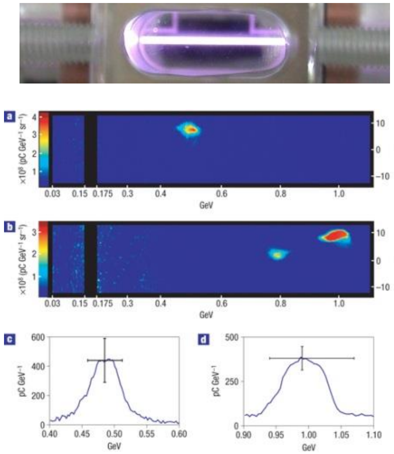
C2: Laser Science and Quantum Information Processing

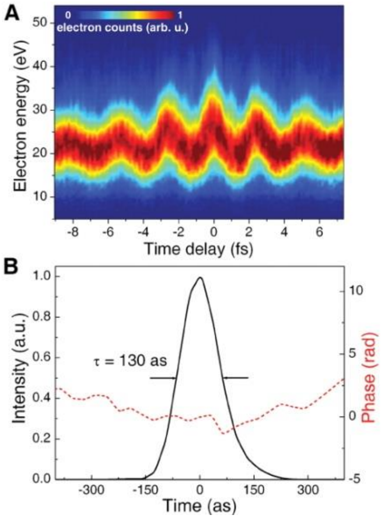
http://tinyurl.com/OxPhC2

ALP: the four ultras

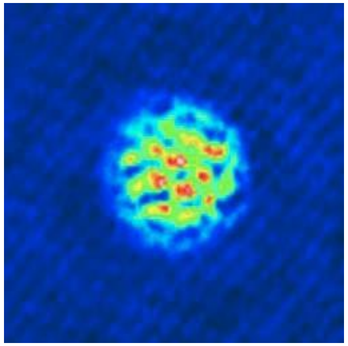
Ultra Strong



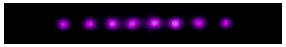
