A high-speed multi-protocol quantum key distribution transmitter based on a dual-drive modulator

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Outline

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- Motivation
  - Network QKD
  - Possible need for multi-protocol capability
- Protocol overview
- State preparation
- Transmitter performance
  - Characterization
  - QKD
  - Stability
- Conclusion

Motivation – Network QKD

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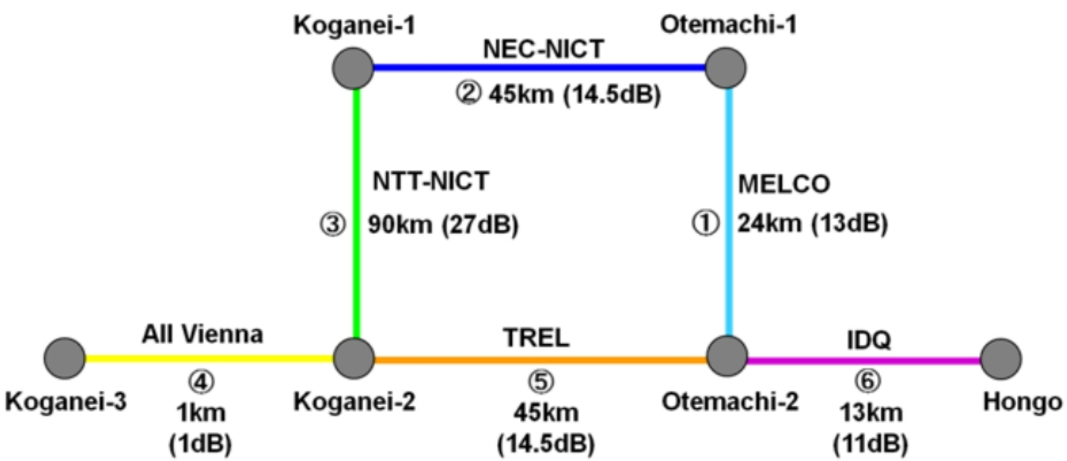
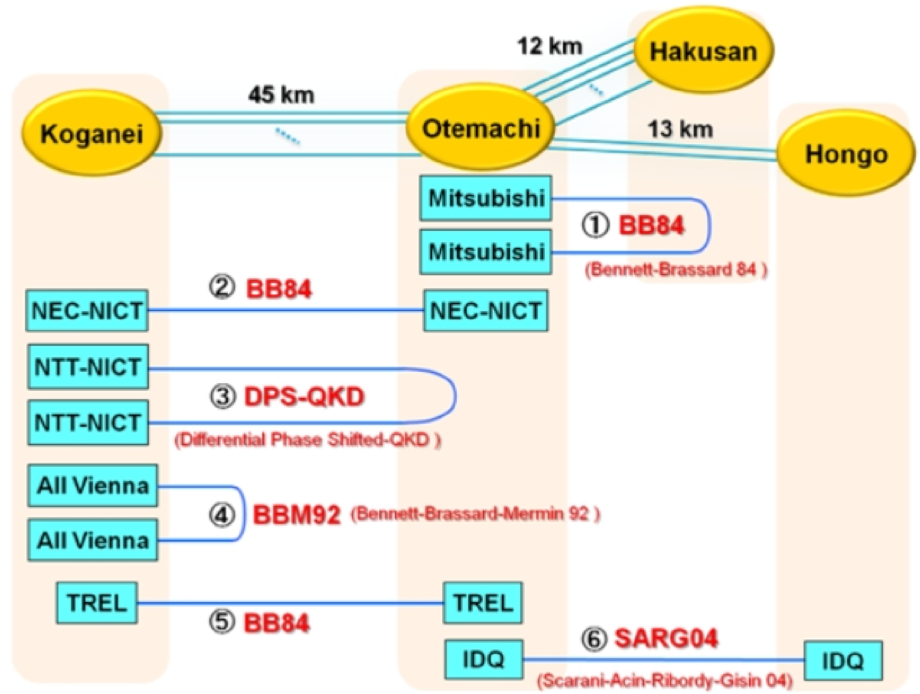
One approach

- Trusted nodes





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Reconfigurable Networks

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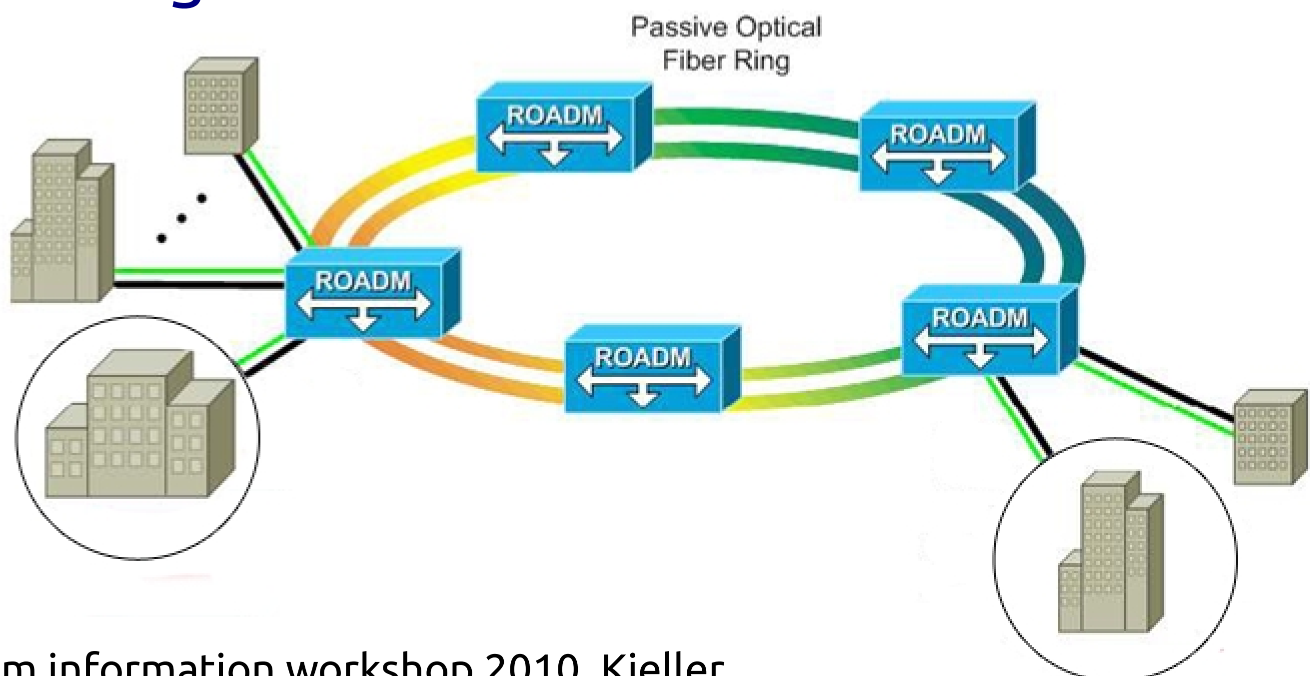
- No need for trusted nodes
- Active optical switching
- Passive optical switching



