GAP Optique Geneva University

Quantum Communications at telecom wavelengths

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GAP-Optique, University of Geneva

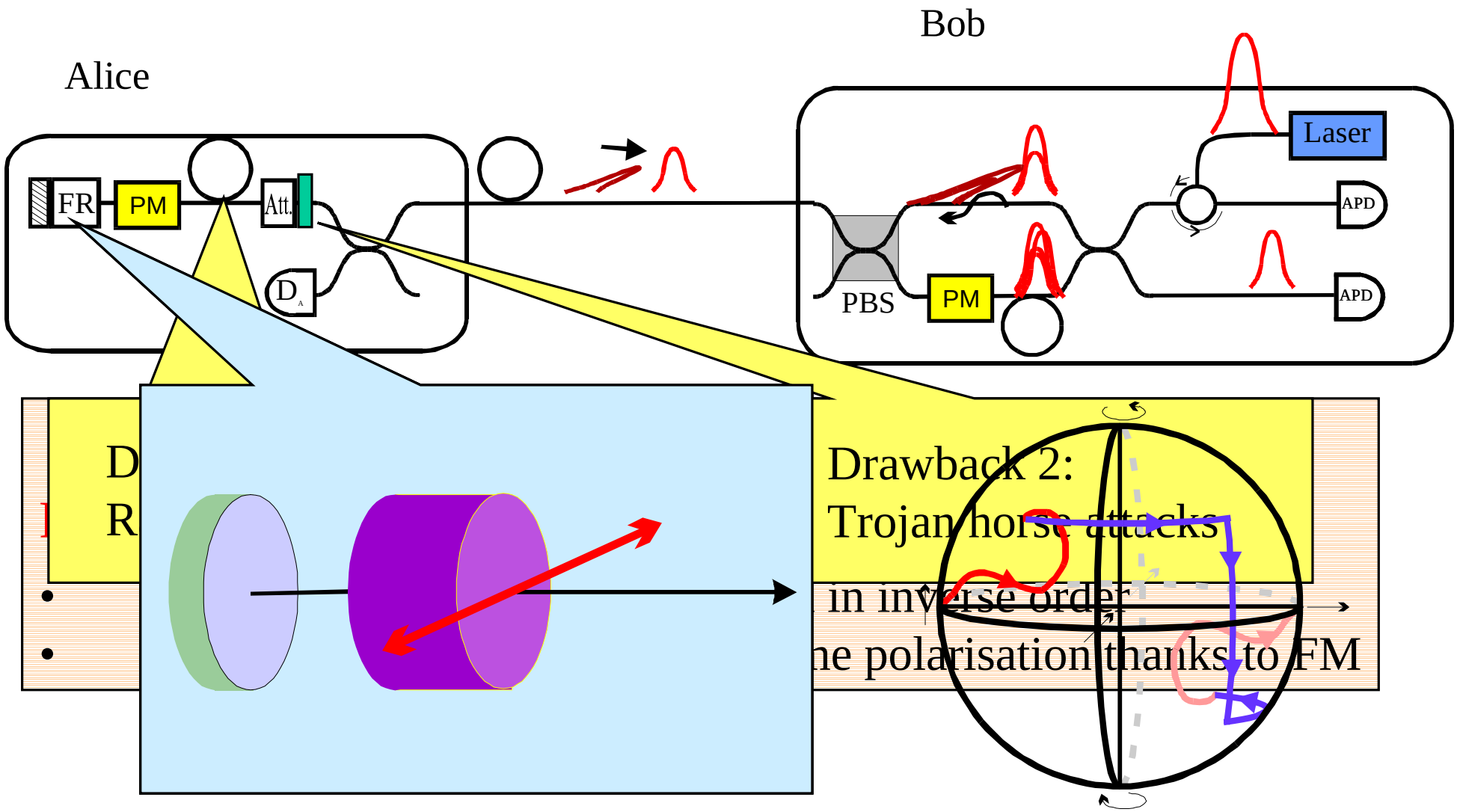
Q crypto over 67 km

Time-bins: $\Rightarrow$ high dimensions

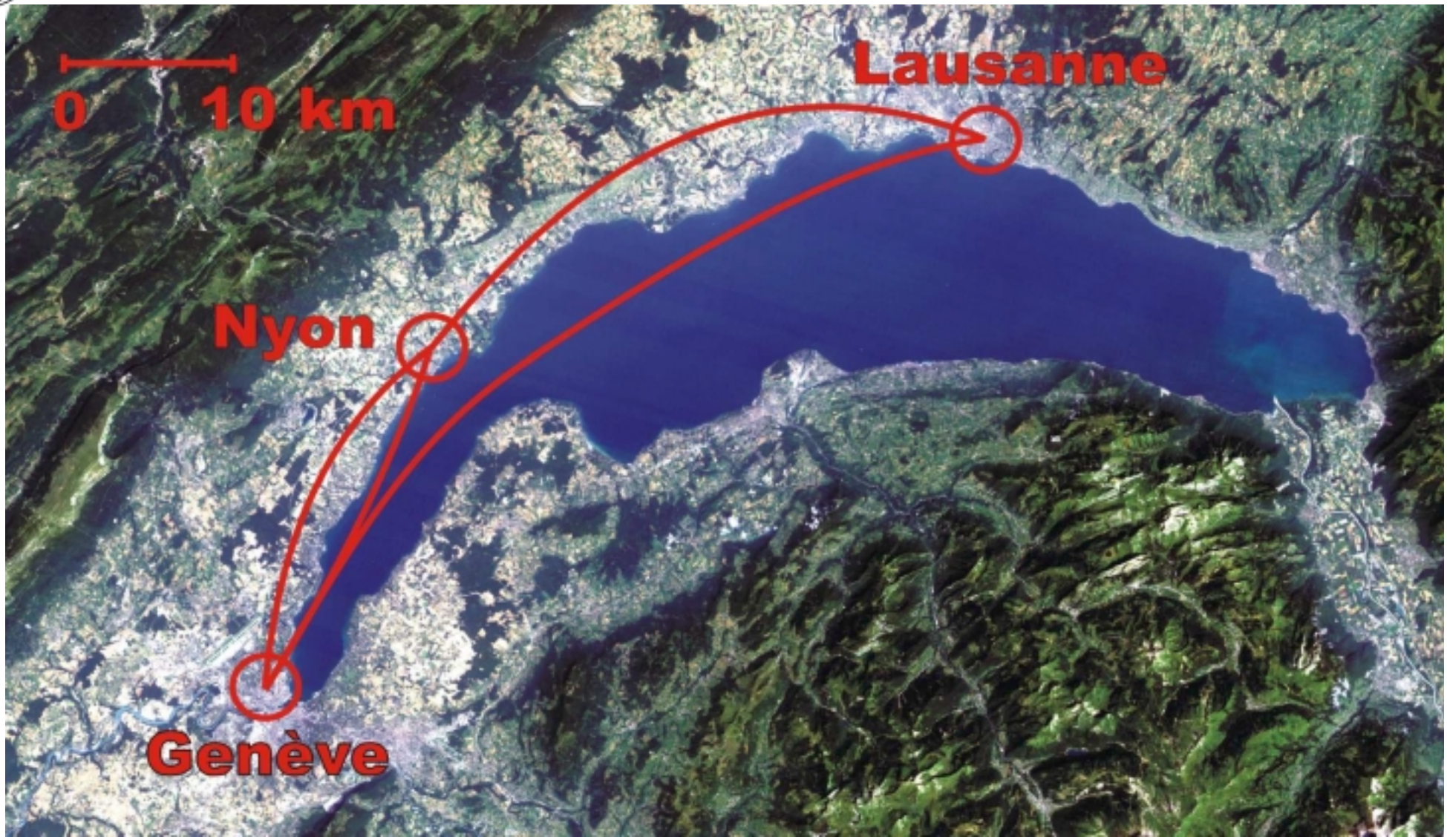
$\Rightarrow$ robustness of non-maximally entangled qubits

