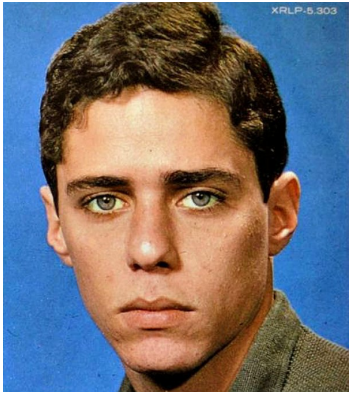
Improving quantum cryptography with computational assumptions

Alex Bredariol Grilo

Quantum information vs. cryptography

Quantum information vs. cryptography



Quantum helps malicious parties

Quantum information vs. cryptography

Quantum helps honest parties

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Quantum information vs. cryptography

Quantum helps honest parties Quantum helps malicious parties

How do quantum resources allow us to achieve better cryptographic protocols?

Quantum 101 (simplified)

Quantum mechanics

Quantum states | Evolution | Measurements

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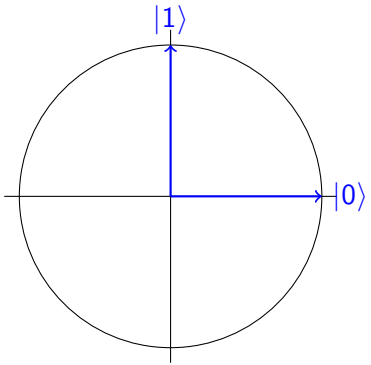
States



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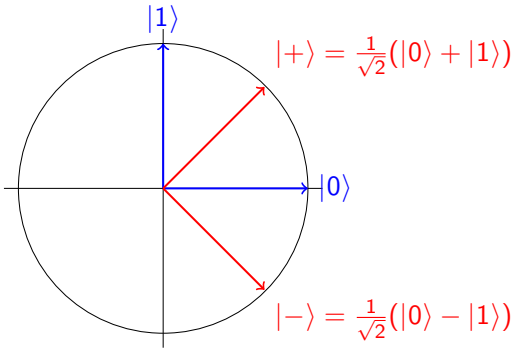

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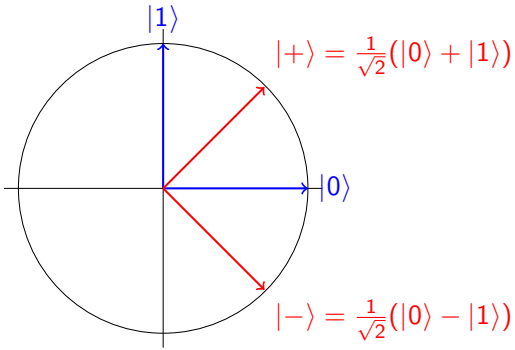

Measurements

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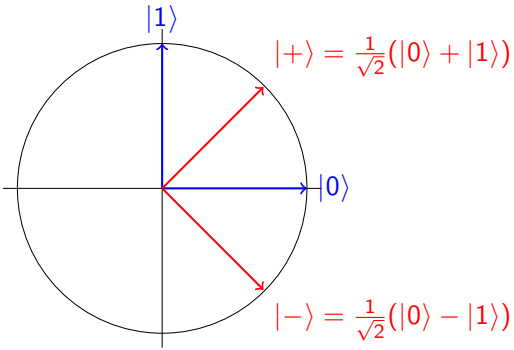

Measurements

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  - Meas. $|0\rangle$, the outcome is 0 w.p. 1
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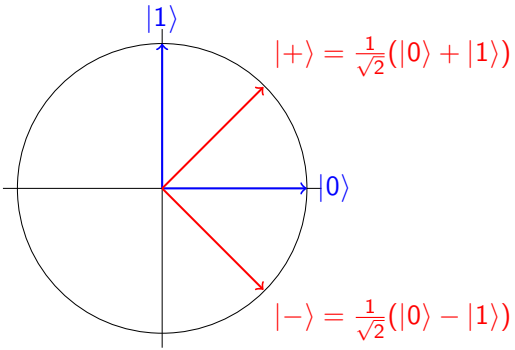

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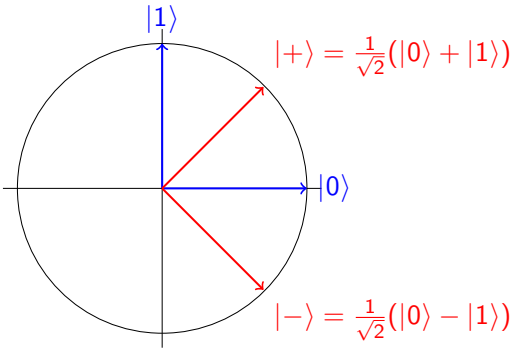

