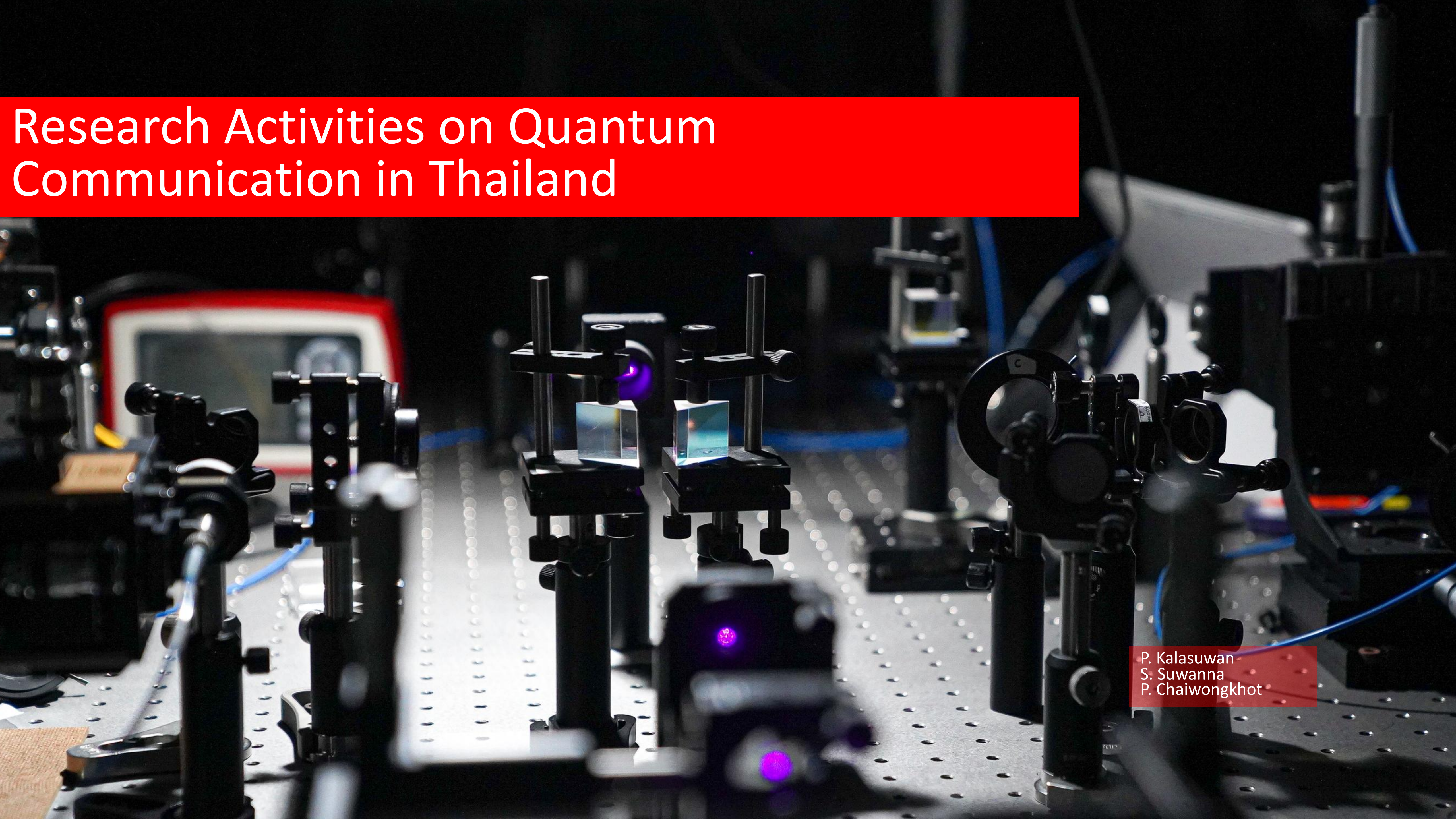


Research Activities on Quantum Communication in Thailand

P. Kalasuwan
S. Suwanna
P. Chaiwongkhot

Prince of Songkhla University

Pruet Kalasuwan
Kritsanu Tivakornsasitorn
Nonthanan Sitpathom
Chalongrat Daengngam
Saroch Leedumrongwatthanakun
Paphavee van Dommelen
Paphon Phewkham
Panupong Vichitkunakorn

Thammasat University

Ekkarat Pongophas
Wanchai Pijitrojana
Yingyot Infahsaeng
Poramed Wongjom
Wasan Maiaugree
Rujipas Bavorntaweepanya
Atirach Ritboon
Santi Phumying

Chiang Mai University

Ukrit Mankong
Suruk Udomsorn
Pipat Ruankham
Duangmanee Wongratanapaisan

Mahidol University

Sujin Suwanna
Pichet Kittara
Pongsakorn Kanjanabut

King Mongkut University of Technology Thonburi

Thanapat Deesuwan
Unchalisa Taetrakul
Rajjawit Sarochvigsit
Vachara Liewrien

Quantum Technology Foundation (Thailand)

Poompong Chaiwongkhot

Ubonratchathani University

Worasak Sukkabot

National Electronics and Computer Technology Center

Kanin Aungskunsiri

Collaborators

- University of Bristol, UK
- Friedrich Schiller University Jena, Germany
- University of Waterloo, Canada
- Keio University, Japan

Thai Quantum Roadmap for ’20-’29)

NATIONAL ROADMAP 2020-2029

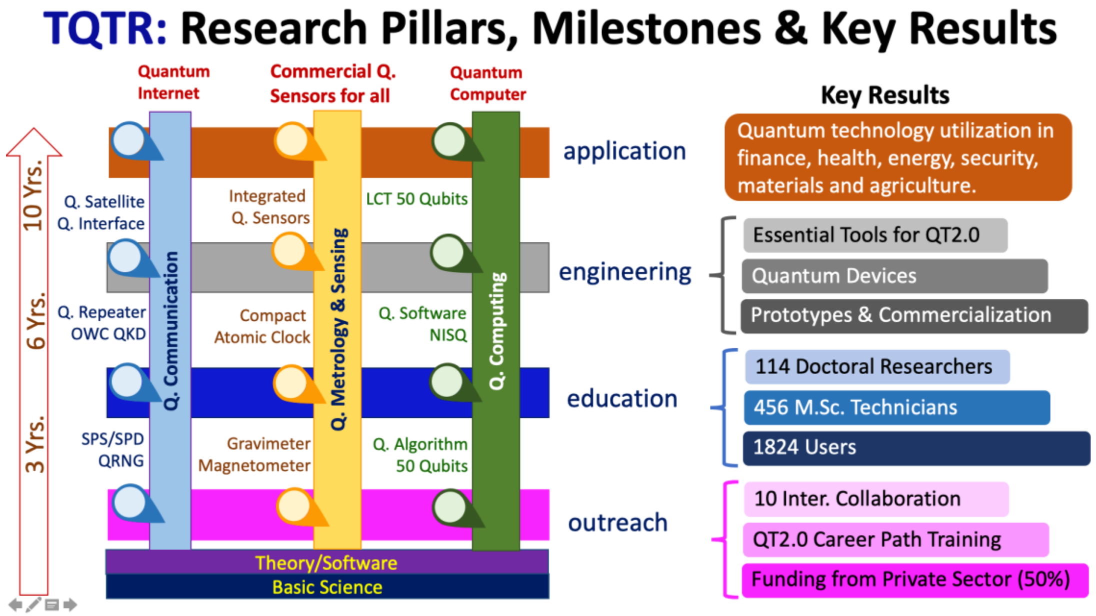
THAILAND QUANTUM TECHNOLOGY

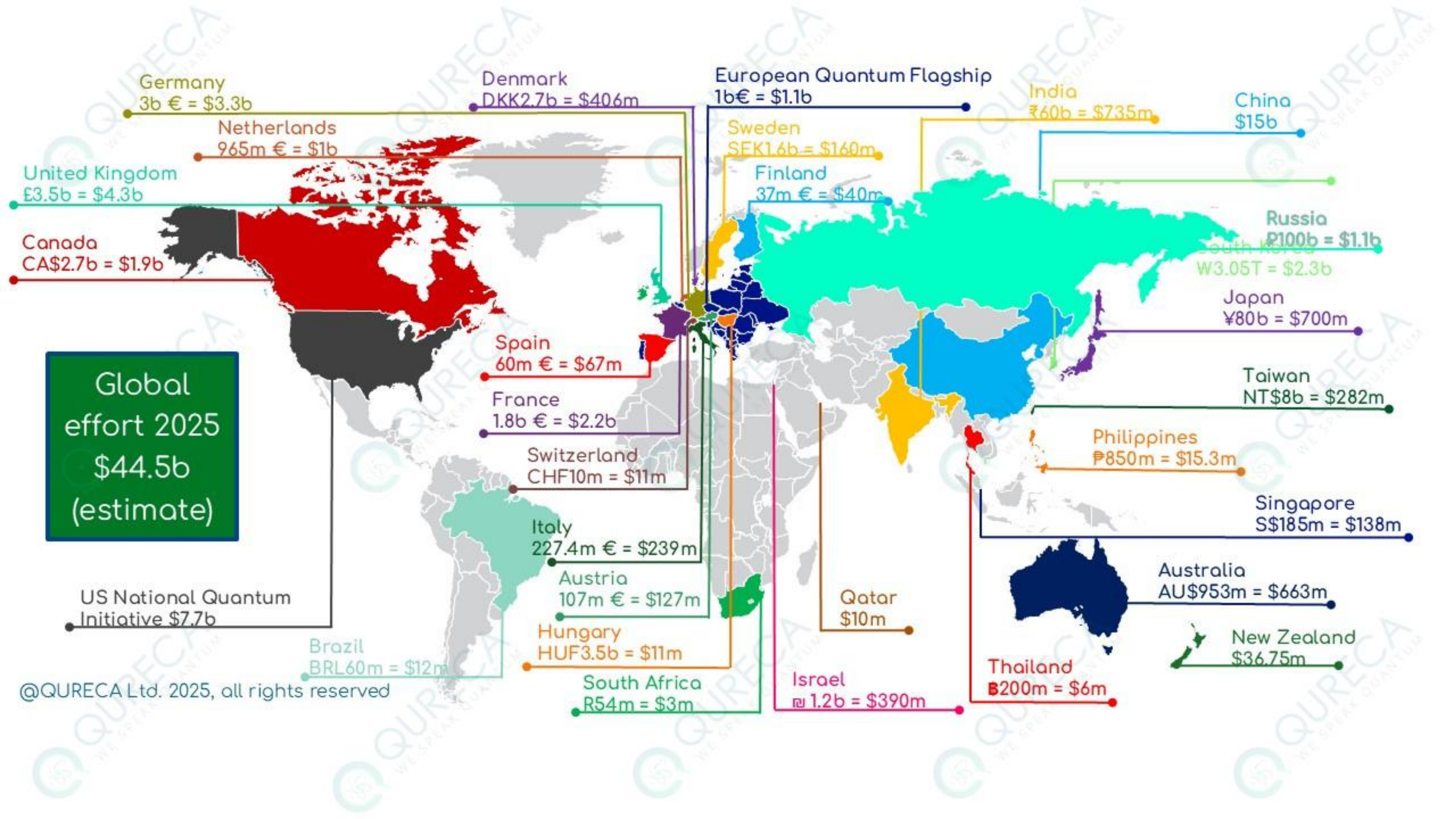
แผนที่นำทางการพัฒนาเทคโนโลยีควอนตัม
ของประเทศไทย พ.ศ. 2563 - 2572

พฤศจิกายน 2562

กระทรวงการอุดมศึกษา วิทยาศาสตร์ วิจัย
และนวัตกรรม

MHESI




Germany
3b € = $3.3b
Denmark
DKK2.7b = $406m
European Quantum Flagship
1b€ = $1.1b
India
₹60b = $735m
China
$15b
Netherlands
965m € = $1b
Sweden
SEK1.6b = $160m
United Kingdom
£3.5b = $4.3b
Finland
37m € = $40m
Russia
₽100b = $1.1b
South Korea
W3.05T = $2.3b
Canada
CA$2.7b = $1.9b
Japan
¥80b = $700m
Spain
60m € = $67m
Global effort 2025 $44.5b (estimate)
France
1.8b € = $2.2b
Taiwan
NT$8b = $282m
Philippines
₱850m = $15.3m
Switzerland
CHF10m = $11m
Singapore
S$185m = $138m
Italy
227.4m € = $239m
Austria
107m € = $127m
Australia
AU$953m = $663m
US National Quantum Initiative $7.7b
Qatar
$10m
Hungary
HUF3.5b = $11m
New Zealand
$36.75m
Brazil
BRL60m = $12m
Thailand
฿200m = $6m
South Africa
R54m = $3m
Israel
₪ 1.2b = $390m
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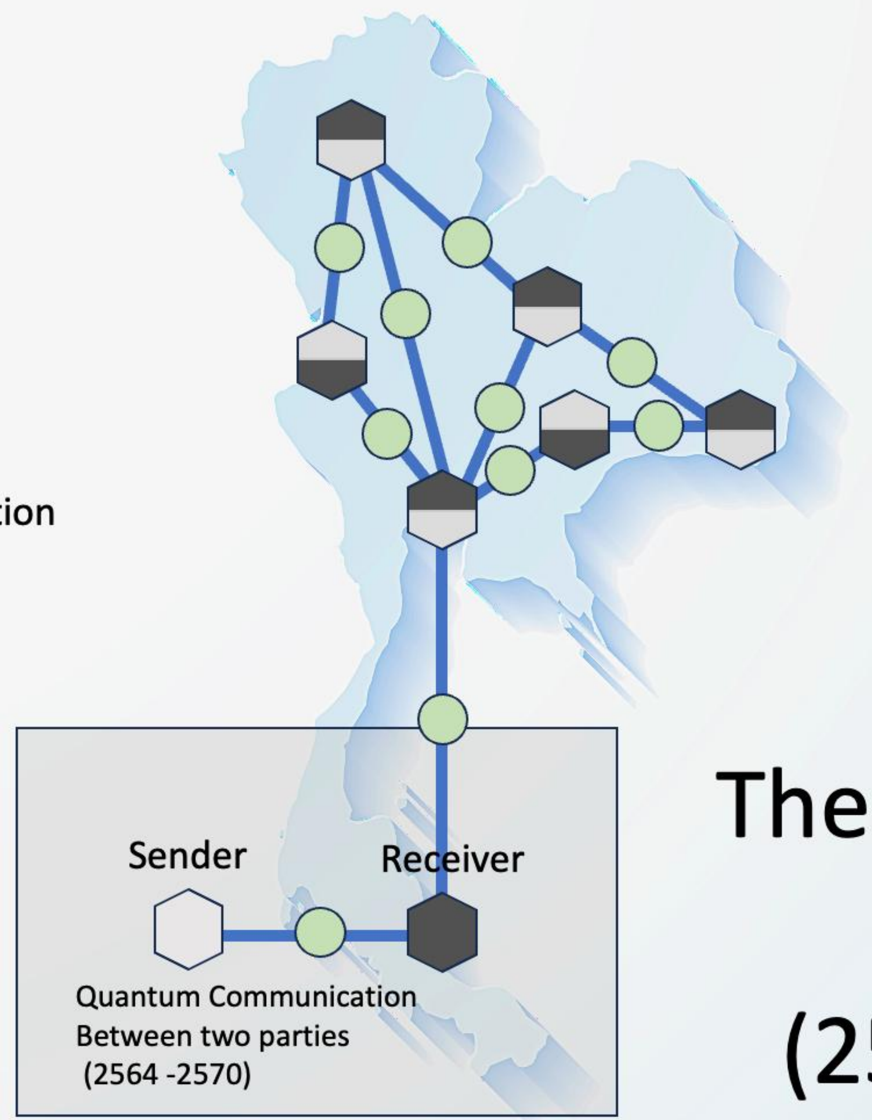
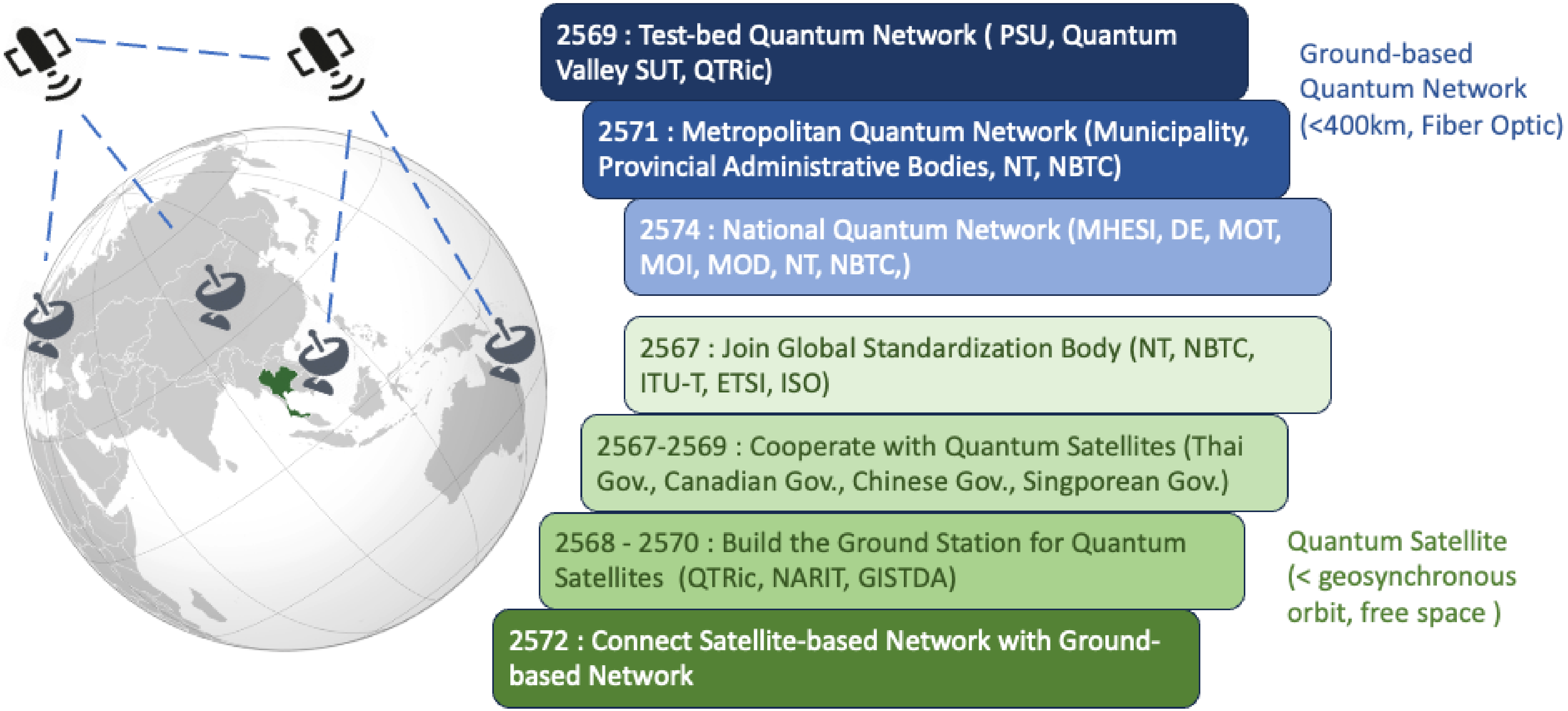
Repeater node

Quantum Communication Channel

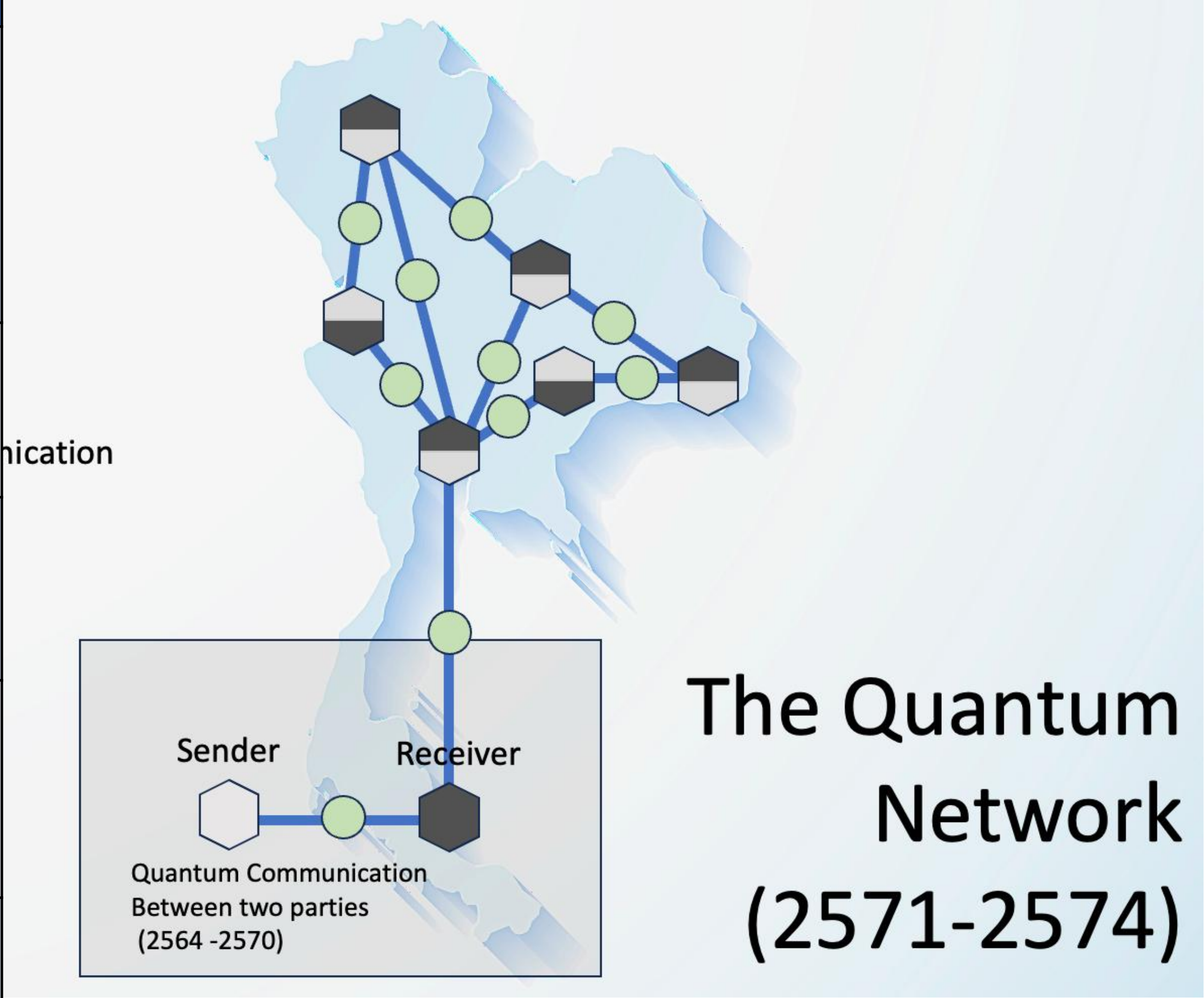


The Quantum Network (2571-2574)

