DLF

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Experiment 41

Interference of two correlated photons

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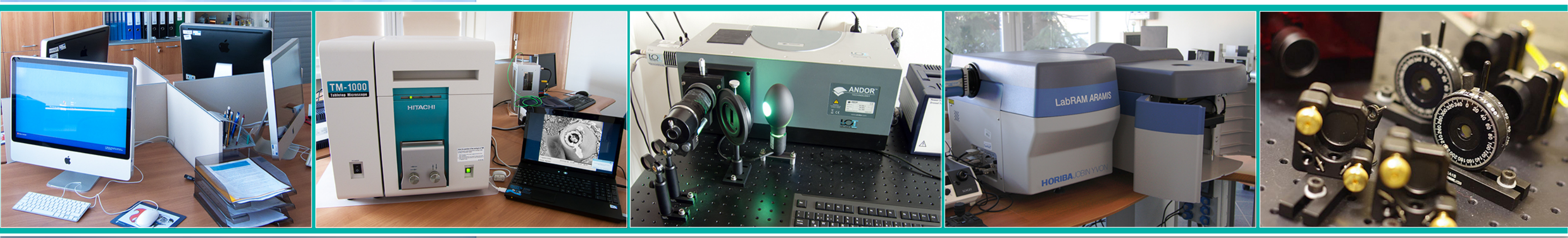
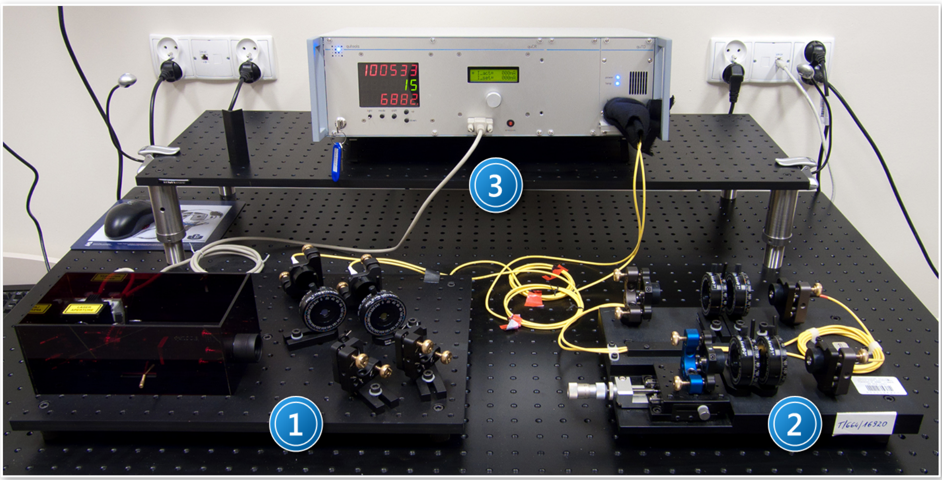


I. Background theory.

1. Description of composite systems in classical and quantum theory.
2. Product and entangled states for bipartite quantum systems.
3. Description of photon polarisation states.
4. Two-photon interference - Hong – Ou – Mandel effect.
5. Natural birefringence.
6. Operation of wave plates.
7. Light polarisers. Glan-Thompson polariser.
8. Parametric down-conversion.
9. Construction and operation of semiconductor lasers.

