HOUSE OF COMMONS

Science, Innovation and Technology Committee

Oral evidence: The UK and CERN, HC 608

Wednesday 6 March 2024

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Watch the meeting

Members present: Greg Clark (Chair); Chris Clarkson; Tracey Crouch; Dr James Davies; Katherine Fletcher; Rebecca Long Bailey; Stephen Metcalfe; Carol Monaghan; Graham Stringer.

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Witnesses

I: Dr Pippa Wells, Deputy Director for Research and Computing and Management Liaison for the United Kingdom of Great Britain and Northern Ireland, CERN; and Christopher Hartley, Head of Industry, Procurement and Knowledge Transfer Department, CERN.

II: Dr Sabine Hossenfelder, Postdoctoral researcher, Munich Centre for Mathematical Philosophy, Ludwig Maximilians University Munich; and Professor Sir David King, Affiliate Partner at SYSTEMIQ, Former Government Chief Scientific Adviser, UK Government, and Senior Strategy Adviser, President of Rwanda.

III: Professor Mark Thomson, Executive Chair, Science and Technology Facilities Council, UK Research and Innovation (UKRI), and Professor of Experimental Particle Physics, University of Cambridge.

Examination of witnesses

Witnesses: Dr Wells and Christopher Hartley.

Q1 **Chair:** The Science, Innovation and Technology Committee today conducts a one-off inquiry into the UK's relationship with CERN, the European Centre for Nuclear Research, to which the committee paid a very instructive visit earlier this year, and several members had visited it previously.

CERN was founded in 1954 and celebrates its 70th anniversary in 2024. It has 23 member states, including the UK, and 10 associate member states. It is most famously associated with the large hadron collider, about which we will talk a little later. There are questions about investment into successors, or additions, to the large hadron collider, which we shall touch on.

There can be a lot of quite technical and scientifically advanced concepts. As you know, the Committee stands in the place of all 650 Members of Parliament and the public, but please do not assume we have the advanced scientific knowledge of you and your colleagues at CERN: help us and the public to understand the big issues at stake.

Without further ado, let me introduce our first two witnesses. Dr Pippa Wells is deputy director for research and computing and management liaison for the United Kingdom at CERN. She has worked at CERN for many years. Christopher Hartley is head of the industry, procurement and knowledge transfer department at CERN. Thank you both for coming to give evidence. Dr Wells, in the spirit of introduction, tell us a bit about CERN and the UK's contribution to it.

Dr Wells: CERN is the world's largest laboratory for particle physics. You have already mentioned that it is our 70th birthday this year. Our facilities straddle the French-Swiss border, near Geneva. The original headquarters were outside the city of Geneva, near the French border.

We are trying to understand the most fundamental particles—the smallest particles—that make up matter and the forces and interactions between them, and how that relates to the evolution of the universe: from the big bang to what we see today.

The UK was one of the 12 founding member states in 1954 and is now one of 23 member states, and is the second-largest contributor. Member states contribute in proportion to their net national income. The UK contributes around 15% of CERN's total budget, which is 1,200 million Swiss francs per year. For the UK, that comes in at around £160 million per year, depending on the exchange rate.

The founding idea of CERN was to do science for peace. Europe was emerging from the second world war and the idea was to do projects much bigger than those that could be afforded by a single European country, and possibly it was also to attract back to Europe from the States people who might have left during the war and in its aftermath.

That is still the case today. We are doing projects that are funded by our 23 member states that could not be done by a single European country.

CERN is best known for its fundamental research, but it is really an engineering lab. People say, "I'm not a physicist; I can't work at CERN." It is the engineers and technicians who design, construct and operate facilities and who are the core of CERN's employees. CERN builds and operates particle accelerators that bring particles very close to the speed of light—very high energy. They either hit a target or the beams and particles are manoeuvred to collide head-on. Our flagship accelerator, the large hadron collider, does exactly that: it collides—head-on—bunches of protons, which are the nucleus of hydrogen atoms.

We have to observe the products of those collisions. It is Einstein's $E=mc^2$ in action. The very high energy of the particles is converted into new particles, which fly out from the interaction point and large particle detectors surround the interaction points.

That is another place where the UK makes a very large contribution. We have a community of 12,000 scientific associates—the users who come to CERN to do experiments. The people employed by CERN are a small fraction of the people doing the experiments. From UK institutes, we have about 900 scientific users, and there are 7,000 users from member states. The UK really has a good fraction of the users from member states.

I have mentioned two technologies—the accelerators and the detectors. The third, very important, technology for CERN is computing information technology. We produce large volumes of data that need to be analysed.

Q2 **Chair:** You said that the subscription equates to about £160 million a year. In addition, through the Science and Technology Facilities Council, the taxpayer contributes to experiments to the tune of about another £20 million or £30 million a year.

Dr Wells: That is correct.

Q3 **Chair:** We are talking about an annual investment of about a fifth of £1 billion a year, which is pretty substantial in science funding terms.

Dr Wells: Indeed.

Chair: Or any terms.

Q4 **Tracey Crouch:** That was a really interesting introduction to CERN, but why is it important? Why does it matter? What does it contribute to society?

Dr Wells: Scientific curiosity is a fundamental element of humanity. People look out at the stars and want to understand how things work. Progress has been driven by fundamental research. It is not research done for the sake of developing products for industry. Over the centuries, it has been understanding how things work and how science works, and that can have knock-on effects. I shall give you an example.

Einstein's theory of general relativity takes Newton's gravity and extends it to understand the big-scale structures. It was a fantastic theory. If we did not have Einstein's theory of general relativity, GPS systems would not work. It is needed to correct time signals from satellites for the effect of differences in gravity on earth and in the orbit of satellites. We might not know right now what applications the fundamental science of CERN could have in future, but we know from the past that these things tend eventually to develop applications. In addition, the technologies that we develop go into wider society and are used in all manner of applications—medical applications, for example.

Another element of putting back to society is that the science at CERN is one of the things that young people find exciting. Particle physics and astronomy is one of the reasons kids study STEM subjects, and we know that we need people with STEM experience. They might not come to work at CERN, or come to CERN to do a doctorate. We have about 3,000 people doing a doctorate degree at any one time on the large hadron collider experiments; about half of them go back into industry. They have had an international experience, learned some high-tech stuff—advanced computing or detector technologies, perhaps—and they take it back into wider society.

We must accept that a rich scientific programme needs elements of fundamental research as part of that full picture, and that is CERN's primary aim.

Q5 **Tracey Crouch:** You used the phrase "scientific curiosity", but £180 million or £190 million per annum is quite an expensive investment in curiosity. As a Minister, I had to apply a return on investment to all our spending. Is there an estimated ROI on the £190 million per annum?

Dr Wells: Studies have been done on the impact on the UK. I cannot give you an exact figure. The methodology gets difficult in putting a currency value on a scientific research paper, for example. People try to apply different methodologies.

Q6 **Tracey Crouch:** Mr Hartley, what role does CERN play in training and employment opportunities for UK nationals?

Christopher Hartley: We have a large variety of schemes, from doctoral students to new university graduates in our graduate programme. We have a lot of outreach to schools. We have, I think, 500 school visits a year from the UK.

We have a programme for what we call training the teachers, or teaching the teachers. Physics or science teachers from the UK can attend specialised schools in CERN to help. It covers the various ranges.

Q7 **Rebecca Long Bailey:** My constituent Dr Conor Fitzpatrick is watching today. He was able to obtain his prestigious academic position at Manchester University as part of a European research grant, based on the research he carried out at CERN. His story, sadly, is unique. What additional outreach measures does CERN conduct, and how do they inspire people of all backgrounds to pursue STEM and become another Conor?

