2016 Conference Transcription

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Session Title	Thriving In Uncertainty
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Moderator	n/a
Speakers	Ben Still
Notes	n/a

Introduction

Moderator	Hello and welcome to Future Everything 2016 Festival Podcast Series. Over two days, in Manchester's iconic Town Hall, we tasked designers, artists, scientists, and many more, to rethink our resources from life, earth and intelligence to community and uncertainty. Our speakers asked what we might need less, and more of, in our near future. Speaking in the Thriving In Uncertainty session, we welcomed award winning science communicator, Dr Ben Still, who talks about some of the most difficult concepts within the realms of science. Ben regularly works with artists to communicate work in physics, and uses Lego bricks to build universes.
Ben Still	Hello, this is now time for something different. I'm going to talk a little bit about uncertainty in nature, because uncertainty comes into any area of science in much the same way as has been taught by other speakers in statistical uncertainties in the data that we have, but also in systematic uncertainties in the way in which we collect that data. I would like to talk about how nature itself is uncertain at the smallest level, so particle physics involves itself with quantum objects. So I wanted to talk about the bizarre quantum world, and even how hard we try. Everything at the fundamental level tends to be uncertain and it's actually sewn into the fabric of nature itself. So this is going to go through a little bit of history first, and I'm going to talk and hopefully explain a little bit more about where this uncertainty comes from. In the late sixteen hundreds, Isaac Newton had an idea that light itself was very much like a ball and reflection was just a bouncing of these billiard like particles. He did some famous experiments involving prisms where he saw the diversion of light splitting into the constituent colours, and then combining again to form white light. He thought that this was just different types of particles of light spreading apart and then combining again to recombine to make white light. But

his contemporary, Christiaan Huygens, who was very much quashed by Newton's prowess at the time, had a different idea, and he thought light was like waves. Newton poo-pooed this idea entirely, because he didn't think light was a wave, because otherwise it would be seen to diffract and spread around objects. And as far as he could see, that wasn't something that light did in the world around him. So for a long time, Isaac Newton's idea of light as a particle reigned supreme.

This was until 1803, when Thomas Young simply made two very small holes in a piece of card and looked at sunlight shining through it, and what he saw was light and dark fringes. I can actually to do this for you. If you look over to the piece of paper over there, can you see the light and dark fringes there? So that's just the double slit experiment, exactly what Thomas Young did. These light and dark fringes weren't something that particles were viewed to do, because if particles were just travelling through two holes, you would expect those particles to just form a pattern essentially shadowing those two holes. Thomas Young could only explain it by going back to Huygens idea that light was in fact a wave. If it was a wave, then the dark patches occur where the crest of a light wave would meet the trough of another light wave through interference, through the two different slits, and you would get a dark patch. The light patches were the addition of a peak of a wave to the peak of another wave that was coming through the two different slits. So Thomas Young was trying to convince us that suddenly now, light was showing us to be not a particle as Newton thought, but as a wave.

Then it got a bit more complicated, because in 1900, Max Planck was trying to explain how we see radiation emitted from special objects, which we call black body emitters. Black body emitters emit a range of radiation depending on their heat. If you measure the radiation that they emit, then you can tell the temperature of the object or vice versa, because there is a very definite distribution of the radiation emitted. The only way that he could mathematically actually explain this, was by saying that light can't be a wave because if it was a wave, then it would explode to infinite energies, very small scales, but he went back to the idea of viewing as a particle. He said that light was pixelated into chunks of energy dependent on the frequency, and he gave this number the Planck constant H, and this was a granulatory of light.

Einstein won his Nobel Prize for this particular piece of work, in 1905, called the Photoelectric Effect. He took Planck's idea of light being particles once more, and was able to explain how electrons are liberated from pieces of metal when ultraviolet light shone upon them. You can increase the brightness of the light and it will increase the number of electrons that are released. But if you increase the energy of the light, you don't get the same kind of increase. If you imagine if you increased the energy of a water wave hitting a beach, you would wash away more sand. But this wasn't what was being seen with light. If you increase the energy, you weren't washing out more electrons, you've still got the same number of electrons coming from the metal.

