2008 was a very exciting year for particle physics... (kind of)

Page last updated at 11:23 GMT, Wednesday, 10 September 2008 12:23 UK

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'Big Bang' experiment starts well

Guide | Science | Engineering | Computing | Q

By Paul Rincon
Science reporter, BBC News

Scientists have hailed a successful switch-on for an enormous experiment which will recreate the conditions a few moments after the Big Bang.

The LHC has been in construction for some 13 years

They have now fired two beams of particles called protons around the 27km-long tunnel which houses the Large Hadron Collider (LHC).

The £5bn machine on the Swiss-French border is designed to smash protons together with cataclysmic force.

Scientists hope it will shed light on fundamental questions in physics.

The first - clockwise - beam completed its first circuit of the underground tunnel at just before 0930 BST. The second - anti-clockwise - beam successfully circled the ring after 1400 BST.

So far, all the beams have been stopped, or "dumped", after just a few circuits.

On Thursday, engineers hoped to inject clockwise and anti-clockwise protons again, but this time they plan to "close the orbit", letting the beams run continuously for a few seconds each.

> **"We will be looking at what the Universe was made of billionths of a second after the Big Bang"**
>
> Dr Tara Shears, University of Liverpool

What is the Large Hadron Collider?

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Hadron Collider halted for months

Superconducting magnets are cooled down using liquid helium

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But a Cern
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The LHC is
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Scientists I

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Page last updated at 18:17 GMT, Monday, 17 November 2008

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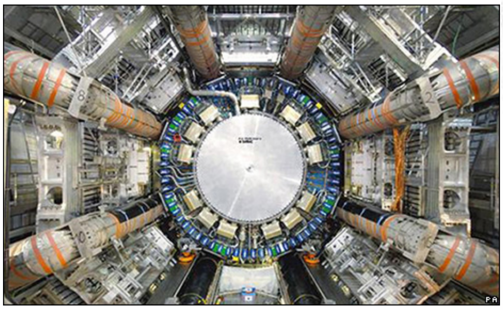
Hadron Collider repairs cost £14m



The £5bn Large Hadron Collider (LHC) is intended to smash protons - one of the building blocks of matter - into each other

Repairing the Large Hadron Collider (LHC) near Geneva will cost almost £14m ($21m) and "realistically" take until at least next summer to start back up.

1

Could 2009 be a scary year for particle physics?

From The Times
September 6, 2008

Large Hadron Collider will not turn world to goo, promise scientists

The 'end of the world is nigh' suspicions have been so powerful that the scientists behind the LHC have published a report to allay their fears

IMAGE :3 of 3

Joanna Sugden

RECOMMEND?

Cancel your plans for next Wednesday, it could be your last day on Earth. Or could it?

If you believe a vocal lobby of doomsayers, at the flick of a switch on the Large Hadron Collider (LHC) next week the world will be consumed from the inside out and turned to a pile of grey goo. Yesterday their apocalyptic warnings were challenged by a report from the scientists behind the project outlining just how safe it is to recreate the Big Bang under the France-Switzerland border.

The Large Hadron Collider - the atom-smashing machine built underneath the Alps - has sent more internet-based harbingers of doom into a spin than it will have atomic particles whizzing around its 17-mile circumference when it is put into action next week. They fear that the energies released will be so powerful that a runaway black hole will be created that will engulf the planet or produce "quantum strangelets" transforming the Earth into a dead lump of "strange matter".

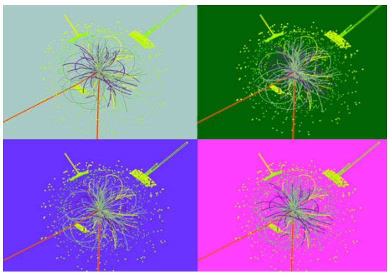
guardian.co.uk

Large Hadron Collider: Scientists' wish list for the LHC

From the particle that gives everything its mass, to mini black holes and extra spatial dimensions, the LHC has the potential to make a host of amazing discoveries

Ian Sample, science correspondent
guardian.co.uk, Wednesday 10 September 2008 13.37 BST

A larger | smaller



Simulation of a detection of the Higgs boson. Photograph: Cern

When the Large Hadron Collider is up to full power, it will be crashing protons together 600 million times per second. After each impact, giant detectors will scour the subatomic wreckage looking for evidence of new physics.