Ultra Fast



Ultra Cold



Ultra Weird



Lasers

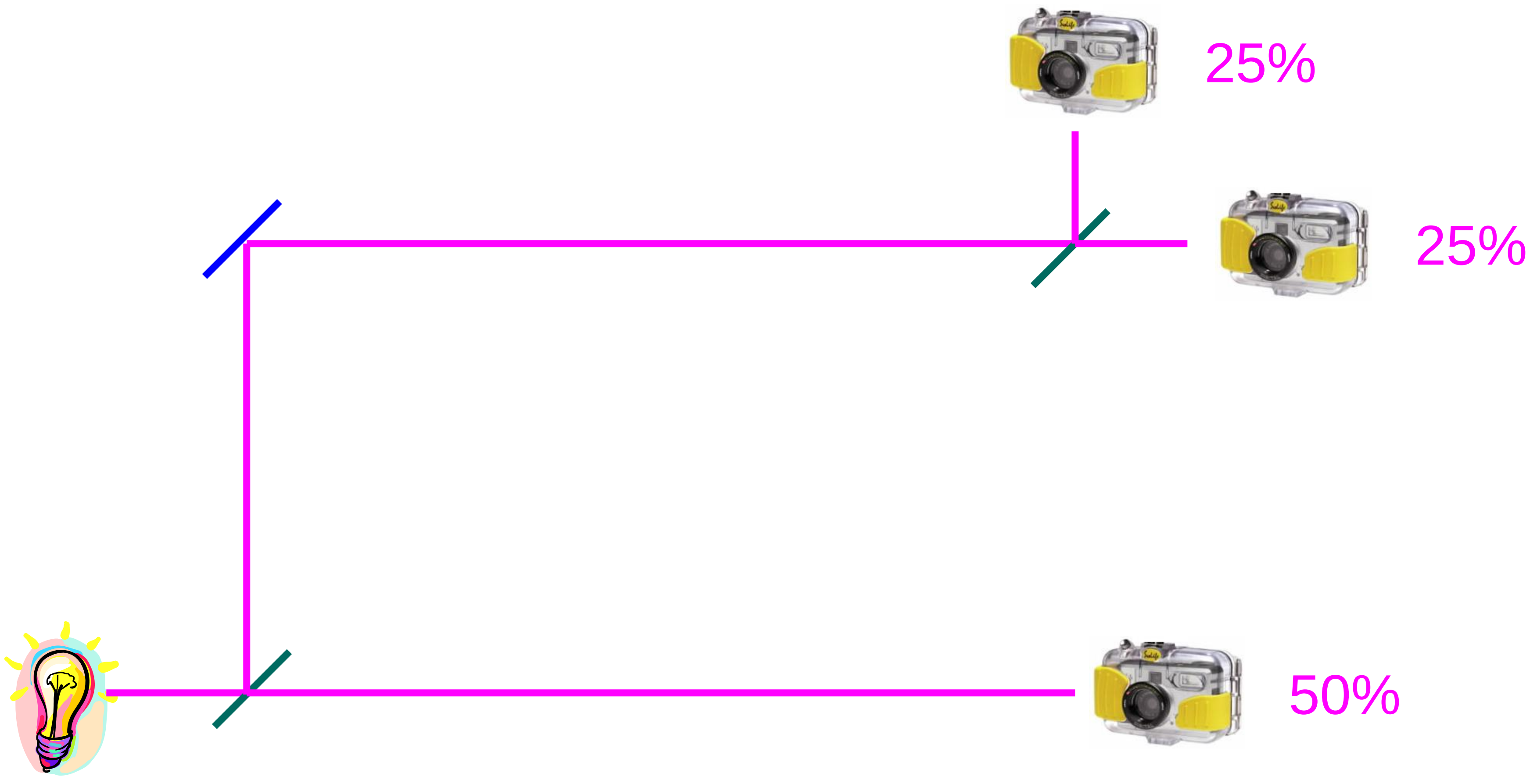
Quantum information

An example

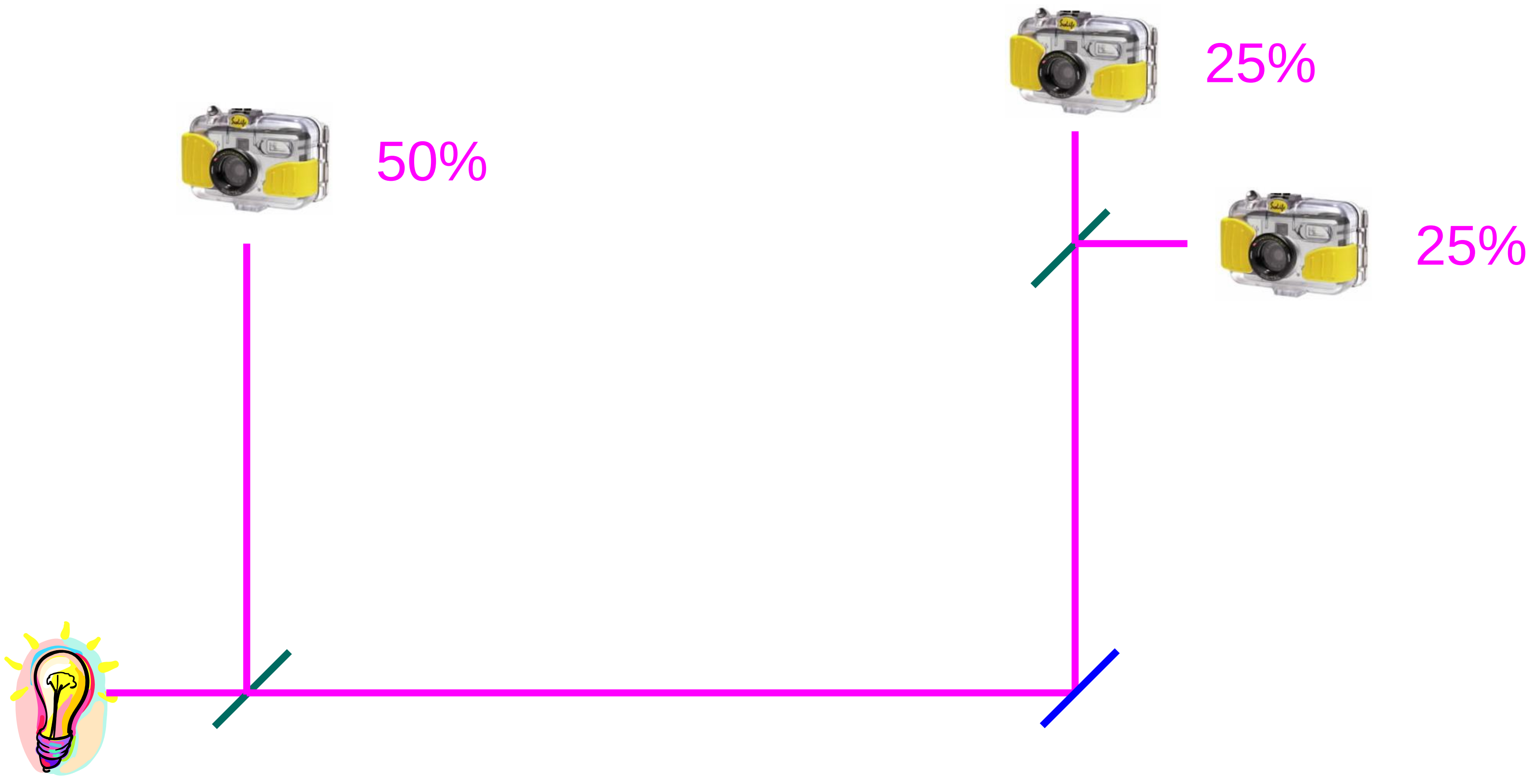
- The Mach-Zender interferometer

- Old fashioned optics or ultra-trendy quantum information theory?

