Novel entangled telecom wavelength multi-photon source for quantum chemistry simulation

V. Saggio[1,*], C. Greganti, M. Radonjic, L. Rozema, I. Alonso Calafell, and P. Walther

[1] *University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria*

* valeria.saggio@univie.ac.at

Introduction

Telecom multi-photon source

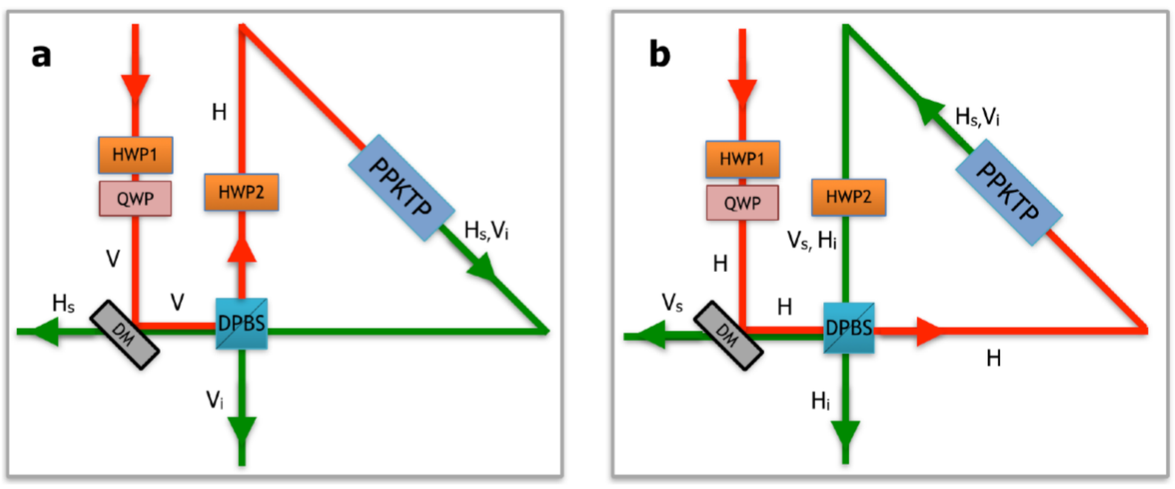
- Photons at telecom wavelength provide the lowest losses in silica optics — around 0.2 dB/Km compared to the 3 dB/Km for the standardly used wavelength of 800 nm;
- To generate an entangled photon pair, the process of *spontaneous parametric down conversion* (SPDC) from a *periodically poled KTiOPO$_4$* (PPKTP) crystal placed into a *Sagnac interferometer* is exploited. With such a scheme it is possible to obtain a source with features of compactness, high brightness and stability;
- The multi-photon source is composed of several photon-pair sources.

Quantum simulators

- Quantum simulators are quantum systems able to mimic other quantum systems, thus being able to tackle problems unfeasible for classical computers, whose exponential slowdown with the size of the system prevents from classically reproducing it;
- Among the possible ways of implementing quantum simulators, one is based on single photon processing;
- By exploiting quantum interference among single photons impinging on beamsplitters it is possible to achieve quantum entanglement which corresponds to ground states of complex correlations in chemical or solid-state systems.

Experiment

Sagnac multi-photon source



HWP: halfwave plate; **QWP**: quarterwave plate; **DM**: dichroic mirror; **DPBS**: dual polarizing beam splitter; **PPKTP**: non-linear crystal.

Vertically polarized light enters the Sagnac loop. Thanks to HWP2, horizontally polarized light impinges on the PPKTP. Due to type-II SPDC, two photons — the horizontally polarized *signal* (s) and the vertically polarized *idler* (i) — are created. The DPBS sends them to two different outputs.

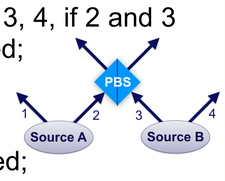
Horizontally polarized light enters the Sagnac loop. Due to type-II SPDC, two photons — the horizontally polarized *signal* (s) and the vertically polarized *idler* (i) — are created. Thanks to HWP2, the polarizations of the two photons are switched. The DPBS sends them to two different outputs.