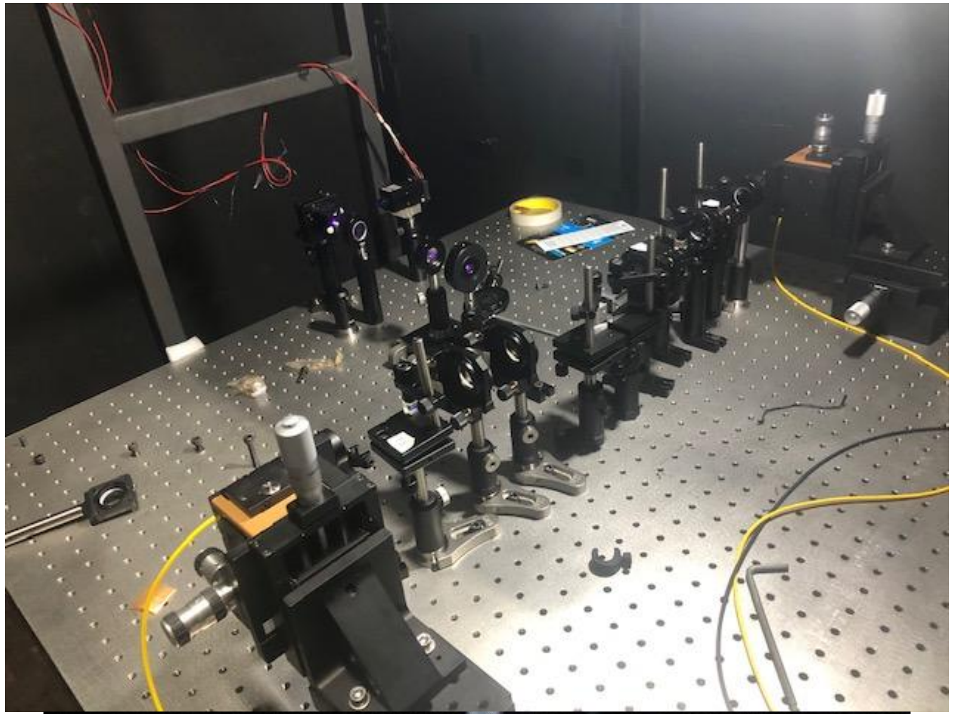


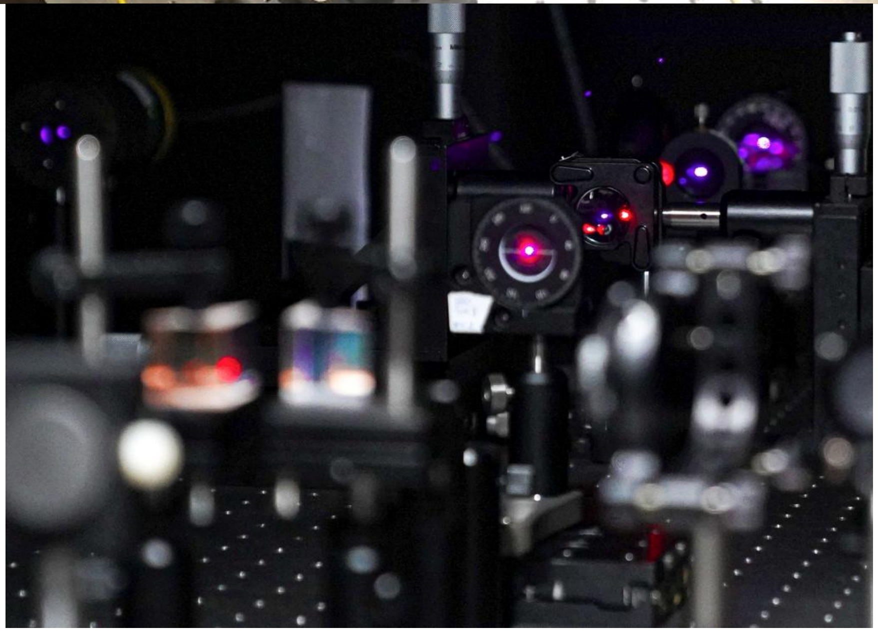
PSU – Prince of Songkla University, SUT – Suranaree University of Technology, NT - National Telecom Public Company Limited (NT), NBTC - National Broadcasting and Telecommunications Commission, MHESI - Ministry of Higher Education, Science, Research and Innovation, DE - Ministry of Digital Economy and Society, MOT - Ministry of Transport, MOI - Ministry of Interior of the Kingdom of Thailand, MOD - Ministry of Defence, ITU-T - Telecommunication Standardization Sector, The International Telecommunication Union (ITU), United Nation, ETSI - European Telecommunications Standards Institute, ISO - International Organization for Standardization, NARIT - National Astronomical Research Institute of Thailand, GISTDA - Geo-Informatics and Space Technology Development Agency, QTRic – Quantum Technology Research Initiative Consortium (Thailand)

	Components	Global Challenge	Progress 2568
	Sender - Single photon source (SPS) - Entanglement source - Quantum Random Number Generator (QRNG)	- Efficient Photon Emitters (EPE) at the chip level and room temperature - High key-rate QRNG - QRNG chips - Chip scale photonic quantum information processing	- Quantum Emitter - QRNG chips - Bulk optic Entangled SPS - Single photon device certification
	Receiver - Single photon detector	-High-speed and Eficient Single photon -Chip scale photonic quantum information processing	- Hybrid-perovskite photon detector
	Repeater node - Enabled Quantum Repeat - High fidelity and long life-time quantum memory	- Enabled Quantum Repeat - High fidelity and long life-time quantum memory	- Quantum Memory
	Quantum Communication Channel - QKD - Network design & optimization - Satellite technology	- Reliable Quantum network - Satellite-based quantum communication	- QKD at short distance (< 100m) - Quantum Network Simulation
Post-Quantum Cryptography Readiness			

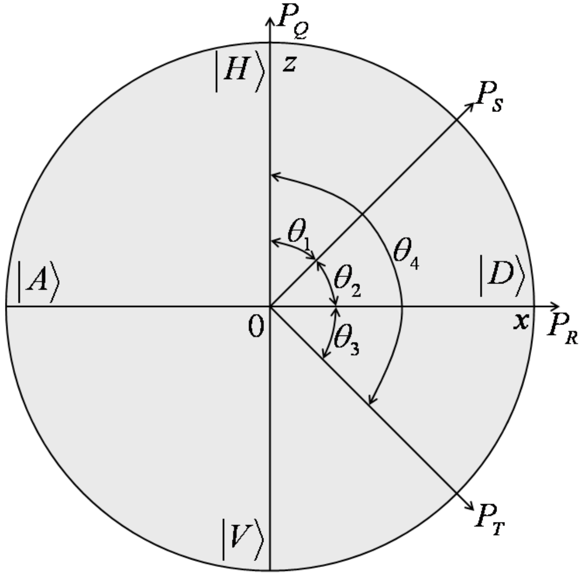


Pruet Kalasuwan, Sujin Suwanna, Poomphong Chaiwongkhot





Entanglement test : reproduce the Nobel 2022 work



$$C(a,b) \equiv Correlation\ function\ \ wihin\ \text{“}a,b\text{”}\ basis$$

$$= \frac{\mathcal{N}(a,b) - \mathcal{N}(a,b_\perp) - \mathcal{N}(a_\perp,b) + \mathcal{N}(a_\perp,b_\perp)}{\mathcal{N}(a,b) + \mathcal{N}(a,b_\perp) + \mathcal{N}(a_\perp,b) + \mathcal{N}(a_\perp,b_\perp)}$$

$$\mathcal{N}(a,b) \equiv \langle I_1 I_2 \rangle\ giving\ outcome\ a,b$$

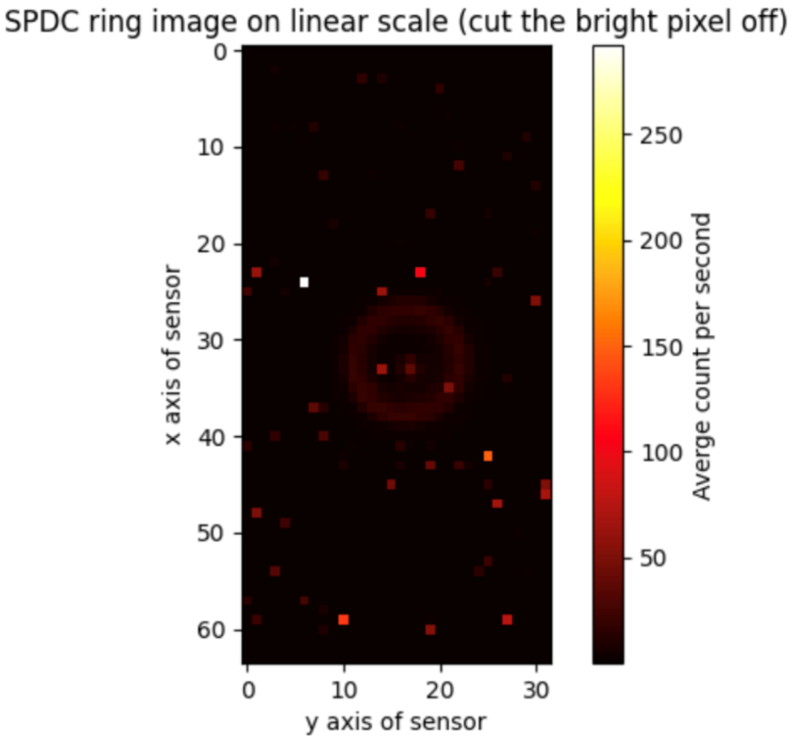
$$S \equiv Bell\ parameter$$

$$= C(Q,S) + C(R,S) - C(Q,T) + C(R,T)$$

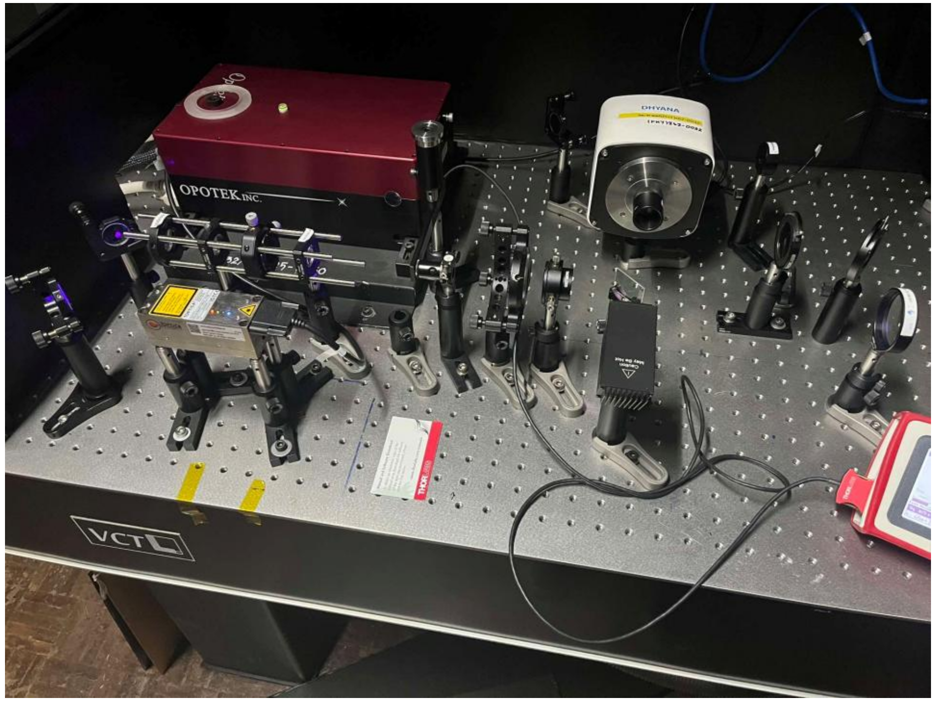
$$\mathrm{C} : S \le 2, Q : S > 2\ \left(\max at\ 2\sqrt{2}\right).$$

Photons image for (future) quantum sensing

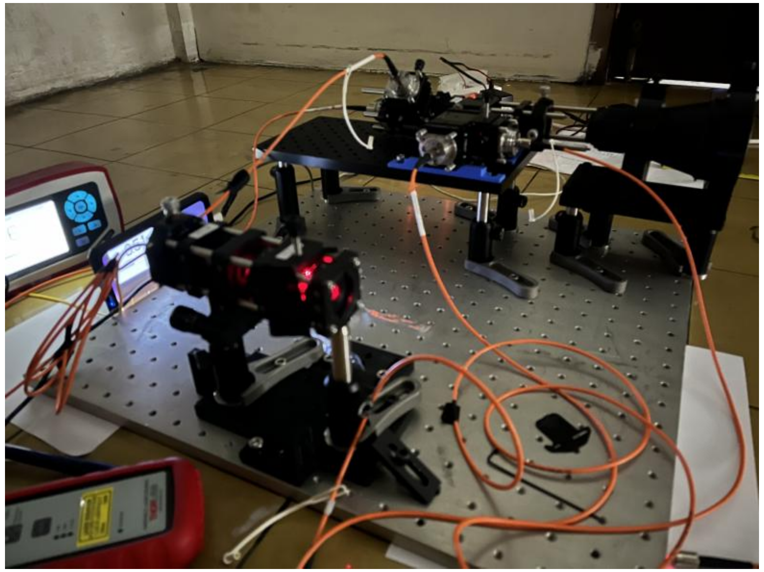
’22

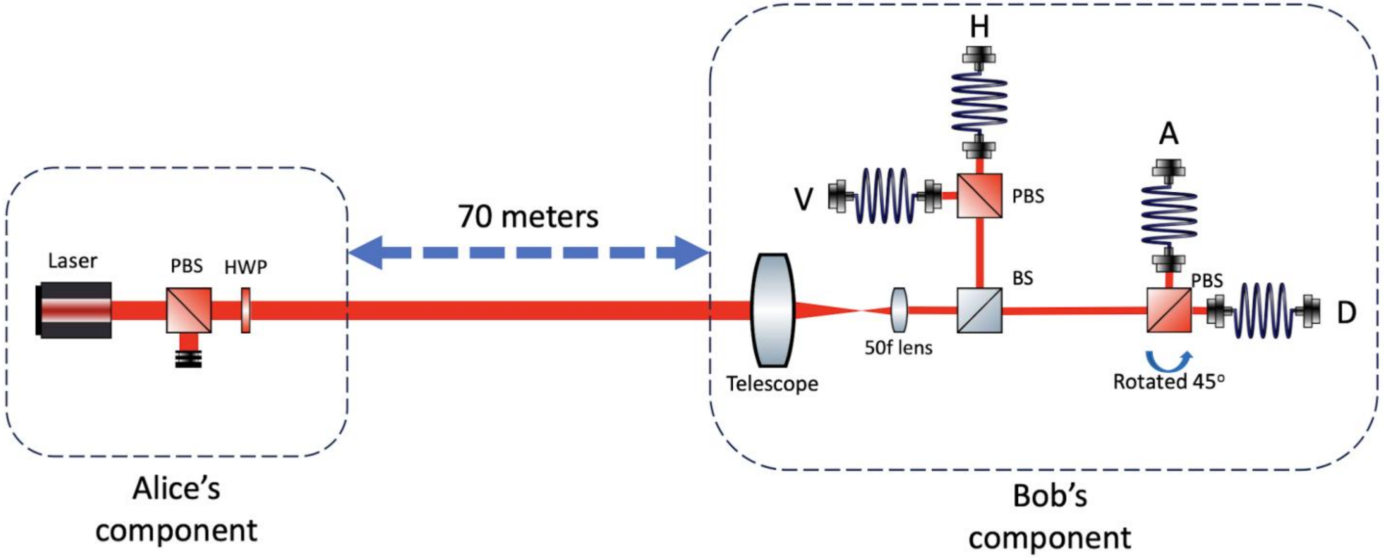


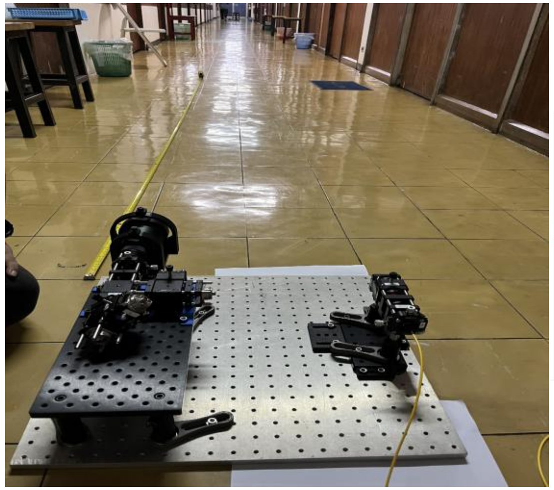
’24

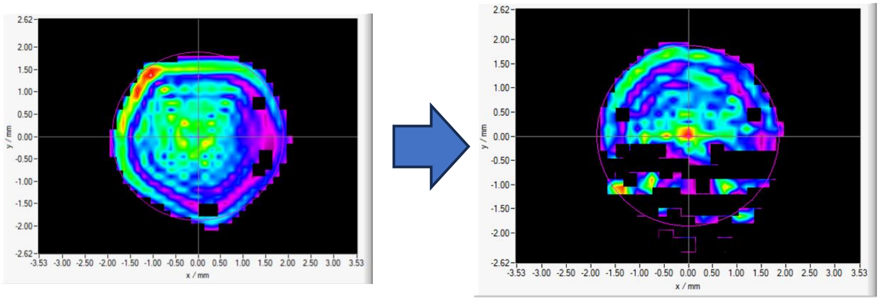


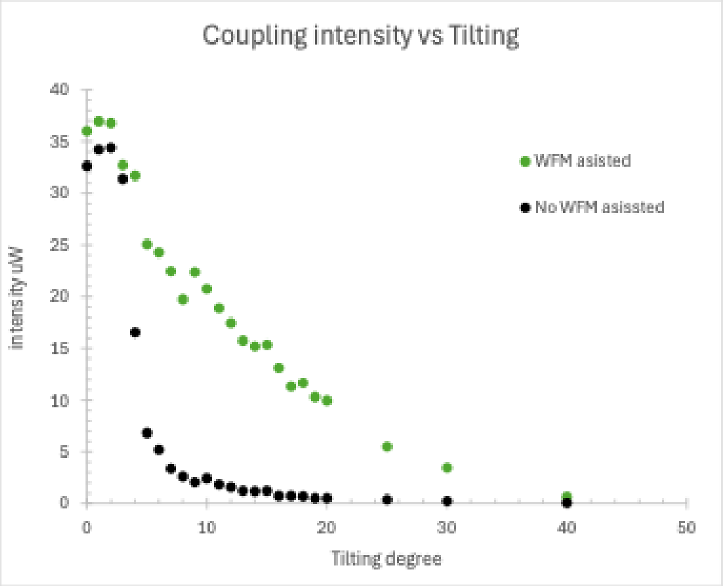
Free-space BB84 demonstration



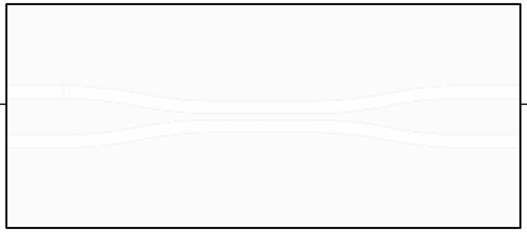


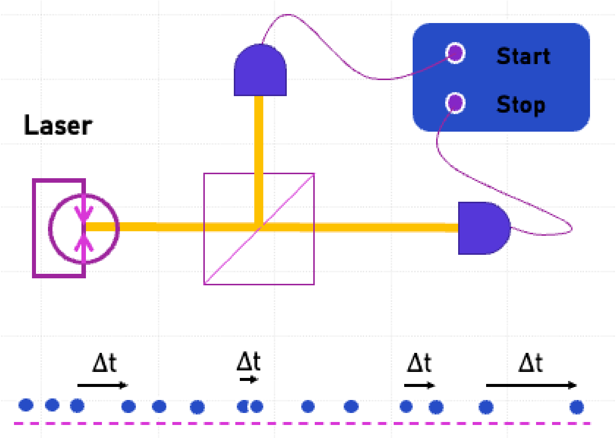


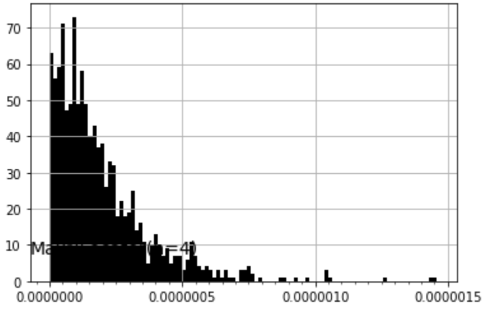




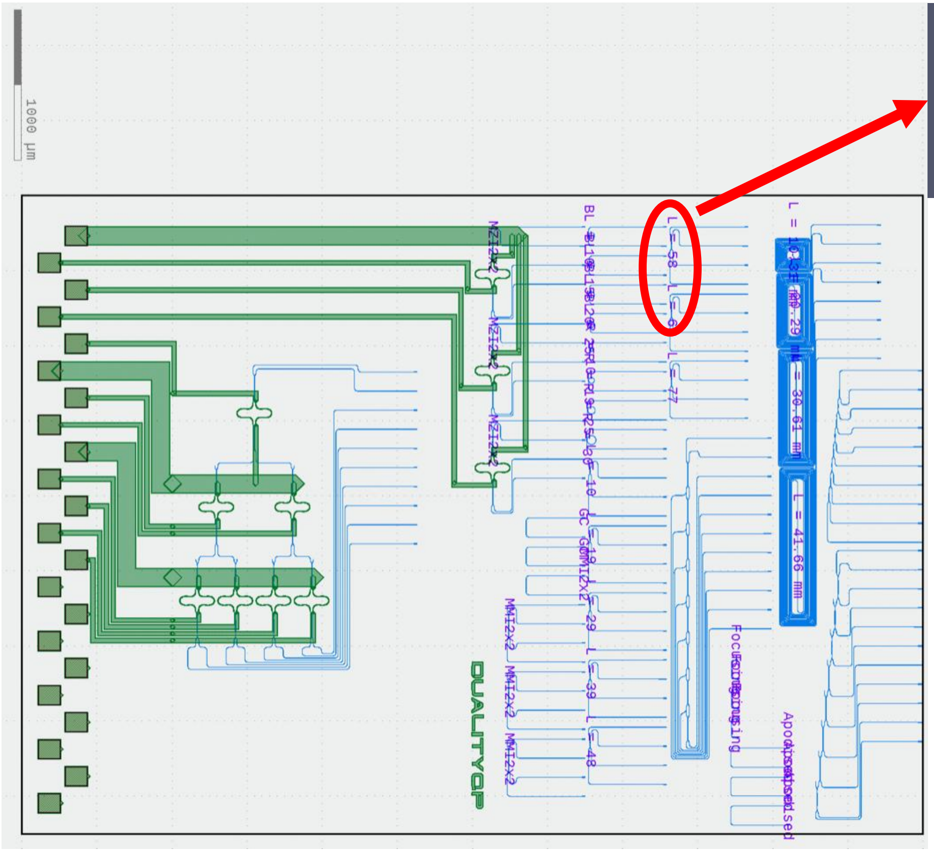
QRNG on chip

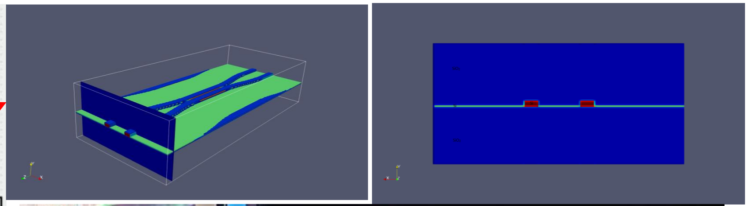


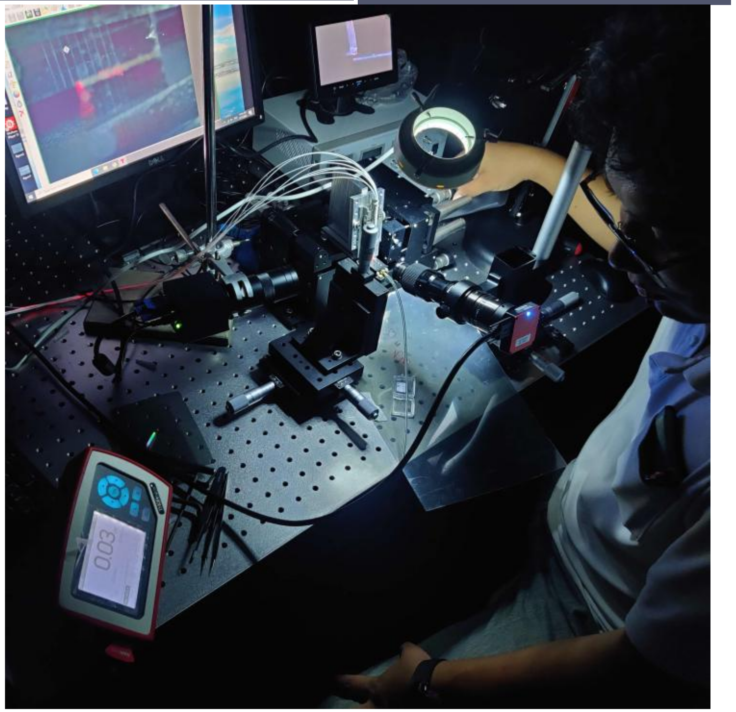




('63)