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Quantum Metro Network

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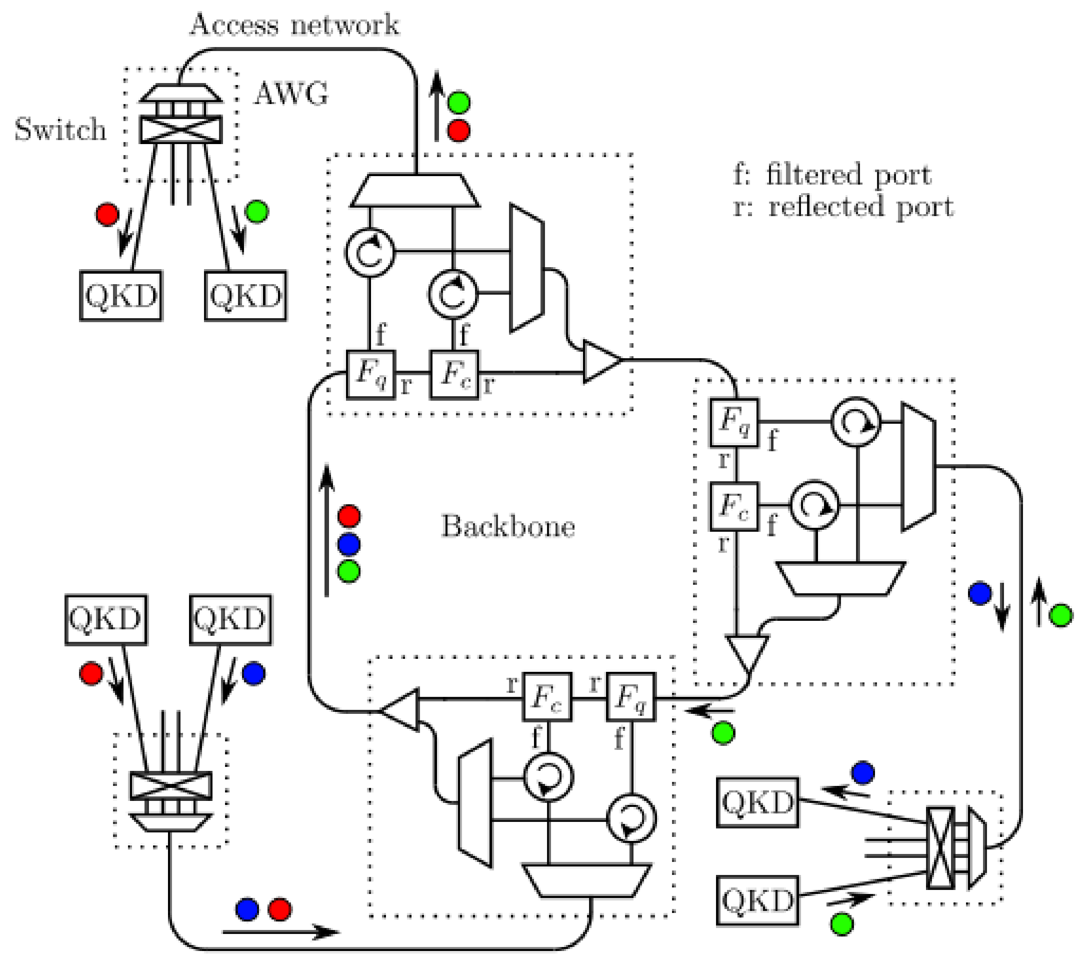
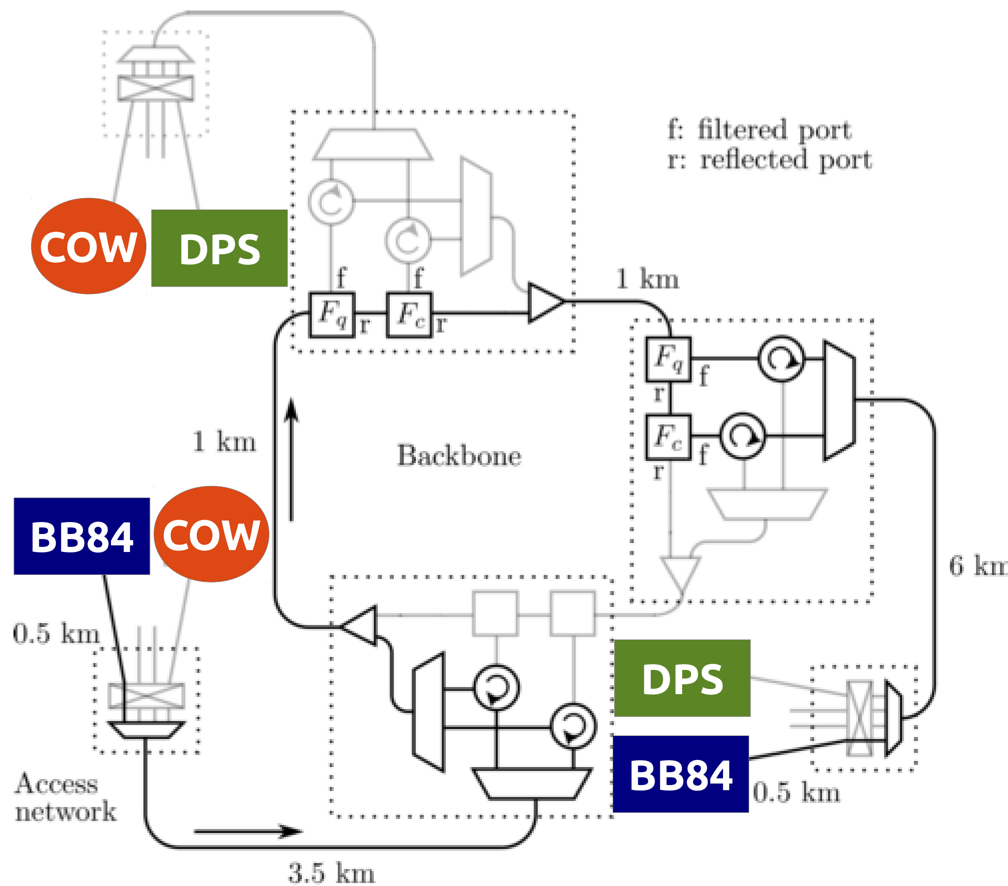
- Wavelength addressable
- All-to-all communication
- Resembles commercial optical networks
  - Core ring
  - Access network



Poster: A. Ciurana, J. Martinez-Mateo, A. Poppe, N. Walenta, H. Zbinden, and V. Martin, "*Quantum Metropolitan Area Network based on Wavelength Division Multiplexing*"

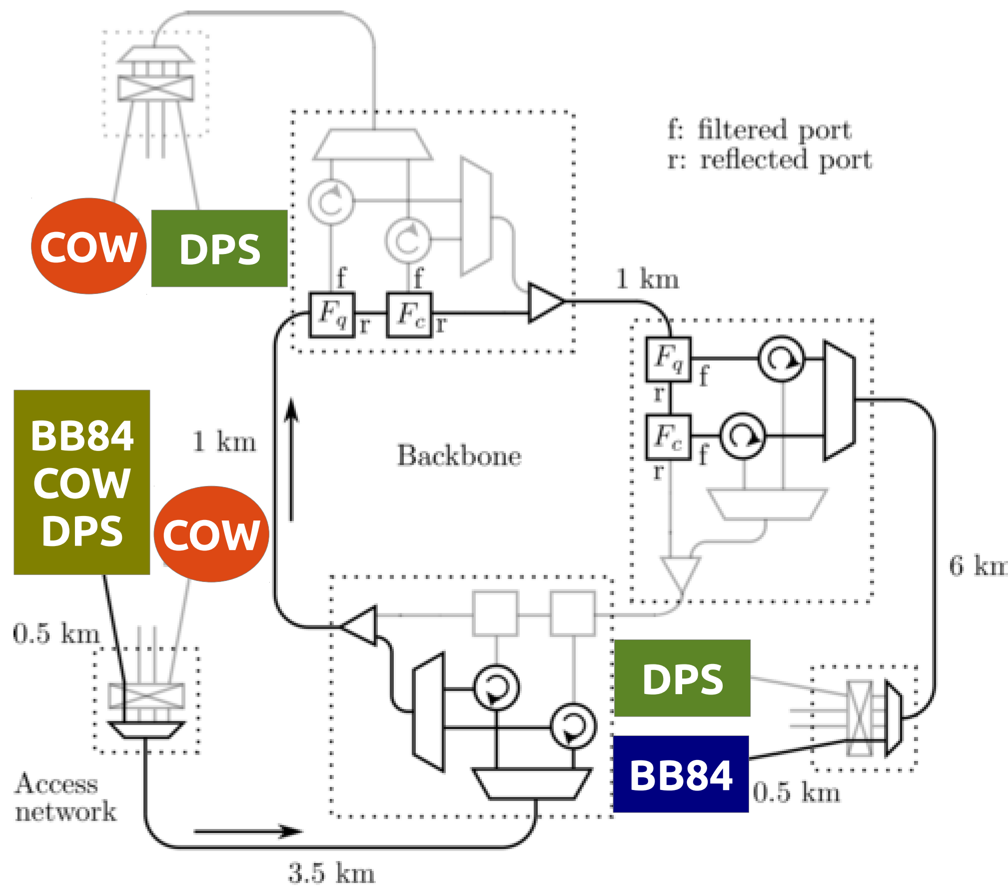
Different protocols?

- Different losses
  - Optimum protocol?
- Different environmental effects
- Commercial systems
  - Rarely the same
  - Patents
- So far systems require dedicated transmitters and receivers



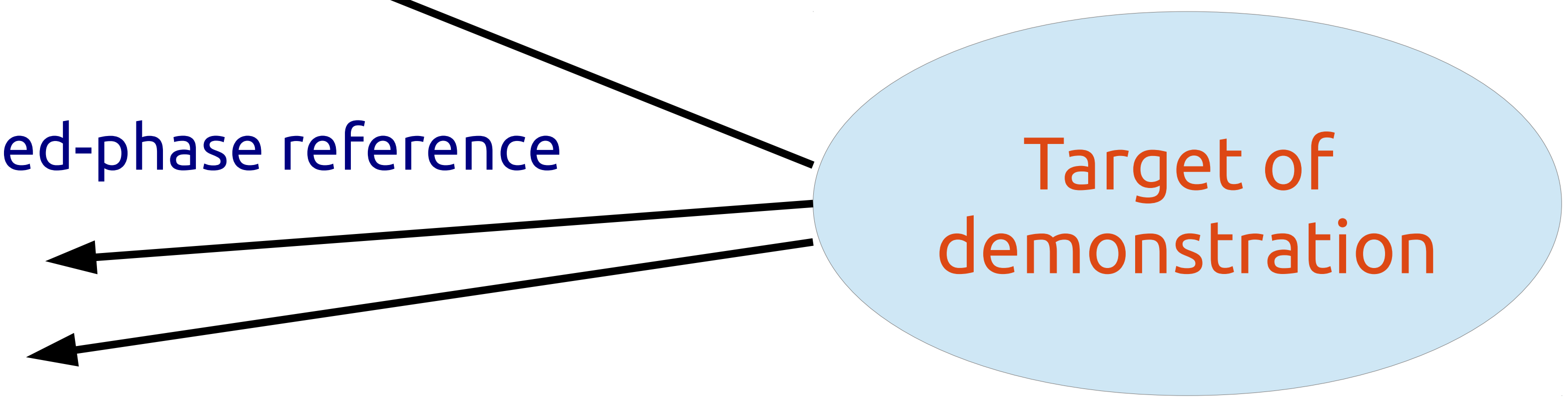
Different protocols?