Dr Wells: We put a lot of effort into identifying UK nationals or people employed at UK institutes at CERN from diverse career paths—apprentices, technicians—and they volunteer to be ambassadors and to go back to their school or university college to give presentations and explain the range of opportunities available at CERN. We are keen to get the numbers up as people take advantage of our apprentice courses and technical courses, because they are the pipeline that feeds into the higher-level positions at CERN or at UK universities.

We are conscious of the fact that an undergraduate or school population turns over very quickly. You cannot do it once and say, "Right, we've told the university or college of somewhere." You have to keep going back. It is nice if the younger people go back—not me. Look at the young technician who has been to CERN and is excited by it—"You can do this, too".

Q8 **Rebecca Long Bailey:** Do you want to add anything, Mr Hartley?

Christopher Hartley: No, I don't think so.

Q9 **Rebecca Long Bailey:** Mr Hartley, how does the UK compare with other international collaborators in winning CERN procurement contracts?

Christopher Hartley: I would say reasonably well. There are two views, and I would like to present it in two ways.

We designed our procurement contracts with two large categories: service contracts and supply contracts. This is to make the institution and all the experiments run. There, the UK is placed fourth—consistently fourth—in our 23 member states and 10 associate member states. In supply contracts, the UK is currently fifth for contracts awarded—or, more accurately, payments made to UK companies.

Historically, while the positioning is okay if you look at it in terms of numerical financial value, it has been far below what CERN and, from the UK perspective, we would want. We have been working with UK Government representatives, particularly colleagues in STFC, to improve that. Over the last two years in particular we have seen very significant growth compared with the payments to UK companies on the supply contracts in 2021. We had a 46% improvement in 2022 and approximately 45% in 2023. If you combine those, you see that between 2021 and 2023 we doubled payments to UK companies under supply contracts.

Q10 **Chris Clarkson:** Mr Hartley, I will stay with the same theme. You say that the UK does reasonably well on supply, but given the cash value of what we are putting in, we would like to see more of a return on investment. What engagement is taking place with UK businesses to drive more R&D and the commercialisation of research? I appreciate that not all of it can be commercialised, as Dr Wells said, and an application will be found for some of it later, but what engagement is there with business?

Christopher Hartley: I would like to draw a distinction, first, if I may, between what CERN does with all its member states, and then say a few words about the focus on the UK, because improvement of the UK situation is so important to us.

CERN partakes in a range of activities to encourage interactions with business. All member states and associate member states have industrial liaison officers, with whom we work very regularly to ensure they are aware of upcoming commercial opportunities and form a bridge with companies and organisations in their member states so that they are aware of CERN-specific procedures and how to work with CERN. We do that with all member states. We also organise welcoming days for companies to visit us, and we do days focused on particular themes. We might, for example, be very interested in purchasing new cryogenic systems and would invite all member states to be aware of our upcoming needs.

We have put in place—it was a priority from the UK side and from the CERN management side—some specific actions with the UK. A member of my team has a weekly meeting with the UK industrial liaison officer to make sure we are aware of the opportunities becoming available for commercial companies and can therefore have early identification and outreach to companies that we believe may be suitable suppliers for the contracts. In addition, we do a monthly strategic meeting looking at the barriers—perceived or real—that make it particularly difficult for UK companies to work with CERN and to see how we can address them.

Within our procurement system and rules we have been using a particular element: limited tendering. When a country is doing particularly badly in our procurement and has a low coefficient, we can use that to target procurement to the member state, assuming we can generate sufficient competition. When the UK was lower than it is today, we were able to do that in the IT domain. The significant increase in the last two years came from using specific tools to assist the UK.

Q11 **Chris Clarkson:** Notwithstanding that targeted process, the general procurement system is an open one. Is there a reason CERN uses that model rather than one linked to contributions—the one ESA uses, for example?

Christopher Hartley: The European Space Agency has a concept of a fair or just return on each of its major projects. It is important to understand that it does it across major programmes or activities. That is divided between different missions. It works very well for it on those individual missions. It allows it to divide work equitably in those programmes relative to the contributions. That also means it is often working with the prime contractors, so there is a transfer of knowledge and decision making to those contractors. Agencies such as ESA have great expertise, but they rely on prime contractors to work with them and share the work between them.

CERN retains the prime contractor knowledge. Dr Wells mentioned engineering knowledge. We are very much an engineering laboratory. A lot of that knowledge is held within CERN, and it is interesting to retain that knowledge.

In any procurement system, one is always balancing various parameters of what you are trying to achieve—typically, cost, schedule and quality. When you introduce a return coefficient, there is a danger that you have to sacrifice one of your other parameters to ensure there is a balance on the return. You may potentially increase costs or reduce quality because you have to award contracts in a certain way, rather than taking the best the market has to offer at the time.

Q12 **Chris Clarkson:** It is the old adage: you can have quickly, cheaply or well, but you can only pick two of them.

Christopher Hartley: Yes. We are adding an additional one: everybody has to get a fair share of the cake.

Q13 **Chair:** When we were a member of Horizon Europe we took more out than we put in, because the prestige and quality of British science was better than average. Here, notwithstanding the prestige and excellence of British science, we have heard in answer to Rebecca and to Chris that, on procurement, technical UK companies are under-performing. When it comes to people working at CERN, we contribute about 15% of the budget but have only about 7.5% of those employed. With previous European and other international collaborations we got more out than we put in, yet here we get far less. Surely there is a big problem.

Christopher Hartley: As I hope I said in my answers, on the procurement side we are very aware of this, which is why we have dedicated initiatives. To say that we had 100% improvement in the last two years is a clear indication that we agree with you and are addressing the problem.

Q14 **Chair:** And in terms of employment?

Dr Wells: Again, we are trying to understand why UK nationals are not applying, or, if they are, why they are not being successful. It is a multiprong problem.

From the point of view of scientific users, the UK science community is getting their fair share of the facilities. We also do rather well in leadership positions—directorate and department heads and head of the legal service. We need to keep filling the pipeline so that we gradually increase staff numbers in the coming years. We want to work on it with STFC.

Q15 **Katherine Fletcher:** As a scientist, I want to enumerate this doubling. What financial value have we gone from in 2021 to 2024?

Christopher Hartley: Under the supply contracts in 2021 just over 11 million Swiss francs were paid to UK companies, and well over 22 million were paid in 2023.

Q16 **Katherine Fletcher:** It is significant, but it is probably 10-ish/teens per cent of the overall annual contribution to the UK.

You mentioned the UK industrial liaison officer. That sounds like a really sensible innovation. Who does he work for? Does he work for you guys?

Christopher Hartley: He works for STFC. He is based at STFC but interacts directly with us. They also have some representation in CERN.

Q17 **Katherine Fletcher:** How does the role get to industry? Is it linked to the business Department, to a Catapult or to industry bodies?

Christopher Hartley: The STFC liaises with DSIT, obviously, and works directly with UK supplier companies. It organises and performs regional roadshows, where it reaches out, has presentations about CERN and upcoming opportunities and contacts industry in specific areas.

Q18 **Katherine Fletcher:** Any company watching this should go straight to an STFC roadshow to take advantage of CERN opportunities.

Christopher Hartley: Absolutely.

Q19 **Chair:** Is that paid from the STFC budget, the research budget?

Christopher Hartley: I do not feel qualified to comment on how it is paid within STFC.

Q20 **Chair:** We will hear from Professor Thomson later.

That is not from the CERN subscription. We are paying extra from UK funds to remedy a problem in CERN, as we might see it or think about it.

Dr Wells: We also ran events at CERN that CERN funds, so there is something coming out of the CERN budget. We need to get companies on site so they meet the engineers who have the deep knowledge about what is needed and have a proper conversation on the technical details and specifications of calls for tender that might be coming up.

