Bidirectional Quantum Channels Enter Quantum Security

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http://fisica.unicam.it/qog/

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Outline

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Protocols

One-Way

- Bennett & Brassard, 1984 Go
- Ekert (E91) and Bennett (B92)

Two-Way

- Dense Coding [Bennett & Wiesner, PRL **69**, 2881 (1992)] Go
- Ping-Pong [Boström & Felbinger, PRL **89**, 187902 (2002)] Go
- Protocols based on entanglement
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  - [Degiovanni et al., PRA **69**, 032310 (2004)]
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  - A. Beige, B.-G. Englert, C. Kurtsiefer, and H. Weinfurter, J. Phys. A **35** 407

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The Protocol

Lucamarini & Mancini, PRL **94**, 140501 (2005)

- Single qubit (*no entanglement*)
- Two-Way Protocol

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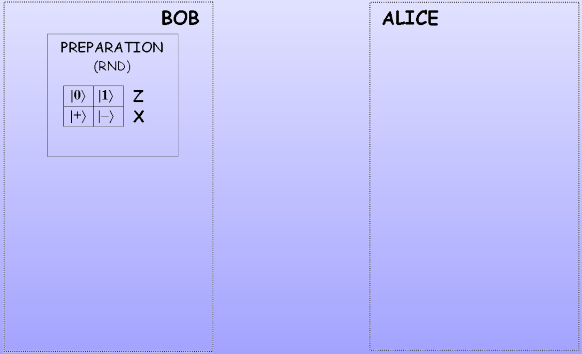
How it works!



Decoding

$$\mathrm{I}|0,1\rangle = |0,1\rangle \qquad \mathrm{I}|+,-\rangle = |-,+\rangle$$

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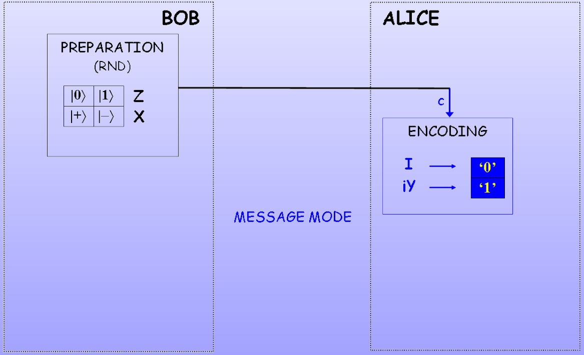

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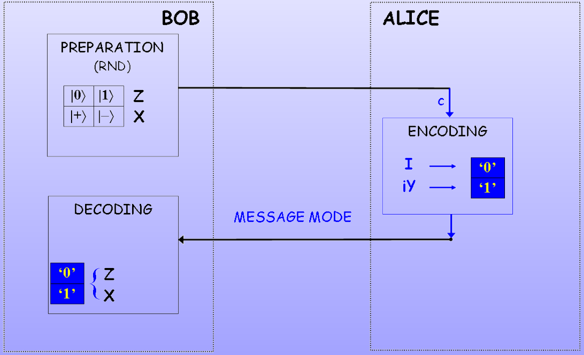

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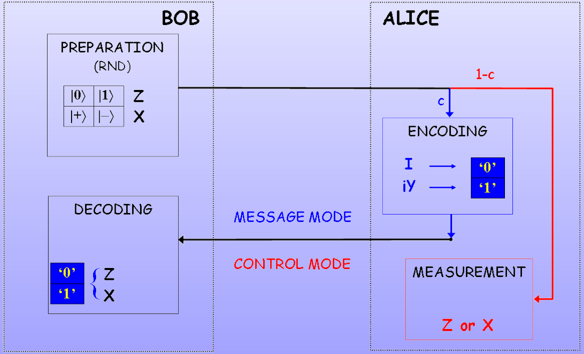

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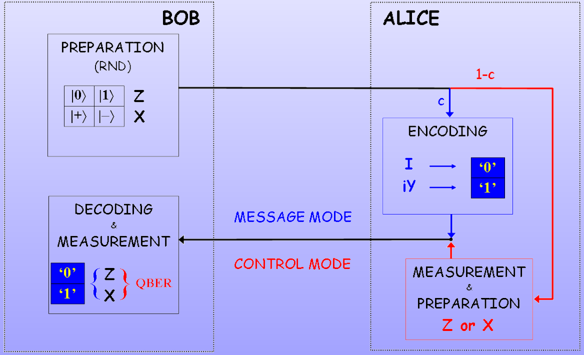

