Science – Physics – Model of Matter transcript

(Duration 12 minutes 41 seconds)

Presenters: Dr Mark Scarcella – User Experience designer and particle physicist
Hilary Coolican – Literacy and Numeracy Strategy Advisor

(warm inspirational music)

Hilary: Hi, everyone. I'd like to introduce you to Mark Scarcella. He works for the Department of Education, but he also has a PhD in physics and worked on the Higgs boson projects. I have some questions for Mark to help us in understanding the Standard Model of matter, but more importantly, how is it that we know that we don't know everything yet? So I'm going to start with, first question, which is how did you become interested in this in the first place?

Mark: Hi, so, back in school, I basically studied chemistry, physics, and biology for my HSC and a lot of maths. So I was definitely into science and sciences, and I remembering year 12 physics, doing, I think it was called quanta to quark at the time, which was the kind of the particle physics module. And I remember just looking at these tables of really strangely named things like, you know, baryons and mesons and leptons and quark-gluon plasmas and all this strange stuff. And I just thought, what the hell is all that? I need to know about it. So, that kind of got me on that path. And then when I got to uni, I just studied science at uni and in my third year, I was given an opportunity to do a little research project and I sought out the, they call it the high energy physics group, and they were doing work on particle physics with a lot of other universities around Australia, actually, and overseas. Did a little project with them and then on to my honours with them as well. And then they asked if I wanted to do a PhD, so I was kind of stuck with that same group for a good eight years.

Hilary: Thank you. So, when you were doing this study, and you took on your PhD, what is it that you actually studied?

Mark: Sure, so I was working on an experiment called the ATLAS experiment, which is one of the big detectors, they call them, on the Large Hadron Collider. So, this experiment is huge, 20-metre tall, 40-metre long, can think of it like a camera, it's there to take pictures of what happens when two protons run into each other. And it takes pictures of all of this stuff that comes flying out in all directions. And we can kind of work backwards to kind of piece together the puzzle to work out what happened in those fractions of a second when they collided. And so, my project was looking at could we detect this thing called the Higgs boson? Now at the time, the Higgs boson hadn't been discovered yet, it had been predicted since about the '60s. And this particle is kind of responsible, in our Standard Model of particle physics, for giving things mass. So, the reason we have the property of mass in all of our particles is because of those funky properties of this thing called the Higgs boson. And the LHC kind of was designed to search for the Higgs boson, one of its design parameters. So, my research was can we find that Higgs boson? And the way we want to find it is by looking at its decay products. And it can decay in many different ways, and the ones we were looking at were things called tau leptons. So, there's lots of levels here, but a tau lepton is like a very heavy electron and they themselves don't live very long. They kind of break apart into other things as well almost immediately. So, my research was taking the final products of what happened if we were to create a Higgs boson, that decayed into two tau leptons, then further decayed. Can we detect that against all the other random stuff that happens when you bang these things together? So, a Higgs boson is like one in a billion collisions, you know. These things are very rare to be produced, but we were trying to look for them. So that's what my research was on. And there's one other thing about it is that because this is so complicated, I was looking at, can we use computers and machine learning to kind of help us make all these distinctions between good events, we call them, good bangs of the particles, and bad ones that we don't care about. So, we were kind of using artificial intelligence in a way to see if it could help us detect these particles.

Hilary: How absolutely fantastically exciting. So, you actually went over to CERN.

Mark: I did.

Hilary: You studied there, how long were you there for and what was that like?

Mark: It was pretty cool, my first time I went was in my first year of the PhD and went for three months. So, over Christmas of 2013, I think it was. And I've got my CERN T-shirts and my cool little badge here, which I always keep. It was pretty crazy. So we got to live in the south of France, in a little town called Saint Genis. And then every day we'd walk or drive across the border into Switzerland in going to CERN. It looked like, from the top, it wouldn't look like much. It was just all the grey buildings and it was winter, so it was in the snow as well. But then, suddenly you just walk past a building and look in and there's this amazing technology and pipes and machinery. I'm not an engineer and I had no idea what that was about, it was incredible. But the actual Large Hadron Collider itself, this 27-kilometre long tunnel 100 metres under the ground, when it's running, you don't get to go down there. So, in a matter of fact, I was just backpacking through Europe a few years before that, before I'd even done particle physics and I actually got a tour of CERN and got to see it all. Got to see the accelerator down underground, which was pretty amazing and then going back there to work there was fun.

 The lunch area was interesting, so all these people, all the scientists would go to these restaurants and they'd call them R-one and R-two, for restaurant one and restaurant two. And I'm sitting there, and then, you know, my supervisor one day was like, oh, that's a Nobel prize winner over there and this guy discovered this particle and these people were just there with you, just having lunch. It was pretty amazing.

Hilary: That would be really, really exciting. I mean, that is the equivalent of back in the days when scientists were rock stars and that really used to exist. So, do you feel that your work then contributed to making a difference to understanding it and how much further do you think we can go? They're are two different questions, I know, and they kind of segue into the other.

Mark: So yeah, I think my work, so everything was part of a team, but these massive projects that, the ATLAS experiment had 3,000 people on the author list. So, whenever a paper is published, there's 3,000 names. And by doing my research, my name gets to go on every paper created by the ATLAS collaboration. So, I was lucky enough to have my name on the discovery of the Higgs boson on paper, which is pretty amazing to me.

Hilary: Congratulations, that's very exciting. Very exciting.

