The Higgs boson and beyond was organised, with help from a few friends, by researchers from the UK Particle-Physics groups that collaborate on the ATLAS and CMS experiments, at the Large Hadron Collider, near Geneva.

The institutes and people involved with the exhibit were as follows:

**Exhibit team**

The Higgs boson and beyond was made possible through help and support from the participating institutes (left), and from:

- STFC: Science and Technology Facilities Council
- CERN: European Laboratory for Particle Physics
- GridPP: UK Computing for Particle Physics
- Higgs Centre for Theoretical Physics
- SEPnet: South East Physics Network
- Artwork and design: Rebecca Pitt
- Booklet editor: Karl Harrison
- Exhibit coordinators: Wahid Bhimji, Cristina Lazzeroni, Konstantinos Nikolopoulos

**The Royal Society summer science exhibition 2014**

30th June 2014 to 6th July 2014

THE ROYAL SOCIETY

6 Carlton House Terrace, London SW1Y 5AG
The discovery of the Higgs boson was a momentous occasion, but what lies beyond could be even more exciting.

The Higgs boson and beyond

The existence of the Higgs boson was first suggested in 1964, as part of a theory that explains how elementary particles, the point-like building blocks of nature, can have non-zero mass. Its observation by the ATLAS and CMS experiments, at the Large Hadron Collider, in Geneva, was a scientific milestone. Subsequent studies, with more data, have consolidated the discovery, and prompted the award of the 2013 Nobel Prize in Physics to two of the key contributors to the original theoretical developments: François Englert and Peter Higgs.

In August 2013, when it was looking likely that the year’s Nobel Prize in Physics would be awarded for work relating to the Higgs boson, Kostas, Wahid and I had discussions with other particle physicists about how we could highlight the science behind the prize. It quickly became clear that what we wanted to show was how the discovery of the Higgs marks the end of one journey, but the start of an exciting new journey, to unknown lands. The result is The Higgs boson and beyond. Like its predecessor, this has involved researchers from all of the eighteen UK institutes participating in the ATLAS and CMS experiments.

Why, then, is the Higgs boson so relevant? Well, without it our world would be very different. Elementary particles would all have zero mass, with dramatic consequences. For example, electrons would be unable to enter into orbits around protons and neutrons, and so atoms couldn’t form. The physics of elementary particles ultimately underlies everything we know and experience, and this is why I find it so fascinating. I hope that you too will find fascinating The Higgs boson and beyond.

Why it matters
Cristina Lazzeroni
Putting together a science exhibit is hard work, but one thing I really like is that it makes me think about what I do, and why it’s relevant. So when a new particle, the Higgs boson, was discovered, in 2012, I jumped at the opportunity of telling everybody all about it. This led to the staging of Understanding the Higgs boson at the 2013 Royal Society Summer Science Exhibition.

What comes next
Wahid Bhimji
People often ask me if the discovery of the Higgs Boson means that our work is done. Actually, this discovery doesn’t come close to answering all of our questions about the Universe. For one thing, the fact that the Higgs particle isn’t as heavy as theory suggests, is a strong hint there’s something still to be discovered, for example the new particles introduced by the theory of supersymmetry. Also, astronomical measurements indicate that most of the mass of the Universe is in the form of dark matter, and we don’t know what this is. Ultimately, we want to create a Theory of Everything, which brings together our understanding of elementary particles, and our understanding of gravity, which is key for describing the motion of galaxies and planets. So there’s still a lot to do, and we’ll need to create even higher energies, and even bigger machines, to do it!

What we know
Konstantinos Nikolopoulos
The observation of a new particle is always a major event, but what do we really know about the particle announced in July 2012? The detailed work to map out this particle’s basic properties began immediately after the discovery.

Thanks to the excellent performance of the Large Hadron Collider, and of the ATLAS and CMS experiments, we have been able to establish that the new particle closely resembles the Higgs boson predicted by the Standard Model, the set of theories that describes the physics of elementary particles.

