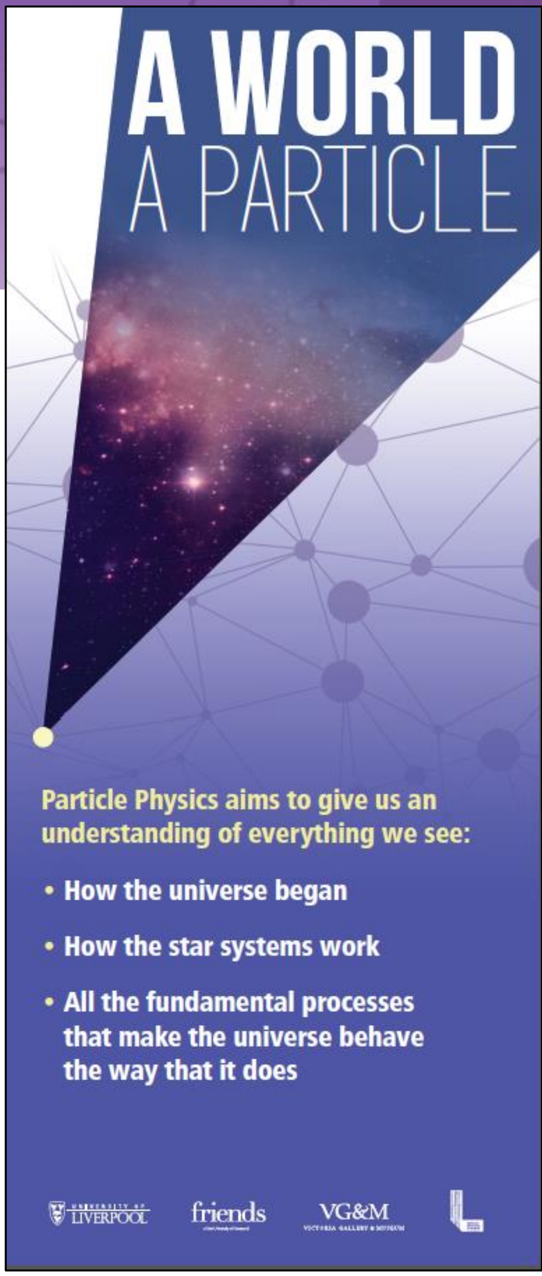
Large Print Guide

A WORLD A PARTICLE

Particle Physics aims to give us an understanding of everything we see:

- How the universe began
- How the star systems work
- All the fundamental processes that make the universe behave the way that it does



Demistification Zone

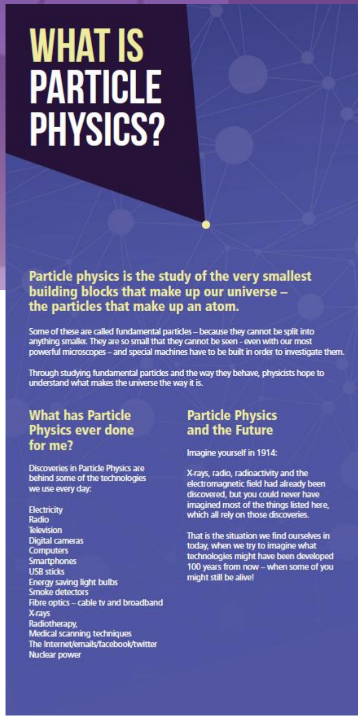
(The Side Rooms)

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

From main doors to end, left to right.

WHAT IS PARTICLE PHYSICS?



Particle physics is the study of the very smallest building blocks that make up our universe – the particles that make up an atom.

Some of these are called fundamental particles – because they cannot be split into anything smaller. They are so small that they cannot be seen – even with our most powerful microscopes – and special machines have to be built in order to investigate them. Through studying fundamental particles and the way they behave, physicists hope to understand what makes the universe the way it is.

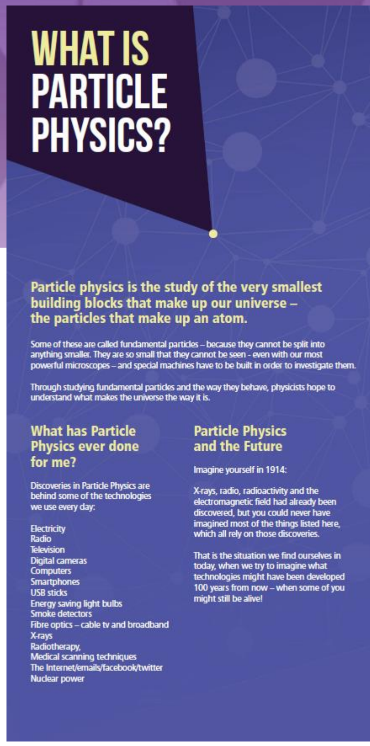
Particle Physics and the Future

Imagine yourself in 1914:

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

X-rays, radio, radioactivity and the electromagnetic field had already been discovered, but you could never have imagined most of the things listed here, which all rely on those discoveries. That is the situation we find ourselves in today, when we try to imagine what technologies might have been developed 100 years from now – when some of you might still be alive!



What has Particle Physics ever done for me?

Discoveries in Particle Physics are behind some of the technologies we use every day:

Electricity

Radio

Television

Digital cameras

Computers

Smartphones

USB sticks

Energy saving light bulbs

Smoke detectors

Fibre optics – cable tv and broadband

X-rays

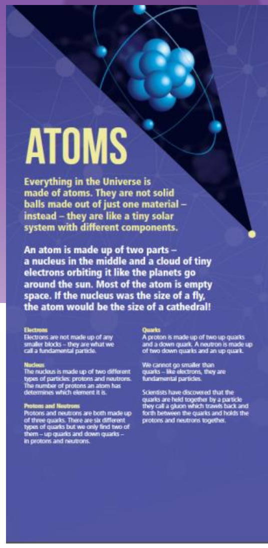
Radiotherapy,

Medical scanning techniques

The Internet/emails/facebook/twitter

Nuclear power

ATOMS



Everything in the Universe is made of atoms. They are not solid balls made out of just one material – instead – they are like a tiny solar system with different components. An atom is made up of two parts – a nucleus in the middle and a cloud of tiny electrons orbiting it like the planets go around the sun. Most of the atom is empty space. If the nucleus was the size of a fly, the atom would be the size of a cathedral!

Electrons – Electrons are not made up of any smaller blocks – they are what we call a fundamental particle.

Nucleus

The nucleus is made up of two different types of particles: protons and neutrons. The number of protons an atom has determines which element it is.

Protons and Neutrons

Protons and neutrons are both made up of three quarks. There are six different types of quarks but we only find two of them – up quarks and down quarks – in protons and neutrons.

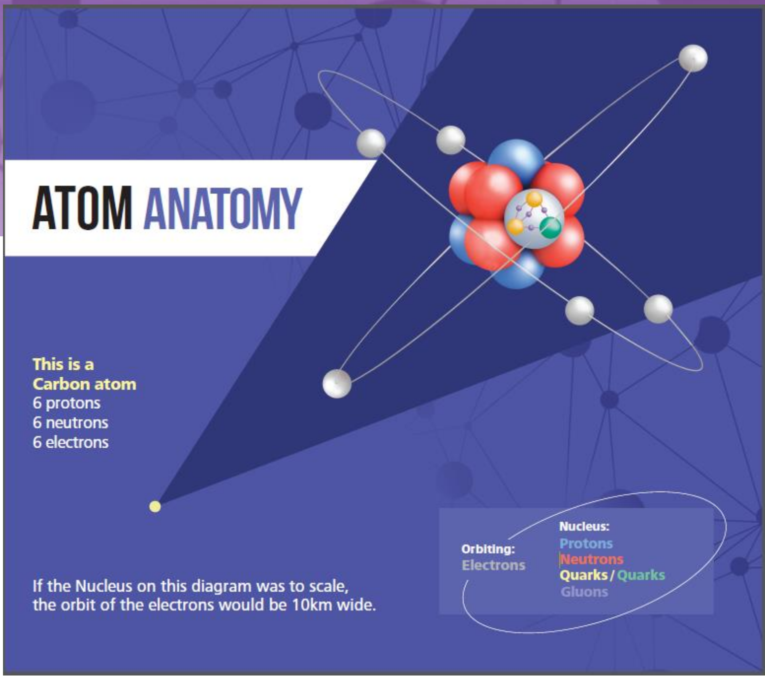
UNIVERSITY OF LIVERPOOL

VG&M VICTORIA GALLERY & MUSEUM

Quarks

A proton is made up of two up quarks and a down quark. A neutron is made up of two down quarks and an up quark. We cannot go smaller than quarks – like electrons, they are fundamental particles. Scientists have discovered that the quarks are held together by a particle they call a gluon which travels back and forth between the quarks and holds the protons and neutrons together.

ATOM ANATOMY



This is a Carbon atom:

6 protons

6 neutrons

6 electrons

If the Nucleus on this diagram was to scale, the orbit of the electrons would be 10km wide.

Orbiting:

Electrons

Nucleus:

Protons

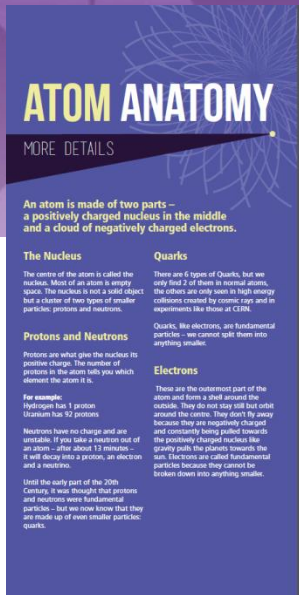
Neutrons

Quarks / Quarks

Gluons

ATOM ANATOMY

MORE DETAILS


ATOM ANATOMY

MORE DETAILS

An atom is made of two parts – a positively charged nucleus in the middle and a cloud of negatively charged electrons.

The Nucleus

The centre of the atom is called the nucleus. Most of an atom is empty space. The nucleus is not a solid object but a cluster of two types of smaller particles: protons and neutrons.

Protons and Neutrons

Protons are what give the nucleus its positive charge. The number of protons in the atom tells you which element the atom it is.

For example:
Hydrogen has 1 proton
Uranium has 92 protons

Neutrons have no charge and are unstable. If you take a neutron out of an atom – after about 13 minutes – it will decay into a proton, an electron and a neutrino.

Until the early part of the 20th Century, it was thought that protons and neutrons were fundamental particles – but we now know that they are made up of even smaller particles: quarks.

Quarks

There are 6 types of Quarks, but we only find 2 of them in normal atoms, the others are only seen in high energy collisions created by cosmic rays and in experiments like those at CERN.

Quarks, like electrons, are fundamental particles – we cannot split them into anything smaller.

Electrons

These are the outermost part of the atom and form a shell around the outside. They do not stay still but orbit around the centre. They don't fly away because they are negatively charged and constantly being pulled towards the positively charged nucleus like gravity pulls the planets towards the sun. Electrons are called fundamental particles because they cannot be broken down into anything smaller.

An atom is made of two parts – a positively charged nucleus in the middle and a cloud of negatively charged electrons.

The Nucleus

The centre of the atom is called the nucleus. Most of an atom is empty space. The nucleus is not a solid object but a cluster of two types of smaller particles: protons and neutrons.

Protons and Neutrons

Protons are what give the nucleus its positive charge. The number of protons in the atom tells you which element the atom it is.

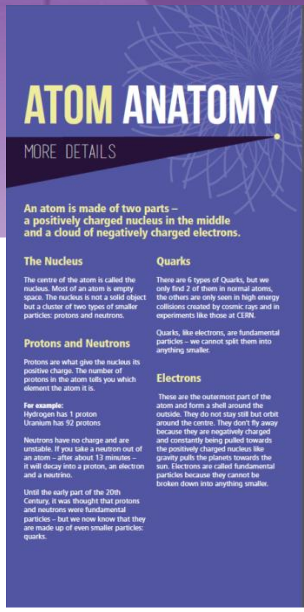
For example:

UNIVERSITY OF LIVERPOOL

VG&M VICTORIA GALLERY & MUSEUM

Hydrogen has 1 proton

Uranium has 92 protons



Neutrons have no charge and are unstable. If you take a neutron out of an atom – after about 13 minutes – it will decay into a proton, an electron and a neutrino.

Until the early part of the 20^{th} Century, it was thought that protons and neutrons were fundamental particles – but we now know that they are made up of even smaller particles:
quarks.

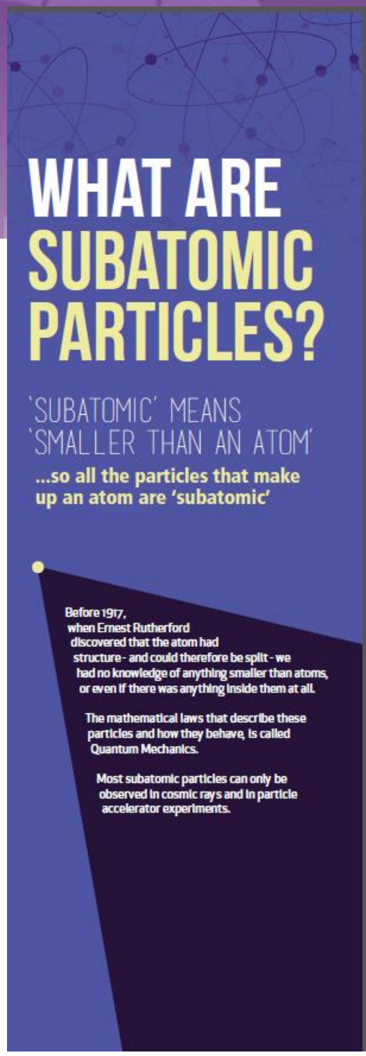
Quarks

There are 6 types of Quarks, but we only find 2 of them in normal atoms, the others are only seen in high energy collisions created by cosmic rays and in experiments like those at CERN. Quarks, like electrons, are fundamental particles – we cannot split them into anything smaller.

