SECRET

SECuRe quantum communication based on Energy-Time/time-bin entanglement

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Istituto Nazionale di Fisica Nucleare
Sezione di Padova

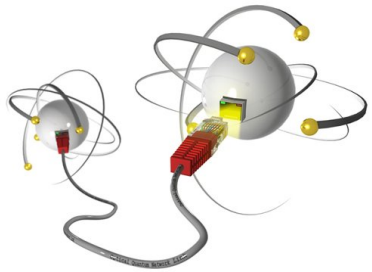
Quantum Technologies within INFN: status and perspectives

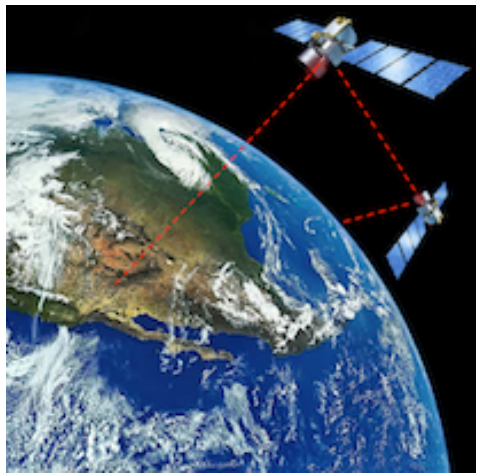
Summary

Summary

What is Quantum Communication?

- Quantum Communications is the ability of faithful transmit quantum states between two distant locations
- Creation of a quantum network
- Applications in security: QKD
- Ground QKD have progressed up to commercial stage using fiber-cables

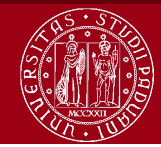




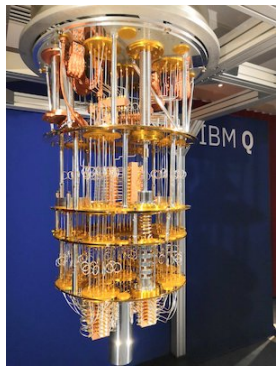
Possible issues with classical cryptography

- Classical cryptography is based on (currently) hard computational problems
- Breakthrough in classical algorithm can broke security

Possible issues with classical cryptography

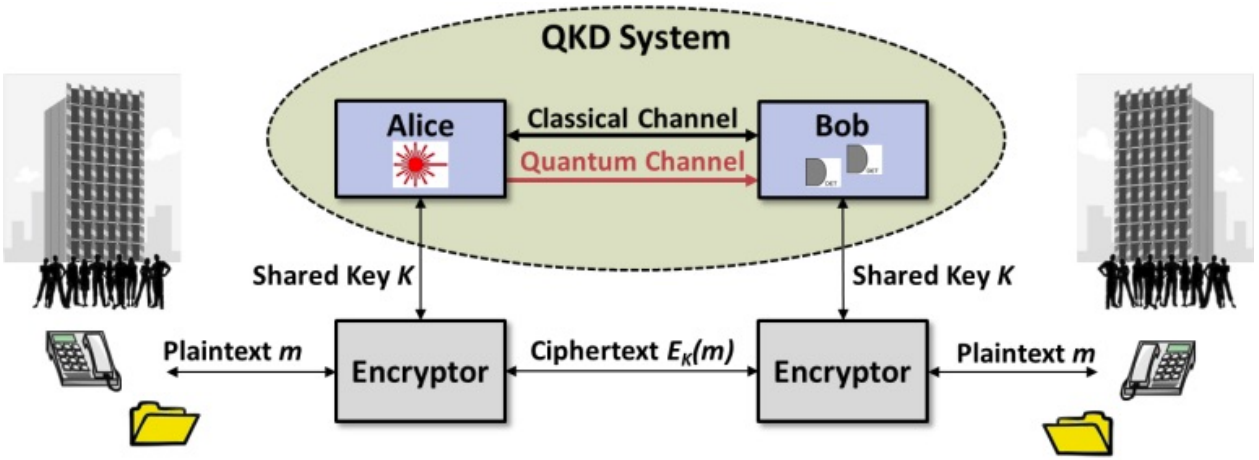


- Classical cryptography is based on (currently) hard computational problems
- Breakthrough in classical algorithm can broke security
- Quantum computer will broke some classical cryptograpic scheme (RSA)



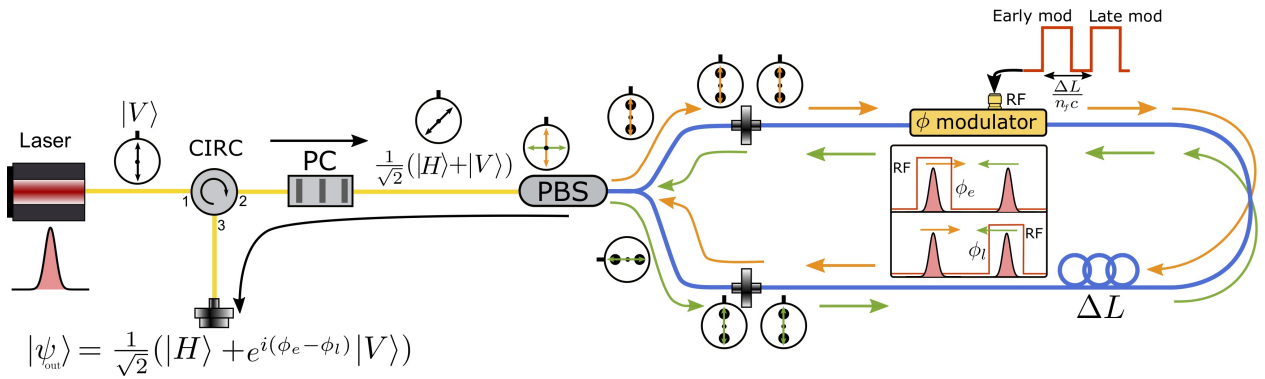
QKD: quantum key distribution

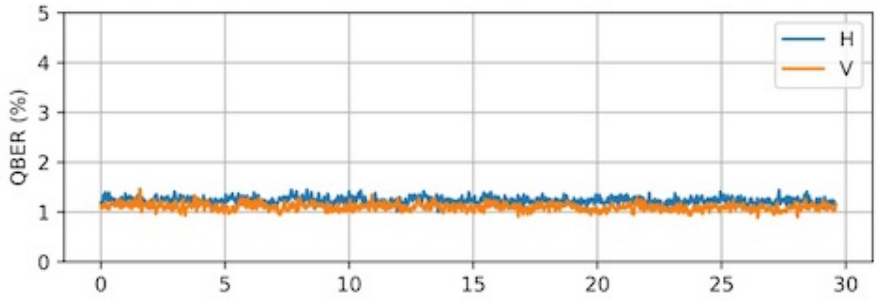
- QKD: security based on physics
- Exploit quantum mechanics laws for establishing secure keys

