)}$), bulk, nonlinear crystals. Given the fact that the parametric gain of SPDC process is very low, an effort has been made to enhance the brightness of the entangled photon pairs by placing the non-linear crystal in a Sagnac interferometric loop.

A Sagnac loop involves a nonlinear crystal placed inside a loop configuration, with the pump beam split and made to travel in both clockwise and counterclockwise directions. This bidirectional setup effectively doubles the probability of generating entangled photon pairs compared to single-pass methods. In traditional setups, walk-off (caused by birefringence in nonlinear crystals) requires compensation. Whereas in the Sagnac loop, the downconverted photons bear same polarization and travel equal distances in both directions, thereby eliminating the need for additional walk-off correction optics.

The experimental setup is illustrated in Figure 1. A continuous-wave (CW), single frequency, UV laser (Coherent OBIS SX, 40 mW) serves as the pump laser. A 10 mm long, 1 × 1 mm^2, single grated PPKTP (Periodically poled Potassium titanyl phosphate) (Raicol) crystal with a period of Λ = 3.425 µm is employed for Type-0 (e --> e+e) phase-matched down-conversion of the pump beam at 405 nm.

ENTANGLED PHOTON SOURCE

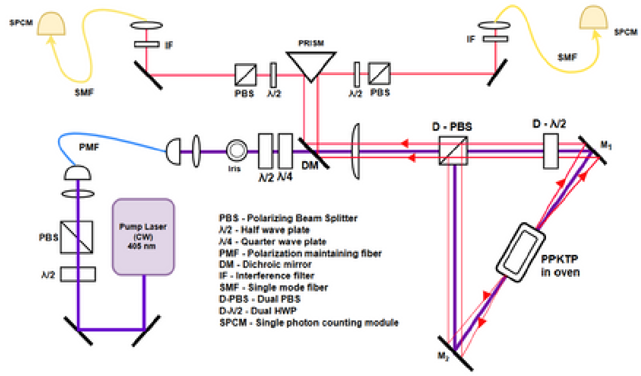

Figure 1: Experimental setup of Entangled photon source

A plano convex lens with a focal length of f = 200 mm is utilized to focus the pump beam at the center of the PPKTP crystal. Although Type-0 SPDC does not inherently produce entangled photon pair, we have developed an innovative scheme to generate a maximally entangled Bell pair utilizing a Sagnac interferometer. This setup includes a dual wavelength Polarizing beam splitter cube (D-PBS), a dual wavelength Half-wave plate (D-λ/2), and two high reflectivity mirrors (R > 99 %), designated as $M_1$and M_2, for both 405 nm and 810 nm wavelengths.

Half waveplate (HWP) and Quarter waveplate (QWP) at 405 nm, positioned before the D-PBS, manipulates the polarization of the pump beam so as to achieve an equal superposition of the reflected, vertically polarized (V) and transmitted, horizontally polarized (H) light at the output ports of the D-PBS.

The V-polarized pump photons travelling in the clockwise (CW) direction within the Sagnac interferometer generate $|VV\rangle$ polarized SPDC photons at 810 nm due to Type-0, non-collinear phase-matching in the PPKTP crystal. The D-λ/2 plate alters the polarization of both the pump and SPDC photons from $|H\rangle$ to $|V\rangle$ and vice versa. The $|VV\rangle$ polarized SPDC photons moving in the CW direction of the Sagnac interferometer are converted to |HH⟩ polarized photons and pass through the D-PBS. Concurrently, the |H⟩ polarized pump photon travelling in the counterclockwise (CCW) direction is transformed into |V⟩ polarization after passing through the D-λ/2 plate, again generating |VV⟩ polarized, non-collinear SPDC photons in the same PPKTP crystal. The D-PBS subsequently combines the SPDC photons produced in both CW and CCW directions and the same, broadband plano convex lens is used to collimate the now generated SPDC photons. The actual photo of the experimental setup is as shown in Figure 2.

These entangled photons are now directed to a right angle prism mirror via a dichroic mirror for ease of coupling into a single-mode fiber. The two discrete paths are therein named *Signal* and *Idler*. Irises are utilized to gather opposite points on the ring for entanglement analysis (CHSH inequality). An interference filter (FBH810-10, 810 ± 10 nm) is employed to filter out residual pump photons before they enter the single-mode fiber. These fibers are equipped with a fiber based polarization controller to ensure that the photon's polarization is preserved. To assess the degree of polarization entanglement, the fiber-coupled entangled photons are directed to fiber-coupled Single photon counting modules (SPCMs) (Excelitas) after passing through a polarizer (HWP+PBS). The output from the SPCMs are then connected to a time-correlated Single photon counter (Time Tagger, Swabian Instruments) for recording single photon and coincidence counts.

For an input pump power of 0.6 mW, the heralding efficiency of the photon pair is maximized (~13%) and the coincidence visibility of the photon pair is optimized across the ***Horizontal (H)*** and ***Vertical (V)*** measurement bases. For ***Anti-diagonal (A)*** and ***Diagonal (D)*** measurement bases, both PPKTP crystal and the lens are mounted on a X-translation stage and visibility is thereby maximized, in equaling both the CW and CCW paths.