Q21 **Carol Monaghan:** You have highlighted the benefits of blue sky research and research for research's sake. What we are trying to get at is whether this is value for money and whether other places that research for research's sake could produce better economic outcomes.

Fifteen per cent of CERN's budget comes from the UK, but we hear about a lack of procurement going to UK companies. Mr Hartley, should UKRI or the UK Government be doing more to get more companies winning contracts?

Christopher Hartley: My view is that it is very much a three-party approach. We in CERN need to do the outreach. We need to ensure that our procedures and the information we make available are transparent and clear and that there is a level playing field. We need to work with UKRI and STFC, and there is the industrial component as well. UK businesses need to have the appetite to work with us. They need to understand the benefits.

I referred to the roadshows. It is very important that we explain how we do business, because when we have our own specific procurement systems there is always the risk that businesses will look at certain things and say, "That's too complicated; it isn't worth it as it is only one contract." They need to understand the potential long-term relationships.

In an organisation that is 70 years old, very often we see that there are suppliers who, once in place, continue to be suppliers—

Q22 **Carol Monaghan:** France seems to do quite well from contracts. Geographically, it is well placed. How much does it contribute?

Christopher Hartley: The French contribution is slightly less than that of the UK. They pay about 14% of the CERN budget, if I remember correctly.

You are probably better placed than I am to comment on it, but I understand that in many international organisations the host state and geographically close states have a significant advantage. For contracts on the maintenance of roads on-site or for reroofing, we are extremely unlikely to convince a UK company to set up an operation close to Geneva to re-fence the site. That tends to have a very natural influence and to be from France or Switzerland, the local economies.

Q23 **Carol Monaghan:** Deep science and engineering could come from other places.

Christopher Hartley: Absolutely, yes.

Dr Wells: CERN's key product is scientific results—publications. Each of the large experiments at the large hadron collider has put out hundreds of papers, and UK scientists are signing those papers. It is difficult to put a monetary value on pushing the frontiers of knowledge. This is our business and we are doing that. The UK is a key partner in achieving it. If you focus entirely on industrial procurement, it perhaps leaves aside the main product of the organisation.

Q24 **Carol Monaghan:** Will you tell us a little about the future collision collider? What is it? Does the project have widespread support among the physics community? How will it benefit science and wider society?

Dr Wells: Research at CERN has, over the decades, discovered various particles that are components of our standard theory, which we call the standard model of particle physics. It does a fantastic job of explaining and predicting the results of collider experiments, but it explains only 5% of the mass and energy in the universe.

It has various other problems. We do not understand why there is not the same amount of matter and antimatter in the universe—why there is not enough matter left over to make committee rooms, and so on. We want to understand more. We want to understand how to advance the missing parts of the theory to have a better overall picture of the evolution of the universe. To do that, we have a project to upgrade the intensity of the large hadron collider—the so-called high-luminosity large hadron collider.

That will continue to run until 2041. It started operation in 2010. These are decades-long projects. Before the large hadron collider, there was a collider in the same tunnel, the large electron-positron collider, which started in 1989.

I tell you that because we are now in the process of a technical and financial feasibility study for a future circular collider—FCC—and that programme will last about 50 years. It will start about 20 years from now, if it is approved. It would start with an electron-positron machine, which would measure in extreme detail the properties of the heaviest fundamental particles that we know. It would try to see whether their properties are exactly what is predicted by the standard model, or whether subtle differences give us a clue to what is going on beyond.

In the second phase, we could put a hadron collider in the same tunnel. The technical feasibility study in progress has looked at about 100 different possible layouts for the future circular collider and chosen one that seems the most beneficial, in terms of satisfying all the requirements of the two phases of the project. It has a circumference of 91 km. It is on average 200 metres underground, because it has to be in the rock that is of good quality for tunnelling, which is the molasse, in the Geneva region. It also has to get under Lake Geneva and the Rhône river. That is what sets the depth—being able to avoid those obvious constraints.

In the placement, the use of as much local infrastructure and existing CERN infrastructure as possible has also been looked at in detail; for example, where can we connect to electricity supplies, or to converter stations, that already exist, and what is the minimum amount of new road building that would be needed? All those environmental considerations have fed into finding the optimum placement and length of this tunnel, and being able to connect to the existing CERN facilities that would help in preparing the beams to go into the big new collider.

Q25 **Carol Monaghan:** From what you are saying, we can understand the benefit to science from that deep understanding and discovery, but what about society? Is there a societal benefit from the spinouts and engineering advances, or is there something else that society will get from this?

Dr Wells: I think the societal benefits will continue in the same manner as they have. For example, we need to develop new high-field magnets for the eventual hadron collider option, so we will need research and development on how to make high-field magnets—not necessarily at liquid helium temperatures, but maybe higher-temperature superconductors. If you can achieve something like that, the same technologies can be used to make other—

Q26 **Carol Monaghan:** Energy networks, for example.

Dr Wells: Energy networks for power—equally, high-temperature superconducting cables for energy transmission.

You also asked whether this is widely approved, and I wanted to explain.

Q27 **Carol Monaghan:** I am conscious of time, Dr Wells. The Chair will start getting upset.

Dr Wells: In brief, the strategy for particle physics in Europe is set by an exercise called the European strategy for particle physics, which was first completed in 2006 and is updated every six to seven years. This feasibility study was the top priority of the previous update, and will be an input to the next update. It is a bottom-up exercise involving thousands of scientists—not just particle physicists but astronomers and nuclear physicists. So it has very widespread support in the scientific community.

Q28 **Carol Monaghan:** I think, Mr Hartley, you wanted to say something. If you can in 10 seconds, that will be great.

Christopher Hartley: Very briefly, I just want to say that when we talk about energy networks it is not a hypothetical concept. We have our knowledge transfer agreements and we are working today with companies—in Scandinavia, for example, investigating a major problem that they have with offshore windfarms. There is a tremendous loss of electricity before it is delivered to the end customer. We are working with a company right now to use the same technology that Dr Wells referred to, to improve their transmission lines.

We are also working with Airbus, which is working on zero-emissions aircraft—hydrogen-powered aircraft—and needs superconducting cabling technology to keep their weight down. Those are real projects that we are working on today.

Q29 **Chair:** May I just check: are the funds being used to develop the case for the future circular collider coming out of current CERN subscriptions?

Dr Wells: The future circular collider is a collaborative effort, so it is partly studies done by CERN, but, again, as with all CERN collaborations, there are about 130 different institutes involved.

Q30 **Chair:** It has not been decided that it will be embarked on, so are funds being taken from those that have been committed to current experiments, to make the case for a future piece of infrastructure? Is that a fair summary?

Dr Wells: The CERN medium-term plan for the budget includes elements of research and development, and studies for the future. It has to, otherwise you are not ready for when you finally come to ask member states for approval.

Christopher Hartley: And that plan is approved by all member states.

Q31 **Graham Stringer:** You have helped us with some information about the future circular collider. Why was the mid-term report on it not made publicly available?

Dr Wells: The feasibility study is a five-year study, which will be completed in 2025, at which point it will be made public. This was scrutiny of the progress so far, to be sure that it is going in the right direction. A lot of the input is available on the CERN future circular collider website, but the overall report was not made public because we are still working on exact details of the geological surveys and some of the negotiations with the host states, and so on. That is why the full report was not made public at this stage.

Q32 **Graham Stringer:** But would it do any harm to make it public? When you are talking about such large amounts of public money, isn't it better to be as transparent as possible?

Dr Wells: Indeed, and being open is a fundamental part of CERN's DNA. The issue here is that it is a work in progress. Some of the numbers are preliminary and we did not want to put it out at this stage, until we could be really sure that the study had been thoroughly completed.