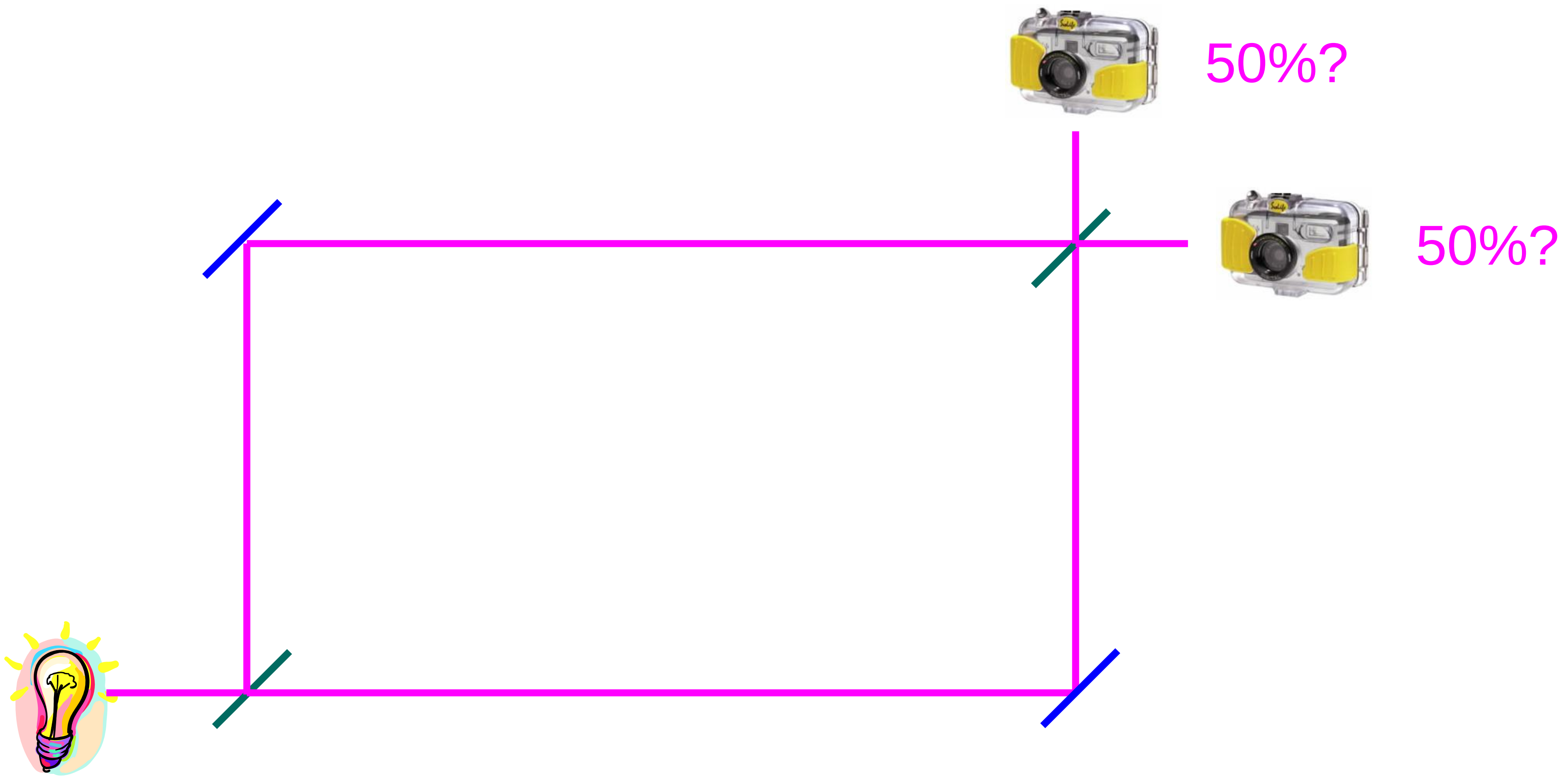
Mach-Zender Interferometer



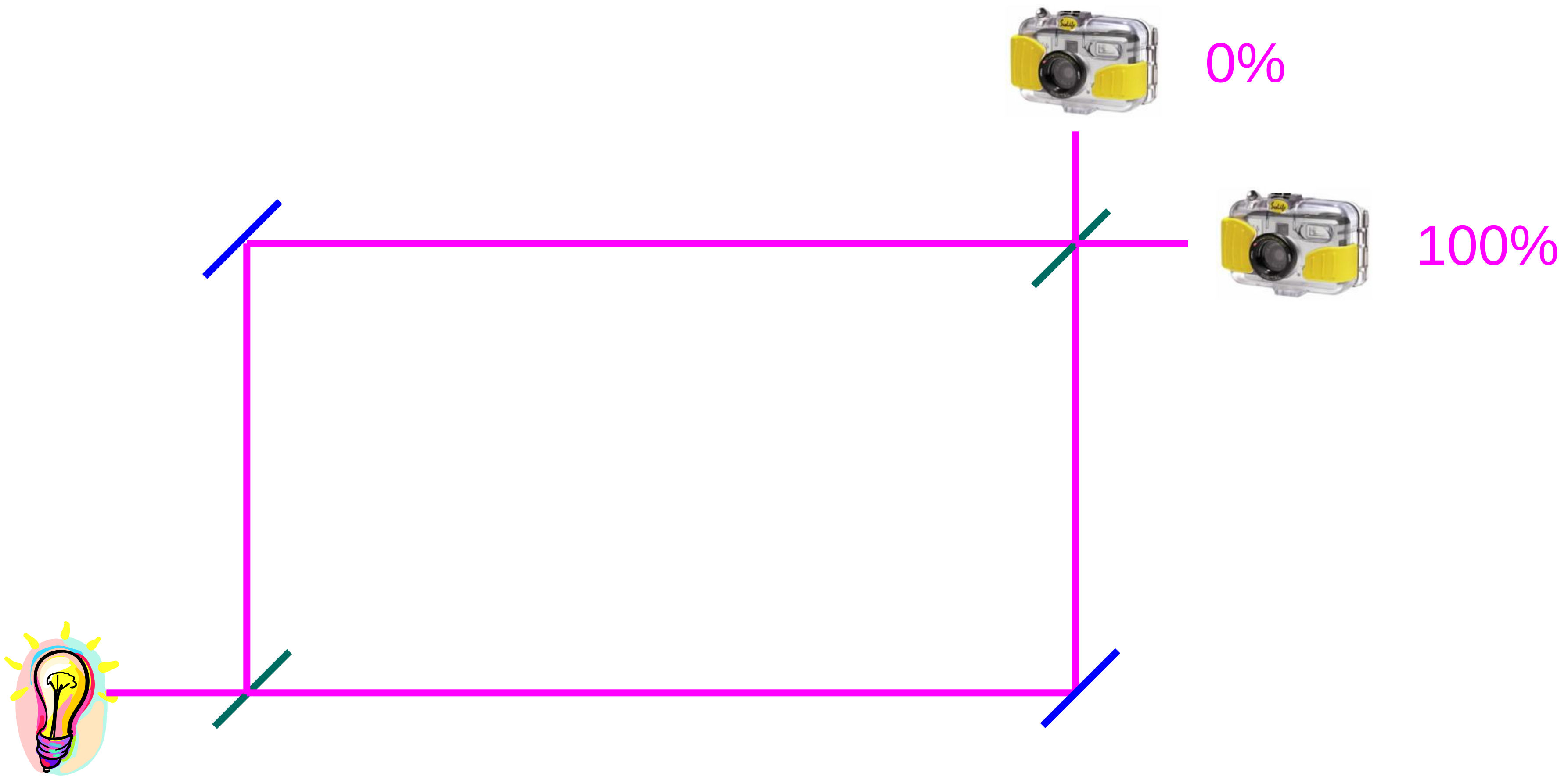
Mach-Zender Interferometer



Mach-Zender Interferometer



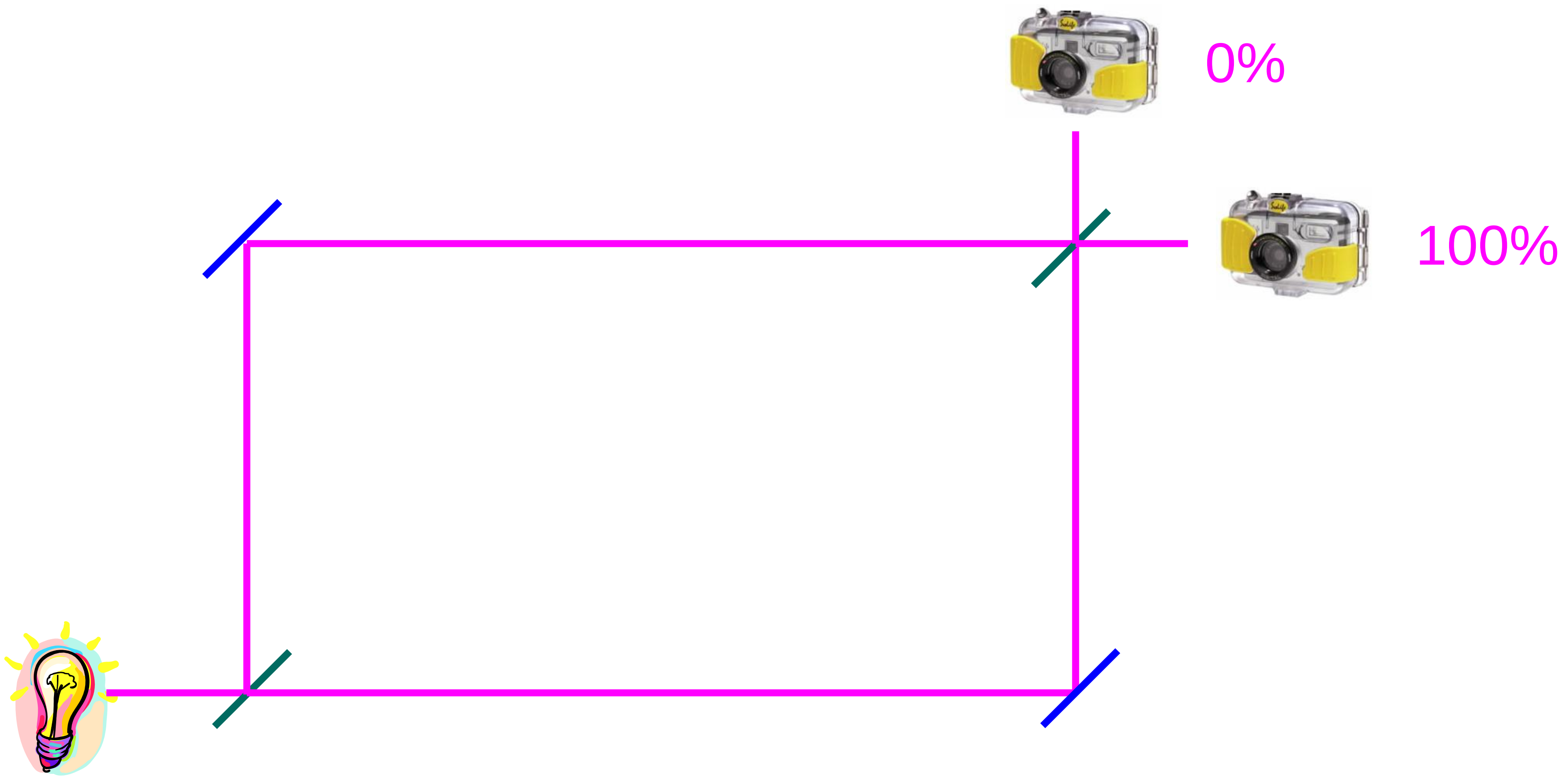
Mach-Zender Interferometer



How can this happen?

- Fairly easy to understand with classical light waves: interference between the two paths
- Also works when the light is so dim that there is only one photon in the apparatus at any one time
- Also works with electrons, neutrons, buckyballs, etc.

How can this happen?