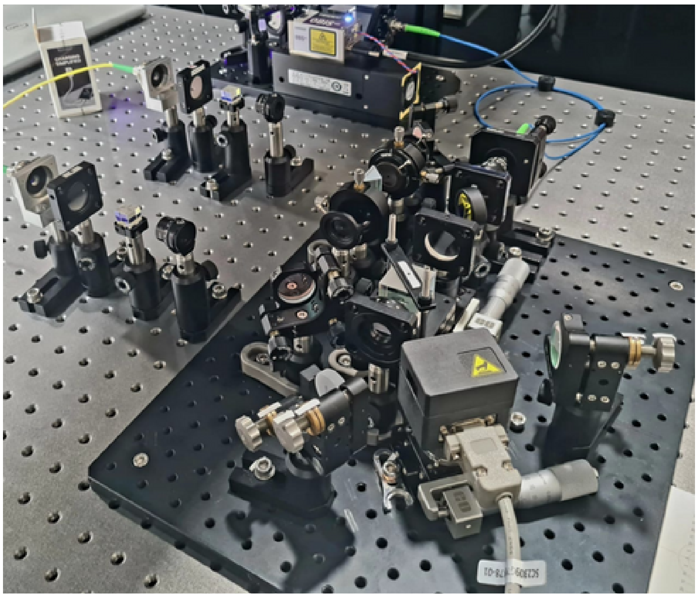

Figure 2: Laboratory setup of the Entangled photon source @ QuBit Studio, C-DAC Bengaluru

RESULTS

The Bell pair generated from the above setup is-

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}(|HH\rangle - |VV\rangle)$$

The measured visibility of the polarization entangled photon pair in the **H/V** basis is ~**99.5%** while in the **A/D** basis, it is ~**96%**. The calculated S value of the source is **2.72 ± 0.05** (2<S≤2√2), affirming strong quantum correlations between the photon pair. Figure 3 depicts the Visibility curve recorded for 5 seconds for all the four measurement bases.

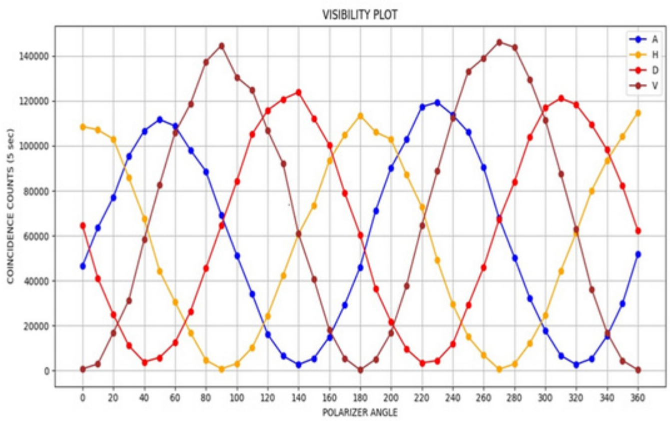

Figure 3: Visibility plot in all the four bases

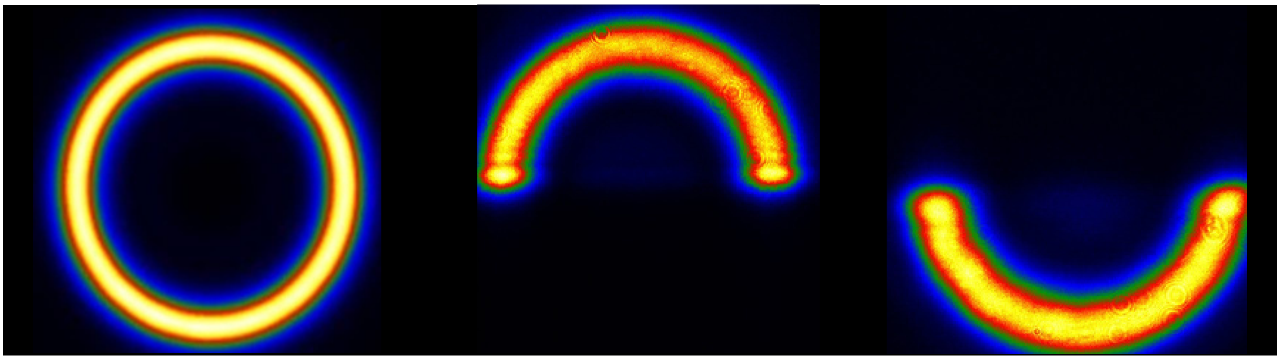

Figure 4: From left to right, CCD captured images of (i) superimposed $|HH\rangle$ and $|VV\rangle$ downconverted rings at 810 nm (ii) upper half of the SPDC ring after prism, (iii) lower half of the SPDC ring after prism

APPLICATIONS

- **Quantum Computing:** In Linear Optical Quantum Computing, single and entangled photons are manipulated with beam splitters, waveplates and detectors to perform computations. Photons represent qubits and entanglement enables gate operations. Entangled photons also enable efficient scaling of qubits in Computing, owing to joint state of the said photons.
- **Quantum communication:** Entangled photons enable operations like QKD and teleportation. It is also used in Quantum repeaters.