Previously detected elementary particles behave as if they’re spinning. Measurements indicate that the new particle has no spin, matching the theoretical expectations for the Higgs boson.

The new particle decays rapidly, to pairs of force carriers (W bosons, Z bosons or photons), or to a matter particle and corresponding anti-matter particle. Within the current experimental precision, of about twenty to thirty per cent, the measured decay rates are in agreement with calculations in the framework of the Standard Model.

Studies to date set the stage for even more detailed investigations in the future, with upgraded accelerator and detectors. We will be looking for deviations from the theoretical predictions, which would signal physics beyond the Standard Model, a really exciting possibility!
How the world is built

All everyday objects seem to be made from just three types of basic building block – the up quark, the down quark, and the electron.

Powers Of Ten

Physics deals both with very big numbers and with very small numbers. These numbers are often shown as multiples of 10 to some power, written as a superscript.

DNA

Pairs of deoxyribonucleic acid (DNA) molecules form a double-helix structure that encodes genetic information in living organisms. Each structure contains around $2 \times 10^9$ atoms of just 5 different types: hydrogen, oxygen, carbon and phosphorus.

The up quark, down quark and electron are the basic building blocks of everyday objects. The electron neutrino is involved in radioactive decays, and in processes that power the stars.

Elements and isotopes

Atoms grouped together form an element if they all have the same number of protons. If they also all have the same number of neutrons, they form a particular isotope of the element. A single element can have several naturally occurring isotopes.

Grain of Salt

$10^{23}$ atoms

Human

$7 \times 10^7$ atoms

Planet Earth

$10^{25}$ atoms

Water molecule

$10^{-7}$ m to $10^{-4}$ m

Atoms and molecules combine to form microscopic structures

A human cell contains 46 DNA double helixes and around $1 \times 10^{12}$ atoms.

$10^{-18}$ m

Elementary particles – no detected structure

The diameter of an atom is more than 10,000 times the diameter of its nucleus.

Ions

An atom that loses or gains electrons, and so becomes electrically charged, is an ion.

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Particles outside of the Standard Model

None of these particles have been detected experimentally. The graviton is introduced by theories of gravity. Other particles are added by supersymmetry.

Forces that affect particles

- subject to electromagnetic force
- subject to weak force
- subject to strong force

Particles of the Standard Model

Only these particles have been detected experimentally.

Particles and Anti-Particles

Each particle has an anti-particle, with identical mass but oppositely signed charge values.

Fermions and Bosons

Particles behave as if they’re spinning and are identified as fermions or bosons depending on the amount of spin. Spin values are integer or half-integer multiples of a quantity known as the Dirac constant. Fermions can always be told apart, for example in terms of energy or direction of spin, but bosons may be identical. The whole of chemistry depends on the fact that electrons are fermions.

Hadrons

Quarks and anti-quarks aren’t detected as free particles, but are bound together in composite objects, as one of three types of hadrons. These are baryons (three quarks), anti-baryons (three anti-quarks) and mesons (quark and anti-quark).

Supersymmetry

Theories for improving on the Standard Model have been developed around a concept called supersymmetry. This adds additional Higgs bosons, and makes the boson world a mirror image of the fermion world. The simplest formulation is the Minimal Supersymmetric Model. As they haven’t so far been detected, supersymmetry particles, if they exist, must be heavier than their partners in the Standard Model.
For an interaction or decay to be fully described by a diagram, the particles involved need to be indicated. Each line and vertex is shorthand for a lengthy mathematical expression. Multiplying together the expressions for all parts of the diagram gives a measure of how often the process represented occurs.
Mass and the Higgs boson

Elementary particles acquire mass through interactions with an energy field, where the Higgs boson acts as energy carrier.

The mass of a hydrogen atom is much higher than the combined masses of the electron and quarks from which it is built. Most of the mass of an atom comes from the energy of holding quarks together inside protons and neutrons.