Q33 **Graham Stringer:** Going back to the physics, I always thought it rather remiss of physicists and astronomers to miss 95% of the universe. To simplify it in the way that the objective of the large hadron collider was always explained to the world—that you were looking for the Higgs boson—will this project be a success if you find dark matter, and is the other thing you are looking for an explanation of why we are here, and why there is matter and not antimatter?

Dr Wells: The large hadron collider was addressing several questions. One was whether there is a Higgs boson: yes. Is it exactly what we predict in the standard model? That is a work in progress, measuring its properties more precisely, which will continue.

There are experiments at CERN, at the LHC and another facility, trying to understand matter and antimatter. We know from the way galaxies move and from large-scale structures in the universe that there must be something else exerting gravity that is not visible stars. Dark matter is not some speculation. There is observational evidence that there must be either dark matter or something else playing the same role.

We have not yet found any direct signal for dark matter at the large hadron collider so now we have to explore more theories. If we do not actually see it, that is a result. If you do not find it, you exclude a lot of possible models and constrain the theory explanation that you will have to come to in the end. It is a subtle thing, but not finding something is already giving you an awful lot of information.

Q34 **Graham Stringer:** So that is one of the objectives—

Dr Wells: We cannot say we will find dark matter, because we do not know what it is. We do not know how strongly it interacts. We are configuring experiments in as many different clever and cunning ways as we can, to make sure we have not missed a signal, and we are exploring. If we knew the answer, we would not need to do the experiment.

Q35 **Graham Stringer:** I understand that. There are two very big questions for any large amount of public money to be spent on science. One is the objectives—what you are looking for at that particular time, what you understand and why you are going in that particular direction in that field. The other is how you compare and contrast, and argue against investing in other pretty fundamental parts of science—the origin of life might be one, or consciousness: really fundamental questions in science that are yet to be answered. How would you in simple terms explain or justify the particular niche within physics, including against other fundamental questions?

Dr Wells: My view is that you need a balanced portfolio. You have to decide what the important questions for humanity are, and address several thrusts. You do not say, "I'm not going to do life sciences because I want to do physics." You need the broader set of—

Q36 **Graham Stringer:** That is almost self-evidently true, isn't it, but I am asking how you justify the very large amounts of money for CERN as against, potentially, very large amounts of money for the study of consciousness?

Dr Wells: The study of consciousness—

Q37 **Graham Stringer:** Or the origin of life: the fundamental questions.

Dr Wells: As I said—I am sorry to repeat myself—these are all very important fundamental questions. To me, the physics, the origin of the universe, and so on, have always been what I am interested in, and it is something that inspires young people. It is not niche, from that point of view.

Christopher Hartley: With the very challenging conditions that we create in CERN in our accelerator and in our experiments, when we talk about the companies working with us, there is the numerical—the financial—value of the contracts that they receive. Also, our requirements are so specific and so challenging that we find the vast majority of companies that work with us say that they improve their skills and products, and that that opens additional markets for them. Sometimes, setting really challenging requirements for very specific conditions really gives a badge of quality and a new level of reference for those companies when they work in other areas. Taking on the biggest questions helps you to develop your capabilities for other industries.

Q38 **Chair:** Given how fundamental these questions are, should they be investigated at a global level, in terms of future facilities? In other words, should the future collider be a global endeavour rather than a CERN, principally European, endeavour—as the Square Kilometre Array in astronomy is a global initiative?

Dr Wells: CERN is a global endeavour at this stage. The people coming to do the experiments have 110 different nationalities. If I take the example of one of the large hadron collider experiments, it has about 180 universities and labs from 40 different countries collaborating. The scientific collaboration spans the globe.

Q39 **Chair:** Does the US subscribe to CERN?

Dr Wells: It does not give a regular subscription—

Q40 **Chair:** That is what I mean, really. Should the powers like that be included?

Dr Wells: It does pay membership fees to be part of the experiments. It has made extremely significant in kind and cash contributions to the large hadron collider. We have a kind of reciprocity arrangement. CERN is participating in constructing some things for the neutrino physics programme in the US, so it is a partnership. We would definitely hope that partners such as the US would give a significant contribution to the future circular collider. There are US scientists taking part in the feasibility study—some of the specific magnet R&D, for example. It is based in Europe and is originally a European organisation, but now it is truly global.

Chair: I am very grateful for your evidence this morning. Dr Wells and Mr Hartley, thank you very much for coming to give evidence in person.

Examination of witnesses

Witnesses: Dr Hossenfelder and Professor Sir David King.

Q41 **Chair:** Let me introduce our next panel of witnesses. Professor Sir David King joins us in person in the Committee Room. He has been known to Parliament over the years, extensively, as a former Government chief scientific adviser and because he was the Government's permanent special representative for climate change between 2013 and 2017. He was the founding director of the Smith School of Enterprise and the Environment at Oxford. Sir David, thank you very much for coming.

Joining us virtually from Germany I am pleased to see on the screen Dr Sabine Hossenfelder, who is a researcher at the Munich Centre for Mathematical Philosophy, based at the Ludwig Maximilian University of Munich. Thank you both for joining us.

Sir David, you have, I think, expressed some concerns about the next phase—the proposed collider that has been referred to in the first panel. What are your concerns?

Professor Sir David King: Yes, basically my main point is the opportunity cost to other areas of research. I have been involved in quite a few curiosity-driven research projects, such as the Kennedy Apollo programme, which I was directly involved in for a while. It was aimed at getting a person landed on the moon. That was achieved, and now I am going to draw a strange comparison with the three billionaires in the United States who plan once again to put a person on the moon. I say that the opportunity cost of this is massive and we are not going to see the benefits from repeating what has already been done, in this way.

To move on to other very good examples of curiosity-driven research, DNA was curiosity-driven in my university, Cambridge, as there was a challenge by various biologists who said that surely these things in biology have structures. There was a big thought around that, no, they were too plastic to have structures. Then X-ray diffraction was utilised. The work was done alongside physicists in Cambridge—totally interdisciplinary—and they finally emerged with the structure of DNA. That was curiosity-driven, but look at the follow-through on it. It has been enormous, with benefits to humanity from understanding not just what DNA is but its structure, and then tackling various medical problems in that way.

My own field is solid surfaces. I moved into that field 50-plus years ago and there was no understanding at the atomic or electronic level of the structure of a surface. Surfaces were challenging because it is a breaking point in symmetry. I took on this problem alongside, I think, half a dozen other global leaders, and what emerged was a complete understanding of surface structures and, among them, silicon.

Of course, the whole internet revolution depends on having computers, which are all driven not by transistors, as we had in the old days, but by tiny little devices that have megabytes on them. So what we have seen is curiosity-driven research, and I stress that what emerged was not just understanding but the application of those discoveries.

Now, of course, we are all delighted—this takes me back to when I was a young man, when I was as interested in astronomy as any other aspect of science: yes, it provides that sort of interest for young people. The excitement draws you into the field and then you can be productive in whatever area. The excitement around the discovery of the Higgs boson might in itself have been justification for the enormous amount of money spent on building the large hadron collider, which is 77 km in circumference. I was privileged to be down there to see it under construction. It is an amazing piece of engineering and physics; but what if I ask myself, "Well, Higgs did predict the boson and then it was discovered, and that is a very satisfactory way for science to proceed, but what benefit comes to humanity from this discovery?" It is purely curiosity-driven.

The higher energy you go to, the more particles you will discover and, yes, it will provide a more complete understanding. I was talking about the large hadron collider being the last chance for this community to do some significant work, otherwise we go from 77 km to 91 km, and what is the end point? There is no end point because energies can always be increased and there will be new discoveries in that process. I am really concerned about the opportunity costs from UKRI's expenditure.