ACKNOWLEDGMENTS

We pay our heartfelt gratitude to Prof. C. M. Chandrashekar, Department of Instrumentation and Applied Physics, IISc Bengaluru, for his indispensable and hallowed assistance in building the polarization entangled photon source. We also thank MeitY for funding us in realizing the entangled photon source.

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MR. SRICHARAN NARASIMHA

Sricharan Narasimha is a Knowledge Associate at the Centre for Development of Advanced Computing (C-DAC), Bengaluru. In his role at C-DAC, Sricharan is part of the Quantum Technology Group, contributing primarily towards building hardware for Photonics based Quantum Computing. He is also involved in initiatives such as the development of Quantum Network Simulator, which are pivotal to India's advancements in quantum technology.

INSIDE THE MINDS

EXCLUSIVE INTERVIEW

RESEARCH INTERESTS

Dr. Saptarishi Chaudhuri is an experimental physicist with core research interest in laser cooling and trapping of neutral atoms.

INDIA'S FIRST

He has built several state of the art research laboratories, including the first Bose-Einstein Condensate in India.

CURRENT RESEARCH

Quantum degenerate gas of neutral Sodium and Potassium atoms

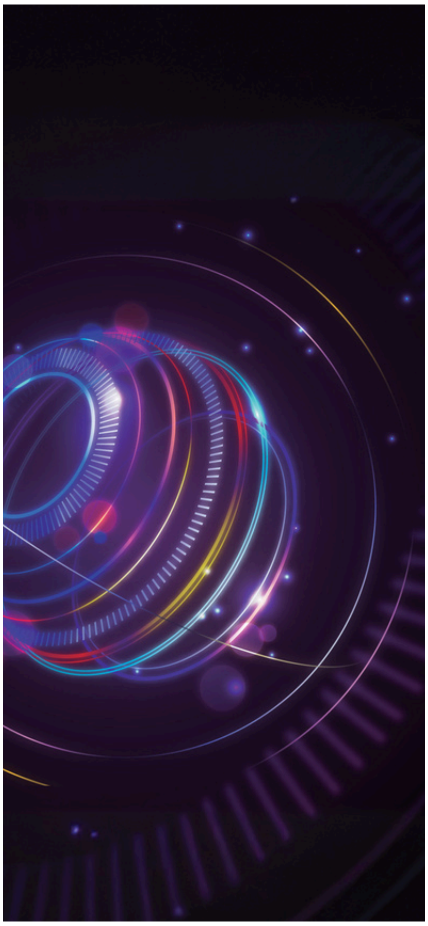
Experimental research on Spin Correlation Spectroscopy in neutral atoms and high precision spectroscopy of cold Rydberg atoms.

Neutral atom & Trapped ion based Quantum computers under NQM

DR. SAPTARISHI CHAUDHURI

Light and Matter Physics, RRI Bangalore

Can you explain the key challenges you faced in developing laser cooling and trapping systems for neutral atoms, and how you overcame them?



These experimental platforms for laser cooling and trapping of neutral atoms are fairly sophisticated and require multiple technologies to be seamlessly integrated. Ultra-stable lasers, extreme high vacuum, precision optical and optomechanical components, and electronics components are all used to develop the final system. There is no single turn-key instrument which is available to purchase to get started with the experiments. Therefore, it had been challenging to plan, procure, install, calibrate and in a large number of cases manufacture components before everything could be put together to make the final system in a working condition. Only after this phase, we are now in a position to study several interesting physics results using this new hardware.

I was fortunate to have supporting colleagues, enthusiastic and hard-working students who quickly developed high-end skills and able engineers over the past years to plan and execute tasks so that the challenges could be overcome. Moreover, the support from my institution's administration as well as several funding agencies including DST, MeitY have been crucial in overcoming the challenges.

What are the limitations of trapping lifetime in your experiments, and how do you overcome them?

One of the major limitations arise from the requirement of the ultra-high vacuum environment. The atoms are typically trapped using optical and magnetic fields and they are very easy to be knocked out of the trap if a hot, rouge atom or molecule collide with them. Therefore, it is essential that we pump out all the unwanted atoms and create an ultra-high vacuum environment, typically 14 orders of magnitude below the atmospheric pressure! Another life-time limiting cause is the photon scattering from the trapped atoms by the trapping light itself. We have recently studied that different atom-atom interaction mechanisms, if not controlled properly, can also reduce the trapping lifetime significantly as well. Therefore, we carefully study all these effects and find an optimized parameter regime where everything works perfectly and we have a life-time of an atom in the trap of nearly a minute or so. This large lifetime helps in conducting further experiments with these trapped atoms.

DR. SAPTARISHI CHAUDHURI

Light and Matter Physics, RRI Bangalore

INDIA'S FIRST BOSE-EINSTEIN CONDENSATE

Having built India's first Bose-Einstein Condensate, how do you see the field of BEC research evolving, and what applications do you foresee in the near future?