Mass-energy equivalence
An object’s energy content, \( E \), and mass, \( m \), are related by the speed of light, \( c \)

\[ E = mc^2 \]

Gravitational mass
measures ability to create, and be influenced by, gravitational forces:

\[ F = G \frac{M_m M_r}{r^2} \]

Inertial mass
measures resistance to change in speed or direction:

\[ F = ma \]

In everyday language, mass and weight are often used interchangeably. Technically, the weight of an object is the force on the object due to gravity. Weighing scales measure an object’s energy content, which is the product of mass and the speed of light squared.

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The mass of an object is the measure of its inertia, or resistance to acceleration, and is a fundamental property of the object. Mass is a property of an object, and weight is the force exerted on an object due to gravity.

An electronvolt is the energy gained by an electron in passing through 1 volt, and corresponds to a mass of \( 1.78 \times 10^{-36} \) kg.

Particle masses are expressed as their energy equivalent. An electronvolt is the energy gained by an electron in passing through 1 volt, and corresponds to a mass of \( 1.78 \times 10^{-36} \) kg.

1. Theory of electroweak force, unifying electromagnetic and weak forces, developed by Sheldon Glashow. This theory introduced the W* and Z* as carriers of the weak force. The formulation required that these have zero mass, inconsistent with the force’s short range.

2. Mass mechanism shown by Abdus Salam and Steven Weinberg to be able to account for the masses of quarks and leptons.

3. Mass mechanism, explaining how the carriers of the weak force can have non-zero mass, proposed by six physicists, in three groups.

4. Mathematical consistency of electroweak theory, including the mass mechanism, formally proven by Gerard ’t Hooft and Martinus Veltman.

5. W* and Z* first detected, by UA1 and UA2 experiments.

6. Higgs boson first detected, by ATLAS and CMS experiments.

An energy field, known as the Higgs field, is present everywhere in the Universe.

The Higgs boson is a short-lived particle that transfers energy between the Higgs field and other particles; it is an energy carrier.

The energy that a particle gains from the Higgs field is detected as the particle’s mass.

Higgs field

Particle with no mass

The theory of the Higgs field is able to explain how elementary particles can have non-zero mass. Why different particles have different masses remains a mystery.

The Higgs boson and the origin of mass

The physicists involved were: Robert Broust and François Englert; Peter Higgs; Gerald Guralnik, Carl Hagen and Tom Kibble. The proposed explanation required a new type of particle: the Higgs boson.

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Colliding particles

The European Laboratory for Particle Physics (CERN) hosts the world’s highest-energy particle accelerator: the Large Hadron Collider.

Particle sources

Electrons can be obtained by heating a metal wire (thermionic emission), for example by passing an electric current through it.

Protons can be obtained from hydrogen gas, using a device called a duoplasmatron. This generates electric fields that break down the hydrogen molecules, separating them into protons and electrons.

Creating particle beams

Charged particles can be accelerated to higher energies using electric fields, and can be steered using electric and magnetic fields. The particles can then be focused into beams.

Highest energies are achieved using radiofrequency cavities. These are metal chambers, containing an electric field with peaks and troughs that switch many times a second. As a particle moves through a chamber, it’s pushed along in much the way that a surfer is pushed by waves on the sea. The peaks and troughs cause particles in a beam to group together in bunches.

Particle energies are measured in multiples of the electronvolt (eV), the energy gained by an electron accelerated through 1 volt.

- kiloelectronvolt (keV) = 1,000 eV
- megaelectronvolt (MeV) = 1,000,000 eV
- gigaelectronvolt (GeV) = 1,000,000,000 eV
- teraelectronvolt (TeV) = 1,000,000,000,000 eV

Collider parameters

When two particles collide, their energies can be used in the creation of new particles. At a collision energy, $E$, the probability of creating a particle of type $X$, is represented by a quantity known as the cross section, $\sigma(X,E)$. This is conventionally measured in multiples of a unit called the barn, $b$, where $1 b = 10^{-28}$ m$^2$. The collision rate is expressed in terms of a luminosity, $L$, measured in units of inverse barn per second ($b^{-1}s^{-1}$).

