Total Width of 125 GeV Higgs Boson

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By using the LHC and Tevatron measurements of the cross sections to various decay channels relative to the standard model Higgs boson, the total width of the putative 125 GeV Higgs boson is determined as $6.1^{+7.7}_{-2.9}$ MeV. We describe a way to estimate the branching fraction for Higgs decay to dark matter. We also discuss a No-Go theorem for the $\gamma\gamma$ signal of the Higgs boson at the LHC.

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The total width of the 125 GeV Higgs-boson signal is of intrinsic interest, but it is generally very difficult to determine the total width Γ_{tot} of a narrow resonance like the Higgs boson. Moreover, the determination of this quantity is also an important test of the Higgs mechanism of the Standard Model (SM). A sizable deviation from the SM prediction would directly indicate new physics. The Higgs width can be measured at a γ-γ collider[1] or a $\mu^+\mu^-$ collider[2] through its line shape, and such facilities are under consideration.

We will present a simple method to determine the total width $\Gamma_{h^0}^{\mathrm{tot}}$ of the 125 GeV Higgs signal h^0 by using LHC and Tevatron measurements with the SM Higgs boson h^0_{SM} as a benchmark. We will apply this method to the data of the putative Higgs-boson signal with mass 125 GeV. Pre-LHC studies[3–6] were made of a similar ilk.

Outline of the method   The h^0 total width is given by the sum of partial widths that can be normalized to the h^0_{SM} partial widths.

$$\Gamma_{h^0}^{\mathrm{tot}} = \sum_{A\bar{A}} \Gamma_{h^0 \to A\bar{A}} = \sum_{A\bar{A}} \gamma_{AA} \Gamma_{h^0_{\mathrm{SM}} \to A\bar{A}}, \quad \gamma_{AA} = \frac{\Gamma_{h^0 \to A\bar{A}}}{\Gamma_{h^0_{\mathrm{SM}} \to A\bar{A}}} \ . \tag{1}$$

For the 125 GeV Higgs, we consider the channels $A\bar{A} = b\bar{b}, \tau\tau, gg, WW^*, ZZ^*, c\bar{c}, \gamma\gamma, Z\gamma$. γ_{AA} is the ratio of the h^0 partial width of the $A\bar{A}$ channel to that of h^0_{SM}. The cross sections of a given channel relative to the h^0_{SM} expectation is given by

$$XA \equiv \frac{\sigma(X\bar{X} \to h^0 \to A\bar{A})}{\sigma(X\bar{X} \to h^0_{\mathrm{SM}} \to A\bar{A})} = \frac{\gamma_{XX}\gamma_{AA}}{\Gamma_{h^0}^{\mathrm{tot}}/\Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}}} \tag{2}$$

where X is the initial parton in the proton participating in the fusion process. Then, we can obtain $\Gamma_{h^0}^{\mathrm{tot}}$ via measurements of the ratios of Eq. (2) following Eq. (1). Equation (2) is derived from the proportionality of $\sigma(X\bar{X} \to h^0 \to A\bar{A})$ to the corresponding decay width $\Gamma_{h^0 \to X\bar{X}}$ and the branching fraction $BF(h^0 \to A\bar{A})$, that is, $\sigma(X\bar{X} \to h^0 \to A\bar{A}) \propto \Gamma_{h^0 \to X\bar{X}} \cdot BF(h^0 \to A\bar{A})$.

In Eq. (1), $\Gamma_{h^0}^{\mathrm{tot}}/\Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}}$ is represented by

$$\Gamma_{h^0}^{\mathrm{tot}}/\Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}} \equiv R = 0.58\gamma_{bb} + 0.06\gamma_{\tau\tau} + 0.24\gamma_{VV} + 0.09\gamma_{gg} + 0.03\gamma_{cc}, \tag{3}$$

where we use the BF of h^0_{SM} in Table I of Ref.[7] and assume $\gamma_{WW^*} = \gamma_{ZZ^*}(\equiv \gamma_{VV})$ as is the case for spontaneous symmetry breaking via the $SU(2)_L$ Higgs doublet.[8] γ_{cc} can be approximated by unity in Eq. (3) since γ_{cc} is a subleading contribution.