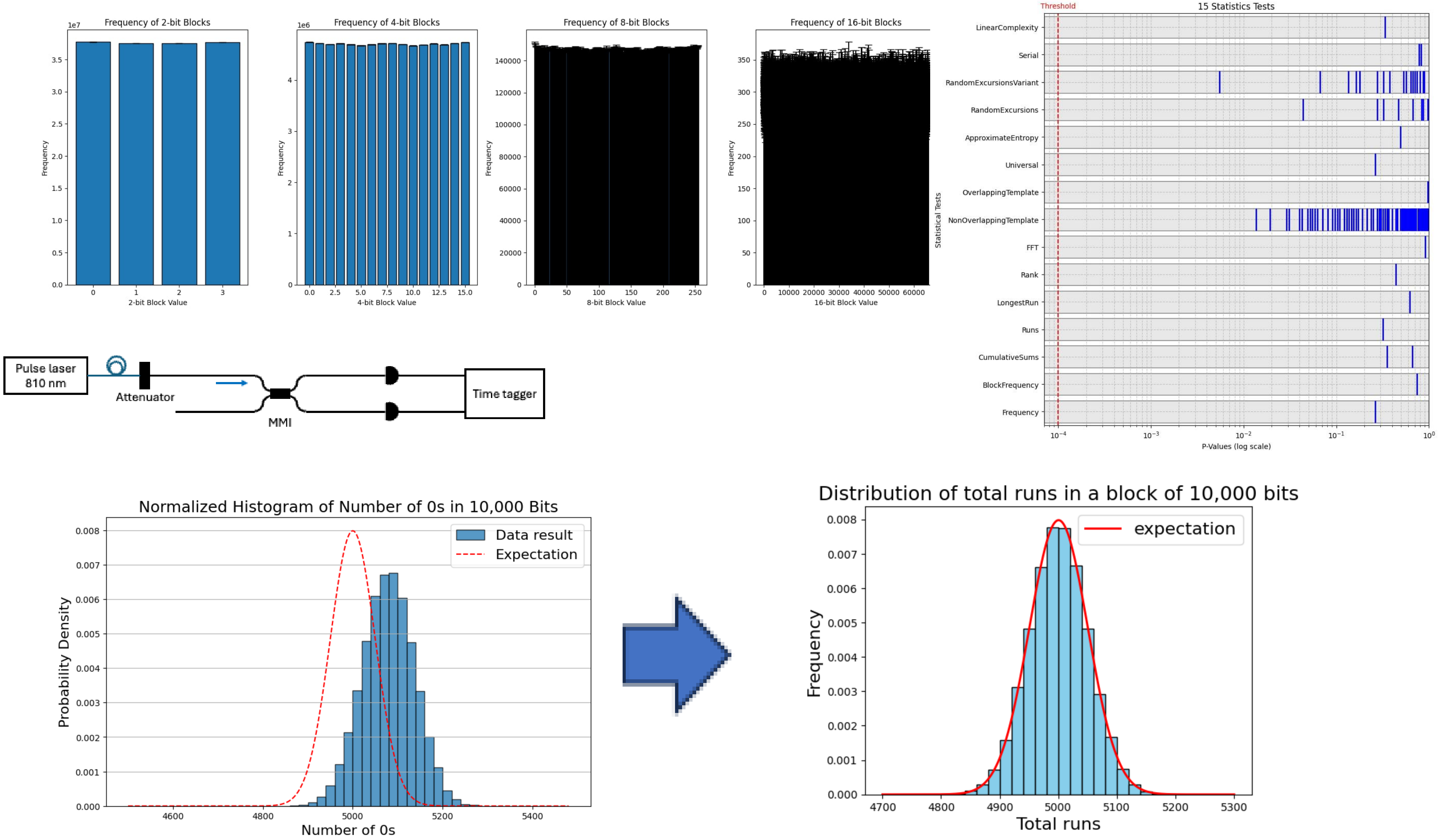






DUALITY QUANTUM PHOTONICS

('65-'66)



Frequency of 2-bit Blocks
2-bit Block Value
Frequency
Frequency of 4-bit Blocks
4-bit Block Value
Frequency of 8-bit Blocks
8-bit Block Value
Frequency of 16-bit Blocks
16-bit Block Value
15 Statistics Tests
Threshold
LinearComplexity
Serial
RandomExcursionsVariant
RandomExcursions
ApproximateEntropy
Universal
OverlappingTemplate
NonOverlappingTemplate
FFT
Rank
LongestRun
Runs
CumulativeSums
BlockFrequency
Frequency
Statistical Tests
P-Values (log scale)
Pulse laser
810 nm
Attenuator
MMI
Time tagger
Normalized Histogram of Number of 0s in 10,000 Bits
Data result
Expectation
Probability Density
Number of 0s
Distribution of total runs in a block of 10,000 bits
expectation
Frequency
Total runs

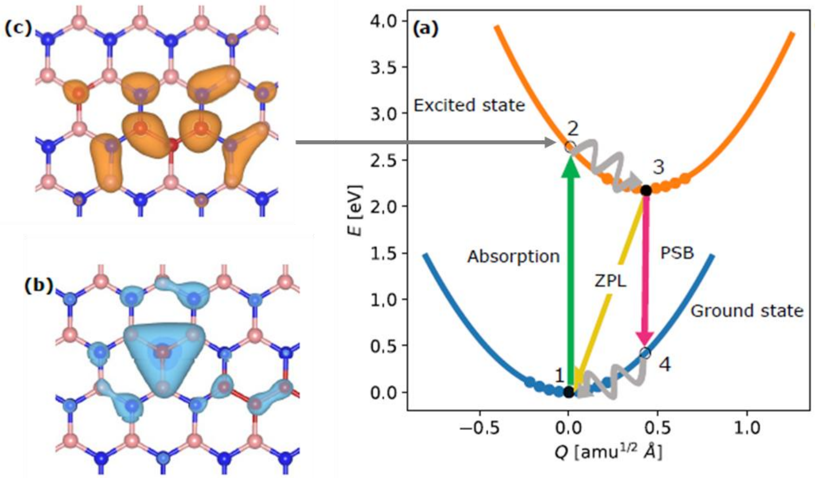
Emission Wavelengths and Photophysical Properties of hBN Defects

Wavelength for Quantum Technology (nm)	Other systems in quantum technology	Compatible hBN defects	Defect transition energy (eV)/ wavelength (nm)
552	PbV^- (diamond)	S_BV_B	2.252 / 550.7
		In_BV_N	2.237 / 554.4
		In_NV_B	2.236 / 554.5
589	Na-D2	O_BV_B	2.110 / 587.6
590	Na-D1	Ti_NV_B	2.100 / 590.5
		V_NV_BTi	2.097 / 591.3
602	GeV^- (diamond)	$Er_BN_BV_N$	2.063 / 601.1
606	$Pr^{3+}:Y_2SiO_5$	* Sn_BV_B	2.037 / 608.8
620	SnV^- (diamond)	V_NV_B	2.024 / 612.7
637	NV^- (diamond)	** Al_N	1.918 / 646.6
656	Fraunhofer line	P_NV_B	1.810 / 673.4
738	SiV^- (diamond)	V_BV_B	1.678 / 738.8
780	Rb-D2	Er_BV_B	1.592 / 778.7
		Er_NV_B	1.590 / 779.6
793	$Tm^{3+}:Y_2SiO_5$	In_BV_B	1.540 / 805.2
795	Rb-D1	$Er_NN_BV_N$	1.537 / 806.8
		Al_BV_B	1.535 / 807.9
850	Telecom-1	Er_NV_N	1.473 / 842.0
852	Cs-D2		
862	V_{Si}^- (silicon carbide)	$Er_BV_N^-$	1.427 / 869.0
894	Cs-D1	* $Er_BV_B^+$	1.398 / 886.9
1330	Telecom O-band	O_NS_N	0.946 / 1310.2
1550	Telecom C-band	* Er_B^+	0.789 / 1572.3

* Transition between VB or degenerate (ground) state and an unoccupied non-degenerate (excited) state.

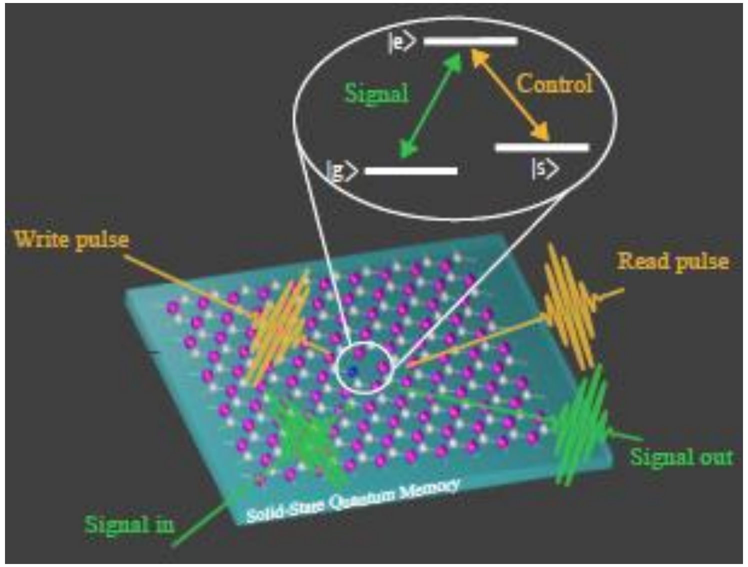
** Transition between double-occupied (degenerate) ground and unoccupied degenerate excited state.

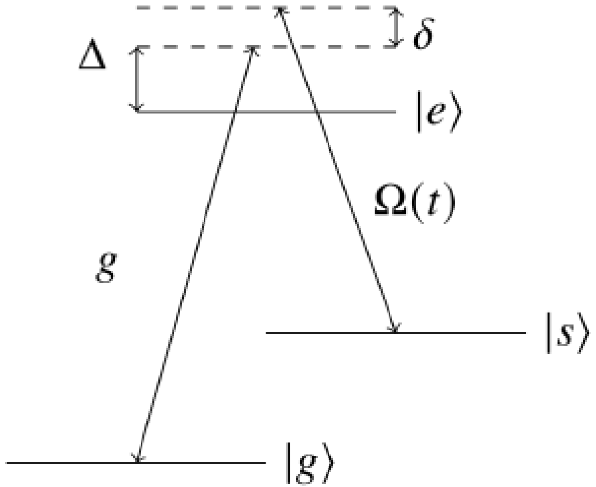
Photophysical Properties	Defects Al_N	Defects P_NV_B
Transition order	1st	1st
Most stable configuration	Singlet	Doublet
Spin transition	↑ - ↑	↓ - ↓
ZPL (nm)	682	673
ΔQ (amu$^{1/2}$Å)	0.83	0.70
HR	2.86	1.87
DW	0.06	0.15
Excitation polarization (°)	5.38	5.02
Excitation In-plane ratio	0.61	1.00
Emission polarization (°)	54.62	16.85
Emission In-plane ratio	0.99	1.00
E_0 (eV)	1.82	1.81
μ_{e-h}^2 (Debye^2)	2.59×10^4	9.46×10^4
Γ_R (1/s)	4.74×10^2	1.70×10^6
τ_R (ns)	2.11×10^6	5.89×10^5
ODMR	unlikely	unlikely

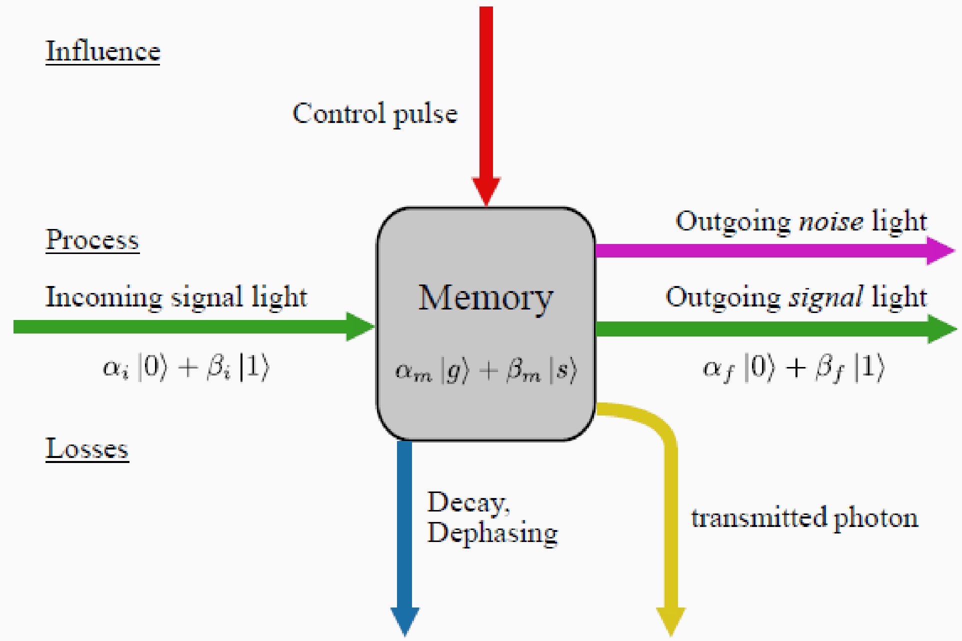


J. Phys. Chem. Lett. (2023), 14, 6564-6571, Nanomaterials (2022), 12, 2427.

Single Atom Solid State Quantum Memory





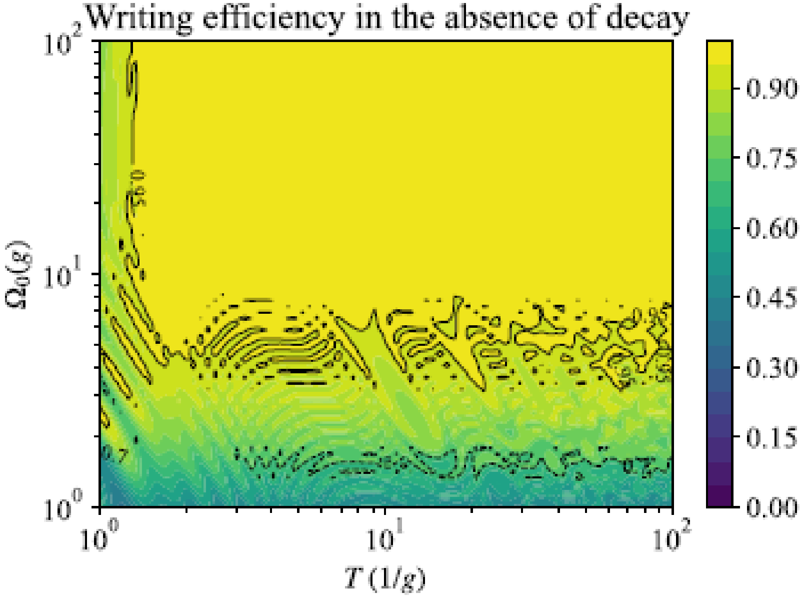


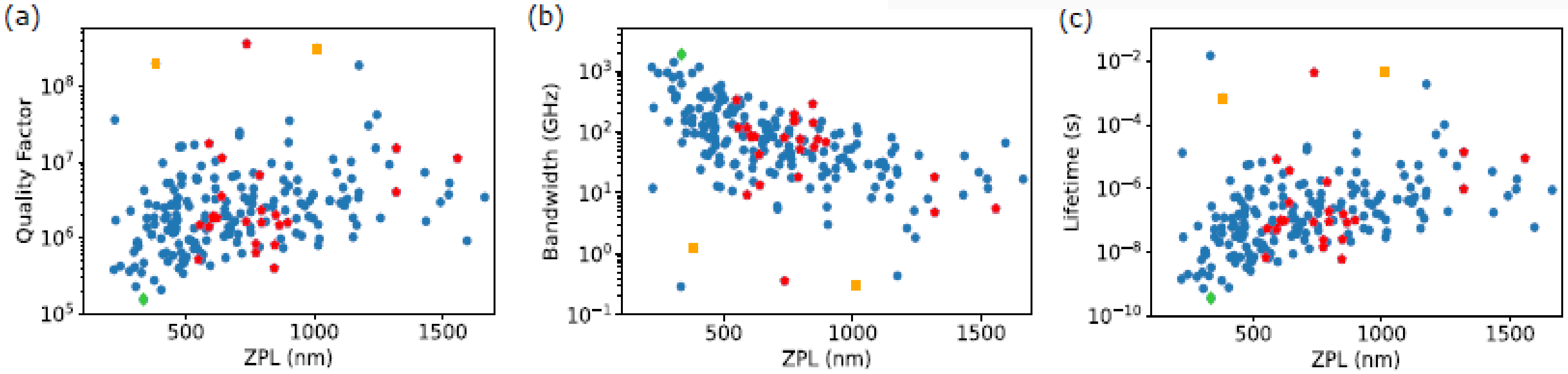
$$H(t) = \hbar\left(g\hat{a}\hat{\sigma}_{eg} + \Omega(t)\hat{\sigma}_{es} + \text{H.c.}\right) + \hbar\Delta\hat{\sigma}_{ee}$$

$$\Delta = \frac{1}{2}\left(C^2\sigma_\Delta^2 \pm \sqrt{C^4\sigma_\Delta^4 + 4C^2\sigma_\Delta^2\omega_{\text{ge}}}\right).$$

$$C = \frac{\langle e|\,\hat{\mathbf{d}}\cdot\vec{\epsilon}\,|g\rangle}{\sqrt{2\hbar\varepsilon_0 V}} = \frac{g}{\sqrt{\omega_1}}.$$

$\Delta \propto$ |di. trans. moment|, $\frac{1}{\sqrt{V}}$, $\sqrt{\omega_{\text{ge}}}$, and σ_Δ





C. Cholsuk et al. arXiv:2405.12749v1

Credit: Takla Nateeboon APL Quantum 1, 026107 (2024)

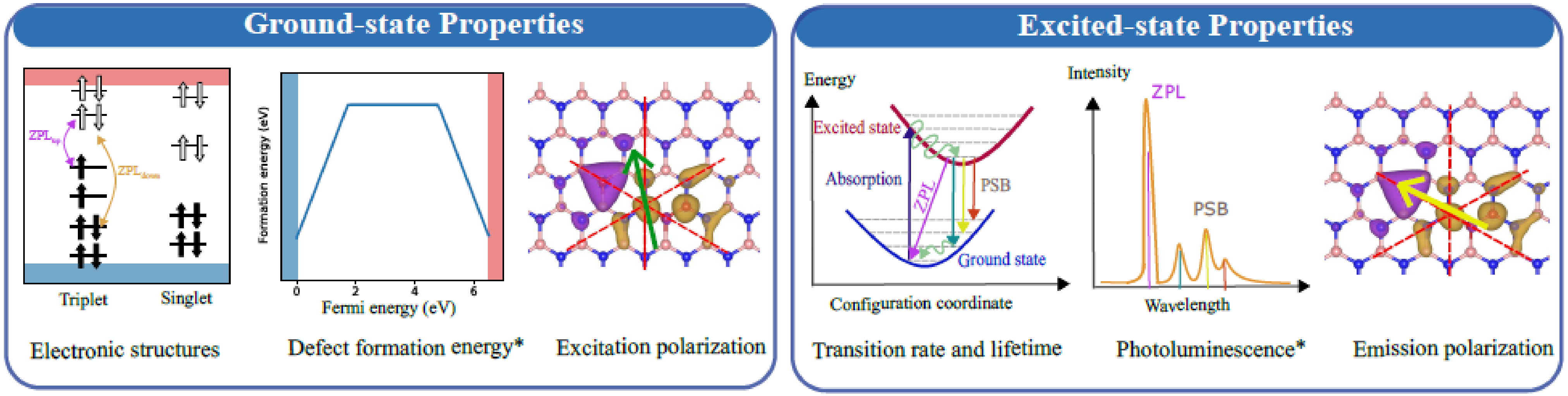
Summary: Quantum Emitters and Quantum Memory

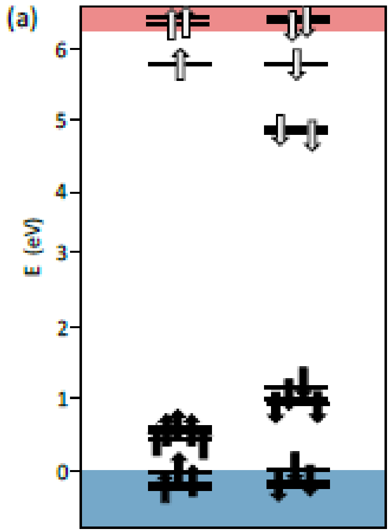
www.h-bn.info

maintained by Technical University of Munich TUM

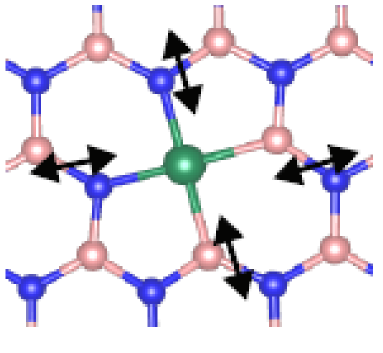
The h-bn defects database

C. Cholsuk et al. arXiv:2405.12749v1





- 257 electronic transitions are found to feature ISC based on DFT.
- Most defects require quality factor of 10^6 for 95% efficiency with bandwidth of 10^2 GHz
- Quality factor and bandwidth depend on radiative transition rate.
- Optimizing a defect yields higher improvement than fine-tuning, i.e., via strain.