The rate, $N(X)$, of collisions where a particle of type $X$ is created is the product of cross section and luminosity:

$$N(X) = \sigma(X,E) \times L.$$
Detecting particles

The ATLAS and CMS experiments use giant detectors for precise measurements of particle collisions.

Basics of particle detection

When a particle passes through a piece of material, it may interact with the electrons and quarks from which the material is built. The particle then transfers energy to the material at points along its path. A particle detector is designed to measure how much energy is deposited by particles that cross it, where, and when. A detector can be characterised by how well it measures energy and position, by time response, and by the types of particle it detects.

The retina of the eye and the sensor of a digital camera are both examples of particle detectors. They measure energy deposited by photons, at different points, over a short time interval. They then generate electrical signals to identify points where this energy is above a threshold.

Bunches of protons cross up to 40,000,000 times a second in experiments at the Large Hadron Collider. The experiment detectors must be reset after each crossing.

ATLAS and CMS

The detectors of ATLAS and CMS, the two general-purpose experiments at the Large Hadron Collider, have a similar basic design. Each is roughly cylindrical in shape, and built up in layers. The two detectors differ in the technology used. Detector sizes reflect the distances over which particles must be measured for accurate determination of paths, momentum and energy.

Tracking detectors

Tracking detectors are optimised for measurement of position, and allow reconstruction of the flight paths of charged particles. These detectors are intended to have little effect on a particle’s speed and direction, and so must contain minimal material. High-precision tracking detectors are often built from thin layers of silicon, each divided into pixels or strips. The technology is like that used in camera sensors, but satisfying requirements for large area, fast response, and radiation resistance. A detector layer records a hit in each pixel or strip that is crossed by a charged particle, and where the particle interacts.

Larger tracking detectors are typically built from chambers, or other containers, filled with gas. A charged particle crossing the gas results in a hit being recorded in a nearby sensor wire. Particle paths are reconstructed by fitting curves to hits in different detector layers. Paths can then be combined to identify particles that have a common origin, for example coming from a decay. Tracking detectors are usually placed in a magnetic field. A charged particle follows a curved path in the field, and the curvature gives the particle’s momentum (product of mass and velocity).

Muon detectors

A muon detector is a large-volume tracking detector that’s shielded by material, often in the form of calorimeters. It allows identification of muons, as the only charged particles able to pass through the material.

Calorimeters

Calorimeters are detectors optimised for measuring particle energies, and include large blocks of dense material. After a particle enters a calorimeter, its interactions can produce new particles, which can themselves interact. This results in a shower of particles, which extinguishes as all of the original particle’s energy is lost to the calorimeter material. The detector records a signal for each block, dependent on the amount of energy absorbed.

Thinner devices, called electromagnetic calorimeters, are used to measure the energies of photons, electrons and positrons. Thicker devices, called hadronic calorimeters, are used to measure the energies of charged and neutral hadrons.

Proton beams cross in the middle of the detector. Particles produced in resulting collisions travel through the different detector layers.
On 4th July 2012, a discovery was cautiously announced: "CERN experiments observe particle consistent with long-sought Higgs boson".

Before the discovery

The mass of the Higgs boson can't be directly calculated in the Standard Model, but can be linked to other quantities. By early 2012, it had been significantly constrained by measurements of the masses of the top quark and W boson. These were consistent with the Higgs boson having a mass in the range 115 GeV to 127 GeV, and were incompatible with higher values.

Observation of a new particle

Protons were first circulated in the Large Hadron Collider on 10th September 2008. Nine days later, an electrical connector between two of the accelerator’s helium-cooled superconducting magnets failed under test. This resulted in a rapid release of helium gas, which caused extensive damage. The accelerator was shut down for remedial work, and not restarted until 20th November 2009. The first period of operation for physics studies was March 2010 to February 2013, with proton collisions at energies of 7 TeV and 8 TeV.

