Experimental bit commitment based on quantum communication and special relativity

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Perimeter Institute for Theoretical Physics, Waterloo, Canada

August 9, 2013
[arXiv:1306.4801]

Bit commitment – the primitive

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- **correct**: If Alice and Bob are honest then Alice always accepts the opening.
- **binding**: If Alice is honest then there is at most one bit that Bob can successfully open.
- **hiding**: If Bob is honest then Alice learns nothing about his commitment until the open phase.

Bit commitment – the no-go

- Quantum mechanics does not allow for a bit commitment that gives perfect (or close to perfect) security to both parties [Lo,Chau'96; Mayers'96].
- There exist protocols that give partial security to both parties, the trade-offs are known [Spekkens,Rudolph'01; Chailloux,Kerenidis'11].

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RELATIVISTIC BIT COMMITMENT

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4. (verify) Alice's agents verify whether the outcomes provided by Bob are consistent with the BB84 states.

Security

Proven secure in
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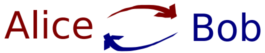
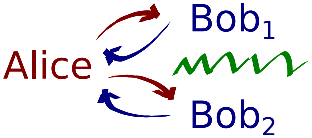


Open phase



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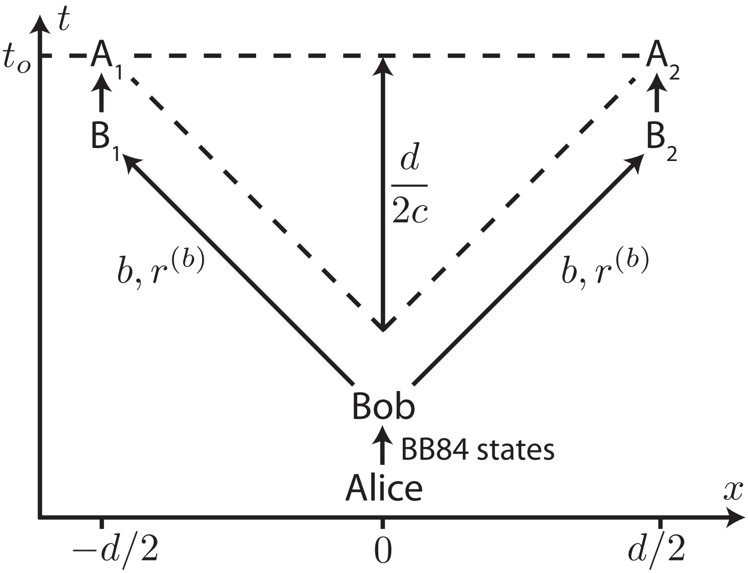
Commit phase | Open phase

not possible classically
[quantum advantage]

Relativistic realisation



Implementation issues

Source: We do not use a single photon source. We use a weak coherent source with phase randomisation:

$$\rho = \sum_{r=0}^{\infty} p_r |r\rangle\langle r|,$$

$$\text{where} \quad p_r = e^{-\mu} \cdot \frac{\mu^r}{r!},$$

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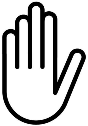
Channel and Bob's detectors: They are not perfect. They introduce bit-flip errors and losses.

Implementation issues and fixes...



on ONE hand
noise or losses make
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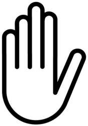

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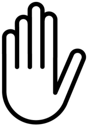

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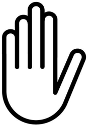

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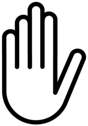

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need to try a bit harder...

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A fault-tolerant protocol - Security

One-commitment steps (honest execution):

- Alice sends N pulses, Bob reports detecting n of them
- Let

$$p_{\mathrm{det}} = n/N$$

- After Bob revealed the commitment, Alice calculates the QBER:

$$\mathrm{QBER} = n_{\mathrm{err}}/n'$$

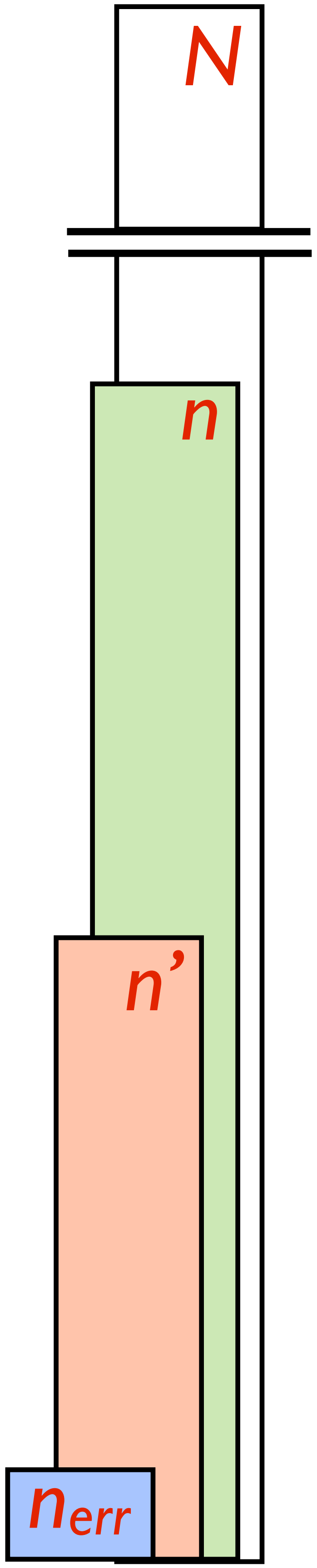
Number of errors within n'

Number of detections with same basis for preparation and measurement

- Security is possible only if

$$p_{\mathrm{det}} > \frac{1 - \mathrm{e}^{-\mu}(1+\mu)}{1 - \frac{\mathrm{QBER}}{\lambda}} \qquad \lambda \approx 14.6\%$$

- Calculate the security parameter from the finite stats



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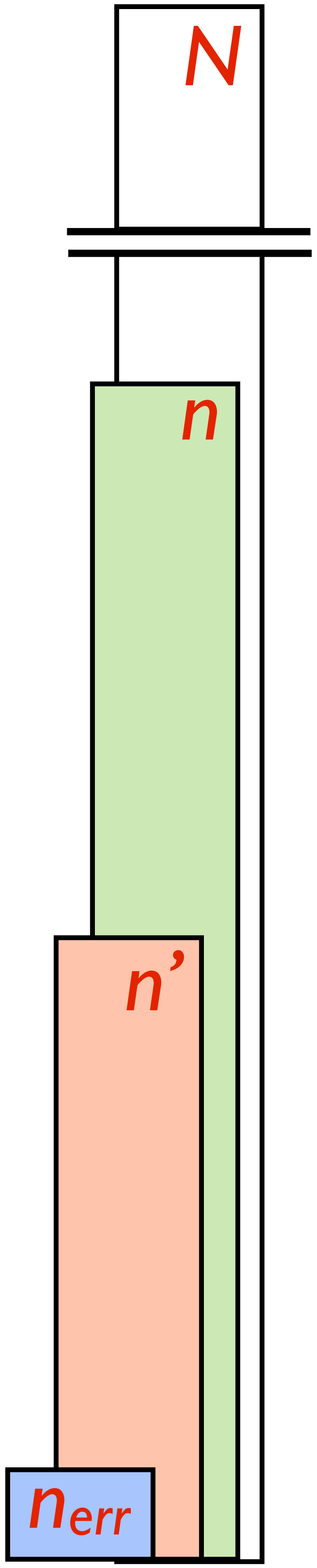
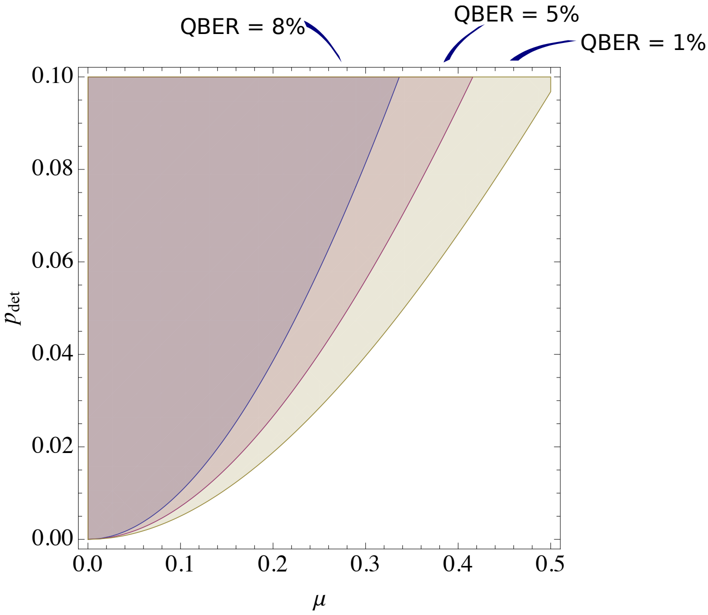
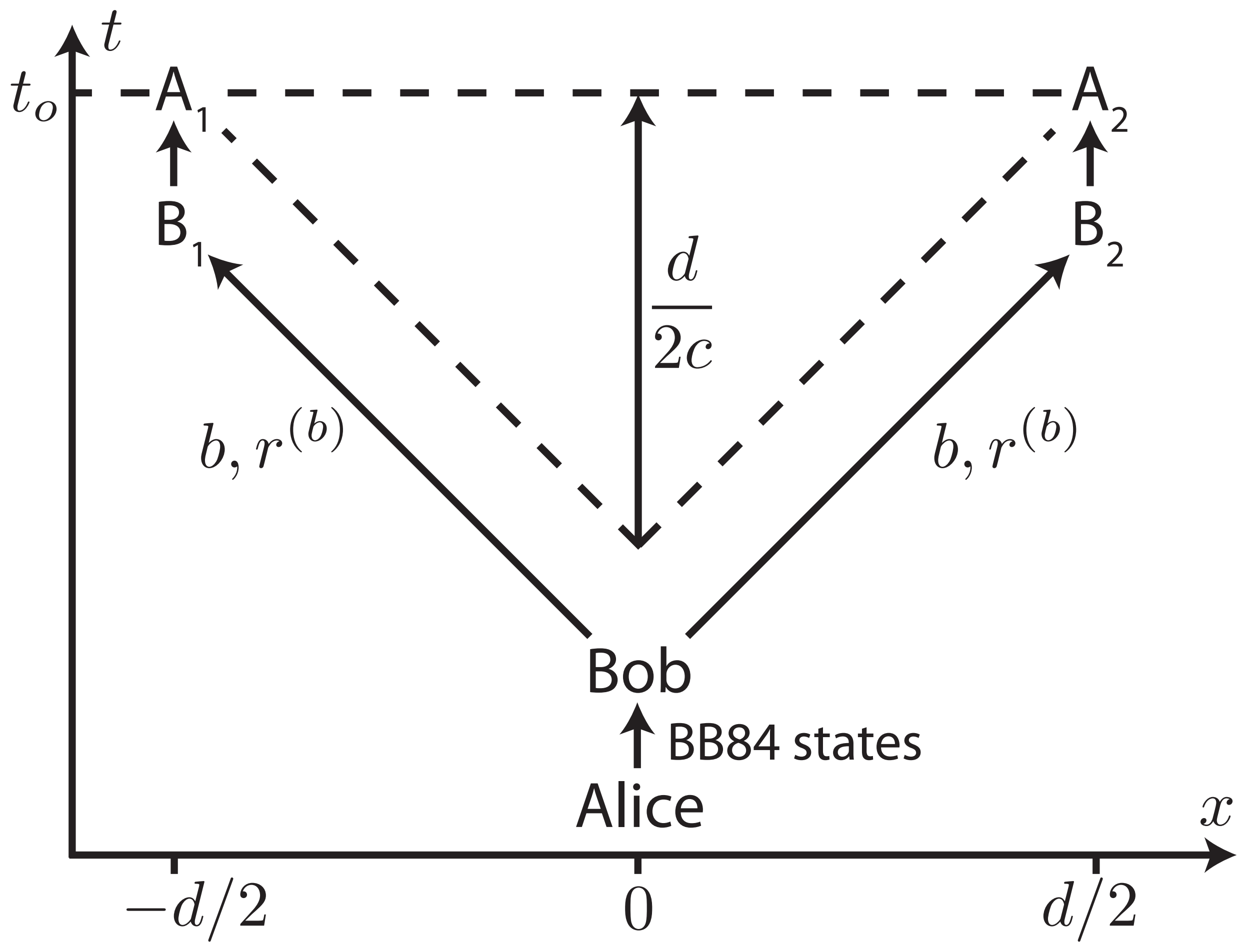


Feasibility plot



A more practical version of Kent'12 protocol



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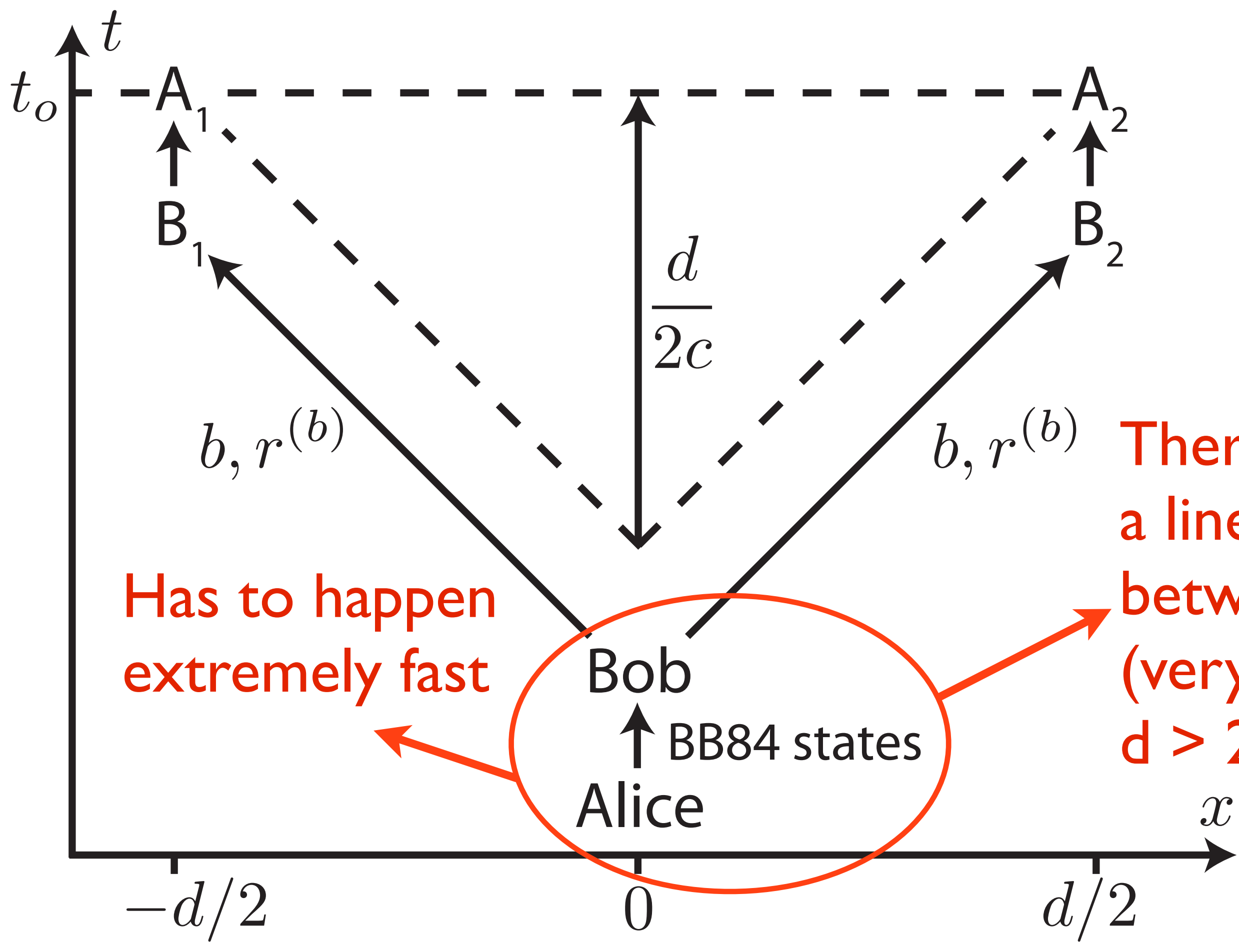