It was an wonderful opportunity for me several years ago to be part of a small team who built the first Bose-Einstein Condensate (BEC) experiment. Globally, research using BEC as a tool to explore various aspects of quantum technology has progressed with an extremely fast pace. There is a huge amount of opportunity to explore both fundamental physics as well as developing technology using BEC. Precision gravimeters, atom interferometers are just a few examples where BEC can be used efficiently.

What is Bose-Einstein Condensate (BEC)?

In condensed matter physics, a Bose–Einstein condensate (BEC) is a state of matter that is typically formed when a gas of bosons at very low densities is cooled to temperatures very close to absolute zero, i.e., 0 K (−273.15 °C; −459.67 °F). Under such conditions, a large fraction of bosons occupy the lowest quantum state, at which microscopic quantum-mechanical phenomena, particularly wavefunction interference, become apparent macroscopically.

Your current work involves simultaneous quantum degenerate gases of Sodium and Potassium atoms. What are the specific advantages or unique phenomena you aim to explore with this combination of elements?

This simultaneous trapping and cooling of Sodium and Potassium atoms is a unique experimental facility in our group. At ultra-low temperatures, the quantum properties of atoms are more prominent over the classical physics. One interesting and largely unexplored area of physics is how mass and spin imbalanced atoms interact in the framework of quantum mechanics. Moreover, how the statistical properties of a large number of such atoms gets modified in presence of these inter- as well as intra-species interactions is a critical question from fundamental physics point of view. The combination of Sodium and Potassium offers another advantage where a lighter mass atom, Sodium, can mediate interactions between two heavier Potassium atoms. All these interactions can be controlled very precisely in our experimental system using an external magnetic field. Also, Potassium having both Bosonic as well as Fermionic isotopes, we are in a position to explore both Bose statistics and Fermi statistics in the same platform. Such Bose-Bose and Bose-Fermi quantum mixture allows for exploration of exotic quantum phases of matter. Our goal is to delve deep into such quantum phase transition which can only be studied using these types of systems. In the recent past we have looked into responses of a cold Potassium atoms in presence of both inter and intra-species interactions. These recently published results open up very interesting research avenues and can shed light on the understanding of conductivity in materials in presence of interactions.

Another set of experiments we have performed is that of studying the spin properties of atoms. Now, the spin-spin interaction between Sodium and Potassium at ultralow temperatures can lead to understanding of magnetism and we are presently exploring such physics using this system.

DR. SAPTARISHI CHAUDHURI
Light and Matter Physics, RRI Bangalore

Could you elaborate on your work in high precision spectroscopy of cold Rydberg atoms? How does this research contribute to advancements in quantum technologies?

This was an work performed in collaboration with my colleagues at Raman Research Institute, particularly with the research group of Prof. Sanjukta Roy. We had systematically identified a large number of Rydberg energy levels using two photon excitation schemes and using an experimental technique called Electromagnetically Induced Transparency (EIT). This work lead to development of technical know-how in preparing precise Rydberg state in a neutral atom – in this particular case Rubidium atoms. The Rydberg atoms are large macroscopic version of an atom where the outer electron is extremely loosely bound and very far from the nucleus. Two atoms in close proximity under this optical Rydberg excitation easily become entangled and this can be used as a tool to build quantum computers using neutral atoms.

With your expertise in quantum technologies, what future developments or breakthroughs are you most looking forward to, and why?

The most exciting near future development will be in deploying usable quantum devices including operational quantum computers utilizing laser cooled neutral atoms trapped in the optical tweezer arrays. I am presently a lead Principal Investigator under the DST's National Quantum Mission which was announced in 2024. Our multi-institutional technology group is developing both neutral atom and trapped ion based quantum computers. We have an extremely enthusiastic team comprising of experts in atoms trapping as well as ion trapping technologies spread over seven institutes in the country. Our teams are presently closely working together to develop several systems and sub-systems which will soon be in a position to demonstrate practical quantum logic and analogue operations. We are also looking forward to collaborate with many more experts, agencies, industries and start-ups as well as to younger researchers to accelerate this progress.

> “Our multi-institutional Technology Group is advancing quantum computing by developing systems based on both neutral atoms and trapped ions as part of the National Quantum Mission.

DR. SAPTARISHI CHAUDHURI

Light and Matter Physics, RRI Bangalore

Quantum Currents

> India is no longer waiting to catch up; we are setting the pace. Quantum technologies will shape the nation's future, and we are determined to lead this global revolution.

