What can we do with entangled photons?

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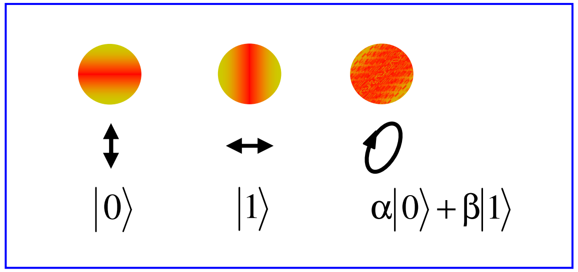
outline

- qubits, photons, entanglement
- how to entangle photons
- quantum computer
- quantum standards
- outlook

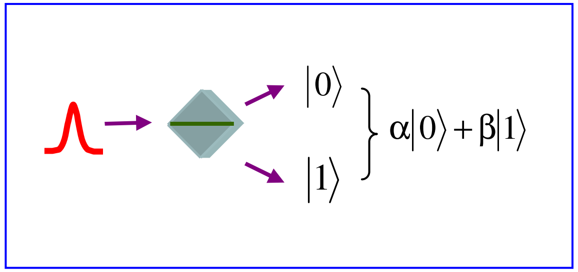
qubits, photons, entanglement

qubit

single photon



polarization



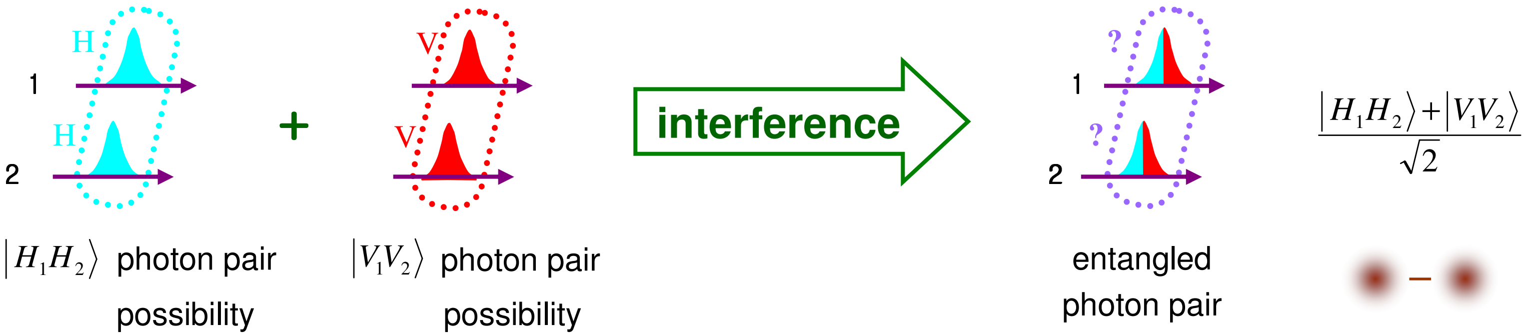
path

entangled state   superposition; cannot be decomposed into a direct tensor product

(e.g.)   2-photon entangled state $|\psi\rangle = \frac{|H_1 H_2\rangle + |V_1 V_2\rangle}{\sqrt{2}} = \frac{|H\rangle_1 \otimes |H\rangle_2 + |V\rangle_1 \otimes |V\rangle_2}{\sqrt{2}} \neq |\text{1st photon}\rangle \otimes |\text{2nd photon}\rangle$

how to entangle (concept)

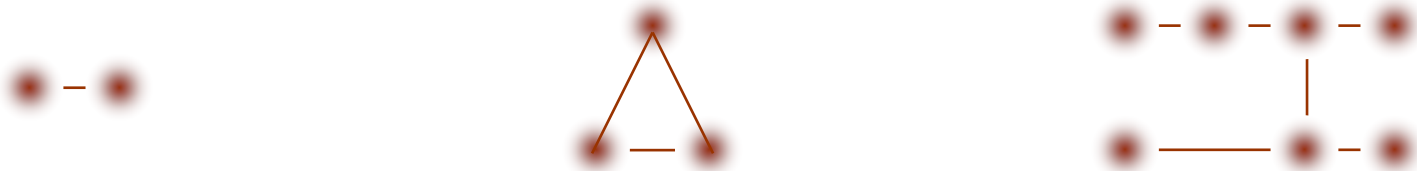
superpose two kinds of 2-photon states (photon pairs)



