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Fast single-photon detectors and real-time key distillation enable high secret-key-rate quantum key distribution systems

Fadri Grünenfelder, Alberto Boaron, Giovanni V. Resta, Matthieu Perrenoud, Davide Rusca, Claudio Barreiro, Raphaël Houlmann, Rebecka Sax, Lorenzo Stasi, Sylvain El-Khoury, Esther Hänggi, Nico Bosshard, Félix Bussières & Hugo Zbinden

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ID Quantique SA, Acacias, Genève, Switzerland
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Cryptography Is Omnipresent...

- E-banking

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- E-banking
- Secure web browsing

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- Secure web browsing
- Encrypted messaging services

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- Cash withdrawal at ATMs

Cryptography Is Omnipresent...

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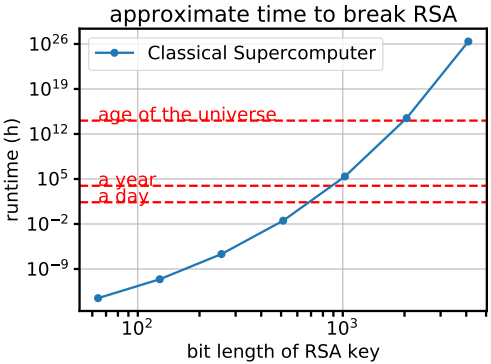
- Secure web browsing
- Encrypted messaging services
- Electronic voting
- Cash withdrawal at ATMs
- And many more...

...but Todays Cryptosystems Are Threatened



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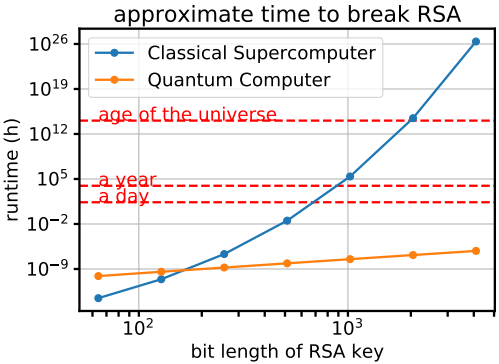

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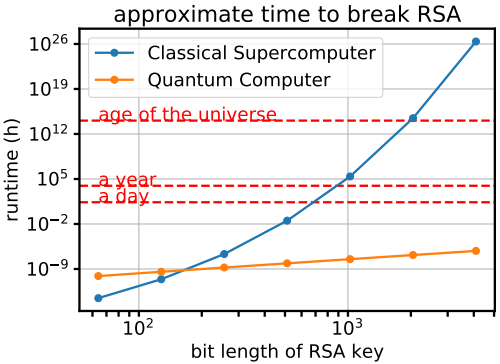
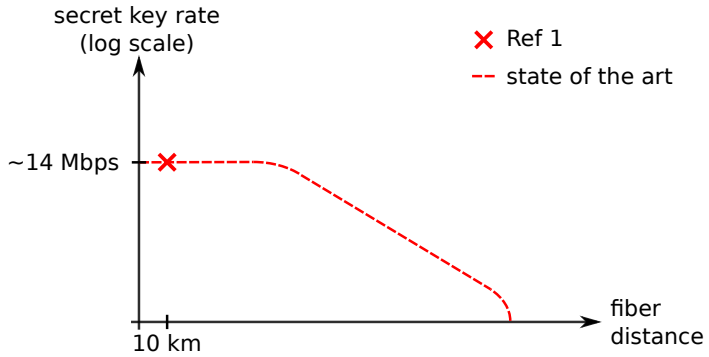


→ Use One-Time-Pad together with Quantum Key Distribution (QKD)

Goal of Our Experiment



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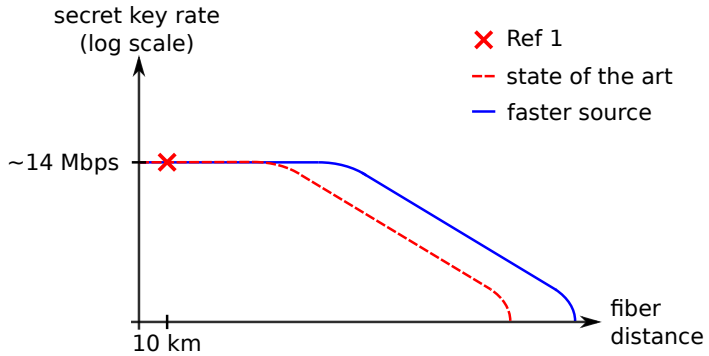

