Colliding Particles
Classroom teaching resources

The Colliding Particles project is designed to support the 'How Science Works' element of key stage 4 of the national curriculum. The films have been made to illustrate aspects of the way in which science develops. They show scientists discussing their work, how they collaborate and compete, and the relationship between experiment and theory in science.

Although the idea of the Standard Model of particle physics and the existence of the Higgs particle are unlikely to be part of the formal curriculum for most students, these films can still be used when you wish to discuss aspects of HSW and to stimulate interest in the process of scientific discovery. Because the scientists are describing an on-going process of discovery, the films have a natural 'story' thread running through them.

When to use this films

- **Atomic structure and sub-atomic particles**

  Most students learn something about the nuclear model of the atom; they may also learn about Rutherford's alpha-particle scattering experiment which confirmed the nuclear model. Since then, scattering experiments have confirmed the existence of protons and neutrons in the nucleus, and of the quarks which make up protons and neutrons (hadrons). The LHC can be thought of as the next step in this process of discovery.

- **Theory and experiment**

  This film shows clearly the way in which theory and observation interact in science. Observations require explanatory theories; the theories must be tested by using them to make testable predictions. You could use this as a model and ask students how this has worked in other areas of science (e.g. evolutionary theory in biology, plate tectonics in geology)

- **In the news**

  The LHC is not a single experiment; rather, it is a giant scientific instrument with many possibilities for experimentation. Announcements of new findings will appear in the media, and these films can be used to help students understand what they have seen.

- **Before a visit by a scientist**

  Invite a scientist to come and talk about their work. (It doesn't have to be related to the LHC.) Because students are often unclear about how scientists work, some advance preparation is needed. Show the film as a stimulus and ask students to devise a series of questions that could be put to the scientist, or a series of headings under which they could make notes.

- **Careers in science**

  The film can be used to show the different roles played by members of a scientific research team. In particular, Adam (the postgraduate research student) can be used as an example of someone who is moving from being taught science to 'doing science'.

Showing the films

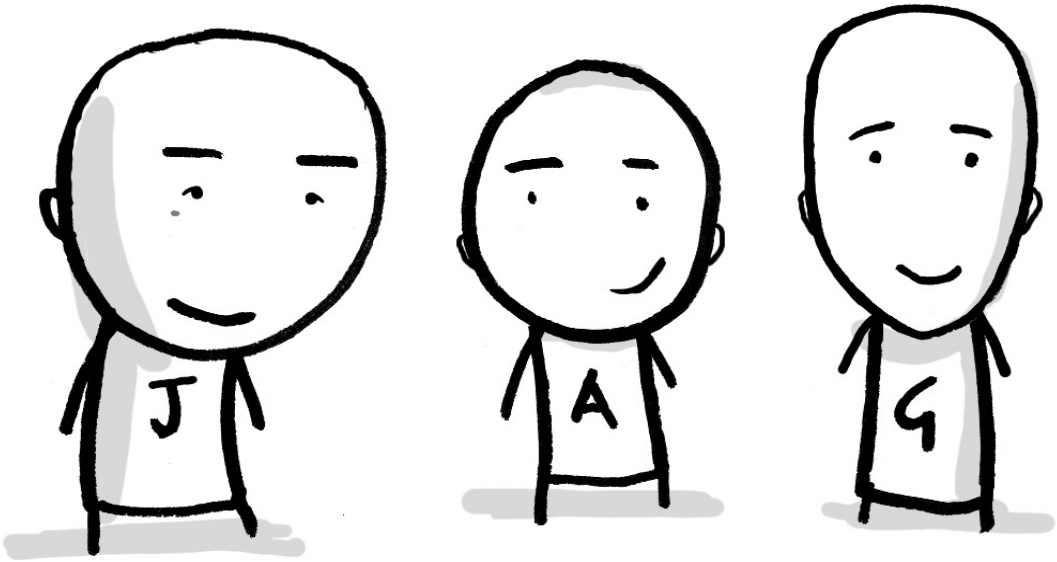
The film is available in 2 versions from the project website at http://www.collidingparticles.com/teaching_resources/index.html

The original version plays all the way through, and the 'Classroom Edits' break the films into themed sections with spaces in between for easy pausing.

The original version of the film can be shown straight through and uninterrupted. This will allow students to start recognising the different personalities involved.
Subsequently, the 'Classroom edit' can be shown in sections (see Summary below), with a discussion of the main points arising after each section.

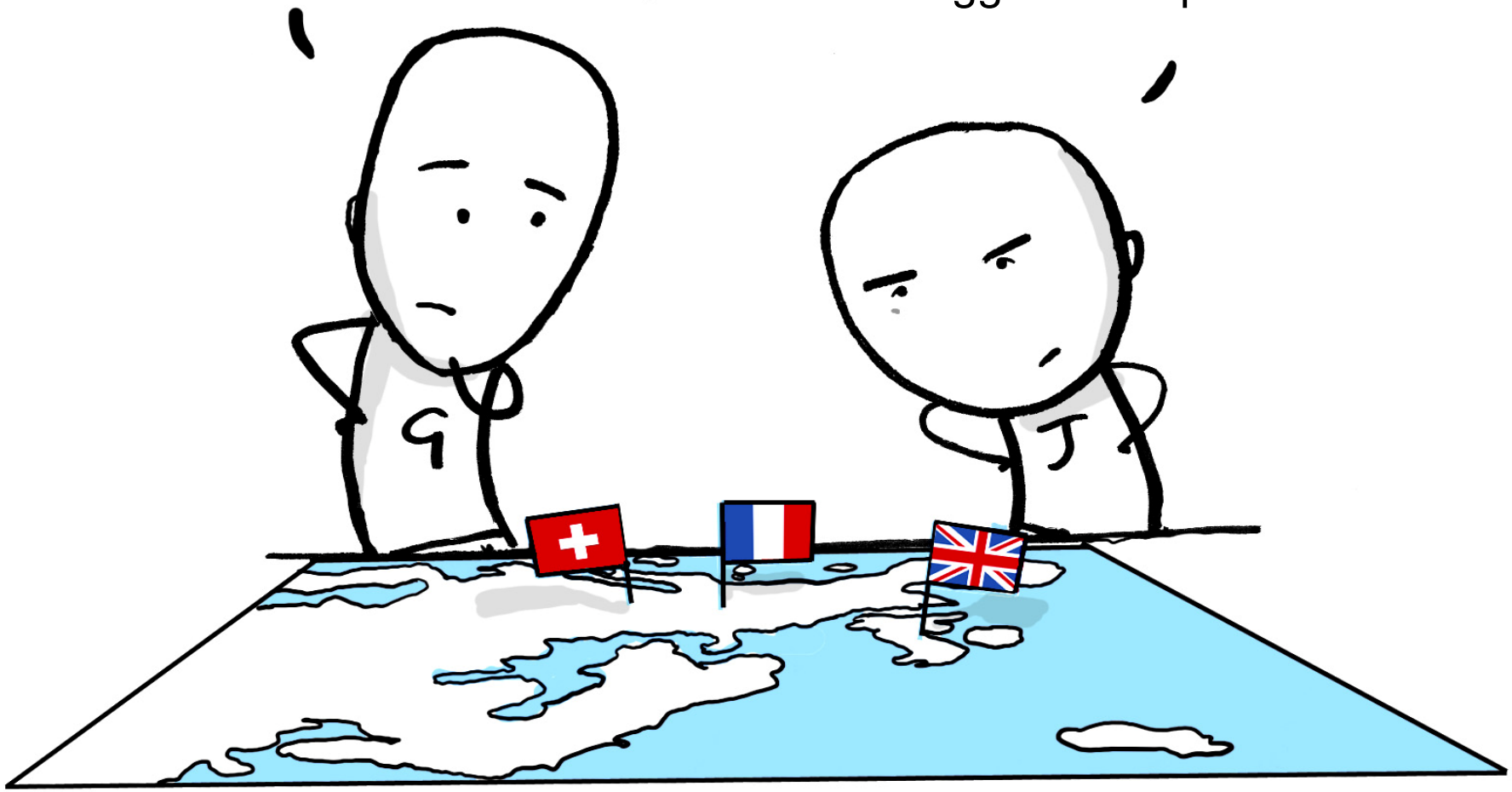
Working Together

Scientific Collaboration
or Conspiracy?

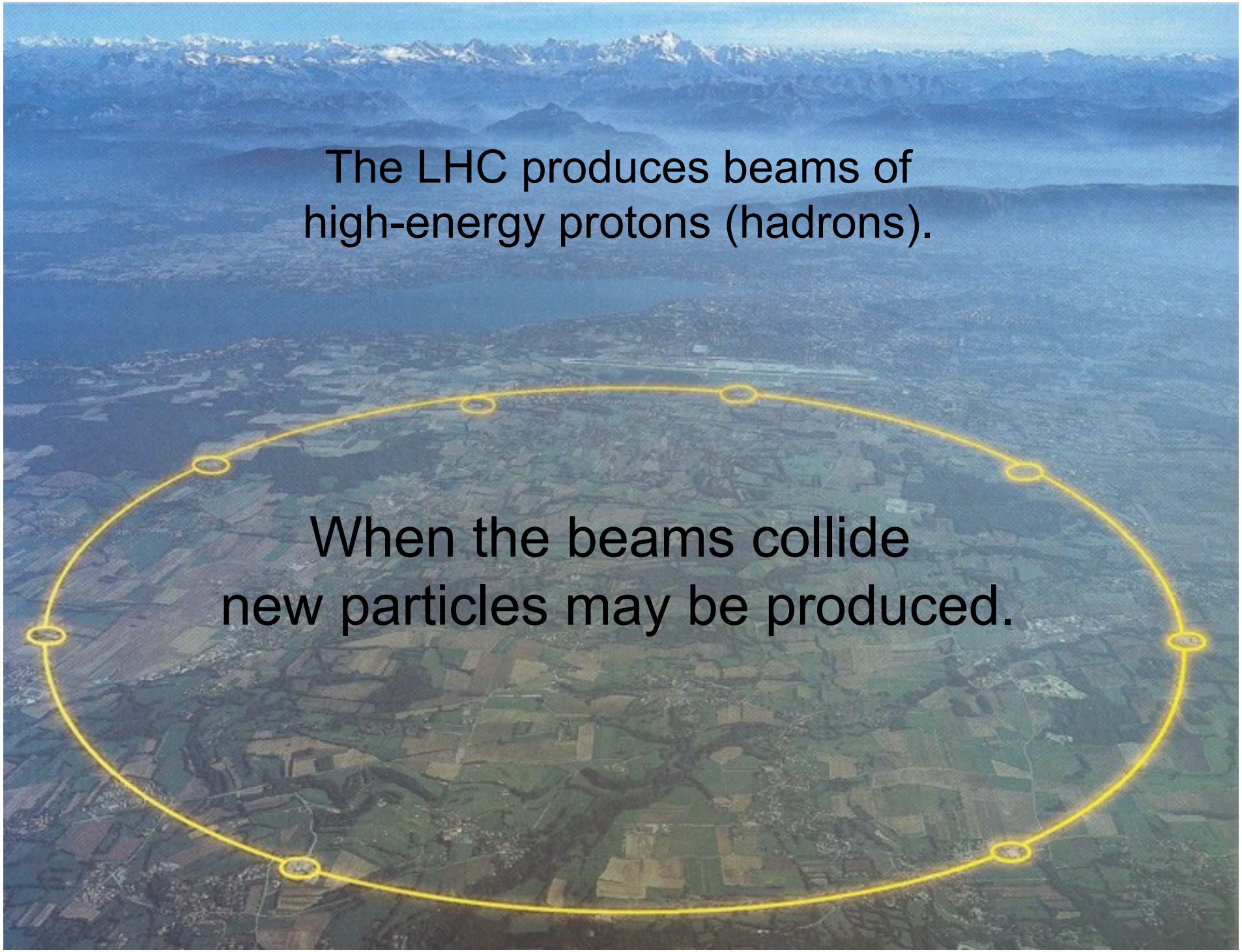


They're building the LHC in Geneva.

The biggest ever particle smasher.

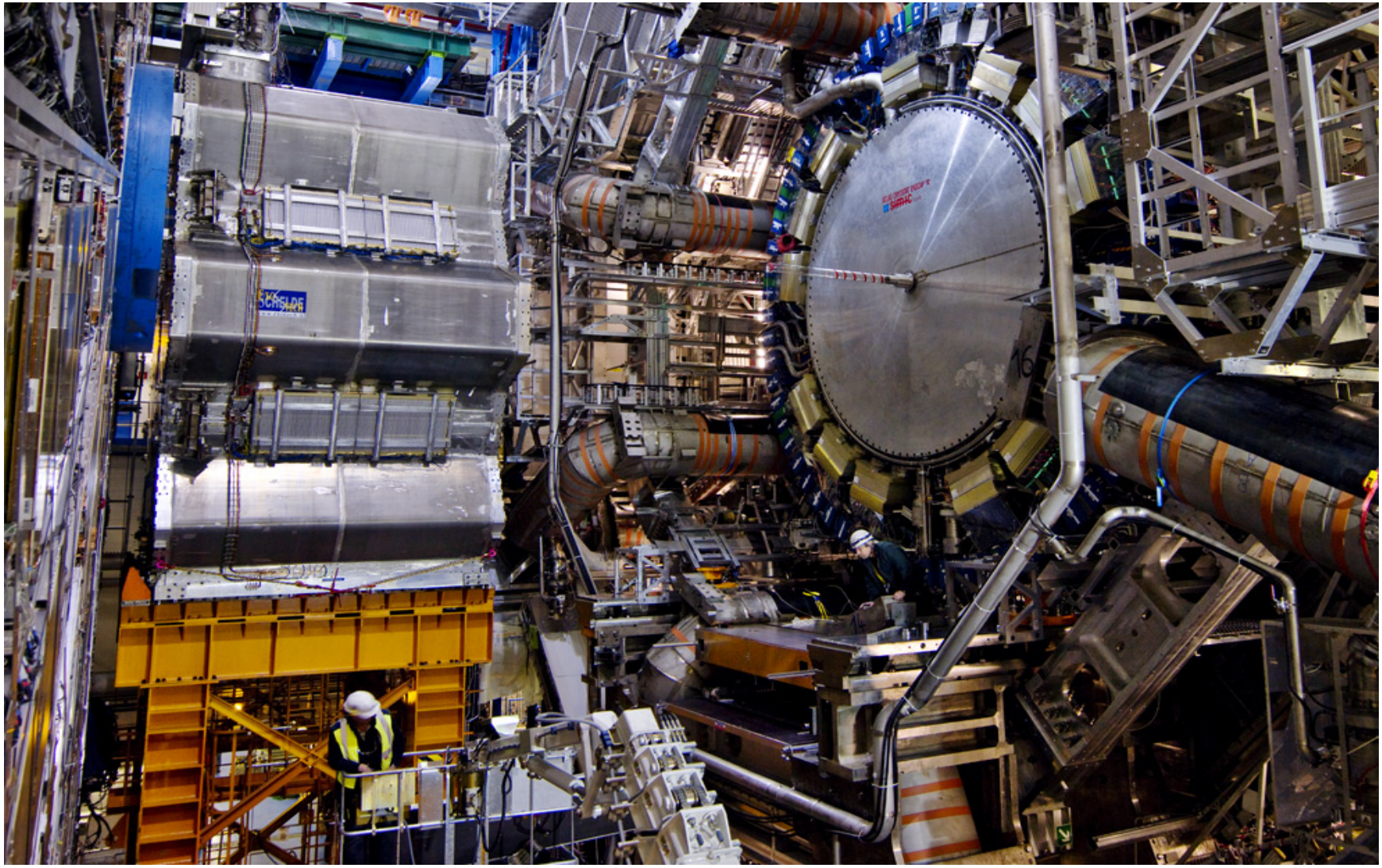


*The Large Hadron Collider


The LHC produces beams of
high-energy protons (hadrons).
When the beams collide
new particles may be produced.