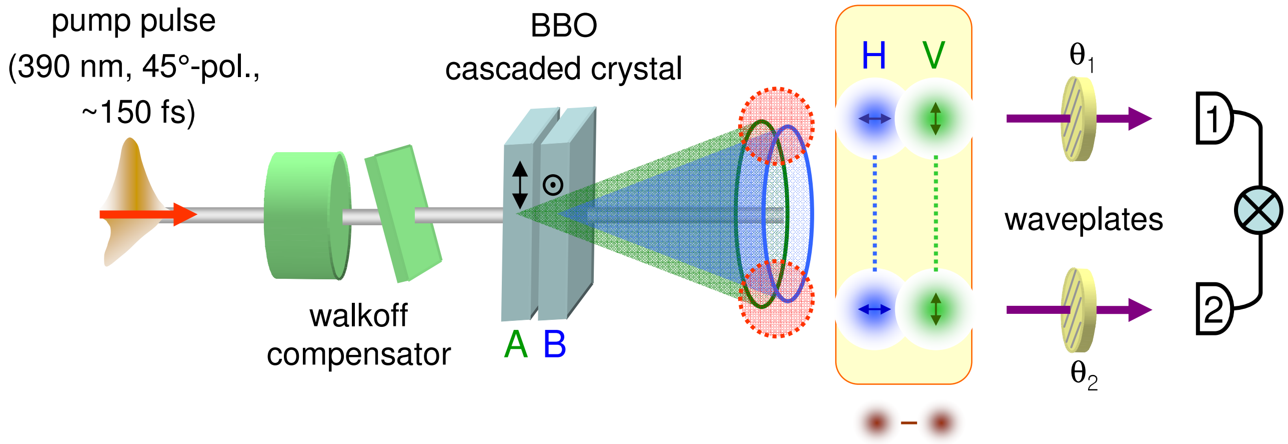
$$\frac{|H_1H_2\rangle + |V_1V_2\rangle}{\sqrt{2}}$$

cluster state (graph state)

(Raussendorf & Briegel, PRL 2001)



how to entangle (in practice)



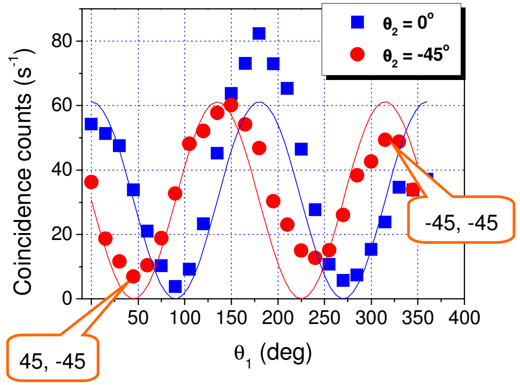
(Nambu et al., PRA 2002)

theory

coincidence detection

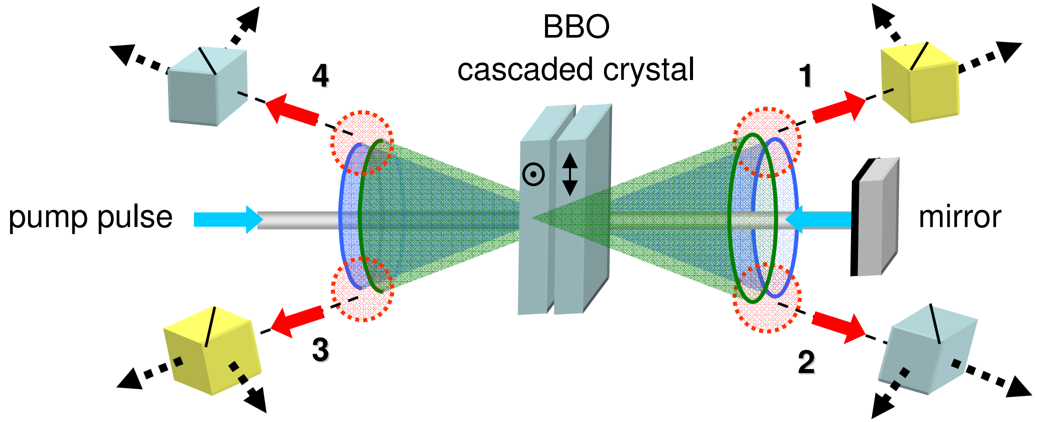
(θ_1, θ_2)	classic: mixed	quantum
(0, 0)	50%	50%
(0, 90)	0%	0%
(45, 45)	25%	50%
(45,−45)	25%	0%

