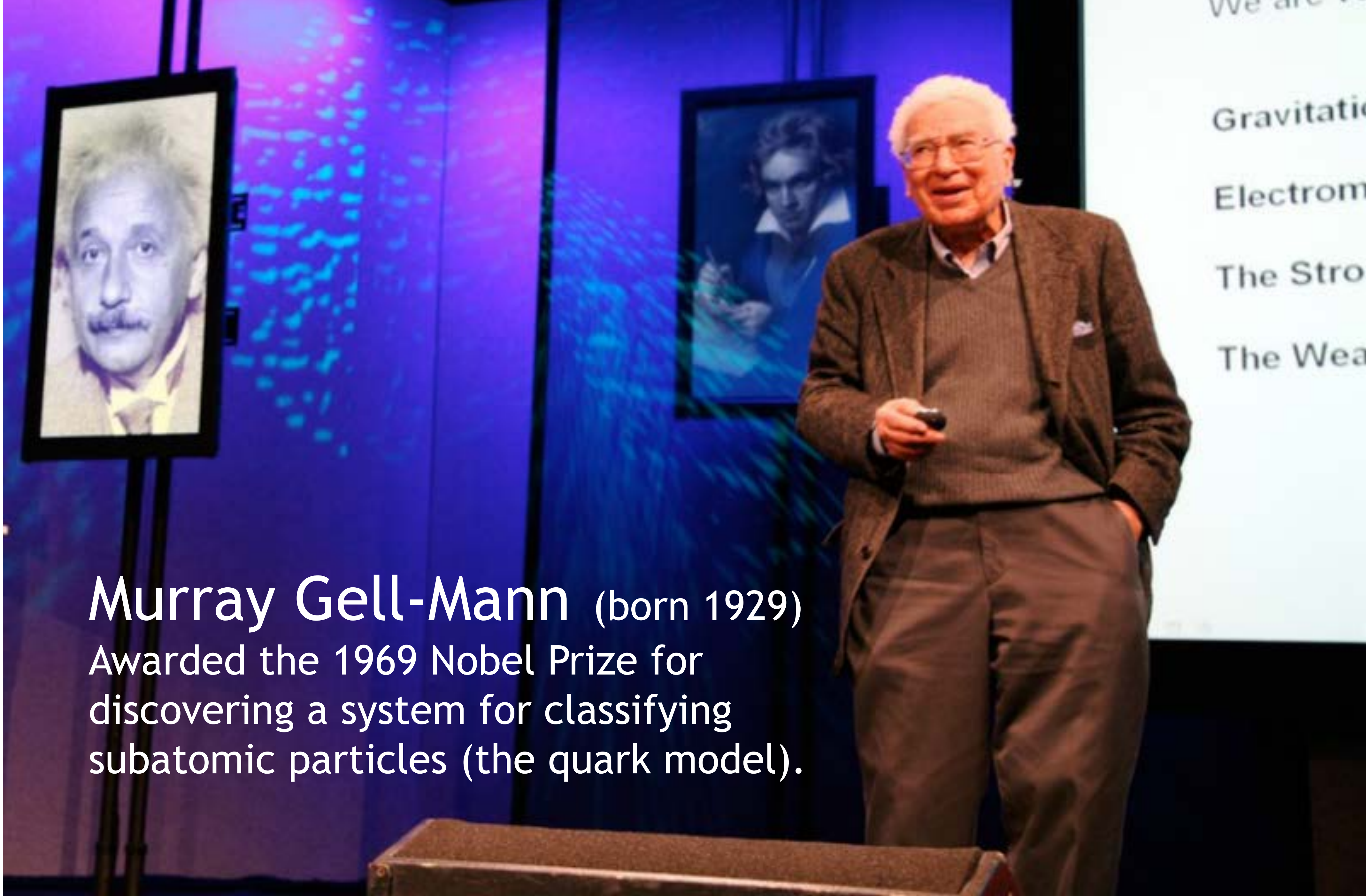
The story of quarks

spice
secondary teachers' enrichment program

The University of Western Australia
Achieving International Excellence

Government of **Western Australia**
Department of **Education**



Murray Gell-Mann (born 1929)

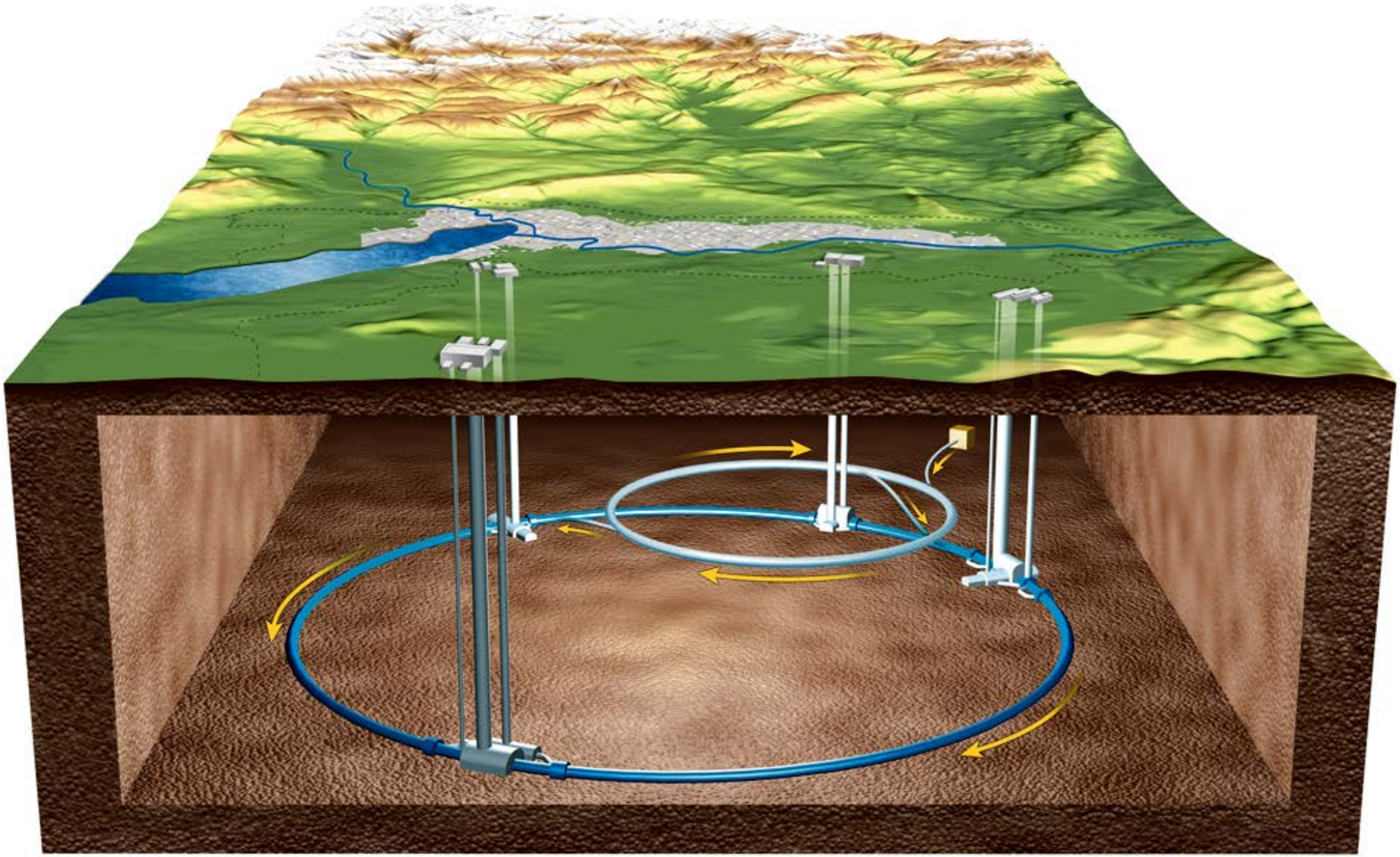
Awarded the 1969 Nobel Prize for discovering a system for classifying subatomic particles (the quark model).