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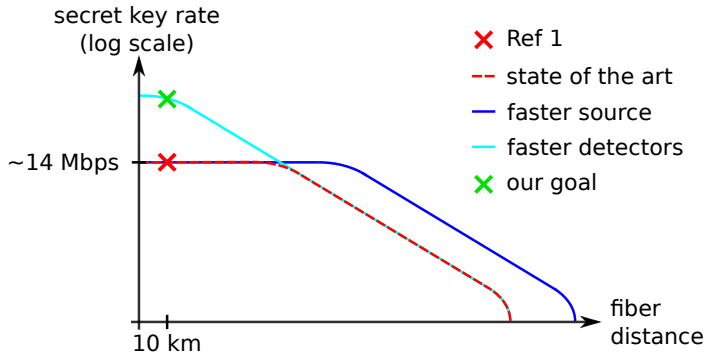

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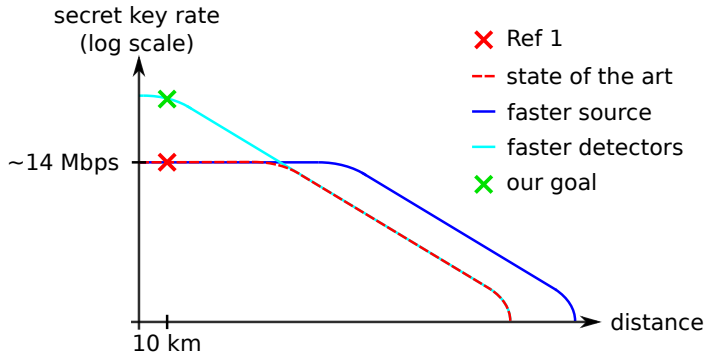

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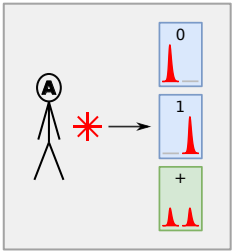
Simplified Bennett-Brassard-1984 (BB84) with Time-Bin-Encoding



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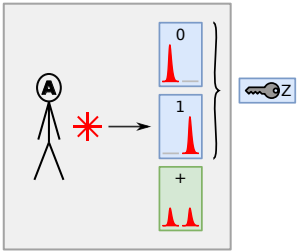

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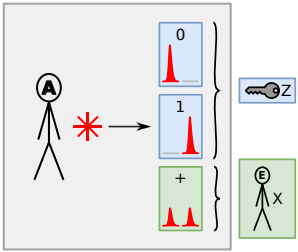

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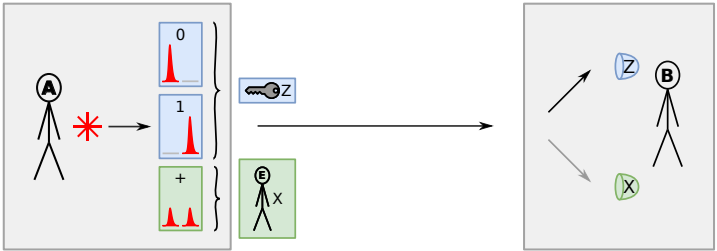

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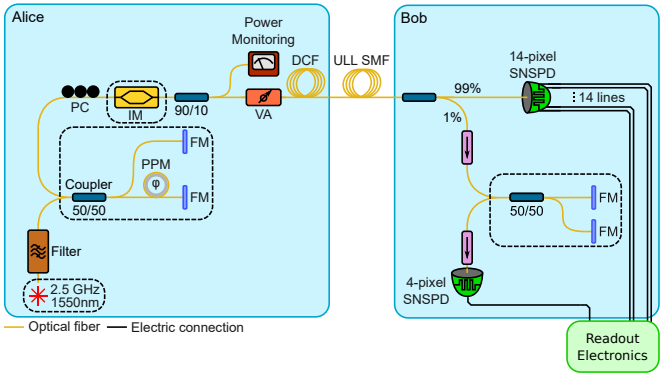
Alice
Power
Monitoring
DCF
ULL SMF
PC
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90/10
VA
FM
PPM
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2.5 GHz
1550nm
Bob
14-pixel
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99%
14 lines
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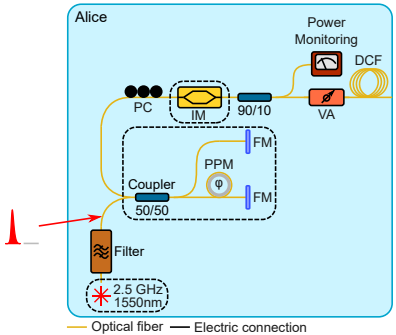
FM
4-pixel
SNSPD
Readout
Electronics
Optical fiber
Electric connection