Scientists have some pretty good hunches about what the machine might find, from creating never-before-seen particles to discovering hidden dimensions and dark matter, the mysterious substance that makes up 25% of the universe.

2

2009 should be *the* really exciting year!

Page last updated at 08:25 GMT, Monday, 28 September 2009 09:25 UK

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LHC gets warning system upgrade

By Paul Rincon
Science reporter, BBC News

Cern has spent about 40m Swiss Francs (£24m) on repairs

Engineers hope an early warning system being ... Large Hadron Collider could prevent incidents which shut the machine last year.

The helium leak last September, which resulted fro... between magnets, has delayed the start of science ... more than a year.

Officials aim to re-start the collider, known as the ... November.

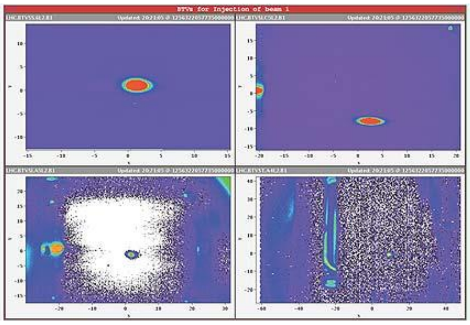
Telegraph.co.uk

The Large Hadron Collider at Cern is fired up for first time since 'quench'

The Large Hadron Collider at Cern in Geneva has been fired up for the first time since its high-profile failure last year.

By Tom Chivers
Published: 12:32PM GMT 27 Oct 2009

The huge particle accelerator successfully powered some protons and lead ions around short sections of its 17-mile ring on Friday, and everything seemed to be working correctly.



The cross-section of the ion beam flowing through the LHC, just before the ALICE detector Photo: CERN

Engineers and scientists (http://http://www.telegraph.co.uk/science/) have been warily putting it through its paces for the first time since its catastrophic breakdown, or "quench", which happened when two of the LHC (http://www.telegraph.co.uk/science/large-hadron-collider/) 's huge superconducting magnets suffered a short circuit within days of it powering up (/science/large-hadron-collider/3352108/Large-Hadron-Collider-broke-down-hours-after-launch.html) .

Page last updated at 13:46 GMT, Friday, 16 October 2009 14:46 UK

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LHC gets colder than deep space

By Paul Rincon
Science reporter, BBC News

... for hints of the elusive Higgs boson particle

...(LHC) experiment has once again ... places in the Universe.

...ave now been cooled to their operating ...71C; -456F) - colder than deep space.

...particle beams around the LHC are ... using liquid helium.

...d-to-end in a 27km-long circular tunnel ...order.

...t milestone ahead of the collider's ...r half of November.

...en a ...nch" ...m to

> "It's a bit like firing knitting needles from across the Atlantic and getting them to collide half way"
>
> James Gillies, director of communications, Cern

BBC Radio 4 Material World: One year on from the LHC's switch-on

...e ...l up ...ce.

...periment ever built, the Large Hadron ...itions just after the Big Bang. It is ...ganization for Nuclear Research (Cern),

... fired down pipes running through the ...avel in opposite directions around the ...eed of light.

...tunnel, the proton beams cross paths, ...th cataclysmic energy. Scientists hope ...bris of these collisions, revealing ... the nature of the cosmos.

The University of Edinburgh
School of Physics & Astronomy

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Hot off the press: Edinburgh joins the LHC effort!

Home › News & Events › Edinburgh joins the ATLAS collaboration

Edinburgh joins the ATLAS collaboration

Published on Tue, 20 Oct, 2009 at 15:36

Physicists from Edinburgh are to join the quest for the Higgs boson particle at CERN in Switzerland.

The ATLAS detector (toroidal magnet system)

The researchers will join the international ATLAS collaboration seeking to verify the existence of the theoretical sub-atomic particle, a crucial part of the Standard Model of Particle Physics and Cosmology.

The ATLAS experiment aims to address the most important unsolved questions in the universe, i.e., whether or not, the Higgs boson exists, and what the fundamental particle mass generation mechanism is. It could also discover the origin of dark matter and new physics models of nature (e.g. super-symmetry).

