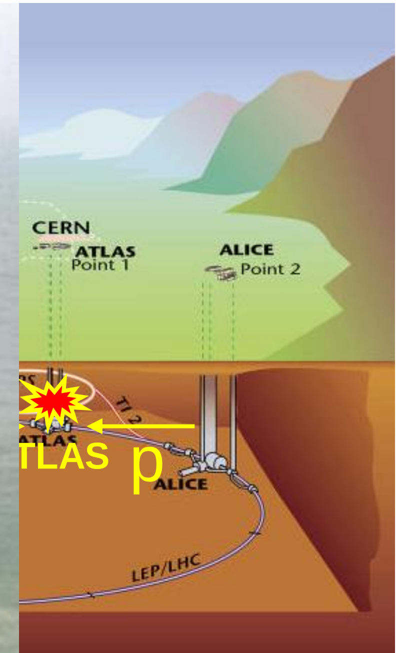
Introduction to Particle Physics I

Sinéad Farrington

18th February 2015

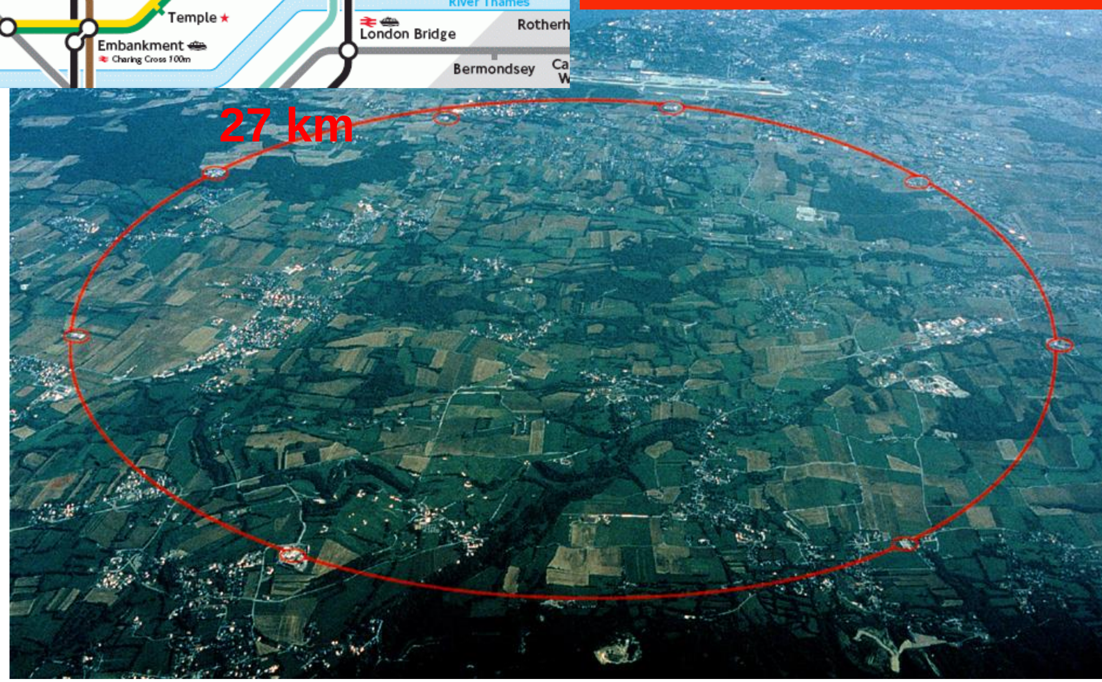
The Large Hadron Collider



- Collisions of … nergy
- Supercondu…
- 2808 bunche…
  - 99.9999… ions per second
  - Interactio… conds

