C2: Laser Science and Quantum Information Processing

http://tinyurl.com/OxPhC2

ALP: the four ultras

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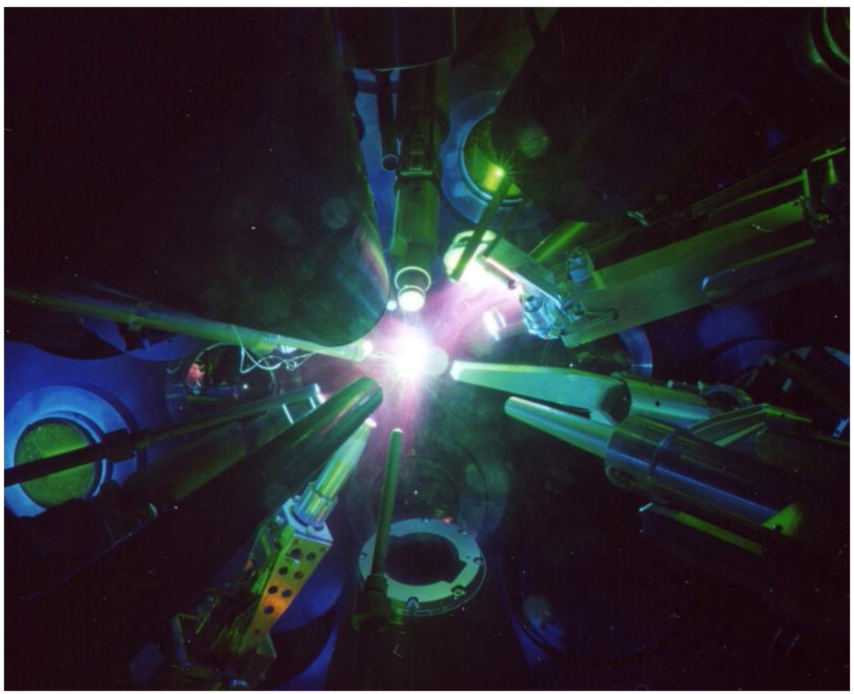
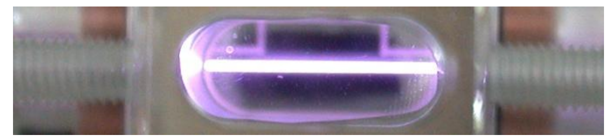
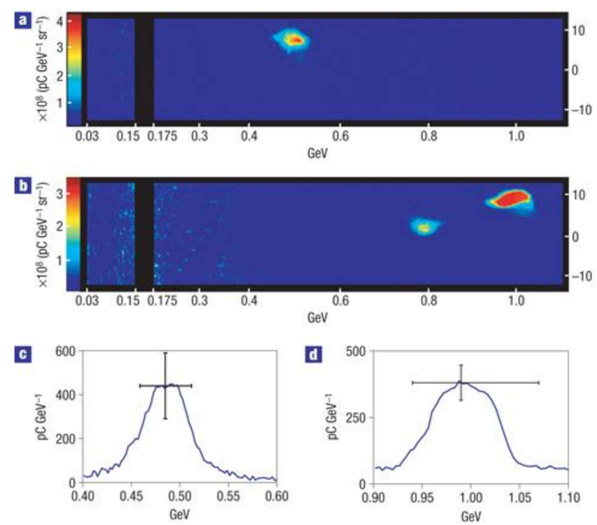
Ultra Strong – using really intense lasers to form plasmas and build particle accelerators, initiate fusion, etc.