Quantum Network Simulation

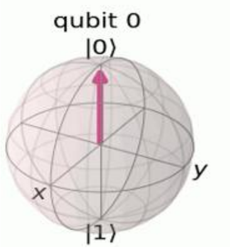
Credit: Poramet Pathumsoot

qwanta

Pauli noise

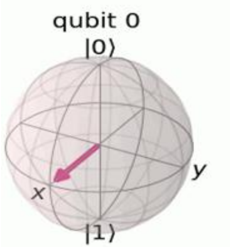
X

Bit flip



Z

Phase flip



Pauli noise has a probability of propagating through quantum gate operation via a transformation.

Fidelity F is a measure of how close two quantum states which indicates the quality of a qubit

$$F(\rho, \sigma) = (tr\sqrt{\sqrt{\rho}\sigma\sqrt{\rho}})^2$$

σ: actual state

ρ: desired state

$$0 \leqslant F(\rho, \sigma) \leqslant 1$$

0: completely wrong

1: actual is the same as desired

Quantum state of 1 qubit

$$|\psi\rangle = a|0\rangle + b|1\rangle = \begin{bmatrix} a \\ b \end{bmatrix}$$

$$|a|^2 + |b|^2 = 1$$

Even more general representation of quantum state, density matrix

$$\rho = \sum_{i,j=1}^{n} p_{ij}|i\rangle\langle j| = 1\}$$

Gate error
with probability **p_gate** apply Pauli error instead of gate

Depolarizing error
error after create Bell pair

Noise model in qwanta

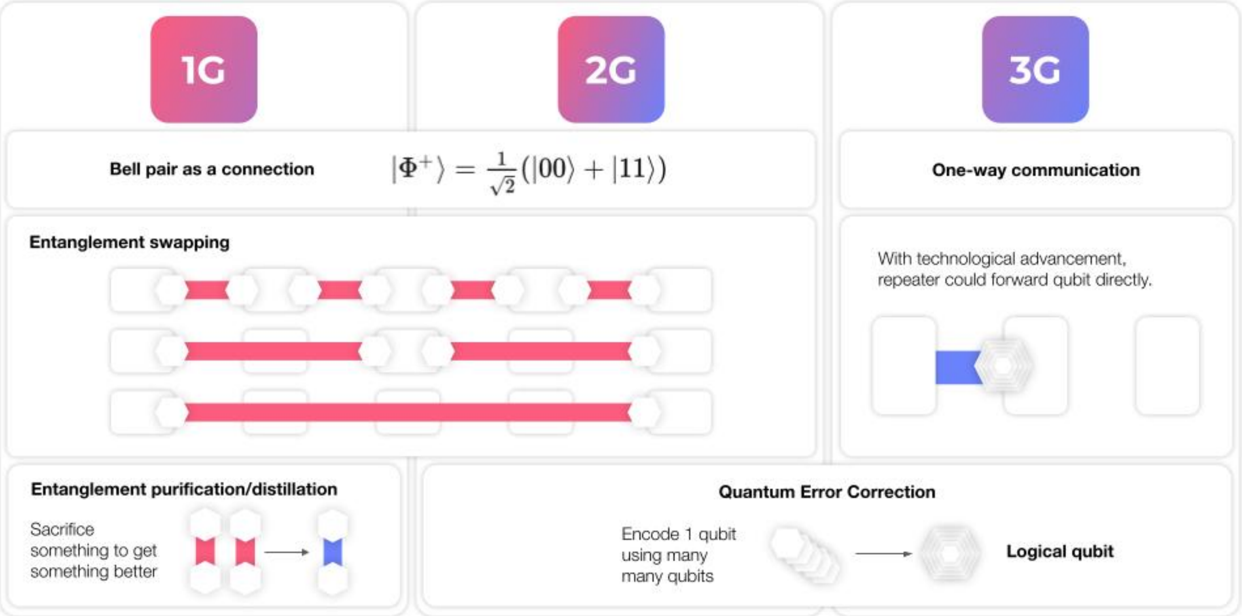
Measurement error
with probability **p_meaErr** to apply Pauli noise on measurement result

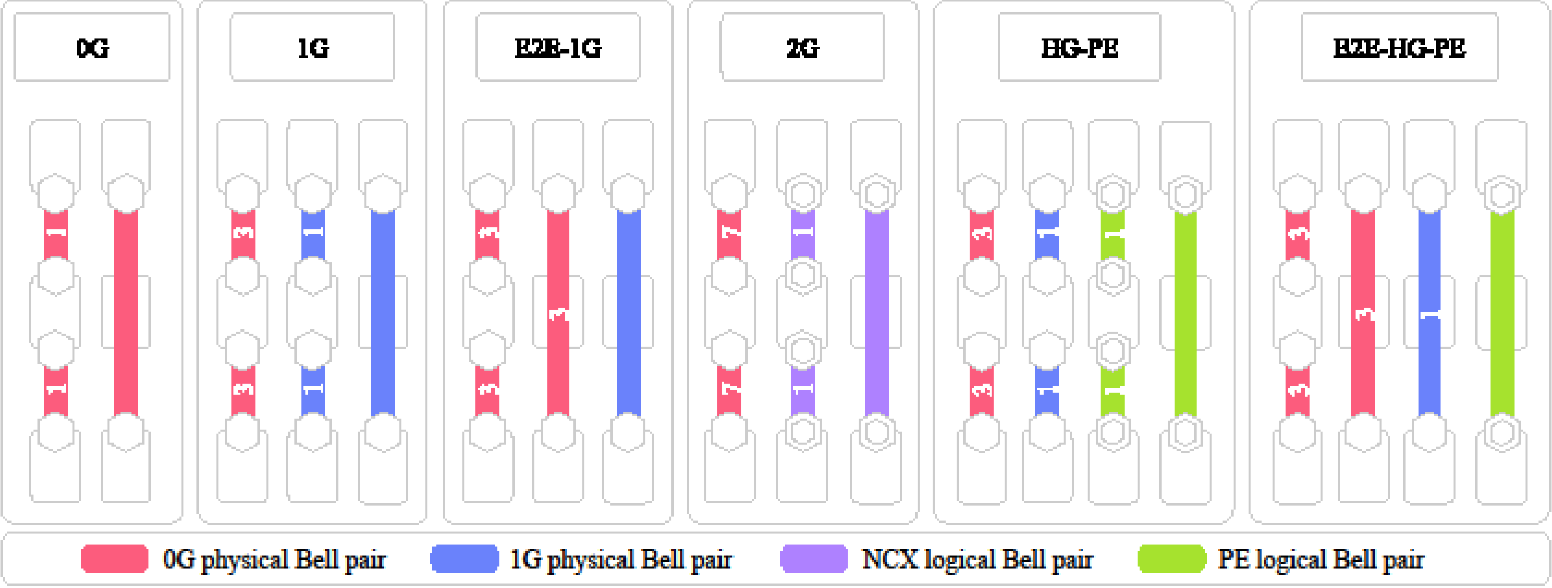
Memory error
with probability depend on time of measurement

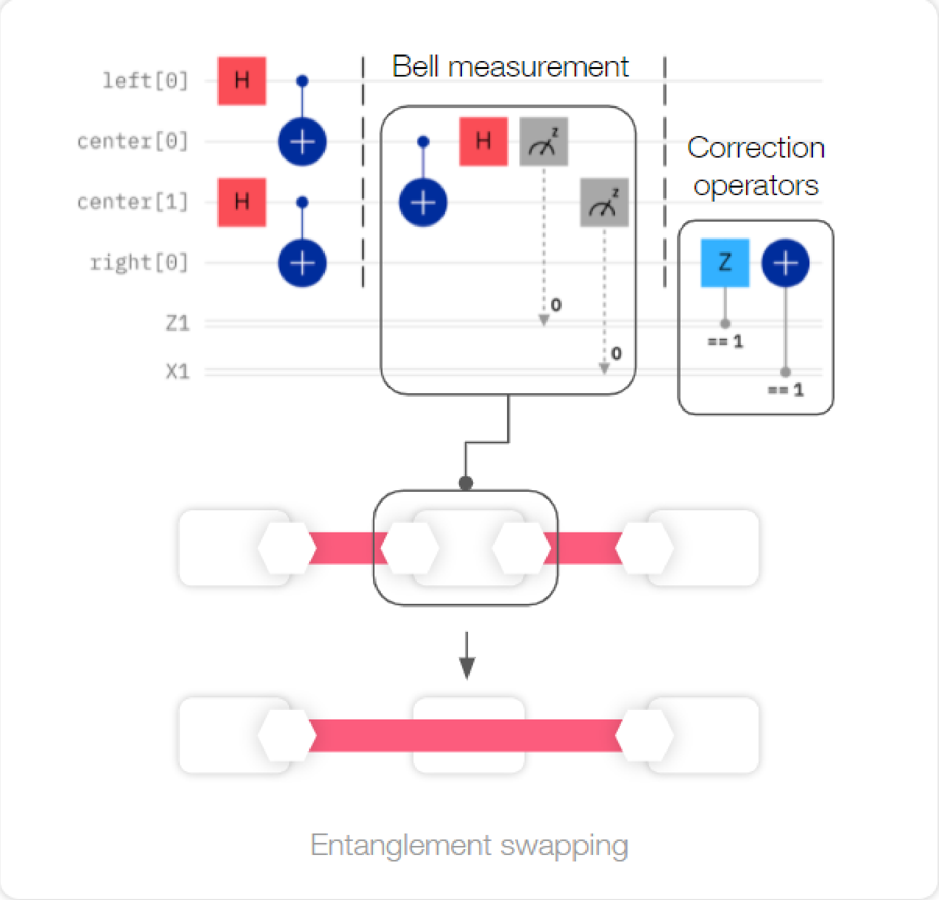
Photon loss directly related to this error

qwanta will calculate fidelity after applying all of noise models in qubit by using a technique called "**direct fidelity estimation**"

Quantum Communication Strategy Analysis



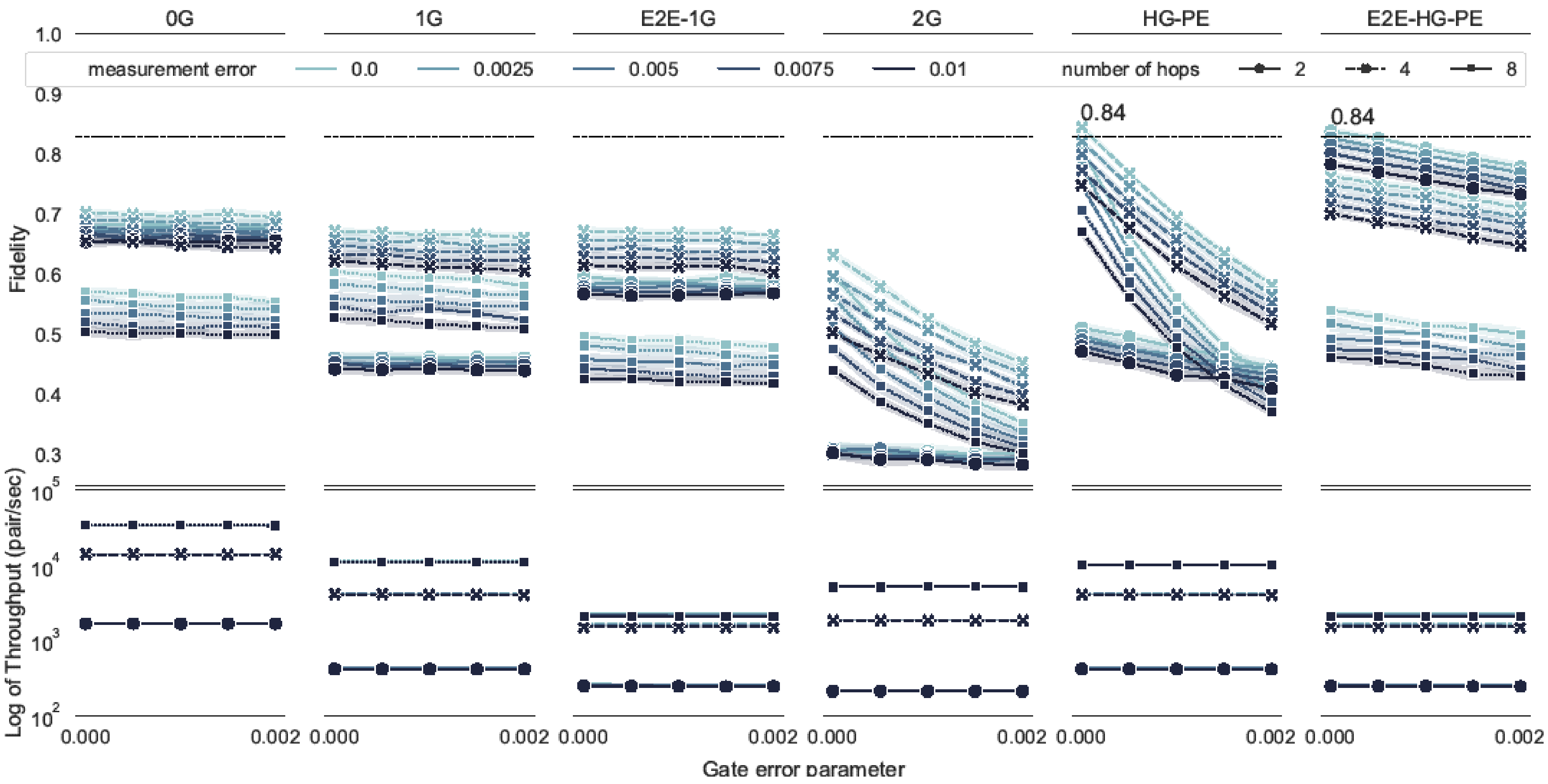




- Simulate and compare various scenarios of quantum communication strategies.
- Optimize fidelity and throughput.

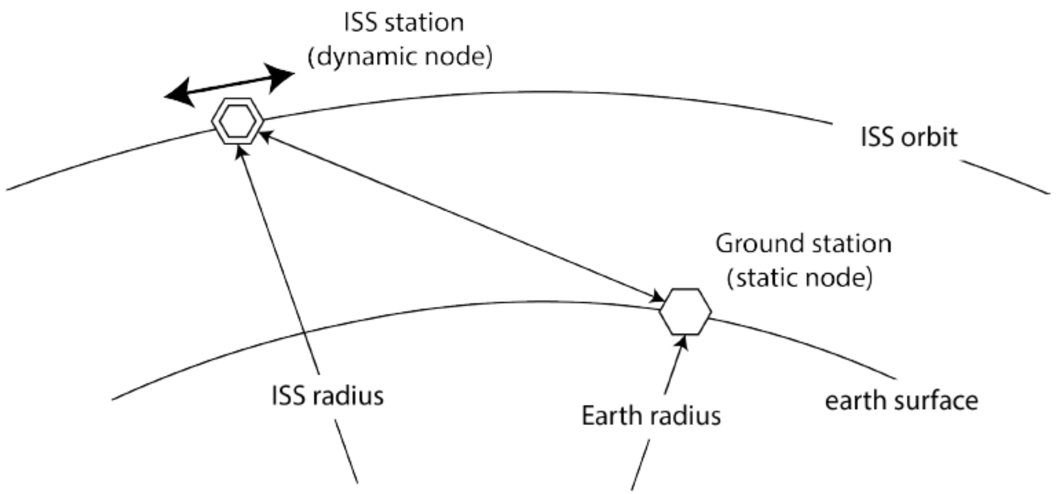
Credit: Poramet Pathumsoot

Quantum Communication Strategy Analysis



Toy Model: Three-Nodes Quantum Network with Ground Stations

Research model



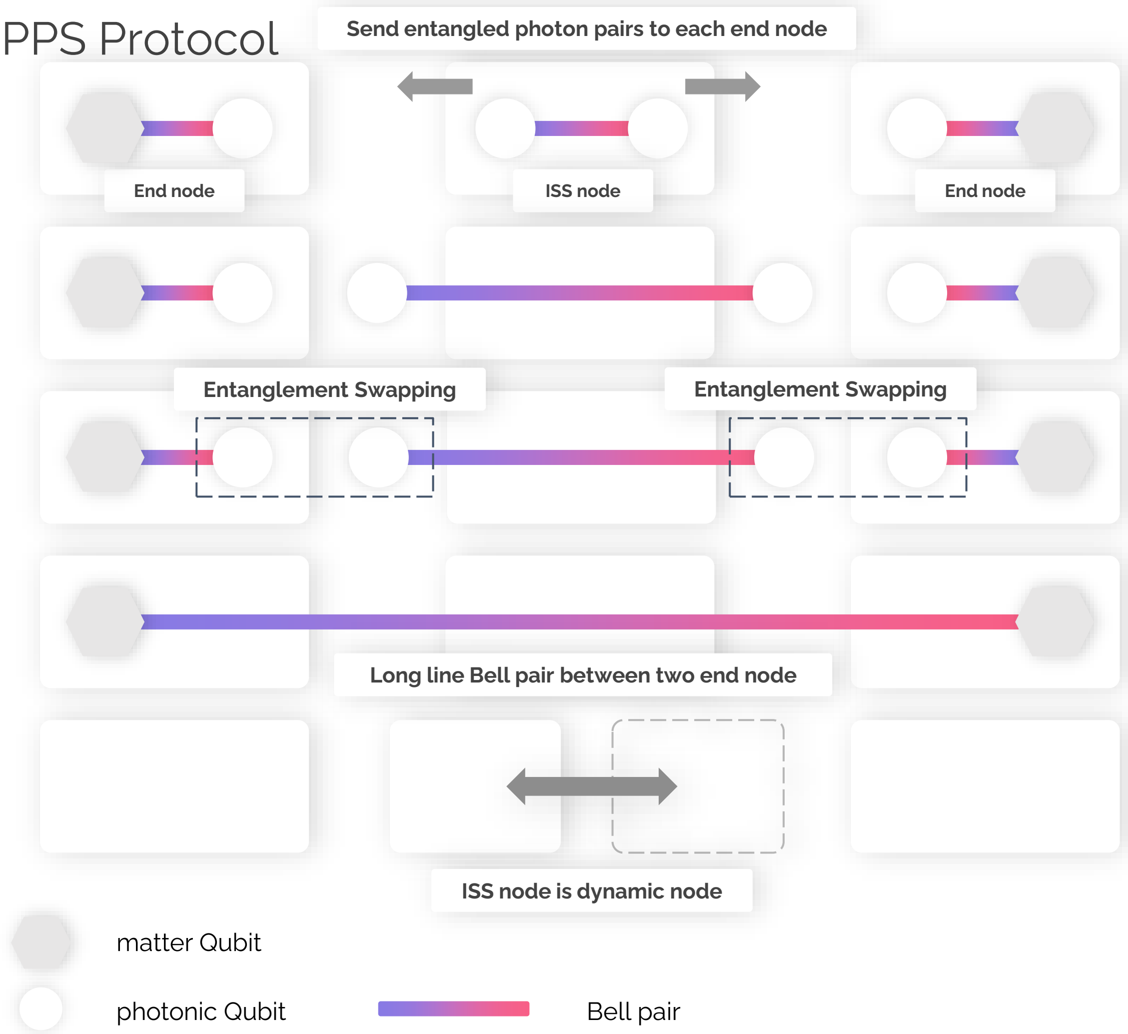
End nodes

- Bangkok
- Songkhla
- Chiang Mai

Middle node

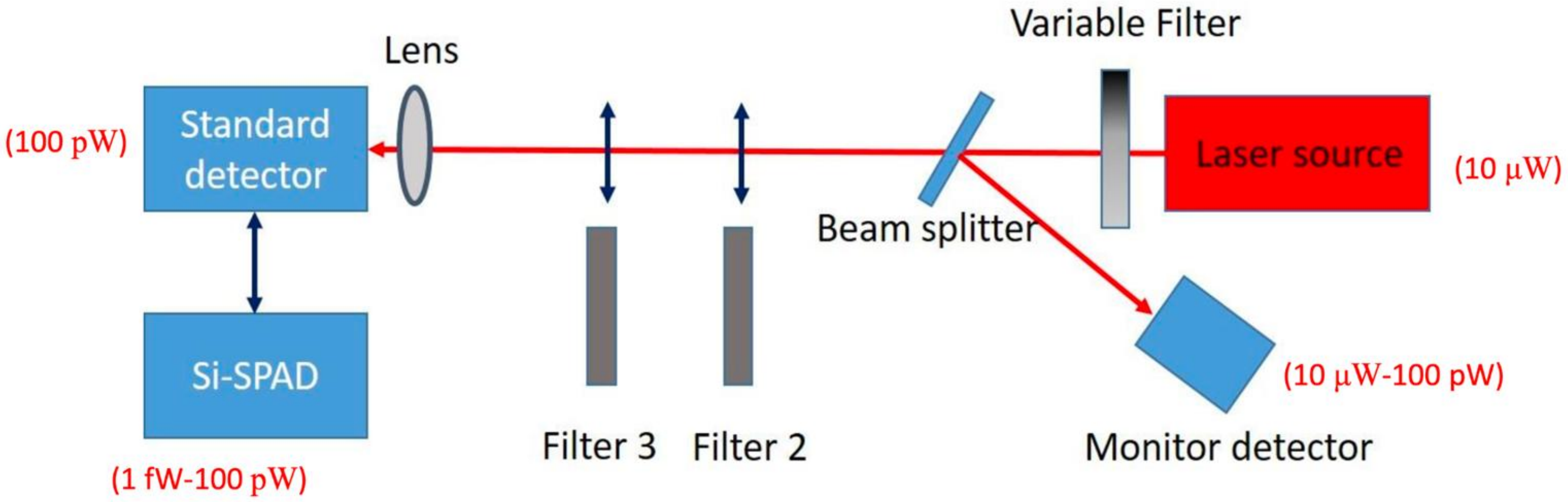
- International Space Station (ISS)

