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The Mysterious Higgs Boson

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ABSTRACT

Recently the CMS and ATLAS collaborations at the LHC observe independently a new particle with mass ~ 125–126 GeV, consistent with the standard model (SM) Higgs boson. The Higgs boson is considered as the final particle of the SM. It is an important particle because it is responsible for the Higgs mechanism by which all particles acquire mass. But its mass is not specified in the SM. It has some unique properties which give a special status to it in the table of elementary particles of the SM. Recently, it is claimed that graphene, the 2010 Nobel Prize winning two-dimensional nonmaterial, would help physicists to probe the Higgs boson's secrets. It is also claimed that the Higgs boson might interact with dark matter and there exists relation between the Higgs boson and dark matter. Again the mass of the Higgs boson can be predicted in the Z' models. In this review article, we discuss these issues briefly.

Keywords: *Higgs boson, dark matter, graphene, Z' boson*

1. INTRODUCTION

Today we know that there are four types of fundamental forces in nature: gravitational force, electromagnetic force, weak force and strong force. The standard model (SM) [1, 2] unifies the strong, electromagnetic and weak force. The forces (electromagnetic, weak and strong force) are mediated by the gauge bosons: the photon(γ); the W^+, W^- and Z^0 boson; and the gluons respectively. There are 6 types of quarks and 6 types of leptons in the SM. Quarks are called up (u), down (d), charm (c), strange (s), top (t) and bottom (b). Leptons are called electron (e^-), electron-neutrino (ν_e), muon (μ^-), muon-neutrino (ν_μ), tau (τ^-) and tau-neutrino (ν_τ). Table1 shows the particle content of the standard model. All the 24 particles listed in Table1 have been discovered. The final particle of the SM, the Higgs boson (H), has not been confirmed experimentally yet. It is theoretically predicted by Englert, Brout, Higgs, Guralinik, Hagens and Kibble [3–6]. It is very important because it is responsible for the mechanism (Higgs mechanism [3,4]) by which all particles acquire mass. The Higgs mechanism allows the generation of particle masses preserving the gauge symmetry of electroweak interactions.

Table 1: The Standard Model

Fermions (spin – ½)		Gauge bosons (spin – 1)		
Leptons	Quarks	Weak	Electromagnetic	Strong
ν_e ν_μ ν_τ	u c t	W^+, W^-, Z^0	γ	Eight colored gluons
$\bar{e}$ $\bar{\mu}$ $\bar{\tau}$	d s b			

The standard model suggests that just after the big bang all particles were massless. As time passed on, the universe cooled and temperature fell below a critical value, an invisible field called the 'Higgs field' filled all space [7]. The particle associated with the Higgs field is called the Higgs boson. Although the Higgs field is not directly measurable, accelerators can excite this field and can detect the Higgs boson. So far, experiments using the world's most powerful accelerators have not observed any Higgs bosons, but indirect experimental evidence suggests that it is possible in future. Since the Higgs field is a scalar field, the Higgs boson has no spin, and hence no intrinsic angular momentum. The Higgs boson is also its own antiparticle and is CP-even. One of the important properties of this field is that the Higgs field is exactly the same everywhere whereas the magnetic or gravitational fields vary from place to place. When particles are moving in a uniform Higgs field, they change their velocities i.e. they accelerate. The Higgs field exerts a certain amount of resistance or drag, this is the origin of inertial mass.

In the SM, the Higgs field consists of two neutral and two charged component fields. Both of the charged components and one of the neutral fields are Goldstone bosons, which act as the longitudinal third-polarization components of the massive W^+, W^- and Z^0 bosons. The quantum of remaining neutral components corresponds to the massive Higgs boson. In the SM, there is only a single Higgs particle. But super symmetric extensions of the SM predict the existence of different Higgs particles. The minimal super symmetric extension of the SM (MSSM) predicts the smallest number (five) of Higgs boson [8–10]: two CP-even neutral Higgs boson h and H, a CP-odd neutral

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Higgs boson A, and two charged Higgs particles $H^{\pm}$. The lightest neutral Higgs particle h^0 has the same properties as the standard Higgs boson but by virtue of super symmetry, its mass is below 140 GeV.