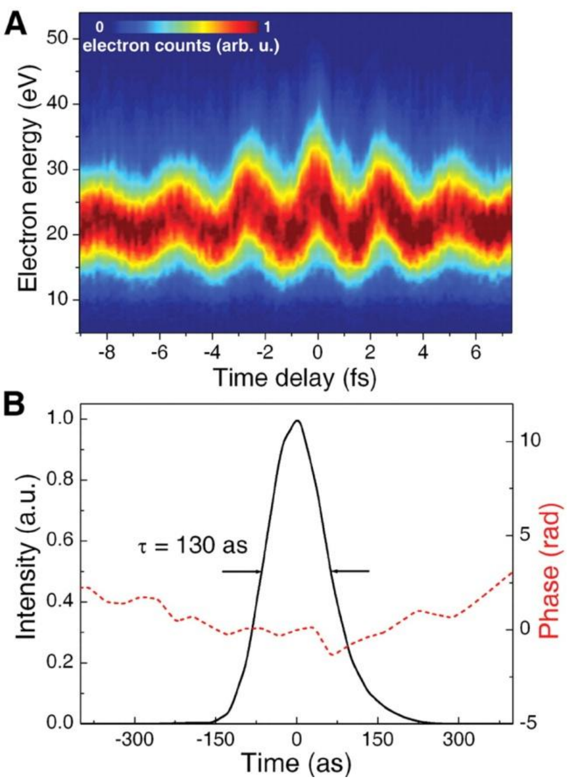


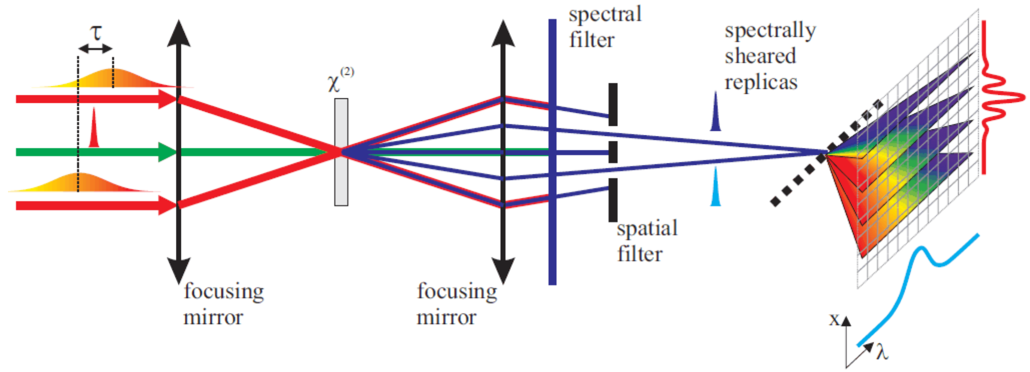




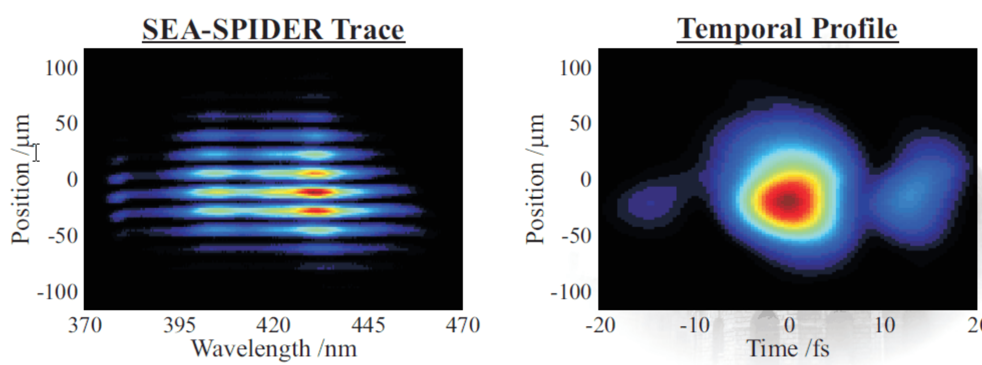
ALP: the four ultras

Ultra Fast – generating and characterising the shortest possible light pulses



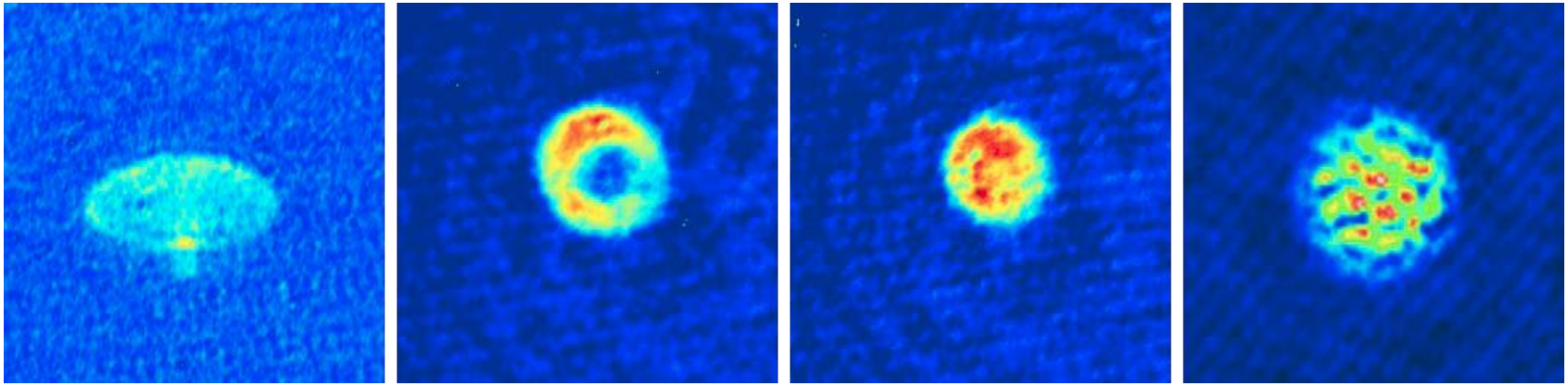


$$I(\omega, x) = I^{dc}(\omega, x) + 2I^{ac}(\omega, x)\cos[\Phi(\omega, x) + Kx]$$



