Prepare a response for each of the following prompts below (300-500 words overall).

1: There is a whole scientific community interested in providing an indisputable proof that nature violates Bell's inequality. Explain why the Big Bell Test assures that they closed all the loopholes and what does it imply for our understanding of the universe.

Scoring criteria
(2 pts) Complete: *Defined the concept of loophole in Bell's inequality context. Described the freedom of choice loophole. Summarized the arguments of the Big Bell Test collaboration about why they are closing the freedom of choice loophole.*
(1 pt) Partially Complete: *Defined the concept of loophole in Bell's inequality context. Described the freedom of choice loophole.*
(0 pt) Incomplete: *Defined the concept of loophole in Bell's inequality context.*

2: Gamification is a powerful tool that can be used in several contexts, such as marketing and generation of products. Explain how The Big Bell Test experiment utilized gamification for generating random numbers and imagine and discuss other possible applications of gamification in quantum computing.

Scoring criteria
(2 pts) Complete: *Described how the Big Bell Test Game works. Explained the process done by the Big Bell Test collaboration for generating random numbers. Gave one possible application of gamification in quantum computing.*
(1 pt) Partially Complete: *Described how the Big Bell Test Game works. Explained the process done by the Big Bell Test collaboration for generating random numbers.*
(0 pt) Incomplete: *Described how the Big Bell Test Game works.*

3: Choose two of the thirteen nodes of the Big Bell Test experiment and compare their physical system, degree of freedom measured, rate of bits consumed and total number of bits, how where the bits used, how long the experiment took, and the distance between Alice and Bob.

Scoring criteria

(*2 pts) Complete:* Compared the physical system and degree of freedom that each node used, and also compared the rate of bits consumed and total number of bits. Described how bits were used, how long the experiment took and the distance between Alice and Bob.
(1 pt) Partially Complete: Compared the physical system and degree of freedom that each node used, and also compared the rate of bits consumed and total number of bits.
(0 pt) Incomplete:
Compared the physical system and degree of freedom that each node used.

Answer to question 1:

Bell's theorem proves that quantum physics is incompatible with local hidden variable theories. John Bell analyzed the quantum entanglement, he concluded that if measurements are performed independently on the two separated halves of a pair, then the assumption that the outcomes depend on hidden variables within each half implies a constraint on how the outcomes on the two halves are correlated. This constraint was called Bell's inequality. Then, Bell showed that in quantum physics correlations violate the inequality. So, the Bell tests have found that the hypothesis of local variables is incompatible with nature.

There may be problems of experimental design that can violate the experimental findings, such problems are called loopholes. Violation of Bell's inequality with entangled particles presents a challenge. One of the challenges is that the possibility to communicate between the stations is eliminated, additionally, the choice at one station can influence a measurement result at the other station. This is called a **locality loophole**. If communication is possible, a station(or Alice and Bob, it doesn't matter) can respond using knowledge of both input settings, considering the Bell inequality invalid. The locality conditions thus require that stations A and B and their respective free input bit generations to be separated in such a way that signals traveling at the speed of light cannot communicate the local input setting of station A to station B, before the output value of station B has been recorded, and vice versa. Also, the input bits should not be able to influence the preparation of the entangled state. **Detection loophole** disregarding trials in which a station does not produce an output bit would allow the boxes to select trials based on the input setting. The fair sampling assumption thus opens a detection loophole. The selected subset may show a violation even though the set of all trials may not[1].

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[1] arXiv:1508.05949v1 "Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km", 2005

The **freedom-of-choice loophole** (FoCL) is an example of a loophole occurring in Bell's inequality, describing the idea that experimenters have total freedom to choose the experimental setup, but what if there were "hidden variables" correlated with the experimental setup. These variables will make the results appear quantum entangled, when in fact they weren't the result of quantum mechanics. "FoCL describes the possibility that "hidden variables" influence the setting choices. As we cannot guarantee such freedom within local realism, the tests must assume physical indeterminacy in the hidden-variable theory", as it was mentioned in the article.

The human capacity for free choice removes the need for assumptions about physical indeterminism, allowing FoCL to be closed.

Bell himself said that human choices could be considered as "free variables" in a Bell test, which was an idea to make humans a "system of choice" (so-called Bellsters).