Super symmetry [11–15] is a hypothetical symmetry between fermions and bosons. Unlike traditional symmetries, super symmetry does not treat bosons and fermions as two different classes of particles. The super symmetry operation converts bosons into fermions and vice versa. For each particle, it predicts the existence of a super partner (hence, doubles the SM particle spectrum) which should have the same properties [10] but with a spin different by a unit ½ and also a different mass as super symmetry must be broken in nature. But super particles are not detected experimentally so far and are expected at the LHC [16] in the coming years.

The existence of Higgs boson is related to the spontaneous breaking of electroweak symmetry and to the generation of elementary particle masses. The Higgs boson is highly unstable and once produced decays very quickly to either a fermion-antifermion pair or a pair of bosons. By energy conservation, the Higgs mass m_H, must be at least twice that of the particle in the pair to which it decays. The mass of the SM Higgs boson is given by $m_H = \sqrt{2\lambda}$ v, while the vacuum expectation value of the Higgs field v = 246 GeV is fixed by the Fermi coupling but the quartic Higgs self-coupling λ is not pre-determined; hence, the Higgs mass is not predicted. Constraints, at the theoretical as well as experimental level, restrict the value of Higgs mass quite strongly. Mahbubani [17] gives limits on the Higgs mass as 110 GeV $\leq m_H \leq$ 250 GeV in arbitrary extension of split super symmetry. We [18] have predicted the mass of Higgs boson as $m_H \approx$ 120 GeV. The four LEP collaborations, ALEPH, DELPHI, L3 and OPAL were searching for the neutral Higgs boson in the SM. The lower bound on the mass of the SM Higgs boson obtained from LEP data [19, 20] is 114.4 GeV at 95% CL. The SM Higgs boson is also searched at the Fermilab Tevatraon $p\bar{p}$ (proton-antiproton) collider. At the Tevatron, the mass range 162–166 GeV at 95 % CL [21] is excluded for the Higgs boson but an excess of events has been detected in the range 120–135 GeV [22–24].

Recently, on 4th July 2012, the CMS and ATLAS detector at the LHC have discovered a new particle. The CMS detector, using the data samples corresponding to integrated luminosities of 5.3 fb^{-1} at 8 TeV, has measured the mass of this new particle as $125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV [25] with 5.8 standard deviations (σ). The ATLAS detector, using the data samples corresponding to integrated luminosities of 5.8 fb^{-1} at 8 TeV, has measured the mass of this new particle as $126.0 \pm 0.4\,(\text{stat.}) \pm 0.4\,(\text{syst.})$ GeV [26] with 5.9 standard deviations. It is found that the properties of this new particle are compatible with those expected for a SM Higgs boson but more study is required for fully confirmation [27].

The outline of this review article is as follows: in Section 2, some unique properties of the Higgs boson have been discussed. In Section 3, we discuss graphene and how it would help physicists to probe the Higgs boson's secrets. In Section 4, we discuss dark matter and the Higgs boson. In Section 5, we discuss Z' gauge boson briefly and then discuss that the Higgs boson mass can be predicted from different models considering Z' boson contribution. Finally we present our conclusions in Section 6.