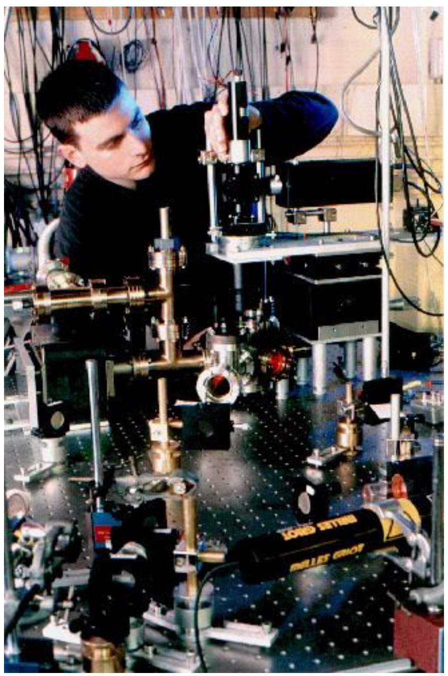
ALP: the four ultras

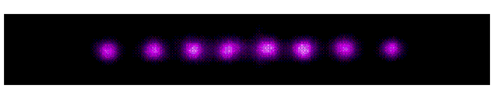
Ultra Cold : Form Bose-Einstein Condensates from trapped atoms to study quantum effects

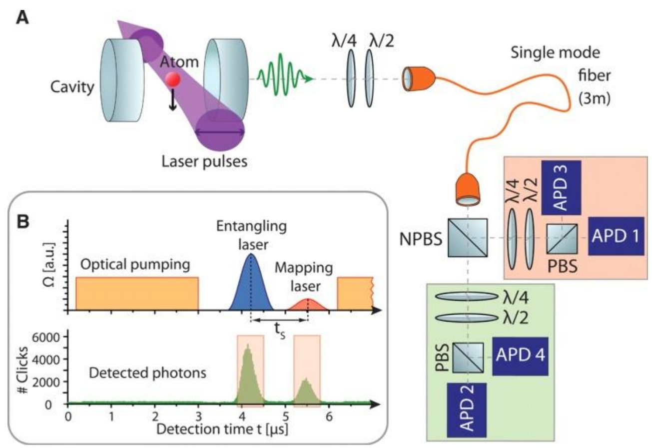


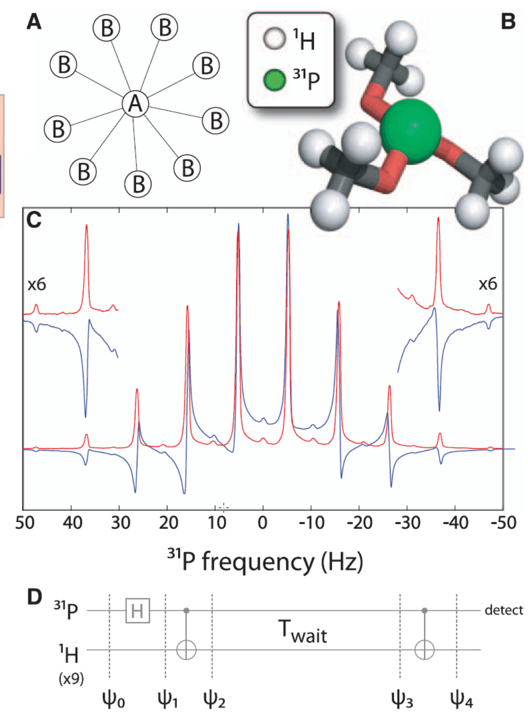
ALP: the four ultras

Ultra Weird – harnessing parallel universes to perform impossible information processing tasks