The Big Bell Test Collaboration tested quantum entanglement with the help of 100,000 Bellsters worldwide. Bell tests are about producing large numbers of entangled pairs and making random measurements on certain properties of particles in each pair. It turned out that when the measurement choices are made by humans, rather than by random number generators, the FoCL can be closed. The BBT Collaboration used a variety of entangled particles and systems including photons, atoms, and superconducting devices. The collaboration showed that with the help of community random numbers can be collected from a large number of people, leading to allow human participation in laboratory experiments. All these imply that physics is weird and there are a lot of proven theorems that can be violated in physics and the experiments are always there to show the result.

Answer to question 2:

A Bell test is an experiment to decide whether the world is really as weird as quantum mechanics says it is. Quantum physics seems to observe the world from other angle. Niels Bohr, a towering figure in quantum mechanics, even claimed that observables such as "the position of the atom" have no meaning until someone measures them. If this is true, the act of observation at least alters and maybe creates the world, quite the opposite of an independent reality.

The Big Bell test is a worldwide physics experiment powered by human randomness. This a successful example of gamification, that helped the science a lot. To encourage participants to contribute a larger number of more unpredictable bits, the input was collected in the context of a video game, The BIG Bell Quest, implemented in javascript to run directly in a device's web browser. The BIG Bell Quest is designed to reward sustained, high- rate input of unpredictable bits, while also being engaging and informative. An interactive explanation first describes quantum nonlocality and the role played by participants and experimenters in the BBT.

As in any scientific experiment, the BBT creators wanted to be sure of the precision our result, to know that the effect we are observing is really a consequence of the properties of the physical world. A common way to reduce the uncertainty on the result of an experiment is to repeat it many times and then check if the results are statistically significant. The player is then tasked with entering a given number of unpredictable bits within a limited time. And the fact that people vary from each other as much they can was very significant in terms of result. A machine learning algorithm (MLA) attempts to predict each input bit, modelling the user's input as a Markov process and updating the model parameters using reinforcement learning.

Scoring and level completion reflect the degree to which the MLA predicts the player's input, motivating players to consider their own predictability and take conscious steps to reduce it, but the MLA does not act as a filter: all input is passed to the experiments. Bellster input showed unsurprising deviations from ideal randomness 27. Modern video-game elements were incorporated to boost engagement (animation, sound), to encourage persistent play (progressive levels, power-ups, boss battles, leaderboards) and to recruit new players (group formation, posting to social networks). Different level scenarios illustrate key elements of the BBT: human input, global networking, and measurements on quantum systems. A gaming component handles the BBT website, participant accounts management, delivery of game code (javascript and video), score records and leaderboards. In parallel, a messaging component handles data conditioning, streaming to experiments, and reporting of participant choices generated via the game. The timing of input bits was used to identify robot participants and remove their input from the data stream.

In my opinion, the same game can be given to animals to play, to make the results as close to nature as possible, but of course it is very resource demanding. An example of application of gamification could be the engagement of people in the quantum communication via cloud, so they can send data via a game with the use of quantum network, this can be a way of testing the trustworthiness of quantum internet. But some progress is a must for this gamification example to implement.

Answer to question 3:

For the investigation we took nodes 9 and 12.

Below is the table giving basic information on the Node 9 Bell test using entanglement between a photon and a collective atomic excitation, driven by human randomness and node 12 post-selection loophole-free energy-time Bell test fed with human-generated inputs.

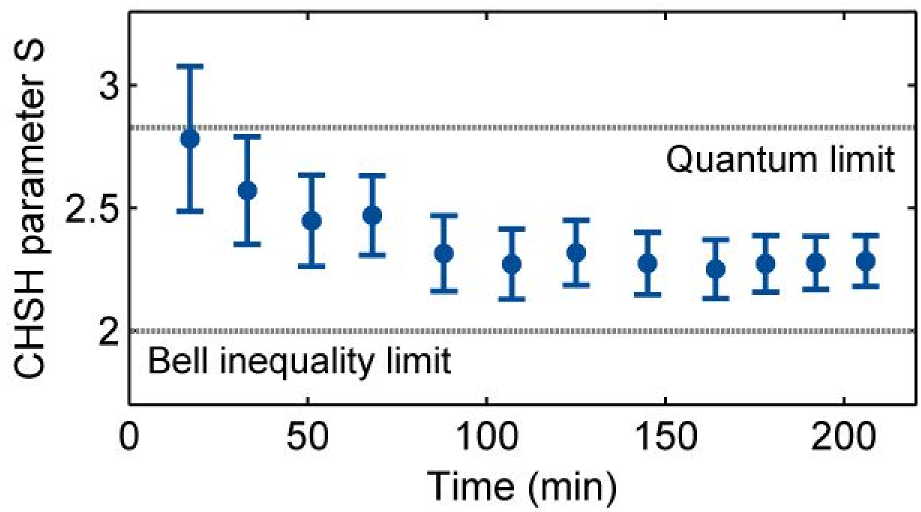
ID	Lead Institution	Location	Entangled system	Rate	Ineq-uality	Result	Statistical significance
9	ICFO	Barcelona, ES	γ-atom ensemble	125 bps	$\|S\|\leq 2$	$S=2.29\pm 0.10$	2.9σ
12	CONCEP-CION	Conception, CL	γ time-bin	52 kbps	$\|S\|\leq 2$	$S=2.43\pm 0.02$	20σ

