II. Physikalisches Institut – Entanglement in $H^* \to ZZ$

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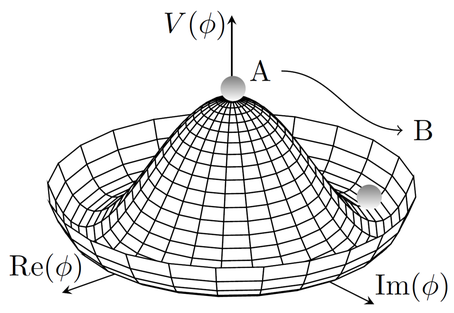
The Higgs Boson

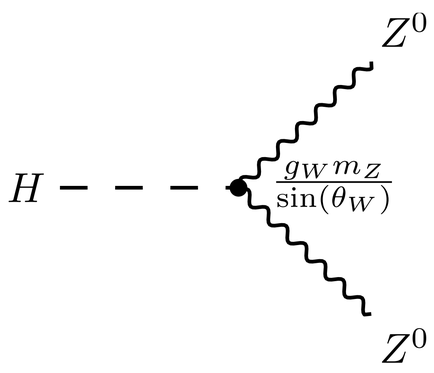
Due to the nature of the theory involved in the description of elementary particles, particle masses are forbidden. This problem is solved by the implementation of the Higgs field with which the particles interact.
A process called *symmetry breaking* yields the masses of the particles.



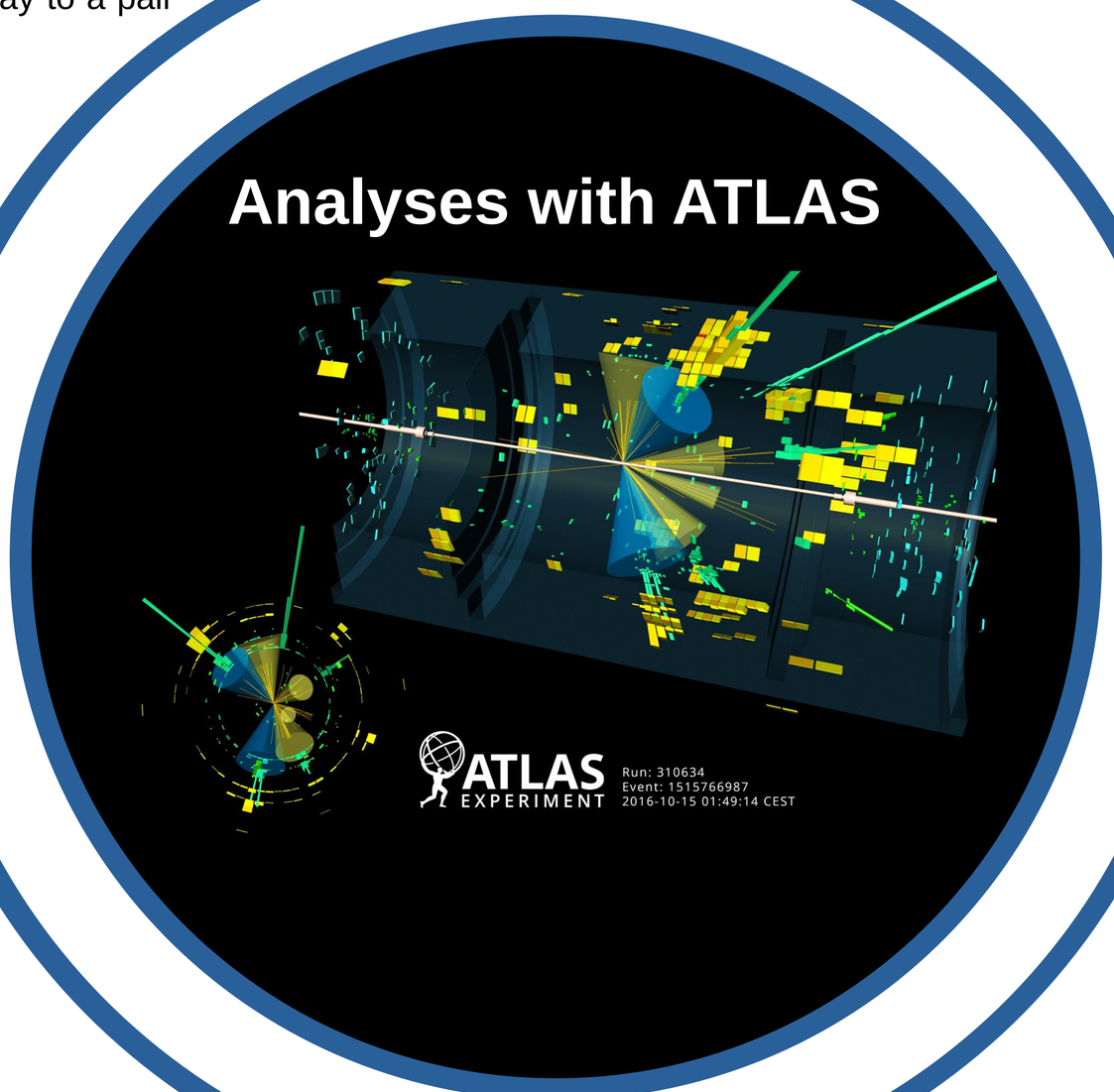
The Higgs boson is the excitation of the Higgs field and a fundamental particle of the Standard Modell.
It was the last fundamental particle to be discovered in 2012 by ATLAS and CMS at Large Hadron Collider.