- All people might want to communicate
- Potential need to move to multi-protocol capability
- Aim
  - Develop a multi-protocol transmitter



Families of Protocols

- Discrete variable
  - BB84
  - SARG
  - B92
- Distributed-phase reference
  - COW
  - DPS
- Continuous variable
- Measurement device independent
- Device independent



- V. Scarani, H. Bechmann-Pasquinucci, N. J. Cerf, M. Dusek, N. Lütkenhaus, and M. Peev, “*The security of practical quantum key distribution*,” Rev. Mod. Phys. 81, 1301–1350 (2009)

Coherent one-way

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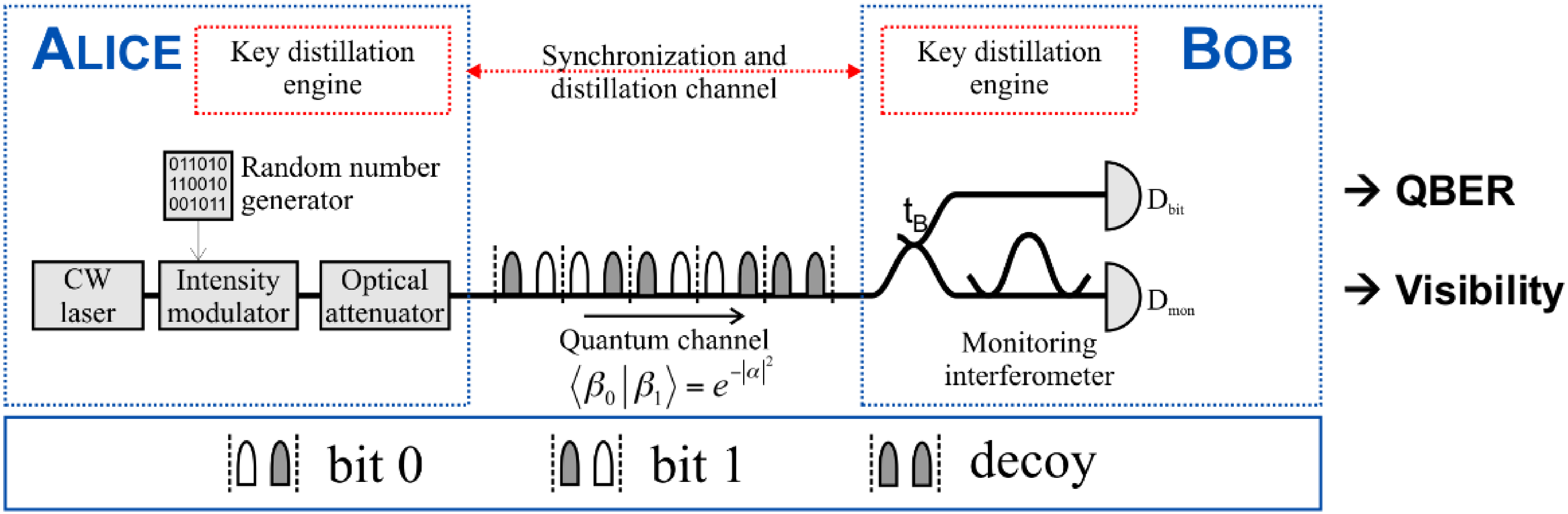
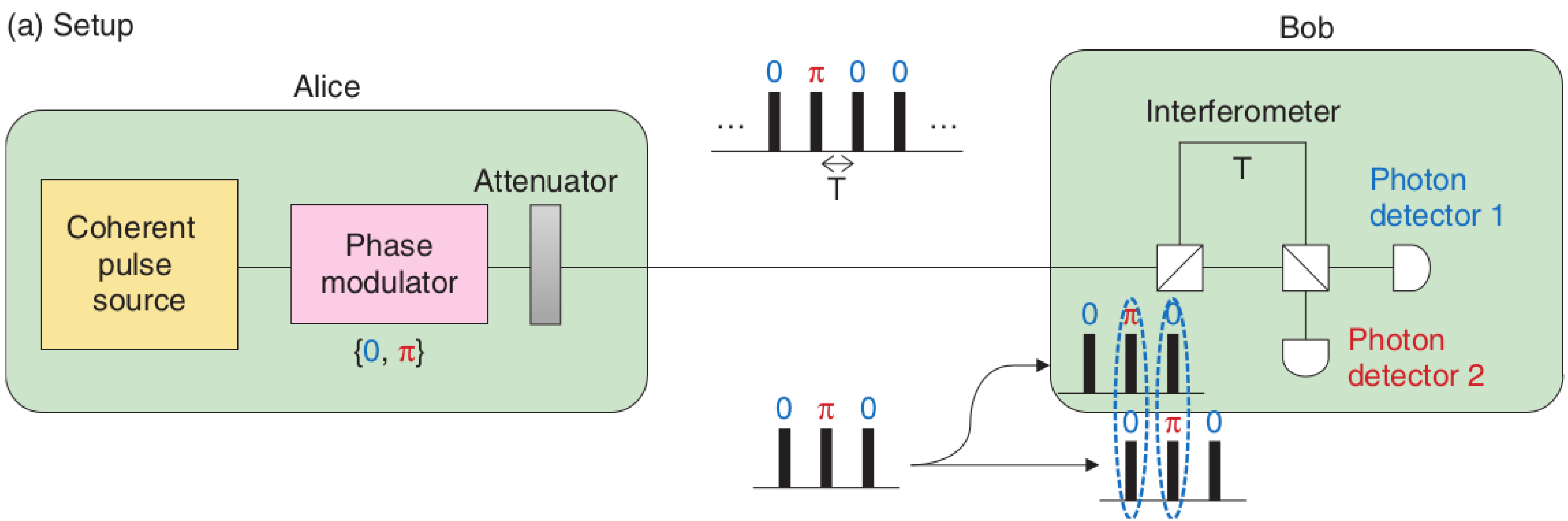


Live demonstration in the industrial exhibit area

- **Real-time post processing**
- **One-time pad encryption or 100 Gbps AES**

- D. Stucki, N. Brunner, N. Gisin, V. Scarani, and H. Zbinden, "*Fast and simple one-way quantum key distribution*," Appl. Phys. Lett. 87, 194108 (2005)
- C. Branciard, N. Gisin, and V. Scarani, "*Upper bounds for the security of two distributed-phase reference protocols of quantum cryptography*," New J Phys. 10, 013031 (2008)

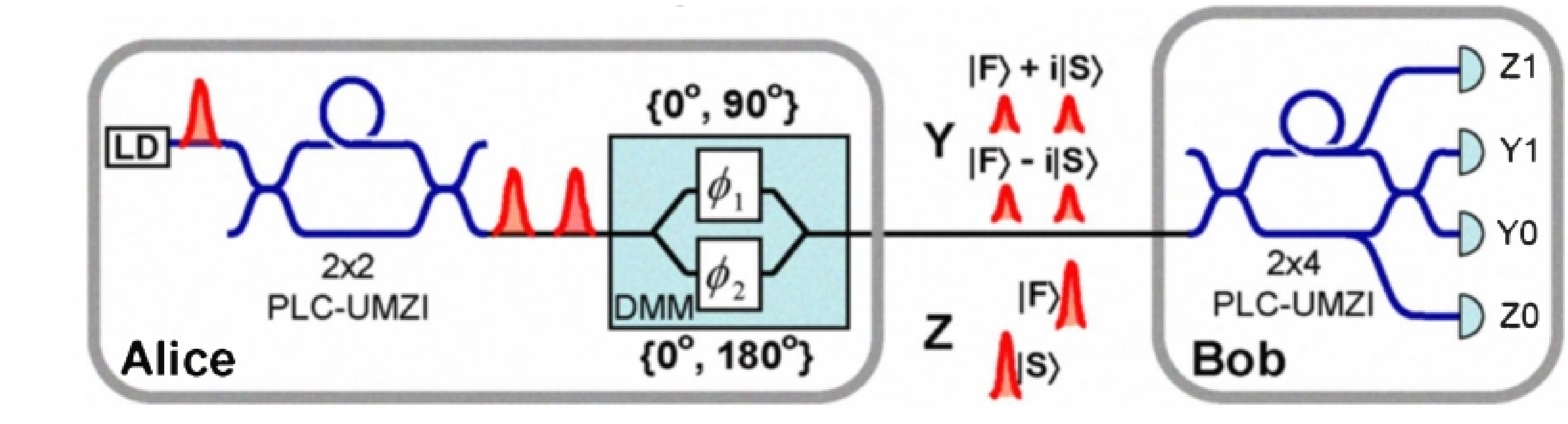
Differential phase shift



- CW laser with pulse carver or mode-locked laser required

- K. Inoue, E. Waks, and Y. Yamamoto, "*Differential phase shift quantum key distribution*," Phys. Rev. Lett. 89, 037902 (2002)
- Yasuhiro Tokura and Toshimori Honjo, "*Differential Phase Shift Quantum Key Distribution (DPS-QKD) Experiments*", NTT Technical review, www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201109fa8.html

