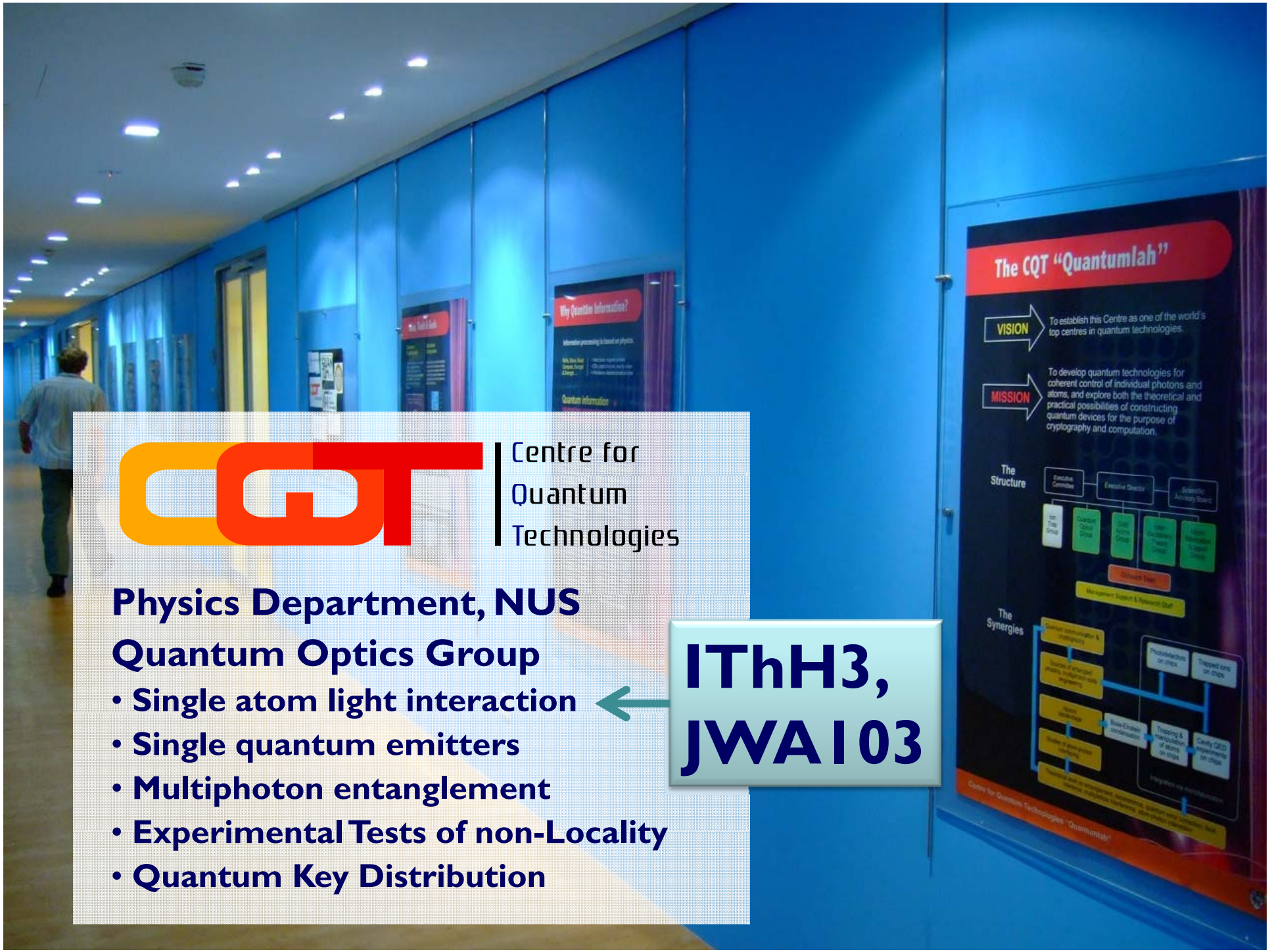
Centre for Quantum Technologies, Singapore

CQT QUANTUM OPTICS GROUP

Entanglement-based Free Space Quantum Cryptography in Full Daylight

Ilja Gerhardt, Matthew P. Peloso, Caleb Ho,
Antía Lamas-Linares and Christian Kurtsiefer



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Physics Department, NUS

Quantum Optics Group

- **Single atom light interaction**
- **Single quantum emitters**
- **Multiphoton entanglement**
- **Experimental Tests of non-Locality**
- **Quantum Key Distribution**

IThH3, JWA103

Introduction to QKD

- **Quantum Cryptography = Quantum Key Distribution**
  - Have a Random Number at two locations

    One-time pad for encryption

- **1980ies: Prepare and Send**
  - Bennet Brassard, BB84
  - Send single Photons, non-cloning theorem
- **1990ies: Entanglement Based… why?**

Prepare and Send

- **Need for Random Numbers**

- **Different Photons, different Colors?**
  - Dimensionality of Hilbert space needs to be known for security

Entanglement based QKD

- **Ekert 1991 (E91)**
  - Let's measure two qubits of an entangled entity
  - Perfect (Anti)correlation
  - Bell's inequality violated

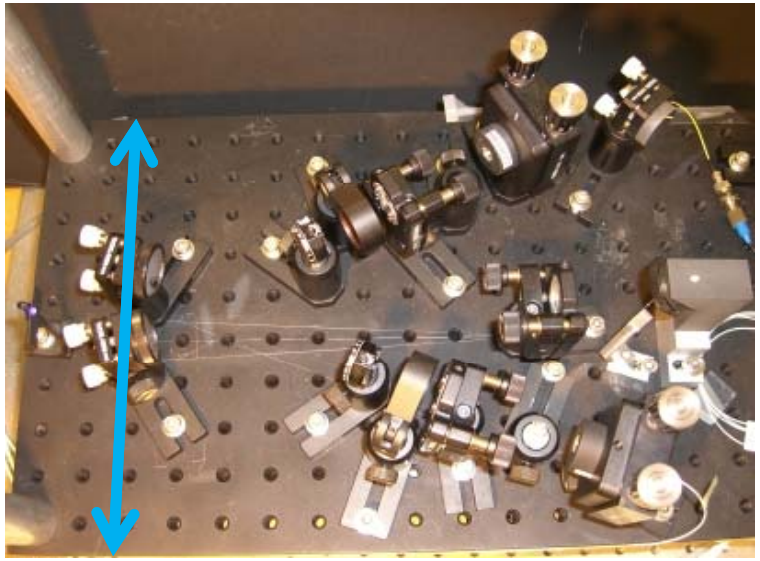
$$|\Psi\rangle^- = \frac{1}{\sqrt{2}}(|HV\rangle - |VH\rangle)$$