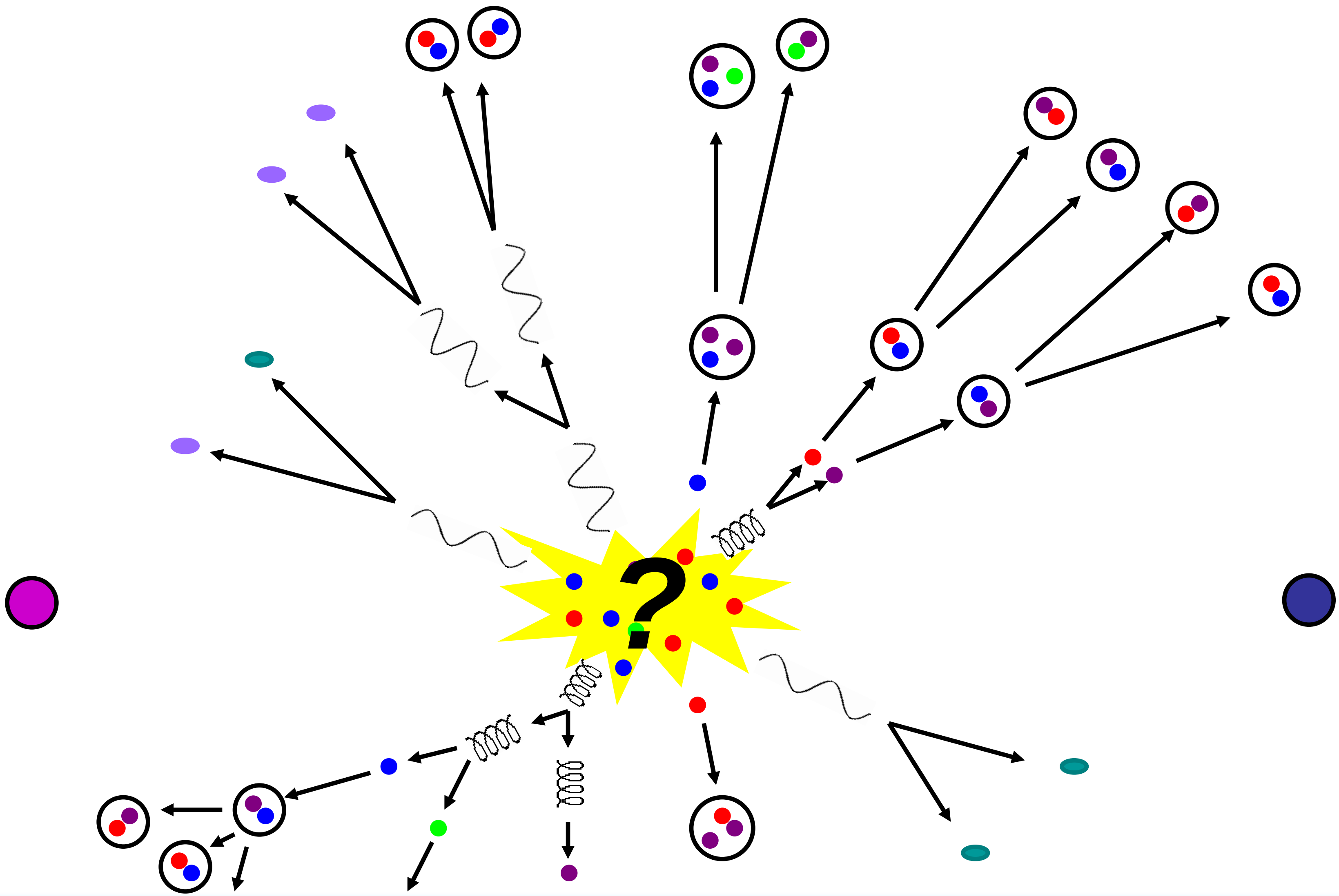
The Large Hadron Collider

	LHC	Circle line
Circumference	27km	22.5km
Depth	100m	15m
Diameter	3.8m	3.4m



Particle Collisions

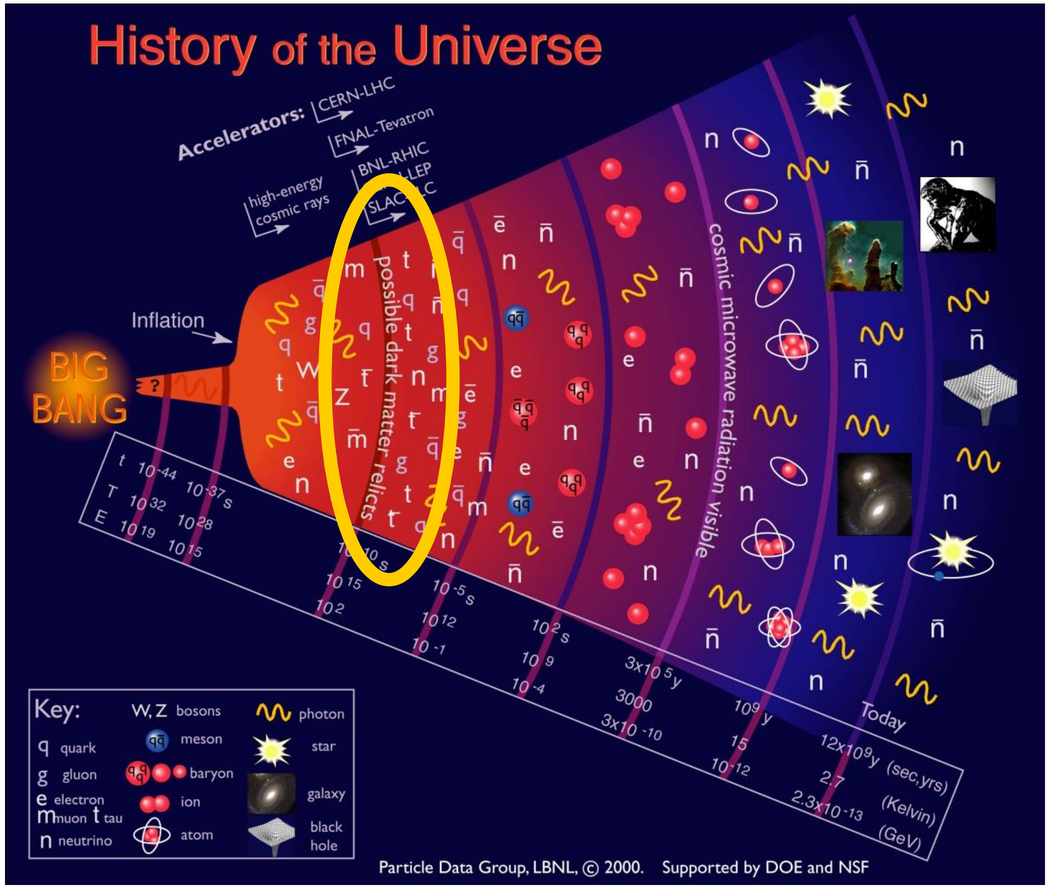
Two particles collide at very high energy
New particles are produced which we detect and study



Why?

