Marco Gersabeck

I'm Dr. Marco Gersabeck, I'm a Reader in particle physics. I lead the local team working on the LHCb experiment, that’s one of the four big experiments at the Large Hadron Collider. And if you include the PhD student research staff and engineers and technicians involved in this activity, we're about 35 people working on this experiment.

Dave Espley

Obviously, particle physics is your background. How did that lead to you getting involved with CERN? Was it a direct, straight line?

Marco

Yeah, very much so in my case. I started off at the end of my undergrad doing a diploma thesis in Germany, where I'm from, on an experiment at CERN looking for rare decays of some so-called “strange” particles. And then I moved to Glasgow for a PhD and with that joined the LHCb experiment and have stayed on that experiment ever since.

Dave

So what does the work involve?

Marco

I mentioned the large team that we have already, so it's extremely broad. We have to design the experiments that we use and then do R&D on the technologies. Because very often the types of technologies we need for these are extremely sophisticated and normally don’t exist at the time when we dream them up. So the first stage is the R&D really. And then that leads on to the construction of the experiment. We've just upgraded the LHCb experiment, which is in its new form now starting to take data. So over the last few years, our team here has constructed very much the heart of the experiment modules for what we call the vertex locator - that's the detector component that sees the first signals of the particles after collision. So once we've constructed the detector, we then need to operate it, so we have teams in the control room at the experimental site. So I was lucky to be there again for the first time in a long while last week. And it was just buzzing with, I don't know, 30 or 40 people working on all sorts of systems. And a number of Manchester people are involved on the frontline there. And that really requires everything from making sure that the cooling and powering of the detector’s work as planned, to reading out the data processing of the data calibration of the detector and so on. And then once the data are read out, then comes the physics analysis and that is obviously what drives our activity. But it's really these other stages that I've mentioned - and there are a few more - on the software and computing side that I haven't gone into, that form the basis of all our work, that underpin the work. But then on the physics analysis side, what drives our team is largely two things. It's understanding matter/anti-matter differences - so we work a lot with particles that are made of quarks - those are the most fundamental building blocks of matter, of atomic nuclei that are fundamentally built of quarks. And there are a specific set of particles that are containing one quark and one anti-quark, so an anti-matter quark. So they have anti-matter kind of built into them. They don't exist naturally - they have to be produced in some high energy collisions that can happen at a collider like the Large Hadron Collider or naturally in cosmic ray collisions, so when cosmic particles hit the atmosphere, collisions happen there as well and would produce particles like that. And then what we do is we study their behaviour and we compare the behaviour linked to matter interactions and to antimatter interactions. And we want to find and study in detail the differences because what's driving this is the knowledge that the universe is made up of matter, and not of anti-matter. However, at the Big Bang, going back all the way to the beginning, the big bang produced matter and antimatter in equal amounts, and when they come together, they annihilate; however, there was a small amount, a relatively small amount of matter left over. And that is what constitutes today's universe; and why that matter was left over and no anti-matter was left over - that is the main question that really drives us. And we want to understand a little bit more about that.

Dave

It's weird for someone like me who’s not a scientist to hear things like “a relatively small amount of matter was left over - and that's the universe(!)”.

Marco

Yeah, it’s really just a one in a billion asymmetry - that the rest has indeed annihilated, as one would expect. And that has led to, again, an enormous amount of energy. And that exists as the cosmic microwave background; it was discovered many decades ago. And this radiation that one can see everywhere in the universe wherever one looks - that echo of the Big Bang if you want - that still exists, but there is this tiny amount that that makes up all the stellar matter of the galaxy.

Dave

Yeah, I think I remember reading Bill Bryson’s book about the universe and he said that's responsible for in pre-digital TVs, that's responsible for this staticky picture you get, that's cosmic radiation – is that correct?