Mark: There were 6,000 names, but you know, I'm on it. But then, yes, so my work on using machine learning and stuff has been taken by other teams, and other teams, you know, working parallel to me on it. And that's now kind of the way that we detect particles, this kind of, you know, Higgs boson experiments on that ATLAS experiment is to use machine learning and these kinds of more computationally heavy ways of detecting things.

So this definitely made an impact, but in terms of how far can we go in understanding particle physics, there's a lot. So, the big issue is that there's this gap in our understanding, we know how physics works here, where we are, and we, you know, predicted the Higgs boson for a long time and we found it, and that's amazing. And we think we know how stuff should behave at what we call the Planck limit, so like at the tiniest, tiniest possible everything, we kind of, we know the physics breaks down. We know that it doesn't work anymore, but there's about, I think, 16 orders of magnitude. So what, 10, and 16 zeros of energy between here, where we know how it works, and here where don't know. And scientists just think there's got to be something else new in there. We can't just have the same old physics, but 16 zeros' worth of energy levels.

Hilary: There's place for a new Einstein. You know, we had the theory of relativity, we're moving on, we had the old physics, classical physics, then we've got the new modern version. So there's going to be a 21st century one.

Mark: Oh, definitely. There's a lot being done in a theoretical sense, so I'm an experimental particle physicist. So I write computer code to analyse databases, basically. But there's the whole other side, which is the theoretical physicists, and these are the people that come up with these crazy ideas, things like supersymmetry and an extra dimensions and, you know, micro-black holes and all this crazy stuff that sounds amazing and kind of goes over my head a lot of the time. But that's where these predictions will happen that we'll then go and test it at accelerators. So, you know, engineers are an amazing part of the project, you know, it's not just scientists, but there's engineers involved too. There's your theoretical physicists and everyone be working together and yeah, someone might have that amazing idea that then we can then one day detect.

Hilary: With the particle accelerators, you said that when you were over in CERN, that you couldn't go down there when it was operating, but then you were doing analysis of the work. So, how does it work? Because you said that there were the good reactions and then the ones that weren't favourable. So, exactly how did that work for you?

Mark: Sure, so, I'll start with just the particle accelerator itself. So, there's lots of different kinds, but the one at CERN is a hadron accelerator, so hadrons are things like protons and neutrons and they, and lead ions, lead ions, they get used as well, but this is a big ring, it's 27 kilometres long, a hundred meters underground. And it's cooled to a fraction of a degree above absolute zero, super-cooled magnets. And the way it works is that there are these little electric, oscillating electric fields that go back and forth really quick. And as a little bunch of protons comes along, it gets a kick by this electric field, and it gets kicked along, along, along, along. And each time it gets a kick, it increases its speed or it its energy. And then the magnets, these big super-cooled superconducting magnets are used to bend the path of the protons around in circles. So, this is a little like Thompson's charge-to-mass experiments. So, you put an electron beam through a magnet and it bends, exactly the same thing in the particle accelerator. And it's like a vacuum tube as well to accelerate them. And so, all that technology is now embedded in quite old physics. And so, these protons go around and around and around, getting faster and faster, faster in opposite directions. There's two kind of beam pipes like this, and one goes that way and one goes this way. And they get faster and faster and faster, until it's about the energy of a freight train, but imagine it on the size of a mosquito. So, there's super amounts of energy on these tiny, tiny, tiny, little bunch of protons. And then at four points around the ring they collide, so the two beam pumps it's cross and something happens hopefully. And one of those four points was ATLAS, the experiment that I worked on. There's also CMS, which is Compact Muon Solenoid, and then those, ATLAS and CMS, kind of do the same physics, but with different machines, so that you can compare them, compare to the statistical differences and things. When they collide, most of the time, nothing happens. It's just like these particles just miss each other. Sometimes they glance off a little bit and bounce, but sometimes they'd bang together.

Hilary: Yeah.

Mark: And then, with mass energy equivalence, so, Einstein's E equals MC squared, all of that energy can be turned, sometimes, into mass. And so, the Higgs boson, what I was looking at, is a very heavy particle, they discovered it in about 125 giga-electron volts. Compare that to a proton, which is about one giga-electron volts,GeV being a unit of measurement of mass or energy.

Hilary: Yes. -:

Mark: So, sometimes all that energy of the beams gets converted into the mass of this Higgs boson, and then as I was saying earlier, it's very unstable, so it immediately breaks apart into more energy and smaller bits of mass. And then our detectors sit around this collision site. And so, right around the beam pipe, like literally centimetres away, are silicon chips like you'd find in a digital camera. And they can detect light or particles or whatever comes through. Then as they actually move out through the shells and this detector, it's like an, I mean, really 20-meters in diametre, there's different kinds of detectors that look at different kinds of particles. And your hope is that at the very end, you've captured everything, so nothing escapes, you'd catch it all. There are a few things that escape called neutrinos, that we can't catch, but don't worry about that. We catch it all and then we try and put the puzzle back together to understand what happened at that core. And hopefully you might sometimes, you know, one in a billion or one in a trillion times, find a Higgs boson. So that's how that accelerator, you go from literally, it's like a gas bottle of hydrogen that just sits there. You can see just a red bottle on the wall, and that is what Higgs boson was in somewhere, you know? And it comes out into these big accelerators, bang, we look at the data, we troll through billions of literally billions of events with our computers. You send jobs across the seas on this big computing network called the grid. It's running 24/7, you submit your code and it runs in Taiwan, and then it's over in Canada and then your results come back and there's graphs everywhere. And then eventually, hopefully, you can find very, very small statistical differences, but enough to let you know that you've found something new.

Mark: So exciting, that's really well explained. Thank you very much. I hope people appreciate that.

 (whooshing)(crackling)

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