Standard Model Higgs Searches at the LHC

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My proposed research plan aims to either exclude or find evidence for a light Higgs boson with the ATLAS experiment at the LHC. In preparation for this, I intend to continue to develop my work in the ATLAS high-level trigger and to contribute to the first measurement of top-quark cross section in ATLAS. If signs of a Higgs boson candidate are indeed observed, I propose to determine whether the particle found is CP-even or CP-odd. This could be crucial measurement to confirm or reject the evidence of a SM Higgs. I propose to join University College London (UCL) to pursue this research.

1 Introduction: Higgs physics

The first proton beams circulating in the Large Hadron Collider (LHC) initiated a new and exciting era in particle physics research. The first two years after the 2009 LHC re-start should see a re-discovery of the Standard Model of particle physics (SM). The observation of known SM processes will be essential to both understand the experiments and the accelerator, and to make important measurements in a hitherto unexplored energy region.

In the Standard Model, the mechanism of electroweak symmetry breaking explains the different intrinsic strenghts of the electromagnetic and weak interactions, as well as the origin of the mass of fundamental particles. The Higgs boson is a sub-product of this mechanism, predicted by the SM but never observed. The existence of this particle is needed in detailed calculations of several electroweak observable quantities. Turning this argument around, precision measurements of such quantities provide an indirect measurement of the Higgs boson mass. Numerical fits to these measurements result in a Higgs boson mass, (the only free parameter in the model) of $m_H = 84^{+34}_{-26}\,\mathrm{GeV/c^2}$. This can be expressed as a one-sided 95% confidence level limit of $m_H < 154\,\mathrm{GeV/c^2}$. The central value has in fact already been excluded by direct searches performed at the Large Electron Positron collider (LEP) at CERN. These resulted in a lower m_H limit of $114\,\mathrm{GeV/c^2}$. Finally, recent results from the D0 and CDF experiments, running in the Tevatron collider at lower energy than the LHC, have excluded a SM Higgs boson with a mass of $170\,\mathrm{GeV/c^2}$. In summary, there are good reasons to believe that a ”light” Higgs boson exists near to the lower limit of $114\,\mathrm{GeV/c^2}$. If this is indeed the case, then it must be either found or excluded at the LHC. This will, however, be especially challenging in the low-mass region.

2 Finding a light Higgs at the LHC

The Higgs boson is short-lived, and its decay mode depends strongly on m_H. Its existence must be inferred from the measurement of the decay products. A Higgs boson with a mass in the range between $114\,\mathrm{GeV/c^2}$ and $\sim 140\,\mathrm{GeV/c^2}$ decays mostly to a *b*-quark pair, with a branching ratio BR$\sim 90\%$ or to a τ-lepton pair (BR$\sim 9\%$). These events are difficult to disentangle from the huge SM background, and so the search must include channels where the Higgs boson is produced together with other particles [1].

In the $t\bar{t}H(H \to b\bar{b}$ channel, the Higgs boson is produced together with a top-quark pair, $t\bar{t}$, and decays to a *b*-quark pair. The top quarks can decay semileptonically to a lepton (electron, muon or tau), a neutrino, and a *b* quark ($t \to bl\nu$) . It can also decay hadronically into a *b*-quark and two other quarks of any flavour, most frequently *u* or *d* ($t \to bqq'$).

Recent ATLAS results, in the channel where one top quark decays semileptonically achieved a significance of around 2 for $30fb^{-1}$. This sensitivity needs to be enhanced, to make this channel a significant

[1] The one viable exception $H \to \gamma\gamma$, which, on the other hand, has a very small branching ratio.

contributor to a light Higgs discovery. I believe this can be achieved in two ways: by investigating the decay channel where both tops decay semileptonically ("all-lepton" channel), and by applying a jet substructure analysis technique which is being pioneered at UCL [2].

The "all-lepton" channel, where both top quarks decay semileptonically, wasn't examined in ATLAS so far, since it corresponds to only around 10% of the $t\bar{t}H$ events. While this is a disadvantage, I propose to use the cleaner event structure (4 *b*-jets and 2 leptons) to facilitate the event selection and to improve the background rejection. I believe that what is lost in statistics can be regained from the more striking final state topology, such that this channel can be best indicted for obtaining the first evidence of a Higgs boson in $t\bar{t}H$ production. The jet substructure technique has the potential to provide both a better resolution of the Higgs boson mass and a more efficient signal identification. This technique applies to events where the relativistic Higgs decays into two, almost collinear *b* quarks, which result in a single hadronic jet. Disentangling and measuring the jet components is essential to recover those events.

My work on the $t\bar{t}H(H \rightarrow b\bar{b})$ and particularly on the $t\bar{t}H(H \rightarrow invisible)$ channel, where the Higgs boson decays to new particles which escape detection, will be very valuable for this analysis. The "all-lepton" channel presents similar challenges to the $t\bar{t}H(H \rightarrow invisible)$ channel, since both have multiple sources of missing transverse momentum.

3 Triggering on the Higgs

The first task in any collider data analysis, and especially in the search for new physics, is to ensure that the relevant collisions are recorded for later analysis. The LHC produces 40 million collisions each second in the centre of the ATLAS detector. Of these, only around 200 collisions can be recorded for later analysis. It is therefore necessary to decide, in real time, which collisions may contain interesting events. This is achieved in ATLAS by a three-level triger system, which reconstructs collision events using fast algorithms and partial event readout.