Channel	$b\bar{b}$	$\tau^-\tau^+$	WW^*	ZZ^*	gg	$c\bar{c}$	$\gamma\gamma$	$Z\gamma$
Br(%)	57.7	6.32	21.5	2.64	8.57	2.91	0.228	0.154

TABLE I. Branching fractions (BF) of the SM Higgs boson with mass 125 GeV as predicted in ref.[7]. The total Higgs width is $\Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}} = 4.07$ MeV with an uncertainty of $\pm 4\%$.

Illustrations of width determination   The 5 γ-parameters, $(gg, b\bar{b}, \tau^+\tau^-, VV$ and $\gamma\gamma)$, can be determined by LHC and Tevatron measurements of the corresponding ratios in Eq. (2). Then the value of $\Gamma_{h^0}^{\mathrm{tot}}$ is determined by

$$\Gamma_{h^0}^{\mathrm{tot}} = \Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}} \cdot (0.58\gamma_{bb} + 0.06\gamma_{\tau\tau} + 0.24\gamma_{VV} + 0.09\gamma_{gg} + 0.03) \tag{4}$$

with $\Gamma_{h^0_{\mathrm{SM}}}^{\mathrm{tot}} = 4.07$ MeV[7]. The small $\gamma\gamma$ and $Z\gamma$ contributions can be neglected here.

The experimental values of the ratios of Eq. (2) at $m_{h^0} = 125$ GeV reported by CMS[9, 10] and by ATLAS[11] are given in Table II, along with the ratio for the $b\bar{b}$ channel inferred from the latest Tevatron data[12]. A χ^2 fit gives the estimated values of the γ_{AA} parameters in Table III.

Because of the strong correlations between $\gamma_{bb,\tau\tau}$ and $\gamma_{\gamma\gamma}$, loose upper limits are obtained for these quantities from the present data. We obtain the value $\Gamma_{h^0}^{\mathrm{tot}} = 6.1 \ ^{+7.7}_{-2.9}$ MeV. However, the determination will be much improved (see e.g. Refs.[3, 5]) as the data increase. The 2012 LHC run is expected to accumulate an integrated luminosity 15 fb^{-1} per experiment at 8 TeV and those data can be combined with the data from the 5 fb^{-1} at 7 TeV. If all the LHC uncertainties become half the present ones and the central values remain the same, the value of $\Gamma_{h^0}^{\mathrm{tot}}$ becomes $\Gamma_{h^0}^{\mathrm{tot}} = 3.4 \ ^{+2.3}_{-1.5}$ MeV.

$\gamma\gamma$ Enhancement   The $\gamma\gamma$ cross section seems to be enhanced compared with h^0_{SM}, although this could be an upward statistical fluctuation. In the SM it is given theoretically by the triangle loop diagrams of the W-boson and top quark.

$\sigma/\sigma_{\rm SM}$		CMS[9, 10]	ATLAS[11]	Tevatron[12]
$q\bar{q} \to V b\bar{b}$	$Vb = \gamma_{VV} \cdot \gamma_{bb}/R$	$1.2^{+2.1}_{-1.9}$	$-0.8^{+1.8}_{-1.7}$	2.0 ± 0.7
$gg \to \tau^-\tau^+$	$g\tau = \gamma_{gg} \cdot \gamma_{\tau\tau}/R$	$0.63^{+1.00}_{-1.28}$	0.0 ± 1.7	
$gg \to \gamma\gamma$	$g\gamma = \gamma_{gg} \cdot \gamma_{\gamma\gamma}/R$	1.62 ± 0.68	$1.6^{+0.8}_{-0.7}$	
$gg \to WW^*$	$gW = \gamma_{gg} \cdot \gamma_{VV}/R$	0.40 ± 0.55	0.20 ± 0.62	$0.0^{+1.0}_{-0.0}$
$gg \to ZZ^*$	$gZ = \gamma_{gg} \cdot \gamma_{VV}/R$	$0.58^{+0.94}_{-0.58}$	$1.4^{+1.3}_{-0.8}$	
$VV \to \gamma\gamma$	$V\gamma = \gamma_{VV} \cdot \gamma_{\gamma\gamma}/R$	$3.8^{+2.4}_{-1.8}$[10]		
$q\bar{q} \to V A\bar{A}$	$qA = \gamma_{VV} \gamma_{AA}/R$			