$\Rightarrow$ Q teleportation at telecom λ

The plug&play setup



QC over 67 km, QBER ≈ 5%



+ aerial cable (in Ste Croix, Jura) !

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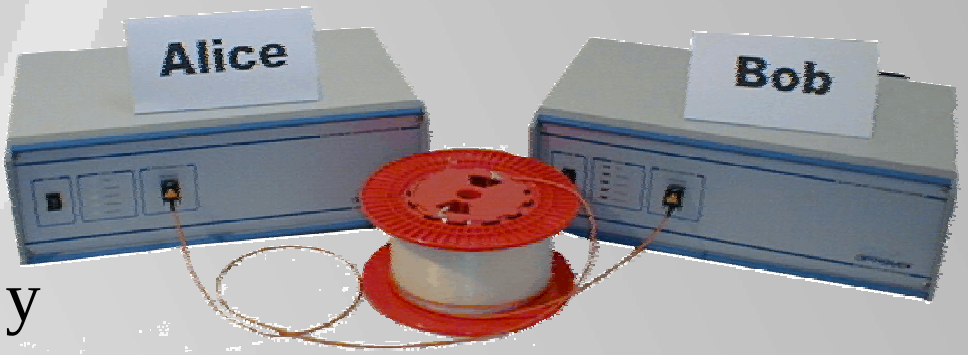
- Company established in 2001
  - Spin-off from the University of Geneva



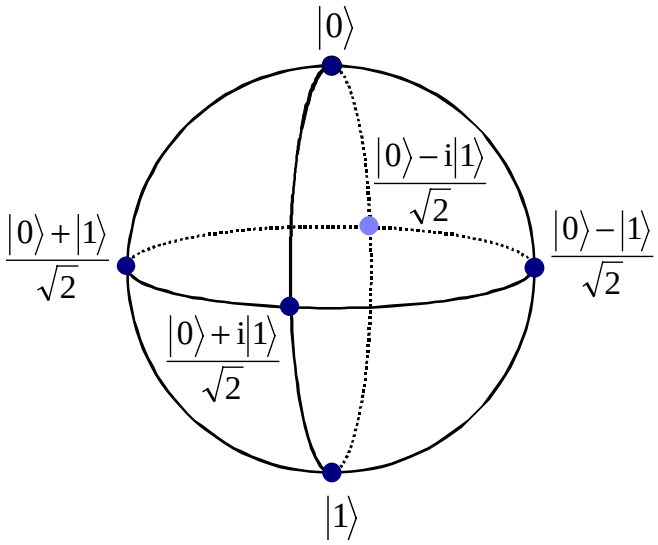
- Products
  - Quantum Cryptography (optical fiber system)
  - Quantum Random Number Generator
  - Single-photon detector module (1.3 µm and 1.55 µm)
- Contact information

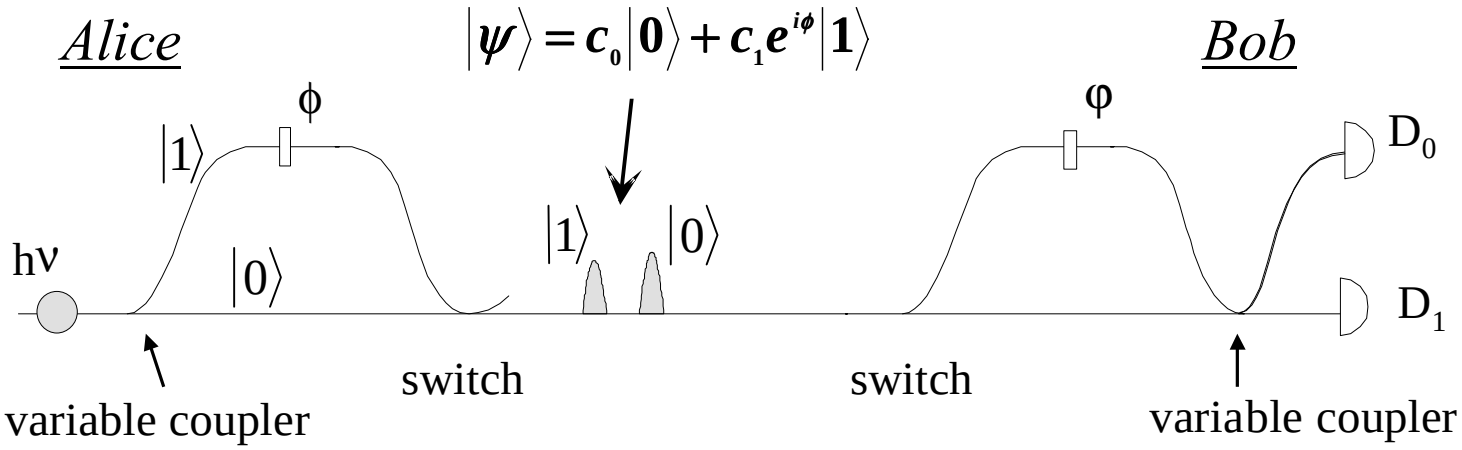
email: info@idquantique.com

web: http://www.idquantique.com

The qubit sphere and the time-bin qubit

- **qubit :** $|\psi\rangle = c_0|0\rangle + c_1 e^{i\phi}|1\rangle$
- **different properties** : spin, polarization, *time-bins*
- **any qubit state can be created and measured in any basis**





