INFN Istituto Nazionale di Fisica Nucleare Sezione di PAVIA

Does reduction of a particle wave function take a time?

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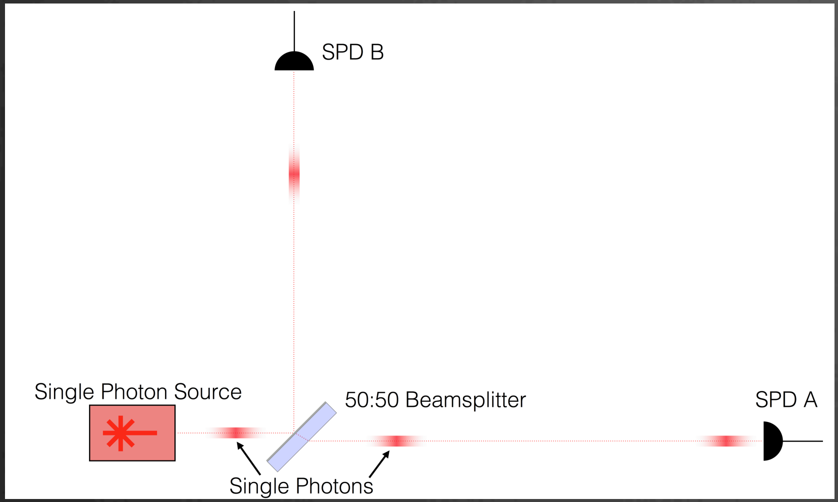
Conceptual scheme



No LASER pulses, single photon regime mandatory (LIDAR)

$$|\Psi> = 1/\sqrt{2}\,(|\gamma(A)> + |\gamma(B)>)\,|D_A(0)>\,|D_B(0)> \rightarrow$$

$|D_A(+)>\,|D_B(0)>$, p=1/2

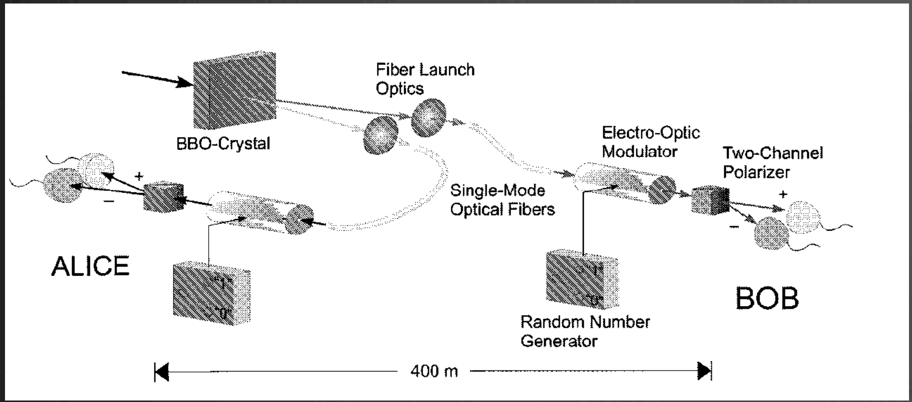
$|D_A(0)>\,|D_B(+)>$, p=1/2

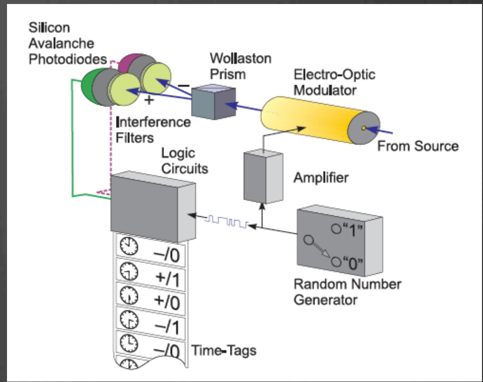
↑

Reduction postulate: "immediately" after the completion of the measurement the state of the system is one of the terms of the superposition.

