



QUANTUM OPTICS GROUP

Dipartimento di Fisica, Sapienza Università di Roma

Quantum Interferometry

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Incontro CNISM

Roma 13/06/2012

CNISM



consorzio nazionale interuniversitario per le scienze fisiche della materia



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**Quantum
Mechanics**

**QUANTUM
INFORMATION**

**Computer
Science**

**Information
Theory**

Cryptography

QUBIT

$$\alpha |0\rangle + \beta |1\rangle$$

$$\alpha, \beta \in \mathbb{C} \quad e \quad |\alpha|^2 + |\beta|^2 = 1$$



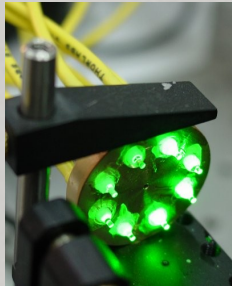
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PHOTONIC QUBIT

- **Polarization:** $\alpha|H\rangle + \beta|V\rangle$

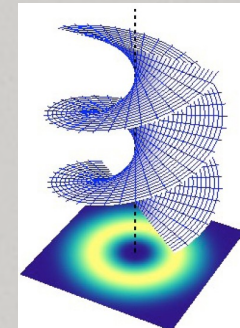
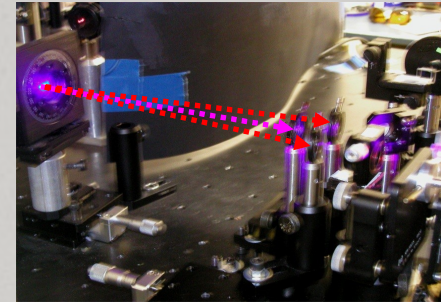
- **Spatial mode:**



- ☆ Generation of particular families of high-dimensional multi-qubit quantum states
- ☆ Increment the power of many quantum information protocols by increasing quantum correlations between many optical paths

- **Orbital angular momentum:**

orbital angular momentum (OAM) of light, associated to the transverse amplitude profile allows the implementation of a higher-dimensional quantum space, or a "qudit", encoded in a single photon.





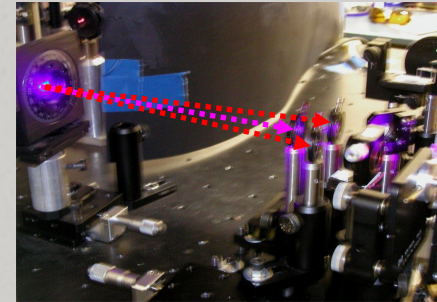
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PHOTONIC QUBIT

- Polarization: $\alpha|H\rangle + \beta|V\rangle$

- Spatial mode:



[1] A.Rossi, G.Vallone, A.Chiuri, F.De Martini, and P.Mataloni, Phys. Rev. Lett. **102**, 153902 (2009).

[2] A.Chiuri, G.Vallone, N.Bruno, C.Macchiavello, D.Bruß, and P.Mataloni, Phys. Rev. Lett. **105**, 250501 (2010).

[3] A.Chiuri, G.Vallone, M. Paternostro, and P.Mataloni, Phys. Rev. A **84**, 020304(R) (2011).

[4] A.Chiuri, V.Rosati, G.Vallone, S.Pádua, H.Imai, S.Giacomini, C.Macchiavello, and P.Mataloni, Phys. Rev. Lett. **107**, 253602 (2011)

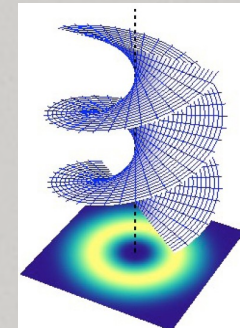
- Orbital angular momentum:

[1] E.Nagali, F.Sciarrino, L.Marrucci, B.Piccirillo, E.Karimi, E.Santamato, Phys. Rev. Lett. **103**, 013601 (2009).

[2] E.Nagali, L.Sansoni, F.Sciarrino, L.Marrucci, B.Piccirillo, E.Karimi, E.Santamato, Nature Photonics **3**, 720 (2009).

[3] E.Nagali, D.Giovannini, L.Marrucci, S.Slussarenko, F.Sciarrino, Phys. Rev. Lett. **105**, 073602 (2010).

[4] A. Cabello, V.D'Ambrosio, E.Nagali, F.Sciarrino, Phys. Rev. A **84**, 030302 (2011).