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Summary

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- Alice does not need to know the incoming state to encode a bit using either identity or polarization-flip
- Bob decodes Alice's message measuring in the same basis he prepared the state

Features

- Deterministic protocol, i.e. the information is *deterministically* conveyed from one user to another!
- No qubits are discarded (wrong basis in BB84)
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- Alice performs a projective measurement on the qubit along a basis randomly chosen between Z and X
- She then sends the projected qubit to Bob, who measures it in the same basis he prepared the state
- Public debate on results

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- If Eve is not on the line, the users must find perfect *double correlation*: *Double* (BB84) check on the channel → (at least BB84) security

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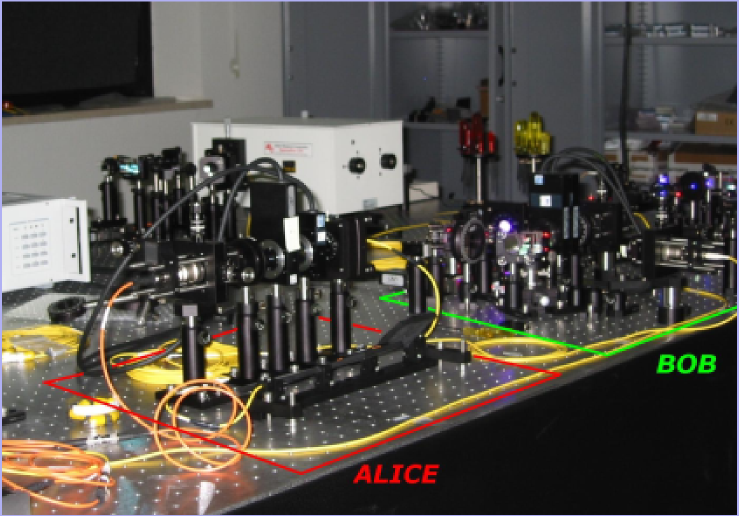

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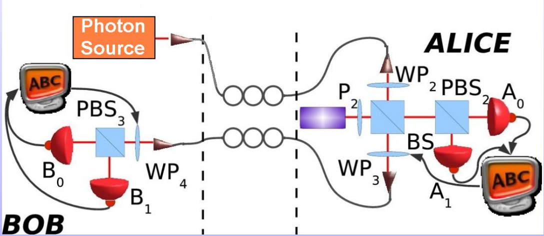
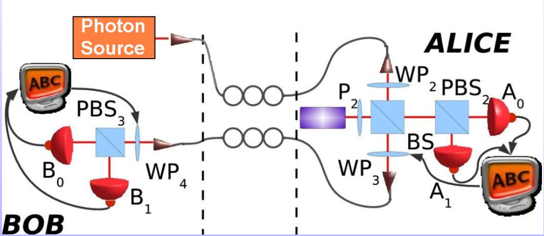


Experiment

Setup - Communication Tests



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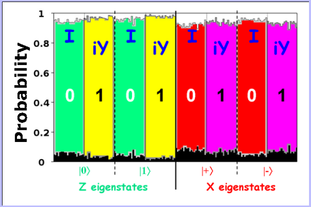

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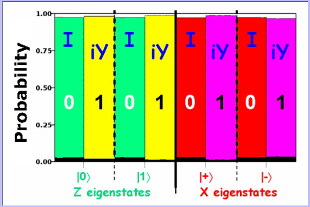

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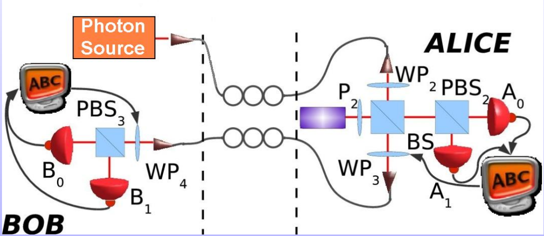

