Search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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Abstract

We present a search for Higgs boson pair production, with the $b\bar{b}b\bar{b}$ final state. This analysis uses the full 2015 and 2016 data collected collected by the ATLAS Collaboration at $\sqrt{s} = 13$ TeV, corresponding to 3.2 ± 0.2 fb^{-1} of 2015 and 32.9 ± 1.1 fb^{-1} of 2016 pp collision data. Improvements with respect to the previous analysis are mainly in the boosted regime, where the resonance signal is between 2500 GeVand 3000 GeV. The data is found to be compatible with the Standard model, and no signs of new physics have been observed. The results are interpreted in the context of the bulk Randall-Sundrum warped extra dimension model with a Kaluza-Klein graviton decaying to hh, with the coupling $k/\bar{M}_{\rm Pl}$, chosen to be in the allowed range $1.0 - 2.0$. The results are also interpreted with the Type 2 two-Higgs doublet model (2HDM) where the neutral heavy CP-even H scalar decays to hh.

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Everything is meaningless.
Even the sentence above.

Acknowledgments

Thanks to everyone the ATLAS collaboration, who has supported this remarkable program and has contributed to every bit of the result in my thesis. Sir Issac Newton said he was standing on the gaint's showlders to see far and deep into the nature. Similarly. I am standing on the ATLAS(member)'s showlders–it's eight stories high so I hope ATLAS doesn't shrug. Without the excellent work on detector design, commisioning, operational works, reconstruction, data processing, performance studies and recommendations, software support, computing support, and analysis discussions and guidance, I could not have completed this thesis. I truely and sincerely thank all ATLAS members for their contributions.

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Introduction

Why do we look for $hh \to 4b$?

There are two types of analysis in particle physics. The first one is measurement, which yeilds a observable with an uncertainty. This could either imrpove our knowledge of the Standard Model, or show some inconsistency with the Standard Model. The other type is search, which generally assumes some new physics model and try to justfy in data wether the new model is justified in some observables. A successful search turns the subject into a measurement, yet a null result will set a new limit for a given physics model.

Knowledge knows no bounds.

Creator

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Motivation for searches beyond the Standard Model

1.1 The Standard Model and the Higgs Boson

The Standard Model(SM) is the best description of the microscopic world [1,2,3,4]. The SM consists of fermions (spin $\frac{1}{2}$) and bosons (integer spin) as shown in Figure 1.1, which interact through: electromagnetism (EM), the strong nuclear force and the weak nuclear force. Fermions are the basic building blocks of matter, which consist of three generations of Leptons (e, μ, τ, ν_e, ν , ν_{tau}) and quarks (u, d, c, s, t, b). They all interact iva the weak force. In addition, the charged leptons and quarks interact via the EM force and the quarks also interact via the strong force. Bosons are force mediators. EM force mediates through the photon γ, the strong force meidates through the gluon g, and the weak force mediates through $W^{\pm}$ and Z bosons.

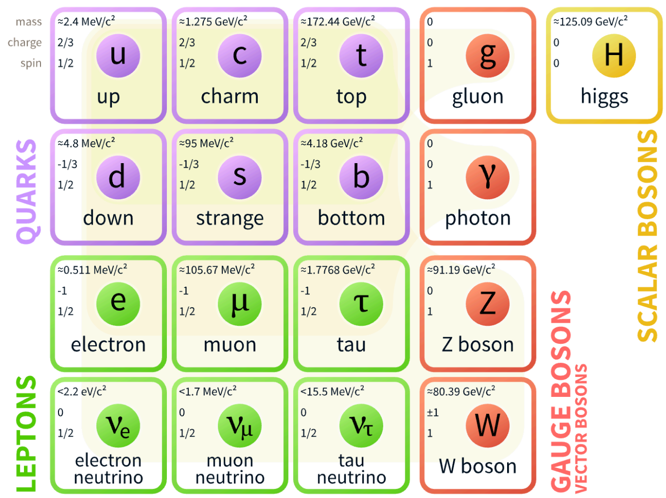

Figure 1.1: Fermions and bosons of the Standard Model and their properties [3].

However, in SM, due to the gauge invriance under $SU(2)_L$, fermions have to be massless in order to have pure left handed states. The bosons must also be massless as required by the gauge principle. The Higgs mechanism introduces a scalr Higgs field with nonzero vaccum expectation values, which impledes and interacts with the propagation of gague bosons and fermions, hence gives them valid mass terms [2]. This broken symmetry of the Standard Model predicts the extra particle degree of freedom as the Higgs boson. The terms inside the Higgs potential are shown in equation 1.1.

$$V(\varphi_h) = \lambda v^2 \varphi_h^2 + \lambda v \varphi_h^3 + \frac{1}{4}\lambda \varphi_h^4 \tag{1.1}$$

where v corresponds to the vaccum expectation value of the field, determined to be around 246 GeV. The first term gives the Higgs mass, m_h, as $\sqrt{2\lambda}v$, measured to be 125.09 $\pm$ 0.24 GeV. The second term provives an hhh vertex, which corresponds to the trilinear coupling of the Higgs boson.

This means that a two Higgs production (di-Higgs) can happen through a single Higgs even within the Standard Model.

1.2 Di-Higgs in the Standard Model

There has been many literatures about modifications of Higgs self coupling. Using standard model measurements and their precisions, we can constrain the self coupling parameter to an order of magnitude, see note.

1.3 Di-Higgs in Beyond the Standard Model Physics

1.4 Di-Higgs Decay and search perspectives

Di-Higgs decay is the combination of single Higgs decays. The partile width for Higgs to fermions and bosons (one of them is off-shell) at tree level are shown in equation 1.2[2] :

$$
\begin{gathered}
\Gamma(h \rightarrow f\bar{f}) = \frac{N_c \sqrt{2} G_F m_f^2 m_h}{8} \\
\Gamma(h \rightarrow VV^*) = \frac{1}{2} \int_0^{M_H^2} \frac{dq_1^2 M_V \Gamma_V}{(q_1^2 - M_V^2)^2 + M_V^2 \Gamma_V^2} \int_0^{(M_H - q_1)^2} \frac{dq_2^2 M_V \Gamma_V}{(q_2^2 - M_V^2)^2 + M_V^2 \Gamma_V^2} \frac{\sqrt{2} \quad v G_F m_h^3}{32} \sqrt{\lambda(q_1^2, q_2^2; m_h^2)} [\lambda(q_1^2, q_2^2; m_h^2) + 12 \frac{q_1^2 q_2^2}{m_h^2}]
\end{gathered} \tag{1.2}
$$

where N_c is the number os colors, m_f is the fermion mass, G_F is the Fermi constant. Hence, given the measured Higgs mass, tthe larges brancing ratio is to the $b\bar{b}$. Although there is no direct coupling between h and $\gamma\gamma$ at tree level, this decay can happen through W or top loops.

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