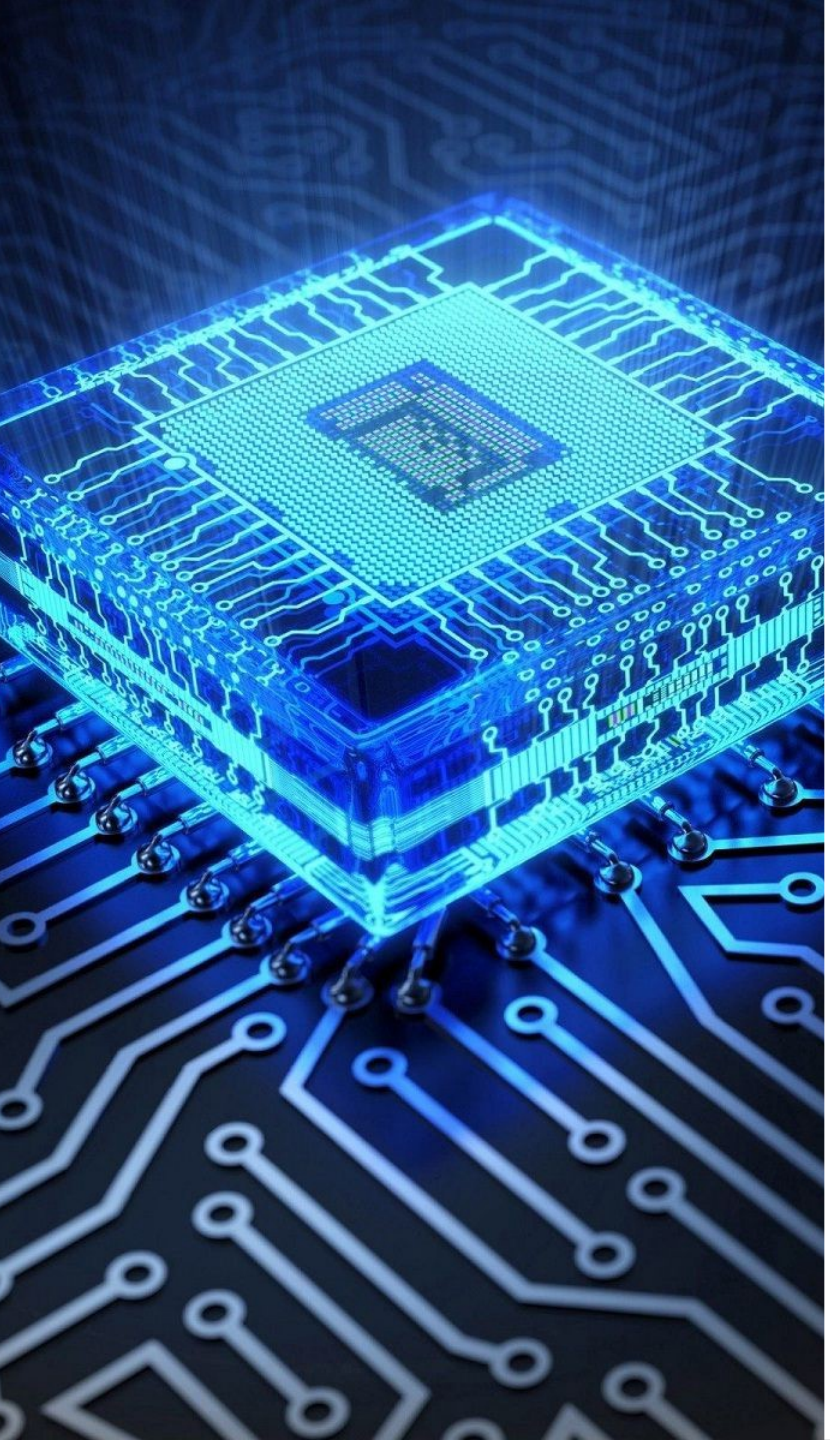


High-rate QKD with silicon photonics

Likang Zhang*, Wei Li*, Hao Tan, Yan-Lin Tang, Kejin Wei
Sheng-Kai Liao, Cheng-Zhi Peng, Feihu Xu and Jian-Wei Pan

National Laboratory for Physical Sciences at the Microscale
University of Science and Technology of China (USTC)

Chip-based QKD

hallenges in Practical QKD

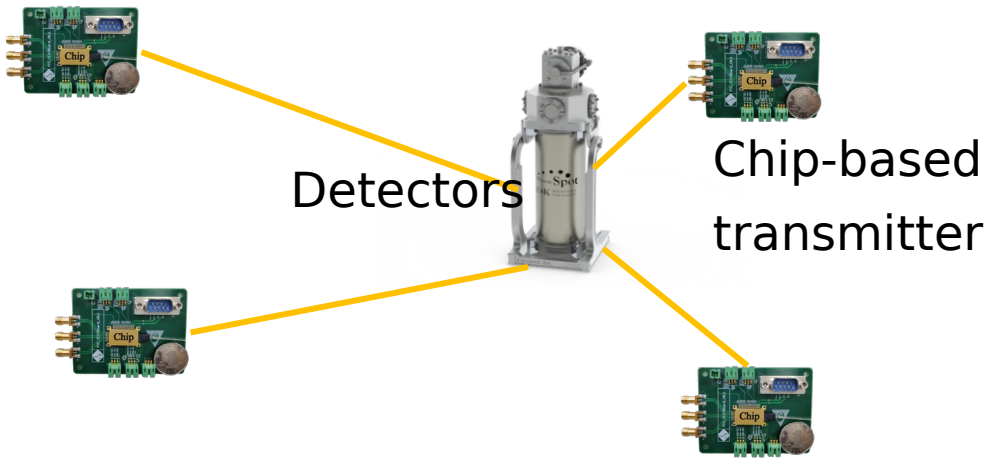
Expensive (Lasers, high-bandwidth modulators, single photon detectors)

Large-scale and Heavy

Solution: Integrated platform

1. Low cost: mass manufacture
2. Integrated and Miniaturized

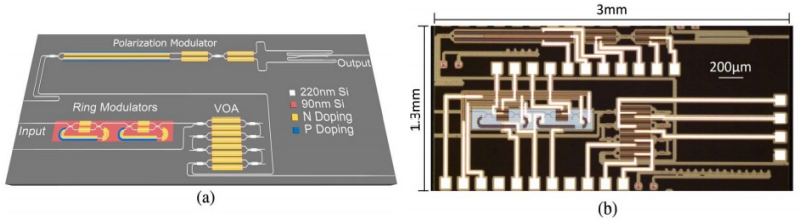
Future: Chip-based QKD network



Integration is inevitable for future developments !

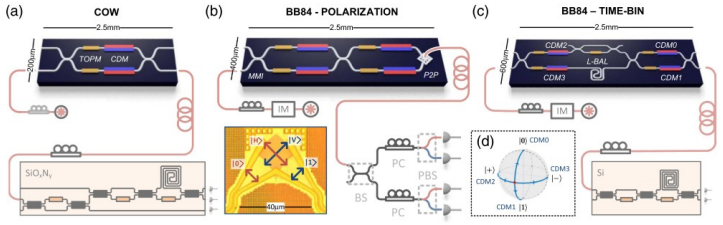
Recent works in chip-based QKD

First Si QKD transmitter



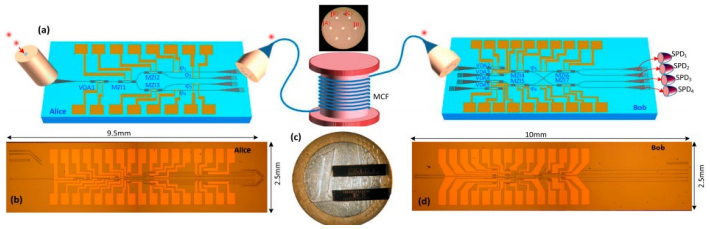
C. Ma et al., *Optica* 3, 1274 (2016)