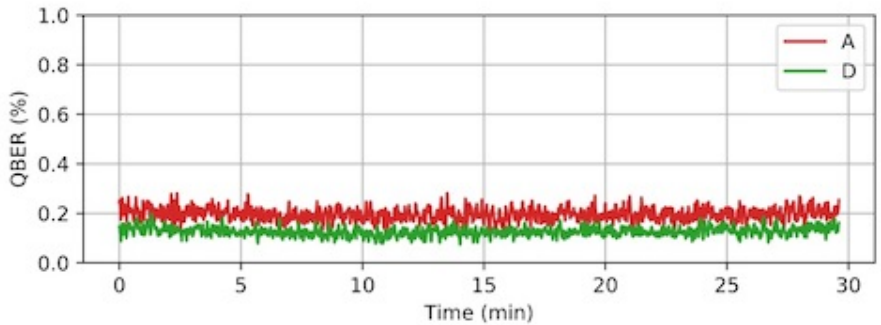


Quantum state encoder

POGNAC = POlarization saGNAC







6 May 2019

OSA The Optical Society | 100 Since 1916

New All-Fiber Device Simplifies Free-space Based Quantum Key Distribution

Robust encoder switches polarization 1 billion times a second; could facilitate global quantum encryption network

ScienceDaily

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New all-fiber device simplifies free-space based quantum key distribution

Robust encode
bal quantum en

Date: May 6

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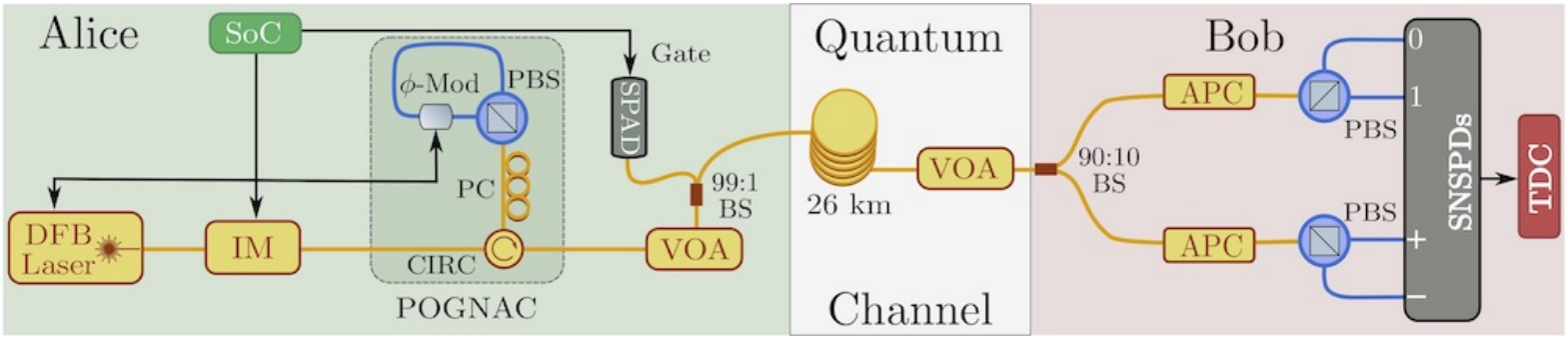
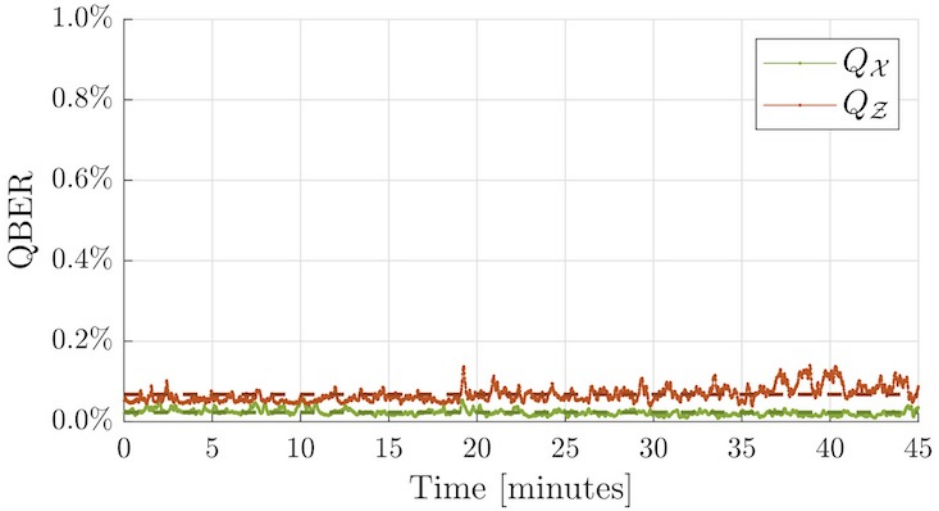
New all-fiber device simplifies free-space based quantum key distribution