- Dr. Jitendra Singh,
Hon'ble Union Minister of State (Independent Charge),
Science and Technology

Indian Army and C-DAC collaborate to establish Centre of Excellence for Defence Technologies

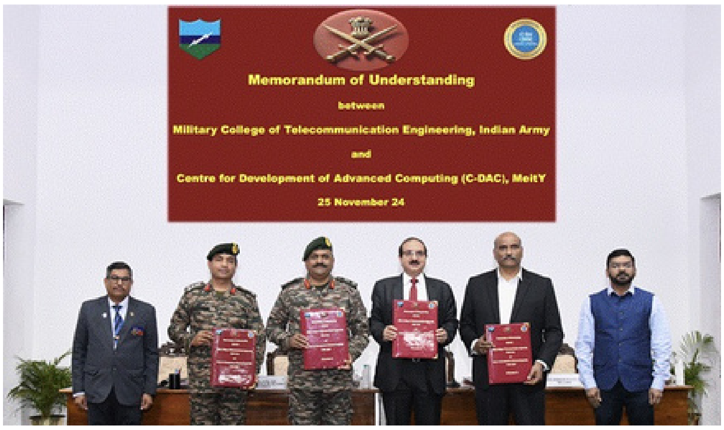


Photo: PIB

The Indian Army, in partnership with the Centre for Development of Advanced Computing (C-DAC), has established a Centre of Excellence (CoE) at the Military College of Telecommunication Engineering (MCTE) in Mhow. This collaboration aims to drive research and development in advanced technologies specifically tailored for military applications, furthering India's goal of self-reliance in defence technology.

The CoE will focus on several key technological areas, including Quantum Computing, Cyber Security, Wireless Communication, Digital Twin, Sensory Augmentation, and Unmanned Aerial Systems (UAS). The partnership is designed to accelerate innovations and provide solutions for the Indian military's evolving needs, with the intention of creating indigenous technologies for defence.

The CoE will serve as a hub for applied research, fostering collaboration between MCTE, C-DAC, and other MeitY organizations. Objectives include developing and testing field-ready prototypes in various technology areas and organizing workshops, seminars, and training programs to enhance skill development for both military and civilian personnel.

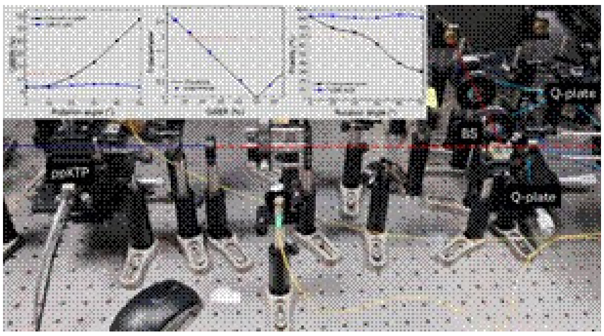
Shri. Bhuvnesh Kumar, Additional Secretary to the Government of India, MeitY, highlighted the CoE's role in fostering collaboration and applied research. Lt. Gen. K H Gawas expressed confidence in its potential to drive defence advancements, while Shri. E. Magesh, Director General, C-DAC, emphasized leveraging advanced computing to strengthen India's defence capabilities.

Source: PIB

DRDO and IIT Delhi organize demonstrations of various Quantum Communication Technologies

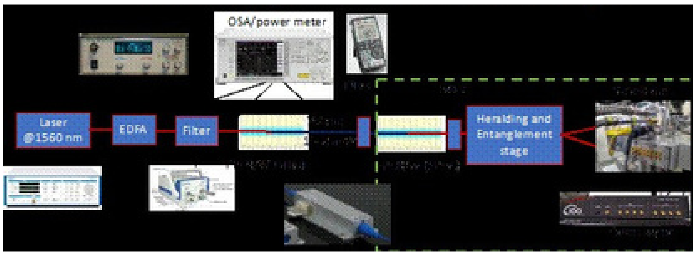
The DRDO Industry Academia–Centre of Excellence (DIA-CoE) at IIT Delhi has successfully demonstrated advanced quantum communication technologies in New Delhi. As part of a collaborative initiative, researchers developed entanglement-based quantum key distribution (QKD) techniques to enable secure and resilient communication. In a laboratory setting, they achieved entanglement distribution and QKD over a 50 km fiber link. Additionally, a field test on the IIT Delhi campus demonstrated these capabilities over an 8 km optical fiber link, marking a significant step toward real-world deployment of quantum-secure networks.

In another milestone, scientists successfully demonstrated free-space entanglement distribution using the BBM-92 protocol. The experiment achieved secure quantum communication between two tables 20 meters apart in a laboratory setting and extended the range to 80 meters in an open-space environment. This demonstration marks significant progress in developing short-range free-space quantum communication systems.



Hybrid Photon based Free-space Quantum Key Distribution Testbed

Hybrid entanglement has been demonstrated in a free-space environment, achieving a Quantum Bit Error Rate (QBER) of approximately 6% over a 10-meter distance in the laboratory. Additionally, efforts are underway to develop QKD systems capable of supporting multiple independent channels driven by a single source, yielding promising results. These advancements pave the way for more flexible, multi-protocol quantum communication systems, enhancing the potential for secure and scalable quantum networks.



Different Stages Involved in All Fiber Based QKD

In achieving the above breakthrough, an all-fiber heralded photon source with second-order correlation function (g^2 ~ 0.01) at rates reaching hundreds of kHz is developed. This innovation is vital for single-photon generation, a critical requirement for secure quantum communication. An all-fiber entangled photon source has also been developed with high visibility. The Bell test parameter for this source is more than 2.6, exhibiting strong quantum entanglement, which is essential for protocols like BBM-92.

