IFT–P.081/2000

Searching for Anomalous Higgs Couplings in Peripheral Heavy Ion Collisions at the LHC.

S. M. Lietti, A. A. Natale, C. G. Roldão and R. Rosenfeld

Instituto de Física Teórica, Universidade Estadual Paulista,

Rua Pamplona 145, CEP 01405-900 São Paulo, Brazil.

(September 27, 2000)

Abstract

We investigate the sensitivity of the heavy ion mode of the LHC to anomalous Higgs boson couplings to photons, $H\gamma\gamma$, through the analysis of the processes $\gamma\gamma \to b\bar{b}$ and $\gamma\gamma \to \gamma\gamma$ in peripheral heavy ion collisions. We suggest cuts to improve the signal over background ratio and determine the capability of LHC to impose bounds on anomalous couplings by searching for a Higgs boson signal in this reaction. We also examined Higgs production via pomeron-pomeron fusion and found it to be several orders of magnitude smaller than the $\gamma\gamma$ processes.

14.80.Cp

Typeset using REVTEX

I. INTRODUCTION

The Higgs boson is the only particle in the Standard Model (SM) that has not yet been confirmed experimentally. It is responsible for the mass generation of fermions and gauge bosons. The search for the Higgs boson is the main priority in high energy experiments and hints of its existence may have been already seen at LEP [1] at around $m_H \sim 115$ GeV. However, once found the detailed study of its couplings could give information on the mass generation mechanism and on physics beyond the Standard Model.

An intermediate-mass Higgs boson could also be produced in peripheral heavy ion collisions through photon-photon and pomeron-pomeron interactions [2,3]. This possibility, in the context of the SM, has been explored in detail in the literature [4–6], with the general conclusion that the chances of finding the standard model Higgs in the photon-photon case are marginal and negligible in the pomeron-pomeron case.

However, the Standard Model is only an effective low energy theory of a more complete model and one expects deviations from its predictions. A convenient way to parameterize deviations of the Standard Model predictions is the effective theory approach [7]. In this scenario, we assume that the existence of new physics, associated to a high–energy scale Λ, can manifest itself at low energies via the process of integrating-out heavy degrees of freedom. These effects are then described by effective operators involving the spectrum of particles belonging to the low–energy theory. At this point we have two possibilities: either the Higgs boson is light and it should be included in the effective operators or the Higgs boson is heavy and should also be integrated out. In this work we will adopt the former possibility, where the gauge group $SU(2)_L \otimes U(1)_Y$ is linearly realized. In this case, the effective lagrangian will generate anomalous Higgs couplings.

In this Letter we explore the capabilities of peripheral heavy ion collisions in constraining anomalous Higgs couplings, which could in principle arise from new physics beyond the SM. We analyse the processes $\gamma\gamma \to b\bar{b}, \gamma\gamma$ and pomeron-pomeron $\to b\bar{b}, \gamma\gamma$. After simulating the signal and background, we find optimal cuts to maximize their ratio. We show how to use energy and invariant mass spectra of the final state $b\bar{b}$ or photon pair in order to identify the presence of a Higgs boson and extract information about its couplings. Finally, we compare the bounds on the anomalous couplings that will be possible to extract from our analyses to bounds coming from other processes in different machines.

II. ANOMALOUS HIGGS COUPLINGS AND EFFECTIVE LAGRANGIANS

In the linear representation of the $SU(2)_L \otimes U(1)_Y$ symmetry breaking mechanism, the SM model is the lowest order approximation while the first corrections, which are of dimension six, can be written as

$$\mathcal{L}_{\text{eff}} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n \quad , \tag{1}$$

where the operators $\mathcal{O}_n$ involve vector–boson and/or Higgs–boson fields with couplings f_n [8]. This effective Lagrangian describes the phenomenology of models that are somehow close to the SM since a light Higgs scalar doublet is still present at low energies. Of the eleven possible operators $\mathcal{O}_n$ that are P and C even, only three of them modify the Higgs–boson couplings to photons [9,10],

$$\begin{aligned}
\mathcal{O}_{BW} &= \Phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \ , \\
\mathcal{O}_{WW} &= \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \ , \\
\mathcal{O}_{BB} &= \Phi^\dagger \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \Phi \ ,
\end{aligned} \tag{2}$$