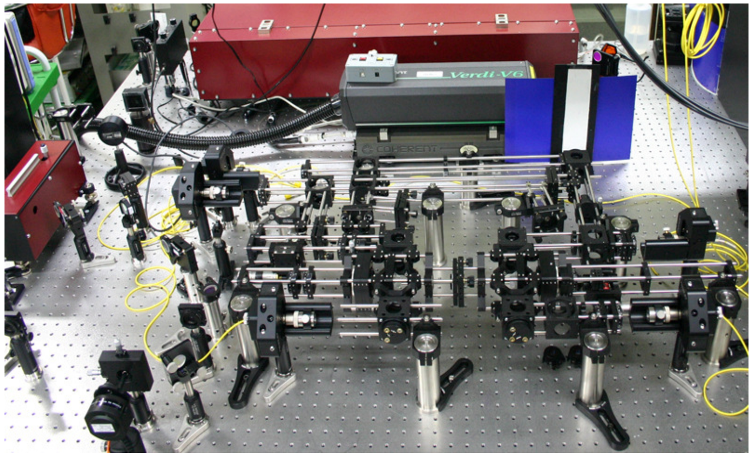
experiment



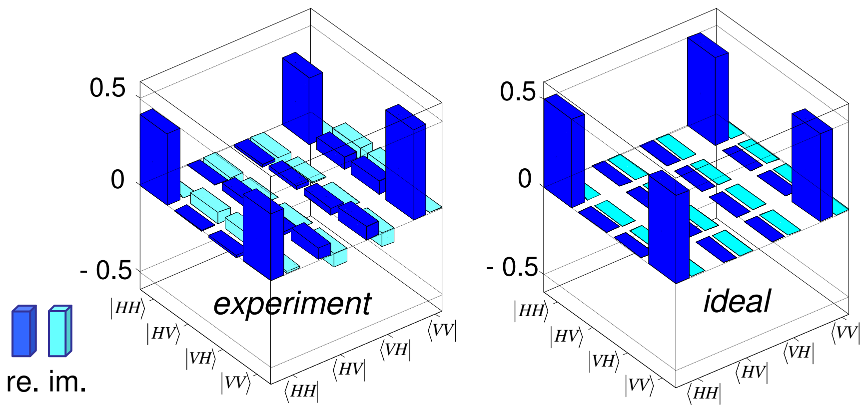
(HS Park et al., OSK 2007)