Q42 **Chair:** Let me bring in your fellow witness and we will hear some other questions that will enable you to expand on that.

Dr Hossenfelder, you have written of some concerns, which, I think, are allied to what Sir David has said. Tell us your concerns about the focus of expenditure on the proposed new circular collider.

Dr Hossenfelder: I entirely agree with what Dr Wells said earlier: progress is driven by fundamental research. I agree, but at any moment in time there are many areas in which we could do fundamental research. We have to be very careful about choosing the right ones, because, as Dr King just said, there are always opportunity costs.

I am very worried that if we spend a huge amount of money building this bigger collider, it will attract a lot of people working in this discipline; they will be intelligent, smart people who are not available to work on other things where they might have a bigger societal impact. There are only so many skilled people who also have the interest to work on this stuff and they will be drawn from related areas like materials science, artificial intelligence and climate physics. There will be fewer people available for those.

Dr King just said that if we go to higher energies, more particles will be discovered. I think that particle physicists wish that that was true, but there is absolutely no reason for that to be the case. It is true that we have some observations out in the cosmos that are normally attributed to dark matter, but, for one thing, it is not sure that dark matter actually exists and, even if it exists, it is not clear that it is made of a particle and, even if it is made of a particle, it is not clear that this bigger collider would find it.

I remind you also that pretty much all the particle physicists I know were pretty convinced that the large hadron collider would find the particle that makes up dark matter. That was not the case and now the predictions have been moved to the next, bigger, collider; but there is no reason why that should find the particle. As to the other questions that were alluded to—what dark energy is and the matter and antimatter asymmetry—I think the chances that the new collider will tell us anything are even smaller.

Chair: Thank you very much. Let us go into a bit more detail on that.

Q43 **Stephen Metcalfe:** Sir David, I think you told the BBC that it would be reckless to spend £12 billion on a future circular collider. What would you spend it on?

Professor Sir David King: Thank you; a good question. I am now supporting Tim Palmer, the professor of atmospheric physics, a theoretician based in Oxford, who published a paper in 2010 asking why we are not spending more money on understanding the risks associated with climate change.

I will say a little to back that up. A 37-year experimental observation of ice melting from Greenland has recently been published. It is an extraordinarily detailed study, with, for example, the involvement of double satellites, and has been very expensive. The discovery is that over the 37 years the loss of ice has averaged 30 million tonnes per hour and it is estimated that over that 37-year period about 1 trillion tonnes of ice have been lost from Greenland. Scientists are cautious about their conclusions, but that looks very much as if the ice on Greenland is now melting irreversibly due to climate change that has already happened.

When we look at challenges facing humanity today, that surely has to be the biggest challenge: the impacts of climate change. When the melting ice from Greenland has all melted, the average of global sea levels will have risen by 7.5 metres or 24 feet. We certainly would not be sitting comfortably here with that sort of sea level rise.

It may take 200 years, but I think we have a need to worry about a distant future. If we can look back at our civilisation's history over thousands of years, we surely have to look beyond 50 years; but it now looks very likely that, even in 50 years' time, loss and damage from the impacts of climate change, and in particular what is happening around the north pole region, are such that we are losing at least a quarter of a trillion dollars a year. That is loss and damage that we were not getting just 10 years ago. This is the big challenge; so what do we need?

Q44 **Chair:** Briefly, if you would, Sir David. We have quite a few more questions to get through.

Professor Sir David King: What we need is a CERN for climate change so that we have the ability, for example, to predict for every part of the world, with a detailed capability, what the challenges will be—every part of the world is going to be challenged in a different way—so that we can adapt to those processes; but it is much more than that.

Q45 **Stephen Metcalfe:** Thank you for that. It is public funding that is potentially going to go towards funding this—or not. What process do you think Governments' funding bodies should go through when they consider investment in large scientific infrastructure, to make sure we are getting the best impact—it is always about return on investment, but return can be intellectual as well—and to ensure that we are spending our money as wisely as we can?

Professor Sir David King: This is precisely why I very much welcome what this Committee is investigating, because normally we follow precedent. Here we have a community of 11,000 or 12,000 scientists who have put a very good case forward—although that case is questionable, as we have just heard—for continuing with their work. It is a very difficult question. Can we say, "No, that's it"? The United States did. They were in the particle physics arena and withdrew when they thought there were other opportunities in the science area.

I think that the Select Committee has a very difficult task, which is to look at this as an opportunity cost. I do not think that in the situation in the world today—the way our biosystems and our entire civilisation are being challenged—it is really fit for purpose. It is not giving us the opportunity to manage these crises. It is looking askance at something that is absolutely fascinating but that will not provide solutions to the problems that we face.

Q46 **Stephen Metcalfe:** We may be part of that system of deciding funding. Who else should be involved? Bearing in mind that I think it is right that politicians do not make specific funding decisions—they can make recommendations—should it be a panel of senior scientists, a mix of business people, scientists and politicians? How do we make these decisions? There are big amounts of money. You have highlighted probably the biggest threat that the planet faces. We know we need to do more. It is a balance.

Professor Sir David King: Your question is obviously the big one. You can put in a recommendation, but you are going to say, "Well, Britain is one part of 23 nations supporting this." However, I think it has to be recognised that the British voice in science and as the future for science is very strong. It is still very strong; we have a historical base here and people do take notice of what we say. Whatever you say—what the Parliament of Britain says—will really have an impact on the issue. It is not something we should duck, because each one of us is responsible for the decision making.

Obviously, I would like to see the same discussion happening across Europe and the contributing nations. We ought to be stimulating a discussion of that kind. Give it back to the science community and I believe it will simply say, "Let's take precedent," which is the way it has normally operated. There is a real risk that we simply follow precedent.

May I pick up on what our colleague has been saying? It is also an opportunity cost for these brilliant minds being drawn into this research, instead of going into discovering solutions to problems that face us in the future.

Q47 **Stephen Metcalfe:** You were the chief scientific adviser to the Government from 2000 to 2007. If you were still wearing that hat, would you be quite as forceful in your views as you have been recently? Would you be advising the Prime Minister not to spend £12 billion on this but to do something else?

Professor Sir David King: I think I was quite forceful when I was chief scientific adviser. My position is that I am always true to myself. I will always give advice that I believe is the right advice, so I would do exactly that.

Q48 **Carol Monaghan:** The Science, Innovation and Technology Committee is all for spending money on science; we are all for supporting good science, and we all understand the benefits that science can produce. Is there a danger, in a hypothetical future in which funding for CERN is reduced, that that money would go not into climate research but to some other pet Government project?

Professor Sir David King: That is a very difficult question. I cannot decide how this money should be used because others will make that decision. There is a very real probability that the money will be disbursed among various different existing channels of funding.

Q49 **Carol Monaghan:** Or not at all.

Professor Sir David King: Or not at all. It could even mean the Government withdrawing that sum of money from science research, which I think is what you are suggesting might happen. That would be disastrous. I should not say what the Committee should be doing, but it needs to look at a given budget and how that should be spent, not suggesting that maybe if we do not spend it this way, it will disappear. Your point is a still a good one.

Carol Monaghan: In fairness, we do that as well, but we are not the ones who hold the purse strings, unfortunately—or maybe fortunately.

Q50 **Chair:** Dr Hossenfelder, from an international point of view, the point Carol Monaghan was making was that you might lose this. You talk about an opportunity cost, but it may go to other valuable parts of public expenditure—schools, hospitals and the like—rather than science. Do you assess that as a risk internationally for subscribers other than the UK?