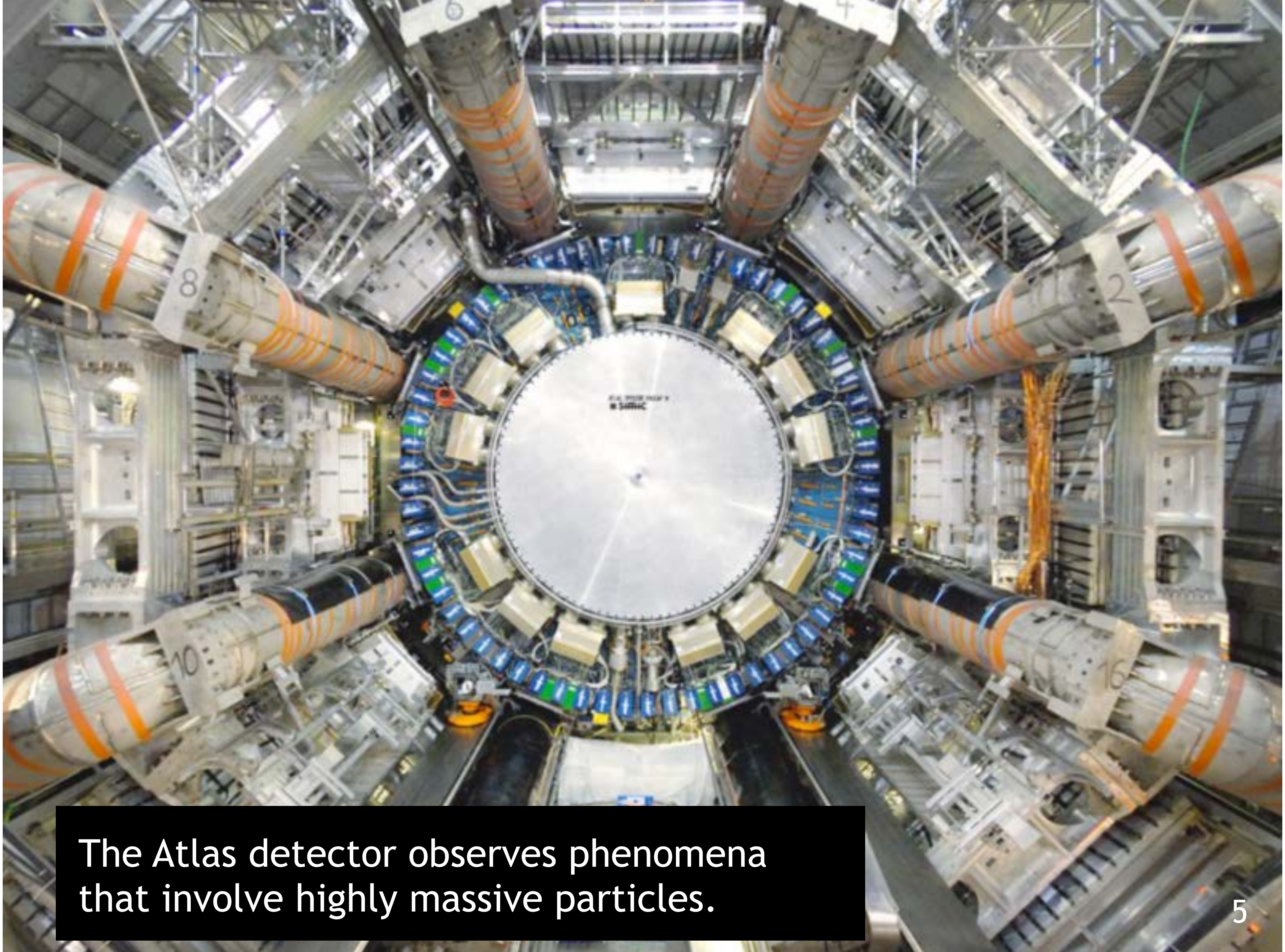
photo by Jurvetson (flickr)

The Large Hadron Collider (LHC)

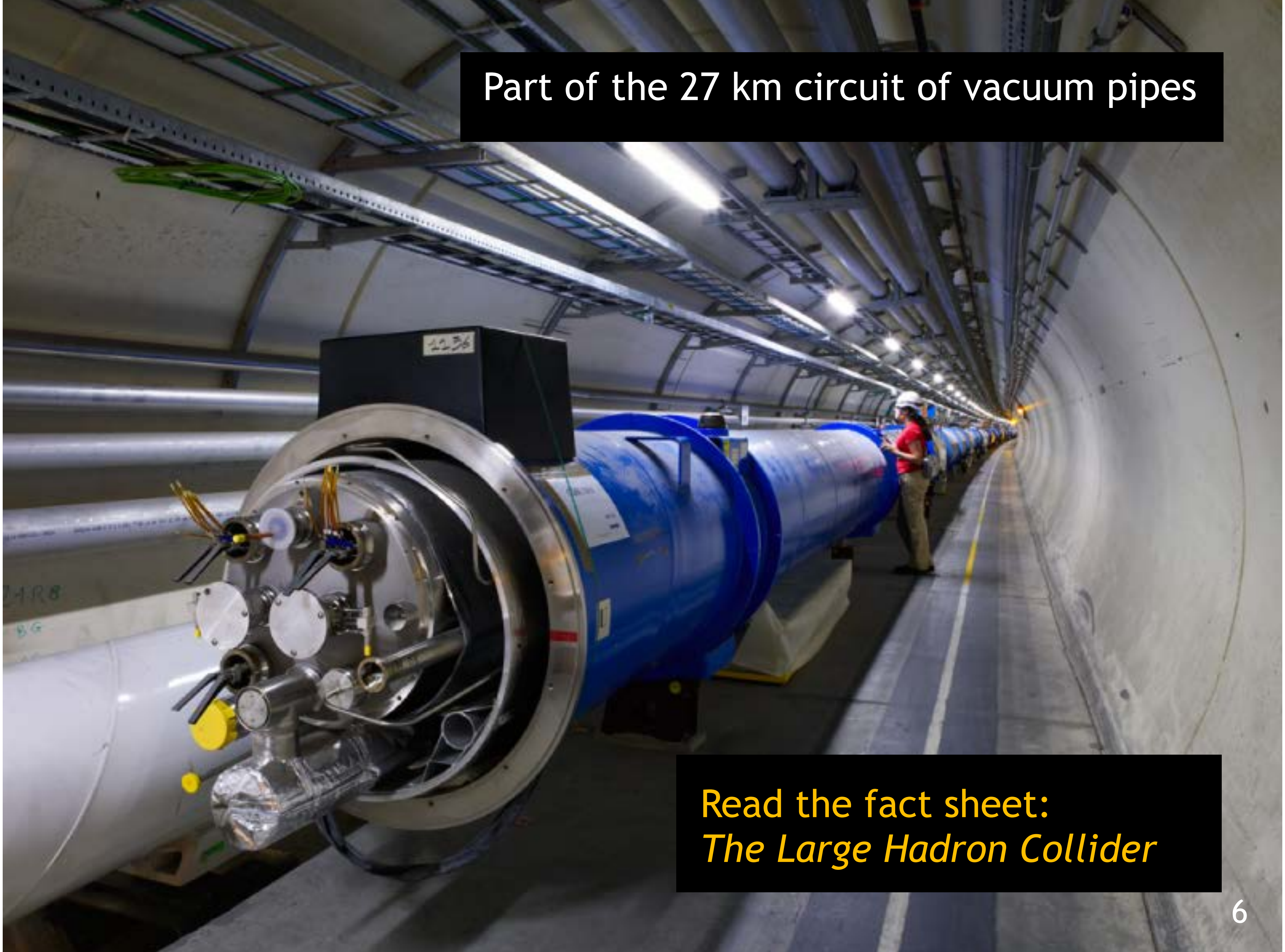
The LHC sits astride the border of France and Switzerland, near Geneva.