The present proposal concerns an experiment able to establish whether the collapse of a <u>single particle</u> wave function requires a finite time to happen, especially when the wave function is made up of distant parts.

State of the art

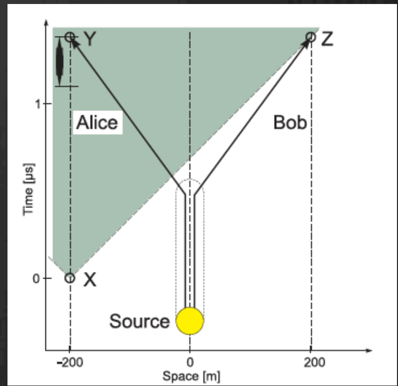




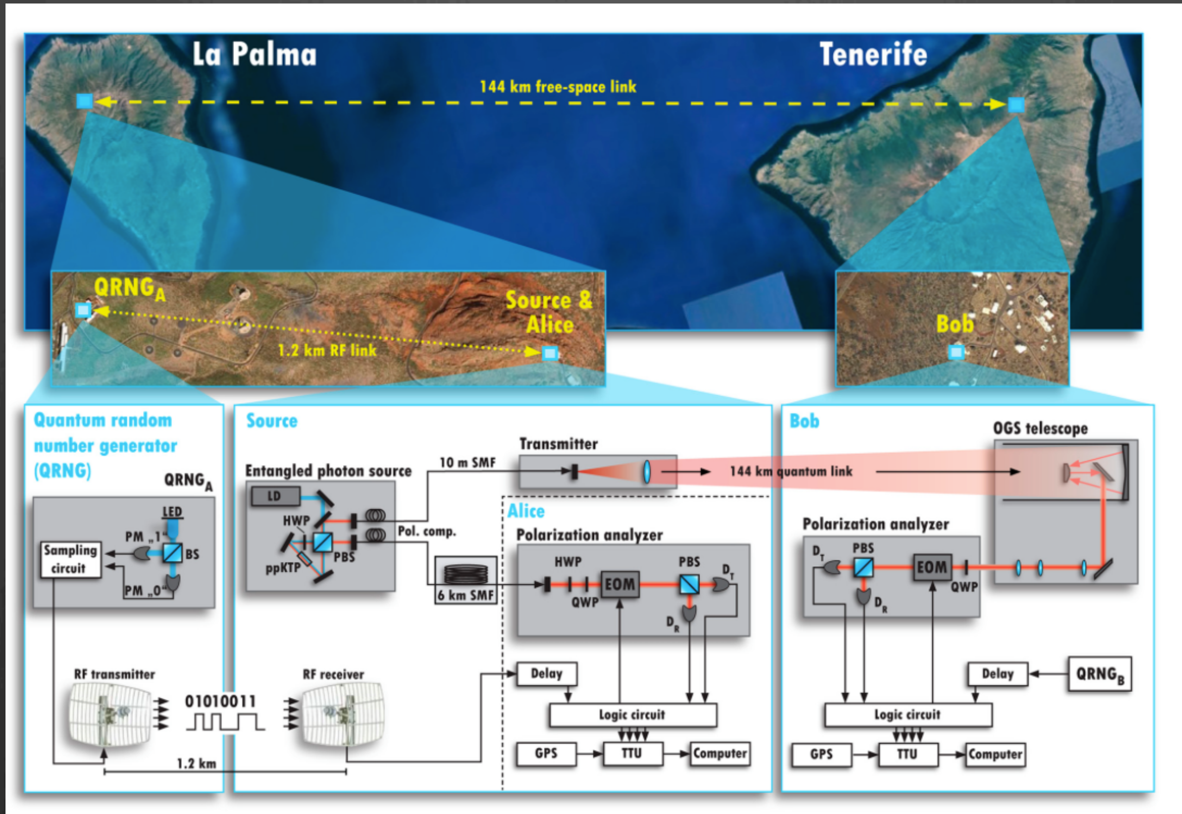
EPRB correlations (*spooky action at a distance*…) and Bell's inequality violations (CHSH) well explored;

