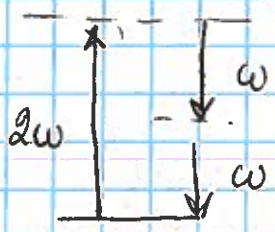
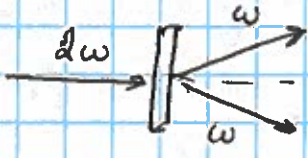
Quantum correlations and entanglement

Parametric down conversion



one high frequency photon converts into two ~~less~~ lower frequency photons

To match momentum conservation



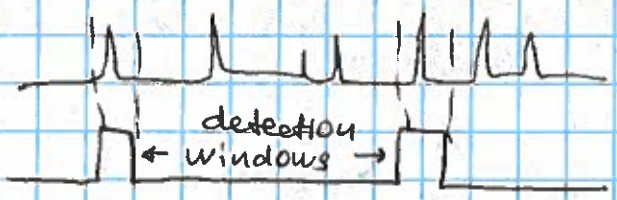
Because they are created as pair, the two generated photons are strongly correlated / entangled in time, propagation direction, polarization

Twin photons are the basis of most single photon sources — one photon is detected, heralding the presence of the other



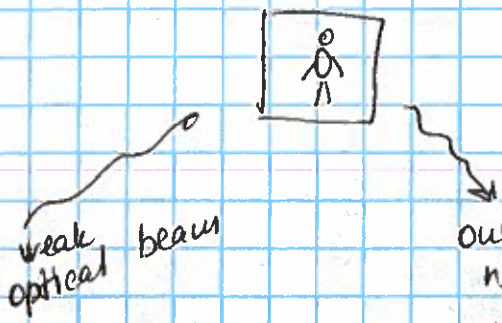
we know there is a single photon here at time t

The knowledge of photon timing is extremely important to ~~increase~~ allow reliable photon detection: only the signal around the photon emission time is recorded, reducing the influence of the dark noise



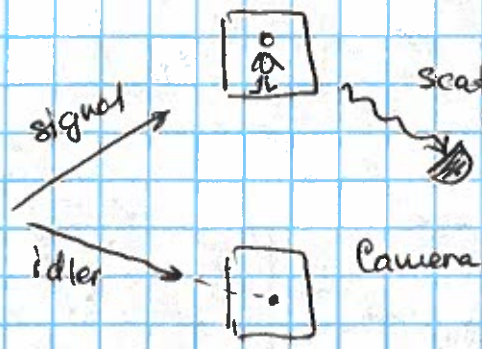
← single photon detector record: both signal and dark noise

What else can we do with correlated photons? How about ghost imaging



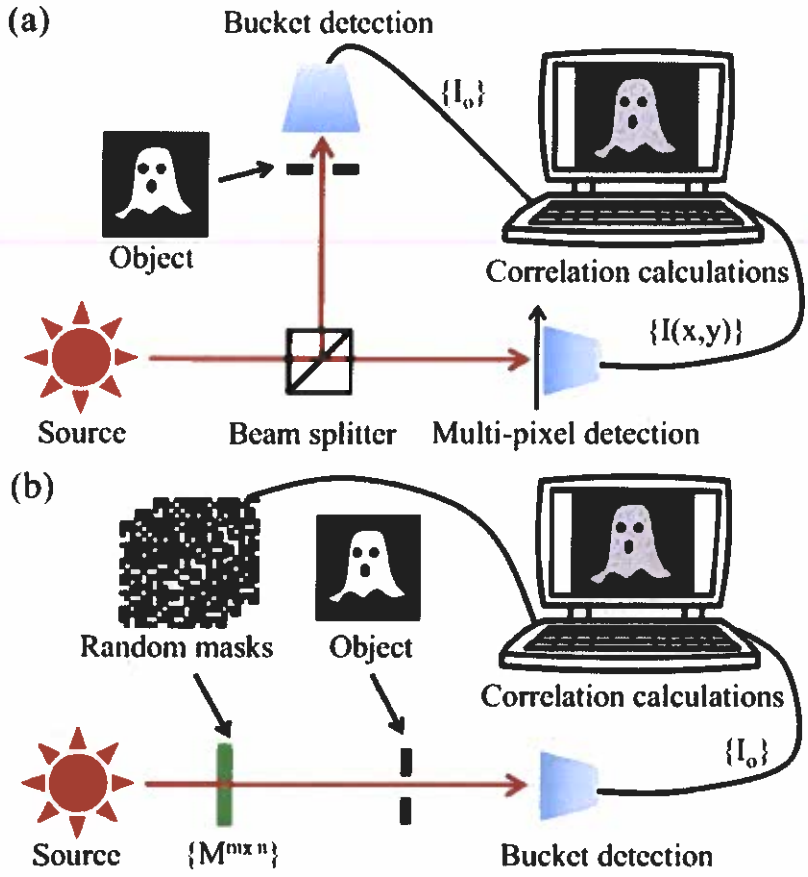
Task: discretely recreate a shape of a target such that this surveil area is undetectable.

only a few photon returns → recreating the image ~~creates~~ requires very long time and special camera