where Φ is the Higgs doublet, $\hat{B}_{\mu\nu} = i(g'/2) B_{\mu\nu}$, and $\hat{W}_{\mu\nu} = i(g/2)\sigma^a W^a_{\mu\nu}$, with $B_{\mu\nu}$ and $W^a_{\mu\nu}$ being respectively the $U(1)_Y$ and $SU(2)_L$ field strength tensors. In the unitary gauge, the anomalous $H\gamma\gamma$ coupling is given by

$$\mathcal{L}_{\text{eff}}^{\text{HVV}} = g_{H\gamma\gamma} \ H A_{\mu\nu} A^{\mu\nu} \ , \tag{3}$$

where $A_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ and

$$g_{H\gamma\gamma} = -\left(\frac{g M_W}{\Lambda^2}\right) \frac{s^2 (f_{BB} + f_{WW} - f_{BW})}{2} \ , \tag{4}$$

with g being the electroweak coupling constant and $s \equiv \sin\theta_W$.

The operator $\mathcal{O}_{BW}$ contributes at tree level to the vector–boson two–point functions, and consequently is severely constrained by low–energy data [11,9]. The present 95% CL limits on these operators for 90 GeV $\leq m_H \leq$ 800 GeV and $m_{\text{top}} = 175$ GeV read [12],

$$-1.0 \leq \frac{f_{BW}}{\Lambda^2} \leq 8.6 \ \text{TeV}^{-2} \ . \tag{5}$$

The remaining operators can be indirectly constrained via their one–loop contributions to low–energy observables, which are suppressed by factors $1/(16\pi^2)$. Using the “naturalness” assumption that large cancellations do not occur among their contributions, we can consider only the effect of one operator at a time. In this case, the following constraints at 95% CL (in units of TeV^{-2}) arise [12]

$$-24 \leq \frac{f_{WW}}{\Lambda^2} \leq 14 \quad , \quad -79 \leq \frac{f_{BB}}{\Lambda^2} \leq 47 \ . \tag{6}$$

These limits depend in a complex way on the Higgs mass. The values quoted above for the sake of illustration were obtained for $M_H = 200$ GeV.

There are also limits coming from direct Higgs searches at LEP II [13], Tevatron [14] colliders. The combined analysis [15] of these signatures yields the following 95% CL bounds on the anomalous Higgs interactions (in TeV^{-2}):

$$-7.5 \leq \frac{f_{WW(BB)}}{\Lambda^2} \leq 18$$

for $m_H \leq 150$ GeV. These limits can be improved by a factor 2–3 in the upgraded Tevatron runs. The 95% CL bounds on the anomalous Higgs interactions (in TeV^{-2}) coming from direct Higgs searches via gluon gluon fusion at LHC [16] collider are

$$-0.35 \leq \frac{f_{WW} + f_{BB} - f_{BW}}{\Lambda^2} \leq 0.46 \quad \text{and} \quad 2.8 \leq \frac{f_{WW} + f_{BB} - f_{BW}}{\Lambda^2} \leq 3.6 \ . \tag{7}$$

for $m_H \leq 150$ GeV.

The anomalous Higgs interaction f_{BW} can also be constrained by their effect on the triple gauge–boson vertices, but this is not the case for f_{WW} nor f_{BB}. Assuming that large cancellations do not occur among the contributions of the operators f_{BB}, f_{WW}, and f_{BW}, we evaluate our limits considering the effect of only one operator at a time. We also present the case where all f_{BB}, f_{WW}, and f_{BW} have a common value, which we call f_{all}.

III. SIMULATIONS

In order to perform the Monte Carlo analysis, we have employed the package MadGraph [17] coupled to HELAS [18]. Special subroutines were constructed for the anomalous contribution which enable us to take into account all interference effects between the QED and the anomalous amplitudes. The phase space integration was performed by VEGAS [19].