Particle collisions are often referred to as events. A direct search for a Higgs boson aims to select events with a Higgs boson (signal) and to reject those without (background). This is a significant challenge. Fewer than 1 event in every 1,000,000,000 is a signal event, and signal and background can have similar characteristics.

One strategy is to consider decays of the Higgs boson where all of the particles from the decay can be measured. This is the case for decays to two photons and to two Z bosons. In the latter case, the 2 bosons can each decay to a charged lepton and its anti-particle, and it is these that are detected. Measurements of the energy and direction of the particles from the decay allow reconstruction of the mass of the original particle. In a search, particles consistent with the signal decay are selected, but may actually come from a background process.

The plot of reconstructed masses typically has a smooth shape for the background, with a bump corresponding to the signal, if present.

Results from ATLAS and CMS, on 4th July 2012, showed bumps in the distributions of masses reconstructed from two photons and two Z bosons. These indicated the existence of a previously undetected particle, with a mass of about 125 GeV. The fact that the new particle decayed into bosons meant that it must itself be a boson. The measured mass was in the allowed range for the Higgs boson, from the constraints of the Standard Model.
Measuring the Higgs boson

Measured properties of the Higgs boson have been found to agree with expectations from the Standard Model. Since the discovery of the Higgs boson, many more events have been collected and analysed in the ATLAS and CMS experiments. This has increased the signals for decays to two photons and to two Z bosons. It has also allowed observation of other decays: to two W bosons, to two bottom quarks, and to two tau leptons. The rates at which the different decays occur have been measured. Within large uncertainties, they agree with the rates predicted by the Standard Model.

Decays

- Higgs decay to two bottom quarks
  - $b\gamma b$
  - ATLAS

- Higgs decay to two tau leptons
  - $\tau\tau$  $H_0$
  - CMS

- Higgs decay to two photons
  - $\gamma\gamma$  $H_0$
  - CMS

- Higgs decay to two W bosons
  - $W^+W^-$  $H_0$
  - CMS

- Higgs decay to two Z bosons
  - $Z^+Z^-$  $H_0$
  - CMS

Improving measurements

Measurements of the Higgs boson are consistent with the Standard Model, but suffer from large uncertainties. Fuller understanding of the observed Higgs boson requires measurements of higher precision. These require collection of more, and better, data.

International Linear Collider

The International Linear Collider has been proposed for colliding electrons and positrons at energies from 0.25 TeV to 1 TeV. Collisions of this type, between elementary particles, are simpler to analyse than collisions between composite particles, such as protons. In this sense, they produce better data for precision measurements. Decay rates of the Higgs boson could potentially be measured with an accuracy at the per-cent level. If approved, construction of the International Linear Collider could be completed for the late 2020s. The machine would then have an operational life of twenty to thirty years.

Spin

If a particle decays, the way in which it spins affects the angular distribution of the emitted particles. Measurements have been made of emission angles for photons from decays of Higgs bosons. The resulting distribution has large uncertainties, but is consistent with a decaying particle that has zero spin. This is as expected for the Higgs boson in the Standard Model.

Upgrades to the Large Hadron Collider

A series of upgrades is planned for the Large Hadron Collider, defining a rich physics programme up to the early 2030s. The upgrades will raise the energy of proton collisions to 14 TeV, and will allow higher luminosity. The result will be to increase the rate at which Higgs bosons are produced, giving more data. A drawback of higher luminosity is that it means more collisions for every beam crossing. Work is in progress on detector improvements to cope with the more challenging environment, and ensure high-quality data.

