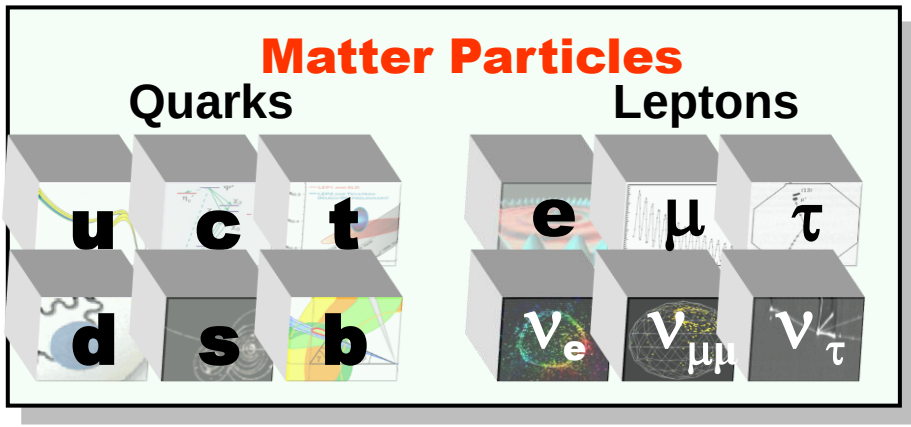
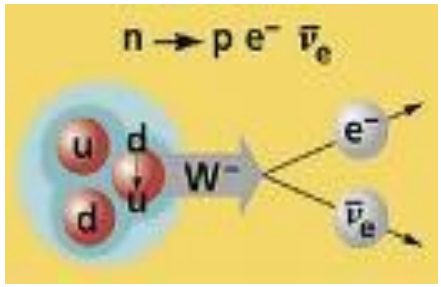
Particles and forces

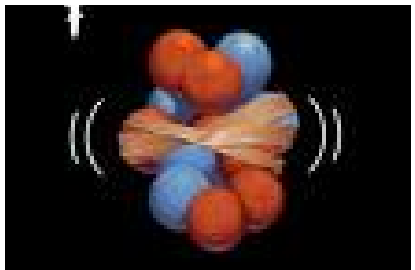
Centuries of physics reduced the building blocks of matter to just 6 quarks and 6 leptons



Also, all natural phenomena have been reduced towards 1950 to just 4 fundamental forces:

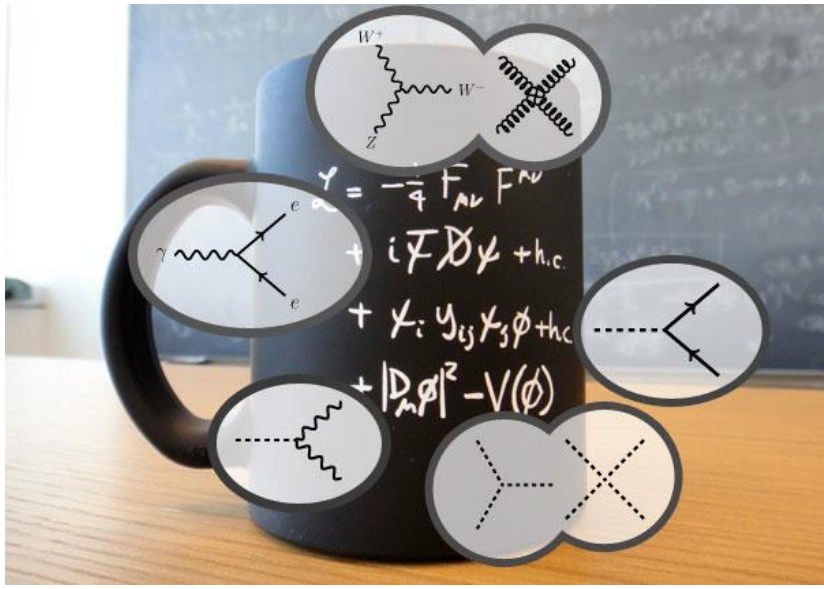
- Gravitational
- Electromagnetic
- Weak Nuclear
- Strong Nuclear