The Large Hadron Collider is 50–175 m below ground level





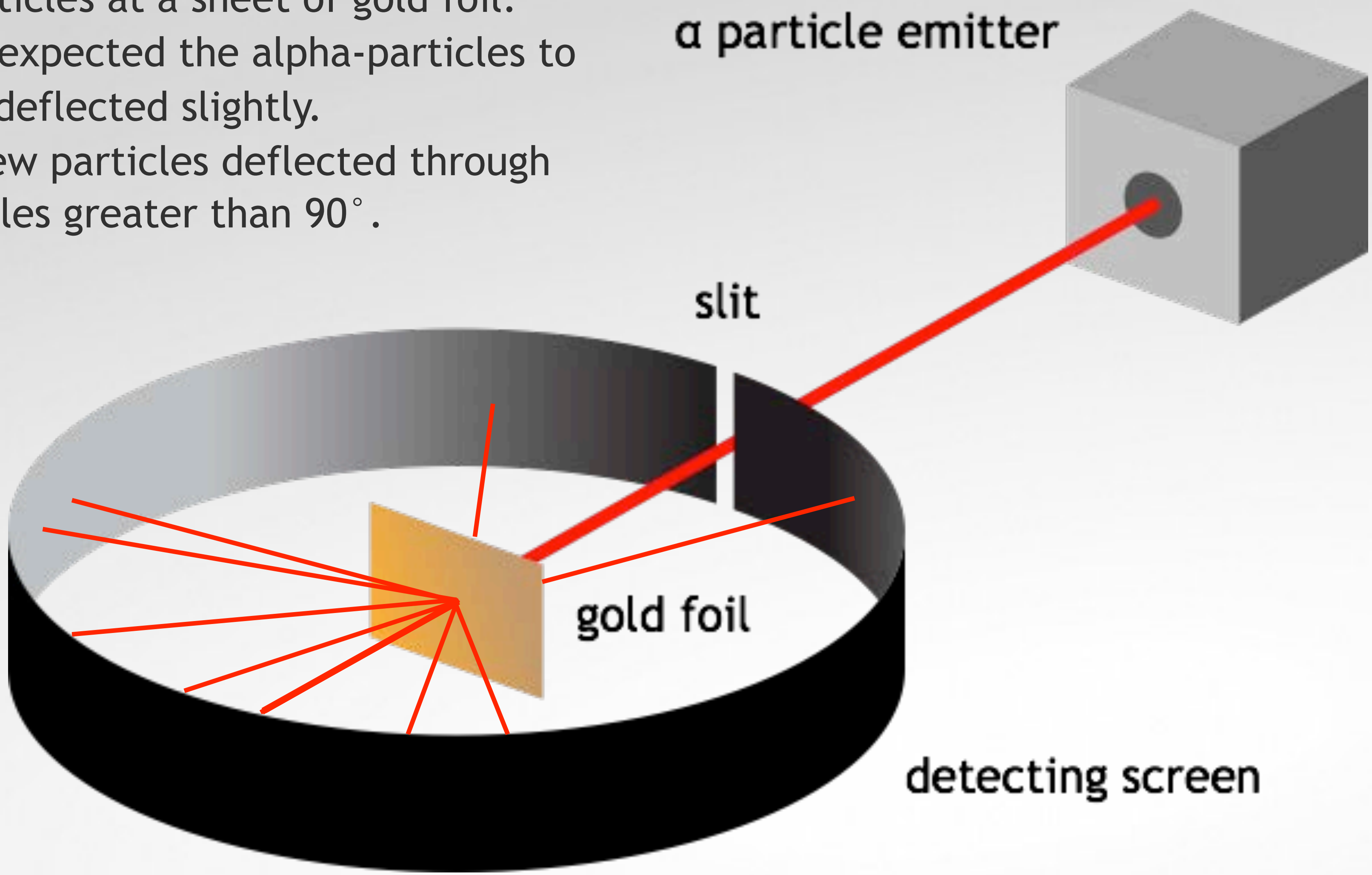
The Atlas detector observes phenomena that involve highly massive particles.


Part of the 27 km circuit of vacuum pipes
Read the fact sheet:
The Large Hadron Collider

Why is it likely that ‘new’ particles will be discovered in the LHC?

