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Addendum to Mesons with Beauty and Charm: New Horizons in Spectroscopy [Phys. Rev. D 99, 054025 (2019)]

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We add to our recent analysis of $(c\bar{b})$ spectroscopy a new Figure and a remark about the prospects for discovering orbitally excited $3P$ states in the $B_c + \gamma$ spectrum.

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In a recent Article [1], we analyzed the expected spectrum of $(c\bar{b})$ mesons in the framework of a novel "frozen-α_s" potential in which the value of the strong coupling that governs the Coulomb component saturates at large distances. There we made predictions for the level spectrum, decay modes, and production rates in pp collisions at the Large Hadron Collider. In the discussion surrounding Figure 8 of Ref. [1], we highlighted the possibility that E1 electric-dipole transitions from the $2P \to 1S$ levels might offer an imminent opportunity to establish orbitally excited levels. We pointed to the $2^3P_2(6750) \to B_c^*\gamma$ line as an especially promising target for experiment, because of the favorable production cross section and 409-MeV photon energy.

We gave the significant E1 and M1 electromagnetic transition rates and the $\pi\pi$ cascade rates through the $3S$ levels in Table VI of Ref. [1], along with the total widths in the absence of strong decays, and estimated the production rates for all those levels in Table VIII of that Article. Although all the ingredients are there, we did not specifically comment of prospects for establishing the $3P$ states. We repair that omission here.

We show in Figure 1 cross sections × branching fractions for the spectrum of E1 photons in decays of the $3P_J$ to $1S$ levels. (Since the $3S$ levels should lie above flavor threshold, we neglect feed-down from $3S \to 3P$ transitions. Cross sections for the physical $3P_1^{(\prime)}$ states are appropriately weighted mixtures of the 3^3P_1 and 3^1P_1 cross sections.) Although the yields are approximately four times smaller than those for the $2P \to 1S$ lines, the higher photon energies may be a decisive advantage for detection. The $3^3P_2(7154) \to B_c^*\gamma(777\text{ MeV})$ line is a particularly attractive target for experiment.

Experiments at the Large Hadron Collider have demonstrated the feasibility of E1 spectroscopy in the $(b\bar{b})$ family, discovering and characterizing χ_{b1}'' and χ_{b2}'' [2]. Observation of some $(c\bar{b})$ P-wave states should be possible with the data sets now in hand.

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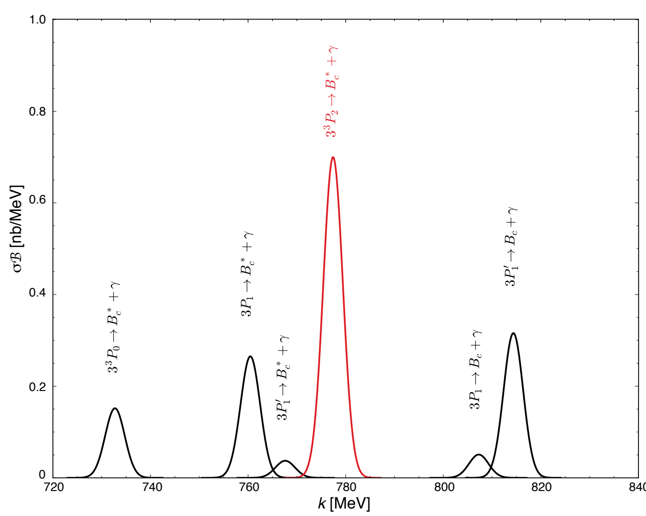

FIG. 1. Photon energies k and predicted yields of E1 transitions from $3P \to 1S$ $(c\bar{b})$ states. Photon momenta and E1 branching fractions are taken from from Table VI of Ref. [1]; production rates are taken from Table VIII. The $3P$ masses inferred from transitions to B_c^* will be shifted downward because of the missing $B_c^* \to B_c\not\gamma$ photon in the reconstruction. We model Gaussian lines with standard deviation 2 MeV.

[1] E. J. Eichten and C. Quigg, Phys. Rev. D **99**, 054025 (2019), arXiv:1902.09735 [hep-ph], where (as here) states are labeled by the principal quantum number, n.

[2] G. Aad *et al.* (ATLAS Collaboration), Phys. Rev. Lett. **108**, 152001 (2012), arXiv:1112.5154 [hep-ex]; R. Aaij *et al.* (LHCb Collaboration), Eur. Phys. J. **C74**, 3092 (2014), arXiv:1407.7734 [hep-ex]; JHEP **10**, 088 (2014), arXiv:1409.1408 [hep-ex]; A. M. Sirunyan *et al.* (CMS Collaboration), Phys. Rev. Lett. **121**, 092002 (2018), arXiv:1805.11192 [hep-ex]. These articles label states by the radial quantum number, $n - L$.

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