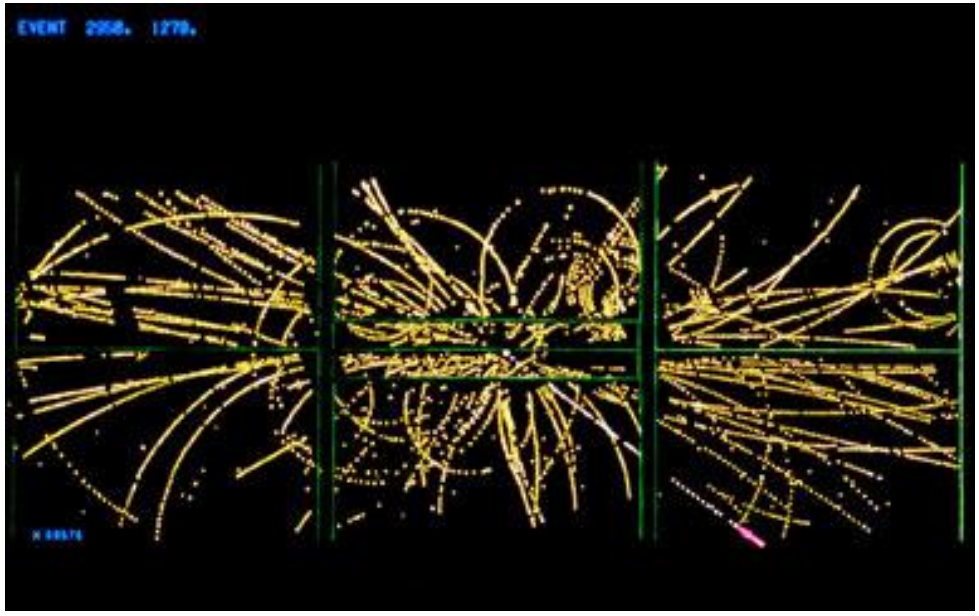


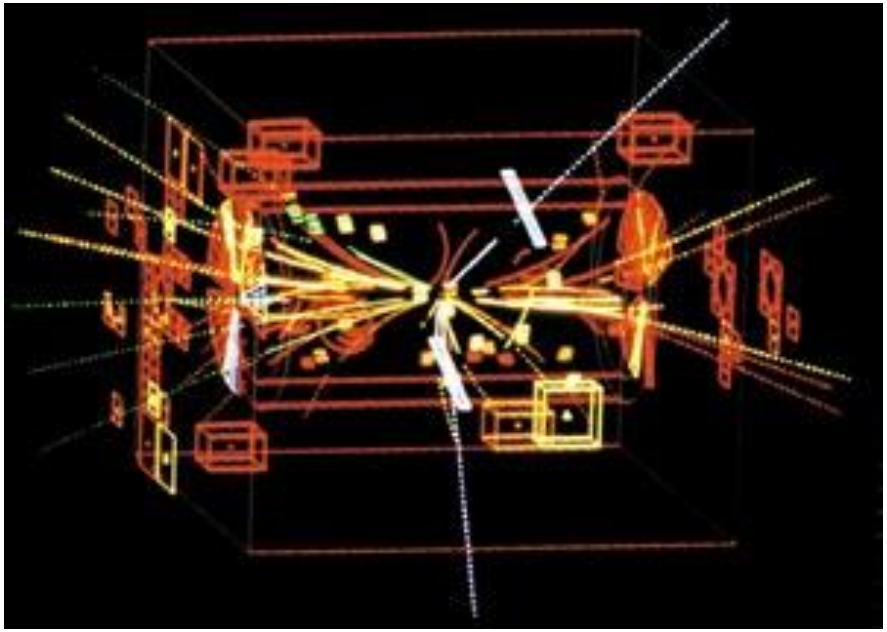


Electroweak theory

A theory was developed during the 60's to unify electromagnetic and weak force. Many experimental confirmations (discovery of electroweak carriers W and Z at CERN in 1983)



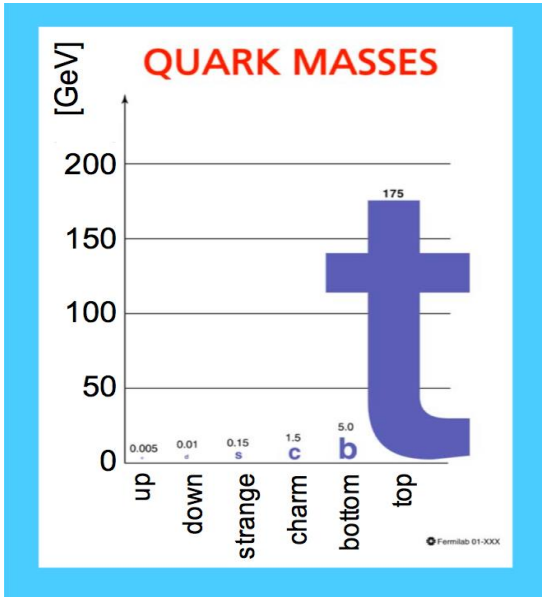




What about masses?

The EW theory is based on strong symmetries between particles and forces.