Understanding the Universe

Big Bang



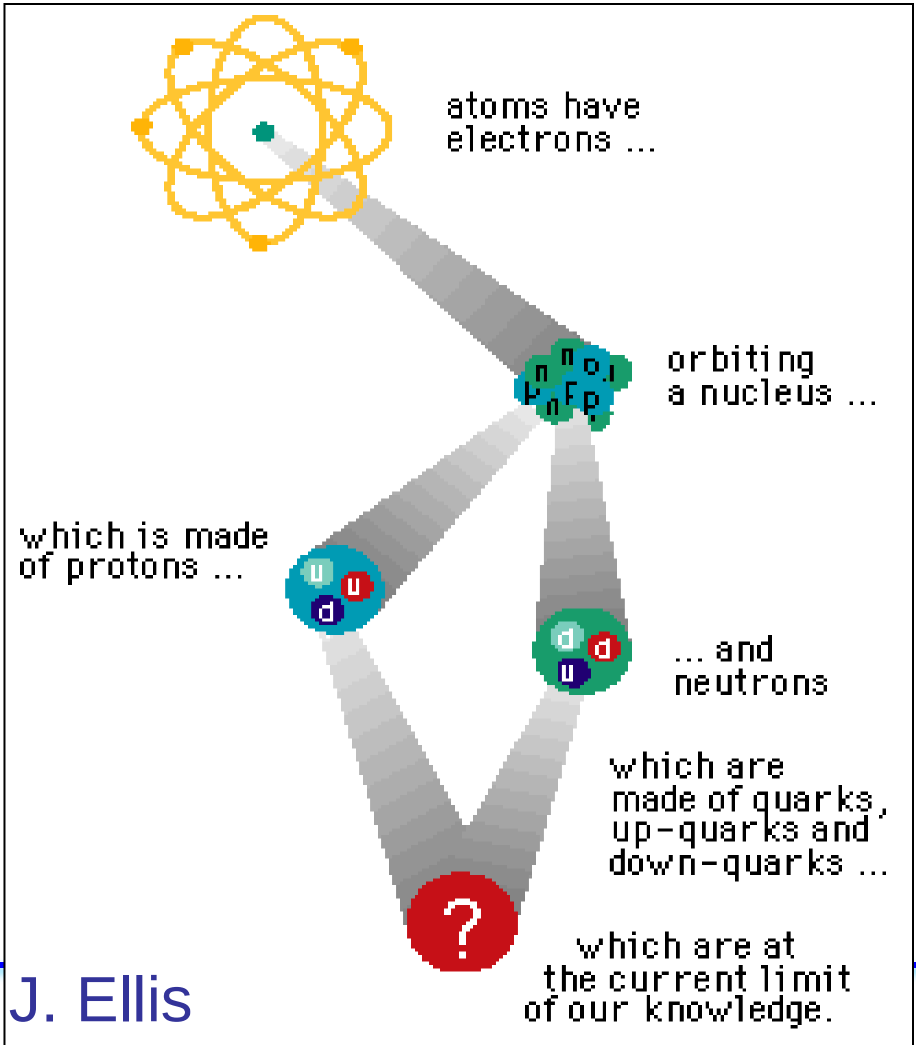
now

Older ….. larger … colder ….less energetic

Sinead Farrington, University of Warwick

How do we do it?

- **To probe the conditions of the early universe we smash particles together**



The Energy Frontier

- Size of structure we can probe with a collider like LHC

$$= \ h \, / \, p$$ (de Broglie, 1924)

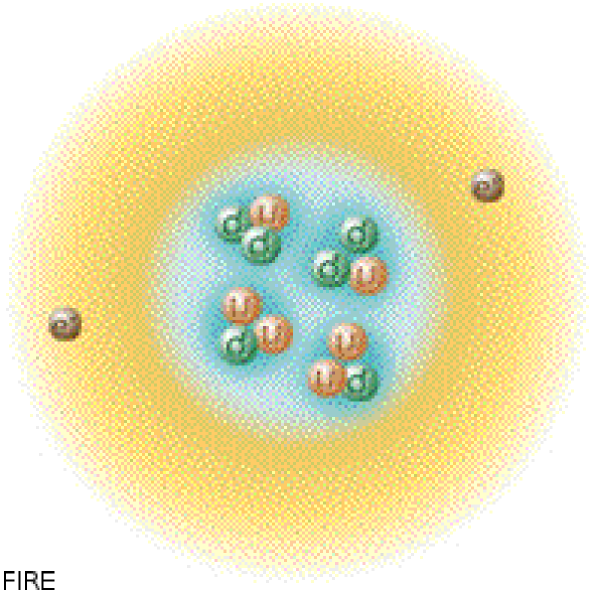
h = Planck's constant = 6.63 x 10^{-34} Js

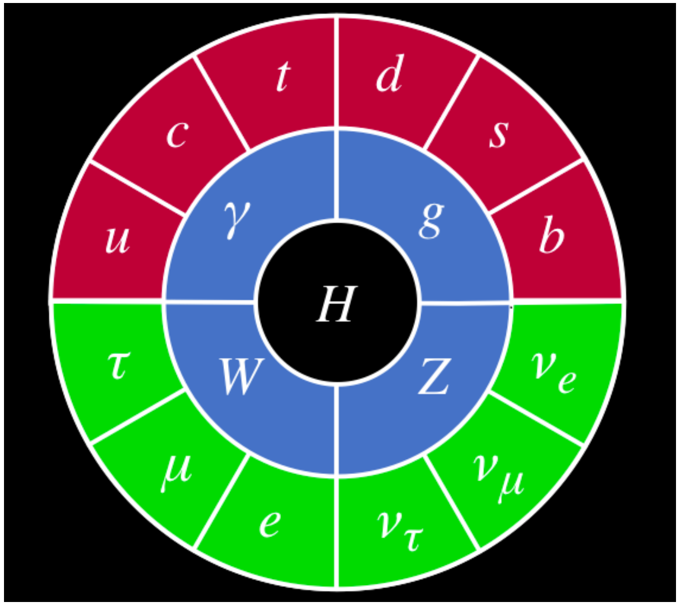
p = momentum of protons

- The larger the momentum (energy), the smaller the size probed

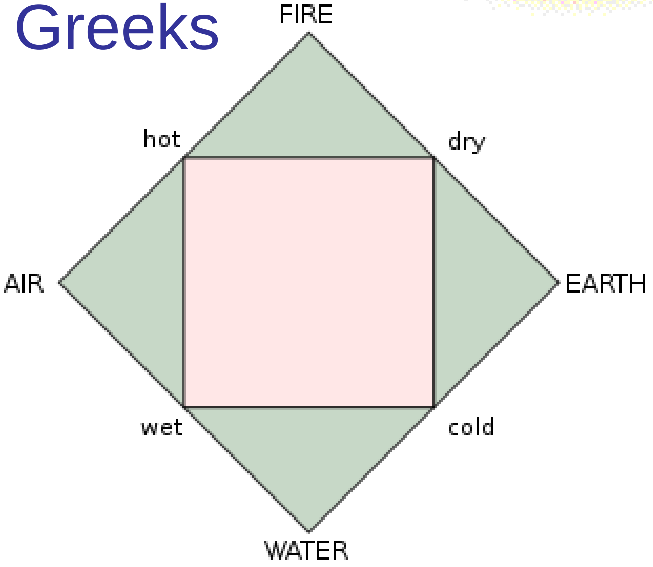
Standard Model of Particle Physics

- Strong, weak and Electromagnetic forces
- Describes interaction of matter particles by the means of force carrier particles