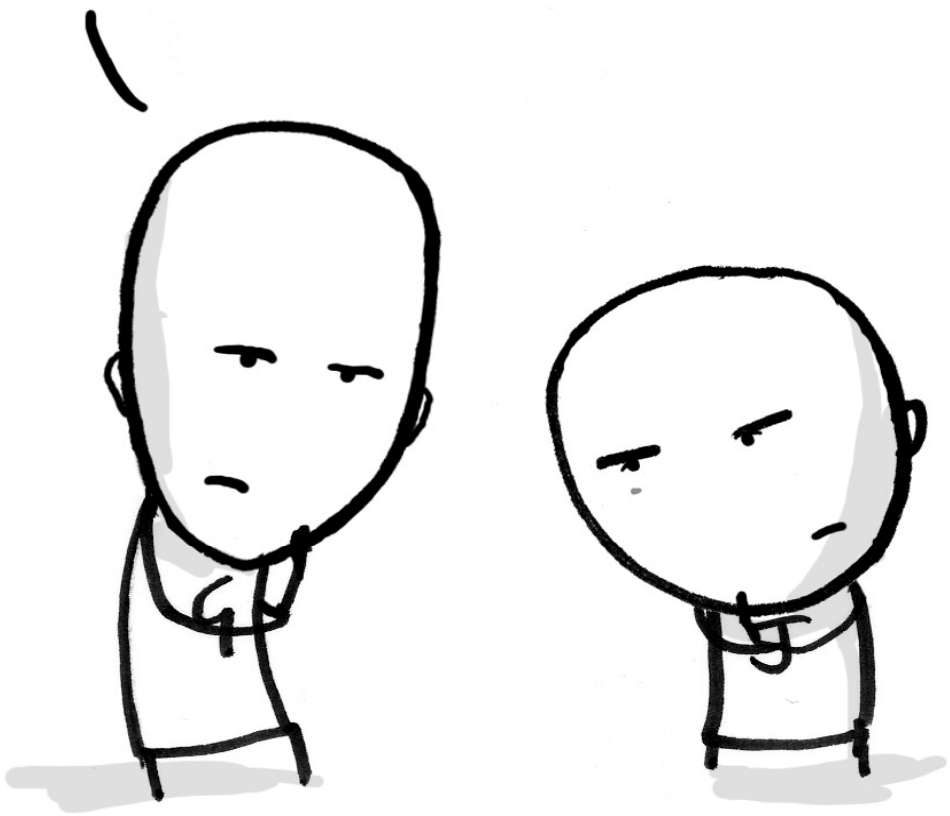
They’re looking for ideas of how best to run the experiments.

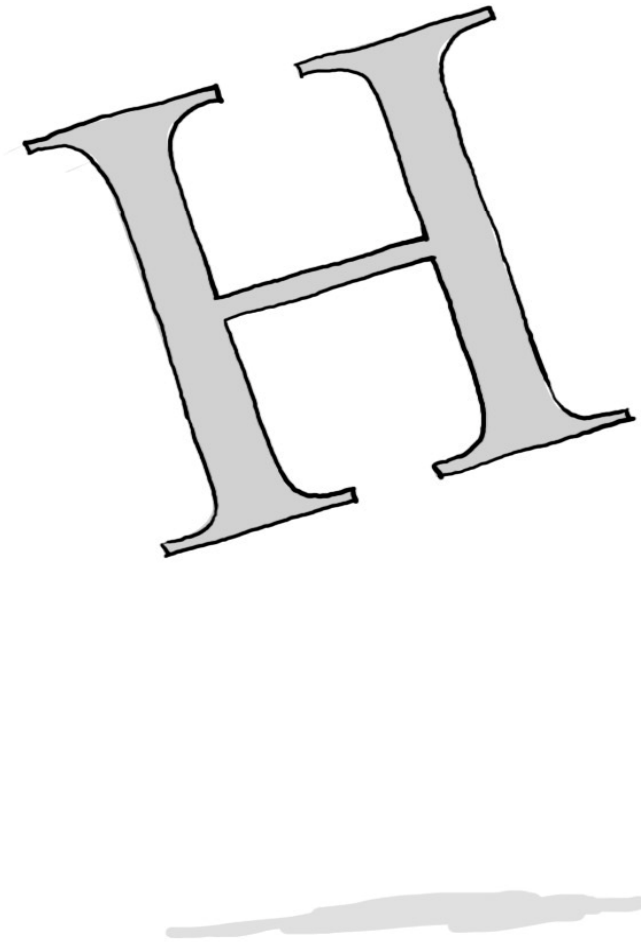
Perhaps we can cook something up between us.



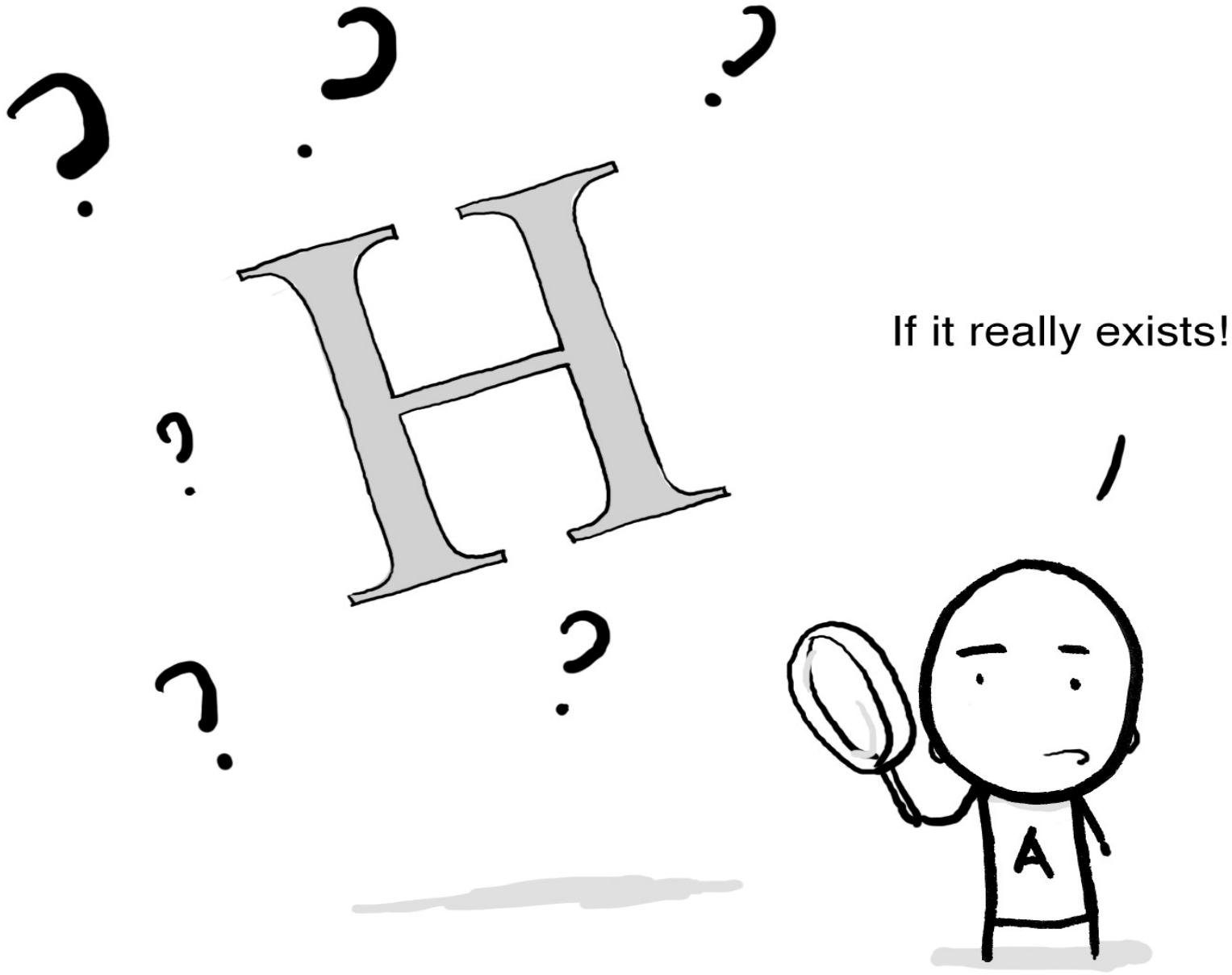
The ATLAS detector is one of the experiments which will detect the particles produced in the collisions.

There’s a chance that the ATLAS detector will come up with evidence for the Higgs particle.





The Higgs particle is a fundamental particle, which explains why other particles have mass ...

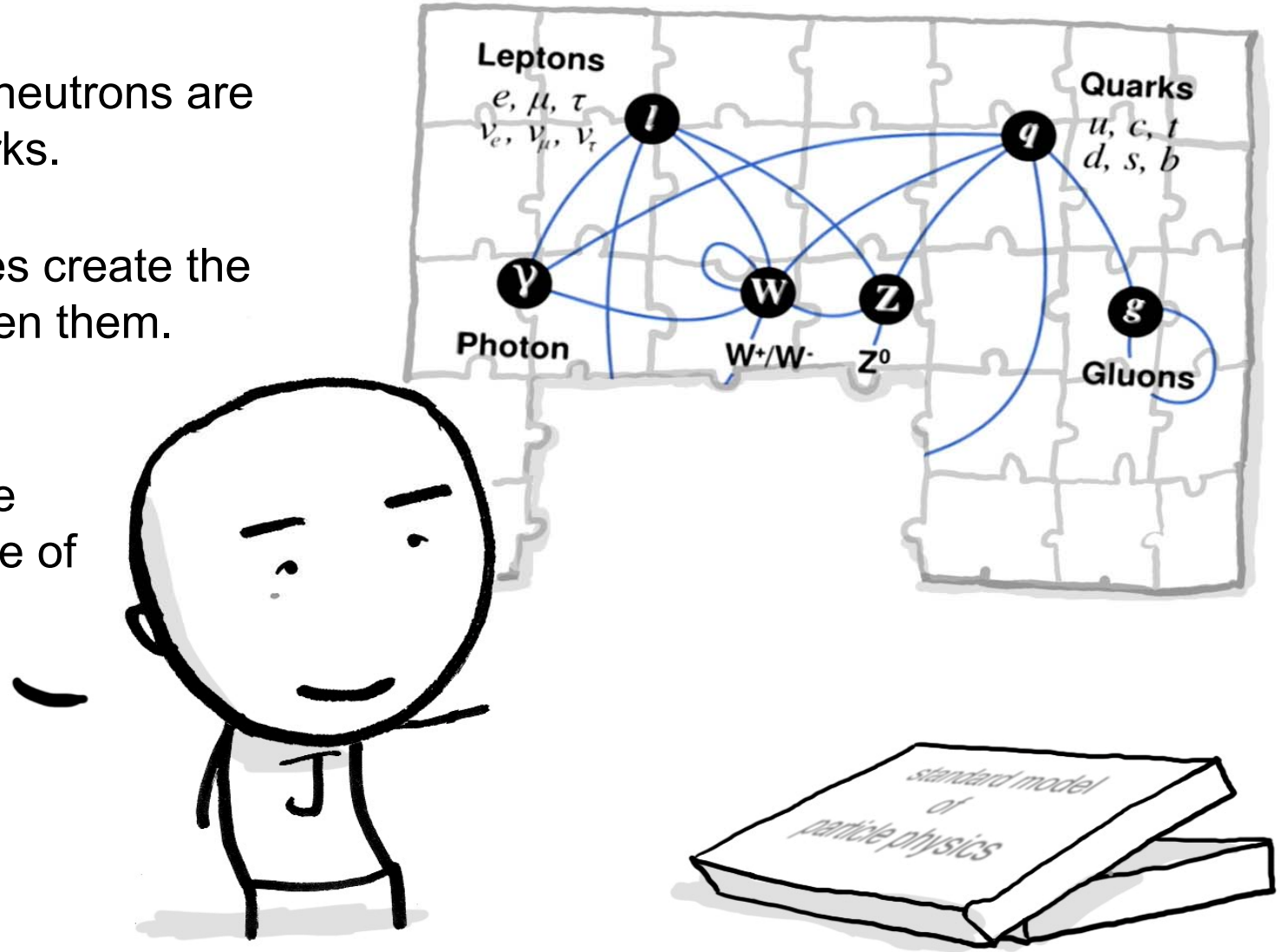

H
If it really exists!
A

Atoms are made of protons, neutrons and electrons.