High-speed modulation



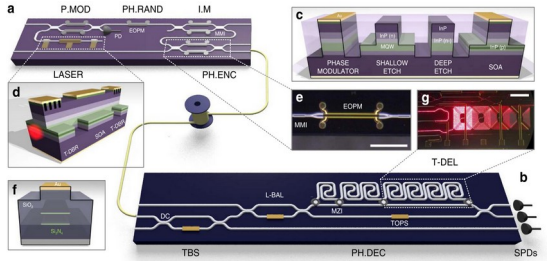
P. Sibson et al., *Optica* 4, 172 (2017)

High-dimensional protocol



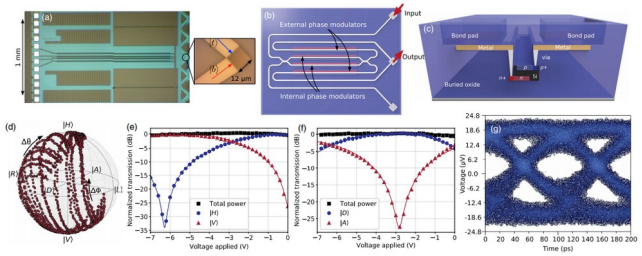
Y. Ding et al., *npj Quantum Inf.* 3, 25 (2017)

First InP QKD transmitter



P. Sibson et al., *Nat. Commun.* 8, 13984 (2017)

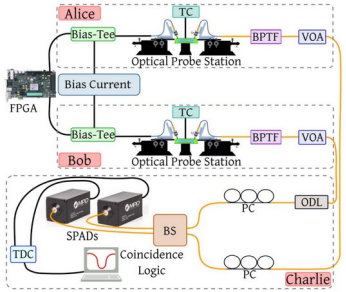
Metropolitan field test



D. Bunandar et al., *PRX* 8, 021009 (2018)

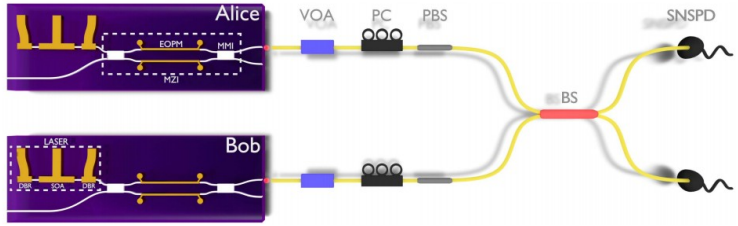
Integrated lasers

On Si

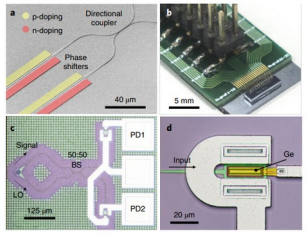


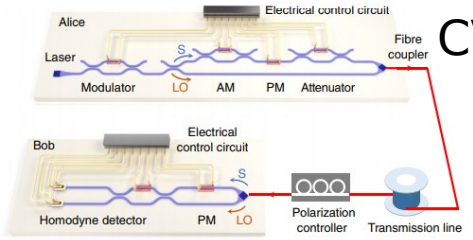
C. Agnesi et al., *Optics Letters* 2, 44 (2019)

On InP



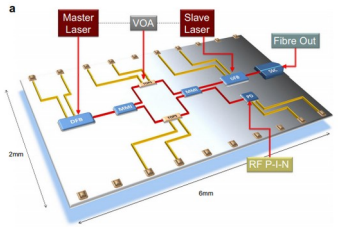
H. Semenenko et al., *Optics Letters* 2, 44 (2019)





CV-QKD integrated system

G. Zhang et al., *Nat. Photonics* 13, 839 (2019)



Modulator free transmitter

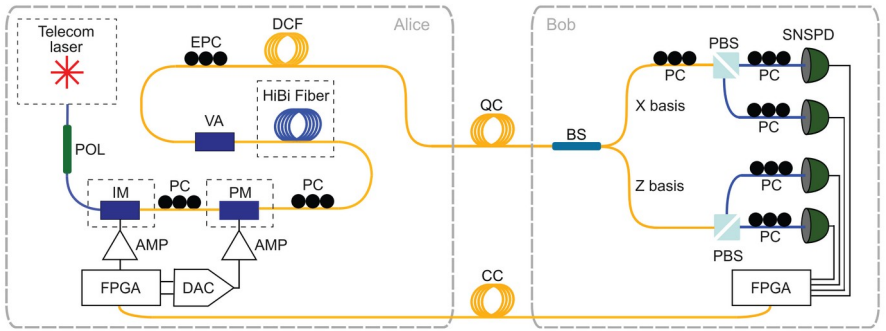
T. K. Paraïso et al., *npj Quantum Inf.* 5, 42(2019)

Challenges in chip-based QKD

- Mediocre secure key rate
- Low extinction ratio under high-speed modulation
- Stability

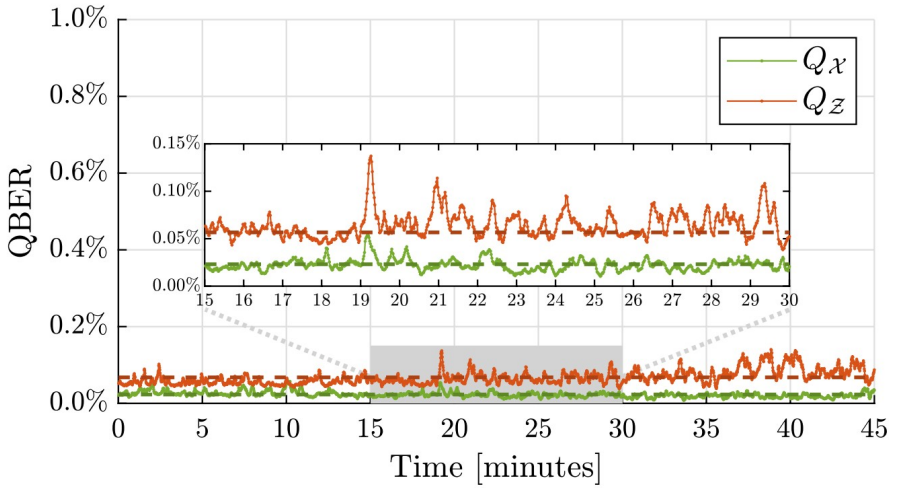
How to achieve higher key rates?