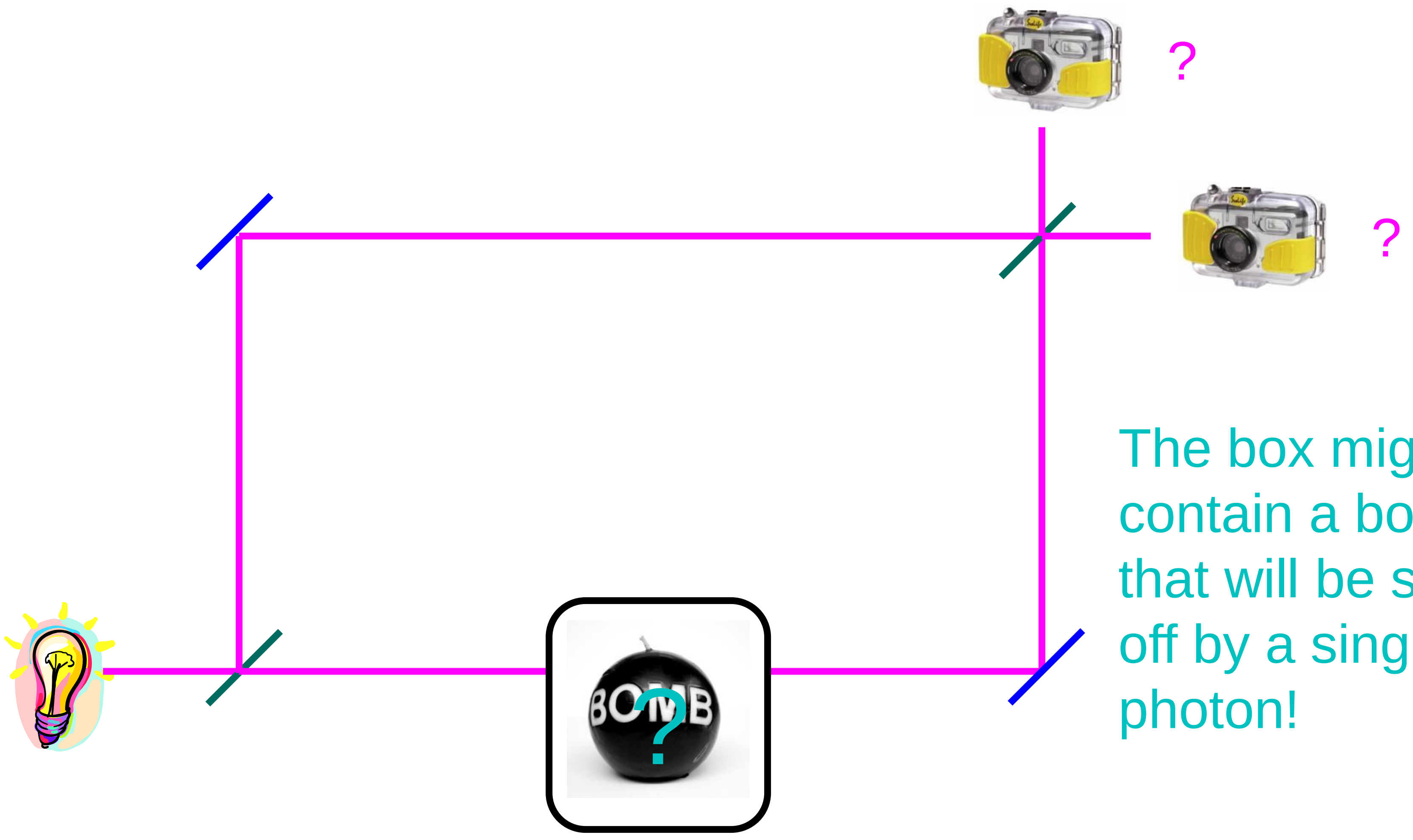


Every photon travels along *both* paths!

Elitzur–Vaidman bomb tester

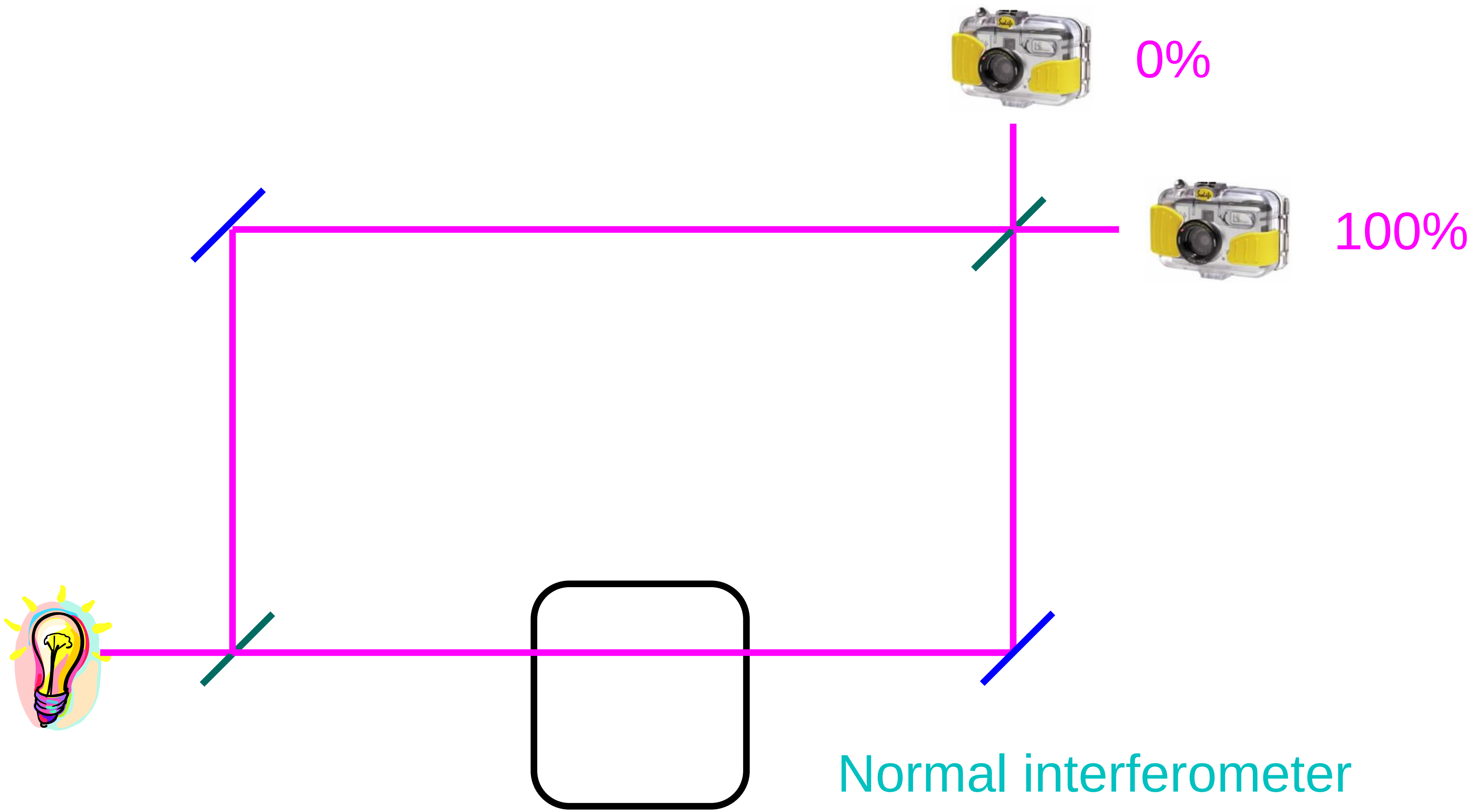
The box might contain a bomb that will be set off by a single photon!

