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Measuring the Higgs-charm coupling with heavy quarkonia

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We present a calculation of the Higgs boson decay into a quarkonium plus a photon and show that the branching ratio is sensitive to both the magnitude and sign of the Higgs-heavy quark coupling. Our numerical results include relativistic corrections, as well as logarithms of the Higgs mass divided by the heavy quark mass resummed to all orders in α_s, which is carried out in the next-to-leading logarithmic accuracy. The resulting branching ratio shows that the Higgs-charm coupling should be measurable at the high-luminosity LHC.

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1. Introduction

In this proceedings contribution, we explore the possibility of measuring the Higgs-charm coupling through the exclusive production of a J/ψ and a photon in Higgs boson decays. For details of the calculation, we refer the readers to Refs. [1, 2, 3].

We compute the decay $H \to V+\gamma$, where H is the Higgs boson, and $V = J/\psi$ or Υ is a vector quarkonium, using the nonrelativistic QCD (NRQCD) factorization approach. The process $H \to V+\gamma$ proceeds through two mechanisms. In the direct process, the Higgs boson decays into a heavy quark-antiquark pair, which emits a photon and then evolves into a quarkonium. In the indirect process, the Higgs boson decays into a photon and a virtual photon through a top quark or a vector boson loop. Then, the virtual photon decays into a quarkonium. The direct amplitude is proportional to the Higgs-charm coupling, while the indirect process is independent of the Higgs-charm coupling. The two processes interfere, which makes the decay $H \to V+\gamma$ sensitive to the magnitude and sign of the Higgs-charm coupling.

For the direct amplitude, we compute relativistic corrections in the NRQCD factorization formalism. We also resum logarithms of m_H/m_Q, where m_H is the Higgs boson mass, and m_Q is the heavy quark mass, to all orders in α_s, in the next-to-leading logarithmic accuracy.

The remainder of the paper is organized as follows. We compute the direct and indirect amplitudes in Sec. 2. The numerical results are given in Sec. 3, and conclude in Sec. 4.

2. Calculation of the Amplitudes

2.1 Direct amplitude

A straightforward calculation of the direct amplitude $H \to V+\gamma$ in the light-cone approach gives

$$i\mathscr{M}_{\rm dir} = \frac{i}{2} e e_Q \kappa_Q \overline{m}_Q(\mu) (\sqrt{2} G_F)^{1/2} f_V^\perp(\mu) \left(-\varepsilon_V^* \cdot \varepsilon_\gamma^* + \frac{\varepsilon_V^* \cdot p_\gamma p_V \cdot \varepsilon_\gamma^*}{p_\gamma \cdot p_V} \right) \times \int_0^1 dx T_H(x,\mu) \phi_V^\perp(x,\mu), \tag{2.1}$$

where, e is the electric charge, e_Q is the fractional charge of the heavy quark Q, $\overline{m}_Q$ is the $\overline{\rm MS}$-quark mass, G_F is the Fermi constant, $f_V^\perp$ is the decay constant of V, ε_V and p_V are the polarization vector and the momentum of V, ε_γ and p_γ are the polarization vector and the momentum of the photon, respectively, μ is the factorization scale, x is the momentum fraction of the Q inside the V. κ_Q is an adjustable parameter for the $HQ\bar{Q}$ coupling. In the standard model (SM), $\kappa_Q = 1$. $T_H(x,\mu)$ is the perturbative, hard-scattering kernel. $\phi_V^\perp(x,\mu)$ is the light-cone distribution amplitude defined by

$$\frac{1}{2}\langle V|\bar{Q}(z)[\gamma^\mu,\gamma^\nu][z,0]Q(0)|0\rangle = f_V^\perp(\mu)(\varepsilon_V^{*\mu} p_V^\nu - \varepsilon_V^{*\nu} p_V^\mu) \int_0^1 dx e^{ip^- zx} \phi_V^\perp(x,\mu), \tag{2.2}$$

with the normalization $\int_0^1 dx \phi_V^\perp(x,\mu) = 1$. $[z,0]$ is the gauge link that makes the operator gauge invariant.

We compute the LCDA $\phi_V^\perp(x,\mu)$ and the decay constant $f_V^\perp(\mu)$ formally in NRQCD up to linear orders in α_s and v^2 [2, 4, 5]. We take the nonperturbative NRQCD long-distance matrix elements from Ref. [6]. $T_H(x,\mu)$ is known to next-to-leading order (NLO) in α_s [4, 5]. The LCDA and the decay constant follow evolution equations whose kernels are known to NLO in α_s [7, 8, 9, 10, 11, 12]. We take the formal NRQCD expression for the LCDA and the decay constant to be $\phi_V^\perp(x,\mu_0)$ and $f_V^\perp(\mu_0)$ at $\mu_0 = m_Q$ and evolve them to the scale $\mu = m_H$. We compute $T_H(x,\mu)$ at the scale $\mu = m_H$. By plugging in the evolved LCDA, the decay constant, and $T_H(x,\mu)$ into Eq. (2.1), we obtain the direct amplitude, including relativistic corrections or relative order v^2, and logarithms of m_H/m_Q resummed to all orders in α_s in the next-to-leading logarithmic accuracy.