The upgraded Large Hadron Collider should allow rates for different decays of the Higgs boson to be measured to better than 10%.
The mass of the Higgs boson

On short timescales, an elementary particle can emit and reabsorb other particles. A neutral elementary particle can also convert temporarily to a charged particle and its anti-particle. The energy associated with such processes contributes to a particle’s total energy, and is known as self-energy. This may be negative (energy lost) or positive (energy gained). A particle’s measured mass can then be regarded as the sum of a bare mass and a self-energy.

Contributions to the self-energy from conversion and emission processes down to a chosen distance can be calculated in the Standard Model. The bare mass can be deduced as the difference between the measured mass and the self-energy.

The Standard Model fails below about $10^{-33}$ m, where gravity needs to be taken into account. Down to this distance, most particles have self-energies that are small. The exception is the Higgs boson, where the calculated self-energy is large and negative. The implied bare mass is around $10^{19}$ GeV, compared with the measured mass of about 125 GeV. Although technically possible, the enormous difference between bare mass and measured mass for the Higgs boson is considered suspect.

This difference is referred to as the hierarchy problem or fine-tuning problem.

Several possibilities for eliminating the fine-tuning problem are being investigated by the ATLAS and CMS experiments.

**SUPERSYMMETRY**

Supersymmetry introduces a fermion partner for each boson of the Standard Model, and a boson partner for each fermion. The Higgs self-energy contributions from a Standard Model particle and its supersymmetry partner would tend to cancel out. The bare mass would then become similar to the measured mass.

**COMPOSITE HIGGS**

A Higgs boson that is a bound state of two fermions would have a certain size. This would define a lower limit for evaluating self-energy contributions, potentially reducing the bare mass.

**EXTRA DIMENSIONS**

The mass of the Higgs boson could be distributed over more spatial dimensions than the three experienced in everyday life. The measured mass would then be only a fraction of the true mass, which could be close to the bare mass.

The different possibilities aren’t mutually exclusive, and each can lead to a variety of different models.

The Standard Model provides no explanation of either dark matter or dark energy. Dark matter could be accounted for by new types of particle. These would need to have non-zero mass, to be stable, and to interact only weakly with the particles of the Standard Model.

One suggestion is that dark matter interacts with the Higgs boson to gain mass, but otherwise has no Standard-Model interactions. Dark-matter particles would then exist in relative isolation from the particles of the Standard Model. Models based on this idea are known as hidden-valley models or as Higgs-portal models.

Another suggestion is that dark matter is made from the lowest-mass supersymmetry particles.
UK researchers on the ATLAS and CMS experiments make key contributions to studies of the Higgs boson and beyond.

Groups from eighteen UK institutes are involved in experiments at the Large Hadron Collider. Their work is mostly funded by the Science and Technology Facilities Council. Additional support comes from organisations such as the Royal Society and the European Research Council, and from industrial partnerships.

People who train as particle physicists develop specialist and general skills that make them highly sought after. Some spend their working lives in particle-physics research, some combine research with consultancy work, some decide to change career. Particle physicists have gone on to work in areas as varied as fashion, big-data analytics, asset finance, publishing, and Formula-1 racing.

First employment in particle physics, in the UK or another country, is usually on a fixed-term contract, of one to three years. This will be either at a University, or at a national or international research laboratory. Some contracts are linked to research fellowships, which can include funding for equipment and travel.

Subsequent employment may be through further fixed-term contracts, or through a permanent position. Permanent University positions usually combine teaching and research, with possible progression from Lecturer to Reader to Professor.

As well as the standard route, people also come to work in particle physics after University study in a variety of other subjects. These include engineering, computer science, and mathematics.

First job – University or research laboratory

Fixed-term contracts or permanent position

Undergraduate degree

DPhil or PhD

Non-physics background

Fitting in a social life

Working at CERN had a big effect on my family life, as I met my husband there. I’m now based in the United Kingdom, and work part-time, so that I can devote time to both work and family.

Useful skill from particle physics

I find that — unlike my lecture notes — some of the code I write is still useful! I’ve been able to transfer some of it into other projects.