  = eavesdropper knowledge can be eliminated via PA

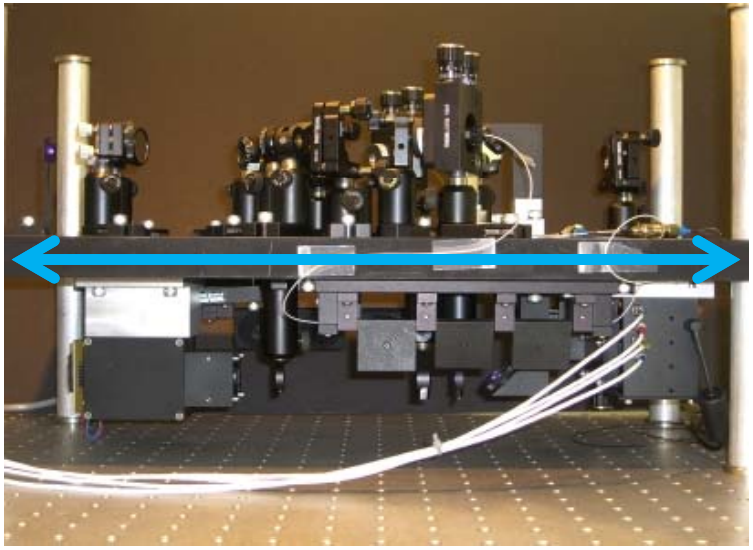
- **Photons for convenience…**
- **Freespace: Ad-hoc set-up**

Entanglement based QKD

- **Pairsource: BBO, lean & compact**
  - Strong temporally correlated ☺
  - Broader than dimmed lasers ☹



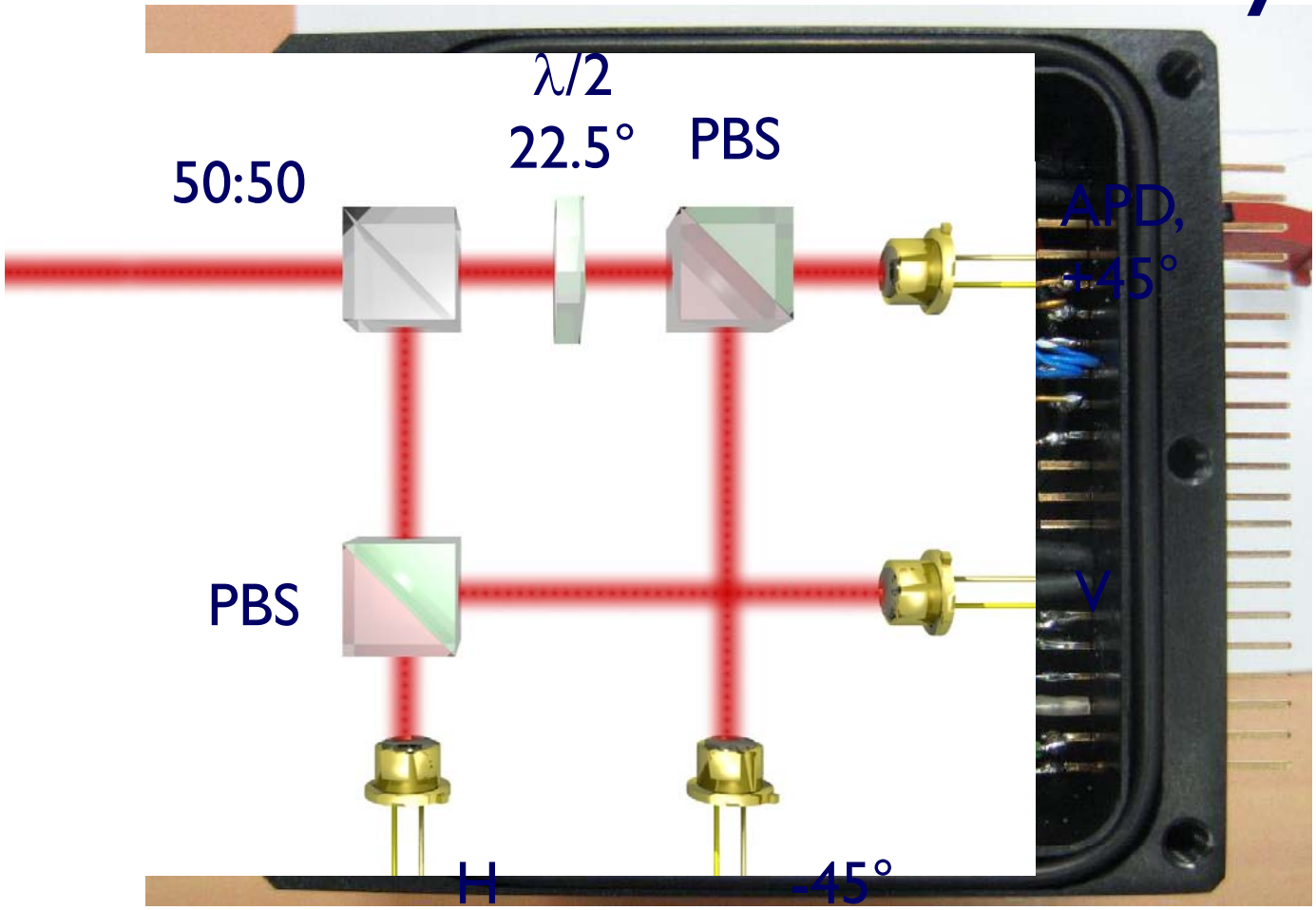
10”