TABLE II. $XA \equiv \sigma(X\bar{X} \to h^0 \to A\bar{A})/\sigma(X\bar{X} \to h^0_{\rm SM} \to A\bar{A})$: The observed Higgs-signal cross section at the LHC from various processes relative to the standard model Higgs at $m_{h^0} = 125$ GeV are given by CMS[9] and by ATLAS[11]. $VV \to \gamma\gamma$ is determined by CMS from di-jet diphoton events[10]. The $b\bar{b}$ signal of the second row is inferred from the recent Tevatron data[12]. R is the h^0 total width relative to that of $h^0_{\rm SM}$ with the same mass. See Eq. (3).

$A\bar{A}$	$b\bar{b}$	$\tau^-\tau^+$	WW^*	ZZ^*	gg	$\gamma\gamma$
γ_{AA}	$1.8^{+3.1}_{-1.1}$	$1.1^{+3.8}_{-2.7}$	$1.34^{+0.57}_{-0.45}$	$1.34^{+0.57}_{-0.45}$	$0.57^{+0.48}_{-0.25}$	$4.3^{+5.2}_{-1.8}$
$BF(h^0 \to A\bar{A})(\%)$	$68.7^{+14.9}_{-17.1}$	$4.5^{+8.2}_{-11.7}$	$19.1^{+6.5}_{-1.0}$	$2.3^{+0.8}_{-0.1}$	$3.2^{+0.3}_{-0.4}$	$0.65^{+0.09}_{-0.06}$
$\Gamma_{h^0 \to A\bar{A}}(\text{MeV})$	$4.2^{+7.3}_{-2.6}$	$0.3^{+1.0}_{-0.7}$	$1.2^{+0.5}_{-0.4}$	$0.14^{+0.06}_{-0.04}$	$0.20^{+0.16}_{-0.09}$	$0.04^{+0.05}_{-0.02}$

TABLE III. γ_{AA} obtained by the fit to the data in Table II. One-sigma statistical uncertainties are given. Partial widths of the 125 GeV Higgs $\Gamma_{h^0 \to A\bar{A}}$ and the BF are also given. The total width is estimated to be $\Gamma^{\rm tot}_{h^0} = 6.1\,^{+7.7}_{-2.9}$ MeV. In the SM all the γ_{AA} are unity and the total width is $\Gamma^{\rm tot}_{h^0_{\rm SM}} = 4.07$ MeV[7].

If a new heavy fermion and/or a heavy scalar couple to the SM Higgs, and their masses are generated by the Higgs mechanism, the $\gamma_{\gamma\gamma}$ and γ_{gg} are given (see e.g. Ref.[13]) by

$$\gamma_{\gamma\gamma} = \left(\frac{\frac{7}{4}1.19 - \frac{4}{9}1.03 - \frac{N_c}{3}Q_f^2 - \frac{N_c}{12}Q_S^2}{\frac{7}{4}1.19 - \frac{4}{9}1.03} \right)^2, \quad \gamma_{gg} = \left(\frac{-\frac{1}{6}1.03 - \frac{C_f}{3} - f_S\frac{C_S}{12}}{-\frac{1}{6}1.03} \right)^2, \tag{5}$$