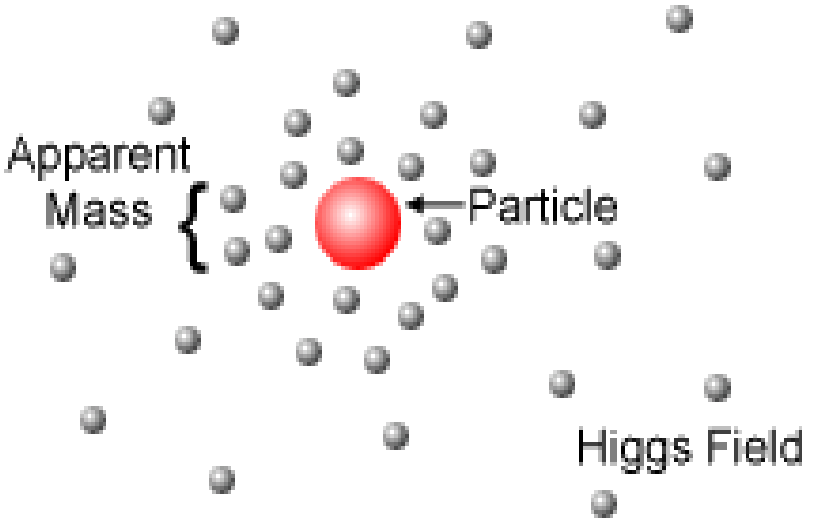
Leptons and quarks in fact behave very similarly between them, but have very different masses!



To keep the symmetry, quarks and leptons need to have zero intrinsic mass

Mass is in fact an acquired property:

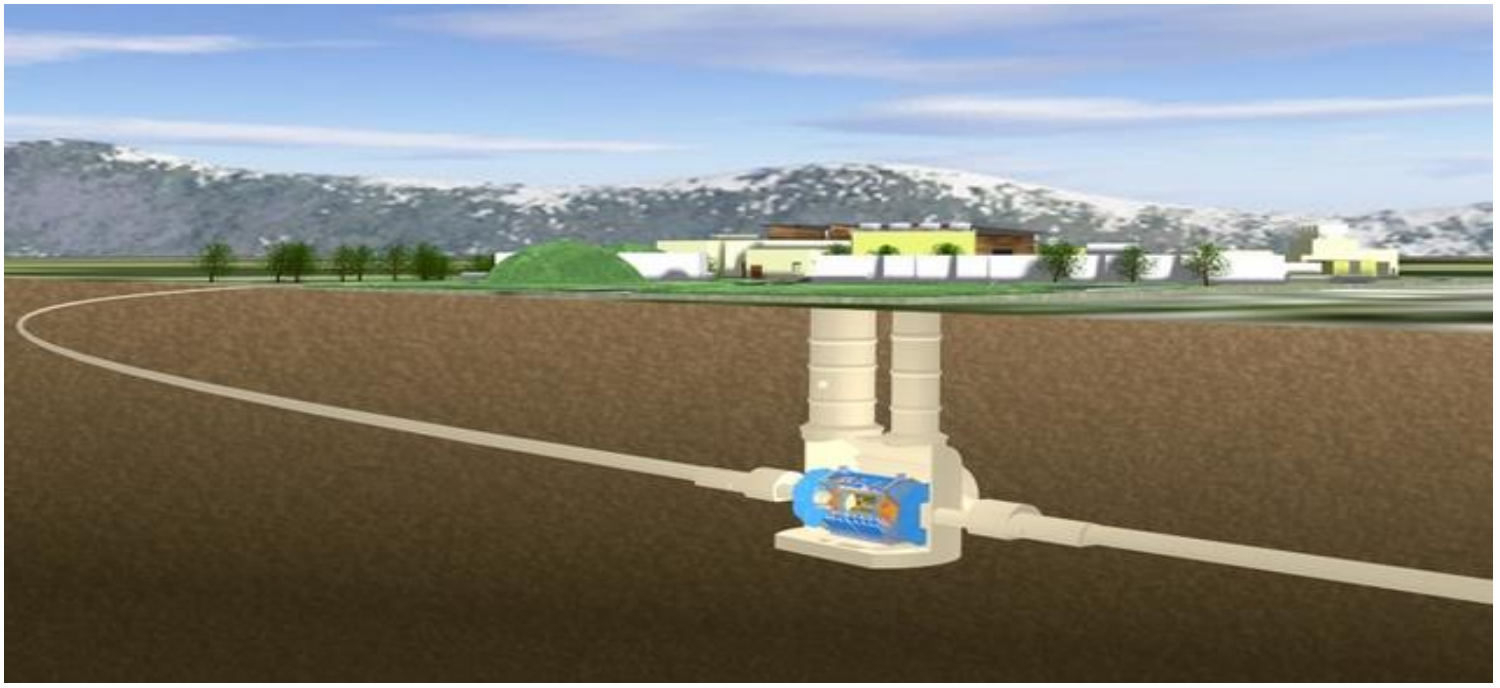
massless particles gain mass interacting with an external Higgs field, that fills the whole universe

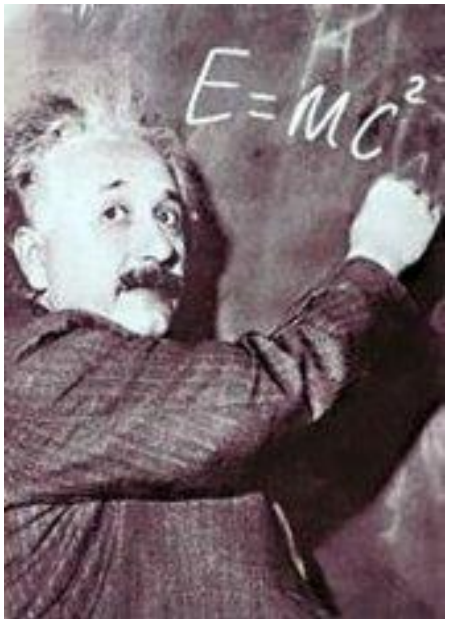


How to make a Higgs boson?