The photon distribution in the nucleus can be described using the equivalent-photon or Weizsäcker-Williams approximation in the impact parameter space. Denoting the photon distribution function in a nucleus by $F(x)$, which represents the number of photons carrying a fraction between x and $x + dx$ of the total momentum of a nucleus of charge Ze, we can define the two-photon luminosity through

$$\frac{dL}{d\tau} = \int_\tau^1 \frac{dx}{x} F(x) F(\tau/x), \tag{8}$$

where $\tau = \hat{s}/s$, $\hat{s}$ is the square of the center of mass (c.m.s.) system energy of the two photons and s of the ion-ion system. The total cross section $AA \to AA\gamma\gamma \to AAX$, where X are the particles produced by the $\gamma\gamma$ process, is

$$\sigma(s) = \int d\tau \frac{dL}{d\tau} \hat{\sigma}(\hat{s}), \tag{9}$$

where $\hat{\sigma}(\hat{s})$ is the cross-section of the subprocess $\gamma\gamma \to X$.

We choose to use the conservative and more realistic photon distribution of Cahn and Jackson [5], including a prescription proposed by Baur [3] for realistic peripheral collisions, where we must enforce that the minimum impact parameter (b_{min}) should be larger than $R_1 + R_2$, where R_i is the nuclear radius of the ion i. A useful fit for the two-photon luminosity is:

$$\frac{dL}{d\tau} = \left(\frac{Z^2\alpha}{\pi}\right)^2 \frac{16}{3\tau} \xi(z), \tag{10}$$

where $z = 2MR\sqrt{\tau}$, M is the nucleus mass, R its radius and $\xi(z)$ is given by

$$\xi(z) = \sum_{i=1}^{3} A_i e^{-b_i z}, \tag{11}$$

which is a fit resulting from the numerical integration of the photon distribution, accurate to 2% or better for $0.05 < z < 5.0$, and where $A_1 = 1.909$, $A_2 = 12.35$, $A_3 = 46.28$, $b_1 = 2.566$, $b_2 = 4.948$, and $b_3 = 15.21$. For $z < 0.05$ we use the expression (see Ref. [5])

$$\frac{dL}{d\tau} = \left(\frac{Z^2\alpha}{\pi}\right)^2 \frac{16}{3\tau}\left[\ln\left(\frac{1.234}{z}\right)\right]^3 . \tag{12}$$

In the case where the intermediary particles exchanged in the nucleus-nucleus collisions are pomerons instead of photons, we can follow closely the work of Müller and Schramm [6] and make a generalization of the equivalent photon approximation method to this new situation. The cross section for particle production via two pomerons exchange can be written as

$$\sigma_{AA}^{PP} = \int dx_1 dx_2 f_P(x_1) f_P(x_2) \sigma_{PP}(s_{PP}), \tag{13}$$

where $f_P(x)$ is the distribution function that describe the probability for finding a pomeron in the nucleus with energy fraction x and $\sigma_{PP}(s_{PP})$ is the subprocess cross section with energy squared s_{PP}. For $f_P(x)$ we use the pomeron distribution determined by Donnachie and Landshoff [20] and use a Gaussian form factor to obtain [6]:

$$f_P(x) = \frac{(3A\beta_0 Q_0)^2}{(2\pi)^2 x}\left(\frac{s'}{m^2}\right)^{2\varepsilon} \exp\left[-\left(\frac{xM}{Q_0}\right)^2\right] , \tag{14}$$

where $\beta_0 = 1.8$ GeV^{-1} is the pomeron-quark coupling, A is the atomic number of the colliding nucleus, and $Q_0 = 60$ MeV arising from the nuclear form factor (see, e.g., Drees et al. in [4]). M is the nucleus mass, m is the nucleon mass, $\varepsilon = 0.085$ and $s' = x^2 M^2$.

