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GLUONIA ENHANCEMENTS OF THE HIGGS BOSON HADRONIC WIDTHS

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ABSTRACT

We use scalar Gluonia Dominance of the anomalous trace of the energy momentum tensor and some results from QCD low-energy theorems and spectral sum rules in order to analyze the hadronic and $\gamma\gamma$ widths of a light Higgs boson of the Standard Model with a mass below the charm threshold. Large enhancements of the $\pi\pi$ and $\eta\eta'$ modes occur respectively on the top of the $\sigma(0.9)$ and $G(1.6)$ poles, while the $\gamma\gamma$ width can be important around the G mass. Consequently, the Higgs into $\mu^+\mu^-$ branching ratio, which is about 10^{-2} on these gluonia poles, is much smaller than naively expected. Values of these various widths versus the Higgs boson mass are given. A search for the Higgs boson from the study of the $\pi\pi$ and $\eta'\eta$ invariant masses could be feasible.

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The search for the Higgs boson is the most fundamental test of the nature of electroweak breaking. Despite a large amount of experimental and theoretical effort, we have not yet firm limits on the Higgs parameters of the Standard Model. In particular, there is no clean exclusion of a neutral Higgs mass below 2 GeV^{1,2)} as the experimental bounds suffer from the uncertainties of the estimate of the Higgs into $\mu^+\mu^-$ branching ratio. Moreover, the analysis of the inclusive modes from decays of heavy quarkonia and/or from hadronic experiments needs a good theoretical determination of the Higgs hadronic and $\gamma\gamma$ decays. Motivated by these problems and by the renewed interest in the light Higgs physics if there exists a weak isodoublet of quarks or leptons with a mass of about 80 and 110 GeV respectively, we reconsider in this note the hadronic and $\gamma\gamma$ widths of a Higgs boson having a mass below the charm threshold. Our aim is to study the effects of the scalar gluonia $\sigma(0.9)$ and $G(1.6)$ which are known^{3,4)} to couple with the anomalous trace of the energy-momentum tensor :

$$4\Theta_\mu^\mu \equiv \beta(\alpha_s)G_{\mu\nu}G^{\mu\nu} + 4(1 + \gamma_m(\alpha_s)) \sum_{u,d,s} m_i \bar{\psi}_i \psi_i. \quad (1)$$

$\beta(\alpha_s)$ is the β function, $G_{\mu\nu}$ is the gluon field strength, γ_m is the mass anomalous dimension, ψ_i is the quark field and m_i is the quark mass. These mesons are also known to satisfy well the QCD tests on scalar gluonia⁴⁾ while their existence is confirmed experimentally from $\pi\pi, \gamma\gamma$ scattering⁵⁾ and πp ⁶⁾ data.

1. THE HADRONIC DECAYS

The estimate of the Higgs (hereafter denoted H) hadronic decay can be done by using the dilaton theorem⁷⁾:

$$\langle B, H | A \rangle = \frac{i}{v} \langle B | \Theta_\mu^\mu | A \rangle, \quad (2)$$

where A and B are states not containing the Higgs boson H and $v \equiv G_f \sqrt{2}^{-1/2} = 246 \text{ GeV}$ is the weak scale. In this paper we shall limit ourselves to the case where A and B are pseudoscalar mesons and photons. Eq. 2) indicates that the H -decay is controlled by the hadronic matrix element in the RHS which can be estimated in QCD. Assuming that the