EPPS Protocol

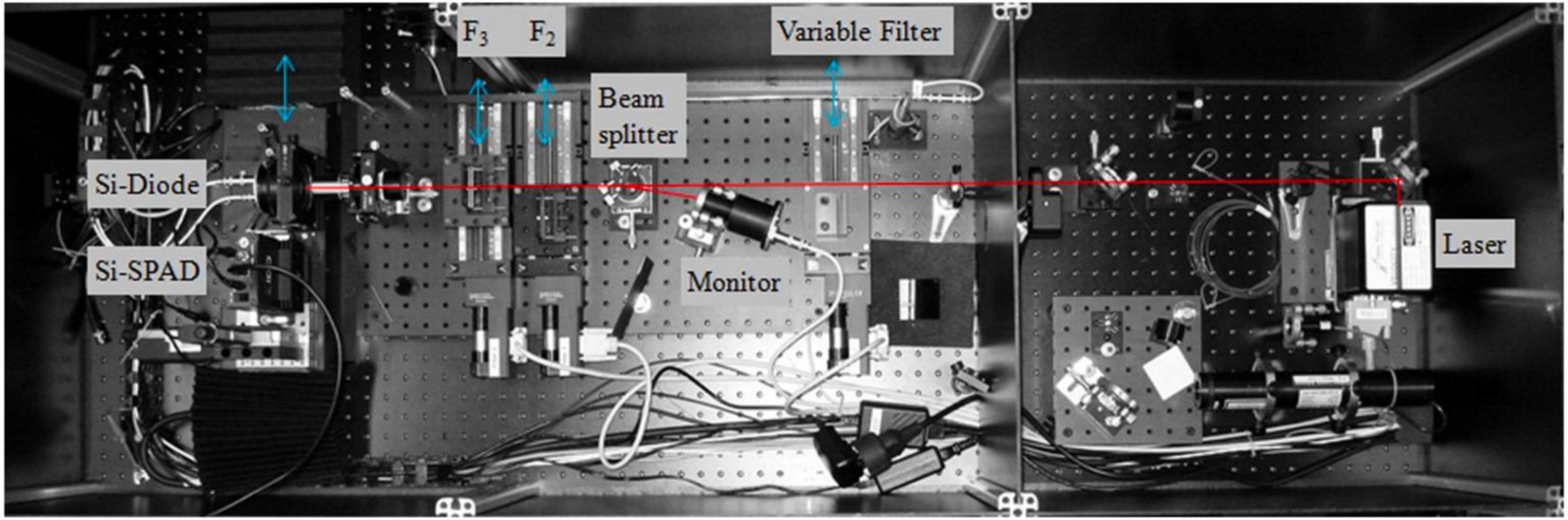


Credit: Poramat Chianvichai

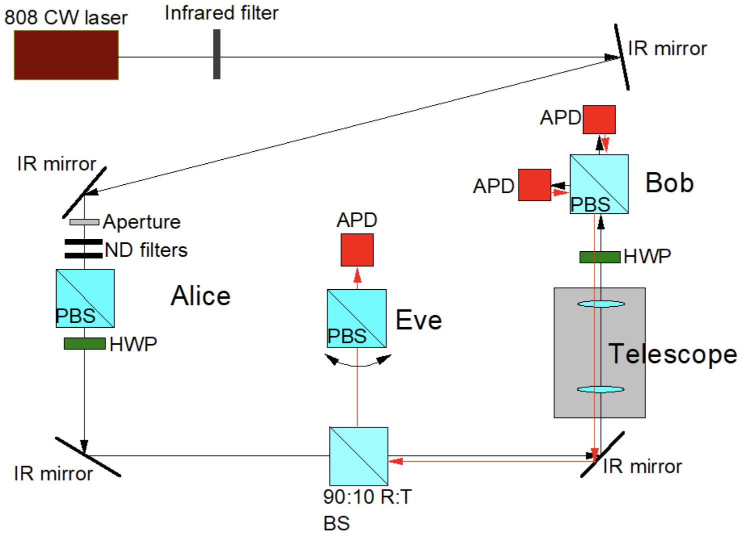
Single-Photon Device Certification Facility

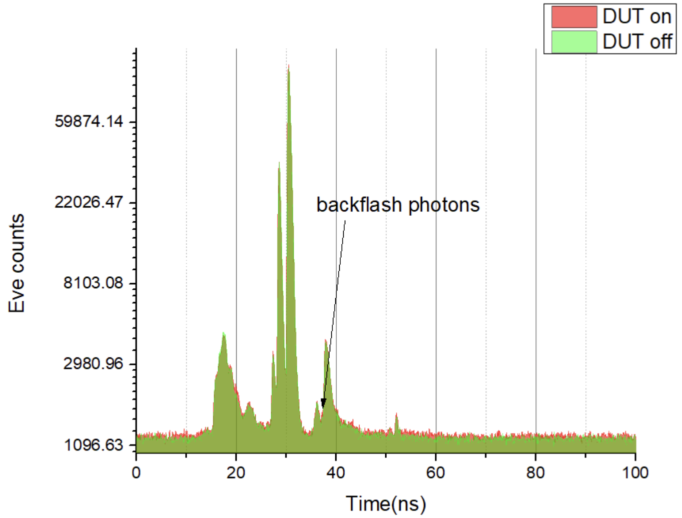


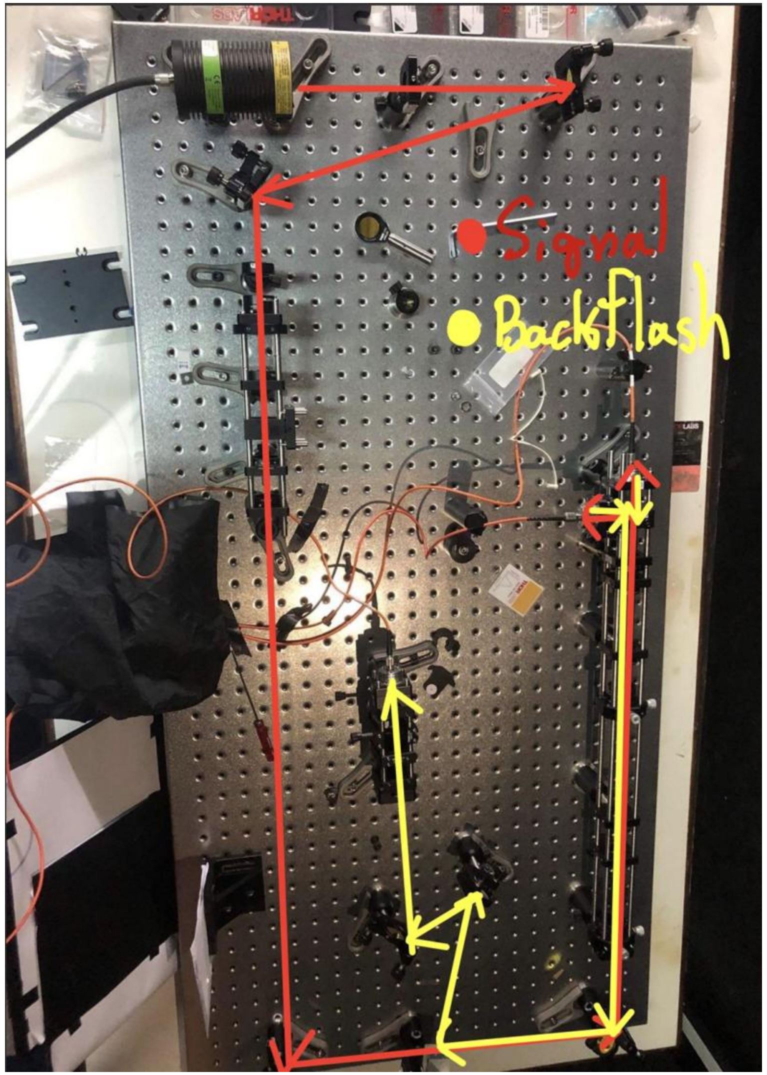
Dr. Kanokwan, NIMT



Attack on QKD system







International Actions

Check for updates

NIST Internal Report
NIST IR 8547 ipd

Transition to Post-Quantum Cryptography Standards

Initial Public Draft

Dustin Moody
Ray Perlner
Andrew Regenscheid
Angela Robinson
David Cooper

...ion is available free of charge from:
...//doi.org/10.6028/NIST.IR.8547.ipd

Bundesamt für Sicherheit in der Informationstechnik

Deutschland
Digital•Sicher•BSI•

Implementation Attacks against QKD Systems

MAS Monetary Authority of Singapore

Regulation | Development | Monetary Policy | Bonds & Bills | Currency | Publications | Statistics | News | Careers

Home / News / Media Releases / 2024 / MAS Collaborates with Banks and Technology Partners on Quantum...

Media Releases | Published Date: 14 August 2024

MAS Collaborates with Banks and Technology Partners on Quantum Security

Singtel | UOB | HSBC | Monetary Authority of Singapore | DBS | OCBC | SPEQTRAL

Singapore, 14 August 2024… The Monetary A...
Memorandum of Understanding (MoU) to em...
(QKD) [1] in financial services. QKD can help fi...
threats posed by quantum computing.

International Telecommunication Union

ITU-T **Technical Report**

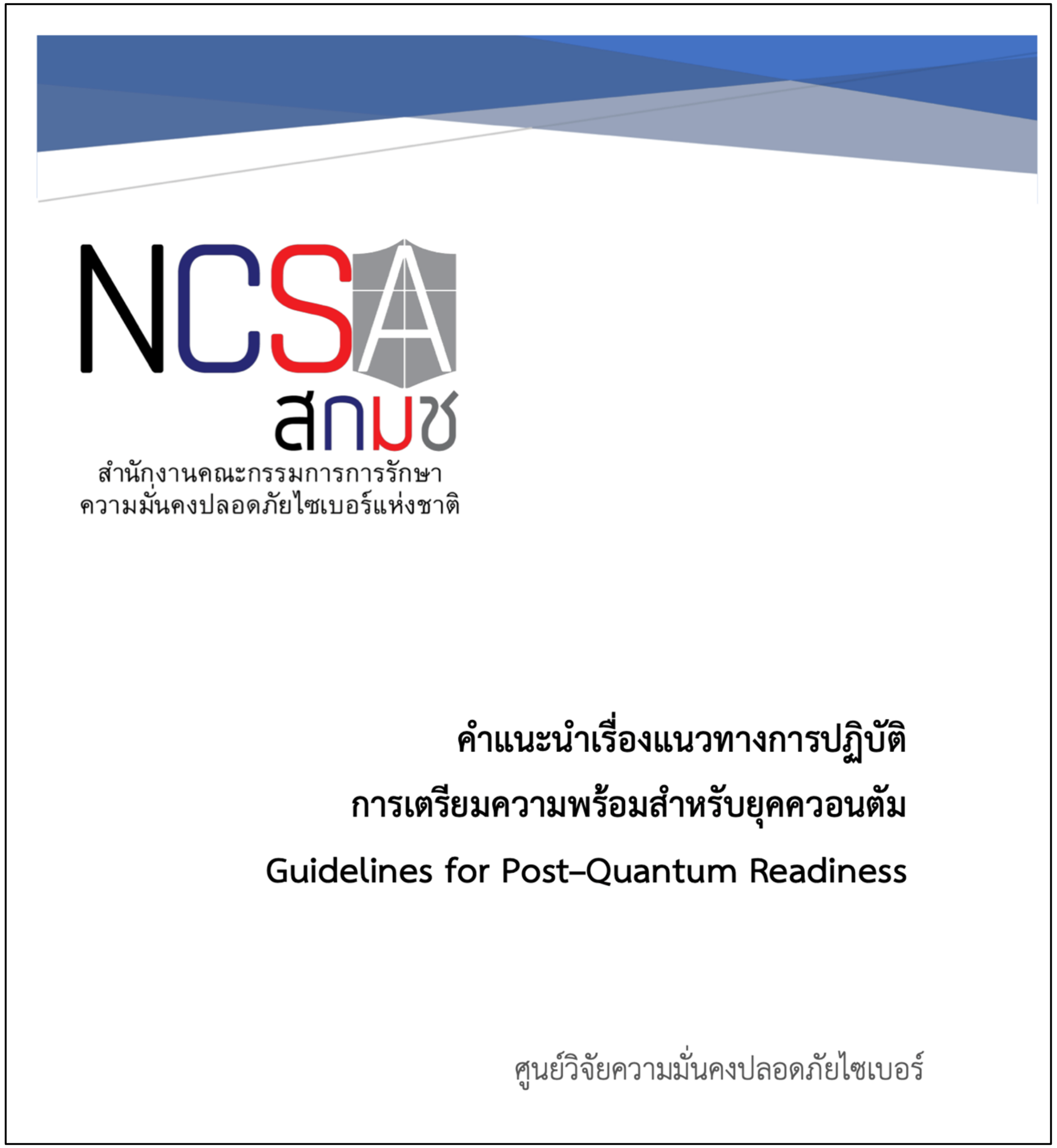
TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

(24 November 2021)

ITU-T Focus Group on Quantum Information Technology for Networks (FG QIT4N)

FG QIT4N D2.3-part 1
Quantum key distribution network protocols: Quantum layer

Thai NCSA's Quantum Readiness Guideline


NCSA
สกมช
สำนักงานคณะกรรมการการรักษา
ความมั่นคงปลอดภัยไซเบอร์แห่งชาติ

คำแนะนำเรื่องแนวทางการปฏิบัติ

การเตรียมความพร้อมสำหรับยุคควอนตัม

Guidelines for Post-Quantum Readiness

ศูนย์วิจัยความมั่นคงปลอดภัยไซเบอร์

Compliance checklist and QKD adoption guideline are under consideration

https://drive.ncsa.or.th/s/52GYxAqMfDNZjEZ

Conclusion

	Components	Global Challenge	Progress 2568
	Sender - Single photon source (SPS) - Entanglement source - Quantum Random Number Generator (QRNG)	- Efficient Photon Emitters (EPE) at the chip level and room temperature - High key-rate QRNG - QRNG chips - Chip scale photonic quantum information processing	- Quantum Emitter - QRNG chips - Bulk optic Entangled SPS - Single photon device certification
	Receiver - Single photon detector	-High-speed and Eficient Single photon -Chip scale photonic quantum information processing	- Hybrid-perovskite photon detector
	Repeater node - Enabled Quantum Repeat - High fidelity and long life-time quantum memory	- Enabled Quantum Repeat - High fidelity and long life-time quantum memory	- Quantum Memory
	Quantum Communication Channel - QKD - Network design & optimization - Satellite technology	- Reliable Quantum network - Satellite-based quantum communication	- QKD at short distance (< 100m) - Quantum Network Simulation
Post-Quantum Cryptography Readiness			

ESTABLISHMENT OF INTEGRATED ECOSYSTEM FOR QUANTUM TECHNOLOGY RESEARCH IN THAILAND

โครงการการสร้างและเสริมแกร่งระบบนิเวศแบบบูรณาการ
สำหรับการวิจัยทางเทคโนโลยีควอนตัม ระดับประเทศ

QTRic

สอวป
สำนักงานสภานโยบายการอุดมศึกษา
วิทยาศาสตร์ วิจัย
และนวัตกรรมแห่งชาติ

NARIT

QuTE
QUANTUM TECH ENDEAVOR

สร้างคน
ข้ามพรมแดน

u.reka
DEEP TECH DISCOVERY

ThEP

SEAGATE

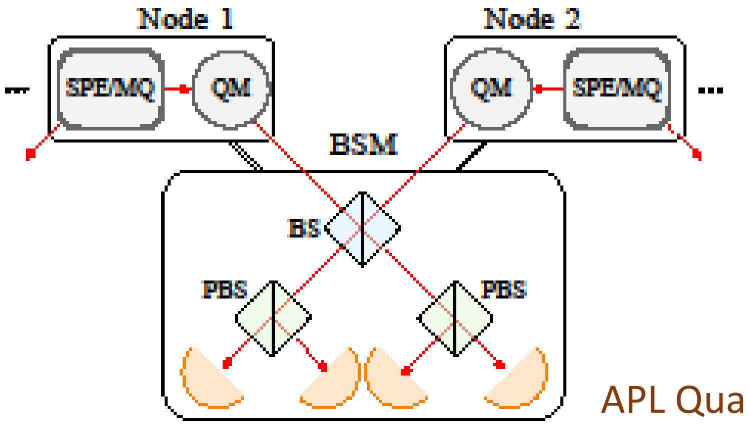
DIGITAL
VENTURES

Mahidol University
Wisdom of the Land

Topics of Interests

- quantum network
- quantum random number generator
- single photon generation
- quantum memory
- distributed quantum computing
- quantum optical metrology
- dynamics of open quantum systems
- quantum decoherence
- foundation of quantum theory

Theory/Simulation/Experiment



APL Quantum 1, 026107 (2024)

TUM

Quantum Communication System Engineering

Prof. Dr. Tobias. Vogl, C. Cholsuk, A. Kumar, ...

Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Keio University

Prof. Dr. R. Van Meter, P. Pathumsoot, M. Hadijek, ...

JAIST
JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY
1990

Prof. Dr. Ryo Maezono

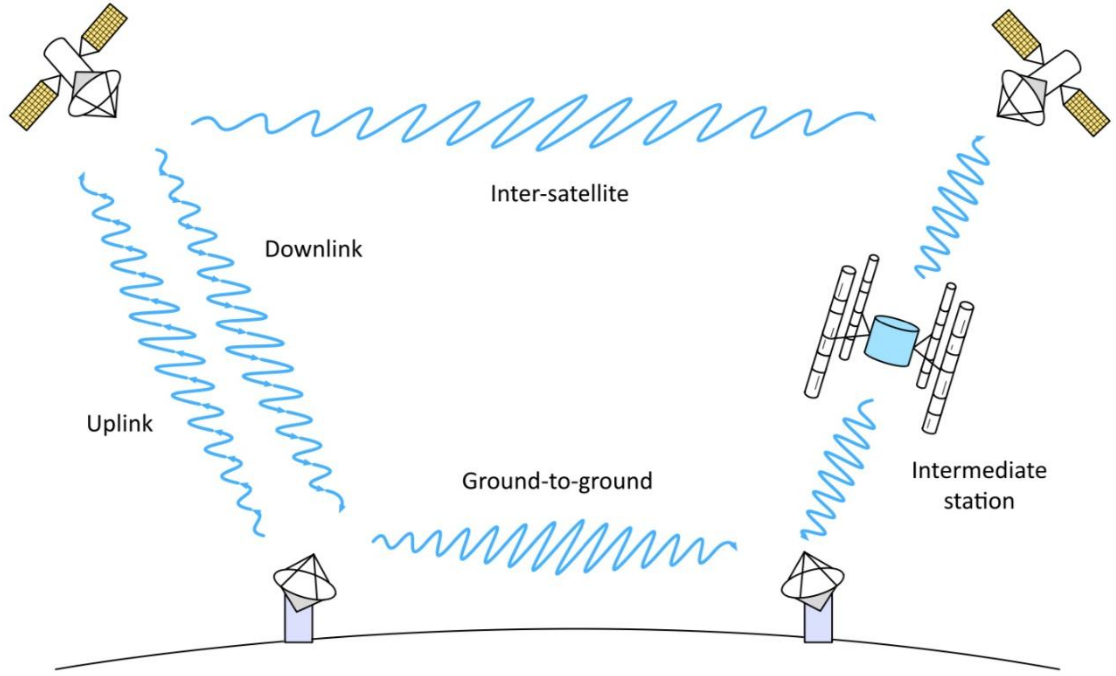
Computational Spintronics
Sanvito Research Group
Trinity College Dublin