Marco

You can pick up some of that. It was indeed discovered by engineers who were calibrating very sensitive antennae. And they picked up some what they thought to be static noise and they picked it up wherever they pointed the antennae, because indeed the radiation **is** simply everywhere. And yeah, if you're looking at the right sort of wavelength, indeed you can see that.

Dave

The kind of stuff you're talking about is really fundamental to, you know, life, the universe and everything, for want of a better phrase(!). Would you say that the LHC has enabled us to make a step-change in our understanding of physics? Is it *that* significant what we've managed to, you know, study in the last 20 years or however long it is since we've had the LHC?

Marco

Yeah, we've now been running for a bit more than ten years. And yeah, I mean obviously the biggest discovery of the LHC, no doubt, was the discovery of the Higgs Boson in 2012. And that was a very important discovery, because it also happened not exactly at the mass that people were most expecting it to be. So that really confirmed what we call the standard model of particle physics. And we've discovered so much more since then. We've actually discovered something like 60 new particles, out of which the Higgs boson is just one - it's the most prominent and certainly the most impactful. But I mentioned earlier, the particles consisting of quarks and antiquarks; we've for the first time discovered particles containing four quarks and one antiquark. So these five quark or pentaquark states – they have been proposed since the quark model was invented in the sixties… in the very first paper this state was proposed, but it was never seen. And this is something that the LHCb experiment was able to show; by now we have several candidates, several discoveries for different pentaquarks with different masses, different core compositions, and so on. And that's just one example of quark matter that behaves in a rather exotic way. And where we've really helped push the field forward and find new states that tell us more how quarks interact and how they build these particles that are that are produced in collisions.

Another thing that we have discovered - I mentioned the matter/anti-matter asymmetry that we're after, and there we've made a very significant discovery. I said that there are these particles made of quarks and anti-quarks and there are four specific combinations of these that are electrically neutral and these can turn periodically into their anti-matter equivalent and back. So they oscillate between two electrically neutral states and these four variants of that do that with a varying frequency. And linked to that we can look for matter/anti-matter asymmetries in that process. This goes back to the first discovery of matter/anti-matter asymmetry in one of these systems in 1964, and was then confirmed in the early 2000s in two other systems. And it wasn't until 2019 when LHCb made the discovery of matter/anti-matter asymmetry in the final, in the fourth of these systems. And that is a system containing the so-called “charm” quark. And that's also what I've been working on for the last ten years. So this really completed the picture in a way, but it also opens questions because we can't say for sure whether what we've seen there is purely explained by the standard model of particle physics, or whether the asymmetry that we've observed may be linked to some new particles that have yet to be discovered, that add to the asymmetry - because the asymmetry that we have observed is a little bit larger than theoreticians have predicted. Now, these predictions with charm particles are extremely difficult, so the question isn't quite settled yet, but it is one of the potential routes of finding particles or traces of particles that are beyond the standard model of particle physics, and that's basically what we want. We know there must be physics beyond this standard model because it can't explain the matter/anti-matter asymmetry in the universe. I mentioned we found some of this asymmetry, but what we found is simply not enough to explain what's happening in the universe. So other processes must contribute to that, and that must be physics that goes beyond the standard model and that's what drives many of our searches. So that's one possible area where we can find that, and that's what drives many of the activities in LHCb and also the other experiments at the large Hadron collider.

Dave

Sure, yeah. So again, it's fascinating to me. There seems to be sort of… there's two things that jump out to me. There’s the fact that in a number of cases, you predict that something must be the case and the LHC, years later, is proving, yes, you were correct, that is the case. And, you sort of cited that the Higgs boson must exist. And yes, we found it - it does. But then there’s the other side of it which is, as you said, the stuff we don't know - it's exciting to get into that field and maybe, you know, the work that we do doesn't just reinforce or prove our existing hypotheses, it actually takes us to a new area where we have to sort of almost throw out our hypotheses and realise that there's a there's a new model, potentially, of physics.