With 45 degree polarized input light, it is impossible to tell whether the signal and the idler at one DPBS output are horizontally or vertically polarized!

Entanglement is created: $|\psi^-_{s,i}\rangle = \dfrac{|H_s V_i\rangle - |V_s H_i\rangle}{\sqrt{2}}$

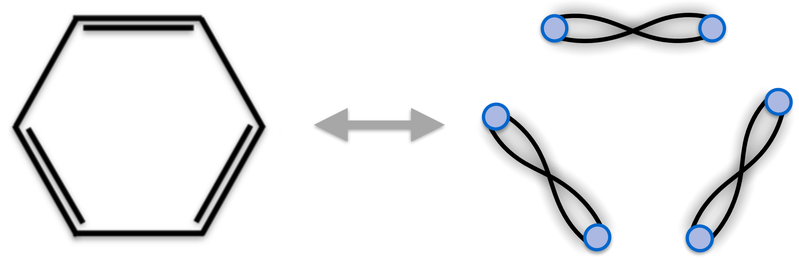
T. Kim *et al.*, Phys. Rev. A **73**, 012316 (2006)

- Given two photon-pair sources, one generating the entangled pair 1, 2 and the other one 3, 4, if 2 and 3 are sent to two adjacent ports of a beam splitter, one ends up with 2 and 3 being entangled;
- As a consequence, 1 and 4 will also get entangled, even though they never interacted;
- With a series of beam splitters, all the photons from the different sources can get entangled;
- In the experiment, three Sagnac photon-pair sources have been built, so that **six photons** can be processed.



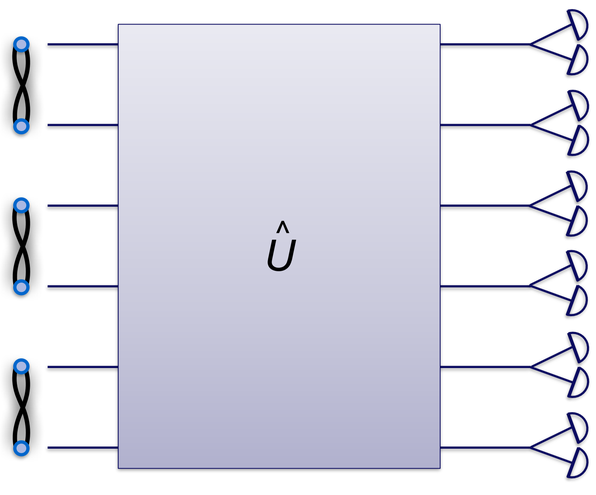
Benzene simulation

Electronic spins are mapped to polarization entangled photon pairs:



Given the spin pairing functions for the ground state of benzene in the Rumer basis,

the approximate ground state of benzene in the *spin-coupled valence bond* (SCVB) approach is: $|\psi_{gs}\rangle = \alpha\big(\bigcirc + \bigcirc\big) + \beta\big(\bigcirc + \bigcirc + \bigcirc\big)$



Simulation of benzene ground state is possible by sending the three entangled photon pairs into a linear optical circuit, where *tunable directional couplers* (TDCs) — optical fiber devices acting as beam splitters with a tunable splitting ratio — are installed.

It is possible to simulate the ground state of benzene as well as arbitrary real combinations of Rumer basis states by simply tuning the TDC parameters. The tuning enables the change of the α and β coefficient values, so that new combinations of the spin pairing functions can be achieved.

X.-s Ma *et al.*, Nat. Phys. **7**, 399-405 (2011)

Summary and outlook

- Entanglement between six photons coming from a novel multi-photon source at telecom wavelength is exploited to simulate the ground state of the benzene molecule;
- Next directions will provide for a larger number of photons by building for instance a fourth Sagnac photon pair source. There is reason to believe that the increase of the number of photon pairs will open up the possibility for the study of more complex molecules, which represents a striking step towards the study of more and more complex quantum systems.

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