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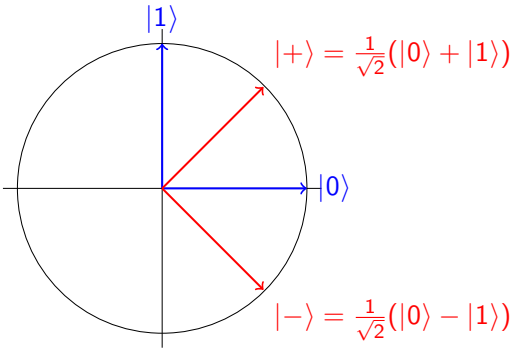

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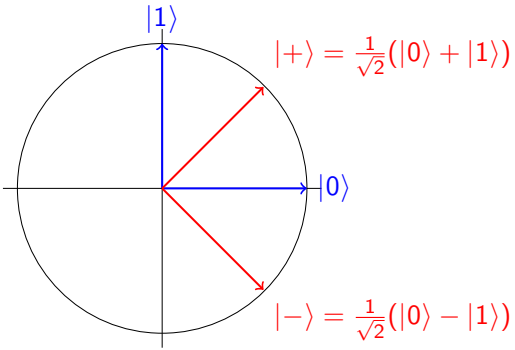

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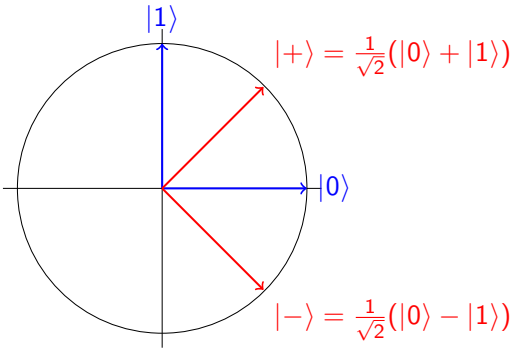

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State collapses after measurements

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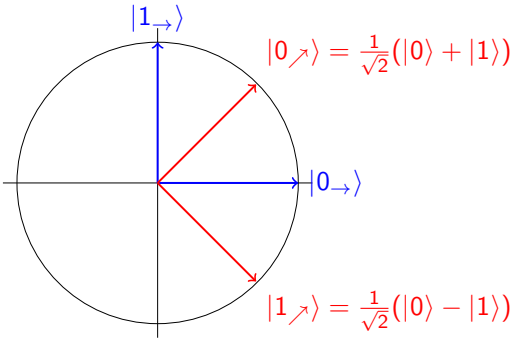

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Key agreement

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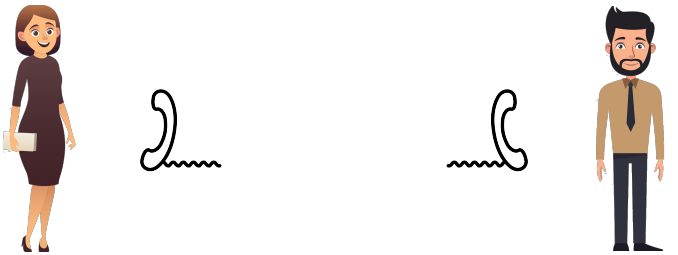
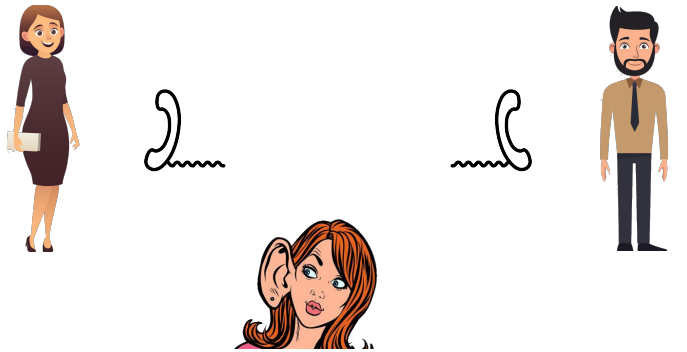


Goal: Alice and Bob want to share a common random key k over the phone

Key agreement



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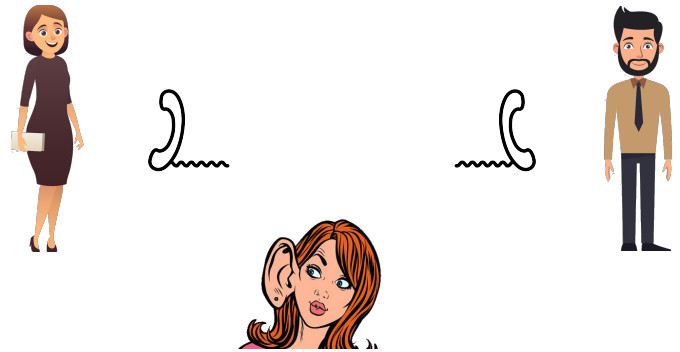

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Security: They want k to be unknown to potential eavesdroppers
Classical information-theoretically secure key agreement is impossible!