19”

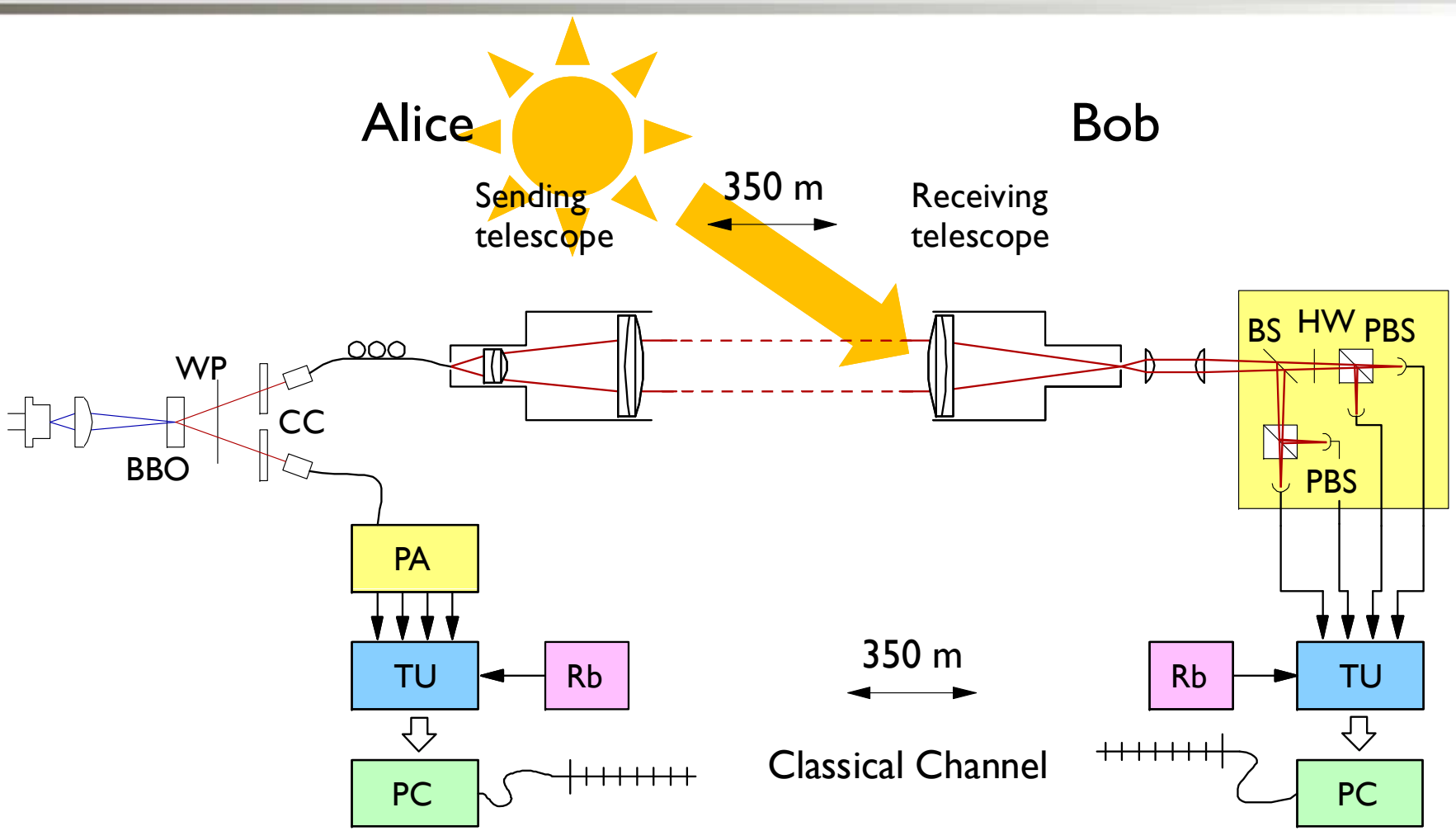
Detection of Photons

- **Detection: Polarization analyzer**



J.G. Rarity et al., J. Mod. Opt. 41, 2345 (1994)

Setup

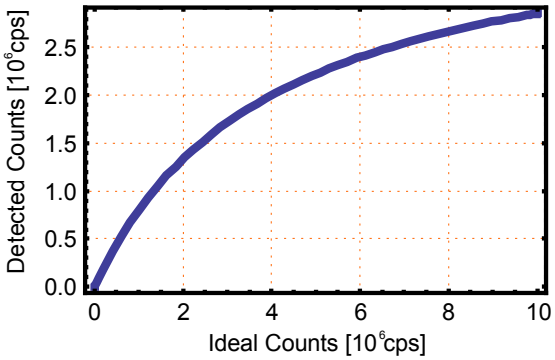


M. Peloso et al., New J. Phys. **11** 045007 (2009)

Problems in Daylight

- **Destruction of detectors**
- **Non-linearity of the detector**
  - Saturation