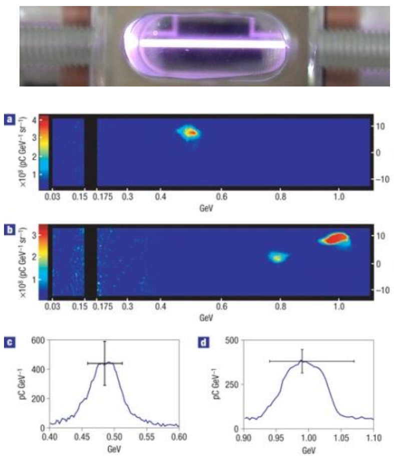


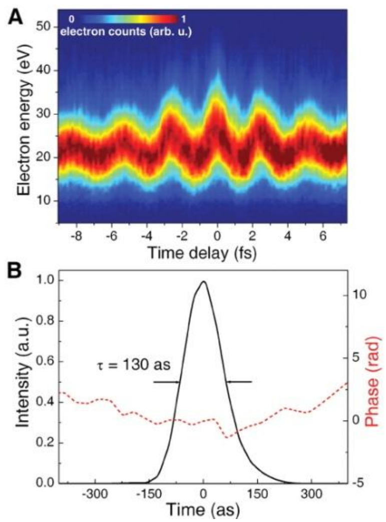


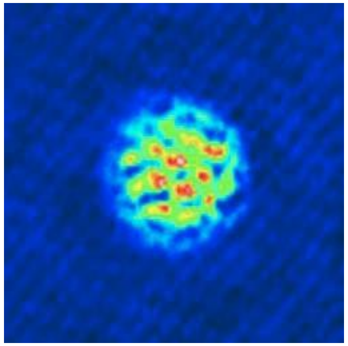


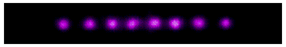
ALP: the four ultras

Ultra Strong | Ultra Fast | Ultra Cold | Ultra Weird









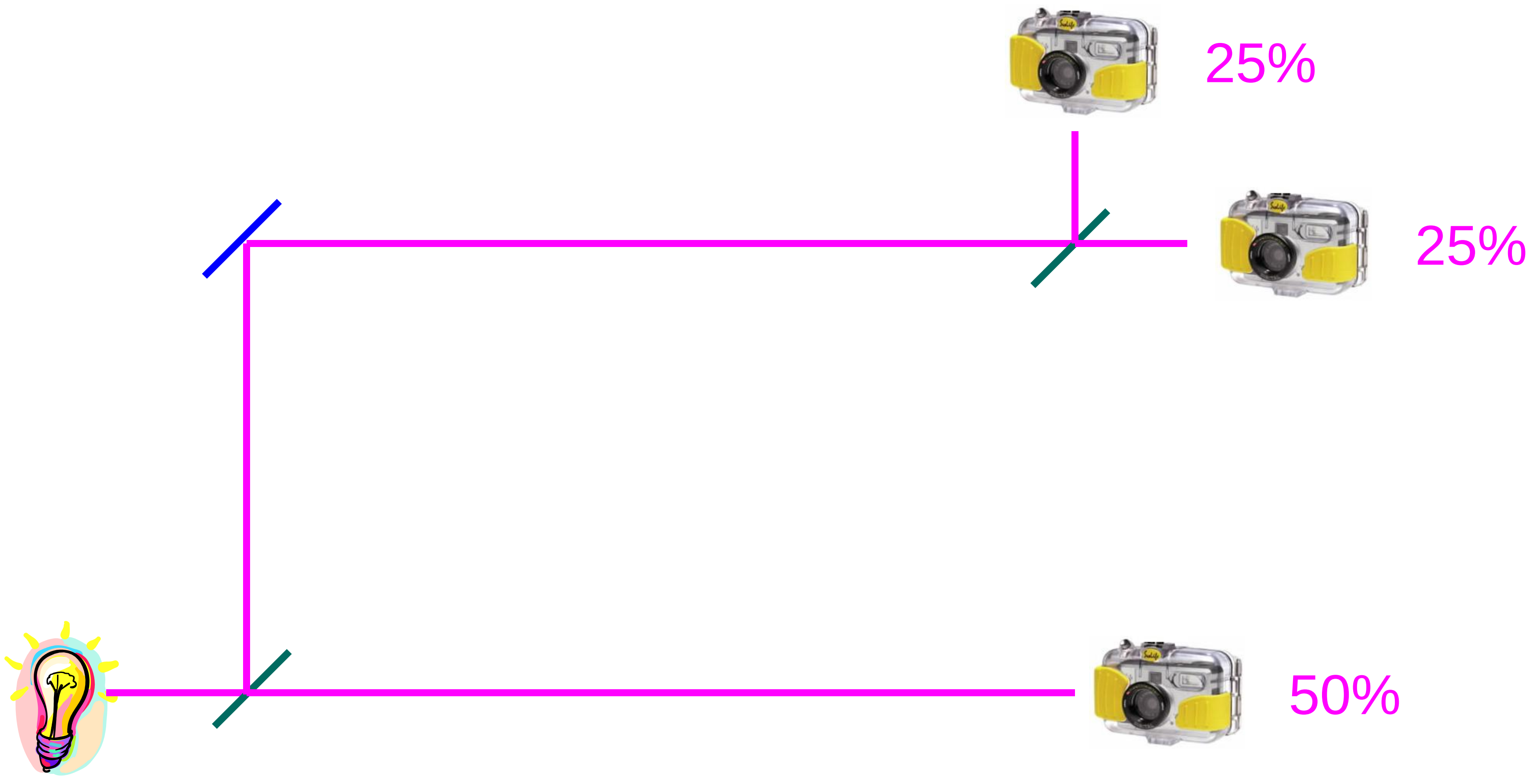
Lasers

Quantum information

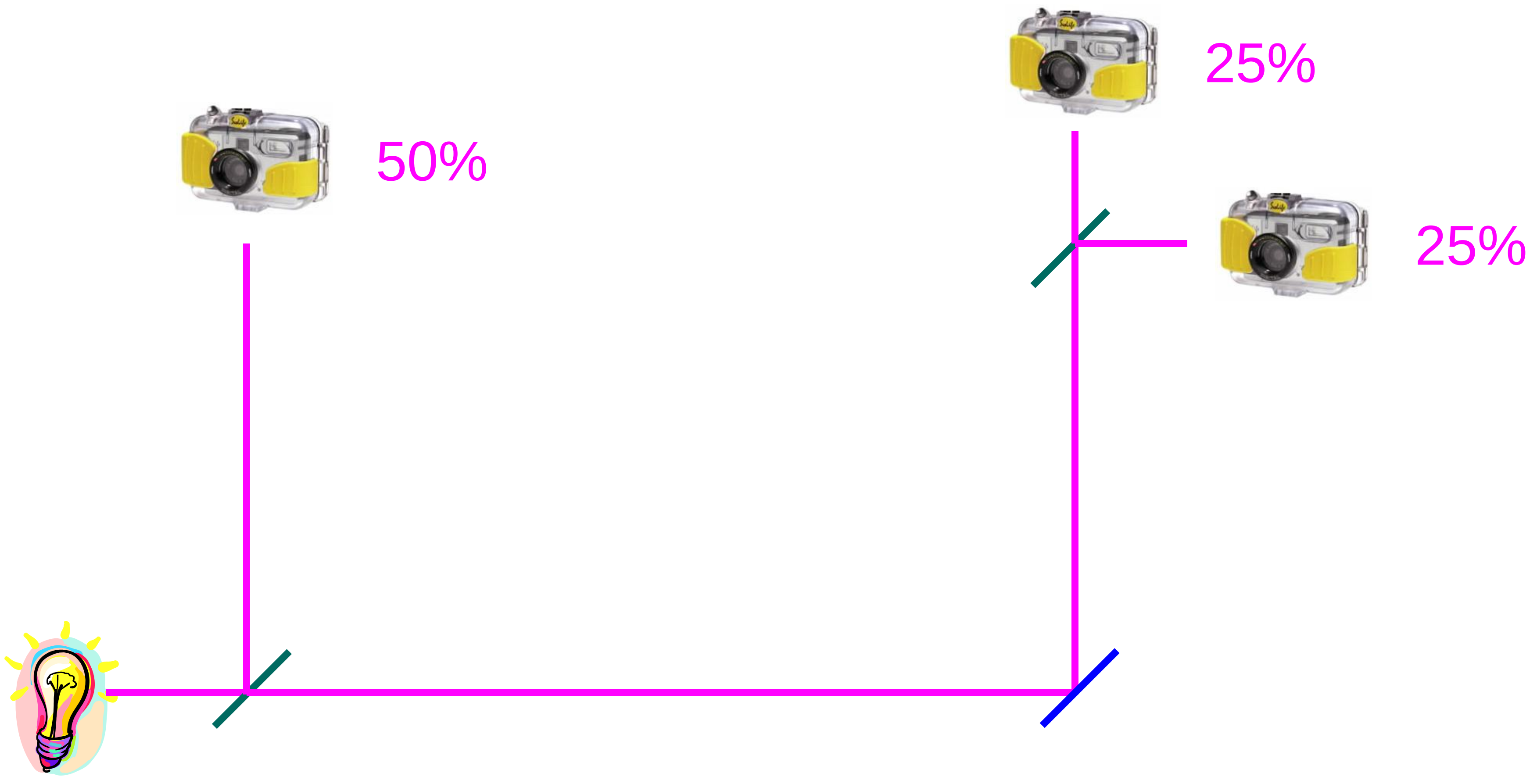
An example

- The Mach-Zender interferometer
- Old fashioned optics or ultra-trendy quantum information theory?