Marco

Absolutely. And there are currently also some tensions in other areas to do with the electron and its heavier partners, the muon and the tau. According to the standard model, they should all behave in the same way - they only differ in their mass, and all the rest – they should behave in the same way. Now there are a set of measurements that do seem to indicate that that is not quite the case and it does appear that possibly the muon is the odd one out for some reason. And if that is really proven to be the case, then that would unambiguously indicate that there is something beyond the standard model. And there are, as I said, a number of analyses, a number of measurements, that don't *quite* fit with the standard model. I'm very cautious in how I express that because the signals aren't extremely strong yet. But these signals don't just exist from LHCb; they exist in other experiments doing physics with quark matter, but also, for example, at the Fermilab g-2 experiments that that a year and a bit ago released their first result, where they also show that there may be a difference between what they call the anomalous magnetic moment of the muon and what theory predicts. Again, there, the jury is still out; it’s not quite at a level that that we would call a discovery, but all of these things do point in a certain direction, and there potentially being something quite exciting.

Dave

I was looking at the CERN website and it talks about the LHC and says that the current LHC is equivalent, metaphorically, to setting two needles ten kilometres apart and firing them so they actually meet in the middle, and it’s that degree of accuracy that we're talking about. But obviously there's been proposed, I believe, an even larger collider, many degrees of magnitude bigger than the LHC. Where are we up to with that, is that going to happen, do we know or is it still a proposal at the moment?

Marco

This is a proposal that is very actively being looked at. So the idea there is… well, maybe I'll backtrack slightly. I'm motivated a little bit because what we do is we build these colliders to have a certain collision energy and with that energy, we can produce new particles. And there are two ways of observing signals of particles beyond the standard model. And that is either by direct observation of such new particles. And in order to produce them, one has to have the energy that is equivalent to their mass: e=mc squared. That's as simple as it is. And if you're looking for particularly heavy particles, then you need to have that high energy. The alternative is these particles participate in some quantum loops, and thereby modify the behaviour of certain processes. And that is very much what we do in LHCb. We look very precisely at the behaviour of particles and try to spot differences in this and try to spot where this behaviour differs and thereby indicates the presence of other particles. But to come back to the direct production – there one really needs this energy. And we know from a number of theories, but also from these hints that we see here and there, there are potential explanations, and all of these involve particles that are many tera-electron volts heavy - this is the unit of energy that we use, and the LHC as it's restarting right now, it has reached a collision energy of 13.6 tera-electron volts. So that is the maximum energy that can be involved in such a collision. Now we haven't found any directly produced particles yet. We may well, because it is not just a collision energy - one also needs the amount of data to find the particles, because there are other processes that need to be separated and that does take very high precision measurements. So in the coming decade or two there will be very, very interesting measurements yet to be done at the Large Hadron Collider. However, there is this absolute limit of the energy. And what we're discussing at the moment is the proposal to go to a collider that can deliver 100 TeV - teraelectron volts - in energy, so about a factor of seven or so higher, in energy. So we can there produce much heavier new particles. And this is indeed a very interesting range of particle masses, where many models point that there could well be something there. In order to do that - I mentioned at the very start it's often that when we conceive these ideas of new experiments or new accelerators, we don't have the technology. That is very much the case here as well. We need much stronger magnets because these particles, when they when they circulate in these tunnels, they are held on a circular trajectory by magnets. The circle can't be too small because there is a certain radiation that is related to the radius of this circle, so if the circle is too tight, the particles would radiate off more energy than we can add to them in the acceleration process. So then you just can't accelerate them any further, can't give them more energy. So therefore we need to go to a bigger circle. In this case, for the hundred teraelectron volt collider, we would need to go to a 100 kilometre circumference collider, and that is what is what is being studied at the moment. With such a tunnel, of a hundred kilometre circumference, one can then do different things. One can indeed look at proton-proton collisions as are happening in the Large Hadron Collider right now, and reach these 100 tera electron volts in energy, produce these super heavy particles hopefully, and make fantastic discoveries. There are other machines also being discussed and that is an electron-positron collider. Positrons are anti-matter electrons and they would not collide at that energy, but because they are also affected by these losses, from going around the corner basically, they very much would benefit from a larger radius ring. And therefore the second option where we're discussing, possibly as a predecessor, is an electron-positron collider in this 100 kilometre tunnel that would then be able to make very high precision studies of the Higgs boson, possibly produced in pairs, and really allow very high precision studies that are not possible currently at the Large Hadron Collider. But also at the same time, I mentioned the sort of two main motivations for these machines: experiments like LHCb that are highly specialised in doing other things that are not the sort of main driver behind the design of the accelerator and things like that would also be possible in the future with even higher precision to search for these indirect signals of physics beyond the standard model.