- S.J. Freedman and J.S. Clauser,
Phys. Rev. Lett. **38**, 938, 1972;
- A. Aspect, P. Grangier and G. Roger,
Phys. Rev. Lett. **47**, 460, 1981;
Phys. Rev. Lett. **49**, 91, 1982;

G. Weihs, T. Jennewein, C. Simon, H. Weinfurter and A. Zeilinger
"Violation of Bell's inequality under strict Einstein locality conditions",
Phys. Rev. Lett. **81** (1998) 5039



State of the art (ii)



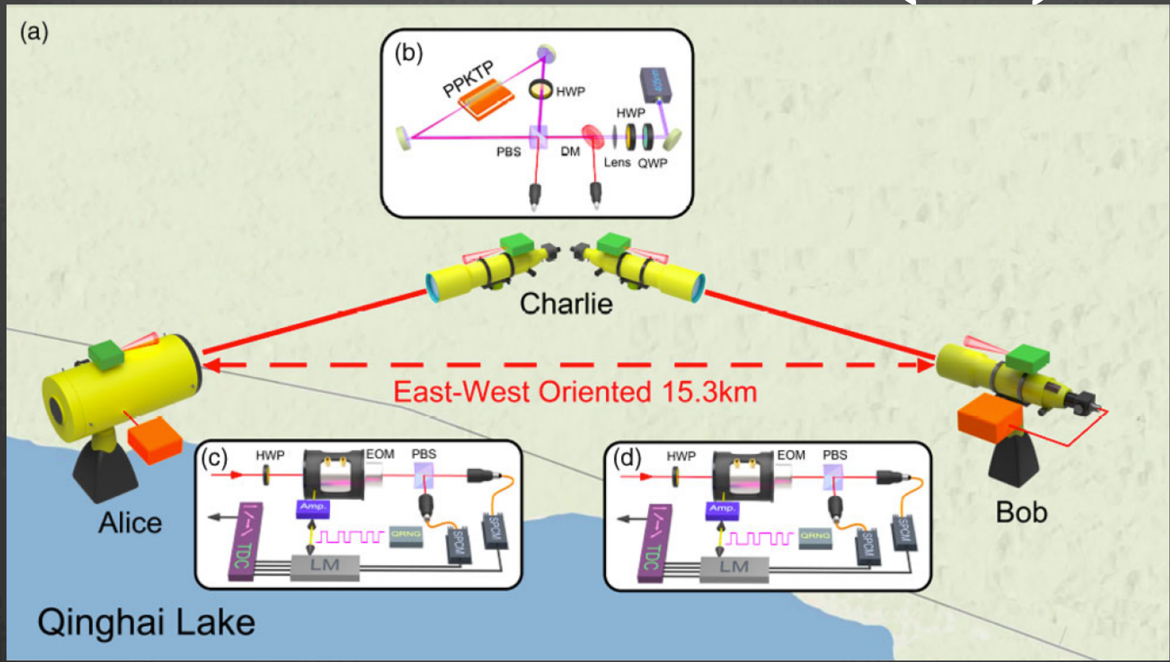
Also over geographic distances:
T. Scheidl,R. Ursin, J. Kofler, S. Ramelow, X.S. Ma, T. Herbst,
L. Ratschenbacher, A. Fedrizzi, N. Langford, T. Jennewein, A. Zeilinger
"Violation of local realism with freedom of choice",
Proc. Natl. Acad. Scie. U.S.A., 107:19708-19713, 2010.

State of the art (iii)

- So, Bell's inequality violations tested
  (fair sampling, locality loophole, freedom of choice…)

- One could still ask whether the *spooky action at a distance* propagates at a finite velocity c'
  (see for instance P. H. Eberhard, *Quantum Theory and Pictures of Reality*, Springer, Berlin, 1989, p. 169)

State of the art (iv)



$|\Psi\rangle = 1/\sqrt{2}\,(|H\rangle_A|V\rangle_B - |V\rangle_A|H\rangle_B)$ at C sent via telescopes to A and B;
Detection events *spacelike* separated; common time reference *via* IR laser pulses;
Polarization analyzing units driven by a QRNG.