II. Experimental tasks.

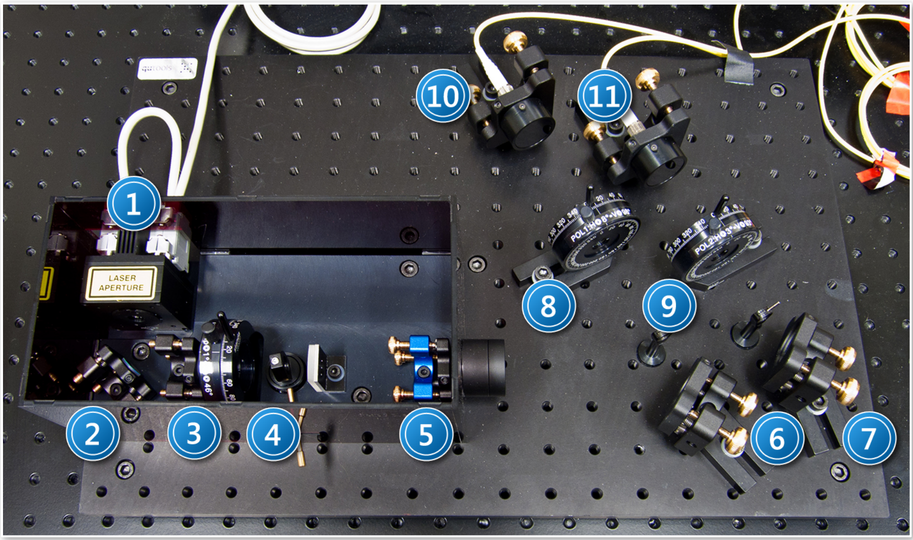
1. Refer to the experimental setup shown in *Pictures 1 – 4* and in *Figures 5 – 8 in Appendices A – C.*



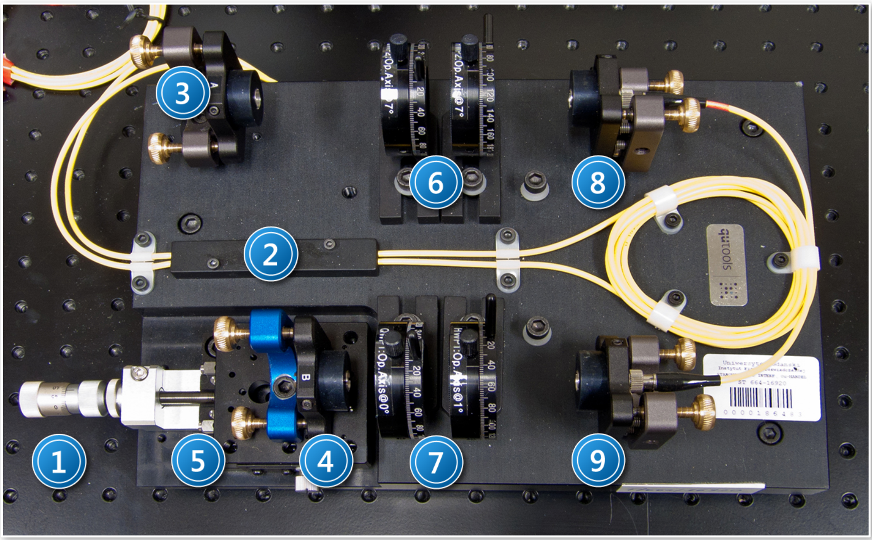
Picture 1. Experimental setup to study the properties of polarisation-entangled photon pairs: 1 – system for demonstrating entanglement visibility; 2 – system for studying two-photon interference; 3 – multi-function unit: power supply – controller – single-photon detector.

2. Set up an interference effect using a spatially correlated photon source (1 in *Picture 1*), guided by the experimental setup shown in *Picture 1*.
3. Before taking any measurements, check all the connections for the whole setup.
   Ensure that:
   • the BBO crystal produces photons of a single polarisation (e.g., V photons by setting the half-wave plate at the source (3 in *Picture 2*) in the horizontal position (to H);
   • the laser power supply current is set to 41 mA;
   • the fibre outputs of the qu2PI setup are connected to the single-photon detector inputs (14) and (15)*, Figure 8*;
   • both ends of the quED source fibres are connected to couplers 3 and 4, *Picture 3* or to both arms of the qu2PI setup and the quED source fibre marked with black tape is connected to the input of the fibre coupler 4 in *Picture 3* in arm B of the qu2PI setup;

• there are interference filters in fibre couplers 8 and 9 in *Picture 3*;
• translation stage 5, *Picture 3,* is more or less in the middle of its travel range (about 12 mm from the right-hand edge).