2. PROPERTIES OF THE HIGGS BOSON

The Higgs boson has some unique properties [10] which give a special status to it in the table of elementary particles of the SM: (i) Matter particles have spin ½, gauge particles have spin 1 but Higgs boson has spin zero. At present there are no known elementary scalar bosons in nature, although many composite spin-0 particles are known. Since it has integer spin, it is a boson but it does not mediate gauge interactions. (ii) The Higgs particle interacts with or couples to elementary particles proportionally to their masses: the more massive is the particle, the stronger is its interaction with the Higgs boson [28]. (iii) It does not couple to the neutrinos, which are considered as massless particles. (iv) The Higgs boson does not couple directly to photons and gluons (in case of gluons, a direct coupling is also absent because the Higgs boson does not carry color quantum numbers). However, couplings can be induced in an indirect way through quantum fluctuations. (v) According to Heisenberg's uncertainty principle, the Higgs boson can emit pairs of very heavy particles (for example, top quarks) and immediately absorb them, but these virtual particles can, in the meantime, emit photons or gluons. Higgs-photon-photon and Higgs-gluon-gluon couplings are then generated. However, they are expected to be rather small, as they imply intermediate interactions of the virtual particles to photons and gluons, which have a small intensity. (vi) The Higgs boson has self-interactions. The magnitude of triple and quartic self-interactions is proportional to the Higgs boson mass (in fact, Higgs mass squared) [29].

3. GRAPHENE AND THE HIGGS BOSON

Graphene [30,31] is a monatomic layer of graphite with carbon atoms arranged in a two-dimensional

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honeycomb lattice configuration. The electronic structure of graphene can be modeled by two-dimensional mass less relativistic fermions. It is a two-dimensional nonmaterial with many superior material properties which are not matched with the ordinary metal and semiconductor. It is the thinnest material in the universe and the strongest ever measured. Its charge carriers, exhibit high mobility, have the smallest effective mass (it is zero) and can travel micrometer-long distances without scattering at room temperature [32]. It has excellent electrical, thermal and optical properties. This property gives rise to numerous applications both in applied science and in theoretical physics [33,34]. It is a new star in material science. The Nobel Prize in physics for 2010 was awarded jointly to Andre K. Geim, University of Manchester, UK and Konstantin S. Novoselov, University of Manchester, UK "for groundbreaking experiments regarding the two-dimensional material graphene".

Electrons in graphene obey a linear dispersion relation i.e. $E = \hbar k v_F = p v_F$, where $p = \hbar k$ is momentum and v_F is the velocity of electrons in graphene, known as Fermi velocity, $v_F \sim c/300 = 10^6 m s^{-1}$. Here, $E \ \alpha \ p = \sqrt{p^2 + 0}$ implies the effective rest mass is zero [Since, the energy of a particle having rest mass m_0 and moving with a velocity u in a medium is $E = \sqrt{p^2 u^2 + m_0^2 u^4}$]. Thus, the charge carriers in graphene have zero effective mass and move at a constant velocity. Electrons in graphene are not actually massless. The effective mass is a parameter that describes how an electron at particular wave vectors responds to applied forces. Since the velocity of electrons confined on graphene remain constant that indicates that the parameter (effective mass) vanishes.

Whether graphene is a semiconductor or a metal? There are different views regarding this matter (a) Graphene has often been called a zero-gap semiconductor because the density of states is given by $D(E) = |E| / 2\pi\hbar^2 v_F^2$, which vanishes at E = 0. But it is observed that the conductivity of graphene is independent of the Fermi energy and the electron concentration as long as variations in effective scattering strength are neglected. That is why, graphene is regarded as a metal [35] rather than a zero-gap semiconductor. (b) Usually metals require only one energy band to describe them but semiconductors require two energy bands (conduction band and valance band) and an energy gap between them. Graphene has two bands, one for particles which is empty and other for antiparticles (holes) which is filled, but there is no gap between the two bands. That is why, graphene is considered as a hybrid [36] between a metal and a semiconductor. (c) According to some scientists, graphene is a semi-metal [37].

Recently [38], it is claimed that graphene would help physicists to probe the Higgs boson's secrets. When we compress graphene it ripples and displays a sort of symmetry breaking. Again we know that the Higgs mechanism explains the symmetry breaking. That is why, Prof. Pablo San-Jose at Madrid's Institute for Material Science says that the ripple effect of graphene would give hints about the Higgs field and the Higgs boson, which gets its mass from vibrations in the Higgs field. It is also observed that small spontaneous ripples can be formed in graphene with temperature fluctuations even if without compression or pressure. Furthermore, it is expected that graphene might help us to understand the mechanisms behind the formation of the universe.