During the first half of the fellowship, I propose to continue to develop my current work within the ATLAS trigger. My position as trigger software validation co-coordinator will allow me to use the lessons learned from the first collected data to identify the weaknesses of the software and promote the necessary changes. The strong trigger involvement of the UCL group would make it an ideal place to develop this activity. My role as trigger contact person in the design of the analysis data format also provides an excellent opportunity to influence the design in the sense of enhanced useability and reliability.

To select as many Higgs events as possible while staying within the 200 Hz readout constraint, will be a challenging task. My role as trigger contact person within the Higgs group provides me with a valuable opportunity to contribute in this area and identify the strategic trigger needs of the Higgs analyses. In addition to the need for an efficient trigger, the use of a set of backup triggers that allow a reliable and unbiased estimation of efficiencies is essential.

The second half of the fellowship will correspond to a period when the LHC will run with increasing luminosity. This places stringent constraints on the trigger system, due to an increased number of overlapping collisions in each beam crossing and due to the increased rate of interesting events. An upgrade effort is starting, which is essential for high luminosity operation of ATAS. A fast hardware-based charged track reconstruction algorithm is an essential piece of this upgrade, and includes a strong participation from UCL, which I propose to join.

4 Top pair production cross section

Measurements of well-known Standard Model processes will be a fundamental basis to the discovery of new physics. One of the essential milestones in this process will be the observation of $t\bar{t}$ production. The complexity of the $t\bar{t}$ final state, makes it an excellent testing ground for reconstruction techniques. Achieving a measurement of the top cross section in ATLAS will mean that a good control of the various sources of systematic uncertainties has been obtained.

[2] J.Butterwoth et al., Phys.Rev.Lett. 100, 242001 (2008)

It is expected that an accumulated data set corresponding to 100 pb^{-1} of integrated luminosity will be sufficient to determine the $t\bar{t}$ production cross section with less than 10% uncertainty. This data could be accumulated during the 2009 LHC run. I propose to contribute to this analysis during the first half of the felowship. An obvious area of contribution would be to study the trigger efficiency in the busy environment of top-pair events. This analysis will rely on single lepton triggers, for which it is in principle possible to obtain an unbiased efficiency estimate using samples of Z^0 or $W^\pm$ events. On the other hand, this needs to be verified by a set of backup triggers which can provide an unbiased estimation of the the efficiency. My experience of the trigger software will be hugely valuable me in this task.

5 Higgs CP quantum number

After obtaining the first measurement of $t\bar{t}$ production cross section at the LHC energy, roughly half-way through the fellowship, all conditions would be set for a search of the Higgs boson in the "all-lepton" channel, $t\bar{t}H \to (bl^+\nu)(\bar{b}l^-\bar{\nu})(b\bar{b})$.

If evidence for a Higgs boson is found, the next step will be to measure the parameters of the Higgs boson candidate, and so to verify whether it corresponds to the SM prediction, or if it is part of a more complex scenario. Part of this task can be achived by observing the Higgs in different channels, and also the ratios of Higgs cross section in these channels. For example, the observation of a Higgs candidate in the $H \to \gamma\gamma$ excludes a spin 1 particle.

If I will find evidence for a Higgs boson in the $t\bar{t}H(H \to b\bar{b})$ channel, I intend to measure its CP quantum number. The observation of a CP-odd Higgs candidate, would exclude the SM Higgs, which is CP-even. As an example, the Minimal Supersymmetric Standard Model (MSSM) scenario, contains a different Higgs sector. This is the most popular extension of the SM, and predicts the existence of new particles, including a good Dark Matter candidate. In the MSSM there are five Higgs bosons: h^0 and H^0 which are CP-even, A^0 which is CP-odd, and two charged bosons $H^\pm$.

The measurement of the Higgs CP quantum number could therefore be crucial to distinguish between the SM Higgs and other scenarios. It can be achieved in the $t\bar{t}H(H \to b\bar{b})$ channel by fully reconstructing the top-quark 4-momenta and calculating discriminating variables which are a combination of these 4-momenta [3]. The full reconstruction of the top quarks requires the $t\bar{t}H \to (bl^+\nu)(\bar{b}qq')(b\bar{b})$ channel, where only one of the top quarks decays semileptonically, so that only one high-transverse momentum neutrino is present in the event.

6 Summary

In summary, I propose a research programme that leads to a search for a light Standard Model Higgs boson with the ATLAS experiment in the $t\bar{t}H(H \to b\bar{b})$ channel. In preparation for this analysis, I plan to concentrate on the development of a trigger strategy which ensures that Higgs events are recorded efficiently. I also plan to contribute to the measurement of the $t\bar{t}$ cross section in ATLAS, using the first period of LHC collision data. This will be the ideal training ground for a Higgs boson search.

The search for evidence of a light Higgs boson concentrates on the events where both top quarks decay semileptonically: $t\bar{t}H \to (bl^+\nu)(\bar{b}l^-\bar{\nu})(b\bar{b})$. If the search is successful, then using the decay channel $t\bar{t}H \to (bl^+\nu)(\bar{b}qq')(b\bar{b})$ would allow discrimination between a CP-even and a CP-odd Higgs candidate.

I believe my experience of data analysis in both the LHC environment and HERA, together with my expertise of the ATLAS trigger, make me ideally suited to play a leading role in this research programme. The UCL group has crucial expertise in many of the areas relevant for this research, which make it the perfect place to carry out this programme.

To facilitate the execution of this research programme, and to allow the communication of research results at conferences, I am requesting some additional support. This consists of an anual average of 2000 pounds for travel and subsistence, and a further 2000 pounds for computing consumables.

[3] Gunion and He, PRL 76, 24 4468, (1996)