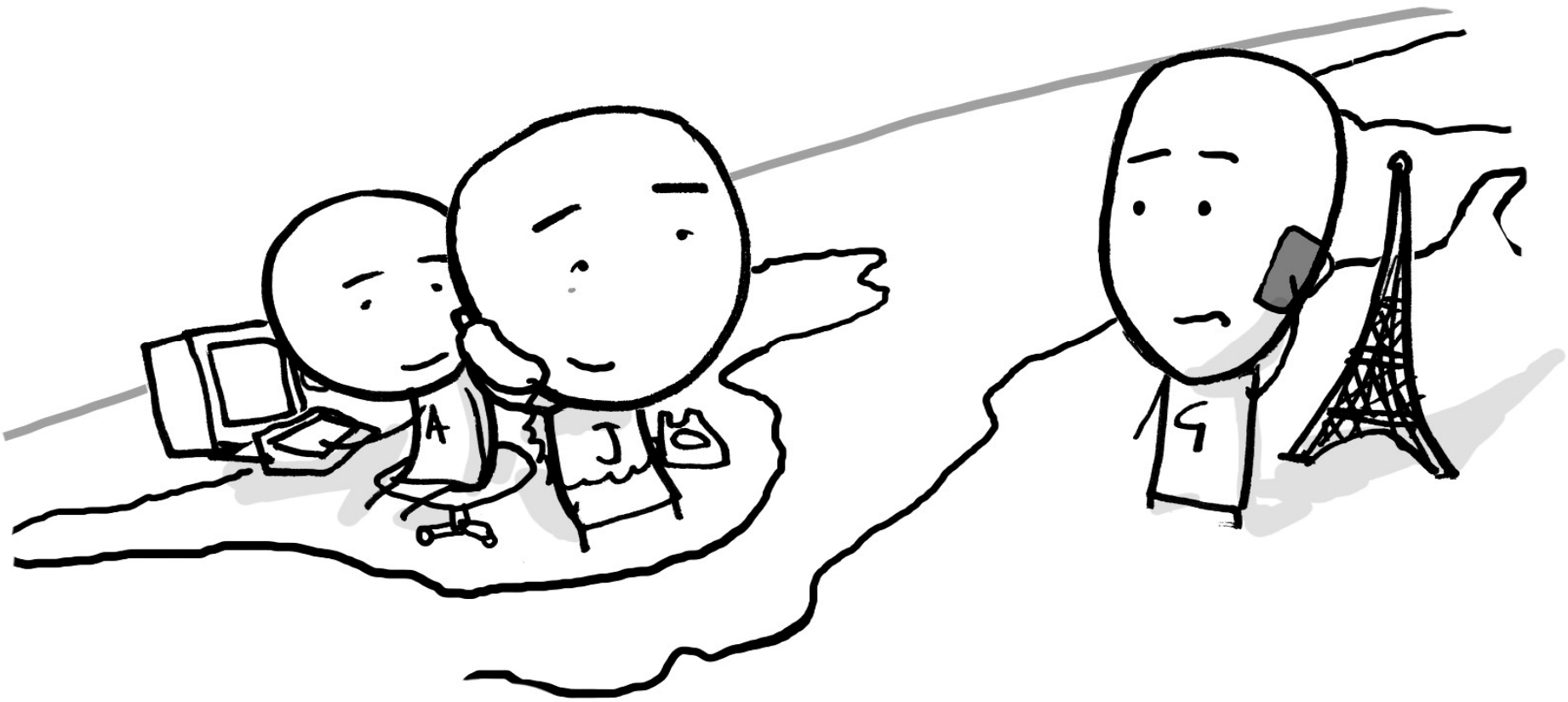
Protons and neutrons are made of quarks.

Other particles create the forces between them.

The Higgs particle is the missing piece of the jigsaw.

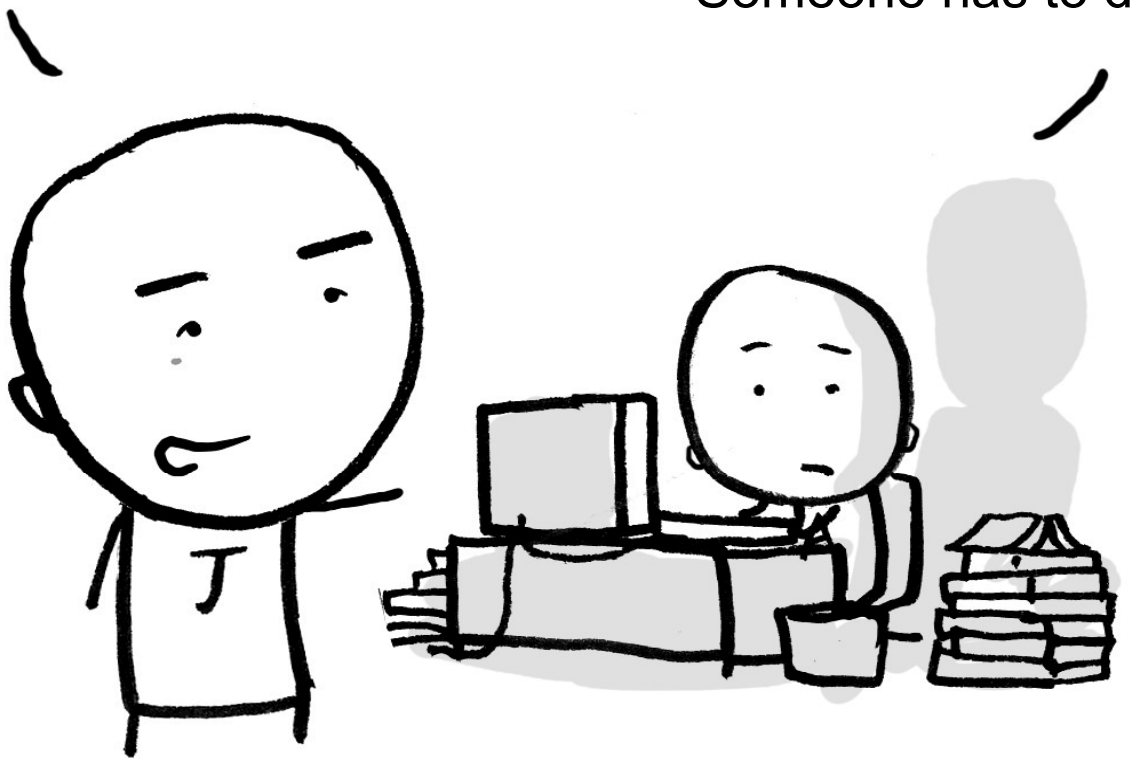


We'll work up some ideas
on how to best run the
LHC experiments



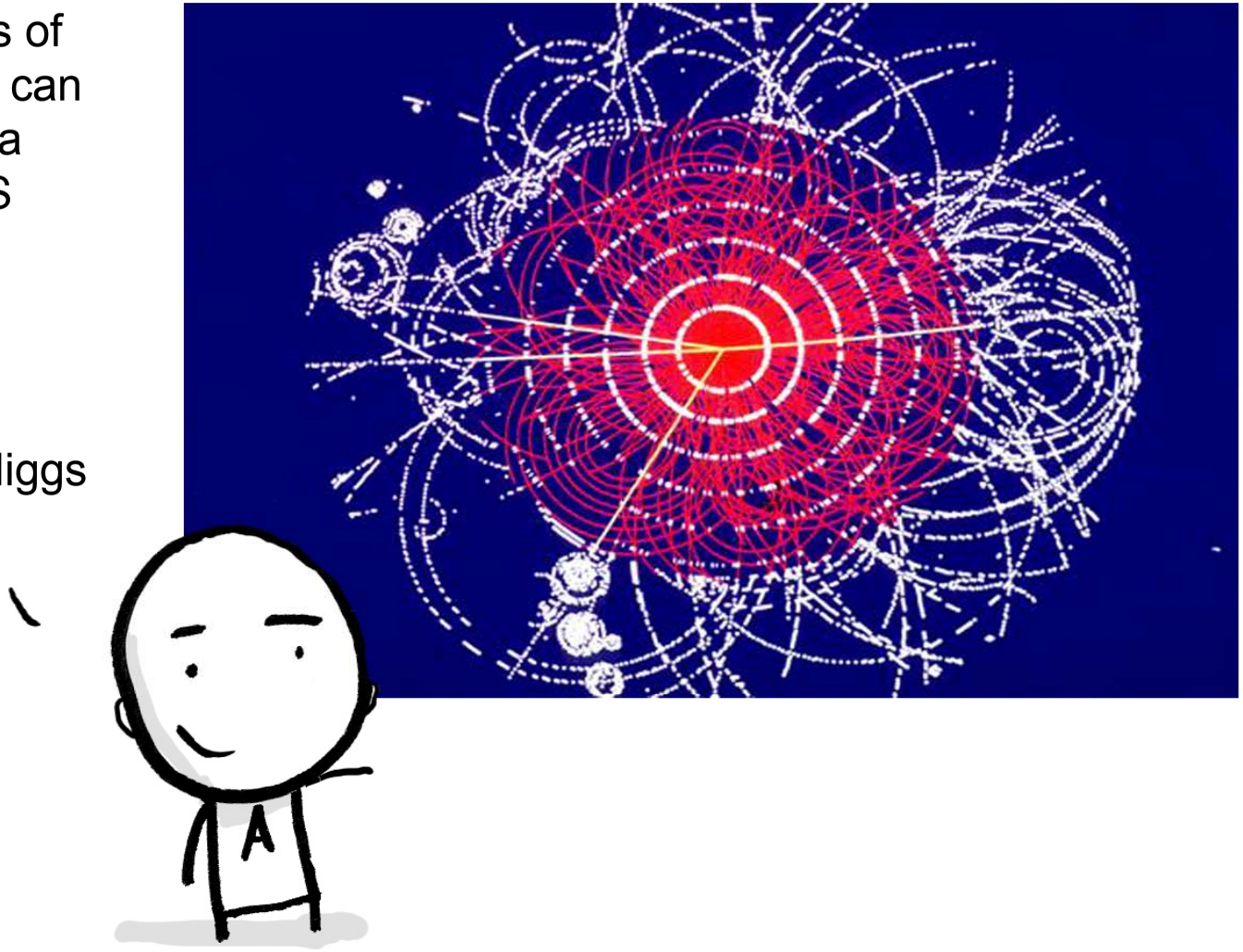
We’ll get Adam to write the computer programs to test our ideas.

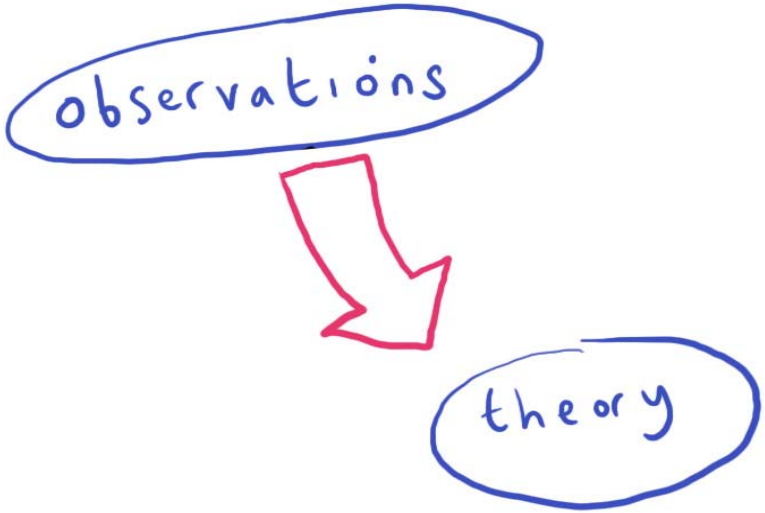
Someone has to do all the work.



We've got ideas of how computers can analyse the data from the ATLAS detector at the LHC.

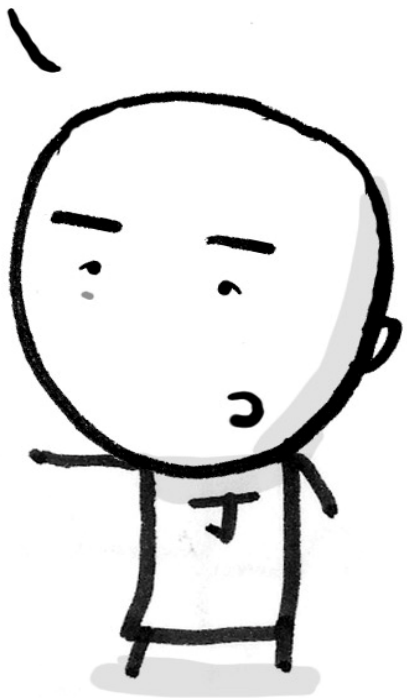
This is what we might see if a Higgs breaks up.

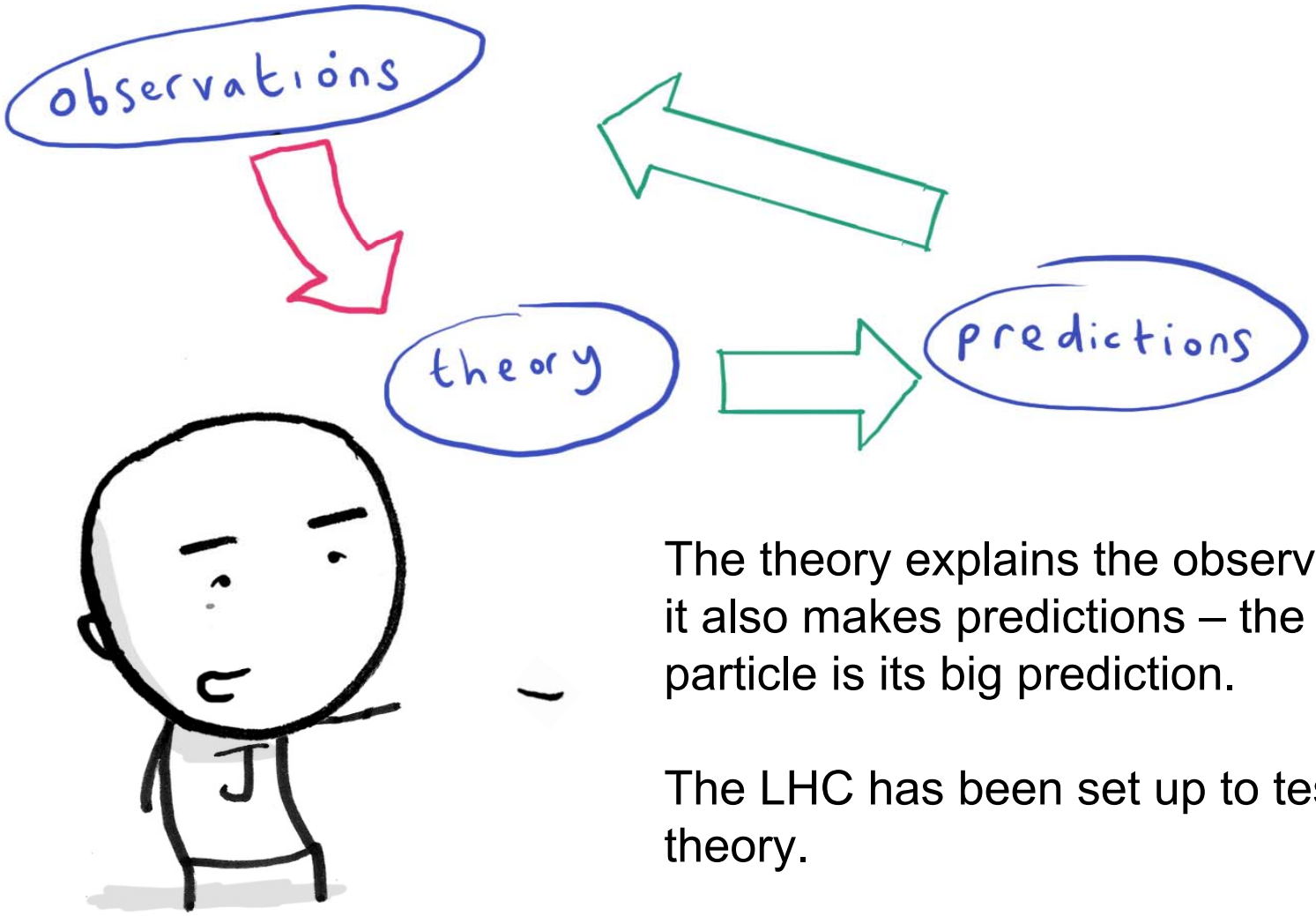




We’re testing one of the big theories of science, the Standard Model of particle physics.

Like any scientific theory, it starts from observations – what particles and forces do we know about?

