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Higgs decays into dark matter particles

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ABSTRACT

In this paper, we calculate the energy radiated and the coupling constant of dark matter particles when Higgs decays into $n(=2,3,\dots,n)$ *number of dark matter particles having equal masses.*

Keywords: *Coupling constant, dark matter, Higgs boson, invisible decay, vacuum expectation value.*

I. INTRODUCTION

Higgs boson is a spin zero and even parity particle with mass around 125.5 GeV [1 – 3]. Higgs can decay into both visible and invisible matter. Our focus is on the invisible decays of Higgs boson. Jackson et al. have discussed [4] the interaction between Higgs boson and weakly interacting massive particles (WIMPs) of dark matter. The correlation between the Higgs mass and the abundance of dark matter has been predicted by Hertzberg [5]. The masses of dark matter particles produced in Higgs decay varies according to the variation in the energy radiated. So, detecting the energy radiated in the invisible decay modes of Higgs boson, we can find the masses of the dark matters particles produced.

In this paper, first we have derived the general formula describing the energy radiated for the Higgs decaying into n dark matter particles having equal masses. Then, the expression for the coupling constant of dark matter particles when Higgs decays into n dark matter particles having equal masses has been derived. In calculating the coupling constant of dark matter particles we have used the relation $m_\chi = g_\chi \mathrm{v}$. The mass of Higgs boson is given by $m_H = \sqrt{2\lambda}\mathrm{v}$. Here m_H and m_χ represent the mass of Higgs boson and dark matter particle respectively. v is the vacuum expectation value of Higgs field. The coupling constant of the dark matter with vacuum is represented by g_χ and λ represents the Higgs self coupling constant.

The paper is organised as follows: In Sec. 2, the energy radiated for the Higgs decaying into n number of dark matter particles having equal masses has been discussed. In Sec. 3, the expression for coupling constant of dark matter particles when Higgs decays into n dark matter particles having equal masses has been derived. The variation in the masses of the dark matter particles when Higgs decays into different number of dark matter particles of equal masses for a fixed value of the energy radiated and the variation in the dark matter coupling constant of the dark matter particles with vacuum has been calculated. In Sec. 4, we discuss our results.

II. ENERGY RADIATED FOR THE HIGGS DECAYING INTO DARK MATTER PARTICLES

Higgs can decay into two dark matter particles of equal mass and the energy radiated in this process can be written as [4 – 8]:

$$E_\gamma = \left(m_H^2 - 4m_\chi^2\right)/2m_H \qquad (1)$$

where, E_γ is the energy radiated in this decay process, m_H is mass of Higgs and m_χ is the mass of dark matter particles produced. The required condition is $m_\chi \leq m_H/2$.

When Higgs decays into three dark matter particles having equal masses, the energy radiated in this process can be written as:

$$E_\gamma = \left(m_H^2 - 9m_\chi^2\right)/2m_H. \qquad (2)$$

The required condition is $m_\chi \leq m_H/3$. Similarly, the energy radiated in the decay of Higgs into four dark matter particles having equal mass is given below as:

$$E_\gamma = \left(m_H^2 - 16m_\chi^2\right)/2m_H. \qquad (3)$$

The required condition is $m_\chi \leq m_H/4$.

In general, the energy radiated in the decay of Higgs into n dark matter particles having equal masses can be written as:

$$E_\gamma = \left(m_H^2 - n^2 m_\chi^2\right)/2m_H. \qquad (4)$$

The required condition is $m_\chi \leq m_H/n$.

Equations (1), (2), (3) and (4), represent the variation of energy radiated when Higgs decay into different number of dark matter particles having same masses.