Elitzur–Vaidman bomb tester

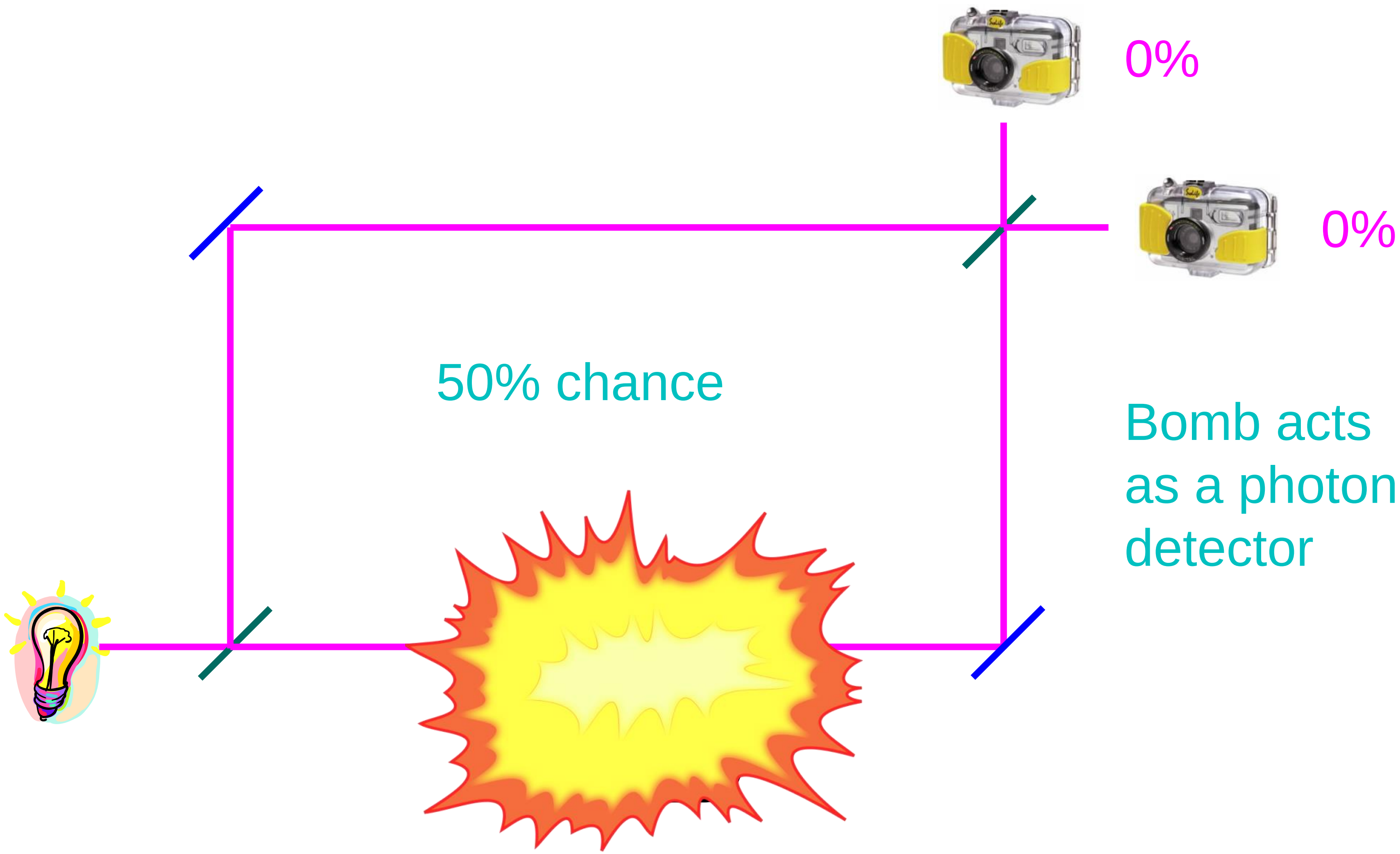


The box might contain a bomb that will be set off by a single photon!