H-decay into pairs of pseudoscalars is dominated by intermediate gluonia states (Gluonia Dominance), one can deduce the width :

$$\Gamma_{H \rightarrow \pi^+ \pi^- + \pi^0 \pi^0} = \frac{3}{2} \frac{1}{8\pi} \frac{1}{v^2} \sum_{\sigma, G} \frac{(M_S^2 f_S g_{S\pi^+\pi^-})^2}{|D_S|^2} \frac{1}{2M_H} \left(1 - \frac{4m_\pi^2}{M_H^2}\right)^{1/2}, \quad (3)$$

where :

$$\langle 0 | 4\Theta_\mu^\mu | S \rangle = \sqrt{2} f_S M_S^2, \quad (4)$$

$$D_S \equiv (M_H^2 - M_S^2) + i M_S \Gamma_S, \quad (5)$$

and $g_{S\pi^+\pi^-}$ is the gluonia coupling to pion pairs. We have neglected the effect of the $S^*(975)$ because its coupling to the quark component of Θ_μ^μ vanishes in the chiral limit ($m_i = 0$)⁸⁾. QCD low-energy theorems applied to the vertex $\langle \pi | \Theta_\mu^\mu | \pi \rangle$ allow us to derive the sum rule⁴⁾ :

$$1/4 \sum_{\sigma, G} g_{S\pi^+\pi^-} \sqrt{2} f_S / M_S^2 = 1, \quad (6)$$

where the effects of $f_0(1.3)$ can be neglected as its decay constant is smaller than that of the $\sigma(0.9)$. Neglecting the small $g_{G\pi\pi}$ coupling as given by the GAMS data ⁶⁾, one can deduce the partial width :

$$\Gamma_{H \rightarrow \pi\pi} = \frac{3}{2} \frac{1}{8\pi} \frac{1}{v^2} \frac{M_\sigma^8}{|D_\sigma|^2} \frac{1}{2M_H} \left(1 - \frac{4m_\pi^2}{M_H^2}\right)^{1/2}, \quad (7)$$

which is shown in Fig.1 where we have used $\Gamma_\sigma = 600 MeV$. We also present in Fig.1, the result¹⁰⁾ obtained without the resonance effects which validity might be questionable for M_H larger than 1 GeV. To leading order in the chiral symmetry breaking terms, the σ coupling to pairs of Goldstone bosons are equal. Therefore, one can easily deduce the $H \rightarrow K \bar{K}$ width in Fig.1.

The $H \rightarrow \eta\eta$, $\eta\eta'$ and $\eta'\eta'$ are affected by the G(1.6) which is known to decay predominantly into the first two modes. The vertex $\langle \eta_1 | \Theta_\mu^\mu | \eta_1 \rangle$ where η_1 is the U(1) singlet meson, is also governed by another low-energy theorem⁴⁾ from which one can deduce the sum rule :

$$1/4 \sum_{\sigma, G} g_{S\eta_1\eta_1} \sqrt{2} f_S = 2m_{\eta_1}^2 = 1.15 GeV^2. \quad (8)$$

Using the η - η' mixing angle $\theta^9) = -(18 - 20)^\circ$, one obtains :

$$\Gamma_{H \rightarrow \eta\eta} = \frac{1}{2} \frac{1}{8\pi} \frac{1}{v^2} \frac{1}{2M_H} \left(1 - \frac{4m_\eta^2}{M_H^2}\right)^{1/2} \left(\frac{M_\sigma^8}{|D_\sigma|^2} + \frac{M_G^4 \sin^4 \theta (1.15 \text{ GeV}^2)^2}{|D_G|^2} \right), \quad (9)$$

while :

$$\Gamma_{H \rightarrow \eta'\eta'} = \frac{1}{2} \frac{1}{8\pi} \frac{1}{v^2} \frac{1}{2M_H} \left(1 - \frac{4m_{\eta'}^2}{M_H^2}\right)^{1/2} \frac{M_G^4 (1.15 \text{ GeV}^2)^2}{|D_G|^2}. \quad (10)$$

Neglecting the $\sigma\eta'\eta$ coupling which is constrained by the $\eta' \rightarrow \eta\pi\pi$ decay, one gets (modulo trivial phase space factors) :

$$\Gamma_{H \rightarrow \eta'\eta} = 2 \sin^2 \theta \Gamma_{H \rightarrow \eta'\eta'}. \quad (11)$$