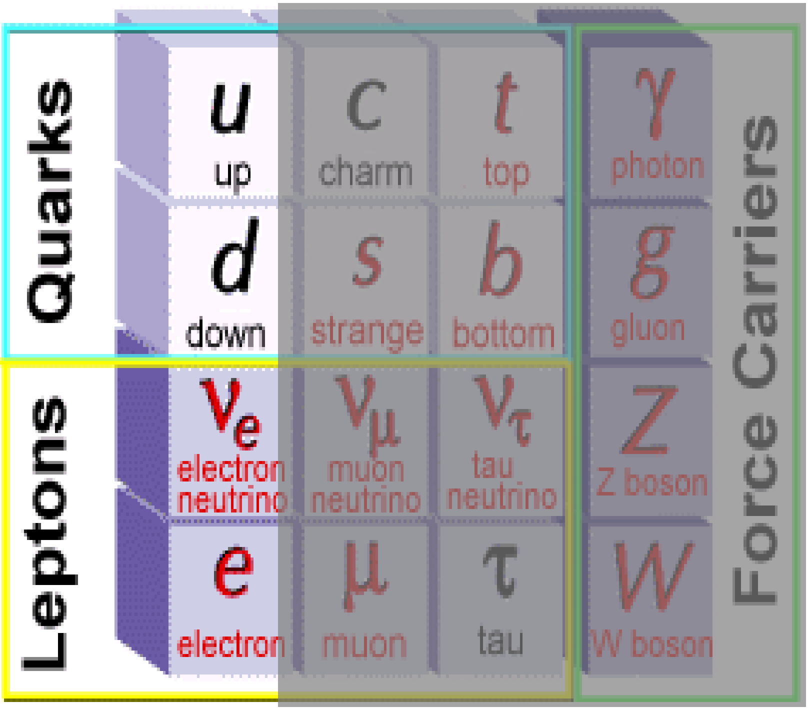
Greeks



Matter Particles

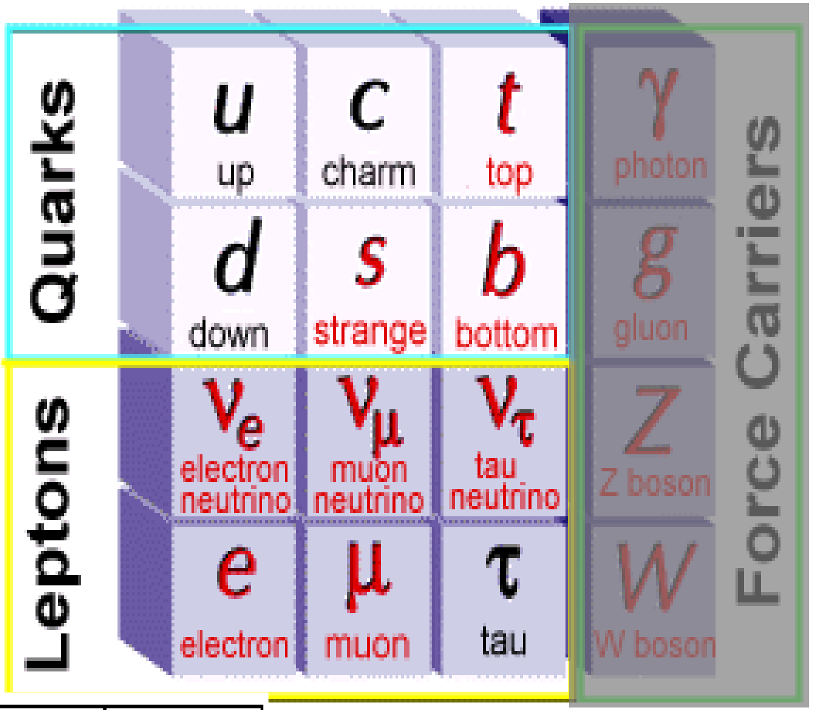
•First generation: these are the only particles needed to make all the matter we see; all chemical elements

Particle	symbol	charge	type
Electron	e-	-1	lepton
Neutrino	ν_e	0	lepton
Up-quark	u	+2/3	quark
Down-quark	d	-1/3	quark



Matter Particles

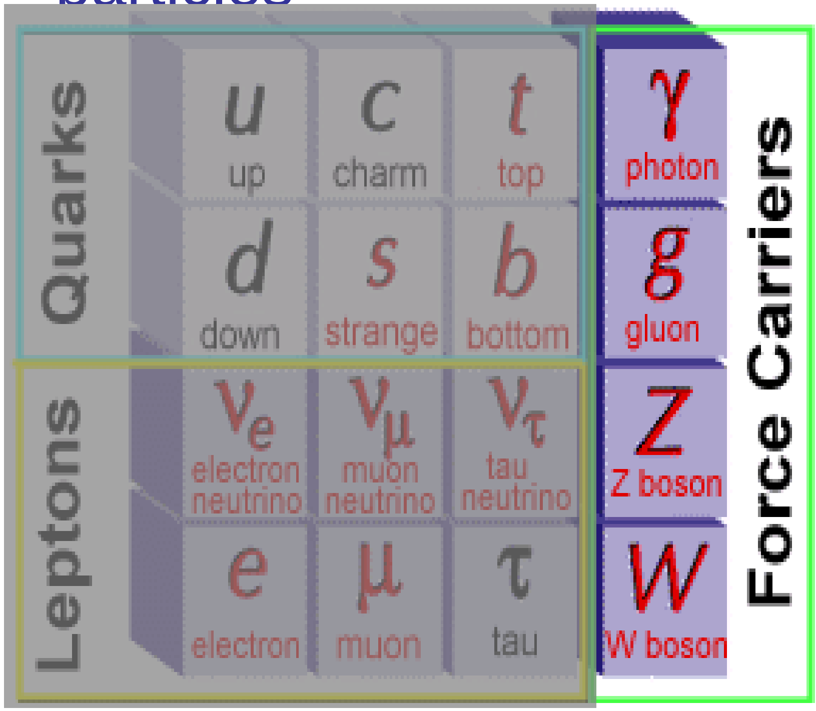
- But we see three generations
  - Undergoing similar interactions
  - Mass hierarchy
  - Each has an antiparticle