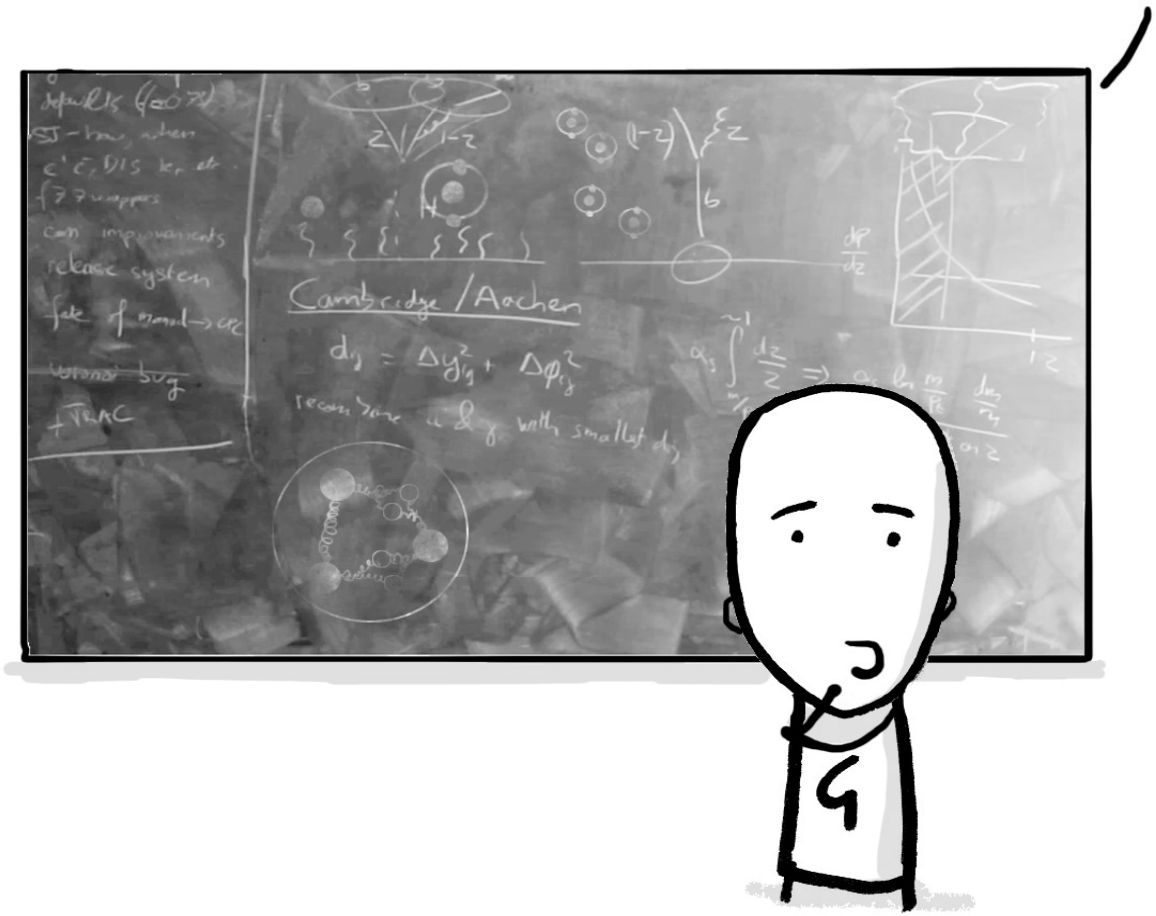




The theory explains the observations, but it also makes predictions – the Higgs particle is its big prediction.

The LHC has been set up to test the theory.

In a sense, we're trying to answer the questions:

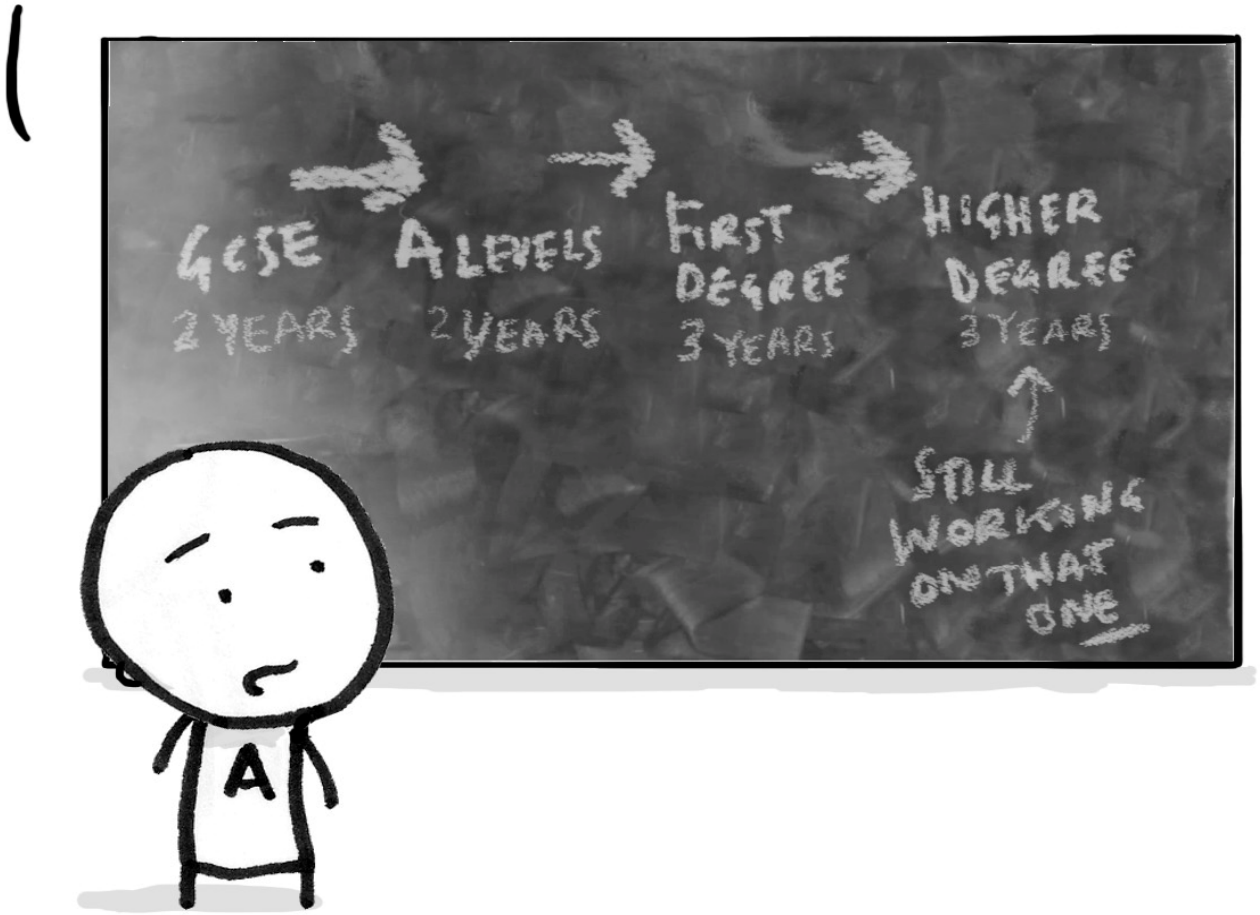


How did we get here?

What is the structure of the world?

We're made of atoms, but what are atoms made of?

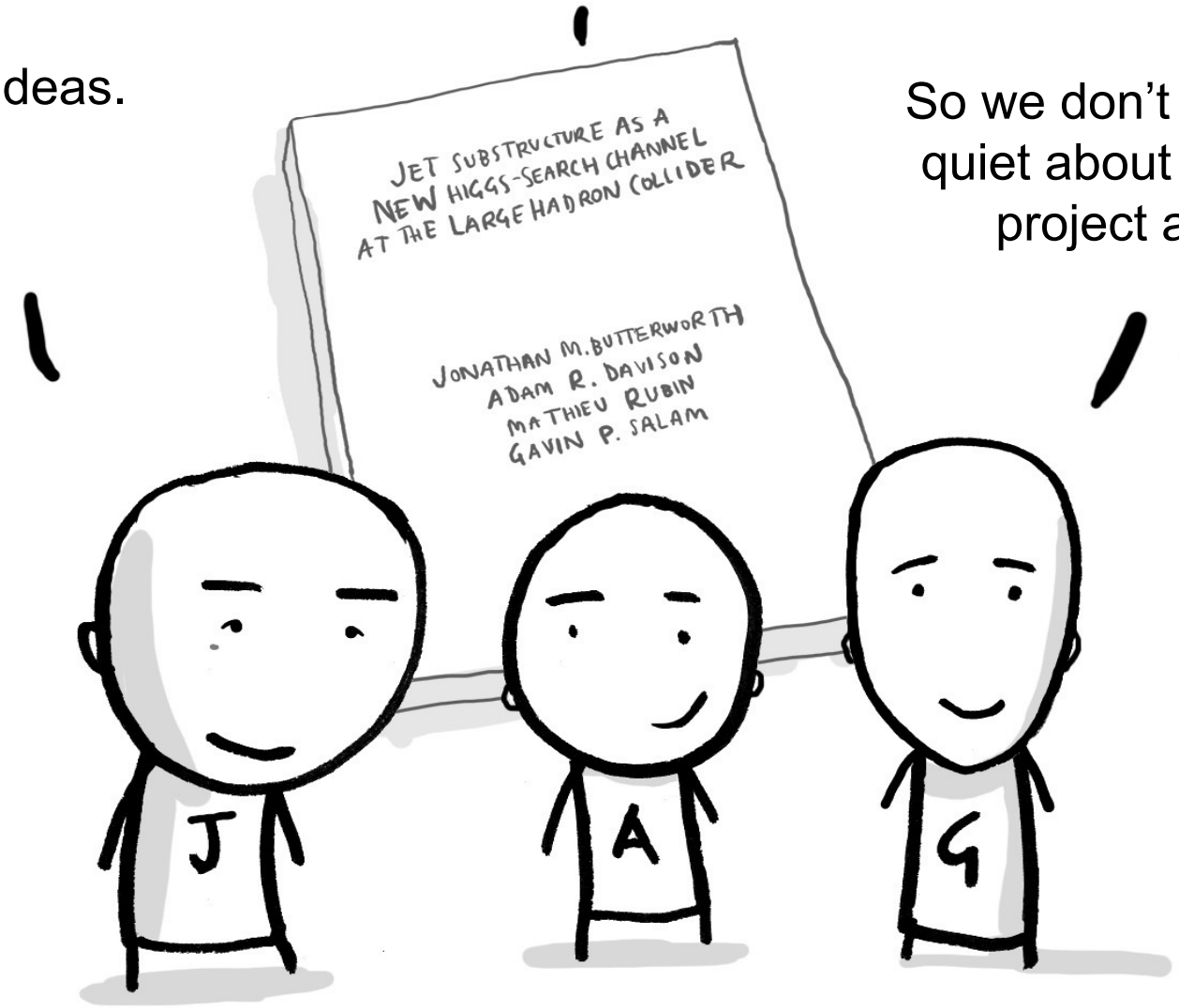
How did I get here?
GCSEs (2 years)



And they've been published in a scientific journal.

We've tested our ideas.

So we don't need to keep quiet about the Eurostar project any more.



So now we try to promote our ideas to the people at LHC.

And we keep developing our ideas.

That means I keep on writing the programs.

Colliding Particles - Episode 1: Codename Eurostar

Teacher's notes

This is the first in a series of films looking at the work of a team of particle physicists involved with the Large Hadron Collider (LHC) and the hunt for the Higgs particle.

How science works (HSW)

These films have been made to illustrate aspects of the way in which science develops. They show scientists discussing their work, how they collaborate and compete, and the relationship between experiment and theory in science.

Although the idea of the Standard Model of particle physics and the existence of the Higgs particle are unlikely to be part of the formal curriculum for most students, these films can still be used when you wish to discuss aspects of HSW. Because the scientists are describing an on-going process of discovery, the films have a natural 'story' thread running through them.

When to use this film

- **Atomic structure and sub-atomic particles**

  Most students learn something about the nuclear model of the atom; they may also learn about Rutherford's alpha-particle scattering experiment which confirmed the nuclear model. Since then, scattering experiments have confirmed the existence of protons and neutrons in the nucleus, and of the quarks which make up protons and neutrons (hadrons). The LHC can be thought of as the next step in this process of discovery.

- **Theory and experiment**

  This film shows clearly the way in which theory and observation interact in science. Observations require explanatory theories; the theories must be tested by using them to make testable predictions. You could use this as a model and ask students how this has worked in other areas of science (e.g. evolutionary theory in biology, plate tectonics in geology).

- **In the news**

  The LHC is not a single experiment; rather, it is a giant scientific instrument with many possibilities for experimentation. Announcements of new findings will appear in the media, and these films can be used to help students understand what they have seen.

- **Before a visit by a scientist**

  Invite a scientist to come and talk about their work. (It doesn't have to be related to the LHC.) Because students are often unclear about how scientists work, some advance preparation is needed. Show the film as a stimulus and ask students to devise a series of questions that could be put to the scientist, or a series of headings under which they could make notes.

- **Careers in science**

  The film can be used to show the different roles played by members of a scientific research team. In particular, Adam (the postgraduate research student) can be used as an example of someone who is moving from being taught science to 'doing science'.

Showing the film

The film is available in 2 versions from the website: the original version, and a special 'Classroom Edit', which break the films into themed sections with spaces in between for easy pausing.

The original version of the film can be shown straight through and uninterrupted. This will allow students to start recognising the different personalities involved.

Subsequently, the 'Classroom edit' can be shown in sections (see Summary below), with a discussion of the main points arising after each section.

Classroom Edit Summary

Gavin Salam, theoretical physicist, University of Paris

Jon Butterworth, experimental physicist, University College London

Adam Davidson, research student, University College London

0:00	Curiosity	Gavin talks about the fundamental curiosity that drives scientific inquiry. atoms ∏ protons/neutrons/electrons ∏ quarks ∏ what else?
1:00	Collaboration	Jon, Adam and Gavin describe the 'Eurostar' collaborative project.
1:40	The Standard Model	Jon and Adam explain the Standard Model - animation. Gavin describes how we can picture the Higgs field and particle.
3:10	Roles	Adam explains the roles of Gavin (theorist), Jon (experimentalist), Adam (research student).
4:30	Hunting the Higgs	Jon and Gavin explain their role in the hunt for the Higgs.
5:40	Ideas and experiments	Animation of LHC Jon describes the interplay between observation, experiment and theory in

		science. Jon explains why such a big experiment is needed.
7:40	The end of the story?	Adam, Jon and Gavin discuss what may come out of the LHC experiments.
9:00	END	

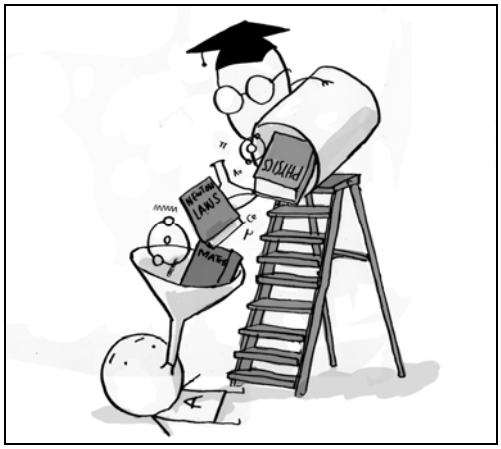
Linking the film and the Powerpoint presentation

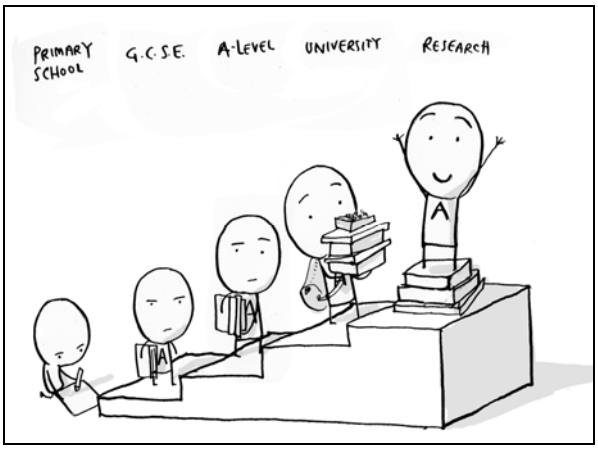
The presentation is designed to be shown after the film. It tells the same story (with the same characters) in a slightly different way, bringing out the main teaching points.