Electrons

These are the outermost part of the atom and form a shell around the outside. They do not stay still but orbit around the centre. They don't fly away because they are negatively charged and constantly being pulled towards the positively charged nucleus like gravity pulls the planets towards the sun. Electrons are called fundamental particles because they cannot be broken down into anything smaller.

WHAT ARE SUBATOMIC PARTICLES



‘SUBATOMIC’ MEANS ‘SMALLER THAN AN ATOM’

...so all the particles that make up an atom are ‘subatomic’

Before 1917, when Ernest Rutherford discovered that the atom had structure – and could therefore be split – we had no knowledge of anything smaller than atoms, or even if there was anything inside them at all.

The mathematical laws that describe these particles and how they behave, is called Quantum Mechanics.

Most subatomic particles can only be observed in cosmic rays and in particle accelerator experiments.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

FUNDAMENTAL PARTICLES

FUNDAMENTAL PARTICLES

Fundamental particles are the smallest things that we know about. They have no detectable internal structure and cannot be broken down into anything smaller. There are two different types of fundamental particles: fermions and bosons.

Fermions – the particles that make up matter

There are two different groups of fermions: quarks and leptons.

Quarks – found inside the atomic nucleus
There are six different types of quarks. By far the most common of these are the two that are found in protons and neutrons: Up quarks and Down quarks.

The other four quarks are called Top, Bottom, Strange and Charm and are only produced when particles collide with very high energy, such as in particle accelerators or cosmic rays from space.

Leptons – found outside the atomic nucleus
There are also six different types of leptons. The most common is the Electron, which orbits around the nucleus to make an atom.

The other types of leptons are Muons and Taus and three different kinds of Neutrinos.

Muons and Taus are similar to Electrons but heavier and only found in high energy collisions.

Neutrinos are the lightest particles we know about - so light that we cannot yet measure their mass accurately. The electric and nuclear forces don't affect them and they pass through matter without leaving a trace. In the time it takes you to read this sentence, several trillion Neutrinos will have passed through you.

Bosons – the particles which carry forces

There are five types of bosons: photons, gluons, W and Z bosons and the Higgs boson.

Photons transmit the electromagnetic force. Every time we see something it is because photons from that object have hit our eye.

Gluons transmit the strong nuclear force, which is the force that holds quarks together to form protons and neutrons and holds the protons and neutrons together to make the nucleus.

W and Z bosons both transmit the weak nuclear force, which is responsible for certain types of radioactive decay.

The Higgs boson transmits the Higgs field, which gives the W and Z bosons mass. It is also believed to give mass to the fermions – but the details are still unclear.

When we look at forces on a subatomic level we see that they do not act on things continuously but instead a particle is given a little nudge every time a force-carrying boson arrives.

This is all still work in progress'

Fundamental particles are the smallest things that we know about. They have no detectable internal structure and cannot be broken down into anything smaller. There are two different types of fundamental particles: fermions and bosons.

Fermions – the particles that make up matter

There are two different groups of fermions: quarks and leptons.

Quarks – found inside the atomic nucleus There are six different types of quarks. By far the most common of these are the two that are found in protons and neutrons: Up quarks and Down quarks.

The other four quarks are called Top, Bottom, Strange and Charm and are only produced when particles collide with very high energy, such as in particle accelerators or cosmic rays from space.


FUNDAMENTAL PARTICLES

Fundamental particles are the smallest things that we know about. They have no detectable internal structure and cannot be broken down into anything smaller. There are two different types of fundamental particles: fermions and bosons.

Fermions – the particles that make up matter

There are two different groups of fermions: quarks and leptons.

Quarks – found inside the atomic nucleus
There are six different types of quarks. By far the most common of these are the two that are found in protons and neutrons: Up quarks and Down quarks.

The other four quarks are called Top, Bottom, Strange and Charm and are only produced when particles collide with very high energy, such as in particle accelerators or cosmic rays from space.

Leptons – found outside the atomic nucleus
There are also six different types of leptons. The most common is the Electron, which orbits around the nucleus to make an atom.

The other types of leptons are Muons and Taus and three different kinds of Neutrinos.

Muons and Taus are similar to Electrons but heavier and only found in high energy collisions.

Neutrinos are the lightest particles we know about - so light that we cannot yet measure their mass accurately. The electric and nuclear forces don't affect them and they pass through matter without leaving a trace. In the time it takes you to read this sentence, several trillion Neutrinos will have passed through you.

Bosons – the particles which carry forces

There are five types of bosons: photons, gluons, W and Z bosons and the Higgs boson.

Photons transmit the electromagnetic force. Every time we see something it is because photons from that object have hit our eye.

Gluons transmit the strong nuclear force, which is the force that holds quarks together to form protons and neutrons and holds the protons and neutrons together to make the nucleus.

W and Z bosons both transmit the weak nuclear force, which is responsible for certain types of radioactive decay.

The Higgs boson transmits the Higgs field, which gives the W and Z bosons mass. It is also believed to give mass to the fermions – but the details are still unclear.

When we look at forces on a subatomic level we see that they do not act on things continuously but instead a particle is given a little nudge every time a force-carrying boson arrives.

This is all still work in progress'

Leptons – found outside the atomic nucleus

There are also six different types of leptons. The most common is the Electron, which orbits around the nucleus to make an atom.

The other types of leptons are Muons and Taus and three different kinds of Neutrinos. Muons and Taus are similar to Electrons but heavier and only found in high energy collisions.

Neutrinos are the lightest particles we know about – so light that we cannot yet measure their mass accurately. The electric and nuclear forces don't affect them and they pass through matter without leaving a trace. In the time it takes you to read this sentence, several trillion Neutrinos will have passed through you.

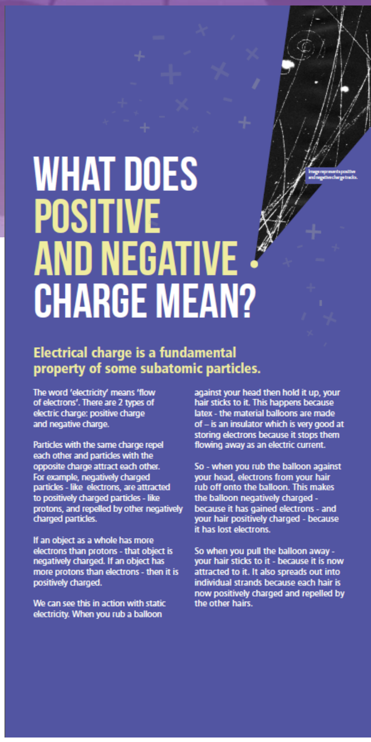
Bosons – the particles which carry force

There are five types of bosons: photons, gluons, W and Z bosons and the Higgs boson. Photons transmit the electromagnetic force. Every time we see something it is because photons from that object have hit our eye.

Gluons transmit the strong nuclear force, which is the force that holds quarks together to form protons and neutrons and holds the protons and neutrons together to make the nucleus. W and Z bosons both transmit the weak nuclear force, which is responsible for certain types of radioactive decay. The Higgs boson transmits the Higgs field, which gives the W and Z bosons mass. It is also believed to give mass to the fermions – but the details are still unclear. When we look at forces on a subatomic level we see that they do not act on things continuously but instead a particle is given a little nudge every time a force carrying boson arrives.

This is all still ‘work in progress’

WHAT DOES POSITIVE AND NEGATIVE CHARGE MEAN?



WHAT DOES
POSITIVE
AND NEGATIVE
CHARGE MEAN?

Electrical charge is a fundamental property of some subatomic particles.

The word ‘electricity’ means ‘flow of electrons’. There are 2 types of electric charge: positive charge and negative charge.

Particles with the same charge repel each other and particles with the opposite charge attract each other. For example, negatively charged particles - like electrons, are attracted to positively charged particles - like protons, and repelled by other negatively charged particles.

If an object as a whole has more electrons than protons - that object is negatively charged. If an object has more protons than electrons - then it is positively charged.

We can see this in action with static electricity. When you rub a balloon against your head then hold it up, your hair sticks to it. This happens because latex - the material balloons are made of – is an insulator which is very good at storing electrons because it stops them flowing away as an electric current.

So - when you rub the balloon against your head, electrons from your hair rub off onto the balloon. This makes the balloon negatively charged - because it has gained electrons - and your hair positively charged - because it has lost electrons.

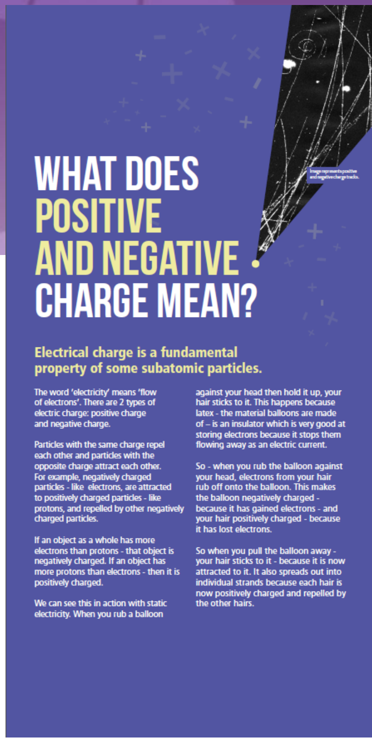
So when you pull the balloon away - your hair sticks to it - because it is now attracted to it. It also spreads out into individual strands because each hair is now positively charged and repelled by the other hairs.

Electrical charge is a fundamental property of some subatomic particles.

The word ‘electricity’ means ‘flow of electrons’. There are 2 types of electric charge: positive charge and negative charge.

Particles with the same charge repel each other and particles with the opposite charge attract each other. For example, negatively charged particles – like electrons, are attracted to positively charged particles – like protons, and repelled by other negatively charged particles.

If an object as a whole has more electrons than protons – that object is negatively charged. If an object has more protons than electrons – then it is positively charged.



WHAT DOES POSITIVE AND NEGATIVE CHARGE MEAN?

Electrical charge is a fundamental property of some subatomic particles.

The word 'electricity' means 'flow of electrons'. There are 2 types of electric charge: positive charge and negative charge.

Particles with the same charge repel each other and particles with the opposite charge attract each other. For example, negatively charged particles - like electrons, are attracted to positively charged particles - like protons, and repelled by other negatively charged particles.

If an object as a whole has more electrons than protons - that object is negatively charged. If an object has more protons than electrons - then it is positively charged.

We can see this in action with static electricity. When you rub a balloon against your head then hold it up, your hair sticks to it. This happens because latex - the material balloons are made of – is an insulator which is very good at storing electrons because it stops them flowing away as an electric current.

So - when you rub the balloon against your head, electrons from your hair rub off onto the balloon. This makes the balloon negatively charged - because it has gained electrons - and your hair positively charged - because it has lost electrons.

So when you pull the balloon away - your hair sticks to it - because it is now attracted to it. It also spreads out into individual strands because each hair is now positively charged and repelled by the other hairs.

WHAT DOES POSITIVE AND NEGATIVE CHARGE MEAN?

We can see this in action with static electricity. When you rub a balloon against your head then hold it up, your hair sticks to it. This happens because latex – the material balloons are made of – is an insulator which is very good at storing electrons because it stops them flowing away as an electric current.

So – when you rub the balloon against your head, electrons from your hair rub off onto the balloon. This makes the balloon negatively charged – because it has gained electrons – and your hair positively charged – because it has lost electrons.

So when you pull the balloon away – your hair sticks to it – because it is now attracted to it. It also spreads out into individual strands because each hair is now positively charged and repelled by the other hairs.

WHY DO QUARKS HAVE FUNNY NAMES?

The names are whimsical inventions of physicists who – once they suspected their existence – had to call them something in order to talk about them!

• The quark model is the idea that particles are made up of different combinations of just 2 or 3 quarks.

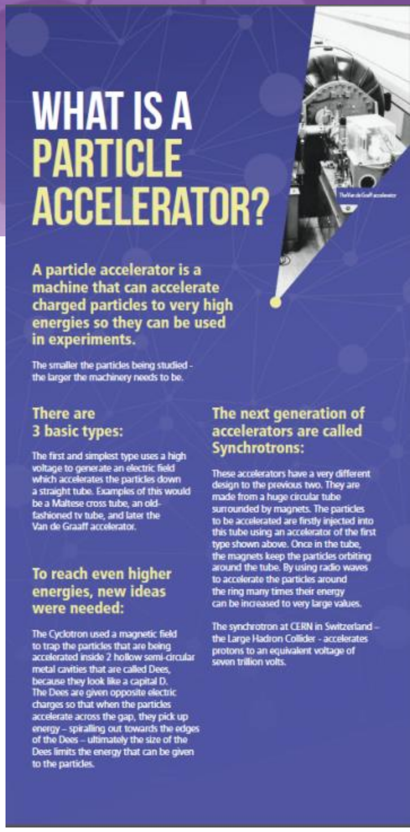
• 3 quarks – called up, down, and strange – was an idea independently proposed by physicists Murray Gell-Mann and George Zweig in 1964. Initially Gell-Mann called them "kworks" and Zweig called them "aces". Gell-Mann was undecided on an actual spelling for the term "kwork", until he found the word quark in James Joyce's book Finnegans Wake. "Three quarks for Muster Mark! Sure he has not got much of a bark And sure any he has it's all beside the mark." As this sounded a bit like 'kwork' he adopted the spelling "quark" which has stuck ever since.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

- In the late 1960s, the existence of a fourth quark was predicted, which was named charm. Physicist Sheldon Lee Glashow is quoted as saying, "We called our construct the 'charmed quark', for we were fascinated and pleased by the symmetry it brought to the sub-nuclear world."