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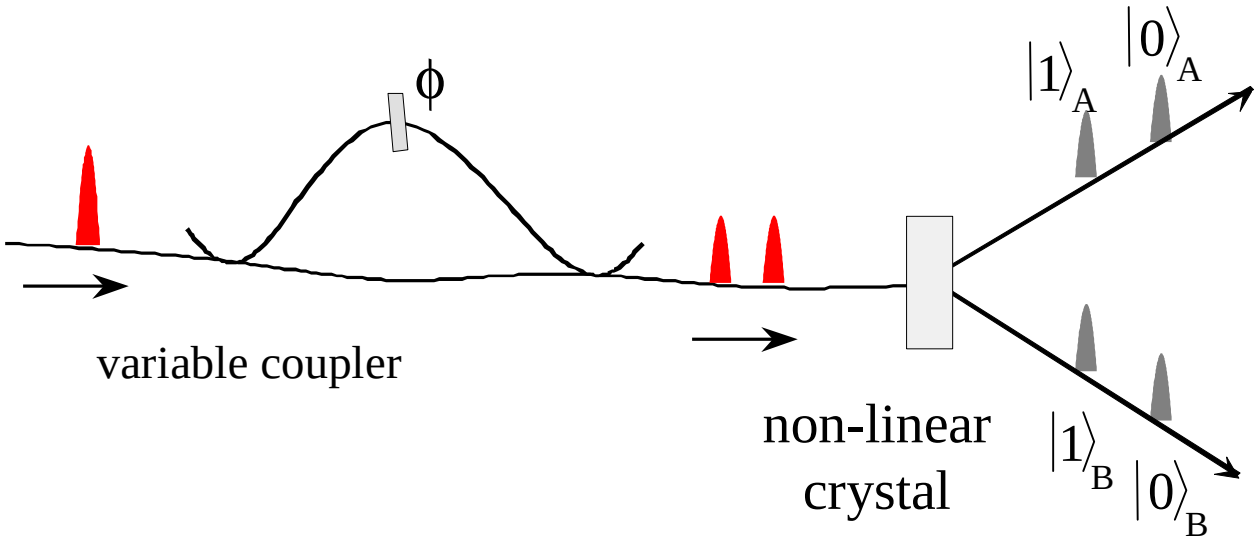
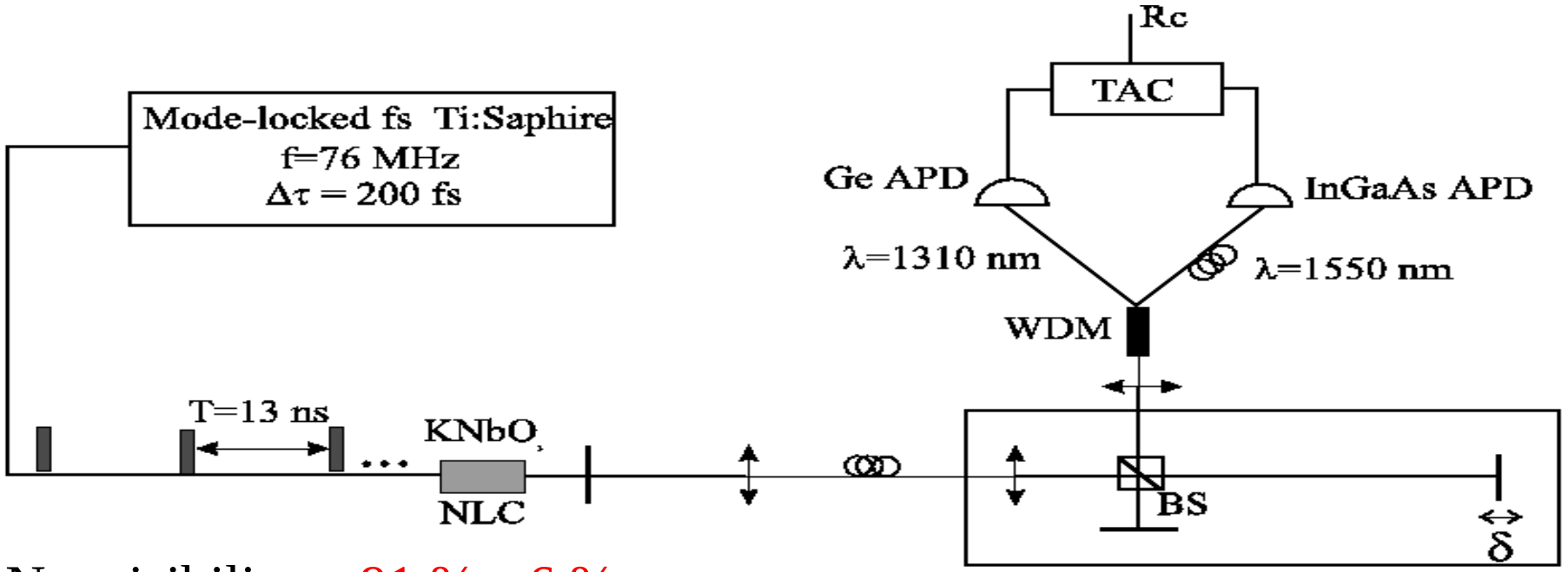
entangled time-bin qubits



$$|\psi\rangle = c_0|0\rangle_A|0\rangle_B + c_1 e^{i\phi}|1\rangle_A|1\rangle_B$$

- depending on coupling ratio and phase ϕ, *maximally and non-maximally entangled states* can be created

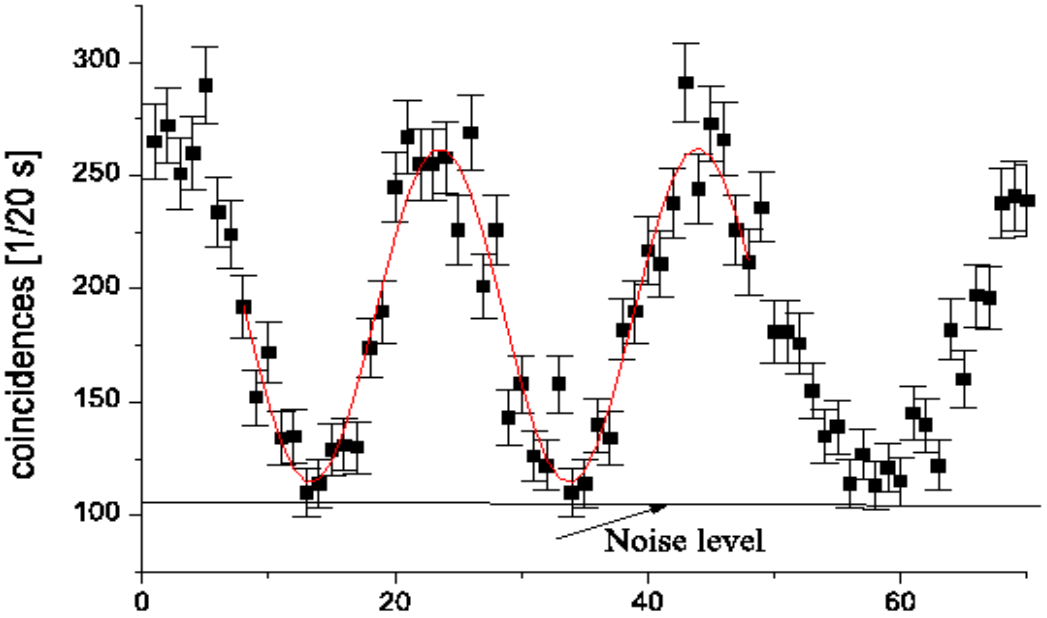
Arbitrary high dimensions



Net visibility = 91 % ±6 %

Entanglement for a two-photon state of dimension at least :