Dave

Is the work you're doing… can it impact everyday life? And what I mean by that is, you know, the lives of non-scientists, for example, or is it just purely theoretical knowledge for its own sake? Which is a good thing in itself, obviously. But are there any implications in the real world, if you like?

Marco

The immediate research outputs, the analysis we do with the data we collect - that is very much of fundamental physics research, so that has no direct implications other than the knowledge gained from that. However, I mentioned a couple of times already all the technological advances that are required to deliver this and there we do have a fair bit of technology and knowledge transfer. One example is, our colleagues built the proton therapy centre at the Christie in the last few years. And the beamline there for this therapy centre was designed by one of our accelerator physicists who in other areas would have been involved in particle accelerator research and also, likewise, we're working with colleagues there on detector development. So the detectors that we develop have uses in medical imaging or related areas. So we are definitely talking to each other and where sort of common ground exists, we're definitely exploiting that. Another area is the area of data science. So I was very brief on that, initially. The amount of data that goes through, that is produced by the detector is absolutely staggering; it's terabytes per second. That needs to be processed and all that processing - the knowledge required for that - is something that is extremely transferable to many areas of big data processing. And that is an area where we simply… I mean, the most direct impact to society is the vast number of students and researchers who we train in this, and who some of them go to all sorts of private or public sector jobs afterwards, outside academia and apply their knowledge there. So this I think is one of the most direct influences that we have and it's pretty unique, really, with the challenges we're facing in particle physics.

Dave

I've got one last question. It's a bit, well not flippant, exactly, but a sort of throwaway question: Do you get frustrated when you see the science you're doing get reduced to tabloidy “Oh my God, they're going to create a black hole and kill us all!” nonsense. Does that frustrate you? Because as a non-scientist my understanding of CERN before I did the research for this interview was, yes, they've got the Large Hadron Collider. Yes, they fire things round and they’ve discovered the Higgs boson. And there's a possibility they might create a black hole and we’ll all die. And that is what it tends to be reduced to in the reporting of science in this country. Is that a frustration?

Marco

To be honest, I do tend to ignore by now the black hole question, because it's been raised so many times when the Large Hadron Collider first started up, and we're not doing anything fundamentally different now, and obviously we're still here first and foremost. But even then, it was shown that there was a minute possibility that we could produce what's called a microscopic black hole. But these things that would evaporate straight away, so they're not stable states and it would be fantastic if we were to produce those and see the sort of aftermath, the decay of such a black hole. That would be a fantastic discovery. We haven't made it yet, but certainly the Large Hadron Collider can't produce a stable black hole that would then eat up the rest of the world. It's a very powerful machine but not that powerful.

Dave

Which is a shame because, you know, that's what it gets reduced to in many ways. And, you know, there's so much, as you've explained, so much exciting stuff you're doing so much fundamentally good science that we’re doing that it's a shame it does get reduced to that - that some journalist somewhere, you know, jumps on that microscopic possibility of a black hole and it becomes a headline, and that's what everyone thinks about CERN, which is bizarre. But yeah. Thanks for correcting the record on that!

Marco

There are many other very exciting discoveries that we keep making and will keep making over the next decade or two.