Higgs theory

Emeritus Professor Peter Higgs predicted the existence of the Higgs particle while working at the University in the 1960s. If experiments at CERN's massive atom-smasher prove the Professor's theory correct, he is tipped to win the Nobel Prize for physics.

Joining the research at CERN are Dr Philip Clark, Dr Victoria Martin, Dr Andy Buckley, Dr Wahid Bhimji and Dr Andy Washbrook together with students Ben Wynne, Ben Smart and Brendan O'Brien and technician Andrew Main.

They will work on the ATLAS detector, one of four experiments analysising collisions at the Large Hadron Collider as it aims to recreate the conditions of the Big Bang.

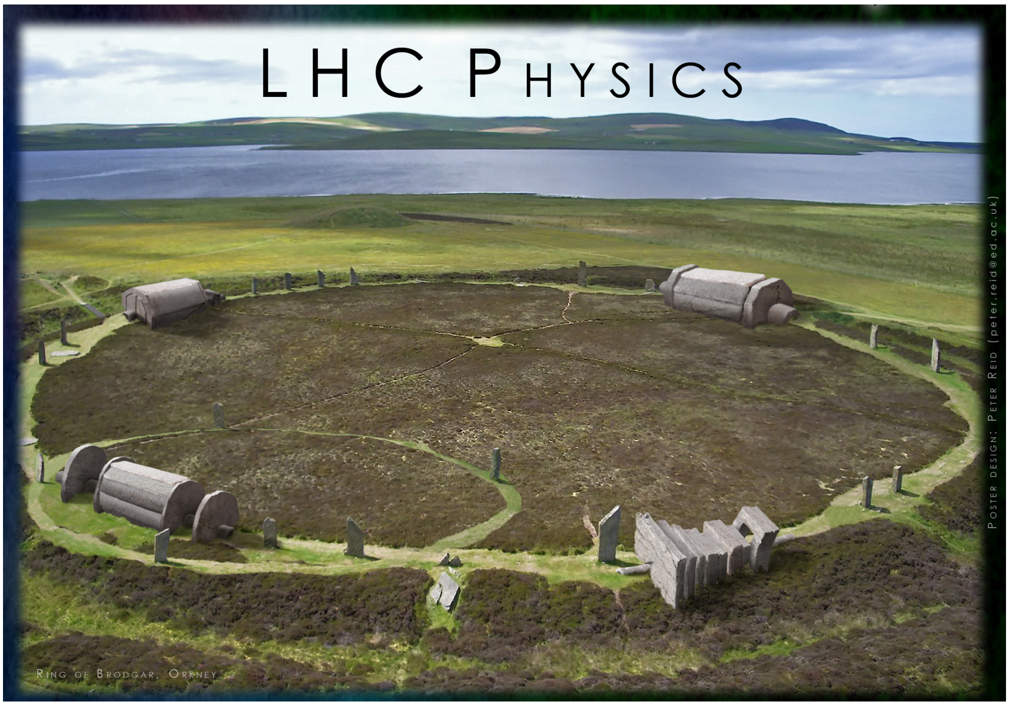
Impact of research

Their work will involve modelling and simulating the particle collision process in order to understand the detector response and the complex data produced by the experiments. They will also contribute to the operation of the detector itself and provide software to manage the data produced.

Subatomic Physics:

Particle Physics Lectures

“Physics of the Large Hadron Collider”



Particle Physics Lectures Outline

Lecture 1 - Introduction
- The Standard Model of particle physics
- The fundamental particles and forces

Lecture 2 - Practical Particle Physics
- Measuring particle physics
- Units, decays, scattering
- Quantum numbers

Lecture 3 - Quantum Electrodynamics (QED)
- Anti-particles
- Quantum description of electromagnetism
- Feynman diagrams

Lecture 4 - The LHC
- Particle acceleration
- Colliders

Lecture 5 - The ATLAS Detector
- Interactions of particles in matter
- Collider Detectors

Lecture 6 - Particle Physics at Past Colliders
- The Large Electron Positron Collider
- Evidence for quarks and colour
- $e^+e^- \rightarrow$ hadrons

Lecture 7 - Protons, Quarks and Strong Interactions
- Gluons, hadronisation
- Quark Confinement
- Running coupling constant