Rutherford's experiment

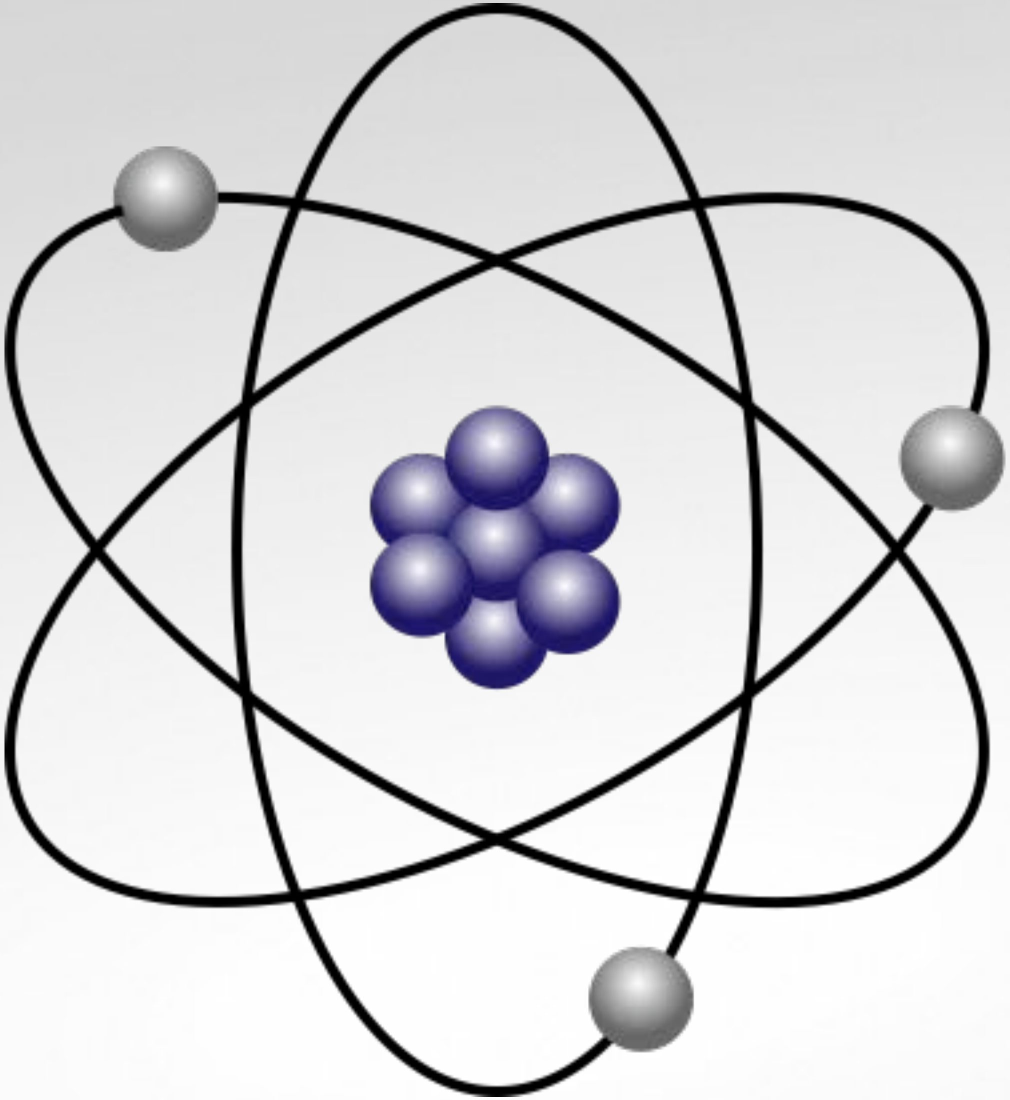
In 1911, Rutherford fired alpha-particles at a sheet of gold foil.
He expected the alpha-particles to be deflected slightly.
A few particles deflected through angles greater than 90°.



What conclusions did Rutherford draw from this experiment?

Rutherford's model of the atom

Rutherford explained his results via a model for the atom that had a very small positively charged nucleus with negatively charged electrons orbiting like planets around a star.

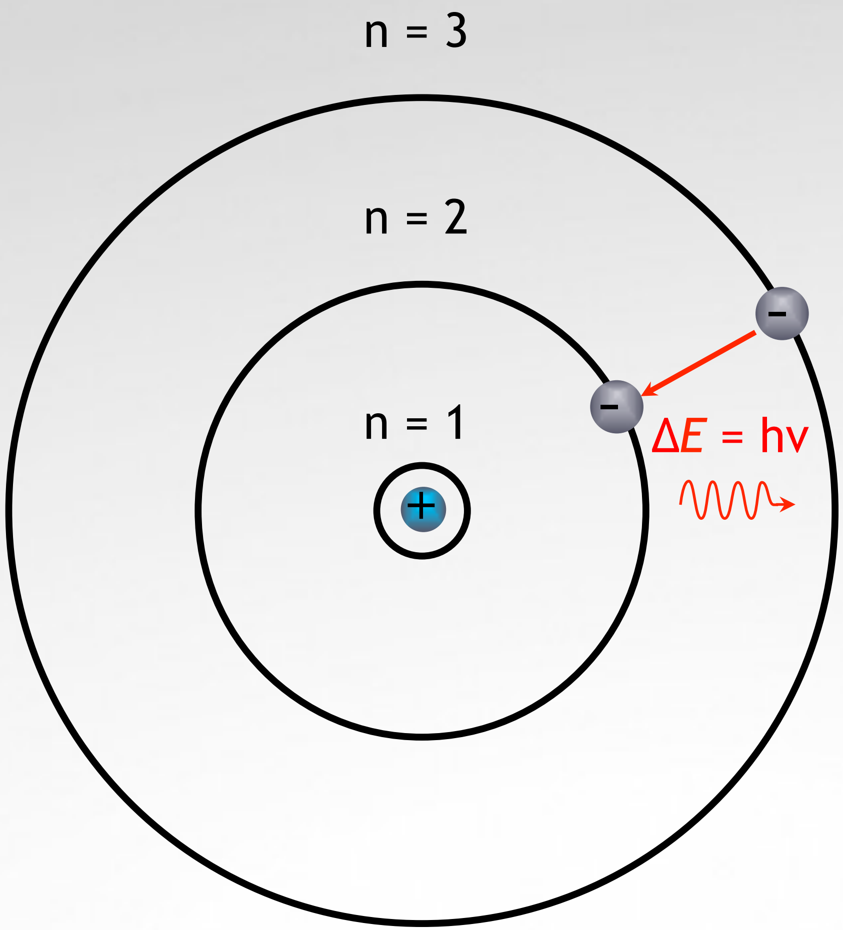


Why did many scientists object to Rutherford's model at that time?

The Bohr-Rutherford atom

Bohr believed that electrons only exist in discrete (quantised) energy levels in which they don't radiate energy as they orbit the nucleus.