Time-phase BB84

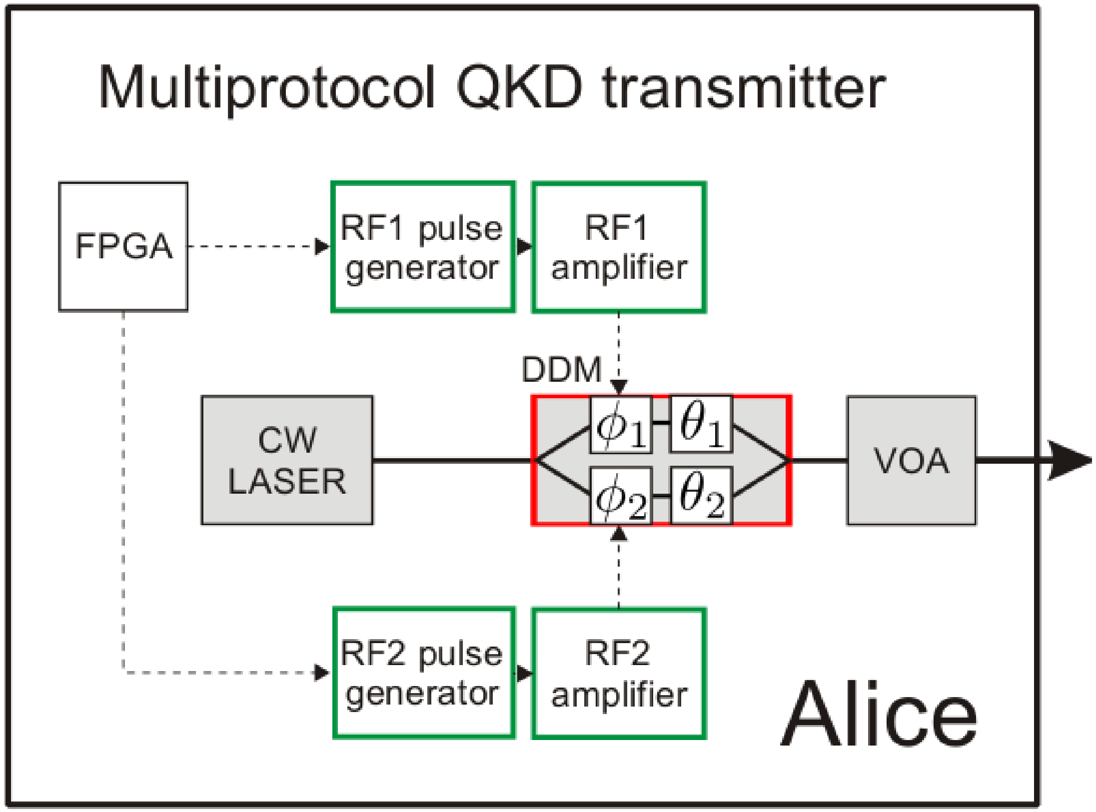


- Requires matched interferometers at Alice and Bob
- Inherently phase randomized

- K. Yoshino, et. al., "*Dual-mode time-bin coding for quantum key distribution using dual-drive Mach-Zehnder modulator*," in 33rd European Conference and Exhibition of Optical Communication (ECOC, 2007), pp. 1–2 (2007)
- K. Yoshino, et. al. "*High-speed wavelength-division multiplexing quantum key distribution system*," Opt. Lett. 37, 223–225 (2012)
- A. Tomita, et. al., "*High speed quantum key distribution system*," Opt. Fiber Technol. 16, 55 – 62 (2010)

New transmitter

- Simplified version
- 1 Electo-optic modulator
  - Phase and intensity control
- No interferometer at Alice



Dual-drive modulator

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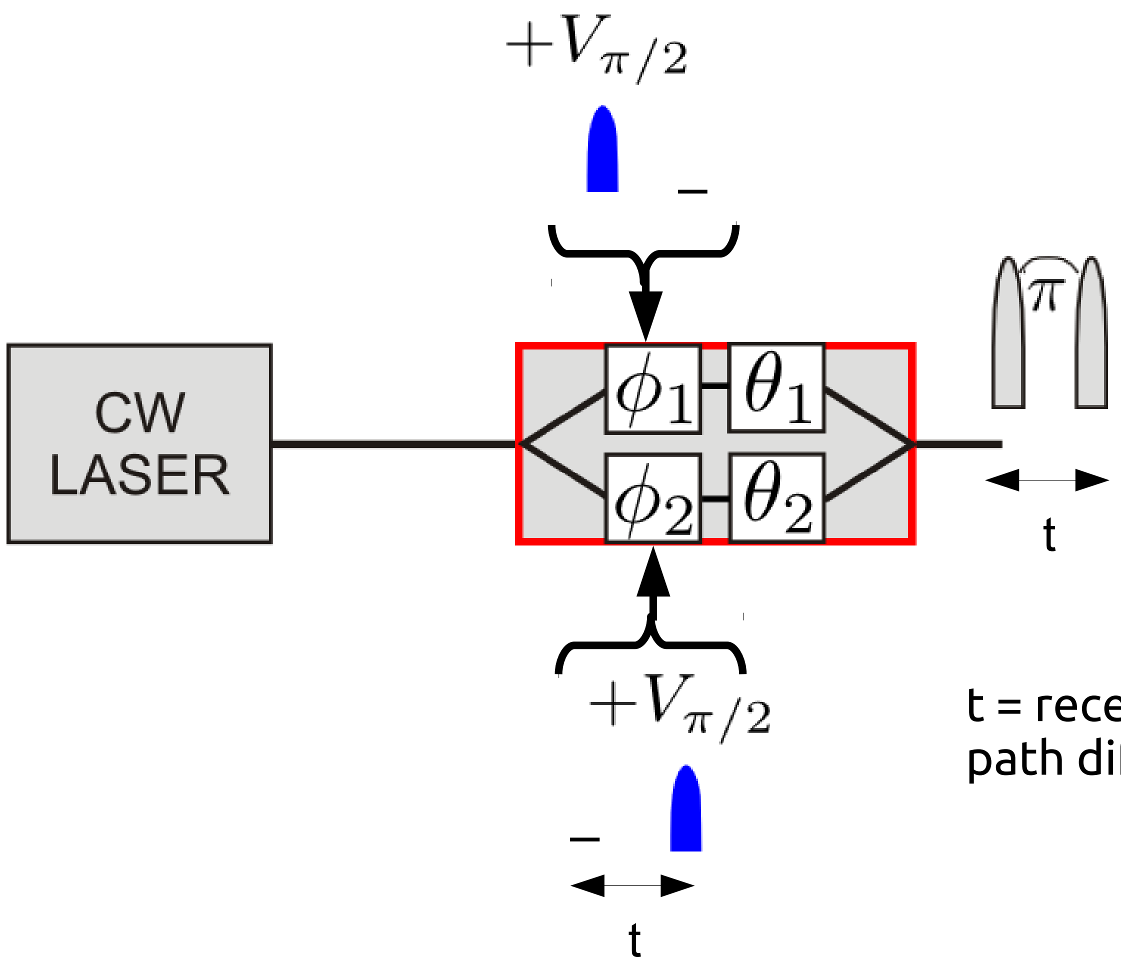
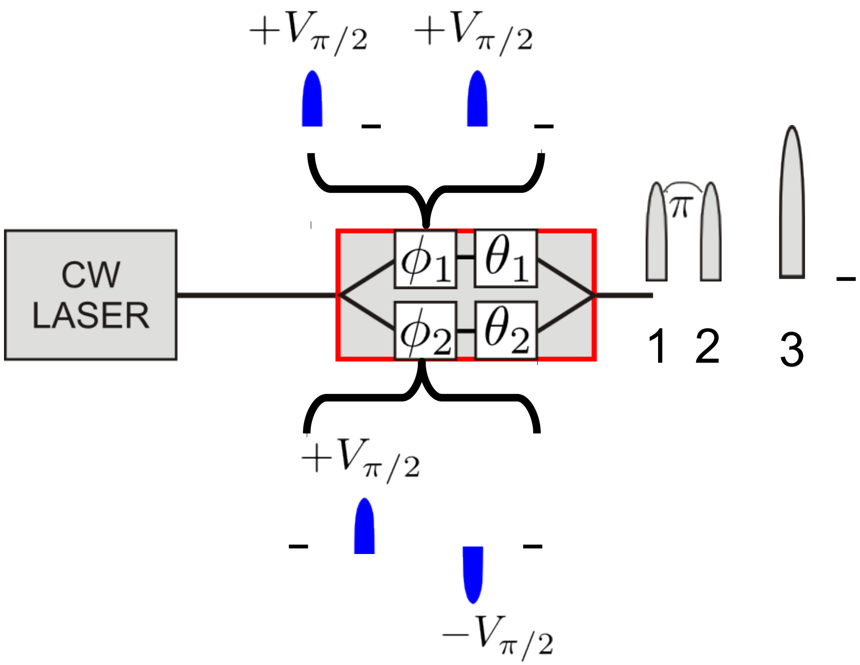
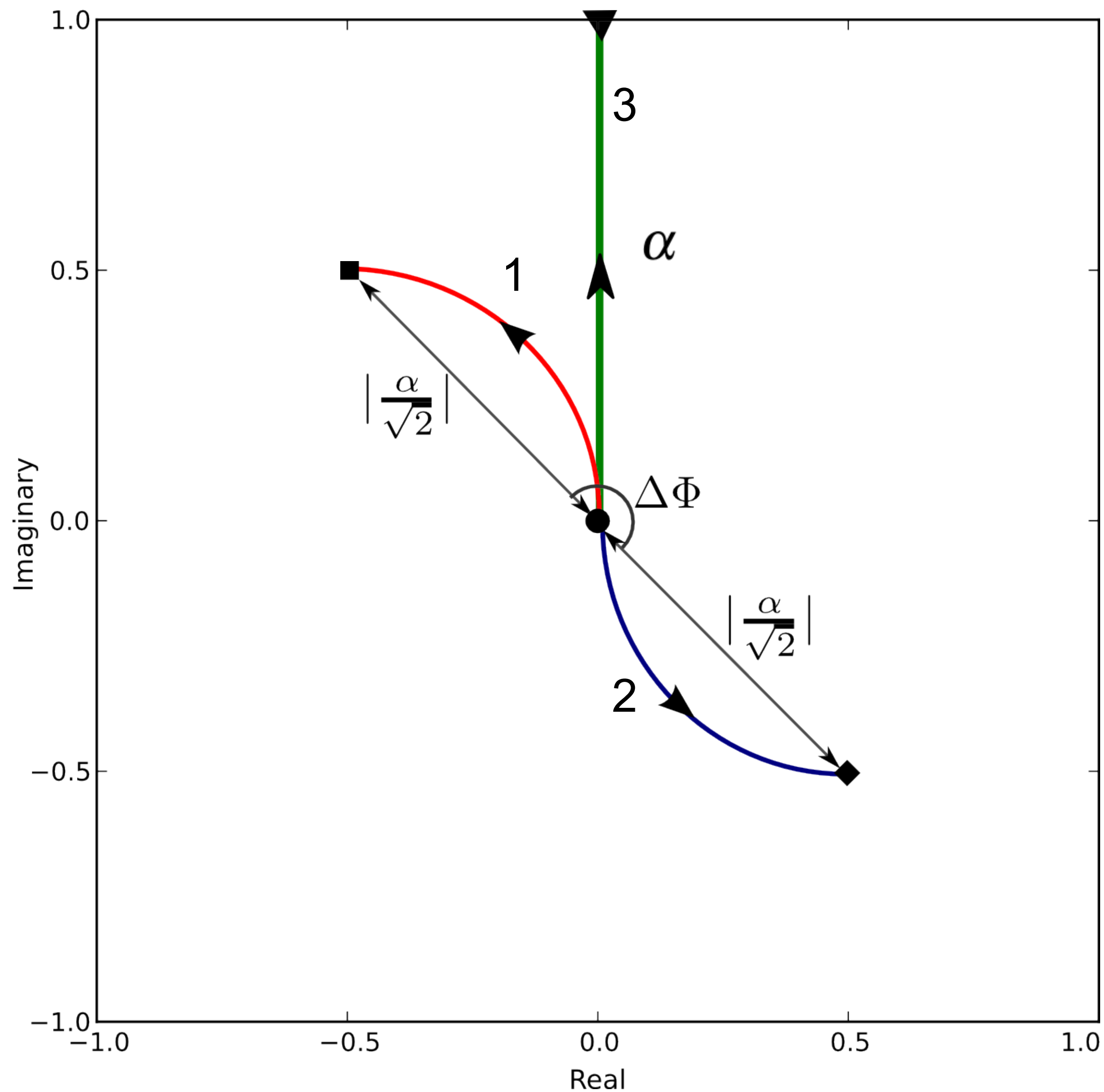