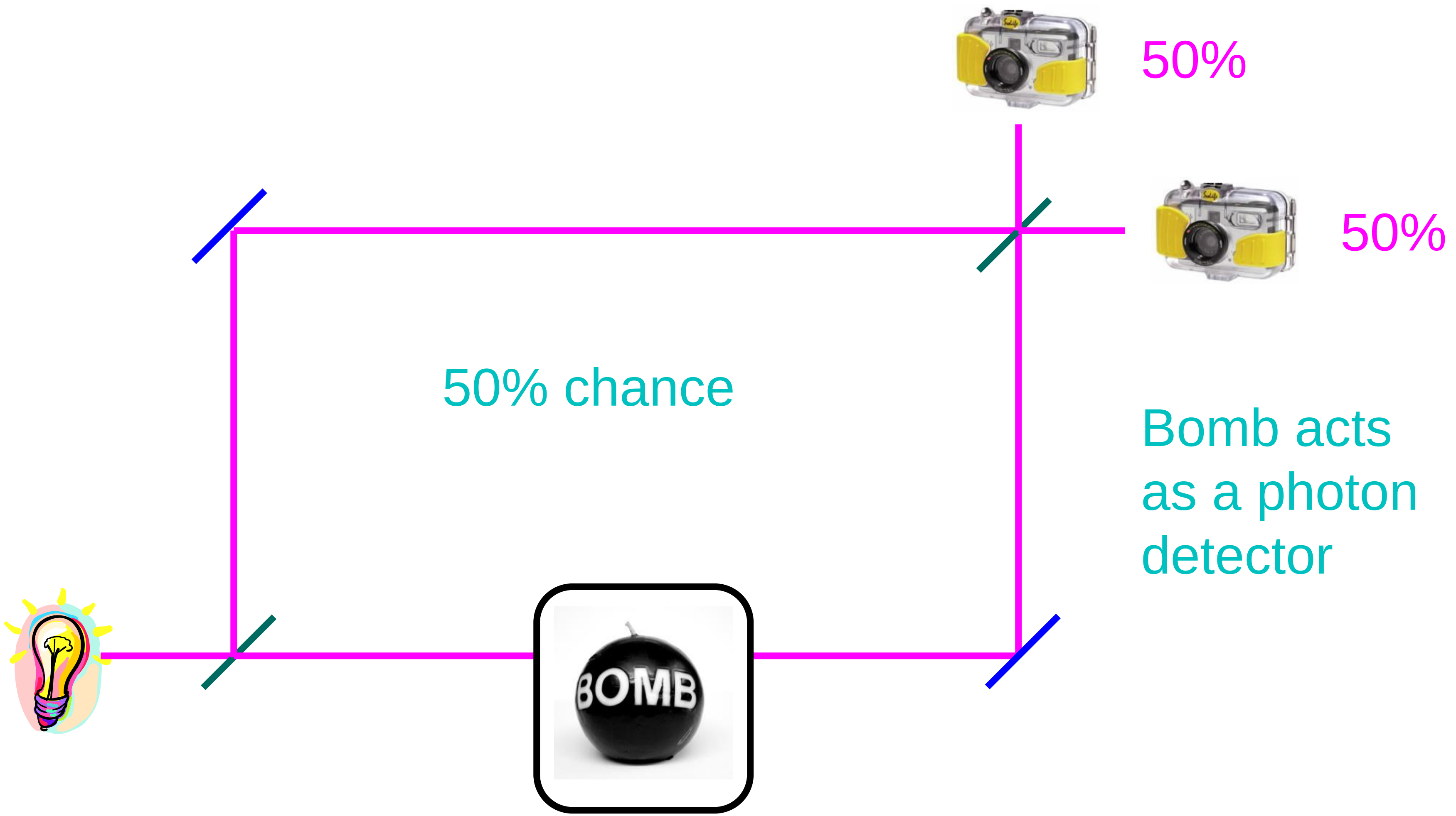
No bomb



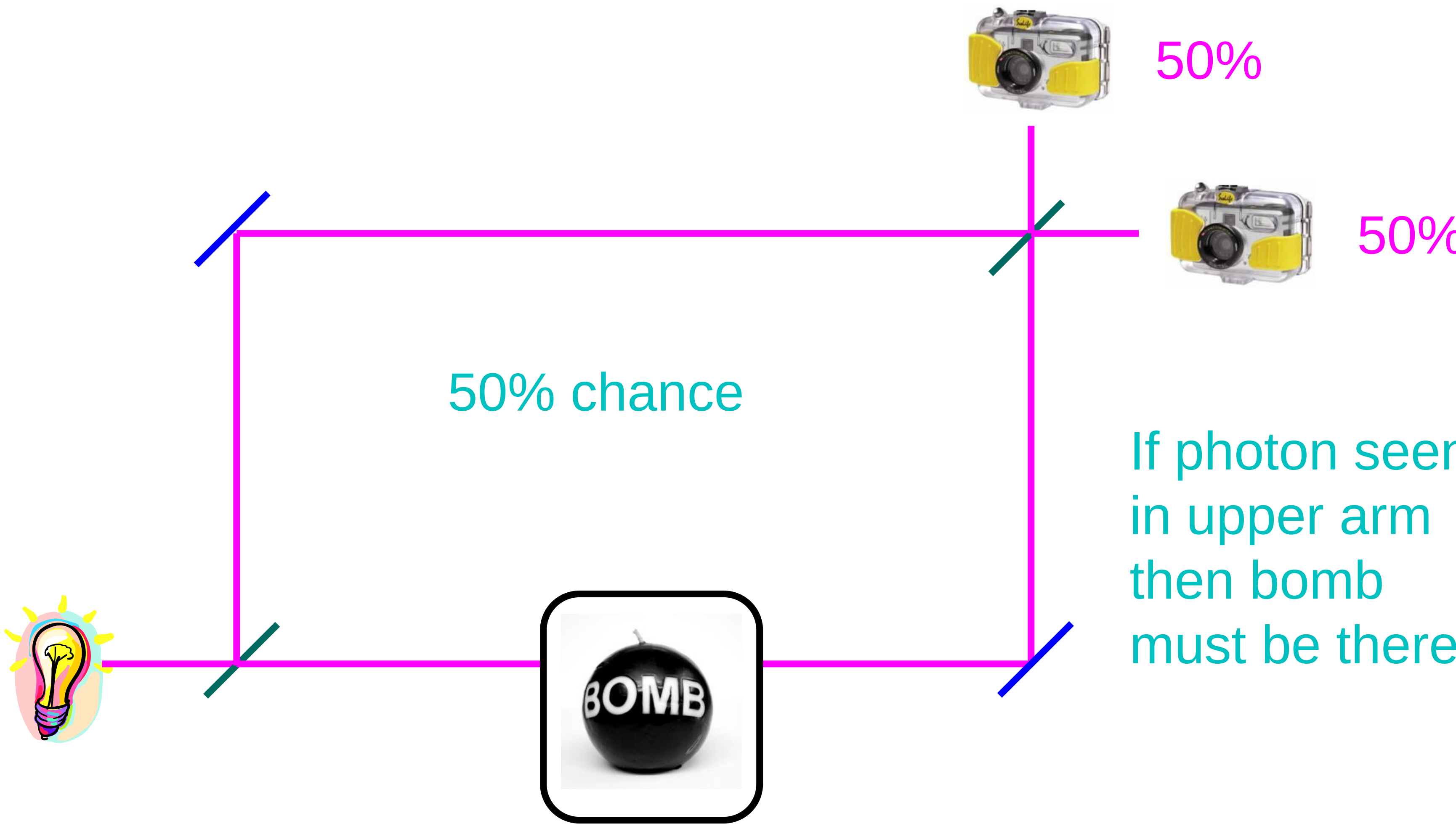
Bomb



Bomb



Bomb



If photon seen in upper arm then bomb must be there!

Quantum Information

- Counterfactual measurements
- Harnessing the power of parallel universes to do the impossible
- *Quantum information theory is what you get when you take linearity seriously*

So what do you study?

<u>C2. Laser Science and Quantum Information Processing</u>

Knowledge of the laser physics covered in paper B3 will be assumed.

Lasers:

Line broadening mechanisms, linewidths and gain saturation. Q-switched operation. Modelocking. Frequency control and frequency locking. Solid state lasers. Semiconductor lasers. Fibre lasers. Ultrafast lasers: chirped pulse amplification, terawatt and petawatt laser systems.

Examples of laser systems: Nd:Glass, Nd:YAG. Ti:sapphire; Er:Glass fibre lasers and the Er-doped fibre amplifier (EDFA); AlGaAs and GaN semiconductor lasers.

Optics:

Diffraction. Ray matrices and Gaussian beams. Cavity eigenfunctions: the concept of cavity mode, the stability criterion, cavity design. Beamsplitters. Transverse coherence and Michelson stellar interferometer. Longitudinal coherence: optical coherence tomography and Fourier transform spectroscopy. (Not correlation functions, Wiener-Khintchine theorem). Optics in Structured Materials: optical fields in planar waveguides and fibres.

Amplitude and phase modulation of light using the linear electro-optic effect. Second harmonic generation. Phase matching. Sum and difference frequency generation and optical parametric down conversion.

Quantum optics:

Elementary introduction to quantum fields and photons. Light-matter interactions and the Jaynes-Cummings model. Generation and detection of nonclassical states of light: parametric down conversion and photon entanglement, photon action at a beam splitter, bosonic statistics. Berry and Pancharatnam phases.

Quantum mechanics and Quantum Bits:

Two level systems as quantum bits. Superposition states, the Bloch sphere, mixed states, density matrices, Pauli matrices. Single qubit dynamics (gates): NOT, square root of NOT-gate, Hadamard, phase shift, networks of gates, the measurement gate.

Implementations: atom/ion in a laser field, photon polarisation, spin in a magnetic field. Mechanisms: Raman transitions, Rabi flopping, Ramsey fringes, spin echoes.