$$r' = r(1 - r'\tau_{\mathrm{d}})$$



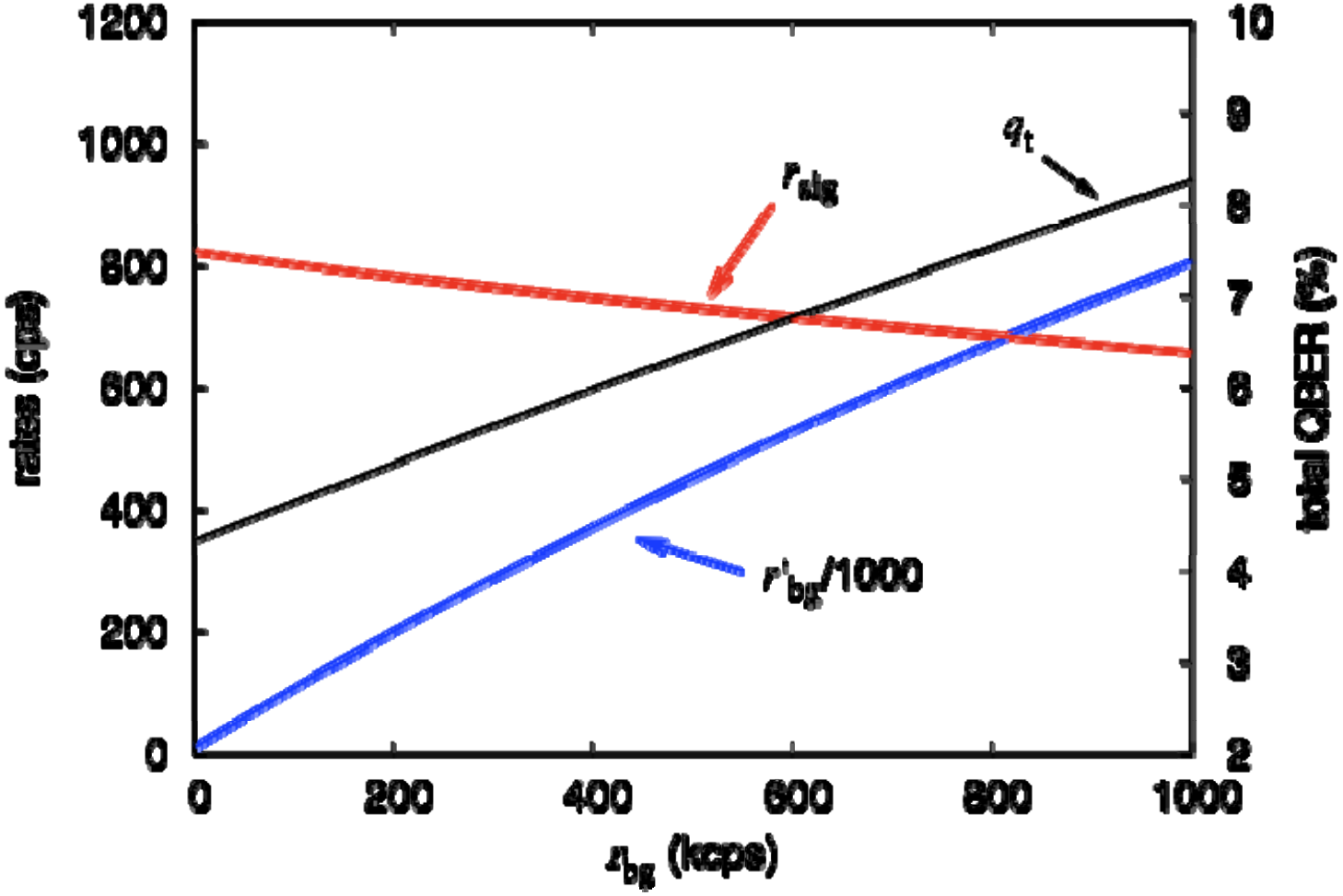
- **Accidental clicks**
  - Confused with real coincidence events (QBER)

$$q_{\mathrm{t}} = \frac{1}{r_{\mathrm{sig}} + r_a}\left(q_{\mathrm{i}} r_{\mathrm{sig}} + \frac{1}{2} r_a\right)$$

- **Fluctuations of ~30dB (day/night)**

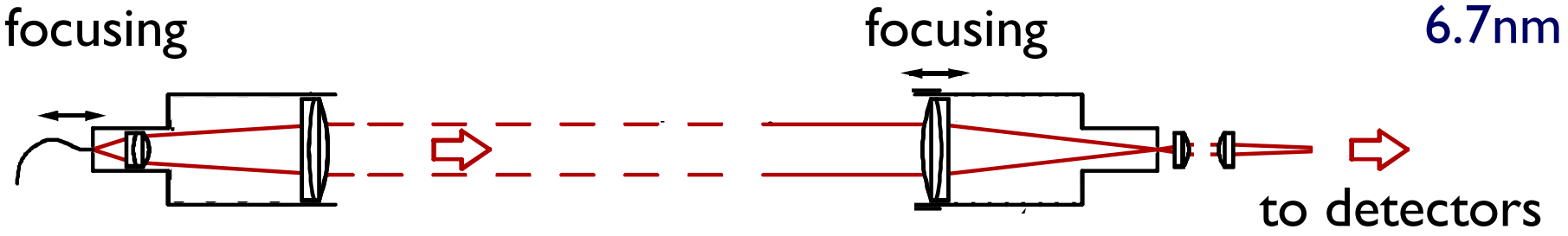
M. Peloso et al., New J. Phys. **11** 045007 (2009)