Alternative career

As a child, I always wanted to be an astronaut.
Rebecca Lane
PhD Student, High Energy Physics Group, Imperial College London

**What I do**
I work on the CMS experiment, searching for Higgs decays to two tau leptons. My work is entirely computer based, and relies heavily on efficient programming.

**The habitat**
Seeing results that I’ve produced pop up in journal articles, talks, and posters is very nice!

**What friends and family think about my work**
Awe at the fact that I work at CERN, complete incomprehension about what I actually do.

**Making school physics more appealing to girls**
I think that it can help if female scientists make themselves accessible to school students, by visiting schools and helping with outreach activities.

**Where I started**
I studied for my undergraduate degree at the University of Oxford. I was drawn to the place itself and history.

Monica Vazquez Acosta
Research Associate, High Energy Physics Group, Imperial College London

**What I do**
I work on the CMS experiment, searching for Higgs decays to tau leptons.

**Memorable experience**
One of the most exciting moments in my career was when the first proton beams were injected into the Large Hadron Collider. After years of preparation, this was the start of a new era in particle physics.

**Where I started**
I studied theoretical physics at the Universidad Autónoma de Madrid. After graduating, I pursued a career in experimental high-energy physics, as I was interested in testing theories that I’d learned as a student.

**Alternative career**
I’m interested in advanced radiotherapy techniques for cancer treatment.

**Curious fact**
I come from the Canary Islands, where we have two world-leading observatories.

Carl Gwilliam
Research Associate, Particle Physics Group, University of Liverpool

**What I do**
I work on the ATLAS experiment, searching for a Higgs decay that, so far, hasn’t been seen.

**What family and friends think about my work**
The strangest reaction that I’ve ever had is: “Physicist — do you put the bubbles in Fizzy drinks?”

**How I became interested in particle physics**
My interest in physics was driven by a great teacher. I remember him explaining radioactive decay with M&M sweets. We did an A-level module on particle physics, and I was captivated by the thought of looking into the very building blocks of nature.

**Where I started**
I studied for my undergraduate degree at the University of Liverpool. I was worried that it was going to create black holes, with catastrophic results.

**Long meetings**
Sometimes it’s hard to balance my social life against the excitement of searching for new physics. This gets easier with experience.

**Advice to younger self**
Relax, work and things will be fine.

Elisabetta Pianori
Research Fellow, Elementary Particle Physics Group, University of Warwick

**What I do**
I work on the real-time selection of interesting collisions in the ATLAS experiment, and on studies of the Higgs boson. Every day is different. Some days I’m needed at the experiment control room; some days are filled with meetings; some days I work by myself in my office, trying to solve problems!

**The best bit**
What I love most is the people. Knowing and learning is great, but it’s even better when done together.

**The worst bit**
Also the people trying to get hundreds of physicists to work together is very hard. We each tend to have strong opinions.

**Useful skills from particle physics**
I’ve developed strong analytical skills, and a creative approach in problem solving.

Christos Anastopoulos
Research Fellow, Particle Physics and Particle Astrophysics Group, University of Sheffield

**What I do**
I work on the ATLAS experiment, where I’m searching for Higgs decays to two Z bosons. I spend a lot of time with research students, discussing their results, and planning analysis strategies.

**Long meetings**
Interacting with these great, clever people.

**Advice to younger self**
For both boys and girls, we need to make the subject exciting. Outreach activities are very important in this respect.

**Curious fact**
I drink a lot of coffee, at every possible time of the day.

Alan Barr
Associate Professor of Experimental Particle Physics, University of Oxford

**What I do**
My group and I are hunting for tell-tale signs that particles of dark matter are being produced in the ATLAS experiment. We haven’t found them yet, but there’s still a lot more work to do.

**The best bit**
I love that so many people find our research to be such an inspiration.

**Fitting in a social life**
Sometimes it gets hard to balance my social life against the excitement of searching for new physics. This gets easier with experience.

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