High Clock Rate



F. Grünenfelder et al., *Appl. Phys. Lett.* 117, 144003 (2020).

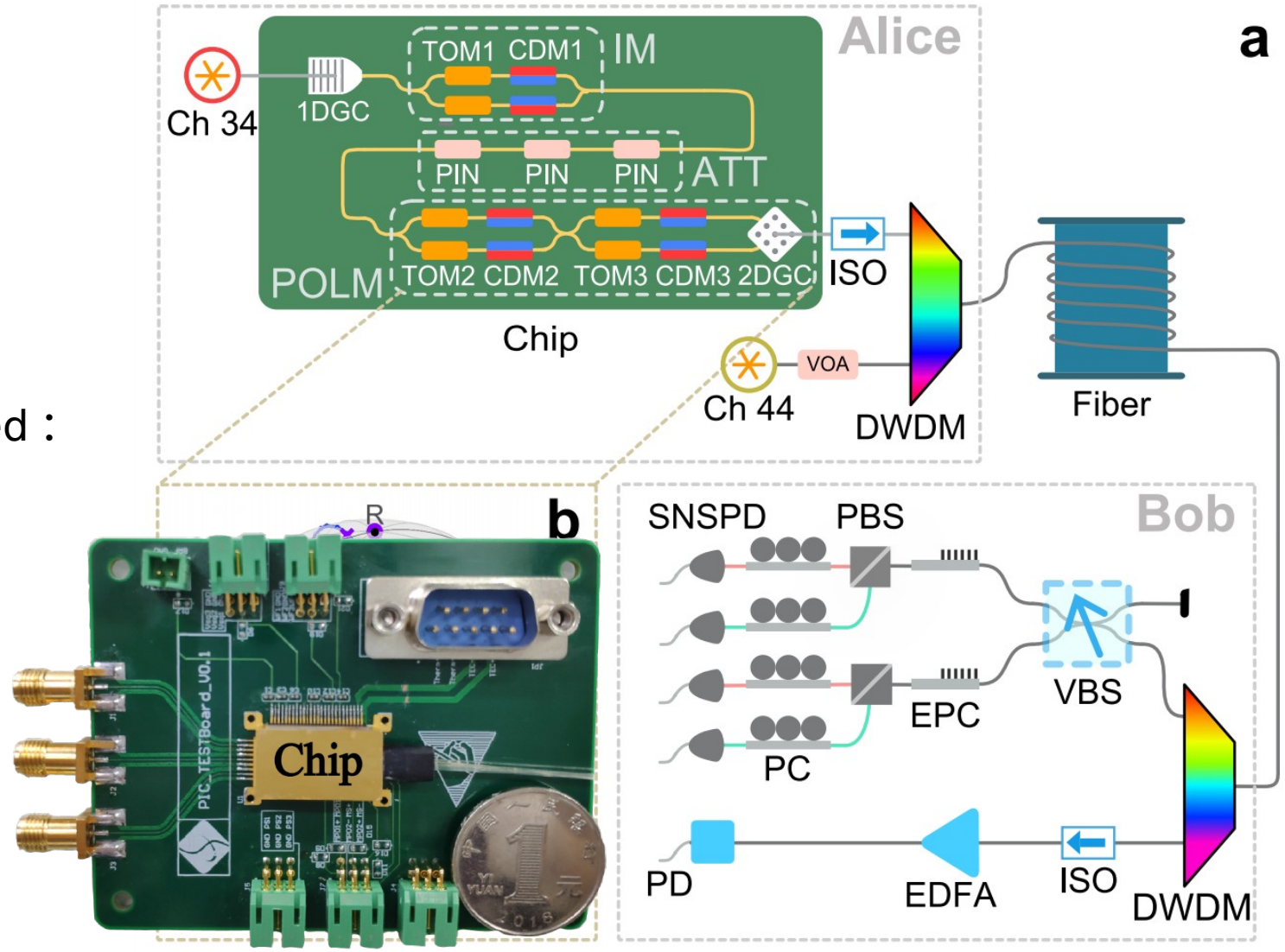
Low Quantum bit error rate



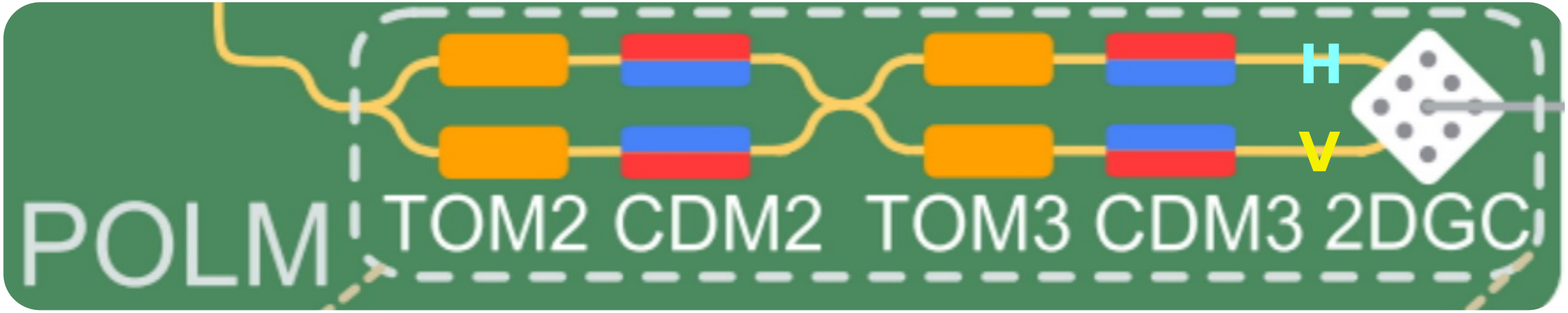
C. Agnesi et al., *Optica* 7, 4 (2020)

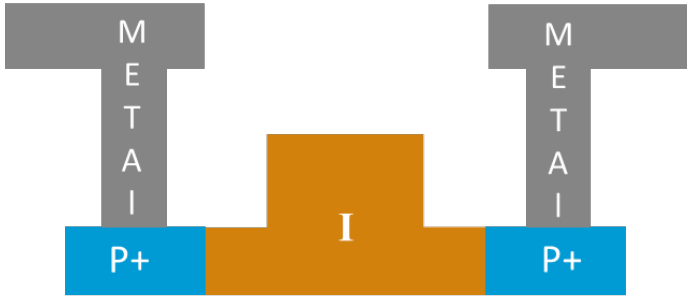
Setup

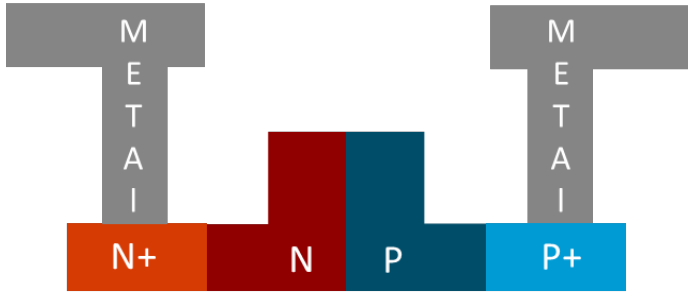
- 1-decoy 4-state efficient BB84 protocol
- 2.5 GHz random modulation
- 0.49% QBER, Two-stage polarization modulation
- Chip: commercially fabricated, integrated :
  - Intensity modulator(IM)
  - Polarization modulator(POLM)
  - Variable attenuator(ATT)
  - $4.8 \times 3mm^2$
- WDM: time synchronization

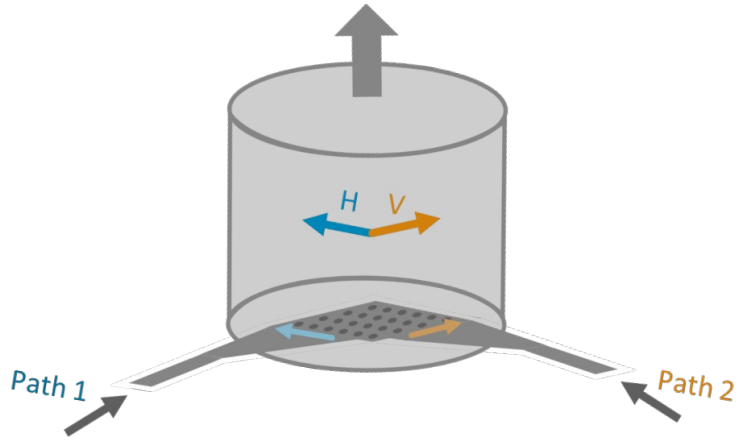


Polarization modulation method









TOM(Thermo-Optic Modulator)

Thermo-optic effect

Bandwidth ~kHz, V_π ~1V

CDM(Carrier Depletion Modulator)