The Higgs boson has distinct properties which makes it particularly interesting for research. It is the only particle in the Standard Model with a spin of 0.

The Higgs boson can decay into a pair of Z^0 bosons. Such decays are of special interest, because the Z^0 bosons can further decay to a pair of leptons.



Analyses with ATLAS



Quantum entanglement is a feature of a composite quantum system. It refers to a state where two particles cannot be described independently.

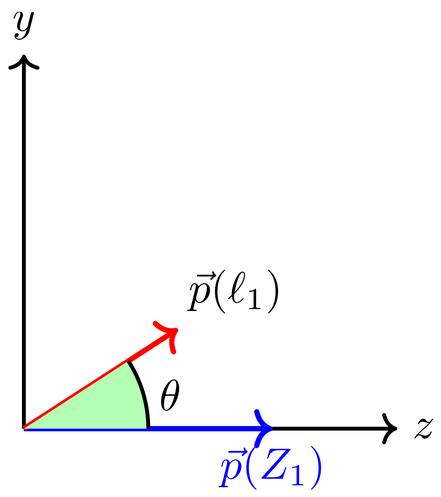
A typical gedankenexperiment consists of a particle with spin 0 decaying into two particle with non-vanishing spin.

Measurement of Alice predetermines the measurement of Bob

The Higgs boson itself is a spin 0 particle. Therefore, the decays to two vector bosons offer a great platform to examine quantum entanglement at the most fundamental level.
In contrast to other entanglement experiments typically performed with photons, the spin of the vector bosons is not directly accessible but via its decay products.

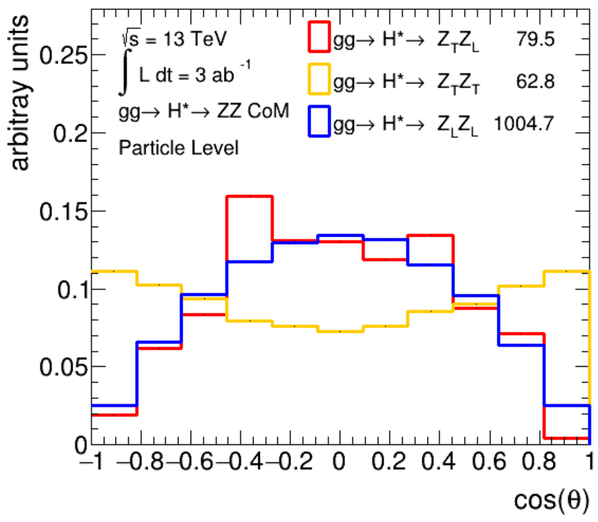
Quantum Entanglement

Decay of Electroweak Gauge Bosons

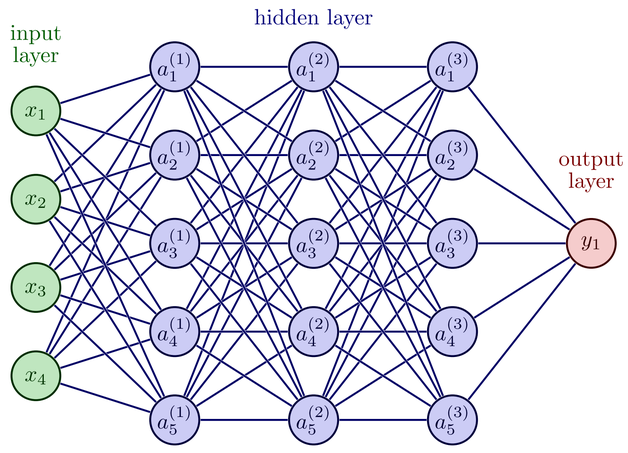


The coupling strength of the electroweak Z^0 boson to leptons is dependent on the spin state of the lepton.
Therefore, the Z^0 boson's spin state can be determined by its leptonic decay products.
More precisely the angle of the lepton with respect to the Z^0 boson's axis of movement is such a kinematic variable.

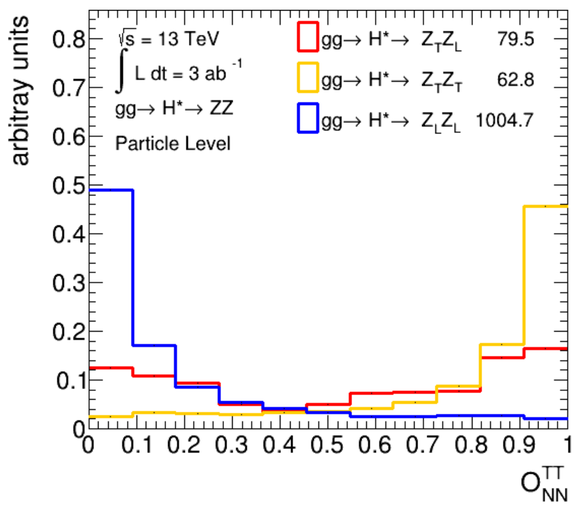
The distribution of the angle θ differs for the polarisation states of the Z^0 bosons.



A *dense neural network* consists of several layers. Each layer consists of nodes, which take the output of each previous node to calculate its output. The input layer's inputs are the kinematic variables of the event. The output layer yields a classifier.



The neural network is trained to separate between two types of events.



This technique was applied to the $H^* \to ZZ$ decay to obtain a variable sensitive to the polarisation state of the Z^0 bosons. Such a variable can then be used in a profile likelihood fit to test different hypothesis of the spin state of the Z^0 boson system.

Deep Learning