where the 1st(2nd) term in the numerator or denominator in $\gamma_{\gamma\gamma}$ represent the W-boson(top quark) loop and $1.19(1.03)$ is the correction from the finite $W(t)$ mass. The first terms in the denominator and the numerator in γ_{gg} are from the top quark loop. Here we have assumed the h^0 couplings to W and t are the same as those of $h^0_{\rm SM}$. The masses of the new particles are assumed to be sufficiently heavy that the mass corrections can be neglected. The numerators and denominators are normalized in Eq. (5) to a fermion contribution. $Q_{f,S}$ is the electric charge of a new fermion(scalar). N_c is the color degree of freedom of a new particle in the loop. $C_{f,S}$ is the quadratic color Casimir factor of the new fermion(scalar). It is $1/2(3)$ in the fundamental(adjoint) representation; $f_S = 1(1/2)$ for a complex(real) scalar. It is an important conclusion that a new fermion or scalar contribution, if it does not have large N_c, works to decrease $\gamma_{\gamma\gamma}$.[18] For example, in the 4th generation model, $(\gamma_{\gamma\gamma}, \gamma_{gg}) = (0.21, 8.7)$. The large γ_{gg} of the 4th generation leads to $R(= \Gamma^{\rm tot}_{h^0}/\Gamma^{\rm tot}_{h^0_{\rm SM}}) = 1.66$, and correspondingly the $WW^*, ZZ^*, b\bar{b}, \tau^-\tau^+$ channels from gluon fusion are enhanced by $\gamma_{gg}/R = 5.2$; $\gamma\gamma$ via gluon fusion is $\gamma_{gg}\gamma_{\gamma\gamma}/R = 1.1$, almost the same as the SM, while $\gamma\gamma$ by vector-boson fusion is strongly suppressed, $\gamma_{\gamma\gamma}/R = 0.12$. If the $\gamma\gamma$ enhancement in the di-photon di-jet events[10] is mainly from VV fusion and the measured value is confirmed, the fourth-generation model will be excluded mass-independently. See also ref.[19]. Similarly, if the enhancement of $VV \to h^0 \to \gamma\gamma$ is confirmed, the interpretation of the 125 GeV Higgs signal as the dilaton or radion[14–16] will be discarded, since the vector-boson fusion to diphoton cross section is strongly suppressed in these models compared with the SM Higgs.

The loop contributions of a new scalar or a new fermion are proportional to dimensionless factors $\lambda_{f,S}$

$$\lambda_f = \frac{\mathcal{Y}_f\, v}{m_f}, \quad \lambda_S = \frac{\mathcal{Y}_{h^0 SS}\, v}{2m_S^2} \tag{6}$$

where $\mathcal{Y}_f(\mathcal{Y}_{h^0 SS})$ is the Yukawa coupling of the new fermion (scalar) and the v is the Higgs VEV $v \simeq 246$ GeV. $\lambda_{f,S} = 1$ corresponds to the the case that the fermion(scalar) mass is generated by the Higgs mechanism. For a heavy particle with no Higgs mechanism for its mass generation, $\lambda_{f,S} \ll 1$ and $\gamma_{gg} \simeq \gamma_{\gamma\gamma} \simeq 1$, so the $\gamma\gamma$ cross section becomes the same as the SM Higgs. To obtain a large enhancement, a $m_{f,S}$ smaller than v is necessary or alternatively the color factor of the new particle is large.
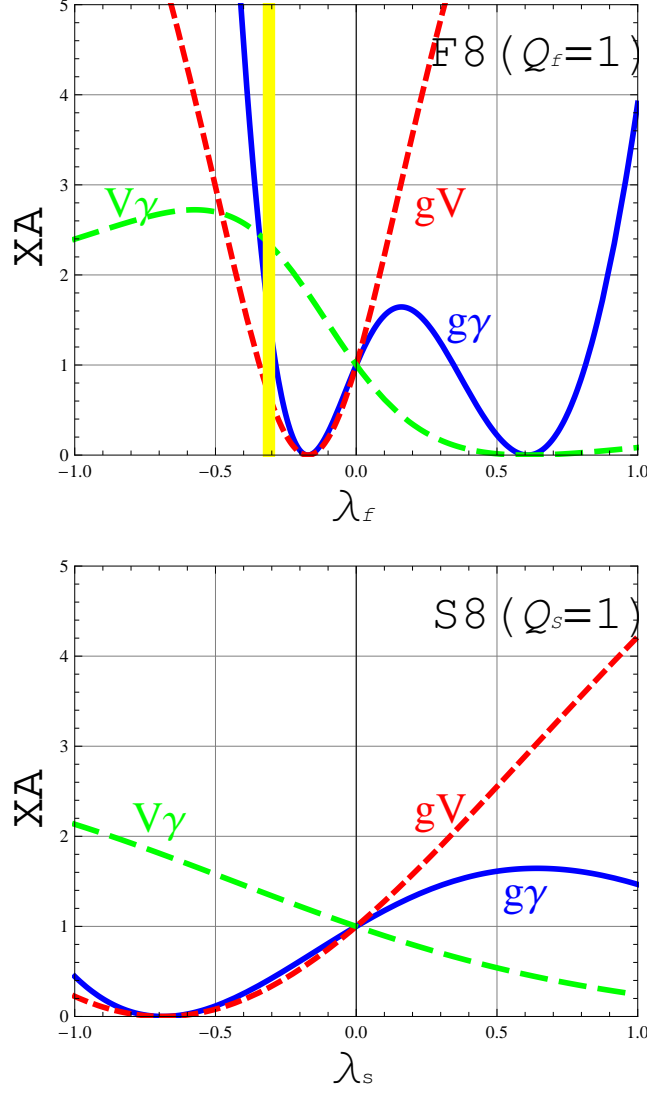
FIG. 1. $\lambda_{f,S}$ dependence of the cross sections of various processes relative to the SM Higgs, for the case of a color-octet fermion (leptogluon:$F8$) with charge $Q_s = 1$ and color-octet scalar ($S8$) with $Q_s = 1$: $XA \equiv \sigma(X\bar{X} \to h^0 \to A\bar{A})/\sigma(X\bar{X} \to h^0_{\rm SM} \to A\bar{A})$. We consider three quantities $XA = g\gamma, gV$, and $V\gamma$, corresponding to $gg \to \gamma\gamma$(solid blue), $gg \to VV(WW^*$ or ZZ^*)(short-dashed red), and $VV \to \gamma\gamma$(long-dashed green). $\lambda_{f,S}$ is the Higgs coupling normalized by the Yukawa couplings giving the masses by the Higgs mechanism. See Eq. (7) for definition. The yellow vertical band in the top panel is preferred by the present data suggesting $\gamma\gamma$ enhancement.

