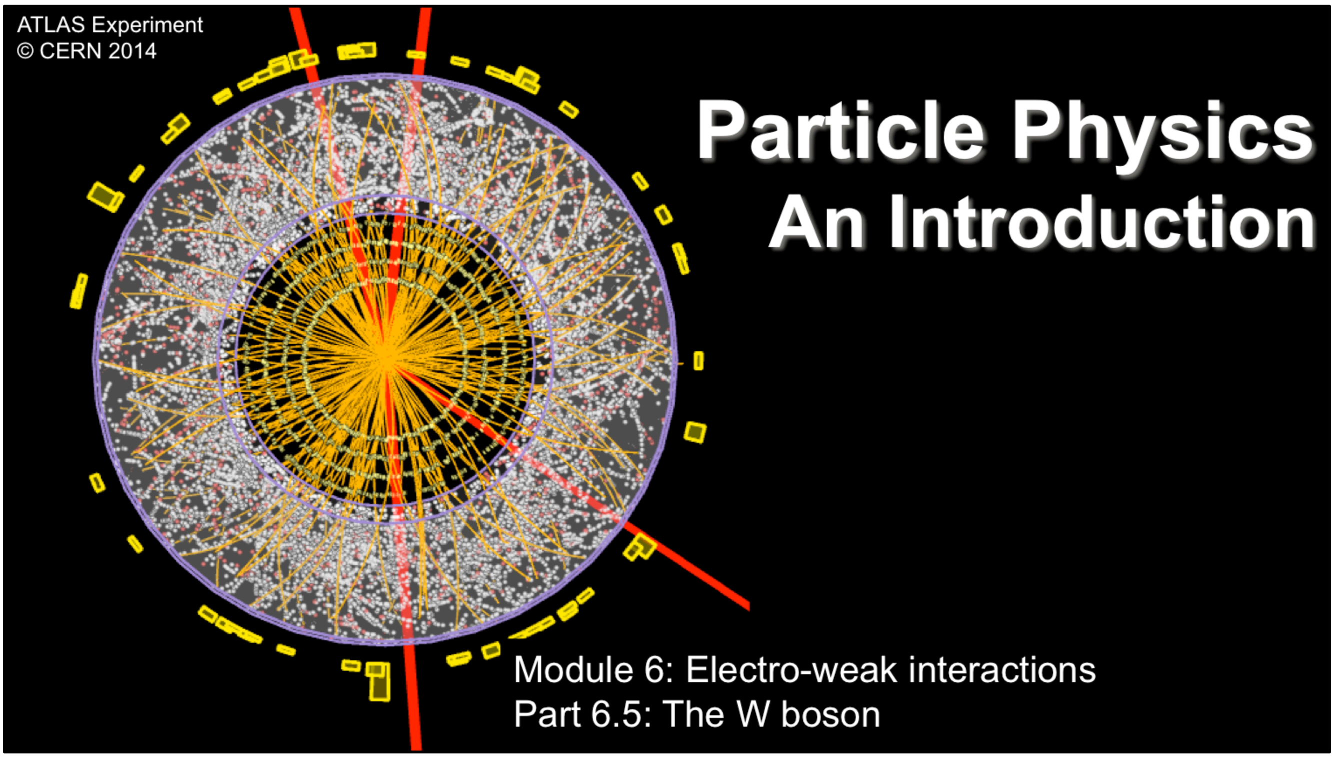
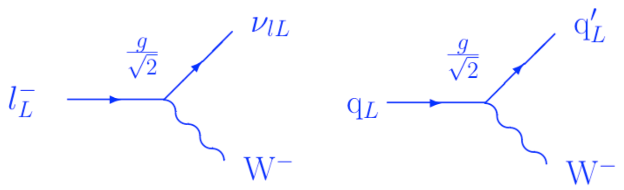


In this 6th module, we are discussing weak interactions.

In this 5th video we will talk about the properties of the W bosons, which transmit the charged weak force and are responsible for weak decays.

After following this video you will know:

- W couplings to matter and forces;
- The W mass and the various ways to measure it.