Setup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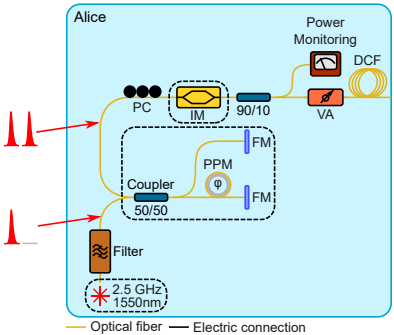
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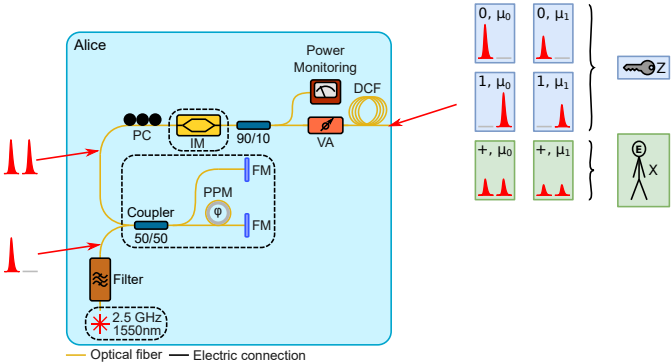
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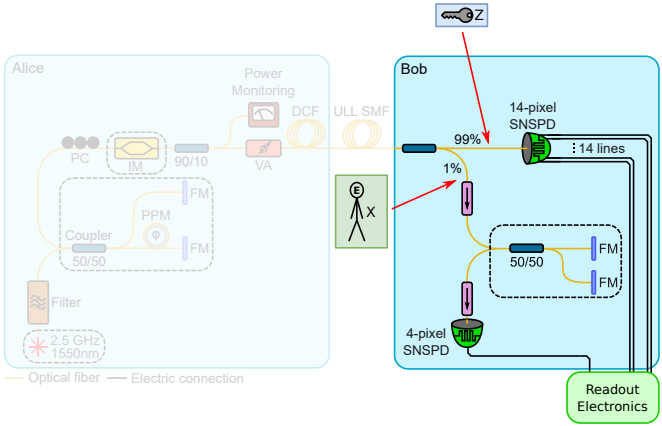
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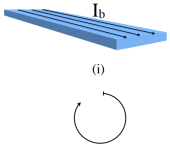
How Do Superconducting Nanowire Single-Photon Detectors (SNSPD) work?



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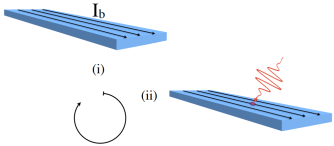

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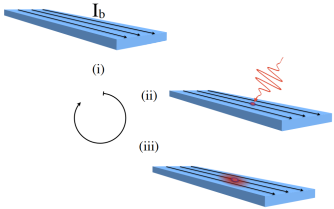

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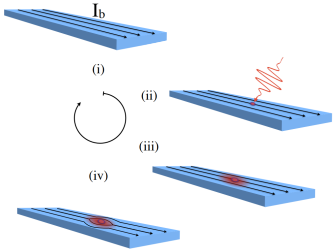

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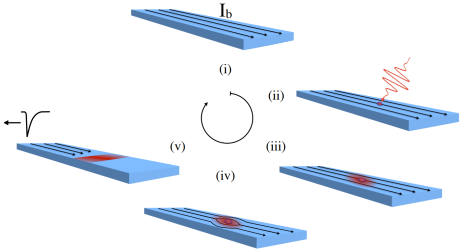

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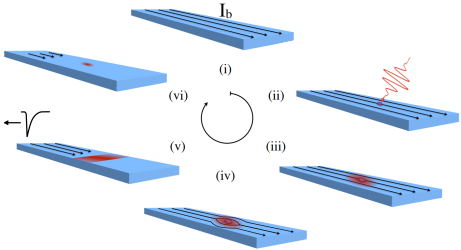