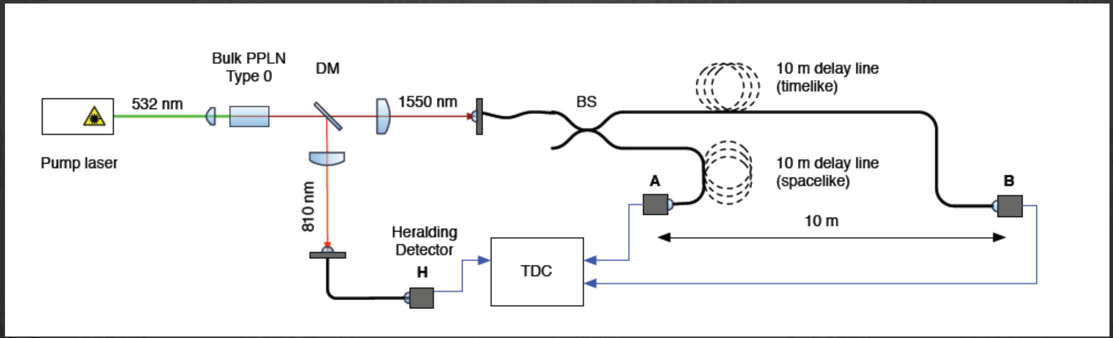
J. Yin, Y. Cao, H.L. Yong, J.G. Ren, H. Liang, S.K. Liao, F. Zhou, C. Liu, Y.P. Wu, G.S. Pan, L. Li, N.L. Liu, Q. Zhang, C.Z. Peng, J.W. Pan
"Lower bound on the speed of nonlocal correlations without locality and measurements choice loopholes",
Physical Review Letters ,110:260407, June 2013.

Careful timing analysis → $V_{SA}/c \geq 1.37 \times 10^4$

State of the art (iii)