Expected Rates at daylight



M. Peloso et al., New J. Phys. **11** 045007 (2009)

Sun & Solutions



-12 dB

- 3-4 dB

100µrad
FOV=10cm

Δt=1ns

M. Peloso et al., New J. Phys. **11** 045007 (2009)

Setup

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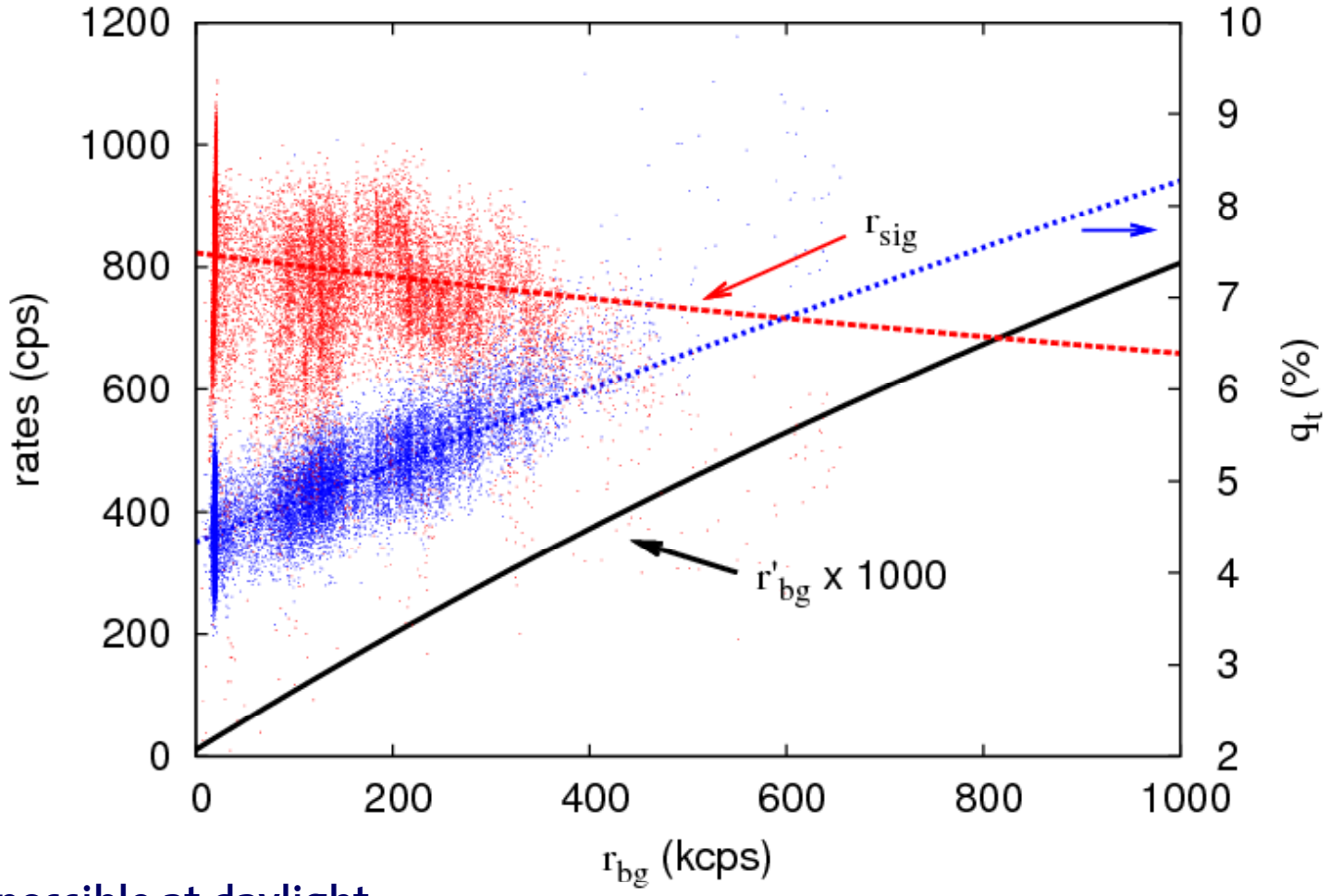
M. Peloso et al., New J. Phys. **11** 045007 (2009)

Measured rates at daylight



- Sync possible at daylight

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Experimental results

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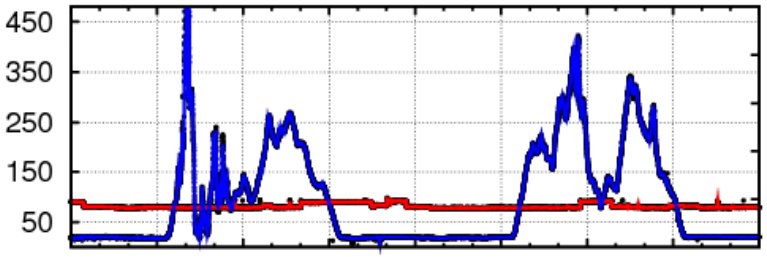
total detection rate at receiver (kcps)



total 'local' detector rate at source (kcps)

M. Peloso et al., New J. Phys. **11** 045007 (2009)

Conclusions

- **Entanglement based QKD in daylight,**

  4 days run without interruption
- **Synchronization works at ambient conditions**
- **Noise Suppression**
  - Spectral
  - Temporal
  - Spatial
- **Brighter Sources…70 pairs/(s mW MHz)**