Node 9 used single-photon/atomic ensemble entanglement

Node 12 used entangled photon pairs

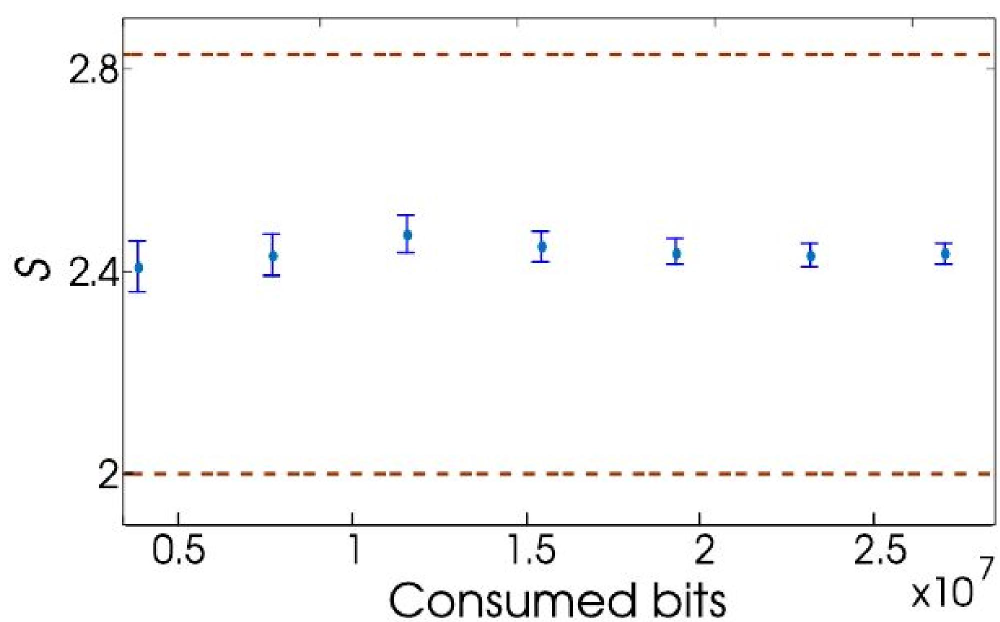
We can see in the article (Fig.2) that active experiments were in photonic physical systems rather than material. In two nodes(9 and 12) the physical systems were photonic hence there have been active experiments.

Node 9: Total number of bits were recorded 1100 photon coincidence events which led to a final CHSH Bell parameter of $S = 2.29 \pm 0.10$. This measurement shows a violation of the Bell inequality $|S| \leq 2$ by approximately three standard deviations. The rate of bits was 125 bps. The data acquisition lasted 3 hours and 26 minutes, during which we performed 364800000 experimental trials. The picture below describes accumulated CHSH Bell parameter S as a function of data acquisition time for the measurement with stored human random numbers for node 9.



Node 12: For each measurement round two bits are used from the BBT server to choose one out of the four possible setting combinations (two settings for Alice and two for Bob).

The experiment was done at a rate of 52 kbit/s while consuming approximately 27 million bits from the BBT database. Cumulative S final value is 2.4331 ± 0.0218, corresponding to a violation of 19.87 standard deviations for a total of 20676 detection events. The propagation distance between the source to Alice is 15 m and from the source to Bob is 45 m, determined mainly by the length of the piezoelectric spooled fiber-optical stretchers (10 m long for Alice's interferometer and 40 m for Bob's).



The rate of bits consumed on node 12 was much more than in node 9. In the picture we see cumulative CHSH violation (S parameter) as a function of the amount of consumed bits. Dashed red lines represent the local bound (2) and the quantum bound($2\sqrt{2}$). Error bars in both subfigures represent the standard deviation.