Lecture 8 - Weak Interactions
- Muon and tau decay
- Weak quark decays

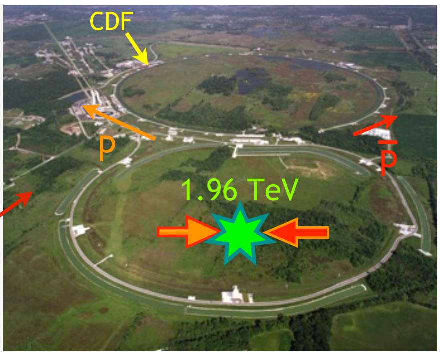
Lecture 9 - Electroweak and the Higgs boson
- W and Z bosons
- The Higgs mechanism

Lecture 10 - Beyond the Standard Model
- Supersymmetry
- Extra dimensions ...

Particle Physics and Me

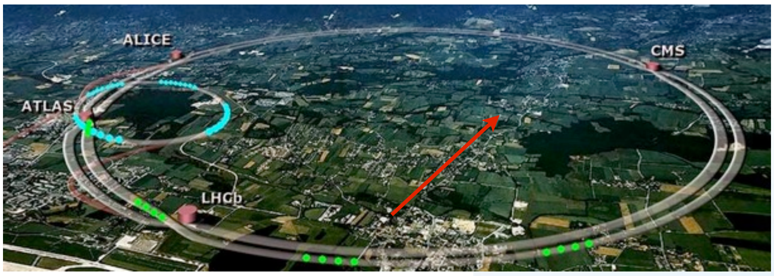
Dr Victoria Martin

JCMB room 5419 victoria.martin@ed.ac.uk



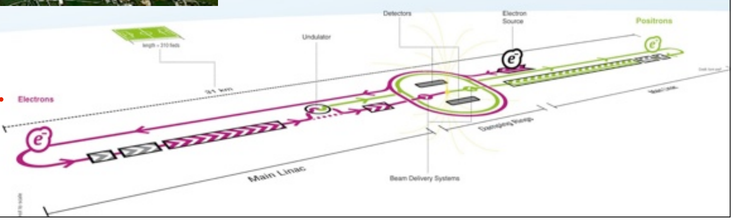
My research deals with Particle Physics at Colliders.
I'm currently involved with three projects:

1. The CDF experiment at the Fermilab Tevatron, near Chicago. The Tevatron collides protons and anti-protons at ~2TeV.



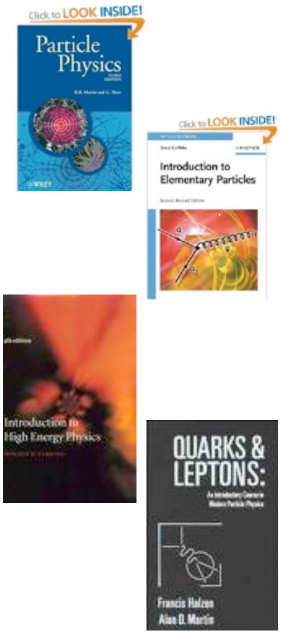
2. The ATLAS experiment at the Large Hadron Collider. The LHC collides protons on protons at 14 TeV.

3. The international linear collider (ILC). Design is to collide electrons and positrons at 0.5 - 1 TeV (or more?)



Books etc

- In conjunction with attending the lectures you will need to read around the subject to fully understand the material.



Most up to date:

- *Level of this course:* Particle Physics, by B.R. Martin & G. Shaw, 3rd edition (Wiley 2008)
  - 10 copies in JCM Library
- *More advanced:* Introduction to Elementary Particles by D. Griffiths, 2nd edition (Wiley 2008)
  - 4 copies in JCM Library

Oldies (but goodies):

- Introduction to High Energy Physics - D.H. Perkins, 4th edition (CUP 2000)
- Quarks and Leptons –F. Halzen & A.D. Martin (Wiley 1984)