Dr Hossenfelder: Yes. People constantly warn me about this. It is definitely something that people worry about in other countries. I have to say that this is a very difficult decision to make. Maybe it is more important to build schools and have a programme for getting people out of poverty, so it is not really something I can speak about a lot. I come at this very much from the perspective of the scientist. At this moment in time there are other research areas in the foundations of physics where the money would be better invested.

Q51 **Katherine Fletcher:** Dr Hossenfelder, I confess that I went to CERN and bought the standard model fridge magnets. I am captivated by the science of it and the opportunity exactly to understand these open questions, but as a parliamentarian I have to ask and investigate some of the more difficult questions. There is always a dark corner of the internet where you can find something, but I did come across your material. If I am right, you and others are saying that particle physicists talk about answering the big questions, but their record of success is not there, outside the Higgs boson; for example, supersymmetry seems to have gone, dark matter has not been discovered and some of the rhetoric about what large colliders can achieve scientifically versus the experiments positioned within them and their ability to answer the questions. Will you elaborate a little bit on the gap between the joy of it and your concerns about the actuality of it?

Dr Hossenfelder: Particle physicists are very interested in particle physics. I speak to other particle physicists and they are excited about being part of this collaboration and building such a big device, as Dr Wells said. It is a lot about engineering and there is a lot of technology output and so on, to which I would generally say, "If that's what you want, you could more directly invest in that."

When it comes to the big questions, I do not think that this bigger collider will help us all that much. As you have already noted, a lot of big statements have been made since the 1980s about what the bigger colliders would find, starting with Tevatron in the United States, then LEP, the previous collider at CERN, which we have already heard about, and now the larger hadron collider. It was supposed to find more than just the Higgs boson and it did not. I think that is because of some problems with the predictions that physicists made, but this is a longer story.

Q52 **Katherine Fletcher:** Would you be so bold as to say that using colliders is not going to answer the questions they seek to answer? I do not want to put words in your mouth; I am just trying to understand the nature of your concerns.

Dr Hossenfelder: I do not think it is going to answer the questions that you have heard about in this meeting. If you talk to particle physicists, they have much more specific questions they want to answer. For example, they want to measure more precisely the mass of this particle or its interaction with some other particles. Those are questions that this bigger collider is basically guaranteed to give an answer to, but they are not very interesting questions.

Q53 **Katherine Fletcher:** What would you have us do instead to examine some of those more fundamental questions of what dark energy is, what dark matter is and why we have the matter/antimatter imbalance? How would you attack the problem?

Dr Hossenfelder: To find out more about dark matter you do some astrophysics experiments—the stuff that is already on the way basically with a satellite mission and CERN. There are more high-precision experiments, which again are already on the way—for example, direct detection experiments, and so on.

When it comes to the more general question of what we should do in the foundations of physics, I do not think there is enough investment in studying the foundations of quantum physics, with all that new technology that is already being heavily invested in. A lot of money and smart people in the UK are going into quantum technologies, quantum computing, quantum information, quantum optics and all this kind of stuff, but there is very little fundamental research. To me, that is an obvious thing to do where a lot of progress could be made.

Chair: I thank both witnesses for their evidence today. It has necessarily been a brief session, but I think we have very clearly the essence of your case. We are very grateful to have both of you here, in particular to have Sir David back in front of the Committee.

Examination of witness

Witness: Professor Mark Thomson.

Q54 **Chair:** I introduce our final panel, of one. Again, the witness is familiar to the Committee. Professor Mark Thomson is executive chair of the Science and Technology Facilities Council, the council within UKRI that principally funds the UK's contribution to CERN. Professor Thomson is, very relevantly, professor of experimental particle physics at the University of Cambridge. He was previously employed at CERN, where he played a leading role in the study of the W and Z bosons.

Thank you very much indeed, Professor Thomson. You have been kind enough to sit through the evidence this morning. You have heard the to and fro. Concerns have been expressed about the value for money that the UK is getting from its subscription in two particular respects, among others: procurement and the employment of UK scientists. Give us your reaction to what you have heard this morning.

Professor Thomson: I share those concerns. When I took over this job six years ago, one of the things I looked at was whether we were extracting the value of our investment in all of our international subscriptions, not just CERN. I think the answer was that, scientifically, absolutely yes. We get fantastic value out of it, but in terms of industrial return and perhaps the training opportunities for our early-career scientists we were not getting as much as we could do.

We have started to put in place measures to increase the return on investment in that sense, and that was part of the motivation for putting together the UK's strategy for engagement with CERN, which was a joint STFC, BEIS and DSIT endeavour. It was a start to address those issues.

As you heard from Chris Hartley earlier, we are beginning to see positive evidence and changing things in the right direction. It is putting real focus on trying to get better value out of the subscription. It is a very valid question. I think the concerns expressed by the members of this Committee are absolutely the right ones, but with the right measures we can turn that around. That is what we are trying to put a lot of focus on at the moment.

Q55 **Katherine Fletcher:** It is very good to see you again, Professor. How do you think we got ourselves into this position? How did we end up with a mismatch between the UK's commitment to and joy in fundamental physics and a huge differential compared with some of the other states in terms of what we were receiving directly?

Professor Thomson: Not wanting to criticise our previous approach, I do not think we put enough focus on the economic benefits of our subscriptions.

Q56 **Katherine Fletcher:** It was, "Thanks. We've got the internet and that'll do"?

Professor Thomson: Not quite. We use industrial return as a good example. Previously, within my organisation international liaison sat within our research department effectively. We have now moved that into our business and innovation department—the people who work with business all the time. Strengthening the approach is strengthening the benefits. Our way of working collaboratively and raising these issues with CERN to solve them is again part of the solution. We have seen a big shift over the last few years. We still have a way to go.

On the personnel or human return, that is still work in progress. CERN has changed the way in which its early-career schemes are structured. I think that will be very beneficial for the UK. We need to keep pressing on what measures we can put in the implementation of our strategy and change the dial on those measures as well. It is doable, but it requires focus. Our approach is to look at the scientific benefits—we all know they are really important—and put increased focus on not just the science but all those other benefits.

Q57 **Katherine Fletcher:** Quite famously, the LHC is heading for an upgrade; it has been through only a very small percentage of all the different collisions it can do and we are going to speed that up. How far down that process would you go in terms of evidence of scientific discovery, off the back of the investment in the LHC, before you committed to the FCC?

Professor Thomson: That is a very good question. What we are doing at the moment through CERN is not to make a commitment to the FCC, but we are putting in place all the feasibility and design work that is necessary if we want to start that project in the 2040s. We are now doing the work to enable work to start in the 2040s.

Q58 **Katherine Fletcher:** Do you know what the cost is? Obviously, it is coming out of the current budget. Are we talking of 10 or 20 million quid a year?

Professor Thomson: I do not know. We could give you the actual number in writing. It is a small fraction of the CERN budget. I cannot remember the exact number.

Q59 **Katherine Fletcher:** Forgive me for interrupting you. Go on.

Professor Thomson: What we are doing at the moment is the design work to make this an option for the future. For that to be realised, we will have to do two things. First, we have to make the scientific case. I believe there is a very strong scientific case for the FCC, but we will have to convince others of that. Within the UK, as with all other major investments, we will have to make a business and economic case for why the UK is investing in this through the normal Green Book procedure.

Q60 **Katherine Fletcher:** I completely agree with both those sentences, but do we make that decision tomorrow or let the LHC run through, say, 50% of its collision dataset before making that decision, which would be in, what, five or 10 years?

Professor Thomson: It would probably be in five or 10 years' time. I think that is genuinely an open question. We have not got to the point where we are making decisions. The next stage was referred to by Dr Wells. There is a European strategy for particle physics. There is a Europe-wide agreed approach for what the priorities are. That will be updated in the next few years and it will lay out the pathway, potentially, for the future circular collider, if that is the route forward, and the timescales.