There is a cheese called quark but this has nothing to do with these names!



WHAT IS A PARTICLE ACCELERATOR?

A particle accelerator is a machine that can accelerate charged particles to very high energies so they can be used in experiments.

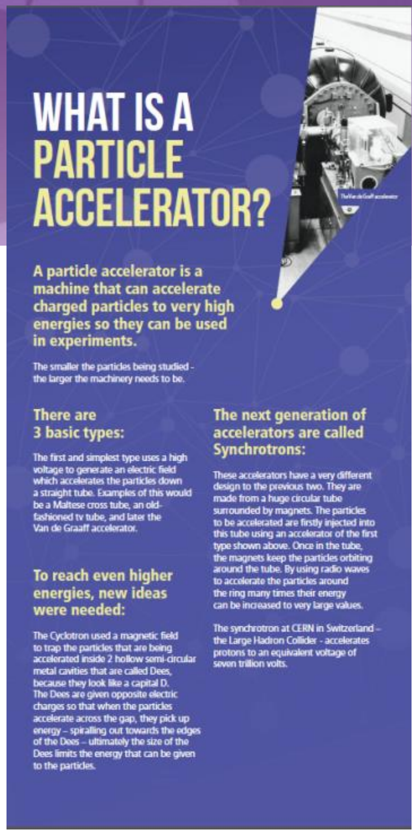
The smaller the particles being studied – the larger the machinery needs to be.

There are 3 basic types:

The first and simplest type uses a high voltage to generate an electric field which accelerates the particles down a straight tube. Examples of this would be a Maltese cross tube, an oldfashioned tv tube, and later the Van de Graaff accelerator.

To reach even higher energies, new ideas were needed:

The Cyclotron used a magnetic field to trap the particles that are being accelerated inside 2 hollow semi-circular metal cavities that are called Dees, because they look like a capital D. The Dees are given opposite electric charges so that when the particles accelerate across the gap, they pick up energy – spiralling out towards the edges of the Dees – ultimately the size of the Dees limits the energy that can be given to the particles.



The next generation of accelerators are called Synchrotrons:

These accelerators have a very different design to the previous two. They are made from a huge circular tube surrounded by magnets. The particles to be accelerated are firstly injected into this tube using an accelerator of the first type shown above. Once in the tube, the magnets keep the particles orbiting around the tube. By using radio waves to accelerate the particles around the ring many times their energy can be increased to very large values. The synchrotron at CERN in Switzerland – the Large Hadron Collider – accelerates protons to an equivalent voltage of seven trillion volts.

THE EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

The Large Hadron Collider at CERN is the largest and most powerful particle accelerator ever built.

It was designed and built in collaboration with over 10,000 scientists and engineers from over 100 countries. Physicists from the University of Liverpool have been involved in the project from its inception.

Physicists hope that the experiments at CERN will give us new insight into the fundamental nature of the Universe.

The name CERN is from the acronym for the French ‘Conseil Européen pour la Recherche Nucléaire’ - or European Council for Nuclear Research - a provisional body founded in 1952 with the mandate of establishing a world-class physics research organisation in Europe. At that time, pure physics research concentrated on understanding the inside of the atom, hence the word ‘nuclear’. Today, our understanding of matter goes much deeper than the nucleus, and CERN's main area of research is particle physics - the study of the fundamental constituents of matter and the forces acting between them. Because of this, the laboratory operated by CERN is often referred to as the European Laboratory for Particle Physics.

WHAT IS THE HIGGS BOSON

AND WHY IS IT IMPORTANT?

WHAT IS THE HIGGS BOSON

AND WHY IS IT IMPORTANT?

On the 4th July 2012, physicists at CERN announced that they had found a particle that looked and behaved the way they expected a Higgs boson to look and behave. This is the culmination of 50 years of research and is a huge leap forward for science.

In the early 1960s, the first theories about how the universe works started to emerge. However, there was a problem. When physicists used these theories to look at the weak force - one of the forces in the atomic nucleus - they found that it didn't behave as predicted.

The problem was that the weak force only acted over a very short distance whilst early theories said it should act over a large distance. This meant that the bosons - force transmitting particles - that carried the weak force must be very heavy, but these early theories suggested that they should have no mass at all.

Between 1963-64, physicists - including Peter Higgs - had been working to solve this problem. The solution that Peter Higgs proposed was that there was an invisible field - which we now call the Higgs field - across the whole universe. This would act in such a way as to give mass to the weak force bosons - like cosmic treacle that stuck to the particles and made them slow and heavy. This solution potentially solved the problem, and in 1967 it was built into a new theory - called the Standard Model - developed to explain why everything we see around us behaves as it does. But physicists had no way of knowing if they had found the right solution or not.

Fortunately, the Higgs field theory also predicted the existence of another particle, the Higgs boson. Physicists knew that if they found this particle, they would prove that the Higgs field exists and the Standard Model would be verified.

If they didn't find the Higgs boson, then it would mean that the Higgs field theory could be wrong and consequently, the whole of the Standard Model could possibly be wrong!

On the 4th July 2012, physicists at CERN announced that they had found a particle that looked and behaved the way they expected a Higgs boson to look and behave. This is the culmination of 50 years of research and is a huge leap forward for science.

In the early 1960s, the first theories about how the universe works started to emerge. However, there was a problem. When physicists used these theories to look at the weak force – one of the forces in the atomic nucleus – they found that it didn't behave as predicted.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

The problem was that the weak force only acted over a very short distance whilst early theories said it should act over a large distance. This meant that the bosons – force transmitting particles – that carried the weak force must be very heavy, but these early theories suggested that they should have no mass at all.

WHAT IS THE HIGGS BOSON

AND WHY IS IT IMPORTANT?

On the 4th July 2012, physicists at CERN announced that they had found a particle that looked and behaved the way they expected a Higgs boson to look and behave. This is the culmination of 50 years of research and is a huge leap forward for science.

In the early 1960s, the first theories about how the universe works started to emerge. However, there was a problem. When physicists used these theories to look at the weak force - one of the forces in the atomic nucleus - they found that it didn't behave as predicted.

The problem was that the weak force only acted over a very short distance whilst early theories said it should act over a large distance. This meant that the bosons - force transmitting particles - that carried the weak force must be very heavy, but these early theories suggested that they should have no mass at all.

Between 1963-64, physicists - including Peter Higgs - had been working to solve this problem. The solution that Peter Higgs proposed was that there was an invisible field - which we now call the Higgs field - across the whole universe. This would act in such a way as to give mass to the weak force bosons - like cosmic treacle that stuck to the particles and made them slow and heavy. This solution potentially solved the problem, and in 1967 it was built into a new theory - called the Standard Model - developed to explain why everything we see around us behaves as it does. But physicists had no way of knowing if they had found the right solution or not.

Fortunately, the Higgs field theory also predicted the existence of another particle, the Higgs boson. Physicists knew that if they found this particle, they would prove that the Higgs field exists and the Standard Model would be verified.

If they didn't find the Higgs boson, then it would mean that the Higgs field theory could be wrong and consequently, the whole of the Standard Model could possibly be wrong!

Between 1963–64, physicists – including Peter Higgs – had been working to solve this problem. The solution that Peter Higgs proposed was that there was an invisible field – which we now call the Higgs field – across the whole universe. This would act in such a way as to give mass to the weak force bosons – like cosmic treacle that stuck to the particles and made them slow and heavy. This solution potentially solved the problem, and in 1967 it was built into a new theory – called the Standard Model – developed to explain why everything we see around us behaves as it does. But physicists had no way of knowing if they had found the right solution or not.

Fortunately, the Higgs field theory also predicted the existence of another particle, the Higgs boson. Physicists knew that if they found this particle, they would prove that the Higgs field exists and the Standard Model would be verified.

If they didn't find the Higgs boson, then it would mean that the Higgs field theory could be wrong and consequently, the whole of the Standard Model could possibly be wrong!

Large Print Guide

A WORLD A PARTICLE

Particle Physics aims to give us an understanding of everything we see:

- How the universe began
- How the star systems work
- All the fundamental processes that make the universe behave the way that it does

The Display Case

(Start on side with museum door behind you)

From left to right, in Sections, top row then bottom.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

The Greeks

The Greek Philosophers in particular, speculated on the fundamental nature of matter.

Empedocles c. 490–322BC – proposed that all matter was made up of a combination of four elements: earth, air, fire and water.

Democritus c.460–370 BC
Introduced the concept of the atom – the smallest particle into which anything can be broken.

Aristotle c.384–322BC
Introduced a fifth element – aether – and regarded this as a basic building block used in ‘the heavens’.

The Alchemists
200BC – 1700AD

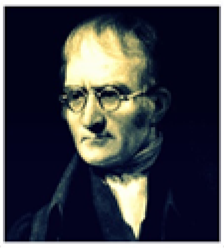
People were aware that some forms of matter could seem to change – when wood burns, it turns to smoke and ash, metal workers could turn ore into copper, bronze and other metals.

This raised the idea that that it might be possible to change one type of object into another. Alchemy was the attempt to find a way of changing base metal into gold. Because of the potential of financial rewards – the alchemists often worked in total secrecy, and recorded their experiments in code.

This in turn meant that any useful science that did come out of their experiments was kept secret – significantly slowing the development of experimental chemistry and physics.

The Early Chemists

Isaac Newton (1643–1727) is remembered as one of the great scientists of all time, and as the founder of scientific method. He produced the theory of gravity, made contributions to optics and invented calculus – but he was also interested in alchemy and carried out many secret experiments in the hope that the theories might be valid.



John Dalton (1766–1844) revived the idea that all matter consisted of tiny particles called atoms. He published the first table of atomic weights in 1803 and developed the theory that atoms could not be created or destroyed, and that chemical reactions are a rearrangement of atoms.

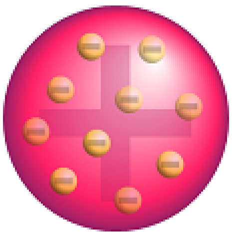
Joseph Proust (1754–1826) experimentally verified that some substances were compounds of different elements, and that the proportions of these elements were fixed in precise ratios. These experiments supported Dalton's ideas.

Dmitri Ivanovich Mendeleyev (1834–1907) arranged the elements that were known at that time into a table – subsequently called the Periodic Table, based on their masses and their chemical properties.

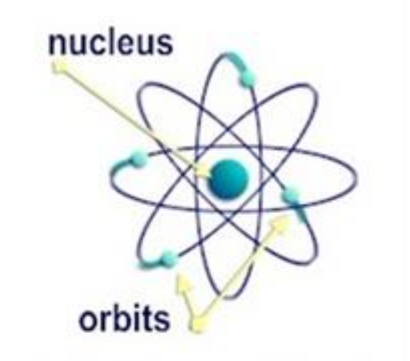
1909

The Geiger-Marsden Experiment – also known as the Rutherford Gold Foil Experiment – was an experiment to prove the structure of the atom.

This experiment was carried out by Hans Geiger and Ernest Marsden whilst under the direction of Ernest Rutherford at the University of Manchester.



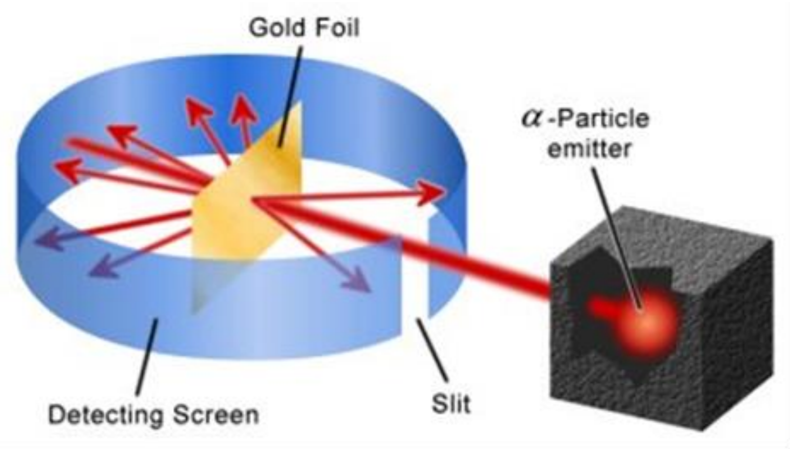
Plum pudding model.