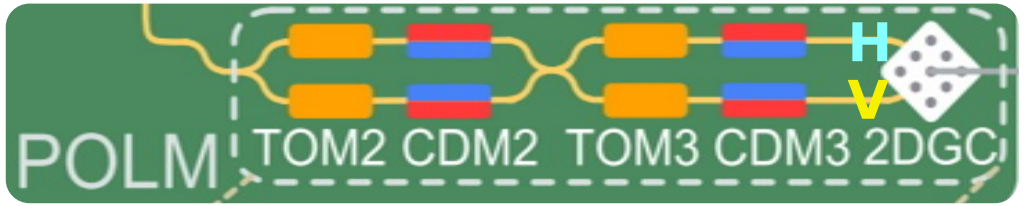
Plasma dispersion effect

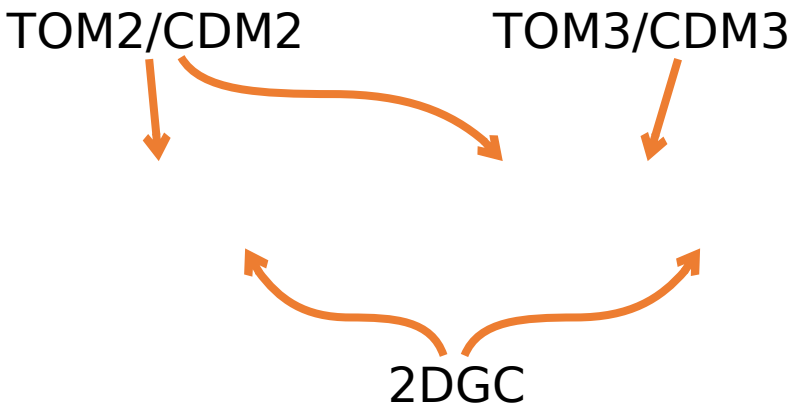
Bandwidth ~GHz, V_π ~5V

2DGC(2-Dimensional Grating Coupler)

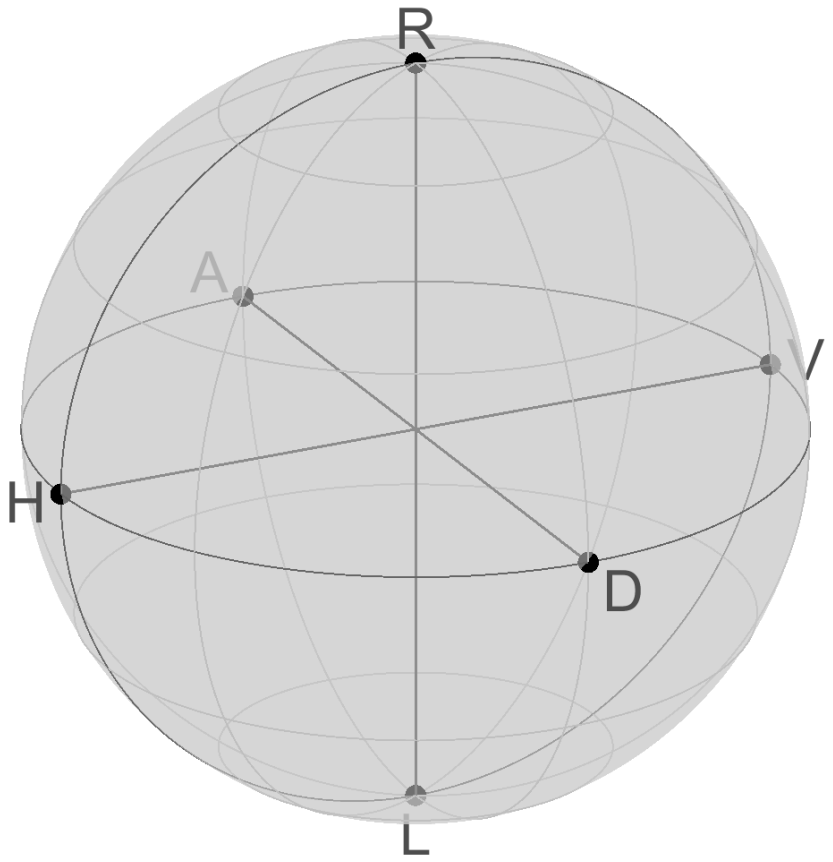
Path to polarization converter

Polarization modulation method



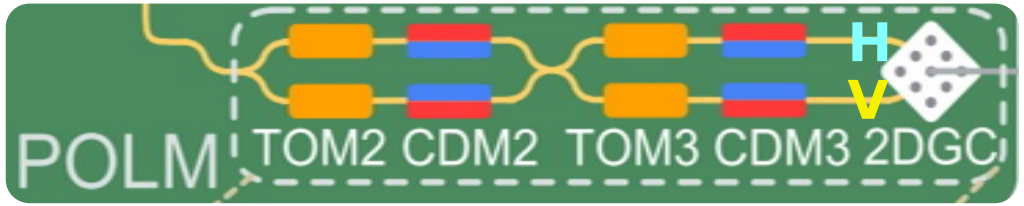


Ideal polarization modulation



Ideal polarization states

Polarization modulation method

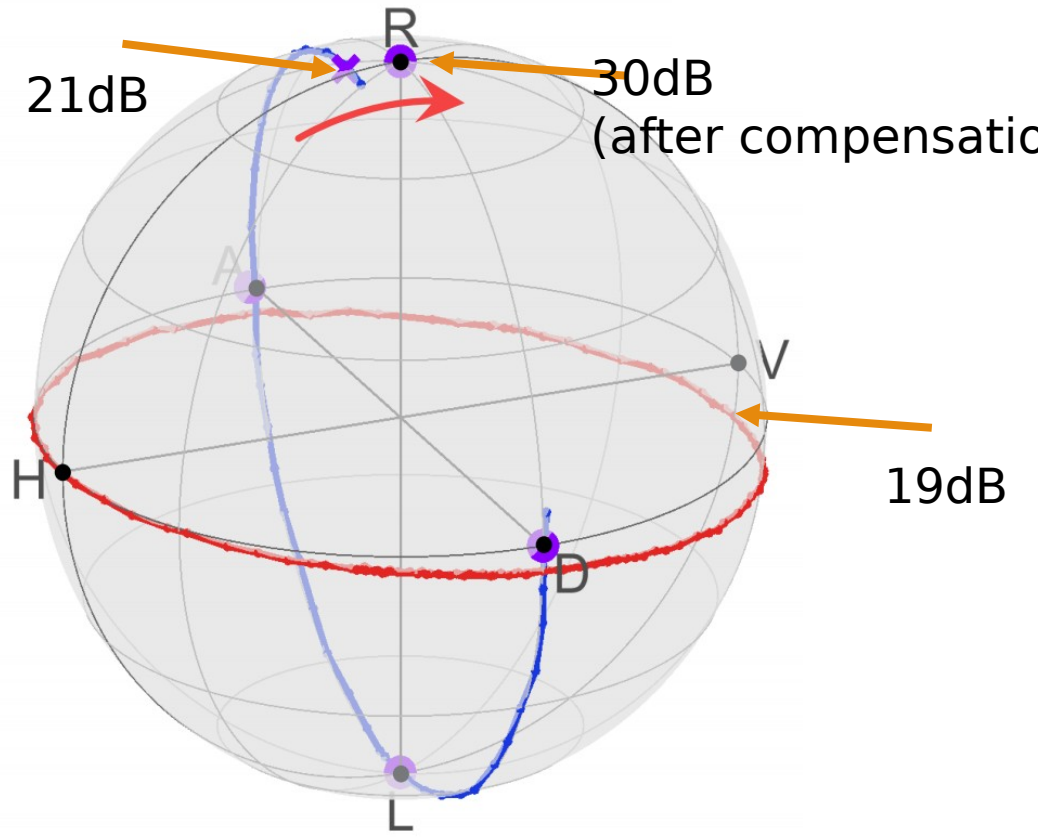


Imperfection:

- 2D Grating Coupler:
- CDM:

Compensation:

- Tune CDM2 to compensate loss of CDM3

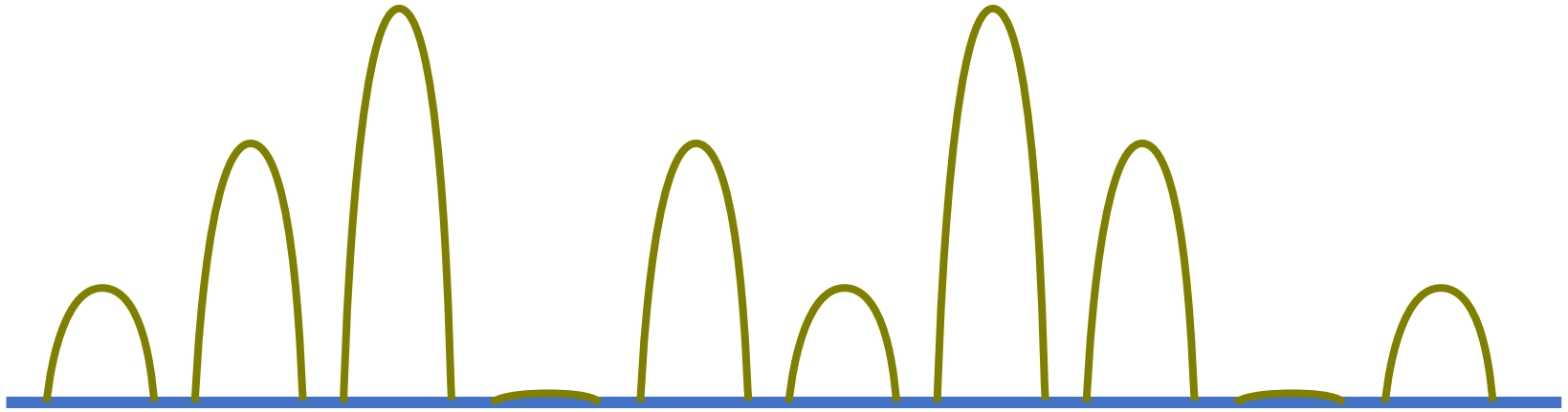


Experimental modulation results

High speed electronics

Commercial solution: AWG+RF amplifier

- Expensive
- AC coupled: Changing one influences other amplitudes



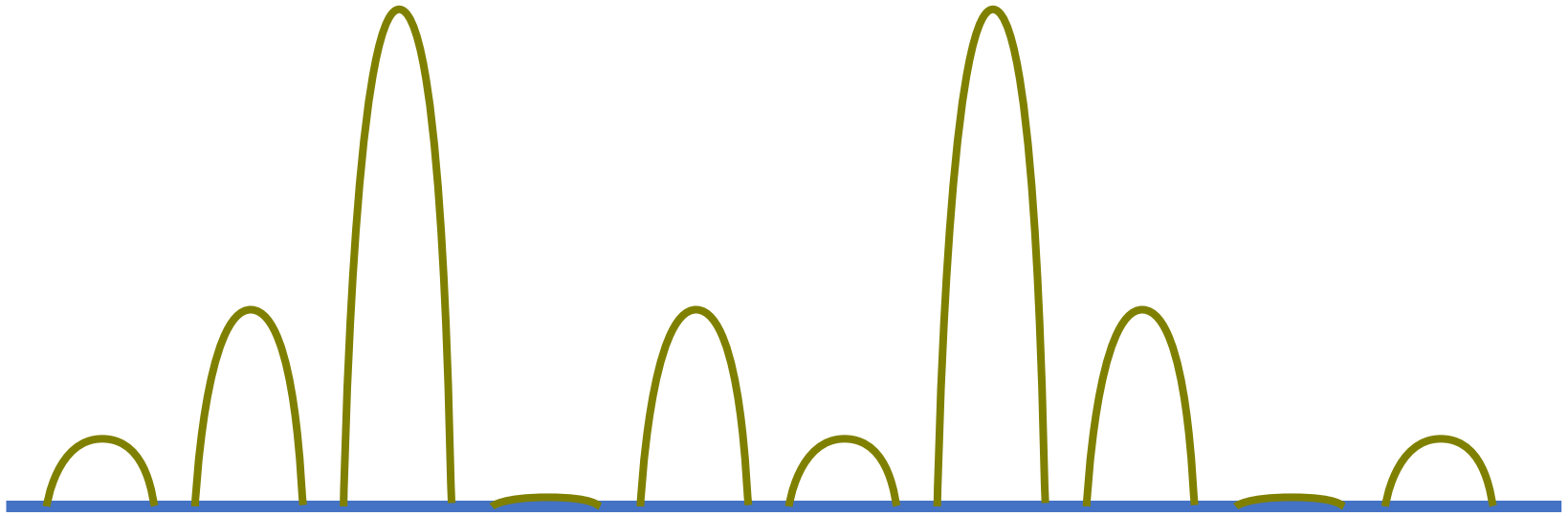
Modulation signals in QKD:

- Randomized
- Multiple amplitudes for decoy intensities and encoding states

High speed electronics

Commercial solution: AWG+RF amplifier

- Expensive
- AC coupled: Changing one influences other amplitudes



Modulation signals in QKD:

- Randomized
- Multiple amplitudes for decoy intensities and encoding states

High speed electronics

Home-made FPGA electronic board

Commercial solution: AWG+RF amplifier

- Expensive
- AC coupled: Changing one influences other amplitu

Advantages

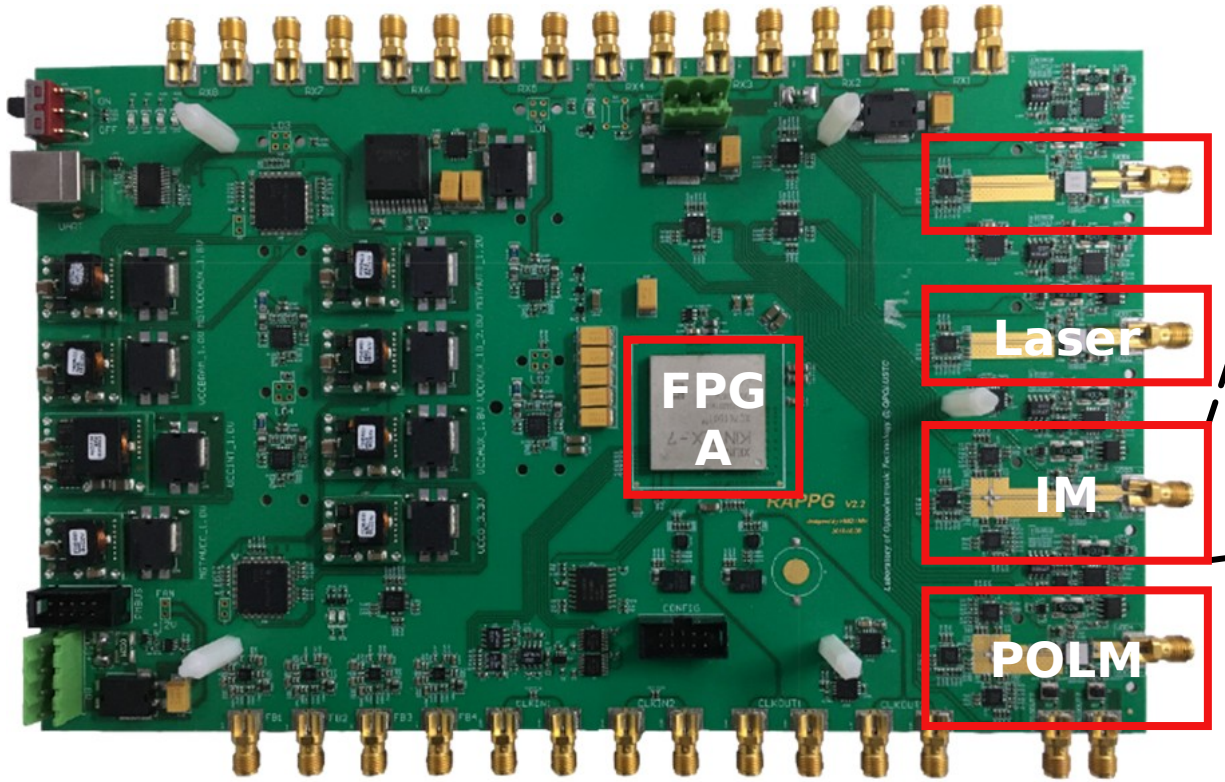
- Cost-efficient
- DC coupled: Different amplitudes are uncorrelated and can be independently controlled