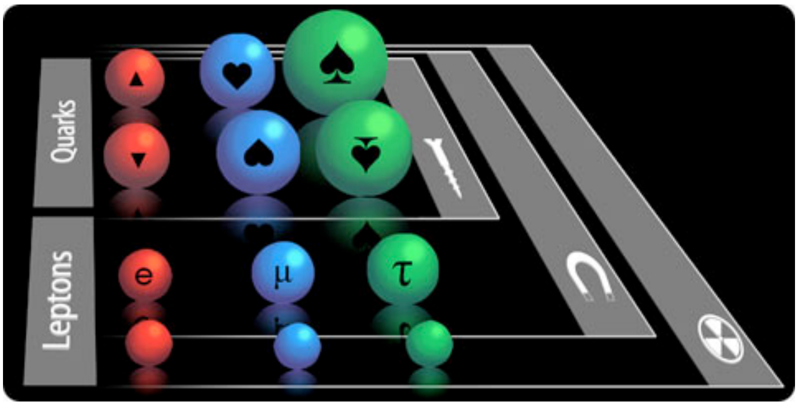
Further Resources:

- For more information that you could ever need on every particle ever: http://durpdg.dur.ac.uk/lbl/
- Information about LHC and LHC physics: www.cern.ch www.atlas.ch

Subatomic Physics:

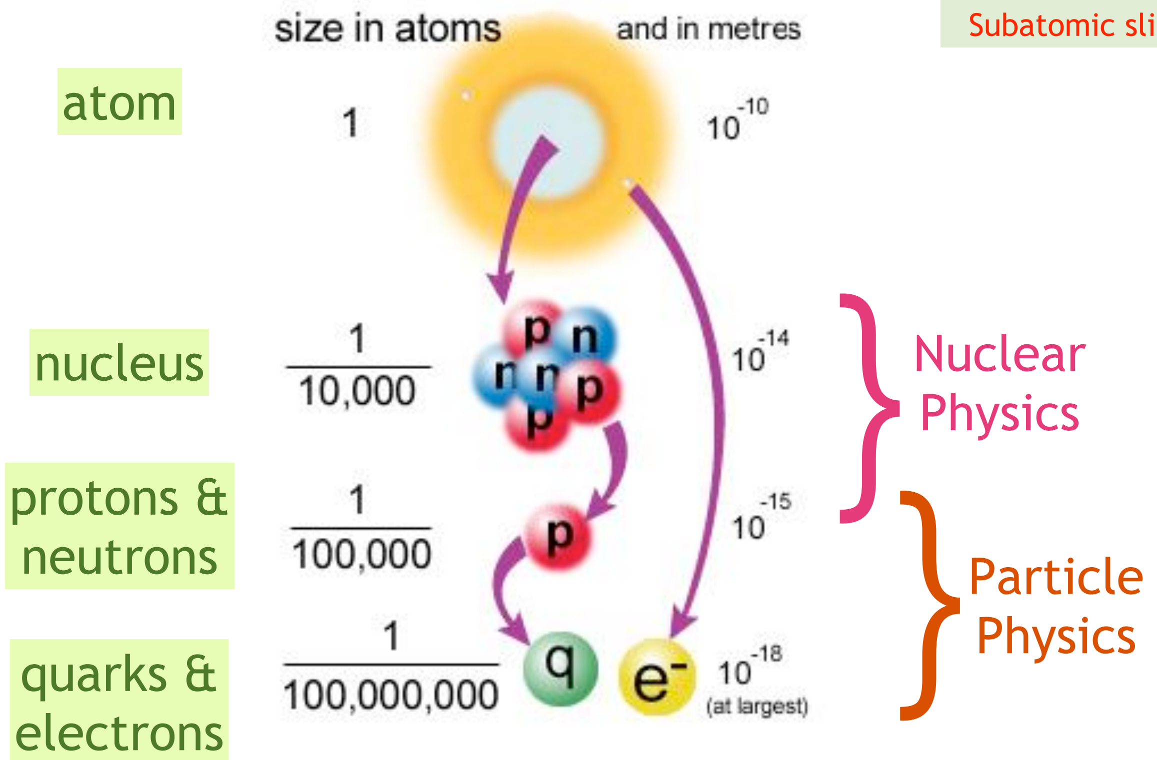
Particle Physics Lecture 1

Our current understanding:
"The Standard Model of Particle Physics"