We computed the cross section of the subprocess $PP \to H$ using the pomeron model of Donnachie and Landshoff [21]. In this model it is assumed that the pomeron couples to the quarks as an isoscalar photon [21]. This means that the cross section $PP \to H$ can be obtained from suitable modifications on the cross-section for $\gamma\gamma \to H$. Another aspect to be considered is that the pomeron-quark-quark vertex (assuming that even in the anomalous case the photon couple to quark loops) is not point-like, and when either or both of the two quark legs in this vertex goes far off shell the coupling is known to decrease. So the quark-pomeron coupling β_0 must be replaced by

$$\tilde{\beta}_0(q^2) = \frac{\beta_0\, \mu_0^2}{\mu_0^2 + q^2}, \tag{15}$$

where $\mu_0^2 = 1.2$ GeV^2 is a mass scale characteristic of the pomeron, and in the case of Higgs boson production $q = m_H/2$ measures how far one of the quark legs is off mass shell. We assumed that the cross section for the anomalous Higgs production is obtained dividing the anomalous $\gamma\gamma H$ coupling by the fine-structure constant α and multiplying by $9\tilde{\beta}/16\pi^2$, where $\tilde{\beta}$ is giving by Eq.(15) and $9 = 3^2$ is a color factor [6]. For $m_H = 115$ GeV one obtains $\tilde{\beta}_0 \sim 6.5 \times 10^{-4}$ GeV $^{-1}$ and $9\tilde{\beta}/16\pi^2 = 3.7 \times 10^{-5}$. This is the main reason for the negligible signal that we will obtain for the diffractive Higgs boson production in the next section.

We consider Ca-Ca collisions since they are the most promising ones to put limits on the anomalous couplings because of the larger luminosity of the Ca beams, and also because pomeron-pomeron processes are more effective for lighter ions [22]. The energy for $^{40}_{20}$Ca considered was 140 TeV/beam with a luminosity of 5×10^{30} cm^{-2} s^{-1} = 0.158 fb^{-1}year^{-1} at LHC [23].

IV. RESULTS

In our analyses we computed the SM and anomalous cross sections for the Higgs production via photon-photon and pomeron-pomeron fusion in peripheral heavy ion collisions at LHC using similar cuts and efficiencies as the ones ATLAS Collaboration [24] applied in their studies of Higgs boson searches.

We begin our analyses imposing the following acceptance cuts

$$p_T^{\gamma(b)} > 25 \text{ GeV} \quad , \qquad |\eta_{\gamma(b)}| < 2.5 \quad , \qquad \Delta R_{\gamma\gamma(b\bar{b})} > 0.7 \ , \tag{16}$$

and taking into account an efficiency for reconstruction and identification of one photon or one bottom of 80%.

In order to improve our limits on the anomalous couplings, we have studied several kinematical distributions of the final state particles. The most promising one is the invariant mass of the final particles, since the anomalous interactions occur mainly for the Higgs boson produced on-shell.

For instance, the number of SM events for the process $\gamma\gamma \to b\bar{b}$ with $m_H = 115$ GeV falls from ∼2565 to ∼158 when the cut $|m_{b\bar{b}} - m_H| < 5$ GeV is applied. The number of pure anomalous events $\gamma\gamma \to H \to b\bar{b}$ with $f_{all} = 10$ TeV^{-2} is 1642 and is unaffected by the invariant mass cut. The significance of a anomalous signal, given by $\mathcal{S} = N_{signal}/\sqrt{N_{SM}}$, is enhanced by a factor of 4 when the invariant mass cut is used.

Therefore, for the photon-photon initial state, we collected the final state $\gamma\gamma$ and/or $b\bar{b}$ events whose invariant masses fall in bins of size of 5 GeV around the Higgs mass

$$m_H - 5 \text{ GeV} < m_{\gamma\gamma(b\bar{b})} < m_H + 5 \text{ GeV} \tag{17}$$

in order to evaluate our results.

Considering the set of cuts (16) and (17), the luminosity and efficiencies discussed above, and a Higgs mass of 115 GeV, the number of Standard Model events for the process $\gamma\gamma \to \gamma\gamma$ is 2.4 $\times 10^{-2}$ while for the process $\gamma\gamma \to b\bar{b}$ is 158. Since we expect nearly zero events for the process $\gamma\gamma \to \gamma\gamma$, a 95% CL limit for the anomalous couplings is obtained when its contribution generates 3 events. For the process $\gamma\gamma \to b\bar{b}$, a 95% CL signal is obtained when the number of SM events (158) is changed by a value of $2 \times \sqrt{N_{SM}(=158)} \sim 25$.