Table 1

	$E_\gamma(GeV)$			
$m_\chi(GeV)$	$n = 2$	$n = 3$	$n = 4$	$n = n$
7	62.2	61.25	59.9	$63 - 0.1944n^2$
14	59.9	56	50.6	$63 - 1.6n^2$
21	56	47.25	35	$63 - 1.75n^2$
28	50.6	50.6	13.25	$63 - 3.11n^2$
35	43.6	19.25	0	$63 - 4.86n^2$
42	35	0	0	$63 - 7n^2$
49	24.9	0	0	$63 - 9.53n^2$
56	13.22	0	0	$63 - 12.4444n^2$
63	0	0	0	$63 - 15.75n^2$

The values of the energy radiated for Higgs decaying into n number of dark matter particles having equal masses are shown in Table 1. We take mass of Higgs $m_H = 126$ GeV, for our calculation. Mass of dark matter particles within the range $m_\chi = 7$ GeV $-$ 63 GeV [8]. From Table 1, it is observed that when $n = 2$, $E_\gamma = 0$ for $m_\chi = 63$ GeV, when $n = 3$, $E_\gamma = 0$ for $m_\chi = 42$ GeV and when $n = 4$, $E_\gamma = 0$ for $m_\chi = 31.5$ GeV.

III. DARK MATTER COUPLING CONSTANTS

Simplifying equation (1), we get the mass of the dark matter for Higgs decaying into two dark matter particles as:

$$m_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{2}\ . \tag{5}$$

The required condition is $E_\gamma \leq m_H/2.$ Introducing, $m_\chi = g_\chi v,$ in equation (5), we get the expression for coupling constant of dark matter when Higgs decays into three dark matter particles having equal masses:

$$g_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{2v}. \tag{6}$$

Thus solving equation (1) we are getting two values of m_χ. Since g_χ cannot be $-ve$, so we have to choose only $+ve$ values of g_χ as the coupling constant of the dark matter which has been given by equation (6).

Simplifying equation (2), we get the mass of the dark matter for Higgs decaying into three dark matter particles as:

$$m_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{3}\ . \tag{7}$$

For this case also the required condition is $E_\gamma \leq m_H/2.$ Comparing with $m_\chi = g_\chi v,$ we get the expression for coupling constant of dark matter when Higgs decays into three dark matter particles having equal masses:

$$g_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{3v}. \tag{8}$$

Similarly, simplifying equation (4), we get the mass of the dark matter for Higgs decaying into n dark matter particles as:

$$m_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{n}\ . \tag{9}$$

And the required condition will be $E_\gamma \leq m_H/2.$ Comparing with $m_\chi = g_\chi v,$ we get the expression for coupling constant of dark matter when Higgs decay into n dark matter particles having equal masses:

$$g_\chi = \frac{\sqrt{m_H\,(m_H - 2E_\gamma)}}{nv}. \tag{10}$$

Equations (5), (7) and (9) show the variation in the masses of the dark matter particles when Higgs decays into different number of dark matter particles having equal masses for a fixed value of the energy radiated. Equations (6), (8) and (10) show the variation in the dark matter coupling constant of the dark matter particles with vacuum when Higgs decays into different number of dark matter particles of equal masses for a fixed value of the energy radiated.

Table 2

	$n = 2$		$n = 3$		$n = 4$		$n = n$	
$E_\gamma(GeV)$	$m_\chi(GeV)$	g_χ	$m_\chi(GeV)$	g_χ	$m_\chi(GeV)$	g_χ	$m_\chi(GeV)$	g_χ