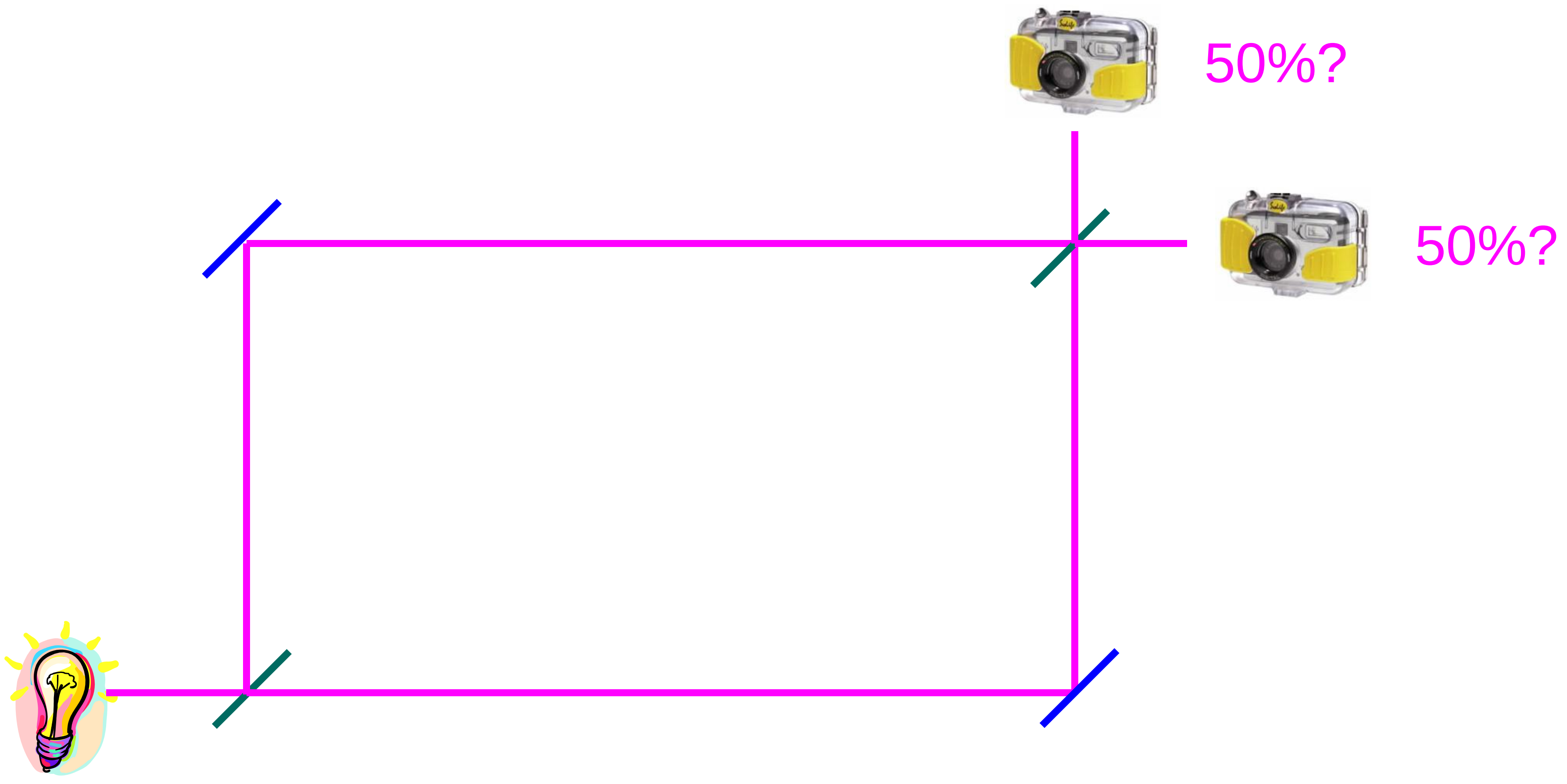
Mach-Zender Interferometer



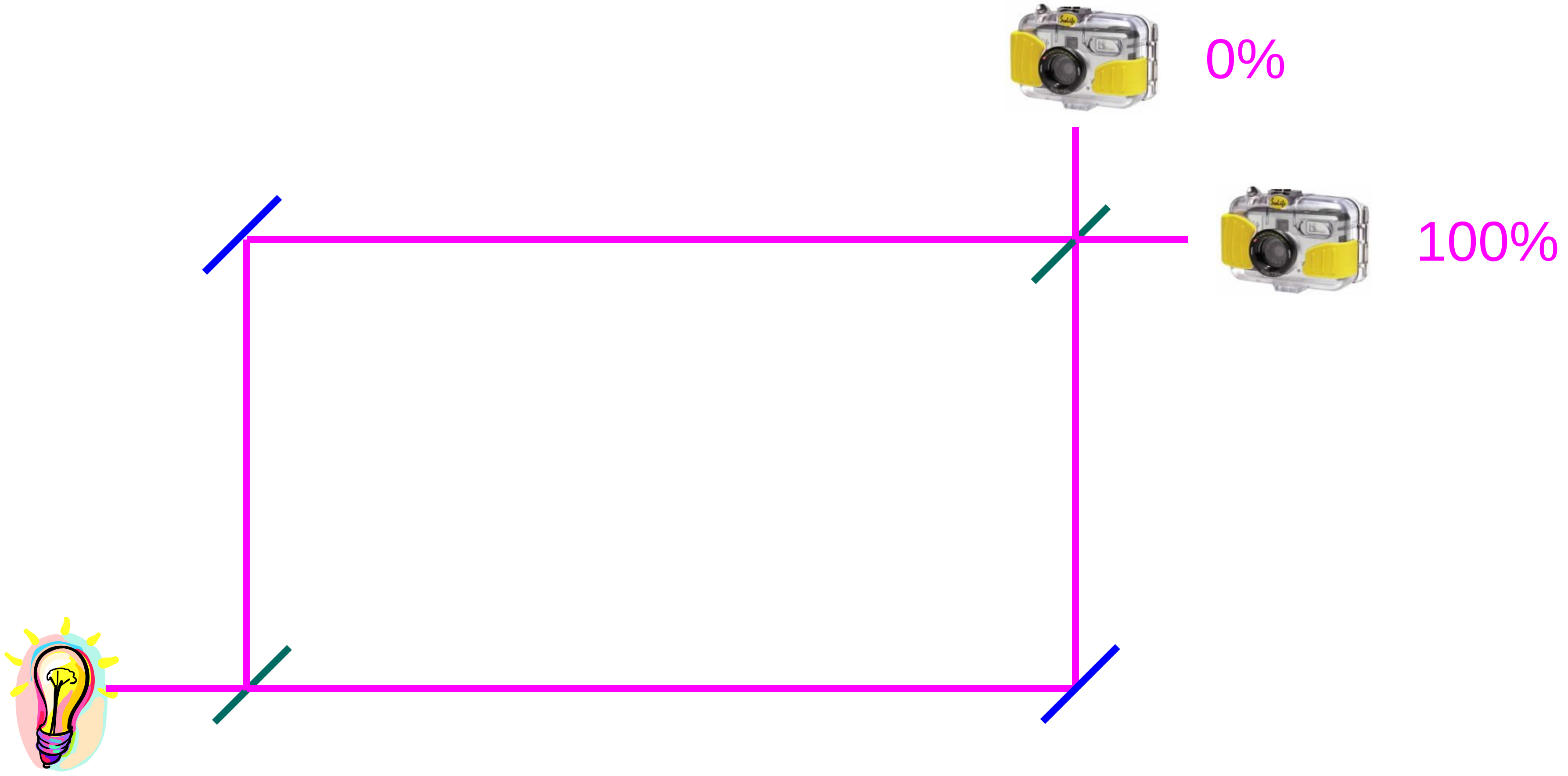
Mach-Zender Interferometer



Mach-Zender Interferometer



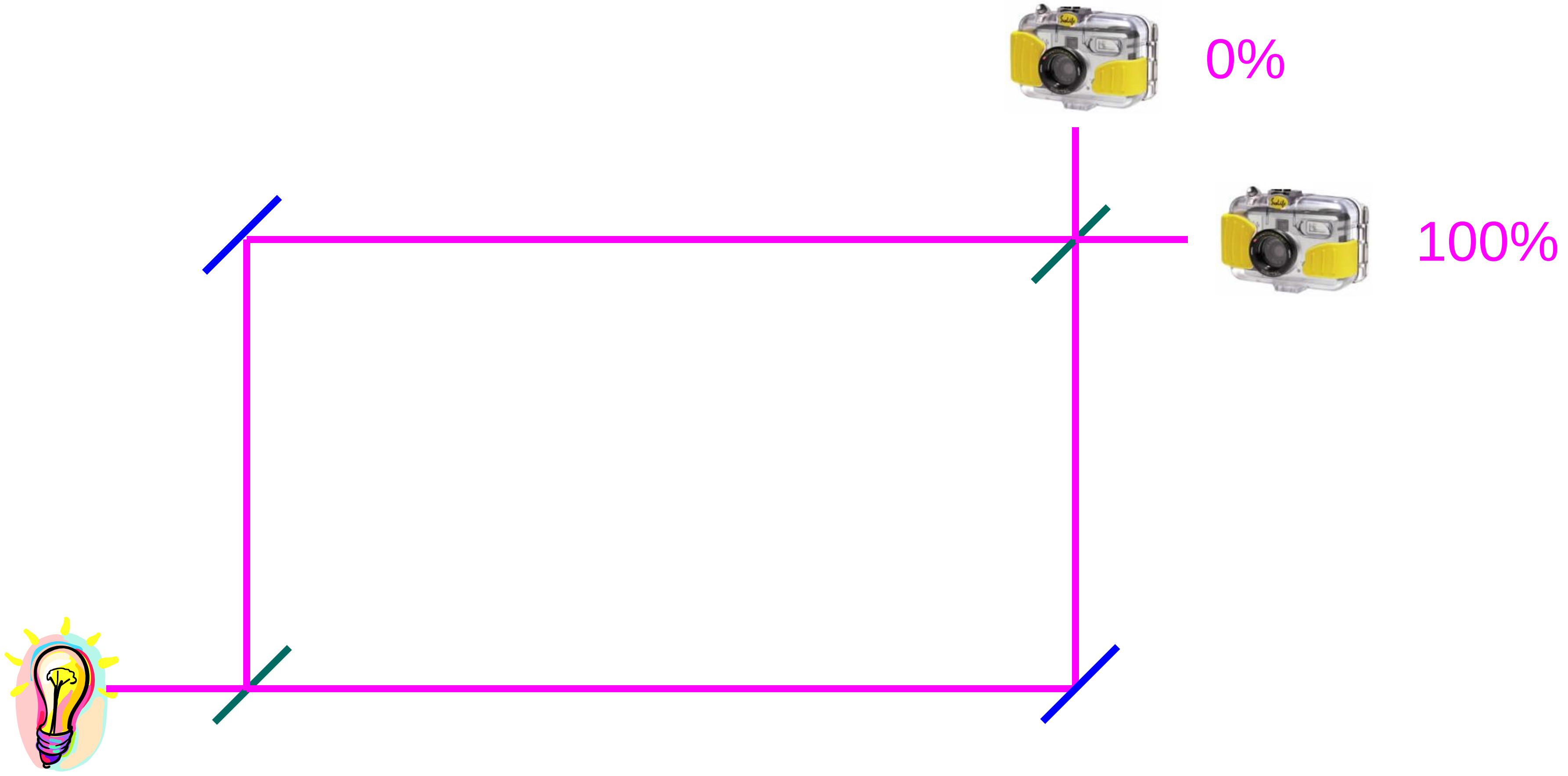
Mach-Zender Interferometer



How can this happen?