From the Atom to Subatomic

from introductory Subatomic slides



History of the Universe

from introductory Subatomic slides

10^{-43}s		Universe goes through superfast inflation
10^{-32}s	10^{27} °C	Post inflation - soup of electrons, quarks and other particles
10^{-6}s	10^{13} °C	Quarks clump into protons and neutrons
10^{2} s	10^{8} °C	Superhot fog (protons and electrons not yet bound into atoms). Primordial nucleosynthesis (up to ^{4}He)
3×10^{5} yr	10^{5} °C	Electrons combine with protons and neutrons to form atoms (H, He)
1×10^{9} yr	-200 °C	Star/Galaxy formation synthesis of heavier nuclei
15×10^{9} yr	-270 °C	First stars die and eject heavy nuclei into space - further star formation (and planets)

Time

Particle Physics (from 10^{-32}s to 10^{-6}s)

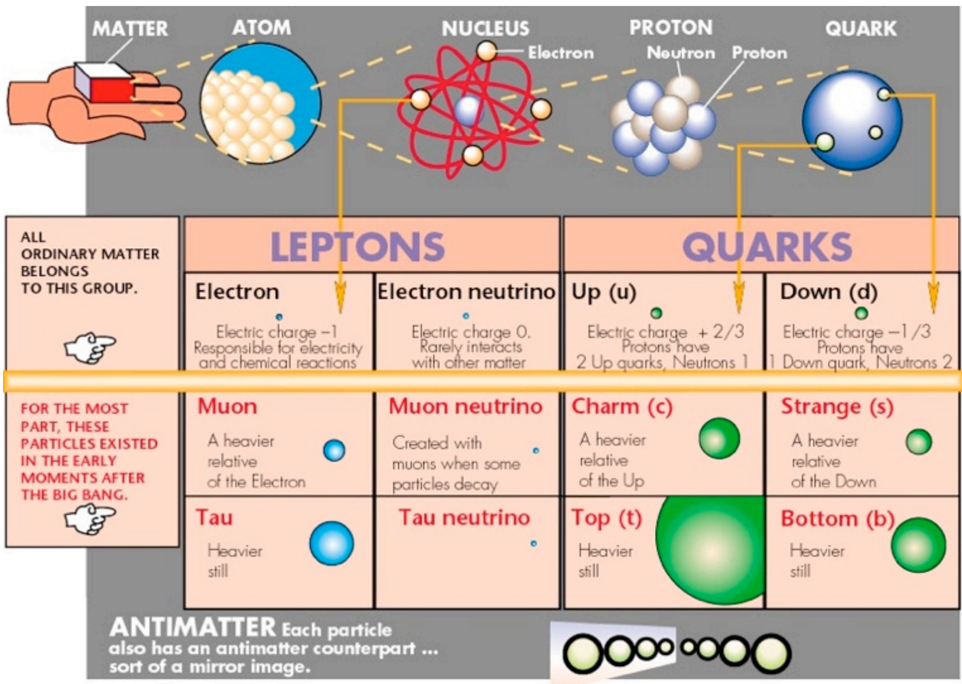
Nuclear Physics (from 10^{-6}s to 10^{2} s)

Subatomic physics looks at:

- (very) short distances
- (very) early time in the universe
- (very) high energy densities

The Standard Model

The current understanding of the fundamental particles and the interactions between them is called the "**Standard Model of Particle Physics**".



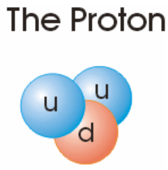
Boson-mediated **FORCES**	
Gravity	?
Electro-magnetism	γ photon
Weak	$W^{\pm}$, Z^{0}
Strong	gluons

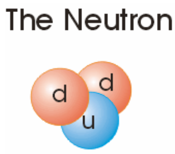
Basic Particles (1st Generation)

The particles that you know already, *e.g.* from beta decay: $\mathbf{n} \rightarrow \mathbf{p}\, e^{-}\, \overline{\nu_e}$

Leptons
Electron and neutrino

Quarks
Nucleons are bounds states of up-quarks and down-quarks





Basic Constituents of Matter
Four spin-½$\hbar$ **fermions**

Particle	Symbol	Electric Charge	Type
electron	e^{-}	-1	lepton
neutrino	ν_e	0	lepton
up-quark	$\mathbf{u}$	+2/3	quark
down-quark	$\mathbf{d}$	−1/3	quark

- Nuclear physics description of beta decay: $\mathbf{n} \rightarrow \mathbf{p}\, e^{-}\, \overline{\nu_e}$
- Particle physics description of beta decay: $\mathbf{d} \rightarrow \mathbf{u}\, e^{-}\, \overline{\nu_e}$

- In addition to electric charge, every quarks carries an additional “colour charge” quantum number: either red, blue or green.