The M_H -behaviour of these different decay modes are shown in Fig.1, where one should note the considerable enhancements of the $\pi\pi$ and $\eta'\eta$ modes on the tops of the σ and respectively the G. The $\pi\pi$ mode on the σ is about a factor 29 larger than the usual estimate without the resonance effect. With this value we obtain the branching ratio :

$$\frac{\Gamma_{H \rightarrow \mu^+\mu^-}}{\Gamma_{H \rightarrow \pi\pi}} = 10^{-2}, \quad (12)$$

in agreement with the result in Ref. 11) obtained from a different approach. Above the $\eta'\eta$ threshold, our result suggests that the most dominant mode is the $\eta'\eta$ one. On the top of the G(1.6) we have :

$$\frac{\Gamma_{H \rightarrow \mu^+\mu^-}}{\Gamma_{H \rightarrow \eta'\eta}} = 2.410^{-2}. \quad (13).$$

The total hadronic branching ratio from these two-body decays and normalized to the one into $\mu^+\mu^-$ are shown in Fig.2. We have not included in the sum the $H \rightarrow N\bar{N}$ width as we might expect that the gluonia effect is quite small in this channel. Moreover, the estimate in Ref. 12) indicates that this width is much smaller than the ones shown in Fig. 1).

2. THE $\gamma\gamma$ DECAYS

Previous analysis based on the Gluonia Dominance can be used for the estimate of the Higgs into $\gamma\gamma$ width where we use the gluonia couplings to $\gamma\gamma$ obtained in Ref. 4) from an Euler-Heisenberg-type effective Lagrangian. From the relations of these couplings with the gluonia decay constant f_S , the $H \rightarrow \gamma\gamma$ width reads :

$$\Gamma_{H \rightarrow \gamma\gamma} = \frac{1}{64\pi} \frac{1}{v^2} \frac{\alpha^2}{60^2} \frac{2}{16} M_H^3 \sum_{\sigma, G} \frac{f_S^4 M_S^8}{|D_S|^2} \frac{\pi^2}{\beta_1^2} \left(\sum_{u, d, s} \frac{Q_i^2}{m_i^4} \right)^2, \quad (14)$$

where Q_i and m_i are respectively the quark charge and constituent mass . We show this resonance contribution in Fig.3 where one should notice a large uncertainty in the estimate owing to the inaccuracy on the determination of the gluonia decay constant . One should notice that one can have an enhancement on the $G(1.6)$ pole compared to the recent estimate in Ref. 13) if the gluonia couplings are found in the range suggested in Ref. 4) Outside the poles the gluonia effects on the $\gamma\gamma$ width are smaller than the estimate in Ref 13) which is expected to be valid only for M_H less than 1 GeV.

CONCLUSIONS

We have studied the effects of gluonia on the hadronic and $\gamma\gamma$ decays of the Higgs boson with a mass below the charm threshold . We have found large enhancements of these modes implying a substantial decrease of the $\mu^+\mu^-$ branching ratio. A search for a Higgs boson from the analysis of the $\pi\pi$ and $\eta'\eta$ invariant masses could be done with high resolution detectors and spectrometers. The rate of Higgs production relative to the gluonia production rate is about the ratio of their widths within this context of Gluonia Dominance of the Higgs decay.

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FIGURE CAPTIONS

Fig.1 : Behaviour of each Higgs hadronic mode versus its mass. The dashed line is the estimate of the $\pi\pi$ width without the resonance effect.

Fig.2 : Behaviour of the Higgs total hadronic mode versus its mass.

Fig.3 : Behaviour of the Higgs $\gamma\gamma$ mode versus its mass :the dashed line is the estimate in Ref. 13) extrapolated to higher Higgs masses and for $C=-19/9$. The shaded area is limited by the predictions obtained from the two extreme values of the gluonia decay constants in Ref. 4).

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- Fig. 1 -

- Fig. 2 -

- Fig. 3 -