Rutherford's Nuclear Model of the Atom

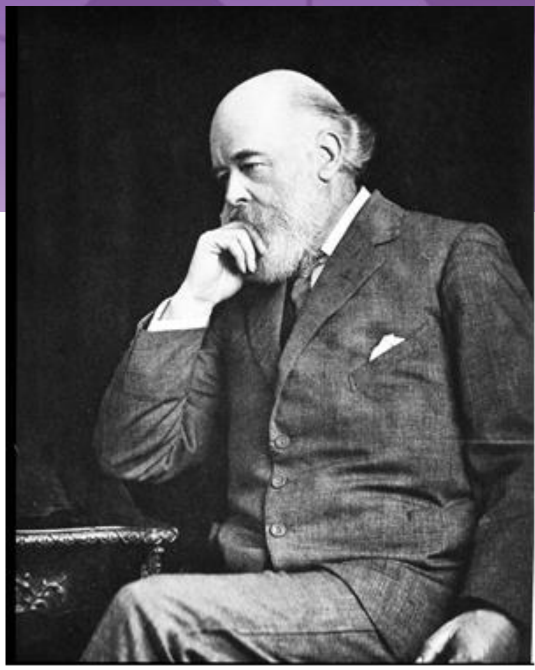
The unexpected result of the experiment demonstrated – for the first time – the existence of the atomic nucleus, replacing the existing theory of the 'plum pudding' model of the atom.

Rutherford famously stated that the result of the experiment was like firing a cannonball at a piece of tissue paper and having it bounce back and hit you.



Oliver Lodge

1851 – 1940

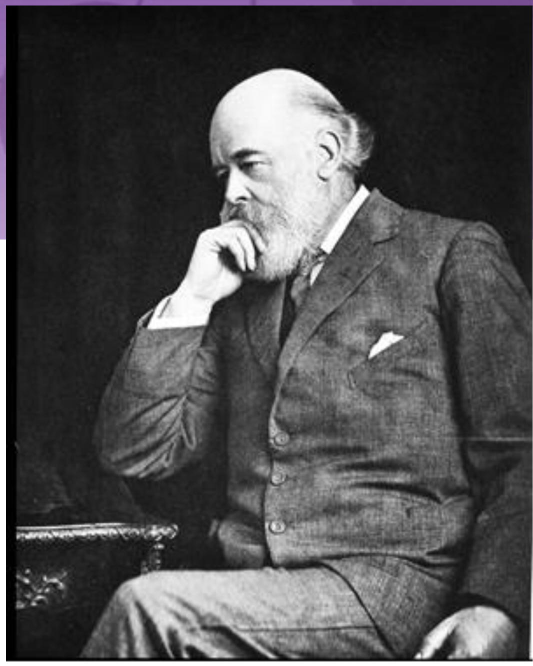


Liverpool's First Professor of Physics 1881 – 1900

It was Oliver Lodge's personal intervention that led to the Victoria Building being one of the first in the country to be built with electric lighting.

He discovered electromagnetic waves (which include light, radio waves and microwaves) travelling along wires in 1888 and went on to develop the first radio – giving the first public demonstration (in Oxford) in 1894 – before the work of Marconi. In Liverpool, he often sent radio signals to his home from the clock tower of this building – which caused complaints as it set off local telephones.

He was one of the first to put the newly discovered x-rays to medical purposes, using them in 1896 to locate a bullet which had become lodged in a boy's hand. The x-ray photographic films he invented reduced the amount of time needed to take an x-ray – from several hours – to minutes, paving the way for the x-rays we have today, and making them much safer.



One of his biggest experiments was an attempt to measure the Earth's drift through the ether. The ether was widely believed to be an invisible substance that occupied all space and through which all waves and energy moved. We now know that a material ether doesn't exist – and Lodge helped take physics towards this conclusion – by showing that the ether couldn't be electrified or magnetised, and that it wasn't pulled along by objects that passed through it. In fact, he couldn't detect it at all.

Like a lot of early physicists, Lodge was very interested in spiritualism – carrying out experiments on people who claimed to be mediums. Because of his work on radio –

and discoveries such as the electromagnetic field, he thought that there might be a physics explanation behind their claims.

He left the University of Liverpool in 1900 to become the Principal of the new University of Birmingham.

Rectifier Tube

This tube was invented by Sir Oliver Lodge. The rectifier valves prevented inverse voltage, which had a negative effect on the pressure in the ion tube. The valves were used in a series with the x-ray tube.

The distinctive red coloured glass is the result of a specific exhaustion method which keeps the vacuum stable under all conditions.

A pear-shaped glass Crookes tube incorporating a metallic Maltese cross.

This was used to demonstrate the linear path of electrons emitted by the cathode. A similar pear shaped gas tube (without the cross) was used by Rontgen in 1896 when he discovered x-rays.

The following year at Liverpool Sir Oliver Lodge designed the first metal (aluminium) x-ray tube.

What are X-Rays?

X-rays were an accidental discovery which resulted from studying another kind of radiation, cathode rays, in tubes similar to the one displayed above.

When the tubes were evacuated and a high voltage applied between the two electrodes, an invisible radiation was produced which caused the glass near the Maltese cross to glow green – with the cross casting a shadow.

Eventually the cathode rays were shown to be the particles now known as electrons but before this, in 1895, W.K. Rontgen found that by striking the glass they produced another invisible kind of radiation (X-rays) which caused crystals placed outside the tube to glow.

This is a copy of the first X-ray ever taken – of Rontgen's wife's hand.

UNIVERSITY OF LIVERPOOL

VG&M

VICTORIA GALLERY & MUSEUM

The nature of both cathode rays and X-rays was a major discussion topic at the British Association meeting in Liverpool in 1896.

When Oliver Lodge gave a public lecture on X-rays in this building, almost 1000 people squeezed into the lecture theatre, and he had to push his way past people on the stairs to get in.

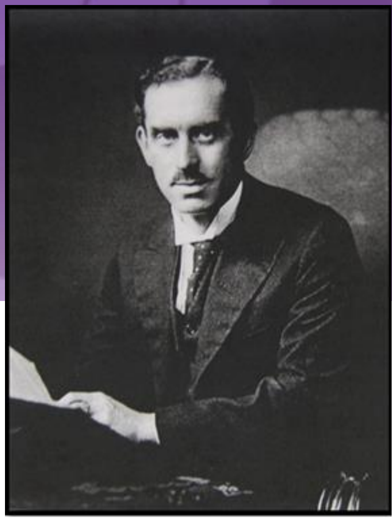
The First Radiology Department

In 1896 Orthopaedic surgeon, Sir Robert Jones, asked Oliver Lodge to assist with the X-ray of a boy who had shot himself in the hand. The bullet was identified in the third carpo-metacarpal joint.
Jones saw how helpful X-rays had been in finding the pellet and asked Thurstan Holland to establish a new X-ray department at Royal Southern Hospital in 1896. That year alone - Holland did 261 clinical radiological examinations at the Southern and an account of this work was given to the Liverpool Medical Institution in 1937.

See our X-ray Interactive using copies of Thurstan Holland's X-rays and dress up as a radiologist!

Charles Barkla

1877 – 1944



Nobel Prize for Physics in 1917

Born and educated in the North West, Charles Barkla was Oliver Lodge’s most brilliant student, and Liverpool's First Nobel Prize Winning Physicist. He received the award in recognition of his discovery of the relationship between X-rays and atomic structure.

Barkla was one of the first scientists to help reveal the true nature of X-rays and – through later applications of his findings – the nature of the atom. Barkla’s discovery showed that every different type of atom emits different wavelengths of X-rays which allows us to tell them apart. This is called X-ray spectography. Today, X-ray spectography is being used on Mars by the Mars Rovers – robots sent there to explore and analyse the Martian soil.

Barkla's work helped to show that the number of electrons in an atom is the same as the number of protons – which led to the concept of an atomic number – and better understanding of the Periodic Table. Before this, little was known about the

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

properties of elements or the significance of their atomic numbers.

Barkla's work became the cornerstone upon which a greater understanding of atomic structure was built. His later research also served as a starting point for the development of quantum mechanics – the mathematical model developed to explain complex atomic theories.

The Nobel Medal for Physics

The name of the Nobel Laureate is engraved on the plate below the figures, and the text 'REG. ACAD. SCIENT. SUEC.' represents the Royal Swedish Academy of Sciences.

The Nobel Medal for Physics was designed by Swedish sculptor and engraver Erik Lindberg and represents Nature in the form of a goddess resembling Isis, emerging from the clouds and holding in her arms a cornucopia. The veil which covers her cold and austere face is held up by the Genius of Science.

The inscription reads: Inventas vitam juvat excoluisse per artes loosely translated as ‘And they who bettered life on earth by their newly found mastery.’

The words are taken from the Aeneid, the 6th song, verse 663:

Lo, God-loved poets, men who spake things worthy Phoebus' heart; and they who bettered life on earth by new-found mastery.

The Aeneid is a Latin epic, written by the Roman poet Virgil between 29 and 19BC. It tells the story of Aeneas, a survivor of the Trojan War, who makes an epic journey from his native Troy (in modern Turkey) to Italy, where he becomes the ancestor to the Romans.

Virgil expanded upon the disconnected tales of Aeneas' wanderings and his vague association with the foundation of Rome, and fashioned it into a compelling founding myth - or national epic - that all at once managed to link Rome to the legends of Troy, glorify traditional Roman virtues and legitimise the rule of the

Emperor Augustus as a descendant of the founders, heroes and gods of Rome and Troy.

The hero Aeneas was already known to Greco-Roman legend and myth, having been a character in the Iliad – Homer's tale of the Trojan War – composed in the 8th century BC.

James Chadwick

1891– 1974

Nobel Prize for Physics in 1935

James Chadwick Studied Physics at Manchester University under Ernest Rutherford, where he conducted research into gamma rays and radiation. In 1913, he won a scholarship to study beta radiation under Hans Geiger. After the outbreak of war, he was interned in Germany, but was allowed to continue his research in a makeshift lab in the internment camp.

When Rutherford moved to Cambridge in 1919, Chadwick was invited to follow him. Chadwick's work focussed on the Atomic nucleus, which many physicists believed to be composed of protons and electrons. After acquiring some polonium, Chadwick was able to prove the existence of the neutron and he wrote several articles on this in 1932.

He was awarded the 1935 Nobel Prize for his discovery of the Neutron.

By 1934, Chadwick was keen to move forward with the new technology that he believed was necessary to make further new discoveries, but Rutherford was unwilling to make the size of financial investment that was necessary to build a Cyclotron.in 1935, after being promised the necessary funding for a cyclotron, Chadwick came to Liverpool as professor of physics. Chadwick transformed the Liverpool Physics Department into one which was able to stand comparison with any in the world in the fields of nuclear and high-energy particle physics.
Chadwick led the UK team at the Manhattan Project. Among many honours, he received a knighthood in 1945, and was made Companion of Honour for services to science in 1970.

Quotes:

James Chadwick, in 1941,
'I wish I could tell you that the bomb is not going to work, but I am 90% sure that it will'.

Sir James Mountford, Vice Chancellor of the University, speaking after Chadwick’s death:

‘Whatever the future of our University may be there is one glory that is imperishable: James Chadwick once lived and worked amongst us’.

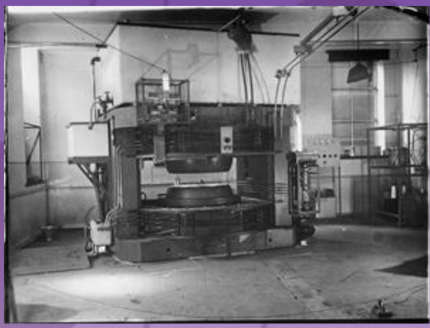
Sphinthariscope (1924)

Made by Adam Hilger Ltd for James Chadwick

Used by Chadwick during his early experimental work on the structure of the nucleus, this is a development of the Spinthariscope – a device invented by William Crookes in 1903 which showed the presence of alpha particles via the individual flashes of light they produce when they interact with a target made of zinc sulphide.

It is effectively low power microscope for observation of the light flashes – which has its optical path turned through a right angle. This enables observations to be made without the radiation flux from the experiment entering the eye of the observer, so reducing the risk of radiation damage to the eyes.

Chadwick and the 37” Cyclotron



Chadwick came to Liverpool in 1935 and immediately initiated a new research programme in nuclear physics.

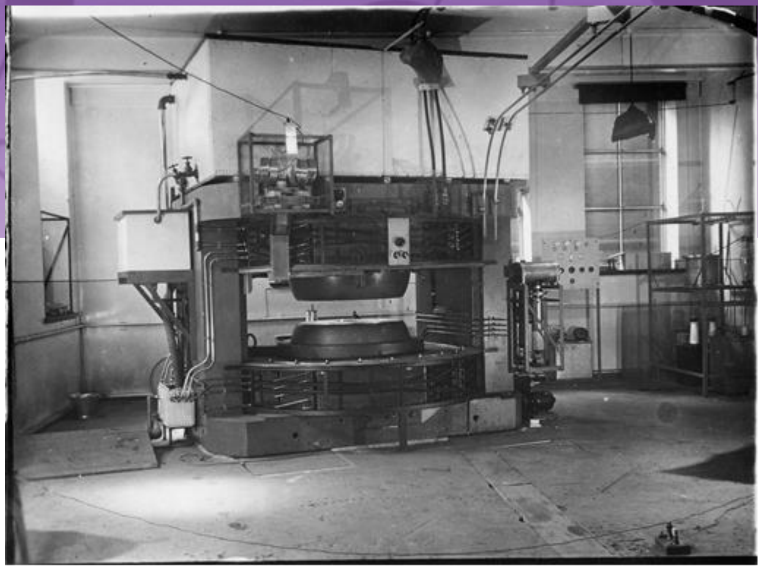
At that time the main experimental technique used in nuclear studies involved the study of the process which occurred when a beam of nuclear or sub-nuclear particles interacted with a nuclear target. In the early stages of this work the beams used were those produced by naturally occurring nuclear particles (alpha particles) from radioactive materials. This was the technique used by Chadwick for his Nobel Prize winning experiment.