Quantum-key distribution (simplified)

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	Basis
$\|\phi_1\rangle = \|+\rangle$	$\nearrow$
$\|\phi_2\rangle = \|0\rangle$	$\rightarrow$
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$\nearrow$	$-$
0	1
$\rightarrow$	0
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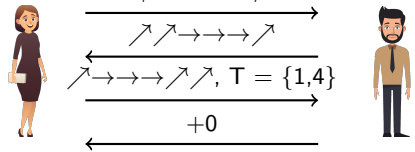

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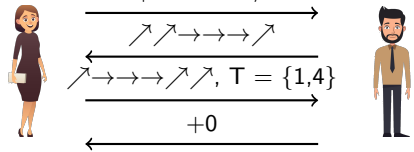

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Intuitively, if Eve tries to eavesdrop the quantum state, it collapses

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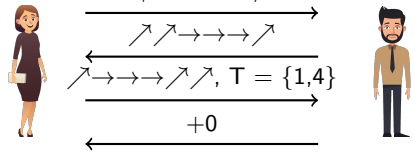

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- Complete protocol and formal security proof is more cumbersome

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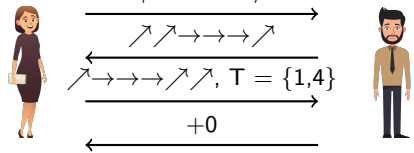

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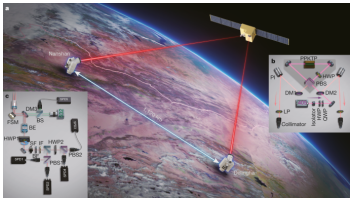

Beyond QKD

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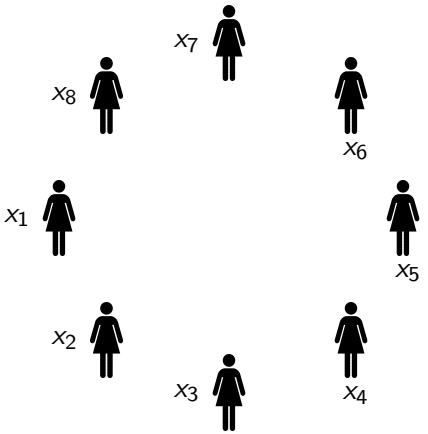
What if we use computational assumptions?

1. Quantum protocol for multi-party computation from weaker computational assumptions
2. Improving the round complexity of QKD

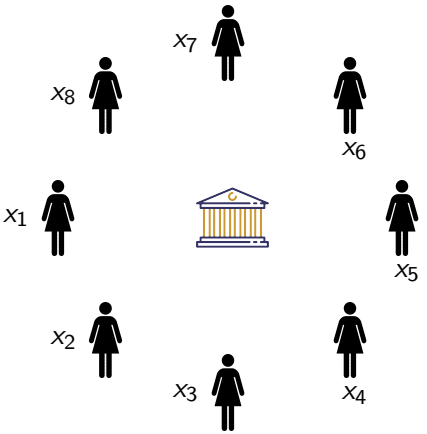
Quantum protocol for multi-party computation from weaker computational assumptions

Multi-party computation



Goal: Compute $f(x_1, ..., x_8)$ without revealing their input

Multi-party computation



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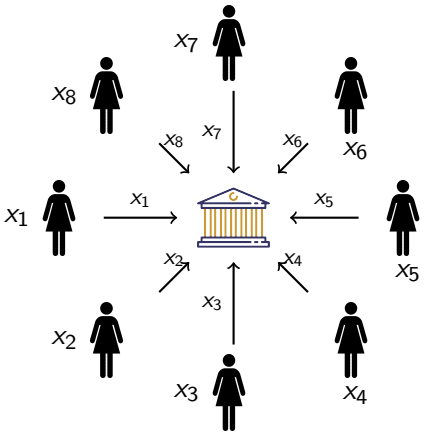
Ideal world

Multi-party computation



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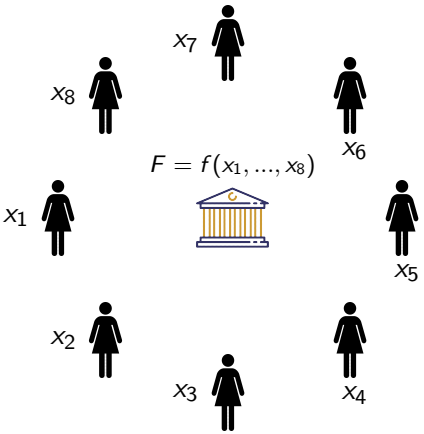