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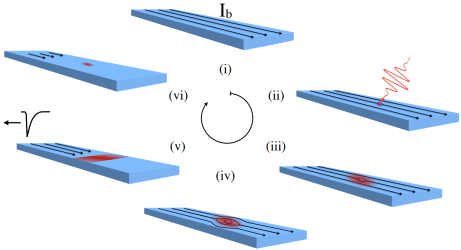

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Important characteristics:

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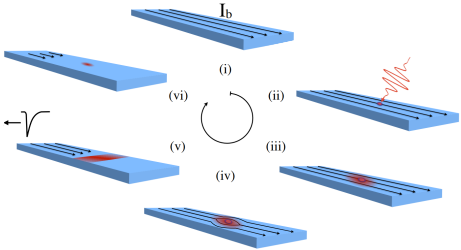

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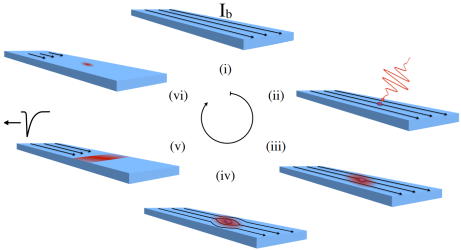

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Important characteristics:

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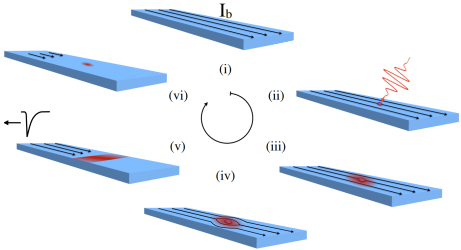

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Important characteristics:

- Recovery time
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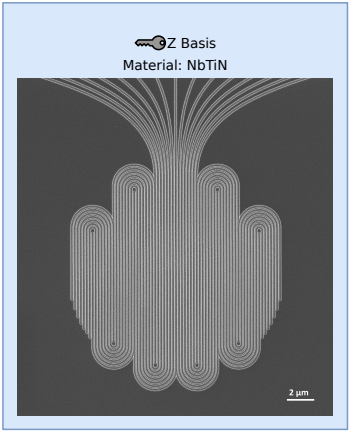
- (Dark counts)

SNSPD - Design



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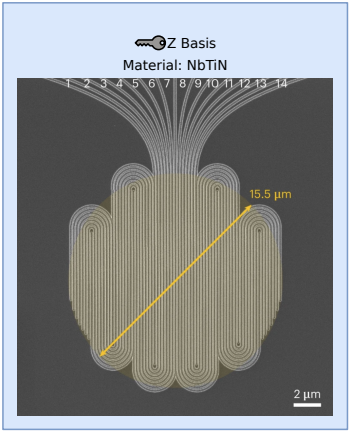
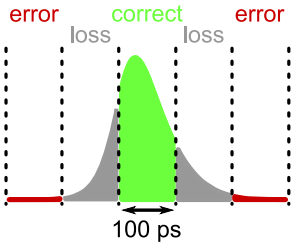
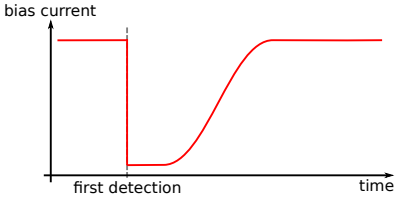


Jitter in QKD

Temporal jitter increases Quantum bit error rate (QBER) and introduces loss



Amplitude Jitter



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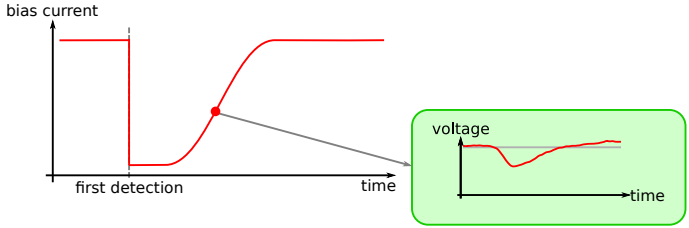