4. DARK MATTER AND THE HIGGS BOSON

In 1933, the astronomer Fritz Zwicky measured the velocities of galaxies in the Coma cluster, which consists of about 1000 galaxies, and concluded that the total mass of this cluster was much smaller than its total mass implied by the motion of cluster member galaxies. He had found that many of the thousands of galaxies in the cluster move at speeds faster than the escape velocity expected from the amount of visible matter. From this Zwicky realized that the cluster had contained more unseen mass to keep these galaxies bound together i.e. the dark matter. According to the standard model of cosmology, our universe contains 4 % visible (baryonic) matter, 23 % dark matter and 73 % dark energy [39]. There are many evidences for the existence of dark matter in the universe but its exact nature is unknown. We do not know what the underlying theory of dark matter is, what the detailed particle properties of it are, nor the particle spectrum of the dark sector. Some of its possible properties [40] are: (i) Dark matter does not interact electromagnetically. (ii) It has no electrical charge and cannot decay into charged particle pairs or photons. Such events would be detectible as some characteristic form of radiation. (iii) Dark matter is 'collisionless'. But this can only refer to inelastic or reactive collisions. (iv) Dark matter particles feel no other force than gravitation and can exchange energy or momentum only by elastic gravitational interaction or by direct collisions. (v) The observation of the rotation curves of spiral galaxies adds an additional constraint to the properties of DM particles. The constancy of the rotation velocity in the outer regions, where dark matter dominates the mass distribution requires a matter

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density profile decreasing with distance from the center as $1/r^2$. The radial dependence of DM density can only be understood, so that the energy which they take up from the gravitational field can be transferred from radial into thermal motion. (vi) These constraints show that the dark matter behaves just like an ideal gas under the influence of gravitation, but the kinetic energy of the individual dark matter particles must be less than the excitation energy of ordinary atoms or molecules. Such an ideal gas of low mass particles and with low energy density would scarcely be able to condense into closed structures like galaxies or galaxy clusters, as energy gained from the gravitational field would build up a pressure, which would counteract further concentration. By a self-enhancing process this DM concentrates into a state, where it dominates over ordinary matter. (vii) The dark matter should be stable (at least very long lived), and should be both electrically and colour neutral. Very recently, it is expected that a neutral dark matter particle may possess an electric dipole moment or a magnetic dipole moment [41].

There are several well-motivated particle physics candidates for dark matter e.g. massive neutrinos, super symmetric dark matter (neutralinos) and axions. While no such matter has been directly observed in the laboratory, its existence has been suspected. In other words, we can say 'dark matter' is still in dark [42,43]. Most excitingly, these candidates are potentially detectable in experiments currently under development. The existence of dark matter would be very important not only for astrophysics but also for particle physics, since it is needed to explain the properties of particle physics models.

In 2009 [44], it was suggested that the Higgs boson might interact with weakly interacting massive particles (WIMPs) of dark matter. It is expected that there is relation between Higgs boson and dark matter, Since (i) the Higgs field does not directly couple to the quanta of light (photons), and (ii) it generates mass. Dark matter is responsible for the discrepancy between the apparent observed mass of the universe and its actual mass. Again dark matter does not interact with the electromagnetic force, but whose presence can be inferred from gravitational effects on visible matter. Recently, Hertzberg [45] has predicted a correlation between the Higgs mass and the abundance of dark matter. His theoretical result is good agreement with current data. He has predicted the mass of Higgs boson as 125.7 ± 0.6 GeV.