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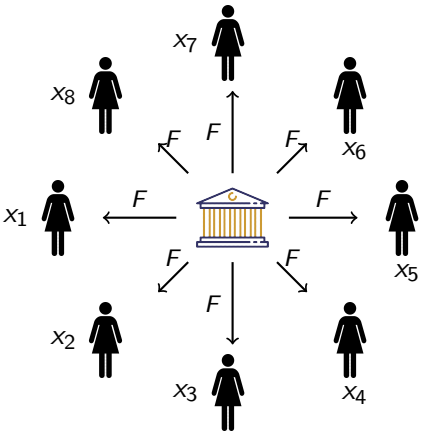

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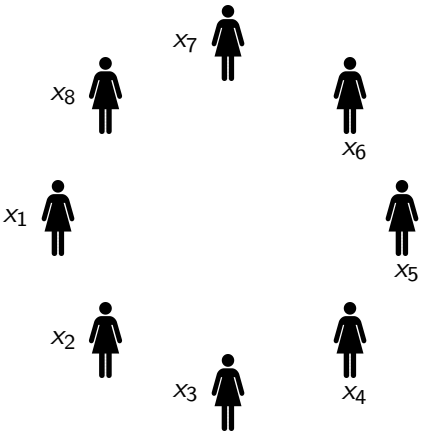

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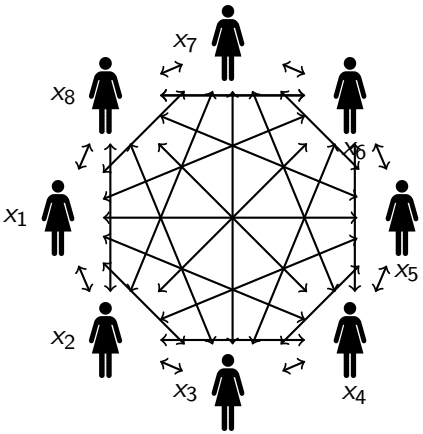

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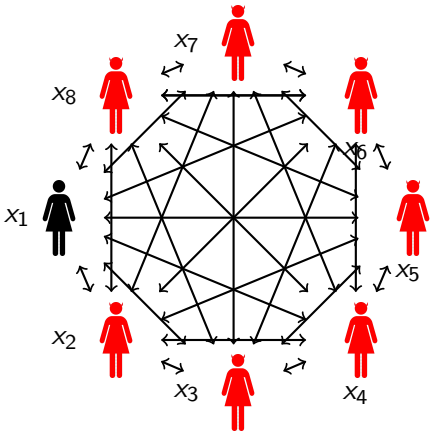

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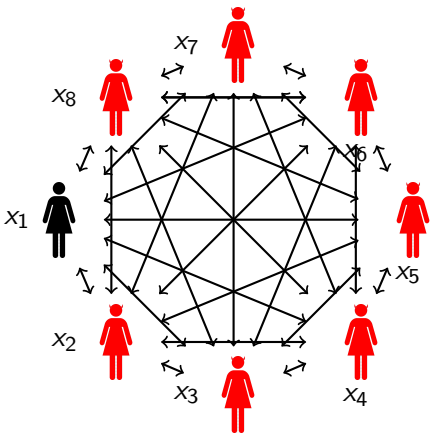

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Theorem [MMP'12]

MPC cannot be built from OWF in a black-box way

Oblivious transfer

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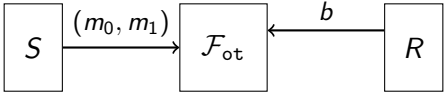
Ideal functionality

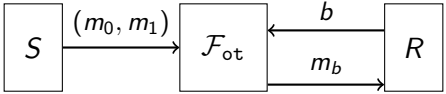
Oblivious transfer

Ideal functionality



Oblivious transfer

Ideal functionality



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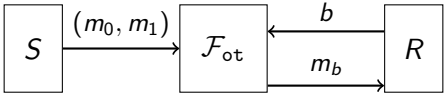
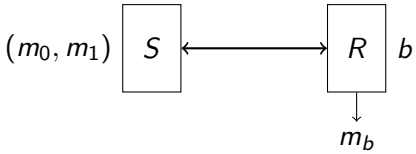


Real world



MPC from Quantum+OWF

- IPS'08: MPC protocols from $\mathcal{F}_{ot}$

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Corollary

Quantum protocol for MPC from OWF

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Classical protocols require PKE assumptions

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- D**G**ILYY'24+IYYL**G**D'25: Implementing quantum OT in the lab

