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Higgs scalar in heavy-vector-meson decays

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For both $\Upsilon(9.5, \bar{b}b)$ and $T(\bar{t}t)$, the decay into Higgs scalar plus photon is calculated, employing a triangle-diagram estimate for the dependence of this decay matrix element on the Higgs-scalar mass. This mass dependence gives a significant supression, but the decay should still be readily observable, if energetically allowed.

The resonance $\Upsilon(9.5)$ discovered recently[1] is presumably a $(\bar{b}b)$ bound state analogous to $\psi(3.1)$. Indeed, there is some evidence[2] supporting a charge $|e_Q| = \frac{1}{3}e$ rather than $\frac{2}{3}e$ for the constituent quarks. Quantum flavor dynamics (QFD) then predicts that, for sequential left-handed doublets to cancel the triangle anomaly in an $SU(2)\times U(1)$ theory, there must exist a sixth flavor of quark, t. The ground-state $(t\bar{t})$ vector T meson is expected to be accessible, for example, to the PEP and PETRA e^+e^- machines soon to come into operation.

A second prediction of QFD theory is the existence of a Higgs boson (H). The mass of this boson is not predicted, although lower bounds have been proposed.[3,4,5] We shall assume it to be lighter than the T meson. Discovery of a Higgs boson will strongly support the spontaneously-broken-gauge-theory (SBGT) aspect of QFD. It is generally accepted[6,7] that the discovery of intermediate vector bosons, with the predicted masses, supports the idea that the correct broken symmetry [e.g., $SU(2)\times U(1)$] has been identified, but does *not* uniquely establish the SBGT mechanism.

Recently, it was pointed out[8] that the decay $\Upsilon \to H\gamma$ might be a good place to find H provided the mass M_H were below 9.5 GeV. For the T meson, of course, the situation is still more favorable. One rather strong assumption made in Ref. 8, however, is that the matrix element is independent of the Higgs mass; using this assumption Wilczek arrived[9] at

$$[r = (M_V{}^2 - M_H{}^2)/M_V{}^2]$$

$$\frac{\Gamma(V\to H\gamma)}{\Gamma(V\to\mu\mu)} = \frac{G_F M_V{}^2 r}{4\sqrt{2}\,\pi\alpha}\,. \tag{1}$$

One expects the nonrelativistic bound-state approach to give reliable predictions (within, say, a factor 2) in certain kinematic limits. For example, the leptonic decay of Υ is given as $\Gamma(\Upsilon\to e^+e^-) = 1.07$ keV (Refs. 10 and 11) while experiment[12] yields 1.3 ± 0.4 keV. For the $H\gamma$ decay, we therefore expect Eq. (1) to hold in the region $M_H\to 0$ or, equivalently, $r\to 1$.

In our model, we attempt to take account of the M_H dependence of the amplitude $V\to H\gamma$, and will arrive at significant and important differences from the predictions of Eq. (1). Our values for the rate $V\to H\gamma$ are more than an order of magnitude below the simple estimate of Eq. (1), when the Higgs-scalar mass is a substantial fraction of the vector mass (i.e., r appreciably different from one). Nevertheless, the decay should still be observable.

To evaluate the matrix element, we use the triangle diagram of Fig. 1 for the process $V(p_1) \to H(p_2)+\gamma$. The vertex is straightforwardly calculated to be

$$T_{\mu\nu}(p_1,p_2) = A(r)(p_{2\mu}p_{1\nu} - p_1\cdot p_2\, g_{\mu\nu})\,. \tag{2}$$

Setting M_V equal to twice the quark mass in the loop, which corresponds to zero-binding energy in the nonrelativistic approximation, we have

$$A(r) = -\frac{2}{r} + \frac{1}{r^2}\int_0^1 dx\left[\frac{r+(1-2x)^2}{x}\right] \times \ln\left[1+\frac{4rx(1-x)}{(1-2x)^2}\right]\,. \tag{3}$$

We then define a factor $F(r)$ as

$$F(r) = \left[\frac{rA(r)}{A(1)}\right]^2\,. \tag{4}$$

and use $F(r)$ to modify the naive formula, Eq. (1),

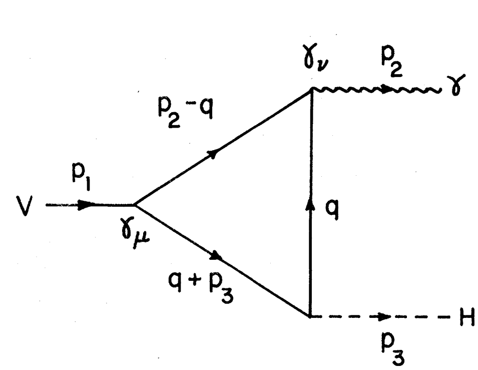

FIG. 1. Triangle diagram for $V\to H\gamma$ where $V=\Upsilon$, T and $q=b, t$, respectively.