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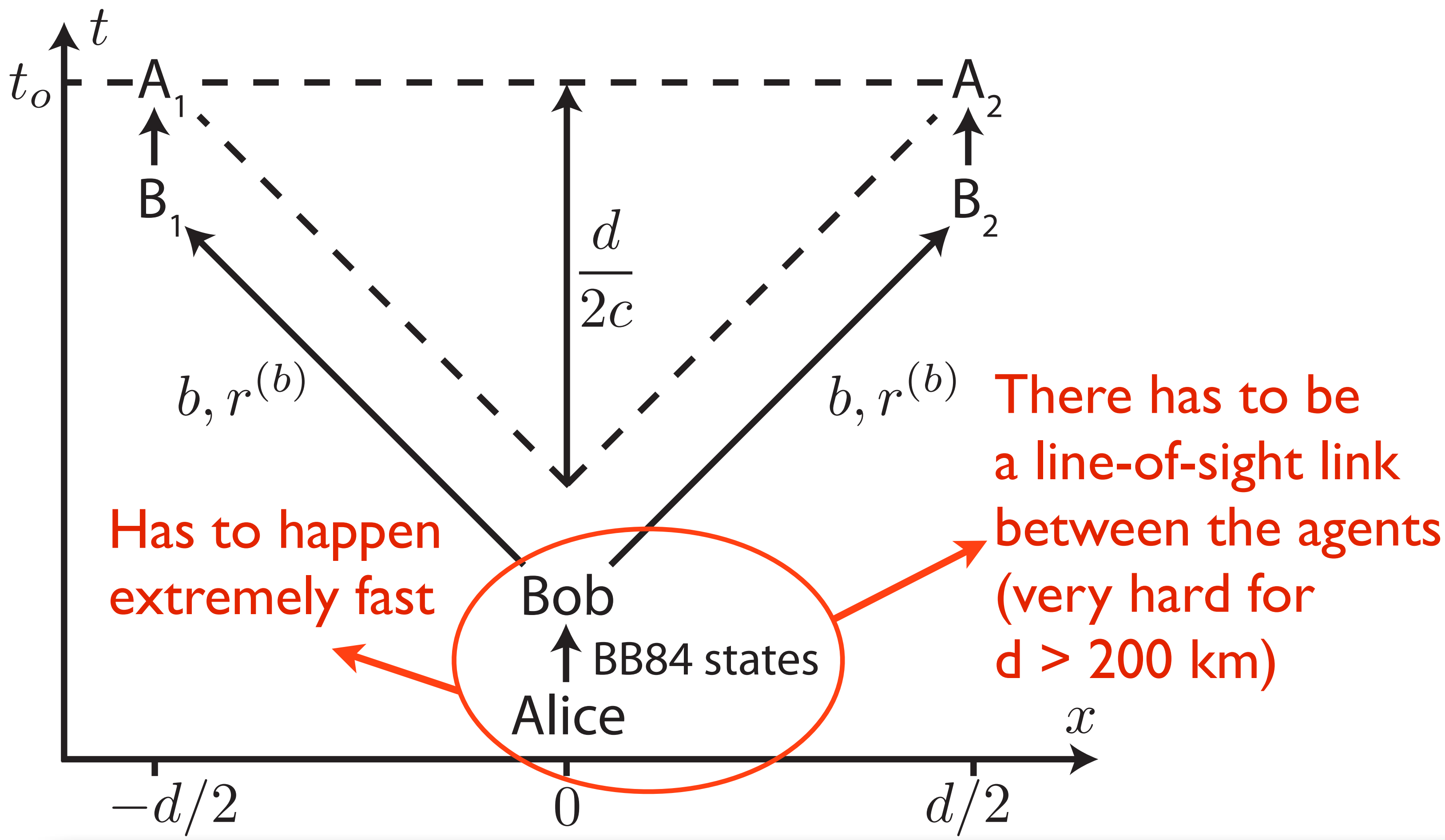

Y. Liu, Y. Cao, M. Curty *et al.* arXiv:1306.4413

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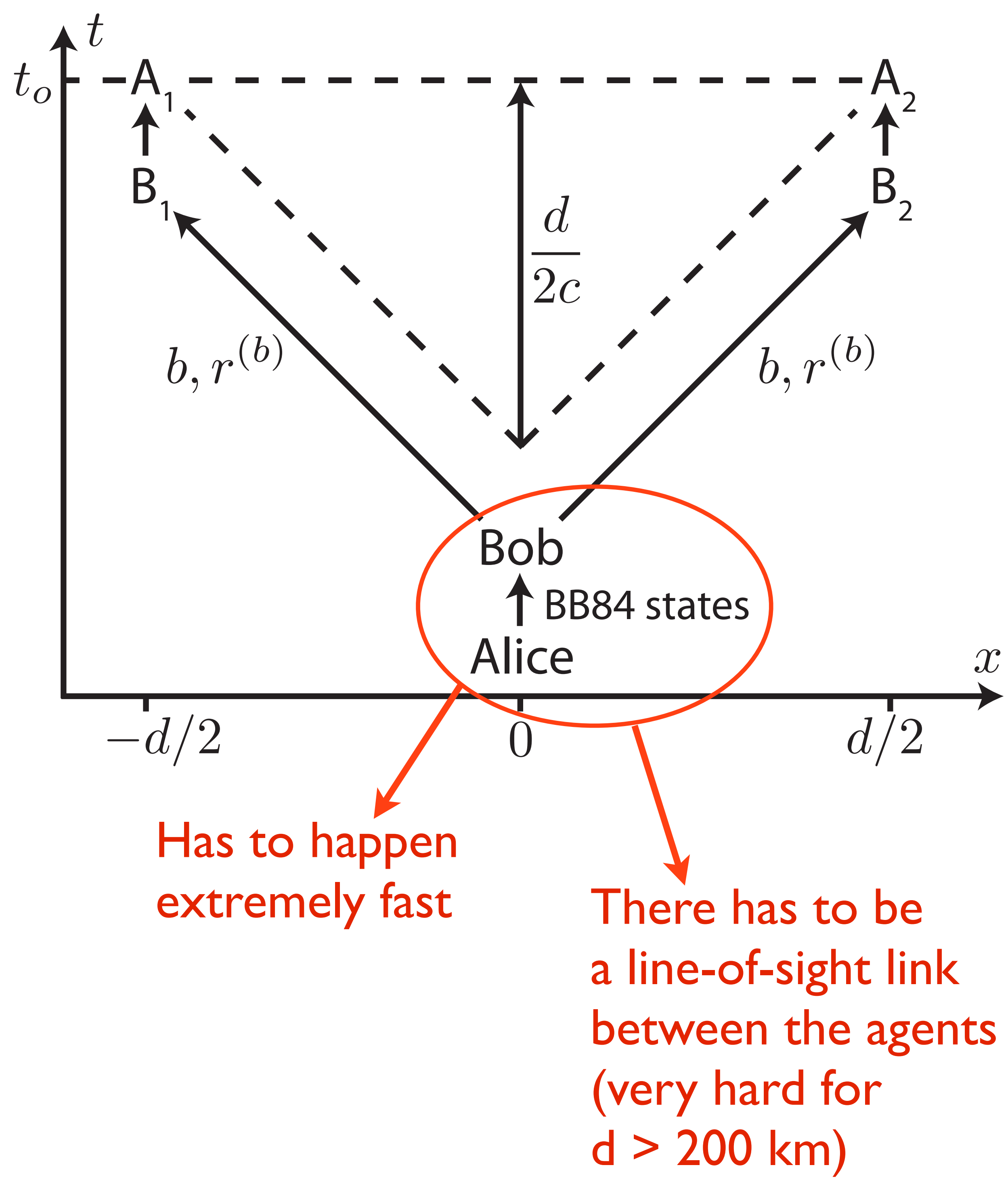

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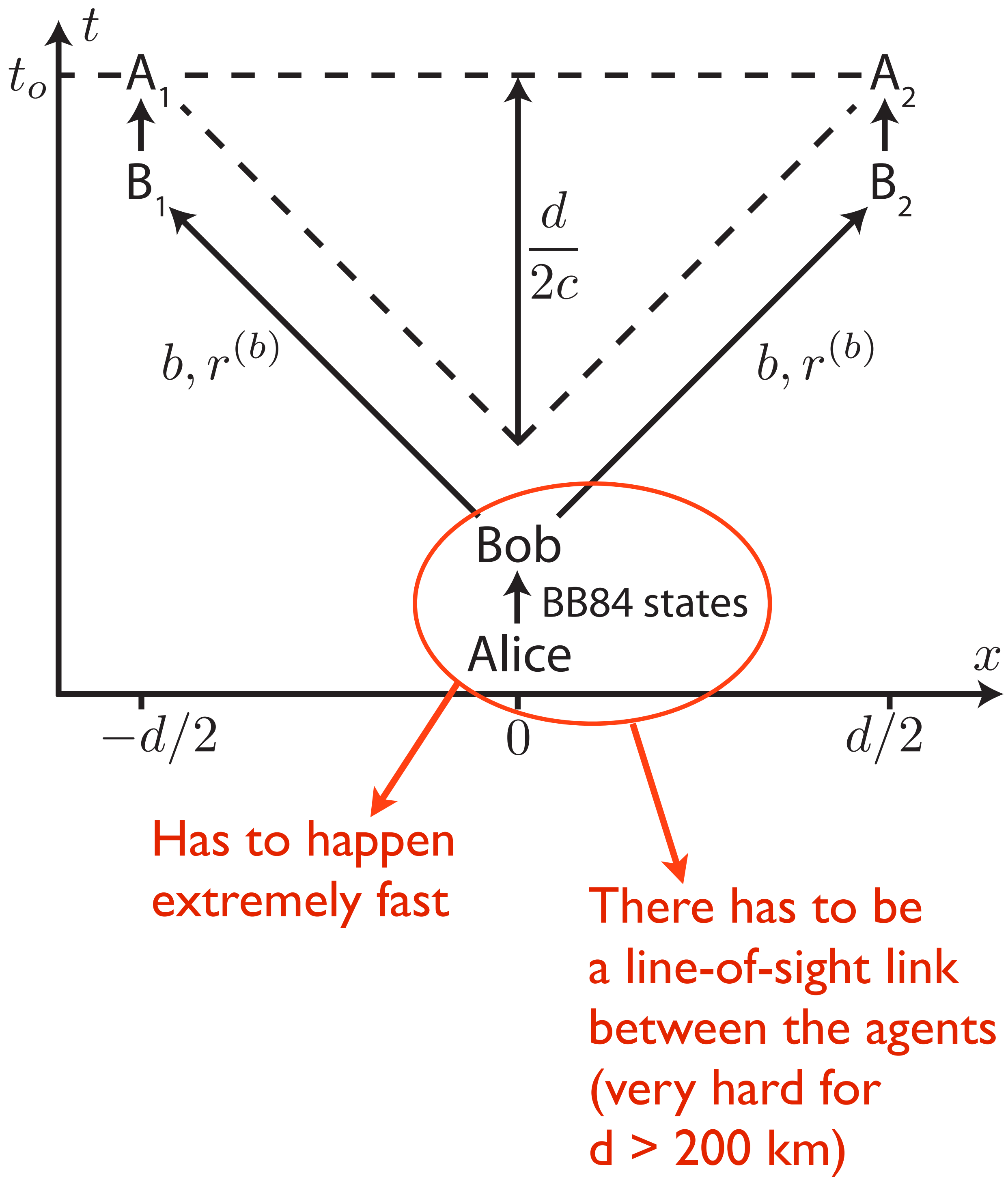

