Join us on November 30:

the BIG Bell Test

Worldwide quantum physics experiments powered by human randomness
WORLDWIDE EXPERIMENT

IQQO/OEAW, Vienna, Austria
CEFOP/Universidad de Concepción, Concepción, Chile
EQuS -- University of Queensland, Brisbane, Australia
CQC2T -- Griffith University, Brisbane, Australia
CAS -- University of Science and Technology of China, Shanghai, China
LPMC -- Université Nice/CNRS, Nice, France
Ludwig-Maximilian University, Munich
ICFO, Barcelona
ETH Zurich, Zurich
• Light is made by particles. Other particles you know are for example protons and electrons.

• Quantum mechanics is the branch of physics that describes the wave properties of all submicroscopic particles using a mathematical formalism.

• In the theory of quantum mechanics, the wave nature of particles results in the uncertainty principle: the particles do not obey deterministic laws of motion, but the theory predicts only probabilities. Through the wave equation of quantum mechanics, wavefunctions are associated to the particles; the square of the amplitude of such wavefunction is proportional to the probability of finding the particle in a given region of space at a certain instant.
MEASUREMENT IN QUANTUM MECHANICS

• Measurable quantities are called observables (energy, position, momentum…)

• Classically one single particle is fully described by its position \(x(t)\) and momentum \(p(t)\) (related to its velocity). In quantum mechanics a system is described by its quantum state, which contains the probabilities of possible positions and momentum.

• More generally, a quantum state provides a probability distribution for the value of each observable: position \(x(t)\) and momentum \(p(t)\) cannot be known exactly at the same time.

• The uncertainty principle asserts there is a fundamental limit to the precision with which certain pairs of physical observable of a particle, known as complementary variables, can be known simultaneously.

• For position and momentum such limit is defined by the following:  

\[
\Delta x \cdot \Delta p \geq \frac{\hbar}{2}
\]
Other complementary variables are:

- Energy and duration
- Spin on different axis...

Consider a “quantum toy”: we can be measure its shape (square or circle) or a complementary observable, its color (red or blu). Let assume I prepare a “quantum blue toy”.

Then:

- If I measure the color I always get blue.
- If I measure its shape and then its color, I get 50% blue and 50% red outcome.
ENTANGLEMENT

• Quantum entanglement is the “characteristic trait” of quantum mechanics: two (or more) systems cannot be described independently.

• By measuring two entangled systems, we observe correlations that cannot be explained by classical physics.

• Simple example: if a particle has spin “up” in the z-axis, by measuring its spin in the x-axis or in the y-axis, the result is random (50% spin “up”, 50% spin “down”). However, by considering two particles in a singlet entangled state, by measuring the spin of the two particles on the same axis (any direction), the results will be always opposite.

• Such behavior has been experimentally observed even when the two particles are very large distance, but (!!) you cannot use such phenomena to exchange information at velocity higher than c.
SCOPE OF THE BIG BELL TEST

- Entangled states lead to experimentally testable properties (Bell's theorem) that allow us to distinguish between quantum theory and alternative classical (non-quantum) models.

- Any “classical” theory must satisfy:

\[ S = \langle A_1 \otimes B_1 \rangle + \langle A_1 \otimes B_2 \rangle + \langle A_2 \otimes B_1 \rangle - \langle A_2 \otimes B_2 \rangle \leq 2 \]

where \( \langle A \otimes B \rangle \) is the correlation of the outputs when A is measured on the first system and B is measured on the second.

- Measurements on entangled states may violate the bound:

\[ S_{QM} = 2\sqrt{2} > 2 \]
LAYOUT OF THE EXPERIMENT

- In the BBT, laboratories around the world will prepare entangled quantum particles: electrons, photons, atoms, and superconductors.
- Through the Internet, an army of participants, the *Bellsters*, will generate a series of 1 or 0 (\(\heartsuit\) or \(\heartsuit\)).
- Such sequence will be reinforced using a random generator system at ICFO.
- The particles will be tested according to the generated random sequences.
HOW THE RANDOM SEQUENCE IS USED

• The zeros and ones are distributed to labs around the world.
• In these labs there are Alices and Bobs, who are waiting for such input to make their measurements (device $A_1$ or $A_2$ for Alice and $B_1$ or $B_2$ for Bob) on twins (entangled) particles generated at their labs.
RANDOMNESS

- Alice makes the measurement on one twin, Bob on the other one (independent measurements)
- 1 and 0 are used to decide what type of measure they have to perform (select randomly device $A_1$ or $A_2$ for Alice and $B_1$ or $B_2$ for Bob)
- In order to perform a Big Bell test randomness must be used
CONCLUSION

• The statistical analysis performed on the results will allow to determine if quantum mechanics predictions are correct or not

• In particular such result will be helpful in determining if reality can be described by a local realistic theory or not

Be part of this huge experiment on November 30

For more infos

http://thebigbelltest.org/