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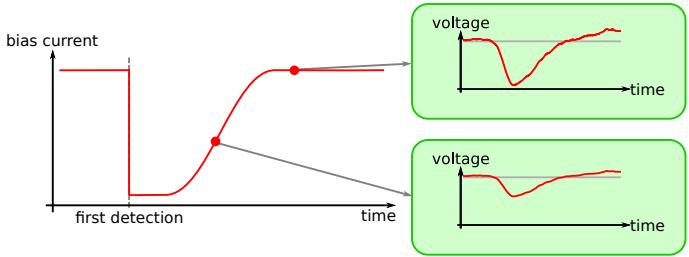
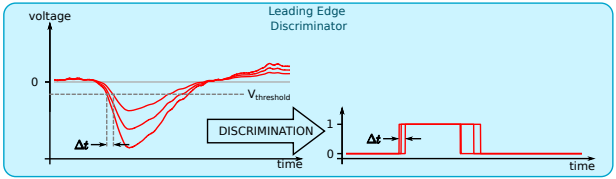


Detection Electronics - How to Minimize Amplitude Jitter?



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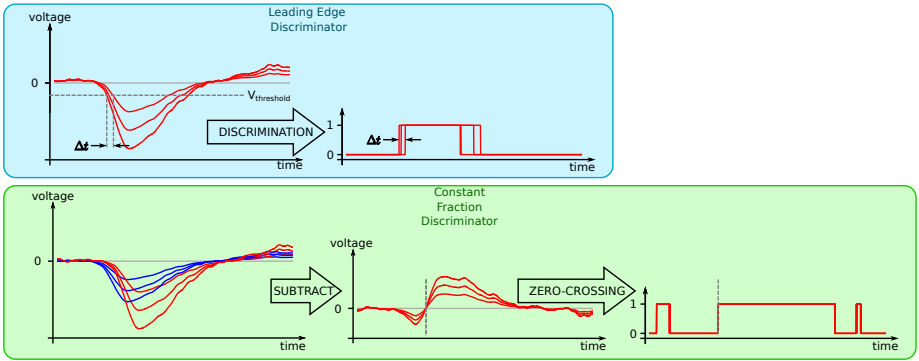

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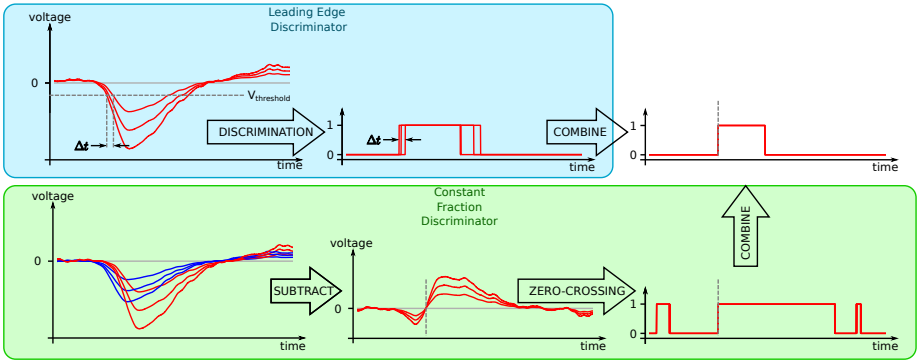

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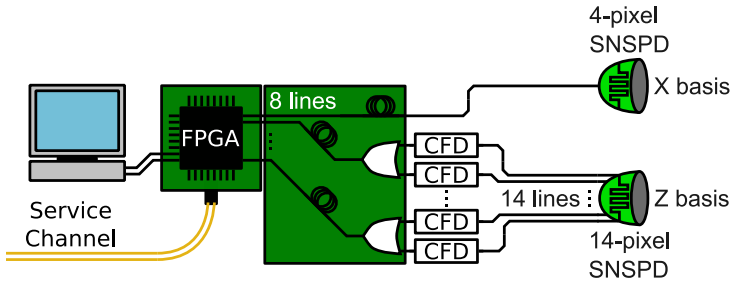
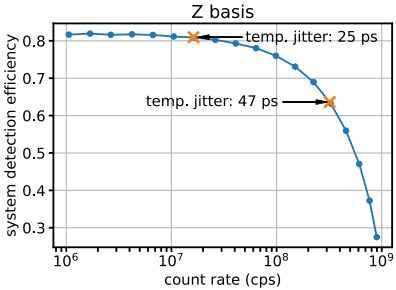
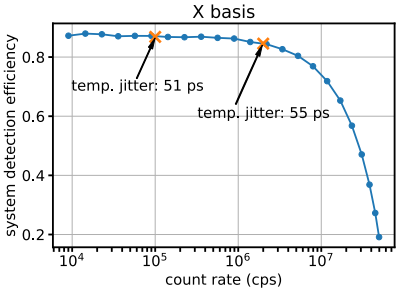