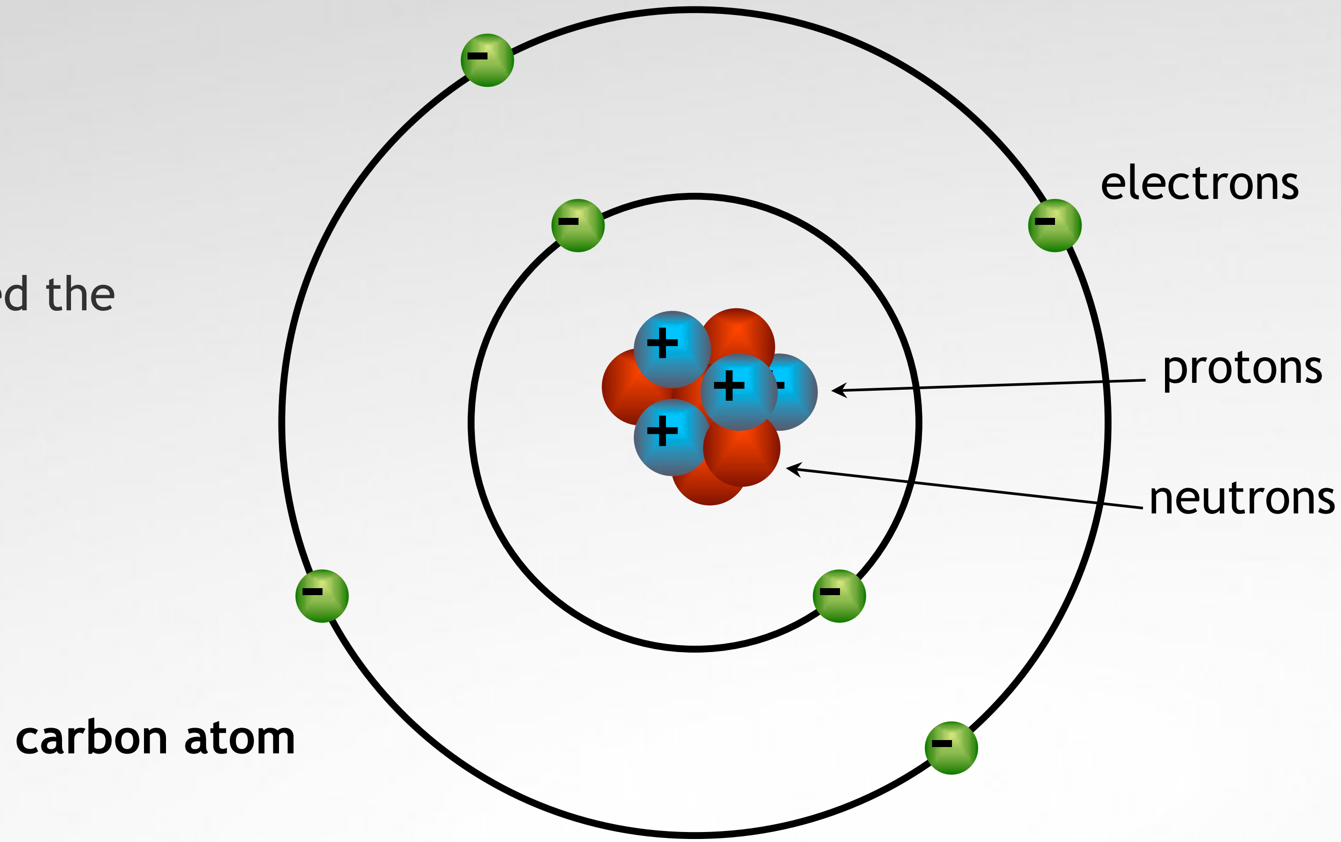
Electrons only radiate energy when they move to lower energy levels.



What do we now know is wrong with this model?

The neutron

In 1932, Chadwick discovered the neutron.



Does this now complete the picture of atomic structure?

More recent discoveries

During the 1930s and 1940s, physicists studied interactions between matter and radiation, including cosmic rays. Many ‘new’ sub-atomic particles were discovered.