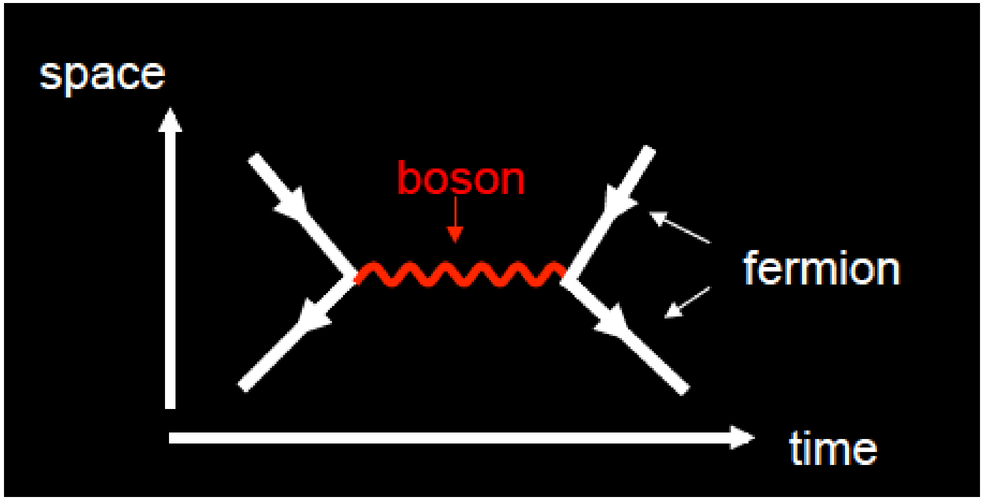


First Generation		2nd Generation		3rd Generation		Charge e
Electron Neutrino	ν_e	Muon neutrino	ν_μ	Tau neutrino	ν_τ	0
Electron	e-	Muon	μ-	Tau	τ-	-1
Up quark	u	Charm quark	c	Top quark	t	+2/3
Down quark	d	Strange quark	s	Bottom quark	b	-1/3

Forces

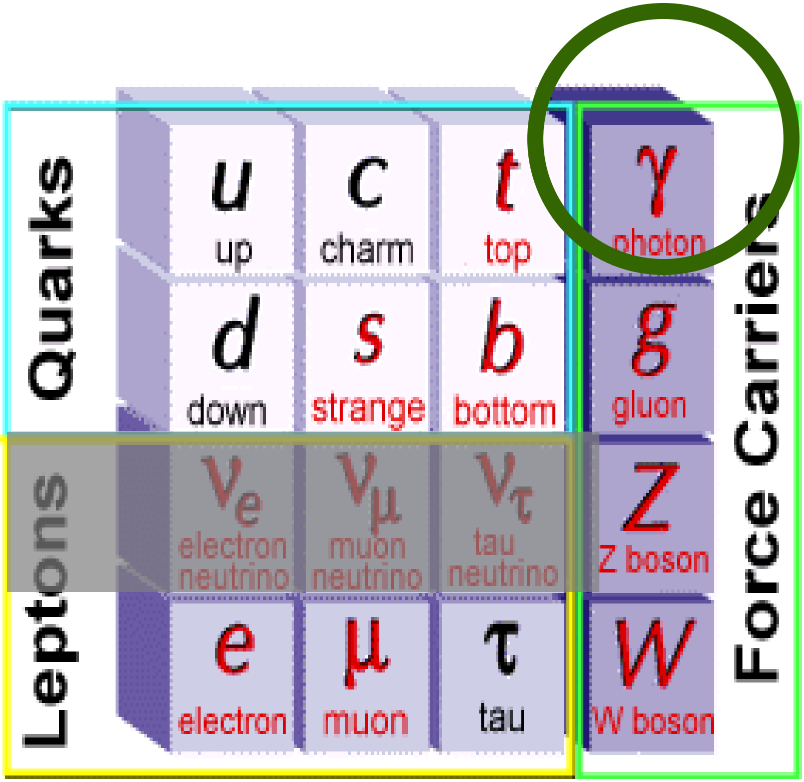
•In the Standard Model, we depict (and calculate) forces as the exchange of a force-carrier boson, between particles