Trinity College Dublin

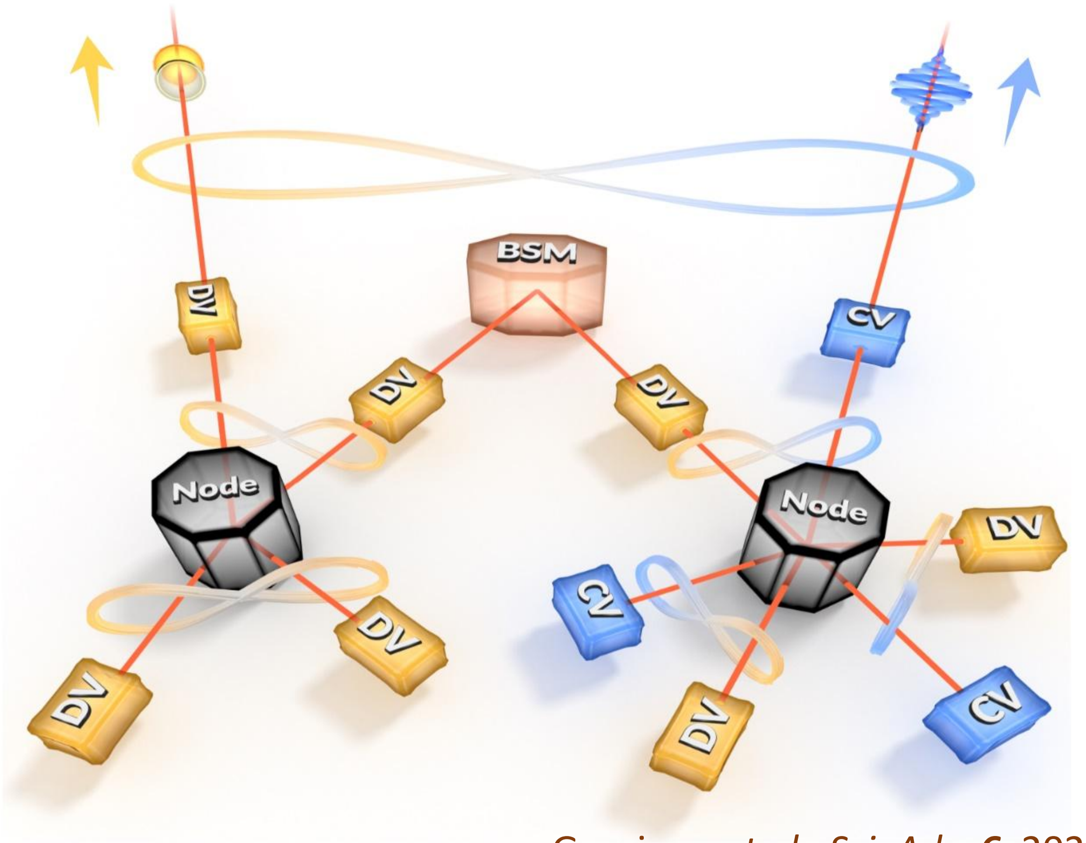
Prof. Dr. Stefano Sanvito, R. Hunkao

Siam Photon

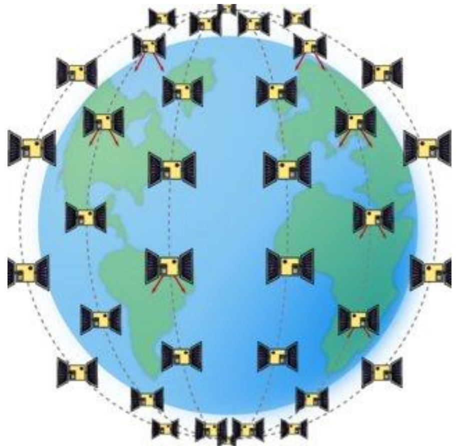
Quantum Networks

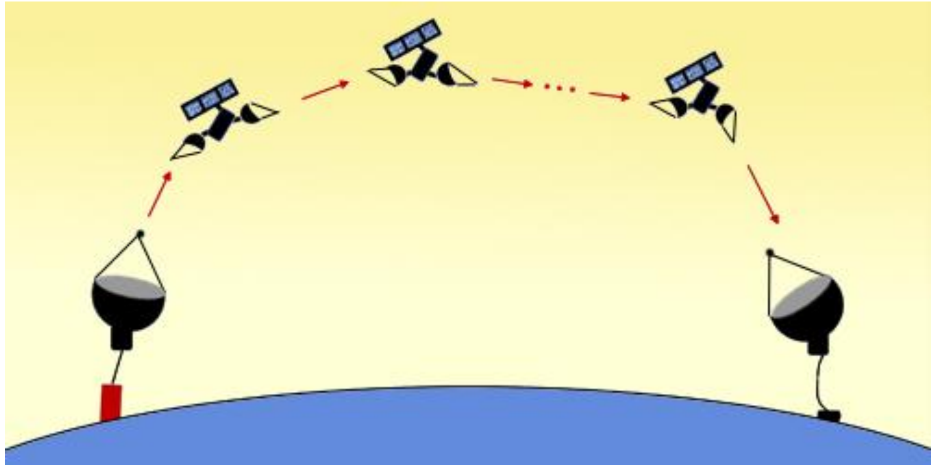


Gonzalez-Raya *et al*. Comm. Physics. **7**:126, 2024



Guccione *et al*. *Sci. Adv.* ***6***, 2020



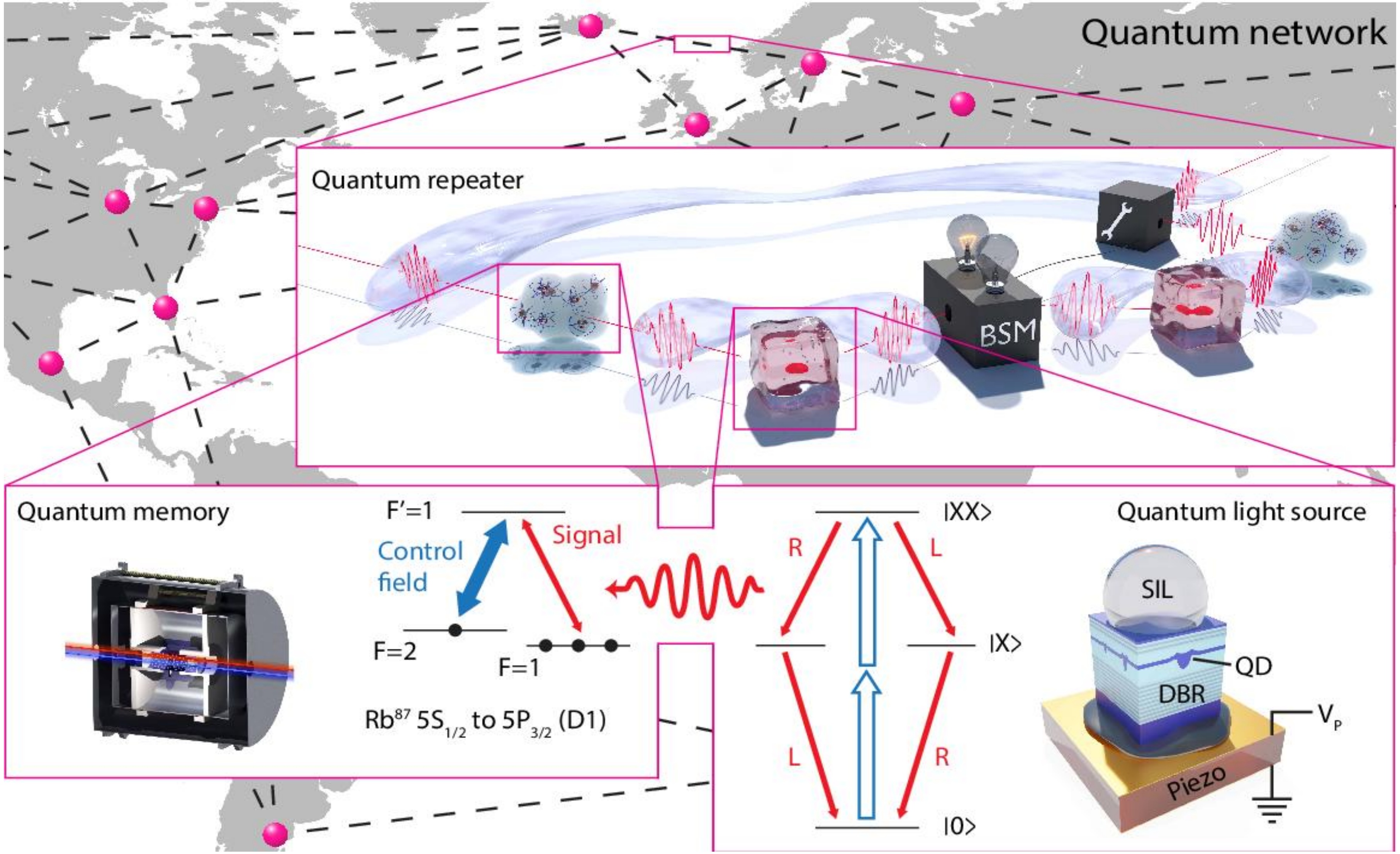


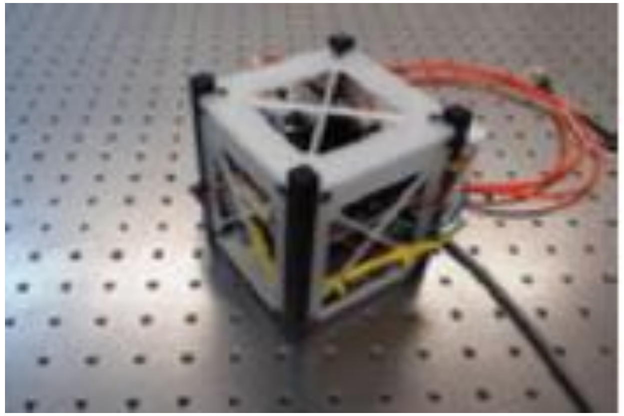
www.qnulabs.com/quantum-communication-satellite-series/

Pain points: quantity and quality of qubits.

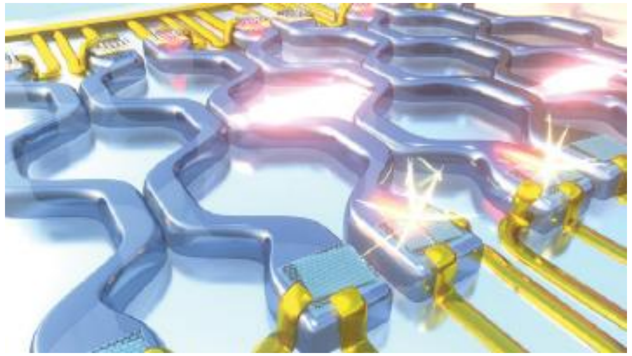
Quantum network for
- distributed quantum computing
- quantum communication/key distribution
- GNSS synchronization and navigation
- network of quantum sensors

Single Photon Source/Quantum Memory

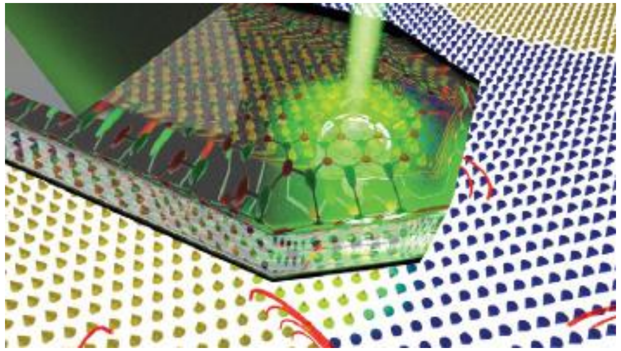




Quantum Communication



Quantum Computing



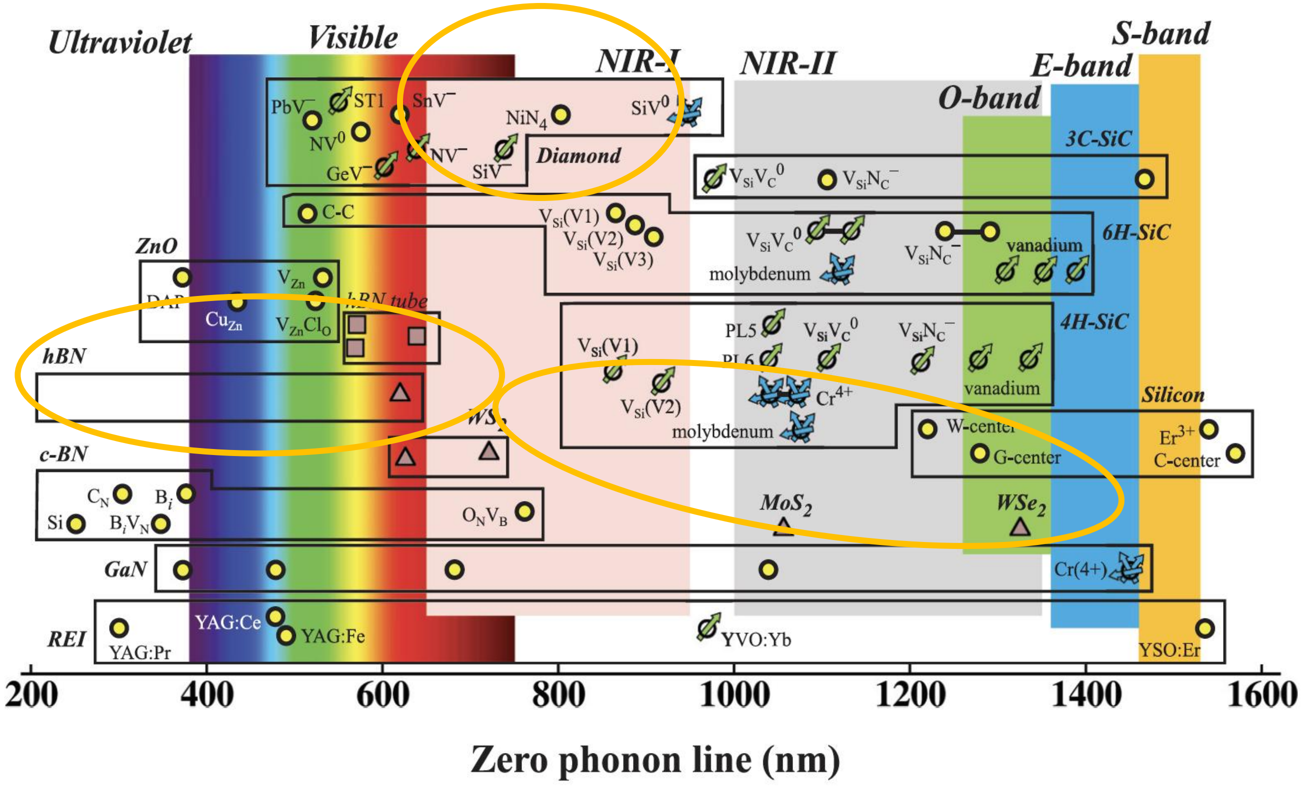
Quantum Sensing

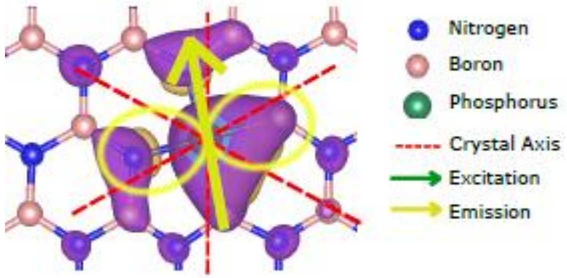
L. Schweickert et al. (2018), arXiv:1808.05921
A. RP. Montblanch, Nat. Nanotechnol. 18, 555–571 (2023).

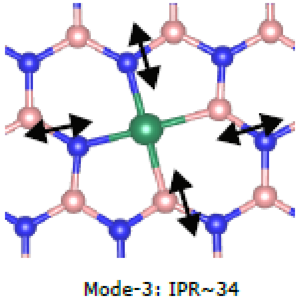
Computational Quantum Materials to Identify SPS/QM

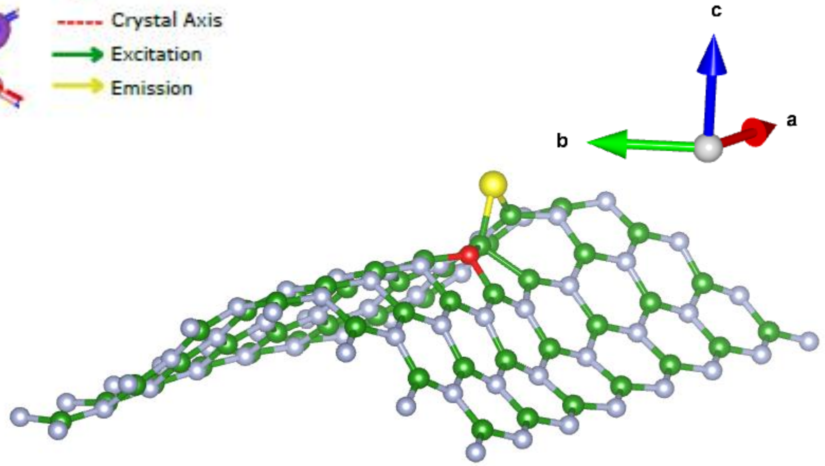
- quantum single photon sources/emitters (SPE/QE)
- quantum memory (QM)
- strain engineering to fine-tune emission wavelength
- light-matter interaction: channeling phonon interaction for ZPL.

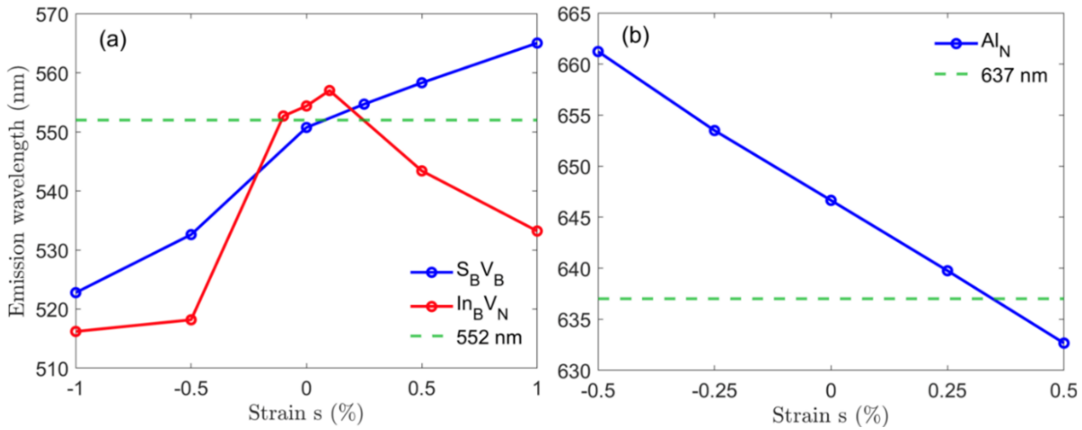
- photo-physical properties, including phonon effects
- engineering parameters/tuning (e.g. using strain, …)
- environmental effects (thermal effect, decoherence,…)







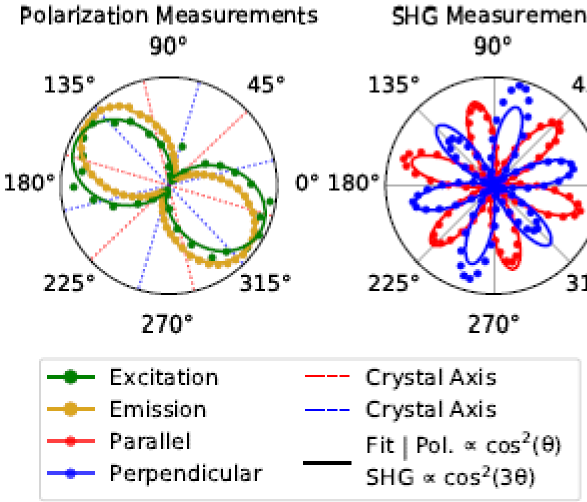


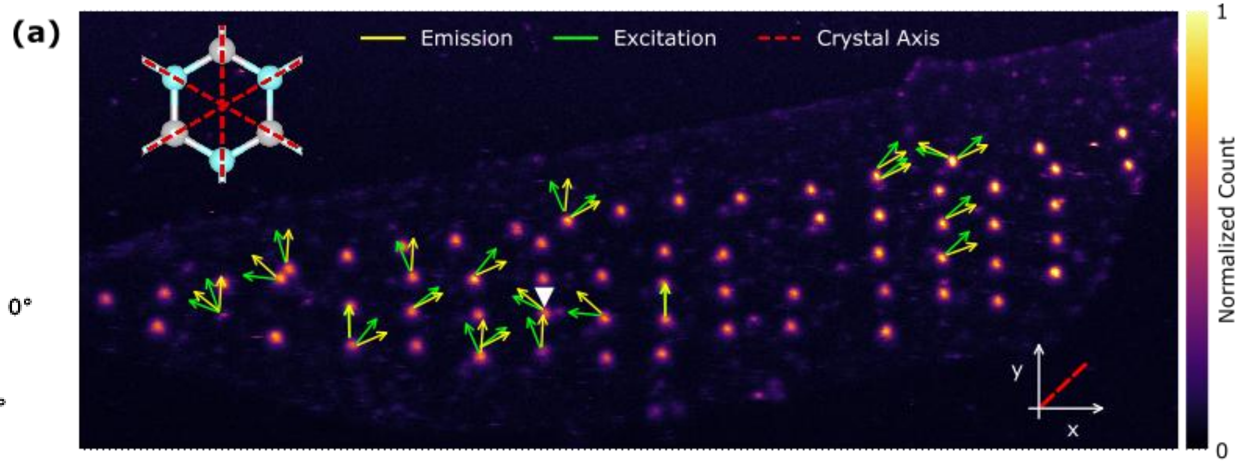


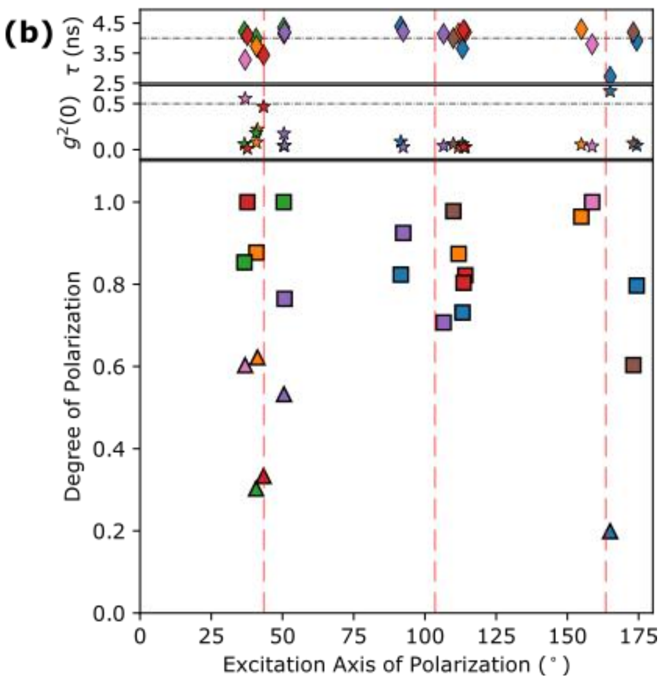
Zhang, G., et al. (2020). *Applied Physics Reviews*, 7, 3.

Experiment: Polarization Dynamics

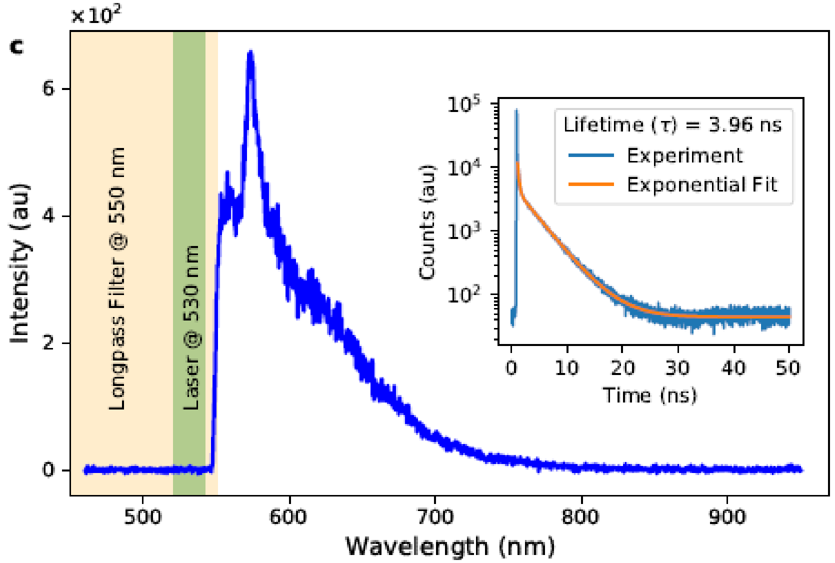
- Experiment done at IQS, FSU-Jena, Germany

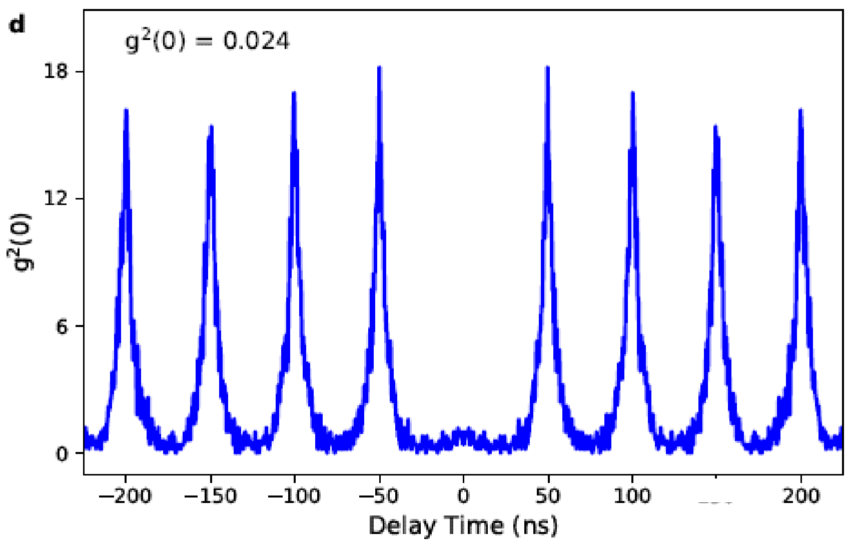


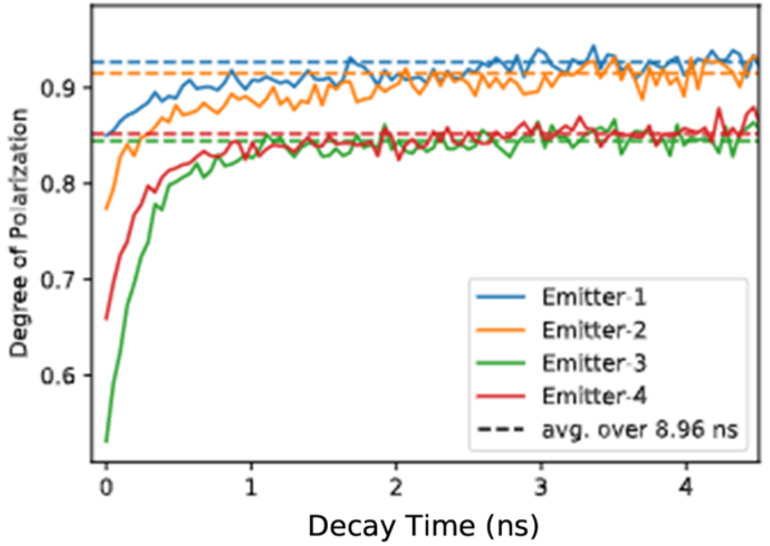




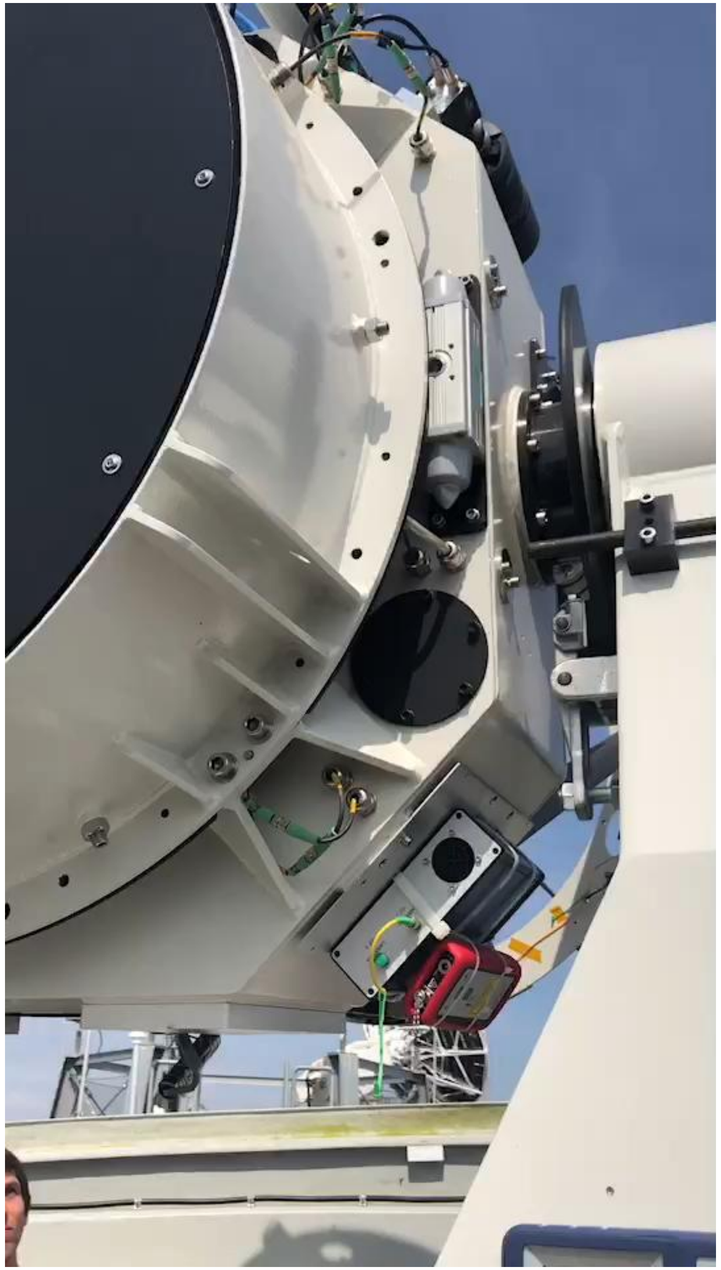
APL Mater **11**, 071108 (2023).
J. Phys. Chem. Lett. **14**, 6564–6571 (2023).
ACS nano **18** (7), 5270–5281 (2024).