In 1932 it was discovered that beams of nuclear particles could be produced artificially with an accelerator which allowed the structure of atomic nuclei to be studied in much greater detail. Chadwick realised the importance of this development and obtained funding for the construction of a cyclotron, a type of nuclear particle accelerator which had recently been developed in the USA. This device required a large and expensive electromagnet which made the particles travel in circular orbits where they were accelerated by applying a large number of successive electrical impulses.

The 37 inch (maximum orbit diameter) cyclotron, which was installed in the basement of the George Holt building, became operational in 1939.

The most important parameter of an accelerator is the energy of the particles in the beam it produces – this is normally measured in eV (electron volts). This cyclotron could accelerate deuterons, a nucleus containing one proton and one neutron, to an energy of 8 MeV (million electron volts).

The 37” Cyclotron



James Chadwick was encouraged to come to Liverpool by the promise of the facilities and funding necessary to build a Cyclotron – at the time this was at the cutting edge of science and was only the second to become operational in the country. He started recruiting staff to work with the cyclotron as soon as he arrived in 1935. The parts were made in Manchester by Metropolitan Vickers in 1937/38, and it became operational in September 1939.

After all the effort that Chadwick and his team had put into getting the Cyclotron operational, the medical research programme he had originally planned for it was interrupted by the war. Once the process of neutron induced nuclear fission was discovered – national priority was given to study of the possibility of producing a nuclear weapon. By 1941, as a result of the Cyclotron experiments, Liverpool physicists had calculated with remarkable accuracy the amount of Uranium needed for a bomb to explode. Their results are within 1% of the calculations used today.

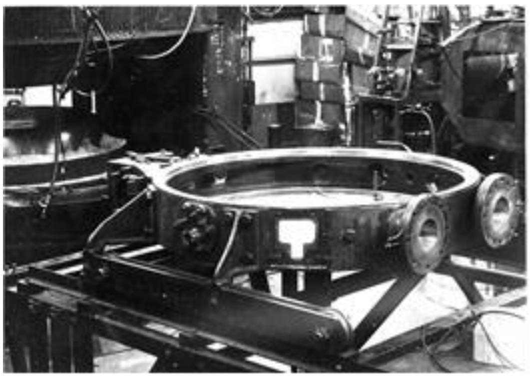
After the war the Cyclotron was refurbished and continued to do valuable work for another decade. In 1952 it was relocated to the Nuclear Research Laboratory on Mount Pleasant.

The 37” Cyclotron

A Cyclotron uses a magnetic field to trap the particles that are being accelerated inside 2 hollow semi-circular metal cavities - called Dees because they look like a capital D.

The Dees are given opposite electric charges to each other - one positive - one negative. The particles accelerate across the gap between the Dees and pick up energy. Once inside the Dees the particle is not accelerated but is moved in a curved path by the magnetic field. After a short time, the particle arrives back at the gap between the Dees. But by now the charges on the Dees have been swapped over so the particle is again accelerated across the gap.

By repeating this process many times the particles can be given much more energy than was possible in the first design of accelerators. However as the particle gains energy – it spirals outwards towards the edges of the Dees – and ultimately this limits the energy that can be given to the particles.



James Chadwick's Geiger Counter Made for him by Geiger

The Geiger tube (Geiger – Muller tube) is a metal tube filled with an inert gas
(typically argon) which has a thin wire electrode along its centre.

When an alpha or beta particle enters the tube it generates ionisation in the gas – which is the process of the separation of electrons from their parent atoms.

A high voltage (~ 1000V) is applied to the electrode during operation which accelerates the electrons towards the electrode and generates an ionisation avalanche in the gas. This produces an electrical pulse when either an alpha or beta particle enters the tube – which can be fed to some form of counting mechanism. Alpha particles have a very short range in matter typically a few cms in air and a fraction of 1mm in solid materials. This tube therefore has a very thin window at one end (probably made of mica).

A Geiger counter can be constructed in a compact and portable form – which has been used extensively for detecting and monitoring the presence of radioactive materials in the environment. One mode of operation is to convert the pulses to sound so monitoring the presence of radioactivity via the traditional audible click rate.

1939 – A Fateful Year

At the same time as Britain and Germany were preparing for war, nuclear fission was discovered by Otto Hahn and Lise Meitner.

Scientists across the world became simultaneously aware of the possibility of a nuclear weapon. Chadwick regularly worked and collaborated with German scientists, and knew that their work would progress in parallel with his own.

The Nazi anti-Jewish programme caused many scientists to leave Germany – among them was Joseph Rotblat who came to Liverpool to work with Chadwick. Others were Otto Frisch and Rudolf Peirls – working in Birmingham – who in 1940 would design the first theoretical framework for the detonation of an atomic bomb.

The 37” Cyclotron in Liverpool became operational, which allowed Chadwick and Rotblat to make the necessary calculations to establish the critical mass necessary to make a nuclear bomb feasible.

Notebooks from Los Alamos

These notes belonged to Jimmy Hughes who was one of the scientists from the University of Liverpool who worked with James Chadwick on the Manhattan Project. Although Hughes remained in England, his work was important to the success of the project.

The scientists who went to Los Alamos in 1943 were:

James Chadwick
Joseph Rotblat
Otto Frisch
Don Marshall

The Quantum mechanics notes were by Edward Teller and Emil Konopinski.

Even though all the scientists working on the project were at the top of their field, the physics they were using was at the absolute cutting edge of new research, so 'Los Alamos University' was set up to ensure that they were all working at the same level and had access to the newest calculations.

Triple Proportional Counter

1950

Used by John Holt with the 37” Cyclotron

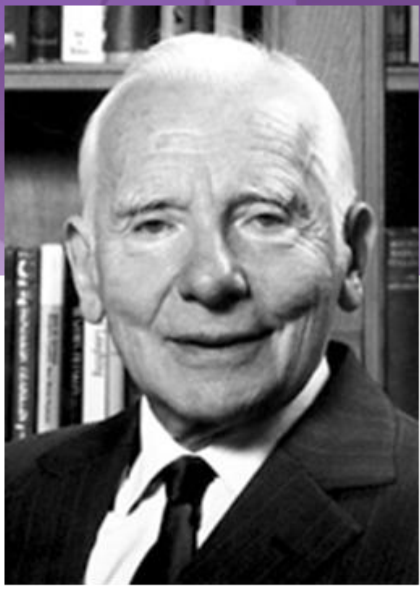
John Riley Holt was an experimental Physicist who dedicated his working life to research in nuclear and particle physics at the University of Liverpool. He gained both his BSC and PhD at Liverpool and his work on establishing the critical mass of Uranium contributed to the work of Chadwick’s team at the Manhattan Project. He became Liverpool’s Professor of experimental Physics in 1965.

This triple proportional counter was used by Holt to detect scattered protons during deuteron-stripping experiments carried out using the 37” Cyclotron, both at the George Holt Building, and later when it was relocated to the Nuclear Research Laboratory in 1952.

Deuteron stripping occurs when a deuteron nucleus (made from one proton and one neutron) hits a target nucleus and the neutron gets captured by the target nucleus. This leaves the proton carrying on by itself to be detected and measured. The study of this process gives important information about the internal structure of the nucleus that was hit by the deuteron – this information could not be obtained any other way.

Joseph Rotblat

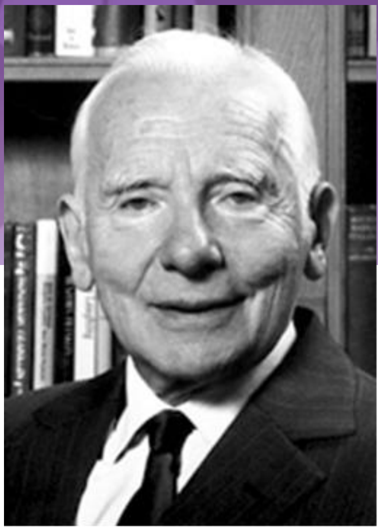
1908 – 2005



Nobel Peace Prize in 1995

Josef Rotblat was born in Poland to Jewish parents. He originally worked as an electrician and attended evening classes before enrolling at the Free University of Poland in Warsaw, where he received his doctorate. He undertook research at the Radiation Laboratory of the Polish Scientific Society and was appointed Assistant Director of the Atomic Physics Institute in 1937.

His work on the fission process led him to speculate that a large number of rapid fissions in a very short time could produce an explosion. Such work caught the eye of James Chadwick at Liverpool University and in 1939 he was appointed Oliver Lodge Fellow. Chadwick was keen to build a Cyclotron, and Rotblat shared this ambition. Due to the Nazi invasion of Poland, his wife was stranded and was unable to follow him. After the war ended it was confirmed that she had died in a concentration camp.



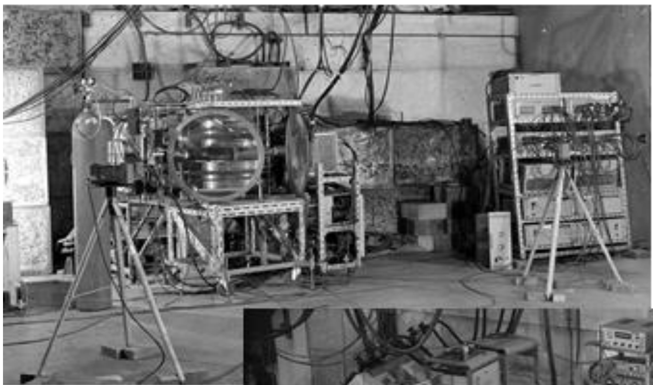
Despite his misgivings regarding the idea of a nuclear weapon, Rotblat began working with Chadwick on a nuclear bomb, which the Government's Maud Committee hoped would act as a deterrent against Nazi Germany due to the almost certain knowledge that they would have a parallel programme. Under Chadwick's leadership, Rotblat and three other members of Liverpool University's Physics department joined the Manhattan project in the USA.

In December 1945, when Chadwick learned that the Germans had abandoned their nuclear plans, Rotblat had serious misgivings about the Manhattan Project's objectives and resigned. He was only able to leave after he disproved accusations of being a Soviet spy - Even so he was not allowed to re-enter the USA until the 1960s.

He returned to Liverpool to resume his career - as Senior Lecturer and Acting Director of Research in Nuclear Physics.

The Nuclear Research Lab Mount Pleasant

When Rotblat returned from America in 1945 he took charge of the planning of the new Nuclear Research Laboratory. He was instrumental in getting permission for the lease of the land from the Catholic Church.
By the time the 156” Synchrocyclotron became operational in 1954, Rotblat had already left to take up his new position at St Bart’s Hospital in London.



UNIVERSITY OF LIVERPOOL

G&M
ALLERY & MUSEUM

Joseph Rotblat:

The Post-War Years

Rotblat had strongly opposed the use of nuclear bombs against Japan in August 1945, and this led to the work which distinguished
his post-war career.

He moved to St. Bartholemew's Hospital as Professor of Physics in 1949 to focus on Medical Physics and champion research into the medical and biological benefits of Radiation. He retired from the post in 1976.

After the Bikini Atoll nuclear test in 1955, Rotblat signed the Russell-Einstein Manifesto and began his life-long campaign against nuclear warfare.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

From 1957, he was a leading member of the 'Pugwash Conference on Science and World Affairs' a conference of scientists which first met in Pugwash, Nova Scotia, with the aim of getting international co-operation to control nuclear developments and promote Soviet-Western scientific dialogue during the Cold War.

Rotblat was Secretary-General of Pugwash from 1957 to 1973 and President from 1988 to 1997.

In 1963, the campaign of Rotblat and others led to the Partial Nuclear Test Ban Treaty.

He won the Albert Einstein Peace Prize in 1992, was elected a Fellow of the Royal Society in 1995 and knighted in 1998.

In 1995, he was awarded the Nobel Peace Prize in for his work to promote the use of nuclear research for medical and peaceful purposes.

He was a co-founder of the Stockholm International Peace Research Institute and a member of the World Health organisation's Advisory Committee on Medical Research.

'Above All, Remember Your Humanity'

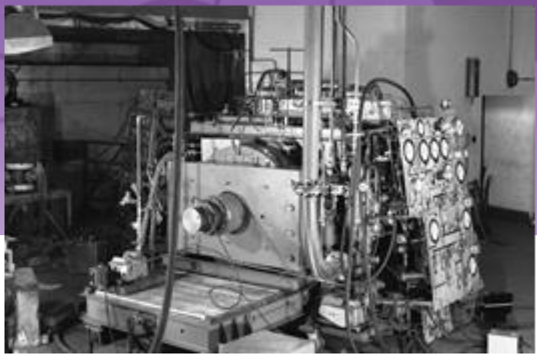
The 156” Synchrocyclotron

The 156 inch synchrocyclotron was built to create pions, exotic particles that had been discovered in cosmic rays in 1947. Pions were made by firing protons at a target at very high speeds, requiring a much larger acceleration loop than the 37 inch Cyclotron.