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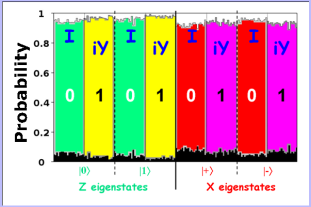

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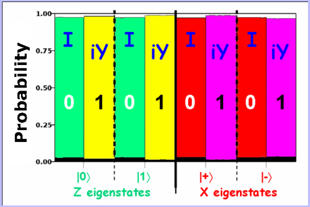

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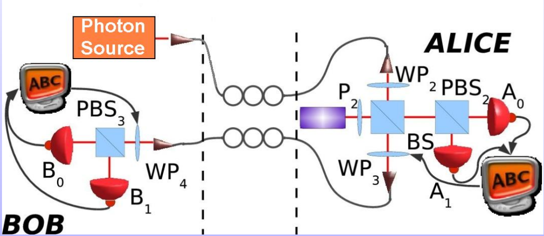

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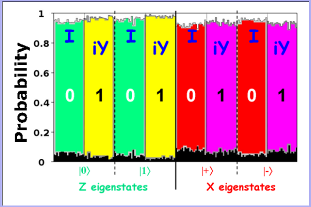

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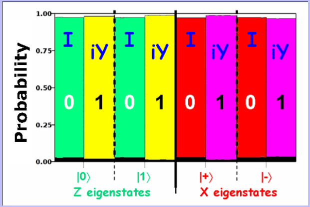

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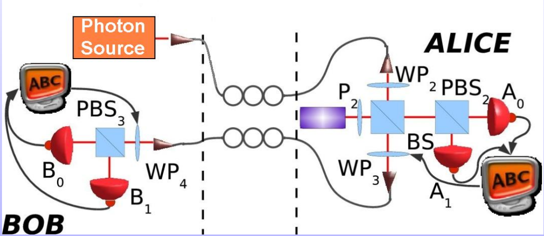

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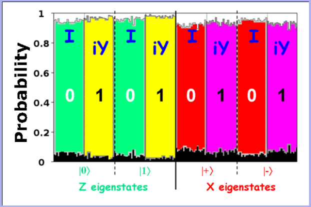

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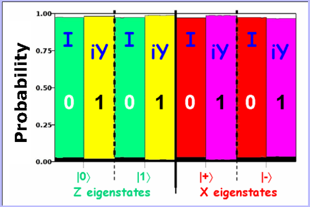

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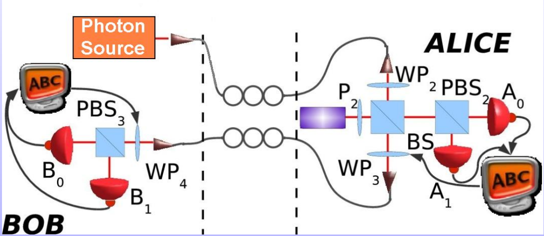

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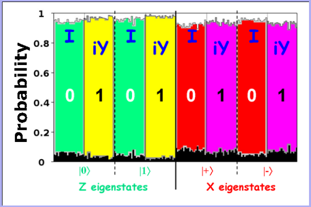

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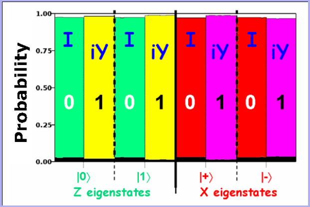

Experiment

Discussion on the Message Mode

Quantum Key Distribution

- *Distribution* of a key vs. *generation*
  - Error Correction

Quantum Direct Communication

Can Alice send to Bob a *meaningful* string ?

Problems ...