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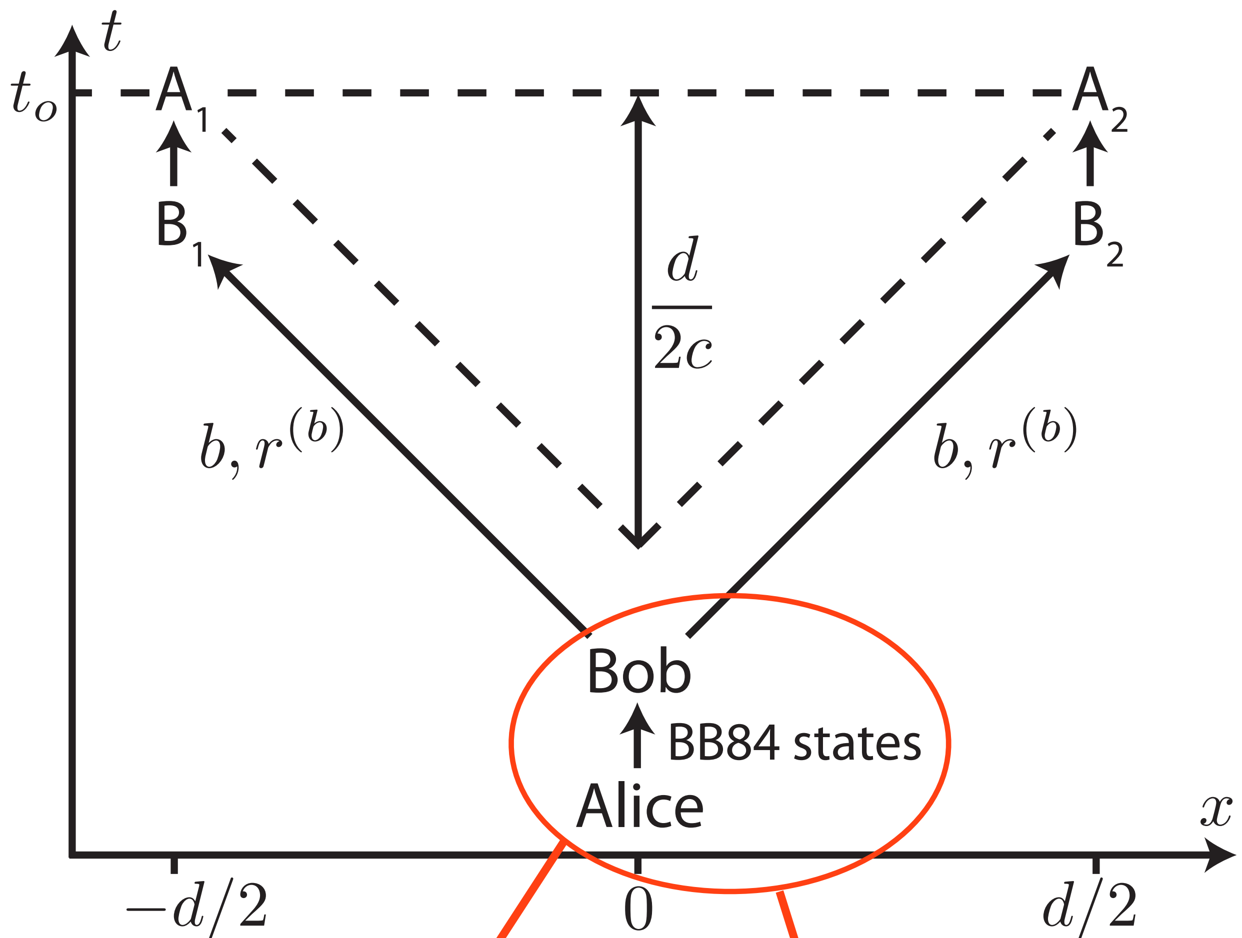

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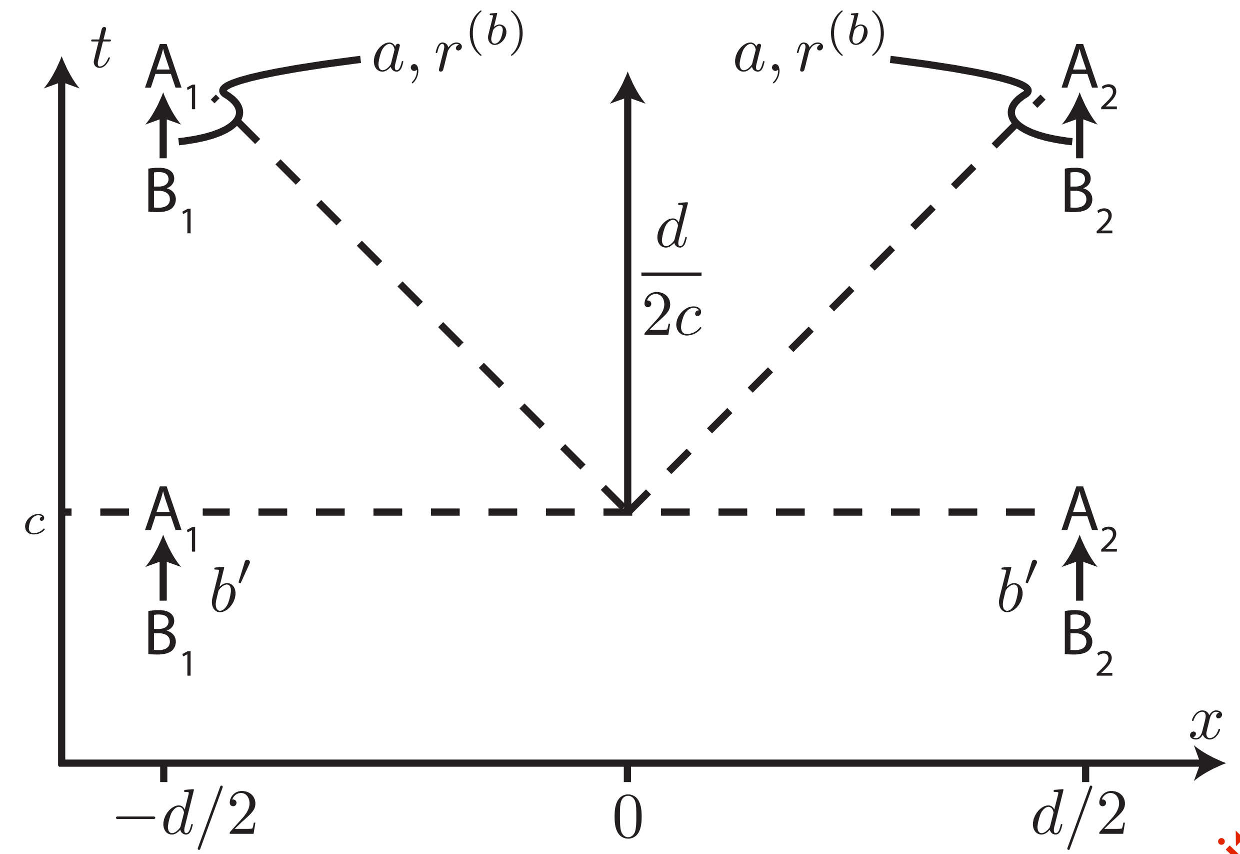

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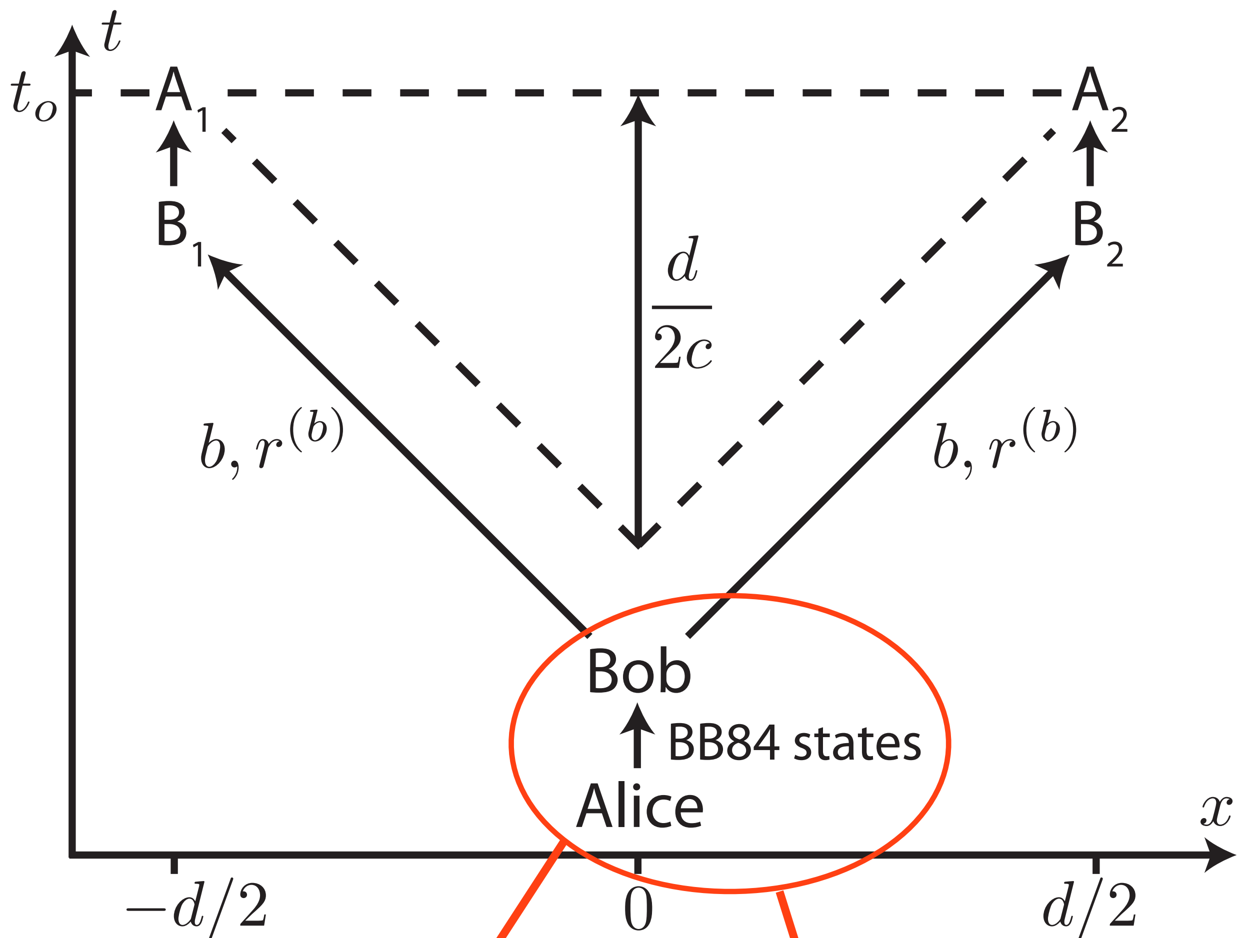

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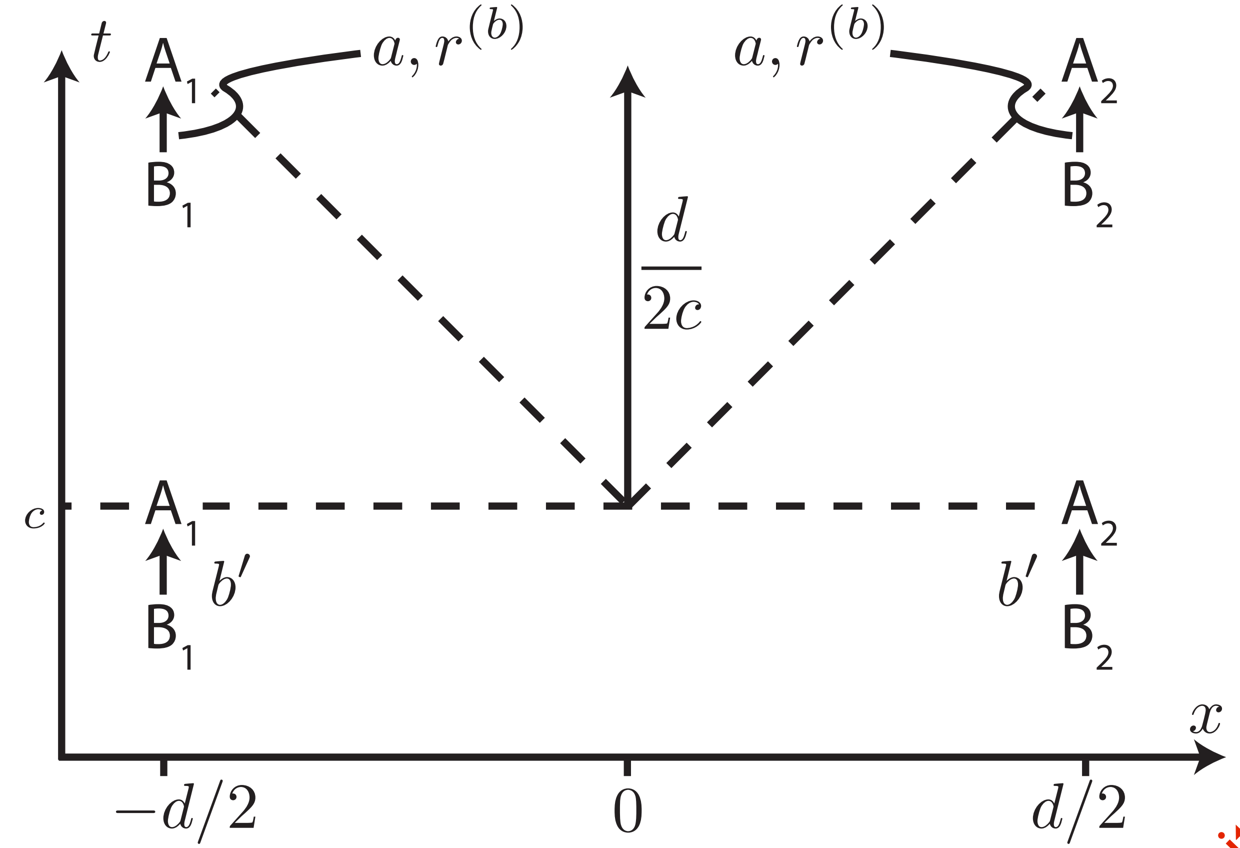