The cross section ratios of various processes relative to the SM Higgs are plotted versus $\lambda_{f,S}$ in the cases of color-octet fermion (denoted as $F8$, also called leptogluon[17]) and color-octet scalar ($S8$) in Fig. 1.

The $S8$[25] is an interesting possibility. It was discussed in the context of Higgs underproduction[26, 27] at LHC for the circumstance that this new scalar has light mass and the Higgs boson has sizable branching fraction to this scalar channel. If the mass of this color-octet scalar is generated by the Higgs mechanism, following Eq. (5), by using $N_c = 8(C_S = 3)$, the γ-values of a $Q_s = 1$ charged scalar are $(\gamma_{\gamma\gamma}, \gamma_{gg}) = (0.35, 6.0)$. For a new scalar without a Higgs origin for its mass generation, the sign of the coupling λ is arbitrary. In the $S8$ case of Fig. 1 both enhancement factors, $g\gamma$ and $V\gamma$, are less than ~ 2. Similar results are also obtained for a color-triplet scalar($S3$: leptoquark) and a color-triplet fermion ($F3$). However, the present data seem to suggest WW^* suppression and $\gamma\gamma$ enhancement in gg-fusion and VV-fusion. This tendency is not reproduced by $S8$ but may be realized with $F8$ as can be seen in Fig. 2, where the preferred regions of parameters, $\lambda_f N_c Q_f^2$ and $\lambda_f C_f$, by present data are shown. In the case $F8$(leptogluon), the trends of the present data can be reproduced with $\lambda_f \approx -0.31$ as shown by the yellow vertical
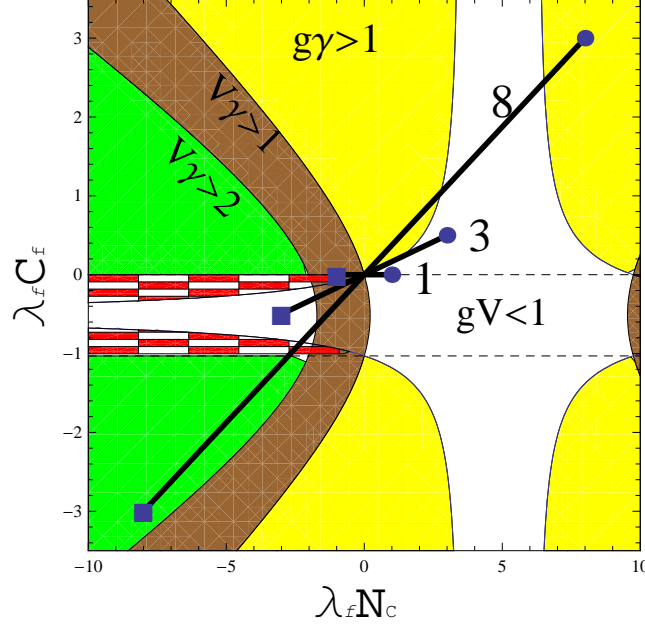
FIG. 2. Regions of $\gamma\gamma$ enhancement in $\lambda_f N_c Q_f^2$, $\lambda_f C_f$ plane in $Q_f = 1$ case. The $g\gamma > 1$ region is divided into 4 colored regions: ($V\gamma < 1; 1 < V\gamma < 2; 2 < V\gamma$) are (yellow;brown;green), respectively. Red meshed region, which is preferred by the present experimental data, corresponds to $V\gamma > 1$ and $gV < 1$, where the latter is between the two horizontal lines, $\lambda_f C_f = 0, -1.03$. Color-octet fermion(leptogluon), Color-triplet fermion, and Color-singlet fermion are shown by solid lines with the end points corresponding to $\lambda_f = -1$(square) and $\lambda_f = 1$(circle). In $Q_f \neq 1$ case, the x-coordinates scale with Q_f^2. $\lambda_f = 1$ corresponds to the case of its mass generated by Higgs mechanism. A color-octet fermion with $Q_f = 1$ is consistent with the red meshed region at $\lambda_f \simeq -0.31$. For a new scalar, the lengths of the theory lines should be scaled by $1/4$; thus, a scalar octet has no overlap with the preferred red meshed region.