Detection System - Results





Secret Key Exchange

	Q_Z (%)	ϕ_Z (%)	sifted key rate (Mbps)	**SKR (Mbps)**

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	0.4	0.8	159.4	**63.6**

Conclusion and Outlook

- Secret key rate in our work[1]:

[1] Grünenfelder, F. et al., Nat. Photon. 17, 422–426 (2023)
[2] Li, W. et al.,Nat. Photon. 17, 416–421 (2023)

Conclusion and Outlook

- Secret key rate in our work[1]:
  - **3.0 Mbps** at 102.4 km ULL fiber

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  - Perfect system: **192 Mbps** at 10 km

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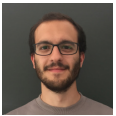
Electronic Engineer

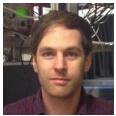
Raphaël Houlmann
QTech Group
FPGA Engineer



Davide Rusca
QTech Group
PostDoc

Matthieu Perrenoud
QTech Group
PostDoc (Alumni)

Rebecka Sax
QTech Group
PhD Student



Félix Bussières
IDQuantique
VP Research & Technology

Sylvain El-Khoury
IDQuantique
Master Student

Lorenzo Stasi
QTech Group/IDQuantique
PhD Student

Nico Bosshard
Hochschule Luzern
(Alumni)

Hugo Zbinden
QTech Group
Professor

Giovanni V. Resta
QTech Group
PostDoc

Alberto Boaron
QTech Group
PostDoc

Esther Hänggi
Hochschule Luzern
Professor

Claudio Barreiro
QTech Group
Electronic Engineer

Raphaël Houlmann
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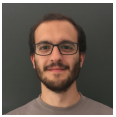
FPGA Engineer



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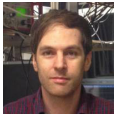

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VIGO QUANTUM
communication center

Quantum Communication Theory Group

Marcos Curty
Professor

Quantum Hacking & Certification Lab

Vadim Makarov
Professor

Quantum Communication Technology Group

Hugo Zbinden
Professor

Thank You for Your Attention!

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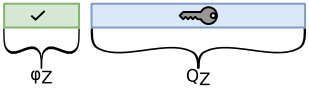
Technology Group

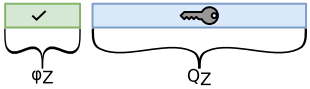
Classical Post-Processing



φ_Z: Phase error rate

Q_Z: quantum bit error rate (QBER)

Classical Post-Processing



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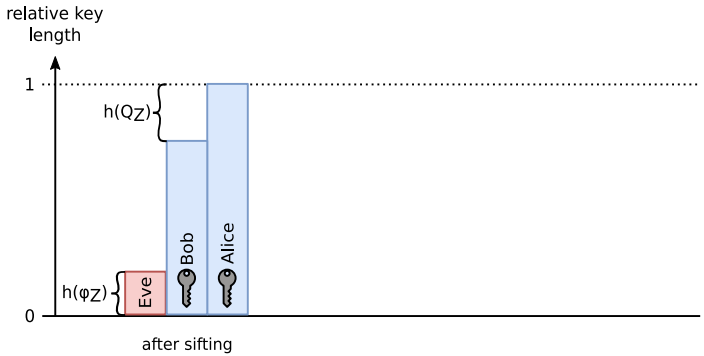

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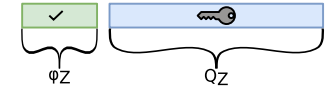