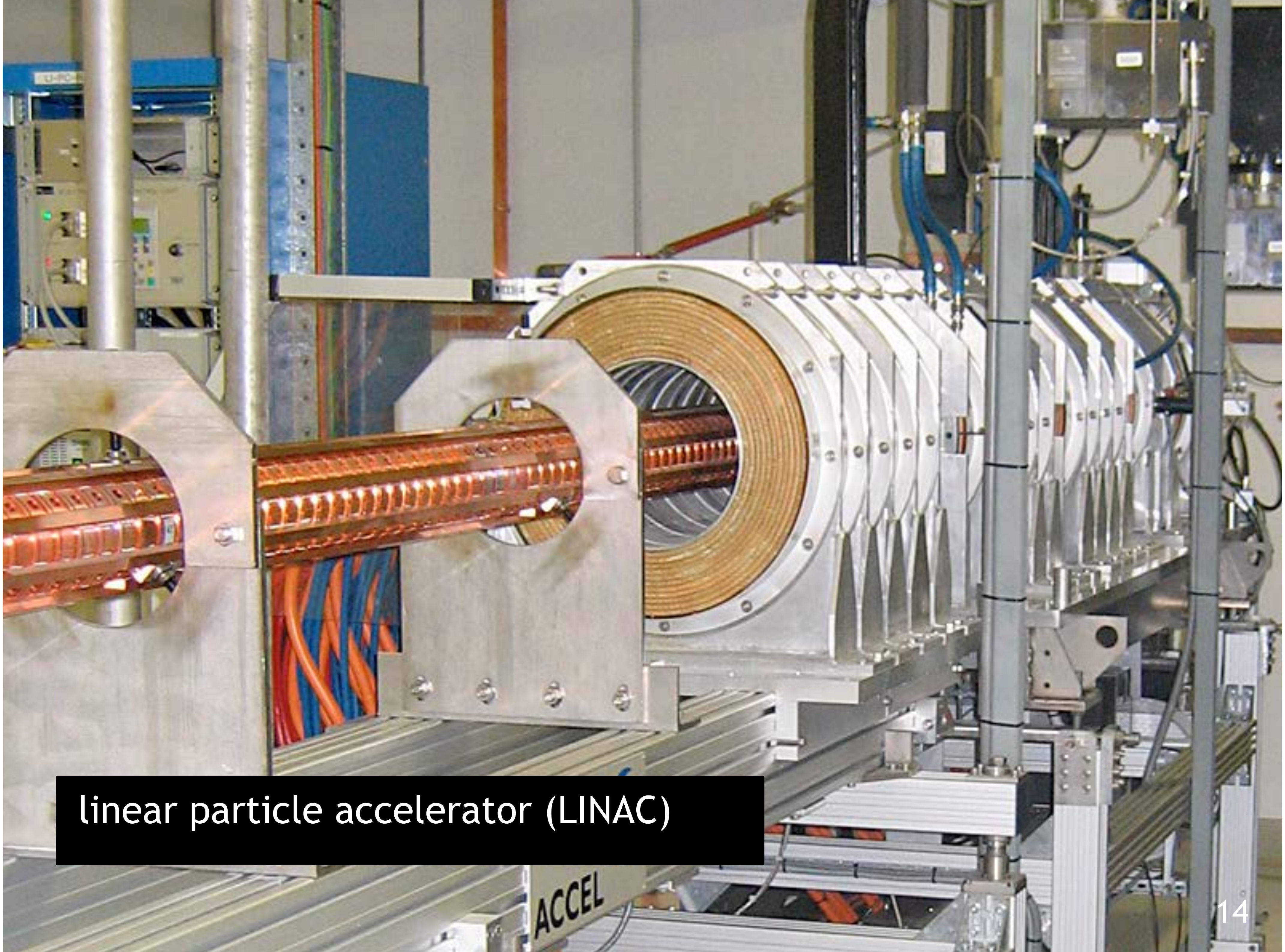
positrons pions kaons

mesons muons neutrinos

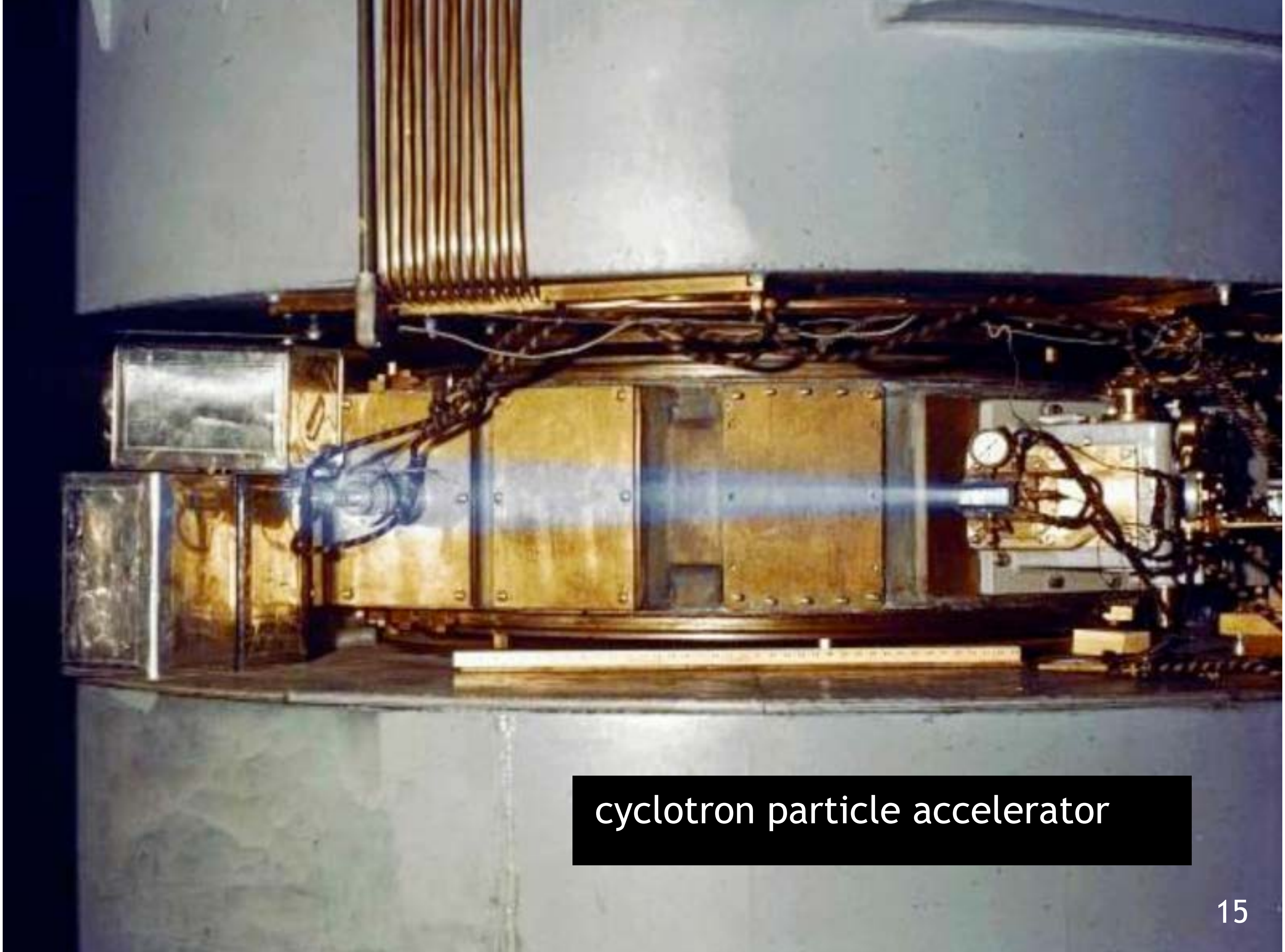
What impact did these new discoveries have on existing theories and models of atomic structure?

Particle accelerators were developed in the 1960s, enabling higher energy interactions to be studied.

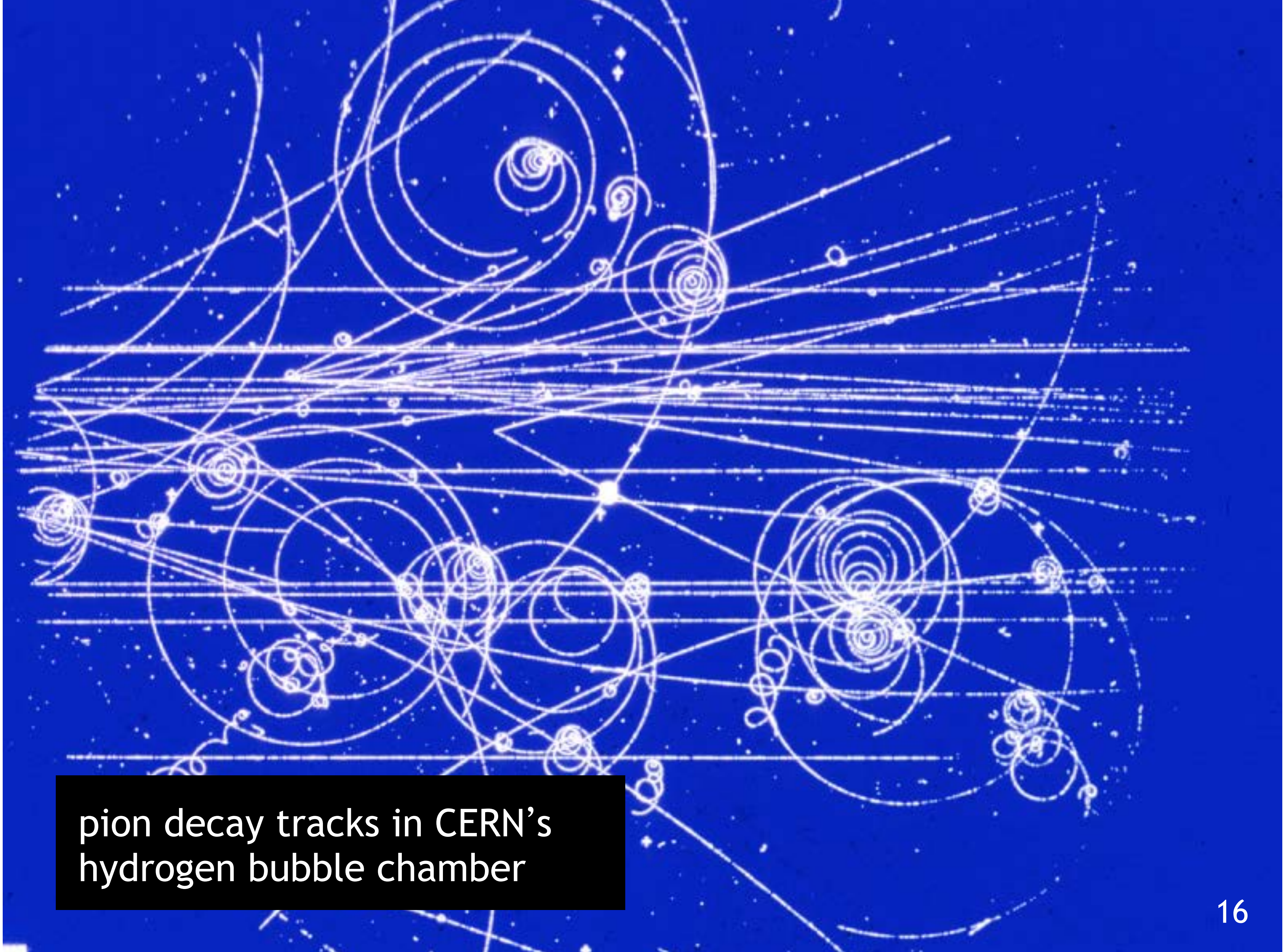
This soon led to the discovery of more than 100 sub-atomic particles, including the antiproton and neutrino.