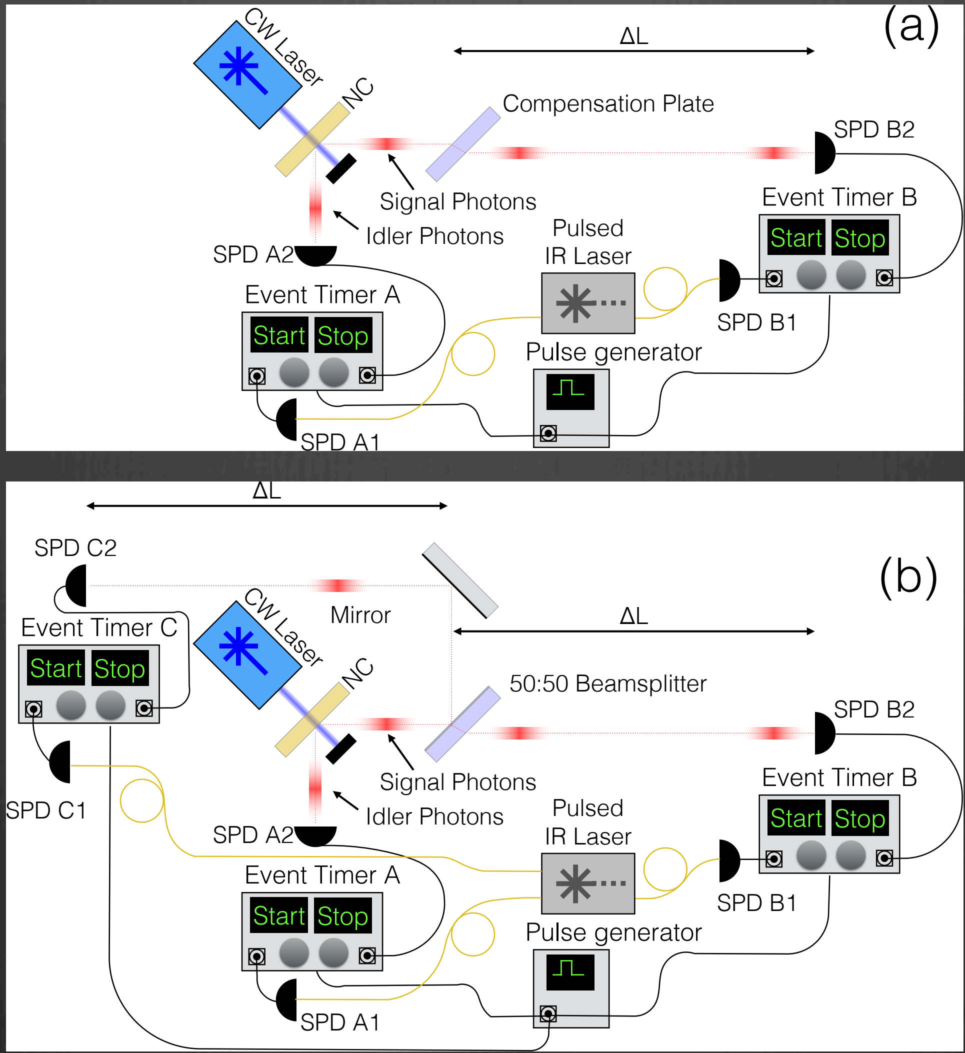
But…

- "Collapse" of a single particle wave function less studied;
- A. Einsten, Solvay Conference, 1927: a particle that, after diffraction from a slit, impinges on an array of detectors can activate only one of them (energy conservation) even in the case in which detection events are space-like separated(!);
- → *antibunching*
- The photon has to "materialize" at one detector or the other,

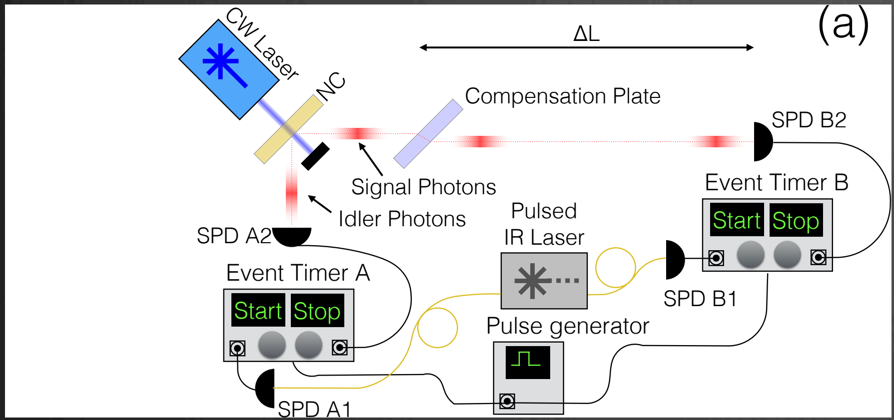


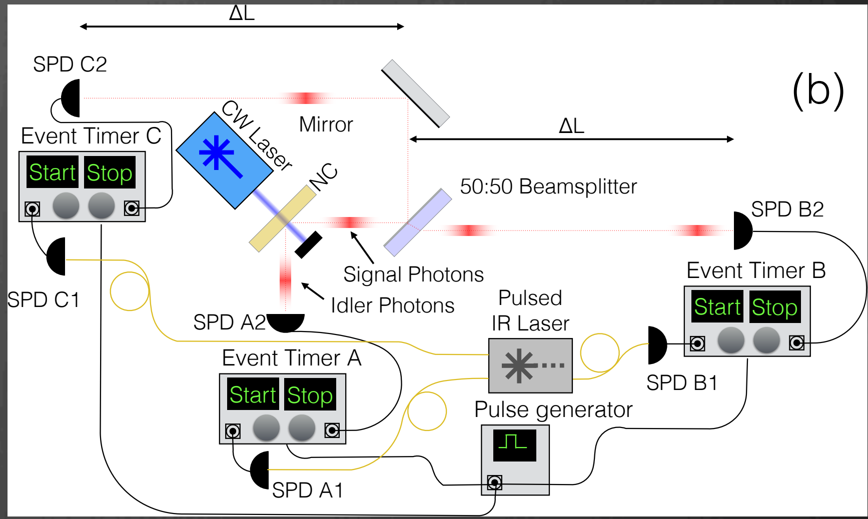
T. Guerreiro, B. Sanguinetti, H. Zbinden, N. Gisin and A. Suarez,
"*Single-photon space-like antibunching*",
Physics Letters A, 376:2174-2177, Jun 2012.