$$D \geq \frac{1}{1-V} = 11$$



Quant-ph/0204165; QIC 2002

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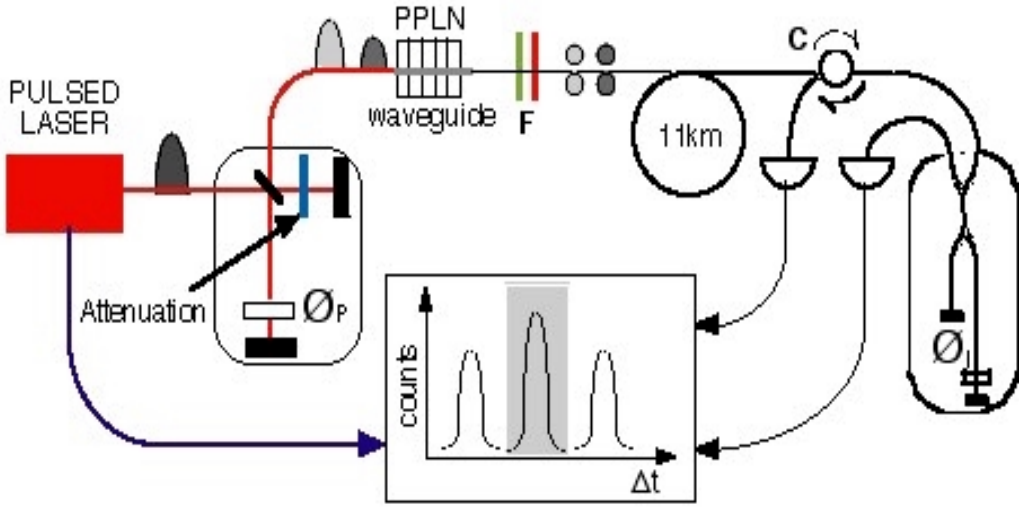
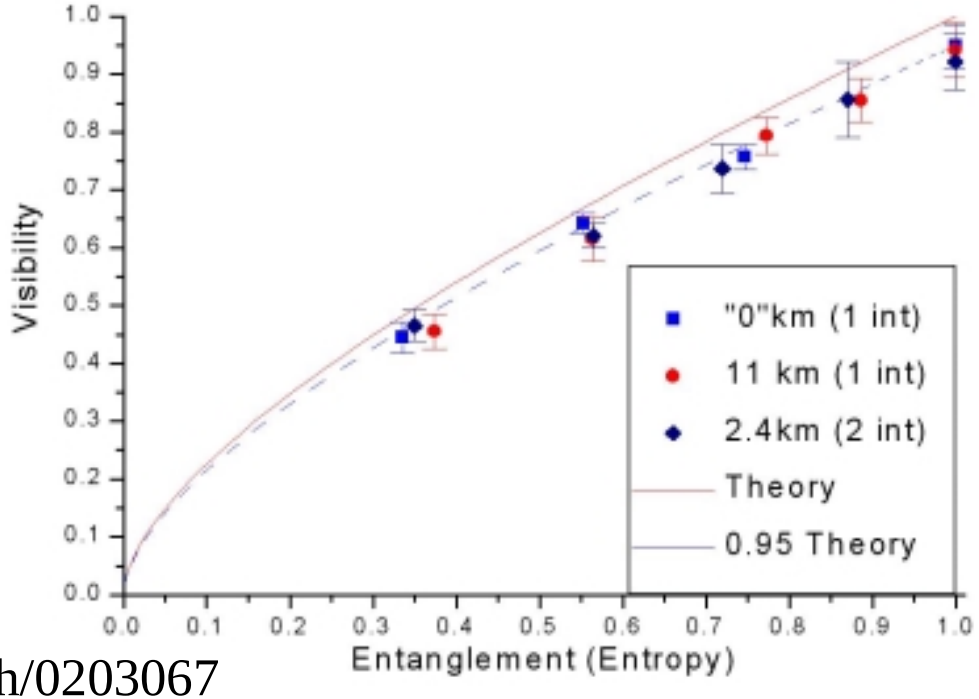
Partially Entangled Time-Bin Qubits



$$|\psi\rangle = c_0|00\rangle + c_1 e^{i\phi_p}|11\rangle$$

$$V = 2c_0c_1$$

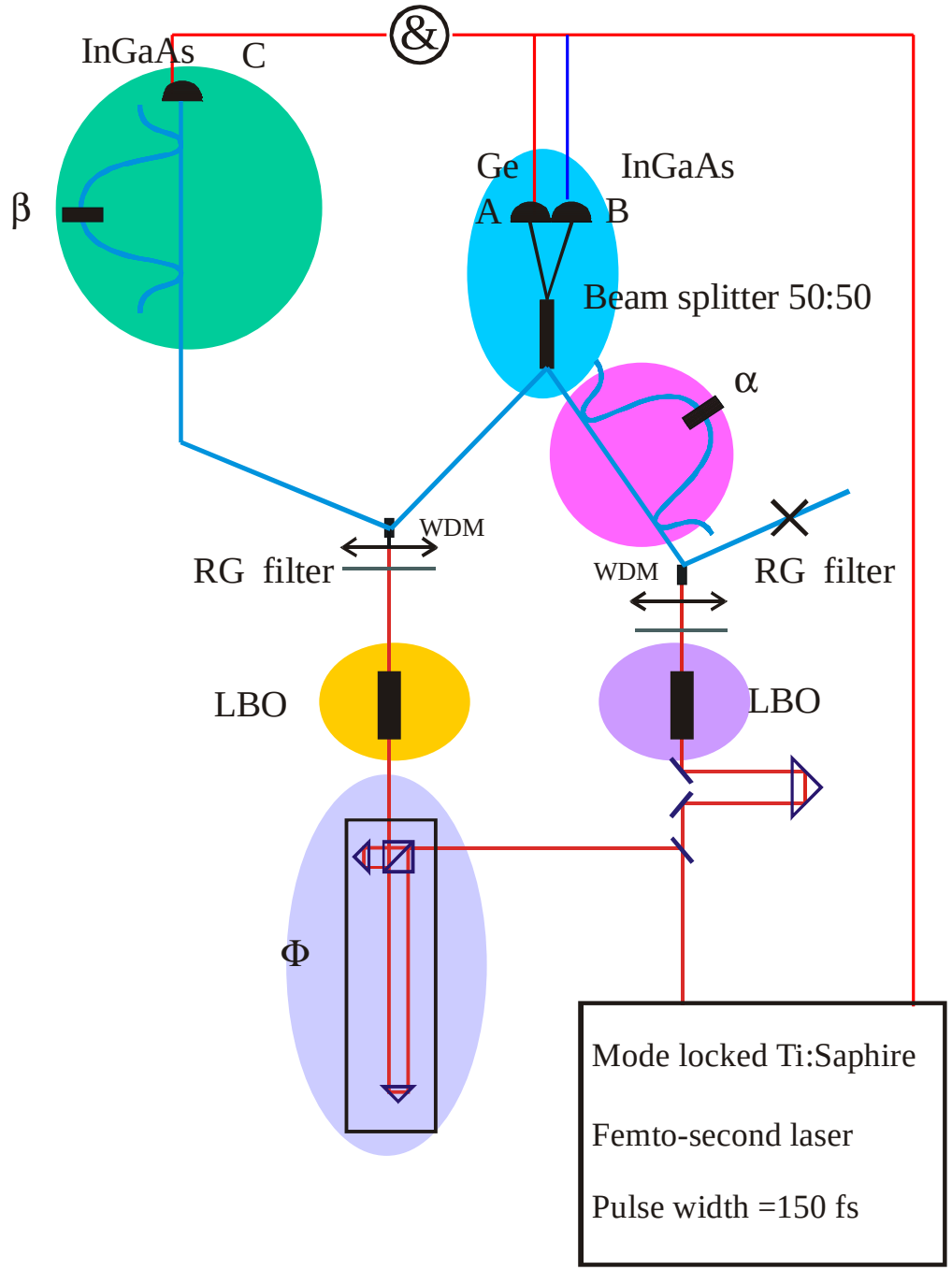
$$E = -c_0^2 \log_2 c_0^2 - c_1^2 \log_2 c_1^2$$