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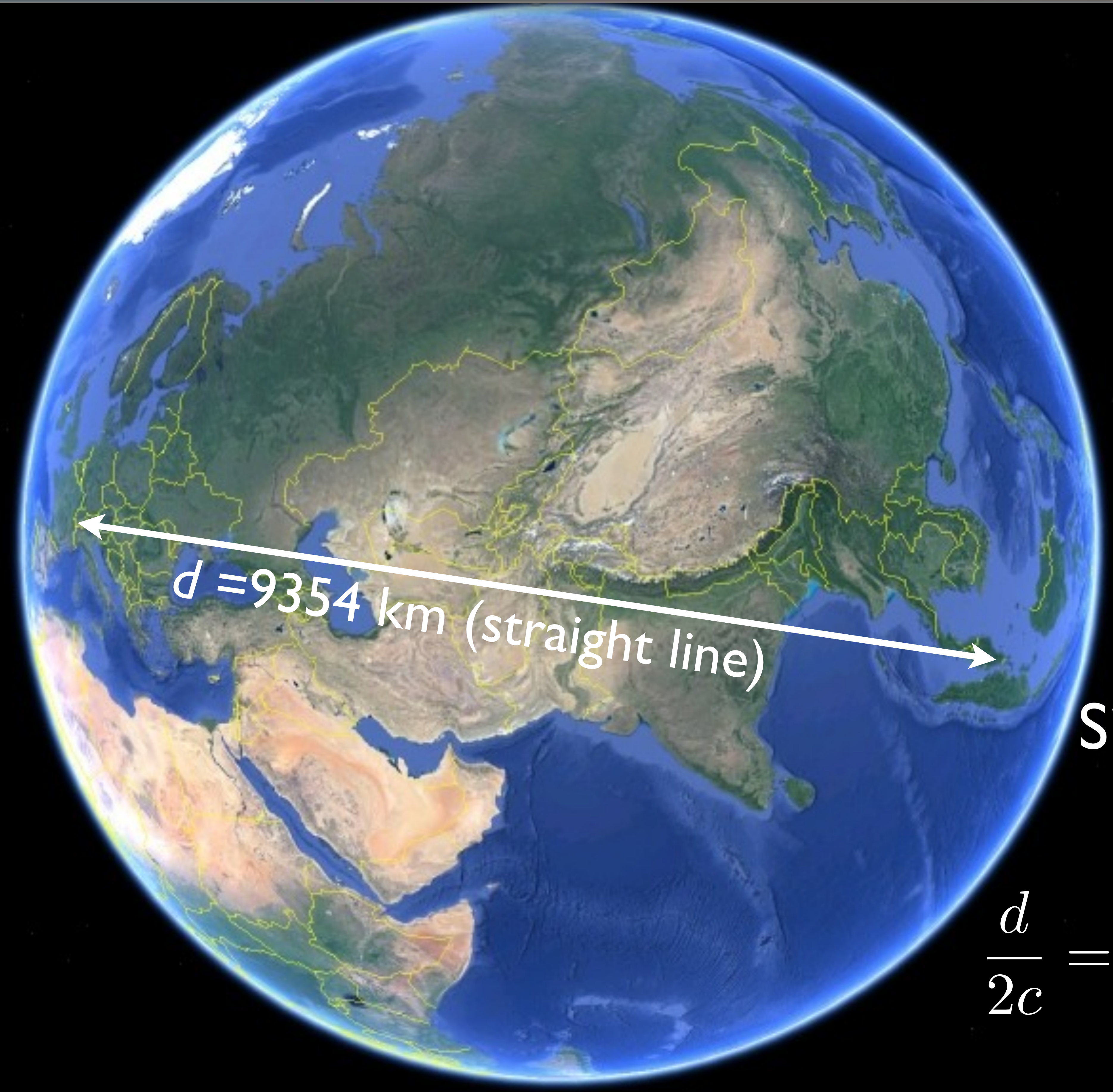
B_1 and B_2 simultaneously reveal a and $r^{(b)}$

Experimental setup - The global picture



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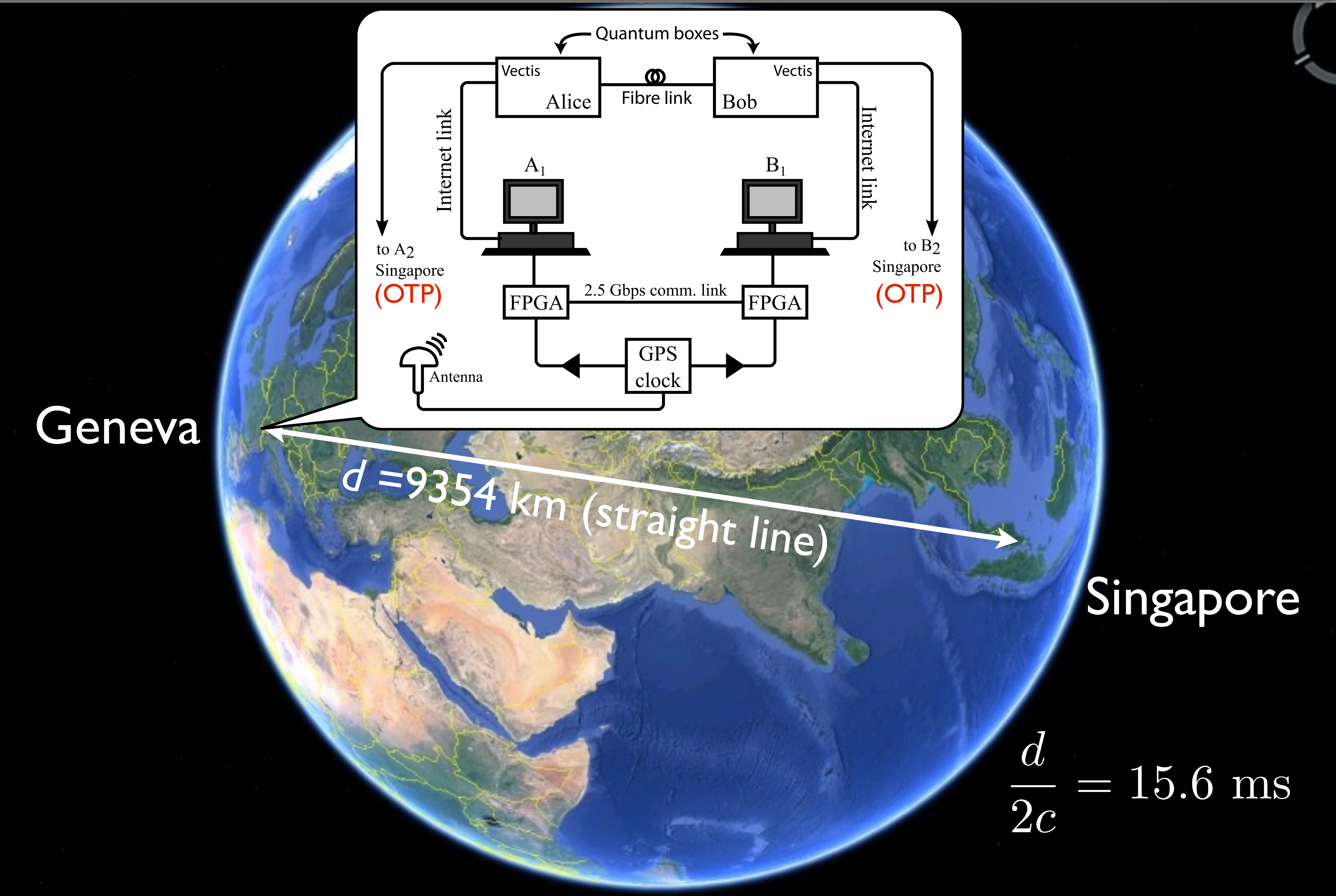

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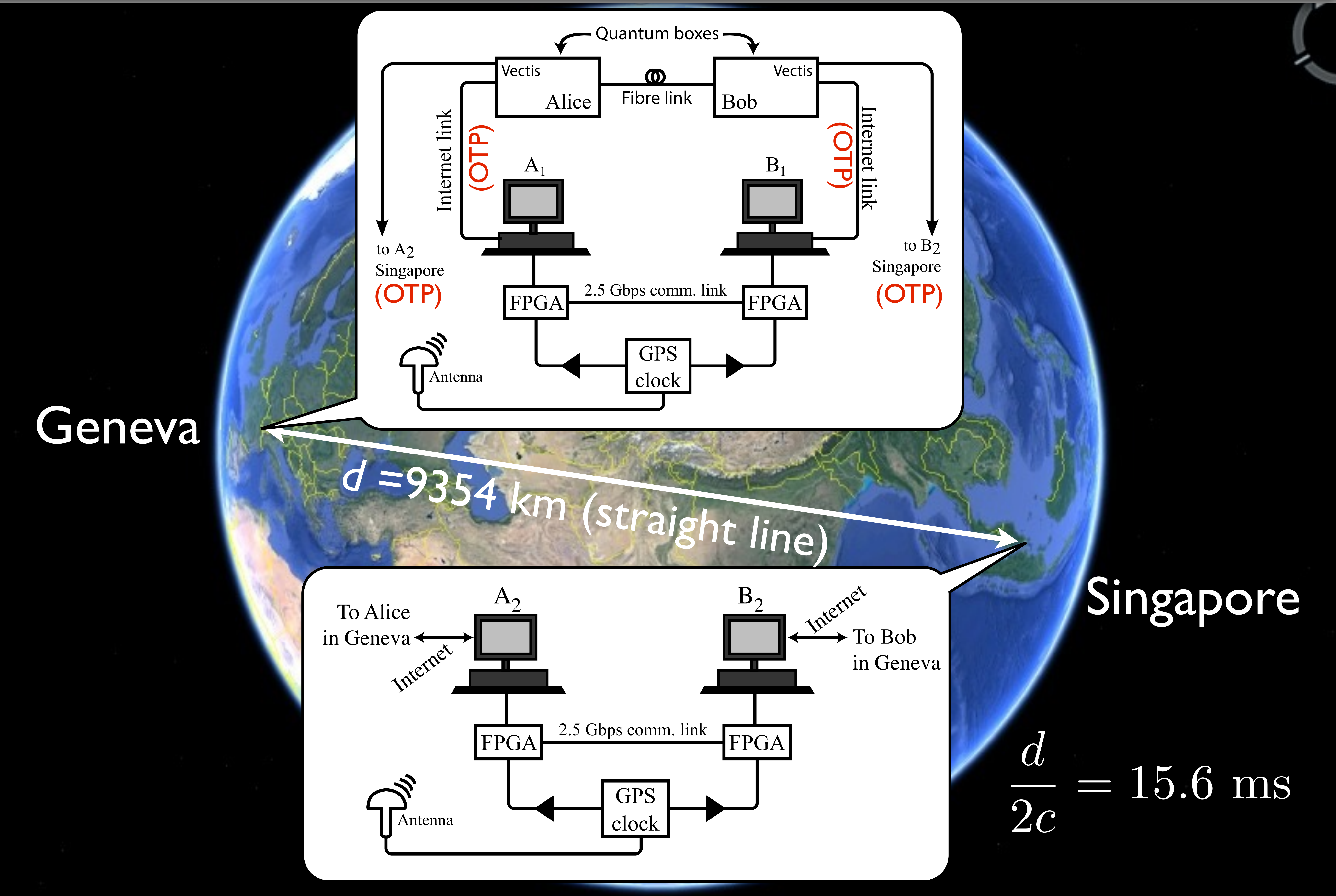

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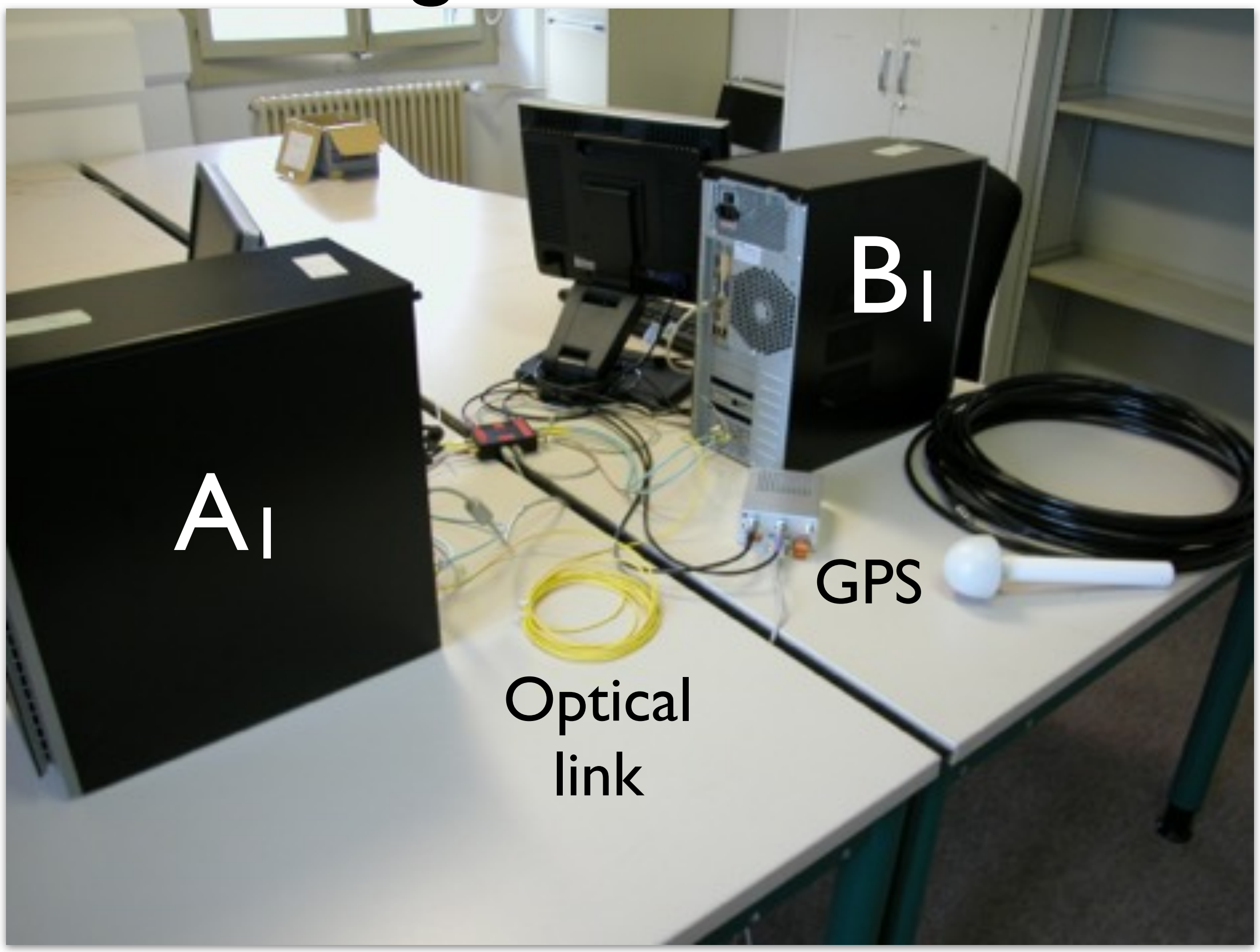
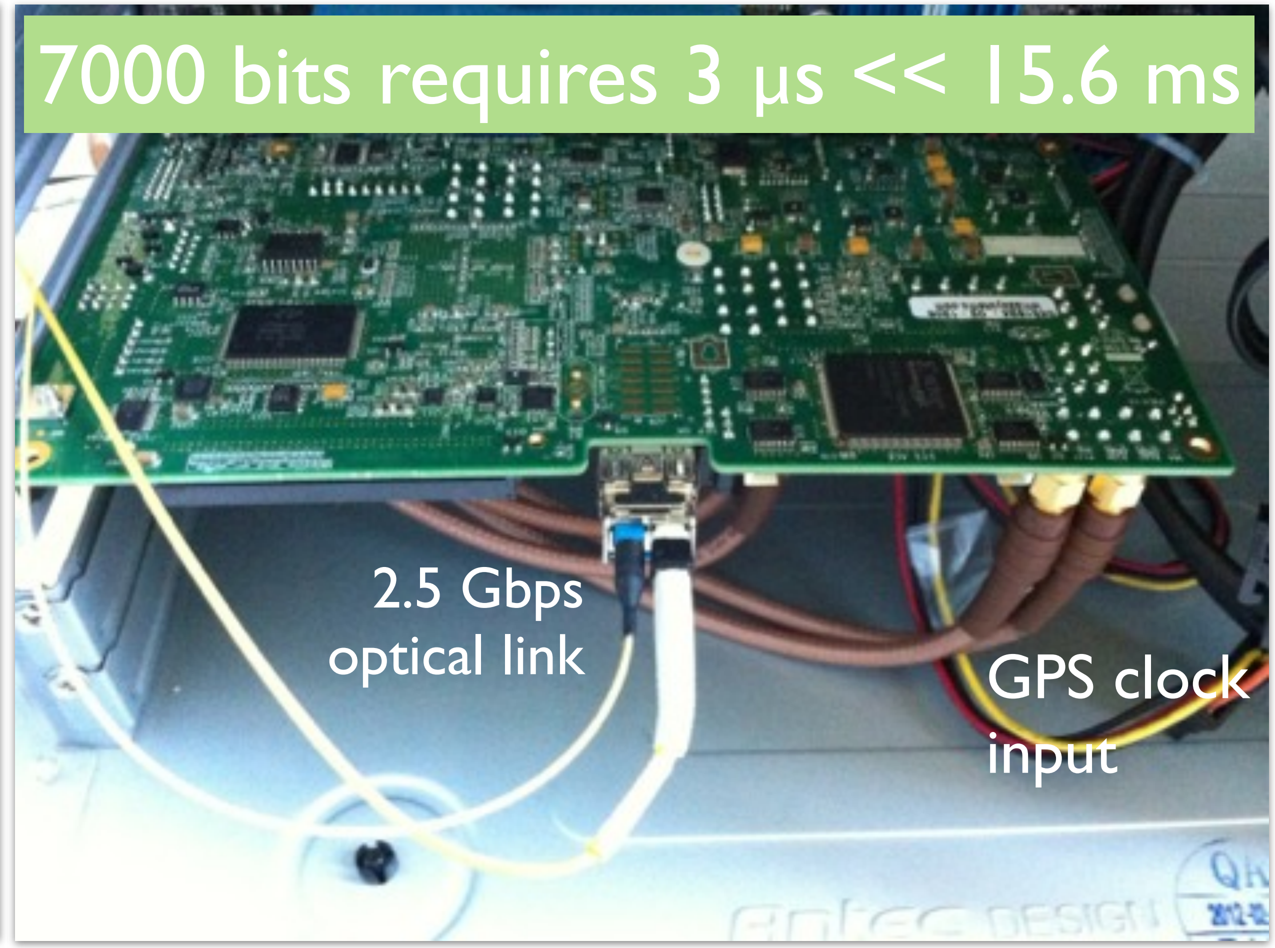
The classical agents : timing performances

