Higgs pair production in the four b quarks final state

Ana Luísa Moreira de Carvalho

Instituto Superior Técnico, Lisboa, Portugal

December 2011

Abstract

Place abstract here. No paragraph breaks.
Keywords: Keyword1, Keyword2, Keyword3, Keyword4, Keyword5

Introduction and motivation

A lot of work as is currently being put into designing and understanding the physics reach of future particle colliders. The hadronic Future Circular Collider (FCC-hh) study, led by CERN, is one of the possibilities that is currently being analyzed. Its baseline design consist of a 100 km ring located in the Geneva area capable of delivering proton-proton collisions at a center of mass energy of 100 TeV. The FCC-hh will deliver a peak luminosity of $\mathcal{L} = 30 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ in its ultimate phase. This will result in $O(30)$ ab^{-1} per experiment. The next milestone for this project is the delivery of a Conceptual Design Report (CDR) by the end of 2018. This document should include a first cost estimate as well as a compilation of preliminary analysis that illustrate the physics potential of such an accelerator.

A particularly interesting process to be studied in future colliders is the production of pairs of Higgs bosons (or di-Higgs production). This process is sensitive to the value of the Higgs boson triple coupling that determines the shape of the Higgs potential and therefore plays a crucial role in the electroweak symmetry breaking mechanism. The Feynamn diagram that provides sensitivity to the triple coupling is shown in figure 1.

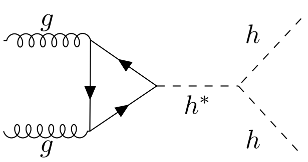

Figure 1: oi

However, searches for di-Higgs production are extremely challenging mainly because the cross section of this process is very small, of the order of tens of femtobarns (fb). Even with the entire dataset that is expected to be accumulated during the LHC's (including its high luminosity upgrade) lifetime ($O(3)$ ab^{-1}), it is very unlikely that we will be able to declare the observation of this process. Therefore, the discovery of di-Higgs production relies on future colliders making it a key benchmark process.

In this work we focus on the final state with four b quarks. The branching ratio (BR) of $h \to b\bar{b}$ is approximately 58%. Therefore this final state maximizes the cross section times branching of the $hh \to b\bar{b}b\bar{b}$ process. However, for this final state, the dominant background is multijet production through quantum chromodynamics (QCD) processes whose cross section is a lot larger than that of the signal. Nonetheless, it is a well known characteristic of QCD interactions that the partons (and jets) produced tend to a low transverse momentum (p_T). This indicates that exploring a high p_T region of the phase space could be the key to suppress the QCD multijet background. Such region is called boosted due to the high Lorentz boost of the objects involved. In this kinematic regime, traditional jet reconstruction algorithms, that establish a one to one correspondence between the partons and the jets, begin to fail because the ΔR distance between the b quarks, $\Delta R(b\bar{b})$, gets increasingly smaller as the p_T of the mother Higgs boson, $p_T(h_1)$, increases. This is shown in figure 1. State of the art jet reconstruction techniques use a single jet with a large R parameter to reconstruct both b quarks as a single jet that is used as a *proxy* for the Higgs boson. In order to extract as much information as possible from this jets it is important to analyze its intrinsic structure, referred to as substructure. Such techniques are fairly recent and usually explore the existence of well defined energy maximums inside a large R jet. For example, a jet that contains the two b quarks coming from the decay of a Higgs boson is expected to be more compatible with the existence of two subjets than a jet produced by a QCD process.

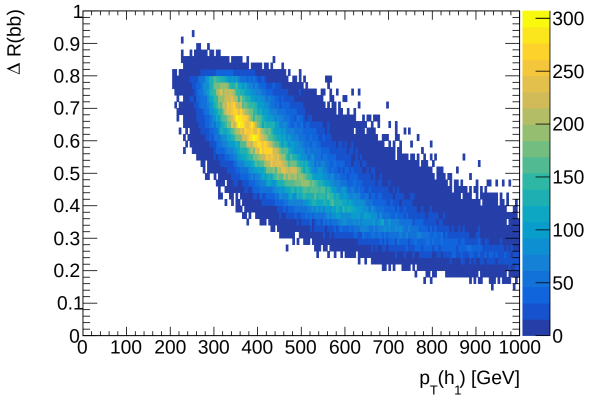

Figure 2: oi

From the point of view of detector design for the FCC-hh, as well as for future upgrades of existent detectors such as the ATLAS one, the granularity of the hadronic calorimeter (HCAL) is a key parameter because it greatly influences the ability of the detector to resolve the substructure of large R jets.

The main goal of this project is to use boosted di-Higgs production in the four b quarks final state to study the influence of the granularity of the HCAL in the significance ($S/\sqrt{B}$) that can be achieved.