You could choose to focus on one or more of the following:

- How scientists collaborate and how they compete
- How scientists make their work known to others
- How people progress to become scientists
- The relationship between experiment and theory
- Human curiosity as a driving force in science

Becoming an Expert



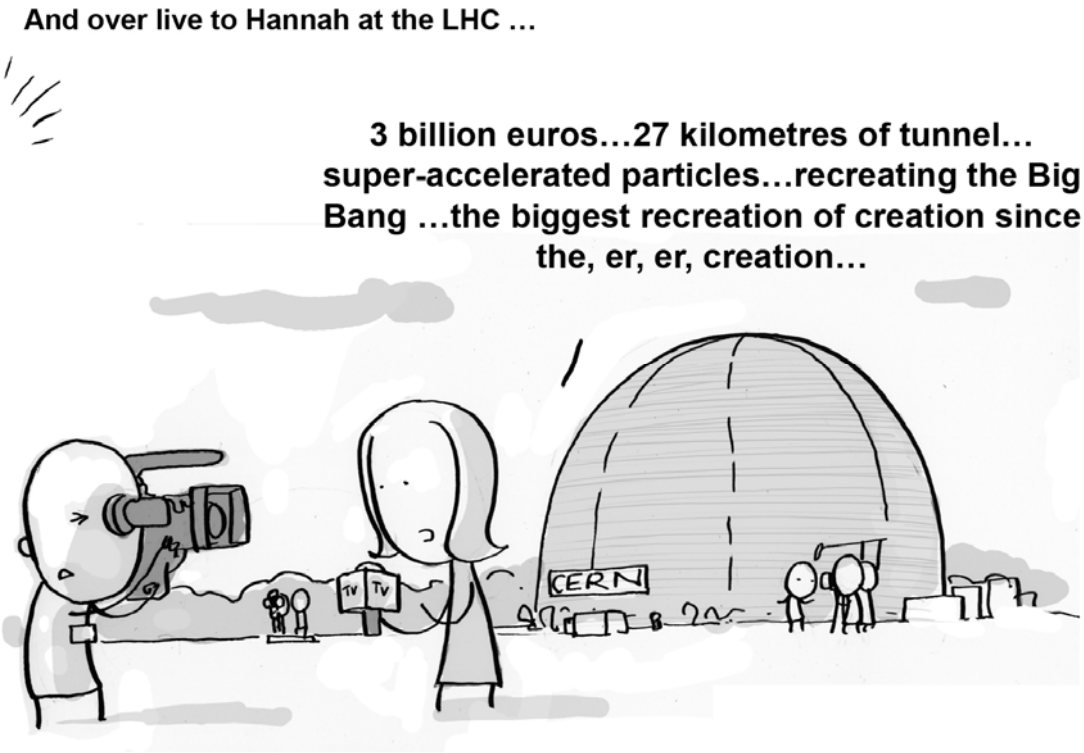


In the film, Adam describes what it feels like to become the leading expert on a particular subject. We all become 'experts' of one kind or another – for example, when we learn to swim, or ride a bike, or speak a language, or bake a cake.

Think about some of the expertise that you have, and how you got it. Decide whether or not you agree with the following points.

- You need a teacher if you are going to learn something new.
- Learning is bound to be boring, but it's worth it in the end.
- Learning is easy when you are young, but it gets harder as you get older.
- When you start learning, you don't know which things will be useful to you in the end.
- It would be satisfying to be the world's leading expert on a particular topic.
- Expert scientists are usually out of touch with everyday reality.

Reporting Big Bang Day



The film shows television crews reporting the first day of operation of the Large Hadron Collider at the CERN lab in Geneva.

Here are some reasons why it might be important to report scientific events such as the start-up of the LHC. Discuss these suggestions – which do you think are the most important, and why? Can you add any more?

- CERN and the LHC are an example of international cooperation.
- We have all paid towards the LHC – roughly £3 per person in the UK, and a total of 3 billion euros.
- The LHC may tell us more about the history of the early Universe, just after the Big Bang.
- Thousands of people have worked on this project.
- TV reports about the LHC will encourage more people to study science.
- Scientists think it's important that people know about their work.

Explaining the LHC

In the film, you can see TV crews from around the world describing the Large Hadron Collider (LHC). The journalists involved get their information from the scientists and engineers involved in the project. Then they have to make it understandable for their viewers, and they must make it interesting – exciting, even.

Your task is to prepare a brief (60 seconds or less) news item about the LHC. Your report might include some or all of the following:

- An explanation of what the LHC is for.
- How it is constructed.
- What goes on inside it.
- How much it cost.

An information sheet, with information provided by the CERN lab, is available. (You can find out more from the CERN website, www.cern.ch)

Here are two ways to carry out this activity, working with a partner:

Approach 1: Role play

You and your partner have different roles:

- the TV journalist
- the scientist

The scientist has the information sheet. The journalist questions the scientist in order to get the information listed above. The scientist gives information which is as accurate as possible.

The journalist then writes a script, making the information as exciting and relevant as possible to the TV audience.

Approach 2: Working together

You and your partner are both journalists. You have been supplied with the information sheet by the CERN press office.

Together, write a script, making the information as exciting and relevant as possible to the TV audience.

What does LHC stand for?

LHC stands for Large Hadron Collider. **Large** due to its size (approximately 27 km in circumference), **Hadron** because it accelerates protons or ions, which are hadrons, and **Collider** because these particles form two beams travelling in opposite directions, which collide at four points where the two rings of the machine intersect.

How much does it cost?

The cost for the machine alone is about 3 billion Euros.

Why large?

The size of an accelerator is related to the maximum energy obtainable. In the case of a collider, this is a function of the radius of the machine and the strength of the magnetic field that keeps particles in their orbits. The LHC re-uses the 27 km circumference tunnel that was built for the previous big accelerator, LEP. The LHC uses some of the most powerful magnets and radiofrequency cavities in existence. The size of the tunnel, magnets, cavities and other essential elements of the machine, represent the main constraints that determine the energy of each proton beam.

Why collider?

A collider (that is a machine where counter-circulating beams collide) has a big advantage over other kinds of accelerator where a beam collides with a stationary target. When two beams collide, the energy of the collision is the sum of the energies of the two beams. A beam of the same energy that hits a fixed target would produce a collision of much less energy.

Why hadrons?

The LHC will accelerate two beams of particles of the same kind, either protons or lead ions, which are hadrons. An accelerator can only accelerate certain kinds of particle: firstly they need to be charged (as the beams are manipulated by electromagnetic devices that can only influence charged particles), and secondly, except in special cases, they need not to decay. This limits the number of particles that can practically be accelerated to electrons, protons, and ions, plus all their antiparticles.

Why is the LHC built underground?

The LHC re-uses the tunnel that was built for CERN's previous big accelerator, LEP, dismantled in 2000. The underground tunnel was the best solution to house a 27 km circumference machine because it is cheaper to excavate a tunnel rather than acquire the land to build at the surface and the impact on the landscape is reduced to a minimum. In addition, the Earth's crust provides good shielding for radiation.
The tunnel was built at a mean depth of 100 m, due to geological considerations and its depth varies between 175 m (under the Jura) and 50 m (towards Lake Geneva).

What are the main goals of the LHC?

Our current understanding of the Universe is incomplete. The Standard Model of particles and forces I has been tested by various experiments and it has proven particularly successful in anticipating the existence of previously undiscovered particles. However, it leaves many unsolved questions, which the LHC will help to answer:
Why does matter have mass? Can we find the Higgs boson, the particle which will explain mass?
Matter and antimatter must have been produced in the same amounts at the time of the Big Bang, but from what we have observed so far, our Universe is made only of matter. Why? The LHC could help to provide an answer.
Heavy ion collisions at the LHC will provide a window onto the state of matter that would have existed in the early Universe. When heavy ions collide at high energies they form for an instant a fireball of hot, dense matter that can be studied by the experiments.

Colliding Particles - Episode 2: Big Bang Day

Teacher's notes

This is the second in a series of films looking at the work of a team of particle physicists involved with the Large Hadron Collider (LHC) and the hunt for the Higgs particle.

How science works (HSW)

These films have been made to illustrate aspects of the way in which science develops. They show scientists discussing their work, how they collaborate and compete, and the relationship between experiment and theory in science.

This film looks at two aspects of the life of science:

The experience of learning to be a scientist, up to the point where an individual becomes the expert in their field.

The presentation of science in the media.

It does this by looking at the day (10 September 2008) when proton beams were first sent round the accelerator rings of the LHC. Media crews are shown reporting the event and Adam Davison, a postgraduate student, describes how his scientific education led to him becoming part of the project.

When to use this film

- **The Big Bang**

  At GCSE and Standard Grade, most students learn about the Big Bang theory of the origin of the Universe. Evidence to support this theory has come from astronomers' observations of distant galaxies, but it has also come from experiments performed by particle physicists, including those at CERN. It is a remarkable feature of physics that it has succeeded in uniting our theories of the largest and smallest objects – the Universe and fundamental particles.

  This film can give students an impression of the scale of the experiments now needed to extend this work – a far cry from the Manchester lab where Rutherford, Geiger and Marsden elucidated the nuclear structure of the atom.

- **Scientific collaboration**

  The film gives an impression of the number of people involved in a large-scale experiment such as the LHC – scientists, engineers, IT staff, support staff. We can see aspects of how they work together. Adam describes how, despite being a small cog in a big machine, he has a place as the 'expert' in his own field.

- **In the news**

  The LHC is not a single experiment; rather, it is a giant scientific instrument with many possibilities for experimentation. Announcements of new findings

will appear in the media, and these films can be used to help students understand what they have seen.

The film also shows how media organisations operate in practice, with TV crews and reporters mingling with scientists. The reporters sometimes seem to be struggling with their material and with the technology. Adam explains his role on the day, helping to ensure that the media people were given interesting material to report.

This provides an opportunity to consider why and how science is reported in the media. See the Activity sheet **Reporting Big Bang Day**.

The film shows the challenge of presenting difficult scientific ideas to a general audience. Students can tackle a similar task through role play – see the Activity sheet **Explaining the LHC**. This can be approached in two ways. In one approach, one student is the LHC scientist while the other is a journalist who must extract information about the LHC and convert it into an interesting news item. In the other approach, two students work together to convert the information provided into a script.

- **Learning about science**

  Students often complain that learning science (and other subjects) is 'boring'. Adam describes how he too found that science could be boring at school. This can be an opportunity to discuss whether this is inevitable, and also to consider education as an introduction to a subject which has its own body of knowledge and skills.

  See the Activity sheet **Becoming an expert**.

  An alternative approach would be to get students to draw a flow chart of a process in which they've become an expert, outlining the different stages of learning and understanding, and then reflect this back to where they are in their physics studies.

- **Careers in science**

  The film can be used to show the different roles played by members of a scientific research team. In particular, Adam (the postgraduate research student) can be used as an example of someone who is moving from being taught science to 'doing science'.

Showing the film

The film can be shown straight through and uninterrupted. This will allow students to start recognising the different personalities involved.

Alternatively, the film can be shown in sections (see **Summary**), with a discussion of the main points arising after each section.

Students could be encouraged to focus on one or more of the following:

- How scientists become expert in a particular field
- How scientists make their work known to others

- How science is presented to the public

Film 2: Big Bang Day – 'Classroom Edit' summary

Adam Davison, research student, University College London and CERN Geneva

0:00	Media morning	International TV crews set the scene for the opening of the LHC.
0:42	Arriving at CERN	Adam describes the contrast between how he imagined CERN and his impressions when he first arrived there.
1:57	Media mayhem	More media action – and confusion.
(2:15)	(The LHC)	An explanation of the purpose of the LHC.
2:34	CERN Staff	Adam describes the different roles of the people who work at CERN.
3:25	The Big Day	Adam describes the excitement of being at CERN on the day of the LHC start-up.
(3:35)	(The size of the LHC)	A description of the scale and cost of the LHC.
4:18	Adam's role	Adam describes his role at CERN and in the LHC project.
(4:25)	(Under control)	Inside the LHC control rooms at CERN.
5:23	On the day	Adam describes his role on the day of the LHC start-up.
6:03	How I got here	Adam describes how he found his science education.
7:12	Becoming an expert	Adam describes the satisfaction which comes from the change from being taught to being the expert.
(8:21)	(Success)	Back in the control room, the beam tests have been successful.
9:02	END	

Communicating science

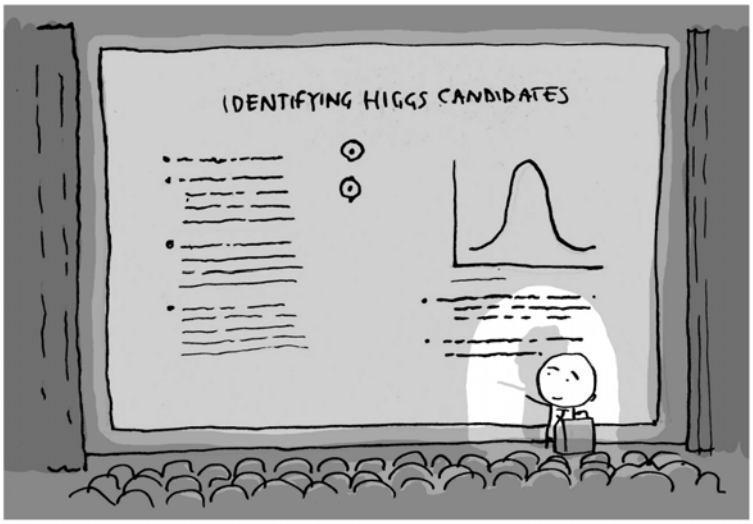
Jon and his colleagues have already published a scientific paper about their ideas for analysing the results from the Large Hadron Collider. Now he is on his way to present his ideas at a major conference in Philadelphia, USA.