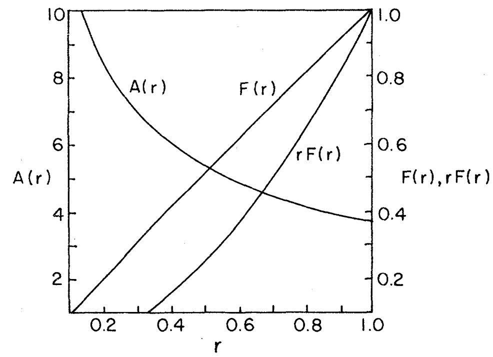

FIG. 2. Plot of $A(r)$, $F(r)$, and $rF(r)$ versus r as defined by Eqs. (3), (4) of the text.

multiplicatively, i.e.,

$$\frac{\Gamma(V\to H\gamma)}{\Gamma(V\to\mu\bar{\mu})}=[\text{value from Eq. (1)}]\times F(r). \qquad (5)$$

The suppression factor disappears in the limit $M_H \to 0$ since $F(1)=1$.

The importance of $F(r)$ can be seen from Fig. 2, which plots $A(r)$, $F(r)$, and $rF(r)$. The $rF(r)$ plot shows the reduction in the branching ratios of Eq. (5) as the Higgs-scalar mass approaches the vector-meson mass.

The quantity pertinent to the experimental observation of the Higgs-scalar–photon decay of heavy vector mesons in the e^+e^- annihilation is

$$\int \sigma(e^+e^-\to V\to\text{hadrons})d\sqrt{s}\,B(V\to H\gamma), \qquad (6)$$

where

$$B(V\to H\gamma)=\frac{\Gamma_l}{\Gamma_h}\,\frac{\Gamma(V\to H\gamma)}{\Gamma_l}. \qquad (7)$$

For $\Upsilon(9.5)$, the expression (6) is found to be

$$9.74\times10^{-2}rF(r)\text{ pb GeV}, \qquad (8)$$

and for T, for masses $M_T=(20;25;30)$ GeV we find[13] for the expression (6)

$$(3.60;3.68;3.78)rF(r)\text{ pb GeV}. \qquad (9)$$

These are plotted in Fig. 3.

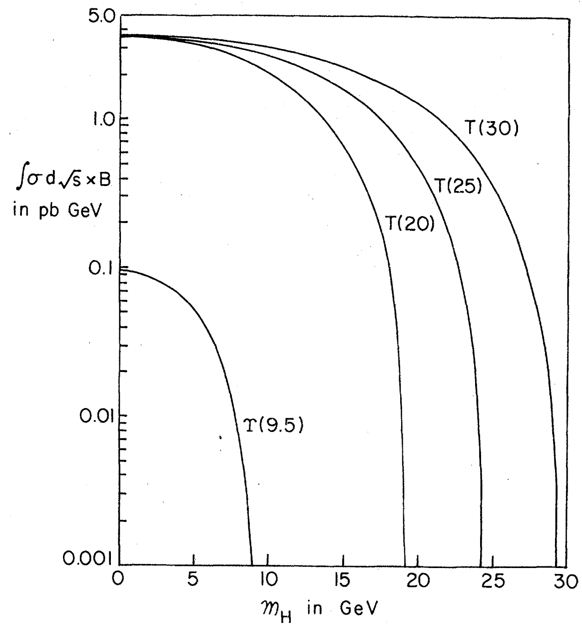

FIG. 3. Plot of $\int \sigma(e^+e^-\to V\to\text{hadrons})\,d\sqrt{s}\,B(V\to H\gamma)$ in pb GeV versus m_H in GeV as defined by Eq. (6) of the text.

The experimental signature of decays $\Upsilon\to H\gamma$, $T\to H\gamma$ is excellent. For suppose $m_H=10$ GeV, say, then from formulas in Ref. 14 one deduces that $\Gamma(H\to\tau^+\tau^-)/\Gamma(H\to\text{all})\approx25\%$ and, from Ref. 15, the decays $\tau\to\mu\nu\bar{\nu}$ and $\tau\to e\nu\bar{\nu}$ are each $\approx20\%$ of $\tau\to$ all. Thus, about 2% of the $H\gamma$ final states will contain $(\mu^\pm e^\mp)$, and no hadrons, to give a unique identification when a quasimonochromatic photon is also detected. Of course, the decay of H into charmed mesons can also be used as a trigger.

For the e^+e^- experiment, our predictions are readily converted, using knowledge of the energy resolution, luminosity, and the detection efficiency, into numbers of events per day or per hour. Remarkably large numbers result. For example, with a beam width of 2 MeV and a luminosity of $10^{32}/\text{cm}^2$ sec, from Fig. 3 we obtain seven events/hour for the $\Upsilon(9.5)$ decay with 6 GeV Higgs-scalar mass, and 1.5 events/minute from $T(25)$ for 20 GeV Higgs-scalar mass. For the particular identification $(\mu^\pm e^\mp)$ mentioned above, the rates are times 2%. For a beam width 50 MeV at PEP or PETRA, the total rate is times 4% but still at a readily observable level.

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