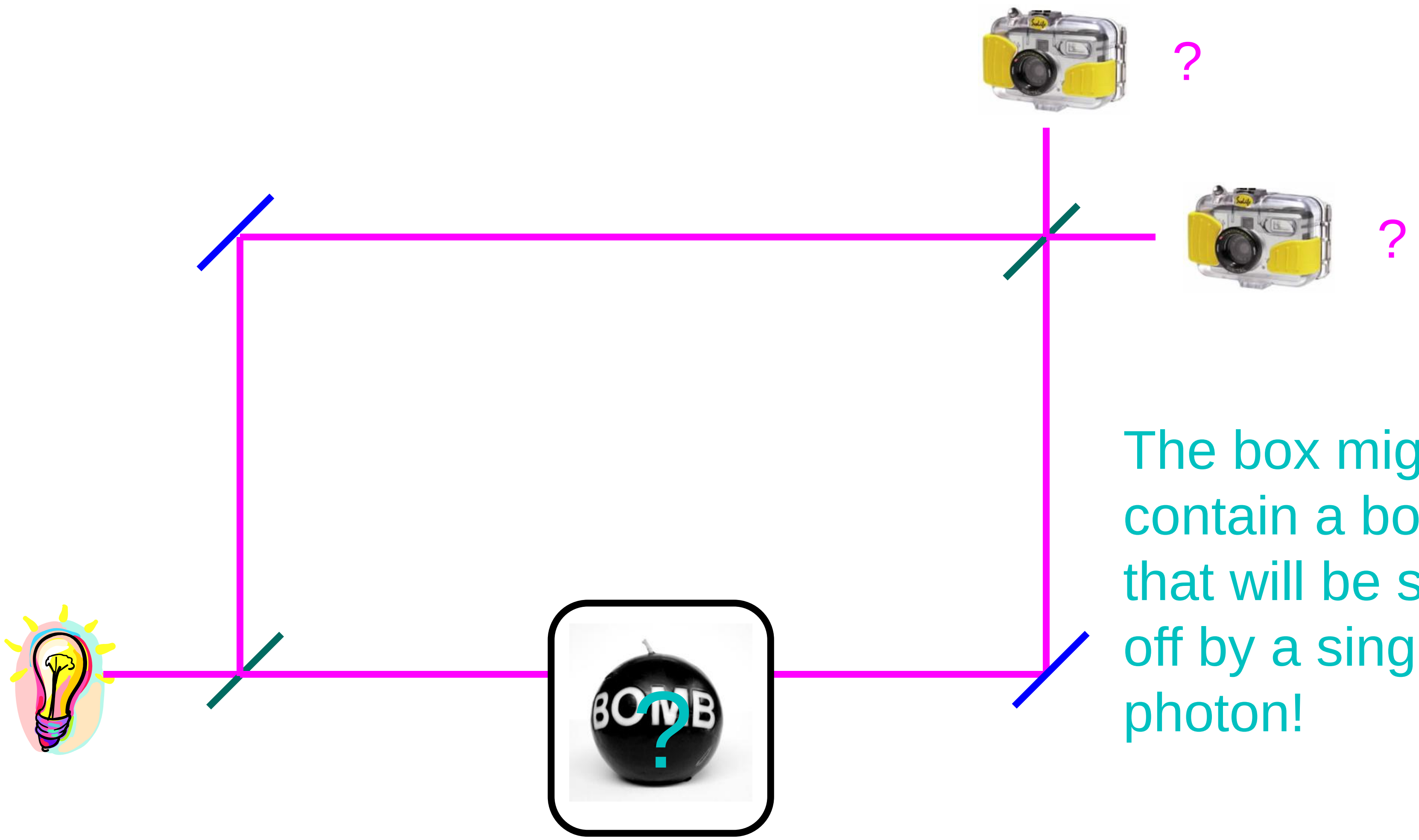
- Fairly easy to understand with classical light waves: interference between the two paths
- Also works when the light is so dim that there is only one photon in the apparatus at any one time
- Also works with electrons, neutrons, buckyballs, etc.