“virtual” Higgs bosons are everywhere, but to prove their existence we need to produce real ones

High-energy proton beams collide at the centre of giant detectors: the kinetic energy is transformed into mass



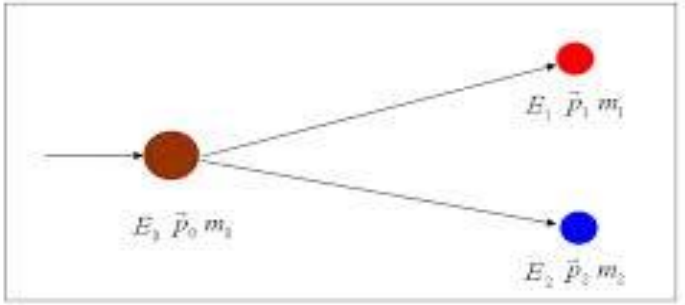


But like all heavy particles, the Higgs decays immediately after its production.

We have to infer its production from the decay products

Discoverying the Higgs: the invariant mass method

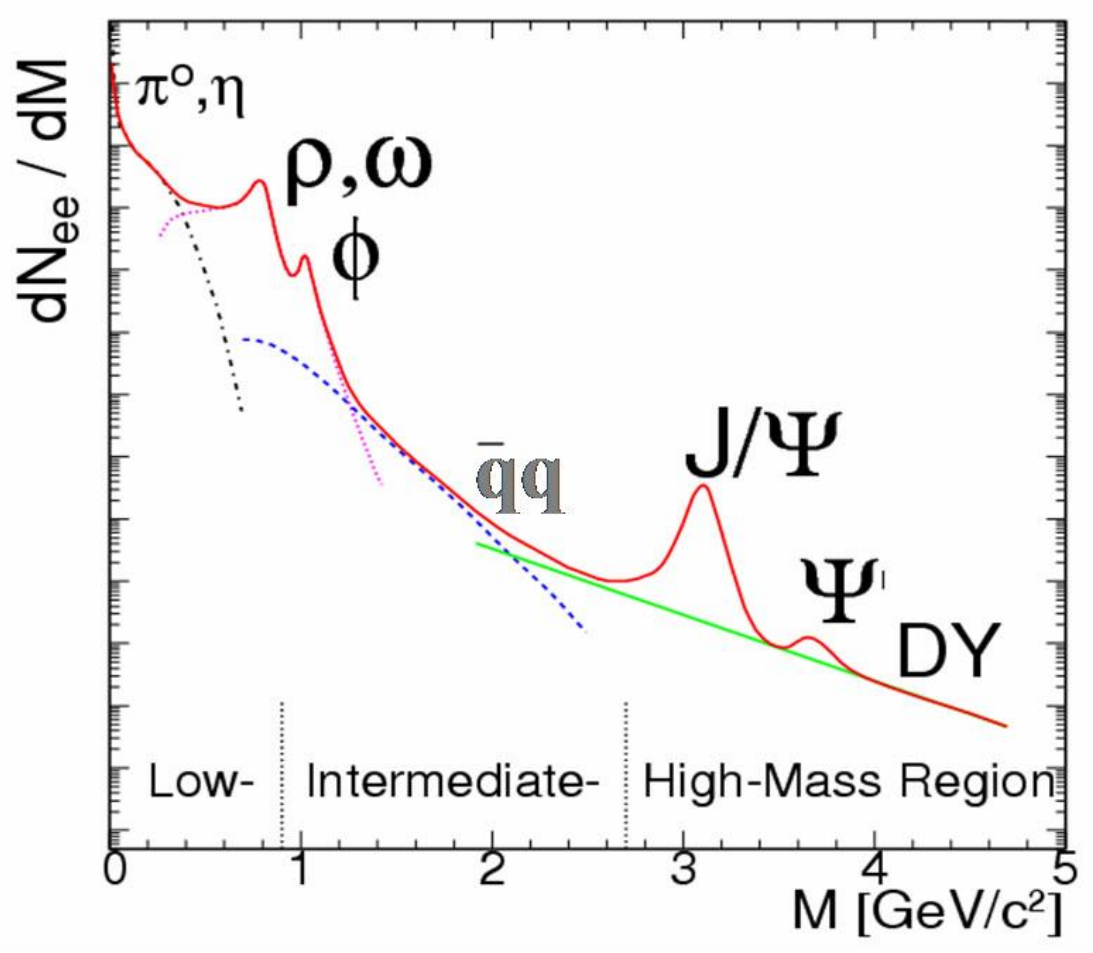
"invariant" mass of decay products equal to that of the parent particle that produced them