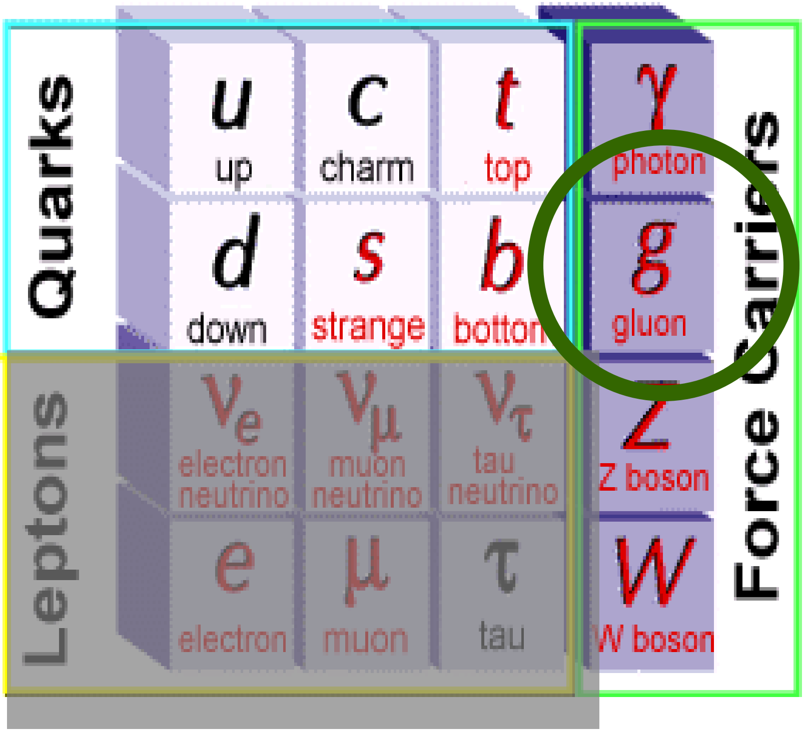
Electromagnetic Force

- Mediated by the photon
- Acts on particles carrying electric charge



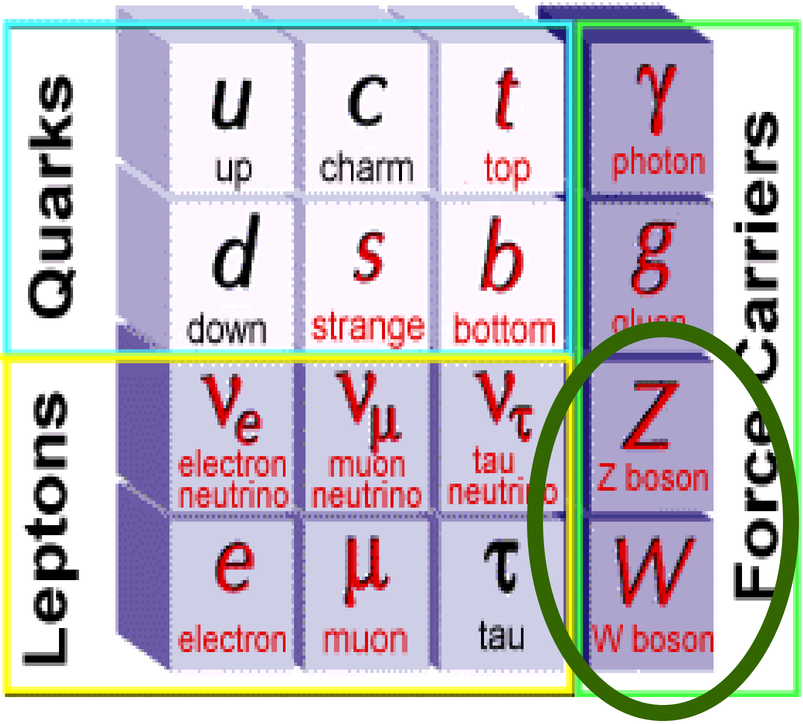
Strong Force

- Mediated by the gluon
- Acts on particles carrying colour charge



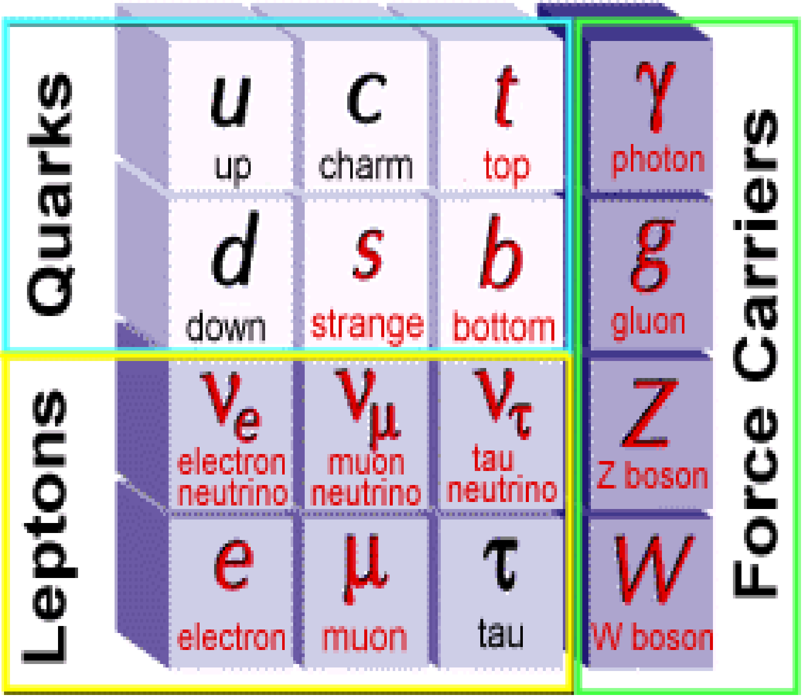
Weak Force

- Mediated by the W, Z bosons
- Acts on all matter particles



Gravitational Force

- Mediated by the Graviton?
- Acts on all massive particles



Relative Strengths of Forces

Each force has an intrinsic strength

Electromagnetism:

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

$$\alpha = \frac{q_1 q_2}{4\pi\varepsilon_0 \hbar c} = \frac{g^2}{4\pi}$$

$$F = \frac{\alpha}{r^2}$$

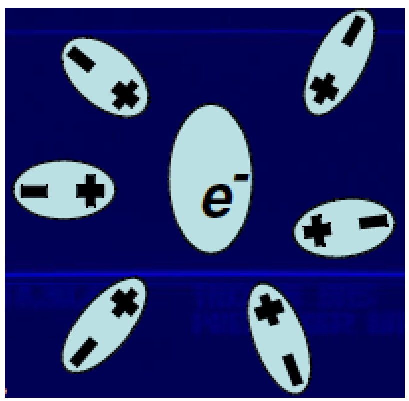
Relative Strengths of Forces

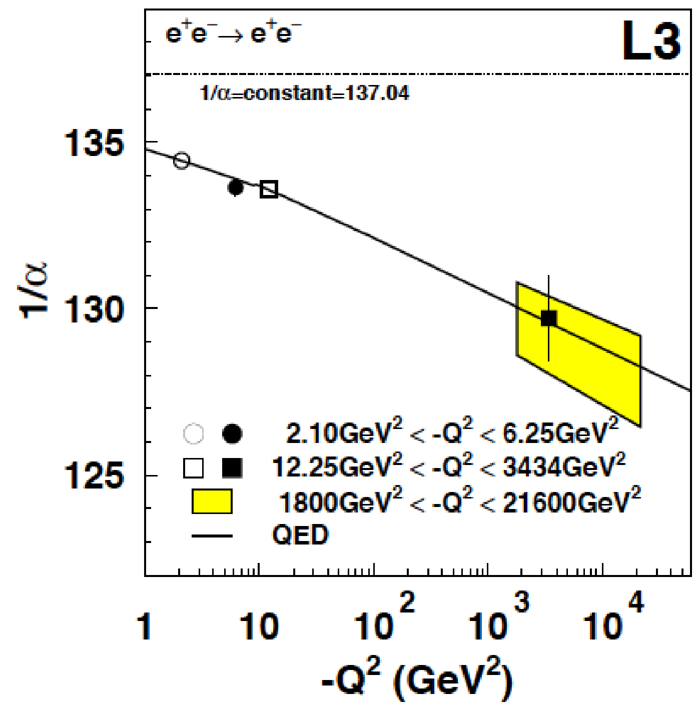
Each force has an intrinsic strength

Strong:	$\alpha_s \sim 1$
Electromagnetic:	$\alpha_{em} \sim 1/137$
Weak:	$\alpha_W \sim 10^{-6}$
Gravity:	$\alpha_g \sim 10^{-40}$