R.T.Thew *et al.* quant-ph/0203067

teleportation setup

I. Marcikic et al., quant-ph/0205144



Creation of a qubit

Creation of an entangled pair

Creation of a photon

Creation of any qubit to be teleported

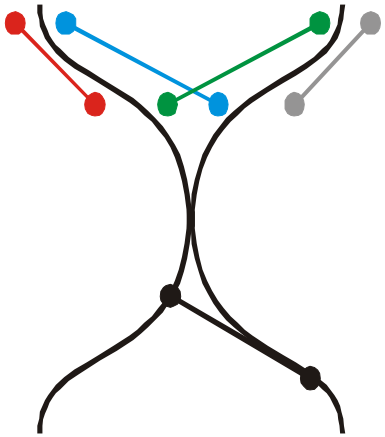
The Bell measurement

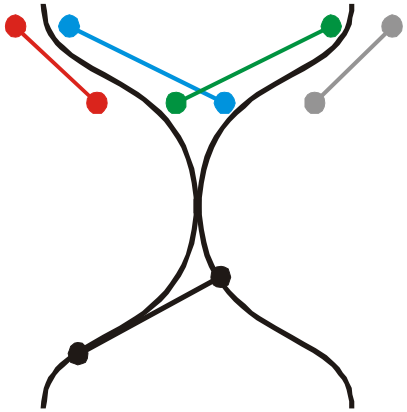
Analysis of the teleported qubit

Coincidence electronics

4-fold

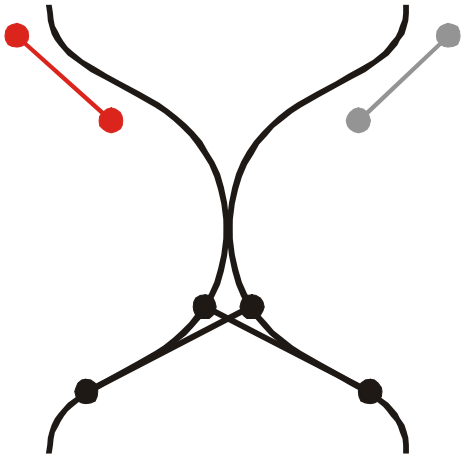
Bell measurement

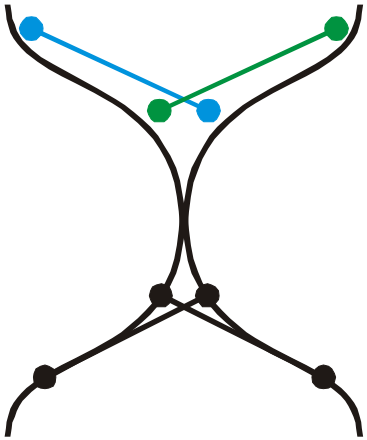




$$|\rangle|\rangle \qquad |\rangle_A|\rangle_A \quad |\rangle_B|\rangle_B \quad |\rangle_A|\rangle_B \quad |\rangle_A|\rangle_B$$

$$|1\rangle_1|0\rangle_2 \mapsto i|0\rangle_A|1\rangle_A + i|0\rangle_B|1\rangle_B - |0\rangle_A|1\rangle_B - |1\rangle_A|0\rangle_B$$





$$|0\rangle_1|1\rangle_2 + |1\rangle_1|0\rangle_2 \mapsto i\left(|0\rangle_A|1\rangle_A + |0\rangle_B|1\rangle_B\right)$$

$$|0\rangle_1|1\rangle_2 - |1\rangle_1|0\rangle_2 \mapsto |0\rangle_A|1\rangle_B - |1\rangle_A|0\rangle_B$$