In Table I we present the 95 % CL limits for f_{BB}, f_{BW}, f_{WW}, where each individual contribution is studied setting the others to zero, and for $f_{all} = f_{BB} = f_{BW} = f_{WW}$ for $m_H = 115$ GeV. We notice that the limits for the individual contributions as well as for f_{all} are very similar, which indicates that large cancellations do not occur among the anomalous contributions of f_{BB}, f_{BW}, and f_{WW} .

In Table II we present the limits for f_{all} considering a Higgs mass in the range (120–180) GeV. The limits are more stringent in the $\gamma\gamma \to b\bar{b}$ case, where the number of events is larger. The limits get worse for $m_H > 160$ GeV because the total Higgs width increases due to the opening of W^+W^- decay channel.

The pure anomalous contribution to the process $\gamma\gamma \to b\bar{b}$ is quadratic in the anomalous coupling because there is only one anomalous vertex in this case. Since the interference between the SM and anomalous contributions shifts the minimum of the parabola, there are two allowed regions for the couplings in the $\gamma\gamma \to b\bar{b}$ case , as exemplified in Fig. 1, where the number of $b\bar{b}$ events in the LHC heavy ion mode as a function of the anomalous coupling f_{all} is shown together with the SM 95% CL region for $m_H = 115$ GeV.

For the pomeron-pomeron initial state, considering the same set of cuts, luminosity and efficiencies used for the $\gamma\gamma$ initial state, the number of Standard Model and signal events for both $\gamma\gamma$ and $b\bar{b}$ productions are several orders of magnitude smaller than photon-photon initial state. For example, even for $f_{all} = 100$ TeV^{-2} and $m_H = 115$ GeV, the number of anomalous events is much smaller than one, being $\sim 1 \times 10^{-3}$ and $\sim 3 \times 10^{-4}$ for the processes $PP \to \gamma\gamma$ and $PP \to b\bar{b}$ respectively. Therefore no limits are obtained for the anomalous couplings through the pomeron-pomeron initial state processes analysis.

V. CONCLUSIONS

In this work we have studied the sensitivity of the heavy ion mode of the LHC to anomalous Higgs boson couplings to photons, $H\gamma\gamma$, through the analysis of the processes $\gamma\gamma \to b\bar{b}, \gamma\gamma$ and $PP \to b\bar{b}, \gamma\gamma$ in peripheral heavy ion collisions.

Our best limit for the photon-photon initial state comes from the process $\gamma\gamma \to b\bar{b}$, which is (in TeV^{-2}),

$$-0.4 \leq \frac{f_{WW,BB,BW}}{\Lambda^2} \leq 0.5 \quad ,$$

and is comparable to limits coming from the proton-proton mode of the LHC.

We find that the signal from pomeron-pomeron initial state processes turns out to be several orders of magnitude smaller than photon-photon initial state processes, and therefore no limits are obtained for this case.

In conclusion, the limits for anomalous Higgs couplings that can be obtained in peripheral heavy ion collisions at the LHC via electromagnetic processes are one order of magnitude tighter than the limits that can be obtained in the upgraded Tevatron and comparable to limits coming from the proton-proton mode of the LHC.

ACKNOWLEDGMENTS

This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), by FINEP (PRONEX) and by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

REFERENCES

[1] See `http://delphiwww.cern.ch/~offline/physics_links/lepc.html`.

[2] G. Baur, J. Phys. **G24** (1998) 1657 .

[3] G. Baur, K. Hencken and D. Trautmann, hep-ph/9810418; C. A. Bertulani and G. Baur, Phys. Reports **163** (1988) 299 ; G. Baur, in *Proceedings of the CBPF International Workshop on Relativistic Aspects of Nuclear Physics*, Rio de Janeiro, 1989, edited by T. Kodama *et al.* (World Scientific, Singapore, 1990), p. 127; G. Baur and C. A. Bertulani, Nucl. Phys. **A505** (1989) 835.

[4] E. Papageorgiu, Phys. Rev. **D40** (1989) 92; Nucl. Phys. **A498** (1989) 593c; M. Grabiak *et al.*, J. Phys. **G15** (1989) L25; M. Drees, J. Ellis and D. Zeppenfeld, Phys. Lett. **B223** (1989) 454; M. Greiner, M. Vidovic, J. Rau and G. Soff, J. Phys. **G17** (1991) L45; B. Müller and A. J. Schramm, Phys. Rev. **D42** (1990) 3699; J. S. Wu, C. Bottcher, M. R. Strayer and A. K. Kerman, Ann. Phys. **210** (1991) 402.