One of the challenges about which there are concerns is leaving a big gap between the LHC and the next project, because all that happens then is that you start to lose capability. It is not necessarily scientific capability we are concerned about; it is the engineering capability. Once you have lost the expertise in high-field magnets, for example, it is very hard to build that up again. There are lots of dimensions to your question, but I think it is an excellent one.

Katherine Fletcher: I think that by 2041 or 2044 the capability loss will not be high-field magnets, given the way the field is moving. What we will lose is unknown; we do not know what it is yet. It is interesting, but I am very conscious of time.

Q61 **Dr Davies:** If we take a step back, can we ask the general question: why should the UK be committed to CERN?

Professor Thomson: As a personal view—I will return to the economic view—CERN is one of the pinnacles of not just particle physics but physics research. It is a beautiful paradigm of international collaboration to answer the most difficult questions out there.

All major economies around the globe are investing in this type of research because they see not just the cultural and scientific value—Dr Wells made those points—but that by investing in facilities like CERN one is trying to answer the most difficult questions out there. To do that, you have to invent new technologies. You cannot apply existing technologies to answer new questions.

My view is that by developing those new technologies you drive other areas of science. I mentioned one example when you visited. When designing some of the silicon sensors for the LHC detectors we had to make them very radiation-hard. Our team at the Rutherford Appleton Laboratory did that work with Richard Henderson at the Laboratory of Molecular Biology in Cambridge to develop the technique of cryo-electron microscopy, which again needed radiation-hard sensors. He won the Nobel prize for that. That technique of cryo-EM is changing structural biology. By driving technology to do the hard physics you have an impact on other areas of science. That is why we need to be in it. If we are not, we start to lose that technological edge.

Q62 **Dr Davies:** Is Britain submitting a candidate for the next CERN director general?

Professor Thomson: You would have to ask the Foreign Office and DSIT colleagues that question.

Q63 **Dr Davies:** Okay, fair enough. Do you think that the Foreign Office, DSIT colleagues and the SFTC are liaising with CERN member states over that possibility to a sufficient degree?

Professor Thomson: That would be for the Foreign Office, I think.

Q64 **Dr Davies:** Okay, right. I will not pursue that any further.

You have told us that you are committed to the idea of a future circular collider. Why should the UK Government be committed to it? What are the reasons?

Professor Thomson: I am committed to doing the right feasibility study. I also believe the science case is correct. I also believe it is the best machine to do that science. Until we have a full understanding of the cost and can make that economic argument, that is the point we will have to take a decision. One thing that has not come out, perhaps, in some of the previous evidence to this committee is that we will not be asking for a significant amount of additional money on top of the CERN subscription.

The costs of the future circular collider will largely come out of the CERN subscription plus, hopefully, additional contributions from non-member states, the US being one possibility if it chooses to do so, and possibly additional contributions from the host states, again, if they choose to do that. That is where we are. This is not asking for a large amount of additional money on top of the budget.

Q65 **Dr Davies:** Are you concerned that the funding for this project could divert funds from other infrastructure projects? "No" is the answer to that.

Professor Thomson: It is part of our ongoing commitment to CERN. As long as that remains—I strongly believe it should—it is not really asking for a large additional amount of money. I am not too concerned about that.

Within the Science and Technology Facilities Council, we invest in lots of large research infrastructures, CERN being one of them—the biggest. The Square Kilometre Array was mentioned previously. We look at that portfolio and try to balance the science and our investments to get the best science as well as the best technological return. We are always balancing infrastructure investments, and we do that now across UK Research and Innovation for our long-term infrastructure portfolio.

Q66 **Chair:** You said that the next director general of CERN is a matter for the Foreign Office. We are the second largest contributor to CERN. We do not have the current director general. We are noted for the calibre of our scientists. Surely, we ought to have a candidate. Why is it a matter for the Foreign Office rather than something that is open—you said that transparency is the hallmark of CERN? Surely, we should be doing this in public.

Professor Thomson: I agree. In the previous director general campaigns for CERN, there have been UK names in the mix, and I hope that would happen in the current campaign.

Chair: Graham Stringer and Katherine Fletcher have some supplementaries.

Q67 **Graham Stringer:** I have a quick follow-up to that question, and then I have another one. Maybe I should know the answer, but why does the Foreign Office nominate, and not—

Professor Thomson: Sorry, I did not say the Foreign Office nominated, but potential engagement with other countries at the diplomatic level would sit with the Foreign Office.

Q68 **Graham Stringer:** What is the process? If one of our distinguished scientists is to be nominated, do they apply or are they approached?

Professor Thomson: There are multiple routes. An open recruitment campaign will launch sometime in April, I believe. Countries are able to nominate. Individuals are able to self-nominate. Then there is a rather complex process through the scientific policy committee of CERN—a little like a search committee that narrows the field. Then it goes to CERN Council, the council of the member states of CERN, which is where the international dimension comes in. That is often a ministerial or foreign ministry decision. It is an international governmental organisation.

Q69 **Graham Stringer:** You heard the arguments of David King and Dr Hossenfelder. From what you have said, you do not agree with them. Can you approach the points that those two academics made?

Professor Thomson: Of course, I respect the opinions. Particle physics and astronomy—big science, our big investments—are a significant part of our physics research programme, just looking at physics on the whole. If you look at the amount of money that the UK spends on physics compared to the rest of the portfolio—I would have to give you a number offline if you wanted that—you see that this is not the largest fraction of UKRI's research investments. The Institute of Physics would make the case that physics needs a larger investment because of the economic benefits. In terms of that research portfolio, we are not out of balance.

As for the opportunity costs in terms of people, which was an interesting point, I would argue it the other way. Big projects like CERN or astronomy attract more people into the field. The Science and Technology Facilities Council is very keen to promote this big, exciting science and to reach out to diverse audiences and less-privileged audiences—diversity in that sense—to try to encourage more people to go into science. Most of the people who go into particle physics do not stay there; they will go out into other fields of science, they will go out into industry, and they will pick up skills in artificial intelligence. There is a valid argument to make—and we would be able to make that—that by making these investments you are increasing the pool of talent. There are nuanced arguments in all these areas.

Q70 **Graham Stringer:** We are doing a parallel inquiry into astronomy at the moment, and one of the facts that has come up is that, since PPARC was abolished, physics and astronomy have lost out—the change in the funding councils meant there was less cash. Do you think that is true? Do you also think it is an argument that could be used to support these substantial amounts of money?

Professor Thomson: I do not think the transition from PPARC to STFC was the issue. The issue that people have seen is, effectively, the long-term, flat-cash budgets and then increased costs of doing research. That pushes down capacity.

As part of this initiative to get the most value out of our big research investments, we have prioritised investments in early-career researchers. We have turned that around in some sense. We are now investing more money in supporting the exploitation of these big facilities, and that basically means supporting more early-career researchers. That was an active decision to prioritise increasing the number of researchers benefiting from these facilities. That did not happen in the 2010s, but we are now turning that around. That was an active decision to prioritise people, and that is having an impact. It was not the transition to the research councils; it was more a funding issue.

Q71 **Graham Stringer:** I have a final question that I asked earlier panellists. It may be a question that is impossible to answer—how you choose between different areas of fundamental research—but it is a decision that has to be made, whether there is a straightforward answer to it. One of the recommendations from the Nurse report from nine years ago was to put the funding councils together so that those decisions could be made. Do you think that has worked, and are those rather difficult questions being approached now?

Professor Thomson: We are part of the way there. There have been real success stories from the creation of UK Research and Innovation. To come back to the topic today, one of the big areas—it touches on the previous session—is that our community within STFC has worked much more closely with the quantum communities in EPSRC, the Engineering and Physical Sciences Research Council, looking at how we start to use quantum technologies to address some of these fundamental questions about the universe. That was funded through a UKRI initiative. We came together, made the science case, and we are now working, as I say, on driving technology but to do fundamental science. By doing that, we are driving the quantum technologies as well.