Corollary

(Practical?) Quantum protocol for MPC from OWF

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CK/BBCS protocol (I)

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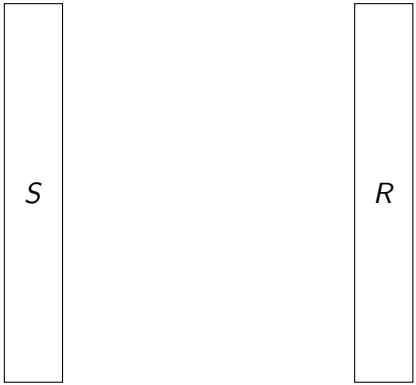
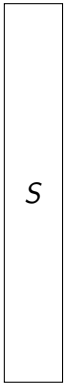


CK/BBCS protocol (I)

$\vec{x} \in \{0,1\}^\lambda$

$\vec{\theta} \in \{\rightarrow, \nearrow\}^\lambda$



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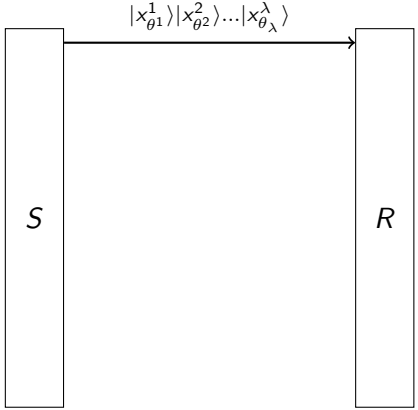

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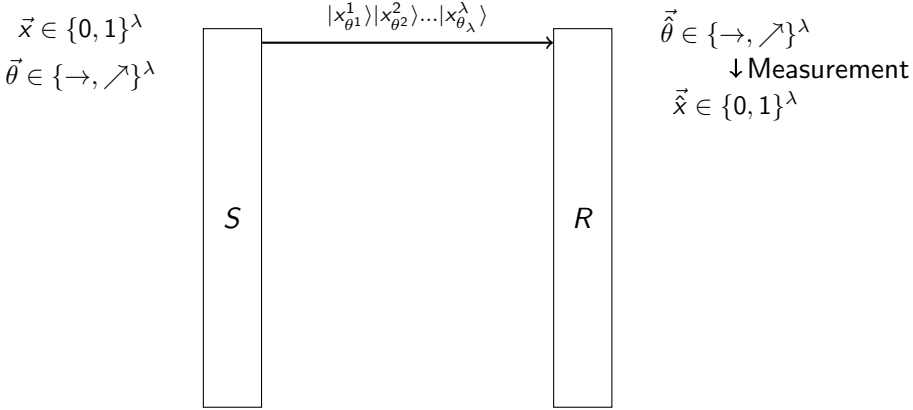

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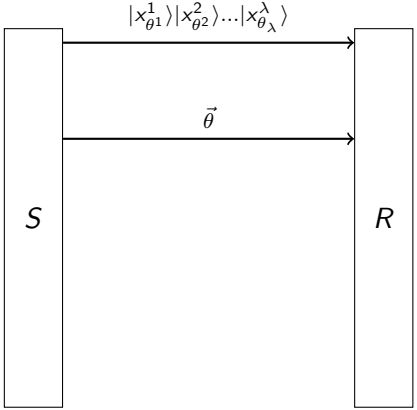

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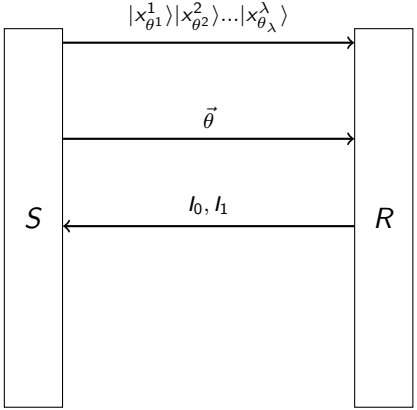

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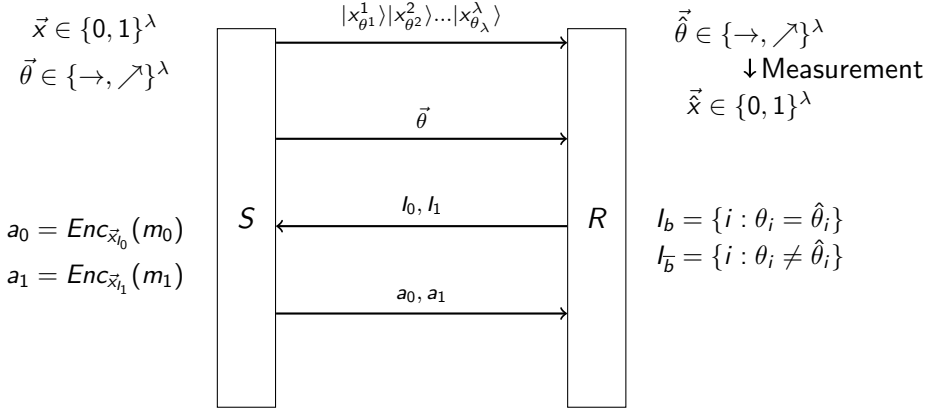