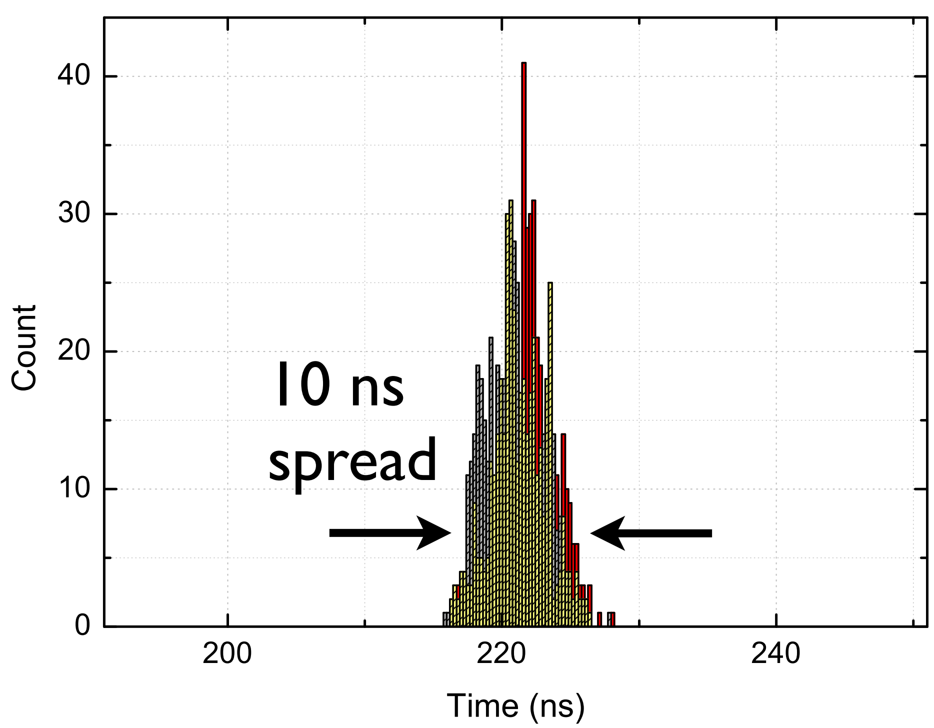
Classical agents in Geneva



FPGA boards



Timing accuracy of the FPGAs with a GPS for A_1 and another for B_1

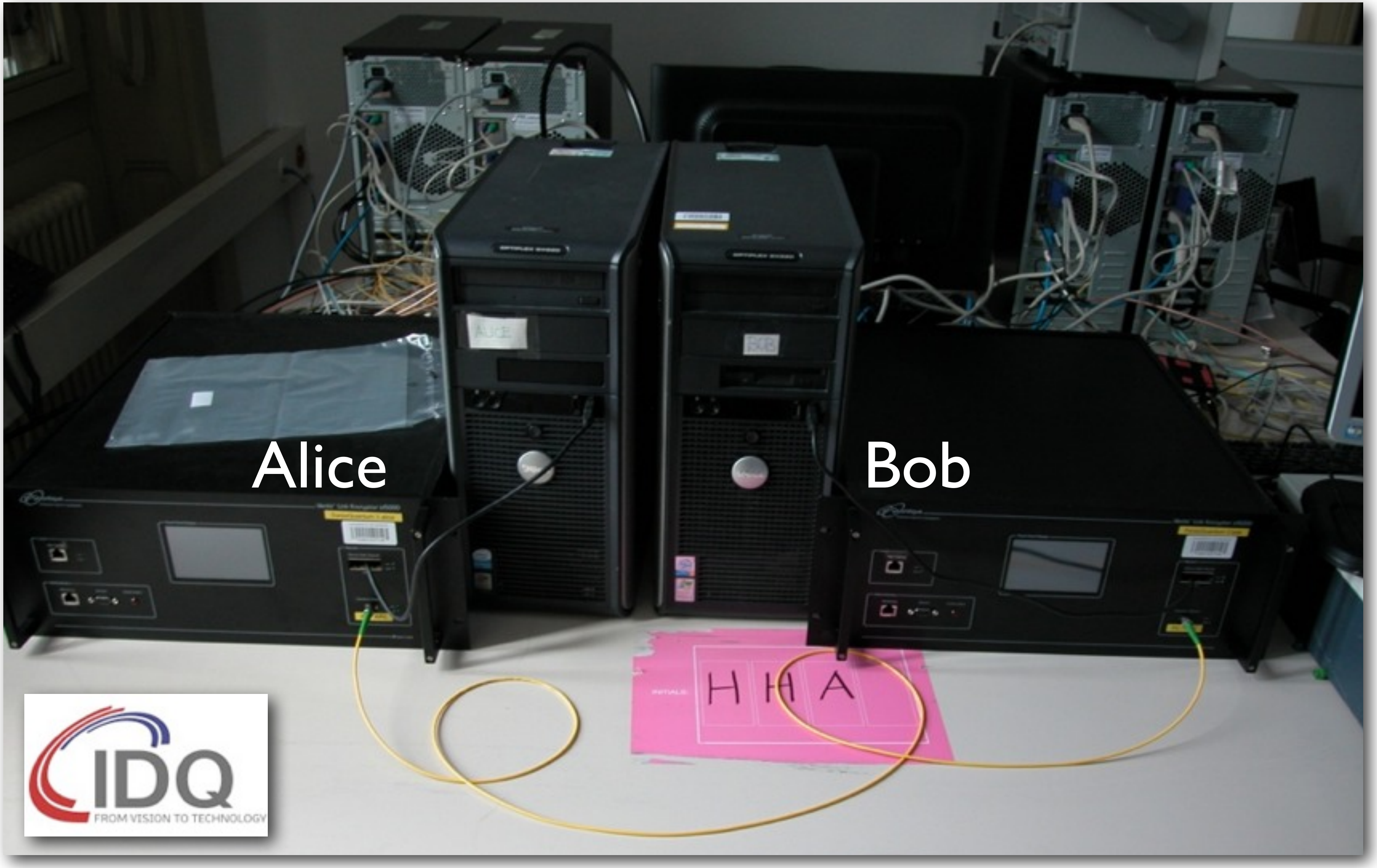


Other tests showed that

- B1 and B2 are in sync to within 100 ns
- Synchronization is maintained over the 15 ms of the protocol

The quantum boxes (Geneva)

Commercial QKD system by IDQ "Vectis 5100"



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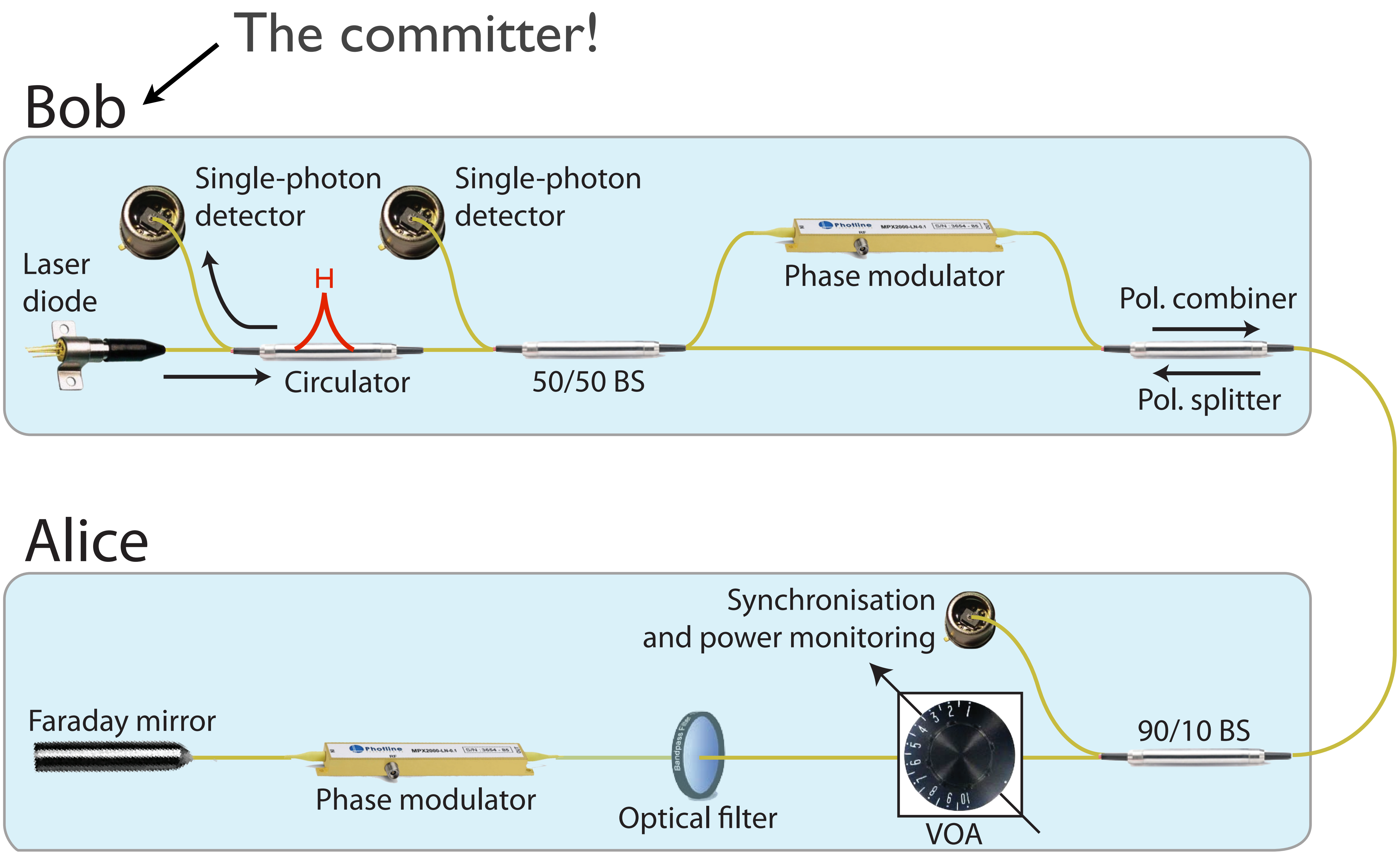