$$(E_0, p_{0x}, p_{0y}, p_{0z}) = (E_1, p_{1x}, p_{1y}, p_{1z}) + (E_2, p_{2x}, p_{2y}, p_{2z}) = (E_1 + E_2, p_{1x} + p_{2x}, p_{1y} + p_{2y}, p_{1z} + p_{2z})$$

$$\Rightarrow E_0^2 - (\vec{p}_0 c)^2 = (m_0 c^2)^2 = (E_1 + E_2)^2 - (\vec{p}_1 c + \vec{p}_2 c)^2$$

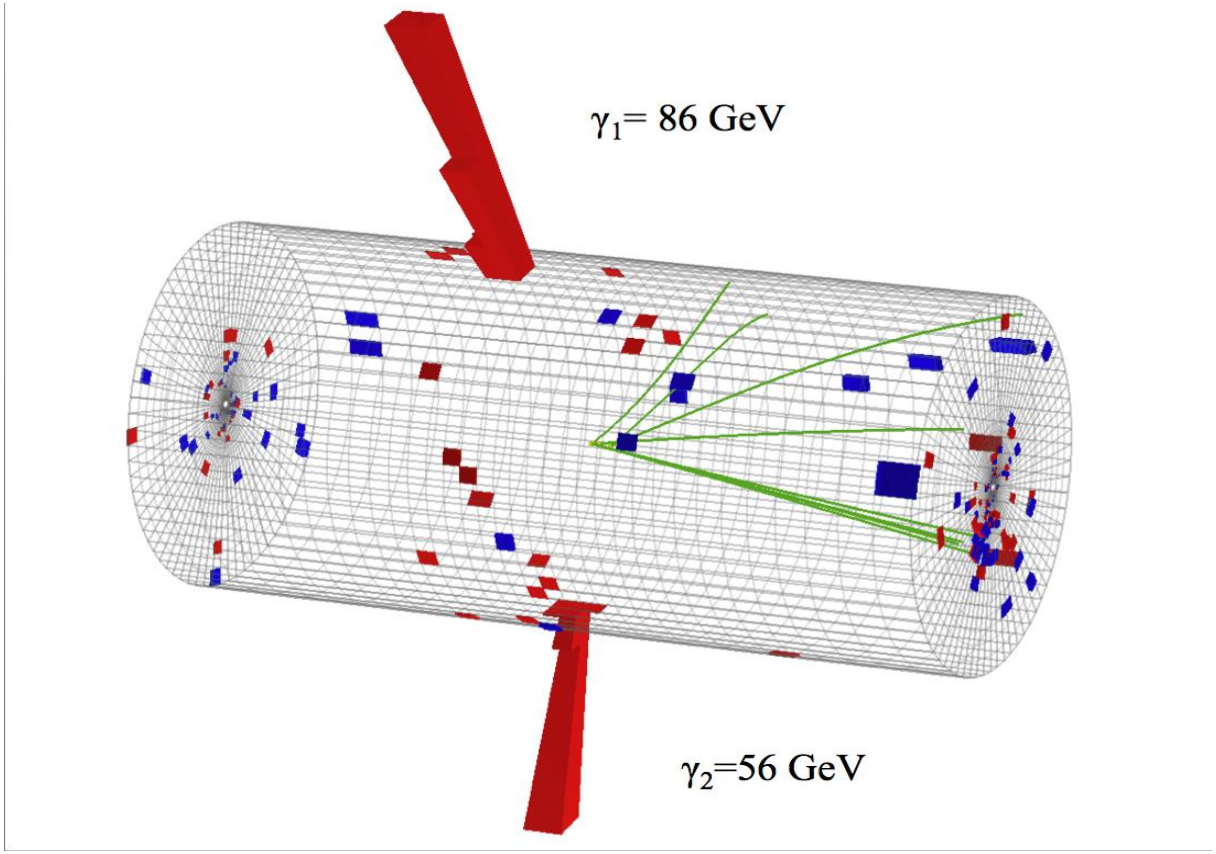
$$\Rightarrow m_0 c^2 = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 c + \vec{p}_2 c)^2}$$



To prove that a particle was produced:

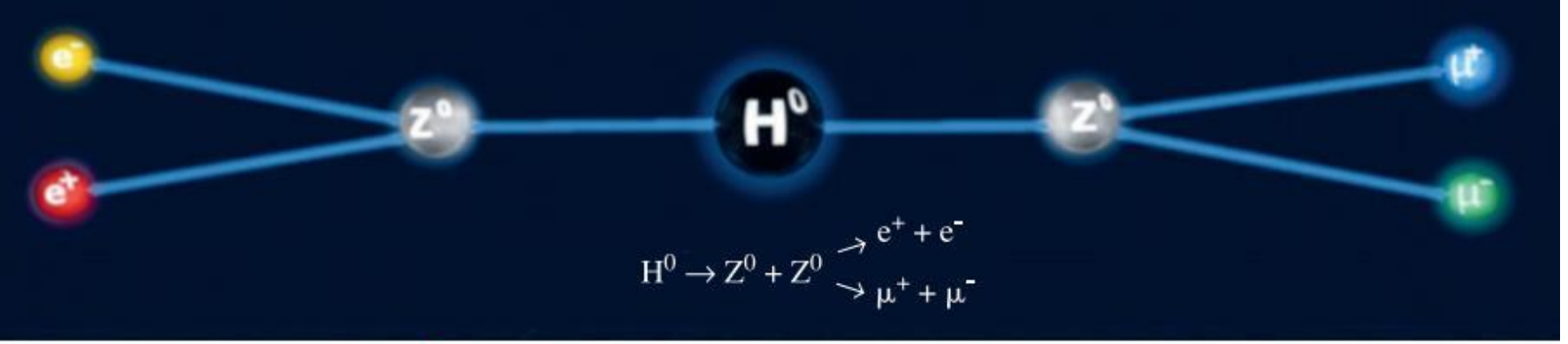
- Look for the collisions with the expected decay products
- Calculate their invariant mass
- Look for "spikes" in the invariant mass distribution
- Make sure signal can't be just a fluctuation of the background