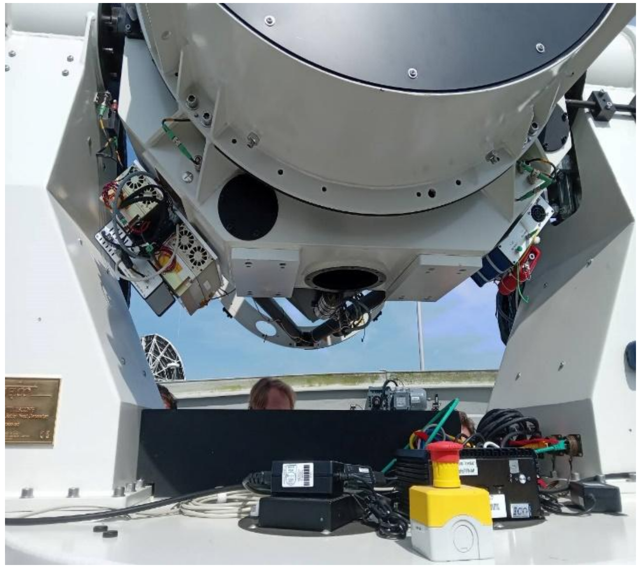


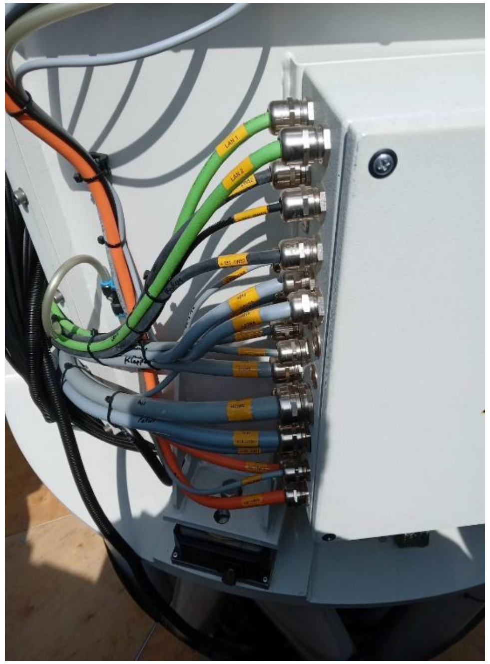


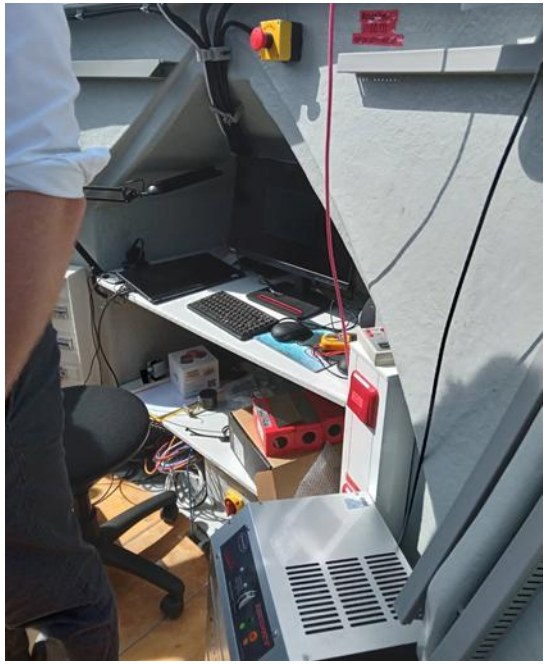


Quantum Network Engineering



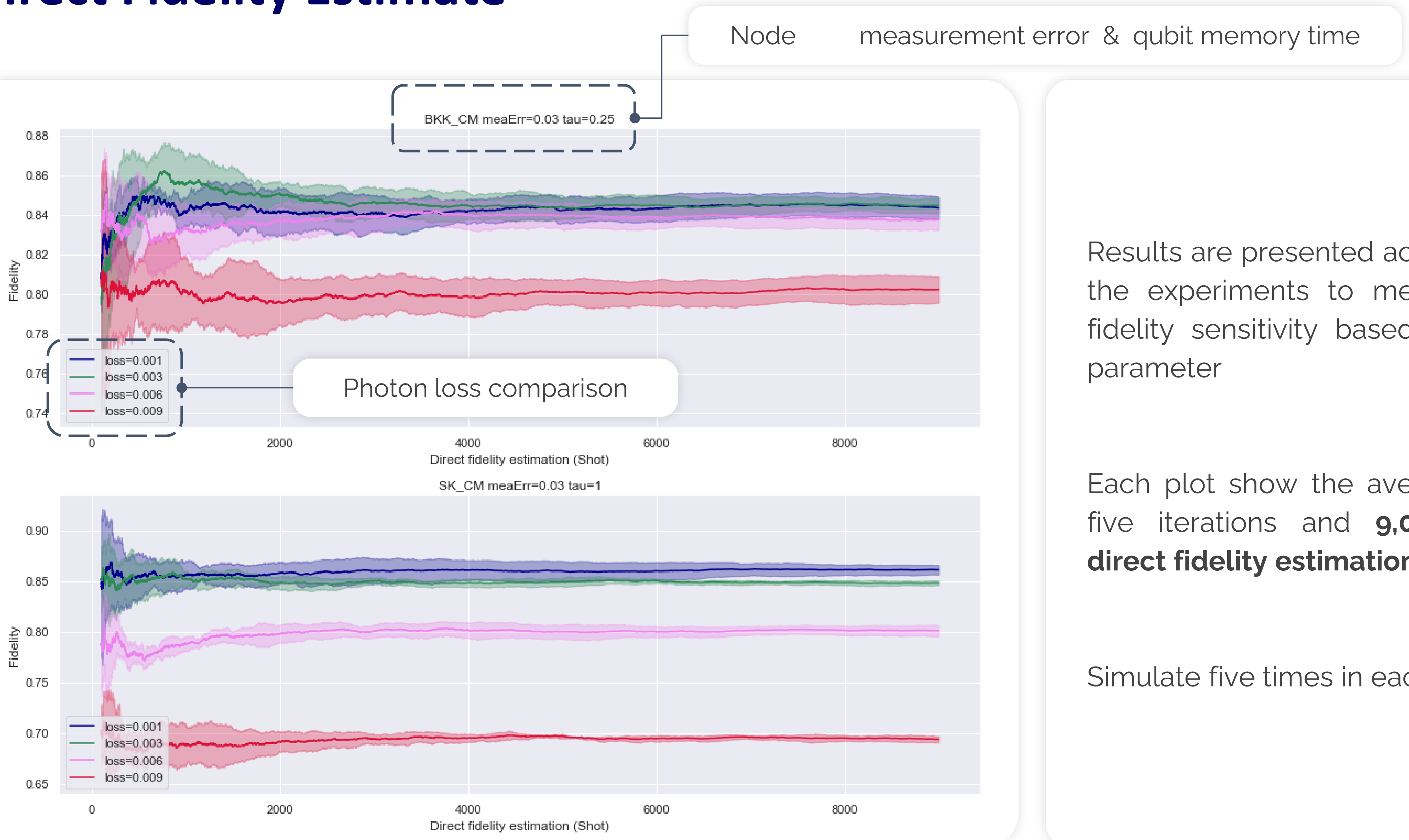






Credit: Deutsches Zentrum fur Luft-und Raumfahrt (DLR), Oberpfaffenhofen

Direct Fidelity Estimate



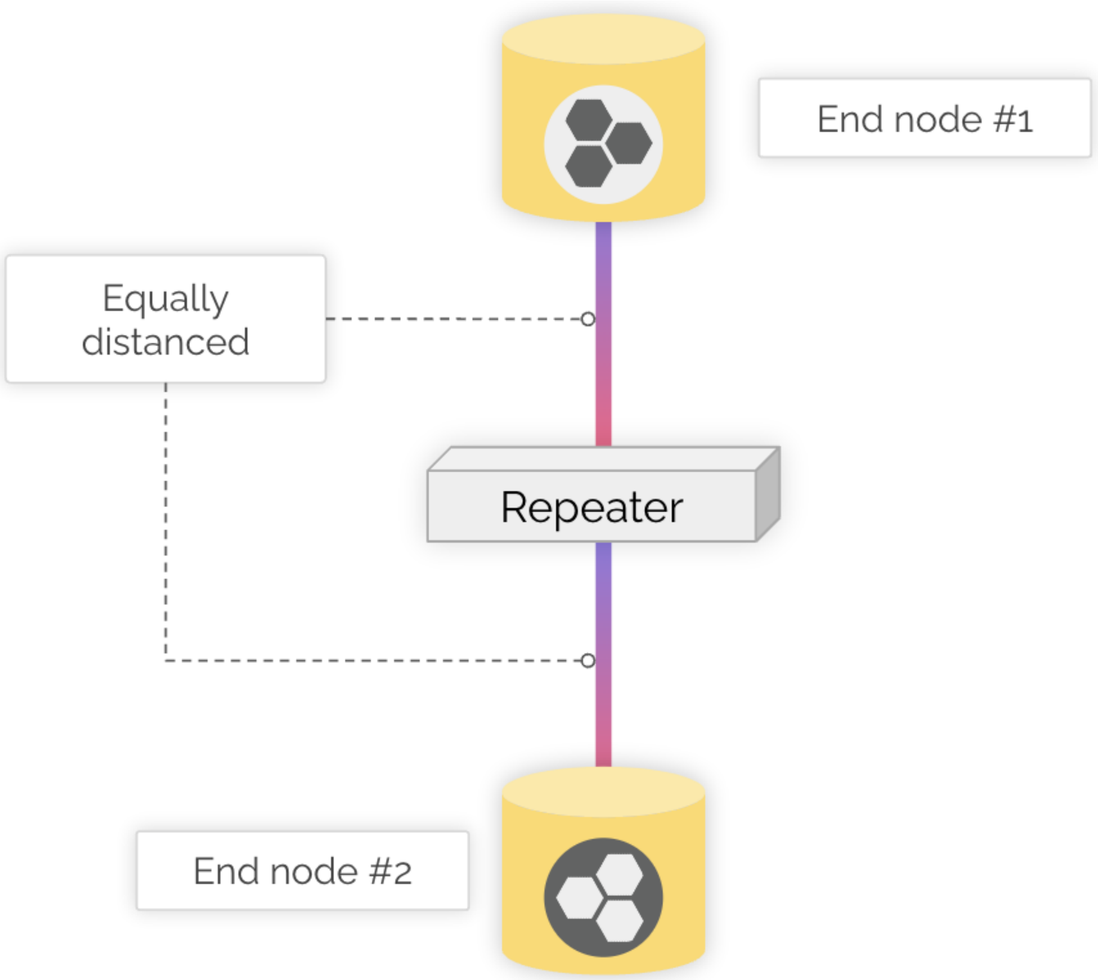
Results are presented according to the experiments to measure the fidelity sensitivity based on input parameter

Each plot show the average form five iterations and **9,000 shots direct fidelity estimation**

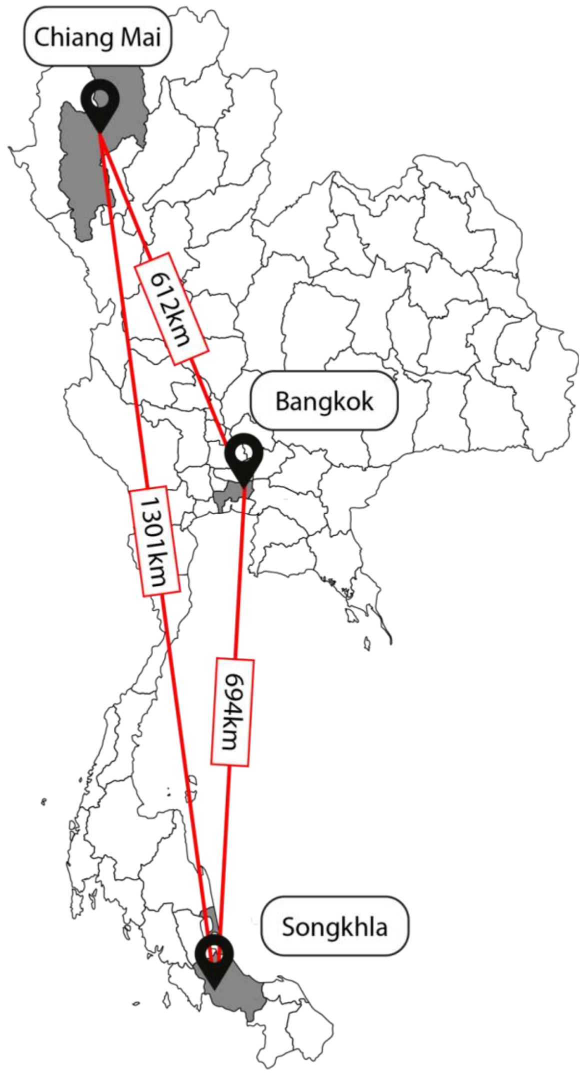
Simulate five times in each case.

Toy Model: Three-Nodes Quantum Network

Equally distanced nodes on a line



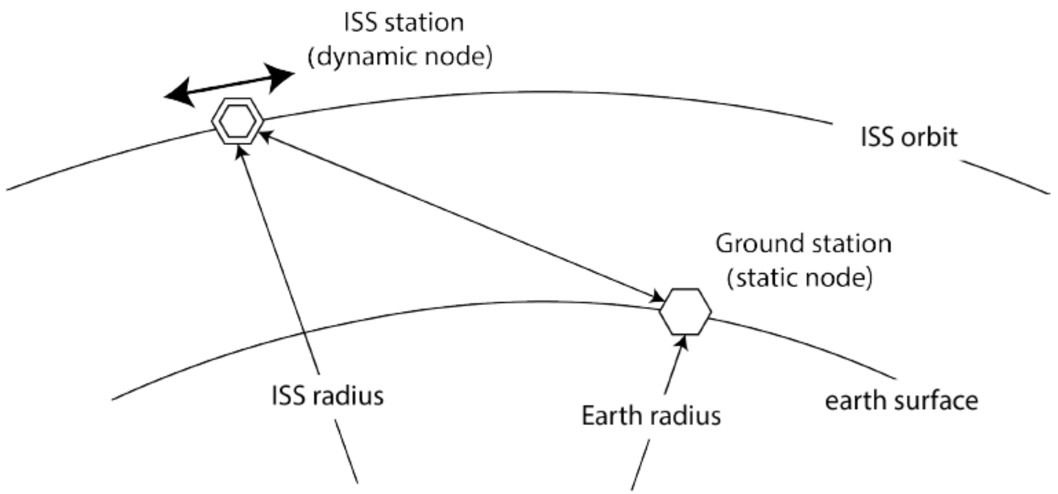
Real locations of three nodes in Thailand



Credit: Poramat Chianvichai

Toy Model: Three-Nodes Quantum Network with Ground Stations

Research model



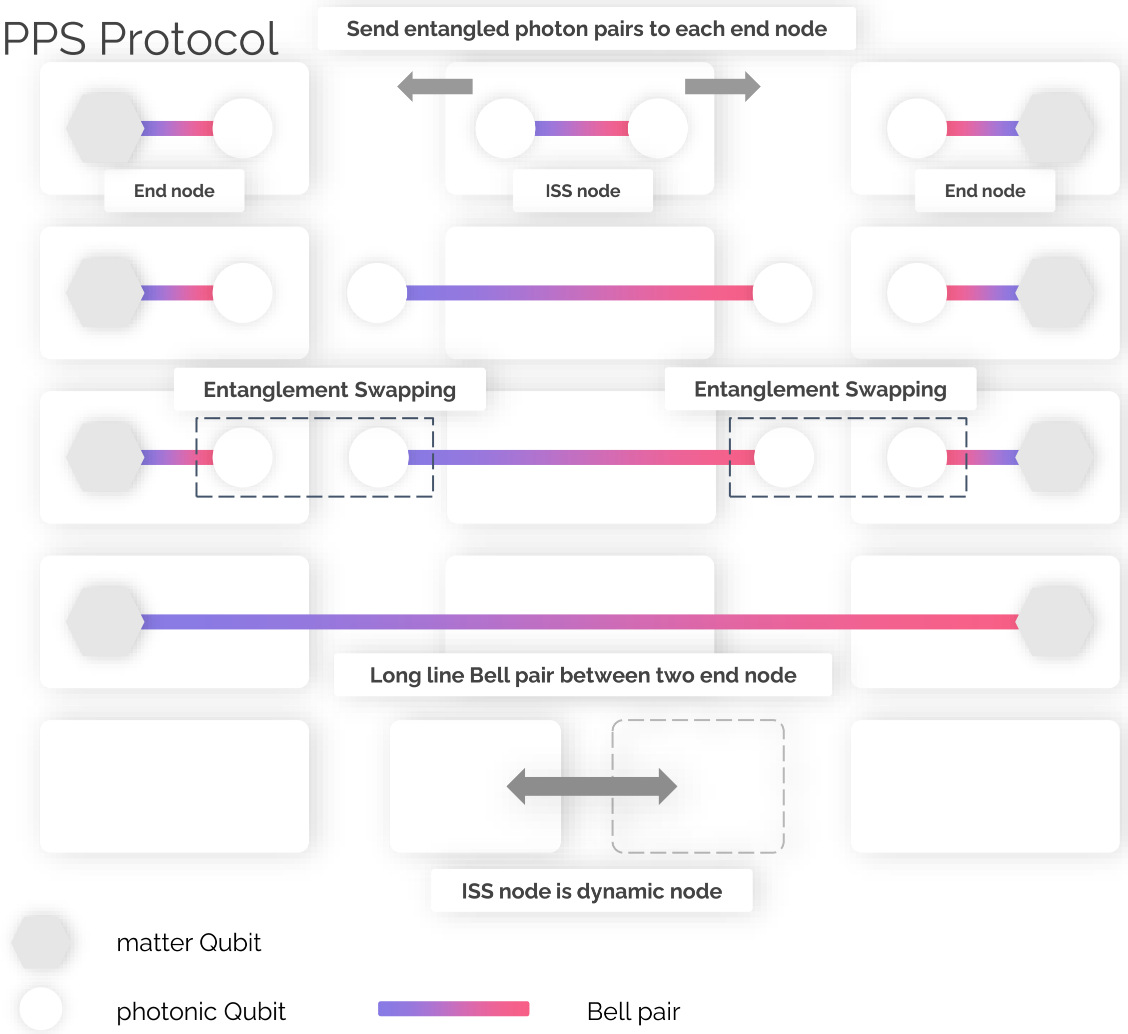
End nodes

- Bangkok
- Songkhla
- Chiang Mai

Middle node

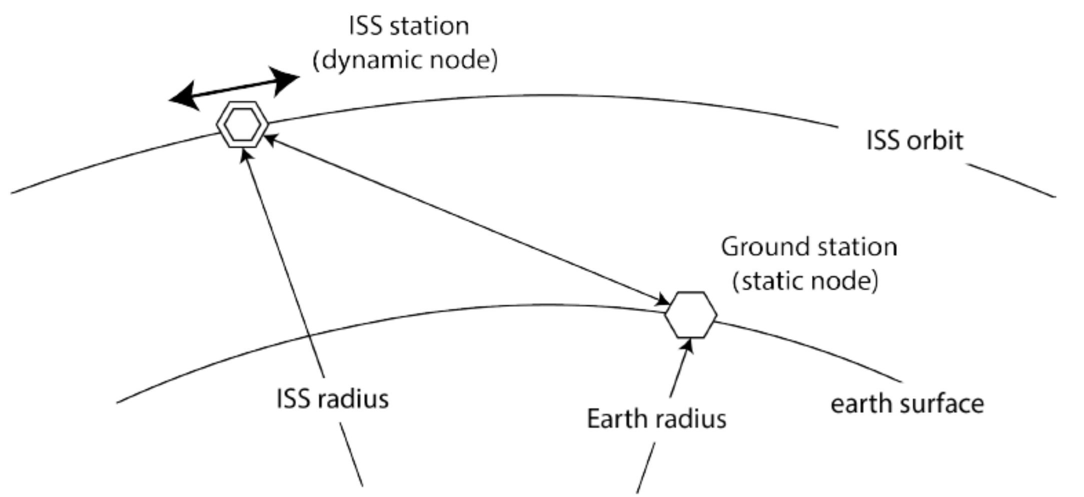
- International Space Station (ISS)

EPPS Protocol



Credit: Poramat Chianvichai

Simulation of Three-Node Network of Thailand



Noise that affect quantum network

- photon loss
- qubit memory time
- measurement error

Indicate with **fidelity**

EPPS model

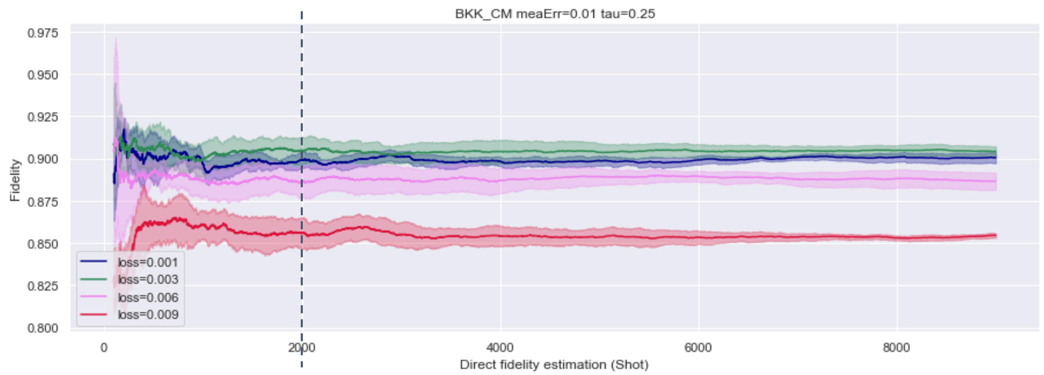
Ground station

- Bangkok
- Songkhla
- Chiang Mai

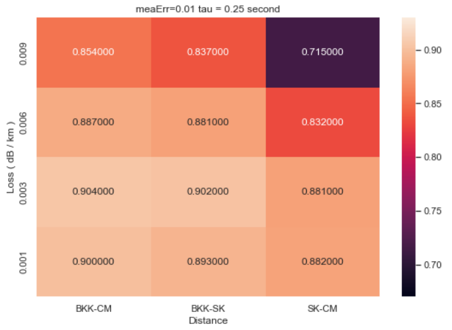
Middle node

- ISS trajectory

With **`qwanta`**, we performed direct fidelity estimation of 9,000 shots to find converged value of the fidelity. However, after 2000 shots, most simulation cases converge to a definite value