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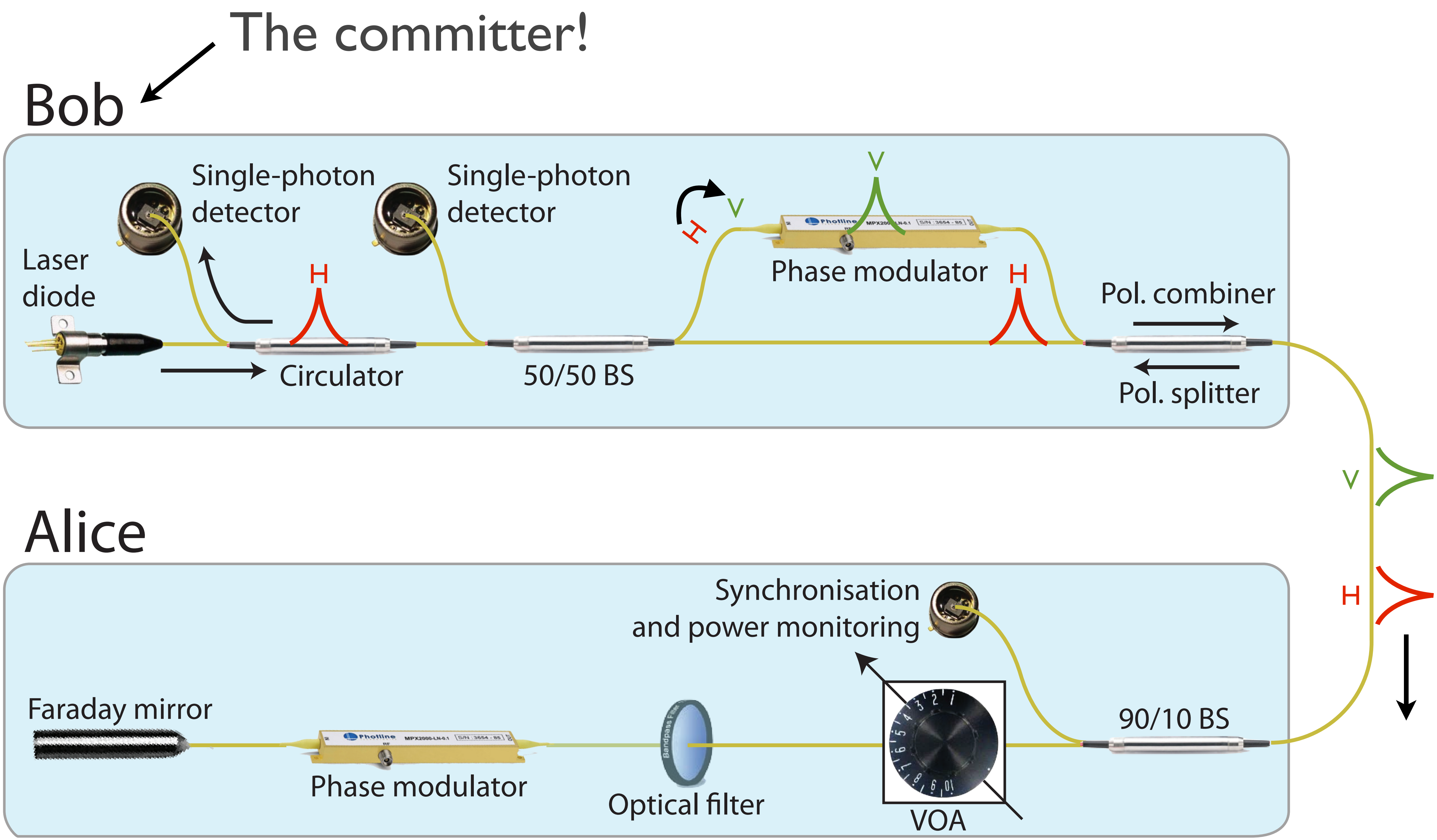

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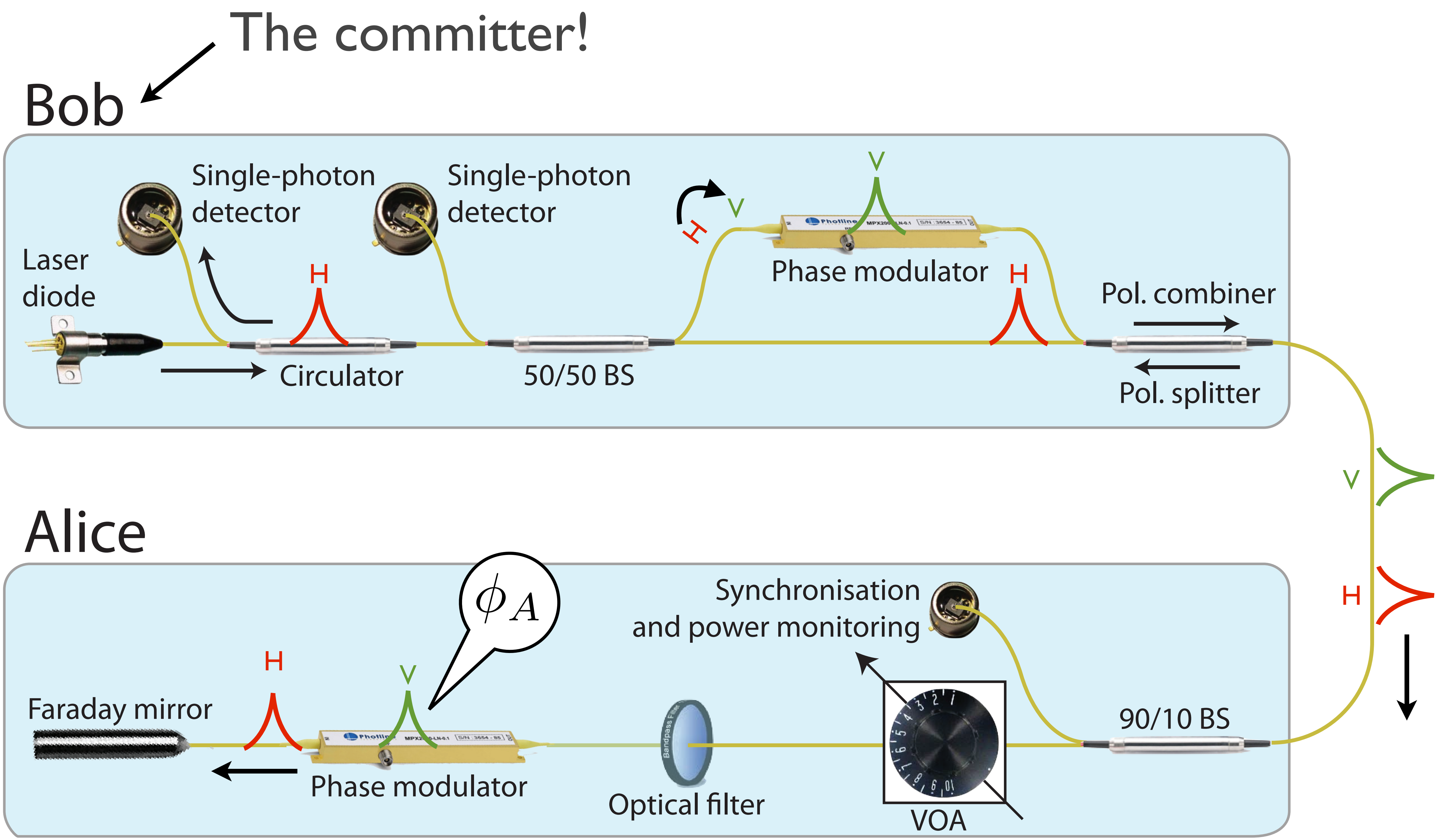
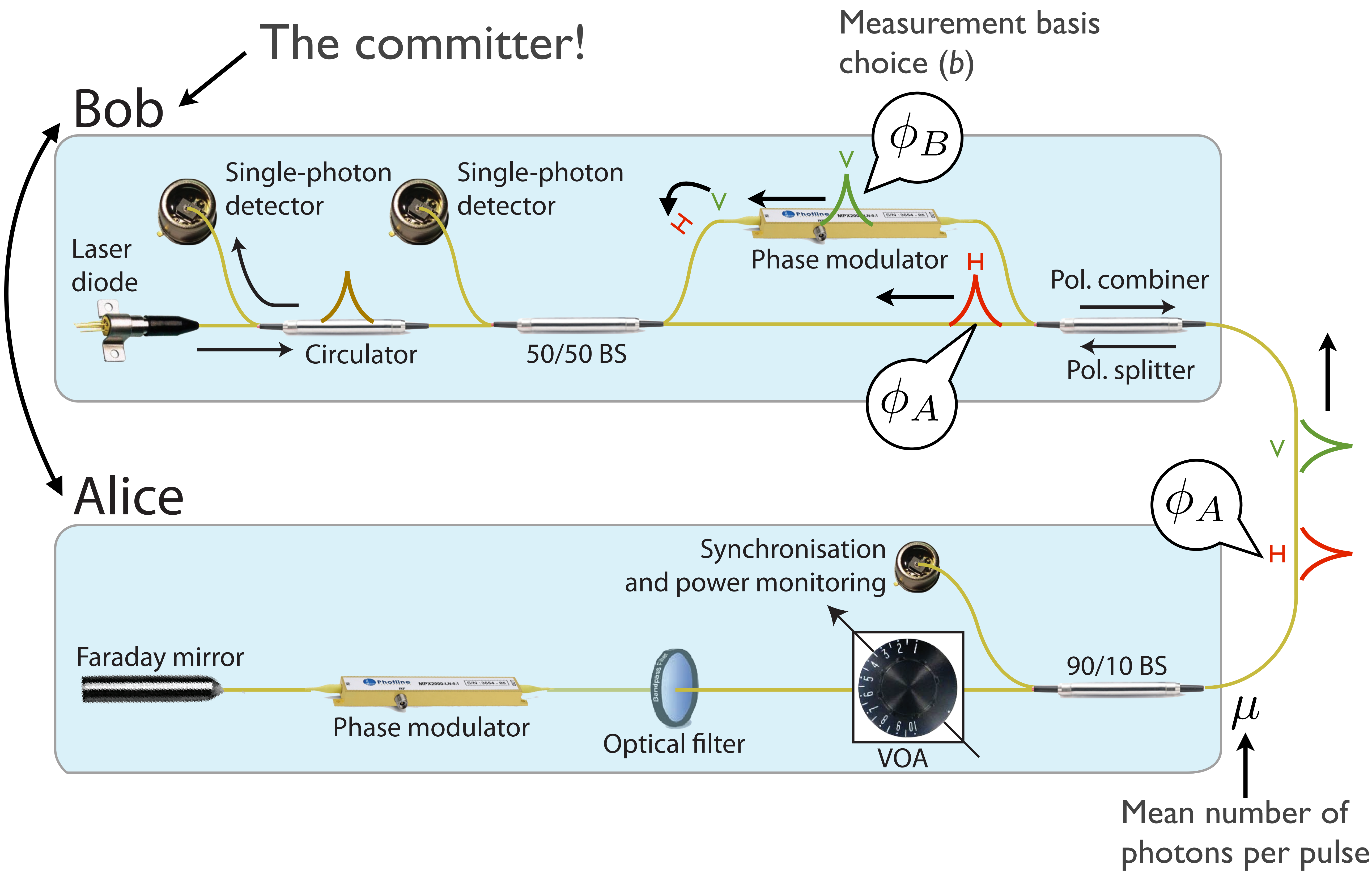


Qubit preparation
(phase encoding)

The quantum boxes (Geneva)



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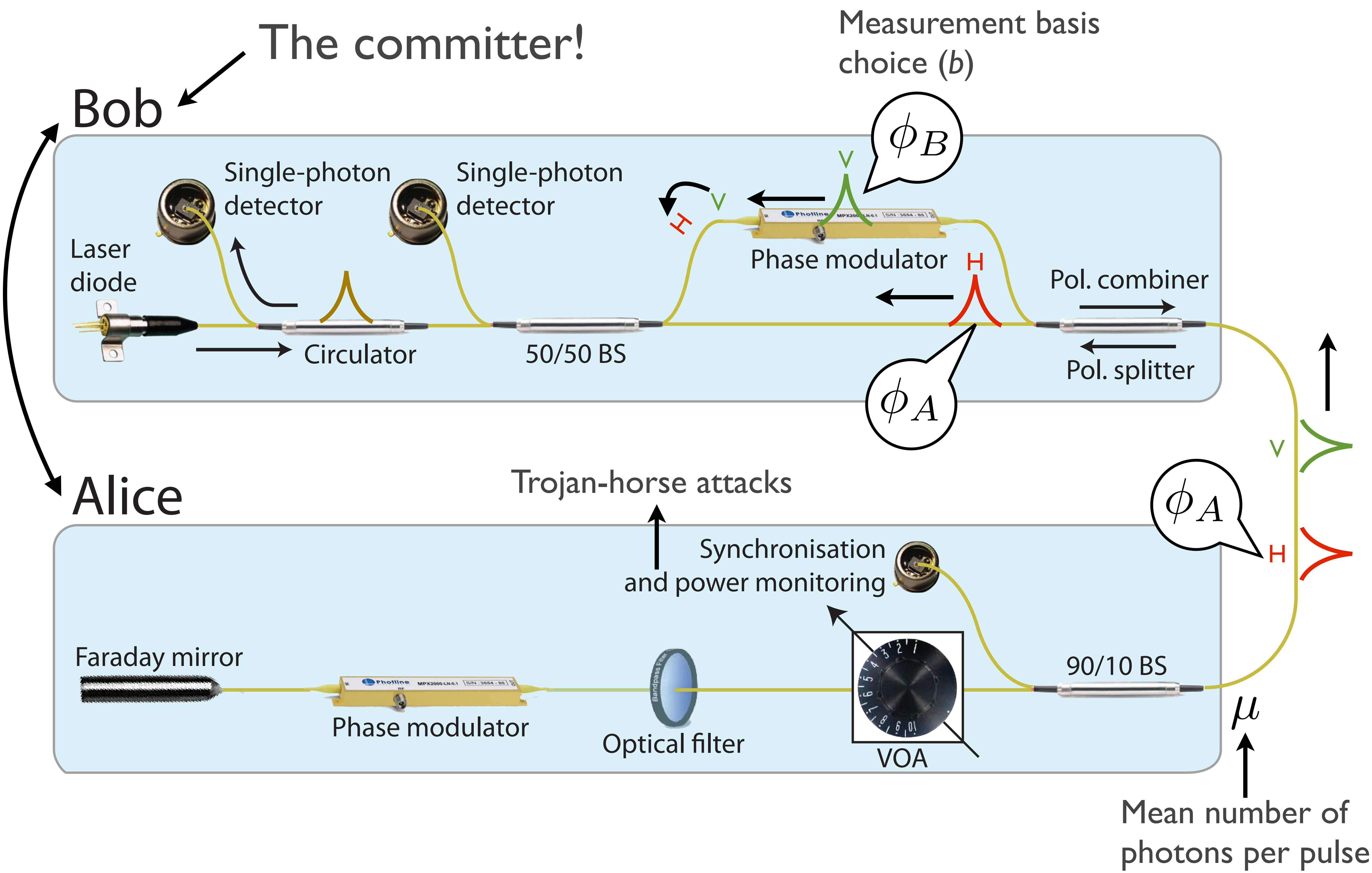