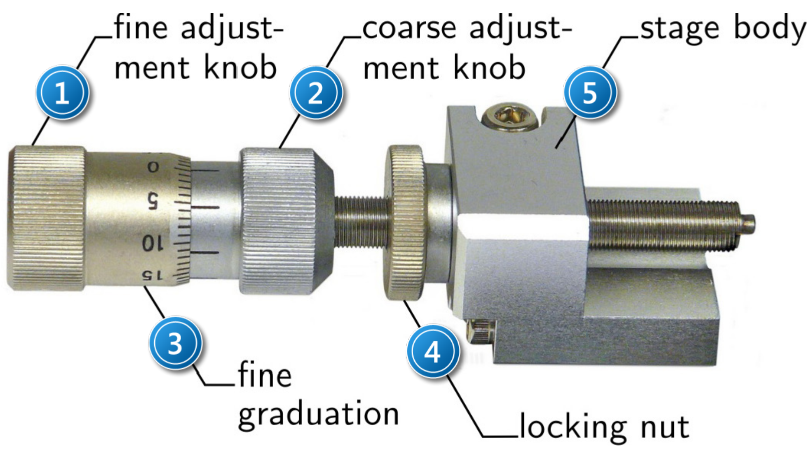
Picture 2. quED I layout for demonstrating the quality of entangled photon pairs: 1 – laser; 2, 6, 7 - mirrors; 3 – half-wave plate; 4 – initial conpensation crystal (YVO_4); 5 – BBO crystal; 8, 9 –polarisers; 10, 11 – optical fibre with couplings.



Picture 3. qu2PI setup for demonstrating two-photon interference: 1 – micrometer screw; 2 – Beam splitter (50:50); 3, 4 – fibre coupler inputs; 5 – translation stage; 6, 7 – dual systems: quarter-wave plate QWP and half-wave plate HWP; 8, 9 – fibre coupler outputs.

4. After checking all the required settings from step II.3., start searching for the Hong – Ou – Mandel interference dip by changing the optical path in arm B of the qu2PI setup. This is achieved by adjusting the translation stage 5 in *Picture 3* to introduce a linear shift.

5. Release lock 4, *Picture 4*, to allow the screw to turn and the stage to shift.



Picture 4. Micrometer screw with description of elements (qutools – Operations Manual for qu2PI): 1 – fine-adjustment knob (50 µm per revolution); 2 – course-adjustment knob (500 µm per revolution); 3 – precise scale (each 1 µm); 4 – knob locking nut 2; 5 – stage body.

6. Start observing coincidence counts in the single photon detector display while at the same time turning the stage's coarse feed screw 2*, Picture 4*, in steps of about 10^{o}, moving the table towards the right-hand edge.

   After each rotation of about 10^{o}, wait about 1 second for the detector's indicator to stabilise.

   Continue to shift the stage, patiently watching the detector.

   After noticing the decline in the number of coincidences, use the locking nut 4, *Picture 4* to lock the course-adjustment knob and continue searching for the dip with the fine-adjustment knob 1, *Picture 4*.
7. After finding the interference minimum, determine the stage displacement range for which the minimum is "clearly visible".
8. Perform several measurements of the coincidence counts by changing the optical path length in steps of 5 µm while noting the coincidence counts.

   Every time, use the fine-adjustment screw starting from a position where the dip in counts begins, then continue taking readings for distance and coincidence counts by turning the screw in the same direction as before.

   Do not record an interference minimum by just reversing the stage – due to mechanical reasons, an error will be introduced of about ±2 µm.
9. Plot a graph of the number of coincidence counts versus change in optical path length (stage offset) in arm B in the range of the observed interference minimum.
10. By fitting a curve, determine the location of the Hong – Ou – Mandel minimum.
11. Estimate the half-width of the recorded interference minimum.
12. Assuming that the half-width of the interference minimum corresponds to the length of the photon wave packet, compare it with the wavelength of light source (810 $\pm$ 10 nm).