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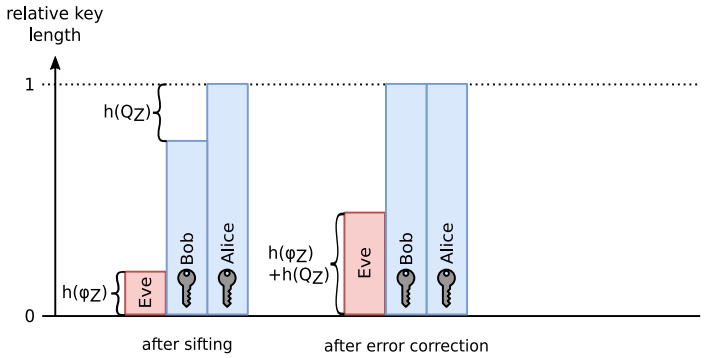
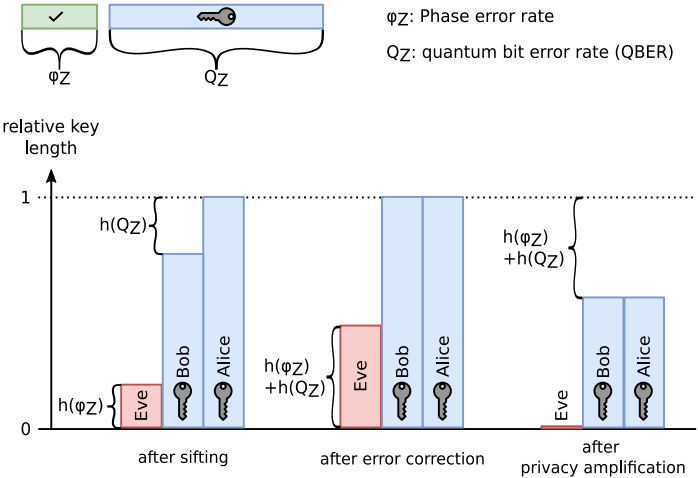
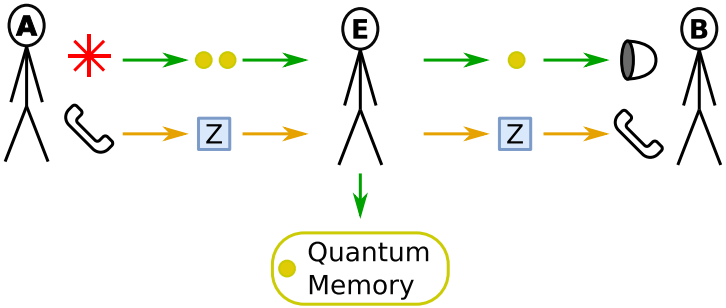


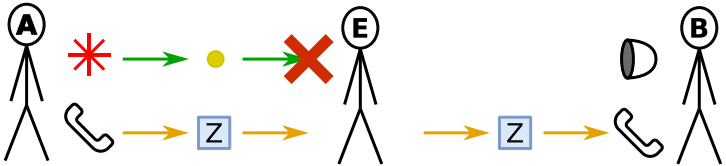
Classical Post-Processing



QKD with Coherent States

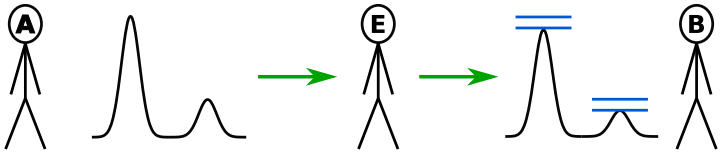


QKD with Coherent States

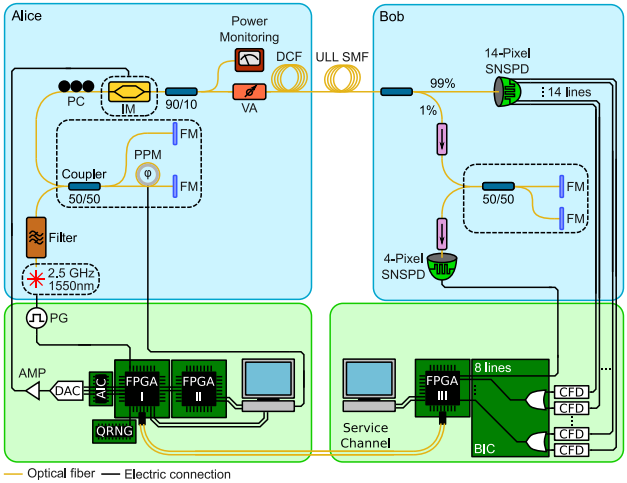


Decoy States

Decoy States



Complete Setup



High SKR Time-Bin QKD - Results

fiber length (km)	att. (dB)	μ_0	μ_1	p_{μ_0}	$p_{Z,A}$	$p_{Z,B}$	R_{sift} (Mbps)	ϕ_Z (%)	Q_Z (%)	SKR (Mbps)
10.0	1.58	0.49	0.22	0.74	0.65	0.99	159.4	0.8	0.4	63.6
102.4	16.34	0.46	0.20	0.79	0.66	0.99	7.8	1.0	0.3	3.0