Experimental set-up (i)



Experimental set-up (ii)





- CW Laser ω_P → Nonlinear crystal → parametric down conversion: *idler* + *signal*, $\omega_P = \omega_I + \omega_S$ → *idler* sets time tag, best time resol. available ~ 40 ps → *signal* sent to a beam splitter and to distant detectors (B2/C2) → events recorded by two independent event timers;
- Common time reference to synchronize evt logs: pulsed IR laser sent to all evt timers + single pulse generator to set the start of the experiment;
- $\tau = \Delta L/c + 2\Delta L/c'$

Feasibility

- Photon counting statistics
  Emission rate: pair emission rate about R ≈ 10 MHz
  (larger emission rates entail a too large probability of multiple pair emission)
  $\mathbf{L}_2 = 2\mathbf{L}_{out} + 2\mathbf{L}_f + \mathbf{L}_C + 2\mathbf{L}_D \approx 45$ dB
  L_{out} = outcoupling from the source = 2 dB
  L_f = filtering losses = 5 dB
  L_C = 3 (BS) + 2 (coupling to o.f.) dB
  L_D = 13 dB (5% detection efficiency at both SPD's)

  → several hundreds of *idler-signal* coincidences per second

- Single photon Fock state? This will be checked by the heralded version
  of the Hanbury Brown Twiss (HBT) experiment: detection of triple coincidences
  between *herald* and *heralded* photon after BS → *antibunching*

Feasibility (ii)

- Main result: resolving a (would be) delay $\tau' = 2\Delta L/c'$ in single photon t.o.f. with or w/o BS
- Limiting factor: SPD time jitter ($\tau_{SPD} \approx 40$ ps for best commercially available detectors)
- At best we have

$$c'/c = 2\Delta L/c\ \tau_{SPD}$$

Possible results

- <u>NO DELAY</u>: lower bound collapse velocity (*c'*);
- assuming ~ 40 ps for the reaction time of SPD, ~ 30 m the distance of SPD's from the source (Pavia Lab.) the limit that can be cast is

$$c'/c = 2\Delta L/c\ \tau_{SPD} \sim 5000$$

- <u>YES DELAY</u>: *new physics effect!!*
- Standard QM does not model collapse, it is assumed as a postulate; *that's fine, FAPP*…
- If delay, necessary to generalize QM to describe collapse as a physical process

Perspectives

In case of no delay:

- Increase sensitivity → go to geographic distance
- Two physical limitations: atmospheric absorption and diffraction
- Absorption: at the used wavelength (800 nm) maximum atmospheric trasparency (attenuation=0.1 dB/Km at optimal atmospheriche conditions)
- Use of reflecting telescopes (diameter ~ 30 cm) allows to reach distances of the order of 100 Km (attenuation by diffraction ~ 7 dB)
- Limit: $c' \sim 10^7\, c$.

Perspectives (ii)

In any case:

- The quantum measurement problem → possible (realist) solution: spontaneous collapse of the wave function (GRW/CSL models)
- The models imply deviations from "texbook QM" (*new physics!!*)
- Possible testbed: superpositions of states of "mesosystems" (work in progress)

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