As protons reach speeds close to the speed of light, an effect called relativity means that they get heavier. The faster they get, the heavier they get, and the longer they take to complete a lap of the acceleration loop. This means that the changing charges that push the proton round the loop get out of sync with the proton and so it slows down. In order to keep the proton accelerating, the pattern of changing charges needs to continuously alter to stay in sync with the proton. This was done by the rotating condenser.

The 156 inch synchrocyclotron was the first machine in the world to be able to deflect the proton beam out of the accelerating loops to hit a target in a different part of the machine. Before this, all targets had to be inserted into the acceleration loop whilst the machine was in operation – a risky and difficult process.

The 10” Hydrogen Bubble Chamber



The design of the liquid hydrogen bubble chamber at Liverpool was started late in 1956, and it was ready for testing by the end of 1958. In January 1959 sensitive conditions were achieved for the first time.

There are many technical problems involved with bubble chambers, but the main problem with liquid hydrogen is bringing its temperature down to 250°C and maintaining it at that value. It used to take 10 hours to cool and fill the chamber, by first spraying liquid nitrogen – and then liquid hydrogen – on to an enclosed part of the chamber wall. The liquid hydrogen sprayed on to the chamber wall kept the chamber cold while operating, and also quickly removed the heat produced during compression.

To cut down heat input to the chamber by radiation, it was placed in a vacuum tank and between the walls of this tank and the chamber was a chromium plated copper shield attached to reservoirs containing liquid nitrogen.

Conduction to the chamber was minimised by suspending it from the vacuum tank lid by a narrow stainless steel tube and clamping part of the nitrogen shield around it.

The Van de Graaf  Accelerator

This was a tandem VDG that could accelerate particles up to 12 Million electron volts (12 MeV). The central electrode was charged up to about 6 million volts (the voltmeter which proves it is displayed here). This attracted atoms that had been given a negative charge. When these atoms reached the centre of the machine they had electrons stripped off, which gave them a positive charge. This positive charge was now repelled by the positive electrode so gained another boost in energy. A clever technique – and why it was called a Tandem VDG.

The Van de Graaf did a lot of work on studying the structure of atomic nuclei and enabled Liverpool to become world leaders in the analysis of gamma ray spectra emitted by rapidly spinning nuclei.

It was installed in a specially built hall in 1960, and ran until 1980 when the more powerful ~18 MeV Nuclear Structure Facility (NSF), also a VDG, came online at Daresbury in 1980. The building it was housed in is now part of the Surface Science department.

H1 Radial Drift Chamber

The HERA accelerator, at the Deutsches Elektronen Synchrotron (DESY) in Hamburg, was built to study interactions between quarks and leptons.

Radial wire geometry drift chambers (RWDCs) were installed in the forward track detector of the Hl experiment at HERA to simultaneously provide accurate track space points and to identify electrons by means of transition radiation.

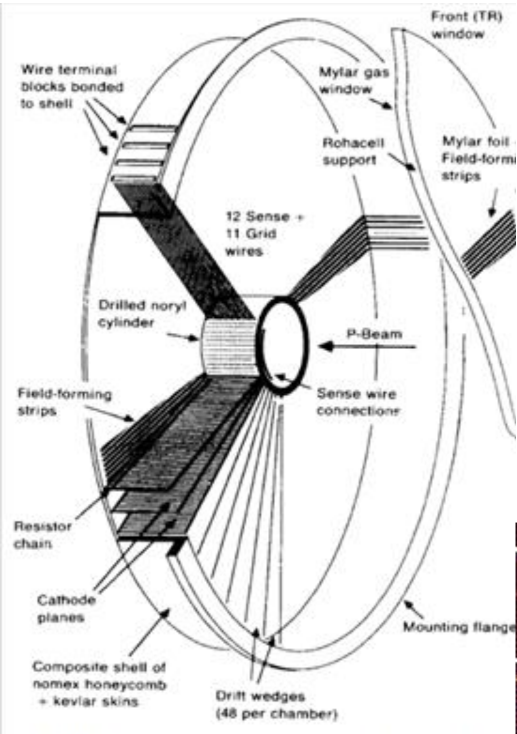
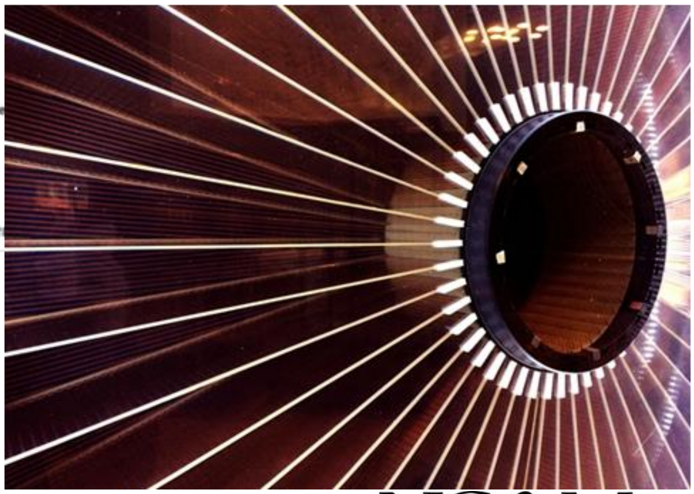


Fig. 11.11 Schematic blow-up of the radial-wire drift chambe



UNIVERSITY OF LIVERPOOL

VG&M VICTORIA GALLERY & MUSEUM

Abstract from the Publication of the MAP Computer:

A. Moreton, G.D. Patel and T. Bowcock

The Monte-Carlo Array processor (MAP) has been designed using commodity off the shelf (COTS) items to provide CPU requirements of full event simulation for the LHC experiments. The solution is however completely general, so any CPU intensive application with limited input requirements can be run on the system.

Operating control software has been written to manage the data flow over the 100 Base T Ethernet connecting the 300 nodes (400 MHz PIIs) to the 6 master control nodes (700 MHz PIIIs each with 500Gb of disc). Upgrade to 1000 nodes is planned.

Job control software that allows the user to run the same job on all nodes, whilst allowing for small differences in initialisation parameters between nodes has also been written.

GMAP is the GRID aware MAP control software. This allows remote job preparation and submission using globus toolkit for authentication and communication. The software will be available and opens the possibility for doing massive Monte Carlo production over several remote MAP sites simultaneously.

University of Liverpool, Spring 2000

UNIVERSITY OF LIVERPOOL

VICTORIA GALLERY & MUSEUM

The accelerator- target experiments covered in this exhibition are effectively all microscopes looking at the nuclear and sub-nuclear world.

There is a fundamental physics principle which states that as the structural detail being studied becomes smaller, the interaction (beam) energy required becomes higher. It follows that there has been a continuous growth in accelerator size (and cost) since the Chadwick era.

This type of research has also become group based rather than the work of individuals. This is well illustrated by the fact that whilst Chadwick's Nobel prize-winning paper had a single author and publications from the Cyclotron era research typically had two to five authors, current publications can have in the region of 1000 authors.

There has always been a link between nuclear and particle physics – the study of the very small – and astrophysics – the study of the very large. One example of this is the realisation in the mid-20th century that the energy source of the sun is nuclear fusion. In recent times this link has becoming stronger, and part of the case for the construction of the Large Hadron Collider was that it will create conditions – on a very small scale – which are the same as the state of matter in the very early stages of the of the 'big bang ' ….. the moment the universe began.

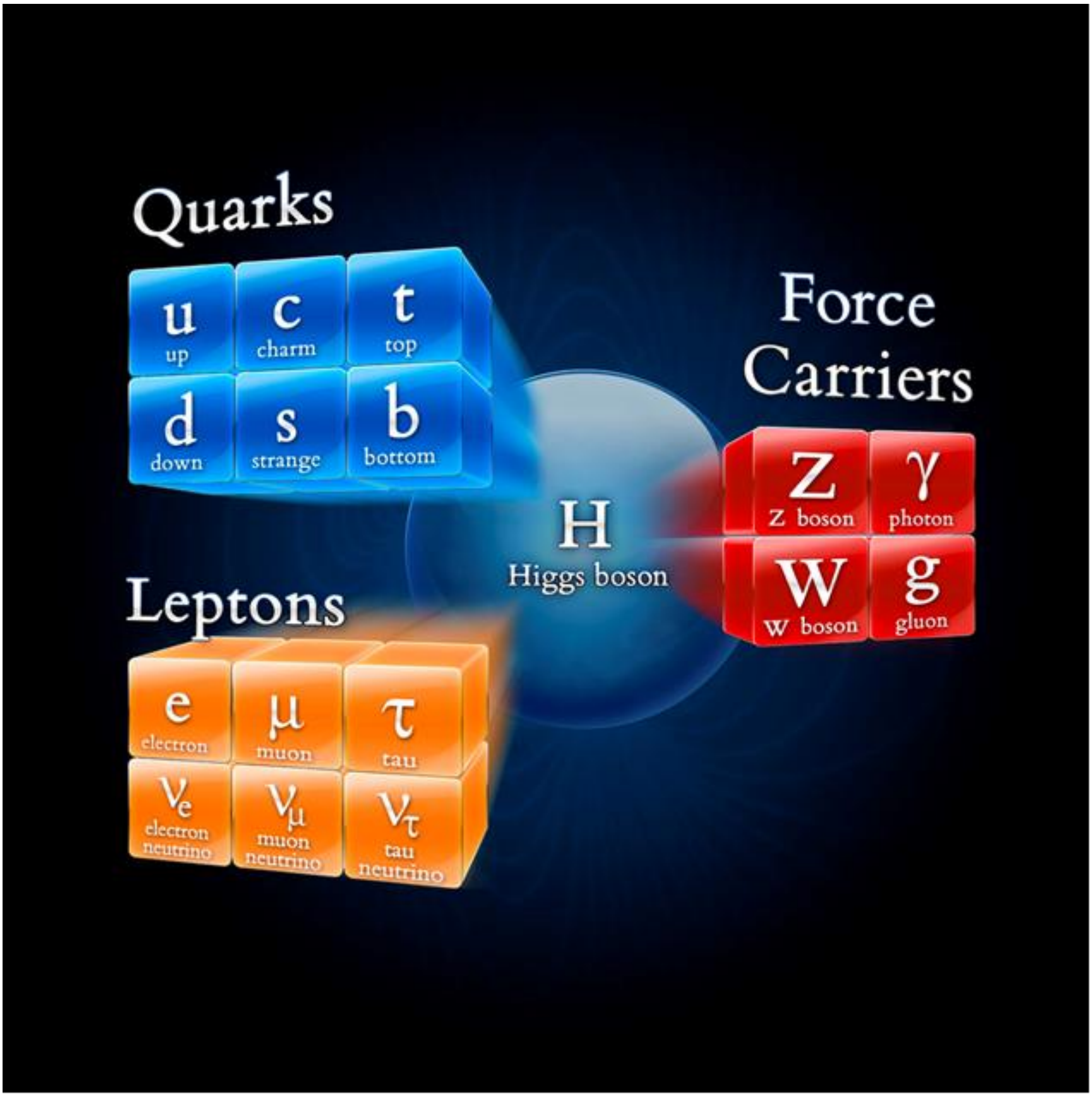
The European Organisation for Nuclear Research (CERN)

The Large Hadron Collider at CERN is the largest and most powerful particle accelerator ever built.

It was designed and built in collaboration with over 10,000 scientists and engineers from over 100 countries. Physicists from the University of Liverpool have been involved in the project from its inception.

Physicists hope that the experiments at CERN will give us new insight into the fundamental nature of the Universe. The name CERN is from the acronym for the French 'Conseil Européen pour la Recherche Nucléaire' – or European Council for Nuclear Research – a provisional body founded in 1952 with the mandate of establishing a world-class physics research organisation in Europe. At that time, pure physics research concentrated on understanding the inside of the atom, hence the word ‘nuclear’. Today, our understanding of matter goes much deeper than the nucleus, and CERN's main area of research is particle physics - the study of the fundamental constituents of matter and the forces acting between them. Because of this, the laboratory operated by CERN is often referred to as the European Laboratory for Particle Physics.

Its discovery helps confirm the mechanism by which fundamental particles get mass. These fundamental particles of the Standard Model are the quarks, leptons, and force-carrier particles.