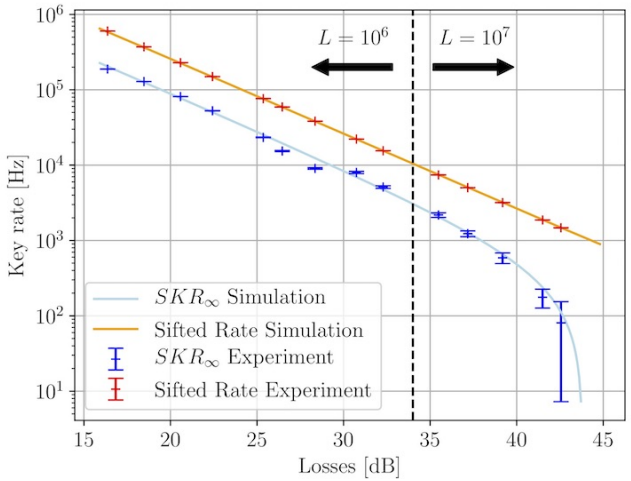
6 May 2019

C. Agnesi, M. Avesani, A. Stanco, P. Villoresi, **GV**, *Optics Letters 44, 2398 (2019)*

Test with fiber-link







- Lowest intrinsic QBER ever reported (<0.07%)

C. Agnesi, *et. al.* **[arXiv: 1909.12703]**

Summary

QuantERA project

SECRET

Secure quantum communication based on energy-time/time-bin entanglement

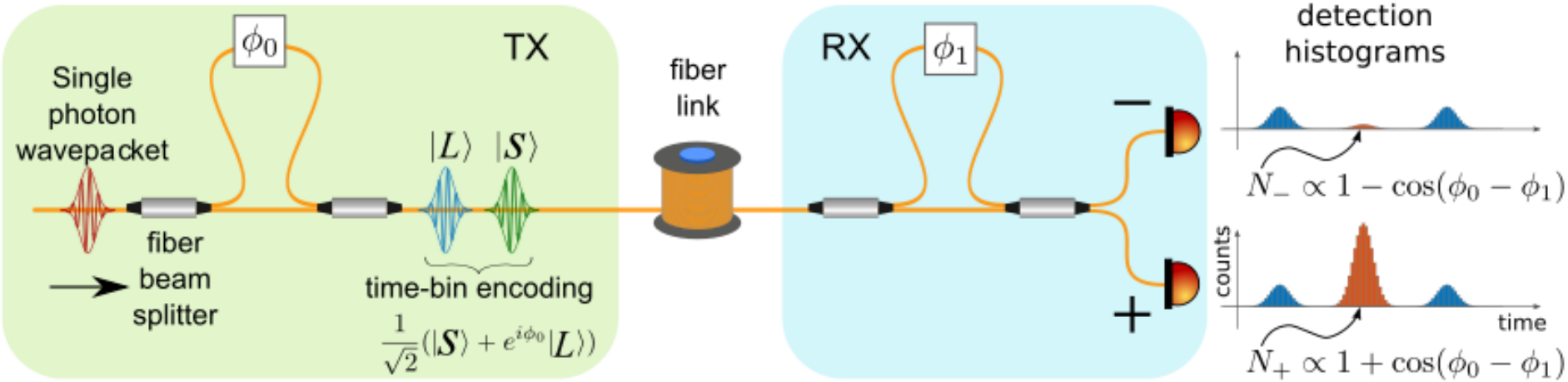
Partners:

- PI: Linköping University - **Sweden**
- INFN/UniPD - **Italy**
- Universidad de Sevilla - **Spain**

Time-bin encoding

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|S\rangle + e^{i\phi_0}|L\rangle)$$

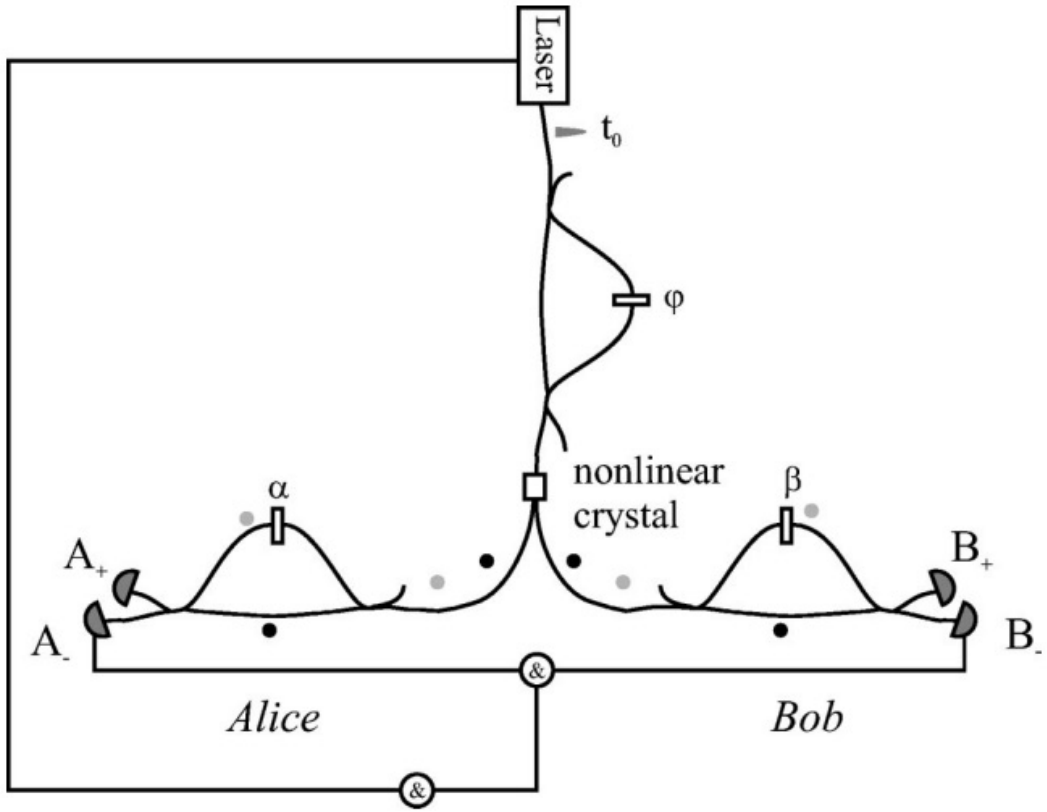
Relative phase to encode the qubit



Time-bin is robust in fiber-optic propagation!