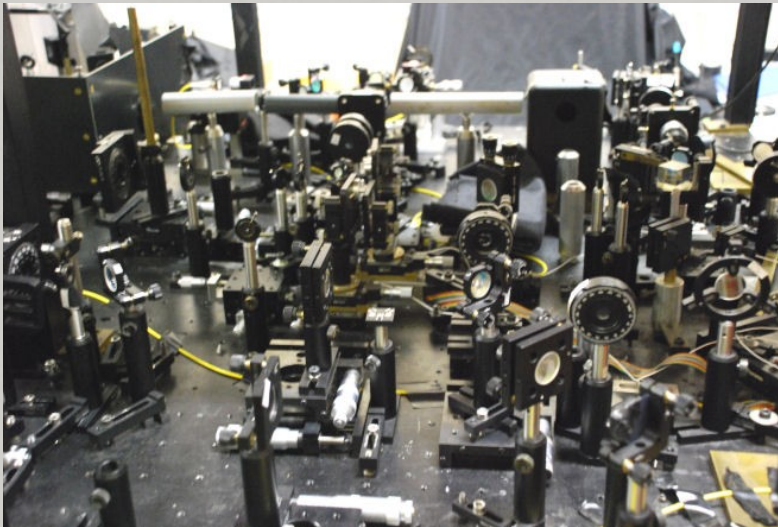




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Main limitations to experimental photonic quantum informations



Huge setups

Unavoidable interaction between quantum system and environment

- LOSSES
- DECOHERENCE

Possible solutions:

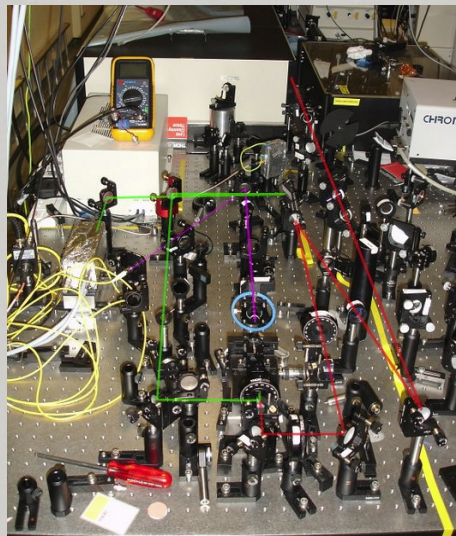
- Go integrated
- Overcome losses by coherent amplification



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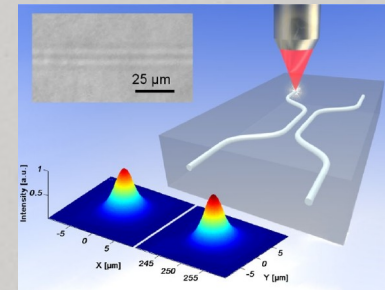
Bulk optics



Stability
Precision
Physical size



Integrated systems by ultrafast laser writing technique



Support and manipulate
polarization encoded qubit !!

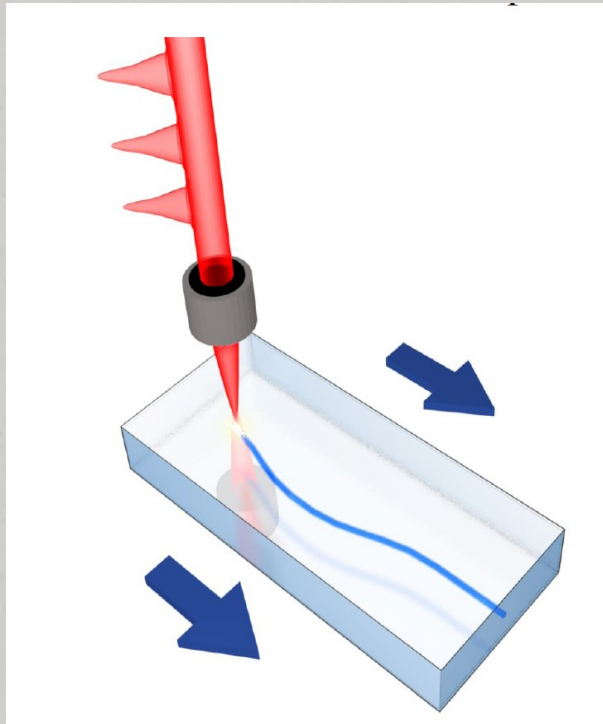
[1] L. SANSONI, F. SCIARRINO, G. VALLONE, P. MATALONI, A. CRESPI, R. RAMPONI, R. OSELLAME, Phys. Rev. Lett. 105, 200503 (2010).

[2] A. CRESPI, R. RAMPONI, R. OSELLAME, L. SANSONI, I. BONGIOANNI, F. SCIARRINO, G. VALLONE, P. MATALONI, Nat. Commun. 2:566 (2011), doi:10.1038/ncomms1570.