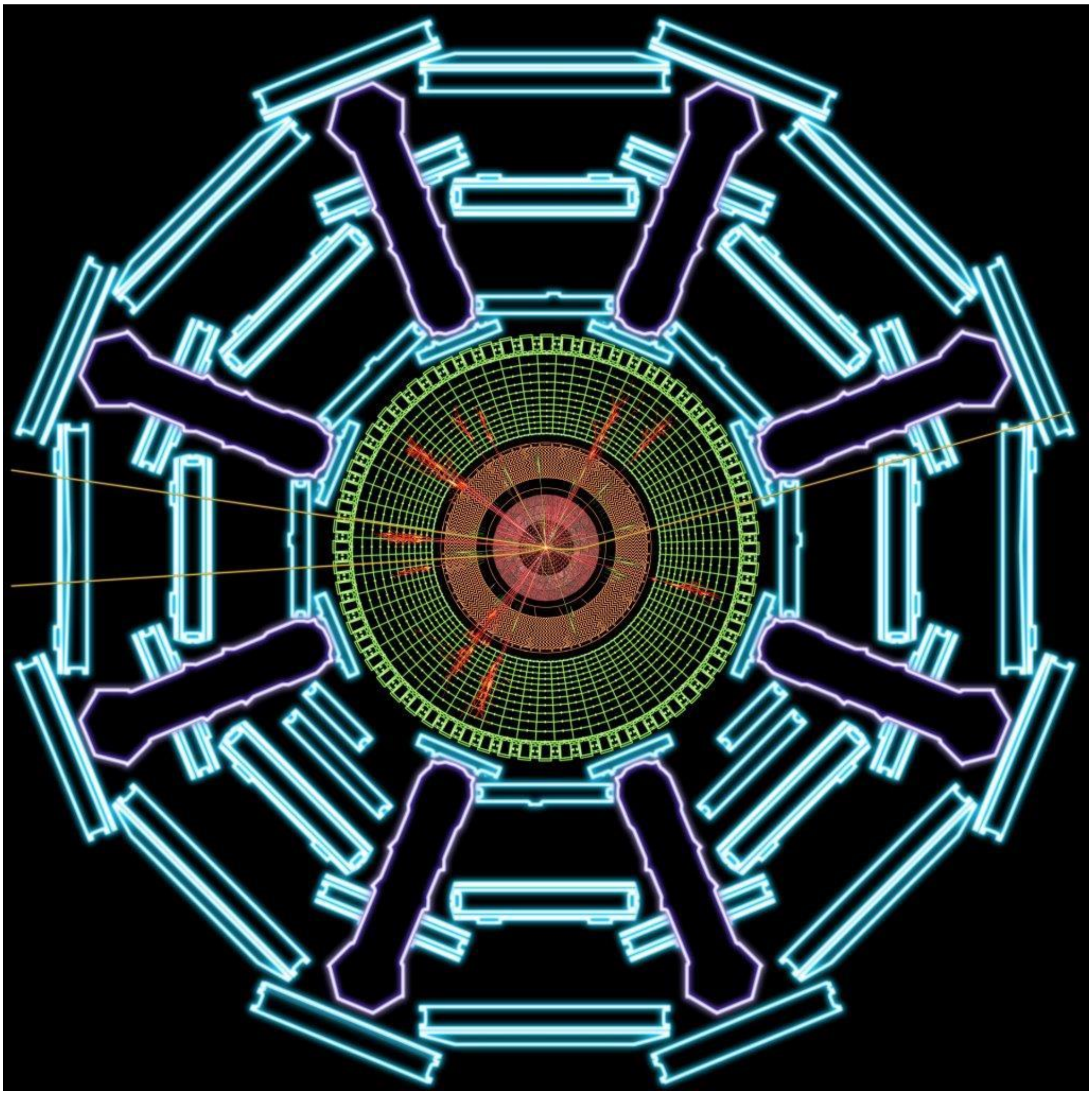
VG&M
VICTORIA GALLERY & MUSEUM

The Higgs Boson:
Life-Size

The large image on the back wall of our museum is actually a life-sized picture of a Higgs Event in the Atlas Experiment at CERN.

The whole picture would have been 22 metres across, so what you see on the wall is just the centre of it.

Our image is 8 metres wide.



Theory and the Future

Theoretical particle physics attempts to develop the models, theoretical framework and mathematical tools to understand current experiments and make predictions for future experiments.

There are several major interrelated efforts being made in theoretical particle physics today.

One important branch attempts to better understand the Standard Model and its tests. This work probes the limits of the Standard Model and aims to expand our understanding of nature's building blocks.

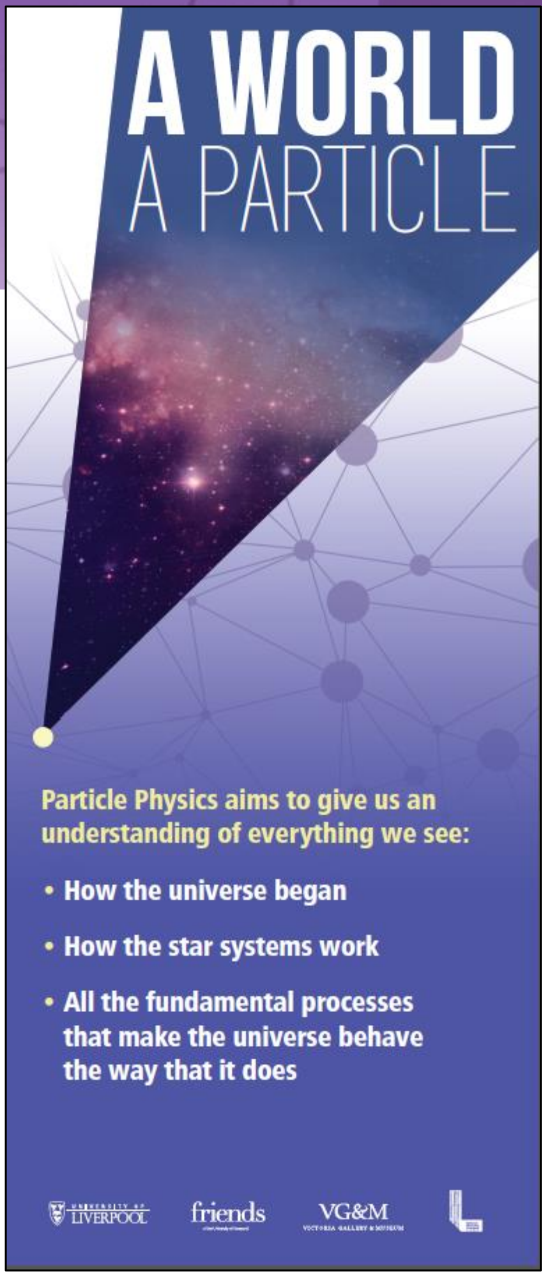
Another major effort is in model building, where model builders develop ideas for what physics may lie beyond the Standard Model (at higher energies or smaller distances). This work is constrained by existing experimental data.

A third major effort is string theory. String theorists attempt to construct a unified description of quantum mechanics and general relativity by building a theory based on small strings rather than particles. If this theory was ever successful, it might be considered a ‘theory of everything’.

The primary goal pursued by all these efforts is to find and understand what may lie beyond the Standard Model.

Large Print Guide

A WORLD A PARTICLE



Particle Physics aims to give us an understanding of everything we see:

- How the universe began
- How the star systems work
- All the fundamental processes that make the universe behave the way that it does

The Main Room

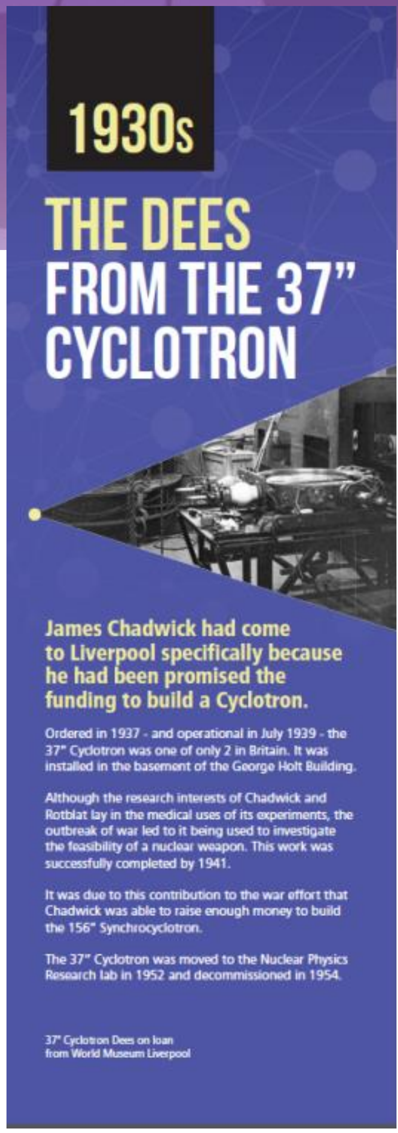
UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

From left to right.

1930s

The Dees from the 37” Cyclotron



James Chadwick had come to Liverpool specifically because he had been promised the funding to build a Cyclotron.

Ordered in 1937 – and operational in July 1939 – the 37” Cyclotron was one of only 2 in Britain. It was installed in the basement of the George Holt Building.

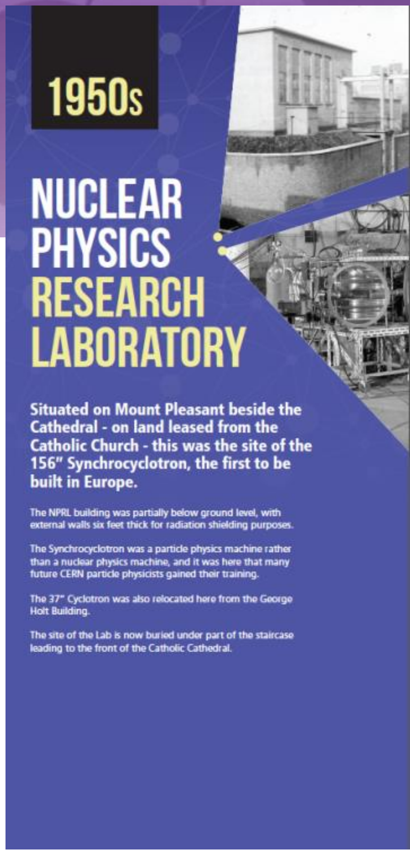
Although the research interests of Chadwick and Rotblat lay in the medical uses of its experiments, the outbreak of war led to it being used to investigate the feasibility of a nuclear weapon. This work was successfully completed by 1941.

It was due to this contribution to the war effort that Chadwick was able to raise enough money to build the 156” Synchrocyclotron.

The 37” Cyclotron was moved to the Nuclear Physics Research lab in 1952 and decommissioned in 1954.

1950s

Nuclear Physics Research Laboratory



Situated on Mount Pleasant beside the Cathedral – on land leased from the Catholic Church – this was the site of the 156” Synchrocyclotron, the first to be built in Europe.

The NPRL building was partially below ground level, with external walls six feet thick for radiation shielding purposes.

The 37” Cyclotron was also relocated here from the George Holt Building.

The Synchrocyclotron was a particle physics machine rather than a nuclear physics machine, and it was here that many future CERN particle physicists gained their training.

The site of the Lab is now buried under part of the staircase leading to the front of the Catholic Cathedral.

UNIVERSITY OF LIVERPOOL

VG&M VICTORIA GALLERY & MUSEUM

Post-War Developments

In the late 1950s it became obvious that any new accelerator projects would be too large to be the responsibility of a single university, and would need to be funded and built at a national or international level.

Two such projects were started in the UK, a 7000 MeV proton synchrotron at Harwell and a 4000 MeV electron synchrotron called NINA at Daresbury (near Warrington). The synchrotron is an improved version of the Cyclotron which – proportionally – uses a much smaller (and hence cheaper) magnet system.

A group under John Holt became involved in the design of component parts for NINA in the early 1960s. This was the effective end of the Liverpool department's involvement in accelerator design and construction. After this, the main departmental research effort went into the design of detectors and the analysis of data produced by experiments carried out at NINA and later at CERN and DESY.

There was also a strong move to set up an international facility which resulted in the birth of CERN at Geneva in 1957. A number of the technical experts in the Liverpool Physics

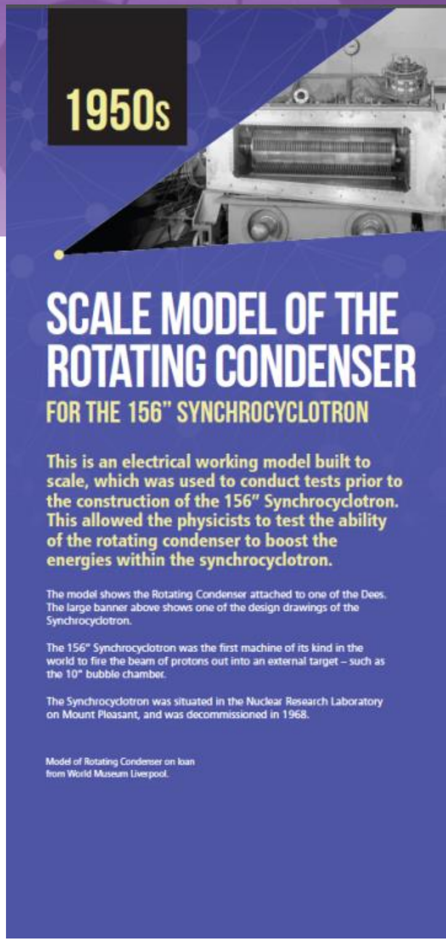
Department moved over to CERN – which set up a parallel accelerator development programme.

The international programme eventually replaced the national programmes in the mid 1970's

The World Wide Web was originally developed at CERN (Tim Berners-Lee 1990) for transferring the large amounts of experimental data from CERN to other participating institutions.

1950s

¼ Scale Model of the Rotating Condenser for the 156” Synchrocyclotron



This is an electrical working model built to ¼ scale, which was used to conduct tests prior to the construction of the 156” Synchrocyclotron. This allowed the physicists to test the ability of the Rotating Condenser to boost the energies within the Synchrocyclotron.

