Higgs decay through the ZZ(*) channel

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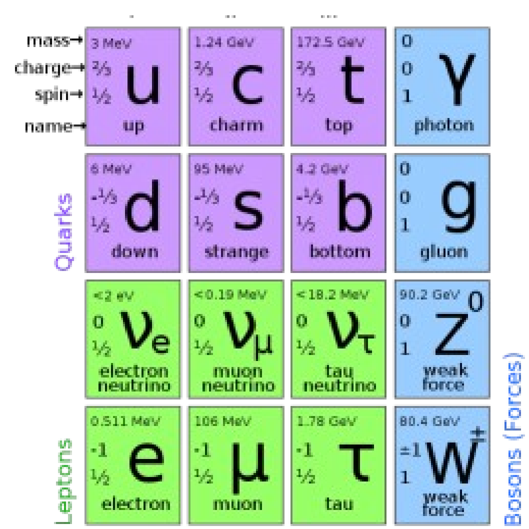
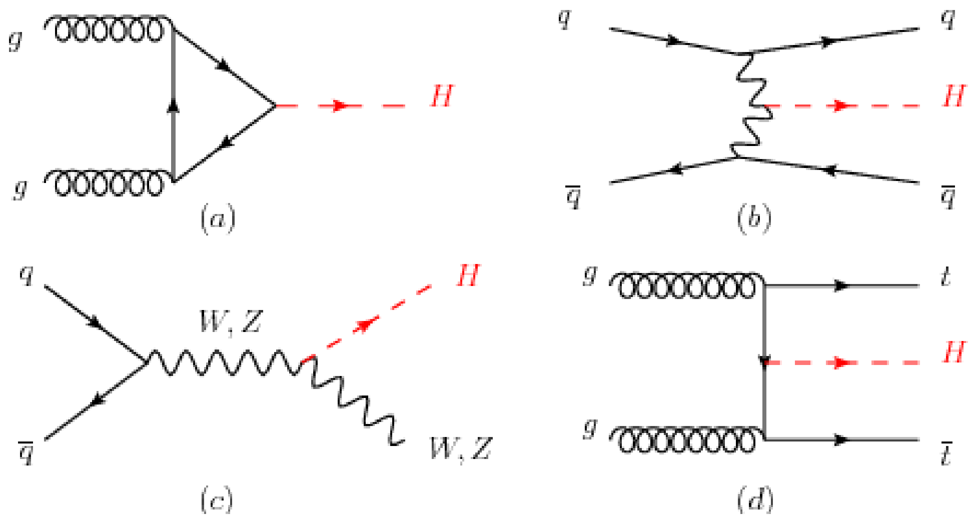
About the Higgs Boson – SM

Over the last five decades, the SM has been successful in describing High Energy Physics (HEP) interactions. The Higgs Mechanism which is responsible for breaking the electroweak symmetry in the SM, allows to explain the origin of the mass of elementary particles and also predicts the existence of a scalar boson, known as the Higgs Boson.



Production of the Higgs Boson in the LHC

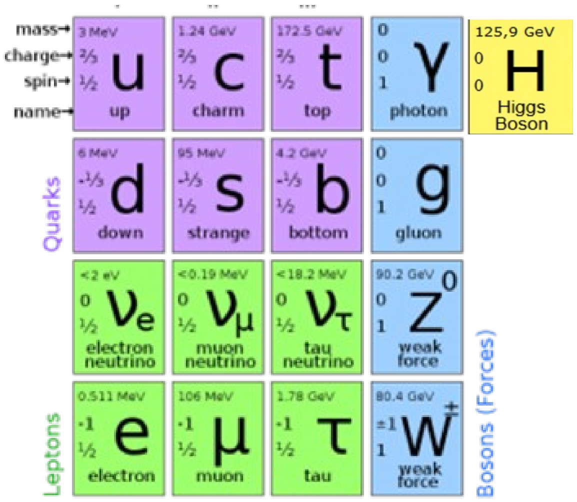
In order to create Higgs Bosons at LHC, proton-proton collisions with high Center of Mass energy were used (7, 8, 13 and 14 TeV). To achieve such high energy, beams of protons are accelerated and bent using electric and magnetic fields. During a collision, several processes can take place to create Higgs Bosons:



Higgs Boson Decay Channels

There are several final states for a Higgs Boson after his decay. The main experimentally accessible channels for the decay are:

- $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ (Golden Channel)
- $H \rightarrow \gamma\gamma$
- $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$
- $H \rightarrow bb$
- $H \rightarrow \tau\tau$



(ℓ = electron/muon, τ = tau lepton, b = bottom quark, γ = photon, ν = neutrino)

The Golden Channel ZZ(*) – Why?

The 4-lepton final state decay is the so-called golden channel as it has the clearest and cleanest signature of all the Higgs' decay modes. (Isolated) leptons are more easily detectable and traceable in the ATLAS detector:

- WW(*) channel – 2 neutrinos are created – no direct ATLAS detection;
- bb channel – 2 bottom quarks are created – hadronizes into jets;
- ττ channel – only detects τ decay products – cannot detect the neutrinos produced and fully reconstruct the event
- γγ channel – low event frequency – high number of background photon pairs

ZZ(*) - ATLAS Event Selection

In the ATLAS detector, there are different triggers for each lepton/lepton pair in the decay products. This trigger will determine whether the event should be recorded or not. This is usually done by establishing a lower limit to the transverse momenta of the leptons.

Example: For the single-muon trigger, the transverse momenta threshold is 18 GeV for the 7 TeV data and 24 GeV for the 8 TeV data.

Event Data Selection for Analysis

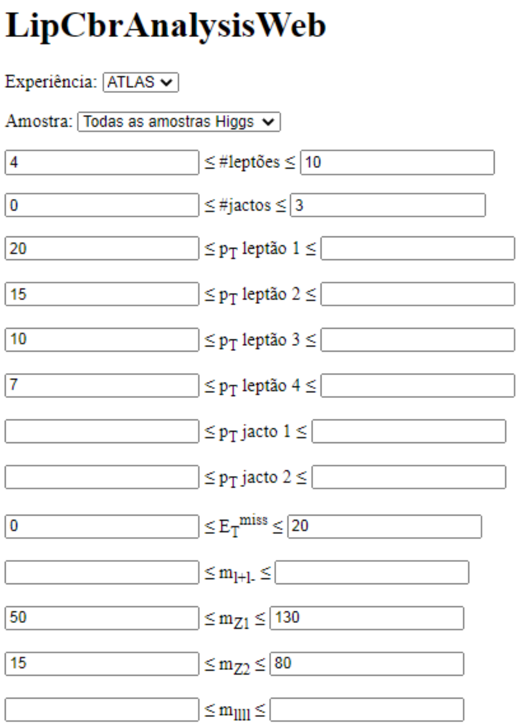
For an improved signal to background ratio, we did further selection in some of the event's properties. These properties include selecting the number of leptons and jets, lepton and jet's transverse momenta, missing transverse energy and the mass of the Z boson pair.

For this analysis (13 TeV Data), we restricted our search to events with few jets, small missing transverse energy (no neutrinos) and having at least one real Z boson.

Selections
#Leptons ≥ 4
#Jets ≤ 3
Lepton 1 pT ≥ 20 GeV
Lepton 2 pT ≥ 15 GeV
Lepton 3 pT ≥ 10 GeV
Lepton 4 pT ≥ 7 GeV
50 GeV ≤ Z1 Mass ≤ 130 GeV
15 GeV ≤ Z2 Mass ≤ 80 GeV

Event Data Analysis - Simulations and Normalizations

In order to look for new physics in the LHC, one has to directly compare the experimental data with the simulated theoretical data using the SM. But often the simulations have some discrepancy with the data and so it is required some form of normalization to the simulated data. In this data (13 TeV), we normalize the dominant background (ZZ) using a control region with no Higgs Boson. Comparing the data and the simulation, we can obtain a scaling factor so that the number of event in both are the equal.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Experiência: ATLAS