5. Z' BOSON AND THE HIGGS BOSON

The Z' gauge boson is an electrically neutral spin 1 particle. This particle is known to naturally exists in well-motivated extensions of the standard model [46,47]. In particular, they often occur in GUTs, left-right symmetric models, Little Higgs models, superstring theories and theories with large extra dimensions. The mass of Z' boson is not constrained by theory. It can be anywhere between E_{weak} and E_{GUT}. A broad class of super symmetric extensions of the Standard Model predict a Z' boson whose mass is naturally in the range 250 GeV < $M_{Z'}$ < 2 TeV [48]. The current experimental searches of the Z' boson from Drell-Yan cross sections at Tevatron have put lower limits on the mass range 0.6 – 1.0 TeV at 95 % CL depending on the specific models [47]. From the electroweak precision data analysis, the improved lower limits on the Z' mass are given in the range 1.1– 1.4 TeV at 95 % CL [49]. These limits on Z' boson mass favours higher energy ($\geq$ 1 TeV) collisions for direct observation of the signal. It is also possible that the Z' bosons can be much heavy or weak enough to escape beyond the discovery reach expected at the LHC. In this case, only the indirect signatures of Z' exchanges may occur at the high energy colliders [50]. Recently, we [51] have predicted the mass of Z' boson in the range of 1352 GeV – 1665 GeV from $B_q^0 - \overline{B_q^0}$ mixing (q = d, s). For an experimentalist a Z' is a resonance 'bump' more massive than the Z of the SM which can be observed in Drell-Yan production followed by its decay into lepton-antilepton pairs [52]. For a phenomenologist a Z' boson is a new massive electrically neutral, colourless gauge boson (equal to its own antiparticle) which couples to SM matter. For a theorist it is useful to classify the Z' according to its spin, even though actually measuring its spin will require high statistics.

The Z' boson [53] may be considered as an excited state of the ordinary Z boson in models with extra dimensions at the weak scale. The Z' boson is not discovered experimentally yet. It is expected that it will be discovered at the LHC [54]. The Z' may be discovered by detecting excess signals from backgrounds near its resonance in the dilepton invariant mass distribution [55]. With 100 fb^{-1} of data, the LHC can discover a Z' with a mass up to 4.5 TeV at $\sqrt{s}$ = 14 TeV. Z' physics with early LHC data has recently been discussed in [56]. They expect that the LHC at 7 TeV with integrated luminosity of 5 fb^{-1} and 0.8fb^{-1} at 8 TeV will greatly improve on current Tevatron mass limits on Z' boson. Their results are based on the narrow width approximation in which the leptonic Drell-Yan Z' boson cross-section depends on the Z' boson mass. In the B–L model, the Z' boson predominantly couples to leptons. Recently, considering both the $Z'_{B-L} \to e^+e^-$ and $Z'_{B-L} \to \mu^+\mu^-$ decay channels, Z'_{B-L} discovery potential

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at the LHC for 7 TeV has been discussed in [57]. The LHC is being able to discover the Z'_{B-L} boson up to masses of 1.2 TeV for 1 fb^{-1}, while at the Tevatron a 5σ discovery will be possible up to a value of the mass 0.9 TeV. A 2σ exclusion at the LHC could be possible up to $M_{Z'}$ = 1.6 TeV for 1 fb^{-1} (both with electrons and muons). If a Z' boson is discovered at the LHC, it will be important to compare its properties as measured at the LHC with the constraints of the electroweak (EW) fits [58]. The accurate measurement of its properties and its invisible decay rate is of great interest for possible observation of extra dimensions. The properties of the Z' boson are strongly correlated with the mass of the Higgs boson [59]. The Z' decaying to the Higgs pair can possibly serve as a good channel for Higgs search. Chanowitz [58] has discussed the effect of $Z-Z'$ mixing on the m_H. In these Z' models these effect limited the mass of the Higgs boson to $m_H \leq$ 300 GeV. Recently in the Z' models Chanowitz [60] has predicted the value of the Higgs boson mass ~ 120 GeV, which satisfies the LEP II lower bounds (m_H > 114 GeV). More interestingly, we [18] have predicted the mass of the Higgs boson as $m_H \approx$ 120 GeV in a flavor-independent potential model where considering the Z' boson contributions we have studied the mass differences ΔM_K (in $K^0 - \bar{K}^0$ system) and $\Delta M_{B_d^0}$ (in $B_d^0 - \overline{B_d^0}$ system).