The LHC and the ATLAS detector

The Large Hadron Collider (LHC) is housed by the European Organization for Nuclear Reasearch (CERN) and located beneath the Franco-Swiss boarder in the Geneva area. It consists of a 27 km ring dedicated (most of the time) to delivering proton-proton collisions at a center of mass (CM) energy of $\sqrt{s} = 13$ TeV. The two main purpose experiments, ATLAS and CMS, are dedicated to the search for any hints of new physics. The LHCb experiment is dedicated to the study of beauty particles and the ALICE experiment is optimized to study heavy ion collisions.

The ATLAS detector is a multipurpose particle physics apparatus with forward-backward symmetric cylindrical geometry. The inner tracking detector (ID) consists of a silicon pixel detector, a silicon microstrip detector, and a straw-tube transition radiation tracker. It is contained in a superconducting solenoid magnet that provides a 2 T magnetic field and surrounded by a high-granularity liquid-argon sampling electromagnetic calorimeter (ECAL). The ECAL covers the pseudo-rapidity range $|\eta| < 3.2$. The hadronic calorimetry in the pseudorapidity range $|\eta| < 1.7$ is provided by a scintillator-tile calorimeter (TileCal). For $|\eta| > 1.5$ liquid-argon calorimeters extend the pseudorapidity range to $|\eta| = 4.9$. The LAr calorimeter is divided in end-cap and forward. These cover the pseudorapidity ranges $1.5 < |\eta| < 3.2$ and $3.2 < |\eta| < 4.9$. In the end-cap the segmentation is $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ for $1.5 < |\eta| < 2.5$ and 0.2×0.2 for $2.5 < |\eta| < 3.2$. In the forward region the segmentation is $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$. The muon spectrometer (MS) surrounds the calorimeters and it is the outermost layer of the detector. It is composed of Monitored Drift Tubes and Cathode Strip Chambers.

The FCC-hh and the baseline detector

The FCC-hh baseline design consist of a of a proton-proton circular collider with a maximum CM energy of $\sqrt{s} = 100$ TeV housed by a 100 km tunnel in the area of Geneva. It will deliver a peak luminosity of $\mathcal{L} = 30 \times 10^{34}$ cm^{-2}s^{-1} in its ultimate phase which will result in a $O(30)$ ab^{-1} per experiment. This machine will extend the research program of the LHC (and of the HL-LHC) after these have reached their full discovery potential, by around 2040.

The design of the FCC-hh baseline detector has been greatly based on that of the ATLAS and CMS experiments, in particular the central barrel. The layers and sub detectors are arranged in the same order and perform very similar roles. The ID detector covers the pseudorapidity range $|\eta| < 6$ and it will be instrumented with pixel and strip detectors. The ECAL covers the pseudorapidity range $|\eta| < 6$. The proposed layout is a LAr sampling configuration with lead, glue and steal plates as absorbers. The granularity is expected to be two to four times better than for the ATLAS ECAL. The hadronic calorimeter covers the pseudorapidity range $|\eta| < 6$. It is divided in barrel, end-cap and forward that cover the pseudorapidity ranges $|\eta| < 1.3$, $1.0 < |\eta| < 1.8$ and $2.3 < |\eta| < 6.0$. For the barrel and end-cap calorimeters, the expected segmentation $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ while for the forward calorimeter it is $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$. Overall, this corresponds to approximately four times the ATLAS HCAL granularity. The MS cover the pseudorapidity range $|\eta| < 6$ and it consists of a layered structure of gas chambers.

State of the art

The searches performed so far for di-Higgs production covered different decay channels and targeted not only the SM production but also some BSM scenarios where this process is enhanced. Neither could achieve enough statistical significance to declare the observation of this process nor found any deviation from the SM predictions.

The most stringent limit comes from a combination of searches using up to 36.1 fb^{-1} of proton-proton collision data at a center of mass energy $\sqrt{s} = 13$ TeV recorded with the ATLAS detector. The combination is performed using the analysis searching for $hh \to b\bar{b}b\bar{b}$, $hh \to b\bar{b}\tau^+\tau^-$ and $hh \to b\bar{b}\gamma\gamma$. The combined observed (expected) limit on the non-resonant Higgs boson pair cross-section is 0.22 pb (0.35 pb) at 95% confidence level, which corresponds to 6.7(10.4) times the predicted SM cross-section. The ratio of the Higgs boson self-coupling to its SM expectation ($k_\lambda = \lambda_{hhh}/\lambda_{hhh}^{SM}$) is observed (expected) to be contrained at 95% CL to $-5.0 < k_\lambda < 12.1 (-5.8 < k_\lambda < 12.0)$.

Monte Carlo studies assessing the feasibility of searches for di-Higgs production at the High Luminosity LHC and at the FCC-hh have been performed. [REPRESENTATIVE STUDIES AND REFS]

Studies on the impact of the granularity of the calorimeters in the spatial resolving power of hadronic showers and on the resolution of jet mass and substructure variables greatly influenced the baseline design of the FCC-hh. For two Kaons with an energy of 100 GeV each and with a truth level separation equal to 0.035 it is shown that for a segmentatin of $\Delta\eta \times \Delta\phi = 0.022 \times 0.022$ both particles can be resolved in the HCAL [REF]. [RESOLUTION+OVERLAP STUDIES]

Simulation setup

The main backgrounds for di-Higgs searches in the $b\bar{b}b\bar{b}$ are multijet and $t\bar{t}$ production. All other sources of background, including processes involving Higgs bosons, are found to be negligible [REF]. In addition to these, we also consider the irreducible background as a separate sample.