Higher Generations

Nature replicates itself: there are three **generations** of quarks and leptons

1st Generation		2nd Generation		3rd Generation		charge, e
electron	e^{-}	muon	μ^{-}	tau	τ^{-}	-1
electron neutrino	ν_e	muon neutrino	ν_μ	tau neutrino	ν_τ	0
down quark	$\mathbf{d}$	strange quark	$\mathbf{s}$	bottom quark	$\mathbf{b}$	−⅓
up quark	$\mathbf{u}$	charm quark	$\mathbf{c}$	top quark	$\mathbf{t}$	+⅔

Ordinary Matter: built from the 1st generation

Higher Generations:
- copies of $(\nu_e, e^{-}, \mathbf{u}, \mathbf{d})$
- undergo identical interactions
- only difference is mass of particles
- generations are successively heavier

Why 3 generations?
symmetry/structure not understood!

Antiparticles

More in PP Lec 2 (& Quantum Physics §14.5)

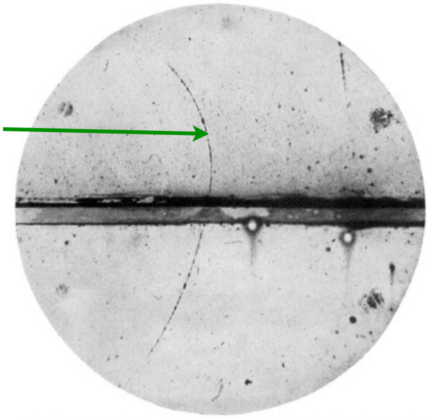
Combining relativity and quantum mechanics implies **every particle has a corresponding antiparticle**

Antiparticles of the SM particles are **antimatter**

Compared to its matter partner, an antiparticle has:

- equal mass
- opposite electric charge
- opposite "additive" quantum numbers

"Track" left by a positron



Example: positron (e^+) antiparticle of the electron ("anti-electron")
Discovered in 1931 by Carl Anderson

Notation: bar over symbol or minus ↔ plus

e.g. for first generation: $\mathrm{u} \leftrightarrow \bar{\mathrm{u}} \quad \mathrm{d} \leftrightarrow \bar{\mathrm{d}} \quad e^- \leftrightarrow e^+ \quad \nu_e \leftrightarrow \bar{\nu}_e$

Subatomic Forces

from introductory Subatomic slides

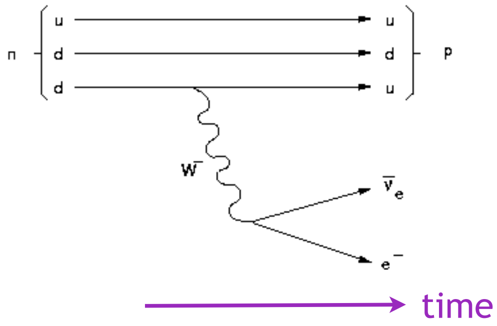
- At subatomic scales interactions between particles and nuclei are caused by the **three subatomic forces:**
  - The **electromagnetic** force
  - The **weak** nuclear force
  - The **strong** nuclear force
- The interactions due to these forces are evident in:
  - **Scattering:** e.g. scattering of protons on protons at the LHC
  - Particle **Decay**: e.g. decay of radioactive nuclei, decays of cosmic-ray muons
  - Nuclear **Fission** and **Fusion,** e.g.: reactions in a nuclear reactor

$$^{235}_{92}\mathrm{U} + \mathrm{n} \to {}^{236}_{92}\mathrm{U} \to {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3\mathrm{n}$$

The Forces of Particle Physics

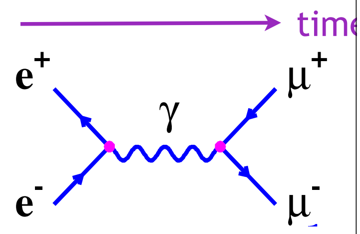
Strong	Electromagnetic
• Strongest force • Acts on quarks only • propagated by (8) gluons, g	• 2nd strongest force • Acts on charged particles • propagated by photon, γ
Weak	**Gravity**
• 3rd strongest force • Acts on all particles • propagated by $W^{\pm}$ and Z^0 bosons	• weakest force - negligible at PP scale • Acts on all particles

- Quantum mechanical description uses "messenger particles" to propagate the force between particles.
- Messenger particles are spin-1$\hbar$ bosons
- *e.g.* beta decay $\mathbf{n}\rightarrow\mathbf{p}\ e^-\ \bar{\nu}_e$ propagated by a W^- boson



What do the particles do?