6. CONCLUSIONS

The standard model (SM) of particle physics is the best theory that physicists currently have to describe the nature. The Higgs boson is considered as the final particle of the SM. It is an important particle because it is responsible for the Higgs mechanism by which all particles acquire mass. It has not been confirmed experimentally yet. If the Higgs boson exists, it is an integral and pervasive component of the material world. Its mass is not specified in the SM. Its mass is constraints as 114 GeV $\leq m_H \leq$ 1.4 TeV [61,62]. We [18] have predicted the mass of Higgs boson as $m_H \approx$ 120 GeV. Recently [63] in compactified string/M theories it is predicted that there will be a single SM Higgs boson with a mass in the range 105 GeV $\leq m_H \leq$ 129 GeV depending on $\tan\beta$ (the ratio of the Higgs vacuum expectation values in the MSSM). For $\tan\beta$ > 7, the prediction is 122 GeV $\leq m_H \leq$ 129 GeV. From the recent results of the ATLAS [26] and CMS [25] detectors the mass of SM Higgs boson is found to be $126.0 \pm 0.4\,(\text{stat.}) \pm 0.4\,(\text{syst.})$ GeV and $125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV respectively. A Higgs particle with mass of ≈ 125 GeV would be a triumph for the SM [64]. Recently, by combining electroweak precision data with the results of Higgs boson searches at LEP 2, the Tevatron and the LHC, Erler [65] determine the mass of Higgs boson to m_H = 124.5 $\pm$ 0.8 GeV at the 68% CL. Recently [66], in finite unified theories (FUTs) the mass of Higgs boson is predicted in the range 121–126 GeV. From the above discussion it is clear that the ranges of mass of the SM Higgs boson predicted in the string theory, at the LHC, the result obtained by Erler and in FUTs are nearly same. The LHC will continue to collect the data regarding the Higgs boson till the end of 2012. The LHCb experiment is also planning to study the Higgs boson. We expect that these experiments will tell us whether the Higgs boson exists or not [67,68]. If the discovery of the Higgs boson will be confirmed, two new directions of physics will open up [69]: (i) the detailed investigation of the Higgs will be done to conform to the SM paradigm or to show deviations due to new physics. (ii) there will be investigations for the new physics which complements the Higgs boson, whether super symmetry or extra dimensions or new strongly-interacting particles or…?

One important property of the new particle (expected to be the Higgs boson) is its intrinsic spin. In the SM it is a spin-0 particle. The LHC physicists have already said that it is a boson. So it may have spin 0, 1, 2 or some other integer [70]. Since this new particle decays into pairs of photons (photons are spin-1 bosons), its spin cannot be 1. Again physicists do not have unrealistic theories involving bosons with spin greater than 2. So now the task is to determine whether it is a spin-2 or a spin-0 scalar boson.

Recently [38], it is also claimed that graphene would help physicists to probe the Higgs boson’s secrets. Again the Higgs boson might interact with dark matter [44] and there exists relation between the Higgs boson and dark matter. In the Z' models, the mass of the Higgs boson is limited to $m_H \leq 300$ GeV [58]. Thus, although the Higgs boson belongs to the SM of particle physics its study is a very challenging and fascinating topic which interplays between different branches of physics like particle physics, condensed matter physics and cosmology.

REFERENCES

[1] P. B. Renton. 1990. Electroweak Interactions, Cambridge University Press, Cambridge.

ARPN Journal of Science and Technology

http://www.ejournalofscience.org

[2] D. Griffiths. 1987. Introduction to elementary particles, John Wiley and Sons, Singapore.

[3] P. W. Higgs. 1964. Phys. Lett. 12, 132.

[4] P. W. Higgs. 1964. Phys. Rev. Lett. 13, 508; P. W. Higgs. 1966. Phys. Rev. 145, 1156.

[5] F. Englert and R. Brout. 1964. Phys. Rev. Lett. 13, 321.

[6] G. S. Guralinik, C. R. Hagens and T. W. B. Kibble. 1964. Phys. Rev. Lett. 13, 585.