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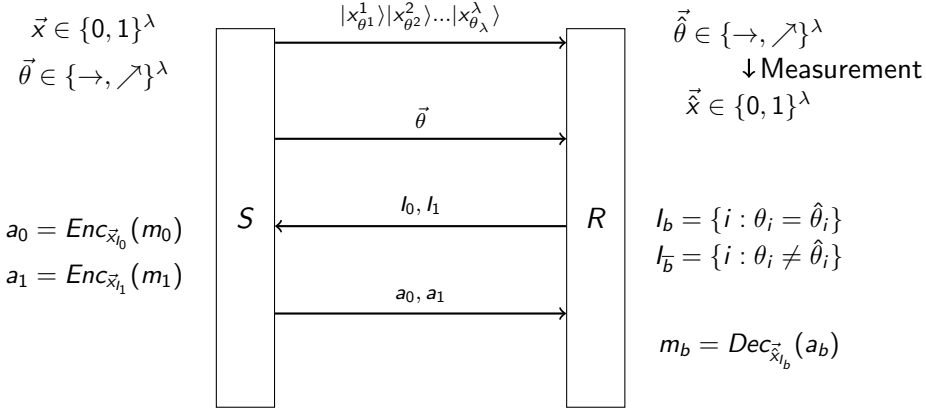

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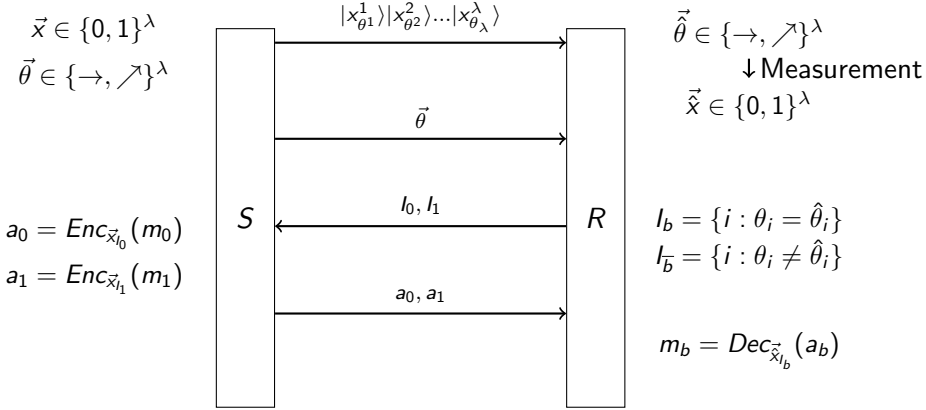
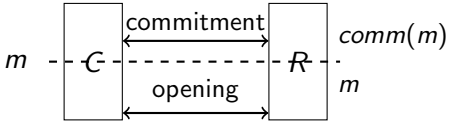


Attack for malicious receiver: $\tilde{R}$ waits $\vec{\theta}$ to measure the qubits using the right basis

Bit-commitment with simulation security



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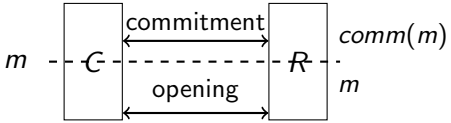
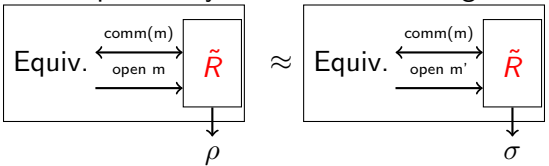


Equivocality: "simulation" hiding



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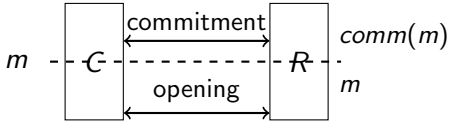

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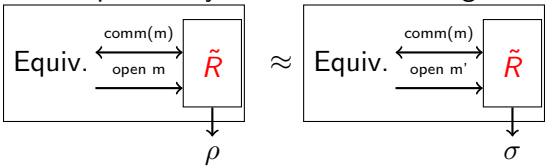
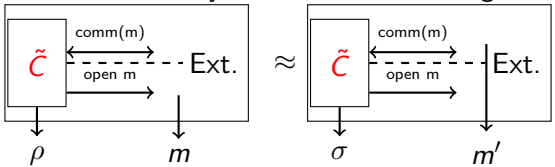