multi-photon entanglement





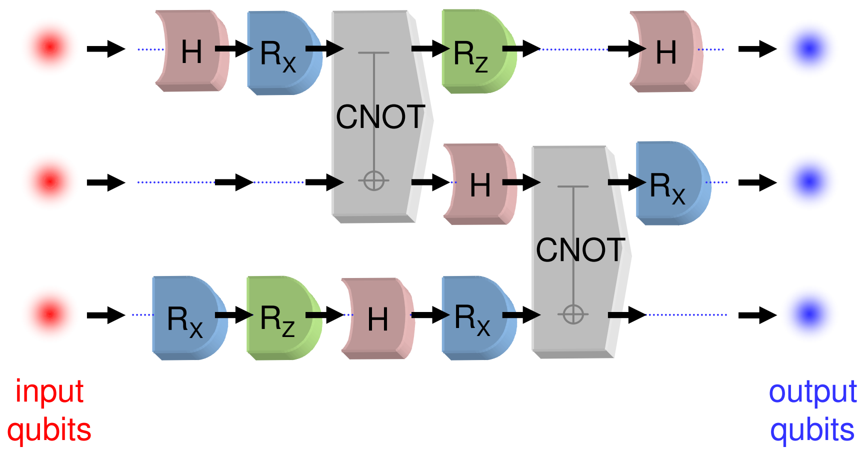
light path interferometer



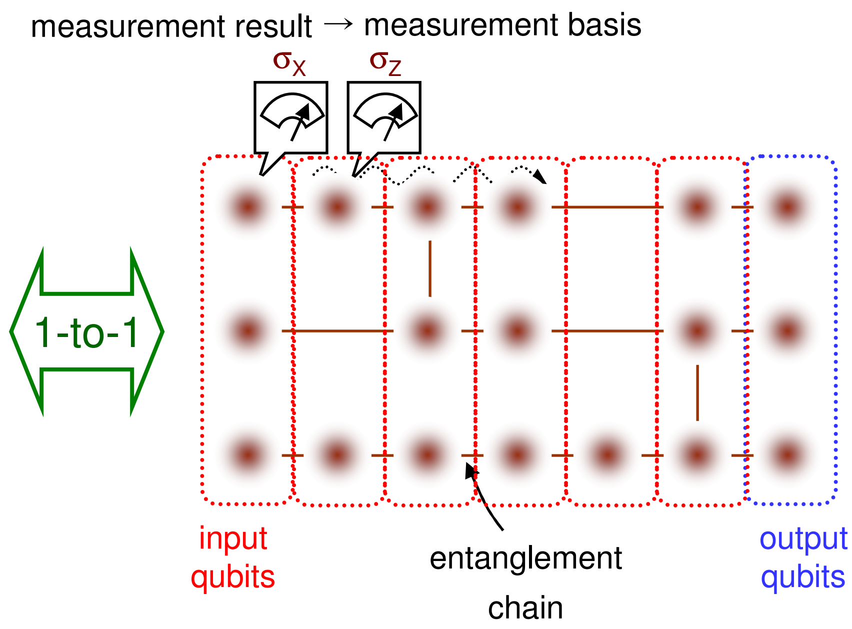
quantum state tomography

(HS Park et al., OSK 2007)