	Q_f	λ_f		Q_s	λ_s
$F1$	5/3 (2)	-0.9(-0.7)			
$F3$	5/3 (2)	-0.2(-0.3)	$S3$	5/3 (2)	-1.0 (-0.9)
$F6$	1(5/3)	-0.38(-0.32)			
$F8$	1(4/3)	-0.31(-0.3)			
$F10$	4/3 (2)	-0.13(-0.12)	$S10$	4/3 (2)	-0.50(-0.45)
$F27$	5/3 (2)	-0.034(-0.032)	$S27$	5/3 (2)	-0.14(-0.13)

TABLE IV. Solution satisfying the $\gamma\gamma$ enhancement for $SU(3)$ representations with dimensions≤ 27. $F3, S10$ represent the color-triplet fermion, color-decouplet scalar, for example. The typical values of λ satisfying $g\gamma > 1, V\gamma > 2$, and $gV < 1$ are given.

band of $F8$ in Fig. 1, for which $(g\gamma, gV, V\gamma) = (1.52, 0.67, 2.35)$. If the Yukawa coupling of the leptogluon is the same as top quark, but the sign of λ is reversed, its mass is estimated to be $m_{F8} = m_t/0.31 \simeq 500$ GeV. The corresponding $Z\gamma$ partial decay width is almost the same as the SM Higgs: $\gamma_{Z\gamma} = 1.04$. Then, a $Z\gamma$ cross section ratio via gluon fusion 0.69 ± 0.09 is predicted, which is almost the same as gV.

More generally, Fig. 2 is a vector space that can be used in identifying new particle contributions from experimental measurements of the XA.

Solutions satisfying $g\gamma > 1$, $V\gamma > 2$, and $gV < 1$ for lower-dimensional representations of $SU(3)_c$ are summarized in Table IV.

It is very difficult to obtain $V\gamma > 2$ and $g\gamma > 1$. This constitutes a NO GO theorem. Only the $F8$ (and $F6$) are possible if we limit the charge of the new particle $Q_f \leq 1$. For still higher dimensional color representations, the theory lines do not overlap with the preferred region for the $Q \leq 1$ case as can be deduced from Fig. 2.

The possibility of light stop and light stau in the MSSM are discussed in ref.[20–22][23]. The effect of the stop loop is suppressed compared with top-quark loop because stop is scalar, and the chargino contribution is suppressed by the absence of color. The stau effect is suppressed by both. The $\gamma\gamma$ production ratio generally does not deviate much

from unity in SUSY.

Similarly, in the Universal Extra Dimension model, where the KK-modes of W-boson, quarks, and leptons contribute to the loop, at most a 50% enhancement of $\gamma\gamma$ is found for the allowed region of parameters[24].