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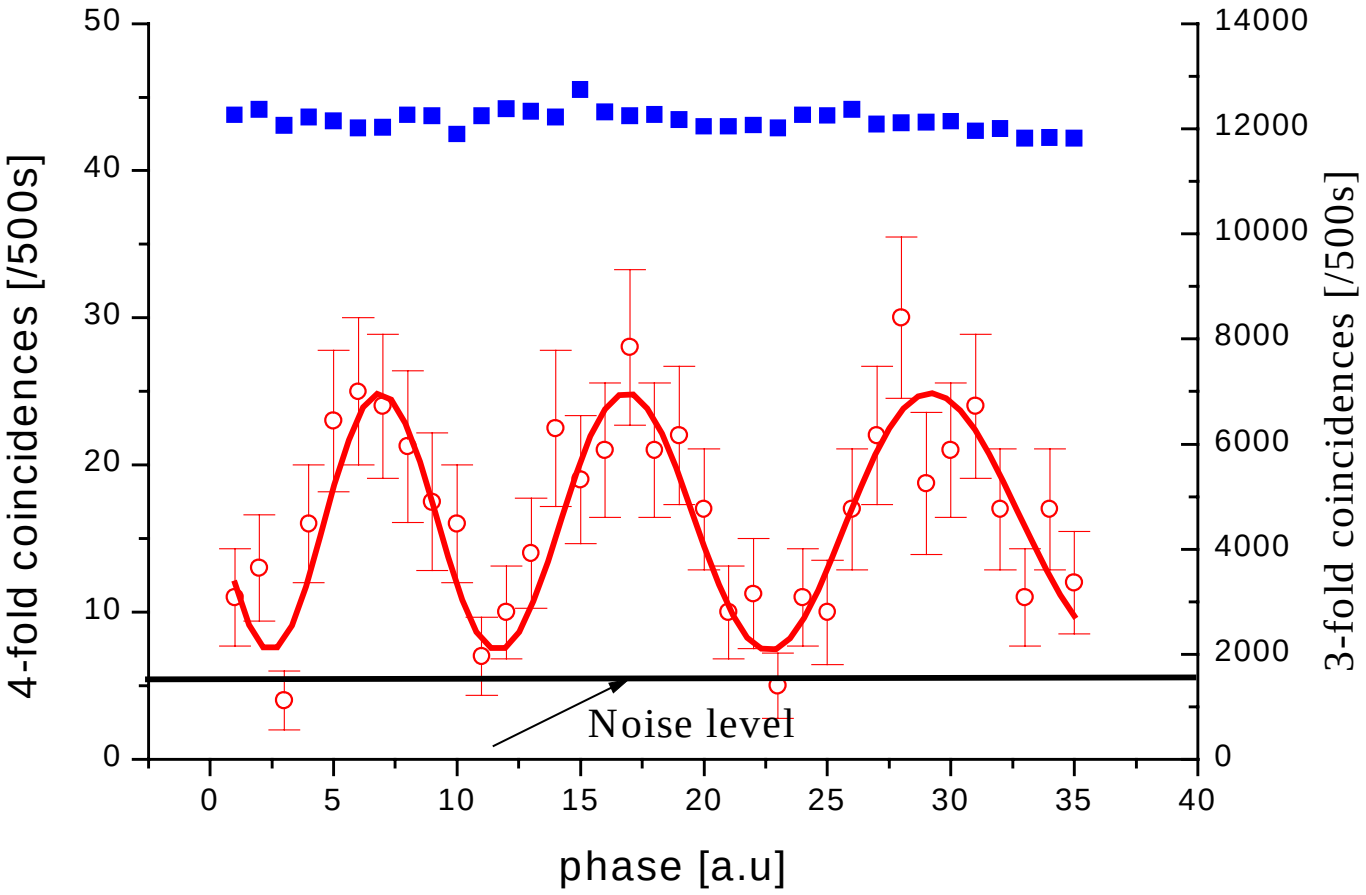
Teleportation of a time-bin qubit
equatorial states



- 2 photons +laser clock (1310&1550nm)
- 3 photons+laser clock

Raw visibility :

V_{raw}=56 ± 5 %

Net visibility :

V_{net}=83 %±8%

Fidelity for equatorial states : $F_{eq} = \frac{1+V_{raw}}{2}$ =78 ± 3 %

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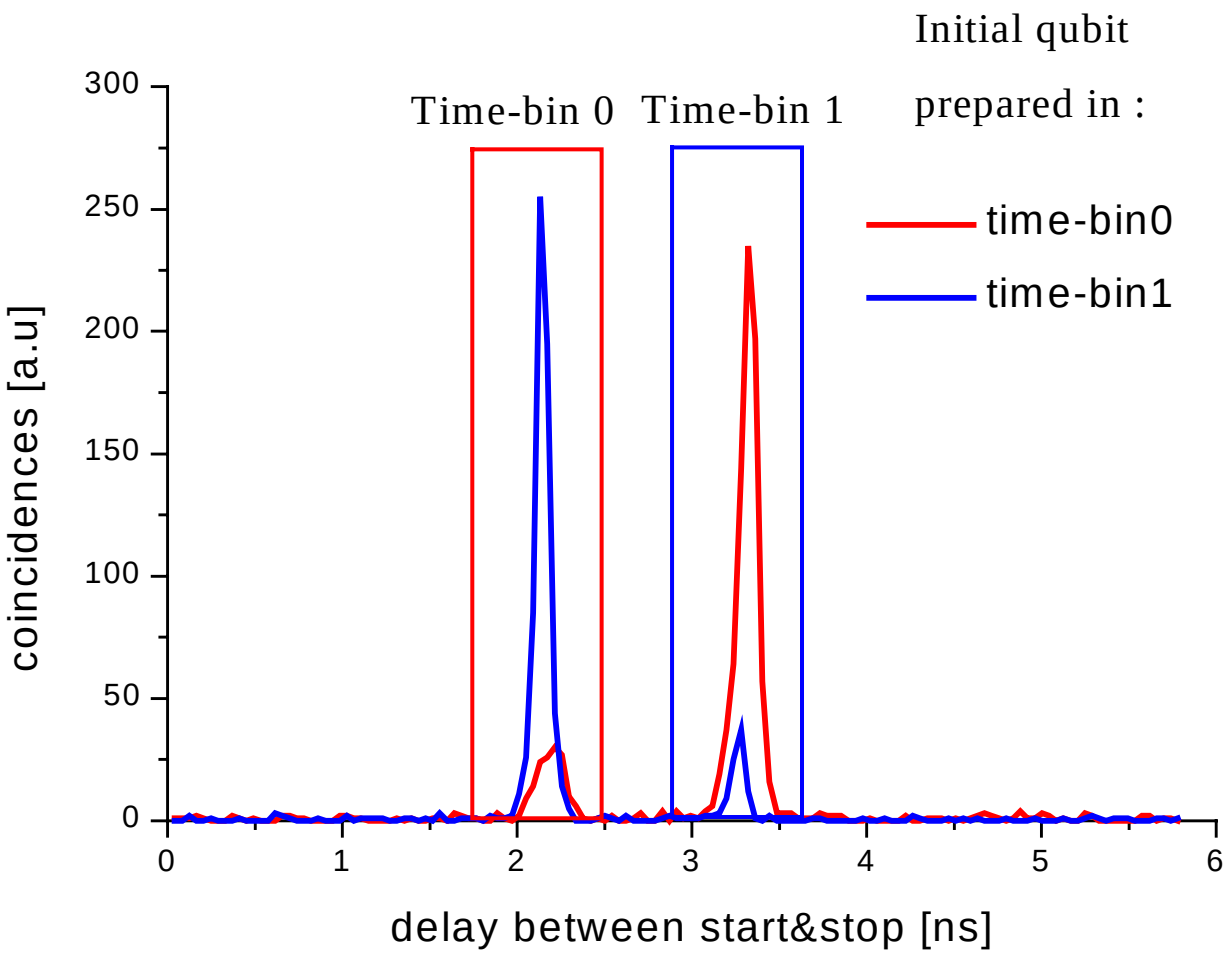
Teleportation of a time-bin qubit