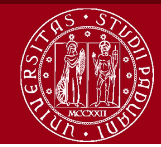
Time-bin entanglement

time-bin entanglement: $|\psi\rangle = \frac{1}{\sqrt{2}}(|S\rangle_A|S\rangle_A + e^{i\phi}|L\rangle_A|L\rangle_B)$



Phys. Rev. A 66, 062308 (2002)

Time-bin Bell's inequality loophole



- Bell's inequality: if violated, the experiment cannot be described by a local deterministic theory.

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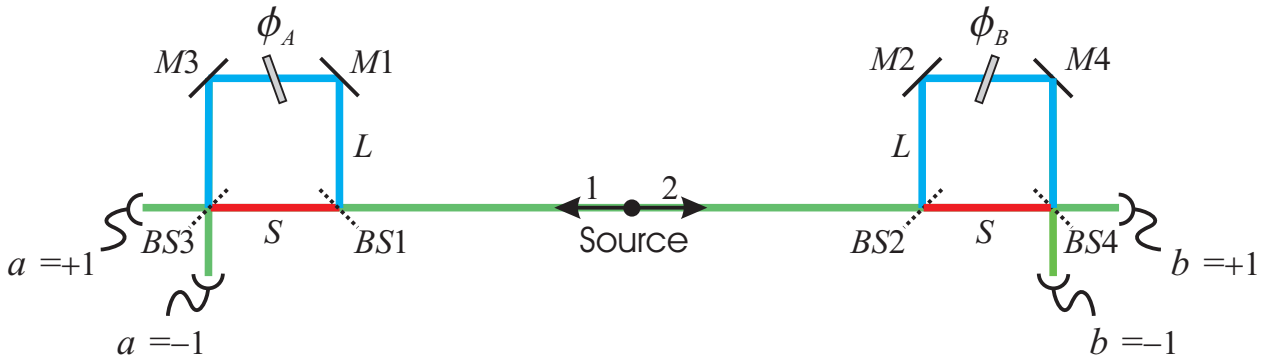
- loophole for time-bin entanglement: the subensemble of selected events can depend on the phase settings



S. Aerts, P. G. Kwiat, J.-Å. Larsson, and M. Zükowski, Phys. Rev. Lett. 83, 2872 (1999)

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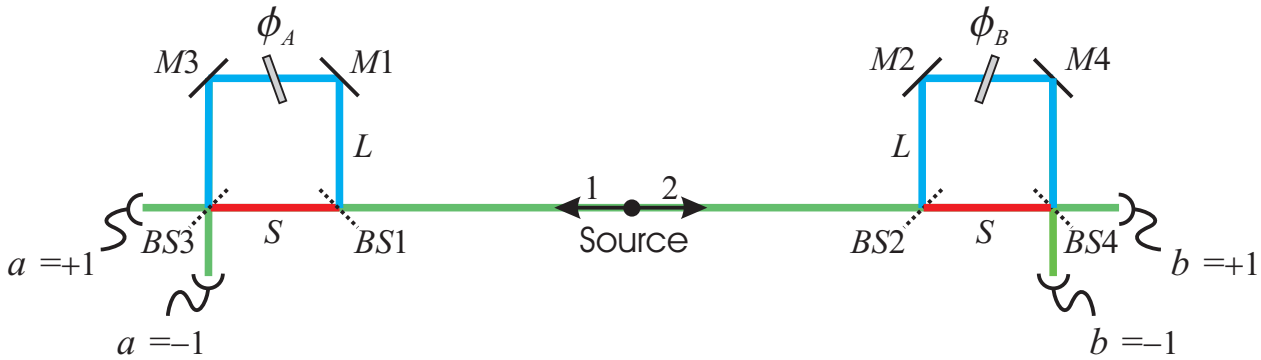
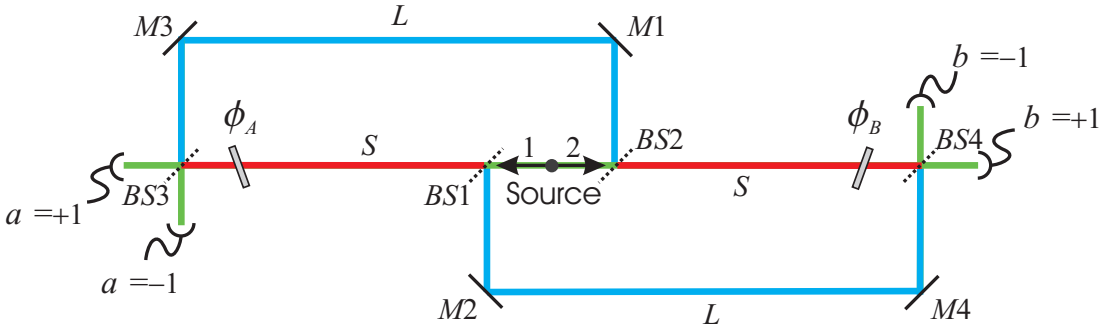


S. Aerts, P. G. Kwiat, J.-Å. Larsson, and M. Zükowski, Phys. Rev. Lett. 83, 2872 (1999)

- classical model is possible due to post-selection.