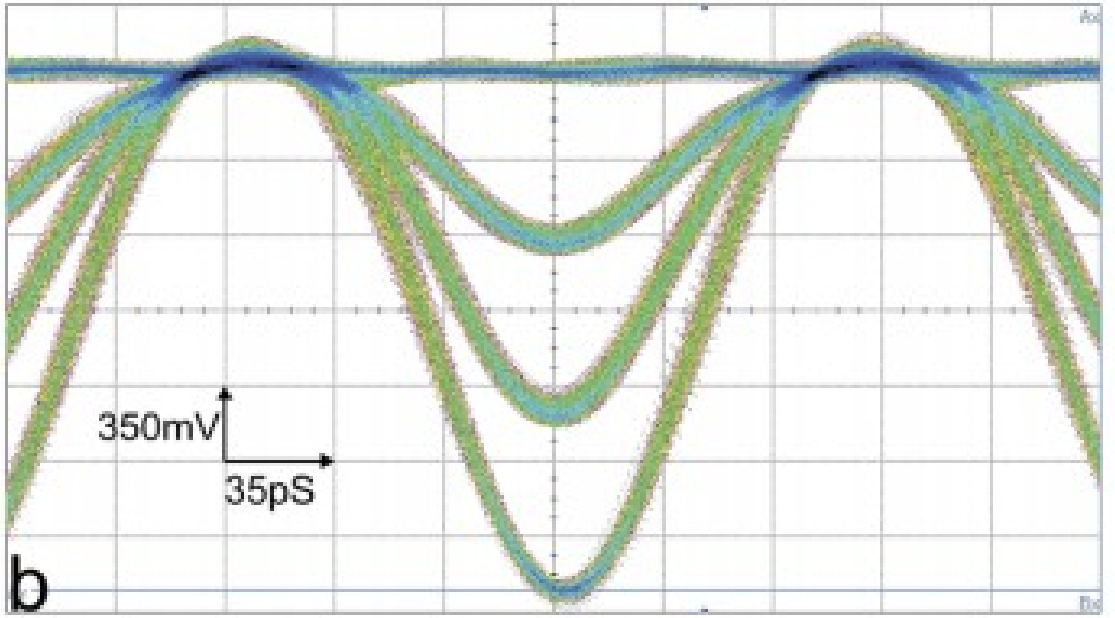
- 10G Sample/s, 7.5Vpp max
- IM/POLM channel: Four adjustable independent levels
- DC coupled out

X. Liu et al., *Rev. Sci. Instrum.* 91, 024705 (2

High speed electronics

Home-made FPGA electronic board





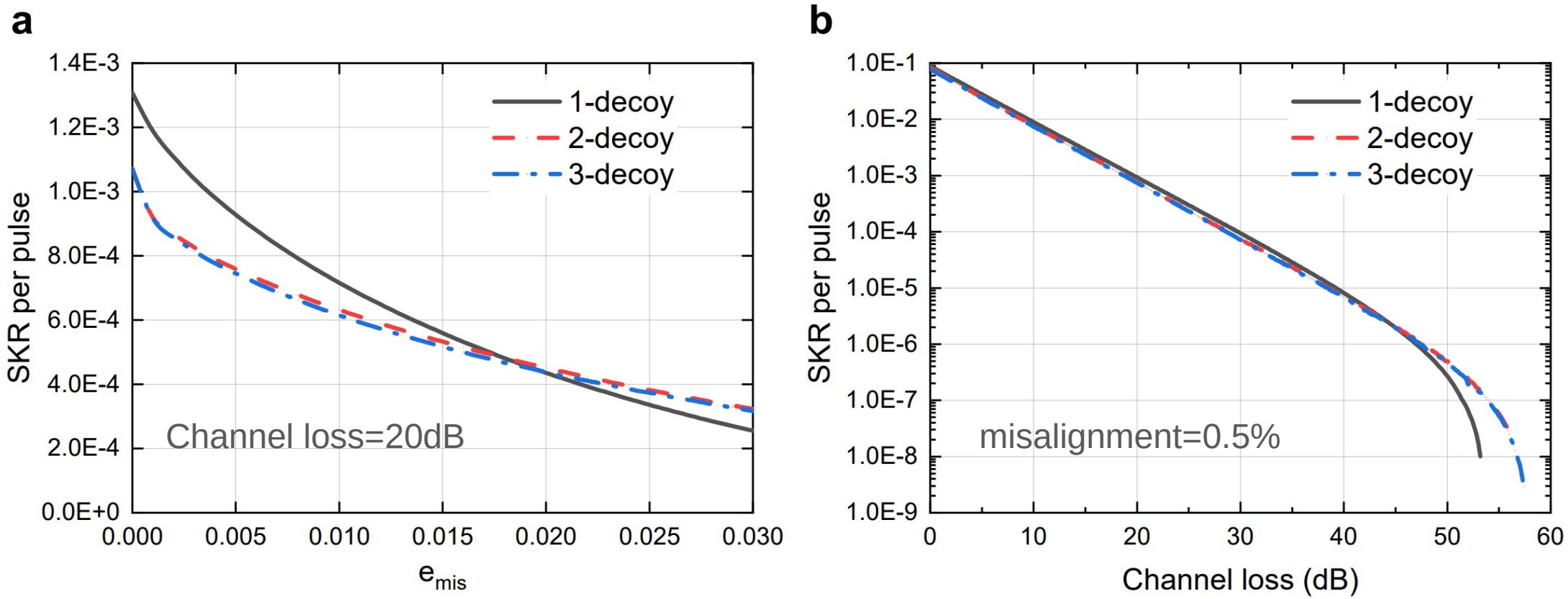
- 10G Sample/s, 7.5Vpp max
- IM/POLM channel: Four adjustable independent levels
- DC coupled out

- Three amplitude-modulated and synchronized pulses
- Pulses are combined to generate the desired pattern with multiple amplitudes

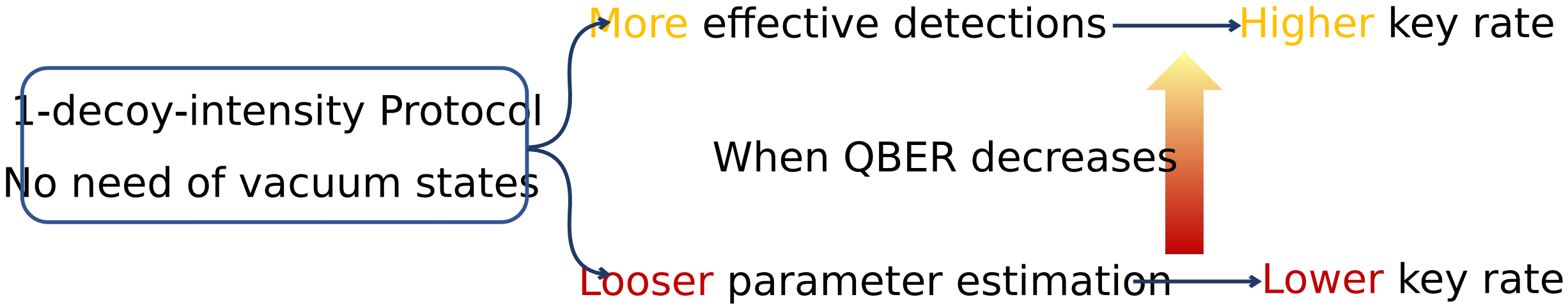
X. Liu et al., *Rev. Sci. Instrum.* 91, 024705 (20

-decoy-intensity 4-encoding-state BB84 Protocol

- Simple to perform
- Security against general attacks
- The highest secure key rate(SKR) in our system