3	61.5	0.25	41	0.1667	30.75	0.125	$123/n$	$0.5/n$
6	59.925	0.2436	39.95	0.1624	29.9625	0.1218	$119.8/n$	$0.5/n$
9	58.325	0.2371	38.8833	0.1581	29.1625	0.1185	$116.65/n$	$0.474/n$
12	56.685	0.2304	37.79	0.1536	28.3425	0.1152	$113.37/n$	$0.461/n$
15	55	0.2236	36.6667	0.1491	27.5	0.1118	$110/n$	$0.447/n$
18	53.25	0.2165	35.5	0.1443	26.625	0.1082	$106.5/n$	$0.433/n$
21	51.45	0.21	34.3	0.1394	25.725	0.1046	$102.9/n$	$0.418/n$
24	49.55	0.2014	33.0333	0.1343	24.775	0.1007	$99.1/n$	$0.403/n$
27	47.625	0.1936	31.75	0.1291	23.8125	0.0968	$95.25/n$	$0.387/n$
30	45.6	0.1854	30.4	0.1236	22.8	0.0927	$91.2/n$	$0.371/n$
33	43.475	0.1767	28.9833	0.1178	21.7375	0.0884	$86.95/n$	$0.354/n$
36	41.25	0.1677	27.5	0.1118	20.625	0.0838	$82.5/n$	$0.335/n$
39	38.885	0.1581	25.9233	0.1054	19.4425	0.0790	$77.77/n$	$0.316/n$
42	36.375	0.1479	24.25	0.0986	18.1875	0.0739	$72.75/n$	$0.296/n$
45	33.675	0.1369	22.45	0.0913	16.8375	0.0684	$67.35/n$	$0.274/n$
48	30.74	0.125	20.4933	0.0833	15.37	0.0625	$61.48/n$	$0.25/n$
51	27.5	0.1118	18.3333	0.0745	13.75	0.0559	$55/n$	$0.224/n$
54	23.81	0.0968	15.8733	0.0645	11.905	0.0484	$47.62/n$	$0.194/n$
57	19.45	0.0791	12.9667	0.0527	9.725	0.0935	$38.9/n$	$0.158/n$
60	13.75	0.0559	9.1667	0.0373	6.875	0.0279	$27.5/n$	$0.112/n$
63	0	0	0	0	0	0	0	0

The masses of the dark matter particles when Higgs decays into n number of dark matter particles of equal masses for a fixed value of the energy radiated and the coupling constant of the dark matter particles with vacuum when Higgs decays into n number of dark matter particles of equal masses for a fixed value of the energy radiated are shown in Table 2. Here, we observe that for $E_\gamma = 63\ \mathrm{GeV},\ m_\chi = 0,$ for every cases. Since for each case we get the same condition $E_\gamma \leq m_H/2.$

IV. RESULTS AND DISCUSSIONS

Higgs can decays into two or more than two dark matter particles and the energy radiated in every case is different. Energy radiated for the Higgs decaying into$n$ dark matter particles is given by equation (4).

Comparing with $m_\chi = g_\chi v$, we get the expressions for coupling constant of dark matter satisfying the condition $v \neq 0$. The values of the energy radiated for Higgs decaying into n number of dark matter particles having equal masses has been shown in Table 1. We have taken the mass range for dark matter particles $m_\chi = 7\ \text{GeV} - 63\ \text{GeV}$ [8]. When $n = 2$, $E_\gamma = 0$ for $m_\chi = 63\ \text{GeV}$, when $n = 3$, $E_\gamma = 0$ for $m_\chi = 42\ \text{GeV}$, when $n = 4$, $E_\gamma = 0$ for $m_\chi = 31.5\ \text{GeV}$. We observe that $E_\gamma = 0$ for $m_\chi = 63\ \text{GeV}$, for any number of dark matter particles when Higgs decay into n number of dark matter particles of equal masses for a fixed value of the energy radiated and the constant of the dark matter particles with vacuum when Higgs decay into n number of dark matter particles of equal masses for a fixed value of the energy radiated is shown in Table 2. We observe that for $E_\gamma = 63\ \text{GeV}$, $m_\chi = 0$ for any number of dark matter particles produced in Higgs decay. Using the general formula as shown in Table 1, we can find the number of dark matter particles which a Higgs can decay so that the energy will sbe zero. As shown in Table 2, we can find the mass m_χ and the coupling constant g_χ, for any number of dark matter particles having equal masses obtained from the Higgs decay. Hope our results will be experimentally verified in the coming future.

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