When the bucket clicks, we actually can figure out at what point it hit the target, since its position is correlated, and it can be measured on camera

Confession: we need correlated photons but not necessarily entangled


(a)
Bucket detection
$\{I_o\}$
Object
Correlation calculations
$\{I(x,y)\}$
Source
Beam splitter
Multi-pixel detection
(b)
Random masks
Object
Correlation calculations
$\{I_o\}$
Source
$\{M^{m\times n}\}$
Bucket detection

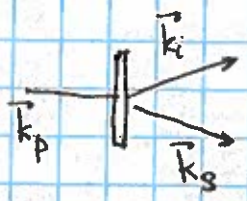
Einstein - Podolsky - Rosen paradox (EPR)

Quantum mechanics postulates that it is impossible to have a precise information about the position and momentum of a quantum object

Uncertainty principle $\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$

$\Delta x, \Delta p$ - uncertainties in a particle position and momentum

Einstein suggested that one can go around this principle using entanglement

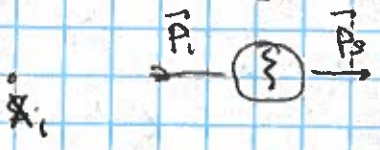


$\underbrace{\vec{k}}_{\text{known}} = \vec{k}_i + \vec{k}_s \qquad \vec{p} = \hbar\vec{k}$

emitted at the same time
move with c → position known

We can measure position of one photon and momentum of the other, and because they are correlated, it looks like we now know position and momentum for both - paradox?

In original Einstein's argument he used a spontaneously splitting molecule



$\vec{p}_s + \vec{p}_i = 0$
$x_i + x_s = 0$

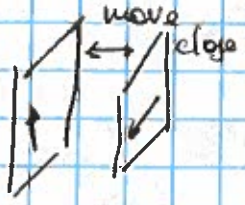
Quantum entanglement: two qubits are in inseparable quantum superposition. If one measures, the state of the other instantly changes as well

Single nonlinear crystal



Two polarizations for signal and idler are the same (we assume, they can be; the exact configuration depends on how one can realize the phase matching condition

$|\psi\rangle = |V,V\rangle_{s,i}$ (correlated)

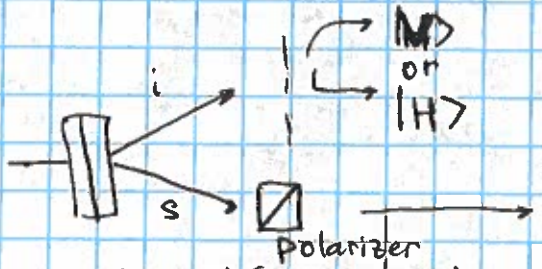


If we have to produce the photons, we need two such crystals to create an entangled state

$$|\psi\rangle = \frac{1}{2}\left(|V,V\rangle_{s,i} + |H,H\rangle_{s,i}\right)$$

Here we don't have either photon in a distinct state, if we measure the polarization of the signal photon, it will be equally probable to be either horizontal or vertical

However, if we also measure the polarization of the idler, it will always match



$$|\psi\rangle = \frac{1}{2}(|V,V\rangle + |H,H\rangle)$$

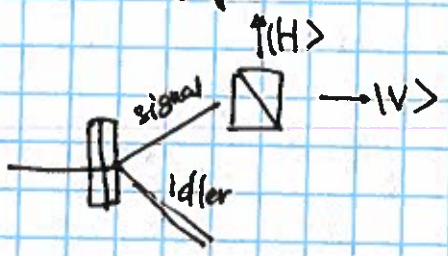
non-separable quantum state

Signal is vertical → idler is vertical

or

Signal is horizontal → idler is horizontal

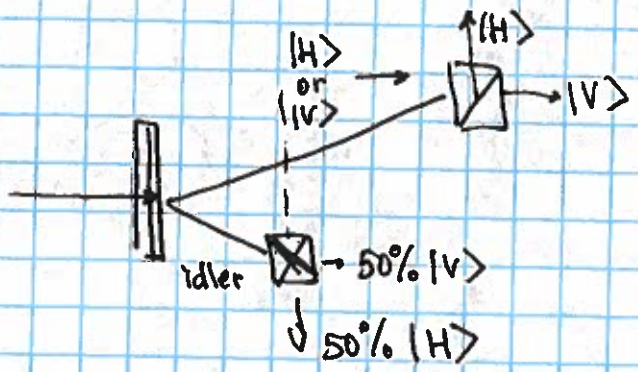
The collapse of the wave function is instantaneous, so at some point people consider if one can use it to transfere information faster than speed of light (spoiler - no!)



$|\psi\rangle = \frac{1}{2}(|H,H\rangle + |V,V\rangle)$

50% H, 50% V

If the idler state is measured before, the output of the signal measurement will always match, but the outcome of the idler measurement is random



HVHVVHHVV

match

HVHVVHHVV...

If the idler is measured first, the consecuent signal measurement will match the outcome of the idler measurement. But it is impossible to see that correlation w/o comparing the results, and that is limited by the light speed.