Removing the loohole



A. Cabello, A. Rossi, **GV**, F. De Martini, P, Mataloni

Phys. Rev. Lett. 102, 040401 (2009)

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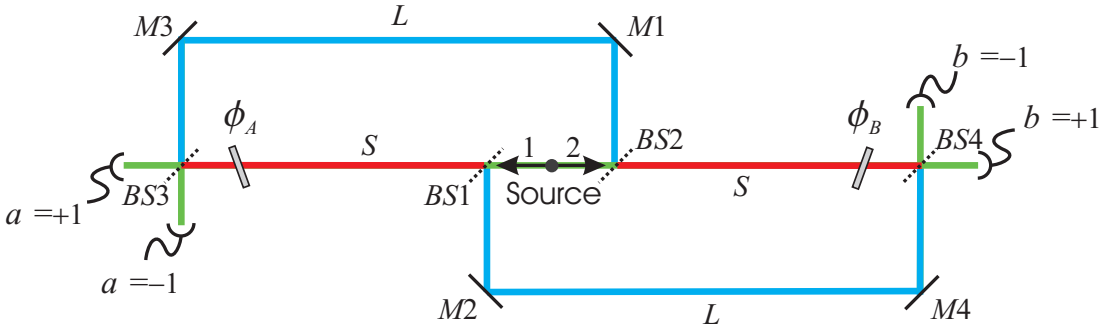

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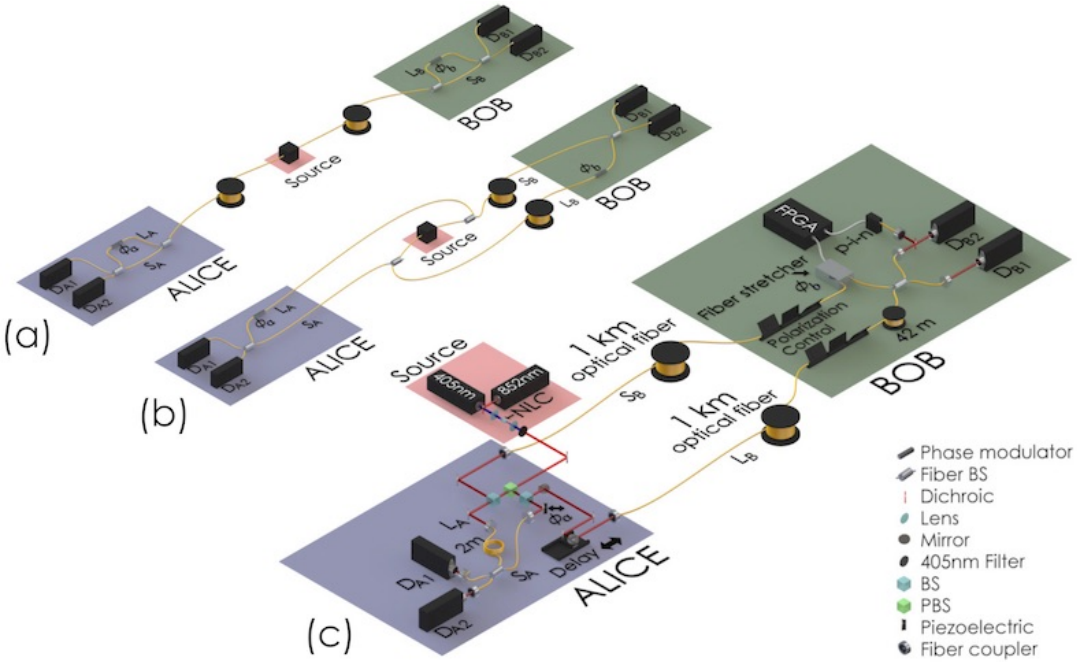
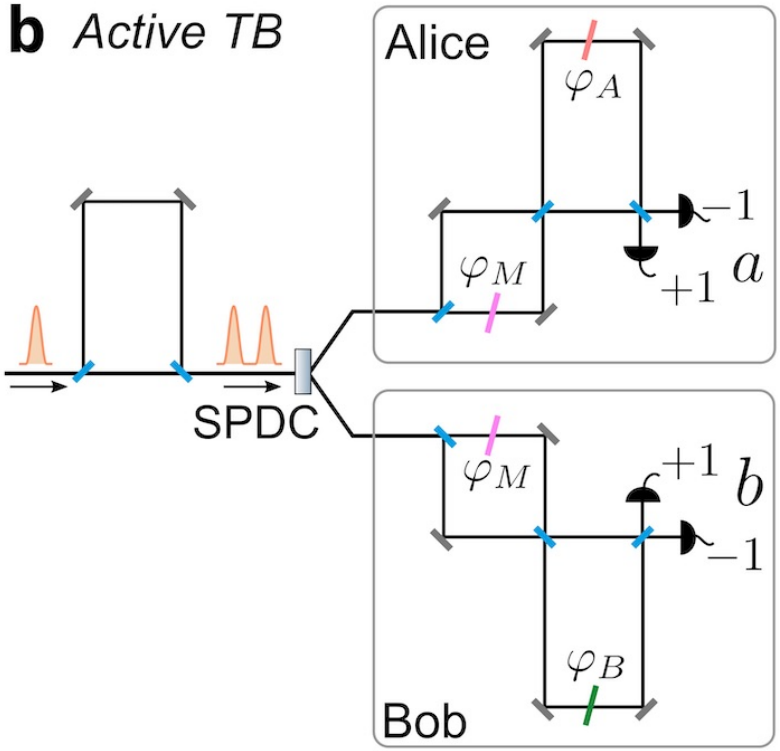
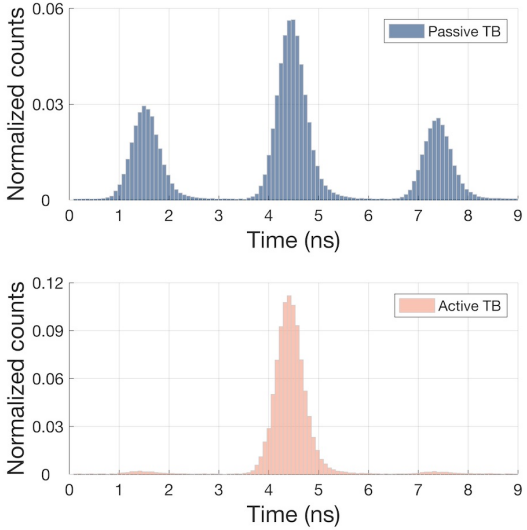


Nat. Commun. 4, 2871 (2013)
Phys. Rev. Lett. 115, 030503 (2015)

New post-selection free

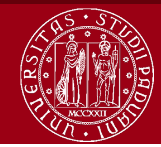
Post-selection-loophole-free Bell violation
with genuine time-bin entanglement