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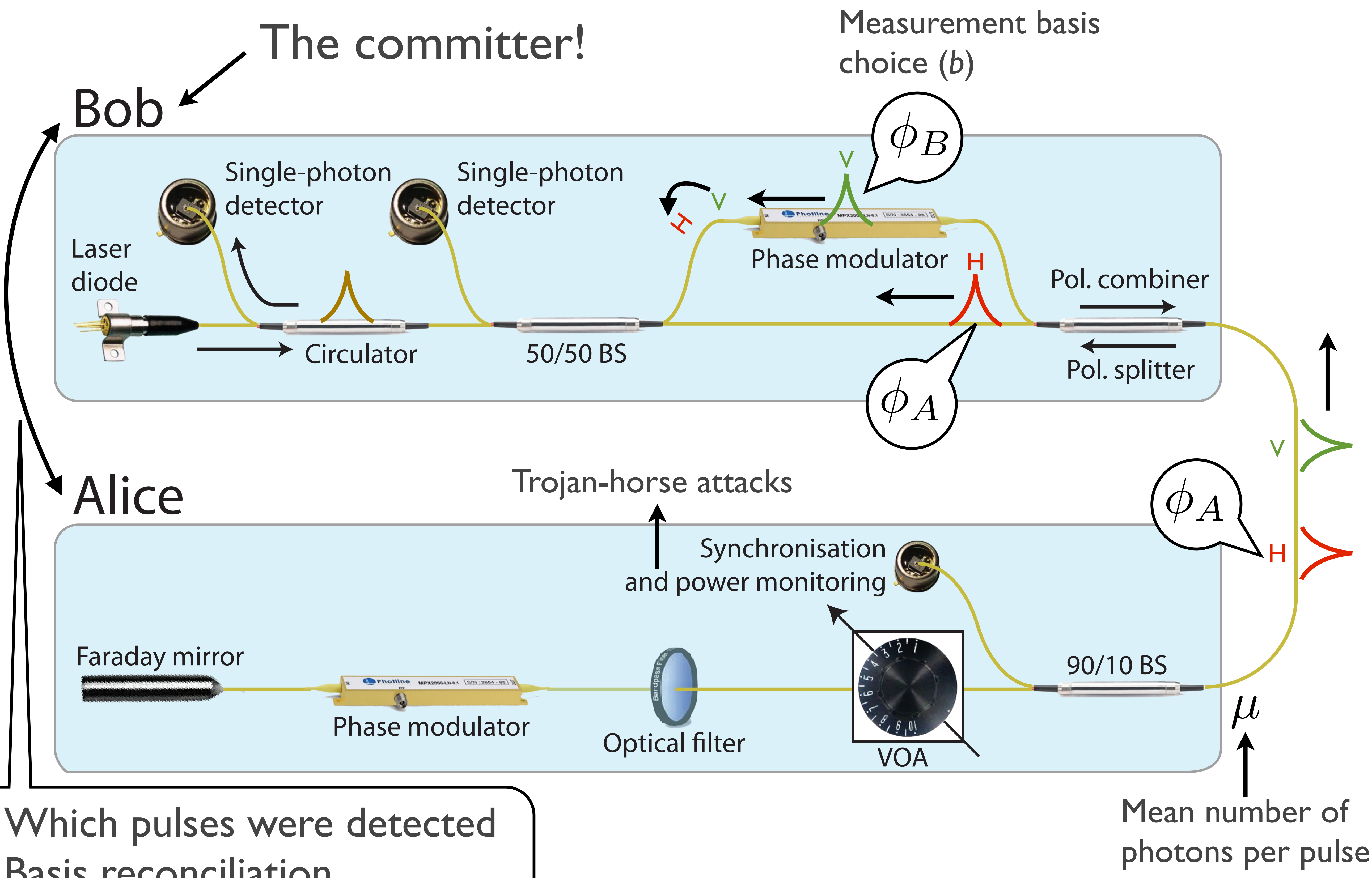

- Which pulses were detected
- Basis reconciliation

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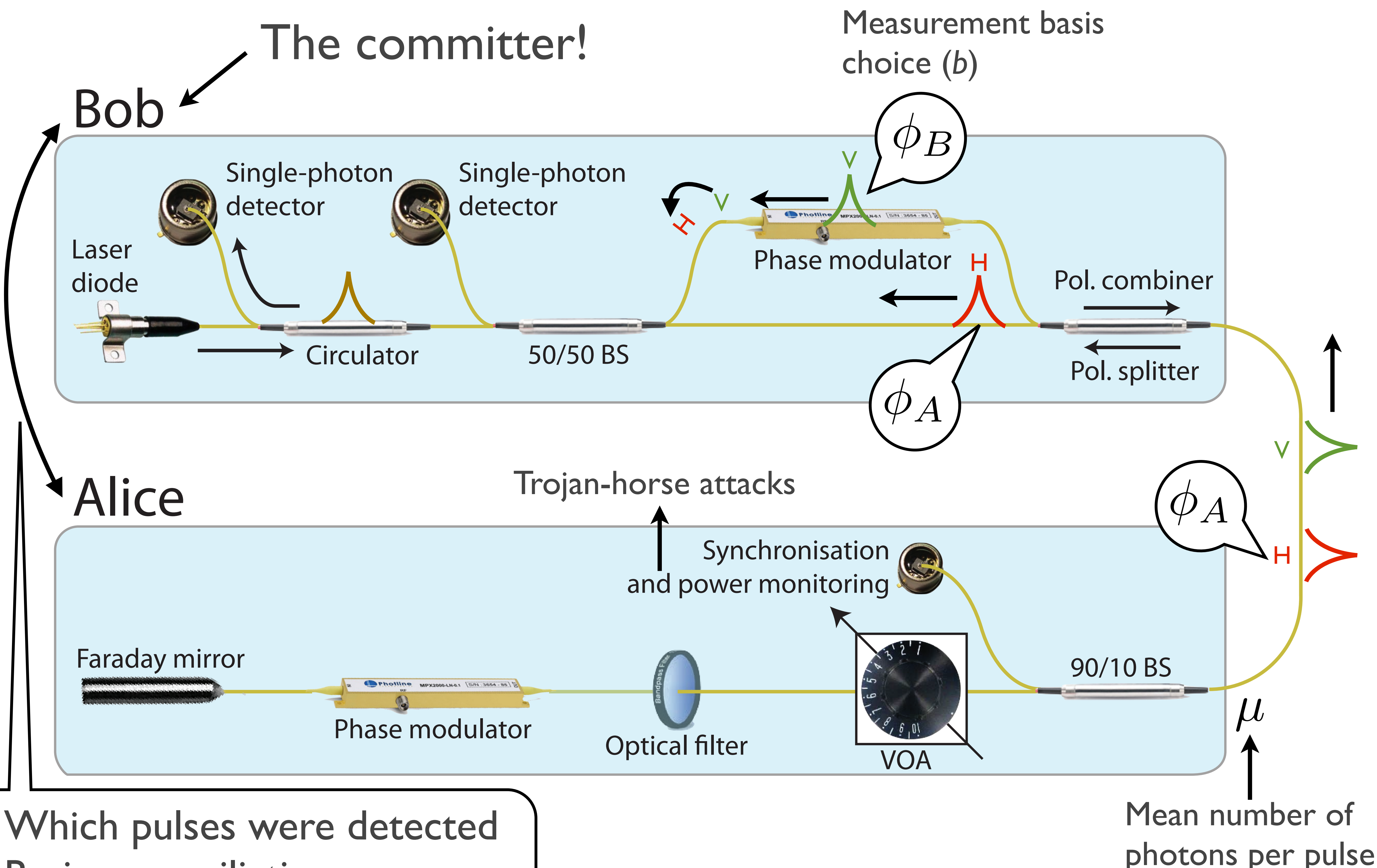

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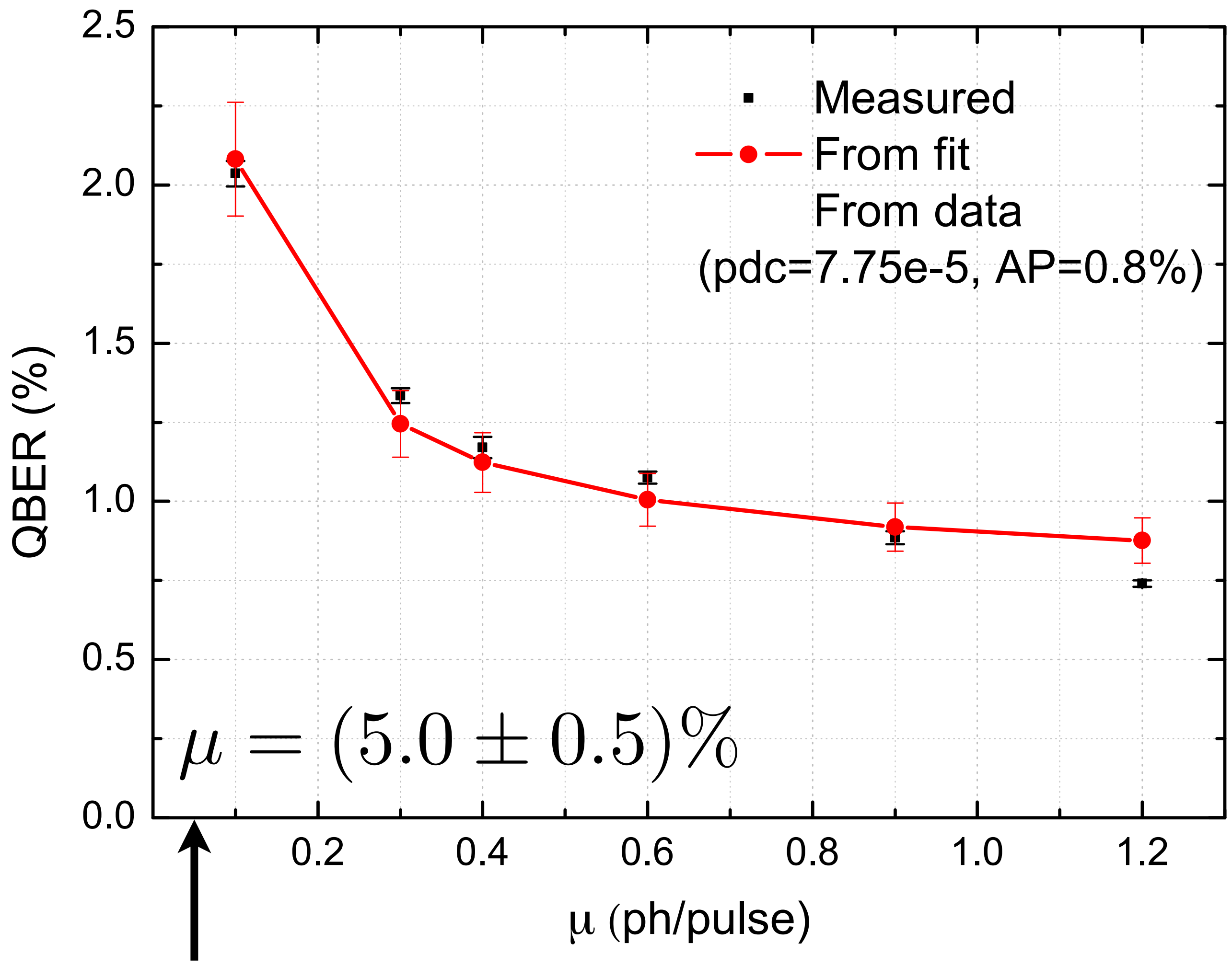
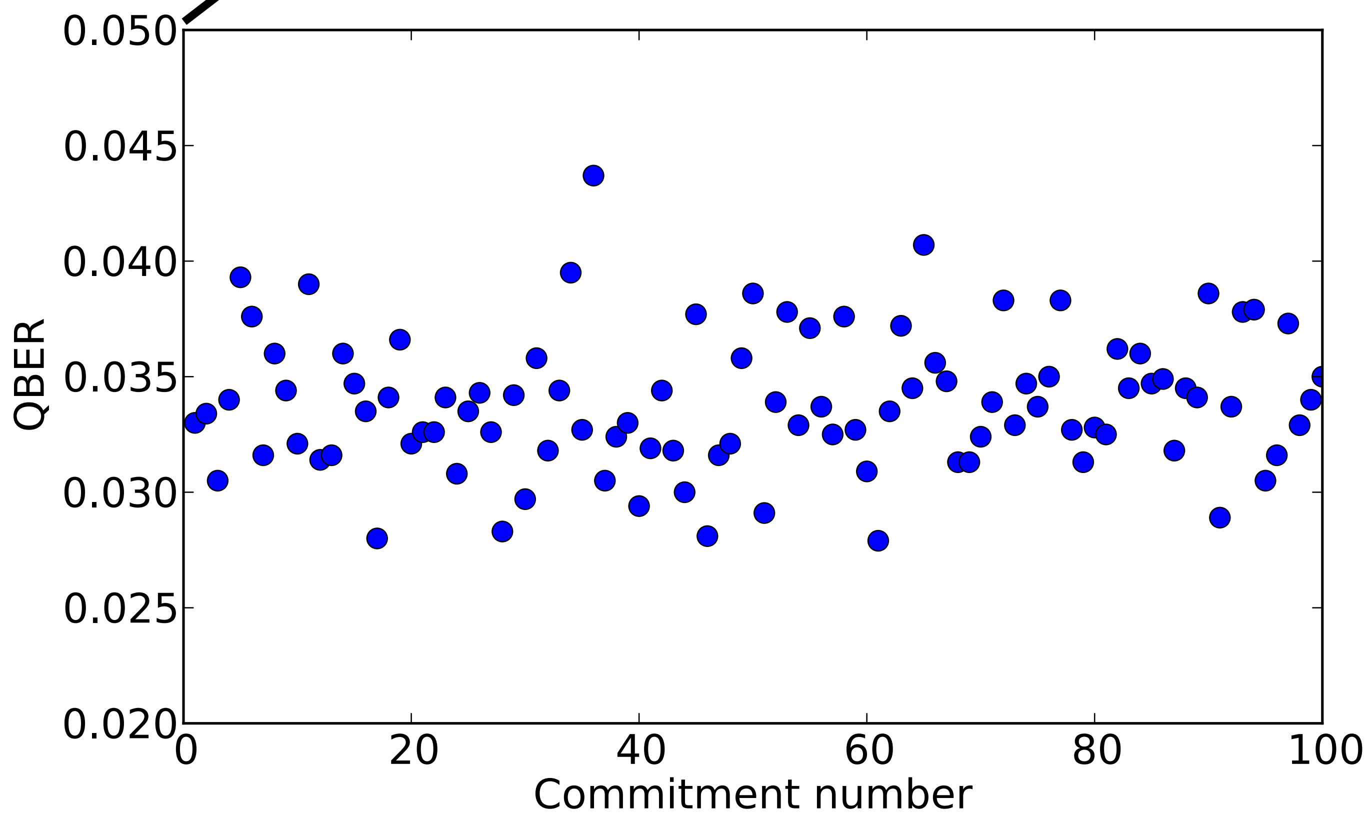
The quantum boxes (Geneva) : performances