Two-photon final state

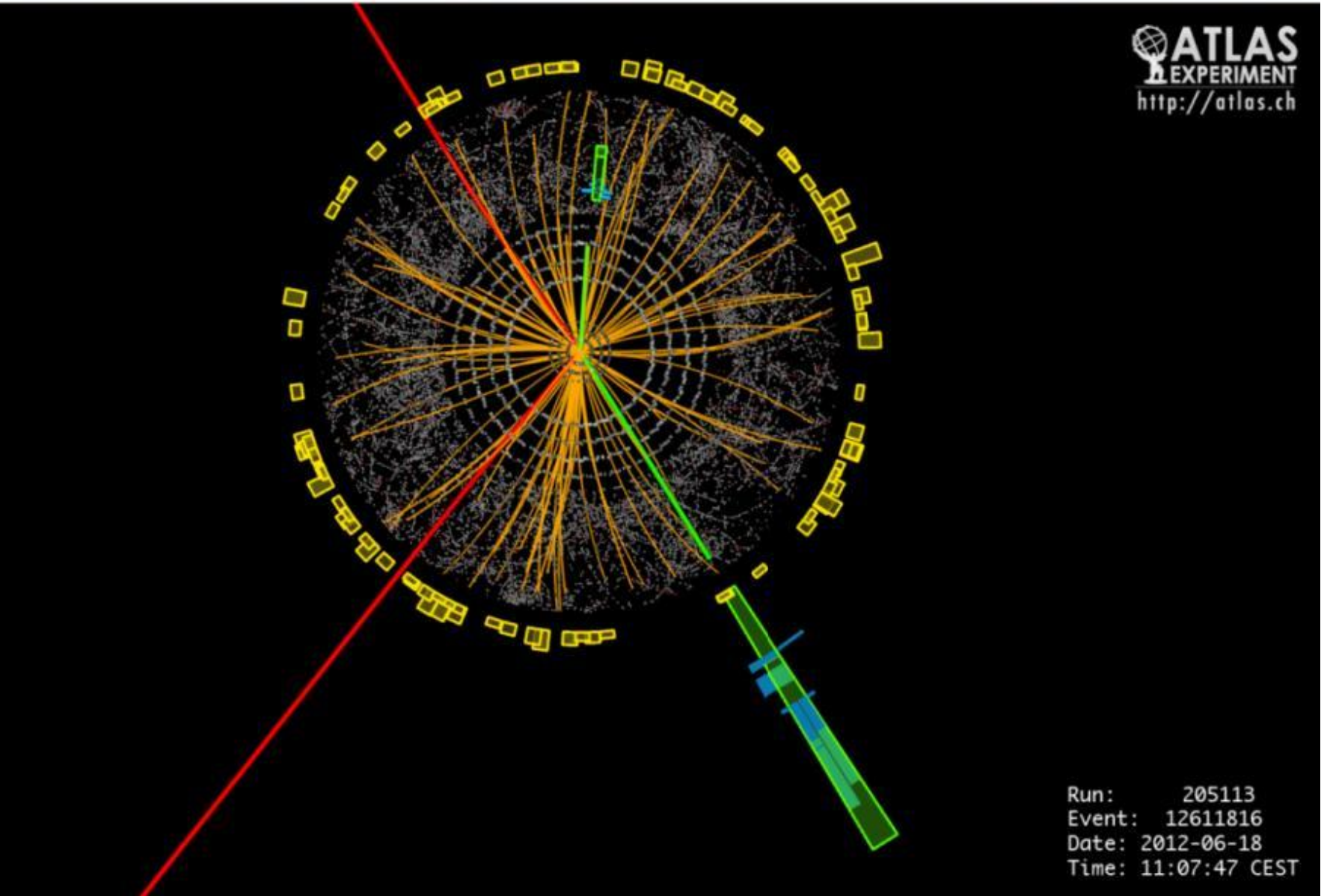


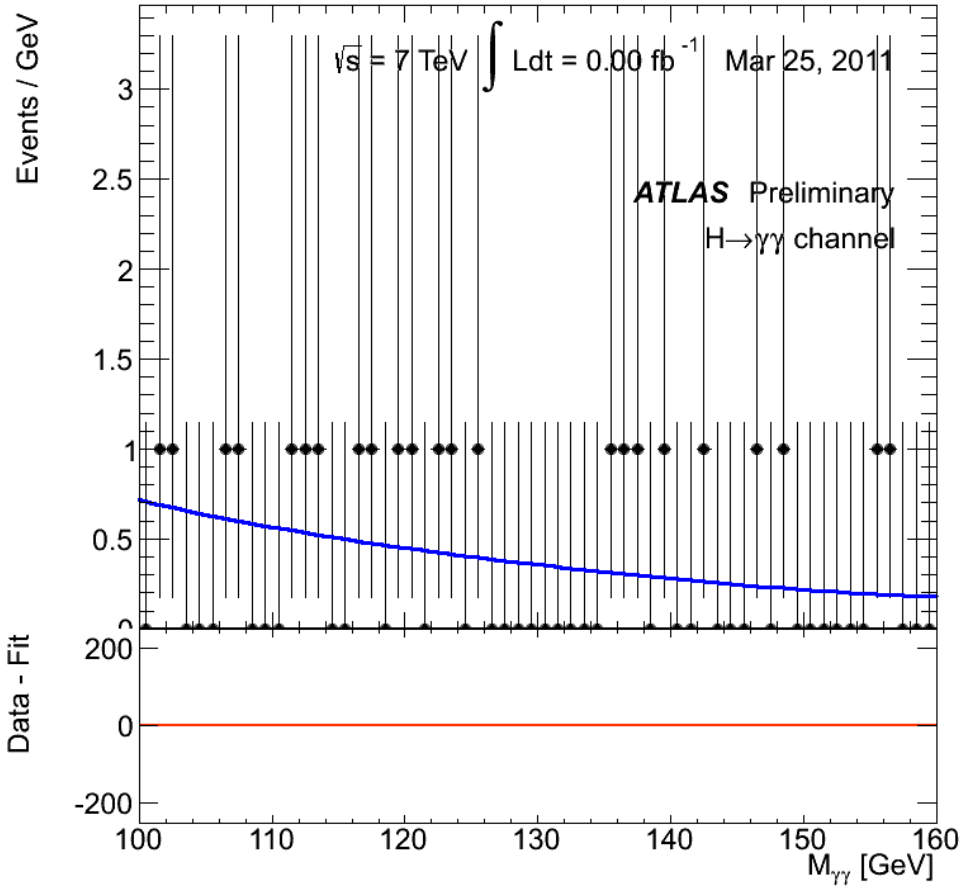
There is no way of knowing if this is a result of a Higgs decay or if it is a background

Proof of Higgs production comes from statistical analysis of the invariant mass of thousand of events



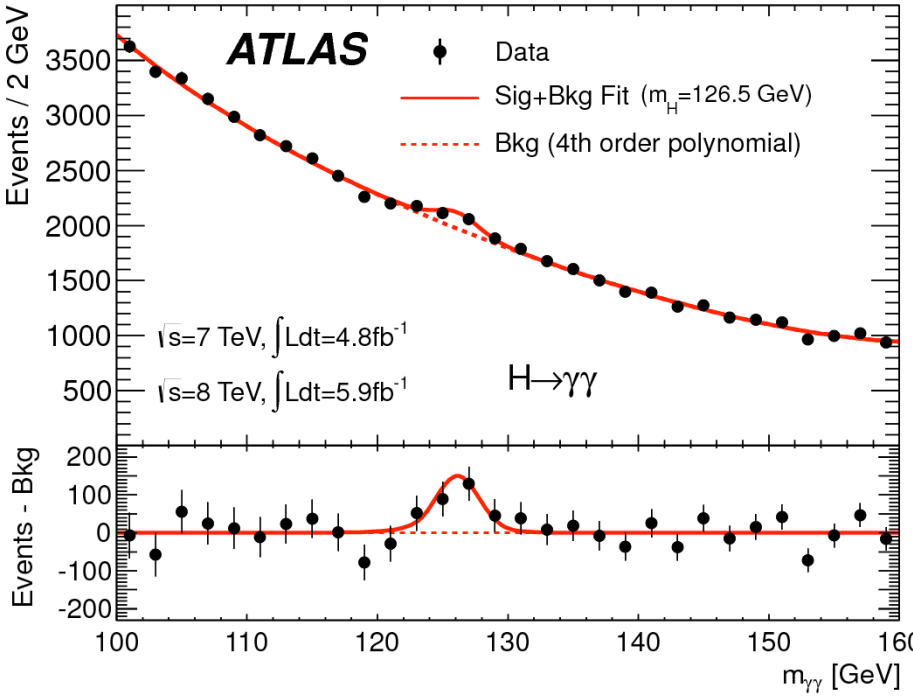
$$H^0 \rightarrow Z^0 + Z^0 \begin{matrix} \rightarrow e^+ + e^- \\ \searrow \mu^+ + \mu^- \end{matrix}$$