III. Apparatus.

Setup for quED I:

1. Semiconductor laser (λ = 401.5 nm, 10 mW).
2. 3 mirrors.
3. Lenses.
4. Half-wave plate.
5. 2 polarisers.
6. Bi-refringent crystal YVO_4.
7. Non-linear crystal BBO (β - BaB_2O_4).
8. Optical fibre couplers.
9. Single-mode fibre.
10. Band filters.

Setup to study interference qu2PI:

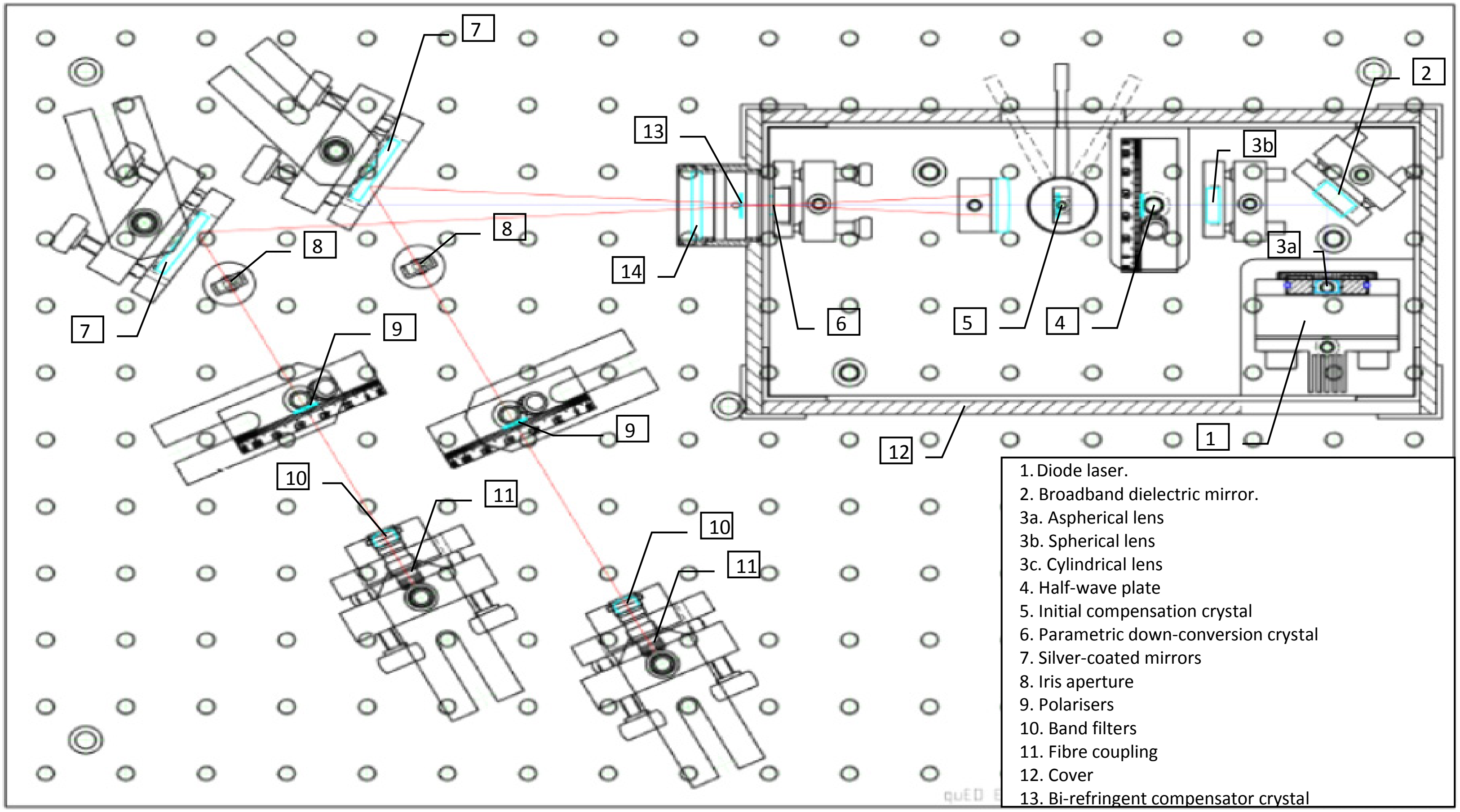
1. 4 fiber-optic couplers.
2. Beam splitter (50:50).
3. 2 quarter-wave plates, 2 half-wave plates.
4. 2 interference filters (803 $\pm$ 2 nm, FWHM = 10 $\pm$ 2 nm).
5. 2 optical fibres.
6. Linear translation stage with micrometer screw.
7. Single-photon detector.