Choosing μ : security trade-off

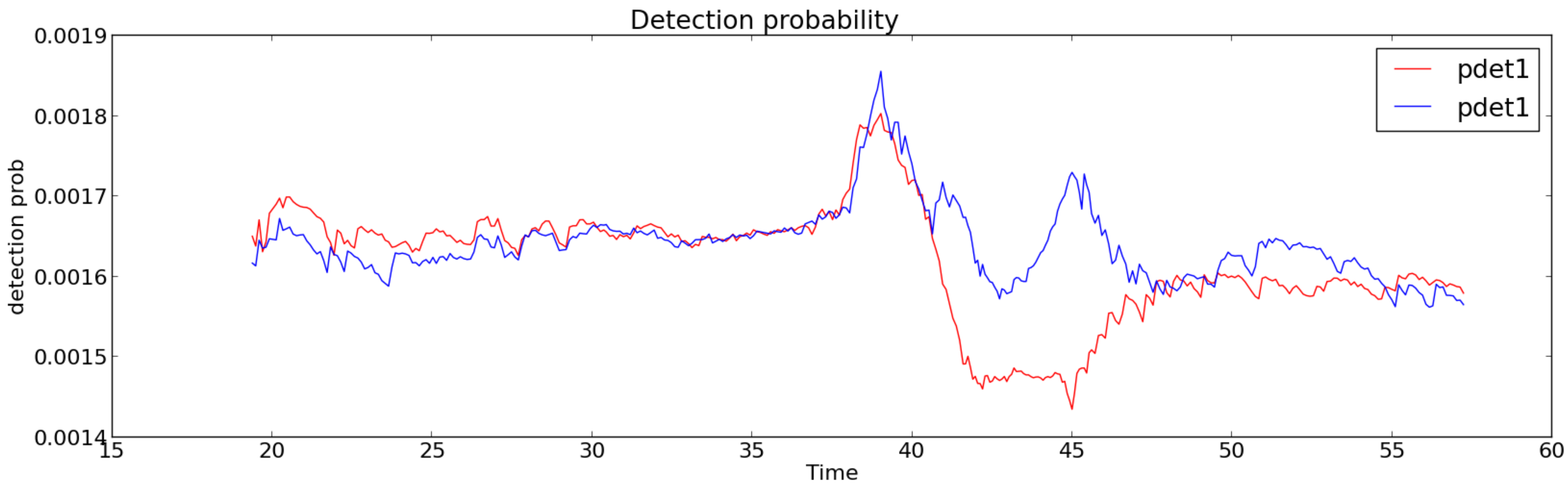


Took 5% as the maximum QBER for finite statistics analysis



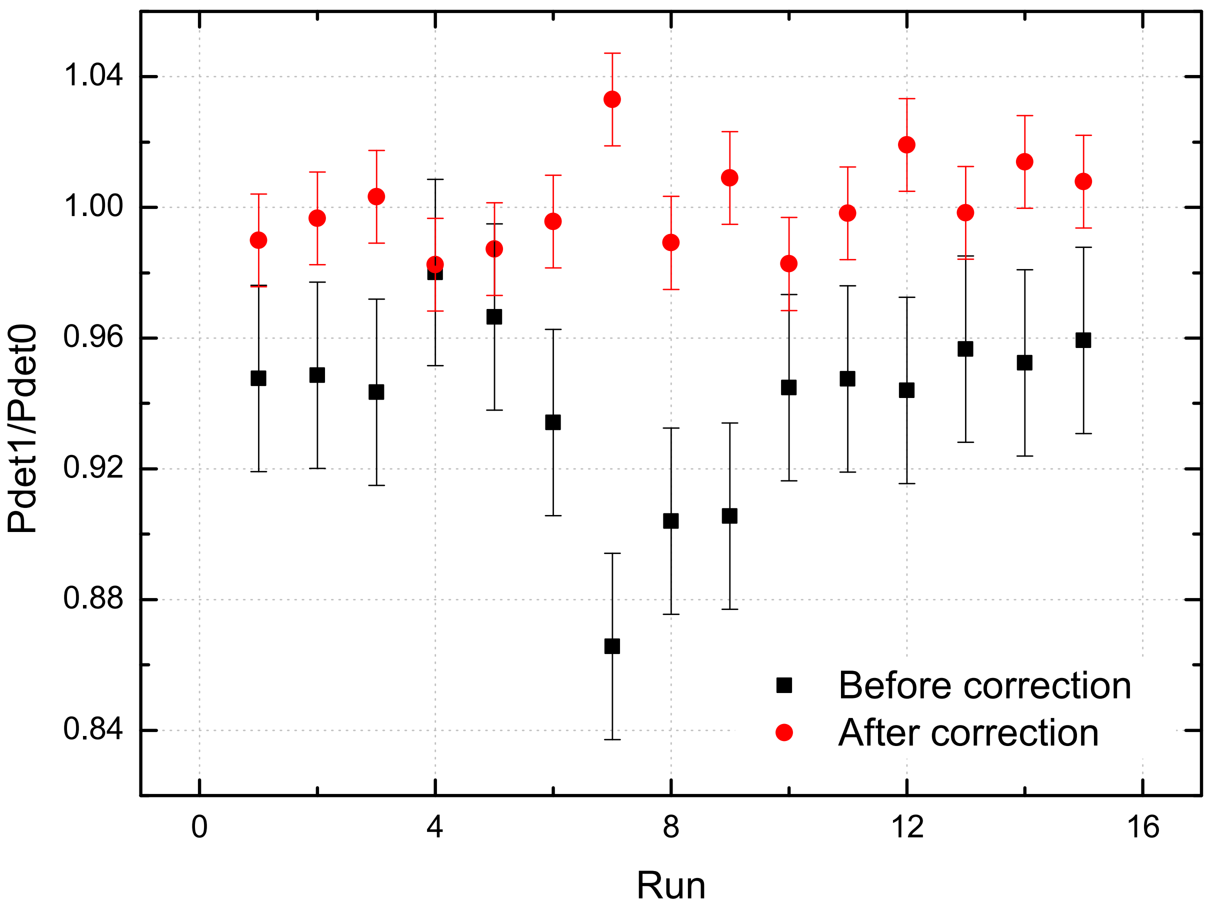
The quantum boxes (Geneva) : performances

Stability of the detection probability : Bob must monitor!



Basis detection probability mismatch: side-channel!

Software bias elimination.



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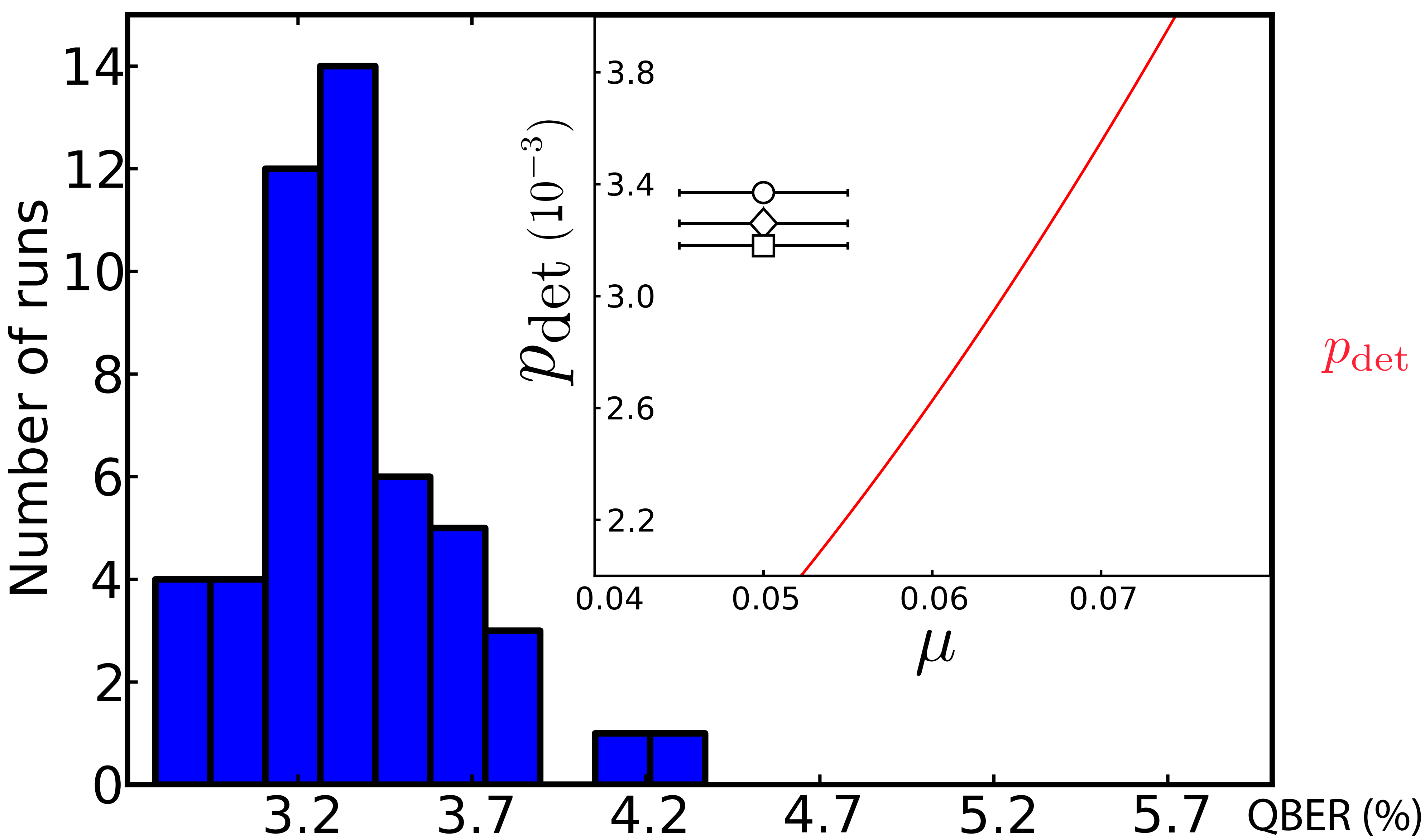
Results: 50 commitments of bit 1 from 7000 detections at Bob's



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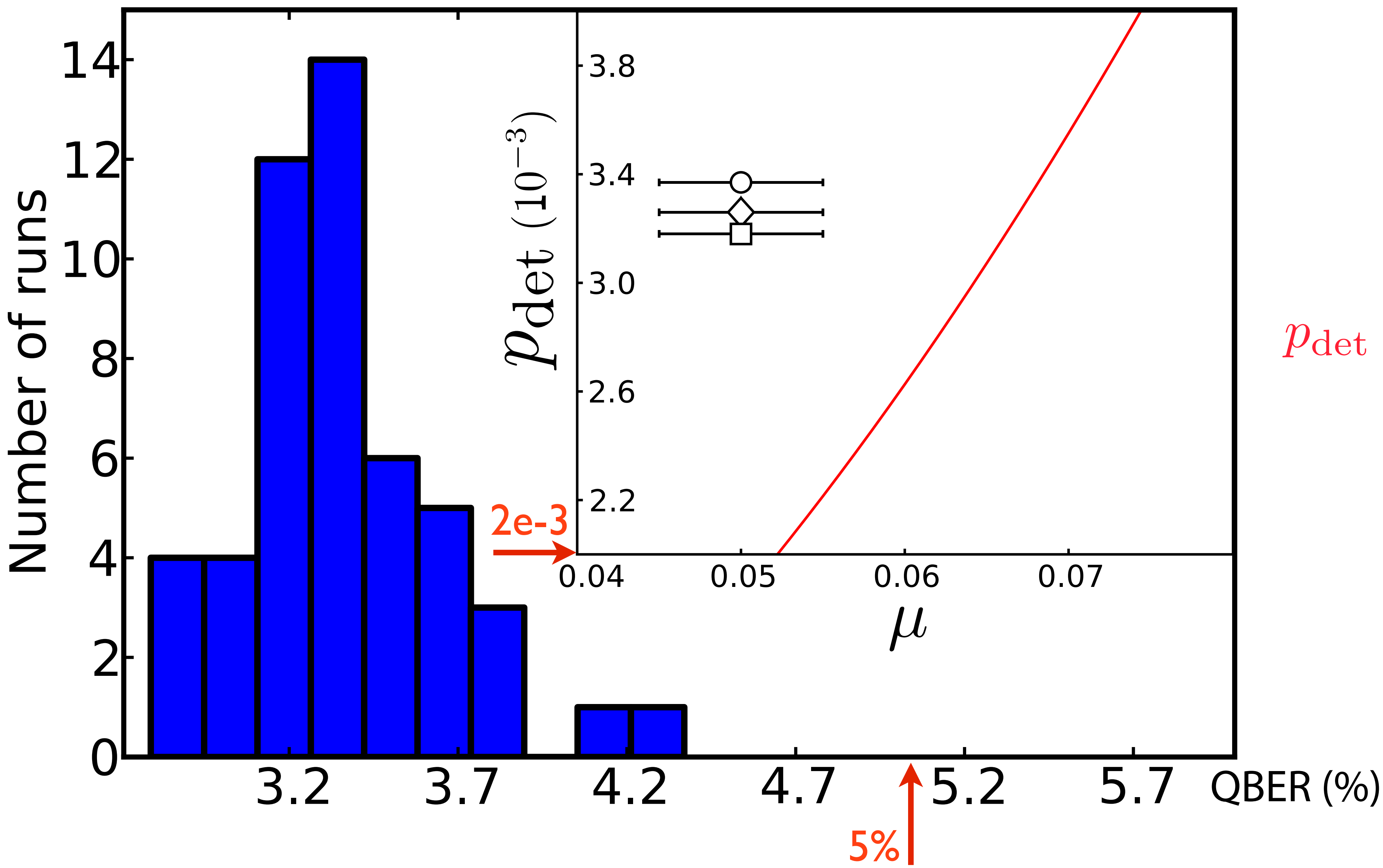
Results: 50 commitments of bit 1 from
7000 detections at Bob's



$$p_{\rm det} > \frac{1 - {\rm e}^{-\mu}(1+\mu)}{1 - \frac{\rm QBER}{\lambda}}$$

Security parameter

$$\epsilon \leq 5.5 \times 10^{-8}$$

Summary and outlook

- First implementation of bit commitment using quantum communication and special relativity
- Closing on the maximum commitment time allowed on the surface of the Earth

- Possible extensions for sustained commitments with constant communication at each round? (Kent'05)

UNIVERSITÉ DE GENÈVE

NUS National University of Singapore

UNIVERSITY OF CAMBRIDGE

PI

QSIT Quantum Science and Technology
National Centre of Competence in Research

IDQ FROM VISION TO TECHNOLOGY

OSCILLOQUARTZ