F. Vedovato, et al., Phys. Rev. Lett. 121, 190401 (2018)

SECRET project



So far, only Bell's inequality violation with genuine time-bin entanglement

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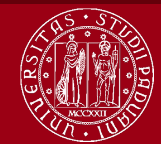

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Main target of SECRET:
genuine energy-time entanglement-based quantum communication applications

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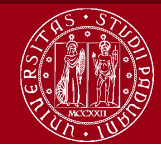


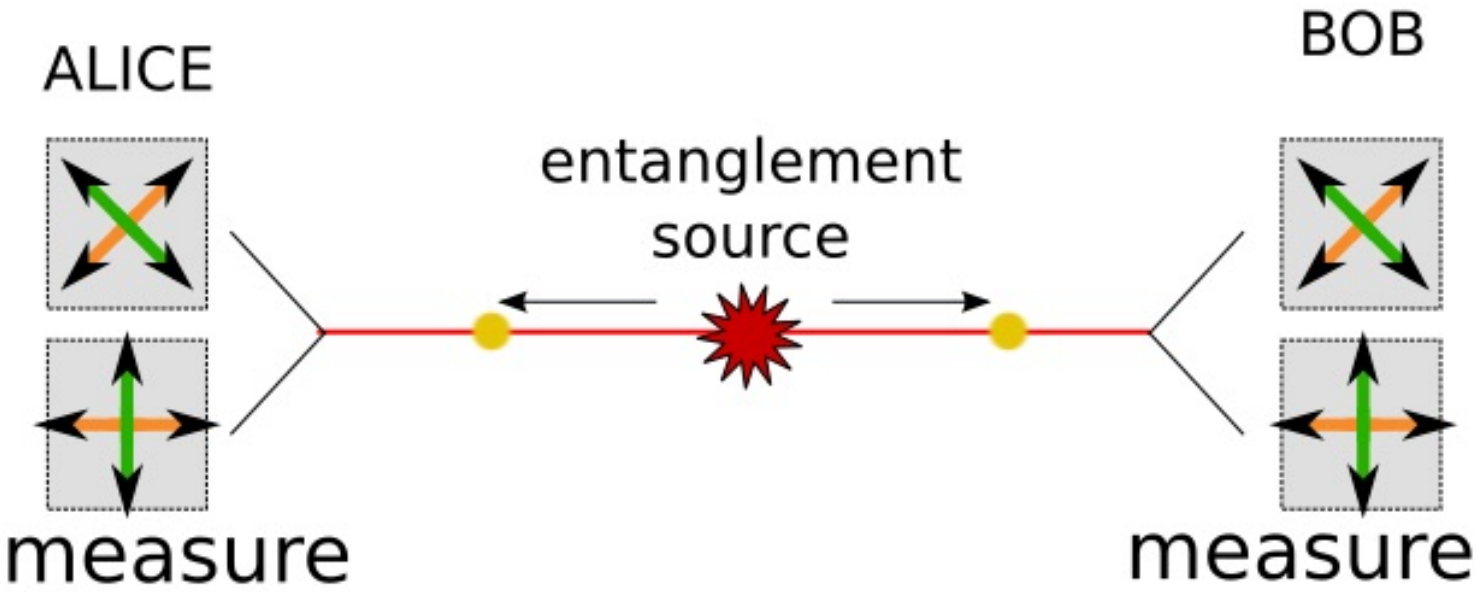
So far, only Bell's inequality violation with genuine time-bin entanglement

Main target of SECRET:
genuine energy-time entanglement-based
quantum communication applications

- **Objective 1**: Quantum communication
- **Objective 2**: entanglement swapping and/or teleportation
- **Objective 3**: integrated photonics technology

Objective 1

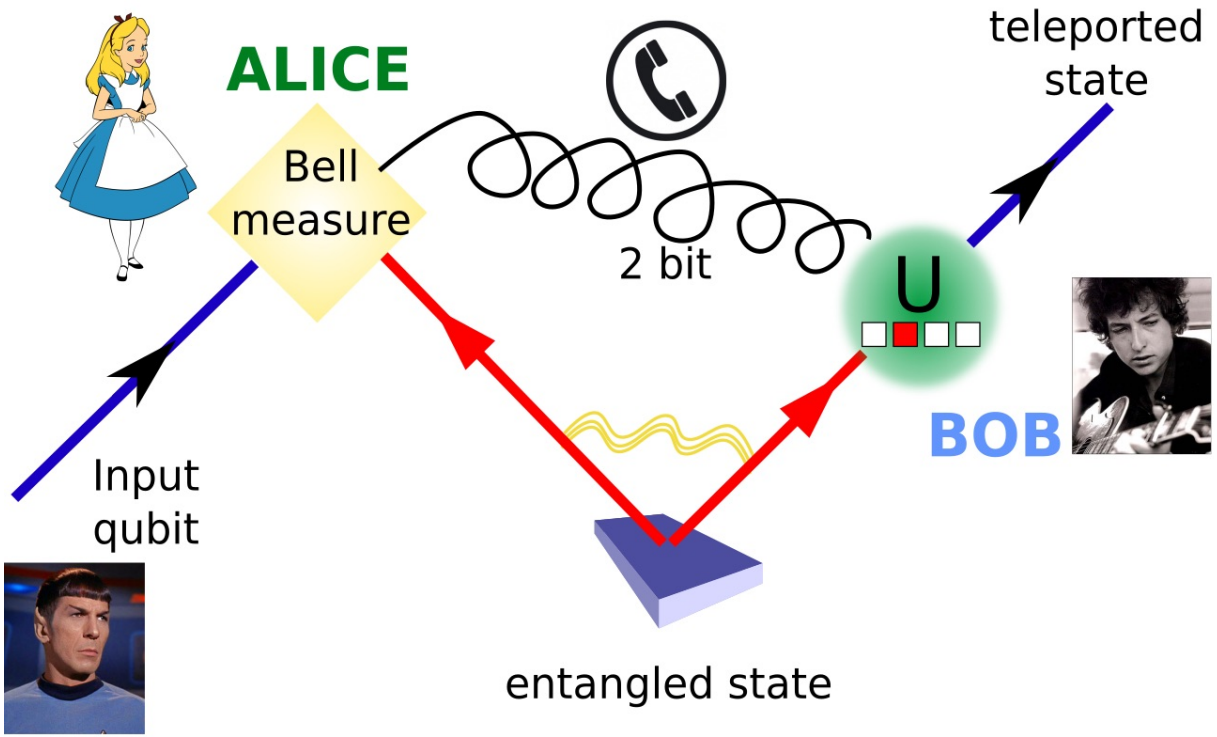
Quantum communication exploiting
ET entanglement without post-selection loophole