IV. Literature.

1. M. Alicka, R. Alicki – „*Pracownia Informacji Kwantowej / Quantum Information Laboratory*", skrypt Uniwersytetu Gdańskiego, 2011.
2. M. Nielsen, I. Chuang – "*Quantum Computation and Quantum Communication"*, Cambridge, 2000.
3. L. Mandel, E. Wolf – "*Optical Coherence and Quantum Optics*", Cambridge 1995.
4. D. Greenberger, A. Zeilinger – "*Physics World*", **8 ,** Nr 9, 33 (1995).
5. W. A. Shurcliff, S. S. Ballard – "*Polarized Light*", Princeton 1964.
6. M. Born, E. Wolf – "*Principles of Optics*", Cambridge University Press, Cambridge 1999.
7. O. Svelto – "*Principles of Lasers*", Plenum, New York 1998.
8. W. S. C. Chang – "*Principles of Lasers and Optics*", Cambridge University Press, 2005.
9. J.A. Buck – "*Fundamentals of Optical Fibres*", NJ: Wiley – Interscience, Hoboken, 2004.
10. A. Peres – "*Quantum Theory: Concepts and Methods*", Kluwer Academic Publishers, 1993.
11. W. Demtröder – "*Atoms, Molecules and Photons: an Introduction to Atomic - , Molecular- and Quantum – Physics*", Springer, Berlin 2006.
12. D. Dehlinger, M.W. Mitchell – "*Entangled photon apparatus for the undergraduate laboratory",* Am. J. Phys. **70**, 989 – 901 (2002).
13. S. Nakamura, G. Fasol – "*The blue laser diode*", Springer, Heidelberg 1997.
14. H. Paul – "*Introduction Quantum Optics from Light Quanta to Teleportation*", Cambridge University Press, Cambridge 2004.
15. M. Le Bellac – "*A Short Introduction to Quantum Information and Quantum Computation*", Cambridge University Press , Cambridge 2006.