For free-space quantum communication experiments, free-space heralded single-photon source has been demonstrated with a heralding rate of over 4 million counts/sec. This development enables robust free-space quantum communication.

Key components such as single-photon sources which include Lithium-Niobate-On-Insulator (LNOI), superconducting nanowire single-photon detectors (SNSPD), and periodically poled non-linear crystals are being indigenized through projects at IIT Delhi in collaboration with Defence Research and Development Organisation (DRDO) labs, including DYSL-QT and SSPL. Funded under the Directorate of Futuristic Technology Management's deep tech initiatives, *DIA-CoE* is advancing quantum communication technologies like Quantum Key Distribution, Quantum Sources, Quantum Detectors, and Non-linear Crystals.

Source: PIB

DST announces selection of eight pioneering StartUps for Support Under National Quantum Mission and the National Mission on Interdisciplinary Cyber-Physical Systems

Photo: DST

In a significant step towards establishing India as a global leader in quantum technology, Union Minister of State (Independent Charge) for Science and Technology, Dr. Jitendra Singh announced the selection of eight pioneering StartUps for support under the Department of Science and Technology's newly formulated guidelines. These startups, chosen under the National Quantum Mission (NQM) and the National Mission on Interdisciplinary Cyber-Physical Systems (NMICPS), represent the forefront of innovation in this rapidly evolving field.

Each of the selected StartUps is set to make impactful contributions in their respective domains of quantum technology. Bengaluru-based QNu Labs is spearheading advancements in quantum communication by developing end-to-end quantum-safe heterogeneous networks. Similarly, QPiAI India Private Ltd., also from Bengaluru, is working on building a superconducting quantum computer, marking a milestone in quantum computing. Dimira Technologies Pvt. Ltd., based at IIT Mumbai, is focusing on indigenous cryogenic cables which are essential for quantum computing, while Prenishq Pvt. Ltd., from IIT Delhi is developing precision diode-laser systems that are vital for the sector's growth.

In quantum sensing and metrology, QuPrayog Pvt. Ltd., from Pune is innovating optical atomic clocks and related technologies, and Quanastra Pvt. Ltd., from Delhi is developing advanced cryogenics and superconducting detectors. Meanwhile, in the area of quantum materials and devices, Ahmedabad's Pristine Diamonds Pvt. Ltd., is creating diamond materials for quantum sensing, and Bengaluru's Quan2D Technologies Pvt. Ltd., is advancing superconducting Nanowire Single-photon Detectors.

Reflecting on India's rise as a quantum powerhouse, Dr. Jitendra Singh drew attention to the visionary policies of Prime Minister Narendra Modi, which have created an enabling environment for innovation. "India is no longer waiting to catch up; we are setting the pace. Quantum technologies will shape the nation's future, and we are determined to lead this global revolution," he said. The announcement aligns with India's broader vision for technological self-reliance and innovation by 2047. With this initiative, the minister remarked, the selected StartUps are not just participants in a technological mission but torchbearers of India's ambition to emerge as a global leader in quantum science.

The event was graced by the presence of distinguished leaders in science and technology, including Dr. V.K. Saraswat, Member (S&T), NITI Aayog; Prof. Abhay Karandikar, Secretary, Department of Science & Technology; Dr. Ajai Chowdhry, Chairman, Mission Governing Board (MGB), National Quantum Mission; and Dr. Kris Gopalakrishnan, Chairman, MGB, NM-ICPS.

Source: DST

Himalayan heights potentially perfect for India's 'Quantum Leap' to Space, Study Finds

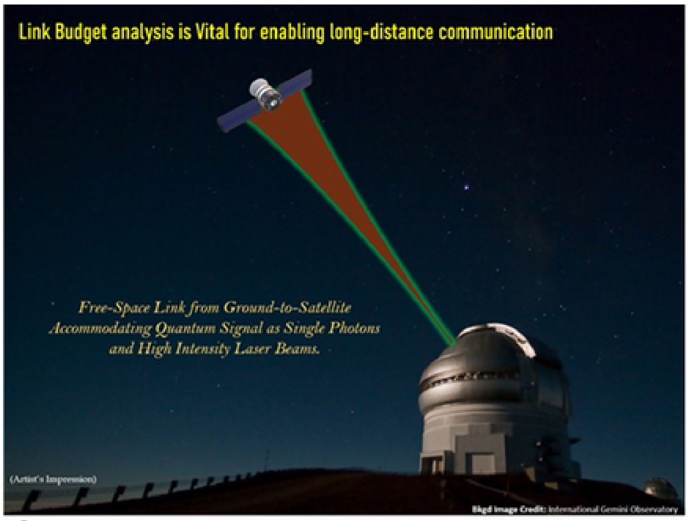


Photo: DST

In a groundbreaking study, scientists from the Raman Research Institute (RRI) have identified the Indian Astronomical Observatory (IAO) in Hanle, Ladakh, as the prime location for beaming quantum signals into space. This research marks a pivotal step in advancing satellite-based quantum communications, including Quantum Key Distribution (QKD), which is vital for global-scale secure communication.