quantum computer



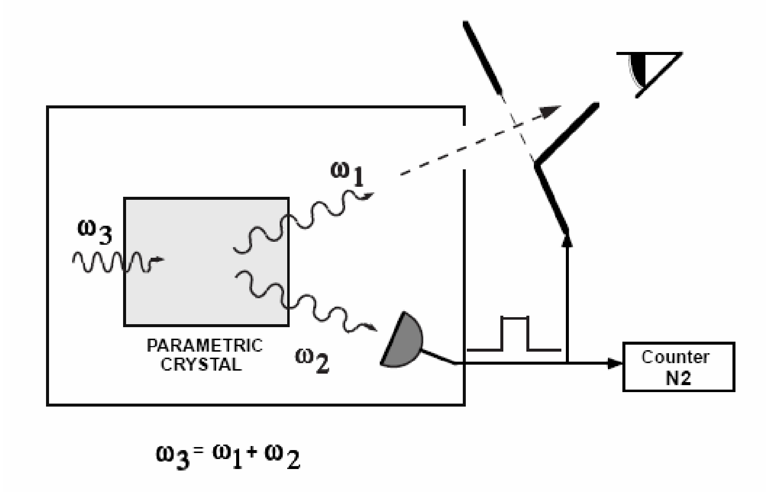
quantum circuit



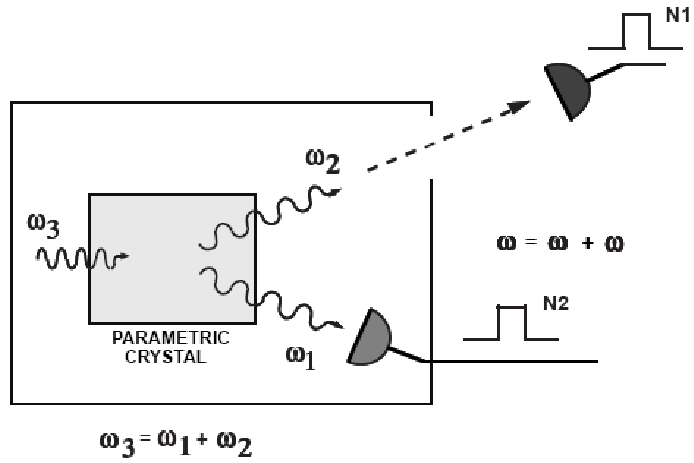
cluster state

quantum standards

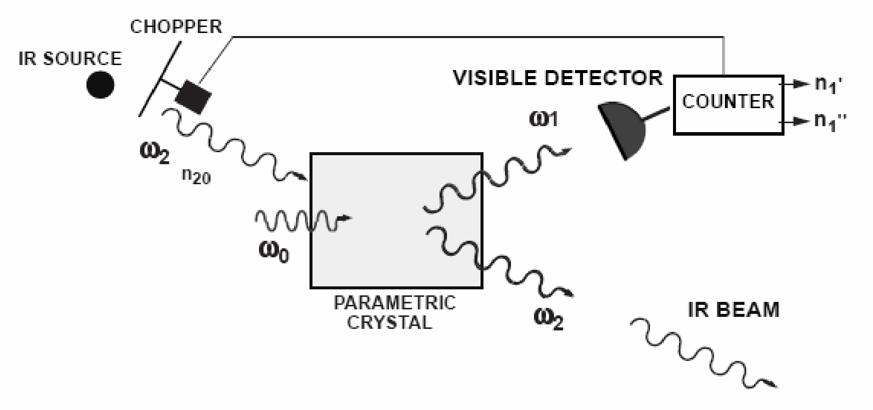
absolute photon source



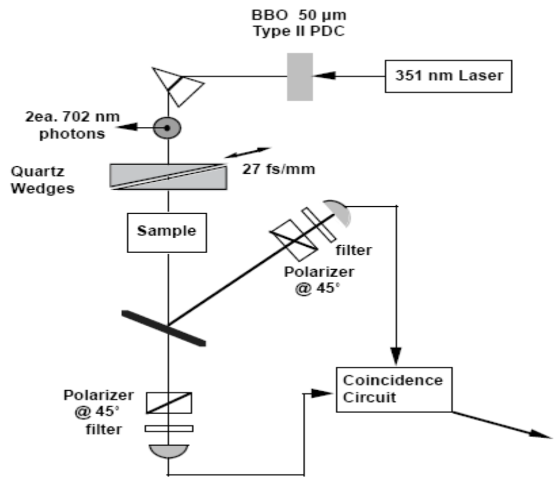
absolute quantum efficiency



absolute radiance

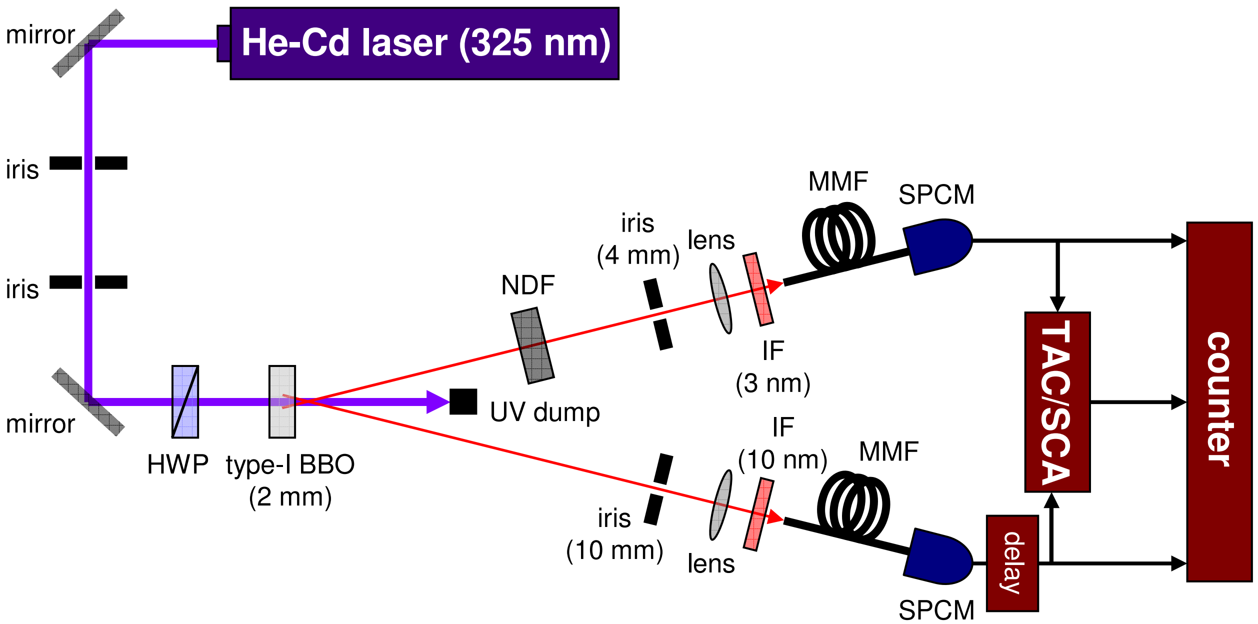


quantum ellipsometry



(Sergienko, CXLVI Int'l School of Physics "Enrico Fermi")

calibration of absolute quantum effiency



quantity	type	standard uncertainty	uncertainty contribution
total single count rate	A	16.2	-2.2x10-4
background single count rate	A	1.9	2.6x10-5
total coincidence count rate	A	8.9	4.1x10-4
accidental coincidence count rate	A	1.7	-7.6x10-5
TAC dead time	B	2.9x10-9	6.7x10-5
collection efficiency			4.8x10-4

collection efficiency @ OD 0: (31.0 ± 0.1) (%)

collection efficiency @ other OD: (31.1 ± 0.1) (%)

(MS Kang et al., to be submitted to Metrologia)

outlook

▪ what to do next

- increase # of photons in entanglement
- improve quality of entanglement
- measure uncertainties affecting quantum standards

▪ future challenges

- demonstration of quantum computation
- realization of quantum standards