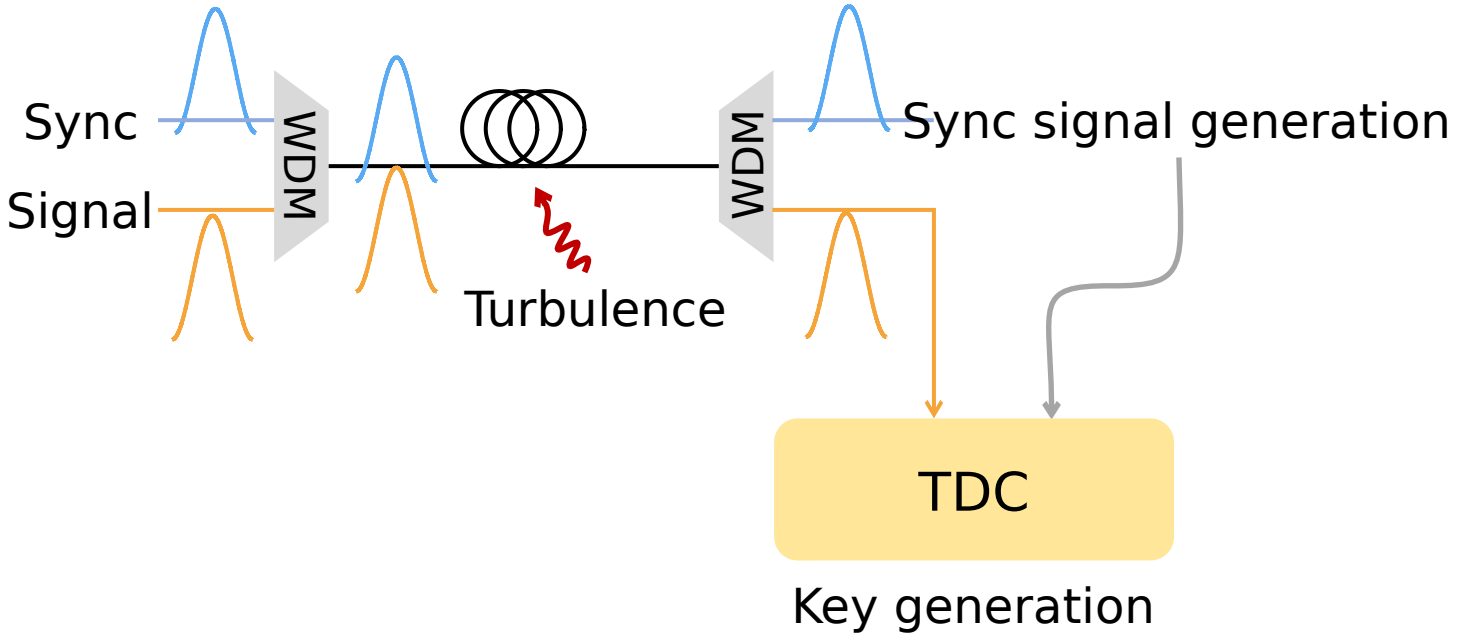
1-decoy-intensity 4-encoding-state BB84 Protocol



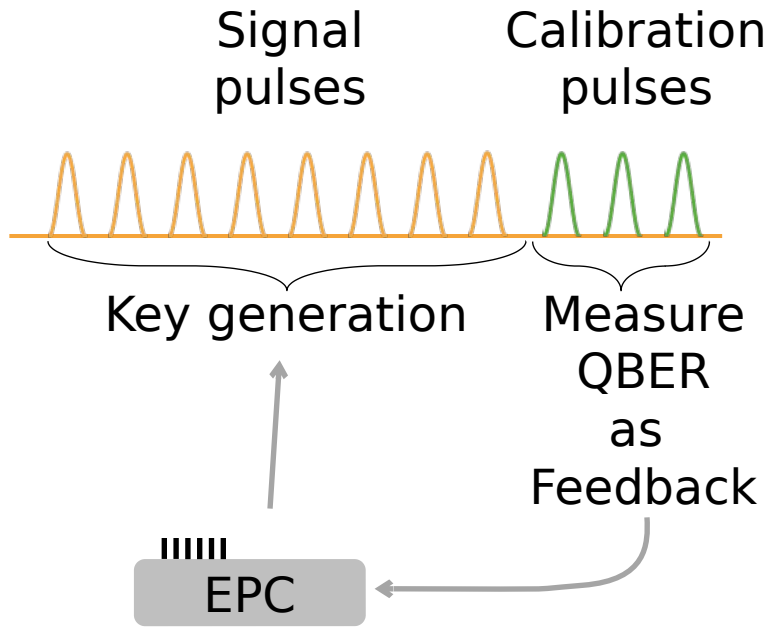
Rusca, Davide, et al. Appl. Phys. Lett. 112.17 (2018): 171

Continuous runs without maintenance

- Time Synchronization + Polarization Feedback
- Continuous run(>7h) with nearly non-degrading secure key rates