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  - Error Correction $\longrightarrow$ identical keys
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Two-Way QCP

Review

LM05 Protocol
- The Protocol
- Message Mode
- Control Mode

First Telecom Window
- Experiment
- Incoherent Individual Attack
- Eavesdropping Simulation
- Imperfect Equipment

Third Telecom Window
- Phase Encoding

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noisy lossless channel

- Individual attacks: a probe on each qubit and measuring the probe *singularly*
- Coherent attacks: Eve processes several qubits coherently
  - Collective attacks: a probe on each qubit but measuring several probes *collectively*
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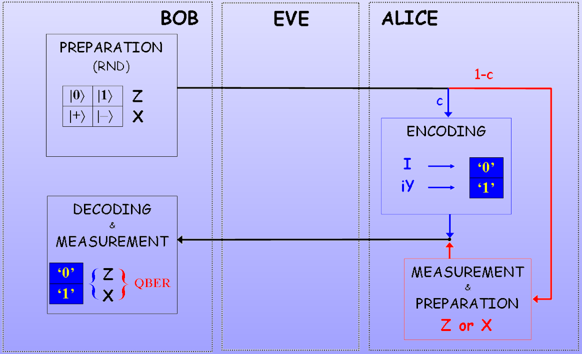
Incoherent Individual Attack

Eve's probes



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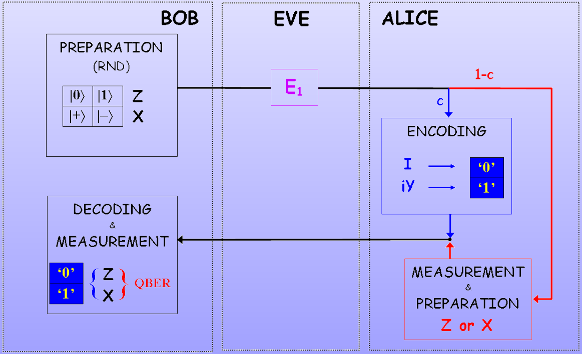

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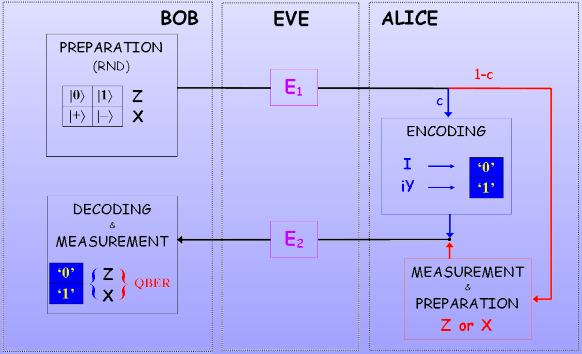

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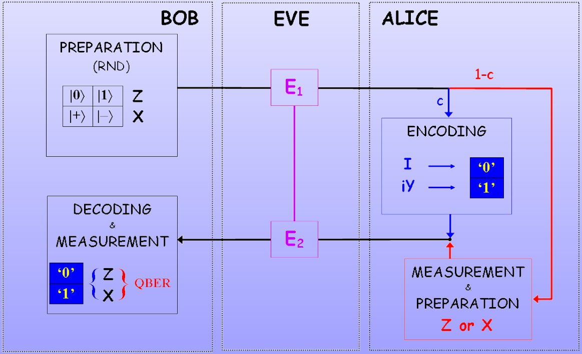

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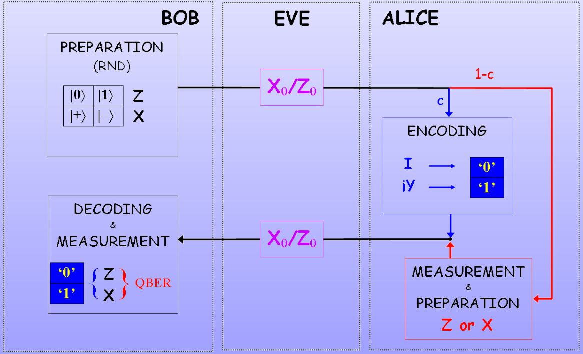
Eavesdropping Simulation

A. Ceré et. al, PRL **96**, 200501 (2006)



Same unitary operation on the forward and backward paths

Eavesdropping Simulation

Mutual Information

- The Shannon Mutual Information $I(\alpha, \beta)$ can be estimated from the QBER
- Condition for distillation of a secure key: $I(A, B) \geq \min[I(A, E), I(B, E)]$