That is just one example of where something was at the boundaries between two different research domains but now has been enabled by the formation of UKRI. Has everything worked perfectly? We are still only six years into UKRI, but the direction is very positive.

Q72 **Katherine Fletcher:** We are trying to examine whether we are getting value for money and whether we are approaching the fundamental questions in the right way. You said that you are absolutely convinced that the science case is correct for the FCC. Will you just put on record why? If this needs to slip into techie, that is cool. We are trying to translate, but I am always slightly frightened of word soup—"counterpoint the surrealism of the underlying metaphor".

Professor Thomson: Okay, I will try to do that.

First, this is not my opinion; this is the opinion of the wider particle physics community: the next frontier should be a machine that focuses on looking at the Higgs boson. The reason for that is that the Higgs boson is nothing like any of the other particles. It is completely different. It is the reason we are all here and the reason we have mass; otherwise we would all be flying across the universe. That would not be very pleasant. All of our particles would be massless.

The Higgs boson determines the size of atoms because it determines the mass of electrons, so it is absolutely fundamental. It is everywhere in the vacuum. It is a really odd object. It is unique. It is the only particle we have ever seen that has no spin. We do not really understand its properties.

The interesting thing about the Higgs is it gives mass to everything else. If there is anything else out there that we do not know about, we expect the Higgs to connect to it. That is really the driving argument around, "Let's study this really odd object and see if it actually looks like what we think it does." Then, because it might connect to anything else that is out there, the idea is that it is the window through which we might discover stuff we do not know. This is discovery science. You are never guaranteed. That is phase 1 of the FCC.

Q73 **Katherine Fletcher:** Can I just come in on that? We have discovered the Higgs, and we are wrong; it is 126 GeV. Is that right? We have discovered that with the LHC. If we can see it with the LHC, why do we need a bigger one?

Professor Thomson: There are a lot of measurements you can do with the LHC, but to do some of the other measurements, to really measure its properties precisely so we can understand whether the Higgs boson is decaying into things that we cannot see, which it could well be—invisible particles, which is possible—you cannot see that at the LHC. You can measure that at the Higgs factory and you can measure all the couplings precisely. There are very strong scientific arguments for using that Higgs boson to discover the uncharted world of particle physics out there.

Q74 **Katherine Fletcher:** What is the one experimental data output that you think would seal the case for the FCC? Is it a very clear energy loss in a box marked, "We don't know what's here," from one of the collisions? What is it?

Professor Thomson: For me—this is a personal opinion—it is measuring those couplings, measuring how strongly the Higgs interacts with all the other particles and whether that aligns with the predictions we see at the moment. More importantly, you can measure how often the Higgs is decaying into things you do not see.

Q75 **Katherine Fletcher:** With the LHC.

Professor Thomson: No, with the future circular collider.

Q76 **Katherine Fletcher:** No, sorry, this is what I am getting at. What piece of information that is currently accessible to us experimentally or potentially will create the case for the FCC?

Professor Thomson: That is an excellent question. We know we can make some of the measurements of the properties of the Higgs boson at the LHC. For these more subtle ones, we cannot do that. That is why the global science community, and certainly the European community, believes that a Higgs factory to study these properties in immense detail is the right next machine.

Q77 **Katherine Fletcher:** No, I hear very clever people say, "This is absolutely what we need," but it is big money and a big sum on trust. Is there any absence of data that gives us the indicator that these people are right?

Professor Thomson: As I say, it is a question of the nature of the Higgs boson. The only way we are going to find out the nature of the Higgs boson in real detail and use that as a window for discovery is a machine like the future circular collider. We can go so far at the LHC.

Q78 **Katherine Fletcher:** Is it not worth collecting 95% of the additional data? Should we just shut it down and build the FCC? If there is no data that is going to come out that makes the case for the FCC, why do we not just say, "The LHC is Betamax. Let's build a VHS and just do it properly"? Why wait until 2040?

Professor Thomson: There are two separate questions here. The physics case for the FCC is there because of the Higgs part. The physics case for the high-luminosity LHC is at the high-energy discovery frontier. We heard in the previous session about supersymmetry. It may or may not be there. We do not really know yet. We have taken about 7% of the LHC data. We have not seen anything yet. If you are exploring the unknown, there are two ways of doing that: the precision measurements of the Higgs or smashing stuff together hard and doing that for a long time and really digging into that data. This is discovery science, so there is no guarantee, but we need to take that data to come to the conclusion that there is nothing there at the LHC.

Q79 **Katherine Fletcher:** Here is why I am bothered, and I promise I will stop. You have a theoretical prediction from Professor Higgs and others that says, "If you look somewhere here, you will find this," and that was shipped around and a lot of people put their hands in their pockets and said, "Great." We are now saying there seems to be a gap in the case for the next step when a lot of it is disproving a negative. I am very conscious of time, and I wonder whether that is something that we could return to.

Chair: Perhaps Professor Thomson can just answer that briefly.

Professor Thomson: I am not quite sure I have the question.

Q80 **Katherine Fletcher:** What is it that is convincing people that we need higher energies to understand a thing that we have seen successfully at lower energies?

Professor Thomson: The future circular collider is not a higher-energy machine; it is a more precise machine that, in its initial stages, collides electrons, enabling you to make the precision measurements so that you can understand in detail the properties of this very mysterious particle.

Q81 **Katherine Fletcher:** Are you effectively saying that because it is a slightly older design, the detectors at the LHC are looking it at it through a net curtain and you want to look at it through a microscope?

Professor Thomson: We will go with that.

Katherine Fletcher: Great. Thanks very much.

Professor Thomson: Thank you.

Q82 **Chair:** It has been a fascinating morning. It is evident that the Committee shares everyone's interest in and enthusiasm about the science, but as a Committee of Parliament questions have to be asked about priorities and future priorities.

Were the FCC to be built, I think the UK contribution would be about £1.3 billion—a huge amount of money. We had a one-off session on fungi a few weeks ago, which is minutely funded by comparison, yet research in fungi is responsible for the discovery of penicillin in years past, which has probably saved half a billion lives. These are important questions, scientific questions and, in some respect, ethical questions on the best deployment of taxpayers' money. These are the reasons behind our questions.

Are you confident that spending £1.3 billion, should we make the case for a future circular collider, compares well with such alternatives? On Graham's point, do we have the right forum to decide that? Is UKRI best placed to decide between that or research into genetics or these colliders?

Professor Thomson: I will come back to the fact that we will have to make a Green Book business case for this investment focusing on the economic benefits.

I would like to step back to the previous discussions. The origin of a lot of the techniques we use in other areas of science—X-ray diffraction or synchrotrons, which are the machines that we use to study biological matter, or neutron scattering, the machines we have at Harwell to look at material sciences and biological systems—was particle physics. By driving the technology, we are providing the tools to understand biological systems. I do not think you can look at it purely in isolation. You have to look at how it contributes to other areas of science in the long term.

Q83 **Chair:** As the structure for deciding that, is UKRI adequate? It might be a step forward, but can it resolve these questions?

Professor Thomson: UKRI, I would argue, certainly over the last four years in terms of our major infrastructure investments has come together and made decisions looking across all domains, including arts and humanities, social sciences, biological sciences and physical sciences, and prioritised infrastructure investments between the two, not at the scale of this but at the scale of a few hundred million pounds. That has worked incredibly effectively within UKRI.

Chair: Good. Professor Thomson, I am very grateful, as the Committee is, for your evidence this morning and for that of all our witnesses.