t = receiver interferometer path difference

$$|\alpha\rangle \rightarrow = e^{i\left(\frac{\theta_1+\theta_2+\phi_1+\phi_2}{2}\right)} \cdot \cos\left(\frac{\theta_1-\theta_2+\phi_1-\phi_2}{2}\right)|\alpha\rangle$$

State preparation

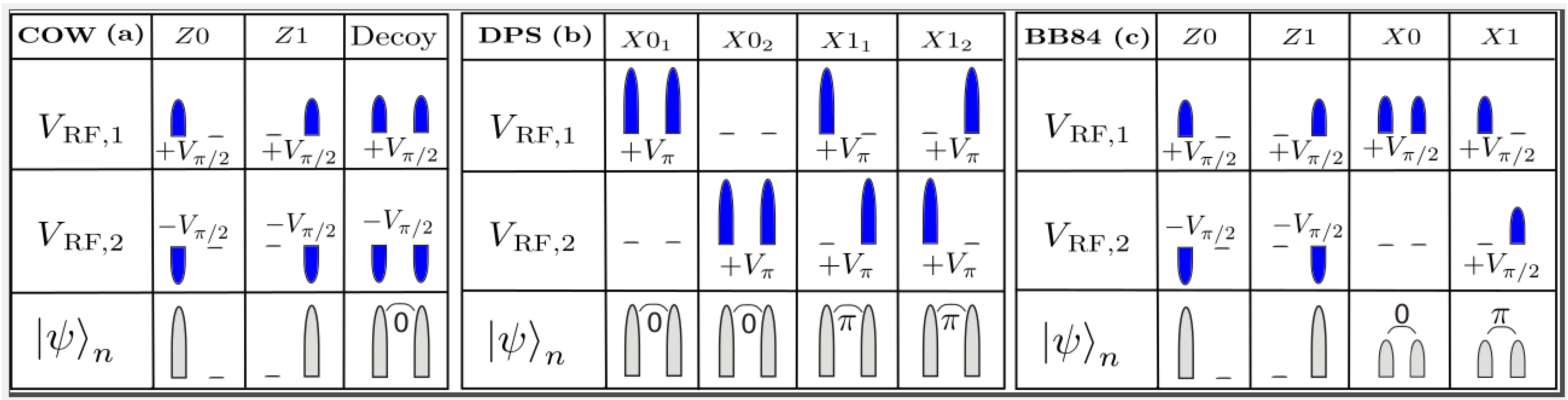




$$Re[\psi] = \frac{1}{2}\left[\cos\phi_1 - \cos\phi_2\right]$$

$$Im[\psi] = \frac{1}{2}\left[\sin\phi_1 - \sin\phi_2\right].$$

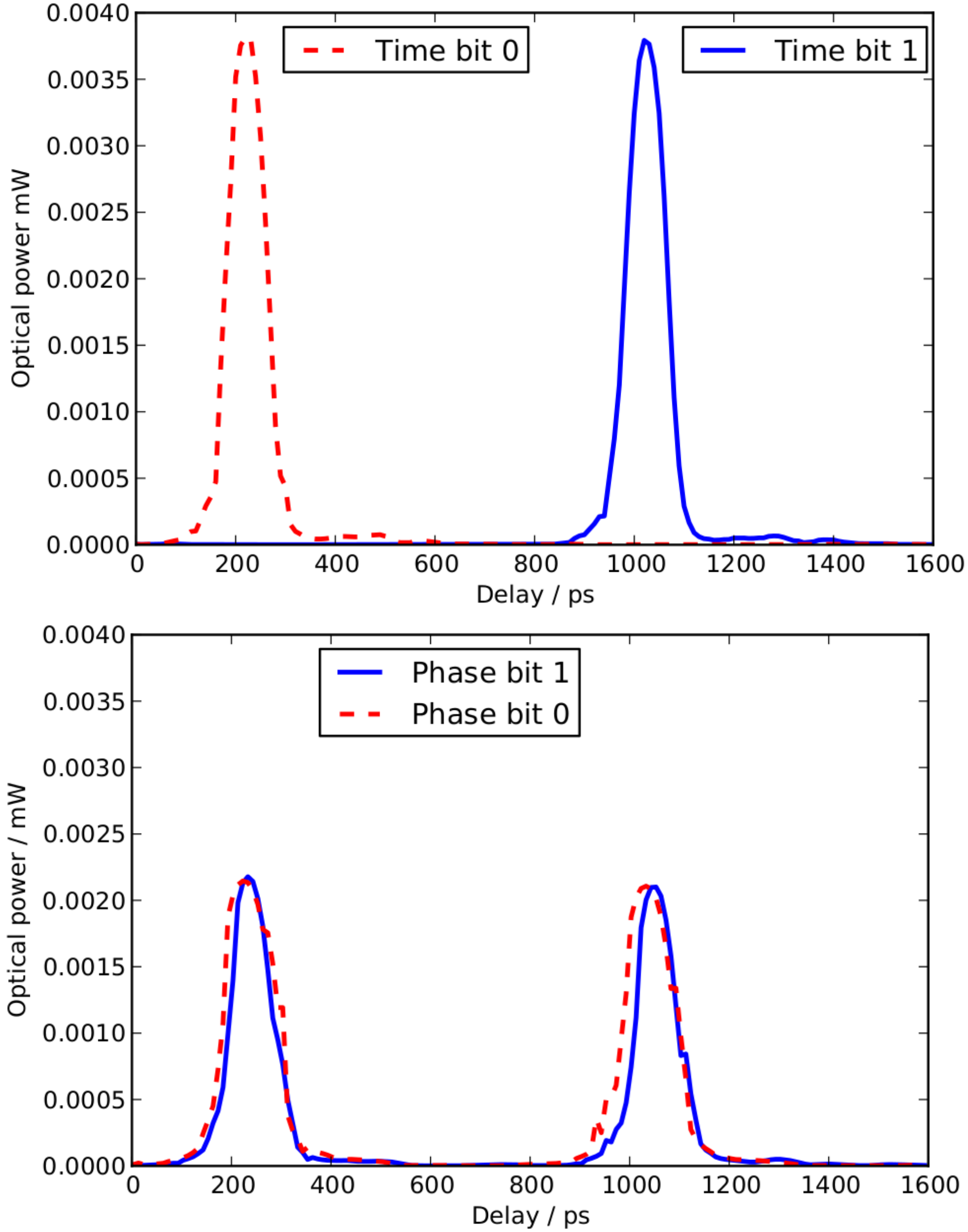
Coding scheme



- All states necessary can be produced