linear particle accelerator (LINAC)



cyclotron particle accelerator



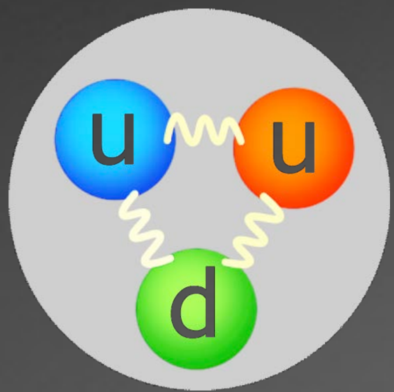
pion decay tracks in CERN’s hydrogen bubble chamber

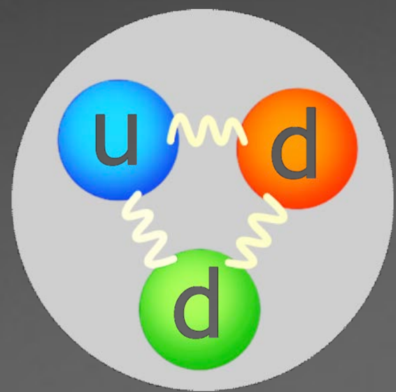
pion decay tracks in CERN's streamer chamber

Quarks

In 1969, the quark model was proposed to make sense of the increasing numbers of sub-atomic particles.
The first generation quarks were called up and down.

proton





neutron

Protons and neutrons are made of up and down quarks.

Quarks

The model was gradually expanded to six quarks:

quark	**up**	**charm**	**top**
charge	+⅔ e	+⅔ e	+⅔ e
mass	2.5 MeV/c^2	1270 MeV/c^2	171 000 MeV/c^2
quark	**down**	**strange**	**bottom**
charge	–⅓ e	–⅓ e	–⅓ e
mass	5 MeV/c^2	105 MeV/c^2	4200 MeV/c^2

By 1995, all six quarks had been identified in experiments.

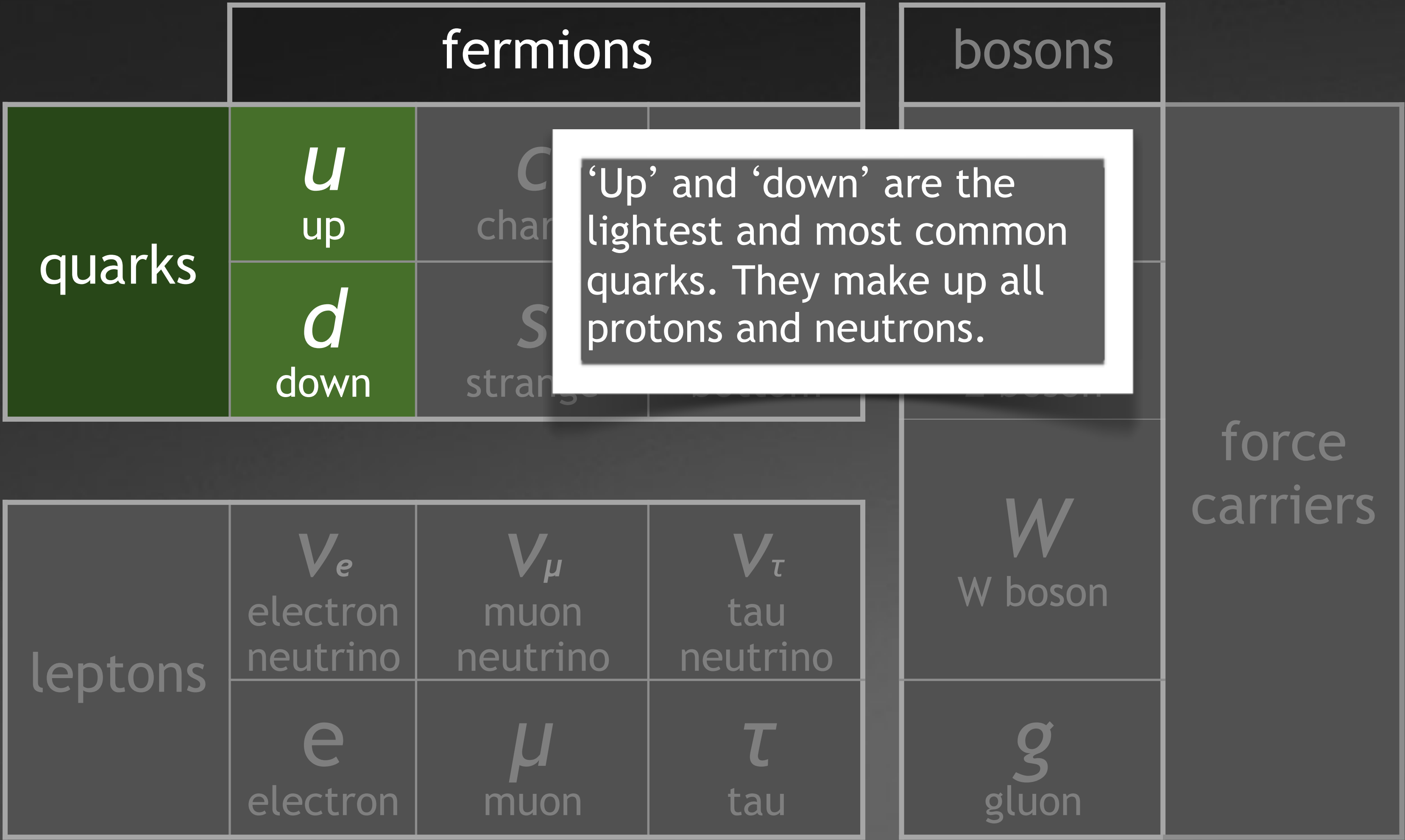
The standard model

We now believe that all matter is made up from six quarks and six leptons, held together by forces carried by bosons.

	fermions			bosons	
quarks	*u* up	*c* charm	*t* top	γ photon	force carriers
	d down	*s* strange	*b* bottom	*Z* Z boson	
leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	*W* W boson	
	e electron	*μ* muon	*τ* tau	*g* gluon	

For most particles, there is a corresponding antiparticle with the same mass but opposite electrical charge. For example, the electron's antiparticle is the positron.

The standard model



'Up' and 'down' are the lightest and most common quarks. They make up all protons and neutrons.