As you watch the film, think about the different ways in which scientists communicate their ideas and get feedback from other scientists. Pay close attention to the poster session at the conference because your task will be to prepare a poster about **how scientists communicate** when you have watched the film.

Conference talk

Jon gives a talk during one of the lecture sessions.

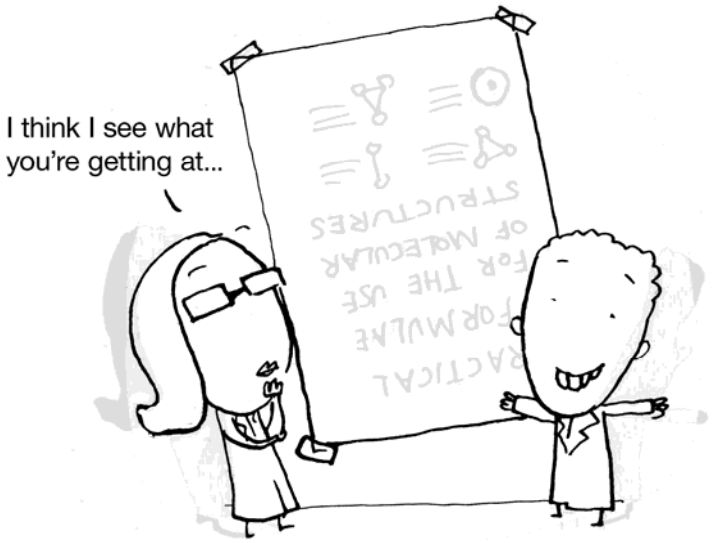
- What is the venue like?
- How does Jon get his ideas across?
- How do people let Jon know what they think about his talk?



Poster session

Authors stand in front of their posters and discuss them with other scientists.

- What is a scientific poster like?
- Why might a scientist present a poster rather than giving a talk?



Informal conversation

During the conference there are many opportunities for scientists to chat to each other.

- What are the benefits of talking face-to-face?

The Internet

Jon phones home over the Internet.

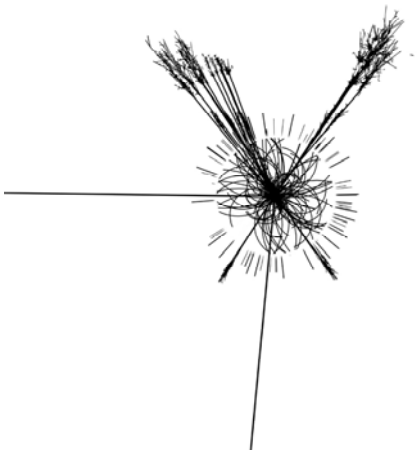
- In what other ways do scientists use the Internet to share their ideas?

Now prepare your own poster entitled **How scientists communicate**. Make it as graphic as possible – a picture is worth a thousand words.

Discuss your poster with another member of the class. Have you missed anything out? Could you have got your ideas over in a better way?

Creativity in Science

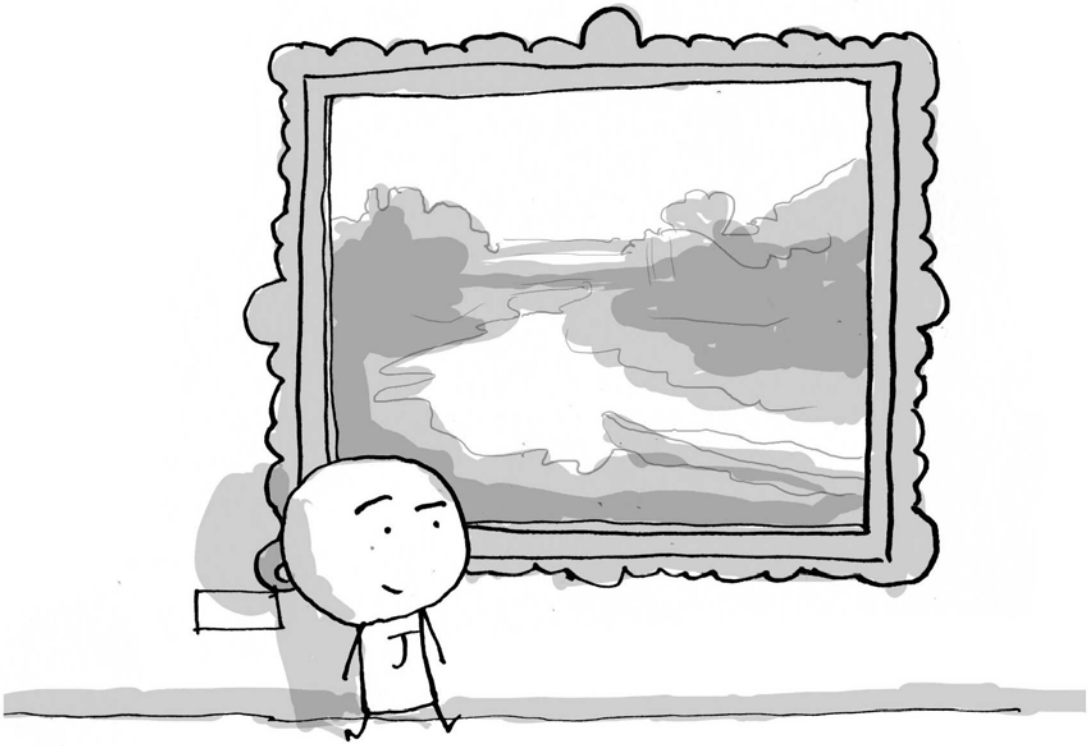
Particle physicists are using the Large Hadron Collider to find out what happens when two beams of protons collide head-on at high energy. They hope to see something like the image on the right – this will help them to decide whether the Higgs boson really exists.



At present, this particle is simply the product of the creative imagination of Peter Higgs of Edinburgh university. It is over 40 years since he suggested its existence – that's a long time to wait to find out if you are right!

A scientist looks at art

In the film, Jon visits an art gallery and talks about creativity and imagination, comparing the creativity of artists and scientists. Most scientists have pictures in their heads which help them to understand what is going on; although the pictures may sometimes be misleading.



Scientists use their imagination a lot.

- They make an observation and they wonder, “What might have caused that?” This can lead to a new theory, a way of explaining things.
- They wonder, “What will happen if …” and that can lead to a new experiment, a new way of finding things out.

Here’s an example. In 1827, the botanist Robert Brown was using a microscope to observe pollen grains in water. He noticed tiny specks moving about within the pollen grains. At first, he thought that this might be a sign that these materials were alive – some kind of ‘life force’ kept them moving.

However, he tested this theory by using fine grains obtained by grinding up rocks – nothing could be deader than rock. And these grains also moved about.

Brown didn’t have an explanation for what we now call **Brownian motion**. Nowadays all scientists believe that the tiny grains were moving about because they were being pushed about by even smaller particles – the molecules of the water in which they were floating. These molecules must be too small to be seen.

Today all scientists accept this explanation of Brownian motion. But it took a great leap of creative imagination to come up with the theory in the first place.

Discuss the part played by creative imagination in Brown’s work. **Suggest** an alternative explanation for Brown’s observations, and think about how you could test it. **Draw** a picture to show how you imagine the molecules of water might push a pollen grain. **Compare** your picture with someone else’s.

Rutherford’s alpha-particle scattering experiment was an important experiment (performed in 1910) which showed that atoms have nuclei. Find out about the experiment and the imaginative theory that explained the results:

- What did the experimenters Geiger and Marsden actually see?
- What picture did Rutherford use to explain the findings?
- Draw a diagram and explain how it links the experimental observations to the theory of atomic structure.

Colliding Particles - Episode 3: Conference Season

Teachers Notes

This is the third in a series of films looking at the work of a team of particle physicists involved with the Large Hadron Collider (LHC) and the hunt for the Higgs particle.

How science works (HSW)

These films have been made to illustrate aspects of the way in which science develops. They show scientists discussing their work, how they collaborate and compete, and the relationship between experiment and theory in science.

The first film showed the team of physicists, based in London and Paris, as they prepared to present their ideas about how data from the LHC could be analysed. The second film showed one of the scientists (Adam Davidson) and his involvement in 'Big Bang day' – the day when the LHC was first switched on.

This third film follows Jon Butterworth as he goes to present the team's ideas at a major international conference in Philadelphia. It concentrates on two aspects of How Science Works: communication and creativity.

When to use this film

- **Scientific communication**

  GCSE science students need to know a little about the ways in which scientists communicate. Scientific publications ('papers') are the most formal part of this. However, this film shows that there are several more informal ways in which scientists can present their ideas and get feedback from their colleagues.

  The activity sheet provides a structured approach to developing students' understanding of how scientists communicate.

  The film could also be used as a starting point for an activity where students make their own presentations to the class about an area they have researched.

- **Scientific creativity**

  Towards the end of the film, we see scientists who are attending the conference enjoying a visit to the local art gallery. While some choose to spend the time in further discussions of their work, Jon takes the opportunity to compare creative thinking in science and art. He describes both of these as ways of seeing the world and explains the importance of mental images as an aid to scientific thinking.

In their studies of art, students will have come across different genres such as pop art and surrealism. You could discuss how these operate: what constraints do they work within and how do they change the way we see the world?

You could also look back to artists such as Leonardo da Vinci for whom representations of nature were closely related to scientists' developing understanding of the world.

Showing the film

The film can be shown straight through and uninterrupted. This will allow students to obtain a general view of the nature of a scientific conference.

Subsequently, the film can be shown in sections (see **Summary**), with a discussion of the main points arising after each section.

One approach would be to use the activity sheet to structure students' viewing of the film. This concentrates on the first 7 minutes or so of the film, concerned with scientific communication. You could pause the film after each section and discuss briefly the answers to the questions (see below).

The activity sheet **Communicating science** asks students to prepare a poster on How scientists communicate. This could be a homework activity. (Students could re-view the film from the collidingparticles.com website.) Then, to give a flavour of a conference poster session, they could pin their posters up and discuss them with other members of the class.

The activity sheet **Creativity in science** discusses the role of imagination and creativity in science. Devising a new theory, designing a new experiment – these are both creative acts. The activity sheet asks students to think about two 'particle' experiments (Brownian motion and Rutherford's alpha scattering) with which they are likely to be familiar. How do 'images' play a part in understanding these important experiments?

Notes on the activity sheet: Communicating science

Students are provided with a number of stimulus questions to guide their viewing. Here are some notes on these questions:

Conference talk

- What is the venue like? – Several big lecture halls are used, with the possibility of seating hundreds of people.
- How does Jon get his ideas across? – Speaking, using a slideshow on the screen.
- How do people let Jon know what they think about his talk? – questions and answers at the end of the talk, conversation immediately after, possibility of having a chat late on.

Poster session

- What is a scientific poster like? – Title plus author details; mixture of text, graphics, data etc.
- Why might a scientist present a poster rather than giving a talk? – work-in-progress can be presented without the formality of a lecture presentation. Also, at large conferences there is not enough time for everyone to make a presentation, and poster sessions provide a democratic platform for people to present their work.

Informal conversation

- What are the benefits of talking face-to-face? – People can respond immediately to suggestions; can get to know people you might collaborate with; people can make more tentative suggestions in a less formal setting.

The Internet

- In what other ways do scientists use the Internet to share their ideas? – conference presentations appear on internet; email; discussion groups; webpages; access to on-line journals; etc etc.

Notes on the activity sheet: Creativity in science

It is difficult to picture what is going on in a giant experiment like the LHC. Nobody ever sees the beams of particles or the explosion of debris which erupts from the point of collision. The detectors pick up a tiny flash of energy and computers crunch this data to produce images on screens.

The traditional Brownian motion experiment has parallels with this. What we see depends on what we think we are seeing. To see the jittering motion of smoke grains in air, one could imagine that they are alive. This is, of course, an incorrect conclusion but, in Brown's day, it was not unreasonable. It took a leap of imagination to come to another conclusion.

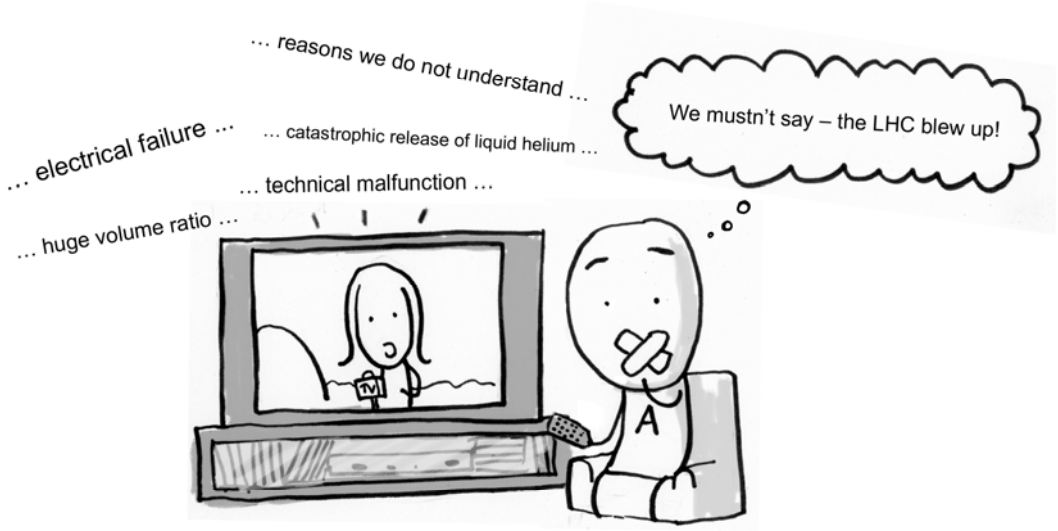
One approach to this activity would be to demonstrate Brownian motion using an illuminated smoke cell, preferable projected for the whole class to see. Don't give the game away at the start; allow students to suggest their own ideas. Emphasise that these suggestions are examples of scientific creativity.

Go on to remind them that air is made of invisible molecules. How could these contribute to a creative explanation of the observations? Conclude by discussing how, once a scientific image or model is implanted in our minds, it can become a powerful tool in explaining all sorts of phenomena.

Colliding Particles - Episode 4: ***Problems***

Activity sheet 1

Problems and progress in science



In the film, four scientists who work on the LHC (Large Hadron Collider) talk about their work.

- What is it like being a research scientist?
- And how does science make progress?

Read the following statements before you watch the film. As you watch the film, or afterwards, number the statements in the order in which the topics appear.

	For a scientist, numbers are often better than simple descriptions.
	It can be incredibly frustrating when your work does not make progress.
	New instruments can increase scientists' ability to find out about the fundamental laws of nature.

	Scientists often reduce a complex, insoluble problem to a simpler one which they are more likely to be able to solve.
	Scientists try to describe, predict and explain.
	Some scientists work collaboratively, others are more individualistic.
	Sometimes it's harder selecting the problem than solving it.

Now choose two or three of the statements above and think up other examples which illustrate the same idea. Your examples could come from your studies of science or from what you know of the history of science.