We simulate the signal and background Monte Carlo samples using a fast simulation workflow. MadGraph5 aMC@NLO is used to compute the matrix elements of a given process. Showering and hadronization of colored particles are handled by Pythia8 and the detector response is parameterized using Delphes3.

The irreducible background is generated with an extra jet with $p_T > 200$ GeV at generator level. This guarantees that the pairs of b quarks are boosted enough to increase the probability of being reconstructed as a single jet. The multijet background is simulated as $jj + 0/1/2\ j$ where j stands for a light or b jet. To make the simulation more efficient, this background is generated in several H_T regions where H_T is the scalar sum of the p_T of all the partons at generator level. The $t\bar{t}$ background is simulated as $t\bar{t} + 0/1/2\ j$.

Analysis

The analysis that we implemented targets the boosted kinematic regime in which both Higgs bosons are reconstructed using large R jets. The expected event topology is illustrated in figure 6.

The events are reconstructed using particle flow (or calorimeter) jets with $R = 0.8$ clustered with the anti-k_T algorithm. The events are required to have at least two jets. Each jet is required to have two subjets, both b-tagged. In addition, both jets are required to have $p_T > 200$ GeV. These cuts consist of the event pre-selection.

The b-tagging is implemented using truth level information. The b-tagging and mis tagging efficiencies are extracted from the FCC-hh detector default Delphes card, implemented by the FCC-hh study group.

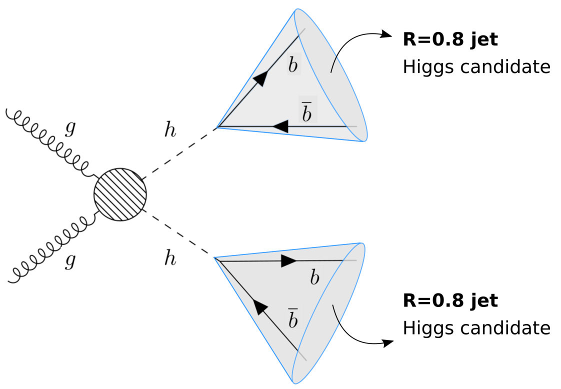

Figure 3: oi

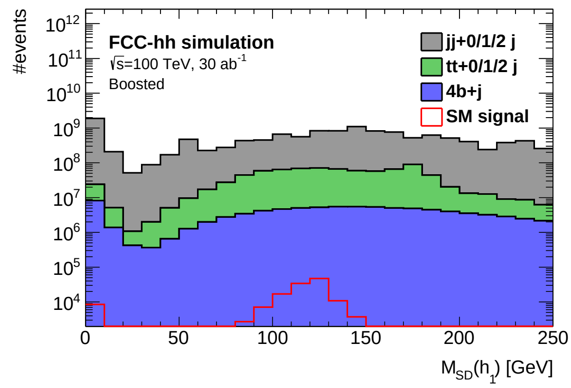

Figure 4: oi

Results

Conclusions

Conclusions, future work and some final remarks...

Acknowledgements

The author would like to thank ...

References

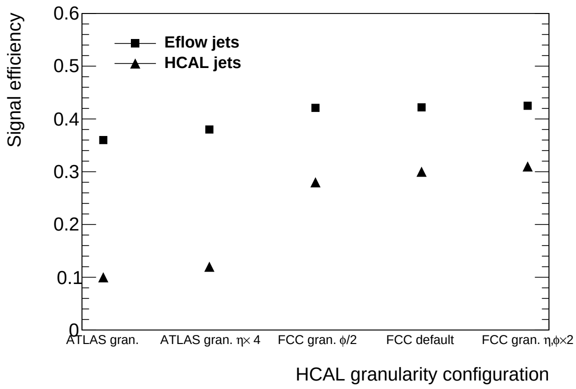

Figure 5: oi

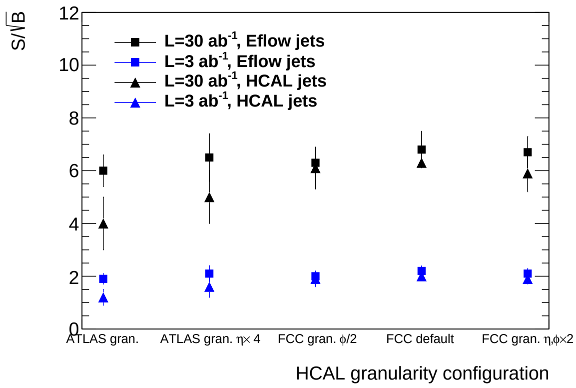

Figure 6: oi