QKD by entangled photons with untrusted entangled-source

Objective 2

Development of novel building blocks based on genuine energy-time entanglement: entanglement swapping and/or teleportation



Objective 2

Development of novel building blocks based on genuine energy-time entanglement: entanglement swapping and/or teleportation

entanglement between particles that never interact

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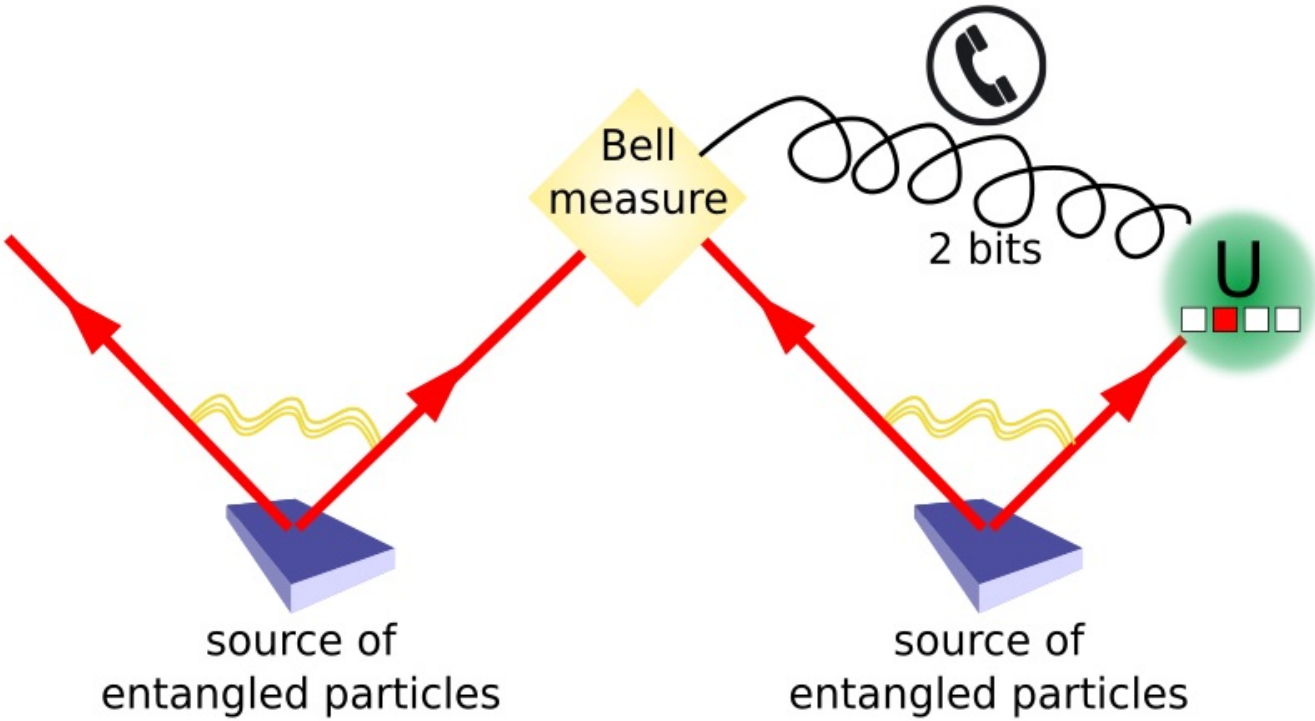
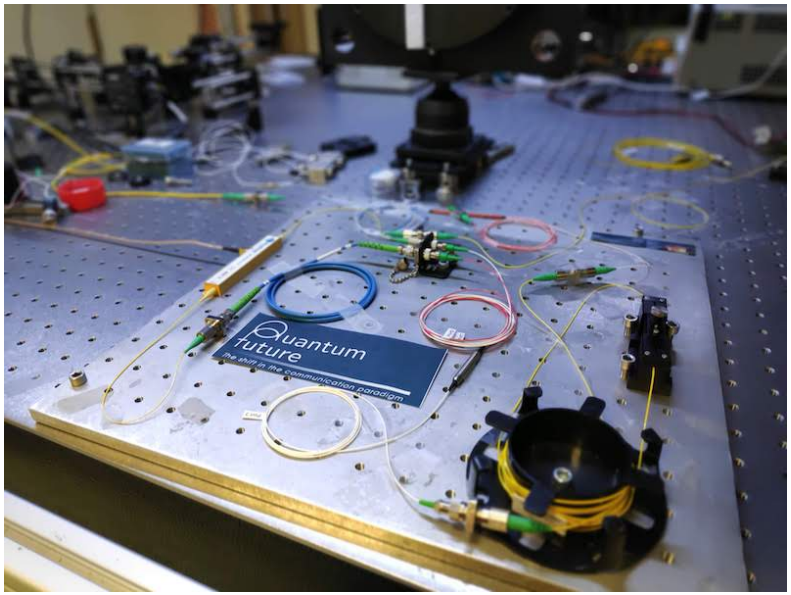
Development of novel building blocks based on genuine energy-time entanglement: entanglement swapping and/or teleportation