M. Peloso et al., New J. Phys. **11** 045007 (2009)

Thanks for your attention

http://qolah.org

Interested in Single Molecules?
IThH1, Thursday, 2:30pm, Room 315

Rates in Daylight

- **Sifting / Signal rate:**

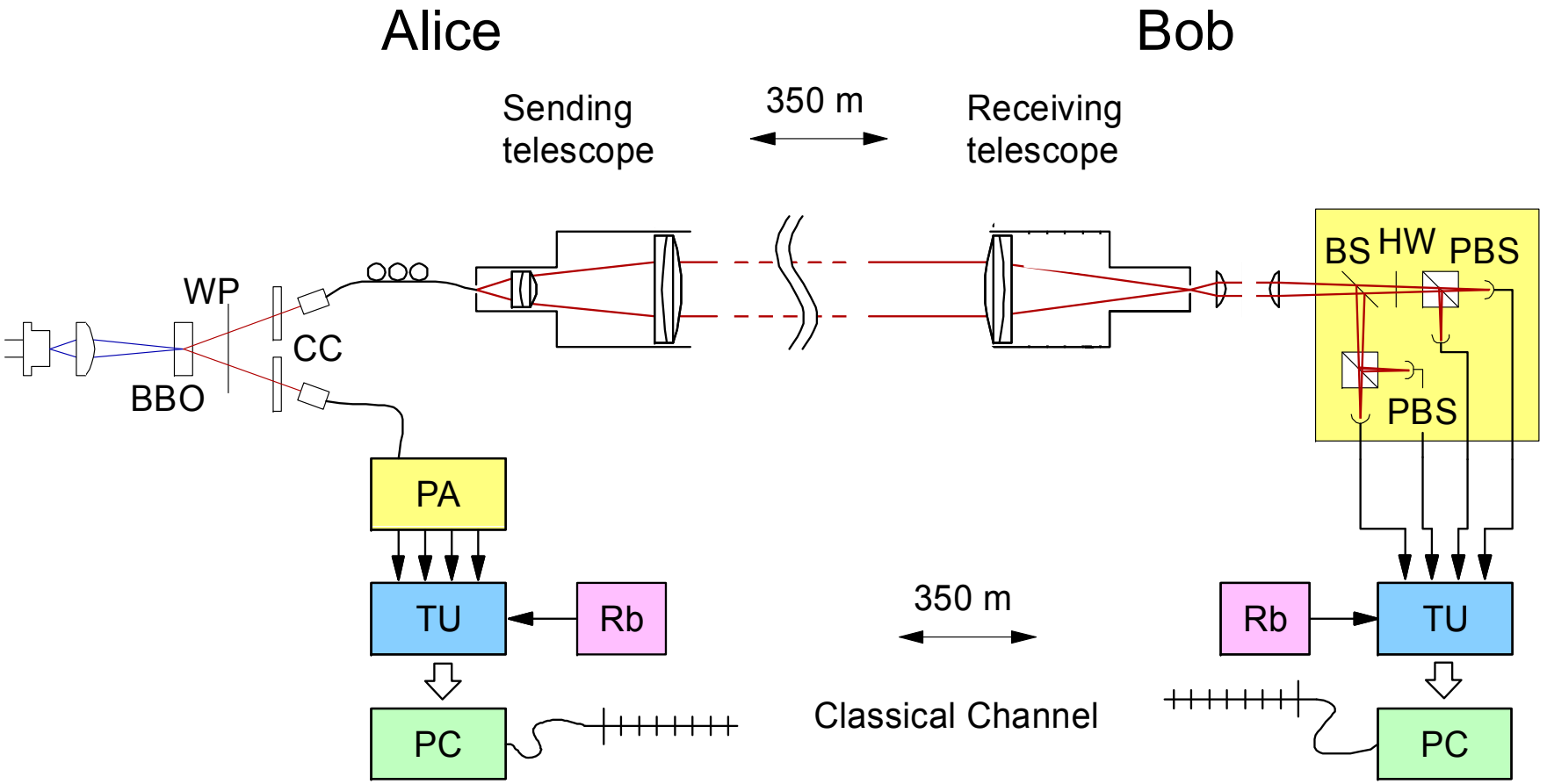
$$r_{\mathrm{sig}} = r_{\mathrm{c}} T/2$$

$$r'_{\mathrm{sig}} = \alpha r_{\mathrm{sig}} = \frac{r_{\mathrm{c}} T/2}{1 + (r_{\mathrm{bg}} + r_2 T)\tau_{\mathrm{d}}/4}$$

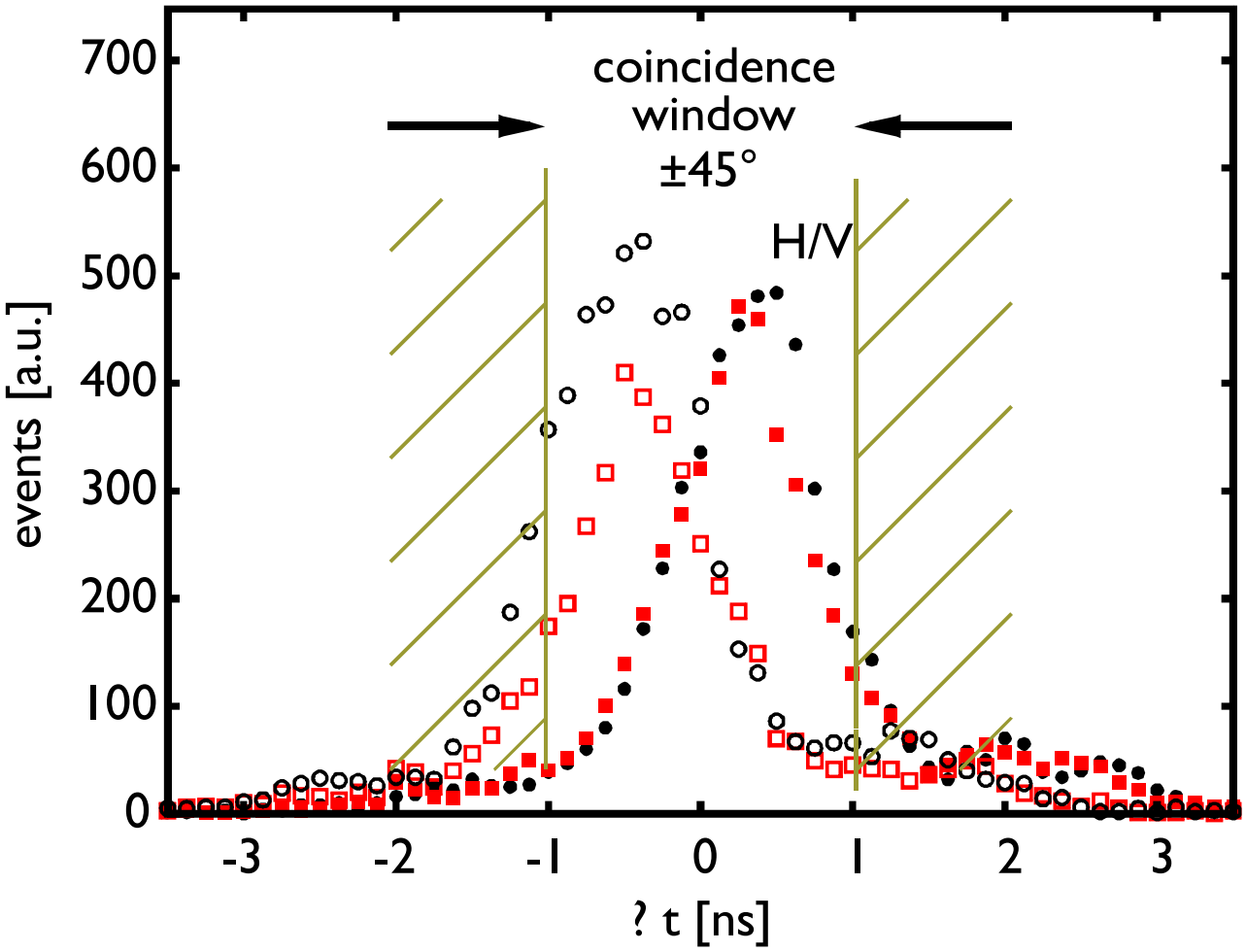
- **Accidentals:**

$$r_a = r_1 \left(r_{\mathrm{bg}} + T(r_2 - r_{\mathrm{c}})\right) \tau_{\mathrm{c}}/2$$