Then Duane Taylor, in 1909, did Young's experiment, but dialled down the intensity of light. He dialled it down so low that one particle of light was seen appearing on his photographic plate. It seemed that light was arriving in lumps and chunks. But over time, once all these lumps and chunks had arrived, low and behold he got the same pattern that Thomas Young saw. So although light was being emitted and arriving in chunks, it seemed that the pattern it produced was a pattern that could only be attributed to a wave.

So what was going on here? Light is something called a quanta. Light and all of subatomic particles are something very different to a particle or a wave in a classical sense. It's something that is a mixture of the two, but not exactly one or the other. It's very much like the 'weeping angel'. I don't know if you've ever watched Dr Who, but the weeping angels in Dr Who only move when you're not looking at them, and quantum particles are very similar. They behave wave-like when you're not looking at them, so quite sinister. But when you look at them they seem all innocent and you actually see them acting like particles. That's probably the best analogy I could come up with.

So what does this lead to? If these things are acting wave-like in some cases and point-like particles in others, what does this mean? Louis de Broglie, was the person that extended this idea from light to particles. He said, 'if light is doing this, why don't other subatomic particles do this? Surely electrons and other things would'. So he said 'that means that electrons would have a wavelength, just like we can measure light to have a wavelength.'

Soon after, these gentlemen, Davisson and Germer, actually through firing electrons through a crystal, were able to see the same interference patterns with electrons that Young saw back in 1803 with light. This was now proving that although this is a bizarre nature, it seems that all of these subatomic particles do behave in the same kind of way. So it was basically the double slit experiment. So what you were seeing is, if we put these particles, photons, or electrons through the double slit one by one, you gradually built up a picture. What we ended up seeing was that that picture didn't look exactly as we expected. So although you have an idea about what to find out… and this Mona Lisa picture is my analogy for all of particle physics. It's essentially trying to find out that underlying wave-like nature by building up point by point, through pieces of data, the underlying picture, and I'll go through that a lot more.

Where does uncertainty come in? Uncertainty comes in an interesting way. This is just another example of the double slit experiment using other pieces of equipment. So if we dial down the light intensity of a light source, so that we're getting individual particles of light, these individual photons coming through one by one, and we have a photon detector here which is counting these. If we add in a very complicated piece of equipment called a beam splitter, which is essentially just a piece of glass which will reflect fifty percent of the light and let fifty percent of the light transmit through, and we have two light detectors. What we expect is, we get counts of individual photons, and we get to see this nicely, and we get a fifty percent chance of it going to this detector and a fifty percent chance of it getting to that detector, on average. If we add in an extra beam splitter and some mirrors so that we're now passing it into this beam splitter, fifty percent is being reflected, fifty percent is being transmitted. It then goes to this other beam splitter, in which fifty percent should be reflected and transmitted.

Do we expect to see a fifty-fifty split still? In fact, what we don't see is that these photons, although being emitted as particles, they interfere. They interfere in the same way that they did when they travelled through the double slit. This is just essentially with the two beam splitters. Imagine them as the double slit in the experiment. The interference, again, means that we see only hits in this detector and not in this one. If you're bringing the analogy to the double slit it's as if the peak is meeting a trough at this point, so we don't get any probability that we're going to see a photon in this detector. Whereas the peak is meeting the peak through this path, and it means that we see all of the photons coming into this detector.