Extractability: "simulation" binding



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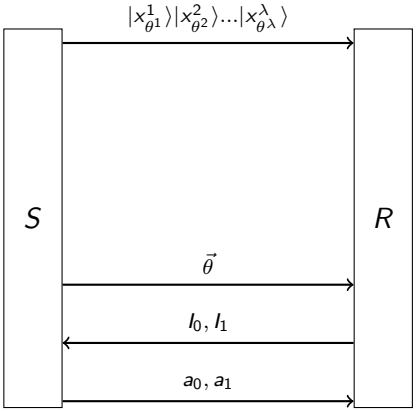

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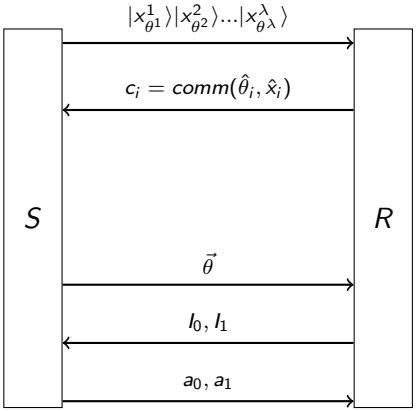

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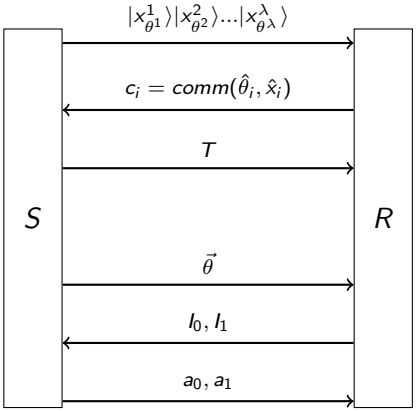

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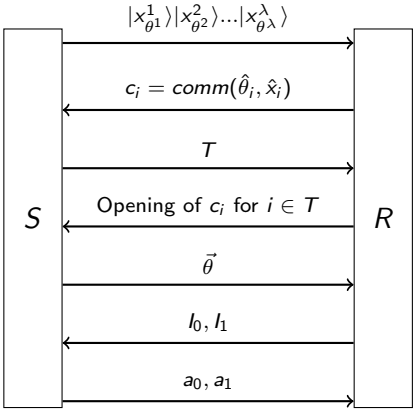

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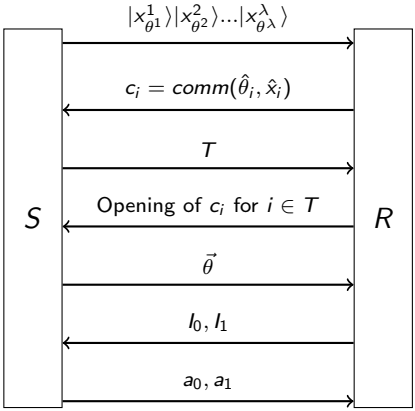

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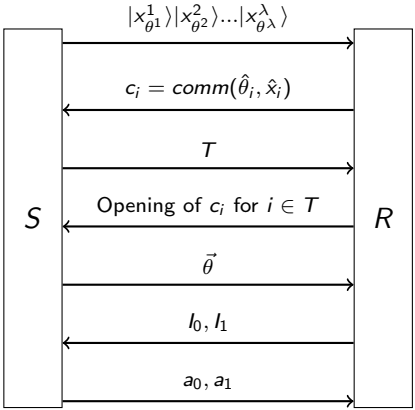

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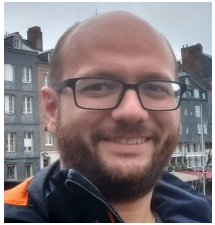
Implemententing commitment scheme with simulation security from OWF

Implemententing commitment scheme with simulation security from OWF

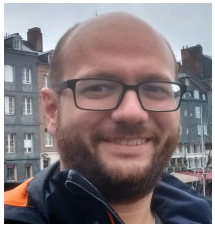
[BCKM21]	[GLSV21]
1. (Black-box) equivocality compiler	1. Equivocal commitment from Naor's commitment and zero-knowledge
2. Extractable commitment from equivocal commitment and quantum communication	2. Unbounded-simulator OT from equivocal commitment
	3. Extractable and equivocal commitment from unbounded-simulator OT and quantum communication

Features:

• **Black-Box** use of one-way functions	• **Constant-Round** OT in the CRS model
• **Statistical** security against malicious receiver	• **Statistically binding** extractable commitment



We have a protocol that only uses BB84 states.