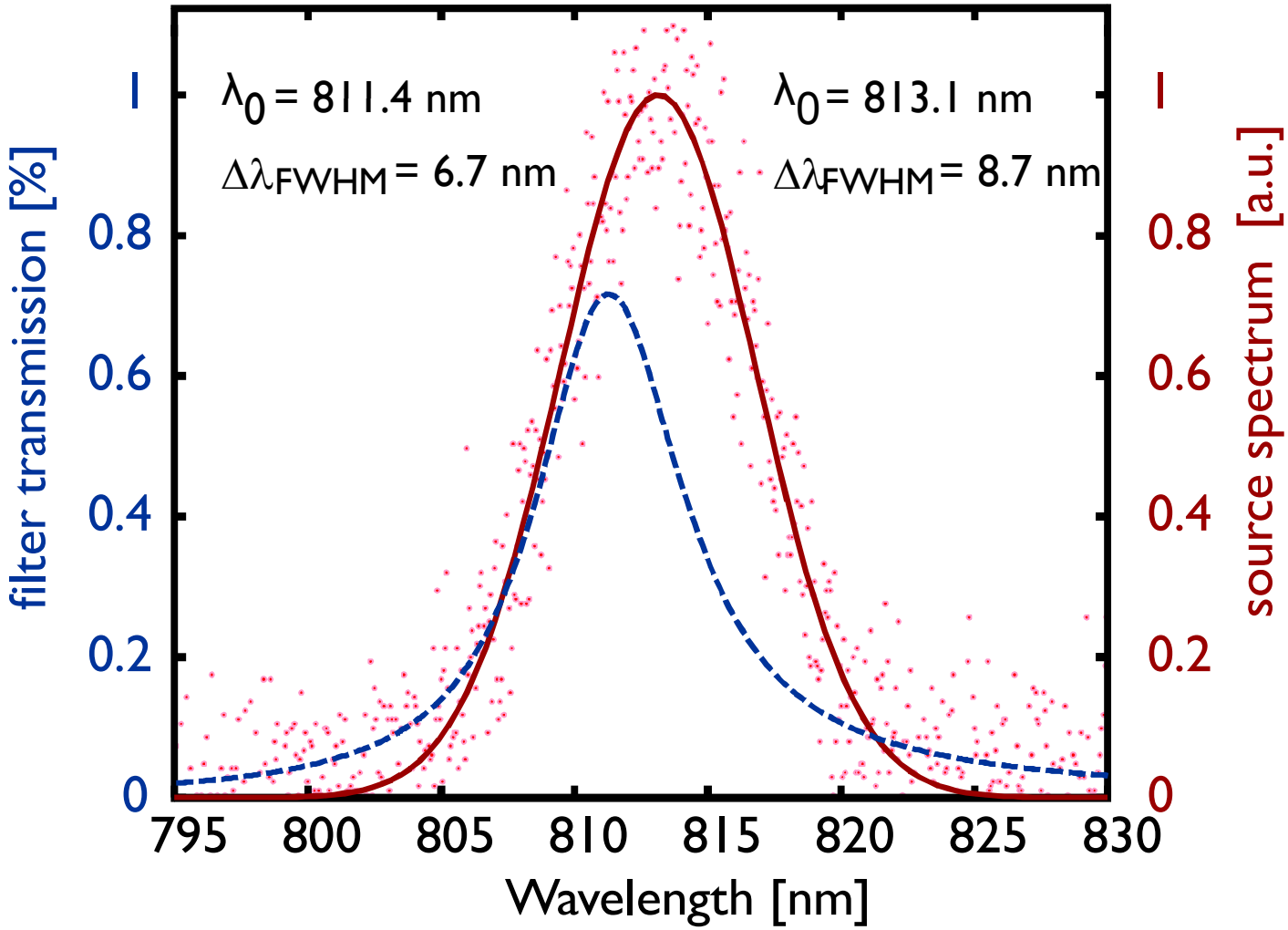
Setup


Alice
Bob
Sending telescope
350 m
Receiving telescope
WP
CC
BBO
BS
HW
PBS
PBS
PA
TU
Rb
350 m
Rb
TU
Classical Channel
PC
PC