For example, the statement

> New instruments can increase scientists' ability to find out about the fundamental laws of nature.

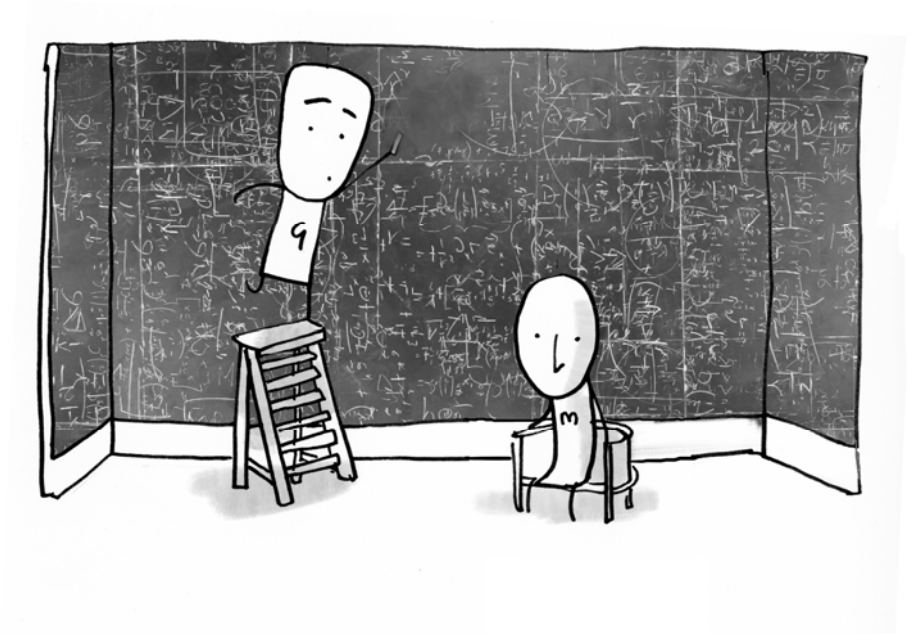
could be illustrated by Galileo and the telescope – his observations helped to confirm the heliocentric model of the solar system.

Colliding Particles - Episode 4: ***Problems***

Activity sheet 2

Struggling on

Research can be so frustrating….
….especially when you can't find the board rubber.



In the film, Mathieu describes how he can become demotivated when he is struggling to solve a problem. But this is part of his training to become a professional scientist.

A recent book looked at people who are successful– sportsmen and women, musicians, speakers of foreign languages, scientists. It found that, typically, they spend 10 000 hours in training or studying before they reach the top of their chosen field. Very few achieve success without long experience.

1. If you were to train for a sport every day after school, how long would it take you to clock up 10 000 hours? Could you manage this?

2. Many people are dedicated to a particular hobby and invest thousands of hours in it. Think of some examples. What motivates people to devote themselves to one activity?

3. Research scientists often work long hours. It can be a competitive business – you won't get the Nobel Prize for being the second person to discover the Higgs boson. How can Mathieu's training help him to stay in the race?

Describing with analogies

Music can help when you've run out of ideas

At the end of the film, Gavin explains that the LHC will help physicists understand more about the laws of nature. Particles in the LHC have greater energies than in the old machine (the Tevatron), and this means that the LHC will give us a higher-energy view of the fundamental laws which govern how matter behaves.

Gavin uses the analogy of music. If you can only hear the lowest notes with the lowest frequencies, you will find it hard to recognise the tune. It's like hearing only double-basses in an orchestra, or the drums or bass guitars in a rock band.

With the LHC, physicists will be able to hear more – the cellos in the orchestra. That means it will be easier to deduce what the whole orchestra is playing.

Describing using analogies like this is an important way of getting ideas across.

1. What is an analogy?

2. Is Gavin's analogy a good one? Explain your ideas.

3. Can you think of another analogy to get across Gavin's idea about the LHC? You might start like this:

- With the Tevatron, it was like looking through a keyhole into a secret room …

Colliding Particles - Episode 4: ***Problems***

Activity sheet 1 - Notes

Problems and progress in science

This activity can be carried out while watching the film – it is intended to help students follow the 'plot' of the film. (It may help students to cut out the statements and move them around on slips of paper until they are happy with the order.)

Here are the statements in the order which the ideas appear in the film. (Students should have numbered them on the activity sheet thus: 2 – 4 – 7 – 6 – 1 – 5 – 3.)

	Scientists try to describe, predict and explain.
	For a scientist, numbers are often better than simple descriptions.
	Sometimes it's harder selecting the problem than solving it.
	It can be incredibly frustrating when your work does not make progress.
	Some scientists work collaboratively, others are more individualistic.
	Scientists often reduce a complex, insoluble problem to a simpler one which they are more likely to be able to solve.
	New instruments can increase scientists' ability to find out about the fundamental laws of nature.

Colliding Particles - Episode 4: ***Problems***

Activity sheet 2 - Notes

There are two separate activities on this sheet.

Struggling on

This looks at the need for determined practice over a long period of time if success is to be achieved. A simple calculation shows that, to achieve 10 000 hours of practice will take over 10 years at 3 hours per day – that is typically what professional sportspeople or musicians have put in by the time they are 21.

You might compare this with the instant success apparently offered by TV talent shows such as *Britain's Got Talent* – in fact, the performers have often worked extremely hard over a long period.

Mathieu describes his feelings of frustration when a problem proves intractable. At such times, Gavin plays the piano. You could discuss other strategies which students have used.

Describing with analogies

An analogy is something familiar which has aspects which parallel those of the idea we are trying to convey.

Gavin's analogy between music and particle physics is a good one. With older accelerators, we were looking at the low-energy end of the possible particle interactions. Adding the LHC gives a chance to see higher-energy effects. The parallel with music is that, if we only hear the low-energy bass notes, we are unlikely to be able to identify the tune.

You could try playing a recording with the bass turned up and the high notes cut out. Gradually bring up the treble and the tune becomes clear.

Another analogy might come from photography. A black and white photograph can show a scene; colour tells us more. Adding ultraviolet can reveal still more – for example, the markings on a flower which act as honey-guides for bees.

Film Summary

Gavin Salam, theoretical physicist, University of Paris

Mathieu Rubin, research student, University of Paris

Jon Butterworth, experimental physicist, University College London

Adam Davison, research student, University College London

0:00	What science does	Gavin talks about science: describe, predict, explain quantitative rather than qualitative
0:50	Selecting the problem	Gavin: it's often harder selecting the problem than solving it.
2:00	Frustration	Gavin and Mathieu at work; Mathieu describes the frustrations of research.
2:27	Pressing on	Collaborator or individualist? Persistence in solving problems
3:40	LHC predictions	Gavin explains that 'jets' are a simplification, needed to explain observations from LHC.
4:30	The LHC goes down	Official talk about the engineering breakdown at LHC. Jon and Adam tell it like it is.
6:30	Music of the universe	Gavin explains the parallel between hearing music and understanding the fundamental structure of the universe.
7:40	End	

Colliding Particles - Episode 5: ***Collidonomics***

Activity Sheet 1

Scientists getting together

In the film, we see scientists working together in some different situations. During the film, watch out for the three situations in the table below.

- For each situation, write a brief description of its purpose.
- Then write a few adjectives to describe the way of working. You might use words like:

competitive - collaborative - public - nerve-wracking - sharing - supportive …

funding meeting	***function:*** ***description:***
workshop	***function:*** ***description:***
conference	***function:*** ***description:***

Colliding Particles - Episode 5: ***Collidonomics***

Activity Sheet 2

Making the case for scientific research

In the film, Jon and his colleagues have to make the case for continued funding for their work, and for the inclusion of their ideas in the official programme of the LHC.

Jon explains why he thinks his work deserves to be funded using public money.

- As you watch the film, think about the questions shown in the table below.
- Summarise what Jon's answers to the questions are.
- Comment on his answers – does he make a good case? Would your answers be different?
-

Why does science need to be funded?	***Jon's answer:*** ***Your comments:***
Do scientists work in an 'ivory tower', free from public scrutiny?	***Jon's answer:*** ***Your comments:***
Why do we do particle physics?	***Jon's answer:*** ***Your comments:***
What are the benefits of doing particle physics?	***Jon's answer:*** ***Your comments:***
Why is public funding necessary?	***Jon's answer:*** ***Your comments:***

Should we be doing this work? Or are there better things we might spend our time and money on?	***Jon's answer:*** ***Your comments:***

Colliding Particles - Episode 5: ***Collidonomics***

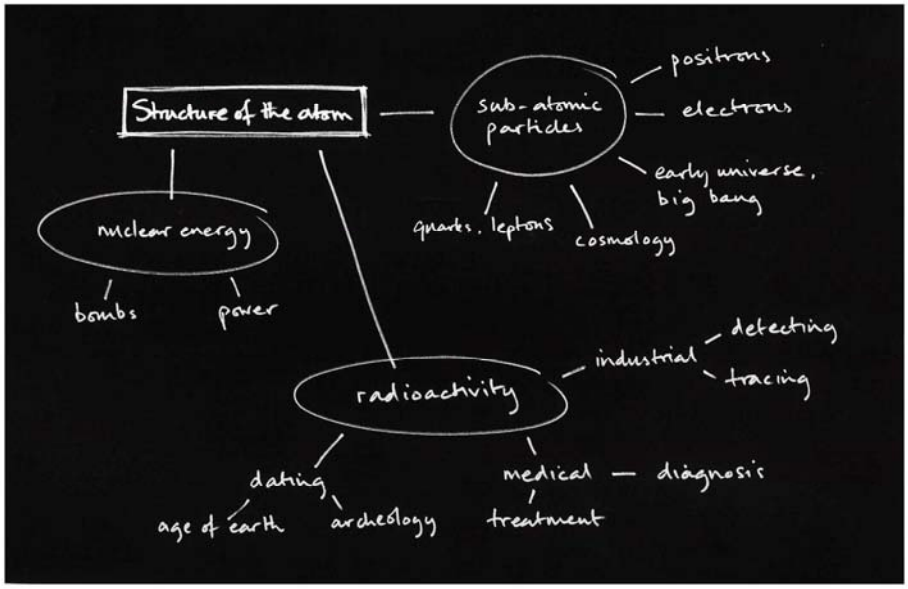
Activity Sheet 1

An avalanche of ideas

In the film, Jon suggests that the LHC project is part of a human effort to understand the world around us. Its benefits are unpredictable – who knows what we will be able to do with new knowledge in the next hundred years?

If we go back a century, we didn't know about the structure of the atom, DNA and the genetic code, galaxies, antibiotics etc. 150 years ago, we didn't know about electromagnetic waves and the periodic table of the elements. It took decades for these discoveries to become established in our understanding of the world, and to be put to use for the benefit of humanity.

The chart shows some of the cascade of discoveries which followed on from the discovery in 1910 of the structure of the atom.



1 Look at the chart. Which things are of practical benefit? Which help us to understand the universe and our place in it?

2 Which things might have been predicted before their discovery?

3 Make your own chart to show the different discoveries which have followed since scientists first discovered electromagnetic waves and the electromagnetic spectrum.

Colliding Particles - Episode 5: ***Collidonomics***

Teachers Notes

Scientists getting together

This activity is intended to help students focus on the different ways in which scientists get together – they don't spend their lives working away in their own private worlds. Scientists have to make the case for funding their work, and they have to share their ideas both while they are developing and when they have reached conclusions.

funding meeting	***function:*** scientists put the case to their peers and to the funding body to have their particular projects funded. ***description:*** competitive, public, nerve-wracking etc. Careers are on the line!
workshop	***function:*** scientists meet informally, present their current work to individuals or small groups, share ideas, comment and criticise. ***description:*** collaborative, relatively private, sharing etc.
conference	***function:*** scientists present their findings and ideas to a public audience; detailed results are made available via internet. The audience can ask awkward questions. ***description:*** competitive, public, nerve-wracking etc.

Activity sheet 2 - Notes

Making the case for scientific research

In the film, Jon's narration builds up the case for public support of work like his with the LHC. Many students will question whether it is really worth the money. The questions will help students to identify Jon's arguments and then comment on them.

Here are Jon's main points:

Why does science need to be funded?	***Jon's answer:*** You can't make progress simply by thinking; experiments are needed, and they cost money.
Do scientists work in an 'ivory tower', free from	***Jon's answer:*** You are put on the spot when you have to make a case for funding.

public scrutiny?	
Why do we do particle physics?	***Jon's answer:*** It's part of a human effort to understand the world around us.
What are the benefits of doing particle physics?	***Jon's answer:*** The benefits are unpredictable – who knows what the discovery of the Higgs might lead to?
Why is public funding necessary?	***Jon's answer:*** No commercial sponsor would fund a project whose benefits are uncertain and lie in the distant future.
Should we be doing this work? Or are there better things we might spend our time and money on?	***Jon's answer:*** There are other big problems to be solved (disease, sustainable energy etc), but questions about the nature of matter and the universe are also important.

You could follow up this activity by asking students how they would decide between rival projects such as the LHC, a manned exploration of Mars or a vaccine for malaria.

Activity Sheet 3 – Notes

An avalanche of ideas

This activity is intended to show that there can be a long timescale between a scientific discovery and the working out of its implications. Some consequences of a discovery may have practical uses, others may change our picture of the world.

Our understanding of the structure of the atom has had consequences in many areas, and many of these were unpredictable a century ago.

Students can devise their own chart showing the consequences of the discovery of electromagnetic waves and the electromagnetic spectrum, a topic which appears in most GCSE Science specifications.