North&South poles



$$F(|0.1\rangle) = \frac{P(|1,0\rangle)}{P(|1,0\rangle) + P(|0,1\rangle)}$$

$$F(|0,1\rangle) = 88\% \pm 4\%$$

$$F(|1,0\rangle) = 84\% \pm 4\%$$

$$F_{tot} = \frac{2}{3}F_{eq} + \frac{1}{3}F_{p} = 80.5\ \% \pm 3\ \%$$

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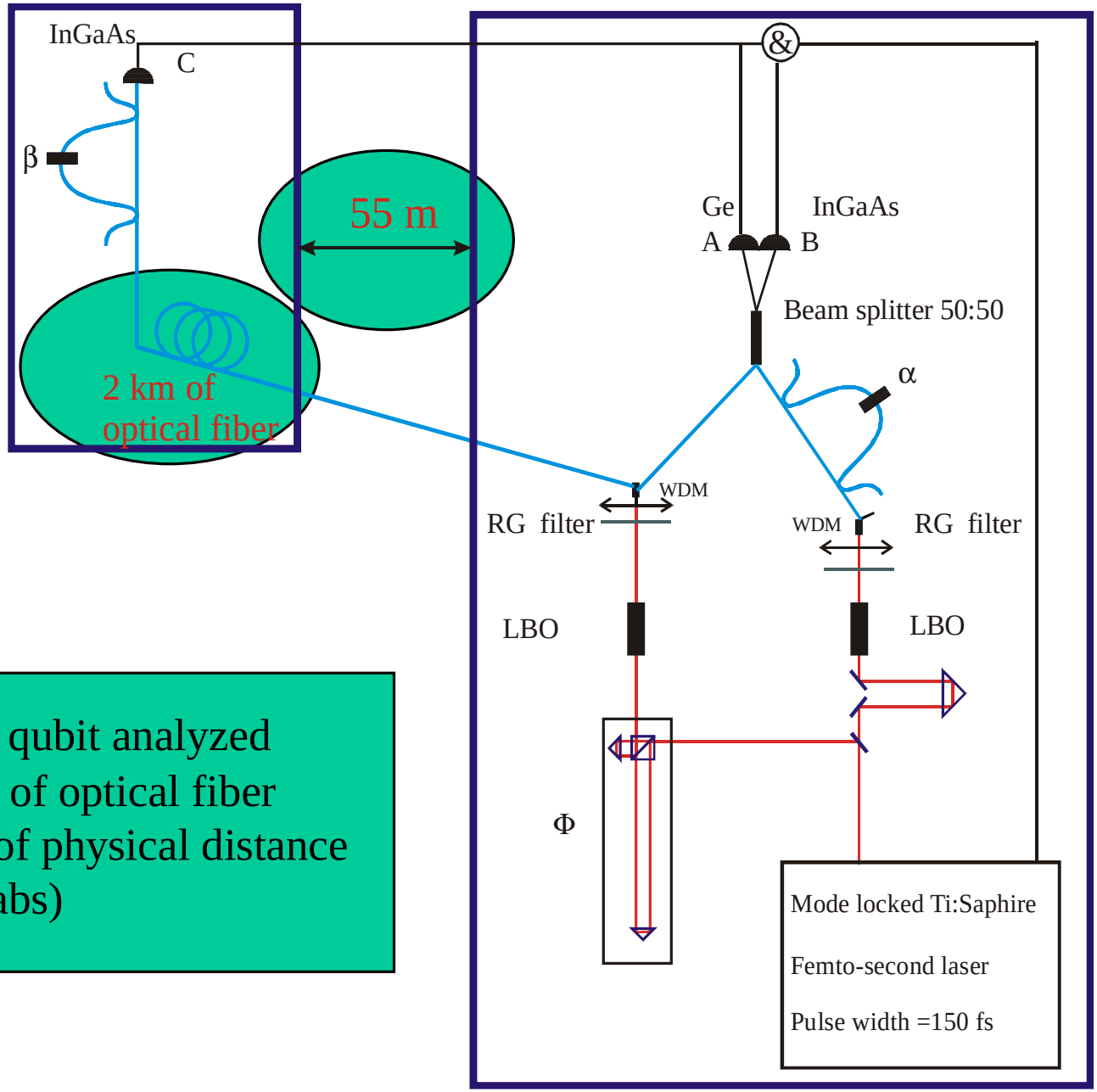
Long distance quantum teleportation



- Teleported qubit analyzed after 2 km of optical fiber and 55 m of physical distance (separate labs)

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Results for long distance teleportation

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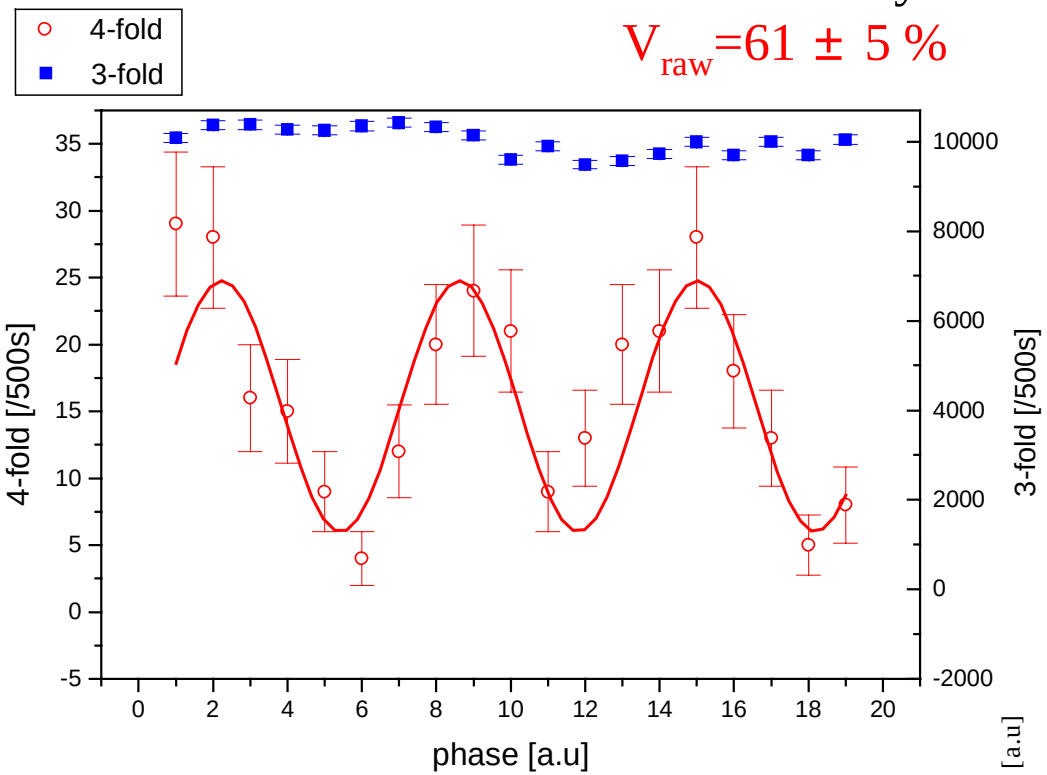
Equatorial states



Raw visibility :

V_{raw}=61 ± 5 %

Fidelity for equatorial states :