[7] M. Cid and R. Cid. 2010. Physics Education, 45(1), 73 (IOP Publishing).

[8] A. Djouadi. 2008. Phys. Rep. 457, 1 [arXiv :hep-ph/0503172].

[9] A. Djouadi. 2008. Phys. Rep. 459, 1 [arXiv :hep-ph/0503173].

[10] A. Djouadi. 2011. in the book Mass and Motion in General Relativity edited by L. Blanchet, A. Spallicci and B. Whiting, Springer, pp. 1 – 23.

[11] S. Adams. 2000. Frontiers Twentieth-Century Physics, Talor and Francis Ltd, London.

[12] G. Kane and M. Shifman. 2000. The Supersymmetric World, World Scientific Publishing Co. Pte., Singapore.

[13] S. K. Soni and Simmi Singh. 2000. Supersymmetry, Narosa Publishing House, India.

[14] S. Sahoo and M. Goswami. 2007. IAPT Bulletin, 24(5), 140.

[15] M. E. Peskin. 2008. ArXiv:hep-ph/0801.1928.

[16] G. Brumfiel. 2011. Nature, 471, 13.

[17] R. Mahbubani. 2004. ArXiv:hep-ph/0408096.

[18] S. Sahoo, A. K. Meikap and L. Maharana. 2006. Mod. Phys. Lett. A, 21, 275.

[19] W.–D. Schlatter and P. M. Zerwas. 2011. ArXiv: 1112.5127 [physics.hist-ph].

[20] ALEPH, DELPHI, L3, OPAL collaborations, and LEP Working Group for Higgs Boson Searches. 2003. Phys. Lett. B, 565, 61 [arXiv: hep-ph/0306033].

[21] CDF and DO collaborations. 2010. Phys. Rev. Lett. 104, 061802.

[22] CDF collaboration. 2012. Phys. Rev. Lett. 109, 111802 [arXiv: 1207.1707 [hep-ex]].

[23] CDF and DO collaborations. 2012. Phys. Rev. Lett. 109, 071804.

[24] DO collaboration. 2012. Phys. Rev. Lett. 109, 121802 [arXiv: 1207.6631 [hep-ex]].

[25] S. Chatrchyan et al. (CMS collaboration). 2012. Phys. Lett. B, 716, 30 [arXiv: 1207.7235 [hep-ex]].

[26] G. Aad et al. (ATLAS collaboration). 2012 Phys. Lett. B, 716, 1 [arXiv:1207.7214 [hep-ex]].

[27] G. Bernadi and M. Herndon. 2012. arXiv:1210.002 [hep-ex].

[28] M. Duhrssen et al.. 2004. Phys. Rev. D, 70, 113009.

[29] A. Djouadi, J. Lykken, K. Monig, Y. Okada, M. Oreglia and S. Yamashita. arXiv:0709.1893 [hep-ph].

[30] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov. 2004. Science, 306, 666.

[31] K. S. Novoselov et al. 2004. arXiv:cond-mat/0410631.

[32] A. K. Geim. 2009. Science, 324, 1530.

[33] A. K. Geim and A. H. MacDonald. 2007. Physics Today, 60(8), 35.

[34] M. I. Katsnelson, Materialstoday. 2007. 10(1-2), 20 .

[35] T. Ando. 2009. NPG Asia Mater. 1(1), 17.

[36] A. H. Castro Neto. 2010. Materialstoday, 13(3), 1.

[37] N. M. R. Peres, F. Guinea, and A. H. Castro Neto. 2006. Phys. Rev. B, 73, 125411 [arXiv:cond-mat/ 0512091].

ARPN Journal of Science and Technology

http://www.ejournalofscience.org

[38] http://www.searchthenetnow.com/graphene-could-help-physicists-probe-the-higgs-bosons-secrets

[39] M. J. Rees. 2003. Atrophysics, 361, 2427.

[40] E. Fischer. 2011. arXiv:1104.2525 [physics.gen-ph].