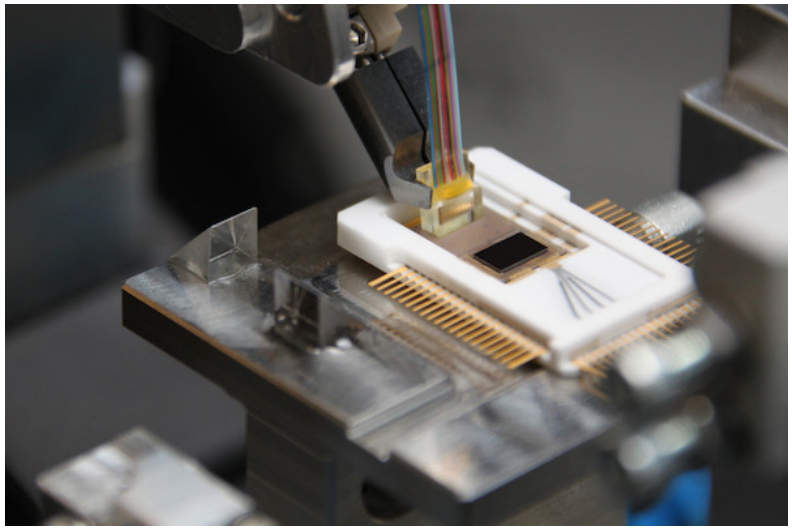


Objective 3

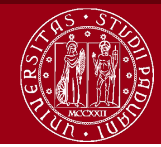
Implementation of genuine ET entanglement by using integrated photonics technology



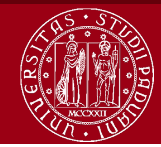
$\Rightarrow$



Summary



Device Independent Protocols



- Bell inequality introduced to rule out local deterministic theory.

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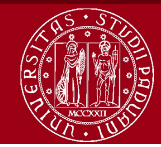

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- It has been violated in many different experiments (photons, ions, diamonds, atoms....) and also loophole-free violations demonstrated

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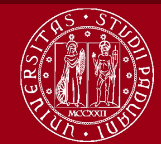
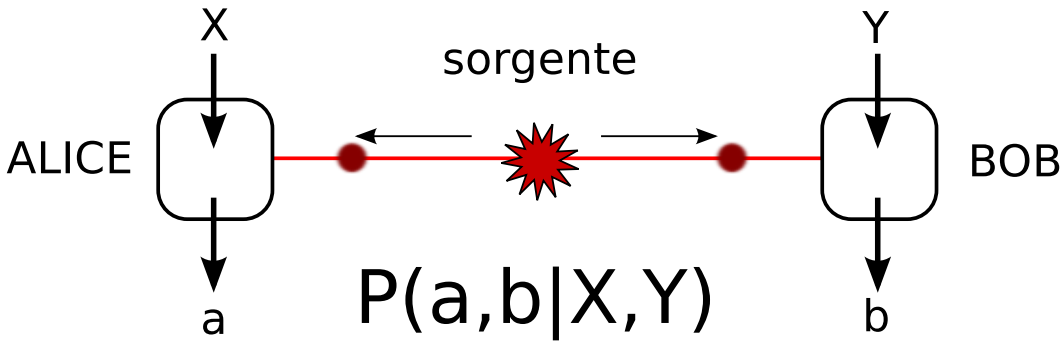


- Bell inequality introduced to rule out local deterministic theory.
- It has been violated in many different experiments (photons, ions, diamonds, atoms....) and also loophole-free violations demonstrated
- The Bell inequality can be used as a tool to certify entanglement: device-independent protocols

Device Independent Protocols



ALICE
X: choice of the measurement basis
a: output of the measurement

BOB
Y: choice of the measurement basis
b: output of the measurement

The following probabilities are measured:

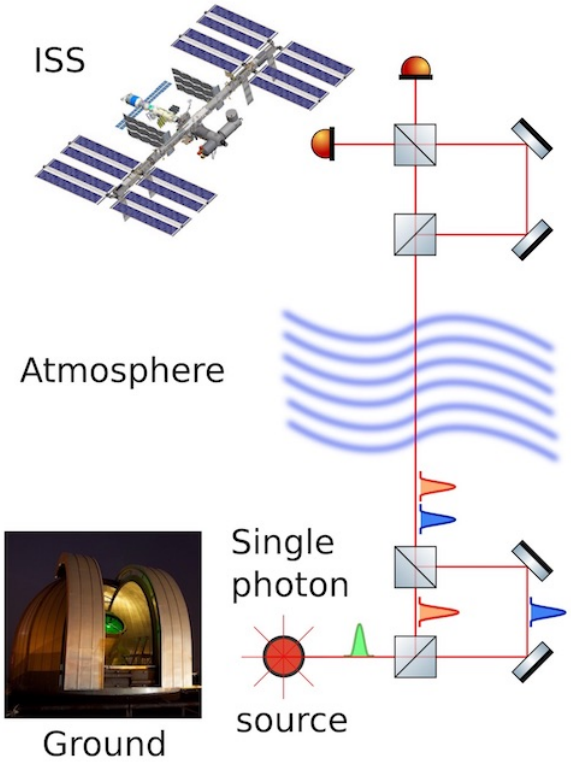
$$P(a, b|X, Y)$$

If the above probabilities violate a Bell Inequality, entanglement between Alice and Bob can be proved

Phys. Rev. Lett. **98**, 230501 (2008); New Journal of Physics **11**, 045021 (2009)

Fundamental physics

Gravitational redshift with single photons



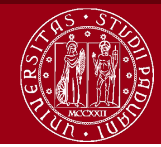
$$\lambda = 800 \text{ nm}$$
$$h \sim 400 \text{ km}$$
$$\ell = 6 \text{ km}$$

$$\Delta\phi = \frac{2\pi\ell}{\lambda}\frac{gh}{c^2} \sim 2 \text{ rad.}$$

- Possibility of measuring space-time curvature on quantum interference
- No predicted effect on photons in the Newtonian limit

Rideaut, *et al.*, Class. Quantum Grav. 29 224011 (2012)

Summary



Conclusions

- Energy-time entanglement fundamental for the future Quantum Internet: compatible with the optical fiber infrastructure

- Tool to connect quantum computers in different locations.
- Integrated photonic circuits can provide large advantages for interferometric stabilization, and speed of operation

THANK YOU FOR YOUR ATTENTION!

QuantumFuture

The shift in the communication paradigm

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