Appendix A

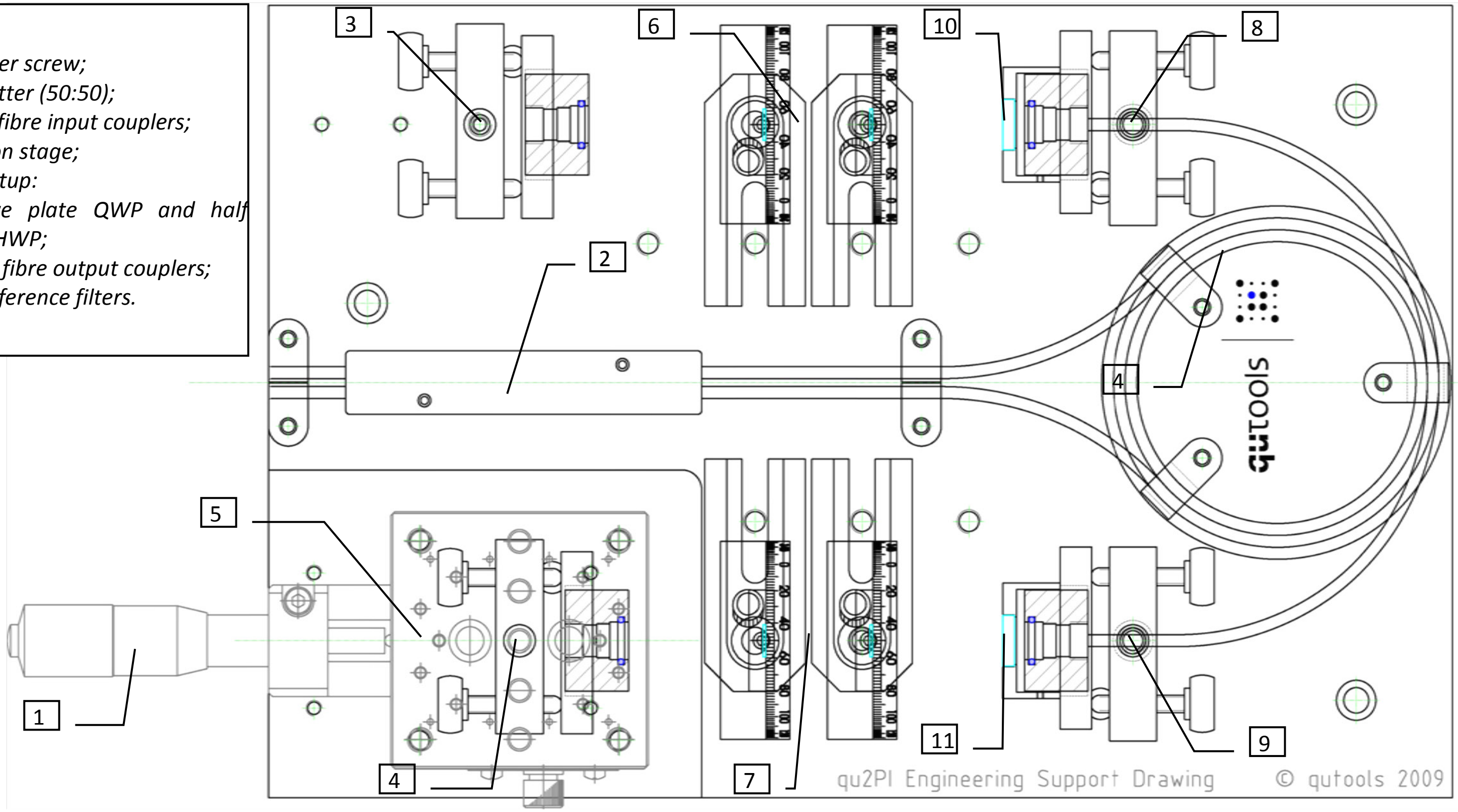
Figure 3. Schematic overview for the experimental setup to test pairs of polarisation-entangled photons



Appendix B

Figure 6. Schematic overview of the qu2PI setup to study two-photon interference

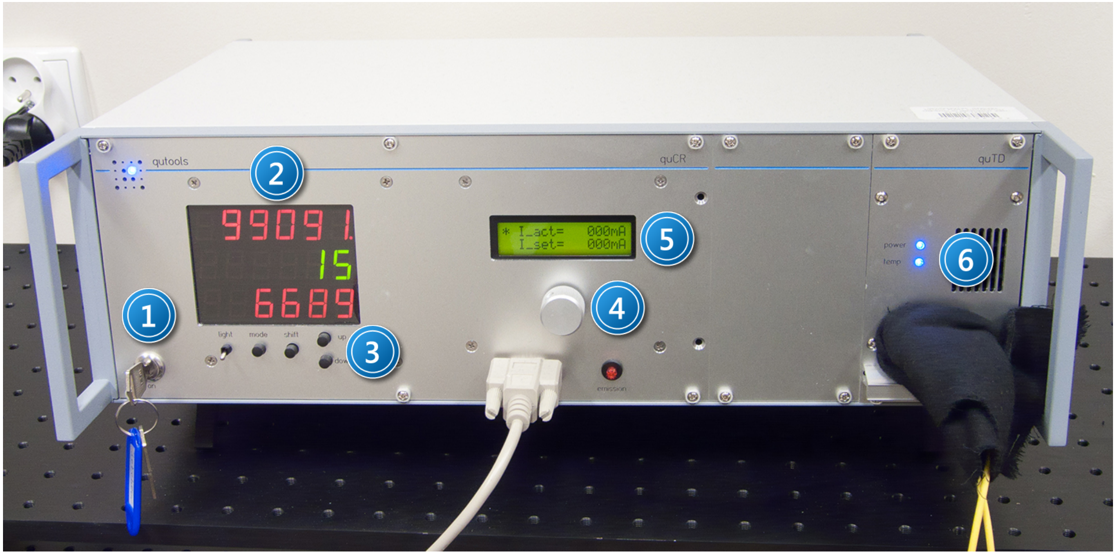
1. Micrometer screw;
2. Beam splitter (50:50);
3, 4.Optical fibre input couplers;
5. Translation stage;
6, 7. Dual setup:
quarter-wave plate QWP and half wave plate HWP;
8, 9. Optical fibre output couplers;
10, 11. Interference filters.



