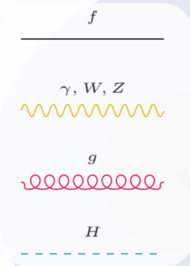
FEYNMAN DIAGRAMS

Feynman diagrams (named after theoretical physicist Richard P. Feynman) are found in almost every paper published by ATLAS and are a powerful tool to visually represent particle interactions, as well as to conduct elaborate calculations. This sheet covers the basics of how to read Feynman diagrams, taking as an example one possible mode of production and decay of a Higgs boson at the LHC.

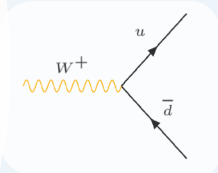
THE BUILDING BLOCKS

Lines: Each line represents a particle:

- a **straight line** is for a fermion (electron, muon, neutrino, quark, ...)
- a **wavy line** is for a photon or a W or Z boson
- a **curly line** is for a gluon
- a **dashed line** is for a Higgs boson



Vertices: These represent an interaction. Certain rules must be obeyed when connecting lines into a vertex. Some of these rules are general – e.g. conservation of electric charge and momentum – while others depend on the details of the theory. This example shows a W boson decaying into a quark and an antiquark.

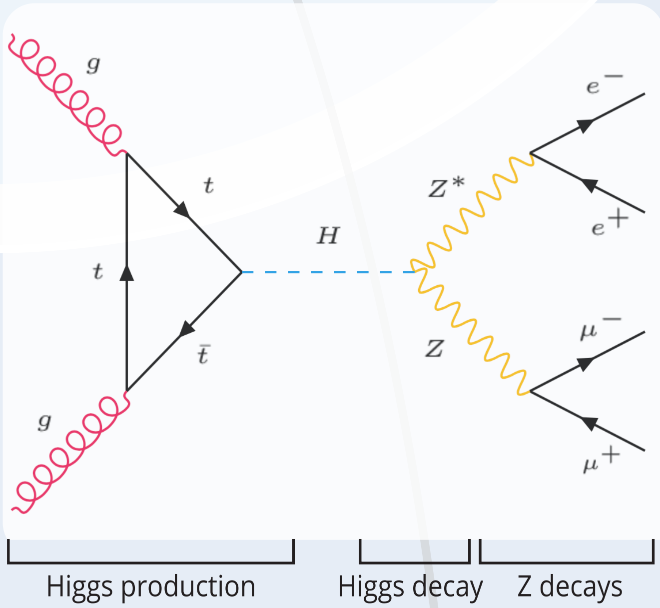


Directionality: In a Feynman diagram, usually the horizontal direction represents time, moving forward from left to right, and the vertical direction represents space (roughly speaking). This means that incoming particles are on the left and outgoing particles on the right. Fermion lines are usually drawn with arrows, where particles that enter a reaction (initial state) point towards the vertex, while those exiting the reaction (final state) point away from the vertex. The opposite is true for antiparticles. Although this might seem to imply that antiparticles are moving backwards in time, we prefer to think of the direction of the arrows as the flow of (electric) charge.

Real versus virtual particles: In the theory we differentiate between "real" and "virtual" particles. Real particles obey Einstein's well-known energy-momentum-mass relation. For virtual particles however, this mathematical relationship is broken. As a consequence, virtual particles can only appear between vertices in a diagram, connecting real particles, and can never be observed experimentally. They are mainly used as calculational tools.

AN EXAMPLE: THE HIGGS BOSON

Higgs production:
The left side of this Feynman diagram represents the main production mode of the Higgs boson at the LHC. The incoming particles are two gluons, one from each colliding proton. The gluons then exchange a virtual top quark, which produces a virtual top-antitop pair. This pair then annihilates to produce a real Higgs boson.
Higgs decay:
The Higgs boson only lives for about 10^{-22} seconds, so it cannot be detected directly. It can decay to different types of particles (depending on which vertices are allowed by the theory). Here we show its decay to two Z bosons, one of which is virtual (Z*).
Z boson decays:
The final step is the decay of the Z bosons into an electron-positron and muon-antimuon pair. These can be detected by ATLAS and allow us to reconstruct the Higgs boson.



ONE FINAL NOTE

There are many (actually, infinitely many!) possible Feynman diagrams that describe a given process, all of which contribute to the probability of that process to occur in nature. However, they do not all contribute equally: the more vertices a diagram contains, the lower its probability and the less it contributes. Therefore, to reach a targeted precision, we can usually get away with only including the simplest diagrams – which we call leading or next-to-leading order diagrams.

ATLAS EXPERIMENT

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