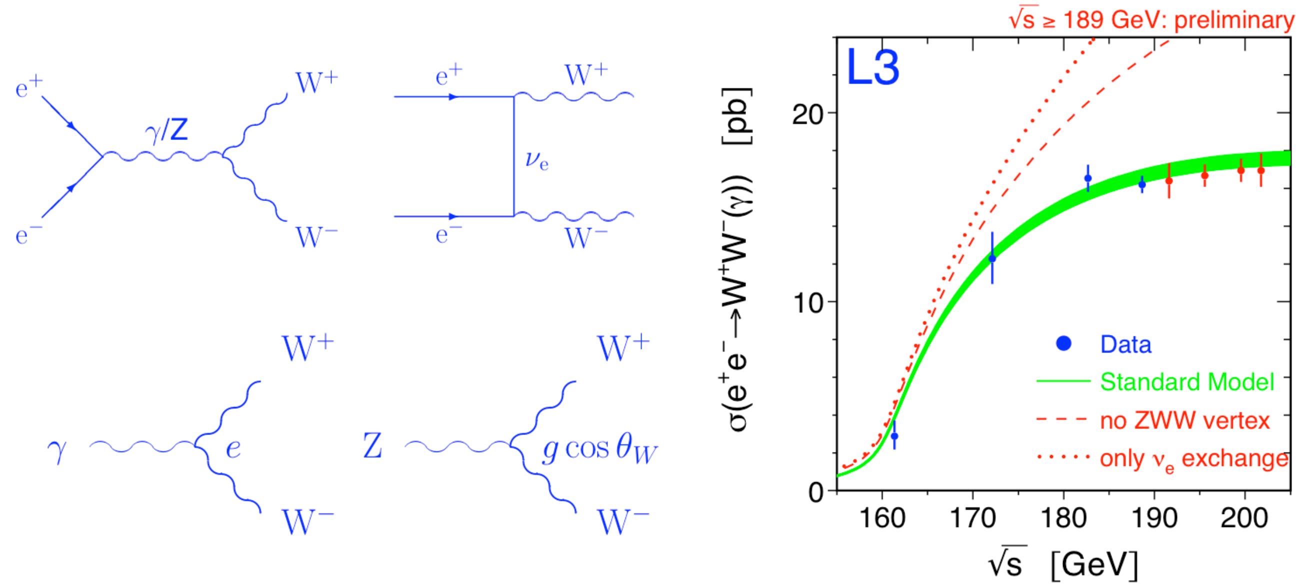
W propagator:

$$\sim \frac{1}{q^2 - M_W^2} \underset{q^2 \leq m_\mu^2 \ll M_W^2}{\propto} \frac{1}{M_W^2}$$

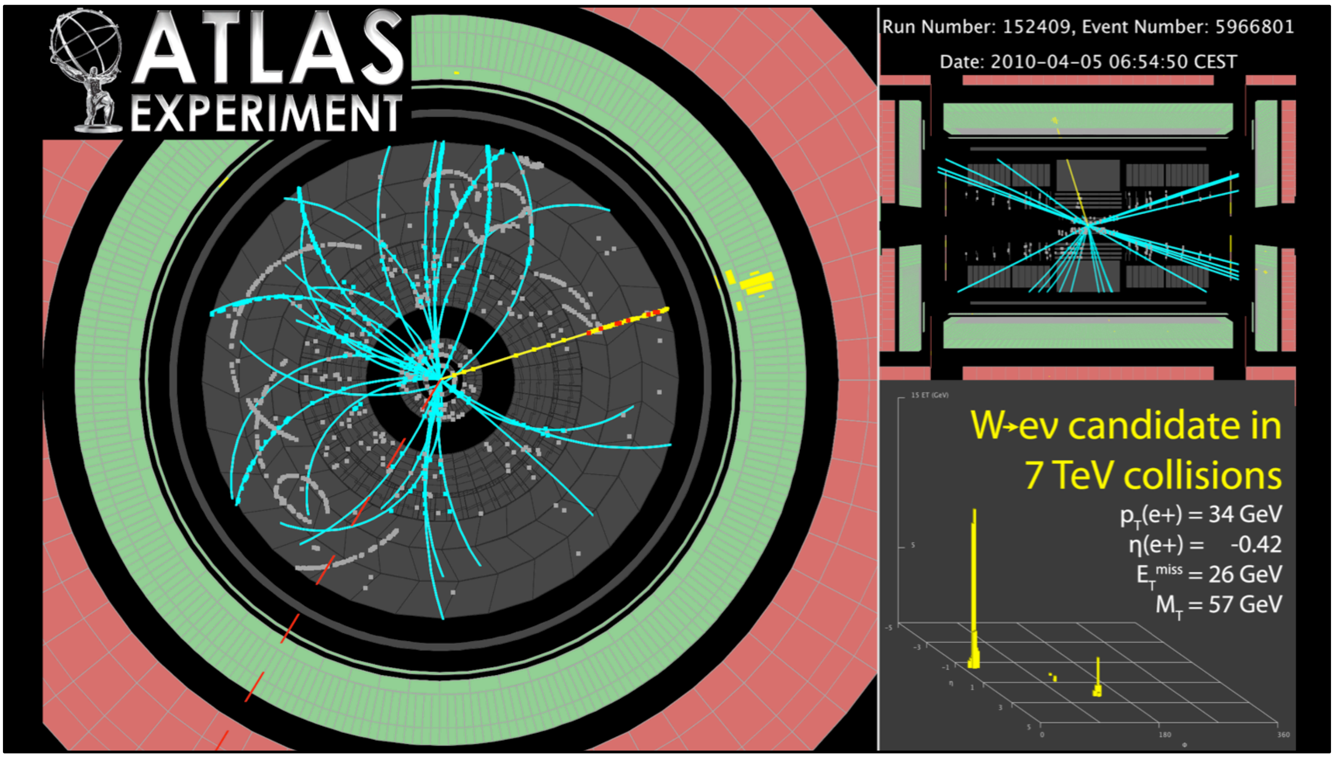
Fermi coupling constant:

$$\frac{G_F}{\sqrt{2}} = \left(\frac{g}{\sqrt{2}}\right)^2 \frac{1}{4M_W^2}$$

- In video 6.3 we already defined the **couplings** of the W's to matter.
- In video 6.4 we have reviewed the method to measure the **Fermi constant,** which applies to processes with $q^2 \ll M_W^2$ and thus defines the intensity of the weak force at low energy.
- The question is now how to measure the **mass of the W boson**.



- This is done using **two different methods**, which have comparable accuracy.
- The 1rst method determines the mass by measuring the **energy threshold** for the production of W pairs in e^+e^- annihilation.
- We already noted that the vector bosons **W and Z themselves carry electro-weak charges**: $W^\pm$ have an electric charge, both $W^\pm$ and Z have a non-zero weak isospin. There is thus an interaction vertex among electro-weak bosons with the couplings indicated here.
- These vertices fix the values of the **electro-weak couplings** in a unique manner, and at the same time for interactions between bosons and between fermions and bosons.
- Charged bosons can then be produced in **pairs** by the e^+e^- annihilation.
- The **position of the threshold** for W pair production and the shape of the cross section at threshold determine the mass of the W boson with good precision.



- A second method for the mass determination is to measure the four-momenta of the decay products and form their **invariant mass**.
- Since the mass is a relativistic invariant, we do not need to produce the W at rest. For **two-body decays** at high energy, this means measuring energy and direction of the particles.
- The example shows an event seen by the **ATLAS** experiment at the LHC, which contains a high energy **positron** shown by the yellow track in the central detector, and the corresponding energy deposition in the calorimeter, also shown in yellow.
- The **neutrino,** the second decay product of the $W^+ \rightarrow e^+ \nu_e$ decay, leaves no trace in the detector, but manifests itself as **missing energy and momentum**.
- The momentum balance is indeed only guaranteed in the plane **transverse to the beam**, because gluons and quarks carry a variable fraction x_{BJ} of the incident proton momentum. However, analyzing the kinematics in the transverse plane alone allows for a good precision measurement of the W mass.

$$\begin{aligned}\text{Threshold :} \quad & M_{\mathrm{W}} = (80.376 \pm 0.033)\,\mathrm{GeV} \\ \text{Invariant mass :} \quad & M_{\mathrm{W}} = (80.387 \pm 0.016)\,\mathrm{GeV} \\ \\ \text{PDG average :} \quad & M_{\mathrm{W}} = (80.385 \pm 0.015)\,\mathrm{GeV}\end{aligned}$$

- The **results** of the two methods are in good agreement and can be averaged because they are independent.
- Compared to the Z mass measurement, the **precision** reached with the threshold and invariant mass methods is 10 times less than if one measures the mass by a resonance, as we will see in the next video.

- In the next video we will in fact talk about the properties of the Z boson, which transmits the weak neutral interactions.