To evaluate the viability of transmitting quantum signals through Earth's atmosphere, the RRI team conducted atmospheric simulations for both uplink and downlink quantum communication scenarios. Their study assessed three renowned observatories across India: the Indian Astronomical Observatory (IAO) in Hanle, Ladakh; the Aryabhatta Research Institute of Observational Sciences (ARIES) in Nainital, Uttarakhand; and the Mount Abu Observatory in Rajasthan.

Researchers from RRI examined the feasibility of using three different ground station locations in India for uplink-based quantum communication, while also evaluating beacon signals for both uplink and downlink scenarios. They simulated the atmospheric conditions of various geographical regions in India and conducted a dedicated link budget analysis for each of the three locations. Among these, the IAO Hanle was identified as the most suitable site for uplink-based quantum communication.

Nestled in the pristine heights of Ladakh, Hanle offers a unique set of natural advantages. This cold, arid desert experiences extremely low levels of atmospheric water vapor and oxygen, making it highly favorable for quantum communication experiments. Winter temperatures in Hanle can plummet to as low as -25 to -30 degrees Celsius, further contributing to its suitability.

“Hanle offers all the required natural settings for setting up a ground station and undertaking quantum communication over long distances,” said Professor Urbasi Sinha, head of the Quantum Information and Computing (QuIC) lab at RRI, an autonomous institute funded by the Department of Science and Technology, Government of India.

The study’s findings are presented in the paper titled “Estimating the Link Budget of Satellite-Based Quantum Key Distribution (QKD) for Uplink Transmission Through the Atmosphere,” published in EPJ Quantum Technology by Springer Nature. Researchers Urbasi Sinha and Satya Ranjan Behera from the QuIC lab detailed their work in the 370 THz (810 nm) signal band. Using open-source data, they analyzed key meteorological parameters, including temperature, humidity, and atmospheric pressure, from the three selected sites to evaluate their suitability for satellite-based QKD.

This study highlights India’s strides in quantum research, paving the way for secure and scalable communication technologies that could transform global data security and network reliability.

Source: PIB

Building India's Quantum Future: Key Takeaways from ISQCI-2024

"The City of Joy" hosted the prestigious International Symposium on Quantum Computing and Innovations (ISQCI-2024) on 17th and 18th December 2024, a landmark event in India's quest for quantum technology leadership. Organized by C-DAC Patna, C-DAC Kolkata, and C-DAC Center in North East, with the support of the Ministry of Electronics and Information Technology (MeitY), ISQCI-2024 brought together a distinguished gathering of experts, researchers, industry leaders, and policymakers. This year's theme, exploring the Future Frontiers of Quantum Technologies, highlighted cutting-edge advancements in quantum theory, quantum computing, and their broader applications.

Building on the success of its inaugural edition in Varanasi last year, ISQCI-2024 provided a vital platform for sharing cutting-edge research, fostering collaboration, and exploring the transformative potential of quantum technologies. The symposium delved into key areas such as Quantum Computing, Quantum Sensing, Quantum Communication and Cryptography, and Quantum AI, featuring expert talks and insightful panel discussions.

A key objective of ISQCI-2024 was to position eastern India as a prominent hub for quantum technologies. By uniting regional players and fostering a vibrant ecosystem, the symposium aimed to accelerate India's progress in this critical field, aligning perfectly with the goals of the National Quantum Mission.

Participants gained invaluable insights into the latest advancements in quantum technologies and their potential applications. The symposium also served as a valuable networking opportunity, connecting researchers, industry leaders, and policymakers to forge collaborations and shape the future of quantum technologies in India and globally.

DST along with AICTE Announces Undergraduate Courses for Quantum


Photo: DST

The Department of Science and Technology (DST) in collaboration with All India Council for Technical Education (AICTE) announced a dedicated curriculum at the undergraduate level, to create a thriving quantum-trained ecosystem in India as part of the National Quantum Mission.

The National Quantum Mission from the Government of India is a decisive step in accelerating the nation's research and technology development in this field. Such research and technology development will require a highly skilled workforce through immediate initiatives in teaching and training.

The curriculum will help impart training for developing this workforce to enable them to reach global standards and simultaneously address the multi-disciplinary needs of quantum technology development - from basic to applied research.

While institutes of national importance have begun programs to this end, expanding such training to a larger pool of institutes across the country can enable the nation to tap into the vast resource of students who can then participate in the mission to accelerate its progress towards its goals. The course would be taken up for implementation by AICTE-approved institutions across the country.

The course structure includes all four verticals of Quantum Technology - Quantum Computing, Quantum communications, Quantum sensing and metrology, and Quantum materials and devices. The proposed curriculum constitutes a minimum of 18 credits with both theory and lab courses. Each course amounts to 3 credits, thereby making the minor program span a minimum of 6 courses.