[3] L. SANSONI, F. SCIARRINO, G. VALLONE, P. MATALONI, A. CRESPI, R. RAMPONI, R. OSELLAME, Phys. Rev. Lett. 108, 010502 (2010).



Laser writing technique for devices able to transmit polarization qubits



- ☆ Femtosecond pulse tightly focused in a glass
- ☆ Combination of multiphoton absorption and avalanche ionization induces *permanent and localized refractive index increase* in transparent materials
- ☆ Waveguides are fabricated in the bulk of the substrate by translation of the sample at constant velocity with respect to the laser beam, along the desired path.



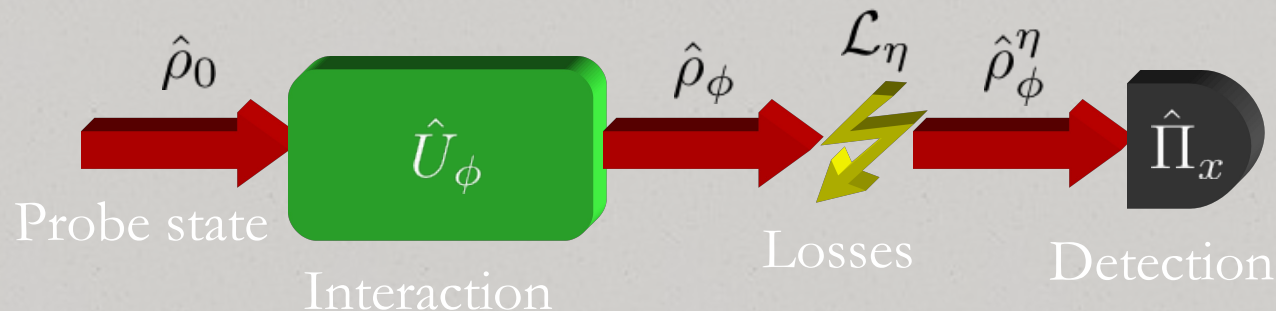
L. Sansoni, *et al.*, *Phys. Rev. Lett.* **108**, 010502 (2012).



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Quantum interferometry in lossy conditions

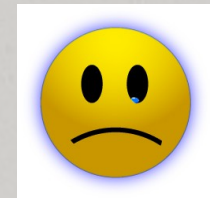


CAN WE PROTECT THE PROBE STATE FROM DETRIMENTAL EFFECTS OF LOSSES?



Easy solution: Increase the size of the probe state !!

NOT FEASIBLE IN A MINIMALLY INVASIVE PHASE ESTIMATION SCENARIO



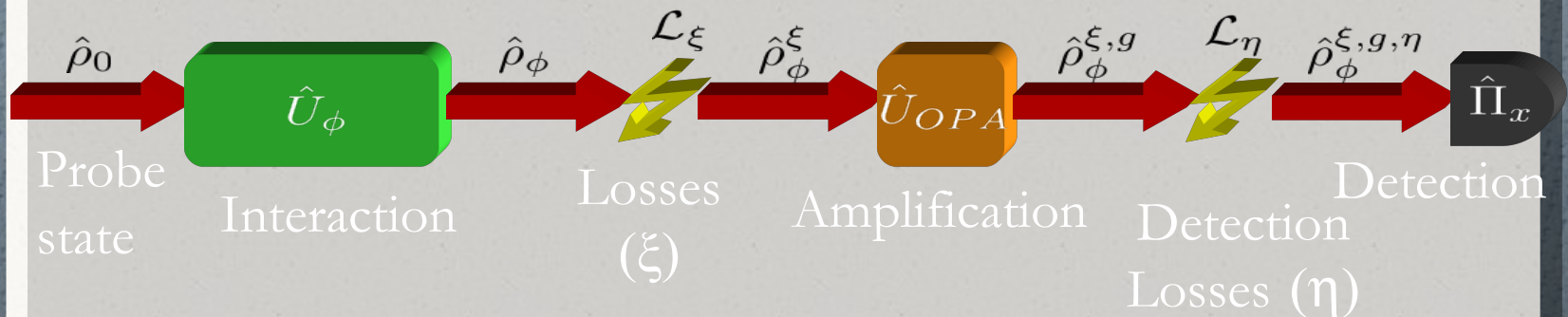


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Quantum interferometry in lossy conditions

CAN WE PROTECT THE PROBE STATE FROM DETRIMENTAL EFFECTS OF LOSSES?