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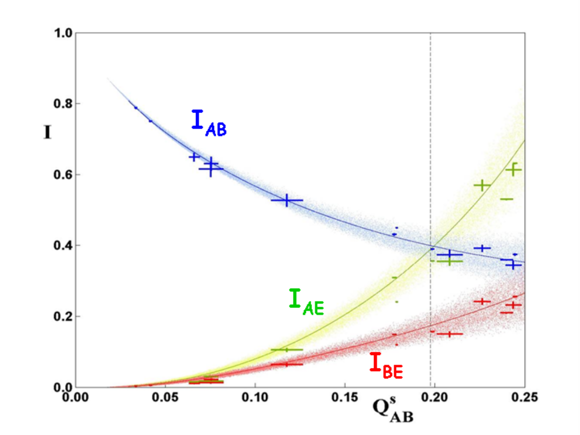

- $I(A,B) \geq I(B,E)$ always
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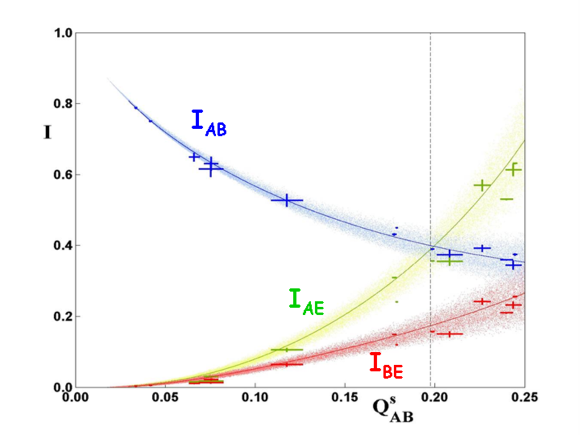

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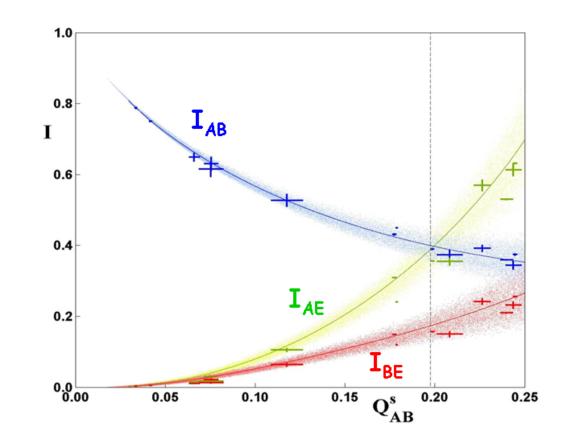

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Imperfect Equipment
Losses

- Faint-Pulses: attenuated laser which accidentally/uncontrollably contains more than one photon
- Detectors:
  - avalanche (click or no-click)
  - quantum efficiency less than one
  - dark counts
- Lossy channel: photons are lost in a double-trip

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Relevant Threat

PNS-attack

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Secure Rate [Following N. Lütkenhaus, PRA, **61**, 052304 (2000)]

P. D. Townsend, IEEE Photonics Technol. Lett., **10**, 1048 (1998)

$\lambda = 830$ nm
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$\Gamma_C = 8$ dB
$d_B =$
$5\,10^{-8}$ cnts/slot
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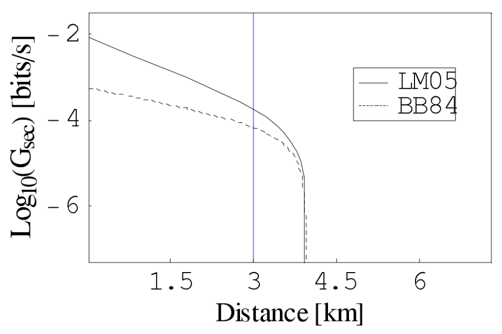

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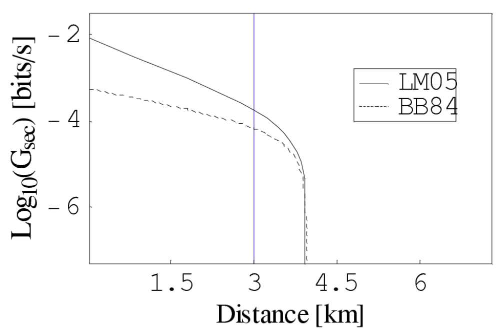