After this shots, it seem stable



Credit: Poramat Chianvichai

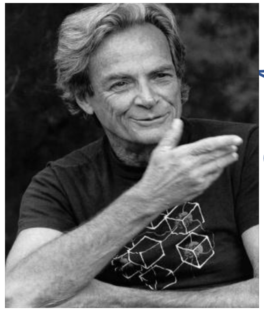
Yielding a minimum threshold of F = 0.71

- Measurement error 0.01
  - good enough for any cases
- Measurement error 0.03
  - SK-CM with 0.009 dB/km loss not good to implement QKD
- Measurement error 0.05
  - SK-CM with 0.009 dB/km loss not good to implement QKD

References

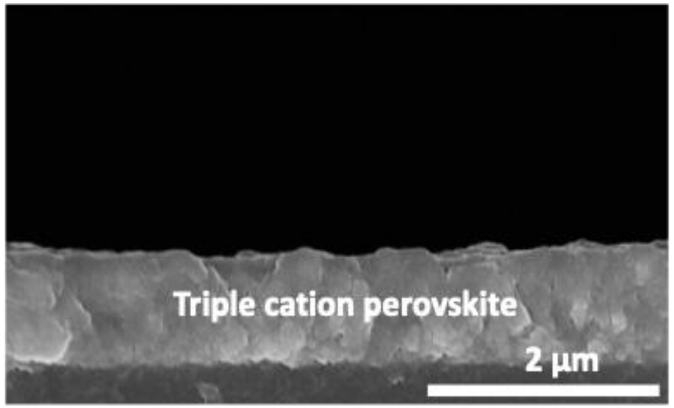
1. C. Cholsuk et al. arXiv:2405.12749v1, hBN defects database at www.h-bn.info
2. T. Nateeboon et al., “Modeling the performance and bandwidth of single-atom adiabatic quantum memories” APL Quantum (2024) 1, 026107.
3. C. Cholsuk et al., “Identifying electronic transitions of defects in hexagonal boron nitride for quantum memories”. Advanced Optical Materials (2024), **12**, 2302760.
4. A. Kumar et al. “Polarization dynamics of solid-state quantum emitters. ACS nano (2024), **18** (7), 5270–5281.
5. C. Kumar et al., “Comparative study of quantum emitter fabrication in wide bandgap materials using localized electron irradiation.” ACS Applied Optical Materials (2023) **2** (2), 323-332.
6. C. Cholsuk et al., “Comprehensive scheme for identifying defects in solid-state quantum systems” J. Phys. Chem. Lett. (2023), **14**, 6564-6571.
7. A. Kumar et al., “Localized creation of yellow single photon emitting carbon complexes in hexagonal boron nitride,” APL Mater (2023), **11**, 071108
8. C. Cholsuk et al., “Tailoring the emission wavelength of color centers in hexagonal boron nitride for quantum applications” Nanomaterials (2022), **12**, 2427.
9. P. Pathumsoot et al., “Modeling of measurement-based quantum network coding on a superconducting quantum processor,” Phys. Rev. A (2020) **101** (5), 052301.
10. P. Pathumsoot et al., "Optimizing Link-Level Entanglement Generation in Quantum Networks with Unequal Link Lengths," 2021 25th International Computer Science and Engineering Conference (ICSEC), Chiang Rai, Thailand, 2021, pp. 179-184.
11. qwanta source at GitHub https://github.com/PorametPat/qwanta

Physics of Computation Conference Endicott House MIT May 6-8, 1981

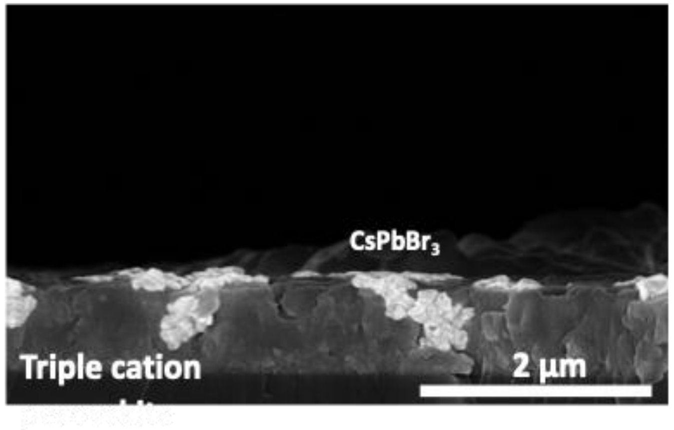


Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.

CsFAMA-based Photodetectors

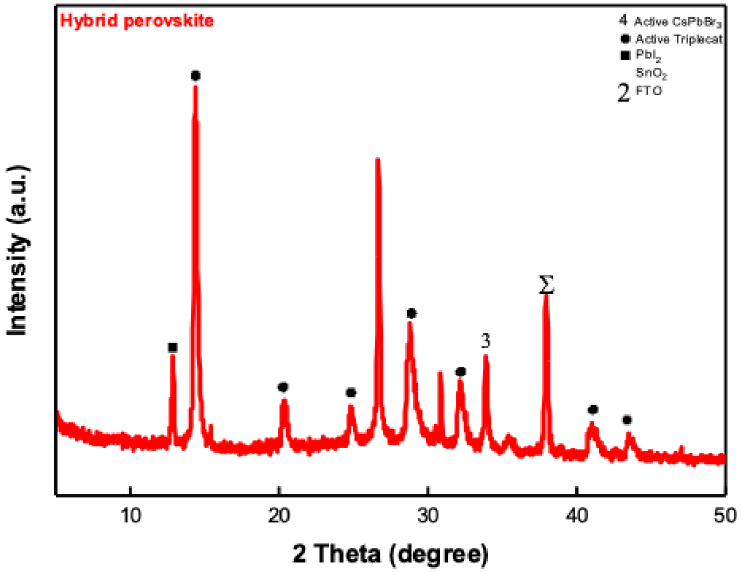


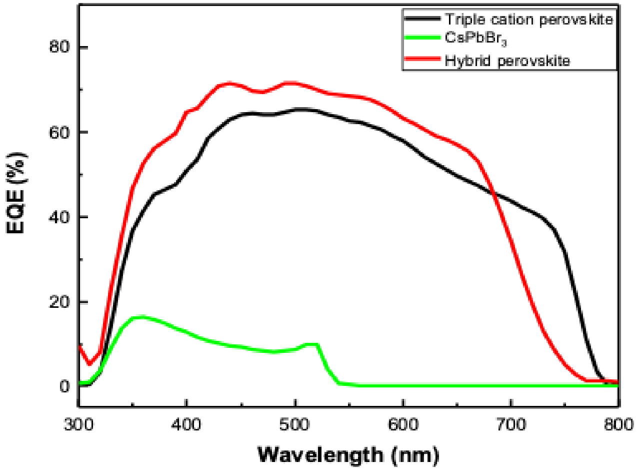
CsFAMA

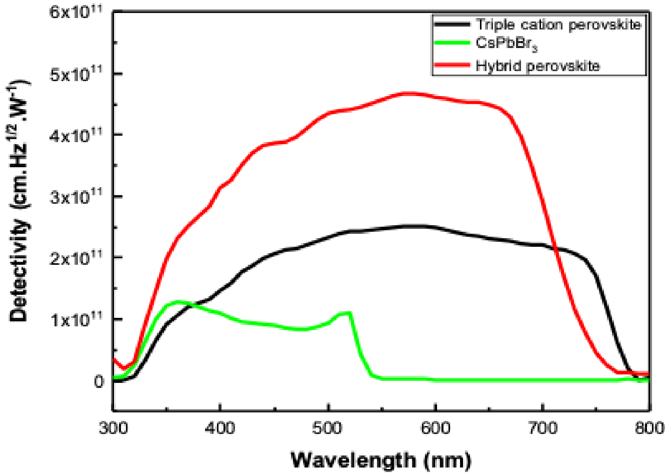


hybrid perovskite

($CsFAMA+CsPbBr_3$)







Light conversion range : 300-750 nm

Quantum Efficiency : 40-70%

P. Ruankham

D. Wongratanapaisan

P. Kanjanabut


IBM Q
System One


IBM Quantum
HERON
133 QUBITS
TUNABLE-COUPLER

Development Roadmap

IBM **Quantum**

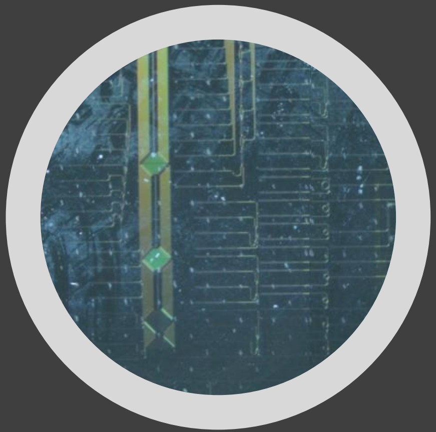
	2016–2019 ✓	2020 ✓	2021 ✓	2022 ✓	2023 ✓	2024	2025	2026	2027	2028	2029	2033+
	Ran quantum circuits on the IBM Quantum Platform	Released multi-dimensional roadmap publicly with initial aim focused on scaling	Enhanced quantum execution speed by 100x with Qiskit Runtime	Brought dynamic circuits to unlock more computations	Enhanced quantum execution speed by 5x with Quantum Serverless and execution modes	Improve quantum circuit quality and speed to allow 5K gates with parametric circuits	Enhance quantum execution speed and parallelization with partitioning and quantum modularity	Improve quantum circuit quality to allow 7.5K gates	Improve quantum circuit quality to allow 10K gates	Improve quantum circuit quality to allow 15K gates	Improve quantum circuit quality to allow 100M gates	Beyond 2033, quantum-centric supercomputers will include 1000's of logical qubits unlocking the full power of quantum computing
Data scientists						Platform						
						Code assistant ◎	Functions	Mapping collections	Specific libraries			General purpose QC libraries
Researchers					Middleware							
					Quantum Serverless ✓	Transpiler service ◎	Resource management	Circuit knitting x p	Intelligent orchestration			Circuit libraries
Quantum physicists			Qiskit Runtime									
	IBM Quantum Experience ✓		QASM 3 ✓	Dynamic circuits ✓	Execution modes ✓	Heron (5K) ◎	Flamingo (5K)	Flamingo (7.5K)	Flamingo (10K)	Flamingo (15K)	Starling (100M)	Blue Jay (1B)
	Early ✓ Canary 5 qubits Albatross 16 qubits Penguin 20 qubits Prototype 53 qubits	Falcon ✓ Benchmarking 27 qubits		Eagle ✓ Benchmarking 127 qubits		Error mitigation 5k gates 133 qubits Classical modular Up to 133x3 = 399 qubits	Error mitigation 5k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 7.5k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 10k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 15k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error correction 100M gates 200 qubits Error corrected modularity	Error correction 1B gates 2000 qubits Error corrected modularity

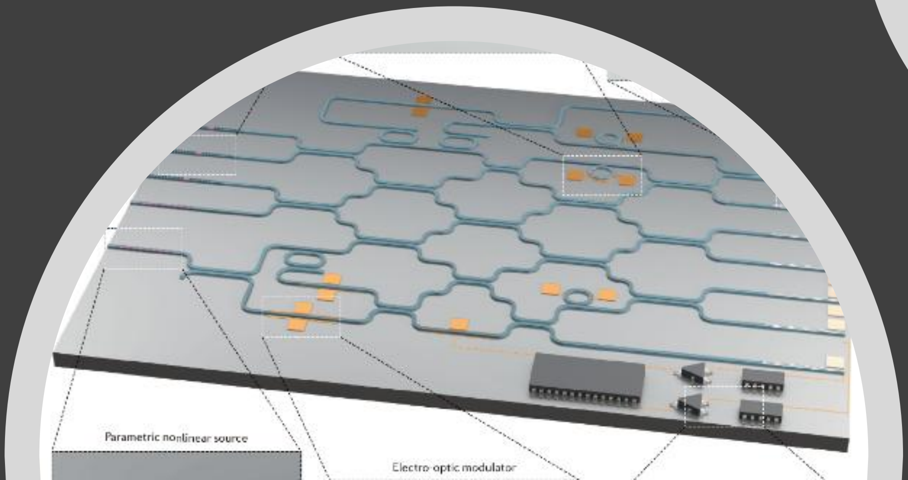
✓ Executed by IBM

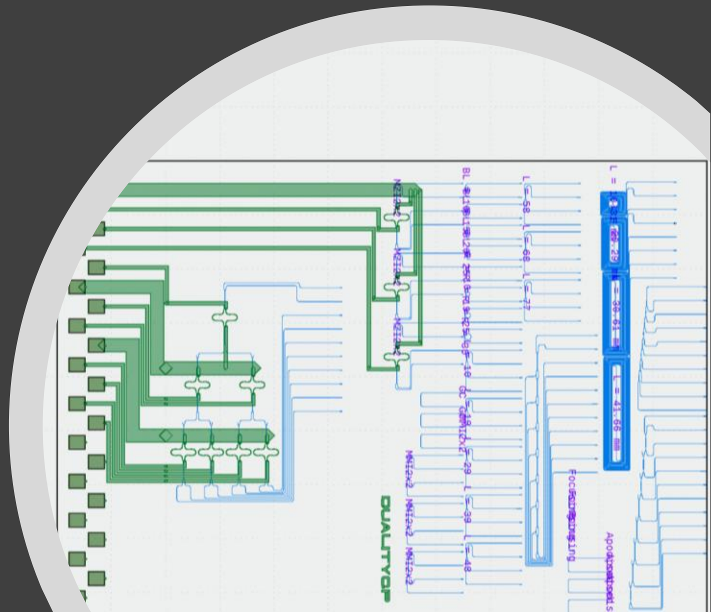
◎ On target

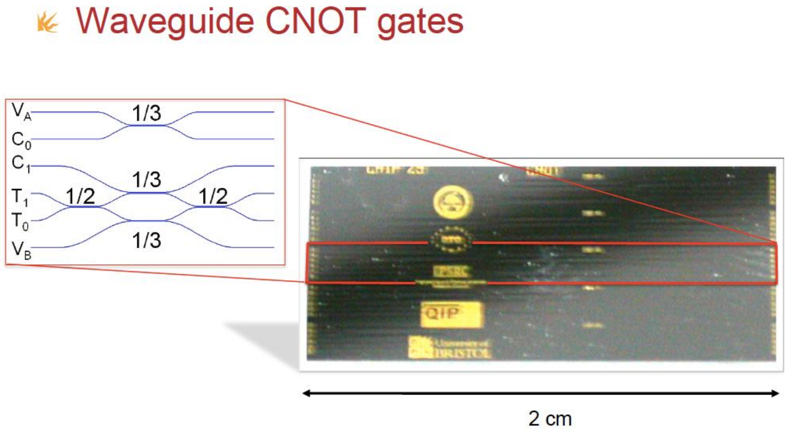
Optical Devices on chips

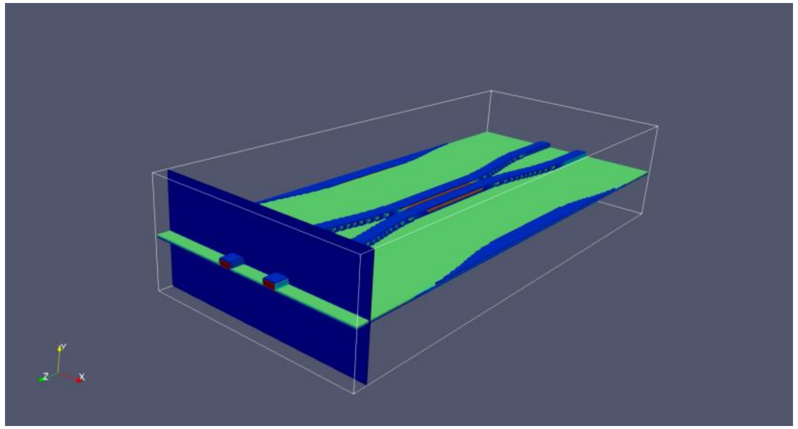
- Quantum gates inside a single chip

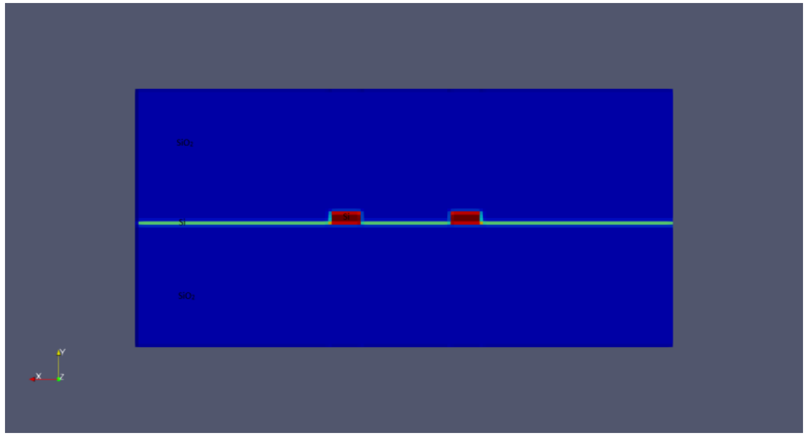


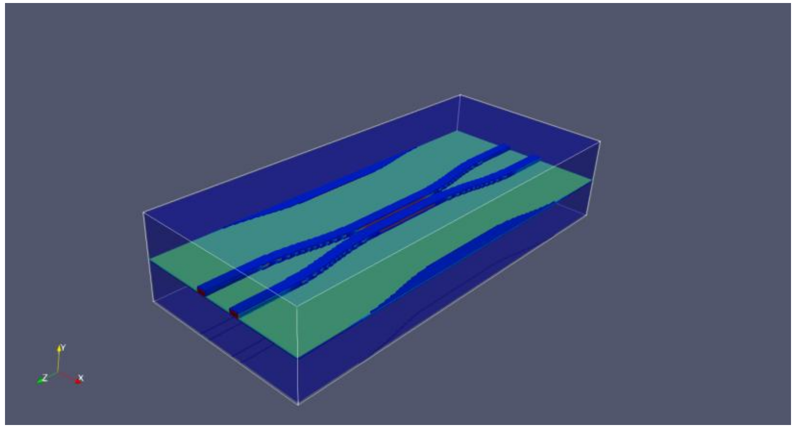












Photonic chip design

Thai-based photonic chip foundry

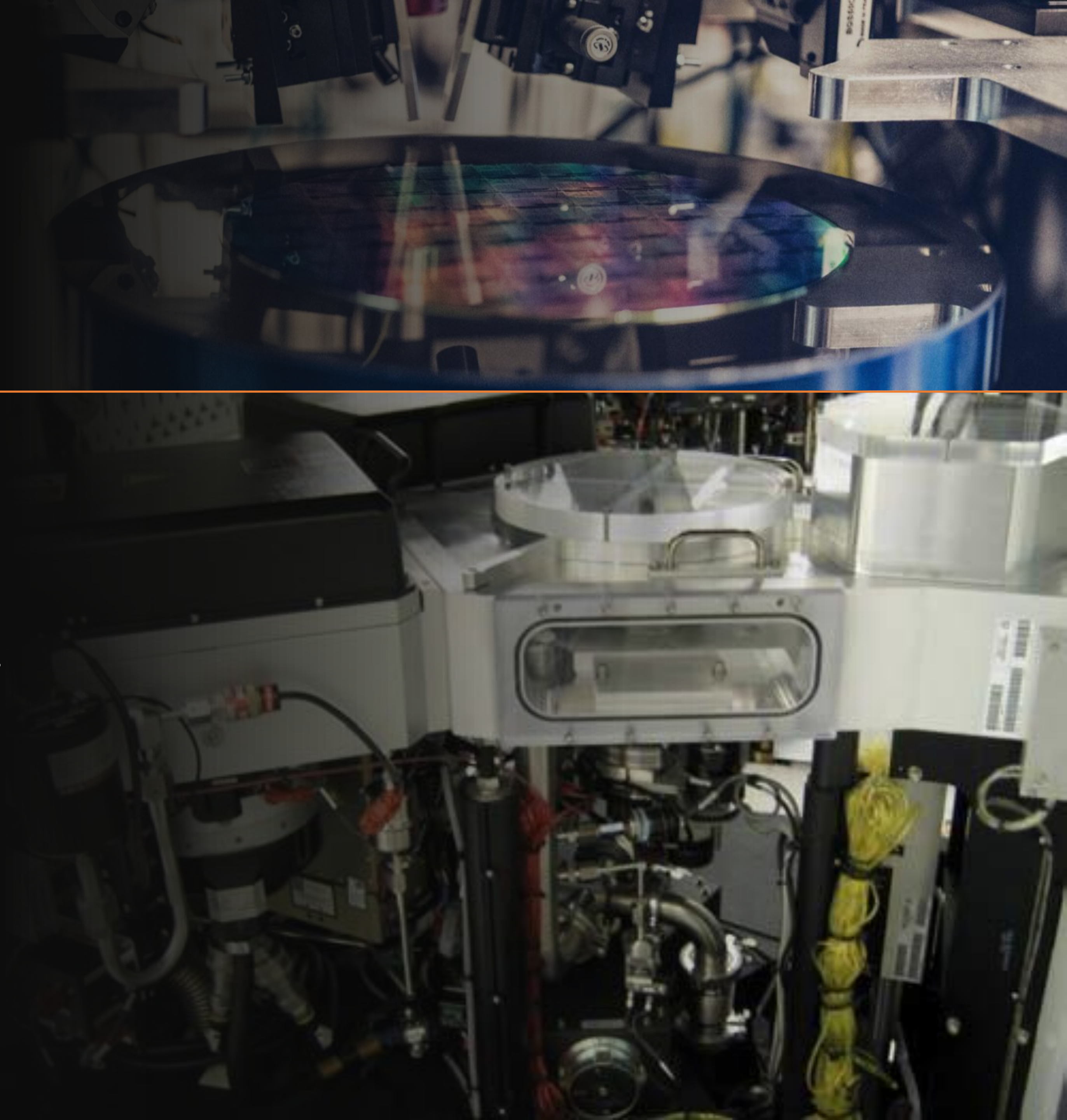
photonic integrated circuits using facilities in Thailand

i. LPCVP : NECTEC

ii. RIE – Reactive Ion Etching : NECTEC

iii. Photo-Lithography : SLRI, PSU, NARIT

iv. PECVD : NECTEC



Photon source for chip technology