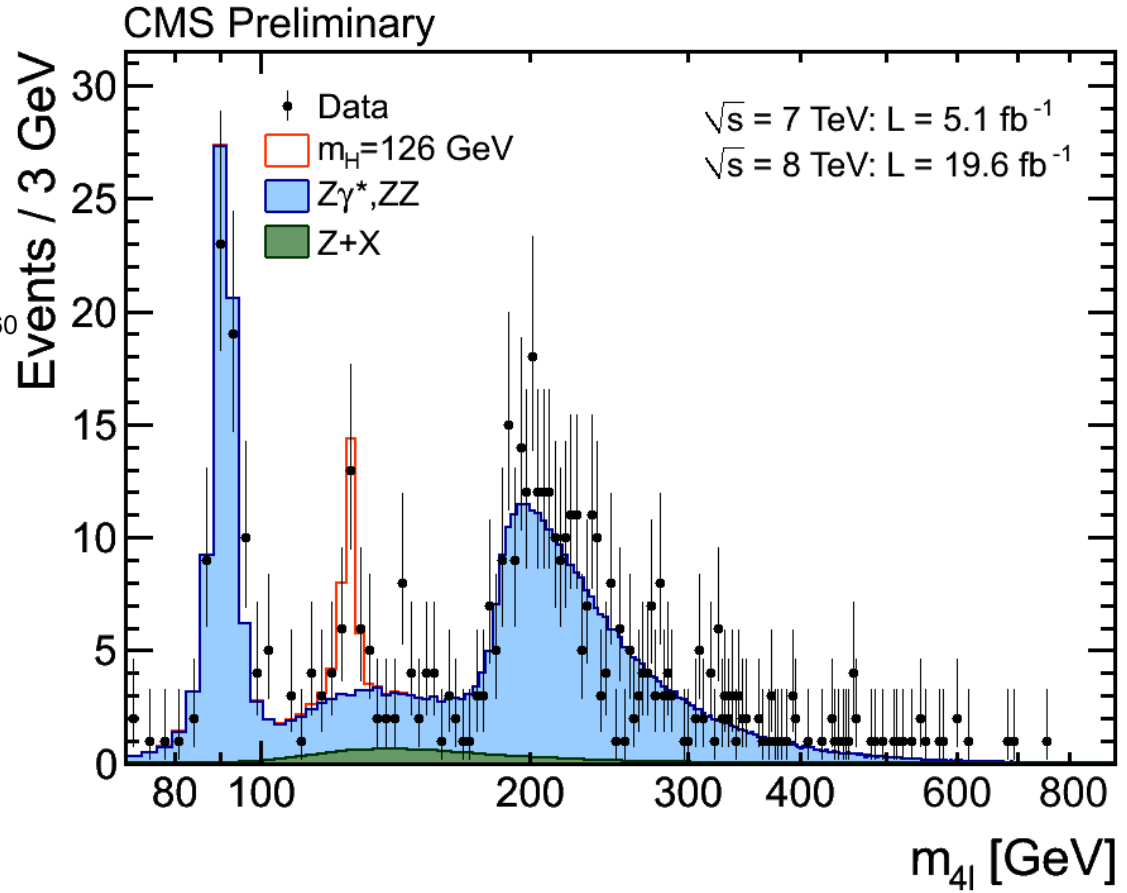




Invariant mass distributions

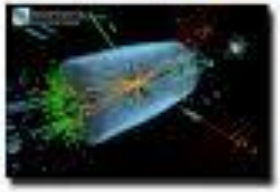
Invariant mass distributions





In both cases, a clear peak is visible at 126 GeV
It is the same particle, decaying into two photons and four leptons, as predicted by the Higgs theory!

The Higgs discovery



The Higgs boson, proving the validity of this theory, was discovered by ATLAS and CMS in 2012.

All properties of this new particle measured so far are compatible with those of the Standard Model Higgs boson

After almost 50 years from their original articles, F.Engelert and P.Higgs shared the Physics Nobel prize in 2013