Pulse shape

- Pulses after the dual-drive modulator
- 90 ps (fwhm)
- Linear scale



Pulse shape

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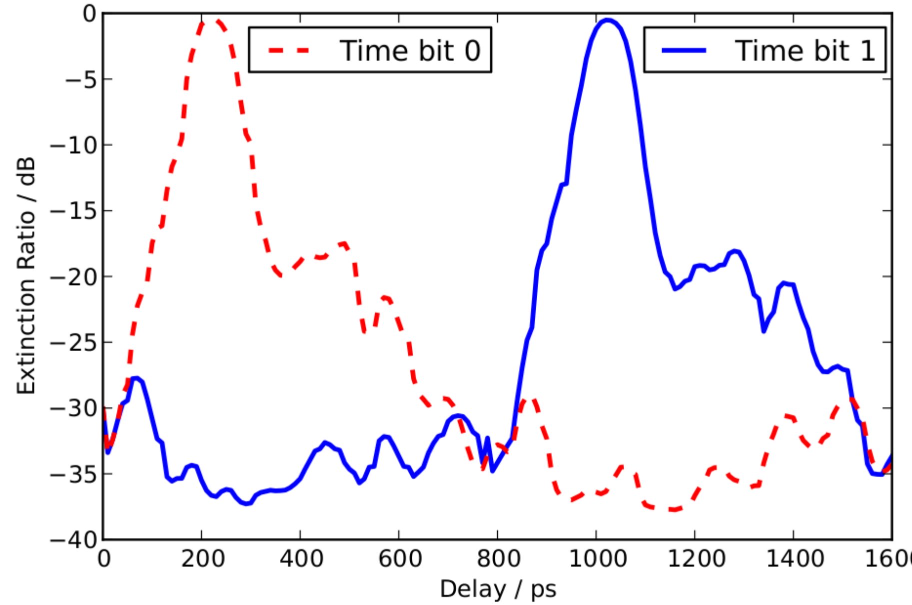
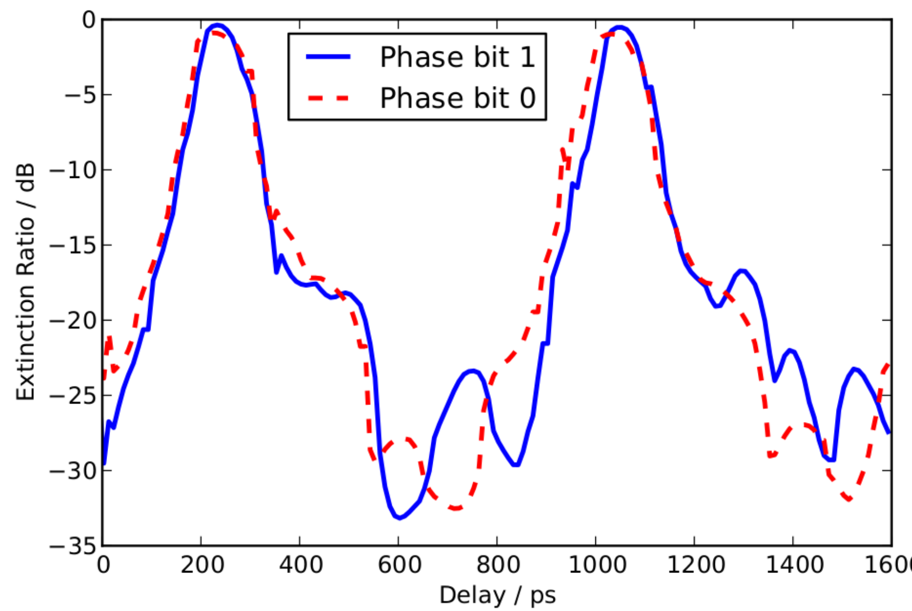
- Extinction ratio
  - >27 dB
  - Less than 0.2% QBER in time basis
- Logarithmic scale





Clock frequency optimization

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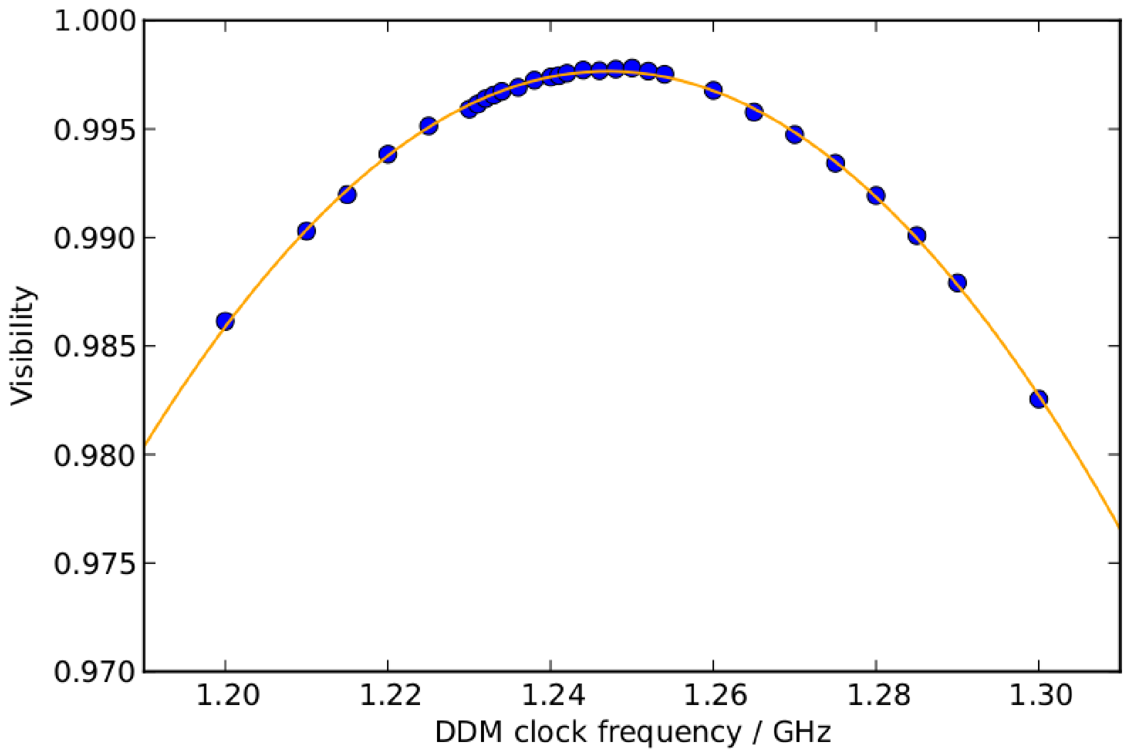
- 20 MHz clock accuracy corresponds to
  - 0.01% QBER