How can this happen?



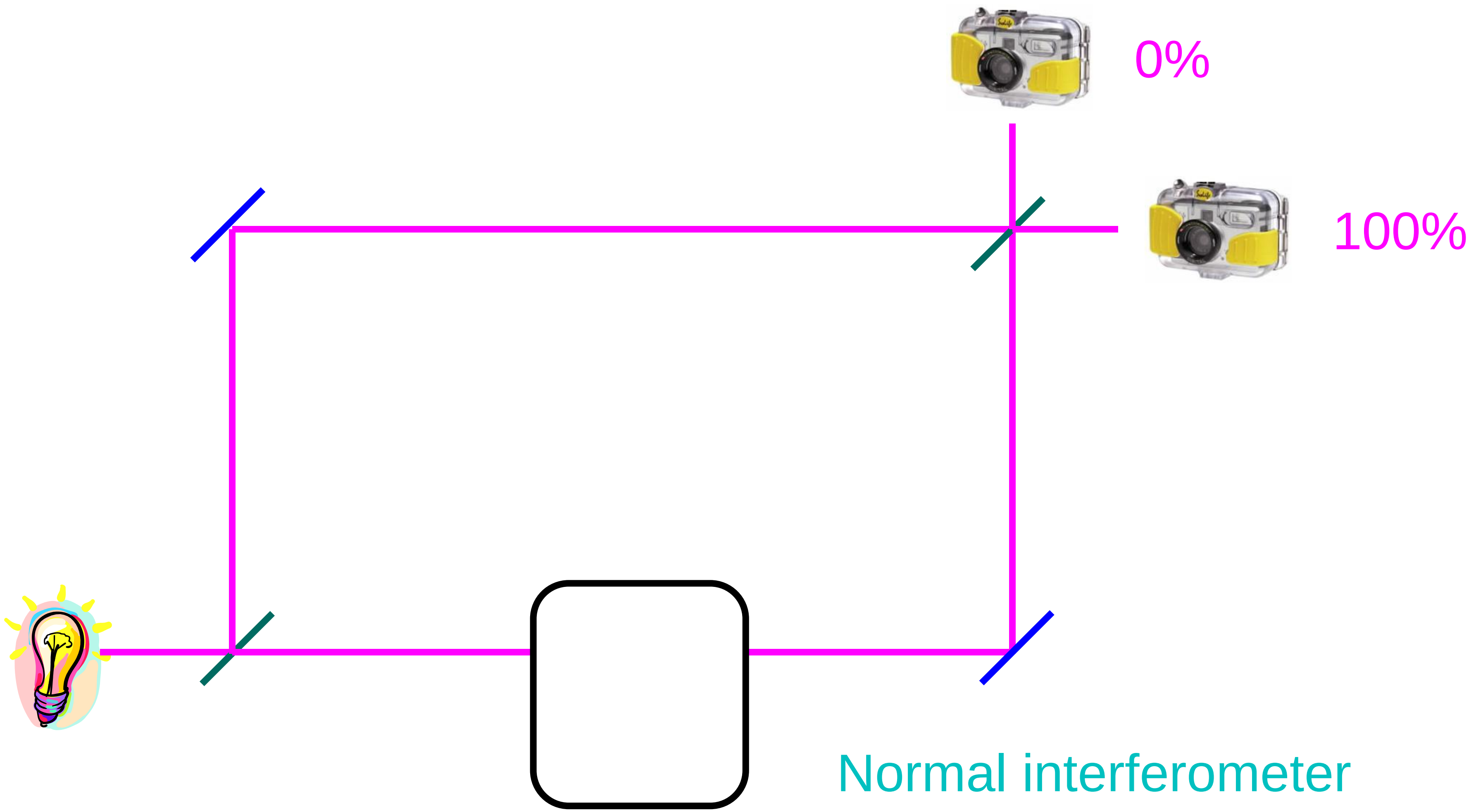
Every photon travels along *both* paths!

Elitzur–Vaidman bomb tester



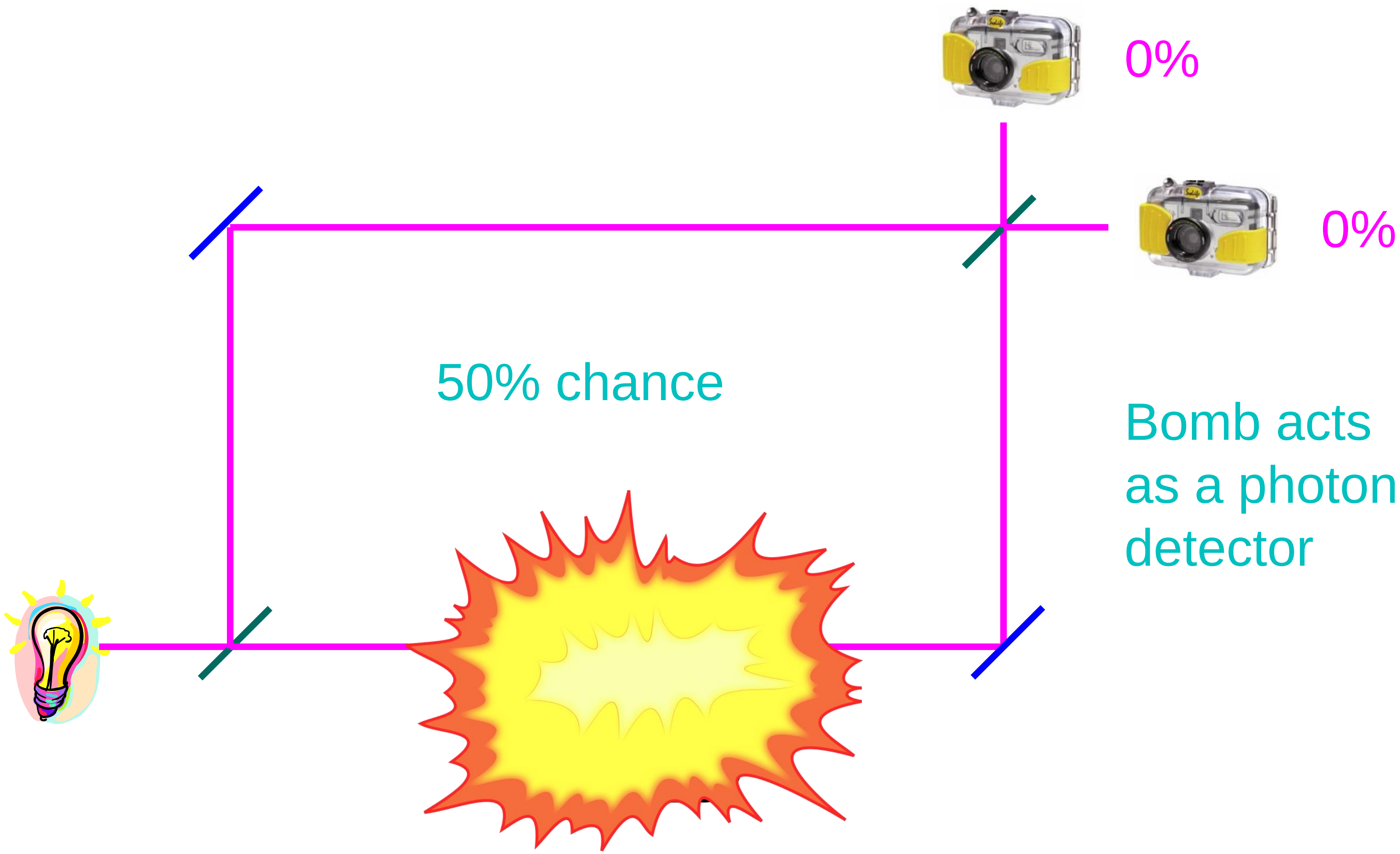
The box might contain a bomb that will be set off by a single photon!