[41] V. Barger, W-Y. Keung and D. Marfatia. 2011. Phys. Lett. B, 696, 74 [arXiv: 1007.4345 [hep-ph]].

[42] S. Sahoo. 2010. Asian J. Sci. Technol., 7, 135.

[43] S. Sahoo and M. Goswami. 2005. Physics Education (IAPT), 22(3), 171.

[44] C. B. Jackson, S. Servant, G. Shaughnessy, T. M. P. Tait and M. Taoso. 2009. arXiv: 0912.0004 [hep-ph].

[45] M. P. Hertzberg. 2012. arXiv:1210.3624 [hep-ph].

[46] P. Langacker. 2009. arXiv:0909.3260 [hep-ph]; P. Langacker. 2009. Rev. Mod. Phys., 81, 1199 [arXiv: 0801.1345 [hep-ph]]; P. Langacker. 2003. arXiv: hep-ph/0308033.

[47] J. Beringer et al. (Particle Data Group). 2012. Phys. Rev. D 86, 010001; A. Abulencia et al., [CDF Collaboration]. 2006. Phys. Rev. Lett. 96, 211801 [arXiv:hep-ex/0602045].

[48] J. D. Lykken. 1996. arXiv:hep-ph/9610218.

[49] J. Erler et al.2009. J. High Energy Phys. 0908, 017 [arXiv:0906.2435 [hep-ph].

[50] O. Cakir, I. T. Cakur, A. Senol and T. Tasci. 2010. Eur. Phys. J. C. 70, 295.

[51] S. Sahoo, C. K. Das and L. Maharana. 2011. Int. J. Mod. Phys. A, 26, 3347.

[52] E. Accomando et al. 2011. Phys. Rev. D, 83, 075012 [arXiv:1010.6058 [hep-ph]].

[53] S. N. Gninenko, N. V. Krasnikov and V.A. Mateev. 2008. Phys. Rev. D, 78, 097701 [arXiv:0811.0974 [hep-ph]].

[54] H.–S. Lee. 2009. Phys. Lett. B, 674, 87 [arXiv: 0812.1854 [hep-ph]].

[55] M.-C. Chen and J. Huang. 2010. Phys. Rev. D, 81, 055007 [arXiv: 0910.5029 [hep-ph]].

[56] E. Accomando et al. 2011. Phys. Rev. D, 83, 075012 [arXiv: 1010.6058 [hep-ph]].

[57] L. Basso et al. 2010. PoS ICHEP2010, 381 [arXiv: 1011.0872 [hep-ph]].

[58] M. S. Chanowitz. 2008. arXiv : 0806.0890 [hep-ph].

[59] A. Ferroglia, A. Lorca and J. J. Vander Bij. 2007. Ann. Phys. (Leipzig) 16, 563 [arXiv:hep-ph/0611174].

[60] M. S. Chanowitz. 2010. Phys. Atom. Nucl. 73, 680.

[61] A. Gulov and A. Kozhushko. 2011. Int. J. Mod. Phys. A, 26, 4083 [arXiv: 1105.3025 [hep-ph] (2011)].

[62] Higgs boson from Wikipedia, November, 2012.

[63] G. Kane, P. Kumar, R. Lu and B. Zheng. 2011. arXiv:1112.1059 [hep-ph].

[64] A. Djouadi. 2012. arXiv: 1203.4199 [hep-ph].

[65] J. Erler. 2012. arXiv: 1201.0695 [hep-ph].

[66] S. Heinemeyer, M. Mondragon and G. Zoupanos. 2012. arXiv:1201.5171 [hep-ph].

[67] E. Cartlidge. 28 October 2011. Nature, doi:10.1038/news.2011.619.

[68] W. Murray. 2012. arXiv:1201.4576 [hep-ex].

[69] J. Ellis, M. K. Gaillard and D. V. Nanopoulous. 2012. arXiv:1201.6045 [hep-ph].

[70] M. Chalmers. 2012. Nature, 488, 572.