2.2 Indirect amplitude

The indirect amplitude is given by

$$i\mathscr{M}_{\rm ind} = \frac{i g_{V\gamma}\sqrt{4\pi\alpha(m_V)m_H}}{m_V^2}\left[16\pi\frac{\alpha(m_V)}{\alpha(0)}\Gamma(H\to\gamma\gamma)\right]^{1/2}\left(-\epsilon_V^*\cdot\epsilon_\gamma^* + \frac{\epsilon_V^*\cdot p_\gamma p_V\cdot\epsilon_\gamma^*}{p_\gamma\cdot p_V}\right), \quad (2.3)$$

where α is the electromagnetic coupling, and we ignore the invariant mass of the γ^* in $H\to\gamma\gamma^*$ by computing the amplitude from $\Gamma(H\to\gamma\gamma)$ [13, 14]. $g_{V\gamma}$ is computed using the leptonic decay rate of the V by

$$g_{V\gamma} = -\frac{e_Q}{|e_Q|}\left[\frac{3m_V^3\Gamma(V\to\ell^+\ell^-)}{4\pi\alpha^2(m_V)}\right]^{1/2}. \quad (2.4)$$

3. Numerical Results

V	α_V	β_V
J/ψ	11.71 ± 0.16	$(0.627^{+0.092}_{-0.094})+(0.118^{+0.054}_{-0.054})i$
$\Upsilon(1S)$	3.283 ± 0.035	$(2.908^{+0.122}_{-0.124})+(0.391^{+0.092}_{-0.092})i$
$\Upsilon(2S)$	2.155 ± 0.028	$(2.036^{+0.087}_{-0.089})+(0.293^{+0.069}_{-0.069})i$
$\Upsilon(3S)$	1.803 ± 0.023	$(1.749^{+0.077}_{-0.078})+(0.264^{+0.062}_{-0.062})i$

Table 1: Values of the parameters α_V and β_V in $\Gamma(H\to V+\gamma) = |\alpha_V - \beta_V\kappa_Q|^2\times10^{-10}$ GeV for $V = J/\psi$ and $\Upsilon(nS)$.

Our results for the decay rate $\Gamma(H\to V+\gamma)$ are given in Table 1 for $V = J/\psi$ and $\Upsilon(nS)$ for $n = 1,2$ and 3. The branching ratios $\mathrm{B}(H\to V+\gamma)$ for $V = J/\psi$, $\Upsilon(nS)$, $n = 1,2$, and 3, in case κ_Q deviates from the SM value, are shown in Fig. 1.

4. Conclusions

We present calculations of the decay rate $\Gamma(H\to V+\gamma)$ where V is a vector quarkonium, which is sensitive to the magnitude and phase of the Higgs-heavy quark coupling through a quantum interference. Working in the nonrelativistic QCD factorization formalism, we include relativistic corrections in the direct amplitude. We also resum logarithms of m_H/m_c to all orders in α_s in the next-to-leading logarithmic accuracy.

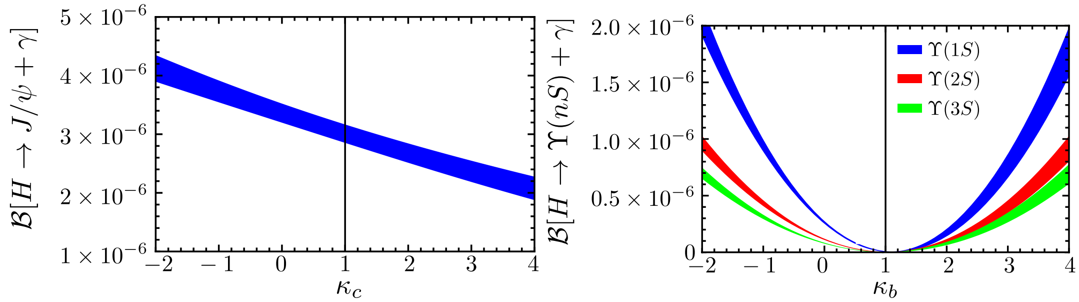

Figure 1: Branching ratios $B(H \to V + \gamma)$ for $V = J/\psi$, $\Upsilon(nS)$, $n = 1, 2$, and 3.

We presented decay rates and branching ratios for $H \to V + \gamma$ when the Higgs-heavy quark coupling deviates from the standard model. For $V = J/\psi$, the Higgs-charm coupling should be measurable at the high-luminosity LHC. When $V = \Upsilon(nS)$, the standard model branching ratios are too small to be measurable at the LHC. Hence, a measurement of the $H \to \Upsilon(nS) + \gamma$ may indicate a large deviation in the Higgs-bottom quark coupling from the standard model value.

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