Running Couplings

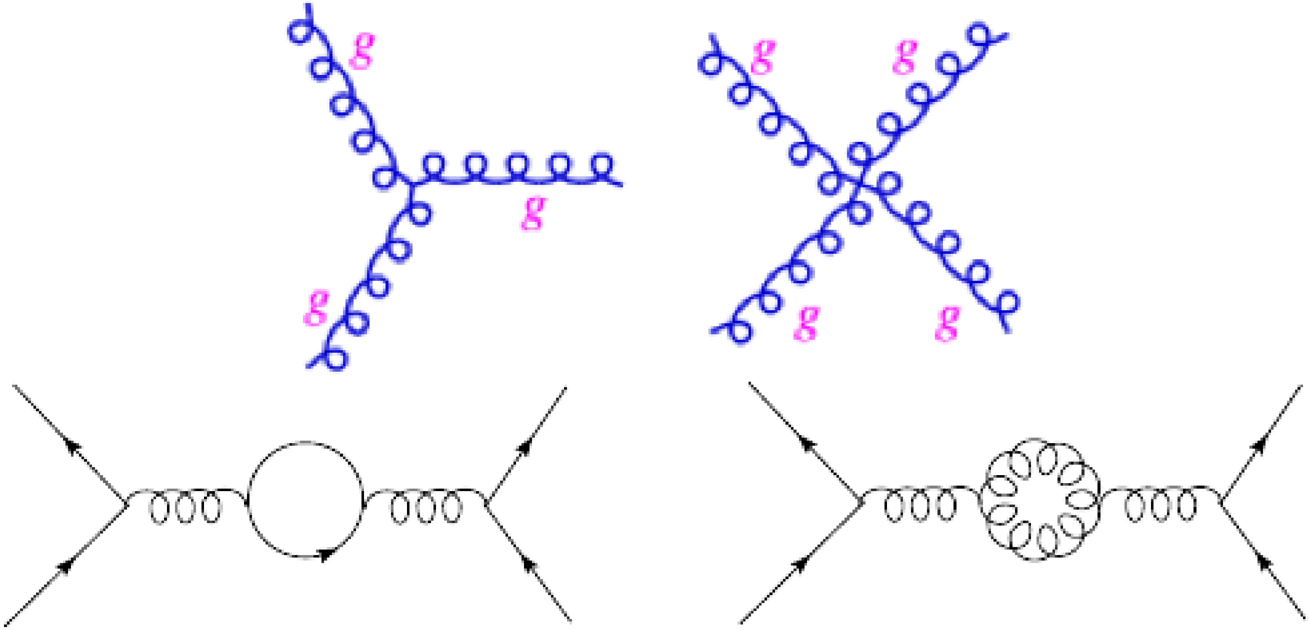
- When is a constant not a constant?
- The forces' intrinsic strengths change with distance (or momentum) scale
- Electromagnetic screening process: the bare particle charge is screened by e^+e^- pairs





Running Couplings

- When is a constant not a constant?
- The forces' intrinsic strengths change with distance (or momentum) scale
- Strong force screening process: same as EM but has an additional effect



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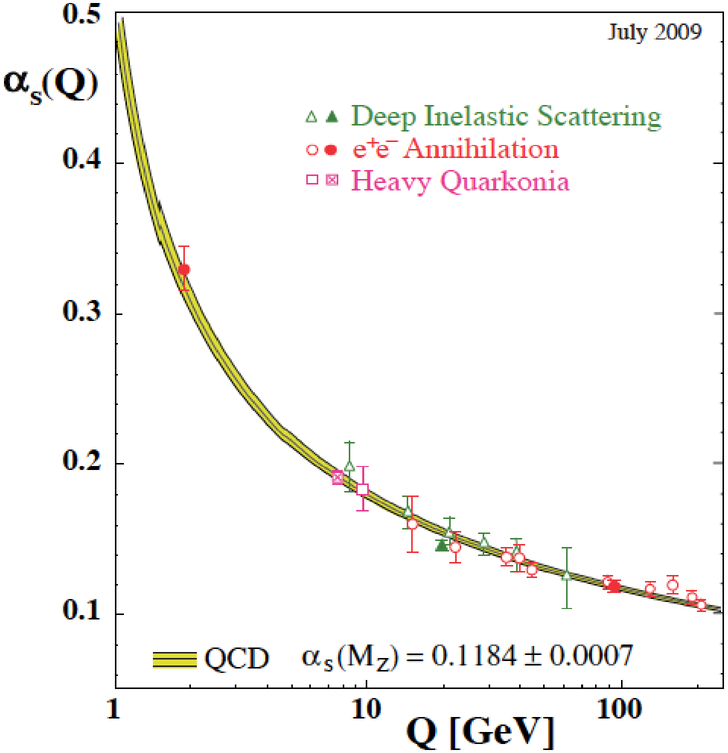
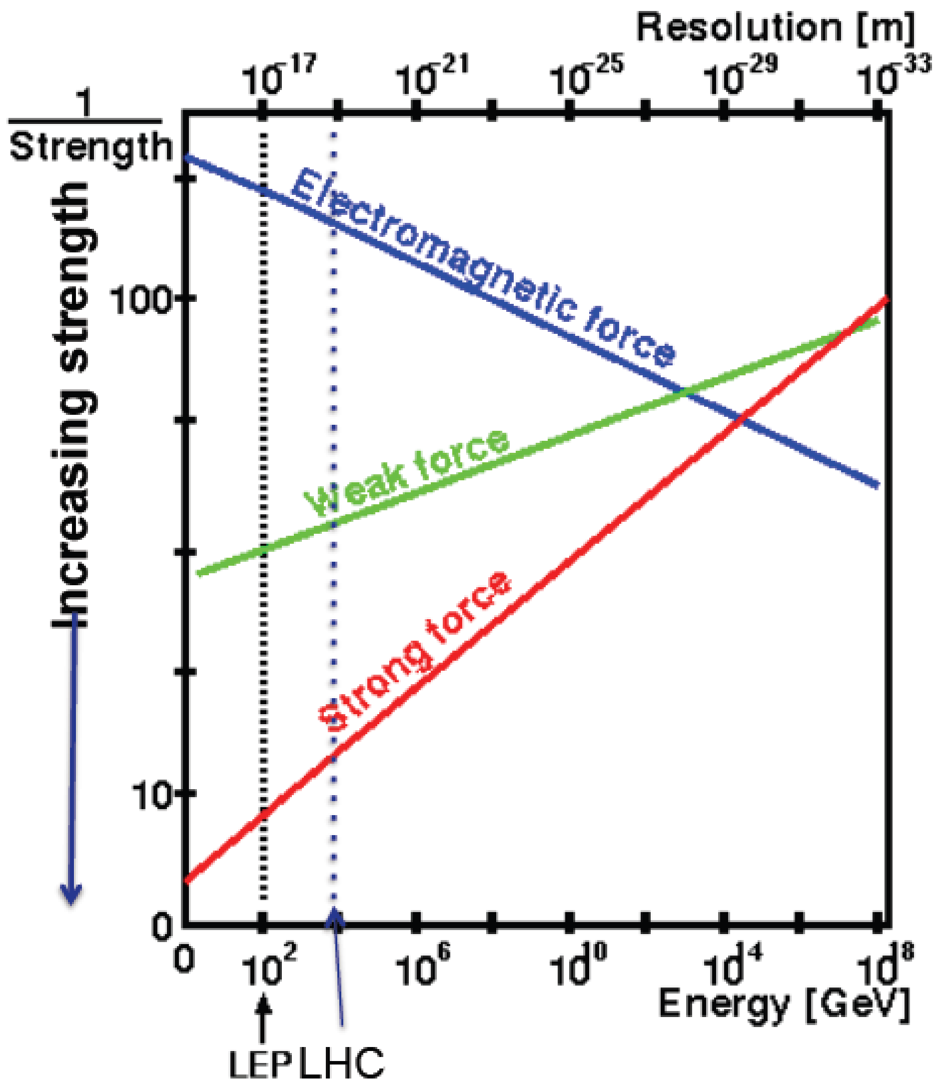