Multi-protocol test platform

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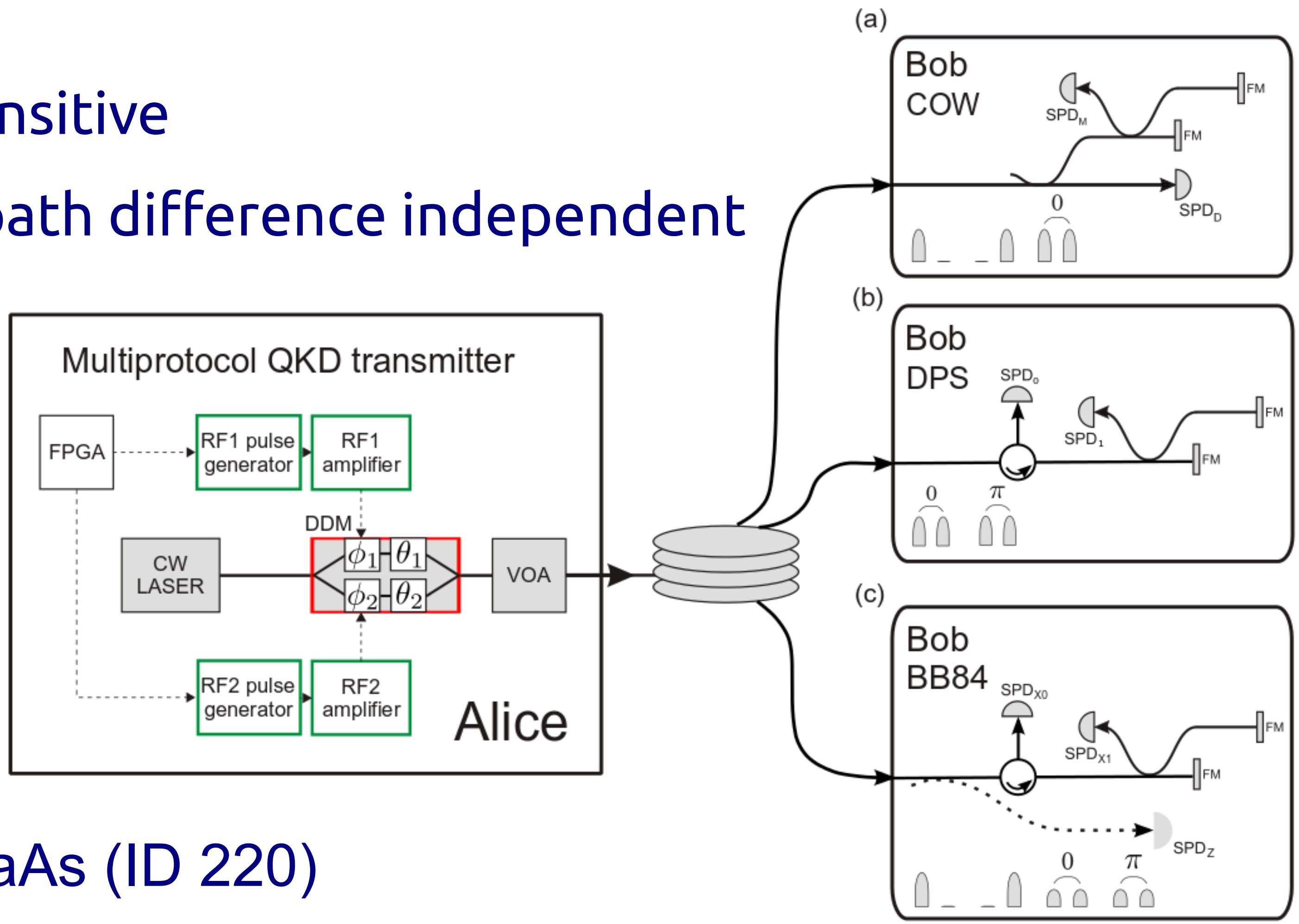
Specifications

- Polarization insensitive
- Interferometer path difference independent



Detectors

- Free running InGaAs (ID 220)

- T. Lunghi, C. Barreiro, O. Guinnard, R. Houlmann, X. Jiang, M. A. Itzler, and H. Zbinden,“*Free-running single-photon detection based on a negative feedback InGaAs APD*,” J. Mod. Opt. 59, 1481–1488 (2012)

QKD engine

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Sifting	Timing and base information
Error estimation	Direct comparison or sampling
Error correction	LDPC forward error correction
Error verification	Universal hashing
Privacy amplification	Toeplitz hashing
Authentication	Polynomial hashing

- 1.25 GHz
- FPGA distillation engine

- Block length 10^6
- Most tasks are protocol independent

Poster: Nino Walenta, et. al. "*Continuous coherent-one way QKD and data encryption at up to 100 Gbits/s*", Industrial exhibit area, QCrypt 2013.

COW performance

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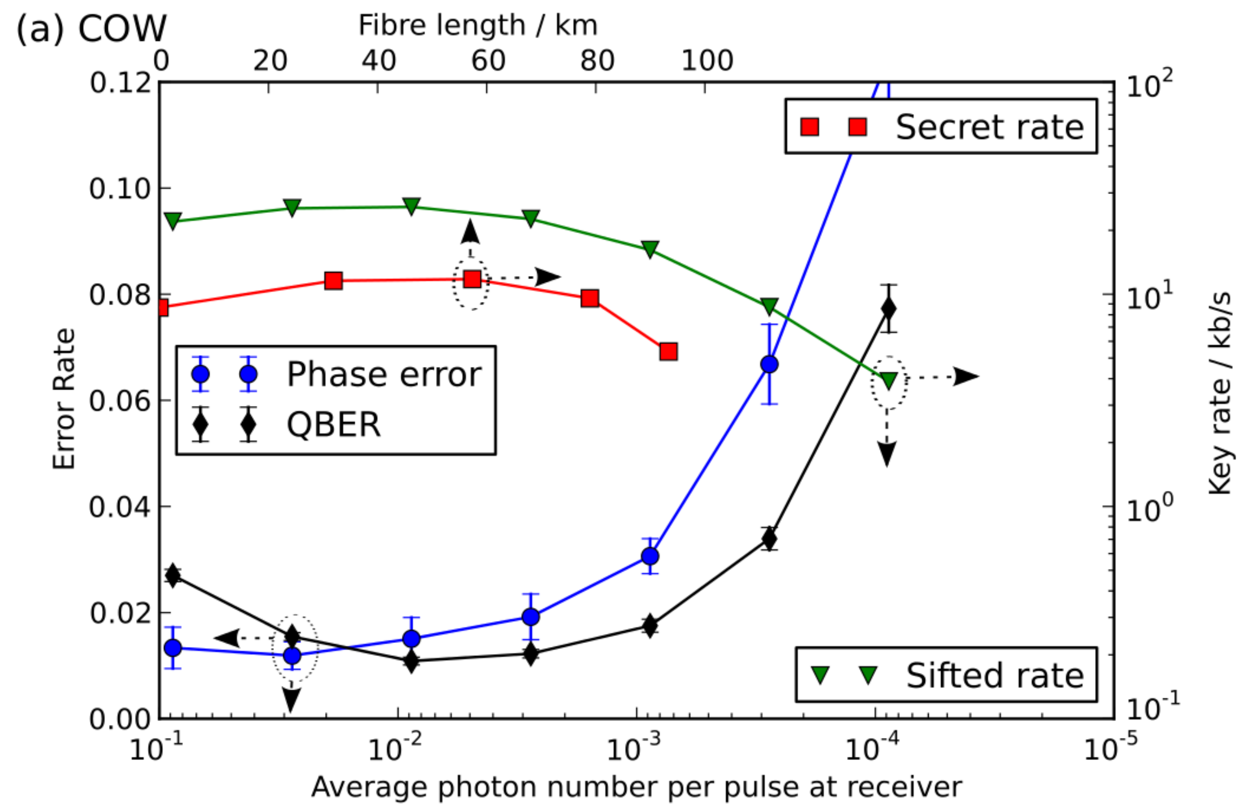
With dark counts

- QBER < 1.5%
- Phase error < 2%



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DPS performance

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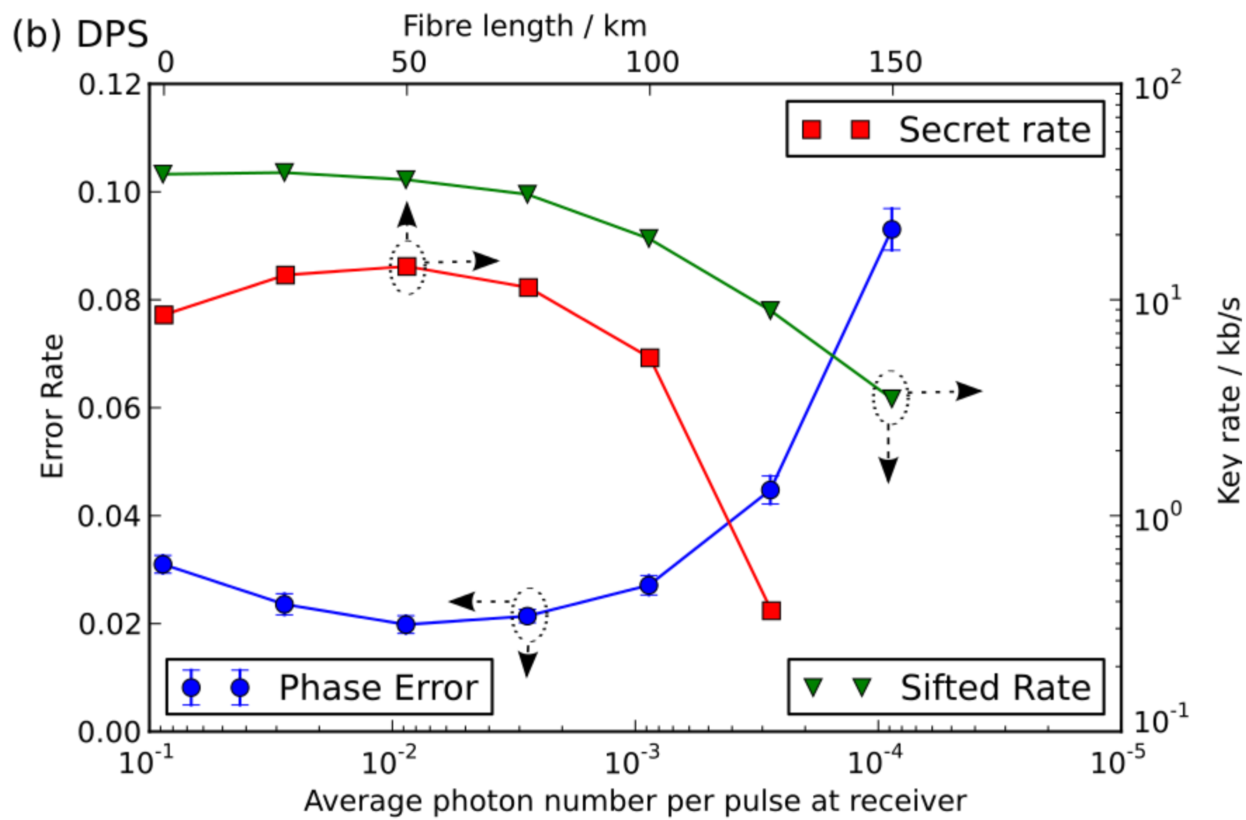
With dark counts