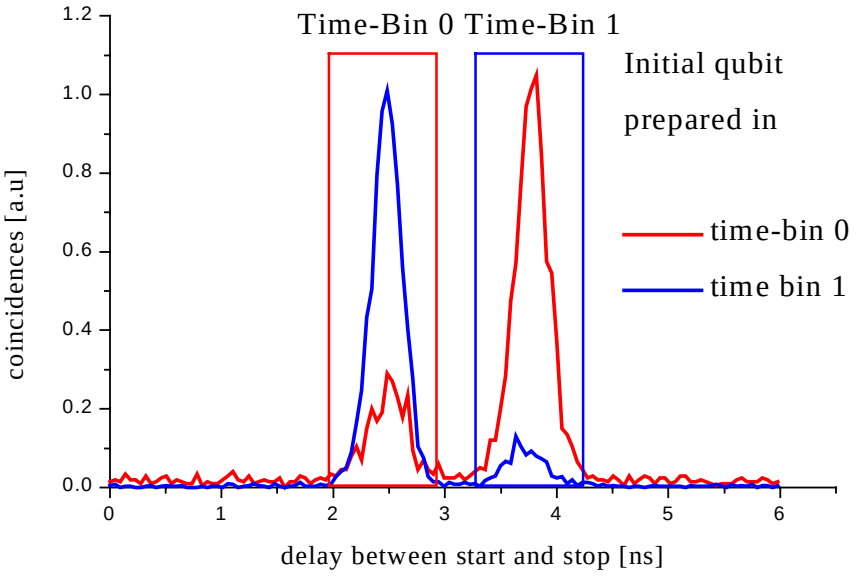
$$F_{eq} = \frac{1+V_{raw}}{2} = 80.5 \pm 2.5\ \%$$

Fidelity for north&south poles :

$$F(|0,1\rangle) = 88 \pm 3\%$$

$$F(|1,0\rangle) = 77 \pm 3\%$$

North & south poles



Fidelity for Q teleportation over 2km

$$F_{tot} = \frac{2}{3}F_{eq} + \frac{1}{3}F_{p} = 81.2\ \% \pm 2.5\ \%$$

Quantum teleportation as Q repeater (even without Q memory)

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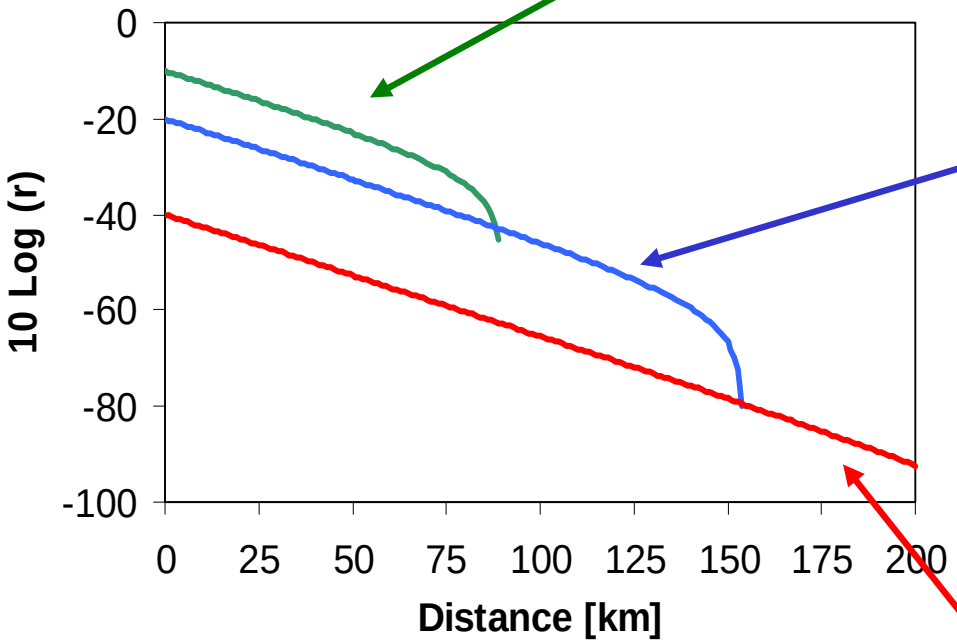
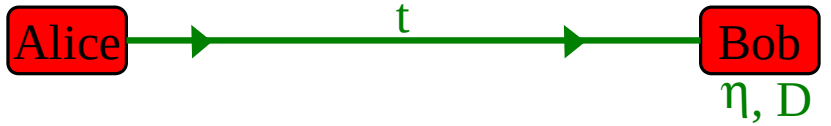
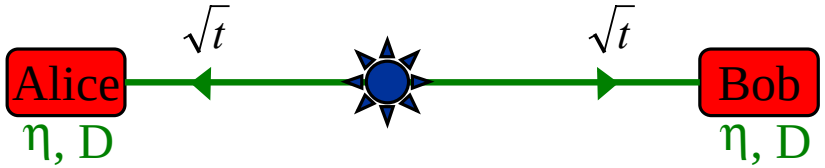
At telecom λ, the QBER is dominated by detector noise:





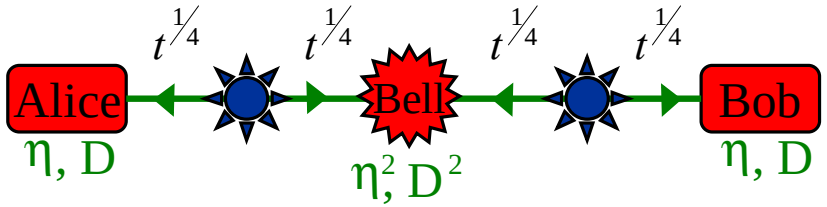
$$C = t \cdot \eta \qquad Q = D \cdot (1 - t \cdot \eta)$$



$$C = t \cdot \eta^2$$

$$Q = \left(1-\sqrt{t}\eta\right)^2 D^2 + 2\sqrt{t}\eta\left(1-\sqrt{t}\eta\right)\cdot D$$

$$= \left(\sqrt{t}\eta + \left(1-\sqrt{t}\eta\right)D\right)^2 - t\eta^2$$



$$C = t \cdot \eta^4$$

$$Q = \left(t^{1/4}\eta + \left(1-t^{1/4}\eta\right)D\right)^4 - t\eta^4$$

η = 0.1 det. efficiency;

D = 10^{-4} dark count;

α = 0.25 dB/km attenuation

N. Gisin et al., Rev.Mod.Phys. 74, 145-195, 2002

Conclusion

- **qubits and entangled qubits can be realized using time-bins.**
- **entangled qudits in arbitrary high dimension d can be realized.**
- **partially entangled qubits are robust over 11 km.**
- **Q teleportation**

  with:

  - *telecom wavelength*
  - *two different crystals (spatially separated sources)*
  - *from one wavelength (1300 nm) to another (1550 nm)*
  - *first time with time-bins (ie insensitive to polarization fluctuations)*
  - *over 2 km of fiber and 55 meters of physical distance*
  - *mean fidelity : ≈81% both in the lab and at a distance*

= the possibility to teleport the "ultimate structure" of an object from one place to another, without the object ever being anywhere in between