No bomb

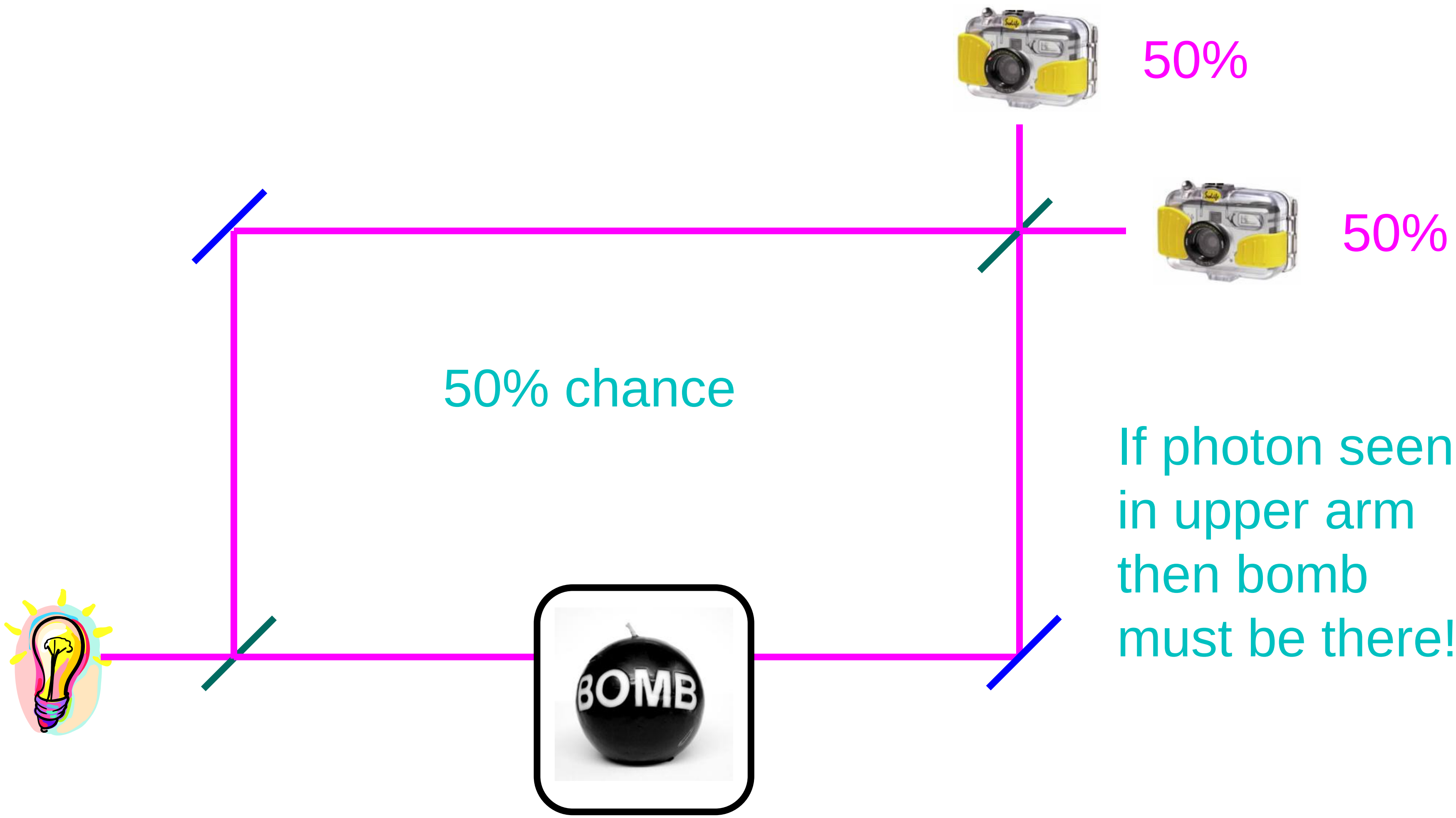


Normal interferometer

Bomb



Bomb


50%
50%
50% chance
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?

C2: Laser Science and Quantum Information Processing
Knowledge of the laser physics covered in paper B2.III 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.
Non-linear Optics: Crystal symmetries and the linear electrooptic tensor. Amplitude and phase modulation of light using the linear electro-optic effect. Second harmonic generation. Critical,non-critical and quasi-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. EPR, the four Bell states, the Bell inequalities.
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.

Laser Science

Quantum Information Processing

Quantum Optics

Laser Science (15)

- 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 (19)

- 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 (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 foolish to 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@qubit.org