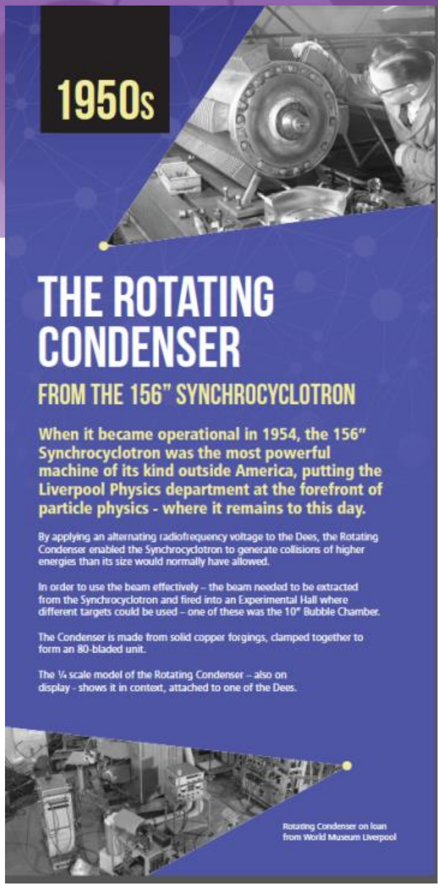
The model shows the Rotating Condenser attached to one of the Dees. The large banner above shows one of the design drawings of the Synchrocyclotron.

The 156” Synchrocyclotron was the first machine of its kind in the world to fire the beam of protons out into an external target – such as the 10” Bubble Chamber.

The Synchrocyclotron was situated in the Nuclear Research Laboratory on Mount Pleasant, and was decommissioned in 1968.

1950s

The Rotating Condenser from the 156” Synchrocyclotron



When it became operational in 1954, the 156” Synchrocyclotron was the most powerful machine of its kind outside America, this put the Liverpool Physics department at the forefront of particle physics – where it remains to this day.

By applying an alternating radiofrequency voltage to the Dees, the Rotating Condenser enabled the Synchrocyclotron to generate collisions of higher energies than its size would normally have allowed.

In order to use the beam effectively – the beam needed to be extracted from the Synchrocyclotron and fired into an Experimental Hall where different targets could be used – one of these was the 10” Bubble Chamber.

UNIVERSITY OF LIVERPOOL

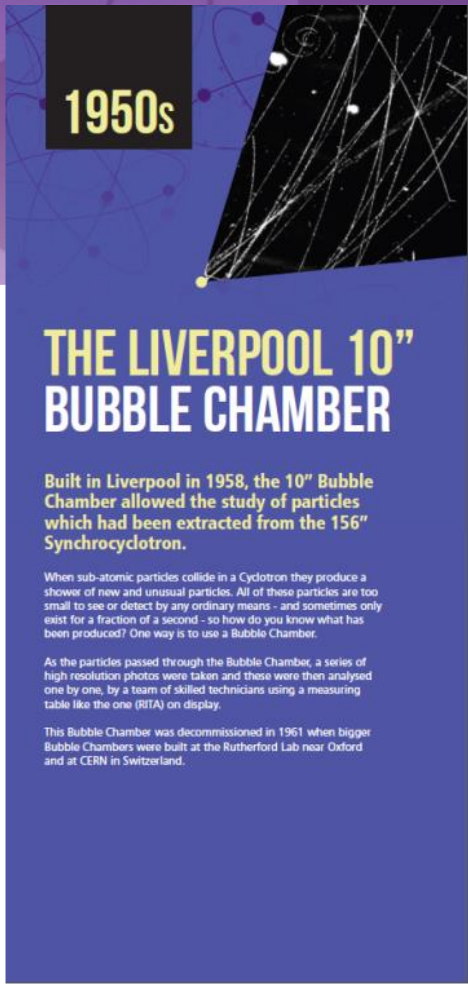
VG&M
VICTORIA GALLERY & MUSEUM

The Condenser is made from solid copper forgings, clamped together to form an 80-bladed unit.

The ¼ scale model of the Rotating Condenser – also on display – shows it in context, attached to one of the Dees.

1950s

The Liverpool 10" Bubble Chamber



This Bubble Chamber was built in Liverpool in 1958 and was used with the Liverpool 156" Synchrocyclotron.

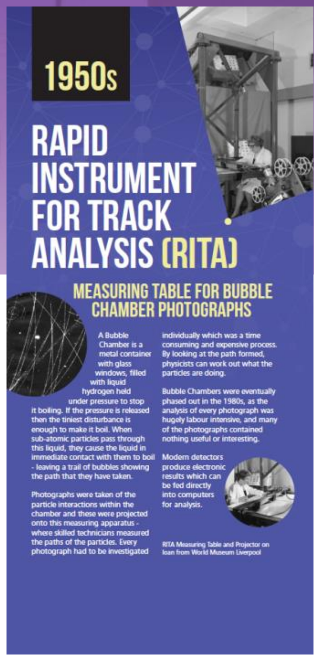
The 10" Bubble Chamber allowed the study of particles which had been extracted from the 156" Synchrocyclotron.

When sub-atomic particles collide in a Cyclotron they produce a shower of new and unusual particles. All of these particles are too small to see or detect by any ordinary means - and sometimes only exist for a fraction of a second - so how do you know what has been produced? One way is to use a Bubble Chamber.

As the particles passed through the Bubble Chamber, a series of high resolution photos were taken and these were then analysed one by one, by a team of skilled technicians using a measuring table like the one (RITA) on display.

This Bubble Chamber was decommissioned in 1961 when bigger Bubble Chambers were built at the Rutherford Lab near Oxford and at CERN in Switzerland.

1950s



Rapid Instrument for Track Analysis (RITA)

Measuring Table for Bubble Chamber Photographs

A Bubble Chamber is a metal container with glass windows, filled with liquid hydrogen held under pressure to stop it boiling. If the pressure is released then the tiniest disturbance is enough to make it boil. When sub-atomic particles pass through this liquid, they cause the liquid in immediate contact with them to boil – leaving a trail of bubbles showing the path that they have taken.

Photographs were taken of the particle interactions within the chamber and these were projected onto this measuring apparatus – where skilled technicians measured the paths of the particles. Every photograph had to be investigated individually which was a time consuming and expensive

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

process. By looking at the path formed, physicists can work out what the particles are doing.

Bubble Chambers were eventually phased out in the 1980s, as the analysis of every photograph was hugely labour intensive, and many of the photographs contained nothing useful or interesting.

Modern detectors produce electronic results which can be fed directly into computers for analysis.

1960s

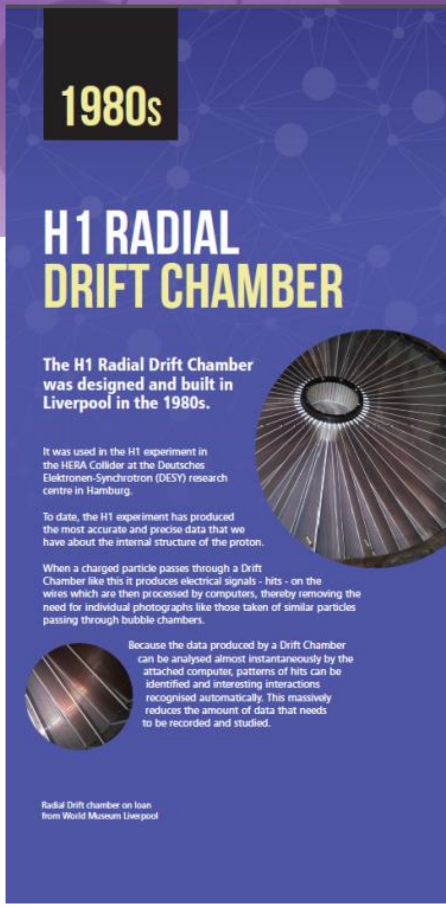
Model of The Liverpool Tandem Van de Graaf Accelerator

This scale model was delivered to the Physics Department in advance of the construction of the Liverpool Tandem Van de Graaf Accelerator.
Delivered in 1960 and switched on the following year – it was installed in a specially built hall near the Chadwick Tower and ran until 1980.

The Tandem Van de Graaf did a lot of work studying the structure of atomic nuclei and enabled Liverpool to become world leaders in the analysis of gamma rays emitted by rapidly spinning nuclei.

This machine was closed down when the more powerful Nuclear Structure Facility – also a Van de Graaf, with a design energy of 20 million volts – came online at

Daresbury in 1980. Liverpool's nuclear physicists relocated to Daresbury, where their most important work was the study of superdeformed nuclei – which have a rugby ball shape with the long axis twice as long as the short axis. This work was world leading for a number of years.



1980s

H1 Radial Drift Chamber

The H1 Radial Drift Chamber was designed and built in Liverpool in the 1980s.

It was used in the H1 experiment in the HERA Collider at the Deutsches Elektronen-Synchrotron (DESY) research centre in Hamburg.

To date, the H1 experiment has produced the most accurate and precise data that we have about the internal structure of the proton.

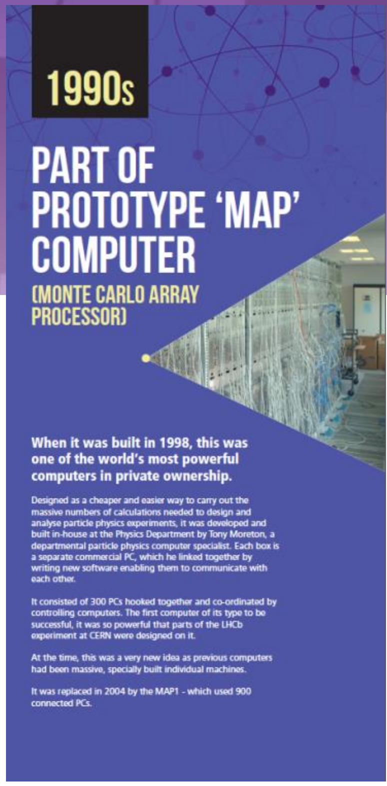
When a charged particle passes through a Drift Chamber like this it produces electrical signals – hits – on the wires which are then processed by computers, thereby removing the need for individual photographs like those taken of similar particles passing through bubble chambers.

Because the data produced by a Drift Chamber can be analysed almost instantaneously by the attached computer, patterns of hits can be identified and interesting interactions recognised automatically. This massively reduces the amount of data that needs to be recorded and studied.

1990s

Part of Prototype 'MAP' Computer

(Monte Carlo Array Processor)



When it was built – in 1998 – this was one of the world's most powerful computers in private ownership.

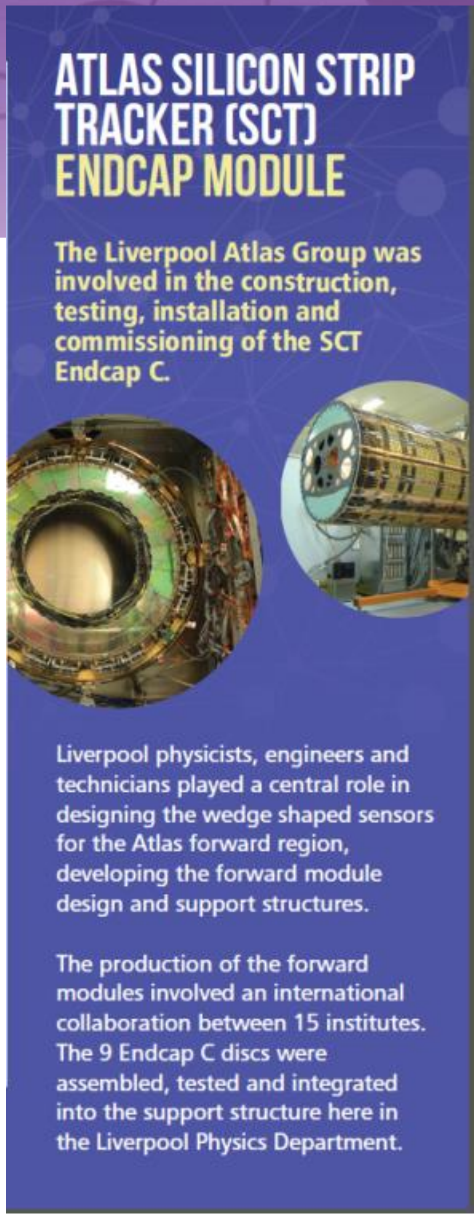
Designed as a cheaper and easier way to carry out the massive numbers of calculations needed to design and analyse particle physics experiments, it was developed and built in-house at the Physics Department by Tony Moreton, a departmental particle physics computer specialist. Each box is a separate commercial PC, which he linked together by writing new software enabling them to communicate with each other.

It consisted of 300 PCs hooked together and co-ordinated by controlling computers. The first computer of its type to be successful, it was so powerful that parts of the LHCb experiment at CERN were designed on it.

At the time, this was a very new idea as previous computers had been massive, specially built individual machines.

It was replaced in 2004 by the MAP1 – which used 900 connected PCs.

Atlas Silicon Strip Tracker (SCT) Endcap Module



The Liverpool Atlas Group was involved in the construction, testing, installation and commissioning of the SCT Endcap C.

Liverpool physicists, engineers and technicians played a central role in designing the wedge shaped sensors for the Atlas forward region, developing the forward module design and support structures.

The production of the forward modules involved an international collaboration between 15 institutes.

The 9 Endcap C discs were assembled, tested and integrated into the support structure here in the Liverpool Physics Department.

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM

UNIVERSITY OF LIVERPOOL

VG&M
VICTORIA GALLERY & MUSEUM