Possible Dark matter contribution   When we consider the possible decay to dark matter channel, $\Gamma_{h^0}^{\rm tot}$ is replaced by the decay width to the visible channels $\Gamma_{h^0}^{\rm vis}$ in LHS of Eqs. (1), (3), and (4), while Eq. (2) is unchanged. The $\Gamma_{h^0}^{\rm tot}$ in Eq. (2) now includes the partial decay width to the dark matter channel $\Gamma_{h^0 \to D\bar{D}}$ as[29]

$$\Gamma_{h^0}^{\rm tot} = \Gamma_{h^0}^{\rm vis} + \Gamma_{h^0 \to DD} \equiv F \cdot \Gamma_{h^0}^{\rm vis}, \quad \Gamma_{h^0}^{\rm vis} \equiv \sum_{A\bar{A}=b\bar{b},\tau^-\tau^+,VV,gg,c\bar{c}} \Gamma_{h^0 \to A\bar{A}} \cdot \tag{7}$$

The detection of the Higgs invisible decays at hadron colliders has been studied in refs.[30, 31]. The factor $F(\geq 1)$ is related to the BF to dark matter D by

$$BF(h^0 \to D\bar{D}) = \frac{F-1}{F}. \tag{8}$$

Our method of fitting the quantities of LHS of Eq. (2) now determines $\gamma'_{AA} \equiv \gamma_{AA}/F$, not γ_{AA}, since in Eq. (2) $\Gamma_{h^0}^{\rm tot}/\Gamma_{h^0_{\rm SM}} = F \cdot \Gamma_{h^0}^{\rm vis}/\Gamma_{h^0_{\rm SM}} = F \cdot R$ where R is given by the second equality of Eq. (3).

In many models, such as the MSSM in the decoupling limit, the WW^* and ZZ^* couplings are nearly the same as those of the SM Higgs boson: $\gamma_{VV} \simeq 1$.[28] In this case, the value of γ_{VV}/F obtained by our method gives directly the value of $1/F$ which in turn gives $BF(h^0 \to DD)$ following Eq. (8). The best-fit value of γ_{VV}/F in Table III is $1.34\,^{+0.57}_{-0.45}$ which suggests $F \simeq 1$. A very large BF[32] to invisible decay channel is disfavored[33]. $BF(h^0 \to D\bar{D}) < 0.46$ in 95% confidence level from the present data.

Concluding remarks   We have presented a method of determining the total width of the putative 125 GeV Higgs-boson. The measurements of the $\gamma\gamma$ cross section of the Higgs signal relative to that of the SM will discriminate many candidate models of new physics. It is difficult to obtain a theoretical enhancement of the $\gamma\gamma$ signal of more than 2. This constitutes a No-Go theorem. For a charge $Q \leq 1$, this theorem is evaded with a new light-mass fermion with color octet(leptogluon) or color-sextet and a negative Higgs coupling. Such a colored state can be directly tested[34] by LHC experiments.

Measurements of the vector-boson fusion process and the vector-boson bremsstrahlung processes (c.f. Table II) can significantly improve the uncertainty on the total Higgs width estimate.

Accurate measurement of the ratio of the $\gamma\gamma$ to ZZ^* cross sections would determine $\gamma_{\gamma\gamma}/\gamma_{VV}$, independently of the value of γ_{gg}.

The branching fraction for the decay of the Higgs boson to dark matter can be inferred in the decoupling limit of the WW^* and ZZ^* couplings of any two Higgs doublet model[35].

The methods presented in this Letter should be useful when higher statistics data are acquired on the Higgs signal. One must be cautious about over-interpreting the data until the Higgs signal is fully established.

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[1] J. F. Gunion and H. E. Haber, Phys. Rev. D **48**, 5109 (1993).

[2] V. Barger, M. Berger, J. Gunion and T. Han, Phys. Rept. **286**,1 (1997).

[3] D. Zeppenfeld, Phys. Rev. D**62**, 0.13009 (2000) [hep-ph/0002036]; hep-ph/0203123v1.

[4] A. Belyaev and L. Reina, JHEP **0208**, 041 (2002) [hep-ph/0205270].

[5] M. Duhrssen, S. Heinemeyer, H. Logan, D. Rainwater, G. Weiglein, and D. Zeppenfeld, Phys.Rev. D70, 113009 (2004) [hep-ph/0406323].

