Higgs boson(s)

- **Why do we need them?**
- **What do they look like?**
- **Have we found them?**

Quantum Electrodynamics predicts one **massless spin-1** gauge boson

PHOTON

Quantum Chromodynamics predicts $(3^2-1) = 8$ **massless spin-1** gauge bosons

GLUONS

Quantum Flavour Dynamics predicts $(2^2-1) = 3$ **massless spin-1** gauge bosons

?

W and Z boson are NOT massless

Mass of **W** bosons… **80 GeV**

Mass of **Z** bosons … **91 GeV**

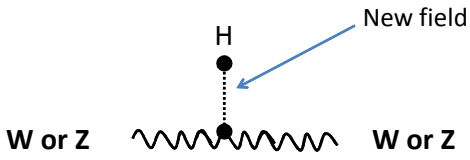
Weigh more than a copper atom

- **Massive** spin-1 particles have **3** polarisations
  - Helicity = **+1** or **0** or **-1**

- **Massless** spin-1 particles have only **2** polarisations
  - Horizontal or vertical polarised photons
  - Helicity = **+1** or **-1** only
  - **Longitudinal polarisation is lost!**

W and Z bosons need extra degree of polarisation as massive

Giving mass to the W and Z



W and Z bosons **pick up** mass from **interaction** with new **scalar field**

Pops out of vacuum & modifies propagator

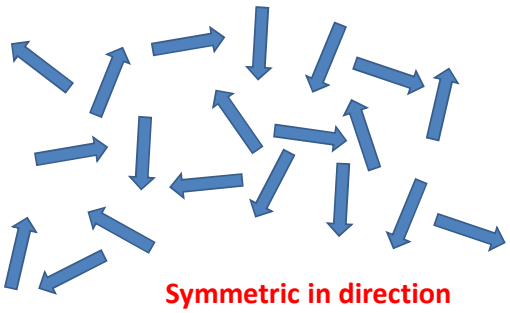
"Higgs" field

- Field must have **non-zero vacuum value everywhere**
- Universe **filled** with "relativistic ether" of this field
- **Coupling** to the field gives **mass** to **W** and **Z**

Symmetry breaking & the Higgs field

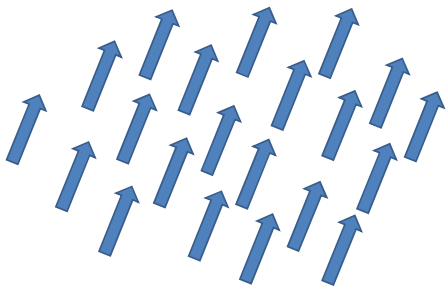
- Require: underlying theory is **symmetric**
- **Vacuum** or ground state has **broken** symmetry

Magnetic material at **high temperatures**



Symmetric in direction

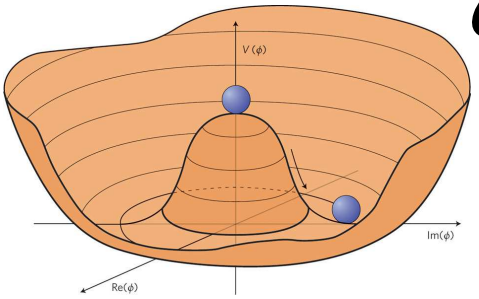
Magnetic material at **low temperature**



Symmetry broken – special direction

Broken symmetry for a complex field

ϕ



Standard Model has complex doublet

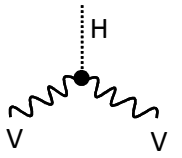
$$\begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$$

- **4** degrees of freedom
- **3** end up as longitudinal polarisations of W and Z bosons
- **1** left over – excitation of the field – **Higgs Boson**

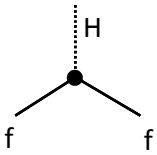
In the Standard Model the **SAME** Higgs field gives mass to the:

- **W boson**
- **Z boson**
- **all** the quarks and leptons

Higgs couplings to mass



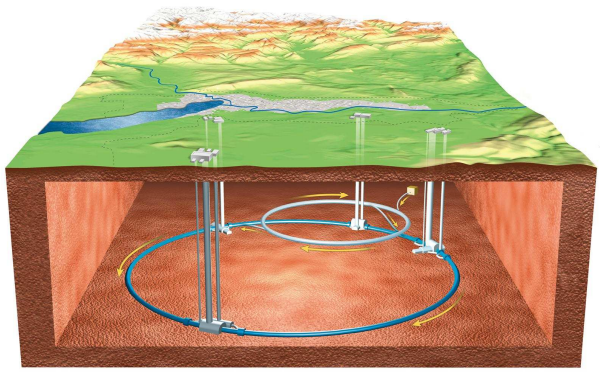
$$g_{HVV} = \frac{2m_V^2}{v}$$



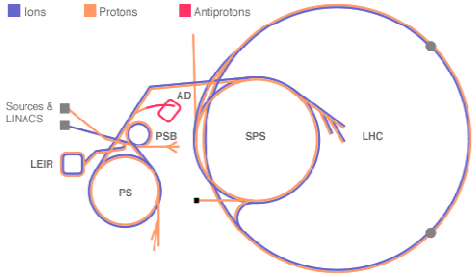
$$g_{Hf\bar{f}} = \frac{m_f}{v}$$

Higgs boson **production** and **decay**

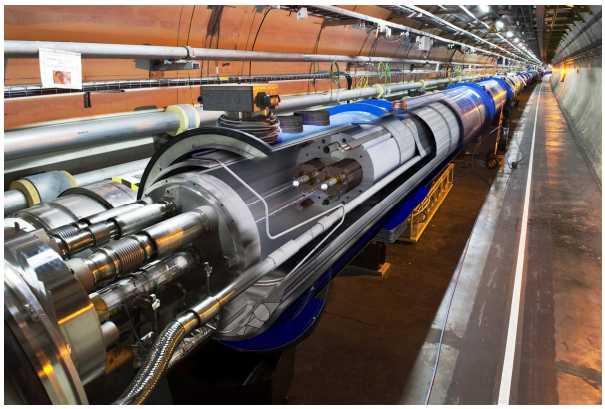
Blackboard

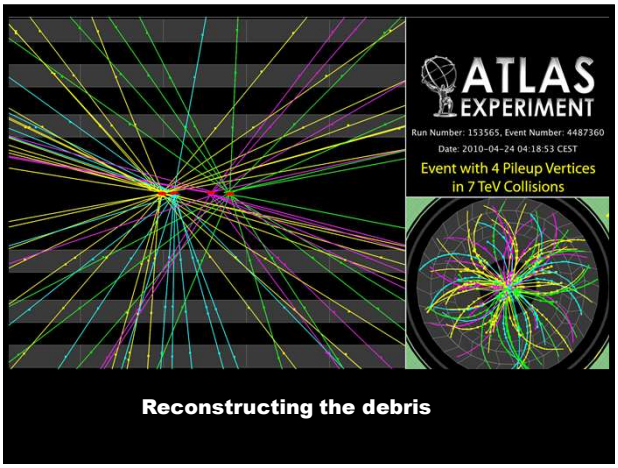


Accelerator complex @ CERN

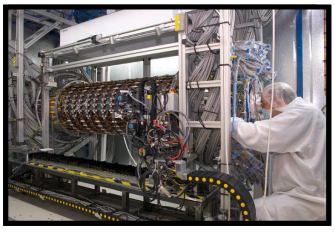


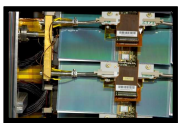
LINear **AC**celerator

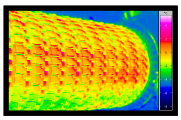




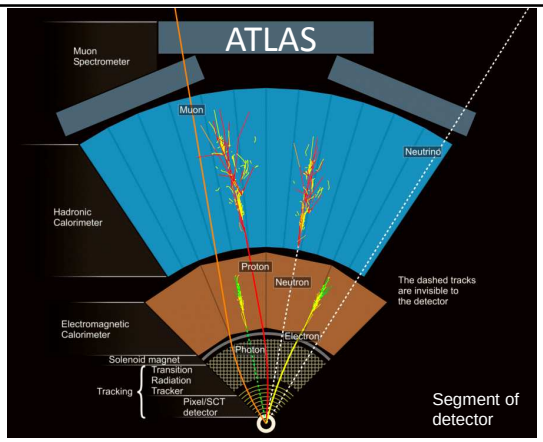
Detectors…

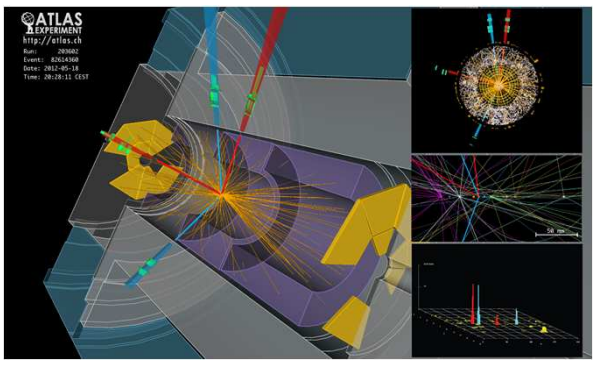




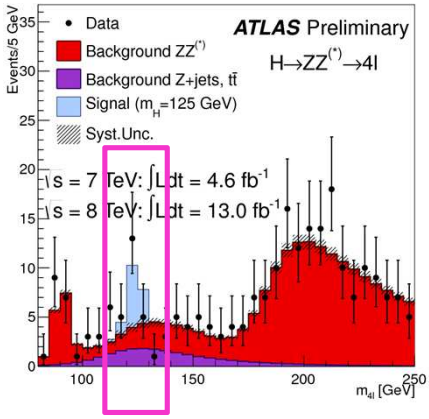


•Robotic assembly of precision silicon tracker – Denys Wilkinson Building

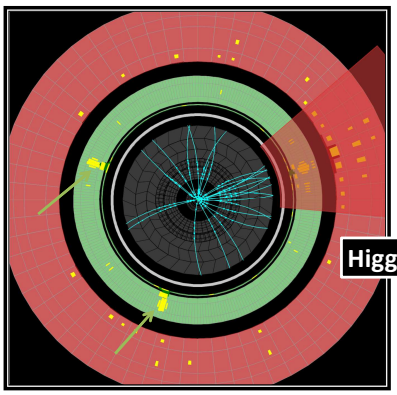




H → Z + Z* → (e^+ + e^-) + (e^+ + e^-) candidate

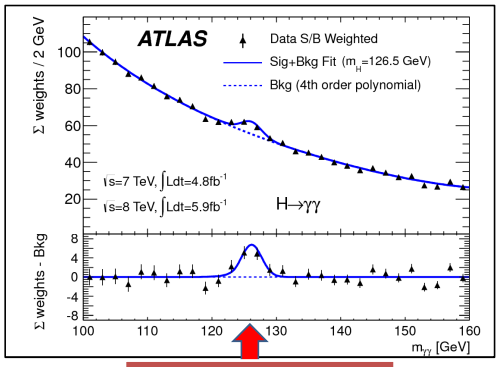


A collision producing 2 high-energy **photons**



Higgs → γ + γ ?

Higgs → 2 photons



Bump at mass of new particle