I've talked about these things being wave-like and particle-like for a reason, because when they're wave-like, we can explain the momentum very well. The momentum of these particles is described by the frequency of the wave. If you have a wave which stretches out into infinity in both directions, and it has a regular period, then it's got a very well defined frequency. In quantum physics, that means it has a very well defined momentum. So if we're certain about the frequency, then we can be certain about the momentum of it. But that wave stretches out into infinity, so we don't have an idea of the exact location of this wave-like nature of the particle. If we add together lots of different frequencies, what we get is a like a beat. If you're thinking about waves as sound, you get a beat. Instead of a pure tone you get a beat. The beat means that it's very well understood in terms of position, but to achieve this we've had to add together lots of different frequencies of wave. We're now uncertain about the momentum of the particle because the frequency relates directly to momentum.

So it turns out that with these quanta, we cannot be certain about both the momentum and the position of a particle, and this is totally different to the idea of classical physics, where if we know the energy and angle that we kick a football, we can calculate whether it's going to go in the goal or not. This exact thing means that there is always going to be uncertainty in any final state calculation of a quantum object. You may know its initial position, or you may know its initial momentum, but there will always be an uncertainty on the other, which means that you can't predict with certainty where this particle is going to end up. It builds into nature the idea that we're unsure of the evolution of nature at that scale.

So a photon striking a double slit, at one time produces interference, but if we're there to look at it, that interference pattern breaks down. This is just a consequence of the uncertainty principle. If you are looking to see which slit your photon that you're firing goes through, then you have a very good idea of its location. If you have a very good idea of its location, the uncertainty principle says that you can't know anything about its momentum. If you can't know very much about its momentum, then the frequency or that wave-like nature breaks down, and so it behaves more particle like. Whereas, if you're not looking at the slit, you don't know whether it goes through slit one or slit two. You have no idea about its position. It can behave as that wave and actually interfere. The same thing happens with this other set up, which I said is just an analogy. If we follow this path and we end up getting a hundred percent in here, but if we observe and see whether our photon has taken this bottom path or not, again, what

	happens is it breaks down, because we've determined a particular path, we've determined a particular location, the wave-like nature of it, the certainty on the momentum breaks down, and suddenly it behaves as if it was a bouncing particle. So it may be bizarre, but this is how nature works at the smaller scales and it's just something I wanted to discuss in this realm. So we can tell when someone is watching, and if anyone is interested in quantum computing, this is a very strong argument for quantum computing and cryptography as well. If you want to make sure that your data is safe, if you're sending a message that is quantumly crypto-graphed through a data line, it will basically breakdown into gobbledygook for anyone that's trying to intercept it. You will know when you receive that data packet if it's actually been observed or not, because it would breakdown into something again that doesn't make sense to you. Just to you show again about particle physics, and resolving that Mona Lisa picture, this is an animated gif which is from the CERN experiments, the Large Hadron Collider. This is the ATLAS experiment actually, looking at these particle events. Pixel by pixel essentially, or data point by data point, building up a picture of masses of particles that they're seeing in their detector. What they saw, you obviously start off with absolutely huge arrow bars on these things, and that is associated with the uncertainty in the detector, but also with these statistics, the fact that you haven't built up enough data points. As you see after a while, those uncertainties become very, very small and you might see a little bump, a little bit of something that was unexpected. The blue line is what was expected through previous knowledge, and then suddenly this bump was seen, and this bump is the Higgs boson. It wasn't just seen when looking at two photons, those two particles of light within the detectors, it was also seen when looking at things like electrons and the heavier versions, the muons. Again, if you build up that dataset and you zoom in, you see that you get these bumps, and taking into account these uncertainties, you can see that this bump is statistically significant. In particle physics, statistically significant usually means above five standard deviations away from what you would expect to be this baseline, and if you see that kind of deviation from the expectation of the underlying model, then something new is happening. Again, this is the Higgs as seen with those particles. I hope I've given you a brief overview and convinced you that uncertainty is something that is very important, because we can't escape. It's part of nature.
	We hoped you enjoyed Ben's talk and thanks for listening. You can hear the rest of the talks from 2016 at futureeverything.org/2016podcasts.

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