[6] R. Lafaye, T. Plehn, M. Rauch, D. Zerwas and M. Duhrssen, JHEP **0908**, 009 (2009) [arXiv:0904.3866 [hep-ph]].

[7] A. Denner, S. Heinemeyer, I. Puljak, D. Rebuzzi, and M. Spira, arXiv:1107.5909v2.

[8] We could optionally assume one more constraint $\gamma_{bb} = \gamma_{\tau\tau}$ which is predicted in most Higgs models.

[9] CMS collaboration. Plenary talk by Marco Pieri at the Moriond conference on March 7, 2012. http://indico.in2p3.fr/conferenceProgram.py?confId=6001. CMS-PAS-HIG-12-008.

[10] The CMS collaboration, arXiv:1202.1487v1[hep-ex]; arXiv:1202.1488v1[hep-ex].

[11] The ATLAS collaboration, ATLAS-CONF-2012-019, March 7,2012.

[12] The TEVNPH Working Group for the CDF and D0 Collaboration, FERMILAB-CONF-12-065-E .

[13] G. Cacciapaglia, A. Deandrea, and J. Llodra-Perez, JHEP **0906**, 054 (2009).

[14] V. Barger, M. Ishida, Wai-Yee Keung, Phys. Rev. D**85**, 015024 (2012).
V. Barger and M. Ishida, Phys. Lett. B**709**, 185 (2012).

[15] H. Davoudiasl, T. McElmurry, and A. Soni, Phys. Rev. D**82**, 115028 (2010).

[16] Kingman Cheung, Tzu-Chiang Yuan, arXiv:1112.4146 [hep-ph].
Kingman Cheung, Phys.Rev. D63, 056007 (2001).

[17] K. H. Streng, Zeit. Phys. C**33**,247 (1986).

[18] This is not the case when there are many heavy particles. Numerically, $\gamma_{\gamma\gamma} > 1$ when an additional 4 generations of quarks and leptons contribute.

[19] K. Ishikawa and M. B. Wise, arXiv:1107.1490v2[hep-ph].

[20] D. Carmi, A. Falkowski, E. Kuflik, and T. Volansky, arXiv:1202.3144v1[hep-ph].

[21] L. Maiani, A. D. Polosa, and V. Riquer, arXiv:1202.5998v1[hep-ph].

[22] M. Carena, S Gori, N. R. Shah, C. E. M. Wagner, arXiv:1112.3336v1[hep-ph].

[23] In ref.[22] the light stau effect on the $\gamma\gamma$ cross sections is discussed. A 50% $\gamma\gamma$ enhancement is possible with a very light stau mass ~ 100 GeV, close to the LEPII constraint. In this case, the production rate by the gluon fusion is the same, and the $b\bar{b}, WW^{*}, ZZ^{*}$ cross sections via gluon fusion are almost the same as for the SM Higgs boson.

[24] G. Belanger, A. Belyaev, M. Brown, M. Kakizaki, and A. Pukhov, arXiv:1201.5582v1[hep-ph]

[25] S. Schumann, A. Renaud, and D. Zerwas, JHEP 1109, 74 (2011).

[26] B. A. Dobrescu, G. D. Kribs, and A. Martin, arXiv:1112.2208v2.

[27] Y. Bai, J. Fan, and J. L. Hewett, arXiv:1112.1964 [hep-ph].

[28] This is not the case for the triplet Higgs model. See, H. E. Logan and M.-A. Roy, arXiv:1008.4869v2 [hep-ph].

[29] H. E. Logan and J. Z. Salvail, arXiv:1107.4342v1.

[30] O. J. P. Eboli and D. Zeppenfeld, Phys. Lett. B**495**, 147 (2000).

[31] H. Davoudiasl, T. Han, and Heather E. Logan, Phys. Rev. D **71**, 115007 (2005).

[32] K. Belotsky, D. Fargion, M. Khlopov, R. Konoplich, and K. Shibaev, Phys.Rev. D68 (2003) 054027 [hep-ph/0210153].

[33] N. Desai, B. Mukhopadhyaya, and S. Niyogi, arXiv:1202.5190v1 [hep-ph].

[34] T. Han, I. Lewis, and Z. Liu, arXiv:1010.4309v2.

[35] V. Barger, H. E. Logan, G. Shaughnessy, Phys. Rev. D**79**, 115018 (2009).