[5] R. N. Cahn and J. D. Jackson, Phys. Rev. **D42** (1990) 3690.

[6] B. Müller and A. J. Schramm, Nucl. Phys. **A523** (1991) 677.

[7] S. Weinberg, Physica **96A** (1979) 327; J. F. Donoghue, E. Golowich and B. R. Holstein, *Dynamics of the Standard Model* (Cambridge University Press, 1992).

[8] W. Buchmüller and D. Wyler, Nucl. Phys. **B268** (1986) 621; C. J. C. Burgess and H. J. Schnitzer, Nucl. Phys. **B228** (1983) 454; C. N. Leung, S. T. Love, and S. Rao, Z. Phys. **31** (1986) 433.

[9] K. Hagiwara, S. Ishihara, R. Szalapski and D. Zeppenfeld, Phys. Rev. D **48** (1993) 2182.

[10] K. Hagiwara, R. Szalapski, and D. Zeppenfeld, Phys. Lett. **B318** (1993) 155.

[11] A. De Rújula, M. B. Gavela, P. Hernández, and E. Massó, Nucl. Phys. **B384** (1992) 3.

[12] K. Hagiwara, S. Matsumoto, and R. Szalapski, Phys. Lett. **B357** (1995) 411; S. Alam, S. Dawson, and R. Szalapski, Phys. Rev. **D57** (1998) 1577.

[13] O. J. P. Éboli, M. C. Gonzalez–Garcia, S. M. Lietti, and S. F. Novaes, Phys. Lett. **B434** (1998) 340.

[14] F. de Campos, M. C. Gonzalez–Garcia, and S. F. Novaes, Phys. Rev. Lett. **79** (1997) 5210; M. C. Gonzalez–Garcia, S. M. Lietti, and S. F. Novaes, Phys. Rev. **D57** (1998) 7045; F. de Campos, M. C. Gonzalez–Garcia, S. M. Lietti, S. F. Novaes, and R. Rosenfeld, Phys. Lett. **B435** (1998) 407.

[15] M. C. Gonzalez–Garcia, S. M. Lietti, and S. F. Novaes, Phys. Rev. **D59** (1999) 075008.

[16] O. J. Eboli, M. C. Gonzalez-Garcia, S. M. Lietti and S. F. Novaes, Phys. Lett. **B478** (2000) 199.

[17] T. Stelzer and W. F. Long, Comput. Phys. Commun. **81** (1994) 357.

[18] H. Murayama, I. Watanabe and K. Hagiwara, KEK Report 91-11 (unpublished).

[19] G. P. Lepage, J. Comp. Phys. **27** (1978) 192, and "Vegas: An Adaptive Multidimensional Integration Program", CLNS-80/447, 1980 (unpublished).

[20] A. Donnachie and P. V. Landshoff, Phys. Lett. **B191**, (1987) 309 ; Nucl. Phys. **B303** (1988) 634.

[21] A. Donnachie and P. V. Landshoff, Nucl. Phys. **B244**, (1984) 322 ; **B267** (1985) 690.

[22] C. G. Roldão and A. A. Natale, Phys. Rev. **C61** (2000) 064907.

[23] E. Papageorgiu, hep-ph/9507221.

[24] Atlas Technical Proposal, `CERN/LHCC/94-43`.

Anomalous Coupling	$\gamma\gamma \to H \to \gamma\gamma$	$\gamma\gamma \to H \to b\bar{b}$
$f_{BB}(\text{TeV}^{-2})$	$(-3.07\ ,\ 5.69)$	$(-0.35\ ,\ 0.49)$ and $(2.10\ ,\ 2.95)$
$-f_{BW}(\text{TeV}^{-2})$	$(-3.07\ ,\ 5.69)$	$(-0.35\ ,\ 0.49)$ and $(2.10\ ,\ 2.95)$
$f_{WW}(\text{TeV}^{-2})$	$(-3.08\ ,\ 5.70)$	$(-0.35\ ,\ 0.49)$ and $(2.12\ ,\ 2.97)$
$f_{all}(\text{TeV}^{-2})$	$(-3.07\ ,\ 5.69)$	$(-0.35\ ,\ 0.49)$ and $(2.11\ ,\ 2.96)$

TABLE I. 95 % CL allowed regions for f_{BB}, f_{BW}, f_{WW}, and f_{all} for $m_H = 115$ GeV.