Amostra: Todas as amostras Higgs

4 ≤ #leptões ≤ 10

0 ≤ #jactos ≤ 3

20 ≤ p_T leptão 1 ≤

15 ≤ p_T leptão 2 ≤

10 ≤ p_T leptão 3 ≤

7 ≤ p_T leptão 4 ≤

≤ p_T jacto 1 ≤

≤ p_T jacto 2 ≤

0 ≤ E_T^{miss} ≤ 20

≤ m_{l+l-} ≤

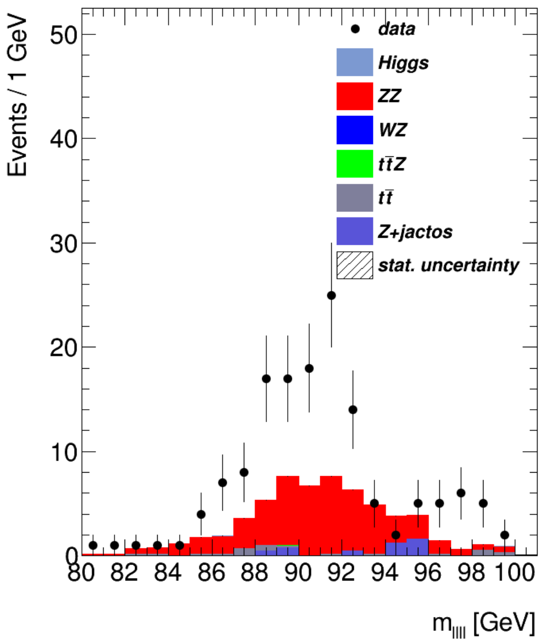
50 ≤ m_{Z1} ≤ 130

15 ≤ m_{Z2} ≤ 80

≤ m_{llll} ≤

Event Data Analysis - Simulations and Normalizations

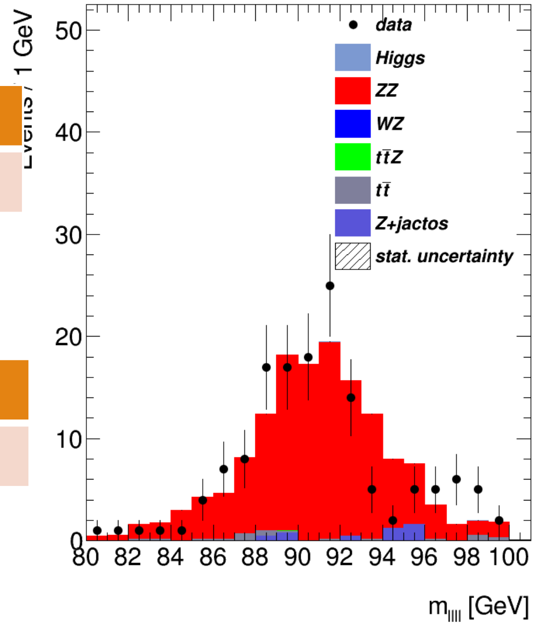
For reference, here's how the normalization looks like for the previous data selection:



Before ZZ background normalization

Control Region
4ℓ Mass ≤ 100 GeV

Scale Factor
2.59 ± 0.24

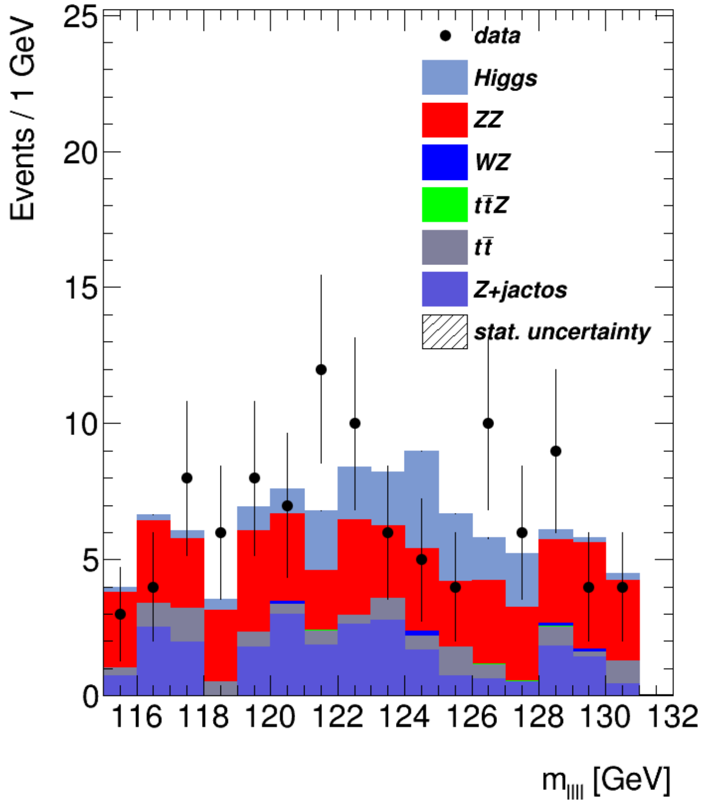


After ZZ background normalization

Results – Significance and Signal Strength

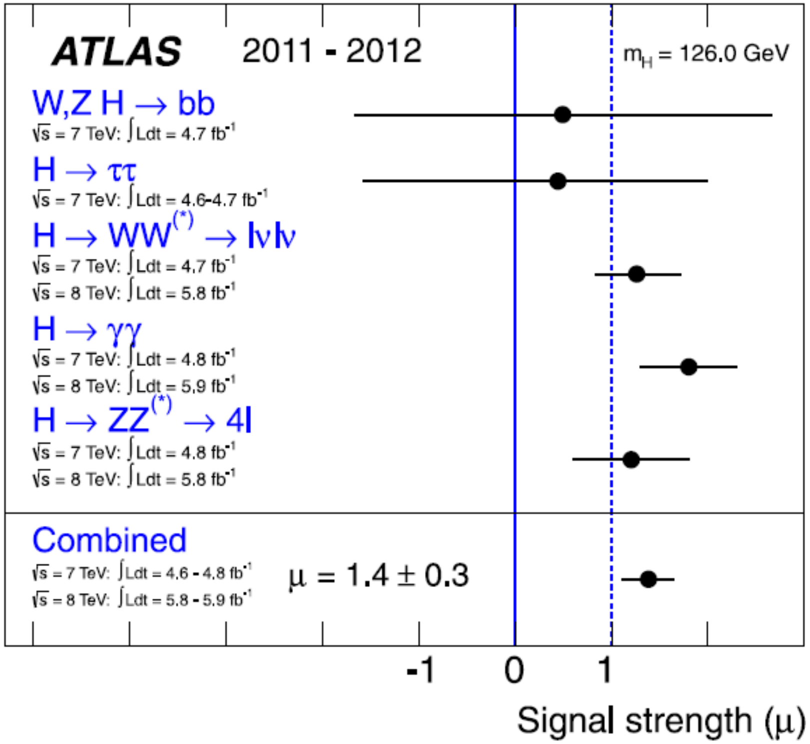
After the data analysis, we should know how **significant** our signal is (whether our signal is a statistical fluctuation or a discovery). So, we select the mass region where we expect Higgs Boson signal. After further analysis we obtained the number of Higgs Boson events (24 ± 12). Dividing this number by the uncertainty of number of events, we can obtain the significance of the signal. In this case we obtained a result of 2.34 σ.

Signal Region
115 GeV ≤ 4ℓ Mass ≤ 131 GeV



Results – Significance and Signal Strength

We can also compare the experimental number of Higgs events with the theoretically predicted value. The **signal strength** (in this case, is the ratio between the experimental and theoretical cross-sections) measures how close our experimental data is to the SM prediction. The signal strength obtained in our analysis was 1,2 ± 0,6.



Final Remarks

In this internship, a lot of statistical methods used in experimental physics were explained and explored.

It allowed us to obtain a great insight of how the Higgs Boson was discovered.

It also gave us an idea how it is to work in this area of physics.

We would like to thank LIP and our coordinators for the opportunity to take part in this internship.