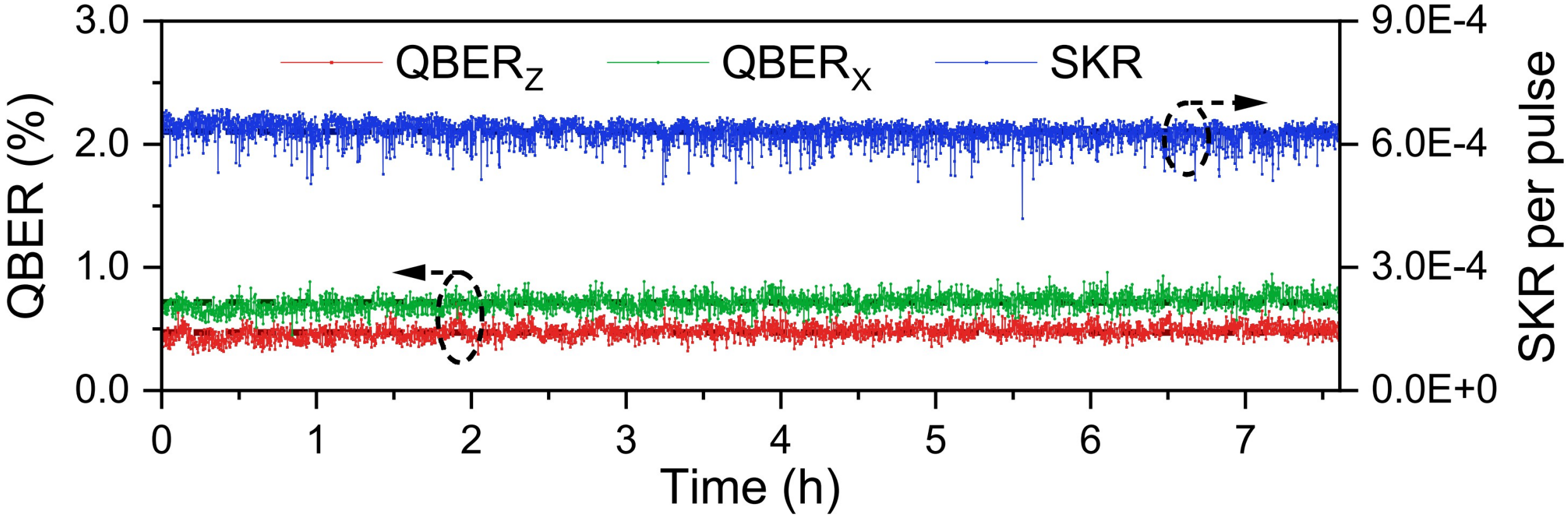
Time Synchronization



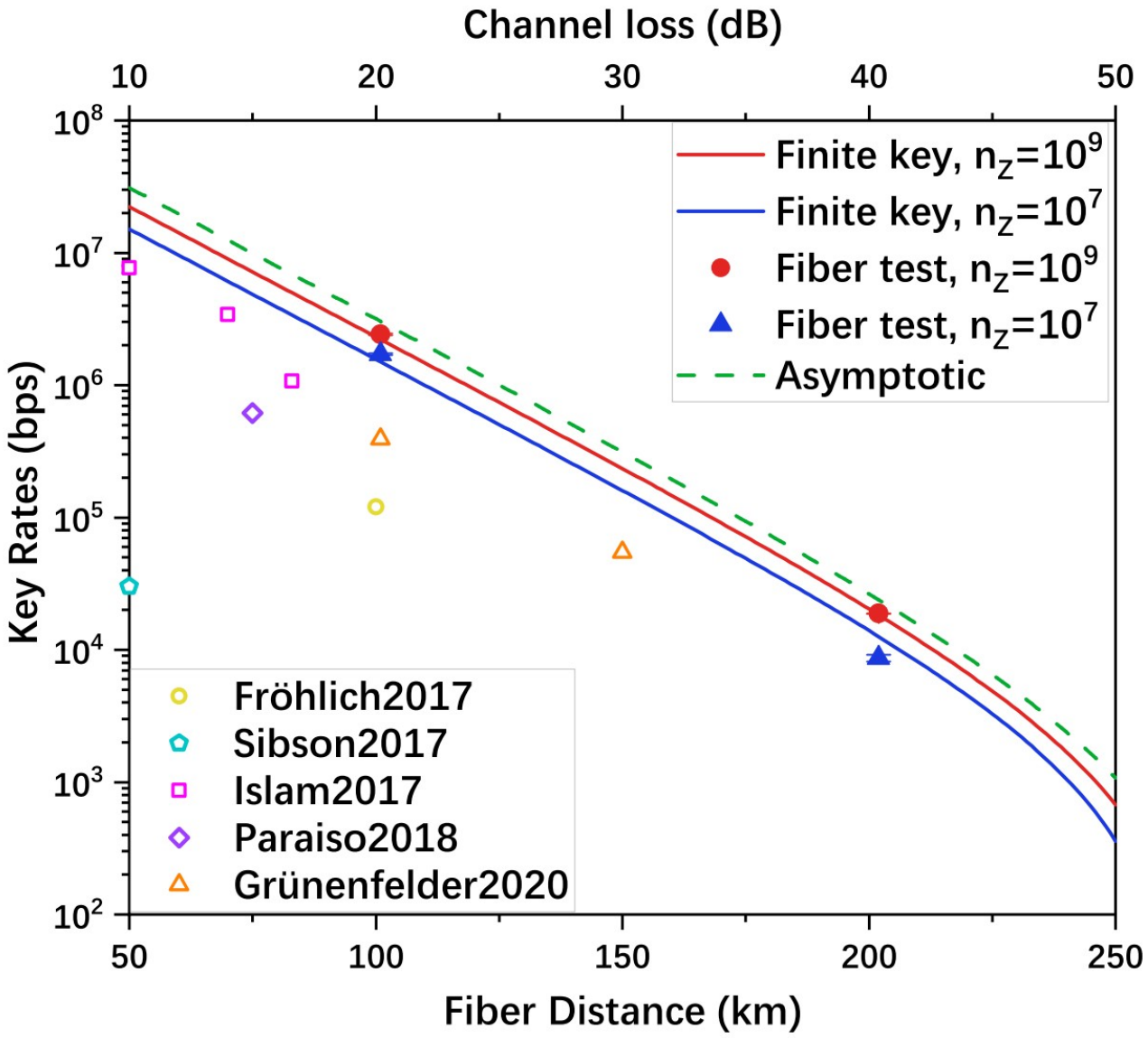
Polarization Feedback

Continuous runs without maintenance

- Time Synchronization + Polarization Feedback
- Continuous run(>7h) with nearly non-degrading secure key rates



Results



- 2.42 Mbps @ 101 km fiber channel (19.6 dB)
- One of the ***highest*** rates reported
- Robust, miniaturized and low-cost

Next Step:

- High-bandwidth QKD network
- Electronics+Photonics Integration

Acknowledgement

Prof. Feihu Xu

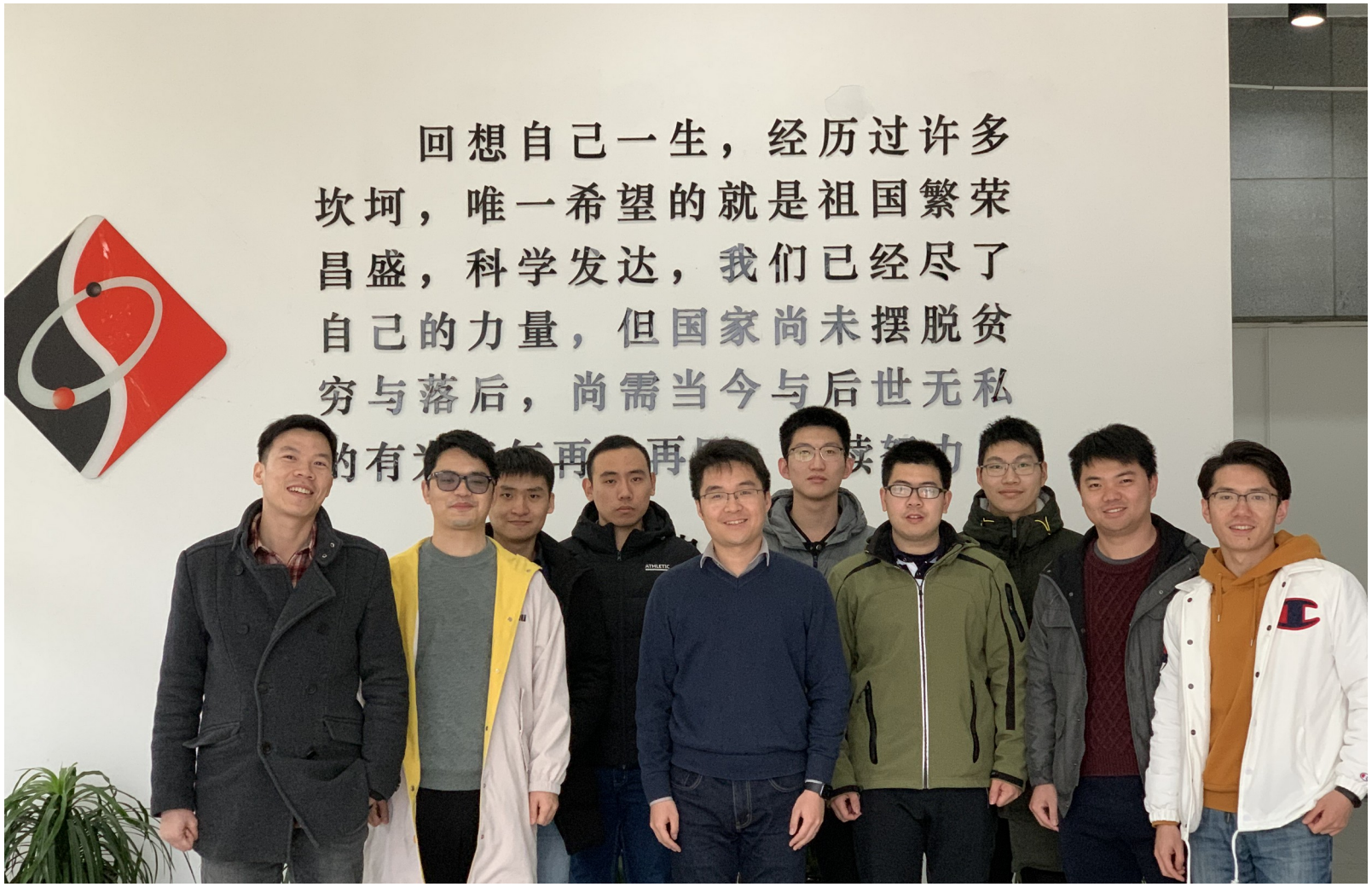
Prof. Jian-Wei Pan

Funding

CHINESE ACADEMY OF SCIENCES

国家自然科学基金委员会 NSFC

中华人民共和国科学技术部
Ministry of Science and Technology of the People's Republic of China



Our Team

Thank you for your attention!