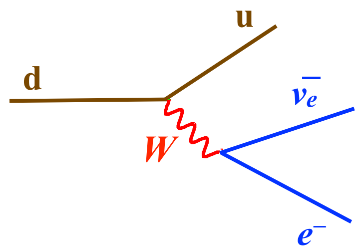
see: JH D&R lectures 2, 14, 15

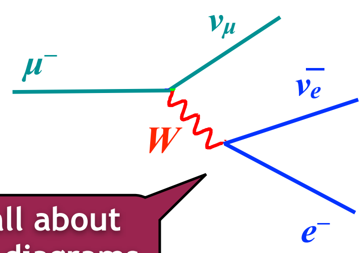


Particles interact via one of the forces: strong, electromagnetic or weak.

Two main interactions:

- **Particle scattering**
  - can be elastic or inelastic
  - we'll mainly consider inelastic scattering
  - *e.g.* scattering of electron and positron, producing a pair of muons $e^+e^-\rightarrow\mu^+\mu^-$
- **Particle decay**
  - *e.g.* Beta decay: $\mathbf{d}\rightarrow\mathbf{u}\ e^-\ \bar{\nu}_e$
  - *e.g.* Muon decay: $\mu^-\rightarrow e^-\ \bar{\nu}_e\ \nu_\mu$





We'll learn all about these type of diagrams throughout the course

Hadrons: Mesons & Baryons

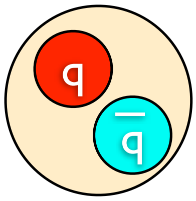
- Free quarks have never been observed - quarks are locked inside **hadrons**
- Hadrons are bound states of quarks: either (**qqq**) or ($\mathbf{q\bar{q}}$)
- Charge of hadron is always integer multiple of electric charge, e
- Colour charge of hadron is always neutral
- Two types of hadrons - **mesons** and **baryons** (also anti-baryons! $\overline{\mathbf{qqq}}$)

Mesons = $\mathbf{q\bar{q}}$

Bound states of quark anti-quark pair

Bosons: spin 0, $1\hbar$, $2\hbar$

e.g. pions



$$\pi^+ = (\mathrm{u\bar{d}})$$
$$\pi^- = (\mathrm{\bar{u}d})$$
$$\pi^0 = \frac{1}{\sqrt{2}}(\mathrm{u\bar{u} - d\bar{d}})$$

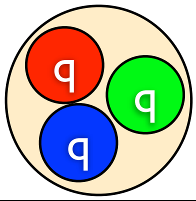
Baryons = qqq

Three quark bound states

Fermions: spin $1/2\hbar$, $3/2\hbar$ ...

e.g. proton (uud), neutron (udd)

anti-baryons *e.g.* anti-proton



$$p = (\mathrm{uud})$$
$$n = (\mathrm{udd})$$
$$\bar{p} = (\mathrm{\bar{u}\bar{u}\bar{d}})$$

Summary

The Standard Model of Particle Physics

An elegant theory that describes accurately (almost) all measurements in particle physics

Matter

- fermions, spin-½$\hbar$
- 3 generations of quarks & leptons

Quarks and Leptons			Charge, e
ν_e e	ν_μ μ	ν_τ τ	0 −1
u d	c s	t b	+2/3 −1/3

- Antimatter partner for each fermion
- Quarks bind together to form hadrons - **mesons** and **baryons**

Forces

- mediated by the exchange of spin-$1\hbar$ bosons

Interaction	Gauge Bosons	Charge, e
Strong	gluons, g	0
Electro-magnetic	Photon, γ	0
Weak	W, Z	0, ±1
Gravity	graviton?	0