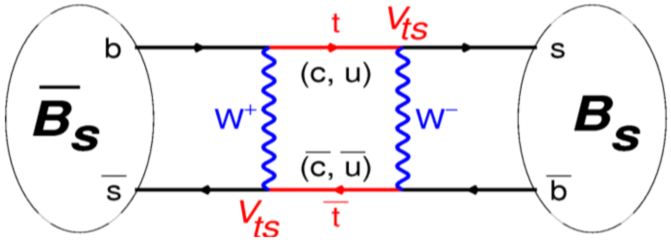
Unification?



Compare the Forces

EM force	Weak force	Strong force
Electric charge (1)	Weak charge (2)	Colour charge (3)
Massless photon	Massive $W^{\pm}$,Z	8 massless gluons
Coupling g	Coupling g_W	Coupling g_s

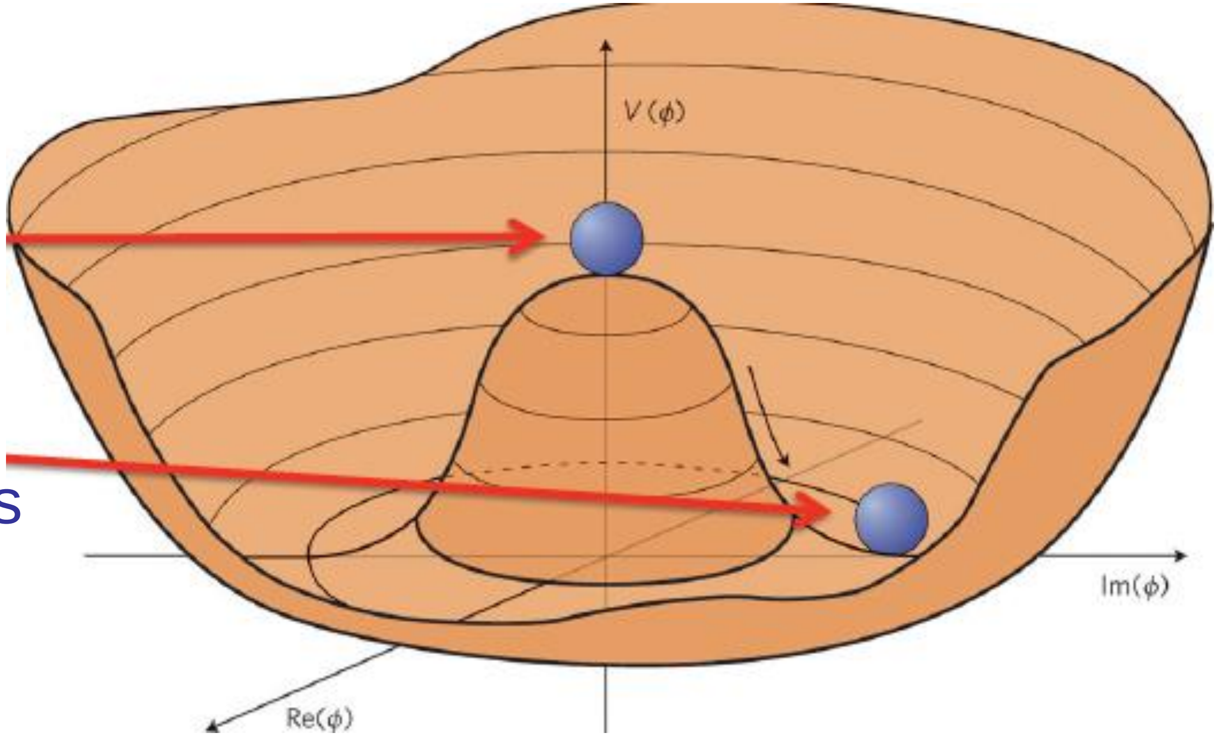
Allows quark flavour to change so that matter can change into antimatter



Higgs Boson

- **Introduced to give mass to W and Z bosons**
  - Requires a new potential to be added to the Standard Model
  - Introduction of "complex doublet" implies 4 new degrees of freedom, 3 of which are the W^+, W^- Z boson mass
  - Fourth is the Higgs boson itself

Massless bosons



Spontaneous symmetry breaking

Summary

- **The Standard Model describes the fundamental particles and the forces that act among them**
  - Forces are mediated by force-carrier bosons
  - While the forces are mediated in a common way, they display different phenomena

- **Tomorrow's lecture: Experimental measurements**
  - How do we know what we know?
  - What does a data analysis look like?

    (Example: The Higgs Search)

- **Question… Relative merits of pp, p$\bar{p}$, e^+e^-**