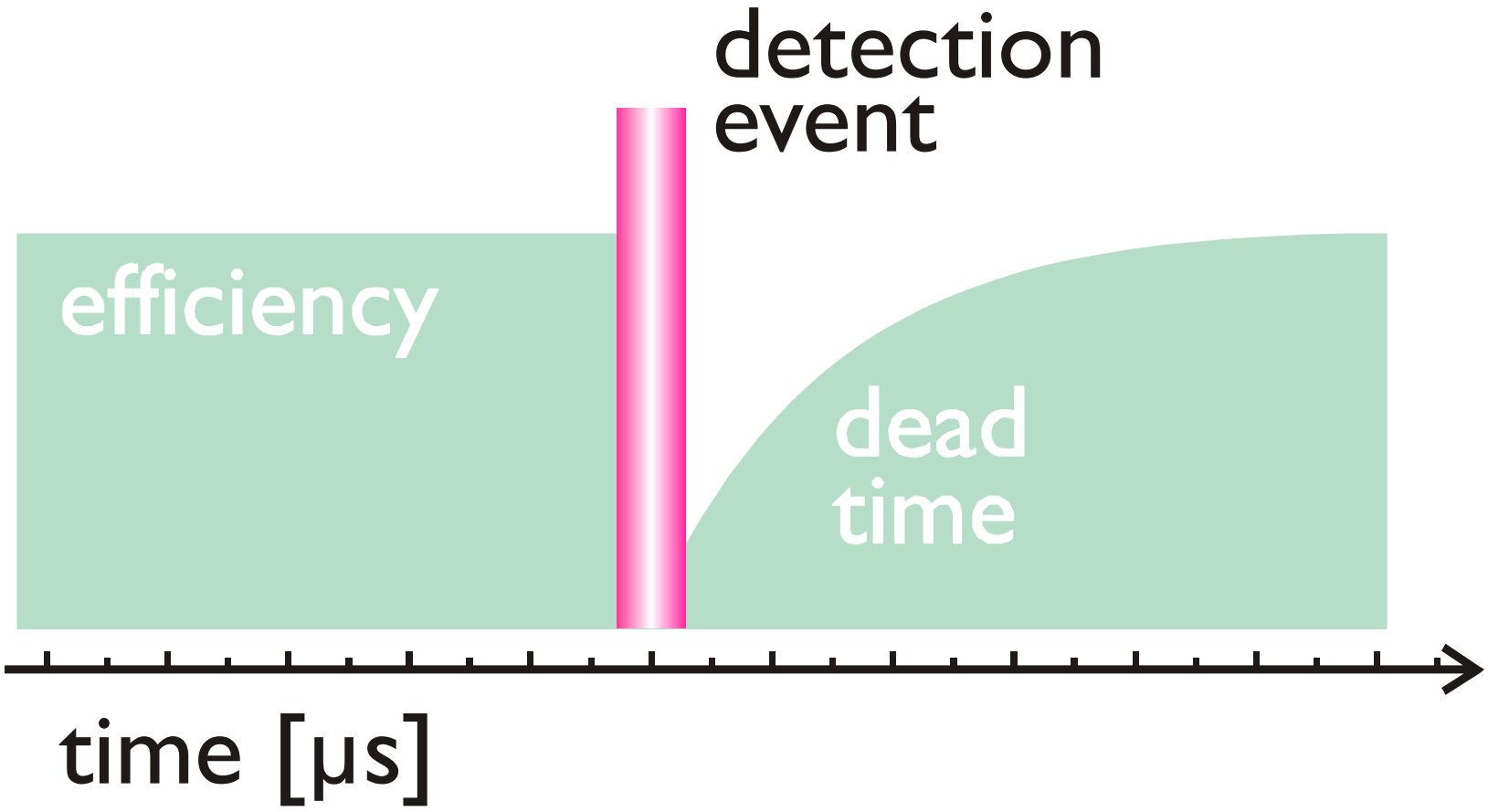
Coincidence Counting



Spectral filtering



Dead time



Correlation Matrix

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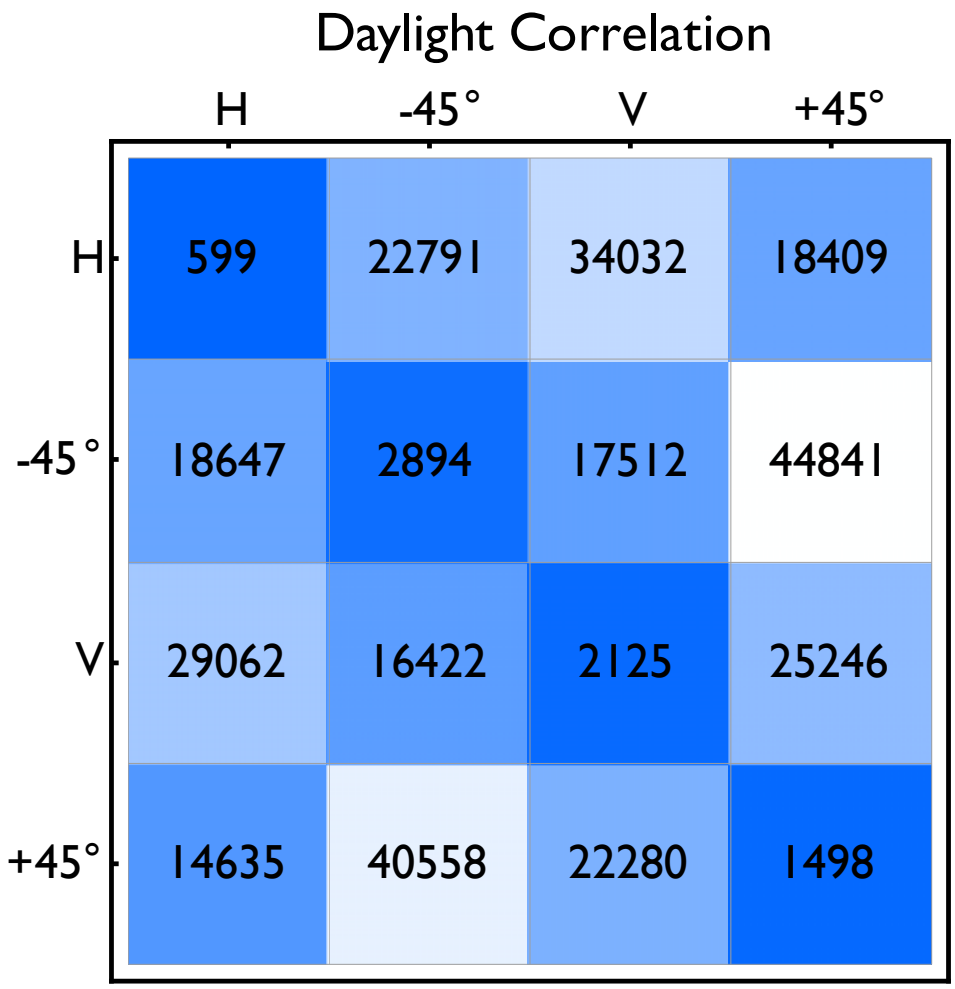

Entanglement Based QKD

- **Source of entanglement (BBO-Crystal)**

Time	Alice	Bob
19:35:01:…	H	V
19:35:01:…	-45	+45
19:35:01:…	V	H
19:35:01:…	V	H
19:35:01:…	-45	+45
19:35:01:…		