The standard model

	fermions			bosons
quarks	*u* up	*c* charm	*t* top	
	d down	*s* strange	*b* bottom	
leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W boson
	e electron	μ muon	τ tau	*g* gluon

'Charm', 'strange', 'top' and 'bottom' are heavy quarks. They rapidly decay to form 'up' and 'down' quarks. They are only produced in high energy collisions.

The standard model

	fermions			bosons
quarks	u up	c charm	t top	γ photon
	d down	s strange	b bottom	Z Z boson
leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	
	e electron	μ muon	τ tau	

Leptons include electrons and neutrinos. Neutrinos often travel close to the speed of light, have no electric charge, and can travel through matter almost undisturbed. They have a small mass.

The standard model

fermions

quarks

u up | *c* charm | *t* top

leptons

e electron | *μ* muon | *τ* tau

bosons

γ photon

Z Z boson

W W boson

g gluon

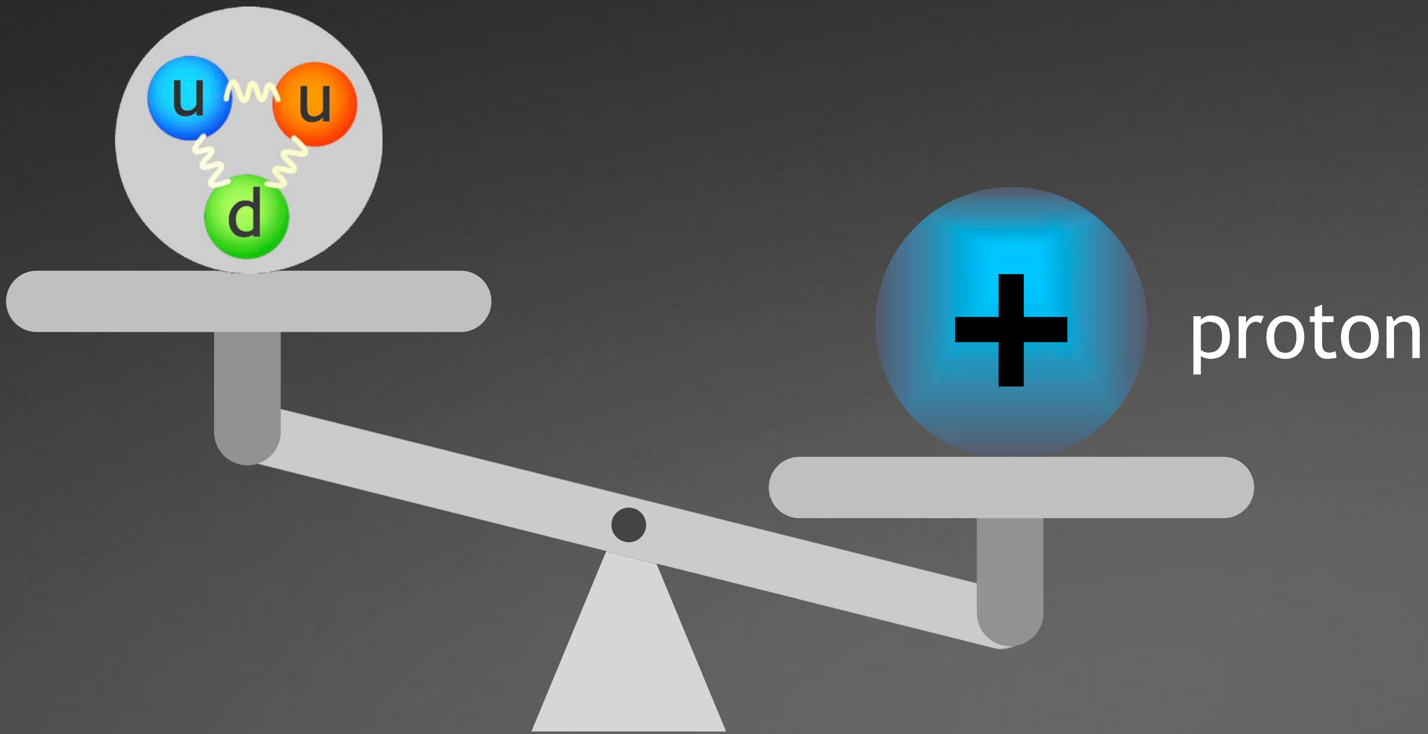
force carriers

Bosons are force carriers.

Photons carry the electromagnetic force. *W* and *Z* bosons carry the weak force that is reponsible for radioactive decay. Gluons carry the strong force that binds quarks together.

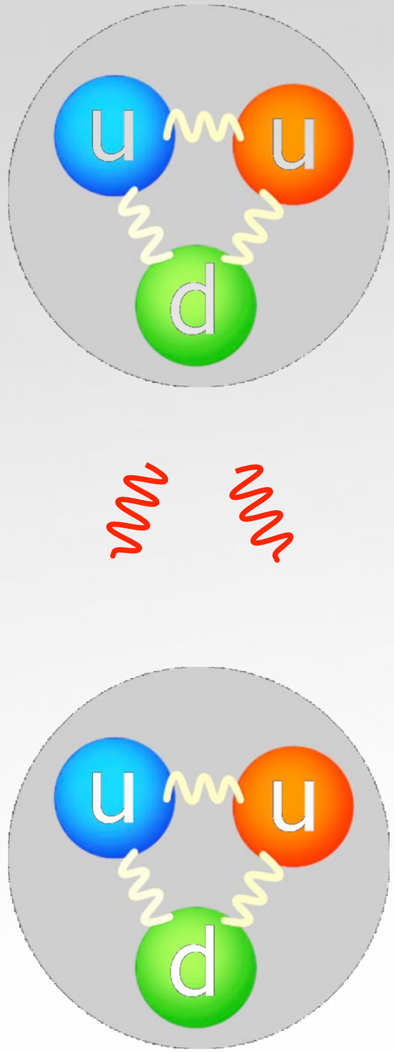
A question of mass

The total mass of the quarks in a proton only accounts for 9% of its mass.



Why don’t masses of the quarks add up to the mass of the proton?

A question of charge



The electrostatic force of repulsion between two protons 1.6×10^{-15} m apart in the nucleus of an atom is **90 N.**

The strong force, which holds quarks together, also stops the nucleus from flying apart.

What can you deduce about the magnitude of the strong force?

The Higgs boson

u up	*c* charm	*t* top
d down	*s* strange	*b* bottom

ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino
e electron	μ muon	τ tau

γ photon
Z Z boson
W W boson
g gluon

H Higgs boson

The Higgs boson:

- is the last of 61 particles predicted by the *standard model* to be discovered;
- is responsible (through the Higgs field) for giving other particles their mass;
- and has a large mass, so it can only be produced when huge amounts of energy are released.

Can you suggest why the Higgs boson took so long to be discovered?

Naming the quark

Murray Gell-Mann originally named the quark after the sound made by ducks. He was undecided on how to spell it, until he found the word 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.
>
> James Joyce, *Finnegans Wake*

Source: http://en.wikipedia.org/wiki/Quark

ast0591 | version 1.2 revised January 2014

spice

secondary teachers' enrichment program (science)