Faculty Development Programs in the areas of Quantum Technologies are also proposed to be carried out to enable educators to effectively meet the goals of the minor program. These programs will provide faculty with the tools and knowledge required to teach cutting-edge concepts in quantum technologies, ensuring they stay updated with the latest advancements. Such sustained teacher training efforts will not only enhance the quality of the training imparted to students but will also foster a culture of research and innovation among faculty. Over the years, this will lead to long-term benefits, producing a highly skilled workforce and positioning India as a global leader in this transformative field.

Apart from this course, National Quantum Mission in collaboration with AICTE is also planning to support the creation of labs to aid teaching in the areas of quantum technologies, writing of books for the course, and quantum awareness programmes.

The announcement featured the participation of several distinguished figures, including Professor Ajay K. Sood, Principal Scientific Advisor to the Government of India; Professor Abhay Karandikar, Secretary of the Department of Science and Technology; Dr. Ajai Chowdhry, Chairman of the Mission Governing Board (MGB), National Quantum Mission; and Professor T.G. Sitharam, Chairman of AICTE.

Source: DST

CONFERENCES

UPCOMING EVENTS 2025

FEB 23 — **QAIO 2025**
Quantum Artificial Intelligence and Optimization, , Porto, Portugal

FEB 24 — **QIP 2025**
28th Annual Quantum Information Processing Conference, Raleigh, United States

MAR 16 — **APS Global Physics Summit**
Largest Physics research conference at Anaheim, CA

MAR 31 — **QCNC 2025**
International Conference on Quantum Communications, Networking, and Computing, Nara, Japan

APR 06 — **QML@ICASSP2025**
Workshop on Quantum Machine Learning in Signal Processing and Artificial Intelligence, Hyderabad, India

APR 20 — **Les Houches School of Physics**
Fault-Tolerant Quantum Computing: Theory and Current State of Play, Les Houches, France

MAY 04 — **CLEO 2025**
Conference on Lasers and Electro-Optics, Long Beach, United States

MAY 15 — **Q2B TOKYO 2025**
The Roadmap to Quantum Value, Tokyo, Japan

MAY 20 — **QUANTUMatter 2025**
5th Quantum Matter International Conference, Grenoble, France

JUN 15 — **Quantum Information**
Quantum Information, Benasque, Spain

JUN 23 — **CLEO 2025**
European Conference on Lasers and Electro-Optics (CLEO®/Europe), Munich, Germany

JUN 24 — **WORLD OF QUANTUM**
World of QUANTUM 2025, Munich, Germany

AUG 25 — **SQA**
Superconducting Qubits and Algorithms, Delft, Netherlands

CONFERENCES

UPCOMING EVENTS 2025

AUG 25

QCrypt 2025

QCrypt '25, Sanya, China

AUG 31

QCE 2025

IEEE Quantum Week, Albuquerque, United States

SEP

TQC Conference 2025 - 20th edition

The Theory of Quantum Computation, Communication and Cryptography (TQC) at India (Tentative)

NOV 31

Supercomputing Conference 2025

The International Conference for High Performance Computing, Networking, Storage, and Quantum at St. louis, MO

PUBLICATIONS

List of selected publications in Quantum Technologies during October to December 2024

Quantum cellular automata for quantum error correction and density classification. *October 2024*	Physical Review Letters, 133(15), 150601 *Guedes, T. L., Winter, D., & Müller, M.*
Realization of High-Fidelity CZ Gate Based on a Double-Transmon Coupler. *November 2024*	Phys. Rev. X 14, 041050 *Rui Li, Kentaro Kubo, Yinghao Ho, Zhiguang Yan, Yasunobu Nakamura, & Hayato Goto*
Quantum Walk Computing: Theory, Implementation, and Application. *November 2024*	Intelligent Computing, Vol 3, 0097 *Xiaogang Qiang, Shixin Ma, and Haijing Song*
Coined quantum walk on a quantum network. *November 2024*	Physical Review A, 110(5), 052428 *Bhavsar, J., Shekhar, S., & Santra, S.*
Entanglement and iSWAP gate between molecular qubits *November 2024*	Nature (2024) *Lewis R. B. Picard, Annie J. Park, Gabriel E. Patenotte, Samuel Gebretsadkan, David Wellnitz, Ana Maria Rey & Kang-Kuen Ni*
Quantum teleportation coexisting with classical communications in optical fiber. *December 2024*	Optica Vol. 11, Issue 12, pp. 1700-1707 (2024) *Rui Li, Kentaro Kubo, Yinghao Ho, Zhiguang Yan, Yasunobu Nakamura, & Hayato Goto*
Quantum error correction below the surface code threshold *December 2024*	NaturePages 1–3 (2024) *Google Quantum AI and Collaborators*
Initial state preparation for quantum chemistry on quantum computers. *December 2024*	PRX Quantum, 5(4), 040339 *Guedes, T. L.Fomichev, S., Hejazi, K., Zini, M. S., Kiser, M., Fraxanet, J., Casares, P. A. M., ... & Arrazola, J. M.Winter, D., & Müller, M.*

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