Higgs Mass(GeV)	$\gamma\gamma \to H \to \gamma\gamma$	$\gamma\gamma \to H \to b\bar{b}$
120	$(-3.06\ ,\ 5.74)$	$(-0.35\ ,\ 0.49)$ and $(2.17\ ,\ 3.01)$
130	$(-3.04\ ,\ 5.86)$	$(-0.36\ ,\ 0.49)$ and $(2.31\ ,\ 3.15)$
140	$(-3.00\ ,\ 6.03)$	$(-0.36\ ,\ 0.48)$ and $(2.50\ ,\ 3.35)$
150	$(-2.92\ ,\ 6.29)$	$(-0.37\ ,\ 0.47)$ and $(2.82\ ,\ 3.67)$
160	$(-2.59\ ,\ 6.89)$	$(-0.36\ ,\ 0.44)$ and $(3.70\ ,\ 4.54)$
170	$(-9.55\ ,\ 13.5)$	$(-4.57\ ,\ 10.6)$
180	$(-11.1\ ,\ 14.8)$	$(-5.97\ ,\ 12.6)$

TABLE II. 95 % CL allowed regions for f_{all} in TeV^{-2} for different Higgs boson masses.

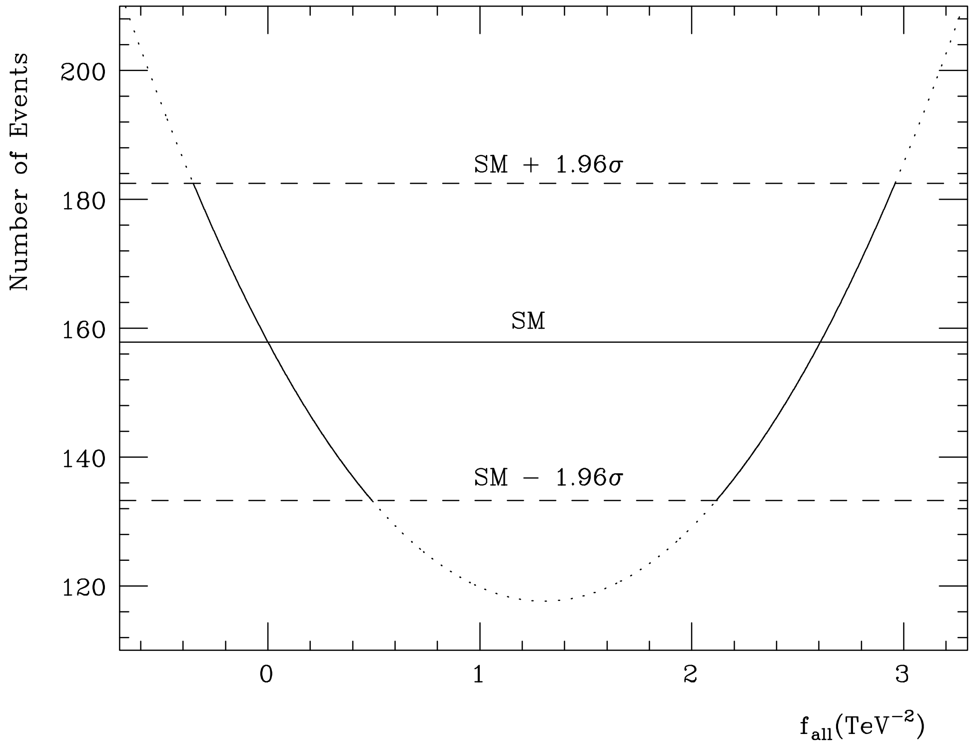
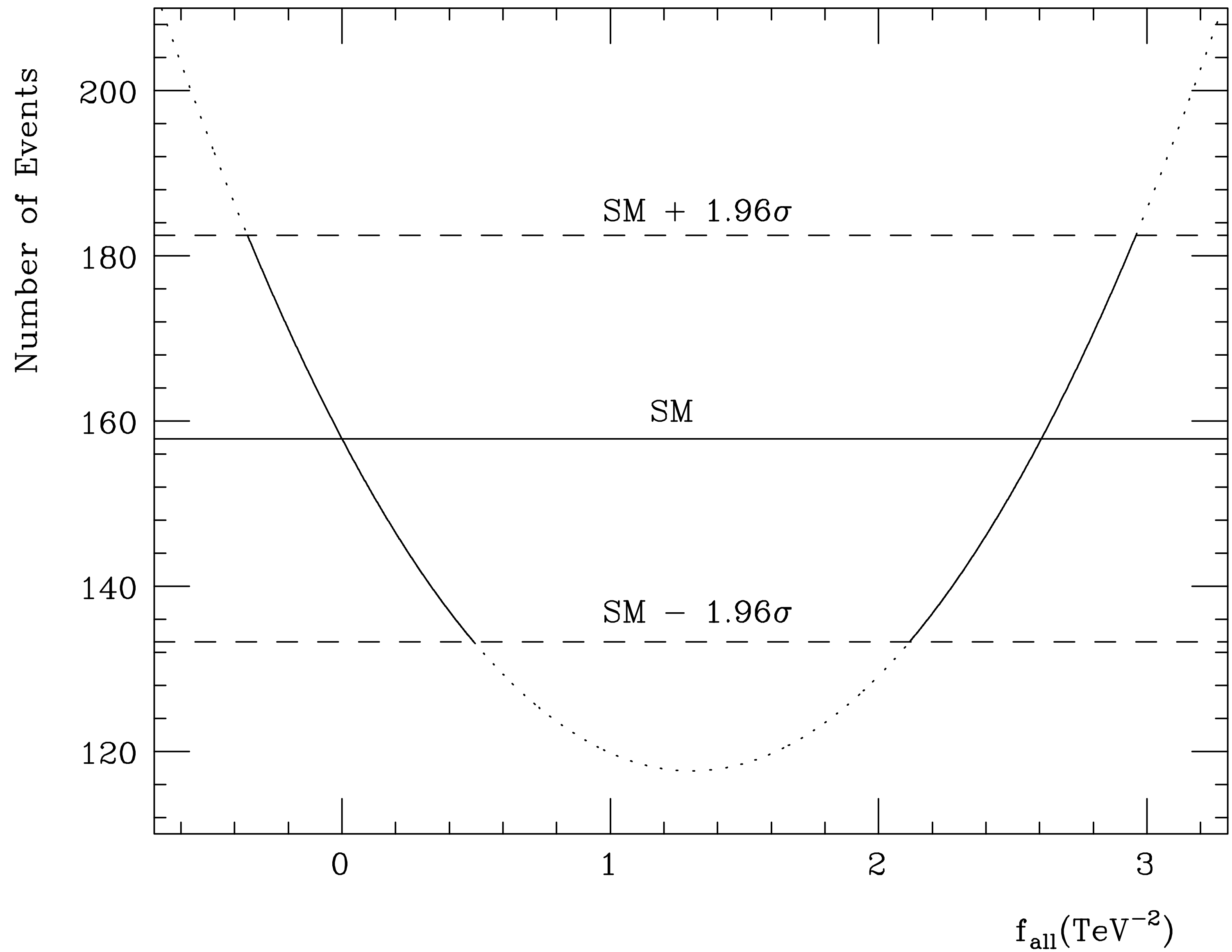


FIG. 1. Number of $b\bar{b}$ events in the LHC heavy ion mode as a function of the anomalous coupling f_{all} for $m_H = 115$ GeV. The solid horizontal line is the number of events in the SM and the two dashed horizontal lines give the 95% CL region. The solid part of the parabola represents the allowed region.


Number of Events
200
180
160
140
120
SM + 1.96σ
SM
SM − 1.96σ
0
1
2
3
f_all(TeV^-2)