Appendix C

Single-photon detector instructions

1. Turn on the single-photon detector (by turning the key 1 in *Picture 7* and *Figure 8*).



Picture 7. Measuring unit – controller, multifunction power supply, single-photon detector: 1 – main switch; 2 – count display: 3 – count function keys; 4 – laser settings dial; 5 – laser settings display; 6 – APD module indicators.

2. Wait until the blue temperature LED goes off (13 in *Figure 8*) on the detector front panel. This is equivalent to fixing the temperature of the cooling laser to the desired value of -30 ^{0}C.

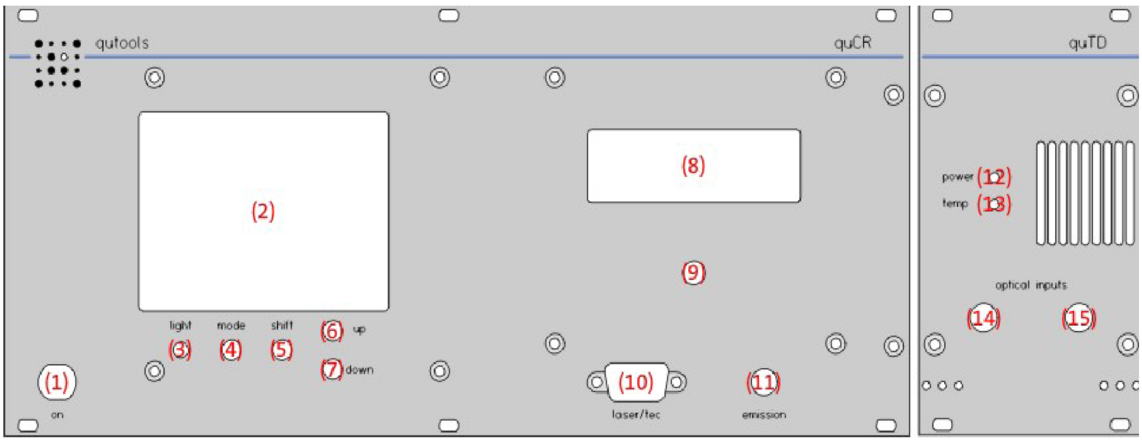


Figure 8. Schematic overview of the measuring unit front panel.

3. Check the display 5 in *Picture 7* (8 in *Figure 8*) to see whether temperature T set is around 22 ^{o}C (this value was set in the programming). If this is not the case, adjust the temperature with the temperature knob 4 in *Picture 7* (9 in *Figure 8*).
4. Set the pumping laser power supply's current I (operating current) to 41 mA (with dial 3 in *Figure 8*).
5. Set the integration time to 5 seconds with knob 7 in *Figure 8* (to reduce fluctuations).
6. The number of coincidence counts is displayed as the central green number on the detector display 2*, Picture 7*.

Hint

The green numbers on the detector display indicate the number of coincidences; the red upper and lower numbers show the number of single photons in the specified integration period for each APD* channel.

* APD stands for Avalanche Photo Diode – the diode uses an avalanche effect in Geiger mode to count the number of single photons in the measuring channel.