Decoherence (simple treatment). Separable and inseparable (entangled) states of two spin systems. Two qubit gates: controlled-NOT, controlled-phase. Universality of gates (result only). Characterising an unknown state, state and gate fidelity (very basic), the no-cloning theorem. Local realism, EPR, the four Bell states, the Bell inequalities, GHZ states.

Quantum Computation:

Reversible computation with unitary gates. Quantum parallelism and readout. The Deutsch and Grover algorithms. Other quantum algorithms: Shor (result only), quantum simulation. Error correction (3 qubit code for phase or flip only) and decoherence free subspaces. DiVincenzo criteria. Experimental methods with trapped atoms and ions. The controlled phase gate by "collisions". Optical lattices and massive entanglement. Experimental methods with NMR. Qualitative treatment of other quantum computing technologies.

Quantum Communication:

Elementary ideas about information content. Quantum dense coding. Testing Bell inequalities. Quantum key distribution, the BB84 protocol and detecting eavesdropping (only intercept/resend strategy). EPR based cryptography. Fibre and free space cryptography, polarisation and phase encoding. Phase encoding methods. Quantum teleportation and entanglement swapping.

Laser Science

Quantum Information Processing

Quantum Optics

Laser Science (2/6)

- Lasers: main laser types, Q-switching, modelocking, pulse compression
- Optics: ray matrices, Gaussian beams, coherence
- Non-linear optics: frequency doubling and sum and difference generation

Quantum Information (3/6)

- Quantum Information: qubits, logic gates, interaction of light and matter
- Technologies: atoms, ions, NMR
- Quantum Computation: Deutsch, Grover, Shor, error correction
- Quantum Communication: Bell states, entanglement, quantum cryptography, teleportation

Quantum Optics (1/6)

- Quantum theory of light, and the interaction of light and matter
- Non-classical states of light
- Berry’s phase and other geometric phases

Things go better with…

- C2 goes well with many options, but C3, C4 and C6 seem to be most popular
- A mixture of theory and experiment; mathematical but not too complicated!
- Can concentrate on one part (but can’t completely ignore the other parts!)

Finding out more

- C2: http://tinyurl.com/OxPhC2
- QIP: Nature 404, 247 (2000)
- Lasers: Nature 424, 831 (2003)
- Email Jonathan Jones or Vlatko Vedral