- Phase error 2% (min)



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BB84 Performance

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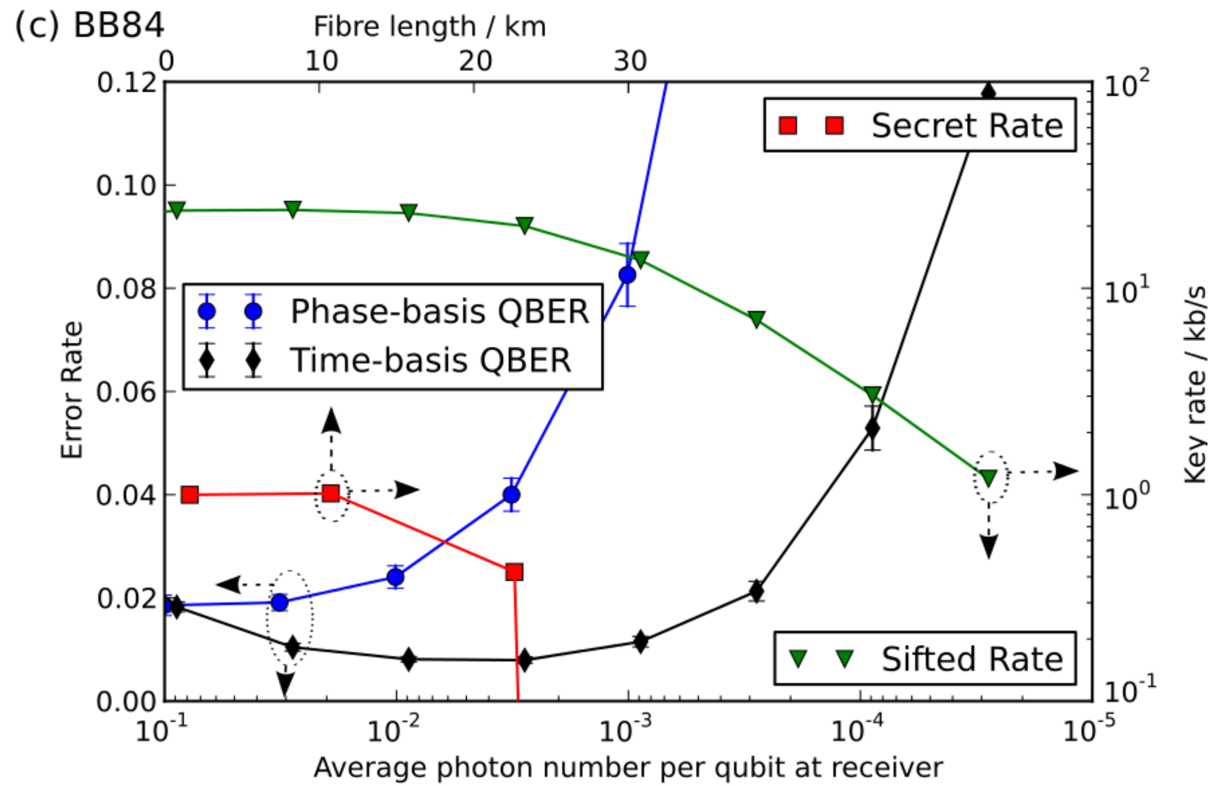
With dark counts

- QBER < 1%
- Phase error < 2%



- H.-K. Lo and J. Preskill, "*Security of quantum key distribution using weak coherent states with nonrandom phases*," Quantum Info. Comput. 7, 431–458 (2007)

Optical QBER

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Measure of transmitter performance

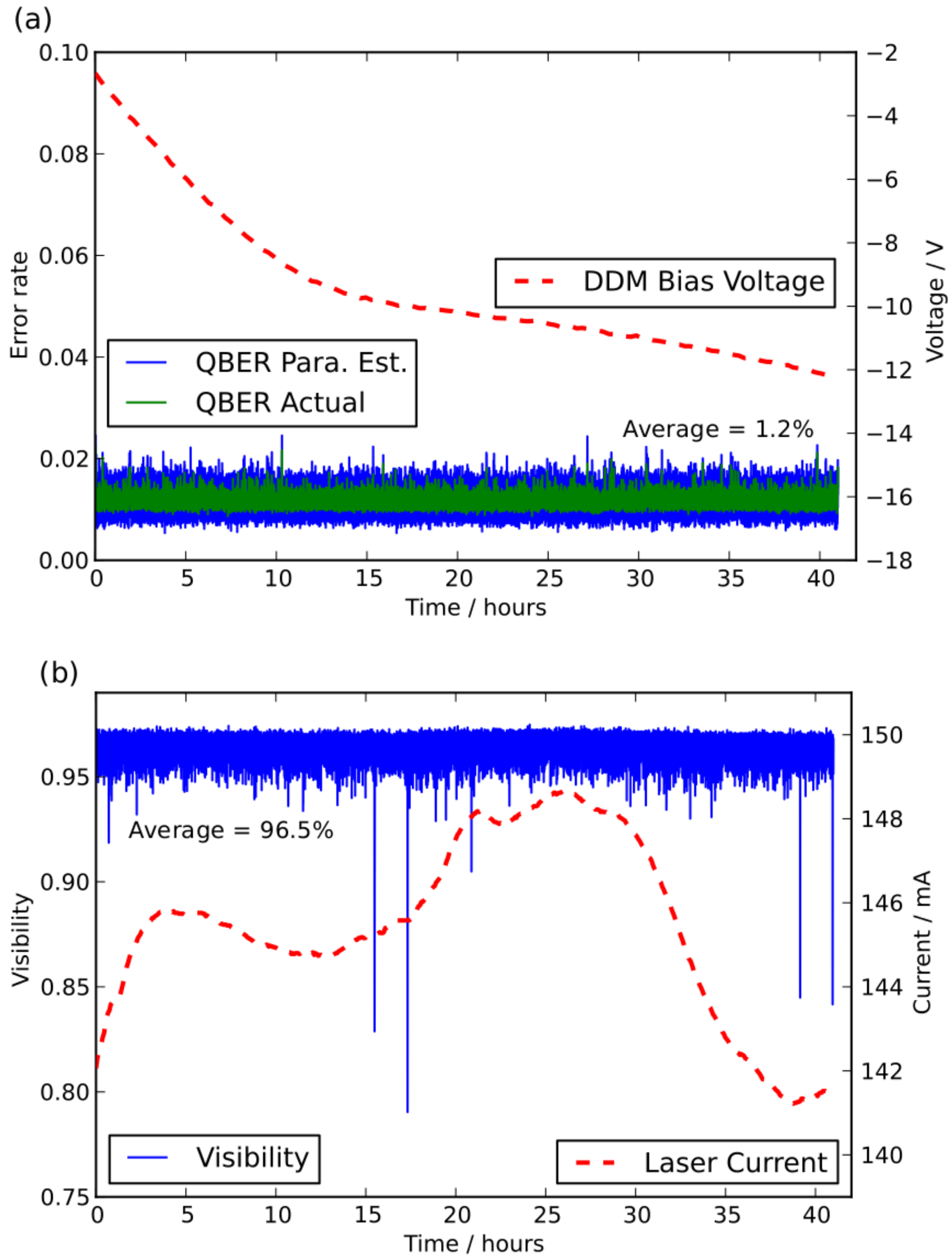
- Subtracting dark counts

Protocol	Phase basis $QBER_{opt}$	Time basis $QBER_{opt}$
DPS	$1.83 \pm 0.19\%$	N/A
COW	$0.92 \pm 0.41\%$	$0.89 \pm 0.08\%$
BB84	$1.51 \pm 0.16\%$	$0.58 \pm 0.06\%$

System stability

Automatic tracking of QBER and Visibility

- Modulator bias voltage
- Laser current



Conclusion

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- Demonstrated multi-protocol transmitter
  - No interferometer
  - 1.25 GHz (flexible)
    - Crucial for addressing different receivers
  - Easily stabilized
  - Performance comparable to protocol dedicated transmitters
- Further development
  - Decoy state preparation
  - Phase randomization
  - Full integration with high speed QKD platform

Thank you

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Antonio Ruiz-Alba

arXiv:1306.5940 [quant-ph]

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