Film Summary

Jon Butterworth, experimental physicist, University College London

Pippa Wells, project leader, Atlas Inner Detector, LHC, CERN, Geneva

Gavin Salam, theoretical physicist, University of Paris

Adam Davison, research student, University College London

0:00	Funding for science	Jon briefly explains the need for funding in science, especially for experimentalists.
0:35	Funding meeting	Members of the particle physics community present their bids for funding for the next year or two. Jon describes the UK's contribution to CERN and the LHC.
2:10	Public funding	Jon explains the need for public funding, leading to the question: Why do we do particle physics in the first place?
2:35	LHC progress	Pippa describes the emotional rollercoaster that followed the opening and subsequent failure of the LHC.
3:35	Unpredictable benefits	Jon explains that we cannot foresee the outcomes of an experiment like LHC. It's part of a human quest to understand the world around us.
4:15	Scientific workshop	Gavin describes the origins of his collaboration with Jon at an annual workshop where scientists share their ideas in a democratic forum.
5:30	Preparing the case	Adam prepares to make the case for the Eurostar idea becoming an official part of the ATLAS project.
6:40	Reconnecting ATLAS	Pippa's team have tested, optimised and calibrated the giant detector, ready for the restart of the LHC.
7:20	Making a presentation	Adam makes his presentation before a tough audience, responds to questions from the floor.
8:30	Should we?	Jon gives his answer to the question: Should we be doing this work? Are there better things we might spend our time and money on?
9:15	End	

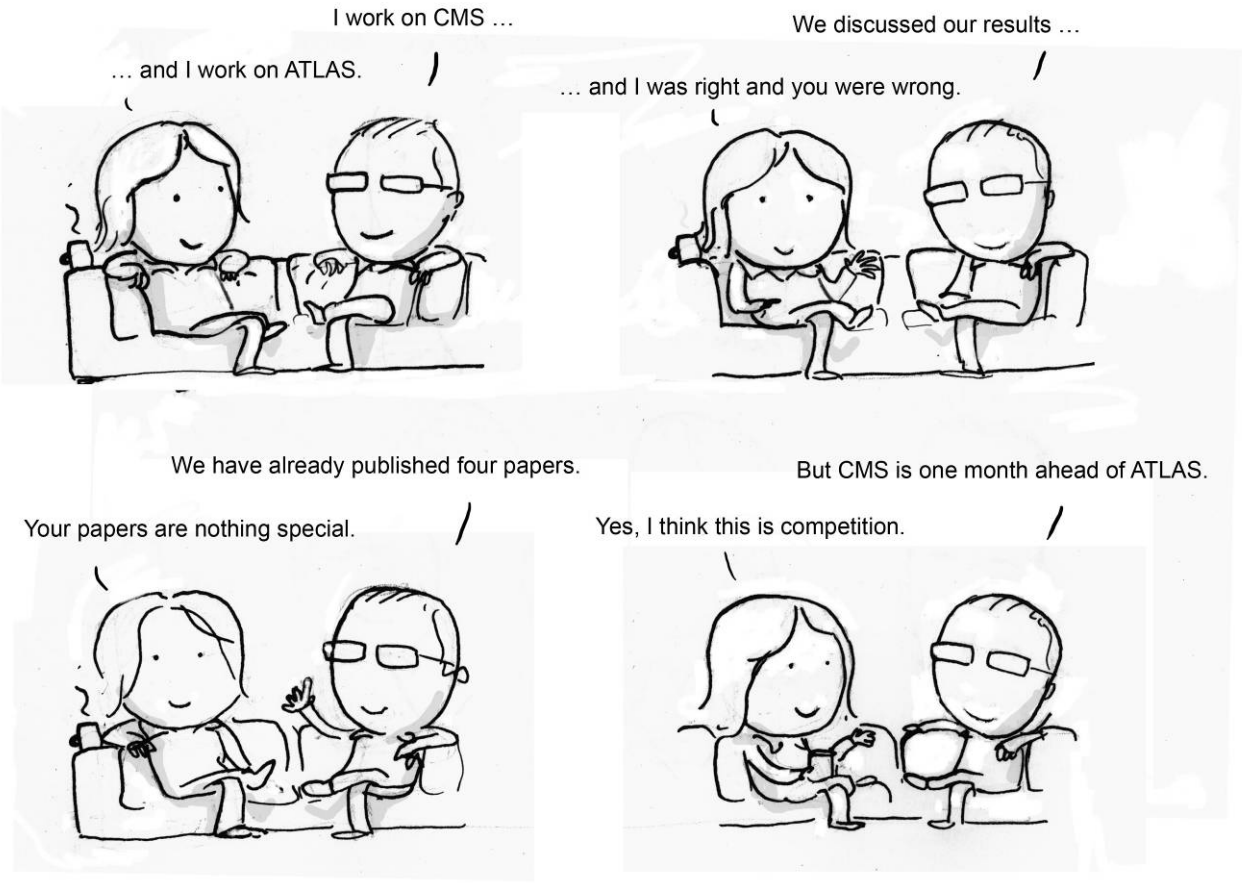
Colliding Particles - Episode 6: ***Beam***

Activity Sheet 1

Two experiments, two teams – competition!

At the Large Hadron Collider (LHC) there are two giant underground particle detectors, ATLAS and CMS. Beams of energetic protons travel around the collider tunnel in opposite directions so that they collide and the sprays of particles and energy that result are detected.

The two teams of scientists operating the detectors are hoping to make new discoveries in particle physics – but only one team can be first.



Here are two things to think about while watching the film:

1 In the film, the scientists describe some of the emotions they feel while working on the project. Complete the table by making notes about when they might feel each of the emotions listed.

challenge	
satisfaction	
rivalry	

2 Benedetto says, “We compete, but we couldn’t live without each other.” The film explains why it is useful that there are two experiments working in competition with each other. What are the benefits of this?

Colliding Particles - Episode 6: ***Beam***

Activity Sheet 2

The Large Hadron Collider (LHC) is producing its first data. In the film, the scientists talk about these early results. Some of the terminology they use may be unfamiliar.

It will help you to understand what is said in the film if you read the following points made by speakers in the film and discuss the answers to the questions.

1 "There are two **collaborations** working at LHC: ATLAS and CMS."

What does the word 'collaborations' mean here?

2 "If we shut down the computers to change the software we will lose run time and than means less data. We need lots of data because the results all depend on the **statistics**."

What does the word 'statistics' mean here?

3 "At present, the collisions are not producing any new **physics**, they are simply confirming known physics."

What does the word 'physics' mean here?

4 "Because we have two experiments, the results from the second one will be used to **validate** those from the first one."

What does the word 'validate' mean here?

Colliding Particles - Episode 6: ***Beam***

Notes

This film focuses on the competition that exists between the two teams of scientists who are working with the detectors (ATLAS and CMS) at the LHC. They talk about their personal emotional responses to problem-solving, competition and rivalry. They discuss the benefits that may also come from having two competing teams.

Activity 1

Two experiments, two teams – competition!

This activity encourages students to think about scientists' personal responses to the work they are doing at the LHC, and the effects of having two competing teams working on the same site.

The questions should be introduced before the students watch the film, and then they should complete their answers during and after the viewing.

At the end, compare answers and ask whether students have been surprised about anything they have seen.

1

challenge	Scientists like the challenge of having a problem to solve.
satisfaction	Solving a problem brings a personal sense of satisfaction.
rivalry	Because there are two teams trying to solve the same problem, there is rivalry between them – only one team can be the first with the answer.

2 Three benefits of competition:

Teams work harder and seek to get as much good data as quickly as possible.

One team will be the first to find the answer but the other will validate the results of the first (if they find the same answers).

Being first to discover something can help you get more funding for experiments in the future.

Activity 2

LHC – the first runs

The LHC scientists use some unfamiliar terminology in describing their work. It may help your students if you ask them to interpret the statements given on the worksheet.

You could either allow students to say what they think the statements mean, watch the film, and check whether they were correct, or give the correct interpretations before watching.

1 "There are two collaborations working at LHC: ATLAS and CMS."

Here, the word 'collaborations' refers to the collaborative teams running each of the detectors.

2 "If we shut down the computers to change the software we will lose run time and than means less data. We need lots of data because the results all depend on the statistics."

Here, the word 'statistics' refers to the fact that the most significant results (eg the existence of the Higgs boson) will be deduced from data gathered from many millions of collisions. Statistical analysis will be needed to determine whether a new particle or event has been informed; there won't be a single collision that shows up the existence of the particle.

3 "At present, the collisions are not producing any new physics, they are simply confirming known physics."

Here, the word 'physics' refers to the results of the experiments which can be explained in terms of the established laws of physics. 'New physics' would describe any new phenomena which are revealed by later experiments.

4 "Because we have two experiments, the results from the second one will be used to validate those from the first one."

Here, the word 'validate' suggests that, although one of the experiments may be the first to find something new, these results will be confirmed by the second experiment (assuming they both come to the same conclusions). This will give greater confidence in the results.

Film Summary

Tiziano Camporesi, CMS run co-ordinator

Benedetto Gorini. ATLAS run co-ordinator

Ariella Cattai, ATLAS cooling co-ordinator

Gigi Rolandi, CMS physics co-ordinator

Rachel Wilken in the CMS control room

Jon Butterworth, Experimental Physicist attached to ATLAS

0:00	Solving problems	Tiziano Camporesi and Benedetto Gorini describe the personal pleasure of solving problems in science.
1:00	CMS control room	Rachel Wilken describes the satisfaction of work coming to fruition.
1:30	Two experiments	Tiziano and Benedetto explain that there are two competing experiments (CMS and ATLAS). If both get the same results, this will provide validation of the findings. Rachel and colleagues explain why they want to maximise the amount of data collected.
3:50	Getting competitive	Jon explains that particle physics is a small world. Ariella and Gigi argue over the number and quality of published papers. ATLAS is a month behind CMS.
6:00	Missing energy	Rachel explains that a V-shaped pattern of jets suggests that there is 'missing energy' – something to be explained.
6:40	Testing times	Tiziano explains that, at this early stage, the detectors are tested by ensuring that they can reproduce established physics results.
8:00	First, best – and civilised	Jon explains that everyone wants to be first and best. Tiziano describes the competition as 'very civilised'. Rachel describes the satisfaction at the end of a run.
9:50	End	

Colliding Particles - Episode 7: ***Data***

Activity Sheet 1

How scientists live

This film shows many aspects of the lives of scientists. Your task is to spot some of them as you watch the film.

Below, you will find a list of things scientists think about and do. While you watch the film, put them in order.

(There are two ways to do this. Either number the points 1, 2, 3 … in the order that they appear while you watch, or write the points on slips of paper and put the slips in order while you watch.)

	Presenting results
	Discussing ideas with other scientists
	Taking examinations
	Moving from one job to another
	Arguing for more funding for research
	Discussing how science develops
	Socialising with other scientists
	Debating the value of other people's results
	Worrying about their future careers

At the end, explain what you saw in the film which illustrates each point.

Colliding Particles - Episode 7: ***Data***

Activity Sheet 2

So much more to know ..

How science develops

Towards the end of the nineteenth century, scientists thought that physics was more or less complete. They knew about forces and motion (Newton's laws), and about electricity, energy, waves and particles. All that remained was to tidy up the loose ends.

The twentieth century proved how wrong they were. And today, the LHC scientists are hoping to get new results which will test the Standard Model of fundamental particles and forces.

In the film, scientists discuss how science develops. Each generation builds on the work of the generations before. Sometimes old ideas must be thrown out. Some new ideas may be difficult to find.

In this activity, you are going to examine some metaphors for the way in which science develops.

What to do

Read all three descriptions. Then you have a choice:

- Either make a comic strip to show how science (or a particular area of science) develops.

- Or devise your own metaphor for the way science develops.

Metaphor 1: Doing science is like exploring a landscape. Sometimes you seem to be getting nowhere. Then you climb over a high mountain and, beyond, you see a whole new vista beyond. Sometimes you discover a new, simple route to a place you have already explored.

Metaphor 2: Doing science is like constructing a large building. You start with a small building, then you add an extension. Then an extra floor. Then you join up to a neighbouring building. Sometimes you knock down whole sections of your growing building.

Metaphor 3: Doing science is like mining. You dig a shallow pit and find some old remains. You dig deeper and reach solid rock. You dig sideways until you reach softer rock. Occasionally your mine workings meet and join up with someone else's.

Colliding Particles - Episode 7: ***Data***

Teachers Notes

This film focuses on the team (Jon, Gavin and Adam) as the first results start to come through from the LHC experiments. They (and others) discuss how the scientific view of the world develops. At the same time, they are thinking about the future. Gavin and Adam are changing jobs; Jon is concerned about economic threats to scientific research.

Activity 1

How scientists live

This activity is designed to be carried out while watching the film. Because the film illustrates so much about the life of scientists, it is worth asking students to spot various aspects as the film progresses.

You might wish to show the film with the timeline showing, so that students can note the time at which different points appear and you can easily run through to see the point they have noticed.

The table below shows some possible occasions where points arise; there are others.

	Presenting results	(2:45, 3:05) at the conference, Tevatron and LHC results
	Discussing ideas with other scientists	(0:10) Adam and Jon on the train; (1:05) at the conference, etc
	Taking examinations	(6.50) Adam's PhD exam
	Moving from one job to another	(5:40) Gavin moving from Paris to Geneva; (8:05) Adam discusses where other students have moved to
	Arguing for more funding for research	(8:40) Jon is at the demo against the cuts; (8:55) a speaker explains how cuts 20 years ago led to the brain drain
	Discussing how science develops	(4:30) At the conference social event; (6:05 and 10:20) Gavin talks about how science progresses
	Socialising with other scientists	(4:30) At the conference social

		event
	Debating the value of other people's results	(2:35) The Tevatron results are presented and discussed
	Worrying about their future careers	(10:00) Adam discusses where he may be in 2 years' time

Activity 2

How science develops

This is a rather open-ended activity, inviting students to think about how science grows. You could discuss students' ideas after they have spent some time considering the metaphors. Points to think about:

- Science advances by devising new theories. Theories make predictions which can be tested.
- Science also advances by devising new techniques. These may involve new instruments, new mathematical techniques or new ways of thinking.
- Science doesn't always go forwards. Sometimes, whole branches of science must be abandoned.

How can these points be built into the metaphors?

Showing the film

The film is available in 2 versions from the website: the original version, and a special 'Classroom Edit', which break the films into themed sections with spaces in between for easy pausing.

The original version of the film can be shown straight through and uninterrupted. This will allow students to start recognising the different personalities involved.

Subsequently, the 'Classroom edit' can be shown in sections (see Summary below), with a discussion of the main points arising after each section.

Before showing the film, you may find it helpful to your students to explain the terms listed in the glossary below. (They appear in the first 4 minutes or so of the film.)

Glossary

LHC: The Large Hadron Collider, the particle accelerator at CERN (Geneva) which is now producing its first results.

Standard Model: The fundamental model of physics which says that matter is made up of just a few fundamental particles (quarks and leptons) which interact via four fundamental forces.

ICHEP: The International Conference on High Energy Physics, held every other year.

Tevatron: A particle accelerator in the US, older than the LHC and capable of lower energies.

Higgs: The particle, postulated in the Standard Model, which can explain why matter has mass – but does it exist? The LHC may find the answer.

Classroom Edit Summary

Gavin Salam, theoretical physicist, CERN

Jon Butterworth, experimental physicist, University College London

Adam Davidson, research student, University College London

0:00	Data	Jon and Adam are on their way to a conference in Paris. They hope to hear some of the first data from the LHC. Jon suggests that the Standard Model may soon need to be revised.
0:50	Conference	The ICHEP conference in Paris. Adam and Jon are reviewing the programme of talks. Gavin explains that the rumour of exciting results from the Tevatron accelerator is probably unfounded. The LHC is taking over from the Tevatron because it can produce collisions with higher energies.
3:12	First results: ATLAS experiment	In a conference session, the first results from the ATLAS team at the LHC are reported.
3:54	Sarkozy	President Sarkozy of France addresses the conference, warning of the threats to science.
4:43	Conference reception	Scientists meet for a social occasion in the natural history museum. They talk about how they see science and why it is important to continue developing new scientific ideas.
5:55	Moving on	Gavin is moving from Paris to Geneva. He explains that particle accelerators with

		millions of billions more energy are needed to answer today's big questions.
7:05	Final exam	Adam faces the examiners at the end of his PhD course. He discusses his uncertain future.
8:41	Science cuts	The UK government has announced reductions in the scientific research budget. At the demo, Jon explains that the UK is strong in science and that he doesn't want to see that destroyed.
11:00	END	