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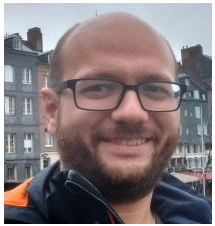

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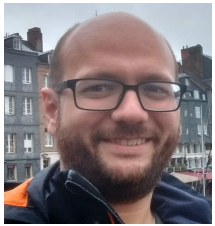

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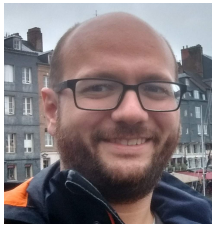

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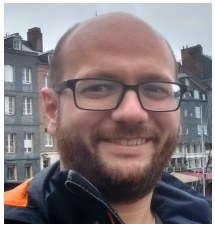

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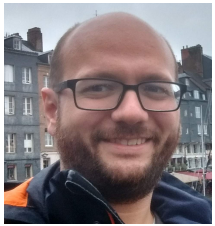

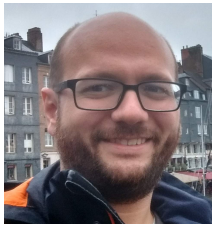

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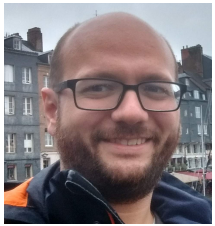

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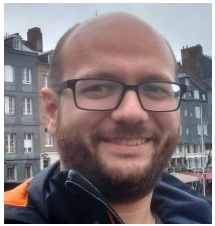

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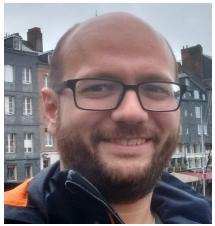

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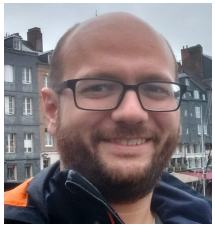

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How many bits of security do you achieve?

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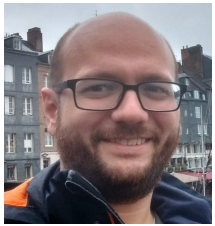
This λ again...

And the classical post-processing?



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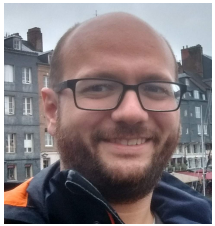

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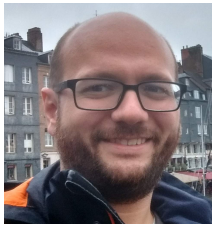

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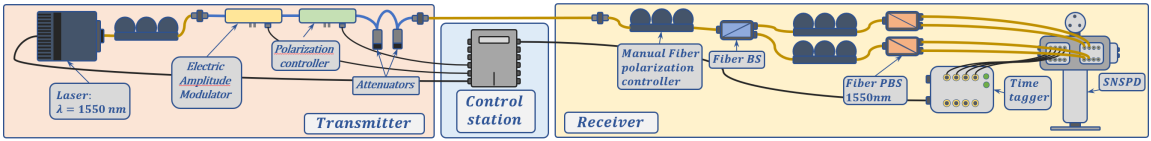
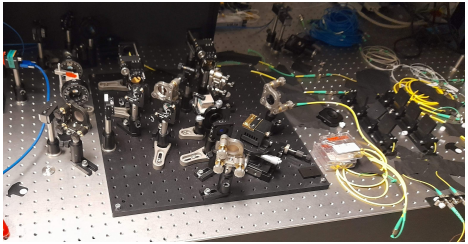
Practical protocol [D**G**ILYY'24] $\leftrightarrow$ Experimental implementation [IYYL**G**D'24 – on-going]

	BCKM21 numerical analysis	**DGILYY24 implementation profiling**
N_{BB84}	$1.7 \cdot 10^{13}$	$2.1 \cdot 10^{6}$
N_{RNG}	$1.3 \cdot 10^{16}$	$1.5 \cdot 10^{9}$
N_{PRG}	$6.6 \cdot 10^{15}$	$1.7 \cdot 10^{7}$
M_{seed}	$8.5 \cdot 10^{17}$ *bytes*	$2.5 \cdot 10^{10}$ *bytes*
$T_{acqBB84}$	197 *days*	2.1 *s*
T_{exec}	–	13 *min* 5 *s*

Implementation





Improving the round complexity of QKD

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- quantum communication: technologically challenging but round-efficient
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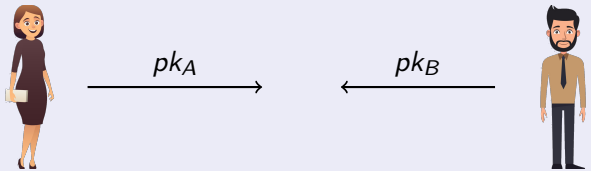

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EPR pairs

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Thank you for your attention!