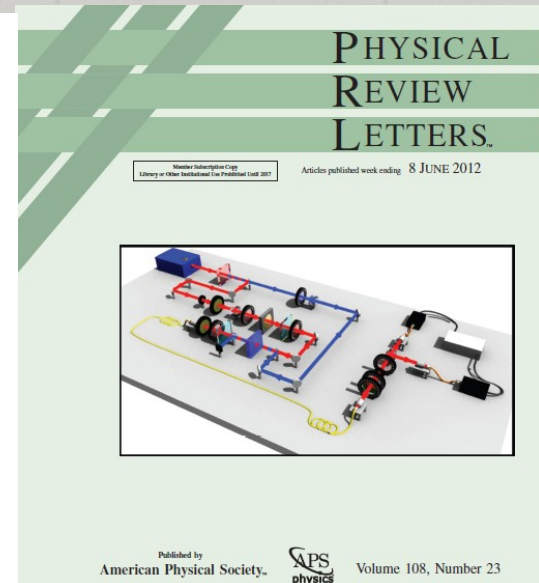
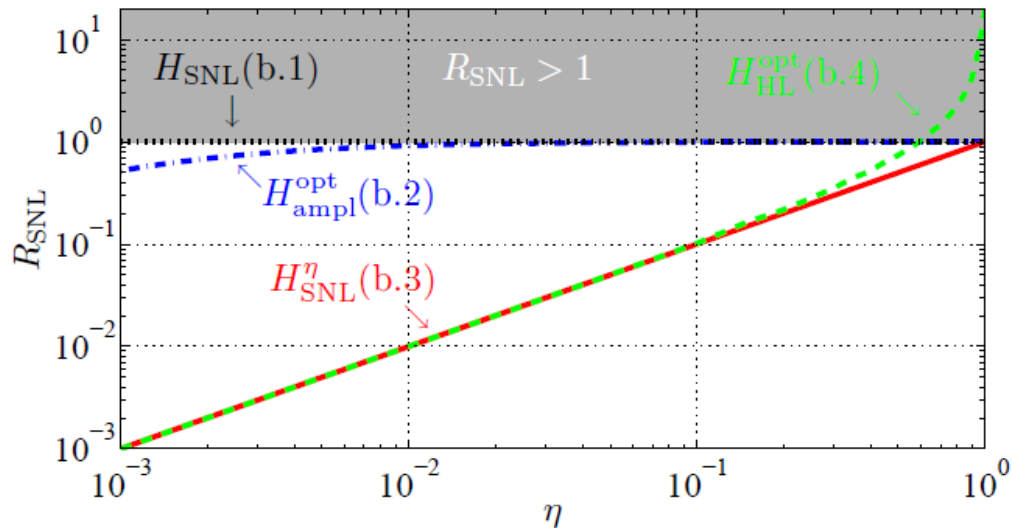
- ★ Preserves the minimally invasive character of the interaction
- ★ Protects the probe state from losses





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Quantum Fisher Information H represents the maximum amount of information which can be extracted from the probe state by optimizing over all the possible measurement strategies.

N. Spagnolo, C. Vitelli, V.G. Lucivero, V. Giovannetti, L. Maccone, F. Sciarrino, *Phys. Rev. Lett.* 108, 233602 (2012)

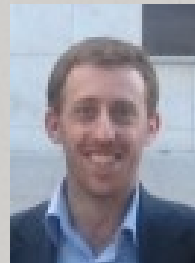


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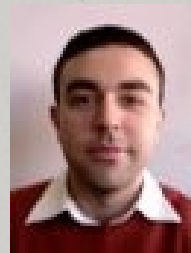
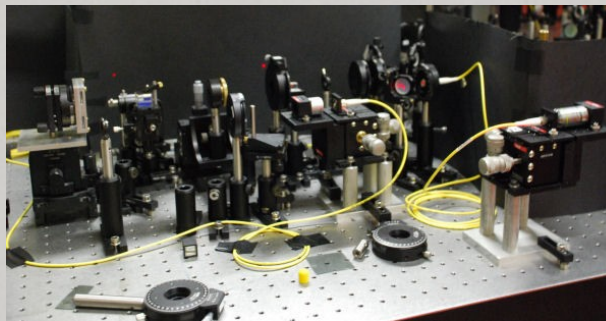
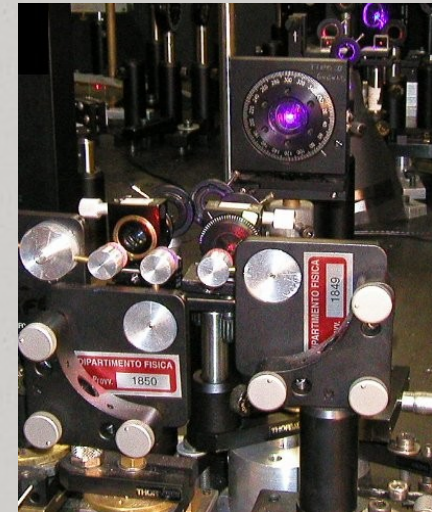
G21



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**Linda
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**Vincenzo
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