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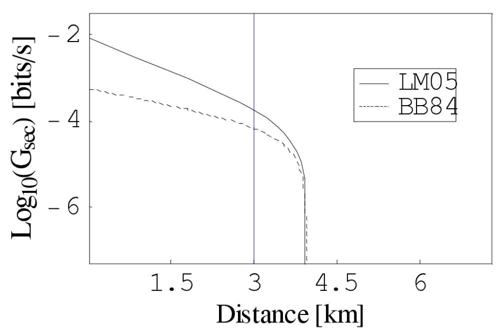

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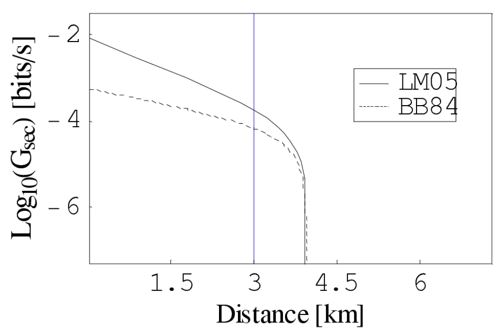
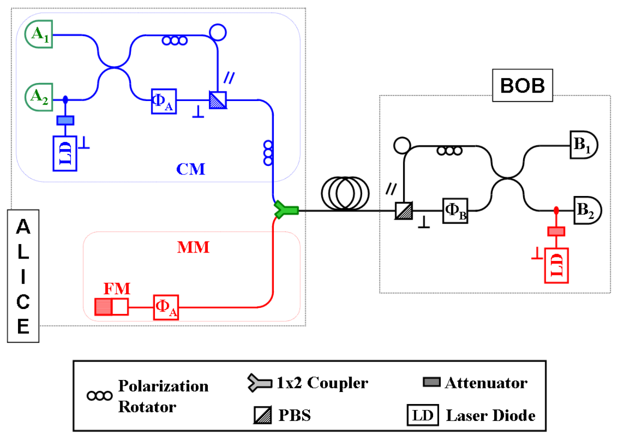


Phase Encoding

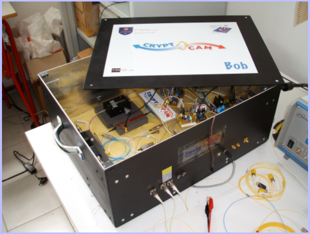
Scheme



Phase Encoding
Implementation

Alice

Bob



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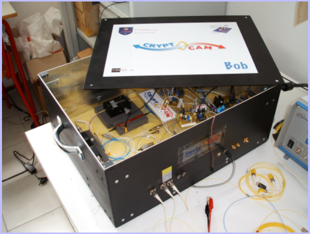

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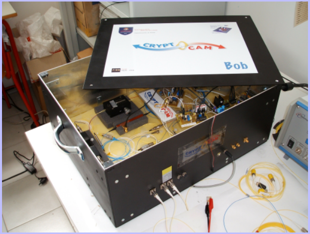

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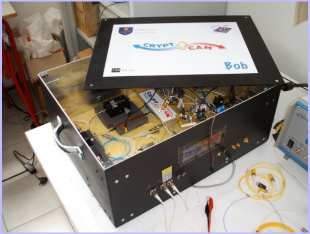

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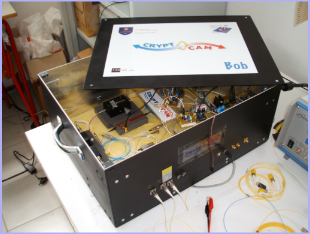

Conclusion

Results

- We have shown an experimental test of LM05.
- Modulating the noise on the channel to simulate Eve's IIA disturbance, we have estimated the mutual informations and shown the range of security of the protocol for IIA on lossless channel.
- Higher secure rate even for lossy channel and imperfect devices on short-middle distances.

Improvements

- No direct, contextual transmission of string of bits.

On the way

- real-time running two-way protocol @1550nm.

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Founding

IST – Integrated Project ‘Qubit Applications’ (QAP)

MIUR – FIRB 2001 and PRIN 2005